THE LONGITUDE OF THE GALACTIC CENTER AS DERIVED FROM THE INTENSITIES OF DETACHED CALCIUM LINES

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According to recent investigations by F. H. Seares,\(^1\) there is considerable evidence in favor of the idea that the center of the larger galactic system is identical with the center of the system of globular clusters, placed by H. Shapley\(^2\) approximately in galactic longitude 325° and at a distance of approximately 20,000 parsecs from the sun. J. H. Oort's center of galactic rotation lies in the same direction, although at a somewhat smaller distance. His work has been amply confirmed by J. Schilt, J. S. Plaskett and others, so that it is safe to regard the direction \(l = 325^\circ\) as fundamental in our Milky Way system. B. Lindblad and others have advanced the hypothesis that the observed distribution of stars is mainly an effect of dark nebulous masses in the vicinity of the solar system, and that the actual center is hidden from us.

H. Shapley and his collaborators\(^3\) have undertaken a detailed study of the region near the galactic center. It appears that there is a notable concentration of cluster-type variable stars in the vast star-clouds near the center, at a distance of about 14,400 parsecs. Many variables lie beyond the center, and there are a number of extra-galactic nebulae within a small angular distance from the point \(l = 325^\circ, b = 0^\circ\) (or \(a = 17^h5; \delta = -30^\circ\)). Accordingly, in comparatively small angular distances from the center, the line of sight encounters no obstruction from dark matter. If we consider a series of observations covering the whole galaxy and complete to a certain given apparent magnitude, the average distance of the stars must be a function of galactic longitude, being greatest in \(l = 325^\circ\) and least in \(l = 145^\circ\). The exact form of the relationship depends upon the distribution of dark matter as well as upon the concentration of the stars toward the center, and is therefore not known, but the curve is probably symmetrical and its maximum and minimum are defined as stated.

The determinations of the Ca\(^+\) intensities in early type stars, which I
made at the Harvard College Observatory, are fairly uniform with respect to limiting magnitude. It might therefore be expected that the mean intensity of an interstellar line would vary with galactic longitude. The intensity

$$I = I_0 e^{-\beta D}$$

where $\beta$ is the absorption coefficient per parsec and $D$ is the distance in parsecs. What we observe is

$$\Delta m = -2.5 \log I/I_0 = 2.5 \text{ mod. } \beta D$$

If $\beta$ is constant, the observed value of $\Delta m$ is directly proportional to the distance. Stronger lines should therefore predominate near the galactic center. In reality we do not know whether or not $\beta$ is quite constant over large distances. It is probably fairly constant up to $D = 1000$

![Diagram showing relationship between galactic longitude and average intensity of interstellar calcium lines.](image)

parsecs, but seems to decrease for greater distances from the sun. Whether or not it is a function of galactic longitude cannot be determined from the observations. A. S. Eddington has shown that the degree of ionization of the interstellar Ca-gas is that of a gas of density $\rho \delta$ in thermodynamic equilibrium, where $\rho$ is the density of the interstellar gas and $\delta$ is the "dilution-factor" determined in such a way that the density of radiation between $\gamma$ and $\gamma + d\gamma$ in interstellar space is $1/\delta I(\gamma T)d\gamma$. The density of radiation increases as the galactic center is approached, so that $\delta$ decreases. But the density of interstellar calcium probably increases—at least this is the most natural hypothesis. Indeed, if the interstellar gas is directly due to expulsion from stellar atmospheres by radiation pressure, we should have very nearly $\rho \delta = \text{const.}$, and $\beta$ would be independent of galactic longitude. In any case it is extremely unlikely that a change in $\beta$ would exactly offset the variation in mean distance.
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The observations furnish direct evidence that \( \beta \) is really a function of galactic longitude. In Astrophysical Journal 67, 370, 1928, figure 2, I have given a graphical representation of the Ca\(^+\) intensities in four shadings:

- Very strong: \( \Delta m \geqslant 3.7 \)
- Strong: \( 3.2 \leqslant \Delta m < 3.7 \)
- Weak: \( 2.8 \leqslant \Delta m < 3.2 \)
- Very weak: \( \Delta m < 2.8 \)

For convenience of computation I have introduced the following new units of intensity:

<table>
<thead>
<tr>
<th>CHARACTER OF LINES</th>
<th>INTENSITY IN NEW UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very strong</td>
<td>+2</td>
</tr>
<tr>
<td>Strong</td>
<td>+1</td>
</tr>
<tr>
<td>Weak</td>
<td>−1</td>
</tr>
<tr>
<td>Very weak</td>
<td>−2</td>
</tr>
</tbody>
</table>

One unit in the new scale corresponds roughly to a step of three or four hundredths of a stellar magnitude. Means for every 30° in \( l \), between \( b = +10° \) and \( b = -10° \), were then taken. They are shown in table 1, expressed in the new units. Every entry of the table corresponds to the mean from six squares each having 10° on the side, as shown in the figure referred to above. Only in a few cases there were blank squares in the figure, due to an insufficient number of stars in these regions. In such cases the number of squares used was smaller. It seemed best not to use any of the squares in high galactic latitudes because of their small number and unsymmetrical distribution. There is also a tendency for the lines to be fainter in the higher galactic latitudes.

This series of values can be represented by an equation of the form

\[
\text{TABLE 1}
\begin{array}{ccc}
\text{MEAN GAL. LONG.} & \text{NO. OF SQUARES USED} & \text{MEAN INTENSITY IN NEW UNITS} \\
15 & 4 & +0.25 \\
45 & 6 & +0.33 \\
75 & 6 & +0.83 \\
105 & 6 & -0.33 \\
135 & 5 & -1.40 \\
165 & 4 & +0.75 \\
195 & 6 & -0.33 \\
225 & 6 & -0.17 \\
255 & 6 & +0.50 \\
285 & 6 & +0.33 \\
315 & 6 & +0.83 \\
345 & 4 & +1.75 \\
\end{array}
\]
\[ \Delta m = K + X \cos (l - \alpha) \]  
(1)

where \( \alpha \) is the direction of maximum intensity. A graphical solution gives for the unknowns

\[ \alpha = 325^\circ \]
\[ K = +0.2 \text{ units} \]
\[ X = 0.6 \]

These values can be improved by a least-squares solution. Differentiating (1) we obtain for our observational equations

\[ d(\Delta m) = dK + \cos (l - \alpha) dX + X \sin (l - \alpha) d\alpha. \]  
(2)

Considering as unknowns the corrections to the preliminary values, \( \Delta \alpha, \Delta K, \Delta X \), I have made a rough computation which yields the following final results:

\[ \alpha = 337.6^\circ \pm 18^\circ \text{ (probable error)} \]
\[ K = +0.28 \pm 0.15 \]
\[ X = 0.67 \pm 0.20 \]

The direction \( \alpha \) very nearly coincides with the direction toward the galactic center. The results are shown in figure 1 in which the curve is drawn for \( l = 325^\circ \). In the computations equal weights were given to all observations. If the three points determined from only four squares each are omitted, we get a slightly different curve, as shown by the dashed lines. The value of \( \alpha \) would not, however, be appreciably affected. The least-squares solution reduced the sum of the squares of the residuals from 429 to 414. The probable error of one point on the diagram is \( \pm 0.5 \) in the new units.

While it is possible that the results of the intensity estimates are affected by systematic errors, I do not think that they are serious in this case. It so happens that the position of the center is only 30° distant from the equator, so that systematic differences between northern and southern hemispheres would not much affect the results, and these are probably the only ones that might be feared.

2 Ibid., J., 49, 311, 1919.
5 Der Innere Aufbau der Sterne, p. 478, 1928.