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The Halo of the Milky Way

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Abstract. We show that the star counts in the spheroid of the Milky Way are not symmetric about the $l = 0°$, $l = 180°$ plane. The minimum counts are found towards $l = 155°$. The Galactic longitude of maximum star counts depends on the magnitude and color selection of the halo stars. We interpret this as evidence that the spheroid population is triaxial with a major axis oriented 65° from the line of sight from the Sun to the Galactic center, and approximately perpendicular to the Galactic bar. Large local star concentrations from tidal debris and possible tidal debris are also observed. A full understanding of the Galactic spheroid population awaits position information and three dimensional space velocities for a representative set of stars in every substructure. Tangential velocities for many stars will be provided by current and planned astrometry missions, but no planned mission will measure stars faint enough to unravel the more distant parts of the spheroid, which contain the majority of the spatial substructure. This paper uses data from the Sloan Digital Sky Survey (SDSS) public data release DR3.

1. Introduction

While the Milky Way galaxy gives us a much better view of the individual component stars than any other galaxy, it is difficult to view our galaxy as an assembled whole. New surveys such as 2MASS and SDSS (York et al. 2000; Gunn et al. 1998), are allowing us to start assembling the global picture one star at a time. Other surveys that are in progress such as RAVE, GAIA, Pan-STARRS, UKIDSS/VISTA, and SDSS II/SEGUE will extend our view of the stars not only in positional information but also in kinematic information for a large number of Galactic stars.

2. Evidence that the spheroid is not symmetrical

SDSS color-magnitude Hess diagrams such as Figure 11 of (Newberg et al. 2002) show two populations with distinct turnoffs (see Fig. 1). The brighter population has a turnoff at $g - r \sim 0.4$ and is associated with the thick disk. The fainter population has a turnoff at $g - r \sim 0.3$, and is associated with the spheroid. Fig. 1 shows the color-magnitude selection boxes for thick disk, spheroid, and faint spheroid data samples selected from SDSS-DR3.

Fig. 2 shows the number counts of spheroid stars as a function of position in the Galaxy from SDSS DR3. Where there are no counts, we have no data.

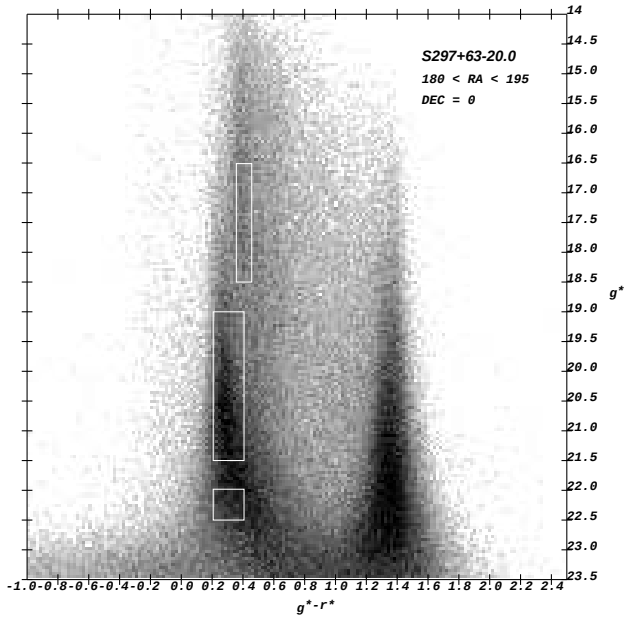

Figure 1. SDSS color-magnitude Hess diagram, reprinted from Figure 11 of (Newberg et al. 2002). All magnitudes are reddening-corrected. Overlaid are color-magnitude selection boxes for the thick disk (top), spheroid (middle) and faint spheroid (bottom). There was also a $u-g > 0.4$ color cut to exclude UV excess quasars.

Note that the number counts do not appear to be symmetric about the Galactic center. Fig. 3 shows this numerically, by plotting star counts along several lines of constant Galactic latitude. There are more spheroid stars in quadrant IV than in quadrant I, and the minimum is at $l = 155°$ rather than $l = 180°$, as we would have expected.

Fig. 4 shows that the spheroid number counts are not significantly asymmetric about the Galactic equator. Fig. 5 shows the star counts for the thick disk selection for all of DR3, while Fig. 6 shows quantitatively that the thick disk is symmetric about $l = 0°, 180°$.

