

HARVARD COLLEGE OBSERVATORY

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A Stellar System of a New Type. — A large rich cluster with remarkable characteristics appears on photographs received from the Boyden Station. Since nothing quite like it is now known, a detailed though preliminary description is given in the following pages. First noted on a long-exposure Bruce plate, the assembly of hazy images near the plate limit was thought to be an extended cluster of galaxies, such as the well-known system in Coma. Subsequent photographs made with the southern 60-inch reflector show, however, that the individual members are stars rather than spheroidal galaxies.

The position of the center of the new cluster in the constellation of Sculptor is $0^h 55^m.4$, $-34^\circ 14'$ (1900), about 2° south of σ Sculptoris; galactic coordinates are 243° and -83° . On first inspection the clustering of images appears to be half a degree in diameter, and circularly symmetrical, without conspicuous central condensation. Intermingled with the faint star images are a number of recognizable images of external galaxies. The most outstanding feature of the group is the extreme faintness of the brightest individual members. The Cramer Hi-Speed plate on which the object was first noted was of abnormal sensitiveness; if it had been of average speed, and sky conditions also average, the Sculptor cluster would not have been found. Using the star-count method, and making carefully the necessary extrapolations required for this high latitude and for such faint magnitudes, we find that stars are shown to magnitude 19.5, or perhaps one- or two-tenths of a magnitude fainter.

It has been impossible to duplicate effectively with the Bruce telescope the

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original three-hour plate, A 18005, which was made on September 25, 1935, by Mr. de Villiers; but an exposure of four hours on July 15, 1937, under moderate seeing conditions (A 19578), showing stars to magnitude 19.2, also records a few thousand individual objects in the cluster.

OBSERVATIONS

1. In the early study of the Sculptor cluster it was important to establish the reality of the system — to make sure that the images on the Bruce plate did not arise from some peculiarly defective emulsion. Before photographs with the southern 60-inch reflector could be made, verification was obtained from the southern patrol plates. It is of interest that the scores of available plates made with the telescopes of intermediate size show no trace of the cluster, whereas the largest instruments (24-inch and 60-inch) can record its individual stars, and the very small cameras, with sufficiently long exposures, although not reaching within four magnitudes of the individual stars, can record the cluster as a whole, thanks to the small scale of the plate.

A plate of the AK series, No. 521, made intermittently on the five nights of October 9, 10, 12, 13, and 14, 1908, with a total exposure of $23^h 16^m$, shows the Sculptor cluster as a faint patch of light. If the position had not already been known, the object would have escaped detection, or would have been classed as one of the frequent density variations of background on photographic plates. The plate was made by Professor Bailey with a 1-inch lens of 13-inches focal length when he was on a site-testing expedition to South Africa. The more modern and faster patrol-camera plates, such as those made with the 3-inch Zeiss-Tessar lens or the 3-inch Ross-Lundin lens, show the cluster better. From two such plates, each of three hours exposure, microdensitometer tracings have been made, but since the plates are not calibrated, they can give little useful information on the total amount or distribution of light in the cluster. They show that the diameter exceeds half a degree, but they do not establish as large angular dimensions as the star counts described below.

2. There is no nucleus in the Sculptor cluster or conspicuous central star or stars. The concentration of images does not prevent satisfactory star counting on the Bruce plate, except at the faintest limit. There is probably little or no Eberhard effect.

