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A COMPUTER STUDY OF GALACTIC STRUCTURE

by John Kounis

The shape and structure of our galaxy have been studied by astronomers for decades in an attempt to reveal the properties of the galaxy in which we live and its relationship to other galaxies. Among the pioneers of galactic astronomy are Harlow Shapley and Edwin Hubble whose work in galactic astronomy widened man's understanding of the universe in the early 20th century.

In order to determine these properties of our galaxy, a large-scale analysis of many stars is necessary which would represent at least a small percentage of the total number of stars in the galaxy. Their similarities and differences have to be evaluated in order to determine their relation to the overall galactic system. Since the earth is within the Milky Way, we are in a very awkward position to study our galaxy; thus, we try to do the best we can by searching out to its furthest visible members and analyzing their properties.

One aspect of galactic structure which merits studying is the correlation between different types of stars and the galactic plane. This would reveal the extent of scattering of these types of stars within the galaxy.

To conduct such a study, it soon became evident that some kind of star catalogue would be necessary on a medium compatible for computer analysis. Thus, the U.S. Naval Observatory Photometric

Catalogue was purchased on magnetic tape from the Astronomical Data Center in Strasbourg, France. This catalogue contains photometric data for approximately 35,000 stars of all spectral classes. Of these stars, approximately 10,000 were selected from the O, B, A, and F spectral classes.

The U.S. Naval Observatory catalogue did not contain any direct distance information; therefore, the distance to the stars had to be determined by their spectroscopic parallaxes. From the stars' spectral and luminosity classes (i.e. in 09V, 09 would be the spectral classification, and the Roman numeral V would be the luminosity classification), the stars' approximate absolute magnitudes could be determined. By subtracting the stars' apparent magnitudes from their absolute magnitudes, their distance moduli can be calculated which, in turn, are used to determine the distances to the stars.

To evaluate the extent that the stars corresponded to the true galactic plane, the stars were fitted to the best fit plane with a method known as least squares fitting. A plane was fitted to each of the four groups of stars from the different spectral classes selected, and the error in each estimation was determined by calculating the distance between the galactic center and the fitted plane. If the estimation of the galactic plane were perfect, the distance should have been zero. The greater the distance calculated, the greater the error in the estimation is.

The different spectral classes studied yielded remarkably different results. The hotter and younger 0 stars corresponded very closely to the true galactic plane. For a distance of 10,000 parsecs to the galactic center, the error calculated for the plane determined by this spectral class was 900 parsecs. This is an error of about 5°. This error increased through the B and A spectral classes and reached a maximum of 9233 parsecs for the class F stars; this error corresponds to almost 45°!

I believe that the reason for these errors is related to star formation within the galaxy. The younger class 0 stars probably defined the most accurate plane because they were the youngest stars selected and had the least opportunity to be affected by random motions. As the age of the stars increase, and they are classified under later spectral classes such as B, A, and F, they have a greater opportunity to be affected by more random motions which scattered them to a greater degree than the younger stars.

Various methods were also employed to graphically represent galactic structure. A computer program produced 4 graphs, 3 of them representing different planes of the galaxy and one representing the stars plotted according to their spherical coordinates, right ascension and declination, as seen from the center of the galaxy. Graph 1 is the graph produced by the computer representing the X-Y plane of the galaxy. This graph reveals no apparent spiral arms as have been detected with radio telescope observations at the 21 cm. wavelength. This is significant because it shows that the stars are not as tightly correlated to the spiral arms of our galaxy as the hydrogen regions are. Graph 2 reveals the correlation of the stars to the galactic plane to a great extent. The stars appear to lie within a narrow band stretching across the graph which seems to be the galactic plane. Graph 3 depicts the stars plotted according to their spherical coordinates as seen from the center of the galaxy. It also shows the correlation of the stars to the galactic plane because of their alignment to a line determining a great circle on the celestial sphere. Graph 4 represents a latitudinal cross section of the galaxy.

The purpose of this paper was to make an attempt to give us a better view of our galaxy. The methods employed analyzed the optically visible stellar population of out galaxy and its properties rather than radio telescope observations. This was just a slightly different approach to galactic astronomy by turning to optical observations for the necessary information.

APPENDIX A

Equations Used to Determine Stellar Distances

The U.S. Naval Observatory catalogue had limited information; thus, the stellar distances and coordinates had to be derived from the following equations:

The distance ρ was determined by each star's spectral class, luminosity class, and B-V color index. From the star's spectral and luminosity classes the average absolute magnitude M and B-V color index could be determined. Then the distance was calculated from the following:

$$\Delta_{B-V} = (B-V_{star}) - (B-V_{average})$$

$$\log p = \frac{(m_{visual}) - (m_{absolute})}{5} + 1$$

Correcting for interstellar reddening, the distance is determined by the following:

$$p = 10^{\left(\log p - \frac{3.0\,\Delta_{B-V}}{5}\right)}$$

APPENDIX B

The conversion from rectangular to spherical coordinates with the origin centered at the earth and vice-versa were done by the following equations.

