SO AND SMOOTH-ARM Sa's WITHIN THE HUBBLE SEQUENCE

Allan Sandage
Mount Wilson and Las Campanas Observatories of the
Carnegie Institution of Washington

ABSTRACT

S0 and smooth-armed Sa galaxies are generic to the Hubble sequence, not formed by environmental stripping.

I. INTRODUCTION

Because S0 galaxies are flattened disks without spiral arms, speculation began already in the 1950's (Spitzer and Baade 1951) that they are formed by the secondary processes of gas stripping from parent spirals, leaving the daughters inert. The clearest statement of envitonmental formation is given by van den Bergh (1976) where he extends Baade's (1963)[1] suggestion that S0's and other "anemic" spirals form a parallel sequence with normal gas-rich spirals, differing from their "parent" spirals only in their gas and dust content.

This view has received wide attention, and a large school of galaxy strippers has arisen. If true, a major revision in the Hubble sequence would be required.

The contrary view (Sandage, Freeman, and Stokes 1970, SFS) is that S0 and smooth-armed Sa galaxies naturally form the early terminus of the disk systems. S0's are earlier than Sa types and are a transition to the flattened E galaxies (Hubble 1936; Sandage 1961), initially placed at that point in the sequence by the extreme values of some distributed parameter (eg., density or specific angular momentum). Evidence in support of this generic viewpoint is discussed in the next sections.

II. SURFACE BRIGHTNESS DISTRIBUTIONS

That S0 and smooth-armed Sa's cannot be stripped Sb and Sc galaxies is seen by looking through a telescope, an archaic activity evidently not now practiced by strippers.

E. Athanassoula (ed.), Internal Kinematics and Dynamics of Galaxies, 367–372.

https://doi.org/10.1017/S0074180900033283 Published online by Cambridge University Press

In work related to the Revised Shapley Ames Catalog (Sandage and Tammann 1981) photographs of all listed galaxies were taken with the Mount Wilson, Palomar, and Las Campanas reflectors. To check the telescope setting, most fields were visually inspected. The fact, known generally to old visual observers, was rediscovered that Sd and Sc galaxies were extremely difficult to see with large scale reflectors, Sb's easier, Sa's still easier, whereas all S0 and E galaxies stand like beacons in the focal plane.

This progressive change of surface brightness with Hubble type is shown quantitatively in Figures 1a and 1b where the average V_{mag} surface brightness within a photoelectric blocking diaphragm A/D(0) is plotted for various Hubble types. The photoelectric data are taken from standard literature sources (eg., de Vaucouleurs and de Vaucouleurs 1961; Sandage 1975; Sandage and Visvanathan 1978; Griersmith 1980). The shape of the line is from integrating the standard growth curve (Sandage 1975, Table B1), but forced through the E plot.

The E and S0 galaxies have nearly the same surface brightness distribution. However, as soon as evidence of arms appears (i.e., in S0/a types), the average surface brightness at any A/D(0) > 0.1 decreases. That dust is not a problem is shown in panels 4 and 5 of Fig. 1a by dividing the Sa's into dust-free and dust-present systems.

