THE HUBBLE ATLAS OF GALAXIES

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## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>vii</td>
</tr>
<tr>
<td>Galaxies</td>
<td>1</td>
</tr>
<tr>
<td>Description of the Classification</td>
<td>7</td>
</tr>
<tr>
<td>Preface to the Illustrations</td>
<td>27</td>
</tr>
<tr>
<td>Table of Data for Galaxies in the Atlas</td>
<td>29</td>
</tr>
<tr>
<td>Illustrations of Galaxies</td>
<td>1</td>
</tr>
</tbody>
</table>
Preface

IN 1953 Dr. Edwin Hubble was preparing an atlas of photographs to illustrate his revised classification system for galaxies. The motivation for his revision came from an inspection of photographs taken of all galaxies brighter than $m_v = 13.0$ north of $\delta = -30^\circ$ on the largest available scale. This magnificent set of plates was accumulated principally by Hubble from 1919 to 1948 with the Mount Wilson 60- and 100-inch telescopes. The revised system was completed by him between 1936 and 1950, but, unfortunately, the details of neither the revision of the classification nor the plans for the atlas were finished before his death in September 1953. Some notes and the fragments of a manuscript were found among his papers. They were sufficiently detailed to suggest the ideas that lay behind his new procedure, but there were only a few indications about which galaxies were to be considered prototypes of the various subclasses, or which ones were to be illustrated. When the decision was made to proceed with the atlas, it was clear that some additional work must precede the compilation and presentation of the material if justice was to be done to Hubble’s insight and ideas.

It is impossible to know what combinations of facts Hubble had utilized to reach his conclusions. Many of his major points were equally difficult to understand because the notes were not detailed. However, implicit in the philosophy of science is the belief that any given scientific result can be reached by a number of diverse paths. In the particular case of this atlas, I inspected the same set of large-scale reflector plates that Hubble had used for his work. During this inspection, the notes and the conclusions of Hubble served as a guide to understanding what he had condensed and collated from the material. The reasons for his conclusions became clear as galaxy after galaxy was studied. The major groups, such as Sa, Sb, Sc, etc., were of course obvious, but the subgroups and the possible relations among them that his material suggested began to emerge and make sense. It should be emphasized that the major groupings and the suggested similarities which are discussed in the “Description of the Classification” are principally due to Hubble. I have acted mainly as an editor, not an editor of a manuscript but rather an editor of a set of ideas and conclusions that were implicit in the notes, in Hubble’s grouping of galaxies into lists, in his notations on plate envelopes, in conversations with him from 1949 to 1953, and in the scheme as it emerged from inspection of the same material that he had used to define his system.

The detailed descriptions of the classes in the descriptive section are of mixed origin. Preliminary drafts of the sections on E, SO, Sa, and SBO galaxies were found in Hubble’s papers. These formed the skeleton of the present discussion. However, changes were made in part of the notation, in the descriptions of the individual galaxies (based on recent data obtained with the 200-inch), and in the relations of the subgroups.

There is hope that this atlas is close to what Hubble himself had planned to publish. The format, the choice of galaxies to illustrate, the descriptions of these galaxies, and the division and notation of the subgroups were not specified by Hubble, but the present atlas may be an approximation to his original design for an illustrated volume.

The work of making the photographic reproductions from the original
negatives was done in the laboratory at the Mount Wilson offices by Stuart Bowen under the direction of William C. Miller, the staff photographer. The excellence of the reproductions is due in large part to the skill of these two men. Their willingness to experiment and their patience with the whims of the compiler made this part of the work easy.

It is a particular pleasure to thank Robert E. Sears, chief night assistant on the 200-inch telescope, for his aid in obtaining many of the plates used in this atlas. He worked not only with me but with every other observer whose plates appear in this book. Observing at a telescope, even under the best conditions, is tedious. Under the worst, it can be cold and miserable. Sears was a great help.

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Galaxies

WHAT are galaxies? No one knew before 1900. Very few people knew in 1920. All astronomers knew after 1924.

Galaxies are the largest single aggregates of stars in the universe. They are to astronomy what atoms are to physics. Each galaxy is a stellar system somewhat like our Milky Way, and isolated from its neighbors by nearly empty space. In popular terms, each galaxy is a separate "island universe" unto itself. The average density of matter in a galaxy is only $10^{-23}$ gram for every cubic centimeter. If this matter were spread over all of space in a uniform way, a density of only $10^{-30}$ to $10^{-31}$ g/cm$^3$ would result. Less than one-millionth of the total volume of the universe is occupied by condensations of matter.

It is almost certain that individual galaxies have not always been what they are today. We see the universe some 10 billion years after its last creation, but clues to its initial conditions remain. There has not been sufficient time for them to be obliterated, and if the proper observations are made and are properly interpreted, we can hope to reconstruct a history of its evolution. This hope drives cosmologists to think, causes large telescopes to be built, and makes observers work on cold winter nights. The hope is not vain. We do stand a chance of understanding the universe. And the present generation, with its great telescopes and its physical theories, may catch glimpses of the early stages of time.

A renaissance is occurring today in astronomy. It began in the 1920's when physicists and theoretical astronomers asked, "What are the stars?" The theory of the stellar interior was developed by Eddington, his predecessors, his contemporaries, and his followers. The essence of the theory was published in one of the most important books ever written, Eddington's *Internal Constitution of the Stars*. This work opened the way for modern theories of stellar evolution—a field that is now in its infancy but which promises to consolidate many of the isolated facts in astronomy.

The theory of stellar structure combines the small-scale phenomena of the atoms with the intermediate-scale phenomena of the stars. But during the 1920's science was also advancing in cosmology, which has as its scope the largest-scale phenomena possible to observe—those of the universe itself. We are now at the crossroads. Insights deriving from the theory of stellar evolution are being applied to cosmological data from the universe at large. Out of the combination we now have a reasonable account of the formation of the elements, the beginnings of a theory for the evolution of galaxies themselves, and explanations for the presence or absence of all components of the stellar contents of galaxies. There is an exciting time ahead, limited only by the size of the telescopes and the ingenuity of the workers. This first chapter of the Hubble Atlas sketches cosmological thinking in the field of galaxies and the major change in it that took place in 1920. Some of the problems that lie in the immediate future for which there is good hope of a solution are then suggested.

Faint, nebulous objects with a discernible surface area have been known in the sky since the invention of the telescope. Speculation as to their nature was not confined to astronomers, but such men as Immanuel Kant (1724-1804), Emanuel Swedenborg (1688-1772), and Thomas Wright (1711-1786)
entered the field. These three men introduced and discussed on purely philosophical grounds the island-universe hypothesis, which held that the small white nebulae scattered over the sky were systems of stars at such great distances that the individual stellar contents could not be distinguished. Owing to the lack of observational data, the idea did not flourish but remained one of the many unproved scientific speculations so characteristic of the period.

Although the nature of the nebulae was not understood until much later, catalogues of the objects were made by many of the prominent observers of the eighteenth and nineteenth centuries. The first major discovery survey was that of Sir William Herschel (1738-1822), who, by visual methods, systematically observed the northern sky from England with telescopes of his own design and manufacture.

Herschel, a professional musician in his early years and later the first president of the Royal Astronomical Society and the private astronomer to King George III, was one of the most influential and industrious observers of all time. His catalogue of nebulae and star clusters was begun in the 1780s. A copy of a preliminary catalogue of 1000 nebulae and clusters was presented in the Philosophical Transactions of 1789 by a second edition containing 969 additional entries and in 1802 by a third list of 500 nebulae.

Herschel, John, continued the work of his father by taking the telescopes to South Africa. The Herschel Catalogue of Nebulae was published by Sir John Herschel in the Philosophical Transactions of 1864. It contains 507 objects, of which 15 were discovered by the two Herschels and 106 by others. This catalogue is of great historical interest, but it noted that Winneu, A more complete and complete one was published in J. L. 11 Dreyer in 1889.

The field days of the cataloguers were over by 1908. Positions and descriptions of nearly 15,000 nebulae and star clusters were known, but the true nature of the nebulae was still a mystery. The solution of the problem belonged to the era of great telescopes and photographic plates which began in 1908 with the construction of the 60-inch reflector on Mount Wilson, and continued with the completion of the 100-inch telescope on the same mountain. These instruments, each the largest in the world when it was built, gave the necessary data. The question ultimately reduced to the problem of distances to the nebulae. If these distances were small compared with the size of our own galaxy, the white nebulae were members of our galaxy. If the distances were very large, the nebulae were probably systems of stars in their own right. Hubble summarized the problem in his book The Realm of the Nebulae in the following way:

The question of the distances was frequently put in the form: Are nebulae inland units? The solution came unexpectedly and dramatically. The chain of events began in 1917 with the chance discovery of a nova in NGC 6946 by Ritchey with the 60-inch telescope [Harvard Bulletin 641, July 28, 1917]. This particular nova was not important in itself. It reached only 14.6 apparent magnitude. But the discovery caused Ritchey to look back through the entire plate collection of the Mount Wilson Observatory to see whether similar events had occurred in other nebulae. The search netted two novae which occurred on plate M 141 of the Andromeda Nebula (M 31) taken with the 60-inch in 1909. The announcement of Ritchey’s discovery in NGC 6946 stimulated H. D. Curtis, in the Lick Observatory, to inspect old plates taken with the Crossley 36-inch reflector. Curtis’s discovery in NGC 4222 mid two in NGC.
Galaxies

4321, and reported the discoveries in Harvard Bulletin 642. All three of the stars were undoubtedly supernovae in the modern notation, but this separation into normal and supernovae was not made until much later.

Curtis discussed the six novae known in 1917 for their connection with the island-universe hypothesis, and, cautiously, stated his belief that these novae favored the extragalactic nature of the white nebulae. The two jokers in this deck of six novae were S Andromedae and Z Centauri. S Andromedae appeared near the center of the Andromeda Nebula (M31) in 1885 and reached 7.2 visual magnitude. Z Centauri was discovered near the center of NGC 5253 in July 1895, when it was about 7th magnitude. Both these novae were abnormally bright and gave discordant values for the distances. However, two months after the announcement of Ritchey's discovery of the nova in NGC 6946, various workers had assembled a list of eleven novae in seven different nebulae, four of them in M31.

Shapley discussed the implication of the data (Publications of the Astronomical Society of the Pacific, 29, 213, 1917) for the island-universe hypothesis, and concluded, as did Curtis, that, if the novae in spirals were comparable with the twenty-six known at that time in our own galaxy, M31 must be about a million light years distant—which made the nebulae external galaxies. Curtis believed this conclusion; Shapley did not. Shapley argued that the data were conflicting because of two points: (1) S Andromedae would have to be much brighter than other novae found in M31, and (2) van Maanen's measurements of the proper motions of the spiral arms of nebulae showed large values. Van Maanen's angular displacements, combined with a great distance demanded by the island-universe theory, gave velocities in spiral arms close to or greater than the velocity of light! And so the debate began. And the history of this debate is at once fascinating and sobering to any student of science.

The two principal figures in the controversy between 1917 and 1921 in the United States were H. D. Curtis and Harlow Shapley. Both men strongly believed their own position. Belief is never an entirely rational thing. It comes partly from a logical sifting of all facts, but also from intuition and deep philosophical yearnings for a system of ideas. Everyone, once his belief is set, will rationalize the facts to suit himself. The debate in question is an excellent example of the process. We, in 1960, have an almost unique test case here. The arguments, pro and con, as they were advanced in 1917 to 1921, constitute a psychological study of the first order. Perhaps the fairest statement that can be made is that Shapley used many of the correct arguments but came to the wrong conclusion. Curtis, whose intuition was better in this case, gave rather weak and sometimes incorrect arguments from the facts, but reached the correct conclusion. The most powerful statements by these astronomers were published in the Pubs. A. S. P., 31, 261, 1919, by Shapley in a paper entitled "On the Existence of External Galaxies," and in the Journal of the Washington Academy of Sciences, 9, 217, 1919, by Curtis in a paper called "Modern Theories of Spiral Nebulae." Every student of the subject should read these two papers.

A third man entered the debate in 1919: Knut Lundmark, in Sweden. In the interval between 1917 and 1919, twenty-two novae had been discovered in M31. They were analyzed by Lundmark in his doctor's thesis in 1920. Lundmark made the assumption that novae in M31 were objects comparable to novae in our own stellar system, and, with his preliminary absolute magnitude calibration of $M_p = -4$ at maximum, arrived at a distance to M31 of 650,000 light years. Lundmark neglected S Andromedae in this computation and assumed that two classes of novae existed—an "upper class," now identified as supernovae, and a "lower class," now identified as normal novae. Because of the discrepant case of S Andromedae, which at Lundmark's distance to M31 would have an absolute magnitude of $M_v = -16.0$, the problem was not definitely solved in the minds of most astronomers. Furthermore, van Maanen's proper motions of the knots in spiral arms of seven nebulae seemed to put an absolute quietus on the island-universe hypothesis. An impasse had clearly been reached.

But both sides continued to marshal their arguments. Lundmark, during a visit to the Lick Observatory in 1921, began a study of the near-by Sc galaxy M33. He obtained a number of slitless spectra of its spiral arms. The brightest resolved stars in the arms showed normal spectra. Lundmark commented...
The Hubble Atlas

in a paper in *Pash. A. S. *n., 33, 324, 1921, "Some objects [in the arms] have a nebular spectrum but most of the objects belonging to the spiral show a strong continuous spectrum without bright lines. It is of course hard to give the au unite spectral type but a solar or somewhat earlier type seems to be predominant. From the spectral evidence it seems probable that the spiral nebula 11 insists of ordinary stars, clusters of stars, and some nebular [i.e., gaseous] materiaP, IR later, in the same paper, "If we attribute to the brightest re-

solved stars in the spiral arms [aJL/33] an absolute magnitude of 05 we get a parallax for the nebula of: ir=0000009. This corresponds to a distance of 100,000 light years, which is very close to the modern value.

Out other doubt clouted the issue in these early years. The 60-inch tele-

scope had been used on many objects by Ritchey and Pease to photograph the outer regions of U1 and MJL. These galaxies are so near (they are mem-

bers of the Local Group) that the separate stars in the spiral arms are easily re'olved; for example the 100-inch negative print of M33 in the *Astr physical Journal* 127, SU, IVSH. But the early observers did not describe the ph\fe@phH as if resolution into stars had occurred; rather, they oiled the resoluKl obju'U *with images "softer" than those of "tor-

iral stars. Most astronomers therefore qu\Sed that stars had not been detected in MUI and MJL. Arguments comparing the apparent magnitudes of M3I nebulous ite's with [it] in our own *Khby were not taken seriously. Th* opinion of the ipph@phH the resolution of MUI into stars was Hikod by Sh\phly in 191 1 in a new:1, 1. N. 11, 21th, 191).

With two mg n's 5 6 and 5, 6 the authors of the *Astr Physical Journal* in " If the nebulae are easily re'olved then they should not be con-

sidered individual stars. Even in Mes-

sor 33, the most conspicuously clustered of the brighter spirals, it is easy to distinguish the superposed stellar images and the "softer" nebular condensations. It is possible, however, to see a resemblance of these diffuse nebulous objects to extremely distant stellar clusters, but unless we introduce further unverified assumptions the analogy breaks down when the observed evidences are compared.

The culmination of the argument was reached in the famous Shapley-Curtis debate held before the National Academy of Sciences on *April 20, 1920. Two*

papers were published in the *Bulletin of the National Research Council*, volume 2, part 3, May 1921. The concluding paragraphs of each paper illustrate the situation. Shapley stated:

It seems to me that the evidence, other than the admittedly critical tests depend-

ing on the size of the galaxy, is opposed to the view that the spirals are galaxies of stars comparable with our own. In fact, there appears as yet no reason for modify-

ing the tentative hypothesis that the spirals are not composed of typical stars at all, but are truly nebulous objects. Three very recent results are, I believe, distinctly serious for the theory that spiral nebulae are comparable galaxies—(1) Scars's deduction that none of the known spiral nebulae has a surface brightness as small as that of our galaxy; (2) Reynolds's study of the distribution of light and color in typical spirals, from which he concludes they cannot be stellar systems; and (3) H. van Maanen's recent measures of rotation in the spiral M31, corroborating his earlier work on Messier 101 and 81, and indicating that these bright spirals cannot reasonably be the excessively distant objects required by the theory.

Curtis's concluding arguments are not summarized in a single paragraph, and so his points cannot be quoted in detail. His final paragraph is:

I hold, therefore, to the belief that the galaxy is probably not more than 30,000 light-years in diameter; that the spirals are not intra-galactic objects but island universe, like our own galaxy, and that the spiral*, as external systems, indicate to us a greater universe into which we may penetrate to distances often million to a hundred million light-years.

Curtis neither side had convinced the other. New data were needed to pl\fe@plh beyond question that nebulae were external galaxies of di-

mensions comparable to our own. It opened the last frontier of astronomy, and interpretation of cepheid variable stars in M31, Mill, j+d NGC 6822*. This discovery settled the controversy once and for all. It proved beyond doubt that nebulae were external galaxies of di-

mensions comparable to our own. It opened the last frontier of astronomy, ani ph\fe@phH the universe. Galaxies are the unit of nature that define the granular structure of the universe itself.

The announcement of Hubble's discovery was dramatic. It occurred at the *SHi-i of the American Astronomical Society, held in Wais-hig-

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Galaxies

the entire Society knew that the debate had come to an end, that the island-universe concept of the distribution of matter in space had been proved, and that an era of enlightenment in cosmology had begun. Both Shapley and Curtis were present at the meeting. Perhaps they exchanged comments over a drink and a cigar.

An abstract of Hubble's paper was published in the *Publications of the American Astronomical Society*, 5, 261, 1925. It was reprinted in the *Observatory*, 48, 139, 1925. Hubble followed his announcement by three exhaustive papers on the stellar contents of M31, M33, and NGC 6822, in which data on the cepheids were presented, together with discussions of novae and the brightest resolved stars. These papers appear in the *Astrophysical Journal*, 62, 409, 1925; 63, 236, 1926; and 69, 103, 1929.

The way was now open for an earnest attack on the cosmological problem, for it was clear for the first time that a fair sample of the universe was available for study with large telescopes.

The master problem in cosmology is to understand the distribution and motions of galaxies as they relate to the origin and evolution of the universe. Two distinct approaches are possible and necessary. First, the stellar content of galaxies must be described, classified, and studied. The classification should relate class properties of the objects by finding a continuous sequence of forms. This is possible if the galaxies have really evolved and if both the old and the new forms exist at the present time. The problem is analogous to proving biological evolution by reading the fossil record and classifying the bones in a continuous sequence.

The second approach is a study of the way galaxies, as systems, define the large-scale distribution and motion of matter in the universe. Hubble pioneered in both these approaches. (With regard to the second approach, it suffices to say that its elucidation led to the discovery of the expansion of the universe, with all the consequences for geometry and relativity. A discussion of this phase of Hubble's work is out of place in this atlas, because we are concerned here only with the geometrical forms of the galaxies themselves.)

A system for the classification of galaxies was presented by Hubble to the I. A. U. in 1925 and was later published in the *Astrophysical Journal*, 64, 321, 1926. This system, or a slight variation of it, has been universally adopted. The present atlas describes Hubble's last revision and illustrates the complete sequence of classification from the E galaxies through the true spirals to the irregulars. Hubble was careful, in all his writings on the classification problem, to avoid an evolutionary connotation to the sequence of forms. He did introduce the terms "early" and "late" galaxies as a convenience of terminology, but he specifically pointed out that these temporal words did not signify to him a direction of evolution, or even that evolution of a given galaxy through the sequence ever occurs. This attitude is maintained in the present atlas, at least in the presentation of the classification. However, facts deriving from the stellar content of galaxies of different types (Sa, Sb, Sc, etc.), combined with the theory of evolution of individual stars that has developed in recent years, make it clear that the problem of the evolution of galaxies can be approached today on other than speculative terms.

Study of the illustrations in this atlas immediately reveals one fact. There is an almost one-to-one correspondence between the presence of dust and the presence of bright, blue O and B stars. Such stars are known to be very young because their nuclear energy sources can last for only a few million years. Since they are visible today, they must have been created within the last several million years. It is invariably the Irr, Sc, and SBe galaxies that contain these young stars. Sb and SBB galaxies have bright resolved stars, but they are fainter than those in the Irr, Sc, and SBe systems. The presence of dust and highly resolved spiral arms goes hand in hand with other characteristics of the spiral arms. Whenever the arm system is tightly wound, as in Sa and early Sb galaxies, there is little or no resolution of the arms into stars, and there is very little dust. Star formation is not going on in these galaxies now; the dust has been used up; and the arms, which were loosely wound and highly branched in the Sc stage, have wound themselves tight against the periphery of the lens by the shearing and stretching action of the differential velocity field. A hint of this process is discussed in the Sb section in the next chapter and also in the legends to the illustrations, especially in the description of NGC 5055.
The Hubble Atlas

The Sa, SbA, SO, SBO, and E galaxies show little or no resolution into bright stars or H II regions. Star formation has apparently stopped completely, because all the necessary dust has been used up. These galaxies contain stars that are very old and are in a state of evolution characterized by such star clusters as M3 and M67 in our own galaxy. Baade's study of the stellar content of the central regions of M31 and the outer regions of NGC 205 and M32 proves this point. No new stars are being formed here; there is no dust; and the star that arc resolved (see page 2 of the illustrations) are red giants at the top of a globular-cluster-like color-magnitude diagram.

Each successive generation of star formation uses up the raw material (dust and gas) until little of that material is left. The differential velocity field in each galaxy (plus perhaps magnetic fields) controls the nature of the spiral arms. When star formation ceases, the arms tighten and gas available for star formation. The past years permit the problems to be formulated with some confidence, but the solutions are still in the future.

This is not the place to present in detail the evidence for these ideas. The present treatment here that, before any theory of evolution has a chance of being tested, of galaxies must first be made, and the necessary data are already available in the collections of direct photographs. As regards the problem of the structure and dynamics of the nebulae, the two elements are in quite different stages of development. On the one hand, current discussions of dynamic* are largely hypothetical because they depend upon internal motions (both as radial velocities), and such data are almost wholly lacking. For instance, the direction of rotation with respect to the spiral pattern is not generally agreed upon by all astronomers, nor is it known whether the points of ejection of the arms rotate with the nebulae or remain fixed in space. Until these essential questions are settled by sound observational evidence, the discussion of the origin and development of spiral arms will remain speculative. On the other hand, the structural form of nebulae* can be investigated with confidence because the necessary data are available in the collections of direct photographs taken with large reflectors.

