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BULLETIN
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NATIONAL RESEARCH COUNCIL

THE SCALE OF THE UNIVERSE

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PART I

BY HARLOW SHAPLEY

EVOLUTION OF THE IDEA OF GALACTIC SIZE

The physical universe[1] was anthropocentric to primitive man. At a subsequent stage of intellectual progress it was centered in a restricted area on the surface of the earth. Still later, to Ptolemy and his school, the universe was geocentric; but since the

*This address and the following one by Dr. Heber D. Curtis are adapted from illustrated lectures given on the William Ellery Hale Foundation before the National Academy of Sciences, April 26, 1920. The authors have exchanged papers in preparing them for publication in order that each might have the opportunity of considering the point of view of the other.

[1]The word "universe" is used in this paper in the restricted sense, as applying to the total of sidereal systems now known to exist.

time of Copernicus the sun, as the dominating body of the solar system, has been considered to be at or near the center of the stellar realm. With the origin of each of these successive conceptions, the system of stars has ever appeared larger than was thought before. Thus the significance of man and the earth in the sidereal scheme has dwindled with advancing knowledge of the physical world, and our conception of the dimensions of the discernible stellar universe has progressively changed. Is not further evolution of our ideas probable? In the face of great accumulations of new and relevant information can we firmly maintain our old cosmic conceptions?

As a consequence of the exceptional growth and activity of the great observatories, with their powerful methods of analyzing stars and of sounding space, we have reached an epoch, I believe, when another advance is necessary; our conception of the galactic system must be enlarged to keep in proper relationship the objects our telescopes are finding; the solar system can no longer maintain a central position. Recent studies of clusters and related subjects seem to me to leave no alternative to the belief that the galactic system is at least ten times greater in diameter—at least a thousand times greater in volume—than recently supposed.

Dr. Curtis,[1] on the other hand, maintains that the galactic system has the dimensions and arrangement formerly assigned it by students of sidereal structure—he supports the views held a decade or so ago by Newcomb, Charlier, Eddington, Hertzsprung, and other leaders in stellar astronomy. In contrast to my present estimate of a diameter of at least three hundred thousand light-years Curtis outlines his position as follows:[2]

> As to the dimensions of the galaxy indicated by our Milky Way, till recently there has been a fair degree of uniformity in the estimates of those who have investigated the subject. Practically all have deduced diameters of from 7,000 to 30,000 light-years. I shall assume a maximum galactic diameter of 30,000 light-years as representing sufficiently well this older view to which I subscribe though this is pretty certainly too large.

I think it should be pointed out that when Newcomb was writing on the subject some twenty years ago, knowledge of those special factors that bear directly on the size of the universe was extremely fragmentary compared with our information of to-day.

[1]See Part II of this article, by Heber D. Curtis.

[2]Quoted from a manuscript copy of his Washington address.

In 1900, for instance, the radial motions of about 300 stars were known; now we know the radial velocities of thousands. Accurate distances were then on record for possibly 150 of the brightest stars, and now for more than ten times as many. Spectra were then available for less than one-tenth of the stars for which we have the types to-day. Practically nothing was known at that time of the photometric and spectroscopic methods of determining distance; nothing of the radial velocities of globular clusters or of spiral nebulae, or even of the phenomenon of star streaming.

As a further indication of the importance of examining anew the evidence on the size of stellar systems, let us consider the great globular cluster in Hercules—a vast sidereal organization concerning which we had until recently but vague ideas. Due to extensive and varied researches, carried on during the last few years at Mount Wilson and elsewhere, we now know the positions, magnitudes, and colors of all its brightest stars, and many relations between color, magnitude, distance from the center, and star density. We know some of these important correlations with greater certainty in the Hercules cluster than in the solar neighborhood. We now have the spectra of many of the individual stars, and the spectral type and radial velocity of the cluster as a whole. We know the types and periods of light variation of its variable stars, the colors and spectral types of these variables, and something also of the absolute luminosity of the brightest stars of the cluster from the appearance of their spectra. Is it surprising, therefore, that we venture to determine the distance of Messier 13 and similar systems with more confidence than was possible ten years ago when none of these facts was known, or even seriously considered in cosmic speculations?

If he were writing now, with knowledge of these relevant developments, I believe that Newcomb would not maintain his former view on the probable dimensions of the galactic system.

For instance, Professor Kapteyn has found occasion, with the progress of his elaborate studies of laws of stellar luminosity and density, to indicate larger dimensions of the galaxy than formerly accepted. In a paper just appearing as *Mount Wilson Contribution*, No. 188,[1] he finds, as a result of the research extending over some 20 years, that the density of stars along the galactic plane is quite appreciable at a distance of 40,000 light-years—giving a

[1]The *Contribution* is published jointly with Dr. van Rhijn.

diameter of the galactic system, exclusive of distant star clouds of the Milky Way, about three times the value Curtis admits as a maximum for the entire galaxy. Similarly Russell, Eddington, and, I believe, Hertzsprung, now subscribe to larger values of galactic dimensions; and Charlier, in a recent lecture before the Swedish Astronomical Association, has accepted the essential features of the larger galaxy, though formerly he identified the local system of B stars with the whole galactic system and obtained distances of the clusters and dimension of the galaxy only a hundredth as large as I derive.

SURVEYING THE SOLAR NEIGHBORHOOD

Let us first recall that the stellar universe, as we know it, appears to be a very oblate spheroid or ellipsoid—a disk-shaped system composed mainly of stars and nebulae. The solar system is not far from the middle plane of this flattened organization which we call the galactic system. Looking away from the plane we see relatively few stars; looking along the plane, through a great depth of star-populated space, we see great numbers of sidereal objects constituting the band of light we call the Milky Way. The loosely organized star clusters, such as the Pleiades, the diffuse nebulae such as the great nebula of Orion, the planetary nebulae, of which the ring nebula in Lyra is a good example, the dark nebulosities—all these sidereal types appear to be a part of the great galactic system, and they lie almost exclusively along the plane of the Milky Way. The globular clusters, though not in the Milky Way, are also affiliated with the galactic system; the spiral nebulae appear to be distant objects mainly if not entirely outside the most populous parts of the galactic region.

This conception of the galactic system, as a flattened, watch-shaped organization of stars and nebulae, with globular clusters and spiral nebulae as external objects, is pretty generally agreed upon by students of the subject; but in the matter of the distances of the various sidereal objects—the size of the galactic system—there are, as suggested above, widely divergent opinions. We shall, therefore, first consider briefly the dimensions of that part of the stellar universe concerning which there is essential unanimity of opinion, and later discuss in more detail the larger field,

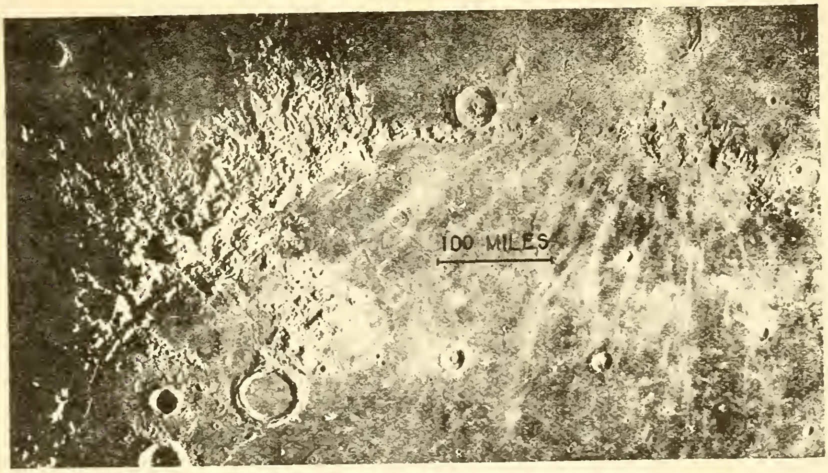

FIG. 1.—The region of the Apennines on the surface of the moon as photographed with the 100-inch reflector. Photograph by F. G. Pease.

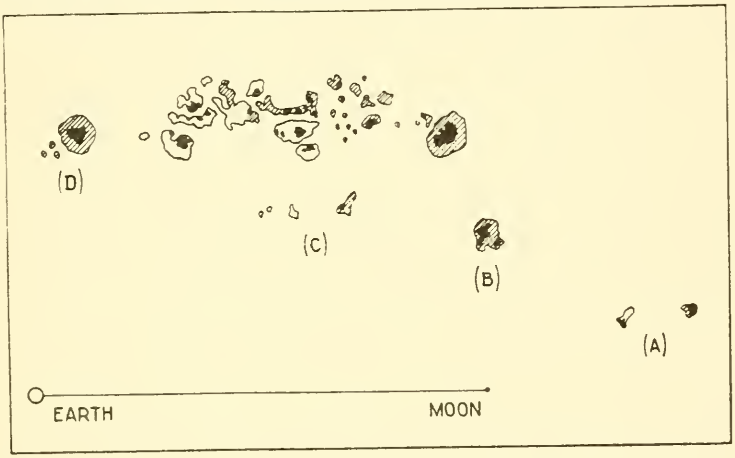

FIG. 2.—A group of sun-spots first appearing in February 1920 and lasting for about 100 days. The shaded and unshaded regions indicate magnetic polarities of opposite signs. Drawing by S. B. Nicholson.

FIG. 3.—Two successive photographs on the same plate of the diffuse nebula N. G. C. 221, made with the 100-inch reflector to illustrate the possibility of greatly increasing the photographic power of a large reflector through the use of accessory devices. The exposure time for the picture on the left was fifteen minutes; it was five minutes for the picture on the right, which was made with the aid of the photographic intensifier described in *Proc. Nat. Acad. Sci.*, 6, 127, 1920. In preparing the figure the two photographs were enlarged to the same scale.

where there appears to be a need for modification of the older conventional view.

Possibly the most convenient way of illustrating the scale of the sidereal universe is in terms of our measuring rods, going from terrestrial units to those of stellar systems. On the earth's surface we express distances in units such as inches, feet, or miles. On the moon, as seen in the accompanying photograph made with the 100-inch reflector, the mile is still a usable measuring unit; a scale of 100 miles is indicated on the lunar scene.

Our measuring scale must be greatly increased, however, when we consider the dimensions of a star—distances on the surface of our sun, for example. The large sun-spots shown in the illustration cannot be measured conveniently in units appropriate to earthly distance—in fact, the whole earth itself is none too large. The unit for measuring the distances from the sun to its attendant planets, is, however, 12,000 times the diameter of the earth; it is the so-called astronomical unit, the average distance from earth to sun. This unit, 93,000,000 miles in length, is ample for the distances of planets and comets. It would probably suffice to measure the distances of whatever planets and comets there may be in the vicinity of other stars; but it, in turn, becomes cumbersome in expressing the distances from one star to another, for some of them are hundreds of millions, even a thousand million, astronomical units away.

