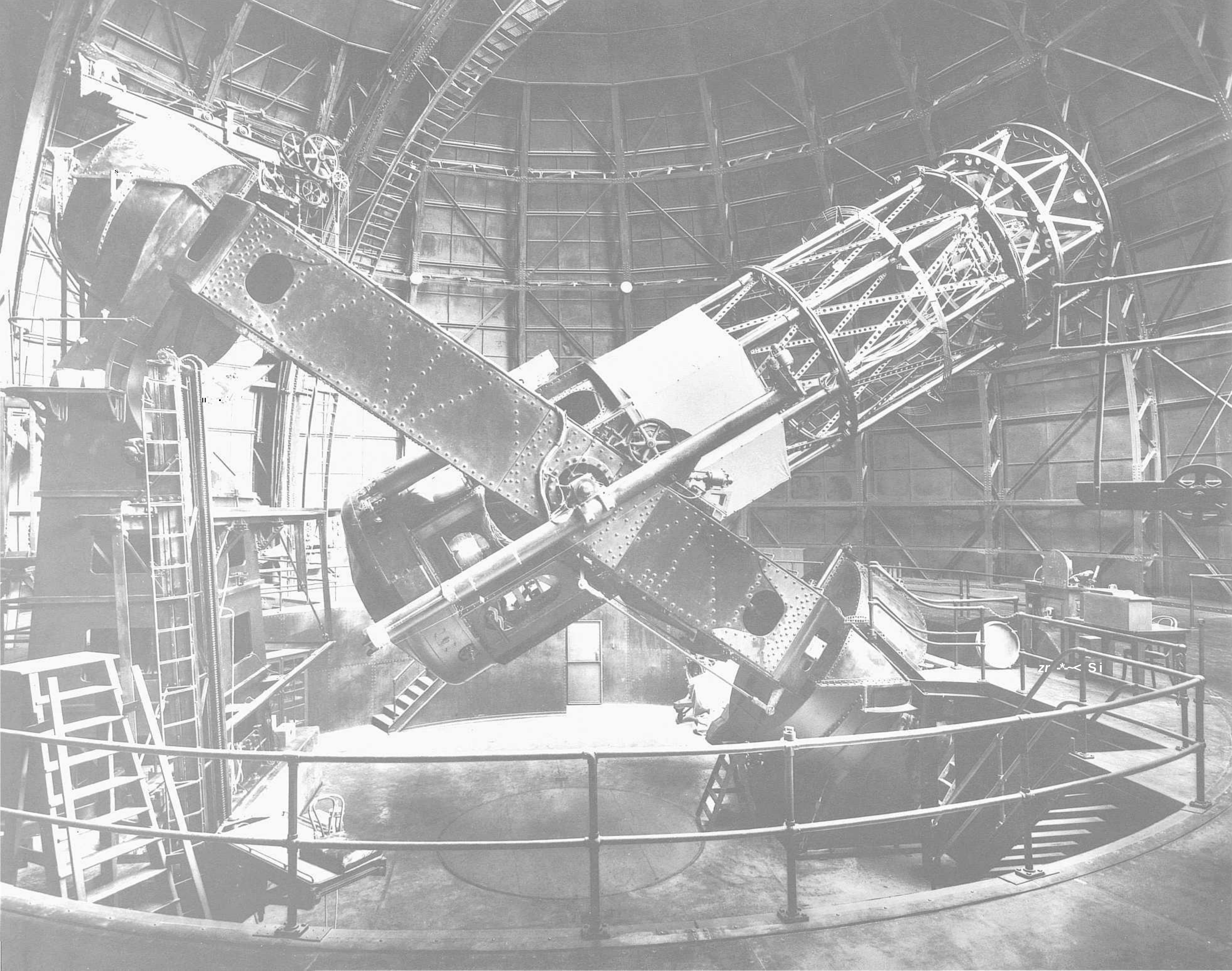

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THE CARNEGIE ATLAS OF GALAXIES

THE CARNEGIE ATLAS OF GALAXIES

Volume I

by

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and

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*Codes used in **the** short tables accompanying **the** illustrations throughout **the** atlas are summarized on pages 8-9. Notations employed in the classifications of galaxy type **are** treated in chapter 3 (e.g., pp. 14, 18).*

*The endpapers depict the **several** telescopes where most **of the images** printed in this atlas were obtained. At the front of Volume I are views of the 1 00-inch Hooker Telescope, Mount Wilson Observatory, California. At **the** back of Volume I are scenes showing **the** 60-inch telescope at Mount Wilson. (The solar **tower** telescopes are also seen **in** the outdoors print.) Shown at the front **of** Volume If is **the** 200-inch Hale Telescope **at the Palomar** Observatory, California. At **the** back of Volume 11 are scenes at the Carnegie Institution s **Las** Cumpanas Observatory: close views are provided of the 2.5-meter du Pont Telescope and the. 1.0-meter Swope Telescope.*

The galaxy shown on the cover of Volume I is NGC 5746. Depicted on the cover of Volume II is ISGC 2997.

*This second (1996) printing of the. atlas is identical to **the first** printing except for a small number of incidental **corrections.***

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PREFACE

This two-volume atlas has heen made to accompany and supplement *A Revised Shapley-Ames Catalog Of Bright Galaxies* (Carnegie Institution of Washington Publication 635, 1981, 1987, hereafter the RSA). It also extends, refines, and more completely illustrates the galaxy classification system set out in *The Hubble Atlas of Galaxies* (Carnegie Publication 618, 1961).

During the observing program mounted to compile the RSA we became convinced that an extensive atlas of photographs would be useful, both as a textbook of the system of galaxy classification used in the RSA and as an illustrated compendium to aid in planning observing programs on bright galaxies. The Hubble Atlas had proven of such use since the early 1960's, even as it was only a partial collection of photographs.

The RSA classifications were made from direct photographs obtained during the Carnegie survey program begun in 1910, which throughout its 80-year course employed telescopes with the largest available plate scales. Photographs, however, contain far more information than can be told by classifications. Given the evident responsibility to preserve this unique photographic record, we deemed that the way to make the collection available for widest possible use was to compile this atlas.

Our hopes to complete an all-sky classification program began in the mid-1960's, coincident with initial plans for a Carnegie southern observatory. Construction of the Las Campanas Observatory in the central Chilean Atacama desert, driven in the early 19 70\s by the single-minded vision and effort of Horace W. Babcock, director of the then Mount Wilson and Palomar Observatories, opened the South to the classification project. The 1-meter Swope Telescope was built as a pilot instrument. The du Pont 2.5-meter reflector followed, made possible by the gilt of Crawford and Margaretta Greenewall and by additional funds voted by the Carnegie Institution trustees. Private funds thus provided construction costs for these powerlul survey telescopes, whose optics, designed by Drs. Ira S. Bowen and Arthur Vaughan, produce fields of view of unprecedented size with superb optical definition.

An all-sky survey was now possible, and in L974 we began efforts to obtain photographs not only of galaxies in the South unobservable from the California observatories lint also of those northern galaxies where improved plate material was deemed necessary.

In 1975 a new photolab was constructed at the offices of the Carnegie Institution's astronomy department in Pasadena. Equipment to handle 20" X 20" photographic plates was obtained and integrated into the plan for the facility, together with semi-automatic print-processing equipment to make large quantities of work-prints from original negatives. The expense of developing this modern photolab was met by a special financial appropriation by Philip Abelson, then president ol the Carnegie Institution.

Work on the final collection of original plates was done in the Pasadena photolab from 1970 to 1985, supported in part by a grant from NASA to augment the other work in the photolab. A change in the Carnegie operations in Pasadena in 1985 resulted in the curtailment of the work at the Carnegie photolab. Through the foresight and great kindness of Dr. Riccardo Giacconi, director ol the Space Telescope Science Institute (STScl), the extensive remaining photolab work required to complete the atlas was transferred to the new NASA photolab set up by Bedke at the Baltimore offices ol STScl under contract with the Computer Sciences Corporation (CSC). We are greatly indebted to STScl and to CSC for this support, without which this atlas would not have been completed.

As might be expected in a work of this magnitude, many people have been involved over the years; contributors ranged from the construction, maintenance, and night assistant crews at the remote mountain sites of Mount Wilson, Palomar, and Las Campanas, to the production crews of the photolabs, the editorial offices, and the printing presses through which various parts of the work has traveled. From this large assemblage we need to acknowledge especially those whose extraordinary service, advice, and help brought the venture to completion.

A NASA grant for the years 1982-1985 provided funding to complete the Las Campanas survey and to augment the Pasadena photolab personnel during this period, making possible the first phase of the photographic work.

We are pleased to thank Drs. H. W. Babcock and R. J. Brucato for undertaking part of the extensive observing activities at Las Campanas needed to complete the survey. Their substantial contribution to the final observing program in Chile is seen in the observer designations shown with the plate numbers for the panel illustrations.

The extensive photographic work at the STScI photolab was done under the direction of Bedke by Alan N. Havrilla and Skip Westphal; we are particularly indebted to them for their skill and dedication in making the final publication prints from the copy negatives. The retouching of the photographic prints was done with skill by Susan Giuliano.

The editing of the manuscript, the organization of the printing tests (with the final decision to contract with Allen Press for their superior printing techniques, overseen by James Pusch), and the attention to the details of publication were done by Ray Bowers of the Carnegie Institution, to whom belongs great credit for the final product. We respected most of his superior blue pencil. His expert associate in the several editorial phases was Patricia Parratt Craig. The artistic merits of the book design are due to the talent of Francesca Moghari.

We are grateful to Ann Finkbeiner, member of the faculty of the Johns Hopkins writing seminars, for so carefully reading part of the manuscript and showing, by example, what superior writing could be like. Early versions of the manuscript were also read by Geoffrey Burbidge for scientific content, and his suggestions were generally followed. Particular acknowledgement is owed to Bruno Binggeli for discussions on the philosophy of classification, including the ideas why imagination, in the sense of Poe, is the principal (perhaps the only) way to break the hermeneutical circle and to start.

This project, carried out over 25 years starting in the mid-1960's, had been watched by Francis and Louisa Moseley, long-time friends of the Carnegie Institution and of this venture. Publication of the atlas has been made possible by a most substantial subsidy-grant by the Moseley family's Flintridge Foundation, defraying the bulk of the manufacturing cost. The volumes in this first printing are thus offered at a price far lower than the actual cost of production. The intent is that the volumes reach the hands of the young astronomers who will produce the coming spectacular developments in the new century.

Francis Moseley, inventor and engineer extraordinary; Louisa Moseley, artist and friend to poets and to scientists—this atlas has seen completion and publication because of your support of basic science both in principle and in practice.

—A.S. and J.B.
August 1992

CHAPTER 1

CLASSIFICATION IN SCIENCE

Francis Bacon, said to be the inventor of the scientific method, enshrined classification as the first step to objective truth. To the modern mind, such a beginning in a new science is so natural as hardly to justify discussion. Yet the process of classification is not, in fact, simple, and claims for its objective validity stir continuing debate among philosophers of science.

Classification is inherent in the architecture of the human brain. The mind searches for order even where none exists. In laboratory tests where total randomness has been built into collections of non-classifiable things, experiments show that the brain attempts to impose order nonetheless. It simply makes up classification systems, imposing order on true chaos.

Bacon (1620) understood the problem. In an often quoted passage near the beginning of the *Novum Organum* he wrote,

> *The human understanding, from its peculiar nature, easily supposes a greater degree of order and equality in things than it really finds; and although many things in nature be sui generis and most irregular, [the classifier] will yet invent parallels and conjugates and relatives, where no such thing is.*
>
> (Aphorism 45)

Given such behavior, can any classification be made independent of the classifier? Do the unconscious predilections of the classifier infect all devised classifications? And would such infection block progress toward an objective understanding of nature?

Consider the central problem of ihe present alias. Suppose we develop a galaxy classification system which, as a result of our prejudices, wrongly indicates a continuity across the various morphological types. Suppose we then relate the false continuity to another continuity in some apparently critical parameter. Such a parameter in the process of galaxy formation might be, for example, the density contrast in the protogalactic medium relative to the mean density in the neighborhood. The range in this variable might seem to produce the range in morphological type. But the interpretation would be wrong if the perceived continuity in nature does not in fact exist.

Fortunately there are examples in science which show that the classifier's initial prejudices can be removed. Such classification systems have succeeded in correctly driving certain disciplines far beyond the confines of the systems themselves. Examples include (1) the Linnean classification of species in biological taxonomy, which eventually led to the 20th century synthesis of evolution, speciation, and biological development, and (2) the classification system of the geological column, which led to the idea ol the very ancient Earth and the succession of geological periods in its evolution.

Perhaps the strongest example in physical science is Mendeleyev's classification of the chemical elements and subsequent invention of the periodic table. Mendeleyev, the greatest chemist of his time, had for years studied the properties of the known chemical elements. In an 1869 paper, he presented a table in which the chemical elements were placed in an order where those elements having similar chemical properties were aligned vertically. Seven rows, called periods, some with more than twenty entries, completed the table. Where necessary, Mendeleyev left gaps in the table where, in a given row (period), no element was then known. New elements filling those gaps were later found, proving predictability of the classification. The remarkable scheme organized most of the relevant properties of all the known chemical elements. Independently in the same year, Lothar Meyer, working not with the chemical properties but with the atomic weights, arrived at the same ordering.

Mendeleyev and Meyer's classification was so powerful that 50 years later it led Bohr directly to the modern theory of atomic structure of the chemical elements. Bohr combined the Mendeleyev-Meyer classification system with the Pauli exclusion principle for electrons in different atomic states. The Mendeleyev-Meyer ordering by chemical periods was the same as the ordering by atomic states (Pauli shells). Nothing of this quantum physics had been known to Mendeleyev and Meyer, yet their classification system contained the seed of that much later development.

Manifestly, the Mendeleyev-Meyer classification was not infected by any prejudice of the mind. It truly describes nature. Order was not imposed by the classifier: rather it was discovered from the classification itself. A great classification system has such power.

THE METHOD OF MULTIPLE ITERATION

Successful codifiers of powerful classifications generally begin by immersing themselves for long periods in the data. The initial cataloging may test many potential parameters: the data may be organized into small units, often on individual cards that can be filed and re-filed in a semi-infinite series of trials, seeking a system that remains coherent without exception or contradiction.

The search for the system evolves by multiple iterations, between initial inductions from the data on the one hand and subsequent deductions from tentative hypotheses on the other. The interplay between induction and deduction, between facts and imagination, is repeated many times. The repetition moves the classification away from its subjective beginnings containing the prejudices of the classifier toward objective reality independent of the classifier. The arrangements are torn apart and reassembled as often as necessary to avoid contradiction and to accommodate each new piece of data. Ideally, as the system is gradually refined, only those parameters relevant to nature remain. The system becomes mature when, like the system of Mendeleyev and Meyer, it attains the power of prediction.

HOW TO BEGIN: CAN EMPIRICISM OR RATIONALISM SUFFICE?

It is all very well to describe the process of multiple iteration to hone a classification, progressively removing the classifier from the classification. But how do we begin? To select initially which parameters are potentially relevant must we already have an understanding of the whole problem, unavailable until the classification itself is complete? The problem is known as the dilemma of the hermeneutical circle[1]. As Aristotle wrote, acquiring knowledge requires prior knowledge, which initially is unavailable.

For the empiricist, how to start comes simply from previous observation; knowledge of the world starts only from the senses. Nature must be observed and interrogated, not analyzed a priori, devoid of experience. The extreme empiricist claims that no whiff of theory may be allowed into the *initial* classification procedures, decisions, and actions. The data themselves must initially flood the classifier. The mind must be cleansed neutral of any

[1] Hermeneutics, derived from Hermes—the Creek god of information and communication—is usually defined as the science or art of interpretation and explanation. Its role in the philosophy of science and the dilemma it poses in the induction/deduction problem is discussed by Radnitzky (1973). Usher (1980) gives an introduction to the problems raised by the hermeneutical circularity in many areas of astronomy.

interpretation. Conan Doyle often quoted Sherlock Holmes about the method:

> *It is a capital mistake to theorize before you have all the evidence. It biases the judgement.*
>
> (Doyle, 1887. A Study in Scarlet. Cli. Ill)
>
> *[If one does so] before one has data, one begins to twist facts to suit theory instead of theory to fit farts.*
>
> (A Scandal in Bohemia)
>
> *[One must not] get into habit of telling a story backward [from the theory to the facts.]*
>
> (The Problem of Tlior Bridge)

All this is pure Baconian.

Extreme rationalists argue the other way around. They hold instead that everything real can be found by rational thought alone. Their view, espoused by Herman Bondi in a well-known paper some 30 years ago, is that "whenever there is a conflict between a well developed theory and the observations, it is the observations that invariably have proved to be wrong."

Eddington (192 6), in a famous passage in *The Internal Constitution of the Stars*, wrote that a physicist of even modest attainments who had never seen the sky could postulate the existence of the stars purely from calculations based on fundamental physics. Eddington (who *had* seen the sky, thus weakening his philosophical position) did indeed attempt to do similar feats in some of the central parts of physics in his book *Fundamental Theory.* This spectacular attempt to prove the rationalist position was quite remarkable, although its physics is now generally regarded as a brilliant failure.

Neither Bacon with induction nor Aristotle and Eddington with rational deduction can break the circle for us to let the game begin. Neither tells us how *initially* to decide relevance.

An illuminating clue is offered in the early history of galaxy classification. Simple description, based on no physical parameters and therefore making no choice of relevance, proved unproductive, as in the systems of Wolf (1908) and of Vorontsov-Velyaminov *et al.* (1962, 1963, 1964, 1968). On the other hand, Hubble correctly guessed that the presence or absence of a disk, the openness of the spiral-arm pattern, and the degree of resolution of the arms into stars, would be highly relevant. Il was an indefinable genius of Hubble that enabled him to understand in an unknown way, neither Baconian nor Aristotelian, thai this start to galaxy classification had relevance to nature itself.

Edgar Allan Poe (1849) addressed the mailer of genius and how to start. In his *Mellonta Tauta* and in llie beginning of *Eureka,* Poe dismissed the methods of both Bacon and Aristotle as the paths to certain knowledge. He argued for a third method to knowledge which he called imagination; we now call it intuition, and we recognize it in Hubbie's case.

Although imagination alone cannot build the road to objective knowledge, we claim that it can point the traveler in the right direction. Indeed, we believe that imagination provides the elusive opening with which to break the hermeneutical circle. Imagination, or genius, or intuition, lets the classification *start* so that the successive iterations, back and forth between the empirical and the rational, hone the product until il eventually conforms to nature. Only then is the dross of the classifier skimmed away and a true order in nature, if it exists, revealed.

The discovery of a classification system, seemingly so simple at the beginning, is, in fact, extraordinarily complicated. But have we made it so by raising captious doubt about the prejudices of the classifier, where none indeed exist in fact? The Zen master may have had it right when he admonished:

> *When eating, eat*
> *When sleeping, sleep*
> *When classifying, classify.*

Simply start, and like Poe, trust in the imagination.

GALAXY CLASSIFICATION

The *Hubble Atlas of Galaxies* (Sandage 1961, hereafter either Hubble Atlas or HA) was assembled in the late 1950's to illustrate the system of galaxy classification invented by Edwin Hubble (1922, 1926, 1927). Sometime between 1936 and 1950 Hubble made an important revision to his first system, but he published no account of it before his death in 1953. Manuscript notes concerning the revision were found in Hubble's papers. Based on these notes, a textbook of galaxy classification was set out as part of the Hubble Atlas. The revision is discussed on page 7 of that volume.

In subsequent decades, an all-sky photographic survey of the bright galaxies listed in the Shapley-Ames Catalog was completed using the large telescopes on Mount Wilson, Palomar, and Las Campanas in Chile. The new observations showed the need to expand the revised Hubble system by adding intermediate classes and by adding details to the older standard Hubble classes.

The revisions introduced before 1975 were outlined in an interim review by Sandage (1975a). These and additional ehanges and extensions made since include the following.

(1) The morphological boxes are narrowed by introducing the intermediate types of E/SO, SO/a, Sab, and Sbc between the wide Hubble E, SO, Sa, Sb, and Sc types, along with parallel intermediate classes in the barred sequence. This follows Holmberg's (1950, 1958) introduction of intermediate classes with his notation Sb~, Sb$^+$, Sc~, Sc$^+$, etc.

(2) The strength of SO classification criteria signaling the presence of a disk is recognized; the SO and SBO galaxies are designated subtle (S), intermediate (I), or pronounced (P) according to the degree of departure of the SO luminosity profile from the characteristic sharp luminosity cutoff of *K* galaxies. We retain the distinction of the three SO profile criteria. SO i, SOo. and SO3, invented in the Hubble Atlas (p. 11).

(3) In the very wide Sa and SBa morphological boxes, subtypes designating lateness arc introduced, based on current star-formation rates in the arms, size of the bulge-to-disk ratio, and the extent of the dust content.

(4) Luminosity classes for the spirals introduced by van den Bergh (1960a,b,c) are incorporated into the formal classification symbols. The classification criteria used here for these classes have been described and illustrated in *A Revised Shapley-Ames Catalog of Bright Galaxies*, pp. 96—127 (Sandage and Tammann 1981, 1987; hereafter RSA, RSA1, or RSA2).

(5) How the spiral arms are connected to the central region is introduced, whether starting tangent to an internal ring (r types) or starting from the center or the ends of a bar (s types). These features were invented but not incorporated in the formal notation used in the Hubble Atlas (pp. 23—26).

(6) Types later than Sc were introduced, adding the Scd, Sd, Sdm, and Im classes (and analogous barred types), as advocated by de Vaucouleurs (1959b), following Shapley (1950). This brings Lundmark's Magellanic Cloud type back into the system (Lundmark 1927).

(7) A formal class of "Amorphous" galaxies is introduced (Sandage and Brucato 1979), thereby eliminating Nubble's Irr class by dividing such galaxies between the Amorphous, the Sm, and the Im types. Holmberg's (1950, 1958) Irr I and Irr II classes are accounted for in this way as well.

(8) Dwarf galaxies are integrated into the standard classification system (Sandage and Binggeli 1984, Fig. 1).

These developments have been generally described piecemeal in the literature; the purpose of the present atlas is to provide a current (c. 1992) textbook of the galaxy classification system based on these revisions to the original Hubble system.

THE CARNEGIE BRIGHT GALAXY SURVEY

This atlas is the end product of the Carnegie Institution's long venture to obtain images of the brightest galaxies in the sky. The effort began with the photography of selected fields by Ritchey (1910) upon his completion of the Mount Wilson 60-inch reflector in 1909. It was continued by Pease (1917, 1920) using the 60-inch and then the Hooker 100-inch telescope, which came into operation at Mount Wilson in 1919.

Hubble and Baade expanded the program into a selected northern sky survey, carried out between the early 1920's and 1941. In an attempt to understand the diversity of galaxy forms, Hubble set out to complete the Shapley-Ames sample north of declination —20° using the Mount Wilson telescopes. In spite of these efforts, by 1948 high-quality plates had been obtained in good seeing for only part of the northern, and none of the southern, sky.

In 1949 a systematic program was begun using opportune observing time at the 200-inch Hale Telescope upon its commissioning at Palomar. To be sure, the classification program was secondary to the primary work at the Mount Wilson and Palomar Observatories, whose astronomers were heavily engaged in the new fields of stellar populations and stellar evolution and in the recalibration of the extragalactic distance scale. But such investigations also added to the growing collection of photographic plates available for taxonomic work. The galaxy illustrations in the 1961 Hubble Atlas were simply chosen from this plate collection as it existed in 1958.

From the developing knowledge of stellar evolution in the 1960's, it became evident that galaxy classification studies offered vast insights into questions of galaxy formation. With this as motivation, Sandage began a program in the early 1970's to complete the classification of all galaxies in the Shapley-Ames Catalog using high-resolution plate material; the effort required the completion of the northern sky survey using the Palomar Hale Telescope, and extension of the project to the South. The necessary survey began on a regular basis at Palomar in the late 1970's, and was completed for the northern fields by 1985. Upon construction of the 2.5-meter du Pont reflector at the Las Campanas Observatory, the southern observations were begun in 1977 and were finished in 1985.

Most of the plate material in the total collection has the high spatial resolution of 20—50 picture elements per millimeter. The telescopic focal-plane plate scales are 27 arc sec/mm for the Mount Wilson 60-inch reflector, 16 arc sec/mm for the Hooker 100-inch telescope, 29 arc sec/mm for the Swope 1-meter Las Campanas telescope, and 11 arc sec/mm for both the 200-inch Hale and the 2.5-meter du Pont Telescopes.

The galaxy classifications made from this high-resolution survey material are listed in the RSA. The present atlas is based on this classification system and, except for rare cases of reclassification, the galaxy types adopted here are the same as in the RSA2.

THE IDEA OF CONTINUITY IN THE CLASSIFICATION

How well has Hubble's starting guess as to relevance of morphological parameters succeeded in producing an objective classification system without contradiction? Hubble realized the danger of the hermeneutical circularity (see Chapter 1) in his claim that his classification contained no theoretical ideas. This, of course, was an illusion. He knew of (and he knew that he knew of) the **cosmogonical** ideas of Jeans (1928) concerning rotating, flattened **liquid** ellipsoids in a possible relation with the forms of E galaxies.

Hubble also drew upon intuitive ideas of continuity in his introduction of a "hypothetical" SO class in 1936, before the class had been discovered observationally. In **his** unpublished notes, c. 1940, he wrote,

> *The transition from £7 to Sa appeared so abrupt that, if real, it might be regarded as cataclysmic. With accumulating data, and especially with the increasing number of good photographs with the 100-inch reflector, the situation has clarified. Numerous systems are now recognized which are later than £7 but shoiv neither bars nor spiral structure. These nebulae fill the supposed gap between £7 and Sa and remove the excuse for postulating a cataclysmic transition.*
> [emphub nddi-d)

These notes suggest that by the late 1930's Hubble had already abandoned his claim that the system represented a pure Baconian arrangement **of** forms with no imposed judgments. He required continuity (and perhaps even evolution) *between* elliptical and Sa spiral galaxies, shown by his use of such expressions as "gap between E and Sa" types, "transition," and "cataclysmic process."

Did Hubble *impose* continuity by positioning morphological boxes along the sequence in the way he did? Indeed, is the apparent continuity along the sequence real? Understanding galaxy formation and the possible subsequent evolution through the morphological sequence hinge on this point.

Current evidence is that the continuity is indeed real. First, recall that the SO class was found *after* its hypothetical postulation as the provider of continuity betweeen the E and the spiral classes (Hubble 193 6b, Fig. 1); the case is similar to Mendeleyev's prediction of the elements gallium, scandium, and germanium from the Mendeleyev-Meyer periodic table before they were known. Second, such physical parameters as hydrogen content, rotational velocity, average age of the stellar content, and color—physical parameters not used in any way to define the classification—vary continuously along the sequence. The conclusion is that the modern classification indeed describes a true order among the galaxies, an order not imposed by the classifier.

The data-base used here is much larger and more refined than that available for the Hubble Atlas, and therefore provides a stronger case for continuity along the sequence than we could **make in 1961. The continuity** is now seen not only in (a) the transitional forms linking E, SO, and Sa (onus, to be discussed in Chapter 3, but also in (b) tin' systematic progression ol' the spiral **patterns** along the **entire** spiral **sequence from** SO/a **through Scd** types, (c) the progressive, systematic **change in** the **morphology** ol' luminous bars, (d) the systematic **change** ol' **the** dust lanes **in** these bars from SBa to **SBc** galaxies, (e) the patterns ol' the **"dust** only"' arms in the Sa though Sc galaxies of lliis type, and (I) many **other** features discussed **in the descriptions** here.

A purpose of this atlas is to **present** the evidence for this continuity. 'The ultimate purpose of the **classification** is to understand galaxy formation and evolution.

PRODUCTION OF THE ATLAS

Beginning in about 1977. negative photographic work-prints were made of all the candidate original plates **available** in the photographic survey files **in the plate archives** of **the (then)** Mount Wilson and **Palomar** Observatories or that were **obtained in** the 1977-1985 observing campaign at Las **Campanas** and Palomar. Copy positives were then made of each of the original plates. Enlarged negative work-prints were then made from the copy positives. This early work was carried out in the Pasadena photolab of the Carnegie Observatories between 1980 and 1985.

The negative work-prints were used lo format the sections of this atlas, ordered by the morphological types. The classifications had previously been **determined** from the same **plates.** They formed the basis of the types given in the RSA1 and RSA2 (Sandage and Tammann 1981, 1987). The **planning** of the individual pages of the atlas to describe the continuum along **the** classification sequence was done at The Johns Hopkins University during Sandage's 18-month leave of absence from Carnegie (1 986-1987). At the same time, Bedke was organizing the photolab at the Space **Telescope Science Institute,** following his **departure** from the Carnegie photolab **upon** its reorganization in Pasadena in 1985.

Upon completion of the formatting decisions for the 340 panels of the atlas proper and the 14 panels of the summary, printing of the final individual photographs from the copy negatives and positives began at the Space Telescope Science Institute photolab, operated by Computer Sciences Corporation under Bedke's direction. The final assembly of the panels was done there.

TECHNICAL DESCRIPTION OF THE ATLAS AND CODES USED

The atlas proper (Chapter 5) consists of 340 panels illustrating 1168 individual galaxies. The galaxies are arranged in the order of the present classification sequence, starting with diskless E galaxies and ending with the Sm and Im late-type dwarfs and the Amorphous types.

Most of the 1246 galaxies of the original Shapley-Ames Catalog (1932) are illustrated. However, adequate plates have not been obtained for about 6% of the Shapley-Ames entries and are not included, but no gaps in the illustrated classification sequence result from this incompleteness. A few galaxies not in the Shapley-Ames Catalog, mostly Im dwarfs, are included to complete the description for parts of the dwarf classification scheme (Sandage and Binggeli 1984).

Summarizing illustrations are placed in the summary set out in Chapter 3. These 14 panels highlight the principal classification criteria used in the atlas proper, and also include single panels illustrating the continuous change in the bulge-to-disk ratio along the sequence (panel S11) and the continuity in the multiple-arm pattern of the NGC 488 type from very early Sa to late Sc forms (panels S12 and S13). The progressive change in the spiral pattern in the dust-only-armed galaxies along the entire sequence is shown in panel S14.

Technical information on the galaxies and the plates used is provided in the descriptions facing each illustration panel, as follows.

The first line of each heading shows (1) the galaxy name, (2) the adopted morphological type, taken generally from the second edition of the RSA (Sandage and Tammann 1987) but occasionally revised from the present material, and (3) other information including (a) the panel numbers if the galaxy is shown elsewhere here, (b) the page in the Hubble Atlas (Sandage 1961) if shown there, (c) membership in known groups or clusters of galaxies, such as the Virgo Cluster (from the Virgo Cluster Catalog, VCC; Binggeli, Sandage, and Tammann 1985) or the Fornax Cluster (from the Fornax Cluster Catalog, FCC: Ferguson 1989), (d) if the plate was taken with a Racine wedge, giving secondary images to the bright stars, (e) the number in the Karachentsev (1987) catalog of close companion galaxies, if listed there.

Additional classification symbols for the SO, SBO, Sa, and the SBa galaxies are placed beneath the main morphological type. The symbols used with SO and SBO galaxies are P for pronounced, I for intermediate, and S for subtle SO characteristics, according to whether the departure of the SO luminosity profile from the sharp luminosity cutoff characteristic among E galaxies is large or small. Three symbols are used in the Sa and SBa sections (panels 59-107). (1) A division is made within the broad Sa and SBa morphological boxes by subdividing the boxes into four segments—"very early," "early," "intermediate," and "late,"—depending on the nature of the star formation in the arms judged from the number of knots in the arms, presumed to be HII regions or individual stars. The symbols are VE, E, I, and L. (2) The bulge-to-disk ratio is denoted by L, I, and S, for "large," "intermediate," and "small," in the second set of symbols. (3) The dust content is quantified on a scale of from 0 to 1 in the third set of symbols.

The second line shows the telescope, the plate number, and the observer. The telescope designations are

S	Mount Wilson 60-inch reflector
H	Mount Wilson 100-inch Hooker Telescope
Bex	Mount Wilson 10-inch refractor when it was operated in South Africa by Karl Henize
PS	Palomar 48-inch Schmidt telescope
PH	Palomar 200-inch Hale Telescope
PR	Carnegie 60-inch reflector at Palomar
CF	Las Campanas 1-meter Swope Telescope
CD	Las Campanas 2.5-meter du Pont Telescope

The plate numbers for plates taken alter 1958 are from the respective standard observatory record books. Before that date, both **at** Mount Wilson and at Palomar, individual numbers in each observer's personal record books provide **the** numbering system. (The new numbering system went into effect upon the retirement of Rudolph Minkowski, the last member of the original nebular department of the Mount Wilson and Palomar Observatories.)

The observers are

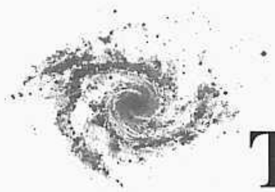
B	W. Baade
Bedke	**.1. Bedke**
Bm	W. A. **Baum**
Br	**R. J.** Brucato
D	A. Dressier
Duncan	J. C. Duncan
Gregory	T. Gregory
II	E. Hubble
HB	H.W. Babcock
Hendricks	D. 0. Hendricks
Henize	K. Henize
KW	K. Wakamatsu
MH	M. L. Humason
Mi	R. Minkowski
Monet	D. Monet
Pease	F. G. Pease
Ritchey	G. W. Ritchey
Rose	J. Rose
S	A. Sandage
Seares	F. H. Seares
Sch	F. Schweizer

The third line shows the date of the plate.

The fourth line gives the emulsion type plus filter. Most plates have blue-sensitive emulsions (Seed 30, Cramer Hi-Speed Special, Eastman 103aO) with an effective wavelength of 4400 Å and a bandwidth of about 1000 Å. Some few plates are on a yellow-sensitive emulsion (Eastman **103aD)** with **effective** wavelength of 5500 Å and a bandwidth again of 1000 A. A **few** plates are also in the near red (Eastman **L03aE),** with an **effective** wavelength of 6500 Å and a bandwidth of about 1500 A.

The last line is the exposure lime.

SUMMARY OF THE CLASSIFICATION



The sequence of the descriptions in this chapter is generally from E through SO, and then through the ordinary spiral sequence (SO/a, Sa, Sab, Sb, She, Sc, Scd, Sd, and Sm), followed by the barred sequence. The ordinary spiral types are illustrated in summary panels SI through S6. The barred branch is illustrated in the summary panels beginning with S7.

Note that this sequence differs from that used in the atlas proper. The panels there go from early to late, with the ordinary and the barred morphological boxes interspersed. That scheme shows continuity in the star-formation rate along both sequences regardless of the presence of a bar. We consider the change of the star-formation rate with time to be the primary physical determinant of morphological type (Chapter 4).

But in this chapter, separate treatment of the barred and ordinary spirals helps show that the visual appearance of the mean components of form (disk, bulge, a bar or not, arms and whether they attach to the center or to a bar) are controlled more by the dynamics than by the current star-formation rate.

E Galaxies

(Panels SI, 1-24)

Three features define the classification of E galaxies. (1) Biaxial symmetry of a smooth luminosity profile exists; the luminosity distribution is nearly symmetrical about both the major and the minor axis. (2) There is no prominent disk, judged in the most-flattened forms by inspection and in the less-flattened forms by inference based on the sharp cutoff of the luminosity profile (contrasted with the extended envelopes in SO types). (3) There is no recent star formation, inferred from the absence of luminous blue and red supergiants.

The luminosity profile is a smoothly decreasing function of distance from the center, following a modified 1 lublile profile defined by Oemler (1976) as

$$/(/\bullet) = /(0)(i + r/6)^{-2} \exp[-(r/a)^2],$$

where 6 is the "core" radius and *a* defines a cutoff sharpness thai is stronger than the r^{-2} dependence of the original Hubble (1930) luminosity law.

To the eye on photographic plates, E galaxies appear to have a range of *a* (cutoff) values. The sharpness of the luminosity cutoff is often discussed in terms ol "compactness" for particular E galaxies (panels 1-24). When the luminosity profile reaches a particular shallow gradient at large radii, showing what appears to be an envelope, the galaxy is classed SO. The presence or absence of such an envelope is often the deciding criterion between the E and the SO classes.

The presence of the envelope in galaxies seen nearly face on is interpreted as the signature of a disk, presumed to be seen explicitly as pointed-ended isophotes in similar galaxies seen nearly edge on. E galaxies, by definition, have no such envelope features.

The presence or absence of dust is not used as a classification criterion. Some E galaxies fulfilling the three classification criteria have dust patches and remain classified as E types.

E galaxies show a range ol apparent flattenings horn E0 to E6. The flattening index is defined as]()(« - *b)/a*, where *<i* and *b* are the apparent major and minor axis diameters (not to be

confused with the *a* and *b* of the core and cutoff radii in the equation above).

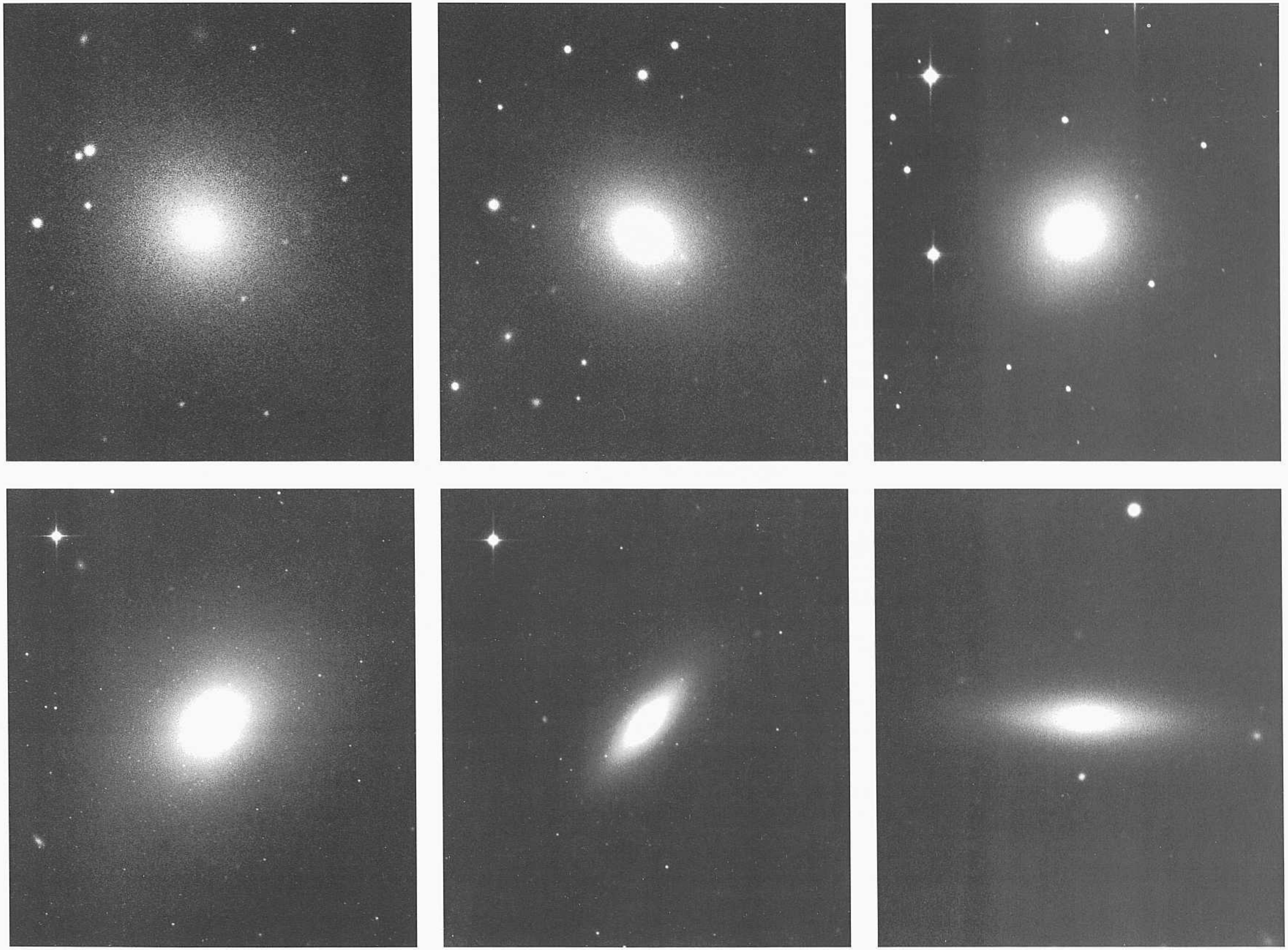
The most-flattened form that definitely has no disk is E6. Disks are usually seen in the more highly flattened E galaxies, such as NGC 3115 (originally classed as E7 using early plates), and in many SO galaxies such as NGC 4251, NGC 4179, NGC 5422, and NGC 3203 on summary panel S2. Only two galaxies in the RSA2 are now classified as E7 (NGC 4342 and NGC 4623). NGC 4623 is shown on the summary panel SI; note the absence of a disk which, even if judged present, would be weak compared with the prominent disks in the SO galaxies summarized in panel S2.

The true distribution of intrinsic flattenings can be recovered from the apparent flattening distribution if the true three-dimensional figure is an oblate spheroid (two equal axes with the third smaller than the other two). On this assumption, the true flattening distribution is a function that is peaked at about E3 (an axis ratio *alb* of 1.5), decreasing toward both the spherical and the highly flattened ends of the distribution (Sandage, Freeman, and Stokes 1970; Noerdlinger 1979). If the intrinsic form has three unequal axes, the recovery of the true flattening distribution from the observed apparent distribution has no unique solution.

Six typical E galaxies that span the range of apparent flattenings are shown in the summary panel SI. NGC 4623 (panel 13) is the only "true" E7 in the RSA2, but even in this case there is a faint suggestion of a disk, as described in panel 13. A tentative alternative classification is (E/SO?), taking cognizance of a possible subtle disk.

The absence of disks in E galaxies is the principal reason for supposing that the initial star formation in E galaxies occurred in a time interval shorter than the dynamical collapse time of the protogalaxy gas from a larger volume (see Chapter 4). If so, star formation was completed before the occurrence of energy dissipation by gas-gas collisions. *Dissipation alivays forms a disk.* The absence of significant dissipation early in E-galaxy formation (gas-gas collisions in the original protogalaxy) shows that initial star formation used up all the available gas before a disk could form. Because this time interval is short, the present stars in E galaxies (and in the bulges of spirals) are old.

IC 4296 EO panel 2 CD-1861-HB April 6/7, 1981 103aO 75 min	NGC 777 El panel 4 PH-7826-S Sep 2/3, 1980 103aD + GG11 17 min	NGC 1549 E2 panel 5 CD-1704-S Jan 5/6, 1981 103aO 75 min
NGC 4365 E3 panels 7, 18 CD-792-S VCC 731 Feb 23/24, 1979 103aO + Wr2c 75 min	NGC 4564 E6 panel 13 CD-733-S VCC 1664 Feb 2/3, 1979 103aO + Wr2c 45 min	NGC 4623 E7 panel 13 PH-628-B VCC 1913 June 20/21, 1952 103aO + GGl 45 min



PANEL

SI

E/SO, SO/E Galaxies

*(Panels 25-29; not illustrated in **the** summary panels)*

T hirty galaxies are listed as E/SO or SO/E types in the RSA2; all but two are illustrated in this atlas.

On short-exposure plates showing only the central regions, no evidence of a disk or extended envelope is seen; the morphologies of the central regions are pure E. On longer exposures showing the outer regions, the envelopes are extended, unlike pure E halos. The flattening ratio of the extended envelope is generally different from that of the central E-like bulge. This is taken to be evidence of a weak disk.

Because of the subtlety of the outer envelope feature, i.e. a shallower luminosity gradient than in E galaxies, such galaxies are often misclassified when using plates having small linear plate-scales. Many of the E/SO galaxies classified here from long exposures taken with the large reflectors have been previously misclassified in the older literature, as discussed in many of the descriptions in this atlas.

SO Galaxies

(Panels S2, 30-53)

Histories of how the SO class was introduced have been set out elsewhere (Sandage 1975a; HA, p. 10). The first literature reference to Hubble's discovery of the class was made by Spitzer and Baade (1951), based on Baade's prior discussions with Hubble sometime between 1936 and 1942.

The classification criteria for SO galaxies are threefold. (1) A disk is present, seen directly in the nearly edge on galaxies of this type or, in the more-face-on galaxies, betrayed by an extended envelope. The far-envelope cutoff in SO galaxies differs fundamentally from the sharper cutoff in E galaxies. (2) Spiral structure is totally absent in the disk. (3) There are no recently formed luminous stars, shown by an absence of resolution into stars brighter than absolute magnitude Mg = -1.5.

The presence or absence of dust has no role in the classification. Nor have any of the stellar content parameters, such as the presence of recent star formation, the neutral hydrogen content, the CO content, and the X-ray properties. The classification is based solely on the presence of a disk and the absence of spiral arms.

The more-detailed description of the SO characteristics given in the HA is not repeated here. The classification criteria described there remain standard. However, as in the RSA, we have added a flattening index, shown in parentheses after the formal class notation. As explained in Chapter 2, we have also indicated the subtlety of the SO morphology, based on the degree to which a disk is either visible or inferred. The three notations are (S) for "subtle," (I) for "intermediate," and (P) for "pronounced" SO characteristics.

The three types of SO forms introduced in the HA are retained here. Galaxies of SOj subtype, where the luminosity profile is smooth and exhibits no apparent discontinuity in gradient upon visual inspection of photographic plates, are illustrated in panels 30–37, arranged in the order of the flattening.

Galaxies of the SO2 subtype, where subtle departures from smoothness in the profile exist, are illustrated on panels 38—42. Note that an intermediate subdivision of SO 1/2 has also been introduced.

Galaxies of subtype SO3 (again with an intermediate subdivision, SO2/3) are illustrated on panels 42—45. Galaxies of this subtype show evidence of dust, either as partial lanes (the SO9/3 intermediate subdivision) or as complete dust rings. The latter appear to be circles; they show no spiral pattern like that seen in the "dust-only arm" real spirals, where the arms formed of dust are truly spiral arcs.

Other features of the SO class are illustrated; these include the prolate cases (panels 45 and 46), galaxies with boxy bulges (panel 47), and galaxies with unusual dust patterns (panels 48 and 49). A summary of the salient features of the entire SO class is given at panel 53 as well as in panel S2 here.

The three galaxies in the top row of panel S2 are prototypes of the SO] subtype. There is no sign of dust. The luminosity profile is smooth, exhibiting what often appears to be three luminosity zones but in actuality having no luminosity breaks between them. The visual appearance of three zones may be an artifact of the human eye-brain connection tending to interpret a change in the luminosity gradient as a discontinuity.

NGC 3245, at the upper left in panel S2, has an extended luminosity profile rather than a sharp cutoff as in E galaxies. We interpret this to be a disk seen at an intermediate viewing angle. The disks in the two other SO galaxies in the top row are evident.

NGC 32 03 , in the middle of the bottom row, is an $S0_2$ prototype. Two ansae are embedded half-way out in the disk. Excellent examples of the form are on panel 47. If the luminosity difference between the edge of the bulge and the ansae deepens, owing to a relatively opaque dust ring, the SO 3 subtype would result.

The internal dust ring characteristic of SO3 subtypes is seen in NGC 4429, at the right of the bottom row in panel S2 . The best examples of SO3 galaxies are displayed on panels 43-45. NGC 4429 has embryonic smooth arms. It is the prototype example of a transition galaxy between the SO class and the very early Sa class.

SO/a, SO/Sa Galaxies

(Panel S2, various panels from 59-84)

A hirty-nine RSA galaxies of types SO/a, SO/Sa, SBO/a, and SBO/SBa are listed in the binning table of the RSA, p. 7 5. All but one are illustrated here in the early parts of the Sa and SBa sections.

The principal discriminating criterion for the SO/a and SO/Sa classifications is a departure of the luminosity profile from strict elliptical symmetry. The departure is caused by two diametrically opposite luminous features emerging from the bulge. The features are not parts of circular arcs but are "massive sweeps" that spiral outward much like the more-conspicuous and better-formed *arms* in the earliest pail of the Sa and SBa sequences.

These spiral features arc subtle in the earliest galaxies o(the SO/a type. They would he missed on small-scale plate material. It is in this and in the early Sa and SBa part of the classification sequence thai many current (1992) literature classifications differ from those given here. Misclassifications in these sections have led to noise in correlations relating galaxy classes to physical parameters, such as the neutral hydrogen content (Hogg. Roberts, and Sandage 1993).

The classifications SO/a and SO/Sa differ in the subtlety of the embryonic arms; the former has subtler "arm" stubs than the latter.

Beginning with galaxies of this type and continuing through the Sa and SBa sequences (panels 61—107), we have added three subsidiary descriptors: lateness (based on the degree of star formation in the arms), bulge-to-disk ratio, and the dust content (see Chapter 2).

These secondary descriptors for nearly all SO/a, SO/Sa, SBO/a, and SBO/SBa galaxies are (VE,L,0), denoting (very early) smooth arms, large bulge-to-disk ratios, and no evident dust content, respectively.

NGC 442 9, on panel S2, is a prototype example of the SO/Sa transitional class.

INGC 3245 SO!(5) panels 32, 33
H-2160-H (P)
Jan 29/30, 1941
Cr-Hi-Sp-Sp
60 niin

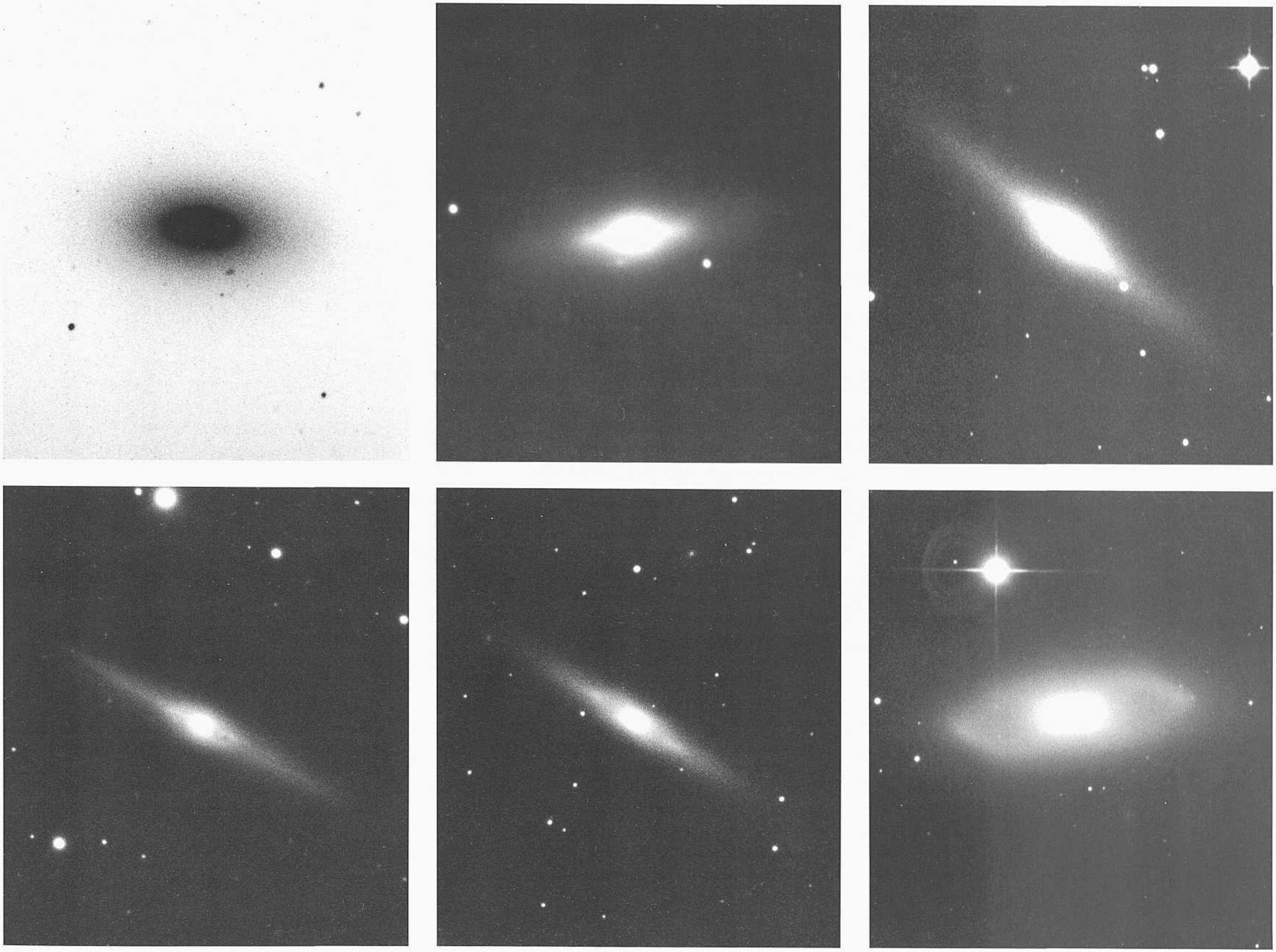
NGC 5422 Sa or $S0_3(8)$ panel 50
PH-7739-S (P) Racine wedge
June 11/12, 1980
103aO
12 niin

NGC 4251 S0,(8) panel 36
PH-7987-S (P)
Feb 1/2, 1981
103aO
12 min

NGC 3203 $S0_2(7)$ panel 47
CD-1394-S/Br (P)
March 22/23, 1980
103aD + GG495
60 min

NGC 4179 S0i(9) panel 36
CD-2102-S (P)
March 18/19, 1982
103aD + GG495
45 niin

NGC 4429 $S0_3(6)$/Sa pec panel 60
CD-710-S (VE,I,0) VCC 1003
Jan 30/31, 1979
103aO + Wr2c
45 niin



PANEL

S2

THE ORDINARY SPIRALS Sa THROUGH Sd

The variation of three classification criteria first set out by Hubble (1926, 1927)—bulge size, size of the opening angle of the spiral pattern, and rate of recent star formation—is quantized into seven morphological boxes, containing the Sa, Sab, Sb, Sbc, Sc, Scd, and Sd types, respectively.

The terms "early" and "late" refer to the placement of the morphological boxes along the classification sequence. Sa galaxies are early; Sd galaxies are late. These traditional terms, initially arbitrary, are unfortunate: there is a danger of inferring an evolutionary implication, but the designations have no such meaning. No ideas of temporal or developmental change have been used in defining or in assigning the classification types; both have been done by morphology alone.

A further subdivision distinguishes the spiral-arm type, whether (a) multiple-armed (MAS) or (b) grand design (GD), generally two-armed, spirals. Each type is found in the eai'liest part of the Sa section and can be traced throughout the Sb, Sc, and Sd classes and in the parallel barred classes as well. Hints of this continuity within the total classification sequence are given in the Hubble Atlas (see the description to NGC 5055, HA, p. *15)*, where a preliminary tracing of the NGC 488 multiple-fragmentary-arm pattern (MAS types) was set out in the Sa through the Sd sections. Prototypes for MAS galaxies are NGC 488 (panels S3, S12, 115, 116) and NGC 2841 (panels S4, S12, 142): a prototype for GD galaxies, predominantly having only two major arms, is NGC 3269 (Sa; panels S3, 63).

The basic (s) and (r) subclassifications, which indicate how the arms begin in the inner regions, can be first identified in the Sa section. The arms begin near the center in the (s) types in ordinary spirals, or at the ends of the bar in the barred types. They begin tangent to an internal ring in the (r) types in both ordinary and barred types.

Sa Galaxies

(Panels S3, 61-88)

Sa galaxies are the earliest of the spirals having well-defined arms. True spiral arms first appear in this section, although embryonic arms are present in the transition type SO/Sa (panels 59-60).

The general Sa characteristics are (1) large bulges, (2) the arms are very tightly wound, as defined by the small opening angle of a fitted logarithmic spiral (the pitch angles of the Sa logarithmic spirals are near 0°; Kennicutt 1981), and the rate of recent star formation (stars and HII regions) in the arms is near zero in the very early smooth-armed Sa galaxies, and is small but finite in the later part of the Sa section (Hogg *et al.,* 1993).

The Sa morphological box is very large. The earliest forms are similar to NGC 2681 (early arm type, large bulge-to-disk ratio, 1/4 dust type) (panels 62, 87; HA, p. 9) where (a) the arms are smooth, (b) they show no evidence of recent star formation, and (c) they are ill-defined, only slightly clearer than the embryonic arms of the SO/a class. The latest Sa galaxies at the border with the Sab morphological box have well-defined arms that show evidence of a moderately high rate of recent star formation. Examples are NGC 1371 (E/I,I,l/4) (panels S3, 64, 80, 88), and NGC 2775 (I,L,l/3) (panels S12, 78,87).

Galaxies of the (r) subtype are particularly evident in the Sa class, featured individually on panels 66-69.

The galaxies in the Sa section are organized in five groups.

(1) The smooth-armed Sa types are on panels 61-65, showing a continuity in the progression from the earliest SO/a to the later grand design, smooth-armed spirals such as NGC 718 and NGC 3269. The smooth multiple-armed types are on panel 62.

(2) The ring, near-ring, and broken-ring types are on panels 66—7 1, generally ordered by the degree of lateness within the Sa morphological box, and also ordered by the ring type (panels 70-71 compared with galaxies on panels 66-69).

(3) Also beginning in the Sa section are the galaxy forms where the spiral arms are defined entirely by dust lanes; no recent star formation is evident in the dust. The Sa galaxies of this type, on panels 72—76, are arranged progressively from very early Sa to the border of the Sa with the Sab morphological box.

(4) The continuity of the MAS type along the Sa section, and the similarity of Sa galaxies of this type, albeit progressing from early to late, are illustrated on panels 77-80.

(5) A summary of the multiple-armed Sa type, arranged from early to late, is on panel 87. A similar summary, again in a progression from early to late, of grand design Sa galaxies is on panel 88. A less-detailed summary where arm types are mixed is at panel S3, showing the continuity with the later MAS prototype Sab galaxy, NGC 488.

The prototypes of the smooth-armed early Sa's are NGC 32 69 and NGC 7096, shown in the first two frames in the top row of panel S3 . The smooth arms in such early Sa's are red, similar to the color of E and SO galaxies (Kennicutt and Edgar 1986), thereby showing no evidence of recent star formation. Each is of the two-principal-armed (grand design) type rather than the multiple-armed (MAS, or filamentary) type, of which NGC 488 in the middle of the bottom row is the prototype. The recent star-formation rate is near zero in the early Sa's, increasing to a small rale in **the** latest Sa's, such as NGC 1371 and NGC 2460 in the bottom row of **panel** S3. The current star-formation rate in all Sa galaxies is **smaller than** in Sb and much smaller than in Sc galaxies, as is dear by comparing the galaxies on panel S3 with those on panels S4—S6.

Sah Galaxies

(Panels 108-119; not illustrated ***in*** *the* ***summary panels)***

JL he classification criteria for **the** Sab galaxies, lying between the Sa and the Sb classes, are (1) the central bulge is smaller than in Sa galaxies, larger than in Sb types, and nearly always devoid of recently formed stars, (2) the current star-formation rate in the arms is higher than in all galaxies of class Sa but lower than in Sb galaxies, and (3) the arms are slightly less tightly wound and dominate the apparent morphology seen in the overall image more than in Sa galaxies.

The luminosity class as defined by van den Bergh (1960b,c) for Sb and Sc, is introduced into the formal classification notation at this stage. The class assignment is made from the regularity of the spiral pattern, sometimes called the geometrical entropy. These classes range from I through IV on an arbitrary scale defined by the prototype examples illustrated in the RSA (Sandage and Tammann 1981, 1987, pp. 96-127). The luminosity classes in this atlas are on the system defined in that catalog.

NGC 3269 Sa panel 63
CD-616-Br (VE,I,O) Antlia 184
Jan 4/5, 1979
103aO + GG385
45 min

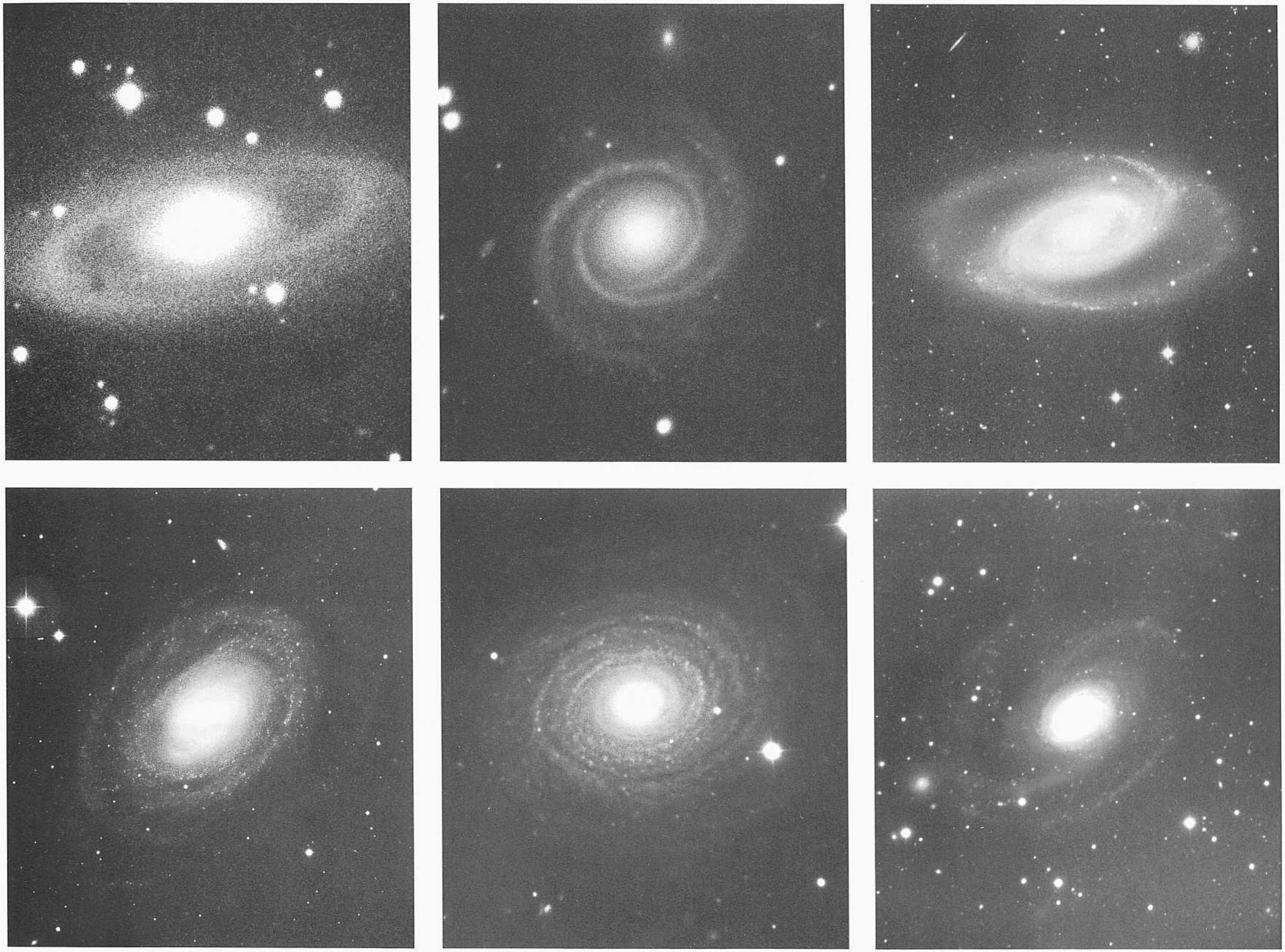
NGC 1371 Sa(s) panels 64, 80, 88
CD-495-S (E/I,I,1/4)
Sep 26/27, 1978
103aO + GG385
45 min

NGC 7096 Sa(r)I panels 68, 88
CD-518-S/Br (I,L,0)
Sep 29/30, 1978
103aO + GG385
45 min

NGC 488 Sab(rs)I panels 115, 116, S12
PII-1053-S
Aug 24/25, 1955
103aO
30 min

NGC 1350 Sa(r) panels 71,88
CD-543-S (L,I,1/2)
Oct 1/2, 1978
103aO + GG385
45 min

NGC 2460 Sab(s) panels 111, 145
PII-7898-S
Nov 6/7, 1980
IHaJ
120 min



PANEL

S3

PANEL

S4

Sb Galaxies

(Panels S4, 124-153)

The many features of the spiral pattern first identified in the Sa section and traced through the Sah types are also seen throughout the Sb section, but characterized by the "later" manifestations. Subclassification divides the (r) and (s) spiral subtypes, which describe how the arms are connected to the central regions, and the grand design (generally two-armed) and filamentary, multiple-armed spiral (MAS) types.

The most-pronounced difference between Sa and Sb spirals is the smaller central bulge of the Sb's, well seen in the illustrations. The arms in Sb galaxies are intermediate between those of Sa and Sc galaxies in their domination of the total impression of the galaxy image.

The 30 panels of the Sb class are organized by luminosity class: within each class, grand design (GD) spirals precede the MAS types.

Galaxies of type Shi, the highest luminosity class, are illustrated on panels 124-128: GD forms are at panels 124-126, MAS types at panels 127-128.

ShI-II galaxies are on panels 129—134: GD types are at panels 129-131, MAS at 132-134.

Sbll galaxies are on panels 135-141: GD arc at 135-137. MAS at 138-139, and intermediate types at 140-141 .

The Sbll-III galaxies are at panels 142-144; no separation into the two spiral types is made.

Peculiar galaxies having a predominant SI) morphology are on panels 146-148.

Typical Sb bulge sizes are shown in the galaxies thai are nearly edge on at panels 149-152.

Illustrations of Sb galaxies that are interacting pairs are on panel 153.

Five of the six prototype Sb galaxies on panel S4 are of the MAS type. NGC 5054 at the lower right has arms of the grand design type, though there are three such arms rather than the more usual pattern of two.

Most of the galaxies on this summary page are of bright luminosity class I—II.

NGC 2841 Sb panels 142, S12
PII-36-S
Nov 7/8, 1951
103aO + WG2
25 min

NGC 3675 Sb(r)H panels 139, S13, S14
PII-7632-S
April 28/29, 1979
103aO
12 min

NGC2613 Sb(s)(II) panel 139
CD-154-S
Feb 3/4, 1978
103aO + GG385
45 min

NGC 3223 Sb(s)I-II panel 13-1
CD-1455-S/Br
May 7/8, 1980
103aO + GG385
45 min

NGC 6384 Sb(r)1.2 panel 127
PII-7812-S
Sep2/3, 1980
1<>3aO
12 niin

NGC 5054 Sb(s)I-II panel 130
CD-819-S
Feb 26/27, 1979
103aO +Wr2c
45 min

Sbc Galaxies

*(Panels 1 **71—198;** one galaxy **on** panel S5)*

The intermediate Sbc class is defined by a morphology later than Sb but earlier than Sc in (1) the size of the nuclear bulge, (2) the openness of the arms, and (3) the regularity and the dominance of the spiral pattern in the total morphology of the form. The nuclear bulge is often moderately small, as in the earliest of the Sc galaxies.

The principal criterion separating the Sbc and Sc forms is the greater coherence of the Sbc arm pattern seen over the full image. Comparison of prototypical Sbcl galaxies, such as NGC 15 66 (panel 171) and NGC 5194 **(M51;** panel 172), with the **Scl** prototypes, NGC 4303 (panel 213) or NGC 5457 (Ml 01; panel 218), illustrates the differences in the coherence of the arm patterns.

The first 13 panels (171-183) show Sbc galaxies of the grand design type of both the (r) and (s) variety. Galaxies of luminosity class I and **I-II** that show characteristics of both the grand design and the multiple-arm pattern are on panel 184. Almost-pure MAS types are on panels 185—192, ordered by luminosity classes ranging from I to **II.**8.

The highly unusual galaxy NGC 1808, having high dust content and evidence for extension of the dust above the **fundamental** plane, is on panel 193.

Highly inclined Sbc galaxies are illustrated on panels 194—195, showing the **smallness** of the Sbc bulges compared with those of Sab (panels 112-114) and Sb (panels 149-154) galaxies seen at similar inclinations.

Sc Galaxies

*(**Panels** S5, S6, 213-292)*

The morphological box that contains the most RSA galaxies is Sc (see RSA Fig. 1, page 91). Of the 639 ordinary spirals of types Sa through Sd in the RSA, 2 96 are Sc galaxies.

Characteristics change progressively from the Sa to the Sc sections in the standard criteria related to the nuclear bulge and the character of the arms. In Sc galaxies (1) the nucleus is generally very small, yet present, unlike its absence in most Sd, Sm, and Im galaxies, (2) the arms have an open pattern, defined as a relatively large angle between the spiral locus and the osculating circle at any given point in the spiral (the opening angle is, of course, constant with changing radius for logarithmic spirals), and (3) the rate of recent star formation in the arms is high compared to the rate in Sa and Sb arms.

Much ol the total range in the van den Bergh luminosity classes exists within the Sc section. The progressive variation in luminosity class is manifested by the large range in the morphology of the spiral arms, complicating classification within the Sc section and showing the need for dividing the section into subsections by luminosity class and by spiral-arm (GD or MAS) **type.**

Detailed descriptions of the luminosity class criteria in the Sc section are given on pages 98-10 9 of the RSA (Sandage and Tammann 1981, 1987) for Scl through ScIII-IV galaxies. The variations of the arm morphology, illustrated there, show the prototypes upon which the classifications in the present atlas are based.

The features of the (s) and (r) arm-attachment varieties, and the continuity of development among these types, stressed in the earlier-type descriptions, are evident throughout the Sc sequence. The summary illustrations in the RSA show the development.

The organization of the atlas illustrations for the very wide Sc section is as follows.

(1) Scl galaxies are presented in panels 213-221; this subsection is further subdivided into the GD type, where two principal arms exist (panels 213-215). and the multiple-armed types (MAS), where the spiral arms are filamentary and cover much of the underlying disk (panels 216—221).

(2) ScI-II galaxies on panels 222-234 are divided into the GD (panels 222-228) and the MAS (panels 229-234) subtypes.

(3) The largest single section illustrates Sell galaxies (panels 235-258). Grand design Sell's are on panels 235-240: thin, multiple-armed galaxies (MAS types) are on panels 241-247; intermediate-thickness, multiple-armed galaxies are at panel 248; MAS galaxies having massive spiral arms, in the sense of Reynolds (1927a,b), are on panels 249-253; filamentary spiral-armed galaxies having arms similar to but later than those of NGC 488 are on panels 254-255; galaxies with faint outer "fossil" arms are on panels 256-257.

(4) ScII-III galaxies having thin arms are on panels 259-265; those having arms of intermediate thickness are on panels 266-268; those with massive arms in the sense of Reynolds are on panel 272.

(5) ScIII high-surface-brightness galaxies are shown in panels 273-274.

(6) An assembly of multiple-armed (MAS) Sc galaxies having arms similar to but later than those in NGC 488 is shown on panels 277-279. Inspection shows the continuity of the NGC 488 form—a continuity that can be traced from the early Sa at least to this late position in the Sc section.

(7) Interacting galaxies where at least one galaxy is of class Sc are shown on panels 280-284.

(8) Highly inclined Sc galaxies, classified by the size of the central bulges, are shown on panels 285—291.

(9) Peculiar Sc galaxies are shown in panel 292.

Four of the six Sc galaxies illustrated in the summary panel S5 here are of the highest-luminosity classes (I or I-II). The arms are regular, and the fragments belonging to each can generally be traced without uncertainty. Note the absence of easy traceability in the two later-luminosity-class Sc prototype galaxies in this panel: NGC 3184 has arms that are more fragmented than those of NGC 1566 or NGC 2997. The fragmentation is even more pronounced in NGC 5055. In both NGC 3184 and NGC 5055, the inter-arm region is less distinct than in luminosity-class-I Sc galaxies of the MAS type, such as NGC 1232 (panel 216) or NGC 5364 (panel 217).

NGC 1566 **Sbc(s)1.2** panel 171
CD-1697-S
Jan 4/5, 1981
103aO + **GG385**
45 min

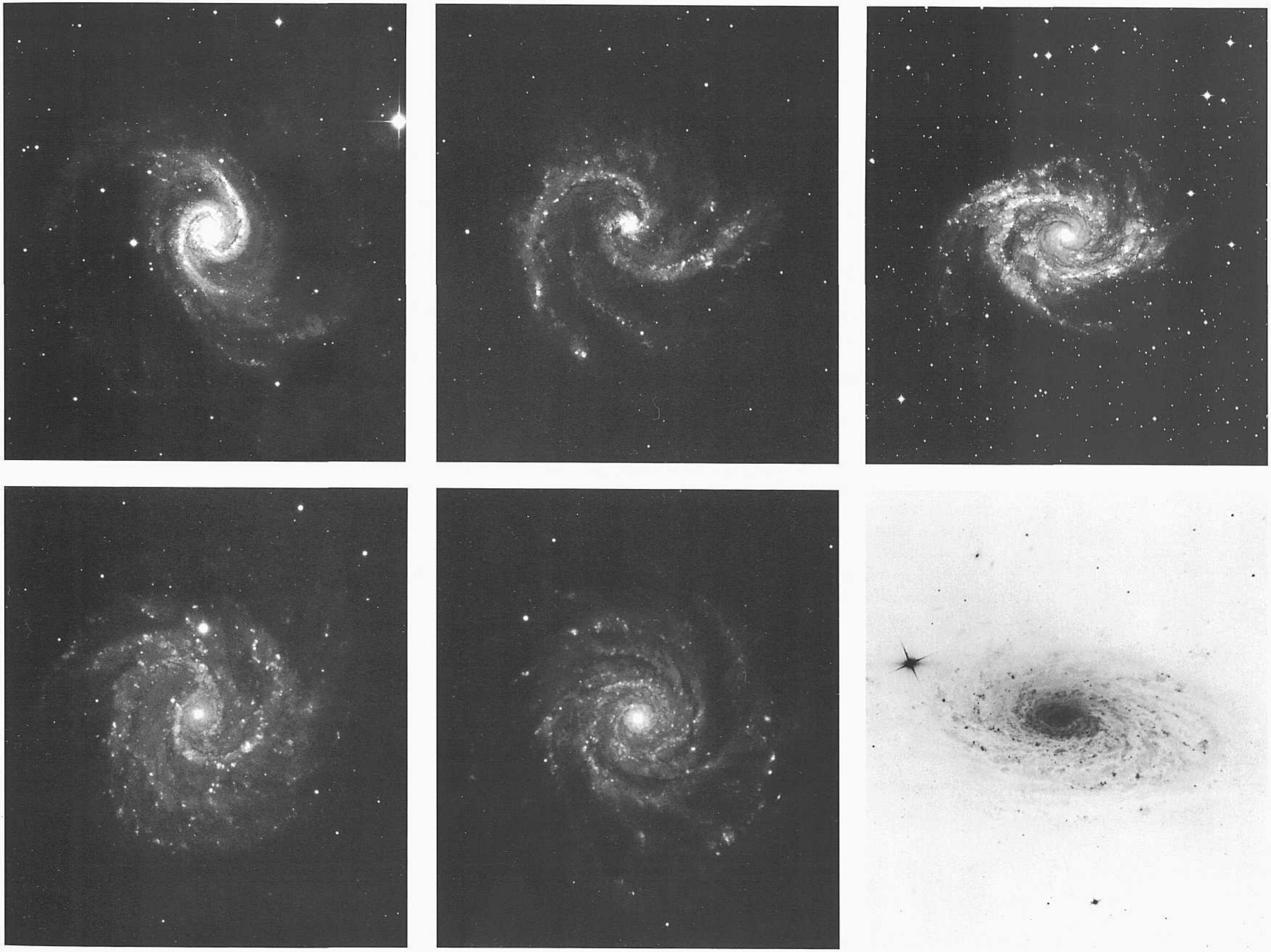
NGC 3184 Sc(r)II.2 panel 237
PH-7993-S
Feb 2/3, 1981
103aO
12 min

NGC 5247 Sc(s)I-II panel 223
CD-2197-S
March 30/31, 1982
103aO + GG385
45 min

NGC 3938 **Sc(s)I** panels 219, 220
PH-7637-S
April 28/29, 1979
103aO
12 min

NGC 2997 Sc(s)1.3 panel 222
CD-740-S
Feb 3/4, 1979
103aO + GG385
45 min

NGC 5055 Sbc(s)ii-m panel 191
H-93-Dimcan
May 14/15, 1926
E33
180 min



PANEL

S5

Scd Galaxies

(Panels 314-320; one galaxy on summary panel S6)

Galaxies later than Sc have progressively less-well-defined spiral arms and have only a very small or no central bulge. Seen on edge, as in the 14 Sc, SBc, SBcd, and Sd galaxies on panels 318-320, no central bulge is evident.

The rate of recent star formation is robust. The parts of arms that are evident as spiral segments are filled with bright young stars and HII regions. Even in the absence of evident arms, the disk is covered with star-forming regions, generally in associations but often in relatively isolated areas over much of the disk as well.

The absolute magnitudes are appreciably fainter than those of galaxies of earlier types. Because the RSA is a magnitude-limited catalog, the distances of these late-type RSA galaxies are also generally smaller than those of the earlier galaxy types. Hence, many galaxies of this type in the RSA and this atlas are highly resolved into stars, HII regions, star clusters, and associations. Such galaxies are particularly important for study of the local extragalactic distance scale.

Sd, SBd, Sm, SBm, and Im Galaxies

(Panels S6, S10, 321-332)

The spread within Hubble's original Sc morphological box was vast. The galaxies shown now in the Sc section of this atlas (panels 213—292) and many of the galaxies on summary panel S6, here, were classified as Sc by Hubble. Later, Shapley and Paraskevopoulos (1940) and Shapley (1950) divided the Hubble Sc box in two, and called the later part of the original Sc box type Sd.

Even later types than Sd were reintroduced by de Vaucouleurs (1959b) following Lundmark's (1927) original inclusion of Large Magellanic Cloud (Sm) and Small Magellanic Cloud (Im) types. In the present classification, we have placed these galaxies at the end of the Sd sequence. These types provide lead-ins to the dwarf irregulars of the SMC type (Im) and the dwarf E galaxies such as NGC 4286 (dE,N; panel 20) in the dwarf classification system devised by Sandage and Binggeli (1984).

This extension of the system for the dwarfs attaches smoothly to the standard classification system for the earlier, more-luminous types. The whole of the classification thus maintains a continuum in the morphological forms over its total range.

The classification of the dwarfs is summarized in Fig. 1 (this page), modified from the original paper (Sandage and Binggeli 1984). Prototype examples of the various parts of the marked dwarf sequences are illustrated in the atlas accompanying that paper. Very few dwarfs are in the RSA because of its bright apparent magnitude limit; the Blue Compact Dwarfs (BCD) are not illustrated in the present atlas because of their absence in the RSA.

The six prototype galaxies in this very late part of the classification sequence are shown on panel S6 here. NGC 300 is the latest Sc shown, situated at the junction of the Sc with the Scd morphological box.

NGC 45 is the Scd prototype. The spiral arms are still well traceable although quite chaotic. NGC 4395 is closely the same, although the spiral pattern is not quite as well defined; the assigned type is Sd.

NGC 7793 is a later Sd; the spiral pattern is more diffuse than that of NGC 4395, but it still is present.

The last two galaxies in the bottom row are of the Magellanic Clouds type, one an Im and the other an Sm similar to the Large Magellanic Cloud.

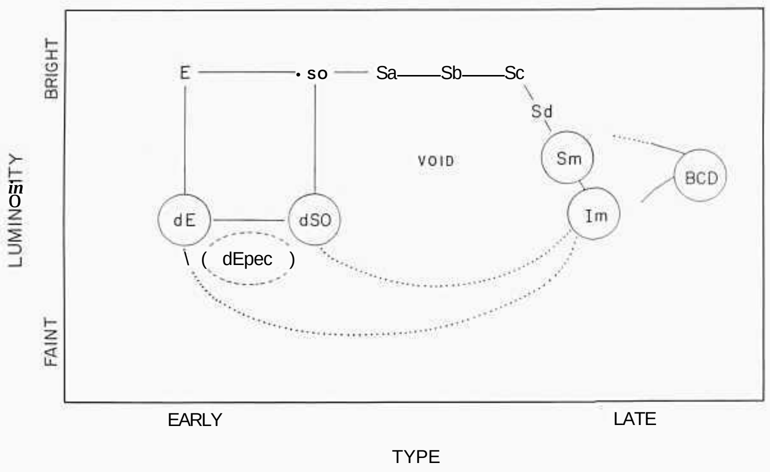


FIG. 1. The dwarf classification system of Sandage and Binggeli (1984) in its relation to the remainder of the classification system presented in this atlas. The great void between the dwarfs and the Sa, Sb. and Sc Hubble types is real; there are no dwarf spirals. Dotted lines indicate the possible relation between early- and late-type dwarfs.

NGC 300 Sc(s)II.8 panel 261
CD-2043-Bedke/Gregory
Nov 2/3, 1981
103aD + GG485
121 min

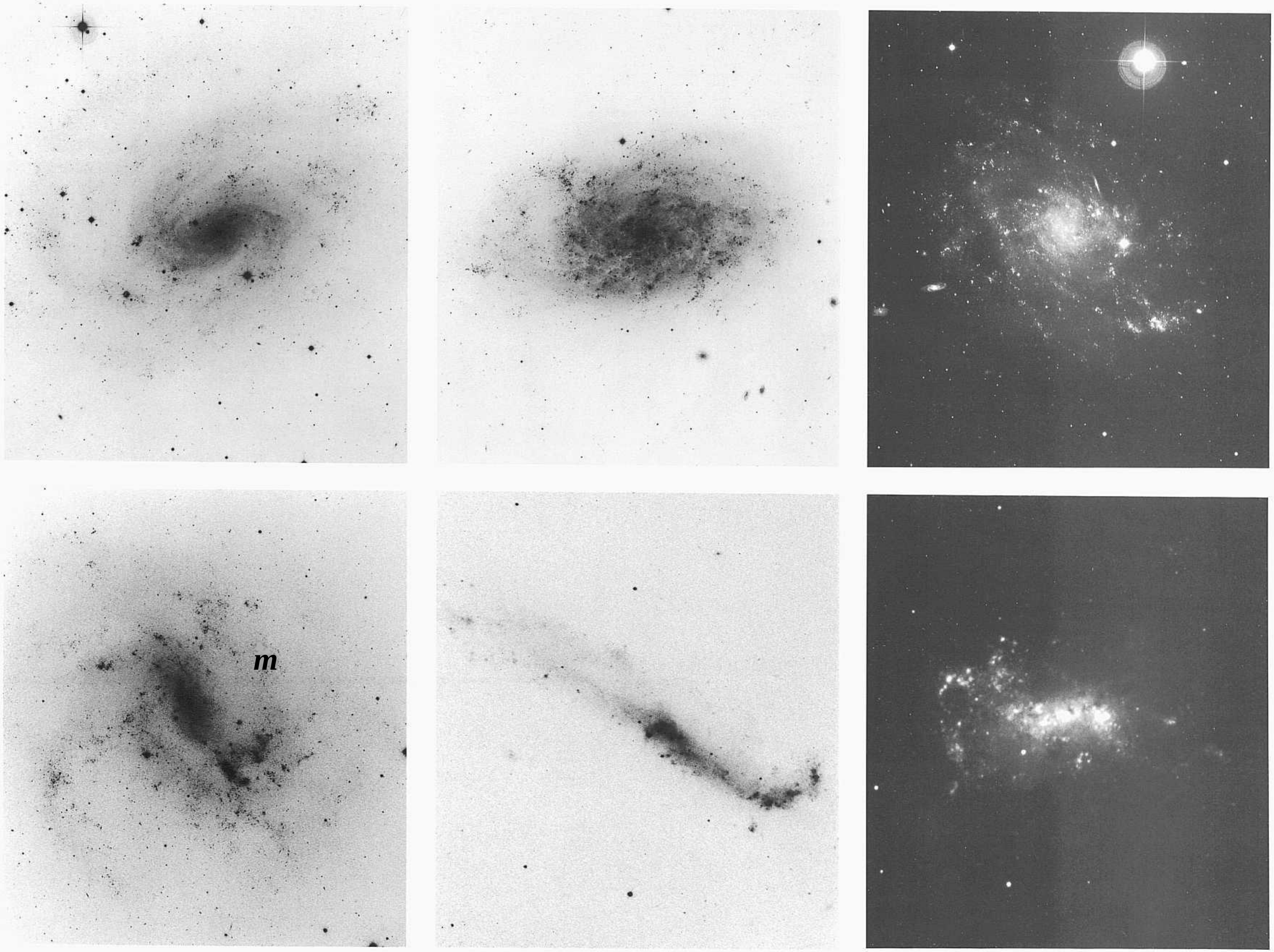
NGC 4395 SdIII-IV panel 324
PH-7145-S
Feb 1/2, 1976
103aD + GG11
45 min

NGC 7793 Sd(s)IV panel 321
CD-51O-S
Sept 28/29, 1978
103aO + GG385
45 min

NGC 4656/4657 Im panel 327
H-3633-S
Feb 18/19, 1963
103aO + GG13
27 min

NGC 45 Scd(s)III panel 314
CD-540-S
Ocl 1/2, 1978
103aO + GG385
45 miii

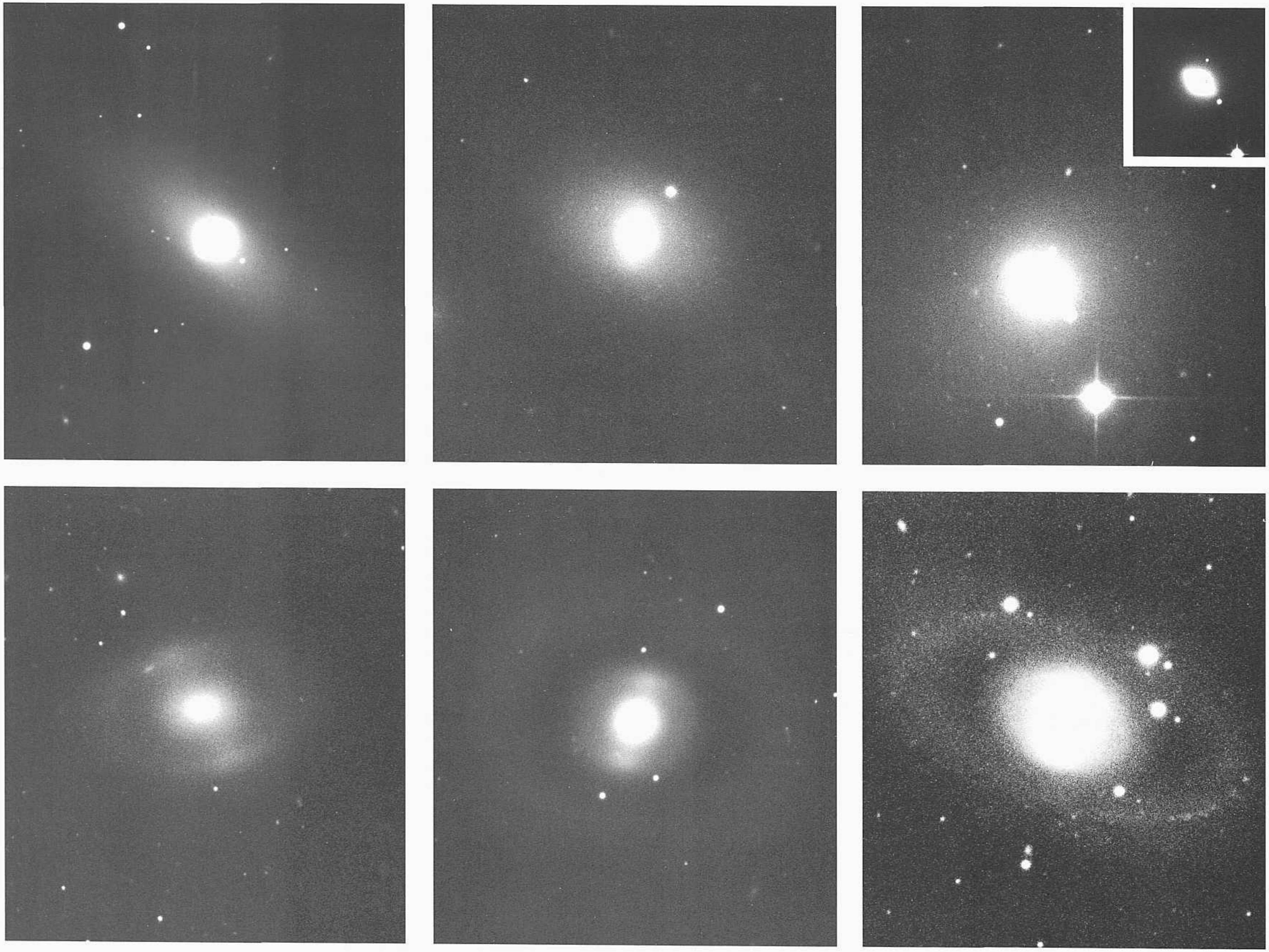
NGC 4449 SmlV panel 326
B-523-B
June 26/27, 1935
Imp. Eel.
20 min



PANEL
S6

PANEL

S7



THE COMPLETE BARRED SEQUENCE FROM EARLY TO LATE

SBO Galaxies

(Panels S7, 54-58)

T he three subtypes of SBO galaxies, introduced in the HA and retained here, are defined by the character of the bar.

The bar in SBO j galaxies is simply a deviation from elliptical symmetry where the central bulge (sometimes called the lens in the HA) is an oval whose major axis makes an angle with the major axis of the intermediate disk and the external envelope. Galaxies of this subtype are on panels 54, 55, and part of 56.

Galaxies are denoted SBO2 where the bar extends only partway across the intermediate disk, becomes indistinct in inner regions, and continues, after a gap, onto an external ring (or rim), lorming two opposite regions of enhanced luminosity. In these galaxies, the bar is defined by the two bright ansae on the rim of the intermediate luminosity zone, placed diametrically opposite one another. Examples are on panels 56 and 57. A prototype is NGC 2859 on panel S7 here and also on panel 58. It is also shown in the Hubble Atlas, page *42*. Another excellent example is NGC 4340, also on the S7 panel here and on panel 57.

Many of the SBO galaxies of the SBO2 type have detached or semi-detached external rings of the type well shown by NGC 2859 and NGC 5101 (panels 58, 100, 101, 103). The classification notation for such galaxies is a prefixed R, aw in $RSB0_2$/3(0)/a for NGC 1543 (panels 100, 102). The prototype example of RSB0 galaxies with a detached external ring is NGC 3945 ($RSB0_2$) at the lower right of panel S7 here.

Galaxies having a well-defined sharp bar extending across the entire disk are called SBO3. There appear to be no pure SBO3 galaxies in the RSA binning table, although NGC 2950 and NGC 4371, both on panel 57, are classed RSBO9/3 and SBO9/3, respectively. Where a type-3 bar is present, embryonic spiral arms are seen and the type is mixed between SBO and SBa, denoted by SB0;j/SBa. Many transition galaxies of this type exist, such as the prototype example NGC 4643 ($SB0_3$/SBa; panels 96, 107).

The transitional barred 2/3 form also shows in the later SBa galaxies, such as NGC 5101 (panels 100. 101, 103), NGC 5701 (panels 100, 101, 104), and NGC 2217 (panels 101, 104, 107). Prototype examples of the intermediate 2/3 bar form are NGC 4371 ($SB0_2/_3$(r)(3); panel 57), NGC 936 ($SB0_{2/3}$/SBa; panels 90, 106), NGC 1543 ($RSB0_{2/3}$(0)/a; panels 100, 102), and NGC 3637 ($RSB0_{2/3}$/SBa: panel 89).

Note that the flattening class is also often included as part of the notation for SBO galaxies, as in E and SO galaxies.

NGC 3384 SB0i(5) pane154
PH-27O-S
Dec 10/11, 1952
103aD + GGll
25 min

NGC 4340 RSBO, panel 57
CD-1854-HB
April 4/5, 1981
103aO
75 min

NGC 5473 SB0i(3) pane154
PH-7626-S
April 27/28, 1979
103aO
10 niin

NGC 2859 $RSBO_2$(3) pane158
PH-852-S
Nov 2/3, 1954
103aO
30min

NGC 1574 $SB0_2$(3) panel 56
CD-1690-S
Jan3/4,1981
103aO + GG385
45min

NGC 3945 RSB0-, panel 58
PH-7980-S
Feb 1/2, 1981
103a0
12 min

SBO/a, SBO/SBa Galaxies

(Panels 89-90; not illustrated in the summary panels)

Galaxies of this type are similar to those of types SO/a and SO/Sa, but have a bar structure resembling those in the SBO section (panels 54-58). There is hint of spiral structure in the deviations from elliptical symmetry in the disk outer regions. Often these deviations appear as large-scale spiral "sweeps" emerging from the central regions. These broad features are the earliest expression of the massive arras seen in the later morphological sections, in the sense described by Reynolds (1927a.b).

There is no evidence of recent star formation in any galaxy of this type. All galaxies shown on panels 89 and 90 have the VE or E arm subclassification. The better-defined arm pattern later in the SBa morphological box gives evidence of recent star formation in the arms, but not yet here.

THE BARRED SPIRAL SEQUENCE

The summary panels S8-S10 illustrate the morphological progression of barred spirals from very early to moderately late types. Panel S8 shows the progression of the (s)-subtype spiral pattern, where the arms begin from the ends of the bar. Panel S9 shows the (r) subtype, where the arms begin tangent to an almost-complete inner ring. Panel S10 continues the illustrations into the latest part of the barred sequence from SBc to SBd.

SBa Galaxies

(Panels S8, S9, ***91-107)***

The SBa galaxies, like their Sa counterparts, show a continuous variation of morphological characteristics from early to late within their long section. Because of the large size of the morphological box, the SBa galaxies are again subdivided according to (a) star-formation rate in the arms, (b) bulge-to-disk ratio, and (c) dust class, as described in Chapter 2. This auxiliary classification is shown in parentheses, placed below the main class in the descriptions.

The early SBa prototype of the smooth-armed barred spirals is NGC 7743, on panel 91. Such galaxies, together with similar smooth-armed Sa spirals (panels 61—65), are generic to the sequence, not products of environmental processes (Sandage 1983a).

The progressive development of the SBa(s) and SBa(r) forms from early to late is illustrated in panels 92—96.

Shown on panels 97-99 are galaxies having internal rings, whether complete or broken, and very tightly wound spirals that nearly overlap to form an apparent **internal** ring. The breaks would not be resolved in the overlap region on poor **plate material,** and such galaxies would be judged to have a complete internal ring.

Finally, the spectacular category of wide-outer-ring, or near-ring, SBa galaxies are shown on **panels** 100—105. NGC 1291 is an early prototype (panels S8, 100, 102). Later examples include NGC 5101 (panels 100, 101, 103; HA, p. *42)* and NGC 2217 (panels 101, 104, 107; HA, p. *43).* The outer, nearly circular segments of two oppositely directed spiral segments form a nearly complete, very wide outer ring; the arm fragments almost overlap after each has unwound by half a revolution. The pattern is similar to, but is much earlier than, the Sb and SBb galaxies having the NGC 210 look (panel 124; HA, p. *22),* where inner and outer spiral arms have different pitch angles and open far from the central disk and bulge.

Summaries of the SBa subclasses are on panels 106 and 107.

SBab Galaxies

(Panels 120-123; ***not*** *illustrated in the summary panels)*

Like the Sab galaxies, the morphological characteristics of the SBab's are intermediate between the adjacent types (SBa and SBb). The nature of the intermediate characteristics is best seen from the examples themselves on panels 120-123, contrasting with the illustrations of SBa galaxies on panels 91-107 and SBb on panels 154-170.

SBb Galaxies

(Panels S8, S9, 154-170)

The indicator of morphological type that becomes prominent in the SBb section is the pair of oppositely directed straight dust lanes at the two leading edges of the bar; the lanes emerge from the nucleus in a well-defined pattern seen repeatedly from galaxy to galaxy. The prototype example is NGC 1300 (panels S8, 154: HA, p. *45),* but many variations occur within the SBb section, as shown in the illustrations and spoken to in the descriptions.

The distinction between the (s) and the (r) manner of spiral-arm origin at the inside of the pattern is greatest in the SBb section. The pure prototypes are NGC 1300 for the (s) subtype, where the arms spring from the ends of the bar, and NGC 4999 (panels S9, 159) for the (r) subtype, where the arms begin tangent to an internal circle or to a luminous ring. Mixed (rs) and (sr) types also exist, where the internal ring is broken and the arms begin some distance downstream from the ends of the bar. The descriptions with the illustrations note these variations.

The SBb galaxies are arranged in the 17 panels 154-170 by luminosity class I, **I-II,** and II, and then by (s) and (r) subtypes within these classes.

SBb(s)I galaxies are at panels 154-155; SBb(s)I-II at 156-158. Comparable (r) subtypes are at panels 159-164. Transition (rs) subtypes are on panel 165. The luminosity class II (s) types are at panel 166; the (r) and the (rs) mixed types are on panels 167-168. Heavy and light prints of the (s), (r), and (rs) subtypes are shown on panels 169—170.

SBbc Galaxies

(Panels S9, 199-212)

The classification criteria are intermediate between SBb and SBc galaxies. A prototype example is NGC 1365 (panels S8, 199), where the bar is less straight and the arms are more open than in the prototype SBb galaxy NGC 1300 (panels S8, 154).

As in SBb galaxies, a characteristic feature is the pair of dust lanes threading the bar near its leading edges. These emerge from the center and generally extend to the ends of the bar; in (s) subtypes the arms spring from the ends of the bar, and in the (r) subtypes a partial ring exists on which the arms begin tangentially, often downstream from the ends of the bar.

The SBbc galaxies on the 14 panels in this section are arranged by luminosity class and by spiral-arm pattern (MAS or GD) within each class.

Galaxies of the higher luminosity classes of I and I-II are shown on panels 199-206. Grand design (s) types of these luminosity classes are at panels 199-201, GD (r) types at 202-203. The filamentary-arm (MAS) galaxies, mostly (r) types, are on panels 204-206.

The SBbc galaxies of luminosity class II cover panels 207-211. They include grand design types of (s) and (rs) subtypes, panels 207-209; transitional galaxies between GD and MAS types are at panel 210, and the MAS galaxies of luminosity classes II and II-III are at panel 211.

Interacting galaxies where at least one of the members is of this type are on panel 212.

SBc Galaxies

(Panels S9, S10, 293-313)

The characteristics of SBc galaxies are (1) high resolution of bar and spiral arms into stars and II11 regions, (2) near-absence of a nuclear bulge, (3) openness of the spiral pattern, and (4) dominance of the spiral pattern in the overall morphology, in contrast to the bulge dominance in SBa galaxies.

The 76 SBc galaxies on the 21 panels (293-313) illustrating this section are arranged generally in order of luminosity class, showing thereby the progression within the SBc morphological box from regularity of the arm pattern in SBcI to chaos in SBcIII galaxies.

The (s), (r), and (rs) patterns persist throughout the section, describing how the spiral arms are attached either to the ends ol the bar or to a semi-ring upon which the arms emerge tangentially.

SUMMARY OF BARRED SPIRALS OF THE (S) SUBTYPE

(Panel S8)

The six prototype SB spirals on this panel are of the SB(s) type, and all are of the two-main-armed grand design type.

The morphologies of these prototype galaxies range from early SBa to SBbc: all are of high luminosity class.

NGC 1291 SBa panels 100, 102
CD-507-S
Sep 27/28, 1978
103aO + **GG385**
45 min

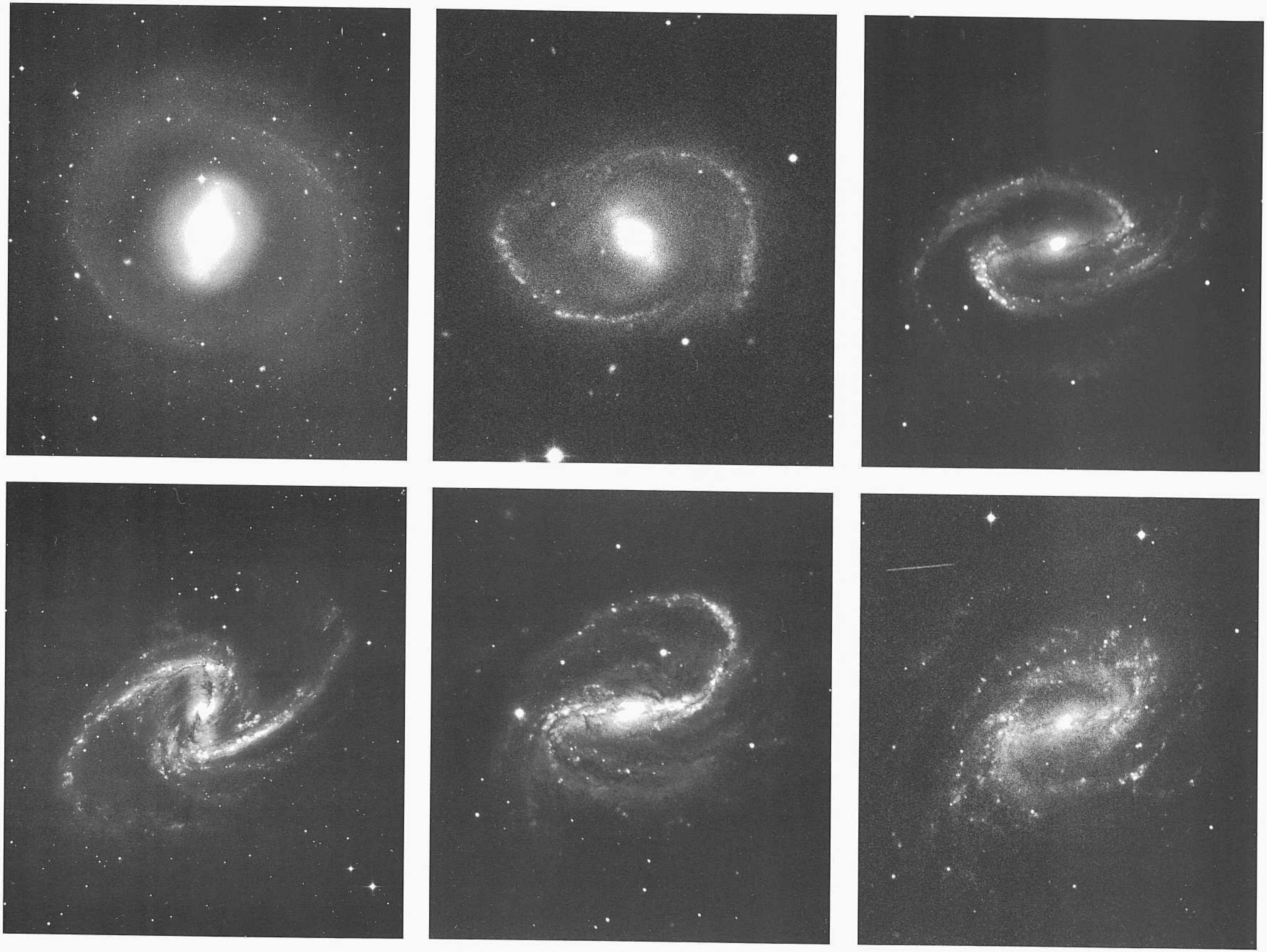
NGC 1358 SBa(s)I panels 100, 107
CD-544-S
Oct 1/2, 1978
103aO
45 min

NGC 1300 SBb(s)I.2 panel 154
PH-75-H
Oct 14/15, 1950
103aO
30 min

NGC 1365 SBbc(s)I panel 199
CD-1668-S
Dec31/Jan 1, 1980/1981
103aO
75 min

NGC 7479 **SBbc(s)I-II** panel 200
PH-152-H
Oct 14/15, 1952
103aO
30 min

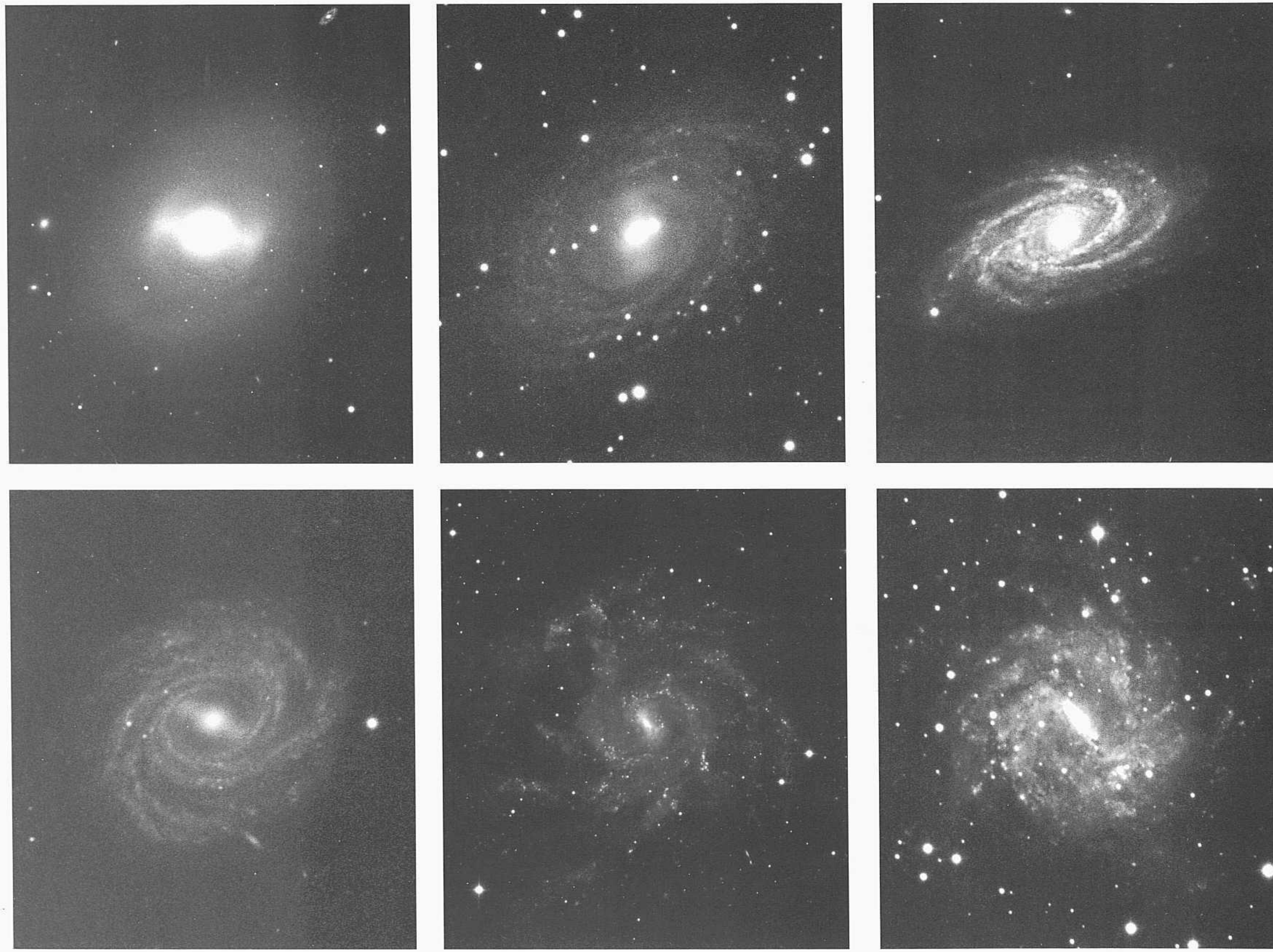
NGC 4123 SBbc(rs)I.8 panel 201
CD-1847-HB
April 3/4, 1981
103aO
75 min



PANEL

S8

PANEL
S9



SUMMARY OF BARRED GALAXIES OF THE (r) SUBTYPE

(Panel S9)

Galaxies on panel S9 are mostly of the (r) subtype. The panel illustrates the progression of barred types from early SBa(r) to intermediate SBc(r).

The (r) subtype is evident in the first four prototype examples here, although the rings are incomplete, often broken, and formed by nearly overlapping tightly wound parts of opposite (s)-type segments; hence the (rs) designation is given. The breaks are even wider in the two right-hand galaxies in the bottom row which, as a consequence, are called (s) subtypes. The breaks are less pronounced than in the (s) prototype NGC 1300 (panels S8, 154).

It is evident from these examples that the resolution into stars and HII knots changes nionotonically along the sequence. No recent star formation is occurring in the early SBa types. Current star formation is high in the middle SBc types whose prototype is NGC 3059 (panel 308, and at the lower right here).

NGC 936 SB0_2«/SBa panels 90, 106
CD-494-S
Sep 26/27, 1978
103aO + GG385
45 min

NGC 1169 SBa(r)I panels 96, 106
PH-7533-S
Nov 4/5, 1978
103aO + GG13
15 min

NGC 3145 SBbc(rs)I panel 202
CD-790-S
Feb 23/24, 1979
103aO + GG385
45 nun

NGC 4999 SBb(rs)! panel 159
CD-1835-HB
April 1/2, 1981
103aO + GG385
45 min

NGC 7424 Sc(rs)II.3/SBc(s)II.3 panel 295
CD-1511-S/Br
Aug 4/5, 1980
103aO + GG385
45 min

NGC 3059 SBc(s)III panel 308
CD-742-S
Feb 3/4, 1979
103aO + Wr2c
45 nun

SUMMARY OF INCREASING STAR-FORMATION RATE IN SBC(S) GALAXIES

(Panel S10)

The six SBc, **SBcd,** and SBd galaxies illustrated here show the increase in disorder and the increase in the star-formation rate from middle SBc to middle SBd types. All galaxies on this page are of the (s) subtype. NGC 2525 and NGC 7741 are particularly good examples.

NGC 5597 SBc(s)II panel 298
CD-1569-S/Br
Aug **10/11,** 1980
103aO + GG385
45 min

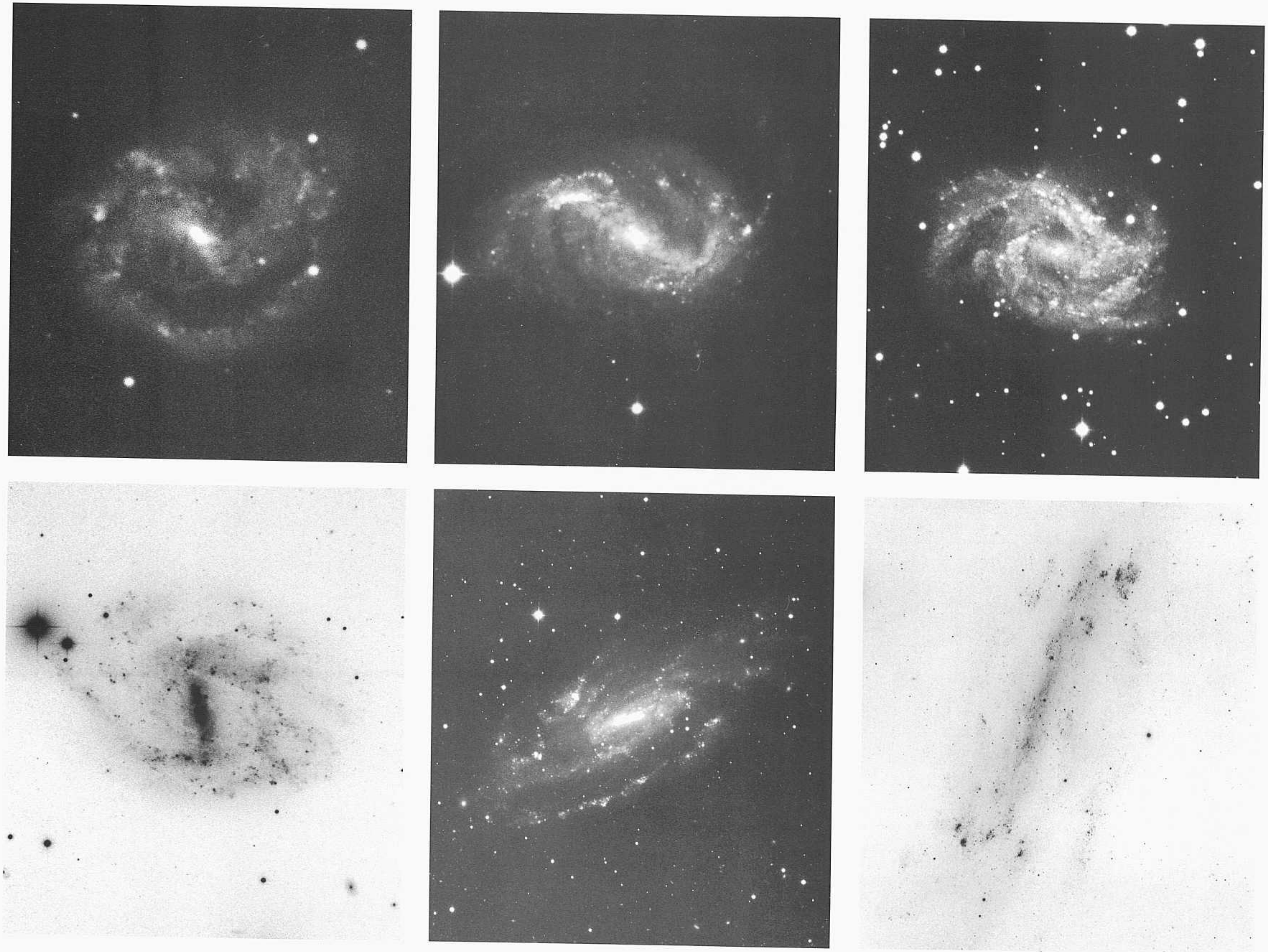
NGC 7741 SBc(s)II.2 panel 297
PH-66-H HA, p. *49*
Oct 13/14, 1950
103aO
30 min

NGC 7496 SBc(s)II.8 panel 303
CD-1163-Br
Aug 22/23, 1979
103aO + GG385
45 min

IC 5201 SBcd(s)II panel 316
CD-1533-S/Br
Aug 6/7, 1980
103aO + GG385
45 min

NGC 2525 SBc(s)II panel 298
CD-779-S HA, p. *49*
Feb 22/23, 1979
103aO + GG385
45 min

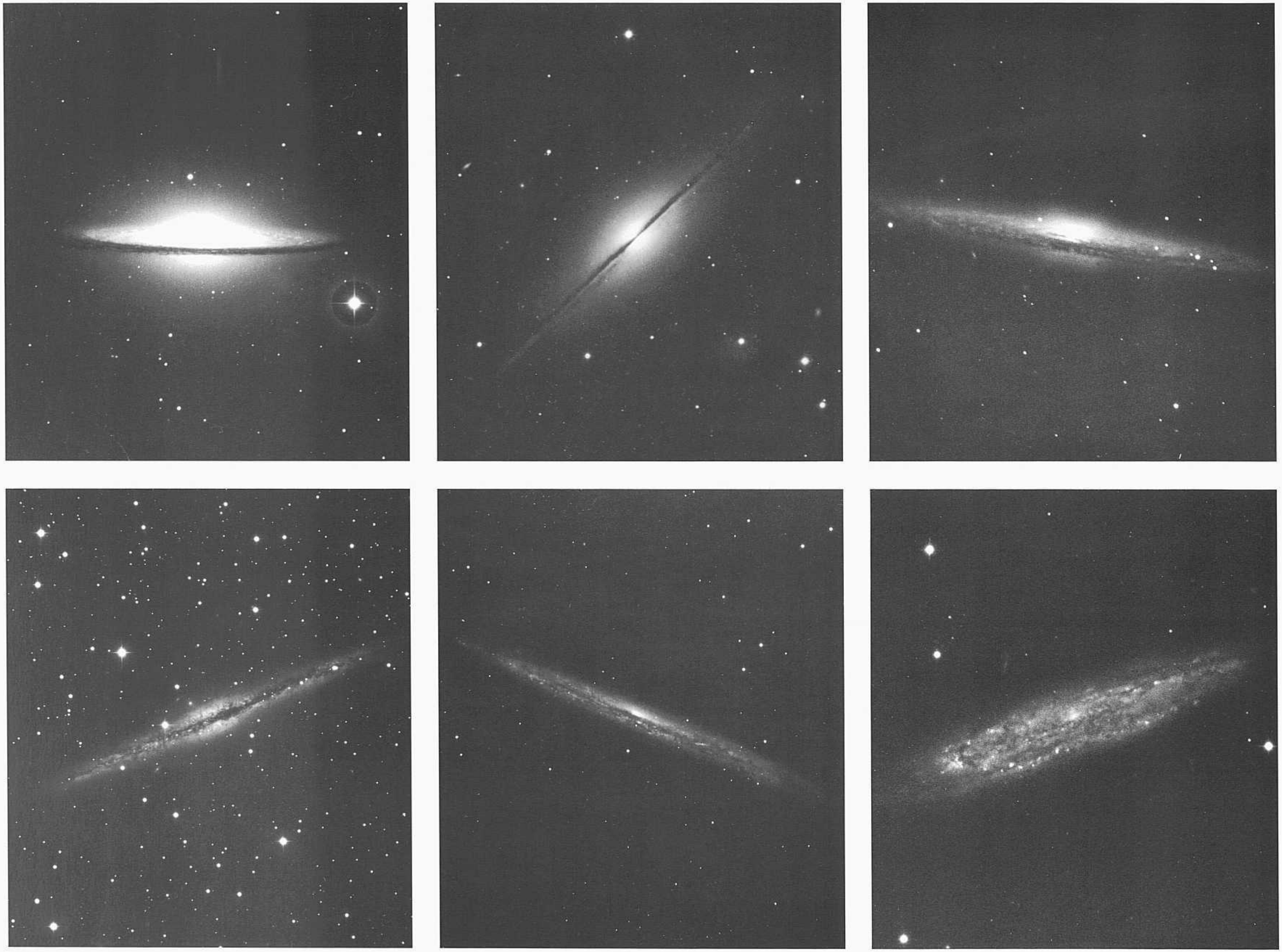
NGC 4236 SBdIV panel 324
PH-4506-S
April 13/14, 1964
103aO
20 min



PANEL
SIO

PANEL

S11



SUMMARY OF THE VARIATION OF BULGE SIZE ALONG THE SEQUENCE

(Panel SI 1)

One of the three classification criteria along the spiral sequence is the size of the central amorphous bulge compared with the size of the disk. The bulge size, seen best in nearly edge on galaxies, decreases progressively, while the current star-formation rate and the geometrical entropy of the arm pattern increases, from early Sa to Sd, Sm, and Im types.

In the six prototype galaxies shown on this page, the inferred type, based on the size of the central bulge, varies from intermediate-to-late Sa in NGC 4594 (stars are forming in spiral arms seen in the disk; Lindblad, 1951), to late Sc in NGC 3495, where the bulge is nearly absent and where the spiral pattern is apparently moderately chaotic.

NGC 4594 Sa7Sb~ panel 113
PH-96-MH HA, p. *24*
March 16/17, 1950
103aO
30 min

NGC 7814 S(ab) panel 112
PH-770-S
Aug 23/24, 1954
103aO
25 min

NGC 5746 Sb panel 151
CD-1843-HB
April 2/3, 1981
103aO
75 min

NGC 891 Sb(onedge) panel 152
PH-208-S HA, p. *25*
Nov 10/11, 1950
103aO + WG2
30 miii

NGC 5907 Sc(on edge) panel 289
PH-186-MH HA, p. 25
May 10/11, 1950
103aO
40 miii

NGC 3495 **Sc(s)II-III** panel 287
CD-1840-HB
April 2/3, 1981
103aO + GG385
45 min

SUMMARY OF THE PROGRESSIVE CHANGE OF THE MAS PATTERN ALONG THE SEQUENCE

(Panels S12, S13)

Galaxies on this and the next summary panel are of the multiple-armed (MAS) type, whose prototype is NGC 488, shown in the middle of the bottom row. The multiple-arm pattern exists throughout the spiral sequence among both non-barred and barred types.

These two panels trace the change in the MAS pattern progressively along the sequence. The 12 prototype galaxies are arranged in order of their lateness, from very early Sa here to middle Sc in the next panel. Non-barred and barred types are shown. The sequential progression is across the top row first, then the bottom row.

NGC 1317 Sa panel 62
CD-719-S FCC 22
Feb 1/2, 1979
103aO +Wr2c
45 niin

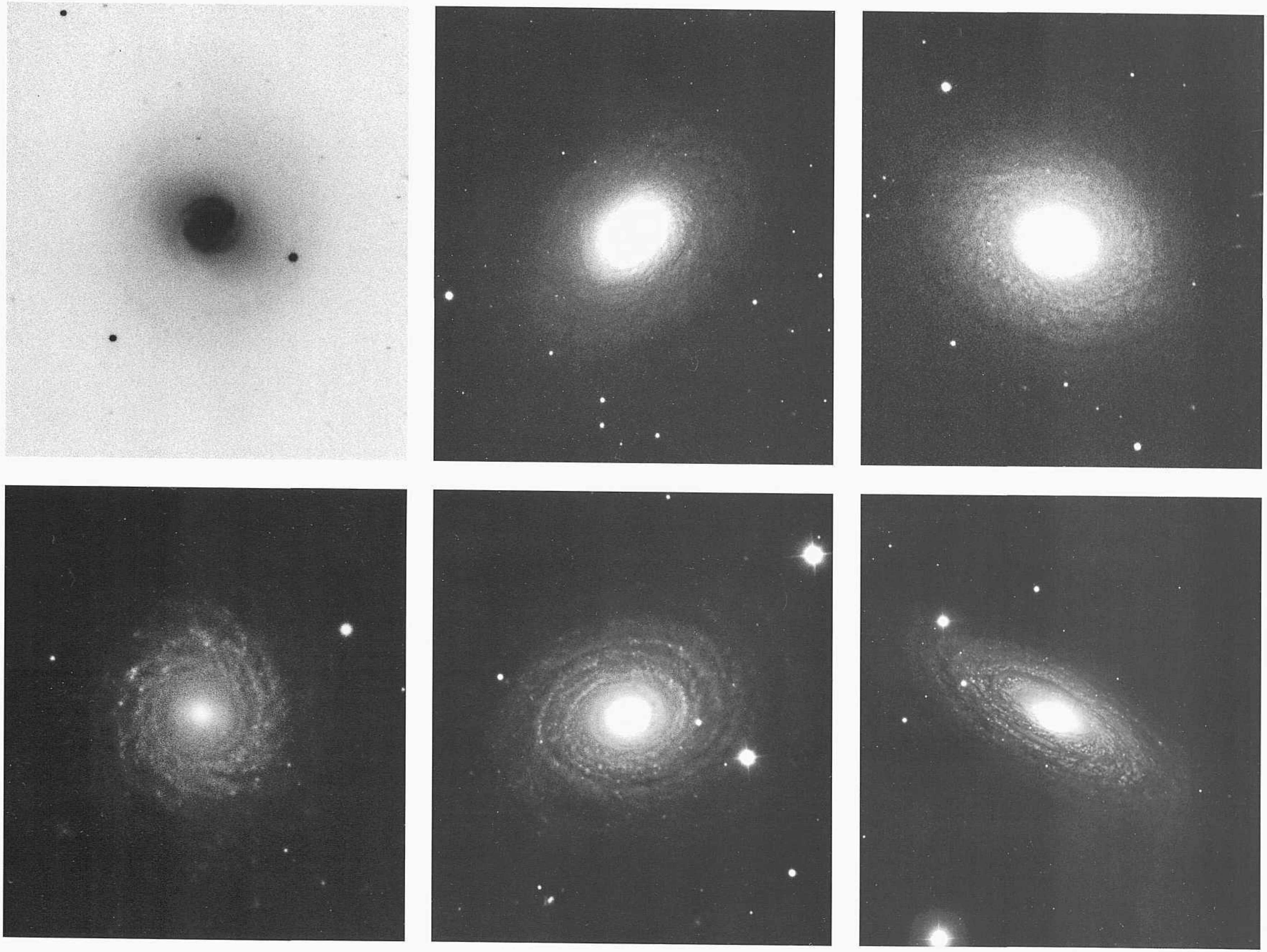
NGC 4699 Sab(sr) or Sa panels 78, 87, 118
CD-1872-HB HA, p. *16*
April 10/11, 1981
103aD + GG495
45 niin

NGC 2775 Sa(r) Panels 78, 87
CD-1658-S HA, p. *10*
Dec 29/30, 1980
103aD + GG495
60 niin

NGC 7371 SBa(r)II panels 96, 106
CD-5O1-S
Sep 27/28, 1978
103aO + GG385
45 niin

NGC 488 Sab(rs)I panels 115, 116, S3
PH-1053-S HA, p. 25
Aug 24/25, 1955
103aO
30 min

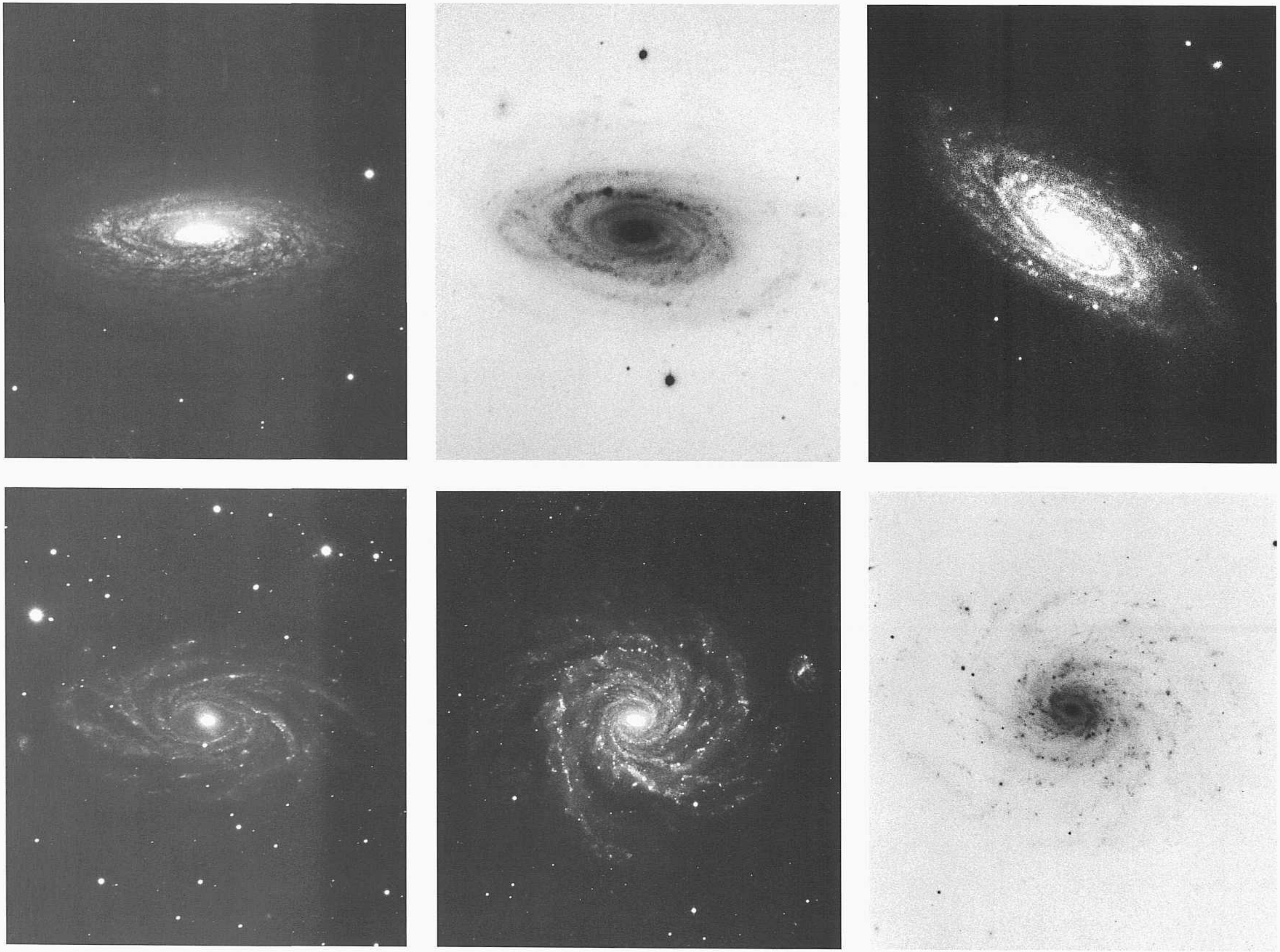
NGC 2841 Sb panels 142, S4
PH-36-S HA, p. *14*
Nov 7/8, 1951
103aO + WG2
25 niin



PANEL
SI 2

PANEL

SI 3



The summary on this page continues the illustration of the multi-arm spiral (MAS) pattern, which contrasts with the mainly two-armed grand design spirals. The galaxies here are of Sb, Sbc, and Sc types, and show how the multiple spiral arms of the NGC 488 type change progressively along the later parts of the spiral sequence, forming a continuum.

NGC 3675 Sb(r)II panels 139, S4, S14
PH-7632-S
April 28/29, 1979
103aO
12 min

NGC 2336 SBbc(r)I panel 204
PH-7703-S
Feb 11/12, 1980
103aO
12 min

NGC 7782 Sb(s)I-II panel 133
PH-7693-S
Sep 26/27, 1979
HlaJ
75 min

NGC 1232 Sc(rs)I panel 216
HA, p. *32*
CD-679-Br
Jan 26/27, 1979
103aO + GG385
45 min

NGC 7606 Sb(r)I panel 127
CD-1577-S/Br
Aug 10/11, 1980
103aO + GG385
45 min

NGC 3486 Sbc(r)1.2 panel 184
PH-8022-S
Feb 3/4, 1981
103aO
12 min

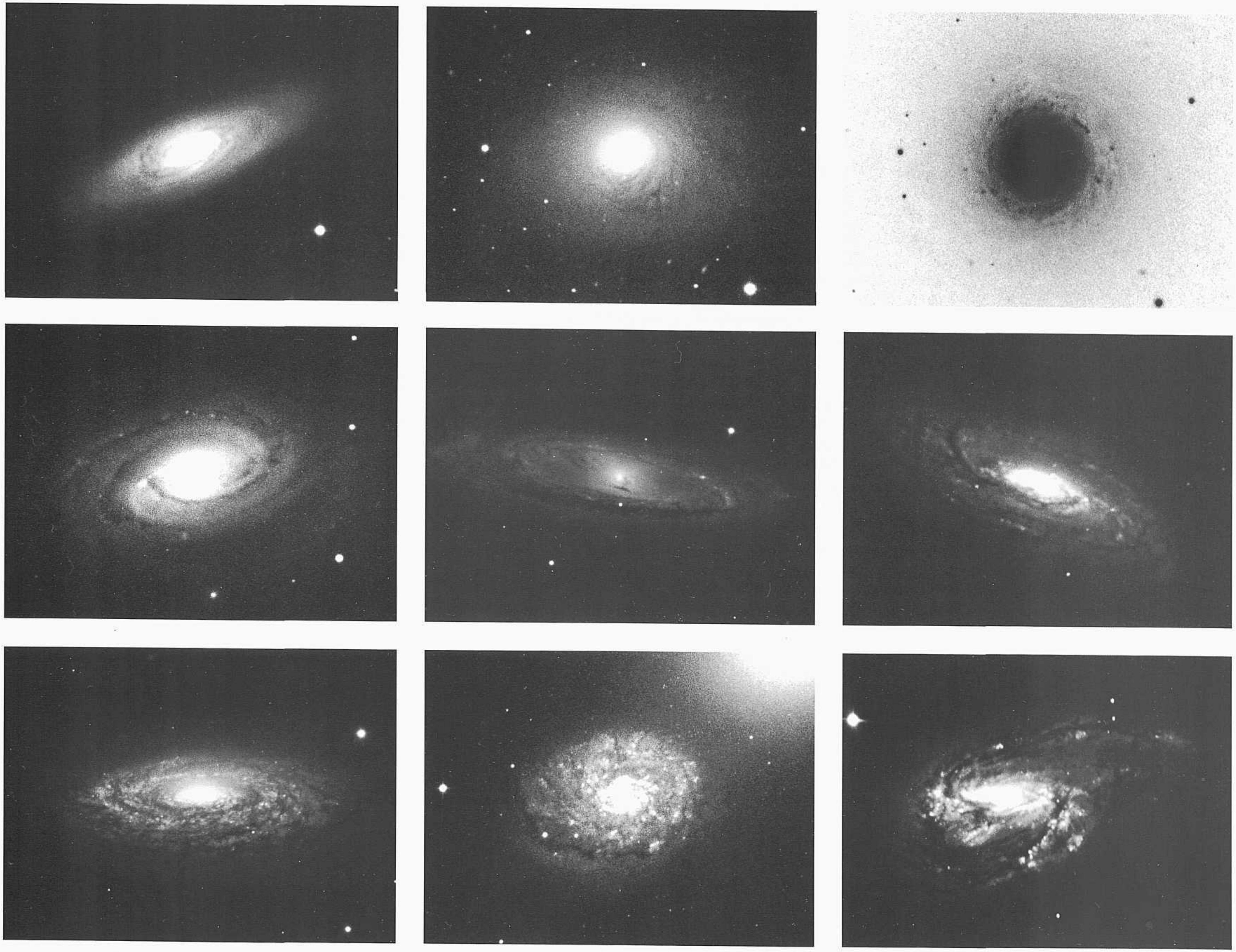
SUMMARY OF GALAXIES WHERE THE ARMS ARE DEFINED PRIMARILY BY DUST

***(Panel** S14)*

The subset of disk galaxies having spiral arms defined principally by dust lanes rather than by luminous, starlight-dominated arms is illustrated here. In the top row the arms are defined solely by dust: in the bottom row luminous star arms exist, but their dust content is very high.

Very unusual cases of such galaxies are NGC 1386 (panel 76, and top-left in panel S14 here), NGC 7377 (panel 75, and top-middle here), and NGC 4450 (panel 110, and left panel of the middle row here), where the arms are defined only by the dust. The most unusual galaxy of this type is NGC 7377, where there is no evidence of recent star formation in the spiral pattern. Where does the dust come from, what is its age, and why is it in such a regular spiral pattern centered on the nucleus?

NGC 1386 Sa panel 76 CD-718-S FCC 179 Feb 1/2, 1979 103aO + Wr2c 45 min	NGC 7377 $S0_{2/3}$/Sa pec panel 75 CD-519-S/Br Sep 29/30, 1978 103aO + GG385 45 min	NGC 7213 Sa(rs) panel 75 CD-1033-Br July 21/22, 1979 103aO + GG385 45 min
NGC 4450 Sab pec panel 110 H-2432-H HA, p. *13* May 17/18, 1947 **103aO** 25 min	NGC 3623 Sa(s)II panel 77 H-494-H HA, p. *11* Nov 26/27, 1924 S30 75 min	NGC 5005 Sb(s)II panel 139 H-2170-II HA, p. *13* June 29/30, 1941 Cr-Hi-Sp-Sp 45 min
NGC 3675 Sb(r)II panels 139, S4, S12 PH-7632-S April 28/29, 1979 103aO 12 min	NGC 4647 **Sc(rs)III** panels 51, 278 CD-802-S VCC 1972 Feb 24/25, 1979 103aO + Wr2c 45 min	NGC 3627 Sb(s)II.2 panel 137 H-2363-H HA, p. *23* Nov 29/30, 1946 IIaO 10 min



PANEL
SI 4

Amorphous Galaxies

(Panels 334-340)

A new class of galaxies called Amorphous was introduced in 1979 (Sandage and Brucato 1979) and is retained here. The type replaces the Irregular class, which Hubble introduced for galaxies that did not fit elsewhere in his system; he defined such galaxies as systems having no rotational symmetry and no spiral pattern.

However, two distinct types of galaxies having these characteristics had been forced into his single Irregular class, making their treatment in the Hubble Atlas and in a later review (Sandage 1975a) unsatisfactory. Holmberg (1958), understanding the problem, divided Hubble's Irr class into two groups, called Irr I and Irr II, based on color.

Irr I galaxies were blue and generally were highly resolved into individual predominantly blue stars. Irr I are called Sm and Im types here. Many of the Holmberg Irr II galaxies show a different kind of morphology. Their unresolved light has an amorphous appearance. The image generally has a high surface brightness and often has Ha filaments covering the disk. Examples are M82, NGC 1569, NGC 625, NGC 1705, and others shown in panels 334—340. In the descriptions of individual galaxies in this atlas, a case is made that each of these galaxies is in an episode of intense star formation, sometimes called a starburst, and each has one or more supergiant star clusters whose intense ultraviolet flux from associated OB stars is driving the gas out of the parent galaxies by supergalactic winds (Arp and Sandage 1985). M82 (panel 334) is the prototype example.

CHAPTER 4

THE MEANING OF THE CLASSIFICATION

Neither a collection of facts nor the classification system derived therefrom is an end in itself; each is simply an early step in the development of a nascent science. If collection and classification went no further, the result would be as shallow as a phone book in describing human nature. To discover order out of which understanding can develop, the classification must eventually be interpreted.

In a famous apology for interpretation, William Herschel (17 85) wrote:

> *If we would hope to make any progress in an investigation of this delicate a nature [on the Construction of the Heavens], we ought to avoid tivo opposite extremes, of which I can hardly say which is the most dangerous. If we indulge a fanciful imagination and build worlds of our own, we tnust not wonder at our going wide from the path of truth and nature.... On the other hand, if we add observation to observation, without attempting to draiv not only certain conclusions, but also conjectural views from them, we offend against the very end for which [the] observations ought to be made.*

We classify galaxies so that we can understand their formation and evolution. No one believes that galaxies originated in their present forms; they must have evolved since birth. There must have been a time before galaxies existed, and that time can be dated. Powerful evidence lies in the consistency of the three independent time scales, based on, respectively, (1) the initial formation of the chemical elements, (2) the ages of the oldest stars in the Galaxy, and (3) the redshift-distance relation of the expanding universe. Each of these scales is related to a different creation process, each of which is itself presumably related to the origin of the universe. The three clocks show similar and compatible ages, thereby providing the principal cornerstone of the standard model of both cosmology and cosmogony, and to the notion that galaxies were born at some stage in the early events.[1]

What conclusions can be drawn concerning galaxy formation, given that the morphological characteristics of **the** galaxies show continuity along the sequence and that many **physical** parameters also vary continuously along the same sequence? Among these are (1) the neutral hydrogen content in types from E to Sd, Sm, and Im (Roberts 1969, 197 5), (2) the bulge-to-disk ratio (panel S11), (3) the color, which measures the current rate of star formation, (4) the maximum rotational velocity (Kennicutt 1981), and (5) the shape of the rotational curve with radius as **a** function of morphological type among disk galaxies (Rubin *et al.* 1985).

First a caveat: any conclusion drawn here from presently known facts cannot be expected to endure in the same way that is hoped for the classification itself. History reveals that most such interpretations are short-lived. We need only read the journals of 100 years ago in physics, astronomy, chemistry, biology, or in any other science, to see how ephemeral have been the interpretations.

---

[1] **But** to give a voice to those who, for a variety of reasons, **question the** standard model, it must **be** said **that** this **astounding agreement among** the three **quite different** time scales may not be as **complete** a proof as it seems. In the steady state cosmology, where galaxies form continuously and **where there is** no **creation** time for **the** cosmos itself (the age of the universe is infinite), the *average* age of a galaxy is $(3H_0)^{-1}$, where Ho is the Hubble constant measuring the rate of the expansion. If //(, is **in** the range of 40-50 km **s** "' Mpc"[1], this average galaxy age would itself be 7-8 X 10^9 years. **Our** Galaxy, whose age is -IS X 1()[J] years, would need be only about twice the average age of all the galaxies.

The **approximate** agreement of the time scales is a **necessary but** not sufficient condition for the correctness of the big bang creation model. **However, much** other evidence exists favoring such a model.

The vast progressive advance in all sciences insures such ephemerality. It cannot be expected to be different today.

Nevertheless, science builds upon itself. Interpretations offer a start—a necessary basis for improvement. To heed Herschel's admonition, it is obligatory eventually to stop adding observation to observation concerning the classification and begin seeking explanations. To this end we summarize here a picture of galaxy formation, partly from facts about Galactic structure and partly from the facts within the classification itself. The picture outlined here is of course elementary, given the vast detail of the galaxy forms. Only the most central of the parameters within the classification are considered.

CLUES FROM OUR GALAXY

The development began with the general dynamical inquiries of Jeans (1928) into the conditions for gravitational instability, now believed to be the prerequisite for galaxy formation. In the 1950's, the development of ideas of stellar evolution and the new concepts of stellar populations prepared the way for inquiries into the formation of the Galaxy itself.

The data on stellar kinematics and chemical compositions were put together by Eggen, Lynden-Bell, and Sandage (1962, hereafter ELS) in such a way to suggest that the Galaxy formed by collapse from a larger volume, perhaps semiregularly, or perhaps somewhat stochastically (Searle and Zinn 1978). The principal evidence was that the oldest Galactic stars are moving on plunging, nearly radial, orbits toward the Galactic center. Younger, more-metal-rich stars are moving in orbits that are less eccentric. The youngest, most-metal-rich stars move in very nearly circular orbits. From these data, ELS concluded that (1) the Galaxy formed by collapse, (2) the collapse was "rapid," in the sense that the radial velocities (toward the center) of the gas clouds out of which the first stars formed were higher than their circular velocities (the absolute time-scale being unimportant), and (3) the Galactic disk is a dissipative structure, the dissipation circularizing the orbits of the gas left over in the disk after completion of the initial collapse.[a]

The picture of an early, rapid collapse on a time scale of at most several billion years furnished an explanation for the observed correlations between the eccentricities of the stellar orbits, the ages of the stars, the stellar velocities perpendicular to the Galactic plane, and the stellar metallicities (Sandage 1986c for a review). The same picture naturally explained the existence of the three major morphological components of the Galaxy—the disk, the thicker bulge, and the nearly spherical halo.

In this picture, the stars in the bulge, thick disk, and halo should be the oldest stars in the Galaxy. Once such stars are formed, star-star interactions are too infrequent to change the stellar orbital energy. The orbits on which these earliest stars were born from the plunging gas clouds are generally nearly the same as the orbits they have today. The decisive clue showing that the formation of the Galaxy was by collapse is, then, that the shapes of the stellar orbits and the ages of the stars are related. The first halo stars with plunging orbits toward the Galaxy center must have formed before the creation of the nascent gaseous disk. Observations of the shapes of the orbits combined with the newly discovered method of age-dating the stars have confirmed this.

This evidence from our own Galaxy can be generalized to other galaxies to explain the classification sequence itself. The most fundamental aspect of the sequence is the separation into disk and diskless systems.

If a protogalaxy is to *avoid* the formation of a disk, stars in the collapsing gas clouds must form rapidly, consuming most

[a] The dissipation of the initial energy of motion (the kinetic energy) of the gas occurred by inelastic gas-gas collisions, the resulting heal being radiated away from the **protogalaxy by** atomic processes in the gas. Dissipation is generally **discussed** as **the cooling** of the initial Galaxy. The process leads to the disks present in the SO, SBO, and spiral galaxies.

of the available gas in a time short compared with the time it would have taken the gas to settle into a disk. Said differently, whether a disk is formed or not depends on the ratio of the star-formation time to the collapse time. Rapid star formation consumes the gas before gas-gas collisions take effect, and no disk is formed; there is no remaining gas to form it.

The presence of both a disk and a halo in our Galaxy shows that the ratios of two time scales—that of star formation and of free-fall collapse—had different values in different parts of the Galaxy during the collapse. The range in these time-scale ratios is what spreads galaxies along the classification sequence, from pure E galaxies having all halos and no disks, to late spiral galaxies of types Sd and Sm, with all disks and no halos.

THE INITIAL STAGE OF GALAXY FORMATION

A prevalent view is that the primeval density fluctuation that became the Galaxy began expanding with the general expansion of the universe. Because this fluctuation was over-dense, its expansion rate lagged behind the mean expansion of the universe surrounding it. Its own gravity slowed its expansion, separating it from its surroundings. Furthermore, the lag varied among different parts of the protogalaxy; different parts had different densities and therefore lagged at different rates.

The protogalaxy can be pictured as a series of concentric shells, the inner shells having the highest densities, the outer shells the lowest. The innermost shells, with their higher self-gravity, reversed their expansion and collapsed first.

From the Newtonian mechanics of such a contracting cloud (see Field 1975), the collapse time in free-fall is $t_{ff} \sim (G\rho)^{-1/2}$, where G is the gravitational constant and p is the density. From this it follows that the lower-density shells take longer to collapse. Each shell acts like a mini-Friedmann universe having its own deceleration parameter, and each, therefore, its own collapse time (Sandage 1962, equation 12).

The star-formation time (the time to consume the gas) also depends on the density, but with a different **power** of **the** density than does the collapse time. Hence, the crucial ratio **of collapse time** to star-formation time is itself a function of the shell density. Clearly, disks **form** when the collapse time is short compared with the star-formation time. Disks do not form when this condition is reversed.

The disk, once formed by dissipation, retains a fraction of the original gas. Later-generation gas is recycled through the stars that are born continuously from the available disk gas. The process increases the metal abundance of the continuously recycling gas (Hoyle 1954). This recycling gives relations between stellar age, chemical composition, and orbital eccentricity.

Detailed discussions of the ELS formation picture and the Galaxy morphology of halo, bulge, and disk as revealed by stellar kinematics are given elsewhere (Sandage and Fouts 1987; Sandage 1990, with discussion of differing pictures of the finer points [Searle and Zinn 1978] and the timing of the process).

APPLICATION TO THE CLASSIFICATION SYSTEM

In the ELS picture, the initial rate of star formation in E galaxies is enormously high, and the available gas is consumed before the collapse is completed, preventing, as discussed above, the formation of a disk. Accordingly, in diskless systems the bulk of the star formation is accomplished in the first few billion years **after** initial formation, and thus most stars in diskless systems are now old. But in disk systems, stars form over the entire lifetimes of late-type galaxies.

In systems such as SO and early Sa galaxies near the beginning of the disk classification sequence, a disk, bulge, and halo will co-exist when part of the gas is not converted to stars in the initial star-formation process. The prototype example is NGC 4594 (panels 113 and SI 1).

What spreads the galaxies along the classification sequence is the fraction of gas left over after the initial collapse (Sandage, Freeman, and Stokes 1970, hereafter SFS). This fraction depends on the strength of the initial density fluctuation 8p/p, a conclusion based on the argument given earlier that both the star-formation time and the collapse time depend on the density, but with different powers of the density. Those protogalaxies with the largest density contrast become E galaxies, lacking disks; their *initial* star-formation rate is the highest within the classification sequence.

Identifying the strength of the initial density contrast as the parameter that spreads the galaxies along the classification sequence gives straightaway an understanding of why the bulge-to-disk ratio varies continuously along the sequence. Very little disk gas is left over in the SO galaxies. A large fraction of the supply is left over in the Sc and Sd types where there is virtually no observed bulge or halo. In Sc's and Sd's the gas has collapsed to a plane faster than stars can form from it in a halo or, more likely, in a bulge. In groups and clusters of galaxies, where the mean density is high, the initial density fluctuation must also have been high. Hence, E galaxies naturally form in dense regions; spirals form in low-density regions where the density contrast is smaller. This point explains the density-morphology correlation discovered by Hubble and Humason (1931) and quantified by Dressier (1980).

The picture also makes clear why the observed present-day star-formation rate varies in the same way, being highest in galaxies of type Sd and Sm and lowest in the E, SO, and early Sa sections of the classification. Only a little gas—the raw material out of which new stars form—is left over in the early sections, but much in the later.

It is, of course, understood that no galaxy appears today as it was in its *earliest* times. We must suppose, for example, that E galaxies during the free-fall phase of their collapse were bright, with supergiant blue stars forming spectacularly rapidly, undoubtedly in clumps and clusters, the envelopes of which were later stripped giving the smooth distribution of halo stars. The central parts of these clumps still exist as globular clusters in the halo. But after this fast beginning, were galaxies early-on distributed along the Hubble sequence close to where they remain today? Or has significant evolution occurred along the sequence such that the parent forms are no longer recognized? If the latter, the present classification sequence would be a product of evolution rather than initial conditions.

To approach the problem of evolution within the sequence, the variation of the star-formation rate with time in galaxies at different places along the Hubble sequence has been calculated (Sandage 1986d). The conclusion, based on the ELS model and the conjecture (SFS 19 70) that the amount of gas left over in the disk determines the initial morphological type, is that the Hubble sequence can be understood by the time-rate-of-change of the star-formation rate in galaxies of different type. The results showed that very little evolution within the sequence has occurred, and therefore that the Hubble forms existing after about three billion years have remained pristine. This conclusion was first reached by Roberts (1963) in a fundamental paper.[3]

This model of differing star-formation rates as a function of time for galaxies of different types is summarized in Figs. 2 and 3. The picture is based on differences in the star-formation rate caused by differences in the initial density contrast. The vertical lines toward the left divide the history of the formation process into (1) the free-fall collapse era and (2) the later dissipative collapse era during which the thick and thin disks are formed. The star-formation and the free-fall collapse times are called t_s and *tfj*, respectively, in both diagrams.

During the formation of the diskless E galaxies, and during the phase in which the halos of the SO and spiral galaxies are formed, the star-forcnation rate is high, noted in the diagrams by t_s « *tff*. But during the later disk formation, the star-formation time is longer than the collapse time, meaning that gas is left over in the disk before it has turned into stars.

[3] Of course, a few special cases exist, such as close encounters, mergers, and starburst (present-day BCD and Amorphous) galaxies, which apparently change form on time scales short compared with the Hubble time. But such cases may be the exception rather than the rule.

From this it follows that if *all* the gas has gone into stars before time tjj has elapsed, as to the left of the dotted vertical lines in Figs. 2 and 3, then only a bulge and a halo are formed, as in E galaxies. (Note that the integral under the curves in these two diagrams gives the total mass converted into stars.) On the other hand, if not all the gas is converted before time {^because the initial star-formation rate is smaller in protospirals than in protoelliptícals, a disk is formed. More gas is left over in the disks of Sa's than in SO's, more in Sb's than in Sa's, and so on through the sequence, until the gas dominates the disks of Sd and Sm galaxies.

Figure 2 also shows that the star-formation time relative to the collapse time must differ *even within the elliptical sequence* from EO to E6. The initial star-formation rate in the highly flattened E6 galaxies is sufficiently lower than in non-flattened EO galaxies so that *some* dissipation had time to occur before all the gas was converted to stars. (The dotted E6 curve is farther to the right than the EO curve.) The dissipation caused the potential energy of position (in material that will become the halo) to be partly destroyed in E6 systems by dissipation. This causes a nonisotropic stellar velocity ellipsoid to be set up, leading to a flattening of the resulting equilibrium configuration of the stars. The flattening is not due to rotation but to the dissipative destruction of the potential energy in the early gas-gas collisions. There is more dissipation in E6 galaxies than in EO types. As noted previously, the released energy is ultimately radiated away by quantum mechanical processes in the collapsing gas.

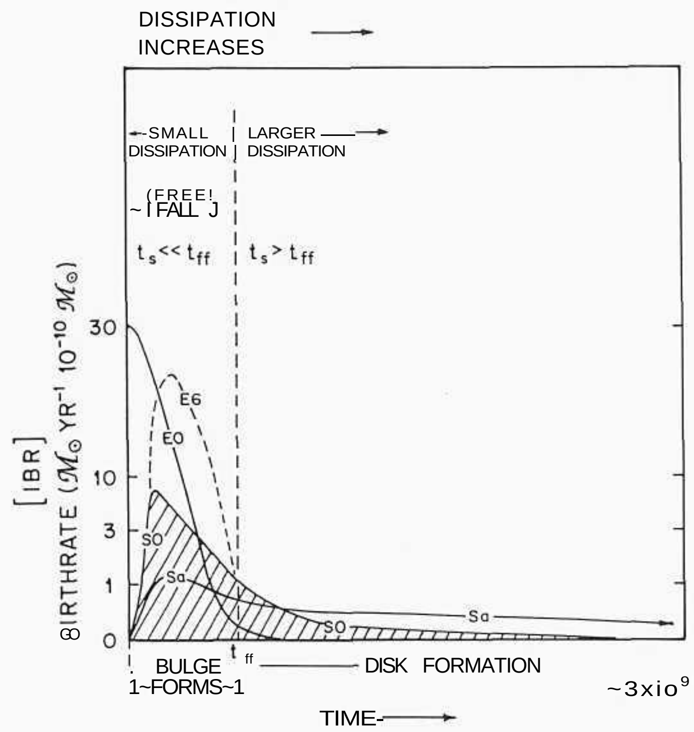
Note the prediction from Figs. 2 and 3 that the present-day surface brightness of the disks should be a progressive function of position along the classification sequence. Gas, not yet converted into stars, still exists in the Sa disks, whereas most such gas that was once in the SO's is now in stars, which, unlike the gas, are luminous. Hence, the disks of Sa galaxies are expected to have a lower surface brightness than those of SO galaxies of the same total mass. A similar decrease in the surface brightness along the sequence is also expected in the later Hubble types. Observation confirms the prediction (Sandage 1983a).

Other implications of Figs. 2 and 3 follow.

(1) The progressive difference in integrated birthrates among Sa, Sb, Sc, Sd, and the Sm types during the lime of bulge formation determines the bulge sizes of these galaxies.

(2) The ratio of the areas under each curve to I he left and to the right of the vertical t'y line determines the bulge-to-disk ratio.

(3) The area under the curves to the right of the vertical line, extended to the present epoch, determines the present surface brightness attributable to the oldest stars (older than, for example, 2 X 10^9 years) of the disk. To illustrate the point, tin- integrals under the SO curve in Fig. 2 and under the Sm curve in Fig. 3 are shown hatched.



FIO. 2. The formation history of bulge and disk components of E, SO, and Sa galaxies, depending on the rate of star formation (expressed in solar masses of stars formed per year per 10^{10} solar masses of the content of the parent protogalactic cloud).

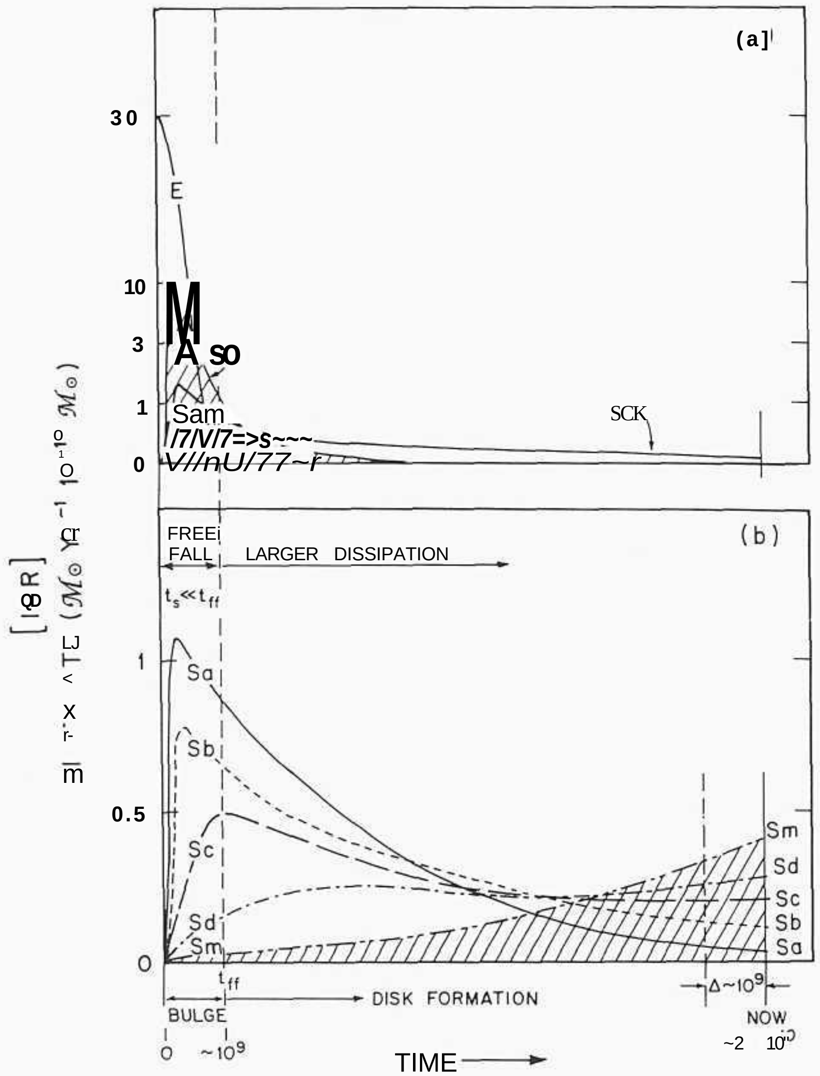


FIG. 3. Same as Fig. 2 but for Sb, Sc, Sd, and Sm as well as E, SO, and Sa types.

(4) The intersection of each curve in Fig. 3 with the vertical line marked "now" shows the present stellar birthrate for each Hubble type (each curve to be normalized to the total mass of the galaxy).

(5) The ratio of the area under each curve in the 10^9-year time interval shown in the second panel of Fig. 3 near the present "now" epoch, to the total time (the age of the disk), gives the relative color of the integrated disk light. Young stars appear only in the last 10^9-year interval, whereas the older stars of the disk are made in the time interval to the left of the second-to-last vertical line.

Figures 2 and 3 explain, then, the five principal facts of observation pertaining to the classification sequence.

(1) The bulge-to-disk ratio is a function of Hubble type.

(2) The disk surface brightness varies systematically with Hubble type.

(3) Integrated color varies progressively with bulge-to-disk ratio and with Hubble type.

(4) The mean age of the disk is a function of Hubble type.

(5) The present-day star-formation rate per unit mass for Sc, Sd, and Sm galaxies is much higher than for SO, Sa, and Sb galaxies.

The principal summarizing conclusion of this picture is this. The driving parameter that determines the ratio of star-formation time to collapse time is the density *contrast,* and if this parameter is a continuous variable, then the classification sequence from E through Sm types is expected to be a true continuum. This continuity has been repeatedly emphasized in this atlas.

The classification system developed and illustrated here has been made on the basis of morphology alone, without *a priori* notions such as the discussion given in this chapter. We, as classifiers, would have you believe that this morphology, ordered by some version of a modified Hubble classification such as is given here, must ultimately drive the theory and sharpen the explanations.

CHAPTER 5

THE ATLAS

The E Classification Section

NGC 7145 EO triplet
CD-1123-Br
Aug 20/21, 1979
103aO + GG385
45 mill

NGC 7145 is the prototype of a pure E galaxy. For **all** members of this class **the** luminosity profile / (r) is well described by the modified Hubble law (Oemler 1976). This is a Hubble (1930) power law at large radii but truncated by a decreasing exponential. A family of profiles is generated by the Oemler equation where the family parameter is the ratio of the envelope to core radius (Oemler's alpha to beta ratio). Variation of this ratio describes the variation of compactness of galaxies within the E section.

Although the position of the dividing line between non-compact E galaxies and the SO class (with the extended outer envelope) is arbitrary, compactness relative to the SO form is the classification criterion for E galaxy morphology. It seems likely that lack of compactness in the envelope of SO galaxies is the signature of a disk.

NGC 7145 is a member of a wide triplet (Sandage 1975b) having similar redshifts. The members are NGC 7145 here (v_o =1865 km s^{-1}), NGC 7144 (EO) at the lower right on this panel (v_0 = 2055 km s"'), and NGC 7155 (SBO; panel 56; v_o = 1829 km s~^{1}). The angular separations from NGC 7145 are 23'for NGC 7144 and 102' for NGC 7155. At a mean redshift distance of 38 Mpc (H = 50) the projected linear separations are 260 and 820 kpc, respectively, similar to separations in the Local Group between our galaxy. M33. and M3 **1**.

NGC 7507 EO
CD-1098-Br
Aug 18/19, 1979
103aO + GG385
45 min

NGC 7507 is a prototype example of a pure E0 galaxy. Globular clusters exist in the envelope.

A nucleated dwarf dE5,N companion exists at a separation of 4.5' nearly due west. The projected linear separation would be 42 kpc assuming a redshift distance of 32 Mpc (v_o = 1600 km a'^{1}; II = 50).

NGC 3379 EO Leo Gr #25
PH-270-S
Dec 10/11, 1952
103aD + GG11
25 min

NGC 3379 forms the central triplet with NGC 3384 (SBO; panels 54, S7) and NGC 3389 (Sc; panel 253) of the extended Leo Group. The redshifts of NGC 3379 and NGC 3384 are similar at v_o = 759 km s^{-1} and v_o = 638 km s~^{1}, respectively. Many dwarf ellipticals and dwarf Im galaxies are associated with the group (Ferguson and Sandage 1990).

NGC 5812 E0
CD-1838-HB
April 1/2, 1981
103aD + GG495
45 min

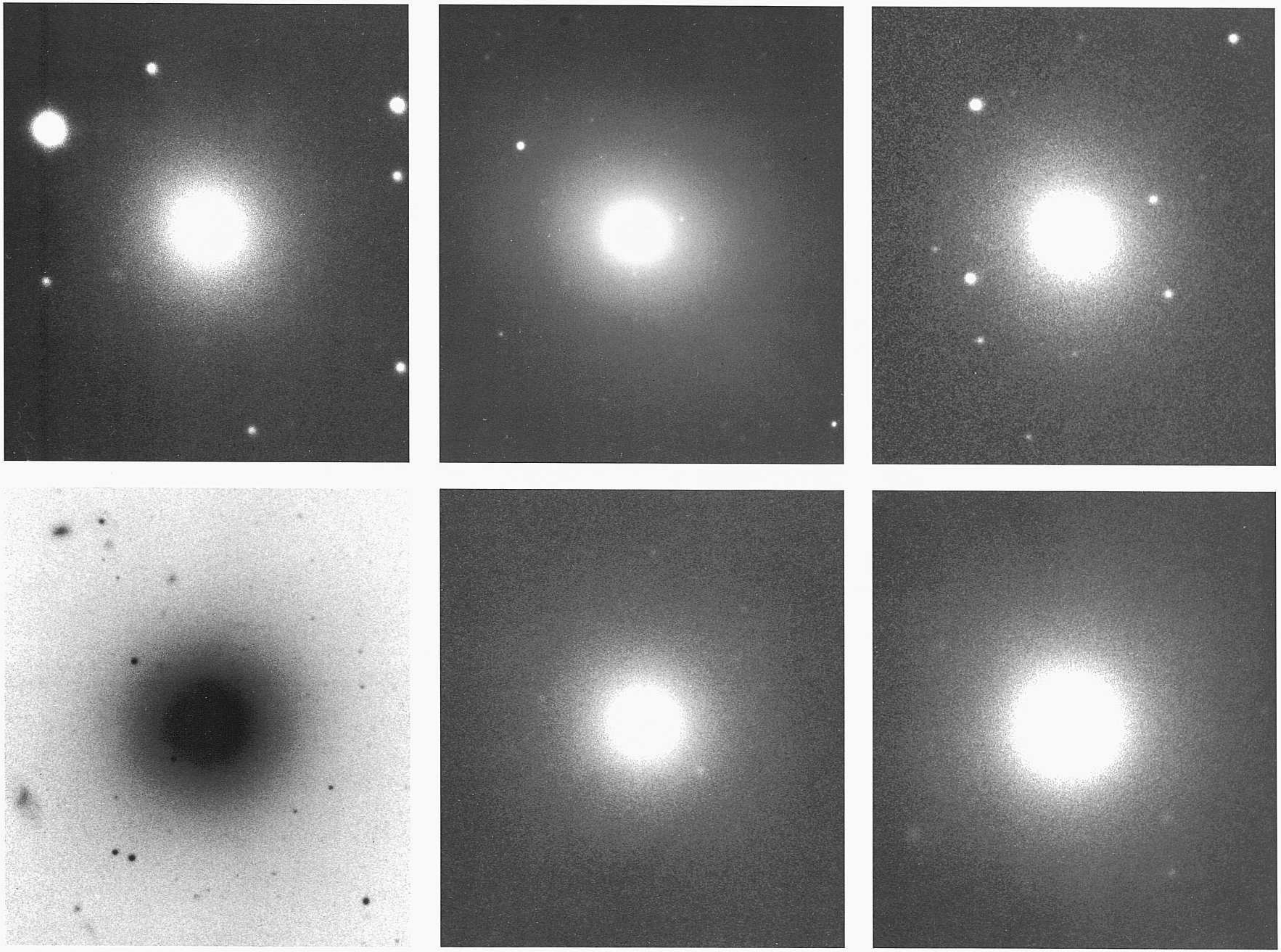
NGC 5812 is close to IC 1084 at 4.8' separation. Several dE dwarf elliptical candidates for companions also exist within 15' of NGC 5812. The redshift of NGC 5812 is v_0 = 1946 km s"'.

NGC 2434 EO
CD-739-S
Feb 3/4, 1979
103aD + GG495
45 min

NGC 2434 is a normal prototype E0 with no bright dwarf companions.

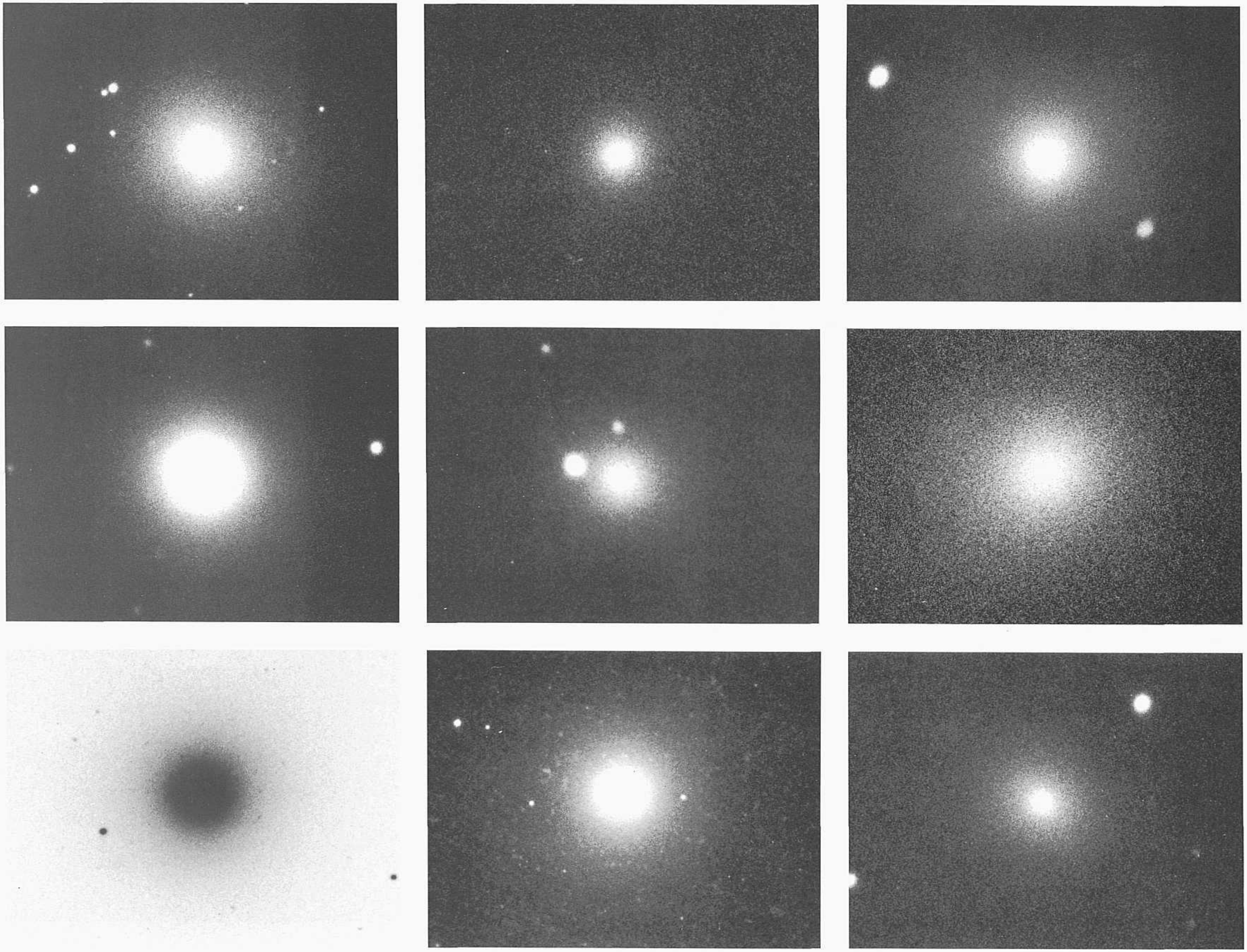
NGC 7144 EO member of triplet
CD-1071-Br
Aug 17/18, 1979
103aO + GG385
45 min

NGC 7144 is the brightest member of a triplet composed of NGC 7145 (E0; panel 1) and NGC 7155 (SBO; panel 56); the triplet is described on this page under NGC 7145.



PANEL
1

PANEL
2



IC 4296 **EO** **IC 4296 Gr**
CD-1861-HB **panel SI**
April 6/7, 1981
103aO
75 niin

IC 4296 is the brightest galaxy of a loose group having more than ten possible members. The mean redshift of the known members is $<v_o>$ = 3648 km s~[1] . Coordinates and individual redshifts for some of the members are given elsewhere (Sandage 1978).

NGC 4283 EO panel 20
PH-676-S
Feb 7/8, 1954
103aO + WG2
45 niin

NGC 4283 is in an apparent (but probably optical) triplet **with** NGC 4278 (El; panel 20) and NGC 4286 (dE,N/Im; panel 20). The redshifts are v_o (4278) = 594 km s"', v_o (4283) = 1053 km s"[1], and v_o (4282) = 615 km s"" Evidently NGC 4283 may be in the background.

Whereas NGC 4278 has many globular cluster candidates over its face (panel 20), NGC 4283 here has only a few, the brightest **of** which arc fainter than the brightest in NGC 4278, consistent with placing NGC 4283 in the background.

NGC 1379 EO FCC 161
CD-718-S
Feb 1/2, 1979
103aO + Wr2c
45 nun

NGC 1379 is near the center of the Fornax Cluster (Ferguson 1989: Ferguson and Sandage 1990) and is among the ten brightest members of the cluster. A few globular cluster candidates exist in the envelope, seen in the negative print here.

NGC **4915** **EO**
S-1671-H
June 3/4, 1937
Imp. Eel.
40 **min**

NGC 4915 is a compact K0 as classified on the lightly exposed Mount Wilson **60-inch plate** used here.

