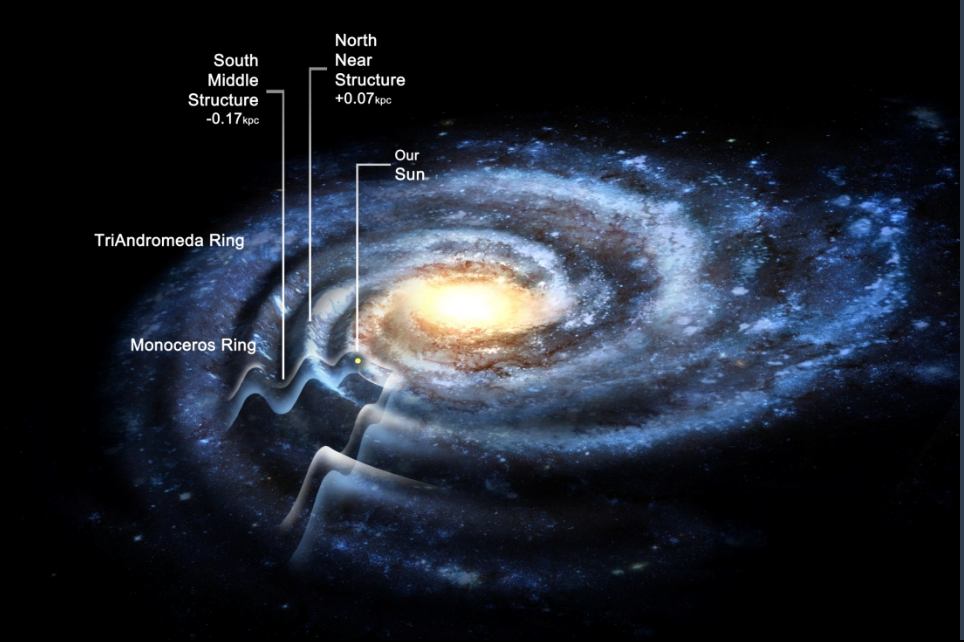


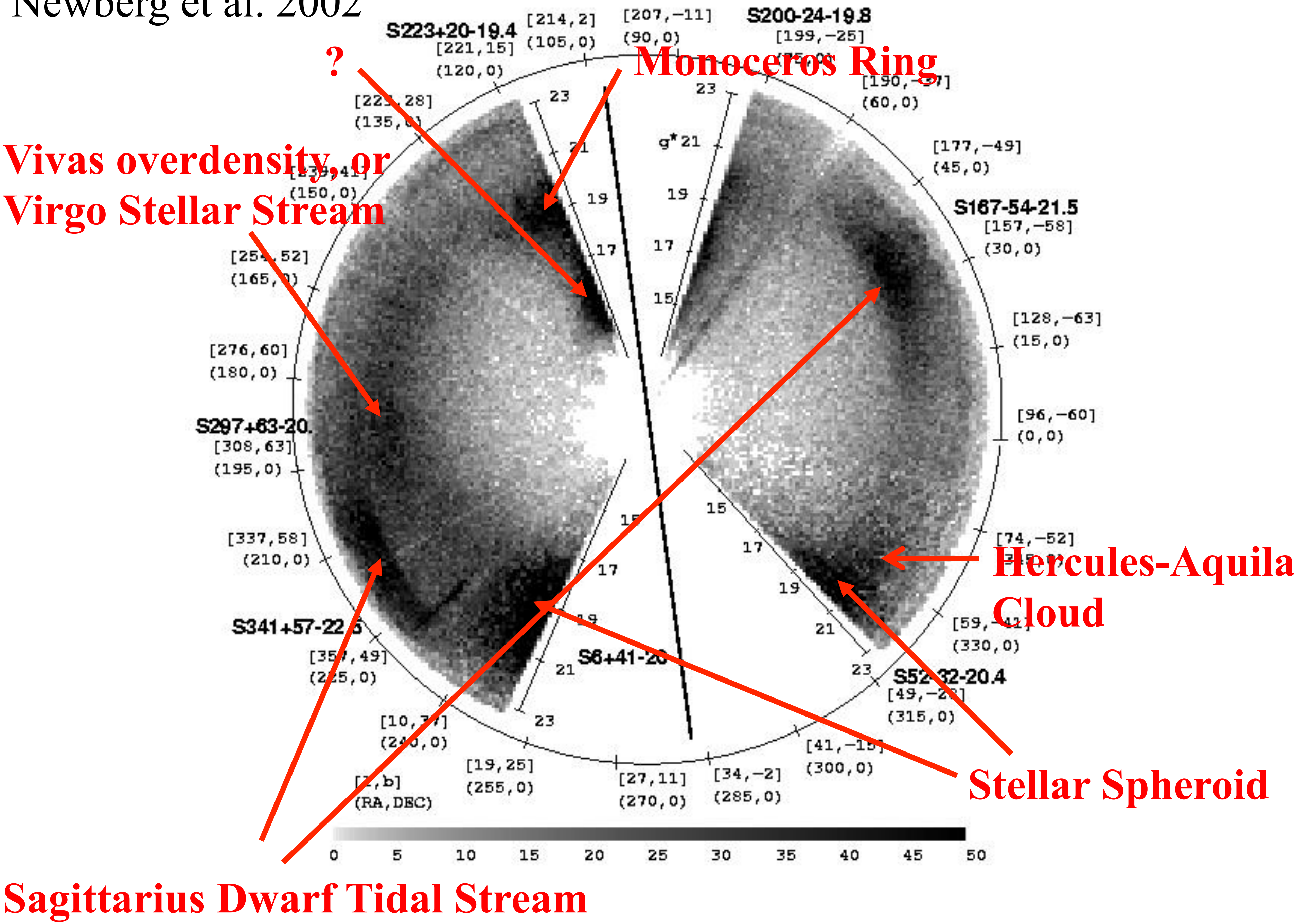
Rings and Radial Waves in the Disk of the Milky Way

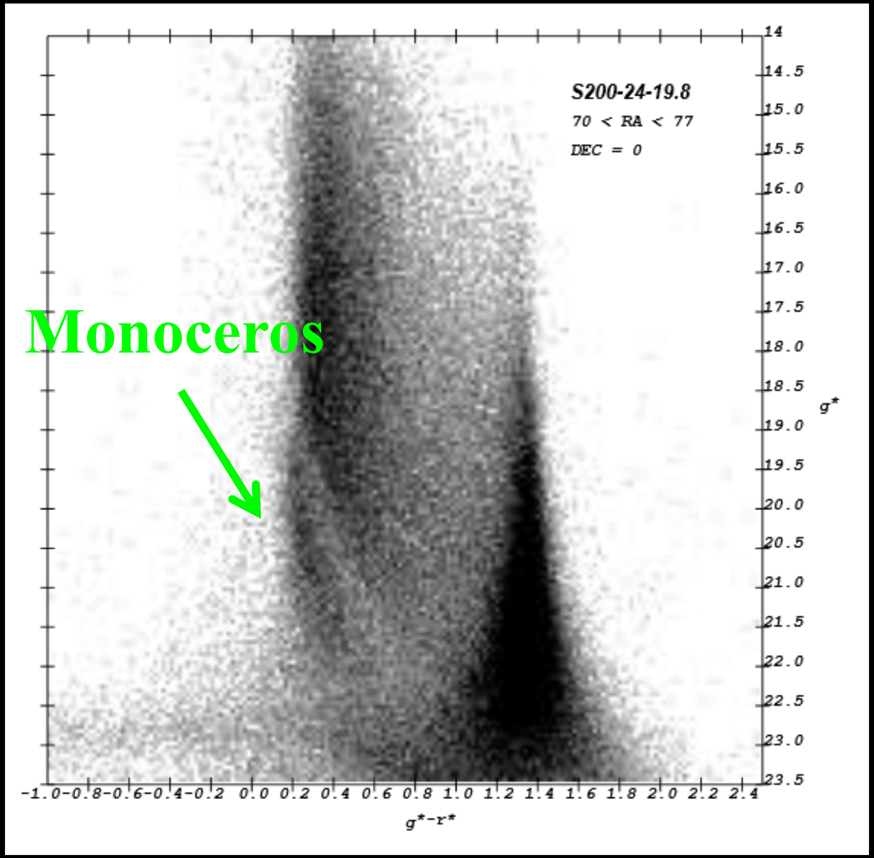
Xu, Newberg, Carlin, Liu, Deng, Li, Schönrich & Yanny, ApJ, in press, 2015