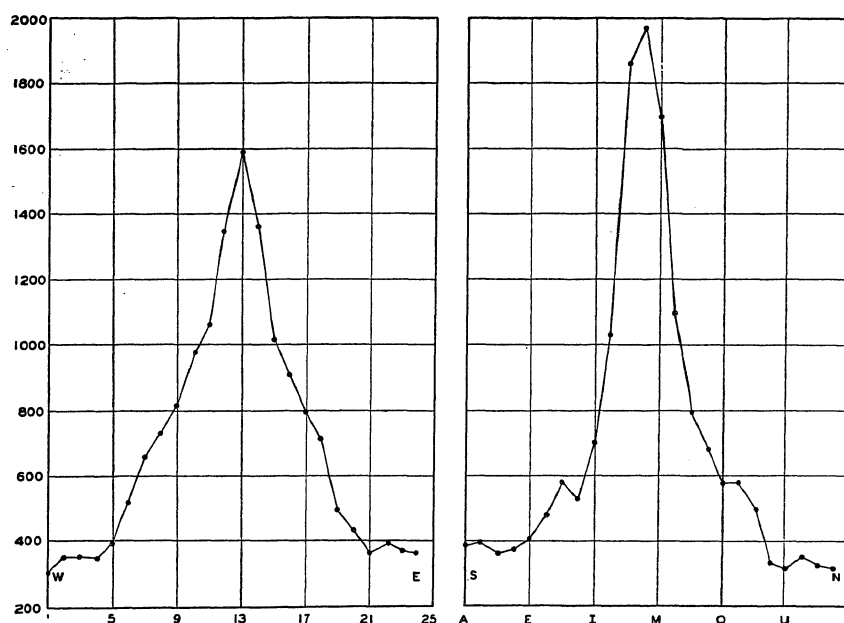


FIGURE 1.- ASYMMETRY OF SCULPTOR CLUSTER

T A B L E I

DISTRIBUTION OF STARS OVER FOUR SQUARE DEGREES

		S																								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
A		15	17	19	17	13	15	19	13	19	17	20	16	17	15	12	20	23	16	13	20	14	11	14	13	368
B		12	16	15	16	13	31	17	18	9	14	16	13	16	16	15	19	25	15	18	17	16	16	11	18	392
C		17	16	18	16	11	26	15	15	15	17	15	14	12	13	8	19	20	17	20	11	12	12	17	9	365
D		16	14	18	17	18	23	15	18	15	11	10	18	12	12	9	17	19	11	26	15	12	16	15	14	371
E		16	18	21	15	13	26	16	19	16	25	15	19	11	18	9	16	17	13	21	22	12	21	15	11	405
F		15	14	17	18	15	16	15	21	24	30	25	17	25	30	17	18	21	13	22	28	21	22	16	15	475
G		14	20	13	8	17	16	29	32	38	26	26	19	32	29	36	26	33	33	25	17	26	17	23	26	581
H		10	19	13	22	21	22	27	19	26	23	22	21	28	31	26	36	22	27	21	23	20	20	18	14	531
I		13	14	10	10	11	32	39	39	36	40	40	48	67	44	33	30	44	40	25	17	12	18	11	24	697
J		12	11	12	10	16	22	48	46	53	68	74	101	128	109	74	64	51	47	18	15	12	18	13	16	1038
K		10	8	20	15	14	35	54	69	85	121	135	203	272	224	152	135	99	73	26	26	19	15	28	15	1853
L		9	10	8	15	18	23	46	61	89	125	189	258	332	259	154	123	95	60	25	14	17	14	13	11	1968
M		13	15	14	16	22	27	65	67	77	112	165	220	242	188	186	95	63	56	23	20	20	19	21	16	1702
N		7	14	11	13	25	24	46	51	57	77	92	114	137	105	83	53	35	44	19	20	17	21	11	13	1089
O		16	14	14	10	10	26	28	43	51	43	39	73	65	74	60	60	40	30	18	11	16	15	19	12	787
P		16	20	12	23	24	22	37	36	40	41	38	54	48	38	33	31	23	29	24	25	18	14	18	17	681
Q		11	12	16	23	18	13	23	32	22	33	31	33	33	37	33	31	26	42	29	19	11	13	13	19	573
R		9	12	19	15	12	16	32	26	40	38	35	29	28	34	38	21	26	31	30	19	19	14	17	15	575
S		16	21	16	15	25	23	17	18	27	26	18	17	21	16	20	32	19	27	27	16	15	21	20	20	493
T		17	16	13	11	17	12	11	20	17	14	11	13	13	14	18	9	12	16	11	13	13	12	11	14	328
U		10	12	13	14	13	13	12	19	16	15	13	10	13	12	12	11	22	17	13	16	11	12	7	7	313
V		16	14	19	11	14	16	17	16	14	12	10	13	15	11	16	13	18	19	14	16	8	17	12	16	347
W		10	12	12	14	13	23	15	17	10	15	11	16	8	13	11	10	16	20	16	15	7	14	13	13	324
X		9	15	13	8	16	11	15	14	14	17	11	17	11	10	14	13	15	15	15	14	12	13	12	12	316
		309	356	389	658	810			1061			1586			1009			784			499			360	368	
		354	352	513	729	960			1356			1352			902			711			429			385	360	