NGC 3348 **EO**
S-416-H
Nov 24/25, 1924
E40
50 **min**

NGC 3348 is a prototypical E0 with no peculiarities. The two images close to the main galaxy image are stars, as shown by **the** sharpness of the images and from **the** diffraction pattern visible on the original plate for the **brighter** image. The print **here** is highly **enlarged** from the original Mount Wilson 60-inch **plate.**

NGC 5044 **EO** **NGC 5044 Gr #84**
CD-819-S
Feb 26/27, 1979
103aO + Wr2c
45 min

NGC 5044 is the central and the brightest member of a rich group that contains many dE dwarf members and a few Im and Sm dwarf candidates. The mean redshift of the group is $<v_o>$ = 2048 km s[1] (Ferguson and Sandage 1990).

NGC **5061** **EO**
H-1791-H
April 14/15, 1937
Imp. Eel.
40 min

On **the** original Mount Wilson 100-inch plate of NGC 5061 used **here,** [here is *a* very weak suggestion of an **incipient** disk similar lo thai in NGC 3111 (SO/a; panels **50,** 53) **but much** more **subtle.** The **high southern** declination of this galaxy at —26° gives a large **zenith** angle at MOUTH Wilson. The weak suggestion of a disk **(which would** require an K/SO **classification)** requires better plate **material.**

NGC **1453** E0 **NGC 1453 Gr**
PH-7949-S
Nov 8/9, 1980
103aO
12 miu

NGC 1453 is a dominant **member** of a loose group of at least **ten early-type** galaxies. The candidates for **membership** have a wide range of apparent magnitude. Bright members of the group include NGC 1441 (Sa) and NGC 1449 (SO). Redshifls, either from the USA or from Sandage (1978). are u_o(1441) = 4162 km s"', u_o(1449) = 4003 km s"', and u_0 (1453) = 3979 km s .

NGC 5198 **El?**
S-1657-H
May **4/5,** 1937
Imp. Eel.
55 **min**

The classification for NGC 5198 of El given in the RSA2 was made from an early Mount Wilson 60-inch **plate, from** which a classification of E/SO is also possible. The classification in the RC2 from the same Mount Wilson plate is El (uncertain), based on **the** suggestion of an extended envelope **characteristic** of SO galaxies. The image is not compact. Belter plate material is **required.**

NGC 6776 El pec (ripple)
CD-1030-Br
July 21/22, 1979
103aO + GG385
45 niin

NGC 67 76 is classed in the RSA2 as El pec (merger?), a misnomer within the principles of classification: a classification notation should not suggest a genesis for a particular form. The notation here is changed to "ripple," following Schweizer (1980, 1982) and Schweizer and Seitzer (1988), although this convention is not consistently followed in this atlas. "Shell" would be an equally appropriate notation, following Malin (1979) and Malin and Carter (1980).

The ripple, or shell, structure is subtle and is not visible in the print here. On the original plate it can be traced as a hemispherical arc concentric with the center of the main image and whose edge extends one-third again beyond the distance to the center of the bright star seen here in position angle 4 o'clock. In the absence of the partial shell, NGC 6776 would be classified as a normal El galaxy.

NGC 7626 El NGC 7619 Gr
CD-1129-Br
Aug 20/21, 1979
103aO + GG385
45 min

NGC 7626 is the second-brightest member of the NGC 7619 group (Humason, Mayall, and Sandage 1956, Table XI), whose mean redshift is $<v_o>$ = 3836 km s"[1]. Both NGC 7619 and NGC 7626 have a central historical role in the discovery of the linear redshift-distance relation. Humason (1929), on a suggestion by Hubble, tested if larger redshifts existed than the highest value of 1800 km s~[J] previously measured by Slipher. Humason used NGC 7619 to measure a redshift twice as large as Slipher's largest, giving Hubble (1929) the basis to suggest that the most fundamental fact of observational cosmology, the redshift-distance relation, was about to be discovered.

The group, dominated by NGC 7619 and NGC 7626, contains many bright early-type members and a number of dE dwarf elliptical candidates. Redshifts of six of the brightest members have been listed by Humason, Mayall, and Sandage (1956). The group is called Peg I in Sandage (1975b, Table 4).

NGC 7796 El
CD-1078-Br
Aug 17/18, 1979
103aO + GG385
45 **min**

NGC 7796 is an isolated prototype El galaxy. There are no globular clusters in the envelope brighter than B = 23, as expected because the redshift of v_o = 32 63 km s^{-1} gives a distance modulus of m - M = 34.0 mag (H = 50), consistent with the absence of globular clusters brighter than M_B =—11. Brightest globular clusters, which normally reach $M\%$ = —9, should become visible only at magnitude fainter than B = 25 , which is well below the present plate limit.

IC 2006 El Fornax Cluster ?
CD-1117-Br
Aug 18/19, 1979
103aO + GG385
45 **min**

IC 2006 is a normal, non-compact El galaxy. It lies just outside the Fornax Cluster Catalog boundary (Ferguson 1989) on the east side (Ferguson and Sandage 1990, Fig. 5). It is probably associated with the cluster, based on comparison of its redshift of v_o = 1280 km s"[l] with the cluster mean redshift of $<v_o>$ = 13 66 km s^{-1}'. Its apparent magnitude of Bf=12.3 is about 2 mag fainter than the brightest cluster member, which is NGC 1365, B_T = 10.2.

IC 3896 El
CD-1037-Br
July 22/23, 1979
103aO + GG385
45 min

IC 389 6 is a normal, non-compact El. It is in low galactic latitude (b = 13°), which accounts for the high density of foreground Galactic stars. The field is transparent; many background galaxies are visible on the original plate.

NGC 5813 El NGC 5846 Gr
CD-21O6-S panel 4
March 18/19, 1982
103aD + GG495
30 min

NGC5813 is in the group of galaxies having similar redshifts (Humason, Mayall, and Sandage 1956, Table XI) that contains NGC 5806, NGC 5813 here, NGC 5831, NGC 5838, NGC 5854, and NGC 5846, which is its dominant member. The mean redshift of the group (Sandage 1975b) is $<v_o>$ = 1808 km s~'. The group is #50 in the catalog of de Vaucouleurs (1975). The morphology of NGC 5813 is that of a normal, medium-compact El.

NGC 636 El Racine wedge
PH-7945-S
Nov 8/9, 1980
103aO
12 min

NGC 636 is a normal isolated El galaxy. The 2 00-inch Palomar plate used here was taken with a Racine wedge, giving secondary images 5 mag fainter than the primary, separated by 18 arc seconds. The "object" at position angle of 7 o'clock is the secondary image of the (evidently) bright, sharp nucleus of NGC 63 6 itself.

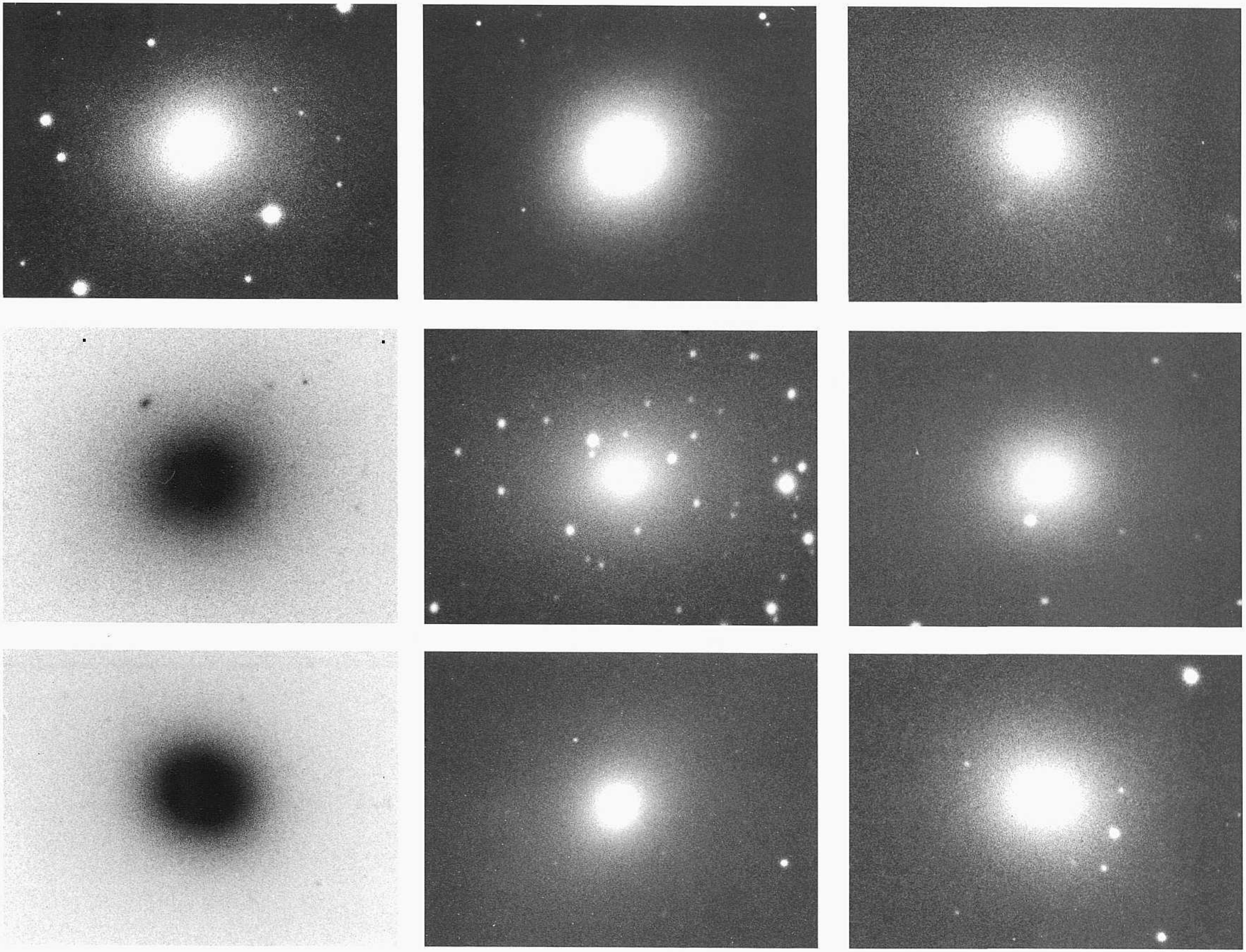
NGC 5796 El pec
CD-1447-S/Br
May 6/7, 1980
103aD + GG495
45 min

NGC 5796 is a moderately compact El galaxy. A dust lane is suggested on the original plate, whose center is near position angle 9 o'clock on the print here. The dust lane is the reason for the "pec" suffix to the type. The object in the envelope at position angle 7 o'clock is a foreground star.

NGC 5793 (Sb: on edge), separated by 4', may be in the background. The redshifts are u_o(5793) = 3446 km s"[1] and u_of5796) = 2871 km s"' (Sandage 1978).

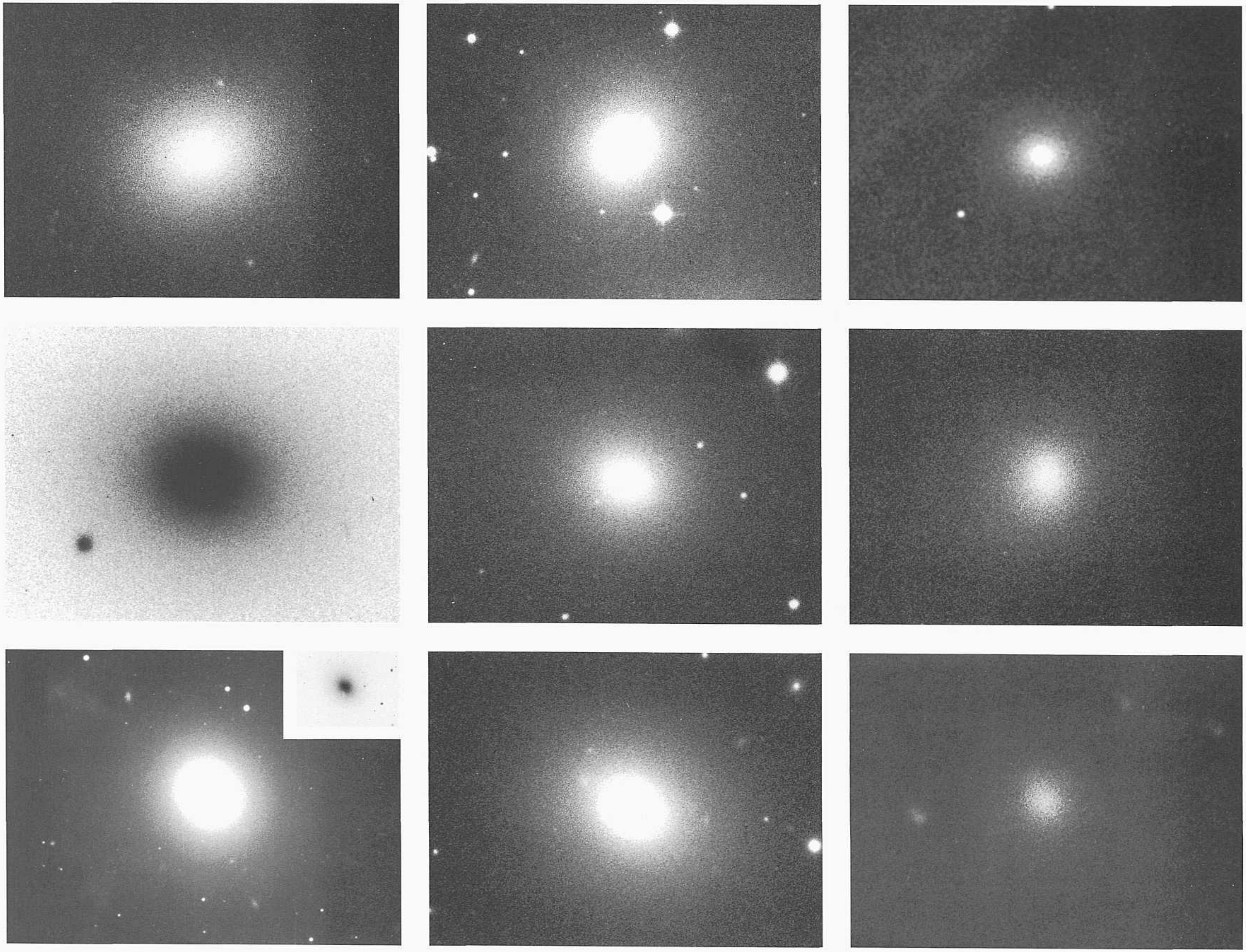
NGC 6721 El pair?
CD-1026-Br
July 21/22, 1979
103aO + GG385
45 min

NGC 6721 is a normal El of medium compactness. It may form a binary pair with IC 4806 (Sb), which is 14.4' distant. The redshifts are u_o(6721) = 4316 km s"[1], from the RSA2, and $t>_o$(4806) = 4249 km s~[J] , from Huchtmeier and Richter (1989). The mean redshift distance is 86 Mpc (H = 50), giving a projected linear separation of 360 kpc for the pair.



PANEL
3

PANEL
4



NGC 3962 El
CD-1870-HB
April 10/11, 1981
103aD + GG495
45min

NGC 3962 has the standard morphology of a medium-compact El galaxy.

NGC 3608 El small group
PH-7646-S
April 29/30, 1979
103aO
10 niiii

NGC 3608 forms an apparent group with NGC 3607 [$S0_3$(3); panel 44] and NGC 3605 (E5; panel 12), as the central members of a more-extended group (#49 in the catalog of de Vaucouleurs, 1975). The redshifts are v_o = 587 km s~\ 828 km s \ and 1105 km s"' for NGC 3605, NGC 3607, and NGC 3608, respectively. No resolution into globular clusters occurs in any of these early-type galaxies.

The morphology of NGC 3608 is that of a moderately compact prototype E1.

NGC 4374 El VCC 763
CD-723-S M84
Feb 1/2, 1979
103aO + Wr2c
45min

NGC 43 74 is one of the brightest galaxies in the Virgo Cluster. Its total apparent blue magnitude is By= 10.2 . The two brightest galaxies in the cluster are NGC 4472 (B_T = 9.3; panels 18, 2 6) and NGC 4486 (B_T = 9.6; panel 17).

A few globular clusters exist in the image of the envelope, but they are much rarer in this galaxy than in either NGC 4472 or NGC 4486.

Very faint dust patches exist near the center, shown in the insert negative print made from a plate (H-2 71-H, Feb 20. 1923) taken by Hubble with the Mount Wilson 100-inch Hooker Telescope. The image to the right of the bulge in this insert print is an artifact of the multiple exposures; the plate was moved between several successive exposures.

NGC 3309 El Hydra Cluster
CD-690-Br
Jan 27/28, 1979
103aO + GG385
45min

NGC 3309 is one of the central galaxies in the Hydra Cluster (Abel! Cluster 1060). Other bright galaxies near NGC 3309 are NGC 3308 [S0!(0,3)], NGC 3311 [E/S0(0)]. and NGC 3312 (Sab; panel 114). This rich cluster, whose mean redshift is $\langle v_0 \rangle$ = 3 700 km s~[1]. contains many dE dwarJ ellipticals. The cluster lies close to the direction of the hot pole of the 3° microwave background radiation (Shaya 1984; Tammann and Sandage 1985).

NGC 3 309 has a prototype El morphology.

NGC 3258 El Antlia Gr #111
CD-1407-S/Br
March 23/24, 1980
103aD + GG495
60min

NGC 3258 is one of the brightest members of the Antlia Group, which has many members, including dE, Sm, and Im dwarfs (Ferguson and Sandage 1990). The morphological type is that of a moderately prototypical compact El .

NGC 777 El group
PH-7826-S panel SI
Sep 2/3, 1980
103aD + GG11
17min

NGC 777 is in the field of NGC 7 78 (Sb) at a separation of 7'. Other Dreyer galaxies in the neighborhood include NGC 783. NGC 785, NGC 789. NGC 793. and NGC 798. Many have redshifts that are closely similar to v_0 = 5248 km s^{-1} for NGC 77 7. This redshift is among the highest in the RSA.

NGC 4494 E1
S-1906-H
Jim 26/27, 1946
103aO
60min

NGC 4494 is an isolated galaxy with standard morphology of a prototype E1.

NGC 5813 El panel 3
H-658-H
May 6/7, 1926
E40
75min

NGC 58 1 3, shown here again, repeating the illustration on the preceding page, is from an earlier Mount Wilson plate taken with the 100-inch Hooker Telescope.

NGC 5638 El **pair**
S-1419-H
May 20/21, 1933
E40
60min

NGC 5638 forms a physical pair with NGC 5 63 6 (SBa of the NGC 3081 type) at 2.3' separation. The redshifts are closely similar at u_o(5636) = 1647 km s~' from the HR 2 1-cm catalog, and u_D(5638) = 1592 km s' from the RSA2 . The mean redshift distance of 32 Mpc (// = 50) gives the small projected linear separation of 22 kpc.

The print is from a weak Mount Wilson 60-inch plate, which should be repeated.

All galaxies on this panel have classifications of E2 in the RSA2 .

NGC 3193 **E2** **quartet**
PH-156-MH
April 14/15, 1950
103aO
30 min

NGC 3193 is a member of a famous quartet whose other members are NGC 3185 (SBa: panel 99), NGC 3187 (Sc/SBc; panel 276), and NGC 3190 (Sa; panel 76). The redshifts of the four galaxies are similar. The mean velocity of the **quartet** from the listings of highest accuracy in PT-NV is $\langle v_o \rangle$ =1295 km s"'. as corrected to the centroid of the Local Group by the precepts of the RSA2.

NGC 3193 is a **typical** E2 galaxy. A very few candidates for associated globular clusters exist in the envelope.

NGC **1549** **E2** **Dorado Gr #35**
CD-1704-S **panel SI**
Jan 5/6, 1981
103aO
75 min

NGC 1549 is a companion of the famous SOj/.? galaxy NGC 1553. which has the pronounced "bright outer rimmed" disk (panel 39). Both galaxies are in the Dorado Group (Ferguson and Sandage 1990). The individual redshifts of the pair are i>$_o$(1549) = 991 km s~' and v_0 = 1053 km s^{-1}.

No globular cluster candidates are present in the image. NGC 1549 has a prototype E2 morphology.

NGC 6758 **E2** **NGC 6769 Gr**
CD-1027-Br
July 21/22, 1979
103aO + **GG385**
45 **min**

The morphology is that of a classical E2 having no peculiarities. The galaxy is a possible member of a group whose eponymous member is NGC 6769. Likely members of the group immediately associated with NGC 6758 include IC 4829. IC 4831 , IC 4832. IC 4837 (panel 284), IC4839. IC4840, and IC4936. The nearest of these to NGC 6758 is IC 4829 (Sa) at 8.1' separation. The mean redshift of those members of the NGC 6769 Group catalogued elsewhere (Sandage 1975b. Table 2; panel 153) is $\langle v_o \rangle$ = 3953 km s"^{1}.

NGC 3268 **E2** **Hydra Cluster**
CD-646-Br
Jaii 4/5, 1979
103aO + GG385
45 niin

Like NGC 3309 on the preceding page, NGC 3268 is near the center of the Hydra Cluster, which is Abell Cluster #1060 in the Abell Cluster Catalog (1958). The morphology of the galaxy is prototypical E2 class.

NGC 2986 **E2**
CD-1374-S/Br
March 20/21, 1980
103aD + GG495
45 **min**

NGC 2 986 is a moderately compact, normal E2. An anonymous Sa, probably in the background, is 2 .4' distant.

NGC 1404 E2 FCC219
CD-718-S
Feb 1/2, 1979
103aO + Wr2c
45 min

NGC 1404 is the third-brightest galaxy in the Fornax Cluster (discounting NGC 1316), and is near the center of the cluster (Fig. 5 of Ferguson and Sandage 1990), 9'south of NGC 1399 (El; panel 19). The morphology is that of a - normal E2 .

NGC 1395 **E2**
H-1784-H
Feb 4/5, 1937
Imp. Eel.
40 **min**

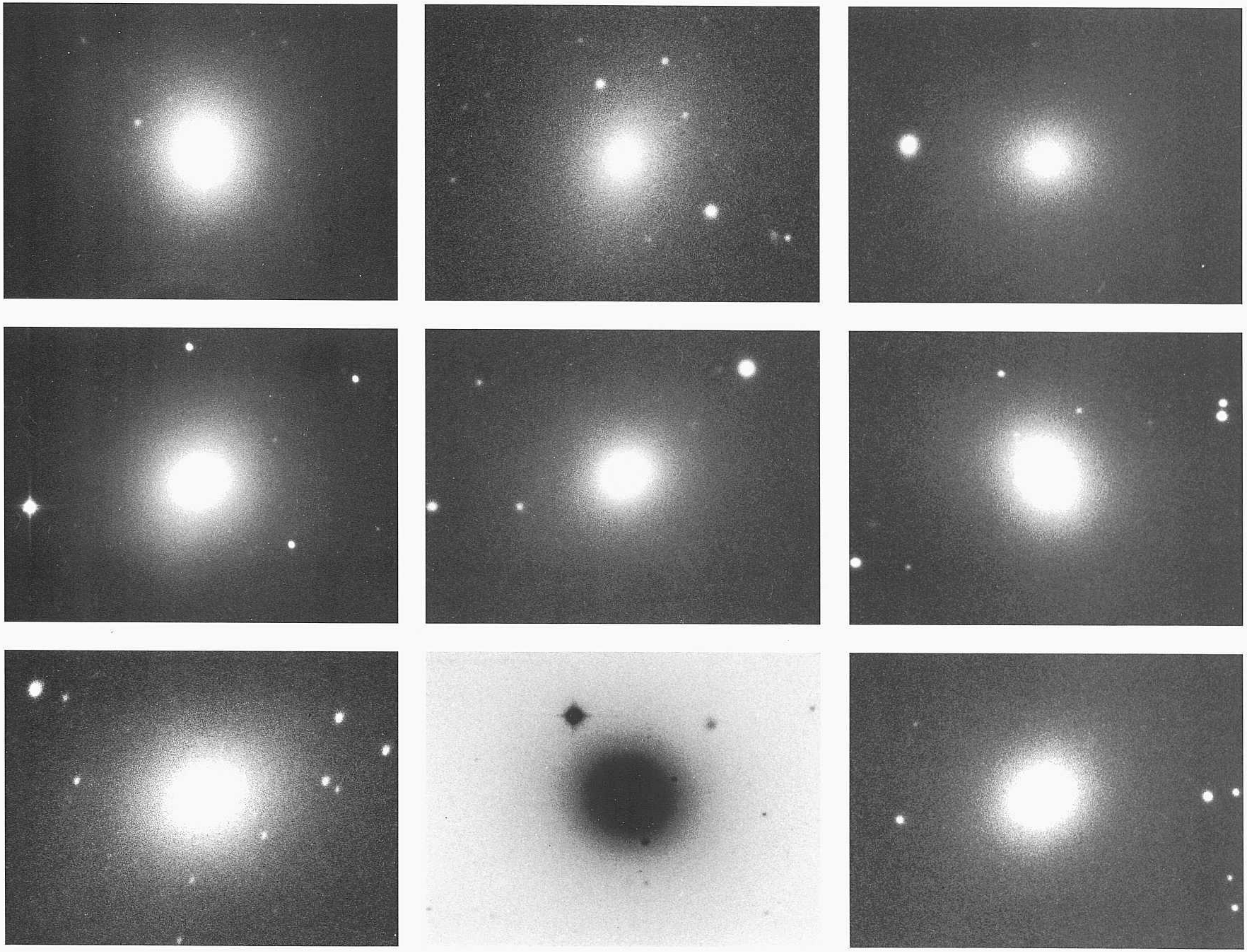
NGC 1395 is an isolated, moderately compact, normal E2 galaxy whose redshift is v_0 = 1664 km **s"^{1}.**

IC 3370 **E2** pec
CD-1286-S/Br
March 9/10, 1980
103aD + GG495
45 min

There is structure interior to the otherwise nearly normal exterior E2 image of IC 3370 here. On a short-exposure du Pont plate, a bright nucleus of finite size (3") is surrounded by a faint *dish* buried within the first 10% of the image shown here.

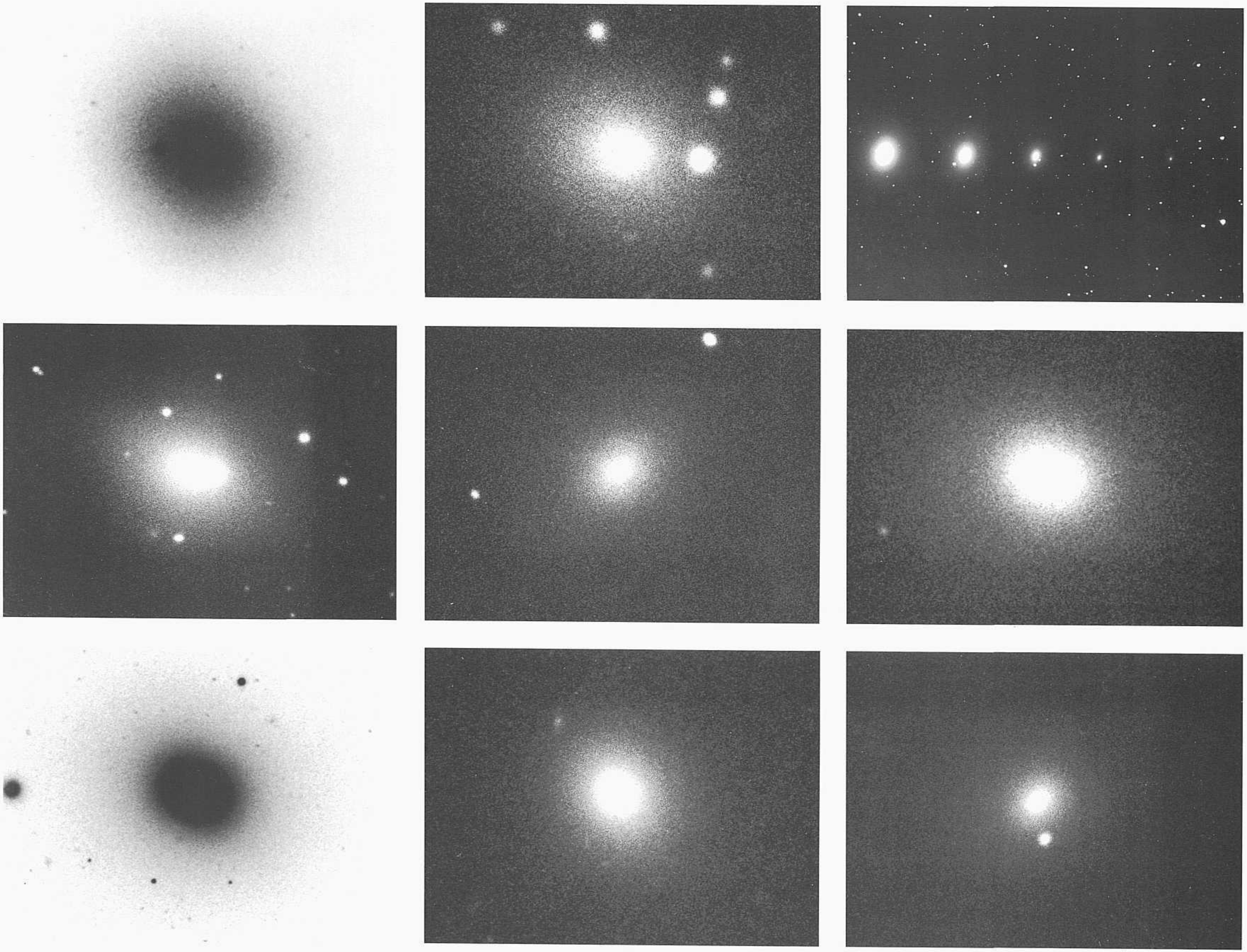
NGC 3087 **E2**
CD-1384-S/Br
March 21/22, 1980
103aD + GG495
45 **min**

NGC 3087 is a compact E2 whose redshift is v_n = 2372 km s^{-1}.



PANEL
5

PANEL
6



NGC 4478 E2 VCC 1279
CD-743-S
Feb 3/4, 1979
103aO + Wr2c
60 niin

NGC 4478 in the Virgo Cluster is the nearest bright galaxy to NGC 4486 (M87), which is the dominant galaxy in Virgo subcluster A (Binggeli, Tammann, and Sandage 1987). It is a moderately compact E2 galaxy, 2.5 mag fainter than M8 7.

NGC 6482 E2
PH-7813-S
Sep 2/3, 1980
103aO
12 min

The image of NGC 6482 here is distorted by ihe presence of a bright foreground star 8" from the center. The galaxy, discounting this contaminating star, has a normal E2 morphology.

NGC 4261/Anon VCC 344 E3 VCC 345/344
CD-1339-S/Br
March 14/15, 1980
103aO
75 niin

This normal E3 galaxy, listed in the Virgo Cluster Catalog (Binggeli, Sandage, and Tammann 1985), is in the region of the more-distant W cloud (Binggeli, Tammann. and Sandage 1987). The very compact (M32-like) EO galaxy, listed as VCC 344, is at the left-middle edge of the print here.

The redshift of NGC 42 61 is $i>_o$ = 2075 km s^{-1}.

NGC 2888 E2 (SO?)
CD-1367-S/Br
March 17/18, 1980
103aO + GG385
45 niin

The luminosity gradient of NGC 2888 is shallow enough in its outer envelope to put the classification at tin[1] border between the morphological boxes of the E, E/SO , or even SO types. On the original plate the faint envelope can be traced to the position of the bright star to the right of the galaxy in the print here. The classification of El in the RC2 is based on a Mount Wilson 100-inch plate on which the outer envelope is not visible.

NGC 4589 E2
S-1915-H
April 2/3, 1940
103aO
60 min

A classical E2 morphology is evident from this Mount Wilson 60-inch plate.

NGC 5017 E2 N5044 Gr #5
CD-819-S
Feb 26/27, 1979
103aO + Wr2c
45 niin

NGC 5017 is in the NGC 5044 Group (see Ferguson and Sandage 1990 for a catalog and map). It is a normal E2 with no peculiarities.

NGC 221 cE2 Local Gr
H-154-H panel 14
Sep 3/4, 1921 M32
Seed 30
multiple times

M32 . a companion to M3 I (Hubble Atlas, p. *18;* panel 149 here), is the prototype galaxy for the highly compact E galaxy form (cE types). The effective surface brightness of galaxies of ihis type is higher than normal at the relevant absolute magnitude (Sandage and Perelmutler 1990. Fig. 1 I).

The print here contains five images made in a series of exposures on the same plate taken by Hubble with the Mount Wilson 100-inch Hooker Telescope.

The compactness of M32 extends to the central regions, as shown by the nearly starlike fifth image in the print here.

NGC 2300 E3 pair?
PH-7566-S
Nov 7/8, 1978
103aO
12 min

NGC 2300 forms an optical pair with NGC 22 76 (Sc: panel 263) at a separation of 6.3'. The redshifts $t>_o(2276)$ =2648 km $s^{"1}$ and $u_o(2300)$ = 2190 km s^{-1} differ enough to question a physical association.

NGC 23 00 has *a* normal E3 morphology.

NGC 5557 E2 small group
S-553-B
April 9/10, 1937
Imp. Eel.
60 min

NGC 5 55 7 has a normal E2 morphology. It forms a wide configuration (separation of 19') with the interacting binary pair of NGC 5 544 and 5545 (Arp 199, VV210. Karachentsev 422). The redshifts are $i\text{-}_0(5544)$ = 3 1 39 km s⁻' and $u_{,(}(5545)$ = 3 1 45 km s^{-1} from Karachentsev, and $u_o(5557)$ = 3243 km s~' from the RSA2 . The mean redshift distance of 64 Mpc (// = 50) gives a projected linear separation of iNGC 5557 from the interacting pair of 350 kpc.

NGC 5357 E3 IC 4329 **Cluster**
CD-1084-Br
Aug 18/19, 1979
103aO + GG385
45 mill

NGC 5357. with a redshift of u_a = 4782 km s^{-1}. may be an outlying member of the IC 4329 cluster, whose mean redshift is <u_o> = 4320 km s~' (Sandage 19751)). NGC 5357 has a normal E3 galaxy morphology.

NGC 7619 E3 Peg 1 Cluster
CD-1129-Br
Aug 20/21, 1979
103aO + GG385
45 min

NGC 7619 is the brightest member of the Pegasus I Cluster, whose mean redshift of the listed members is <i'$_0$> = 3836 km s^{-1} (Sandage 1975b). As described in the comments for NGC 7626 (panel 3), NGC 7619 played a major role in Hubble's (1929) formulation of the redshift-distance relation. It was the galaxy used by Humason (1929) to obtain the largest redshift known at the lime. The two spectra taken by Humason that showed the highest redshift known at that time required exposures of 33 and 45 hours with the Mount Wilson 100-inch Hooker reflector. (Much-superior spectra can be obtained today with modern spectrographs and detectors in less than one minute).

The morphological type of i\GC 7619 is normal E3.

NGC 4365 E3 VCC 731
CD-792-S panels 18, SI
Feb 23/24, 1979
103aO + Wr2c
55 min

NGC 4365, one of the brighter members of the Virgo Cluster, is associated with the Virgo subcluster B centered on NGC 4472. The blue magnitude of NGC 4365 is B_T = 10.6. which is 1.3 mag fainter than B_T = 9.3 of NGC 4472. the brightest galaxy in the cluster (Binggeli, Sandage, and Tammann 1985).

Globular clusters are evident, the few brightest of which are at the same apparent magnitude as the brightest globular clusters in NGC 4486 (panel 17), although bright clusters are much fewer in NGC 4365 than in NGC 4486.

NGC 3557 E3 NGC 3557 Gr
CD-1424-S/Br
March 25/26, 1980
103aD + GG495
45 min

NGC 3557 is the eponymous galaxy of a group of moderately bright galaxies whose mean redshift is <I>,,> = 2527 kms"^{1} (Sandage 1975b). Other members of the group include NGC 3564 and NGC 3568.

The morphology of NGC 3557 is prototypical E3.

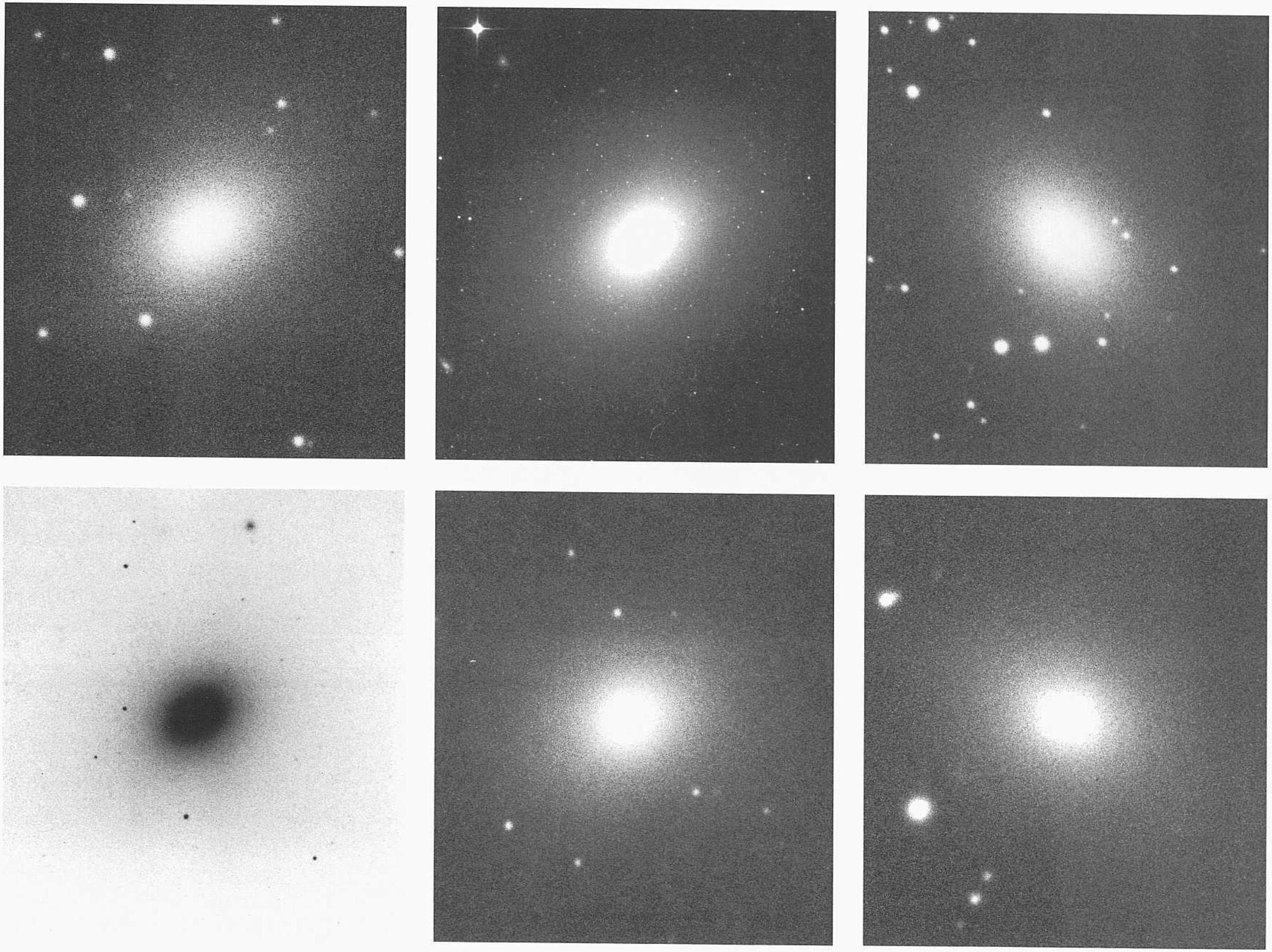
NGC 3250 E3
CD-1408-S/Br
March 23/24, 1980
103aD + GG495
50 min

NGC 3250 is a normal, moderately compact prototypical E3 galaxy.

It is in the rich region of the Hydra-Centaurus Supercluster near the Antlia Cluster (Sandage 1975b: Ferguson and Sandage 1990). but 4° south. A survey and a radial velocity study of the region is given by Hopp and Materne (1985). where the relation of NGC 3250 to the neighboring galaxies is set out (their Fig. 1).

NGC 7168 E3
CD-1555-S/Br
Aug 8/9, 1980
103aO + GG385
45 min

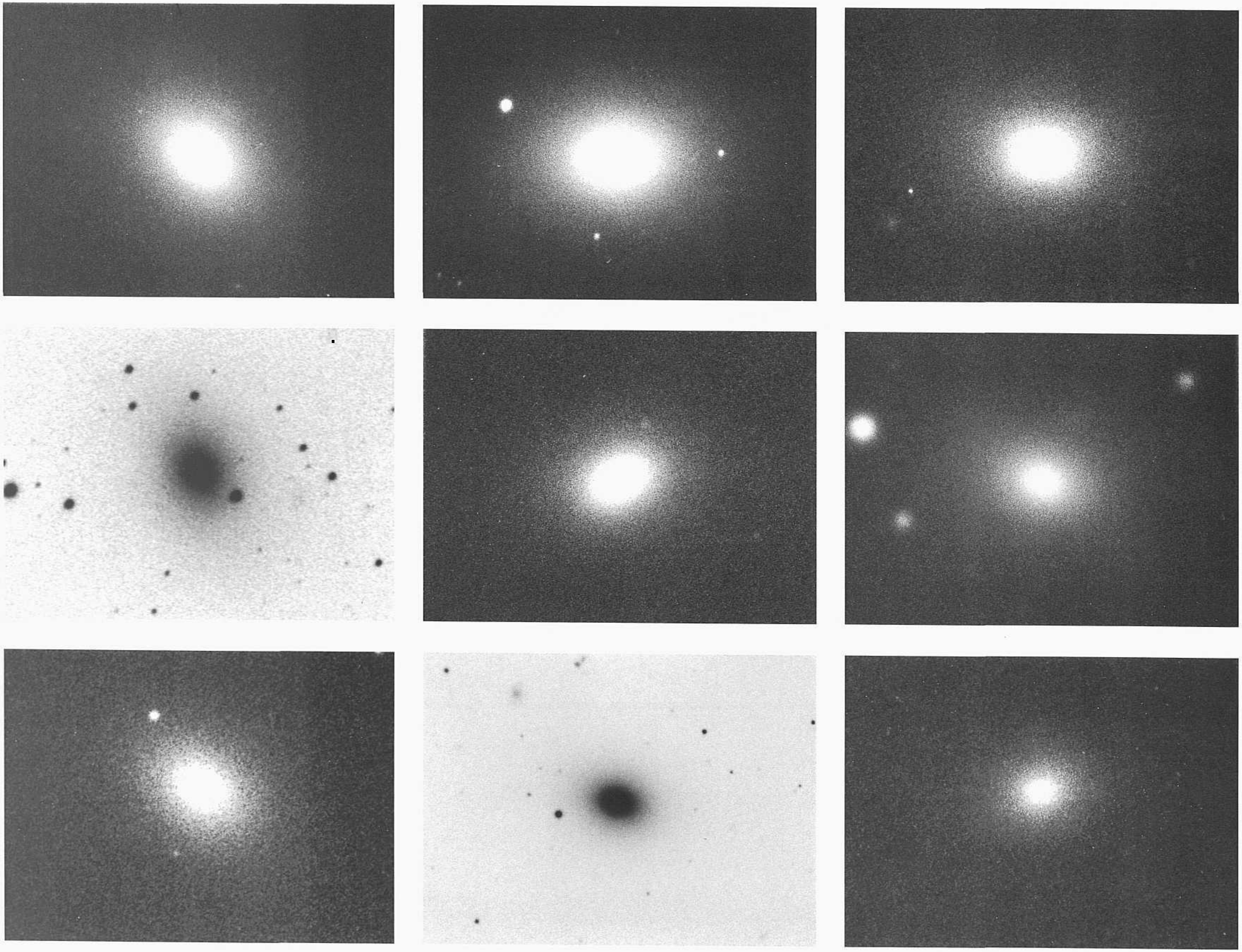
NGC 7168 has the morphology of a normal E3 with a slightly extended envelope. A possible fainter companion (SO pec, dust) of unknown redshift exists at 3' separation.



PANEL
7

PANEL

8



NGC 533 E3 group
PH-7825-S
Sep 2/3, 1980
103aD + GGll
17 min

NGC 533 is the brightest galaxy in an apparently associated group of E and SO galaxies. Many candidate dE dwarf ellipticals exist over a field of radius ≤ 1 5' surrounding NGC 533.

NGC 533 forms a pair with NGC 521 (SBc; panel 293) at 14.6'separation. The redshifts are similar, at $u_o(533)$ = 5664 km s~[1] and y_o(52 1) = 5223 km s^{-1}. At the mean redshift distance of 109 Mpc (*H* = 50), the projected linear separation is 460 kpc, similar to distances within the Local Group.

The pair is 3° north of the Abell cluster A194, whose brightest member is NGC 545 (radio source 3C 40) at a similar mean redshift of 5400 km s'" (Sandagc 1972 for the cluster photometry). The similarity of the redshifts of the NGC 533/521 pair with that of the cluster A194 at a projected separation of 6 Mpc suggests that the region is part of a larger complex at a mean redshift of about 5500 km s^{-1}.

HA 85-2 (A1852-54) E3 IC 4796 Gr
CD-2207-S
March 3 I/April 1, 1982
103aO + GG385
30 min

This galaxy is a member of the IC 4796 group at mean redshift $\langle v_o \rangle$ = 2653 km s^{-1} (Sandage 1975b).

NGC 3091 E3 group
CD-1422-S/Br
March 25/26, 1980
103aD + GG495
4'5 min

NGC 309 1 is the dominant member of a group containing NGC 3096 and about ten fainter candidate members, including several dE dwarf ellipticals.

NGC 1700 E3
PH-156-H
Oct 14/15, 1952
103aO
30 min

NGC 1700 is a non-compact E3 with an extended envelope, placing the morphological type near the border of the E/SO morphological box. NGC 1699 (She 11) is 6.6' distant. There is no evidence for globular clusters in the image, but none should be expected given (IK[1] large distance modulus of *m* — *M* = 34.5 mag based on the redshift of v_o = 3929 km s~'.

NGC 1521 E3
CD-1732-S
Jan 11/12, 1981
103aD + GG495
45 min

NGC 1521 is an apparently isolated normal E3. NGC 1518 (Sc; panel 272), al 22' separation, has a much smaller redshift at v_o = 9 1 *4* km s'" than NGC 1521 al v_o = 4170 km s~'.

NGC 4786 E3
CD-1882-HB
April 11/12, 1981
103aO
75 min

NGC 4786 is an apparently isolated normal E3 galaxy. The nearest Dreyer galaxy is NGC 4775 (Sc; panel 268), which is well in the foreground: the redshifts are i>$_o$(4775) = 1375 km s~[1] and u_o(4786) = 4454 km s~[1].

NGC 3078 E3
CD-1404-S/Br
March 23/2 I, 1980
103aD + GG495
20 min

NGC 3078 is a moderately compart, normal E3. It has no bright neighbors within 15'. The galaxy appears to be isolated.

NGC 2749 E3 **group?**
PI 1-797 I-S
Feb 1/2, 1981
103aO
12 min

NGC 2749 has a normal E3 morphology, ll is in a moderately rich field of other Dreyer galaxies which includes NGC 274 1 ,2744,2745, 2747, 275 1. and 2752. Some of these have redshifts (Palumbo *el al.* 1 983 ; Huchtmeier and Richter 1989) similar to that of NGC 2749. D„(2 749) = 4143 km s⁻'.

NGC 2314 E3 pair
S-4853-Seares
Feb 1919
emulsion unknown
about 1 hr

NGC 23 14 forms an apparent pair with IC 2174 (SO) at 5.8' separation. The redshift distance of 82 Mpc. based on the redshift of $v_{()}$ = 4079 km s'" of NGC 2314. gives a projected linear separation of 1 3 8 kpc.

The morphological type of NGC 2314 is E3 of average compactness.

IC 1459 E4 Grus Gr
CD-572-S
Oct8/9, 1978
103aD + GG495
30 niiii

IC 1459 is the brightest galaxy in the Grus Group, which is a loose group of wide extent (Sandage 1975b). IC 1459 is the brightest member and is isolated, having only a few spirals **nearby.** The two centers of concentration of the group are IC 1459 and NGC 7496 **(SBc;** panels 303. S10). NGC 7531 (Sbc; panel 175), NGC 7582 **(SBab; panel** 122), NGC 7590 (Sell), and NGC 7599 (Sell). The brightest galaxy in this second concentration is NGC 7582. The mean redshift of the group is $<v_o> = 1580$ km s~^{1}.

The nearest **Dreyer** galaxy to IC 1459 is IC 5265 (Sb? on edge), 6.5' distant, which is a projected linear separation of 60 kpc.

NGC 5576 E4(tides?) triplet
CD-1837-HB
April 1/2, 1981
103aO + GG385
45 inin

NGC 5576 forms a triplet with NGC 5574 **(SO/a;** panel 59) at 2.7' and NGC 5577 at 10.1' separation. The three galaxies have similar redshifts of $u_o(5574) = 1612$ km s~^{1}, $\mathbf{u_o(5576)} =$ 1424 km s^{-1}. and $i?_o(5577) = 1455$ km s^{-1}, for a mean $<v_o> = 1497$ km s^{1}. At the redshift distance of 30 Mpc ($H = 50$), the projected linear separations from NGC 5576 are 23 kpc for NGC 5574 and 88 kpc for NGC 5577.

NGC 5576 has a prototypical E4 morphology of average compactness.

NGC 7097 E4
CD-mi-Br
Aug 18/19, 1979
103aO + GG385
45 inin

NGC 7097 is a prototypical E4.

NGC 2325 E4 **group**
CD-726-S panel 10
Feb 2/3, 1979
103aD + GG495
60 niin

NGC 2325 is a prototypical E4, well isolated from any other Dreyer galaxy, yet is the dominant member of a group of about 10 dE dwarf candidates (within a radius of 15').

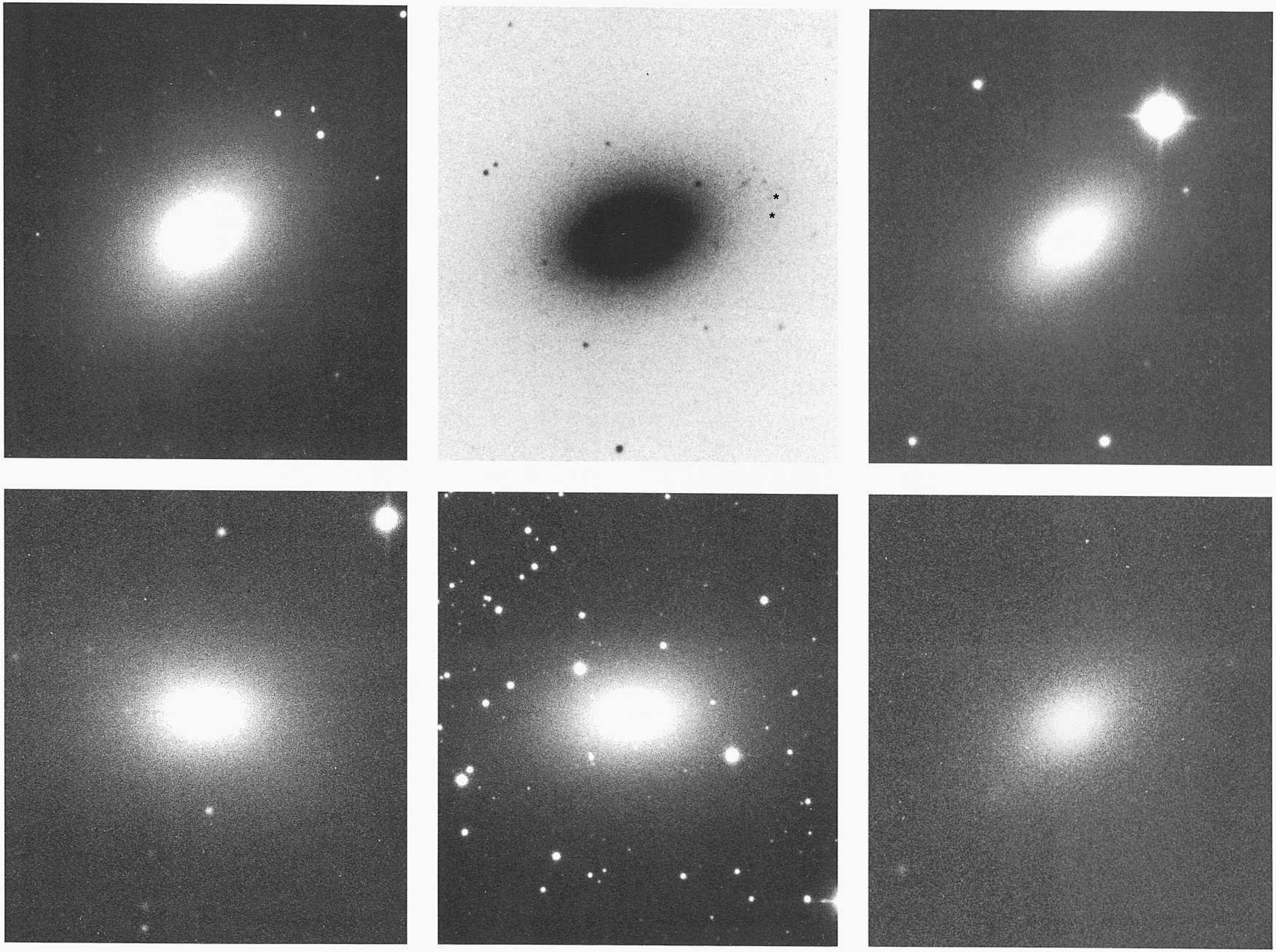
A detail of the smooth central region is shown on panel 10.

NGC 2974 E4
CD-1382-S/Br
March 21/22, 1980
103aD + GG495
45 min

NGC 2974 is a prototypical normal E4 galaxy of average compactness. It is isolated: no other Dreyer galaxy is within several degrees.

NGC 3872 E4
CD-2209-S
April 1/2, 1982
103aD + GG495
45 min

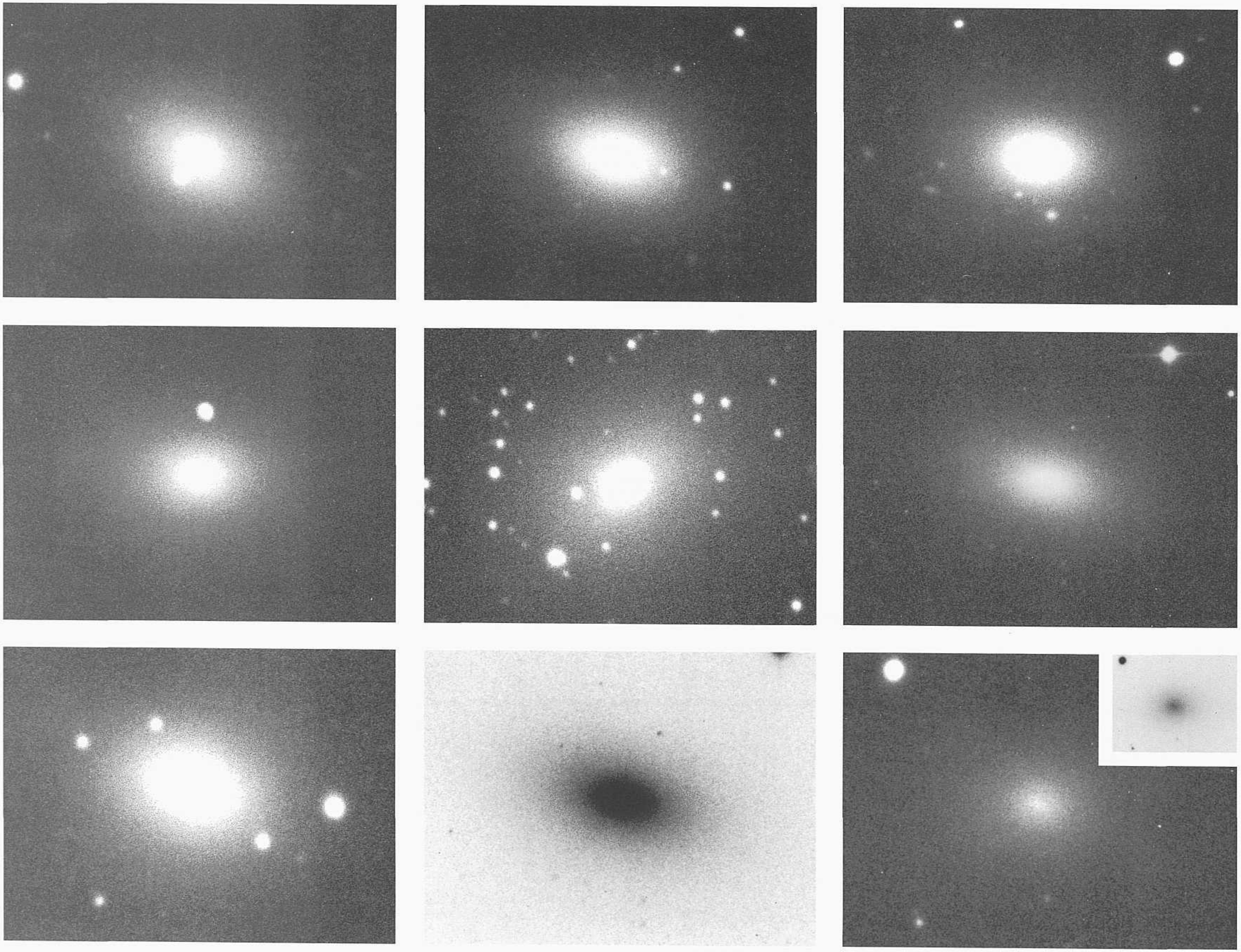
NGC 3872 is a normal E4 of moderate-to-high compactness. It is apparently isolated, not a member of any known group.



1'ANEL
9

PANEL

10



NGC 2865 E4 (SO?)
CD-1366-S/Br
March 17/18, 1980
103aO + GG385
17 mill

NGC 2 865 is classified in the RSA as E4, based on a Mount Wilson 100-inch plate. However, inspection of a new Las Campanas 100-inch plate suggests an E/SO or SO classification. An extended envelope is present, characteristic of the SO class. If the E4 classification is kept, NGC 2 865 is at the extreme border of the E and E/SO morphological box. Data on the surface brightness profile would be of interest to compare with similar data for the more-compact E galaxies identified in this section of this atlas.

NGC 5322 E4 (E/SO)
S-521-H
May 15/16, 1926
E40
90 niin

The classification of E4 for NGC 5322 is based on the early Mount Wilson 60-inch plate shown here. An extended envelope exists, although it is less pronounced than that of NGC 2685. NGC 5322 is near the border of the E and E/SO morphological boxes. It is noted in the RC1 that the classification is possibly SO", based on the same 60-inch plate used here.

NGC 6851 E4 Telescopium Gr
CD-1048-Br
Aug 12/13, 1979
103aO + GG385
44 niin

NGC 68 51 is a member of the loose Telescopium Group (de Vaucouleurs 1956a), whose dominant members are NGC 6861 (SO: panel 43) and NGC 6868 (E/SO: panel 26). The mean redshift taken from nine members of the group is $<v_o>$ = 2733 km s"[1] (Sandage 1975b). The image of NGC 6851 is diffuse. Its position in the classification sequence is late in the E morphological box, close to the border with the E/SO box.

NGC 3706 E4
CD-1281-S/Br
March 9/10, 1980
103aD + GG495
45 niin

NGC 3 706 has a prototypical E4 morphology of moderate compactness. It is much more compact than the three galaxies in the left-hand column. NGC 3706 is near the middle of the E morphological box.

NGC 3136 E4 (E/SO)
CD-1356-S/Br
March 16/17, 1980
103aO + GG385
45 min

NGC 3136 is a diffuse E4 with compactness near that of the E/SO class; it has an extended envelope. The galaxy is classed as a possible SO^- in the RC1, based on a Mount Stromlo 30-inch plate.

NGC 4742 E4
CD-1848-HB
April 3/4, 1981
103aO
75 min

NGC 4742 is in a complex field containing many Dreyer galaxies within several degrees. The nearest galaxy in projection is NGC 4760 (SO or CD: panel 30), which, however, is in the background with redshift v_o = 4451 km s^{-1}. The redshift of NGC 4762 is v_0 - 1114 km a"[1].

NGC 4742 is a normal E4 that is moderately diffuse. It is in the E morphological box, about two-thirds the way toward the E/SO boundary. The negative print here is made with high contrast to show the outer envelope. The positive print in the middle panel at the right shows the more-central regions.

NGC1339 E4 FCC 63
CD-1717-S
Jan8/9,1981
103aO
75 min

NGC 1339 is a moderately bright member of the Fornax Cluster (Ferguson 1989). of apparent magnitude Bj = 12.7. The brightest cluster member is NGC 13 99 (K.I: panel 19), B_T = 10.6. NGC 1339 is about i ° northwesl of the cluster center as an outlying member of the cluster (Ferguson ami Sandage 1990. Fig. 5). It has a normal M- morphology near the center of the E morphological box.

NGC 4742 El
CD-1848-HB
April 3/4, 198 1
103aO
75 min

A negative print of the same galaxy is shown in the bottom pane) of the middle column of this page. The more-central region of NGC 4742. a prototype *FA* galaxy, is shown here.

NGC 2325 E4 panel 9
CD-750-S
Feb4/5, 1979
IllaJ + Wr2c
20 min

This print from a short-exposure IllaJ Las Campanas plate shows the bright, central region of NGC 232 5, giving a smooth profile to the center, which is typical of E galaxies. A deeper print of NGC 2325 is on the preceding panel.

IC 5105 **E5**
CD-1090-Br
Aug 18/19, 1979
103aO + GG385
45 iiiin

IC 5 1 05 has the prototype morphology of a moderately compact, normal E5 galaxy. Its redshift is high for **Shapley-Ames** galaxies, v_0 = 5340 km s^{-1} . From the large redshift and the bright **apparent** magnitude, it follows that the absolute magnitude is among the brightest known for field galaxies, **at** M_{BT} = -22 .5 .

NGC 720 E5
PH-7947-S
Nov 8/9, 1980
103aO
12 nün

iNGC 72 0 is a prototype E5 galaxy of average compactness.

NGC 4660 **E5 (E/SO)** **VCC 2000**
CD-802-S **panel 19**
Feb 24/25, 1979
103aO + Wr2c
45 min

There is a disk in the outer isophotes of NGC 4660, yet the deviations from pure ellipses are subtle enough that the type was called E5 in the RSA and RC2. It was independently classified as E3/S0j(3) in the Virgo Cluster Catalog (Binggeli. Sandage, and Tammann 1985) from the same Las Campanas plate shown here. The near-disk is visible in this negative print as the family of pointed outer isophotes.

NGC 6909 **E5 (E/SO)**
CD-1058-Br
Aug 16/17, 1979
103aO + GG385
45 min

The outer region of NGC 6909 has a more-shallow luminosity gradient than is present in a pure (prototype) E5 galaxy similar to NGC 720 at the left. On the original plate the bright central bulge almost separates the image into two intensity zones, as is discussed in many of the SO descriptions. The lack of a compactness appropriate for a pure E5 morphology is sufficiently apparent to place the galaxy near the end of the E morphological box, near the border of the E/SO box.

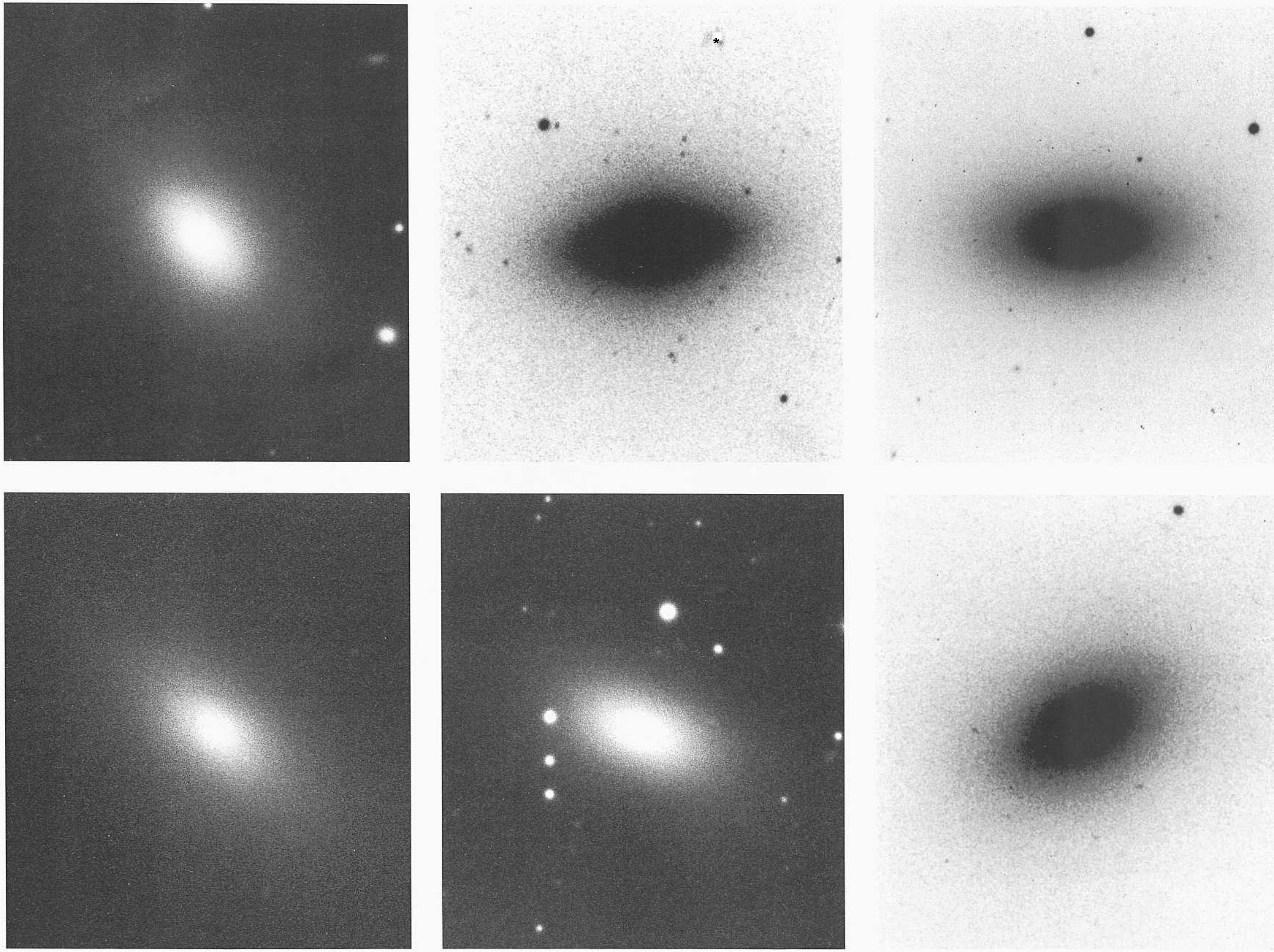
NGC 4473 **E5** **VCC 1231**
CD-724-S
Feb 1/2, 1979
103aO + Wr2c
60 min

NGC 4473 has a prototypical E5 morphology of moderate compactness. The galaxy is in the middle of the E morphological box where the luminosity gradient is moderately shallow, but yet is compact enough to be far from the E/SO boundary.

NGC 4476 **E5 pec(dust); SO,3(5)** **VCC 1250**
CD-743-S **panel 12**
Feb 3/4, 1979
103aO + Wr2c
60 min

NGC 4476 is classed as E5 pec(dust) in both editions of the RSA. It is classed as $S0_3(5)$ in the Virgo Cluster Catalog based on the Las Campanas plate used here, and is also classed SO in the RC2 based on a Palomar 2 00-inch plate, in both cases because of the presence of an extended envelope.

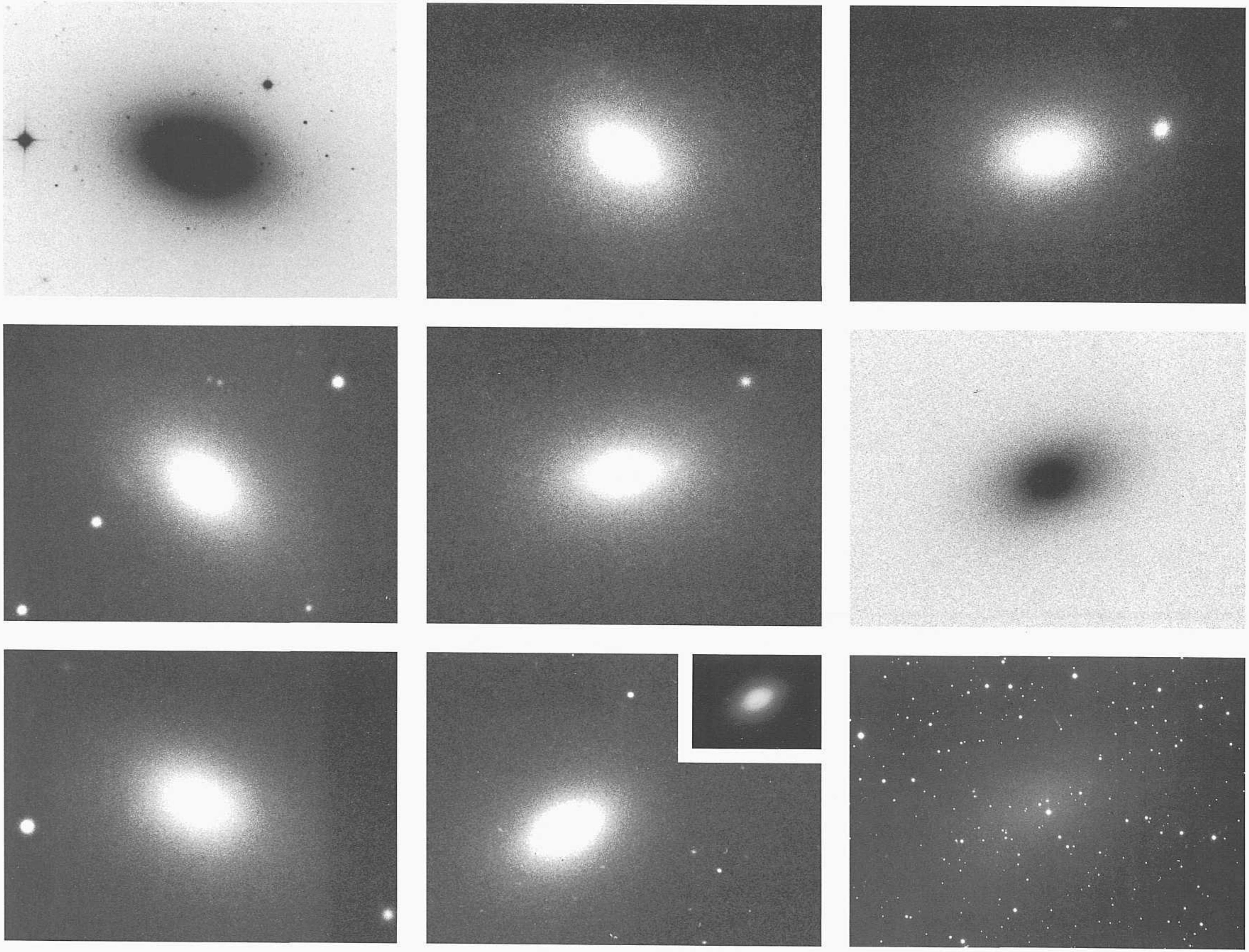
The $S0_3$ subclassification is due to the presence of an internal dust lane buried in the central image, invisible in the overexposed print here. The dust lane is seen in the insert print in the middle bottom illustration of panel 12.



PANEL

11

PANEL
12



NGC4621 E5 VCC 1903
CD-1340-S/Br panel 32
March 14/15, 1980
103aO
75 niin

NGC 4621. situated in the eastern outskirts of the Virgo Cluster, is closer to subcluster A than to subcluster B (Binggeli, Tammann. and Sandage 1987). It has prototypical ES morphology. The isophotes are ellipses with no pointed tips, characteristic of a disk. Such types would require an E/SO or SO classification. The image has moderate compactness and no evidence of an outer envelope.

NGC 4645 E5
CD-1430-S/Br
March 25/26, 1980
103aD + GG495
40 niin

NGC 4645 has the prototype morphology of a pure E5 with no indication of an SO disk. It is located near the center of the major concentration in the Centaurus complex (Dickens, Currie, and Lucey 1986, Fig. 1) which is the high-density Centaurus Cluster (Lucey, Currie, and Dickens 1986.Fig. 1).

NGC 439 E5 NGC 439 Cluster
CD-1147-Br
Aug 21/22, 1979
103aO + GG385
45 min

NGC 439 is the brightest galaxy of a small cluster of at least 30 members ranging in luminosity over at least 8 mag, containing many dE dwarf ellipticals. The second-brightest galaxy in the group is NGC 441 ($SB0_2$(r)/a very early; panel 95) at 2.5' separation. The redshift of NGC 439 of v_o = 5650 km s~' gives a redshift distance of 113 Mpc (H = 50) for a projected linear separation of NGC 441 from NGC 439 of 82kpc.

The morphology of NCC 439 is prototypical E5 with no evidence of an SO disk, as in NGC 3115 (panel 50), for example.

NGC 227 E5(E/S0)
CD-1131-Br
Aug 20/21, 1979
103aO + GG385
45 niin

NGC 227 is not a prototypical E5, as are the three galaxies in the left column. Inspection of the original plate reveals the suggestion of a disk (slightly pointed outer isophotes along the major axis). However, the feature is subtle enough to be invisible on the print here, where the morphology appears as a normal E5 type.

NGC 3818 E5
CD-1864-HB
April 7/8, 1981
103aD + GG495
45 min

The same description given for NGC 227, above, also applies to NGC 3818. The suggestion of an incipient disk is even more subtle, yet definite. Incipient disks in galaxies classed as E in many of the standard catalogs such as the RC2 and the RSA, may be common.

NGC 4476 E5 pec(dust);$S0_3(5)$ VCC 1250
CD-743-S panel 11
Feb 3/4, 1979
103aO + Wr2c
60 min

The prints of NGC 4476 shown here on the facing page are from the same plate used for the image of this galaxy at panel 11 . The insert print here shows the SO3-like dust ring buried in the central region.

NGC 4073 E5
CD-1298-S/Br
March 10/1 1, 1980
103aD + GG495
60 nu̇n

NGC 4073 is in a rich field of early-type galaxies west of the ridge line of the Local Supergalactic plane (supergulactic Latitude —12°). However, NGC 4073 is in the background, as judged from its redshifl of v_0 " 5670 km s^{-1}. which is higher than the redshift v_o = 100(1 km s^{-1} expected for galaxies in the Local Supercluster. The large redshifl and the bright apparent magnitude of li_r = 12.7 make NGC 4073 among the intrinsically brightest field galaxies in the RSA at M_r = -22.5.

The morphology is typical E5 of moderale compactness. The image to the right and above the major axis on the facing print is of a highly compact (M32-like?) cE2 galaxy of presently unknown redshift (c. 1990).

NGC 3605 E5 pair or triplet
PH-7649-S
April 29/30, 1979
103aO
10 min

NGC 3605 forms an apparent pair with NGC 3607 [$S0_3(3)$; panel 44] at a separation of 2.7', and perhaps a triplet by adding NGC 3608 (El: panel 4) at a separation of 5.8'. Several candidate dwarf elliptical companions exist in the field. NGC 3605 is the faintest of the three principal galaxies of the group.

The morphology of NGC 3605 is prototypical E5. There is no evidence for a disk, as would be seen in a flattened SO.

NGC 147 dE5,N Local Gr
PH-225-B panel 16
Aug 18/19, 1950
103aO + GG1
26 min

The surface brightness of NGC 147, the dwarf elliptical companion to M31, is very low. There is a bright nucleus, seen as the slightly fuzzy object immediately above the brightest star in the frame near the center of the print. A more complete description of the galaxy and its stellar content is given on panel I 6.

All galaxies on this page are highly flattened. The classification criterion that separates the E and SO morphology is the absence or presence of a disk. A disk, buried in an envelope morphology of an E7, is seen in NGC 3115 (panel 50), originally classed as E7 by Hubble but now classed as SO/a because of its evident disk and the additional evidence of spiral arms.

None of the galaxies on this page have as obvious a disk as NGC 3115, although some possess an incipient suggestion of the feature. There are very few pure E galaxies with this degree of flattening (Sandage, Freeman, and Stokes 1970); hence the galaxies on this page are very rare as a pure E form. It now seems likely that no true E7 galaxies exist but that the flattening distribution of pure E galaxies stops at E6.

NGC 4697 E6 panel 19
PH-374-B
May 5/6, 1951
103aO + GG11
30 min

The insert **print** of NGC 4697 is made from a Mount Wilson 100-inch plate. In the printing, the major axis of the photograph has been rotated slightly relative to the main print.

NGC 1537 E6
CD-1275-S/Br
March 9/10, 1980
103aO + GG385
45 nûn

NGC 1537 is a prototype E6 with no evidence of a disk.

NGC 821 E6 Racine wedge
PH-7828-S
Sep 2/3, 1980
103aD + GGll
20 iiiin

There is a most subtle suggestion of an incipient disk in NGC 82], shown by the slight sharpening of the outer isophotes on the major axis.

The plate was taken with a Racine wedge giving secondary images to the bright stars that are 5 mag fainter at a separation of 18". The bright star in the upper left corner of this frame shows this secondary image, as also does the galaxy itself (to the lower right of the main body). Evidently NGC 821 has a very bright central unresolved nucleus of apparent magnitude about $B = 18$.

NGC 1209 E6
H-1695-H
Dec 21/22, 1935
I.E.
60 min

The print of NGC 1209 here, made from a Mount Wilson 100-inch plate, shows the morphology of a normal E6 galaxy with no evidence of an SO disk.

NGC 4564 E6 VCC 1664
CD-733-S panel SI
Feb 2/3, 1979
103aO + Wr2c
45 min

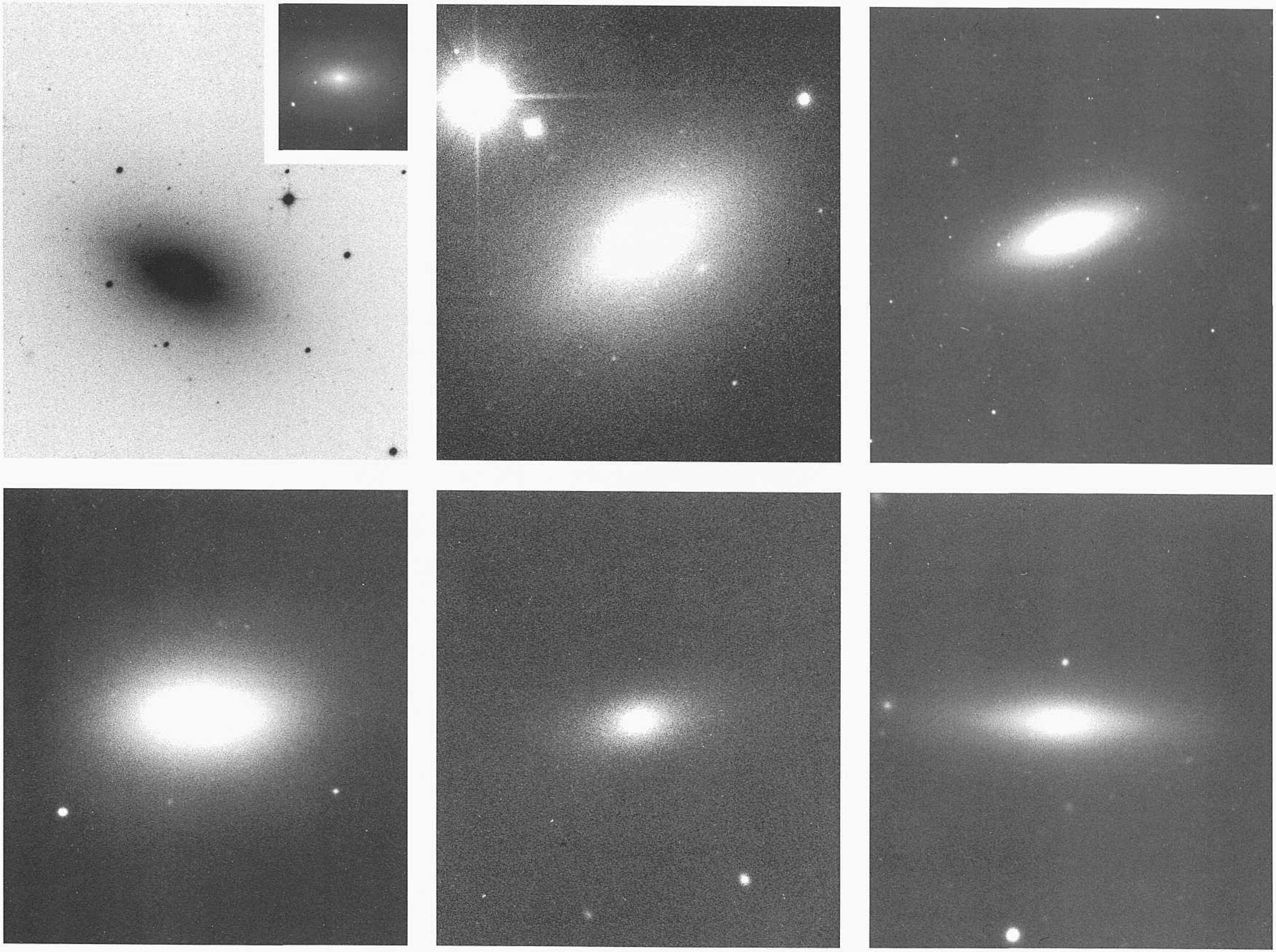
NGC 4564 is in the southeastern corner of subcluster A of the Virgo Cluster complex in a rich field of mixed morphology. The Sc galaxies NGC 4567 and NGC 4568 (panel 281) are the nearest Dreyer galaxies.

No evident disk is present. The type is pure E6.

NGC 4623 E7 VCC 1413
PH-628-B panel SI
June 20/21, 1952
103aO + GG1
45 min

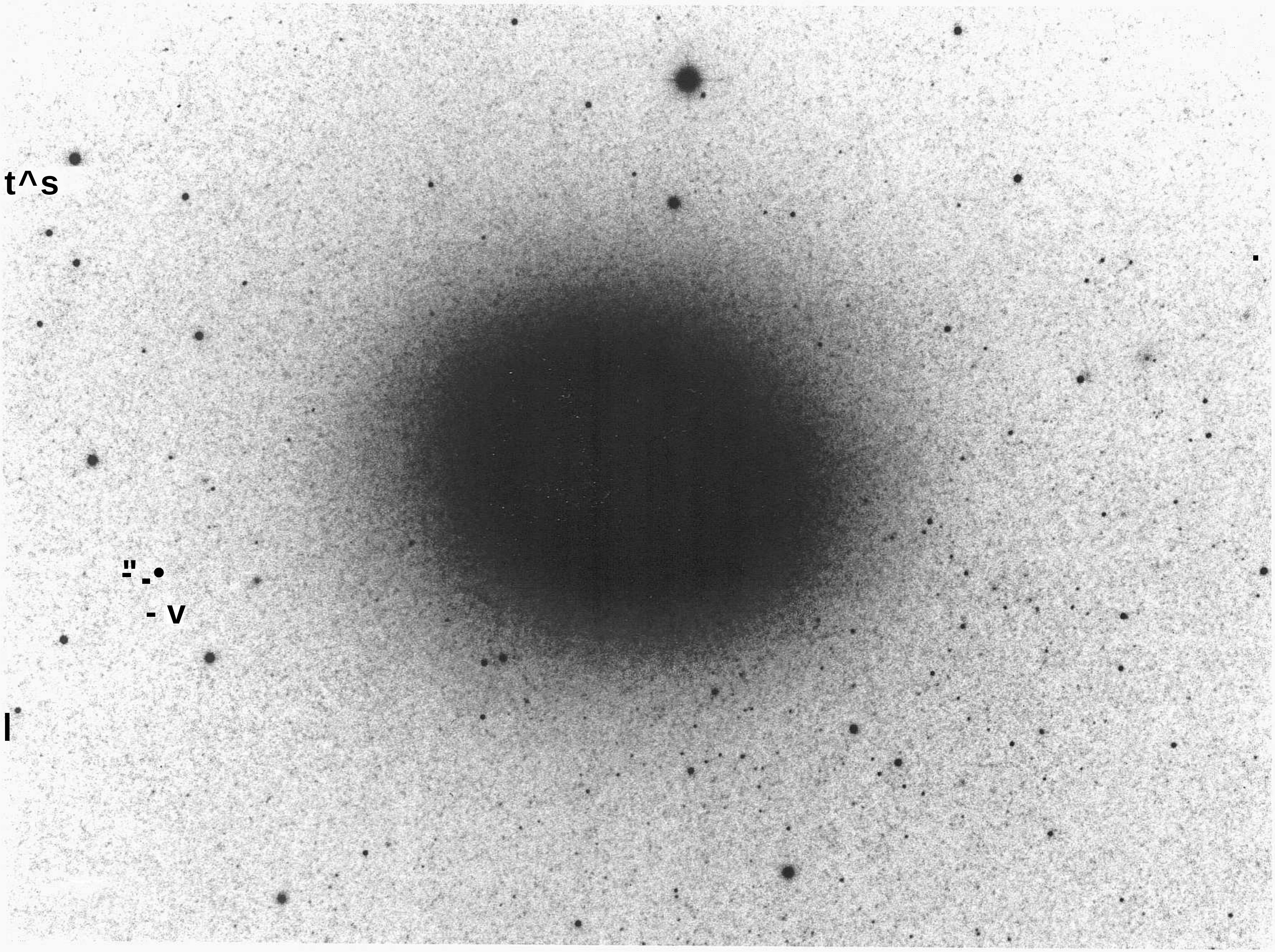
NGC 4623 here and only one other galaxy (NGC 4342; panel 23) are classed as pure E7 in the RSA2. AH other such highly flattened early-type galaxies are classed SO based on tbe presence of a disk. Because E7's are so rare, one questions if NGC 4623 and NGC 4342 themselves might have disks, making E6 galaxies the flattest of the pure E forms.

The outer isophotes on the major axis in NGC 4623 are very slightly **pointed,** suggesting a weak disk. However, the effect is subtle enough that we have retained the E7 classification here until measured isophotal maps become available.



PANEL
13

PANEL
14



NGC221	**cE2**	**Local Gr**
PH-229-B	**M32**	**panel 6**
Aug 19/20, 1950		
103aE + Wr #25		
90 min		

M32, a companion to M3] (Sh: Hubble Atlas, p. ***18:*** panel 149 **here),** has had **an** important historical **role** in **understanding the stellar** content of E galaxies. As late **as** 1 93 5, it was not known if **early-type** galaxies **were composed** of stars **or** were **structures with** a **luminous central** region surrounded **by nonluminous particles which** scatter the **central light (ten Bruggencate** 1930). If **the** latter is the case, polarization should **occur.** Polarization **of the outer** envelope light was looked **for by** Sinclair Smith (1935) using the Mount Wilson 100-inch telescope, **but** was not found. For this **and** other reasons. Smith favored **the** idea **that** E galaxies **are** composed of stars **fainter** than the brightest stars resolved in later-type spiral galaxies, a correct conjecture but not proved at the time.

The proof was achieved **by Baade** (1944a) upon his resolution **of** M32 into stars **with the** Mount Wilson 100-inch Hooker reflector. The resolution is well shown in the print here, made from a Palomar 2 00-inch plate. The individual stars are just beginning to resolve out of **the** general background luminosity. A color-magnitude diagram of these brightest stars **is** given by Freedman (1989).

The absolute magnitude of M32 is faint at /tfj. = —15.5, yet the surface brightness **is** high, unlike in other dwarf E galaxies in this luminosity range (Binggeli, **Sandage,** and Tarenghi **1984, Fig. 8).** The high surface brightness, among the highest known for any E galaxy (Kormendy 1986), supports the view that **M32** has been stripped of an extensive outer envelope by the tidal action of M3 1 . Following the tidal stripping, the center of M32 became of **even higher** surface brightness owing to **partial** collapse (dynamical cooling).

Morphologically, regardless of the process of formation, M32 is the prototype of compact, low-luminosity cE galaxies of high **surface** brightness, called class cE.

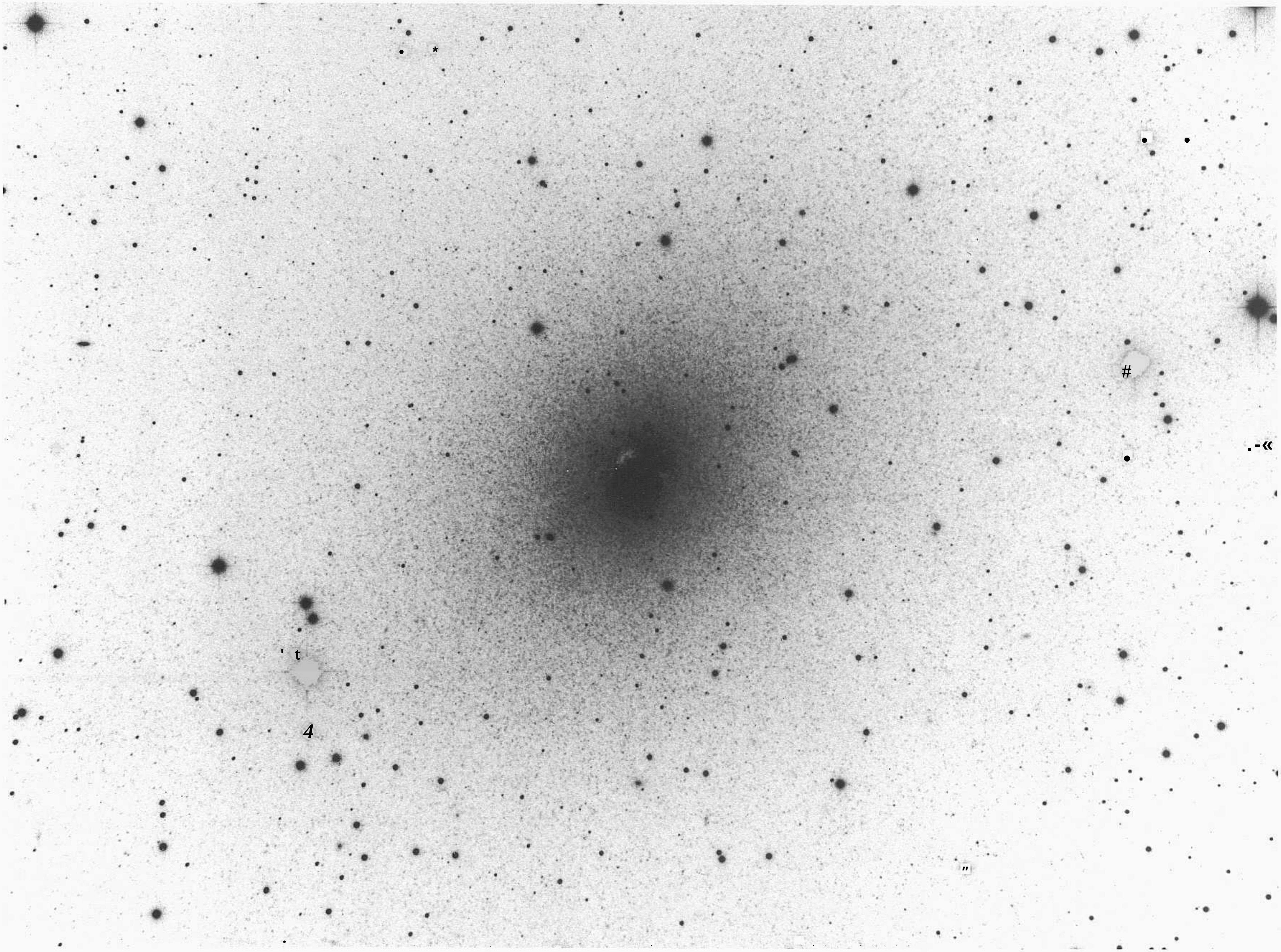
NGC 185 dE3 Local Gr
PH-531-B HA, p. *3*
Sep9/10, 1951
103aD + GG11
60 niin

NGC 185 is one **of** the five galaxies in the Local Group **that Baade** (1944a,b) resolved into stars at Mount Wilson in his well-known experiment that was **the** last stage in **his** development of the population concept (see **Sandage** 1986c for a review of this history). The absolute magnitude is **faint** at ***M-p*** =—14.6. The morphological type is nearly prototypical dE3 (see Sandage and Binggeli 1984 for the system of dwarf classification), **except** for the **evident** dust **patches** near the center. The low surface brightness is characteristic of dK galaxies of this absolute magnitude (Binggeli. Sandage. and Tarenghi 1984. Fig. 8).

The surface brightness distribution was studied early by Hodge (1963. 1971). Large numbers of RR Lyrae stars have been discovered by Saha and Hoessel (1990) with a mean magnitude of <V> = 25.0. Planetary nebulae have also been identified (Ford. Jacoby, and Jenner 197V).

At least three globular clusters can be identified in the image here: the brightest is below the center at a position angle of about 5:30 o'clock as oriented here. NGC 185 has a similar distance as M3 1, and is a companion to it at a projected linear separation of 105 kpc.

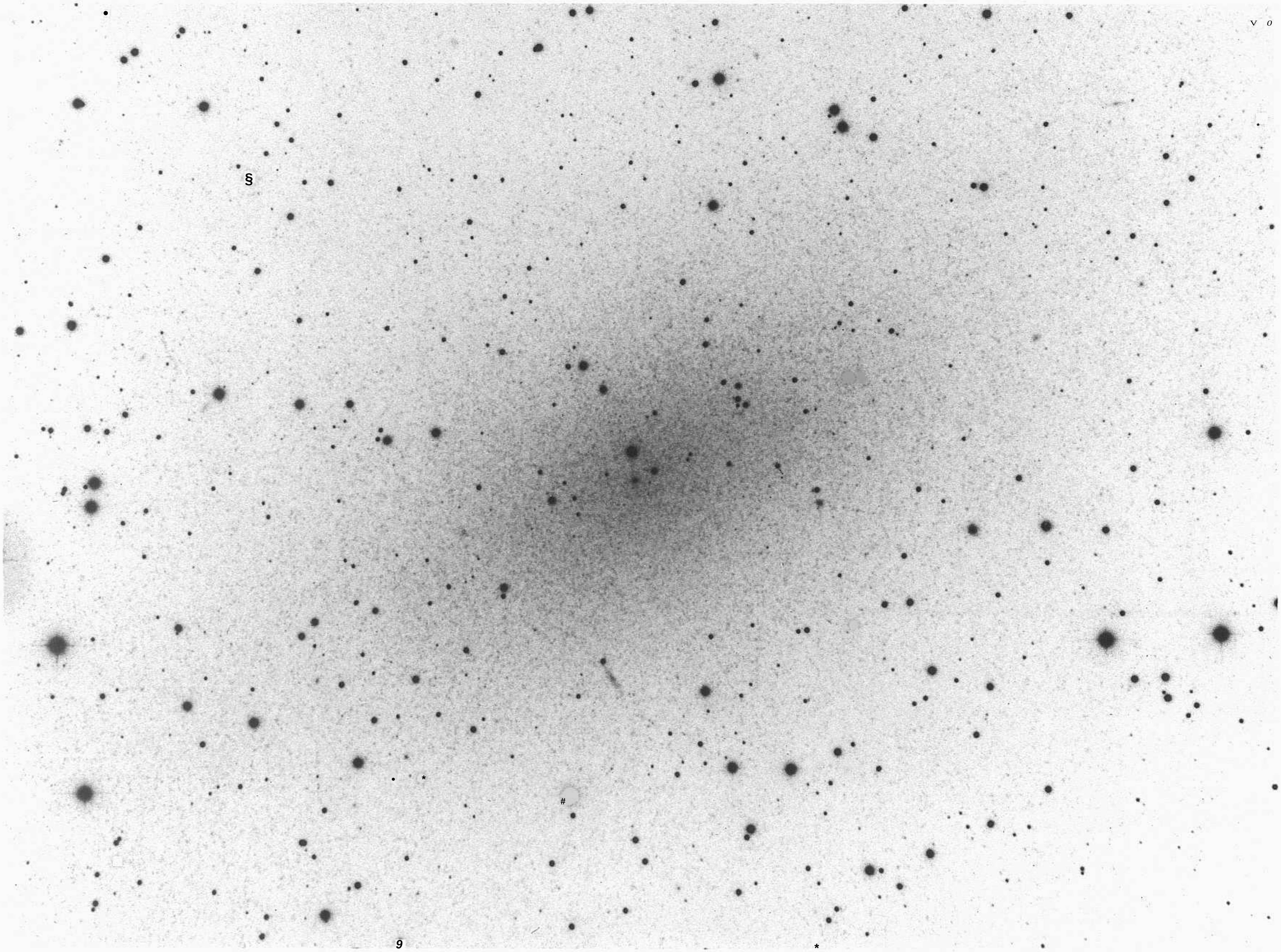
Additional photographs are shown in the original **paper** by Baade (1944b) and in the Hubble Atlas (p. 3).



PANEL

15

PANEL
16



NGC **147** **dE5,N** **Local Gr**
PH-171-B **panel 12**
Aug8/9, 1951
103aD + GGll
60 min

The very low surface **brightness of NGC** 147 is seen in **the** positive **image on** panel 12. The image here shows **the** resolution into individual **stars.** The print is **made** from a yellow **Palomar** plate by Baade.

The galaxy is the **prototype of** a **nucleated** dE.N **dwarf** elliptical of the **type** seen throughout the Virgo Cluster (see Sandage and **Binggcli 1**984, for an atlas), in the **Fornax** Cluster (Caldwell and Bolhun **1987; Ferguson 1989),** and in many **groups** of early-type galaxies (Ferguson **and** Sandage 1990).

The nucleus is the fuzzy **object** just below the brightest star near the **center** of **the print. It** is fainter than the two **probable** globular **clusters,** identifiable here by **their** unsharp appearance in the right part of the print about halfway between the top and the bottom borders.

The absolute **magnitude** of NGC 147 is Mg_T = -14.4. Galaxies like NGC 147 would be well visible in the Virgo Cluster survey and are then, in fact, included in that catalog (Binggcli, Sandage, and Tammann 1985); see Table I of Sandage and Binggeli (1984).

RR Lyrac variables have been discovered and studied (Saha and Hoessel 1987). The surface brightness distribution of the global image has been discussed by Hodge (1963, 1971, 1976).

NGC 4486 EO VCC 1316
PH-422-MH M87 HA, p. 2
April 15/16, 1952
103aO
30 min

NGC 4486 is the second brightest galaxy in the Virgo Cluster, after NGC 4472 . It is near the center of the high-density subeluster A (Binggeli, Tammann. and Sandage 1987), which contains many dE dwarfs.

The galaxy was known from early times to be abnormal in its stellar content relative to the general elliptical class. Hubble (192 6) stated that E galaxies "show no evidence of resolution" into stars, but in a footnote he wrote "NGC 4486 (M87) may be an exception. On the best photographs made with the 100-inch reflector, numerous exceedingly faint images, apparently stars, are found around the periphery." But following Hubble's (1932) identification of globular clusters in **M31** and Baade's (1944a,b) resolution of Local Group galaxies into much fainter stars than the clusters, the objects in M87 described by Hubble as stars were identified as globular clusters by Baum (1955) and by Sandage (1961).

Their number in M8 7 is exceedingly high. The specific frequency is a statistic defined by Harris and van den Bergh (1981) as the number of clusters per unit *My* =—15 luminosity. Its value is *S* = 15 for NGC 4486 (Harris 1988). This number is exceeded only in NGC 1399 (panel 19) in the Fornax Cluster and in NGC 33 11 in the Hydra Cluster, and is equaled in NGC 48 74 (panel 2 1) in the Coma Cluster.

Harris finds that the galaxies with the highest specific globular cluster frequencies are at the centers of galaxy clusters that are rich in nucleated dE.N dwarf ellipticals, suggesting that the **globular** clusters in the giant-dominant galaxies were once nuclei of dE.N dwarfs that have merged with the giant and decayed by dynamical friction, an idea originally at**tributable** to Binggeli and to K. C. Freeman.

The print of M8 7 here shows the wide extent of the M87 globular cluster system. The evidence available in 1990 (Harris 1986; 1988, Fig. 2) is that the spatial distribution of the globular clusters in M87 has a larger scale length than that of the halo light, suggesting that the globular cluster system in M8 7 formed earlier than the stellar halo.

M87 is also unusual in the presence of the optical jet that starts at the unresolved (at the 0.5" level) bright nucleus.

NGC 4486 EO VCC 1316
PH-422-MH M87 HA, p. 2
April 15/16, 1952
103aO
30 min

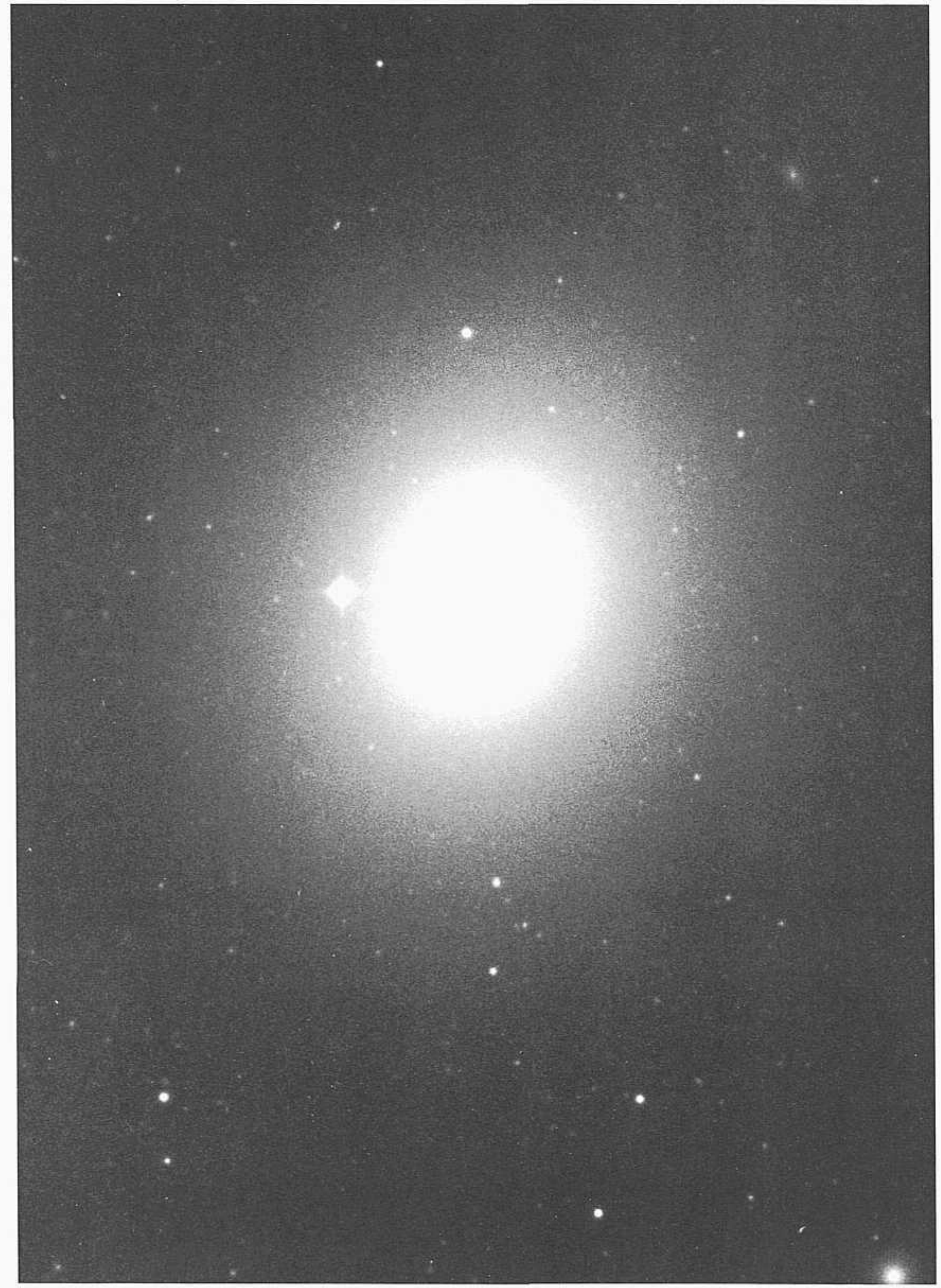
The print of NGC 4486 here is made from the same plate used for the deeper image at the left. In this low-contrast print it is seen that the globular cluster system has a steep density gradient toward the center. Counts near the center are affected by incompleteness due to the high surface brightness of the M87 envelope, making a comparison of the radial gradient of the cluster system and of the envelope light difficult; yet the difference between the gradient of the cluster counts and the luminosity gradient is very large (Harris 1988).

NGC 4486 EO VCC 1316
PH-83-S M87 HA, p. 2
Dec 26/27, 1951
103aO + WG2
2 min

The M87 jet, shown here to be buried in the high-surface-brightness central regions of NGC 4486, was already known to Curtis (1918). Note that the enlargement of this print is greater than that of the other two prints on this page.

PANEL
17

PANEL
18



NGC4365 E3 VCC 731
PH-459-S panels 7, SI
March 8/9, 1953
103aD + GG11
30 niin

NGC 4365, a bright **member of the** Virgo Cluster near **subcluster B,** is also shown on panel 7. Although the **globular cluster** population is high, as seen **in the print** here, the **specific** frr-qu**ency** (the nuinb**e**r p**er unit** *Mn* = —I 5 luminosity) is not as high as in M87 **(Harris** 1988).

NGC **4472** **El/S0i(l)** **VCC 1226**
CD-716-S **panel 26**
Jan31/Fel> L, 1979
103aO + Wr2c
-15 miu

NGC 4472 is **the brightest** galaxy in **the** Virgo Cluster **(Binggeli, Sandage, and** Tammann 1 985), and is the **center of** Virgo **subcluster B. A** few of the **globular** clusters in the **envelope are well** seen in **this** print. The **total number of its** globular clusters is **smaller** than in INGC **4486 by at least a factor of** three. Harris (I'MWt) **lists** a specific frequency **of** 5 = 5,5, which is **near the** average **of** all K galaxies. The **specific frequency of S = IS for** NGC **4486 is abnormally** high. **An explanation** for the high **number** in MM7 may be related **to** its position in the highest **concentration** of dE.N nucleated **dwarf elliptical** "companions" in **the** Virgo Cluster. **NGC** 1472 is at **the** center of Virgo Cluster- **subcluster** B. which docs not have the high **concentration of nucleated** dK.lN galaxies **(Binggeli,** Tarn ma **nn,** and **Sandage** 1987) **that** is seen in Virgo subcluster A. Conceivably, the globular cluster's in MH7 **were** once the nuclei of dE.N galaxies **that** have **since** been tidally disrupted and have sunk into **the** M87 envelope by dynamical friction.

Harris (1986) states **that, as** in NGC 4486. the radial profile **of the** globular' clusters in NGC 4472 is less steep than **the** underlying **luminosity** profile **of** the stellar envelope **of** the parent galaxy.

NGC **1399** **El** **FCC 213**
CD-718-S
Feb 1/2, 1979
103aO + Wr2c
45 min

NGC 13 99 is **the** brightest E galaxy in **the** Fornax Cluster (Ferguson 1989). Hanes and Harris (1986) measure the specific globular cluster frequency to be high, at S = **16.** The system of clusters is visible in the print here but less prominently than in NGC 4486 (panel 17) where S = 15. However, the counts by Hanes and Harris suggest to them that the specific globular frequency is, in fact, comparable to M8 7, taking into account that Fornax is 0.3 mag more distant than Virgo.

NGC 4660 **E5 (E/SO)** VCC **2000**
CD-802-S **panel 11**
Feb 24/25, 1979
103aO + Wr2
45 min

NGC 4660 is in the Virgo Cluster. The globular cluster candidates in the outer regions are well shown in the negative print here. The high brightness of Lhe globular cluster candidates suggests that NGC 4660 may be closer than the core of the Virgo Cluster: its brightest globular clusters are brighter than those in M8 7.

NGC 4697 **E6** **HA, p.** ***1***
PH-374-B **panel 13**
May 5/6, 1951
103aO + GG1
30 min

NGC 4697 in the southern extension of the Virgo Cluster has an appreciable globular cluster population, visible on this Palomar 200-inch plate, taken in poor seeing. Even so, the globular cluster images are clearly visible near the **limit** of the negative **print.** The specific globular cluster frequency listed by Harris (1988) is S - 4.1, which seems low in view of the large number of images seen here.

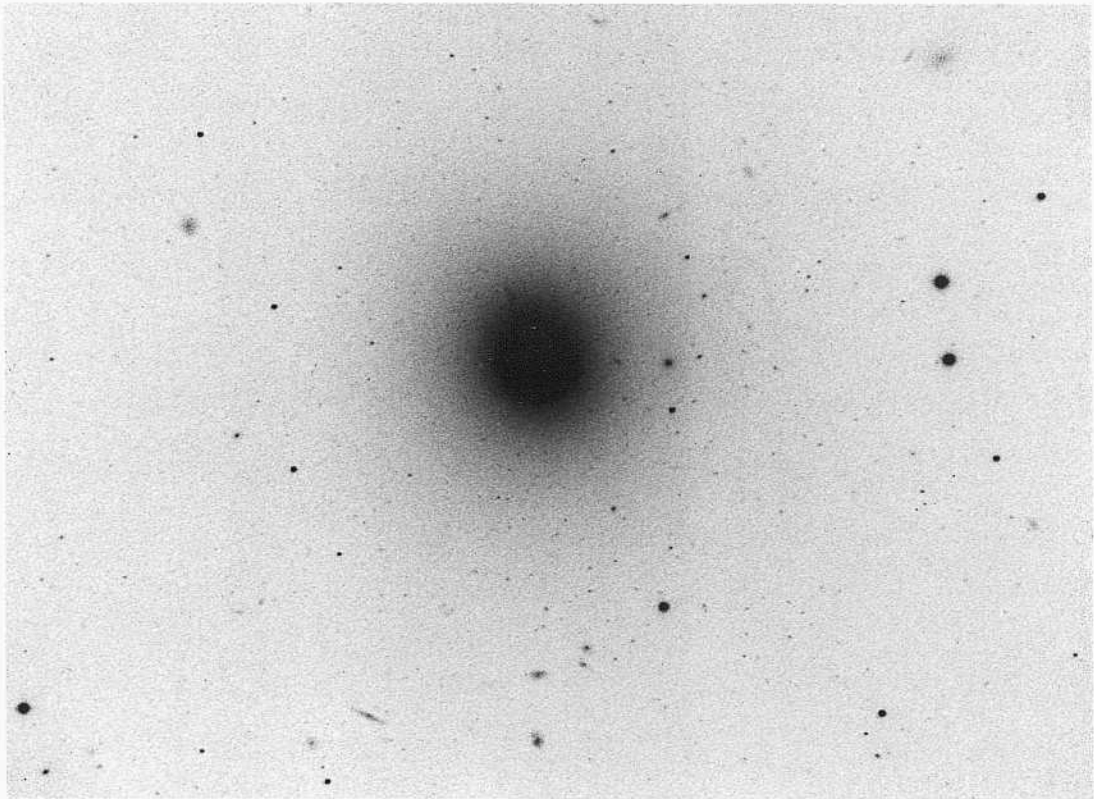
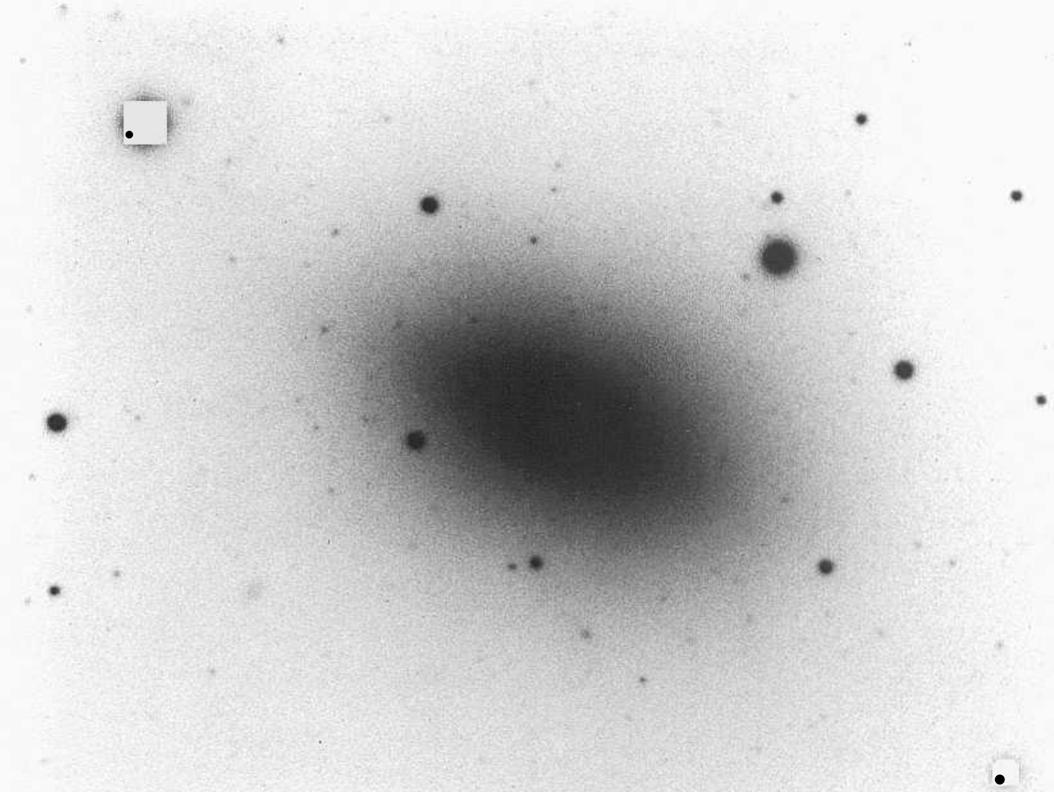
The galaxy is also shown on panel 13.

NGC 3377 E6 **Leo Gr #24**
PH-53-S **HA, p.** ***1***
Nov 29/30, 1951
103aO + WG2
30 **min**

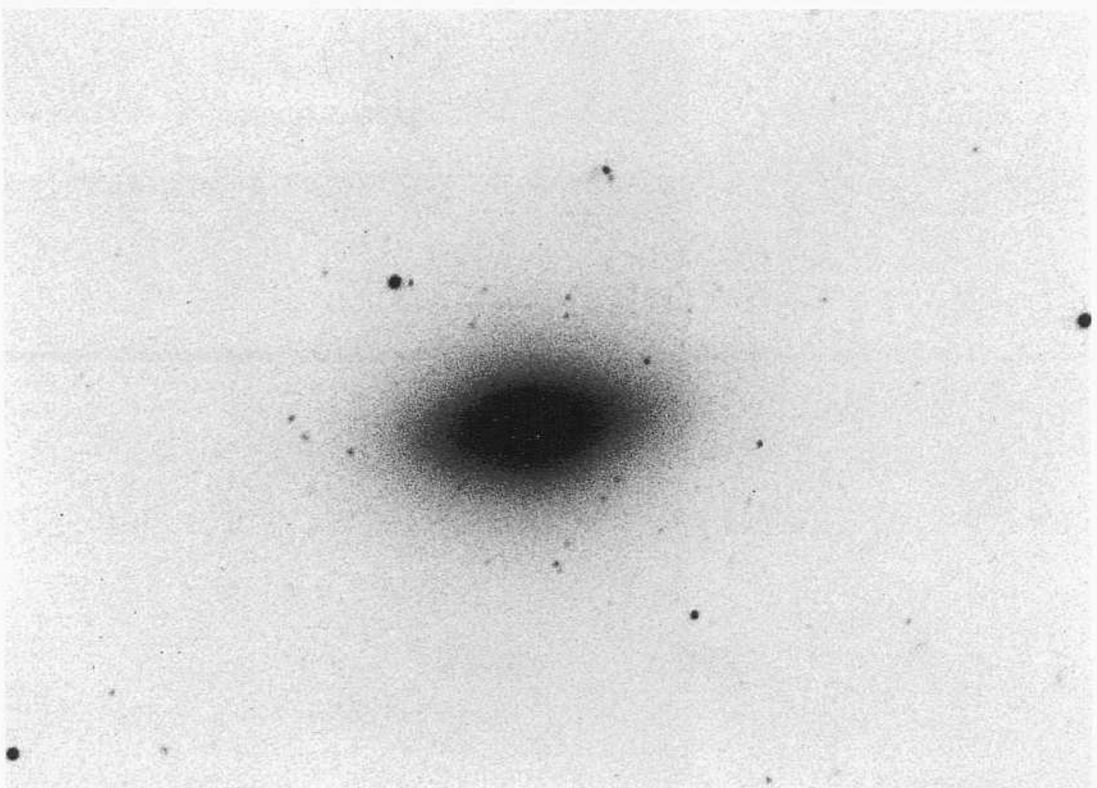
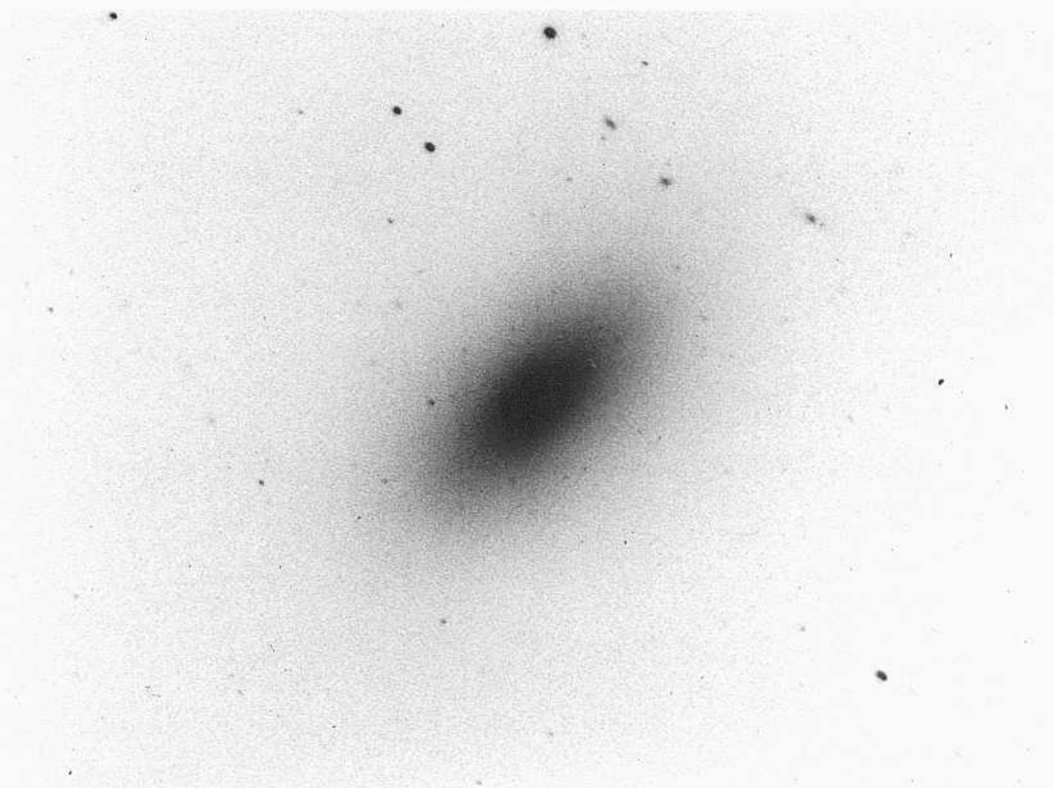
NGC 3377 is a bright elliptical in the Leo Group, which is closer by about 0 .4 mag than the Virgo Cluster core (Ferguson and Sandage 1990). The faint globular clusters in the outer image are seen well here. The specific globular cluster frequency listed by Harris is S = 2.8, which, as with NGC 469 7 above, seems low considering the number of cluster candidates seen on the original plates.

The morphological type of NGC 3377 is prototypical E6. There is no evidence for a disk. The outer isophotes on the major axis appear elliptical with no sharp tips, which would be present if there were a disk.

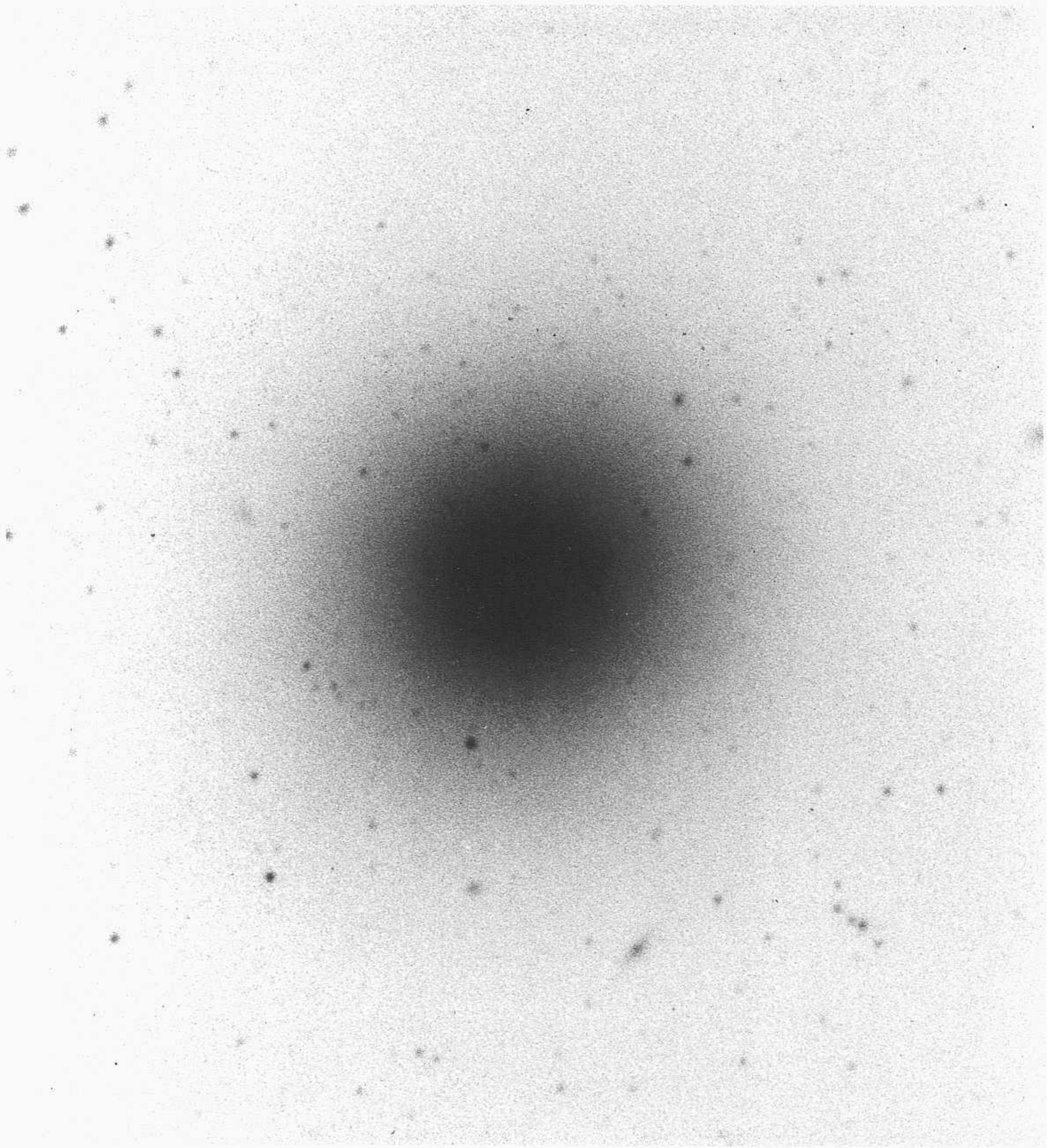
A very-low-surface-brightness dwarf companion exists near NGC 3377, listed as #23 in the Leo Group Catalog (Ferguson and Sandage 1990) and as NGC 3377A in the RC2. It is of mixed morphology, Im/dE, N (Sandage and Hoffman 1991), similar to IC 32 75 in the Virgo Cluster (Reaves 1956).

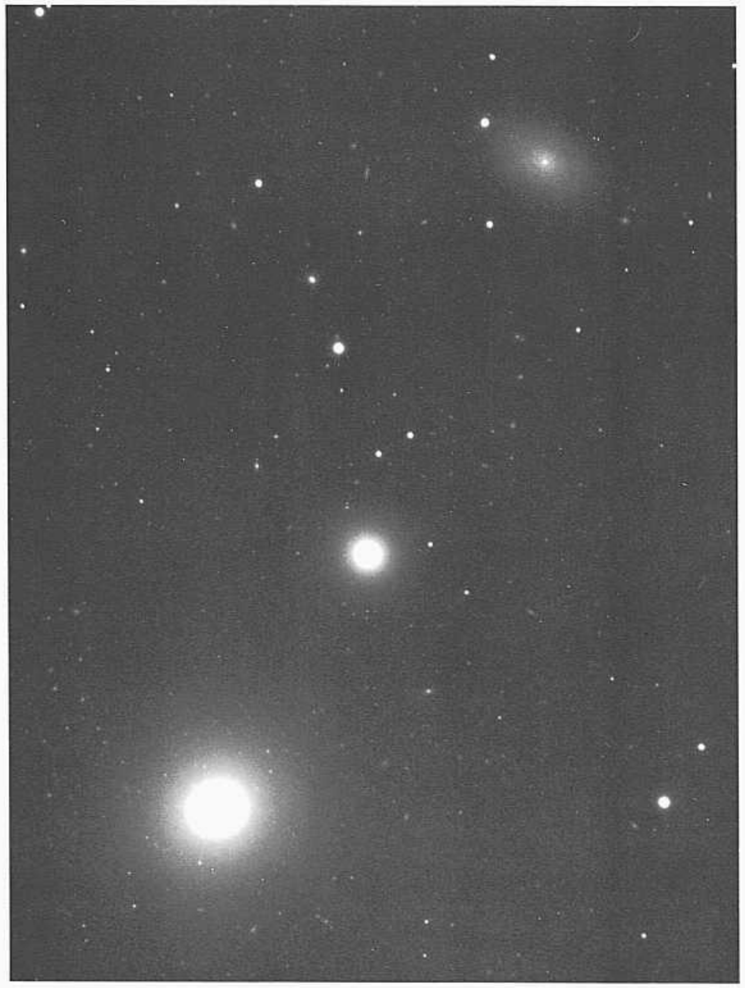



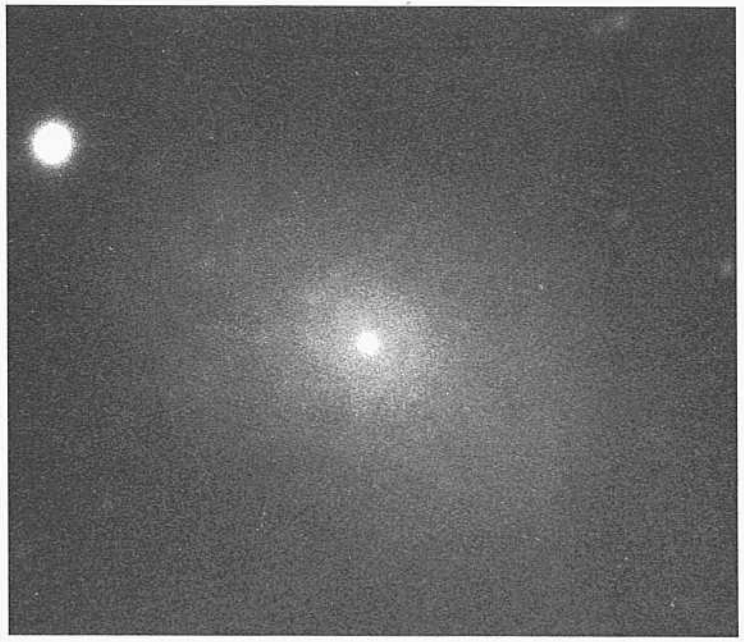
PANEL
19

PANEL
20







NGC4278 El HA, p. *1*
PH-676-S pair
Feb 7/8, 1954
103aD + GGll
45 niin

NGC 4278 (redshift v_o = 584 km s"') forms a pair with the dE,N/Im mixed[1]-morphology dwarf companion NGC 4286 {redshift v_o = 600 km s^{-1}) and is in the field of NGC 4283 (panels 2, 20) which, at v_o = 1053 km s^{-1}, is probably in the background.

The very many globular clusters over the face of NGC 42 78 are well seen in the negative print here. The specific globular cluster frequency listed by Harris (1988) is high at S = 8.3; this value compares with the average for all globular clusters in the list by Harris of *S* = 5.0. Note again that S = 1 5 for the unusual case of NGC 4486 (M87).

NGC 42 78 was one of the first E galaxies in which HI 21-cm radiation was detected (Gallagher *et al.* 1977). The origin of the neutral hydrogen may be the long-sought gas shed from evolving stars by the normal processes of stellar evolution (Sandage 1957. Faber and Gallagher 1976). Emission lines in the spectra of the center were discussed by Osterbrock (1960), following their discovery by Humason in a number of E galaxies.

NGC 4278/4283/4286 El/EOA1E,N/Im HA, p. *1*
PH-676-S
Feb 7/8, 1954
!03aD + GG11
45 iniii

The projected spatial configuration of the three galaxies is shown here from the same plate used for the print of NGC 4278 al the left. NGC 4278 is the brightest galaxy in the frame at the lower left, NGC 4283 is in the middle, and the dE.N/Im mixed-morphology dwarf NGC 428 6 is at the upper right. The orientation of this print and the one on the right is north to the right, east at the top.

NGC 4286 dE,N/Im
PH-676-S
Feb 7/8, 1951
103aD + GGll
45 min

NGC 4286 is a companion to NGC 4278. Its bright nucleus and low-surface-brightness disk are characteristic of classical d E.N nucleated dwarf elliptical galaxies (Sandage and Binggeli 1984; Binggeli, Sandage. and Tarenghi 1984). However, the disk is not smooth but shows evidence of star formation (or clusters) within it. The knots in the disk, not well seen on the original yellow plate here, are blue, and they show well on the available 200-inch blue plates.

Neutral hydrogen has been detected at a redshift of v_0 = 600 km s^{-1} by Hoffman with the Arecibo 305-meter radio telescope. The morphological appearance of NGC 42 86 suggests that it has a mixed morphology of Im irregulars exhibiting current star formation and the dead dE,N dwarf elliptical types (Sandage and Hoffman 1991).

NGC 741 EO W 175
PH-7827-S
Sep 2/3, 1980
103aD + GG11
20 niin

NGC 741 is the center of a small group of compact elliptical galaxies (Humason. Mayall, and Sandage 1956. Table XI). The mean redshift of the three brightest group members is $<v_n>$ = 5612 km s"1 (Palumbo *et al.* 1983). At this writing (1990) it is unknown if the faint image to the immediate right of NGC 741 itself in the insert print is a star or is the sharp nucleus of a sinking satellite in the envelope of NGC 741. The EO image farther to the right in the main print is the companion galaxy NGC 742. It and NGC 741 itself compose VV 175 in the catalog of Vorontsov-Velyaminov (1977). The main galaxy-is also the radio source 4C 05.10.

NGC 6854 E0 + E1
CD-1050-Br
Aug 12/13, 1979
103aO + GG385
45 min

The angular separation of the companion from NGC 6854 (which is the primary) is 12". The projected linear separation is small at 6 kpc, based on a redshift of v_o = 5578 km s~l and a redshift distance of 112 Mpc (H = 50). The redshift of the companion is within 200 km s^{-1} of that of the primary (Sandage 1978).

NGC 4782/4783 EO(tides)/El(tides) W 201
H-2535-H 3C 278
May 4/5, 1948
103aO
30 min

This pair of E galaxies within a common envelope is the strong radio source 3C 278. It is also VV 201 in the catalog of Vorontsov-Velyaminov (1977). A bridge of luminous material exists between the two nuclei. The inner envelopes of each galaxy deviate from circular symmetry; the distortion in NGC 4783 (the image to the right) is more pronounced.

The large redshift difference is 656 km s^{-1}; the individual values are u_o(4782) = 3773 km s^{-1} and u_o(4783) = 4429 km s\ The angular separation of the pair is 46". Assuming a mean redshift for the system of $<v_o>$ = 4100 km s~l, giving a redshift distance of 82 Mpc (H = 50), the projected linear separation is small at 18 kpc, explaining the large redshift difference as the high orbital velocity of a close pair.

NGC 750/751 EO/EO W 189
H-712-H Karachentsev #46
Oct 12/13, 1926 HA, p. *2*
E40
60 min

The angular separation of the centers of this obviously interacting pair is 21". The individual redshifts listed in the Karachentsev catalog are «$_o$(750) = 5325 km s"1 and u_o(751) = 5337 km s~l. The redshift distance is 107 Mpc, giving a small projected linear separation of 11 kpe.

The envelope of each component is distorted: each is distended outward away from the line of centers or, alternatively, each is compressed toward the companion. The luminous bridge is evident between the companions.

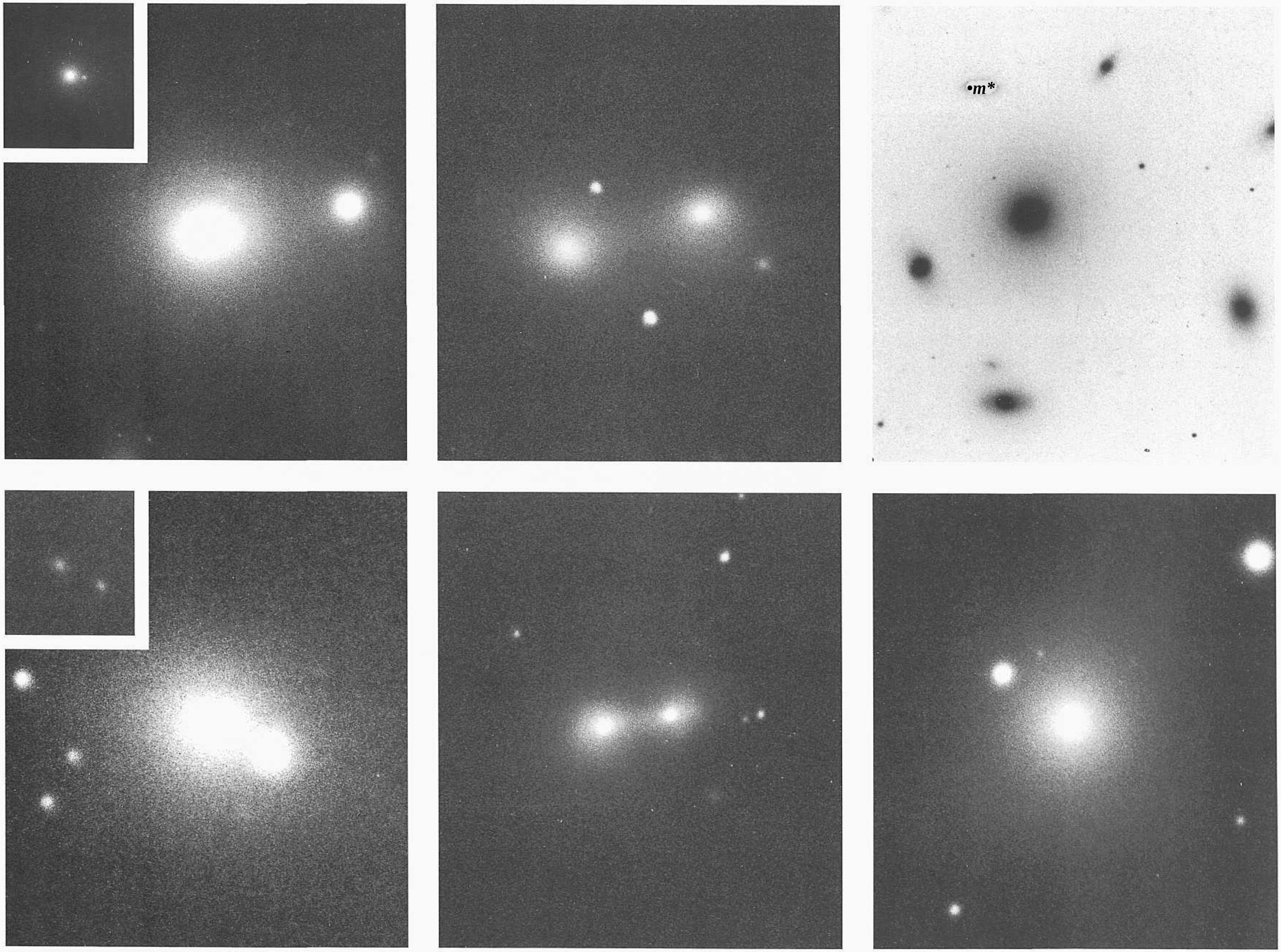
NGC 4874 E0 Coma Cluster
PH-4763-Bm
May 25/26, 1965
103aD + GGll
30 min

NGC 4874 is at the center of one of the two main concentrations of the Coma Cluster. This galaxy is the second brightest in the cluster; the first is NGC 4889 (panel 23) at the center of the other main concentration.

No obvious interaction exists between NGC 4874 and other cluster members; such interaction is evident in NGC 4782/4783 and NGC 750/751 at the left. The field at the center of the Coma Cluster is shown here to illustrate the very high concentration of Coma Cluster galaxies around one of the principal central ellipticals. The mean redshift of the Coma Cluster is $<v_o>$ = 7143 km s"1 (Sandage and Tammann 1990).

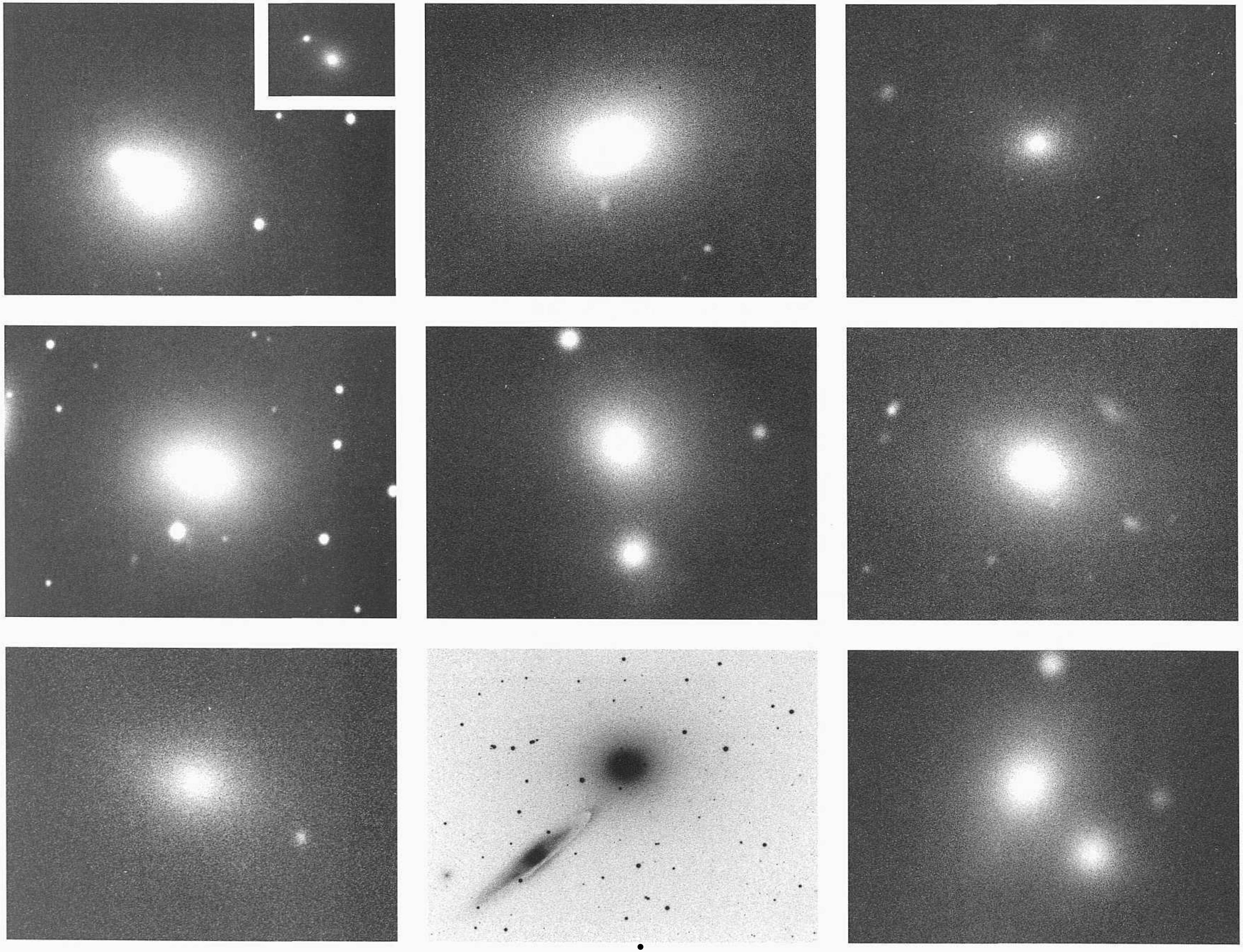
NGC 2924 E0
CD-1368-S/Br
March 17/18, 1980
103aO + GG385
45 min

NGC 2924 is an apparently isolated EO with a standard morphology at a redshift of v_0 = 4374 km s^{-1}. It is retained here in the interacting section, albeit incorrectly, for completeness after the layout for this atlas became frozen.



PANEL
21

PANEL
22



NGC 4936 E2 group
CD-1288-S/Br
March 9/10, 1980
103aD + GG495
45 min

NGC 4936 is the brightest in a group of at least 12 members (Sandage 1975b, 1978) at an adopted mean redshift of $\langle v_o \rangle$ = 3048 km s^{-1}. The redshift of the compact companion galaxy is not presently known (c. 1990). The angular separation of the pair is 11.9". At the redshift distance of 61 Mpc (H = 50), the projected linear separation is small- at 3.5 kpc.

NGC 6876 E3 Pavo Gr
CD-1068-Br
Aug 17/18, 1979
103aO + GG385
45 min

NGC 6876 is the brightest E galaxy in a small group in Pavo whose mean redshift is $\langle v_o \rangle$ = 3785 km s~' (Sandage 1975b). The companion is the normal E5 galaxy NGC 6877, off the left border of the print here. The angular separation of 82" corresponds to a projected linear separation of 30 kpc. The redshift difference between the pair is about 170 km s~^{1} (Sandage 1978). There is no evidence of interaction between NGC 6876 and 6877.

NGC 2693 E2 pair
PH-7953-S
Nov 8/9, 1980
103aO
12 min

NGC 2693 is the brighter galaxy of an apparent pair with NGC 2694, at separation of 54". NGC 2694 is a compact E0 just off the print to the left of NGC 2693, which is the only galaxy shown in the highly enlarged print here. The redshifts listed by HMS (Humason, Mayall, and Sandage 1956) are u_o(2693) = 4998 km s"' and u_o(2694) = 5165 km s~^{1}, indicating an obvious physical pair. The projected linear distance is 27 kpc using a redshift distance of 102 Mpc. There is no sign of a luminous bridge between the galaxies despite the small projected separation.

NGC 5982 E3 pair
PH-7273-S
July 22/23, 1976
103aO + GG13
25 min

NGC 5982 is close in projection to NGC 5981 (Sc? on edge) at a separation of 6.3' and to NGC 5985 (SBb; panel 160) at a separation of 7.7'. However, the redshift of NGC 5981 *(v_o =* 1894 km s^{-1}) is sufficiently different from that of NGC 5982 *(v_o* = 3046 km s~') to show non-kinship. But the redshift of NGC 5985 (u_0 = 2694 km s^{-1}) is sufficiently similar to suggest that NGC 5982 and NGC 5985 form a wide physical pair.

The morphology of NGC 5982 is prototypical E5.

NGC 2672/2673 E2 (tides) Karachentsev #1 75
PH-7970-S E0 (tides)
Feb 1/2, 1981
103aO
12 min

NGC 2672 forms a physical pair with NGC 2673 (EO tides), with separation of 33". The brightest galaxy near the center of the print here is NGC 2672. The E0 companion is to the lower right. The image near the top border is a star.

The pair is clearly in encounter. On the original plate the faint outer envelope of NGC 2673 is displaced outward, away, and slightly to the right of the line of centers in the orientation of the print here. The redshift difference is large, at 461 km s"' (but smaller than that of NGC 4782/4783 on panel 21). The individual redshifts are t)$_o$(2672) = 4109 kms"^{1} andy$_D$(2673) = 3648 km s^{-1}, as listed in the Palumbo *et al.* (1983) catalog. From a redshift distance of 78 Mpc *(H* = 50), the projected linear separation of the pair is small, at 12 kpc.

NGC 5090/5091 E2 group
CD-2104-S Sa
March 18/19, 1982
103aD + GG495
45 min

NGC 5090 and NGC 5091 form an apparent pair in a small group containing NGC 5082, 5086, 5090A, 5090B, and several candidates for dwarf ellipticals. The redshift of NGC 5090 is v_o = 2790 km s"^{1}, which differs sufficiently from v_0 = 3424 km s"^{1} of NGC 5091 to suggest that the pair is a chance projection in the line of sight. There is no evidence of interaction between the galaxies.

The morphology of NGC 5090 is prototypical E2.

NGC 1199 E2 group
S-1691-II
Ocl8/9, 1937
Imp. Eel.
55 min

NGC 1199 is the brightest in a small group of early-type galaxies including NGC 1180, 1181, 1188, 1189. 1190, 1191, NGC 1192, and perhaps NGC 1209 (panel 13). The v_0 redshifts of NGG 1199 and NGC 1209 arc 2686 km s^{-1} and 2652 kms^{-1}, respectively. The reproduction here is from a Mount Wilson 60-inch plate.

NGC 3158 E3 cluster
PH-7975-S
Feb 1/2, 1981
103aO
12 min

NCC 3158 is the brightest member of a small cluster of early-type galaxies; the cluster has more than 30 members, including a number of candidates for low-luminosity dwarf ellipticals. The mean adopted redshift in an early study is $\langle v_o \rangle$ = 7008 km s~^{1} (Humason, Mayall. and Sandage 1956: Sandage 1975b). Most of the images in the print here are faint galaxies associated with the cluster.

NGC 2832 E3 (tides) Arp 315
PH-7972-S
Feb 1/2, 1981
103aO
12 min

NGC 2832 is the brightest member of a group that includes NGC 2825, 2826. 2827, 2828, 2829, 2830. 2831, 2833. 2834, and NGC 2839 at an uncertain mean redshift of about 6000 km s^{-1} (Humason, Mayall, and Sandage 1956). The orientation of the print here is north at the top, west to the right. The print has been made from a very-poor-seeing plate where it is difficult to tell the galaxies from the stars. From the original plate and from Arp's (1966) *Atlas of Peculiar Galaxies,* it can be noted that only two galaxies exist in the print here. NGC 2832 is the brighter of the two. in the center of the print. NGC 2831 (E0 compact) is fainter, to the lower right. NGC 2830 (SO spindle) is just off the print to the lower right. The other two images in the frame are stars.

The spatial relation of the close pair NGC 2831 and NGC 2832 here is in doubt because of the large difference in their redshifts, u„(2831) = 5104 km s~' and u_o(2832) = 6895 km s '.

NGC 5328 **E4** **group**
CD-1449-S/Br
May 6/7, 1980
103aD + GG495
45 **niin**

NGC 5328 is the brightest member of a **group of** about **eight early-type** galaxies covering a wide range **of** luminosity. The galaxies nearest NGC 5328 are in a small area (10 arc min on a side) that is about 2° north of the center of the IC 4329 Group and was included together with NGC 5330 in that group in an early listing (Sandage 1975b). The mean redshift of **the group** listed there is $<v_o>$ = 4320 km s^{-1}.

The morphology of NGC 5328 is normal E4. The two fainter companion galaxies shown in the print are of types E0 and E6/S0.

NGC 4889 E4 Coma Cluster
PH-4763-Bm
May 25/26, 1965
103aD + GGll
30min

NGC 4489 is the brightest galaxy in the Coma Cluster and is the center of one of the two main galaxy concentrations in the cluster. The other is centered on NGC 4874 (panel 21). The adopted redshift of the Coma Cluster is $<v_0>$ = 7143 km s \

NGC 7014 **E5** **NGC 7014 Gr**
CD-1070-Br
Aug 18/19, 1979
103aO + **GG385**
45min

NGC 7014 is the brightest member of a configuration called the NGC 7014 Indus Group in the literature. An early mean redshift for the group is $<v_o>$ = 4934 km s~[1] (Sandage 1975b). The faint, compact E2 galaxy to the left is at a separation of 52" from NGC 7014. One of the several dE (or dSO) **dwarf** candidates **in** the **group** is near the lower-right corner of **the** print.

NGC 4373/IC 3290 E4(SBa) NGC 4373 **Gr**
CD-1284-S/Br
March 9/10, 1980
103aD + GG495
45min

NGC 4373 is the eponymous and the **brightest** member of a group of at least seven early-type galaxies. The mean redshift from the brightest three members is $<v_o>$ = 2996 km s^{-1} (Sandage 1975b). The angular separation of NGC 4373 and its close companion IC 3290 (SBa), shown here, is 2.0'. The redshifts of the pair are close, at v_0 of 3212 km s~[1] and 3137 km s^{-1} (Sandage 1978). At a redshift distance of 63 Mpc (H = 50) the projected linear separation is 37 kpc.

The morphology of the outer regions of NGC 4373 is prototypical E4.

NGC **7623** **E5** **NGC 7619/7626 Gr**
CD-1129-Br
Aug 20/21, 1979
103aO + GG385
45 **min**

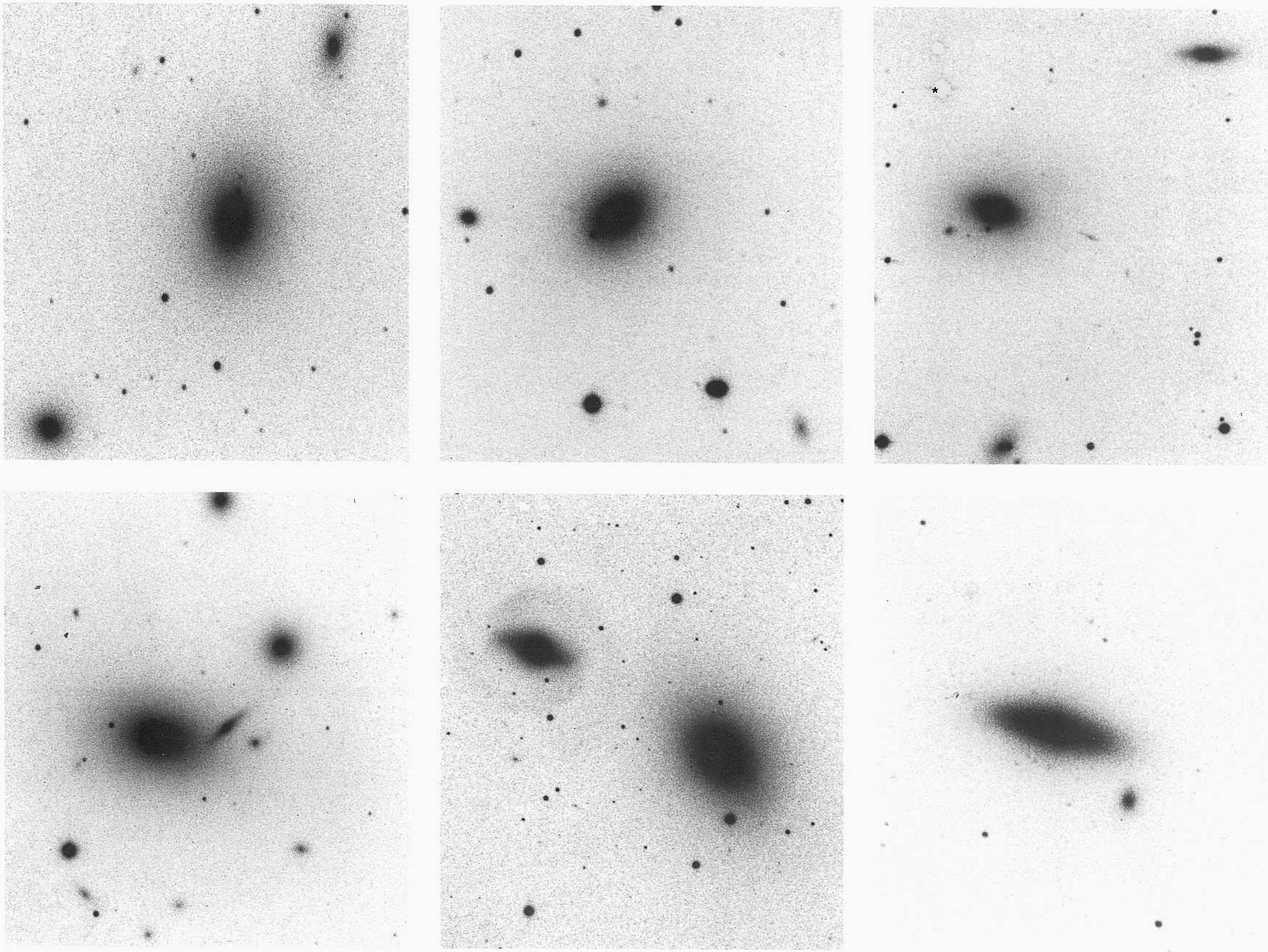
NGC 7623 is one of the bright elliptical galaxies in the NGC 7619 Group whose brightest early-type members are NGC 7619 (E3; panel 7), apparent magnitude *By* = 12.1, and NGC 7626 (E1; panel 3), apparent magnitude By = 12.2. The apparent magnitude of NGC 7623 is *Bf* = 13.4, from the RC2. An early value for the group mean redshift is $<v_o>$ = 3836 km s~[1] (Humason, Mayall, and Sandage 1956).

NGC 7623 is not in the RSA. Its morphology is that of a normal E5 with no indication of an incipient SO disk.

NGC 4342 **E7(S0i)** **VCC 657**
CD-792-S
Feb 23/24, 1979
103aO + Wr2c
55min

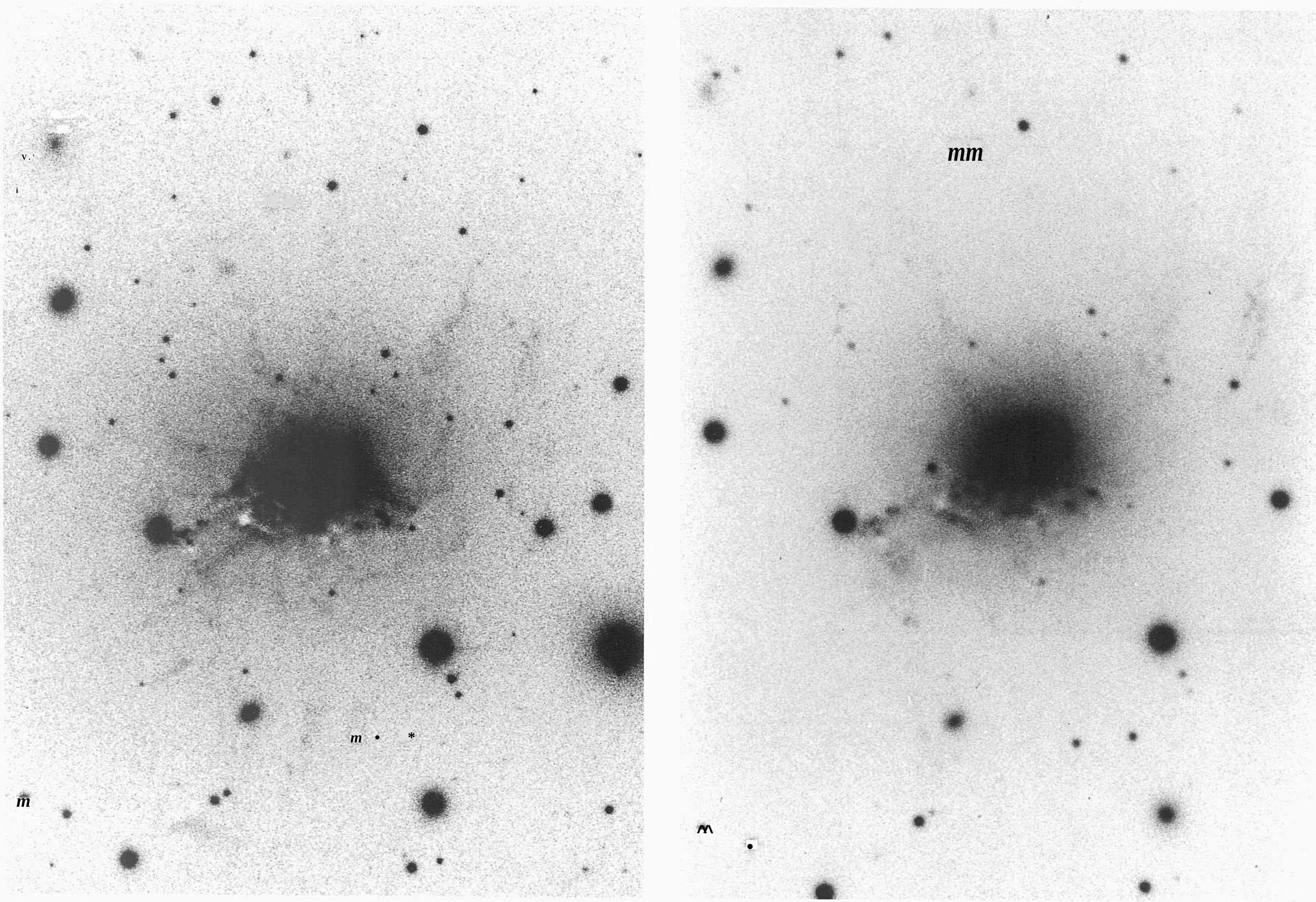
NGC 4342 is in the W Cloud region of the Virgo Cluster Catalog (Binggeli, Sandage, and Tammann 1985) in the immediate neighborhood of the other bright galaxies NGC 4343, IC 3259, NGC 4341 (=IC 3260), and IC 3267. A number of dE dwarf ellipticals exist in the field. (It was understood by Hubble, according to a notation on the plate envelope of a Mount Wilson 100-inch plate taken in 1946, that these images are **of** "possible dwarfs." Hence, Hubble knew already in 1946 that dwarf galaxies existed and presumably, therefore, that a very faint end of the luminosity function existed, now known as the Abell-Reaves exponential tail.)

The morphological type of NGC 4342 is listed in the RSA2 as E7. The type given in the Virgo Cluster Catalog is SOi, suggesting again that pure E7 galaxies may not exist. No evident SO disk is visible on the print here, but it is clear from the original plates that the isophotes on the major axis are pointed and are not pure ellipses.



PANEL
23

PANEL
24



NGC **1275** E pec Perseus **Cluster**
PH-4052-S and PH-4063-S **3C 84**
Nov 4/5 and Nov **5/6, 1962**
103aF + RGl
90 min and **180 min**

NGC 1275 is the center **of** the rich Perseus Cluster whose mean redshift is $\langle v_o \rangle$ = 5460 km s^{-1} (Chincarini and Rood 1971). A photograph of the central region of the cluster over an area of 13 arc min on a side is given **in Burbidge,** Burbidge, and Sandage (1963, Fig. 4). The filaments and plumes connected with NGC 1275 are also shown there (Fig. 5).

Minkowski (1957) discovered two velocity systems in the galaxy, one at v_o = 5200 km s^{-1} and the other at v_0 = 8200 km s^{-1}. He interpreted the data to indicate a high-speed collision of two galaxies. The composite spectral type by Humason, Sc + Sb (Humason, Mayall, and Sandage 1956), favored this interpretation. But in the first comprehensive mapping of the velocity field across the image of NGC 1275 by Burbidge and Burbidge (1965), the data were interpreted to indicate a massive outflow of material from the center similar to that found in M82 (Lynds and Sandage 1963).

The filamentary structure of the image is intricate, shown in a photograph by Lynds (1970) using an interference filter of 55-Å band pass centered on the Hα line at its redshifted wavelength of 6694 Å.

The filamentary structure shown in the print here was made from a superposition printing of two red-sensitive plates (103aF plus a broadband red filter) taken with the Palomar 200-inch telescope.

NGC **1275** **E** pec Perseus **Cluster**
PH-515-B **3C 84**
Oct 4/5, 1951
103aO + GG1
30 min

The **filaments** shown in Hα light in **the print** at **the left** are also **visible; in the broadband** blue image shown here from a **print** made from a single 200-inch **plate by Baade.**

The EISO and SO/E Classification Section

NGC 205 SO/E pec Local Gr
PH-670-B (dE,N pec) HA, p. *3*
Aug 21/22, 1952
103aD + GG11
75 min

NGC 205, the companion to M31 (Hubble Atlas, p. 78; panel 149 here), was first resolved into individual stars by Baade (1944a) with the Mount Wilson 100-inch Hooker Telescope using red-sensitive plates. The print here was made from a Palomar 200-inch plate taken by Baade on a yellow-sensitive emulsion. This plate is not the same used in the Hubble Atlas (p. 3), which was also taken by Baade at Palomar but on a red-sensitive emulsion.

Resolution into stars occurs suddenly at a threshold apparent magnitude of $V = 22$ (Mould, Kristian, and Da Costa 1984). It is the red color of the stars and the presence of the sharp upper luminosity threshold for resolution that led Baade to identify the population properties of the resolved stars with the evolutionary stage of old stellar systems such as globular clusters.

The integrated absolute magnitude of NGC 205 is faint at $Mg_T = -16$. The appearance of NGC 205 on small-scale plates (cf. Zinnecker and Cannon 1985) is consistent with this faint intrinsic luminosity, as judged by the low surface brightness. The image shown there is prototypical of nucleated dE,N dwarf ellipticals of the type that define the class (Sandage and Binggeli 1984). However, on large-scale plates the well-known dust patches in NGC 205 (Baade 1951; Hodge 1973) are prominent, seen also in the print here. The two main patches are to the lower right and near the top of the bright part of the bulge in this print. Dust patches are not typical in prototype dE.N galaxies.

NGC 205 SO/E pec Local Gr
PH-670-B (dE,N pec) HA, p. *3*
Aug 21/22, 1952
103aD + GG11
75 min

A portion of the image from the same plate used for the main print of NGC 205 at the left is shown here to see better the brightest globular clusters associated with this galaxy (Hubble 1932; Hodge 1973).

The brightest cluster is slightly to the right of the major axis, about one-third the way from the lower border of this print. This, and clusters like it in the body of the M31 disk, were important for Baade's (1944a) case, justifying his identification of the resolved stars as similar to stars at the tip of the giant branches in globular clusters. His point was that on the original plates where the resolution into stars in the outskirts of the globular clusters themselves was seen, the cluster stars resolved at the same magnitude as the stars over the image of NGC 205 itself. A hint of that fact can be imagined from the image of the globular cluster in the print here.

NGC 205 SO/E pec Local Gr
H-159-H HA, p. *3*
Sep 6/7, 1921
S30
80 min

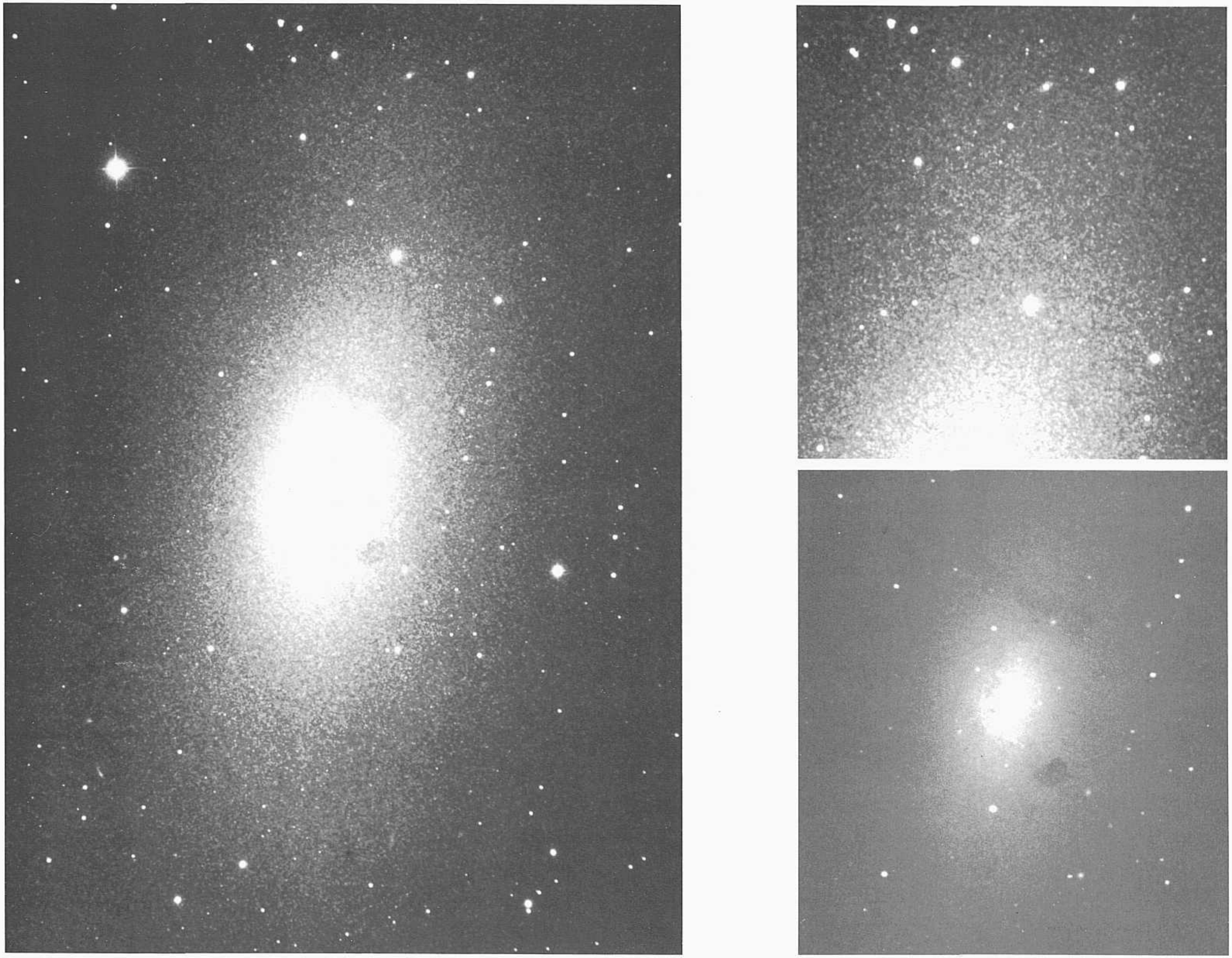
There was, however, an early false clue concerning the nature of the stellar content of NGC 205, and from it, a mistaken generalized uncertainty concerning the stellar content of all E galaxies. Both here and in NGC 4486 (the prototype giant E galaxy, panel 17), resolution occurred into a few outstandingly bright images. (In the case of NGC 4486, the objects are globular clusters, not individual stars.)

The same situation was known for NGC 205 even from the earliest Mount Wilson plates, c. 1920. It was known that very bright starlike images exist near the center of NGC 205. The Mount Wilson plate used for the image on the facing page here, taken by Hubble with the 100-inch Hooker Telescope in 1921, clearly shows their existence.

From a spectacular, near-ultraviolet plate by Baade (1951), it finally became understood that these images are of hot, young, high-luminosity stars that have just formed.

This is one of the few known cases of recent star formation in an apparently old E galaxy environment. But because NGC 205 is so close, and therefore can be studied with unusual detail, it may be that the presence of dust and a low rate of current star formation are more common in E galaxies than is now (1990) believed.

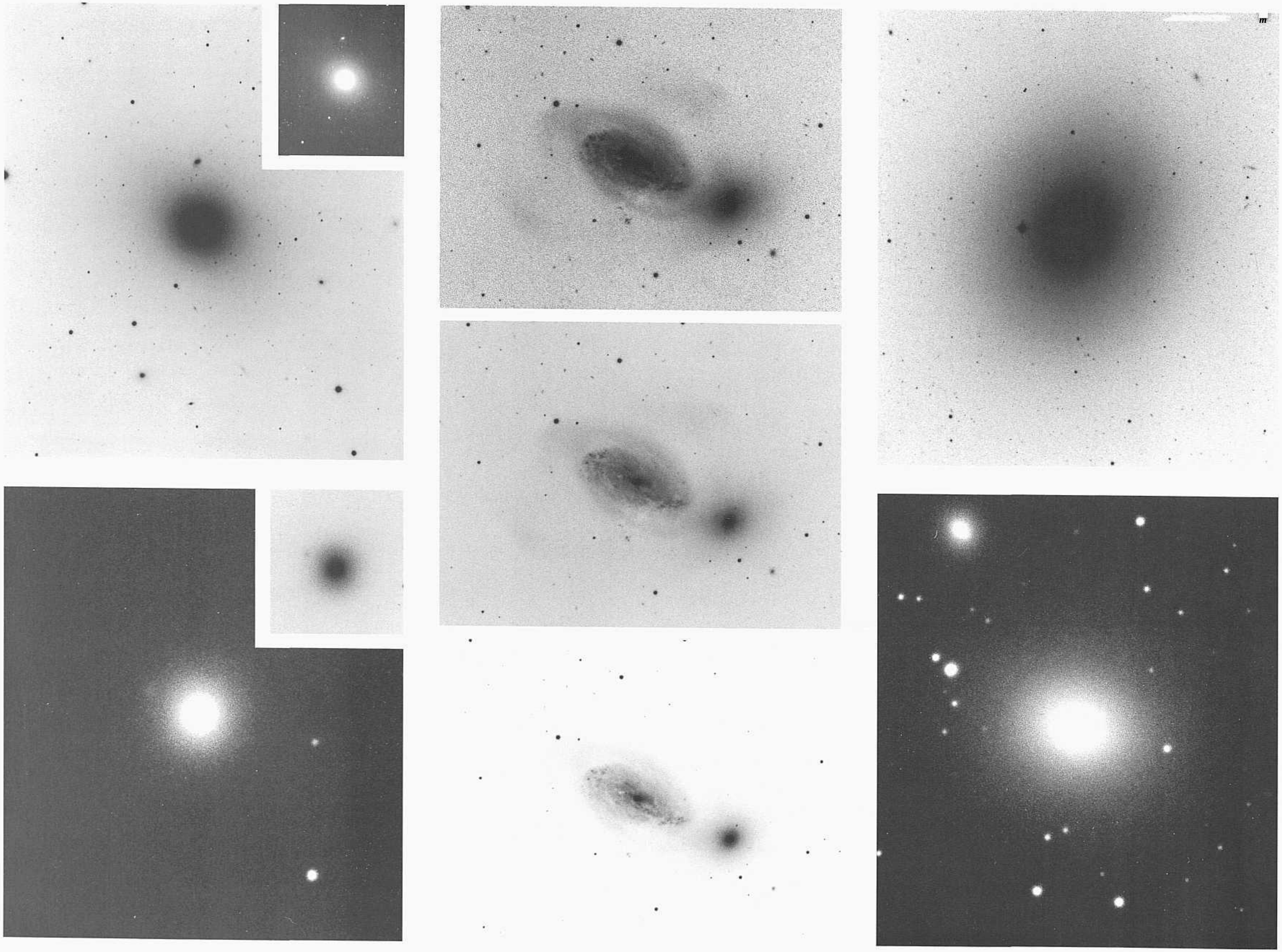
The colors of the young-star-forming regions in NGC 205, and the ages that can be inferred from them, have been discussed by Price and Grasdalen (1983). Early measurements of the neutral hydrogen content of NGC 205 were made by Johnson and Gottesman (1983).