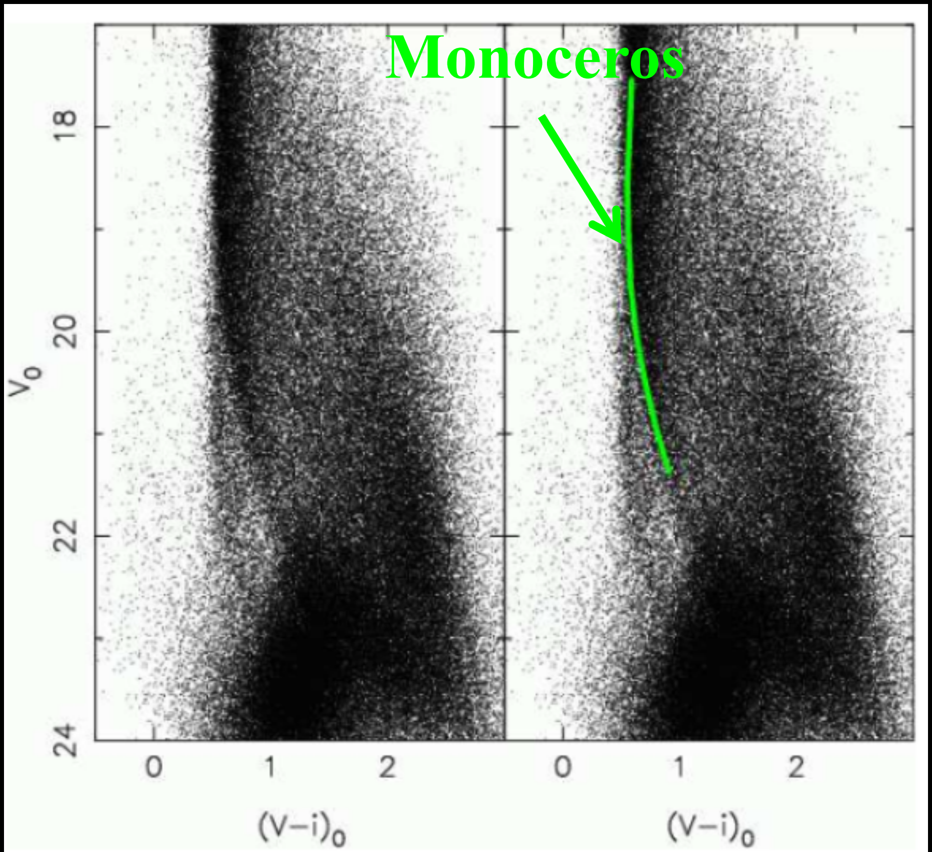
Xu Yan
NAOC, Beijing

We identify an asymmetry in disk stars that oscillates from the north to the south to the north to the south across the Galactic plane in the anticenter direction.

