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STUDIES OF THE GALACTIC CENTER
I. THE PROGRAM FOR MILKY WAY VARIABLE STARS

BY HARLOW SHAPLEY

HARVARD COLLEGE OBSERVATORY

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Ever since the study of the space distribution of globular clusters indicated the eccentric position of the solar system in the Galaxy, I have desired to investigate in detail those distant regions in the southern Milky Way where the center of the galactic system appears to be. The usual statistical methods of elucidating galactic structure from rather indiscriminate counts of stars and from measures of motions in the solar neighborhood seem to be too limited—wholly inadequate, in fact, for analysis of regions some twenty thousand to a hundred thousand light years distant. The so-called Kapteyn universe, for instance, is deduced without regard to local clustering, and it combines the data from all galactic longitudes; many earlier attempts to outline the system did not even allow for differences in galactic latitude. The Milky Way system is obviously a conglomerate of single stars, groups of stars, clusters and great star clouds, seriously obscured in certain regions by nebulosity. A direct attack on the problem of the distances of the individual stars in the Milky Way, of the individual nebulae, and of stellar groups, by methods that reach far and give unambiguous results, appears to be the most satisfactory way of working out the details of galactic dimensions and structure, and in particular of determining the nature of the central regions of the galactic system. The researches undertaken to that end will be reported briefly in a series of notes under the title "Studies of the Galactic Center," but the more extensive details, especially the observations dealing with variable stars and star counts, will be published mainly in the Bulletins or Circulars of the Harvard Observatory.

As a preliminary, it should be recalled that all the known globular clusters, about a hundred in number, form a unified, considerably flattened system of still higher order, symmetrical with respect to the galactic plane. Their distances range from fifteen thousand to about two hundred thousand light years, and the greatest diameter of the system, in the plane of the Galaxy, is between two hundred thousand and three hundred thousand light years. The center of the Galaxy is in the direction of galactic latitude 0°, galactic longitude 327°, and it is so remote that a very asymmetrical apparent distribution is imposed on the globular clusters, which thus appear concentrated in Scorpio, Sagittarius, and the surrounding constellations. Also there appears to be a decided concentration of other remote and highly luminous objects in this same region of the sky, probably the result of the great depth of the Galaxy in the direction of the center, rather than of a real clustering of such objects around the center.

Since the globular clusters are probably good indicators of the form of the Galaxy, of which they are a part, we conclude somewhat tentatively that galactic objects lie in an irregularly circular and much flattened system—a discoidal affair populated by probably not less than 10^{11} stars. Its dimensions may be greater or less than those of the surrounding and concentric system of globular clusters. It is our problem to discover the extent of the Galaxy by direct measurement, instead of continuing to base our estimates largely on the distribution of the globular clusters.

Increasing knowledge of the absolute luminosity of variable stars increases also their usefulness in measuring distances, whether inside the Galaxy, or outside, in globular clusters, Magellanic clouds and extra-galactic nebulae. It now appears that typical Cepheids, cluster type variables, long period variables and to a more limited extent novae and eclipsing binaries, can all be used in the work on galactic dimensions. Ultimately we may use also the planetary nebulae, the open clusters, peculiar types of variables, and stars of extraordinary spectrum and color in this work; and certainly the integrated magnitudes and angular dimensions of globular clusters and extra-galactic nebulae are among the most potent measuring tools, though they are only indirectly used in the present study of galactic structure.

In order to provide material for the general study of faint variable stars as bearing on the Milky Way problem, an extensive observing program was inagurated about five years ago at the Harvard Observatory. The remainder of this note is given to describing the project and reporting some of the preliminary general results.

Variable Star Fields.—The distribution of the centers of the 240 Harvard Milky Way variable star fields is indicated in galactic coördinates in figure 1. It is seen that three parallel series of overlapping fields extend over the whole length of the Milky Way. The separation of the centers is governed by the focal lengths of the principal telescopes used for the study in the northern and southern hemispheres. Some of the cameras with especially short focus and large covering capacity extend at one time over the whole of four to eight fields.