PANEL
25

PANEL

26



The galaxies on this and the next three pages combine the features of E and SO types. On short-exposure plates where only the central galaxian regions are seen, E/SO galaxies have the appearance of a pure E morphology with no evidence of a disk. On longer exposures, the outer regions show a faint extended envelope, often with a different flattening ratio than the central E-like bulge.

This low-surface-brightness, shallow-luminosity-gradient outer envelope is so subtle that the form remains dominated by the nearly pure E-like morphology. Such galaxies are often misclassed from inadequate plate material; the non-E-like extended low-surface-brightness outer envelope (the incipient disk) is missed. To reveal the incipient disk or the faint outer envelope requires long exposures at adequate spatial resolution (i.e., a large plate scale). Many of the transition E/SO galaxies identified here have been misclassified in the older literature.

NGC 4636 E0/S0i(6) HA, p. *1*
PH-371-B
May 4/5, 1954
103aO + GG1
30 min

The central regions of NGC 4636 are E0-like, shown in the insert. However, a faint extended envelope exists with a flattening ratio of about 3 : 1, seen in the main print when viewed at a distance. The major axis of the envelope extends from the lower right to the upper left in the orientation of the print here.

Very many glohular clusters exist throughout the image. A mapping of their projected spatial distribution would answer whether the globular cluster system is flattened like the outer envelope or is EO-like, like the central regions.

NGC 596 E0/S0i(disk) group
PH-7943/7944-S
Nov 8/9, 1980
103aO
12 min

A very-low-surface-brightness thick disk exists that can be seen by viewing the main print here from a distance while moving the head and eyes back and forth. The position angle of the thick disk is from lower left to upper left in the orientation of the print here.

The insert print also shows an apparent two-zone intensity structure in the inner region that is normal for SO galaxies, but not for ellipticals.

NGC 596 forms a wide pair with NGC 584 [SO_x(3,5): panel 32]. These are the brightest two members of a small group that also contains several dE dwarf candidates. Other bright members of the group include NGC 586, NGC 600, NGC 607, and NGC 615 (Sb; panel 131).

NGC 3226/3227 E2/S0i(2) Karachentsev 234
PH-7983-S Sb(s)(tides) panel 153
Feb 1/2, 1981
103aO
12 min

The three images in this column have been made from the same original plate printed to different contrast to show (1) the tidal plumes, one of which connects the galaxies in the top two prints, and (2) the lack of perturbation of the central region of NGC 3227 (Sb) even in the presence of what evidently is a strong encounter.

The separation of the components is 2.2'. The redshifts are u_o(3226) = 1260 km s^{-1} and r_o(3227) = 1102 km s^{-1}, giving a redshift distance of 23.6 Mpc (*H* = 50). The projected linear separation is small at 15 kpc. The pair is number 234 in Karachentsev's catalog of pairs.

The pair is important for understanding the origin oi SO galaxies. (Are they generic to the classification sequence or a result of environmental effects on former spirals?) Other examples of pairs in this atlas where a large classification difference exists and where the evidence is good that the pair is at the same distance include NGC 274/275 (panel 52). NGC 470/474 (panels 84, 189). and NGC 1596/1602 (panels 51. 328).

NGC 4472 EI/S()i(l) VCC 1226
CD-716-S **M49** panel 18
Feb 1/2, 1979
103uO + Wr2c
45 min

NGC 4472 is the brightest galaxy in the Virgo Cluster-. It is near the isoplethic center of Virgo subcluster B (Binggeli, Tammann, and Sandage 1987).

The luminosity gradient in the outer regions appears flatter to the eye than that in pure K types. An extended outer envelope is clearly visible on overexposed plates taken in the dark sky at Las Campanas. It is also well seen in the print on the facing page, made from a 50 X 50 cm Las Campanas Virgo Cluster survey plate. Compare the image in this print with images of normal El galaxies in the previous section.

Many globular clusters exist throughout the image, seen well in this print in the outer envelope and previously discussed on panel 18.

NGC 6868 E3/SO_2/:i(3) **Tel** Gr
CD-1054-Br
Aug 16/17, 1979
103aO + GG385
45 min

NGC 6868 is one of the brightest members of the Telescopium Group (Sandage 1975b), whose mean redshift is <!•;;> = 2733 km s^{-1}.

The two-zone nature of the image, characteristic of the SO class, is suggested in the prinl here and is well seen on the original plate. ISecause of the second luminosity zone which is tin' extended outer envelope, the galaxy clearly is not E3. However, the extended envelope is not as well developed as in the prototype SO class, hence the transition-type E/SO is assigned.

A faint circular segment of a dust lane exists in the outer part (if the disk (apparently seen nearly face on). The lane is just visible, silhouetted against the upper-left part of the outer envelope on the facing print here. If the galaxy were seen more edge on, the lane would be silhouetted against the bulge, as in the more visible $S0_3$ types of that standard morphology described in the next section.

T he morphologies of the galaxies on this page are intermediate between prototype E and prototype SO, based on the character of the luminosity gradients in the outer regions. The luminosity profile at large radii does not fall off as sharply in E/SO as in E galaxies: thus the appearance is that of an extended envelope, albeit more subtly than in SO galaxies. The galaxies are arranged on this page in the order of flattening.

NGC 4406 S0i(3)/E3 VCC 881
CD-743-S M86 HA, p. *1*
Feb 3/4, 1979
103aO + Wr2c
60 niin

The extended outer envelope is more pronounced in NGC 4406 than in most other E/SO cases. It is well shown in the facing print, appearing almost as a two-zone image, characteristic of pure SO types described in the next section.

A few globular clusters exist in the envelope, but the specific globular cluster frequency (number per unit *Mg* = —1 5 luminosity) is much lower than in NGC 4486 (panel 17), NGC 4472 (panels 18. 26). or NGC 4636 (panel 26).

The Virgo Cluster nucleated dwarf elliptical VCC 882 (dE3.N) is at the lower right in this print, whose orientation is south at the top, east to the right.

NGC 5903 E3/S0](3) NGC 5898 Gr
CD-1052-Br
Aug 16/17, 1979
103aO + GG385
45 min

NGC 5903 forms a pair with NGC 5898 [$S0_2$/:J(0): panel 42]: the two galaxies are the brightest members of a small group (Sandage 1975b) that contains a number of dE and dSO dwarfs. The separation of the bright pair is 5.5'. The redshifts are i>$_o$(5898) = 2098 km s$^-$' and u$_o$(5903) = 2378 km s^{-1}, giving a mean redshift distance of 45 Mpc *(H* = 50). The projected linear separation of the pair is 72 kpc.

The shallow luminosity gradient at large radii, seen well on the original plate and in the print here, is the reason for the E/SO transition type.

NGC 1052 E3/S0i(3) NGC 1052 Gr
PH-7890-S
Nov 6/7, 1980
103aO
12 min

NGC 1052 is the eponymous member and the brightest galaxy in the NGC 1052 group, which includes NGC 991. 1022, 1033. 1035, 1042. 1047. 1048, 10 51, and NGC 10 52 here. Many of these are late-type galaxies shown in this atlas. There are also many dE dwarf candidates in the group. The mean redshift from the available data for group members is <v_o> = 1500 km s^{-1}.

NGC 5831 E4/S0i(4)(disk) NGC 5846 Gr
CD-1851-HB
April 3/4, 1981
103aD + GG495
45 min

NGC 5831 is in the NGC 5846 Group, which includes NGC 5 806, 5831 here, 5 838, 5846. and NGC 5854 (Humason, Mayall, and Sandage 1956) and many dE dwarf candidates.

A subtle but unmistakable incipient disk exists, similar to but much weaker than the disk in NGC 3414 [$S0_{1/2}$(0)/a; panels 50, 53]. which is the prototype of embryonic disks. The weak disk in NGC 5831 is buried in the intensity of the bulge, but a hint is present from the slight departure from elliptical symmetry at position angles of 1:30 and 7:3 0 o'clock in the print here. The feature can best be seen by viewing the print from a distance and moving the head from side to side.

NGC 7196 E3/SO_3(3) group
CD-1115-Br
Aug 18/19, 1979
103aO + GG385
45 min

NGC 7 196 is in a group that contains NGC 7168 (E3: panel 7) and NGC 7200 (Sandage 1975b) and a number of dE and 1m dwarf candidates.

The unusual feature of NGC 7196 is the two-zone luminosity distribution near the center, shown in the insert, uncharacteristic of E galaxies but common in SO types (see the next section). The outer envelope isophotes are also slightly distorted, being asymmetric in the same direction as the asymmetry in the center. The direction of the distortion is at right angles to the direction of the fainter E5/S0 companion at the right and below NGC 7196 in the facing print. The inner luminosity pattern seen in the insert resembles that due to the circumscribing dust lane in $S0_3$ prototypes, except that the feature here is extremely close to the center.

NGC 1726 E4/$S0_2$(4) pair
CD-1344-S/Br
March 15/16, 1980
103aO + GG385
45 min

NGC 1726 is paired with NGC 1720 (SBbc) at 8.2′ separation.

The classification feature that distinguishes the morphology of NGC 1726 from a prototype E is the weak internal dust lane that gives an asymmetry to the image similar to that shown near the center of NGC 7196, above (insert). The lane is very weak. It is nearly buried in the intensity of the bulge in the facing print, but can just be seen in faint silhouette against the bulge in the lower third of the image.

NGC 3923 E4/S0i(4) pair
CD-1128-S/Br
March 25/26, 1980
103aD + GG495
40 min

The extended outer envelope, uncharacteristic of pure E types, is well developed in the near-SO morphology of NGC 3923 . A small dust patch is silhouetted against the outer envelope on the lower-right side of the bulge above the major axis of the right side.

At least seven dE,N dwarf ellipticals exist in the field of size 2 5' on a side, centered on NGC 3923. However, this field is not in a cluster; hence the number of dE companions is unusual for such an isolated galaxy. The only nearby NGC galaxy is NGC 3 904 (E2), at 3 7' separation. These two Shapley-Ames galaxies evidently form a pair, with a projected linear separation of 300 kpc based on u$_o$(3904) = 1333 km s'" and w$_o$(3923) = 1509 km s~^{J} , giving a mean redshift distance of 28 Mpc *(11* = 50).

IC 4797 E5/S0i(5) IC 4797 Gr
CD-1451-S/Br
May 6/7, 1980
103aD + GG495
45 min

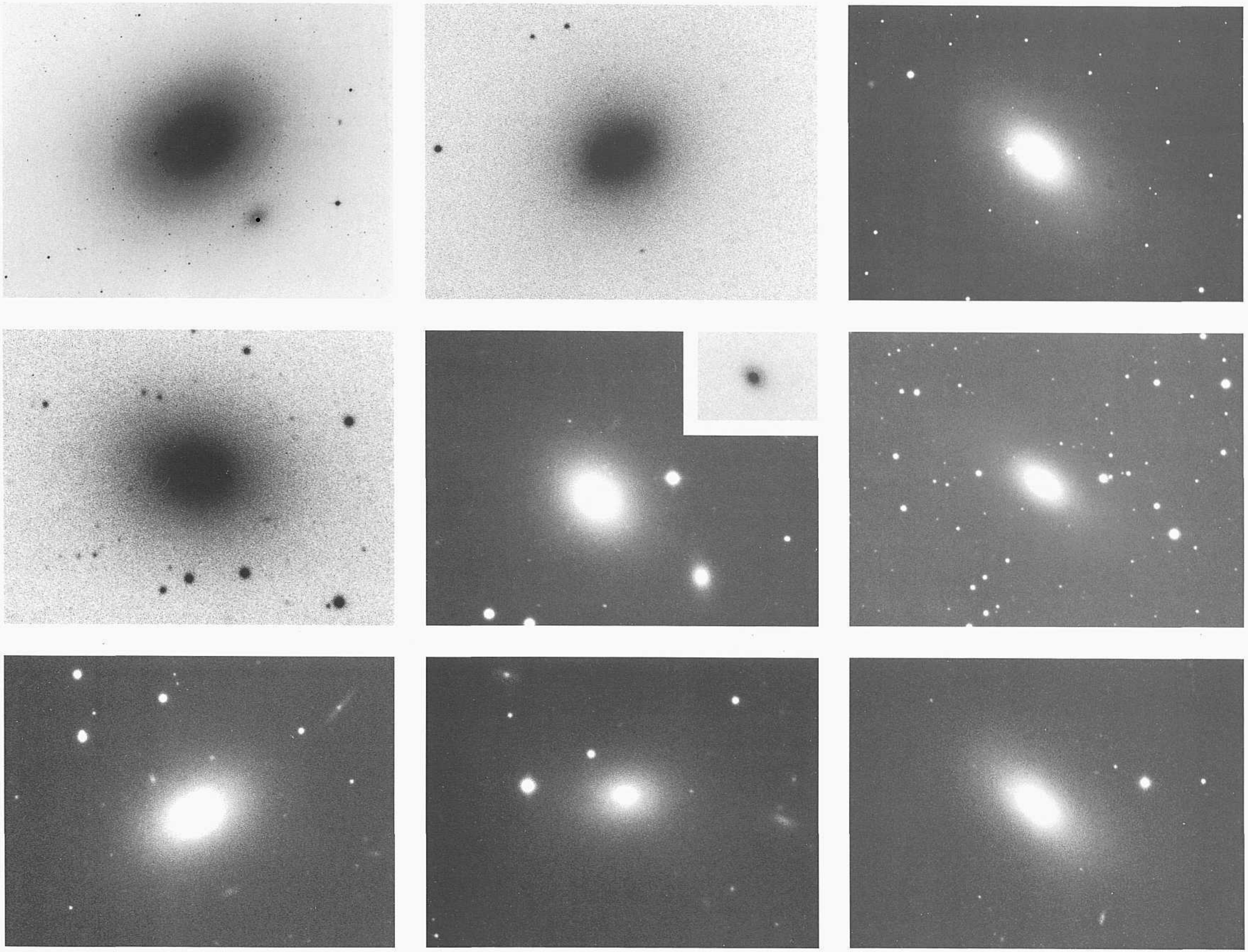
IC 4797 is the brightest galaxy in a group of about five members in a linear chain containing NGC 6707, NGC 6708, IC 4796, IC 4797, and HA 85-2 (= A 1854-54), all with similar redshifts averaging <u$_o$> = 265 3 km s~^{1}.

The classification feature that determines the mixed type of IC 4797 is the extended envelope, seen well in the print here.

NGC 7785 SOt(5)/E5 Racine wedge
PH-7818-S
Sep 2/3, 1980
103aO
12 min

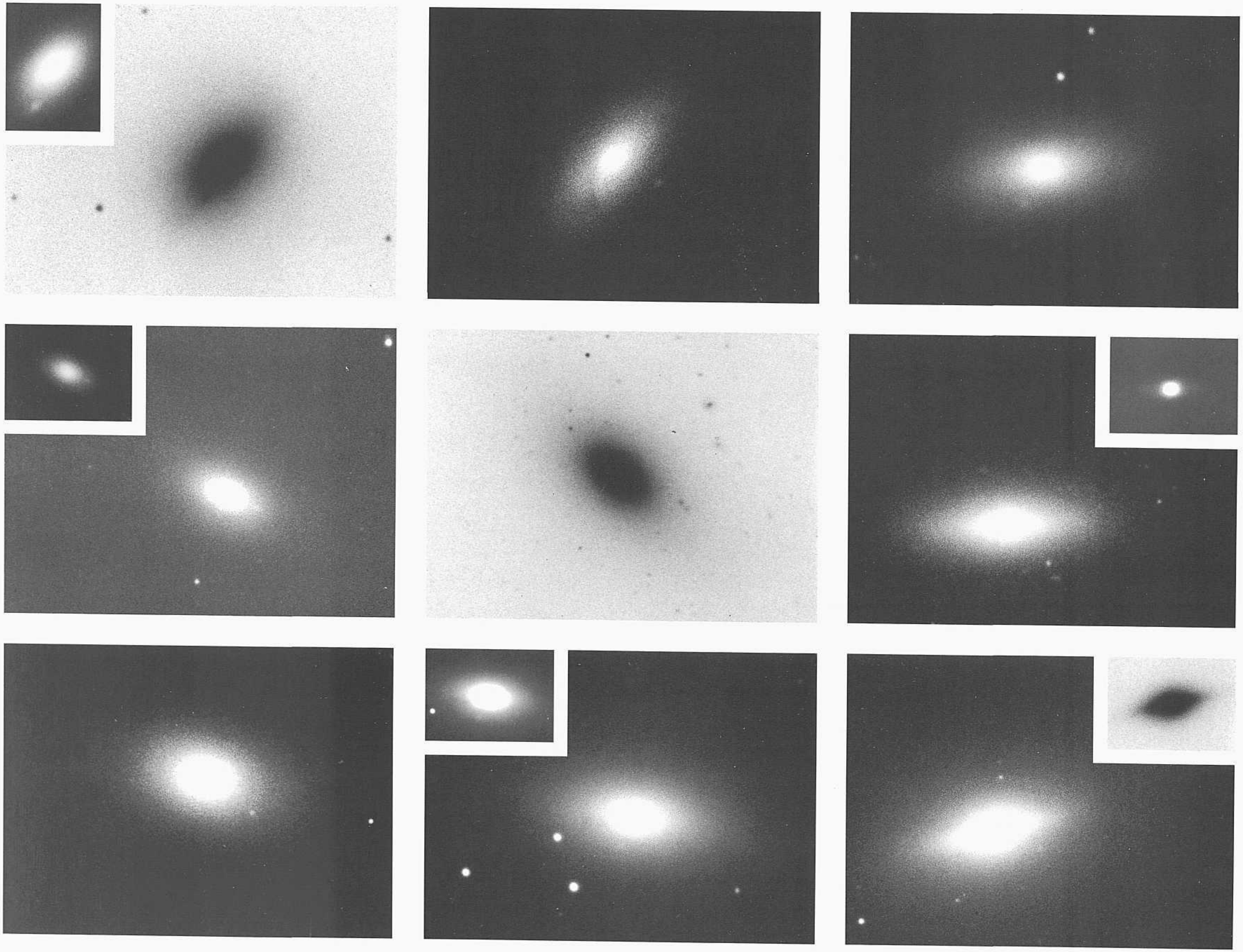
The extended envelope in NGC 7785 beyond the edge of the E5 bulge is the classification feature giving the mixed type.

The plate was taken with a Racine wedge. The bright star has a 5 mag fainter secondary image at 1 8" separation from the primary image.



PANEL
27

PANEL
28



The galaxies on this page continue the E/SO mixed classification form. They are arranged in the order of the flattening.

NGC 3610 E5/S0i(5)
PH-8044/8045-S
Feb 4/5, 1981
103aO
12 min

An incipient disk is present in NGC 3610. It cuts across the lower third of the bright bulge in the orientation of the print here. It appears as an asymmetry in what otherwise would be an elliptically symmetric E5 image.

A very small apparent companion is seen in the insert print to the lower left of the major axis of the bulge. The possible pair is a candidate for a cannibalistic merger.

NGC 4914 E5/S0i(5)
PI1-8061-S
Feb 4/5, 1981
103aO
12 **min**

An extended outer envelope in NGC 4914 can be traced on the original plate to the upper-left and lower-right borders of the main print. The feature is the reason why NGC 4914 is not classed as a pure E5. As in NGC 3610, above, a faint apparent close companion exists in the inner envelope of the main body, shown in the insert. It is near the major axis on the right-hand side.

NGC 1344 E5/SOi(5)
CD-1733-S
Jan 11/12, 1981
103aD + GG495
45 inin

An extension of the envelope in NGC 1344 is more subtle here than in NGC 4914, above, yet the luminosity profile has a shallower cutoff to the eye than in pure E galaxies. A representation of the form would be an Oemler (1976) modified Hubble (1930) profile where the ratio of the Oemler envelope to core radius (his alpha and beta parameters) is larger than in more-compact E galaxies.

NGC 3156 $S0_2$/3(5)/E5
PH-7974-S
Feb 1/2, 1981
103aO
12 **min**

A three-zone luminosity distribution characteristic of the SO class (see the next section) determines the classification of NGC 3156 here. A thin dust lane cuts only part of the bulge on the left side of center in the orientation here.

NGC 1351 E6/S0i(6) FCC 83
CD-1151-Br
Aug 21/22, 1979
103aO + GG385
45 min

NGC 135 1 is a member of the Fornax Cluster (Ferguson 1989). The classification, debatably, could be pure E6. The decision here for a mixed classification is based on a long-exposure Las Campanas plate from the Fornax Cluster survey on which a subtle outer extension to the luminosity profile is suggested.

NGC 4125 E6/S01/2(6)
PII-8085/8506-S
Feb 6/7, 1981
103aO
12 min

An incipient disk exists in NGC 4125 which is definite but much more subtle than in NGC 3115 (panel 50). It is seen almost edge on, and is therefore presumed to be more easily identified as a disk than are disks seen more nearly face on in other galaxies in this E/SO section. Indeed, if a disk exists in nearly face on galaxies it appears only as a subtle extended envelope.

Note the dust patch on the left side of the bulge center in the insert print.

NGC 3613 **E6/S0i(6)**
PII-8046-S
Feb 4/5, 1981
103aO
12 min

The three-zone character of the image of NGC 3 6 1 3. characteristic of the SO type, is seen on the original plate and is suggested in the facing print.

NGC 1366 S0i(7)/E7
CD-1536/1537-S/Br
Aug 6/7, 1980
103aO
45 min

The form of NGC. 1366 is almost E7. Yet there is evidence for a thin disk (as in NGC 3 115, but much weaker here) rather than simply concentric elliptical isophotes as in pure E galaxies. The central bright bulge is less flattened than the outer body shown in the main print.

NGC 3585 SOi(7)/E7
CD-1396/1397-S/Br
March 22/23, 1980
103aD + GG495
60 min

A clear disk in NGC 3585 is seen both in the main print and in the insert.

NGC 1550 E7/SOi(7) VCC 1619
CD-755-S
Feb 4/5, 1979
103aO + Wr2c
60 miii

This Virgo Cluster galaxy has a three-zone SO appearance albeit subtle enough that NGC 4550 is not classed as a pure SO hut rather" as a mixed E/SO type. The galaxy is not a pure SO because of the absence of a disk- which, at the evidently nearly edge on viewing angle, would be expected tn lie similar to the disk so evident in NGC 3 1 1 5 (panel 5(1).

NGC 7041 S0i(7)/E7
CD-440-Rose
Aug9/10, 1978
103aO + Wr2c
90 min

The subtle inner disk, seen already at the edge of the bright bulge in the facing print, shows that the type is not pure E7. However, the disk is not prominent and does not extend throughout the image as in NGC 3115 (panel 50). Rather. the outer envelope (the thick disk) beyond the edge of the bulge has a luminosity profile that is almost E7. although with a slightly shallower cutoff.

NGC 4570 S0i(7)/E7 VCC 1692
H-558-H
May 27/28, 1925
E40
50 nún

There is no sharp disk in NGC 4570 as there is in NGC 3 1 15. Nevertheless, the original plate shows a clear separation between bulge and envelope, slightly burned out in the facing print. A diffuse disk is [iresent. and the luminosity profile from the bulge outward is not continuous in its first derivative as in *K* galaxies, but the SO zone form is subtly evident.

NGC 5350/5353/5351/5355/5358 group
PH-8024-S panel 202
April 27/28, 1979
I03aO
8 nún

The remaining four prints on this page show various galaxies in a group whose brightest members are NGC 5350 (SBhc) and NGC 5353 [S02/3?(7)/E7]. The orientation of the print in the top middle column is west at the top, north to the left. The identification of the brighter galaxies in this group, starting from the top, are the SBbc spiral NGC 5350. the bright flattened SO/EV galaxy NGC 5353, its $S0_3$(prolatc) companion NGC 5354. the E4/S0(4) galaxy NGC 5355. which is three-fourths of the way to the bottom border in the middle, and NGC 5358 [SO] (6)] near the lower-right corner.

The group is part of a larger complex of bright (RSA) galaxies that have nearly the same redshifts: NGC 5313 (v_o = 2588 km s~'); NGC 5326 («„ = 2603); NGC 5350 (v_o = 2305); NGC 5353 (»„ = 2224);NGC 5362 (v_0 = 232 1): NGC 5371 (v_o = 2616); NGC 5383 (v_o = 2322). Many-fainter dE dwarf galaxies that may be part of this complex are also in the area.

NGC 5353/5354 S02/3?(7)/E7 pair
PH-8024-S $S0_3$(prolate)
April 27/28, 1979
103aO
8 nún

The detail is given here of the NGC 5353-NGC 5354 apparent pair from the same original plate used for the wider-angle print above.

There is no sharp disk in the flattened galaxy NGC 5353 but the isophotes are not pure ellipsoids either: they have sharper tips than do rounded ellipsoids at the ends of the major axis. Although the original plate is overexposed in the very-high-surface-brightness interior parts of the image, there is a suggestion that a thin central dust lane exists along the major axis. If true, this feature would require the SO9/3 subtype.

A dust lane cuts across the *minor* axis of the smaller galaxy NGC 5354. The form is similar to the prototype $S0_{.j}$(prolate) galaxy NGC 5266 (panel 45). Only part of the dust lane is visible as a cut-out of the right side of the bulge in the overexposed facing print.

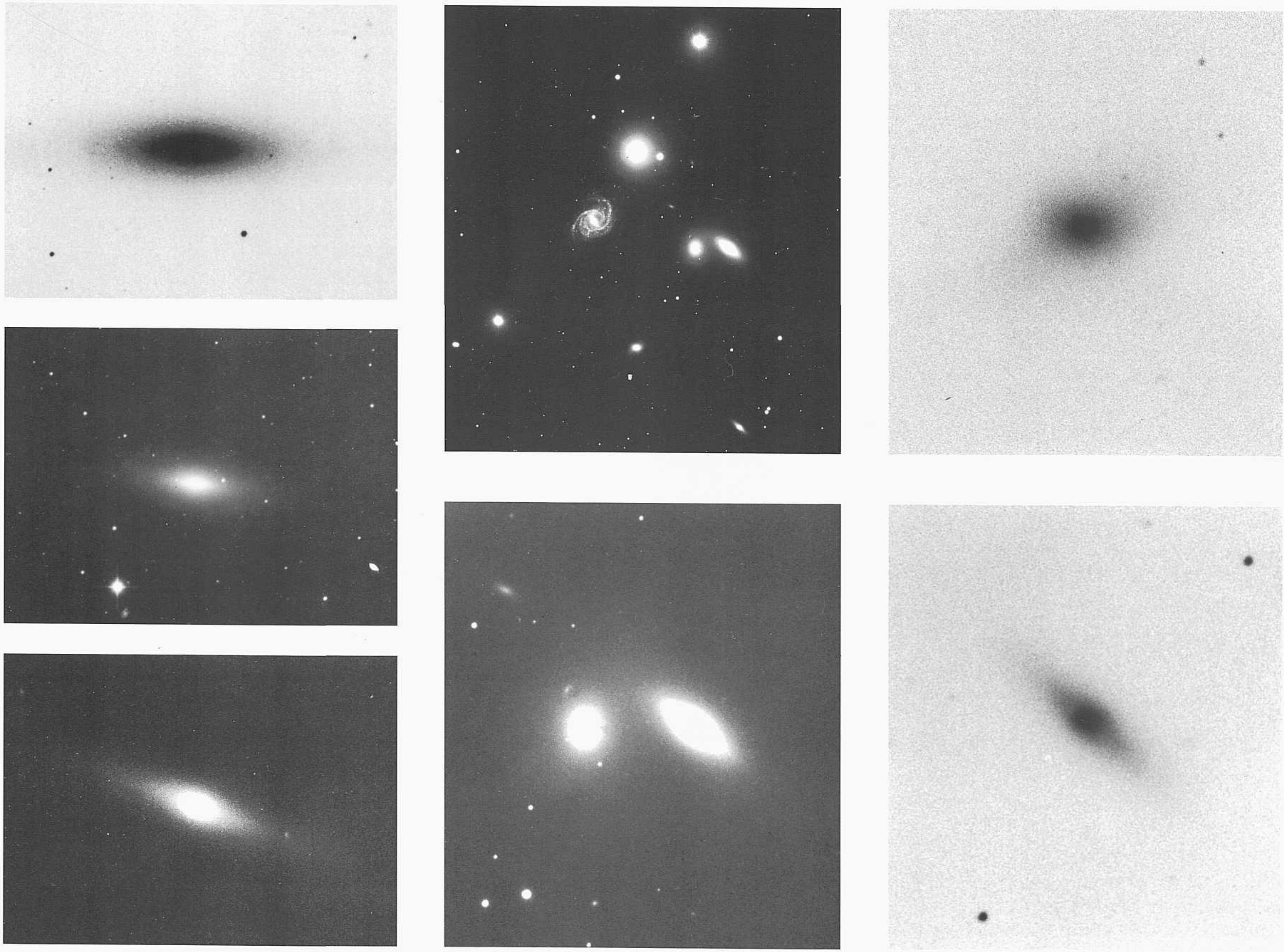
One of the dE (or dSO) dwarf members of the group is seen in this print near the upper-left corner. It is the small, highly flattened, low-surfare-11 rightness image.

NGC 5355 S0i(3)/E3
PH-8024-S
April 27/28, 1979
103aO
8 min

NGC 5355 (not in the RSA) is almost an E3, but it has an extended outer envelope that gives the image a partial two-zone character, common to SO galaxies.

NGC 5358 S0i(6)
PH-8024-S
April 27/28, 1979
103aO
8 min

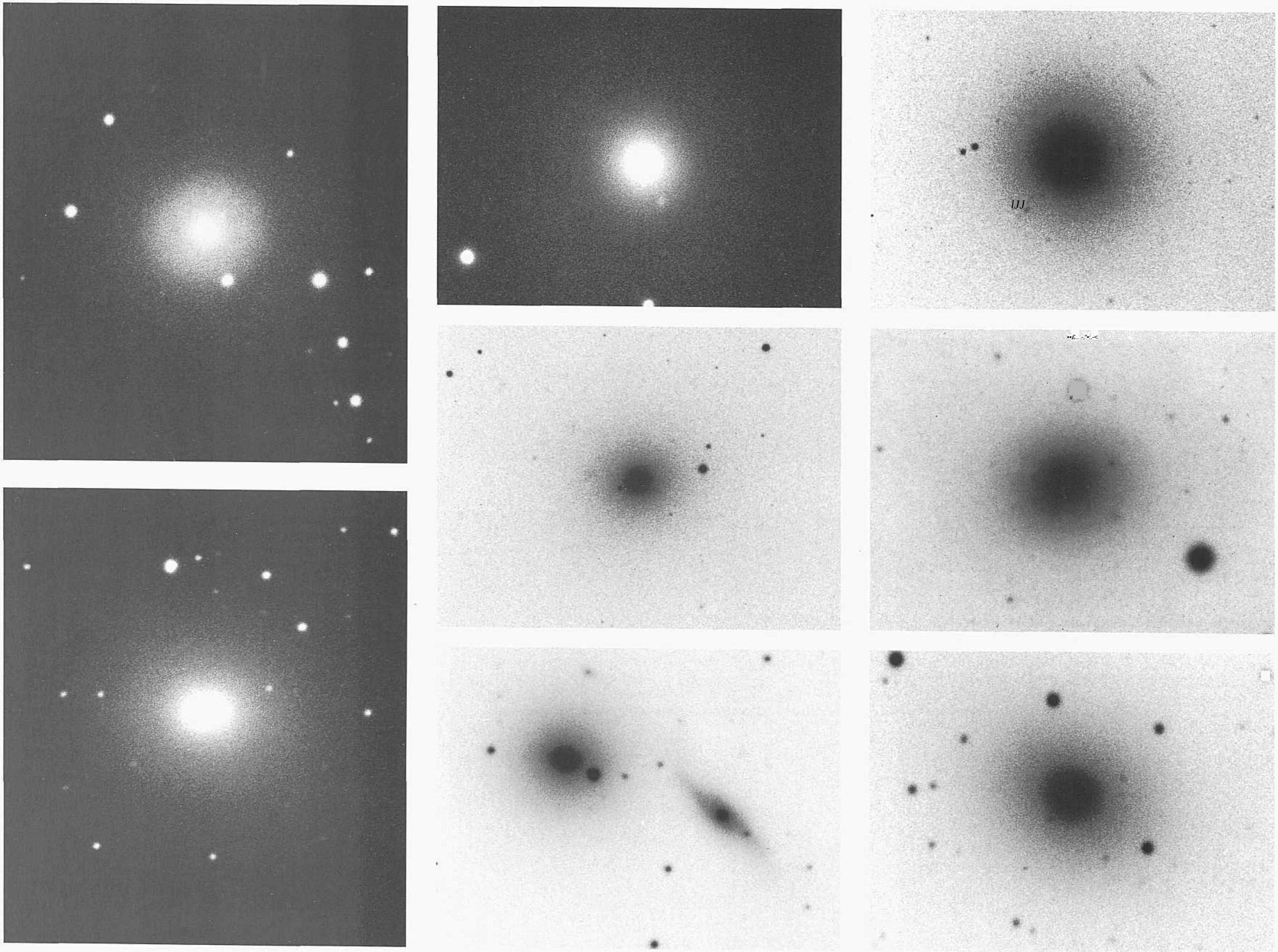
NGC 5358 (not in the RSA) is a typical, highly flattened SO. It has a bright central bulge and a low-surface-brightness disk seen edge on.



PANEL

29

PANEL
30



The SO Classification Section

T he galaxies on this and the next seven pages are of SO subtype SO], arranged in the order of flattening. The classification criteria of this subtype are (1) a luminosity profile shallower than the sharp r$\sim\sim^{2,3}$ radial dependence of E galaxies (a characteristic common to all SO 's independent of the three subclasses), and (2) a smooth luminosity profile with no discontinuity in the gradient. The absence of structure (the smoothness ol the image) differentiates the SO j subclass from the two other SO subtypes. The division of the SO class into three principal subdivisions in the next 23 panels here is the same as in the Hubble Atlas.

As explained in Chapters 2 and 3 (pp. 5, 14), a secondary classification of the SO and SBO galaxies is shown below the main classification symbols, denoting the degree (if SO-ness in the photographic image. The symbols are 1' for "pronounced." I for "intermediate," and S for "subtle."

INGC 2902 S0i(0)
CD-689-Br (P)
Jan 27/28, 1979
103aO + GG385
4-5 min

NGC 2 902 is a prototype of the SOj subtype. The image on **photographic** plates, inspected with the non-linear human eye, appears to contain three distinct concentric luminosity zones separated by apparent "edges" between the zones. Particularly strong examples are NGC 3056 ($S0_{1/2}$; panels 39. 53) and NGC 1553 (SOj/o; panel 39). The inner, high-surface-brightness region resembles a normal E0 galaxy. A fainter but still high-surface-brightness "intermediate" envelope comprises the middle third of the image, well seen on the print here. This deviation of the profile from that of a normal E galaxy generally appears as a sharp apparent edge. It is the principal classification feature common to the SO class.

A third outer luminosity zone of very **low** surface brightness is present in NGC 2 902. This extended envelope can be traced on the plate to about twice the radius of the middle zone: the outer zone is not visible on this print.

The impression of three luminosity zones that appear on visual inspection to have nearly discrete edges is characteristic of the SO class. This feature separates the E and the SO class. Although the apparent discontinuity in the luminosity gradient is quite definite to the eye, the differences are minute in measured profiles. From this it has been supposed (van den Bergh 1989) that the SO class is a mixture of generally misclassified E galaxies, and that the SO class is ill defined.

That the SO class is in fact **well** defined is, however, demonstrated by the continuity throughout the SO classification set out in the next 24 panels here. The differences between the images of E and SO galaxies are generally highly **apparent** on the prints. Among the **prototype** examples is NGC 2902, here. Other examples include NGC 5 193 (SO,; shown here), NGC 5011 **(SO,; shown here), NGC 4379** (SO,; panel 31). NGC 4024 (SO,; panel 3 1), and NGC 3 998 ($S0_i$; panels 31,53).

Apparently, the visual impression emphasizes *changes* of **gradients** (the eye takes the first derivative) rather than the gradient itself. Gradient changes appear as *edges* to the eye. It is this property that makes separation of the E and SO classes by the classical morphologists (using the non-linear photographic plates) more powerful than photometric tracings, giving rise to the false animadversions.

NGC 2902 is a pronounced case **of** deviation of an E galaxy profile, as recognized also in the RC1 by the comment "similar to NGC 1553" (SO,/,; panel 39).

NGC 5419 S0i(2)
CD-1041-Br (I)
July 22/23, **1979**
103aO + GG385
45 min

The extended outer envelope of NGC 5419 is more subtle than in NGC 2902. NGC 5380, NGC 5193, or NGC 5011 on this panel. Nevertheless, the luminosity decay is shallower than in a normal E2 . **The** classification of E4 in the RC2 is therefore not supported here; an outer envelope is present. NGC 5419 is close to the transitional morphological E/SO type. It is early in the SO j morphological box in the classification here.

NGC 5380 S0i(0)
PH-7625-S (P)
April 27/28, **1979**
103aO
10 min

The envelope that begins at what appears as an edge to **the** inner bulge of NGC 5380 is prominent on the plate. It can be seen best on this print when viewed from a distance by moving the head or eyes.

NGC 4760 S0i(2)orcD
CD-1848-HB (I)
April 3/4, 1981
103aO
75 min

This galaxy with an extended outer envelope is not an elliptical but is less extreme in its SO profile than NGC 2902 or NGC 5011 on this page, or NGC 1553 and NGC 3056 on panels 39 and 53. The E0 classification in the RC2 , based on a weak Mount Wilson 100-inch plate, is not supported here.

NGC 5193/5193A S0i(0)/S0i/$_2$(8) IC 4296 Gr?
CD-1066-Br (P)
Aug 17/18, 1979
103aO + GG385
45 min

These galaxies are in or near the IC 42 96 Group. They form a physical pair whose redshifts are **t)$_o$(5193)** = 3491 km s"^{1} and !;$_O$(5193A) = 3366 km s~^{1} (Sandage 1978). From the redshil't distance of 68 Mpc (*H* = 50) and the angular separation of 56", the projected linear separation is small at 19 kpc. There is no evidence for tidal interaction; plumes and gross distortions are absent.

The extended outer envelope in NGC 5193 is pronounced; the edge to the inner region is evident.

NGC 4552 **SOi(O) VCC 1632**
H-2568-H (S/I)
May 25/26, 19 18
103aO
30 min

NGC 4552 is *a* **clear SO rather than an E.** The **extended outer envelope** is definite, although not pronounced: the SO characteristics are intermediate. The departure **from** a **normal** E **morphology** is well shown in the print here. The EO classification in the KC2. based on the 1'OSS paper prints, is inappropriate.

NGC 6958 SO **i(3)**
CD-426-Rose (I/P)
Aug 6/7, **1978**
103aO + \V2c
60 min

The **SO nature** of **the morphology** of NCC 6958 is well shown **in** the **print** here. The extended envelope is pronounced. The **E1 classification in** the RC2 . bused mi a **Mount Stromlo** 3 0-inch plate, is not supported **here.**

NGC 5011 S()i(2)
CD-1499-S/Br (P)
Aug 4/5, 1980
103aO + GG385
45 min

NGC 50 1 **1** is a type example of a classic SO , form. The extensive **outer envelope** deviates, strongly **from a sleeper F profile** and is prominent **in** the print here. The **El** classification in the RC2. based on Cordoba 60-inch plates, is incorrect.

NGC 4379 **S0i(2)** **VCC 784**
CD-783-S **(P)**
Feb 22/23, 1979
103aO + GG385
45 niin

The apparent two-zone character of the image is **well** shown in the negative **print** of NGC 43 79 here. Comparison with images of any of the galaxies in **the** E section shows the evident deviation of the luminosity profile, characteristic of the SO types.

NGC 1172 **S0i(0,3)**
CD-1179-Br **(S)**
Aug 23/24, 1979
103aO + GG385
45 min

The central region of NGC 1172 resembles an EO. The outer extended envelope is flattened, with a flattening index of 3 , giving the combined classification notation.

Condensations in the image suggest globular clusters. The redshift of v_o = 1566 km s~[1] gives a redshift modulus of ***m*** - *M* = 32.5 (// = 50), which is small enough that the objects could be globular clusters.

The SO-type outer envelope is subtle but definite. The El classification in the RC2 , based on POSS prints, is not supported here.

NGC 4024 **S0i(2,5,2)**
CD-1721-S **(P)**
Jan 8/9, 1981
103aO
75 min

The composite image of NGC 4(i24 consists of an E2-like central region (burned out on the main print here but shown in the insert), a flattened disk (or lens) with a flattening index of 5 , and an extended low-surface-brightness envelope of flattening index 2 , well seen in the main print.

NGC 3998 **S0i(3)** **panel 53**
PH-7640-S **(P!)**
April 28/29, 1979
103aO
12 min

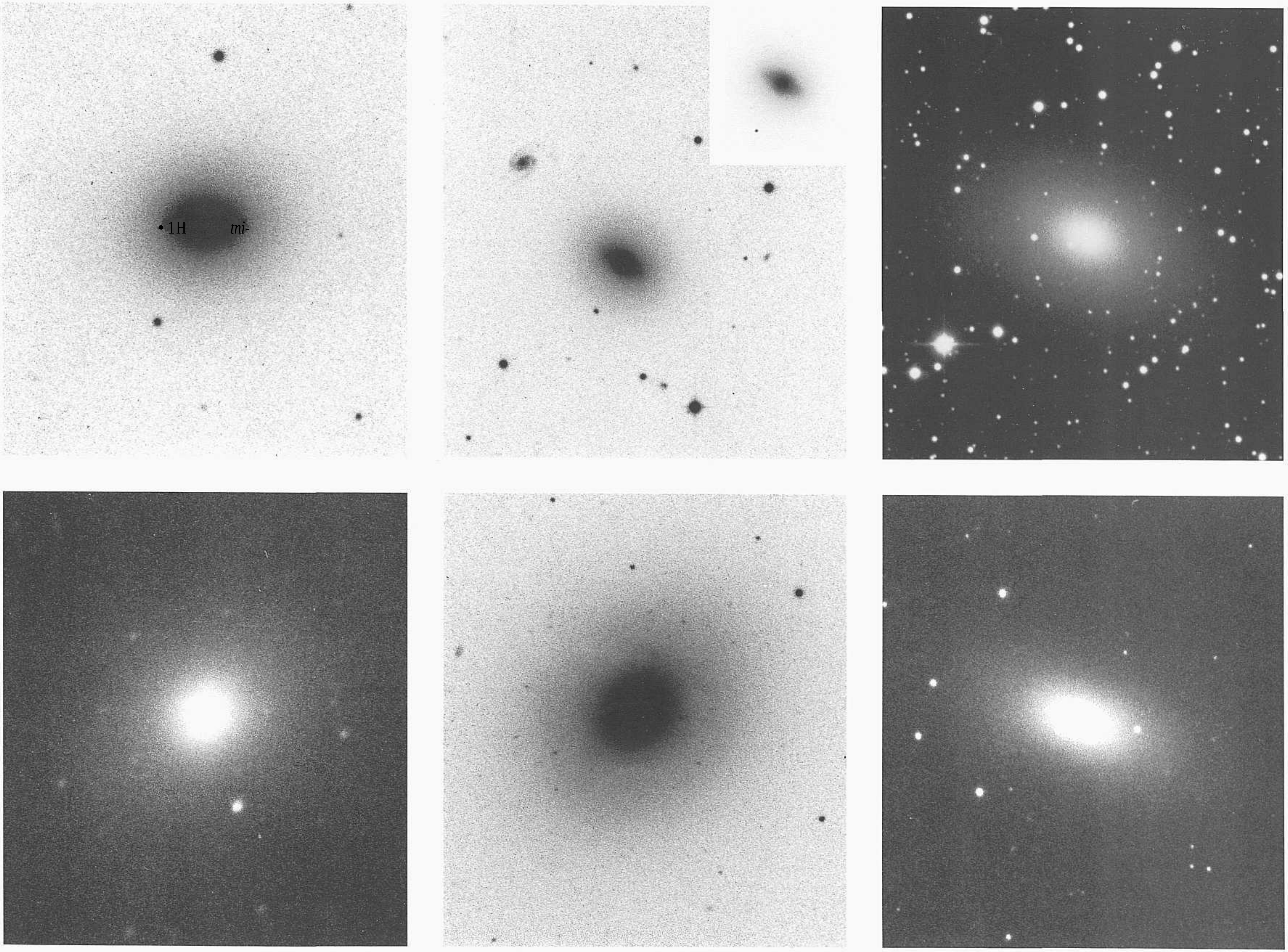
NGC 3998 has pronounced SO characteristics, making it a prototype example of its class. The extended outer envelope with its apparent **sharp** break at the edge of **the central** bulge is well shown in the print here.The distance modulus of *m* — *M* = 3 1 .9, based on a redshift of v_{0} = 1214 km s^{-1} , makes possible the identification of the condensations over the image as globular clusters.

NGC 4976 **S0i(4)**
CD-1466-S/Br **(P)**
May 10/11, 1980
103aO + GG385
45 min

NGC 4976 is a prototypical **example** of a standard SO] galaxy. The outer envelope, and therefore the departure from an E4 profile (which would be steeper), is pronounced. The type of E4P in the RC2, based on a Cordoba 60-inch plate, is inappropriate.

NGC 5791 **S0i(4)**
CD-1103-Br **(S)**
Aug 18/19, 1979
103aO + GG385
45 min

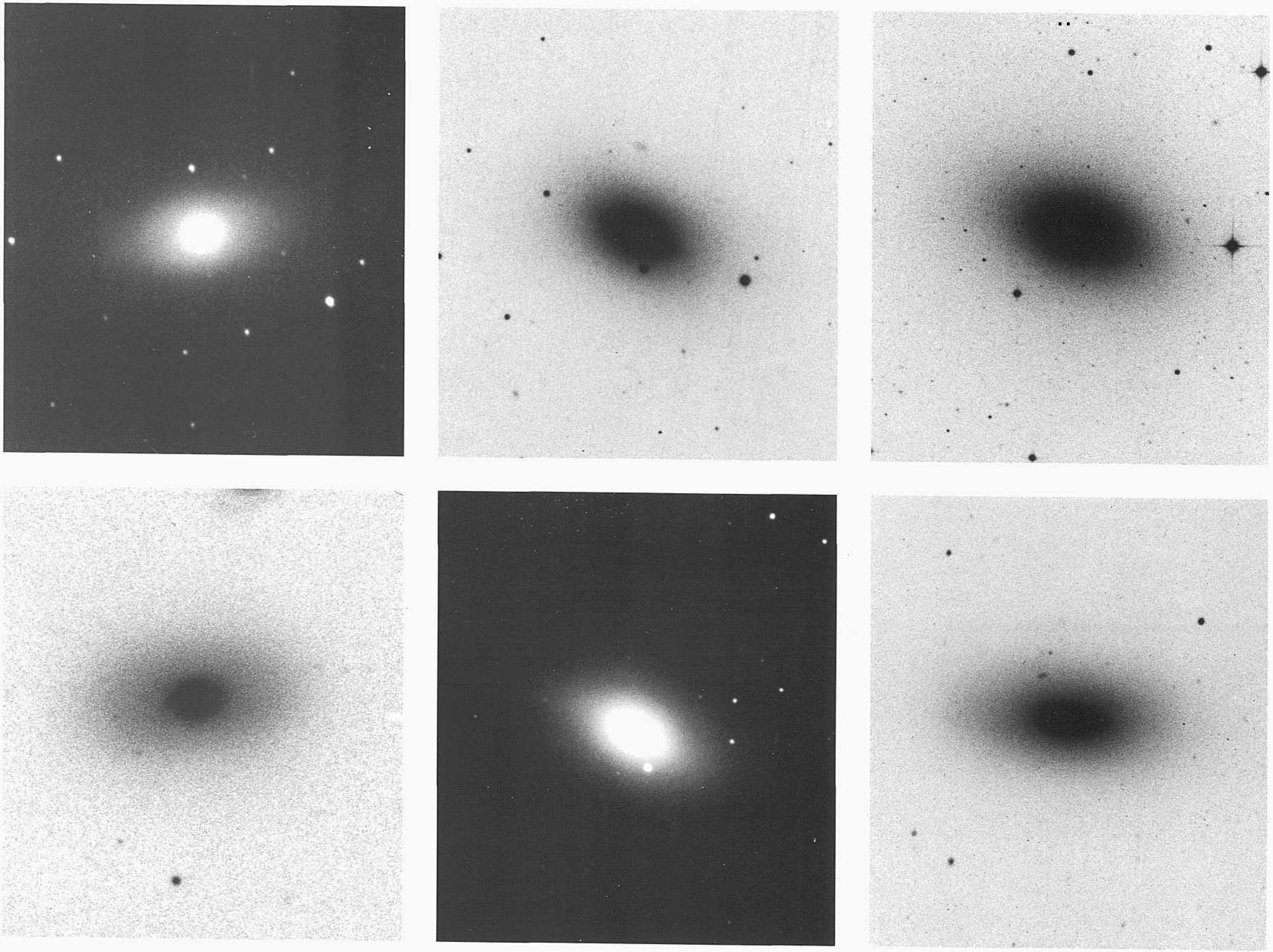
The departure of the profile of NGC 5 791 from that of a normal E4 galaxy is subtle but definite. The galaxy is close to but not in the E/SO morphological box. The classification of E6 in the RC2, based on a Mount Wilson 60-inch plate, is not supported. The **Mount Wilson** plate clearly shows an SO outer envelope, as does the deeper Las Campanas plate used for the **print** here.



PANEL
31

PANEL

32



NGC 2784 S0i(0,4)
H-2560-H (P)
Dec 1/2, 1948
103aO
30 niin

The apparent three-zone SO structure of NGC 2 784 is pronounced on the available plates. The inner two zones, visible on the print here, consist of an EO-like central bulge and an intermediate envelope of flattening index 4. A much fainter outer envelope with the same flattening exists but is not well seen on this print. It can be traced on the original plates to beyond the left and right borders of the print along the major axis, with a corresponding extension along the minor axis, keeping the flattening index of 4. NGC 2784 is an SOj prototype example.

NGC 7302 S0i(4)
CD-1521-S/Br (P)
Aug 5/6, 1980
103aO + GG385
45 niin

NGC 7302 is a type example of a pronounced SOj (4) form showing an extended outer envelope of relatively high surface brightness. The luminosity profile strongly deviates from an E4 morphology.

NGC 7029 S0i(5)
CD-1092-Br (P,disk)
Aug 18/19, 1979
103aO + GG385
45 nún

NGC 7029 has a central bulge embedded in a highly flattened disk similar to that in NGC 3115 (panel 5 0). The bulge and disk, both burned out in the facing print, are surrounded by an extended outer envelope having a flattening index of 5. Only this relatively high surface brightness outer envelope is visible on the print here, but the disk is pronounced on the original plates.

A normal E5 galaxy would be all that could be seen on inadequate plate material; the interior SO disk structure would be hidden. The E6 type in the RC2 , based on a Mount Stromlo 74-inch plate, is not supported.

NGC 584 S0i(3,5)
CD-1169-Br (S/I, rudimentary disk)
Aug 22/23, 1979
103aO + GG385
45 niin

The outer envelope of [NGC 5 84 is definite but more subtle than in NGC 2 7 84 or NGC 7302 on this panel. The envelope is the slightly tilted (rudimentary disk?) feature on either side of the central high-surface-brightness bulge. The major axes of the bulge and of the outer envelope differ in position angle by about 15°. The existence of the tilted outer envelope with a typical SO shallow luminosity profile is beyond doubt, but subtle. The E4 classification in the RC2, based on Mount Wilson 100-inch plates, is not supported. The Mount Wilson plates as well as the Las Campanas plate used here show the SO characteristics.

NGC 4621 E5 **VCC 1903**
CD-1340-S/Br **panel 12**
March 14/15, 1980
103aO
75 min

NGC 462 1 is a normal E5, not an SO. It is shown here to provide a comparison with the definite and pronounced SO types elsewhere on this page. Note the absence of an extended outer envelope in contrast to the envelopes in [NG(1 2784, NGC 7302. and NGC 3245.

NGC 3245 S0i(5) HA, p. 7
H-2160-H (P) panels 33, S2
Jan 29/30, 1941
Cramer Hi Speed Sp
60 min

NGC 3245 has a pronounced prototypical SO i three-zone structure where the .separations between the zones appear to be sharp. The central EO-like bulge is burned out in this print. The lower-surf ace-brightness (but still quite high) inner disk (called the lens in the llubldr Atlas) is seen in the facing print as the E5-like flattened structure. The faint outer envelope, equally flattened, is very well shown in this print.

The print here has been made from the same Mount Wilson 100-inch plate that was used for the illustration in the Hubble Atlas. The outer envelope is better seen on the negative print here than on the positive print there. The central, more circular bulge is shown in the Insert print of the same galaxy on the next panel.

NGC **1201** **SO 1(6)** **HA, p.** *4*
PH-817-S **(P)**
Oct 1/2, 1954
103aO
25 **niin**

NGC 1201 is a clear and **pronounced** SO] **with an** apparent three-zone structure nearly **identical to** NGC 3245 on the preceding page. In the Hubble Atlas NGC 120 1 is described, "to the eye, images of SOj **present** three distinct **luminosity** zones on the original plate. There is an intense nucleus [called bulge in this atlas], an intermediate zone of lower surface brightness, called the lens [the disk in the present atlas] and **the** characteristic faint outer envelope. This description may be **subjective.** The luminosity gradients may be continuous, and the three zones may he a **photographic** effect. The effect does, however, provide criteria for classification."

This 3 0-year-old description remains valid today. Profile measurement o(prototypical E galaxies and of SO's such as NGC 3245 and NGC 1201 here (or any of the galaxies denoted as P for "prominent") should be made to test the statement above.

NGC 7457 S0i(5) **HA, p.** *4*
PH-109-H **(I)**
July **1/2, 1951**
103aO
25 inin

The print of NGC 7457 in the Hubble Atlas was made from a Mount Wilson 100-inch plate. The print here is from a Palomar 200-inch plate taken in poorer seeing. The extended faint outer envelope characteristic of the SO class is evident, showing a definite departure from an E5 luminosity profile although more subtly than in prominent SO galaxies: hence the intermediate strength designation (I) is used here.

NGC 3245 S0i(5) HA, p. *4*
PH-8017-S (P) panels 32, S2
Feb 3/4, 1981
103aO
12 inin

NGC 3245 is also shown on the preceding panel from a different original negative. The description there applies to the image here as well. The insert was made from the Mount Wilson 100-inch plate H-2160-H.

NGC 890 S0i(5)
PH-7675-S (I)
Sep 25/26, 1979
103aO
12 inin

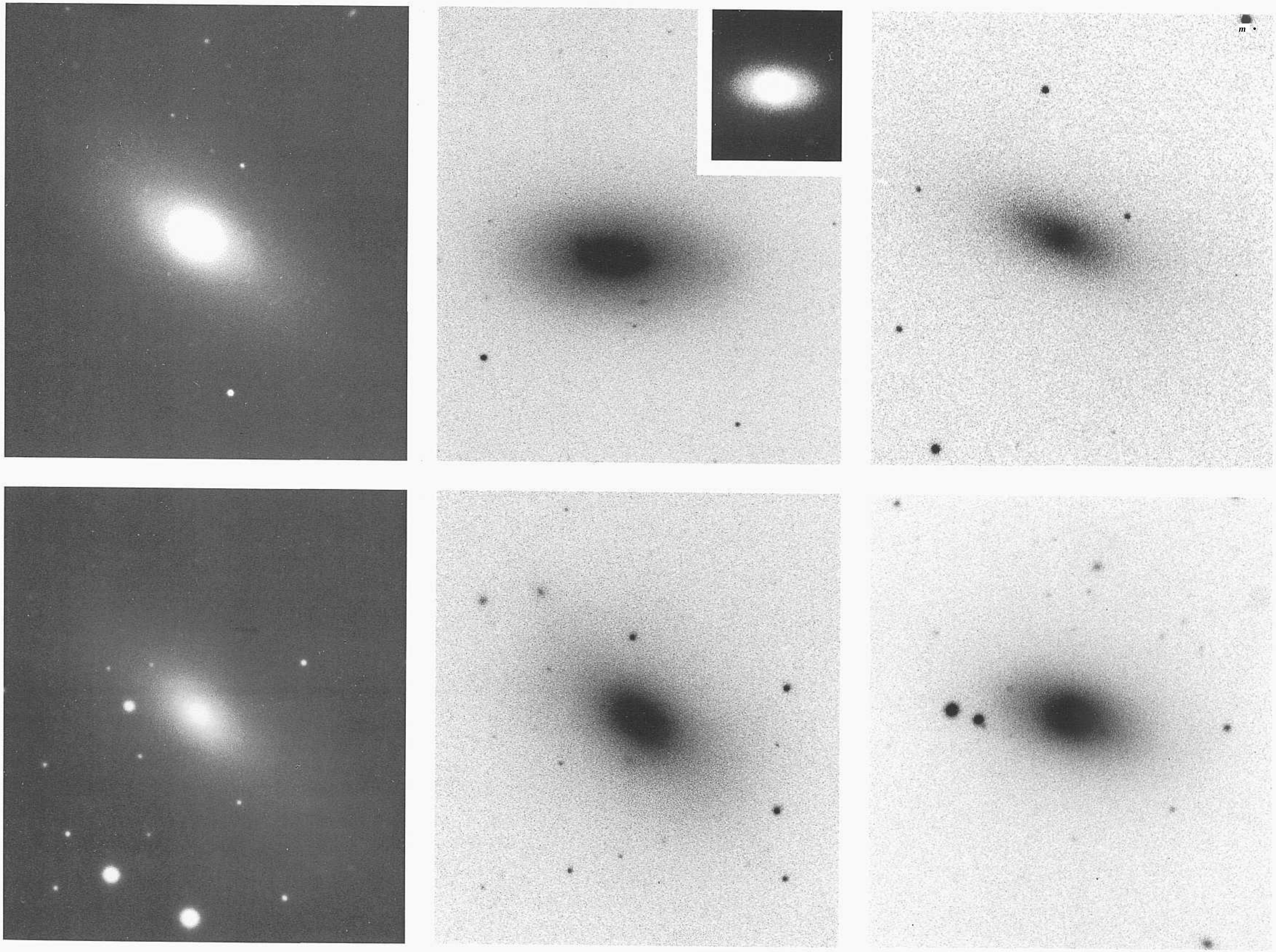
The extensive faint outer envelope in NGC 890 is moderately subtle. It would be confused with an E5 type on inadequate plate material. The SO classification is definite, based on the present plate material.

NGC **7600** **S0i(5)**
PH-7541-S (S)
Nov 6/7, 1978
103aD + **GG11**
25 nün

NGC 7600 is a subtle SO, near the E/SO morphological box. The E/SO classification in the RC2, based on a Mount Wilson 100-inch plate, could he supported here.

NGC 4008 S0i(5)
PH-7986-S (I)
Feb 1/2, 1981
103aO
12 min

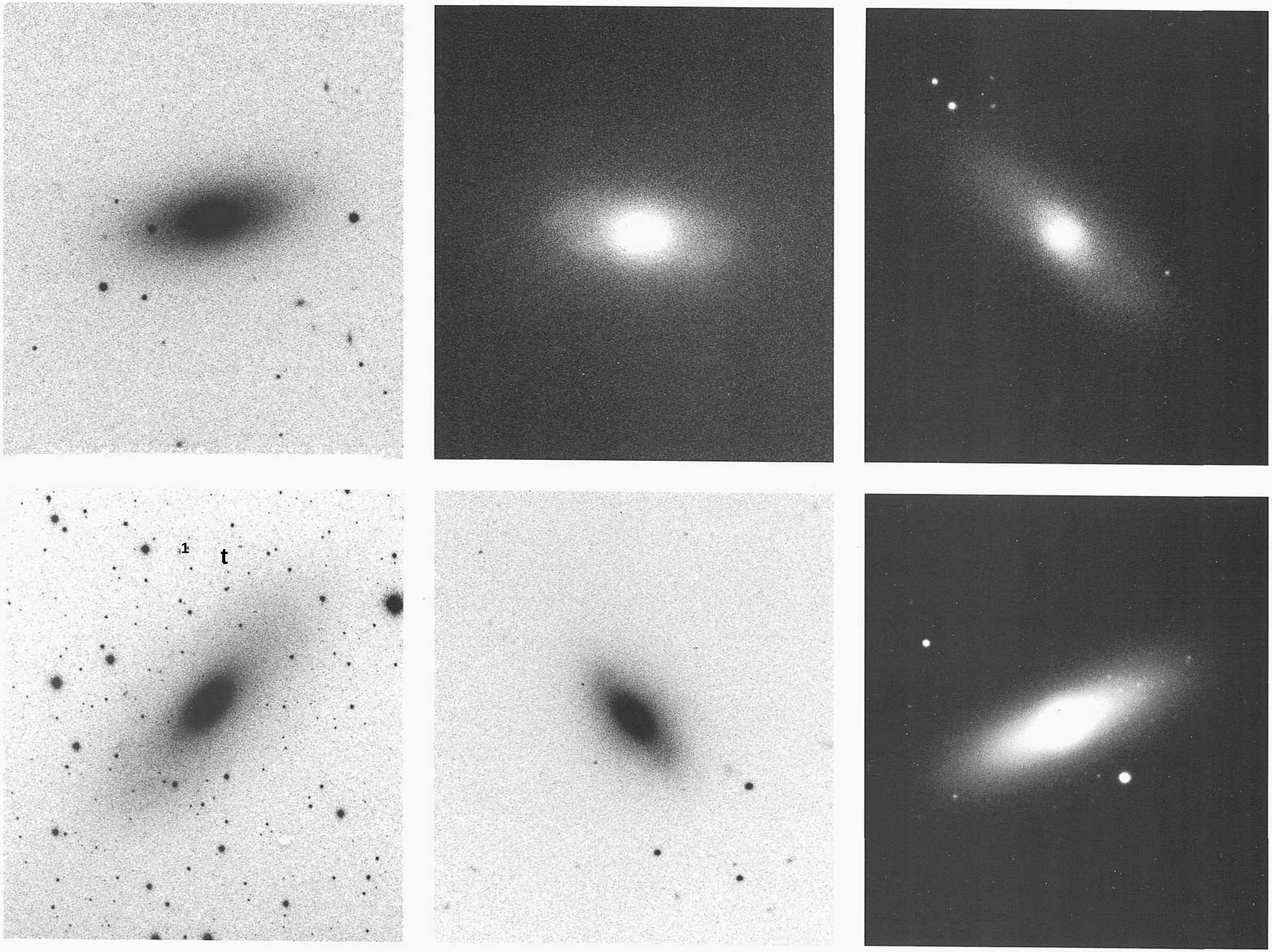
NGC 4008 is a definite SO because of the extended outer envelope, unlike the luminosity profile of an E5. The bright central bulge is similar to an E2 galaxy. The major axis of the outer envelope (of flattening index 5) is tilted relative to the bulge by about 10°. The E5 classification in the RC2, based on a weak Mount Wilson 100-inch plate, cannot be supported. The SO outer envelope is clearly visible on the print here.



PANEL
33

PA^;EL

34



NGC 7166 **S0i(6)** **triplet**
CD-571-S **(P)**
Oct 8/9, 1978
103aD + GG495
30 niin

NGC 7166 forms a possible physical triplet with NGC 7162 (She; panel 190) and NGC 7 162 A (SBd). The separations from NGC 7166 are 10.8' and 14.8', respectively. The known redshifts from the RSA2 are i>$_o$(7162) = 2169 kms"' and u$_o$(7166) = 2 3 76 km s"^{1}. **The 21**-cm velocities reduced to the frame of the Local Group are v_o(7 1 6 2) = 2253 km s~^{1} and u$_o$(7162A) = 2238 km s^{-1}, from the catalog of Huchtmeier and **Richter** (1989). The velocities of the three galaxies are sufficiently similar to suggest a physical triplet.

The mean redshift distance of the triplet is 46 Mpc *(H* = 50). The projected linear distances from NGC 7166 are 144 kpc for NGC 7162, and 200 kpc for NGC 7162A.

The extended outer envelope surrounding an inner E6-like, high-surface-brightness bulge, characteristic of SO's, is clearly present in NGC 7166 on the original Las Campanas plate, although not as prominently on the print here. The original plate supports the classification as a robust SO rather than an E/SO transition type, as given **in** the RC2.

NGC 5102 S0i(5) **NGC 5128 Gr**
CF-642-HB **(P)**
March 25/26, 1974
103aO
81 **niin**

This print of NGC 5102 is from a Swope 40-inch Las Campanas plate. The galaxy is a **prototypical** SO in which the extended envelope of low surface brightness is clearly visible. The galaxy is excessively blue for its SO type (Sandage and Visvanathan 1978a,b). Its neutral hydrogen content is also high **for** its **type.** Recent star formation has evidently **occurred.**

Its very low velocity in the frame of the Local Group, u_o = 183 km s^{-1}, place it just beyond the Local Group; it is presumably a member of the NGC 5128 Group, which also contains the late-type RSA galaxies NGC 5236 (SBc; panels 300, 301) and NGC 5068 (SBc; panel 306). The absolute magnitude of *M^j* = —18.7 puts NGC 5102 among the faintest SO galaxies in the RSA, yet it is brighter by 3 mag than the dSO galaxy NGC 205. Its blue colors are consistent with the faint absolute magnitude, as judged from **the** color-absolute magnitude relation (Sandage **and** Visvanathan 1978a,b).

NGC 4386 **S0i(5)**
PH-7989-S **(P)**
Feb 1/2, 1981
103aO
12 niin

NGC 4386 is a definite SO. based on ihe two-zone structure visible here. The outer envelope is prominent, and the SO class can also be seen on the POSS prints. The transition E/SO classification in the RC2 is not supported here.

NGC 3990 S0(6)/Sa **not in RSA**
PH-7640-S **(P)** **pair?**
April 28/29, 1979
103aO
12 min

NGC 3990 is not in the RSA, **but** it forms an apparent pair **with** NGC 3998 (SO]; **panels** 31,53)ata projected angular separation of 2 .9 ′. It is unclear if the two form a physical pair. The listed velocity of NGC 3998 is v_0 =1214 km s"'; that of NGC 3990 is lower. v_0 = 819 km s"^{1}. Velocity differences this large for physical pairs are known but are rare. If the galaxies are at the same redshift distance of about 2 0 Mpc, the projected linear separation would be small, at 17 kpc, supporting the supposition that the pair forms a close binary because such a large velocity difference can be expected. However, there is no evidence of interaction in the morphology of either galaxy. The extensive envelope of NGC 3998 (panels 31, 53) is not distorted.

The outer envelope of NGC 3 990 seen in the print here is not quite elliptically symmetric but has rudimentary ansae, which resemble the embryonic smooth beginnings of '"smooth arms" in the earliest SO/Sa and Sa **morphological** boxes; hence the mixed classification is used.

IC 5269 **S0(7)/Sa**
CD-573-S **(P)**
Oct 8/9, 1978
103aD + GG495
30 niin

IC 5269 is a **prominent SO with a very** extensive outer envelope, which may have rudimentary, massive embryonic very early Sa-like "arms" in the "disk," which appears **here** as the outer envelope. Compare with the SO/Sa class shown on panels 59 **and** 60.

NGC **1332** **S0i(6)** **pair**
CD-1181-Br **(P)**
Aug 23/24, 1979
103aO + **GG385**
45 min

NGC 1332 forms a **close** physical **pair** with NGC 1331 **(E2),** which is 2.7' **distant** along **the major** axis of the main galaxy; NGC 133 1 is to the left, just beyond the edge of the frame in the print here. The mean redshift of the pair is <i>$_o$> = 1352 km s"^{1}, with a redshift difference of 238 km s"^{1}. At a redshift distance of 27 **Mpc** *(II* = 50). the projected linear separation is small, at 12 kpc.

NGC 1332 is the type example of a **highly** flattened prototypical SO. **The low-surface-brightness** extended outer envelope, *which is a thick disk,* is the edge-on version of the more nearly face-on prominent SO galaxies, such as NGC 4552 [SO^O): panel 30], NGC 5011 [S0,(2): panel 30]. NGC 4379 **[SO** ,(2): panel 31]. and NGC 3998 [SO^); panels 31 , 53]. If these were to be viewed more nearly edge on, their presumed disks would be expected to be as evident as that of NGC 13 32 here.

NGC 1389 S0i(5)/SB0i FCC 193
CD-718-S (I)
Feb 1/2, 1979
103aO + Wr2e
45 inin

NGC 13 89 is near the center of the Fornax Cluster. The extended outer envelope, characteristic of the SO class, is only suggested in the negative print **but** is definite on **the** plate. The galaxy is a clear SO type. The classification of E4 in the RC2 , based on a Mount Stromlo 30-inch plate, is not supported.

The position angle of the major axis of the outer envelope differs from the major axis of the bright central bulge by about 15°.

NGC 4033 S0i(6)
CD-1721-S (P)
Jan 8/9, 1981
103aO
75 min

The several zone structures in NGC 4033, characteristic of the SO class, are evident in the positive and negative prints here. The outer envelope and its deviation from an E6 luminosity profile is prominent on the original plate. The classification of E6 in the RC2 , based on a Mount Wilson 100-inch plate, is inappropriate.

NGC 4350 S0i(8) pair
PH-7662-S (P)
April 29/30, 1979
103aO
12 **min**

NGC 4350 forms a pair with NGC 4340 (RSBO-j: panels 5 7 , S7) at 5 .6' projected separation. The redshifts are similar enough, at t>$_o$(4340) = 775 kms"' and u$_o$(4350) = 1085 km s^{-1} , to suggest a physical pair. The mean redshift <t'$_0$> = 930 km s^{-1} gives a redshift distance of 19 Mpc, which gives the small projected linear separation of 3 1 kpc.

NGC 4350 has a central bulge of high surface brightness and a well-developed disk, which although not as discrete as in NGC 3115 (panel 50), is more definite than simply the flattened ellipsoid seen in E6 galaxies. The presence of the disk, presumed to be the same as the extended outer envelope seen in more-face-on SO's, is the classification discriminant between highly flattened E and highly flattened SO types.

NGC 4128 S0i(6)
PH-8060-S (P)
Feb 4/5, 1981
103aO
12 min

The three-zone appearance of NGC 4128 seen on the original plate is also well visible on the print here. The type is a clear SO. The major axis of the external envelope (the outer disk) makes an angle of about 5° to the major axis of the inner lens, which itself is tipped by another 5° to the axis of the inner bulge.

NGC 4270 S0i(6) VCC 375
CD-1339-S/Br (P)
March 14/15, 1980
103aO
75 min

NGC 42 70 is in a complex region of the Virgo field that contains the W cloud, which is more distant than the Virgo Cluster proper. The large, very-low-surface-brightness dwarf VCC 367, on the main print near the lower right-hand border, is classed ImV? in the VCC with no decision as to cluster membership.

NGC 42 70 itself has the characteristic SO zone morphology (seen best in the insert) of bulge, inner lens, and outer extended envelope.

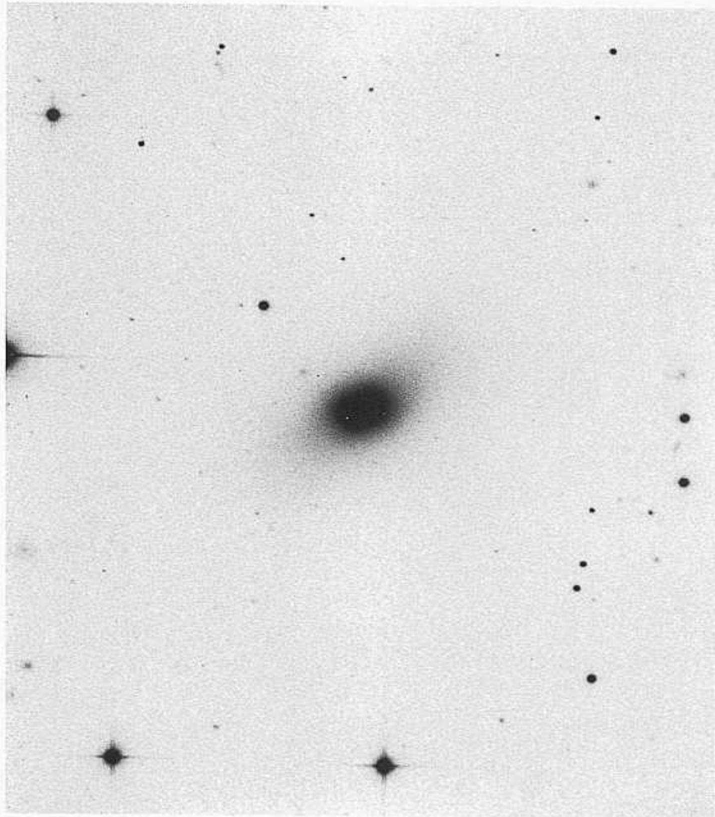
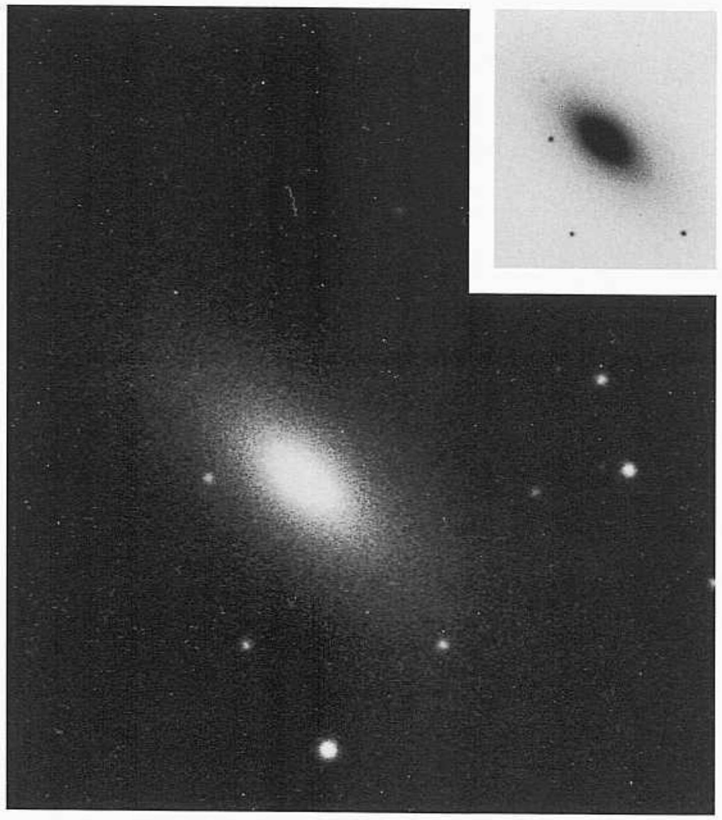
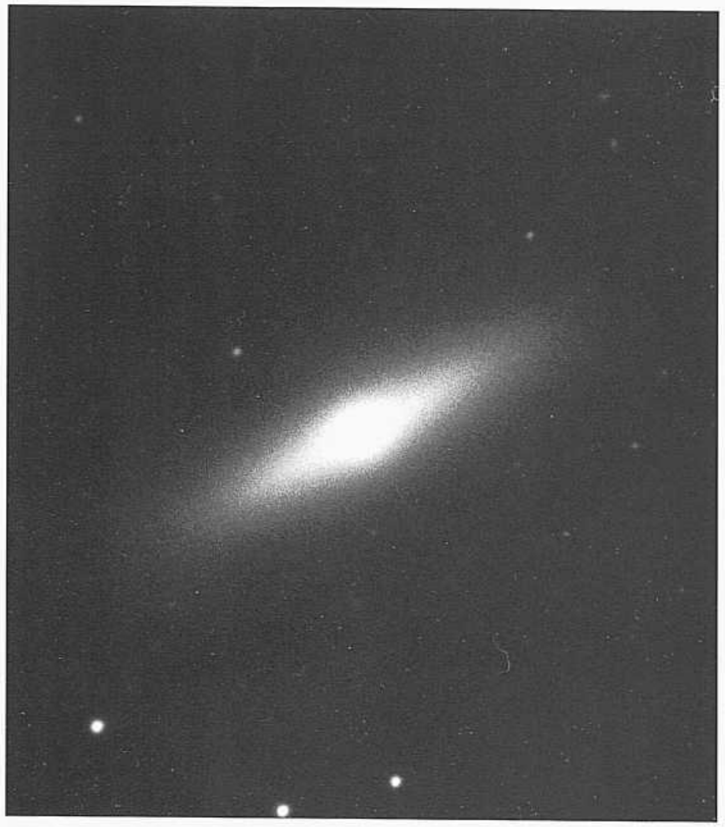
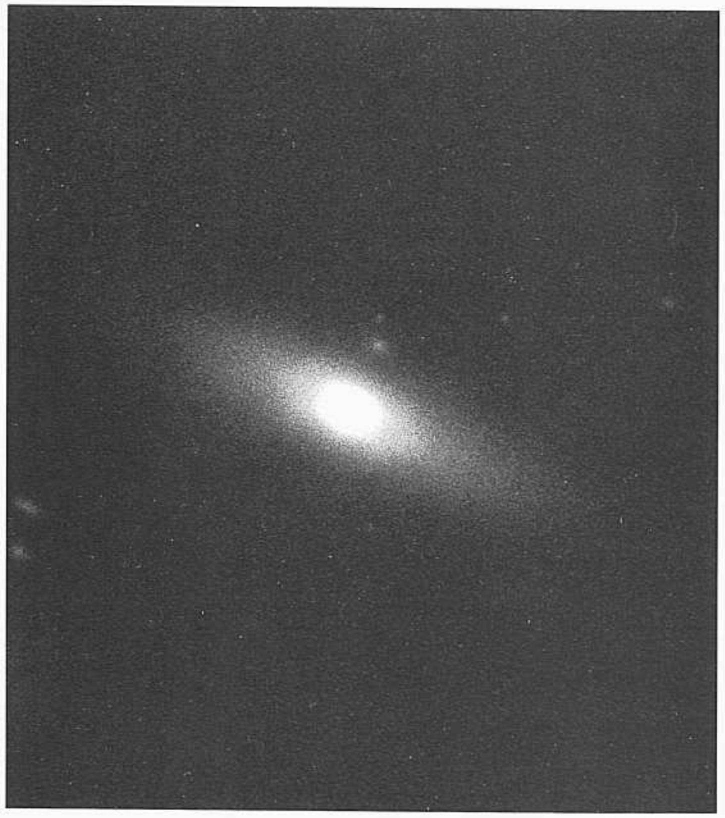
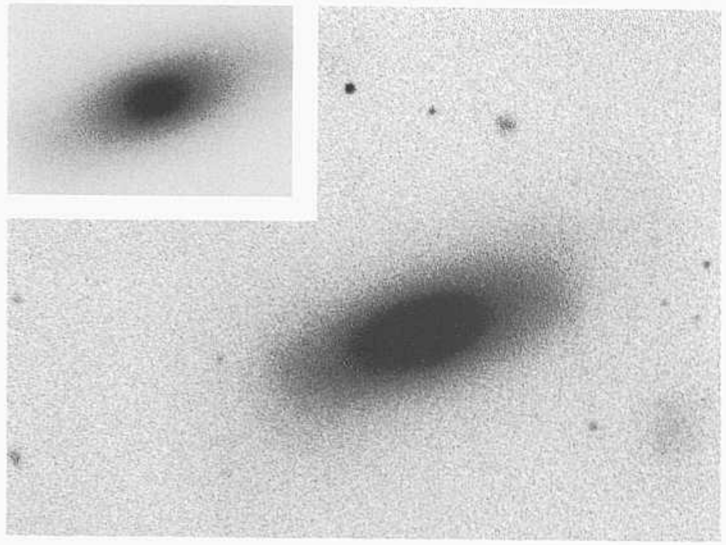
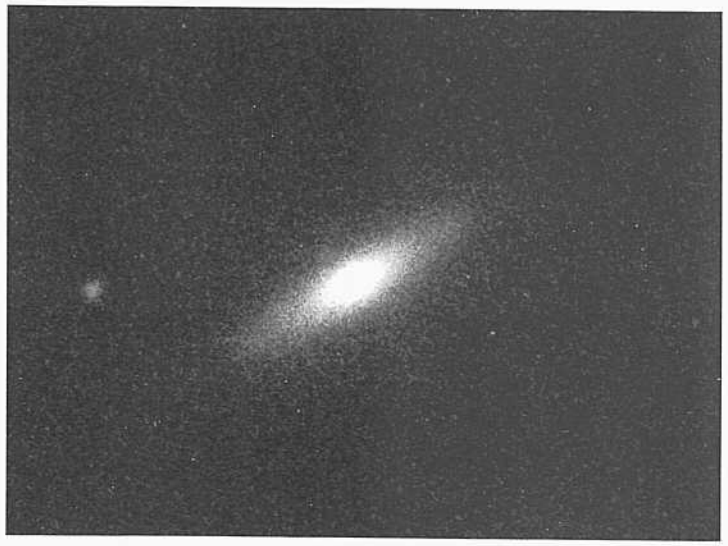
NGC 5493 S0i(7)
H-2537-H (P)
May 4/5, 1948
103aO
25 min

The existence of a highly flattened disk and a central bulge in NGC 5493 is similar to the same morphology in NGC 43 50 and IC 5181 on this panel.

IC 5181 S0i(7) NGC 7213 Gr
CD-1096-Br (P)
Aug 18/19, 1979
103aO + GG385
45 min

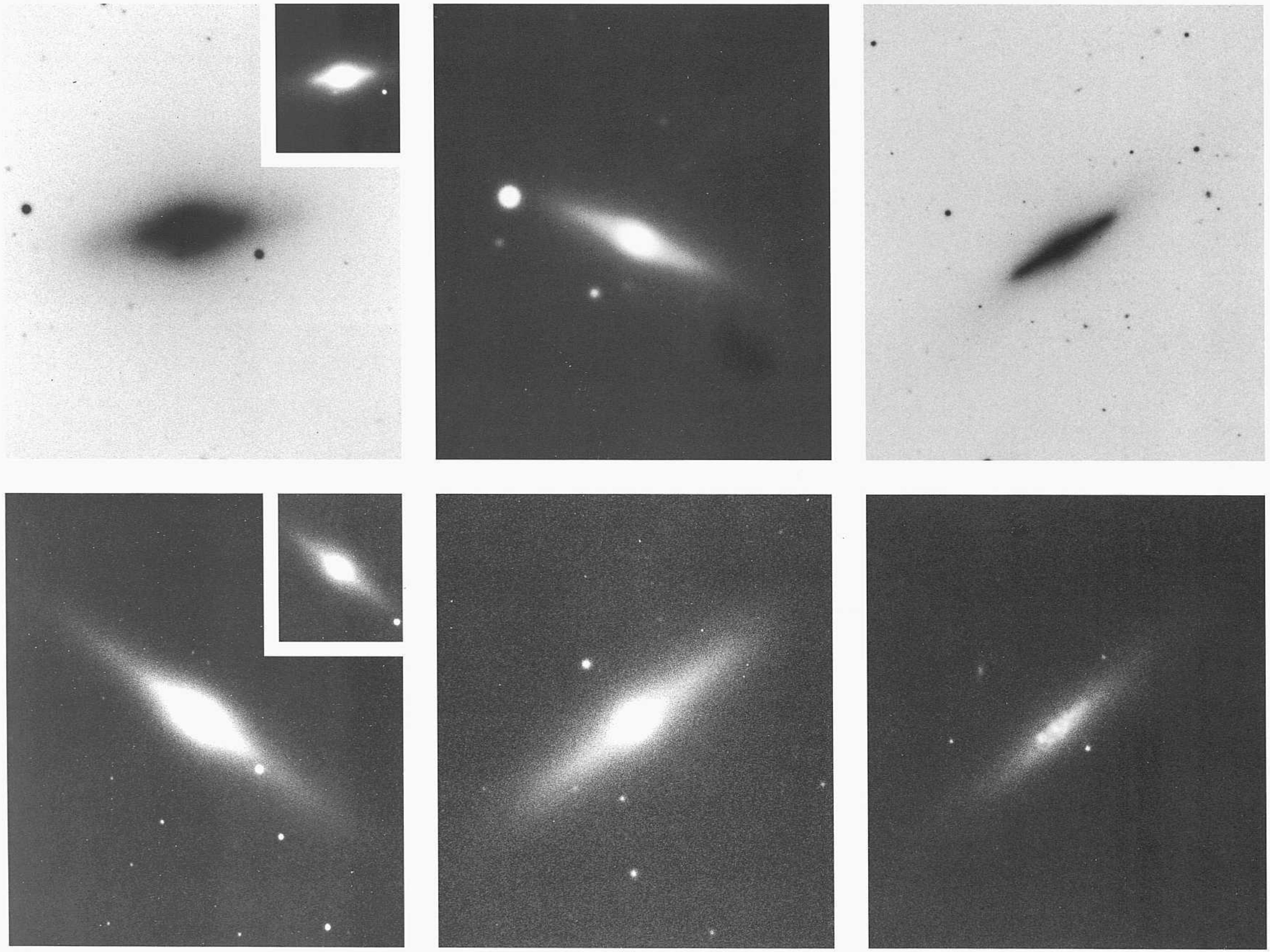
IC 5181 is a member of the loose NGC 7213 Group, containing about seven members at a mean redshift of <v_o> = 1900 km s^{-1} (Sandage 1975b). It forms a pair with NGC 7232A (Sc, nearly on edge) at 8.1' separation at a projected linear separation of 90 kpc.

The presence of the flattened thick disk, evident in the insert, is the SO characteristic.


PANEL
35

PAXEL
36



This and the following panel contain SO galaxies seen nearly on edge. The presence of a disk is the most distinguishing feature and is the deciding criterion between E and SO galaxies. The disks are evident in galaxies seen at this viewing angle. The knowledge gained here that disks exist is why it is supposed that the extended outer envelopes of the less-inclined SO galaxies on the preceding panels are in fact disks. The interpretation is supported by the statistical analysis of the flattening distributions showing that SO galaxies have a highly flattened component, whereas E galaxies do not (Sandage, Freeman, and Stokes 1970). It is clear from such data that SO galaxies represent the beginning of **the** disk sequence of the great river that becomes the spiral morphology later in the classification system.

NGC4251 S0i(8) **panel** S2
PH-7987-S (P)
Feb 1/2, 1981
103aO
12 niin

An inner high-surface-brightness disk is present in NGC 4251. within which a central bulge sits. This inner disk is well shown in the insert. An outer highly flattened structure (halo?), seen in the main print, extends beyond the inner disk.

NGC 4179 S0i(9) panel S2
CD-2102/2103-S (P)
March 18/19, 1982
103aD + GG495
45 inin

The inner and outer disks in NGC 4179 are well seen in the main print and the insert. Note the much greater extent of the outer disk in the main print, using the star near the right-hand part of the major axis as a position marker.

NGC 2732 S0i(8) Racine wedge
PH-7587-S (P)
April 2/3, 1979
HlaJ + GG385
30 min

The prototypical SO pattern of central bulge and fainter-surface-brightness disk is present in NGC 2732. The central bulge is tipped relative to the axis of the disk.

The plate was taken with a Racine wedge giving a secondary image to the bright star 5 mag fainter at a separation of 1 8".

NGC 3630 SO i(9)
CD-1833-HB (P)
April 1/2, 1981
103aO + GG385
45 min

A high-surface-brightness, central El bulge in NGC 3630 is at the center of a highly flattened disk, characteristic of the prototypical SO morphology.

NGC 4452 S0i(10) **VCC** 1125
CD-710-S (P)
Jan 30/31, 1979
103aO + \VV2c
50 min

NGC 4452 has the classic features of an SO on edge, similar to NGC 47 62 on the next panel. The very-high-surface-brightness inner disk has a sharp edge beyond which, us in NGC 4762. a flattened, very-low-surfare-brightness extension exists.

The Sa classification listed in the RC2. based on 48-inch Palomar paper prints, is not supported here.

NGC 4460 SO/Sc
PH-8002-S
Feb 2/3, 1981
103aO
12 min

NGC 4460 has the unusual combination of a lumpy central region, indicating recent star formation, and a smooth, highly flattened outer SO-like disk, thereby yielding the mixed classification. Except for the absence of spiral arms in the outer disk, NGC 4460 might have been similar to the appearance supposed For NGC 4580 (Sc/Sa: panels 86. 276) if it could be seen on edge.

The central bulges in the galaxies on this and the preceding page are of high surface brightness, unlike the central regions of the later type Sc and/or Sd and/or Sm spirals, although both types have disks. *Small,* low-surface-brightness central regions would be required in some SO's in van den Bergh's (1976a) suggestion of a parallel SO sequence to the spiral sequence, which he speculated would be caused by a sweeping of original spirals, resulting in the SO morphology (flattened disk, no spiral arms, little or no gas or dust, generally no recent star formation). The evidence here is clear that there are no such SO a, SOb, SOc, SOd, or SOm types. The original Hubble placement of the entire SO class between the E and the Sa class is evidently the appropriate placement of the SO and the Sa morphological boxes.

The six galaxies on this page continue the examples of SO galaxies seen nearly on edge. All have disks and bright elliptical central bulges.

NGC 4958 S0i(7)
S-327-H (P)
Feb 4/5, 1924
Seed 30
50 min

The central bulge in NGC 4958 resembles an E5 galaxy, but the definite thick disk shows the characteristic SO morphology. The original plate was taken with the Mount Wilson 60-inch telescope.

NGC 3098 SO i(9)
H-2558-H (P)
Dec 1/2, 1948
103a0
30 min

This reproduction of NGC 3098 from a Mount Wilson 100-inch plate suggests a mild form of the boxy, high-surface-brightness central region shown in the much more pronounced cases of NGC 3 203 . NGC 4111, NGC 4215, and NGC 4417. all on panel 47.

NGC 5308 S0i(8)
S-196-Pease (P)
April 4/5, 1913
unknown emulsion
180 min

This early Mount Wilson 60-inch plate of NGC 5 308 by Francis Pease shows a bright central region (burned out in this print), surrounded by a boxy envelope (which is the high-surface-brightness bulge seen in this print), and an extremely thin, moderately bright disk, which has almost as high a surface brightness as the bulge.

NGC 4474 S0i(8) VCC 1242
CD-724-S (P)
Feb 1/2, 1979
103aO + Wr2c
60 min

NGC 4474 is in the Virgo Cluster and in subcluster A centered near NGC 4486. The central bulge is large and is E2-like. The disk has high surface brightness, is definite, and is very well formed.

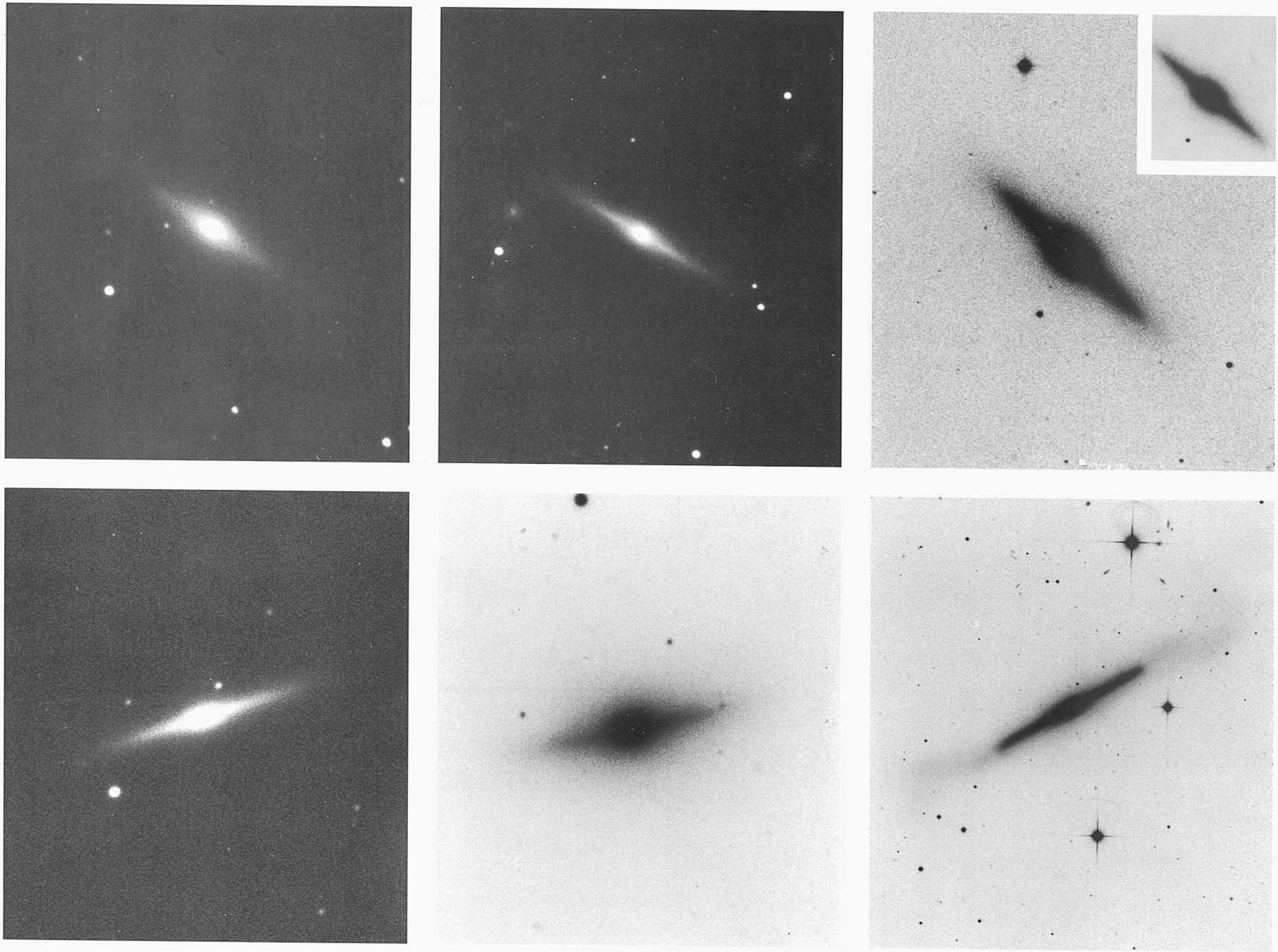
NGC 1381 S0i(8) FCC 170
CD-718-S (P) panel 50
Feb 1/2, 1979
103aO + Wr2c
45 min

NGC 1381 is near the middle of the Fornax Cluster (Ferguson 1989: Ferguson and Sandage 1990). The bulge, shown in the insert, is boxy. The thin disk has a very high surface brightness, characteristic of most SO galaxies, showing again that the SO class cannot have been made by sweeping gas from present-day Sb or Sc galaxies, which invariably have fainter-surface-brightness disks (Sandage 1983a).

NGC 4762 S0i(10) HA, p. *8*
CD-2211-S (P)
April 1/2, 1982
103aO
50 min

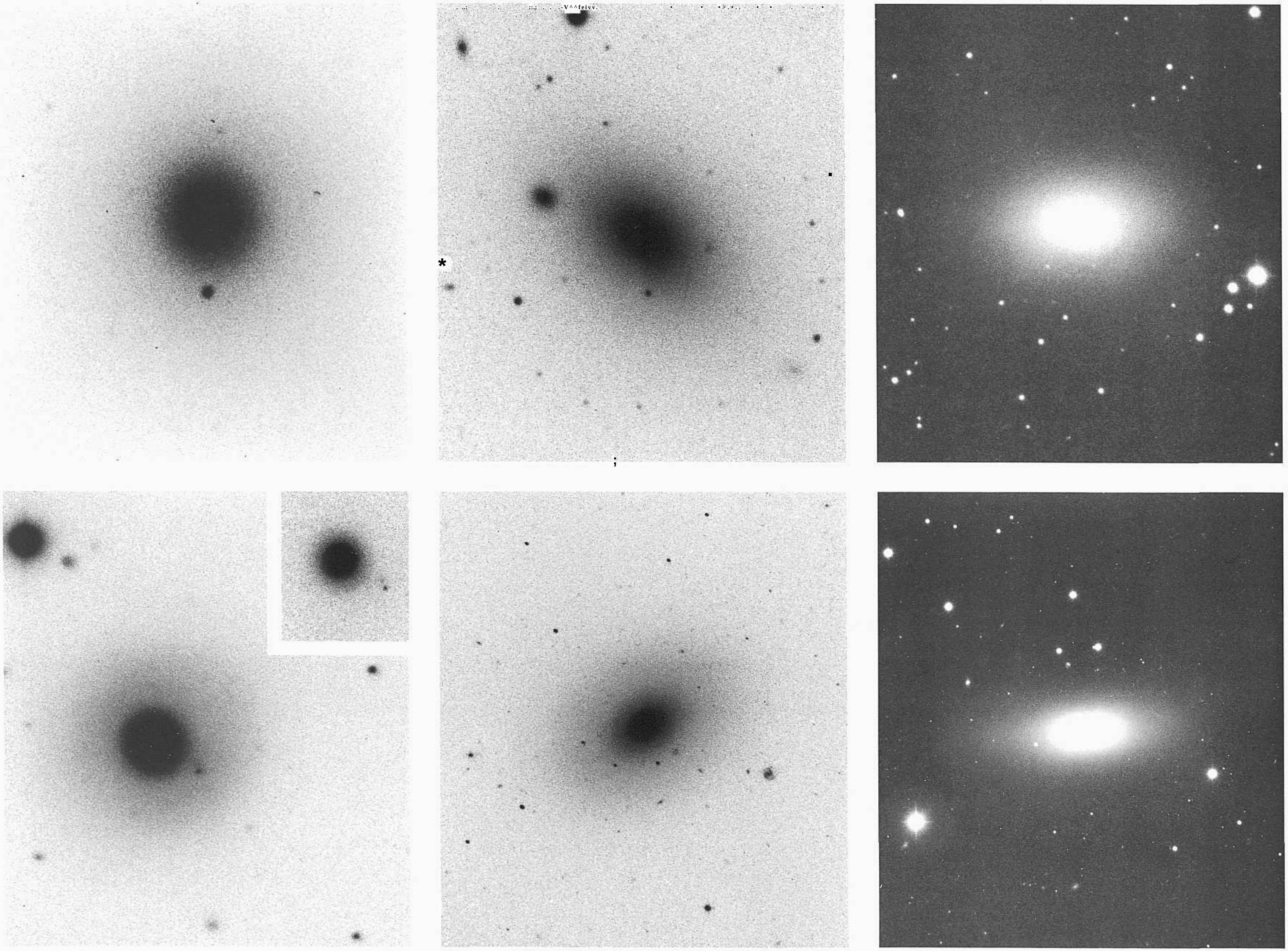
The print of NGC 4762 here is made from a different original negative than was used in the Hubble Atlas (p. *8).* Inspection of the two reproductions and the insert in the Hubble Atlas shows different aspects of the morphology and emphasizes again how the choice of contrast in the darkroom printing affects the final print.

As in NGC 5308 at the top middle, the disk is exceedingly thin in its high-surface-brightness section. This is seen best in the positive print in the Hubble Atlas. The faint "brushes" beyond the edges of the disk are shown here, but are shown at higher contrast in the insert print from a Palomar 48-inch plate in the Hubble Atlas.



PANEL
37

PAiSEL
38



The SO galaxies on this and the following panel have extended outer envelopes characteristic of the SO class but with subtle departures from smoothness in the luminosity profile. The non-smooth envelope features in the envelope are too subtle to be generally visible on these prints, but they are visible on the original plates. However, the departures from symmetry are not as pronounced as in the SO9 subclass; hence the mixed SO 1/0 notation is given.

NGC 4339 S0i/2(0) VCC 648
CD-1329-S/Br (S)
March 13/14, 1980
103aO
75 min

The outer envelope of NGC 4339 beginning at an apparent edge to the central bulge is evident on this print. The morphology is clearly SO because of the departure of the outer luminosity profile from that of an E galaxy. (NGC 4339's is shallower.) The classification of EO in the RC2, based on a weak Mount Wilson 100-inch plate, is not supported here from this Las Campanas plate.

NGC 3065 S0i/2(0) HA, p. 5
PH-854/866/8013/8043-S (P)
Nov 2/3, 1954
Nov 3/4, 1954
Feb 3/4, 1981
Feb 4/5, 1981
103aO
30 min and 12 min

The main print is a superposition of four plates taken with the Palomar 200-inch telescope in 1954 and 1981. The outer circular envelope, shown well in the main print, is of very low surface brightness, requiring the superposition printing.

On visual inspection of the plate, the image consists of the three apparent zones characteristic of many of the galaxies in the first six panels of this SO section. (1) The inner zone, shown only in the insert print, is of high surface brightness and resembles an EO galaxy. This may be the bulge. (2) The narrow intermediate zone seen in the insert has an inner and an outer edge in the main print. It is of intermediate (yet still high) surface brightness. It is well seen even on a weakly exposed early plate from the Mount Wilson 60-inch. (3) The outer very faint envelope is only hinted at on each of the four individual plates in this superposition printing, but is well seen in the composite main print here. The slight structure in this outer envelope is the reason for the mixed SOj/o notation.

Not any of the three-zone structure seen in the prints here is visible in the Hubble Atlas (p. 5) reproduction, made from only one of the plates used here. But the description of the luminosity profile in the Hubble Atlas remains valid.

NGC 4825 S0i/2(3) group
CD-1464-S/Br (I)
May 10/11, 1980
103aO + GG385
45 min

NGC 4825 has a two-zone image, whose SO characteristic is the slightly extended envelope covering an E3 elliptical bulge. Very faint indications of dust (a rudimentary SO3 ring?) is the reason for the SO2/0 classification.

The galaxy is in a very rich field which undoubtedly is a group having NGC 4825 as its dominant member. The E4 galaxy seen in the print here has a separation from NGC 4825 of 50". At the redshift distance of 85 Mpc [v_0(4825) = 4236 km s^{-1}; H = 50]. the projected linear separation of the companion would be small, at 21 kpc, if they are at the same distance, as seems likely. A dE dwarf candidate companion is in the lower-right corner of the print.

NGC 4578 S0i/2(4) VCC 1720
CD-1319-S/Br (P)
March 12/13, 1980
103aO
75 min

The extended outer envelope, characteristic of the SO class, is well seen in the print here from an original Las Campanas 100-inch plate.

IC4889 S0i/2(5)
CD-1043-Br (I)
July 22/23, 1979
103aO + GG385
45 min

The feature requiring the SO $_{1/2}$ mixed type for IC 4889 is the slight, irregular dust lane just visible in the print here at the place where the extended outer envelope meets the apparent edge of the bulge. The dust feature is between position angles 4 o'clock and 6 o'clock in this print.

The well-developed outer envelope with its shallow luminosity profile is well seen on the original plate. The morphological type is, beyond doubt, SO. The E5 classification in the RC2, based on a Boyden 60-inch plate, is inappropriate.

NGC 2768 S0i/2(6)
PH-719-B (I)
April 4/5, 1953
103aO + GG1
20 min

The definite outer envelope of NGC 2768 surrounding an E6 bulge makes the SO classification certain. Very subtle dust patches on either side of the major axis at the ends of *the minor axis* (only hinted at in the print here) requires the SOj/o classification. The patches may be a weak interior polar ring similar to the well-developed dust rings perpendicular to the major axis in the prolate cases of NGC 1947, NGC 2685, NGC 5128, NGC 5266. and NGC 5485. all on panel 45.

The classification of E6 in the RC2, based on a Mount Wilson 60-inch plate, is not supported here.

Both galaxies on this page show pronounced outer envelopes, interpreted as disks of moderately high surface brightness. The two unusual features of these disks are (1) the very shallow luminosity gradient (the luminosity profiles appear almost flat over much of the disk), and (2) the presence of a boundary ring in each galaxy at the edge of the disk. This is a subjective interpretation of the profiles from visual inspection of the original plates. A measured profile of NGC 1553 (Freeman 1975) shows only a *change* in the luminosity gradient, not a discontinuity or a *brightening* at the rim so evident in the insert prints here.

As explained in the description to NGC 2902 (SO i; panel 30) and NGC 1201 (SO j : panel 33), the eye takes the first derivative of a luminosity distribution. A *change* in the gradient appears as a discontinuity in the print.

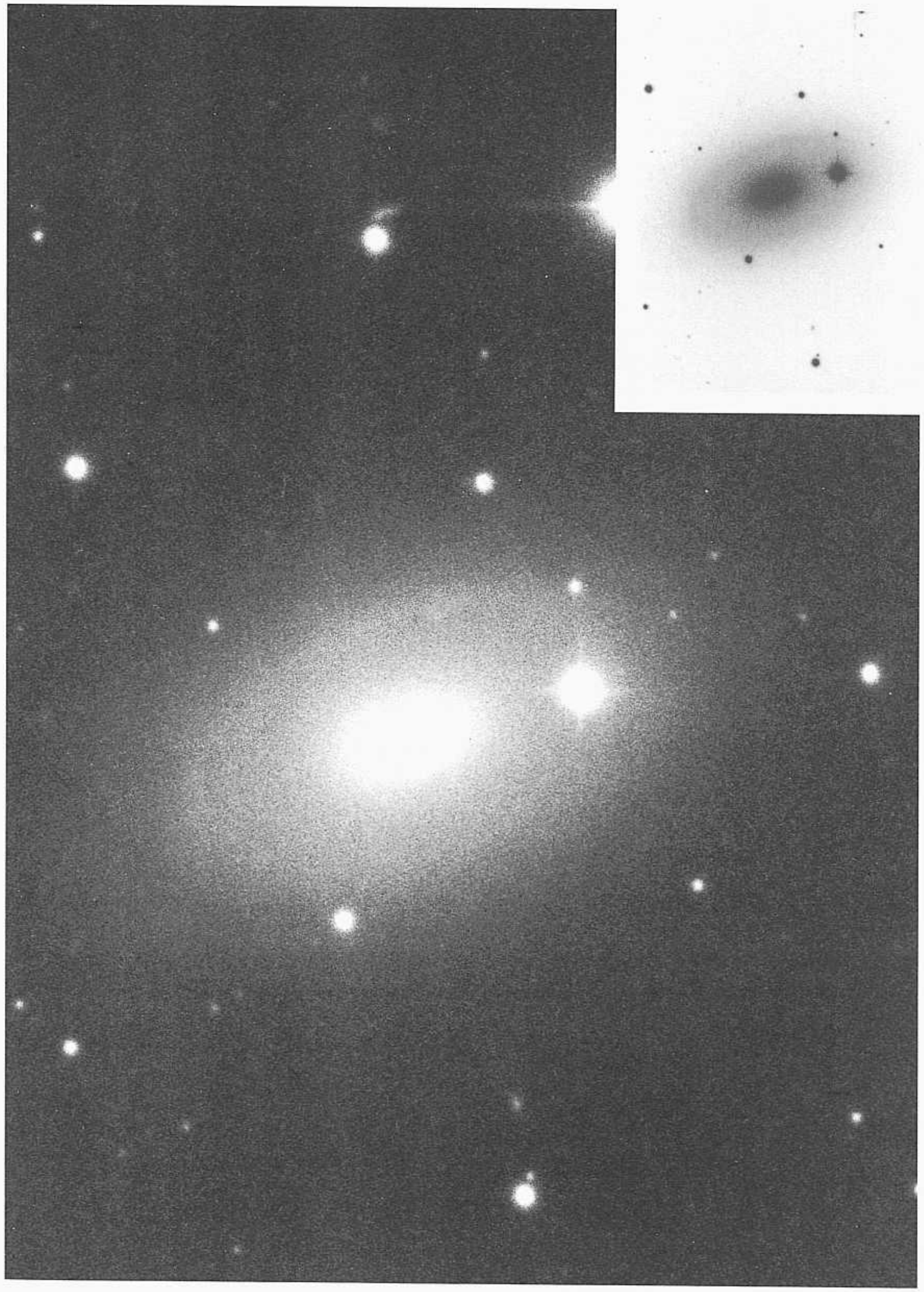
NGC 3056 **S0i/2(5)** pec **panel 53**
CD-1348-S/Br **(P)**
March 15/16, 1980
103aO + GG385
45 min

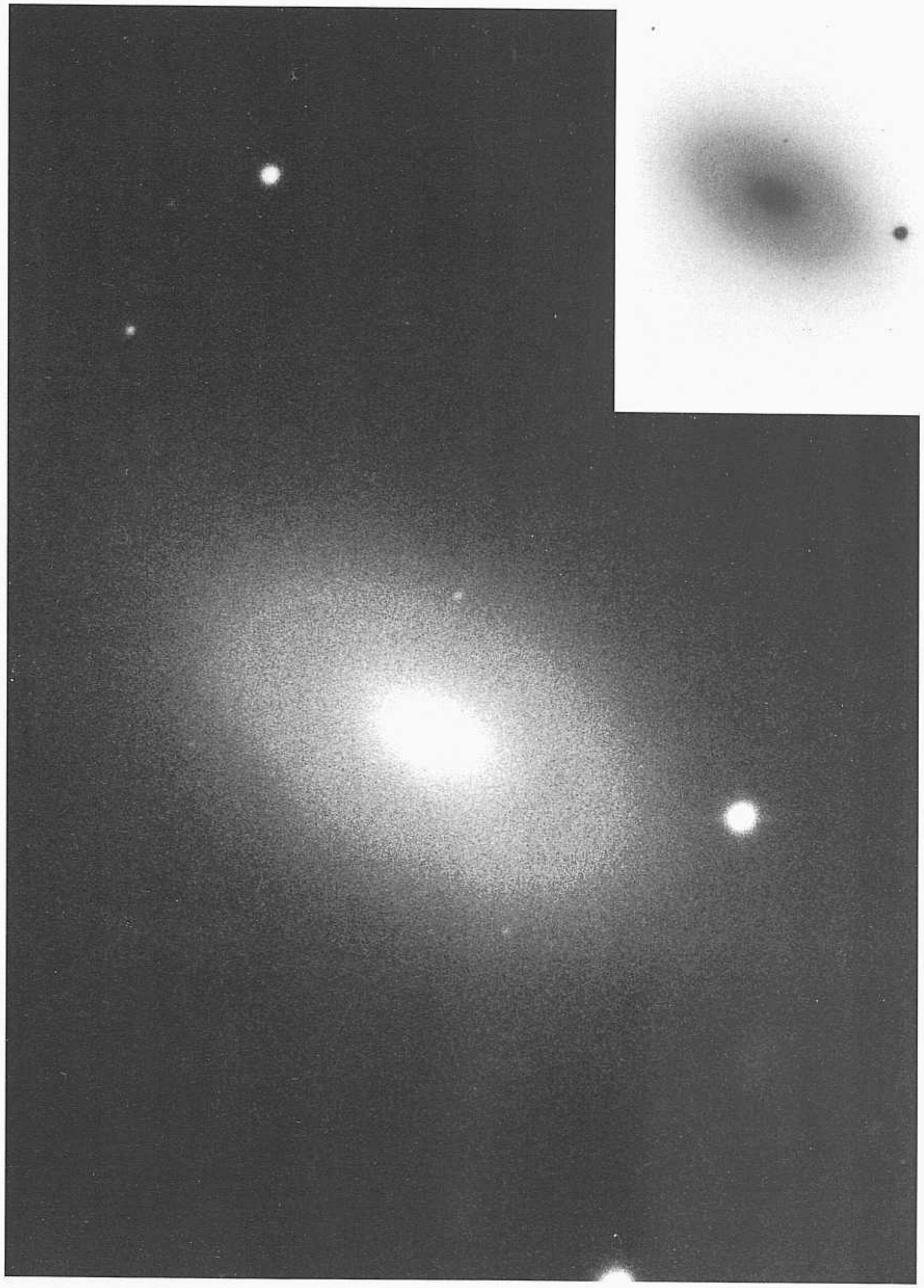
The subtle but evident circular (dust?) structure throughout the disk of NGC 3056 necessitates the mixed SO 1/2 classification. Some star formation may be occurring at the top of the image. This luminosity enhancement, visible only over a small arc of the rim, must be the reason for the external-ring designation of the RSO classification in the RC2, based on a Mount Wilson 100-inch plate.

NGC 1553 **S0i/2(5)** pec **Dorado 37**
CD-651-Br **(P)**
Jan 5/6, 1979
103aO + GG385
10 niin

NGC 1553 forms a pair with NGC 1549 (E2; panels 5, SI) **with** a projected angular separation of 11.5'. The redshifls, corrected to the centroid of the Local Group, are $i;_o$(1549) = 991 km s'" and $\mathbf{w_o}$**(1553)** = 1053 km s"^{1}. **The** galaxies clearly form a physical pair. The redshift distance of 20 Mpc *(H* = 50) gives a projected linear separation of 67 kpc.

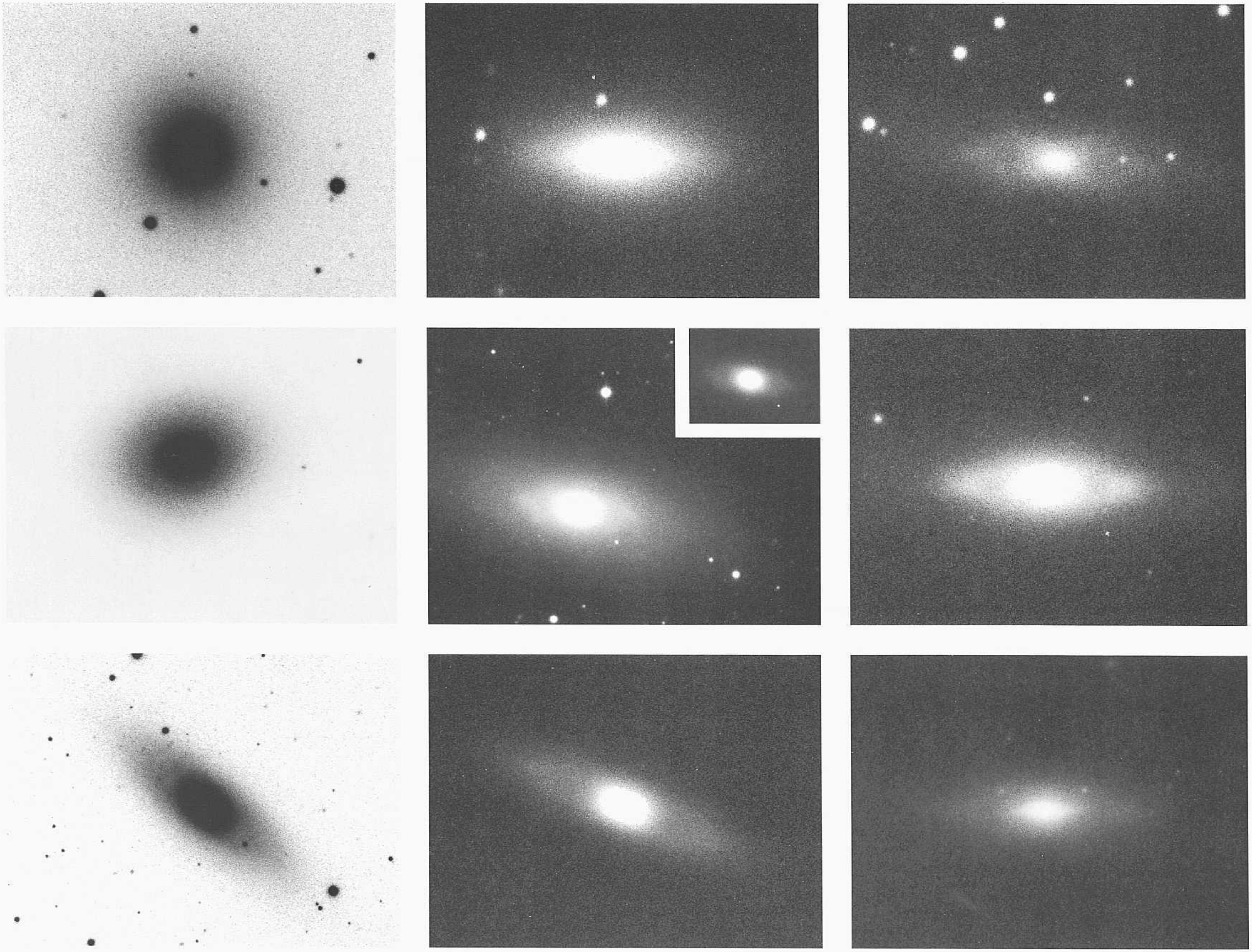
The subtle lanes (dust?) in the disk and the bright boundary lane at the rim of the disk are the reasons for the mixed $S0j/_2$ classification.





PANEL
39

PANEL
40



NGC 7192 $S0_2(0)$
CD-1074-Br (S)
Aug 17/18, 1979
103aO + GG385
•15 niiii

The characteristic three-zone SO structure of NGC 7192 is difficult to see on the print here because of the extremely high surface brightness of the two inner zones. However, those zones exist, and the morphology is similar to that of NGC 3065 ($SO_{1/2}$; **panel** 38). The first two zones appear only as the single circular bulge in the print here. The third zone is the extended outer envelope seen well on this print. It can be traced on the original plate to the distance slightly beyond the star at position angle 7 o'clock here.

The SO classification is definite. The E0 type in the RC2, based on a Mount Stromlo 30-inch plate, is not supported here.

NGC 1411 $S0_2(4)$
CD-1167-Br (P)
Aug 22/23, 1979
103aO + GG385
45 **inin**

The apparent three-zone structure in NGC 1411 is well seen in the negative print here (best viewed from a distance while moving the head). NGC 1411 is a prototype example and is a prime candidate for measurement of the luminosity profile to test if subjective impression of a three-zone description is caused simply by a change of the gradient of the profile (see the description of NGC 1201 on panel 33).

The faint outer envelope can be traced on the original plate to beyond the faint star at position angle 3 o'clock. Structure in the intermediate **envelope** near position angle 7 o'clock is **the** reason **for** the SO_2 subtype designation. This internal thin ring between the second and third components can be traced around the entire image.

NGC 5838 $S0_2(5)$
P1I-1912-B (P)
May **16/17,** 1958
103aO + GG13
20 inin

A low-surface-brightness, extended outer disk surrounds the central EO bulge **of** NGC 5838. The form is similar to what might be expected if NGC 1553 or NGC 3056 on the preceding panel were viewed more nearly edge on.

Breaks in the smooth luminosity in the middle part of the **low-surface-brightness** disk require the $S0_2$ subtype. The large extent and the very shallow luminosity gradient of the disk is unusual. Baade (1963) called the type SO(b), in support of his view that a complete SO sequence existed parallel to the normal spiral a,b,c sequence, once gas is stripped from their disks. (See also van den Bergh, 1976a, for the same supposition.) NGC 5838 is one of the few SO galaxies that have been used to support such **a** revision. A refutation of the suggestion, based on the distribution of surface brightness of the various spiral types, is given in the description **of** NGC 2902 (SO!; panel 30) and in more detail elsewhere (Sandage 1983a).

However, NGC 5838 and the few like it having large, low-surface-brightness disks do not provide evidence for a parallel SO sequence, because their central bulges are of much higher surface brightness than those of Sb, Sc, and Sd galaxies. There are no examples in the RSA of SO galaxies that could once have been like M33 (Sc; panel 262) or NGC 300 (Sc; panels 261, S6), which have no large, bright central bulge characteristic of all SO galaxies.

NGC 5820 **$S0_2(4)$ pair**
PH-7628-S (I)
April 27/28, 1979
103aO
10 **min**

NGC 5820 forms an apparent pair with NGC 5821 (Sbc, **not** in the RSA). 3.6' distant. The galaxies are at a common distance of 69 Mpc (*H* = 50) based on the redshift of $u_o(5028)$ = 3410 km s~' and $i>_o(5821)$ = 3517 km s"[1]. The projected linear separation is 72 kpc. Pairs such as this of mixed morphology arc important for clues as to how the galaxy formation process spreads its products along the **classification** sequence.

NGC 5820 is an SO seen on edge. A **very** faint dust lane down the center of the major axis requires the $S0_2$ subtype. The lane is very much weaker than in NGC 5866 ($S0_3$: Hubble Atlas, p. 6; panel 44); it is invisible here because of the high contrast of the print.

NGC 1527 $S0_2(6)$
CD-1682-S (P)
Jan 2/3, 1981
103aO + GG385
45 **min**

The characteristic SO three-zone form is manifested in NGC 1527 by the intermediate zone and an internal ring of intermediate surface brightness surrounding the bright central bulge. This inner ring appears as bright ansae on the major axis in the print here.

An extended Iow-surface-brightness envelope surrounds these inner structures. The envelope can be traced on the original plate to the brightest star near the major axis on the right side in the lower-right corner of the print. This envelope extends symmetrically on the other side of the bulge as well.

NGC **1461** **$S0_{1/2}(7)$**
CD-1734-S (P)
Jan 11/12, 1981
103aD + GG485
45 min

The pattern in the intermediate zone in NGC 1461 is similar to that in NGC 1527 in the print above. The extended disk here, visible as the **lower-surface-brightness** external zone, is the same feature in NGC 1527 in which the ansae exist. It is also similar to the '"peanut center" jusl outside the central bulge in NGC 1175 in the upper right-hand print on this page.

This pattern, previously described in other galaxies as an internal ring, or a **peanut-like** center, or a "rim to the intermediate zone," is the structure that is seen as a separation of material in boxy SO types such as NGC 4111 and NGC 4215, both in the SO section on panel 47.

NGC 1175 $S0_2(8)$
PH-786O-S **(P)**
Sep 4/5, **1980**
103aO
12 min

The **peanut-shaped** intermediate-luminosity zone **described** in NGC **1461** on this page is well shown in the print here of NGC 1175. The form is moderately common **(cf. Jarvis** 1986). **In** a **photometric** and kinematic study of IC 4767, which is **similar** to NGC **1** 175, Whitmore and Bell (1988) suggest that such galaxies are related to polar-ring galaxies (Sersie 1967; **Schweizer, Whitmore,** and Rubin 1983), whose origins may be due to mergers followed by **precession** of **particular** stellar orbits, **producing** an **X** configuration. Entrance to the extensive **literature,** c. 1988, is from Whitmore and Bell (1988).

NGC 148 $S0_2(r)(6)$
CD-575-S (P)
Oct8/9, 1978
103aD + GG495
30 **min**

The internal ring of the intermediate zone, discussed previously, is well formed in NGC 148. Faint external luminosity extensions exist (not seen in this **print)** beyond the ring along the major axis of this nearly edge-on galaxy.

NGC 2549 $S0_{1/2}(7)$
PH-7923-S (P)
Nov 7/8, 1980
103aO
2 min

NGC 2549 is an edge-on SO with a well-defined inner disk of high surface brightness (nearly burned out in this negative print) and an **intermediate-surface-brightness** envelope (well seen here). A very faint outer envelope, not visible in the print, surrounds these inner regions.

Note again the three-zone description. This three-zone structure, so prominent in this edge-on galaxy, would also show the three luminosity zones if viewed from above, explaining why the three-zone form is so well seen in many of the more-faee-on SO galaxies shown earlier.

NGC 4382 $S0_2(3)$ pec pair
PH-40-B (P) M85
April 20/21, 1950
103aO
30 niin

NGC 43 82 forms a physical pair with NGC 4394 (SBb: panel 165) at 7.8' angular separation. The similarity of redshifts at $u_o(4382)$ = 648 km s^{-1} and $u_o(4394)$ = 853 km s^{-1} suggests a physical pair. At an adopted redshift distance of 15 Mpc {// = 50). the projected linear separation is small at 34 kpc.

The inner region of NGC 4382. shown in the insert, resembles a normal E5. The extensive outer envelope in the negative print has edges, said by Schweizer {1982. 1983. 1986), by Toomre quoted by Schweizer (1983). and by Quinn (1984). to be owed to a dynamical encounter with a dominant giant. The result is a composite galaxy, which they would* identify in this case as NGC 43 82. Other examples of shells and ripples in the outer envelopes of galaxies in this atlas are NGC 474 (RSO/a: panel 84). NGC 7585 (SO/Sa: panel 84). and NGC 5018 (to the right here).

An example of a nucleated dwarf elliptical (dEO.N) is near the edge of the frame near the middle on the right-hand side of the print. It is a likely companion to the NGC 4382/4394 pair.

NGC 5018 $S0_2(4)/a$ pair
CD-1867-HB **(P)** panel 59
April 9/10, 1981
103aO + GG385
45 **min**

NGC 5018 forms a pair with NGC 5022 (Sc nearly on edge), at 7.2' separation. The redshifts from Huchtmeier and **Richter** (1989) are nearly identical, with a mean of $<t;_o>$ = 2 62 0 km $s\sim^{1}$. The redshift distance of 52 Mpc *(H* = 50) gives a projected linear separation of 1 10 kpc.

The central region of NGC 5018 resembles an E3 galaxy. Dust patches are present at the edge of the main body seen in the print here.

The most unusual feature is the sharp outer partial edges ("rims") to the outer envelope, similar to those in NGC 474 (panel 84) and in NGC 4382 on this panel. The outer envelope itself is faint and is just visible even on the negative insert, which is best viewed from a distance and with a movement of the head or eyes. The sharp partial edges to the envelope occur on opposite sides of the bulge. Their rim enhancements cover about 15° of arc on either side of a line inclined by about 2 0° to the major axis of the central E5 structure.

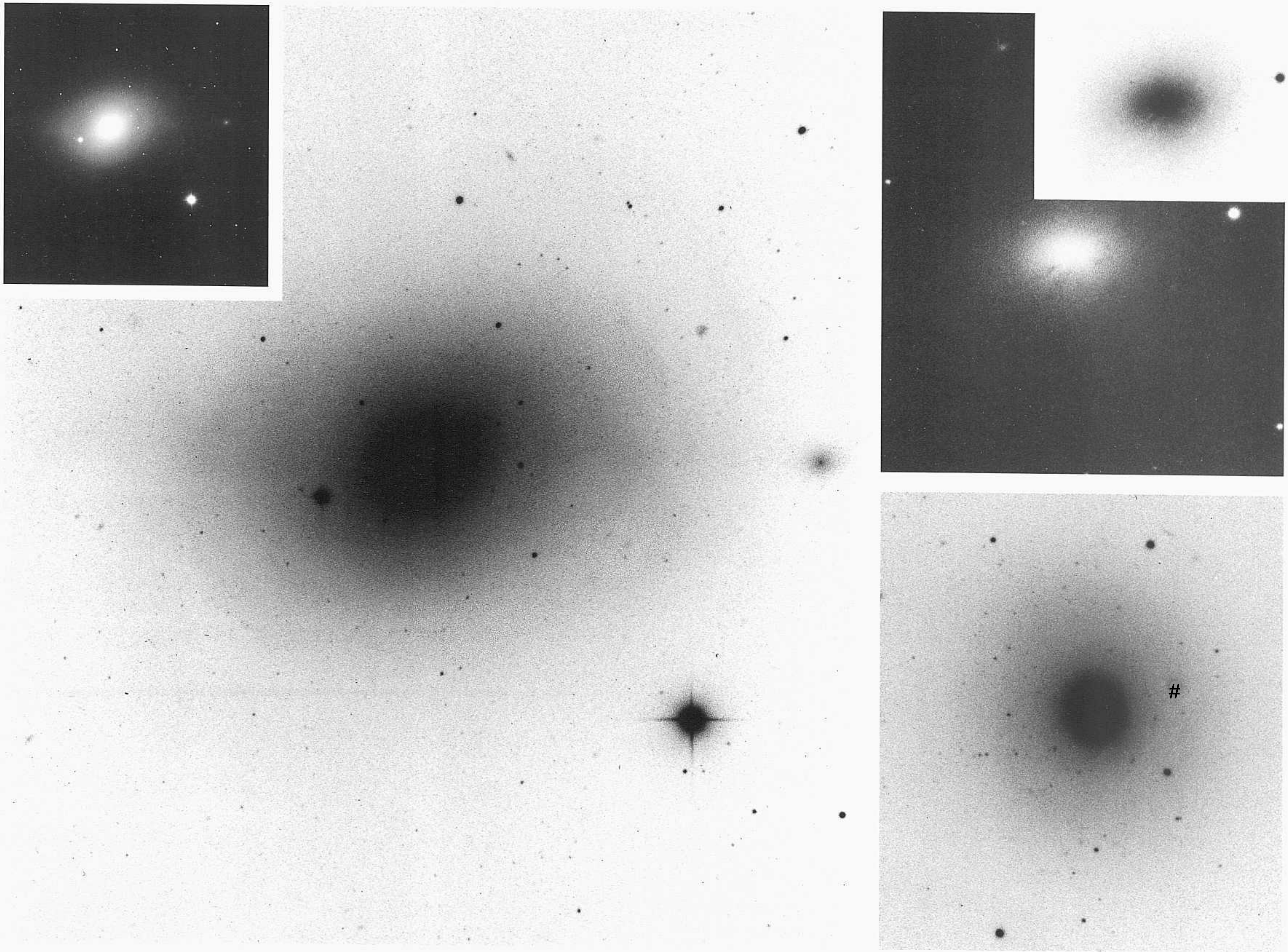
The outer envelope is not circularly symmetric but is broken into broad massive features (the two rims), similar to the earliest Sa type SO/a galaxies shown in later panels. The impression, however, may simply be a result of the positioning of the edges of the Quinn (1984) "shells." Nevertheless, it is this feature that yields the /a part of the type notation.

The classification of E3 in the RC2 , based on a Mount Wilson 60-inch plate, is inappropriate.

NGC 4203 $S0_2(l)$
PH-7661-S (P)
April 29/30, 1979
103aO
12 min

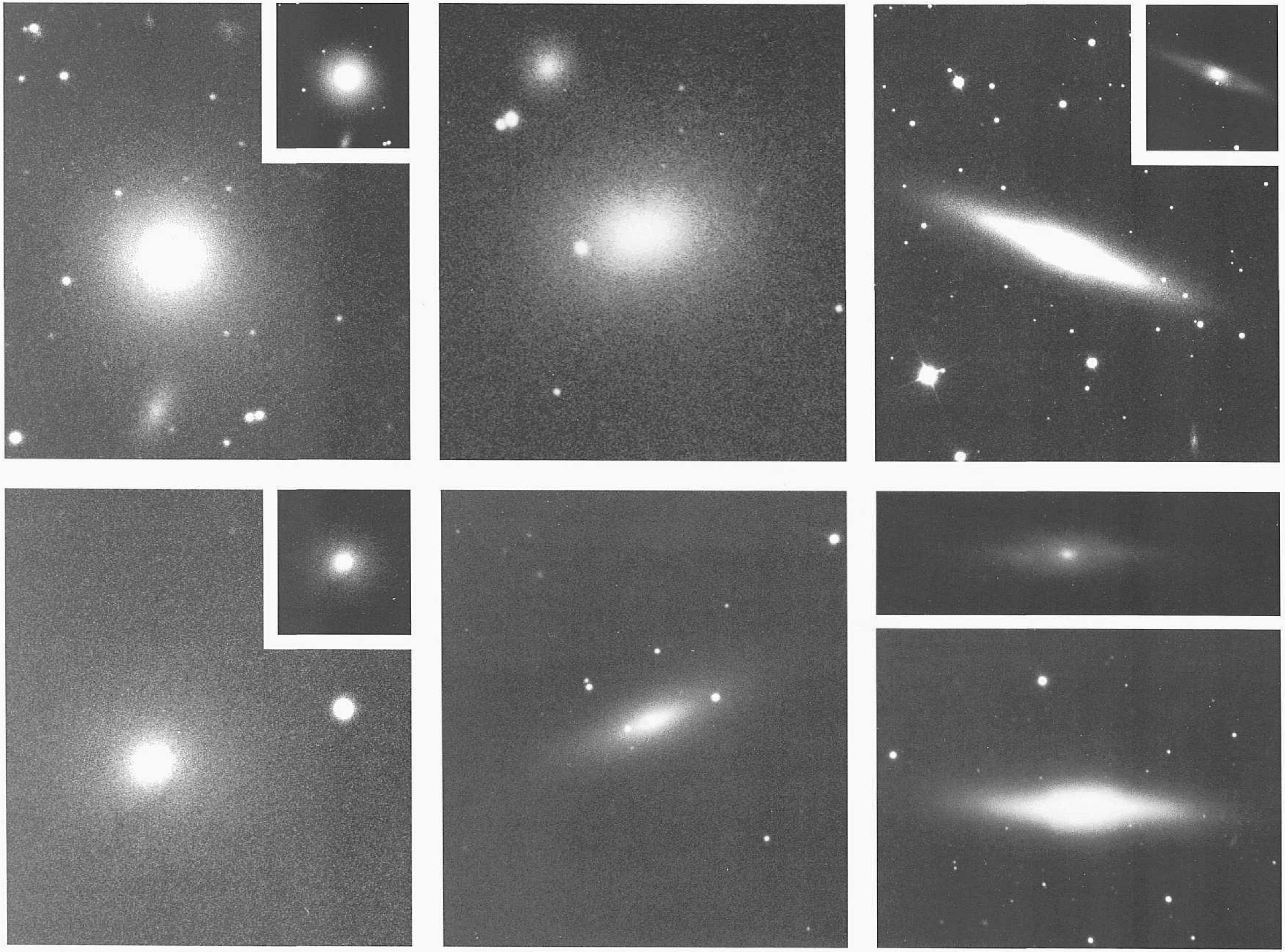
The two luminosity zones of a normal SO are seen clearly in the print here. The outer envelope is of very low surface brightness but is seen well in this high-contrast print. The subtle structures in this envelope (they are perhaps weak dust lanes) **preclude** a simple SO j classification. A stronger dust fragment, close to the border of the inner bulge with the outer envelope (but burned out in this print), is the reason for the SO9 classification.

The many condensations in the outer envelope are evidently globular clusters. A dwarf elliptical companion exists east-southeast of NGC 4203 at a separation of 7.4'. It is of type dE3,N and has a bright nucleus about 1 mag brighter than the brightest condensation in the envelope of NGC 4203 itself. The redshift distance of 2 I Mpc, based on v_o = 1 072 km s' (// = 50), gives a projected linear separation of 45 kpc.



PANEL
41

PANEL
42



Most galaxies on this and the next two pages show evidence of dust, either as partial lanes (the SO/j "transition" subtype) or as complete dust rings around the central bulge (the SO3 subtype).

NGC 5898 S0₂/3(0) group
CD-1052-Br (I)
Aug 16/17, 1979
103aO + GG385
45 min

NGC 5898 forms a pair with NGC 5903 (E3/S0|i panel 2 7) at 5.5' separation, together forming a loose group with several fainter galaxies including dE or dSO types. The redshifts of $u_o(5898) = 2164$ km s^{-1} and $«_o(5903) = 2413$ km s^{-1} (Sandage 1975b, 1978) give a mean redshift distance of 26 Mpc $(H = 50)$. The projected linear separation is 73 kpc.

The weak dust lane across only part of the image is visible on the left side of the main body in the print here. The lane is weak and cannot be traced around the image on the far side, even at this moderately favorable viewing angle. The light from the bulge overcomes the contrast of the far-side lane against the fainter far-side bulge light. This is a common feature of the $S0_3$ galaxies on the following pages. There is no doubt, however, that the lane forms a complete circular ring.

The presence of a faint extended outer envelope and the pronounced difference in the luminosity gradient at the break between the bulge and the envelope make the SO classification unequivocal. The E0 type in the RC2, based on a Mount Wilson 100-inch plate, is not supported here.

One of the dwarf elliptical candidate companions (dE7) in the group is near the bottom-middle border of the print.

NGC 1297 S02/3(0)
CD-1738-S (I/P)
Jan 12/13, 1981
103aD + GG495
45 min

A very faint outer envelope in NGC 1297, not well seen in the print here, signals the definite SO classification. The envelope can be traced on the original plate to a distance about half-way from the center to the bright star near the right-hand border.

A fragment of a dust lane is faintly visible on the print starting at the bottom of the main body and slanting thereafter to the lower left. The lane is real.

NGC 5077 S0i/₂(4) NGC 5077 Gr
CD-1874-HB (S)
April 10/11, 1981
103aO
75 min

NGC 5077 is the eponymous member of a group of about seven galaxies (Humason, Mayall. and Sandage 1956: Sandage 1975b). The redshift of NGC 5077 is $v_0 = 2561$ km s~\ Other Dreyer galaxies close to NGC 5077 are NGC 5070, 5072. 5076, 5079. and 5088. NGC 5088 (Sc: panel 292). with redshift $v_a = 1230$ km s^{-1}, is evidently in the foreground.

The extended envelope of NGC 5077 requires the SO classification. The E3 classification in the RC2 is not supported here.

Dust patches exist at the top and bottom of the main body along the minor axis. They resemble, but are weaker than, the dust lanes in the prolate SO galaxies shown on panel 45. The presence of this near-polar-ring dust lane (presumed to be a complete ring) is the reason for the SO *1/0* subclass.

NGC 4684 S0i(7) HA, p. *4*
H-2524-H (P)
March 7/8, 1948
103aO
30 niin

NGC 4684 is a normal SO ,(7) with a three-zone luminosity structure. However, the intermediate zone is an internal luminous ring surrounding a small, central region similar to those of NGC 148, NGC 1175. NGC 1461, NGC 1527, and NGC 2549 (all on panel 40 in this SO section). The extensive outer envelope, the last of the three zones, insures the SO classification.

The galaxy is shown here among the SOJ/J subtypes because it is early in having a dust lane or a separation of material which, in this case, is the luminous ring in the inner disk. The feature is similar to, but earlier than, that in the real $S0_{2/:J}$ subtypes in NGC 2310 ($S0_{2/3}$) and NGC 7332 (SO_2/-j) on this page.

NGC 23 10 S0₂«(8)
CD-148-S (P)
Feb2/3, 1978
103aO + GG385
10 mill

NGC 23 10 extends the internal pattern described for NGC 4684 on this page. The intermediate luminosity zone is separated from the small, central bulge by a decrease in luminosity just beyond tin[1] bulge but before the outer rim of the second zone. This is either a separation of material or a circular dust zone. Outward from the luminosity decrease is a broad, brighter ring in the disk, which is the termination of the intermediate zone. This feature in the intermediate disk is burned out in the main print but is faintly seen in the insert. The possibility that the luminosity decrease just outside the flattened bulge may be due to dust is the reason for the SO9/3 classification. In its gross properties the pattern is similar to the intermediate region in NGC 5422 (in panel 50. on SO disk formation), also seen edge on.

The main print of NGC 2310 has been overexposed to show the boxy nature of the central region and the large extent of the outer disk.

NGC 7332 S0₂«(8) HA, p. 7
PH-768-S (P)
Aug 23/24, 1954
103aO
30 min

Insert
H-1764-H
July 18/19, 1936
Eastman 40
60 min

The feature seen in NGC 2310 and NGC 4684—a luminosity *decrease* in the inner disk and a luminosity increase farther out in the disk—is present in NGC 7332 as well, but it here manifests itself in the puffed-up boxy nature of the central regions. The bright disk begins beyond the boxy bulge. The form of the central regions is nearly identical to that in NGC 4111 and NGC 4215 in the SO boxy panel shown on panel 47.

NGC 4459 $S0_3(3)$ VCC 1154
CD-724-S (P) HA, p. 5
Feb 1/2, 1979
103aO + Wr2c
60 miii

The internal circular dust lane in NGC 4459, characteristic of S0:i. is prominently seen in the insert. On the original plate it can be traced completely around the central bulge, burned out slightly in the insert print here from a Mount Wilson 100-inch plate.

The extended envelope, showing the two-zone nature of the image, is prominent.

NGC 404 $S0_3(0)$ HA, p. 6
H-2115-H (P)
Oet 13/14, 1939
103aO
55 min

NGC 404 is one of the most puzzling galaxies in the sky because of its very small redshift combined with its lack of resolution into stars and the absence of the low-average-surface-brightness signature expected of dwarf SO galaxies (Binggeli. Sandage, and Tarenghi 1984). The redshift, corrected to the centroid of the Local Group, is only 235 km s~^J^ , as listed in the RSA2. The absolute magnitude is M_{BT} = -17.4, adopting a distance of 5 Mpc. The angular diameter of the main body is 66", giving a small linear diameter of 1 .5 kpc.

The morphology of the image is that of a classic three-zone SO(OJ. The central, high-surface-brightness bulge zone is burned out in the main image here but can be seen in the insert. The boundary between the bulge and the intermediate zone can also be seen in the insert. The extended outer envelope is well seen in the main print. It can be traced on the original plate to the second of the bright stars at the top of the image.

A dust lane cuts across the bulge, in a typical SO^ pattern. The lane, faintly seen in the insert print, is evidently viewed nearly edge on; its back side is buried in the flooding intensity of the bulge, also common in SOj galaxies.

NGC 1400 $S0_3(l)$ 1400 Cr #39
CD-1524-S/Br (P)
Aug5/6, 1980
103aO + GG385
30 min

NGC 1400 and NGC 1407 [EO/SOjfO)] are the dominant members of the NGC 1400 Group (Ferguson and Sandage 1990). which contains many dE and dSO dwarfs. The characteristic SO3 inner dust lane of NGC 1400. seen nearly pole on. is visible in the insert. The extended outer envelope, seen in the main print, is the classification criterion for the SO class itself.

NGC 4696 S03(0) Centaurus Cluster
CD-1866-HB (I/P)
April 9/10, 1981
103aD + GG495
38 niin

NGC 4696 is the brightest member of the rich Centaurus Cluster. Very many dE dwarfs exist in the field surrounding this central galaxy. Although clearly an SO type, the galaxy is not a cD. The morphology is similar to that described for NGC 404 to the left, although the absolute luminosities differ by 5 mag.

To the eye. the luminosity profile appears to consist of three zones, as in NGC 2902 (SOj; panel 30) and other similar SO prototypes described on the preceding pages. The extended envelope can be traced on the original plate to at least the bright star at the upper right in the print here. The arc of the SO 3 dust lane cuts the bulge below its center in the orientation of this print.

NGC 6893 $S0_3(4)$
CD-570-S (P)
Oct8/9, 1978
103aD + GG495
30 min

An extended outer envelope is present in NGC 6893 but is of such low surface brightness that it is hardly seen on this high-contrast negative print. At the other extreme, the central surface brightness of the large bulge is abnormally high. The circular dust lane forms the boundary between the intermediate and the outer zones. It cannot be traced around the far side of the bulge, presumably because of the difference in the contrast-silhouette between the near and the far side of the bulge.

NGC 3665 $S0_3(3)$
PH-7657-S (S)
April 29/30, 1979
103aO
12 min

The characteristic circular dust lane of the SO j subtype is pronounced in NGC 3665, although there is no outer envelope as seen in other SO galaxies.

NGC 5087 $S0_3(5)$
CD-1300-S/Br (S)
March 10/11, 1980
lO3aD + GG495
60 niin

The dust lane, visible in the insert, is buried deep inside the main body of NGC 5087. (The enlargement of the insert print is twice that of the main print; the position of the dust lane within the main body in the main print is found by reducing the size of the insert print twofold, showing that the dust lane is very close to the center.)

The main body has the morphology of a standard E5. There is no zone structure and no extended envelope. Because of this, the SO3 class may be different from the SO^ types in their envelope characteristics. In this regard, note the absence of an outer envelope in some of the type-members described in this SO3 section (NGC 6893, NGC 3665, NGC 5087 here, NGC 6861 next, and NGC 2851 to complete this page). These galaxies might be classed E types with internal dust lanes.

NGC 6861 $S0_3(6)$
CD-1031-Br (S)
July 21/22, 1979
103aO + GG385
45 min

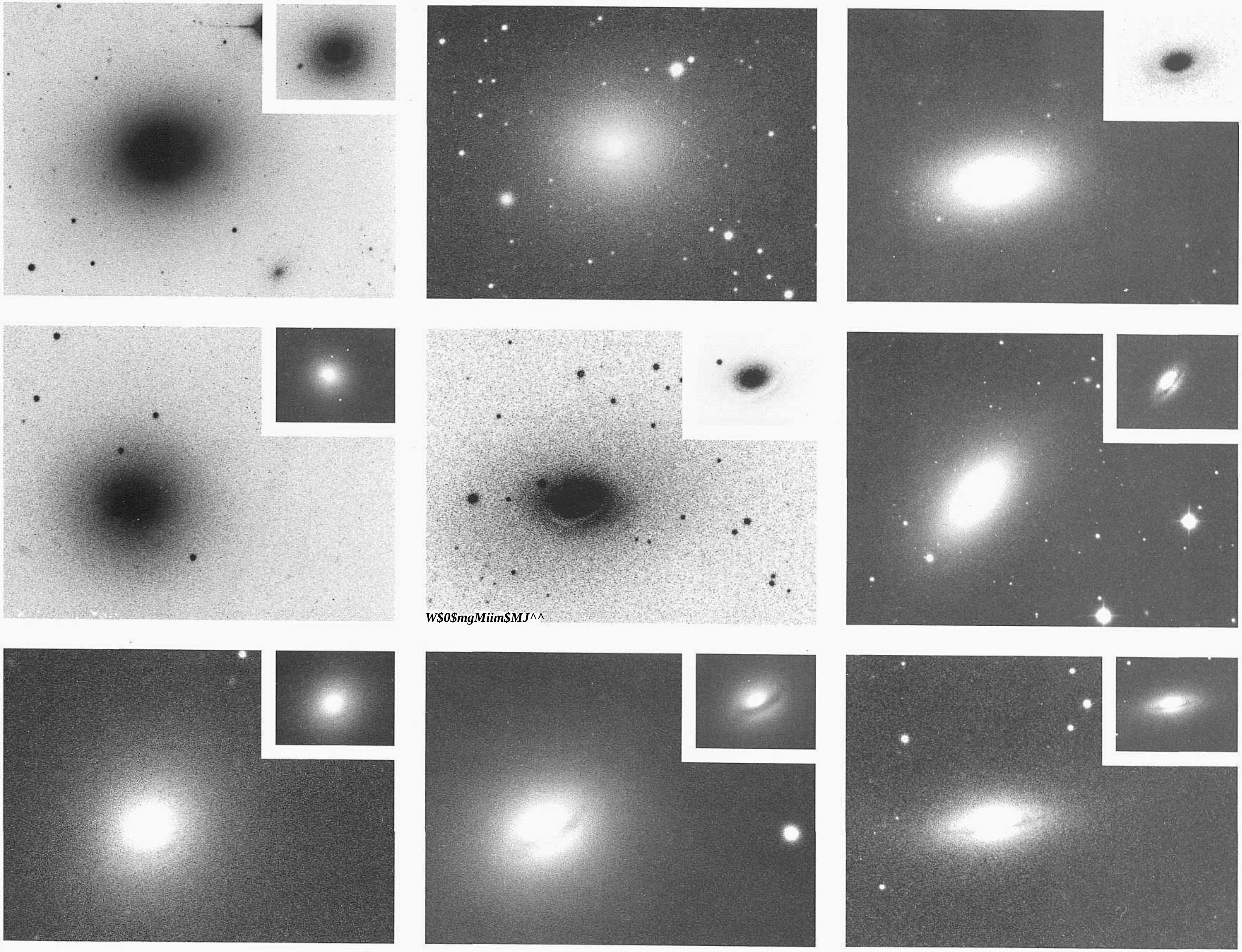
NGC 6861 is similar in all respects to NGC 5087, above. Again, the circular internal dust lane is buried deep within the body of the bulge. The outside luminosity profile of the main body is that of a normal E6 galaxy.

NGC 2851 $S0_3$/Sa not in RSA
CD-799-S (S)
Feb 24/25, 1979
103aO + GG385
45 min

NGC 2851 is in the same field as NGC 2848 (Sc; panel 244), 5 .3' distant. NGC 2 848 is in the RSA hut NGC 2851 is not. The latter is illustrated here to show the dust-lane morphology particularly well. The lane is seen almost edge on and, as usual, can be traced only over the front face of the bulge and disk until it disappears as it bends toward the hack side of the image. The disk extends beyond the dust lane, showing that the lane is interior to an outer disk, as in the previous galaxies with the same feature.

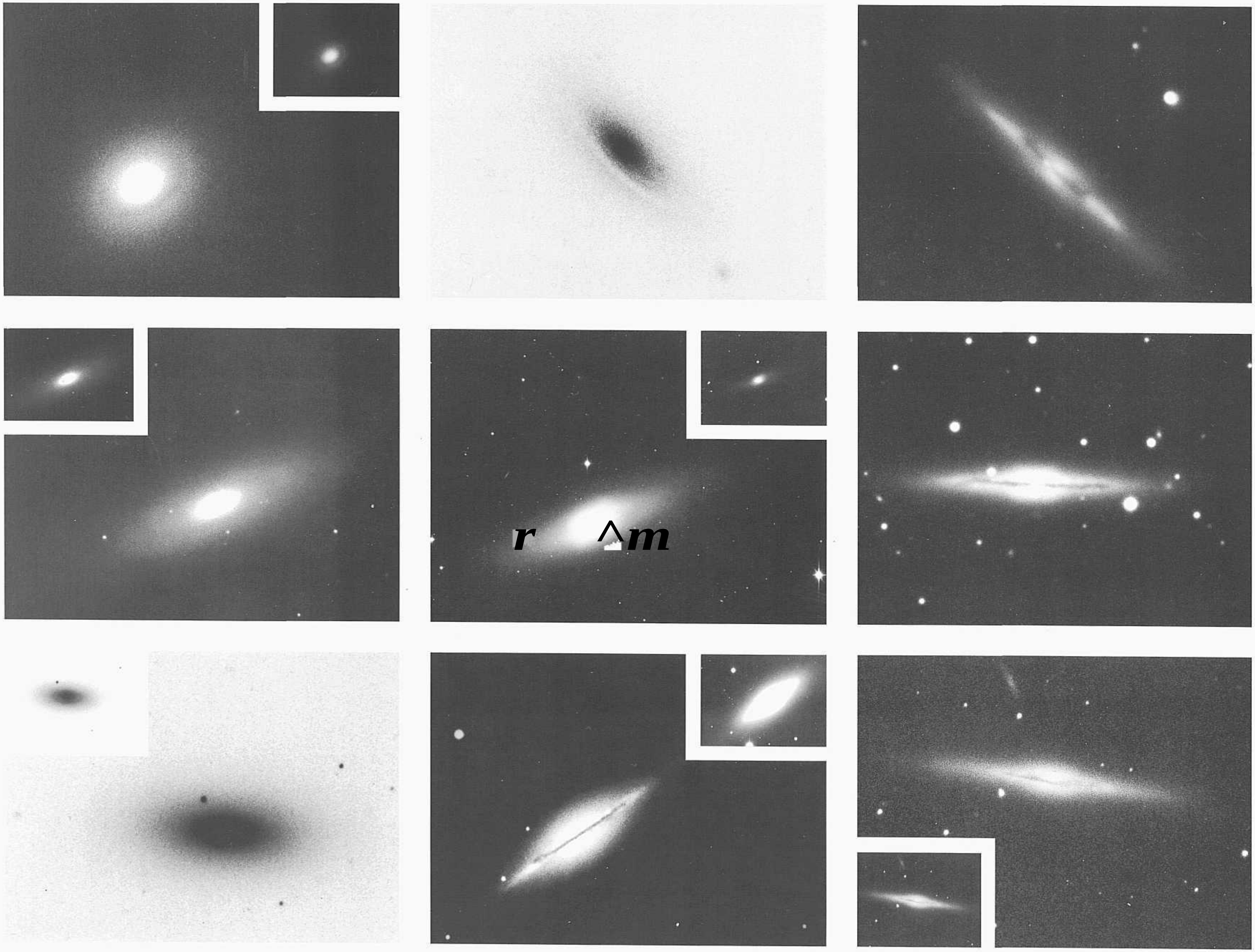
There is no extended envelope. The dust circle is at such a small angle to the sight line that spiral structure, if it exists, would be missed. The bulge character could support an Sa morphology. Hence the classification is in doubt, primarily because of the absence of an outer envelope.

PANEL
43



W0mgMiim$MJ^^

PAiSEL
44



NGC 3607 S0$_3$(3) Karachentsev 278
PH-7650-S (S)
April 29/30, 1979
103aO
2 inin

NGC 3607 is the brightest member of a group that includes NGC 3605 (E5; panel 12) at 2.7' separation and NGC 3608 (El; panel 4) at 5.8' separation. Although NGC 3608 may be in the background judged from the moderately large difference in the redshifts, the difference is not large enough to settle the case. The velocities are u$_o$(3605) = 600 km s~\ u$_o$(3607) = 858 km s~^{J}, and u$_o$(3608) = 1117 km s~^{l}, as listed in Ilumason, Mayall. and Sandage (1956). The projected linear separation of NGC 3605 and NGC 3607 is small at] 1 kpc.

The internal circular dust lane, characteristic of SO3 types, is well formed and is prominent in the print here. It can be traced only for about 270° of its circle before its contrast in silhouette on the far side is drowned by the foreground bulge light.

NGC 4124 S0$_2$(r)(6)
PH-610-B (P)
May 14/15, 1952
103aO + GG1
30 min

NGC 4124 combines the extended disk of low surface brightness of NGC 5838 (SO$_2$, panel 40) with the presence of an internal bright ring surrounding a small nucleus in NGC 148 [S0$_2$(r): panel 40]. The internal bright ring structure is not well shown in the insert because of the small scale of the ring and the interference with the bright central nucleus.

Note the change of classification from S0$_{:j}$ given in the RSA2. The space between the nucleus and the bright internal ring was interpreted in the RSA2 as a circular internal dust ring. We now interpret the feature to be similar to the bright internal ring in galaxies like NGC 148 (panel 40).

In the suggestion by Baade (1963) that SO's form a "parallel" sequence to the normal Sa, Sb, Sc types, and that NGC 4124 would be of class S0(c) is rejected here for the reasons discussed in the paragraphs describing NGC 5838 (panel 40).

NGC 4281 S0$_3$(6) VCC 408
CD-1309-S/Br (I)
March 11/12, 1980
103aO
75 min

NGC 4281 is a prototype example of an S0$_3$. The extended outer envelope is of much higher surface brightness than that of NGC 5838 (S0$_2$; panel 40) or NGC 4124 above. The circular internal dust lane close to the center is shown in the insert.

NGC 5326 S0$_3$(6)/Sa panel 76
PH-8095-S (S)
Feb 6/7, 1981
103aO
12 inin

NGC 5326 is shown and described also in the Sa section, panel 76. The internal dust lane, not now as close to the center as in NGC 4124 and NGC 4281, also on this page, nevertheless is not at the rim of the disk. The disk can be traced to well beyond the position of the dust lane.

NGC 4526 S0$_3$(6) VCC 1535
CD-801-S (P) HA, p. 5
Feb 24/25, 1979
103aO + Wr2e
45 min

The print of NGC 4526 in the Hubble Atlas, made from a Mount Wilson 60-inch plate. shows the internal, SO;j-characteristic ring that is buried very deep in the main body of the image. The 60-inch plate, printed at great enlargement in the Hubble Atlas, clearly shows that the circular internal structure is obscuration rather than a bright rim, in contrast to the cases of NGC 148 (panel 40) and NGC 4124, on this panel.

NGC 5866 S0$_3$(8) triplet
PH-195-MH (I) HA, p. 6
May 13/14, 1950
103aO
30 nun

NGC 5866. also shown in the Hubble Atlas, is famous for the tilted dust lane (Burbidge anil Burbidge 1960) relative to the bright ansae that are the beginning of the thin plane.

It forms a wide triplet with NGC 5879 (Sb; panel 139: v_0 = 929 km s~') and NGC 5907 [Sc (on edge); panels 289, SI 1: v_o = 779 km s~']. The redshift of NGC 5866 is v_o = 824 km s~\ The similarity of the three redshifts suggests that the galaxies form a wide physical group. The separation of NGC 5879 and NCC 5907 from NGC 5866 are 80' and 85', respectively. At a redshift distance of 17 Mpe the projected linear separations from NGC 5866 are 393 kpc for NGC 5879 and 417 kpc for NGC 5907, each smaller than the separation of 700 kpc between M31 and the Galaxy in the Local Group.

A dE2,N dwarf elliptical companion exists at 11.4' separation to the northwest. The projected linear separation is 56 kpc. A possible compact companion (SO?) is closer at 2', almost directly south of NGC 5822. It is outside the frame of the print here but is visible on the two prints in the Hubble Atlas (p. 6).

The extended luminosity that forms an outer thick disk beyond the bright ansae is visible in the insert but is shown better in the heavy print in the Hubble Atlas. This extended luminosity can be traced on the original plate beyond the borders of the insert print here.

NGC 4710 S0$_3$(9) HA, p. 6
H-1982-H (P)
April 23/24, 1938
Eastman 40
60 min

This famous galaxy has bright ansae and a presumed internal dust ring. The print of i\GC 4710 here is made from a different original Mount Wilson 100-inch plate than was used in the Hubble Atlas. The faint outer envelope mentioned in the Hubble Atlas cannot be seen on this reproduction.

The form of the image is a more extreme case (the internal dusl ring is more opaque) of the similar but more-subtle variation of intensity *inside* the ansae in NGC 4215 (SO$_2$, panel 47) and NGC 4111 (S0$_2$; panels 47, 53).

NGC 3390 S0s(8) or Sb
CD-761-S
Feb 20/21, 1979
103aO + GG385
45 min

The internal dust ring witli the outside ansae is similar to features of NGC 5866 and NGC 4710 on this page. The fact that the ring does not define the *rim* of the image but stops *inside* the edge of the luminous disk suggests that the classification is SO3 (because of the internal dust ring) rather than an Sb on edge, but the Sb classification is also possible. The central bulge is boxy.

NGC 3957 S0$_3$(9) pair
CD-1672-S (P)
Dec 31/Jan 1, 1980/1981
103aO + GG385
60 min

NGC 3957 forms a very wide pair with NGC 3981 (Sbc; panel 178) at 39' separation. The redshifts are u$_o$(3957) = 1583 km s~^{l} and v_0 (3981) = 1554 km s^{-1}, suggesting a physical association. The projected linear separation, based on a redshift distance of 31 Mpe (*II* = 50), is 356 kpc. Recall that the distance from our Galaxy to M31 is 760 kpc.

The internal central dusl lane, as in NGC 5866, NCC 4710, and NGC 3390. all on this page, is not at the edge of the image, suggesting the S0$_{:i}$ classification.

Galaxies on this page share the feature of dust lanes *perpendicular* to the major axis of the star light. In some respects they resemble the class of polar-ring galaxies (Sersic 1967; Schweizer, Whitmore, and Rubin 1983), which may be extreme examples of the form here. An early literature summary of the type is by Bertola and Galletta (1978). A later survey resulting in a catalog of southern examples was made by Ilarwarden *et at.* (1981).

NGC 2685 SOs(7) pec **HA, p.** 7
PH-663-5 **(I/P)**
Feb 5/6, **1954**
103aO + WG2
30 min

An early-recognized prototype **member** of the class was NGC 2685. **which** has a series of **helical** dust structures and luminous arcs **perpendicular to the** major axis **of the** image. A description and a **photograph** was given by **Burbidge** and **Burbidge** (1959b) based on a plate taken **with** the McDonald 82-inch **telescope.** The print on **the** facing **page** is made from the same 200-inch plate used **for** the Hubble Atlas.

Spectra by Ulrich (1975) with the slit along **the** brightest helical arc showed that **the** arc structures rotate **with** the rotation axis along the *major* axis **of** the stellar light. This was confirmed by Sehechter and Gunn (1978). who also showed that the underlying SO stellar form itself rotates with its rotation axis along the *minor* axis of the flattened stellar component in the normal way expected for an E or an SO galaxy (Dressier and Sandage 1 9H3). Hence, as in polar-ring galaxies, **there are** two velocity systems whose axes are perpendicular.

A faint outer ring with the same flattening as the **underlying** SO image surrounds the form. This ring, not seen here, is faintly visible on the negative insert print in the Hubble Atlas.

NGC 1947 $S0_{;i}(0)$ pec
CD-1313-S/Br (S)
March 12/13, 1980
103aO + GG385
45 niiii

The print of NGC 1947 here, made from a plate taken in poor seeing, does not show the intricate **detail in** the multiple dust lanes silhouetted against the stellar light of the bulge. At least five lanes are visible on the original plate: they can be traced **outward** (down and to the left in the orientation **of** the **print** here) across the face **of** the bulge. The pattern suggests that the dust is in a plane **perpendicular** to the major axis **of** the old stellar component, whose direction on this print is from the lower left to the upper right. If so, the dust would be in a "polar-ring'" orbit.

The outer isophotes of the bulge light are almost circular. The image of the stellar component can be traced on the original plate nearly to the left and right borders of the main **print.**

NGC 5485 **S03(2) pec (prolate)** **pair?**
PH-7627-S **(P)**
April 27/28, 1979
I03a0
10 min

NGC 5485 forms what is **probably** an optical pair **with** NGC 5486, 6.4' distant. The redshift difference is large, based on $u_o(5485)$ = 2 110 km s''' and $\mathbf{u_o(5486)}$ = 1525 km s^{-1} from Huchlmeier and **Richter** (1989), reduced to the centroid **of** the Local Group by the precepts of the RSA. Two probable dwarf companions (a bright **dE5** and a very faint dEO of low surface brightness) exist at 1.6' and 3.7'.

The image of the underlying old stellar light on the original plate has an SO3 shape, with the dust lane perpendicular to the major axis (best seen in the insert). Unlike NGC 2685 or NGC 1947, above, there is only one principal dust lane.

NGC **5266** S0a(5) pec **(prolate)**
CD-1101-Br **(S)**
Aug 18/19, 1979
103aO + **GG385**
45 **min**

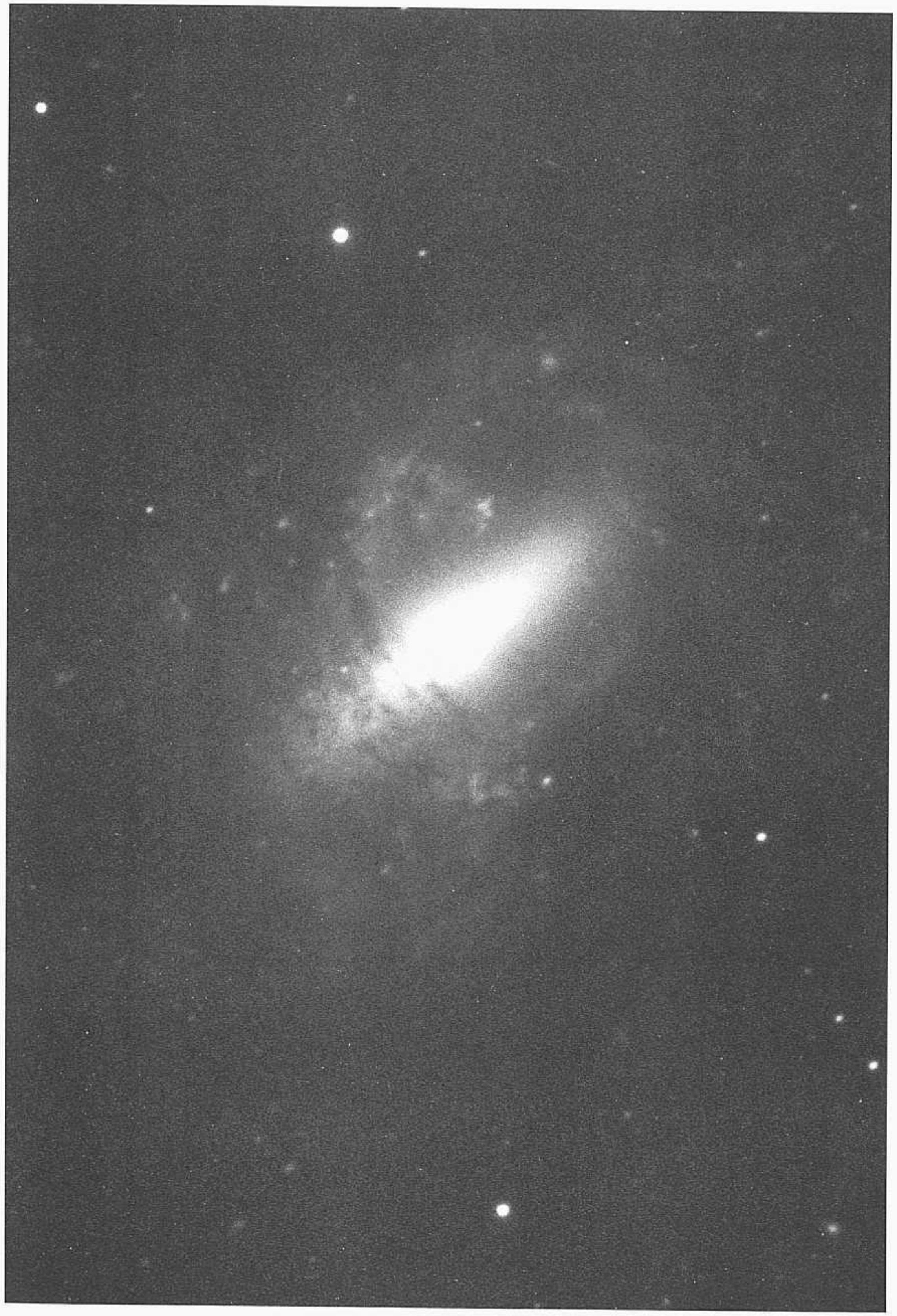
This famous case, NGC 5266, is the best example of an encircling dust lane perpendicular to the major axis of an underlying SO galaxy- The structure of the dust ring is best seen in **the** insert prints. It is well shown in silhouette against the front side of the bulge and can be traced against the fainter regions of the main body as it turns to disappear behind the back side of the SO(5) galaxy. The dust lane is much more regular than the similar pattern in NGC 5128 below and on the next panel.

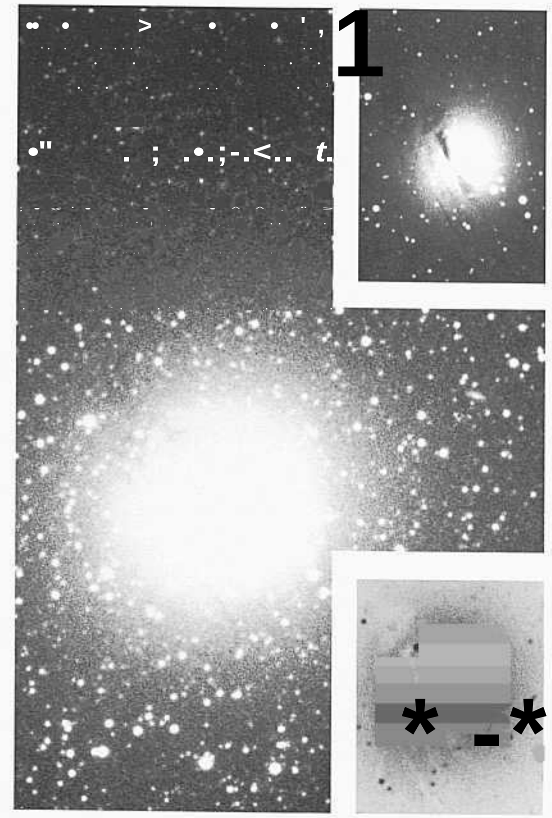
A detailed photometric and kinematic study of both the dust feature and the stellar main body of NGC 5266 has been made by Varnas *et al.* (1987).

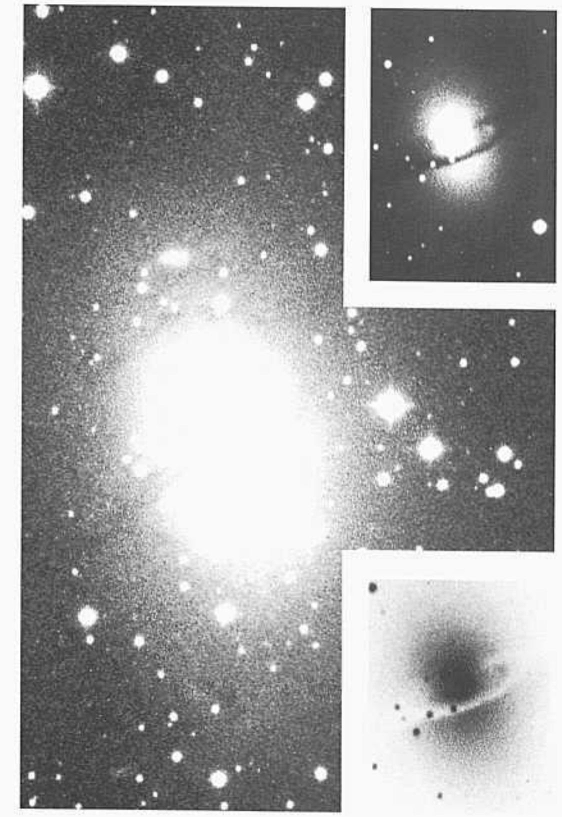
NGC 5128 SO + S **pec** **HA, p.** *50*
CD-2229-Monet **(S)** **panel 46**
April 19/20, 1982
IIIaF + RG610
240 min

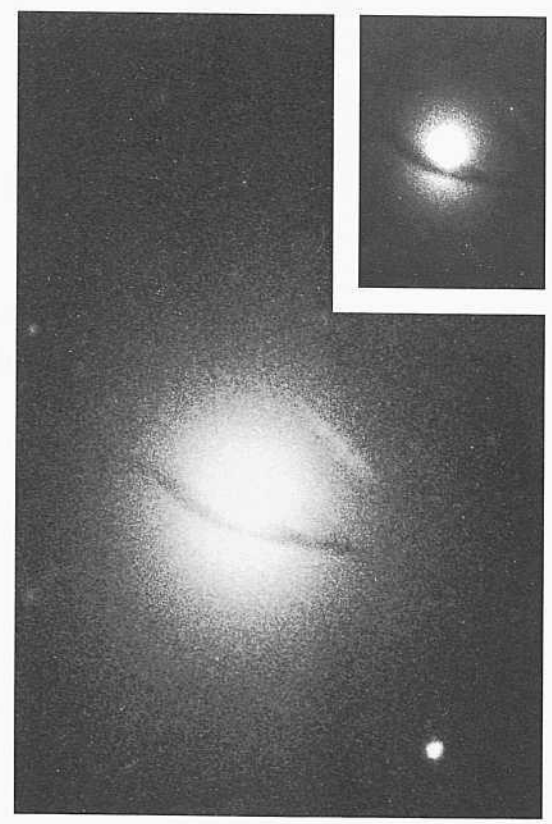
NGC 5128 is the first recognized and the most famous example of the combination of a dust feature and an early-type galaxy, shown here in a print made from a Las Campanas 100-inch plate taken by Monet on a red emulsion. The galaxy is also illustrated in the Hubble Atlas, where early literature references to the radio **properties** are given, having become known just at the time **of** publication.