Newberg et al. 2002





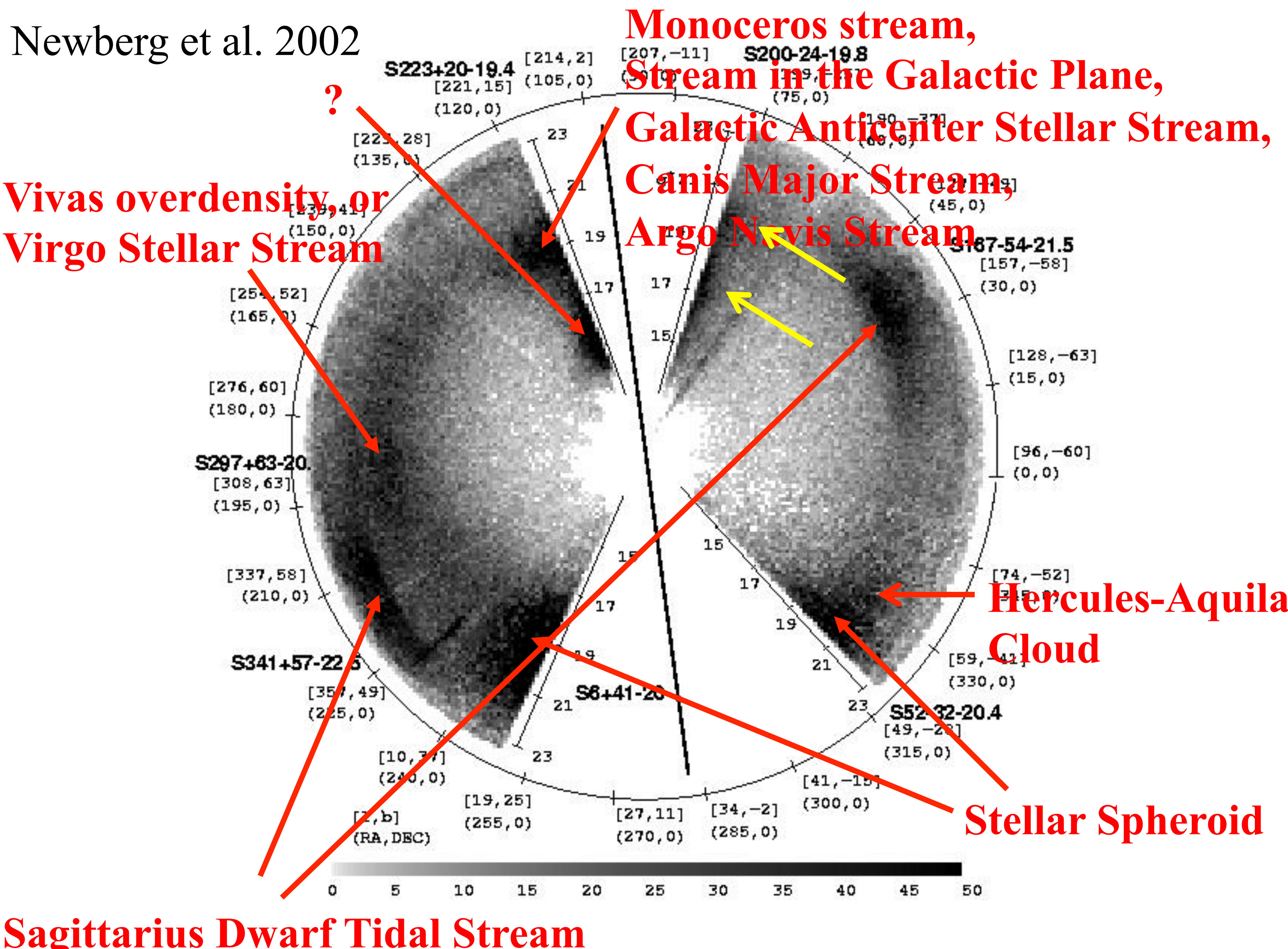


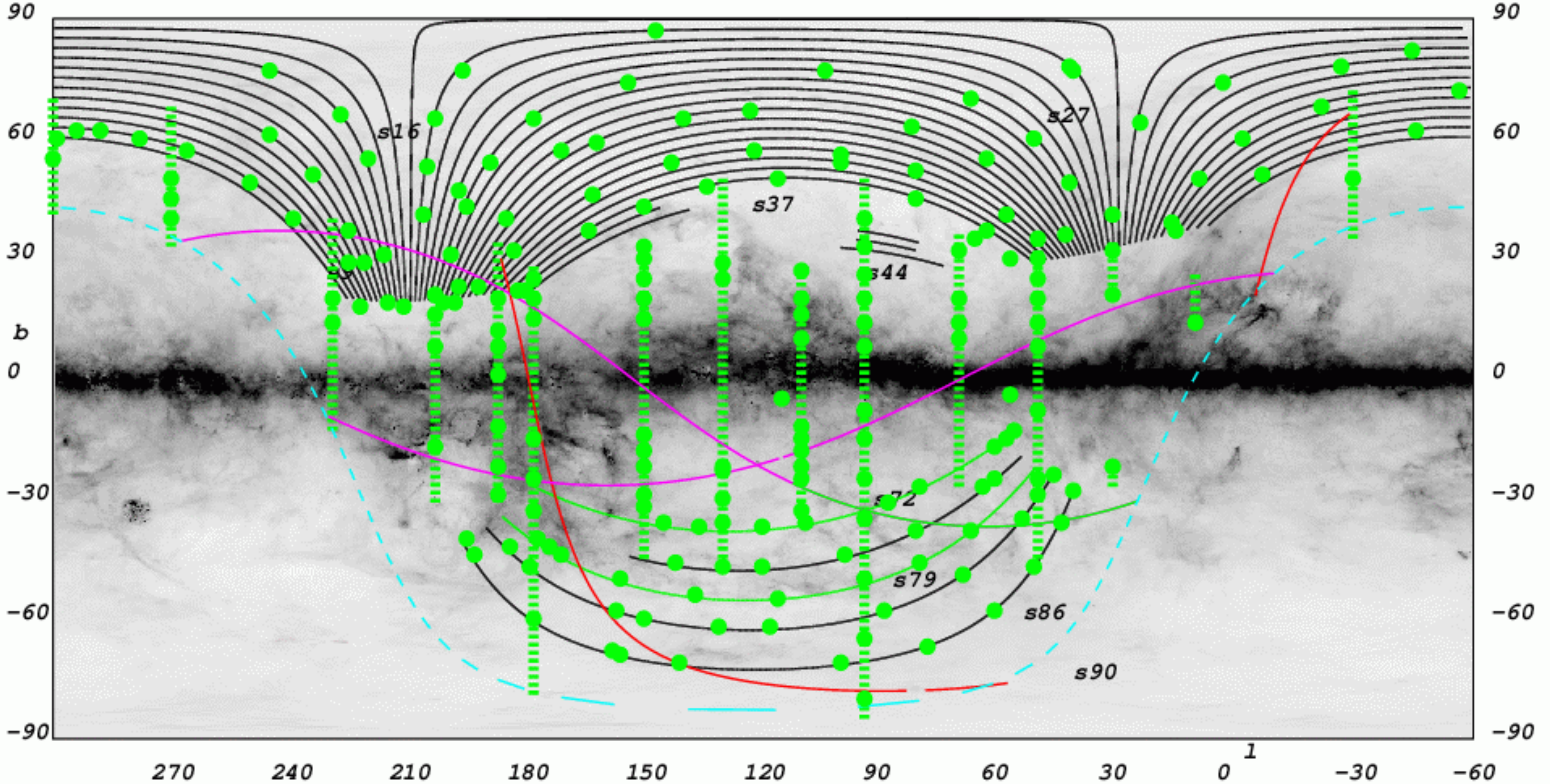
(l,b)=(200°, -24°)
Newberg et al. (2002), Figure 15

(l, b) = (123°, -19°)
Ibata et al. (2003), Figure 6

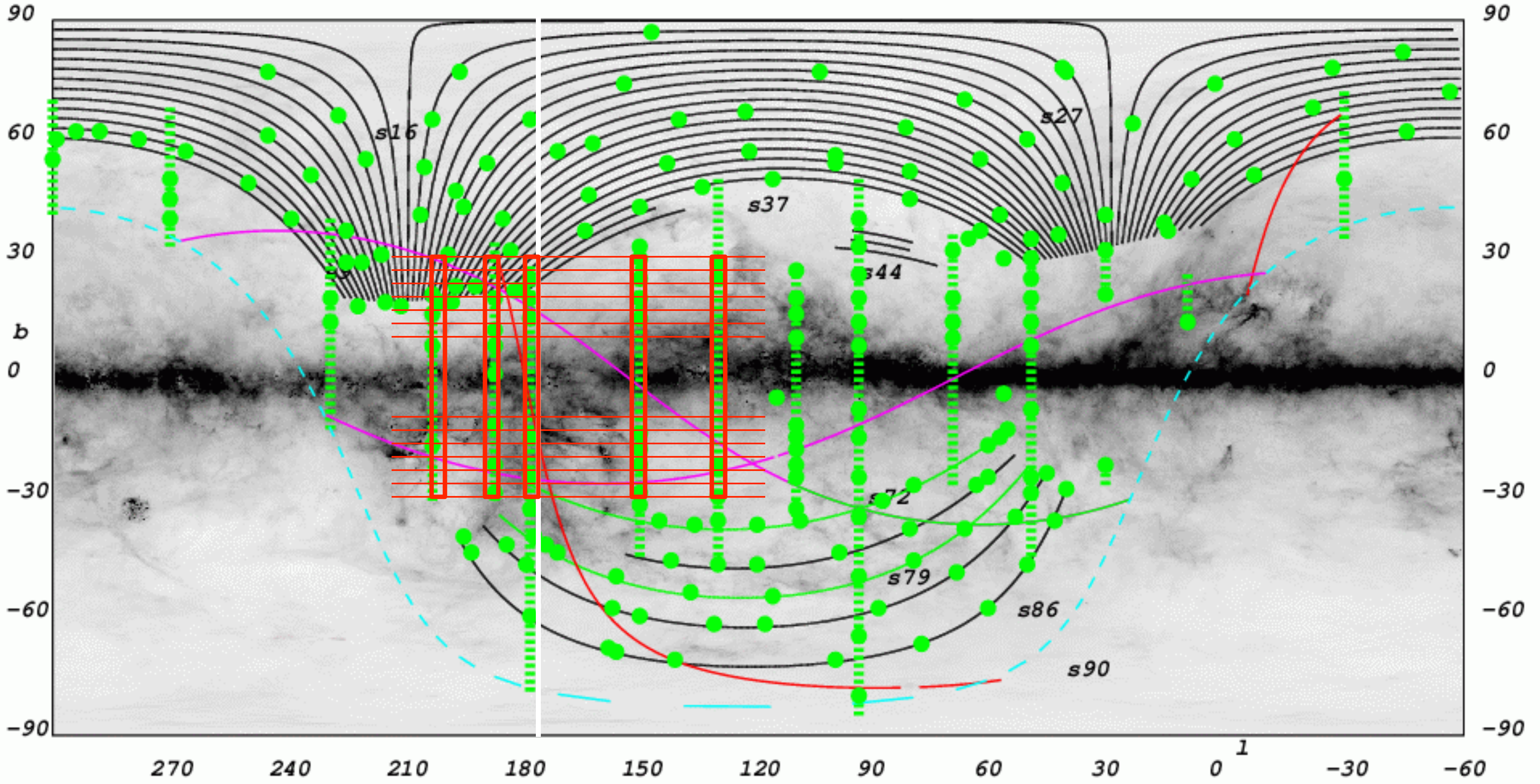
The early papers differed on the identification of Monoceros in the south, leading to a decade of confusion in the literature.