This leads us to abandon the astronomical unit and to introduce the light-year as a measure for sounding the depth of stellar space. The distance light travels in a year is something less than six million million miles. The distance from the earth to the sun is, in these units, eight light-minutes. The distance to the moon is 1.2 light-seconds. In some phases of our astronomical problems (studying photographs of stellar spectra) we make direct microscopic measures of a ten-thousandth of an inch; and indirectly we measure changes in the wave-length of light a million times smaller than this; in discussing the arrangement of globular clusters in space, we must measure a hundred thousand light-years. Expressing these large and small measures with reference to the velocity of light, we have an illustration of the scale of the astronomer's universe—his measures range from the trillionth of a billionth part of one light-second, to more than a thousand light-centuries. The ratio of the greatest measure to the smallest is as 10^{33} to 1.

It is to be noticed that light plays an all-important rôle in the study of the universe; we know the physics and chemistry of stars only through their light, and their distance from us we express by means of the velocity of light. The light-year, moreover, has a double value in sidereal exploration; it is geometrical, as we have seen, and it is historical. It tells us not only how far away an object is, but also how long ago the light we examine was started on its way. You do not see the sun where it is, but where it was eight minutes ago. You do not see faint stars of the Milky Way as they are now, but more probably as they were when the pyramids of Egypt were being built; and the ancient Egyptians saw them as they were at a time still more remote. We are, therefore, chronologically far behind events when we study conditions or dynamical behavior in remote stellar systems; the motions, light-emissions, and variations now investigated in the Hercules cluster are not contemporary, but, if my value of the distance is correct, they are the phenomena of 36,000 years ago. The great age of these incoming pulses of radiant energy is, however, no disadvantage; in fact, their antiquity has been turned to good purpose in testing the speed of stellar evolution, in indicating the enormous ages of stars, in suggesting the vast extent of the universe in time as well as in space.

Taking the light-year as a satisfactory unit for expressing the dimensions of sidereal systems, let us consider the distances of neighboring stars and clusters, and briefly mention the methods of deducing their space positions. For nearby stellar objects we can make direct trigonometric measures of distance (parallax), using the earth's orbit or the sun's path through space as a base line. For many of the more distant stars spectroscopic methods are available, using the appearance of the stellar spectra and the readily measurable apparent brightness of the stars. For certain types of stars, too distant for spectroscopic data, there is still a chance of obtaining the distance by means of the photometric method. This method is particularly suited to studies of globular clusters; it consists first in determining, by some means, the real luminosity of a star, that is, its so-called absolute magnitude, and second, in measuring its apparent magnitude. Obviously, if a star of known real brightness is moved away to greater and greater distances, its apparent brightness decreases; hence, for such stars of known absolute magnitude, it is possible, using a simple formula, to determine the distance by measuring the apparent magnitude.

It appears, therefore, that although space can be explored for a distance of only a few hundred light-years by direct trigonometric methods, we are not forced, by our inability to measure still smaller angles, to extrapolate uncertainly or to make vague guesses relative to farther regions of space, for the trigonometrically determined distances can be used to calibrate the tools of newer and less restricted methods. For example, the trigonometric methods of measuring the distance to moon, sun, and nearer stars are decidedly indirect, compared with the linear measurement of distance on the surface of the earth, but they are not for that reason inexact or questionable in principle. The spectroscopic and photometric methods of measuring great stellar distance are also indirect, compared with the trigonometric measurement of small stellar distance, but they, too, are not for that reason unreliable or of doubtful value. These great distances are not extrapolations. For instance, in the spectroscopic method, the absolute magnitudes derived from trigonometrically measured distances are used to derive the curves relating spectral characteristics to absolute magnitude; and the spectroscopic parallaxes for individual stars (whether near or remote) are, almost without exception, interpolations. Thus the data for nearer stars are used for purposes of calibration, not as a basis for extrapolation.

By one method or the other, the distances of nearly 3,000 individual stars in the solar neighborhood have now been determined; only a few are within ten light-years of the sun. At a distance of about 130 light-years we find the Hyades, the well known cluster of naked eye stars; at a distance of 600 light-years, according to Kapteyn's extensive investigations, we come to the group of blue stars in Orion—another physically-organized cluster composed of giants in luminosity. At distances comparable to the above values we also find the Scorpio-Centaurus group, the Pleiades, the Ursa Major system.

These nearby clusters are specifically referred to for two reasons.

In the first place I desire to point out the prevalence throughout all the galactic system of clusters of stars, variously organized as to stellar density and total stellar content. The gravitational organization of stars is a fundamental feature in the universe—a double star is one aspect of a stellar cluster, a galactic system is another. We may indeed, trace the clustering motive from the richest of isolated globular clusters such as the system in Hercules, to the loosely organized nearby groups typified in the bright stars of Ursa Major. At one hundred times its present distance, the Orion cluster would look much like Messier 37 or Messier 11; scores of telescopic clusters have the general form and star density of the Pleiades and the Hyades. The difference between bright and faint clusters of the galactic system naturally appears to be solely a matter of distance.

In the second place I desire to emphasize the fact that the nearby stars we use as standards of luminosity, particularly the blue stars of spectral type B, are members of stellar clusters. Therein lies a most important point in the application of photometric methods. We might, perhaps, question the validity of comparing the isolated stars in the neighborhood of the sun with stars in a compact cluster; but the comparison of nearby cluster stars with remote cluster stars is entirely reasonable, since we are now so far from primitive anthropocentric notions that it is foolish to postulate that distance from the earth has anything to do with the intrinsic brightness of stars.

ON THE DISTANCES OF GLOBULAR CLUSTERS

1. As stated above, astronomers agree on the distances to the nearby stars and stellar groups—the scale of the part of the universe that we may call the solar domain. But as yet there is lack of agreement relative to the distances of remote clusters, stars, and star clouds—the scale of the total galactic system. The disagreement in this last particular is not a small difference of a few percent, an argument on minor detail; it is a matter of a thousand percent or more.

Curtis maintains that the dimensions I find for the galactic system should be divided by ten or more (see quotation on page 172); therefore, that galactic size does not stand in the way of interpreting spiral nebulae as comparable galaxies (a theory that he favors on other grounds but considers incompatible with the larger values of galactic dimensions). In his Washington address, however, he greatly simplified the present discussion by accepting the results of recent studies on the following significant points:

Proposition A.—The globular clusters form a part of our galaxy; therefore the size of the galactic system proper is most probably not less than the size of the subordinate system of globular clusters.

Proposition B.—The distances derived at Mount Wilson for globular clusters *relative to one another* are essentially correct. This implies among other things that (1) absorption of light in space has not appreciably affected the results, and (2) the globular clusters are much alike in structure and constitution, differing mainly in distance. (These relative values are based upon apparent diameters, integrated magnitudes, the magnitudes of individual giants or groups of giants, and Cepheid variables; Charlier has obtained much the same results from apparent diameters alone, and Lundmark from apparent diameters and integrated magnitudes.)

Proposition C.—Stars in clusters and in distant parts of the Milky Way are not peculiar—that is, uniformity of conditions and of stellar phenomena naturally prevails throughout the galactic system.

We also share the same opinion, I believe, on the following points:

a. The galactic system is an extremely flattened stellar organization, and the appearance of a Milky Way is partly due to the existence of distinct clouds of stars, and is partly the result of depth along the galactic plane.

b. The spiral nebulae are mostly very distant objects, probably not physical members of our galactic system.

c. If our galaxy approaches the larger order of dimensions, a serious difficulty at once arises for the theory that spirals are galaxies of stars comparable in size with our own: it would be necessary to ascribe impossibly great magnitudes to the new stars that have appeared in the spiral nebulae.

2. Through approximate agreement on the above points, the way is cleared so that the outstanding difference may be clearly stated: Curtis does not believe that the numerical value of the distance I derive for any globular cluster is of the right order of magnitude.

3. The present problem may be narrowly restricted therefore, and may be formulated as follows: Show that any globular cluster

is approximately as distant as derived at Mount Wilson; then the distance of other clusters will be approximately right (see Proposition B), the system of clusters and the galactic system will have dimensions of the order assigned (see Proposition A), and the "comparable galaxy" theory of spirals will have met with a serious, though perhaps not insuperable difficulty.

In other words, to maintain my position it will suffice to show that any one of the bright globular clusters has roughly the distance in light-years given below, rather than a distance one tenth of this value or less:[1]

Cluster	Distance in light-years	Mean photographic magnitude of brightest 25 stars	
		Apparent	Absolute
Messier 13	36,000	13.75	−1.5
Messier 3	45,000	14.23	−1.5
Messier 5	38,000	13.97	−1.4
Omega Centauri	21,000	12.3:	−1.8:

Similarly it should suffice to show that the bright objects in clusters are giants (cf. last column above), rather than stars of solar luminosity.

4. From observation we know that some or all of these four clusters contain:

a. An interval of at least nine magnitudes (apparent and absolute) between the brightest and faintest stars.

b. A range of color-index from −0.5 to +2.0, corresponding to the whole range of color commonly found among assemblages of stars.

c. Stars of types B, A, F, G, K, M (from direct observations of spectra), and that these types are in sufficient agreement with the color classes to permit the use of the latter for ordinary statistical considerations where spectra are not yet known.

d. Cepheid and cluster variables which are certainly analogous to galactic variables of the same types, in spectrum, color change, length of period, amount of light variation, and all characters of the light-curve.

[1]In the final draft of the following paper Curtis has qualified his acceptance of the foregoing propositions in such a manner that in some numerical details the comparisons given below are no longer accurately applicable to his arguments; I believe, however, that the comparisons do correctly contrast the present view with that generally accepted a few years ago.

e. Irregular, red, small-range variables of the Alpha Orionis type, among the brightest stars of the cluster.

f. Many red and yellow stars of approximately the same magnitude as the blue stars, in obvious agreement with the giant star phenomena of the galactic system, and clearly in disagreement with all we know of color and magnitude relations for dwarf stars.

5. From these preliminary considerations we emphasize two special deductions:

First, a globular cluster is a pretty complete "universe" by itself, with typical and representative stellar phenomena, including several classes of stars that in the solar neighborhood are recognized as giants in luminosity.

Second, we are very fortunately situated for the study of distant clusters—outside rather than inside. Hence we obtain a comprehensive dimensional view, we can determine relative real luminosities in place of relative apparent luminosities, and we have the distinct advantage that the most luminous stars are easily isolated and the most easily studied. None of the brightest stars in a cluster escapes us. If giants or super-giants are there, they are necessarily the stars we study. We cannot deal legitimately with the average brightness of stars in globular clusters, because the faintest limits are apparently far beyond our present telescopic power. Our ordinary photographs record only the most powerful radiators—encompassing a range of but three or four magnitudes at the very top of the scale of absolute luminosity, whereas in the solar domain we have a known extreme range of 20 magnitudes in absolute brightness, and a generally studied interval of twelve magnitudes or more.

