Red Dwarfs As Related to Galactic Structure

An Honors Thesis (HONRS 499)

by

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June, 1996

Graduation: July, 1996
ABSTRACT:

This thesis addresses the topic of red dwarf stars and how they relate to galactic structure. Results from previous observations are used to analyze the stellar density of nearby red dwarfs. Making assumptions based on a simple model, the stellar densities did not follow an expected pattern so the assumptions were analyzed one by one in an attempt to construct a more accurate model. Stellar surface densities based on observations were computed and compared to expected stellar surface densities. The observed surface densities were not consistent with the expected ones. The reason for the differences is yet unknown.
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1. Introduction

While astronomers have been working hard to map out the stars of the Universe, and especially the stars in our own Milky Way Galaxy, little is known about Red M dwarf stars. They are very faint stars so the only ones we can study well are very close to us. That limits the studies considerably.

In 1984-86, Dr. Thomas Jordan and Dr. Thomas Robertson took twenty-four objective-prism plates and twenty-four direct plates centered on J. C. Kapteyn's Selected Areas (SA) 92-115. SAs 96-108 were taken at Kitt Peak National Observatory (KPNO) and the others were taken at Cerro Tololo Interamerican Observatory (CTIO). The plates were examined for possible M dwarf stars. The stars' positions (right ascension and declination), and visual magnitudes were derived from the direct plates while spectral types were derived from the objective-prism plates. Absolute magnitudes were estimated from the spectral types of standard stars. Distances were calculated using the absolute and visual magnitudes. For each SA, a list of M dwarfs was compiled. Four square degrees were scanned on some of the plates and others were scanned over twenty-five square degrees so the number of stars per square degree was calculated for each SA. The average stellar surface density for each observatory was also computed. From this information, it was clear that the M dwarf stars were not uniformly distributed in the different SAs nor were the averages for the different observatories similar. (See Figure 1). CTIO's average was much higher.

I also attempted to find information on the distribution of red dwarfs in our galaxy to see if it would match my distributions. I was unable to find any graphs on the longitude distribution of M dwarfs. For many stellar populations, information can be found on their stellar distribution
in the galaxy. The distribution is usually described in terms of scale heights for the young thin
disk, the old thin disk, and the thick disk. Again, there is very little data available on the
distribution of M dwarfs. I did find some scale height information on M dwarfs in our galaxy
(Kroupa, Tout, and Gilmore, 1993). It did not give scale heights for the different disks, though. I
use the scale height information I found later in this paper.

In the absence of detailed models a more simple model must be assumed. The following
describes the basic assumptions upon which our models are based:

Stars distributed with

1) no variation in longitude (azimuthal symmetry) (small distances)
2) no variation in radial distance in the plane (small distances)
3) no clusters adding to star counts
4) no interstellar extinction limiting star counts (small distances)
5) no dark nebulae reducing star counts (small distances)
6) no giants counted as dwarfs
7) sun in middle of galactic plane
8) density decreasing exponentially up and down from the values in the plane with scale height
9) star density given by luminosity function

2. Purpose of the Project

The purpose of our project was to use the information described above to explain the variations in numbers of stars. We wanted 1) to know if the difference in average surface density between the two observatories was real and, if so, what its cause might be and 2) to determine the source of the differences for SAs 96, 98, and 99 from the average for KPNO. We divided the project into two parts. Amanda Ulman studied the data from CTIO while I studied the data from KPNO. We used the same techniques in our evaluations and worked together frequently so the results from both studies should be consistent and in some cases both sets of results will be given in this paper.

3. Difference in Averages for KPNO and CTIO

3.1 Comparing Limiting Magnitudes

Next, I attempted to determine why there was such a difference in the counts from KPNO and CTIO. Initially, I thought that the telescope used from CTIO must be more powerful and therefore able to detect stars to a fainter limiting magnitude. Miss Ulman and I separated our
stars by absolute magnitude and used the method described by equation 14-5 in Zeilik, Gregory, and Smith (1992) to determine our limiting magnitudes. The equation,

$$\log N(m) = 0.6m + C,$$

which assumes a uniform star density, is "an expression for the number of stars of a given absolute magnitude within a certain area of the sky brighter than apparent magnitude m where the constant C incorporates the dependence on M (absolute magnitude), w (solid angular area), and D (number of stars per unit volume)" (Zeilik, Gregory, and Smith, 1992). Due to the small numbers of stars in our samples we combined absolute magnitudes of 8.4 with 8.84 and 9.5 with 9.69. We were looking for the place on the graphs where, within the error bars, the slope of the curve dropped below 0.6. I determined the limiting magnitude for KPNO to be 12.5. (See Figures 2-5.) Since the plates taken at CTIO were mostly scanned for only four square degrees, Miss