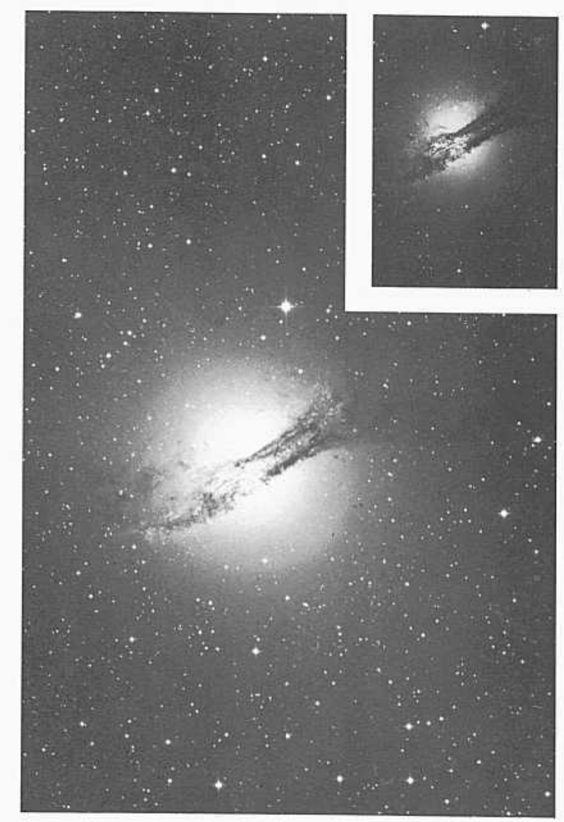
The elongation of the underlying old stellar population whose major axis is perpendicular to the dust lane was recognized by Baade **and** Minkowski (1954). It is well shown in a **deep** photograph printed to optimum contrast in van den Bergh (1976b) and in Graham (1979). The elongation is not well shown in the **print** here, neither in the insert nor the main **print.** The luminosity **of** the stellar component in Graham's reproduction (his Fig. 1) can be traced nearly **to** the right border of the main print here. The major axis **of** the **flattened** image **of** the **underlying** SO form extends from **the** lower right to the upper **left** on this print.





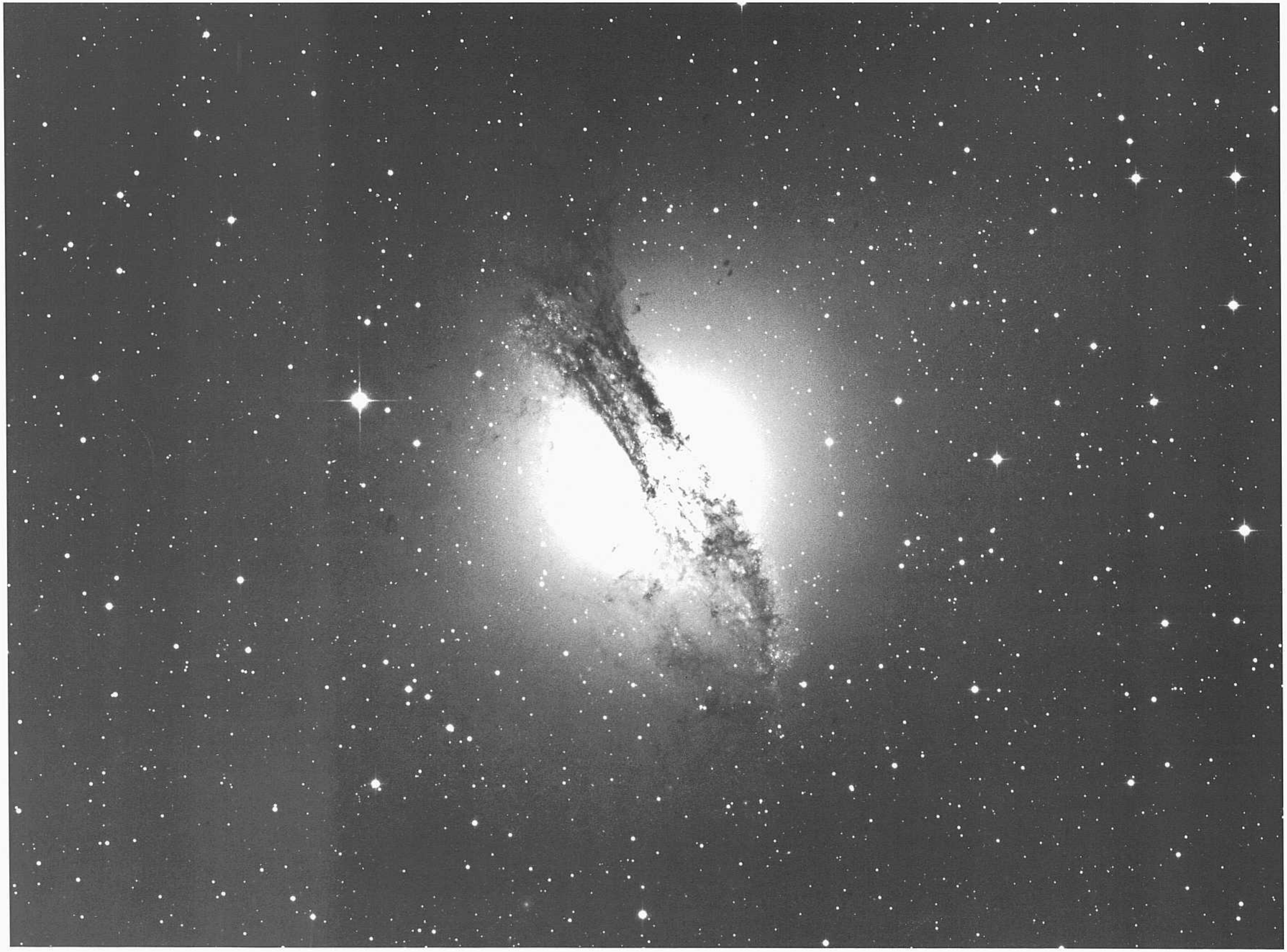






PANEL
45

PANEL
46



NGC 5128 **SO + S pec** **HA, p.** ***50***
CD-2229-Monet **(S)** **panel 45**
April 19/20, 1982
HIaF+ RG610
240 miii

The print here is from the same plate by Monet used for the print on the **preceding** page. The orientation is **north to** the **left,** west at the top.

The faint oute**r** (1iffu**se** surface Iight. filamentary features, and the **HII** regions discovered **by** Blanco *et al.* (1975) are as far beyond the lower-left corner of the print as **that** corner is from the **center** of **the** galaxy. The faint outer isophotes traceable on van **den** Bergh's (1976b) and on Graham's (1979) high-contrast prints extend to a distance from the center **equal** to the distance to the left and right **borders** of the print here. The **major** axis of the **flattened** underlying old-star population is from the lower left to the upper right.

Much photometric and **spectroscopic** work has been done since the early description of NGC 5 1 28 was written in the Hubble Alias. The rotation of the dust lane was established by Burbidge and **Burbidge** (1959a) and was confirmed and the results extended by Graham (19 79). The kinematics are satisfied by a model in which the dust lane is a disk whose **front** and back sides are both visible and which is view'ed at an angle that is 17° from edge on. The disk is rotating such that the northwest side of the disk (the upper-left side of the dust lane here) is receding. The maximum velocity difference between the northwest and the southeast (lower right) ends of the disk (the dust lane) is 700 km s~^{1}, corrected to what would be observed edge on. This rotational velocity, of course, is very high.

The rotation of the stellar component whose major axis is at right angles to the dust was finally established by Bertola, Galletta, and Zeilinger (1985) in an impressive study. Their measured rotational gradient oi the old star component was 2 km s^{-1} arc sec^{-1} in the sense that the southwest side (upper right) is receding. The maximum velocity difference in their measurements between the southwest and the northeast ends of their long slit placed along the major axis of the stellar component is 160 km s~^{1}. This, combined with their measured velocity dispersion of 140 km s^{-1}. when placed in the velocity/dispersion diagram of Ulingworth (19 7 7) and of Binney (19 78), show that the old stellar component is a rapid rotator, simitar to almost all SO bulges (Dressier and Sandage 1983). (The result shows almost certainly **that** the form of the *old stellar component* of the galaxy is not prolate.)

The kinematic results **of the Burbidges, of** Graham, and of Bertola. **Galletta,** and **Zeilinger** establish, as in NGC **2685** and in **NGC 5266 on** the preceding panel, the presence **of two velocity** systems **whose angular momentum** axes **are** at right angles to each ot her. as in polar-ring galaxies (compare **Schweizer, Whitmore,** and **Rubin** 1983).

The galaxy **type of the old stellar component** is uncertain. The **photometry of van** drn **Bergh** (1976b) shows **that the luminosity profile is thai** of a typical elliptical over **the central part of the** image. **This, however, is true for** most SO **bulges.** It is miIy in **the** outer **envelope that the SO characteristics** appear. **We leave the type** us uncertain.

Nevertheless. **NGC** 5 128 **and the** other galaxies on **the preceding panel** are **so** unusual **that, in general, they** cannot **be** used as **examples to understand** ihc normal SO galaxy types. In each ease some special **event may** have taken place. (Compare kahn and **Woltjer L959; Tubbs** 1980: **Simonson** 1982: van Albada. **Kotanyi,** and Sehwarzsehild 1982: **Steiman-Gameron** anil **Durisen 1** 982: others.)

The four galaxies on this page are seen edge on and have boxy central regions. Other similar galaxies shown in this atlas include NGC 1175 (panel 40), NGC 1381 (panels 37, 50), NGC 2310 (panel 42), NGC 2549 (panel 40), NGC 3390 (panel 44), NGC 5422 (panels 50, S2), and NGC 7332 (panel 42).

NGC 3203 $S0_2(7)$ panel S2
CD-1314-S/Br (P)
March 22/23, 1980
103aD + GG495
60 min

The boxy center in NGC 3203, slightly burned out here, is almost identical to NGC 42 L5, below. A central E-Iike bulge is separated from the beginning of the bright part of **the highly** flattened disk (which appears as two oppositely placed ansae) **by** a region of decreased luminosity that is puffed up into a peanut-like (boxy) thick disk in the central region. NGC 1175 (panel 40) is an extreme example of **the** form. Perhaps the entire region inside the ansae should he **considered** to be the bulge because in many examples it is known to be rapidly rotating (compare **Kormendy** and Illingworth 1982: Dressier and Sandage 1983), as in NGC 128 (panel 52). NGC 1175, and NGC 7332. In these galaxies the rotation curve rises from the center outward but flattens to be level at the radius where the ansae of the bright disk begins. (See **the** data **for** the type example of NGC 7332 in Dressier and Sandage 1983.)

NGC 4215 S0i(9) VCC 166
CD-1416-S/Br (P) HA, p. 6
March 24/25, 1980
103aO
75 inin

NGC 4215 is in the Virgo region but is in the W cloud to the south and west of Virgo subclusters A and B (Binggeli, Tammann, and Sandage 1987). Its high redshift of v_o = 1942 km **s**$^{-1}$ probably puts it in the W cloud behind the Virgo Cluster core.

NGC 4215 is the type-example for the four galaxies on **this** page. The description of the **peanut-shaped** central region and the bright ansae given for similar examples on previous pages applies here as well.

The decrease in luminosity between the center and the beginning of the ansae may be **a** milder form of the internal dust lane in SO 3 types seen in more-face-on galaxies (SO section, panels **43,** 44). The phenomenon may be related to the apparent internal dust lane at the same place in the famous edge-on example of NGC 4710 [$S0_{.5}$(9): panel 44]. The example in NGC 4215, here, of the subtler appearance of a luminosity decrease in the intermediate region **(apparently a** separation of material) is common. Many **field** examples of SO galaxies of this type exist in almost any random field photographed, for example, with the Las Campanas du Pont **Telescope** on 50 X 50 cm plates. It is **a** very common form.

NGC **4417 S0i(7) VCC 944**
CD-717-S (P)
Jan 31/Feb 1, 1979
103aO + Wr2
45 min

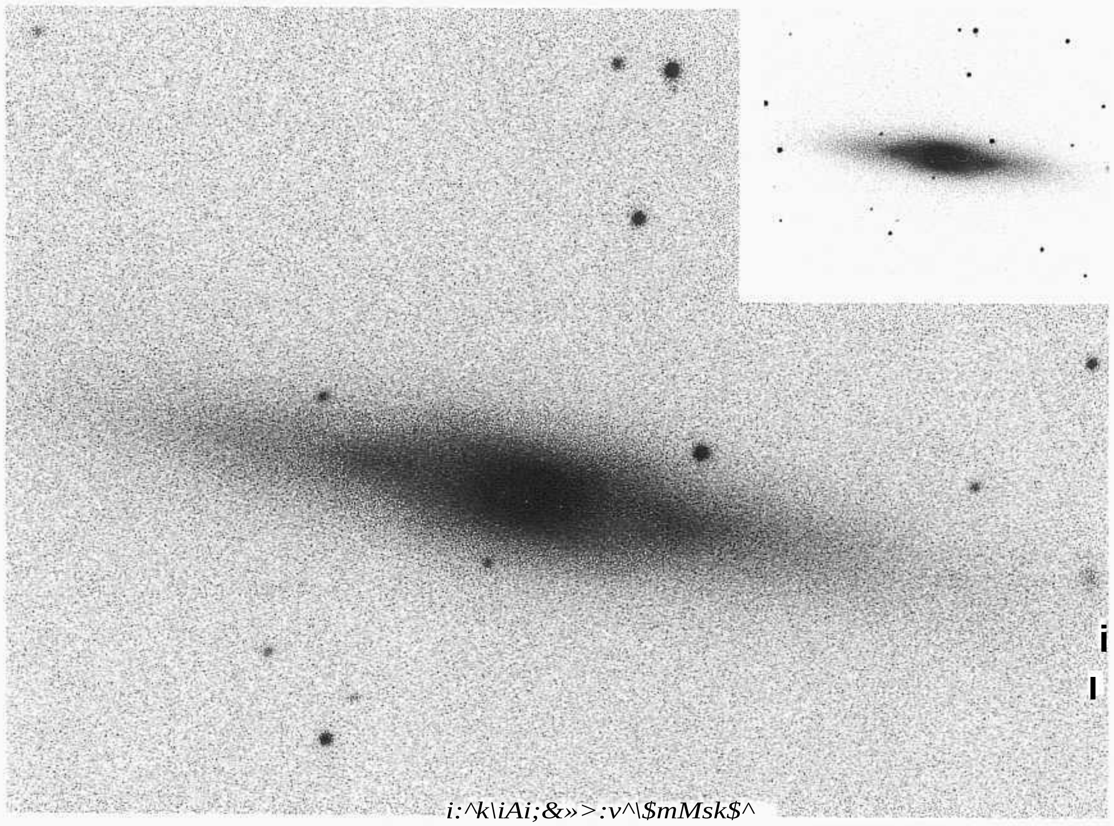
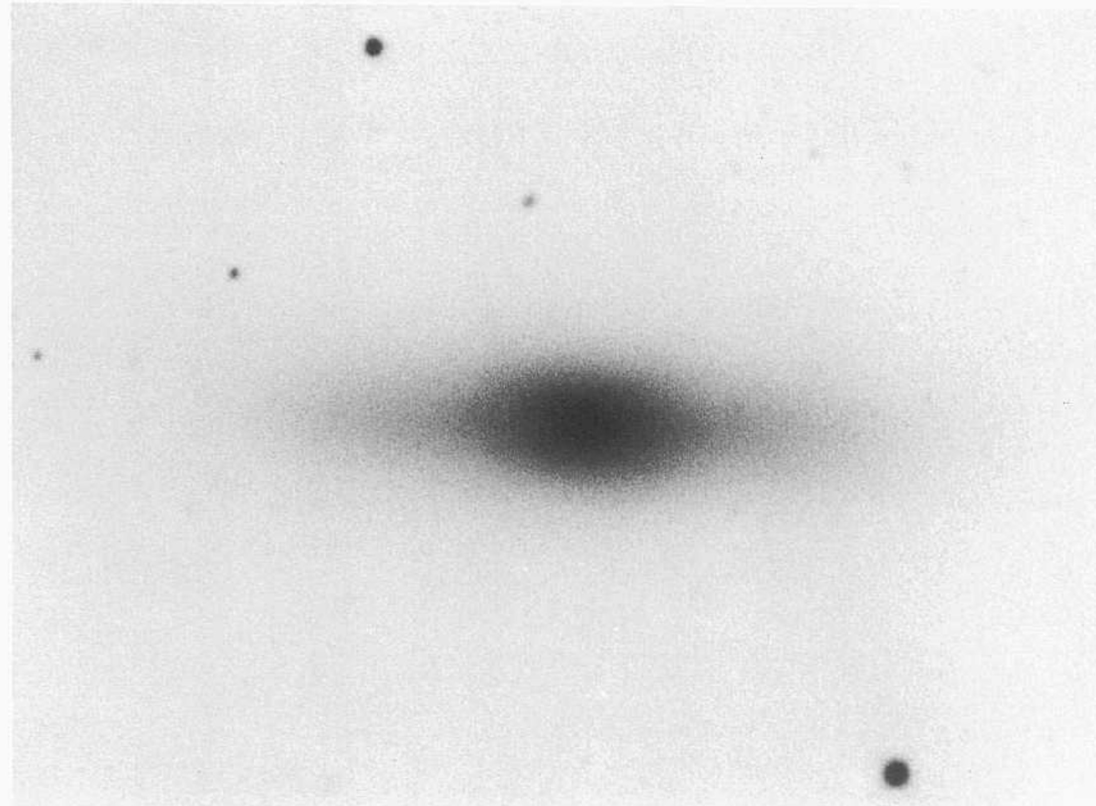
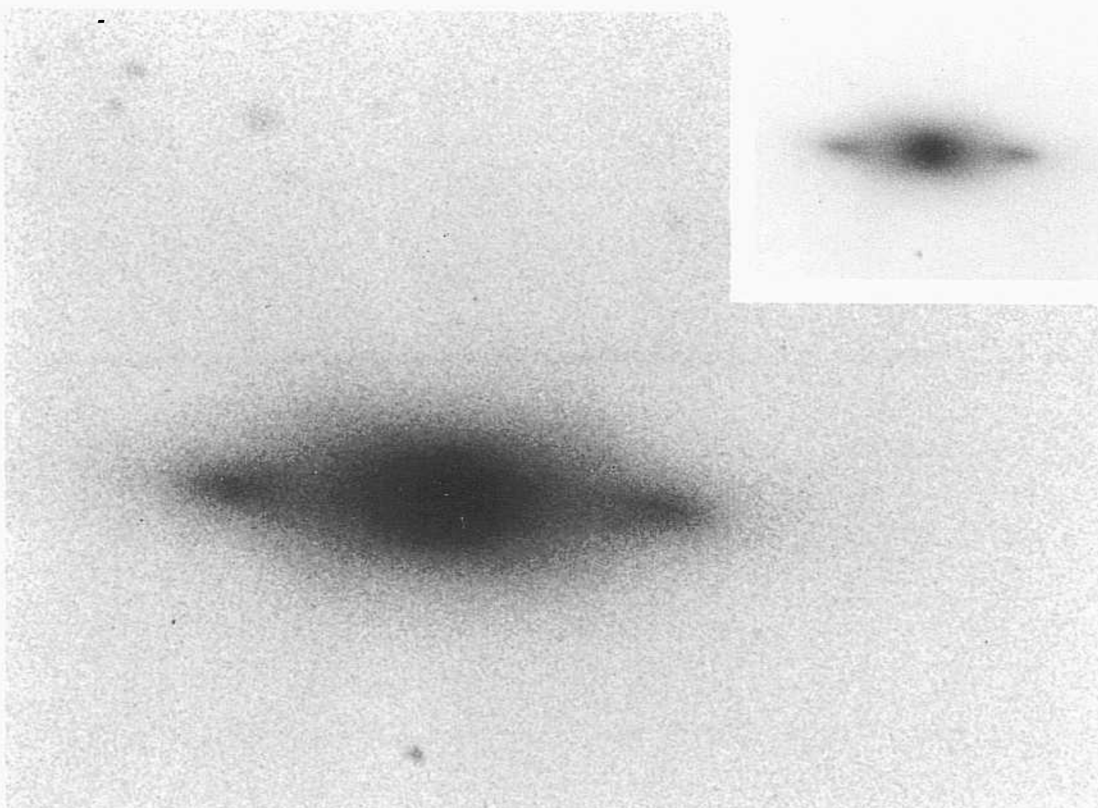
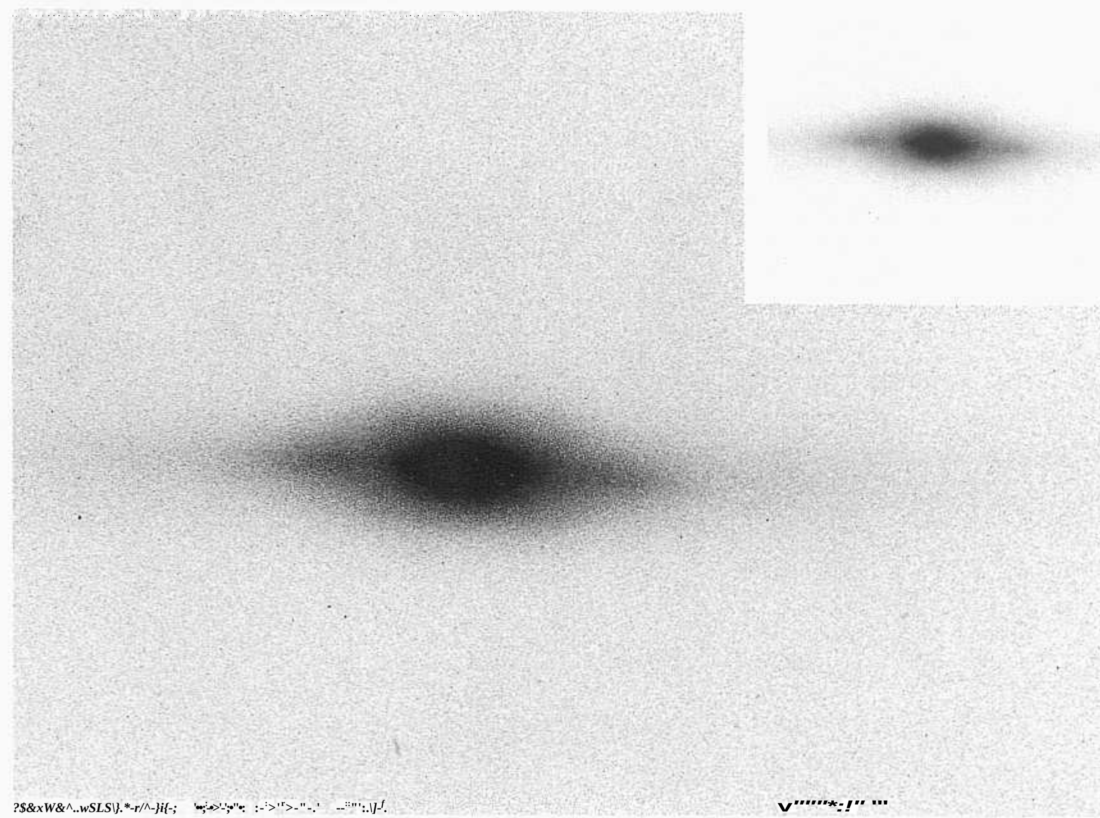
NGC 4417 is located about 1.5° north of the center of Virgo subcluster B, **which** is centered on NGC 4472 (Binggeli. Tammann, and Sandage 19 87).

The morphology of NGC 4417 is a milder case of the "peanut-center" **morphology** of NGC 1175 (panel 40), NGC 3203 (this page), and NGC 4215 (this page). There is no strong evidence for the presence of the ansae or for a decrease in luminosity in the intermediate **region** between the center and the beginning of the disk. Hence, the morphological subtype is SOj rather than $S0_2$.

NGC 4111 $S0_2(9)$ **HA, p.** 6
PH-1854-B (P) panel 53
April 17/18, 1958
103aO + GG1
25 min

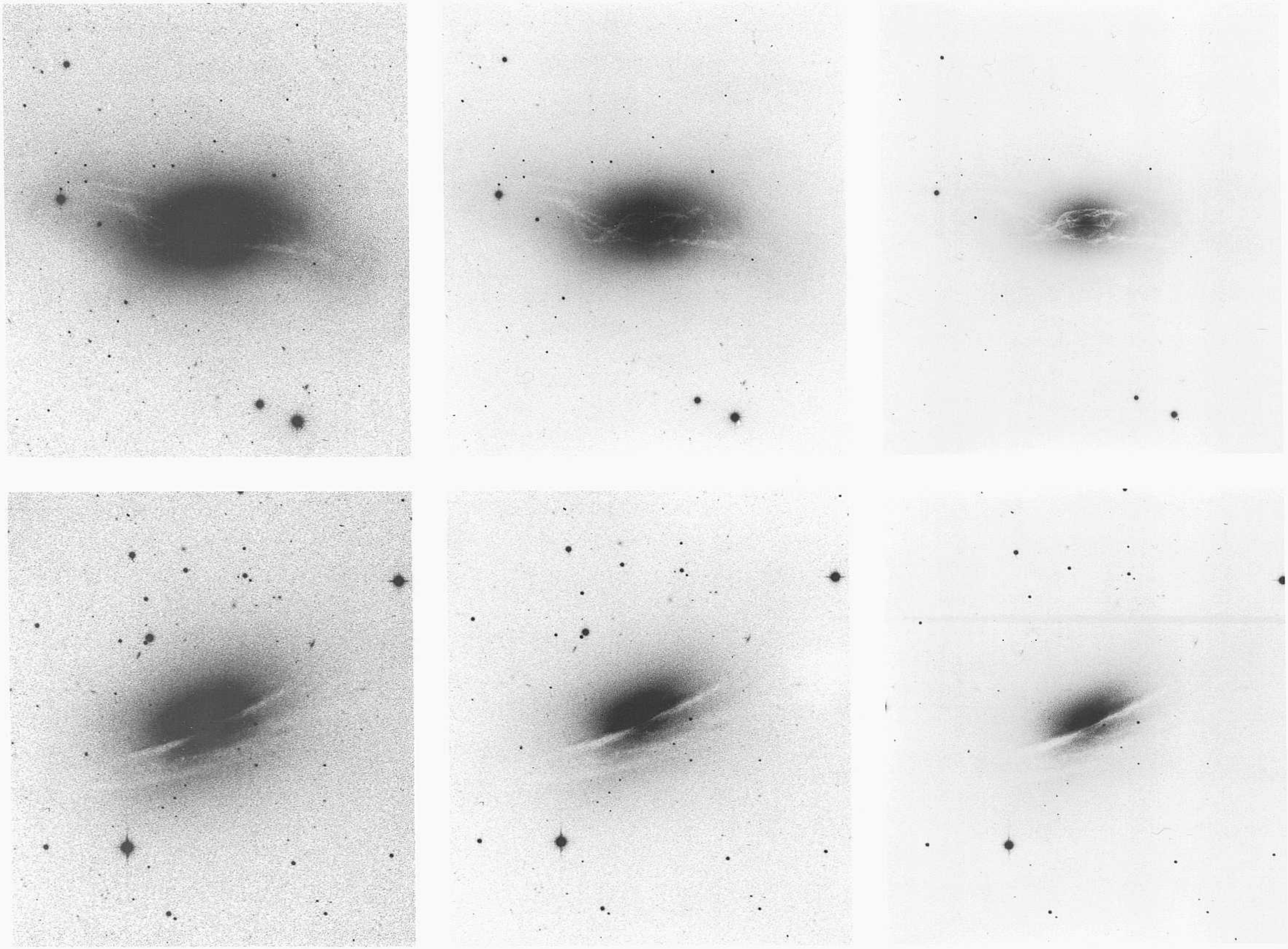
NGC 4 111 is midway between the extreme **example** for the decrease in luminosity in the intermediate region seen in NGC 42 15 (left) and the subtler expression of the effect in the edge-on galaxy NGC 2549 (panel 40). The decrease in luminosity between the edge of the bulge and the beginning of the disk in NGC 4111, seen well in the insert here, may be due to a weak dust ring or to a **separation** of material. The presence of the decrease calls for the $S0_2$ subtype.

The galaxy has a very high rotational velocity. An early measurement and discussion by Mayall and Lindblad (1970) gave a velocity difference between the center and the disk at 3 0" distance of 400 km s~^{1}, making NGC 4111 one of the fastest rotators known.

PANEL
47

PANEL
48



The galaxies on this and the next panel are peculiar because their dust lanes are unusual. All three images in the top row are NGC 4753. All three in the bottom row arc NGC 2907.

NGC 1753	SO prc	HA, p. *H*
PH-1861-B	(S?)	
April 18/19, 1958		
103aO + CGI		
25 min		

NGC 4753 is probably outside the classification sequence. II we force it into the classification we do so on the same basis usnl by Hubble, [f the absorption lanes were removed, the underlying luminosity distribution would approximate an SO form.

The three images here, printed to different contrast levels, have been made from a different original plate than was used in the Hubble Atlas (p. S).

The dust lanes are very thin, delicate, and coherent (continuous) over the long arcs that arc traceable. They show no rotational symmetry, as is common to dust lanes in the disks of spirals where the pattern is apparently governed by the rotation of the disk.

The view in the positive print in the Hubble Atlas complements the view here from the negative prints.

The morphological peculiarities have been reproduced in a remarkable theoretical modeling study by Steiman-Cameron, Kormendy, and Durisen (1992). where they were able to reproduce the dust-lane pattern nearly precisely.

NGC 2907	S0a(6) pee
CD-674-Br	(dust+disk)
Jan 24/25, 1979	
HaO + GG385	
180 nún	

At least Iour dust lanes can be traced in silhouette against the bulge of NGC 2907. The patiein is similar to that in NGC 1 947 (panel 45) exeept that here the lanes are parallel to the major axis of the bulge rather than perpendicular to it as in NGC I 947. The lanes, as they track across the lower edge of the image, suggest that the dust is in a plane that we view almost edge on. permitting the stacked silhouetting of lour separate dust spiral arms that is seen.

NGC 4933 S0$_3$ pec (tides) pair
CD-2120-S (P)
March 20/21, 1982
103aO
50 niin

NGC 4933 is a clear case of interaction, with consequent distortion of the dust disk in the brighter member and an evident lidal plume to the right of the E2 galaxy. The projected angular separation of the two main galaxies is 0.9'. The fainter Scd galaxy in the field to the left of NGC 4933 is separated by 2.5'. There is no indication that this galaxy is physically connected with the main pair.

The redshift of NGC 4933, corrected to the centroid of the Local Group, is v_o = 3070 km s~^{1}. The projected linear separation of NGC 4933 from its E2 companion is small at 16 kpc, suggesting that this is indeed an encounter.

The most obvious unusual feature is the warped dust disk, similar to that in NGC 3190 (Sa; panel 76). which presumably has also been warped by an encounter.

NGC 2911 S03(2) or SO pec
CD-167O-S (S)
Dec 31/Jan 1, 1980/1981
103aO + GG385
4-5 nün

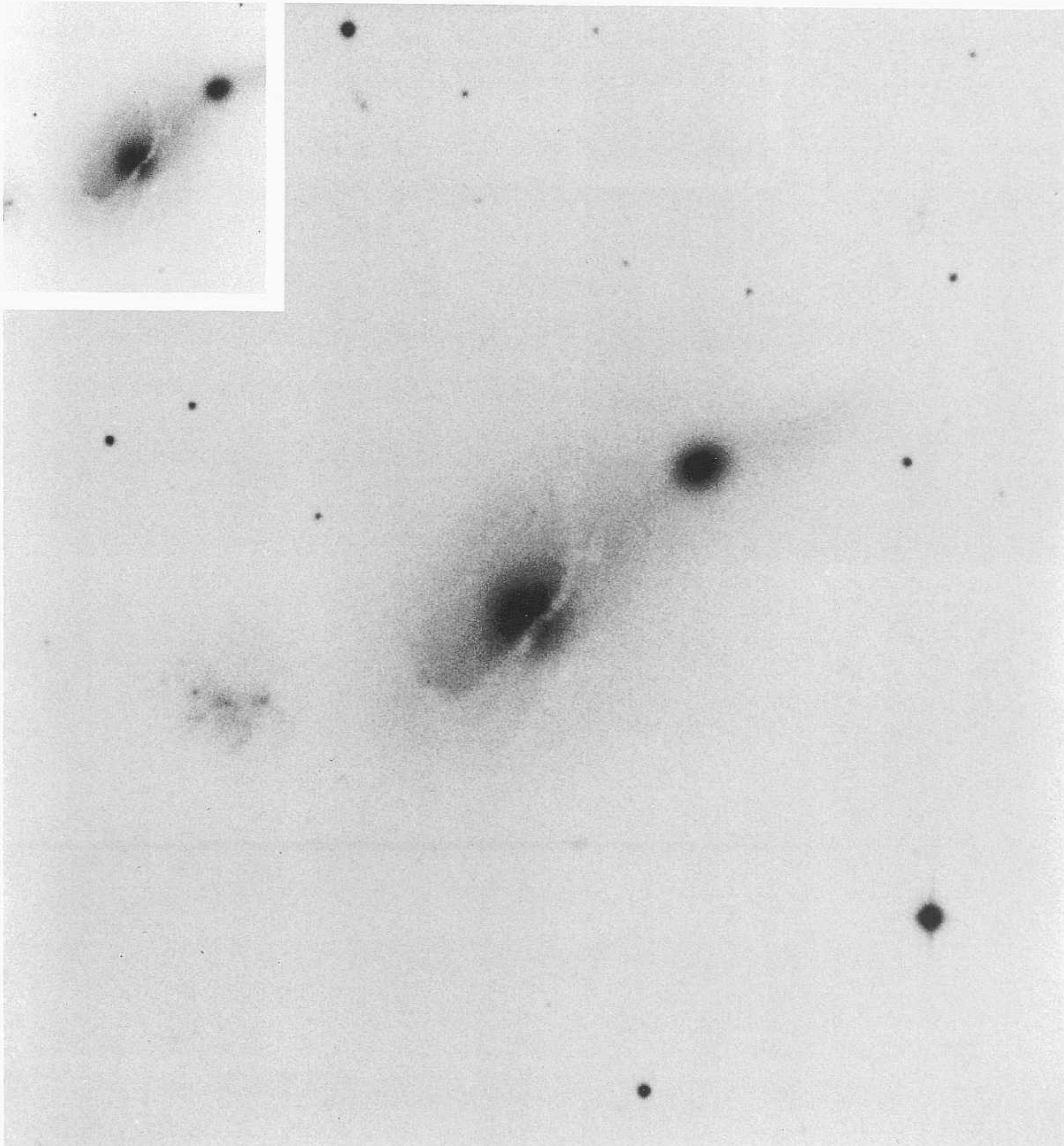
NGC 2911 is in an apparent group that includes NGC 2912. 2913, 2914, and 2919. The closest bright galaxy to NGC 2911 is NGC 2914 (Sa) at 4.8' separation. If the pair has nearly the same redshift as NGC 2911, v_o = 2 997, the projected linear separation of the pah- would be 84 kpc (H = 50).

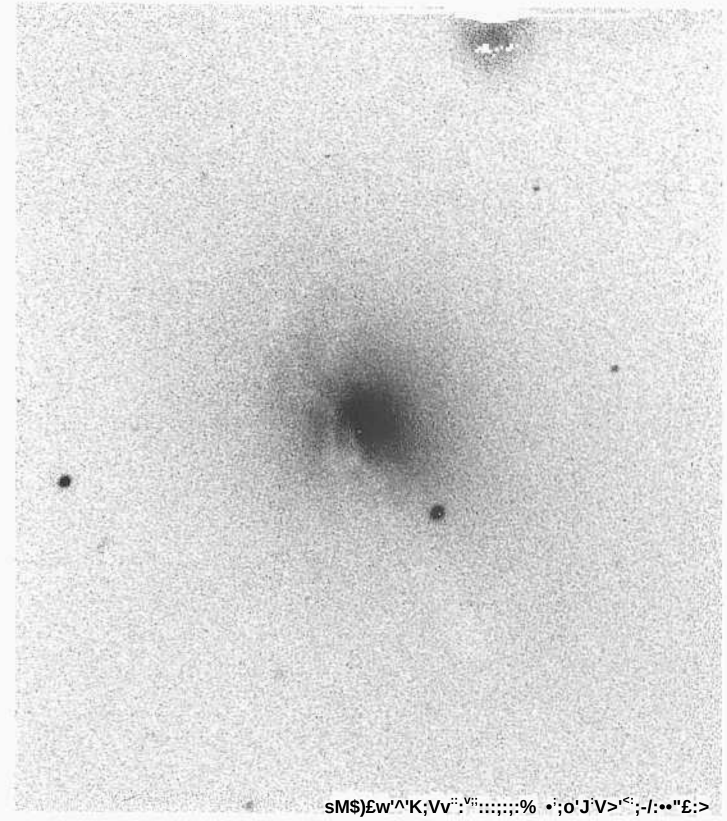
The dust lanes silhouetted against the E/SO main body resemble those in NGC 1947 and NGC 2907, described on the preceding pages.

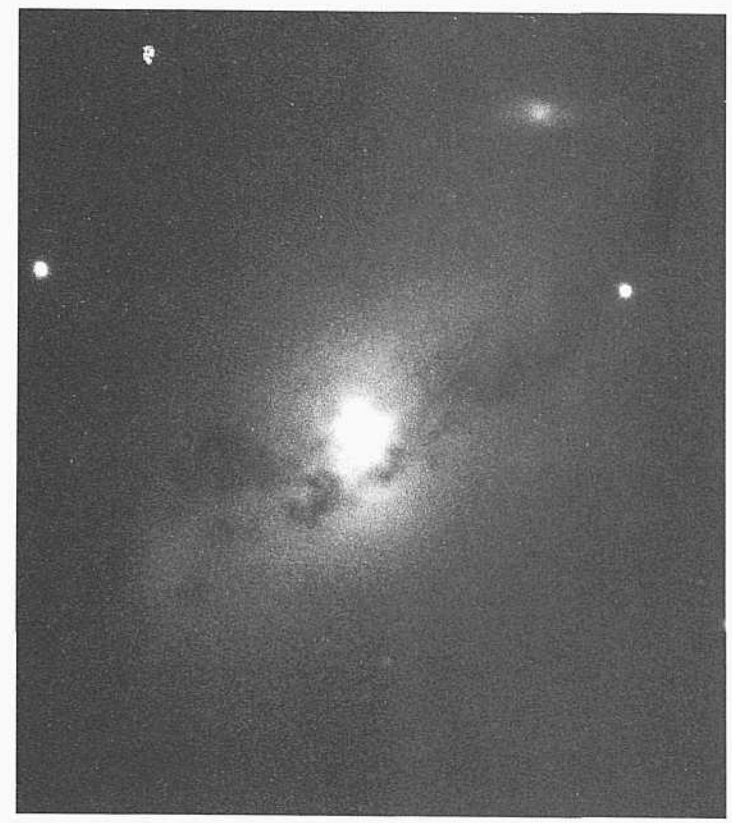
NGC 2968 Amorphous or SO3 pec pair
PH-7603-S
April 3/4, 1979
IHaJ + GG385
30 min

NGC 2968 may form a physical pair with NGC 2964 (Sc: panels 240, 251). The redshifts are f_o(2964) = 1292 km s'" and 1^(2968) = 1576 km s~J . The angular separation is 6.2'. The projected linear separation would be 53 kpc using a redshift distance of 29 Mpc (*H* = 50).

The chaotic dust pattern silhouetted against the background SO/Am main body shows no rotational organization, similar to the chaos in NGC 4753 on the preceding panel, and probably in NGC 2911, above, as well.

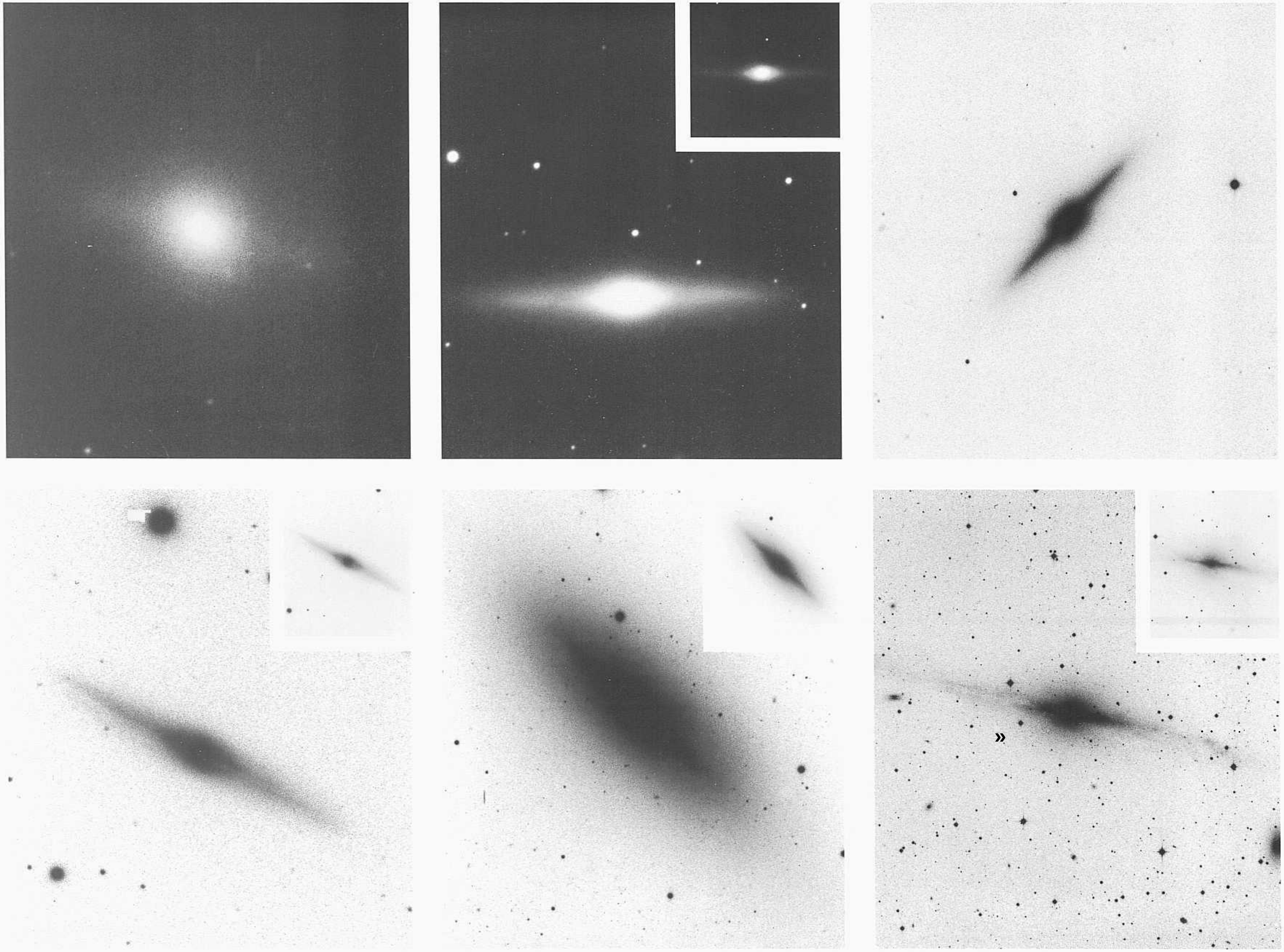






PANEL
49

PANEL
50



NGC 3414 S0i/$_2$(0)/a panel 53
PH-7985-S (VE, L, 0)
Feb 1/2, 1981
103aO
12 inin

NGC 3414 is the single best example in the RSA of a galaxy having a dominant central bulge and a rudimentary disk of very low surface brightness. The disk in NGC 3414 is of much lower mass than the well-developed disks of SO and spiral galaxies at every stage of the spiral (disk) sequence.

The simplest conclusion, independent of the details of the generally unknown process of galaxy formation, is that disks form by dissipation. In a dissipative collapse, the potential energy of position in the protogalactic gas is radiated away by atomic processes. This permits the gas that has not turned into stars in an initial formation episode to settle into a plane, forming a disk, as is described in Chapter 4. Bidges and halos of E galaxies have turned their protogalactic gas into stars on a time scale short compared with the free-fall collapse time, and no disk is formed. Disks are dissipative structures; halos are not.

NGC 3414 is an important link between the pure E sequence where no disks exist and the disk sequence of the SO and spiral galaxies. It has a dominant bulge indicating rapid star formation relative to the free-fall collapse time and therefore little dissipation, yet it has the rudiments of a disk, showing that some very small fraction of the protogalactic gas suffered dissipation and collapsed to the plane. The disk-to-halo ratio in NGC 3414 is among the smallest of any galaxy in the RSA.

NGC 5422 Sa or S0s(8) panel S2
PH-7739-S (P) Racine wedge
June 11/12, 1980
103aO
12 min

NGC 5422 is a classical SO with a semi-boxy central region and an extended and prominent thin disk.

NGC 4026 S0i/$_2$(9)
PH-7654-S (P)
April 29/30, 1979
103aO
12 inin

NGC 4026 is later in the sequence of edge-on SO galaxies than NGC 3414 or NGC 5422. in the left column here. There is a dip in disk luminosity between the central bulge and the outer disk instead of a smooth disk intensity gradient. This dip feature is similar to that in NGC 3203, NGC 4215. and NGC 411 1 (panels 47, 53). The intensity decrease is clue either to a weak circular internal dust lane or a separation of material. In any case, the presence of a high-surface-brightness disk is definite, showing that the type is SO rather than a flattened E where no disk exists or a late-type spiral in which the disk surface brightness would be considerably smaller (Sandage 1983a).

NGC 3115 S0i(7)/a HA, p. *1*
PH-61-S (P)
Nov30/Dec 1, 1951
103aO + WG2
30 min

At one time called an E7, NGC 3115 is a type example of an edge-on thin disk galaxy having a prominent, thick envelope (a thick disk). The well-developed, high-surface-brightness, very thin disk is shown well in the insert. The overprinted main print shows the problem of classifying early-type galaxies using small-scale and/or overexposed plates where features are buried and lost in the high-surface-brightness envelope. The classification would have been K7 from such plate material if based on images similar to the main print here. The galaxy is classed E7/S0! in the Hubble Atlas.

However, deep CCD exposures, which have a large dynamic range, show hooks at the two ends of the major axis of the disk, showing that NGC 3115 in fact has a spiral structure (Silva. Boroson. and Thompson 1989), requiring the mixed classification notation SO/a. This, of course, is uncertain because of the nearly edge-on aspect angle, but the spiral hooks are real.

The plate used for the reproduction here is different from the one used in the Hubble Atlas. The description there contains information not contained here.

NGC 1381 S0i(9) FCC 170
CD-718-S (P) panel 37
Feb 1/2, 1979
103aO + Wr2c
15 min

NGC 138 1 in the Fornax Cluster, is also illustrated on panel 37. The galaxy has a boxy bulge and a very-high-surface-brightness thin, smooth disk, characteristic of the SO class. Disks in SO galaxies generally have much-higher surface brightness than the disks of the average spiral galaxies later in the sequence (Sandage 1983a). showing that SO galaxies cannot have been formed by sweeping present-day spirals.

NGC 5084 S0|(i{)
CD-1855-HB (P!)
April 4/5, 1981
103aO
75 min

The large bulge and the high-surface-brightness thin disk in NGC 5084> are characteristic of SO galaxies on edge. The very-high-surface-brightness inner part of the disk is well seen in the insert print. Much-fainter extensions to the disk can be traced to large distances in the main print. Dust lanes exist in the outer region of the faint disk, seen in the main print on the lelt side of the image.

NGC 5084 is perhaps a transition galaxy between the pure SO type, such as NGC 1381, NGC 4026. and NGC 5422 on this panel, and the Sa galaxies where dust occurs throughout their outer disk regions.

It is not known if the E5 galaxy partially seen at the lower-right border of the main print, 8' southwest of NGC 5084, is a physical or an optical companion. The bright SBc galaxy. NGC 5068, 50' distant to the northwest (not on this print) is in the foreground.

NGC 7135 SOi pec (merger)
CD-46-D
Aug 17/18, 1977
103aO + GG385
45 niin

The **two** unusual features of NGC 7135 are its plume and its sharp shell. Similar plumes in other galaxies are evidently due to tidal interaction (e.g.. NGC 4933: panel 49). The sharp shell is similar to the shells in NGC 4382 (SO2; panel 41). NGC 5018 ($S0_2$/a: panels 41. 59). NGC 474 (RSO/a: panel 84), and NGC 7585 (SOj/Sa; panel 84). The shells have sometimes been attributed to mergers (Quinn 1984; Schweizer 1986: **Schweizer and Seitzer** 1988).

A candidate for a companion galaxy possibly involved in the merger is within the common envelope at the right side of the bulge. This object may also have a nucleus slightly **displaced** from the center of its apparent disk.

The inner part of NGC 7135 seen in the insert has a two-zone appearance typical of ordinary SO *1* types.

NGC 4649/4647 SOi(2) **VCC 1978**
H-ll-H (S) VCC 1972
Jan 26/27, 1920 Se(rs)III M60
Seed 30 **panel 278**
75 min

The two galaxies here form a close optical pair with an angular separation of 2.5' in the Virgo Cluster region but south and far to the east of the core of subcluster A. The redshifts are similar at u_D(4647) = 1331 km B' and t;$_o$(4649) = 1 142 km s^{-1}. The lack of evidence of tidal interaction, either as tidal plumes in the SO component or as a distortion of the spiral structure of NGC 4647. suggests that the galaxies are at different distances. At the common distance scaled to 22 Mpc for the Virgo Cluster, their projected linear separation would be small at 16 kpc; some sign of an encounter would be expected.

NGC4649 is Messier 60. **It** has a **prominent** extended envelope characteristic of SO 1 morphology. The E2 classification in the RC2 , based on a **Palomar** 200-inch plate, is **inappropriate.**

NGC 7232/7233 S03(7) **or Sb** **pair**
CD-1113-Br Sa(late)
Aug 19/20, 1979
103aO + **GG385**
45 **min**

The orientation of the top and bottom prints, showing the same field, is north at the bottom, east to the right. NGC 7232 is the flattened galaxy to the left, NGC 72 33 (Sa pec) is on the right. The pair forms an apparent (but optical?) triple with NGC 7232B (Scd) 4' north of NGC 72 33. **[HI** scans quoted by Huchtmeier and Richter (1989) show that the redshift of NGC 7232B either is greater than 3000 km s^{-1} or that the 21-cm redshift search was defective]

The redshifts are i>$_0$(7232) = 1668 km s^{-1} and u_o(7233) = 1873 km s^{-1}, from Huchtmeier and Richter (1989), reduced to the centroid of the Local Group. The angular separation of the pair is 1.8', giving the small projected linear separation of 1 8 kpc.

The high-contrast print suggests a tidal bridge between the galaxies. The arms of NGC 72 33 are smooth and massive, and may be tidally induced.

NGC 7232/7233 $S0_3$(7) or Sb **pair**
CD-1113-Br Sa (late)
Aug 19/20, 1979
103aO + GG385
45 **min**

The low-contrast print is made from the same Las Campanas plate used above. The difference between the smoothness of the outer arms in NGC 7233 and the appearance of the inner regions, chopped up by dust, is the basis for suggesting that the outer smooth arms of NGC 7233 are tidally induced.

The central dust lane in NGC 7232 betrays either an SO3 form with exterior ansae or a later spiral type seen edge on.

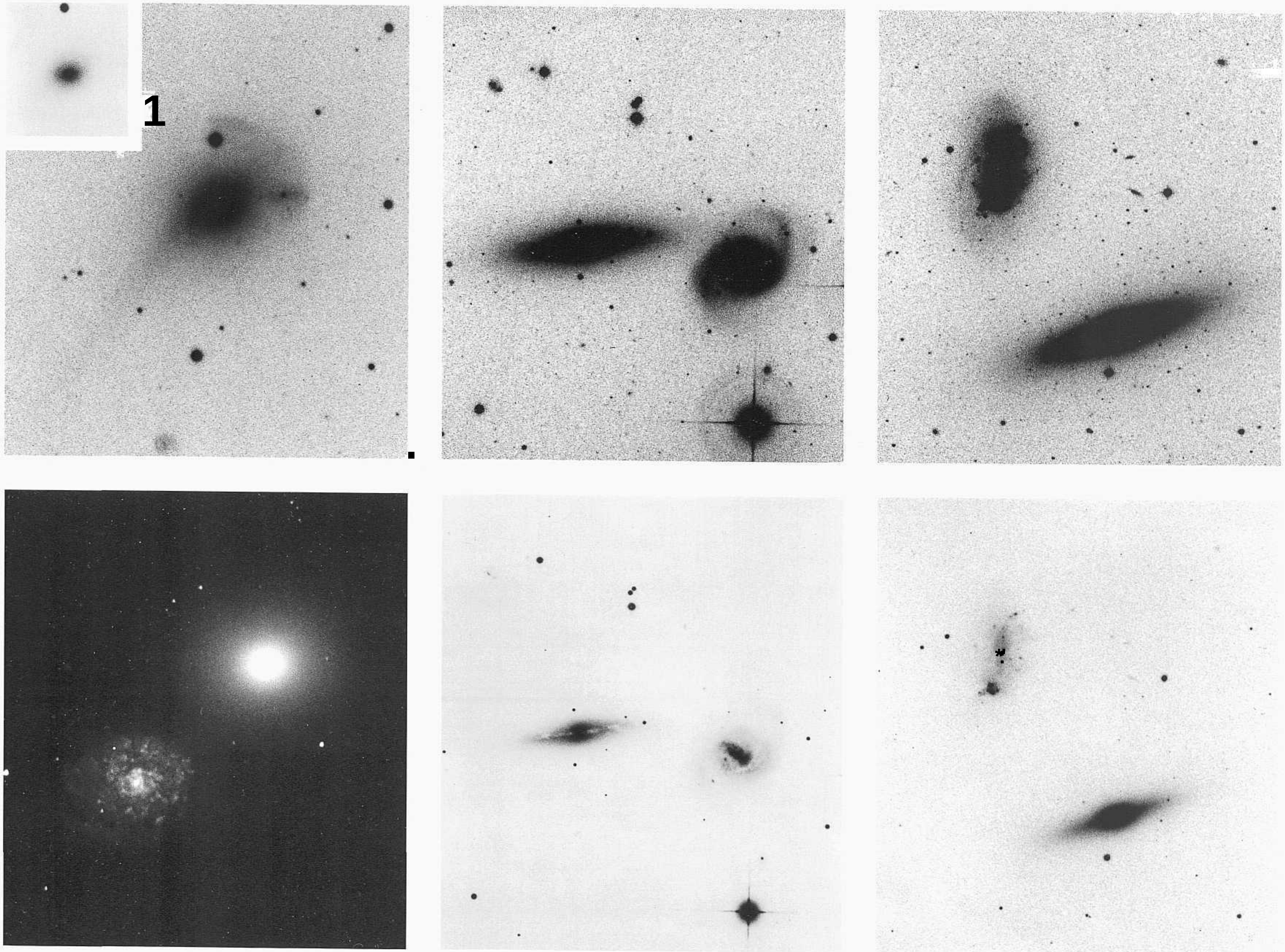
NGC 1596/1602 S0i(7) **pair**
CD-676-Br (P) **panel 328**
Jan 25/26, 1979 SBm
IlaO + GG385
180 min

These two galaxies form a physical pair of greatly dissimilar types. NGC 1569 is a classical SOj with a boxy bulge and a well-defined, high-surface-brightness disk. NGC 1602 is a star-forming Sm galaxy having a knot of bright **HII** regions. Because of the dissimilar types and their undoubted physical relationship, the pair is important in understanding that the formation of SO galaxies is generic to the classification sequence: SO' s are not secondary forms made from what were once spirals by some process such as gas sweeping; they are intrinsic to the sequence.

The angular separation of the pair is 3.1'. The redshifts listed by Huchtmeier and Richter (1989) and corrected to the centroid of the Local Group are v_o(*l* 596) = 1324 km s^{-1} and y_o(1602) = 1382 km s^{-1}. The projected linear separation is small at 24 kpc based on a redshift distance **of** 27 Mpc (***H*** = 50).

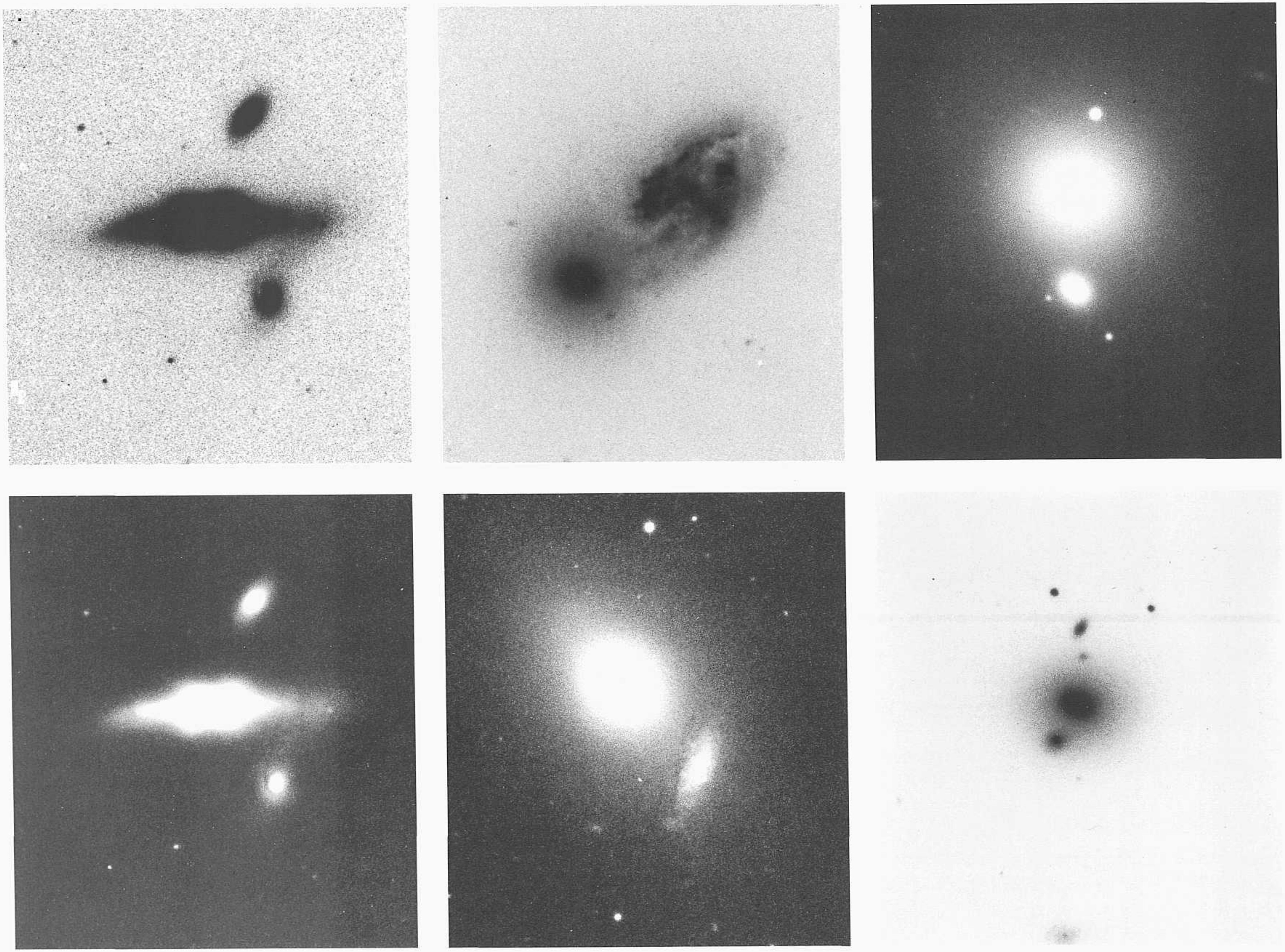
NGC 1596/1602 S0i(7) **pair**
CD-652-Br (P) **panel 328**
Jan 5/6, 1979 SBm
103aO + GG385
10 min

The print here is made from a different Las Campanas 100-inch du Pont plate from the one used for the print above. The SO morphology of NGC 1596 is well seen by the existence of the bright disk and the boxy bulge. The knot of **HII** regions in NGC 1602 and the other evidence of star formation over its face are well seen here.



PANEL
51

PANEL
52



NGC 128 $S0_2(8)$ pec HA, p. 7
PH-771-S (P)
Aug 23/24, 1954
103aD + GGll
30 niin

NGC 128 is the dominant member **of** a group of at least five galaxies; two of the other group members arc the fainter companions shown in this print and the one below. The five brightest **group** members arc NGC 125. 126, 127, 128. and 130. The two companions to NGC 128 shown here are NGC 130 **[$S0_x(6)$]** above and NGC 127 [$S0_3$ pec] below NGC 128. The **prints** are made from the same original plate used in the Hubble Atlas.

The angular separations from NGC 128 arc 0.9' for NGC 130 and 0.8' for NGC 127. The redshift of NGC 128 is v_0 = 4439 km s~\ **giving** a redshift distance of 89 Mpe (H = 50). The projected linear separations are small, at 23 kpc and 21 kpc for NGC 130 and NGC 127, respectively, from NGC 128.

The connecting bridge between NGC 127 and NGC 128 **clearly** shows interaction.

NGC 128 **$S0_2(8)$** pec **HA, p.** 7
PH-771-S **(P)**
Aug 23/24, 1954
103aD + GG11
30 **min**

The principal features **in** NGC 128 in the **positive print** here are (1) the pronounced **peanut-shaped** bulge, similar to but more extreme than the same form in NGC 1175 (SO?, panel 40) and others on the same panel, and (2) the beginnings of a bright disk that **is** bent in its extension beyond the left-hand (south) ansa.

The luminous bridge seen well in the top print contains dust visible in projection against the north ansa. Curiously, the internal dust ring of NGC 127, which is the reason for its SOg classification, cannot **be** traced in the part of the image of NGC 127 closest to NGC 128. It **is as if** the ring is broken and the dust that was there is now seen in silhouette against the north side **of** the disk in NGC 128.

NGC 274/275 SOi(O) pair
PH-262-Mi (P)
Sep 13/14, 1956 S **pec(lides)**
103aO
20 **min**

This is an unambiguous case of an **encounter** of two disparate galaxy types, similar to NGC 1596/1602 on the preceding page. NGC 274 with a redshift of v_0 = 1894 km s~[1] is nearly projected onto **the** image of NGC 275 [S **pec(tides)],** which has virtually the same redshift. v_o = 1889 km s^{-1}. The angular separation of the pair is **44".** The **redshift distance** of 38 Mpc (// = 50) gives **a** very small projected linear separation **of** 8 kpc.

NGC 274 has the morphology of a classical S0i(0). Its image is undisturbed. There are **no** tidal plumes, nor is the **characteristic** two-zone circularly symmetric image distorted, as might **be expected** if the encounter was progressing toward merger, suggesting that **the** binary pair is extended in the line **of** sight.

NGC 275 has the morphology of a late-type spiral, but its form is **not** as regular as that **of** most **high-surface-brightness** Sc galaxies. The many knots, presumably **Mil** regions, suggest recent star formation.

The presence of a normal SO galaxy in a physical pair **with** a star-producing Sc galaxy shows that SO galaxies arc not a result of sweeping gas from a parent spiral to form an SO. If the SO morphology of NGC 274 was produced that way, why was not its close companion NGC 275 affected **equally?** SO galaxies are generic to the Hubble sequence, not a result of later evolutionary processes (Sandage 1983a).

IC 5328 S0i(3)
CD-1035-Br (I)
July 21/22, 1979
103aO + GG385
45 **min**

IC 5328 forms a close pair with IC 5328A (Sc), at 0.8' separation. The redshift of IC **5328Ais** unknown (c. 1990). The redshift of IC 5328 is v_o = 3011 km s^{-1}. The angular separation of the pair (optical?) is 43". If the pair is **a** physical association at the redshift distance of 60 Mpc (// = 50). the projected linear separation of the pair would be small at 14 kpc.

The isophotes of IC 5328 do not appear to be distorted by the presence of the companion. The two-zone appearance of the image is characteristic of a normal SO] galaxy.

NGC **5846** **S0i(0)** **group**
CD-1496-S/Br **(I)**
July 31/Aug 1, 1980
103aO + GG385
45 min

NGC 5846 is **the** brightest in a **group of perhaps ten** members, **as originally defined by** Humason. Mayall. and Sandage (1956. Table XI) at a mean **redshift of** <V_0> = 1808 km a^{-1}. The pair shown **here with the** close angular separation of 35" has **a redshift difference of 554 km** s^{-1} **which,** although **large, is not uniquely** so lor close pairs. The **redshifts** arc **y_o(5846) = L714 km s^{-1}** and **$t>_0$(5846A)** = 2268 **km** s~[1]. If **the** pair is a binary **at the** mean redshift distance of 40 **Mpc** (*H* = 50). **the** projected linear separation would be small at 7 **kpc,** supportive of **the** large velocity **difference. However,** there is **no** evidence **for a physical bridge** between the galaxies.

The **morphology** of NGC 5846 is prototypical SO1 with an **extended** envelope that **is not characteristic** of ellipticals. The type **of** *Ki)* listed in the RC2, based on a **Palomar 200-inch** plate, is **not supported** here.

NGC 4377 **S0i(3)** VCC **778**
CD-783-S **(P!)**
Feb 22/23, 1979
103aO + Wr2c
45 **min**

The bright galaxy of this apparent quartet has an S0j morphology **with** two p**rinc**ipa**1** luminosity zones, based[1] on visual inspection of photographic plates. At this writing (e. 1990), the individual redshifts **of the companions** are unknown. The angular separation **of the** three companion E galaxies from NGC 4377 are 33". 20", and 20". The lack of signs of tidal interaction or distortion of the classical SOj **luminosity profile** in NGC 4377 might suggest **that no** merger is occurring and that the quartet may be a projection **coincidence.** Individual redshifts are **required.**

If all four galaxies arc at the same **redshift** distance of NGC 4377 *(v_0 -* 1227 **km** s"[1]) **of 24** Mpc ***(II*** = 50), the **projected** linear separations **of** the companions from tin* main galaxy are very small at **4** kpc, 2.3 kpc, and 2.3 **kpc.**

Detailed descriptions of each of the six SO-type examples on this summary page have been given on the relevant panels and are not repeated here. The types on this page range from prototypical $S0_1$ (NGC 3 998) through $S0_3$ (NGC 6893) with its characteristic circular interior dust lane. Examples of a rudimentary disk in a dominant bulge galaxy (NGC 3414), and a typical high-surface-brightness $S0_2$ disk galaxy (NGC 4111) complete the summary of normal SO morphology on this page. The unusual bright-rim case of NGC 3056 is also shown.

NGC 3998 — $S0_1(3)$ (P!) — panel 31
PH-7640-S
April 28/29, 1979
103aO
12 min

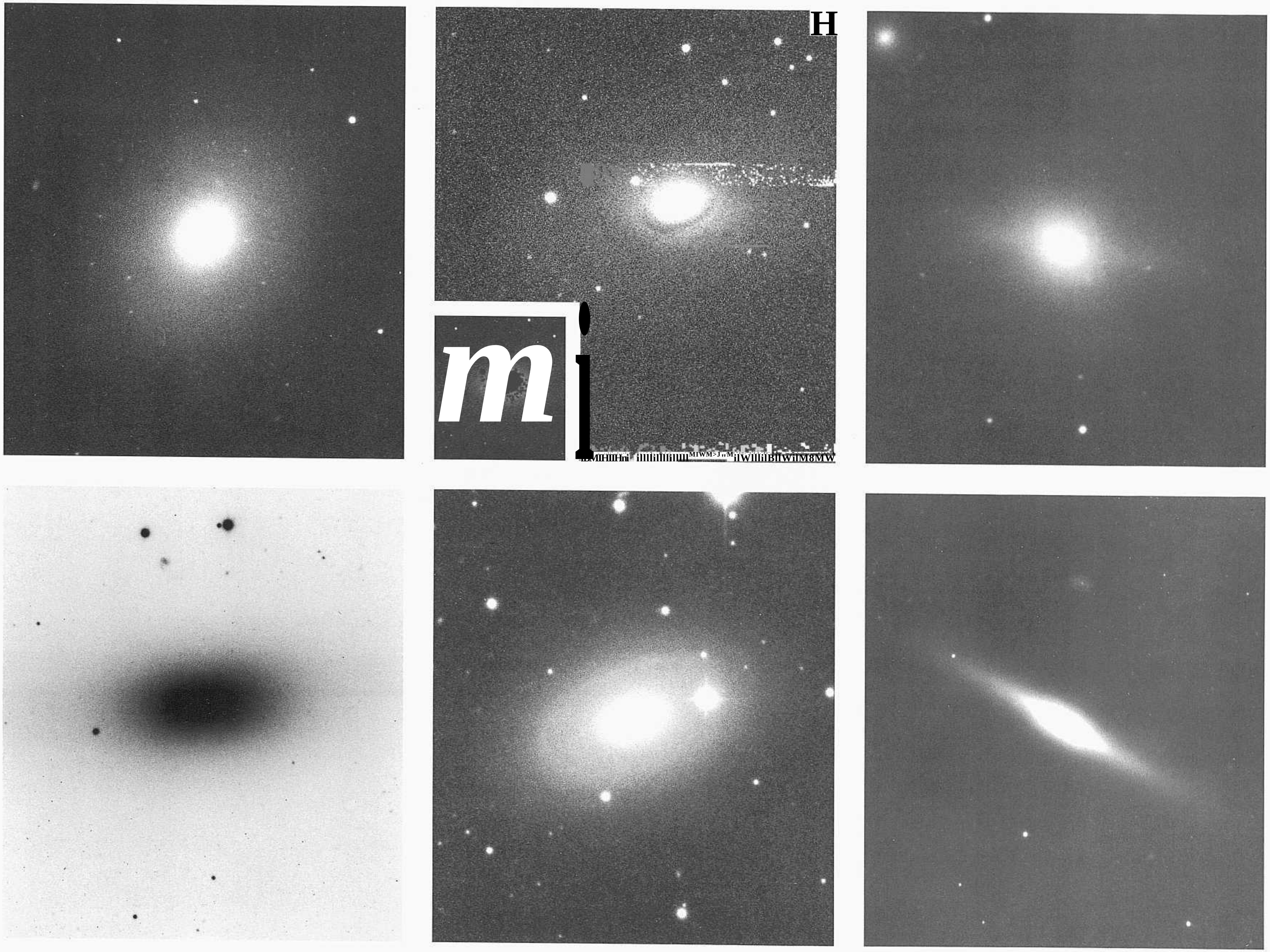
NGC 6893 — $S0_3(4)$ (P) — panel 43
CD-570-S
Oct 8/9, 1978
103aD + GG495
30 min

NGC 3414 — $S0_{1/2}(0)$/a (VE, L, 0) — panel 50
PH-798-S
Feb 1/2, 1981
103aO
12 min

NGC 2768 — $S0_{1/2}(6)$ (I) — panel 38
PH-719-B
April 4/5, 1953
103aO + GG1
20 min

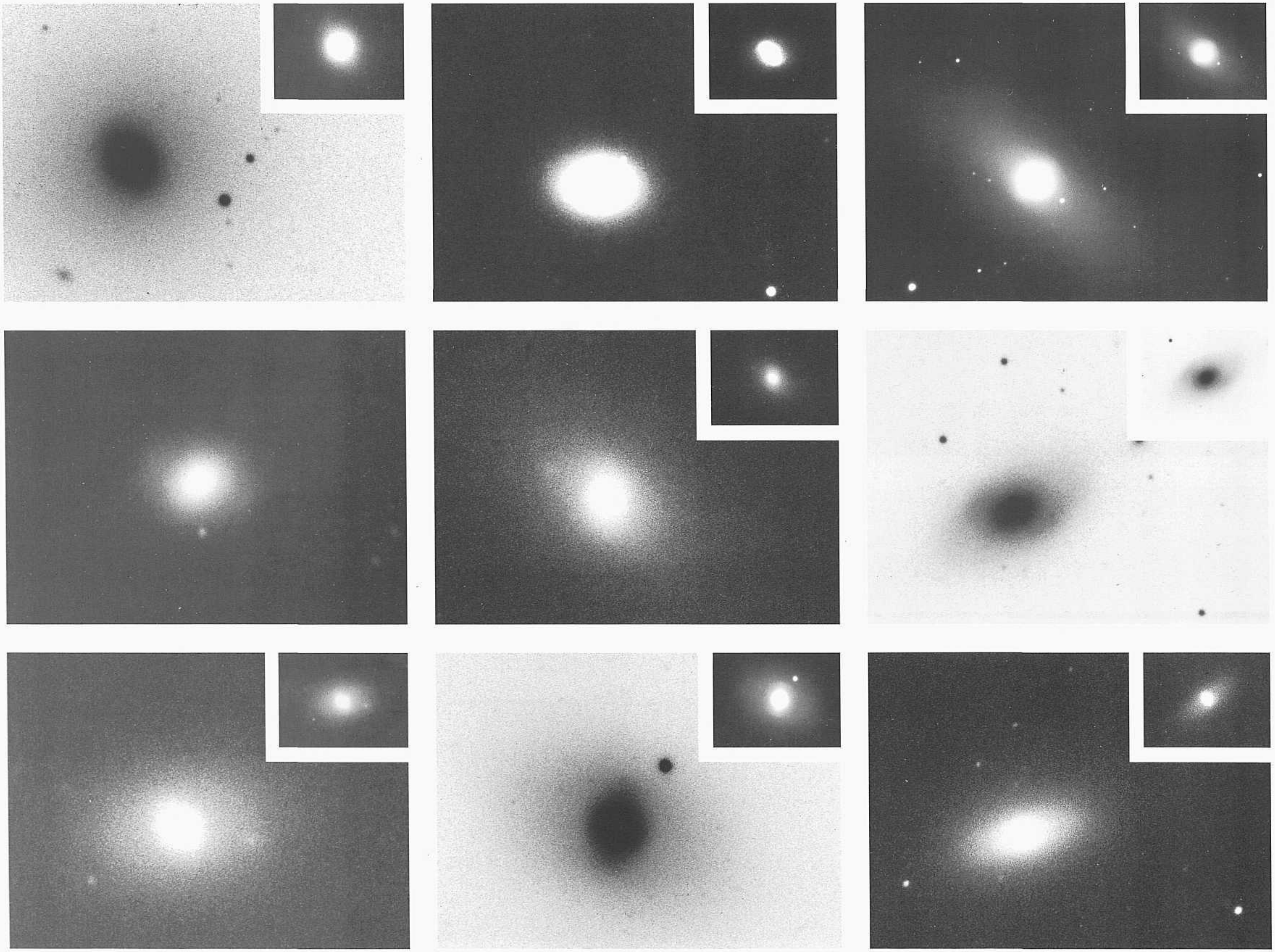
NGC 3056 — $S0_{1/2}(5)$ pec (P) — panel 39
CD-1348-S/Br
March 15/16, 1980
103aO + GG385
45 min

NGC 4111 — $S0_2(9)$ (P) — HA, p. 6; panel 47
PH-1854-B
April 17/18, 1958
103aO + GG11
25 min



PANEL
53

PANEL
54



The SBO Classification Section

NGC 4267 SBOi VCC 369
PH-632-B (P)
June 21/22, 1952
103aO + GG1
30 min

The remarkably extended, very faint outer envelope in NGC 42 67 can be traced on the original plate to beyond the two bright stars to the right of the bulge on the print here. The bulge is flattened, and has the beginnings of a disk embedded in the nearly circular envelope. (The latter may be either a halo or an outer disk seen face on.) The flattening of the bulge is interpreted as the bar because its major axis makes a large angle (about 80°) with the major axis of the outer envelope, characteristic of barred galaxies. In an ensemble of barred galaxies, the position angle of the bar is independent of the position angle of the intermediate disk in which the bar is embedded. (Note that the disk is called the lens in the Hubble Atlas.)

NGC 4754 SB0i(5) VCC 2092
H-282-H (P)
April 15/16, 1923
Seed 30
135 inin

NGC 4754 forms a wide pair with NGC 4762 (S0|i panel 37), at an angular separation of 10.7'. The pair is in the far eastern part of the surveyed Virgo Cluster region (Binggeli, Sandage, and Tammann 1985).

NGC 4754 is classed as SBO because the major axis of the central high-surface-brightness bulge is nearly at right angles to the major axis of the extensive faint outer envelope, which we take to be the disk in projection. This envelope is of low surface brightness, and is seen most easily on the print here by viewing from a distance and moving the head or the eyes rapidly. The central region, at right angles to the envelope, is here called the bar. In the orientation of this print, its major axis is directed from lower left to upper right.

NGC 3458 SBOi
PH-7715-S (P!)
Feb 11/12, 1980
103aO
12 min

NGC 3458 has the same pattern described above for NGC 42 67 and NGC 4754. The central elongated bulge, which is the bar, makes an angle of about 60° with the major axis of the extended disk.

IC 2035 SBO](4) pec
CD-164-S (I)
Feb 5/6, 1978
103aO + GG385
30 min

A comparison of the main and the insert prints (both enlarged to the same scale and printed to the same orientation) shows that the central, high-surface-brightness region of IC 2035 (which is the bar) is elongated, with its major axis at an angle of about 40° to the major axis of the envelope. The envelope itself has two apparent luminosity zones. The outermost zone of this three-zone form (counting the central bar), characteristic of SO galaxies, is only a very narrow annulus, just visible in the main print here.

NGC 2880 SBOi
PH-7902-S (I)
Nov 6/7, 1980
103aO
12 nun

NGC 2880 has a three-zone form, with each of three zonal isophotes tilted relative to its neighbor. The central, high-surface-brightness regions (the central zone seen well in the insert) has a major axis at position angles of about 4 and 10 o'clock in the orientation of the print here. The intermediate envelope, also shown well in the insert, has a major-axis position angle at about 5:30 and 11:30 o'clock. This intermediate component is seen as the central region of the main print (the true central nuclear region shown in the insert is burned out). The outer envelope (the disk?) in the main print again has the major-axis orientation of the central nuclear region. The intermediate region is, then, the bar.

NGC 2880 is the subtlest galaxy with this morphology. In the literature of the 1990's, the form is generally called "twisted isophotes." More-prominent illustrations of the pattern are NGC 4483 at the right on this page and NGC 3412 on the next panel, where the pattern of three zones with very different orientation is striking.

NGC 5473 SB0i(3) panel S7
PH-7626-S (P)
April 27/28, 1979
103aO
10 min

The bar that emerges from the central (nearly circular) bulge is definite in NGC 5473. In the orientation of the prints here, the bar has the position angle 12:15 and 6:15 o'clock. The bar terminates on the "edge" of a faint flattened

(NGC 5473 continued on next page)

Examples are shown on this and the next page of galaxies whose forms are similar to SO galaxies hut where the symmetry in the disk is broken by the (often subtle) presence of an internal structure described as a bar. When the bar is simply a deviation from elliptical symmetry, the galaxy type is SBO | . On the other hand, a well-defined sharp bar, such as in NGC 4608 ($SB0_3$/a; panel 97), calls for bar subtype 3. Many prototype examples of SBO3 bars are set out in the SBO/SBa classification section (e.g. NGC 4643, panels 97, 107: NGC 510 1 , panels 1 00, 101, 103; etc.)

Galaxies where the bar does not extend completely across the face of the underlying intermediate disk (called the lens in the Hubble Atlas) are called SBO2- There are two diametrically opposite regions of enhanced luminosity on the rim of the intermediate zone: these regions, together with the internal bulge, constitute the bar.

Note that the subscript on the SB bar classification has a different meaning than the subscript in the SO class, where it denotes a dust class.

Many of the SBO galaxies in the RSA are of the diffuse bar SBOj type; details shown on this and the next panel are subtle. Many of the prints show that the images are not far different from SO types. These galaxies will usually be misclassified as SO or even E types on small-scale and/or overexposed plates.

NGC 3384 SB0i(5) Leo Gr #26
PH-270-S (P) panel S7
Dec 10/11, 1952
103aD + GG11
25 nün

NGC 33 84 is one of the brightest galaxies in the Leo Group (Ferguson and Sandage 1990, where a map is given), whose closest other bright members are NGC 33 79 (E0; panel 1) at 7.2' separation, and NGC 3389 (Sc; panel 253) at a 6.3' separation from NGC 3384. The mean redshift for the group listed by Ferguson and Sandage (1990) is $<u_o> = 909$ km s"[1].

The central circular bulge has two small luminous projections (position angles at 1 and 7 o'clock in the prints here) that extend to the periphery of the faint, highly flattened envelope whose major axis is at right angle to that of the projections. The form is similar to that of most of the other galaxies on this page.

NGC 4483 SB0i(5) VCC 1303
CD-716-S
Jan 31/Feb 1, 1979
103aO + Wr2c
45 min

NGC 4483 is in the Virgo Cluster, near the center of subcluster B (Binggeli. Tammann, and Sandage 198 7). The intermediate luminosity zone (which is the bar and is well shown in the insert) is tilted relative to the central bulge. It is also tilted relative to the outer envelope (the disk), which is the third zone. The pattern is characteristic of SBO galaxies. NGC 4483 is a prototypical example.

NGC 16 SBO 1 (4)
PH-7542-S (S)
Nov 6/7, 1978
103aD + GGll
25 min

The major axis of the central bar is nearly at right angles to the low-surface-brightness envelope.

NGC 3-112 SB0i/2(5) Leo Gr #49
CD-1699-S (P!)
Jan 4/5, 1981
103aO + GG385
45 niin

NGC 3412. listed in the Leo Group catalog (Ferguson and Sandage 1990), has the low velocity (t'_o =731 km s^{-1}) characteristic of the group.

The intermediate luminosity zone, which is the bar, has a major axis inclined by about 35° to the major axis of the low-surface-brightness extended envelope, interpreted as the disk.

Note that the brightest part of the insert print is the most interior of the three zones, characteristic of SO galaxies. This first (interior) zone is the bulge. The flattened bulge is aligned with the outer envelope (the third zone), but not with the bar that is well seen as the inclined intermediate zone in the main print. In the insert print, the bar is the faint inclined envelope that surrounds the bulge. The disk, which dominates the main print, is not seen in the insert print.

The central bulge and the third zone of the extended envelope (the disk) have a common orientation in the projected image in most galaxies on this and the preceding panel. It is the intermediate zone (i.e. the bar) that has a different orientation from the first and third zones. This is the reason for interpreting the intermediate zone as a bar.

NGC 4346 SB0i(8)
PH-7988-S (P)
Feb 1/2, 1981
103aO
12 min

The bright central region is tilted by about 10° to the major axis of the outer highly flattened envelope, shown well here in the main print.

NGC 1023 SB0i(5) NGC 1023 Gr
PH-164-S (P)
Sep 22/23, 1952
103aO + Wr2c
20 niin

NGC 1023 may be the brightest member of a group identified by Humason, Mayall, and Sandage (1956). Two possible dwarfs (Im types), of the eight such dwarfs mentioned in the Hubble Atlas as group candidates, are shown in the Hubble Atlas (p. 40).

The deviation of the intermediate-zone orientation from that of both the central nuclear region (shown in the insert) and the outer extended envelope (shown in the main print) is characteristic of SBO types.

A low-surface-brightness Im dwarf companion is to the left and slightly below the major axis of the NGC 1023 envelope in the main print here.

NGC 4233 SB0i(6) VCC 220
CD-781-S (P)
Feb 22/23, 1979
103aO + GG385
45 min

The elongation of the central, nearly circular dominant bulge, at an angle of about 70 ° to the major axis of the flattened envelope, accounts for the SBO classification.

NGC 4442 SB0i(6) VCC 1062
CD-717-S (P)
Jan 31/Feb 1, 1979
103aO + Wr2c
45 niin

The tilt of the central bright bulge of NGC 4442 by about 15° to the extended flattened envelope necessitates the SBO classification.

NGC 5195 SBOi pec HA, p. *26*
PH-57-MH panels 172, 177
Feb 13/14, 1950
103aO
30 niin

NGC 5195 is outside the classification system. Its form is undoubtedly affected, at some level, by the encounter with M5 1 . The type assigned here is based on a guess as to the luminosity profile if the overlying dust pattern were removed.

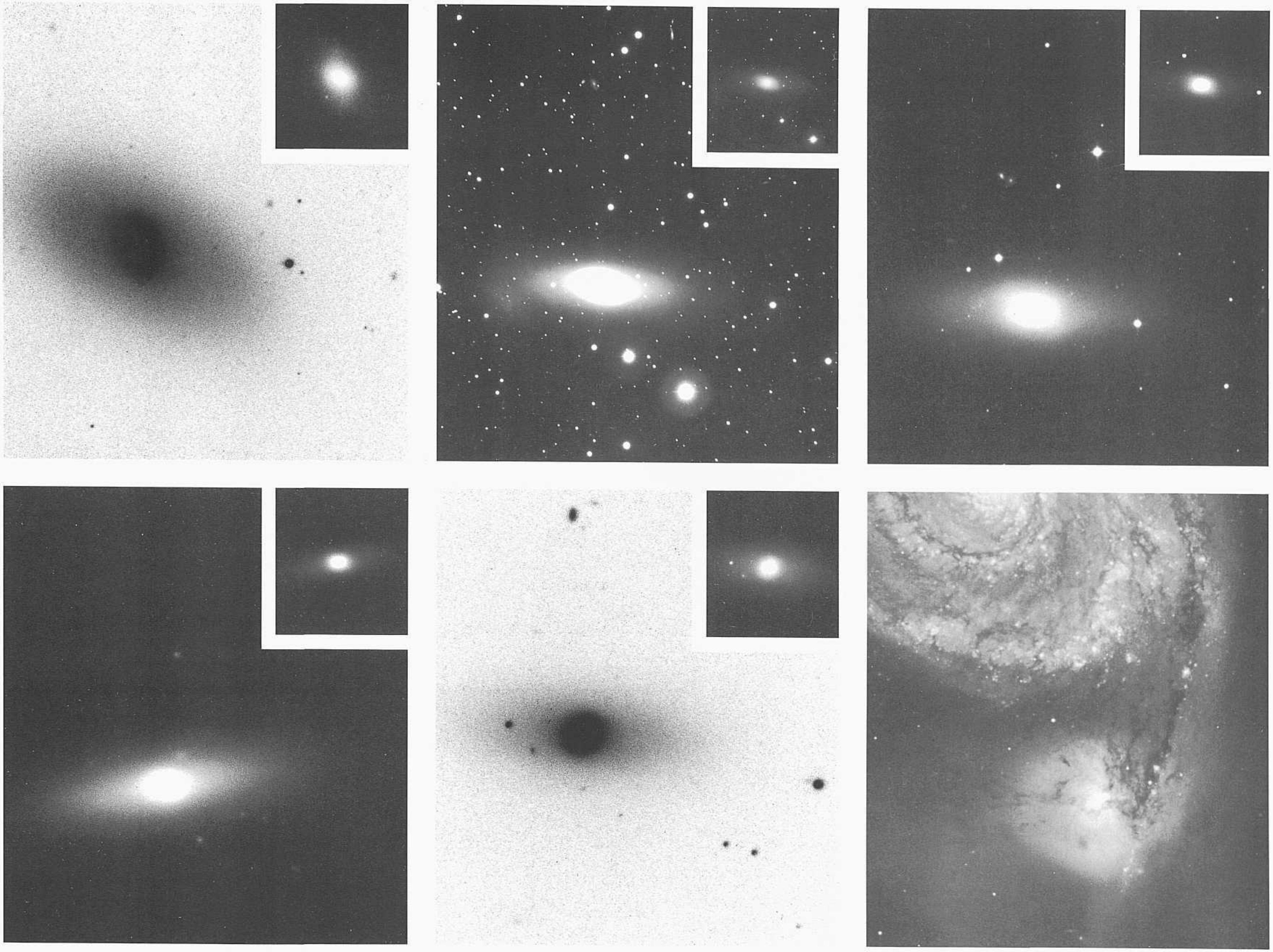
The description in the Hubble Atlas (p. *26)* suggests that the morphology has similarities to the Amorphous class (panels 333—340), which includes M82 and NGC 307 7.

Color-subtraction images of M5 1 and NGC 5195 were given by Zwicky (1955).

(IS'GC 5473 continued from previous page)

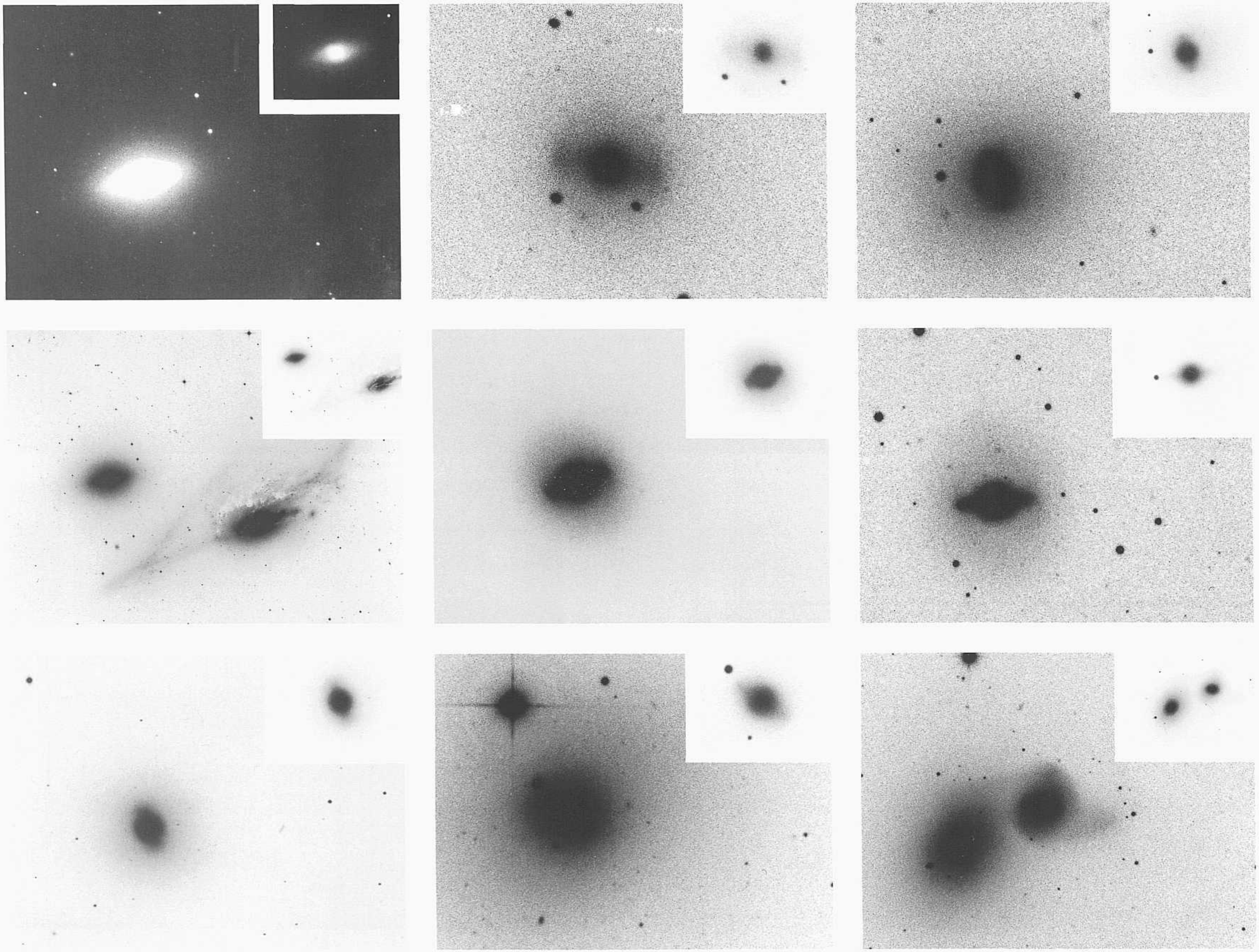
envelope whose position angle of its major axis is 3:30 and 9:30 o'clock.

This pattern, where the bar ends at the periphery of the disk (the lens in the language of the Hubble Atlas), is the common form in many early-type barred galaxies, especially in the SBO/Sa transition morphological box (e.g., NGC 936, $SB0_{2/s}$/a, panels 90, 106, S9; NGC 3300 and NGC 3637, SBO/a, panel 89) and in the SBa class (e.g., NGC 2787, panels 57 and 95; NGC 4643 and NGC 7079, panel 97; NGC 3081, panels 99 and 107).



PANEL
55

PANEL
56



NGC 4435 SB0i(7) VCC 1030
CD-743-S (P) panel 153
Feb 3/4, 1979
103aO + Wr2c
60min

NGC 4435 forms an optical pair with NGC 4438 (Sb tides; shown below and on panel 153) near the center of Virgo Cluster subcluster A associated with NGC 4486.

The central bulge in NGC 4435 has an elongated image whose major axis makes an angle of about 70° to the major axis of the disk, as shown in the insert. The difference in the tilt of the isophotes of the bulge and the extended outer envelope is the classification criterion for the SB class.

NGC 4435/4438 SB0i(7) VCC 1030
CD-743-S (P) VCC 1043
Feb 3/4, 1979 Sb?(tides) panel 153
103aO +Wr2c
60min

The galaxy seen below and to the right of NGC 4435 is NGC 4438, whose outer disk is highly disrupted. From the form of the shreds that apparently have been torn away from the disk of NGC 4438, the supposition would be that a tidal interaction is occurring. However, the redshifts are very different, at i>$_o$(4435) = 753 km s~J and v$_o$(4438) = -115 km s~', showing either that the peculiar morphology of NGC 4438 is not due to tides or that the encounter is one of exceptionally high velocity.

The angular separation of the pair is 4.4', which is a projected linear separation of 28 kpc using a Virgo Cluster core distance of 21.9 Mpc (m - *M* = 31.7). The disturbed nature of the dust lanes in the center of NGC 4438 (seen in the insert) and the dust patches and large warp to the luminous plane on the side closest to NGC 4435 are the circumstantial evidence that an interaction is occurring. The very high velocity difference of 868 km s~' suggests a hyperbolic encounter.

NGC 1387 SB0$_2$ pec FCC 184
CD-718-S (I/P)
Feb 1/2, 1979
103aO + Wr2c
45min

NGC 1387 is close to the center of the Fornax Cluster (Ferguson 1989). The elongation of the bulge within the extended, nearly circular, very faint outer envelope is the feature necessitating the SB classification. The envelope is definite and pronounced, characteristic of the SO class. The envelope is best seen here by viewing the print at a distance and moving the head or eyes rapidly.

There is a suggestion of globular clusters in the envelope, seen in the main print.

NGC 2646 SBO2
PH-7927-S
Nov 7/8, 1980
103aO
12min

The faint but moderately well defined SB0$_2$ bar in NGC 2646 ends at the sharp edge of the envelope, where the two opposite points on the rim of the envelope show a slight increase in intensity. This feature—increased intensity at the ends of the bar—is a common phenomenon of barred galaxies throughout the classification sequence and will be seen many times in the later panels. (The disk, which is circular here, is seen in the main print.)

NGC 4262 SBOi VCC 355
PH-905-S (P) HA, p. *42*
March 24/25, 1955
103aD + GGll
45min

The high-surface-brightness stubby bar that emerges from the bulge in NGC 4262 stops short of the outer edge of the luminosity zone of intermediate surface brightness, seen here in a negative print. This form differs from that of NGC 2646, above, where the bar terminates *on* the rim of this zone (which is the intermediate disk seen nearly face on).

A very faint, concentric outer envelope (not seen in the print here) exists surrounding the two zones shown in the main print. These three luminosity zones are similar to those described often in the preceding SO section.

NGC 1574 SB0$_2$(3) panel S7
CD-1690-S (P)
Jan 3/4, 1981
103aO + GG385
45min

The image seen in the overprinted main print of NGC 1574 here is that of a prototypical S0i(0). The very faint, outer extended envelope (a disk seen face on) can be traced at least to the distance of the bright star to the upper left of NGC 1574. However, the galaxy is not an SO but has a bar (or a rudimentary disk) that emerges as two opposite extensions from the central bulge, shown in the insert enlarged to the same scale as the main print. The non-barred classification as SO in the RC2, based on a Mount Stromlo 30-inch plate, is inappropriate because of the complication in the center.

The image has the three-zone structure characteristic of SO galaxies. The bar (or internal disk), which extends from the bulge, ends where the second (intermediate) zone terminates. This internal pattern is similar to that of NGC 4262, above. The vast external. Low-surface-brightness envelope that exists in NGC 1574 surrounds these two intermediate zones.

There is a suggestion of globular clusters in the extended halo. This is plausible because the distance, based on the redshift of u_o = 701 km s"^{1}, is small at *D* = 14 Mpc (m - *M* = 30.7).

The galaxy is close to the Dorado Group (Ferguson and Sandage 1990) but is outside the catalog area there.

NGC 7744 SBO i(3)
CD-574-S (P)
Oct8/9, 1978
103aD + GG495
30min

The three-zone structure of the image in NGC 7744 is seen by comparing the insert anil the main prints here. The edge of the intermediate zone and the presence oi the extended envelope is evident in the main print. The stubby, semi-diffuse bar that terminates at the edge of the intermediate zone is shown in the insert.

NGC 7155 SBO
CD-1062-Br
Aug 16/17, 1979
103aO + GG385
15min

The bar in NGC 7155 terminates near the edge of the envelope seen on the main print. But the isophotes of the envelope squeeze down into a peanut shape; the two opposite indentations of the peanut are at the place in the envelope reached by the end ol the bar.

NGC 4106/4105 SB0/a(tides) pair
CD-1445-S/Br (VE, L, 0) panel 105
May 6/7, 1980 S0]/$_2$(3)
103aO + GG385 (P)
45min

This pair is one of the premier examples of the effects of tidal interaction. The circumstantial evidence is strong that a close encounter is occurring. The redshifts are u$_o$(4105) = If)23 km s~' and u$_o$(4106)= 1905 km s"'. The angular separation of 1.2' corresponds to a projected linear separation of only 12 kpc at the redshift distance of 35 Mpc (// = 50).

The tidal arms (massive and smooth) in NGC 4106 have evidently been pulled out by the encounter. The formal barred classification is due to the non-circularly symmetric luminosity distribution in the interior envelope from where the ends of the tidal arms emerge. One arm connects to NGC 4105 as a bridge and the other is oppositely directed.

No evidence is seen of a distortion of the elliptical isophotes in NGC 4105. which is the SO 1/->(3) companion, shown best in the insert. The importance of this observation is that even in a close encounter where one of a pair is highly affected, the other can appear to he normal. The same conclusion was seen in NGC 4435/4438 in the left column on this page.

NGC 4612 RSBO1/2 VCC 1883
PH-621-B (P) HA, p. *42*
June 18/19, 1952
103aO + GG1
30 niiii

NGC 4612 is at the extreme eastern part of the **Virgo** region surveyed for the Virgo Cluster Catalog (Binggeli, Santiago, and Tammann 1985), and is not associated with the cores of either Virgo **subclusters A** or **B. Its redshift** is $v_Q = 1745$ km s"[1].

The three luminosity zones characteristic **of** SO types are well seen in the insert. The outermost two of the zones are seen in the main **print.** The **tilt** of the major axis of the intermediate region is **about** 45° from the major axis of the outer envelope. This tilt is the feature necessitating the SBO classification, and defines the bar.

A very-low-surface-brightness outer ring is visible on the original plate but is hardly visible on **the** overprinted main print. The ring has the same flattening and the same position angle of its major axis as the outer envelope of the main body. The identical flattening and orientation of the ring and the disk show that the ring is a disk, not a halo. It is the same feature seen in NGC 2685 ($S0_3$ pec; Hubble Atlas, p. 7: panel 45 here). Semi-detached outer rings of this type are present in several other galaxies on this and the following panels.

In many of these cases, the luminosity in the region between the outer edge of the disk and the inner edge of the ring is lower than it would be by an extension of the disk luminosity profile. The effect is that parts of the ring look as if they are detached from the outer edge of the disk. The type example for this ring morphology and the associated void region between it and the inner disk is the Sab galaxy NGC 4736 (RSab: Hubble Atlas, p. *16:* panel 119 here), which has a prominent ring. An SBO-type example is NGC 2859, shown on the following panel and in the Hubble Atlas (p. *42).*

NGC 2950 RSBO2/3 HA, p. *42*
PH-665-S
Feb 4/5, 1954
103aO + WG2
30 min

NGC 2950 is shown in the Hubble Atlas (p. *42)* with an air-brush drawing of the outer ring described above for NGC 4612, drawn there as an incomplete ellipse.

The original plate used here is the one used in the Hubble Atlas. The description there is still valid, as is the drawing there of the two ansae that end on the rim of the envelope. These ansae are the bar in the characteristic morphology of the barred structure: the feature is also seen in NGC 4371 and NGC 4340 on this page, and in many galaxies in the SBa section, such as NGC 936 (panels 90, 106, S9).

NGC 3892 SBO2
CD-2152-S
March 25/26, 1982
103aO + **GG385**
45 **min**

The diffuse bar in NGC 3892 terminates at the edge of the very-faint-surface-brightness disk just barely visible in the main print here. The rim luminosity of the disk is enhanced in partial arcs at the two opposite termination points of the bar. These small sectors of a complete rim ring can be traced only for about 5° on either side of both ends of the bar. The pattern is nearly identical to that seen in the external ring in NGC 4340 (at the immediate right), but it is much more subtle in NGC 3892 here.

NGC 3516 RSBO2
PH-7716-S (I)
Feb 11/12, 1980
103aO
12 min

The partial external ring that is semi-detached from the main body in NGC 3516 is well seen in this negative print. The two opposite regions of decreased luminosity between the outer edge of the inner disk and the external ring is shown here at position angles 4 and 10 o'clock in the orientation of the print. The axis of the line through these two regions of decreased luminosity makes an angle of about 20° with the axis of the bar. The bar is burned out on this negative print. However, it is well formed and is almost vertical in the print here.

NGC 4371 SB0$_2$/3(r)(3) VCC **759**
CD-1318-S/Br
March 12/13, 1980
103aO
75 **min**

The two regions of enhanced luminosity in NGC 4371 at the end of **the** bar at the rim of the inner disk are well shown in this negative print. As in NGC 3892 to the lower left and NGC 4340 below, this luminosity enhancement of the rim can be traced for about 5° on either side of each termination of the bar.

NGC **4340 RSBO2 VCC 654**
CD-1854-HB panel S7
April 4/5, 1981
103aO
75 **min**

NGC 4340 is one of the best examples of the form described on this page for NGC 3892 and NGC 4371 as an enhancement of the ring at the edge of the disk at the two termination points of the bar. Note here, as in NGC 3516 and NGC 4371 above, the two areas of decreased luminosity at position angles of about 2:30 and 8:30 o'clock on the facing print. Athanassoula (1984) attributes these regions of decreased luminosity to a sweeping-out of material by dynamical processes associated with the L3 Lagrangian points. **As** it is a common feature in barred galaxies, and as it occurs at the same positions relative to the bar in these galaxies, one suspects that the phenomenon is a dynamical effect associated with the bar.

NGC 2787 **SBO/a Racine** wedge
PH-7588-S (VE, L, 0) panel 95
April 2/3, 1979
IllaJ + GG385
30 **min**

NGC 2787 is another example of the form often described on this page. The galaxy is evidently highly inclined to the line of sight because of the large flattening of the disk and the partial ring enhancement at the two ends of the bar.

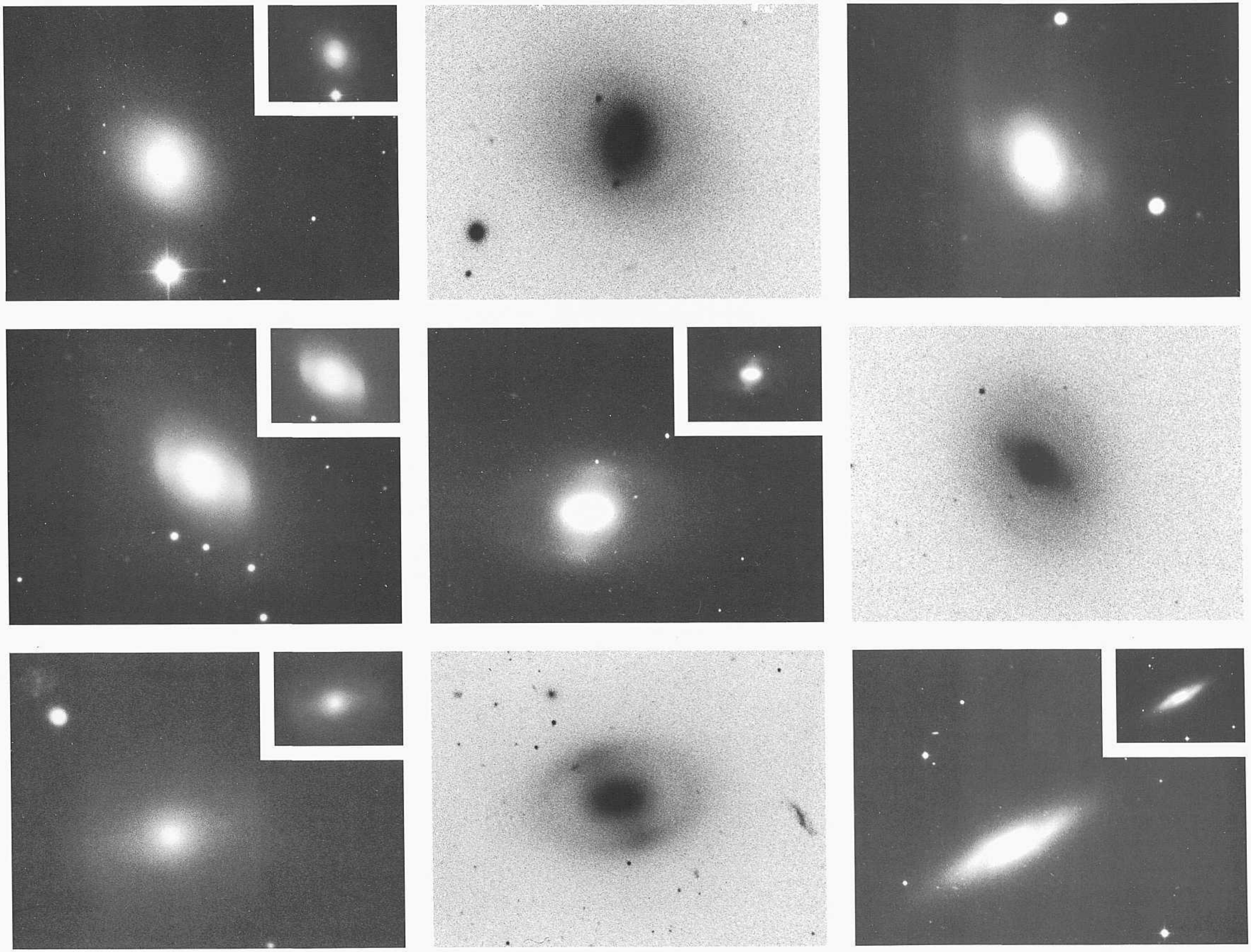
NGC 1440 SB0i/$_2$/a N1400Gr#lll
CD-1601-S/Br (VE, I, 0)
Aug 12/13, 1980
103aO + GG385
75 min

NGC 1440 is one of the brightest members of the NGC 1400 Group, which is part of the larger Eridanus cloud complex. The group name is G 31 in a catalog by de Vaucouleurs (1975). Many dE and Im dwarfs exist in the group catalog of Ferguson and Sandage (1990).

The morphology of NGC 1440 is different from most other SBO galaxies shown on this and the preceding panels. The bar is definite. Thin luminous arches exist in the outer part of the disk. The disk itself is not elliptically symmetric but tucks in at each end of the bar, similar by some measure to the double gamma (T) form of the outer structure of NGC 7702 (RSa: panel 66). The arcs and this tucking feature account for the /a classification notation.

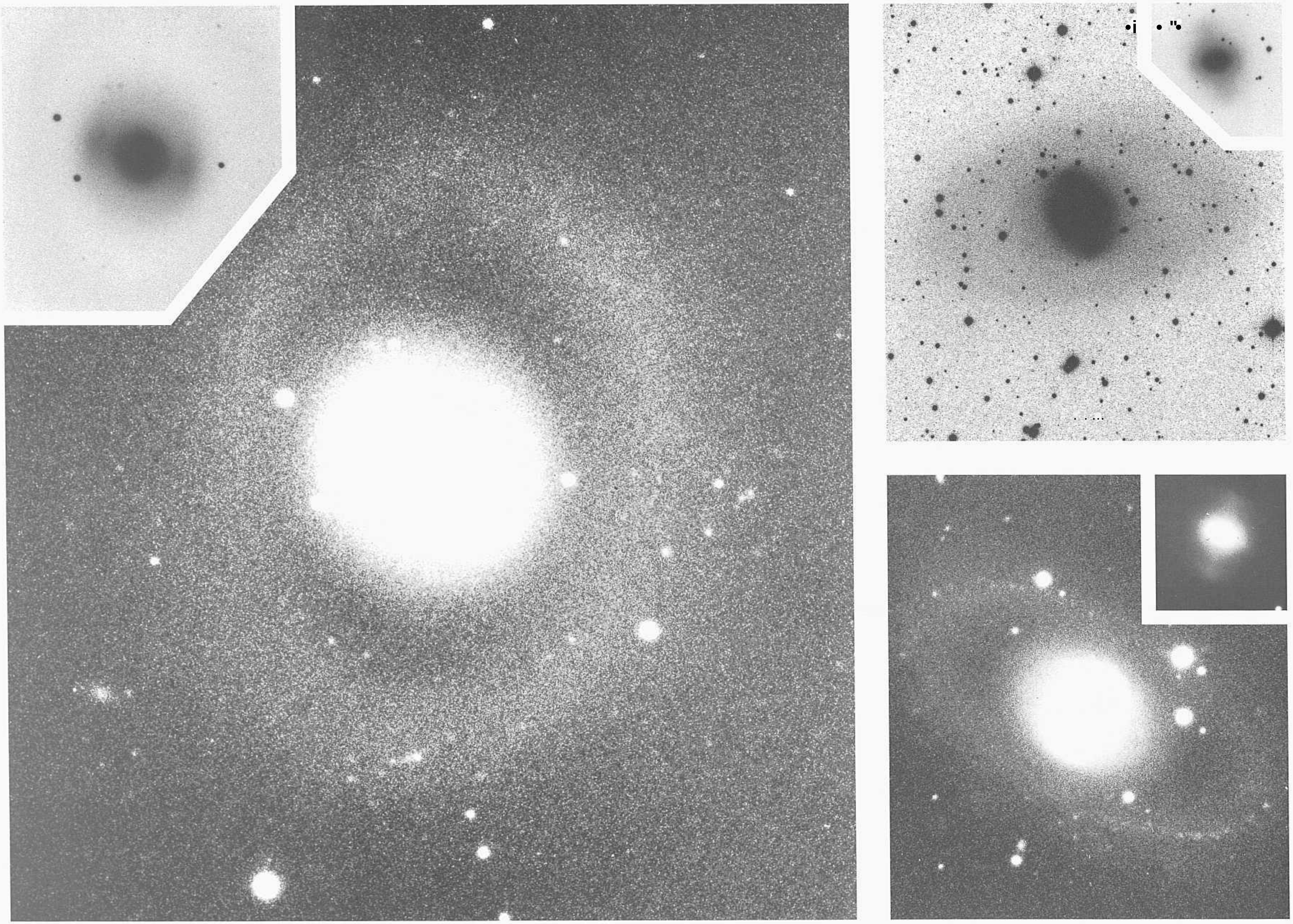
NGC 4425 **SBO pec or Sa pec VCC 984**
CD-743-S (I) panel 60
Feb 3/4, 1979
103aO + Wr2c
60 min

The two ansae emerging from the box-like (bar-like?) center of NGC 4425, seen in the insert, are not symmetrically placed along the major axis but emerge on opposite sides of the major axis, similar to features in the very-early-type SO/a galaxies seen in the first few pages of the Sa sequence, such as NGC 1380 (panel 61), NGC 3271 (panel 61), NGC 4293 (panel 59), NGC 4429 (panels 60, S2), and NGC 4503 (panel 61).



PANEL
57

PANEL
58



NGC 2859 RSB0_2(3) **HA, p.** *42*
PH-852-S **panel S7**
Nov 2/3, 1954
103aO
30 inin

The two prints **of** NGC 2 859 here were made from the same original 2 00-inch plate used for the **Hubble** Atlas.

NGC 2 85 9 **is the type example of the RSB0_2** class. The bar is fuzzy and indistinct. There is a brightening **of** the rim of the disk at two **opposite** ends. The bar makes an angle of 70° with the major axis of the envelope and of the outer **ring,** which appears to be detached from the inner regions. The detachment is shown belter on the small-scale insert print in **the Hubble** Atlas.

The boundaries of the outer ring are indistinct, but the inner edge is sharper than the outer, similar ring seen in NGC 47 3 6 **(RSab;** Hubble Atlas, p. 7 6: panel 1 19 here).

As described for NGC 3516, NGC 4340, and NGC 43 71 on the preceding page, the most prominent areas of decreased luminosity between the edge of the inner disk and the inner edge of the outer ring are nearly at right angles to the bar. This phenomenon is understood as the L3 Lagrangian points of the bar potential that determines the dynamics of stellar orbits (Athanassoula 19 84).

NGC **5365** **KSB0_2**
CD-1039-Br
July 22/23, 1979
103aO + GG385
45 **niin**

The common pattern described on tin- **previous** page is **well** shown in the main print and **the insert** of NGC 5365 from a Las Campanas 100-inch plate. The internal bar makes an **angle of** 90° **to the direction** of the major axis (if **the** disk. The major axis of the central **bulge** lias **the same direction** as **the** major axis of the outer disk **and** of the **bright** ring around **this** disk. The **high-contrast** main **print** shows **that the** disk is filled with luminosity. There is, however, a negative intensity gradient **in the intermediate** region of **the** disk, similar to the near **void** between the disk and the ring in NGC 21)59 at the left, and in **NGC** 4736 **(RSab; Hubble** Atlas, p. *16;* panel I 19 here), mentioned before. Note again, as with NGC 2859 on this panel and with NGC 35 16 and NGC 4340 on the previous (inc. that the areas of greatest **depletion of** the disk luminosity occur nearly at right angles to **the** bar.

NGC 3945 **RSBO2** **panel S7**
PH-7980-S
Feb 1/2, 1981
103aO
12 iiiin

NGC 3945 is a premiere example and a prototype of the SB0_2 subclass of barred SO galaxies. The central bulge is flattened, its major axis aligned with the major axis of the external ring, as is common for this form, repeatedly discussed. The fuzzy **indistinct** bar, shown well in the insert, terminates on the moderately sharp edge of the disk. A fully detached (at least at high luminosity levels) external ring surrounds the inner regions. Although there are intensity variations around the outer ring, the ring can be **traced** over its **complete circumference.**

The SOIa and SOISa Classification Sections

NGC4143 S0i(5)/Sa
PH-7660-S (VE,L,O)
April 29/30, 1979
103aO
12 miii

Two short, smooth, massive embryonic arms, seen best in the insert, emerge from the bulge. Each arm ends within the SO-likc disk at about half the disk radius visible on the main print. The arms are well seen on the original plate but are only hinted at in the insert, shown at the same scale as the main print. To trace the arms in these prints, it helps to know that the arms close up counterclockwise as one moves from their outer tips inward.

The disk has a prototypical SO morphology. The galaxy would be classed SO j using low-resolution and/or heavily exposed plates. The arms, evident on the present plate material, would not be detected. This galaxy is one of the earliest of the transition cases between the pure SOi and the Sa types in the RSA.

NGC 5574 S0i<8)/a pair
CD-1837-HB (VE,L,0)
April 1/2, 1981
103aO + GG385
45 min

NGC 5574 would be classified as a pure SO on low-resolution plates. The listed type is S0j(8) in the RSA1 and is SBO? in the RC2, both based on a 1925 Mount Wilson 100-inch plate by Hubble. The Las Campanas du Pont 100-inch plate by Babcock here shows the same feature of massive stubby arms as in NGC 4143, above. The arms are not visible in this reproduction but are well seen on the original plate. The deviation from symmetry, where the bulge merges with the disk, is less pronounced than in NGC 4143, classed as SO/Sa. This smaller deviation of the morphology from pure SO form is noted by the classification of NGC 4143 as SO/a, rather than SO/Sa.

NGC 5574 forms a pair with NGC 5576 [E4(tides?)]. which is 163" northeast of NGC 5574. The redshifts arc similar at $u_o(5574)$ = 1612 km s^{-1} and $u_o(5576)$ = 1424 km s~^{1}. From the mean redshift distance of 30 Mpc (// = 50) the projected linear separation is small, at 24 kpc. NGC 5576 is shown in the E section on panel 9.

NGC 4767 $S0_2(6)/a$
CD-1442-S/Br (VE,L,0)
May 6/7, 1980
103aO + GG385
45 min

Sets of very faint rings in the intermediate and outer disk of NGC 4767 show a departure from smoothness in what otherwise is a prototypical SO disk of flattening (6). The inner ring is either a separation of material or a very subtle dust lane, explaining the S0> subtype.

NGC 5018 $S0_2(4)/a$ panel 41
CD-1867-HB/Bedke (VE,L,l/4)
April 9/10, 1981
103aO + GG385
45 min

The SO outer envelope (disk?) of NGC 5018 is not elliptical near the edge but is broken into two opposite edges, each of which has a broad spiral pattern. The form is not like NGC 4143 (left) where the definite arms from the edge of the bulge terminate within the smooth disk. Rather, the disk itself has an edge that breaks into two opposite luminosity enhancements, each of which spiral outward. There is no remaining underlying disk beyond these edges. The feature is just visible in the outer parts of the image here. The broken edges appear at 2 and 8 o'clock in this reproduction and *become* the outer part of the disk. The sense of the spiral pattern is clockwise, starting from the outer tip of each broken edge and moving inward.

Dust patches are evident in the inner disk, asymmetrically silhouetted against the bulge. Details of the patch structure of the dust are lost in the reproduction, but the asymmetry of the pattern (it is present on one side of the bulge only) shows that the dust is associated with the disk, not the bulge. Mints of the dust structure are seen along the bottom edge of the image in this print.

NGC 6875 S0/a(ripples) group
CD-1045-Br (VE,L,0)
July 22/23, 1979
103aO + GG385
45 min

NGC 6875 is the dominant galaxy in a small group. The redshift of v_0 = 3030 km s^{-1} gives a redshift distance of 60 Mpc (*H* = 50). Two nuclei exist as shown in the insert, separated by 5". The projected linear separation is extremely small at 1.5 kpc. The outer envelope common to the double nucleus is distorted, suggesting a close encounter. A very faint plume (a one-armed spiral feature) is visible in this negative print starting from the top-right end of the disk and opening toward the left, intersected by the lower-right edge of the insert print and emerging again from behind the insert border further left. Note

(NGC 6875 continued on next panel)

NGC 4293 Sa VCC 460
CD-1880-HB (I,S,1) HA, p. *11*
April 11/12, 1981
103aD + GG495
45 min

Very faint, outer extensions of the disk, burned out here, show non-symmetrical massive spiral sweeps seen in the main print as regions of diffuse, non-symmetrical luminosity. These outer diffuse soft arms are seen better in the Hubble Atlas (p. *11)* insert print, made from a different plate with a different emulsion type.

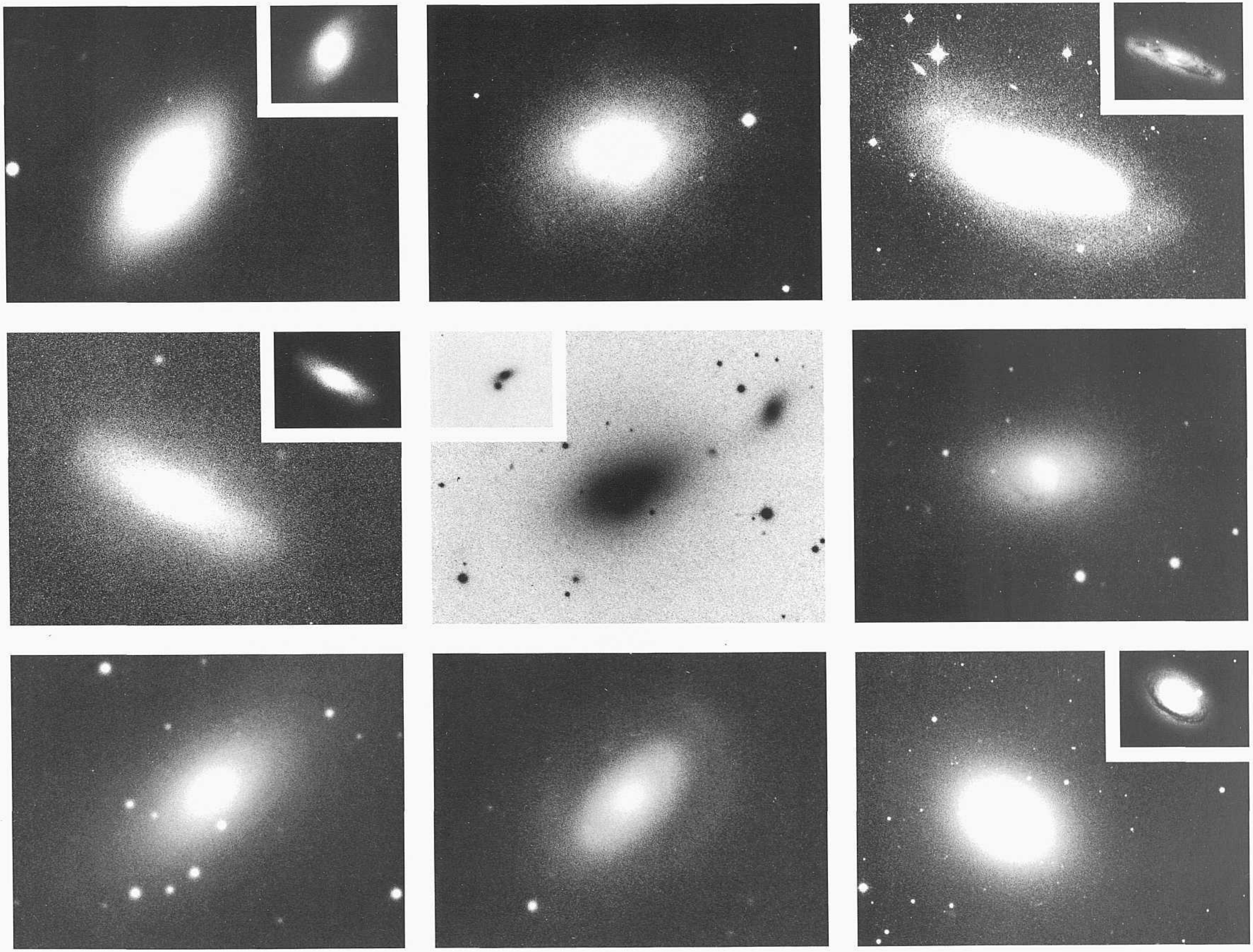
The lower-contrast insert image shows that dust lanes pervade the inner disk. The galaxy type is Sa despite the small nucleus. The spiral pattern of the dust precludes an SO classification. The lack of resolved stars precludes an Sb classification. Arms made of dust alone are known in other Sa galaxies, mentioned in the paragraph on NGC 7007 below and shown as a separate subset of Sa types later on panels 72—76.

NGC 7007 $S0_2$«/a
CD-1531-S/Br (E,L,l/4)
Aug 6/7, 1980
103aO + GG385
45 min

NGC 7007 has a classical SO disk and a nearly spherical bulge. The dust pattern is less regular than in a normal SO3. The lane is not circular nor continuous but shows breaks: hence the 2/3 subclass is assigned. In addition, the dust patches form two distinct lanes, which suggest a rudimentary spiral pattern, similar to but not nearly as well developed nor as prominent as in the "dust arms" class of Sa spirals. In these particular Sa galaxies (compare NGC 2855, NGC 4984, NGC 7377, and others on panels 72-76) the entire spiral pattern is formed by the dust lanes alone, without contribution from associated young stars like those in normal Sb and Sc types. NGC 7007 here has the slightest trace of the phenomenon of dust arms alone.

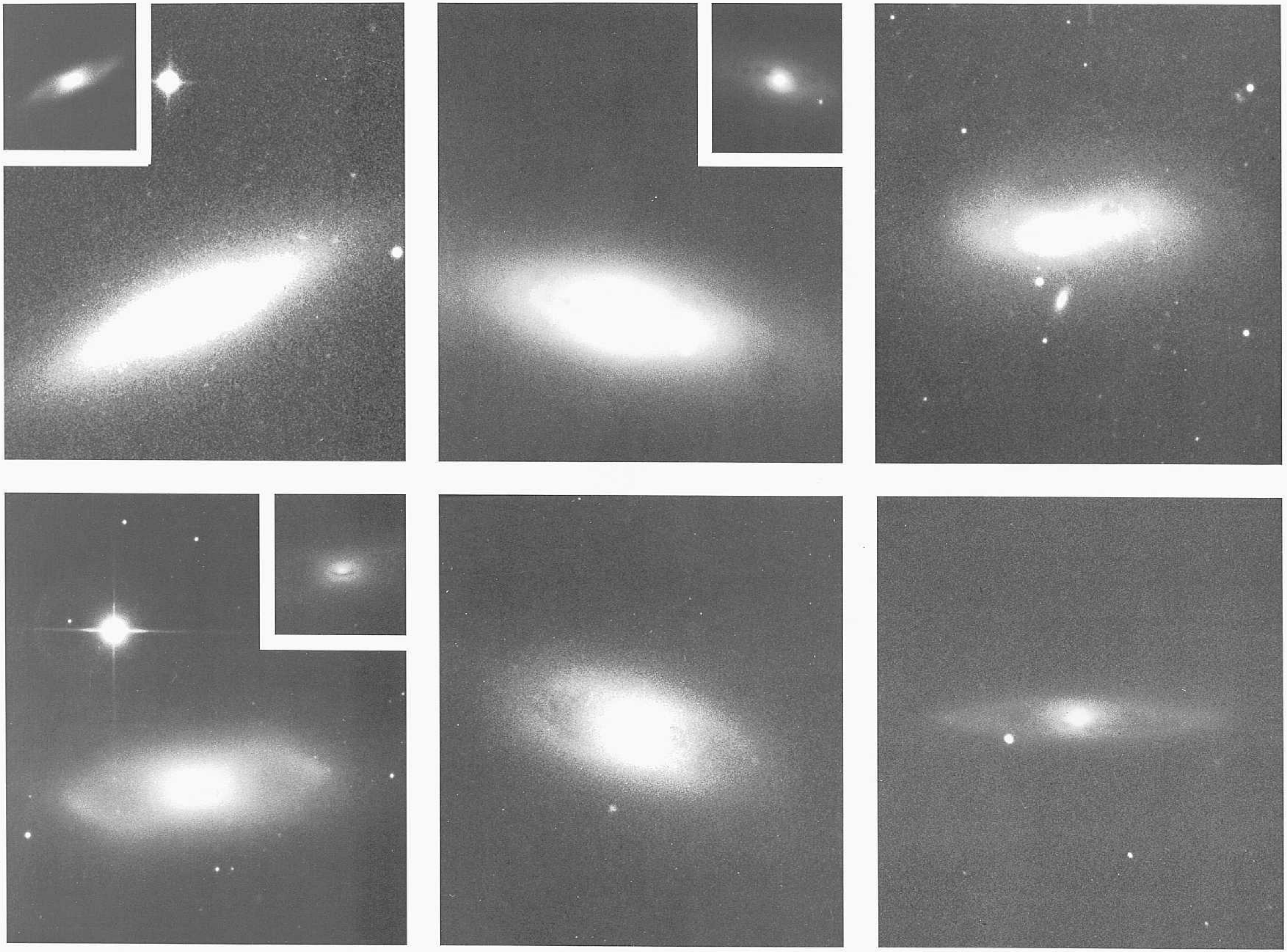
NGC 7049 $S0_3(4)/Sa$ panel 74
CD-1088-Br (E,L,1/4)
Aug 18/19, 1979
103aO + GG385
45 min

The internal dust lane can be traced nearly around the entire image of the inner bulge. The structure in the lane is less smooth than in the pure $S0_{:i}$ subtype's. This feature, together with the suggestion of an incipient spiral structure, are the reasons for choosing the mixed classification of SO/Sa.



PANEL
59

PANEL
60



(NGC 6875 continued from previous panel)

also the faint **apparent plume connection to the** SO galaxy, presently **of** unknown redshift (c. 1990) at the upper right.

NGC 254 **$RS0_2(6)$/a**
CD-428-Rose **(VE,L,0)**
Aug 6/7, 1978
103aO +Wr2
60 min

NGC 2 54 is highly symmetrical. Four principal components determine the classification.

(1) A faint outer ring, denoted by *R,* appears detached from the bright disk, seen best if the print here is viewed from a distance while moving the head or eyes rapidly.

(2) A central circular bulge is prominent. The lack of flattening suggests a spherical figure.

(3) The disk forming the main body **of** the image has a moderately sharp edge, similar to **but** not **as** pronounced as those in the SO galaxies NGC 1553 and NGC 3056, both shown on panel 39. As in NGC 1553. the disk surface brightness remains high **over** most of its area. There is a trough (a decrease) in luminosity **half-way out** between the bulge **and** the edge **of** the inner **disk.** As discussed before, this impression to the eye may only be due to a change of *slope* of the luminosity profile. The presence of the disk without a spiral pattern is the reason for the SO part of the classification. The trough requires the subtype to be SO2.

(4) The luminosity **distribution** near the outer rim of the high-surface-brightness disk is not uniform in azimuth. The rim of the disk brightens at each end of the apparent major axis. These ansae are the embryonic arms described by the /a notation.

NGC **4425** **SBO pec or Sa** **VCC 984**
CD-709-S **(VE,S/I,0)**
Jan 30/31, 1979
103aO + Wr2
45 min

The classification of NGC 442 5 **in** the Virgo Cluster Catalog is SBa with no peculiarities. The type in the RSA2 is SBO pec or Sa pec: it is SBO (uncertain, **spindle)** in the RC2. **The** classification adopted here is Sa with no peculiarities.

Hie two features that suggested peculiarities in the RSA2 are (1) the peanut-shaped bulge (the X feature in the inner bulge seen in the insert) and (2) the twofold symmetry of the surface brightness enhancement in the **disk.** The X shape of the bulge is now recognized as a moderately common feature in early-type galaxies. The deviation from smoothness in the disk surface brightness is identified here with embryonic arms that are smooth and massive.

The intensity enhancements that are the arms, seen well in the insert at the same scale as the main print, are more **pronounced** here than in NGC 4143 on the preceding page. But the phenomenon is the same, showing the beginning of spiral arms in this earliest section of the **Sa** class. The embryonic arm structures are of the same type and are even stronger in NGC 4429 below, showing well the same early arm development.

The main print illustrates the difficulty of classifying galaxies in this early part of the Hubble sequence using overexposed and/or low-resolution images. The form shown in the main **print** is a classical SO type with a boxy bulge, but the insert clearly shows that the type is not SO.

NGC 4429 **$S0_3(6)$/Sa** VCC **1003**
CD-710-S **(VE,I,0)** **panel S2**
Jan 30/31, 1979
103aO + **Wr2**
50 min

The intensity asymmetry in the disk of NGC 4425 above and NGC 4143 on the preceding panel is well developed and is **identified** as **the** early stage of smooth arms in Sa types. The classification of NGC 4429 here differs from that in the RSA2 by the removal **of** the pec suffix. In so doing we now assume that the embryonic arms are normal and are the earliest stage **of** arm "development'" seen as a progressive sequence in the next several panels of the Sa section. (These features in the outer disk were taken to be an outer ring in **the** RC2 . **where the** class is listed as RSO.)

The dust ring in the bulge is **typical of** SO3 types. The galaxy is classed as a mixed type, between SO and Sa, on **the** basis of both the dust pattern and the massive embryonic arms.

NGC 1036 S0s(8)/Sa pair
PH-7608-S (VE,L,l/4)
April 3/4, 1979
IllaJ + GG385
30 miii

NGC 4036 forms **a wide** pair **with** NGC 4041 (Se: panel 268) **with** a separation **of** 17'. The redshifts are $w_o(4036)$ = 1509 km s~' and u_o**(4041)** = 1361 km s"[1]. At **the** mean **redshifl** distance of 29 Mpc the **projected** linear separation of **the** pair is 143 kpc.

The intensity **distribution** in **the** disk **of** NGC 4036 is **not smooth** as **in a** pure SO. Clearly visible on the plates are a number of coherent intensity fluctuations which form a lightly wound spiral pattern. In addition, dust lanes **thread** through the disk in an **embryonic** spiral **pattern.**

Only a hint **of** these subtle **features** is **visible in the main print** and **the** insert. The dust lanes are not as regular as in a pure SO3 type, also indicating a mixed SO/Sa **form.**

NGC 3489 SOs/Sa
II-1020-H (E,I,3/4)
Jan 11/12, 1929
E40
60 min

NGC 3489 is similar to NGC 4429 at the left but is of later type. (The dust in **the** disk is more intricate and **spreads** over more of the area.) Dust lanes, not visible in **this** print because **of** the high intensity **of** the bulge, cut across the **bulge.** From the **structure** of the lanes in silhouette against the bulge, it is clear that the dust is in the disk, not the bulge. The type is partly Sa from (1) the absence of knots **(HII** regions), (2) no sign of **lump**iness in the **disk** due **to** star associations, and (3) the large bulge. The absence of a true spiral **pattern** and the **prominent,** high-**surf**ace-brightness disk are both characteristic of SO types.

NGC **4424** **S(a?) pec** **VCC 979**
CD-717-S **(1.1,1/2)**
Jan31/Feb 1, 1979
L03aO + Wr2
45 min

NGC **4424** is classed as a **possible** Sa. **based on the smooth, massive, semi-spiral** outer envelope. Short-exposure plates **show evidence of** star **formation in the central regions,** burned out **in** this **reproduction, printed to show the** outer envelope. The **galaxy** is **in Ihe Virgo Cluster, about** 1° from the **center** *i)* **subclustcr 15 surrounding NGC 4472. The redshifl** <d r,, - 323 km s[-1] makes it a **highly** likely cluster **member.**

Galaxies within 30' **include NGC** 1117. NGC 4445. NGC 415 **1** . and a **number** of Virgo Cluster dwarfs (VCC 860, 914, 926. 983, 993. 1013.1090.1092.1**L28,**and**I**16**1).**

NGC 4866 Sa **HA, p.** //
H-377-H **(E/I,I/S,l/3)**
July 3/4, 192 1
Seed 30
60 min

NGC 4866 is seen **almost** edge on. 11 is classed as Sa because it is clearly not an SO: there is dust **throughout** the disk in what appears to be a spiral pattern, based on the appearance of **the** outer disk on the right-hand side of the **reproduction. It** is not as **late** as **Sb,** judged from the **lack** of resolution of the disk into knots **(lilt** regions) or stellar associations.

In the **Hubble** Atlas (p. / /). NGC 4866 is **compared** with **NGC** 28 1 1 (panel 65 **here),** also a very early Sa. Other galaxies of the same very early Sa type are shown in the Sa section on panels 6 1-65.

The Sa Classification Section

THE SMOOTH-ARMED Sa SPIRALS

Smooth-armed Sa spirals of the early part of the Sa section are set out in the first five pages of the Sa sequence here. The smooth spiral arms are devoid of recent star formation. Many are in the isolated field, not in clusters or groups, showing that the smooth-spiral-arm phenomenon is generic to the classification sequence and is not a result of environmental effects such as gas sweeping in cluster environs.

Galaxies on panels 61-65 show the progression of smooth arms, from advanced SO/a to the later Sa grand design smooth-armed spirals NGC 718 and NGC 3269. Multiple-armed smooth-armed types are on panel 62. The earliest grand design prototypes are on panel 63, which leads to the later smooth-armed examples on panels 64 and 65.

Throughout the Sa and the SBa sections we have augmented the basic classification with symbols, placed in parentheses below the main class symbol, giving the strength of three of the classification criteria. The first symbol is the degree of resolution of the arms into stars, the second is the size of the bulge, and the third is the amount of dust. The details of this subclassification are explained in Chapter 2 (see page 8). An example is a (VE,L,0) designation, which means very early arm type, large bulge, and zero dust class.

The galaxies on this page show departures from circular symmetry in their disks. These departures are more pronounced and are of the same type as the spiral features in NGC 4143 (SO/a; panel 59) and NGC 4425 (SBO pec or Sa pec; panels 57, 60). The subtlest of the departures are in the galaxies closest to the upper-left part of the facing page. As one proceeds through this page from the upper left to the lower" right and continues into the following few pages, the spiral pattern becomes more pronounced.

Most of these galaxies would be misclassified as SO using low-resolution plates or overexposed images.

NGC 4461 **Sa** **VCC1158**
CD-743-S **(VE,L,0)**
Feb 3/4, 1979
103aO + Wr2
60 min

NGC 4461 is in the Virgo Cluster near the **subcluster A** associated with NGC 4486. The departure from circularity in the luminosity pattern in the otherwise normal SO? disk is subtle, but definite. The departure from circularity **is** the spiral pattern. To fix the eye so as to better trace the **pattern** in this print, note that the sense of **the spiral** pattern is counterclockwise from the outside inward for each of the arms emerging from the bulge at about 1 o'clock and 7 o'clock on this image.

NGC 4503 **Sa** VCC **1412**
CD-733-S **(VE,L,0)**
Feb 2/3, 1979
103aO + Wr2
45 min

NGC 4503 is in the Virgo Cluster **near** subcluster A. The "arms" are the outer part of the disk, separated from the bulge by what appears to be a slight luminosity decrease, most **visible** on the lower-left part of the image at the edge of the bulge. The sense of the spiral pattern in these massive disk parts is counterclockwise as one proceeds from the outside inward.

NGC 1380 **$SO_3(7)$/Sa** FCC **167**
CD-718-S **(VE,L,0)**
Feb 1/2, 1979
103aO + Wr2
4-5 min

NGC 1380 is a member of the Fornax Cluster (Ferguson 1989). The spiral pattern of the massive arms is pronounced and shows moderately well in this reproduction. The arms appear to attach to the bulge at **position** angles of about 5 o'clock and 11 o'clock in the print here. The sense of the spiral pattern is clockwise going from the outside inward.

NGC **5854** Sa
PH-8022-S **(E,S/I,O)**
April 27/28, 1979
103aO
10 min

There are two spiral patterns in NGC 5854. One is very close to the center, and the other is traceable on the original plate to at least the outermost of the two faint stars slightly above the major axis on the left-hand side of the print.

The inner spiral pattern is in the bulge (it forms the bulge) and has the form and the sense of the opening of a stubby S. The outer arms are smooth and massive. They open in the same sense as that of the bulge. Their surface brightness is exceedingly low, but they can be seen beyond the moderately high surface brightness lens to a distance of about twice the diameter of the lens. The high-surface-brightness bulge has a diameter about half that of the lens.

The intensity distribution on the original plate gives the impression of three discrete components, the inner two of which (tin; bulge and **the** lens) have **sharp edges.** But this is **probably** a subjective description of what is a continuous gradient to the intensity **distribution.** The eye

(i\GC 5854 continued on ***next panel)***

NGC **3271** **Sa** **Antlia 224**
CD-646-Br **(VE,I/L,0)**
Jan 4/5, 1979
103aO + GG385
4-5 **min**

NGC 3271 is the central galaxy of the Antlia Cluster (Ferguson and Sandage 1990). The sense of the two smooth massive arms **that** are clearly visible in the print is counterclockwise, moving from the outer tips inward.

A much fainter outer feature exists at about twice the diameter of the main body shown in the print. The feature is called an outer ring in the RC2. where the morphological type of NGC 3271 is listed as RSB0. The axis of this outer ring deviates from the major axis of the buige by about 30°. The ring is not complete but is enhanced in each of two segments symmetrically placed on opposite sides of the image along the major axis of the bulge (nearly horizontal in the print). The RSB0 type in the RC2 is derived by calling the inner structure a bar rather than a spiral and then identifying the intensity enhancements at each end of the **spiral** as similar to the ansae common in SBO types (compare NGC 2859 in the Hubble Atlas, p. *42;* panels 58, S7 here). The type is clearly Sa, based on the image here.

NGC 3267 Sa **AnUia 168**
CD-646-Br **(VE,L,0)** **not in RSA**
Jan 4/5, 1979
103aO + GG385
45 min

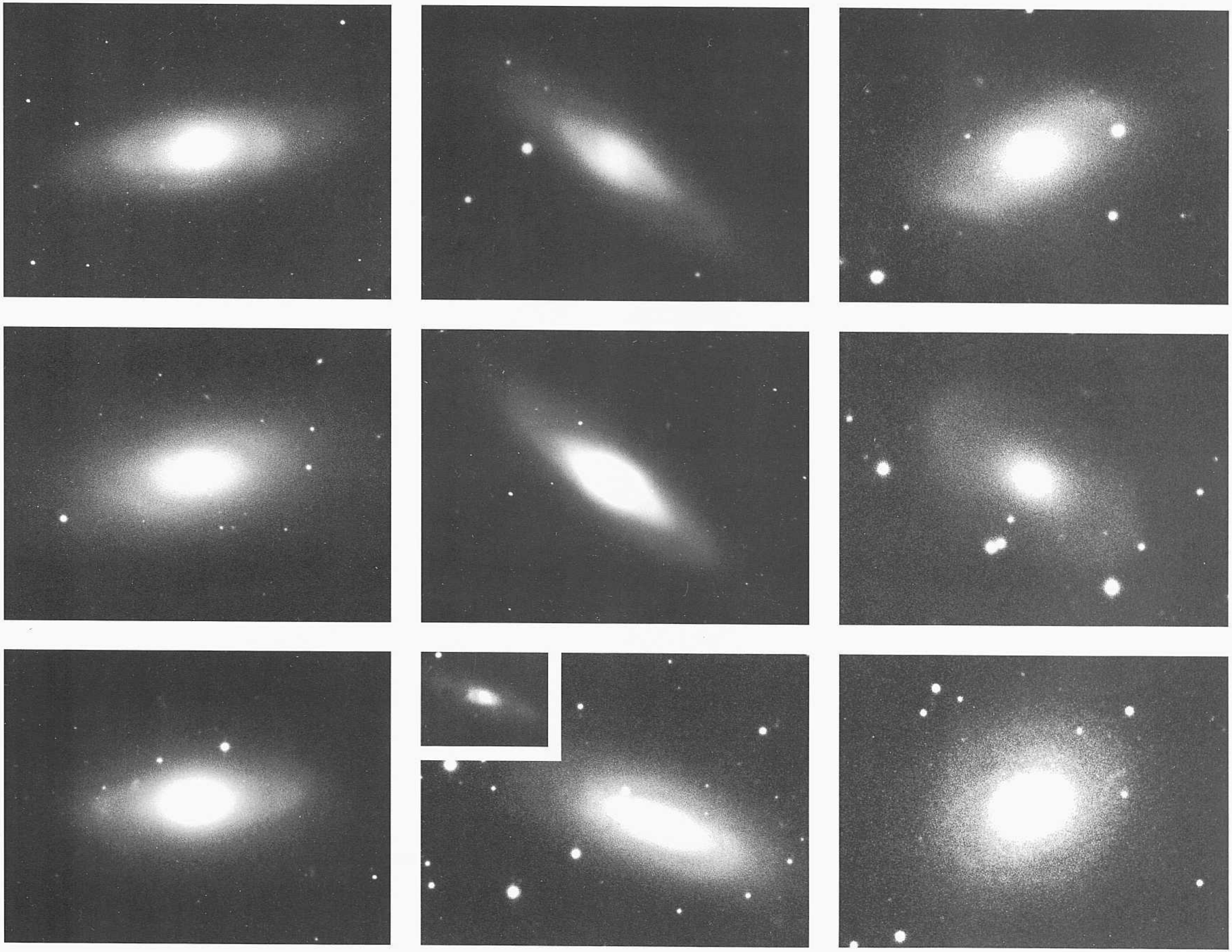
NGC 3267 is near the center of the Antlia Cluster (Ferguson and Sandage 1990). Two smooth, massive spiral features are easily seen as the outer envelope to a high-surface-brightness bulge. The galaxy is not in **the** RSA.

NGC 5121 **Sa**
CD-1302-S/Br **(VE,L,0)**
March 10/11, 1980
103aD + GG495
45 **min**

A definite spiral **pattern** surrounds a bulge and a lens, both burned out in this **print** of NGC 5121. The spiral features are thin, are tightly wound, and are not massive, unlike the arms in the other eight galaxies shown **in** this panel.

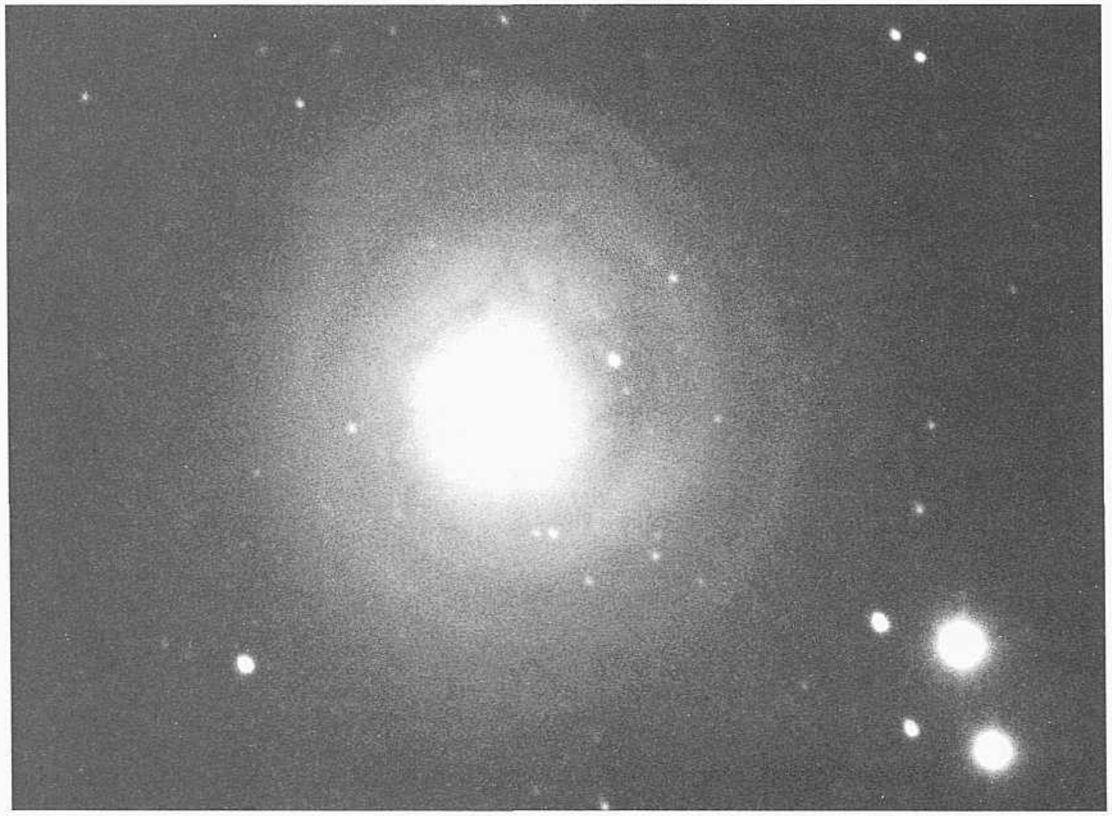
Because the arms are so subtle against the relatively high surface brightness of the disk through **which** they thread, the galaxy was elas-

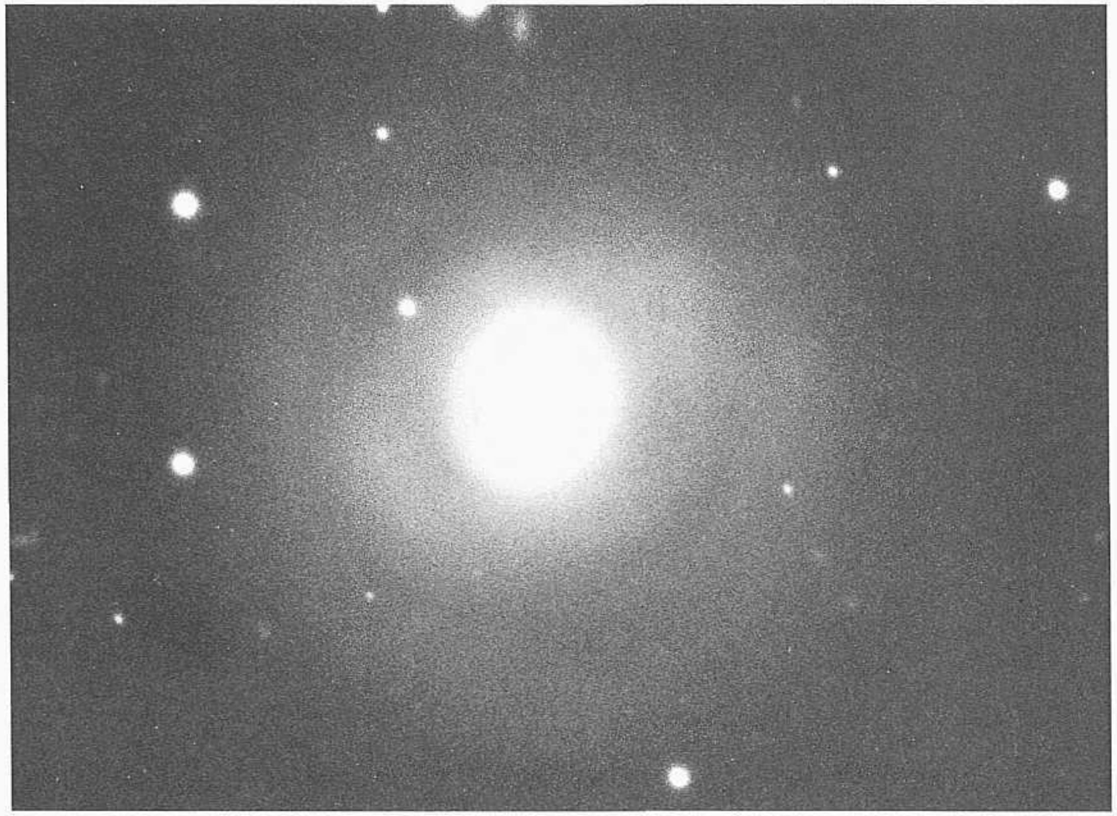
(NGC 5121 continued on next panel)

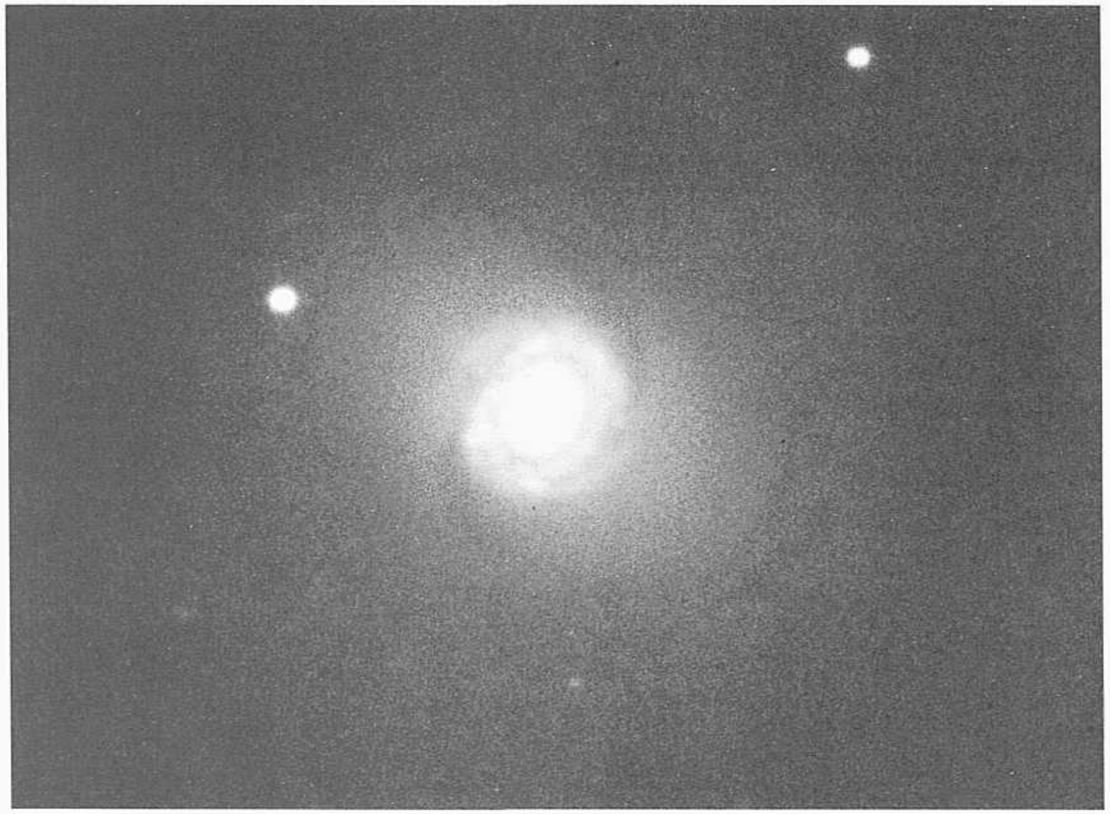


VAN EL
61

PANEL
62







(NGC 5854 continued from previous panel)

and brain take Lhe first derivative of an intensity field: a change of the luminosity gradient appears as an edge to the eye.

NGC3301 Sa
PH-8018-S (VE,5,0)
April 27/28, 1979
IllaJ
75min

The pattern of bulge, lens, and faint, massive, smooth outer arms in NGC 3301 is similar to the pattern in NGC 5854 above. The bulge is invisible in the reproduction; it is buried in the high-surface-brightness lens, which is the dominant feature in the print. The even-higher-surface-brightness bulge is very small (4" X 8"). and is elongated along the major axis of the lens.

The very-faint-surface-brightness outer envelope, which is the spiral pattern with its smooth, massive arms, extends beyond the lens to about twice the diameter of the lens. The beginnings of the outer spiral disk are visible in the print, beginning at a distance from the center near where the three stars straddle the major axis (two below and one above) on the left side. The classification of SBO/a pec in the RC2 is not supported from the present plate material. The galaxy is a normal, very early, smooth-armed Sa near the beginning of the Sa section.

New 5 = A 2020-44 Sa(s)
CD-1505-S/Br (E,I/S,l/4)
Aug4/5, **1980**
103aO + GG385
45min

New 5 has a very small nucleus surrounded by an internal ring, seen in the insert. The disk shows a small dust content but is generally smooth and resembles the lens structures in NGC 5854 and NGC 3301 , above. The smooth, faint-surface-brightness massive arms begin, as in the aforementioned galaxies, from the edge of the lens, which in the print is at the distance of the bright star above the major axis of the lens on the upper-left side.

The outer envelope beyond the edge of the lens is a two-armed spiral, which is easily seen if the print is viewed from a distance. The sense of the spiral is counterclockwise from the outer tips moving inward. As with all galaxies in this panel, these features form the earliest type of smooth arms in these very early Sa galaxies. The smooth nature of the arms is a characteristic of the classification sequence itself. It is not due to environmental effects such as stripping but is generic; to the sequence (Sandage 1983a; Kennicutt and Edgar 1 986).

(NGC 5121 continued from previous panel)

sified as $S0_1(4)$/Sa in the RSA2 . But because the spiral pattern is so pronounced, we now adopt the classification as very early Sa.

The multiplicity of the spiral pattern differs from that in the other eight galaxies in this panel. NGC 5121 has multiple arms, not simply two symmetrical arms. This galaxy is the earliest of the Sa multiple-arm spirals (MAS), which later in the sequence are called filamentary or flocculent (Elmegreen 1981) spirals. In them, the spiral patterns are often difficult to trace within a given arm; there is no given arm because the pattern is fragmented into many small spiral segments. It is a local pattern rather than one that has global coherence (Kormendy and Norman 1979) that gives rise to the so-called grand design (GD) galaxies (Elmegreen and Elmegreen 1982). which have two main, well-defined arms, which define the large-scale pattern.

Both types of spirals exist from early Sa to late Sc in the Hubble sequence. We maintain the distinction throughout this atlas, tracing the development of each type of arm pattern within each section of the classification.

NGC 5121 is among the earliest Sa of the MAS type. MAS-type examples include NGC 4699 (Hubble Atlas, p. *16;* panels 78,87, 118. S12 here), NGC 2775 (Hubble Atlas, p. *10:* panels 78. 87, S12 here), NGC 1357 (panel 68), NGC 7377 with its dust arms (panels 75. S14), NGC 1371 (panels 64. 80. 88. and S3), NGC 6902 (panel 69), and NGC 1350. with its inner arms in the disk (panels 71, 88, S3).

NGC 6340 **Sa(r)I** Racine wedge
PH-7668-S (VE,L,l/4)
Sep 25/26, 1979
IllaJ
75min

NGC 6340 has a scries of tightly wound, almost circular, multiple-fragment, relatively thin outer arms surrounding a bulge and a lens. The lens is the inner disk. The bulge is burned out in the print here. Dust patches are present near the edge of the lens (top center on the print on the bright rim). This is a smooth-armed Sa of the MAS type. Note the double images of the two bright stars due to the Racine wedge. The secondary images are 5 mag fainter than the primary, and the image separation is I 8".

NGC1317 Sa FCC 22
CD-719-S (E,I,l/8) panel S12
Feb1/2,1979
103aO + Wr2
45min

NGC 1317 is a companion to NGC 1316 in or near the Fornax Cluster. The inner spiral pattern is formed by dust: the character of the arms is closer to the MAS type than to a two-armed symmetrical pattern of the grand design type. Spiral patterns can be traced throughout the faint outer envelope. There is a suggestion that part of this outer spiral pattern, just visible in this print when viewed from a distance, is due to dust. The wide-field reproduction in Schweizer (1980) shows the relation of this galaxy to NGC 1316 and to other members of the Fornax Cluster.

NGC 2681 Sa 11A, p. *9*
PH-19I-MH (E,L,l/4) panel 87
May 13/14, 1950
103aO
30 niin

NGC 2681 has broad, smooth, almost circular arms of the MAS type. Dust in an almost circular pattern is present close to lhe center, nearly buried in the bulge on ibis print but shown well on page *9* of the Hubble Atlas. This galaxy. together with NGC 1302 (panel 70). are the earliest Sa galaxies shown in the Hubble Atlas. NGC 2681 is, however, not as early as Lhe galaxies shown on the preceding Iwo pages, for the reasons described there.

NGC 2655 Sa pec
PII-7928-S (EX, I)
Nov7/8.1980
I03a0
12 min

NGC 2655 lias smooth, tightly wound outer arms, of the multiple-armed type, and dust near the center. The fin*? pattern of the dust in silhouette against the bulge is seen in the insert print.

NGC **718** **Sa** **HA, p.** ***11***
PH-792-S **(E,L,O)** **panel 88**
Aug 25/26, 1954
103aO + WG2
30 niin

Two **high-surface-brightness** inner arms emerge from what is either an **internal** ring **surrounding the** inner disk or what is yet another set **of** tightly wound spirals close to the center. Both these interior **features** show well in the reproduction **here** and **in the** print in **the Hubble** Atlas.

Two **symmetrically** placed outer arms **of** low surface brightness can be traced inward until they nearly merge with the high-surface-brightness intermediate set of arms that hug the outside **of the** high-surface-brightness arms for about a **quarter-turn** each. The entire form is highly symmetrical. The galaxy is placed here in the MAS subset **of** Sa galaxies because of the pattern of 4–6 arms.

This galaxy, together with NGC 3269 and NGC 3626. also shown on this page, are the type examples of the smooth-armed Sa class. Both NGC 718 and NGC 3626 are isolated. NGC 3269 is a member of the Antlia Cluster. Because smooth-armed Sa galaxies occur in the **isolated** field, their form is not due to environmental effects but is generic to the **classification** sequence (Sandage 1983 a).

NGC **3269** Sa **Antlia 184**
CD-646-Br **(VE,I,0)** **not in RSA**
Jan 4/5, **1979** panel S3
103aO + **GG385**
45 min

NGC 3269 is the type example **of** the smooth-armed Sa class. The galaxy is **of** the grand design type, having only two arms, very symmetrically placed. The arms are tightly wound and can each be traced for nearly 360°, **which is a rarity.** The tightness of the structure is such that one arm nearly merges with the other after an unwind of 180°. The form is a slightly more open version of the same phenomenon exhibited by NGC 3081 (Hubble Atlas, p. 77; panels 99, 107 here), where the **two** arms nearly overlap, giving Lhe impression of a complete internal ring: **this** impression is not seen here.

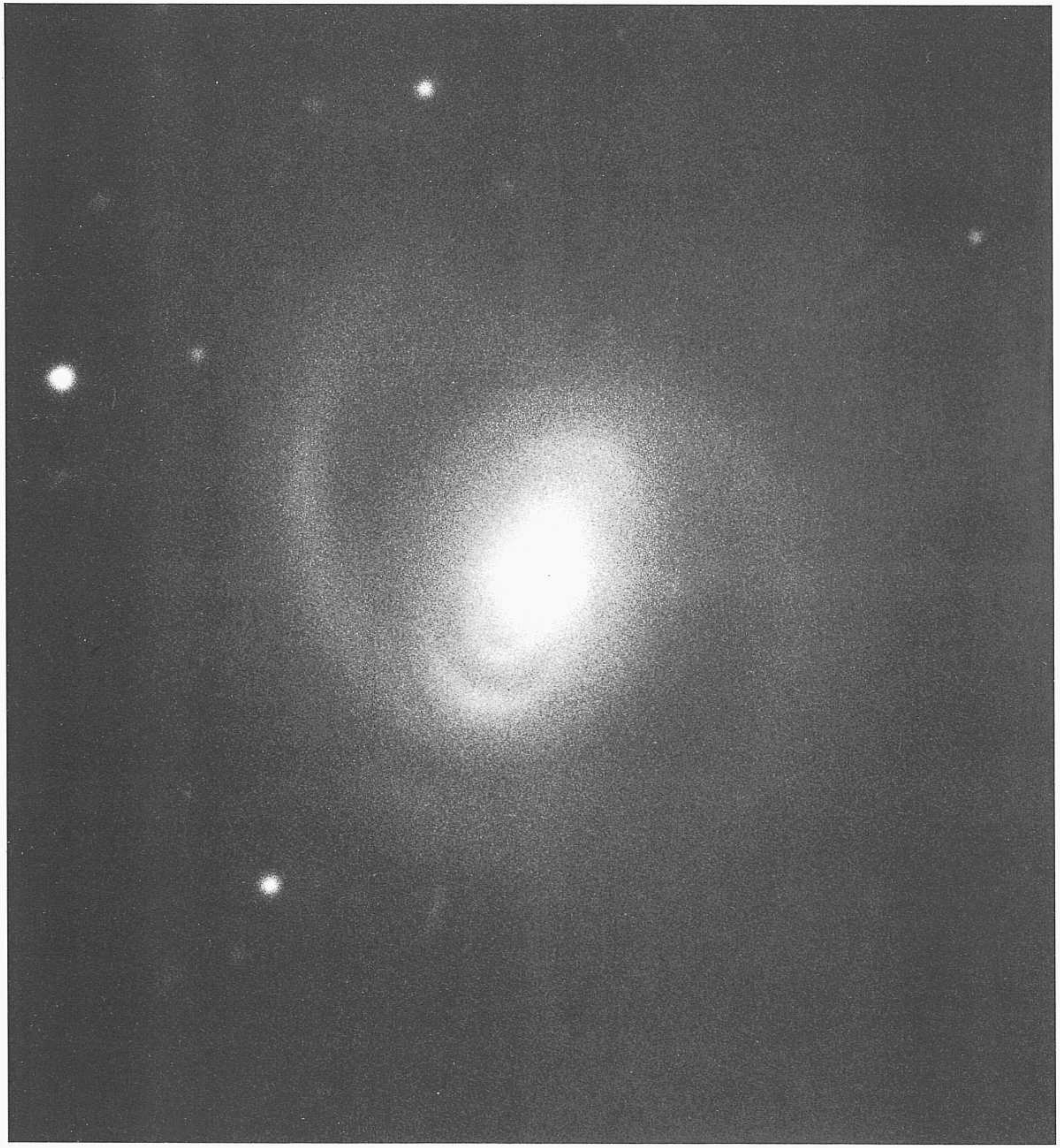
The galaxy is near the center of the Antlia Cluster (Ferguson and Sandage 1990). **It** is **not** in **the** RSA.

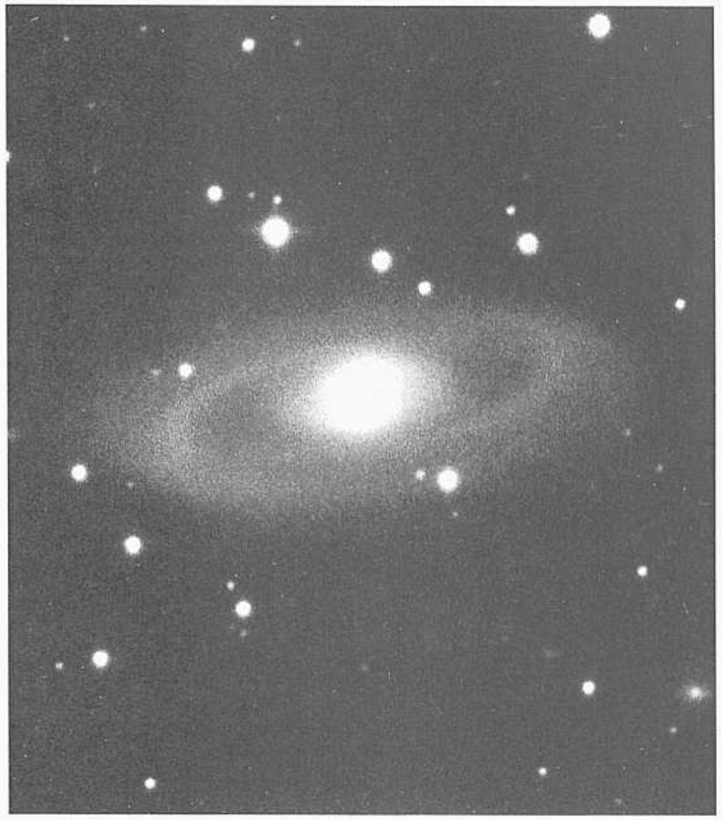
NGC 3626 Sa **panels 64, 74**
PH-7651-S **(E,E/I,l/2)**
April 29/30, 1979
103aO
12 miii

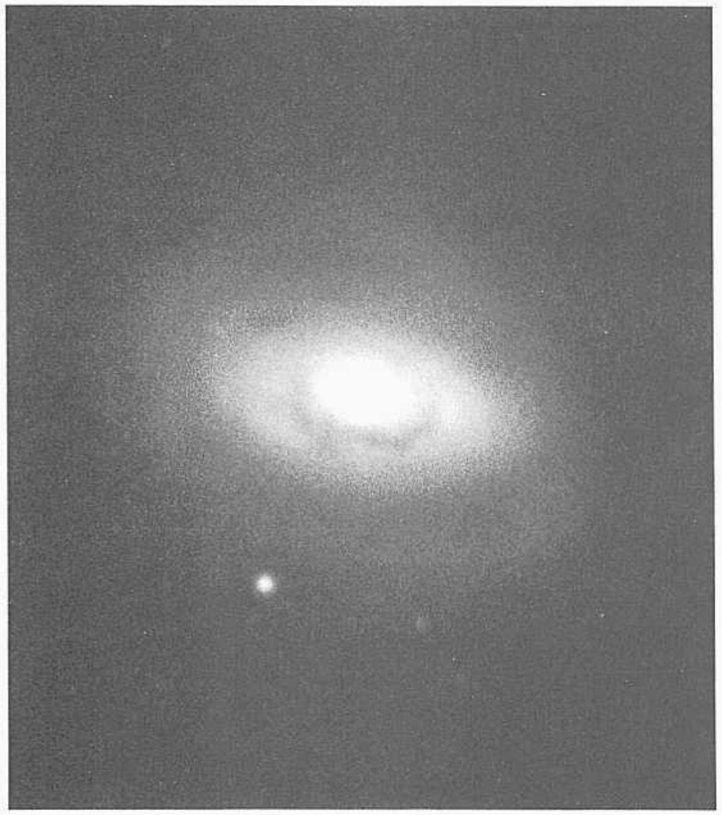
This early Sa galaxy is often misclassed as SO/Sa. It is classed as RSO in the RC2, where the low-surface-brightness outer regions are called a ring. However, the outer structure is spiral, of the same smooth type as in the other two galaxies on tliis page.

The internal dust lane is nearly circular, as in the SO3 types, but unlike these "earlier"' (smoother) SO dust lanes, the lane here can be traced **for** 360° around the image. The reason for the complete dust ring seen in the image here, contrasted to only the partial appearance **of** the dust ring in SO3 galaxies shown in previous pages, is **undoubtedly** the favorable inclination aspect of NGC 3626 and its smaller bulge intensity, reducing the contamination **of** the ring contrast on the far side.

The arms are tightly wound, one arm nearly merging with the other after turning 180°, as in NGC 3269, above. The innermost set of the outer arms is shown better in the print on the next panel. Even fainter structures that may have a spiral pattern exist beyond the **faint** arms visible there and also in the print here when it is viewed from a distance.