The 182 regular fields along the central belt of the Milky Way will contain, of course, a great majority of the discoverable variables and of all other stars of the Milky Way fainter than the twelfth magnitude; but to make the study representative of the whole sky, without actually covering in detail the relatively barren expanses in high galactic latitude, we are supplementing the comprehensive work near the galactic equator with a number of systematically distributed fields in higher galactic latitudes; there are also several supplementary fields in the neighborhood of the center of the Galaxy, and a few elsewhere along the Milky Way.

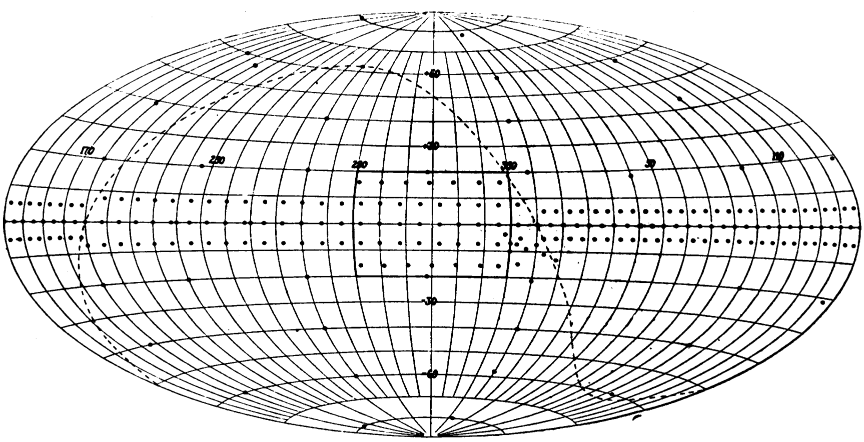

FIGURE 1

Distribution in galactic coördinates of centers of Milky Way variable star fields. Celestial equator is shown by broken line.

For at least three-fourths of the fields the stars down to magnitude 16.5 will be photographed; in special regions near the galactic center and elsewhere, the survey will later be taken to the nineteenth and twentieth magnitudes. The number of plates accumulated, in the ten or fifteen years during which this observing program will be maintained, will naturally depend on the character of the faint variable stars discovered. It will aim to be sufficient for determinations of the periods, ranges and light curves of all the periodic variables discovered. For most of the brighter and many of the fainter variables the secular or long period changes in the periods and light curves can also be found by using plates already available in the Harvard collection. There are, in fact, approximately sixty thousand plates made before the program was started that will be suitable for this research on Milky Way variables. Most of them, to be sure, show stars only to the twelfth magnitude, and are therefore not very effective in the work on the faintest variables.

In the present problem the uncertainty of photographic magnitude standards and the infrequency of reliable comparison sequences of faint stars will again be the most serious hindrance to accurate work on distant stars. It is probable that the absolute magnitudes of most of the fainter variable stars will soon be known with greater accuracy than their apparent magnitudes. Photographic magnitudes have been measured at Harvard for more than eight hundred sequences, well distributed over the sky. It is planned to carry on actively the improvement and extension of the existing magnitude standards in the immediate future; for certainly the problem of stellar distances has become a question of photometry. The concentration of the Henry Draper Extension to Milky Way regions has been largely influenced by the need of faint spectra for both the photometric work and the study of variable stars in the Milky Way.

The Photographic Cameras.—The following tabulation shows the instruments that have been used thus far in the systematic work on the Milky Way fields. The *AC*, *AM*, *AX*, *AY*, *RH* and *RB* series are only in part concerned with Milky Way variables. As used at present their lower magnitude limits range from 11.5 to 14.5. The *AM* and *AY* series have been discontinued for the present. The series marked with asterisks are made at the Boyden Station, at Arequipa or Bloemfontein.

