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A NEW CLASSIFICATION SYSTEM FOR GALAXIES*

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ABSTRACT

1) A new galaxy classification system is proposed in which normal spirals and lenticulars form parallel sequences within which "early" and "late" systems are distinguished by means of their disk-to-bulge ratios.

2) A sequence of "anemic spirals," which occur most frequently in rich clusters, is found to have characteristics that are intermediate between those of vigorous gas-rich normal spirals and gas-poor systems of type S0.

3) The differences between normal spirals (Sa-Sb-Sc), anemic spirals (Aa–Ab–Ac), and lenticulars (S0a–S0b–S0c) are tentatively interpreted in terms of the influence of environment on the evolution of flattened galaxies.

Subject heading: galaxies: structure

I. WHY A NEW CLASSIFICATION SYSTEM IS NEEDED

Current thinking on galaxy classification has its roots in the classical paper of Hubble (1926). Much of the simple beauty of the classification scheme proposed in that paper was lost when Hubble (1936) introduced a more or less hypothetical transitional stage, which he called type S0, *between* elliptical and spiral galaxies. The subsequent evolution of this S0 classification type in the hands of Hubble and Sandage is described in *The Hubble Atlas of Galaxies* (Sandage 1961).

In attempting to apply the Hubble-Sandage system to the classification of galaxies I have, for many years, had the feeling that some types of galaxies do not fit naturally into the framework provided by this scheme. The main problem areas appear to be the following:

a) *Lenticulars*

The classification sequence from $S0_1$ to $S0_3$ (Sandage 1961) is not a sequence of increasing flattening. The $S0_1$ galaxy NGC 4762 (*Hubble Atlas*, p. 8) is one of the flattest edge-on galaxies known. A counterexample is provided by NGC 5866 (*Hubble Atlas*, p. 6) which is an edge-on system of type $S0_3$ which, in the absence of a thin absorption lane, would have been classified E5 or E6.

b) *Galaxies of type Sa*

The classification type Sa has become a repository for galaxies with very different physical characteristics. On the one hand this class comprises objects similar to NGC 1302 (*Hubble Atlas*, p. 9), which have quite large nuclear bulges, and on the other it contains galaxies such as NGC 4866 (*Hubble Atlas*, p. 11) which have a very small nuclear bulge. The only feature common to all of these diverse types of objects is that star formation is not proceeding very vigorously.

c) *Effects of Luminosity*

The Hubble (1936) classification system for spirals was defined in terms of supergiant galaxies. This bias of the Hubble system has, to some extent, been overcome by van den Bergh (1960*a*, *b*, *c*), who extended the original Hubble classification scheme to include the effects of differing galaxy luminosity.

d) *Effects of the Cluster Environment*

The large homogeneous sample of galaxy photographs provided by the glass copies of *The Palomar Sky Survey* has made it clear that the appearance of many galaxies in rich clusters differs from that of field galaxies of similar Hubble type. No account is taken of such differences in any of the major galaxy classification schemes that are presently in use.

II. PROPOSED REVISION OF THE HUBBLE-SANDAGE SYSTEM

From a detailed study of the flattening of S0 galaxies and of spirals Sandage, Freeman, and Stokes (1970) conclude that spiral and lenticular galaxies have the same distribution of true axial ratios. This important result suggests that normal spirals, which exhibit a strong display of Population I, and S0 galaxies (which contain few if any young stars) form parallel sequences. These two sequences differ primarily in their total gas content and hence in the mean age of their stellar populations. The existence of both highly flattened gas-free systems and similarly flattened gas-rich galaxies suggests that there might exist a class of flattened objects with characteristics that are intermediate between those of S0 galaxies and

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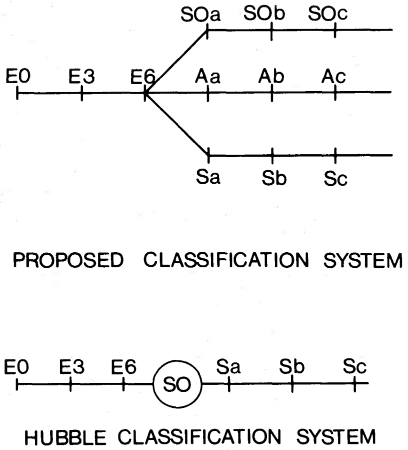