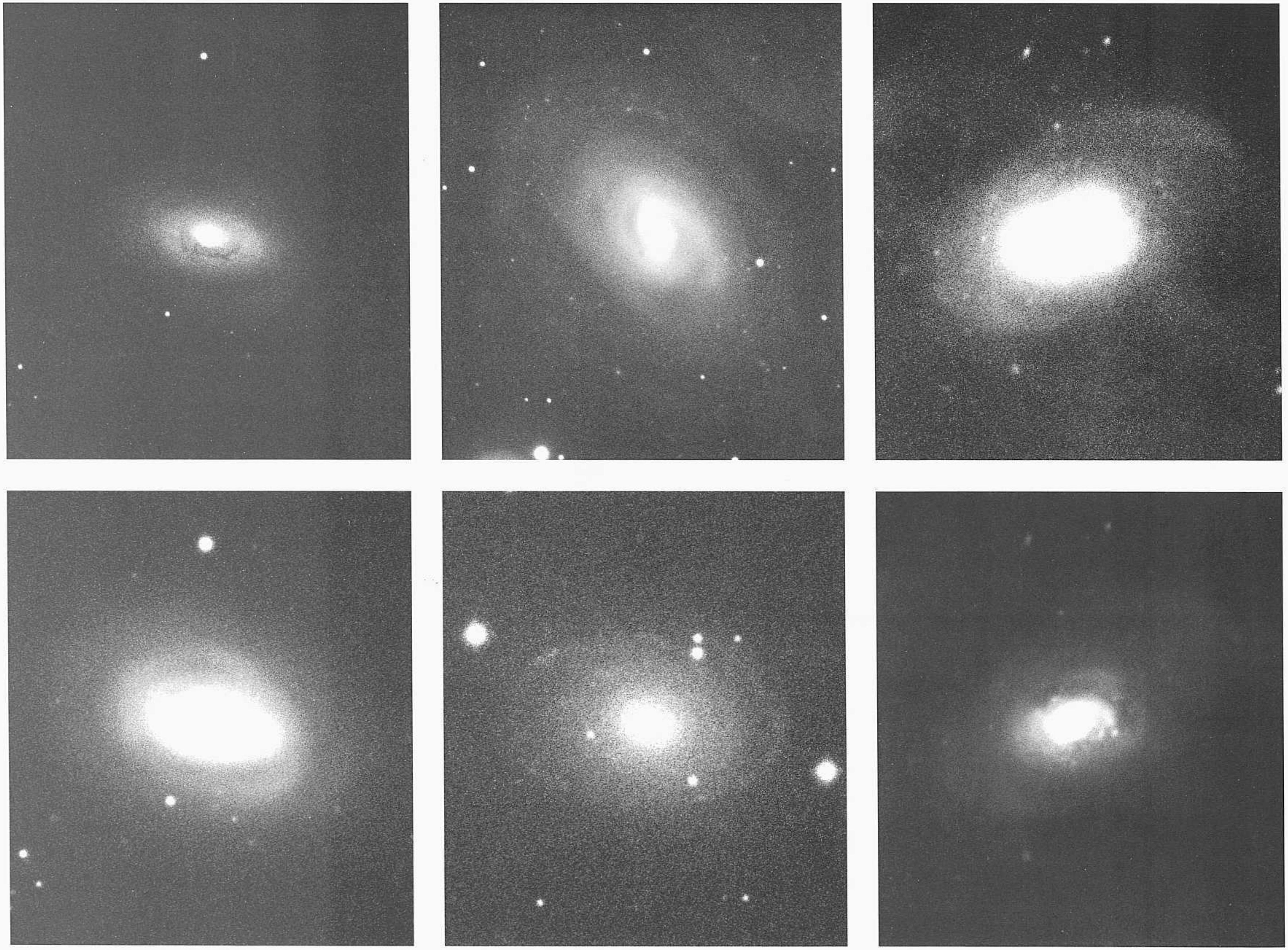






PANEL
63

PANEL
64



NGC 3626 Sa panels 63, 74
CD-1878-HB (E,E/I,l/2)
April 11/12, 1981
103aD + GG495
25 inin

Compare the detail in the dust lane of NGC 3626 in this print with the image of the same galaxy on the preceding panel. The plate used here was taken in better seeing, and it is a yellow emulsion (103aD) rather than blue. Compare it also with the long-exposure image of the same galaxy, below, where the smooth arms are well shown.

NGC 3626 Sa panels 63, 74
PH-7651-S (E,E/I,l/2)
April 29/30, 1979
103aO
12min

This image is from the same plate shown on the preceding page but printed to show the smooth spiral arms. As mentioned on the preceding page, there exist yet fainter structures beyond the arms shown here. They are located as far from the edge of the lens beyond the arms seen here as those arms are from the lens. A hint of the outermost structure is most visible on this print on the lower-right side of the image when the print is viewed from a distance.

NGC 1371 Sa(s) Racine wedge
PH-7456-S (E/I,I,l/4) panels 80, 88, S3
Dec 16/17, 1977
098-04 + RG2
60min

The red emulsion of this plate suppresses the delicate outer arms of the multiple spiral pattern of NGC 1371, where star formation is occurring. These outer arms are shown on later pages of this Sa section (panels 80, 88, S3), where the prints have been made from blue emulsion plates. The purpose of the print here is to show the smooth inner spiral arms, similar to the other smooth-armed Sa galaxies discussed on previous pages. No star formation is occurring in these arms, yel the spiral pattern is definite. The arms are red. similar to the colors of other smooth arms of this class (Kennicutt and Edgar 1986), indicating that stars in the arms are at least 2×10^9 years old.

The plate was taken with a Racine wedge. The brightest star in the print shows the double image where the secondary is separated from the primary by 18" and is 5 mag fainter than the primary. The secondary appears to the right of the primary on this print.

NGC 2179 Sa
CD-497-S (E,I/L,l/4)
Sep 26/27, 1978
103aO + GG385
30min

NGC 2179 is a multiple-armed Sa galaxy of later type than the Sa galaxies on the preceding pages. The arms are almost circular. They are thin and show a few isolated probable 1111 regions along the upper left spiral arm. The filamentary multiple-arm pattern winds through the well-defined disk. The galaxy is among the earliest non-smooth-armed, multiple-armed type (MAS), whose later examples are NGC 2775 (Sa; Hubble Atlas, p. *10;* panels 78. 87. SI 2 here) and NGC 4699 (SaborSa: Hubble Alias, p. ; 6 ; panels 78 . 87, 118, S12 here).

NGC 3611 Sa
PH-7718-S (1,1,1/3)
Feb 11/12, 1980
IllaJ
60min

This and the print below of NGC 36 I I were made from the same plate. The relatively thin, generally smooth spiral arms show little if any recent star formation.

NGC 3611 Sa
PH-7718-S (I.I.1/3)
Feb 11/12, 1980
111:0
60min

Same as above, bul printed to show the evident star formation near the center. The integrated colors of B - V- 0.56 and U - B = 0.05 of NGC 3611 show the presence of star formation. Most galaxies in the preceding panels of this early part of the Sa section have redder- integrated colors, near $I!$ - \ = 0.9 and U-B = 0.4.

NGC 788 **Sa**
PH-7530-S **(E,L,O)**
Nov 4/5, 1978
IllaJ + GG13
60 min

The spiral **pattern** in NGC 788 consists of tightly wound, nearly complete circles. Only the outermost of these features is shown in this **reproduction.** The feature just outside the bright bulge is a broken circle: the break is most easily seen on the left side of the print. The break can also be seen, but less distinctly, symmetrically across the center on the opposite side. It is this symmetry and a suggestion of attachment to the bulge (most prominently on the left side) that gives **the** spiral classification to the arms. The pattern is **the earliest** type of the gamma description made by **Vorontsov-Velyaminov** (1987).

NGC 7779 **Sa** **group**
PH-7693-S **(E,VL,0)** **not in RSA**
Sep 26/27, 1980 **panel 133**
IllaJ
75 **min**

The pattern consists of two opposite, very tight (small pitch angle) spiral arcs, separated from the bulge and lens (disk?) with no visible attachment of either segment to the main body. The arcs are narrow and smooth. This galaxy is in a group with NGC 7778, NGC 7780, NGC 7781, and NGC 7782 in Pegasus at a mean redshift of about 5500 km s^{-1}. The bulge is very large. The arcs are slightly lumpy. The galaxy **is** not in the RSA.

NGC 2811 **Sa** **HA, p.** ***11***
PH-703-S **(E,I,l/2)**
Feb 28/March 1, 1954
103aO + **WG2**
30 min

NGC 2811 is one of the earliest Sa galaxies having well-developed, thin spiral arms. The bulge at the center of a smooth disk has two massive smooth stubs of arms emerging from its periphery. The **high-surface-brightness,** smooth arms terminate at the apparent edge of the disk after about a 45° wrap.

The thin, smooth outer spiral arms are narrow and are of the multiple-armed variety (MAS). Later Sa galaxies of the same type are shown by the prototype cases on panel 77, such as NGC 3449, NGC 5064, and NGC 3623 (all Sa). The later Sb multiple-armed spiral prototypes are NGC 5005 (panels 139, S14 here; Hubble Atlas, p. 75) and NGC 2841 (panels 142.S4,S12 here; Hubble Atlas, p. *14),* and the Sbc prototype MAS galaxy NGC 5055 (panels 191. S5 here: Hubble Atlas, p. 15). The two MAS prototype Sa galaxies shown in the Sa summary on panel SI 2 are NGC 2775 and NGC 4699.

The arms and disk of NGC 2811 are smooth, **showing** no sign of resolution into HII regions. The degree of resolution into star-forming regions increases as we proceed along the classification sequence from Sa to Sab and later.

NGC 3277 **Sa(r)**
PH-7994-S **(I,I/S,l/2)**
Feb 2/3, 1981
103aO
12 min

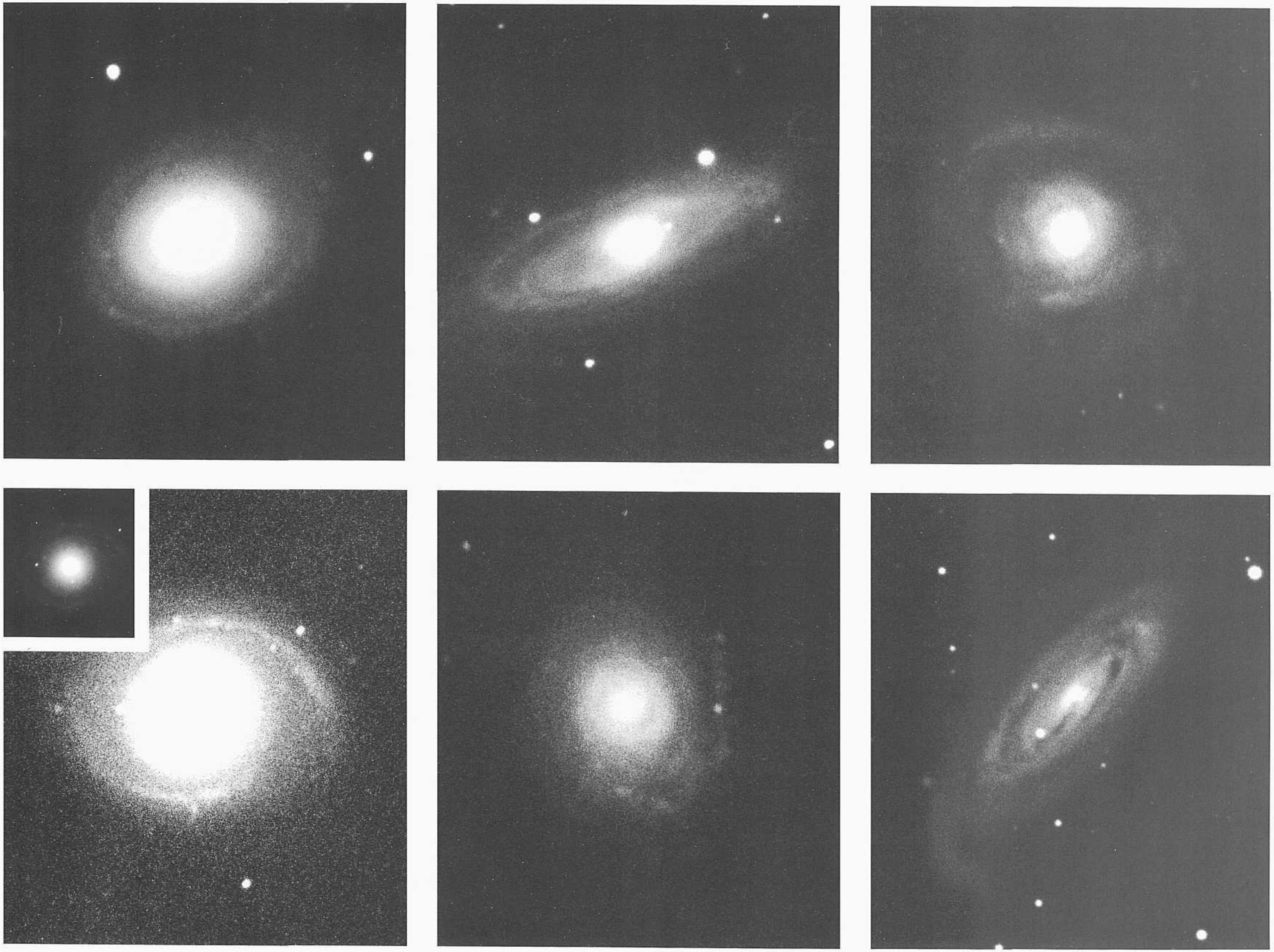
NGC 3277 is a multiple-armed Sa having knots along one of the thin, tightly wrapped spiral arms. The arms start tangent to an inner ring surrounding the small central bulge. The outer thin arms are in fragments that cannot be traced individually for more than about a 120° wrap at most, which is characteristic of the MAS spiral type.

NGC 5548 Sa
PH-7621-S **(E/I,I,l/2)**
April 27/28, 1979
103aO
10 min

NGC 5548 is a Seyfert galaxy with a starlike unresolved nucleus. It has multiple fragments of spiral arms. The outermost fragment is almost circular, with a 180° wrap, as shown in this print in the upper center of this print. However, **all** fragments are in a spiral pattern, connecting to the bulge at its rim. Small-scale images might suggest that the outer brightest arm is a broken ring (hence the classification of PSO/a in the RC2), but the pattern is spiral beyond doubt.

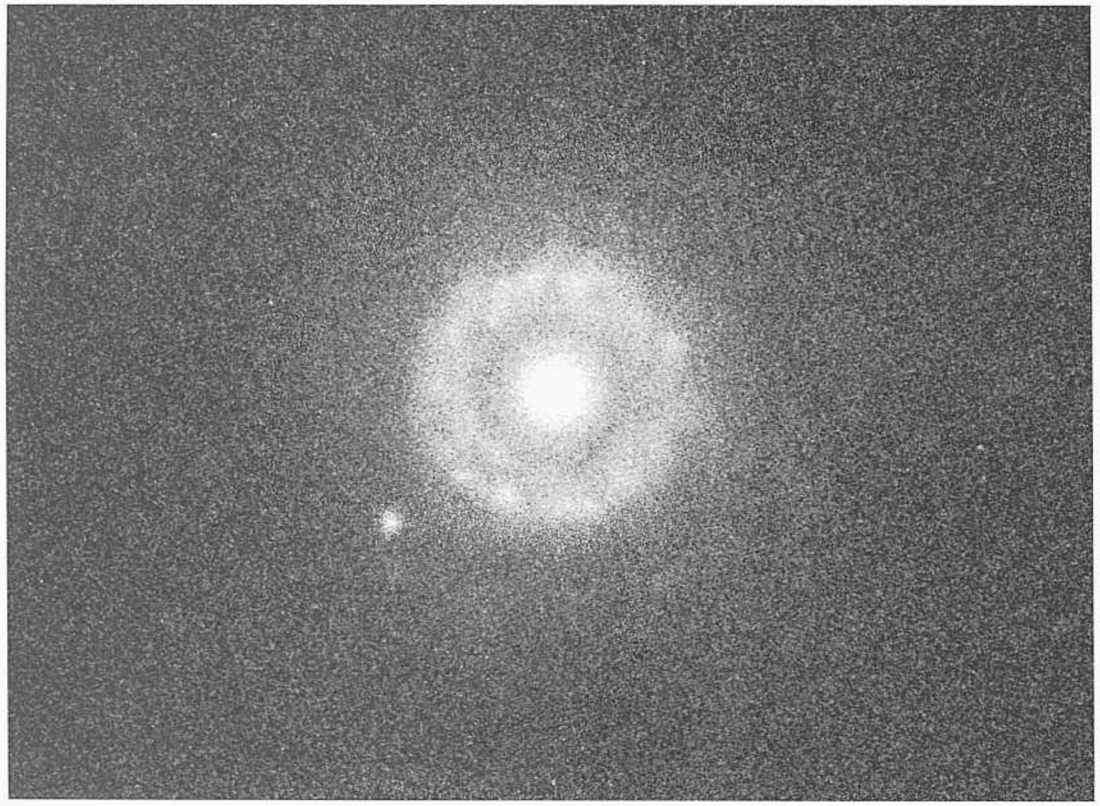
NGC 3281 Sa **Antlia 300**
CD-682-Br **(VE,S,l/2)**
Jan 26/27, 1979
103aO + **GG385**
45 **min**

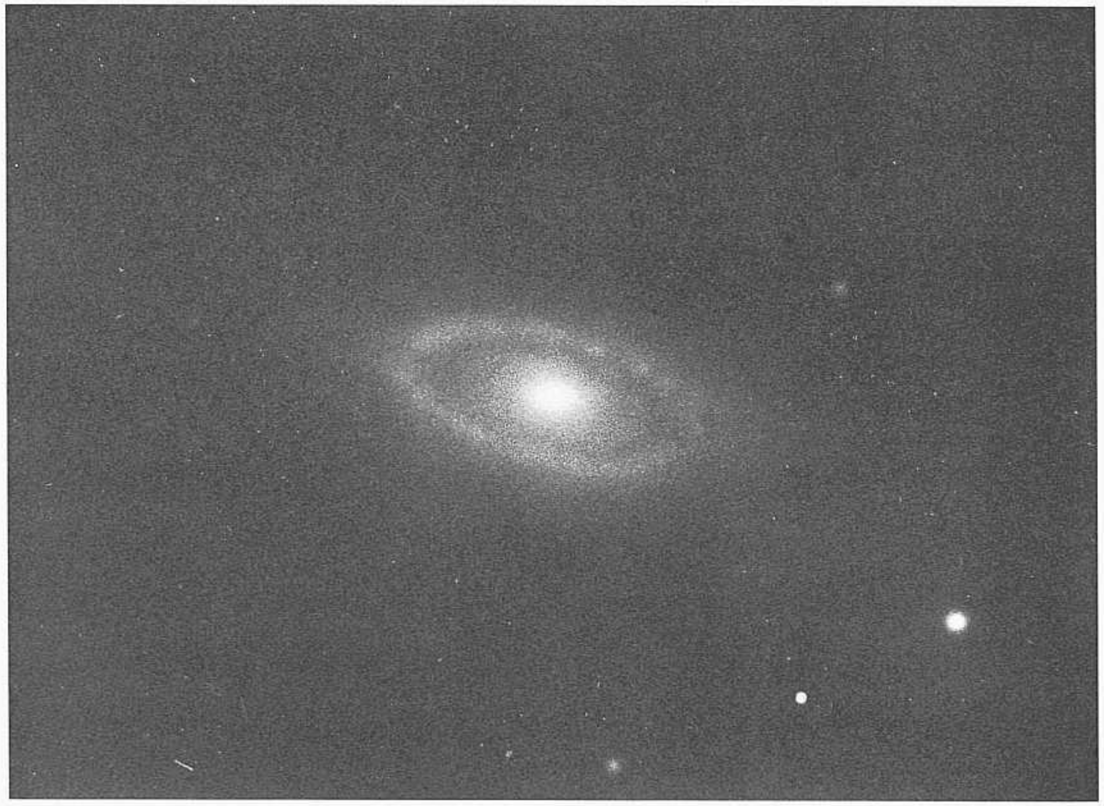
NGC 3281 has smooth arms and a small nucleus, yet the morphological class is Sa because the arms are not resolved into knots. The dust lanes in the disk arc also in a spiral pattern. The galaxy is in the Antlia Cluster (Sandage 1975b), whose mean redshift is $\langle \wedge_o \rangle = 2503$ km s^{-1} (Ferguson and Sandage 1990).

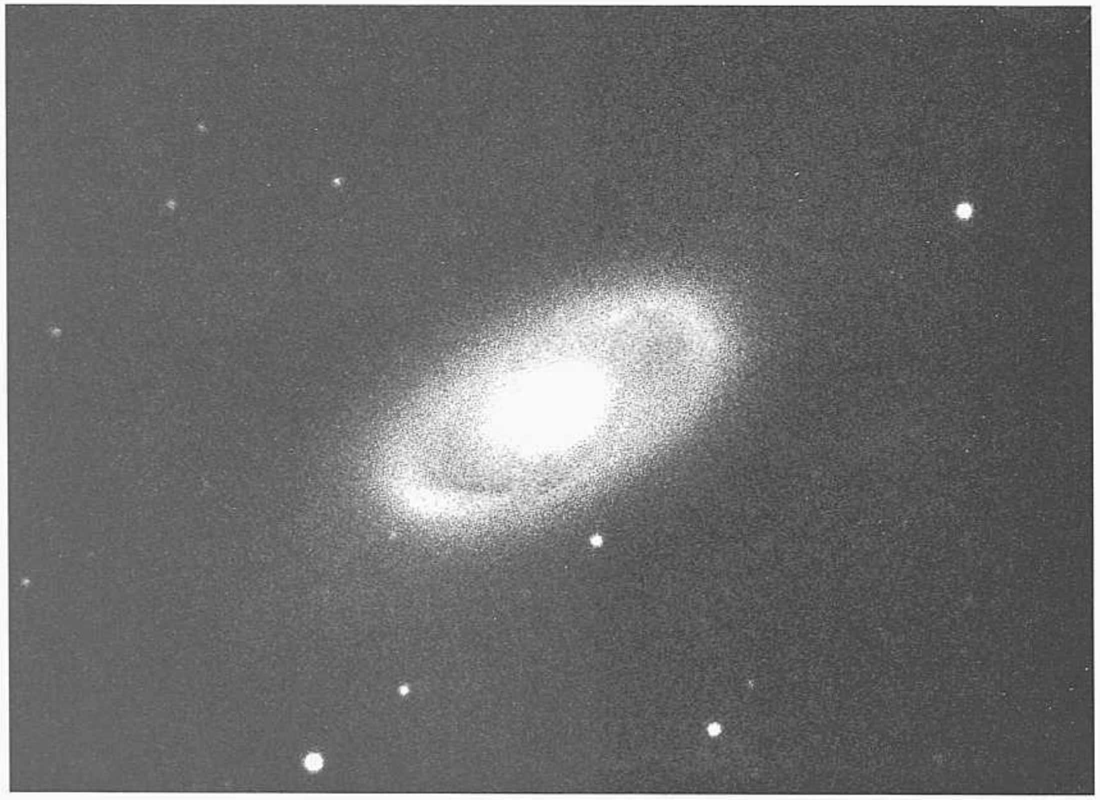


PANEL
65

PANEL
66







T he next six panels show Sa galaxies having as a common feature an almost-complete ring somewhere in its image.

NGC 7742 Sa(r!)
PH-7537-S (-,-,1/2)
Nov 6/7, 1978
103aO
4 min

NGC 7742 is the RSA example of the detached-ring-type galaxies discovered by Hoag (1950). Hoag's anonymous prototype galaxy is well reproduced by Schweizer *et al.* (1987), where the authors also derive the rotational properties of the detached ring and the mass of the bulge.

Theys and Spiegel (1976, 1977) and Lynds and Toomre (1976) suggest that galaxies similar to Hoag's prototype are the result of a close encounter between a primary that has suffered an almost direct hit by a secondary component, one galaxy going closely through the center of the other. Polar-ring galaxies may be a related class.

NGC 7742 is illustrated here as the first of the considerable Sa subclass, shown on the next six panels, that have prominent, rings which are nearly complete. Often, the spiral arms begin at the periphery of the partial ring rather than at the center.

Galaxies of this type are common and occur throughout the spiral sequence. The classification notation for this subclass is (r), as in Sa(r), Sb(r), and Sc(r). The contrasting spiral type, where the arms begin at the center rather than on a partial ring, is denoted Sa(s), Sb(s), and Sc(s). The distinotion between (r) and (s) subtypes for the spiral arms was introduced in the Hubble Atlas and is maintained throughout the classification in the RSA1 . the RSA2 . and here.

NGC 7742 is the earliest of the ring galaxies in the RSA. Most of the forms are generic to the classification sequence rather* than a result of a Theys/Spiegcl/Lynds/Toomre encounter. We presume that this is true for all ring galaxies that have the bulge at the center of the ring and where spiral structure begins on the ring. The regularity of the kinematics of the ring in Hoag's galaxy (Schweizer *et al.* 1987) reinforces this view.

The ring in NGC 7742 appears to be detached from the central bulge. There is structure in the ring similar to that seen in Hoag's galaxy (Schweizer *et al.* 1987). But NGC 7742 differs from that prototype. A set of low-surface-brightness, tightly wound, multiple spiral arms exist outside the ring in NGC 7742. These arms begin on the ring. They are very faintly seen on the print here, best viewed from a distance.

NGC 7702 RSa(r)
CD-493-S (-,-,1/3)
Sep 26/27, 1978
103aO + GG385
45 min

Two very tightly wound spiral arms that nearly overlap after each unwraps by about 1 80° appear, at first sight, to be a complete bright ring varying in intensity along its periphery. But the "ring."' in fact, is broken. The pattern is the same as in NGC 3081 (SBa: Hubble Atlas, p. *11:* panels 99, 107 here) and NGC 3185 (SBa; Hubble Atlas, p. *43:* panel 99 here).

Two oppositely directed dust lanes exist on the inside of the bright arms forming the inner broken ring. The most prominent of the lanes is on the left side of the central bulge in the print here.

Outside the bright near-ring is a very faint narrow outer structure that surrounds it, invisible in the print here. It can be described as two Greek gammas (y) joined with their stems pointing in opposite directions, each toward the center: the structures are the arms of the gammas continued until they meet. In what follows, this configuration is called the double-gamma structure.

Variations on this theme are common in many galaxies in the early part of the Hubble sequence, among both ordinary and barred spirals.

NGC 4321 Sa(r) ring VCC 613
H-1750-H (1,1,1/2)
May 24/25, 1936
Imp. Eel.
50 min

NGC 4324 is in the Virgo Cluster Catalog, but is near the W cloud (Sandage, Binggeli, and Tammann 1 985 b) and may not be a cluster member.

The ring appears to be complete on the available plate and also appears to be separated from the central bulge. The pattern is similar to that in NGC 7 742 on the left. The ring is lumpy, suggesting the presence of HII regions and recent star formation. External to the bulge but internal to the ring are tightly wound spiral patterns in the disk, not visible in this print. It is not clear if these arc composed of dust only, or if they are formed of luminous material.

NGC 4274 Sa(sr) HA, p. *12*
PH-686-S (I.I/I.J) panel 88
Foh 9/10, 1951
103aO + WG2
30 min

Prom poor plate material, NG(1 127 1 would probably be described as having an external ring. However, the pattern is similar to that described for NGC 7702 in the print on the left. The ring is broken. As in NGC 7 702. it is composed of two spiral arms that nearly overlap. The aspect of the line of sight relative to the position angle of one of the arms as it emerges from the inner disk al the edge of the bulge allows the arm overlap In In-seen on the near side of the image at the bottom on this print. The overlap of the two arms on the far side is much less visible because of the overriding luminosity of the bulge and the smaller effect of the dust lanes in separating the arms in the visual impression. (Dust lanes are always more visible on the near side.) The silhouette of the inner dust lanes on the near side against the bulge is striking here.

The bright luminous inner arms with their associated dust arc well seen here. The arms begin near the edge of the bulge: the spiral subtype is (s) (see discussion under NGC 7742 mi this page). A set of fainter outer arms exist. continuing outward from the rim of the broken near-ring; the subtype of this feature is (r). These faint outer arms are well shown in the negative print on the Sa summary page, panel 88.

The galaxy has features both of the multiple-armed spiral (MAS) and the grand design (GD) type if only the two high-surface-brightness inner near-ring arms are considered. 'These arms are lumpy. NGC 42 74 is later along the Sa sequence than NGC 7702 at tin- left, although the basic patterns arc similar.

The positive print and the description in the Hubble Atlas (p. *12)* show the features described here but with a different contrast.

The galaxies on this panel are in the middle third of the Sa morphological box. They are all of later type than the galaxies on the immediately previous pages. In each, there is evidence of recent star formation, based on the suggested presence of HII regions appearing generally as knots in the arms. The knots are, however, fewer than in Sb galaxies, and the arms are generally more tightly wound here.

NGC 6935 **Sa(r)** pair
CD-1517-S/Br (L,S/I,1)
Aug5/6, 1980
103aO + GG385
45 mill

NGC 6935 forms a pair with NGC 6937 (SBc) at 246" separation. The redshift distance of NGC 6937 $(t)_o$ = 4701 km s^{-1}) is 94 Mpo (H = 50), giving a projected linear separation of 112 kpc for the pair.

The spiral arms in NGC 6935 are tightly wound into almost-circular arcs. The many multiple fragments of the MAS pattern can be traced as individuals for only about 120° maximum wrap. The surface brightness of the inner disk and the inner set of arms (the near-ring) is very high. Delicate, nearly circular dust lanes exist inside the near-ring, and are well visible in this print. These outer delicate ares (which are the arms) are smooth and show no sign of recent star formation.

The pattern is similar to that of NGC 7742 on the preceding page, but NGC 6935 is later in the Sa box. The near-ring is not as tightly wound as in NGC 7742, and the outer spiral arms that begin on the ring are of higher surface brightness here.

NGC 4454 Sa Virgo region
CD-699-Br (1,1,1/4)
Jan 28/29, 1979
103aO + GG385
45 min

NGC 4454 is in the Southern Extension of the Virgo Cluster, at RA - I2" 26'". Dec = -01° 40'.

As in NGC 6935 above, a bright near-ring forms an inner spiral pattern. The near-ring is, in fact, composed of three (perhaps four) segments, two of which may attach to the bulge by much fainter threads than the high-surface-brightness material in the broken ring itself. The pattern is similar to that in the SBa prototype "broken ring" galaxy NGC 3081 (panels 99, 107 here: Hubble Atlas, p. / /).

Very faint smooth-armed arcs exist outside the bright broken ring at a distance outward equal to the distance from the center to the edge of the near-ring. One side of this arc is faintly visible in the lower-left part of the print here.

NGC 1079 Sa(s)
CD-506-S (E,I/L,0)
Sep 27/28, 1978
103aO + GG385
45 niin

This and the print below show the outer and the inner structures of NGC 1079 which have high symmetry in the spiral patterns. There are two principal outer arms that are tightly wound. Each contains many knots, presumably small HII regions, all unresolved at 1" resolution.

The outer arms have very low surface brightness. As usual, the place where these arms connect to the rim of the bulge cannot be traced with certainty at the intensity level reached by the plates. The intensity of the arms always drops in the vicinity of the connections near the bulge. The inner arms can be traced on this print into the vicinity of the bulge at about 12 o'clock and 6 o'clock. The arms can then be traced outward over an arc of about 270°, an unusually large wrap except in a few of the most regular galaxies such as NGC 7096 on the next panel.

The outer arm on the left side (at about 9 o'clock) is bifurcated. There is a suggestion that the opposite arm is thickened at a position angle of about 3 o'clock, again showing the high symmetry of the image. This symmetry suggests a grand design type.

The galaxy is isolated. The nearest bright galaxy is NGC 1097 (RSBbe: panel 201 here; Hubble Atlas, p. *46)* separated by 1° 20' southeast and at a much different redshift. There are no obvious companions to NGC 1079. The grand design features in NGC 1079 are not, then, due to perturbative interaction.

NGC 1079 Sa(s)
CD-506-S (E,I/L,0)
Sep 27/28, 1978
103aO + GG385
45 min

The print of NGC 1079 here is from the same plate as above, printed to show the high-surface-brightness, smooth inner arms. These attach to the bulge at about the same position angle as the faint outer arms. A thin dust lane exists on the inside of the bottom inner arm.

At least four arms exist in this galaxy—two inner and two outer. The pattern is neither filamentary nor simply two-armed of the usual grand design type.

NGC 2781 Sa(r)
CD-653-Br (I,L,l/3)
Jan 5/6, 1979
103aO + GG385
45 min

The common features shared by NGC 2781 with the preceding three galaxies on this page are (1) an internal set of tight, inner spiral arms that are almost a ring but are broken into a spiral pattern, (2) a set of very faint outer arms, and (3) a high symmetry to the pattern. NGC 2781 is remarkably similar to NGC 1079 (at the left) in most of these features.

The inner set of high-surface-brightness arms nearly overlap one another after half a revolution. They are nearly burned out in this print. On the original plate they show knots that are probably HII regions. Considerable dust, not visible on this print, is present in the inner arms. The inner arms can be traced a full 180° until each nearly meets its companion arm on its way out, a feature not present in the inner arms of NGC 1079 because the wrap is not nearly as extensive. But the feature of a nearly complete broken ring (i.e., the 180° wrap) is highly visible in the inner arms of NGC 6935 and NGC 4454, similar in this feature to all galaxies on this page.

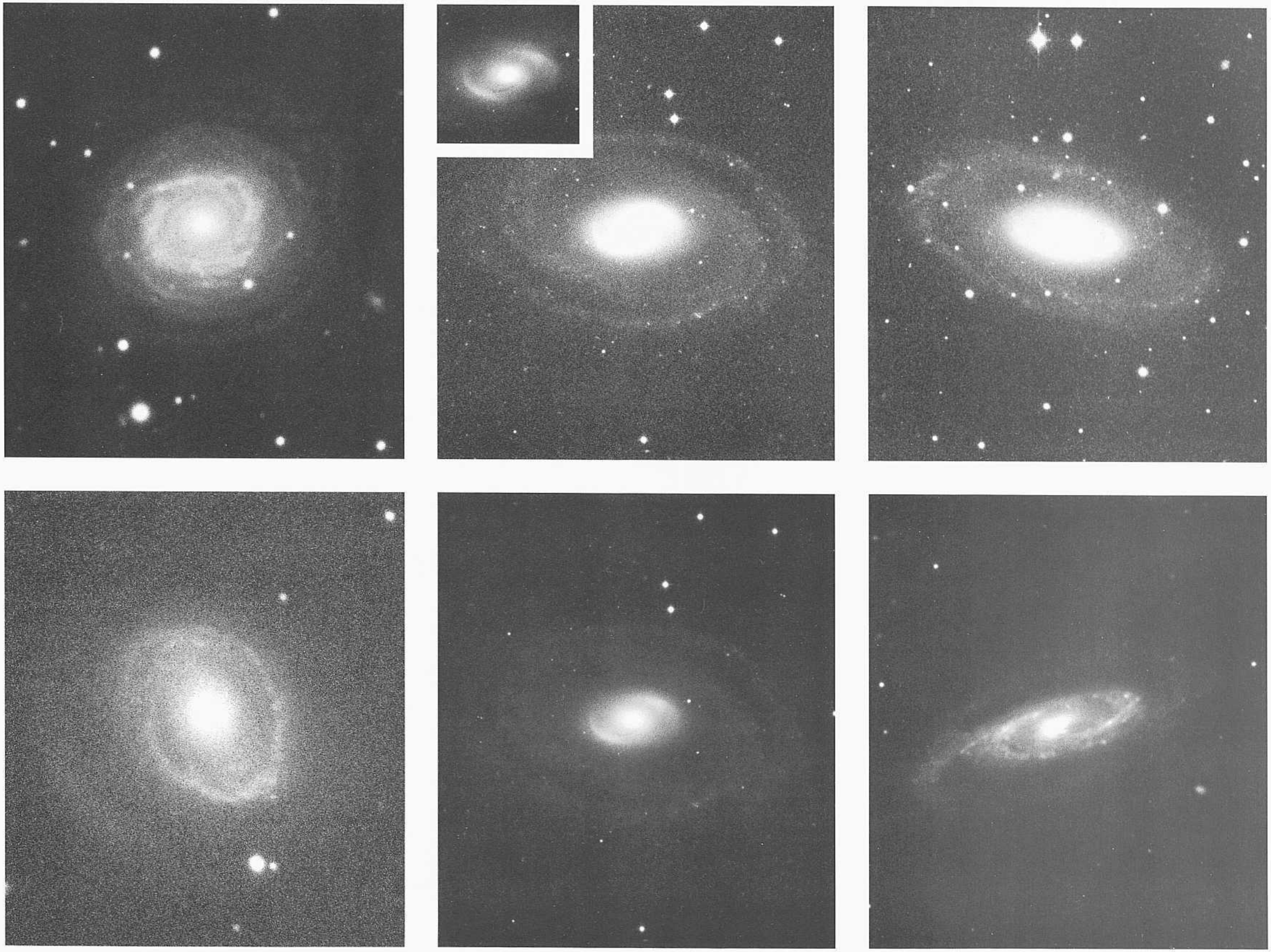
The set of two symmetrical outer arms is similar to those in NGC 1079. The rate of recent star formation in these arms is higher than in NGC 1.079. The slight difference between the two galaxies in the degree of resolution into HII regions shows the progression along the Sa sequence.

NGC 5448 Sa(s)
PH-7582-S (L,S,1)
April 1/2, 1979
103aO + GG385
10 min

NGC 5448 is similar to the other galaxies on this panel in (1) the high-surface-brightness inner arms that, together, form a broken ring, and (2) in the set of very faint outer arms.

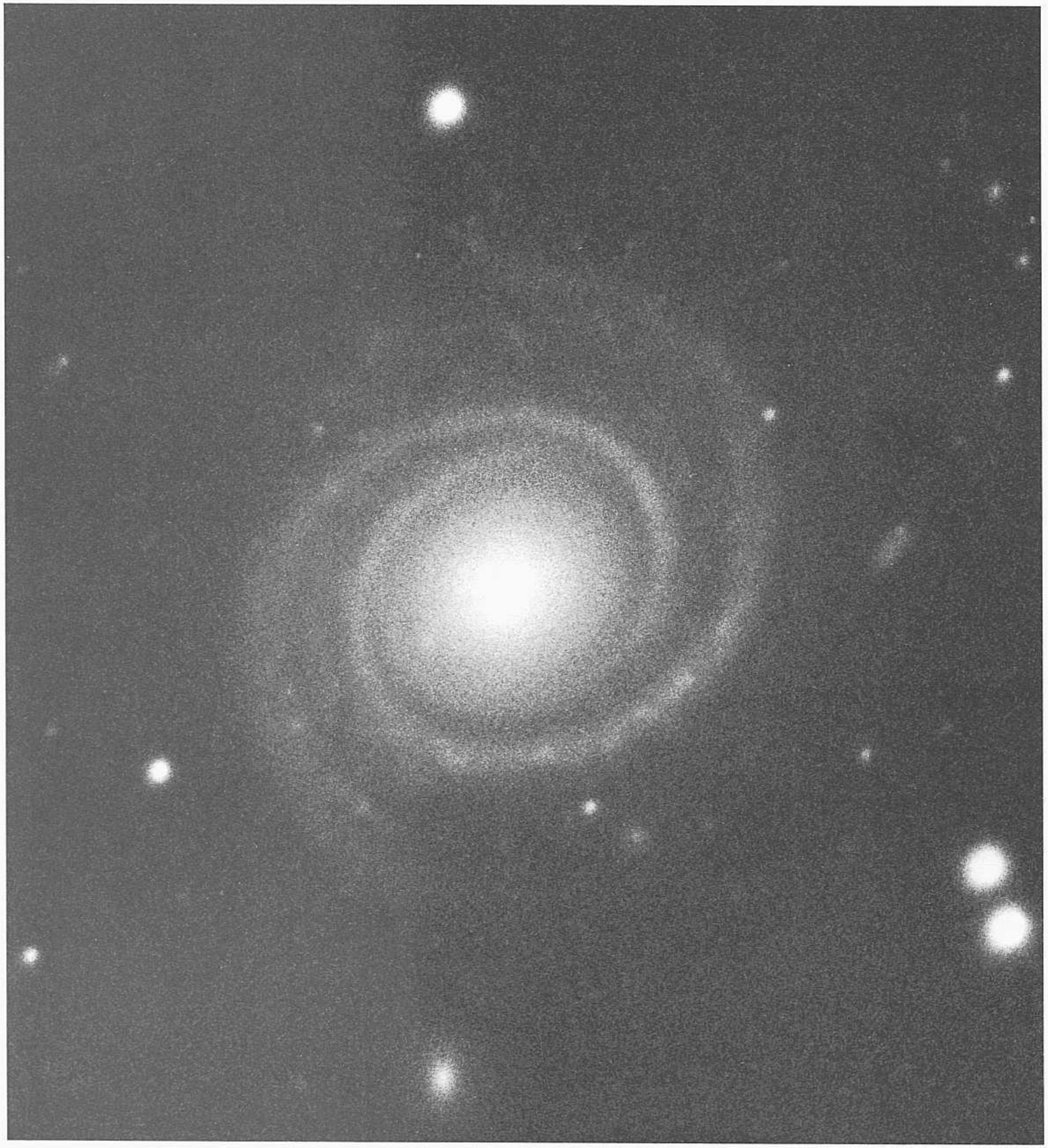
This galaxy is the latest of the type shown on this page. The inner arms are filled with HII regions. The outer arms are regular and have fainter knots which are also probable HII regions. The central bulge is small, but the character of the arms (tightness of the pattern and the small amount of star formation) require the classification to be a late Sa rather than an Sb.

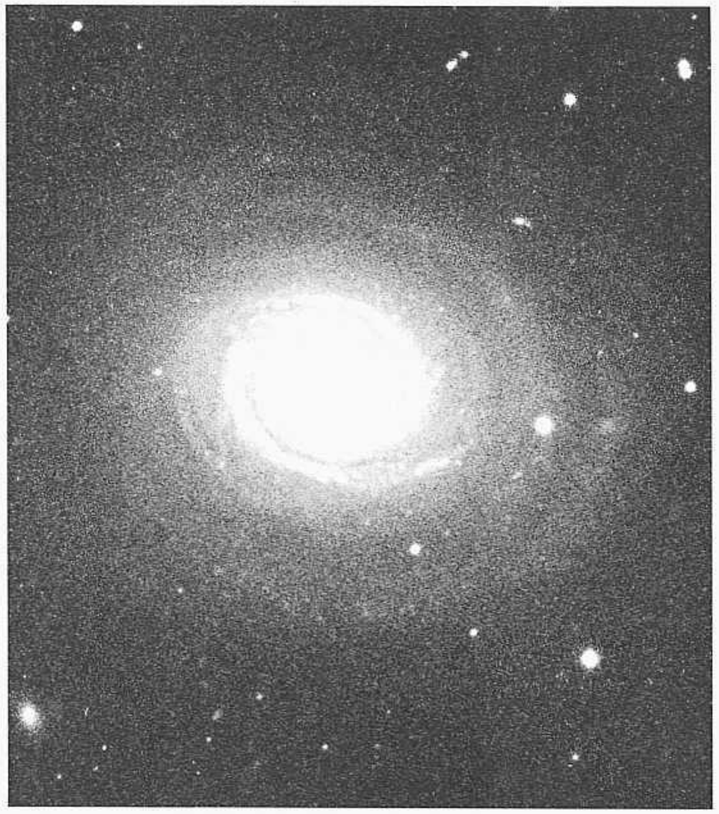
The outer set of arms is best seen by viewing the print from a distance.

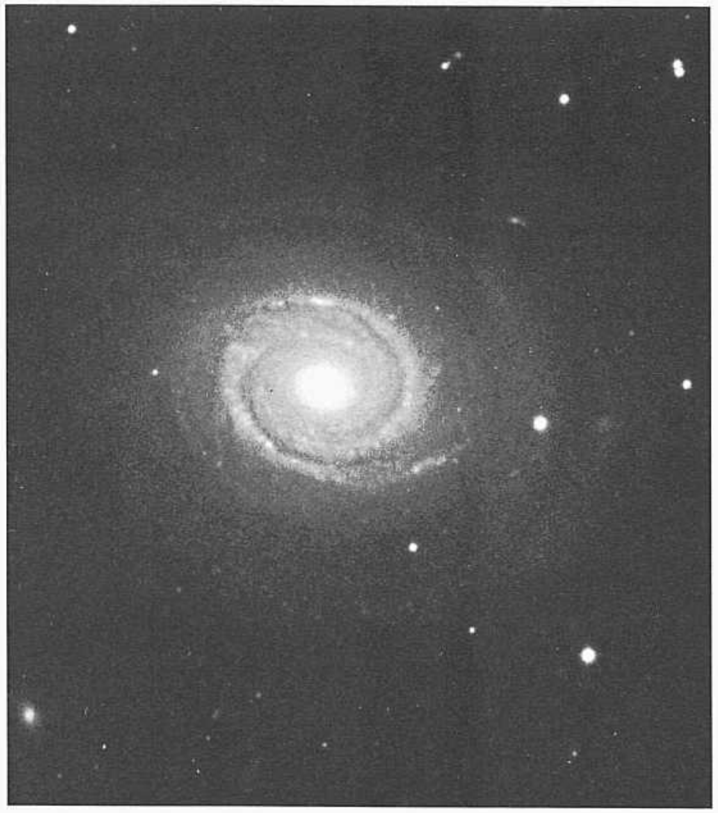


PANEL
67

PANEL
68







NGC 7096 Sa(r)I panels 88, S3
CD-518-S/Br (I,L,0)
Sep 29/30, 1978
103aO + GG385
45 miii

NGC 7096 is **one of the** most **regular spirals** in the sky. **The** arms **form a highly symmetrical** pattern that can **be** traced a rare full 360°. The arms are not **entirely smooths** a ^ew knots exist that are probable **1III regions.**

Although the pattern is **dominated by the** two **principal** arms, two very **much** fainter arms exist between the **two** main arms—structures **thai** have sometimes been **called** fossil arms. **They** are visible **at the limit of this print at** position **angles** of about 2 o'clock and 8 o'clock, widened **on** either side **of** these directions **For** about a **quarter** of **a** revolution.

NGC 1357 **Sa**
CD-545-S **(1,1,1)**
Ocl **1/2, 1978**
103aO + GG385
33 min

This and **the print of the** same **galaxy** below **were** made **from the** same **negative, printed to** show both **the** inner and **the** outer **arms. NGC I 357 has the same pattern bul** is **later along the Sa sequence than NGC 7096 al the left. The brightest** parts **of the** arm **structure arc the two** inner **tightly** wound spirals shown **in the lower print. Note** also **the intricate** spiral, **multi-armed** nature **of the** space **inside** these **two bright segments.** The **bright arms** with their **attendant dust** bines **on** the **inside edges** ol **the arms can** be **traced at their high-surface-brightness level for** about 300° wrap. **Each arm** can **be extended for** at least **two more** entire **revolutions** outside, with **ever-decreasing** intensity.

The **first part of this highly** multi-armed structure can **be** seen in **the top image here, which** is printed **with** hifjh **contrast, wiping** out some **of** the **fine** details. The **ridge-line regions of these** outer arms are much **narrowc**r tlinn is seen in this print.

NGC 1357 Sa
CD-545-S (1,1,1)
Oct 1/2, 1978
103aO + GG385
33 niiii

Th<? description above **applies** also hri·e.

vJTalaxies on this page continue the pattern of the preceding panel, displaying a near-ring from which external fainter arms emerge. The galaxies here are later along the Hubble sequence, as judged by the higher star-formation rate in the arms, betrayed by the increased lumpiness of these arms due to the many HII regions.

NGC 3900 Sa(r)
PH-7630-S (I/L,I,1)
April 28/29, 1979
103aO
10 min

NGC 3900 is of **the** MAS (multiple-armed spiral) type, **but** as in NGC 4274 three panels hack (panel 66). one set of arms, now not so **tightly wound,** are of dominant intensity. At small scale **or** on poorly exposed plates, this could he seen as an internal ring. The galaxy is listed in the RC2 as SO(ring), but this is clearly inappropriate: the multiple, lumpy spiral arms place it in the intermediate-to-late part of the Sa sequence.

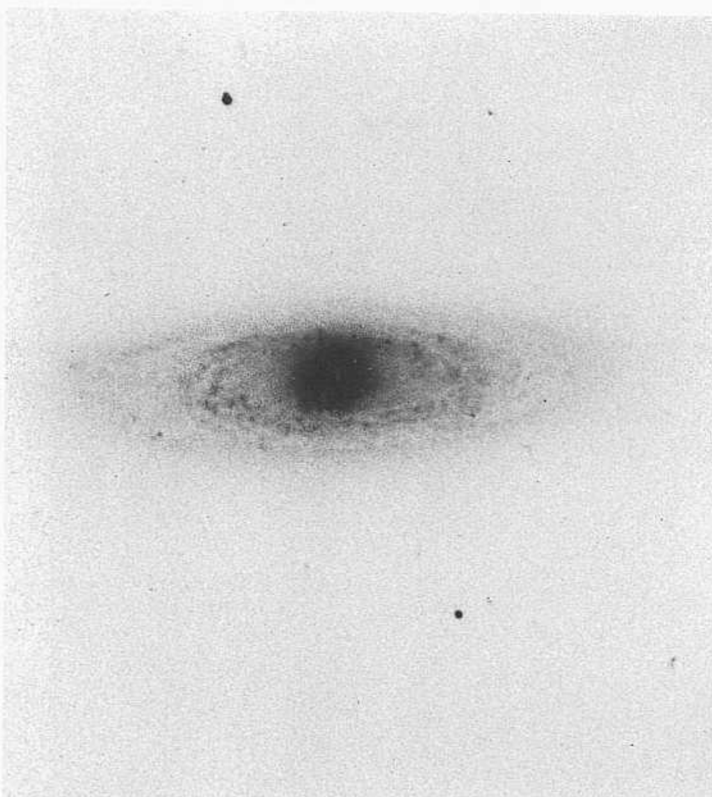
Multiple dust lanes in an MAS pattern thread throughout the inner disk. Parts of the very many fragments of the dust, also in an MAS pattern, are suggested in their silhouette against the near side of the disk in this low-contrast print. On the original plate, at least three additional arms in dust silhouette can be seen against the near-side disk outside (helow on this print) the three arm fragments, well seen. Note that the inner dust fragment is against the bulge itself, and is almost buried in the bulge light.

NGC 4448 **Sa(late)**
PH-8031-S **(L,L,1)**
Feb 3/4, 1981
103aO
2 mill

NGC 4448 has the same pattern as NGC 3900, above, **but** is still later along the Sa section. The galaxy would look very much like NGC 2775 (Hubble Atlas, p. *10:* panels 78, 87. S12 here) if it were **viewed** more face on. The SBab(r) type listed in the RC2, based on a Mount Wilson 100-inch plate, is **inappropriate** because there is no bar on that plate or on several 200-inch plates, one of which is used for the print showing the bulge region here.

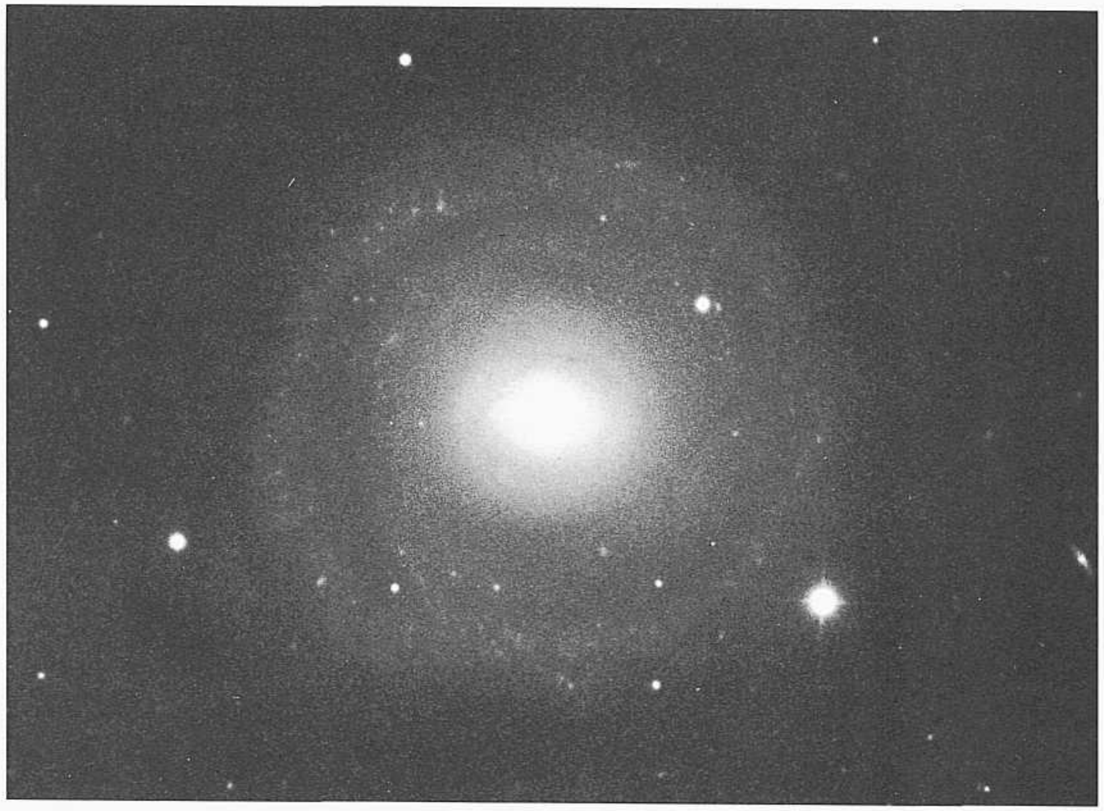
NGC 6902 Sa(r)
CD-481-S (I/L,S,l/2)
Sep 23/24, 1978
103aO + GG385
60 mill

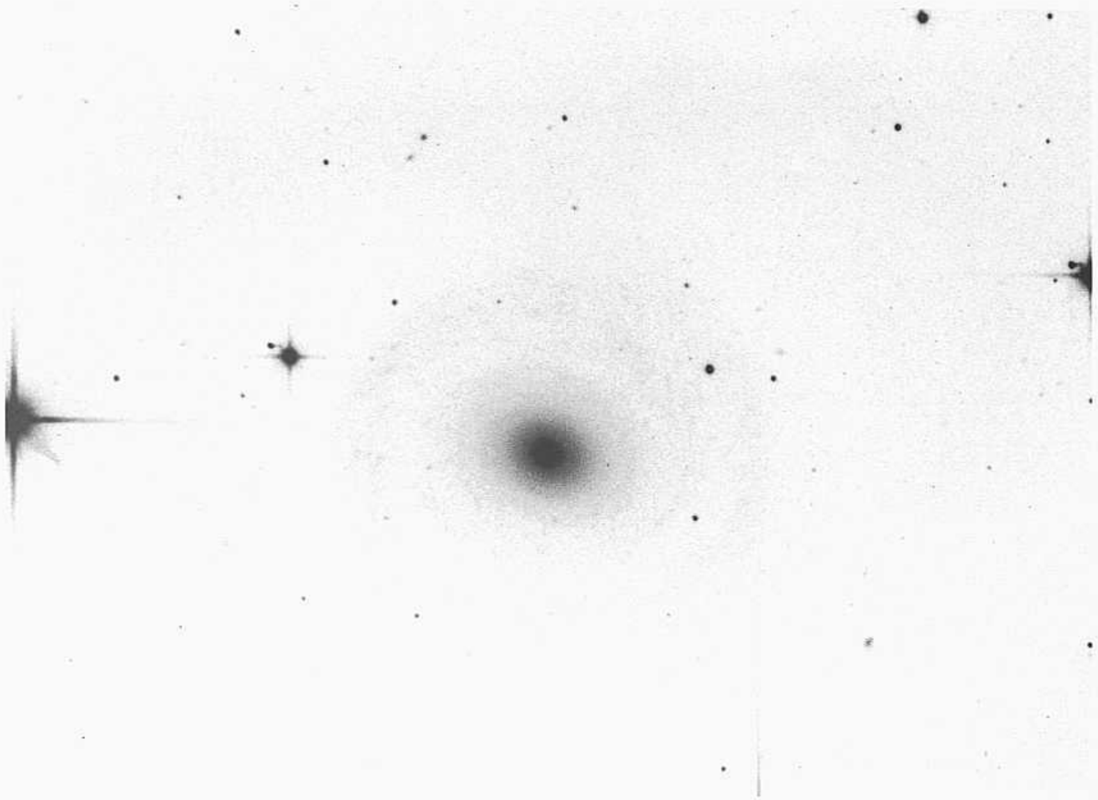
Multiple faint arms in this late Sa galaxy start from a high-intensity internal ring, similar to all galaxies shown on this and the preceding several pages. The central bulge is small, and the internal ring, seen in the insert, printed to the same scale, is nearly as complete as in NGC 7742 on **panel** 66. The outer arms of the MAS pattern are faint, but they are not smooth. They contain many small knots that betray a small but finite star-formation rate if the knots are HII regions.



PANEL
69

PAX EL
70





The galaxies on this page are Sa types that span the length of the Sa morphological box from early to moderately late. The feature they have in common is an (inter structure, which on low-resolution plates has often been called a ring rather than a spiral pattern. However, all the galaxies here are spirals, and the external structures are broken rings in the sense described on panels 66 and 67.

NGC 7020 RS0_2(5)/RSa
CD-483-S (E,I,0)
Sep 23/24, 1978
103aO + GG385
56 min

The external broken ring in NGC 7020 comes closest of the four on this page to being a complete ring, which explains the classification of RSO in the RC2. The classification here is mixed, at RSO/RSa, because of the two symmetrically placed ansae at the rim of the lens (the disk), resembling the embryonic arms of the SO/Sa types on panel 60, such as NGC 4425 and NGC 4429. The similarity to the very early Sa types on panel 61, such as NGC 4461, NGC 4503, NGC 1380, and NGC 3271, is also noted.

NGC 7020 is not a pure SO because of these spiral-like enhancements at the rim of the disk. The galaxy is similar to NGC 2962 (RSB0_2/Sa; panel 93), where the enhancements are called the ends of a bar rather than embryonic spiral structure as here.

The faint outer near-ring is not complete in NGC 7020. It is composed of two nearly overlapping spiral segments similar to those in NGC 3081 (Hubble Atlas, p. *11;* panels 99, 107 here). These near-ring spiral arms are slightly lumpy, indicating current star formation, albeit at a very low rate.

NGC 4378 Sa(s) VCC 785
CD-1309-S/Br (1,1,0) HA, p. *10*
March 11/12, 1980 Racine wedge
103aO + Wr2
75 min

The classification of NGC 4378 is RSa in the RC2, but the outer feature called *R* in this notation does not form an outer ring. It has a clear spiral pattern.

The many small knots in the outer arms suggest incipient star formation. The surface brightness of the arms is very low. The negative print here is from a Las Campanas plate taken with a Racine wedge; note the double images with a magnitude difference of 5.5 mag, separated by 18". The spiral pattern is filamentary, of the MAS type, not of the grand design.

NGC 1302 Sa HA, p. 9
CD-578-S (E,L,O)
Oct 8/9, 1978
103aO + GG385
40 min

NGC 1302 is similar to NGC 2681 (Hubble Atlas, p. 9; panels 62, 87 here) but is considerably later along the length of the Sa morphological box. The print here is from a Las Campanas plate taken in better seeing than the Palomar plate used in the Hubble Atlas.

The outer arms contain numerous small knots, indicating current star formation albeit at a very low rate. The two arms are nearly circular, imitating a ring, but they each attach to the rim of the disk in their inner parts. The attachments appear in the print at position angles of about 5 and 11 o'clock. The arms then wind outward and can each be traced for at least a 360° wrap. Characteristic of other galaxies of this type (panel 67), they nearly overlap after a 180° wrap, giving the false impression of a ring.

NGC 3358 **Sa(r)I** **panel «8**
CD-191-S (1,1,1/2)
Feb 7/8, 1978
103aO + GG385
45 min

NGC 3358 is a still-later example of the form described on this page. The tightly wound double arms almost overlap after a 180° wrap. The feature is well seen here because the inclination is ideal for its display. The arms attach onto the rim of the disk at position angles of **about** I and 7 o'clock, and, after winding outward for 180°, each encounters the outer regions of the other arm, which has wound outward for 360°.

The rate of star formation in the arms is much higher than in NGC 1302, above, or in NGC 4378, at the left. The evidence is the higher surface brightness and the more-prominent presence of HII regions in the arms.

Spiral dust lanes appear in the bulge, largely burned out in this print. A narrow prominent dust lane appears on the outside of the inner arm attached to the bulge at 5 o'clock and winding outward in the upper part of the print. There is dust in the other arm which, however, is not as well silhouetted.

The galaxy type is Sa, without an external ring. The mixed type RS0/a:RSB0/a in the RC2, based on a Cordoba 60-inch plate, is not supported here.

NGC 1350 **Sa(r)** panels **88, S3**
CD-543-S **(L,I,l/2)**
Oct 1/2, 1978
103aO + GG385
45 inin

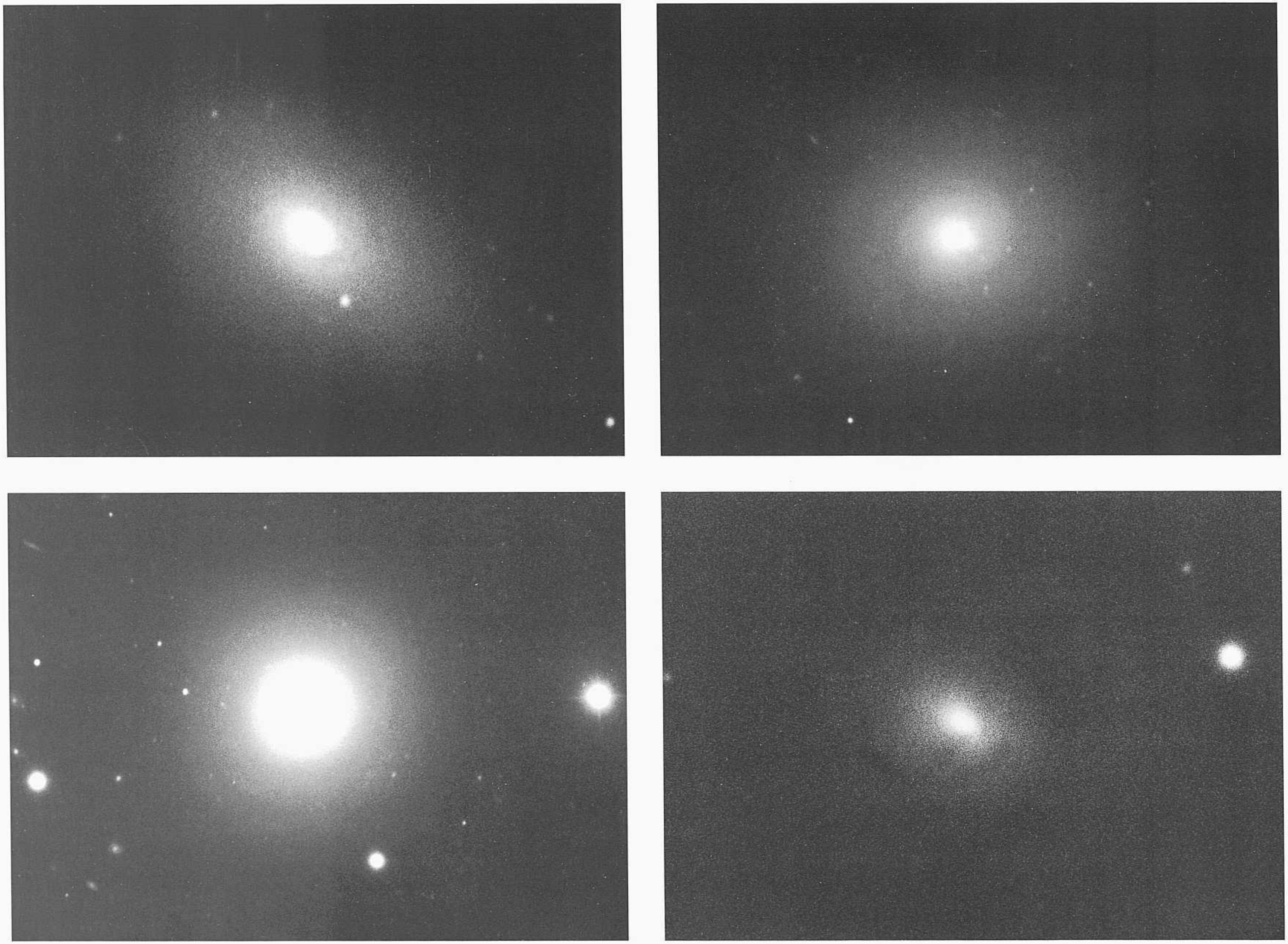
NGC 1350 **is** the latest of the broken-ring spiral types in **the** Sa section. It is at the end of **the** progression of **this** form **within** the **Sa morphological** box that also contains the earlier Sa **galaxies on** panels 67 and 70. The progression, **in** order, is formed by NGC 1302 (panel 70), NGC 4454 (panel 67). NGC 1079 **(panel** 67), NGC 2781 **(panel** 67). and NGC 3358 (panels 70. 88). NGC 1350. here, is also shown **on** the Sa summary, panel 88. as a type example **of a grand design** spiral **with** two major arms.

The two main outer arms are prominent in the negative print on panel 88. They **appear** as **low-surface-brightness** features in the image here, which **is** printed to **emphasize** the inner spiral fragments and **the** dust throughout the **high-surface-brightness** disk. These faint **outer** arms begin from the inner near-ring, which is more massive and has a higher star-formation rate than the earlier Sa galaxies of this type. Many fragments of dust **spiral** patterns exist in the inner near-ring.

The outer arms can be traced for a wrap of about 180°. at which **point** the end of each meets the beginnings of the opposite arm. The spiral **pattern** stops at this point, far beyond the edge of the disk. These outer arms are filled **with** small **HII** regions.

NGC 1 350 is the latest galaxy with Sa morphology. It marks the transition to later Sab types. It is classed **PSBab(r)** in the RC2. There is no bar **on the plate** material here.

PANEL
72



Shown on this and the next four panels are galaxies where the spiral pattern is either defined entirely by the dust lanes or where dust is a dominant feature in whatever spiral pattern there is. The progression ol the forms on these live pages is from very early Sa to the boundary of the Sa section with the Sab morphological box.

NGC 4150 $S0_3(4)$/Sa HA, p. *4*
PH-1910-B (VE,I,O)
May 16/17, 1958
103aO + GGI3
20 mill

NGC 4150 lias a typical SO bulge and disk, showing the extended outer envelope characteristic of the SO class. The print here is made to show the inner dust lane lather than the faint and extended outer envelope. This envelope can be traced on the original plate to at least twice the distance from the center of the bright star at the lower right of the major axis. The envelope can be seen best by viewing the print from a distance.

The non-circular dust pattern threading the inner third of the disk is the reason for the Sa classification. If the lane were smoother and more circular, the classification would be SO-j. However, a spiral pattern exists in the dust, opening outward from the lower right part of this print. The dust lane is seen much better here than in the print in the Hubble Atlas (p. *4)* made from an early 100-inch Mount Wilson plate. The galaxy was classed SO] from that plate.

NGC 524 S02/Sa HA, p. 5
PH-829-S (VE,I,0)
Oct2/3, 1954
103aD + GG11
4-5 niin

Nearly circular luminous arcs and a very delicate nearly circular dust arc distinguish NGC 524 from a normal $S0_2$ type. The same pattern is described from the same plate in the Hubble Atlas (p. 5). where the luminous arcs are not quite as visible as in the reproduction here.

NGC 5273 SO/a **HA, p. *n***
PH-668-S (VE,L,0)
Feb 5/6, 1951
I03aO + WG2
30 mill

A definite **spilal patti**·rn in NGC .')27:i threads thi'ough a classical SO disk, well seen when this print is viewed from a distance. The reproduction is ("ruin Ihe same 200-inch plat<* used in the Hubble Atlas, li is not clear if the spiral pattern is due to dual or to a luminous filament.

NGC 5739 Sa Racine wedge
PH-7374-S (E,I,l/3)
June 19/20, 1977
103aO + GG13
10 min

An internal (iusl spiral arm winds from the center of NGC 5739 to aboul 10" below the center on this print. A broad, smooth, luminous spiral are of very low surface brightness, not visible on this print, begins on the opposite side of the galaxy (at the top of the print; the arm unwinds outward on the right side, reaching to about two-thirds the distance from the center to the bright star on tin* right). The plate was taken with a Racine wedge. The bright star at the right has u secondary component made by the wedge that is 18" distant to the upper left and 5 mag fainter.

The galaxy has one of the highest redshifts in the Shapley Ames Catalog, at v_o = 5692 km s^{-1}. The consequent absolute magnitude of i\l^ = -22.5 i^ one of the brightest in the USA. The classification SO/SBO in the RC2 is not supported by the plate material here.

NGC 1316 Sa pec (ripples) FCC 21
CD-719-S (VE,L,l/4)
Feb 1/2, 1979
103aO + Wr2
45 inii

NGC 1316 is **the** radio source Fornax A, located close to or associated with the Fornax Cluster. The galaxy is outside the classification sequence. The type assigned here is done simply to force it into the classification by considering some **features** and ignoring others.

The print shows only the **region** of intermediate intensity. Neither the small nucleus (Sehweizer 1 98 1) nor the outer envelope with its loops and filaments **(Schweizer** 1980) is visible, **but both** these are well seen in the reproductions in Schweizer (1980. 1981).

NGC 1316 is neither an SO nor an Sb. It is classed here as Sa pec on the basis of (1) the large bulge. (2) the dust patches that have spiral segments, and (3) the loops in the outer filaments. Schweizer calls the galaxy a cD but the outer filaments belie this because of the peculiarities of the outer plumes which may be tidal signatures of a merger.

Schweizer's (1980. Fig. 1) deep print shows the **faint-surface-brightness** outer structures that **led to** the compromise type, Sa pec, given here.

NGC 1638 Sa
CD-687-Br (EJU1/4)
Jan 27/28, 1979
103aO + GG385
45 **min**

NGC 163 8 has a definite spiral structure in the disk **of** what would otherwise be an SO. The spirals are caused either by smooth **dust** lanes threading through the disk or by broad, massive, smooth, luminous arms of a more advanced (better-defined) type than shown on the preceding page. One prominent dust lane is clearly seen in the print. The subtle spiral structure throughout **the** disk can best be seen by viewing the print at a distance.

The arms are **of the MAS** type. This galaxy is one of the earliest examples of what are seen as full filamentary arms later in the Sa sequence (panels 7 7—80) and throughout the Sb and Sc sections.

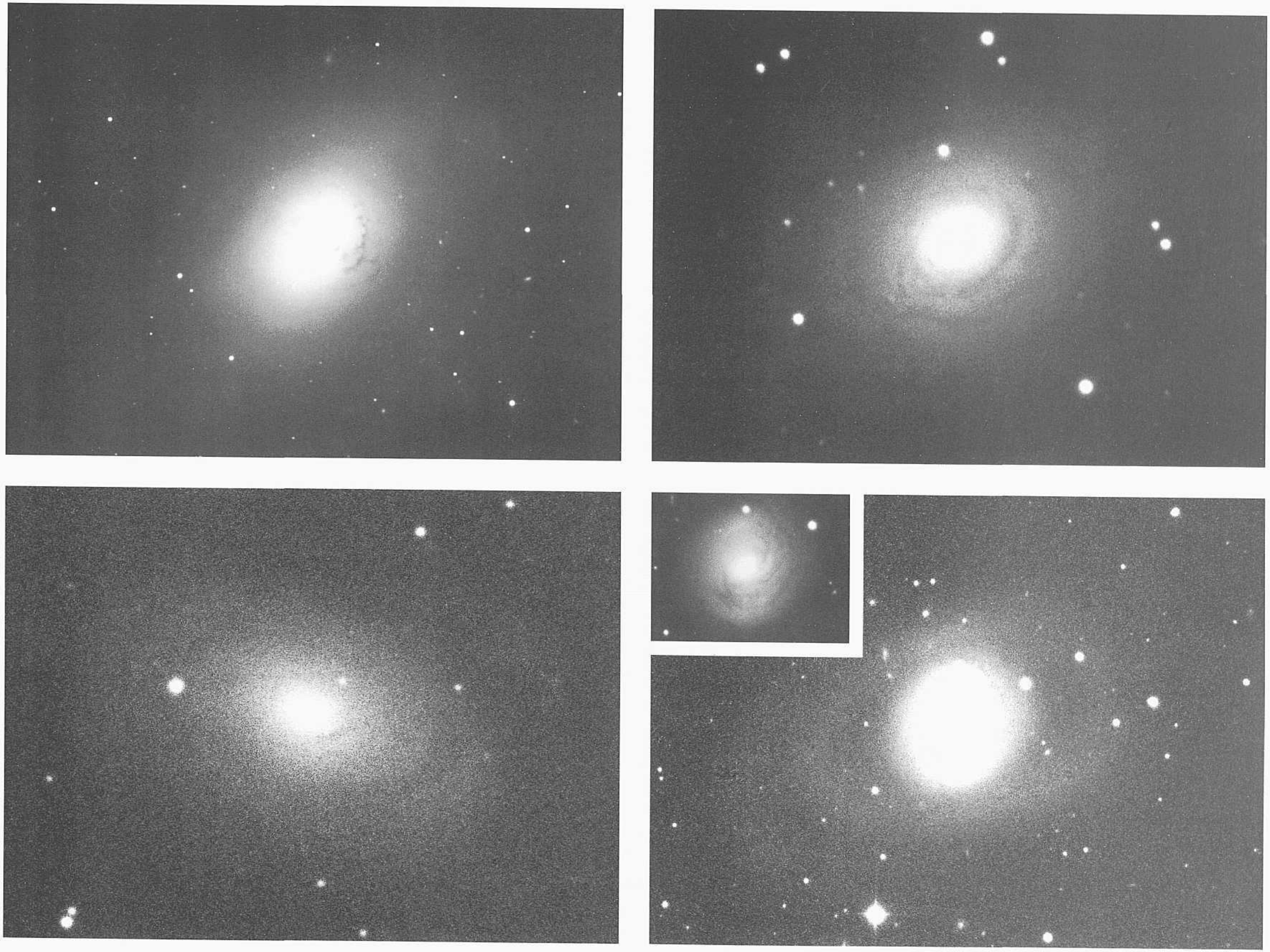
NGC 2855 Sa(r) **HA, p.** 5
PH-704-S (VE, L,l) panel 74
Feb 28/March 1, 1954
103aO + WG2
30 min

Filamentary dust arms of the MAS type thread throughout **the** disk of NGC 28 55. A very faint outer ring, or a nearly circular outer spiral feature (which reaches to the edge of the frame), is concentric with the center. This outer spiral segment is not visible here nor on the print in the Hubble Atlas, which **does,** however, show the inner dust arms well.

NGC 4984 **Sa(s)**
CD-784-S (E,L,1)
Feb 22/23, 1979
103aO + GG385
40 min

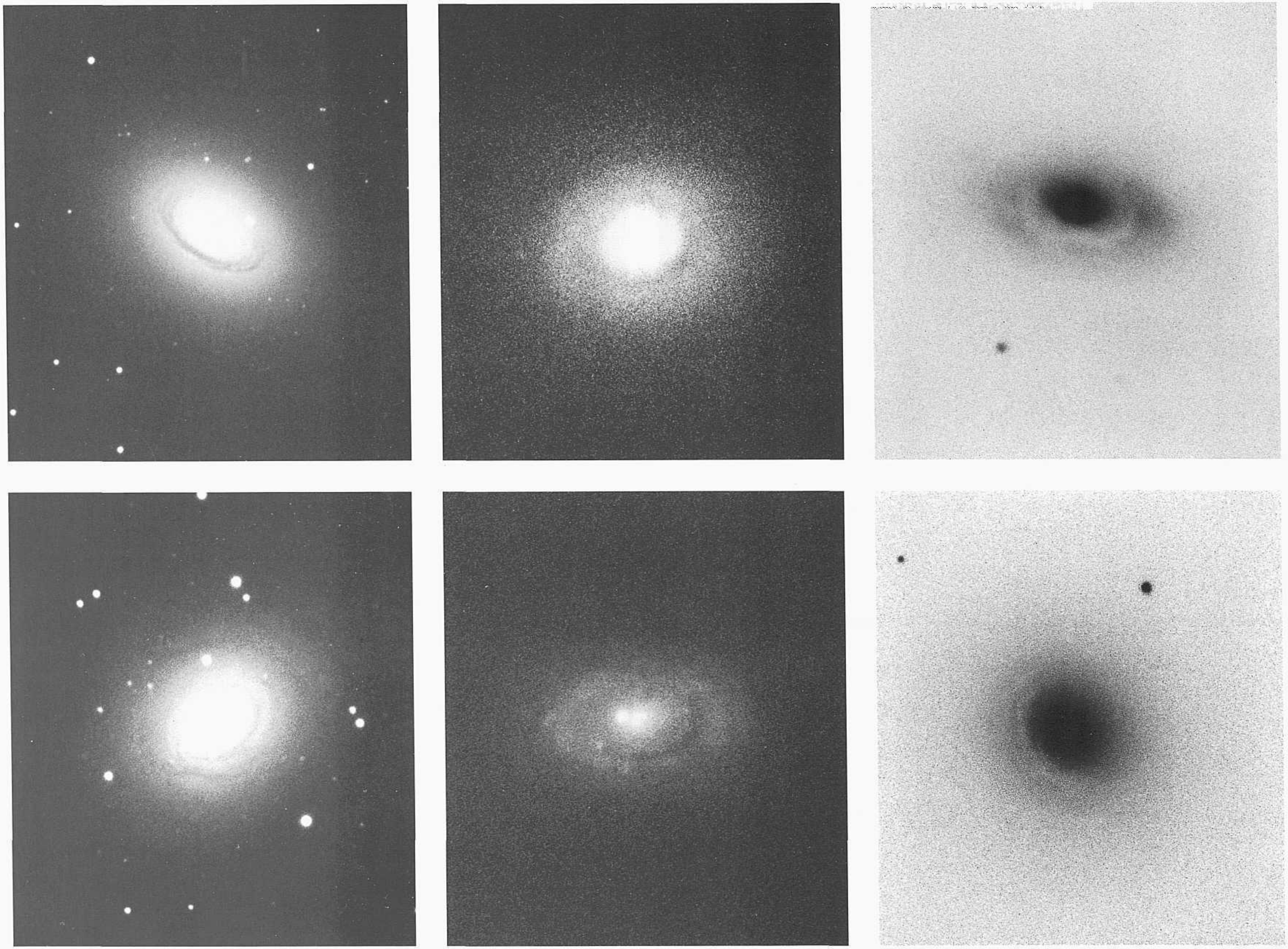
The spiral pattern in the inner disk of NGC 4984 is made up of multiple **dust** arms, shown in the insert. A second set of faint luminous spiral arms, which are smooth and relatively **thin,** exists outside the main body and can be seen on the main **print** by viewing from a distance. The pattern is that of a **two-armed** spiral attached to the main body at about 12:30 and 6:30 o'clock on the print here.

There is yet a fainter spiral arm farther out on the left side of the main print, halfway again as far from the center as the first faint outer spiral. This second outer arm, visible on the plate, is faintly visible on the original print, but may not be visible on the halftone reproduction here. This outer structure has been called a ring in the RC2 classification, as RSO/RSBO, **but** this interpretation is not supported by the material here. Both the inner dust lanes and the two **outer** rings have a spiral pattern. The galaxy is **a** very early Sa.



PANEL
73

PANEL
74



NGC 7049 $S0_3(4)$/Sa panel 59
CD-1088-Br (E,L,l/4)
Aug 18/19, 1979
103aO + GG385
45 min

On the original plate of NGC 7049 the dust lane can be traced around the entire periphery of the bulge. This is very rare, requiring a critical viewing angle for the silhouetting ol' the dust against the intense luminosity of the bulge. There must be enough background intensity in the far disk against which to see the dust lane. Complete rings are, however, seen in more-face-on galaxies of the $S0_{:j}$ and SO/Sa types, such as NGC 3032 at the right.

The lane here is not as smooth as in pure SO3 galaxies. The breakup into several segments, seen well in this print, suggests a tightly wound spiral pattern: hence the mixed type S0:$(4)/Sa is assigned.

NGC 2855 Sa(r) HA, p. 5
PH-704-S (VE,L,1) panel 73
Feb28/March 1, 1954
103aO + WG2
30 min

NGC 2855 is repeated from the last panel to compare its nearly circular dust lanes with the similar galaxies on this page.

The classification of RSO in the RC2 is not supported here.

NGC 3032 RSa pec HA, p. 5
PH-853-S (VE,I,l/4)
Nov 2/3, 1954
103aO
30 min

NGC 3032 is classed as $S0_{:i}$ in the Hubble Atlas and SBO/SO in the RC2, both using the same 200-inch plate. However, there is no doubt that the almost circular dust lane forms a very tight spiral pattern. The dust near-ring can be traced completely around the central bulge, isolating the bright outer luminous ring that itself appears as a tight spiral pattern. This may, however, appear to be spiral simply because of the spiral pattern in the dust.

Very faint outer arms are just visible on the plate but are not seen on this print. They are similar to bul fainter than the arms seen in NGC 3626 (panels 63, 64, and 74).

The nucleus is very bright and is starlike, producing a secondary image on plates taken with a Racine wedge. However, the spectrogram from which the redshift was measured (Humason, Mayall, and Sandage 1956) shows no emission lines characteristic of a Seyfert (1943) galaxy.

NGC 4138 Sa(r)
PH-8000-S (l,S,l/2)
Feb 2/3, 1981
103aO
12 min

The narrow dust lane silhouetted against the disk of NGC 4138, well visible in the print here, can be traced only for about one-fourth of a revolution. The galaxy is clearly neither SO nor Sb. The luminous material in the outer part of the disk forms a spiral pattern. There is no evidence for till knots in the arms. Hence, although the bulge is small, the type must be Sa. The SO (late) classification in the RC2, based on a Mount Wilson 60-inch plate, is inappropriate.

NGC 3626 Sa **panels 63, 61**
PH-7653-S (E,E/I,l/2)
April 29/30, 1979
103aO
2 min

NGC 362f> has been shown on panel 63 lo illustrate the smooth outer arms of such curly Sa galaxies ami on panel 64 to show the interior dust circle. It is shown again here from a short-exposure 200-inch plate In emphasize its similarity to the other galaxies on this page in its dust lane. NGC 3626 is nearly identical lo NGC 3032 at the left in I I) the pattern of the dust, (2) the resulting isolated adjacent luminous ring, and (3) tin' outer very faint smooth spiral arms. The very outer arms, seen here by viewing the print from a distance and moving the head or eyes, pre more visible in NGC 3626 than in NGC 3032 because of the more favorable (larger) inclination to the sight line.

NGC 5631 $S0_s(2)$/Sa
PH-7646-S (VE,L,1/I)
April 28/29, 1979
103aO
12 mill

The pattern of multiple dust lanes seen silhouetted against the bulge of NGC 563 1 in the lower-right part of the print here is similar to the pattern in the other galaxies on this page. The type is close to S0^ but is later because of the multiple dust lanes: hence the mixed type is given here. The classification of SO in the RC2 is based on an early Mount Wilson 60-inch plate.

The illustrations of galaxies in which the spiral pattern is shown almost entirely by dust lanes continue on this page.

NGC 7377 SO2/3/Sa pec panel S14
CD-519-S/Br (E,L,1)
Sep 29/30, 1978
103aO + GG385
45 min

NGC 7377 is one of the most unusual galaxies in this atlas. There is no evidence of recent star formation over an otherwise normal SO disk, yet the entire disk is threaded by a multi-armed spiral pattern composed of dust lanes only. The visible lanes are asymmetric across the image; in the orientation of this print, they are most visible on the lower-right side of the image. We interpret this to be an aspect effect caused by the difference in the background against which the lanes are silhouetted, similar to that seen in later-type spirals at particular inclination angles (Hubble 1943). The origin of the dust and the age of the spiral pattern are central questions that have a bearing on theories of spiral-arm formation.

NGC 7213 Sa(rs) panel S14
CD-1033-Br (IX,3/4)
July 21/22, 1979
103aO + GG385
45 min

NGC 7213 is similar in several ways to NGC 7377 above, but is later in the sequence. It is also more face on. causing a more symmetrical appearance to the multi-armed dust pattern.

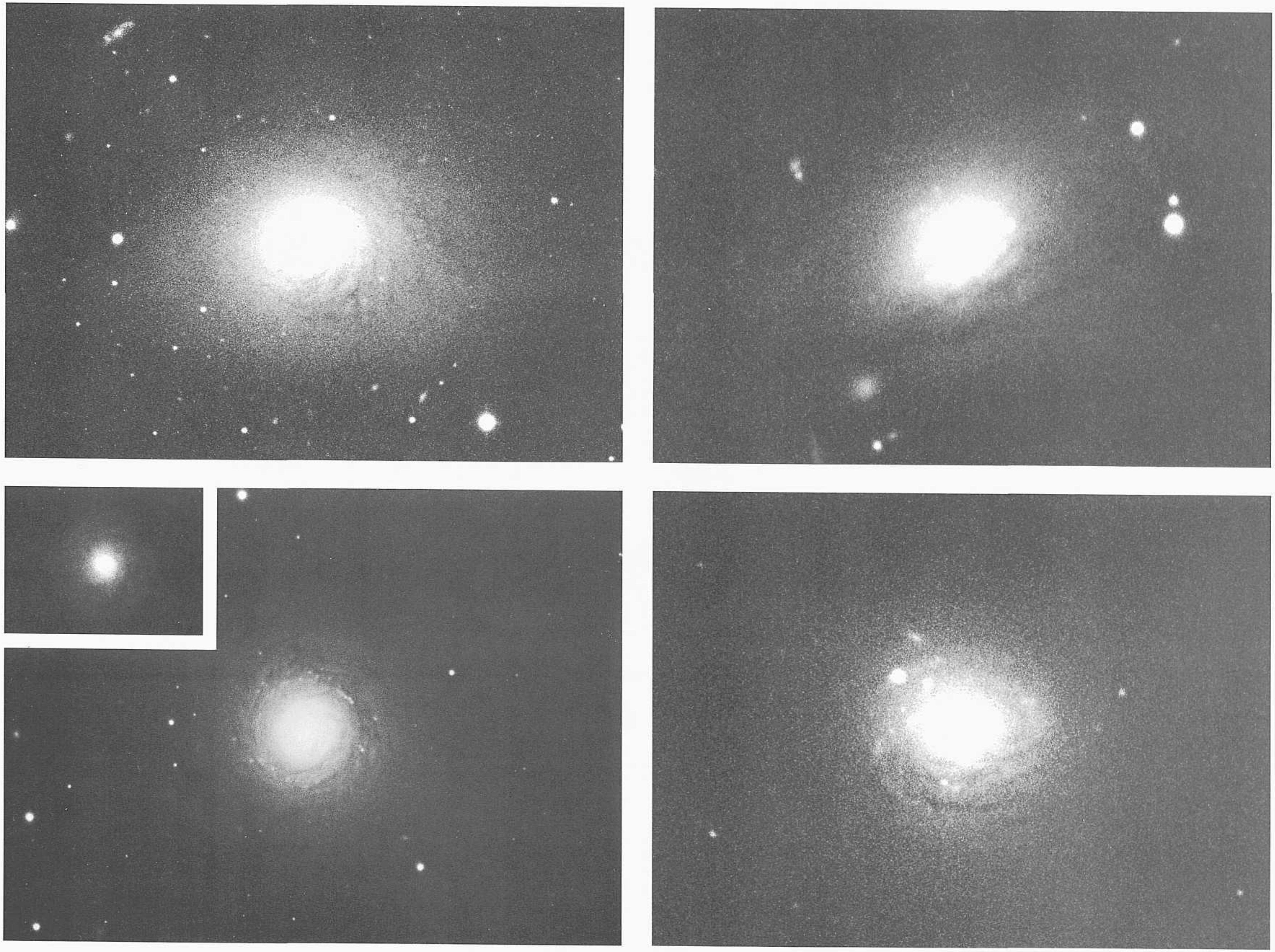
Evidence of recent star formation over part of the pattern is shown by the knots, which are probably small HII regions. The tightly wound multi-armed structure of what again appears to be spiral dust lanes continues into the central regions of the disk and bulge. The attempt in the insert to show this interior structure is unsuccessful.

IC 5063 $SO_5(3)$ pec/Sa
CD-1060-Br (I,L,3/4)
Aug 16/17, 1979
103aO + GG385
45 min

The only arms visible in IC 5063 are the dust lanes silhouetted against the bulge and against the disk in the lower right-hand side of the print. The high visibility of the dust is due to the high inclination of the disk to the line of sight.

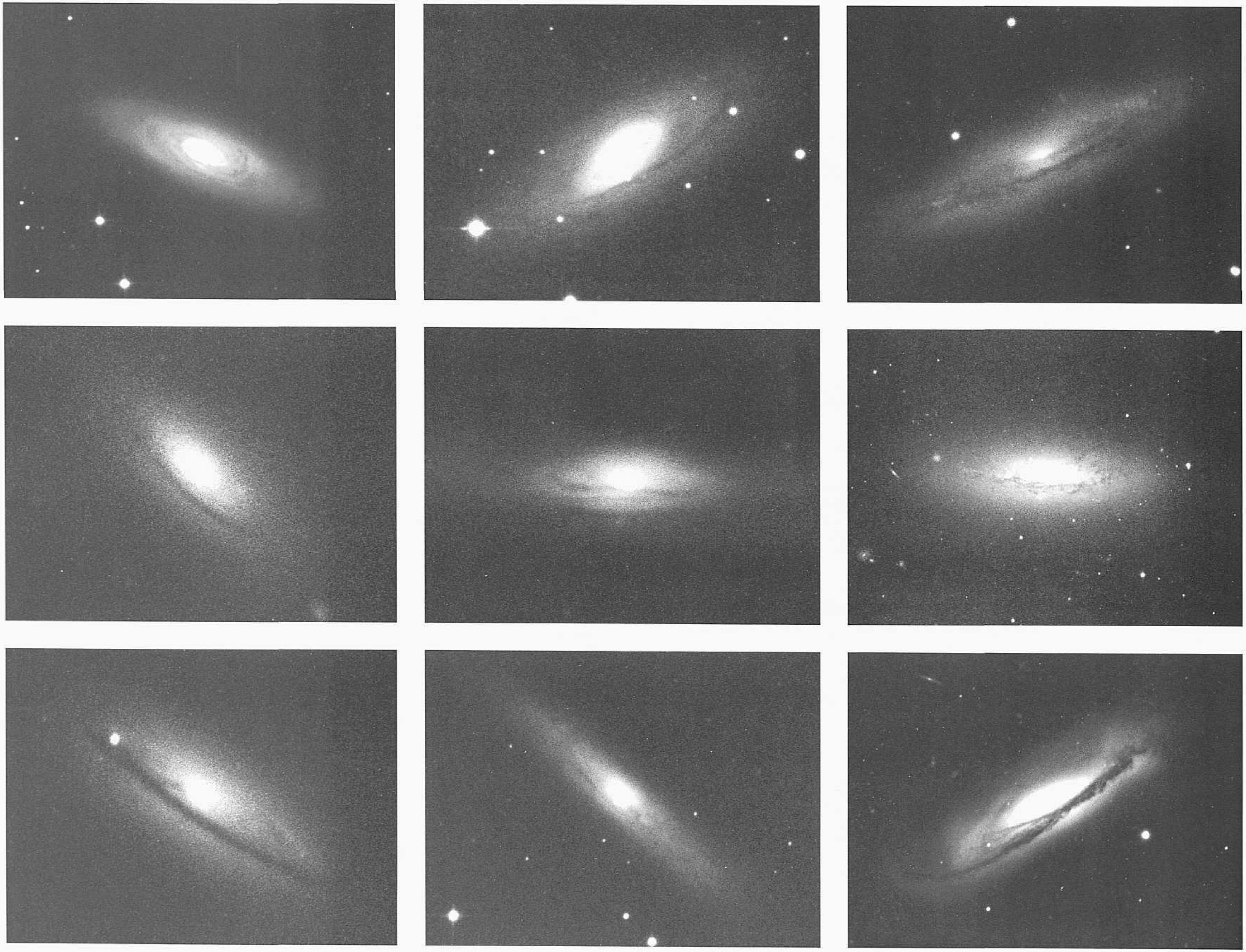
NGC 3619 Sa
PH-8023-S (I,L,1)
Feb3/4, 1981
103aO
12 min

NGC 3619 is similar to NGC 7377 and NGC 7213 on the left. The morphology is about halfway between these two galaxies in the nature of the dust lanes that are the spiral arms. The lanes are well silhouetted against the bulge and disk at the bottom of the print. However, unlike the case in NGC 7377, luminous arms exist, most easily seen at the top of the print. A few knots are present, suggesting a low but finite rate of recent star formation.



PANEL
75

PANEL
16



All galaxies on this page are of type Sa. They are seen at a high inclination to the line of sight, making the internal flust more visible in its silhouette against the bulge and/or the disk.

NGC 1386 Sa FCC 179
CD-718-S (E/1,1,1) panel S14
Feb 1/2, 1979
103aO + Wr2
45 min

NGC 1386 is in the Fornax Cluster (Ferguson 1989). Like the galaxies on the preceding five pages the spiral pattern in NGC 1386 is made entirely of dust lanes. No evidence of HII regions is visible either on this print or on the original plate. What then is the origin and the age of the dust?

NGC 5326 $SO_3(6)$/Sa panel 44
PH-8095-S (E,I,l/2)
Feb 6/7, 1981
103aO
12 min

The morphological class of NGC 5326 is very close to that of a normal SO^, yet there is a hint of luminous spiral structure in the bulge and/or inner disk just inside the dust lane on the right side of the major axis in this print. The galaxy is classified as Sa in the RC2 on the basis of a Palomar 48-inch Schmidt telescope image.

NGC 4224 Sa VCC 199
CD-1416-S/Br (I,S/I,1)
March 24/25, 1980
103aO
75 min

NGC 4224 is in the Virgo Cluster region at the western border (near the W cloud) of the area surveyed for the cluster catalog (Binggeli, Sandage, and Tammann 1985). The VCC redshift of v_o = 2603 km s~[1] puts the galaxy in the probable background (i.e., in the W cloud).

The disk inside the dust lane is filled with spiral structure, both as luminous arcs and as internal dust lanes, only hinted at in the print here. Part of the bulge light is visible below the dust lane in this highly inclined galaxy.

NGC 3885 Sa panel 87
CD-692-Br (E,S,1)
Jan 27/28, 1979
103aO + GG385
4-5 min

The spiral arms in NGC 3885 are defined almost entirely by the dust lanes threading through the smooth disk. The dust lanes internal to the outer lane "on the rim" are only hinted at near the center of this print, which is nearly burned out in the center. The outer dust lanes leave no doubt that the type is early Sa.

The type is listed as SO/a in the RC2, based on a Mount Wilson 100-inch plate.

NGC 5689 Sa
PH-5784-S (E,L,l/3)
April 1/2, 1979
103aO + GG385
10 min

NGC 5689 is seen almost edge on. It has two prominent dust lanes cutting across the large central bulge and across the disk beyond the bulge. A third lane exists immediately below the first two on this print, but it is difficult to see because there is little background light against which it can be silhouetted.

The multiple lanes here betray the multiple dust lane arms in the disk, similar to galaxies such as NGC 7377 (panels 75, S14) and NGC 3619 (panel 75), which are seen more nearly face on.

NGC 4235 Sa VCC 222
CD-1416-S/Br (E,I/S,l/2)
March 24/25, 1980
103aO
75 min

NGC 4235 is in the Virgo region but is probably in the W cloud (Sandage, Binggeli, and Tammann 1985b), a notion that is supported by the high velocity of v_B = 2527 km s~[1].

Intricate dust lanes pervade the disk, only a few of which are visible in the print. As in NGC 5689 above and NGC 7377 on panels 75 and S14, the multiple arms are made entirely of dust lanes. No evidence of till regions is on the plates, either in the smooth disk or associated with the dust arms.

NGC 4586 Sa VCC 1760
CD-1378-S/Br (E/1,S,1)
March 20/21, 1980
103aO + GG385
50 min

NGC 4586 is in the Virgo region but is south of the subclustcr B around NGC 4472 by about 4°. The redshift is low, at v_o = *194* km s^{-1}.

The pattern of dust lanes pervading the disk is present here, as seen in other galaxies on this page and on panel 75. However, there is evidence of star formation in the disk because luminous arms are associated with the dust lanes. This is in contrast to the other galaxies described in previous pages.

NGC 4586 is farther along the Sa sequence than, say, NGC 7377 (panel 75); hence the character of the bulge and disk is early-to-intermediate in the secondary classification here. This character of lateness along the sequence is seen more easily on the plate than on the print. However, the galaxy is not as late along the Sa sequence as NGC 3593, shown immediately below.

NGC 3593 Sa pec
CD-1387-S/Br (1,1,1)
March 21/22, 1980
103aO + GG385
45 min

NGC 3593 shows the most chaotic dust pattern among the galaxies on this panel. The pattern consists of dust patches, rather than lanes, over the face of the disk. But the patches themselves appear to be strewn in spiral patterns over the disk.

A few small Mil regions appear in the main dust arm, left of center, in its crossing of the bulge, but there is no current robust star formation, as would be the case in Sb or Sc types. The disk remains largely devoid of star-forming regions at this epoch. The dust content in rough spiral patterns is the dominant feature here.

NGC 3190 Sa group
PH-149-MH (E/I,L,1)
April L2/13, 1950
103aO
30 min

NGC 3190 is a member of a group of diverse galaxy types having similar rcdshifts, composed of NGC 3185 (SBa; panel 99), NCC 3187 (Sc/SBc; panel 276), NGC 3190 (Sa: this panel), and NGC 3193 (E2; panel 5), with a mean redshift of <u_o> = 1196 km s^{-1} (Humason, Mayall. and Sandage I 956).

The major dust lane in NCC 'A 190 cuts nearly centrally across the bulge, which can be seen also below the dust lane on I hi^ print. A thinner double dust lane is seen on the left of the bulge center; the double lane appears Lo be tilted relative to tin[1] main plane.

The galaxy forms a close pair with NGC 3187. which itself is *a* distorted Sc with two oppositely directed features that may be tidal plumes (panel 276). The result of this interaction may have distorted the dust plane in NGC 3190 here.

The projected separation of NGC 5187 and NGC 3190 is 300". which at the redshift distance of 24 Mpc (// = 50) is a projected linear separation of 35 kpc. At this small distance, there of course is a good case for tidal distortion.

NGC 3190 shows little or no sign of Mil regions either in the bulge or the disk. The type is not SO. Sb, or Sc. By elimination, the type, therefore, is Sa.

The nine galaxies on this panel are all either intermediate or late Sa types. The tightness of the spiral pattern and the lack of the high star-formation rates that begin in the Sab types determine the morphological type. All are of the multiple-armed variety, and all show evidence of dust.

The procedure in classifying any galaxy, if one is certain that any given galaxy can indeed be put into the classification sequence, is to proceed by elimination with a series of questions. "Is the galaxy an SO?" If not, because it has spiral arms, the question then becomes "is it as late as Sc?" If not, "is it as late as Sb or Sab?" If not, it must be Sa. The galaxies on this page have been classified by elimination in this way.

NGC 2844. Sa(r)
PH-7901-S (I:,S:,1:)
Nov 6/7, L980
103aO
12 miii

Dust arms exist throughout **the** disk of NGC 2844. The central bulge is very small, but the tightness of the arms, not shown well in this print, belie a later type than Sa.

NGC 2639 Sa
PH-7935-S (IXJ/2)
Nov **7/8, 1980**
103aO
2 **min**

NGC 2639 has an MAS pattern surrounding a large bulge. The galaxy would resemble closely NGC 2775 (Hubble Atlas, p. *10;* panels 78, 87. SI2 here) if it were seen more nearly face on.

NGC 5064 Sa
CD-812-S (L,L,1)
Feb 25/26, 1979
103aO + GG385
45 min

NGC 5064 has a nearly identical spiral pattern to that of NGC 2639. above.

NGC 4220 Sa(r)
PH-5777-S (I,S,1)
April 1/2, 1979
103aO + GG385
10 miii

NGC 4220 is seen almost on edge. The print is of slightly too high a contrast to show well the two high-surface-brightness arms that, as in galaxies such as NGC 7702 (panel 66), NGC 4274 (panels 66, 88). NGC 3900 (panel 69), and NGC 6902 (panel 69), appear to form an almost-complete inner ring. But again, this feature is an overlapping of two tightly wound spiral arms.

The faint extension of the disk beyond the two bright inner arms (the fragments **of** which show moderately well along the major axis in the print here) can be seen by viewing the print from a distance. A subtle spiral pattern, which may be caused by dust or by smooth luminous arms, can **be** seen in this outer, low-surface-brightness outer disk. The classification S0(r) listed in the RC2..based on a Mount Wilson 60-inch plate, is inappropriate. This galaxy has clear Sa-type spiral arms.

NGC 3449 Sa
CD-648-Br (I,I/L,l/2)
Jan 4/5, 1979
103aO + GG385
33 min

NGC 3449 is similar in many respects to NGC 2639 and NGC 5064, shown at the left.

NGC 3571 Sa
CD-691-Br (I,I/S,1)
Jan 27/28, **1979**
103aO + GG385
45 min

NGC 3571, like NGC 3449, above, is similar to NGC 2639 and NGC 5064 at the left. The inner disk is filled with dust patches that form **fragmented** spiral patterns. The spiral type is of the MAS subset of Sa forms.

NGC 3166 Sa(s) **triplet**
CD-1336-S/Br (I,L,1)
March 14/15, 1980
103aO + GG385
45 min

NGC 3166 is a companion to NGC 3169 (Sb tides: panel 132), 7.5' distant. NGC 3165 (Sd or Sm) is a highly resolved probable companion 4.5' southwest. The mean **redshift** of the NGC 3166-NGC 3169 pair is $\langle v_o \rangle$ = 1116 km s"'. At the redshift distance of 22 Mpc (H = 50), the projected linear separation is small, 48 kpc. The projected linear separation of NGC 3166 and NGC 3165 would be 29 kpc if they are at the same distance.

NGC 3169 (panel 132) has a highly distorted southeast spiral arm, suggesting that a tidal encounter has occurred between the pair.

The spiral pattern over the face of NGC 3166 is made up of dust-lane fragments, similar to, but much less regular than the thin lanes in the dust-lane galaxies on panels 74 and 75, such as NGC 7377, NGC 2855, and NGC 3619. The distribution of the luminosity in the disk of NGC 3166, within which the dust-lane segments thread, suggest that the disk of this galaxy has also been warped by a tidal interaction with NGC 3169.

NGC **1415** Sa/SBa(late)
PH-3071-S (1,1,1)
Sep 8/9, 1958
103aD + GGll
35 min

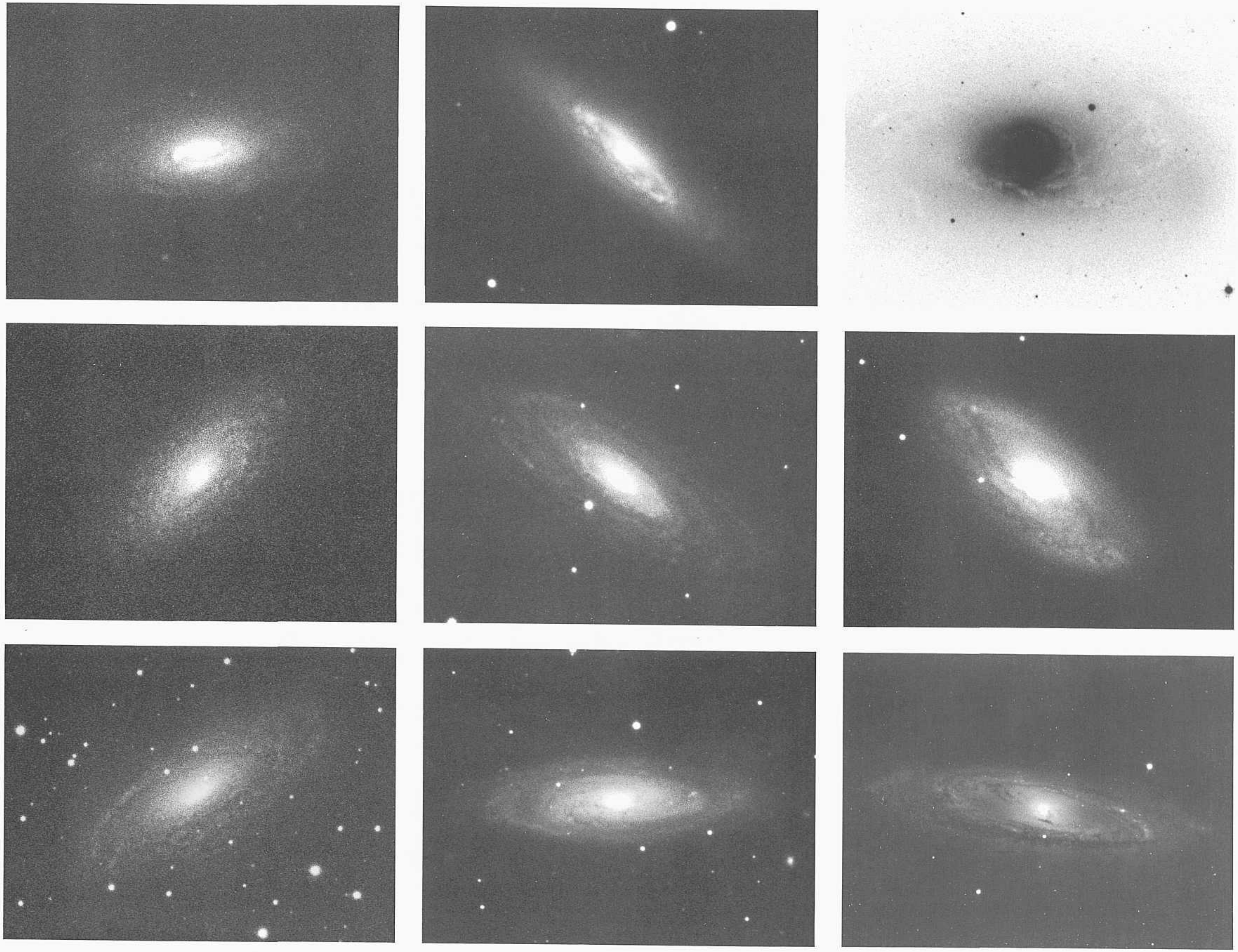
NGC 1415 is similar to NGC 3166, above, and to NGC 2855. NGC 3619, and NGC 7377 on panels 74 and 75, in that the spiral pattern is composed entirely of dust lanes of the MAS type. The distribution of disk light is smooth with only a hint of several lumps that may be small IIII regions. Hence, the current rate of star formation is small. The centra! bulge is of intermediate size. The disk **surface** brightness is high.

NGC 3623 **Sa(s)II HA, p.** ***11***
H-494-H (L,S,1) panel S14
Nov 26/27, 1924
Seed **30**
75 min

This print of NGC 3623 is from the same plate used in the Hubble Atlas. As described there, the galaxy is a type example of the late part of the Sa section. The bulge is small. The spiral pattern is well defined by a combination of dust arms and by the two main bright arms, resembling the form displayed by the galaxies on panels 66 and 69.

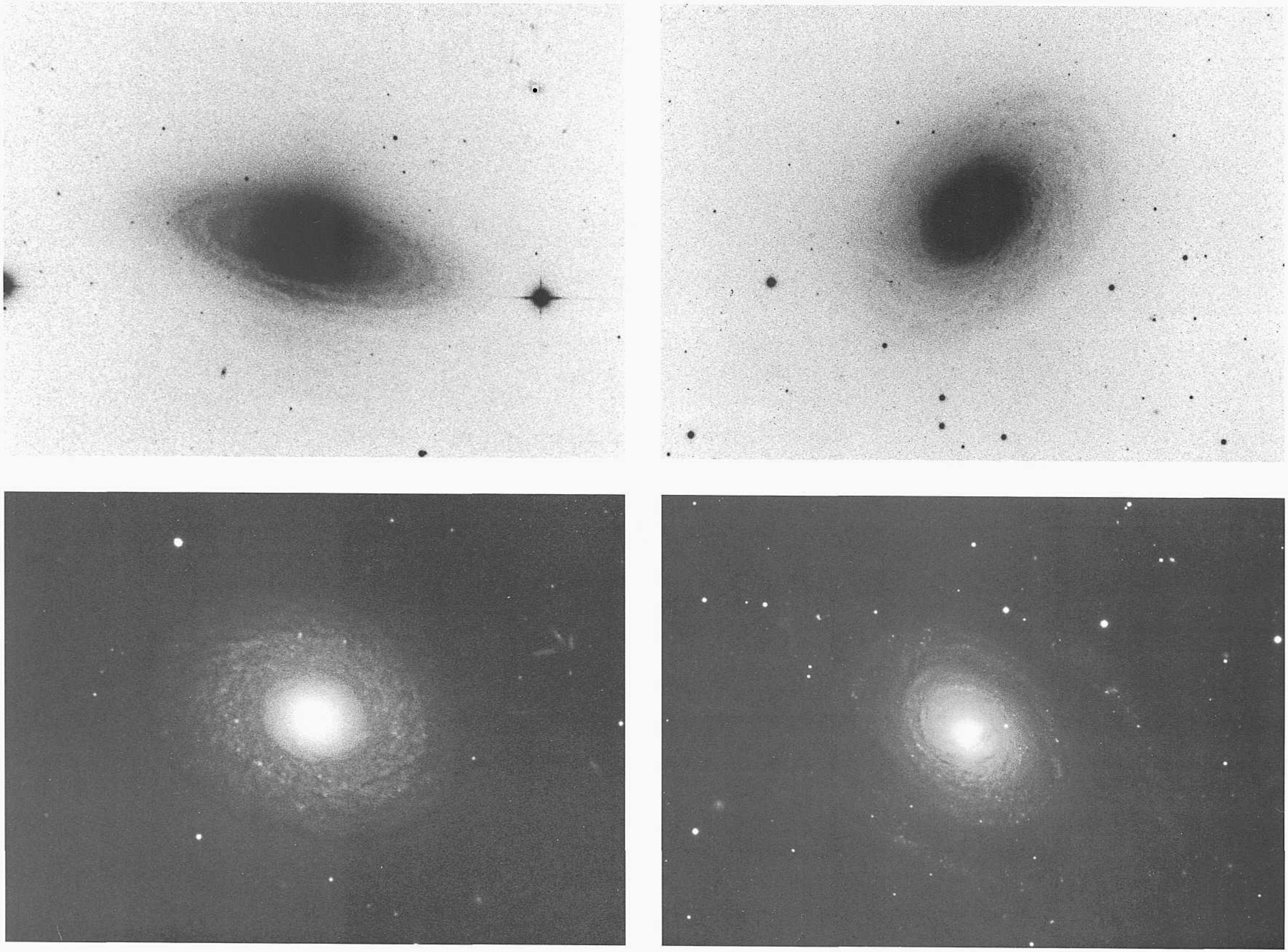
However, the arms in NGC 3623 are defined best by the dust pattern in its silhouette against the disk. The inclination to the line of sight is nearly optimum to show this dust silhouette. Hubble (1943) used NGC 3623 to illustrate the dust asymmetry as a diagnostic to determine which is the near side of a galaxy and thereby to determine the direction of opening of the spiral pattern.

The dust pattern on the near side can be traced across the disk and into the center as a series of spiral fragments, seen in this print on the upper left side of the major axis.



PANEL
77

PANEL
78



VJ^alaxies on this and on the next two panels arc type examples in the late Sa section where the arms are fragmentary (flocculent) and highly multiple (MAS types). They are arranged along the Sa section from early to late, in the progression from the upper to the lower left, then to the upper and lower right prints on each page.

NGC 4698 Sa panels **79, 87**
CD-1881-HB (E/I,I,l/2)
April 11/12, 1981
103aD + GG495
45 inin

The print of NGC 4698 here shows the E-Iike bulge in which there is no evidence of recent star formation or spiral structure. This is in contrast to NGC 4699. at the right, where the MAS pattern can be traced on the original **plate** into the bulge almost to the center.

The low-surface-brightness disk is enhanced in the negative print. It is also well seen in the positive print on the next page and in **the** Sa summary, panel 87.

The spiral arms become prominent only in the outer **part** of the disk. They are **defined primarily** by the dust which forms fragmentary lanes of the **multiple-armed** (MAS) type rather than of the grand design. The silhouette of the several dust lanes against the bulge is well seen in the high-contrast print here, and on the next page and on the Sa summary panel.

Because of (1) **the** smooth inner disk, (2) the large bulge with no recent star formation, and (3) the tightly wound spiral arms, this galaxy is in the earliest one-third of **the** Sa morphological box, **earlier** than the other galaxies on this page. The progression along the MAS subset of the Sa section is shown both here and in the Sa summary, panel 87.

NGC 2775 Sa(r) HA, p. *10*
CD-1664-S (I,L,l/3) panels 87, S12
Dec 30/31, 1989
I03a0 + GG385
60 miii

The place of NGC 2775 in the Sa section is later than that of NGC 4698. above, because the spiral **pattern** is more fully **developed.** However, it is earlier than NGC 4699, at the upper right, because the bulge **for** NGC 2775 here is smooth and **provides** no evidence of spiral arms. In NGC 4699 the arms exist **throughout the** bulge and reach very close to the center of the very inner disk, burned out in the reproduction here.

The spiral-arm pattern in NGC 2775 is highly multiple. It starts abruptly at the **edge** of the smooth central bulge. Several small knots exist in some of the bright fragments **of** arms, especially in the lower-left section of this print. Most of these knots are invisible on a companion Las Campanas yellow (103aD + GG495) plate. Hence, the knots are likely to be **HII** regions, indicating a low but finite rate of recent star **formation.**

The remarkable outer dust lane surrounding the entire pattern is **not** well seen in the low-contrast print here, but it is well seen in the negative print in **the** Sa summary, panel 87 , if the print is viewed **from** a distance.

NGC **4699** Sab(sr) **or** Sa **HA, p.** ***16***
CD-1872-S (I,L,l/3) panels **87, 118, S12**
April 10/11, 1981
103aD + GG495
45 min

The image **of** NGC 4699 **on the** facing page has been printed at a high **contrast to** show the large number of outer, low-surface-brightness spiral **fragments in** the **region** where **the** intensity of the bright bulge decreases sharply as it merges with the **fainter-surface-brightness** disk. The **disk** can be **traced** as **far** again **from the center** as **the** edge of the bulge appears from **the** center **on** the print here. The image here is from a yellow plate. The prominence of the arms relative to the bulge is decreased on yellow compared to blue plates.

A deeper print showing the outer multiple spiral fragments in the **extended disk** is shown on panel 87 in the Sa summary. A compromise-con^-trast print is on page *16* of the Hubble Atlas, made from a blue Mount Wilson 100-inch plate on which the multiple-arm pattern can be traced nearly into the center **of** the image (see description in **the Hubble** Atlas). The **important** point is that the spiral-arm fragments exist over the entire face of the galaxy, showing that the class is later in the Sa sequence than NGC 2775, shown below and to the right.

The **asymmetry in** the silhouette pattern on one side of the bulge relative to the other shows that dust is a significant component of the spiral pattern. To be convinced of this, it is useful to compare the ease with which the dark lanes can be seen on **ihe** lower-right part of the image with the visibility of the lanes in the **upper left.**

IC 5267 Sa(r) panel 79
CD-490-S (I/L,L,1)
Sep 26/27, 1978
I03a0 + GC385
45 **min**

The fragments that are the spiral dust **arms** can he traced against the near side of **the** bright **inner** disk and **into the bulge** on **the** low-contrast print of IC 5267 **here.** The tightly wound spiral pattern in the dust near the **center** gives **way** to luminous outer arms, where many small 1111 regions reveal a **moderate** rate of **recent star** formation. These **thin. multiple, fragmented** arms **are** nearly invisible on this **print bul** *uvr* seen to better advantage on the negative print on the next page.

NGC 1617 Sa(s) panel 87
CD-139-S (I,L,1)
Feb 1/2, 1978
103aO + GG385
50 min

The inner spiral pattern in NGC 1617 is defined almost entirely by fragmentary dust arms pervading the high-surface-brightness disk. A smooth, almost spherical bulge exists at the center of the disk, burned out in this print. The arms, which become luminous in the outer regions, are tightly wound, nearly overlapping the next inner-arm system after a half revolution. The pattern is similar to lhat in the galaxies on panels 69 and 78.

Very few if any HII candidate knots exist in the arms, indicating a lack of appreciable recent star formation.

NGC 4698 Sa panels 78, 87
CD-1881-HB (E/I,I,l/2)
April 11/12, 1981
103aD + GG495
45 min

The nuclear bulge dominates the central region of NGC 4698 on the print here. The dust in the tightly wound spiral arms is seen well in silhouette against the large bulge. The galaxy is shown again in a negative print in the Sa summary, panel 87 , where its relative place in the Sa section is described. It is an early-to-intermediate Sa, in about the first third of the Sa classification box.

NGC 3898 Sa HA, p. 10
PH-9O9-S (I,L,1)
March 25/26, 1955
103aO + Wr2
30 min

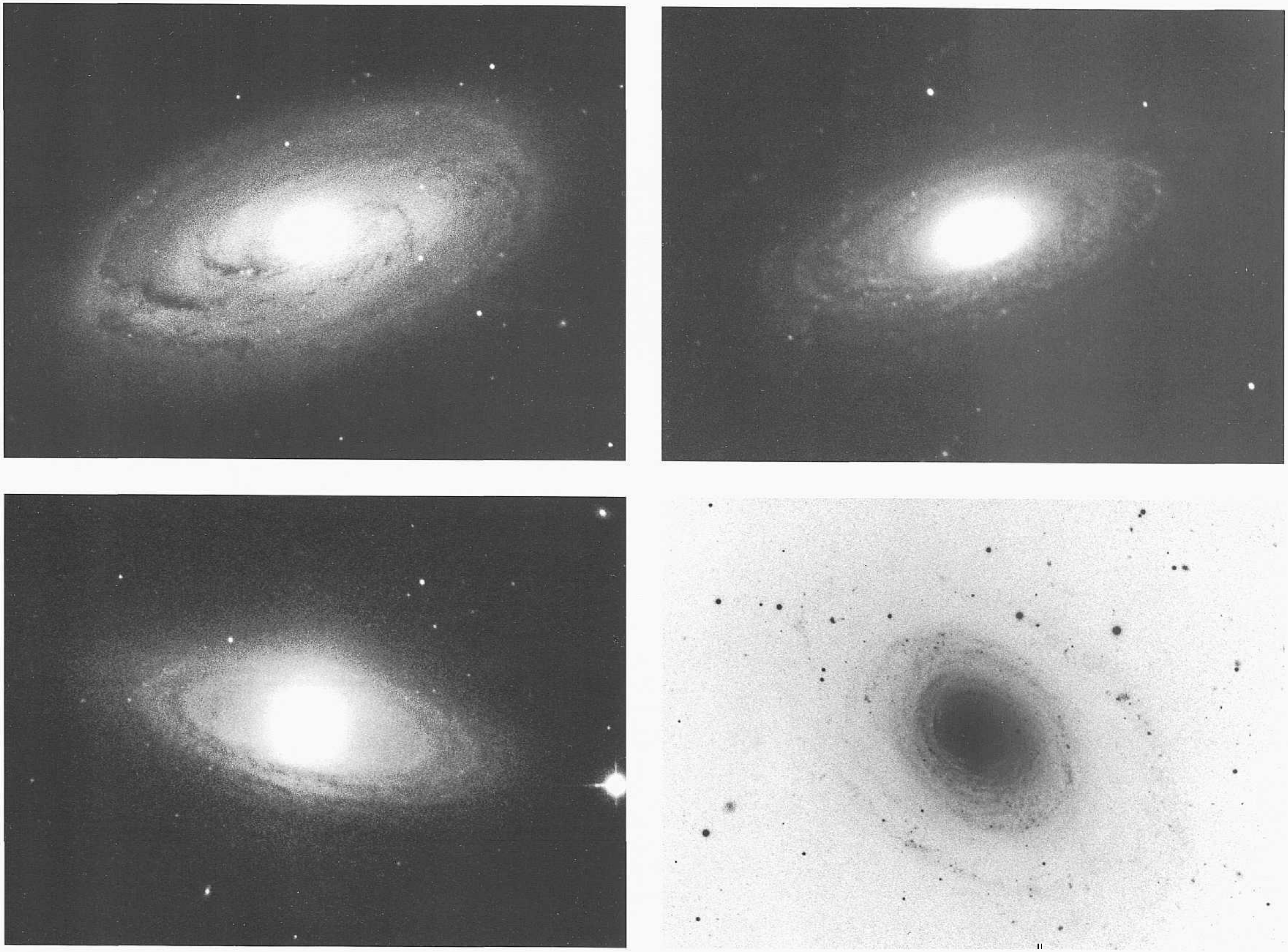
NGC 3898 is described in the Hubble Atlas (p. JO) as the prototype Sa galaxy with multiple arms (MAS type), whose later type-example is NGC 2841 (Sb; Hubble Atlas, p. *14;* panels 142, S4, SI 2 here). The reproduction here is from the same 200-inch plate used in the Hubble Atlas. The galaxy is similar to NGC 4698 at the lower left but is later along the Sa section.

Two very thin outer arms, outlined only by knots (HII regions), are just barely seen in the print here and in the Hubble Atlas. Both arms are on the same side of the image below and above the left half of the major axis. The arms have a wider pitch angle than the inner tightly wound arms. They extend far beyond the main body.

The innermost of these thin outer arms sweeps outward slightly above the field star that is close to the minor axis near the top of the print. This arm can be faintly traced here from the seven HII knots that are just visible, the outer three of which are to the right and slightly above the bright field star. The same feature is present in the Hubble Atlas print. The arm that is still more distant runs approximately parallel to the arm just described, but it is more distant from the center in the same ratio as the first of the two arms. If the knots are HII regions, star formation is occurring in these outer, very-low-surface-brightness arms. The outer arms here are similar to the outlying thin arms in IC 5267 in the negative print below.

IC 5267 Sa(r) panel 78
CD-490-S (I/L,L,1)
Sep 26/27, 1978
103aO + GG385
45 min

The print of IC 5267 shown here was made from the same Las Campanas 100-inch plate used for the print on the preceding page. High contrast is used to emphasize the intermediate and the outer spiral features. The numerous knots in the arms are probably small HII regions. The two outermost arms, well beyond the main body, resemble the two faint outer arms in NGC 3898, above, but they are seen here to better advantage because of the more-favorable inclination angle.



PANEL
79

PANEL
80

NGC 1371 Sa(s) panels 64,88, S3
CD-495-S (E/1,1,1/1)
Sep 26/27, 1978
L03aO + GG385
43 mill

The snitxilli spiral arms in the center of N(J<! I 3 7 I . shown on pane) 64 and in the insert, art-burned nut ín thís prínt, whose purpose is to emphasize the outer (MAS) arms. 'This outer multiple-arm pattern is similar to that for galaxies on the previous two pages, especially NGC 3898 and IC 5267.

The inner arms, shown in ihe insert, arc smooth. Based on these arms alone, *WCA'.* l.'iTI would !)<• classed us Sa. in the early one-third of the Sa morphological box. However, the robust star formation in the outer arms is characteristic of the very late part of the Sa section, close to the boundary with the Sab morphological box.

The galaxies on this and the following four panels are peculiar in some aspect of their morphology. In some cases the peculiarity is evidently due to a close encounter with a companion, causing tidal plumes or other abnormal features. In the following pages, various pairings are set out where the conditions for tidal interaction might exist. The cases are also described where no obvious companion is evident although the morphology is peculiar.

IC 5135 Sa pec **pair**
CD-1553-S/Br **(E/I,L,l/2)**
Aug 8/9, 1980
103aO + GG385
4-5 min

IC 5135 has no close companions: no current interaction is evident. However, IC 5131 is 12' distant to **the** west, and the peculiar (SOj pec) galaxy NGC 7135 (panel 51) with its unusual **plume** (presumably tidal) is 18' distant to the east. The redshifts of $u_o(5135)$ = 4808 km s^{-1} and $u_o(7135)$ = 4889 km s^{-1} are similar enough to assure a common distance. The mean **redshift of** $<v_o>$ = 4848 km s^{-1} gives a redshift distance of 97 **Mpc** (H = 50). The projected linear **separation** of IC 5135 and NGC 7135 is 508 kpe, similar to the distance between our Galaxy and M3 1, at 690 kpc (m - M = 24.2).

Because IC 5135 and NGC 7135 are both peculiar and form a wide pair, a circumstantial case exists that a tidal interaction has occurred in the past and the interacting galaxies have moved apart. However, the time scale belies this possibility. At a separation of 500 kpc and a velocity difference even as high as 200 km s^{-1} (larger than is observed), the time of the encounter would have been 2×10^9 years ago. This is so long a time that any tidal plumes would have disappeared. Hence, the present peculiarities of NGC 7135 and IC 5135 would seem to be generic to the galaxies and are not a result of a previous encounter.

The arms in IC 5135 are smooth. There is no large central bulge nor normal bright underlying disk. There is no coherent central region. The smoothness of the evident spiral arms requires a type classification of Sa if the galaxy is to be put into the classification sequence at all.

NGC 5614/5615/5613 Sa(s)(tides) **HA, p.** 9
PH-669-S **(E/I,I,1)**
Feb 5/6, 1954
103aO + **WG2**
30 **min**

The negative print here has been made from the same 200-inch plate used for the positive print in the Hubble Atlas.

NGC 5615 is the object on the rim **of** the main body of NGC 5614. The more-distant RSB0 galaxy with the almost complete **external ring** is NGC 5613. The ring, however, is not complete but, like NGC 3081 (Hubble Atlas, p. 77: panels 99, 107 here) is composed of **two spiral** segments that nearly overlap after each turns by 180°—a common form described often in this atlas.

The most unusual feature of the NGC 5614/5615 pair is the plume from NGC 5615. An abnormal feature of NGC 5614 is the non-central position of its bright center relative to the tightly wound spiral **pattern.** The center of light is displaced dow'nward (on the print) from the arms that are well defined by the nearly circular dust lanes. Note the few knots that are **probably HII** regions in the upper outer luminous arcs.

The central structures in NGC 5614 are burned out on the negative print here, but the two tightly wound, very bright arms that form a near-ring that surrounds the central bulge are visible on the positive print in the Hubble Atlas. This inner pattern of nearly overlapping bright arms, tangent to which sets of fainter outer arms start, is the same as shown by the galaxies on panel 66 (NGC 7702 and NGC 4274) and panel 69 (NGC 3900, NGC 4448. and NGC 6902; note particularly the insert there).

NGC **5916** Sa pee **triplet**
CD-1433-S/Br **not in RSA**
March 25/26, 1980
103aO + GG385
45 min

NGC 5916 is not in the RSA. It forms a triplet with NGC 5915 [SBbc(s) pec], which is 4.8' northwest of NGC 5916, and with NGC 5916A (Sab?) at 7', also to the northwest.

Both NGC 5915 (panel 212) and NGC 5916 are slightly abnormal. NGC 5915 shows robust star formation in its center (many bright knots) and an amorphous luminous envelope similar to that in NCG 4449 (SmIV: panels 326, S6), **where** robust star formation is also occurring.

NGC 5916 is classed here as Sa **peculiar,** based on the smooth arms, the very small nucleus, and the outer (tidal?) plume.

The redshift of NGC 5915 is v_0 = 2146 km s~^{J} , giving a redshift distance of 43 Mpc. If NGC 5916 and NGC 5915 are at the same distance, their projected linear separation is small, at 60 kpe, showing that tidal interaction is a possibility. The robust star formation in NGC 5915 and the tidal plume in NGC 5916 would be the result.

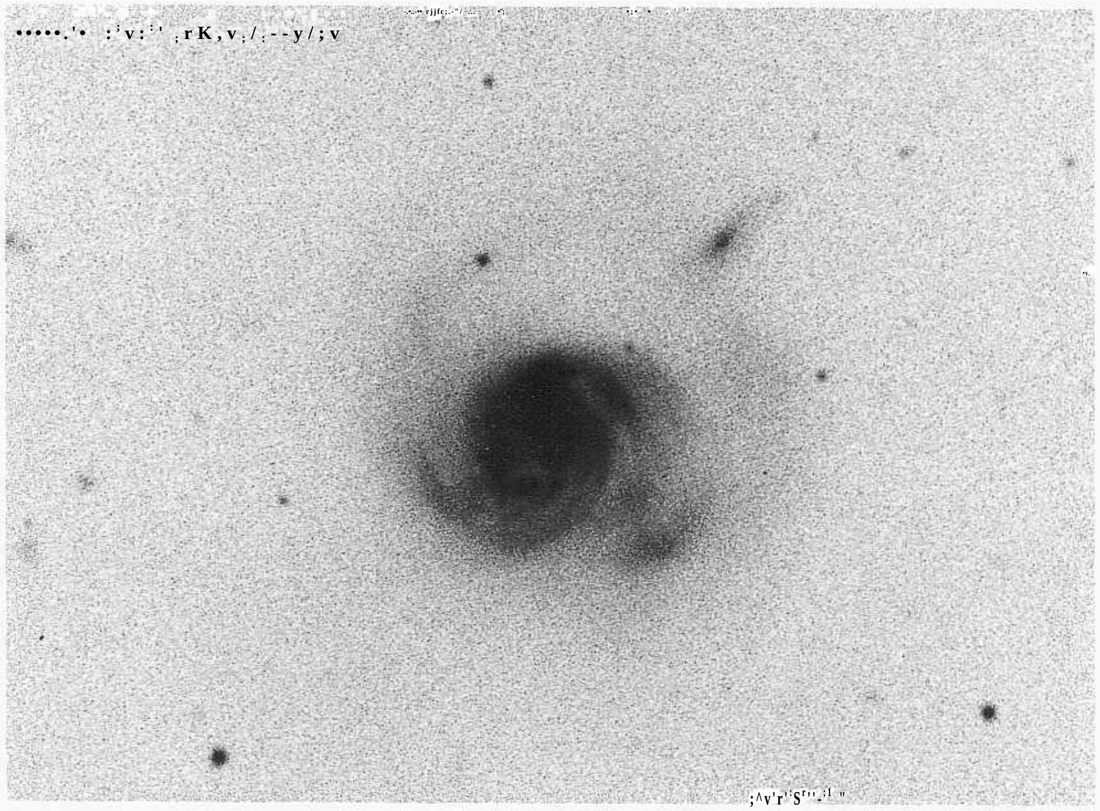
NGC 7769/7770/7771 Sbc(s)(tides?) **group**
PH-7545-S **Sa pec** **panel** 198
Nov 6/7, 1978 **SBab** pec
103aO
12 min

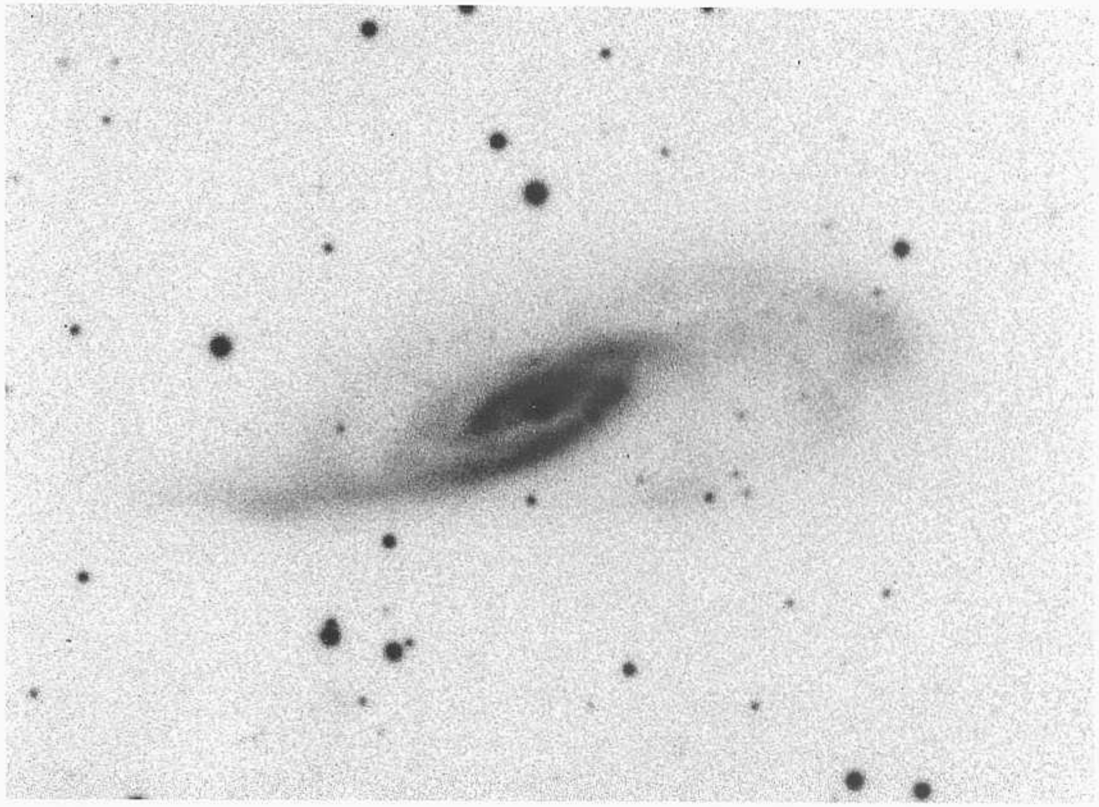
The galaxies shown here form at least a triplet **with** closely the same redshift, as measured by Mayall (Humason, Mayall, and Sandage 1956). The orientation **of** the print is north at the top, east at the left.

NGC 7769 is the large galaxy at the upper right. The type listed in the RSA is Sbc(s)ll(tides?). The tightly wound, interior very bright arms show a high **recent-star-formation** rate evidenced by **the** many **high-surface-brightness HII** regions. Faint, smooth outer arms are well seen in this negative print. These arms alone would give a classification of Sa. However, the inner arms are **of** type Sbc. NGC 7769 is an **example** of the Se/Sa class (panel 86), whose type examples are NGC 5665, NGC 4580, and NGC 7679.

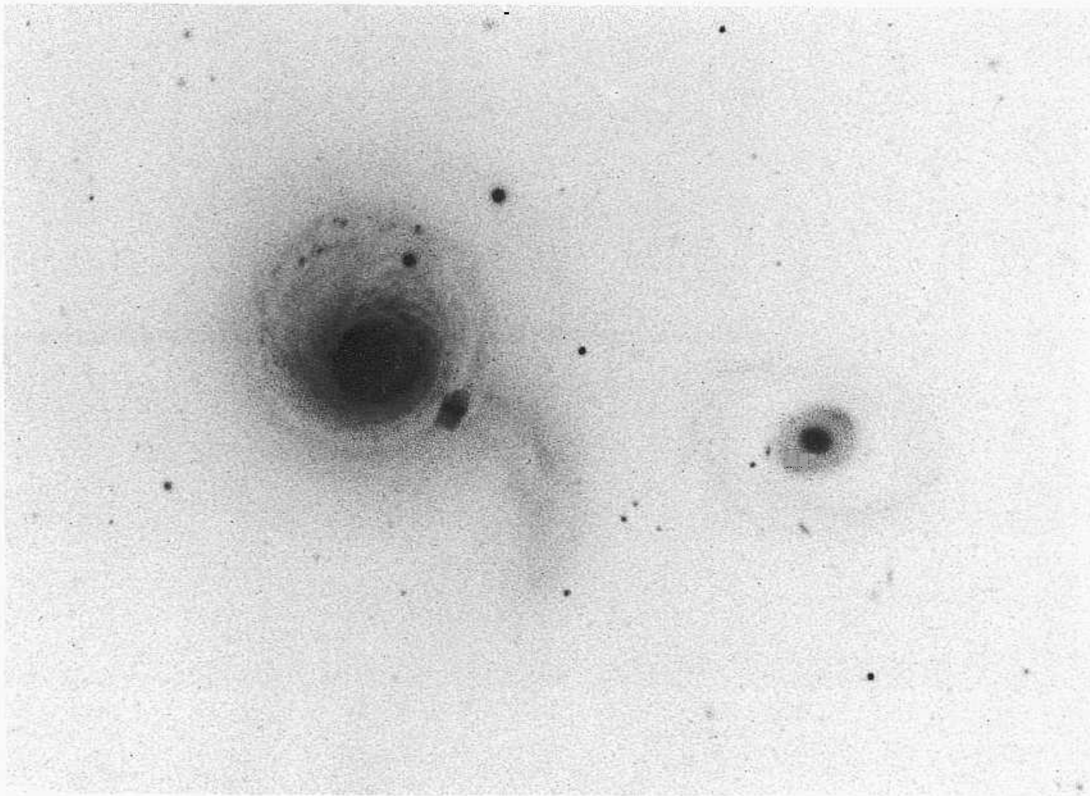
NGC 7 7 70 is the small Sa pee galaxy slightly south and west of the large SBab pec galaxy NGC 7771, Star formation (induced?) is present in the center **of** NGC 7770. The smooth stubby arms visible on the negative print may **be** tidal plumes from the evident close encounter with NGC 7771 .

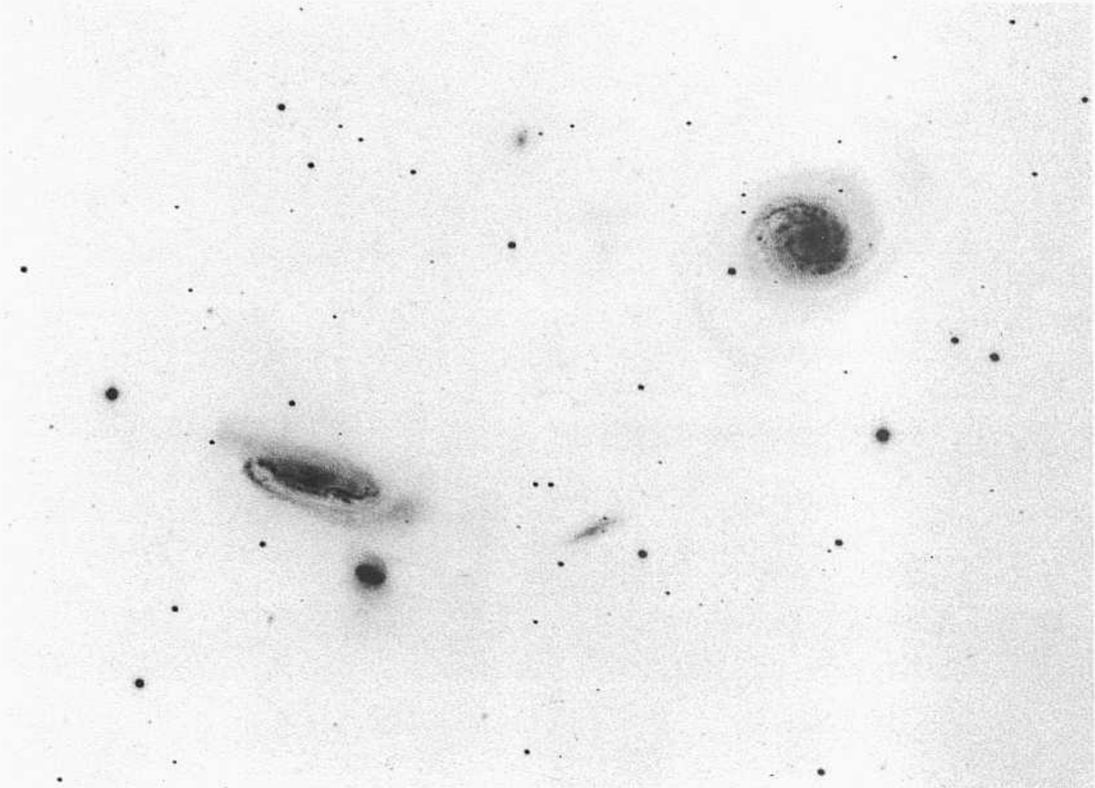
The three major galaxies form a physical triplet. The redshifts are y_o(7 769) = 4349 km i^{-1}, **$t)_o$(7770)** = 4338 km a"^{1}, and u_o(7771) = 42 76 km s^{-1} . The projected angular separations of the two galaxies from NGC 7771 are 60" for NGC 7770 and 315" for NGC 7769. From the mean redshift **of** $<v_o>$ = 4321 km s~^{J} , the redshift distance of 8 6 Mpc (7-7 = 50) gives projected linear separations from NGC 77 71 of 2 5 kpc for NGC 7770 and 130 kpe **for** NGC 7769.



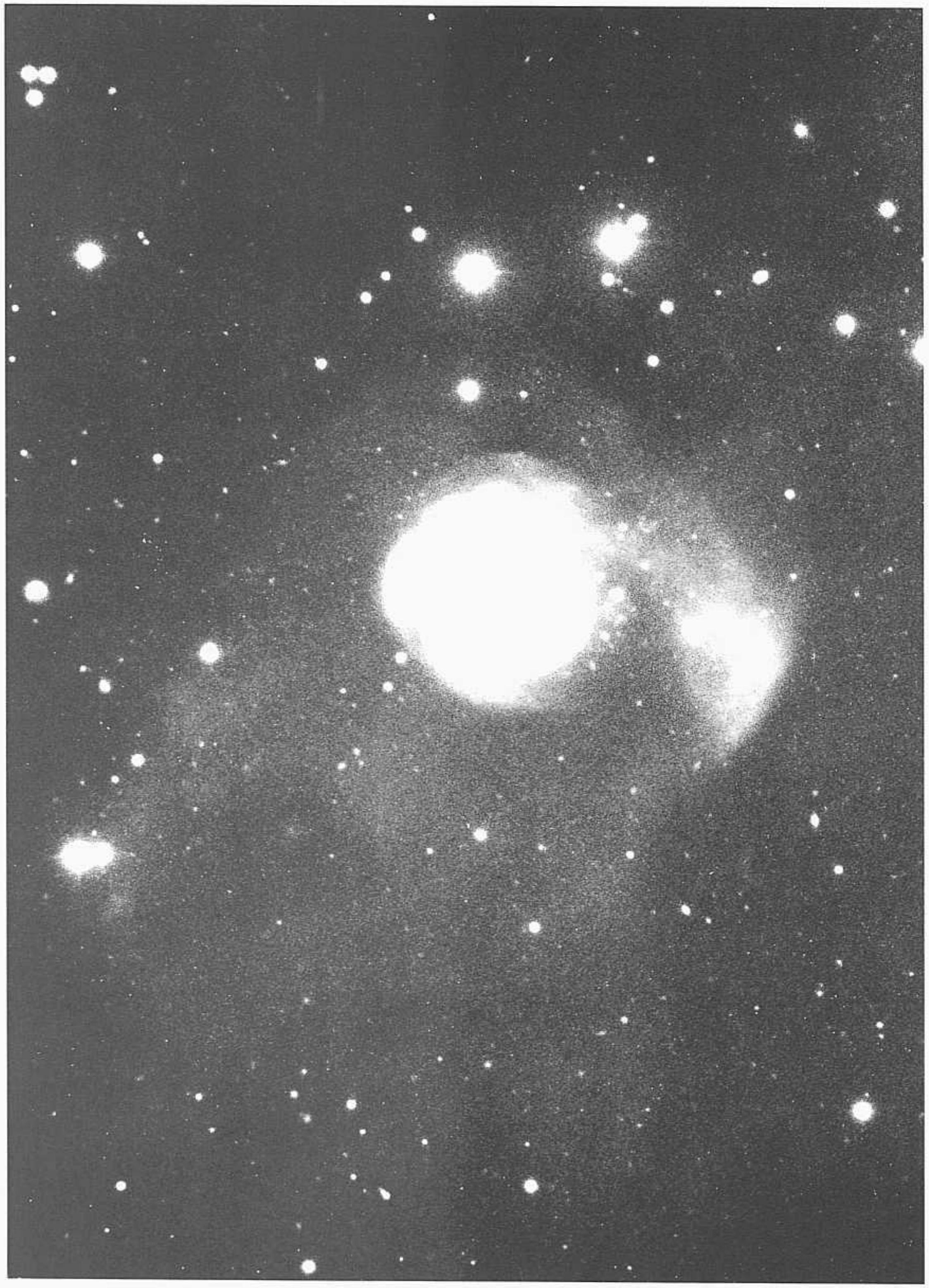


PANEL
81





PANEL
82



NGC 2782 Sa(s) pec
PH-7536-S (E/I,I,1)
Nov 4/5, 1978
IIIaJ + GG13
60 min

The two prints of NGC 2782 on this page are made from the same original plate but are printed to different contrast to show the faint and the bright surface features, keeping the blackness of the sky the same by darkroom contrast-control techniques.

This demonstration shows that it is impossible to judge levels of absolute surface brightness by inspecting photographic prints using the apparent surface brightness of the sky as reference. Darkroom procedures can give any desired relative intensity levels between object and sky, and also within the different parts of an object. An example is the plume to the main image in the leit print, where the feature appears to have nearly the same surface brightness as parts of the center. That this is not the case is seen in the right-hand print, where the plume is nearly invisible.

No close companions to NGC 2782 can be identified as a partner in a close encounter. No companion galaxy can be seen as possible cause of the plume. A few knots exist in the bridge that connects the plume with the main body, but a high rate of recent star formation in the plume itself is absent.

NGC 2782 Sa(s) pec
PH-7536-S (E/I,I,1)
Nov 4/5, 1978
niaJ + GG13
60 min

NGC 2 782 is classed as Sa pec on the basis of the tightly wound and generally smooth spiral arms in the main body shown in this lightly printed image from the same plate used fnr the print at the left. Bright knots, presumed to be 1111 regions, are seen in one of the nearly circular arms to [he left of the bright central region. Fragments of dust lanes in spiral patterns exist throughout the central bulge. The luminous arms are smooth in the outer part (if the image visible here.

NGC 7727 Sa pec Racine wedge
PH-7692-S (VE,L,l/2)
Sep 26/27, 1979
IllaJ
75 niin

The two prints of NGC 7727 here were made from the same original plate but with different contrast control in the darkroom. The properties of such prints for assessing absolute-surface-brightness levels are discussed on the preceding page.

NGC 7727 has similar features in its inner and outer plumes to galaxies such as NGC 7252 (panel 340). which are said to be results of recent mergers (Toomre 1977: Schweizer 1977, 1982. 1983), although NGC 7727 was not included in the list of 11 thought by Toomre to define the class. Other members of the class in this atlas are NGC 520 (panel 340), NGC 3256 (panel 147). NGC 4038/4039 (panel 280), and NGC 7252 (panel 340).

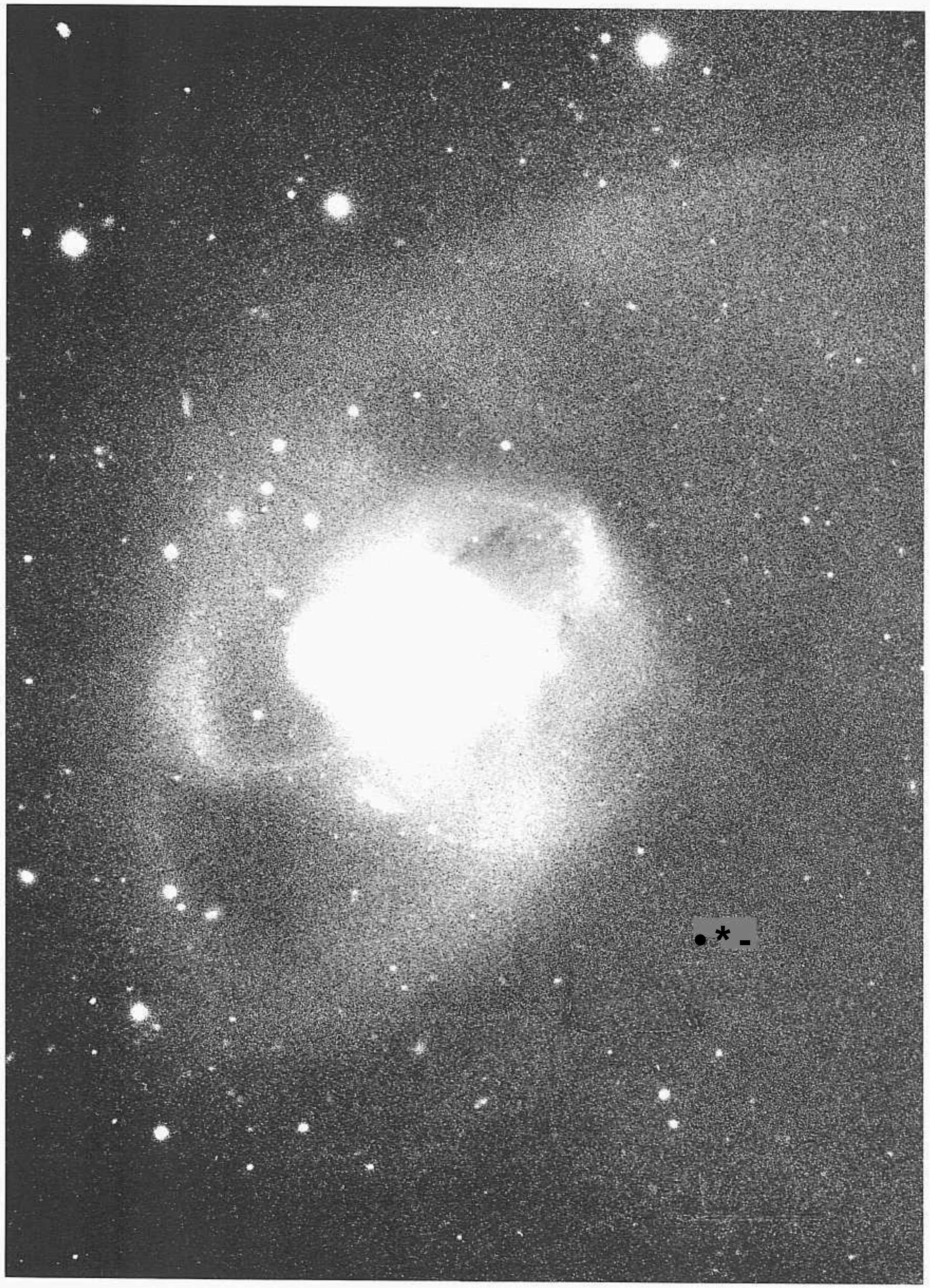
The plumes in NGC 7727 in the left panel are similar to those in NGC 7252 (Schweizer 1982).

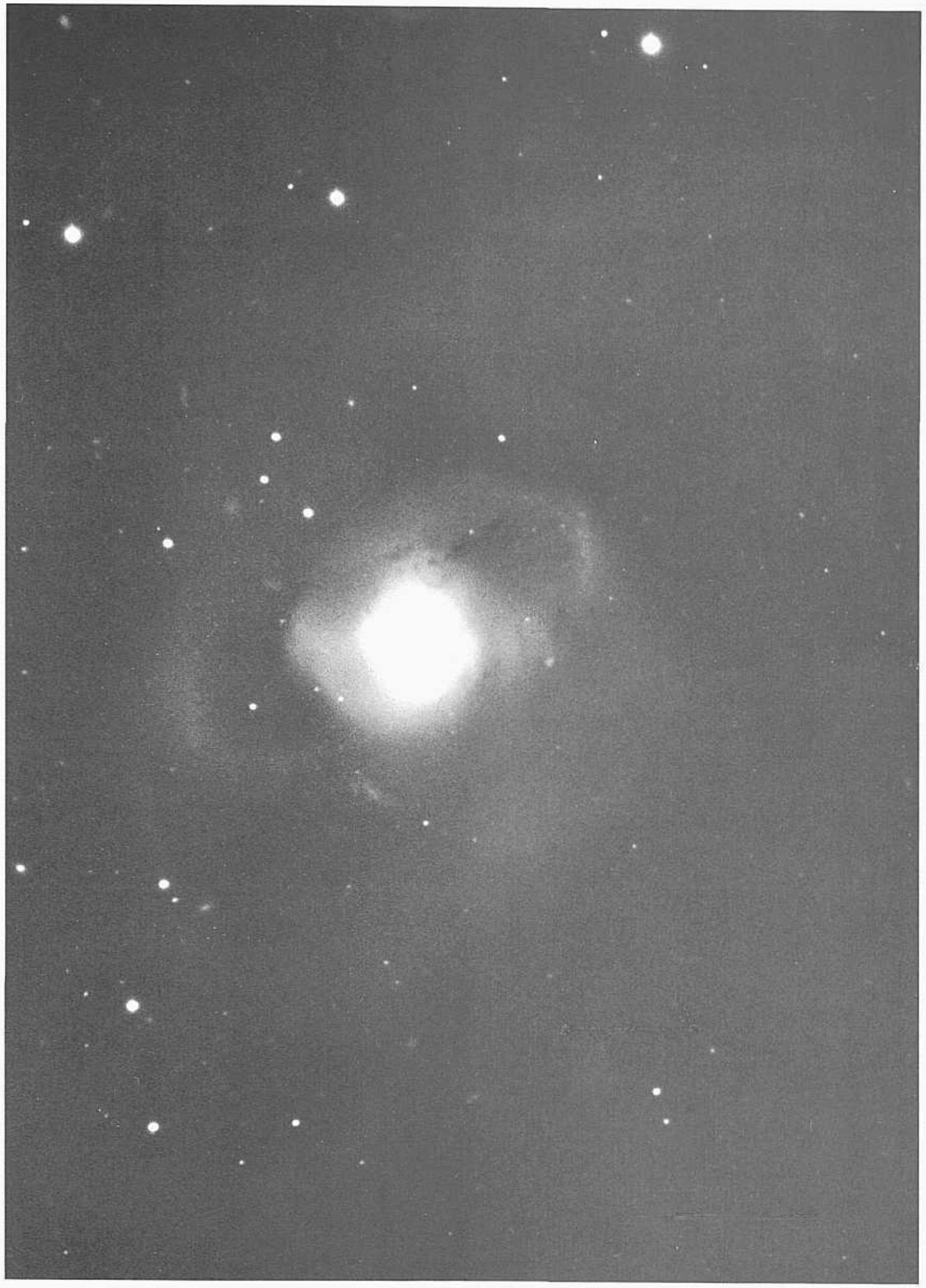
Note that the plate was made with a Racine wedge that produced secondary images to the bright stars separated from the primary by 18" in the south-southeast direction (toward the left and slightly up on the print here). The magnitude difference between the primary and secondary images is 5.0 mag.

NGC 7727 Sa pec Racine wedge
PH-7692-S (VE,L,l/2)
Sep 26/27, 1979
IllaJ
75 niin

The pattern of plumes and near edges to plumes (Quinn 1984) continues into the center of NGC 7727.

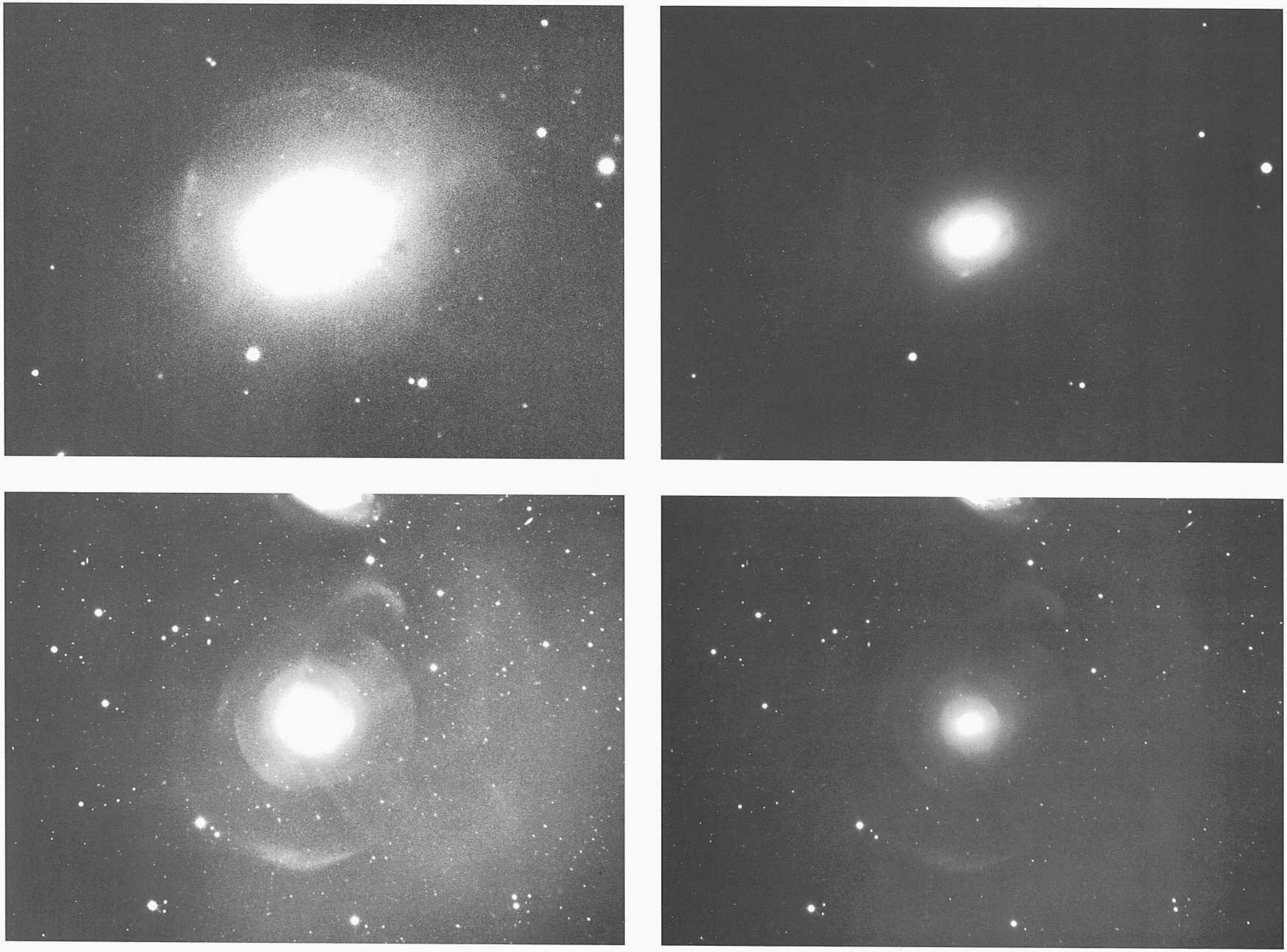
The merger hypothesis for NGC 7727 is strengthened by the presence of two nuclei near the center of the image seen on short-exposure Mount Wilson 100-inch plates taken by Duncan in 1925 and 1938 and by Hubble in 1946. One of these nuclei is at the center of the bulge plus inner disk of the parent galaxy. The other unresolved bright nucleus is well separated from the primary nucleus by 3". However, at 0.8" resolution for the seeing disk, it is not possible to decide if the secondary nucleus is a superposed star or is the nucleus of a proposed, nearly merged previous companion.





PANEL
83

PANEL
84



NGC 7585 S0i(3)/Sa pair
PH-7671-S (VE,L,O) Racine wedge
Sep 25/26, 1979
IHaJ
75 miii

Although two Dreyer galaxies are in **the** vicinity (NGC 7576, 10.7' southwest of NGC 7585, and NGC 7592, 15.2' northeast of NGC 7585), each is so remote that neither can be the cause, via interaction, of the **rim structure** in NGC 7585, which is interpreted **by** advocates to be caused by a recent encounter resulting in a merger (Schweizer 1983; Quinn 1984). **In this** interpretation, the merger occurred long ago and evidence **for** the companion no longer exists.

NGC 7585 and NGC 7576 are probably at similar distances, judged by the approximate equality of the redshifts at $u_o(7576)$ = 3578 km s"[1] and $i>_0(7585)$ = 3356 km s"'. The redshift distance is 69 Mpc *(H* = 50), based on the mean redshift of $<v_o>$ = 3467 km s^{-1}. The projected linear separation of the pair is 2 15 kpe.

If the rim in the image here is due to a merger, the remnants of the required companion have not been found near the center. Unlike the possible double nucleus in NGC 7 727 on the previous panel, NGC 7585 shows no evidence for a second nucleus, but perhaps none is required (Toomre 197 7).

The plate was taken with a Racine wedge. The secondary images are below and slightly to the left in the print here.

Besides the sharp rims, the principal features of the image are the dust patches. The outer patch is visible to the right of the center on this print. A patch on the same side but closer to the center is shown in the more **lightly printed** print at the right.

NGC 474/470 RSO/a pair
PH-7866-S (VE,L,0) Racine wedge
Sep 5/6, 1980 Sbc(s)II.8 panel 189
IHaJ
150 miii

NGC 474 (RSO/a) forms a close double **with** NCC 470 (She: panel 189), partially cut off at the top middle of the print here. The projected separation of the pair is 313". The redshifts arc $u_Q(470)$ = 2643 km s '. and $u_o(474)$ = 2548 km s"'. The mean of $<v_o>$ = 2596 km s~[1] gives a redshift distance of 52 Mpc *(H* = 50) and therefore a projected linear separation of 80 **kpc** for the pair.

The multiple rims at many distances **from** the center of NGC 474 are similar to the theoretical expectations of the effect of mergers calculated by Quinn (] 984: sec also the diagram due to Toomre in Schweizer 1 983). However, the circumstantial evidence is not that a merger has occurred but rather that a close encounter is taking place with NGC 470.

Short-exposure plates taken with the Mount Wilson 100-inch by van Maanen in 193 8 and by Sandage in 1975 fail to show evidence for a merged **companion.** However, the absence of a double nucleus may not be of consequence: it is claimed that direct evidence of a merger would rapidly disappear (Toomre 19 77 in the discussion).

The common feature in NGC 474 and NGC 7585, above, is the exceptionally high surface brightness of the central, almost point-like, nucleus. This feature is seen on the low-contrast prints of both galaxies in the secondary images of the nuclei from the Racine wedge.

The print has been made from the same original plate used for the image on the right.

NGC 7585 S0i(3)/Sa **pair**
PH-7671-S (VE,L,O) **Racine wedge**
Sep 25/26, 1979
HlaJ
75 miii

This print of NGC 7785 is made from the same negative as the image **on the left.**

The **center of** the image is **nearly** featureless except for two small dust patches, one **directly to the right** of **the center, well-silhouetted** against **the** hedge, and the other **directly** below **the first,** not well seen here because ol **the faintness** of **ihe** bulge at this position.

The small, **slightly fuzzy image** below and slightly to the left of the center is the secondary image of the nearly point-like nucleus of NGC 7785 **produced** by tin- **Racine wedge, ll is I !l" from** the center and is 5 mag **fainter** than the primary image. **Except for Scyfert** (1943) galaxies, such Racine wedge secondary images of galaxy centers are very rare because the centers of galaxies seldom have such bright, **point-like** nuclei.

NGC **474/470** **RSO/a** **pair**
PH-7866-S **(VE,L,0)** **Racine** wedge
Sep 5/6, 1980 **Sl>c(s)II.8** **panel 189**
IllaJ
150 **min**

The print has been made from the same original plate used **for** the image on the [eft.

The sharp rimmed arcs continue farther into the center than is visible on the more heavily exposed print al the left. The well-defined, closely circular central bulge appears featureless on short-exposure Mount Wilson 100-inch plates, but it is of exceptionally high surface brightness. Al the center is an almost **unresolved,** very bright nucleus. As in NGC 7585. above, ils secondary image from the Racine wedge is visible to the right of the bulge, slightly below the **cen**terline al what appears to he the edge of the central region. To locate ibis **secondary** image note the relative position of the many **other** Racine wedge images for the bright stars in the field.

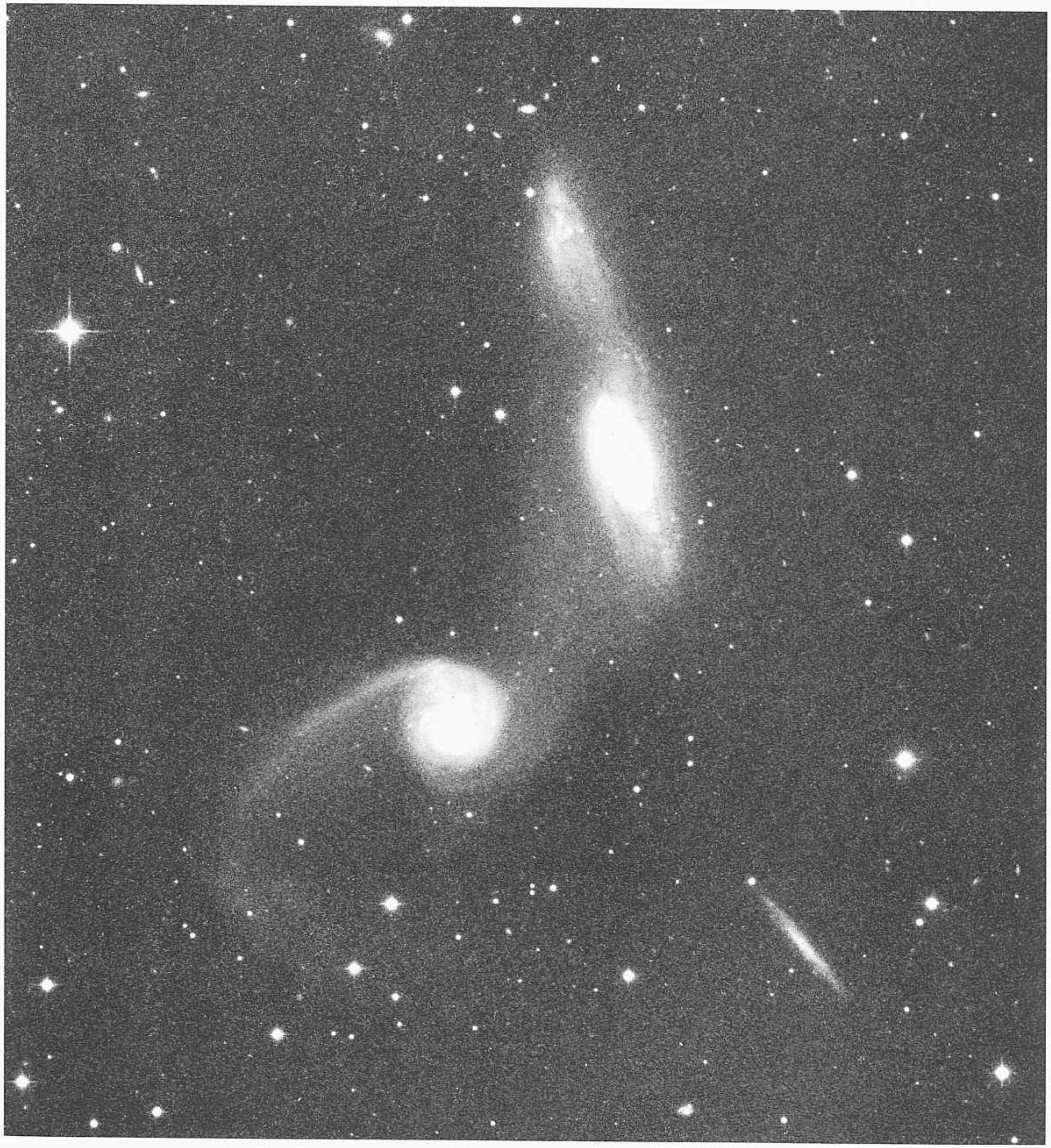
NGC 2992/2993	**Sa(tides)**	**pair**
CD-807-S	**(E,L,1)**	
Feb 25/26, 1979	**Sab(tides)**	
103aO + GG385		
45 min		

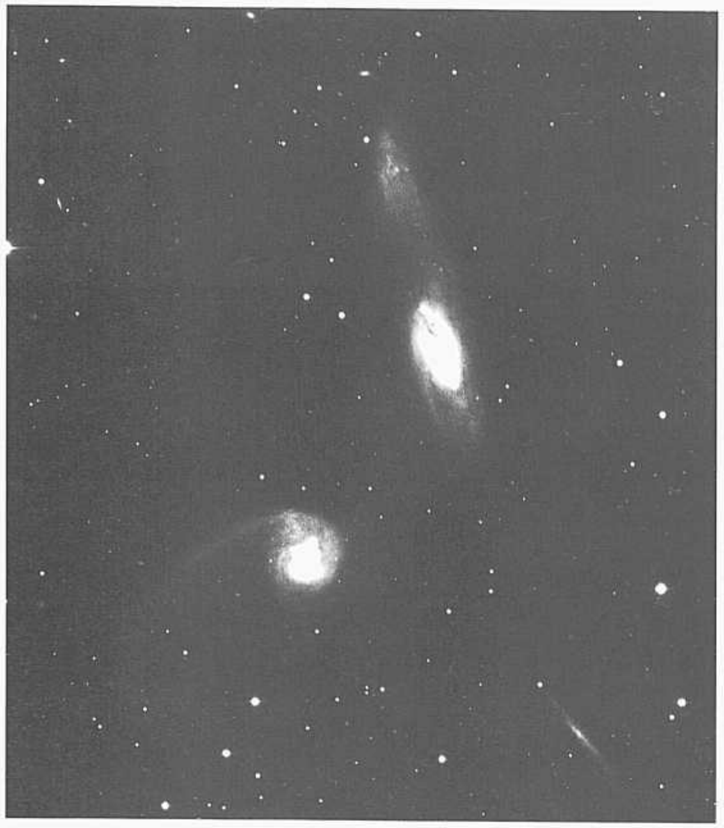
The orientation of **the** print here is north at **the top,** cast **to the left.** NGC 2992 is to **the** north **and** west **of** NGC 2293. which has **the** more **circular** image. The projected separation of **the pair** is **3'.** The **redshifts** are **u_o(2992)= 1** 963 km s^{-1} and **u_o(2993**) = 1868 km s^{-1}. giving a **redshift** distance **of** 38 Mpc (// = 50) **based** on the mean redshift. The **projected** linear separation **of** the **pair** is. then, small at 33 **kpc.**

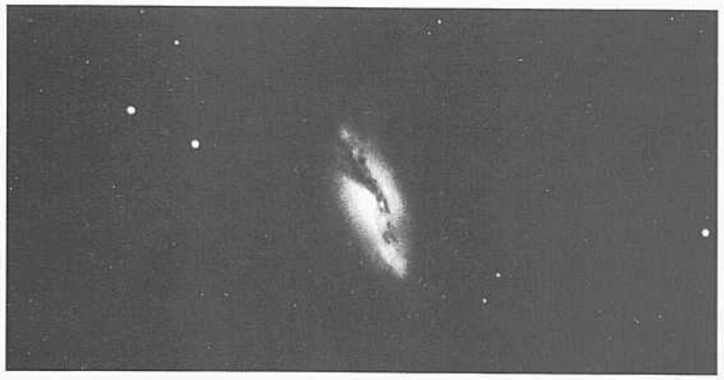
Tidal interaction is clearly **visible.** Luminous material exists between the main bodies **of** the principal components, extending from NGC 2293 to the shred on the north side of NGC 2992. This **apparently** torn-away part of NGC 2992 . of low surface brightness, is evidently a tidal plume that nevertheless has knots that are presumably small **HII** regions.