It is this latter problem of the structural forms to which the present atlas is addressed. The ultimate problems may be stated in the following terms: First is the representation of the observed structure and of the dynamics of nebulae as particular stages in the evolutionary history of stellar systems; second is the problem of inferring the nature of the universe from the observed characteristics of the sample available for inspection. Results obtained during the past years permit the problems to be formulated with some confidence, but the solutions are still in the future.

The significant evidence is accumulating unevenly along the various lines of approach. As regards the problem of the structure and dynamics of the nebulae, the two elements are in quite different stages of development. On the one hand, current discussions of dynamic* are largely hypothetical because they depend upon internal motions (both as radial velocities), and such data are almost wholly lacking. For instance, the direction of rotation with respect to the spiral pattern is not generally agreed upon by all astronomers, nor is it known whether the points of ejection of the arms rotate with the nebulae or remain fixed in space. Until these essential questions are settled by sound observational evidence, the discussion of the origin and development of spiral arms will remain speculative. On the other hand, the structural form of nebulae* can be investigated with confidence because the necessary data are available in the collections of direct photographs taken with large reflectors.

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THE most widely used classification system for galaxies is that proposed by Hubble in 1925 [Transactions of the L.A. U., 2, 1925, Commission 28; Astrophysical Journal, 64, 321, 1926]. A slightly revised version of this first system was later described by him in his book The Realm of the Nebulae (Yale University Press, 1936, chapter II). A review of the system of 1936, prepared by Hubble as an introduction to this atlas, was found in a manuscript fragment among his papers. It is likely that this review was written between 1947 and 1950. A part of the manuscript reads:

The sequence of classification, as originally presented, consisted of a series of elliptical nebulae ranging from globular (E0) to lenticular (E7) forms, and two parallel series of unwinding spirals, normal (S) and barred (SB). Each of the latter series was subdivided into three sections, termed early, intermediate, and late, and designated by the letters a, b, and c, respectively. Thus the early, normal spirals were represented by the symbol Sa, and the early barred spirals by SBa.

The data available in 1936 seemed to indicate a smooth and continuous transition from elliptical nebulae to barred spirals, and, in fact, the first section of the latter series, SBa, exhibited no spiral arms. The corresponding section of the normal series, Sa, contained so many nebulae with fully developed spiral arms that, where arms could not be definitely recognized, their presence was assumed, and the failure to detect them was attributed to effects of orientation or other causes. The procedure was unsatisfactory because it introduced subdivisions in the parallel series of spirals that were clearly out of step. Moreover, the transition from E7 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 E7 but with no trace of spiral structure. Secondly, the series of true spirals, as before, are subdivided into the three sections Sa, Sb, Sc, and SBa, SBb, SBc. In the case of the normal spirals, the change amounts to a subdivision of the former section Sa into the two sections SO and Sa. In the case of the barred spirals the entire former section, SBa, is now termed SBO, and the former section SBb is subdivided into the two sections SBa and SBb. The revisions are summarized in the following table:

<table>
<thead>
<tr>
<th>Old Class</th>
<th>New Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sa</td>
<td>SO</td>
</tr>
<tr>
<td>Sb</td>
<td>SBb</td>
</tr>
<tr>
<td>Sc</td>
<td>SBc</td>
</tr>
<tr>
<td>SBa</td>
<td>SBO</td>
</tr>
</tbody>
</table>

The introduction of the new types leads to a revision of the original assignment of symbols. The original SBa nebulae are now described as SBO, and the original SBb nebulae are redistributed between SBa and SBb. Among the normal spirals, the Sa objects are redistributed between SO and Sa. Otherwise the system remains unchanged.

The transition stages, SO and SBO, are firmly established. In both sequences, the nebulae may be described as systems definitely later than E7 but showing no spiral structure. The next stages, Sa and SBa, are represented by nebulae which class, as was once believed; see The Realm of the Nebulae, pages 45-46, and the legend to figure 1, page 45, of the Yale University Press edition of 1936. A. S.]

A similar group of objects corresponds to the section [called SBa in the 1936 classification]. This situation emphasizes the desirability of redefining the sections of both series in a more comparable manner.

Hubble then goes on to explain the major difference between the classification system of 1936 and the new system described here for the first time.

The revision might be made in various ways but only that actually adopted will be described. First, two new types, SO and SBO, have been introduced to include objects later than E7 but with no trace of spiral structure. Secondly, the series of true spirals, as before, are subdivided into the three sections Sa, Sb, Sc, and SBa, SBb, SBc. In the case of the normal spirals, the change amounts to a subdivision of the former section Sa into the two sections SO and Sa. In the case of the barred spirals the entire former section, SBa, is now termed SBO, and the former section SBb is subdivided into the two sections SBa and SBb. The revisions are summarized in the following table:
The Hubble Atlas

show incipient spiral structure. Fully developed spirals are distributed over the two later stages of each sequence according to the relative extent of the unresolved central region, and the degree to which the arms art resolved and unwound.

With this general description as introduction, we turn to the details of the classification. The classification criteria together with the prototype examples arc presented in the following pages. Most of the galaxies mentioned here are illustrated in this atlas, and more detailed descriptions of the galaxies arc given in the legends facing the illustrations. These descriptions show how the type examples fit into the developing classification sequence.

ELLIPSEAL GALAXIES

The images of elliptical galaxies have complete rotational symmetry. The nuclei are undoubtedly figures of revolution with two equal principal axes; the third, the axis of rotation, is smaller than the other two.

Subclassification into ellipticity groups in made from the geometry of the foci. The individual timing ellipticity indices of the meridian sections are

The surface brightness of true E galaxies decreases smoothly from the nucleus, closely following the equation $I = I_0 (r/a + 1)^{-2}$. Here $r$ is the nuclear distance, and $a$ is a parameter which differs from galaxy to galaxy. The photographic images appear completely smooth with no breaks or inflections in the luminosity gradient. There are no traces of resolution into stars, knots, or H II regions in E galaxies beyond the Local Group. The E galaxies within the Local Group, however, have been resolved into myriads of faint stars by Baade with the 100- and the 200-inch telescopes. This was a major achievement, giving, for the first time, definite knowledge of the stellar content of these systems.

The absolute visual magnitude of the brightest stars in E galaxies is about $M_V = -3.0$. The stars are red with international color indices of about 1.5. They are probably in the same stage of their evolutionary history as stars in globular clusters. E galaxies have no bright blue stars like those in the spiral arms of Sc, Sw, SBb, and SBc systems. There is also no optical evidence for dust. Perhaps the most significant observational fact deriving from the classification of galaxies is the almost one-to-one relation between the presence of dust and the presence of young blue O and B supergiant stars. The converse also holds. Where there is no dust there are no young stars.

We are forced to two conclusions; (1) young stars are formed from dust; (2) E galaxies either never had dust or they transformed their dust into stars at an early epoch and are now incapable of forming new stars. The absence of spiral arms in E galaxies suggests a third conclusion: (3) the presence of dust is essential for the formation and maintenance of spiral patterns. In any event, E galaxies represent an important stage in the evolutionary state which is fairly well understood in the Local Group. No liam %Us art Kittig formed. There is no dust. There are no
spiral arms. E galaxies do, however, have gas at very low densities. The evidence is the presence of emission lines in the spectra due to forbidden \([\text{O II}]\) at 3727, and \(\text{H}\alpha\) which is probably present whenever 3727 occurs. Most E galaxies show this emission.

It should be emphasized that the ellipticities of the images of E galaxies are apparent ellipticities only. They result from the projection of the true spheroid on the plane of the sky. A true E5, for example, can appear in projection as anything from EO to E5, depending on the orientation of the symmetry axis to the line of sight. Because of this effect, many more apparent EO galaxies exist in projection than in space. The effect of projection can be allowed for statistically if it is assumed that the symmetry axes are orientated at random in space (Hubble, *Astrophysical Journal*, 64, 321, 1926; M. A. Machiels, *Bulletin astronomique*, Mémoires et variétés, VI, 322, 1930). A computation shows that the true ellipticities of E galaxies are distributed nearly uniformly from EO to E7 in the true classes.

The isophotal contours of the projected images of E galaxies are similar ellipses (Hubble, *Astrophysical Journal*, 71, 231, 1930) except those of E7 systems, where the ends of the major axes are drawn into sharp points (Oort, *Astrophysical Journal*, 91, 273, 1940). It may be possible to discover the orientation of the rotation axis to the line of sight by precise photometry to determine differences in the isophotal contours between galaxies of different true types but with the same apparent type. But such differences are known to be very small, and they will be difficult to detect.

Eleven E galaxies, ranging from EO to E7, are illustrated in this atlas. The points to note are (1) the smooth texture of the photographic image, (2) the smooth gradient of surface brightness from the nucleus outward, (3) the absence of dust, and (4) the lack of any suggestion of resolution into bright blue stars or knots (compare with any Sb or Sc galaxy, such as NGC 5055 or NGC 4699). Some of the systems illustrated on pages 1, 2, and 3 of the atlas show condensations across the face of the photographic image. This is particularly true of NGC 4486 (M87), NGC 4636, and NGC 4278. These condensations are very likely globular clusters associated with the galaxy in question. The brightest of the condensations have the correct absolute magnitude \((M_{pg} \approx -10)\), and there is every other reason to expect globular clusters to be associated with E galaxies. They are definitely known to occur in M32, NGC 205, NGC 185, NGC 147, and the Fornax system, all of which are E galaxies in the Local Group.

NGC 3115 was originally classified as E7 by Hubble. Plates taken with the 200-inch, however, showed the presence of sharp points at both ends of the major axis. These points had previously been found by Hubble and by Oort in their photometry of 3115. The illustration of this galaxy on page 1 of the atlas shows the feature. The points suggest the beginning of a fundamental plane similar to that found in S0i systems (see the description of S0i in the next section). Consequently, NGC 3115 is no longer considered a pure E7 but rather a “transition” between E7 and S0i.

NGC 4486, besides having an abnormal number of globular clusters, possesses a unique feature in its central regions, namely, a jet of luminous matter starting in the nucleus. A short-exposure plate of this jet is shown on page 2 of the atlas. The spectrum is known to be continuous, with no emission or absorption lines (Humason, quoted by Baade and Minkowski, *Astrophysical Journal*, 119, 222, 1954). The knots in the jet were discovered to be polarized (Baade, *Astrophysical Journal*, 123, 550, 1956). Other reproductions of NGC 4486 and its jet are given by Baade and Minkowski in the references just quoted.

The resolution of E galaxies into stars is illustrated on page 3 of the atlas. NGC 205, NGC 185, and Leo II are shown. All are members of the Local Group. Close inspection of the illustration of NGC 185 and 205 shows that the brightest resolved stars are of the same brightness. This fact explains the observation that resolution does not occur until a critical exposure time is reached, at which time the entire smooth image of the galaxy breaks up into individual stars. This phenomenon is described in two papers by Baade in the *Astrophysical Journal*, 100, 137 and 147, 1944.

NGC 205 and 185 are classed as E peculiar because the luminosity gradient, seen on plates inspected by eye, appears to be less steep than that of M32.
The Hubble Atlas

and most other E systems; i.e., the two peculiar galaxies are less compact. This description is subjective, however. The \( I(r) \) curves probably follow the normal inverse-square relation found to hold for other E galaxies. There are a few dust patches across the face of NGC 205, which do not show well in the illustration. As might be expected, a few bright blue supergiants are associated with this dust. (See the reproduction of the nuclear regions of NGC 205 from a plate taken in ultraviolet light by Baade, *Observatory of the University of Michigan Publications*, no. X, 1950.)

The final E galaxy illustrated is Leo II. This is representative of the class of dwarf ellipticals of low absolute magnitude and extremely low surface brightness. \( He^+ \) class includes the Sculptor and Fornax systems (Baade and Hubble, *Publications of the Astronomical Society of the Pacific*, 51, 40, 1939), the Draco system, and the Leo II system (A. G. Wilson, *Publications of the Astronomical Society of the Pacific*, 67, 275, 1955). Note the lack of compactness, and the extreme resolvability into stars. The color-magnitude diagram for the Draco system is similar to that of globular clusters.

**SO GALAXIES**

The SO class was not recognized in Hubble's first paper on classification in 1926. As more and more large-scale reflector plates were accumulated between 1926 and 1936, the preliminary classification system was modified and refined. Hubble came to believe that a transition type was required to bridge the gap between the ellipticals and the spirals. In Hubble's 1936 description of his classification (see chapter II of The Realm of the Nebulae), a hypothetical transition class SO was introduced, which had not been established observationally. Between 1936 and 1950, however, the photographic survey of the near-by galaxies was completed, and the SO class was established empirically. Its features have never been discussed in the literature. The class is defined by the examples shown in the atlas and is described here for the first time.

SO galaxies have symmetrical forms which are flatter than E7 but which show no spiral structure and no trace of bars. The characteristic features are a bright nucleus, a central lens surrounded by a faint and sometimes extensive envelope, and, in the later stages of the section, circular absorption lanes.

SO galaxies appear to form it transition between the E galaxies and the true spirals. It is well established observationally that no elliptical galaxies exist whose fundamental planes have a larger flattening ratio than 1 to 3, whereas all spiral galaxies have fundamental planes whose flattening ratios are greater than 1 to 3. These results suggest that there exists a critical eccentricity of the central section of E systems. Some type of dynamical instability seems to lie in galaxies whose eccentricity is greater than this critical value. Galaxies that have angular momenta greater than the critical value tend to take up forms whose central sections are more eccentric than E7, and, for these, the instability causes matter to slough off the central regions and to spread out into a thin, disk-shaped structure which constitutes the fundamental plane. The resulting equilibrium form then consists of a dense nuclear region and an envelope. This may not, of course, be a correct description of the formation of the S0 forms, but the observed features of the class can be accounted for in this way. At any rate, the SO appear to be important in any scheme of classification. They lie just above the highly flattened fundamental plane of the true spirals together with the amorphous texture and the absence of spiral arms of the E galaxies. It is of interest that the luminosity distribution of SO galaxies could be obtained by removing the bright background light and dust, and the spatial distribution of spiral galaxies. That is to say, the SO may be thought of as the "residual" or "fossil" of the "E" stars in M11, for example, resembling the "dust" or "fossil" of the "E" galaxies.
The transition from E to SO is smooth and continuous. The gradual merging of the classes introduces uncertainties in the classification of borderline galaxies. The division between E and SO is a matter of definition and is made on the basis of the presence or absence of an outer amorphous envelope or thin fundamental plane surrounding the nuclear regions. The envelope appears to the eye as a change of the gradient of the $I(r)$ curve. The SO gradient appears to be considerably smaller than for E nebulae, but this is subjective and must eventually be studied with microphotometer tracings.

The SO are divided into three major subgroups, SOi, S0$_2$, and S0$_3$. These subgroups represent extension along the sequence from early to late forms. The SOi is the most interesting from the dynamical standpoint because it represents the earliest of the class and is the nearest to the E forms. It is here that the first vestige of the thin fundamental plane appears. The distribution of light across the SOi is continuous, with no trace of absorption lanes or patches and no trace of structure. Except for the flatter intensity decrement, this type resembles E nebulae. Seven examples of SOi are shown in the atlas, six on page 4: NGC 1201, 3245, 3329, 4150, 4684, and 7457. All six are good type examples of intermediate to late SOi. The envelopes in these systems are extensive. The earliest is 4684, where the envelope is not large compared with the nucleus; the latest is 1201. The remaining SOi illustrated is 4762, which is edge-on. This is one of the flattest galaxies known. The classification of S0$_3$ for this system is made on the basis of the intensity distribution along the spindle by analogy with 1201.

SO$_2$ galaxies show the same pattern of nucleus, lens, and envelope as the SOi, but there is some structure in the envelope. On simple inspection, the lens appears to be surrounded by a relatively dark zone followed by a more luminous one. This description, however, represents a subjective interpretation of faint images and is deceptive. On photometric tracings, the luminosity gradients fall continually outward from the nuclei. The dark zone corresponds with a region in which the rate of fall first increases, then slows, and finally approximates the normal value. The form of the curve might be accounted for either by a circular ring of partial obscuration in the middle of the envelope or by a concentration of luminosity near the boundary. Either explanation indicates a segregation of material. Five S0$_3$ are illustrated in the atlas, of which NGC 524 and 3065 are nearly face-on, and 4215, 4111, and 7332 are edge-on. The extreme weakness of the absorption features makes the characteristics of the S0$_3$ difficult to see on the photographic plates and nearly impossible to reproduce adequately. Consequently, they are not well shown in the atlas for NGC 524 or 3065. For 3065, a drawing is given on page 5 of the atlas showing the subjective $I(r)$ curve as the image appears on the photographic plate. Note how the outer sections seem to be segregated from the nuclear regions by the less luminous internal zone.

The weak absorption lane is silhouetted against the bright background of the nuclei in S0$_2$ galaxies seen edge-on. Because the ring is internal, the outer parts of the disk are unaffected and appear as bright ansae. Although the effect is rather inconspicuous because the internal obscuration is not opaque, it can be seen in NGC 4215, which is the best edge-on example. Here the nucleus and the outer regions of the fundamental plane are separated on each side by a zone of lower luminosity. If 4215 were seen face-on, it undoubtedly would resemble 3065. NGC 4111 is a second example of an S0$_3$ edge-on. Finally, 7332, shown on page 7, is a very early S0$_3$ on edge. The plate was overexposed so as to show the peculiar square-shaped nuclear region, but on weakly exposed plates, faint absorption lanes similar to those in 4215 appear close to the center.

Galaxies in the S0$_3$ subgroup exhibit a structureless envelope similar to that of the SOs, but a sharp, narrow, absorption lane is found within the lens. The lane is in an arc concentric with the nucleus. The structure is a later and further developed form of the S0$_3$. The arc appears to lie in or near the fundamental plane, and it cannot usually be traced over a complete circle. The photographs suggest that the arc is buried in the lens, and is overlain by luminous material. Since the most conspicuous portions of the arc generally parallel the major axes of the projected images, the incompleteness of the circles might be accounted for by the orientation effect. Seven examples of S0$_3$ galaxies are shown in the atlas. The type examples are NGC 3032 and 4459.
The Hubble Atlas

shown on page 5. The internal absorption lane in 4459 is quite regular and can be traced through a complete circle. The lane in 3032 is less regular but is still circular. NGC 4526 is inclined greatly to the line of sight. The central lane is silhouetted against the nuclear region. Because of the high inclination, the lane cannot be traced through 360°. SO1 galaxies seen on edge appear as further developed cases of 4215 [SO2] and 4111 [SO3]. The absorption band is seen as a dark lane blocking out the nuclear regions, and, because the ring is not peripheral, bright ansae appear. The finest example is NGC 4710, shown on page 6. The pattern can be reproduced by tipping the symmetry axis of 4459 [SO3, page 5] through 90°. NGC 5866 is another good example. Two reproductions of this system are shown to illustrate the difficulty of separating SO2 and SO3 galaxies from E galaxies on overexposed or small-scale plates.

The transition between normal SO and Sb galaxies is gradual. The absorption rings in SO and Sb galaxies begin to deviate from circular patterns and take on a tightly wound spiral form. Two transitional galaxies are illustrated, 2585 IS0.5 Sd(r) and 5273 IS0.5 Sd(r). The circular pattern in 2585 is broken, Mitl absorption lanes begin to wind outward through the envelope. Because tilt beginnings of these embryo ansae are tangent to an internal ring, the galaxy is of the (r) subtype. In 5273, faint spiral pattern? of lower intensity wind outward from the nucleus. The pattern is faint and difficult to trace.

Two spiral pattern is of the N subtype. Finally, five examples of peculiar SO galaxies are illustrated in the atlas. All five are NGC 128 [SO pec] and NGC 7502 [Sb pec]. The peculiar shape of the minor unions sets these apart from the normal Sb systems.

The third SO pec illustrated is NGC 2685, one of the most unusual galaxies in the entire sky. NGC 2685 has an elongated main body resembling SO galaxies seen edge-on. In addition, a number of narrow bands appear to encircle the galaxy. These bands are fan-like, reversed and are silhouetted against the bright background as narrow absorption lanes. Encircling the entire structure is a faint elliptical ring whose major axis coincides with that of the central regions. Inspection of the photographs suggests that the central region is shaped like a cigar rather than a disk or a pancake as in most other galaxies; that is to say, it may have the shape of a Jacobi ellipsoid rather than a Maclaurin spheroid.

The last two peculiar SO galaxies illustrated are 3718 and 4753. NGC 3718 has a heavy bar of obscuration crossing the face. On plates taken with the 100-inch telescope, the underlying luminosity distribution is that of an SO with a bright nucleus and an extended envelope. Hubble therefore called this system SO pec, because, if the absorbing lane were removed, a normal SO would remain. On 200-inch and 48-inch Schmidt plates, however, two faint extensions to the envelope are seen which emerge from opposite sides of the periphery, suggesting spiral arms. The system looks somewhat like an SBb with the absorption lane constituting the bar. But the bars of all Sb galaxies are luminous, bright features, not absorption bands. The modern data, therefore, place NGC 3718 outside the classification scheme. Finally, NGC 4753 has numerous dark, irregular absorption bands crossing the face. If these were removed, the underlying luminosity distribution would be SOi.

SUMMARY

1. The SO class has three subtypes, SO1, SO2, and SO3.
2. The SO1 are transition objects from the E7 galaxies. The ellipsoids of the central sections are flatter than those of E7. The distribution of light is cymmetrical, with no trace of absorption lanes. The central regions resemble those of E galaxies, but the extensive outer envelope is flattened into a fundamental plane. The Ill plane identifies the S1i.

3. The SO pec have the characteristic pattern of either a separation of material or a faint circular pattern in the envelope. Seen edge-on, the
internal pattern appears as decreased luminosity in a region intermediate between the nucleus and the edge of the envelope.

4. The S0h is a development from S02. A strong internal circular ring is present. The pattern is easily recognized in galaxies on edge. A dark central absorption lane blocks the nucleus, and bright ansae appear in the fundamental plane.

**Classification**

The S0 is a development from S02. A strong internal circular ring is present. The pattern is easily recognized in galaxies on edge. A dark central absorption lane blocks the nucleus, and bright ansae appear in the fundamental plane.

**Summary: SO Section**

**Ellipticals**

EO - a

E7 -

SO

SBO

<

Sals.)

Sa

SBa

FIGURE 1

Sa GALAXIES

NORMAL spiral galaxies emerge from the SO sequence with the appearance of noncircular absorption patterns and definite spiral arms. Although normal spirals show a wide diversity of form, they can be placed in a rough progressive order by three classification criteria: (1) the openness of the spiral arms, (2) the degree of resolution of the arms into stars, and (3) the relative size of the unresolved nuclear region.