Newberg et al. 2002

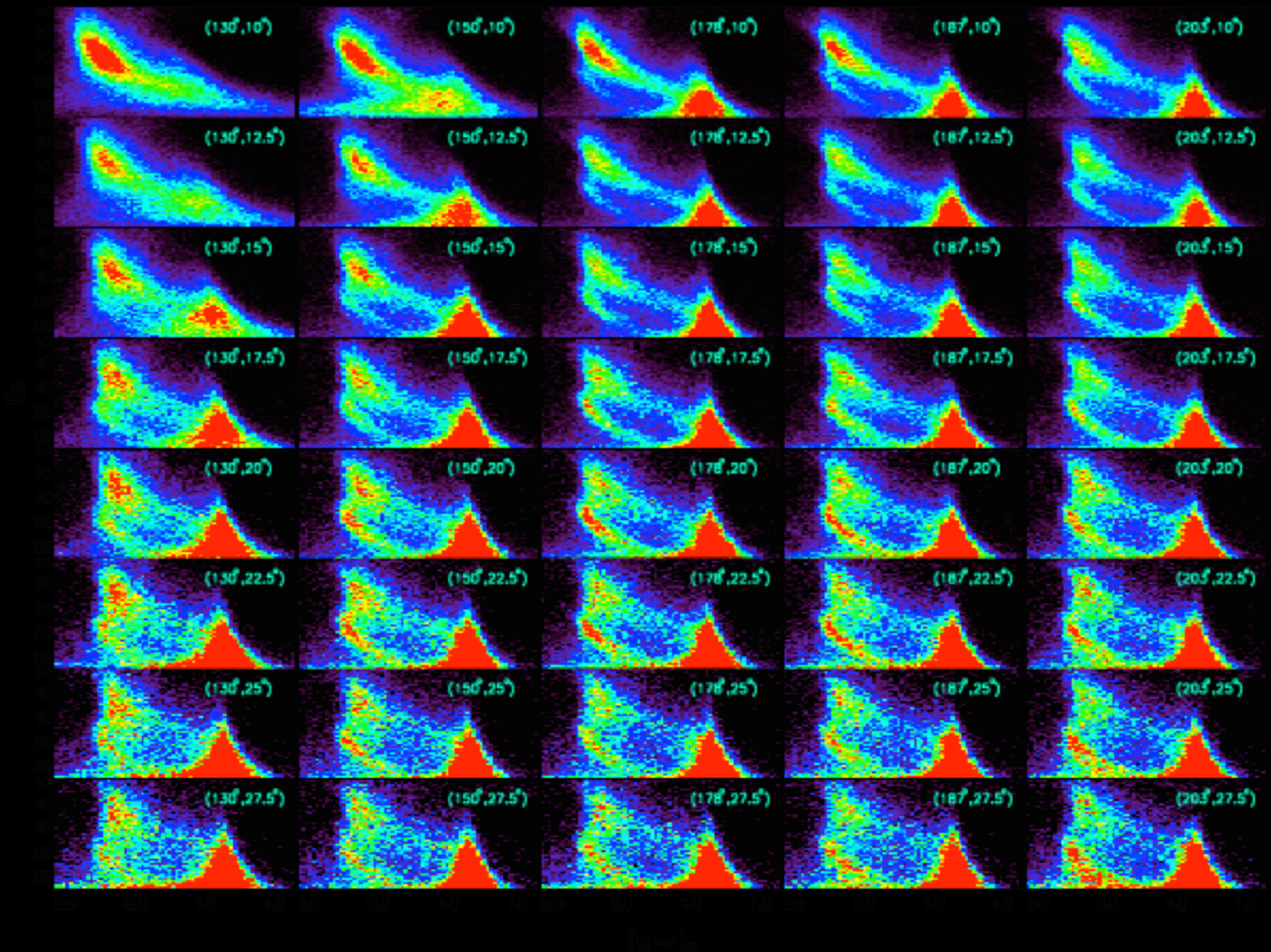




The SDSS also took imaging (and spectroscopic) data along 2.5°-wide stripes at constant Galactic longitude. These stripes cross the Galactic plane.



The SDSS also took imaging (and spectroscopic) data along 2.5°-wide stripes at constant Galactic longitude. These stripes cross the Galactic plane.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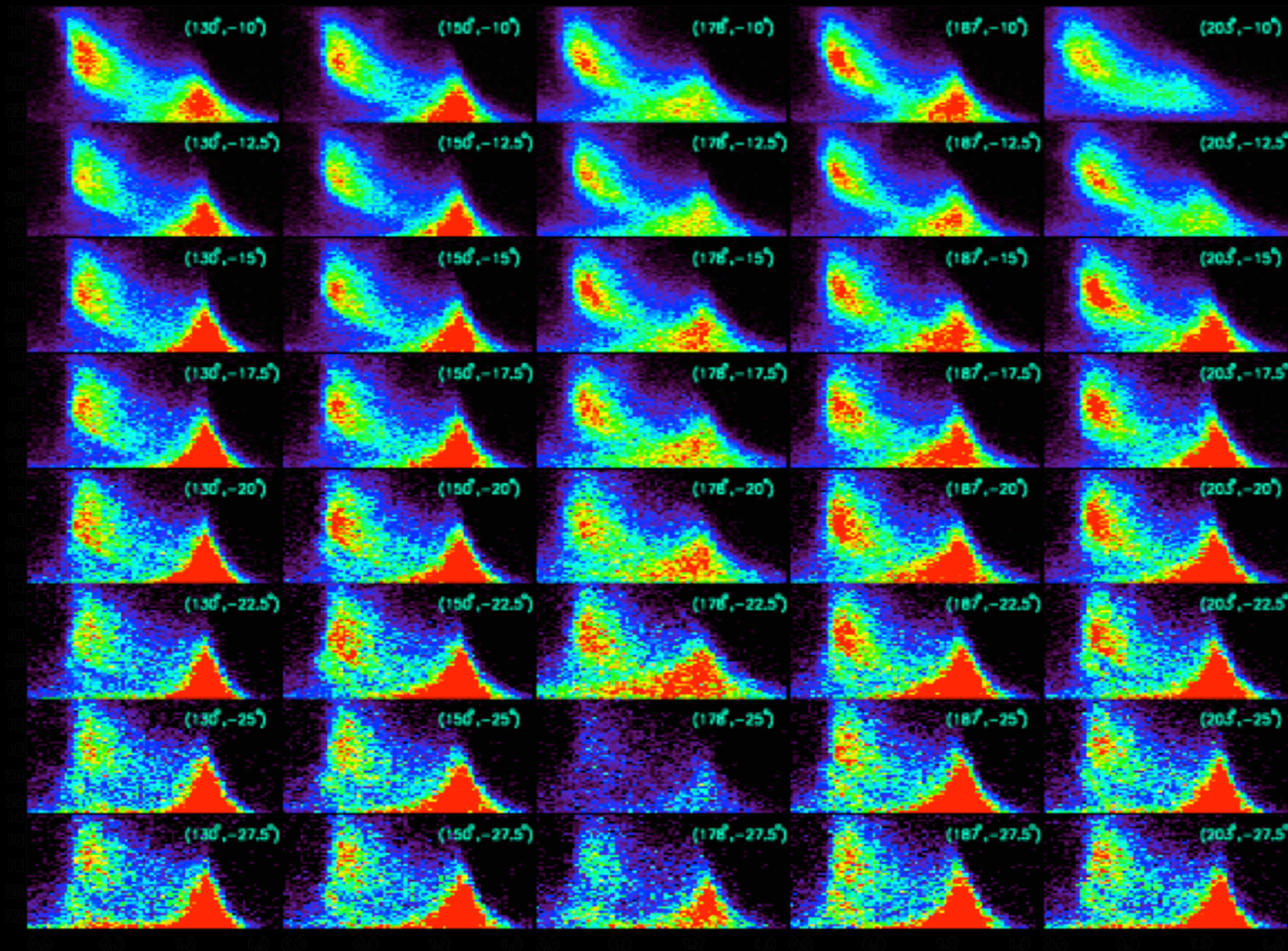