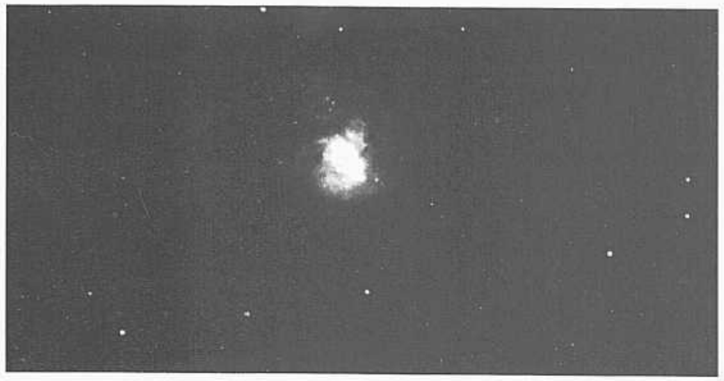
The **smooth extended** arm that starts on the north **edge** of the southern component **of** the pair (NGC 2993) and extends eastward, appears also to be a tidal **plume.**

The prints in **the** right column are from the same plate used for **the** main **print** at the **left.** The top print in this column shows that the shred torn from NGC 2992 and the tidal-plume arm in NGC 2993 are both of low surface **brightness** relative to the central regions of each galaxy. These central regions are shown in the **lower** two prints in the right column. Not shown well here **but** visible **on** the plate is evidence of recent **star** formation in the center of NGC 2992: hence its assigned type is Sab.



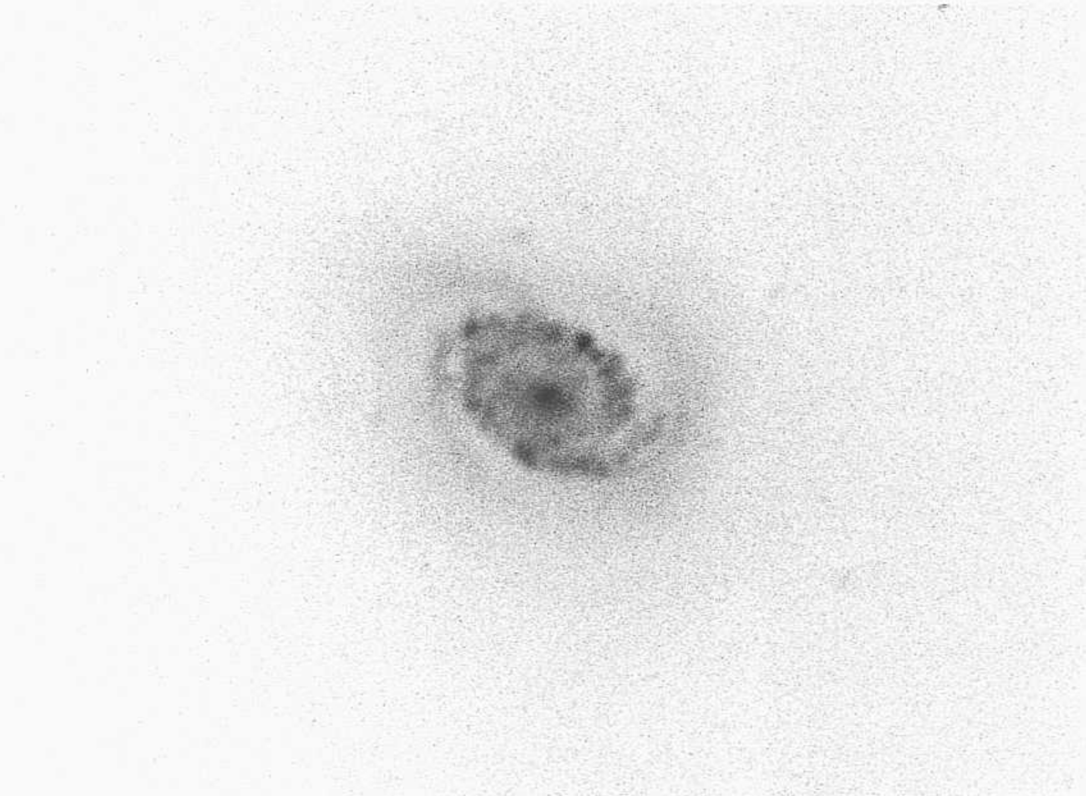


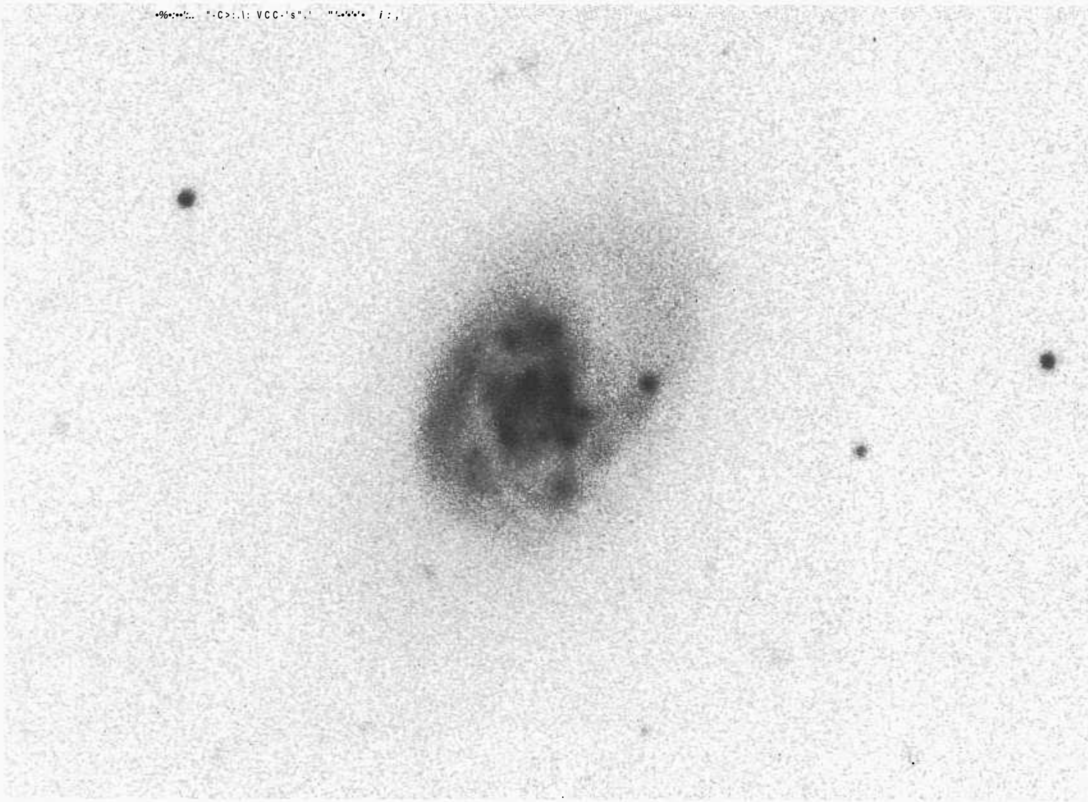


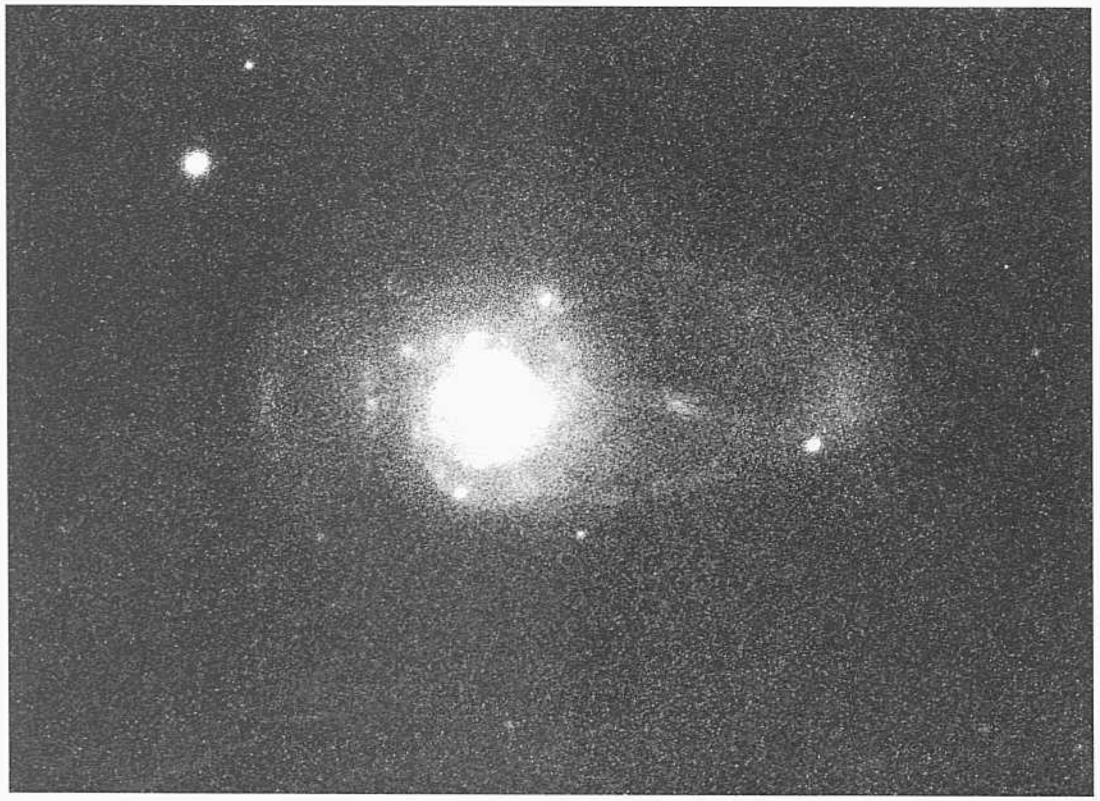


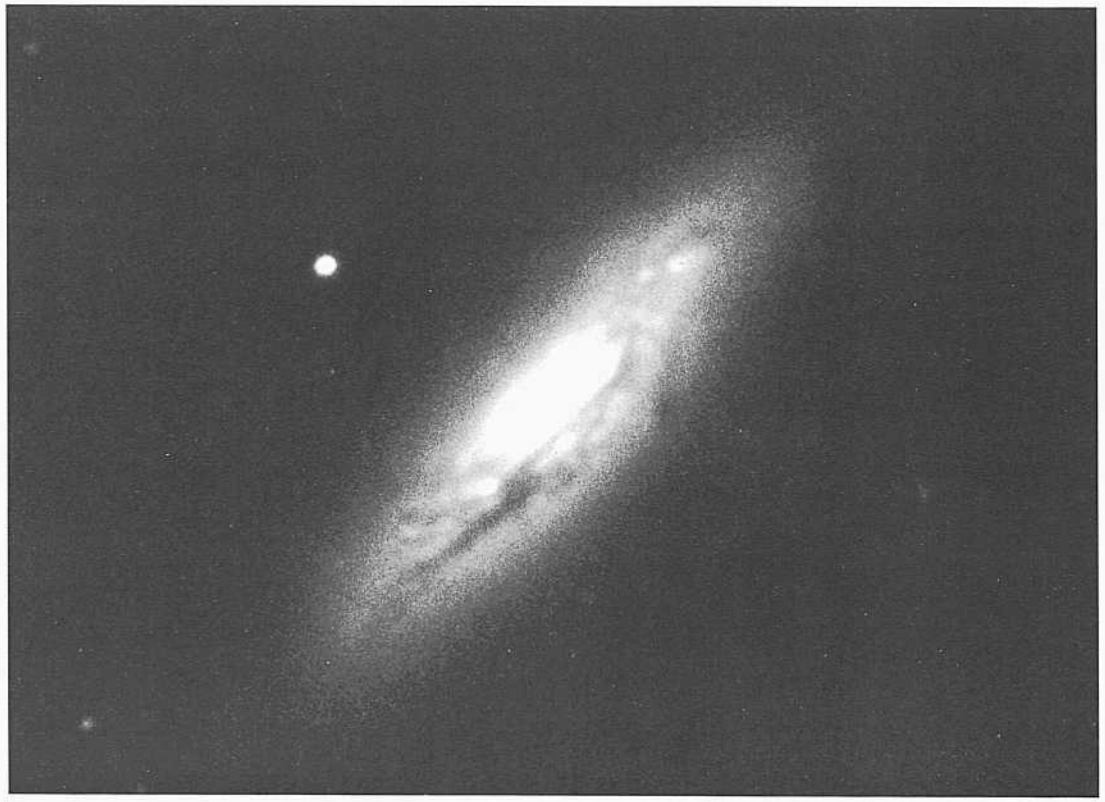
PANEL
85

PANEL
86









The four galaxies on this panel are abnormal enough not to fit into the standard morphological boxes of the classification sequence. Three have characteristics that combine the high star-formation rate of Sc types **with** the smooth-armed properties of Sa galaxies. The fourth, NGC 44 1 9, shows only dust, similar to the galaxies shown on panels 74—76. hut in a more chaotic pattern than galaxies on panel 76. which have similar inclination angles.

NGC 4580 Sc(s)/Sa **VCC 1730**
H-2285-H **HA, p.** ***21***
May 30/31, 1946 **panel 276**
103aO
40 min

The negative print of NGC 4580 was made from the same Mount Wilson 100-inch plate used in the Hubble Atlas. The galaxy is similar **to** the **broken-inner-ring** galaxies on panels 66 and 69, **of** which NGC 42 74 and NGC 6902 are the prototypes. Here, as in those galaxies, the near-ring is the overlapping of two tightly wound arms that start on opposite sides of the bulge after each has unwrapped by 180°. Outer arms begin tangent to this inner near-ring. In NGC 42 **74** (panels 66, 88) and NGC 6902 (panel 69), these outer arms arc **lumpy,** showing evidence of recent star formation.

The outer arms in NGC 4580 are smooth, in stark contrast to the vigorous star formation in the inner near-ring. This star formation in the inner **ring requires** the type **of** the inner part of NGC 4580 to be Sc. The smooth outer arms are incompatible with this class. The mixed type of Sc/Sa calls attention to the phenomenon. The only other galaxies of this type in the RSA2 are NGC 5665 and NGC 76 79, also shown on this page.

NGC 7679 Sc(s)/Sn(tides?) **pair**
PH-7816-S **panel 292**
Sep 2/3, 1980
103aO
12 miii

NGC 7 679 forms a pair with NGC 7 682 (SHa), at 268" separation. The direction of NGC 7 682 relative to **the** print **here** is **to** the right and slightly down, at about a position angle of 3:30 o'clock. The distance of NGC 7682 (not in the RSA) from NGC 76 79 is about four times **the** apparent diameter of the main body **plus** the plume of NGC 7679 shown in **the** print. However NGC 7682 is not distorted or abnormal. It has a symmetrical SBa(s) morphology with **well-**defined, tight, relatively smooth arms.

However, NGC 7679 is abnormal. Its smooth outer arms envelop an inner region of high surface brightness which contains many knots, suggesting a high, current **star-formation** rate and therefore the Sb or Sc type. There are two oppositely directed smooth plumes **charac-teristic** of a tidal interaction.

NGC 7679 and NGC 7682 undoubtedly form a physical pair. The **redshifts** are i'_o(76 79) = 5397 km s~' from the RSA2. and y_o(7682) = 5333 km s^{-1} from the compilation by Huchtmeier and Richter (1989). The redshift distance of 107 Mpc (H = 50) gives a projected linear separation of 139 kpe. suggesting that a tidal **interaction** might have occurred in the past, yet the form of NGC 7 682 is regular. Perhaps the plume in NGC 7679 is not caused by tides but is endemic to the galaxy itself.

The **morphology** of NGC 7 6 79 is similar to that of NGC 4580, above; hence the mixed classification is **required** for the same reasons.

NGC 5665 Sa/Sc **panel** 292
CD-1868-1IB
April 9/10, 1981
103aO
75 **min**

NGC 5665 has man) **I1II knots spread over** an interior- spiral **pattern that, if the form** is **to be** classified, would be **of type Sc. A smooth continuation** of the arm on **the** left side of the print suggests a similarity to NGC 4580, shown at the left, which is the **prototype** of **the** Sa/Se mixed type.

The galaxy is isolated **from** any other **bright** Dreyer listing. The closest Dreyer galaxy is NGC 5645. **which** is 50' south and is **not** a candidate for any postulated interaction. The form of **NGC** 5665 appears to be generic, not environmental.

NGC 4419 **Sa(dust only)** **VCC 958**
CD-2146-S **panel 114**
March 23/24, 1982
103aO
50 **min**

NGC 44 **1** 9 is similar to the ""dust arm only" Sa spirals on panels 74—76, but is more extreme. The galaxy is in the Virgo **Cluster** region, **about** a degree north of the subcluster A **concentration** near NGC 4486. **The** large bulge is the **feature** necessitating the Sa classification. It is illustrated here, **at** the end of **the** Sa **sequence, to emphasize** that NGC 4419 is a late Sa. near the **boundary** of **tin**[1] **Sa** and the Sab **morphological** boxes.

The prototype multiple-armed Sa galaxies are arranged on this page to illustrate the progression from very early to late Sa. The progression spans the length of the Sa morphological box. The progression proceeds from upper left to lower left of the left-hand column, and similarly to the middle and the right-hand columns. Each galaxy has been illustrated on previous pages of the Sa section; the descriptions there give more detail.

NGC 2681 Sa HA, p. 9
PH-191-MH (E,L,l/4) panel 62
May 13/14, 1950
103aO
30 min

The print of NGC 2681 here, also illustrated in tin' Hubble Atlas (p. 9), shows the smooth outer arms to better advantage than the positive print on panel 62. The galaxy is among the earliest of the true Sa's in the RSA. The arcs of arms are spiral and are better defined, albeit broad and smooth, than in the embryonic-armed, mixed-morphology SO/Sa galaxies on panels 59 and 60. The arms in NGC 2681 are multiple rather than of the grand design type shown on the next panel.

NGC 3885 Sa panel 76
CD-692-Br (E,S,1)
Jan 27/28, 1979
103aO + GG385
45 min

NGC 3885 was shown earlier as typical of the "dust arms only" types on panels 72—76. The dust arms define the spiral structure of the MAS .subtype in the early part of the Sa sequence, developing later in the section into luminous arms. NGC 3885 is an early example of this: it is somewhat earlier than NGC 7377, which is another "dust arms only" prototype shown on panel 75.

NGC 1617 Sa(s) panel 79
CD-139-S (I,L,1)
Feb 1/2, 1978
103aO + GG385
50 inin

The internal lanes in NGC 1617 that are the inner spiral arms are well seen in the positive print on panel 79, where the multiple-armed spiral pattern is evident. The outer pattern of moderately smooth luminous arms shows here and on panel 79 as tightly wound fragments. NGC 1617 is later along the MAS Sa sequence than NGC 3385 but is earlier than NGC 4698 below. It is much earlier than NGC 4699 and NGC *21 IS* in the right-hand column.

NGC 4698 Sa panels 78, 79
CD-1881-HB (E/I,I,l/2)
April 11/12, 1981
103aD + GG495
45 min

The dust lanes and the multiple, luminous, tightly wound arms are considerably more developed in NGC 4698 than in NGC 1617, above. The large central bulge dominates the structure at this viewing angle. The spiral arms in the outer part of the disk, seen best in the positive print on panel 79, are still-subtler than in the two galaxies in the right-hand columns, where, especially in NGC 2775, the arms are robust albeit fainter than in Sb and Sc galaxies where the current star-formation rate is higher.

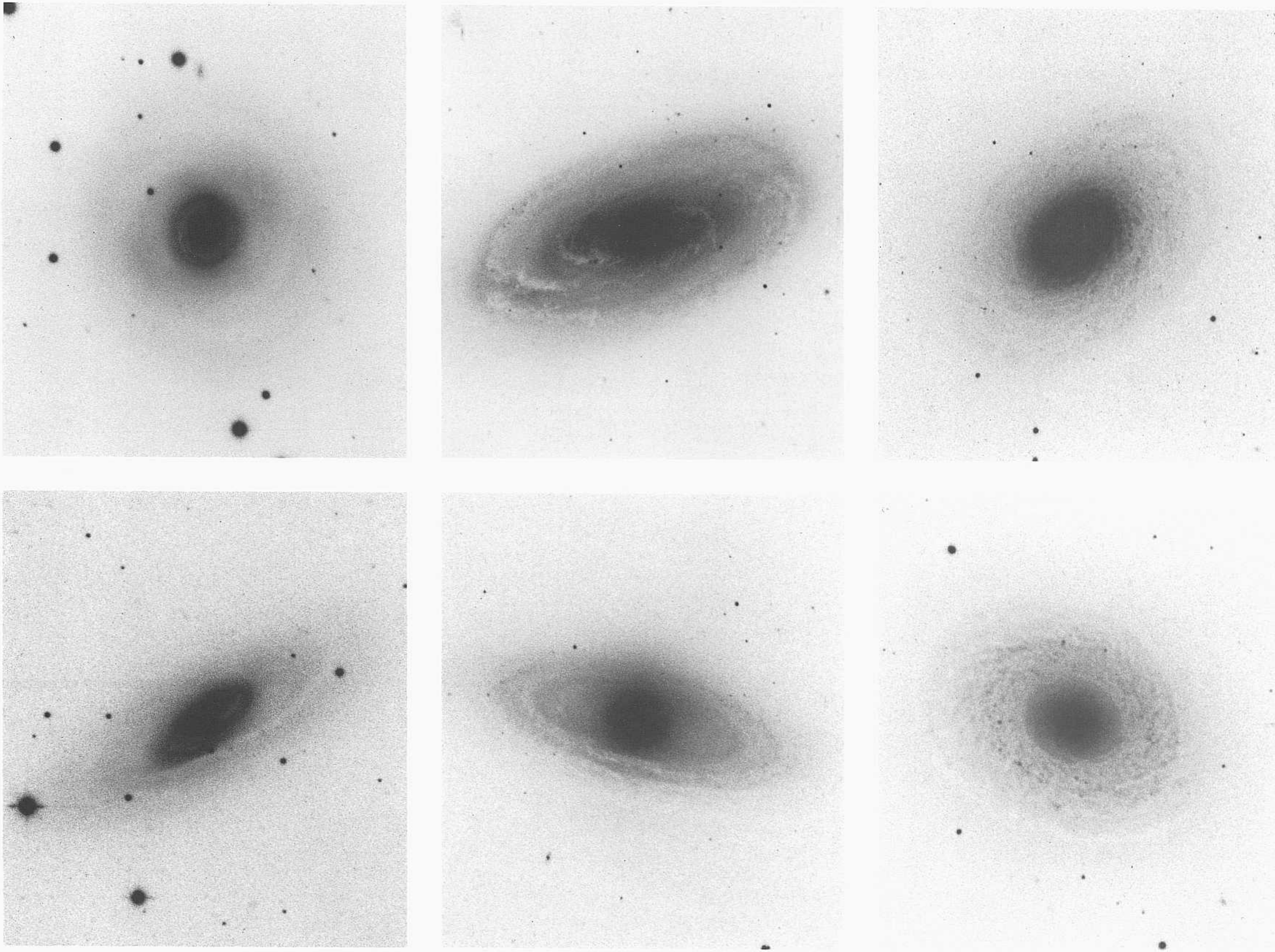
NGC 4699 Sab(sr) or Sa HA, p. *16*
CD-1872-S (I,L,l/3) panel 78
April 10/11, 1981
103aD + GG495
4-5 min

The MAS pattern of fragmentary arms is now well developed, and the knots therein show the lateness of NGC 4699 in the Sa section. Note that the emulsion used here (103aD) is a yellow plate (5000-6000 Å), which suppresses the emission lines in the HI1 regions: a blue plate such as used in the Hubble Atlas shows the Mil knots better, suggesting a later morphological type.

NGC 2775 Sa(r) HA, p. *10*
CD-1664-S (I,L,l/3) panels 78, S12
Dec 30/31, 1980
103aO + GG385
60 min

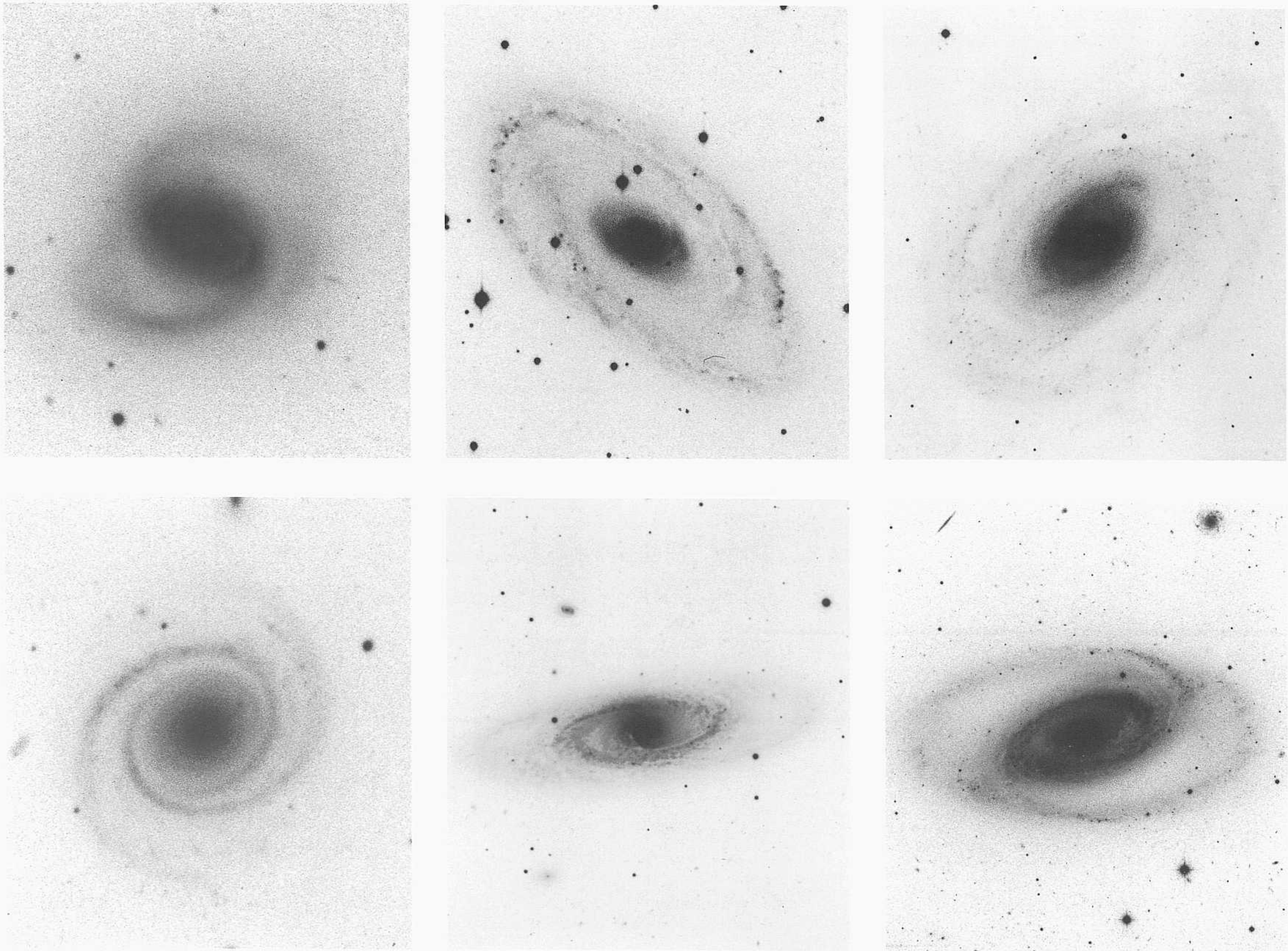
NGC 2775 is the latest Sa of the MAS type with fragmentary arms shown in this atlas. It is the late-Sa example of the NGC 2841 (Sb; Hubble Alias, p. *14:* panels 142, S4, SI2 here) multiple-armed forms in the Sb section, and NGC 628 (Sc; Hubble Atlas, pp. 29, *31:* panel 220 here) or NGC 1232 (Sc: Hubble Atlas, p. *32:* panels 216, SI3 here) in the Sc section. As was emphasized in commentaries in the Hubble Atlas and now throughout this atlas, both the MAS and the grand design strains of spiral structure can be traced separately along the entire spiral sections of the classification sequence, in both the ordinary and the barred spirals.

A summary of the grand design Sa prototypes is on the next panel.



PANEL
87

PANEL
88



NGC 718 Sa HA, p. *11*
PH-792-S (E,L,O) panel 63
Aug 25/26, 1954
103aO + WG2
30 niin

NGC 718 is the earliest of the grand design true Sa galaxies in this alias. Earlier transition cases, such as NGC 4429 [$S0_3(6)$/Sa pec; panels 60. S2], NGC 3271 (Sa: panel 61), or NGC 4503 (panel 61) show a major two-armed symmetry that will develop into a strong grand design form later in the sequence: NGC 718 is the earliest Sa with that robust form. The negative print here is of high contrast, to emphasize the smoothness and the symmetry of the outer spiral pattern. The surface brightness of the outer arms is, in fact, very low relative to the central bulge and to the two smooth, symmetrical, high-surface-brightness inner arms that are well seen in the positive print on panel 63 but which are burned out on the print here. As also seen on panel 63, the inner arms are tightly wound about the central bulge. They can each be traced only for about a quarter turn from their emergence tangent to a tight inner ring. These inner arms are similar to. but are more developed than, the rudimentary "pre-arms" in NGC 4429 (SO-^/Sa pec; panels 60, S2): hence the later classification as an early Sa is awarded rather than the transition SO/Sa type.

NGC 7096 Sa(r)I panels 68, S3
CD-518-S/Br (I,L,0)
Sep 29/30, 1978
103aO + GG385
45 min

NGC 7096 is one of the most symmetrical galaxies in the sky. The very large bulge and the tightness and symmetry of the arms are characteristics of the Sa type. The knots in the arms place NGC 7096 later in the Sa section than NGC 718, above, but earlier than the other Sa galaxies on this page. Note that each of the arms can be traced for a full revolution, characteristic of this type of galaxy, which often appears to have a near-ring when seen at large inclination angles (as in NGC 3358 in the upper middle print).

NGC 3358 Sa(r)I panel 70
CD-191-S (1,1,1/2)
Feb7/8, 1978
103aO + GG385
45 min

The two principal arms of NGC 3358 are similar to those in NGC 718 and NGC 7096 in the preceding two prints, but they contain many more Mil regions and more evidence for dust in the arms. However, the spiral pattern is very similar to that in NGC 7096. The principal arms start tangent to a bright, large bulge and, as in NGC 7096. can each be traced a full 360° of unwrap. On low-resolution plate material. the tightness of the arms and the large inclination angle would make the arms appear to almost overlap, as in the galaxies described on panels 67, 68, and 70, giving the mistaken impression of ring. (See also the description of NGC 3081 in the Hubble Atlas, p. *11.)*

NGC 3358 is later along the Sa section than either NGC 718 and NGC 7096. but is not as late as NGC 4274 below.

NGC 4274 Sa(sr) HA, p. *12*
PH-686-S (I,I/L,1) panel 66
Feb 9/10, 1954
103aO + WG2
30 min

NGC 4274 is of the same grand design type as NGC 3358. above, but is Later along the Sa sequence because of the higher recent star-formation rate evidenced by the more abundant IIII regions in the arms. The internal near-ring impression due to the tightly wound spiral structure is well seen here because of the large inclination angle.

NGC 1371 Sa(s) panels 64, 80, S3
CD-495-S (E/U.1/I)
Sep 26/27, 1978
103aO + GG385
45 min

The inner spiral arms of NGC 1371 arc very smooth, as in tlit* earliest Sa galaxies such as NGC 718 (panels 63. 88). NGC 7096 (panels 68. 88. S3). NGC 3269 (panels 63, S3), and NGC 1079 (panel 67) plus others on panels 64 and 65 in the earliest part of the Sa section. These very smooth, bright inner arms are burned out on this high-contrast print but are well seen in the insert print on panel 80 and especially on panel 64.

The thin outer arms of NGC 1371 have a pattern that is neither grand design (as for the inner smooth arms) nor entirely fragmentary, as on the preceding page.

The arms are sprinkled with knots which cannot be individual stars. (Hedshift is v_0 = 1418 km s^{-1}. giving the modulus to be m — .17 - 32.3; hence brightest stars should not appear brighter than 23 mag, which is much fainter than the knots in the arms seen here.) The knots are. then. probably Mil regions. Their abundance shows that the current rate of star formation in the outer arms is larger than in most Sa galaxies. This galaxy is near the late edge ol' the Sa morphological box.

NGC 1350 Sa(r) panels 71, S3
CD-543-S (L,I,1/2)
Oct 1/2, 1978
103aO + GG385
45 miii

This negative print of NGC 1350 is of high contrast to show the low-surface-brightness outer arms. The inner near-ring structure, emphasized in the descriptions on this page, is nearly binned out on this print hut is well seen in tin* positive print on panel 71. The degree of star formation both in the inner regions and in the outer arms, shown by the abundance of H II regions and the large dust content, place NGC 1350 as the latest grand design Sa in the RSA.

The SBO/SBa Classification Section

Galaxies on this and the next panel form a transition between the SBO and the SBa class. The central regions exhibit a bar structure similar to the bar type described in the SBO section (panels 54-58). However, unlike in the pure SBO class, deviations from elliptical symmetry exist in the disk beyond the central bulge, and these are taken to be rudimentary spiral structure, spread throughout the disk.

The morphology of the deviations that are the arms are similar to those in the SO/a and SO/Sa types (panels 59-61). Again, as in the SO/a and SO/Sa types, the rudimentary arms are subtle and appear generally as massive breaks from elliptical symmetry over much of the disk. The general luminosity distribution is smooth, with no evidence of recent star formation.

NGC 4546 SBOi/Sa
H-1952-H (VE,I,O)
March 3 I/April 1, 1938
E40
55 min

The deviation from elliptical symmetry is so subtle in NGC 4546 that the galaxy is very close to an SBO prototype. But there is a slight break in the luminosity pattern in the upper-left disk region just beyond the edge of the bulge in the print here. The central bulge, **burned** out in this print, is elongated in a nearly vertical direction in this print, inclined at an angle of about 75° to the major axis of the outer disk, which is well seen here. The inclination of the bulge to the disk in this way defines the bar in the SBOj subtype.

NGC 4856 S0i(6)/Sa
CD-1296-S/Br (E,I/L,O)
March **10/11, 1980**
103aO + GG385
45 **min**

Two stubby massive arms are visible in the **print** of NGC 4856 here as they emerge from the inclined central **bulge** at position angles of 12 and 6 o'clock, then crawl into the disk and die. The low-surface-brightness disk is extensive and can be traced nearly to **the upper-right** and lower-left **borders** of the print. The subtle features that are the arms can be seen in the first one-eighth of the di.sk by viewing the print from a distance and moving the head or eyes rapidly.

NGC 3941 **SB0i/$_2$/a**
PH-7638-S (VE,L,0)
April 28/29, 1979
103aO
8 min

The central bulge, the bar, and the outer envelope of NGC 3941 all have different position angles to their major axes. The major axis of the bulge is at position angles of 12:30 and 6:30 in the print here.

The bar is moderately distinct, yet massive, giving an SBO ^*i-i* transition bar subtype. The ansae that define the end of the bar terminate *inside* the envelope near the edge of the disk (the lens, in the language of the **Hubble** Atlas) at position angles of about 3:30 and 9:30 o'clock. This is a common form, present for example in NGC 7155 (SBO: panel 56), the three galaxies on the next panel (NGC 936. NGC 1533, and NGC 4477), and NGC 6942 (SBa: panels 92, 106) as prototypes.

The edge of the low-surface-brightness extended disk has two bright "rim segments"' at opposite directions from the center, nearly in line with the position angle of the axis of the central bulge. The most conspicuous of the arc brightenings occurs on the lower rim between position angles of about 6 and 8 o'clock on the print here. It is very subtle and is best seen by viewing the **print** from a distance: the features are definite on the plate. But these two opposite-rim **brightenings** are. in fact, connected to the ends of the bar, forming "massive" arms. The sense of the arm pattern is counterclockwise, moving from the outer tips inward through the disk. This asymmetry in the outer envelope luminosity distribution is the reason for the transition classification of SI30/a rather than simply SBO.

NGC 3300 SB03/a
CD-1711-S <VE,L,0)
Jan 6/7, 1981
103aO
75 nún

The bar in NGC 3300 is well defined; the bar subtype is therefore SBO3. The long axis of the bar makes an angle of about 70° to the major axis of the low-surface-brightness disk, seen well in the main print. Smooth, massive, ill-defined spiral arms exist in the disk starting **from** the ends of the bar. This form, where the arms start from the ends of the bar, is close to the SB(s) subtype of barred spirals whose prototype is NGC 1300 (Hubble Atlas, p. *45:* panels 154, S8 here).

NGC **5861 SBa**
PH-7623-S (E,I,0)
April 27/28, 1979
103aO
10 min

The stubby, **high-surface-brightness** spiral arms emerging from the central bulge/bar in NGC 5864 are similar to but are better formed than those in NGC 4856 (at the lower left on this panel), seen more nearly face on than NGC 5864, here. The rudimentary spiral pattern in NGC 5864 is similar to that in NGC 4429 (SO^/Sa: panels 60, S2), where the symmetrical smooth, bright arm segments can be traced at high surface brightness for about one-quarter revolution after emerging from the bulge.

The bulge is the bar in NGC 5864. It is inclined by about 50° (lower left to upper right in the print here) to the major axis of the faint external disk. The disk extends beyond the turning point of the bright arms that appear as ansae. It can be traced to the borders of the print at the upper left and lower right, and can best be seen by viewing the print from a distance.

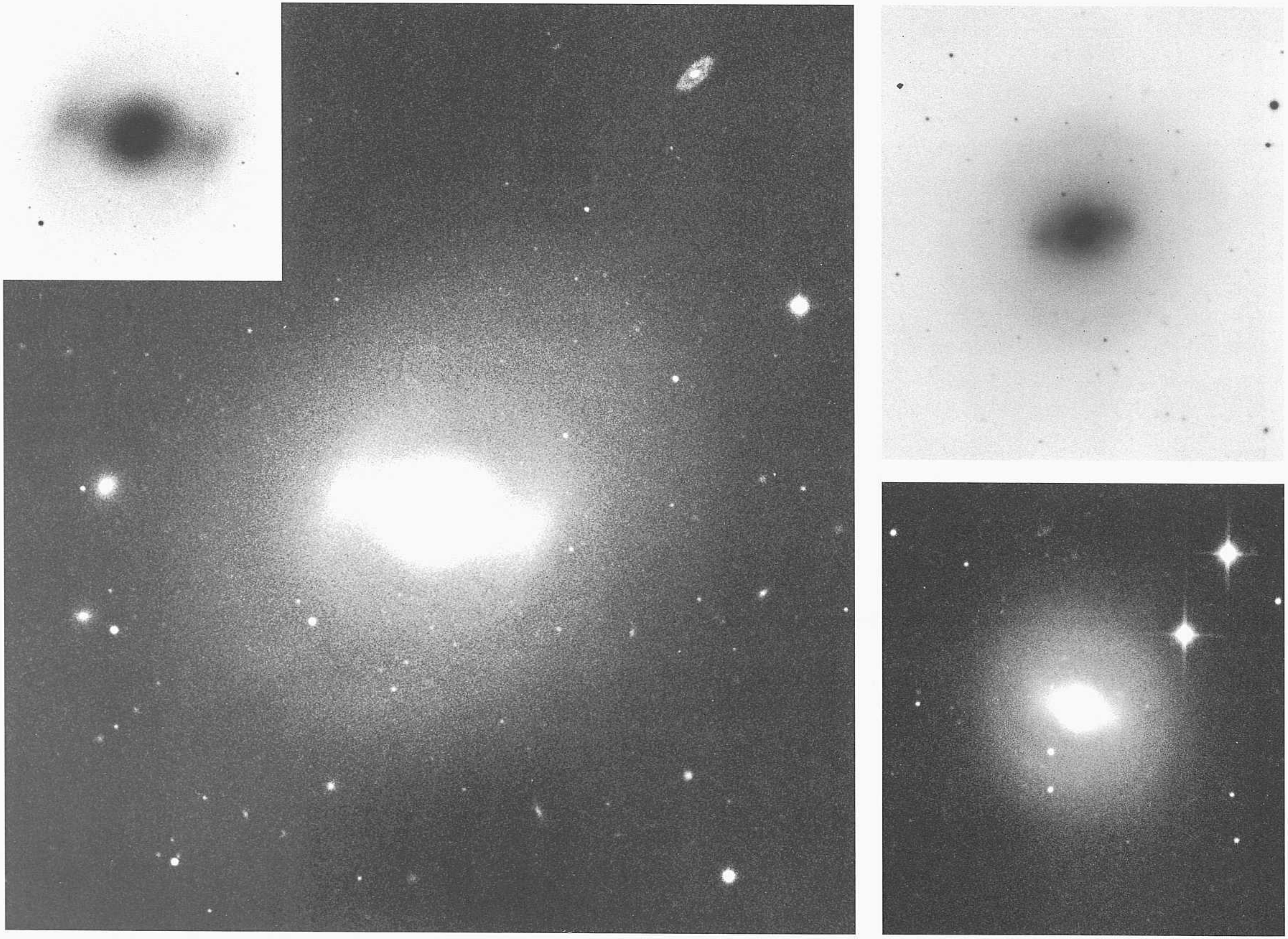
NGC 3637 **RSB0$_2$/3/SBa**
CD-1461-S/Br (VE,L,0)
May 10/11, 1980
103aO + GG385
45 nún

NGC 3637 forms a pair with NGC 3636 (E0. not in the RSA) at a separation of 3.9'. The redshift of NGC 3637 is v_0 = 1625 km s"^{1}. If the pair is at the same redshift distance of 32 Mpc {*H* = 50), the projected linear separation is small, at37kpc.

The well-defined bar ends at the edge of the disk (called the lens in the Hubble Atlas). The bar is nearly burned out at the high contrast used here to show the faint outer region. The orientation of the bar is from the lower left to upper right in the print.

A very-**low-surface-brightness** outer structure appears to be a detached external ring, based on the POSS prints. In the print here when viewed from a distance, the feature is seen to be two segments of massive spiral arms that attach to the inner region at position angles **of** about 3 and 9 o'clock. The unwinding of these smooth arms (in a counterclockwise direction from the center **outward)** creates two regions **of** low luminosity **between** the arms and the inner tlisk. The maximum contrast in the surface brightness of the region between the outer semi-ring (the arms) **and** the rim of the disk occurs at position angles 4 and 10 **o'clock,** nearly at right angles to the **bar. These** regions of lowest intensity, caused by **the effect** of **the** bar potential, have **previously** been **described** for galaxies in the SBO section. It will **be** described extensively on **panels** 100—104 in the next section. NGC 3637 is the earliest galaxy **of** this type in the RSA.

PANEL
90



NGC 936 SB0$_2$/3/SBa group
CD-494-S **(VE,L,O)** **panels 106, S9**
Sep 26/27, 1978
103aO + GG385
45 mill

Tlie liar ends well inside the edge of the disk in all three galaxies on this panel.

Spiral features thread through the disk of NGC 936. They are gem-rally diffuse and ill-defined. The arms are massive, smooth, and in-definite, similar to the pattern in the very early galaxies in the Sa section (e.g.. NGC 2655. Sa pec. panel 62; NGC 268 1. Sa. panels 62. 87 here. Hubble Atlas, p. 9; NGC 6340. Sa. panel 62).

A photometric and kinematic study of NGC 93 6, the prototype of the SBO/SBa mixed form, was made by Kormendy (1983). He compared his observational data with the early theoretical models for the expected velocity fields of barred galaxies made by Miller and Smith (1979) and by Hohl and Zang (1979).

NGC 936 is in a group with NGC 941 (Scd; panel 315) at 12.6' separation, an Anon (SBcd that resolves into III I regions at the same level as NGC 941) at 14.2', NGC 955 (Sb nearly on edge: panel 150) at 44', and several dE and Im dwarf candidates. The mean redshift of the group is $<v_o>$ = 162 3 km s^{-1} . The projected linear separations from NGC 93 6 are 120 kpc for NGC 941, 135 kpc for the Anon, and 415 kpe for NGC 955. This loose group is about half the size of the Local Group.

NGC 4477 SBO]/2/SBa VCC 1253
CD-724-S **(VE,L,0)**
Feb 1/2, 1979
103aO + \Vr2c
60 niin

The bar in [NGC 4477 terminates well inside the full extent of [he disk. Tin' indistinct, ill-defined spiral pattern that threads the disk is similar to the patterns in fvCC 265 5. NCC268 I . and NGC 6340 on panel <>2 of the Sa section.

The galaxy is near the center ol' Virgo Cluster subcluster A thai is associated with NGC 4486.

NGC 1533 SB0$_2$(2)/SBa
CD-1290-S/Br **(VE,L,0)**
March 10/11. 1980
103a() + GG385
45 niin

NGC 1 533 has the same pattern as the other two galaxies on this panel. 'Flu' luminous, noi-quite-circular, nearly opposite are fragments near the edge of the disk are the reason lor the SBO/Sa mixed classification.

The SBa Classification Section

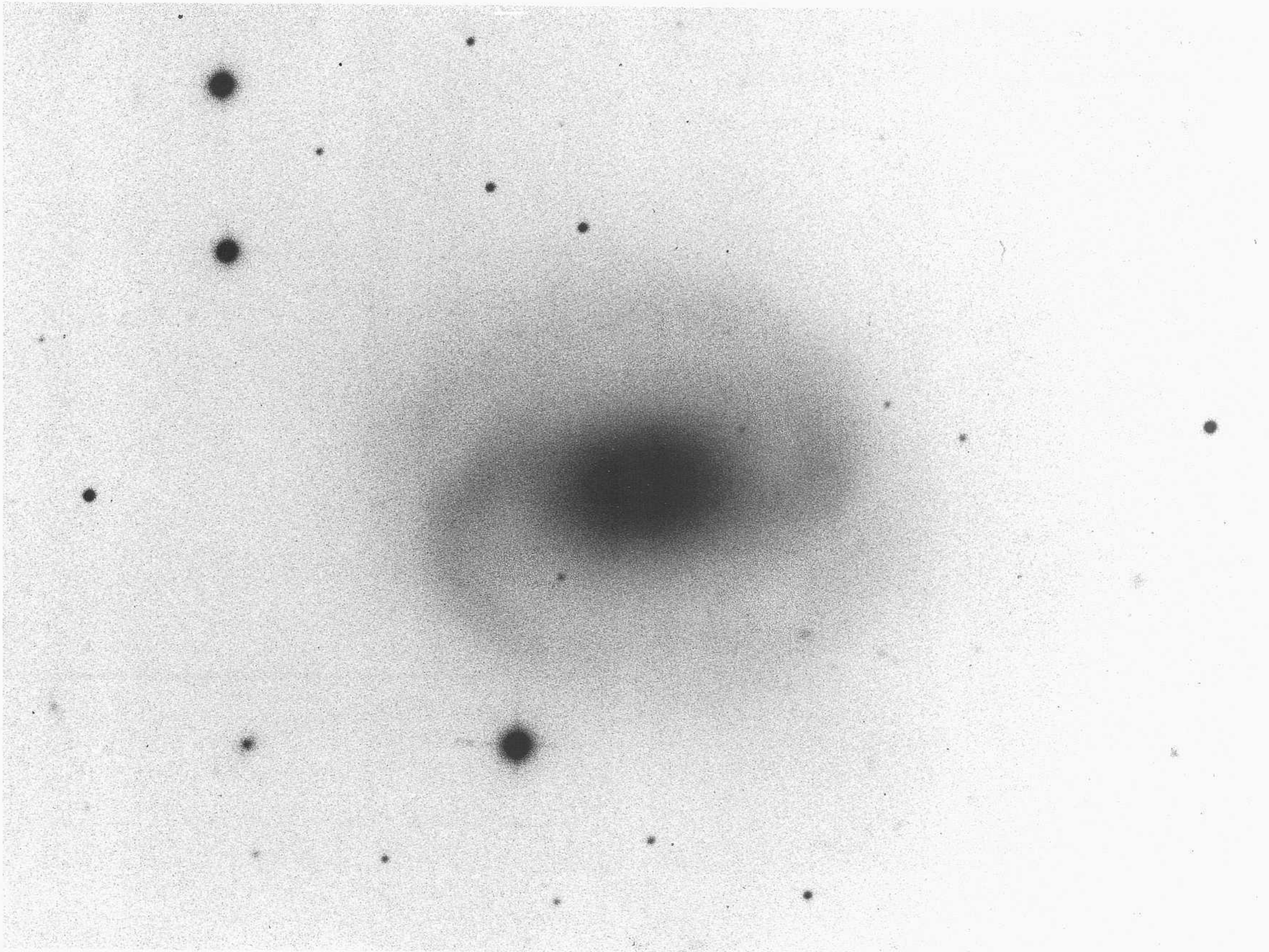
NGC **7743** SBa panel **106**
PH-769-S **(VE,L,0)**
Aug 23/24, 1954
103aD + **GG11**
45 min

NGC 7 743 is the prototype of smooth-armed **SBa** galaxies. Such spirals, including those in the Sa section (SO/a, panels 59. 60. 61-65). are generic to the classification sequence (Sandage 1983 a). They are not products of environmental processes such as gas-sweeping in the harsh environs of cluster centers. NGC 7 743 is isolated in the general field.

The arms, although tightly wound, are not tight enough to form a complete ring. The pattern has been discussed for Sa galaxies on panels 66-7 1.

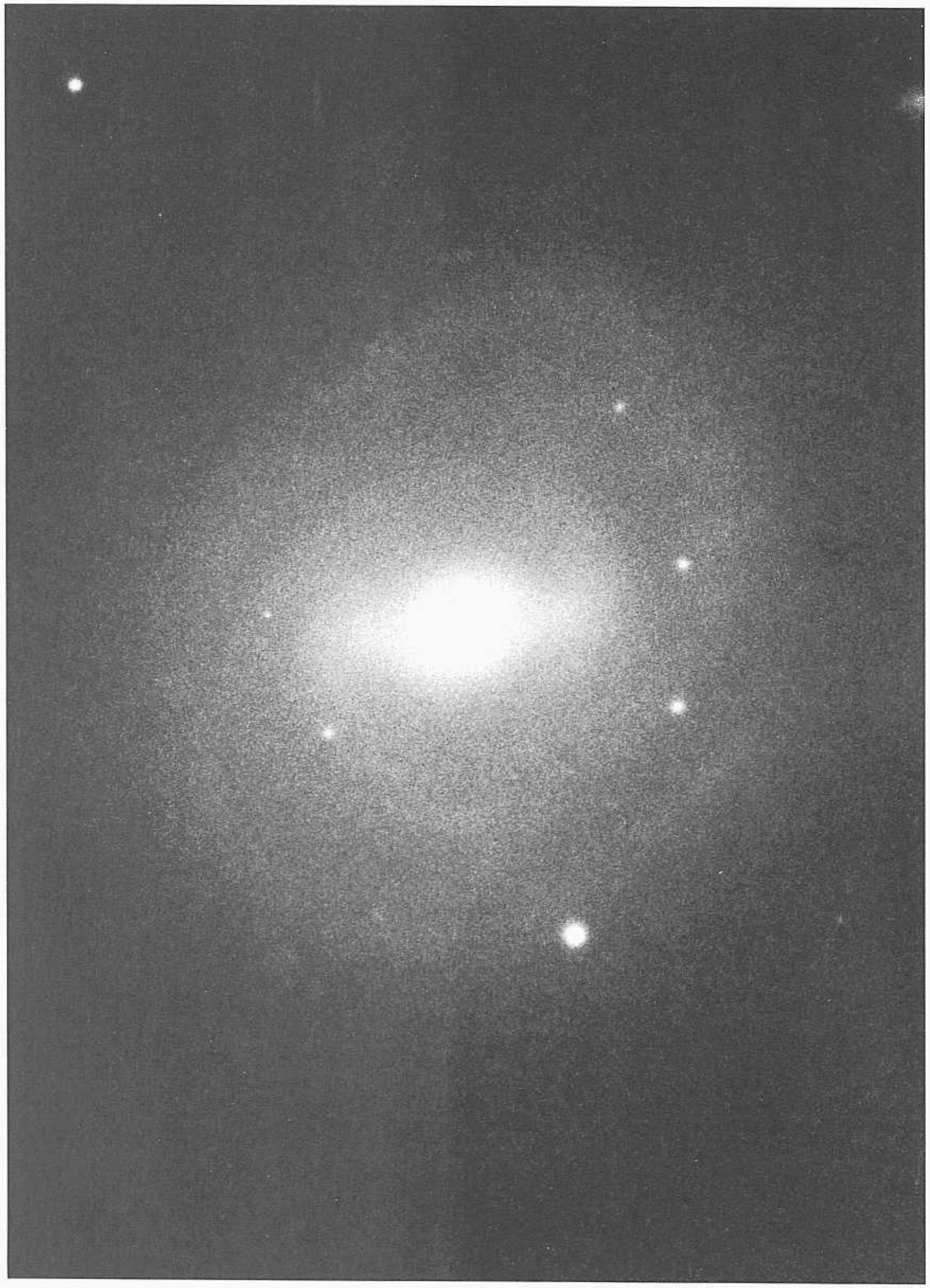
The colors of the smooth arms are red (Kennicutt and Edgar 1986). showing the absence of recent star formation. The same is indicated by the smoothness of the arms and the lack of HII regions in them. Mow. then, can old arms survive in the absence of gas. either to make shocks in a density-wave picture for the formation of spirals, or to make new stars in a stochastic-formation picture where the differential velocity field makes the arms? Gas is needed in both pictures.

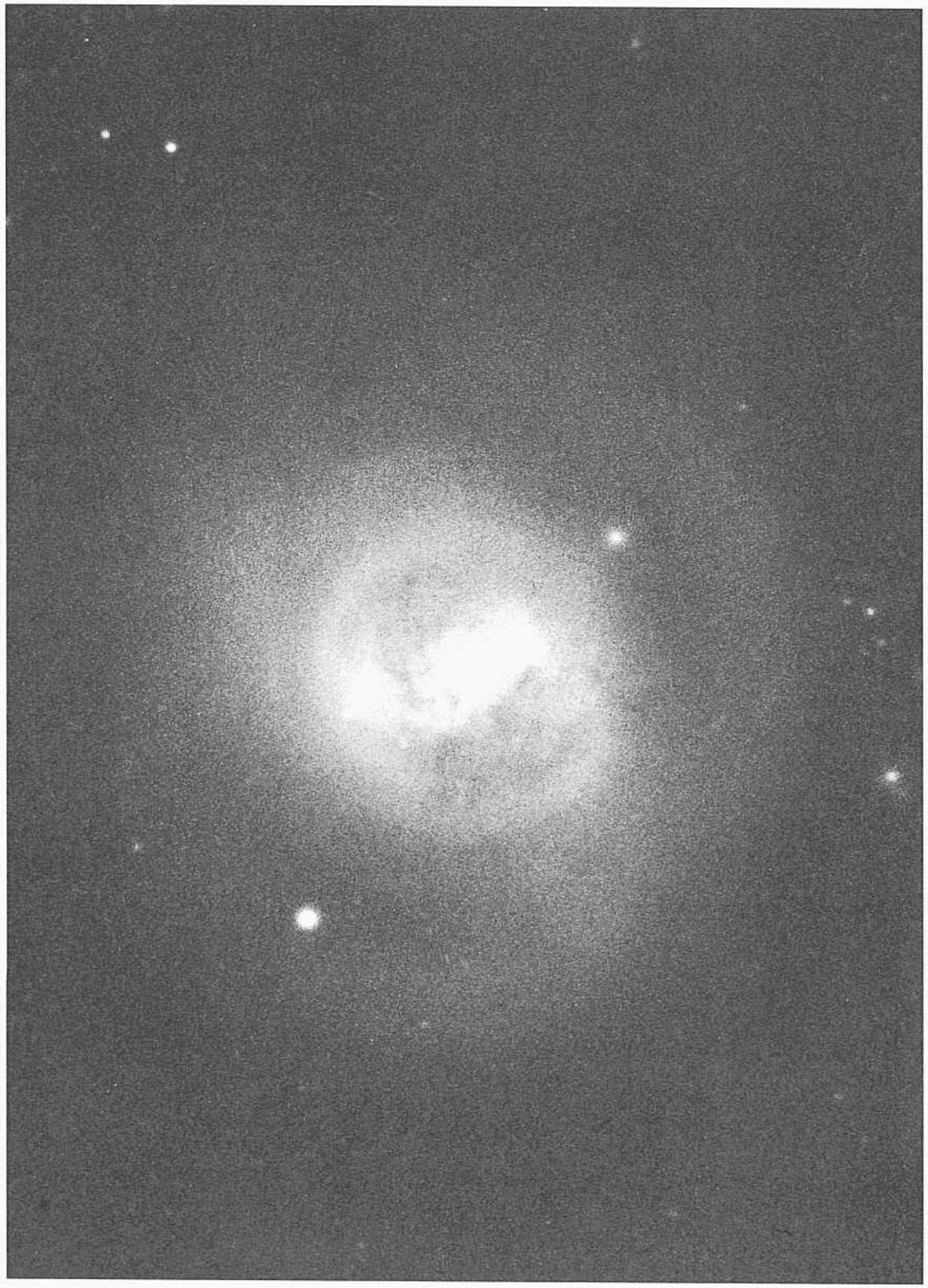
The arms in NGC 7 743 start from the ends of the bar which emerges from the central bulge. The pattern is the earliest example in the **RSA** of the (s) bar type, whose prototype in the middle of the spiral sequence is NGC 1300 (Sb: Hubble Atlas, p. *45:* panels 154. S8 **here).**



PANEL
91

PANEL
92





NGC **6942** **SBa(s)** **panel 106**
CD-1047-Br **(E,I,0)**
July 22/23, 1979
103a0 + **GG385**
35 min

The smooth, massive spiral arms **throughout** the disk of NGC 6942 are definite, **although they** are less **distinct** than in NGC 7743 on **the preceding** panel. The pattern is that of a two-**armed** spiral **with** arms starting **from** the **end** of **the bar, unwinding counterclockwise** as one moves **outward.**

Each arm can he well traced for about 1 1/4 revolutions, almost **overlapping** after each has **unwrapped** by **about** half a **turn. A total wrap** of 450°. as here, is unusually **Large.** However, the arms in NGC 7096 (Sa; panels **68,** 88. S3), **including their** very faint outer parts, **can** also he traced for about 1 1/2 revolutions.

Because of (1) the massiveness of **the** arms. (2) the large wrap and the **overlap of** the arms, and (3) the tightness of the wind, the disk **appears to be filled** with the arms. This **appearance** is similar to that seen in the early Sa galaxies NGC 2655. NGC 2681. and NGC 6340 on panel 62 in the Sa section.

The disk filled with arms causes spiral galaxies in these earliest sections of the Sa and SBa morphological boxes often to be **misclassified** as SO or SBO on low-resolution plates; the arm structure is usually smeared away. The classification of NGC 6942 as SBO in the RC2, based on a Mount Stromlo 30-inch plate, is **inappropriate.** The galaxy is a prototypical SBa, albeit very early **in** the SBa **morphological** box.

NGC 1022 **SBa(r) pec**
CD-560-S **(E,I/S,1)**
Oct 4/5, 1978
103aO + GG385
45 min

NGC **1022** bus **two outer very** smooth **spiral** arms **of** exceptionally **low** surface **brightness. They** can **be** seen in the facing **print** by **viewing the** image from **a distance** and moving **the head or eyes.**

The inner **arms** begin from the **periphery of an almost-complete** circular **ring of** high **surface** brightness. The ring itself, **however,** is **broken** and **forms** a very tight overlapping **bright spiral pattern** of the type often **discussed** in the **Sa** section of near-ring galaxies (Sa: panels 66-71).

The interior of the ring is filled with thin **dust** filaments **arranged chaotically** on either- side of a bright **bar-like center.**

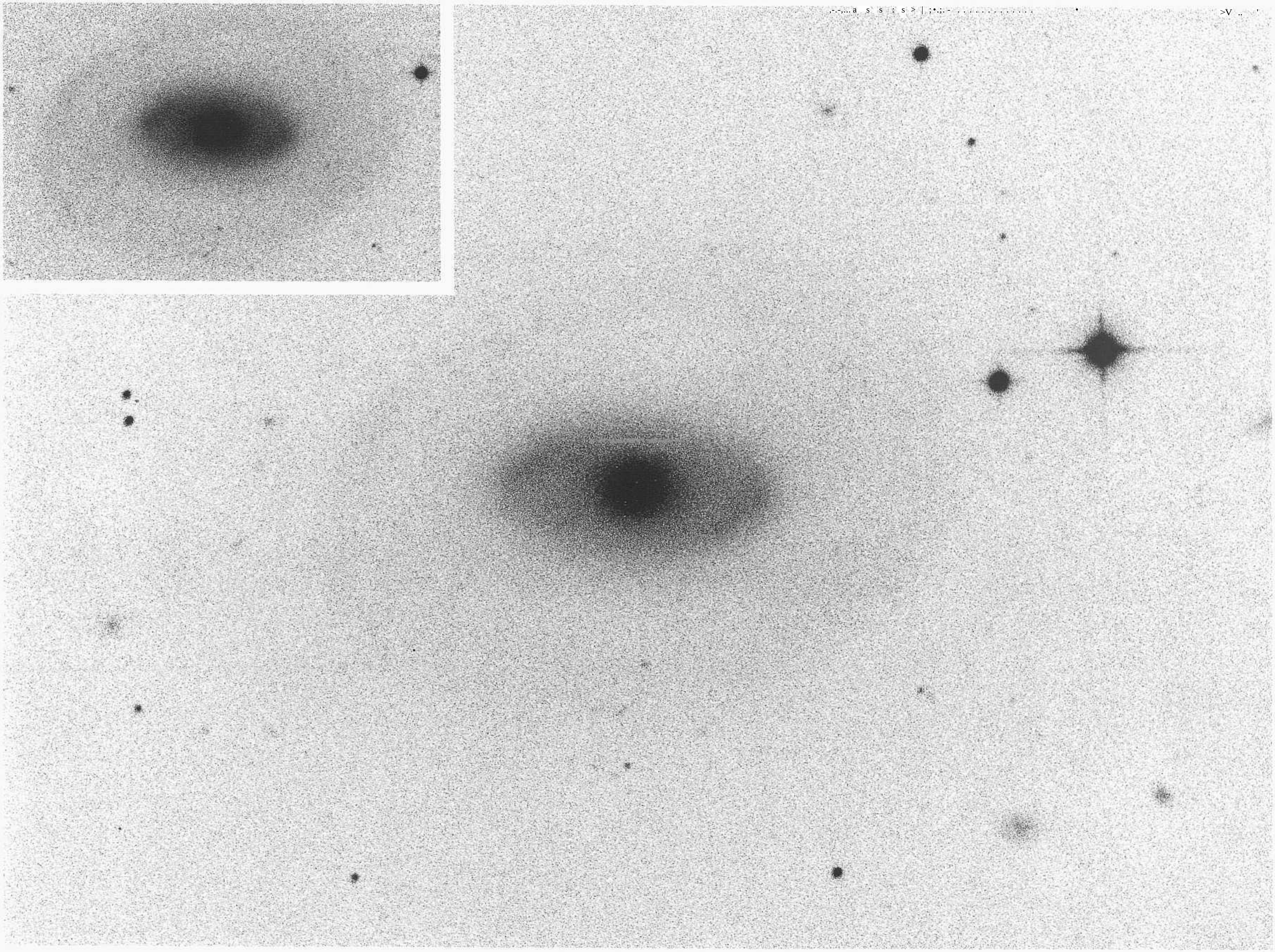
The **pattern** is unusual in combining a late-like bar **region** with smooth outer arms resembling **the** "tide-induced" **arms of** Sa **or** SBa galaxies that have been drawn out by an interacting companion, **for** example NGC 2992 (panel 85) and NGC 2798. NGC 4106. and NGC 4795 (SBO/a or SBa: panels 56. 105). **However, there is no** companion to NGC 1022: its outer smooth-armed structures appear to be generic to **the classification sequence.**

NGC 2962 RSB0_2/Sa
CD-1678-S (VE,I,O)
Jan 1/2, 1981
103aO + GG385
75 niin

The **symmetrical brightening** al two opposite places on the rim of the disk in NGC 2962 (called the lens **in** the **Hubble** Atlas) is the bar. defined by analogy with the clearer cases of the same pattern in NCC 3300 **(SB0_3/a;** panel 89). NGC 936 **(SB0_2/$_3$/SBa; panel 90), and NGC 2983** and NGC 2787 (panel 95).

The **very-low-surface-brightness** outer structure resembles a ring. However, as usual, it is a tightly wound set of nearly overlapping spiral arms having very-low-surface-brightness connections with the central regions, not easily visible in this print. The connections begin al the ansae, which are the two **brightenings** on the rim of the lens. These connections to the central, high-surface-brightness lens occur at position angles of about 3 and 9 o'clock. The connections at first are straight and then suddenly curve into a spiral pattern opening in a counterclockwise direction going outward.

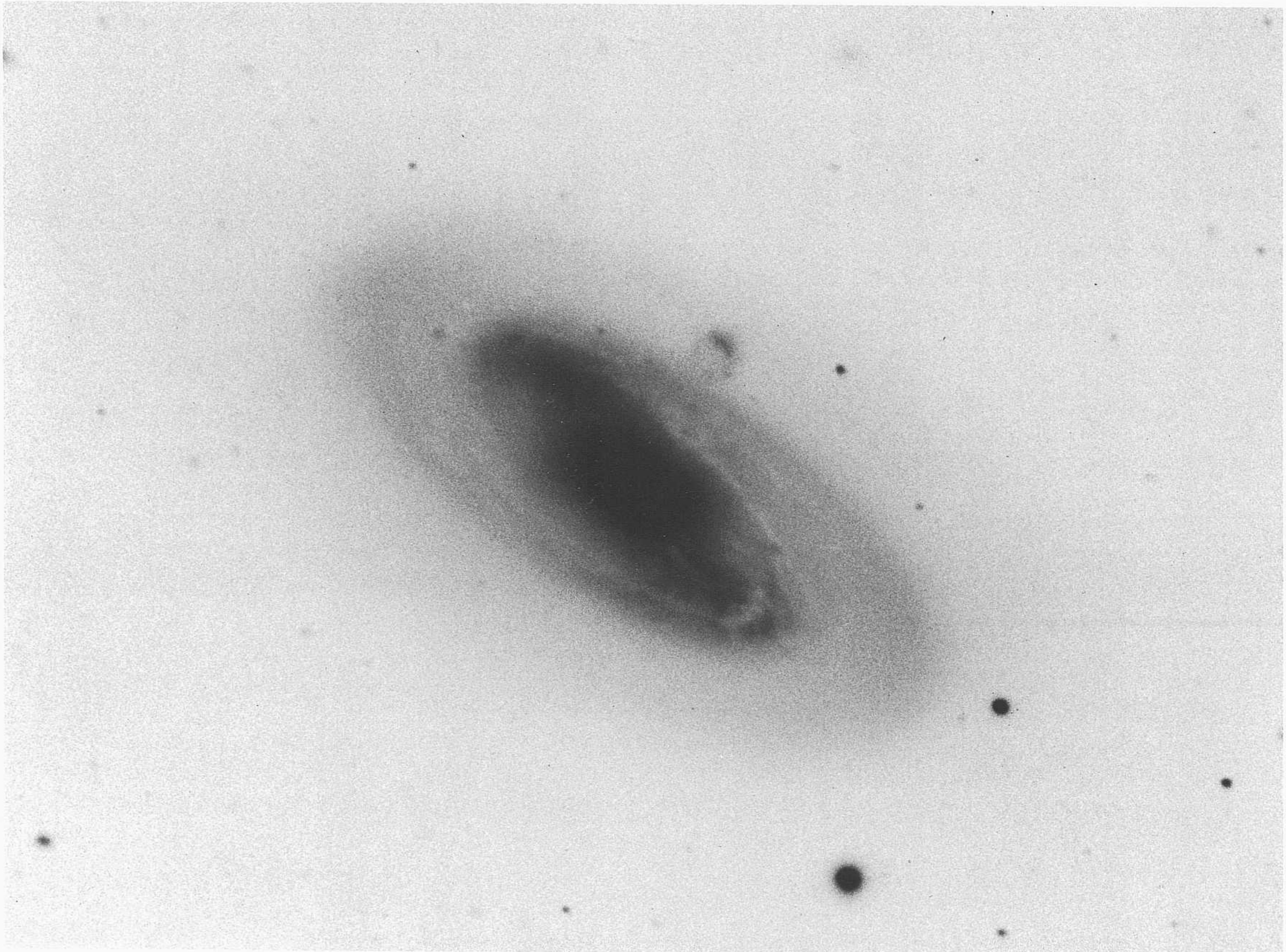
The pattern is the earliest example in this atlas of this type of connection of external spiral arms to the central disk (the lens). The **later** prototype example is the Sb galaxy NGC 210 (Sb; Hubble Atlas, p. *22:* panel 124 here). However, there is a set of inner, high-surface-brightness arms in NGC 210 that are embedded in a **high-surface-brightness** disk. But although no inner arms exist here, the set of outer arms resembles the outer arms in galaxies of the NGC 2 10 type. Galaxies with this morphology are said, on the following panels, to have the NGC 2 10 look.



PANEL

93

PANEL
94



NGC **4260** **SBa(s)** **VCC 341**
PH-7619-S **(E,I,l/4)**
April 27/28, 1979
IHaJ
60 min

NGC 1260 **is in the W Cloud region of the** Virgo **complex.** I is high **redshift,** v_o = 1806 **km** s^{-1}. **suggests** it **is at the greater distance of the W Cloud rather** than **that** of **the Virgo Cluster core.**

[NGC 4260 is one **of the prototype smooth-armed SBa's in the RSA thai have often been used in** discussions **of the origin of smooth-armed early-type galaxies (Sandage L983a). Are such galaxies generic to the classification sequence or are they** results **of environmental processes?** NGC **4260 is important for** the **question. The answer is seen** from **the fact that,** as **with NGC** 7743. NGC 6942. and **NGC** 1022 **on preceding** panels, NGC 4260 is not in **the Virgo Cluster;** it is moderately isolated and shows no evidence of environmental **effects** such as tides **by** a el use encounter. Its **smooth** arms must then **be generic** to the formation process for NGC 42 60 itself.

The **very-high-surface-brightness** central region **containing the bar** is burned **out in tin-**print here. The bar **itself** is **not** as well defined as in the prototype SBh **galaxy** NGC 1300 **(Hubble** Atlas, p. ***45;*** **panels** 154. S8 here), **but** NGC 4260 has bright asymmetrical parts that resemble bright massive **spiral** stubs, **the** most prominent of **which** is seen here **to the upper** left of the bright central bulge.

Well-defined dust lanes exist on the inside edges of the **outer smooth** arms.

Galaxies on this page continue the development of the SBa(s) type begun on the preceding several panels. In this SBa(s) subclass the arms begin at the ends of the bar rather than tangent to an internal (usually broken) ring. These galaxies compare with the (r) spiral subclass.

IC 346 SBO$_2$/a(s) N1400Gr#85
CD-1601-S/Br (E,I,O) notiiiRSA
Aug 12/13, 1980
103aO + GG385
75 **min**

IC 346 is in the NGC 1400 Group whose eponymous member (NGC 1400: SO3) is shown on panel 43 . The group also contains NGC 1452 (SBa; panels 97, 107).

The moderately diffuse bar in IC 346 ends on the rim of the disk. Two stubby smooth-armed segments appear at the ends of the bar and therefore on the rim of the disk as well. The pattern is similar to the ansae seen in NGC 2 787 (below on this page and on panel 5 7), where the stubby-arm pattern also begins on the rim of the disk.

NGC 2787 SBO/a(s) not in RSA
PH-7588-S (VE,L,0) panel 57
April 2/3, 1979
IllaJ + GG385
30 min

NGC 2 787 is also shown in the SBO section SB0/a: panel 57) in a print made from the same plate used here. The ansae at the ends of a diffuse bar emerging from the flattened central bulge terminate on the rim of the disk (called the lens in the Hubble Atlas). The pattern is similar to that in IC 346 above.

NGC 2983 SBa(s)
CD-644-Br (VE,L,0)
Jan 4/5, 1979
103aO + GG385
45 min

This remarkable galaxy is one of the earliest true SBa spirals in the section. At first glance, the bar appears to terminate inside the disk, as in the pattern described on preceding panels, first mentioned in the description to NGC 3941 (SBOi/2/a: panel 89). As described there, other galaxies with the pattern of a bar ending inside the disk include NGC 93 6, NGC 15 3 3, and NGC 4477 (panel 90), NGC 6942 (panels 92, 106), and NGC 7155 (panel 5 6).

But the first glance is not correct. Bright, stubby beginnings of arms start at the ends of the bar. These stubs, however, stop almost immediately. But the arms continue as smooth, diffuse (massive), low-surface-brightness luminous "sweeps" which become the disk and have a twofold reflection symmetry: i.e., they are two diffuse spiral arms, covering most of the disk. These arms appear to form the rim of the disk **but,** in Fact, they form a spiral pattern: each diffuse "sweep" attaches to the ends of the bright ansae (the stubs) at the ends of the bar.

Note the description of the rims and the tucked-in disk at the ends of the bar of NGC 1440 (SB0j/$_2$/a; panel 57). The pattern here is similar except the very smooth massive arms are better defined here. There is no doubt that the type of NGC 2 983 is very early SBa.

The correct typing of this galaxy is impossible on low-resolution or small-scale plates. Although the outer disk would be visible, the diffuse spiral pattern beginning at the ends of the bar would not. The SBO (late) classification in the RC2, based on a Mount Wilson 100-inch plate, is not supported here.

NGC 4245 SBa(s)
PH-7578-S (1,1,1/3)
April 1/2, 1979
103aO + GG385
10 min

NGC 4245 is an early example of a galaxy form that has caused much confusion in the literature and has led to unwarranted conclusions concerning dynamics of rings and pseudo-rings. Except for the bar, the form for NGC 4245 here is the same as has been described in the Sa section, where the near-ring galaxies have been set apart on panels 66—71.

Spiral arms spring from the ends of the bar in a manner similar to that in the SBb(s) prototype NGC 13 00 (Hubble Atlas, p. 4.5; panels 154, S8 here). But the arms here are so tightly wound and the inclination to the line of sight is so great that the two opposite arms appear to almost overlap after each has unwrapped by a half turn.

On casual inspection this near-overlap appears to be a complete ring. Sometimes, when the pattern is less subtle than here for NGC 4245 or for the closely similar case of NGC 5750 (SBa; panel 98), the pattern has been called a broken ring. Examples of these less-subtle cases are NGC 3081 (SBa; Hubble Atlas, p. *11;* panels 99, 107 here), NGC 2217 (SBa; Hubble Atlas, p. *43;* panels 101, 104, 107 here), and NGC 3185 (SBa; Hubble Atlas, p. *43;* panel 99 here).

These examples are of the (s) NGC 1300 spiral subtype. None have internal rings, broken rings, or pseudo-rings. The distinction, of course, is difficult to make on low-resolution plate material. When using such material, the finer subclassifications of (s) and (r) will often be spurious.

NGC 441 SB0$_2$(r)/a NGC 439 Gr
CD-1147-Br (E,L,0) not in RSA
Aug 21/22, 1979
103aO + GG385
45 min

NGC 441 is the second-brightest member of a moderately rich group of at least 15 giant members and a number of dE dwarf candidate galaxies. The brightest member of the group is NGC 439 (E5: panel 12), with redshift of v_o = 5650 km s^{-1}. The angular separation of NGC 439 and NGC 441 is 2.5', giving a projected linear separation of 82 kpc *(H* = 50).

The bar in NGC 441 is well formed. It ends on an internal ring from which the faint external spiral arms originate.

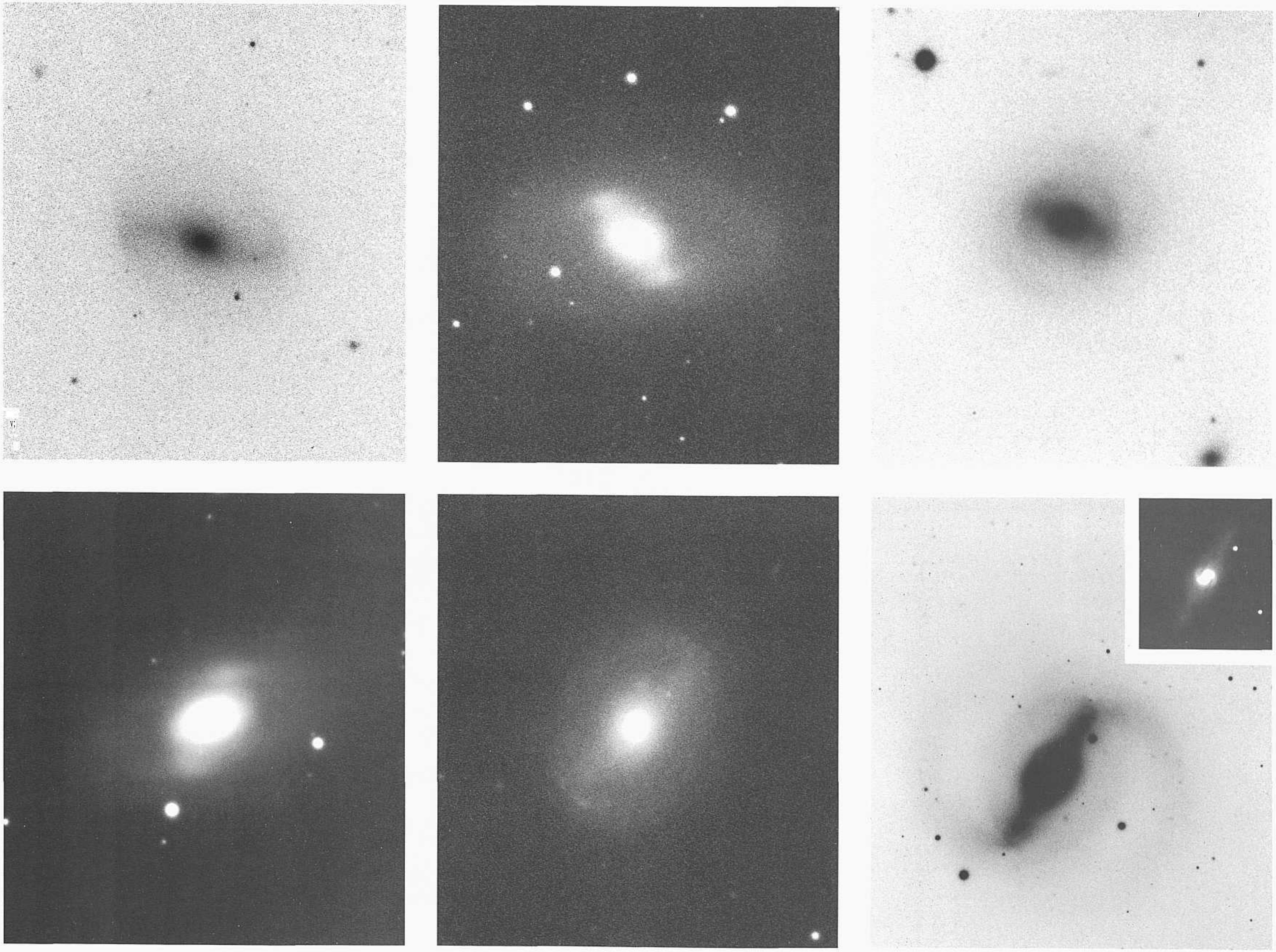
NGC 4314 SBa(rs)pec HA, p. *44*
PH-192-MII (E,L,0) panel 106
May 13/14, 1950
103aO
30 nun

NGC 4314 insert
H-534-H
Jan 31/Feb 1, 1925
E40
45 min

NGC 4314 is peculiar because of the internal structure in the bar, shown in the insert. The main print is from the same original 2 00-inch plate used in the Hubble Atlas (p. *44),* but the insert is from a different original Mount Wilson plate.

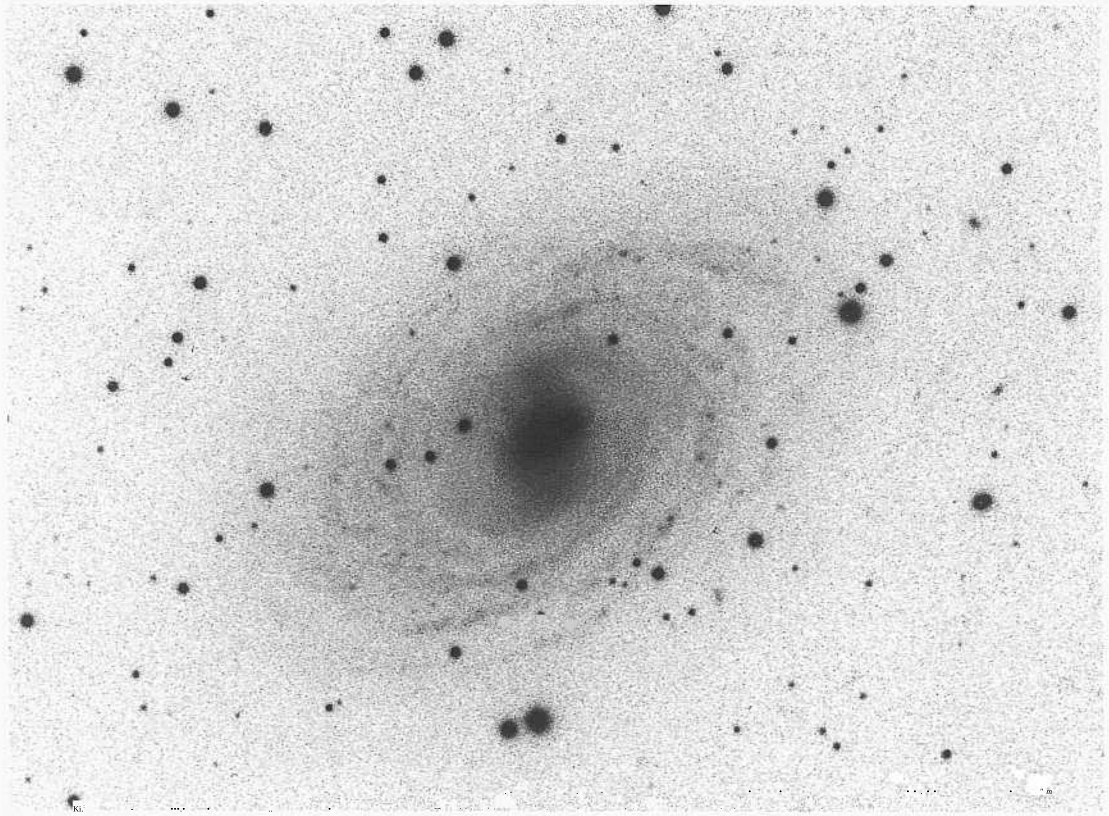
The well-defined bar terminates at the edge of a low-surface-brightness disk. Smooth, low-surface-brightness arms begin from the ends of the bar in the (s) subtype pattern whose prototype is NGC 1300 (SBb: Hubble Atlas, p. *45;* panels 154, S8 here).

The high-surface-brightness spiral pattern within the bar and the central bulge is not connected with the external arms. The sense of the spiral wrap is the same for both the internal and external sets of arms. Knots within the arms of the central spiral show that recent star formation is occurring there. A few dust patches exist in the bar, but otherwise the intensity distribution is as smooth as that of the disk and the outer arms. The age of the stellar populations there is old.



PANEL
95

PANEL
96



NGC 5377 SBa orSa
PH-7580-S (U,l/2)
April 1/2, 1979
103aO + GG385
13 niiii

The central regions of NGC. S377 consist of a bulge, a moderately high .surface brightness disk viewed at a high inclination angle, tightly wound luminous spiral arms seen most easily on the near side of the disk, and dust lanes silhouetted against the bulge and disk on the near-side.

The unusual feature is the set of outer, smooth, very-low-surf *a re-bright ness arms thai emerge from the edge of the disk at position angles of about 3 and 9 o'clock in the orientation of the print here, not well seen in this low-contrast print. The pattern has been described in the paragraphs on NGC 2962. panel 93. The form in NGC 5377 here is an earlier example of the two-armed pattern whose prototype is NGC 210 (Sb; Hubble Atlas, p. *22:* panel 12 I here).

An excellent match to the morphology of NGC 5377 (including the central dust pattern) would result if the surface brightness of tin[1] outer arms in NGC 210 were reduced and if the star-formation rate at the edge of its inner disk were slightly increased. Because the outer arms in NGC 5377 are smooth and faint, this galaxy is the early-SBa (the disk is the bar?) or early-Sa prototype of the NGC 210 form.

NGC7410 SBa or Sa
CD-492-S (I/L,L,1)
Sep 26/27, 1978
103aO + GG385
45 nun

The bright stubby arm segments in the center of NGC 7410. shown in the insert, are later manifestations of the similar but more-rudimentary pattern in NGC 5864- (SBa; panel 89). NGC 4429 ($S0_3$/Sa pec; panels 60, S2) and NGC 4425 (SB0 pec or Sa pec: panels 57. 60). These two internal bright structures are either the bar. by analogy to the bright ansae that are the bars in earlier types (e.g., NGC 2787 and others mentioned on the preceding page), or they form a set of smooth stubby internal ordinary arms, in which case the morphological type of NGC 7410 is Sa.

The outer arms form a multiple-armed pattern (the MAS type) with many dust lanes threading the disk.

NGC 1169 SBu(r)I **panela 106, S9**
PH-7533-S (I,ML,1)
Nov **1/5,** 1978
l03aO + GG13
1 5 mill

The smooth low-surface-hright ness bar (vertical in th<' orientation of the lacing print) ends at the edge of the low-stirface-brightness smooth disk in NGC 1169. The multiple-armed spiral (MAS) pattern emerges from the edge of this disk.

The arms are slightly lumpy, having small faint Illl regions. Tin- redshift al v_Q « 2614 km s^{-1} precludes identification <(these lumps as individual stars: the brightest appear at apparent magnitude B = 22, which at a distance modulus of m - .1/ = 33.6 (// - 50) gives absolute magnitudes of .17 - -I 1 .6. This is brighter than the brightest known stars.

NGC 1169 is aboul midway in the SBa morphological box between the early and the late edges of the SBa section.

NGC 7371 SBa(r)Il panels 106, S12
CD-501-S (L,L,l/2)
Sep 27/28, 1978
I03a0 + GG385
15 min

NGC 737 I is a later SBa than NGC I 169, above, but is of the same subtype. The same description closely applies.

The bar is weak (nearly horizontal in the orientation of this print). It terminates near the edge of a low-surface-brightness disk, tangent to which the multiple-spiral-armed pattern begins. The arms are full of 1111 regions. The galaxy is near the late edge of the SBa morphological box, close to the SBab boundary.

Galaxies on this and the next seven panels have the common feature of an internal ring that is either complete or nearly so, as in NGC 7079 and NGC 1452 on this panel, NGC 3783 on the next panel, and IC 5240 on the panel after. The "ring," although apparently complete when seen on low-resolution plate material, is, as described before, formed by two tightly wound overlapping arms, as in NGC 5750 (panel 98) and NGC 3081 two panels hence; it is not a ring at all. The descriptions for NGC 3081 and NGC 5750 detail the prototypes of this form.

NGC 7079 **SBa**
CD-1105-Br **(VE,L/I,O)**
Aug **18/19, 1979**
103aO + GG385
45 inin

NGC 7079 shows the earliest of the form where the central bar is evident and the external spiral arms are developed into a multi-armed spiral pattern (the MAS subtype) of the (r) type where the arms emerge tangent to the edge of a disk. The "ring" here is the rather **sharp** division between the central and the outside regions. The division may be subjective: a measured luminosity profile is needed.

The insert print shows the presence of the type of bar where the two ansae that are attached to the central bulge define the bar. (Note here that the orientation of the central bulge differs from the position angle of the outer disk—the twist is continuous from the center outward.)

A rudimentary multiple-armed spiral pattern exists in the outer envelope which is identified here as the disk. Part of the spiral pattern is defined by a thin dust lane, seen on the right side of the image in the outer disk which is well visible on this print.

NGC **6684** SBa(s)
CD-16-D **(E,L,0)**
Aug 7/8, 1977
103aO + **GG385**
60 min

The outer arms of NGC 6684 define the double-gamma pattern described for NGC 7702 (RSa: panel 66). The central bulge is of type E1. The bar is definite on the original plate, seen from lower right to **upper** left in the orientation of the facing print.

The two arms spring from the ends of the bar in the (s) arm subtype. They meet after each unwraps by half a turn to form the inverted **double-gamma** pattern.

NGC 357 SBa
PH-7543-S **(VE,I/L,0)**
Nov 6/7, 1978
103aD + GGll
25 min

The bar in NGC 357 is defined by the two opposite ansae, which are tenuously connected to the central bulge by a faint bridge on either side of the bulge. Smooth, faint spiral arms spring from the ends of the ansae to form an almost convincing outer ring. However, the impression is subjective: the ring is not complete. The arms **spiral** outward in a smooth-armed configuration.

NGC 4608 **$SB0_3$/a** **VCC 1869**
CD-1319-S/Br **(E,L,0)**
March 12/13, 1980
103aO
75 min

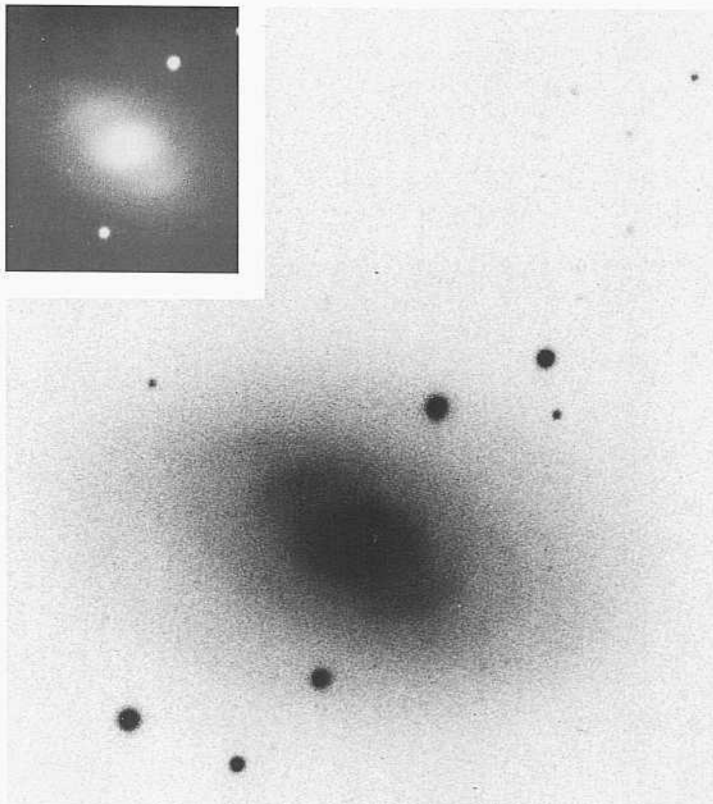
NGC 4608 is in the Virgo Cluster between subclusters A and B (Binggeli, Sandage, and Tammann 1985: Binggeli, Tammann, and Sandage 1987). The bar is very well defined. It ends on a complete ring, inside of which the surface brightness is lower than immediately outside. Faint, non-circular structures outside the ring account for the mixed SBO/a classification.

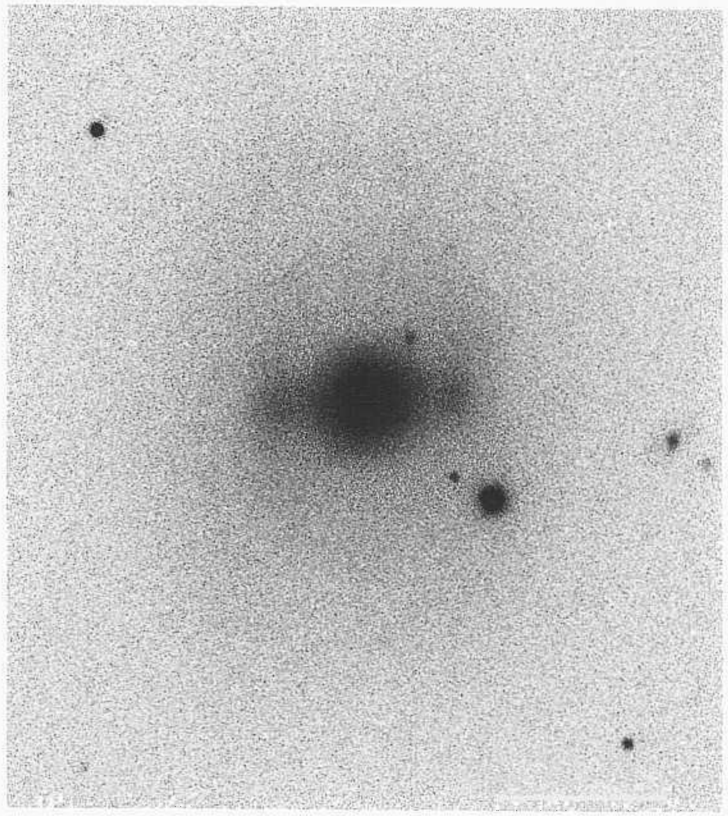
NGC 4643 **$SB0_3$/SBa** **HA, p.** ***42***
PH-688-S **(E,L,0)** **panel 107**
Feb 9/10, 1954
103aO + **Wr2**
30 min

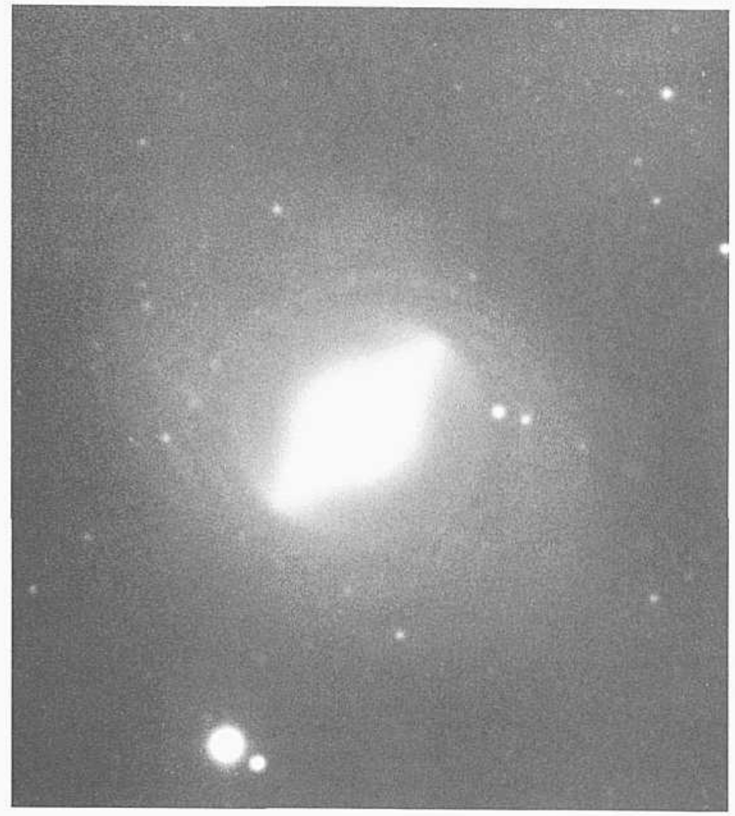
NGC 4643 is nearly identical to NGC 4608 at the left below. The description there applies to NGC 4643 as well.

NGC 1452 **SBa(r)** **panel 107**
CD-208-S **(E,I,0)**
Feb 10/11, 1978
103aO + **GG385**
45 **min**

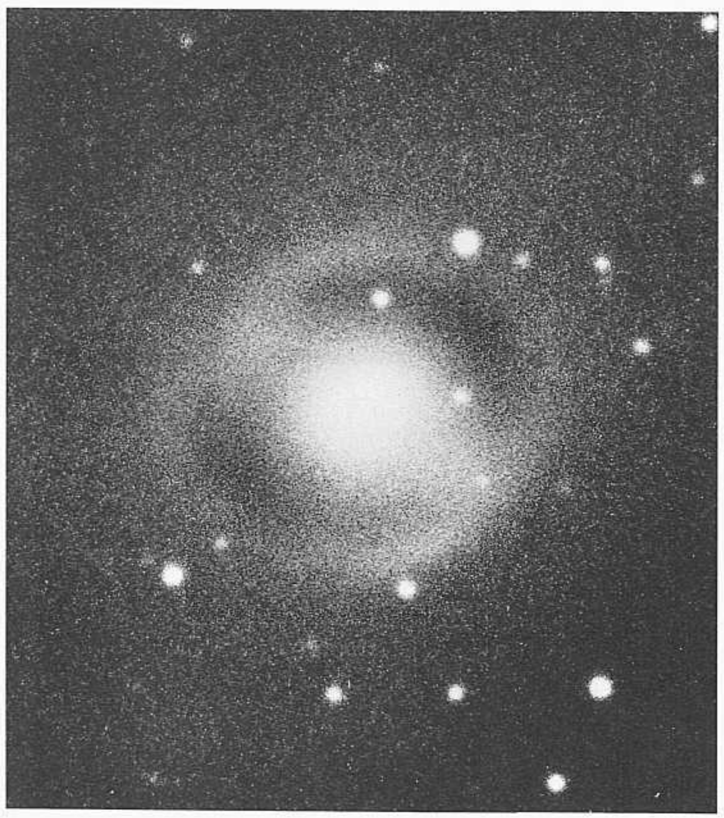
NGC 1452 is similar to NGC 357, NGC 4608, and NGC 4643 on this panel. The spiral structure that begins tangent to the ring upon which the bar terminates is of higher surface brightness and is better defined than in either NGC 4643, above, or in NGC 4608 to the left. The type is SBa beyond doubt. The type of PSBO in the RC2, based on the POSS prints, is inappropriate.

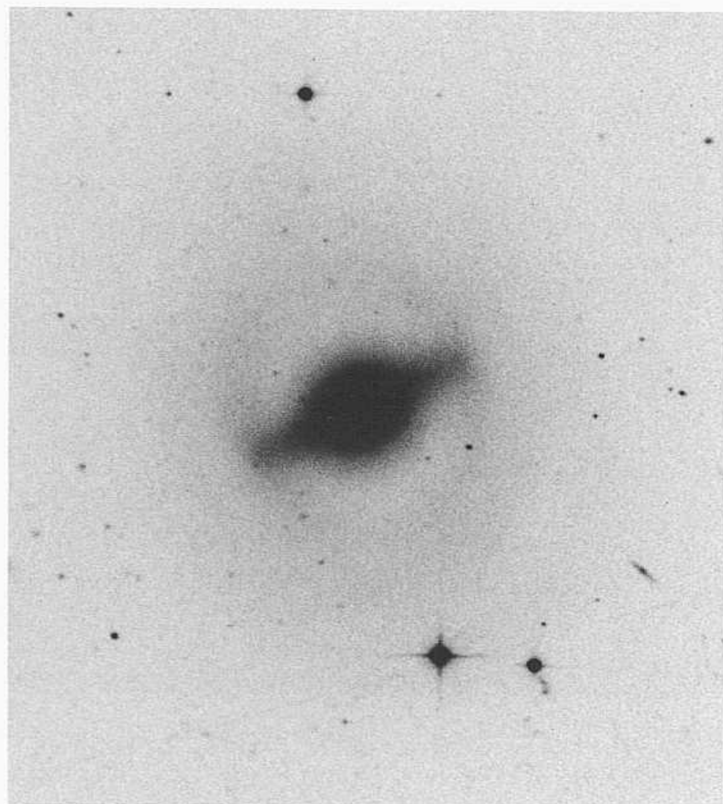


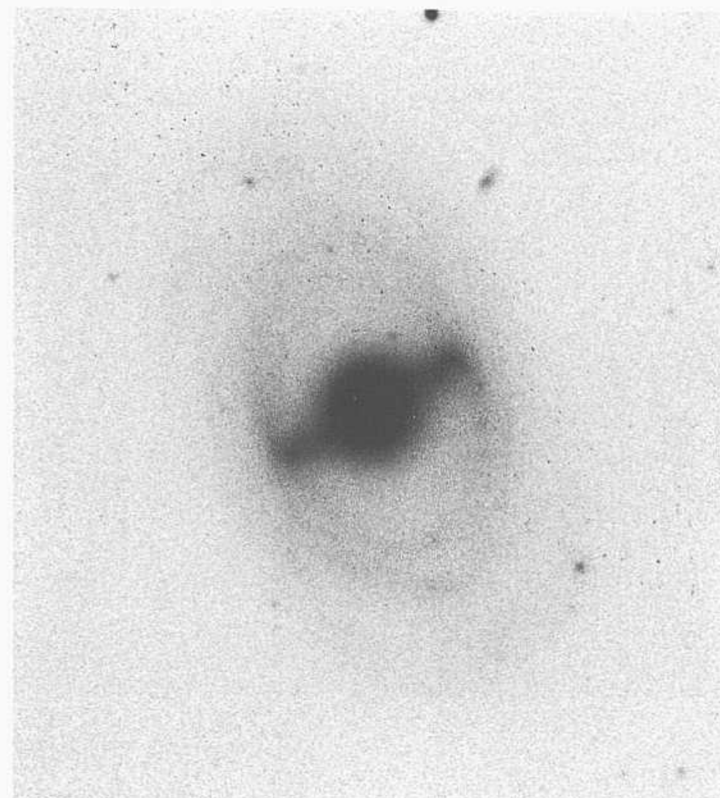




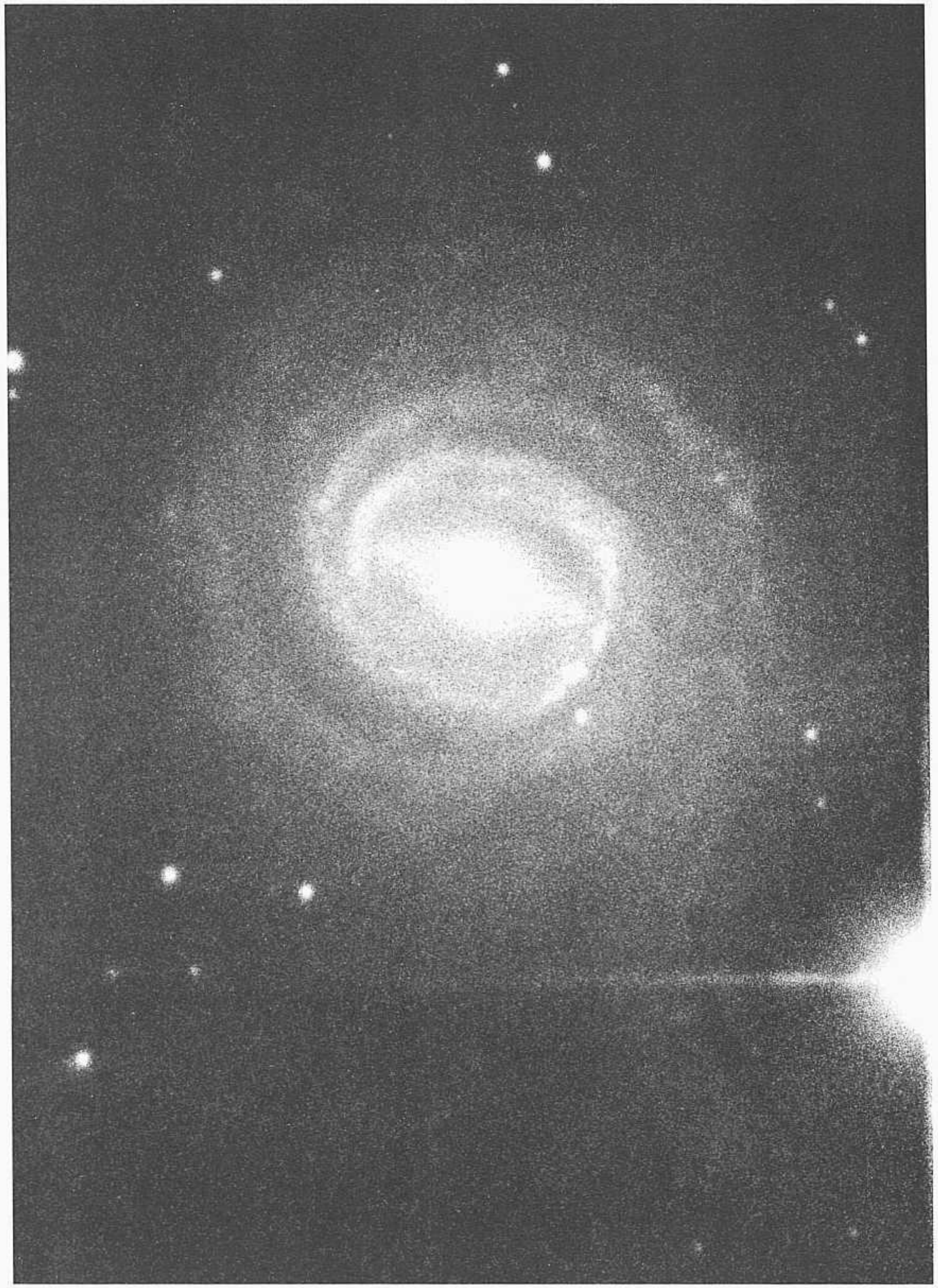
PANEL
97







PANEL
98



NGC 5750 SBa(s)
CD-1401-S/Br (1,1,1/2)
March 22/23, 1980
103aO + GG385
45 niin

The apparent ring is the most prominent feature of NGC 5750. However, close inspection shows that the ring is not complete hut again is made of the tightly overlapping images of two spiral arms starting at opposite ends of the bar. In the orientation of the facing print the arms start from the bar at position angles of 3:3 0 and 9:30 o'clock. One arm comes off the lower-right end of the bar and makes an abrupt left turn, nearly coinciding with the edge of the other arm that begins at the upper-left end of the liar and unwraps counterelockwise by a half turn, whereupon it nearly overlaps with the first arm. The same description, only reversing the role of each arm. describes the pattern to the upper left of the end of the bar there.

The intricate dust lanes, which on the original plate are as thin as the resolution of the image (0.8"). are well silhouetted against the disk on what evidently is the near side of the galaxy.

NGC 3783 SBn(r)l panel 107
CD-158-S (I.I. 1/1}
Fob 3/4, 1978
I03aO + GG38S
15 min

The well-defined bar terminates on the rim of a not-quite-complete ring in NGC 3783. In the upper-left part of the liar (position angle 9:30 o'clock in the print here) the high-surface-brightness ring begins slightly beyond (below on the print) the terminus i)\' the bar. Following the ring clockwise, it bifurcates al about 12 o'clock. The upper segment spirals outward lo form one of the outer smooth arms traceable subsequently for al least 1 1/4 revolutions, similar, for example, lo NGC 7096 (Sa: panels 68, 88, S3). A more-complicated description is necessary lor I lie spiral pattern beginning near the bar terminus on the lower-right part of the major axis.

Note, however, thai the arms arc difficult lo trace as single units. They fragment into brandies and can only approximately be connected as continuous entities. This, of course, is the description of the multiple-armed-spiral (MAS) type of pattern discussed in the* Sa section.

NGC3081 **SBa(s)** **HA, p.** ***11***
CD-665-Br **(ring type, 1/3)** **panel 107**
Jan 22/23, 1979
103aO + **GG385**
45 min

NGC 3081 is illustrated and described in the Hubble Atlas (p. *11)* and has been used on previous **panels** as the prototype for galaxies where the apparent complete ring is made from two tightly wound spiral arms nearly overlapping after each unwraps by a half revolution. Many examples of the form have been previously described in the Sa section on panels 66-71.

The **very-low-surface-brightness** bar mentioned in the Hubble Atlas is seen moderately well in **the** negative print here from a later Las Campanas plate. The bar extends from the lower right to the upper left in the print. It does not reach as far as the apparent ring, but the arms, which are the ring, begin as **smooth** luminosities that turn into the ring, accompanied by two thin dust lanes connecting the bulge through the bar to the insides of the "ring" arms.

These two opposite dust lanes inside the ring are well seen al the upper edge of the right side of the bar and the lower edge of the left side of the bar, both inside the ring. These dust lanes are earliest examples of the linear dust lanes along the bar seen in most SBb galaxies, one of the distinctive features of the class.

The very faint outer spiral arms, not mentioned in the Hubble Atlas, are faintly seen in this print, especially when viewed from a distance. The arms start tangent to the ring at about position angles 3:30 and 9:30 here. Very faint lumps, which may be HII regions, appear in these outer arms.

The innermost region which is the bulge, burned out on this print, has internal parts. The major axis is inclined to the major axis of the ring by about 70°. The orientation of the axis is from the lower left to the **upper** right of the print. At the outer edge of this structure is another bright ring, inside of which is a disk, at the center of which sits a bright center (a nucleus unresolved at the 0.8" level).

NGC 3081 has one of the most complex morphologies of the RSA galaxies. There are rings within rings at the edges of disks within disks, as intricate a structure as in nesting, concentric Russian dolls.

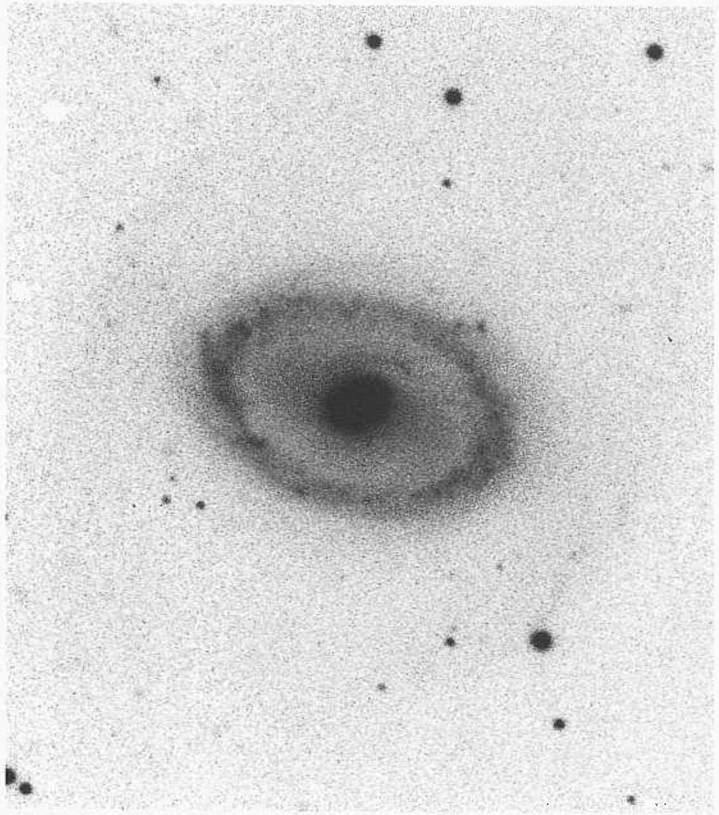
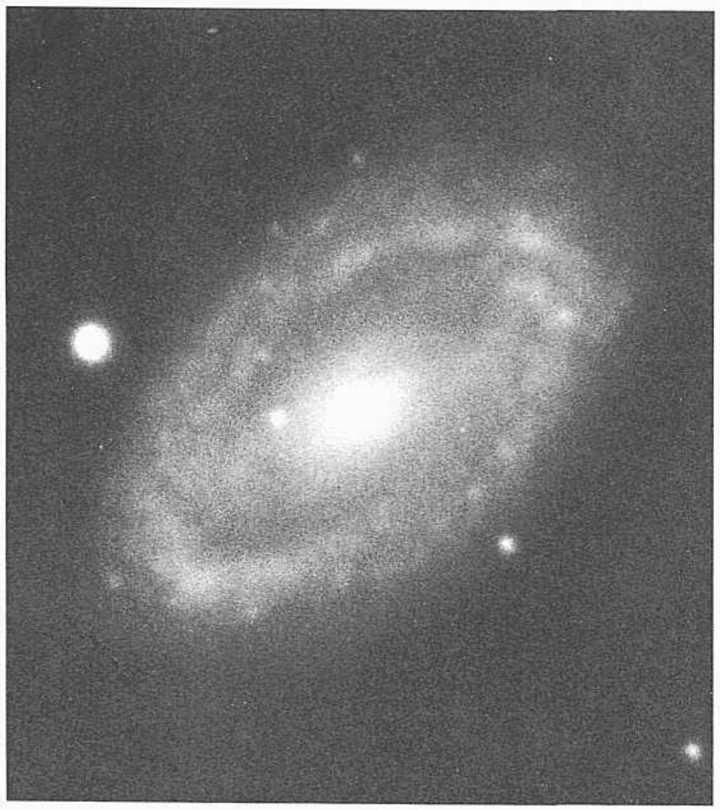
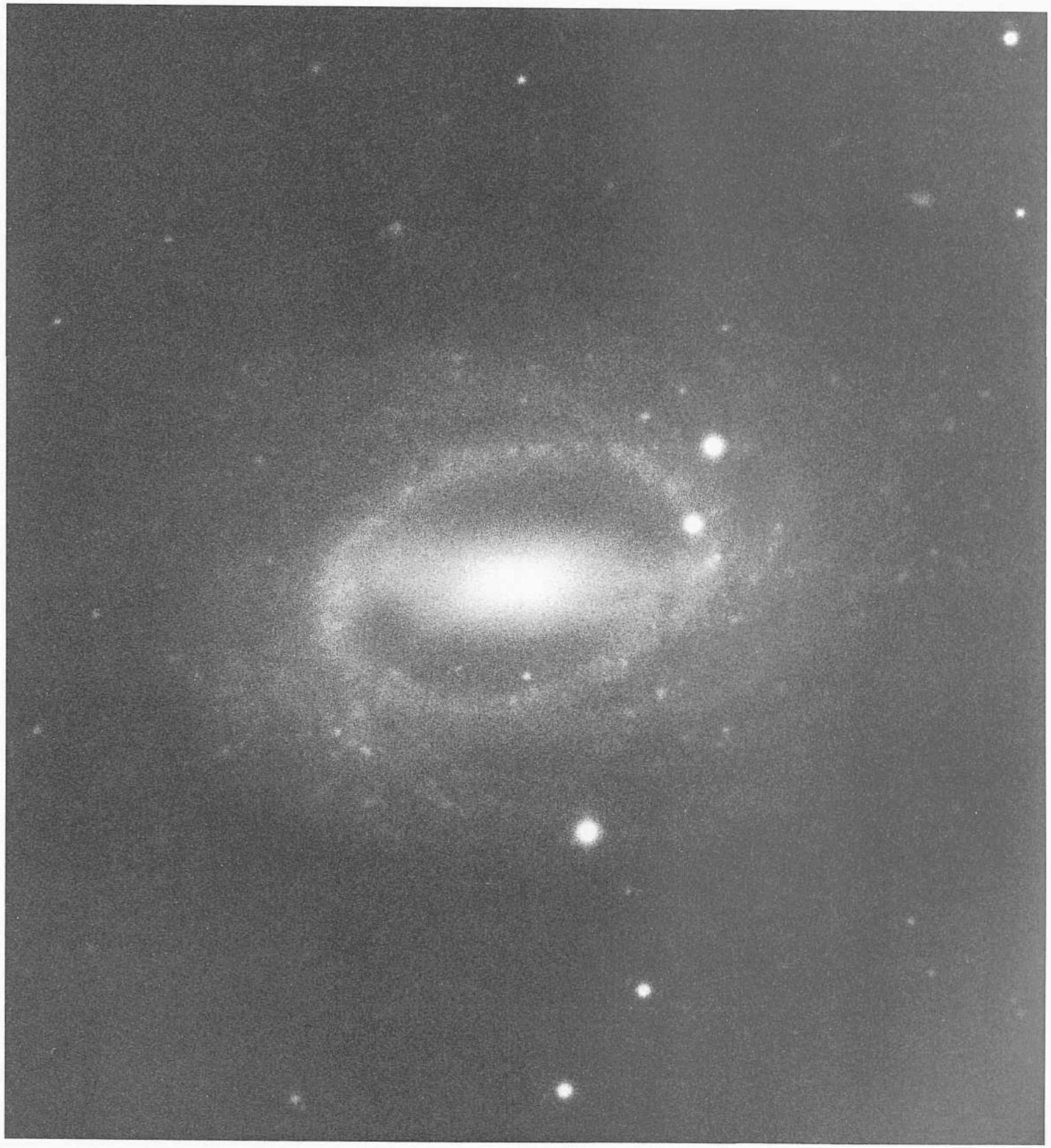
NGC 3185 SBa(s) **HA, p.** ***43***
PH-685-S **(ring type,l/2)**
Feb 9/10, 1954
103aO + **WG2**
30 min

NGC 3185 is in a group with NGC 3 187 (Sc pec, encounter; v_0 = 1500 km s^{-1}: separation 1 I .4': panel 2 76), NGC 3 190 (Sa: v_o = 1384 km s"[1]; separation 10.9': panel 76), and NGC 3193 (E2: v_o = 1307 km s^{-1} : separation 16.6': panel 5).

The morphology of the external regions of NGC 3185, described in the Hubble Atlas (p. 43), is similar to that described for NGC 3081, above. The two separate spiral arms nearly overlap to form an apparent ring if seen on low-resolution plates. This pattern is seen to better advantage here than in the tighter pattern of NGC 3081 above.

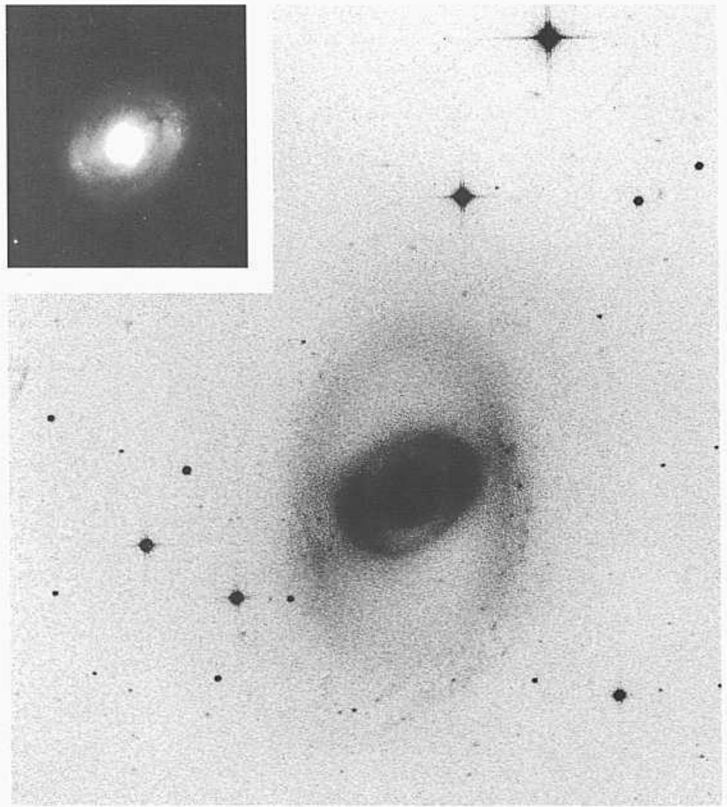
IC 5240 **SBa(r)**
CD-491-S **(L,L,l/2)**
Sep **26/27, 1978**
103aO + GG385
45 **min**

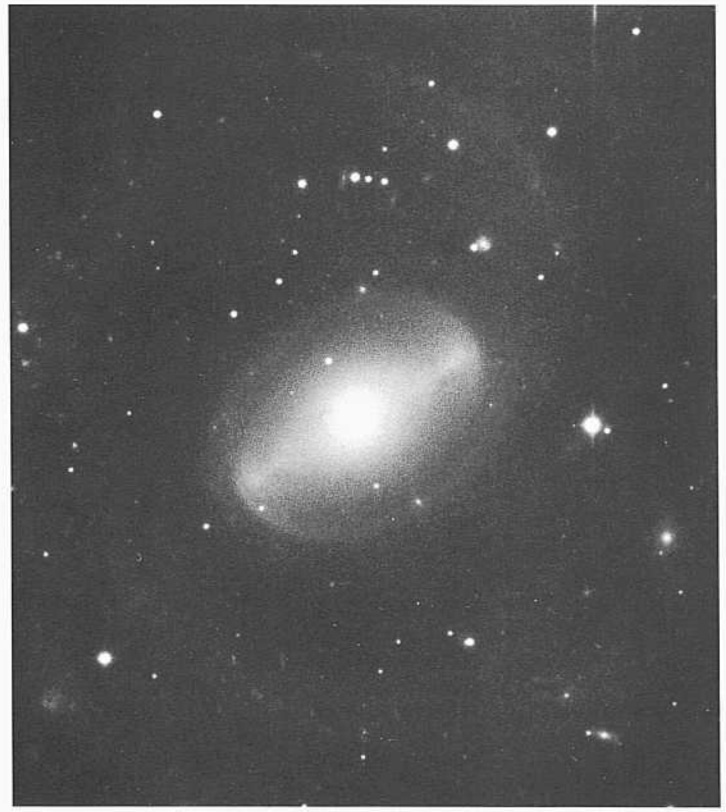
The pattern in IC 5240, where tightly wound separate spirals form a double-gamma shape, is similar to the pattern in NGC 7702 in the Sa section (panel 66). An earlier version of the form is in NGC 6684 (SBa: panel 97).

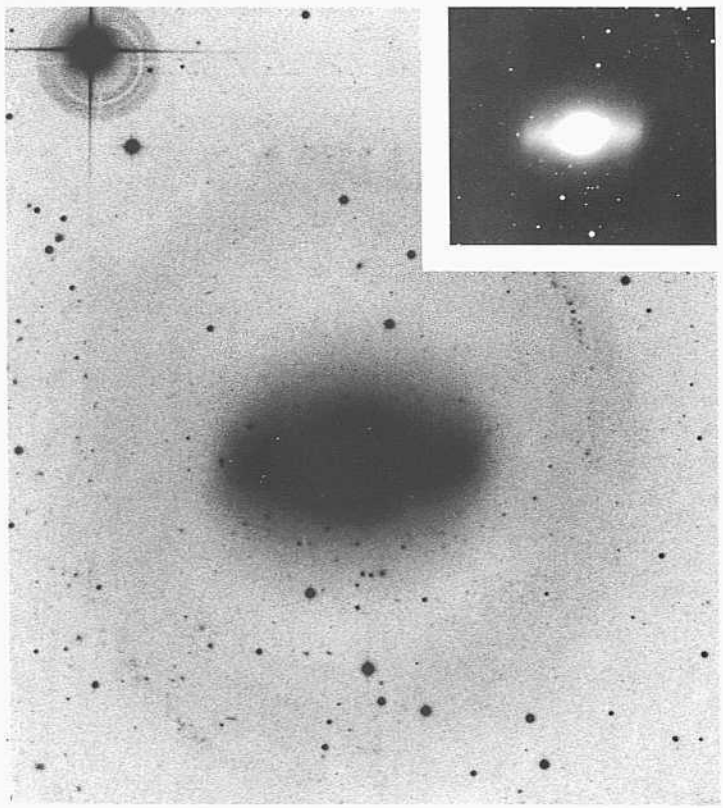




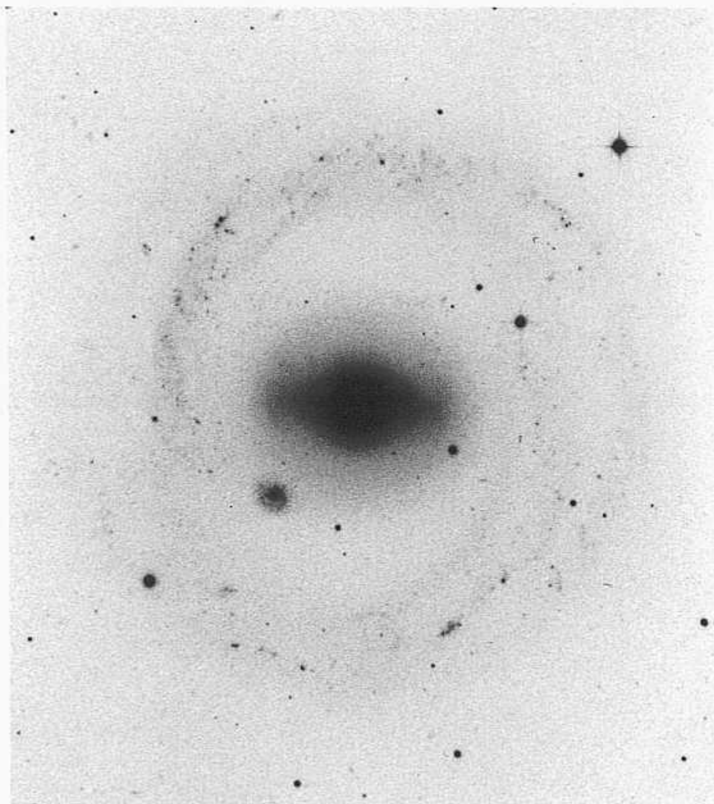
PANEL
99

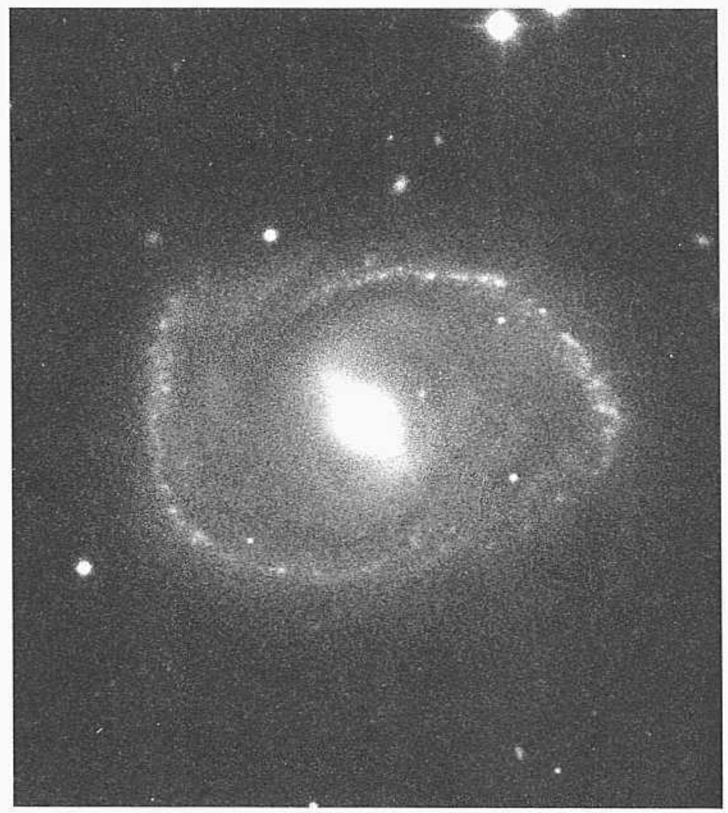
PANEL
100











NGC 1326 RSBa FCC 29
CD-719-S (E,L/I,l/8)
Feb 1/2, 1979
103aO + Wr2c
45 niin

NGC 1326 insert
CD-1667-S
Dec 31/Jan 1, 1980/1981
103a0
75 niin

As in NGC 3081 on the preceding panel, the morphology of NGC 1326 is complex, having internal structures nested within structures near the center. The morphology of the central region is so similar to that in NGC 3081 that much of the latter's description applies here as well.

A low-surface-brightness, ill-defined bar exists, containing the central bulge. The position angle of the bar is 2 and 8 o'clock in the insert print. The bar terminates on a very-high-surface brightness broken ring that itself is the overlapping of two very tightly wound spiral fragments, which start from the ends of the bar and overlap after each unwinds by a half turn. Because of its high surface brightness, as in NGC 3081, this broken ring would be the only feature visible on incompletely exposed plates similar to the insert print.

Again, as in NGC 3081, a faint set of outer arms exist that start tangent to the inner broken ring and form a spiral pattern that overlaps to form an apparent outer ring, similar to the double-gamma pattern of NGC 7702 (Sa; panel 66). NGC 6684 (SBa; panel 97), and IC 5240 (SBa; panel 99). As seen in the high-contrast negative print here, this outer ring has yet a position angle for its major axis different from the angles of the central bulge, the bar, and the inner ring. The outer arms begin on the inner broken ring near where the bar attaches to it (position angles 2 and 8 o'clock).

The prototype pattern of the outer arms is the morphology of NGC 210 (Hubble Atlas, p. *22:* panel 124 here), mentioned before in the descriptions of NGC 2962 (panel 93) and NGC 5377 (panel 96). The form is described more completely in the Hubble Atlas, p. *22.* where NGC 23, NGC 1964, and NGC 615 are also said to possess the pattern, although seen at different inclination angles. Two sets of arms exist—one tightly wound interior set and the outer, more-open outer set. The combination produces the NGC 210 look. The outer pattern if seen nearly face on would be similar to the outer arms of NGC 5701 (middle below) and others like it on this and the following panels (NGC 1291, NGC 1358, NGC 1543, and NGC 5101).

In addition to the complex outer structure in NGC 1326, there is internal structure, mentioned above, in the bulge as well. The bulge is elongated (major axis at about 5 and 11 o'clock in the insert print), with a suggestion of high-surface-brightness, smooth, massive spiral stubs at about 12 and 6 o'clock. As in NGC 3081 (preceding panel), a bright center exists in the bulge.

NGC 1543 RSB02/3(0)/a Dorado Gr #28
CD-695-Br (VE,L,0) panel 102
Jan 28/29, 1979
103aO + GG385
185 inin

NGC 1543 insert
CD-185-S
Feb 7/8, 1978
103aO + GG385
45 niin

NGC 1543 is an outlying member of the Dorado Group (Ferguson and Sandage 1990). The group is part of a larger cloud complex and is called G16 in the group catalog of de Vaucouleurs (1975).

NGC 1543 has what at first glance appears to be an external ring. This feature is common to many of the galaxies on this and the next four panels where the broken-external-ring form is emphasized. The pattern, however, is not that of a detached complete ring but again is composed of two tightly wound spiral arms that nearly overlap after each unwinds by half a revolution.

The points of connection of the external, nearly circular ring-like arms to the rim or the edge of the internal disk are often very faint and hard to identify; yet the connection always does exist. The pattern is similar to how the outer arms of NGC 210 (panel 124) connect to its high-surface-brightness disk. We shall often call this pattern the NGC 210 look in the pages that follow.

The connection of the nearly circular outer spiral pattern to the rim of the inner disk probably occurs in NGC 1543 at position angles near 2:30 and 8:30 o'clock. Note the evidence for star formation in the outer arms at the nearly symmetrical position angles of 2 and 7 o'clock. If NGC 1543 were seen less face on, it would have the NGC 210 look but at a much earlier position in the SBa classification sequence than NGC 210 itself (Sb). The external arms are exceedingly faint here.

(NGC 1543 continued on next panel)

NGC 1291 SBa panels 102, S8
CD-507-S (VE,L,l/8)
Sep 27/28, 1978
103aO + GG385
45 inin

NGC 1291 has the same pattern as NGC 1543, NGC 2217, NGC 5101, NGC 5701, and others shown on this and the next few panels. It, together with NGC 1543, below to the left, is one of the earliest of these examples. The outer nearring is of very low surface brightness. The low-contrast image is printed here to show the bar and the inner disk region, not the faint outer arms. A high-contrast negative image, printed to show these outer arms, is shown on panel 102.

The bar is diffuse. It is not well defined on the original plate. The surface brightness of the central regions is so High that the inner isophotes are lost in the print here, giving a false impression of good definition to the bar which, in fact, is ill defined.

Weak dust lanes exist in the bar, organized in a circulation (spiral) pattern whose sense is clockwise when moving from the inside of the image outward. This is the same sense as in the outer spiral arms whose sense can be seen in the high-contrast image on panel 102 . The pattern of the dust is clearly controlled by rotation.

NGC 5701 (PR)SBa panels 101, 104
CD-1341-S/Br (E,L,0)
Mar 14/15, 1980
103aO + GG385
40 inin

NGC5701 is one of the best examples of the NGC 210 look, defined in previous paragraphs on this panel, hut where the pattern is seen nearly face on.

The diffuse bar, defined by the two faint, luminosity-enhanced ansae, terminates on the rim of a moderately high surface brightness disk. The outer arms, each of which nearly overlaps the other after a half turn, attach to the disk rim at nearly diametrically opposite points. The position angles of the attachment points are at 1 and 7 o'clock in the print here. The attachments can be more easily seen on the high-contrast print on panel 104.

Note the change in orientation of the prints here and there.

NGC 5101 SBa HA, p. *42*
CD-1380-S/Br (E,L,O) panels 101, 103
March 20/21, 1980
103aO + GG385
40 niin

NGC 510 1 is one of the few galaxies of this type in the Hubble Alias (p. *-12).* The other is NGC 2217 (Hubble Atlas, p. *43).*

The purpose of the low-contrast print here is to show the broken-ring nature of the inner disk at the place where the ansae, which define the bar, terminate. This pattern of an inner broken ring in the *disk* (the broad spiral sweeps) is emphasized here and in the three galaxies on tin[1] next page.

The faint arms that make up the outer (second) external broken-ring structure for the NGC 2 10 look (see the discussion of NGC 1543 at the lower left) in NGC 5 10 1 arc just visible on this print near the outer borders. They are well seen on panel 103, where the inner structures shown here are burned out there.

The pattern of these inner "massive" smooth spiral inner disk rims, seen well in the print here, also exists in NGC 2217 on the next page.

NGC 1358 SBa(s)I panels 100, 107, S8
CD-544-S (1,1,1/2)
Oct 1/2, 1978
103aO + GG385
45 niin

NGC 1358 is a later example of the same type of morphology as the other galaxies on this panel having the NGC 210 look. The bar is well defined. The connecting points of the bar and the bright, thin spiral arcs arc poorly defined in very much the same way seen in NGC 2 1 0 itself (Hubble Atlas, p. *22;* panel 124 here), but are even less well defined here.

Based on the existence of many II11 regions in the outer arms, NGC 1358 is in the last third of the SBa morphological box. However, the bar and inner disk are smooth, placing the overall morphology near the middle of the SBa section.

NGC 4596 SBa (very early) VCC 1813
CD-1319-S/Br (VE,L,O)
March 12/13, 1980
103aO
75 min

The images of the four galaxies on this panel have been printed to a contrast showing the pattern of the bar and the inner disk at the place where the ansae of the bar terminate on the rim of the disk. The best example of the form is NGC 4596. which is one of the earliest SBa galaxies in the RSA.

The bar is well defined. The flared ansae end abruptly on the rim of the disk, which, however, is not elliptically symmetrical but is broken at the bar termini where the massive smooth spiral pattern that covers the outer disk begins.

There are no external arms as in the galaxies on the preceding panel. The SBa classification rests solely on the internal massive spiral pattern of the disk at the ends of the bar. A structure of this kind will be generally missed on plate material of low spatial resolution.

The classification of SBO in the RC2. based on a Mount Wilson yellow plate, is not appropriate.

NGC 5701 (PR)SBa panels 100, 104
CD-1341-S/Br (E,L,0)
March 14/15, 1980
103aO + GG385
40 min

The broken-disk pattern at the termination of the bar with the disk, seen well in NGC 4596 to the left, is displayed here in the central regions of the three galaxies shown in this column. The outer regions all have the NGC 210 look to their exterior arm pattern.

Only a hint of the internal broken-disk pattern exists in the central region of NGC 5701. The rim of the disk brightens along two stubby arcs, one at each termination of the bar. The surface brightness of the disk is lower than in either NGC 2217 or NGC 5101. below.

The outer regions of NGC 5701 are shown in prints on the preceding page and on panel 104.

NGC 2217 SBa(s) HA, p. *43*
CD-673-Br (1,1,0) panels 104, 107
Jan 24/25, 1979
103aO + GG385
45 min

The massive smooth inner spiral arms of NGC 2217. which are the broken rims of the disk, are seen well in the print of the central region here. The outer region, shown also in the Hubble Atlas, is seen in a high-contrast print on panel 104. and also in the SBa summary, panel 107.

NGC 5101 SBa HA, p. *42*
CD-1380-S/Br (E,L,O) panels 100, 103
March 20/21, 1980
103aO + GG385
40 min

The broken-disk pattern, where the rims of the disk are the inner massive spiral arms, is as prominent here as in the prototype case of NGC 4596 at the left.

A high-contrast print of the outer regions of NGC 5101 is shown on panel 103.

(NGC 1543 continued from previous panel)

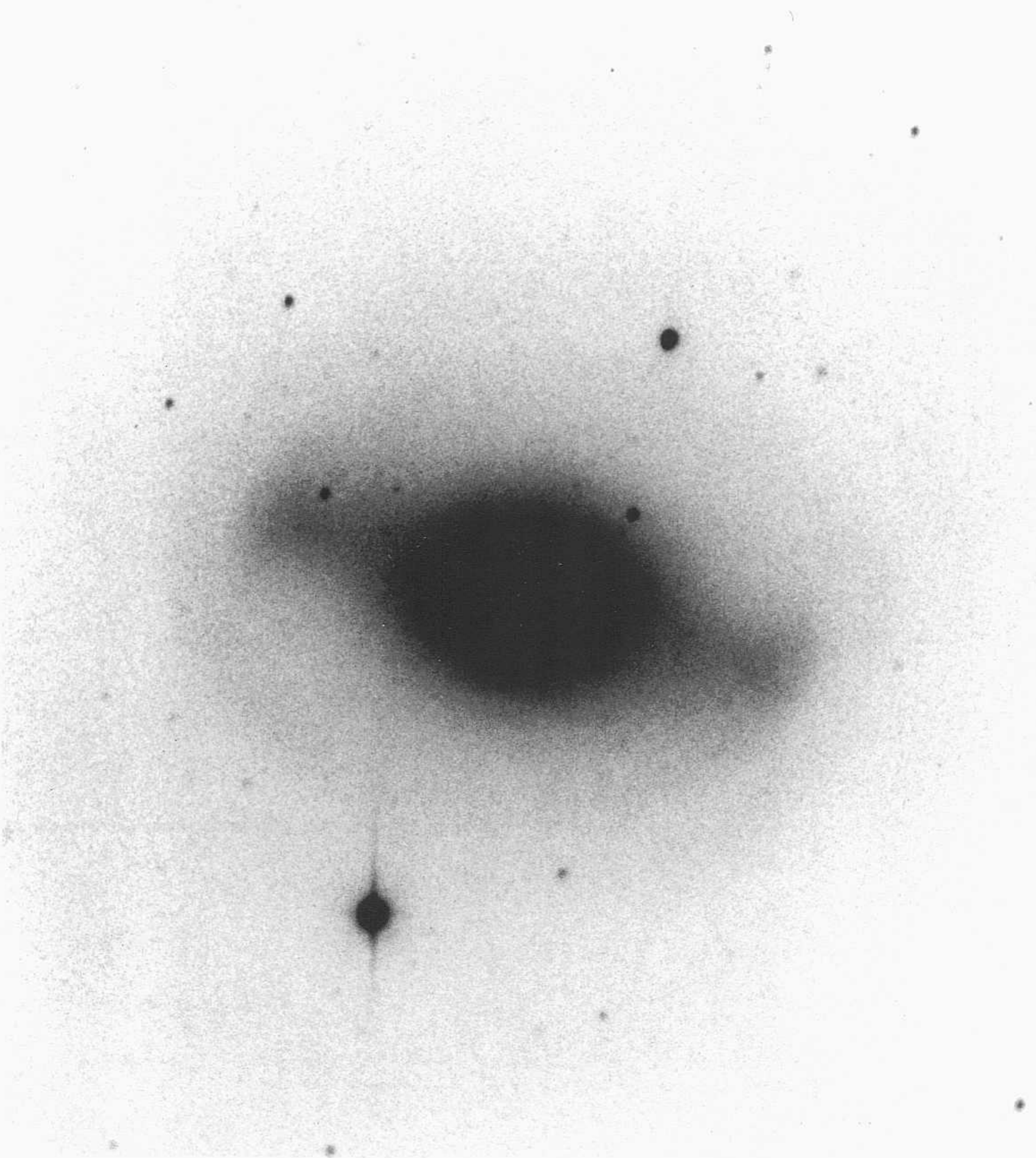
On low-resolution plates such as those from Schmidt telescopes or short-focal-length reflectors, the outer arms appear simply as an extended, smooth halo with only a slight hint, if any, of the spiral structure. The classification of RSBO in the RC2, based on Mount Stromlo 30-inch Reynolds reflector plates, is clearly inappropriate. No SO or SBO galaxy in the standard system has a morphology similar to that evident in the print here.

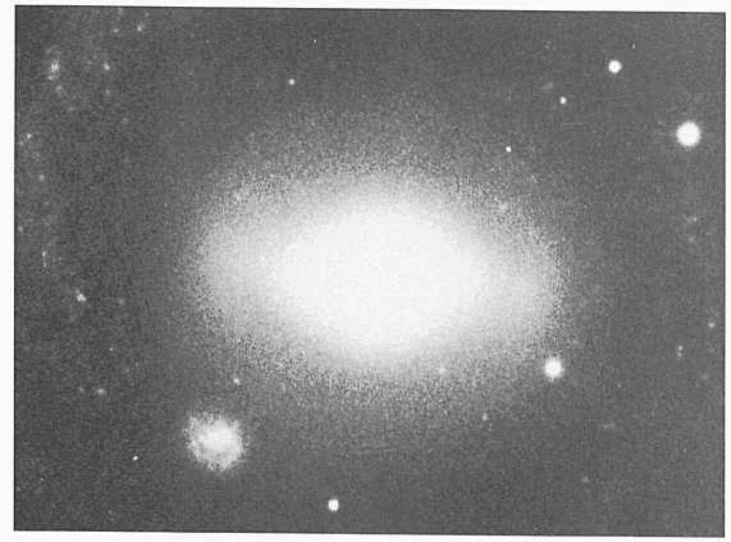
A very-high-contrast image of NGC 1543 is on panel 102. (Note the rotation of the images here and there.)

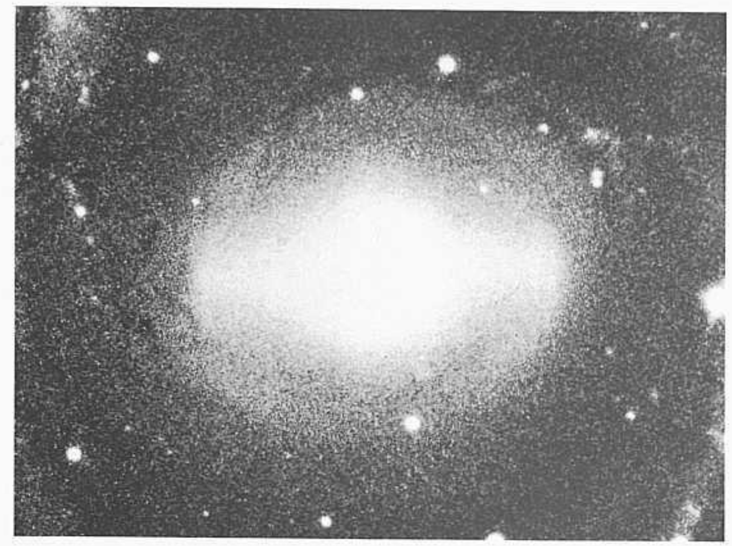
The central bulge is surrounded by a zone of intermediate luminosity. This is not seen in the insert here because of its very high surface brightness, but it exists as an interior halo to the bulge. This two-zone structure appears as one burned-out region in the insert print.

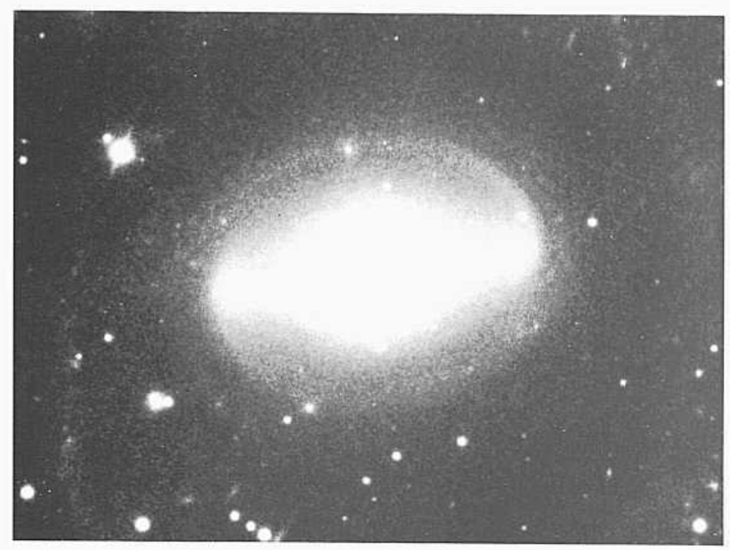
The bulge, as the first zone of the interior pattern, is itself flattened, with its major axis perpendicular to the bar (the direction is vertical in the orientation here).

The two ansae defining the bar stop on the rim of the quite-low-surface-brightness disk. They are only just seen in the insert here but are well visible in the high-contrast main print.

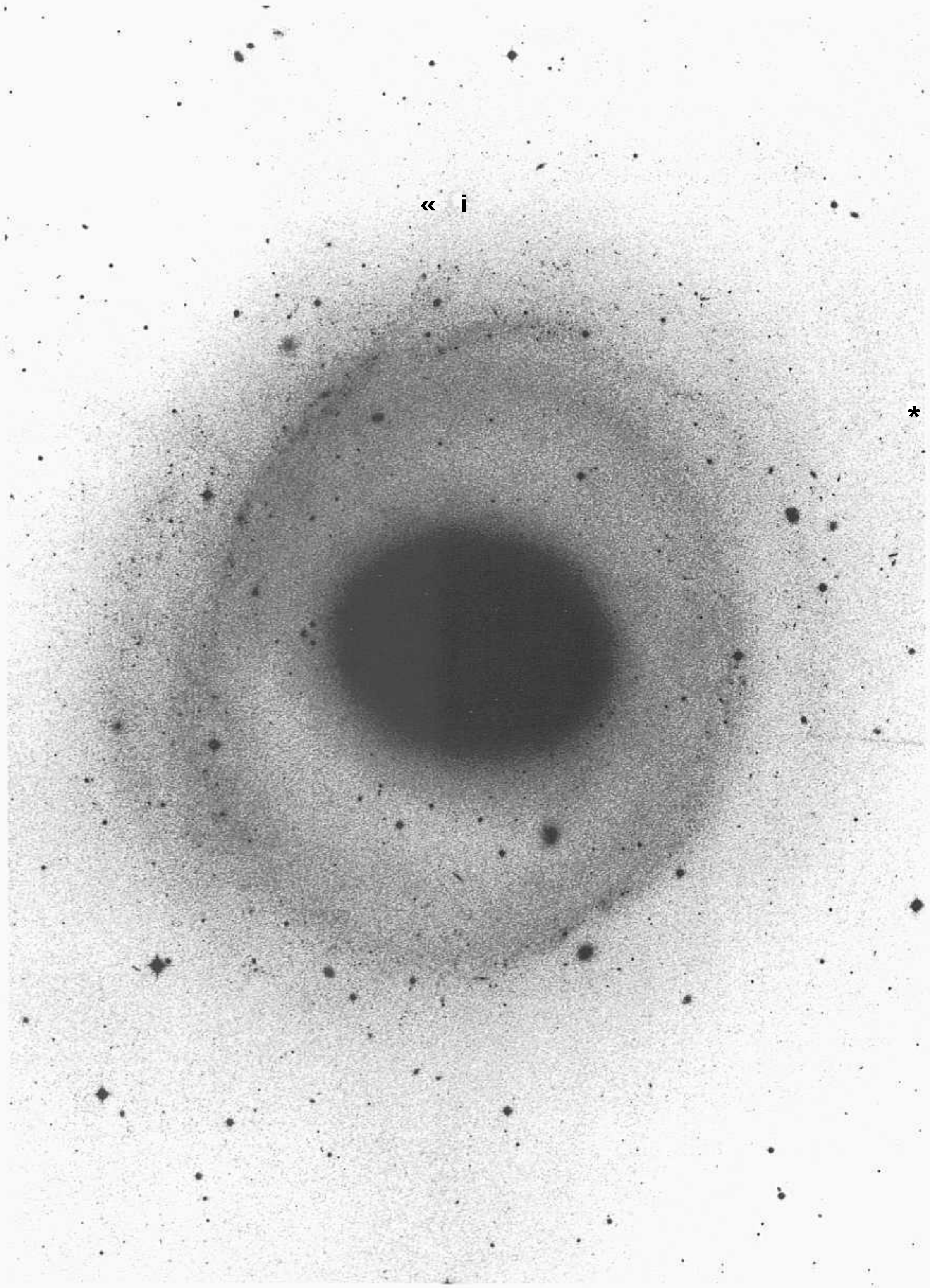


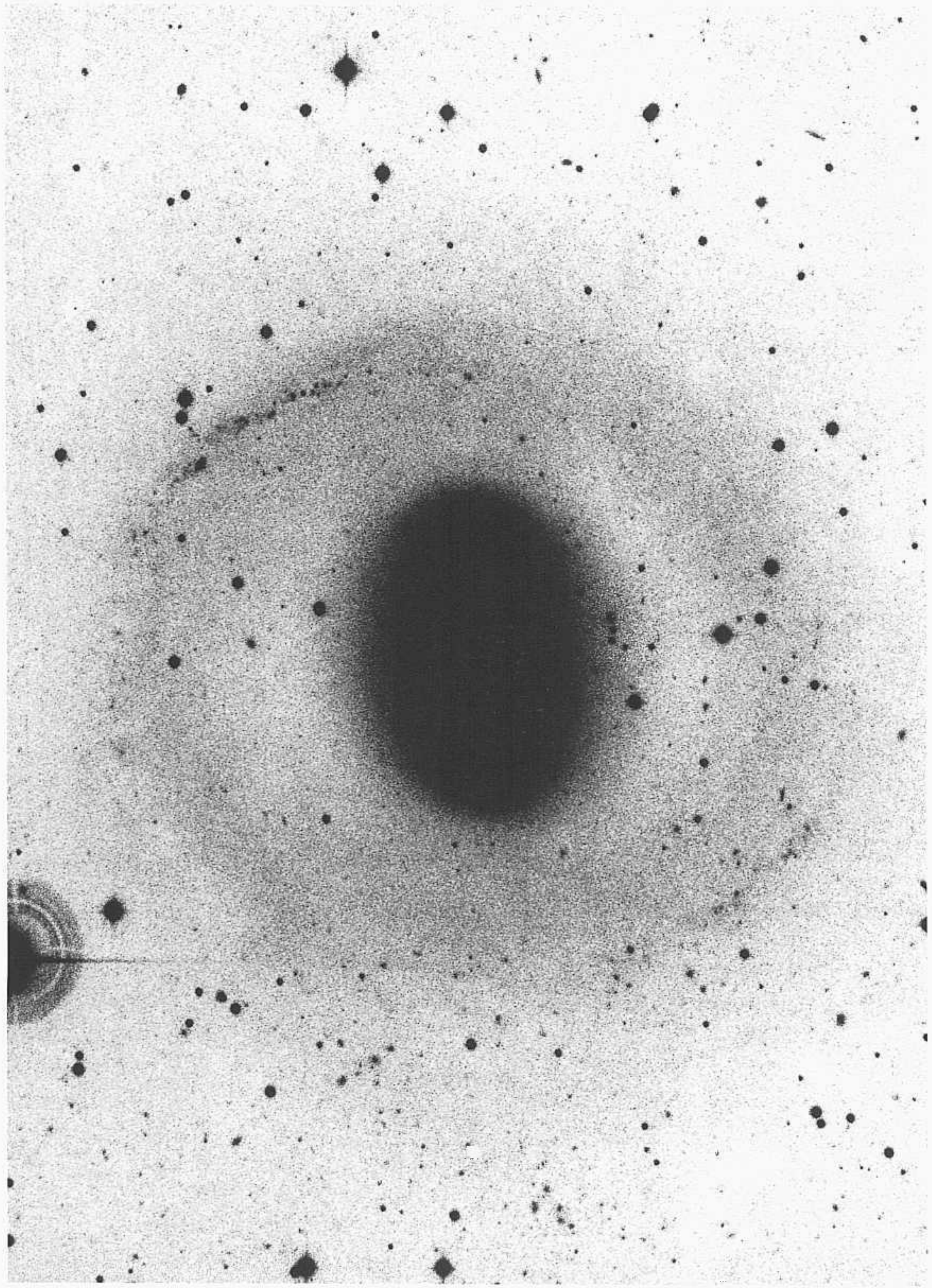






PANEL
102





NGC 1291 SBa panels 100, S8
CD-507-S (VE,L,l/8)
Sep 27/28, 1978
103aO + GG385
45 miii

The central disk and **bar of** NGC 129 **1** are **burned** out here, but the **very-low-surface-brightness** outer arms and the low-intensity region between the edge of the inner disk and the arms show well at this contrast.

The regions **where** the **outer** arms connect (if at all) to the inner- di.sk are indistinct. **The** higli-luminosity disk positions **just** outside the **edge of** the inner disk **where** connections are **probable** are at position angles of about 3:30 and 9:30 o'clock in **the** print **here.**

A small but finite recent star-formation rate is evident in part of the outer arms, shown by the few knots **(presumably 1111** regions) in these thin-armed fragments.

As mentioned in the previous descriptions of other barred galaxies, the two regions of lowest surface brightness in the intermediate disk are just outside the edge of the high-surface-brightness inner disk. These regions are always at **right** angles to the direction of the bar. (See the bar orientation on the low-contrast **print, pane]** 100.) Athanassoula (1984) writes that this pattern is predicted from the theory of the interior dynamics of barred spirals.

NGC **1543** **RSB02/3(0)/a** **panel 100**
CD-695-Bi· **(VE,L,0)**
Jan 28/29, 1979
IlaO + GG385
185 miu

The image of NGC **1** 543 on the **print** here shows the **outer arms** better **than** dors **Lhe low-contrast print** on panel I 00. **(Note thai** the **prints here** and there differ in their **orientation.)**

Two diametrically opposite, **symmetrically** placed regions of recent star formation **exist** in the **outer arms aI position angles I and** III **o'clock on ibis print. In** a **way similar** to [NCC 129 1 at **the** left. **NGC** 5 101 on the next **panel,** and NGC 22 17 (wo panels **ahead,** these regions **of greatest star-formation** rate **in the** arms **occur** at the same **place relative to** the **termination points** of **the bar** on the rim **of** the **inner** disk. **Each occurs** at mean position angles thai are about 15° advanced from the position angle of the **termination** of the bar. always in the **direction** of the unwinding of tin* spiral **outward.**

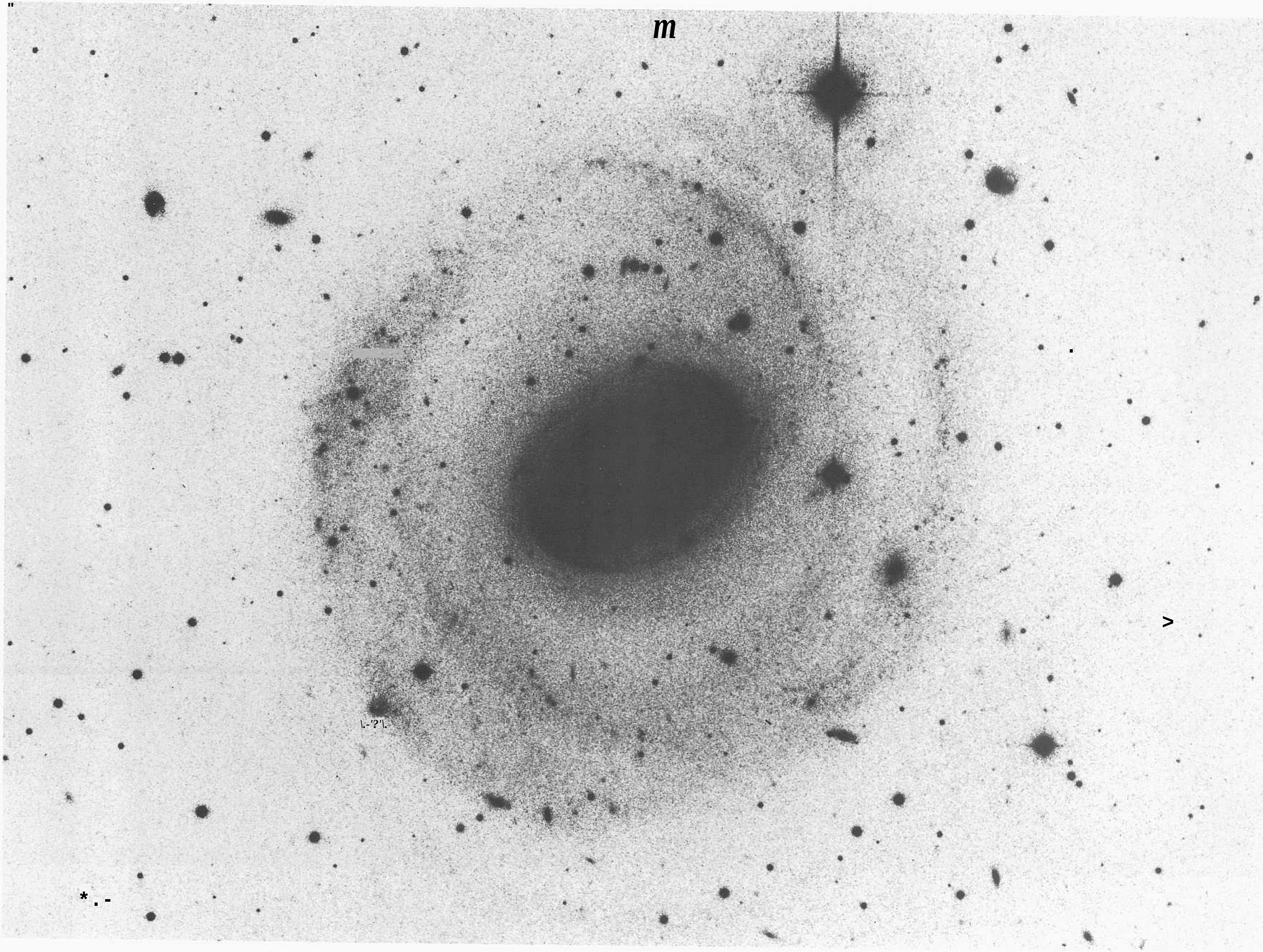
This particular position of **enhanced star** formation **occurs** in the arms of so many barred spirals of this **type** as to suggest that the **bar** induces shocks at particular positions that **are** *fixed* relative to the bar. **This** conclusion is **discussed** at **greater** length in the SBb section.

As in [\GC 129 **1** at the **left** and in **other** barred spirals shown earlier in this section, two symmetrically opposite regions of **low** surface brightness exist in the disk, between the **outer** edge of the inner disk and the **inner** edges of the outer arms. These regions of reduced flux occur at position angles of **about** 2 :3 0 **and** 8 :3 0 o'clock **in** the print **here.** As discussed previously, **these** positions are again at nearly right angles to **the** position angle of the bar. **The phenomenon** is expected (Athanassoula 1981 I.

NGC **5101** **SBa** **HA, p.** ***42***
CD-1380-S/Br **(E,L,0)** **panels 100, 101**
March 20/21, 1980
103aO + GG385
40 mill

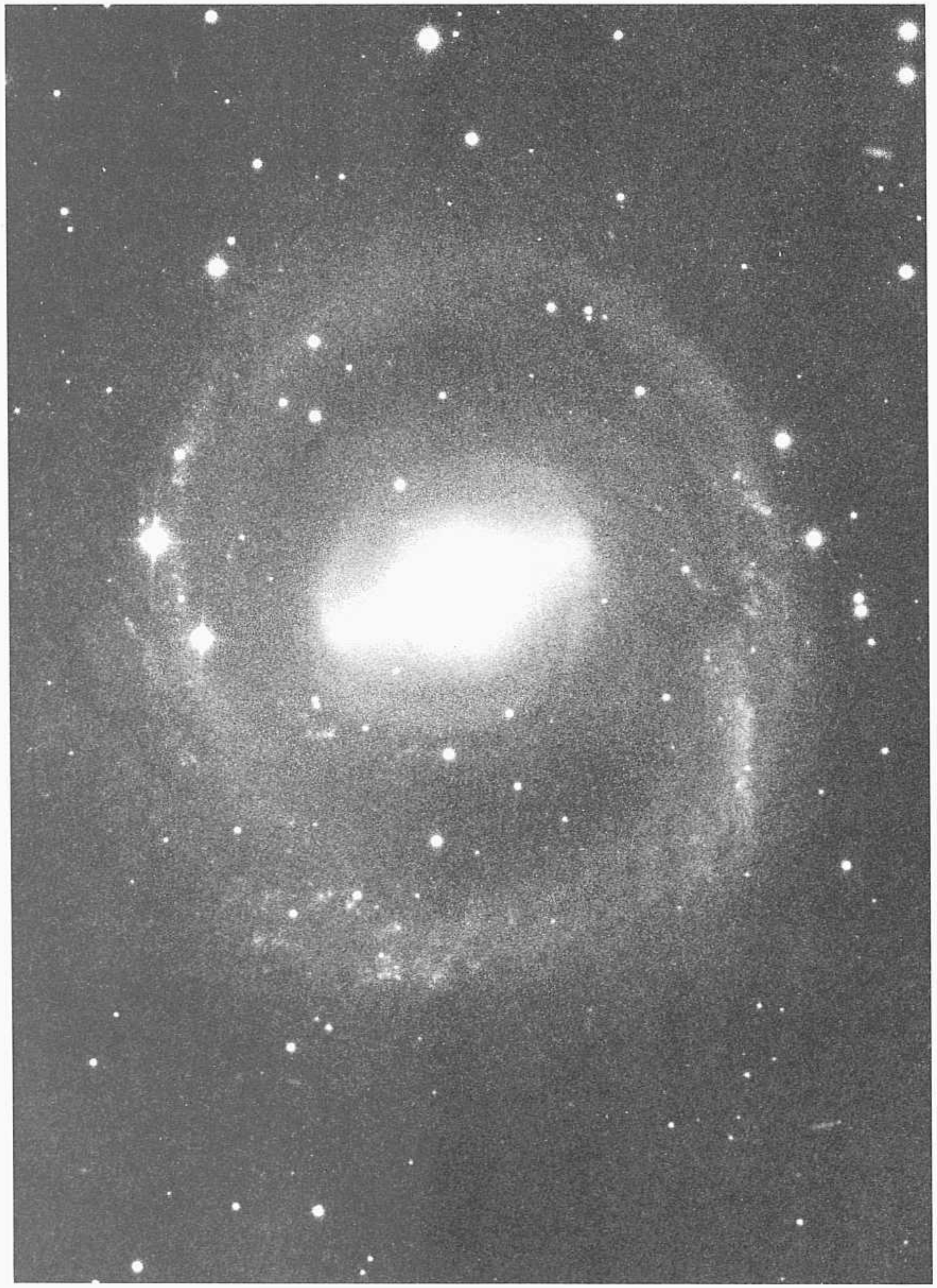
The regions of the bar and the inner disk of NGC 5101 shown in the underprinted images on panels 100 and 101 are **burned** out in the high-contrast print here, but the outer arms are well defined. The regions where these arms connect to the edge of the inner disk are more easily identified here than in either NGC 1291 or NGC 1543 on the preceding page. A higher star-formation rate is also evident in the **thin,** well-defined outer arms here than in these earlier two members of the NGC **210-like** SBa-subclass galaxies. (See the discussion of NGC 1543 on panel 100.)

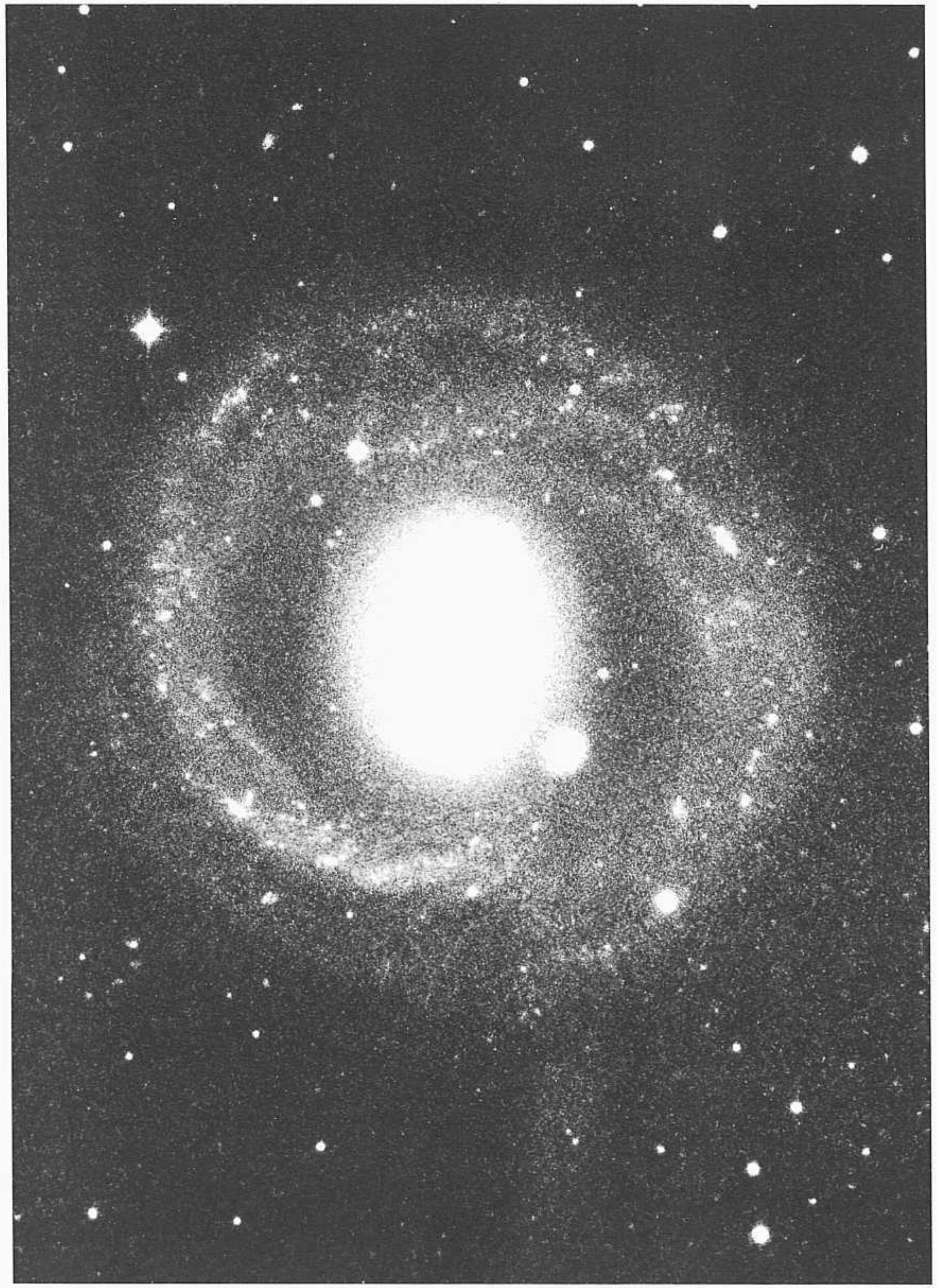
Although the outer spiral arms are of very low surface brightness (see the insert print in the Hubble Atlas), the spiral pattern is definite. The **morphological** type is SBa beyond doubt. The transition classifications of RSBO/a (with an external ring) in the RC2, and of SBO/SBa in the Hubble Atlas, both based on a 200-inch plate, are **inappropriate.**



PANEL
103

PANEL
104





NGC 2217 SBa(s) HA, p. *43*
CD-826-KW (1,1,0) panels 101, **107**
April 30/May 1, 1979
103aO + GG385
30 niin

NGC 2217 has the morphology of the NGC 210 look (see the discussion of NGC 1543 on panel 100) but is earlier than the Sb type of NGC 210. The galaxy is in the intermediate section of the SBa morphological box; it is later in the section than either NGC 1291 or NGC 1543 two panels back but somewhat earlier than either NGC 5101 on the preceding page or NGC 5701 to the right here.

The positions at which the very-low-surface-brightness outer arms connect to the rim of the inner disk are well defined, similar to the good definition of these connections in NGC 5701 to the right, and also in NGC 5101 (panels 100, 101, 103J. These three cases are in contrast to the uncertainty of the connections in NGC 1291 and NGC 1543 two panels back.

In NGC 2217 here, the arms attach to the inner disk at position angles of 1 and 7 o'clock in this print. Each arm can be traced for about half a revolution before it nearly overlaps its opposite partner.

Note the similarity in the way the arms attach to the inner disk here and in NGC 210 (Hubble Atlas, p. *22:* panel 124 here). Note the change in pitch angle of the arms in the space between the rim of the inner disk and the outer arm region where the pattern is nearly circular.

The spiral pattern in NGC 2217 is definite; the morphological type of SBa is beyond question. The RSB0 type given in the RC2 , based on a Mount Wilson 100-inch plate, is inappropriate.

NGC 5701 **(PR)SBa** panels 100, 101
CD-1341-S/Br (E,L,0)
March 14/15, 1980
103aO + GG385
40 nün

NGC 57(1 1 . together with NGC 5 10 I on the preceding panel, are the latest SBa galaxies that have the NGC 2 10 look in this alias.

The regions of attachment of the arms to the rim of the disk are moderately well defined at position angles of 5:30 and 1 1:30 in thia print. Appreciable star formation is occurring in the outer arms. The arms are Fragmentary. They cannot be traced as two single units, but rather they bifurcate into many fragments forming a multi-arm pattern (MAS) over the outer face of the image. The type is SBa beyond doubt. The classification as a transition SBO/a type in the KC2, based on a Mount Wilson 100-inch plate, is not supported here.

All galaxies on this panel show the effects of a close encounter in progress. The assignment of SBa type to each is the best compromise to force each into the classification system. It is not to be imagined that the physical properties of such galaxies are necessarily typical of the undisturbed, generic SBa type. For example, the arms in some such encounters are often tidal plumes, presumably having little resemblance to arms characteristic of the SBa morphology in isolated generic SBa types.

NGC 4106/4105 SBO/a(tides) panel 56
CD-1445-S/Br (VE,L,0)
May 6/7, 1980 $S0_{1/2}(3)$
103aO + GG385 (P)
45 niin

The NGC 4105/4106 pair has also been illustrated previously in the SBO section, on panel 56.