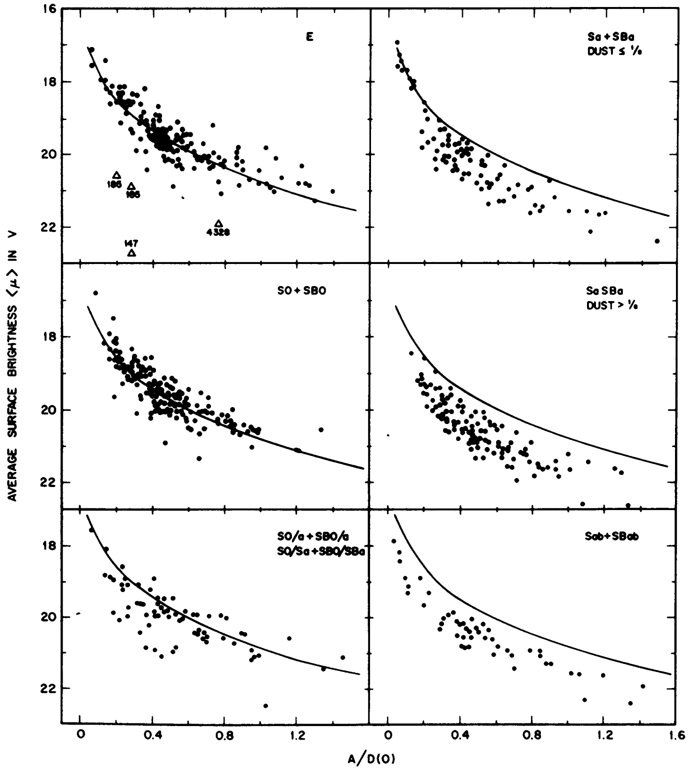

Fig. 1a. The surface brightness in V_{mags} for E through Sab galaxies, averaged over the area inside a radius of A/D(0), where D(0) is ~0.3 of the Holmberg radius. The mean line for E galaxies is repeated in every panel.

https://doi.org/10.1017/S0074180900033283 Published online by Cambridge University Press

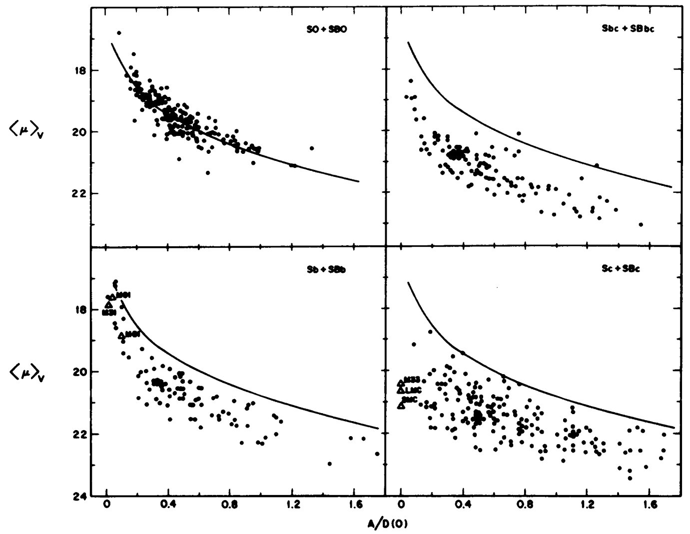

Fig. 1b. Same as Fig. 1a for Sb, Sbc, and Sc galaxies, with the data for S0 galaxies repeated. The absence of the bulge in Sbc and Sc galaxies is evident by inspection of the curves for A/D(0) < 0.2. Hence, if such galaxies are stripped, they will not form the S0 distribution.

To overcome objections about using isophotal D(0) diameters rather than a metric scale length, effective surface brightness, defined as that averaged over the circular radius that contains half the light, has been calculated, as shown in Figure 2. The line through the S0 types is repeated in all panels. S0 galaxies have the highest $\langle SB \rangle_e$ of all types. The progressive decrease with Hubble type is listed in the Table. As before, it can be shown that internal dust absorption is not the cause of the progressive decrease in surface brightness along the Hubble sequence.

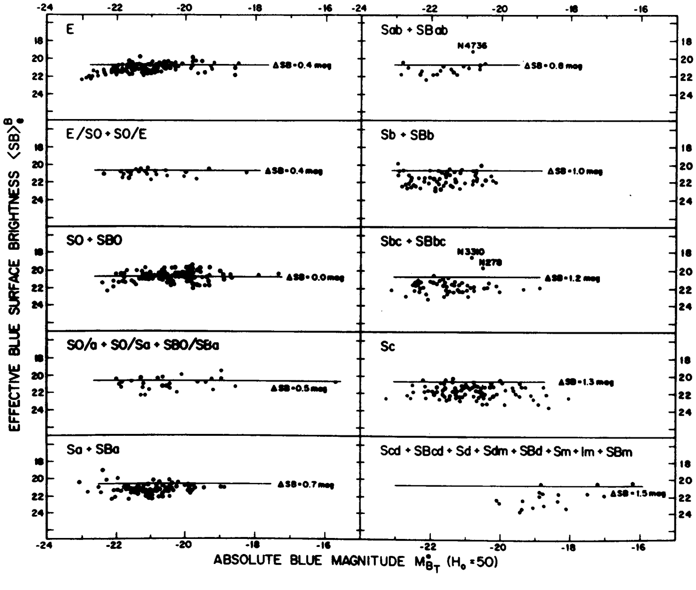

Fig. 2. Effective blue surface brightness vs absolute magnitude $M_{B_T}{}^{\circ}$ for various Hubble types.

https://doi.org/10.1017/S0074180900033283 Published online by Cambridge University Press

Type	ΔSB Relative to S0's	Type	ΔSB Relative to S0's
E	+0.4	Sab + SBab	+0.8
E/S0 + S0/a	+0.4	Sb + SBb	+1.0
S0 + SB0	0.0	Sbc + SBbc	+1.2
S0/a + S0/Sa	+0.5	Sc + SBc	+1.3
Sa + SBa	+0.7	Scd and later	+1.5

Clearly, S0 galaxies cannot be formed by the stripping of late type galaxies of their star producing material because these prospective parent galaxies are already fainter in effective surface brightness than their resulting daughters--an impossibility.