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(178°,−10°)
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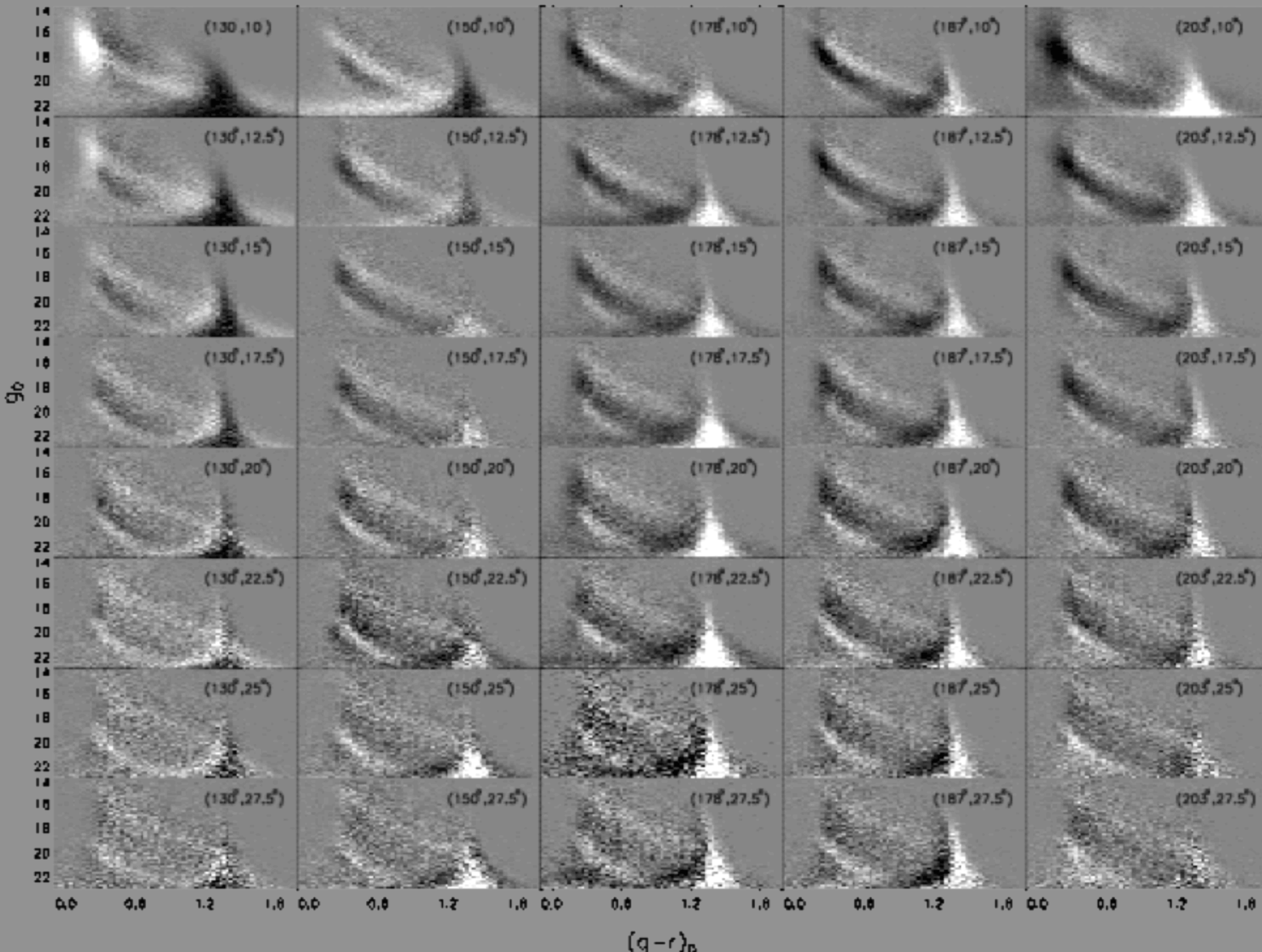
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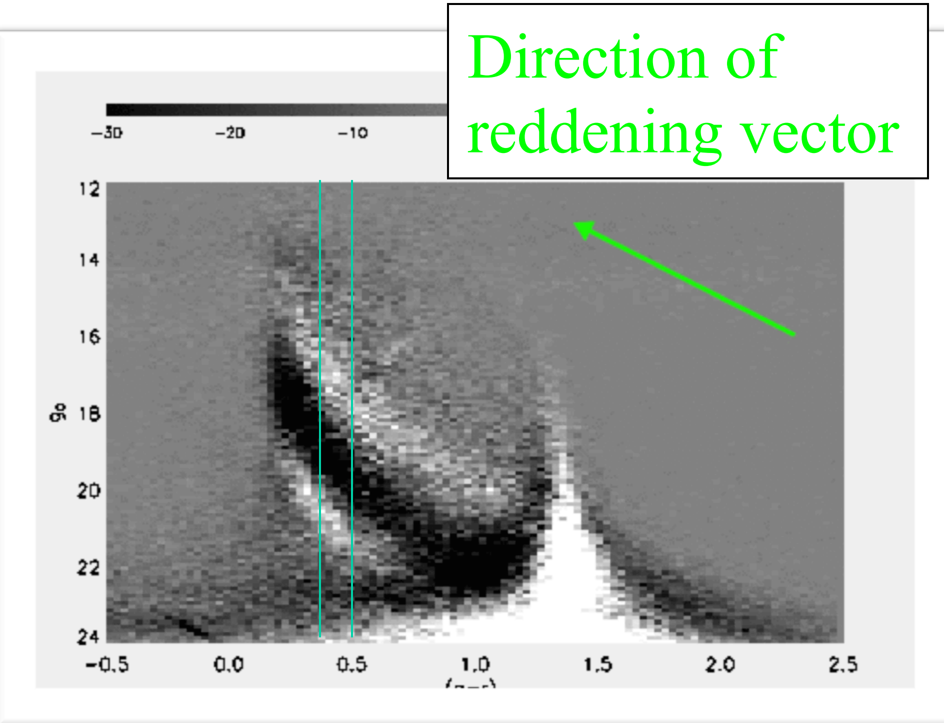
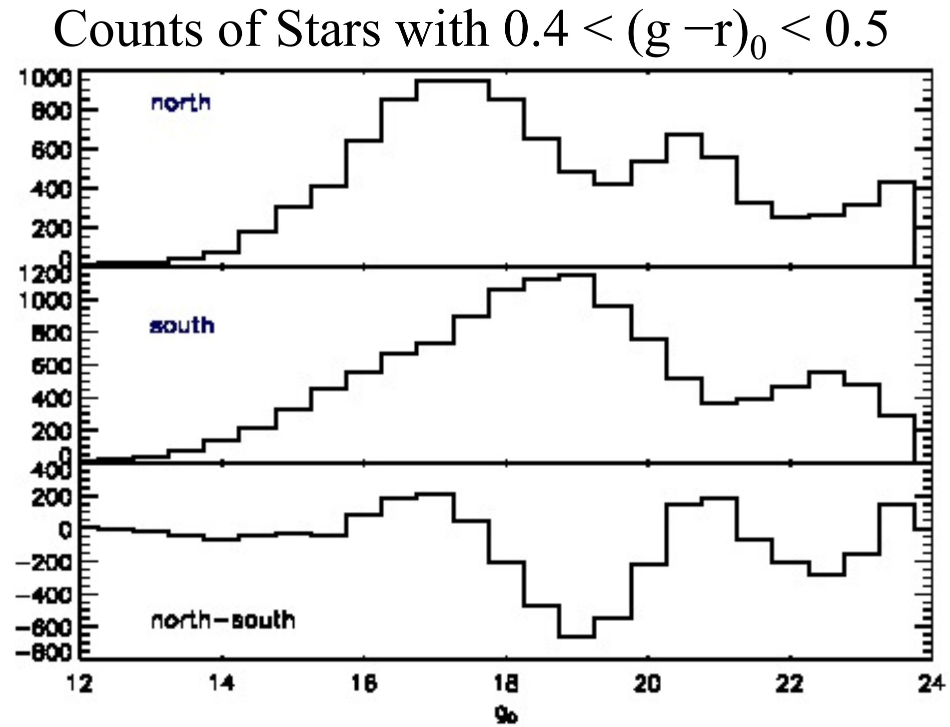
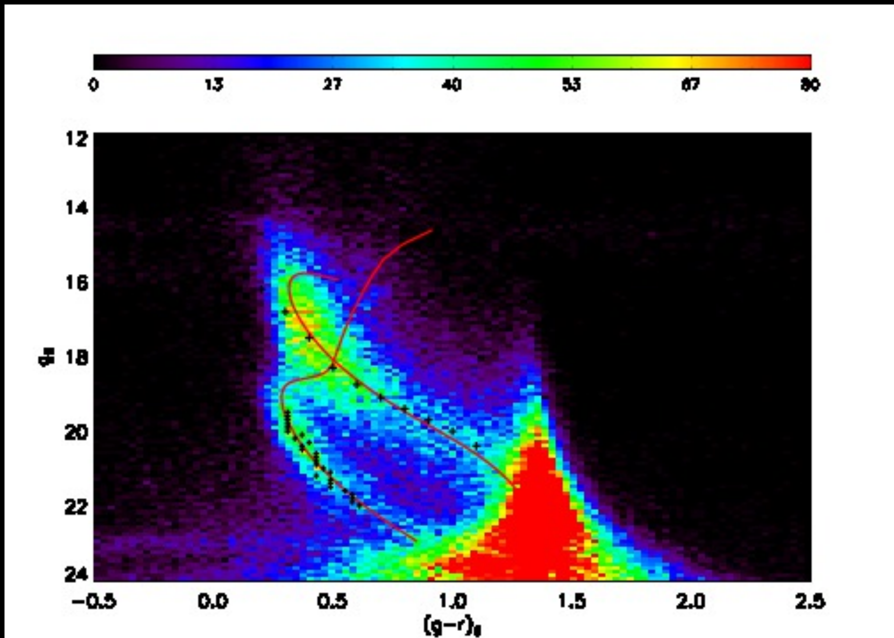
(178°,27.5°)
(187°,27.5°)
(203°,27.5°)
14
16
18
20
22
g_0
0.0
0.6
1.2
1.8
$(g-r)_0$