PROPOSED CLASSIFICATION SYSTEM

HUBBLE CLASSIFICATION SYSTEM

FIG. 1.—Comparison of the provisional classification system proposed in this paper with that of Hubble (1936). The new system comprises parallel sequences of normal spirals (Sa–Sb–Sc), anemic spirals (Aa–Ab–Ac), and gas-free lenticulars (S0a–S0b–S0c).

normal spirals. Such gas-poor objects, in which not much star formation is presently taking place, will be referred to as "anemic" spirals.

A new classification scheme for galaxies, which incorporates a sequence of anemic spirals, is shown in Figures 1 and 2. In this provisional system, galaxies without a disk component are called ellipticals (E0–E6). The conventional Hubble classification of normal spirals is replaced by a system which is based entirely on their disk-to-bulge ratios. These disk-to-bulge ratios are, in a very crude way, related to the relative importance of the two main components in galaxies, i.e., the inner spheroidal component and the outer exponential disk (de Vaucouleurs 1959; Freeman 1970; Sandage, Freeman, and Stokes 1970). The disk-to-bulge ratio is also related to the nuclear concentration of light, which Morgan (1958, 1959) has used as a classification parameter.

Objects which, on the prints of the *Hubble Atlas*, have apparent disk-to-bulge ratios in the range 1 to 3 have been classified Sa; those with disk-to-bulge ratios of 3 to 10 were classified Sb; and those with disk-to-bulge ratios larger than 10 as Sc. An analogous definition was used to define the anemic spirals of type Aa, Ab, and Ac. Similarly S0 galaxies were also divided into types S0a, S0b, and S0c. It should be emphasized that this subdivision of galaxies of class S0 is in no way related to the Hubble-Sandage classification $S0_1$, $S0_2$, and $S0_3$, which does not depend on the relative importance of the central bulge and of the disk subsystems. Many of the galaxies of Hubble-Sandage type $S0_1$ fall on the S0a–S0b–S0c sequence in Figures 1 and 2. Most of the galaxies which have Hubble-Sandage type $S0_3$ are probably more closely related to the anemic spirals than they are to true S0 systems.

The positions of the Sa–Sb–Sc, Aa–Ab–Ac, and S0a–S0b–S0c sequences in a diagram of color versus disk-to-bulge ratio are shown in Figure 3.

It should perhaps be emphasized that the role of S0 galaxies in the classification system outlined above is very different from that originally envisaged by Hubble (1936). Hubble thought of S0 galaxies as a transitional type between ellipticals and spirals. In the scheme illustrated in Figures 1, 2, and 3, lenticular galaxies and spirals form parallel sequences which differ only in their gas content and hence in their rate of star formation.

In order to better define the new classification scheme proposed in this paper, all of the NGC galaxies in *The Hubble Atlas of Galaxies* (Sandage 1961) have been reclassified in the new system described above. The classifications were made using both the photographs in the *Hubble Atlas* and glass copies of the blue plates of the *Palomar Sky Survey*. These classifications, which are listed in Table 1, will be taken to define the Revised David Dunlap Observatory (RDDO) system.

It should probably be emphasized that some features of this system are still quite provisional. In particular

