GALAXIES AND CLUSTERS OF GALAXIES.

R. White JULY 1978

The subject of galaxies and clusters of galaxies is obviously a very broad topic, and cannot be covered uniformly in the time and space allotted. I will therefore speak for the most part only about the forms and systems of classification of galaxies and clusters of galaxies, and refer you to a series of recent review articles and conference proceedings on clusters and galaxies, and there is of course Volume 9 of Stars and Stellar Systems "Galaxies And The Universe" edited by Sandage, though its a bit out of date.

I will have to stress definitions, systems of classification, and available catalogs. These are not the most exciting subjects, but they are a basic prerequisite for understanding the more interesting aspects of the subject.

The remainder of these notes will be in outline form.

Galaxies

Hubble System - original, almost all others are derivative
Figure 1 - Tuning Fork
3 main types E, S&B, SO
E - smooth regular appearance. no signs of gas dust, or structure
number describes ellipticity - 0 ⇒ circular 7 ⇒ major/minor
axis ratio of about 3/1 describes apparent, not intrinsic,
flattening.
S&B - the spirals - two subgroups: normal vs. barred based on
presence or absence of bar
a - c sequence - assigned on basis of 2 parameters
1. central condensation of light (bulge/disk ratio). greatest in a,
least in c
2. quality of arms and tightness of winding. tightly wound,
least apparent in a strongly dominant, open in c
Spirals contain gas and dust in varying degrees intrinsically
flattened.
SO - originally hypothetical. a transition type
Sandage updated Hubble, put in SO's explicitly. disk systems
with little or no gas or dust. tuning fork a continuum.
Irr - irregulars. a minor type. two subcategories, 1 of which
is a continuation of the spiral "tines" of the tuning fork.
Originally, tuning fork was hoped to be evolutionary scheme.
E0 to E7 to SO to Sa to Sc. Thus Sa's "early" Sc's
are late. this view no longer accepted.
See photos in S&S vol 9 or the Hubble Atlas for photographs of
representative galaxies.

Figure 2 shows de Vaucouleurs extension of sequence to
lower case d's and breakup of types into r and s subgroups,
based on presence or absence of inner rings. can be extended
to a volume with intermediate types.
Hubble-Sandage and de Vaucouleurs stress arms at the expense of the
disk/bulge ratio

van den Bergh luminosity class system – to distinguish giants from dwarfs
See Figure 3
appearance of arms a steep function of absolute magnitude
better developed and defined arms and nuclei ⇒ giants.
poorly developed arms and nuclei ⇒ dwarfs
noted dwarfs all Sc or later

Comments on H-S and de Vaucouleurs s.c.
Good for describing detail of arms, but
① arm pattern not fundamental – perturbation on the disk and bulge potential, particular patterns may disappear and then regenerate
② require great detail because of arm criterion ⇒ limited to nearby galaxies, not applicable to most clusters.
③ retain tuning fork with S0 as transitional type
it's been suggested that spirals evolve into S0's by losing gas and dust in a cluster environment. tuning fork implies an evolutionary track from Sc to Sb to Sa to S0. Unlikely – how would disk to bulge ratios change? tuning fork may lead to confusion

Yerkes and related systems
uses only disk/bulge ratio, not character of arms – can classify uniformly out to the closer clusters.
three other advantages
① concentration class parameter vs. stellar content
② new form families (R and D)
③ break with tuning fork.
3 parameters
Concentration class parameter – a f g k (disk/bulge ratio)
a is least central concentration of light, k the greatest

form family,
E, S, B (barred spiral), I (irregular) as in Hubble-Sandage etc.
R – like S0, except a separate branch like S's & B's, and shows the sequence of concentration class.
D – see below.

Inclination class – describes inclination or ellipticity
1 ⇒ circular or face on   7 ⇒ highly elliptical or edge on.

examples : gR7 edge on lenticular galaxy of intermediate
concentration and no gas or dust.
(k) E1 circular Elliptical - k is dropped in practice,
as all E (and D) galaxies are k systems.
fS1 face on Sc.

why use a f g k instead of d c b a ?
Morgan found that concentration class correlates well with integrate spectral type of nuclear regions.! a systems have spectra dominated by OBA stars, k systems have spectra dominated by late giants, f & g systems high composite (mixtures of early and late features.
useful in studying structure and stellar content and evolution in different kinds of galaxies. N.B. conc. class does not indicate content for K's. They are all K.
use lower case analogs of upper case spectral types ⇒ we call a galaxies early, k late, in direct contrast to H-S and de Vaucouleurs.
see Figure 4

D form family - distinct from E
D galaxy - elliptical like nucleus surrounded by extensive envelope
presence of envelope, not size, makes it a D.
large size makes it a cD ⇒ a supergiant D galaxy.
D's never flattened beyond inclination class 4-5
D's appear only in strong density enhancements in rich or poor clusters.
other types appear in varying degrees in clusters and in the field.
D's do not fit on tuning fork, but that is no excuse to ignore them.
D's turn out to be important for X ray and radio astronomy.
See Figure 5 for illustrations of D's as radio sources and compared to other types of galaxies. db's are dumbell galaxies and related to D's. Ignore the Q's and N's.

The proper photoreproduction of the envelope is critical in classifying D's.
Coma (A1656) and Hydra (A1060) each contain a D and an E side by side - emphasizes that envelope, not size determines D nature.

van den Bergh's Hubble revision
See Figure 6
uses bulge/disk ratio, like Yerkes
three parallel sequences – S's, S0's and A's (anemic, i.e.
gas and dust poor, spirals).
claims A's found only in clusters = in process of being swept free and
becoming S0's. Galaxies evolve S → A → S0 – but they
keep their a, b, or c intact. Yerkes says same thing, but
does not define new type for A's. They would be SR's.
S sequence correlates well with color (i.e. spectral type).
A sequence correlates less strongly
S0 sequence correlates not at all. (all R's have K spectra).

