Mapping the Asymmetric Thick Disk: A Search for Triaxiality

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Introduction: The Asymmetric Thick Disk

In 1996, Larsen and Humphreys first reported evidence for an excess of faint blue stars in the inner part of the Galaxy. Looking at only four paired fields near $b \sim 30 - 40^\circ$, they found a 30% excess in the number of blue stars in the first quadrant (Q1) ($l = 20 - 45^\circ$), compared with the complementary longitudes on the other side of the Sun-Center line, in the fourth quadrant (Q4).

To map the extent and shape of the asymmetric distribution and further identify the contributing stellar population, Parker, Humphreys and Larsen (2003) greatly extended the search to 40 contiguous fields from the digitized POSS I (Cabanela *et al* 2003) on each side of the Sun-Center line plus the same number of fields below the plane in Q1. They examined the star count ratio for paired fields in three color ranges: blue, intermediate and red. Halo and thick disk stars dominate the blue color bin; thick disk stars make a significant contribution to the intermediate color range and fainter than 17th magnitude they are comparable to the number of disk stars. The red band is almost exclusively composed of old disk stars. Over 6 million stars were used in the star count analysis.

They found a 25% excess in the number of probable thick disk stars in Q1, $l \sim 20$ to 60° and 20 to 40° above and below the plane compared to the complementary fields ($l \approx 340$ to 300°) in Q4. While the region of the asymmetry is somewhat irregular in shape, it is also fairly uniform and covers several hundred square degrees. It is therefore a major substructure in the Galaxy due to more than small–scale clumpiness. Figure 1 shows a map of the significance parameter (s), a measure of how much the ratio of the observed to expected ratio between Q1 and Q4 deviates from one. Assuming that these are primarily main sequence thick disk stars, with a completeness limit of V ~ 17.5 – 18 mag, they are 1 - 2 kpc from the Sun and about 0.5 to 1.5 kpc above (and below) the plane.

Parker et al (2004) also found an associated kinematic signature. Using velocities from spectra for more than 700 stars obtained with Hydra on WIYN and the CTIO 4-m, they not only found an asymmetric distribution in the v_{LSR} velocities, but the thick disk stars in Q1 have a much slower effective rotation rate compared to the corresponding Q4 stars. A solution for the radial and tangential components of the v_{LSR} velocities reveals a significant lag ~80 to 90 km s^{-1} in the direction of Galactic rotation for the thick disk stars in Q1.