Other evidence against environmental stripping to form S0's include (1) normal S0's occur in the isolated field where no stripping can be expected, and (2) S0's and spirals coexist in pairings that include simple binaries, loose groups, and spiral-rich clusters such as Hercules and the Virgo Cluster core. If S0's were once normal spirals and then stripped, why are their present-day companion spirals not also stripped?

Other interesting features of Fig. 2, useful for other problems are:

(1) Over the absolute magnitude interval $M_B \sim -23$ to ~ -19 the $\langle SB \rangle_e$ is nearly independent of M_B which is Hubble's old relation $m \sim 5 \log \theta$. Hence there is no distance information in angular diameters over this intensity interval.

(2) The spread in M_B within any type is large. Without doubt, it is even larger than shown in Figure 2 because there is an artificial cut-off at faint M_B values due to the bright apparent magnitude limit of the Shapley Ames at $B \simeq 13$. Clearly, the Hubble type earlier than Scd is hardly a function of absolute luminosity, and therefore cannot be used as a distance indicator.

(3) The $\langle SB \rangle_e$ of E galaxies decreases for M_B brighter than ~ -21, possibly due to mergers.

III. - SMOOTH-ARMED Sa's

Because smooth-armed Sa's occur in clusters, it has sometimes been claimed (cf. Wilkerson 1980) that they too are a result of stripping. However, similar to S0's, they also occur frequently in the general field.