3. Interpretation that the spheroid is triaxial

Fig. 7 is a cartoon, looking down on the Galactic plane, depicting the star counts that would be observed at a constant height above or below the Galactic plane for a sample triaxial spheroid. This type of model can explain a minimum in quadrant II, and a maximum in quadrant IV for samples of stars close to the Sun. It predicts that the maximum would switch to quadrant I for stars more distant than the distance from the Sun to the Galactic center.

Fig. 8 shows the star counts for a more distant sample of spheroid stars, and Fig. 9 shows star counts through this figure at constant Galactic latitude. There is some evidence that the peak star counts shifts to quadrant I for this more distant sample, though the presence of the Sagittarius stream makes the interpretation problematic.

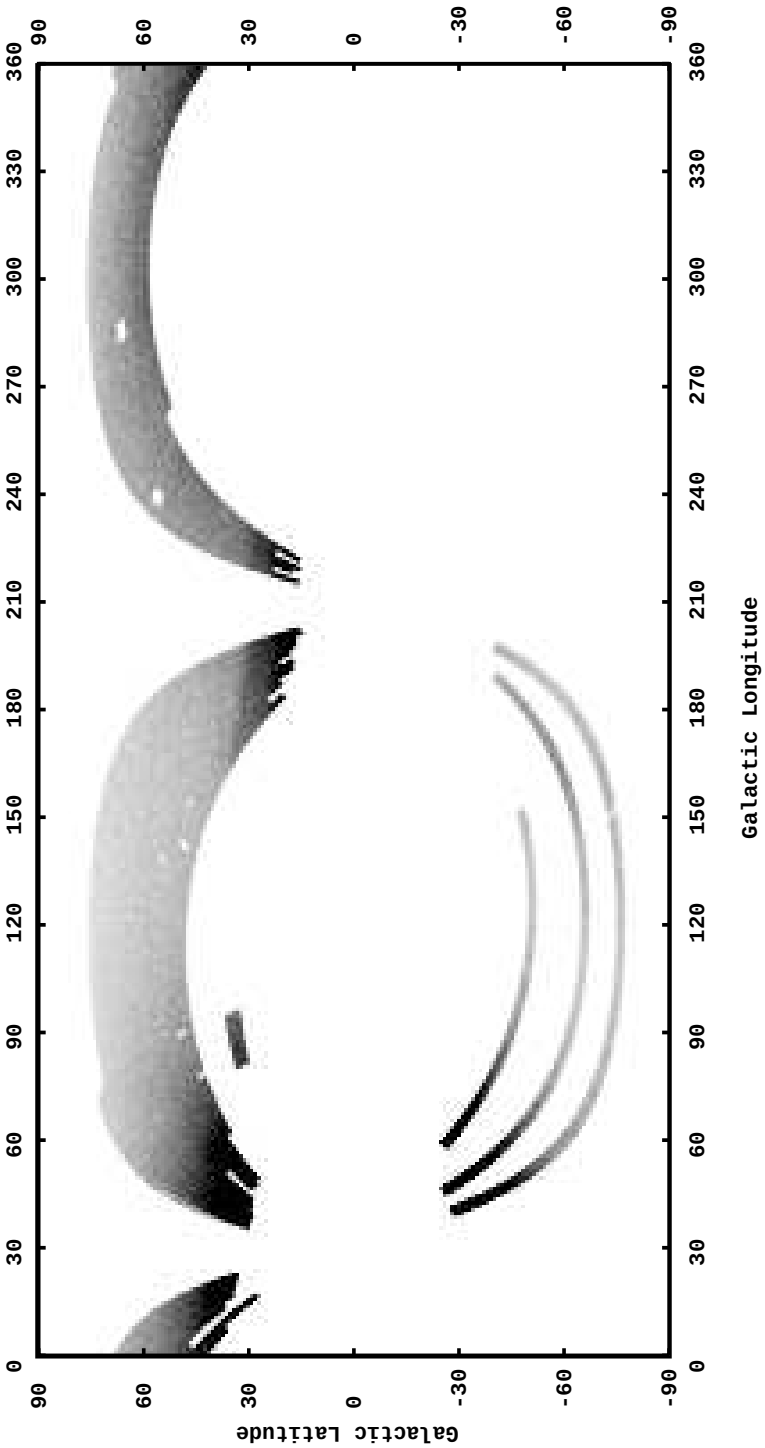

Figure 2. Density of spheroid stars in the sky from SDSS DR3, shown in Galactic coordinates. The densities have not been corrected for the effects of $\cos(b)$. Notice that the density appears smooth - no obvious discontinuities at stripe/run boundaries. Also, the distribution does not appear be be symmetric about $l = 180°$.