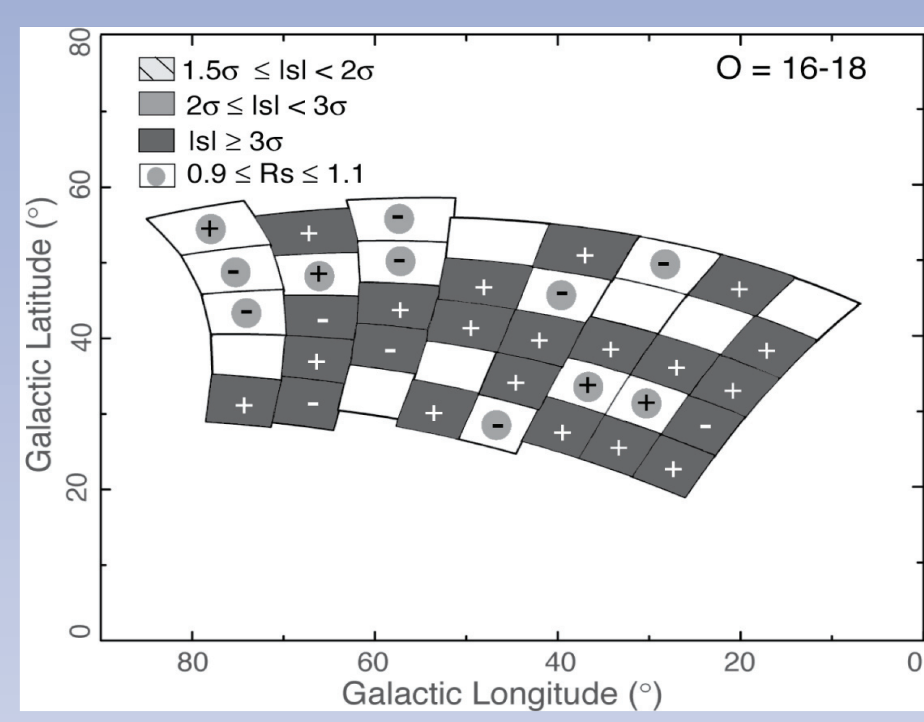

Figure 1: A map in l and b of the significance parameter (s) for the intermediate color bin in the 16 –18 POSS I O (blue) magnitude range, from Parker *et al* 2003. s is a measure of how much the ratio of the observed to expected star counts deviate from one. Note the conspicuous band of contiguous fields with a significant star count excess at $b \approx 30^\circ$ to 40° stretching from $l \approx 20^\circ$ to 60°.

A Search for Triaxiality in the Thick Disk

The distinction between a triaxial thick disk and interaction with a disk bar may be difficult to discern. Indeed, it is unclear which may have formed first, one or both may be the result of mergers, and if the thick disk is triaxial it could be aligned with the bar. **If the thick disk is triaxial and its major axis is in Q1, then we would expect to observe an asymmetry in the star counts out to Galactic longitudes greater than $l = 55^\circ$.**

Therefore by extending the star counts to fainter magnitudes, corresponding to greater distances, we can also search for the asymmetry at higher longitudes. This would be an important observational test for a triaxial thick disk.

Observing Program

We have begun a program of photometric and spectroscopic observations to map the size and extent of the asymmetry along our line of sight and to determine the degree of spatial and kinematic asymmetry above and below the plane.

Using the SMARTS Consortium CTIO 1-meter Y4KCam and the Steward Observatory 90" Bok telescope 90Prime Mosaic imager, we are obtaining wide-field multi-color CCD imaging to fainter completeness limits than the POSS I. This deeper wide-field imaging is necessary to determine the extent along the line of sight of the asymmetry between Q1 and Q4.

Spectra of thick disk candidate stars have been obtained using the Hydra multi-object spectrometer on the WIYN and CTIO Blanco 4-meter telescopes and the Hectospec multi-object spectrometer on the MMTO 6.5-meter. **These spectra are being used to investigate the previously observed kinematic asymmetry to fainter magnitudes in order to test the gravitational interaction hypothesis.**

Figure 2 shows the distribution of our selected fields with respect to the Galactic plane for CCD imaging and spectroscopy.