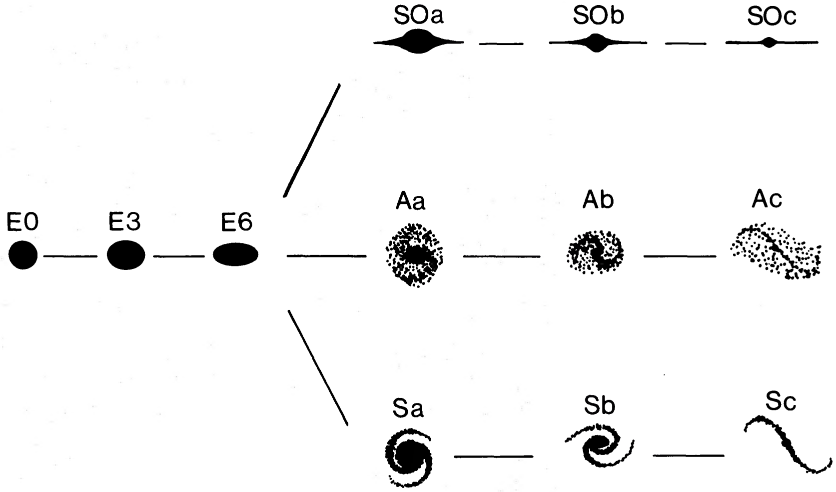

FIG. 2.—Schematic representation of the proposed new galaxy classification system

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it is not yet entirely clear how the sequence of barred S0 systems of differing disk-to-bulge ratio can be unambiguously classified. In Table 1 all classifications of SB0 galaxies have therefore been placed in parentheses.

The transition from type S0 to type A is a continuous one. For purposes of classification both dusty and dust-free galaxies without evidence for a patchy distribution of Population I have been assigned to the S0a–S0b–S0c sequence. Flattened objects, in which some young Population I stars seemed to be present, were assigned to the Aa–Ab–Ac sequence.

III. GAS DEPLETION IN CLUSTER GALAXIES

A number of lines of evidence suggest that the galaxian population of rich clusters differs significantly from that of field galaxies. The preponderance of E and S0 galaxies in very dense clusters such as Coma has been known for many years (cf. Spitzer and Baade 1951). The differences between galaxies in more open clusters, such as Virgo, and those in the general field are somewhat more subtle.

a) *Gas in Spirals*

The following systematic differences are observed between spiral galaxies in the Virgo cluster and their counterparts in the field:

i) The average surface density of neutral hydrogen gas in Virgo spirals of a given type is only 0.5 ± 0.1 times that observed in noncluster spirals of the same type (Davies and Lewis 1973).

ii) At a given disk-to-bulge ratio, Virgo spirals are systematically redder by 0.04 mag than are similar galaxies in the field (van den Bergh 1975). The fact