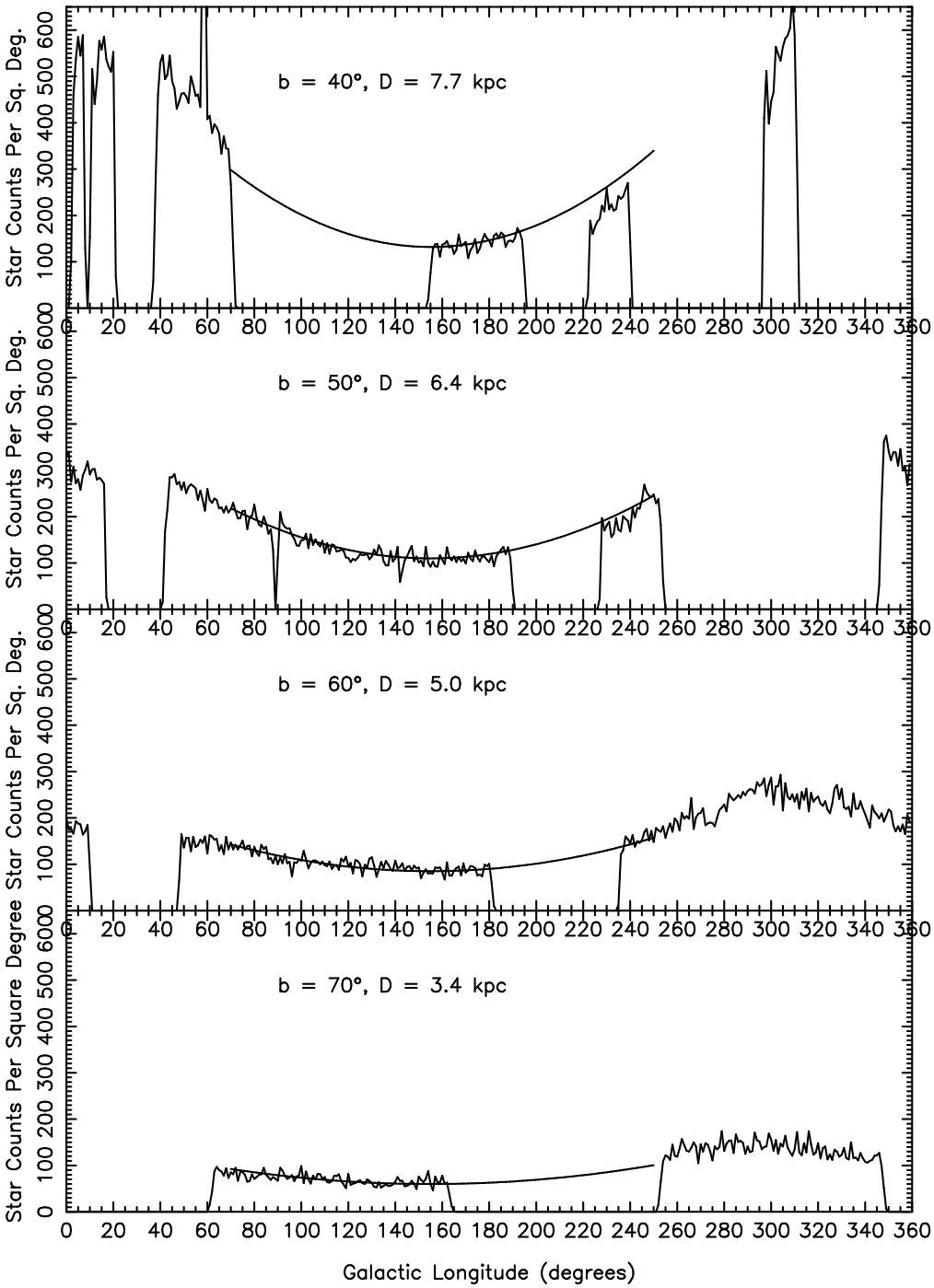

Figure 3. Star counts at constant Galactic latitude. These are plots of the data in Figure 2, along four Galactic latitudes, uncorrected for $cos(b)$ so the "star counts per sq. deg." labels are a bit misleading. Parabolas with minima at $l = 155°$ have been drawn over the data. Spheroid models that are not triaxial would predict a minimum at $l = 180°$. There is also a maximum in the star counts near $l = 300°$, not at $l = 0° = 360°$.