Both galaxies are in the RSA. They unquestionably form an interacting pair. The evidence is the tidal plume in NGC 4106 (to the upper right in the print here) and the tidal bridge that connects the pair. The redshifts are $i_{;o}(4105)$ = 1623 km s^{-1} and $i_{-o}(4106)$ = 1905 km s^{-1}. The angular separation of 1.2' corresponds to the small projected linear separation of 12 kpc at the redshift distance of 35 Mpc (H = 50).

The feature interpreted as a very diffuse bar in NGC 4106 is the intensity enhancement between the inner bulge (flattened, with an almost horizontal major axis) and the diffuse tidal arms. The direction of the major axis of the bar enhancement, not well seen here, is in position angles of 1 and 7 o'clock in this print.

NGC 4795 SBa(s)(tides?) Karachentsev 359
PH-7611-S (E,L,0) Racine wedge
April 3/4, 1979
103aO + GG385
10 min

The morphology of NGC 4795 suggests an encounter in progress. The arms are apparent tidal plumes, one of which terminates on the companion.

The configuration, listed in Karachentsev's (1987) catalog of close pairs that are candidates for binaries, encounters, or early mergers, have redshifts of $D_O(4795)$ = 2610 km s^{-1}, and v_0 = 2463 km s^{-1} (for the fainter companion). The apparent separation of 28" gives the small projected linear separation of 7 kpc at a redshift distance of 50 Mpc (H = 50).

The inner region of NGC 4795 shows a distinct bar that ends on the periphery of the inner disk. This interior morphology appears normal for an SBO or an SBa generic type. However, the broad, massive, smooth spiral arms probably are not generic to the classification sequence but appear to be induced by the encounter.

The original plate was taken with a Racine-Pickering wedge that gives double images where the secondary image is 5 mag fainter than the primary and is separated by 18". The bright star at the bottom of the frame has this secondary image.

NGC 5566 SBa(r)II triplet
PH-908-S (I,L,l/2) HA, p. *43*
March 24/25, 1955
103aD + GGll
45 min

NGC 5566 is in a physical triplet with NGC 5569 (Sc, at upper right in the print here), at 4.2' separation, and NGC 5560 (Sc, lower right at the border, partly cut off), at 5.0' separation. The redshifts listed in Huchtmeier and Richter (1989), corrected to the centroid of the Local Group, are $u_o(5566)$ = 1465 km s^{-1}, $u_o(5560)$ = 1610 km s^{-1} and $f_o(5569)$ = 1669 km s^{-1}. The near equality of these redshifts suggests physical association. The projected linear distances from NGC 5566 are 39 kpc for NGC 5569 and 46 kpc for NGC 5560, at a redshift distance of 32 Mpc.

The center of NGC 5566 has the normal morphology of a late-type SBa with a bright near-ring of the type described and illustrated on panels 97-99 and on the final summary page of this section, panel 107. The prototype examples are NGC 1452 (SBa: panels 97, 107), NGC 3783 (SBa; panels 98, 107), and NGC 3081 and IC 5240 (SBa: panel 99). The internal near-ring in NGC 5566 is formed by two nearly overlapping bright arms, which themselves spring from the ends of the bar in the (s)-like configuration. This internal morphology is burned out in the facing print, made with a contrast that shows the arm structures. Some of the internal morphology is shown in the insert print in the Hubble Atlas (p. *43)*, made from the same plate used here.

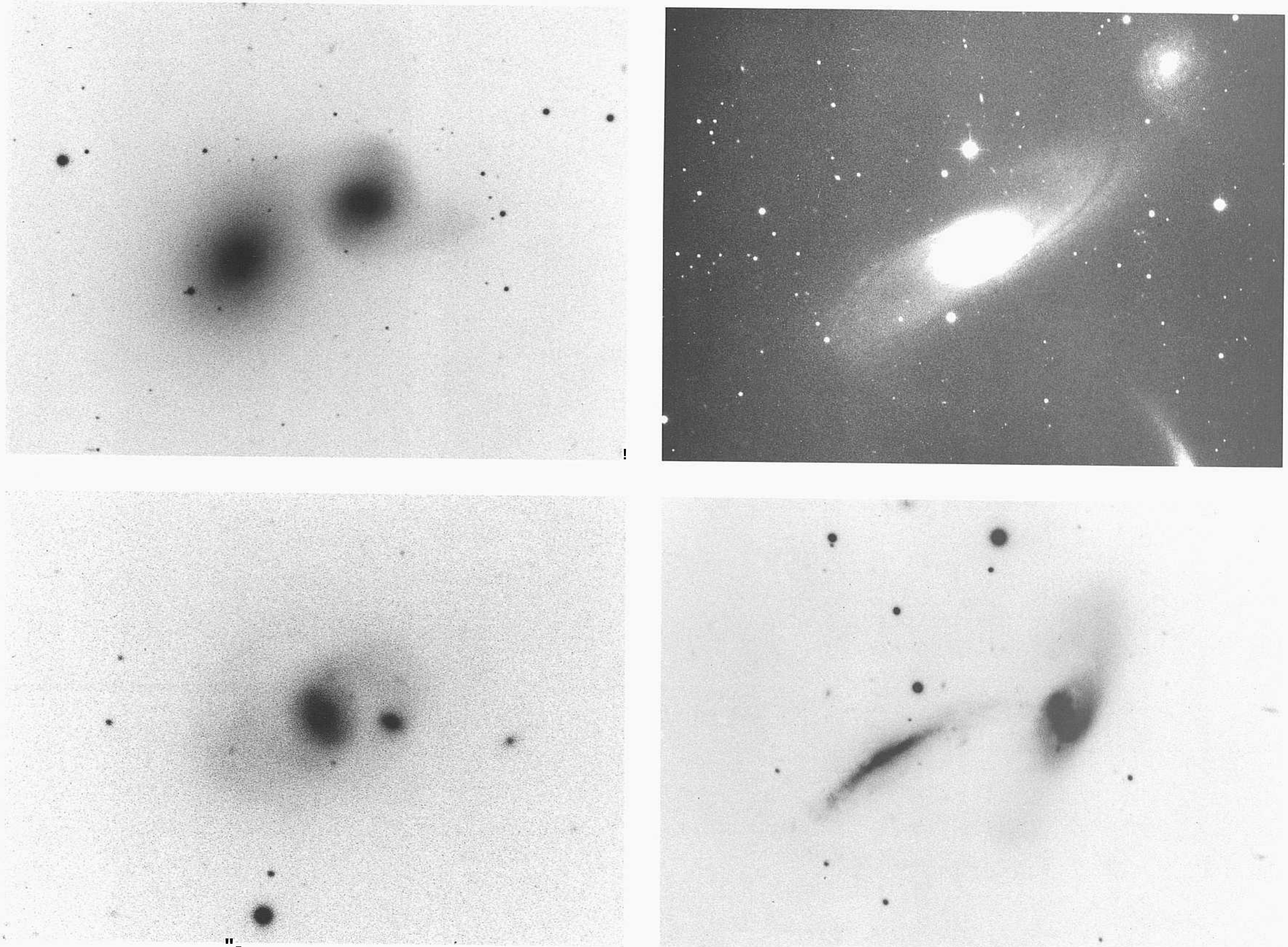
The outer disk of NGC 5566 appears warped. The dust lane in the arm that itself may be a tidal plume is prominent; a symmetrical dust lane exists in the opposite arm but is less prominent, presumably because of poorer silhouetting against an inadequate background.

NGC 2798 SBa(s)(tides) Racine wedge
PH-7460-S (1,1,1) Karachentsev **195**
Dec **16/17, 1977**
103aO + GG385
30 min

NGC 2798 (SBa) at the right and NGC 2799 (Sc, eschatological disruption) at the left are listed in the catalog of multiples by Karachentsev (1987). The 21-cm redshifts are $K_O(2798)$ = 1793 km s^{-1} and $u_o(2799)$ = 1788 km s^{-1}, listed by Huchtmeier and Richter (1989). The angular separation of 1.6' gives a projected linear separation of 17 kpc at a redshift distance of 36 Mpc (H = 50).

The burned-out center of NGC 2798 in the print here contains a bar from which the arms spring as the (s) arm subtype. The two smooth spiral plumes in the outer region of the main galaxy are evidently from the encounter in progress.

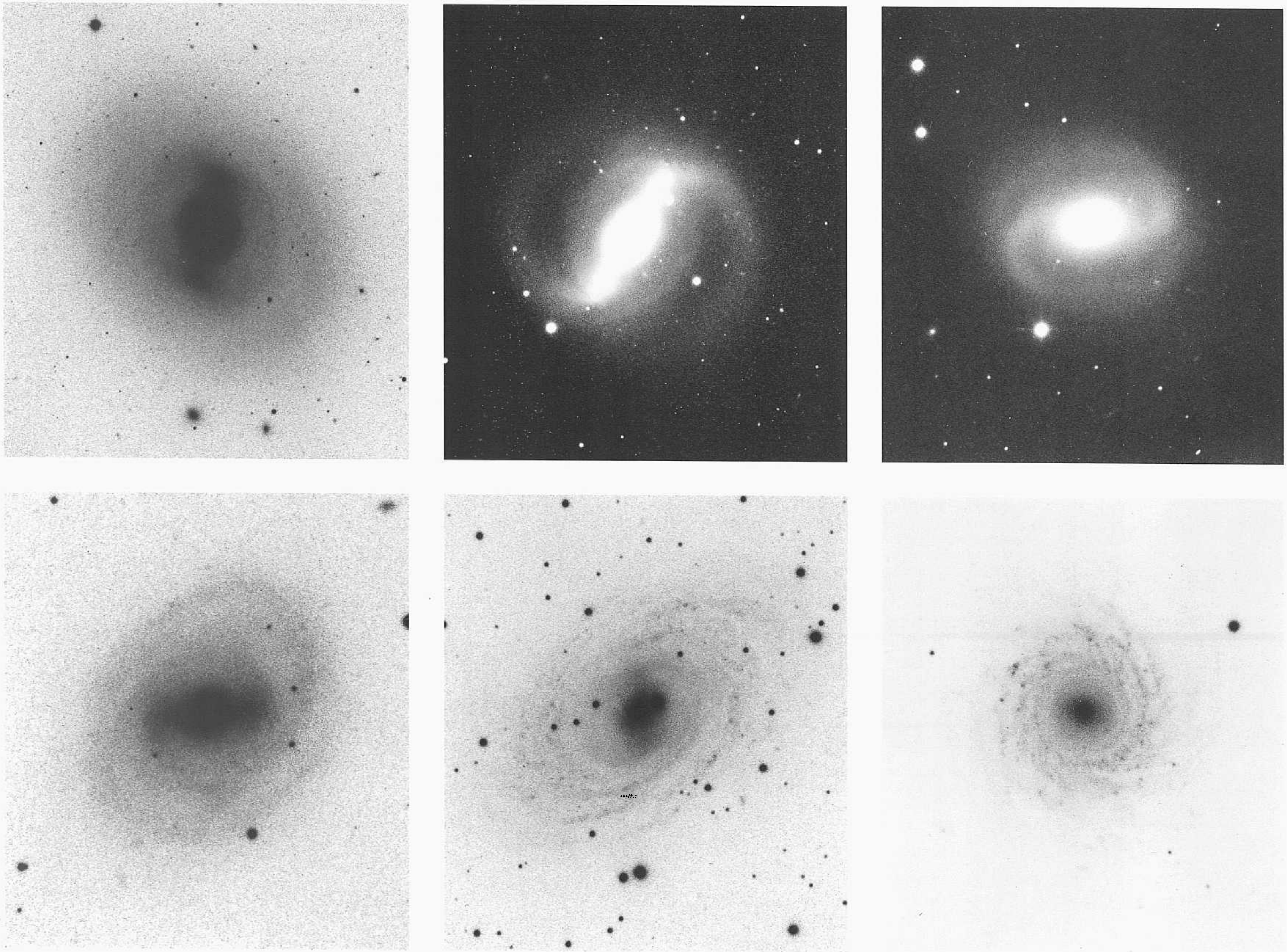
The plate was taken with a Racine wedge. The bright star near the top border shows the secondary image 5 mag fainter than the primary and separated by 18".



PANEL

105

PANEL
106



The SBa galaxies on this panel are of the type where the arms either start from the ends of the bar [the (s) subtype, as in the first four galaxies on the panel reading across from left to right and then down], or start tangent to the smooth edge of the inner disk but where the rim does not have the bright near-ring on its boundary, as in the last two galaxies on this panel. SBa galaxies that have the near-ring morphology arc summarized on the following panel.

The six galaxies here are arranged **sequentially** from early to late SBa. Comparison **of the upper left** image of NGC 936 with the lower right image of NGC 7371 shows **the** long **length** of the SBa classification box, from **the SBO/SBa border to the late** SBa boundary **with** the **SBab** class. The progression is leftward across the top, then across the bottom from the **left.**

NGC 936 SB02«/SBa panels 90, S9
CD-491-S (VE,L,0)
Sep 26/27, 1978
103aO + GG385
45 min

NGC 93 6 is the earliest of the class. Its nearly smooth, extended disk with its internal bar is characteristic of SBO galaxies. A diffuse, massive, ill-defined bul definite spiral pattern exists outside the termination points of ihe bar. The departure from smoothness in that part of the disk outside the bar has the same form as the pattern in NGC 6942, below, but is a much earlier version of it.

NGC 6942 SBa(s) panel 92
CD-1047-Br (E,I,0)
July 22/23, 1979
103aO + GG385
35 min

NGC 6942 is the latest of the smooth-armed spirals shown on this panel. Incipient lumpiness, but at a very low level, exists in the arms, which are smoother than those in NGC 1169 to the right but not as smooth as those in NGC 93 6 and NGC 4314 above. The distinctness of the arms is also intermediate between that of these same two comparison galaxies. The arms here can be better traced than in NGC 936 but not as well as in either NGC 1169 or NGC 7371 to the right.

NGC 4314 SBa(rs) pec HA, p. *44*
PH-192-MH (E,L,0) panel 95
May 13/14, 1950
103aO
30 min

The outer arms in NGC 4314 are smooth, exhibiting no evidence of recent star formation or of dust. The smooth arms of these early parts of the Sa and the SBa sections, defined by the four prototype galaxies on this panel and by the Sa galaxies on panels 61—65, are generic to the sequence; the smooth-armed form is not a result of environmental processes.

NGC 1169 SBa(r)I panels 96, S9
PH-7533-S (I,I/L,1)
Nov 4/5, 1978
103aO + GG13
15 min

NGC 1169 defines the morphology near the middle of the SBa classification box. The spiral-arm pattern is of the multiple, fragmentary type (MAS). Curiously, all MAS galaxies are of the (r) arm type subclass, where the arms start tangent to the disk, rather than of the (s) subclass, where the two major arms spring from the ends of the bar.

The thin, moderately well defined multiple arms in NGC 1169 are more lumpy than in NGC 6942 but not as lumpy as in NGC 73 71 to the right. The inner disk is smooth, showing the absence of recent star formation.

NGC 7743 SBa HA, p. *43*
PH-769-S (VE,L,0) panel 91
Aug 23/24, 1954
103aD + GG13
45 min

NGC 7743 is later in the SBa section than NGC 936 but, from the character of its arms, is slightly earlier in the sequence than NGC 6942. The galaxy is isolated. There is no evidence that environmental effects are the cause of the smooth arms. Rather, from the many smooth-armed Sa and SBa galaxies in the RSA that are not in clusters, the phenomenon is clearly a natural result of the formation process. Smooth-armed Sa and SBa galaxies are generic to the classification sequence.

NGC 7371 SBa(r)II panels 96, S12
CD-501-S (L,L,l/2)
Sep 27/28, 1978
103aO + GG385
45 min

NGC 737 1 is the latest SBa in the RSA. The star-formation rate in the multiple arms is higher than in NGC. 1 169 to the left, bul not as high as in Sb and Sc galaxies. The inner disk is devoid of recent star formation. The arms arc tightly wound (they are nearly circular). All these features give an early spiral class to the inner disk, but clearly not as early as SBO/a or as early within the SBa sequence itself as NGC 936 or NGC 6942.

The questions asked progressively by the morphologist during the classification process begin: "Is the galaxy as early as SBO?" Clearly not here. "Is the galaxy as late as SBb?" No—the arms are too tightly wound, nor are they full enough of III I regions, and the spiral arms are too regular. The classification question then becomes whether NGC 737 1 is at the early or tile late side of the SBa classification box. The boundary between adjacent morphological boxes along the sequence is arbitrary. It is. then, by definition that galaxies like NGC 7371 are of class SBa and that they themselves define the late segment of the SBa section as judged by the outer arms.

The common feature of the six galaxies on this panel is the nearly complete ring. The near-ring is invariably made of two tightly wound bright spiral segments that nearly overlap after each has unwrapped by a half revolution.

The SBa(r) prototype galaxies on this panel are arranged from early to late SBa morphology. The progression through the box is leftward across the top, then across the bottom from the left.

NGC 4643 SB0_3/SBa HA, p. *42*
PH-688-S (E,L,O) panel 97
Feb 9/10, 1954
103aO + WG2
30min

i\GC 4643 is later in the SBa progression than the first three smooth-armed SBa galaxies on the preceding page. Although the spiral pattern is of very low surface brightness, the thin spiral segments starting on the edge of the disk upon which the bar stops are definite and show evidence of recent star formation. The knots are presumed to be incipient HII regions.

NGC 1358 SBa(s)I panels 100, S8
CD-544-S (1,1,1/2)
Oct 1/2, 1978
103aO + GG385
45 min

The bright segments of arms in NGC 1358, which if wound tighter would form a broken internal ring like that in NGC 3081, is later along the SBa segment than the three galaxies in the top row. The regions in which the arms emerge from the ends of the bar are not well defined—a common feature among most galaxies having the NGC 2 10 look. NGC 1350 and NGC 22 IV to the right, are nearly at the same place in the classification sequence, near the middle third of the SBa morphological box.

NGC 1452 SBa(r) panel 97
CD-208-S (E,I,0)
Feb 10/11, 1978
103aO + GG385
4-5 niin

The arms in NGC 1452 are of higher surface brightness than in NGC 4643. At least three half-sets of arms, one set on each side of the bar, are present, forming a tight multi-arm pattern of thin fragments. A few small knots in the arms are suspected to be incipient HII regions.

NGC 2217 SBa(s) HA, p. *43*
CD-826-KW (1,1,0) panels 101, 104
April 30/May 1, 1979
103aO + GG385
30 miii

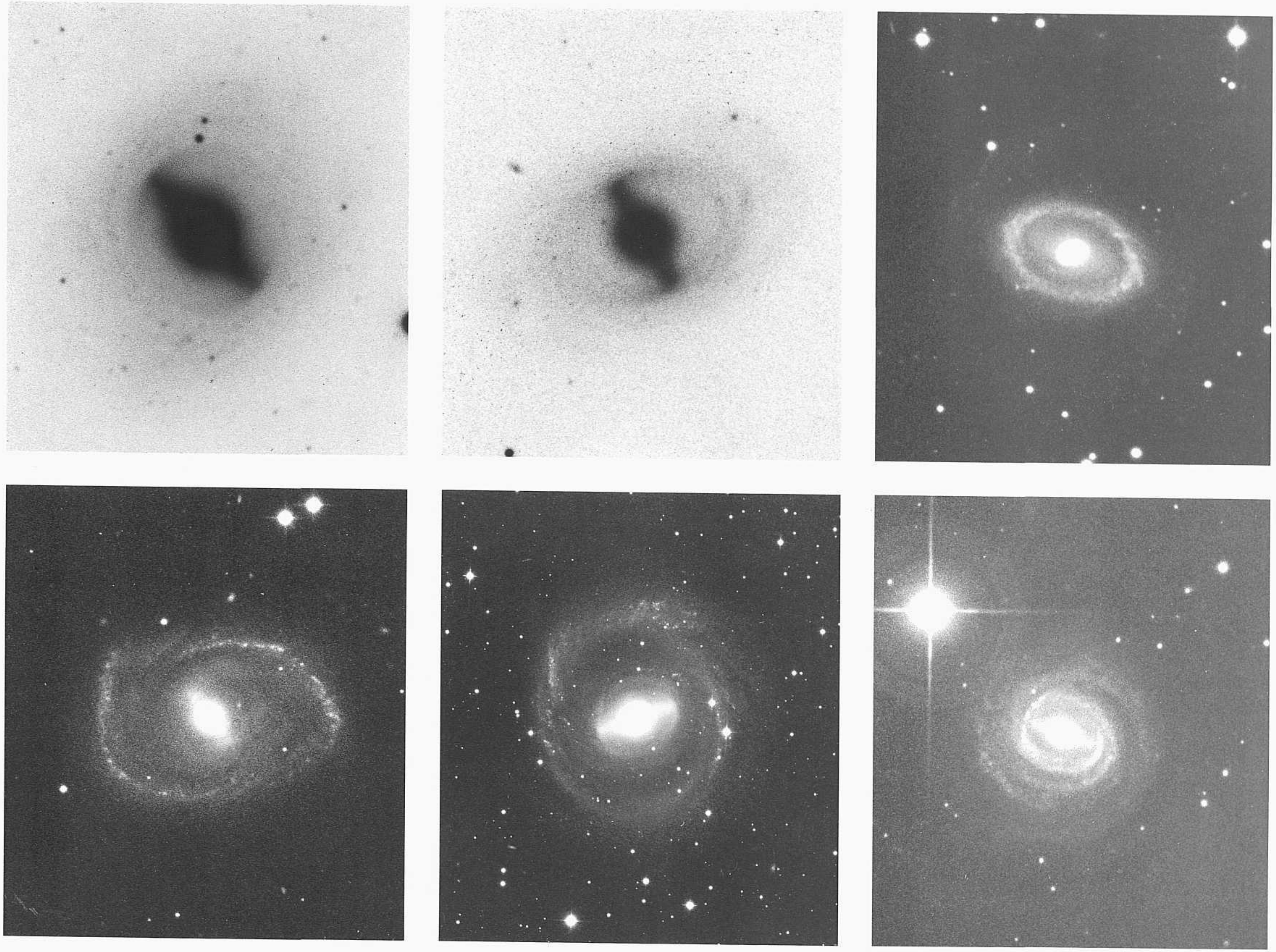
NGC 2217 is a type example of SBa galaxies having the NGC 210 look hut which are viewed nearly face on. The form of the external arms in NGC 2217 and the nature of their attachments to the rim of the inner disk are similar to those of NGC 13 58 at the left which, however, is viewed at a higher inclination angle than NGC 2217, showing more directly the relation of the form here to that of the Sb galaxy NGC 210.

NGC 3081 SBa(s) HA, p. *11*
CD-665-Br (ring type, 1/3) panel 99
Jan 22/23, 1979
103aO + GG385
45 min

NGC 3081 is the prototype for galaxies having bright near-rings shown on the preceding panels of this section. The form is described often in these panels and in the descriptions in the Hubble Atlas.

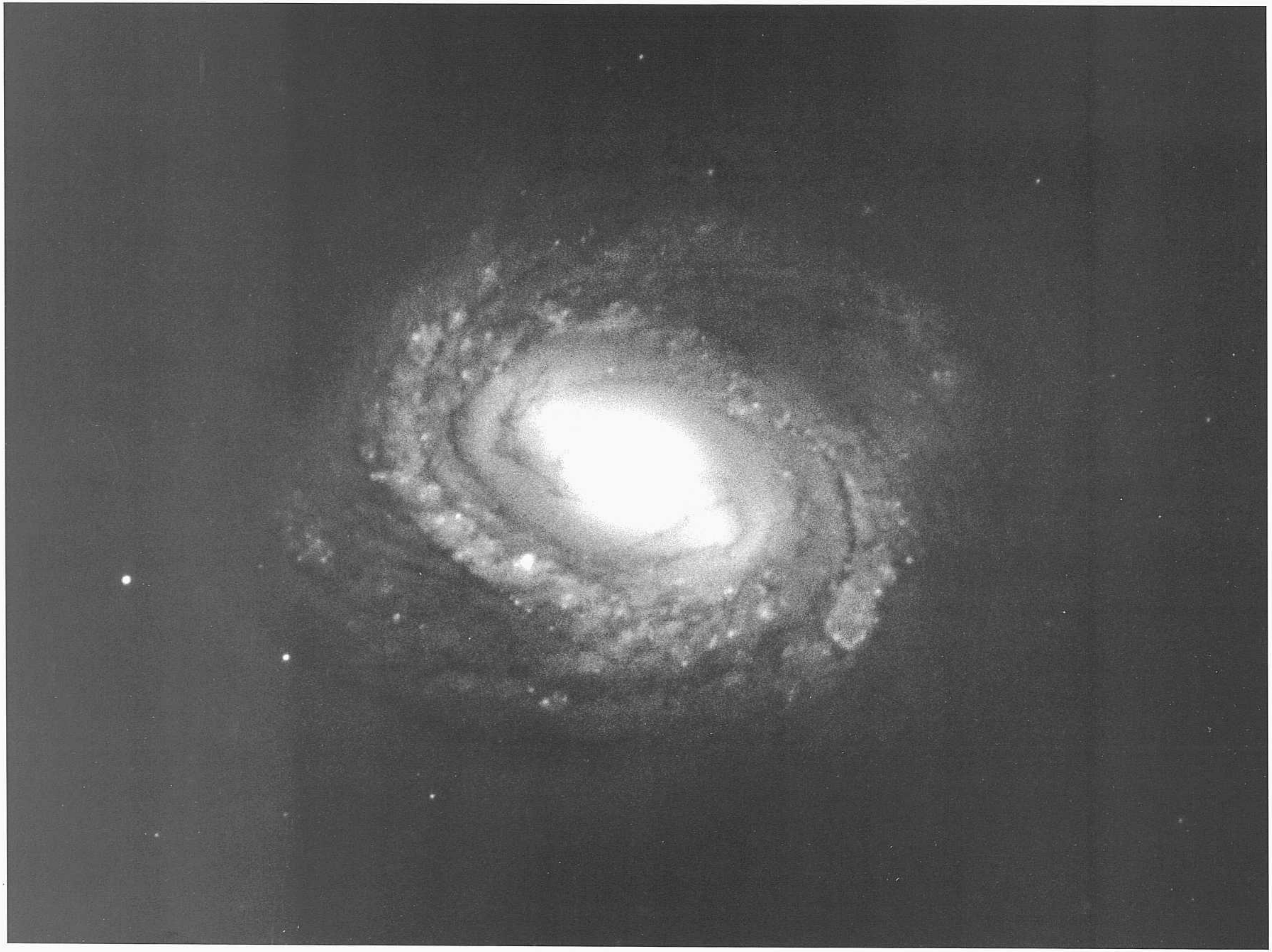
NGC 3783 SBa(r)I panel 98
CD-158-S (1,1,1/4)
Feb 3/4, 1978
103aO + GG385
45 min

NGC 3 783 is the latest SBa(r) galaxy in the RSA. The tightness of the arm wrap, the regularity of the spiral pattern, and the small (albeit finite) rate of star formation in the thin arms show that the type is earlier than SBb but clearly later than early SBa. As with NGC 7371 on the preceding panel, NGC 3783 defines the boundary between late SBa and the early SBab types.



PANEL
107

PANEL
108



The Sab Classification Section

There are no intermediate types, such as Sab, She, or Scd, in the Hubble Atlas. Therefore the morphological boxes that contain the Sa, Sb, and Sc types in that atlas are very long; said differently, the variations in the characteristics within a given morphological type are wide in the original Hubble (1926) system. The intermediate types, recognized in the RC2, the RSA, and this atlas, provide a finer division along the spiral sequence.

The classification criteria for Sab galaxies are (1) a higher current star-formation rate in the arms than in Sa galaxies, (2) arms generally having lower surface brightness than in Sa types, (3) arms that are well defined (the geometrical entropy is high), not as tightly wound as in Sa galaxies but more so than in Sb types, and (4) central regions (bulges) larger than in most Sb galaxies and much larger than in all Sc and Sd galaxies. These statements are equivalent to saying that there is continuity between the Sa and the Sb sections: the characteristics of Sab galaxies are intermediate between those of Sa and Sb types.

NGC4579 Sab(s)II VCC1727
PH-13-Baum **HA, p.** *i:i*
Jan 31/Fel, 1, 1952 **M58**
I03aO + WG2
30 min

NGC 4579 is a prototypical Sab toward the late end of the Sal) section. There are two principal massive arms, threaded throughout by many thin dust lanes. These lanes have kinks and branches that deviate from curves with smooth derivatives. Note the segments of dust branches connecting the bright inner arm in the lower-left quadrant with the fainter arm farther out on the same side that is the extension of the opposite inner main arm in the upper-right quadrant.

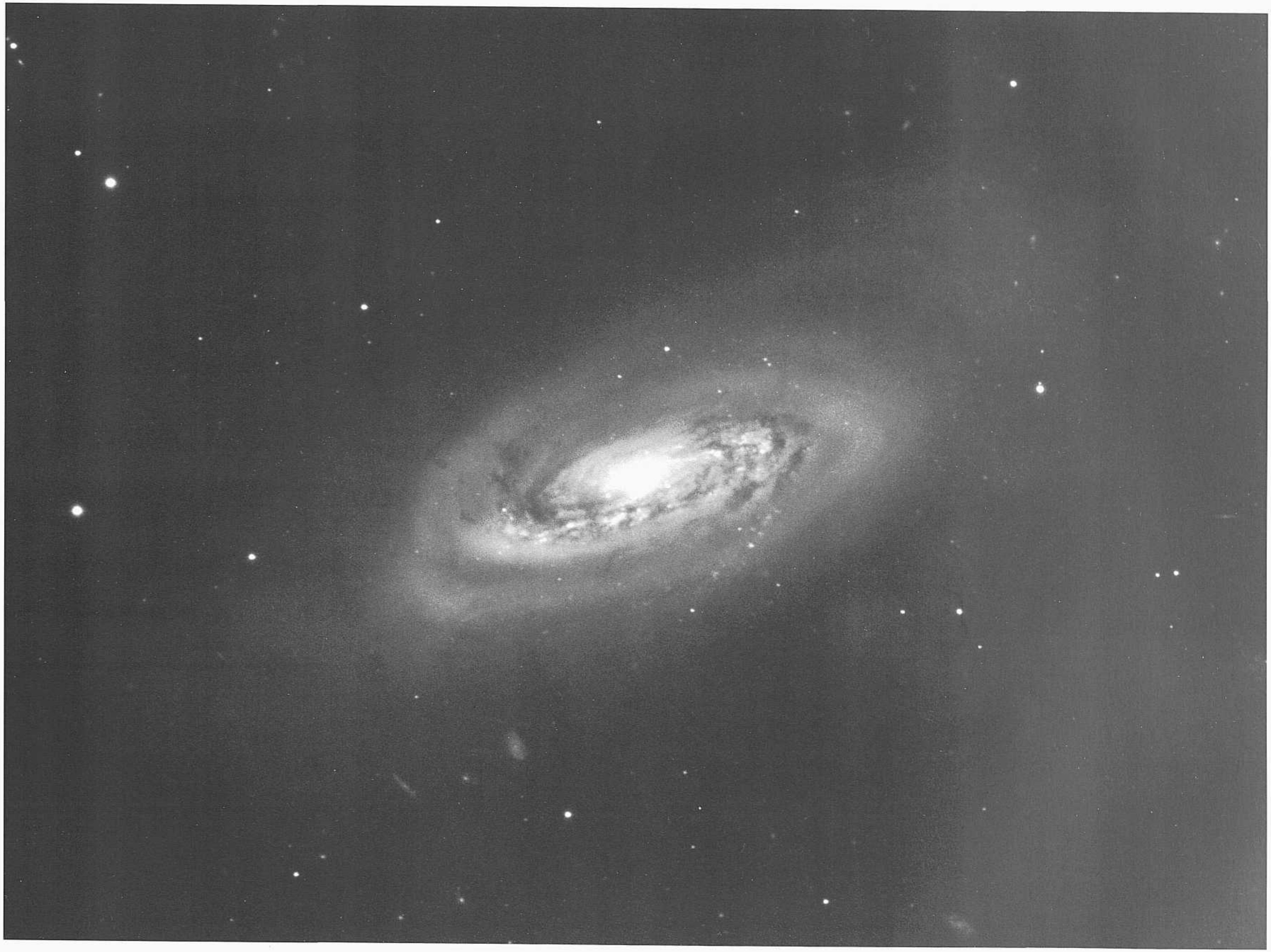
Dust lanes also exist in the smooth, central region. They are only partially seen in the image here, which has been printed to show the outer arms rather than the intricate and delicate interior dust lanes.

In classifying galaxies ol this type, the classifier asks, "Is it an Sa?" If not. it is later. Then. "Is it as late as an Sb?" If not, then it must be an Sab. NGC 4579 is an Sab by this elimination method.

NGC 4569 **Sab(s)I-II** **VCC 1690**
PH-12-Baum **HA, p. *13***
Jaii 31/Feb 1, 1952 **M90**
103aO + WG2
30 min

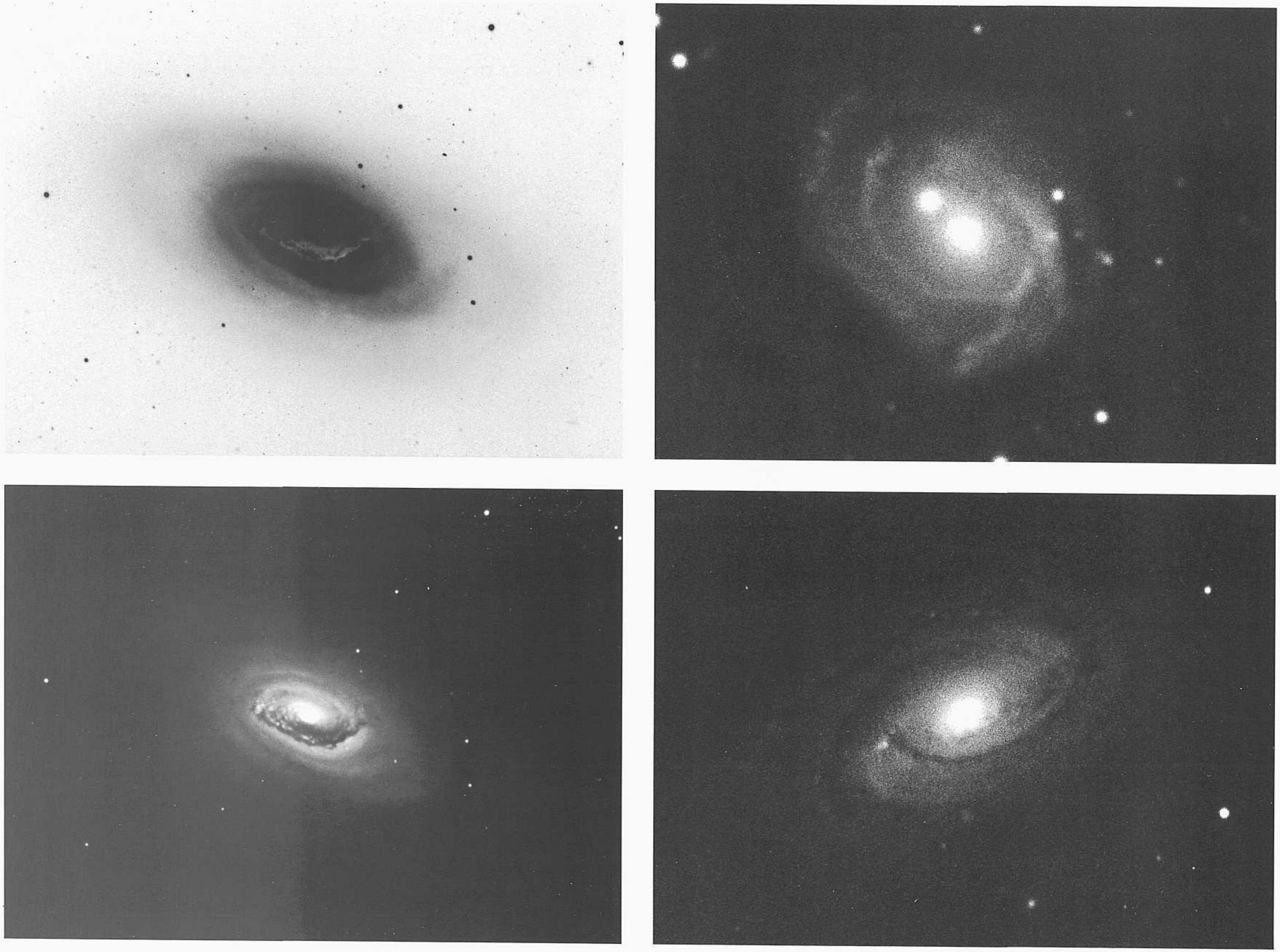
NGC 4569 is **among** the earliest of the Sab types. The outer arms are smooth, similar to the early-type smooth-armed Sa prototypes (NGC 1302. panel 70; NGC 281 1 , panel 65), **but the** massive thick dust lanes in the outer region of the **bulge require** a later classification. Incipient star **formation** in the dust is evident. Small knots, presumed to be small **Mil** regions, exist in the dusty inner arms. The combination of smooth outer arms devoid of much current star formation and the active, very dusty inner region is **moderately** unusual.

The galaxy is in the **direction of** the Virgo Cluster, about 1.5° northeast of the center of **Virgo subcluster A (Binggeli,** Tammann, and Sandage 1987) associated with NGC 4486. The large **angular** size **of** NGC 45 69 and its negative velocity of v_o = —241 km s^{-1} were at one time cited by some to place NGC 4569 in the foreground. However, no galaxies in the RSA outside the Local Group have negative v_o velocities except six galaxies in the direction of the Virgo Cluster, a circumstance that shows that the negative velocity must reflect the large velocity dispersion of Virgo Cluster members. Furthermore, other Sb and Sc galaxies in the Virgo Cluster are as large in angular size as NGC 4569 (van **der** Kruit 1986). There seems **little question** but **that** NGC 4569 is a Cluster member.



PANEL
109

PANEL
110



NGC 4826 **Sab(s)II** **HA, p.** ***13***
S-Ritchey #65 **M64**
May **5/6/7/8, 1910**
blue plate
7 hr* 56 min

The morphology **of NGC** 4826 is nearly identical to that of NGC 4569 on the preceding panel. Massive, smooth outer arms exist which would normally require an early-Sa classification. However, the **central region is** covered with dust to an extent **inconsistent** with a **typical** Sa morphology, yet **the star-formation** rate is low both in the **central** region and in **the** arms. As with NGC 45 69. the compromise classification is Sab.

NGC 4826 **Sab(s)II** **HA, p.** ***13***
S-Ritchey #58 **M64**
March 8/9, 1910
blue plate
4 hr

The images of NGC 4826 **here** and **at the** top are from different original plates, **both** taken by Ritchey in 1910 as tests of the newly commissioned Mount Wilson 60-inch telescope, whose optics were made by Ritchey. The **exposure** on the plate used here was made on a single night. The plate for the top print, above, was made over a three-night interval, exposed **for** a total of 476 minutes.

The massive dust features in the central regions are seen silhouetted against **I**he **bulge** light on the near side. The fact that the asymmetry in the luminosity distribution is parallel to the major axis suggests that the **apparent** dust asymmetry is due to the viewing angle at the high inclination and not to a true nonuniform dust distribution in the plane.

NGC 3865 Sab(r)
CD-1463-S/Br
May **10/1 1, 1980**
103aO + GG385
15 miii

The spiral arms **of** N(»(I 3865 are thin and peculiar. They **form an almost-complete internal** ring, from which a single-armed, spiral **pattern** emerges. The form may be due I> an encounter [one galaxy **dropping** through **another, as in Theys** and Spiegel **(I** 976. **I** 977) and **Lynda** and **Toomre (1 976)]. The** second bright image inside the thin spiral **near-ring** at position angle I I o'clock **is a separate galaxy,** though presently **(1990) of unknown redshift, which would lit the model for the ballistic** galaxy set **oul** by these authors.

NGC 4450 **Sab pee** **HA, p.** ***13***
H-2432-H **panel S14**
May 17/18, 1947
103aO
25 min

The image **of** NGC 4 150 here was made **from** the same Mount Wilson 100-inch plate *u^vd* in the Hubble Atlas. The description there *says* "there is no doubt thai this galaxy lias the same soft massive arms as NGC 4826 [left column here], NGC 4569 [preceding panel] and **NGC** 4579 [two panels hack]."[1]

The unusual feature of the thin dust lane is its place of origin far from the center near what appears to be a small **II1I** region.

NGC 434 Sab(s) triplet
CD-438-Rosc
Aug8/9, 1978
103aO + W2c
60 niin

NGC 434 is the brightest member of a physical triplet whose other members are NGC 434A (S pec, interaction?) at 3.1' separation, and NGC 440 (Shell) at 4.9' separation. The redshifts are $u_o(434)$ = 4783 kms"', $u_o(434A)$ =470 5 km s̄ \ and $u_o(440)$ = 502 1 km s~ . The projected linear separations from NGC 434 arc 87 kpc and 138 kpc for NGC 434A and NGC 440, respectively.

The spiral pattern of NGC 434 has the NGC 210 look (panel 124), described often in the Sa section (see in particular the description of NGC 1543 on panel 100). The outer set of arms is more open than the tightly wound inner spiral pattern defined by the inner dust lanes. Other dust lanes are prominent throughout the farther-out disk. The only evidence for star formation is the string of knots (presumed HII regions) in the spiral arm below the major axis in the print here.

NGC 2196 Sab(s)I
CD-707-S
Jan 30/31, 1979
103aO + GG385
45 min

The spiral arms in NGC 2196 are tightly wound about the large, generally smooth central region (burned out in the print here) which, nevertheless, has a series of very regular spiral arcs (formed by dust) traceable to the center of the image. Present-day star formation is evident in the two main outer arms.

The spiral arms here have features common to the two main types of spiral patterns, the grand design and the multiple-armed-spiral (MAS) types often described in the Sa section. The outer arms of NGC 2196 are of the grand design pattern. The many inside arm fragments have a mini-MAS pattern, but one which is much less pronounced than in the prototype MAS galaxies NGC 2775 (Sa: panels 78, 87, S12), NGC 4380 (Sab: panel 117), NGC 2268 (She: panel 188). NGC 3953 (SBbc: panel 204), NGC 4689 (Sc; panel 277), NGC 4647 (Sc; panels 51,278, S14), and NGC 7 793 (Sd; panels 32 1, S6), and the prototypes of the pattern in NGC 2841 (Sb: panels 142, S4, S12), and NGC 488 (Sab: panels 1 15. 116, S3, S12).

NGC 2985 Sab(s) Racine wedge
PH-7712-S
Feb 11/12, 1980
103aO
12 niin

NGC 2985 is of the MAS type. Fragments of arms can be traced throughout the underlying disk over its entire face, continuing very close into the center. The regularity and tightness of the spiral pattern and the thinness of the arm fragments are the criteria for the Sab classification rather than Sb.

The plate was made with a Racine wedge in the optical path. This gives double images with a magnitude difference of 5 mag and an angular separation of 18".

NGC 7716 Sab(r)I
PH-7277-S
July 22/23, 1976
103aO + GG13
25 min

Like NGC 2196, NGC 7716 has features of both the grand design and the MAS spiral types.

The central part of the image consists of a high-surface-brightness bulge whose major axis position angle is tipped by 15° to the position angle of the smooth inner disk, inside of which no spiral structure exists. Both of these features (the bulge and the smooth inner disk) are nearly burned out on the print here.

The spiral pattern begins at the rim of the smooth inner disk. Knots, presumably HII regions, reside primarily on the rim of the disk. The system of two principal thin, tightly wound arms begins on this rim. As the arms wind outward they fragment into several branches. Many knots (HII regions?) exist in the outer arms, indicating an appreciable recent star-formation rate.

NGC 7126 Sab(s)I pair
CD-1520-S/Br
Aug 5/6, 1980
103aO + GG385
45 min

NGC 7126 forms a close pair with NGC 7125 (Sc/SBc; panel 225) at an angular separation of 6.1'. The redshifts of $u_o(7125)$ = 2910 km s~' and $ti_D(7126)$ = 2888 km s~' suggest a common distance of 58 Mpc, giving a projected linear separation of 103 kpc.

The spiral pattern is of the NGC 210 type. Two sets of arms exist. The outer, lower-surface-brightness set is more open than the inner, high-surface-brightness set, burned out in the print here. The thinness of the arms, the regularity of the pattern, and the small-to-moderate recent star-formation rate justify the Sab classification rather than Sb.

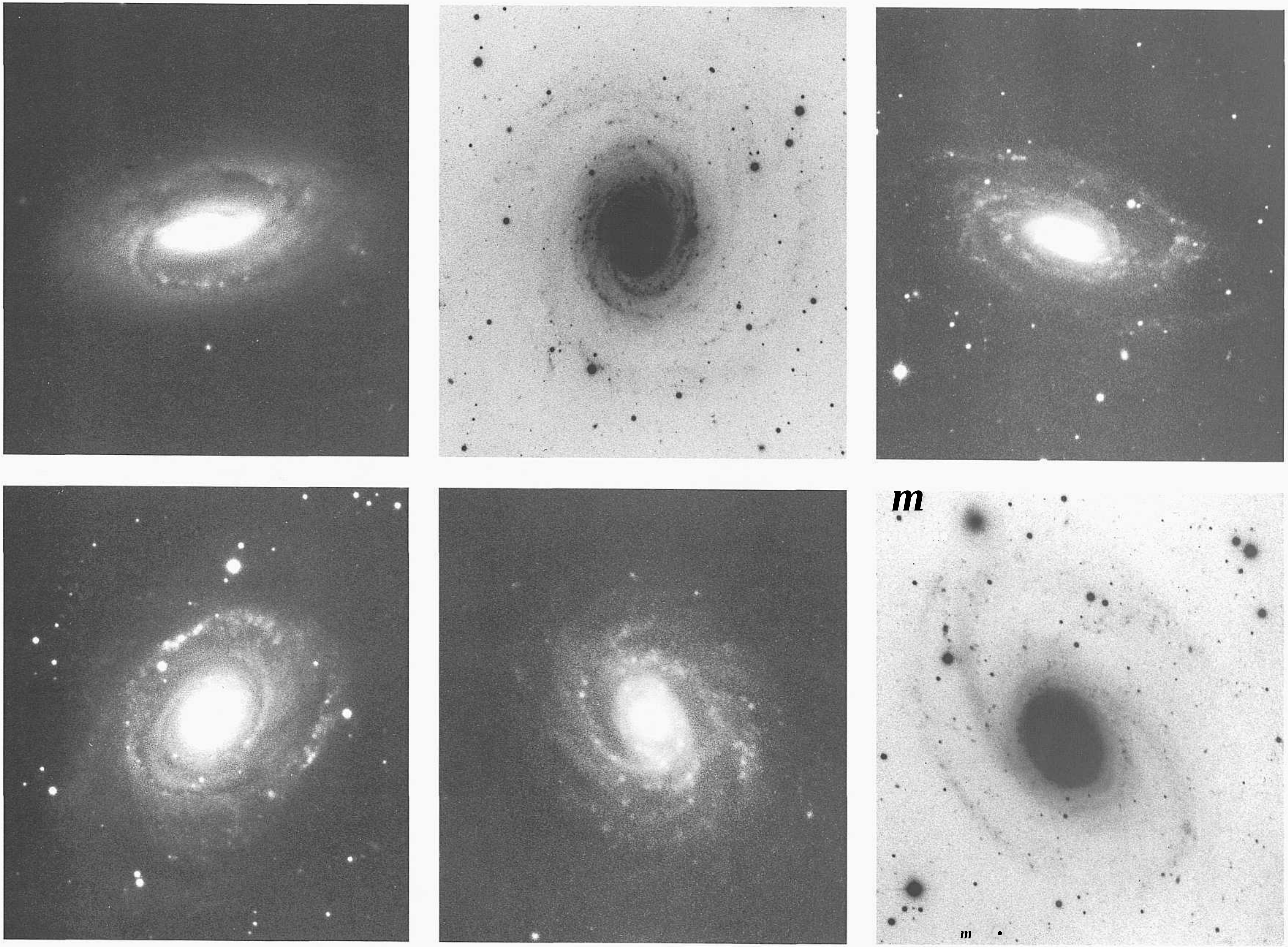
NGC 2460 Sab(s) pair
PH-7898-S panels 145, S3
Nov 6/7, 1980 Racine wedge
IHaJ
120 min

NGC 2460 forms a wide pair with IC 2209 (Scd; Markarian 13) at an angular separation of 5.3'. The redshifts are $i;_o(2460)$ = 1592 km s"' and u_o(IC 2209) = 1503 km s"'. giving a projected linear separation of 48 kpc using a redshift distance of 3 1 Mpc (H = 50).

The outer arms, of the NGC 210 type, are of exceedingly faint surface brightness, shown in the high-contrast print here. A tightly wound multiple-spiral pattern exists in the inner region, burned out on this print.

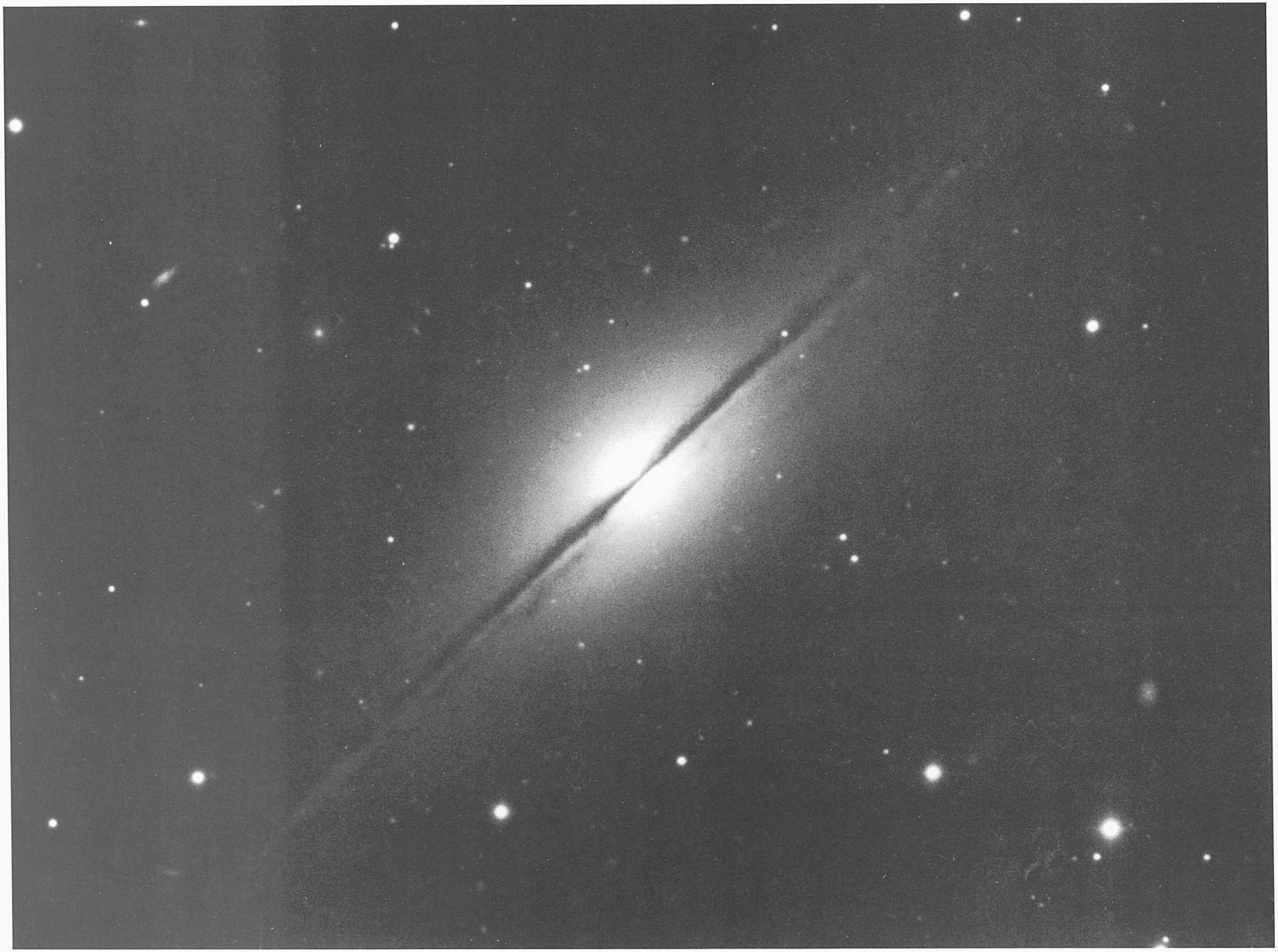
A candidate for a dE,N nucleated dwarf elliptical companion is present at the upper-left border of the print, seen in projection near the end of one of the outer arms. However, this faint, low-surface-brightness galaxy is equally probably in the background, as its morphology is not precisely like prototype dE galaxies (Sandage and Binggeli 1984).

The secondary Racine wedge image is below and slightly to the left of the primary image in the orientation here. Note the different orientation of the image in panel 145.



PANEL
111

PANEL
112



NGC 7814 **S(ah)** **panel SI 1**
PH-770-S
Aug 23/24, 1954-
103aO
25 niin

NGC 7814 is one of those centrally important textbook galaxies where the **various components of galactic** structure are seen directly **because** of the favorable aspect **angle of the line** of sight. The central bulge is flattened, but not to the same **degree** as the exceedingly **thin** disk which is the principal feature of NGC 7814. The bulge light is smooth, giving **no indication of** recent star formation.

Bulge stars have not collapsed to a disk but retain the semi-spherical shape of their initial energy of motion. This shape is **determined** by the nearly **spherical** velocity ellipsoid of the three-dimensional velocity **distribution.** Evidently- stars were formed in the **bulge in a time** that was short compared with the (free-fall) collapse time of the prototype galaxy gas (of about 10^9 years): otherwise, the collapse **would** have continued until gas-gas collisions would have dissipated the potential energy of position, creating a disk with no bulge. (See Chapter 4.)

On the other hand, the paper-thin disk, which is **clearly a highly dissipative** structure, must have formed after the bulge because the gas-gas collisions did occur, dissipating the gravitational energy via radiation by ordinary atomic processes as the **collapse** of the remaining gas proceeded to a plane. This collapse model, after Eggen, Lynden-Bell. and Sandage (1962), with no dissipation in the halo formation and strong dissipation in the disk, is almost self-evident, simply from the form of NGC 7814.

Photometry of the bulge, together with velocity maps of the bulge rotation, are given by Jarvis and Freeman (1985). **Jarvis** and Freeman also discuss the dynamics of bulges as related lo the fraction of the support of the figure due to ordered rotation and the fraction **due** to the kinematical filling of the phase space (i.e., concerning the nature of the velocity ellipsoid, often called pressure support). A definitive discussion of the surface photometry is by van tier Kruit and Searle (1982).

The galaxy is seen nearly, but **not quite,** edge on. The parallel structure in the dust lanes. **appearing as the fainter** lanes **below I** he main lane in **the** print here, **shows thai** we view **the thin** dust layer from slightly above **the** plane on the bottom **side** of the image here, seeing part of the **plane** in silhouette nil the near side (bottom) against the central bulge.

The morphological type is **uncertain,** of course, because of the viewing **aspect** angle. The Sab **type** is supported by the size of the central bulge and the absence of visible star formation in the **disk, which** is, however, **obscured** by the dust in **the** very thin plane. But **the type** is **not Sc,** as **the** bulge is too large, and there is no **evidence** of robust **star** formation in the disk. The type is not Sa because of the high dust content.

NGC 1594 **Sa^{+}/Sb"** **HA, p.** ***24***
PH-96-MH **panel SI 1**
March 16/17, 1950
103aO
30 min

NGC 4594 insert
PH-748-S
May 24/25, 1954
103aO + UG2
115 min

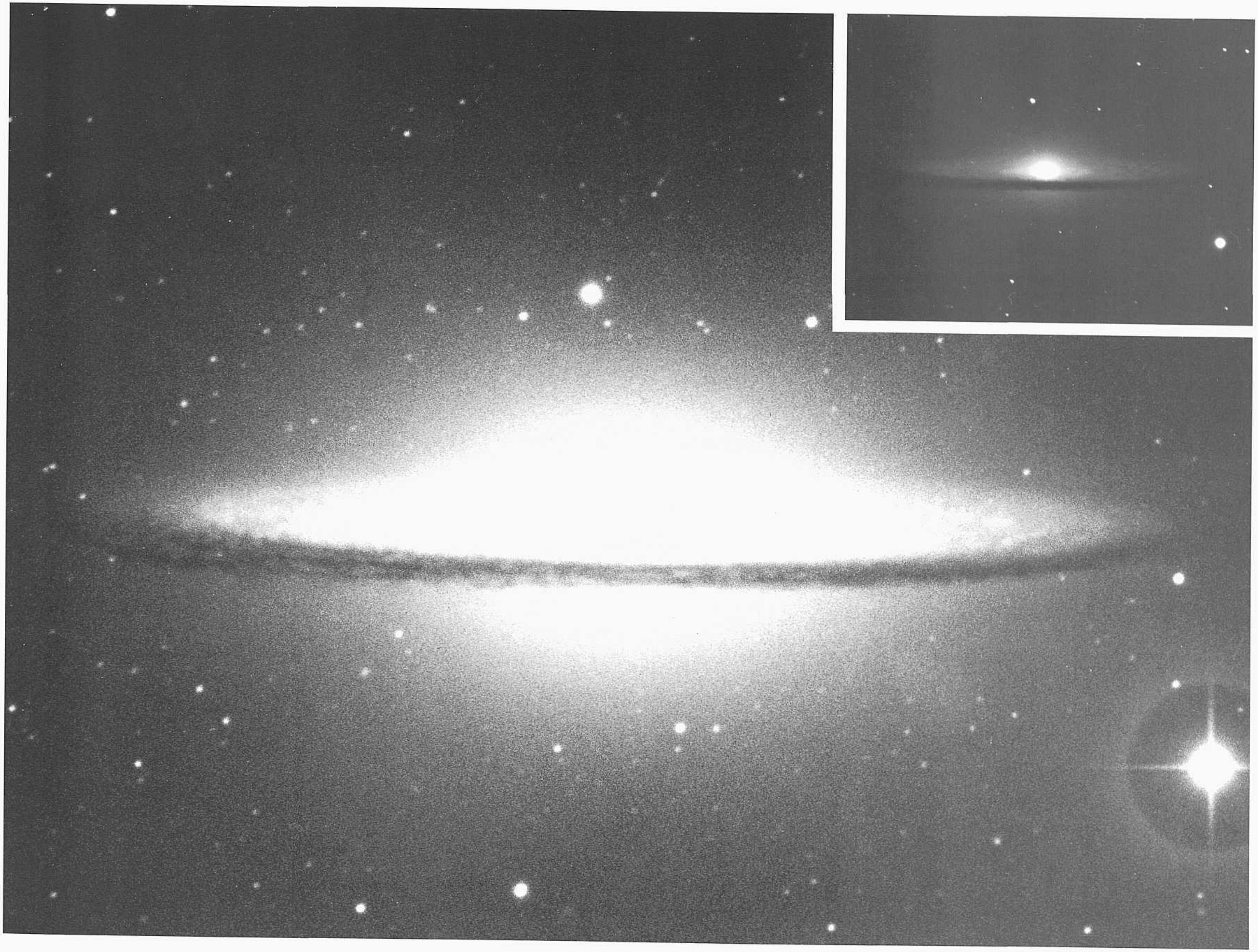
The **form of** NGC 4594 by itself reveals the two main processes in galaxy formation by collapse, much in **the** manner described on the preceding panel for NGC 7814. The processes are (1) free-fall collapse accompanied by star formation so rapid that all the gas in the bulge is changed into stars before completion of the collapse to the plane, and (2) the later formation of the plane by dissipation, the gravitational energy of position being radiated away by atomic processes in the gas-gas collisions of the gas that remains (Eggen. Lynden-Bcll. and Sandage 1962).

The bulge, with its nearly spherical (initial) three-dimensional velocity distribution, is formed on the short free-fall time scale. The disk is formed on a longer time scale determined by the radiation rate and the surface mass density build-up rate as the outer regions of the protogalaxy continue to collapse, probably even into modern times.

NGC 4594 is viewed at a slightly larger inclination angle than NGC 7814, shown on the preceding panel. The front and back sides of the disk are seen in the outer regions of the major axis away from the intense light from the bulge. Knots **(HII** regions) are seen in the disk. This disk appearance might well be observed if NGC 4380 (Sab: panel 117) were seen nearly edge on, although the bulge of NGC 4380 is evidently smaller than in NGC 4594.

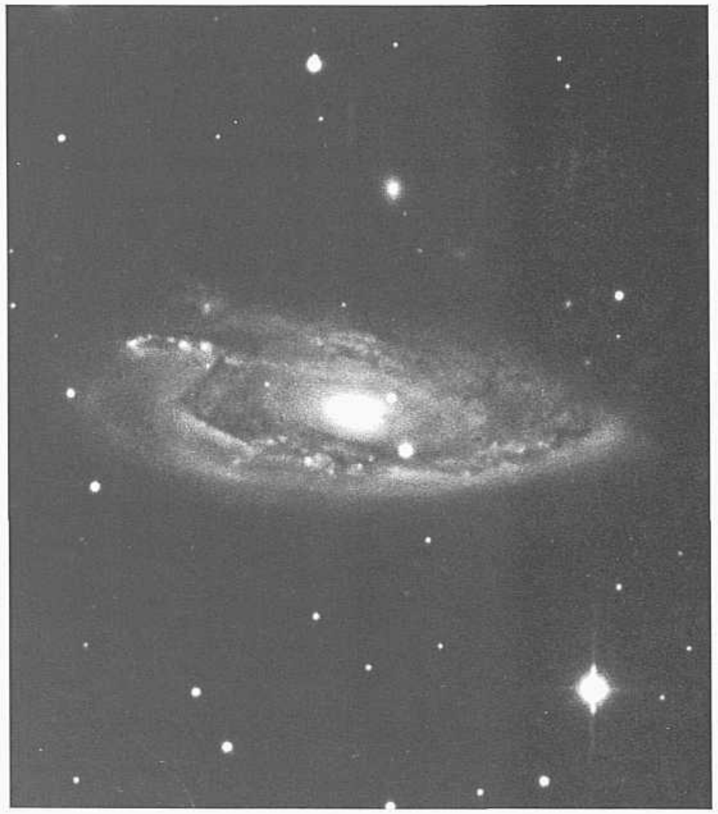
Surface **photometry** is given by van Houten **(1961), Burkhead** (1980), and **Boroson** (1980). Photometric data are also given by Jarvis and Freeman (1985) where, as for NGC 7814, in discussing the dynamics of bulges they **consider** rotation vs. pressure **support** for the bulge stars.

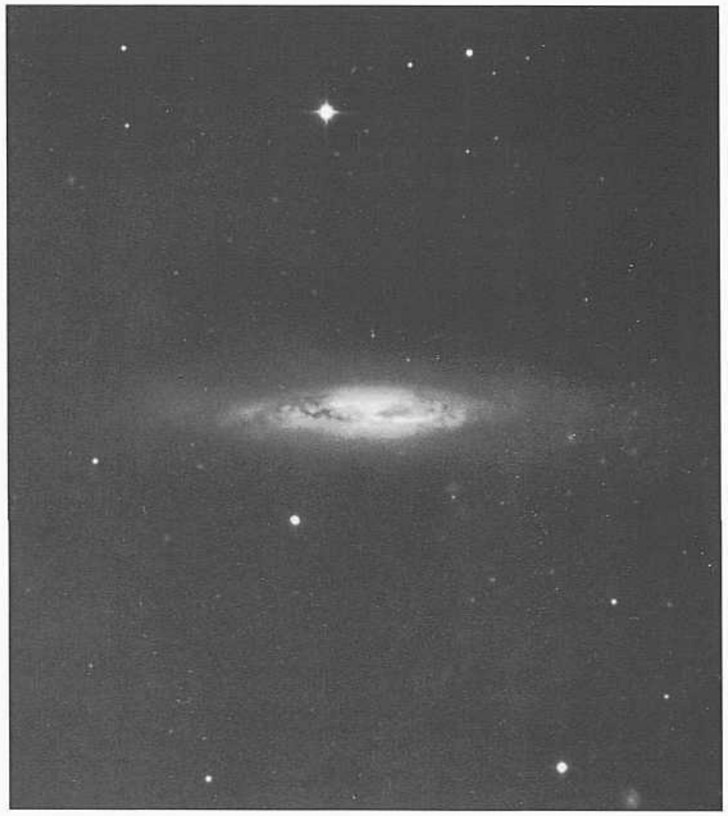
The insert image is from a UV plate (103aO + UG2) which suppresses the bulge and enhances the star-forming **regions** in the disk. From a much deeper UV plate by Baade, shown by Lindblad (1951). the many Mil regions in the disk are easily seen. Lindblad, upon measuring the positions of these knots and **rectifying** the image to face on. attempted to trace the spiral pattern. His reconstruction is that of an MAS **multiple-armed** spiral similar to NGC 4380 (Sab: panel 117) and NGC 488 (Sab: panels 115, 116, S3, S12).

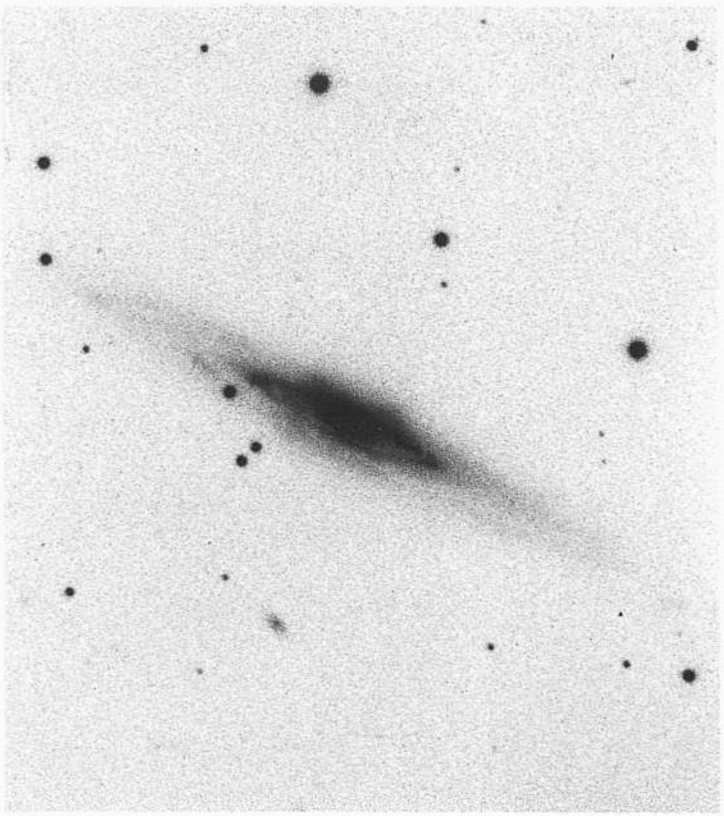


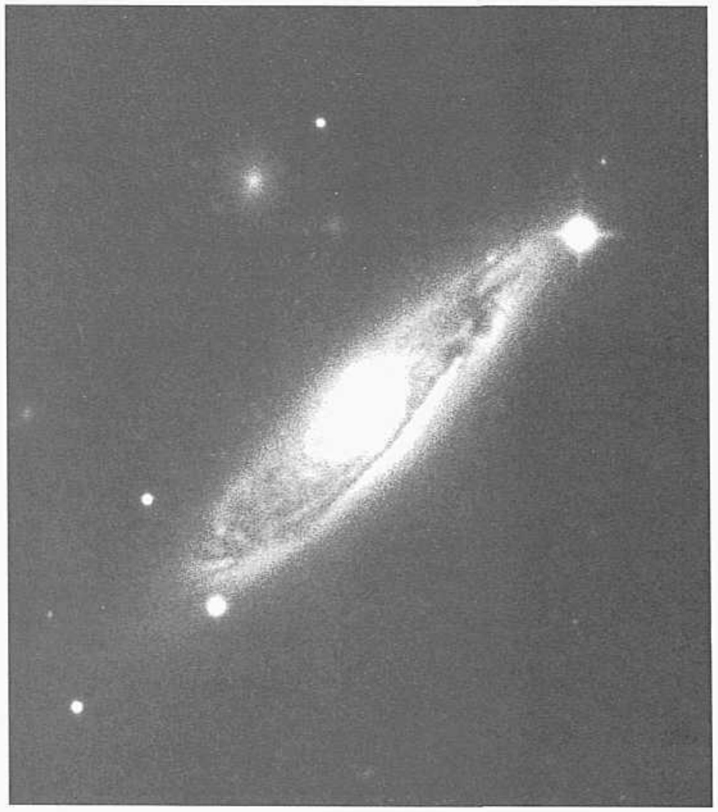
PANEL
113

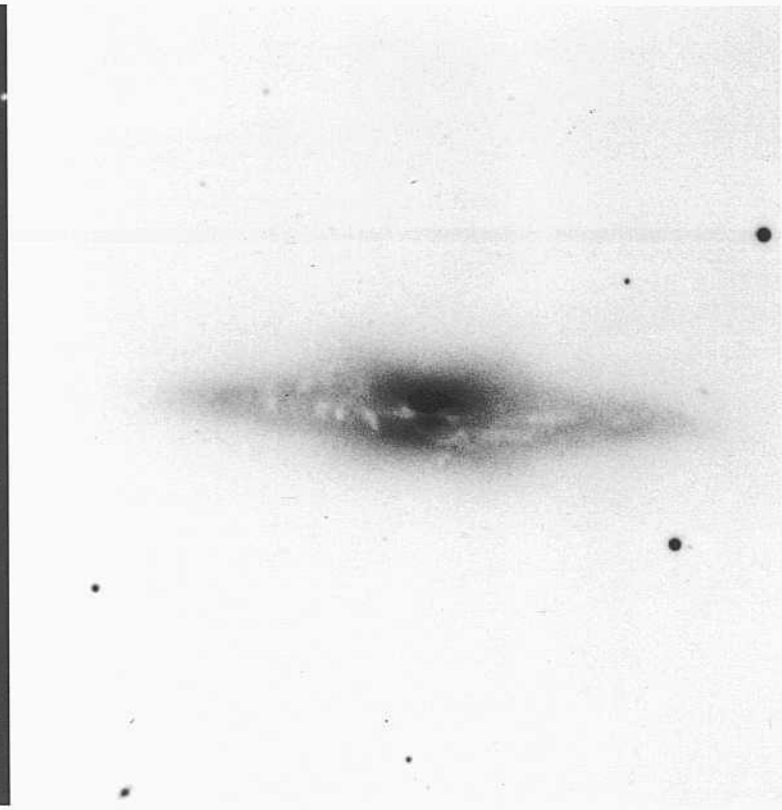
PANEL
114











The six galaxies **on** this panel are highly inclined to the **line of** sight, making **their morphological** types somewhat uncertain. The classifications are based **on** the size of **the** bulge. **the** thinness of the arms, and the small but finite **current** star-formation rate.

NGC3312 Sab(r) Hydra I Cluster
CD-690-Br
Jan 27/28, 1979
103aO + GG385
45 niin

NGC 3312 is the brightest spiral in the region of the Hydra I Cluster (Abell Cluster 1060). Although its velocity of v_o = 2494 km I[1] is smaller than the mean cluster redshift of <v_o> = 34 19 km s~' (Richter, Materne. and Huchtmeier 1982; Richter and Huchtmeier 1983), these authors accept it as a cluster member; the cluster velocity dispersion is 68 1 km s~[1].

The morphology of NGC 3312 is similar to that of NGC 4826 (Sab: panel 110) in its large dust complex in the disk. As in NGC 4826, the dust forms a massive spiral pattern winding through the disk. Knots, presumably **HII** regions, are evidence of a modest current star-formation rate.

NGC 5037 Sab(s) NGC 5044 Gr #68
CD-803-S
Feb 24/25, 1979
103aO + GG385
45 min

NGC 5037 is near the center of the rich NGC 5044 Group, which has an uncertain mean redshift of about <f_o> = 20 50 km s~[1] (Sandage 1978). The group is very rich and contains a large number of dE and dE,N definite dwarf members (Ferguson and Sandage 1991), three of which are in the print on the facing page, all above and to the left of the major axis. The brightest of these is number 7 1 in the NGC 5044 Group Catalog (Ferguson and Sandage 1990).

The morphology of NGC 503 7 is similar to that of NGC 482 6 (which is much earlier) and NGC 3312, above. The similarity is in the large amount of dust in the disk. The spiral arms are tightly wound, similar to those in NGC 3312, above. The central bulge is large.

NGC 4388 Sab VCC 836
CD-723-S
Feb 1/2, 1979
103aO + Wr2c
45 min

The classification of this nearly edge on Virgo Cluster galaxy is based on the similarity of the dust patterns to those in NGC 3 3 I 2 anil NGC 503 7 on this panel.

The disk can he well seen on the original plate. It extends both to the left and right borders of the print here.

NGC 4419 Sa(dust only) VCC 958
CD-2175-S panel 86
March 28/29, 1982
103aO
50 **min**

The similarity of the dust pattern and of the arms of NGC 4419, here, to the morphology of NGC 3312 and NGC 503 7 on this page is the basis of the classification as Sa(dust only). The independent type listed in the Virgo Cluster Catalog (Binggeli, Sandage. and Tainmann 1985) is also Sa.

NGC 2654 Sab:
PH-7534-S
Nov 4/5, 1978
I03a0 + **GG13**
I 5 min

Two sets *at'* thin spiral arms exist in NGC 2654 that are similar to the arm pattern in the more-face-on prototype galaxy NGC 2 10 |Sb: panel 12 1). which defines the form (often discussed in the preceding Sa section).

There is a luminosity extension above the plane in the central regions that has the form of an X. similar to but more pronounced than the peanut bulge shapes common in SO galaxies such as NGC 1 175. I 38 I . lift I .23 1 0.2519. 3203. 3390.4417. 5422. and 7332, described in the SO section. A description of the class, taking tC 4767 as prototype, is by Whitmore and Bell (1988).

NGC 4469 Sab(onedge) VCC I 190
CD-716-S
Jan31/Feb 1, 1979
103aO + \Vr2c
45 min

The large amount of dust, the large central bulge, and the lack of evidence for appreciable recent star formation are the criteria for the classification of NGC 4469 here as Sab.

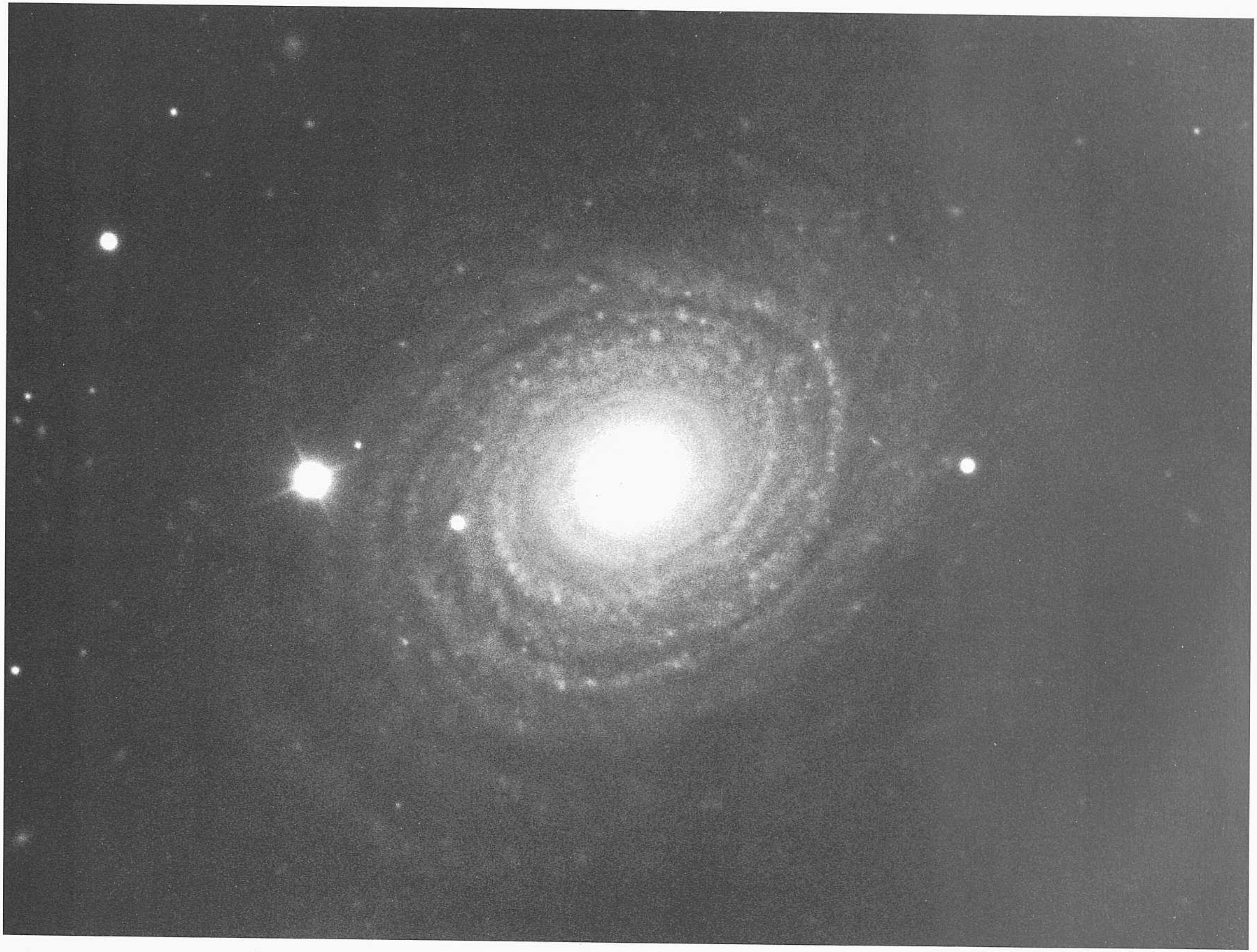
NGC 488 Sab(rs)I HA, p. *15*
PH-1053-S panels 116, S3, S12
Aug 24/25, 1955
103aO
30 min

NGC 488 is **the** prototype galaxy of the **multiple-armed spiral** (MAS) type which can be **traced throughout** the spiral **sequence** from **early** Sa **to** late Sd. Examples of galaxies of this type are NGC 2775 (Sa: panels 78, 87. **S12),** NGC 13 98 **(SBab;panels** 120, 12 **1).** NGC 4380 (Sab; panel 117). NGC 2841 (Sb: panels 142, S4, SI 2). NGC 3 521 (She: panel 188). NGC 42 12 (Sc: panel 2 78). NGC 4647 (Sc; panels 51, 278, S14). NGC 4689 (Sc; panel 277), and NGC 7793 (Sd: panels 321. S6).

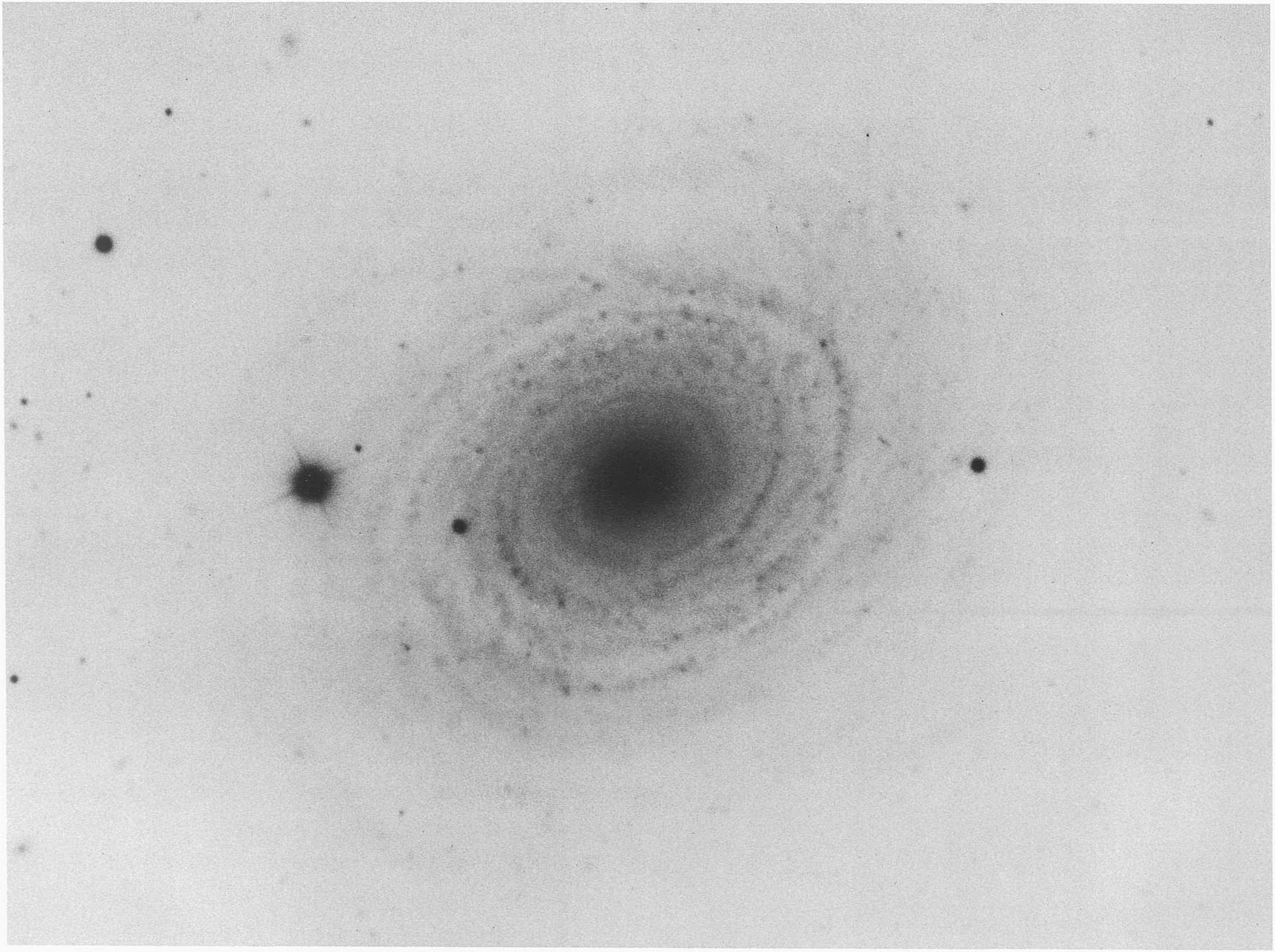
The form consists of **fragments** of strings arranged in a spiral pattern over the face of the disk. No **fragment** can be traced for more than about half a revolution. The spiral pattern Ln NGC 488 **is** very tightly wound, and the individual segments are thin. The arms are lumpy, clearly showing star formation confined to the arms themselves. Star formation does not extend randomly over the disk.

The central bulge is large and smooth. The innermost **spiral pattern,** partly burned out in the print on the facing panel, is composed of dust lanes with the same **spiral** opening angle as the luminous **arms** farther out.

In galaxies of this **type** later in the classification sequence, the arms become thicker, the **spiral** opening angle is wider, and the prominence **of** the central bulge is less.



PANEL
116



NGC 188 **Sab(rs)I** **HA. p.** /;5
PH-1053-S panels 1 15, S3, **S12**
Aug 24/25, 1955
I03a0
30 iiiin

The negative print of **INC(!** 488 here is made from the same plate used on the preceding panel and in the lluhhle Alias. The image there was printed In a different contrast and to a different scale.

An appreciation of the fragmented nature of the MAS type can be gained by attempting to trace any individual fragment as a coherent arm outward. The fragment soon disappears, i> be replaced by an adjacent 1ml separate fragment.

NGC **4380** Sah(s) **VCC 792**
CD-1351-S/Br
March 15/16, 1980
103a0
75 min

If the spiral arms were removed from NGC 4380. **the** extensive **underlying** disk **would** closely **resemble the pronounced** SO galaxies NGC 1553 and NGC 3056 (SO; panels 39, 53).

The arm fragments can he traced Lo within 5" of **the** center **of** NGC 4380 where there is a smooth-textured, small central region **devoid** of recent star formation.

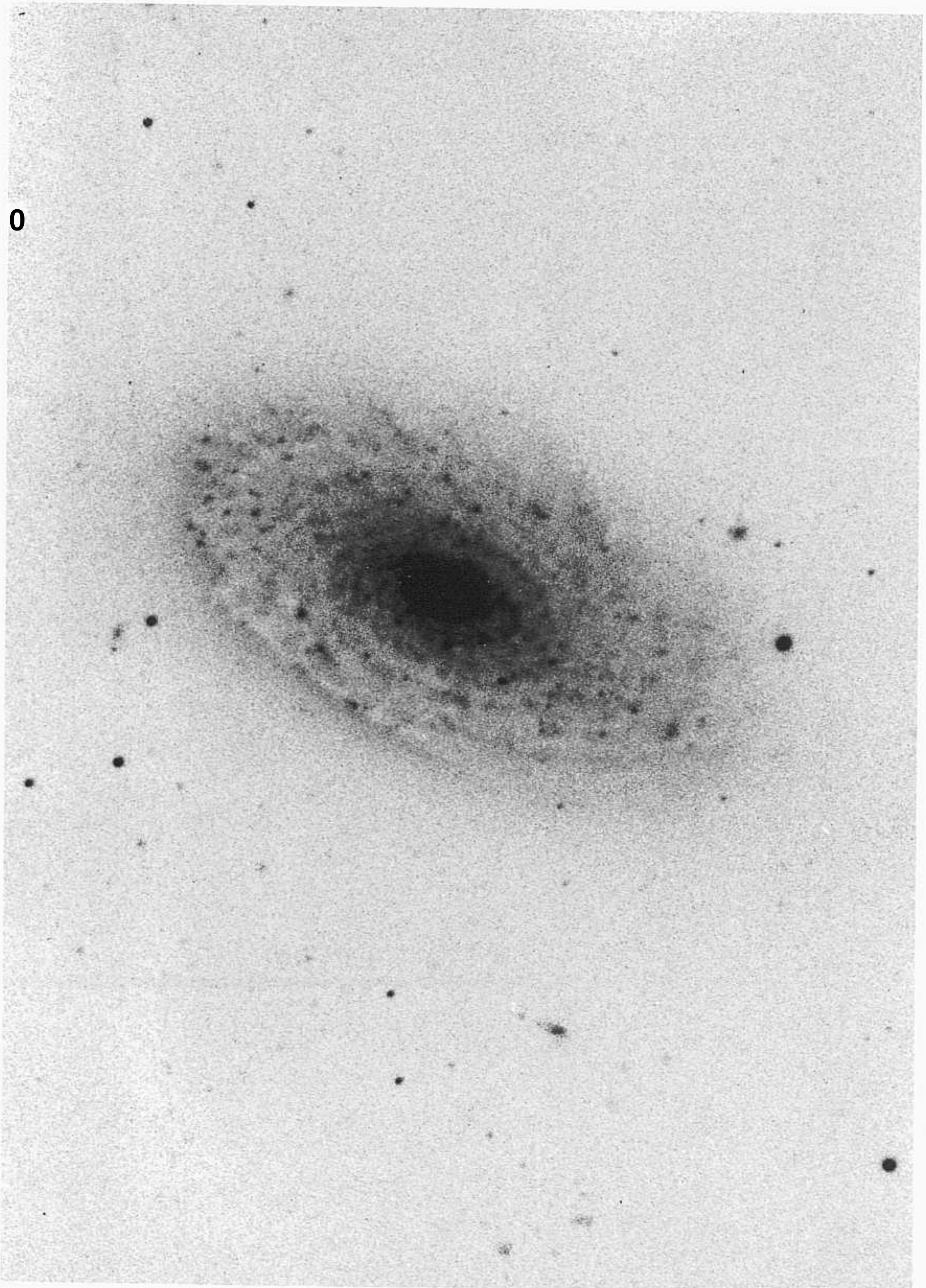
Dust **lanes** are evident on the insides of **the arm fragments,** seen **best** in silhouette against the disk on **the** near side, assumed to he below the major axis in the print here.

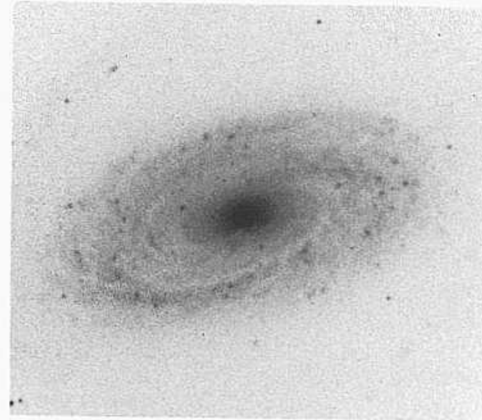
'The galaxy is in the **Virgo** Cluster region, midway **between** Virgo subclusters A and **B** (**Binggeli, Tammann,** and Sand'age 1987). **Its redshift** of v_0 = 967 km s^{-1} is close to the mean **velocity** of **Virgo** Cluster members.

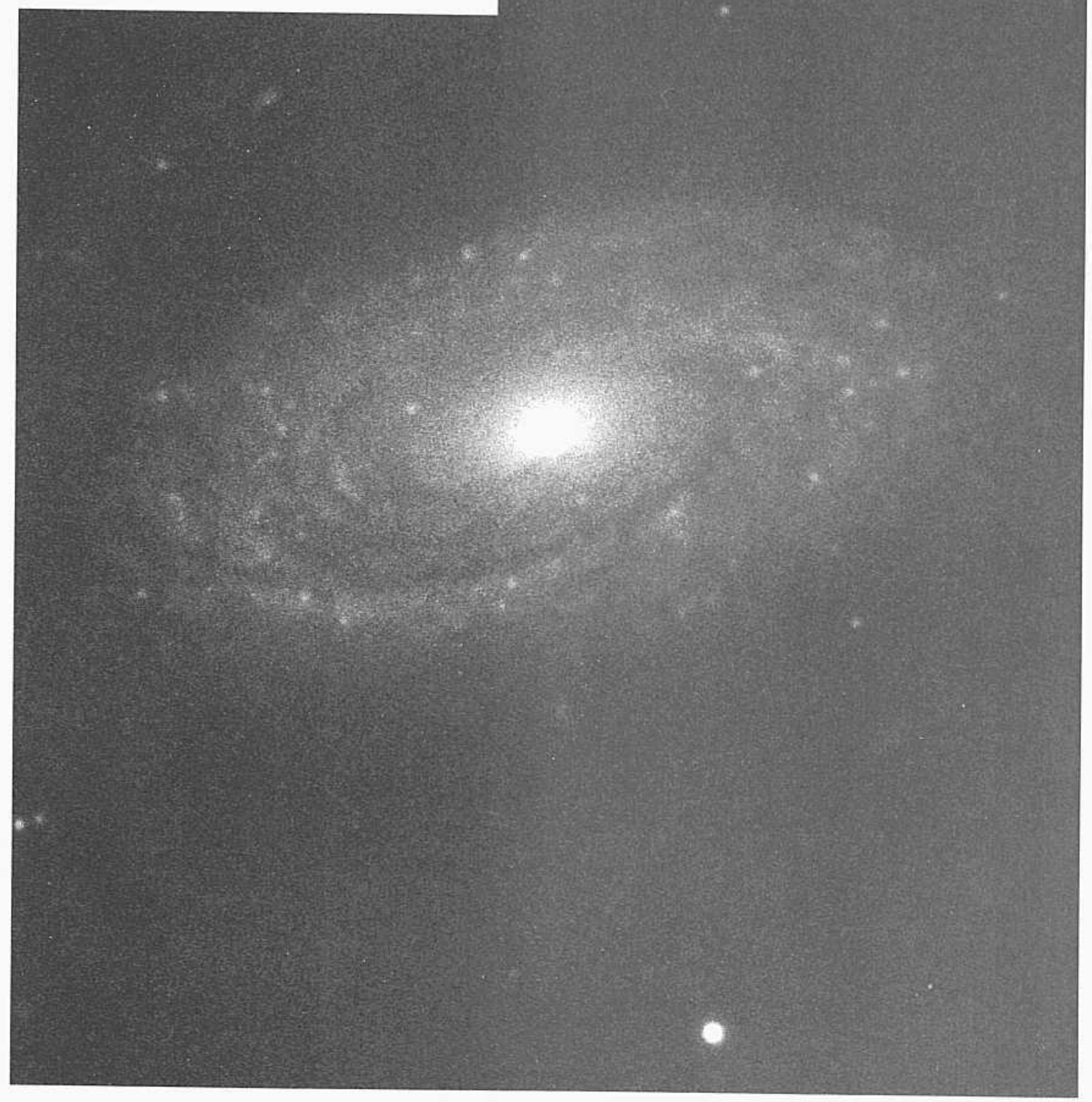
NGC 4941 **Sab(s)II** **HA, p.** ***10***
CD-1310-S/Br
March 11/12, 1980
103aO + GG385
60 niin

The multiple-fragment pattern of the spiral arms in NGC 4941 is similar to. but not as pronounced as, the individual fragments in NGC 488 (preceding two panels), which define **the** MAS class. The dust lanes, generally on the inside of the luminous arms, as usual, arc seen more clearly on one side of the image than the other, presumably owing to different silhouetting against the disk on the near (bottom) and far sides.

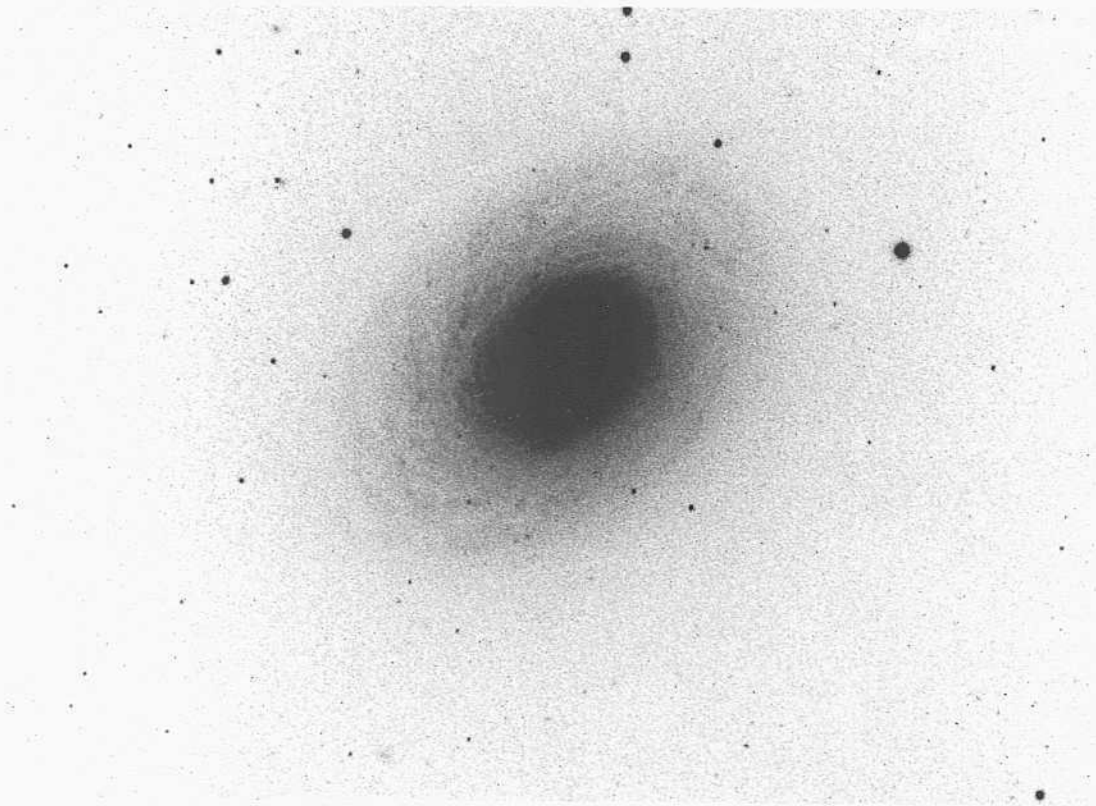
A **set** of very-low-surface-brightness outer arms exist that can just be traced in the negative insert print on this panel.

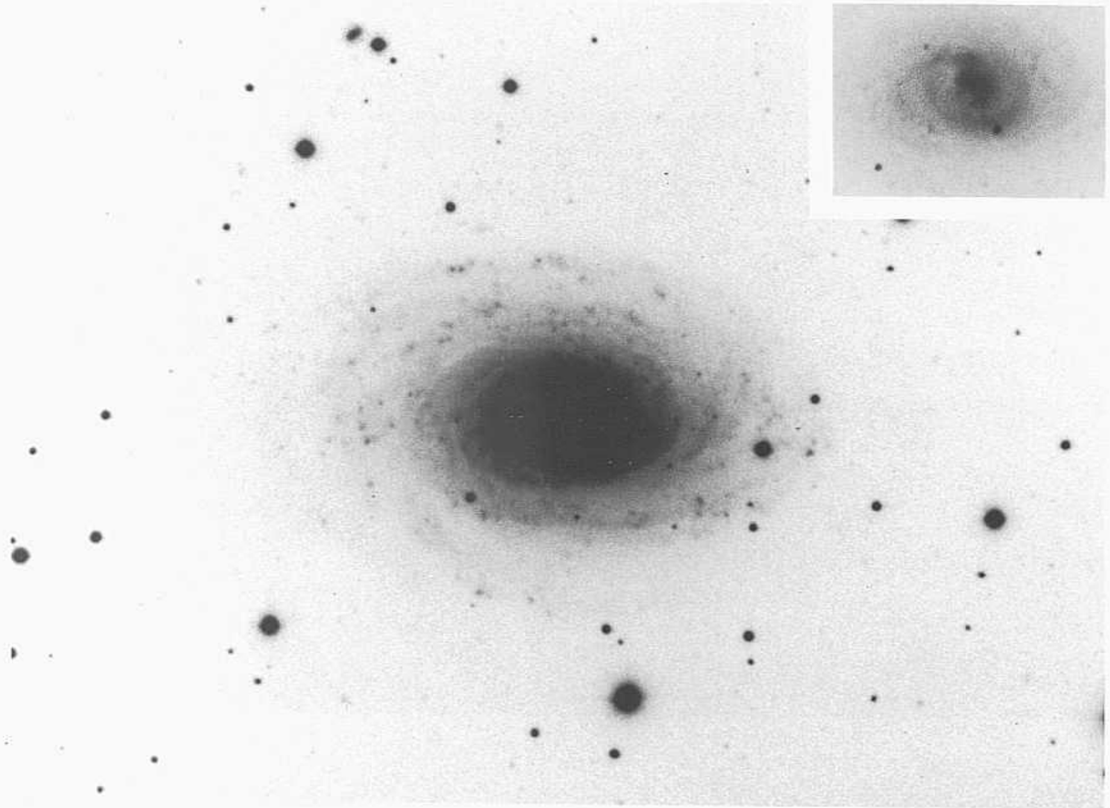


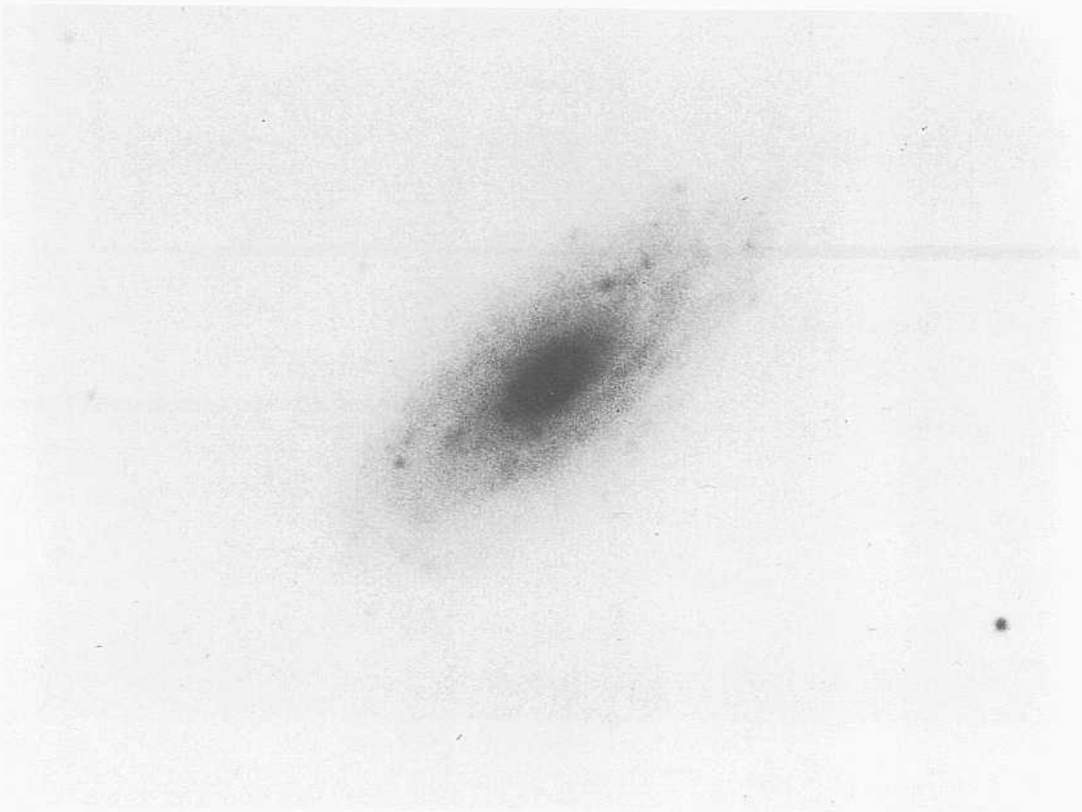




PANEL
118







NGC 4699 Sab(sr) or Sa HA, p. *16*
CD-1872-IIB panels 78, 87, S12
April 10/11, 1981
103aD + GG495
45 miii

This print of NCC 4699 is made from a different plate than was used in the Hubble Atlas. where the intricate spiral structure near the center, burned out here, is well seen. The highly fragmented, very thin spiral strands, defined both by luminous fragments and by dust lanes, can be traced to the center, as emphasized in the Hubble Atlas description from *a* blue plate. The print here is from a yellow plate which suppresses the blue arms, well shown in the Nubble Atlas print.

NGC 4699 is also shown on panels 78. 87. and SI 2 in the Sa section.

NGC 7177 **Sab(r)H.2**
PH-7670-S
Sep 25/26, 1979
HlaJ
75 niin

The multiple-armed, fragmented spiral structure in NGC 7177 is similar to that in NGC 488 in the outer regions but differs in the inner. As shown in the insert, the. inner arms begin on the rim of an inner near-ring of high surface brightness.

The tightness of the outer arms, their thinness, and the only-moderate recent star-formation rate explain the Sab morphological classification.

NGC 3368 **Sab(s)II** **HA, p.** ***12***
PH-869-S **M96**
Nov **3/4, 1954**
L03aO
20 niin

The print of NCC 3368 here is from the same original plate used in the Nubble Alias. The dust lanes are well seen, silhouetted against the near side of the disk.

A very faint single outer arm containing many small Nil regions is only jnsl SITU here, ll emerges from the disk ai position angle about f> o'clock and coils outward lo (he eight and up. extending lo within about one-eighth the distance to the top bolder. It is *svm* belter in the insert negative print in the Nubble Alias. (Note the difference in the orientation of the prints in the Nubble Atlas and here.)

NGC 7690 Sab(s)
CD-513-S
Sep 28/29, 1978
103aO + GG385
45 min

The disk of NGC 7690 is filled with arm fragments that are thicker than in NGC 488. and the multiple arms are less numerous here. Yet the pattern is not that of the grand design type but is intermediate between the MAS and the grand design forms. The surface brightness of the central region, burned out here, is high.

NGC4151 Sab
PH-4194-S
March 1/2, 1963
103aO + GG13
30 min

NGC 4151 is one of the original Seyfert galaxies. The bright starlike nucleus was known already to Curtis (1918). The bright emission-line spectrum of the nucleus was known to Campbell and Paddock **(1918).** The first discussion reporting that the spectrum resembles that of gaseous nebulae was by Mayall (1935). The spectral plates used to define the Seyfert class as originally discussed by Seyfert (1943) had been taken by Humason and by Minkowski with the Mount Wilson 100-inch telescope in the late 1930"s and early 1940's. The beginning of the modern astrophysical analysis of Seyfert galaxies was made by **Woltjer** (1959).

NGC 3285 Sab(s) Hydra I Cluster
CD-1476-S/Br Abell 1060
May 11/12, 1980
103aO + GG385
45 **min**

NGC 3285 is a member of the Hydra I Cluster (Richter. Materne, and Huchtmeier 1982) at a redshift of v_0 = 3049 km s^{-1}, as listed in the RSA2 . The mean redshift of the cluster is $<v_o>$ = 3419 km s^{-1} . **with** a dispersion of 681 km s^{-1} (Richter and Huchtmeier 1983).

The **multiple-armed** spiral lanes are defined principally by the dust.

NGC 4736 RSab(s) HA, p. *16*
PH-423-MH
April 15/16, 1952
103aO
30 min

The print of NGC 4736 here, although made from the same plate used in the Hubble Atlas, has been printed to a different contrast, showing different features.

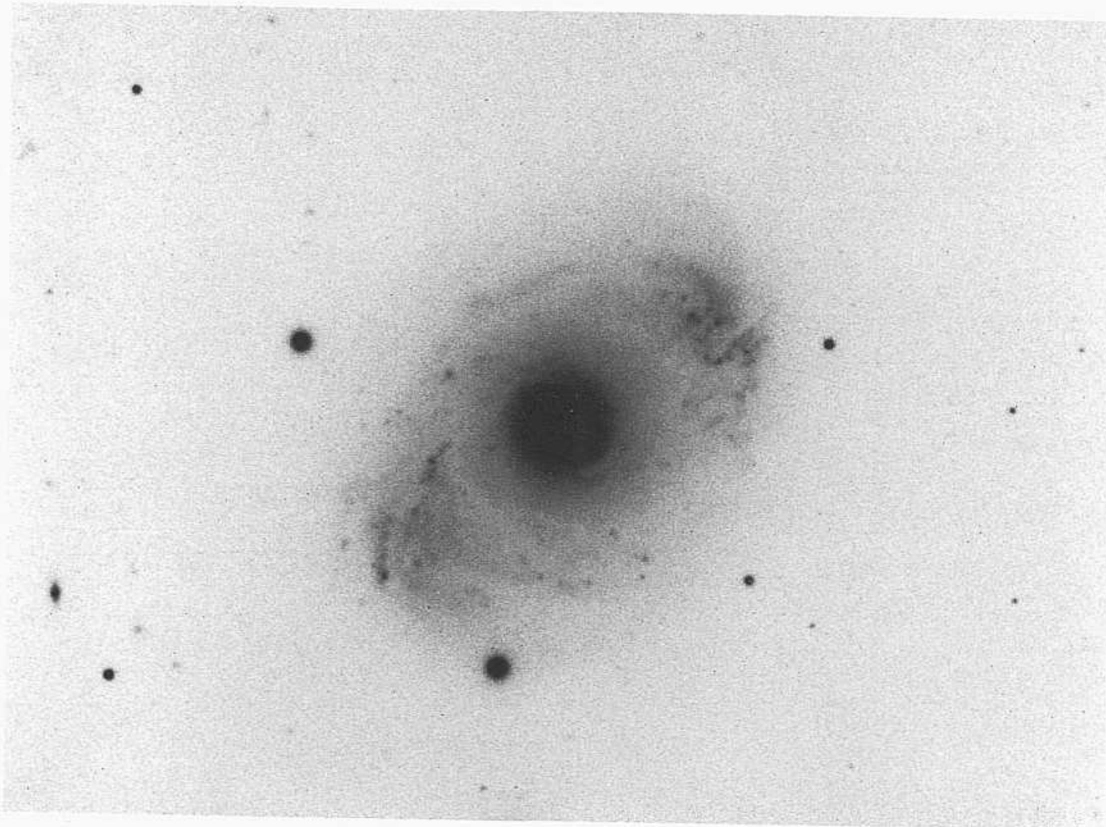
The description in the Hubble Atlas is still generally valid except for the comment there that no spiral exists in the central regions. Central Spiral structure does exist: the tight arms are smooth, with no evidence of recent star formation. (There are no HH-region candidates in the innermost arms.)

The very large variation of the surface brightness across the inner disk makes the **photographic** reproduction of the intricate details of the inner arm structure and the nearly detached outer ring (in which star formation is occurring) impossible to show adequately.

The outer ring is shown well in the Hubble Atlas insert print. Its very low surface brightness is emphasized in the insert print here, where it can be seen best by viewing from a distance and moving the head and eyes. Note the absence of luminosity over most of the area between the edge of the main body and the inner edge of this outer ring. However, as seen in the Hubble Atlas and weakly here, there is a faint attachment of this outer near-ring to the main body on the left side of the major axis of the insert print here.

NGC 3329 Sab HA, p. 4
PH-7981-S
Feb 1/2, 1981
103aO
12 **min**

NGC 3329 was called SO in the Hubble Atlas. The illustration there shows a smooth surface brightness based on a Mount Wilson 60-inch plate which, quite evidently, had inadequate spatial resolution. Later plates with the Palomar 200-inch reflector in 1963 and 1981 clearly show a tightly wound spiral pattern. The degree of resolution into **HII** knots and the size of the central bulge provide the basis for the Sab classification.



PANEL
119

PANEL
120

The SBab Classification Section

NCC 1398 **SBab(r)l** **HA, p.** *17*
CD-201 7-Bedke/Gregory **panel** 12 **I**
Oct 25/26, **1981**
L03aO + GG385
15 niin

The bar across the central lens is burned mil on tlit' heavily printed imago here luil is well seen in the negative print on the next page.

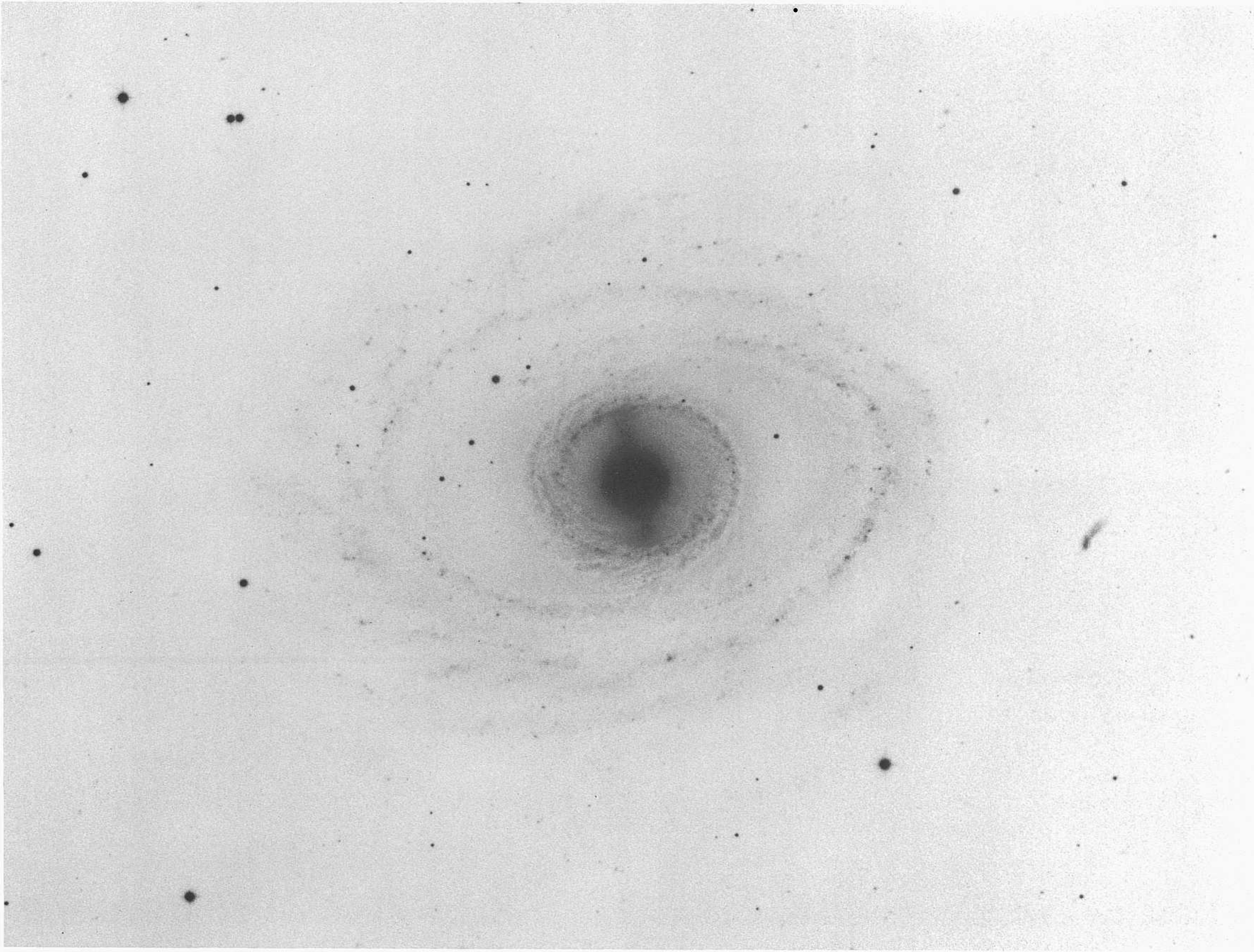
The photographic contrast of the print here has been adjusted l> emphasize the ihin fragments of arms in the outer disk. The two main arms that emerge from tin* rim of the brighl inner disk (the connection is seen best on the nexl panel) branch into a multitude of secondary fragments which themselves arc thin and in which IIII regions are abundant. The main arm emerges from the rim of the lens at the position angle of about 6 o'clock. It can be traced as ;i coherent fragment for a wrap of about 270°. The opposite arm can be traced for only about 200°. Secondary branches begin to occur alter about one-fourth of a revolution in both arms.

NGC 1398 **SBab(r)I** **HA, p.** *47*
CD-2017-Bedke/Gregory **panel 120**
Oct 25/26, 1981
103aO + GG385
45 miii

The prominent liar ends at the rim **of** the **high-surface-brightness** inner disk. (There is no actual **"rim"** but rather a **sharp** change in the gradient of the disk surface brightness, which **appears** to the eye as the edge of the inner disk, also well seen **on** the preceding panel.)

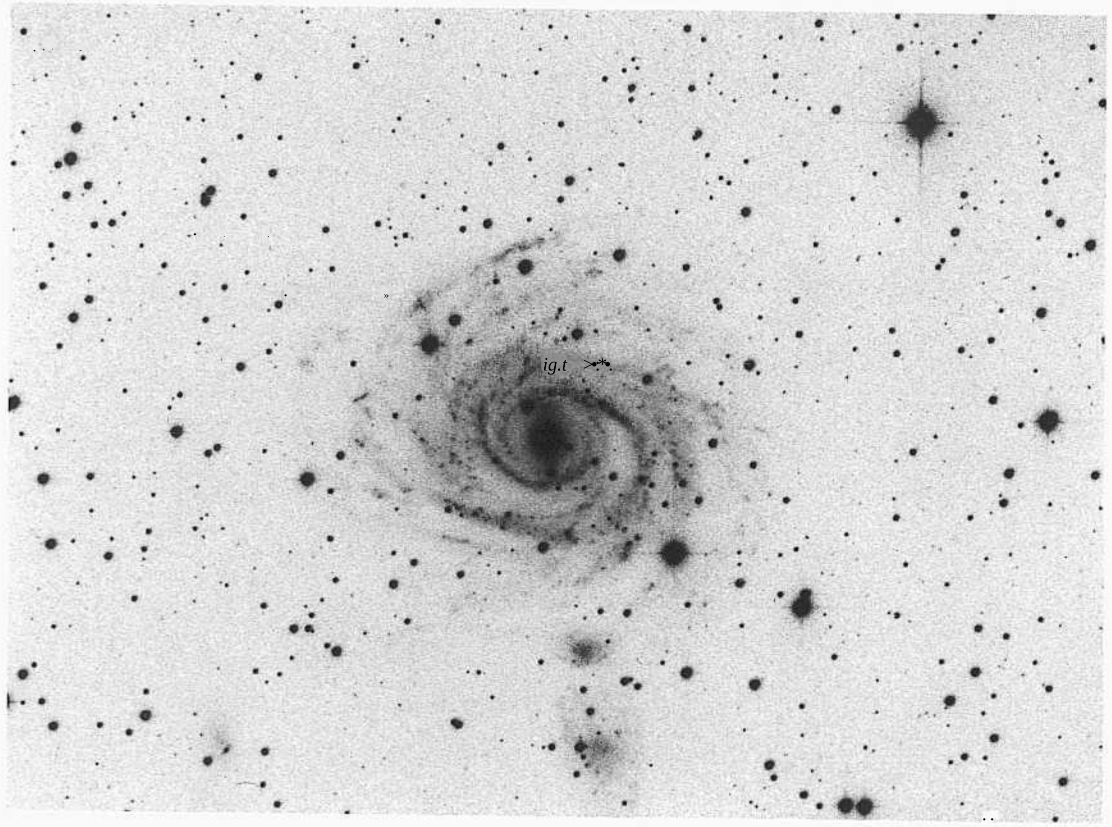
The inner arms that form a near-ring are very tightly wound at the rim of the disk. It is here that **the** two main arms emerge which will **fragment into the** MAS **pattern** farther out. Each begins in the outer region of the lens at diametrically opposite points about 90° from **the** termination points of the bar on the edge of the lens, **a** feature seen and often described in the SBa section.

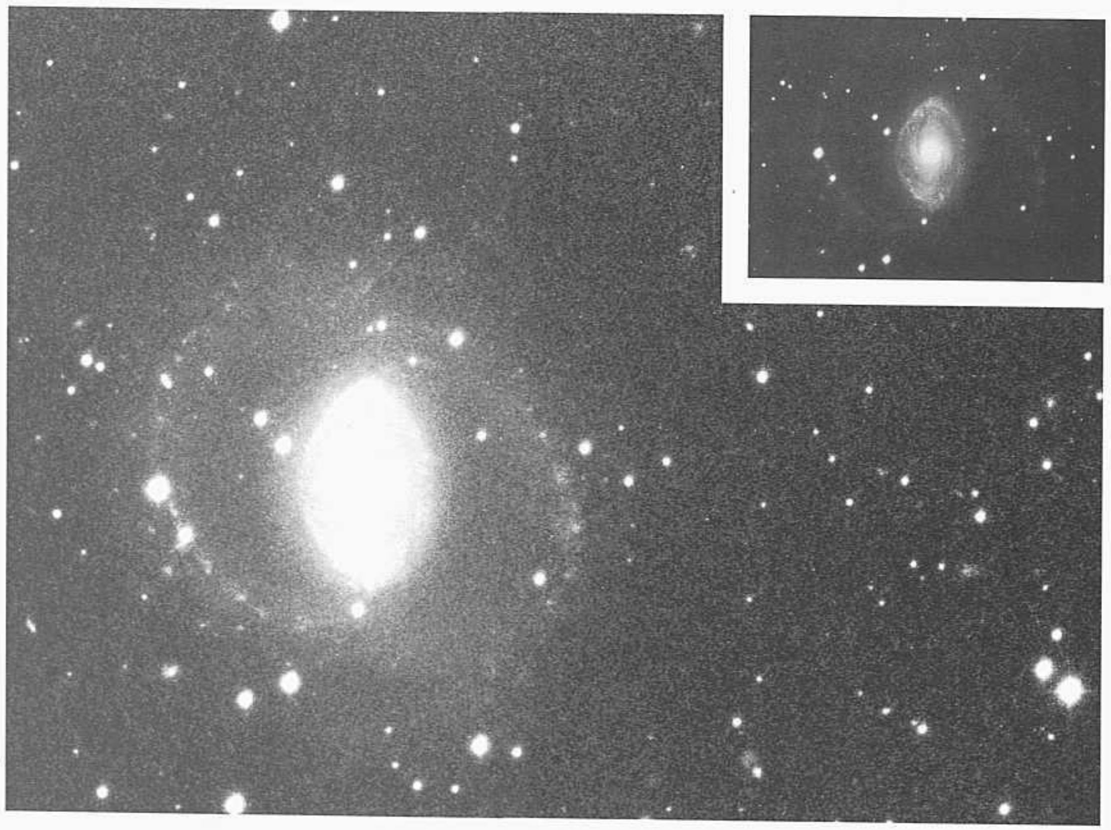
The thinness of the well-defined arms, the tightness of the spiral pattern, and the size of the central smooth **(non-star-forming)** region require the SBab classification. The type in the Hubble Atlas is SBb. NGC 13 98 is clearly among the earliest **of** the SBb galaxies in that atlas. The SBb **morphological** box is divided here into SBab types at the early part, and SBbc at the latest part of that box.

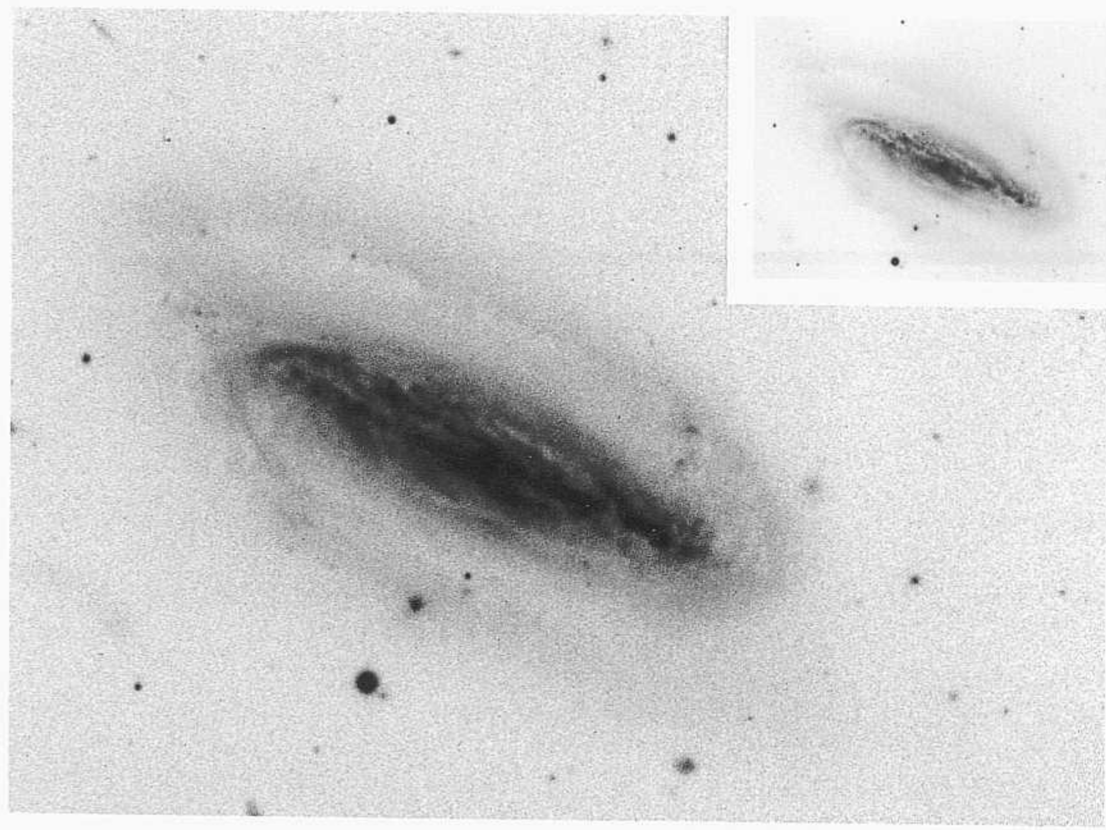


PANEL
121

PANEL
122







G, laxies on this and the next panel arc of the single-set-of-arm type (more or less grand design) rather than the MAS type such as NGC 1398 on the preceding two panels.

NGC 3275 SBab(r)I Antlia Gr #244
CD-131-HB
Jan 6/7, 1978
103aO + GG385
80 miii

NGC 3275 is in the Antlia Group Catalog (Ferguson and Sandage 1990). Its morphological type is listed there as SBI> from an independent classification. The classification of SBab here is arbitrarily earlier than SBI> for the reason used in the RSA2 listing, the thinness of the arms.

The arms do not spring from the ends of the bar. as in the prototype SBb galaxy NGC 1300 (panels 154. S8), but rather start, as in NGC 1389, at a position on the broad bar that is about 90° from the ends of the bar. This is a common feature of SBa(r) subtypes, as discussed in the SBa section.

The arms are tightly wound, each nearly touching one another after unwinding by about half a revolution, as has often been described (compare NGC 3081. NGC 3185, and IC 5240, all shown in the SBa section, panel 99). This feature is often mistaken for an internal ring but is almost always two nearly overlapping separate spiral arms of the grand design type.

NGC 6782 SBab(s)
CD-1028-Br
July 21/22, 1979
103aO + GG385
45 min

The inner near-ring feature described above for NGC 3275 is evident in the insert print of NGC 6782 here. But again, the "ring" is two inner spiral arms that start in the nucleus [hence the subtype (s) rather than (r)] and nearly overlap after each has unwrapped by about half a turn.

Two very thin, regular outer arms of low surface brightness are well seen in the high-contrast main print here. The form is of the NGC 210 (Sb; panel 124) type, often discussed in the Sa and SBa sections.

NGC 3261 **SBab(ra)I-H**
CO-2099-S
March 18/19, 1982
103aO + GG385
15 min

NGC 3261 is in the complex region of the Hydra-Centaurus Supercluster, about 9° south of the rich Antlia Group, but it has nearly the same redshift. at u_0 = 2307 km s^{-1}, as the mean of the Antlia Group. $\langle r_0 \rangle$ = 2503 km s^{-1} (Ferguson and Sandage 1990). The complexity of the galaxy distribution in tln- region is discussed by Hopp and Materne (1985).

The **arm** pattern in NGC 3261 is of the MAS type but is not as fragmented as the prototype galaxies of that form (NGC. 188. NGC 2841. etc.). However, it is not a pure grand design type either. At least ten separate spiral fragments ran be counted.

NGC 7582 SBab(rs) Grus Gr triplet
CD-576-S
Oct8/9, 1978
103aO + GG385
40 nùn

NGC 7582 is the brightest member of a close triplet *oi* large spirals. The triplet is a part of a larger loose group Inning several condensations, (tailed the IC 1459 Grus Group (Sandage 1975b). The two other members of the triplet are NGC 7590 (Se) at 9.4' separation and NGC 7599 (Se) at 12.2' separation. Both an- in the RSA but are not shown in this atlas.

The redshifts are $u_o(7582)$ = 1175 km s^{-1}. $u_o(7590)$ = 1187 km s^{-1}. and $u_o(7599)$ = 1670 km s^{-1}. At a mean redshift distance of 3 I Mpc (// = 50), the projected linear separations from NGC 7582 are 85 kpc and I 111 **kpc,** for NGC 7590 and NGC 7599. respectively.

The spiral pattern in NGC 7582 of two faint outer arms with a different pitch angle from that of a complex inner spiral pattern, has the form of the NGC 2I0 look seen more edge on.

NGC 4507 (New 2) SBab(rs)I
CD-236-S Centaurus Cluster region
Feb 13/14, 1978
103aO + GG385
20 min

NGC 4507 is near the Centaurus Cluster but is north and west of the main concentration (Dickens. Currie, and Lucey 1986). The redshift of v_o = 3226 km s^{-1} (Sandage 1978) is consistent with cluster membership of the Cen 30 part of the Centaurus complex (Lucey, Currie, and Dickens 1986).

The galaxy may be the object called New 2 in the original Shapley Ames (1932) catalog. Its NGC number was not recognized there because of an error in right ascension in the Dreyer NGC catalog and an error in declination in the Shapley-Ames Catalog itself (see de Vaueouleurs 1956a and the RC1).

The morphological type of SBab is based on the tightness, thinness, and regularity of the arms. The galaxy is late in the SBab morphological box, close to the SBb boundary based on the high current rate of star formation, indicated by the numerous HII regions in the arms.

NGC 4462 SBab(s)I-II
CD-1726-S
Jan 9/10, 1981
103aD + GG495
45 min

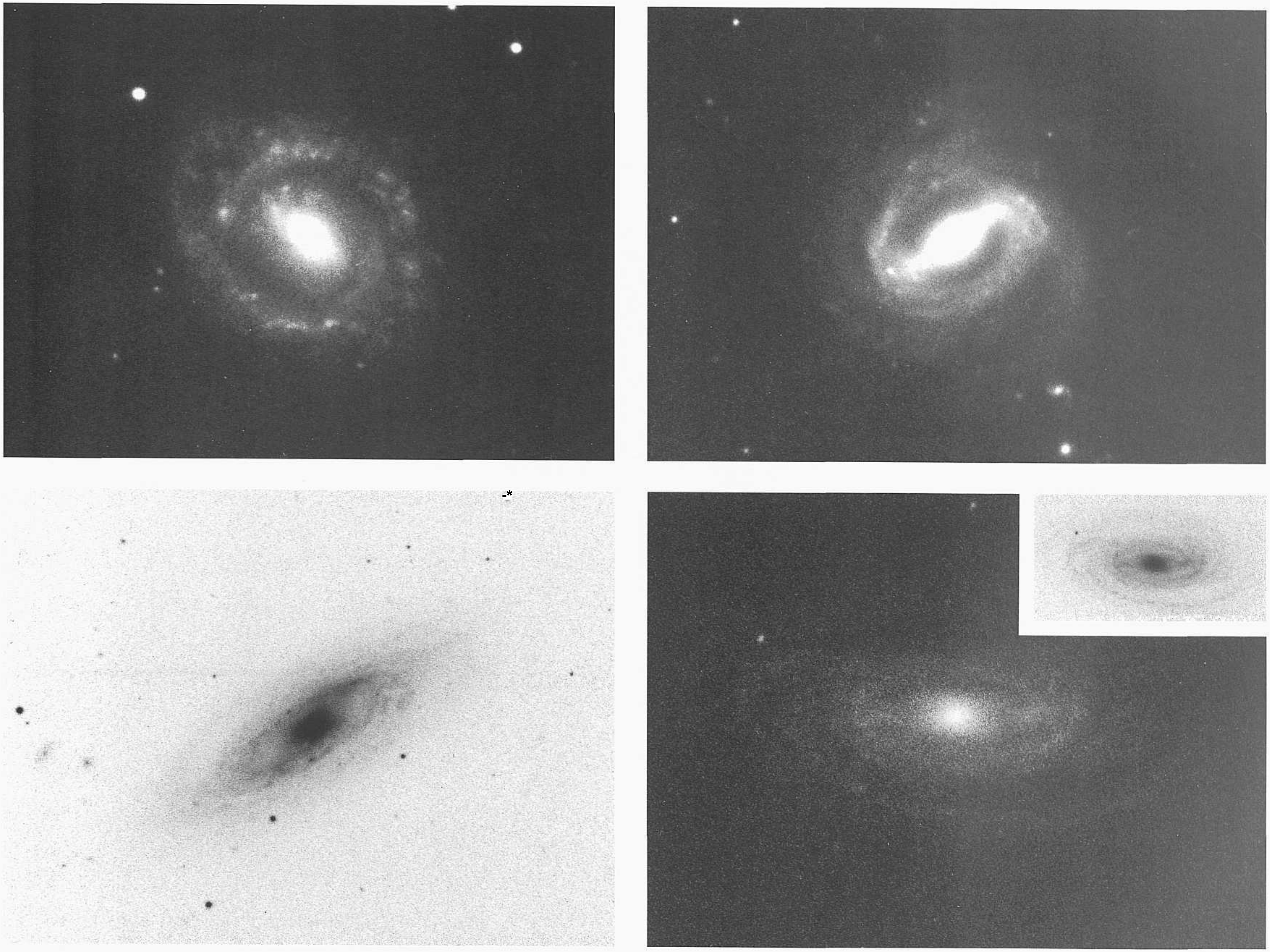
The high inclination of NGC 4462 makes its classification uncertain. The bar is weak but definite on the original plate, crossing the disk at position angles of 1 and 7 o'clock in the print here. The arms are tightly wound, resembling the pattern in the Sa galaxy NGC 4274 (Hubble Atlas, p. 12: panels 66, 88 here.)

NGC 175 SBab(s)I-II HA, p. *43*
PH-773-S
Aug 23/24, 1954
103aD + GG11
40 min

NGC 175 is classed in the Hubble Atlas as a very late SBa. It has the arm pattern of the NGC 1300 type, where the arms spring from the ends of the bar. However, the arms in NGC 175 are more tightly wound as they move outward, nearly overlapping as each unwinds by half a turn. The pattern is similar to that in NGC 3081, NGC 3185, and IC 5240 (Sa section, panel 99). It is this near-overlap, forming a near-ring, that led to the SBab(r) subclassification in the RSA2 rather than the SBab(s) subclass given here.

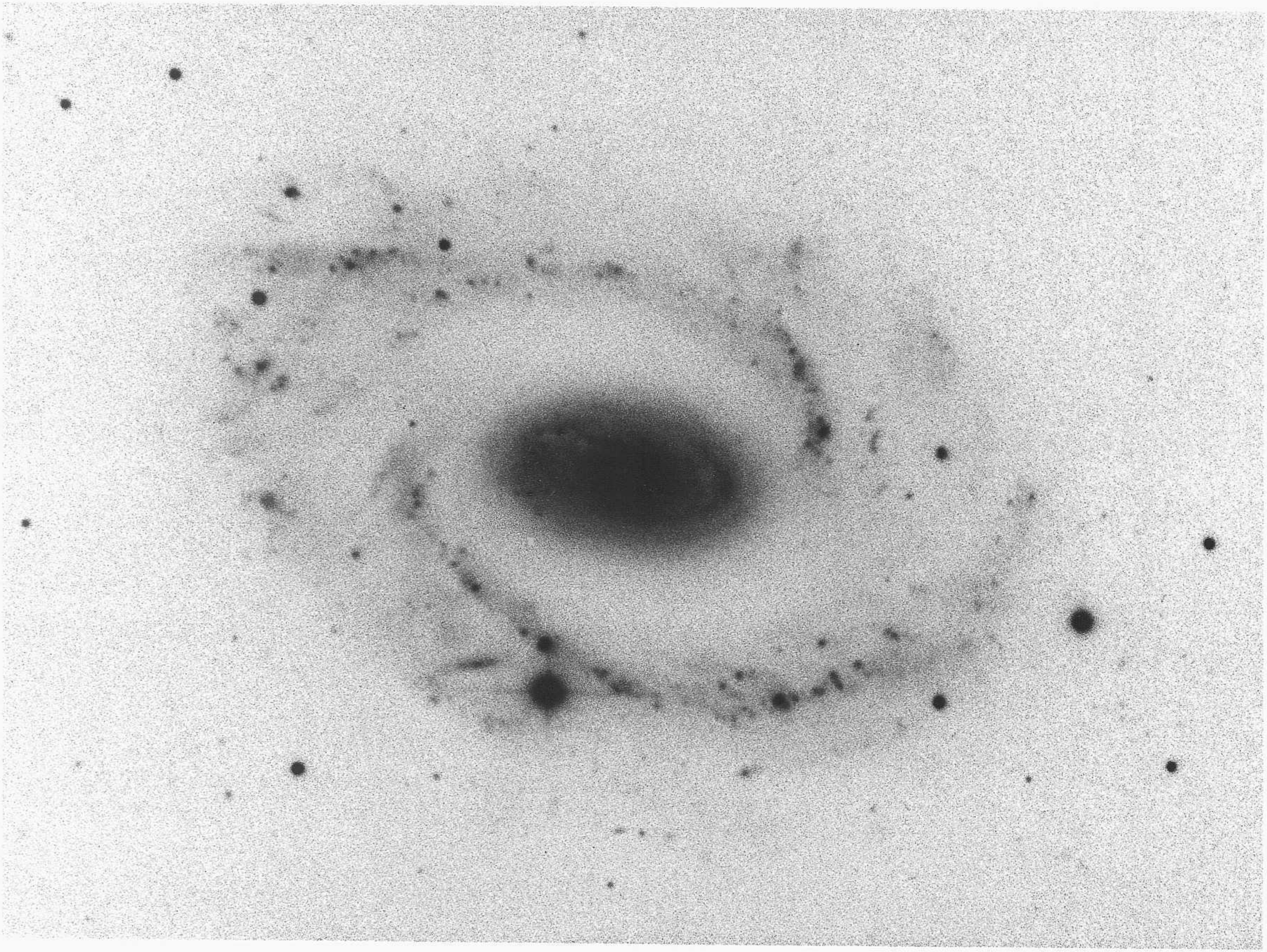
NGC 5641 SBab
PH-8101-S
Feb 6/7, 1981
103aO
12 min

The thinness of the spiral arms and the lack of copious recent star formation is the basis for classifying NGC 5641 as SBab.



PANEL
123

PANEL
124



The Sb Classification Section

NGC210 Sb(rs)I group?
PH-1075-S HA, p. *22*
Aug 25/26, 1955
103aO + GG13
30 min

NGC **2] 0** is **tin- prototype of *a* grand design spiral that has** two **sets** of spiral **arms,** one **near the center that is tightly** wound and **an** outer **sel that is** more open. Examples **of** this **pattern** have been **described** in previous sections **where il** is **called the** NGC 2 10 look. **Particularly good** examples in **the** SBa section arc NGC 2962 (panel 93), NGC 5377 (panel 96), **NGC** 1.326 (panel 100), NGC 570 1 (panels **100,** I 0 I . **104),** NGC 1291 (panels 100, 102. S8). NGC **L358** (panels 100, 107, S8), **NGC** 1543 (panels 100. 102). NGC 5 101 (panels 100. 10 1. **103),** and NCC 2217 (panels 101, 104. 107).

The inner lens of NCC 2 10 has **a high** surface brightness, **making the inner set of tightly** wound arms difficult **to** trace **on the** prints, both here and in **the** Hubble Atlas. The same **original** 200-inch Palomar plate was used **for** both representations.

NGC 210 may form a loose group with NGC 178, NGC 187. NGC 207. and IC 41.

NGC 6753 Sb(r)I
CD-56-D
Aug 19/20, 1977
103aO + GG385
30 min

NGC 6753 has the NGC 210 look but is seen more nearly face on than NGC 210 itself. The tightly wound set of inner arms starts tangent to a very bright internal ring (burned out in this reproduction) at the edge of the bulge. The two main outer arms of wider pitch angle are the continuation of the inner arms.

The galaxy is in the early part of the Sb section. The arms are thin, well ordered, and have only a small-to-moderate current rate of star formation.

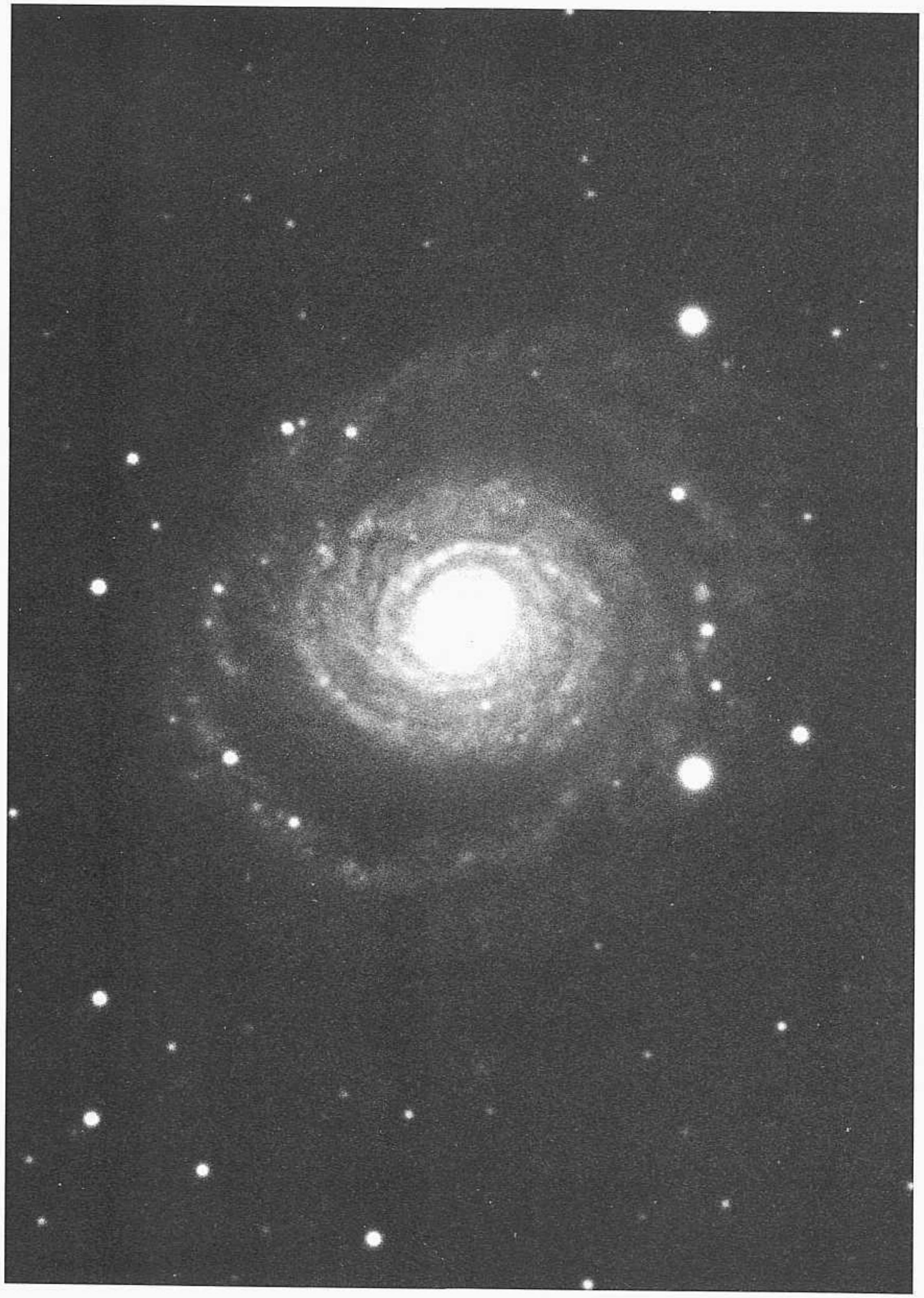
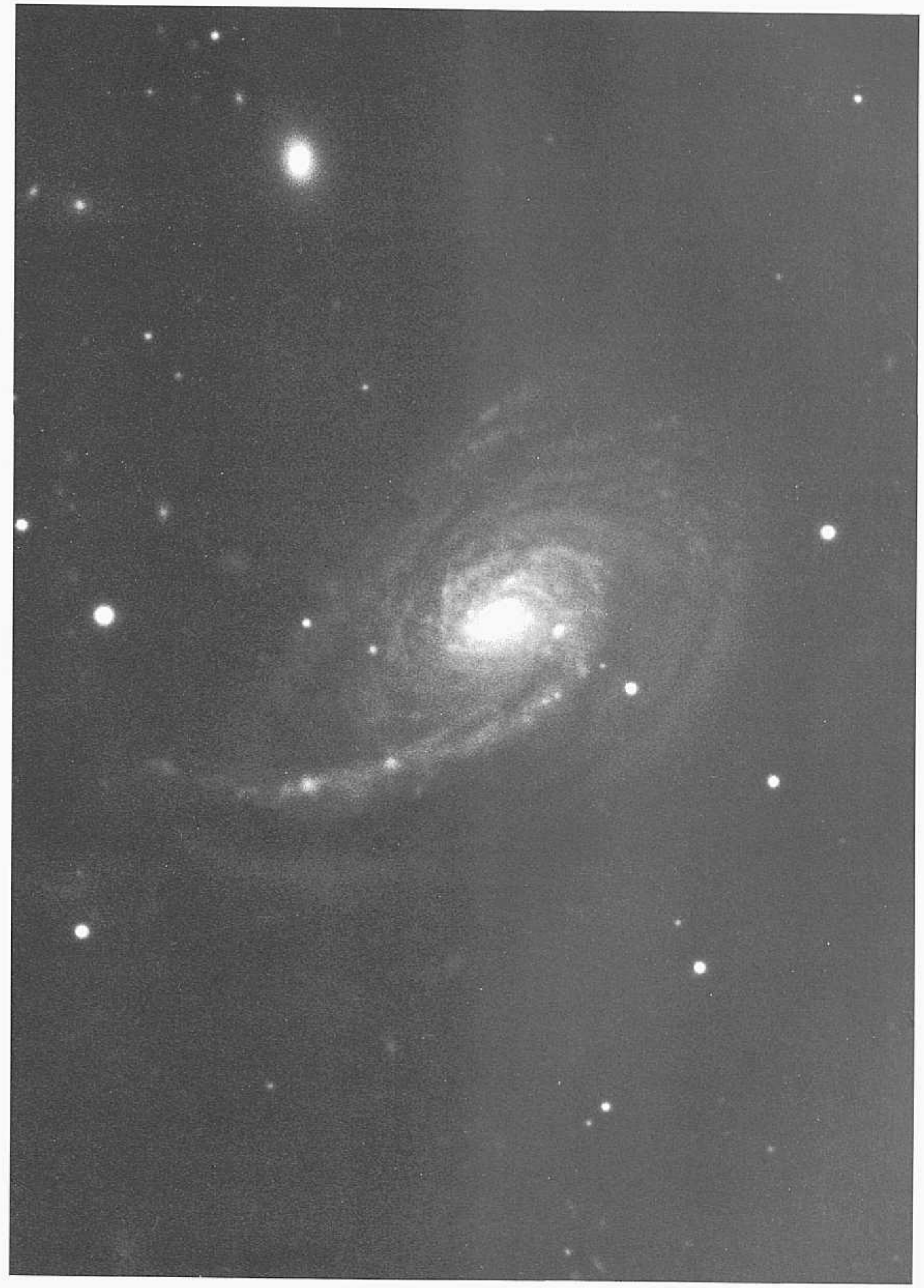
NGC 772 Sb(rs)I pair
PH-7564-S
Nov 7/8, 1978
103aO
12 min

NGC 772 is an early Sb. The arms, although well formed, are relatively smooth, indicating only a small current rate of star formation except in the single high-surface-brightness arm which contains several evident HII regions.

The relatively smooth multiple arms on the opposite side from the prominent arm are defined primarily by the fragments of spiral dust lanes.

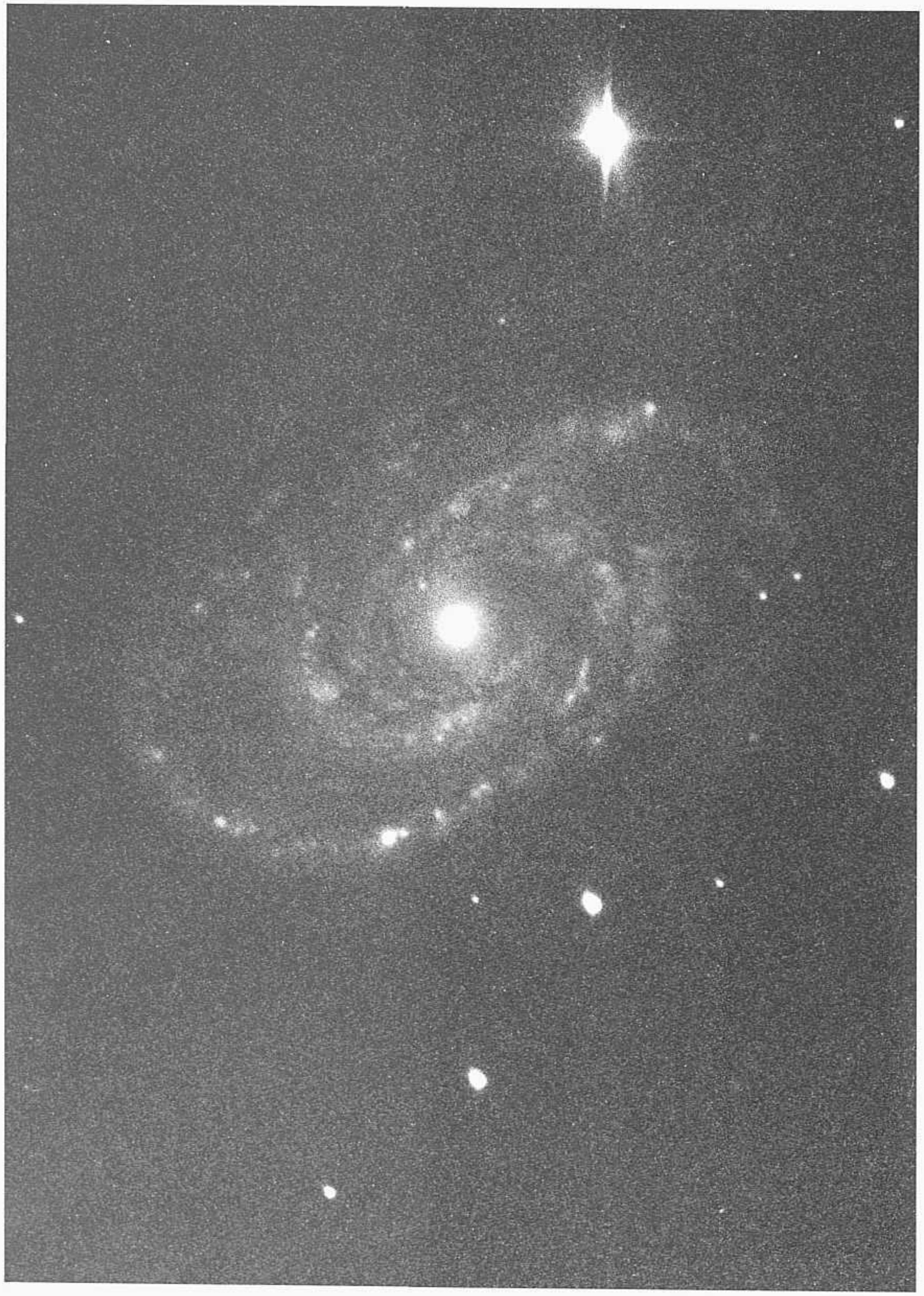
The spiral pattern is intermediate between that of the grand design and the multiple-armed spiral (MAS) types.

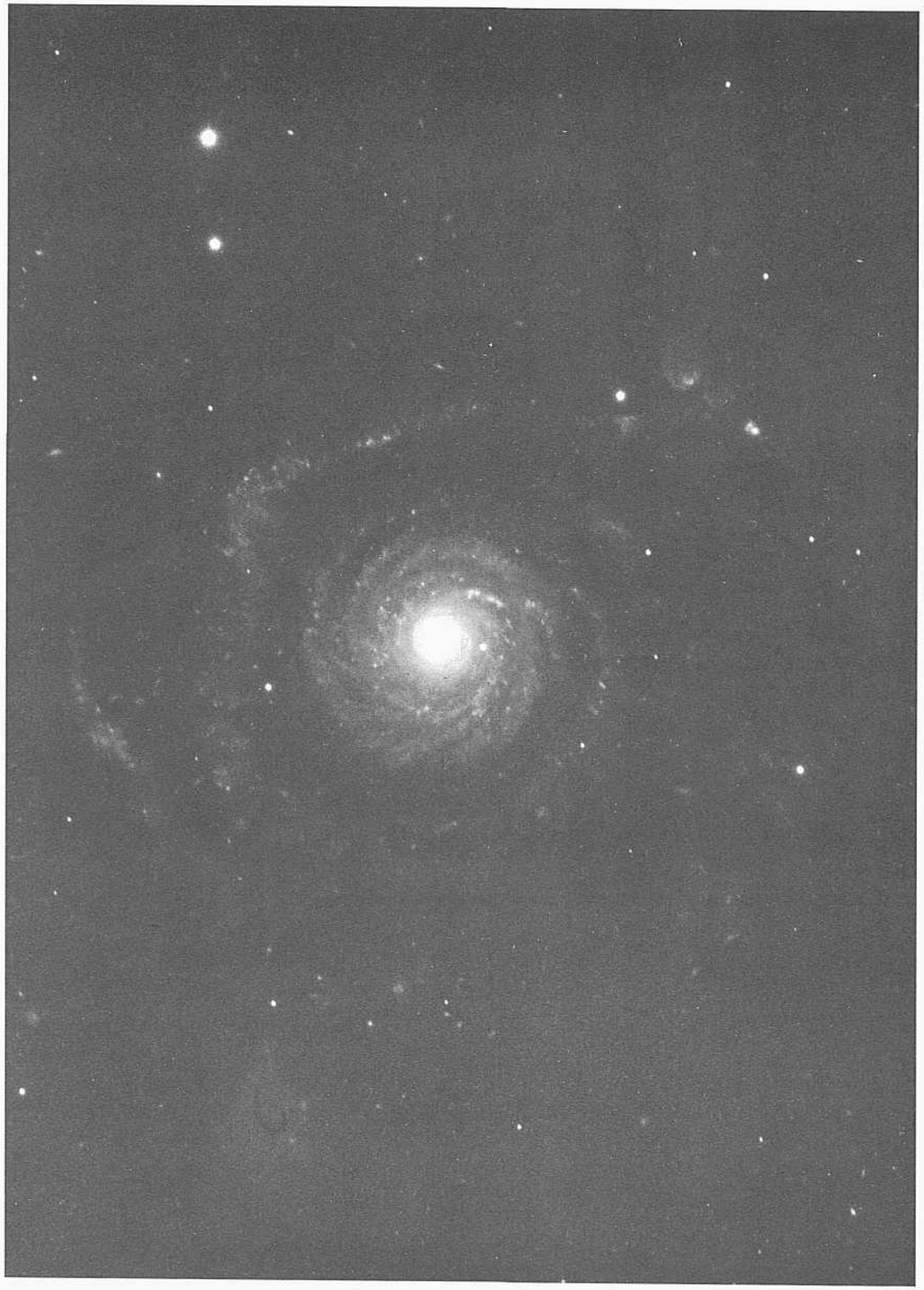
NGC 772 and NGC 770 (E3), at a separation of 3.3', form a binary pair. The redshifts are $u_o(770)$ = 2639 km s''' and $f_o(772)$ = 2660 km s''^{l} . At a mean redshift distance of 53 Mpc (*H* = 50) the projected linear separation of the pair is 51 kpc.

PANEL
125

PANEL
126





NGC 5371 **Sb(rs)I/SBb(rs)I**
H-654-H
April 17/18, 1926
E40
60 niin

The print of **NGC 537** I here is made from a very weak early Mount Wilson 100-inch plate, increased in contrast by control in the darkroom. The suggestion of a bar is evident hut nol prominent. The arms arc thin anil well formed, and contain many apparent 1III regions.

NGC 3642 Sb(r)I
PH-7631-S
April 28/29, 1979
L03aO
10 niin

The spiral arm pattern in N(r(! 3642 is remarkably regular in the inner, high-surf acc-brightness part of the disk. The thinness of the arms and the high regularity of the pattern are the criteria for assigning luminosity class I. The oulcr arms contain many apparent MM regions.

The three galaxies on this panel are of the multiple-armed type (MAS) rather than of the grand design. Although there are many fragments of arms, all are thin, especially in NGC 5033 and NGC 7606; hence the bright luminosity classes are assigned.

NGC 638-1 **Sb(r)1.2** **panel S4**
PH-7812-S
Sep 2/3, 1980
103aO
12 inin

NGC 6384 would have a nearly identieal appearanee to NGC 3642 on the preceding panel if it were viewed more nearly face on.

There is a smooth inner **central** bulge and an inner lens devoid of star formation. The MAS pattern begins tangent to the **rim** of the lens/bulge.

NGC 5033 **Sb(s)I**
PH-8034-S
Feb 3/4, 1981
103aO
12 min

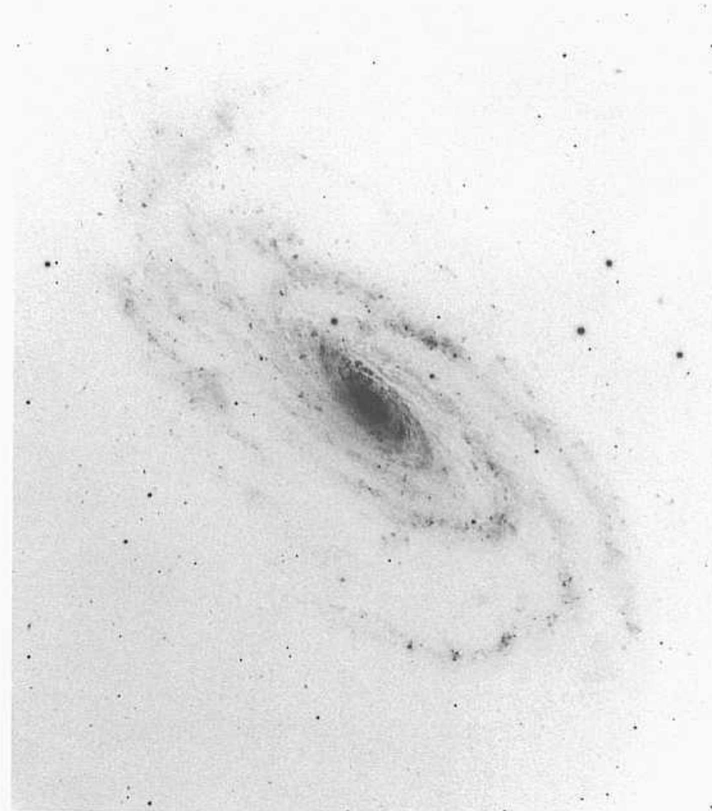
The thinness and regularity of the **multiple** arms in NGC 5033 are the characteristics of the high-luminosity class given to this galaxy. The star-formation rate in the arms is moderate.

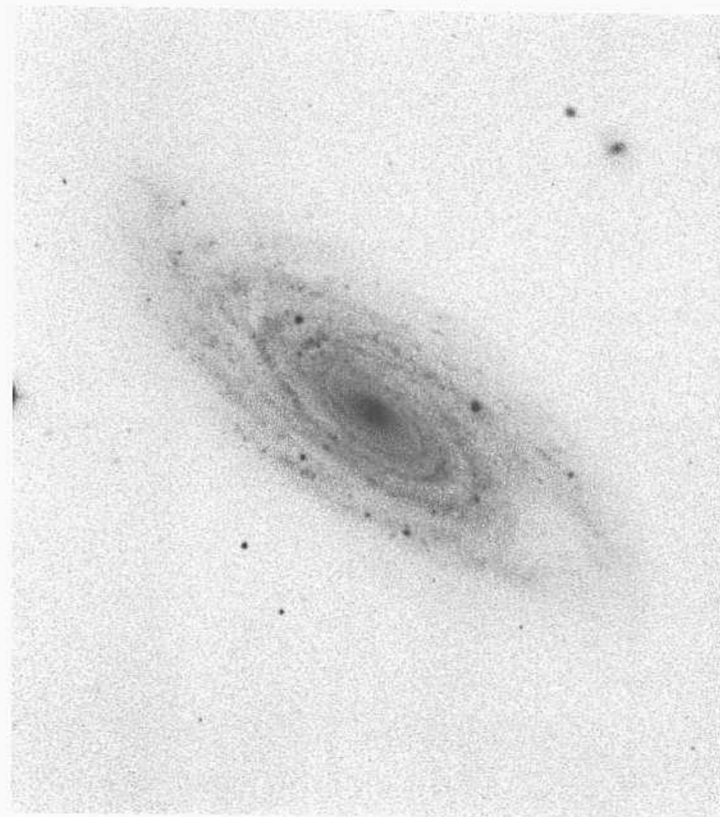
Many small HII regions exist in the arms. It is probable that some of these images are individual stars as well: the redshift is small, at v_0 = 897 km s^{-1}, suggesting a distance modulus of about $m - M = 31$. Brightest blue stars in galaxies reach absolute magnitude of $MQ = —10$. Such stars in NGC 5033 will begin to resolve at B = **21,** which is well above the plate limit here.

Many intricate, thin dust lanes exist within the disk, seen best in silhouette against the evident near side of the bulge.

NGC 7606 **Sb(r)I** **panel S13**
CD-1577-S/Br
Aug 10/11, 1980
103aO
45 min

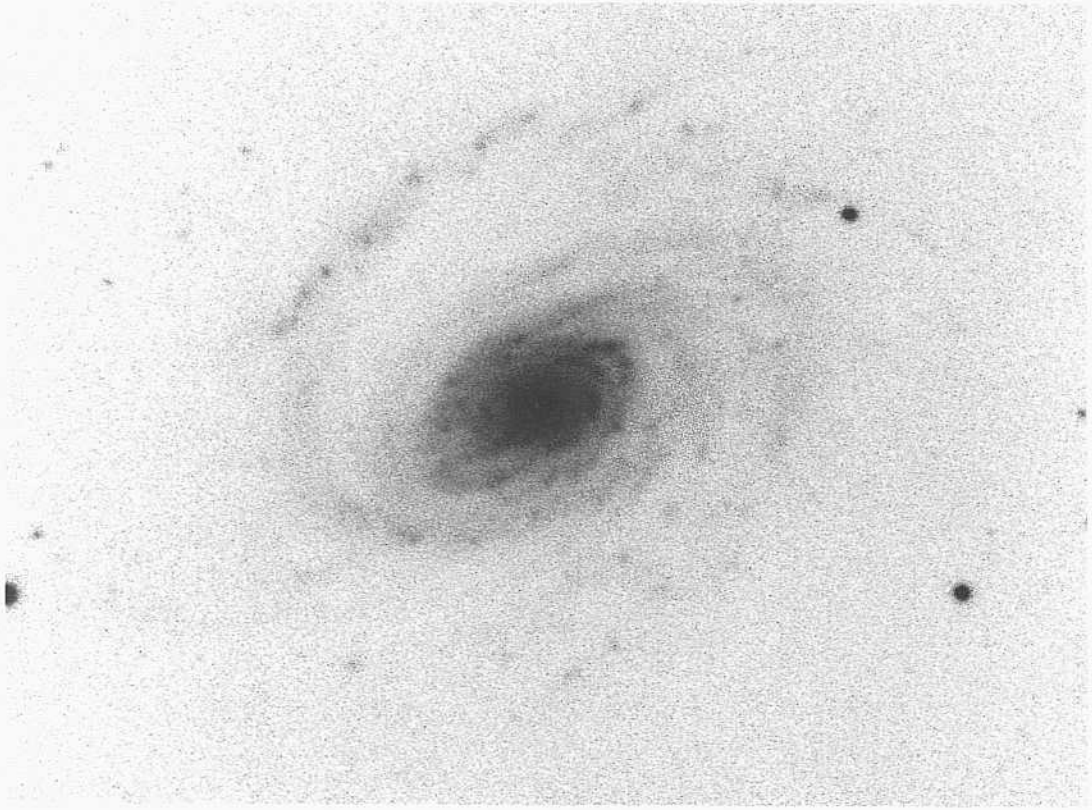
NGC 7606 is a prototype example of the MAS filamentary-spiral-arm class. It would resemble NGC 488 (Sab; Hubble Atlas, p. *15*; panels 115, 116, S3, SI2 here) if seen more nearly face on, although the arms are not quite as regular nor as tightly wound. Hence NGC 7606 is classified Sb rather than Sab as is NGC 488. The lack of a large current-star-formation rate in the arms places NGC 7606 in the early part of the Sb morphological box.

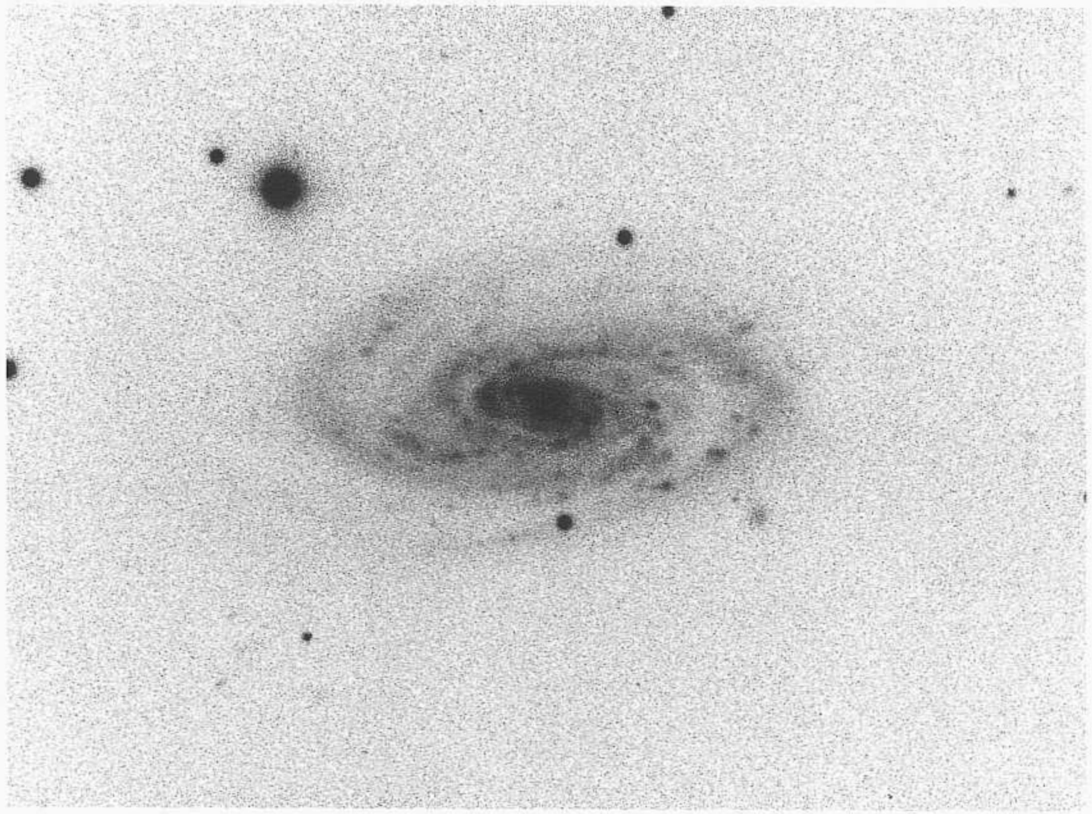


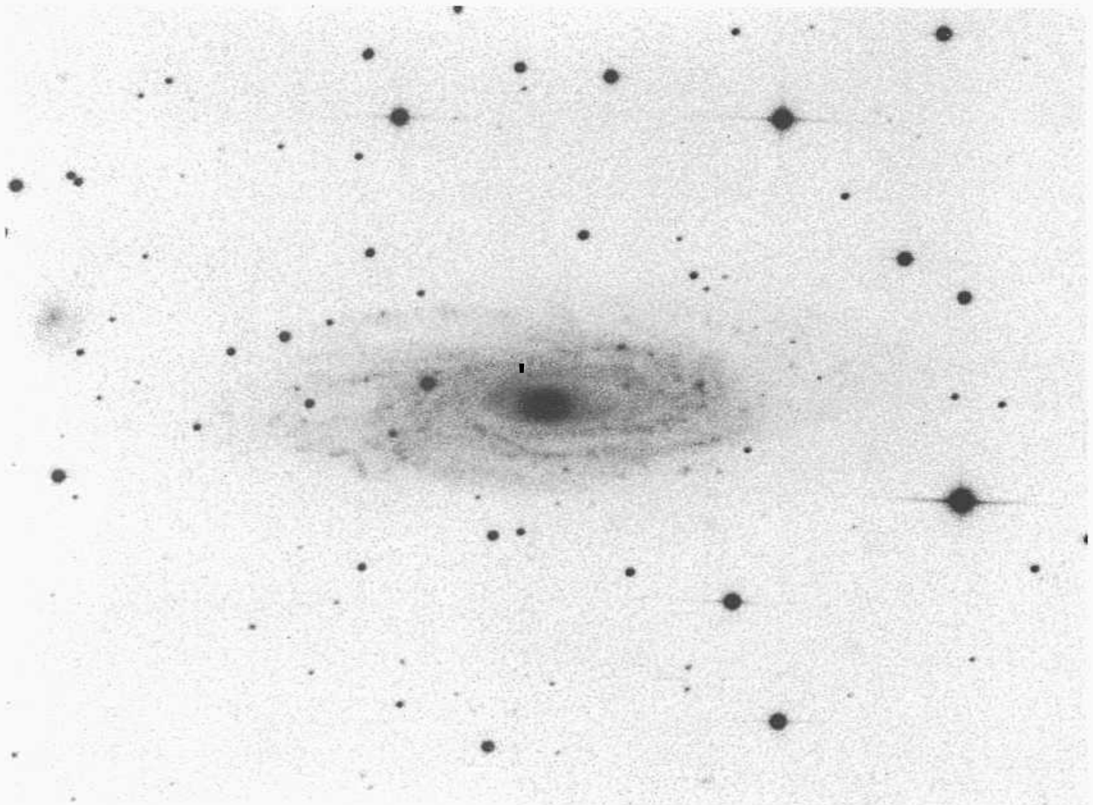


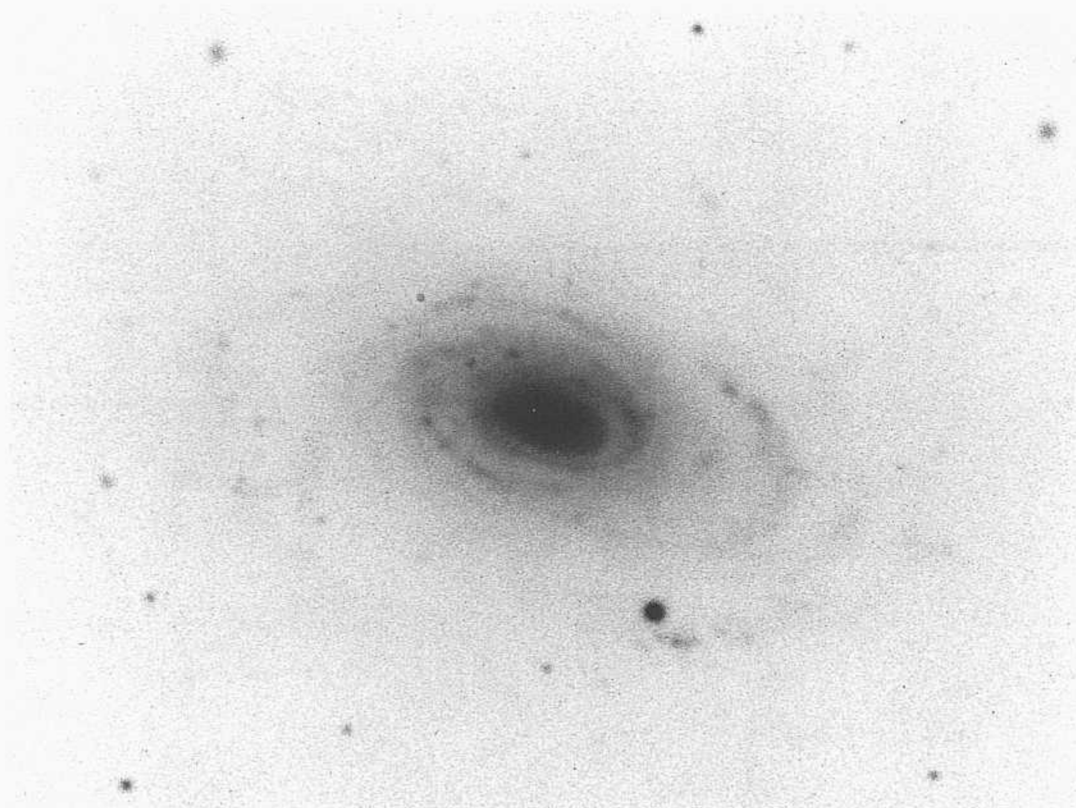
PANEL
127

PANEL
128









The four galaxies on this page are of the MAS fragmented, filamentary-arm type, later in the sequence than NGC 488 but of the same form.