On this basis, the spiral sequence is divided into the three subsections Sa, Sb, and Sc. There is a smooth transition between the sections, and the boundaries are somewhat arbitrary except at the two ends. In general terms, the type SO, from which the spiral sequence emerges, is characterized by a structureless lens and an extended envelope (SO0) or by circular patterns of obscuration (SO2, SO3). The first true spirals are called Sa. They show tightly wound spiral patterns of obscuration, and they may or may not have tight spiral arms of luminous matter. The arms are invariably smooth, with no resolution into stars. Galaxies of type Sb have definite and pronounced spiral arms which, at the beginning of the section (Sab in an old notation), are tightly wound, and at the end become more massive and more open. Regular spiral dust lanes are a prominent feature of the Sb type. The dust is heavier and more conspicuous in Sb than in Sa systems.

The spiral structure dominates Sc galaxies. The arms are the most conspicuous part of the form. They are usually branched, highly resolved into stars, and open or unwound. Spiral dust lanes are a highly important feature of the spiral pattern, but they tend to be more irregular in the Sc than in the Sb systems.

For many years it was thought that the third classification criterion of the relative size of the unresolved nuclear region usually agreed with the criterion of the arms. Inspection of large numbers of photographs shows that, although there is a general correlation of the criteria, there are Sa galaxies (classified by criteria 1 and 2) that have small nuclear regions. The assignment of galaxies to the Sa, Sb, or Sc type is based here primarily on the characteristics of the arms. This does not mean that Sa galaxies do not exist with large amorphous central regions devoid of dust and spiral structure; all Sa galaxies of the 1302 type have this feature. We only wish to point out that a large amorphous central region is not a prerequisite for Sa galaxies.

The earliest galaxies of type Sa shown in the atlas are NGG 2681 JS(t[#]) and NGG 1302 (Sa#) These galaxies have *two set* of amis. The inner set
The Hubble Atlas

Is tightly wound about an amorphous central region. The arms are nearly circular and are difficult to trace except on short exposures. The inserts showing nuclear regions on page 9 of the atlas illustrate the feature. The inner arms of NGC 2681 appear to start tangent to the central nucleus, separated in their junction point to this nucleus by 180°. The arms can be traced for half a revolution where they lap back on each other and almost touch. They are so tightly wound that on casual inspection they appear to form a complete circular ring. The outer arms are multiple. They are difficult to trace because the texture is smooth and of low surface brightness. The arms can be interpreted as either fuzzy luminous filaments or as lanes of obscuring matter winding out through a smooth envelope. This confusion is illustrated by NGC 4378 on page 10 of the atlas. Here both interpretations are possible; either the spiral arms are the luminous filaments, or there are spiral dust lanes obscuring the smooth underlying surface. The evidence from NGC 5140 (not shown), which is a later galaxy of the NGC 1302 type, suggests that it is the luminous filaments that cause the arms.

Sa galaxies can be divided into two major groups, depending on the characteristics of the arms and of the nuclear regions. The NGC 1302 group has a rather large unresolved nuclear region with multiple arms starting tangent to the nuclear bulge. Seven examples are shown. All the galaxies on page 9 and the first three on page 10 of this type* NGC 4866 is the earliest, 2775 is probably the latest of the group. Then multiple*arm Sa galaxies correspond in the NGC 2541, 7331 group of galaxies, and the r = 2M 101 group of Sc galaxies. H I* group forms a predominant strain through the entire spiral sequence. The sequence can be arranged at 1312 (Sa) - 6540 (Sc) - 2775 (Sc) - 4866 (Sb) - 2541 (Sb) - 5015 (Sc) - 2775 (Sc) - 122° (Sa), where the arm* tte**from becoming more open proceeding from the Sc to the Sa. All Sa galaxies %f the Sa group in the atlas %at 4866.

The second major group of Sa galaxies has the arm* from becoming more open proceeding from the Sa to the Sc. All Sa galaxies %f the Sa group in the atlas %at 4866.

The second major group of Sa galaxies has the arms** from becoming more open proceeding from the Sa to the Sc. All Sa galaxies %f the Sa group in the atlas %at 4866.

At the early end and 3623 (page 11) at the late end. NGC 3623 is a very late Sa or early Sb. Here the dust lanes are conspicuous and the arms fairly open. All galaxies on page 11 are of the 4866 group. NGC 4941 on page 10 is another example of this group. Here the nucleus is very small. The tightly wound arms place this galaxy in the Sa class rather than in Sb or Sc. The arms are not completely smooth but are beginning to break up into small knots. NGC 4941 is a very late Sa, or, in an older notation, Sb. In general the spiral patterns of the second subgroup of Sa galaxies are formed by absorption lanes scattered over the main bodies. NGC 4293 (page 71) shows this particularly well with heavy obscuration outlining the main features.

Within the 4866 major group we can separate a homogeneous subgroup of Sa galaxies with a special structural pattern, a typical example being NGC 4274 (page 42). On short-exposure small-scale photographs, galaxies in this subgroup appear to have a narrow internal ring superimposed on the faint background of the envelope. On large-scale photographs, however, it appears that the ring is not complete but is broken at two diametrically opposite places, the pieces having drifted outward to form a spiral pattern. The departure from circularity h not great. This broken ring is connected to the nuclear region by two low-surface-brightness features. On good long-exposure plates the pattern of the spiral arms becomes quite evident, as is seen in the atlas reproduction of 4274. Notice how the two arms almost touch where the one sweeps through ISO and passes near the arm closer to the nucleus. Remnants of this spiral structure are shown in NGC 3368 (page 12), which is of later type and h seen more nearly perpendicular to the line of sight than 4274.

The lastSa galaxy shown is XGC 3081 on page 11. It has a broken external ring of the type just described. The galaxy h similar to NGC 3185 (Sb, atlas 43) except that there h no strong bar connecting the ends of the broken ring. On long-exposure plates a faint bar can be traced in 3081 but its faintness puts this galaxy in the Sa rather than Sb class.
SUMMARY
1. Spiral arms first emerge in the Sa galaxies.
2. The Sa type covers a fairly large section of the spiral sequence. The early Sa have ill-defined arms which are smooth in texture and are tightly wound about the amorphous nuclear regions. The principal classification features are the nearly circular pattern of the arms and the lack of resolution in the arms. Late Sa have prominent dust lanes (e.g., 3623, page 11) and a suggestion of lumpiness in the texture of the arms, showing the start toward resolution. Resolution begins in the early Sb systems and becomes "complete" in the Sc. But the arms are still tightly wound in the late Sa and form nearly circular patterns.
3. The nuclear regions of Sa galaxies can be either large (2775, page 10) or small (4866, page 11). There is not a unique connection between the relative size of the nuclear region and the arm pattern, but there does appear to be a strong correlation between the tightness of the spiral pattern and the lack of resolution of the arms into stars and H II regions.

Sb GALAXIES

The differentiation of an intermediate class Sb between the early and late stages of the spiral sequence is necessarily arbitrary. The two ends of the sequence, Sa and Sc, are easy to define. The Sa spirals have Incipient spiral arms which are usually smooth in texture and are tightly wound in nearly circular patterns about an amorphous central region. The Sc spirals have highly branched, well differentiated arms that are not lightly wound around the nucleus and are well resolved into stars and H II regions. There is much dust in the arms. The nuclear region is usually small and inconspicuous. The large number of galaxies falling between the two extremes are called Sb. Class characteristics are formulated in terms of intermediate criteria between the Sa and Sc. Although the separation may seem vague in principle it works well in practice.

There is considerable extension along the sequence from early Sb to late Sb, and classification at both extremes is difficult. In an older notation the transitional systems were called Sab and SbC, but this finer division is not followed here.

The earliest example of Sb is NGC 4826, shown on page 13 of the atlas. Reproductions from a long- and a short-exposure photograph are given. On the longer exposure the vague, smooth, tight spiral pattern can be seen wound around a large, amorphous nuclear region. The short exposure shows much dust in the nucleus, and this is the feature that classifies NGC 4826 as an Sb rather than an Sa system. The latest Sb galaxies shown in the atlas are NGC 3627, 972, and 4433 on page 23. These galaxies are not in a "linear sequence" from NGC 4826 but represent a different subgroup of Sb. That is to say, the classification sequence is not infinitely narrow perpendicular to the Sa • Sb • Sc direction, but has considerable width which is divided into subgroups. NGC 4826 is in one of the subgroups, and the three galaxies 972, 3627, and 4433 are in another. Nevertheless, the difference in the openness of the arms, the size of the amorphous nuclear region, and the amount and distribution of dust do illustrate change along the sequence of classification from early to late Sb.

The Sb spirals can be separated into two major divisions, corresponding to the 1302 and 4866 division of the Sa. Galaxies in the first division have relatively large amorphous nuclear regions. There are either two predominant arms as in NGC 4579 (page 15) or multiple-arm system as in 2841 (page 14) and 488 (page 15). All galaxies shown on pages 13 to 15 of this type. Galaxies in the second major division of Sb are characterized by small nuclear regions with typical Sb intermediate spiral pattern. All galaxies shown on pages 20 to 23 are of this type.
The Hubble Atlas

Two subgroups are recognized within the first major division. The first, called the 4569 subtype, has soft, thick arms, smooth in texture and of low surface brightness. The arms are tightly wound and may be bounded on their inner edges by dust lanes. The first five galaxies on page 13 are of this subtype. The So galaxy most like this group is M51, shown on page 26.

The second subgroup of the large-nucleus type is comprised of galaxies like NGC 2498 and 488 and is known as 2841 type 8k. All galaxies shown on pages 14 to 19 are of this type. NGC 2498 has a large amorphous central region in which the spiral pattern is present which cannot be traced to within 0.7-mm radius from the center (on the scale of the illustration). This zone resembles an E or SOI galaxy. Many tightly wound spiral segments start tangent to the central zone and wind outward. At first glance the filaments appear to be complete spiral arms, but closer inspection shows that only thin, broken segments are present which cannot be traced in individual arcs for more than 30°. NGC 2498 is among the earliest of the group. The same pattern of amorphous central regions and tightly wound spiral segments is found in all the galaxies shown on page 15. NGC 488 is a particularly good example. Here the segments of amorphous nuclear region are closely coiled to the nucleus. The arms are of this subgroup.

The form progresses through NGC 7217 (page 15) where, on good plates taken with the 200-in. telescope the spiral arms can be traced very close to a smaller amorphous nucleus. The reproduction in the atlas printout and does not show this inner spiral pattern. The surface brightness of the spiral pattern increases toward the center, and the arms do not coalesce until they reach 1-mm radius from the center (on the scale of the illustration). The arms + * + are traceable even do the central region in the magnificent spiral NGC 5105. Distinct spiral patterns can be traced to within 0.7-mm (radio to the center in the illustration). The arms of NGC 5105 form an amorphous nuclear region. Finally, the spiral arcs can be traced very close to the small amorphous bulge, become more tightly coiled, thinner, and more regular. And the nuclear region grows at the expense of the arms, the surface brightness of the central region remaining nearly constant whether it contains arms or is amorphous. This phenomenon may have evolutionary significance, suggesting that a given galaxy evolves from Sc to Sa owing to the kinematical condition of a differential velocity field and the absence of the formation of young O and B stars. These considerations will be discussed in detail elsewhere.

The Sb galaxies forming this sequence are illustrated on pages 14, 15, and 16 of the atlas.

Three large-scale photographs of the nearby Sb galaxies of the multiple-ami type are shown on pages 77, 75, and 19. The arms in NGC 7331 are traced to within 6 mm of the center on the scale of the illustration. The burned-out portion in the illustration is not structureless. The amis of 7331 arc much coarser than those of 5055 or 488. There are many Sb galaxies like 7331. NGC 4527 (shown by Hubble in the Astrophysical Journal, page 112, 1943) and NGC 4216 (page 25, and the atlas, page 11), and 1068 (page 1232) of the Sb, and 2775 (page 1302) of the Sa, and all members of the elliptical and SOI class. From the geometrical forms alone we can place these closely coiled, multiplemarm galaxies in a sequence from Sc to Sa in the order: NGC 3810 (page 30), 1232 (page 32), M101 (page 27), 628 (page 29), 1068 (page 16), 4699 (page 16), 3521 (page 75), 5055 (page 75), 7217 (page 75), 488 (page 75), 2841 (page 14), 2775 (page 70), 3898 (page 70), 2811 (page 77), 6340, and 1302 (page 9). In this order, the arms, starting tangent to the central amorphous bulge, become more tightly coiled, thinner, more regular. And the nuclear region grows at the expense of the arms, the surface brightness of the central region remaining nearly constant whether it contains arms or is amorphous. This phenomenon may have evolutionary significance, suggesting that a given galaxy evolves from Sc to Sa owing to the kinematical condition of a differential velocity field and the absence of the formation of young O and B stars. These considerations will be discussed in detail elsewhere.

The Sb galaxies forming this sequence are illustrated on pages 14, 15, and 16 of the atlas.
In the second major subdivision of the Sb, the nuclear region is relatively small compared with the arm pattern. Fine subdivisions can be made among the many Sb systems in this group. The criteria are the thinness of the arms, the degree of organization of the luminous matter in the arms, and the degree of organization of the dust in the arms. Clearly the three galaxies shown in the top panels of page 20 belong to the same subgroup. Because the nuclear regions are large and the arms are thin and tightly wound, these systems are classified as Sb, but in structure they are similar to M101 of the Sc. The three galaxies in the lower panels of page 20 also seem to form a subgroup. Here the arms appear to be disorganized, with dust scattered somewhat irregularly over the face. These galaxies may be the Sb counterpart of the Sc group characterized by NGC 253, NGC 2903, and the galaxies on pages 30, 34, and 35 of the Sc section.

Galaxies of an interesting special subgroup are shown on page 21. They are characterized by the presence of an internal ring from which the outer spiral arms emerge. These galaxies, especially NGC 3705, resemble the 4274 group of Sa, in which a broken internal ring is a prominent feature. Faint outer arms present in NGC 4750, 4530, and 4725 are shown in the negative Inserts.

Another special subgroup, called NGC 210 galaxies, is shown on page 22. Each of these galaxies has an internal and an external set of arms, but the arms of each set appear to be of different pitch. The best example is NGC 210 itself. Two tightly wound dust arms are present in the central nuclear region. Springing from opposite ends of this region are two arms with open pitch and partial resolution into knots. The same pattern is repeated in NGC 1964, 615, and 23. The arms in the nuclear region are almost circular and are smoother in texture than the outer arms. Furthermore, the central arms are more clearly outlined by the dust than by luminous patterns.

The final subtype of Sb illustrated in the atlas, on page 23, has NGC 3627 and NGC 4433 as its prototypes. Here the face of the galaxy is dominated by a rather chaotic dust pattern forming the spiral structure. The classification is Sb, because the arms are not very open nor is there great resolution of the arms into knots and stars as in the Sc systems. There is too much dust with disorganized patterns to call these galaxies Sa.

Sc GALAXIES

D ominance of multiple spiral arms and small amorphous nuclear regions are the characteristics of Sc galaxies. These features and the high degree of resolution of the open, branched-arm system make Sc galaxies easy to recognize. The detection of resolution in spiral arms depends on distance and on telescope size, but in practice the 60-inch, 100-inch, and 200-inch telescopes give photographs of sufficient scale so that either individual knots (H II regions and associations of stars) or a general lumpiness in the texture of the arms can be detected in galaxies with redshifts as large as 15,000 km/sec. All the near-by bright galaxies are within this limit.

The Sc galaxies exhibit great diversity in form. At least six major subgroups can be distinguished. These groups in general represent development along the sequence of classification from early to late Sc. The largest subgroup of Sc galaxies resembles M101 (page 27). The arms are thin, multiply branched, and loosely wound about a very small nuclear region. They can be traced through about one revolution, although in some galaxies, such as NGC 5364 (page 32), segments of the main arms make nearly two complete turns. But this is rare. Although most Sc galaxies have multiple arms, close inspection of the photographs shows that only two predominant arms emerge from opposite sides of the nuclear region. They wind outward for nearly half a revolution at which point they branch into many individual segments which continue to spiral outward to form the multiple structure. M101 is a particularly good example of this (page 27). The beginning of the two major arms in the central region is shown in the enlarged print of the nucleus on page 31.
The Hubble Atlas

Here the arms begin as dust lanes, lying within a few hundred parsecs of the center of the galaxy, on the inside edge of the luminous matter. The situation is shown even better for M100, where the dust lanes spiral through about 120° very close to the nucleus (upper panel, page 31) and then change into the prominent luminous arms farther out (page 28). (The negative reproduction of M100 in the Astrophysical Journal 127, 513, figure 5, shows the central regions well.)

Nine examples of the M101-type Sc systems are illustrated in the atlas. The 0° emergence, M83, is shown on page 27. It is an intermediate Sc about midway between early Sc and late Sc. M83 and M83 illustrate dispersion within the group. M100 is an early Sc, called Sce in an earlier notation. MS3 is a transitional example between normal Sc and SBc. The two major dust lanes threading into the nucleus from opposite sides of M83 are characteristic of the SBb galaxies. The face-on is not pronounced, however, and MS7 is classed as SSB rather than SBc. Note how the dust lanes in both M83 and MS3 lie on the inside of the luminous arms. This appears to be characteristic of all galaxies. Oth./M101+K galaxies illustrated arc NGC 62k, 4254, 4304, 1+7, 511, M83, and 777. NGC 1469, 1353, 2873, 1137, MS3. M83 illustrates dispersion within the group. M100 is an early Sc, called Sce in an earlier notation. MS3 is a transitional example between normal Sc and SBc. The two major dust lanes threading into the nucleus from opposite sides of M83 are characteristic of the SBb galaxies. The face-on is not pronounced, however, and MS7 is classed as SSB rather than SBc. Note how the dust lanes in both M83 and MS3 lie on the inside of the luminous arms. This appears to be characteristic of all galaxies.

Examples of the third major subgroup of Sc galaxies arc shown on page 30 of the atlas. The prototype galaxy of this group is NGC 1637. Here the arms are not so well defined as in the M101 group. The arms generally start in the nucleus and cover the entire face of the galaxy. Usually they are not well separated and are more difficult to trace than arms in M101 type systems. NGC 3810 (page 30, upper left panel) is an early example of this type. The arms can be traced to within 6 seconds of arc from the center of NGC 3810 (2 mm on the scale of the illustration). The high-intensity central region (containing the inner arms) is similar to that in galaxies described in the NGC 1068 group of Sh (1068, 4699, 3521, 5055, 7217, 4884, and 2884). There may be evolutionary significance to this sequence, with the evolution proceeding in the Sc to Sa direction. The NGC 1637 subgroup is considered to be more advanced along the Sc section than galaxies in the M101 group, for the arm pattern is not so well defined in NGC 1637. The subgroup is midway between the M101 and the NGC 253 groups described below.

NGC 253 (page 34) is a spectacular object. It is very large in angular size and is probably located just beyond the Local Group. The spiral pattern is more difficult to trace than in either the M101 or 1637 groups because of the ill-defined arms and the large internal obscuration caused by dust scattered chaotically across the disk. The arms in galaxies of this group are broad, multiple, and usually highly resolved into knots. Six galaxies of this group are shown on page 55. The illustration of NGC 2903 unfortunately does not show the very complicated internal obscuring pattern across the entire face, but this feature is shown to advantage in the remaining five galaxies on page 55.

In a fifth group of Sc type are galaxies of the M33, NGC 2403 type. Both these systems are near enough to be highly resolved. M33 is a member of the Local Group. The distance modulus is about m - M = 24.5. If the 200-kilometer photo to m = 23.0, thru plates of M33 reach m = -1.5. NGC 2403 is in the M33 group who's is about m = 3.4. Here stars of 4th magnitude are not visible. The spiral arm in both these galaxies is not resolved, but the spiral pattern is evident. Seen at a distance, the spiral arms in both galaxies are not well defined.
greater distance, the arms would appear to be thick and loosely coiled.

The transition between very late Sc and Irr is gradual. There are a number of galaxies whose spiral arms can still be traced but in which the arm pattern is very chaotic and ill defined. These systems have been called Sd by Shapley and very late Sc by Hubble. Four examples of such systems are illustrated on page 37 of the atlas. The group is designated as the NGC 4395 group. Note the very low surface brightness of all four galaxies. Various sections of the galaxy shown in the upper right panel of page 37 are catalogued in the NGC as separate objects. The entire galaxy is known as NGC 4395, 4399, 4400, and 4401. Because of the low surface brightness of this and of NGC 45, the photographic contrast was increased in the reproductions by printing from a copy negative.

**SUMMARY**

1. Sc galaxies have very small amorphous central regions. The spiral-arm pattern dominates the structural form on photographs taken in blue light.

2. Nearly all Sc galaxies have multiple spiral arms loosely wound around the central regions. Two principal arms can generally be traced almost to the very center of the system. Multiple branching creates new arms from the two "parent" arms. The branching occurs after the parent arms have wound outward for about 90°.

3. The arms show a very high degree of resolution into knots, which are mostly HII regions and associations of stars.

4. There is much dust in the spiral arms; usually it lies on the inside of the luminous arcs. Dust amis are traceable into the nuclear regions (see the illustrations of M100, M51, M101, and NGC 628 on page 31).

5. There is great variation of structural form along the section from early Sc to late Sc. Six major subgroups are recognized on the basis of the cleanliness of the arm separation. (There is very clear arm separation in the M101 group, and very poor in the NGC 2903, M33, and NGC 4595 groups.) The division into subgroups, although perhaps somewhat artificial, illustrates the progression along the sequence. The progression is shown in figure 2.

6. The transition from late Sc to Irr is smooth. NGC 4395-4401, NGC 45, and NGC 5204 are transition examples.

**IRREGULAR GALAXIES**

Irregular galaxies comprise 2.8 per cent of the galaxies north of 5°-15° brighter than $m_{	ext{V}} = 13.3$. Irregular systems divide sharply into two groups. Galaxies of the first group are highly resolved into luminous O and B stars and H II regions. The systems show no circular symmetry about a rotational axis. Prominent spiral structure is missing. These galaxies form a continuation of the late Sc form of the NGC 4395 type (page 37). The type
The Hubble Atlas

examples are the Large Cloud and Small Magellanic Clouds. Galaxies of the first type are called Irr I. Galaxies of the second group also show no rotational symmetry. The photographic images are completely smooth in texture, show no sign of resolution into stars, and are often crossed by irregular absorption dust lanes and patches. These systems are called Irr II. The type example for the second group is M82 (page 27.1). Any stars brighter than $H_0 = -4.0$ should be observed. (Compare M82 with M81. Both are at the same distance.) The color index of M82 is $C_r = 0.81$ (Holmberg, Medd. Lunds Aastr. Obs., ser. II, no. 136, 1958), but the spectrum is A5 (Humason et al., Astronomical Journal, 61, 97, 1956). Dust lanes are evident across the entire face of M82. NGC 3077, which probably forms a dynamical companion to M82, and NGC 5195, the companion to M51, are of similar form. Finally, NGC 520 has a smooth texture to the photographic image and, for this reason, is placed with the Irr II group.

