The Centre of the Galaxy.[1]

By Dr. HARLOW SHAPLEY, Harvard College Observatory, Cambridge, Mass., U.S.A.

INTRODUCTION.

FROM current work on the distribution of stars, clusters, and extra-galactic nebulæ, I estimate that at least 90 per cent of the sky is free of obscuring nebulous clouds. It therefore seems like an unhappy caprice in the arrangement of the material world that the centre of the Galaxy is behind impenetrable cosmic clouds, and thus hopelessly concealed from the vision of the only creatures in the whole Galaxy (so far as we know) who are curious about the centre. One investigation after another indicates an obscured region in the southern Milky Way, where the constellations Scorpio, Ophiuchus, and Sagittarius corner together, as the direction to the gravitational and rotational centre of the galactic stellar system. The hundred square degrees immediately surrounding this central point appear to be more than half covered by dark nebulosity; all along the southern Milky Way, within thirty degrees of the centre, the obscuration is heavy; but it is so irregular, fortunately, and so incomplete, that numerous exceedingly faint and distant stars are found in the clear areas. High stellar concentration, behind the obscuring veil that overlies most of the centre, is suggested by the distribution of stars in these transparent regions. Is there a massive galactic nucleus concealed by the dark nebulosity? Or is there an ordinary stellar density comparable with that of the sun's neighbourhood? Is our Galaxy an enormous spiral nebula? Or is it an assemblage of stars and star clouds?

For two or three centuries the philosophical astronomers, recognising that the sun is merely a little brother to many millions of stars, have speculated on the problem of the centre of the universe, or the centre of the Milky Way system. A natural vanity and egocentrism led most speculators to assume that the solar system is central (an assumption that is not yet extinct), but Wright, Kant, Lambert, and others suggested in turn that various conspicuous celestial objects had as good claim to the central place—objects such as Sirius and the Orion Nebula. The measuring of the motions of stars, suggesting rotation about some central mass or masses, has led within the past century to the intimation that the Pleiades or the Perseus clusters might be the controlling central bodies. The more recent extensive star counts have induced various investigators to locate the galactic centre in all quadrants of the Milky Way. Only very recently has astronomical unanimity been approached in placing the direction to the galactic centre in the southern Milky Way, though this was clearly indicated by the analysis of the distances and distribution of star clusters a dozen years ago.

Meanwhile, we have learned of a secondary centre—that of the local system—in the direction of Carina, ninety degrees from the galactic centre; and we have noted, in a preliminary fashion, various other concentrations in special regions of the Milky Way, such as the great star clouds in Cygnus. It is the existence of these localised systems that have led in the past to the variety of results based on undiscriminating counts of stars.

My present discussion of the galactic problem touches on three subjects: the new determination of the direction to the centre, with indications of its distance; the initiation of studies of the variable stars, novæ, nebulæ, clusters, and star clouds in the central region; and a consideration of the probable effect in certain problems of cosmogony of obscuring nebulous clouds.

THE DIRECTION TO THE CENTRE.

My earlier study of the distribution of globular clusters in galactic latitude and longitude was based on less than seventy objects—all the globular systems then certainly recognised. They gave as the direction to the galactic centre the right ascension $17^{h}\cdot5$, declination $-30°$; or, in galactic coordinates, longitude 325°, latitude 0°. This concentration of the globular clusters in the Sagittarius region was of high cosmic significance, however, only because the measures of the distances gave a clear indication that the clusters are certainly a part of the Galaxy and that their space distribution most probably outlines the whole system of thousands of millions of individual galactic stars. The centre of the system of globular clusters could be taken as the centre of the whole Galaxy.

The globular clusters intimated that the sun is some sixty thousand light years from the centre of the system, that it is indeed perhaps half-way out toward the periphery of the greatly flattened discoidal and irregularly assembled stellar system, that the concentration of stars near the sun is merely a local cloud—a sub-system in the Galaxy—and that the scale of measurable space and time is somewhat astonishing when compared with earlier concepts.

Although they are the best tools we have, and are positive and accurate with regard to the direction to the centre, the globular clusters leave something to be desired in the measure of the form and dimensions of the Galaxy. They show a surprising absence from mid-galactic regions—more than appears explainable by nebulous obscuration; they also have peculiarities of their own, and the more distant and difficult clusters do not yet yield precise results. We have, however, been able to increase the number to a little more than one hundred, and to revise the measures of the distances. The plot of the distribution in galactic longitude and latitude is shown in the accompanying diagram (Fig. 1); it indicates that the centre of the globular cluster system lies on the galactic equator (latitude 0°, as before), and that the longitude is $327° \pm 2°$.

The new results, therefore, fully confirm the

[1] Synopsis of the Halley Lecture delivered at Oxford on June 11.

earlier values of the position of the centre. The same value is also indicated qualitatively by the distribution of galactic novæ, planetary nebulæ, and other objects of high luminosity and great distance, and it is shown quantitatively by the distribution of faint galactic stars of all types, as studied by means of selected areas at the Mount Wilson and Groningen Observatories. The results on faint stars, recently published by F. H. Seares, give a value for the direction to the galactic centre differing but three degrees from that above.