NGC 4814 **Sb(s)I**
PH-8062-S
Feb4/5, 1981
103aO
12 inin

The arms in NGC 48 14 arc well defined and- although fragmented, can be traced as individuals (by merging the fragments in mind's eye) for about 1 1/4 revolutions in the ease of the brightest of the arms after it leaves the bright inner disk. In addition to the outer arms, very tightly wound spiral fragments exist throughout this inner disk, burned out in the print here.

NGC 5878 Sb(s)1.2
CD-1420-S/Br
March 24/25, 1980
103aO
75 nún

Many features of NGC 5878 are nearly identical with those of NGC 7606 shown on the preceding panel. There is a smooth, high-surface-brightness bulge and an inner disk devoid of recent star formation. The multiple-arm pattern is similar to that of NGC 488 but is less well defined; hence the type is later than Sab.

NGC 1417 Sb(s)1.3 pair or **triplet**
PH-7920-S
Nov7/8,1980
103aO
12 min

NGC 1117 forms a physical pair will, NGC 14 18 (Salt), al 4.9' separation, and perhaps forms a triple! with IC 344 al a separation of 7.4' hut at unknown reilsliil't (e. 1990). '['lie known redshifts arc ▷,(I I I 7) = 4158 km s~ι. and r,,(1418) = 1256 km s~'. At a redshifl distance of 84 Mpc the projected linear separation of NGC 1418 from NGC 1117 is 120 kpc. The configuration is perhaps a member of a larger group at about the same redshifl containing NGC 1376 (Se: panel 22 1) at v_a = 4293 km s^{-1}.

NGC 5533 Sb(s)I
PH-720-S
April 6/7, **1954**
103aO + WG2
30 min

NGC 5533 would closely resemble NCC 3642 (panel 126) if seen more nearly face on. The type is early Sb. The form is somewhat later than Sa and is certainly earlier than Se: hence the classification is SI) by elimination. The spiral pattern is of the MAS type, similar to that of NCC 488 (Sab), but is later in the sequence.

NGC 3031	Sb(r)I-D	M81 Gr
PH-421-MH		HA, p. *19*
April 15/16, 1952		M81
103aO		panel 332
30 niiii		

NGC 3031 is the type example of a large-bulge, regular, thin-armed Sb galaxy of **the** Andromeda Nebula (M3 1) type but with thinner, more regular arms. Dust lanes thread through the central bulge. The lanes can be traced close to the nucleus, as in M3 1, but are not seen in this print because of the overexposed central region.

The luminous arms cannot be traced as single grand **design** structures, but rather as spiral fragments that branch into many secondary filaments. The dust is generally on the inside of the fragments.

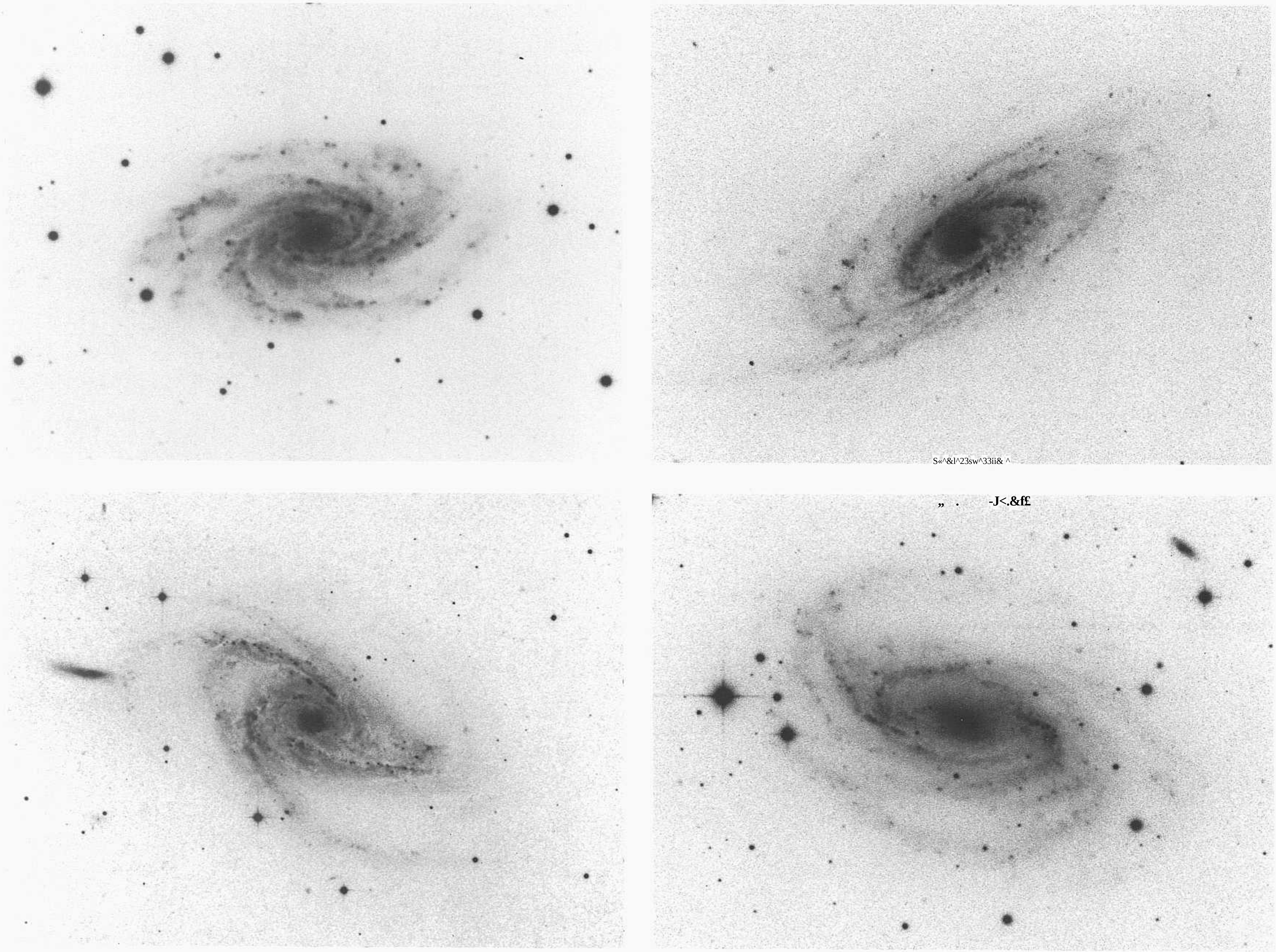
The spiral arms are highly **resolved** into stars beginning at apparent magnitude B = 18. Normal novae, Cepheid variables, and planetary nebulae have also been identified in the resolved stellar content. The distance modulus is m — M = 2 7.7, based on the resolution and identification of these distance indicators, in particular the Cepheid variables.

M8 1 is the brightest member of the M81/NGC 2403 extended group (Holmberg 1950), which includes NGC 2266, NGC 2976, NGC 3077, NGC 4236, IC 2574, M82, Ho I, Ho II, Ho IX, and a number of dE dwarf ellipticals (Kraan-Korteweg and Tammann 1979; Börngen and Karachentseva 1982; Börngen, Karachentseva, and Karachentsev 1984; Börngen, Karachentseva *et al.* 1982).

An intricate pattern of straight dust lanes exists, not connected with the spiral structure, across the central disk (bulge) and across the brighter **spiral** arm on the north-preceding side (lower right). These lanes may be dust in the halo of our galaxy connected with the high-latitude nebulosities that are prevalent in the direction of the M81/M82 pair (Sandage 1976, Plate VI).

PANEL
129

PANEL
130



Galaxies on this and on the next (Our panels are of luminosity class I—II, as is M8 1 on the preceding page. Class I–II grand design (or near-grand-design) galaxies are on this and the next panel. Class I-Il multiple-armed spiral (MAS) galaxies are on the three subsequent panels.

NGC 7083 Sb(s)I-II
CD-1552-S/Br
Aug 8/9, 1980
103aO + GG385
45 min

NGC 7083 has features of both the grand design and the MAS types. Nevertheless, the regularity of the arms and the ability to trace a given arm for most of its wrap (in contrast, for example, to the MAS galaxy NGC 284 1 shown cm panel 142) shows NGC 7083 to he primarily of the grand design type.

The arms can be traced into the center where they begin. Many II11 regions exist, the largest of which have angular diameters of about 2".

NGC 5054 Sb(s)I-II NGC 5044 Gr #137
CD-819-S panel S4
Feb 26/27, 1979
103aO + Wr2c
45 niin

NGC 5054 is an outlying member of the NGC 5044 Group (Ferguson and Sandage 1990, Fig. 8) whose mean redshift is $<v_o>$ = 2 048 km s"[1] . However, the redshift v_0 = 1524 km s~[1] of NGC 5054 is different enough from the mean group redshift to suggest a foreground location.

The two high-surface-brightness main arms are studded with 1111 regions, the largest several of which resolve at about the 2" level.

Note the faint surface brightness of the spiral pattern at the outer extensions of the main arms.

NGC 3705 Sb(r)I-Il HA, p. *21*
CD-1816-S
April 3/1, 1981
103aO + GG385
16 niin

The outer arms of NGC 3705 begin from an inner near-ring of high surface brightness which, as usual, is tin; near-overlaying of two opposite tightly wound inner .spiral arms. The near-ring contains small Mil regions anil interspersed dust lanes. The pattern is similar to that ofNGC 4274 (Sa; panels f>6. !SH). hut NGC 3705 is later in the classification sequence because the central bulge is smaller.

The outer arms are thin and very well defined: hence the high-luminosity-class assignment is appropriate.

NGC 3673 Sb(rs)Ml
CD-1694-S
Jim 3/4, 1981
103aO + GG385
60 min

NGC 3673 is similar to NGC 3705 above (and is therefore similar to the earlier Sa galaxy 4274; panels 66. 88), except that NGC 3673 is seen at a more-face-on orientation. This permits a belter view of the neatly comp[illegible] inner ring from which the left outer arm in the print here appears to begin. The outer arms have more of the characteristics of the grand design than of the MAS pattern.

NGC 615 Sb(r)I-II HA, p. *22*
PH-1077-S
Aug 25/26, 1955
103aO
30 niin

This negative print **of** NGC 615 is made from the same plate used in the Hubble Atlas for the positive print there.

The **form** of the **spiral pattern** is **of** the NGC 2 10 type. The outer arms start **from** an inner near-ring, similar to that in NGC 3185 (Sa; panel 99) but burned **out** in the inner regions in the print here. The arms in NGC 615 are thieker than those in **the prototype** galaxies NGC 2 10 and NGC 1964 at the right, which are of **the** same spiral **type.**

HII regions exist in the arms but are not resolved at the 1 " level.

NGC 2815 Sb(s)I-II
CD-805-S
Feb 25/26, 1979
103aO + GG385
45 inin

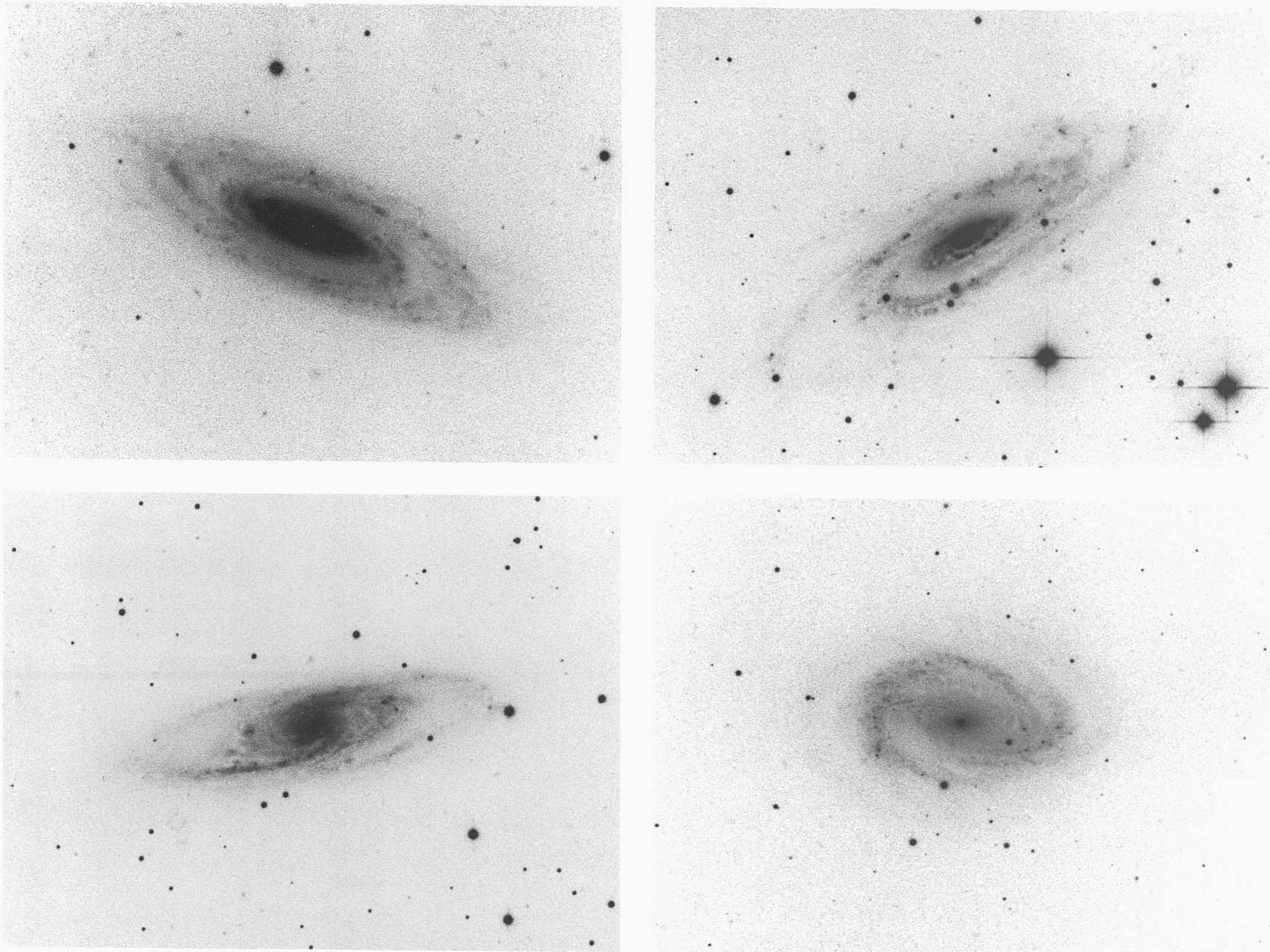
The two **principal high-surface-brightness** arms are thin and well defined. They are tightly wound. Each can be traced until they nearly overlap the opposite arm after a half revolution of unwrap. The form is similar to that of NGC 210.

NGC 1964 Sb(s)I-H HA, p. ***22***
CD-1656-S
Dec 29/30, 1980
103aO + GG385
45 niin

NGC **I** 964 is closely similar to NGC 210. A set of tightly wound inner spiral arms in a **high-surface-brightness** disk change into the more open, two-armed outer **spiral** pattern. Each of the two outer arms can be traced for about three-quarters of a revolution from their origin, tangent to the inner near-ring. The few **Mil** regions in the outer arms are small, unresolved at the 1.5" level.

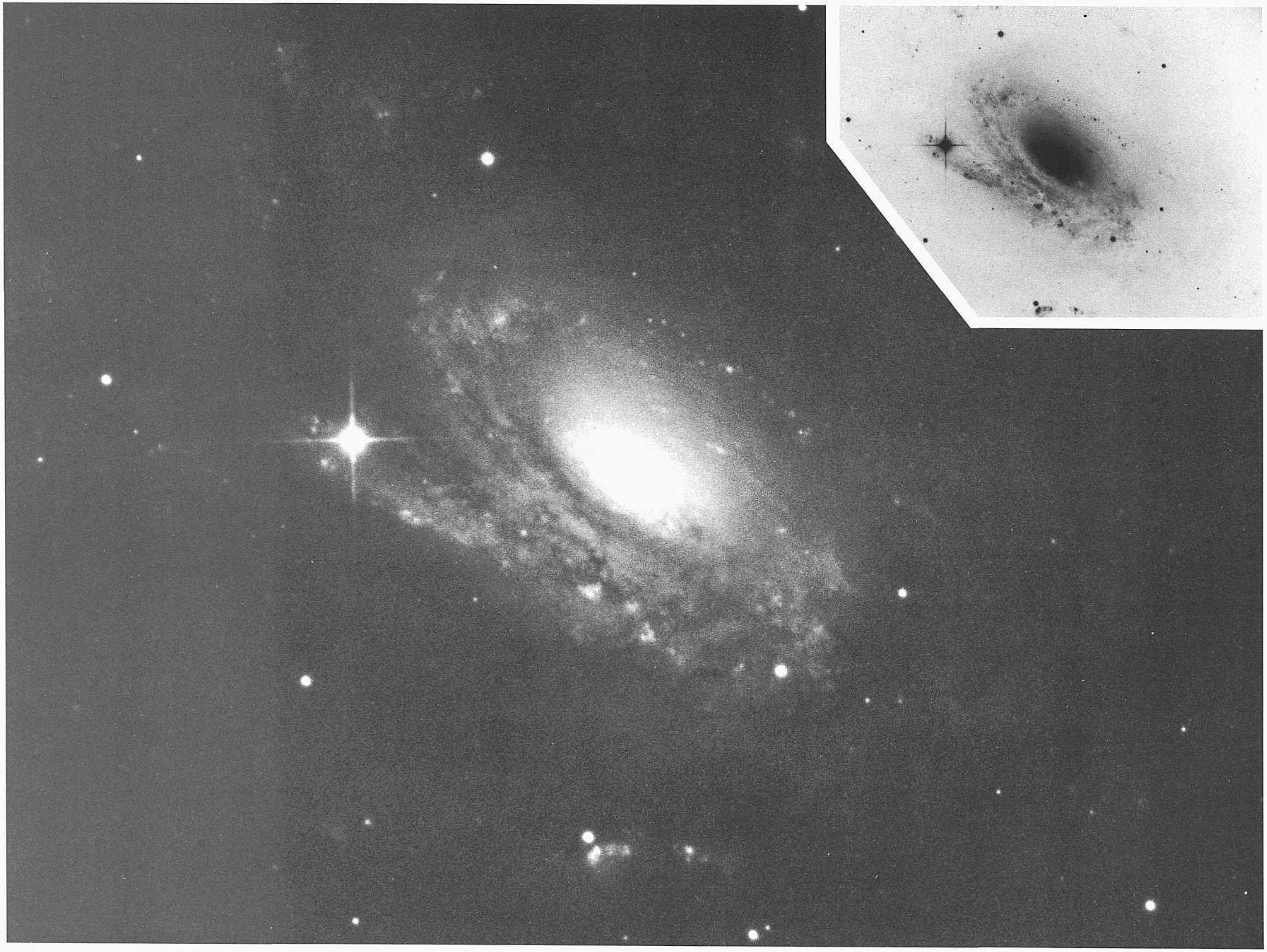
NGC 4050 Sb(r)I-II
CD-17O1-S
Jail 4/5, 1981
103aO + GG385
45 niin

The well-formed **spiral pattern** of the grand design type in NGC 4050 starts tangent to a smooth inner **bulge.** Many small HII regions exist in the **high-surface-brightness** parts of the two principal arms.



PANEL
131

PANEL
132



NGC 3169 Sb(r)I-II(lides) pair
CD-1336-S/Br
March 11/15. 1980
I03a0 + GG385
45 mill

NGC **3169 forms a** pair **with NGC 3166 (Sa; panel 77). 7.7' distant. The galaxies have** closely similar **redshifts,** o_0(3 1 06) = I **1** 66 kin s^{-1} **and** u_o**(3169)** = 1067 km s"'. **At the rcdshifl** distance of 2 2 **Mpc** ***(H* - 50) the projected linear** separation is small, at **49 kpc.**

The warped plane **of NGC 3169** and **the** peculiar **morphology of the** disk **of NGC 3166** almost **certainly verify** that tides **from a** close encounter **have occurred, producing the warped** plane **evident** here.

The dusI lanes are **multiple,** seen **well** in silhouette **against the large** central **bulge. The** spiral **pattern is of the filamentary type.**

fill regions are evident, particularly **iti the bright** arm **on the** near side **Very** faint **outer** arms exist **of** such **low surface brightness that** they are only hinted **at** in **the** print here. **How-ever, bright 1111** regions exist **in these outer arms,** especially in the faint **outer** arm on the near side **where** the **largest** resolves at a diameter of I". **corresponding** to a linear **diameter of** 125 pi-, consistent with the calibration **of III** I-region linear sizes as a function oi galaxy luminosity class (Sandage and Tammann **1974a).**

Galaxies on this and the following page are of the multiple-armed (filamentary) type, whose prototypes are NGC 488 (Sab; panels 115, 116, S3, S12) and NGC 2841 (Sb; panels 142, S4, S12).

NGC 6887 Sb(s)l-II
CD-1519-S/Br
Aug5/6,1980
103aO + GG385
45 **niin**

The tightness and regularity of **the** multiple arms in NGC 688 7 accounts for the Sb classification even though the large bulge component is missing. Based on the size of the bulge alone the type would be late Sc, but the star-formation rate and the tightness of the spiral pattern are the overriding criteria for the earlier type.

NGC 3147 Sb(s)I-II HA, p. ***20***
PH-7961-S
Nov8/9,1980
103aO
12min

The spiral pattern in NGC 3147 is similar to that in NGC 488 (Sab: panels 115, 116, S3, S12), but the star-formation rate is higher in the arms and the smooth bulge is smaller. The arm pattern consists of spiral fragments that can be traced as individual continuous segments **without** branching for only about one-quarter turn. The largest HII regions in the arms have angular diameters of about 3".

NGC 7782 Sb(s)I-H group
PH-7693-S Racine wedge
Sep 26/27, 1980 panel S13
IllaJ
75 niin

NGC 7 782 is the brightest in a group that contains NGC 7778 (El). NGC 7779 (Sa: panel 65), NGC 7780 **(SBab), and** NGC 7781 [S0(8)]. The redshifts are similar at $u_o(7780)$ = 5584 km s"l and $j;_o(7782)$ = 5341 km s"'.

The high regularity of the spiral pattern and the thinness of the arms in NGC 7782 require the bright luminosity class. The arms are tightly wound and multiple. Low-surface-brightness outer arms exist which can be well seen in this print. A central smooth nuclear bulge exists.

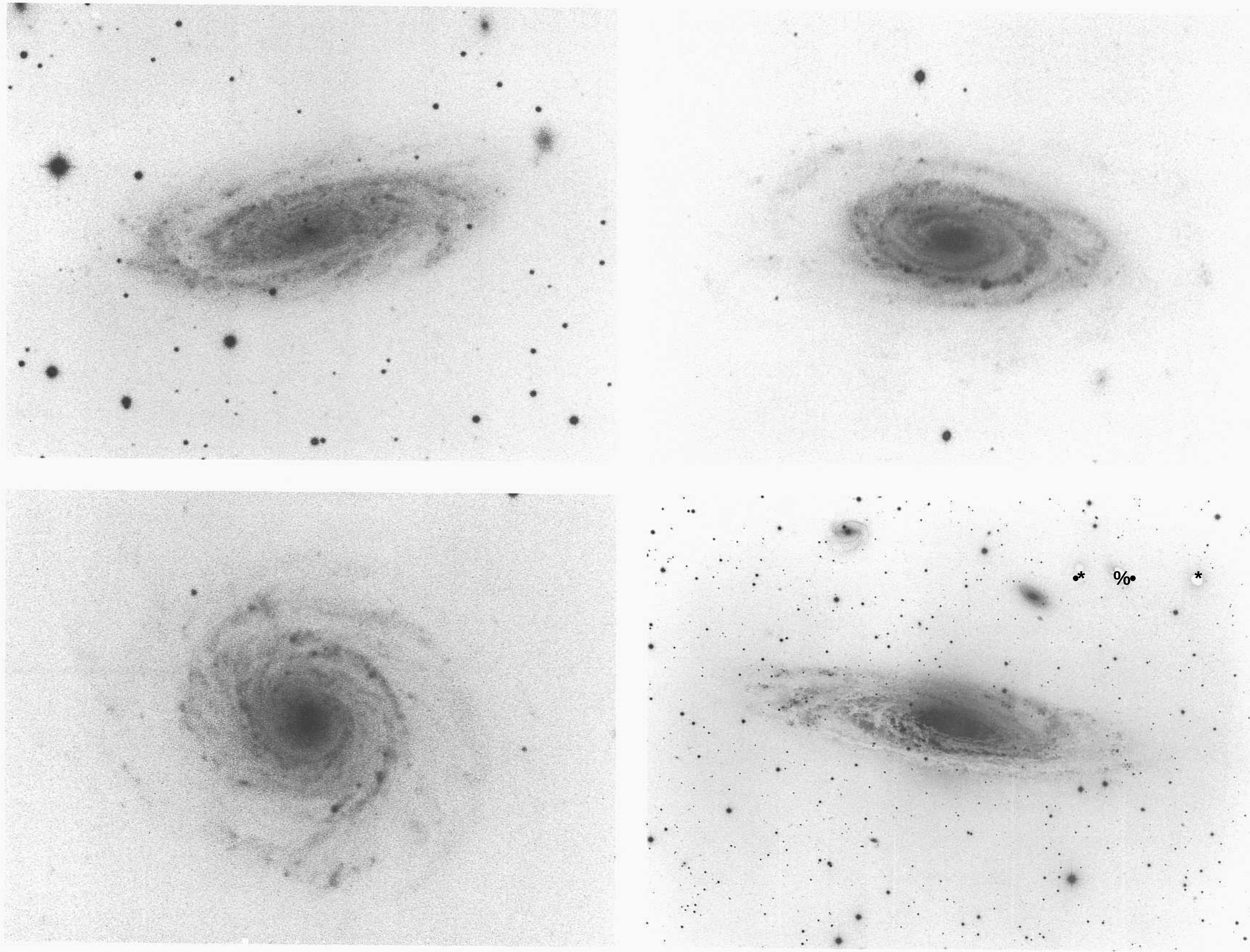
The plate was taken with a Racine wedge, giving secondary images to the bright stars reduced by 5 mag and separated by 18". The two bright stars in this print show these secondary images.

NGC 7331 Sb(rg)I-H Stephan's quintet
PH-64-H HA, p. ***17***
Oct 13/14, 1950
103aO
30min

NGC 7331 has a spiral pattern of the MAS type, similar to that of M31. However, the nuclear bulge is smaller than in M3 1, and the arms in NGC 7331 can be traced closer to the center than in M3 1.

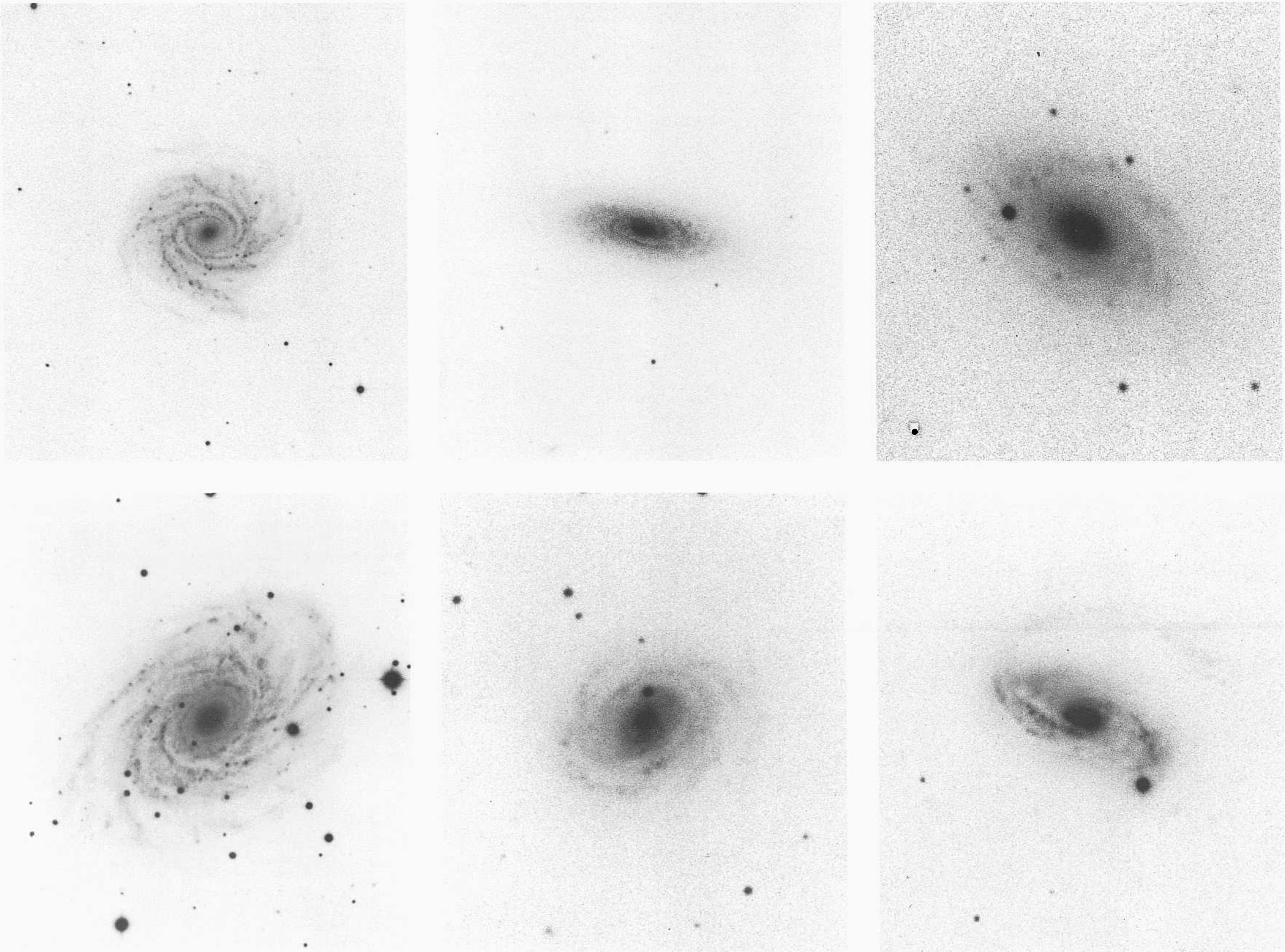
NGC 7331 is superposed on a more-distant group of early-type galaxies with a mean redshift ofabout6000 km s~^{1}, of which Stephan's quintet is **a** subgroup. Three galaxies of this more-distant group can be seen in the print here.

As described in the Hubble Atlas, NGC 73 31 played a crucial role in settling an early problem as to the direction of the opening of the spiral pattern relative to the direction of rotation of the galaxy.



PANEL
133

PANEL
134



NGC 1288 Sb(r)I-II
CD-1722-S
Jan 9/10, 1981
103aO
75 niin

NGC 12 88 is at the western edge of the Fornax Cluster (Ferguson 1989) but evidently is in the background at a redshift of v_o = 4461 km s~^J.

The regular spiral pattern of the MAS multiple-armed type requires the bright luminosity class. Many unresolved HII regions exist in the thin, regular, well-defined arms. The central bulge and disk are smooth and unresolved, indicating an old population.

NGC 3223 **Sb(s)I-II** panel S4
CD-S/Br
May 7/8, 1980
103aO + GG385
45 min

NGC 3223 is about 1.5° northwest of the main concentration of the Antlia Cluster (Ferguson and Sandage 1990) in the complex region of the Hydra-Centaurus Supercluster (Hopp and Materne 1985). The mean redshift of the small Antlia dense cluster in this region is near $<u_o>$ = 2500 km s~'. The redshift of NGC 3223 is v_o = 2619 km s"[1].

The tightly wound, multiple-arm spiral pattern in NGC 3223 is similar to that in NGC 488 (Sab: panels 115, 116, S3, S12), but its arms are slightly less regular and are thicker than in that Sab prototype MAS galaxy. Many HII regions exist in the arms, but all are unresolved at the 1" level.

The central smooth (old-star) bulge is present but is smaller than in NGC 488: hence the later morphological type is required.

NGC 670 Sb(s)I-II
PH-7824-S
Sep 2/3, 1980
103aO
12 min

NGC 670 is a distant (v_0 = 4023 km a"[1]) galaxy whose angular diameter is small compared to other galaxies in the Shapley-Ames Catalog. The KSA isophotal diameter to the SB = 25 'nag sec~ level is 2.4 arc minutes. The spiral pattern of the MAS type is distinct on the original plate. The high-surface-brightness internal near-ring is visible in the negative print here.

NGC 5150 **Sb(r)I-H** group
CD-1135-Br
Aug 21/22, 1979
103a0 + GG385
4-5 min

NGC 5150 is the brightest member of an apparent group that includes NGC 5152 (a spiral disrupted by NGC 5153) and NGC 5153 (E4). The redshift of NGC 5 150 is v_o = 4127 km s~^J. The redshifts of the other two apparent companions (separations of 4.5′ and 5.0′, respectively) are unknown (c. 1990).

The thinness of the spiral arms and their regularity require the bright luminosity class for NGC 5150. The tightness of the pitch angle of the arms, the only-moderate star-formation rate, and the finite size of the smooth central bulge are the reasons for assigning the Sb classification.

NGC 2551 **Sb(r)I-II**
PH-7900-S
Nov6/7, 1980
103aO
12 min

NGC 255 1 has a small angular- diameter (isophotal diameter of I .9' to the level of25 mag sec~). It is well resolved into spiral arms on the original plate. The classification of SO/a in the RC2 . based on a Lick 36-inch Crossley plate, is inappropriate.

The spiral arms are narrow anil well defined. The pattern is midway between grand design and MAS because two main arms can be traced. Although the arms break into fragments, the fragments are far fewer than in NGC 488 or in NGC 1288. shown on this panel.

NGC 23 Sh Ml HA, p. *22*
PH-1039-S
Aug 22/23, 1955
103aO
30 min

NGC 23. shown in the Hubble Atlas using the same original plate used here, has the NGC 210 look. Two sets of arms exist: the inner set is tightly wound. The outer set (one of which is much brighter than the other) is more-loosely wound.

A conspicuous dust lane is seen on the inside of a string of unresolved III! regions in one of the high-surface-brightness inner arms. NGC 23 is distant for a Shapley-Ames galaxy at redshift of v_o = 4836 km s"[1].

Galaxies on this and the next three panels are of luminosity class II, having spiral patterns more like the grand design than filamentary. This means that only a few principal spiral arms exist, not a multitude of spiral fragments. The regularity (geometrical entropy or "beauty") of the arm pattern is the defining criterion for the various luminosity class assignments.

NGC 2889 **Sb(r)H**
CD-806-S
Feb 25/26, 1979
103aO + GG385
45 min

One well-defined, abnormally bright main arm is the prominent feature of the spiral pattern in NGC 2889. **All** the arms are moderately thick relative to the galaxy's size. They are more irregular than in the brighter-luminosity-class Sb galaxies described in the preceding panels.

The central lens is relatively smooth (old stars exist there), but it contains two dust lanes that emerge from the small central bulge (nucleus). The main bright arms begin tangent to the rim of the lens.

NGC 4258 **Sb(s)n** **HA, p.** ***33***
PH-321-MH
April 27/28, **1951**
103aO
30 **min**

NGC 4258 is a nearby galaxy, well resolved into individual stars and HII regions in its two main (inter. Iow-surface-brightness arms. Very-high-surface-brightness inner arms exist, containing a number of high-surface-brightness HII regions.

The resolution into individual stars is less **complete** than in either M81 , with a distance modulus of m - M = 27.7, or in M101 whose distance modulus is m — M = 29.3. The resolution is more complete than for spirals in the Virgo Cluster (m - M ~31.7). Based on these data, the **modulus** cjfNGC 4258 is about m - M = 30. The redshift is small at v_o = 520 km s^{-1}, which, in the absence of very local streaming motions within 10 Mpc (Sandage 1975b, 1986a). is consistent with a **local** Hubble constant of 50 km s^{-1} Mpc^{-1}.

NGC 4192 **Sb II:** VCC 92
CD-2137-S
March 22/23, 1982
103aO
50 min

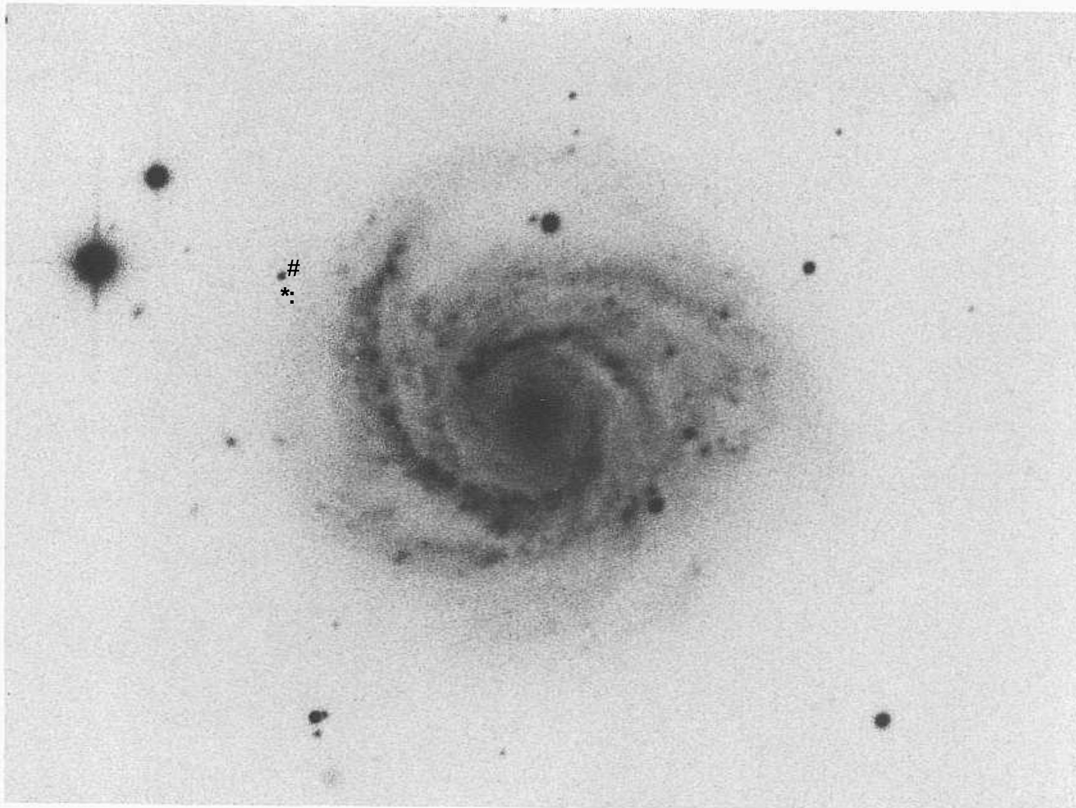
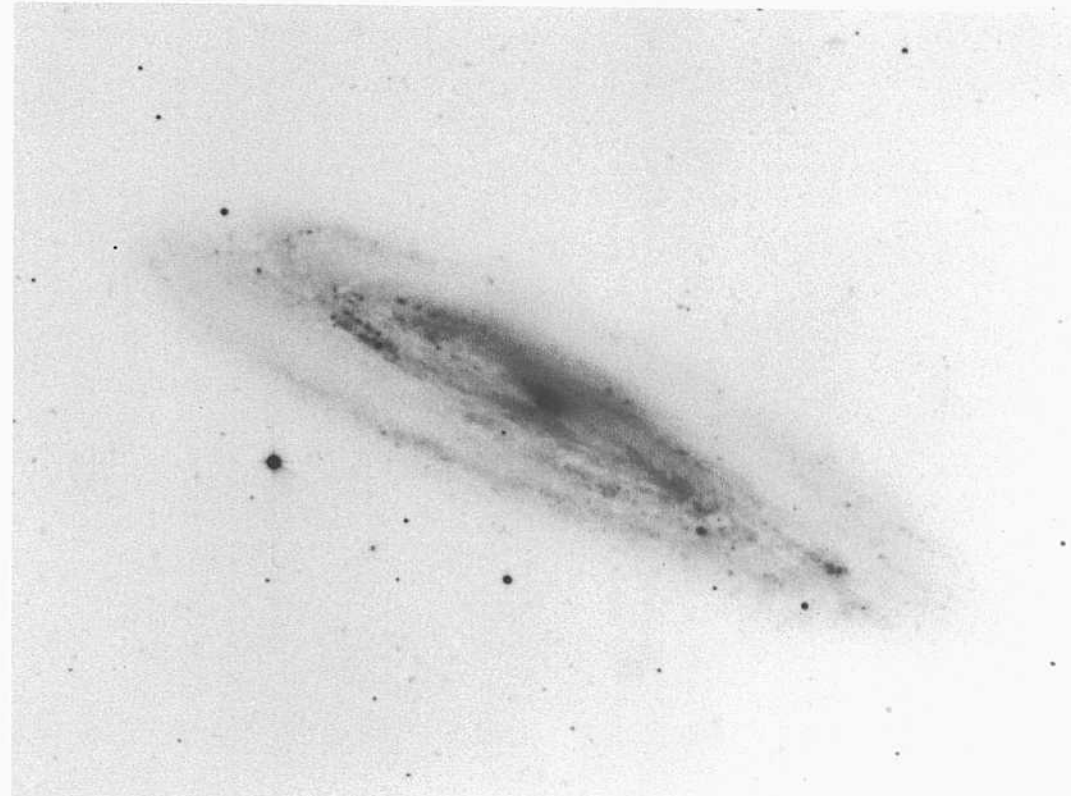
NGC 4192 is in the northwestern corner of the Virgo Cluster survey area (Binggeli, Sandage, and Tammann 1985). It is one of only five galaxies in the RSA having a negative velocity relative to the Local Group, and it is, therefore, beyond doubt a member of the Virgo Cluster. Its velocity reduced to the centroid of the Local Group is v_o = —131 km s^{-1}.

The resolution into stars in NGC 4192 is evidently much less complete than in NGC 4258, below and to the left, although numerous HII regions are present throughout the arms. The **largest** of these resolve at about the 4" level (core diameter).

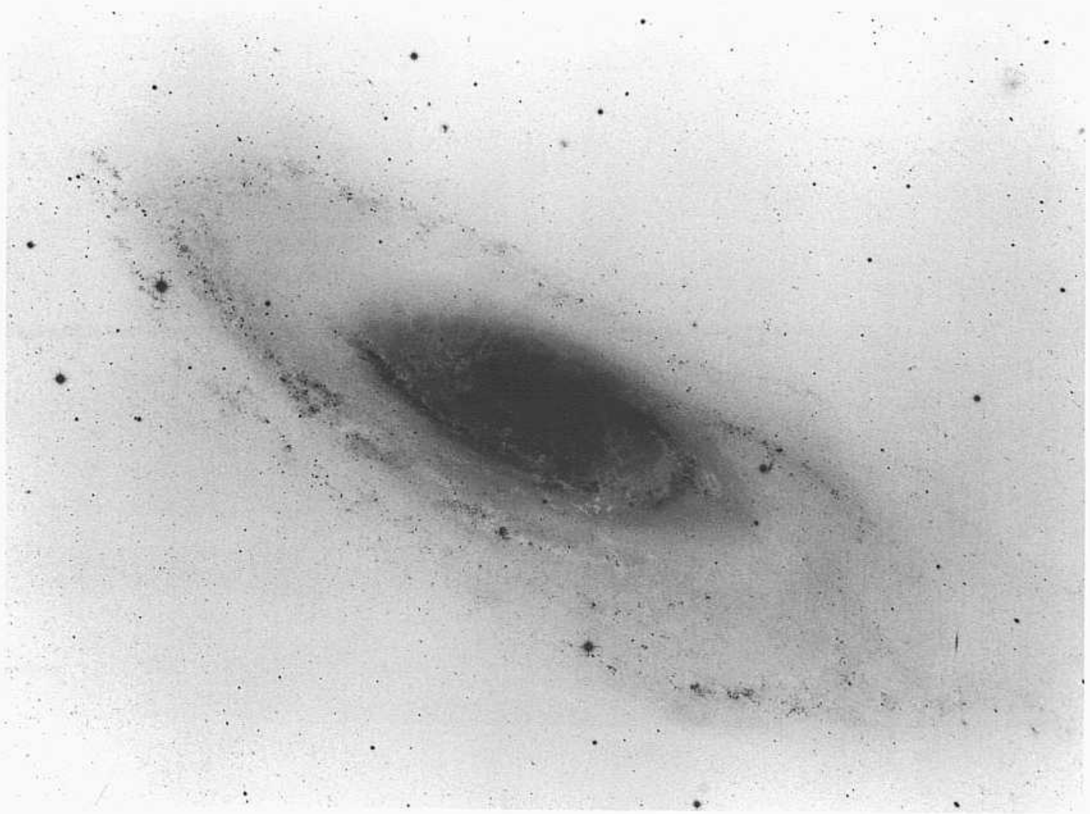
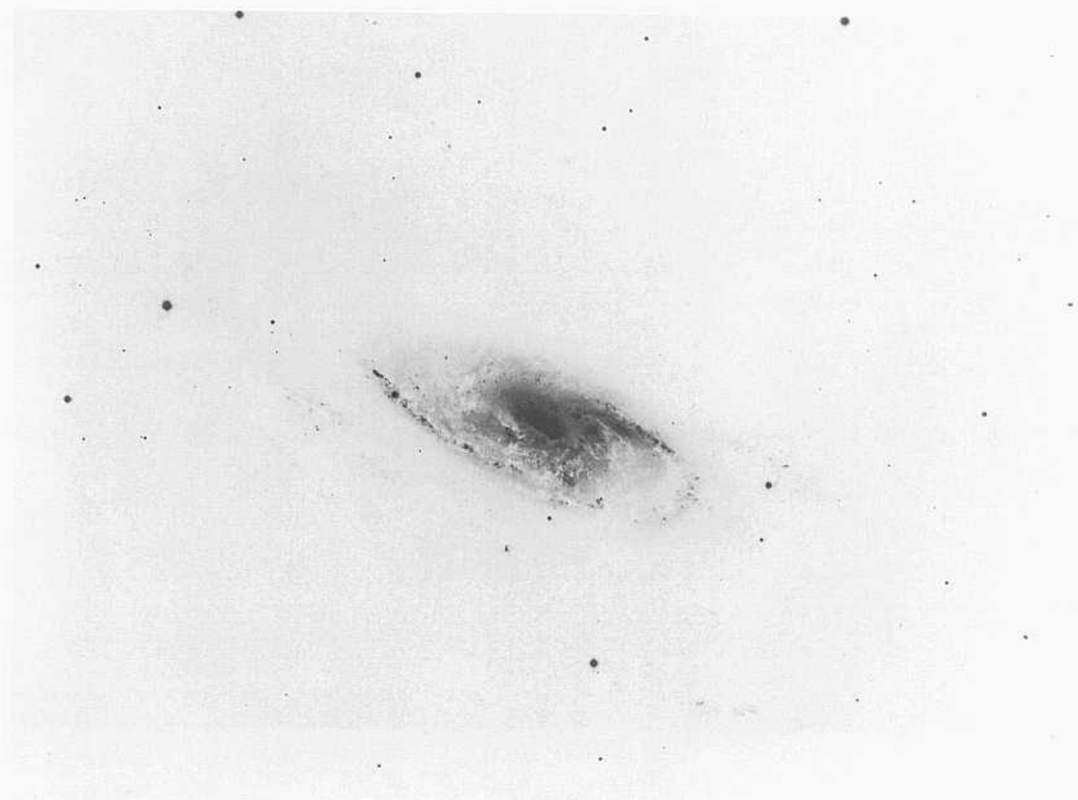
NGC 4258 **Sb(s)II** **HA, p.** *33*
PH-96-S
Jan 3/4, 1952
103aO + WG2
30 min

The region interior to the two bright inner luminous arms in NGC 4258 is filled with dust, which forms semi-spiral chaotic patterns, seen well in silhouette against the central bulge because of the high inclination angle. A negative print by Hubble (1943) shows the dust pattern well.

The largest of the many HII regions in the inner arms has a core diameter of 8" and a halo diameter of 13". At a distance of 10 Mpc these linear diameters of 390 pc and 630 pc, with a mean diameter of 510 pc, are consistent with a calibration of HII size with galaxy luminosity class given elsewhere (Sandage and Tammann 1974a).

PANEL
135

PANEL
136

NGC 1672 Sb(rs)II
CD-778-S
Feb 22/23, 1979
103aO + CG385
45 niin

NGC 1672 is in the Dorado complex (de Vaucouleurs 1975) which is an extension of the main Dorado Group centered on NGC 1553 (Ferguson and Sandage 1990) toward the direction of the LMC. The redshift of the Dorado Group is <^$_o$>= 1056 km s"^{1}: the redshift of NGC 1672 is $v_0 = 1\,130$ km s"'.

There arc four principal outer arms starting as luminous features tangent to the rim of a high-surfacc-brightness lens. Throughout this lens, thin dust lanes define an intricate multi-fragment pattern, best seen in the light print on the left.

Resolution into stars occurs near- the plate limit. The identification of individual stars is impossible until they arc separated by standard methods from the many IIII regions in the arms. The largest of the IIII regions are resolved, having core diameters of about 4": a number exist with diameters of 2". The identification of the largest HII regions can be made best on the print to the left.

NGC 1672 Sb(rs)II
CD-778-S
Feb 22/23, 1979
103aO + GG385
15 niiri

Tile outer spiral arms in iNGC 1672. shown in the heavy print here on the right, are thick, yet the pattern is well defined. One of the Lwo principal arms has a much higher surface brightness than its male on the opposite side: the pattern is similar to that of \\C,(\ 2889 on the preceding panel.

Very faint extensions of the principal arms can be traced as a continuation of the spiral pattern outward for about another' half rotation of the wrap.

The two galaxies on this page continue the Sb II type of the grand design spiral type.

NGC 1961 Sb(rs)IIpec
PH-7549-S
Nov 6/7, 1978
103aO
12 min

The outer spiral arms of NGC 1961 are highly distorted as if by a close encounter, yet no companion galaxy is evident. Nor can any nucleus of such a companion be identified in the vicinity of the main body. NGC 1961 is the principal example of a distorted galaxy of the type cited by advocates of the "merger" hypothesis where there is no sign of a companion. The distortion of the arms in NGC 1961 cannot be ascribed to an encounter or a merger in progress. Rather, the distortion here appears to be intrinsic to this apparently isolated galaxy.

Many HII regions exist in the near-side arms, the largest of which resolve at the 4" level (for the core). This size is large considering the large redshift of v_o = 4147 km s^{-1}.

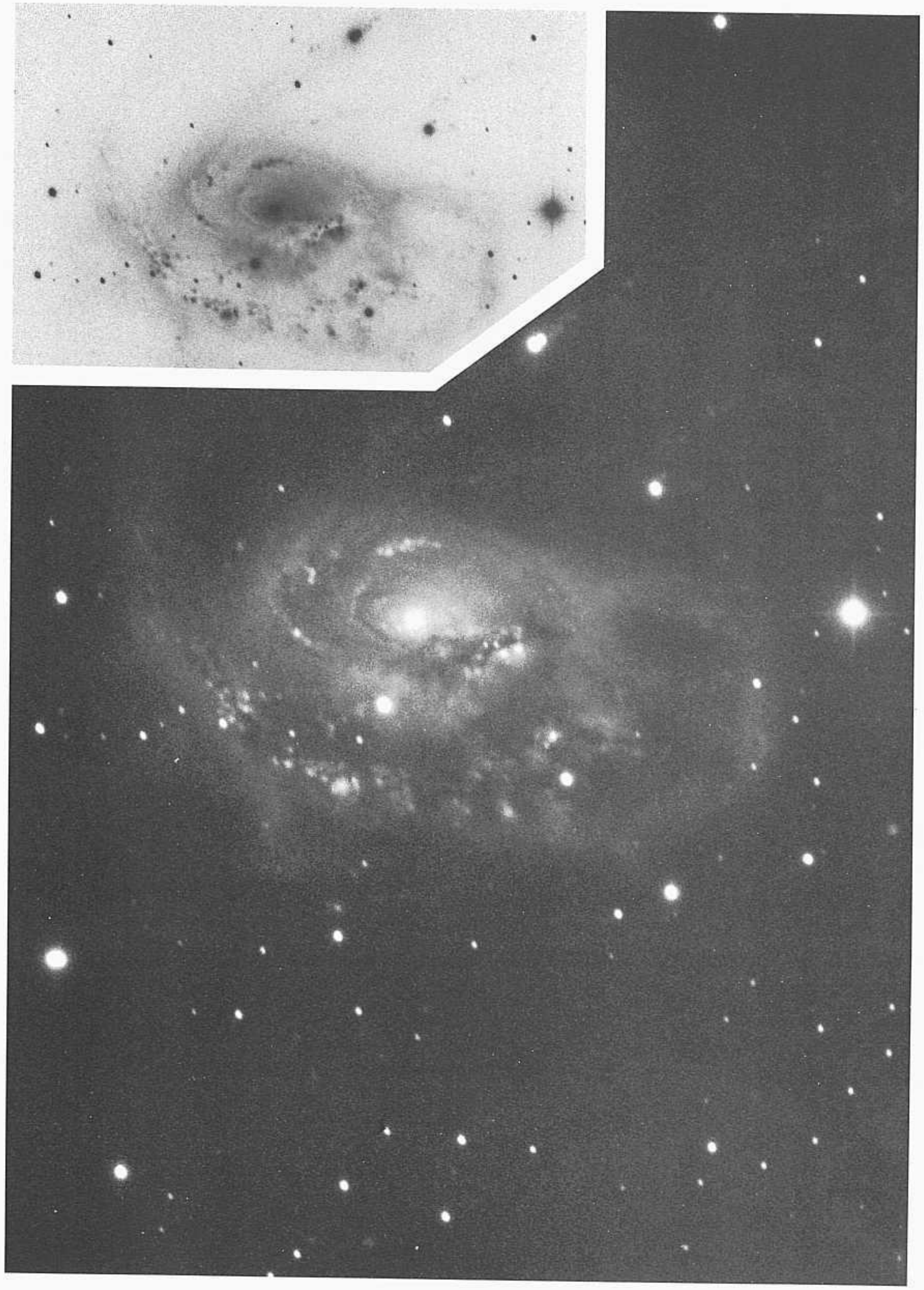
Regular dust lanes define thin spiral fragments in the central parts of the lens.

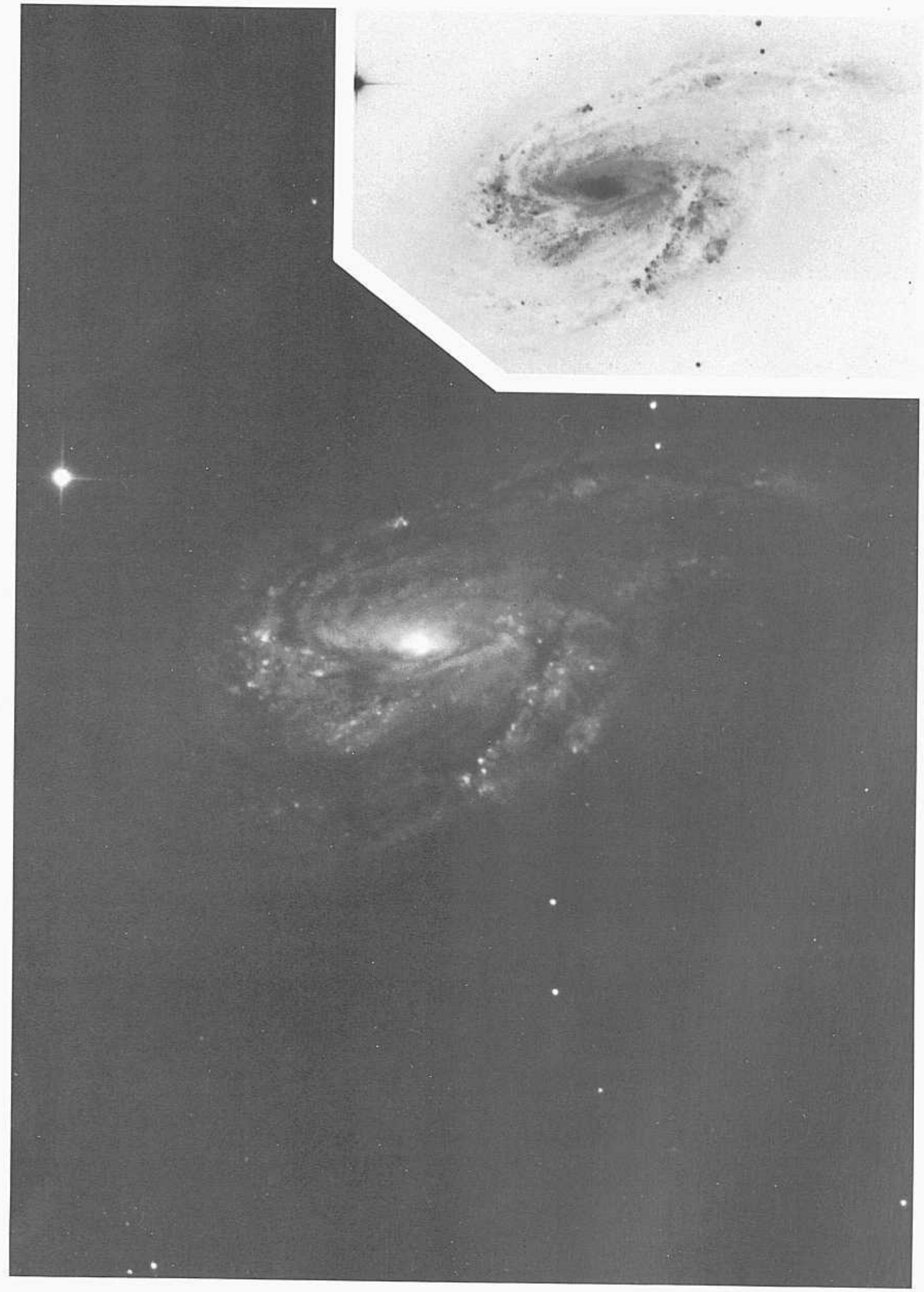
The absolute magnitude of NGC 1961 at M_B = -23.7 is the brightest in the RSA.

NGC 3627 Sb(s)II.2 HA, p. *23*
H-2363-H panel S14
Nov 29/30, 1946
IIaO
10 min

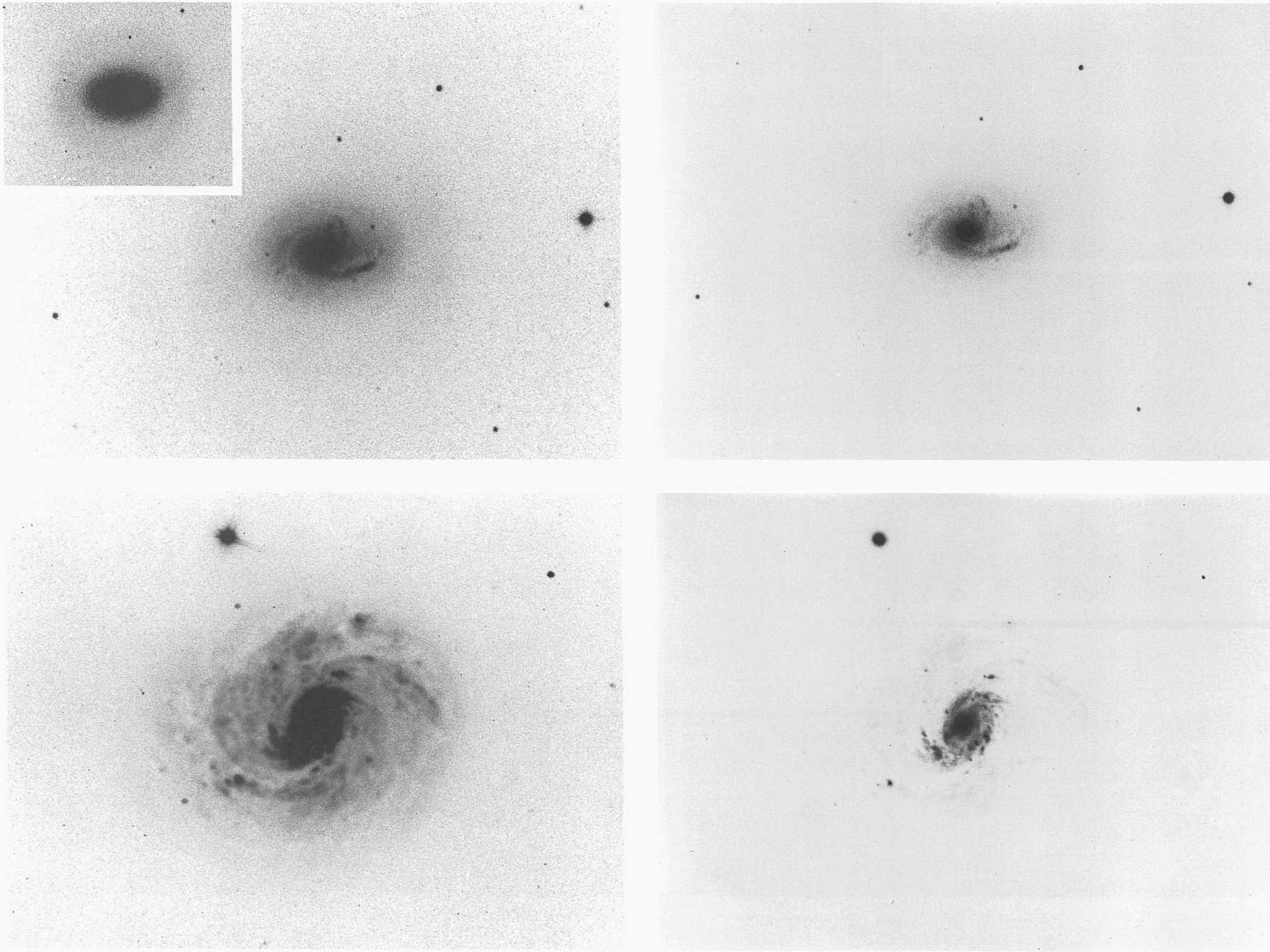
The principal feature of the spiral pattern in NGC 3627 is the great quantity of dust throughout the disk. The disk surface brightness is very high, judged from the intense disk image in the facing print, made with the very short exposure for this plate. (Note the 1946 date, signifying the inevitably slow emulsion speeds of plates of that era, and also note the even slower IIaO. fine-grained emulsion used here compared with the usual faster 103aO emulsion type. Clearly, the disk surface brightness is abnormally high.)'

Many HII regions exist throughout the disk of NGC 3627, often on the outside of the principal dust lanes that define the spiral pattern. The HII regions resolve at about the 2-3" level. The redshift is small at v_o = 593 km s^{-1}, but the resolution into stars is much less pronounced than in NGC 4258 (panel 135), which has about the same redshift.





PANEL
138



NGC 4457 RSb(s)II VCC 1145
H-2481-S HA, p. *9*
Jan 9/10, 1948
103aO
30 min

NGC 4457 is at the southern extreme of the Virgo Cluster Catalog survey region (**Binggeli, Sandage,** and Tammann 1985) toward **the** southern extension along **the** local **supergalactic** plane (de Vaucouleurs 1956b).

The morphology of the spiral **pattern in** NGC 4457 is unusual because **the** star-producing spiral arms are entirely inside a smooth disk which itself is inside an almost complete outer, nearly detached, smooth ring. This disk and ring morphology is characteristic of earlier-type galaxies **but** is unusual in galaxies having well-developed star-producing spiral arms, as in NGC 4457 here.

The galaxy has one **prominent** arm **of high** surface brightness and another, opposite branched, complex of arms that are fainter and are less well defined, seen best in the lighter print at the right. The deeper print on the left shows the disk, within which the arms reside. The insert shows the outer, almost detached, smooth ring of low surface brightness. This feature is composed of overlapping opposite arms which attach to the rim of the disk near the intersections of the ends of the major axis of the disk with its edge.

NGC 1068 Sb(rs)II HA, p. ***16***
H-2336-S
Nov 27/28, 1946
HaO
10 min

NGC 1068 is the prototype for galaxies that have a large and abrupt change of disk surface brightness between the inner and outer regions. Other examples include NGC 4699 (Sa or Sab; panels 78, 87, 118, S12). NGC 4736 (RSab; panel 1 19), and NGC 4800 (Sb; panel 188). all shown on page *16* **of** the **Hubble** Atlas.

The inner and outer spiral pattern in NGC 1068 is shown in the heavy print on the left, made from the same plate used in the Hubble Atlas. A set of very faint, external smooth spiral structures exist far beyond the edge of **the** disk shown here, but seen well in the insert print in **the** Hubble Atlas (p. *16).*

NGC 1068 is one of the original Seyfert galaxies. Galaxies in the class show intense unresolved bright nuclei (mini-quasars) and broad, high-excitation emission lines in **their nuclear** spectra (Seyfert 1943).

NGC **4457 RSb(s)H** VCC **1145**
H-2181-S HA, p. 9
Jan 9/10, 1948
103nO
30 min

The **prinl here of NGC 4457** is **made from the** same **plate** used in **the Hubble** Atlas. The moderately tightly wound arms and **the** dust **on the inside of the main arm are** well **\|°i'n* in **the** reproduction here. Small **IIII** regions exist in parts of the arms.

NGC **1068 Sb(rs)H HA, p. 76**
PH-75-S
Dec 26/27, 1951
103aO + WG2
1 min

The uery-high-surface-brightnesa inner arms in this Seyfert **galaxy** are **well** seen **in the prinl here,** made **from** a **very-short-exposure** plate (**1** -minute exposure) with the **Palomar** 200-inch telescope. Most of the knots **in** tin- **inner** arms and **the** two prominent knots in **the** much fainter intermediate set **of arms** are **IIII** regions, as shown from an existing Ha **interference** filter plate, not shown.

The six galaxies on this page are of the multiple-armed-spiral (MAS) type, similar to the NGC 488 and NGC 2841 prototypes.

NGC 3675 **Sb(r)II** **panels S4, S13, S14**
PH-7632-S
April 28/29, 1979
103aO
12 min

The high inclination of NGC 3675 permits the remarkably high dust content to be **well** seen in silhouette against the near side of the disk. The spiral pattern is similar to that of NGC 488. consisting of a large number of individual spiral **fragments** in close concert with fragments of dust lanes.

The central bulge in NGC 3675 is smaller than in NGC 488 or in NGC 2841. These galaxies are the Sb (MAS) **prototype,** but all are earlier in the Sb morphological box than most of the galaxies on this panel.

The very few knots in the arms of NGC 3675 are presumed to be **HII** regions. All are small, not usefully resolving at the 1-2" level. The redshift of NGC 3675 is v_a = 792 km s"'. The poor resolution into HII regions and stars, despite the very low redshift. shows that the current rate of star formation is low.

NGC 2613 **Sb(s)(II)** **panel S4**
CD-154-S
Feb 3/4, 1978
103aO + GG385
45 min

The spiral pattern of NGC 2613 is more **similar to** that of NGC 2841 (Sb: panels 142, S4, S12) than to any other Sb of the MAS type in the RSA. The arms arc thin and arc *very* multiple, as in NGC 2841. The **main** difference is that the nuclear bulge is nearly non-existent in NGC 2613, whereas it is prominent in NGC 2841, which puts NGC 2841 earlier in the Sb morphological box. The spiral arms can be traced in NGC 2613 nearly to the center, requiring the (s) subtype.

NGC **5005** **Sb(s)II** **HA, p.** ***13***
H-2170-H **panel S14**
June 29/30, 1941
Cr-Hi-Sp-Sp
45 niin

The spiral pattern in NGC 5005 is defined mainly by dust lanes that exist throughout the disk. The most prominent dust lane has a different pitch angle than that of the general spiral fragments. The dust lane cuts across the main spiral pattern on one side of the image. The feature is similar to **that** in NGC 4450 (Sab pec: panels 110. S14 here: Hubble Atlas, p. 13). The lane does not begin in the nuclear region but on the periphery of the high-surface-brightness inner lens.

The current star-formation rate is low although finite: a few small **HII** regions exist that are unresolved at the 1" level.

NGC 5879 **Sb(s)II-m**
PH-7645-S
April 28/29, 1979
103aO
12 min

NGC 5879 is later in the Sb morphological box than either NGC 3675. NGC 2613. or NGC 5005. shown on this panel, because the recent sLar-formalion rate in the MAS arms is higher. The multiple arms **are** thin but are less regular than those in luminosity class II Sb galaxies. Although the redshift is small at v_0 = 929 km s^{-1}, the **HII** regions do not resolve at the 1.5" level. Such small HII regions are common in galaxies of this **morphological** and luminosity class (Sandage and Tammann 1974a).

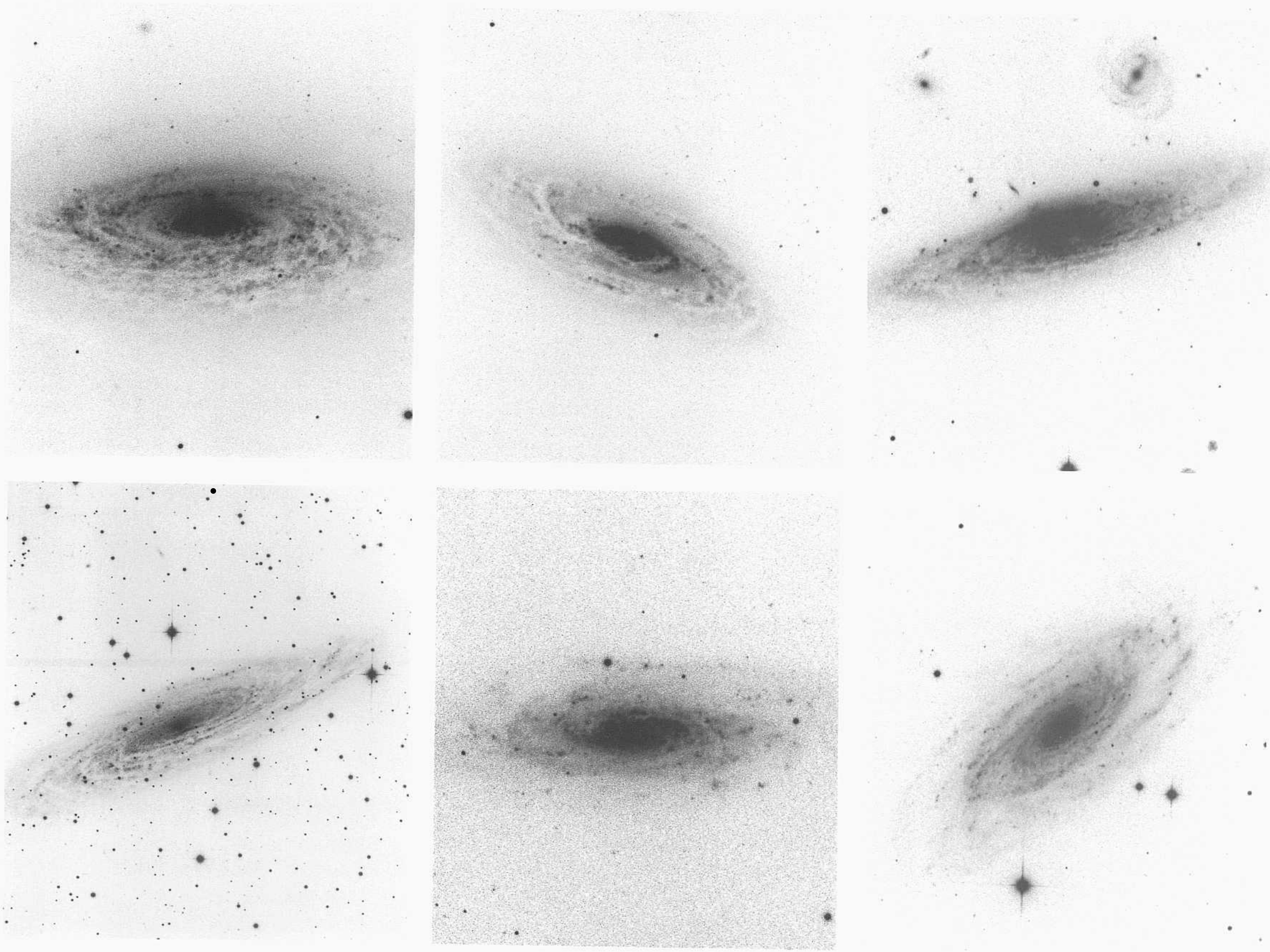
NGC 1515 Sb(s)H
CD-193-S
Feb 8/9, 1978
103aO + GG385
45 niin

The multiple spiral pattern in NGC 1515 is defined by fragments of dust lanes similar to the pattern in NGC 3675 and NGC 5005 on this panel. There is a small nucleus. A weak X-shaped bulge exists out of the plane over the central one-tenth of the image.

Very little current star formation exists. Only about a dozen HII regions **appear** over the face on the well-exposed existing plates.

NGC 1425 **Sb(r)II**
CD-2003-Bedke/Gregory
Oet 22/23, **1981**
103aO + GG385
45 min

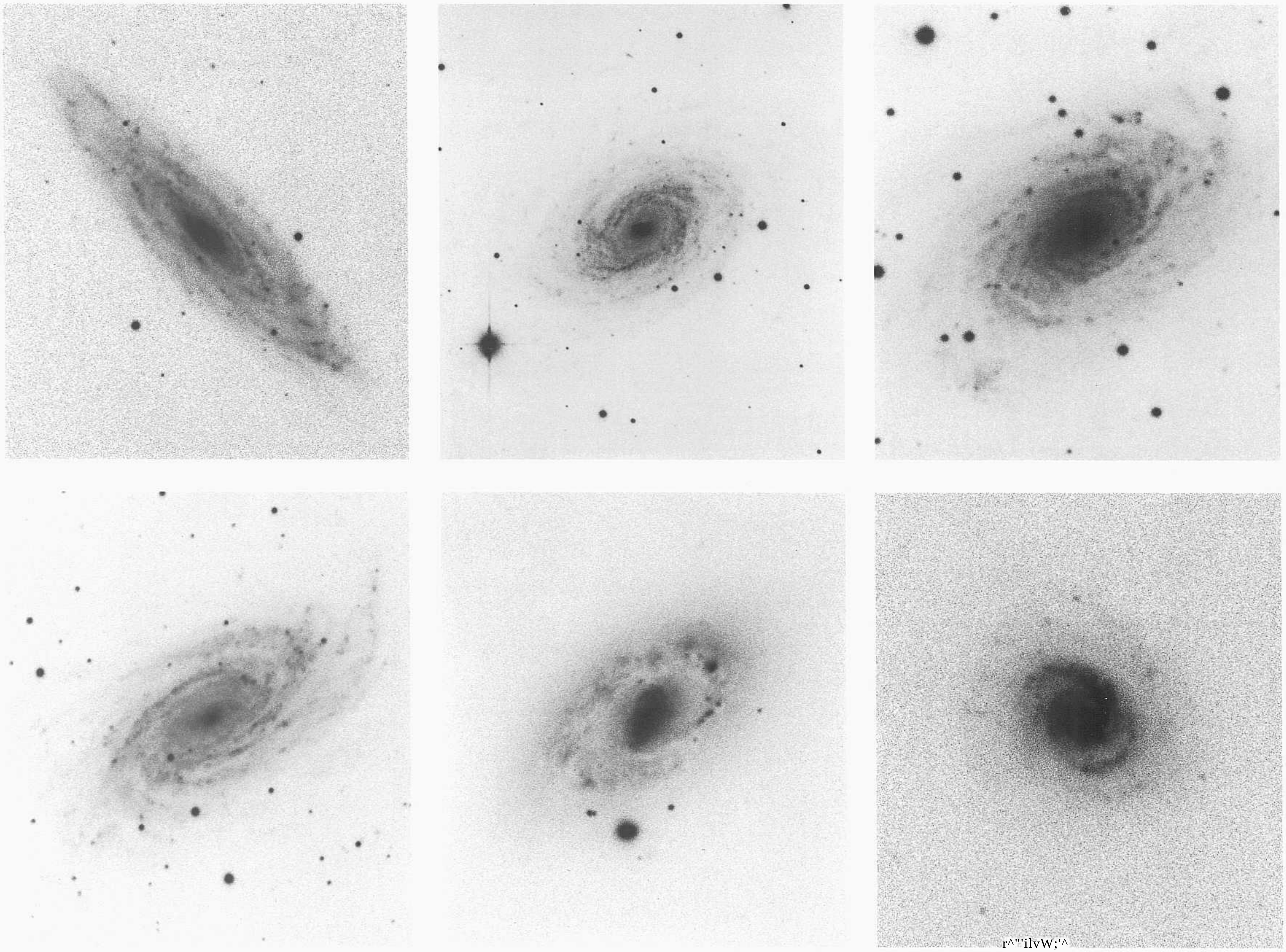
The luminous multiple arms in NGC 1425 are well defined. They start tangent to an unresolved central smooth lens, which is the inner part of the disk. A number of small **HII** regions exist in many of the arm fragments, the largest of **which** resolve at the 2" level. The redshift of NGC 1425 is v_0 = 1440 km s"'.



PANEL

139

PANEL
140



NGC 3254 Sb(s)II
PH-1145-S
Oct 23/24, 1955
103aO + WG2
20 niin

Most of the galaxies on this panel and the next have spiral-pattern features of both grand design and multiple-armed types. In each, more than two main arms exist but the number of spiral fragments is not as extreme as in the pure MAS galaxies, such as NGC 2841 (Sb; panels 142, S4, S12) or NGC 2613 and NGC 3675 on the preceding panel.

The arms in NGC 32 54 can be traced to the center, where sits a very small bulge, or nucleus. A few HII regions exist in the thin, well-defined arms, the two largest of which resolve at the 2" level. The redshift is v_o = 1219 km s"'.

NGC 6943 Sb(rs)II
CD-1596-S/Br
Aug 12/13, 1980
103aO + GG385
4-5 min

The thin arms in NGC 6943, their tight pitch angle, the moderate star formation in them, and the large central bulge with no recent star formation are the standard criteria for the Sb classification. NGC 6943 is the prototypical example of a normal Sb in the middle of the Sb morphological box.

NGC 3241 Sb(r)II
CD-731-S
Feb 2/3, 1979
103aO + GG385
45 min

NGC 3241 is in the complex Antlia region of the Hydra-Centaurus Supercluster. It is about 3° north of the compact Antlia Cluster proper (Ferguson and Sandage 1990), which has a mean redshift of $<v_o>$ = 2786 km s~J . The redshift of NGC 3241 is v_o = 2584 km s"1. Ilopp and Materne (1985) identify six groups in the 10 X 10 degree region (they give a map) with a range of redshifts from 2700 to 4500 km s"'. Evidently, NGC 3241 has the kinematics of the compact central Antlia Cluster itself.

The very-high-surface-brigbtness inner arms in NGC 3241 nearly overlap, forming an almost complete ring. However, the individual pieces that form the tight inner .spiral fragments themselves are hard to trace as two main arms (as in the Sa prototype of this form in NGC 3081 or NGC 3185); rather, three fragments start tangent to the relatively smooth inner disk and. as they unwind, branch and nearly overlap to form the thick inner near-ring. The inner bright arm fragments are Lumpy, and the HII regions are unresolved at the 1" level.

Faint outer arms that also contain HII regions branch from the bright inner set.

NGC 4102 Sb(r)II pee
PH-8057-S
Feb 4/5, 1981
103aO
12 min

At first glance, NGC 4102 appears to be a one-armed spiral. The galaxy does, however, have two arms which start at the periphery of an inner lens and, after each unwinds by half a revolution, nearly overlap. The connection of one of these arms to the lens is easy to find. The connection of the opposite arm is less evident because it is faint in its first 30° of unwind, yet it can be traced to the lens periphery at 180° difference in position angle from the point of connection of the brighter arm.

The arms are thick, each with much dust on its inside edges. Many HII regions exist, especially in the brighter arm. The largest is resolved at 5". The redshift is v_0 = 948 km s'V

NGC. 3038 Sb(s)II
CD-655-Br
Jan 5/6, 1979
103aO + GG385
45 min

NGC 30 38 has a morphology nearly identical to thai of NGC 6943, also mi this pan.-I.

NGC 3177 Sb(s)H
P11-8016-S
Feb 3/1, 1981
I03a0
12 min

The unusual features of NGC 3 17 7 are the principal arm of exceedingly high surface brightness and the difference of that arm's pitch angle compared with that of the opposite arm. The arras overlap after the bright principal arm has unwound by about half a revolution. Wry faint outer arms exist.

The Sb classification is based on the lliinness of the arms, the evident star formation in them, and the size of the central bulge. (Il is smaller than in a normal Sa. yet il exists; therefore, the type must be earlier than Sc.)

A bright supernova ("‚Ar = 17) of type II appeared in 1 947. but of course has laded below the plate limit here.

NGC 1325 Sb(s)H
CD-2002-Bedke/Gregory
Ool 22/23, 1981
103aO + GG385
45 min

Tlie spiral pattern can be traced in NGC 1325 to the center, **although the** surface brightness **of the** arm **fragments** near **the** center is **low.** The many arm **fragments** merge to form a nearly smooth central lens (the inner disk). The outer **arms** are **thin** and **multiple.**

IC 5271 **Sb(rs)n**
CD-1094-Br
Aug 18/19, 1979
103aO + GG385
45 min

The surface brightness of the arm pattern in **IC** 52 **71** is **exceptionally** high. The arm pattern is multifile. However, **the** arms are tightly wound. and are thinner **and** more regular than in the Sc class. This galaxy is late in the Sb morphological box. close to the Sb—She division.

NGC 7184 **Sb(r)II**
CD-1562-S/Br
Aug 9/10, 1980
103aO + GG385
45 min

The central region of NGC 7184 is devoid nï luminous arms. However, dust lanes form fragments of spiral patterns in the otherwise smooth central lens (the inner disk). The luminous multiple arms start tangent to the central lens. The two bright innermost arms are tightly wound and form an almost complete inner ring which, as usual, is not **a** ring but is the overlapping of these inner arms after each has unwound for half **a** revolution.

The arms **are** thin **and** the **spiral** pattern is regular, **requiring** the Sb classification.

NGC 4679 Sb(s)I-II
CD-2177-S
March 28/29, 1982
103aO + GG385
45 **min**

The morphological type of NGC 4679 is Sb because it is later than Sa (the central bulge is small and there is no smooth inner disk) and it is earlier than Sc (the arms are thin and the spiral pattern is moderately **regular).**

The inner arms have high surface brightness owing to numerous **II**11 regions that are unresolved at the *2"* level.

NGC 4527 Sb(s)II VCC 1540
CD-2139-S
March 22/23, 1982
103aO
50 niin

NGC 452 7 is a prototypical Sb similar to M31. It is in the Virgo Cluster Catalog but is about 5° south of subcluster B centered on NGC 4472, and 10° south of subcluster A near NGC 4486. Its redshift is high at v_o = 1738 km s~\ not necessarily meaning that the galaxy is in the background given the complex kinematic pattern and the high velocity dispersion of the Virgo Cluster region (Binggeli, Tammann, and Sandage 1987).

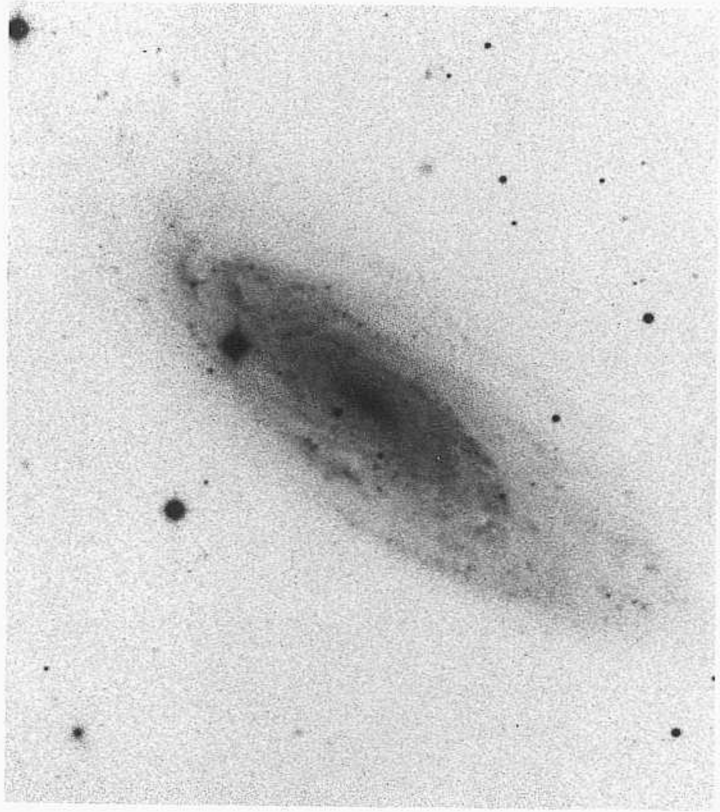
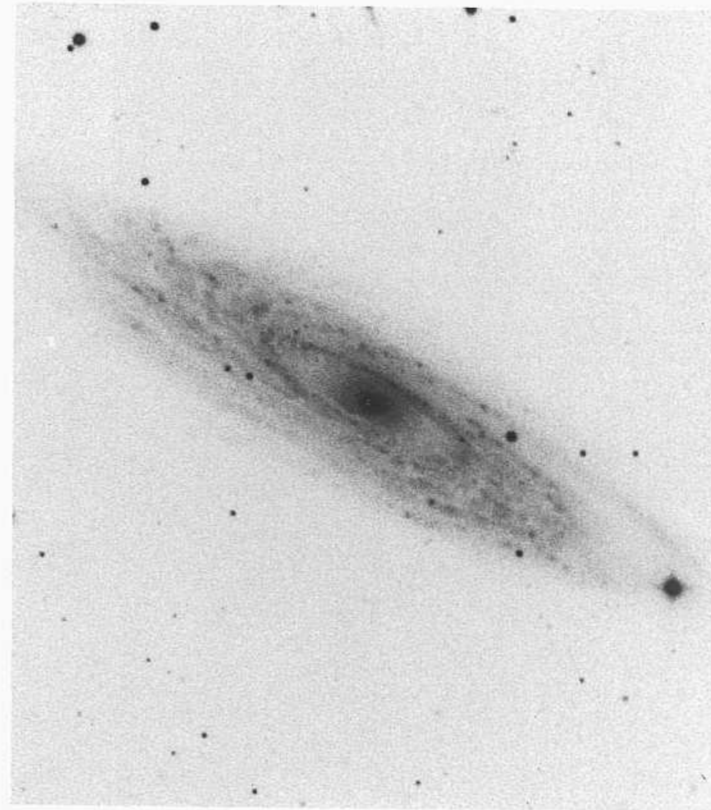
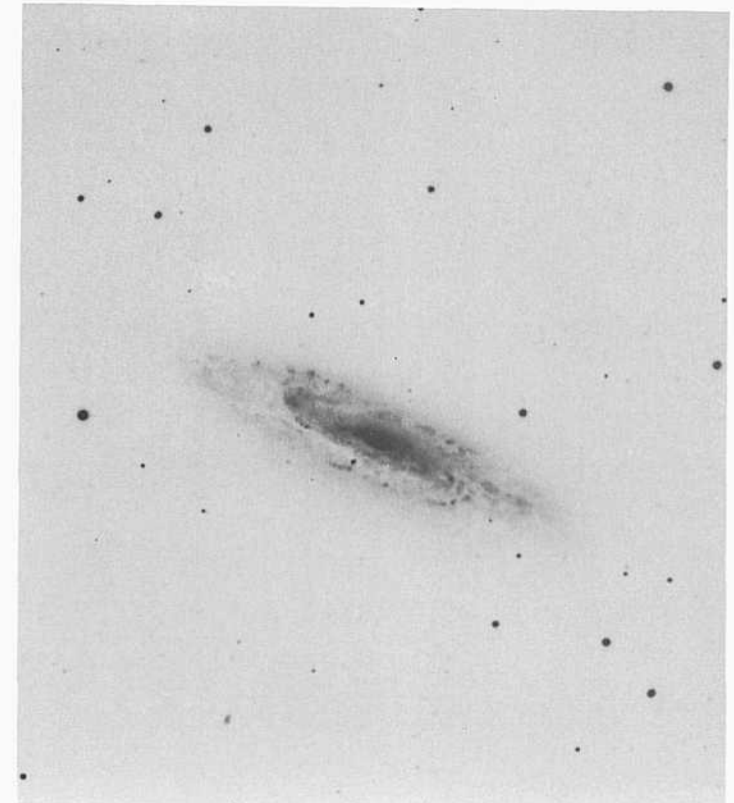
Many **II**11 regions exist in the thin, moderately regular arms, the largest of which resolve at about the *2"* level.

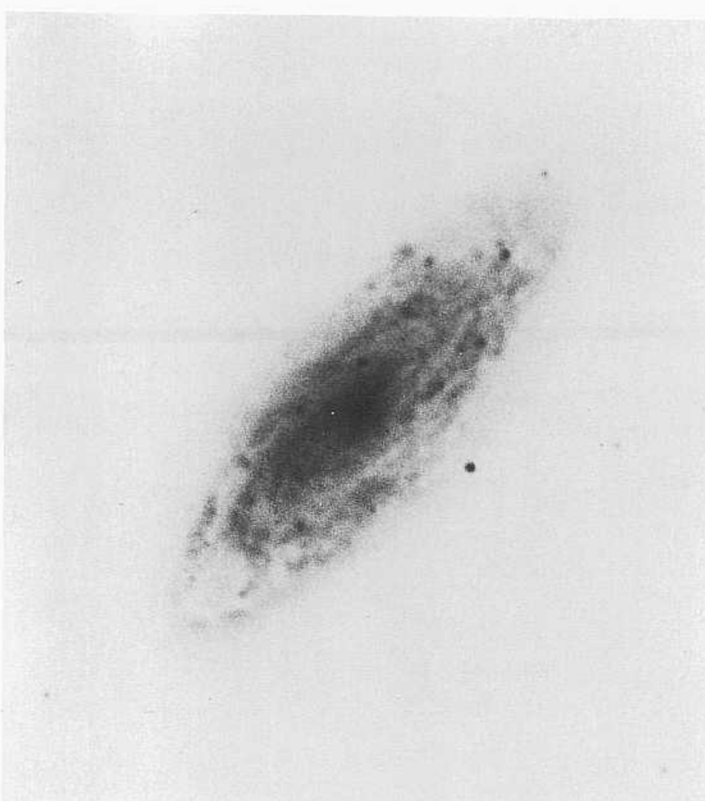
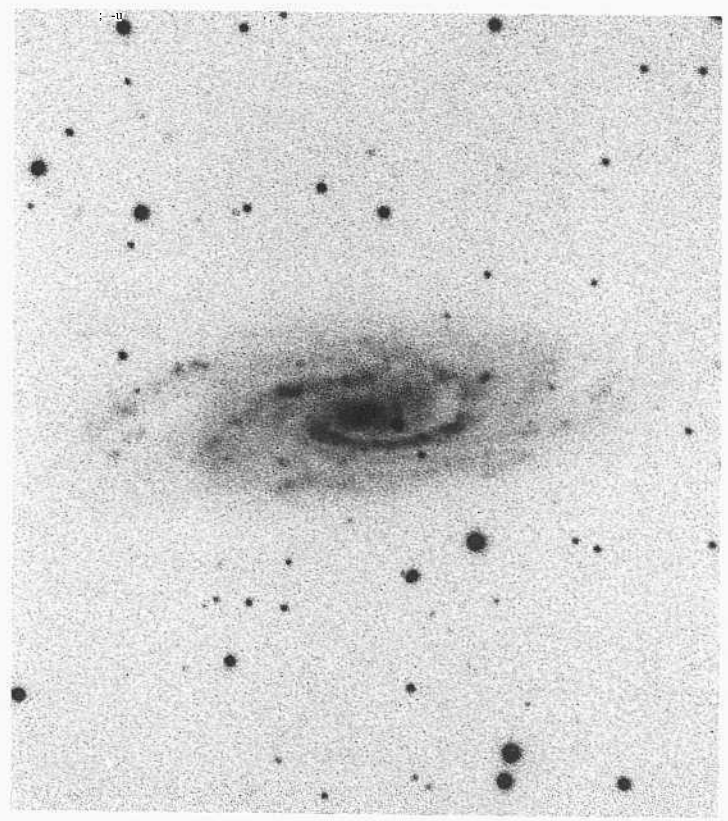
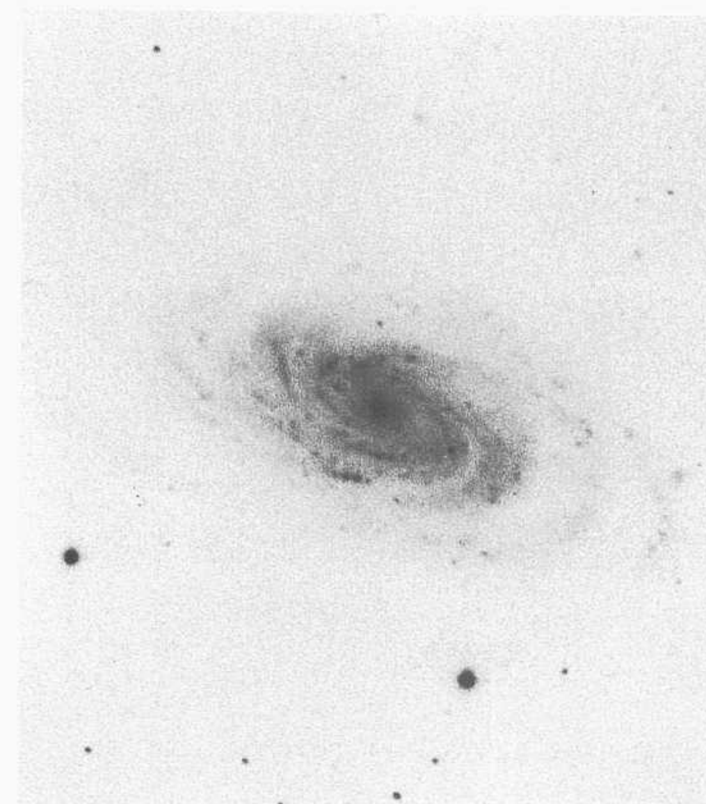
Much dust exists in the disk, well seen in silhouette against the near side of the bulge, causing the characteristic asymmetric luminosity profile between the near and the far side in the highly inclined disk.

NGC 5740 Sb(s)I-II pair
CD-1843-HB
April 2/3, 1981
103aO
75 min

NGC 5 740 forms a wide pair with NGC 5746 (Sb; panels 151, S1l) at **a** separation of 18'. The redshifts are similar at v_o(S740) = 1490 km s"[1] and u_o(5746) = 1638 km s~'. At a mean redshift distance of 31 Mpc, the projected linear separation is **164** kpc, indicating a probable association. The angular separation is only three diameters of NGC 5 746, the larger **of** the **pair.**

IIII regions exist in abundance in the arms of NGC 5740. The largest resolve at about 2" diameter.

PANEL
142

NGC 2841 Sb HA, p. *14*
PH-36-S panels S4, S12
Nov 7/8, 1951
103aO + WG2
25 mill

This prinl of NGC 2841 is made from a different plate than used for the deeper prinl in the 11 ul)Iili' Alias. Tlic photographic contrast here shows well the resolution into many stars and small Nil regions in the thin, intricate, regular distribution of the multiple spiral fragments that provide the spiral pattern.

Tin* central bulge and smooth lens are similar to those in NGC 4K8 (Sab; panels I I .'>. 116. S3. SI *2)* hnt arc smaller in NGC 2841 here. Also I he arm pattern is somewhat less regular, requiring the later classification.

An Met interference plate confirms that some of the knots in the arms arc small Mil regions. They are unresolved at the I" level despite the very small redshift, v_0 = 7 I 4 km s^{-1}. This shows that the intrinsic diameter of the largest MM regions is a strong function of morphological type, being small in galaxies that are this early in the classification sequence. M the distance of NGC 284 1 is 14 Mpc based on its redshift and a quiet Hubble flow in this local region, the largest 1111 regions arc smaller than 70 psc, five times smaller than in Se galaxies of luminosity class I (Sandage and Tammann 197 1a).

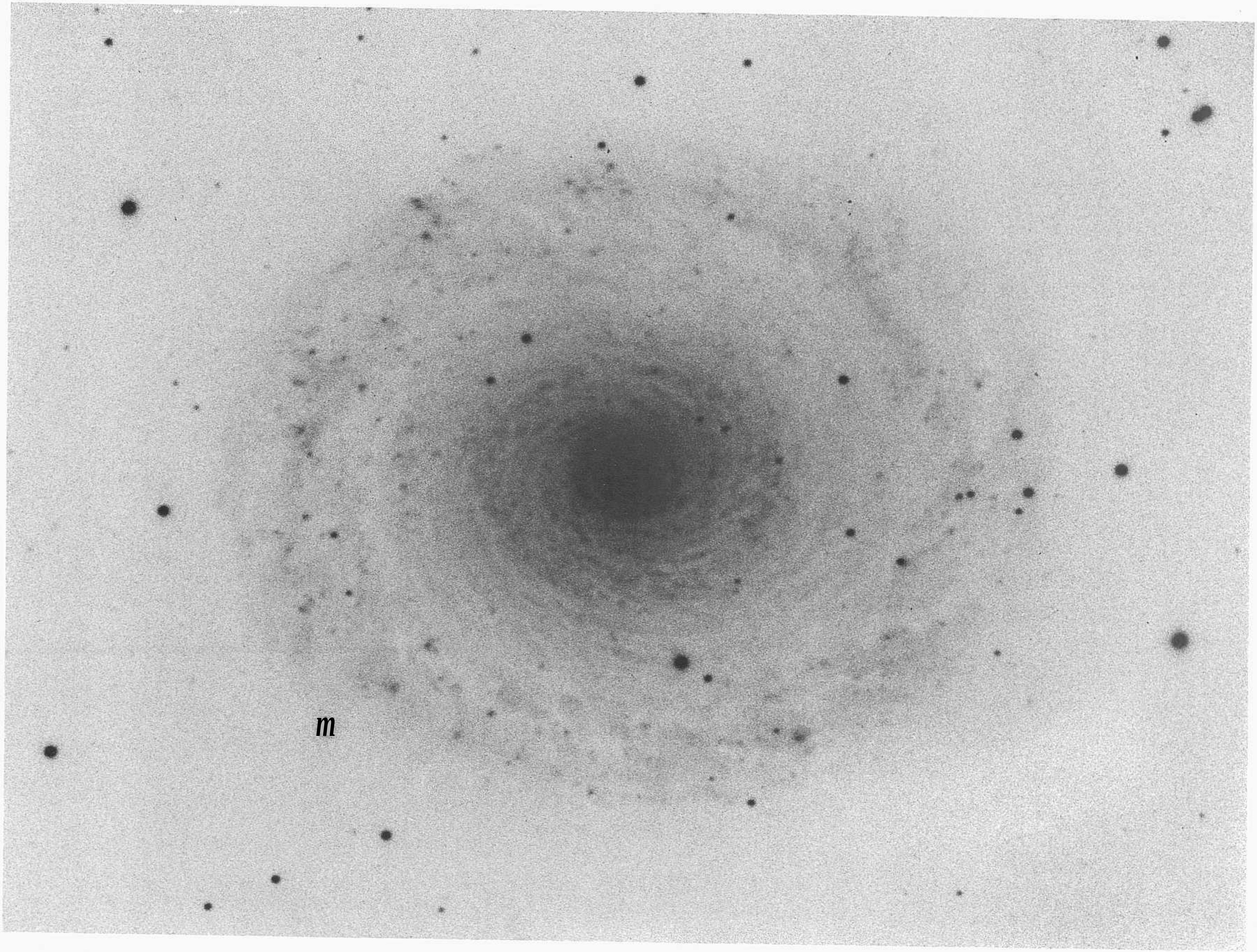
NGC 7217 **Sb(r)II-III** **HA, p.** ***15***
PH-63-H
Oct 13/14, 1950
103aO
30 niin

The negative print of NGC 7217 here is **made from** the same original plate used for the positive print in **the Hubble** Atlas.

The multiple-armed **pattern** is similar to **that** in NGC 488 and NGC 2841. It can be traced to within 1 0" of the center. Many small **III1** regions exist, the largest of which resolves at about **the** 2" level. The redshift of NGC 7217 is v_o = 1234 km s^{-1}.

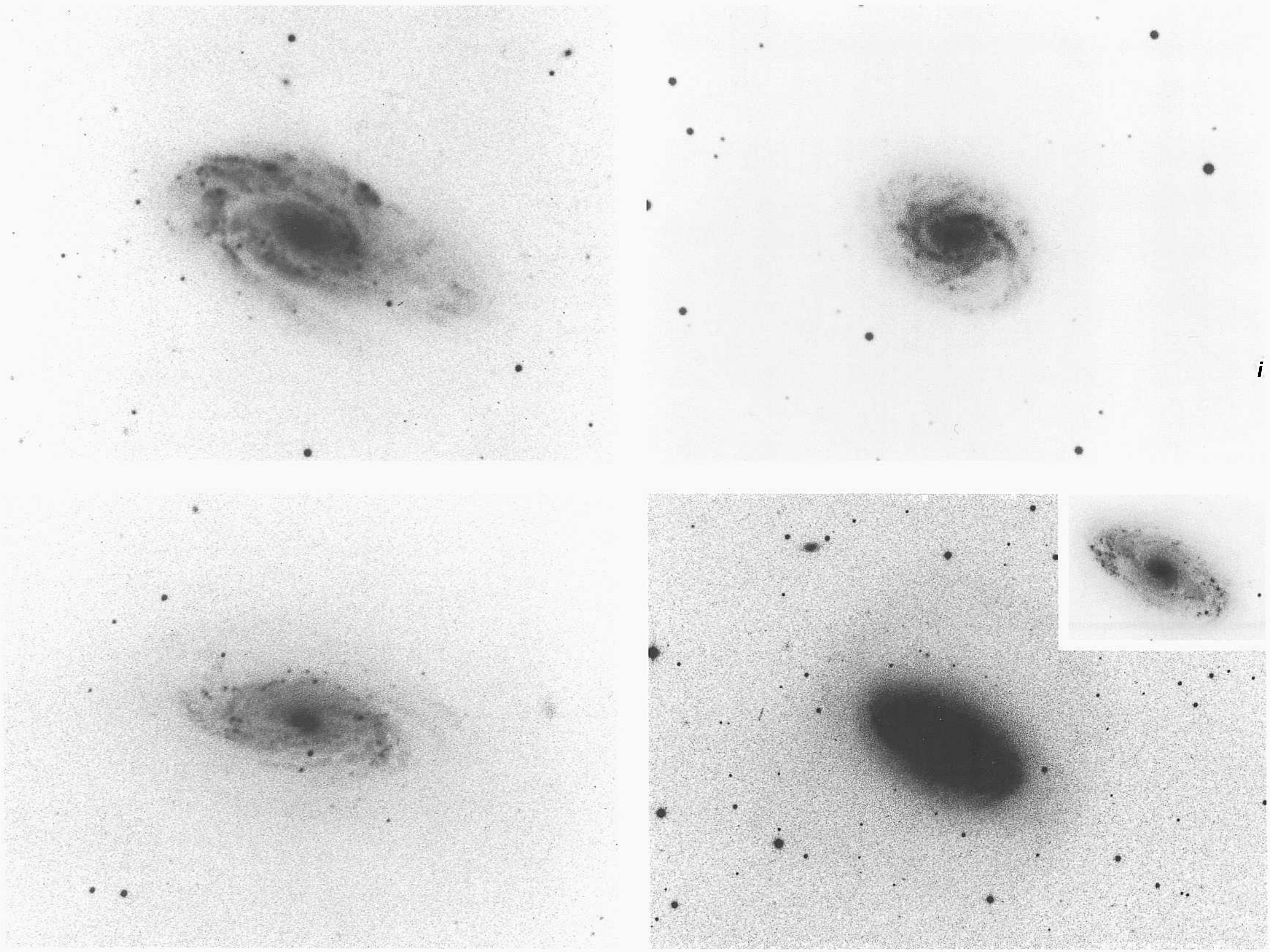
The arms can be traced throughout the disk, and in particular they exist in the low-surface-brightness region between **the** bright inner disk and the outer bright near-ring, which would be called an outer detached ring on low-spatial-resolution plates.

Note that the classification in the RC2 of RSab(r) is inappropriate because there is no outer ring. The misinterpreted feature is the higher-surface-brightness outer arms, which have the same **pitch** angles as the inner spiral **pattern** and which form a continuum **of** arms from the center [(s) type] to the outside. This feature of the bright outer near-ring is the expression in the Sb class here of the form in the earlier **SBa** types of NGC 2217 (panels **101,** 104, 107) and NGC 5701 (panels 100, **101,** 104), and in the later types of NGC 4736 (RSab: panel 119) and NGC 1068 (Sb: panel 138 here, but see the outer ring in the insert print of NGC 10 68 in the Hubble Atlas, p. *16).*



PANEL
143

PANEL
144



The four galaxies on this panel are all of type Sb, but the spiral pattern is less regular than in Sb galaxies of earlier luminosity class. The arms are thick. The spiral pattern reaches its highest degree of disorder in Sb systems of this luminosity class (meaning that the geometrical entropy is high). Type examples and a description of the class are given on page 122 of the RSA, where two of the galaxies shown on this panel are also illustrated.

NGC 7205 **Sb(r)H.8**
CD-451-Rose
Aug 11/12, 1978
098-04 + Wr26
90 min

The central region (the inner disk plus bulge) of NGC 7205 is smooth. The arm pattern starts tangent to the rim of the inner disk. The largest **HII** regions in the thick, high-surface-brightness arms resolve at about 3" diameter. The redshift of NGC 7205 is v_o = 1379 km s"'.

NGC 5806 **Sb(s)n.8**
H-2266-H
May4/5,1946
103aO
40 min

The spiral pattern in NGC 5806 is defined by the fragments of dust lanes that thread through the high-surface-brightness disk and by the several **HII** regions in the ill-defined overall spiral pattern. Very faint outer arms exist beyond the edge of the prominent disk.

NGC 6890 **Sb(s)ll-Ill**
CD-1503-S/Br
Aug4/5,1980
103aO + GG385
45 min

Two zones **of** different surface **brightness** exist in the disk of NGC 6890. The lightly wound thick spiral arms in the inner disk **have very** high surface **brightness.** Sets of **lower-surface-brightness** arms begin **from** the ends of the inner arms and wind outward, **stopping** abruptly to form an apparent edge to **the pattern.**

NGC 5134 **Sb(s)(II-III)**
CD-817-S
Feb 26/27, 1979
103aO + **GG385**
45 min

The spiral pattern in the inner disk of NGC 5134 is dominated by dust lanes, as in NGC 5806. Copious recent star formation is evidently occurring in the outer disk near its edge, evidenced from the many **HII regions that define the spiral** pattern there. The **HII** regions are unresolved at the 1" **level.** The redshift of NGC 5134 is v_o = 1027 km s"'.

The six galaxies on this panel are of miscellaneous Sb forms, shown here to make this atlas more complete in its coverage of the RSA. The type classification is reached by eliminating the Sa and the Sc types.

NGC 473 Sb(r)
PH-7849-S
Sep 4/5, 1980
103aO
12 niin

NGC 473 has a high-surface-brightness internal ring similar to the internal rings in the Sa galaxies NGC 4324, NGC 4580, anJ NGC 7742, and the SBa galaxies NGC 3081 and NGC 3185 shown in preceding sections. The ring in NGC 473 is less smooth than in most of the galaxies just mentioned; hence the later classification Sb is assigned here.

A very-faint-surfaee-brightness disk with some luminous spiral structure exists outside the ring, similar to that in NGC 4580 (Sc/Sa: panels 86, 276) but fainter.

NGC 3415 Sb
PH-7997-S
Feb 2/3, 1981
103aO
12 niin

The very-high-surface-brightness image of NGC 3415 is small for RSA galaxies; the diameter is only 30". The spatial resolution of the print here is poor, but Sb-type spiral arms can be seen on the original plate. The redshift of NGC 3415 is v_o = 3330 km s"^{1}, and the absolute magnitude is bright at iV/g = —22 .

NGC 6810 Sb
CD-1542-S/Br
Aug 7/8, 1980
103aO + GG385
45 niin

The dust lanes silhouetted against the near side of the highly inclined disk of NGC 6810 define the spiral structure. The arm pattern is less open, and the star-formation rate is smaller than in Sc types. The central bulge is smaller and less smooth than in Sa types. The type is Sb by elimination.

NGC 2764 Amorphous or Sb pec panel 195
PH-7602-S
April 3/4, 1979
lllaj + GG385
30 niin

The pattern in NGC 2764 here is similar to that in NGC 972 on panel 148. The highly inclined image is dominated by dust lanes.

IC 5156 Sb(s)II-III
CD-1141-Br
Aug 21/22, 1979
103aO + GG385
45 niin

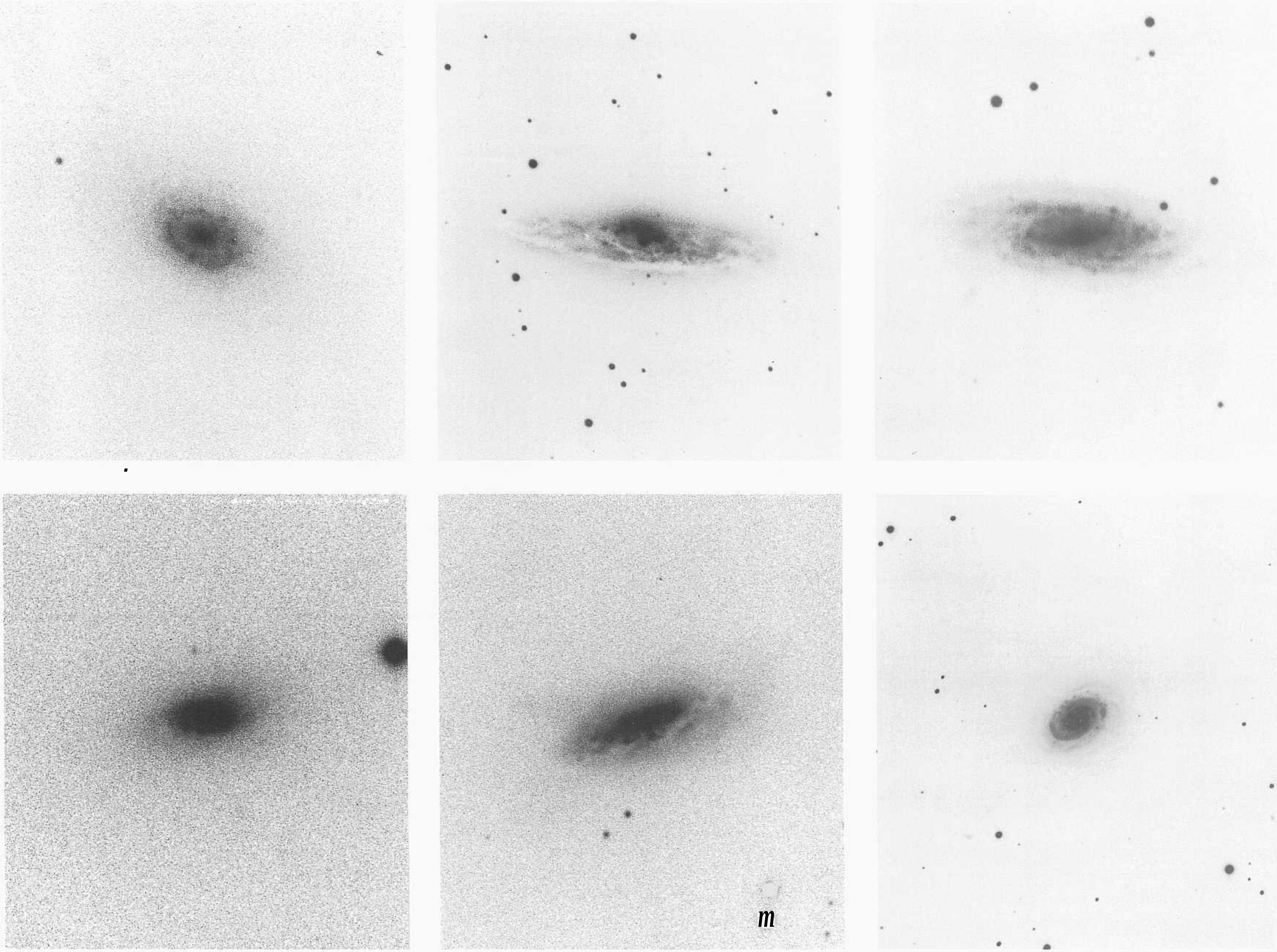
IC 5156 is a prototypical Sb of the MAS type. The arms are tightly wound, are thin, are of high surface brightness, and have a moderate current star-formation rate. The redshift of IC 5156 is u_0 = 2605 kms~^{1}.

NGC 2460 Sab(s) pair
PH-7898-S panels 111, S3
Nov 6/7, 1980 Racine wedge
IHaJ
120 min

NGC 2460 has been shown and described in the Sab section (panel 111). It is illustrated again here to show the difference in the smoothness of the arms between the Sb galaxies in this section (with their higher current star-formation rate) and the Sa and Sab types.

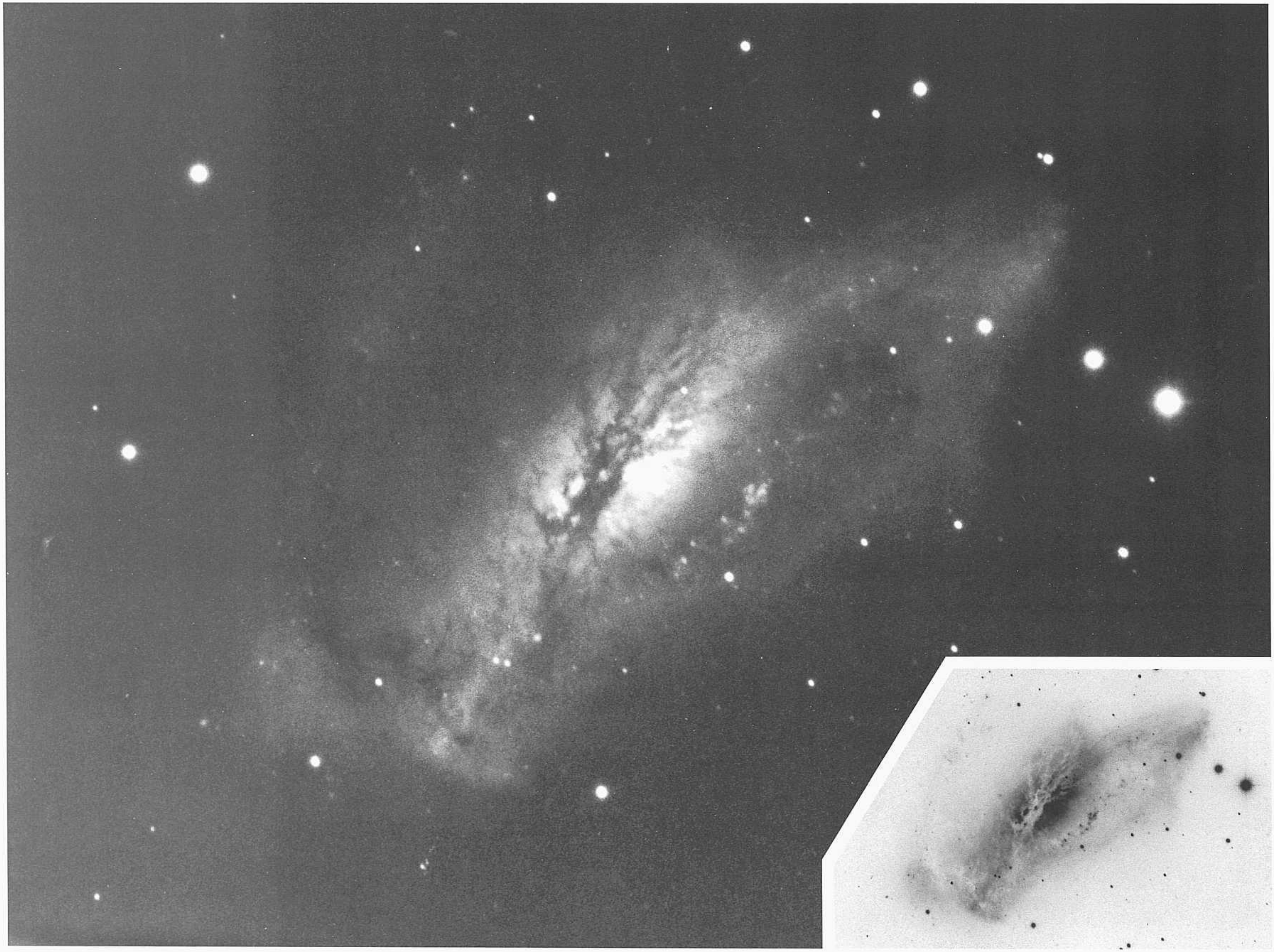
NGC 2460 forms a pair with IC 2209 at a separation of 5.3'. Details are described in the Sab section on panel 111.

This print is made from the same plate as panel 111. Racine wedge secondary images are seen for the brighter stars to the right and below the primary images. Note the different orientation of this print compared with that on panel 111.



PANEL
145

PANEL
146



NGC 2146 **SMI pec**
PI1-88-11
Dec 2/3, 1950
103aO
30 min

The **spiral** arms in [NGC 2 1 46 arc **warped** out **of the plane,** and the **dust** lanes **silhouetted against the bulge are chaotic, A** HUM **1 el of the** distorted **geometry of this nearly edge on galaxy** is given by **de Vaucouleurs (1950).**

The **large** nuclear **bulge (partly hidden h\ the central** dusl lane) and **the** lack **of robust star formation** in **the relatively smooth arms are the** reasons **for assigning** the Sl> **classification.** The **classification** is made **by** elimination, **by noting that the bulge** and arm **characteristics are earlier** than in **Sc** galaxies: **the** dust eontent and its chaotic nature arc **not characteristic of** Sa galaxies **but rather of** Sb's. **But** NGC 2146 may be so peculiar as to **be** outside the **classification** system. A **more-faee-on** view **would be required** to determine **the** extent of **the** peculiarities. The warped-arm pattern suggests a **tidal distortion** due to a close encounter, hut no **candidate galaxy** close **enough for** a tidal **interaction** lias been **identified.**

Star formation is **occurring** in one **of** the **distorted** arms, as is shown by the evident several **Mil regions,** the **largest of which resolves** at about 1 .;V diameter.

PAN 14

NGC 3256 Sb(s) **pec**
CD-190-S
Feb 7/8, 1978
103aO + GG385
45 mill

The two views **of** NGC 3256 are shown on the facing **panel, printed to different** scales and **different** contrast gray scales.

The galaxy is **in** the **complex Hydra-Centaurus Supercluster** region, about 9° south of the concentrated Antlia Cluster (Hopp and Materne 1985: Ferguson and Sandage 1990) whose **redshift** is $<v_o> = 2500$ km s⁻¹. The redshili of NGC 3256 is $v_0 = 2517$ km s^{-1}.

The extended luminous streamer, visible in the image on the left, extends nearly to the right-hand border of the print. A very-low-surface-brightness luminous wisp exists at the position **three-quarters** of the way to the left-hand **border;** it may or may not be associated with the galaxy. This wisp is real, visible on a second plate.

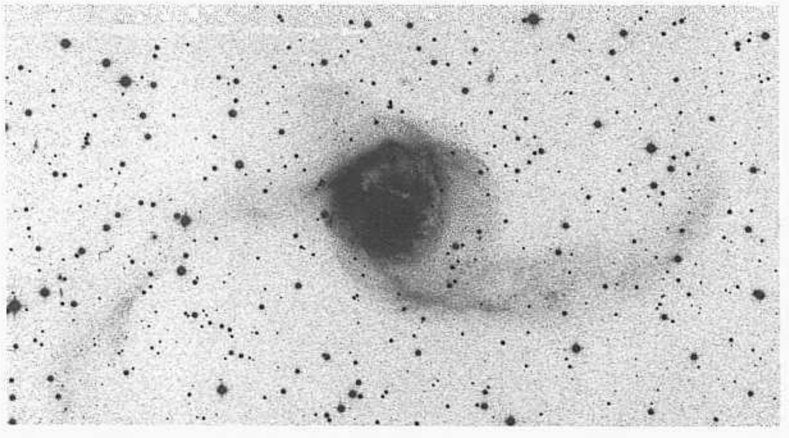
iSGC 3256 has been said to be a galaxy in collision or in a merger encounter (de **Vaucouleurs** 1956a, 1963: Toomre 1977 in the discussion) based on the plume and the nature of tlie central regions (de **Vaucouleurs** 1956a), shown best at the right. This description is challenged at the right.

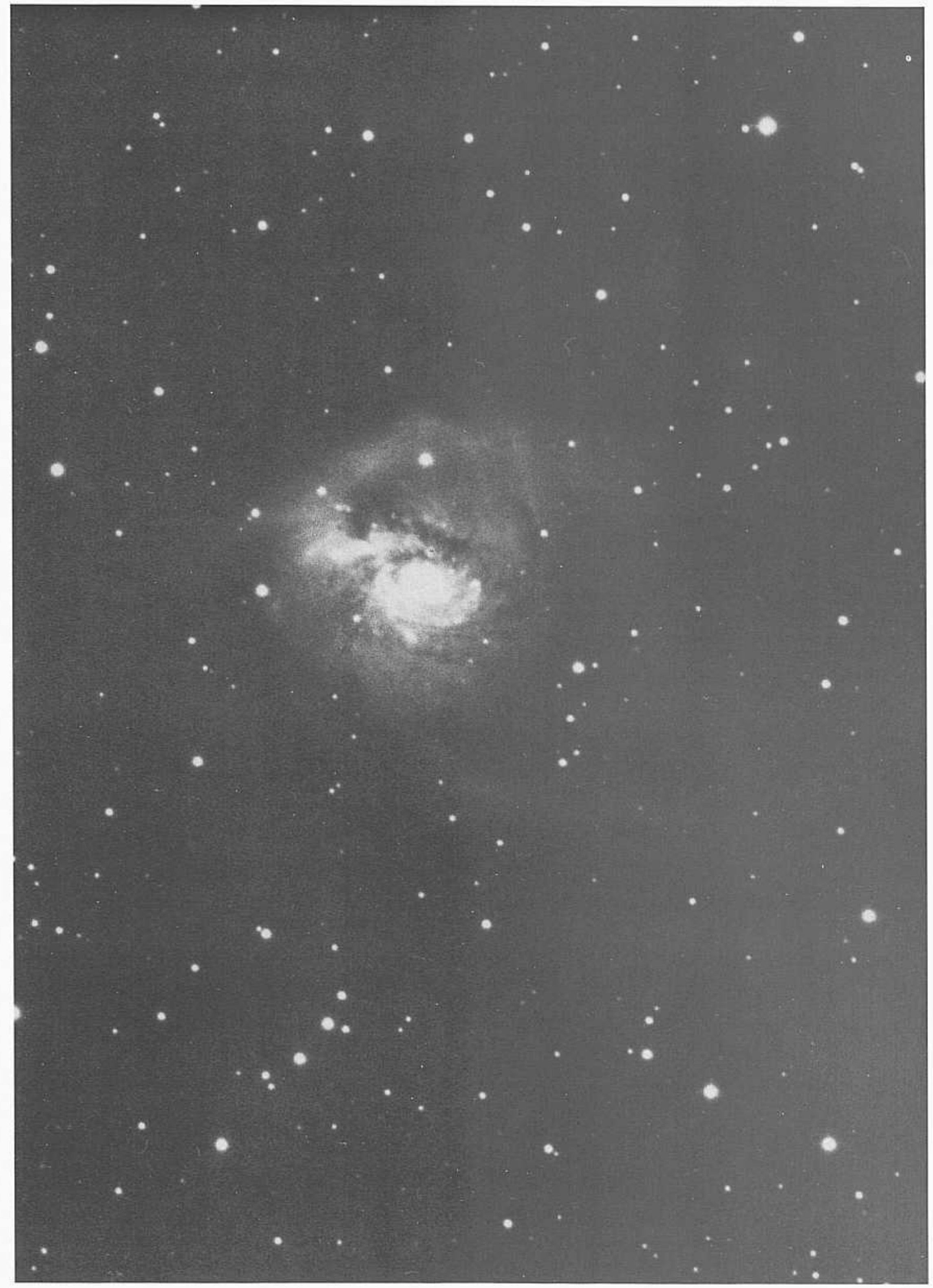
NGC 3256 Sb(s) **pec**
CD-190-S
Feb 7/8, 1978
103aO + GG385
45 niin

The orientation of NGC 3256 in these prints is south at the top, east to the right, given here to identify the features described by de Vaucouleurs (195 6a) as fragments and the nuclei of two colliding galaxies. He describes "2 or 3 nuclei in contact forming a very bright mass 0.6' X 0.3' with fragment 0.5' X 0.15' at 0.3' south preceding."

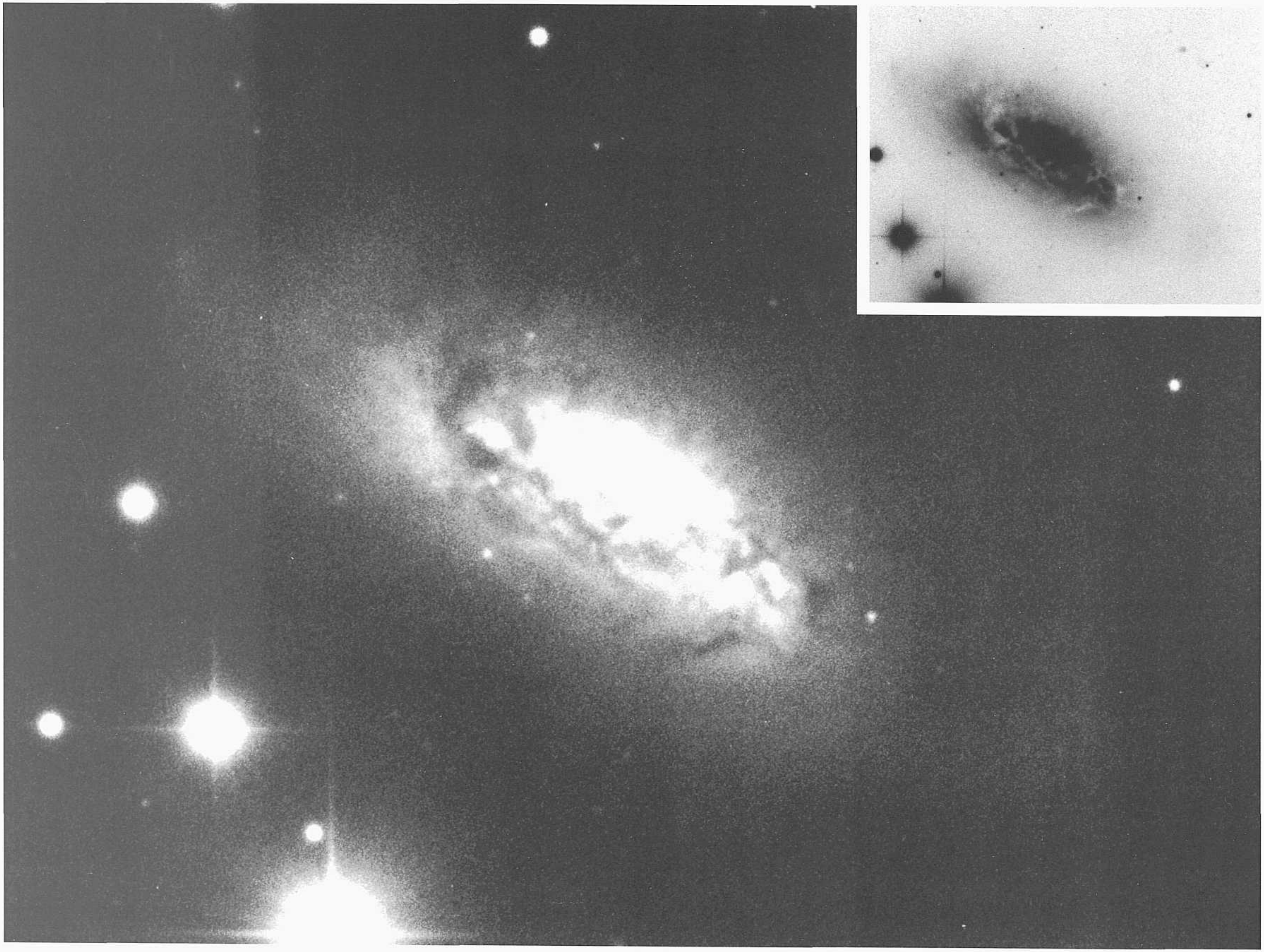
These features in the print to the right are the bright central bulge, partially **burned** out here, and the high-surface-brightness area at the base of the smooth "plume" encircling the top of the main body. Neither of these features were resolved on the Mount Stromlo plate material, and neither of them can be described on the present material as the nuclei of two colliding galaxies.

The luminosity pattern is chaotic, but it is unclear if the pattern is due to collision, to a possible merger, or is an **apparent** pattern caused by dust lanes. The central region on the available Las Campanas 1 00-inch plates appears to be that of a single, albeit disturbed, galaxy with dust lanes that cut the bright bulge, giving the appearance of separate components on low-resolution images. Of course, by their presence the plumes have suggested, by themselves, a merger event (Toomre 1977: Schweizer 1982, 1983, 1986), but the nuclei as described by de Vaucouleurs do not exist.





PANEL
148



NGC 972 Sbpec HA, p. *23*
PH-1055-S
Aug 24/25, 1955
L03aO
30 mill

The original plate used for NGC *)12* here was **also** used **in the Hubble Atlas.**

The **image** is **dominated by the heavy** dust lanes **crossing the** near side **of the high-surface-brightness bulge. On short-exposure plates they obscure much of the bulge** lifilit. On the overexposed **images here, the high-surface-brighlness bulge is evident, showing that the optical** depth in **the** dust is only **about 1 mag.**

The dust lanes **define** a **general spiral** pattern, endìng before the **edge of** a **Low-surface-brightness outer** disk, seen as a smooth luminosity **distribution** on **the** negative insert **print.** Faint, smooth **spiral** features exist in **this** outer disk.

Galaxies on the next four panels are all highly inclined. They are classed Sb on the basis of the size of their central bulge, giving the approximate order of display on these four panels.

NGC **224** **Sbl-II** **Local Gr**
PS-0-Hendricks **HA, p.** ***18***
Sep 29/30, 1948 **M31**
103aO
10 min

The **print** of M3 1 here is made from the first plate taken with the Palomar 48-inch Schmidt telescope after the final optical adjustments had been **made** in 1948. The observer was Don 0. Ilcndrieks. chief optician of the Mount Wilson Observatory and later the Mount Wilson and Palomar Observatories. **Hendricks** had made the optics of the 48-inch Schmidt, with its 72-inch primary mirror, in the optical shop in the Mount Wilson office complex between 1937 and 1941. The superior optics of this largest of the Schmidt telescopes (at the time) is well shown by the print here. The field of view is about 3° on the long side.

A description of M3 1 itself, chief member of the Local Croup, would be similar to that in the Hubble Atlas and is not repeated here.

NGC 2683 Sb(nearly on edge)
PH-7706-S
Feb 11/12, 1980
103aO
12 min

The large angular diameter of the main disk of NGC 2683 is 7'. A principal feature is the X-shaped halo (well seen on the original plate). The nucleus is small and is only seen above the center: the lower part is blocked by the heavy dust in the near side of the disk. The spiral pattern is of the MAS type (multiple arms), defined principally by the dust. Faint outer arms exist. **HII** regions are present, strung along the outer arm that is down and to the right in the orientation of the print here.

The **redshift of** NGC 2683 is unexpectedly **low** at v_0 = 399 km s^{-1}, considering the poor resolution of the stellar content even in the outer arms.

NGC 4216 Sb(s) **VCC 167**
CD-1328-S/Br **HA, p. 25**
March 13/14, 1980
103aO
75 min

NGC 4216 is one of the most famous galaxies in the sky because it is often used in textbooks to illustrate the bulge, disk, dust content, and spiral pattern of typical luminous galaxies near the middle of the Sb classification sequence.

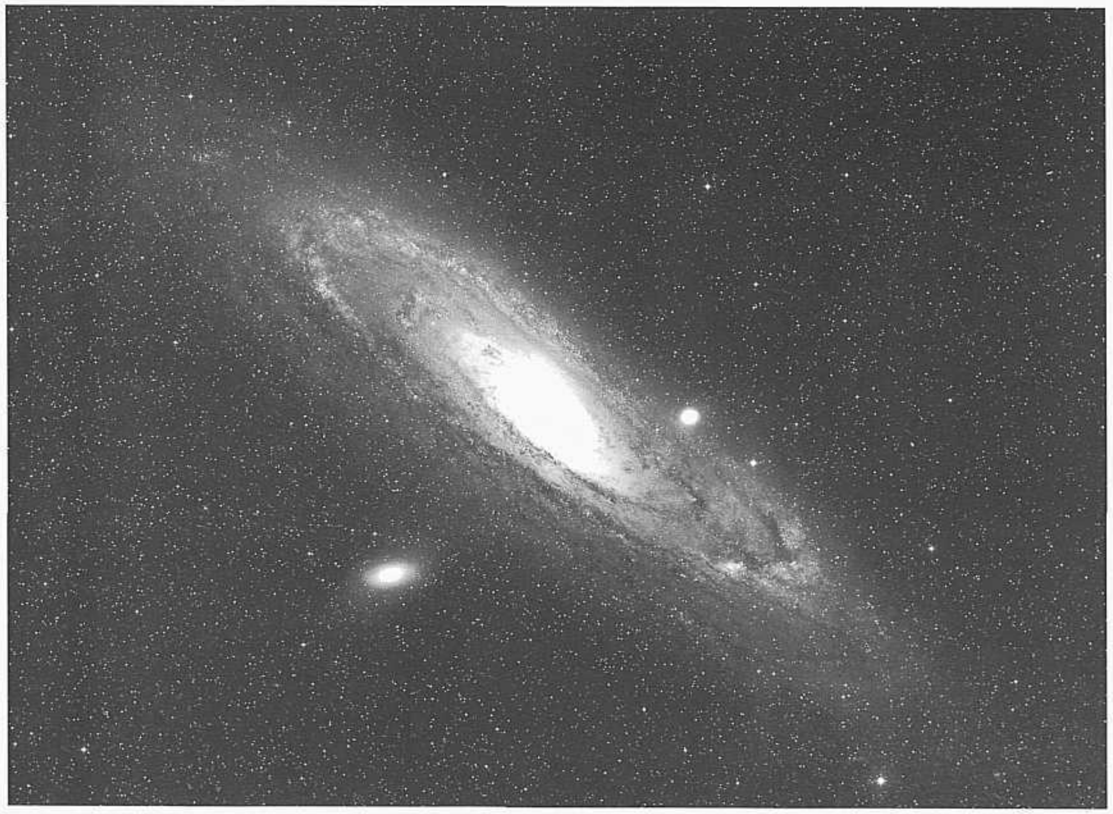
A negative print is given by Hubble (1943) in his discussion of the direction of opening of **spiral** arms relative to the sense of rotation.

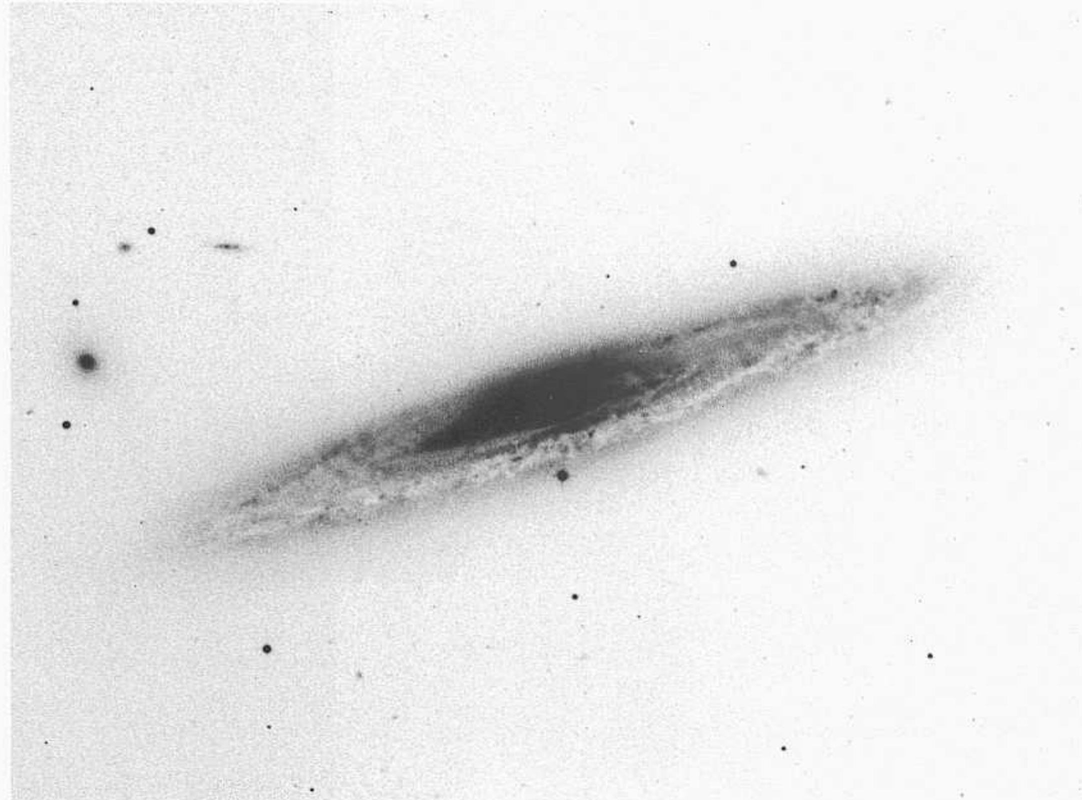
NGC 4216 is in the Virgo Cluster survey region, about 2° west of the center of Virgo subcluster A associated with NGC 4486. Its small redshift, v_o = 121 km s^{-1}, ensures membership in the cluster (in view of the large velocity dispersion of cluster members and the otherwise general quietness of the Hubble flow outside the cluster region).

NGC 779 **Sb(rs)I-II**
PH-7889-S
Nov 6/7, 1980
103aO
12 **min**

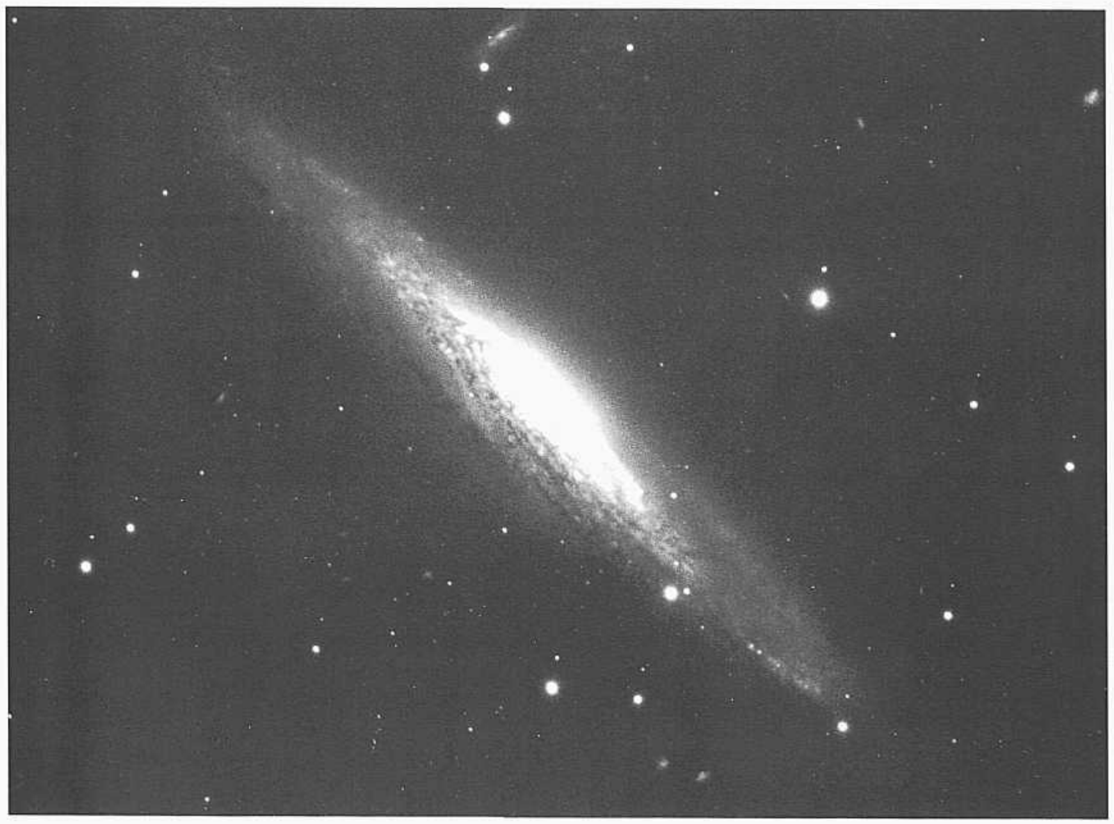
NGC 779 is a multiple-armed spiral similar to NGC 4274 (Sa: Hubble Atlas, p. *12:* panels 66, 88 here), where the tightly wound inner spiral arms of very high surface brightness form a near-ring upon which a fainter outer multiple-armed pattern begins.

The central bulge is smaller than those in M31, NGC 4216, and NGC 2683 on this page, but is larger than those in the four edge-on Sb galaxies three panels hence [NGC 681, NGC 5908, (A0147 + 21)??. and NGC 891],

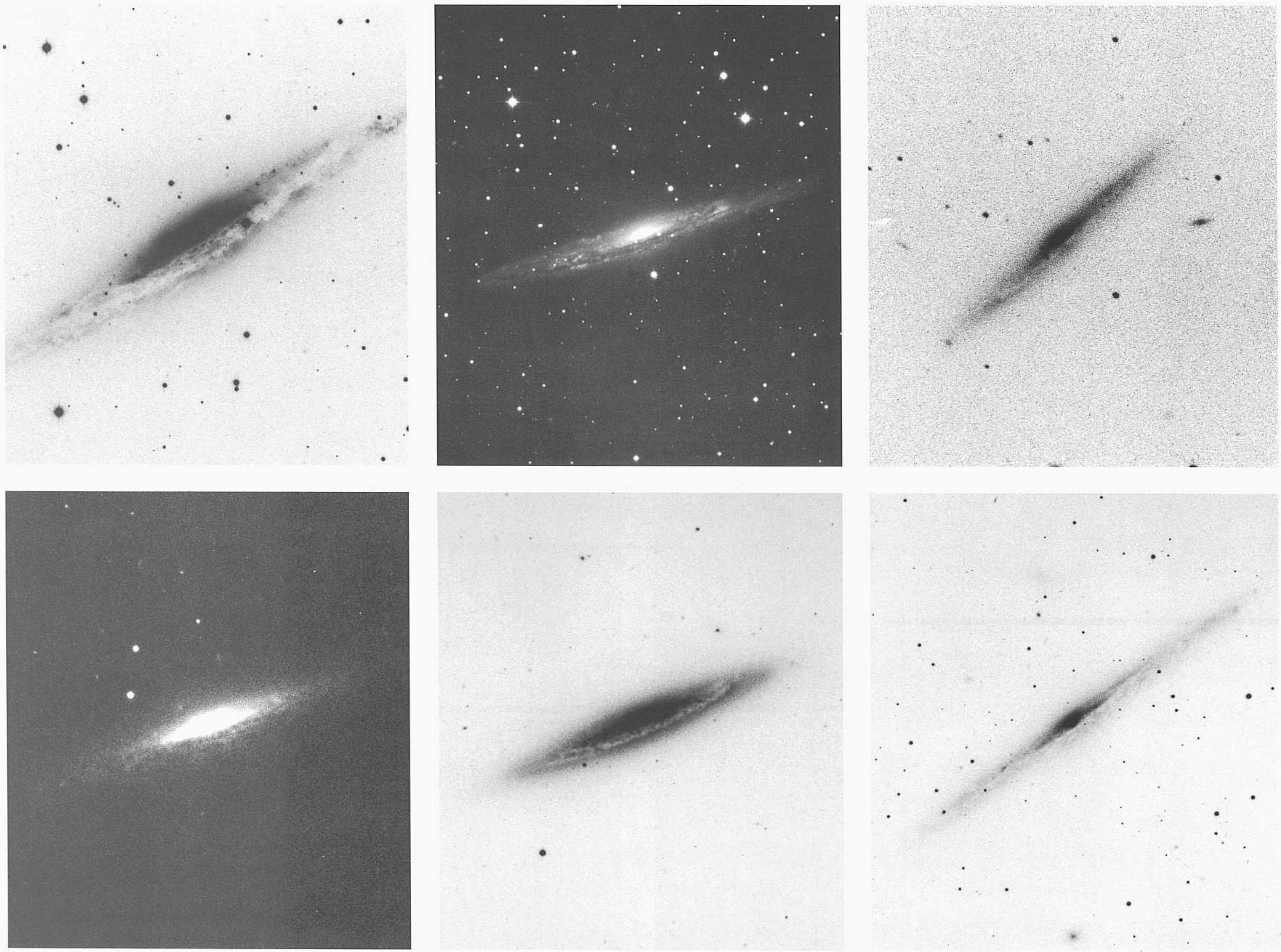




PANEL
149



PANEL
150



NGC 3717 Sb(s)
CD-235-S
Feb 13/14, 1978
103aO + **GG385**
45**min**

NGC 3717 is similar to NGC 2683 and NGC 4216 on the preceding panel in the size of the bulge and the opacity of the dust in the disk. The bulge light above the plane is smooth and has a different scale height than the disk traceable into the center. Therefore in this galaxy at least, the bulge is not the extension of the disk in the center.

A few **HII** regions exist, none of which resolve at the 1" level. The redshift of NGC 3717 is $v_o = 1443$ km s^{-1}.

NGC 955 **Sb** **group**
PH-7842-S
Sep 3/4, 1980
103aO
12min

NGC 955 forms a loose group with NGC 936 (SBO/SBa: panels 90, 106, S9) and NGC 941 (Scd; panel 315) separated by about 1°. The redshifts are u_o(936) = 1512 km s~\ «O(941) = 1717 km s~', and u_o(955) =1641 km s~'. At a mean redshift distance of 32 Mpc (H = 50) the projected linear separation of NGC 955 from the closer NGC 936/941 pair is 570 kpc, similar to the distance of M31 from our Galaxy in the Local Group.

The central bulge of NGC 955 has a very high surface brightness. The galaxy is nearly edge on, showing, as in NGC 4216 and NGC 2683 on **the** preceding panel, the dust lanes that define the MAS spiral pattern in silhouette against the central bulge. The contrast in the image here is so high thai much of the detail in the pattern is lost in the print here. The morphology of NGC 955 is nearly identical to that of NGC 2683.

IC 4351 **Sb(s)I-II**
CD-1525-S/Br
Aug 5/6, 1980
103aO + GG385
45**min**

The central bulge in IC 4351 is smaller than in NGC 4216 on the preceding panel or in NGC 5746 on the following panel, but **otherwise the morphology** is similar to that of NGC 4216. which has about the same inclination to the line of sight. The tightly wound arms are thin. Dust lanes define the pattern at this inclination. There are a few unresolved **HII** regions in the luminous arms.

The redshift of IC 4351 is u_o = 2367 km s^{-1}. Although the galaxy is close to the direction of the **IC** 4329 cluster, which has <(„> = 4320 km s^{-1}, IC 4351 is evidently in the foreground, based on the large **redshift** difference.

NGC 4307 **Sb?** **VCC 524**
CD-732-S
Feb 2/3, **1979**
103aO + Wr2c
45min

The central bulge in NGC 4307 is small. The dust lanes end inside the edge of the disk, and do not extend beyond it as is the case in all other nearly edge on Sb's described so **far.** The luminous extensions beyond the dust border may be smooth arms in NGC 4307, devoid **of** dust.

NGC 4256 **Sb(s)**
S-1997-II
April 12/13, 1918
103a()
30min

The print **of** NGC 4256 here is made **from an** excellent Mount Wilson 60-inch plate **in this high-declination** position, denied **to the Mount Wilson 100-inch** because **of the particular** configuration **of** its mounting.

Except **for the** slightly smaller bulge, **the** morphology **of** NGC 4256 is nearly identical **to that of NGC 4216 on the** preceding panel and NGC 3717 **on this** panel.

NGC 5170 **Sb:**
CD-2149-S
March 23/24, 1982
103aO + GG385
42 min

NGC 5170 has one **of the** smallest bulges **of** the **edge-on** spirals **still** classified **Sb rather** than Sc. The reason for the earlier class is the lack of copious star formation in the disk, contrasting with the **evident** higher rate seen in Sc galaxies on edge, set out later in the Sc section.

Very-low-surface-brightness dwarf <IE companions exist, evidently associated with the main galaxy. Three of them, two above the major axis and one below in the **orientation** of the print here, **appear** in the **reproduction** on the facing panel.

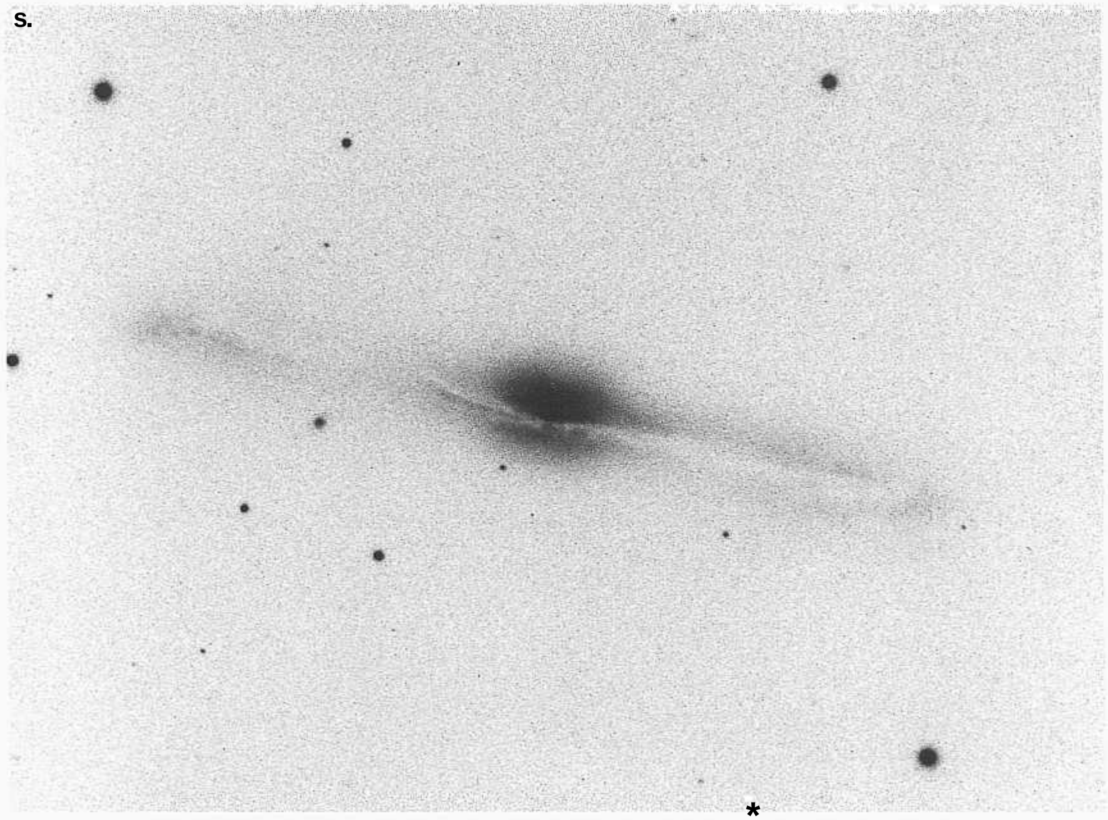
NGC **5746** **Sb** **pair**
CD-1843-HB panel **SI 1**
April 2/3, 1981
103aO
75 **min**

NGC 5 746 is **the** brighter member of the physical pair with NGC 5 740 (Sb; panel 141).

It is seen nearly edge on: the bulge light is visible below **the** near-side dust lane as well as above it. For this to happen when the bulge is moderately small requires the line of sight to be within only a few degrees from exactly edge on.

PANEL
151

PANEL
152



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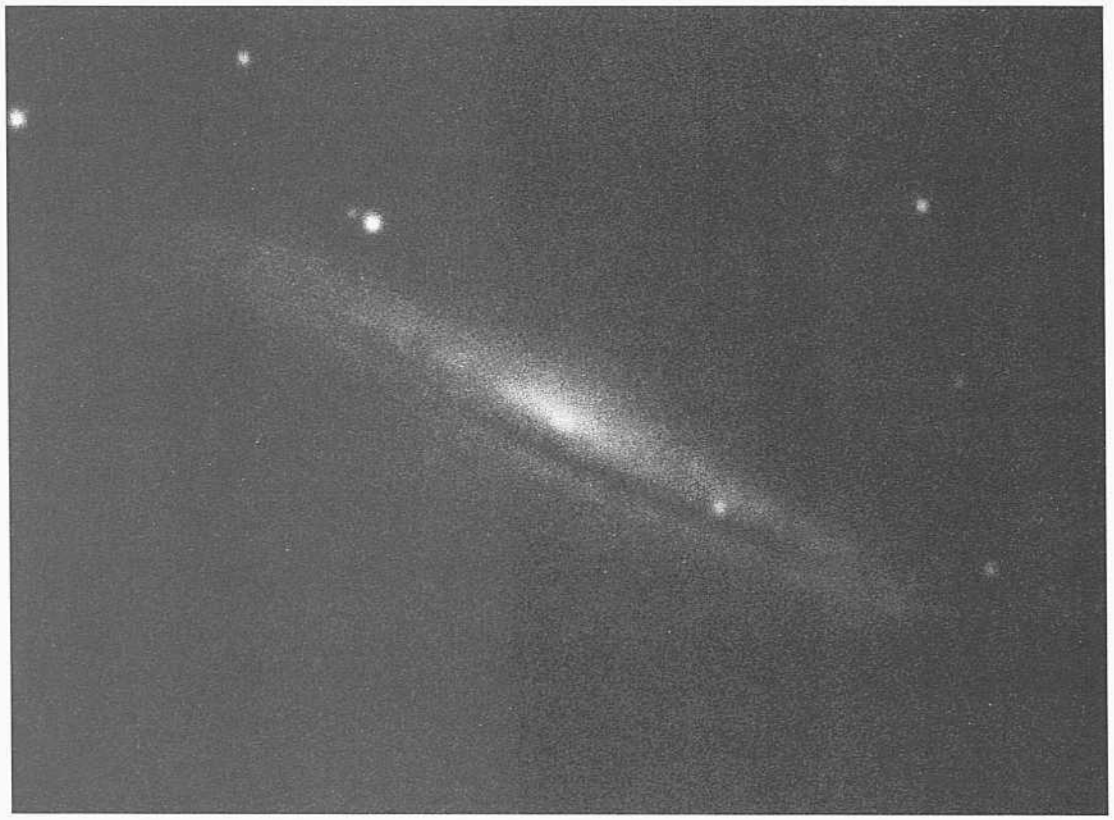


The four galaxies **on this panel arc so nearly on** edge that the central **bulge** light is visible on both sides of **the** dust lane seen in **silhouette** against **the** near side **of** the **bulge** and disk.

NGC 681 Sb
PH-7841-S
Sep 3/4, 1980
103aO
12 niin

Many knots, presumed to be HII regions, exist in the disk of NGC 681. The inclination is so nearly edge on that the spiral pattern cannot be well traced, nor can the direction of unwind of the arms be determined. The pattern is similar to that in NGC 4594 (Sa7Sb~; Hubble Atlas, p. *24,*·panels 113, SI 1 here), which, however, is of earlier type because the central bulge is much larger there than in NGC 681 here.

NGC 5908 Sb(on edge)
PH-7667-S
Sep 25/26, 1979
103aO
12 min

The central bulge is small enough in NGC 5908 to put the galaxy very late in the Sb morphological box, or more appropriately in the Sc box. However, the lack of lumpiness in the disk (seen despite the high inclination angle) precludes the type being as late as Se which the small bulge size would otherwise suggest.

The redshift is $v_{n} = 3467$ km s^{-1}.

(A 0147 +21)?? Sb?(onedge)
PH-4044-S
Nov 2/3, 1962
103aO + GG13
30 min

This galaxy is not in the Shapley-Ames but is shown here to illustrate how difficult was the problem in the 1940's and 1950's to settle the question of whether the spiral arms opened in a direction leading the rotation or following it like a pinwheel rocket. The problem was settled by Hubble (1943) and was discussed again by de Vaueouleurs (1958) in a review of the history and an analysis with new data.

The problem requires identifying the near side of a galaxy's disk either by the position of the dust lane across the bulge (as in the galaxies on this panel) or by the asymmetry of the luminosity pattern in the disk caused by the dust. The opening geometry of the spiral pattern must then be determined. Finally the sense of the rotation must be known from spectra. The most difficult part of this three-piece requirement is to determine the spiral opening geometry, i.e., the sense of the spiral angles. Generally, in galaxies that are tipped enough to the line of sight to determine the near edge, Lhe spiral geometry is uncertain (see de Vaueouleurs 1958).

In the galaxy here, no question remains as to which is the near side, as judged by the dust lane. The sense of the spiral opening can also be determined by the luminosity pattern at the ends of the major axis and by the very faint arm pattern sweeping out of the plane, visible on the 48-inch Schmidt Sky Survey prints but not visible here.

The coordinates of this galaxy have been copied from the general observing log book (Sandage was the observer). They are clearly ineorrect because no galaxy with this image appears at the stated position, shown by inspection of the POSS prints. We have been unable to identify the galaxy or to find its true position in the sky, but its morphology is so interesting that we include it here. Its eventual identification will be of great interest.

NGC 891 Sb(onedge) HA, p. *25*
PH-208-S panel SI]
Nov 10/11, 1952
103aO + WG2
30 min

NGC 891 is seen almost exactly edge on. The dust lane cuts centrally across the small central bulge. The intricate distribution ol the dust out of the plane can be particularly well traced because of the very nearly edge-on orientation.

A definitive discussion and analysis of the luminosity distribution perpendicular to the plane is given by van der Kruit and Searle (1981).

NGC 1438/4435 Sb?(tides) pair
CD-713-S SB0i(7) VCC 1043
Feb 3/4, 1979 panel 56
103aO + Wr2c
60 min

NGC 4438 has a set of smooth luminous plumes that may or may not define a highly distorted plane. If so, the plane is disturbed and the type is Sb(tides) from the existence of a plane and the large centra! bulge. The presence of the dust patches asymmetrically placed across the image suggests that a plane exists and that the form is not simply a bulge with tidal plumes.

Tidal distortion (Toomre and Toomre 1972) caused by a close encounter is suggested by the morphology. The obvious candidate for the perturber is NGC 4435 [SB0(7)] at a separation of only 4.3′- also seen on the print here. However, two points militate against a tidal perturbation: (1) NGC 4435 shows no evidence of tidal effects, and (2) the redshifts of the two galaxies are widely different. The redshifts are $u_o(4435)$ = 753 km s"1 and $u_o(4438)$ = -1 1 5 km s'1. An encounter velocity as high as 868 km s~1 may not produce strong tidal effects because the event is too rapid.

The second-closest large galaxy to this pair is NGC 4406 (S0/E3: panel 27). at a separation of 18'. whose redshift is v_0 = 367 km s~1. Its morphology is as undisturbed as that of NGC 4435.

A possible explanation of the morphology of .NGC 4438 is that a merger is in progress having nothing to do with NGC 443 5. and that the merged parents are not individually visible now. Very short exposures of NGC 4438 show no sign of two components: only a single nucleus exists at the center of the bulge.

A prototype dE,N nucleated dwarf elliptical is to the right of the major axis of NGC 443 8 in the print here, very close to the bulge. It is not listed in the VCC probably because of its close proximity to the main body of NGC 4438 where it evidently was missed in the Virgo Cluster Survey (Binggeli, Sandage, and Tammann 1985).

NGC 5394/5395 Sb(tides) Karaehentsev 404
H-2063-H Sbll
March 23/24, 1939
Agfa Blue
50 niiii

NGC 53 9 5 is the largest member of this pair, which evidently is in the process of encounter. The redshifts listed by Karaehentsev (1987) in his catalog of close pairs are $u_o(5394)$ = 3537 km s~' and v_o(5'i95) = 3579 km s"1.

NGC 3226/3227 E2/S0i(2) Karaehentsev 234
PH-7983-S Sb(s)(tides) panel 26
Feb 1/2, 1981
103aO
12 inin

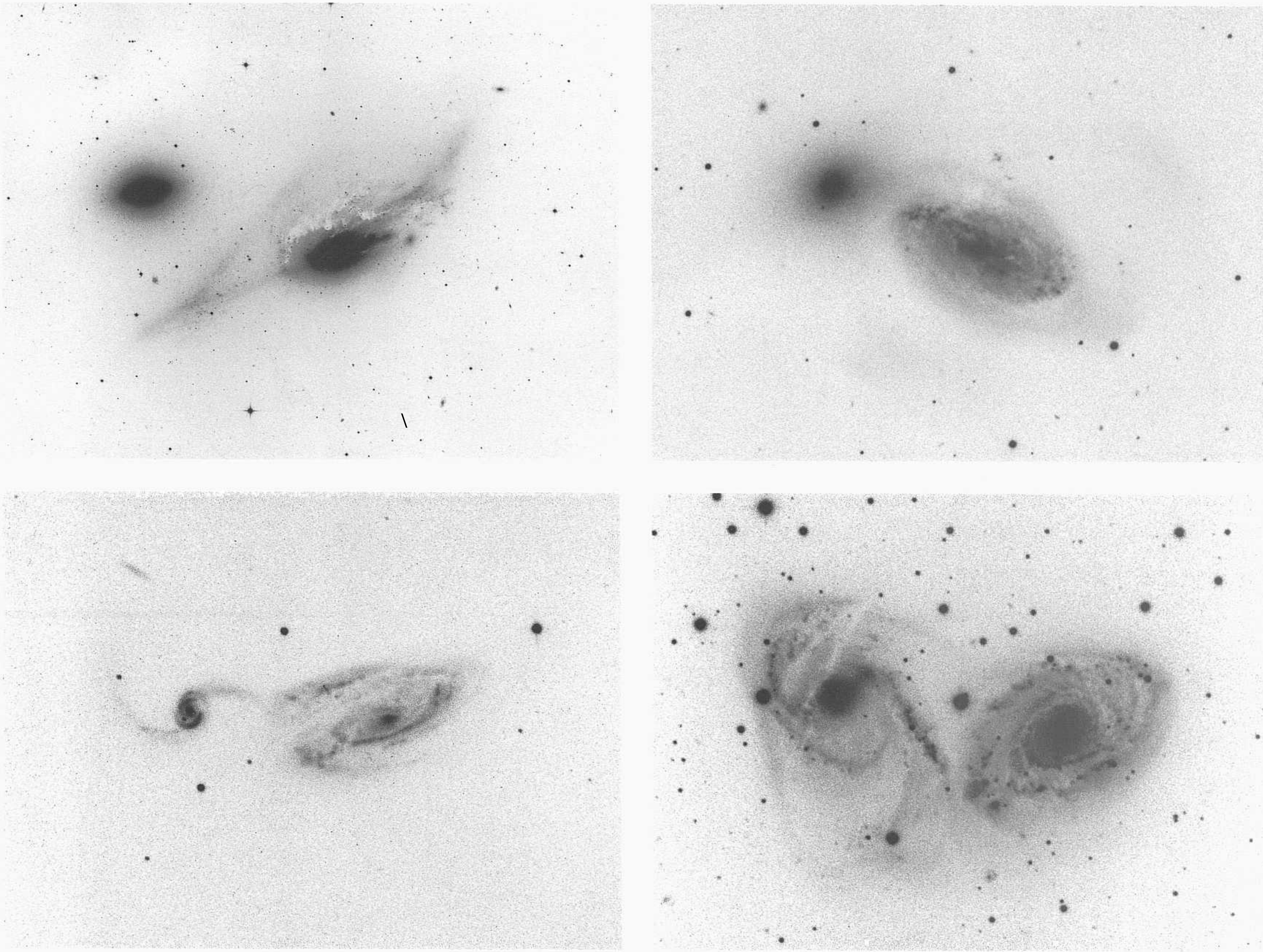
This pair, in an obvious encounter, has been described in the E/SO section. The redshifts are the same to within about 150 km s^{-1}. The noteworthy feature is the very large difference in the individual morphological types: a prototypical SO is paired with a generally normal Sb.

Tidal plumes from NGC 322 7 (the Sb) appear to be present.

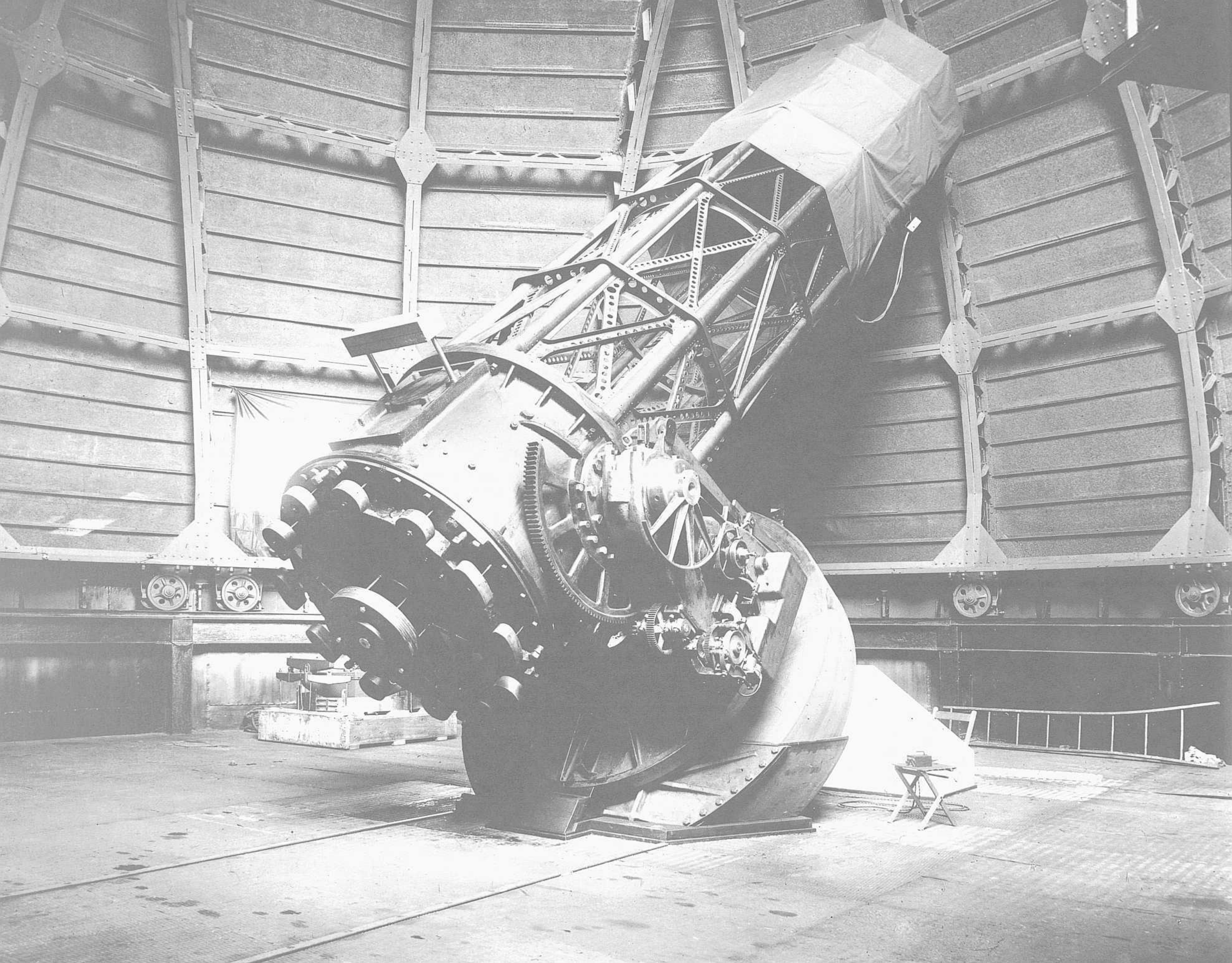
NGC 6769/6770 Sb(r)H small group
CD-552-S SBb(tides)
Oct 4/5, 1978
103aO + GG385
45 min

The orientation of the print here is north at the top and east at the left. NGC 6 7 69 to the west has a central bulge and a smooth inner disk of high surface brightness from which the arms begin tangent to the rim. Dust lanes in a spiral pattern exist on the inside of the well-defined, luminous spiral pattern.

The companion is NGC 67 70 [SBb(tides)]. which is not in the RSA. It has two major thin spiral arms that spring from the ends ol a bar, as in the prototype SBb, NGC 1300. The spiral pattern is, however, disturbed, presumably because" of the tidal encounter. Note the two extra arms, the outer of which is smooth and broad, to the south of the center of NGC 67 70. The redshifts are $u_o(6769)$ = 3712 km s~' and $u_o(6770)$ = 3755 km s-1 . The pair forms a loose quadruple with NGC 6771 [$S0_s(6)$ boxy] at a separation of 3.1' and IC 4842 [S0(6)] at a separation of 10.6'. The v_n redshifts of these latter two galaxies are 4165 km s^{-1} and 3980 km s^{-1}, respectively.



***PANEL* 153**



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