N

In order to set up a magnitude scale, extensive star counts have been made to various magnitude limits in the surrounding field, and the population in the cluster has also been counted to the same limits. Brighter than magnitude 18.2, the excess of objects in the cluster over the average field in this latitude is just less than 100. Of these brighter objects of the cluster, many probably represent the combination of two or more images. It appears safe to conclude that on the basis of the photometric system now available the brightest individual objects in the cluster are of magnitude 18.0. Down to and including magnitude 18.7 there are about 700 cluster stars. From that magnitude the number increases with astonishing rapidity, producing a luminosity curve not unlike that of globular star clusters that are free of highly luminous members — ω Centauri, for example.

3. On the discovery plate, A 18005, a total of 2059 external galaxies have been marked, exclusive of the objects in the one square degree that includes most of the Sculptor cluster, which is a degree from the center of the plate. The average number of external galaxies per square degree is 97 (for the central nine square degrees, the numbers range from 71 to 159). Careful examination of the one square degree occupied by the main part of the cluster shows 129 objects that appear not to be stellar, and are, presumably, normal members of the population of galaxies. Probably none of these background nebulae is physically associated with the Sculptor cluster. Likewise the distribution of galactic foreground stars over the area occupied by the cluster is, to the eighteenth magnitude, uniform with the distribution in the surrounding areas.

4. In Figure 1, and Table I, the results of the star counts to the limit of the plate A 18005 are given for the four square degrees that include the cluster centrally. Field stars to the limiting magnitude 19.5, as well as cluster stars, are of course included in the count, but the background of approximately 400 faint external galaxies has been omitted.

Each number in Table I gives the total census of objects in an area 5' on a side. From the tabulation it appears that the reticle used in the counting was centered about 7' northwest of the point of maximum density in the cluster. The total number of stars is 16,592.

The totals plotted in Figure 1 represent strips each 5' wide and 2° long taken in both the east-west and north-south directions. It appears that the total diameter

TABLE II

ELONGATION OF CENTRAL PART OF SCULPTOR CLUSTER												
		Center	5'	10'	15'	20'	25'	30'	35'	40'	45'	50'
Totals for		n	1853	1038	697	531	581	475	405	371	365	392
E-W strips	1968	s	1702	1089	787	681	573	575	493	328	313	347
		mean	1777	1064	742	606	577	525	449	349	339	370
Totals for		w	1356	1061	960	810	729	658	513	389	352	356
N-S strips	1586	e	1352	1009	902	784	711	499	429	360	385	368
		mean	1354	1035	931	797	720	578	471	375	368	362
Differences												
of Means	+382		+423	+29	-189	-191	-143	-53	-22	-26	-29	+8