6. Let us now examine some of the conditions that would exist in the Hercules Cluster (Messier 13) on the basis of the two opposing values for its distance:

	36,000 light-years	3,600 light-years, or less
a. Mean absolute photographic magnitude of blue stars (C. I. <0.0)	0	+5, or fainter
b. Maximum absolute photographic magnitudes of cluster stars	Between −1.0 and −2.0	+3.2, or fainter
c. Median absolute photovisual magnitude of long-period Cepheids	−2	+3, or fainter
d. Hypothetical annual proper motion	0".004	0".04, or greater

a. *The blue stars.*—The colors of stars have long been recognized as characteristic of spectral types and as being of invaluable aid in the study of faint stars for which spectroscopic observations are difficult or impossible. The color-index, as used at Mount Wilson, is the difference between the so-called photographic (pg) and photovisual (pv.) magnitudes—the difference between the brightness of objects in blue-violet and in yellow-green light. For a negative color-index (C. I. = pg. − pv. < 0.0) the stars are called blue and the corresponding spectral type is B; for yellow stars, like the sun (type G), the color-index is about +0.8 mag.; for redder stars (types K, M) the color-index exceeds a magnitude.

An early result of the photographic study of Messier 13 at Mount Wilson was the discovery of large numbers of negative color-indices. Similar results were later obtained in other globular and open clusters, and among the stars of the galactic clouds. Naturally these negative color-indices in clusters have been taken without question to indicate B-type stars—a supposition that has later been verified spectroscopically with the Mount Wilson reflectors.[1]

The existence of 15th magnitude B-type stars in the Hercules cluster seems to answer decisively the question of its distance, because B stars in the solar neighborhood are invariably giants (more than a hundred times as bright as the sun, on the average), and such a giant star can appear to be of the fifteenth magnitude only if it is more than 30,000 light-years away.

We have an abundance of material on distances and absolute magnitudes of the hundreds of neighboring B's—there are direct measures of distance, as well as mean distances determined from parallactic motions, from observed luminosity curves, from stream motions, and from radial velocities combined with proper motion. Russell, Plummer, Charlier, Eddington, Kapteyn, and others have worked on these stars with the universal result of finding them giants.

Kapteyn's study of the B stars is one of the classics of modern stellar astronomy; his methods are mainly the well-tried methods generally used for studies of nearby stars. In his various lists of B's more than seventy percent are brighter than zero absolute

[1]Adams and van Maanen published several years ago the radial velocities and spectral types of a number of B stars in the double cluster in Perseus, *Ast. Jour.*, Albany, N. Y., 27, 1913 (187–188).

photographic magnitude,[1] and only two out of 424 are fainter than +3. This result should be compared with the above-mentioned requirement that the absolute magnitudes of the blue stars in Messier 13 should be +5 or fainter in the mean, if the distance of the cluster is 3,600 light-years or less, and no star in the cluster should be brighter than +3.

A question might be raised as to the completeness of the material used by Kapteyn and others, for if only the apparently bright stars are studied, the mean absolute magnitudes may be too high. Kapteyn, however, entertains little doubt on this score, and an investigation[2] of the distribution of B-type stars, based on the *Henry Draper Catalogue*, shows that faint B's are not present in the Orion region studied by Kapteyn.

The census in local clusters appears to be practically complete without revealing any B stars as faint as +5. But if the Hercules cluster were not more distant than 3,600 light-years, its B stars would be about as faint as the sun, and the admitted uniformity throughout the galactic system (Proposition C) would be gainsaid: for although near the earth, whether in clusters or not, the B stars are giants, away from the earth in all directions, whether in the Milky Way clouds or in clusters, they would be dwarfs—and the anthropocentric theory could take heart again.

Let us emphasize again that the near and the distant blue stars we are intercomparing are all cluster stars, and that there appears to be no marked break in the gradation of clusters, either in total content or in distance, from Orion through the faint open clusters to Messier 13.

b. *The maximum absolute magnitude of cluster stars.*—In various nearby groups and clusters the maximum absolute photographic brightness, determined from direct measures of parallax or stream motion or from both, is known to *exceed* the following values:

[1]Stars of types B8 and B9 are customarily treated with the A type in statistical discussion; even if they are included with the B's, 64 per cent of Kapteyn's absolute magnitudes are brighter than zero and only 4 per cent are fainter than +2. No stars of types B8 or B9 fainter than +3 are in Kapteyn's lists.

[2]Shapley, H., *Proceedings Nat. Acad. Sci.*, 5, 1900 (434–440); a further treatment of this problem is to appear in a forthcoming *Mount Wilson Contribution.*

	M
Ursa Major system	−1.0
Moving cluster in Perseus	−0.5
Hyades	+1.0
Scorpio-Centaurus cluster	−2.5
Orion nebula cluster	−2.5
Pleiades	−1.0
61 Cygni group[1]	+1.0

No nearby physical group is known, with the possible exception of the 61 Cygni drift, in which the brightest stars are fainter than +1.0. The mean M of the above list of clusters is −0.8; yet for all distant physical groups it must be +3 or fainter (notwithstanding the certain existence within them of Cepheid variables and B-type stars), if the distance of Messier 13 is 3,600 light-years or less. Even if the distance is 8,000 light-years, as Curtis suggests in the following paper, the mean M would need to be +1.4 or fainter—a value still irreconcilable with observations on nearby clusters.

The requirement that the bright stars in a globular cluster should be in the maximum only two magnitudes brighter than our sun is equivalent to saying that in Messier 13 there is not one real giant among its thirty or more thousand stars. It is essentially equivalent, in view of Proposition B, to holding that of the two or three million stars in distant clusters (about half a million of these stars have been actually photographed) there is not one giant star brighter than absolute photographic magnitude +2. And we have just seen that direct measures show that all of our nearby clusters contain such giants; indeed some appear to be composed mainly of giants.

As a further test of the distances of globular clusters, a special device has been used with the Hooker reflector. With a thin prism placed in the converging beam shortly before the focus, we may photograph for a star (or for each of a group of stars) a small spectrum that extends not only through the blue region ordinarily photographed, but also throughout the yellow and red. By using specially prepared photographic plates, sensitive in the blue and red but relatively insensitive in the green-yellow, the small spectra are divided in the middle, and the relative intensity of the blue and red parts depends, as is well known, on spectral type and

[1]The absolute visual magnitude of ϵ Virginis (spectrum G6) is 0.0 according to the Mount Wilson spectroscopic parallax kindly communicated by Mr. Adams.

absolute magnitude; giants and dwarfs, of the same type in the Harvard system of spectral classification, show markedly different spectra. The spectral types of forty or fifty of the brighter stars in the Hercules cluster are known, classified as usual on the basis of spectral lines. Using the device described above, a number of these stars have been photographed side by side on the same plate with well known giants and dwarfs of the solar neighborhood for which distances and absolute magnitudes depend on direct measures of parallax. On the basis of the smaller distance for Messier 13, the spectra of these cluster stars (being then of absolute magnitude fainter than +4) should resemble the spectra of the dwarfs. But the plates clearly show that in absolute brightness the cluster stars equal, and in many cases even exceed, the giants—a result to be expected if the distance is of the order of 36,000 light-years.

The above procedure is a variation on the method used by Adams and his associates on brighter stars where sufficient dispersion can be obtained to permit photometric intercomparison of sensitive spectral lines. So far as it has been applied to clusters, the usual spectroscopic method supports the above conclusion that the bright red and yellow stars in clusters are giants.

An argument much insisted upon by Curtis is that the average absolute magnitude of stars around the sun is equal to or fainter than solar brightness, hence, that average stars we see in clusters are also dwarfs. Or, put in a different way, he argues that since the mean spectral class of a globular cluster is of solar type and the average solar-type star near the sun is of solar luminosity, the stars photographed in globular clusters must be of solar luminosity, hence not distant. This deduction, he holds, is in compliance with proposition C—uniformity throughout the universe. But in drawing the conclusions, Curtis apparently ignores, first, the very common existence of red and yellow giant stars in stellar systems, and second, the circumstance mentioned above in Section 5 that in treating a distant external system we naturally first observe its giant stars. If the material is not mutually extensive in the solar domain and in the remote cluster (and it certainly is not for stars of all types), then the comparison of averages means practically nothing because of the obvious and vital selection of brighter stars in the cluster. The comparison should be of nearby cluster with distant cluster, or of the luminosities of the same kinds of stars in the two places.

Suppose that an observer, confined to a small area in a valley, attempts to measure the distances of surrounding mountain peaks. Because of the short base line allowed him, his trigonometric parallaxes are valueless except for the nearby hills. On the remote peaks, however, his telescope shows green foliage. First he assumes approximate botanical uniformity throughout all visible territory. Then he finds that the average height of all plants immediately around him (conifers, palms, asters, clovers, etc.) is one foot. Correlating this average with the measured angular height of plants visible against the sky-line on the distant peaks he obtains values of the distances. If, however, he had compared the foliage on the nearby, trigonometrically-measured hills with that on the remote peaks, or had used some method of distinguishing various floral types, he would not have mistaken pines for asters and obtained erroneous results for the distances of the surrounding mountains. All the principles involved in the botanical parallax of a mountain peak have their analogues in the photometric parallax of a globular cluster.

c. *Cepheid variables.*—Giant stars of another class, the Cepheid variables, have been used extensively in the exploration of globular clusters. After determining the period of a Cepheid, its absolute magnitude is easily found from an observationally derived period-luminosity curve, and the distance of any cluster containing such variables is determined as soon as the apparent magnitudes are measured. Galactic Cepheids and cluster Cepheids are strictly comparable by Proposition C—a deduction that is amply supported by observations at Mount Wilson and Harvard, of color, spectrum, light curves, and the brightness relative to other types of stars.

Curtis bases his strongest objections to the larger galaxy on the use I have made of the Cepheid variables, questioning the sufficiency of the data and the accuracy of the methods involved. But I believe that in the present issue there is little point in laboring over the details for Cepheids, for we are, if we choose, qualitatively quite independent of them in determining the scale of the galactic system, and it is only qualitative results that are now at issue. We could discard the Cepheids altogether, use instead either the red giant stars and spectroscopic methods, or the hundreds of B-type stars upon which the most capable stellar astronomers have worked for years, and derive much the same distance for the Hercules cluster, and for other clusters, and obtain consequently similar dimensions for the galactic system. In fact, the substantiating results from these other sources strongly fortify our belief in the assumptions and methods involved in the use of the Cepheid variables.

Since the distances of clusters as given by Cepheid variables are qualitatively in excellent agreement with the distances as given by blue stars and by yellow and red giants, discussed in the foregoing sub-sections *a* and *b*, I shall here refer only briefly to four points bearing on the Cepheid problem, first noting that if the distances of clusters are to be divided by 10 or 15, the same divisor should be also used for the distances derived for galactic Cepheids.

(1) The average absolute magnitude of typical Cepheids, according to my discussion of proper motions and magnitude correlations, is about -2.5. The material on proper motion has also been discussed independently by Russell, Hertzsprung, Kapteyn, Strömberg, and Seares; they all accept the validity of the method, and agree in making the mean absolute magnitude much the same as that which I derive. Seares finds, moreover, from a discussion of probable errors and of possible systematic errors, that the observed motions are irreconcilable with an absolute brightness five magnitudes fainter, because in that case the mean parallactic motion of the brighter Cepheids would be of the order of $0''.160$ instead of $0''.016 \pm 0''.002$ as observed.