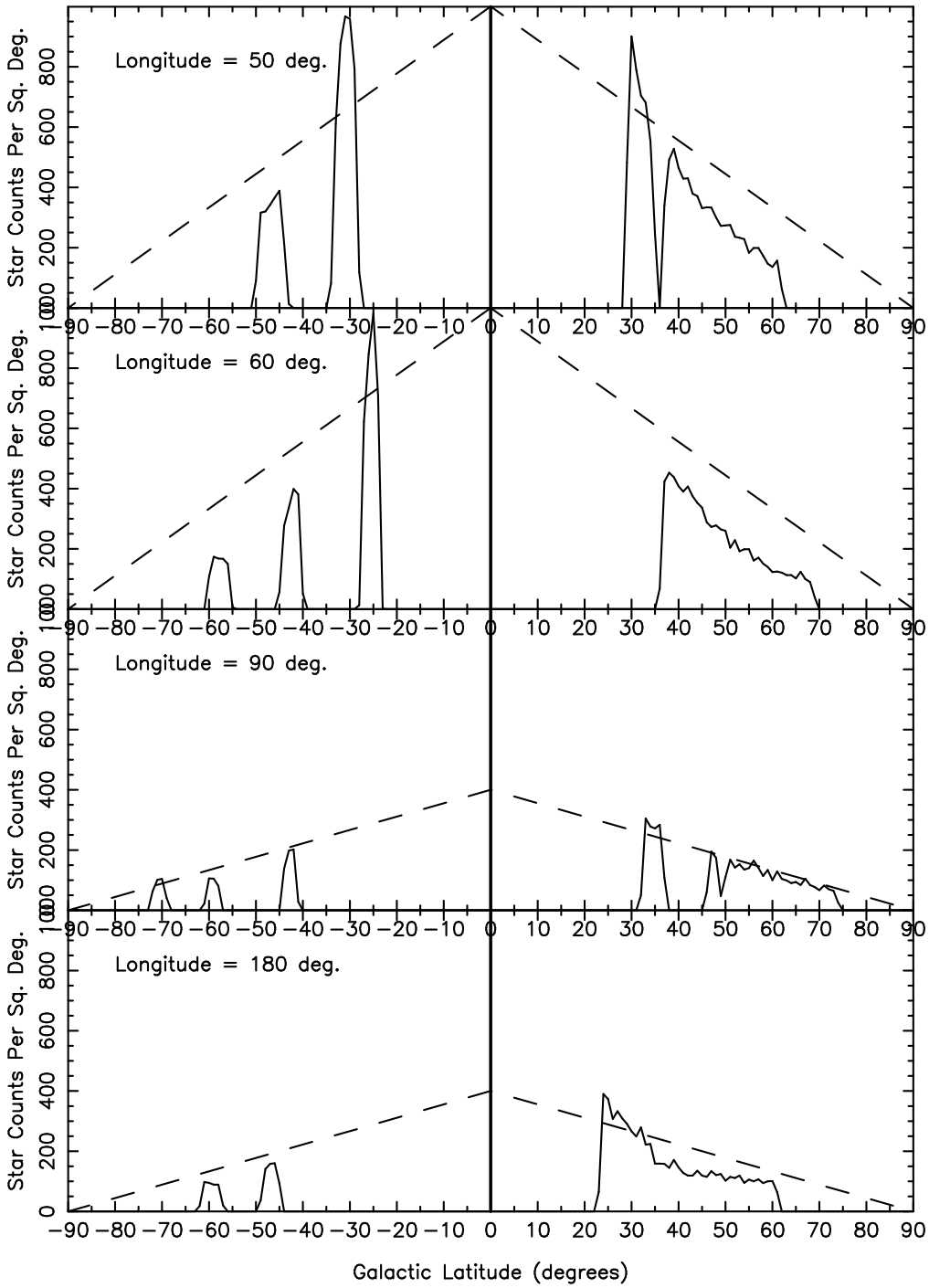

Figure 4. Star counts at constant Galactic longitude. These are plots of the data in Figure 2, along four Galactic longitudes. The dotted lines are drawn to help the eye ascertain the symmetry of the data about the Galactic equator.