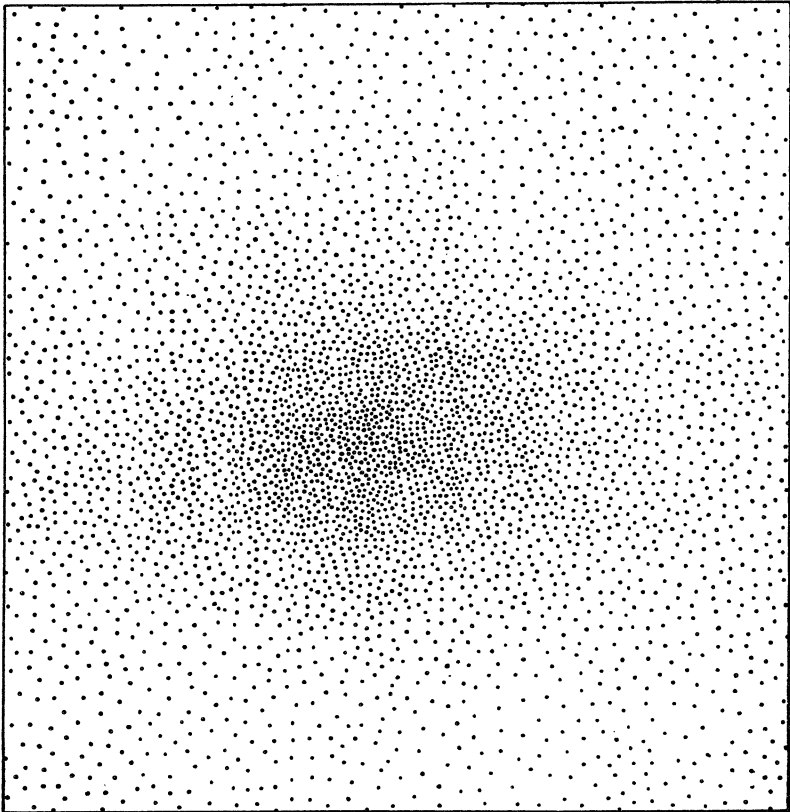


FIGURE 2.— DISTRIBUTION OF STARS IN CENTRAL SQUARE DEGREE

of the cluster is not less than $80'$. There is some indication from the star counts that for the faintest magnitudes obtainable the diameter may approach 2° . Counts to the brighter magnitude limits show that the most luminous objects are more highly concentrated toward the center of the cluster, even over this relatively small observed interval of 1.5 magnitudes.

Although a general inspection of the plate does not show the large diameter revealed by the star count, it does show clearly the east-west elongation of the cluster. Apparently the elongation holds only near the center. At distances greater than $20'$ from the center the east-west elongation disappears and the outline is sensibly circular.

Thus we have from Table I the assemblage of totals in Table II, and the diagram in Figure 2 for the central square degree, in which the number of observed stars in each twenty-five square minutes of arc is represented by two-fifths as many dots.

5. The star counts within two- or three-tenths of a magnitude of the plate limit are difficult, and therefore the data in Table I will not bear too close analysis. On the other hand, fairly accurate magnitude estimates can be made on the Bruce plate to the nineteenth magnitude. With sequences based on star counts, the magnitudes of nearly four thousand of the brighter objects in the central square degree have been estimated by Miss Boyd. Their distribution is given in Table III, which shows at each tenth of a magnitude the total number, N_m , of stars to that limit.

In Figure 3 the photographic magnitude is plotted against $\log N_m$. The value $\log N_m = 3.98$ for $19^m.5$ is obtained from Table I. The circles represent values of $\log N_m$ from van Rhijn's tables for the galactic coordinates 271° and -81° , the points for magnitudes fainter than 18.0 representing a linear extrapolation from his tabulated values. The close representation of the counts by van Rhijn's tables is not surprising, since the magnitude sequence has been based on the van Rhijn system.

From Figure 3 we conclude that the Bruce plate shows 8,400 cluster members brighter than magnitude 19.6 within the central square degree. We estimate that in the whole cluster there are, in round numbers, 10,000 members brighter than this magnitude.