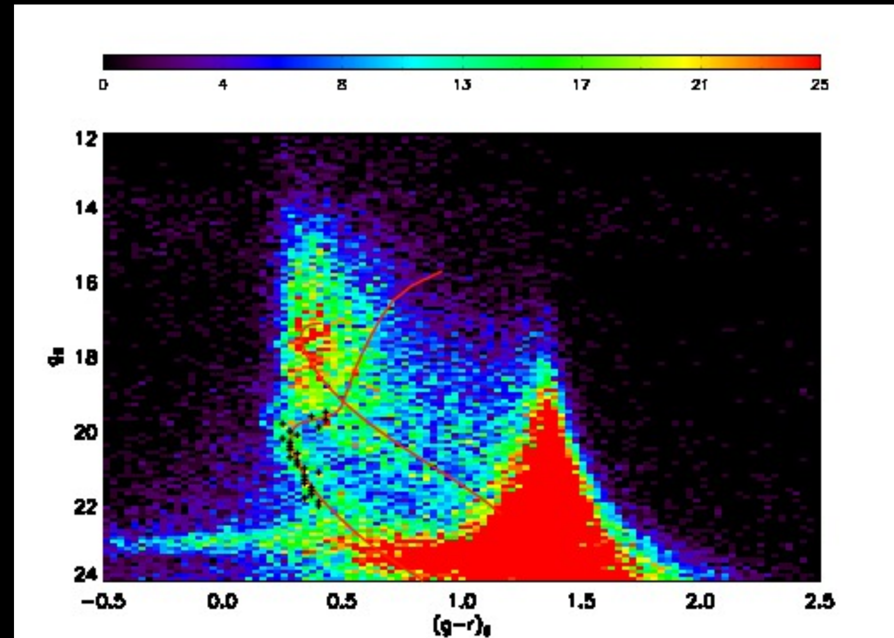


Getting the reddening wrong does not change the result.
The difference in counts is huge – like a factor of two.