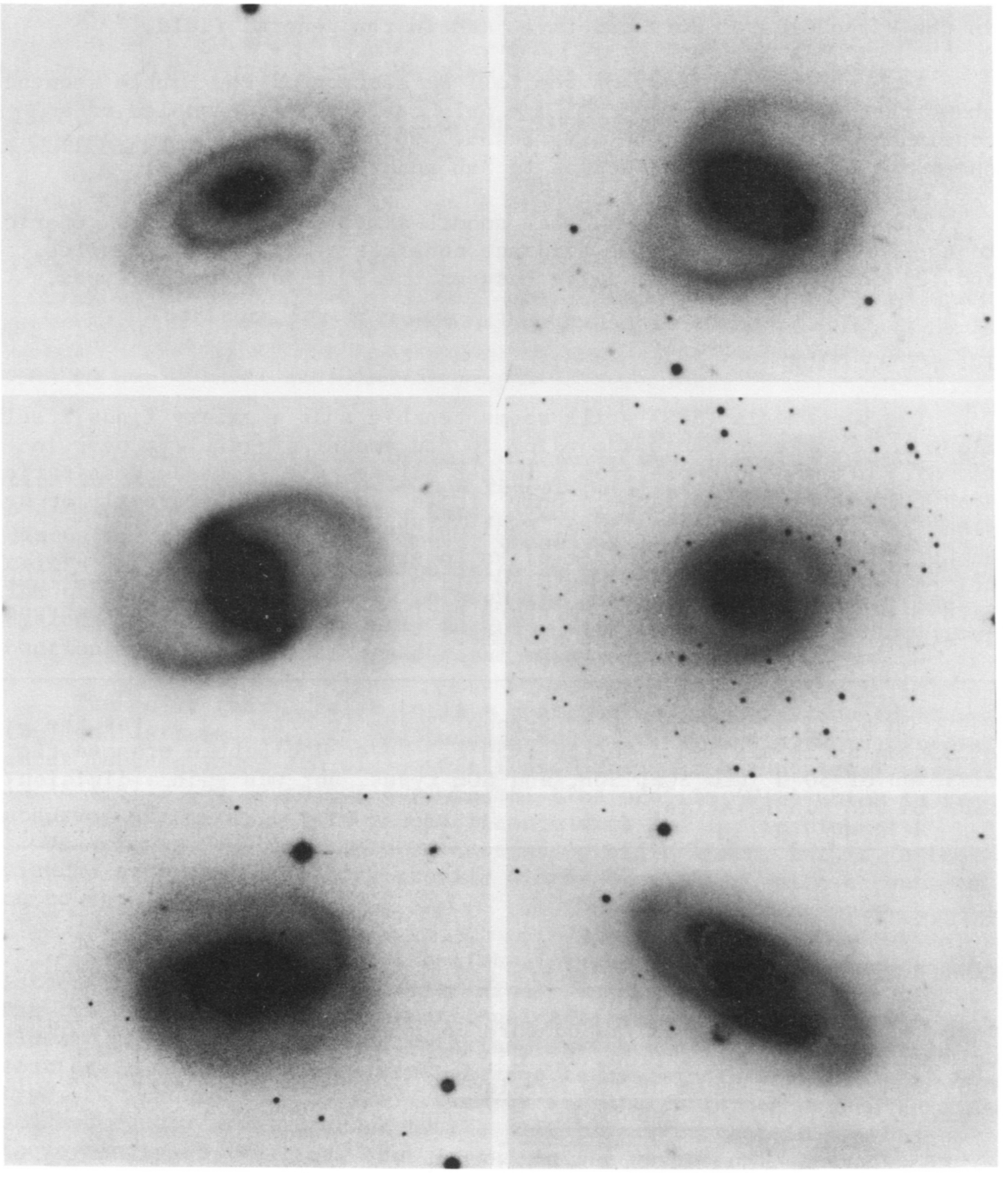

Fig. 3. Six smooth-armed Sa galaxies. Three are in the Virgo Cluster, three are in the general field. The field SBa galaxy, NGC 7743, in the lower left, is also in the Hubble Atlas (p. 43), and discussed there as the earliest part of the continuous Sa sequence. That smooth-armed Sa's occur in the general field also shows that they are not formed by stripping in clusters.

https://doi.org/10.1017/S0074180900033283 Published online by Cambridge University Press

Figure 3 is a panel of six plates of smooth-armed Sa's. Three are in the Virgo Cluster core and three are in the general field.

A morphological study of the full Sa section of the Hubble sequence shows that galaxies in Figure 3 are only the earliest examples of a continuum, within which the arms become progressively less smooth as one moves through the Sa section to Sab and then to Sb types.

The conclusion is, then, that smooth-armed Sa galaxies are generic to the Hubble sequence. The evidence consists of (1) field examples, and (2) morphological continuity between the S0/a and the Sab types.

IV. CONCLUSION

The hypothesis (SFS) still seems tenable that a galaxy finds itself along the Hubble sequence according to the amount of gas left over in the disk after a collapse from a larger volume, with gaseous dissipation near the end of the collapse. Only little evolution subsequently occurs along the sequence. To be sure, copious star formation must have occurred initially in S0 and Sa disks to explain their high surface brightness now, due to the remaining old disk stars. But this gas must have mostly been converted into stars early to account for the low rate of star formation now in these systems.

---

[1]On p. 15 of the quoted reference, Baade incorrectly states the situation as it was known in the 1950's. Never did Hubble propose the division of S0's into S0a, S0b, and S0c types, nor was such a division made in the Hubble Atlas.

REFERENCES

Baade, W.: 1963, Evolution of Stars and Galaxies (Harvard University Press: Cambridge) p. 15.
de Vaucouleurs, G. and de Vaucouleurs, A.: 1961, Mem. R.A.S., 68, 69.
Griersmith, D.: 1980, Astron. J., 85, 789.
Hubble, E.: 1936, Realm of the Nebulae (Yale University Press).
Sandage, A.: 1961, The Hubble Atlas (Carnegie Institution Publication No. 618).
Sandage, A.: 1975, Astrophys. J. 202, 563.
Sandage, A., Freeman, K. C., and Stokes, N.: 1970, Astrophys. J., 160, 831 (SFS)
Sandage, A. and Tammann, G. A.: 1981, A Revised Shapley Ames Catalog (Carnegie Institution Publication No. 635).
Sandage, A. and Visvanathan, N.: 1978, Astrophys. J., 223, 707.
Spitzer, L. and Baade, W.: 1951, Astrophys. J., 113, 413.
van den Bergh, S.: 1976, Astrophys. J., 206, 883.
Wilkerson, M. S.: 1980, Astrophys. J. (Letters), 240, L115.