6. The study of two additional plates should be summarized. The four-hour Bruce plate A 19578 shows 4618 stars in the central square degree, and 7184 for the

TABLE III

THE MAGNITUDES OF 3767 STARS IN THE SCULPTOR CLUSTER

Mag. Limit	No. to Limit	Mag. Limit	No. to Limit	Mag. Limit	No. to Limit	Mag. Limit	No. to Limit
15.7	161	16.6	276	17.5	403	18.4	1031
15.8	169	16.7	288	17.6	434	18.5	1167
15.9	184	16.8	300	17.7	466	18.6	1279
16.0	197	16.9	316	17.8	491	18.7	1432
16.1	206	17.0	340	17.9	567	18.8	1632
16.2	213	17.1	354	18.0	644	18.9	2038
16.3	232	17.2	360	18.1	674	19.0	2835
16.4	256	17.3	380	18.2	759	19.1	3767
16.5	272	17.4	396	18.3	860		

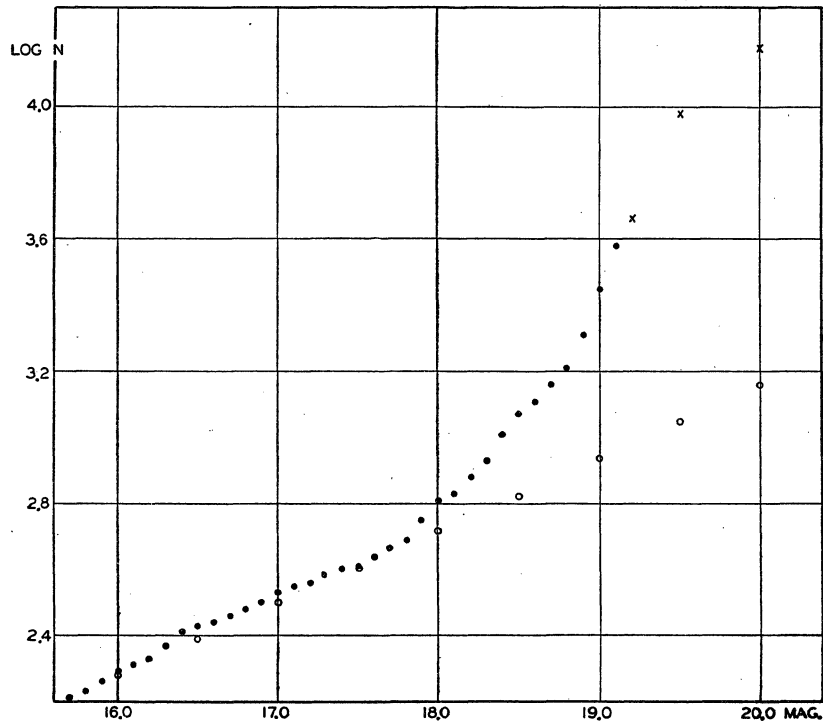


FIGURE 3. - LUMINOSITY CURVE OF SCULPTOR CLUSTER

four square degrees analogous to the area covered in Table I for A 18005. The magnitude limit has been determined from star counts, and checked by comparison with the sequence of stars on A 18005. From the star count in the one-ninth of a square degree in each corner of the four-square degree area, the magnitude limit is 19.4; from counts in two square degrees outside the four-square, the limit is 19.0. We adopt 19.2, noting the uncertainty; and the corresponding point, with log

TABLE IV
DISTRIBUTION OF STARS FOR CENTRAL SQUARE DEGREE ON A 19578

11	10	9	13	8	8	9	4	6	12	9	6	105
10	4	10	13	9	7	5	9	8	10	10	5	100
13	8	10	11	16	17	21	14	6	13	17	10	156
21	18	14	26	20	55	63	45	27	17	13	15	334
10	24	28	24	65	120	137	103	73	33	12	11	640
23	17	25	67	126	205	224	134	68	54	24	18	985
18	28	42	79	121	166	197	152	87	48	26	17	981
16	13	28	44	72	94	111	80	62	35	20	22	597
17	24	30	23	27	58	39	34	47	20	13	20	352
14	16	10	13	20	14	19	11	9	10	7	16	159
11	15	9	12	6	11	10	10	11	6	6	14	121
11	6	7	12	4	8	7	12	5	7	5	4	88
175	183	222	337	494	763	842	608	409	265	162	158	