Catalogs.
N.G.C. & I.C. – familiar to all.
Zwicky – six blue volumes, keyed to Palomar m_p 15.5 and brighter
north of −3°
Uppsala – keyed to Palomar 1.0' diameter limit has measured major &
minor axes in both red and blue, types, cluster affiliation, references.
−3° and north. about 13,000 entries. being extended to south
via ESO/SRC survey essentially complete for −80° to −40°.
other more detailed & specialized catalogs.
de Vaucouleurs – Revised Catalog of Bright Galaxies much detailed data
Arp – interacting
Zwicky – compact and post eruptive from Palomar
Vorontsov-Velyaminov peculiar } from Palomar. in Russian.
morphological }

Clusters Of Galaxies

clustering known since 1930's - Shapley-Ames noted a number of them
1938 Zwicky suggests clustering phenomenon widespread + general
Peebles and others have suggested recently that all galaxies participate in a heirarchy of clustering up to the order of 20 Mpc (superclusters).

Catalogs

Palomar survey allowed a systematic cataloging and study to begin
Southern Survey (ESO/SRC) with its much greater depth and resolution, promises even more information as its copies are distributed and studied

Two main catalogs with which you should become familiar - both based on Palomar Survey (67"/mm)

Abell

2712 rich clusters north of -27° (original Palomar Survey limit).
Abell radius $\doteq 4.6 \times 10^5/cz$ mm on Palomar survey
$\Rightarrow$ 3 Mpc is $H=50$ somewhat arbitrary, but most members fall within it
Clusters with 30 or more galaxies within 2 magnitudes of 3rd brightest and within 1 Abell radius were included in catalog. In terms of completeness, only clusters with 50 or more (Richness 1 and greater) form a complete sample.
Abell cluster often synonymous with rich cluster
Redshift estimated by assuming absolute magnitude of 10th brightest galaxy to be invariant with respect to richness and distance - i.e. a standard candle.
Plate size imposes lower limit to redshift of clusters at ~.02, in order for cluster to be obvious as a density enhancement on a single plate (e.g. Virgo not included), plate magnitude limit imposes maximum redshift of ~.20
Figure 7 shows $m_{10} - \log cz$ calibration and definitions of richness and distance groups.

Note - Coma is richness 2 - about 100 members, but if you go down deeper (more than 2 magnitudes) up to a 1000 can be found.
i.e. when discussing richness, one must specify how deep

Distance group 1 is limit for Hubble Sandage classification, distance group 3-4 for Yerkes.

Figure 8
Distribution of cluster distance 4 and closer.
1 and closer only 19 . 4 and closer 277 ⇒ many more accessible to Yerkes system.
2712 clusters, but only 277 distance 4 and closer ⇒ most are rather distant
Richness distribution
about 1000 richness 0 ⇒ incomplete,
very few very rich clusters.
50% of clusters regular, 50% irregular
Zwicky's catalog (6 volumes - *Catalog of Galaxies and Clusters of Galaxies*)
estimated cluster boundary contours as places where galaxy density was twice the background
Counted down 3 magnitudes from brightest
Has different sample from Abell
Abell clusters are generally Zwicky clusters, but not vice versa.
Zwicky has poorer, sparser clusters. Also, Zwicky may include several Abell clusters within a single contour - that is, he has mixed in super clusters.
Zwicky goes further out (fainter).
Figure 9 summarizes Zwicky's catalog terms.
Figure 10 break down of part of catalog into the various groups.
Note - nearer clusters, over half are open or medium
distant clusters, compact clusters dominate
ie. a selection effect

Cluster Classification
Abell's Regular / Irregular
Zwicky's Compact, Medium Compact, Open.

Bautz-Morgan - very simple system degree of contrast of brightest member with respect to other bright members.
See Figure 11 for definitions and type examples which you should look at.
B-M type not a function of richness
$\sim$20% are I or I-II $\sim$20% II , $\sim$60% II-III or III

Rood Sastry = a blend of Bautz Morgan criteria with general appearance of cluster

See Figure 12

about 30% cD and B 9% L 14% C 15% F 29% I

Other Parameters used to describe clusters

① luminosity function = how galaxies are distributed with magnitude

② core radius = spatial distribution of galaxies about cluster center, as a whole, and as a function of magnitude (mass segregation)

③ galaxy content – as a whole, as a function of magnitude, as a function of distance from cluster center, as a function of time

④ internal velocity dispersions (⇒ virial mass of cluster, degree of mixing and dynamical evolution)

⑤ existence and nature of intracluster medium

How do these things relate to each other and to the already described classifications? Figures 13 and 14 show crude relation, but situation is still far from clear

Two Final topics

Galaxy content vs. cluster compactness vs dynamical evolution

D galaxies in clusters

Galaxy content, Cluster compactness, Dynamical Evolution

See Figure 15

compact clusters generally rich in E and S0 (or R) systems.

open clusters have many spirals, a number of which are early (Yerkes sense type, open clusters have content similar to that of the field

the sequence from compact to open is sequence of increasing proportion of spirals and of the spirals being increasingly earlier in type.

there is also evidence that this is a sequence of decreasing degree of dynamical evolution (compact = most evolved; open = least evolved).