![Figure 2](image1.png)

![Figure 3](image2.png)

![Figure 4](image3.png)

![Figure 5](image4.png)
Ulman had fewer stars to work with, making her data less reliable, but she determined CTIO to have a limiting magnitude of 12.5 also. Therefore, a difference in limiting magnitudes does not explain the difference in surface densities. Our original counts of M dwarfs in each SA were modified, eliminating stars detected beyond the limiting magnitude of 12.5.

Since the limiting magnitudes of the two telescopes did not adequately explain the differences in counts, we began to examine the assumptions for our model.

4. Stellar Surface Density Differences in Selected Areas for KPNO

4.1 Observed Average Stellar Surface Densities

I began by seeing how consistent my stellar surface densities were for KPNO. I took the average and standard deviation of the number of stars per square degree for KPNO and determined how many standard deviations above or below the average each SA was. I computed an average of 1.30 ± 1.55. SA 96 was one standard deviation above average. SA 99 was four standard deviations above average. All of the other SAs were one standard deviation below average. Since SAs 96 and 99 were clearly anomalous, I recomputed the average and standard deviation without them. The new average was 0.72 ± 0.32. The other data points were then distributed more evenly around the average with SA 96 being seven standard deviations above average and SA 99 being eighteen standard deviations above average. Also, SA 98, which showed no red dwarfs, was three standard deviations below average. Since the stars being detected are all relatively close to the Sun, I expected a more uniform stellar distribution. I did not expect galactic structure to create major variations in my stellar surface densities. I then set out to determine why SAs 96, 98, and 99 have such different stellar surface densities than the other areas.
4.2 Checking for Dark Nebulae and Star Clusters

Using the CD-ROMs *The Sky* and *Almagest II*, I checked my SAs for nebulae and star clusters. (See Appendix for star charts.) I thought I might find SAs with few stars to contain dark nebulae. Dark nebulae tend to obscure the incoming starlight, making dimmer stars more difficult to detect. I also thought I might find SAs with many stars to contain star clusters. Star clusters are compact areas within the galaxy with high numbers of stars. SA 98, the one with no M dwarfs, did show a reflection nebula, NGC 2282. SAs 96 and 99 did not show anything that might explain why I found so many M dwarfs there.

4.3 Checking for Contamination by Red Giants

If red giants were contaminating our fields, they would not contaminate uniformly. The distribution of giants varies radially and with longitude. I graphed my stellar surface densities as a function of galactic longitude. (See Figure 6.) Then I compared my graph to a graph showing

![Galactic Longitude Comparison](image)

*Figure 6*
the longitude distribution of giant M stars of type M5 or later found at low galactic latitudes from Blaauw and Schmidt, (1965). Their graph shows the galactic longitudes at which there are high surface densities of M giants. I was hoping that if my graph showed high surface densities at the same galactic longitudes, then I would have some indication of contamination by giants. However, the graph I compared mine to did not seem to confirm that I would expect more Red Giant contamination in SAs 96 or 99.

4.4 Comparing Galactic Latitude Variations

The difference in counts is very evident when looking at the graph of stellar surface densities vs. galactic latitude. (See Figure 7.)

1) The difference in counts between the northern hemisphere, positive galactic latitudes,
significantly different from the counts in the southern hemisphere, negative galactic latitudes. Several recent studies have placed the Sun, and hence our whole solar system, in the northern hemisphere instead of right on the galactic plane, where most of the stars are concentrated. The offset from which we are observing could then possibly explain why there would be more stars when looking into the southern hemisphere.

2) SAs 96, 98, and 99 are all at low galactic latitudes, where contamination by giants would be most likely. Distant red giants are difficult to distinguish from nearby red dwarfs so some of the stars we have classified as dwarfs may actually be giants. I was hoping to identify some of the stars from my SAs as red giants and eliminate them from my counts. I searched for catalogs which might list red giants and was unable to find any such catalogs.