Both trigonometric and spectroscopic parallaxes of galactic Cepheids, as far as they have been determined, support the photometric values in demanding high luminosity; the spectroscopic and photometric methods are not wholly independent, however, since the zero point depends in both cases on parallactic motion.

(2) When parallactic motion is used to infer provisional absolute magnitudes for individual stars (a possible process only when peculiar motions are small and observations very good), the brighter galactic Cepheids indicate the correlation between luminosity and period.[1] The necessity, however, of neglecting individual peculiar motion and errors of observation for this proce-

[1]Mr. Seares has called my attention to an error in plotting the provisional smoothed absolute magnitudes against log period for the Cepheids discussed in *Mount Wilson Contribution* No. 151. The preliminary curve for the galactic Cepheids is steeper than that for the Small Magellanic Cloud, Omega Centauri, and other clusters.

dure makes the correlation appear much less clearly for galactic Cepheids than for those of external systems (where proper motions are not concerned), and little importance could be attached to the period-luminosity curve if it were based on local Cepheids alone. When the additional data mentioned below are also treated in this manner, the correlation is practically obscured for galactic Cepheids, because of the larger observational errors.

On account of the probably universal uniformity of Cepheid phenomena, however, we need to know only the *mean* parallactic motion of the galactic Cepheids to determine the zero point of the curve which is based on external Cepheids; and the *individual* motions do not enter the problem at all, except, as noted above, to indicate provisionally the existence of the period-luminosity relation. It is only this *mean* parallactic motion that other investigators have used to show the exceedingly high luminosity of Cepheids. My adopted absolute magnitudes and distances for all these stars have been based upon the final period-luminosity curve, and not upon individual motions.

(3) Through the kindness of Professor Boss and Mr. Roy of the Dudley Observatory, proper motions have been submitted for 21 Cepheids in addition to the 13 in the *Preliminary General Catalogue*. The new material is of relatively low weight, but the unpublished discussion by Strömberg of that portion referring to the northern stars introduces no material alteration of the earlier result for the mean absolute brightness of Cepheids.

It should be noted that the 18 pseudo-Cepheids discussed by Adams and Joy[1] are without exception extremely bright (absolute magnitudes ranging from -1 to -4); they are thoroughly comparable with the ordinary Cepheids in galactic distribution, spectral characteristics, and motion.

(4) From unpublished results kindly communicated by van Maanen and by Adams, we have the following verification of the great distance and high luminosity of the important, high-velocity, cluster-type Cepheid RR Lyrae:

Photometric parallax	0".003	(Shapley)
Trigonometric parallax	$+0.006 \pm 0.006$	(van Maanen)
Spectroscopic parallax	0.004	(Adams, Joy, and Burwell)

The large proper motion of this star, 0".25 annually, led Hertz-

[1]Adams, W. S., and A. H. Joy, *Publ. Ast. Soc. Pac.*, San Francisco, Calif., **31**, 1919 (184–186).

sprung some years ago to suspect that the star is not distant, and that it and its numerous congeners in clusters are dwarfs. The large proper motion, however, indicates high real velocity rather than nearness, as the above results show. More recently Hertzsprung has reconsidered the problem and, using the cluster variables, has derived a distance of the globular cluster Messier 3 in essential agreement with my value.

d. *Hypothetical annual proper motion.*—The absence of observed proper motion for distant clusters must be an indication of their great distance because of the known high velocities in the line of sight. The average radial velocity of the globular clusters appears to be about 150 km/sec. By assuming, as usual, a random distribution of velocities, the transverse motion of Messier 13 and similar bright globular clusters should be greater than the quite appreciable value of 0.″04 a year if the distance is less than 3,600 light-years. No proper motion has been found for distant clusters; Lundmark has looked into this matter particularly for five systems and concludes that the annual proper motion is less than 0.″01.

7. Let us summarize a few of the results of accepting the restricted scale of the galactic system.

If the distances of globular clusters must be decreased to one-tenth, the light-emitting power of their stars can be only a hundredth that of local cluster stars of the same spectral and photometric types. As a consequence, I believe Russell's illuminative theory of spectral evolution would have to be largely abandoned, and Eddington's brilliant theory of gaseous giant stars would need to be greatly modified or given up entirely. Now both of these modern theories have their justification, first, in the fundamental nature of their concepts and postulates, and second, in their great success in fitting observational facts.

Similarly, the period-luminosity law of Cepheid variation would be meaningless; Kapteyn's researches on the structure of the local cluster would need new interpretation, because his luminosity laws could be applied locally but not generally; and a very serious loss to astronomy would be that of the generality of spectroscopic methods of determining star distances, for it would mean that identical spectral characteristics indicate stars differing in brightness by 100 to 1, depending only upon whether the star is in the solar neighborhood or in a distant cluster.

THE DIMENSIONS AND ARRANGEMENT OF THE GALACTIC SYSTEM

When we accept the view that the distance of the Hercules cluster is such that its stellar phenomena are harmonious with local stellar phenomena—its brightest stars typical giants, its Cepheids comparable with our own—then it follows that fainter, smaller, globular clusters are still more distant than 36,000 light-years. One-third of those now known are more distant than 100,000 light-years; the most distant is more than 200,000 light-years away, and the diameter of the whole system of globular clusters is about 300,000 light-years.

Since the affiliation of the globular clusters with the galaxy is shown by their concentration to the plane of the Milky Way and their symmetrical arrangement with respect to it, it also follows that the galactic system of stars is as large as this subordinate part. During the past year we have found Cepheid variables and other stars of high luminosity among the fifteenth magnitude stars of the galactic clouds; this can only mean that some parts of the clouds are more distant than the Hercules cluster. There seems to be good reason, therefore, to believe that the star-populated regions of the galactic system extend at least as far as the globular clusters.

One consequence of accepting the theory that clusters outline the form and extent of the galactic system, is that the sun is found to be very distant from the middle of the galaxy. It appears that we are not far from the center of a large local cluster or cloud, but that cloud is at least 50,000 light-years from the galactic center. Twenty years ago Newcomb remarked that the sun *appears* to be in the galactic plane because the Milky Way is a great circle—an encircling band of light—and that the sun also *appears* near the center of the universe because the star density falls off with distance in all directions. But he concludes as follows:

"Ptolemy showed by evidence, which, from his standpoint, looked as sound as that which we have cited, that the earth was fixed in the center of the universe. May we not be the victim of some fallacy, as he was?"

Our present answer to Newcomb's question is that we have been victimized by restricted methods of measuring distance and by the chance position of the sun near the center of a subordinate system; we have been misled, by the consequent phenomena, into thinking that we are in the midst of things. In much the same way ancient man was misled by the rotation of the earth, with the consequent apparent daily motion of all heavenly bodies around the earth, into believing that even his little planet was the center of the universe, and that his earthly gods created and judged the whole.

If man had reached his present intellectual position in a later geological era, he might not have been led to these vain conceits concerning his position in the physical universe, for the solar system is rapidly receding from the galactic plane, and is moving away from the center of the local cluster. If that motion remains unaltered in direction and amount, in a hundred million years or so the Milky Way will be quite different from an encircling band of star clouds, the local cluster will be a distant object, and the star density will no longer decrease with distance from the sun in all directions.

Another consequence of the conclusion that the galactic system is of the order of 300,000 light-years in greatest diameter, is the previously mentioned difficulty it gives to the "comparable-galaxy" theory of spiral nebulae. I shall not undertake a description and discussion of this debatable problem. Since the theory probably stands or falls with the hypothesis of a small galactic system, there is little point in discussing other material on the subject, especially in view of the recently measured rotations of spiral nebulae which appear fatal to such an interpretation.

It seems to me that the evidence, other than the admittedly critical tests depending 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 modifying 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) Seares' deduction that none of the known spiral nebulae has a surface brightness as small as that of our galaxy; (2) Reynold's study of the distribution of light and color in typical spirals, from which he concludes they cannot be stellar systems; and (3) van Maanen's recent measures of rotation in the spiral M 33, 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.

But even if spirals fail as galactic systems, there may be elsewhere in space stellar systems equal to or greater than ours—as yet unrecognized and possibly quite beyond the power of existing optical devices and present measuring scales. The modern telescope, however, with such accessories as high-power spectroscopes and photographic intensifiers, is destined to extend the inquiries relative to the size of the universe much deeper into space, and contribute further to the problem of other galaxies.

Part II

By Heber D. Curtis

DIMENSIONS AND STRUCTURE OF THE GALAXY

Definition of units employed.—The distance traversed by light in one year, 9.5×10^{12} km., or nearly six trillion miles, known as the light-year, has been in use for about two centuries as a means of visualizing stellar distances, and forms a convenient and easily comprehended unit. Throughout this paper the distances of the stars will be expressed in light-years.

The *absolute* magnitude of a star is frequently needed in order that we may compare the luminosities of different stars in terms of some common unit. It is that *apparent* magnitude which the star would have if viewed from the standard distance of 32.6 light-years (corresponding to a parallax of 0″1).

Knowing the parallax, or the distance, of a star, the absolute magnitude may be computed from one of the simple equations:
Abs. Magn. = App. Magn. $+5+5\times\log$ (parallax in seconds of arc)
Abs. Magn. = App. Magn. $+7.6-5\times\log$ (distance in light-years).

Limitations in studies of galactic dimensions.—By direct methods the distances of individual stars can be determined with considerable accuracy out to a distance of about two hundred light-years.

At a distance of three hundred light-years (28×10^{14} km.) the radius of the earth's orbit (1.5×10^{8} km.) subtends an angle slightly greater than 0″01, and the probable error of the best modern photographic parallax determinations has not yet been reduced materially below this value. The spectroscopic method of determining stellar distances through the absolute magnitude probably has, at present, the same limitations as the trigonometric method upon which the spectroscopic method depends for its absolute scale.

A number of indirect methods have been employed which extend our reach into space somewhat farther for the average distances of large groups or classes of stars, but give no information as to the individual distances of the stars of the group or class. Among such methods may be noted as most important the various correlations which have been made between the proper motions of the stars and the parallactic motion due to the speed of our sun in space, or between the proper motions and the radial velocities of the stars.

The limitations of such methods of correlation depend, at present, upon the fact that accurate proper motions are known, in general, for the brighter stars only. A motion of 20 km/sec. across our line of sight will produce the following annual proper motions:

Distance	100 l. y.	500 l. y.	1,000 l. y.
Annual p. m.	0".14	0".03	0".01

The average probable error of the proper motions of Boss is about 0".006. Such correlation methods are not, moreover, a simple matter of comparison of values, but are rendered difficult and to some extent uncertain by the puzzling complexities brought in by the variation of the space motions of the stars with spectral type, stellar mass (?), stellar luminosity (?), and still imperfectly known factors of community of star drift.