(mass segregation = cluster attempts equipartition and more massive galaxies fall to center).

Is this sequence of degree of dynamical evolution and form-type content an evolutionary track?

As clusters contract, spirals may be swept free of gas and dust, and thus converted to S0's. If the evolutionary sequence is universal, would expect all clusters to start off same, and therefore would expect that the bulge to disk ratios of S0's in spiral-poor clusters would exhibit same range and proportion as bulge-to-disk ratios of spirals in spiral-rich clusters. A difficult observation not yet performed.

Cluster could continue to evolve with ellipticals forming at the expense of S0's, and cD's forming in the center from the debris or from cannibalization. That is, the form-content and dynamical sequence might be a sequence of Bautz-Morgan types (I's + II being most compact, elliptical rich).

Oemler suggests this is partially the case. Spiral rich evolve into spiral-poor (open to medium-compact), but because he was not convinced that S0's could be converted to E's, he felt the elliptical rich, highly compact "cD" clusters evolved from a different type of initial cluster, which we no longer see.

My findings somewhat different — late spirals became more important (more open clusters), [illegible] became {earlier (Yerkes sense), later (Hubble-Sandage)} on average. Therefore to have sequence be evolutionary path, Sc's would have to be converted to Sb's and then Sa's (i.e. along Hubble tuning fork) or Sc's would be preferentially converted to S0's before the Sa's were. Either difficult to explain — how to convert bulge to disk for example. Also, there are B-M type III clusters that are of the compact, elliptical rich kind, and B-M type I and II clusters of the open, spiral rich kind ⇒ compactness, content sequence is decoupled to some extent from B-M sequence, i.e. from the formation of D's + cD's. I would suggest that the sequence is like the main sequence for stars — a continuity reflecting a range of initial and present parameters, not a universal evolutionary track. A study of the distribution of S0s among the range of bulge-to-disk ratios would be most helpful.

D's + cD's

Originally found only in Abell clusters ⇒ originally only looked for there. Have since been found in poor clusters with as few as five members, and in spiral rich clusters.

Two modes suggested for formation:

1. Dynamical friction – companion galaxies slow down around central galaxy, spiral in, gradually disrupt, material form cD envelope

   $\Rightarrow \langle V^2\rangle^{1/2}_{\text{cD internal}} \approx \langle V^2\rangle^{1/2}_{\text{normal galaxy}} \sim 300$ km/sec.

2. Debris – material stripped from halos of other cluster members by tidal encounters, falls into center, forms envelope

   $\Rightarrow \langle V^2\rangle^{1/2}_{\text{cD internal}} \approx \langle V^2\rangle^{1/2}_{\substack{\text{galaxy orbital motion}\\ \text{in cluster}}} \approx 1000$ km/sec.

measurements hard to do. inconclusive results as yet. both modes could be acting.

cD's can form in small groups – no stripped material.
cD's usually surround by very local density enhancement $\Rightarrow$ favor Dynamical friction.

both methods require cD to be at bottom of density well. $\Rightarrow$ must form in some kind of clustering. however, because of wide range of situations where cD's are found, cluster environment as a whole may not play a decisive role. compact clusters may provide greater likelihood for local central density enhancement $\Rightarrow$ D's and cD's in Abell clusters tend to be formed in the compact types.
cluster type may influence ultimate size of cD.

Nature of cD's, and relation to cluster type, radio and x-ray emission still area of active research.

References.

General:

Clusters of Galaxies.

Abell 1976 in Stars and Stellar Systems, Vol. 9
Bahcall 1977 Annual Reviews Vol. 15
Quintana 1975 IAU Regional meeting, Santiago, Chile, January 1977.
van den Bergh 1977, Vistas in Astronomy 21

Galaxies

Sandage 1976 in Stars and Stellar Systems, Vol 9, Chapter 1.
Tinsley and Larson 1977, Evolution of Galaxies and Stellar Populations — Yale.

Other selected articles;

Yerkes system, cD's, etc.

Morgan, Kayser, White, ApJ 199, 545, 1975 contains the earlier references
van den Bergh Revision Ap. J. 206, 883, 1976
Oemler Ap. J. 194, 1, 1974
White Ap. J. 226, 1978 December 1, in press.

Figure 1

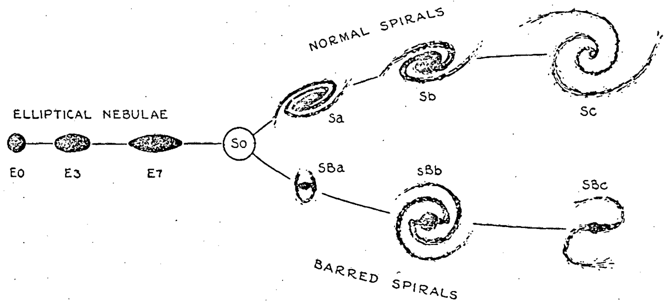


FIG. 2.—Hubble's original tuning-fork diagram as published in 1936 in his *Realm of the Nebulae.*

Figure 2

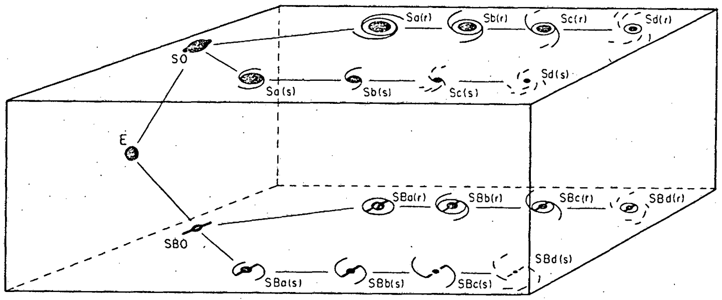


FIG. 3.—First stage of development of the concept of the *classification volume.* Here, the ordinary and barred families are separated onto opposite sides of a box. Within each family, a separation is made into the r and s strains, depending on whether the arrows start from a ring or from the nucleus. Transition cases between the barred and ordinary families are not formally recognized in this visualization, but would fit in the interior of the box, a concept that leads into de Vaucouleurs's generalization shown in figs. 4 and 5. (Rendering of a diagram from Hodge 1966.)