TABLE 1

REVISED DDO CLASSIFICATION TYPES FOR ALL NGC GALAXIES THAT ARE ILLUSTRATED IN THE HUBBLE ATLAS

NGC	Revised Type	NGC	Revised Type	NGC	Revised Type	NGC	Revised Type
23	Sbp	2403	Sc III	4088	Sc II:	4699	Ab II:
45	S IV-V	2523	SBb I	4111	S0a/S0b	4710	Ab
127	Aa:	2525	S(B)cp II?	4150	E2/S0a	4725	S(B)b I
128	S0a(t)p/S0b(t)p	2681	Ab III:	4214	Ir III-IV	4736	Sb^{-}p II:
130	E5	2685	E6 + Stt	4215	Ab III:	4750	Sb III:
157	Sc I	2775	Sa or Sb^{-} II	4216	Sb II	4753	E3p
175	SBb I	2811	Sb II-III	4237	Sb III:	4762	S0b
185	dE1	2841	Sb^{-} I	4244	S IV:	4793	Sc III
205	E6:(t?)	2855	Aa	4254	Sc I	4800	Sb: III:
210	Sb^{-} I	2859	SBa:	4258	Sb^{+}(t?)p	4826	Ab II
224	Sb I-II	2903	Sc I-II	4262	SB0a	4866	Ab III:
253	Scp	2950	(S0Ba)	4274	Sb II-III	4941	Ab/Ac III:
309	Sc I-II	3031	Sb I-II	4278	E1	5005	Sb^{-} II
404	E0	3032	Ab	4293	Ac: III:	5055	Sb^{+} II
488	Sb^{-} I	3034	Pec	4303	Sc I	5101	(ABb)?
520	Pec	3065	Aa/Ab:	4314	(ABb)	5128	E0p
524	S0a	3077	E2p	4321	Sc I	5194	Sc(t) I
598	Sc II-III	3081	Sb III:	4378	Ab II:	5195	Pec(t)
615	Sb II-III	3109	Ir IV-V	4394	SBb II	5204	Sc/Ir IV
628	Sc I	3115	S0a	4395	S IV-V	5236	Sc I-II
718	Ab II:	3145	Sb^{+} I	4406	E3	5248	Sc I
750	E1t	3147	Sb I-II:	4433	Sb/Sc	5273	Aa/Ab III:
751	E0	3185	S(B)b III:	4449	Ir III	5364	Sbp I/Scp I
891	Sb/Sc	3245	E5/S0a	4450	Ab II	5383	SBb II
925	S(B)c II-III	3329	Sa/Aa	4457	A(B)b	5457	Sc I
972	Sbc/Abc?	3351	S(B)b II	4459	S0a:	5566	Abt
1068	Sbp II:/Scp II:	3359	S(B)c II	4486	E1	5614	Sbt
1073	S(B)c II	3367	Sc I	4526	S0(B)b	5866	Aa p
1084	Sc I-II	3368	Sbp	4548	A(B)b II	5907	Sc II:
1087	Sc III:	3377	E5	4565	Sb I:	5962	Sc II
1097	S(B)b I-II	3504	S(B)b II:	4569	Ab I-II/Ac I-II	6181	Sc I
1156	Ir IV	3511	Sc	4579	A(B)b II/S(B)b II	6384	Sb I
1201	S0a	3521	Sb^{+} II	4580	Ac III:	6643	Sc I-II
1232	Sc I	3556	Sc	4593	SBb II	6814	Sb I
1300	SBb I	3623	Sbn II:	4594	Sa	6951	S(B)b I-II:
1302	A(B)b II:	3627	Sb^{+}(t?) II:	4612	Ep?	7217	Sb^{-} II
1398	S(B)b I	3672	Sc II	4631	Sc	7314	Sc II
1637	Scp II	3705	Sb II-III	4636	E1/S0a	7331	Sb I-II
1832	Sc II	3718	Abt?	4643	(ABa)	7392	Sb II:
1964	Sb II	3810	Sc I	4656	Sctt	7457	S0a
2217	(S0Bb)	3898	Sb^{-} II	4684	S0a	7640	A(B)b^{+} II:
2366	Ir IV-V	4062	Sb II:/Sc II:	4691	(ABb)?	7741	SBc II
				4697	E4	7743	Ab

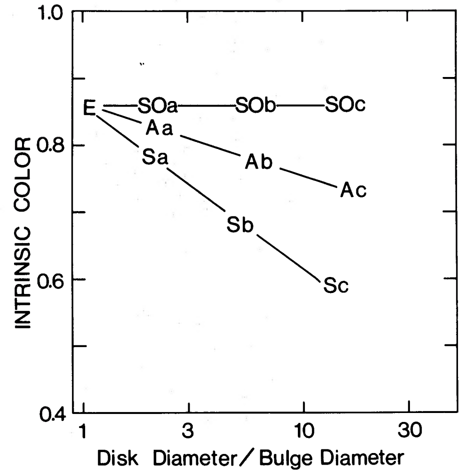

FIG. 3.—Positions of the S0a–S0b–S0c, Aa–Ab–Ac, Sa–Sb–Sc sequences in a color versus disk-to-bulge ratio diagram. This schematic figure is based on the classifications listed in Table 1, and the intrinsic galaxy colors given by de Vaucouleurs and de Vaucouleurs (1964).

that Virgo cluster galaxies of a given Hubble type are redder than their counterparts in the field has also been noted by Holmberg (1958) and by de Vaucouleurs, de Vaucouleurs, and Corwin (1972).

iii) Inspection of photographs of Virgo cluster spirals shows that many (but not all!) of them have a rather anemic appearance which is, no doubt, due to the fact that they are forming stars less vigorously than are typical galaxies of the same type in the field. Since the rate of star formation $f \propto \rho^n$ (Schmidt 1959), the anemic appearance of many Virgo spirals is probably a result of the fact that they are gas-poor. The low rate at which young blue stars are presently being formed also explains why Virgo spirals are, in the mean, redder than are field galaxies of similar types.