It will then be evident that the base-line available in studies of the more distant regions of our galaxy is woefully short, and that in such studies we must depend largely upon investigations of the distribution and of the frequency of occurrence of stars of the different apparent magnitudes and spectral types, on the assumption that the more distant stars, when taken in large numbers, will average about the same as known nearer stars. This assumption is a reasonable one, though not necessarily correct, as we have little certain knowledge of galactic regions as distant as five hundred light-years.

Were all the stars of approximately the same absolute magnitude, or if this were true even for the stars of any particular type or class, the problem of determining the general order of the dimensions of our galaxy would be comparatively easy.

But the problem is complicated by the fact that, taking the stars of all spectral types together, the dispersion in absolute luminosity is very great. Even with the exclusion of a small number of stars which are exceptionally bright or faint, this dispersion probably reaches ten absolute magnitudes, which would correspond to a hundred-fold uncertainty in distance for a given star. However, it will be seen later that we possess moderately definite information as to the *average* absolute magnitude of the stars of the different spectral types.

Dimensions of our galaxy.—Studies of the distribution of the stars and of the ratio between the numbers of stars of successive apparent magnitudes have led a number of investigators to the postulation of fairly accordant dimensions for the galaxy; a few may be quoted:

Wolf; about 14,000 light-years in diameter.
Eddington; about 15,000 light-years.
Shapley (1915); about 20,000 light-years.
Newcomb; not less than 7,000 light-years; later—perhaps 30,000 light-years in diameter and 5,000 light-years in thickness.
Kapteyn; about 60,000 light-years.[1]

General structure of the galaxy.—From the lines of investigation mentioned above there has been a similar general accord in the deduced results as to the shape and structure of the galaxy:

1. The stars are not infinite in number, nor uniform in distribution.
2. Our galaxy, delimited for us by the projected contours of the Milky Way, contains possibly a billion suns.
3. This galaxy is shaped much like a lens, or a thin watch, the thickness being probably less than one-sixth of the diameter.
4. Our Sun is located fairly close to the center of figure of the galaxy.
5. The stars are not distributed uniformly through the galaxy. A large proportion are probably actually within the ring structure suggested by the appearance of the Milky Way, or are arranged in large and irregular regions of greater star density. The writer believes that the Milky Way is at least as much a structural as a depth effect.

A spiral structure has been suggested for our galaxy; the evidence for such a spiral structure is not very strong, except as it may be supported by the analogy of the spirals as island universes, but such a structure is neither impossible nor improbable. The position of our Sun near the center of figure of the galaxy is not a favorable one for the precise determination of the actual galactic structure.

Relative paucity of galactic genera.—Mere size does not necessarily involve complexity; it is a remarkable fact that in a galaxy of a thousand million objects we observe, not ten thousand different types, but perhaps not more than five main classes, outside the minor phenomena of our own solar system.

1. *The stars.*—The first and most important class is formed by the stars. In accordance with the type of spectrum exhibited, we may divide the stars into some eight or ten main types; even when we include the consecutive internal gradations within these spectral classes it is doubtful whether present methods will permit us to distinguish as many as a hundred separate subdivisions in all. Average space velocities vary from 10 to 30 km/sec., there being a well-marked increase in average space velocity as one proceeds from the blue to the redder stars.

2. *The globular star clusters* are greatly condensed aggregations of from ten thousand

[1]A complete bibliography of the subject would fill many pages. Accordingly, references to authorities will in general be omitted. An excellent and nearly complete list of references may be found in Lundmark's paper,—"The Relations of the Globular Clusters and Spiral Nebulae to the Stellar System," in *K. Svenska Vet. Handlingar*, Bd. 60, No. 8, p. 71, 1920.

to one hundred thousand stars. Perhaps one hundred are known. Though quite irregular in grouping, they are generally regarded as definitely galactic in distribution. Space velocities are of the order of 300 km/sec.

3. *The diffuse nebulae* are enormous, tenuous, cloud-like masses; fairly numerous; always galactic in distribution. They frequently show a gaseous spectrum, though many agree approximately in spectrum with their involved stars. Space velocities are very low.

4. *The planetary nebulae* are small, round or oval, and almost always with a central star. Fewer than one hundred and fifty are known. They are galactic in distribution; spectrum is gaseous; space velocities are about 80 km/sec.

5. *The spirals.*—Perhaps a million are within reach of large reflectors; the spectrum is generally like that of a star cluster. They are emphatically non-galactic in distribution, grouped about the galactic poles, spiral in form. Space velocities are of the order of 1200 km/sec.

Distribution of celestial genera.—With one, and only one, exception, all known genera of celestial objects show such a distribution with respect to the plane of our Milky Way, that there can be no reasonable doubt that all classes, save this one, are integral members of our galaxy. We see that all the stars, whether typical, binary, variable, or temporary, even the rarer types, show this unmistakable concentration toward the galactic plane. So also for the diffuse and the planetary nebulae and, though somewhat less definitely, for the globular star clusters.

The one exception is formed by the spirals; grouped about the poles of our galaxy, they appear to abhor the regions of greatest star density. They seem clearly a class apart. *Never* found in our Milky Way, there is no other class of celestial objects with their distinctive characteristics of form, distribution, and velocity in space.

The evidence at present available points strongly to the conclusion that the spirals are individual galaxies, or island universes, comparable with our own galaxy in dimensions and in number of component units. While the island universe theory of the spirals is not a vital postulate in a theory of galactic dimensions, nevertheless, because of its indirect bearing on the question, the arguments in favor of the island universe hypothesis will be included with those which touch more directly on the probable dimensions of our own galaxy.

Other theories of galactic dimensions.—From evidence to be referred to later Dr. Shapley has deduced very great distances for the globular star clusters, and holds that our galaxy has a diameter comparable with the distances which he has derived for the clusters, namely,—a galactic diameter of about 300,000 light-years, or at least ten times greater than formerly accepted. The postulates of the two theories may be outlined as follows:

Present Theory	Shapley's Theory
Our galaxy is probably not more than 30,000 light-years in diameter, and perhaps 5,000 light-years in thickness.	The galaxy is approximately 300,000 light-years in diameter, and 30,000, or more, light-years in thickness.
The clusters, and all other types of celestial objects except the spirals, are component parts of our own galactic system.	The globular clusters are remote objects, but a part of our own galaxy. The most distant cluster is placed about 220,000 light-years away.
The spirals are a class apart, and not intra-galactic objects. As island universes, of the same order of size as our galaxy, they are distant from us 500,000 to 10,000,000, or more, light-years.	The spirals are probably of nebulous constitution, and possibly not members of our own galaxy, driven away in some manner from the regions of greatest star density.

EVIDENCE FURNISHED BY THE MAGNITUDE OF THE STARS

The "average" star.—It will be of advantage to consider the two theories of galactic dimensions from the standpoint of the average star. What is the "average" or most frequent type of star of our galaxy or of a globular star cluster, and if we can with some probability postulate such an average star, what bearing will the characteristics of such a star have upon the question of its average distance from us?

No adequate evidence is available that the more distant stars of our galaxy are in any way essentially different from stars of known distance nearer to us. It would seem then that we may safely make such correlations between the nearer and the more distant stars, *en masse*. In such comparisons the limitations of spectral type must be observed as rigidly as possible, and results based upon small numbers of stars must be avoided, if possible.

Many investigations, notably Shapley's studies of the colors of stars in the globular clusters, and Fath's integrated spectra of these objects and of the Milky Way, indicate that the average star of a star cluster or of the Milky Way will, in the great majority of cases, be somewhat like our Sun in spectral type, *i. e.*, such an average star will be, in general, between spectral types F and K.

Characteristics of F–K type stars of known distance.—The distances of stars of type F–K in our own neighborhood have been determined in greater number, perhaps, than for the stars of any other spectral type, so that the average absolute magnitude of stars of this type seems fairly well determined. There is every reason to believe, however, that our selection of stars of these or other types for direct distance determinations has not been a representative one. Our parallax programs have a tendency to select stars either of great luminosity or of great space velocity.

Kapteyn's values for the average absolute magnitudes of the stars of the various spectral types are as follows:

Type	*Average Abs. Magn.*
B5	+1.6
A5	+3.4
F5	+7
G5	+10
K5	+13
M	+15

The same investigator's most recent luminosity-frequency curve places the maximum of frequency of the stars in general, taking all the spectral types together, at absolute magnitude +7.7.

A recent tabulation of about five hundred modern photographically determined parallaxes places the average absolute magnitude of stars of type F–K at about +4.5.

The average absolute magnitude of five hundred stars of spectral types F to M is close to +4, as determined spectroscopically by Adams.

It seems certain that the two last values of the average absolute magnitude are too low, that is,—indicate too high an average luminosity, due to the omission from our parallax programs of the intrinsically fainter stars. The absolute magnitudes of the dwarf stars are, in general, fairly accurately determined; the absolute magnitudes of many of the giant stars depend upon small and uncertain parallaxes. In view of these facts we may somewhat tentatively take the average absolute magnitude of F–K stars of known distance as not brighter than +6; some investigators would prefer a value of +7 or +8.

Comparison of Milky Way stars with the "average" stars.—We may take, without serious error, the distances of 10,000 and 100,000 light-years respectively, as representing the distance in the two theories from our point in space to the central line of the Milky Way structure. Then the following short table may be prepared:

Apparent magnitudes	Corresponding absolute magnitudes for distances of,—	
	10,000 light-years	100,000 light-years
10	−2.4	−7.4
12	−0.4	−5.4
14	+1.6	−3.4
16	+3.6	−1.4
18	+5.6	+0.6
20	+7.6	+2.6

It will be seen from the above table that the stars of apparent magnitudes 16 to 20, observed in our Milky Way structure in such great numbers, and, from their spectrum, believed to be predominantly F–K in type, are of essentially the same absolute luminosity as known nearer stars of these types, if assumed to be at the average distance of 10,000 light-years. The greater value postulated for the galactic dimensions requires, on the other hand, an enormous proportion of giant stars.

Proportion of giant stars among stars of known distance.—All existing evidence indicates that the proportion of giant stars in a given region of space is very small. As fairly representative of several investigations we may quote Schouten's results, in which he derives an average stellar density of 166,000 stars in a cube 500 light-years on a side, the distribution in absolute magnitude being as follows:

Absolute magnitudes	No. of stars	Relative percentages
−5 to −2	17	.01
−2 to +1	760	.5
+1 to +5	26800	16
+5 to +10	138600	83

Comparison of the stars of the globular clusters with the "average" star.—From a somewhat cursory study of the negatives of ten representative globular clusters I estimate the average apparent visual magnitude of all the stars in these clusters as in the neighborhood of the eighteenth. More powerful instruments may eventually indicate a somewhat fainter mean value, but it does not seem probable that this value is as much as two magnitudes in error. We then have:

Apparent magnitude of average cluster star	Corresponding absolute magnitudes if at distances of,—	
	10 000 light-years	100,000 light-years
18	+5.6	+0.6

Here again we see that the average F–K star of a cluster, if assumed to be at a distance of 10,000 light-years, has an average luminosity about the same as that found for known nearer stars of this type. The greater average distance of 100,000 light-years requires a proportion of giant stars enormously greater than is found in those regions of our galaxy of which we have fairly definite distance data.