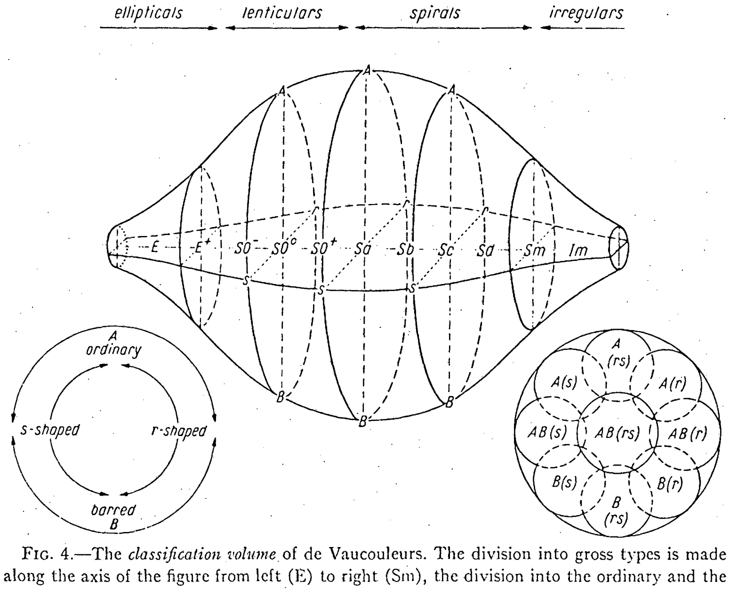


FIG. 4.—The *classification volume* of de Vaucouleurs. The division into gross types is made along the axis of the figure from left (E) to right (Sm), the division into the ordinary and the barred family is by position on the surface (from de Vaucouleurs 1959*a*).

Figure 3

TABLE 1

VAN DEN BERGH'S CALIBRATION BASED ON $H_0 = 100$ km s^{-1} Mpc^{-1}

Type	M_{pg}	Type	M_{pg}
Sb I	−20.4	Sc I	−20.0
Sb I–II	−19.9	Sc I–II	−19.7
Sb II	−19.4	Sc and Irr II	−19.4
Sb II–III	−18.6	Sc and Irr II–III	−18.9
Sb III	−18.0	Sc and Irr III	−18.3
		Sc and Irr III–IV	−18.0:
		Sc and Irr IV	−17.3:
		Sc and Irr IV–V	−16.1:

From *Pub. David Dunlap Obs.*, Vol. 2, No. 6, 1960.