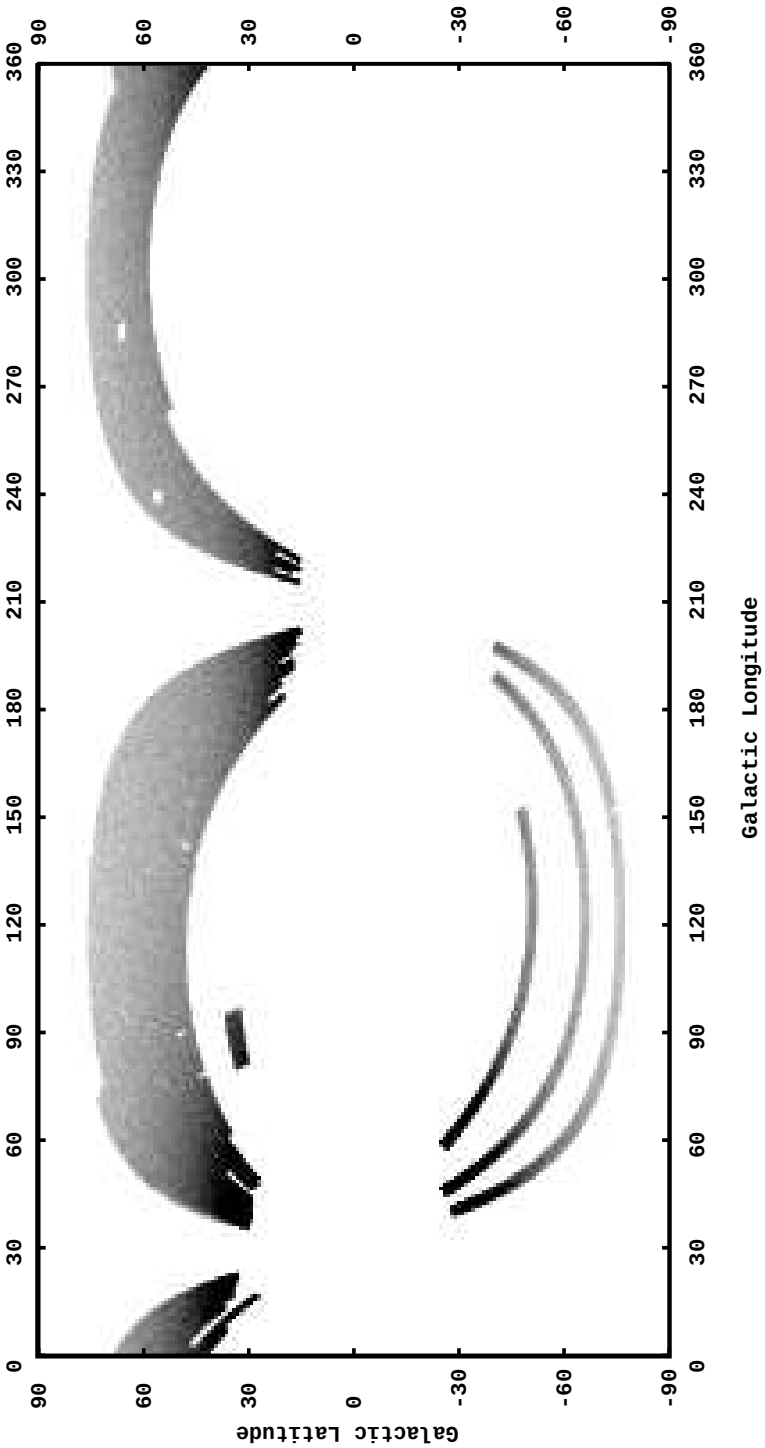

Figure 5. Density of thick disk stars in the sky from SDSS DR3 (see selection box from Fig. 1), shown in Galactic coordinates. The densities have not been corrected for the effects of $\cos(b)$. Notice that the density appears smooth - no obvious discontinuities at stripe/run boundaries. Also, the distribution appears be be symmetric about $l = 180°$.