While it is not impossible that the clusters are exceptional regions of space and that, with a tremendous spatial concentration of suns, there exists also a unique concentration of giant stars, the hypothesis that cluster stars are, on the whole, like those of known distance seems inherently the more probable.

It would appear, also, that galactic dimensions deduced from correlations between large numbers of what we may term average stars must take precedence over values found from small numbers of exceptional objects, and that, where deductions disagree, we have a right to demand that a theory of galactic dimensions based upon the exceptional object or class shall not fail to give an adequate explanation of the usual object or class.

The evidence for greater galactic dimensions.—The arguments for a much larger diameter for our galaxy than that hitherto held, and the objections which have been raised against the island universe theory of the spirals rest mainly upon the great distances which have been deduced for the globular star clusters.

I am unable to accept the thesis that the globular clusters are at distances of the order of 100,000 light-years, feeling that much more evidence is needed on this point before it will be justifiable to assume that the cluster stars are predominatingly giants rather than average stars. I am also influenced, perhaps unduly, by certain fundamental uncertainties in the data employed. The limitations of space available for the publication of this portion of the discussion unfortunately prevents a full treatment of the evidence. In calling attention to some of the uncertainties in the basal data, I must disclaim any spirit of captious criticism, and take this occasion to express my respect for Dr. Shapley's point of view, and my high appreciation of the extremely valuable work which he has done on the clusters. I am willing to accept correlations between large masses of stellar data, whether of magnitudes, radial velocities, or proper motions, but I feel that the dispersion in stellar characteristics is too large to permit the use of limited amounts of any sort of data, particularly when such data is of the same order as the probable errors of the methods of observation.

The deductions as to the very great distances of the globular clusters rest, in the final analysis, upon three lines of evidence:

1. Determination of the relative distances of the clusters on the assumption that they are objects of the same order of actual size.

2. Determination of the absolute distances of the clusters through correlations between Cepheid variable stars in the clusters and in our galaxy.

3. Determination of the absolute distances of the clusters through a comparison of their brightest stars with the intrinsically brightest stars of our galaxy.

Of these three methods, the second is given most weight by Shapley.

It seems reasonable to assume that the globular clusters are of the same order of actual size, and that from their apparent diameters the *relative* distances may be determined. The writer would not, however, place undue emphasis upon this relation. There would seem to be no good reason why there may not exist among these objects a reasonable amount of difference in actual size, say from three- to five-fold, differences which would not prevent them being regarded as of the same order of size, but which would introduce considerable uncertainty into the estimates of relative distance.

The evidence from the Cepheid variable stars.—This portion of Shapley's theory rests upon the following three hypotheses or lines of evidence:

A. That there is a close coordination between absolute magnitude and length of period for the Cepheid variables of our galaxy, similar to the relation discovered by Miss Leavitt among Cepheids of the Smaller Magellanic Cloud.

B. That, if of identical periods, Cepheids anywhere in the universe have identical absolute magnitudes.

C. This coordination of absolute magnitude and length of period for galactic Cepheids, the derivation of the absolute scale for their distances and the distances of the clusters, and, combined with A) and B), the deductions therefrom as to the much greater dimensions for our galaxy, depend almost entirely upon the sizes and the internal relationships of the proper motions of eleven Cepheid variables.

Under the first heading, it will be seen later that the actual evidence for such a coordination among galactic Cepheids is very weak. Provided that the Smaller Magellanic Cloud is not in some way a unique region of space, the behavior of the Cepheid variables in this Cloud is, through analogy, perhaps the strongest argument for postulating a similar phenomenon among the Cepheid variables of our galaxy.

Unfortunately there is a large dispersion in practically all the characteristics of the stars. That the Cepheids lack a reasonable amount of such dispersion is contrary to all experience for the stars in general. There are many who will regard the assumption made under B) above as a rather drastic one.

If we tabulate the proper motions of these eleven Cepheids, as given by Boss, and their probable errors as well, it will be seen that the average proper motion of these eleven stars is of the order of one second of arc per century in either coordinate; that the average probable error is nearly half this amount, and that the probable errors of half of these twenty-two coordinates may well be described as of the same size as the corresponding proper motions.

Illustrations bearing on the uncertainty of proper motions of the order of 0″01 per year might be multiplied at great length. The fundamental and unavoidable errors in our star positions, the probable errors of meridian observations, the uncertainty in the adopted value of the constant of precession, the uncertainties introduced by the systematic corrections applied to different catalogues, all have comparatively little effect when use is made of proper motions as large as ten seconds of arc per century. Proper motions as small as one second of arc per century are, however, still highly uncertain quantities, entirely aside from the question of the possible existence of systematic errors. As an illustration of the differences in such minute proper motions as derived by various authorities, the proper motions of three of the best determined of this list of eleven Cepheids, as determined by Auwers, are in different quadrants from those derived by Boss.

There seems no good reason why the smaller coordinates of this list of twenty-two may not eventually prove to be different by once or twice their present magnitude, with occasional changes of sign. So small an amount of presumably uncertain data is insufficient to determine the scale of our galaxy, and many will prefer to wait for additional material before accepting such evidence as conclusive.

In view of:

1. The known uncertainties of small proper motions, and,

2. The known magnitude of the purely random motions of the stars, the determination of *individual* parallaxes from *individual* proper motions can never give results of value, though the average distances secured by such methods of correlation from large numbers of stars are apparently trustworthy. The method can not be regarded as a valid one, and this applies whether the proper motions are very small or are of appreciable size.

As far as the galactic Cepheids are concerned, Shapley's curve of coordination between absolute magnitude and length of period, though found through the mean absolute magnitude of the group of eleven, rests in reality upon individual parallaxes determined from individual proper motions, as may be verified by comparing his values for the parallax of these eleven stars with[1] the values found directly from the upsilon component of the proper motion (namely,—that component which is parallel to the Sun's motion) and the solar motion. The differences in the two sets of values, 0.″0002 in the mean, arise from the rather elaborate system of weighting employed.

The final test of a functional relation is the agreement obtained when applied to similar data not originally employed in deducing the relation. We must be ready to allow some measure of deviation in such a test, but when a considerable proportion of other available data fails to agree within a reasonable amount, we shall be justified in withholding our decision.

If the curve of correlation deduced by Shapley for galactic Cepheids is correct in both its absolute and relative scale, and if it is possible to determine individual distances from individual proper motions, the curve of correlation, using the same method as far as the proper motions are concerned (the validity of which I do not admit), should fit fairly well with other available proper motion and parallax data. The directly determined parallaxes are known for five of this group of eleven, and for five other Cepheids. There are, in addition, twenty-six other Cepheids or which proper motions have been determined. One of these was

[1] *Mt. Wilson Contr.* No. 151, Table V.

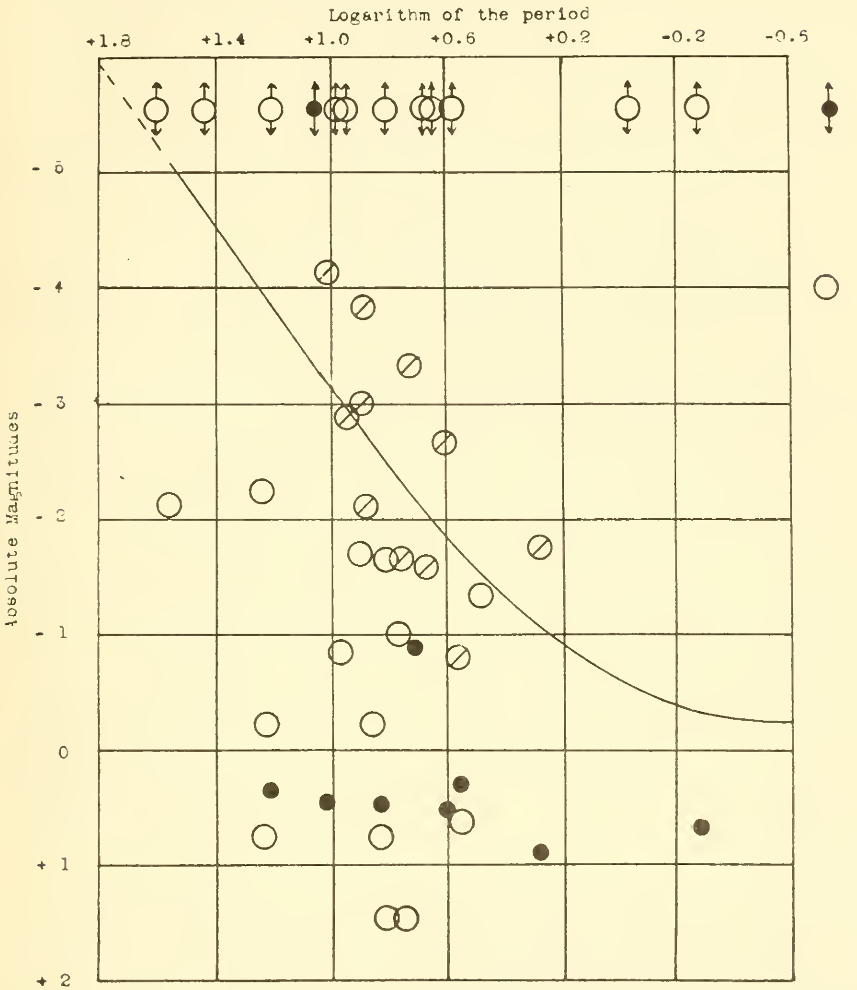

FIG. 1.—Agreement of other data with the luminosity-period correlation curve. Absolute magnitudes calculated from the upsilon component of the proper motion are indicated by circles; the eleven employed by Shapley are marked with a bar. Black dots represent directly determined parallaxes. The arrows attached to the circles at the upper edge of the diagram indicate that either the parallax or the upsilon component of the proper motion is negative, and the absolute magnitude indeterminate in consequence.

omitted by Shapley because of irregularity of period, one for irregularity of the light curve, two because the proper motions were deemed of insufficient accuracy, two because the proper motions are anomalously large; the proper motions of the others have been recently investigated at the Dudley Observatory, but have less weight than those of the eleven Cepheids used by Shapley.

In Figure 1 the absolute magnitudes are plotted against the logarithm of the period; the curve is taken from *Mt. Wilson Contr.* No. 151, and is that finally adopted by Shapley after the introduction of about twelve Cepheids of long period in clusters, twenty-five from the Smaller Magellanic Cloud, and a large number of short period cluster-type variables in clusters with periods less than a day, which have little effect on the general shape of the curve. The barred circles represent the eleven galactic Cepheids employed by Shapley, the black dots those Cepheids for which parallaxes have been determined, while the open circles indicate variables for which proper motions have since become available, or not employed originally by Shapley. For the stars at the upper edge of the diagram, the attached arrows indicate that either the parallax, or the upsilon component of the proper motion is negative, so that the absolute magnitude is indeterminate, and may be anything from infinity down.