Figure 4

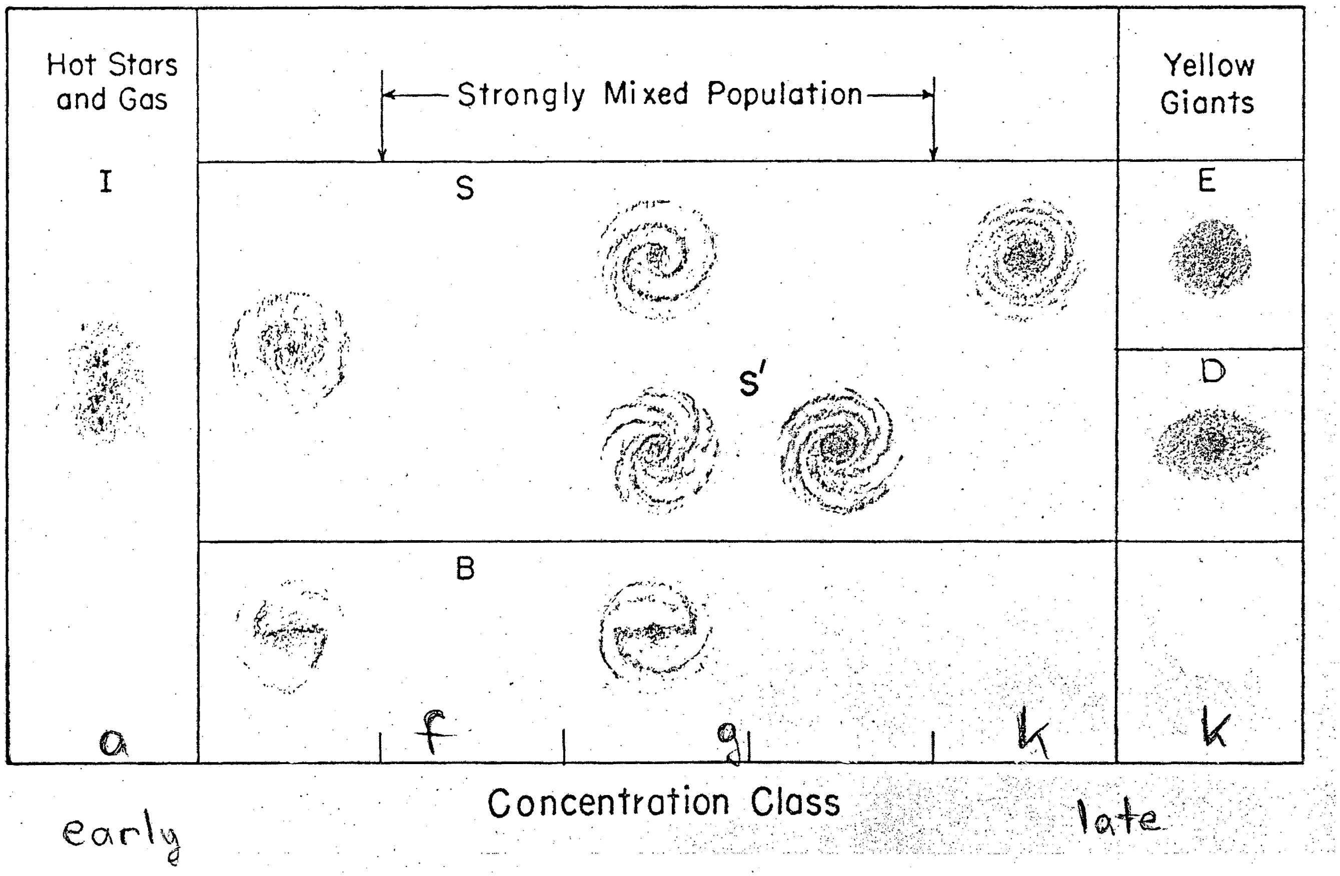
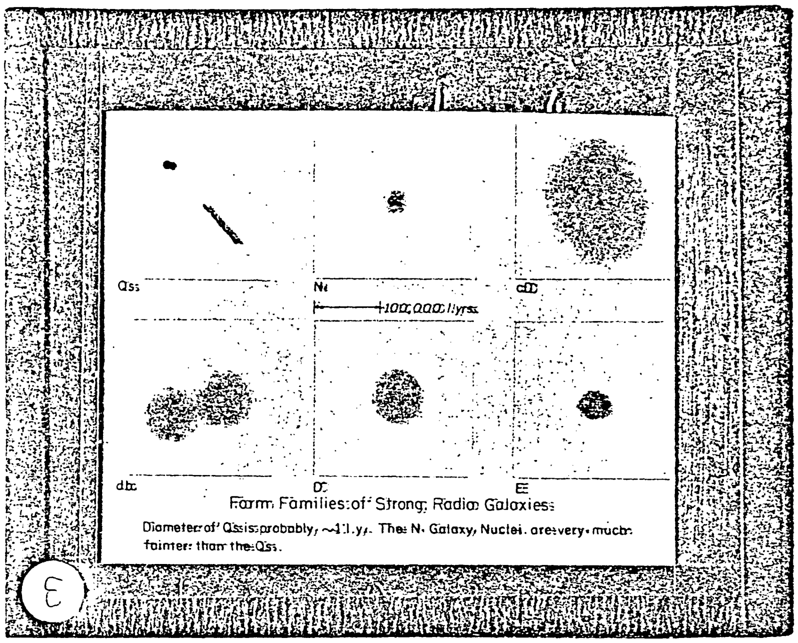


Figure 5



Form Families of Strong Radio Galaxies

Diameter of QSs is probably ~1 l.y. The N Galaxy Nuclei are very much fainter than the QSs.

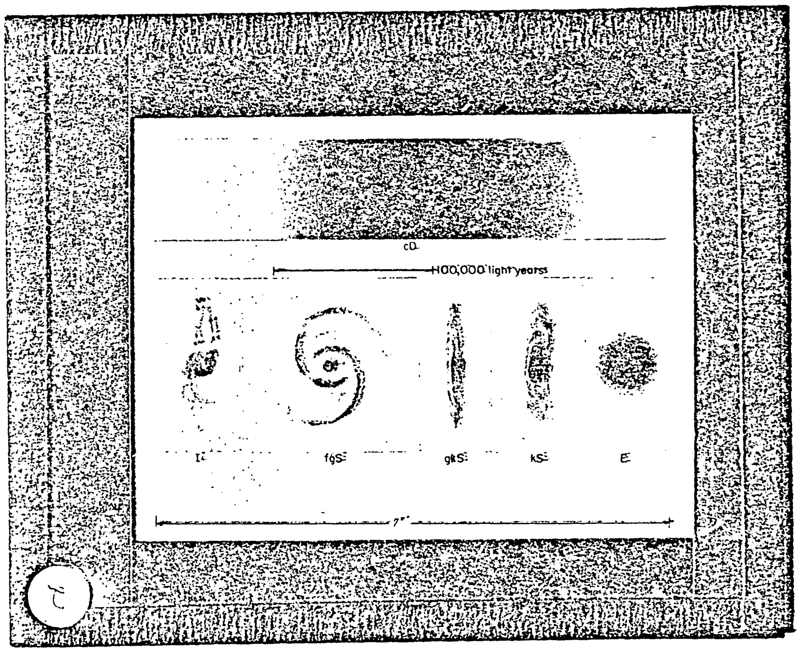
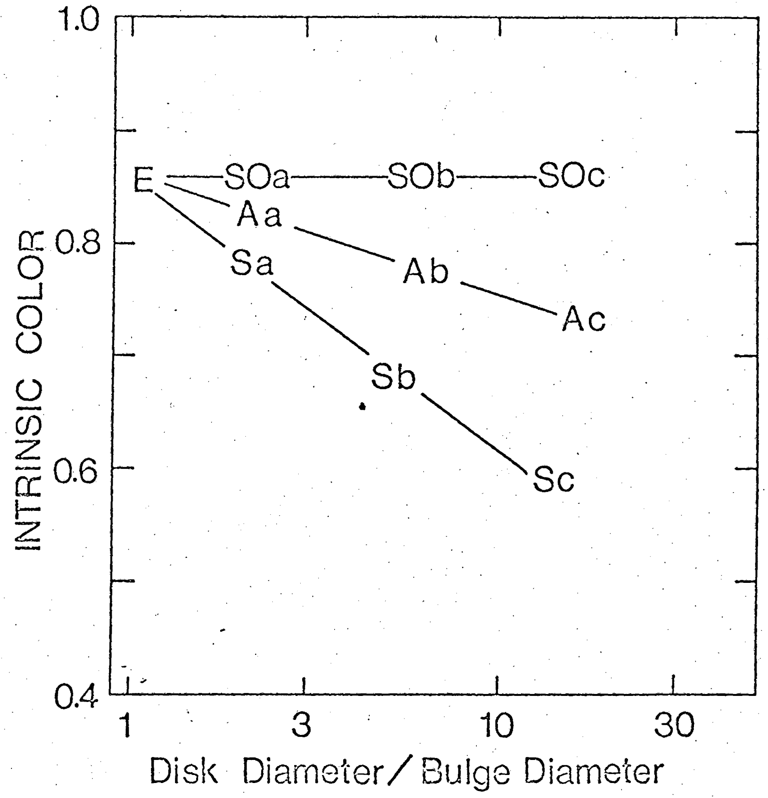