Two of the most extreme examples of Virgo cluster galaxies that are too red for their disk-to-bulge ratios are NGC 4941 and NGC 4866, which are illustrated on pages 10 and 11, respectively, of *The Hubble Atlas of Galaxies* (Sandage 1961). These objects are good examples of members of the anemic spiral sequence. NGC 4941 is classified Ab/Ac III: and NGC 4866 as Ab III: on the Revised DDO System.

It should perhaps be emphasized that not all spirals in the Virgo cluster are anemic. The Sb^+ I galaxy NGC 4501 is a good example of a perfectly normal vigorous spiral in (or projected on) the core of the Virgo cluster. Its neighbor NGC 4548, which is of type A(B)b II, is a fine example of an anemic spiral. This juxtaposition of anemic and vigorous spirals might be due to projection effects. Alternatively it may be assumed that some of the (relatively rare) normal spirals in the cores of rich clusters are on orbits that have only recently penetrated into the dense central regions of these clusters.

Figure 4 (Plate 12) shows a photograph of the anemic spiral NGC 4921, which is the brightest spiral galaxy in the Coma cluster. This object has an unusually low surface brightness and exhibits remarkably diffuse spiral arms. The structural peculiarities of this galaxy are very reminiscent of those exhibited by NGC 4450, NGC 4569 (M90), and NGC 4579 (M58) in the Virgo cluster. In a color versus disk-to-bulge ratio diagram (van den Bergh 1976) the Coma spiral NGC 4921 falls among the most extreme examples of the "anomalously reddened" Virgo cluster galaxies. This suggests that objects in the dense core of the Coma cluster might suffer from even more severe gas depletion than do those in the Virgo cluster.

TABLE 2*

GALAXIES SHOWING [O II] λ3727 EMISSION

Type	S0 Galaxies (percent)	E Galaxies (percent)
Noncluster galaxies.........	27	11
Virgo cluster...............	13	10
Dense clusters.............	0	0

* From Davies and Lewis 1973.

b) *Gas in Ellipticals*

The below-average gas abundance in cluster spirals has its counterpart in the low gas abundance which appears to be indicated for E and S0 galaxies in clusters. According to Davies and Lewis (1973) [O II] λ3727 (see Table 2) occurs far less frequently in galaxies of types E and S0 that are located in clusters than it does in galaxies of similar types that are situated in the general field. Their data (which should be checked by new homogeneous observations) suggest that ellipticals and lenticulars in the Virgo cluster have characteristics that are intermediate between those of galaxies in very dense clusters and galaxies in the field. A number of other lines of evidence, which are discussed in van den Bergh (1975), also support the view that elliptical galaxies outside rich clusters contain more gas than do those in clusters.

IV. DISCUSSION

On the basis of the evidence presented in the previous section one might expect gas-poor lenticulars and anemic spirals to be more common in the Virgo cluster than they are in the field. This suspicion is

TABLE 3*†

RELATIVE FREQUENCIES OF LENTICULARS, ANEMIC SPIRALS, AND NORMAL SPIRALS OF SIMILAR DISK-TO-BULGE RATIO

	S0b (%)	Ab (%)	Sb (%)	n_{ga}
Field...........	0	20	80	56
Virgo...........	14	57	29	14

* From van den Bergh 1976.

† Data for normal systems and for barred systems of a given classification type have been combined.

confirmed by an analysis of the frequency of classification types listed in Table 1. These results, which are collected in Table 3 show that, *at a given disk-to-bulge ratio*, 71 percent of all Virgo cluster galaxies in *The Hubble Atlas* are of the gas-poor types S0b and Ab, whereas only 20 percent of the galaxies that are not situated in the Virgo cluster belong to these types.

It should perhaps be emphasized that the difference in gas content between galaxies *of the same disk-to-bulge ratio* inside and outside the Virgo cluster cannot be accounted for in terms of mass loss by a supernova-driven stellar wind (Mathews and Baker 1971). This is so because the strength of such a wind should be independent of the location of a galaxy in space.