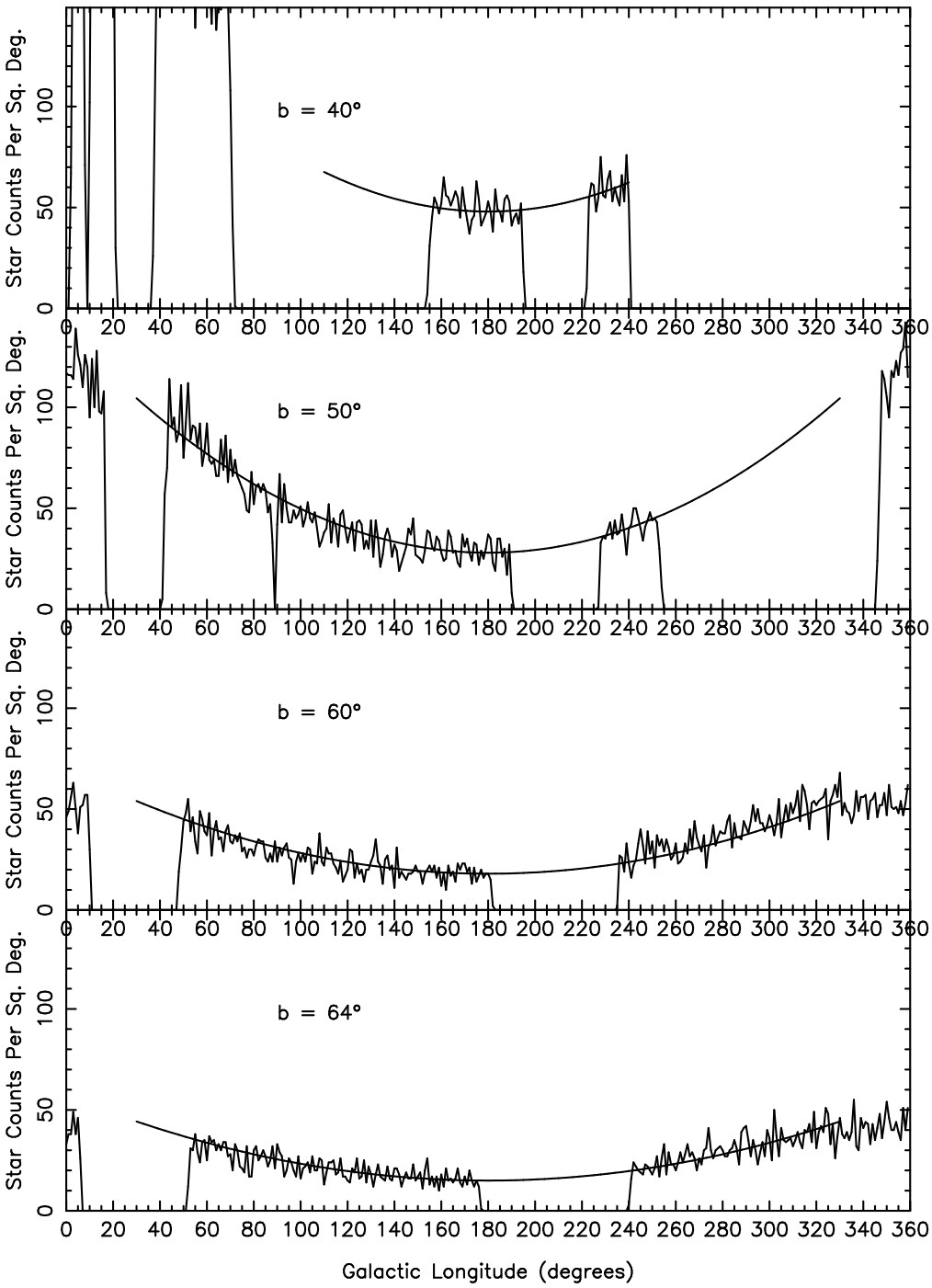

Figure 6. Thick disk star counts at constant Galactic latitude. These are plots of the data in Figure 5, along four Galactic latitudes. These also have not been corrected for $cos(b)$, so the labels as star counts per square degree is a bit misleading. Parabolas with minima at $l = 180°$ have been drawn over the data. The maximum star density is at $l = 0°$, as we expect.

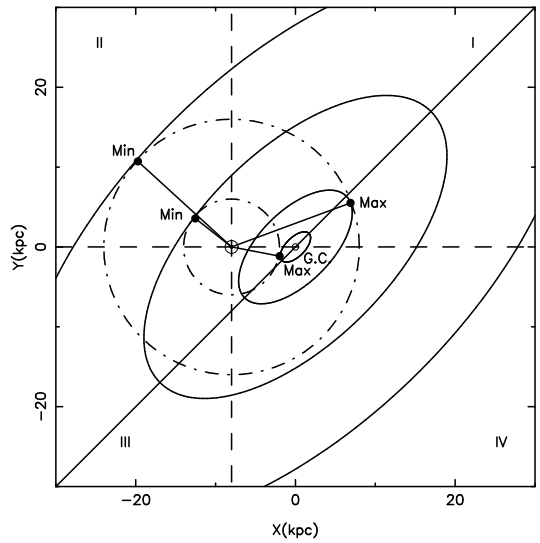

Figure 7. Iso-density star counts for a triaxial spheroid as observed from the Sun. Solid lines show isodensity star counts for a triaxial spheroid with major axis 45° degrees from our line of sight, projected on the Galactic plane. Dashed lines show two projected distances from the Sun. For close stars, the maximum density is in quadrant IV and the minimum is in quadrant II. For distances larger than the Sun-GC distance, the maximum is in quadrant I and the minimum is in quadrant II. For large distances, the minimum is perpendicular to the major axis of the spheroid.