FIGURE 6


1.0
0.8
0.6
0.4
INTRINSIC COLOR
1
3
10
30
Disk Diameter / Bulge Diameter
E
SOa
SOb
SOc
Aa
Ab
Ac
Sa
Sb
Sc

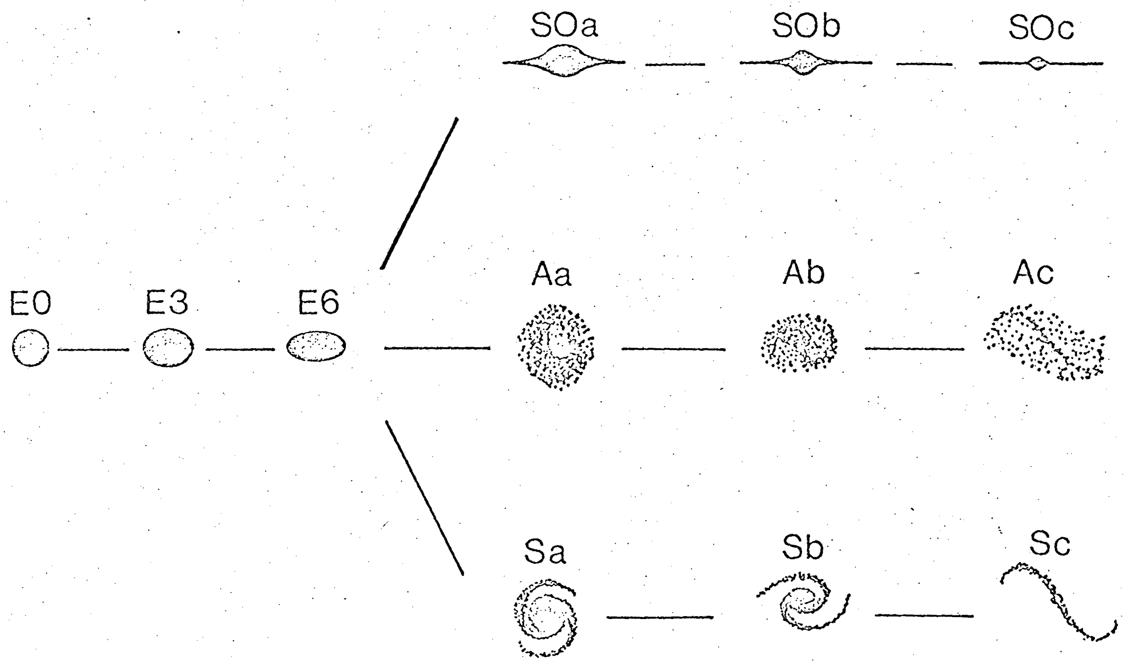

SOa
SOb
SOc
E0
E3
E6
Aa
Ab
Ac
Sa
Sb
Sc

FIGURE 7

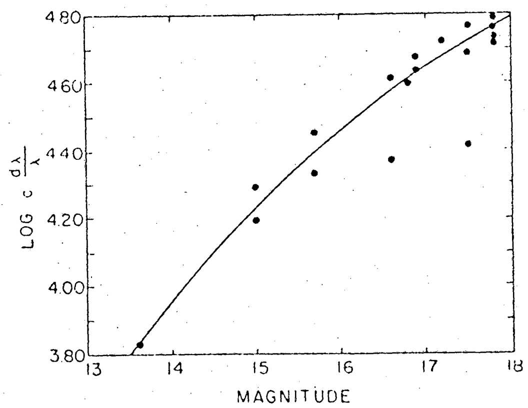


FIG. 3.—*Ordinates:* log $c d\lambda/\lambda$ for clusters of measured red shift included in the catalogue; *abscissae:* photored magnitudes of tenth brightest cluster members estimated with step scale of galaxian images prior to actual compilation of catalogue.