INTRODUCTION

The class of galaxies characterized by a bar across the central regions was first recognized by H. D. Curtis, who assigned to it the provisional name type I bars. The later more convenient term "barred" spirals, represented by the symbol SB, was suggested by Hubble and has been universally adopted. The SB class includes 15 per cent of the brighter galaxies. The members do not differ systematically from normal spirals either in luminosity, dimension, spectral characteristics, or distribution over the sky.

BARRED SPIRALS

27.1. Any stars brighter than $H_0 = -4.0$ should be observed. (Compare M82 with M81. Both are at the same distance.) The color index of M82 is $C_r = 0.81$ (Holmberg, Medd. Lunds Aastr. Obs., ser. II, no. 136, 1958), but the spectrum is A5 (Humason et al., Astronomical Journal, 61, 97, 1956). Dust lanes are evident across the entire face of M82. NGC 3077, which probably forms a dynamical companion to M82, and NGC 5195, the companion to M51, are of similar form. Finally, NGC 520 has a smooth texture to the photographic image and, for this reason, is placed with the Irr II group.
In describing the barred spirals it will be convenient to differentiate (1) the nucleus, (2) a region concentric with the nucleus which has the shape of a convex lens seen in projection, (3) a ring of luminous matter which when present lies on the rim of the lens and in the progression of the (r) subtype develops into the spiral arms, and (4) the envelope or outer region of the galaxy. In addition, there is always present the characteristic feature of the class, a more or less well defined luminous bar extending centrally across the lens and terminating at its rim or on the innermost coils of the spiral arms.

The structural features fall into a sequence in which a simple pattern of bar and ring develops into a pattern of bar and spiral arms. In several respects, such as the unwinding of the arms and their progressive resolution, the sequence resembles that of normal spirals and, like the normal spirals, was originally subdivided into the three distinct sections SBa, SBb, and SBc in the classification of 1936. Hubble found the scheme useful for certain purposes, but evidence accumulated from large-scale photographs between 1936 and 1950 demonstrated a rather serious defect. The subdivisions in the parallel sequences of normal and barred spirals were not comparable, because those galaxies classified SBa showed no spiral arms whatsoever whereas the Sa galaxies were true spirals with the beginnings of real arms. Galaxies classed as SBa according to the 1936 scheme were similar to the new class of transition galaxies, called SO, which Hubble had isolated between the E7 and the Sa systems. The SBa galaxies (1936 style) were the transition objects from the lenticular galaxies E7 to the true barred spirals, much as the SO galaxies furnished the transition between the E7 and the Sa systems. Thus the parallel sequences of galaxies with true spiral arms were represented by two sections (SBb and SBc) in the barred spirals and by three sections (Sa, Sb, and Sc) in the normal spirals. Hubble changed his original classification system to correct this difficulty by adding a new class called SBO. If the bar were removed from galaxies in this class, an SO galaxy would result. It therefore became clear that the objects previously classed as SBa corresponded more closely to the SO systems than to the Sa galaxies along the normal spiral sequence. Consequently, those galaxies called SBa in the 1936 system have been renamed SBO and the remaining barred spirals have been redistributed among the three sections SBa, SBb, and SBc.

**Classification**

**SBO GALAXIES**

The SBO class represents a transitional stage between the elliptical galaxies and the true barred spirals. In this respect, the class is similar to SO in the sequence of normal spirals. The boundary of the SBO is defined on the E side by the presence of the characteristic bar and on the SBa side by the absence of spiral arms. Features common to the entire class are a nucleus, a lens of lower intensity concentric with the nucleus, the bar which usually terminates on the periphery of the lens, and occasionally an outer envelope and/or an external ring. The bar can be either very indistinct and difficult to recognize or well developed and prominent. The development of the bar is interpreted as a progression along the sequence from early to late SBO, and is recognized in the classification by the subdivision into three groups SBOi, SBO*, and SBO3.

The SBOi, the earliest subclass, is distinguished by a broad and poorly defined region of enhanced luminosity which crosses the central lens at some arbitrary angle to the major axis of the nucleus and lens. This enhanced region is the bar of SBOi. The bars are indistinct and difficult to trace on small-scale plates. Consequently, observers with small telescopes will probably confuse SBOi and SOi galaxies. The earliest examples of SBOi in the Shapley-Ames catalogue are 10-23 and 4455, neither of which is shown in the atlas. NGC 4612 (page 42) is the only SBOi illustrated, and its features are rather difficult to see in the illustration. A sketch of the galaxy is shown in the legend; the nucleus, the lens, and the broad inclined region of enhanced luminosity...
The Hubble Atlas

notivity should be noted. This is a type example of SBOi. The inclined region in SBOi galaxies later than NGC 4812 narrows and becomes more distinct until, in the SBOi and SBO, the bar is prominent.

SBOi galaxies have a nucleus, a lens, and a bar. The bar is not continuous from the nucleus to the rim of the lens. It consists of the central nucleus plus two regions of enhanced luminosity at diametrically opposite points of the periphery of the lens. NGC 2859 (page 42) is the type example, with 4262 (page 42) and 2950 (page 42) as members of the group. All three are illustrated in the atlas. External rings are common in the SBO2 and SBO3. NGC 2859 is a particularly good example. It is classed as SBG2R5 in an obvious isolation where (R) designates the existence of the external ring.

SBOa galaxies have bars extending entirely across the face of the lens. This has a development of the partial bars of the SBO2. No examples of pure SBOa are shown in the atlas. The central regions of NGC 4643 (SBOo/SBafr) (page 42) and NGC 519 (SBa(s)) (page 42), however, illustrate the SBO3 characteristics. Here the bar is intense and well developed, and it contributes the major part of the luminosity of the system. Both NGC 4843 and 5101 show incipient spiral structure which puts them in a transition class to SBS. The outer regions of 4643 contain arms starting tangent to a complete ring at the rim of the lens. In NGC 519 the ring is broken at the end of the bar. This broken ring in an early development of a structure that will become bona fide III Ill III the SBS class. This is the point where the bar is still a partially developed bar from a complete internal ring. NGC 4643 and 5101 are the typical examples of this development of the SBS type which are characterized by K7-avite N(X) 4SJ $SBfr$ (\$VHn$ starting tangent to an internal ring) with NCO 1300 $SBfr$ with arms springing from the ends of the bar. This difference in the $UTh$ view of the arm is between 4h13 and 5101 upper c to lie fundamental but will lie $UTh$ in the entire sequence and also along the arms sequence to $Sc$. The notation is the types where the arms spring and $Sc$ to $Sb$. The notation is the types where the arms spring from the bar (like 1300) is a lower-case (s) after the main type symbol. Thus the outer part of NGC 4643 is classed as SBS and that of 5101 as SBS.

**SUMMARY**

1. There are three subtypes, SBOi, SBO2, and SBO3, which differ from one another in the characteristics of the bar.
2. The bar of SBOi galaxies is a broad, indistinct region whose surface brightness is higher than that of the surrounding lens. It is inclined at a random angle to the major axis of the projected image.
3. The bar of SBO2 galaxies does not extend completely across the face of the underlying lens. There are two diametrically opposite regions of enhanced luminosity on the rim of the lens which, together with the nucleus, constitute the bar.
4. The bar of SBO3 galaxies extends completely across the face of the lens. It is narrow, well defined, and bright.

![Summary: SBO Section](image-url)
The SBa is the earliest of the true barred-spiral forms. There is a spread along the sequence from early to late SBa which is recognized by the developing characteristics of the spiral arms. The arms of the early SBa are poorly defined, smooth in texture, broad, and fuzzy. They are usually coiled in a nearly circular pattern around a central region which itself closely resembles the nucleus, lens, and bar of the SB0. The earliest of the SBa is NGC 936 [SBa(s)], which is not shown in the atlas because of the difficulty of reproducing the very faint arms. The earliest SBa illustrated is NGC 7743 [SBa(s)] (page 43). Here the arms are insignificant relative to the nuclear regions; they are smooth in texture and closely wound. There is no trace of resolution. In the later SBa, the arms are relatively narrow and well developed, and some show beginning traces of resolution (NGC 3185, page 43; 175, page 43). The arms here are tightly wound and form nearly circular arcs that appear in projection as elliptical loops.

The spiral pattern can originate in two ways, either by emerging tangent to a complete internal ring at the edge of the lens, as in NGC 5566 [SBa(r), page 43] or by springing from the ends of the bar, as in NGC 175 [SBa(r), page 43] and NGC 3185 [SBa(s), page 43]. As was mentioned in the section on the SB0, these two lines of development are designated (r) and (s), respectively. The two types can be traced throughout the sequence of later forms.

Six examples of SBa are given in the atlas on pages 43 and 441 NGC 175 [SBa(s)], NGC2217 [SBa(r)], NGCS185 [SBa(s)], NGC5566 [SBa(r)], NGC 7743 [SBa(s)], and the peculiar object NGC 4314 [SBa(s)pec].

Descriptions of the six examples will illustrate the features of the class.

NGC 2217 is shown in both positive and negative prints. This galaxy has a well developed nucleus, a lens, and a bar of the SB0 type. The bar extends to the rim of the lens, on which very faint beginnings of spiral arms are found.

These arms start at diametrically opposite points of the rim about 15° around from the termination point of the bar. Consequently 2217 is of the (r) class, although it is a poor example. Casual inspection would suggest that the nearly circular outer parts of the arms form a closed ring separated from the nucleus. But this is not so, because there are broad, faint rim connections which join onto these brighter, outer regions of the arms at almost a 90° angle. This pattern of arms is almost identical to that of NGC 3185 [SBa(s)]. The difference in appearance is an effect of projection. NGC 3185 is inclined considerably to the line of sight, whereas 2217 is nearly face-on. This projection effect makes the two separate arms more easily visible in 3185 than in 2217.

In both galaxies, the arms are very closely coiled and appear to form a closed ring, but close inspection reveals that there are indeed two separate arms which spring from the ends of the bar. Each arm can be traced through 180° until it passes near, and almost joins, the opposite end of the bar. Each arm does pass beyond the other, and each can be traced on the outside of the beginning of the other arm. The same pattern would be produced if the ring had broken away from the bar (just above the bar at one end, and just below at the other) and the broken ends of the ring had drifted outward. This form, which can be traced in NGC 3185 and 2217, can also be seen in NGC 175 and 7743. NGC 3081, a transition between Sa and SBa, shows the same pattern. In NGC 175 the arms are slightly more open than in 2217 or in 7743, and this fact, together with the partial resolution of the arms into knots, places 175 as the latest SBa(s) of the group. The division between SBa and SBb is rather arbitrary, with 175 close to the boundary. In an earlier notation, NGC 175 was called SBak.

The galaxy NGC 5566 is the only good example in the Shapley-Ames catalogue of an SBa(r) north of 1°-3° brighter than m_v IS. The insert of NGC 5566 shows that the broad fuzzy arms emerge tangent to the internal ring characteristic of the (r) subdivision. Two thin dust lanes in the middle of the arms are silhouetted against the luminous background. The appearance of these lanes in the anus of 5566 is significant, for they mark the beginnings of features that can be traced in the later stages of the deification.
The Hubble Atlas

One of the major characteristics of the SBb(s) is the presence of two dust lanes leaving the nucleus one on each side of the bar and extending into the spiral arms. This feature is conspicuously absent in all SBa. The bars of most SBa's are devoid of dust. There is one exception, NGC 4314 [SBa(s)pec], which is illustrated on page 44. This peculiar object has internal spiral arms opening in the same direction as the external arms. The space between the luminous spiral pattern may be dust lanes in analogy with the almost identical pattern in the nucleus of NGC 4321 (M100) [Sc] shown on page 31. A similar but less pronounced internal structure of this same sort may be present in NGC 4245 [SBa].

The final object illustrated in this section of the atlas is NGC 4691 [SBa], which is included with 4314 to show that absorption does occur rarely in other objects. But here the dust is in a quite irregular pattern in contrast to the regular form in 4314. Hubble classed 4691 as SBapec; on the basis of the 200-inch plate shown, I should now classify this galaxy as an Irregular of the MS2 type.

### SUMMARY

1. The characteristic bar is prominent and smooth in texture with no trace of resolution into knots or "islets." No dust hues are present in the bar as in SBa.

2. Spiral arms first appear in the SBa. They are usually closely coiled around the nucleus and the bar; they are often faint and inconspicuous and may be dust lanes in analogy with the almost identical pattern in the nucleus of NGC 4321 (M100) [Sc].

3. The intense nuclear region of the bar is small. The entire bar with the exception of the very tips smooth in texture with no hint of resolution into stars. This completely amorphous structure is similar to the central regions of near-by galaxies.
Sb galaxies (M31, M81, etc.) that it appears likely that no stars brighter than $M_v \approx -3$ are present in the bar of NGC 1300. This assumption is perhaps a bit conjectural because the estimated distance modulus is $m - M = 31.6$ (based on a Hubble constant of 75 km/sec 10^6 parsecs). Lack of resolution with the 200-inch telescope means only that there are no stars brighter than $M_v \approx -8.6$. The fact, however, that the color index of the small central nucleus is 0.54 (Pettit, Astrophysical Journal, 120, 413, 1954) suggests the presence of old stars (like a globular cluster or an elliptical galaxy). There are two straight dust lanes in NGC 1300 which emerge from the nucleus and proceed on opposite sides of the bar. These absorption features bend sharply at the termination of the bar and continue on the inside of the spiral arms. The high-surface-brightness parts of the arms can be traced through about 180°. The arms continue for another half revolution, but with much lower intensity. They can be traced for a total of about 360°. These features in NGC 1300 are characteristic of all SBB(s) galaxies. Four additional SBB(s) systems are shown on page 46 of the atlas. There is no sharp division between the normal spiral sequence and the barred sequence, because many transition galaxies exist. M83, shown on page 2S, is an example of an Sc/SBB(s). It has more of the features of an Sc than of an SBB galaxy, but the characteristic absorption lanes and the suggestion of a bar are evident. The four galaxies on page 46 illustrate the transition between pure SBB(s) [NGC 5383] and SBB(s)/Sb [NGC 6951]. Note the two straight absorption lanes across the face of the bar, the spiral pattern springing at right angles from the ends of the bar, and the nearly circular arm pattern.

The prototype of the ringed subgroup of the barred spirals, SBB(r), is NGC 1398, shown on page 47. Note how the outer spiral arms start tangent to a narrow internal "ring." The ring Is actually not complete but is composed of very tightly wound spiral segments which are thin and well defined. The outer arms are highly branched and of very low surface brightness. There are no absorption features In the bar. Indeed, no SBB(r) galaxy in the Mount Wilson collection has the straight absorption lanes so characteristic of SBB(s).

Classification

1. SBB galaxies have a well defined bar structure which is smooth in texture with no hint of resolution into stars.

2. There are two subgroups. The spiral arms of the SBB(s) group spring from the end of the bar at right angles. Two straight dust lanes in the bar turn sharply at the end of the bar and follow the inside of the spiral arms. NGC 1300 is the prototype. The spiral arms of the SBB(r) group start tangent to an internal ring on which the bar terminates. No dust lanes are present in the bar. NGC 1398 and NGC 2523 are prototypes of this group.

3. Transition objects exist between the (s) and (r) subgroups (e.g., NGC 4593 and NGC 4548), and between the SBB(s) and Sb type (e.g., M83, NGC 1097, and NGC 6951).

SUMMARY

1. SBB galaxies have a well defined bar structure which is smooth in texture with no hint of resolution into stars.

2. There are two subgroups. The spiral arms of the SBB(s) group spring from the end of the bar at right angles. Two straight dust lanes in the bar turn sharply at the end of the bar and follow the inside of the spiral arms. NGC 1300 is the prototype. The spiral arms of the SBB(r) group start tangent to an internal ring on which the bar terminates. No dust lanes are present in the bar. NGC 1398 and NGC 2523 are prototypes of this group.

3. Transition objects exist between the (s) and (r) subgroups (e.g., NGC 4593 and NGC 4548), and between the SBB(s) and Sb type (e.g., M83, NGC 1097, and NGC 6951).
The Hubble Atlas

SBc GALAXIES

The characteristics of SBc galaxies are (1) the high degree of resolution of the bar and of the spiral arms into knots and luminous lumps, and (2) the openness of the spiral arms.

Six SBc galaxies are shown on page 49 of this atlas. As in the SBb, the Slit can be separated into the two subgroups (t) and (s), although the pure ringed type is not common. Most central rings are broken into several segments. An example is NGC 1073 (page 49), where the ring is not complete but breaks about 1/4 from either end of the bar. Of the six galaxies illustrated, three are of the pure SBc(s) type and three are of the combination type [SBd(s)z].

Note the high degree of resolution into stars of NGC 7741. Both the arms and the bar are resolved into knots. This feature of the resolution of the bar is unique to the SBc type. The liars in SBa and SBb galaxies are smooth in texture, with no hint of resolution.
ONE hundred seventy-six separate galaxies are illustrated. The reproductions have been made from plates in the Mount Wilson-Palomar plate collection. The original negatives were obtained with either the 60- or the 100-inch telescope on Mount Wilson, or with the 200-inch reflector or the 48-inch Schmidt telescope on Palomar Mountain.

Technical data for each negative are given in the legend on the page facing the illustration. Each galaxy is identified by either its NGC number, its Messier number, or its special designation; to the right of the galaxy designation is the nebular classification. The north and west directions are indicated by arrows in the upper right-hand corner of the legend. Below the NGC designation is the plate number of the original negative. The prefix of the plate number identifies the telescope, and the suffix identifies the observer responsible for the negative. In the prefix, PH stands for Palomar Hale; PS, Palomar Schmidt; H, the 100-inch; S, the 60-inch. The suffix letters of the plate number stand for the observer. The code is: B = Baade, Bm = Baura, A = Duncan, H = Hubble, Mi = Minkowski, MH = Humason, P = Pease, Ri = Ritchey, S = Sandage. For example, a plate labeled PH-116-H was taken with the 200-inch by Hubble.

One hundred thirteen plates of the atlas were taken with the 200-inch, 54 with the 100-inch, 16 with the 60-inch, 2 with the 48-inch, and 1 with the Mount Wilson 10-inch telescope.

The date when the plate was taken is given below the plate number. The emulsion type plus filter (if any) appears under the date. Most of the plates were sensitive to blue light (XXJJKK:SOOO), but some negatives were obtained with yellow- or red-sensitive emulsions. A variety of plate types were used in the early days, such as Eastman 40, Agla Blue, Cramer High Speed Special, Imperial Eclipse, Seed 30, and Seed 23. These names are abbreviated in the descriptions. Since the war, the blue plates have been Eastman 105aO or Eastman HaO. The blue filters have been Schott WG2 or Schott GG13. Eastman 105aD plates were used for the yellow-green region of the spectrum, and 103aE plates for the red-Ha region. Schott GG11 and either a Schott RG1, RG2, or a red plexiglass filter were used with these plates.

The exposure time of the plates is stated on the next line. Notice that plates taken in the early days had very long exposure times, whereas modern blue plates with the 200-inch are generally exposed for only 30 minutes. This difference illustrates the great increase in speed of photographic materials between 1910 and 1956.

The final datum in the list is the enlargement factor of the reproduction from the original plate. The quoted values are accurate to about 5 per cent. The scale of the reproduction in seconds of arc per millimeter is stated for each galaxy in the following table. It can be computed from the enlargement factor and from the scale of the appropriate telescope. The telescope scales are 1:06/mm for the 200-inch, 16:00/mm for the 100-inch, 27:12/mm for the 60-inch, and 67:00/mm for the 48-inch Schmidt*.

Below the data, a few lines of text describe each galaxy illustrated. Information therein notes features of the image which are present on the original plates but which may be lost in the reproduction. Also, the relation of the particular galaxy to the entire classification scheme is sometimes indicated.

Preface to the Illustrations
The Hubble Atlas

Distance moduli are given for a few objects, quoted as apparent magnitude minus absolute magnitude. The relation of $m - M$ to the distance $r$ in parsecs is $\log r = 0.2(m - M + 5)$. Most of the values for the moduli were determined from the redshifts observed by either Humason or Mayall (Astronomical Journal 67, 97, 1956) together with an assumed rate of expansion of 75 km/sec per 10^7 parsecs (Sandage, Astrophysical Journal, 127, 513, 1958). These distances are not accurate for galaxies whose redshifts are smaller than 1000 km/sec, because the random motions (of the order of 200 km/sec) form an appreciable fraction of the systematic redshift values, causing a rather large error in the computed distance for near-by galaxies.

The following table provides an index of the galaxies illustrated in the atlas. The objects are listed by NGC number. The telescope used, the galaxy type, the page of the atlas on which the galaxy is illustrated, the enlargement, and the scale of the print in seconds of arc per millimeter are given.
Table of Data for Galaxies in the Atlas

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29
The Hubble Atlas

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Illustrations of Galaxies
The central isophotes of NGC 4636 appear circular on short-exposure plates. On these plates, and on the illustration on the right, this galaxy looks like a normal E0. On plates taken with the 48-inch Schmidt telescope, however, a faint elliptical envelope appears whose major axis is at a position angle of 330° (north through east). The ellipticity of the envelope is E4. Its surface brightness is about 24 mag/sq sec. Because of the envelope, this galaxy must be considered a transition to SOi type.

There are many condensations in the atmosphere of NGC 4636 that can be seen on this illustration. They are probably globular clusters of about $M_{pg} = 10.0$.

NGC 4697 is a normal E5 galaxy in the southern extension of the Virgo Cluster. There are a number of condensations whose distribution is centered on the nucleus; they are probably globular clusters. If this galaxy has a modulus of $m - M = 30.7$, which probably applies to the nucleus of the Virgo Cluster, then $M_p$ for NGC 4697 is -20.3. The value $m_p = 10.4$ is from Humason et al. (A.J., 61, 97, 1956, table A1).

NGC 4278 is a typical E1 galaxy. There is a smooth intensity gradient from the center to the outside where the luminosity of the galaxy fades far below the surface brightness of the background sky. There is no outer envelope like that in SO systems.