From the above it would seem that available observational data lend little support to the fact of a period-luminosity relation among galactic Cepheids. In view of the large discrepancies shown by other members of the group when plotted on this curve, it would seem wiser to wait for additional evidence as to proper motion, radial velocity, and, if possible, parallax, before entire confidence can be placed in the hypothesis that the Cepheids and cluster-type variables are invariably super-giants in absolute luminosity.

Argument from the intrinsically brightest stars.—If the luminosity-frequency law is the same for the stars of the globular clusters as for our galaxy, it should be possible to correlate the intrinsically brightest stars of both regions and thus determine cluster distances. It would seem, *a priori*, that the brighter stars of the clusters must be giants, or at least approach that type, if the stars of the clusters are like the general run of stars. Through the application of a spectroscopic method Shapley has found that the spectra of the brighter stars in clusters resemble the spectra of galactic giant stars, a method which should be exceedingly useful after sufficient tests have been made to make sure that in this phenomenon, as is unfortunately the case in practically all stellar characteristics, there is not a large dispersion, and also whether slight differences in spectral type may at all materially affect the deductions.

The average "giant" star.—Determining the distance of Messier 3 from the variable stars which it contains, Shapley then derives absolute magnitude −1.5 as the mean luminosity of the twenty-five brightest stars in this cluster. From this mean value, −1.5, he then determines the distances of other clusters. Instead, however, of determining cluster distances of the order of 100,000 light-years by means of correlations on a limited number of Cepheid variables, a small and possibly exceptional class, and from the distances thus derived deducing that the absolute magnitudes of many of the brighter stars in the clusters are as great as −3, while a large proportion are greater than −1, it would seem preferable to begin the line of reasoning with the attributes of known stars in our neighborhood, and to proceed from them to the clusters.

What is the average absolute magnitude of a galactic giant star? On this point there is room for honest difference of opinion, and there will doubtless be many who will regard the conclusions of this paper as ultra conservative. Confining ourselves to existing observational data, there is no evidence that a group of galactic giants, of average spectral type about G5, will have a mean absolute magnitude as great as −1.5; it is more probably in the neighborhood of +1.5, or three absolute magnitudes fainter, making Shapley's distances four times too large.

Russell's suggestion is worth quoting in this connection, written in 1913, when parallax data were far more limited and less reliable than at present:

> The giant stars of all the spectral classes appear to be of about the same mean brightness,—averaging a little above absolute magnitude zero, that is, about a hundred times as bright as the Sun. Since the stars of this series . . . have been selected by apparent brightness, which gives a strong preference to those of greatest luminosity, the average brightness of all the giant stars in a given region of space must be less than this, perhaps considerably so.

Some reference has already been made to the doubtful value of parallaxes of the order of 0″010, and it is upon such small or negative parallaxes that most of the very great absolute luminosities in present lists depend. It seems clear that parallax work should aim at using as faint comparison stars as possible, and that the corrections applied to reduce relative parallaxes to absolute parallaxes should be increased very considerably over what was thought acceptable ten years ago.

From a study of the plotted absolute magnitudes by spectral type of about five hundred modern direct parallaxes, with due regard to the uncertainties of minute parallaxes, and keeping in mind that most of the giants will be of types F to M, there seems little reason for placing the average absolute magnitude of such giant stars as brighter than +2.

The average absolute magnitude for the giants in Adams's list of five hundred spectroscopic parallaxes is +1.1. The two methods differ most in the stars of type G, where the spectroscopic method shows a maximum at +0.6, which is not very evident in the trigonometric parallaxes.

In such moving star clusters as the Hyades group, we have thus far evidently observed only the giant stars of such groups.

The mean absolute magnitude of forty-four stars believed to belong to the Hyades moving cluster is +2.3. The mean absolute magnitude of the thirteen stars of types F, G, and K, is +2.4 The mean absolute magnitude of the six brightest stars is +0.8 (two A5, one G, and three of K type).

The Pleiades can not fittingly be compared with such clusters or the globular clusters; its composition appears entirely different as the brightest stars average about B5, and only among the faintest stars of the cluster are there any as late as F in type. The parallax of this group is still highly uncertain. With Schouten's value of 0.″037 the mean absolute magnitude of the six brightest stars is +1.6.

With due allowance for the redness of the giants in clusters, Shapley's mean visual magnitude of the twenty-five brightest stars in twenty-eight globular clusters is about 14.5. Then, from the equation given in the first section of this paper we have,—

$$+2 = 14.5 + 7.6 - 5 \times \log \text{distance},$$

or, log distance = 4.02 = 10,500 light-years as the average distance.

If we adopt instead the mean value of Adams +1.1, the distance becomes 17,800 light-years.

Either value for the average distance of the clusters may be regarded as satisfactorily close to those postulated for a galaxy of the smaller dimensions held in this paper, in view of the many uncertainties in the data. Either value, also, will give on the same assumptions a distance of the order of 30,000 light-years for a few of the faintest and apparently most distant clusters. I consider it very doubtful whether any cluster is really so distant as this, but find no difficulty in provisionally accepting it as a possibility, without thereby necessarily extending the main structure of the galaxy to such dimensions. While the clusters seem concentrated toward our galactic plane, their distribution in longitude is a most irregular one, nearly all lying in the quadrant between 270° and 0°. If the spirals are galaxies of stars, their analogy would explain the existence of frequent nodules of condensation (globular clusters?) lying well outside of and distinct from the main structure of a galaxy.

It must be admitted that the B-type stars furnish something of a dilemma in any attempt to utilize them in determining cluster distances.

From the minuteness of their proper motions, most investigators have deduced very great luminosities for such stars in our galaxy. Examining Kapteyn's values for stars of this type, it will be seen that he finds a range in absolute magnitude from +3.25 to −5.47. Dividing the 433 stars of his lists into two magnitude groups, we have:

Mean abs. magn. 249 B stars, brighter than abs. magn. 0	= −1.32
Mean abs. magn. 184 B stars, fainter than abs. magn. 0	= +0.99
Mean abs. magn. all	= −0.36

Either the value for the brighter stars, −1.32, or the mean of all, −0.36, is over a magnitude brighter than the average absolute magnitude of the giants of the other spectral types among nearer galactic stars.

Now this galactic relation is apparently *reversed* in such clusters as M. 3 or M. 13, where the B-type stars are about three magnitudes fainter than the brighter K and M stars and about a magnitude fainter than those of G type. Supposing that the present very high values for the galactic B-type stars are correct, if we assume similar luminosity for those in the clusters we must assign absolute magnitudes of −3 to −6 to the F to M stars of the clusters, for which we have no certain galactic parallel, with a distance of perhaps 100,000 light-years. On the other hand, if the F to M stars of the cluster are like the brighter stars of these types in the galaxy, the average absolute magnitude of the B-type stars will be only about +3, and too low to agree with present values for galactic B stars. I prefer to accept the latter alternative in this dilemma, and to believe that there may exist B-type stars of only two to five times the brightness of the Sun.

While I hold to a theory of galactic dimensions approximately one-tenth of that supported by Shapley, it does not follow that I maintain this ratio for any particular cluster distance. All that I have tried to do is to show that 10,000 light-years is a reasonable *average* cluster distance.

There are so many assumptions and uncertainties involved that I am most hesitant in attempting to assign a given distance to a given cluster, a hesitancy which is not diminished by a consideration of the following estimates of the distance of M. 13 (The Great Cluster in Hercules).

Shapley, 1915, provisional	100,000 light-years
Charlier, 1916	170 light-years
Shapley, 1917	36,000 light-years
Schouten, 1918	4,300 light-years
Lundmark, 1920	21,700 light-years

It should be stated here that Shapley's earlier estimate was merely a provisional assumption for computational illustration, but all are based on modern material, and illustrate the fact that good evidence may frequently be interpreted in different ways.

My own estimate, based on the general considerations outlined earlier in this paper, would be about 8,000 light-years, and it would appear to me, at present, that this estimate is perhaps within fifty per cent of the truth.

THE SPIRALS AS EXTERNAL GALAXIES

The spirals.—If the spirals are island universes it would seem reasonable and most probable to assign to them dimensions of the same order as our galaxy. If, however, their dimensions are as great as 300,000 light-years, the island universes must be placed at such enormous distances that it would be necessary to assign what seem impossibly great absolute magnitudes to the novae which have appeared in these objects. For this reason the island universe theory has an indirect bearing on the general subject of galactic dimensions, though it is, of course, entirely possible to hold both to the island universe theory and to the belief in the greater dimensions for our galaxy by making the not improbable assumption that our own island universe, by chance, happens to be several fold larger than the average.

Some of the arguments against the island universe theory of the spirals have been cogently put by Shapley, and will be quoted here for reference. It is only fair to state that these earlier statements do not adequately represent Shapley's present point of view, which coincides somewhat more closely with that held by the writer.

With the plan of the sidereal system here outlined, it appears unlikely that the spiral nebulae can be considered separate galaxies of stars. In addition to the evidence heretofore existing, the following points seem opposed to the "island universe" theory: (a) the dynamical character of the region of avoidance; (b) the size of the galaxy; (c) the maximum luminosity attainable by a star; (d) the increasing commonness of high velocities among other sidereal objects, particularly those outside the region of avoidance . . . the cluster work strongly suggests the hypothesis that spiral nebulae . . . are, however, members of the galactic organization . . . the novae in spirals may be considered as the engulfing of a star by the rapidly moving nebulosity. (*Publ. Astron. Soc. of the Pacific*, Feb. 1918, p. 53.)

The recent work on star clusters, in so far as it throws some light on the probable extent and structure of the galactic system, justifies a brief reconsideration of the question of external galaxies, and apparently leads to the rejection of the hypothesis that spiral nebulae should be interpreted as separate stellar systems.

Let us abandon the comparison with the galaxy and assume an average distance for the brighter spirals that will give a reasonable maximum absolute magnitude for the novae (*and in a footnote;*—provisionally, let us say, of the order of 20,000 light-years). Further, it is possible to explain the peculiar distribution of the spirals and their systematic recession by supposing them repelled in some manner from the galactic system, which appears to move as a whole through a nebular field of indefinite extent. But the possibility of these hypotheses is of course not proposed as competent evidence against the "island universe" theory. . . . Observation and discussion of the radial velocities, internal motions, and distribution of the spiral nebulae, of the real and apparent brightness of novae, of the maximum luminosity of galactic and cluster stars, and finally of the dimensions of our own galactic system, all seem definitely to oppose the "island universe" hypothesis of the spiral nebulae. . . . (*Publ. Astron. Soc. of the Pacific*, Oct. 1919, pp. 261 ff.)

The dilemma of the apparent dimensions of the spirals.—In apparent size the spirals range from a diameter of 2° (Andromeda), to minute flecks 5″, or less, in diameter.

They may possibly vary in actual size, roughly in the progression exhibited by their apparent dimensions.