INSTRUMENT	SERIES	FOCAL LENGTH (INCHES)	WORKING APERTURE (INCHES)	DIAMETER OF WORKING FIELD (DEGREES)
Bruce 24-inch doublet	*A**	135	24	4.4
Metcalf 16-inch doublet	*MC*	83	16	5
Metcalf 12-inch doublet	*MA*	87	12	5
Metcalf 10-inch triplet	*MF**	49	10	8
Draper 8-inch doublet	*I*	50	8	8
Cooke 4-inch triplet	*MD*	42	4	10
Ross-Fecker 3-inch	*RH*	21	3	15
Ross-Fecker 3-inch	*RB**	21	3	15
Zeiss-Tessar 3-inch	*AX**	13	2	25
Zeiss-Tessar 3-inch	*AY*	13	2	25
Cooke 1-inch	*AC*	13	1	25
Cooke 1-inch	*AM**	13	1	25

Number of Recorded Variable Stars.—The total number of variable stars listed in Prager's 1928 catalogue (which does not include those of the Magellanic Clouds, globular clusters, or spiral nebulae) is 3026. Of these, approximately fifty-five per cent lie in the Milky Way regions. Several hundred additional variables have been discovered within the present year at Harvard and elsewhere. Since this observing program began the numbers of new variable stars found by various workers on Harvard plates are approximately as follows:

S. I. Bailey	58	J. S. Paraskevopoulos	18
C. D. Boyd	180	H. H. Rehnborg	40
A. J. Cannon	90	H. Shapley	34
B. P. Gerasimovič	33	H. H. Swope	385
M. A. Gill	50	W. F. H. Waterfield	25

W. J. Luyten	87	I. E. Woods	250
J. Mohr	60	Miscellaneous	50
		Total	1360

At least two-thirds of these variables are fainter than the fourteenth magnitude. Therefore in general their distances exceed thirty thousand light years.

The Central Region.—Although the whole circuit of the Milky Way is covered in the observing program, it is obvious that more attention should be given to the region in the direction of the galactic center, not only because of our curiosity concerning that part of the universe, but because of the much greater star density—apparent and possibly real. The region between latitudes +20° and −20°, longitudes 290° and 350°, has been laid out for special study (Fig. 2). This is a region rich in discovered

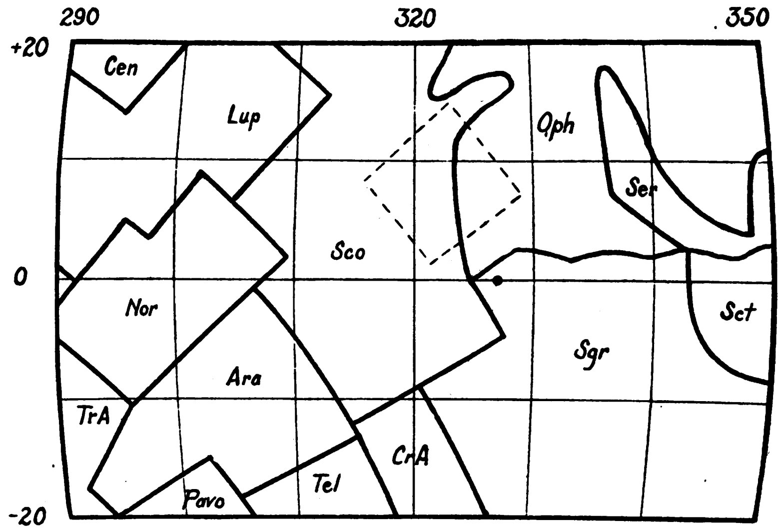

FIGURE 2

Map of the region of special study around the galactic center. The broken-lined quadrilateral is MWF 185, a field rich in variable stars, which is discussed in the following note of the series. The point at 327°, 0°, is the galactic center indicated by globular clusters.

and undiscovered variable stars, and some of it is affected by heavy obscuring nebulosity, which may seriously hamper our investigation of the region. As will appear from subsequent notes, we are studying not only the variables in this region of nearly 60 × 40 = 2400 square degrees, but also the number and distribution of nebulae, clusters and stars of various types. The following note will give a preliminary idea of the distance of the main body of stars near the galactic center and indicate the success with which the investigation of variable stars may reveal important details of the structure of the Galaxy.