The many condensations in the atmosphere of 4278 are undoubtedly globular clusters. There are not so many of them here as in 4486 (M87), but about 50 exist. NGC 4278 is north of the Virgo Cluster, in the south wing of the Ursa Major Cloud.

NGC 3377 is a normal E6 galaxy in a small physical group whose members include 3351 (M95), 3368 (M96), 3379, 3384, 3412, 3489. The redshift of the group averages about 650 km/sec. It is close to, and probably a dynamical unit of, the larger group in Leo whose brightest members are NGC 3627, 3623, etc. (See table XI of Humason et al., A.J., 61, 97, 1956.)
NGC 4486 (M87) is the brightest elliptical galaxy in the Virgo Cluster. The apparent photographic magnitude is about $m_{pg} = 9.7$ (mean of Holmberg and Pettit-Sandage). If $m - M = 30.7$ for the Virgo Cluster, then $m_{pg} = -20.0$ for 4486. This is one of the brightest galaxies known. M31 has $m_{pg} = -20.3$; NGC 128 has $m_{pg} = 21.5$; and a few others are as bright. There is no question that NGC 4486 is on the bright end of the luminosity function.

NGC 4486 is peculiar in two respects. First, a very large number (well over 500) of globular clusters are scattered over the entire image; they show quite well in the outer regions of the illustration. Second, a peculiar jet starts from the nucleus and can be traced for 1500 parsecs in the northwest direction. It is visible on the illustration on the upper right of the facing page.

This galaxy is a source of intense radio emission. The relation of the optical image to the radio source is discussed by Baade and Minkowski in Ap. J., 119, 221, 1954.

The jet in NGC 4486 is well shown in this illustration. The orientation is the same as that of the illustration on the left. The light of the two knots in the jet is polarized. An illustrated discussion of the polarization is given by Baade (Ap. J., 123, 550, 1956).

NGC 750/751 form a double galaxy of two normal E0 systems. The two components are connected by a luminous bridge. An extensive outer envelope surrounds the two nuclei.
The three galaxies shown on the facing page illustrate the resolution of elliptical galaxies into stars. All three are members of the Local Group. The resolution of NGC 185 and NGC 205 was first accomplished by Baade with the 100-inch telescope (Ap. I., 100, 137-150, 1944). The photographs here of 185 and 205 were taken by Baade with the 200-inch.

NGC 185 and NGC 147 together with M31, M32, and NGC 205 form a subunit of the Local Group. All five have distance moduli of about $m-M = 24.4$ to 24.6.

A dust patch near the center of 185 is more easily seen on a photograph by Baade reproduced in the reference dated Leo II System is classified as a dwarf elliptical. The galaxy is within the Local Group and is highly resolved into stars. There is no background surface luminosity as in normal E galaxies, because the stellar content is so sparse. This galaxy is similar to the Sculptor and Fornax systems described in 1936 by Baade and Hubble, Pub., A. S. 357, 51, 485. Leo H, together with three similar stars, was discovered on the Palomar Sky Survey by Hubble and Wilson, Pub., Michigan Obs., 1, 10. Many RR Lyrae stars have been used in 1x= IL. The list of these stars is in the list in Sky and Telescope, January 1954. The intensity gradient of NGC 205 suggests the presence of an outer envelope similar to that of S0 galaxies. Perhaps this is a transition case.

NGC 205 is one of the two elliptical companions of M31. Note how the outer parts of 205 are highly resolved into stars on this 200-inch plate. The brightest of these stars are all of about the same apparent brightness. This explains the observational fact that resolution does not occur until a critical exposure time is reached, at which time the entire smooth image of the galaxy breaks up into individual stars.

NGC 205 has two features uncommon to pure elliptical systems. (1) There are two dust patches near the center of the galaxy. They are not completely opaque. They do not show in this illustration because of the high stellar density near the center, but a negative reproduction of a good 100-inch plate taken by Hubble and published in Sky and Telescope, January 1954, does show the feature. (2) A few blue supergiant stars appear to be associated with dust patches in the center of NGC 205. A negative print from an ultraviolet plate taken by Baade with the 100-inch is given in Pub., Michigan Obs., 10, 10.
NGC 1201 
PH-817-S
Oct. 1/2,1954
103aO
25 min
Enlarged 5.0 X

The six galaxies on the facing page are all classic examples of SO. The image of each is smooth, with no evidence of dust. The galaxies differ from E systems in the luminosity gradients. A faint, extensive envelope is present in all SO galaxies. As this feature does not show well in halftone reproductions it may be partly lost in these illustrations.

To the eye, images of SO present three distinct luminosity zones on the original plate. There is an intense nucleus, an intermediate zone of lower surface brightness, called the lens, and the characteristic faint outer envelope. This description may be subjective. The luminosity gradients may be continuous, and the three zones may be a photographic effect. The effect does, however, provide criteria for classification.

NGC 7457
H-2550-H
Dec. 1/2,1948
103aO
30 min
Enlarged 5.9 X

This is a good example of a typical SO. The galaxy is SO similar to the other SO systems shown on the page that no individual description is necessary.

NGC 4150
Sd
H-433-H
Jan. 31/Febr. 1,1925
E40
35 min
Enlarged 8.3 X

The three zones mentioned in the description of 1201 are well marked here. The outer envelope of 4150 is very extensive. This places 4150 later in the SO classification than NGC 1201. Microphotometer tracings should be made of these galaxies to find the real difference in the luminosity gradients of E and SO galaxies. At present the classification depends entirely on subjective impressions gained from visual inspection of photographic plates.

NGC 4684
SO!
H-2524-M
Mar. 7/8,1948
103aO
30 min
Enlarged 7.1 X

This and 3329 are good type examples of SO galaxies. The three characteristic zones of different luminosity are present.

NGC 3245
SO!
H-2160-H
Dec. 5/6,1941
Cr-Hi-Sp-Sp
60 min
Enlarged 9.0 X

NGC 3245 is one of the best examples of SO shown on the page. The outer envelope is quite extensive. It is often difficult to classify a galaxy which is near the E or SO boundary. NGC 3245 is a "late" SO and there is no difficulty of classification.

The original plate of 3245 shows that the nucleus is spherical and the lens and outer envelope are elliptical.

NGC 3329
S-1732-H
Dec. 5/6,1937
Imp. Eel.
55 min
Enlarged 19.2 X

The description of this galaxy is the same as for the other five systems shown.
NGC 524 shows a pattern of nucleus, lens, and envelope. The lens, on visual inspection of the photographs, appears to be surrounded by a relatively dark zone, followed by a more luminous zone. This description is subjective, however. Microphotometer tracings show that the luminosity decreases continuously outward from the nucleus. The apparent dark zone corresponds to a region where the rate of fall first increases then slows and finally approximates the normal value. (NGC 3065 is similar to 524. The description follows below.)

NGC 3065 shows a similar pattern of nucleus, lens, and envelope. The lens, on visual inspection of the photographs, appears to be surrounded by a relatively dark zone, followed by a more luminous zone. This description is subjective, however. Microphotometer tracings show that the luminosity decreases continuously outward from the nucleus. The apparent dark zone corresponds to a region where the rate of fall first increases then slows and finally approximates the normal value. (NGC 3065 is similar to 524. The description follows below.)

NGC 3032 shows a pattern of nucleus, lens, and envelope. The lens, on visual inspection of the photographs, appears to be surrounded by a relatively dark zone, followed by a more luminous zone. This description is subjective, however. Microphotometer tracings show that the luminosity decreases continuously outward from the nucleus. The apparent dark zone corresponds to a region where the rate of fall first increases then slows and finally approximates the normal value. (NGC 3065 is similar to 524. The description follows below.)

NGC 4459 shows a pattern of nucleus, lens, and envelope. The lens, on visual inspection of the photographs, appears to be surrounded by a relatively dark zone, followed by a more luminous zone. This description is subjective, however. Microphotometer tracings show that the luminosity decreases continuously outward from the nucleus. The apparent dark zone corresponds to a region where the rate of fall first increases then slows and finally approximates the normal value. (NGC 3065 is similar to 524. The description follows below.)
In many respects NGC 404 appears to be a normal S0 with a circular dust lane embedded in a uniform lens and envelope. The lane cannot be traced through a complete revolution. Although this might be explained as a projection effect similar to that of NGC 4459 and NGC 4526 on page 5, the explanation is probably inadequate because the background envelope of 404 (not visible in the illustration) is elliptical. Therefore the fundamental plane of the galaxy is not perpendicular to the line of sight. But the absorption ring is placed along the minor axis of the ellipse. It would have to be along the major axis if the orientation explanation for its incompleteness is correct.

NGC 4111 is classified as an S0 on edge. The nucleus, lens, and outer envelope are all easily visible on the original plate and can probably be made out in this illustration. The surface brightness of the lens is not uniform, but two absorbing streaks appear, in projection, perpendicular to the fundamental plane. They cross the lens near its junction with the nucleus. Such a pattern would be reproduced if NGC 3065 were seen on edge. The internal absorption lane of the galaxy would then appear silhouetted against the bright background.

NGC 4215 has a bright nucleus and an extended lens. The intensity distribution of the lens is not uniform. There is evidence of internal absorption such as would be produced if NGC 3065 (p. 5) or a less dense central ring version of 3032 (p. 5) were to be seen on edge. The absorption across the lens of 4215 occurs as two hazy vertical bands internal to the edge of the galaxy. The ends of the image are bright as in NGC 4710. This would be the case if 3065 were tipped on edge, because no absorption would reach the outside edges.

The dust lane of NGC 5866 does not appear in this illustration. The fact that the image looks like a regular E6 galaxy with no abnormality shows the danger of missing faint but important details on plates taken with small-scale telescopes or with long exposures.
NGC 128 Sdpcc
PH-971-S
Aug. 23/24, 1954
103aD + GG11
30 min
Enlarged 8.0 X
NGC 123 has a peculiar box-shaped nucleus. Otherwise, it resembles a normal SQ| on edge. There is no evidence for absorbing rings perpendicular to the plane such as could explain the indentation of the center of the nucleus. The box-shaped nucleus must therefore be a dynamical feature of the galaxy.

NGC 128 is the brightest member of a group. The two other galaxies appearing with it in this illustration are NGC 127 north preceding and NGC 130 north following 128. Both are dynamical members of the group and are at the same distance as 128. In a luminous bridge between NGC 127 and 128, absorption lanes are seen silhouetted against the north ansa of 128.

NGC 7332 S0, pcc
PH-768-S
Aug. 23/24, 1954
103aO
30 min
Enlarged 3.0 X
Short exposure* of NGC 7332 show that this galaxy is similar to NGC 4111 and NGC 4215. Absorption lanes, in projection*, appear as narrow bands* perpendicular to the fundamental plane. These bands are probably the ends of the internal ring of SO galaxies, like 3C105, seen in projection against the lens. NGC 7332 is classed as a peculiar because of the box-shaped central region, in which it is similar to NGC 128. Otherwise NGC 7332 appears in text: unusual

NGC 2685 S0 pec
PH-663-S
Feb. 5/6, 1956
103aO + WG2
30 min
Enlarged 7.1 X
NGC 2685 is perhaps the most unusual galaxy in the Shapley-Ames catalogue. There are two axes of symmetry for the projected image; most galaxies have only one. The central, amorphous spindle resembles a normal S0 seen on edge. However, helical filaments surround the spindle. Because of projection effects, it is impossible to tell whether these filaments form complete circles around the spindle or whether they start somewhere on the spindle and spiral outward at right angles to its axis. The filaments are seen in absorption when they pass in front of the bright background, but they are luminous when they are not silhouetted. Note how the entire north-east end of the spindle is covered with the projected absorption lanes of the helix.

A luminous external ring around the entire structure may be either a true ring or a complete shell seen in projection.

Many questions are unanswered about this galaxy. Is the central feature a spheroid (with two axes equal as in a plate or pancake), or is it an ellipsoid like a cigar? What is the direction of the angular momentum vector? Is the external ring attached to the central regions, or is it separate?
NGC 3718 SO pec?
S-1802-H
May 23/24, 1938
Agfa Blue
120 min
Enlarged 5.1 X

NGC 3718 and NGC 4753 (below) were classified by Hubble as SO pec because, if the unusual absorption features were removed, the underlying luminosity would resemble SOi galaxies. But, at least for NGC 3718, the form is not this simple. Two faint extensions to the envelope emerge from opposite sides of the periphery in NGC 3718. They suggest spiral arms. This galaxy looks somewhat like an SBB but the absorption lane is the bar. But the bars of all normal SB galaxies are luminous, bright features and are not absorption bands. The modern data, therefore, place NGC 3718 outside the sequence of classification. The insert photograph is from the 48-inch Schmidt.

NGC 4762 SO
H-282-H
Apr. 15/16, 1923
S30
135 min
Enlarged 8.8 X

NGC 4762 has the flattest form of any galaxy known. It is undoubtedly an S0 seen on edge. The nucleus, lens, and extended envelope are all visible on the original plate and probably show in this illustration. Note the very faint outer extensions visible on the insert photograph. This insert was made from a 48-inch Schmidt plate.

NGC 5273 S0/Sa(s)
PH-668-S
Feb. 5/6, 1954
103aO + WG2
30 min
Enlarged 6.0 X

NGC 5273 is a transition between an S0 and an Sa galaxy. A very faint spiral pattern is visible. It is probably due to a thin dust lane that winds outward through the envelope. The lane is not opaque, so that the arms are difficult to trace.
NGC 2681 (Sa) PH-191-MH
May 13/14, 1950
103aO
30 min
Enlarged 4.1 X

NGC 2681 and NGC 1302 (right) are the earliest Sa galaxies shown in the atlas. NGC 2681 has two well defined spiral arms in its central region. These arms, shown in the insert, are very tightly wound about the nucleus. It is probable that the region between the stubby arms and the intense nucleus is filled with dust.

There is a faint and very poorly defined outer spiral structure. The direction of unwinding of the spiral pattern is almost impossible to trace. NGC 2681 is discussed by Lindblad and Brahe in Ap. J., 104, 211, 1946; they give several pictures of the galaxy.

NGC 4457 (Sa) H-2481-H
Jan. 9/10, 1948
103aO
30 min
Enlarged 11.9 X

NGC 4457 has one prominent spiral arm of high surface brightness, and another, fainter arm which is less well defined. These arms are embedded in an envelope of low surface brightness. Dust lanes lie on the insides of the two arms. A faint external ring surrounds the entire structure. The ring may not be completely detached from the more central envelope, because a faint connection is probably present on the east end of the major axis.

NGC 1302 (Sa) PH-670-S
Feb. 6/7, 1954
103aD + GG11
45 min
Enlarged 3.5 X

NGC 1302 is similar to 2681. The inner arms near the nucleus of 1302 are more difficult to trace than those in 2681, but the outer pattern is slightly better defined. It is not known whether the outer structure is due to thin dust lanes winding out through a smooth envelope or to an actual spiral distribution of luminous matter. In any case, the spiral pattern is almost circular; the arms are very diffuse and hard to trace.

NGC 5614 (Sa); 5613 (SB0), 5615 (?) PH-669-S
Feb. 5/6, 1954
103aO + WG2
30 min
Enlarged 6.2 X

Three galaxies are shown in this illustration. The large one is NGC 5614, which is classified as Sa. The knot on the northwest rim of 5614 is called NGC 5615; it may be a separate galaxy in collision with 5614, but the interpretation is uncertain. The SB0 on the left side of the print is NGC 5613. Note its beautiful external ring.

The spiral pattern in NGC 5614 is composed both of tightly wound luminous filaments and interspersed dust lanes. The arms are almost circular. Hence, NGC 5614 is classified as early Sa.
NGC 3898 Sa
PH-909-S
Mar. 25/26, 1955
103aO + WG2
30 min
Enlarged 6.0 X

NGC 3898 is the Sa prototype of multiple-arm spirals of the NGC 2841 [Sb, p. 14] type. The arms in 3898 are very tightly wound about a large amorphous center. The arms themselves are made up of individual segments which cannot be traced as complete arcs for more than 20° to 30°. NGC 3898 is one of the earliest members of a sequence of multiple-arm spirals which can be traced from late Sc to early Sa. Among the members of this sequence are M101 (p. 27), NGC 5055 (p. 15), 488 (p. 15), 2841 (p. 14), 3898 (this galaxy), 2811 (p. 11), and 1302 (p. 9).

NGC 2775 Sa
H-2064-H
Mar. 24/25, 1939
Agfa Blue
80 min
Enlarged 9.2 X

This beautiful spiral is similar to NGC 3898. The spiral pattern is more easily seen because NGC 2775 is observed almost face on. Notice that the arms cannot be traced as individual structures but rather as separate segments, as is true in all multiple-arm galaxies of types Sa and Sb. The arms, with their associated dust lanes, start abruptly at the edge of a completely amorphous central nucleus and lens. The boundary between the lens and the spiral structure is sharp.

Note the thin dust lane on the outside of the entire pattern (about 45 mm from the center on this illustration, along the major axis) ,

NGC 4378 Sa
H-2482-H
Jan 9/10, 1948
103aO
30 min
Enlarged 5.2 X

The spiral pattern in this galaxy is formed either by thin dust lanes threading outward through a uniform envelope or by luminous filaments. The surface brightness of the envelope or the filaments is exceedingly small. It probably averages about 22 mag/sq sec of arc, which is close to the brightness of the night sky. The original plate was triple-printed to bring up the contrast: i.e., a positive contact plate was made from the original negative; a copy negative was made from this positive; a second contact positive was made from the copy negative; and the photographic print was made from this last plate. The illustration is very grainy because of the process.

NGC 4941 Sa/Sb
S-1655-H
May 4/5, 1937
Imp. Eel.
50 min
Enlarged 10.2 X

This galaxy is difficult to classify because of conflicting criteria. The spiral arms are tightly wound. There are only two arms, and they overlap after each has turned through 30°. There is little or no dust in the arms, which are relatively smooth textured with not much resolution into lumps or H II knots. The arms therefore suggest a classification of Sa. The nucleus is very small, however, suggesting a classification of Sb or even Sc. This galaxy shows that the three classification criteria are not always consistent.
AH galaxies on the facing page are in the second major subdivision of Sa systems. They all have predominantly small nuclei, more or less regular, thin, internal dust lanes, and thin spiral arms. The earliest galaxy of the group is NGC 2811; the latest is NGC 3623. NGC 4293 has heavy absorption lanes spread throughout the lens. This galaxy may be the Sa example of the NGC 253 (p. 34) type of Sc spirals.

NGC 4866 is the prototype galaxy of the second major subgroup of Sa systems. Very thin dust lanes are spread throughout the main body. They are not circular but have a tightly wound spiral pattern. NGC 4866 and 2811 probably have a similar spiral pattern, but the projection angles differ in the two galaxies. Notice the small nucleus to NGC 4866. The entire lens is amorphous with no suggestion of resolution into stars.

NGC 3623 is the latest Sa shown in the atlas. In an older notation it would have been called Sab. Note the prominent dust lane silhouetted against the bright background. There is no resolution of the arms into knots, but the photographic image of the lens and arms is not as smooth as for 4866 or 718. A negative reproduction of NGC 3623 is given by Hubble in Ap.J. 97, 112, 1943.

NGC 3081 has two spiral arms which nearly overlap each other, giving the impression of a complete external ring separate from the nucleus. Close inspection of the photograph, however, shows the two separate arms to be very tightly wound. The form is similar to that of NGC 3185, the description of whose arms on page 43 should be read. NGC 3081 differs from 3185 in lacking an intense bar connecting the ends of the broken ring. On long-exposure plates a faint bar can be traced in 3081, but its faintness puts the galaxy in the Sa rather than in the SBa class.
NGC 4274 is the type example of a special subgroup of Sa within the NGC 4866 major group. On short-exposure photographs, all galaxies of this subgroup appear to have a complete narrow ring, separated from the nucleus, and superposed on the faint background light of the lens. Large-scale photographs, however, show that the ring is not complete but is broken at diametrically opposite places, the pieces having drifted outward to form a spiral pattern. This feature is particularly well shown in NGC 4274. The two bright spiral arms that make up the broken ring are easily visible. Notice how the two arms almost touch when the one sweeps through 180° and passes near the arm closer to the nucleus.

Two fainter arms are present in NGC 4274, winding outward through an extended envelope on the outside of the bright arms that form the "broken ring."

NGC 3368 is of the NGC 4274 (left) type but is later along the sequence of classification. Remnants of the "broken ring" are visible in the two arms which begin in the nucleus and circle the rim of the lens. NGC 3368 is seen more nearly face-on than NGC 4274, and so the arms do not appear to overlap as much as in 4274. Very faint filaments, circling the entire inner structure, are visible in the insert. They are connected to the inner lens near the northwest end of the major axis.
NGC 4826 M64 Sb
Ri-65 (601
May 5,6,7,8,1910
7 hrs 56 min
Enlarged 3.7 X
NGC 4826 is the earliest Sb shown in the atlas. This plate was taken by Ritchey in a four-night exposure with the 60-inch. Note the very soft texture to the spiral arms. These arms are nearly circular, and they show no trace of resolution into knots. NGC 4826 is classed as Sb rather than as Sa because of the very heavy dust lane in the center, which is shown below.

NGC 4826 M64 Sb
Mar. 8/9,1910
240 min
Enlarged 3.7 X
This is a shorter exposure of NGC 4826 than the one shown above. The dust pattern in the nucleus is very prominent. The bright filaments, which make up the inner spiral structure, are also visible. Although the strongest concentration of the dust is in a single dark lane, a fainter dust arm can be seen on the inner edge of the last luminous arm on the north side of the galaxy in this illustration.

NGC 4569 M90 Sb
PH-12-Bm
Jan. 31/Feb. 1,1952
10 hrs + WG2
30 min
Enlarged 2.0 X
The soft texture of the spiral arms and the heavy dust lanes near the center of this galaxy are similar to those features in 4826 (left). Spiral arms of this type were described as "massive" by Reynolds and by Hubble. Dust lanes can be traced almost to the nucleus, which is of high surface brightness and about 2 mm in diameter on the scale of this illustration. There is partial resolution of one of the inner dust lanes into knots, which are presumed to be H II regions.

NGC 4579 M58 Sb/SBb
PH-28-Bm
Mar. 31/Apr. 1,1952
10 hrs + WG2
30 min
Enlarged 2.8 X
This galaxy is a much later example of the 4826 subgroup than 4826 or 4569 itself. There are two very faint outer spiral arms which are smooth in texture and are "massive" in the sense of the spiral arms in 4826 and 4569. They do not follow well in the illustration because of their low surface brightness. Two thin dust lanes can be traced in this outer region near the smooth, massive arm, on the north side of the galaxy. More prominent dust lanes, thin and well defined, can be traced on the inside of the bright inner spiral arm. There is a bar of enhanced luminosity across the central amorphous region. This galaxy is a transition between Sb and SBb. Note the partial resolution of the arms into knots.