Conversion from spherical to rectangular coordinates:

$$x = \rho \cos\alpha \cos\delta$$

$$y = \rho \sin\alpha \cos\delta$$

$$z = \rho \sin\delta$$

Conversion from rectangular to spherical coordinates:

$$\alpha = \tan^{-1} \frac{x}{y}$$

$$\delta = \sin^{-1} \frac{z}{R}$$

$$\rho = (x^2 + y^2 + z^2)^{\frac{1}{2}}$$

where α and δ are the right ascension and declination of the stars which were available on the magnetic tape, ρ was calculated in Appendix A.

APPENDIX C

Least Squares Fitting of the Galactic Plane

In order to determine a plane of the form $z = f(x, y)$ where $f(x, y) = Ax + By + C$, the coefficients of the plane are calculated by differentiating of the sum of the squares of the errors $e(n)^*$ and minimizing it by setting it equal to zero.

$$e(n) \triangleq \sum_{j=1}^{n} (f(x_j, y_j) - z_j)^2 = \sum_{j=1}^{n} (Ax_j + By_j + C - z_j)^2$$

$$\frac{\partial e(n)}{\partial A} = \frac{\partial \sum_{j=1}^{n} (Ax_j + By_j + C - z_j)^2}{\partial A} = \sum_{j=1}^{n} \frac{\partial (Ax + By + C - z)^2}{\partial A}$$

$$= \sum_{j=1}^{n} 2x_j (Ax_j + By_j + C - z_j) = 0$$

$$\therefore \quad A \sum_{j=1}^{n} x_j^2 + B \sum_{j=1}^{n} x_j y_j + C \sum_{j=1}^{n} x_j = \sum_{j=1}^{n} x_j z_j$$

Differentiating with respect to the other two coefficients yields:

$$A \sum_{j=1}^{n} x_j y_j + B \sum_{j=1}^{n} y_j^2 + C \sum_{j=1}^{n} y_j = \sum_{j=1}^{n} y_j z_j$$

$$A \sum_{j=1}^{n} x_j + B \sum_{j=1}^{n} y_j + Ci = \sum_{j=1}^{n} z_j$$

This produces the following linear equation:

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* In these equations, n equals the total number of stars in consideration.

$$\begin{pmatrix} A \\ B \\ C \end{pmatrix} \begin{pmatrix} \Sigma x_j^2 & \Sigma x_j y_j & \Sigma x_j \\ \Sigma x_j y_j & \Sigma y_j^2 & \Sigma y_j \\ \Sigma x_j & \Sigma y_j & i \end{pmatrix} = \begin{pmatrix} \Sigma x_j z_j \\ \Sigma y_j z_j \\ \Sigma z_j \end{pmatrix}$$

This equation is then solved by inverting the 3×3 matrix on the left and multiplying it by the 3×1 matrix on the right.

APPENDIX D

Errors in the Determination of the Galactic Plane

Once the coefficients of the galactic plane equation (A,B, and C) are determined by the method described in appendix c, the error in this estimation is approximated by evaluating the distance,, r, between the galactic plane and the galactic center. The method described in appendix b was used to change the galactic center's right ascension, declination, and distance* into rectangular coordinates(x,y,z). Then this distance was calculated by the following equation:

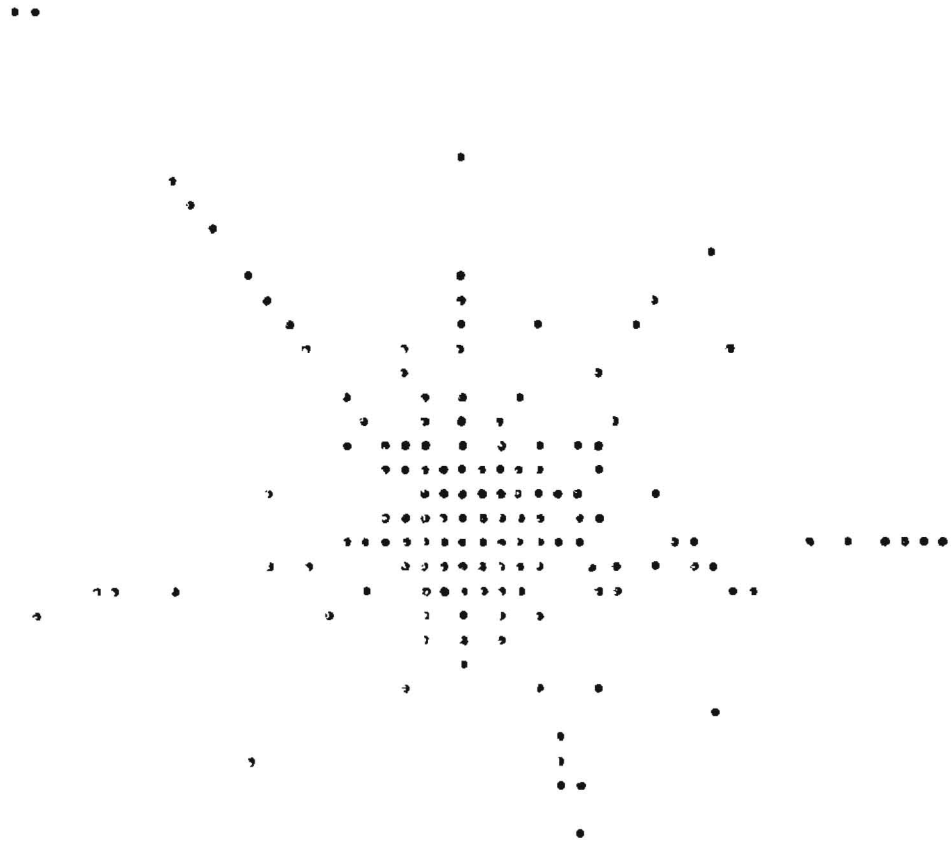
$$r = \frac{|Ax+By+C-z|}{(A^2+B^2+1)^{\frac{1}{2}}}$$