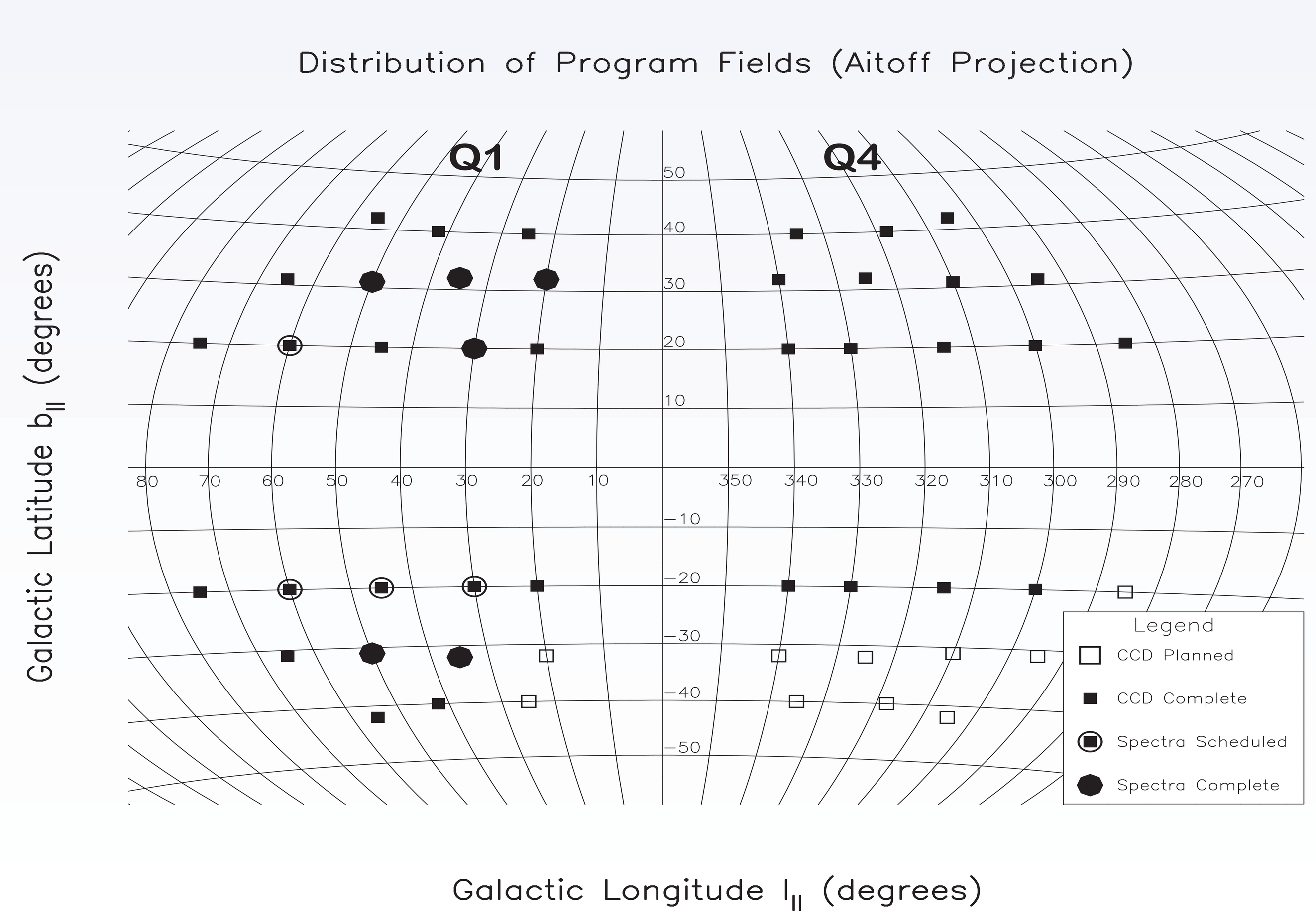

Figure 2: A map in Galactic coordinates showing the paired fields we are observing for this project. Final CCD imaging should take place in October 2008 and the spectroscopic observations (used to distinguish determine the kinematics of the Thick Disk stars we observe) should be completed this coming Spring.

Possible Origins of the Asymmetry in the Thick Disk and Their Observational Consequences

Fossil Remnant of a Merger

A fossil remnant of a merger could be responsible for an asymmetry in star counts. If so, we would predict:

- **A limited areal extent on the sky**, similar to known tidal debris fields in the Milky Way halo.
- We might be able to trace the asymmetry to the tidal debris field of a known Milky Way satellite.