NGC 4450 Sb
H-2432-H
June 29/30,1941
Cr-Hi-Sp-Sp
45 min
Enlarged 3.6 X
This galaxy is not of the 4569 type but is illustrated here to show the prominent dust lane similar to the one in 4450 (above). As in 4450, the lane does not begin in the nuclear region but begins abruptly some distance from the center—an unusual feature in galaxies.
This is the type example of the multiple-arm Sb subgroup. NGC 2841 is the earliest of the group. All galaxies illustrated on pages 14 to 19 are of this type.

NGC 2841 has a central region composed of a bright nucleus (smaller than 15 sec of arc in diameter) and an amorphous lens devoid of dust or spiral structure. The lens resembles an E or SO galaxy. The smooth lens has a major diameter of 100 sec (60 mm on this illustration). Multiple, thin dust lanes begin to spiral outward at the periphery of the amorphous lens. They appear to separate luminous spiral filaments of very complex structure. At first glance the filaments look like complete spiral arms, but closer inspection shows that only thin broken segments are present which cannot be traced as individual arcs for more than 30°.
NGC 488 is of the 2841 type but is slightly later, for the spiral structure can be traced closer to the central regions. There is a change in the characteristics of the spiral arms close to the nucleus. The inner arms are very smooth in texture with no indication of resolution into lumps. These arms can be traced to within 25 sec (radius along the major axis) of the center—about 9 mm on the illustration. The amorphous inner arms can just be seen. As they wind outward, they lose their smooth texture and become "lumpy" with condensations. The luminous arms are nearly circular, with regular dust lanes on their inside edges. The distance modulus to NGC 488 is about $m - M = 32.4$. At this distance, the angular width of the arms corresponds to 300 parsecs. The average distance between arms in the outer regions is about 3000 parsecs. These mines should be compared with values for typical Sc galaxies given in the later sections of the atlas.

NGC 5055 M63 Sb

NGC 7217 Sb

NGC 7217 is of the 2841 type, slightly further along the sequence of classification than NGC 488. The spiral arms are tightly wound and very filamentary. They cannot be traced as separate arms. The filaments are discontinuous segments just as in 2841. The dust lanes and luminous segments can be traced to within 10 sec from the center (4 mm on this illustration). As in 488, the central segments of the arms are smooth in texture. The discontinuity of surface brightness between the inner and outer regions is real. The peculiar feature of this galaxy is the intermediate ring of low surface brightness. The spiral structure can be traced on the original plate throughout the intermediate zone.
Very closely packed and tightly wound spiral arms can be traced to within 12 sec of arc from the center, corresponding to about 4 mm on the scale of this illustration. Note the difference in surface brightness between the inner and the outer regions. The important point, emphasized in the description of 5055, is that spiral arms exist in this inner region of high surface brightness.

The range of surface brightness between the nuclear region and the outer regions, including the external ring, is very great. This illustration does not show the complex structure of the galaxy. The intense central region is devoid of spiral structure. It is 32 sec of arc in diameter (8 mm on the illustration). Tightly wound spiral arms of the kind seen in NGC 4699 (left) begin tangent to this amorphous central region and wind out through a region of lower surface brightness of lens shape with a diameter of 120 sec of arc (35 mm on the illustration). Details of structure in both these regions are invisible here because of the inability of photographic paper to reproduce large intensity differences. A third region, filled with spiral arms, begins at the outer boundary of the second zone. As between the first and second zones, a sharp discontinuity of surface brightness exists between the second and third zones. The spiral structure in the third zone is seen in the illustration. The surface brightness of the third zone appears to go to zero rather suddenly 200 sec of arc from the center. An annular zone devoid of luminosity then begins. This zone of near zero surface brightness continues until the inner boundary of a faint external ring is reached at 260 sec of arc radius from the nucleus. The ring is shown in the insert. It has a fairly sharp inner boundary but fades and is lost in the night-sky radiation at large distances from the center. The ring is not detached from the nuclear region but is connected to the more central regions on the west side.
This galaxy, seen almost on edge, is of the 2841, 5055 type, though the spiral arms do not seem to be as thin and are more easily visible. The increased visibility of the arms may be an effect of projection, because the dust lanes and interspersed luminous arms are silhouetted against the bright background luminosity of the central regions of the galaxy. Spiral arms can be seen to within about 12 sec of arc (radius) of the center (about 6 mm on the scale of the illustration). This illustration does not show the detail in the central regions. The burned-out central region is not amorphous like the center of M31 or M81 but has a spiral structure like that in 5055.

NGC 7331 is one of the galaxies often used in discussions of the direction of rotation of spiral arms. There is no question about which way the arms open in 7331; the debatable point is which is the near and which the far side of the galaxy. The Lindblad School believes that the east side is the near one, in which event the arms would be leading because spectroscopic data show that the north end of the spindle is approaching. The original plate, PH-64-H, from which this illustration was made, appears to settle the argument. A part of the light from the nuclear bulge can be seen beneath the dust line on the west side. The nuclear light can just be seen on this positive reproduction. But a negative print from PH-64-H is given by de Vaucouleurs in Ap. J. 127, 487, 1958 (fig. 5) which shows this particularly well. If the identification of the light with the nuclear bulge is correct, the west is the near side and the spiral arms are trailing.
M31 is probably of the 2841 type of multiple-arm galaxy although it differs from such type examples as 488, 5055, and 4699. The arms in M31 are thicker and less well defined than in these prototypes. Baade has made a long and careful study of M31, both of its geometric form and of its stellar content. A short description of part of this work is given by Baade in his report to the Rome Conference on Stellar Populations (vol. 5 of Ricerche astronomiche, specola vaticana, 1958, pp. 3-21). Baade has noted seven distinct spiral arms in M31 (see table 2 of his report). The inner two arms are dust arms; the outer five arms contain supergiant O and B stars. The first two arms cross the north-following half of the major axis at distances of 3.4 and 8.0 sec of arc from the center. These angles correspond to 1.5 mm and 3.6 mm from the center on the scale of the illustration. Both arms, designated as N1 and N2 by Baade, are within the burned-out central region of the illustration.

The texture of the background luminosity of the central portion of M31 is smooth and amorphous on plates taken with small telescopes. Baade has shown, however, that this central region can be resolved into red stars whose color indices are about international 1.3 and whose absolute magnitudes are about My = –3.0 (Baade, Ap. J., 100, 79, 1944). The resolved images resemble those in NGC 205, which is the E5 companion galaxy west of the center of M31. NGC 205 is illustrated on page 3 of this atlas.

Dust lanes and dust patches are present in the central region of M31. Again, these are not visible on the illustration. But a negative print of lower density is reproduced by Hubble and Sandage in Ap. J., 118, 353, 1953 (fig. 2). The dust arms and patches are similar to those in NGC 3031 (M81) shown on page 19 of this atlas.

M81 has a large amorphous central region in which there is no suggestion of resolution into individual stars. There is no doubt that this region resembles the central part of M31 and that, under the proper conditions, with a large telescope, M81 could be resolved into stars just as Baade resolved M31. The distance modulus of M81 is about $m - M = 27.1$ (Sandage, A. J., 59, 180, 1954). If $M_v = -3.0$ for the brightest stars in the central lens, then $\% = 24.1$. This is beyond the limits of the 200-inch telescope with the Ross f/3.67 lens. Two possibilities exist, however, for achieving the resolution of M81. We can use the f/4.85 lens, which will give about a 1-magnitude increase in the limit, and we can go to the infrared where the absolute magnitude for these globular-cluster-like stars is undoubtedly brighter than -3.0.

Dust lanes, forming a multiple spiral pattern, thread through the central region and are silhouetted against the amorphous, luminous background. These fainter multiple dust lanes do not show in the illustration because of the overexposed central region. They can be traced to within 35 sec of arc from the center (8 mm on this illustration) along the major axis.

The outer dust lanes lie on the inside of the luminous spiral arms. These arms are thin, moderately well defined, and branched near the ends of the major axis. Note the intricate dust pattern at the south-following (southeast) end of the major axis. There is an even more intricate pattern of straight dust lanes, which has no connection with the spiral structure, on the north-preceding end of the major axis. The parallel streaks can be traced across the central lens and across two branches of the brighter spiral arm on the north-preceding side.

The arms are highly resolved into individual stars and H II regions. The stellar contents of M81 are similar to the contents of M31. Twenty-five normal novae have been found; three variables which are definitely cepheids, fifteen other variables which are probably cepheids, seven irregular blue variables of the type known in M31 and M33, and a number of irregular red variables are known. All these stars are brighter than $M_v = -4.5$. 
This and the two galaxies shown in the panels immediately to the right form an intermediate group between the multiple-arm systems like 2841 and 488 of the Sb and the M101 group of the Sc section. The arms in 6384 are thin and tightly wound about an amorphous nuclear region. There is a distinct bar of enhanced surface brightness crossing the central lens along the major axis of the spiral pattern. NGC 6384 is a transition case to SBb.

NGC 4337  Sb
H-1970-H
Apr. 23/22, 1938
E 40
60 min
Enlarged 8.3 X

The three galaxies shown on this bottom panel form a subgroup of Sb similar to the NGC 253-2903 group of Sc (pp. 34 and 35 of the atlas). The arms are not well separated from each other, and they are difficult to trace. They start at the small compact nucleus. Considerable dust is spread throughout the fundamental plane, and the dust arms define the spiral pattern fully as well as tight luminous arms between the dust lanes.

Notice the tightly wound multiple arms of this galaxy. They are thicker than those of 2841, and the nuclear region is smaller. The arms are highly branched. Each of the arms is of almost uniform surface brightness for about one complete revolution, at which point there is a sharp break in the brightness. Fainter extensions of the arm system can be traced on the outside of the brighter arms. The same phenomenon occurs in many galaxies such as 6384 (left) and 3147 (right).

Although there are two principal arms to this galaxy, much internal spiral structure exists up to the amorphous central region, which is 5 mm in diameter on the scale of the illustration.

This galaxy is similar to 6814. Tightly wound multiple arms are present, which can be traced to within 8 sec of arc (2.5 mm on the illustration) from the small, amorphous nucleus. The details of the structure are not too clear on this reproduction from a poor 60-inch plate. The arms are highly branched. Note the faint-surface-brightness arm on the outside of the bright arm on the north side. Whenever two arm systems of different surface brightness occur, the fainter set is always on the outside.

NGC 4062  Sb
H-2246-H
Mar. 7/8, 1946
103aO
60 min
Enlarged 4.1 X

Dust lanes are very conspicuous in 4062 because of its high inclination to the line of sight. These are multiple spiral arms. The structure closely resembles that of 5055 in its outer regions (p. 15). The nucleus of 4062 is very small, only 2 Hm in diameter on the scale of the illustration. A% in 6384 and 6814, the outer spiral arm* are fainter than those close to the nucleus.
All galaxies on the facing page form a special subgroup, in which the spiral pattern emerges tangent to what appears to be an external ring rather than from the nucleus. The ring in 4750 appears to be completely detached from the central nucleus and lens. It is probably composed of two overlapping spiral fragments wound so tightly as nearly to overlap. A very flint external pattern is present, which is shown, but to poor advantage, by the insert, taken with the 48-inch Schmidt.

A supernova was discovered in 4725 on May 5, 1940, by J. J. Johnson at Palomar (Harv. Ann. Card 522). Two photographs of NGC 4725 which show the supernova appear on the back cover of The Sky, February 1941. The supernova can still be seen on this plate taken by Hubble in January 1941, some 9 months after outburst.

The internal ring resembles the similar feature in 4274 (Sa, p. 12). As in 4274, the ring is probably two overlapping spiral arms which just miss each other after a half revolution. The outer arms are of lower surface brightness than the ring. They either start at the ring or are a continuation of the ends of the arms composing the ring. In this respect also 3705 is similar to 4274.

The thin multiple arms of this galaxy arc complex. The brightest arms in the northwest quadrant appear to approach the nucleus at right angles (tangent rather than spiriting inward). There is a single faint arm in the southwest quadrant which crosses one of the regular arms nearly at right angles. This is a very rare feature of galaxies and is particularly well shown here. A few dust lanes can be seen near the crossover point.
This galaxy is probably of the NGC 210 subgroup of Sb. Two sets of arms are present, the inner set being tightly wound and the outer more loosely wound. At first glance there seems to be only one outer arm, but in the insert photograph a faint and more diffuse arm can just be seen starting near the bright star at the southeast end of the major axis. One conspicuous dust lane is present in the central region, on the inside of one of the inner arms. Although NGC 23 is not a good example of the NGC 210 group of Sb, the characteristic feature of two sets of spiral arms of different pitch is present. A supernova appeared in this galaxy in 1955. It was discovered on a plate taken with the 200-inch on October 22/23, 1955.

This galaxy is seen at a high angle of projection. In form it is almost identical to NGC 210. Prominent dust lanes and spiral structure are present in the bright central lens. These inner spiral arms are tightly wound. The two outer spiral arms start tangent to the inner lens and wind through about 300° before they can be traced no longer. They show partial resolution. The plate from which this reproduction was made was taken under poor seeing conditions.

This galaxy is similar to NGC 1964 and NGC 210. The inner spiral structure and the prominent dust lanes can be seen in the bright central lens on the original plate. There are only two outer arms in this galaxy, but they are considerably thicker than the arms of 210. Each of the outer arms can be traced through about 360°. One arm, coming from the periphery of the lens, approaches close to the inner edge of the other arm after the first arm has turned about 180°. This apparent overlapping of the arms is similar to the pattern in NGC 3185 (p. 43), 4274 (p. 12), and others.
NGC 3627 and the other two galaxies shown on the page contain a great deal of dust. Since dust cannot be detected in galaxies unless it is silhouetted against a bright background, it shows best in galaxies that are highly inclined to the line of sight. Numerous good examples are shown in the atlas, among which we mention 2841 (p. 14), 5055 (p. 15), 3521 (p. 15), 7331 (p. 17), M31 (p. 18), 4594 (p. 24), all the galaxies on page 25, M83 (p. 28), and the nuclei of M51 and M101 (p. 31). The dust pattern in NGC 3627 is particularly heavy. The lane going from the southeast to the northeast quadrant is located on the inner edge of the luminous spiral arm. The lane associated with the opposite arm bisects the luminous matter.

The contrast of the reproduction is high. On the original plate, faint dust lanes are scattered throughout the central lens and between the outer arms and the nuclear regions.

The dust lanes are scattered in an almost chaotic fashion across the face of NGC 972. The image looks almost like an irregular galaxy of the M82 type (p. 41). However, a general spiral pattern can be traced with two sets of dust lanes: the prominent dust arm is in the southeast quadrant; the second arm can be seen partly silhouetted in the northwest quadrant. This galaxy is important to settle the question of the direction of the spiral pattern with respect to the rotation vector. The direction of rotation, however, is unknown.

The dust is scattered chaotically across the face of 4433. It is difficult to trace spiral arms in the inner region shown in the illustration. Note the straight, luminous filament on the west side. Two very faint spiral arms, smooth in texture and of low surface brightness, can be traced outside the main body. They do not show in the illustration.
NGC 4594 is very difficult to classify because the fundamental plane is inclined only 6° to the line of sight. The most prominent feature of the photographic image is the dust lane that defines the fundamental plane. It is significant for the physics of the problem that most or all of the dust in any galaxy is confined to a very thin plane, which undoubtedly is the plane perpendicular to the angular momentum vector. This statement concerning the dust can be made from the observational data in only those galaxies whose fundamental planes are nearly in the line of sight. Other examples of such galaxies are shown on page 25.

A remarkable picture of NGC 4594 was published by Lindblad from a plate taken by Baade in ultraviolet light (Pubs. A. S. JP., 63, 133, 1951). The knots and segments of spiral arms can be seen in this photograph. These knots, together with what appear to be almost circular spiral arms, suggest a face-on spiral pattern like that in NGC 488 or possibly 5055.

Another notable feature of NGC 4594 is the large central nuclear bulge. The tight spiral pattern, which of course is nearly imposible to trace, and the large nuclear bulge place NGC 4594 as either a late Sa or an early Sb. There appears to be a concentration of stars or nebular images in the halo of 4594. These are believed to be globular clusters similar to those found throughout the image of 4846 (M87, p. 2). The number of dust spots in 4594 is far below that in M87. The distance modulus of about m - M = 30.6 for 4594 together with a threshold of about 7 < w < 20 for these images puts the absolute magnitude of the brightest condensation at H < 10.0, which matches the brightest globular clusters in our own galaxy.

NGC4594  M104  Sa/Sb
PH-96-MH
Mar. 16/17, 1950
103a0
30 min
Enlarged 6.6 X

NGC 4594 is a spiral galaxy classified as Sa/Sb. The fundamental plane is inclined only 6° to the line of sight, making it difficult to classify. The most prominent feature of the photographic image is the dust lane that defines the fundamental plane. The dust in any galaxy is confined to a very thin plane, which is perpendicular to the angular momentum vector. This observation is significant for the physics of the problem and applies to galaxies whose fundamental planes are nearly in the line of sight. NGC 4594 is shown in a remarkable picture published by Lindblad in ultraviolet light, revealing knots and segments of spiral arms. Another notable feature is the large central nuclear bulge, which suggests a face-on spiral pattern. The concentration of stars or nebular images in the halo suggests globular clusters similar to those found in other galaxies. The distance modulus of about 30.6 for NGC 4594 places the absolute magnitude of the brightest condensation at H < 10.0, matching the brightest globular clusters in our own galaxy.
All galaxies on the facing page are nearly on edge. The pictures show the change in the nuclear bulge along the sequence of classification and the concentration of the dust to a fundamental plane. Note how flat the central cross section of 4565 is. The nuclear bulge is not so large as that of 4594 but is larger than that of 891. 4594 is an Sa or very early Sb. 4565 is classed as an intermediate Sb, and 891 as a very late Sb. De Vaucouleurs illustrates and discusses 4565, 4216, and others in his article on the direction of tilt (Ap. J., 127, 487, 1958).

NGC 891 Sb
PH-208-S
Nov. 10/11,1952
103aO + WG2
30 min
Enlarged 1.2 X

The nuclear bulge in 891 is smaller than that in 4565. The galaxy is classed as late Sb. The dust lane has a very intricate pattern perpendicular to the plane. Thin fingers of obscuration extend at least 30 sec of arc in the Z-direction. The distance modulus of 891 is about $m - M = 29.0$, assuming membership in the NGC 1023 kinematical group (Humason et al., A. J., 61, 97, 1956, table XI) and a Hubble constant of 75 km/sec 10^6 parsecs. At this distance, 30 sec of arc corresponds to 105 parsecs. Energy must be pumped into the dust to keep it distended this far above the plane against the potential energy of the gravitational field. It is believed that NGC 891 is similar to our own galaxy. See the photograph of the dust band in the plane of our galaxy compared with NGC 891 by Osterbrock and Sharpless (Ap. J., 115,140,1952). See also the infrared photographs of Code and Houck, Ap. J., 121, 533, 1955.

NGC 4631 Sc
PH-208-MH
May 15/16,1950
103aO
30 min
Enlarged 1.0 X

NGC 4631 is probably a late Sc. There is no sign of a nuclear bulge. The entire surface is resolved into stars and H II regions. There are many dust patches but no strong dust lane across the spindle as in 4565 or 891. The small companion galaxy north of 4631 is NGC 4627, an E5 or S0a galaxy with indication of globular clusters surrounding the main body. It is likely that 4627 forms a dynamical unit with 4631 similar to the M32, NGC 205, M31 system. However, no redshift is available for NGC 4627.
NGC 5194 is one of the most magnificent spirals in the sky. The entire spiral pattern is dominated by the dust lanes. The two most opaque dust lanes lie on the inside of the two brightest spiral arms. These two principal arms plus their associated dust lanes wind into the central region along an almost perfect spiral path. The dust arms are very highly branched. Thin filaments break away from the main dust path and cross the luminous arms almost at right angles. Multiple secondary dust lanes exist throughout the central lens. Individual dust lanes of the secondary pattern cannot be traced; but, rather, separate segments exist which, when viewed with other segments, form a rough spiral structure. The two main arms can be traced for one and a half revolutions. Branching occurs from one luminous arm to the other after about three-quarters of a revolution. Each branch continues as a separate arm, giving the spiral the appearance of having a multiple-arm structure. Actually the multiplicity is not like that of 2841 or 488 because, in these, two main arms cannot be traced but the multiple filaments begin immediately at the periphery of the amorphous central lens. The companion galaxy NGC 5195 is an Irr of the M82 type. The dust from the northeast arm of 5194 crosses in front of 5195 on the eastern edge, but there are dust patches internal to 5195 itself on the west side. NGC 5195 closely resembles NGC 3077 (p. 41) and M82. Holmberg has found the international color index of the companion to be 0.98. This is redder than his measures of M82 (CI = 0.81) and 3077 (CI = 0.68), but part of the redness may be due to internal absorption. NGC 5194 is close enough to us to be easily resolved into stars along the spiral arms. Many H II regions are present. No clusters, either globular or open, have been identified with certainty. The distance modulus of these two galaxies must be about \( m - M = 27.5 \), which is slightly more distant than the M81 group.

Negative photographs of NGC 5194/5195 showing the dust lanes in both galaxies to good advantage have been published by Zwicky (Pubs. A. S. P., 67, 232, 1955). Also the characteristics of the two principal luminous arms are well revealed by a superposition trick of negatives taken in different colors. Plate IV of Zwicky's paper shows the intricate dust lanes quite well. The details of the dust lanes in the center of 5194 are of interest. The nuclear regions are shown on page 31 of this atlas.
M101 is the prototype of the multiple-arm galaxies of the Sc section. Although many separate arms exist in the outer regions, each one can be traced from a branching of two principal dust arms which begin in the nucleus. This dust pattern is shown in the illustration of the central region on page 31. As in M51, many dust arms exist in the central lens. They cannot be traced as individual arms but rather as separate segments which, when taken together, form a rough spiral pattern. The entire spiral pattern over the face of M51 is dominated by the dust lanes, which usually are on the inside of the bright luminous spiral filaments. The outer segments of the luminous arms are thoroughly resolved into individual stars and a few H II regions. The outer arms are highly branched. The surface brightness of the arms in the northwest quadrant of the spiral is very low, and the resolved stars in these arms are faint. The brightest arms are in the southwest quadrant. Notice the resolved clumps or associations of stars in the brightest arm on the east side. The most conspicuous of the associations is elliptical, with a major and minor axis of 50 sec and 15 sec of arc, respectively. The distance modulus of M101 is about 27.0, which makes the linear dimensions of the association about 620 parsecs by 190 parsecs. The average width of an arm is about 30 sec of arc, corresponding to 380 parsecs. The largest H II regions are about 10 sec of arc in diameter, which corresponds to 120 parsecs. This is smaller by about a factor of 6 than the 50 Doradus complex in the large Magellanic Cloud and smaller by about a factor of 5 than NGC 424 in M33. SO Doradus is about 40 parsecs in diameter; NGC 654, about 320 parsecs.