4.5 Computing How the Offset of the Sun from the Galactic Plane Would Affect Stellar Surface Densities

To see how much the Sun's offset from the galactic plane would affect the number of stars we would expect to count, we calculated the number of red dwarfs we would expect to find in each of our SAs. We assume no density variations in galactic longitude or radius in the plane. The surface density changes as a function of galactic latitude only. The number volume density is normally assumed to be an exponential function of the z-distance from the galactic plane with a scale height (SH). The density per volume, then, would be:

$$\Phi(z) = \Phi(0)e^{-z/SH}$$

The volume sampled is that of a spherical sector having radius r and square sides of fixed angles. We integrate the density as a function of r in a sector of a spherical shell having sides r dl and r db with thickness dr. The volume density must be converted from a function of z to a function of r. Since we assume the volume number density does not vary 1) with radial distance nor 2) with galactic longitude for the distances in the survey, our model is that of an infinite plane parallel slab. The volume number density is normally expressed in the form of the
luminosity function $\Phi(M)$. The absolute magnitudes included are in the range $7 \leq M_v \leq 13$. Thus the surface density is computed from:

$$
N = \sum_{M=M_0}^{M} \int_{r_0}^{r} \Phi(M, z) r^2 \, d\theta \, d\alpha \, dr
$$

Incorporating the offset of the Sun from the galactic plane, we determined:

$$
z = |r \sin(b) + z_{\text{Sun}}|,
$$

or $z$ for above the plane is:

$$
z = r \sin(b) + z_{\text{Sun}}
$$

and below the plane is:

$$
z = -r \sin(b) - z_{\text{Sun}}.
$$

We integrated the number density per volume times volume for both the $z$ value above the galactic plane and for the $z$ value below the galactic plane. For galactic latitudes and distances which stay above the galactic plane, we evaluated the integral for above the plane from zero to $R$. $R$ is the distance determined by an absolute magnitude and the limiting magnitude found earlier using the equation:

$$
R = 10^{(m-M+5)/5}.
$$

The equation does not account for interstellar absorption. The stellar surface density was computed for each of the absolute magnitudes from seven through thirteen and summed to give the total surface density for each given galactic latitude.

For galactic latitudes which cross the galactic plane, we evaluated the integral for above the plane from zero to $R_I$, where $R_I$ is the distance at which $r$ crosses the galactic plane, and added it to the integral for below the plane evaluated from $R_I$ to $R$. (See Appendix for computations.)

We found two articles on the $z$-height for the Sun which gave values of $20.5 \pm 3.5$ pc (Humphreys and Larsen, 1995) and $15.0 \pm 0.5$ pc (Cohen, 1994). We used $20.5$ pc for the offset of the Sun since this result was obtained by observing stars in the visual range. The scale height
was taken from Kroupa, Tout, and Gilmore (1992) and estimated to be 240 parsecs. The $\Phi(0)$ values were found in Wielen, Jahreiss, and Kruger (1983).

Our computed stellar surface densities are compared to our observed stellar surface densities in Figure 8. Ignoring our anomalous areas from before, SAs 96, 98, and 99, our observed surface densities are less than the computed surface densities in the northern hemisphere. In the southern hemisphere, the one observed surface density is just above the computed one. The data does not indicate a uniform dependence on galactic latitude. There must still be a factor missing in our equation.

![Density Comparison](image)

**Figure 8**
5. Conclusions

The anomalous surface densities of SAs 96, 98, and 99 have not been explained by the methods from above. A theoretical explanation is that SA 98, the one with no stars, is located in the most dense part of the Milky Way. The most absorption occurs there, so while there may be red dwarfs there, they are not able to be seen. SAs 96 and 99 are located to either side of the Milky Way. The most dense population of stars is found looking directly into the Milky Way, but the next most dense area is to either side. There is far less absorption in these areas, so while they are not the most populated, they would be observed to be the most populated where absorption is a factor. Also, if there is giant contamination, the most contamination would be expected in these areas observed to be more populated.

The differences between the northern and southern hemispheres also were not adequately explained by my calculations. However, there are different ways to calculate the computed surface densities. First of all, according to the definition of our number densities, the $\Phi(z)$ value for the absolute magnitude of 7 encompasses absolute magnitudes from 6.5 to 7.5. Our brightest observed stars are only magnitude 7.5, so the computed surface density counts too many stars. Making an adjustment by using only a percentage of the surface density for absolute magnitude 7 shifts the curve for the computed values systematically down.