Figure 5

DIVISION OF SAMPLE CLUSTERS AMONG ABELL DISTANCE AND RICHNESS GROUPS

Distance	Richness 0	 1	 2-5	 Total
0	0(0)	1(1)	1(1)	2(2)
1	8(8)	6(7)	4(4)	18(19)
2	0(2)	3(4)	0(0)	3(6)
3	15(48)	5(28)	2(8)	22(84)
4	1(96)	0(57)	0(13)	1(166)
Total	24(154)	15(97)	7(26)	46(277)

Note.--First number in each entry indicates number of clusters retained; number in parentheses indicates number of such clusters in Abell catalog.

NUMBERS OF CLUSTERS OF VARIOUS POPULATIONS IN THE ABELL CATALOG

Population	Number of Clusters
50- 79........	1224
80-129........	383
130-199........	68
200-299........	6
≥300..........	1

Figure 8 (continued)

SUMMARY OF ABELL CLUSTER PARAMETERS

Richness Group	Counts of Galaxies	Distance Group	Magnitude Range (10th brightest galaxy)
0	30-49	1	13.3-14.0
1	50-79	2	14.1-14.8
2	80-129	3	14.9-15.6
3	130-199	4	15.7-16.4
4	200-299	5	16.5-17.2
5	300 or over	6	17.3-18.0
		7	Over 18

Figure 9

Types of Clusters of Galaxies

In the list of clusters of galaxies the individual clusters have been characterized and divided into three groups in accordance with the following classification:

(a) Compact clusters show a single outstanding concentration among the bright member galaxies. Within this concentration ten or more galaxies appear in actual contact. Many of these clusters display a high degree of spherical symmetry.

(b) Medium compact clusters are characterized either by a single concentration where, however, the ten brightest galaxies are not in contact but separated by several of their own diameters, or by several distinct condensations, some of which may be quite compact.

(c) Open clusters contain no very obvious condensations, but in various locations the number of galaxies per square degree is at least five times as great as in the surrounding field, so that the cluster appears as a cloud superposed on the background.

Distances of Clusters

The estimated distances of the clusters are classified according to the following standards, based on the redshifts rather than on a definite distance scale:

Near: $V_s \leq 15{,}000$ km/sec
MD = medium distant: $15{,}000$ km/sec $< V_s \leq 30{,}000$ km/sec
D = distant: $30{,}000$ km/sec $< V_s \leq 45{,}000$ km/sec
VD = very distant: $45{,}000$ km/sec $< V_s \leq 60{,}000$ km/sec
ED = extremely distant: $60{,}000$ km/sec $< V_s$

The following clusters may serve as examples:

Distance	Cluster	Position	V_s
Near	Virgo	1224 + 1320	1,200 km/sec
Near	Coma A	1255 + 2820	7,400 km/sec
MD	Corona Borealis	1520 + 2754	21,000 km/sec
D	Ursa Major II	1055 + 5702	40,000 km/sec
VD	Coma B	1304 + 3110	55,000 km/sec
ED	Hydra II	0855 + 0321	61,000 km/sec

Populations and Diameters of Clusters

The population of a cluster is the number of galaxies actually counted within the outline of that cluster as given on the chart minus the estimated number of background galaxies in the same area. The diameter of the cluster is defined as that of a circle covering approximately the same area as the cluster on the original Survey plate. It is expressed in centimeters, so that it is highly important to know the exact scale of those plates, which is 672 seconds of arc or 11.2 minutes of arc per centi-

FIGURE 10

NUMBERS OF CLUSTERS OF VARIOUS POPULATIONS IN THE FIRST TWO VOLUMES OF THE *Catalogue of Galaxies and Clusters of Galaxies*

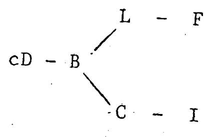
Population	<100	100–199	200–299	300–399	400–499	500–599	≥600
Near:							
Compact	0	2	2	2	0	2	6
Medium compact	6	27	27	9	8	3	14
Open	9	41	27	19	7	1	14
MD:							
Compact	1	9	10	3	2	2	1
Medium compact	25	120	48	26	14	7	10
Open	21	109	33	8	7	3	1
D:							
Compact	19	36	9	3	1	1	3
Medium compact	86	198	60	11	5	3	1
Open	50	164	24	5	1	0	0
VD:							
Compact	139	143	30	2	1	0	0
Medium compact	267	190	36	1	4	0	0
Open	95	97	12	0	0	0	0
ED:							
Compact	465	132	11	0	1	0	0
Medium compact	307	159	10	1	0	0	0
Open	36	18	0	0	0	0	0

FIGURE 11

CRITERIA AND STANDARD CLUSTERS

Type	Description	Standard (Abell No.)
I	Clusters containing a centrally located cD galaxy	2199, 2029
I–II	Intermediate	
II	Clusters where brightest galaxy or galaxies are intermediate in appearance between class cD and the Virgo-type giant ellipticals	194, 1656 (Coma), 2197
II–III	Intermediate	426 (Per), 400
III	Clusters containing no dominant galaxies. This type can be subdivided into III-E and III-S, according to the absence or presence of considerable numbers of bright spirals	Virgo, 2065 (CrB)

FIGURE 12



cD	:	cluster is dominated by a single cD galaxy. This central galaxy frequently has other smaller galaxies embedded in it. Its size should be $\geq$ 3 times that of any other galaxy in the cluster (A401, A2199).
B (binary)	:	cluster has 2 supergiant galaxies separated by $\leq$ 10 diameters of the larger galaxy. Combined size of both $\geq$ 3 times that of any other member (Coma, A154).
L (line)	:	cluster contain 3 or more of its brightest galaxies arranged in a line (A426).
C (core)	:	4 or more of top 10 brightest with comparable separations near the center (A2065).
I (irregular)	:	the cluster galaxies are distributed irregularly, or without a well-defined center (A2151, A1228)
F (flat)	:	several of the top 10 brightest and a large fraction of the fainter galaxies are distributed in a flattened configuration (A397).