The general principle of approximate equality of size for celestial objects of the same class seems, however, inherently the more probable, and has been used in numerous modern investigations, *e. g.*, by Shapley in determining the relative distances of the clusters.

On this principle of approximate equality of actual size:

As Island Universes

Their probable distances range from about 500,000 light-years (Andromeda), to distances of the order of 100,000,000 light-years.

At 500,000 light-years the Nebula of Andromeda would be 17,000 light-years in diameter, or of the same order of size as our galaxy.

As Galactic Phenomena

If the Nebula of Andromeda is but 20,000 light-years distant, the minute spirals would need to be at distances of the order of 10,000,000 light-years, or far outside the greater dimensions postulated for the galaxy.

If all are galactic objects, equality of size must be abandoned, and the minute spirals assumed to be about a thousandfold smaller than the largest.

The spectrum of the spirals.—

As Island Universes

The spectrum of the average spiral is indistinguishable from that given by a star cluster.

It is approximately F–G in type, and in general character resembles closely the integrated spectrum of our Milky Way.

It is just such a spectrum as would be expected from a vast congeries of stars.

The spectrum of the spirals offers no difficulties on the island universe theory.

As Galactic Phenomena

If the spirals are intragalactic, we must assume that they are some sort of finely divided matter, or of gaseous constitution.

In either case we have no adequate and actually existing evidence by which we may explain their spectrum.

Many diffuse nebulosities of our galaxy show a bright-line gaseous spectrum. Others, associated with bright stars, agree with their involved stars in spectrum, and are well explained as a reflection or resonance effect.

Such an explanation seems untenable for most of the spirals.

The distribution of the spirals.—The spirals are found in greatest numbers just where the stars are fewest (at the galactic poles), and not at all where the stars are most numerous (in the galactic plane). This fact makes it difficult, if not impossible, to fit the spirals into any coherent scheme of stellar evolution, either as a point of origin, or as a final evolutionary product. No spiral has as yet been found actually within the structure of the Milky Way.

This peculiar distribution is admittedly difficult to explain on any theory. This factor of distribution in the two theories may be contrasted as follows:

As Island Universes

It is most improbable that our galaxy should, by mere chance, be placed about half way between two great groups of island universes.

So many of the edgewise spirals show peripheral rings of occulting matter that this dark ring may well be the rule rather than the exception.

If our galaxy, itself a spiral on the island universe theory, possesses such a peripheral ring of occulting matter, this would obliterate the distant spirals in our galactic plane, and would explain the peculiar apparent distribution of the spirals.

There is some evidence for such occulting matter in our galaxy.

With regard to the observed excess of velocities of recession, additional observations may remove this. Part of the excess may well be due to the motion of our own galaxy in space. The Nebula of Andromeda is approaching us.

As Galactic Phenomena

If the spirals are galactic objects, they must be a class apart from all other known types: why none in our neighborhood?

Their abhorrence of the regions of greatest star density can only be explained on the hypothesis that they are, in some unknown manner, repelled by the stars.

We know of no force adequate to produce such a repulsion, except perhaps light-pressure.

Why should this repulsion have invariably acted essentially at right angles to our galactic plane?

Why have not some been repelled in the direction of our galactic plane?

The repulsion theory, it is true, is given some support by the fact that most of the spirals observed to date are receding from us.

The space velocities of the spirals.—

As Island Universes

The spirals observed to date have the enormous average space velocity of 1200 km/sec.

In this velocity factor they stand apart from all galactic objects.

Their space velocity is one hundred times that of the galactic diffuse nebulosities, about thirty times the average velocity of the stars, ten times that of the planetary nebulae, and five times that of the clusters.

Such high speeds seem possible for individual galaxies.

Our own galaxy probably has a space velocity, relatively to the system of the spirals, of several hundred km/sec. Attempts have been made to derive this from the velocities of the spirals, but are uncertain as yet, as we have the radial velocities of but thirty spirals.

As Galactic Phenomena

Space velocities of several hundred km/sec. have been found for a few of the fainter stars.

It has been argued that an extension of radial velocity surveys to the fainter stars would possibly remove the discrepancy between the velocities of the stars and those of the spirals.

This is possible, but does not seem probable. The faint stars thus far selected for investigation have been stars of known large proper motions. They are exceptional objects through this method of selection, not representative objects.

High space velocities are the rule, not the exception, for the spirals.

High space velocities are still the exception, not the rule, for the stars of our galaxy.

Proper motions of the spirals.—Should the results of the next quarter-century show *close agreement among different observers* to the effect that the annual motions of translation or rotation of the spirals equal or exceed 0.″01 in average value, it would seem that the island universe theory must be definitely abandoned.

A motion of 700 km/sec. across our line of sight will produce the following annual proper motions:

Distance in light-years	1,000	10,000	100,000	1,000,000
Annual proper motion	″48	″048	″005	″0005

The older visual observations of the spirals have so large a probable error as to be useless for the determination of proper motions, if small; the available time interval for photographic determinations is less than twenty-five years.

The first proper motion given above should inevitably have been detected by either visual or photographic methods, from which it seems clear that the spirals can not be relatively close to us at the poles of our flattened galactic disk. In view of the hazy character of the condensations measured, I consider the trustworthy determination of the second proper motion given above impossible by present methods without a much longer time interval than is at present available; for the third and the fourth, we should need centuries.

New stars in the spirals.—Within the past few years some twenty-seven new stars have appeared in spirals, sixteen of these in the Nebula of Andromeda, as against about thirty-five which have appeared in our galaxy in the last three centuries. So far as can be judged from such faint objects, the novae in spirals have a life history similar to that of the galactic novae, suddenly flashing out, and more slowly, but still relatively rapidly, sinking again to a luminosity ten thousand-fold less intense. Such novae form a strong argument for the island universe theory and furnish, in addition, a method of determining the approximate distances of the spirals.

With all its elements of simplicity and continuity, our universe is too haphazard in its details to warrant deductions from small numbers of exceptional objects. Where no other correlation is available such deductions must be made with caution, and with a full appreciation of the uncertainties involved.

It seems certain, for instance, that the dispersion of the novae in the spirals, and probably also in our galaxy, may reach at least ten absolute magnitudes, as is evidenced by a comparison of *S Andromedae* with the faint novae found recently in this spiral. A division into two magnitude classes is not impossible.

Tycho's Nova, to be comparable in absolute magnitude with some recent galactic novae, could not have been much more than ten light-years distant. If as close to us as one hundred light-years it must have been of absolute magnitude −8 at maximum; if only one thousand light-years away, it would have been of absolute magnitude −13 at maximum.

The distances and absolute magnitudes of but four galactic novae have been thus far determined; the mean absolute magnitude is −3 at maximum, and +7 at minimum.

These mean values, though admittedly resting upon a very limited amount of data, may be compared with the fainter novae which have appeared in the Nebula of Andromeda somewhat as follows: where 500,000 light-years is assumed for this spiral on the island universe hypothesis and, for comparison, the smaller distance of 20,000 light-years.

	Apparent magnitudes	
	Thirty galactic novae	Sixteen novae in Neb. Andromedae
At maximum	+5	+17
At minimum	+15±	+27 (?; conjectured from the analogy of the galactic novae)

	Absolute magnitudes		
	Four galactic novae of known distance	Sixteen novae in Andr. if at distances of,—	
		500,000 l. y.	20,000 l. y.
At maximum	−3	−4	+3
At minimum	+7	+6?	+13?

It will be seen from the above that, at the greater distance of the island universe theory, the agreement in absolute magnitude is quite good for the galactic and the spiral novae. If as close as 20,000 light-years, however, these novae must be unlike similar galactic objects, and of unusually low absolute magnitude at minimum. Very few stars have thus far been found as low in luminosity as absolute magnitude +13, corresponding, at this distance, to apparent magnitude 27.

The simple hypothesis that the novae in spirals represent the running down of ordinary galactic stars by the rapidly moving nebulosity becomes a possibility on this basis of distance (i. e., 20,000 light-years) for the brighter spirals are within the edges of the galactic system (Shapley).

This hypothesis of the origin of the novae in spirals is open to grave objections. It involves:

1. That the stars thus overtaken are of smaller absolute luminosity than the faintest thus far observed, with very few exceptions.

2. That these faint stars are extraordinarily numerous, a conclusion which is at variance with the results of star counts, which seem to indicate that there is a marked falling off in the number of stars below apparent magnitude 19 or 20.

As an illustration of the difficulties which would attend such a hypothesis, I have made a count of the stars in a number of areas about the Nebula of Andromeda, including, it is believed, stars at least as faint as magnitude 19.5, and find a star density, including all magnitudes, of about 6,000 stars per square degree.

If no more than 20,000 light-years distant this spiral will lie 7,000 light-years from the plane of the Milky Way, and if moving at the rate of 300 km/sec., it will sweep through 385 cubic light-years per year.

To make the case as favorable as possible for the hypothesis suggested, assume that none of the 6,000 stars per square degree are as close as 15,000 light-years, but that all are arranged in a stratum extending 5,000 light-years each way from the spiral.

Then the Nebula of Andromeda should encounter one of these stars every 520 years. Hence the actual rate at which novae have been found in this spiral would indicate a star density about two thousand times as great as that shown by the count; each star would occupy about one square second of arc on the photographic plate.

The spirals as island universes: summary.—

1. On this theory we avoid the almost insuperable difficulties involved in an attempt to fit the spirals in any coherent scheme of stellar evolution, either as a point of origin, or as an evolutionary product.

2. On this theory it is unnecessary to attempt to coordinate the tremendous space velocities of the spirals with those of the average star.

3. The spectrum of the spirals is such as would be expected from a galaxy of stars.

4. A spiral structure has been suggested for our own galaxy, and is not improbable.

5. If island universes, the new stars observed in the spirals seem a natural consequence of their nature as galaxies. Correlations between the novae in the spirals and those in our galaxy indicate distances ranging from perhaps 500,000 light-years in the case of the Nebula of Andromeda, to 10,000,000 or more light-years for the more remote spirals.

6. At such distances, these island universes would be of the same order of size as our own galaxy.

7. Very many spirals show evidence of peripheral rings of occulting matter in their equatorial planes. Such a phenomenon in our galaxy, regarded as a spiral, would serve to obliterate the distant spirals in our galactic plane, and would furnish an adequate explanation of the otherwise inexplicable distribution of the spirals.

There is a unity and an internal agreement in the features of the island universe theory which appeals very strongly to me. The evidence with regard to the dimensions of the galaxy, on both sides, is too uncertain as yet to permit of any dogmatic pronouncements. There are many points of difficulty in either theory of galactic dimensions, and it is doubtless true that many will prefer to suspend judgment until much additional evidence is forthcoming. Until more definite evidence to the contrary is available, however, I feel that the evidence for the smaller and commonly accepted galactic dimensions is still the stronger; and that the postulated diameter of 300,000 light-years must quite certainly be divided by five, and perhaps by ten.

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 universes, like our own galaxy, and that the spirals, as external galaxies, indicate to us a greater universe into which we may penetrate to distances of ten million to a hundred million light-years.

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