$N_m = 3.66$, is plotted as a cross in Figure 3. The close conformity with the results from A 18005 is perhaps accidental. The distribution of stars over the inner square degree on plate A 19578 is shown in Table IV.

A two-hour plate with the 60-inch reflector, SB 1258, recently made on the center of the Sculptor cluster by Dr. Paraskevopoulos, extends the survey to the twentieth magnitude. The reflector plate verifies the stellar character of the images. It indicates perhaps that the rate of increase in number with decreasing brightness has diminished, but such a conclusion depends directly on the adopted limit for the reflector plate, which is, relative to the limits of the Bruce plates, uncertain by one- or two-tenths of a magnitude.

Comparing a central area of 76.7 square minutes on the reflector plate with the same area on the two Bruce plates, we find that the number of stars increases by 125 and 75. If there is a proportional increase over the whole inner square degree (a dangerous extrapolation), to the magnitude limit of SB 1258 there are 15,000 stars. The corresponding $\log N_m = 4.18$ for $m = 20.0$ is plotted with hesitation in Figure 3.

DISCUSSION

7. From the observations now available the data that will be most useful in the interpretation of the Sculptor cluster are the following:

(a) The location is high in the south galactic polar cap where there is essential freedom from space-absorption uncertainties, and where the confusion with foreground stars is at a minimum.

(b) The diameter is not less than $80'$; the outer boundary is roughly circular, but within twenty minutes of the center the density contours are distinctly elongated in the east-west direction (Fig. 2).

(c) The central concentration is comparable to that in certain globular clusters, and in some of the spheroidal galaxies. The brighter objects appear more concentrated than those near the plate limits. There is no sharp nucleus, and there are no conspicuous nuclear stars. There are no obvious sub-clusters or irregular nebulae.

(d) The photographic magnitudes of the brightest members (all of which appear to be stellar) are near 18.0, and the luminosity curve rises so steeply that in the interval from 18.0 to 19.5 there are about 10,000 objects.

(e) The surface brightness is remarkably low; the total magnitude is difficult to estimate from photographic plates, but must be somewhat brighter than 10. (It is noteworthy that systems such as the Sculptor cluster may not be uncommon; their luminosity characteristics would enable them to escape easy discovery.)

8. If we knew the absolute luminosity of the eighteenth magnitude members of the Sculptor cluster, we could, with aid of the foregoing information, define the main characteristics of the system on an absolute scale and compare it with other stellar organizations. A projected research may yield the desired information through Cepheid variables, but in the absence of knowledge of the absolute magnitudes we may make various assumptions:

Assumption (1): *brightest stars are of absolute magnitude -1.5 .* The luminosity

maximum of stars in globular clusters has about this value. With $M = -1.5$, the distance, r , is 80 kiloparsecs (space-absorption ignored *), and the linear diameter, d , is 2000 parsecs. The integrated absolute magnitude is about -10 . The object is intergalactic, and a member of the local supergalaxy. Its form, uniform structure, and luminosity distribution are somewhat like those of an open-type globular cluster or a spheroidal galaxy. In diameter and absolute luminosity, however, it resembles the Small Magellanic Cloud or similar irregular galaxies; its surface brightness is not greatly different from that of the Magellanic type system NGC 6822.

Completely without supergiant stars, irregular nebulae, and open clusters, the Sculptor cluster differs, however, very fundamentally from the irregular, generally chaotic, Magellanic type of external galaxy†; and with a diameter more than ten times that of the average globular cluster, its population of stars brighter than absolute magnitude zero probably exceeds the combined population of a dozen globular clusters of the galactic system.