A hydrogen deficiency of the type required to account for the excess redness of galaxies in the Virgo cluster might possibly be understood in terms of the sweeping out of interstellar gas in Virgo spirals by ram pressure (Gunn and Gott 1972). Zasov (1975) has pointed out that such gas loss will take place primarily from the outer regions of galaxies. Alternatively it might, of course, be assumed that some gas from the outer parts of the hydrogen disks of spiral galaxies in dense clusters was lost during tidal encounters. Furthermore, collisions between galaxies could, as was first suggested by Spitzer and Baade (1951), remove the interstellar gas from a few galaxies which have orbits that pass through the dense cores of rich clusters. Finally the pressure difference between the cool gas in the disks of cluster spirals ($n \approx 10^2$ cm^{-3}, $T \approx 10^2$ K) and the hot intragalactic ($n \approx 10^{-4}$, $T \approx 10^8$ K) gas in clusters might affect the evolution of cluster galaxies significantly.

The relatively low gas density which is observed in *some* field E and S0 galaxies could be due to a supernova-driven stellar wind or to occasional explosions which eject gas and trigger bursts of star formation. Once most of the gas has been ejected from a galaxy, it might possibly be kept gas-free by supernova-driven stellar winds.

V. CONCLUSIONS

Canonical views on galaxy evolution suggest that the present morphology of galaxies is predestined by the genetic heritage provided by initial mass and angular momentum. The results discussed above suggest that the evolution of galaxies is also substantially affected by environmental factors. Probably initial conditions determine the present disk-to-bulge ratio of spirals and the flattening of ellipticals. After the initial collapse is completed, most highly flattened galaxies will have a significant amount of gas left in their disks. If all of this gas is retained, it will become a normal spiral. If some gas is swept out, the galaxy will probably become an anemic spiral. Finally a flattened galaxy, from which all of the gas has been removed, will become a lenticular.

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REFERENCES

Davies, R. D., and Lewis, B. M. 1973, *M.N.R.A.S.*, **165**, 231.
de Vaucouleurs, G. 1959, *Handbuch der Physik*, **53**, 311.
de Vaucouleurs, G., and de Vaucouleurs, A. 1964, *Reference Catalogue of Bright Galaxies* (Austin: University of Texas Press).
de Vaucouleurs, G., de Vaucouleurs, A., and Corwin, H. G. 1972, *A.J.*, **77**, 285.
Freeman, K. C. 1970, *Ap. J.*, **160**, 811.
Gunn, J. E., and Gott, J. R. 1972, *Ap. J.*, **176**, 1.
Holmberg, E. 1958, *Medd. Lund Astr. Obs.*, Ser. 2, No. 136.
Hubble, E. P. 1926, *Ap. J.*, **64**, 321.
———. 1936, *The Realm of the Nebulae* (New Haven: Yale University Press), p. 45.
Mathews, W. G., and Baker, J. C. 1971, *Ap. J.*, **170**, 241.
Morgan, W. W. 1958, *Pub. A.S.P.*, **70**, 364.
———. 1959, *ibid.*, **71**, 394.
Sandage, A. R. 1961, *The Hubble Atlas of Galaxies* (Washington: Carnegie Institute of Washington).
Sandage, A. R., Freeman, K. C., and Stokes, N. R. 1970, *Ap. J.*, **160**, 831.
Schmidt, M. 1959, *Ap. J.*, **129**, 243.
Spitzer, L., and Baade, W. 1951, *Ap. J.*, **113**, 413.
van den Bergh, S. 1960*a*, *Ap. J.*, **131**, 215.
———. 1960*b*, *ibid.*, p. 558.
———. 1960*c*, *Pub. David Dunlap Obs.*, **2**, 159.
———. 1976, in press.
Zasov, A. V. 1975, *Soviet Astr.—AJ*, **18**, 426.