Another adjustment can be made with the scale height. The scale height we used was an approximation. Changing it changes the curve for the computed surface densities. Lowering the scale height stretches the curve making the peak found at $b = -10$ higher and making the low points at $b = 60$ and $b = -30$ lower. However, it takes a big decrease in scale height to stretch the curve significantly and while our value of 240 pc is approximate, it is not likely to be this far off.

An additional adjustment involves the value of $\Phi(0)$. This value is derived from a luminosity function that assumes the Sun is in the galactic plane. Making an adjustment for the $z$-offset of the Sun from the plane raises the whole curve uniformly.
Adjusting the three factors just described could result in a better fit of the computed values to the observed values. The biggest difference is found when observing in the northern hemisphere instead of in the southern hemisphere. Most of the values in the southern hemisphere were in Miss Ulman's SAs and she will be able to make more definitive progress based on the information provided in this project. Future refinements might include the addition of interstellar extinction to the model.

REFERENCES:


APPENDIX:
Centre (J2000): RA = 4 h 53 m 18.5, Dec. = 0° 5 40.5

Stars, mag > 10

Secondary entries:

Variable stars, planetary, open cl. solar system bodies, radio-source galaxies, artifacs, blends

Size: 8.4 arcsec

Copyright (c) 1994, D. Priou
Centre (J2000):

RA = 5 h 3 m 23.8 s
Dec. = -1 ° 20 ' 38.8"
Size = 8.4 arcmin

Stars, mag > 10

- Blends, artifacts
- Secondary entries
- Variable stars
- Globular, open clus.
- Planetary, diffuse
- Galaxies
- OSOs, radio-source
- Solar system body
- Fixed personal obj

Almageste 2, copyright (c) 1994, D. Priou
Centre (J2000): RA = 5 h 53 m 49.12, Dec. = +1° 10' 30".

Size: 8.4 arcmin.

Stars, mag > 10.

Blends, artifacts, secondary entries, variable stars, globular, open clusters, planetary, diffuse galaxies, OSOs, radio-sources, Solar system bodies, fixed personal objects.

Almageste 2, copyright (c) 1994, D. Priou
Centre (J2000):
RA = 6 h 55 m 7.2
Dec. = + 0° 0'
Size = 8 40°

Stars, mag > 10

Almageste 2, copyright (c) 1994, D. Priou
Centre (J2000): RA = 7 h 54 m 42.3 s
Dec. = -0° 37' 25" 25 Globular, open cl
Size = 8.40°
Stars, mag > 10

Blends, artifacts, secondary entries, variable stars
Planetary, diffuse
Galaxies
OSOs, radio-sources
Solar system bodies
Fixed personal obj

Almageste 2, copyright (c) 1994, D. Priou
Centre (J2000): RA = 9 h 55 m 56.58 s, Dec. = -0° 23', Size = 8.40' 

• Blends, artifacts
• Secondary entries
• Variable stars
+ Globular, open clus
• Planetary, diffuse
• Galaxies
• OSO radio-source
• Solar system body
• Fixed personal obj

Stars, mag > 10

Almageste 2, copyright (c) 1994, D. Priou
Centre (J2000): RA = 10 h 52 m 31.7, Dec. = -0° 57' 53.4

Blends, artifacts, variable stars, globular, open clusters, planetary, diffuse galaxies, OSOs, radio-sources, solar system bodies, fixed personal objec

Stars, mag > 10

Almageste 2, copyright (c) 1994, D. Priou
Centre (J2000):  
RA = 12 h 42 m 48.1 s  
Dec. = -0° 12'  
Size: 8.40°

Stars, mag > 10

Almageste 2, copyright (c) 1994, D. Priou
Centre (J2000):
  RA = 13 h 35 m 59.6
  Dec. = - 0° 34'
  Size = 8 40°

  ■ Blends, artifacts
  ○ Secondary entries
  ○ Variable stars
  □ Globular, open clusters
  □ Planetary, diffuse
  ■ Galaxies
  ✡ OSOs, radio-sources
  ✡ Solar system bodies
  + Fixed personal obj

Almageste 2, copyright (c) 1994, D. Priou
Centre (J2000) :
RA = 14 h 34 m 57.6
Dec. = -1° 15'
Size : 8.40°
Stars, mag > 10

Almageste 2, copyright (c) 1994, D. Priou