4. Conclusion

The spheroid population may be triaxial with a major axis oriented 65° from the line of sight from the Sun to the Galactic center. This is approximately perpendicular to the Galactic bar. This is surprising since one typically expects bars to have an angular pattern speed larger than could be sustained in the spheroid, but the possible connection should be examined.

Significant substructure is observed in the spheroid population with main sequence turnoffs at apparent magnitudes of $g = 20$ and fainter. Even the GAIA mission will not reach faint enough or distant enough to study the part of the spheroid where we see the most substructure. Thus, the need for newer and better astrometry will be required for the indefinite future.

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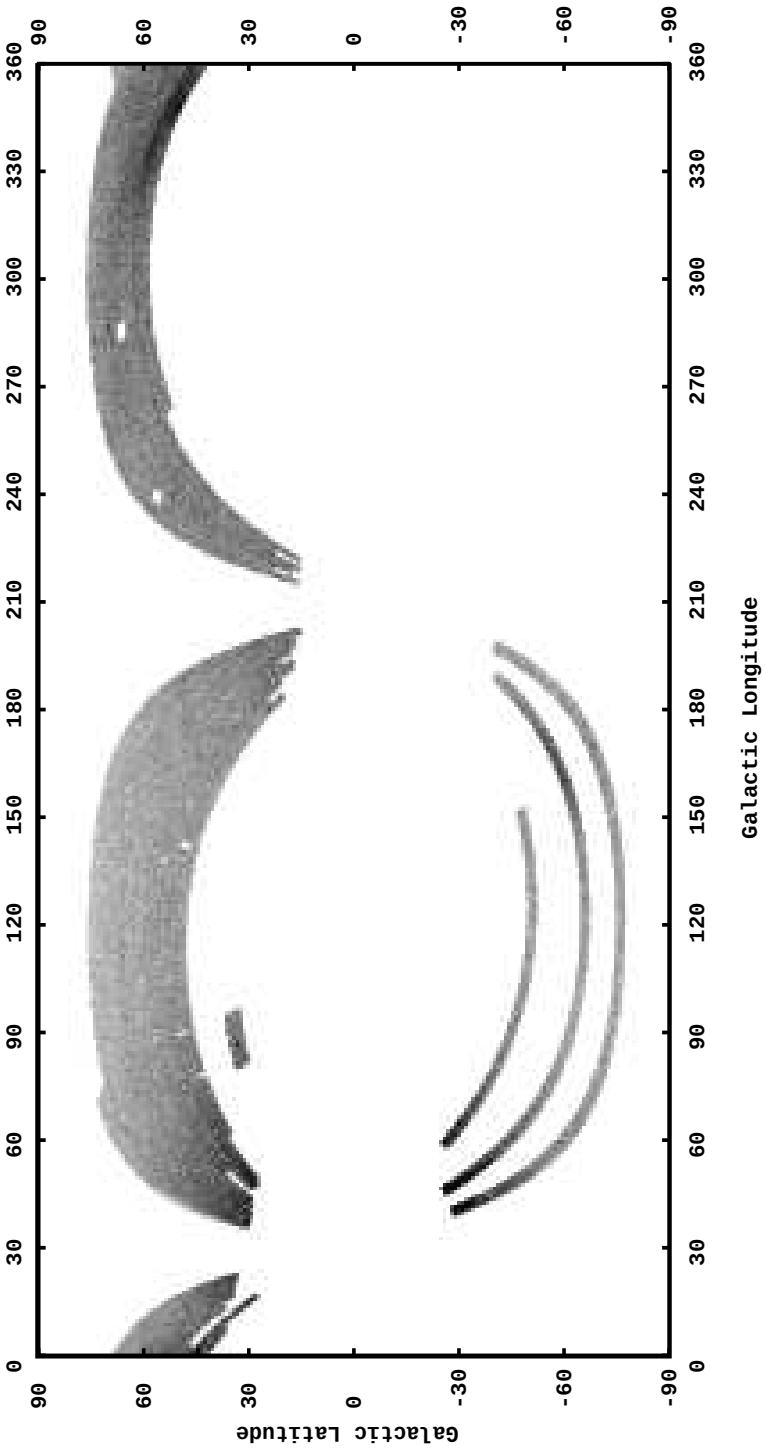

Figure 8. Density of faint spheroid stars in the sky from SDSS DR3 (see selection box from Fig. 1), shown in Galactic coordinates. The densities have not been corrected for the effects of $\cos(b)$. The distribution is not symmetric about $l = 180°$. The Sagittarius tidal stream is clearly visible within 40° of $l = 340°$.