In the above equation, Ax+By+C=z is the form of the galactic plane equation, and the coördinates, x,y, and z, are the coordinates of the galactic center.

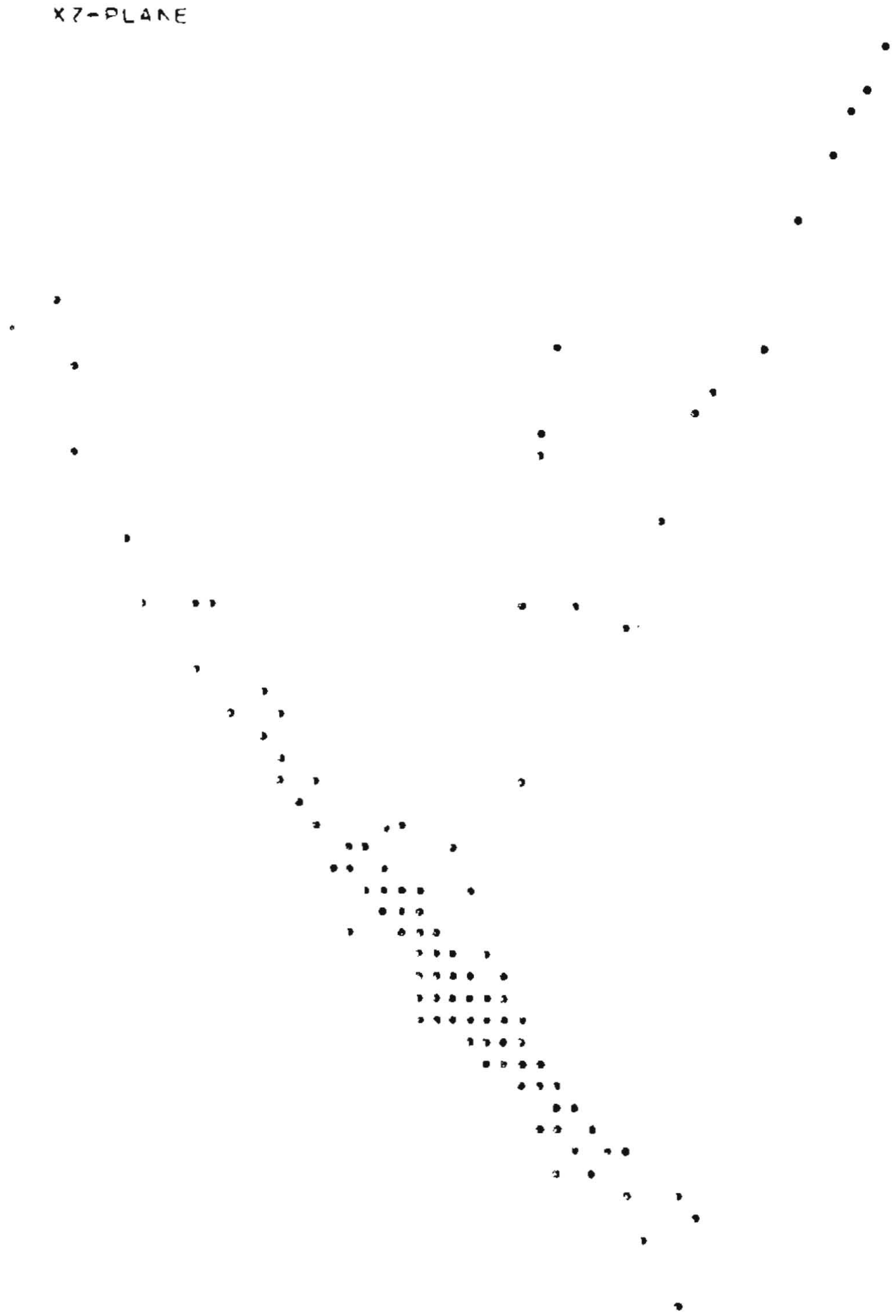
* Taken from Astrophysical Formulae by Kenneth R. Lang.

GRAPH # 1

XY-PLANE



GRAPH # 2



GRAPH # 3

HORIZONTAL AXIS-RIGHT ASCENSION, VERTICAL AXIS DECLINATION AS SEEN FROM THE GALACTIC CENTER

GRAPH #4