Isochrone Fitting

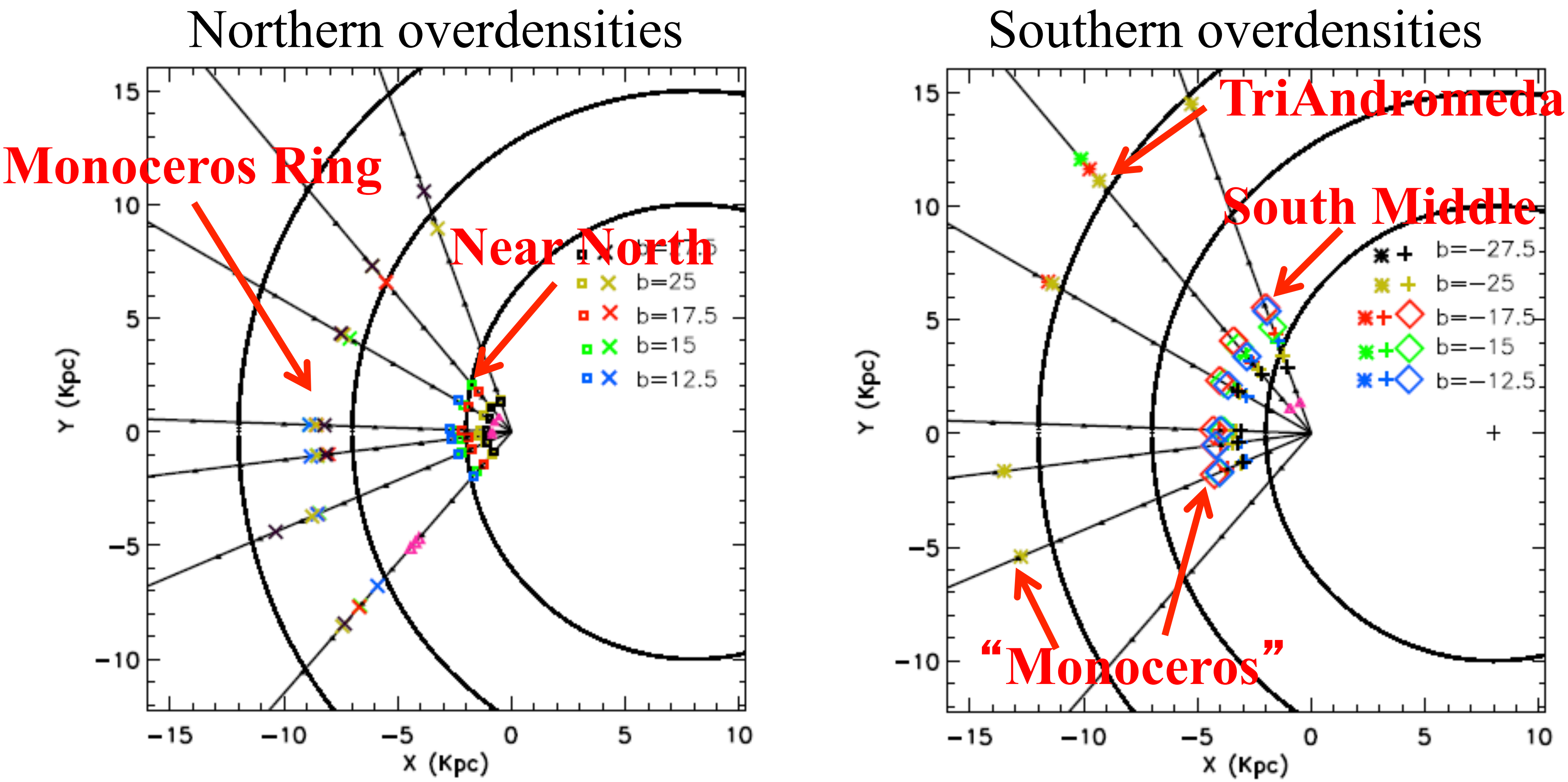


(l,b)=(178°, 15°)



(l,b)=(203°,−25°)

Isochrones were fit to the north near ([Fe/H]=-0.5), south middle ([Fe/H]=-0.88), Monoceros Ring (M5), and TriAnd Ring (M5), using empirical isochrones from An et al. (2009). For the brighter main sequences, peaks were fit to vertical slices of the Hess diagram. For the fainter main sequences, peaks were fit to horizontal slices of the Hess diagram.



We identify and asymmetry in the disk that oscillates from the north to the south to the north to the south, and opens out in the direction of the spiral arms.

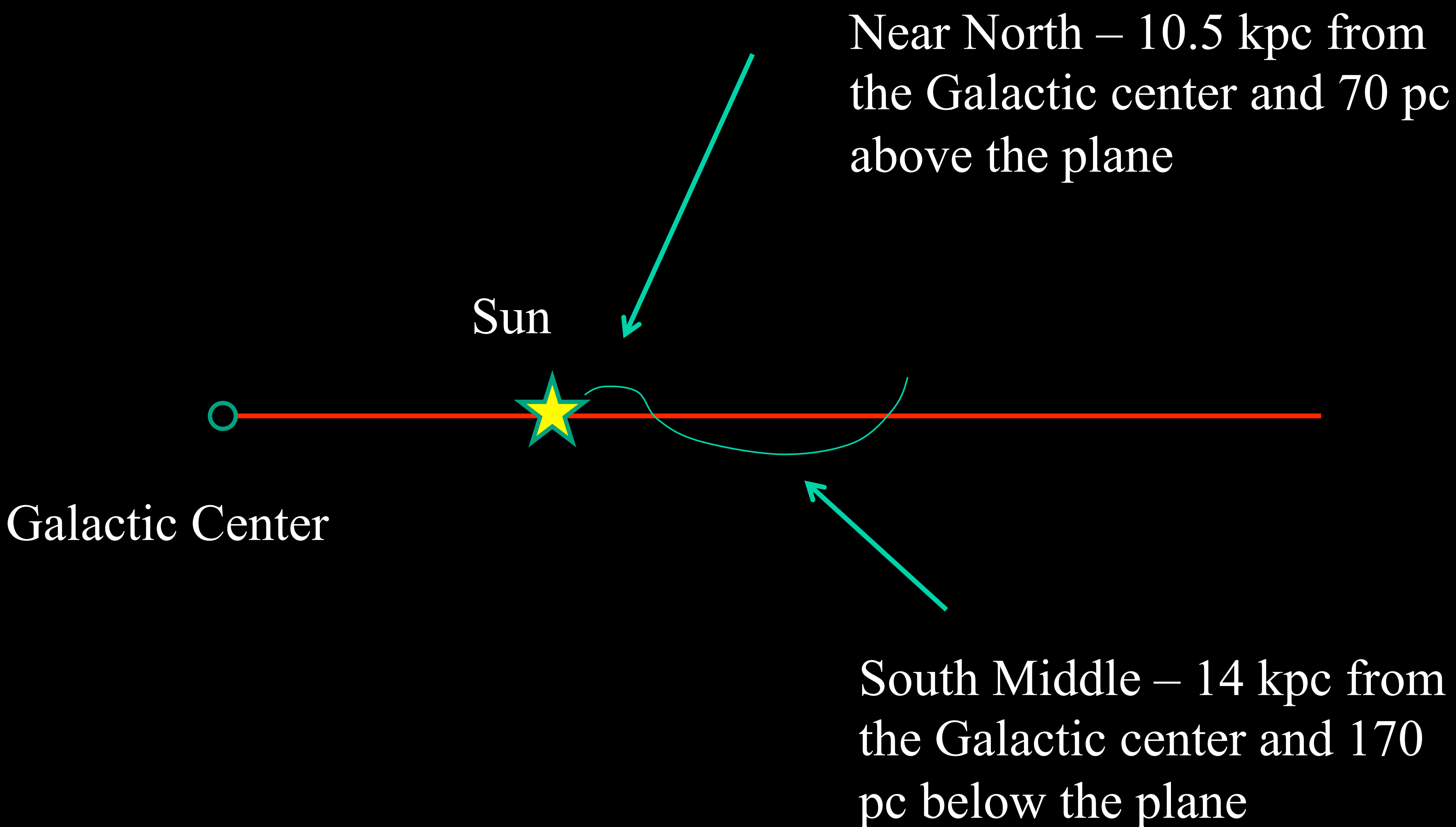
The stars in the nearer overdensities look like disk stars!