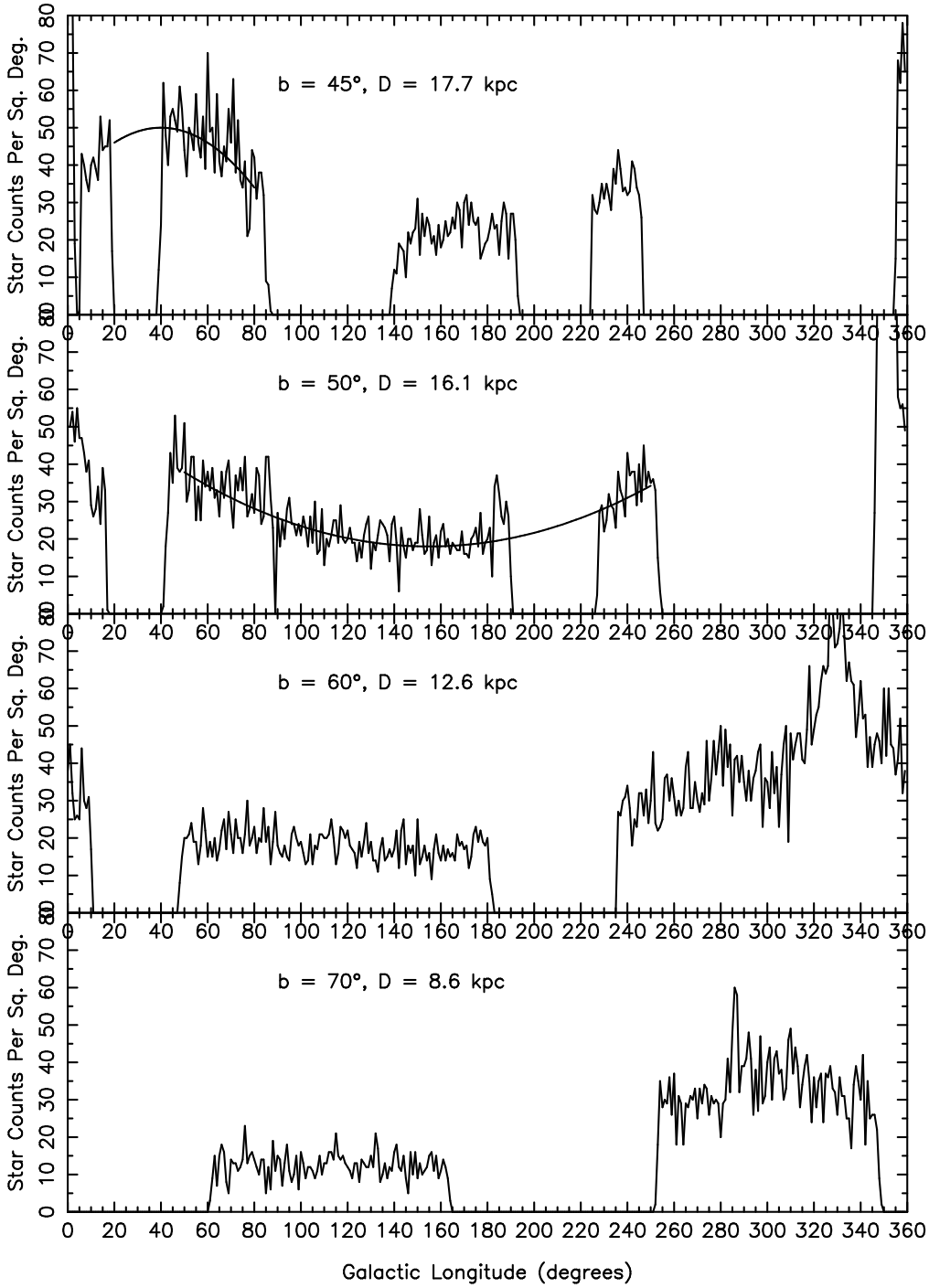

Figure 9. Faint spheroid star counts at constant Galactic latitude. These are plots through the data in Fig. 8. A parabola with minimum at $l = 155°$ has been drawn over the second panel. The star counts on the right half of the plots show the stars from the Sgr dwarf tidal stream. The top panel, which gives the densities of spheroid stars with the largest distances from the Sun as projected on the Galactic plane, shows a peak in the star counts at $l = 40°$.