Many Sc galaxies are of the M101 type. The characteristics of the type are (1) a small nucleus from which the spiral pattern emerges in dust lanes, at first, and farther out in luminous filaments; (2) multiple spiral arms, thin and highly branched in their outer regions; (3) arms well resolved into individual stars and H II regions.

The integrated color indices of Sc galaxies are instructive. Erik Holmberg has measured magnitudes and colors for a number of galaxies, and his results have direct bearing on the classification problem. Spirals like M101, in which the entire structure is dominated by the spiral arms, have blue colors. M101 itself has an international color index of 0.30. Most of the galaxies on page 29 have colors in the range 0.30 to 0.50. The more open, chaotic spirals like M101 or NGC 628 (p. 29) are bluer than spirals like 4321 (M100, p. 29).
NGC 4321 is the brightest spiral in the Virgo Cluster. The galaxy has characteristics of both NGC 5194 (M51) and NGC 5457 (M101). There are multiple arms, but only two of the arms are bright. The faint secondary arms lie between the principal arms on the east side of the nucleus, completely filling the space between the bright arm closest to the nucleus on the north side and the extension of the second main arm in the northeast quadrant after it has spiraled through 360°. The illustration on the facing page was slightly overexposed to show these faint details. A negative reproduction is given in Ap. J., 127, 513, 1958, which shows not only the outer spiral features but also the details of the multiple dust lanes crossing the central lens.

Two principal dust lanes go into the very center of M100 in a spiral pattern. The center is illustrated on page 3. Most of the knots that appear in the two main spiral arms are H II regions, as can be seen from the reproduction of a plate sensitive to Ha and a second plate sensitive to an emission-free spectral region shown in figure 9 of the Ap. J. reference above.

Individual stars do appear in M100, but they are much fainter than the H II regions. Comparison of the illustration of M100 in the atlas with the negative prints in figure 9 of Ap. J., 127, 513, 1958, which shows not only the outer spiral features but also the details of the multiple dust lanes crossing the central lens.

The estimated distance modulus of M100 is $m - M = 50.7$. Measurement on the original plate shows that, at this distance, the linear width of the two spiral arms are about 40 parsecs—about 3 times the width of arms in M51 and about twice what is estimated for our own galaxy.
NGC 628 is of the M101 type of multiple-arm Sc but is more regular and symmetrical. The arms are not so highly branched, and the dust lanes are easier to trace. Again the dust lanes appear mostly on the inside of the luminous arms. Branching of luminous segments does occur from the two main arms which come from the nuclear region. These branches form the multiple-arm pattern. The distance modulus of NGC 628 is about 30.0. At this distance, the approximate width of the arms is 1000 parsecs.

NGC 1084 Sc
H-2354-H
Nov. 29/30, 1946
10 min
Enlarged 7.1 X

The three galaxies at the bottom of the facing page and the six on page 30 form a separate subgroup of SSc in which the spiral pattern is not so well defined as in the M101 type. The arms are usually not so “clean” and in some galaxies not so well separated from each other as those in the M101 group. The one main arm in the northwest quadrant of 1084 is well defined. It is lined on its inside cd°e with a dust lane. The spiral pattern on the east side of 1084 is not easy to trace as a single arm. Several dust lanes and segments of spiral arms are present. Notice the »»»« Biclets of this galaxy.

NGC 4254 M99 Sc
PH-174-MH
Apr. 16/17, 1950
103aE
30 min
Enlarged 2.8 X

NGC 4254 is one of the bright spiral members of the Virgo Cluster. The distance modulus is about m — M=30.7 for this cluster. At this distance, the spiral arms are about 1500 parsecs thick, which is considerably thicker than arms in M101 and thicker by a factor of 1.5 than arms in NGC 628. Dust lanes pervade the entire central lens. Most of the knots along the spiral arms are H II regions. Note the segments of spiral arms which break from the central regions in the northeast quadrant.

NGC 6181 Sc
H-2267-H
May 4/5, 1946
103aO
45 min
Enlarged 7.0 X

Three well defined outer spiral arms are present in this galaxy: two on the east side, and one on the west side. The arms are thin. The distance modulus for 6181 is about m—M=32.4. At this distance, the angular width of the arms corresponds to about 1200 parsecs. Notice the resolution of the arms into H II regions. The spiral pattern in the central regions is quite similar to that in NGC 157 (right).

NGC 4303 M61 Sc
PH-719-S
Apr. 6/7, 1954
103aO + GG13
30 min
Enlarged 2.2 X

NGC 4303 is probably a member of the Virgo Cluster although it lies about 8° south of the main concentration. The redshift of 1557 km/sec makes it a likely candidate. The galaxy has some characteristics of a barred spiral. The central lens does not show well here but is like the lens in NGC 6951 (p. 46). Two thin dust lanes (width about 150 parsecs) wind out through the pseudo bar to the inside of the beginning of the two main luminous arms. Many faint arms are present on the outside of the two bright ones. The many knots in the brighter arms are undoubtedly H II regions.

NGC 157 Sc
PH-1054-S
Aug. 24/25, 1955
103aO
30 min
Enlarged 9.4 X

The first impression of this galaxy is that the entire surface is covered with luminous segments of spiral arms and interspersed dust lanes. One main dust lane is prominent on the inside of the arm that sweeps from the nucleus upward through the northeast quadrant. The amorphous nuclear region is very small, as in all nine galaxies of this special subgroup (NGC 1084, 6181, and 157 on this page and the six galaxies on the next page).
NGC 3810 Sc
H-15-S
Jan. 5/6, 1951
103aO
20 min
Enlarged 5.0 X

NGC 3810 and NGC 5962 (below) are the Sc counterparts to the "two-region-surface-brightness" galaxies like NGC 5055 and 1068 of the Sb section (pp. 15 and 16). Spiral structure can be traced to within about 3 sec of arc radius (1 mm on the illustration) from the center. The distance modulus of 3810 is about $m - M = 30.4$. Three seconds of arc is 200 parsecs at this distance. The width of the outer arms is about 600 parsecs, which is somewhat smaller than the width in M101 or M51. The arms of 3810 are resolved into knots.

NGC 3672 Sc
H-2220-H
Jan. 6/7, 1946
103aO
60 min
Enlarged 5.0 X

NGC 3672 has multiple arms which begin from a very small nucleus. The nucleus is smaller than the seeing disk on the original negative which was about 1 sec of arc. The arms are very thin and well defined in 3672. If the distance modulus is $m - M = 32.0$, the angular width of 5 sec of arc for the brightest arm sweeping through the northeast to the southeast quadrant corresponds to 370 parsecs. These arc very narrow arms compared with the arms in NGC 4088. They do compare with the arms in NGC 4088.

NGC 4088 SBc/Sc
H-2844-H
Jan. 17/18, 1939
Imp, Eel.
60 min
Enlarged 7.1 X

NGC 4088 has only two arms, which start at the end of a bar. This galaxy is closer to a pure SBc than to an Sc, but as it does have features which resemble NGC 157 (p. 29) it is called a transition case. The bar and arms are of the (s) subtype, in which the arms spring from the ends of a bar rather than tangent to an internal ring. The distance of 4088 is probably 0.1 magnitude closer than the Virgo Cluster. Notice the resolution of the face of this galaxy into knots.

NGC 1637 Sc
PH-68-MH
Mar. 15/16, 1950
103aO
20 min

The inner part of 1637, with a diameter of 22 mm on the illustration, is a completely symmetrical two-arm spiral. A second set of spiral arms, which dominate the east hemisphere, start as dust lanes between the nucleus and the main inner arm on the south side. These outer arms give the galaxy an asymmetry because there are no outer arms on the west side to match them. NGC 1637 is closer to us than the Virgo Cluster. The redshift gives a distance modulus of about 293. The arms of 1637 are resolved into stars and H II regions.

NGC 7314 Sc
PH-65-H
Oct. 13/14, 1950
103aO
30 min
Enlarged 3.0 X

The spiral pattern is dominated by dust lanes in NGC 7314. The arm segments on the west side are quite similar. In the closely coiled arms in NGC 7314, the arm segments on the west side are quite similar. The nucleus of 7314 is very small. Spiral structure can be traced out beyond the very center. The distance modulus is about $m - M = 32.0$. The limit of the plate is about $m = 23$. Consequently any resulted knots in the arms are brighter than $M_v = +9.3$.
The four illustrations on the facing page are greatly enlarged reproductions of the nuclear regions of near-by Sc galaxies. The spiral arms which begin near the center of most galaxies are dust arms. The arms usually do not become luminous until they have left the nucleus. There is no question that the dark regions between the luminous arcs in this picture of M100 are filled with dust. Continuations of these dark lanes form the two principal dust arms which wind out through the lens and end on the insides of the two most luminous outer arms. Page 28 gives the complete view of M100. The continuation of the inner dust lanes shown here as they wind outward is best shown in a negative print in Ap. J. 127, 513, 1958.

The nucleus of M101 is similar to that of M100 (above). Two principal dust lanes cut into the very center. It is the dust rather than the luminous arcs that defines the spiral pattern in this region. The two central dust patches, however, unlike those in M100, cannot be traced as single lanes into the outer regions. The entire inner lens of M101 is crossed by segments of dust arms. Although the segments, taken as a whole, define a spiral pattern, they cannot be connected with one another to form continuous lanes.

The entire face of M101 is shown on page 27.

The central dust lanes in NGC 628 are similar to those in M51 (above). They begin tangent to the central lens and do not go into the very nucleus. These two main lanes wind outward on the inside of the principal luminous spiral arms. The entire galaxy is shown on page 29. Plates taken in Ha light show many H II regions in the arms. The largest of these regions is about 100 parsecs in diameter, which is similar to the H II regions in M101 but smaller than the largest ones in either M33 or the LMC.
The spiral arms of all three galaxies illustrated on the facing page are of the multiple-arm M101 type. The feature that distinguishes all three galaxies is either the presence or the suggestion of an internal ring, tangent to which the spiral arms emerge. The arms in NGC 309 are narrow, well defined, and highly branched. The internal ring is almost complete. The spiral structure does not cross this ring and go into the nucleus. The nucleus itself is small (5 sec of arc in diameter) and amorphous.

Compare these three galaxies with the (r) subtypes in the Sb section (p. 21) and in the SBb section (pp. 47 and 48). The closest example of NGC 309 in the SBc section is NGC 1073 (p. 49).

NGC 1232 Sc
PH-74-H
Oct. 14/15, 1950
103aO
30min
Enlarged 2.0 X

There is no complete internal ring in NGC 1232. However, the arms do not spiral out from the nucleus but rather begin tangent to the central amorphous nucleus and lens. Two principal arms originate on this central region. These arms branch into many segments soon after they leave the central lens. The branching of the arm which starts at the west point of the amorphous lens is particularly conspicuous. The arm branches almost immediately at this junction; each separate branch again divides after a turn of 120°. Additional divisions farther on form the multiple-arm pattern. The pattern resembles that of M101 but is slightly more regular.

NGC 5364 Sc
PH-193-MH
May 13/14, 1950
103aO
30min
Enlarged 5.6 X

NGC 5364 is one of the most regular galaxies in the sky. The thin, bright, internal ring appears to be completely closed. There is spiral structure internal to this ring, but the inner arms starting from the nucleus are not well defined. The regular outer arms begin tangent to the bright ring. Two external arms are present. Their junction on the ring is difficult to find. The outer arm on the west side probably begins on the ring at nearly the west cardinal point. The beginning of the outer arm on the east side is near the north cardinal point. The outer west arm can be traced for about 450° from its origin on the ring. The outer east arm can be traced for 340° or one and a half revolutions from its origin. Dust lanes are not conspicuous over the face of this spiral, but faint lanes can be traced on the insides of the two main arms.

The redshift of NGC 5364 is 1357 km/sec (corrected for solar motion), which corresponds to a distance modulus of about \( m - M = 31.3 \). At this distance, the average angular width of the outer spiral arms corresponds to a linear width of 700 parsecs. This is larger by a factor of about 2 than the arms in NGC 488 and M101 but somewhat smaller than the arms in NGC 4254 (p. 29), for example. The spacing between the center of the outer arms on the west side is about 3300 parsecs.
NGC 5248 Sc
PH-209-MH
May 15/16, 1950
103aO 30 min
Enlarged 5.0 X

This magnificent Sc galaxy shows a high degree of symmetry. The two principal inner spiral arms are of high surface brightness. Both arms contain conspicuous dust lanes on their inner edge. There is considerable dust silhouetted against the central lens. It forms multiple spiral lanes starting near the small nuclear region.

Five outer spiral arms of low surface brightness open wide from the central regions. They can be seen in the insert. The outer arms are branched. Two of the five hug the bright central region on the west side; they are stubby arms, of higher surface brightness than the remaining three. Two other of the outer arms start from the end of the bright inner arm at the northwest end of the major axis and can be traced for about 180° from the junction. The remaining outer arm begins at the southeast end of the major axis and spirals north through west. It is branched at its northwest end.

NGC 4258 Sb
PH-321-MH
Apr. 27/28, 1951
103aO 30 min
Enlarged 5.5 X

NGC 4258 is probably a member of the Ursa Major Cloud. The fact that the plane of this galaxy is inclined only 20° to the line of sight partly explains why the dust lanes are so prominent across the central lens of 4258. These lanes are quite chaotic. They do form a very rough spiral pattern throughout the central region. There are two principal luminous arms on the periphery of the bright central lens. Numerous knots, presumably H II regions, are present in these arms. Very faint spiral arms threading through the outer envelope can be seen in the insert. The outer arms are highly resolved into individual stars with the 200-inch. Normal novae have been found, but as yet no cepheid variables are known in 4258. A reproduction of 4258 in negative form, given by Hubble in Ap. J., 57, 225, 1943, shows the intricate detail of the dust pattern in the central region.
This spectacular spiral is the prototype example of a special subgroup of Sc systems. Other members of the group are shown on the next page. Photographic images of galaxies of the group are dominated by the dust pattern. Dust lanes and patches of great complexity are scattered throughout the surface. Spiral arms are often difficult to trace. The arms are defined as much by the dust as by the luminous matter.

Galaxies similar to the 253 class in the Sc can be identified in the Sa and Sb sections. Examples shown in the atlas are NGC 4293 of the Sa section (p. 11) and perhaps NGC 972 and NGC 4433 of the Sb section (p. 23). The dust lanes in NGC 253 itself are conspicuous not only because a great deal of dust is present but also because the large angle of projection under which this galaxy is viewed provides for a radiation background against which the dust is seen. The fundamental plane of 253 is inclined only 12° to the line of sight.

The spiral arms in NGC 253 can be easily traced in this reproduction, but they are more easily seen in a negative print reproduced from the same original and shown by de Vaucouleurs in Ap. J., 127, 487, 1958, figure 8. The arms coming from the southwest end of the major axis are opening out of the page; the arms on the northeast end are going into the page.

The distance to NGC 253 cannot be found from the redshift because the galaxy is so close that any systematic redshift is concealed by the random motions. But the assumption that NGC 253 is like M31 both in linear dimensions and in absolute magnitude gives a distance of about $4 \times 10^5$ parsecs, which is about 5 times that of M31. The corresponding distance modulus is $m - M = 28.0$. These values may be uncertain by a factor of 2.
The internal pattern of dust is almost as intricate in NGC 2903 as it is in NGC 253. The galaxy is seen more nearly face on, and is more distant than 253, so that the delicate dust filaments threading across luminous regions are lost in 2903, but there is no question that these patterns are present. The nucleus is composed of about eight intense knots, presumed to be giant H II regions. The reproduction is overexposed in the central regions and does not do justice to the intricate pattern. Two thin, regular spiral arms are present in the outer regions of 2903.

The spiral pattern is easier to trace in 6643 than in 253. The arms are visible on this plate, owing primarily to the knots (probably H II regions) present over the face of the system. The central nucleus is exceedingly tiny here. The spiral arms are multiple. The internal dust pattern resembles that in 2903 and 253.

NGC 3556 is a member of the 253 class. It is seen almost on edge. A negative print, made from the same original, is shown by de Vaucouleurs in Ap. J., 127, 487, 1958.

Note the lack of a central nuclear bulge. If a large nuclear region were present it would be visible in this photograph because the galaxy is nearly on edge. Compare this illustration with the Sc systems on page 25.

Many condensations are present over the face of NGC 4793. These, together with a small nucleus and internal dust, put NGC 4793 in the 253 class. The condensations are probably H II regions.

The pattern of NGC 253 and 3556 is repeated in this galaxy. Notice the very small nucleus and the ill-defined spiral arms.

NGC 1087 has an extremely small nucleus. There is a multiple spiral structure defined more by the dust lanes than by luminous matter.
NGC 598 (M33) is the nearest Sc to our own galaxy. It is a member of the Local Group. The distance modulus is probably close to $m-M = 24.5$ (Sandage, Ap. J., 127, 513, 1958). The limiting magnitude of the 200-inch is about $m_p = 23.0$. This means that the stellar content of M33 can be studied in detail down to stars of absolute magnitude $M_p = -1.5$. Bright O and B stars, cepheid variables, globular and open star clusters, novae, irregular variables, and H II regions are known in M33. The first extensive study of the stellar content was made by Hubble in 1926 (Ap. J., 63, 236, 1926). No comparable study has been made in recent times.

Spiral structure is easy to trace in M33. The arms are "massive" in the sense used by Reynolds and by Hubble (Observatory, 50, 1927). The arms are completely resolved into bright stars. Most of these are blue supergiants, but there are also at least 3000 red supergiants of $M_y = -5$ which are similar to those found in h and x Persei. The brightest H II region is NGC 604, in the northeast quadrant. This has a linear diameter of about 320 parsecs. Many smaller H II regions abound in the spiral arms. Detailed, large-scale photographs of parts of M33 are given as negative prints in Ap. J., 127, 513, 1958. The integrated color index of the system is CI (International) = 0.40 (Holmberg).

NGC 2403 is similar in form and in stellar content to M33. It is a member of the M81 group. The distance modulus is about $m - M = 27.1$ (A. J. 59, 180, 1954). This is the first galaxy beyond the Local Group in which cepheid variable stars were found with the 200-inch. Twenty-seven variables have been isolated so far (1960). Ten of them are definitely cepheids with periods ranging from 18 to 54 days. Many of the others are undoubtedly cepheids, but periods are not yet available. No novae have been found in NGC 2403. The comparison of the number of novae found in M81 (Sb) and in NGC 2403 (Sc) shows that the same disparity exists as between M31 and M33, and probably indicates that novae are very infrequent in Sc galaxies as compared with Sb.

Over 100 H II regions, many of them irregular in shape, are known in 2403. The largest of the regions measures 20 sec of arc in diameter, which corresponds to 270 parsecs at the assumed distance. This diameter is a bit smaller than that of NGC 604 in M33 and considerably smaller (by a factor of 2.3) than 30 Doradus in the LMC. NGC 2403 and other members of the M81 group are important for the calibration of the extragalactic distance scale.
NGC 925
Sc/SBc
PH-71-S
Dec. 26/27,1951
103aO + WG2
15 min
Enlarged 2.5 X

The four galaxies shown on the facing page are very late Sc. Some authors, including Shapley, have called galaxies of this type Sd. All four systems have rather low surface brightness, have spiral arms which are sometimes difficult to trace, and are highly resolved into stars and H II regions. NGC 925 is a member of a group of galaxies with NGC 1023, 891, 1058, 1003, and IC 239 as members. The mean redshift of this group is about 500 km/sec. The distance modulus corresponding to this redshift is $m-M = 29.0$. There are many H II regions in the arms of 925, the largest of which has an angular diameter of about 5 sec of arc, corresponding to 170 parsecs at the assumed distance.

NGC 45
Sc
PH-116-H
Sept. 24/25,1951
103aO
25 min
Enlarged 2.0 X

NGC 45 has one of the lowest surface brightnesses of any galaxy in the sky. This reproduction has been double-printed from the original 200-inch negative to increase the contrast. The entire face of NGC 45 is covered with resolved stars. There must be very little internal absorption due to dust because many background galaxies can be seen through the main body of NGC 45. This galaxy is a member of a group of near-by systems of large angular diameter which includes NGC 24, 45, 53, 247, 300, and 7793. This is probably the nearest group of galaxies to the Local Group, but it is too far south for adequate work from the northern hemisphere.

NGC 4395, 4399, 4400, 4401
Sc/Irr
S-330-P
Mar. 28/29,1919
S23
4 hr 30 min
Enlarged 3.5 X

This galaxy is so loose and disconnected that visual observers counted each of four of the brighter patches as individual nebulae and catalogued them as separate objects in the New General Catalogue. The surface brightness is so low, and the plate so underexposed, that this reproduction has been double-printed; i.e., a copy negative was made from the original plate, and the print on photographic paper was made from the copy negative. This process increases the contrast. Note the extreme resolution into stars. Spiral arms can be traced, but the general pattern resembles that of the Large Magellanic Cloud.

NGC 5204
Sc/Irr
PH-1170-S
Dec. 14/15,1955
103aO
25 min
Enlarged 6.2 X

Notice that the entire face of NGC 5204 is resolved into stars. It is difficult to trace any spiral pattern in this system. This is a transition case between a very late Sc and an Irr system of the Magellanic Cloud type. NGC 5204 is a member of the M101 group and therefore must have about the same modulus as M101 itself, which is estimated to be $m-M = 27.0$. The limiting magnitude of this plate is about 77.5 = 22.5. Therefore, all resolved stars visible in this illustration are brighter than $M_{pg}=-4.5$. E. Holmberg has studied the integrated properties of NGC 5204, and his paper should be consulted for details (Medd. Lunds Astr. Obs. ser. II, no. 117).
This is the Large Magellanic Cloud. The plate was taken by Dr. Karl Henize with the Mount Wilson 10-inch refractor in the light of Ha. Although the form of this galaxy suggests the lack of rotational symmetry, it is known from the 21-cm radiation of neutral hydrogen (Kerr, Hindman, and Robinson, interpreted by Kerr and de Vaucouleurs (Astroph. J., 8, 508, 1956)) that the LMC is rotating. De Vaucouleurs believes that the LMC has a flattened equatorial plane inclined at $65^\circ \pm 5^\circ$ to the line of sight (Astroph. J., 60, 126, 1955). He also believes that a very faint spiral pattern can be traced over the face of the cloud, but the degree of spiral structure is certainly of a different order from that in galaxies classed as Sa, Sb, and Sc. The idea that this and the Small Magellanic Cloud may be highly flattened systems is interesting because it suggests that irregular galaxies are not so disorganized as first inspection of photographs indicates.