Figure 13

TYPICAL CHARACTERISTICS OF REGULAR AND IRREGULAR CLUSTERS

Parameter	Regular Clusters	Irregular Clusters
Symmetry	Marked spherical symmetry	Little or no symmetry
Concentration	High concentration of members toward cluster center	No marked concentration to a unique cluster center; often two or more nuclei of concentration are present
Types of galaxies	All or nearly all galaxies in the first 3 or 4 magnitude intervals are elliptical and/or S0 galaxies.	All types of galaxies are usually present except in the poor groups, which may not contain giant ellipticals. Late-type spirals and/or irregular galaxies present
Number of member galaxies in range of brightest 7 mag	Order of 10^3 or more	Order of 10^1 to 10^3
Diameter (Mpc)	Order of 1-10	Order of 1-10
Presence of subclustering	Probably absent or unimportant	Often present. Double and multiple systems of galaxies common
Dispersion of radial velocities of members about mean for cluster	Order of 10^3 km s^{-1}	Order of 10^2–10^3 km s^{-1}
Mass derived from virial theorem (see §4)	Order of $10^{15}\mathfrak{M}_\odot$	Order of 10^{12}–$10^{14}\mathfrak{M}_\odot$
Other characteristics	Cluster often centered about one or two giant elliptical galaxies	....
Examples	Coma cluster (No. 1656); CrB cluster (No. 2065)	Local Group, M81 group, Virgo cluster, Hercules cluster (No. 2151)

Figure 14

Classification Schemes of Clusters and Related Characteristics

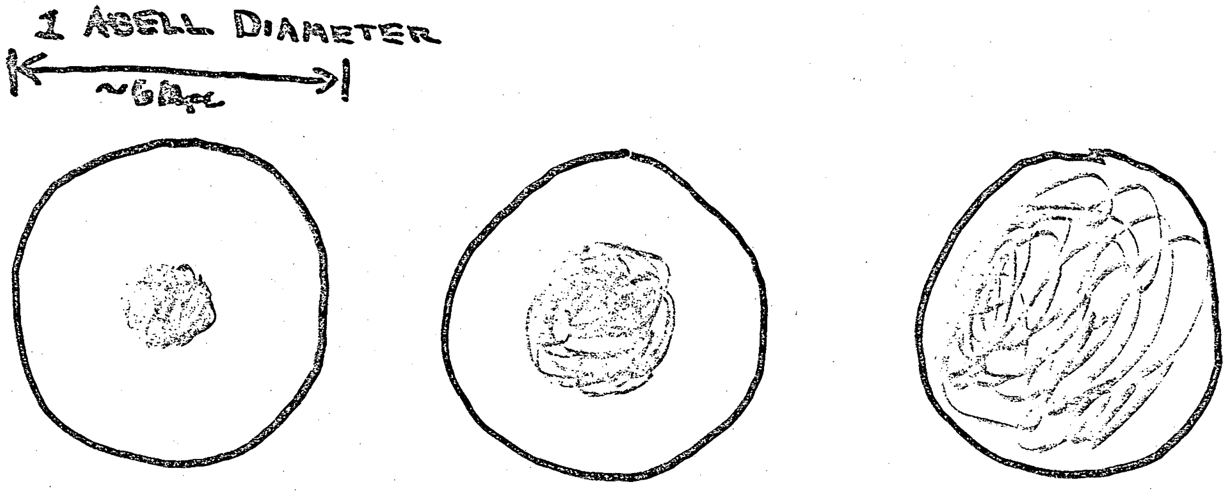
Property/class	Regular (Early)	(Intermediate)	Irregular (Late)
Zwicky type	Compact	Medium-Compact	Open
Bautz-Morgan type	I, I-II, II	(II), II-III	(II-III), III
Rood-Sastry type	cD, B, (L, C)	(L), (F), (C)	(F), I
Content	Elliptical-rich	Spiral-poor	Spiral-rich
∿E:S0:S Ratio	3:4:2	1:4:2	1:2:3
Symmetry	Spherical	(Intermediate)	Irregular shape
Central Concentration	High	Moderate	Very little
Central profile	Steep gradient	(Intermediate)	Flat gradient
Mass segregation	Marginal evidence for $m-m(1) \lesssim 2$ mag	Marginal evidence for $m-m(1) \leq 2$ mag	No segregation
Radio emission (*)	∿50% detection rate	∿50% detection rate	∿25% detection rate
L_R	High	Low	Low
X-ray emission (†)	∿33% detection rate	∿8% detection rate	∿8% detection rate
L_X	High	Intermediate	Low
Examples	A2199, Coma	A194, A539	Virgo, A1228

NOTES: (*) to 0.2 f.u. at 1.4 GHz (Owen 1975). Abell clusters with $z \leq 0.07$

(†) from data on the 3U catalog (Giacconi _et al_. 1974).

FIGURE 15

GALAXY CLUSTERS



compact distribution of the brighter galaxies		open, non-compact distribution of the bright galaxies
type content dominated by E, R late type systems	E, R, and late type spirals	many spirals and the spirals are systematically earlier

increasing proportion of spirals →

the average spiral galaxy becomes earlier in type

← Direction of dynamical and galaxy type evolution ??

This sequence is *not* a sequence of Bautz-Morgan types.