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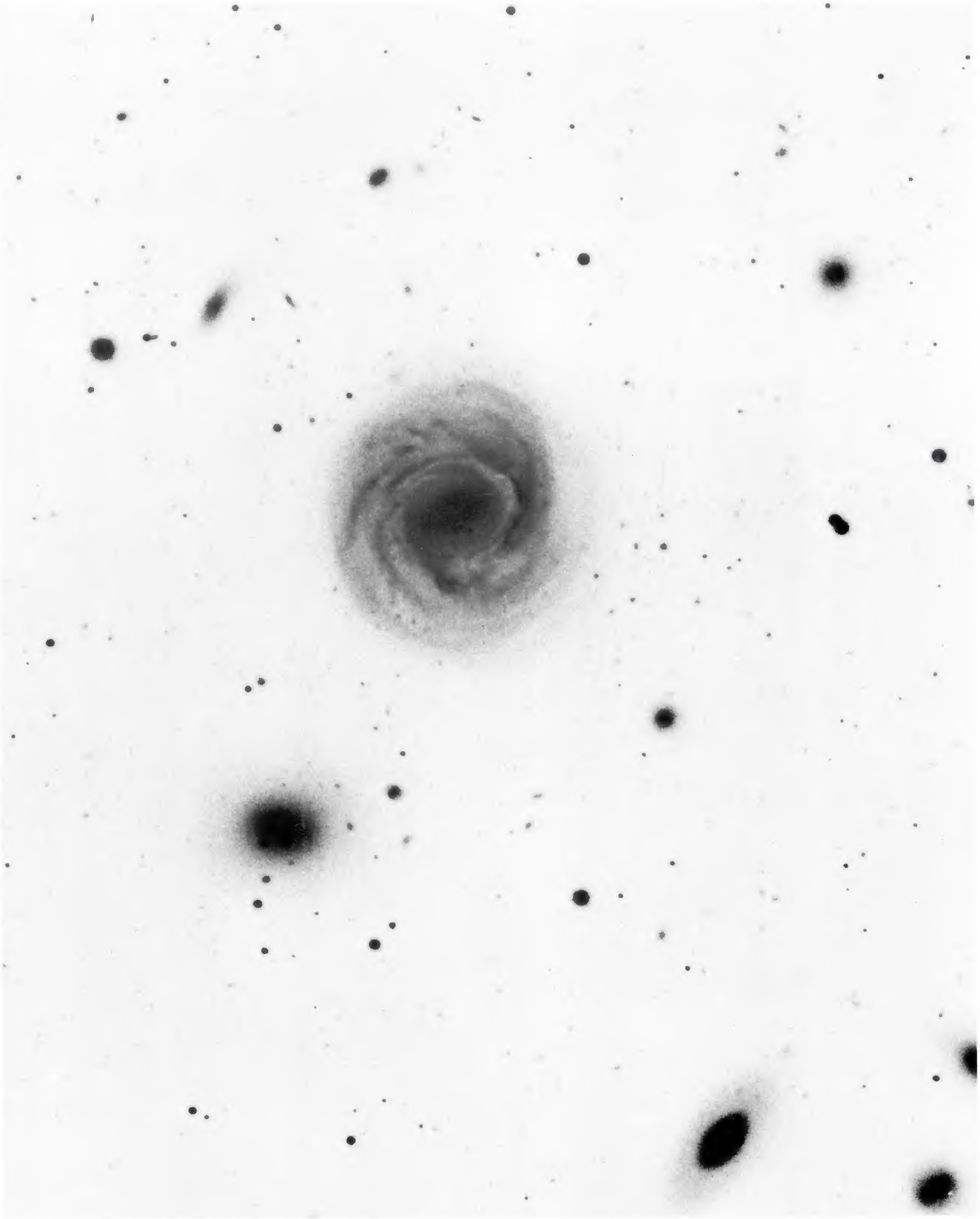

FIG. 4.—45 min (IIIaJ + GG385) exposure (north at top) obtained with the 4 m Mayall telescope of the anemic spiral galaxy NGC 4921 in the Coma cluster. This galaxy, which is intermediate between a normal anemic spiral and a barred anemic spiral, is classified A(B)b I on the proposed new classification system.

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