It has been a natural inference that a flattened stellar system may be in rotation around its centre of mass, that is, in the case of the Galaxy, around a central nucleus, possibly very massive, in the direction of Sagittarius. Weight is lent to this argument by the analogy with external galactic systems, many of which, like the spiral nebulæ, are obviously of rotational form. Studies of the radial velocities and proper motions of the most remote stars of various types by Oort, Schilt, J. S. Plaskett, and others, show definite evidence of rotation around the same centre as that indicated by globular clusters.

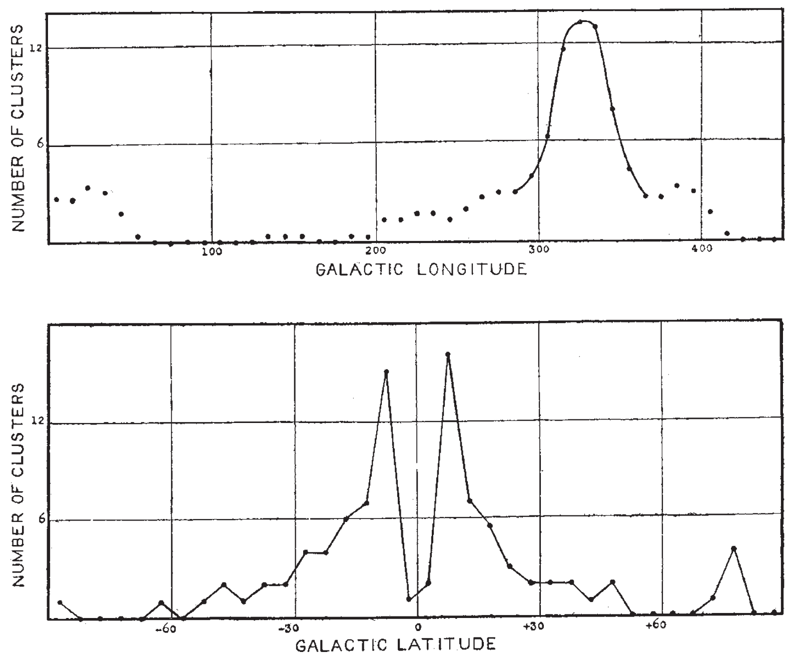

FIG. 1.—Determination of the direction of the centre of the Galaxy.

ANALYSIS OF THE CENTRAL REGION.

The distances of the globular clusters are obtained in part by means of their Cepheid variable stars. Recent work on the variables of the long period class shows that they, too, are of use in the photometric methods of estimating distance. Eclipsing stars also have been used with some success in estimating absolute magnitudes and parallaxes. Since all these types of variables are widely scattered throughout the Galaxy, it is clear that a thorough study of their distribution in space can throw light on the structure of the Milky Way. A few years ago we began at Harvard a systematic study of the variable stars in about two hundred fields that thoroughly cover all of the Milky Way within a belt twenty degrees in width. We devote the time of three telescopes and of many workers to this problem. In addition to the hundred thousand plates already available at Harvard for the study of variable stars in Milky Way regions, we have accumulated several thousand especially suited to the study of the faint variables in the richest fields. Six hundred variable stars have been found within the past year, and preliminary data obtained on their types, periods, magnitudes, and distances. To complete the investigation will probably require ten or fifteen years.

For special concentration we have laid out a region around the galactic centre, extending sixty degrees along the galactic circle and forty degrees in galactic latitude. It is estimated that more than seventy-five per cent of the galactic system lies within these bounds, which enclose less than six per cent of the entire sky. The various investigations of the central regions cannot be described here, except to note that they pertain to the distribution of the extra-galactic nebulæ, the diffuse and planetary nebulæ, the galactic and globular clusters, the novæ, and several classes of variable stars.

In the richly populated star clouds that lie within twenty degrees of the central point, several hundred new variable stars have been found, many of which are so faint that they probably lie beyond the centre. Numerous extra-galactic nebulæ, probably far beyond the outermost limits of the galactic system, are seen within fifteen degrees of the nebulosity-hidden centre, thus indicating that certain regions near the centre are entirely free of obscuring cosmic clouds. In the Sagittarius region we also have some of the most beautiful bright nebulæ, and the highest density of stars for any region of the Milky Way. It is interesting to note that throughout the central region the open or galactic clusters are closely concentrated to a narrow band which is completely avoided by the globular systems. We take this arrangement to indicate that the galactic clusters are relatively near at hand, most of them, like the bright stars, lying between us and the obscuring nebulosity.