The LMC contains many H II regions, open star clusters, globular star clusters, and cepheid variable stars. It and the Small Cloud are the most important single galaxies in the sky, because they are the systems where the tie-in of the absolute magnitudes of cepheids with normal stars must be made. The distance modulus for both clouds is about $m-M = 19.2$. They are 10 times closer to us than M31.


The largest H II region in the LMC is 30 Doradus. It is a complex region containing overlapping Strömgren spheres. Henize gives the dimensions of the nebulosity as 1849 sec by 1781 sec of arc. At a distance modulus of $m-M \sim 19.2$, these angles correspond to 640 parsecs by 615 parsecs. These dimensions are of the same order (a factor of 2 larger) as those of NGC 604 but are much larger than the Orion Nebula and other large Ha complexes that have so far been recognized in our own galaxy.
This galaxy is highly resolved into stars and H II regions. Slight suggestions of a chaotic spiral structure might be made, but the pattern, if present, is very weak.

NGC 2366 Irr I
PH-555-B
Oct. 31/Nov. 1, 1951
103aO + GG1
30 min
Enlarged 2.2X

This galaxy is a member of the M81 group. Note the two separate parts to this galaxy. Several bright H II regions are visible, the two most conspicuous being located together at the southwest end of the larger part. The smaller satellite segment also contains H II regions. All stars resolved in 2566 are brighter than $T_{r} = -4.1$. Most of the resolved stars are blue.

NGC 3109 Irr I
S-524-B
Mar. 6/7, 1937
Imp. Eel.
100 min
Enlarged 4.1X

This galaxy may be a greatly flattened system seen nearly on edge. No spectroscopic measurements for rotation have been published. The face of the galaxy is resolved completely into stars, H II regions, and stellar associations. This reproduction is from a copy negative because the original plate could not be found. There is considerable plate grain caused by the recopying process.

IC 2574 Irr I
PH-706-S
Feb. 28/Mar. 1, 1954
103aO + WG2
30 min
Enlarged 1.6X

This galaxy, sometimes called Coddington's nebula, is a member of the M81 group. Note how most of the H II regions are concentrated at the north end of the "bar." The brightest resolved stars also occur in this region. This giant association is about 1500 parsecs along the major axis (which is almost in the east-west direction). All stars resolved in this reproduction are brighter than $M_{V} = -4.1$.

Ho II Irr I
PH-48-S
Nov. 29/30, 1951
103aO + WG2
30 min
Enlarged 2.0X

This is one of the members of the M81 group. It was discovered by E. Holmberg during his study of the M81 group (Medd. Lund Obs., ser. II, 128, 1950). Its membership in the M81 group was proved by N. U. Mayall's redshift determination (A.J., 61, 97, 1956). The distance modulus of the M81 group is about $m - M = 27.1$. The limiting magnitude of the plate from which this reproduction is taken is about $m_{V} = 23.0$. Hence all resolved stars shown over the face of Ho II are brighter than $M_{V} = -4.1$.

Sextans System Irr I
PH-90-MH
Mar. 15/16, 1950
103aO
20 min
Enlarged 2.6X

The Sextans System is probably an outlying member of the Local Group (see Humason and Wahlquist, A.J., 60, 254, 1955). The distance modulus is probably 25.0. Note the almost rectangular pattern of the resolved stars. The diameter of the concentration of bright stars near the last corner of the pattern is about 200 parsecs.
This is a well known member of the Local Group. Many cepheid variables have been discovered by Baade in IC 1613. The distance modulus is about 24.0. Note the concentration of the brightest stars into one corner of the galaxy. This grouping into large associations is a common feature of Irr galaxies of the Magellanic Cloud type.

NGC 4449  
H-520-H  
Jan. 21/22, 1925  
E40  
105 min  
Enlarged 4.0 X

There are many H II regions in this galaxy, concentrated mostly in the northern part where many knots appear in this illustration. Dust patches are scattered through the central regions. One is particularly well shown on the eastern boundary of the galaxy.

NGC 4656/7  
S-457-H  
Mar. 18/19, 1925  
E40  
110 min  
Enlarged 4.0 X

This peculiar irregular is very asymmetric in its surface brightness. The galaxy on one side of the nucleus is bright; on the opposite side, it is very faint. There are two segments on the faint side. The galaxy is well resolved into stars and H II regions.

Dwarf, 1023 Gr., No. 1  
Irr I/Sc  
PH-337-S  
Jan. 18/19, 1953  
103aO + WG2  
20 min  
Enlarged 4.0 X

Dwarf, 1023 Gr., No. III  
Irr I/Sc  
PH-308-S  
Jan. 8/9, 1953  
103aO + WG2  
30 min  
Enlarged 4.1 X

It is probable that most of the eight are dwarf members of the 1023 group, because a search of a similar area of the sky on adjacent Schmidt plates failed to show any objects of this type. These two reproductions were made from copy negatives; i.e., the original plates have been copied and then printed to increase the contrast.

There may be some suggestion of spiral structure in both 1023, Dwarf I, and 1023, Dwarf III, but it is certainly not well marked. Consequently these two dwarf galaxies are classified with the Irregulars.
NGC 3034 M82 Irrll
PH-51-S
Nov. 29/30, 1951
103aO + WG2
30 min
Enlarged 3.0 X
M82 is the prototype of the irregular galaxies of the second type. Note the extremely filamentary wisps at the boundary of the galaxy. There is no suggestion of resolution into stars or knots, although the distance of M82 is about the same as that of M81 (p. 19).

NGC 3034 M82 Irrll
PH-52-S
Nov. 29/30, 1951
103aO + WG2
5 min
Enlarged 3.0 X
There is much dust across the face of M82. This illustration and the one below are from short-exposure plates. The integrated properties of M82 seem contradictory. The color index of the system as a whole is CI = 0.86 (Stebbins and Whitford, Ap. J., 115, 284, 1952). This color, plus the amorphous texture of the luminous regions, suggests a stellar content like that of elliptical galaxies or the center of Sb galaxies. But the integrated spectral type of M82 is A5 (Humason, A. J., 67, 97, 1956). These features are not understood at present.

NGC 520 Irrll
PH-176-H
Sept. 3/4, 1953
103aD + GG11
40 min
Enlarged 4.0 X
NGC 520 has the smooth texture of M82 and has a prominent absorption patch crossing the face. Thin extensions, of low surface brightness, are visible in this illustration. Inspection of the original plate suggests that NGC 520 is not a collision of two galaxies but rather a system of the M82 type.

NGC 3077 Irr II
PH-896-S
Jan. 23/24, 1955
103aD + GG11
30 min
Enlarged 4.0 X
This is a member of the M81 dynamical group. The texture of the luminous regions and of the absorption patches silhouetted against them is similar to that of M82. Another galaxy with this same pattern is NGC 5195 (the companion to M51 shown on p. 26). Probably NGC 4691 (shown on p. 44) is also of this type.

NGC 3034 M82 Irrll
PH-214-S
Nov. 10/11, 1952
103aD + GG11
30 min
Enlarged 4.0 X
This is a member of the M81 dynamical group. The texture of the luminous regions and of the absorption patches silhouetted against them is similar to that of M82. Another galaxy with this same pattern is NGC 5195 (the companion to M51 shown on p. 26). Probably NGC 4691 (shown on p. 44) is also of this type.
NGC 4262 SBO
PH-905-S
Mar. 24/25, 1955
103aD + GG11
45 min
Enlarged 7.1 X

The bar has bright ansae which terminate inside the apparent boundary of the lens. The ansae are not completely separate from the rest of the bar, as in NGC 2859 (right). Because of this, the galaxy is a transition case between an SB0 and SBO type.

NGC 2859 SB0
PH-852-S
Nov. 2/3, 1954
103aO
30 min
Enlarged 7.1 X

This is the type example of the SB0. The bar is fuzzy and indistinct. There is a brightening of the rim of the lens at two opposite ends. There are no sharp boundaries anywhere. The bar makes an angle of 15° to the minor axis of the envelope and of the outer ring. The external ring appears to be completely detached and unbroken. Its boundaries are very indistinct, but the inner edge is sharper than the outer.

NGC 4612 SBO
PH-687-S
Feb. 9/10, 1954
103aO + WG2
30 min
Enlarged 2.2 X

This is a particularly good example of an SBO galaxy, but the features of the bar are so tenuous that very little shows in the illustration. The pencil drawing below shows the major features. The axis of the bar is inclined about 15° to the minor axis of the lens and of the external ring. This ring is extremely faint and does not show at all in the photograph; its position relative to four of the stars can be found from the diagram.

NGC 4643 SB0/3 SBa(r)
PH-688-S
Feb. 9/10, 1955
103aO + WG2
30 min
Enlarged 3.5 X

The nucleus, lens, bar, and inner envelope of this galaxy are of the SB0 type. There is very faint but definite spiral structure outside the inner envelope, however. There appears to be a circular dust ring which makes a complete revolution touching the ends of the bar. The thin spiral pattern outside the dust ring winds outward through a tenuous outer envelope. A few knots in the spiral arms show the beginning of resolution into what are probably H II regions.

NGC 5101 SB0/SBa(s)
PH-906-S
Mar. 24/25, 1955
103aD + GG11
45 min
Enlarged 4.5 X

The inside lens is "broken" at both ends of the bar. A very faint arm structure begins at the ends of the bar. This pattern is not circular as in NGC 2859 but is broken into a rudimentary spiral pattern shown in the insert. This galaxy would be called SB0g on poor or small-scale plates, but this reproduction from a 200-inch plate indicates an exceedingly early SBa(s).
Note the well developed bar (of the SBOs type) which ends on the rim of the tenuous lens. The arms begin at diametrically opposite points on the rim of the lens about 15° counterclockwise from the termination of the bar. These arm connections are of extremely low surface brightness and are difficult to trace. The connections are nearly tangent to the lens, move straight for about 10 mm (on the illustration), and then turn sharply through 90° and begin the nearly circular arm pattern, which looks at first glance like a complete ring.

The arms do not form a complete ring but lap over each other near their junction after each arm has spiraled through 180°. The pattern is similar to that of the arms in NGC 3185 but is more difficult to trace because of projection effects.

The arms are of very soft and smooth texture. This is the SBA prototype of the (s) subgroup. It resembles NGC 1300 of the SBB(s) sequence. There is no suggestion of dust lanes or absorption patches across the face of this galaxy. On the 200-inch plate there is a hint of a very low-surface-brightness outer elliptical ring concentric with the nucleus with a semimajor diameter of 2 min (65 mm on the illustration).

This galaxy is a very late SBA(s). The arms are tightly wound and form a nearly complete ring as in NGC 3185 (below) and NGC 2217 (left). The arms show limited resolution into knots. They tend to branch into soft filaments which are not tightly wound.

The bar is well developed and of the SBOs type.
This galaxy is peculiar because of the internal structure in the bar. The complete spiral pattern at the center of the bar is not connected in any way with the external arms seen in the negative reproduction on the right. The bar itself is of smooth texture. A few dust patches are superimposed upon the bar. The direction of opening of the two internal spiral arms is the same as that of the very faint external arms shown on the right.

Hubble classified this galaxy as an Sb pec because, on short-exposure plates, the external structures (shown in the insert) looked like spiral arms and the central structure looked like a bona fide bar of a barred spiral. It was evident that the bar had much internal obscuration. This 200-inch plate shows that the external structures are really not arms but complete arcs of luminous matter.

The smooth external arms of low surface brightness and the prominent amorphous bar place this galaxy in the Sb pec class. Note the elliptical lens. The bar terminates on the edge of the lens. The two thin, almost circular spiral arms spring from the ends of the bar. They can be traced for only about 130° before their surface brightness becomes so low that they are lost in the night sky background.
NGC 1300 is the prototype of the pure SBb(s). The bar is distinct and smooth in texture. Two straight dust lanes emerging on opposite sides of the nucleus can be traced to the ends of the bar, where they turn sharply and follow the insides of the spiral arms. The arms form nearly complete ellipses. The foci of each ellipse are the nucleus and the end of the bar of the opposite arm. Each arm can be traced through about 340°.
NGC 5383

No. 195 (60")

Apr. 3/4, 1913

3 hr

Enlarged 14.6 X

Note the two nearly straight dust lanes threading into the bright central region. The lane coming from the lower left appears to cross in front of the nucleus; that coming from the upper right passes behind the nucleus.

NGC 1097

H-2025-H

Oct. 21/22, 1938

Agfa Blue + GG1

90 min

Enlarged 3.9 X

There is a reproduction of NGC 1097 in Observatory^ 78* 125, 1938, by J. L. Stimson which shows the complex nuclear structure. The two straight dust lanes, seen on the face of the broad bar, spiral toward a central point as they reach the bright, overexposed part of the reproduction. This is similar to the pattern near the center of M33 (p. 44) and resembles somewhat that of NGC 4314 (p. 44).

NGC 931

PH-1U-H

Sept. 24/25, 1941

W1

KUaO

10 min

Enlarged 5.0 X

This galaxy, which has features of both SBB and Sb systems, is a transition between these two "pure" spiral types. The two straight dust lanes are prominent. Its bar is tilted 23 degr and is similar to NGC 1097 (above).
This is the type example of the SBb(r). Note how the spiral arms start tangent to an external "ring." The ring is not complete but is composed of nearly circular spiral segments. The faint external arms are difficult to trace as continuous bands. They tend to break into segments. Neglecting the slight discontinuities, the two principal arms can be traced for about one and a quarter revolutions from their origin on the internal "ring."

There are no straight absorption lanes in the bar, as is characteristic of the NGC 1300 type of SBb.
The four illustrations on the facing page show the progressive development of the ringed form along the SBb(r) section. NGC 2523 is the earliest of the four. Note the thin annulus and the nearly complete circular ring. The major axis of the ring and of the spiral pattern is inclined about 6° to the junction of the bar with the ring. In general, barred spirals seen in projection have a random orientation of the position angle of the bar with the major axis of the ring.

NGC 3351 M87
PH-315-S
Jan. 5/6, 1953
103aO + 30 in
Enlarged 6.0X

This is the broken-ring type similar to M83 SBb(r) or 2217 SBa (p. 47). The broken ring forms from the ends of the bar and spiral arms. This peculiarity of forming the broken ring seems to be more common in barred spirals. The broken ring begins at the end of the bar and can be traced for about one and a quarter turns.

NGC 4595
PH-929-S
Mar. 28/29, 1955
103aO + WG2
30 in
Enlarged 4.0X

The internal circular ring is nearly complete but it is of nonuniform brightness around the periphery. The spiral arm begins at the end of the bar. The other begins about 1 h" around the ring (counted counterclockwise) and can be traced for nearly one and a quarter turns.

NGC 4549
PH-914-S
Mar. 26/27, 1935
103aO
Enlarged 3fX

This is the broken-ring type similar to M83 SBa(r) or 2217 SBa (p. 47). The broken ring begins at the end of the bar and spiral arms. This peculiarity of forming the broken ring seems to be more common in barred spirals. The broken ring begins at the end of the bar and can be traced for about one and a quarter turns.

NGC 2523 SBb(r)
PH-850-S
Nov. 2/3, 1954
103aO
30 in
Enlarged 6.0X

The major axis of the ring and of the spiral pattern is inclined about 6° to the junction of the bar with the ring. In general, barred spirals seen in projection have a random orientation of the position angle of the bar with the major axis of the ring.

NGC 3351 M87 SBb(r)
PH-315-S
Jan. 5/6, 1953
103aO + 30 in
Enlarged 6.0X

This is the broken-ring type similar to M83 SBb(r) or 2217 SBa (p. 47). The broken ring forms from the ends of the bar and spiral arms. This peculiarity of forming the broken ring seems to be more common in barred spirals. The broken ring begins at the end of the bar and can be traced for about one and a quarter turns.

NGC 4595 SBb(r)
PH-929-S
Mar. 28/29, 1955
103aO + WG2
30 in
Enlarged 4.0X

The internal circular ring is nearly complete but it is of nonuniform brightness around the periphery. The spiral arm begins at the end of the bar. The other begins about 1 h" around the ring (counted counterclockwise) and can be traced for nearly one and a quarter turns.

NGC 4549 SBb(r)
PH-914-S
Mar. 26/27, 1935
103aO
Enlarged 3fX

The internal circular ring is nearly complete but it is of nonuniform brightness around the periphery. The spiral arm begins at the end of the bar. The other begins about 1 h" around the ring (counted counterclockwise) and can be traced for nearly one and a quarter turns.

NGC 2523 SBb(r)
PH-850-S
Nov. 2/3, 1954
103aO
30 in
Enlarged 6.0X

The major axis of the ring and of the spiral pattern is inclined about 6° to the junction of the bar with the ring. In general, barred spirals seen in projection have a random orientation of the position angle of the bar with the major axis of the ring.

NGC 3351 M87 SBb(r)
PH-315-S
Jan. 5/6, 1953
103aO + 30 in
Enlarged 6.0X

This is the broken-ring type similar to M83 SBb(r) or 2217 SBa (p. 47). The broken ring forms from the ends of the bar and spiral arms. This peculiarity of forming the broken ring seems to be more common in barred spirals. The broken ring begins at the end of the bar and can be traced for about one and a quarter turns.
NGC3367  SbC(sr)
H-2268-H
May 4/5,1946
103aO
30min
Enlarged 8.1 X

This is basically of the 1300 type, but the arms almost coalesce to form an internal ring. The arm starting at the northeast end of the bar winds through about 200° and then branches. The arm coming from the southwest end of the bar is not well defined at its beginning. It branches for the first time after about a 90° turn. Other branching takes place after about 340°. The arm can be traced through a turn of about 400°.

NGC7741  SbC(s)
PH-66-H
Oct. 13/14,1950
103aO
30min
Enlarged 4.1 X

The bar is resolved almost completely into knots. There are dust patches in the bar but no straight lanes as in the NGC 1300 type of SBB. Note the dust lanes on the inside of the spiral arms.

NGC 1073  SbC(sr)
PH-82-H
Nov. 11/12,1950
103aO
30min
Enlarged 2.5 X

The arms do not begin from the ends of the bar but rather about 30° from the bar’s termination. There is no complete circular ring. The arms and the bar are resolved into many knots. There are no straight absorption lanes in the bar.

NGC 2525  SbC(s)
H-2477-H
Jan. 9/10,1948
103aO
30min
Enlarged 6.5 X

This and NGC 7741 are the SbC prototypes of the (s) subgroup. This galaxy is an early SbC. The bar, though not resolved into knots, is not as smooth textured as the bar in NGC 1300; the nucleus at the center is small and has a high surface brightness. The arms are resolved into knots.

NGC 3359  SbC(rs)
PH-55-H
Apr. 27/28,1949
103aO
30min
Enlarged 3.0 X

This is of the broken-ring type. There is a high degree of resolution of both the bar and the arms into knots. This galaxy was illustrated by Hubble in his article showing the first pictures from the 200-inch, *Pubs. A. S. P.*, 61, 121, 1949.

NGC 7640  SbC (s)
PH-115-H
Sept. 24/25,1951
103aO
30min
Enlarged 1.2 X

This galaxy is nearly on edge, but there is little doubt that it is an SbC of the (s) subgroup. The two spiral arms make a sharp angle at the ends of the bar, one arm sweeping behind the bar, the other sweeping nearly in front of it. The arms are resolved into stars.
NGC 5128 is one of the most peculiar objects in the sky. The background resembles that of an EO galaxy, but the wide and highly opaque absorption lane across the center is unique. The lane is much wider and more chaotic than lanes in Sb and Sc galaxies seen on edge. For this aspect, compare 5128 with NGC 4594 (p. 24) or any of the galaxies on page 25.

NGC 5128 is a source of intense radio emission. Observations by Mills show that the strongest emission originates in the absorption band. Baade and Minkowski have published negative prints of NGC 5128 which illustrate both the position of the strong radio source and the features of the dust lane. Bolton, Westfold, Stanley, and Slee (Aust. J. Phys., 7, 96, 1954) found that, in addition to the strong radio radiation of the dust lane, a weaker radiation comes from a nearly circular area 2° in diameter centered on 5128. This area is larger than that in which the optical radiation has yet been traced. The most recent summary of the radio work on NGC 5128 is given by C. A. Shain in the volume of the Paris Symposium on Radio Astronomy, 1958.

Baade and Minkowski believe that NGC 5128 is two galaxies in collision. The geometry of the situation is not completely clear. Several points in the interpretation help in the interpretation. The background luminosity of that part of the image on the northwest side of the absorption lane is smooth, with no dust patches superposed. The surface on the opposite side of the dust lane is covered with a patchy pattern of obscuration. This pattern could be reproduced if the dust were in a thin plane of an Sb or Sc galaxy like NGC 253 (p. 31, for example). If this plane were tipped about 20° to the line of sight with the rotational axis coming out of the paper, the observer would see part of this plane superposed on the background of the EO galaxy but only on the upper half. The lower half of the EO galaxy would be completely free of the image of the Sb and would therefore show no absorption patches. If the background EO galaxy were removed we might expect to see an image somewhat like that of NGC 7331 (p. 17) or possibly NGC 4216 (p. 25) at a slightly greater angle. The absorption lane across 5128 is very wide and does not resemble that in 7331. There may be two reasons for this. The first is a geometrical one, the second dynamical. (1) If we really see a dusty Sb or Sc superposed on an EO, the dust lanes are not expected to look like those of a normal galaxy such as 7331 because there is an intense background radiation field (the EO) upon which the dust of the Sb or Sc can be silhouetted. Any dust present will be much more conspicuous than normally. (2) If an actual collision is taking place, some of the kinetic energy of the center of mass of the galaxies may be transferred to the contents of the galaxies, in particular to the gas and dust. If part of the energy is pumped into the dust layer, this layer will become more distorted against the gravitational potential due to the galaxy as a whole and the lane will appear to be wider and more disorganized than in normal Sb or Sc systems.

J. L. Seyfick has obtained isophotal contours of NGC 5128. He describes the appearance of the image and gives absorption data in Observatory, 78, 24, 1958. He states that "the central region of the band (dark lane), which is more conspicuous in the red light, presents a complex structure formed of chains of condensations—probably chains of high-luminosity O-B stars—separated by lanes of obscuring matter."

50