Assumption (2): *brightest stars are of absolute magnitude -6.5* . The maximum luminosity of stars in external galaxies has approximately this value. We have $m - M = 24.5$, $r = 800$ kpc, $d = 20,000$ pc. The object is beyond the bounds of the local group of galaxies. The measured diameter is matched only by gigantic systems like the Andromeda nebula and our own galaxy. It is, in a sense, an abnormally gigantic spheroidal galaxy of abnormally low surface brightness, with a uniformity, at least in superficial structure, that is not found in the giant highly-nucleated spirals.

Assumption (3): *brightest stars are of absolute magnitude $+5.5$* . No stellar system is known, aside from double and multiple stars, in which the members are of such low luminosity.‡ The modulus of 12.5 corresponds to $r = 3.2$ kpc, and $d = 80$ pc, and the system, with linear dimensions like those of a large star cluster and total absolute magnitude as faint as -3 or -4 , falls within the bounds of the galactic

* The fact that external galaxies are seen abundantly through the cluster shows that no freakish absorption is responsible for the faintness of the magnitudes.

† Dr. Baade for some years has been working at Mount Wilson on the irregular system IC 1613 (see Hubble's *Realm of the Nebulae*, p. 146 (1936), and recent Mount Wilson Annual Reports), which in some respects resembles the Sculptor cluster; but the former contains supergiant stars with absolute magnitudes up to -5.6 , irregular star clusters, and bright nebulosity, and is irregular in structure and outline.

‡ But see one interpretation by Sinclair Smith of the highly-concentrated unresolved spheroidal galaxy Messier 32, with an absolute magnitude of about -13 (Mt. W. Contr., 524, 1935).

system. The richness, 15,000 to the twentieth magnitude, is as unusual as is the luminosity function.

Assumption (4): *brightest objects are of absolute magnitude -16.5* . The integrated luminosities of the brightest members in clusters of external galaxies is of this order. We have $m - M = 34.5$, $r = 80,000$ kpc, $d = 2,000,000$ pc, and the Sculptor cluster is a system composed exclusively (to magnitude 20) of highly condensed spheroidal galaxies, and with twenty times the population of any other known cluster of galaxies.

9. The photographs with the 60-inch reflector make Assumption (4) appear impossible; the eighteenth magnitude cluster members can be compared on the Bruce plates directly with the eighteenth magnitude spheroidal galaxies in the immediate neighborhood, and with the eighteenth magnitude field stars a degree or so away. The stellar nature of the cluster members is practically beyond doubt. Assumption (3) — an astounding rich cluster of dwarf stars within the galactic system — is also extremely improbable.

The first assumption, $M_{18} = -1.5$, seems preferable. It presents the Sculptor cluster as a super-cluster of the globular type and of galactic dimensions; or a symmetrical Magellanic Cloud devoid of its characteristic bright stars, clusters, and luminous diffuse nebulosity; or a nearby spheroidal galaxy, highly resolved, and of abnormally low surface brightness. These phrases are merely different ways of describing the same thing and of pointing out the uniqueness of the object. We may have here a transition type of stellar system.

Several colleagues have helped in various details of this investigation. The assistance of Dr. J. S. Paraskevopoulos, Mrs. S. F. Lindsay, and Miss Constance D. Boyd should be especially acknowledged.

Harlow Shapley

The Radiometric Magnitude of Epsilon Aurigae. — Kuiper, Struve, and Ström-gren (Ap.J., 86, 570, 1937) have proposed a theory of ϵ Aurigae in which the companion of the cF2 star * is a large, semi-transparent star of low temperature. During the phase of total eclipse, the visual light originates in the eclipsed cF2 star. To

* This spectrum is according to the Mt. Wilson classification (Adams, Joy, Humason and Brayton, Ap.J., 81, 187, 1935).