It appears probable that by continuing to feel our way around the edges of the centre-hiding nebulosities, and studying in great detail the stellar distribution in this central region, we shall in time be able to determine the distances of obscuring nebulosities and also to make a better guess at what may lie behind them—a guess as to whether or not our galactic system has a highly massive nuclear concentration of stars, such as is observed in many of the extra-galactic nebulæ.

DARK NEBULÆ, METEORS, AND STARS.

In studying the distribution and distance of the dark nebulosities in the Milky Way, especially those in the direction of the galactic centre, we are led to investigate the various effects of such nebulosity on the apparent distribution, luminosity, and life of the stars. That such nebulosity is of the nature of meteoric dust is now generally accepted. It effectively blocks the light in many regions, and in some others there is a perceptible localised reddening—for example, for the nebulous stars studied by Seares and Hubble. That moving nebulosity may also incite the variability of stars is strongly suggested by the large number of irregular variables found in such regions as Orion.

In our recent spectroscopic work we have found, however, a more significant effect of meteoric nebulosity. In microphotometer tracings of the spectra of stars in the Pleiades, and of other hot stars, a shallow absorption band appears between $H\gamma$ and $H\delta$, in the region where in cooler stars the well-known cyanogen band occurs. The same tracings show on the violet side of the Ca^+ lines, H and K, a wide and fairly strong absorption band, and this region is that where the strongest and most easily excited lines of iron and magnesium are found in the cooler stars. These absorption bands, very prevalent in the hotter stars where molecular band absorption is not to be expected as a normal feature of the hot stellar atmospheres, have apparently been overlooked in the past because specially exposed spectrograms and careful spectrum analysis are required to bring them out. Thus the iron and magnesium 'ultimate-line band' is in a region rarely shown in the ordinary stellar spectrogram, but they are frequently well shown on the Harvard objective prism plates when over-exposed for the photographic regions usually studied.

Without going into further details, we briefly state that these bands in the stellar spectra probably arise from the absorption of starlight by infalling meteors or by comets and meteors moving at high velocities when the periastra of their orbits are near the surfaces of the stars. The bands are the first direct evidence we have had of the existence of enormous quantities of secondary bodies around stars. The high velocities, through the Doppler effect, smear out the structural detail in the bands, and extend their limits beyond the limits shown by laboratory spectra, or shown by ordinary atmospheric cyanogen and iron in the spectra of cooler stars.

The cyanogen, iron, and magnesium absorption might have been anticipated from a consideration of the probable meteoric infall in nebulous regions. The sun appears to be in a part of space fairly free from nebulosity, but extrapolating from the earth's daily intake of some twenty or thirty millions of naked-eye shooting stars, it is found that the sun absorbs at least a million million meteors a second, or more than a thousand tons of iron, magnesium, silicon, and oxygen, if the average mass of a meteor is of the order of only one milligram. The elements just named are the main constituents of the iron and stone meteors that meet with the earth. The 'ultimate line' absorption is not recorded for silicon and oxygen, which is natural, for the most easily excitable lines of silicon and oxygen are not in an available part of the spectrum.

Several hundred spectra showing the absorption band have been studied at the Harvard Observatory by Miss Payne and myself. The heaviest absorption is found in the most heavily nebulous regions. It seems likely that a part of the mass lost by a star through radiation is replaced by the meteoric infall. In the case of our sun the repletion of lost mass is scarcely appreciable, unless we have much underestimated (as is likely) the average size of meteors, or their frequency at the sun's surface. But in the case of stars in dark nebulous clouds, or even in lighter nebulosity such as the Pleiades, the radiative degradation of a star's energy may be much retarded, or balanced, or possibly even reversed. We appear to have found, as a by-product of the study of the region of the galactic centre, an indication that the meteoric matter of the dark nebulæ, and of space in general, can be observed spectroscopically as it feeds the stars.

The Bicentenary of Capt. Cook.

AMONG navigators of all ages, Capt. James Cook stands without a rival. Born amidst humble surroundings and apparently destined to occupy but an obscure station, by the force of natural ability and character and the cultivation of his talents, he raised himself to the highest rank among naval explorers, adding immensely to geographical knowledge and planting the British flag on two of its finest possessions. Cook was born at Marton, in the Cleveland district of Yorkshire, on Oct. 27, 1728, two hundred years ago. His father was but an agricultural labourer and farm bailiff, and Cook himself, as a boy of thirteen or fourteen years, was apprenticed to a shopkeeper near Whitby. But as on many another, the sea exercised a fascination which could not be resisted, and his youth and early manhood were spent in trading vessels of the east coast, and in the course of time he rose to be a mate. The North Sea was his high school and university; his study, the cabin of a collier.

The turning point in Cook's career came in 1755, when from a vessel lying in the Thames he volunteered for service in the Navy. War was imminent, the press-gang was abroad—the very press-gang Watt, as a youth of nineteen, alone in London, went in dread of—and Cook, volunteering for the service, exchanged his cabin in the merchantman for the forecastle of a man-of-war. He soon received promotion, however, and at that time there could have been few, if any, who by their industry,