Triaxial Thick Disk/Inner Halo

A triaxial distribution, with its major axis in Q1, would predict:

- An excess of stars in Q1 versus Q4 along the line of sight above and below the Galactic plane.
- **Expect to observe the star count excess out to greater longitudes than previously observed.**

Interaction of Thick Disk/Inner Halo Stars with the Stellar Bar in the Disk

A rotating stellar bar in the disk could induce a gravitational "wake" (Hernquist and Weinberg 1992, Debattista and Sellwood 1998). The predictions of such a model include:

- An excess of stars in Q1 versus Q4 along the line of sight above and below the Galactic plane.
- **In response to the bar, there should be a measurable lag in rotation in Q1 versus Q4.**

Previous Supporting Observations

An excess of stars is observed in Q1 versus Q4 along the line of sight (See Figure 1). This asymmetry seems to disappear for fields with $l > 55^\circ$. **These observations are consistent with all three models here.**

Given the large spatial extent of the previously observed asymmetry (see Figure 1) and lack of any overlap with the debris field of the Sagittarius dwarf (Ibata *et al* 2001) and the predicted path of the Canis Major dwarf (Martin *et al* 2004), **a merger remnant seems the least likely explanation for the asymmetry feature.**

The line of sight to the asymmetry feature is in the same direction as the stellar bar in the disk recognized by Weinberg (1992) and also seen in Spitzer data (Benjamin *et al* 2005), and the near end of the Galactic bar discussed by Lopez-Correidoira *et al* (1999) and Hammersley *et al* (2000). The disk bar is approximately 5 kpc from the Sun in this direction, thus **the stars showing the excess are between the Sun and the bar, not directly above it. However the maximum extent of the asymmetry along our line of sight is not known.**

The observed lag in the v_{LSR} velocities of Q1 thick disk stars versus their Q4 counterparts **supports the idea of a gravitational "wake" due to the interaction of the thick disk with the stellar bar.**

Preliminary Results

Table 1: The Q1/Q4 Star count ratios for likely Thick Disk stars (based on B-V color range) as a function of V magnitude range for paired high Galactic longitude fields observed for this study. The numbers show no extensive deviations from a symmetric distribution for fields greater than 55° from the Galactic Center.

Q1 Field	Q4 Field	Mag 15-16	Mag 16-17	Mag 17-18	Mag 18-19	Mag 19-20	Mag 20-21
55, +42	305, +42	0.97 ± 0.12	1.33 ± 0.15	1.17 ± 0.11	1.24 ± 0.10	0.90 ± 0.06	0.93 ± 0.05
60, +20	300, +20	1.03 ± 0.06	1.04 ± 0.05	0.96 ± 0.04	0.92 ± 0.03		
65, +31	295, +31	0.78 ± 0.08	0.86 ± 0.07	0.88 ± 0.06	0.94 ± 0.06		
75, +20	285, +20	1.27 ± 0.08	0.99 ± 0.06	1.02 ± 0.06	0.96 ± 0.05		

We see the excess in the counts at $l \sim 55^\circ$ from V = 16 – 19, but not in the higher longitude fields as we expected. So at fainter mags and greater distances we see no evidence for a triaxial thick disk.

This result supports the Parker *et al* (2004) conclusion that the asymmetry feature extends to about $l = 55^\circ$ (or maybe 60° at higher lat.) The $l = \pm 55^\circ$ fields were both observed with the 90 Prime so the counts are complete to >21 mag. The fields observed with the CTIO 1-m are complete to ~19 mag. Note that the ratio returns to 1 for $l = 55^\circ$ at V~19! The excess in this direction is between 1.2 and 4.8 kpc (V = 16 - 19 mag). However at 5kpc at $b = 43^\circ$ we are looking at 3 kpc above the plane and are in the halo, so we may just be seeing the Thick Disk stars disappearing at this height above the plane. We'll have to analyze all of the fields before we know the correct line of sight extent of the feature.

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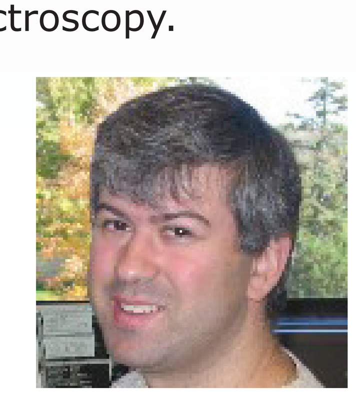
If you have any questions, feel free to contact:



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