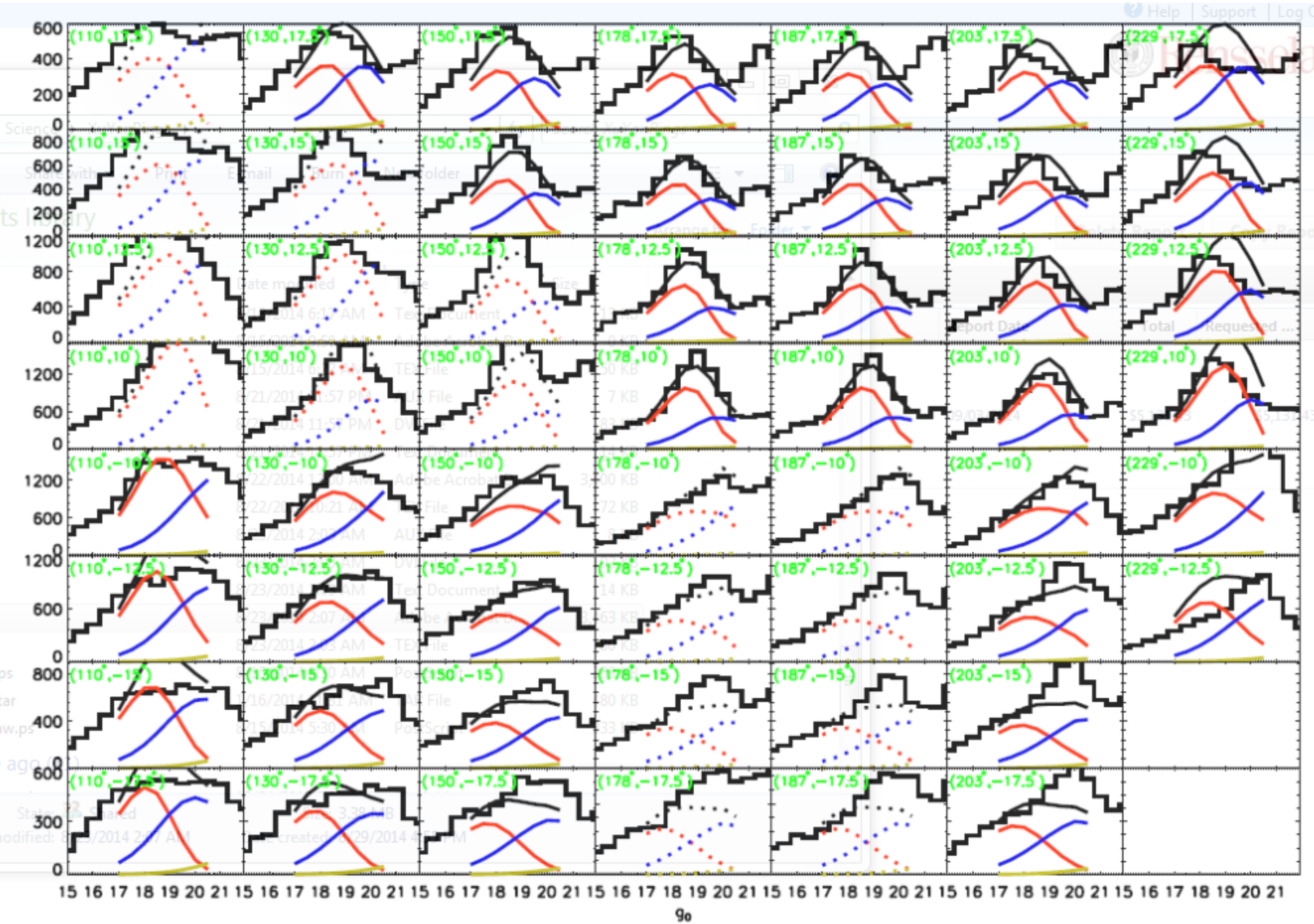
The "north near" stars have the same metallicity and line-of-sight velocity as their southern counterparts, selected with the same colors, apparent magnitudes, and Galactic longitudes, but with opposite Galactic latitude.

In both the north near and south middle structures, the metallicity decreases with distance from the plane, as expected for disk stars.

The stars in the near north and south middle structures have velocity distributions that exactly match the predictions from dynamics calculations of Schonrich & Binney (2012), with no free parameters.

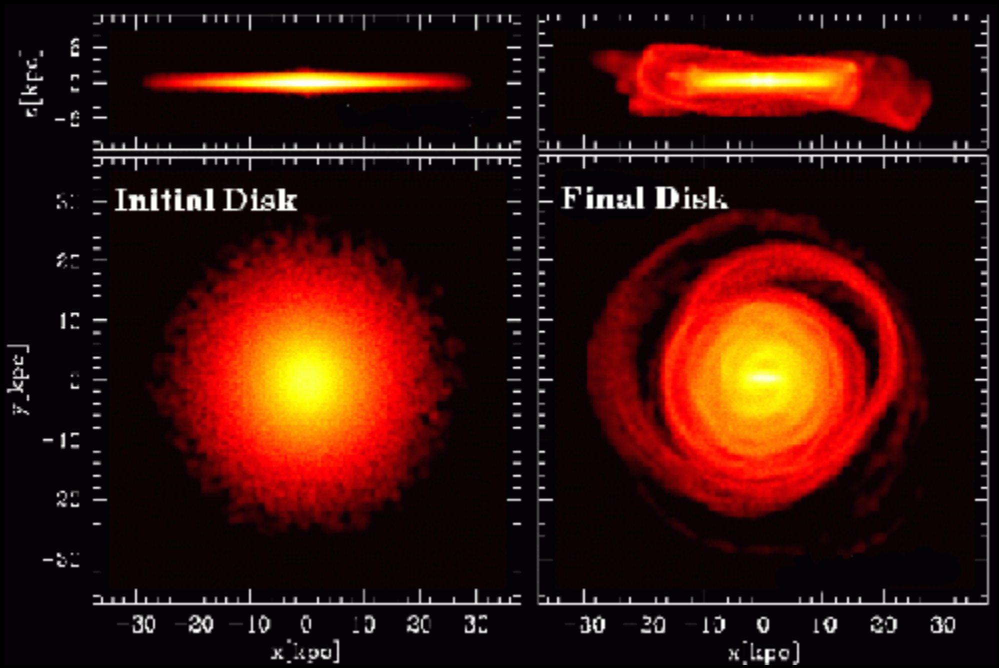
See published paper for details…


Near North – 10.5 kpc from the Galactic center and 70 pc above the plane
Sun
Galactic Center
South Middle – 14 kpc from the Galactic center and 170 pc below the plane



Exponential disk with wave

Subhalo-induced disk oscillations



Kazantzidis et al. (2008) and Younger et al. (2008) suggest that a dwarf galaxy passing through the disk could excite waves.

Purcell et al. (2011) suggest that the dwarf galaxy that purturbed the disk is the Sagittarius dwarf galaxy.

Gomez et al. (2013) find vertical offsets in the disk midplane that are roughly the same size as the ones we see.

Chakrabarti & Blitz (2009) suggest an unknown subhalo perturbed the disk gas. Chakrabarti et al. (2015) may have found it.

The disk of the Milky Way exhibits wavelike bulk motions

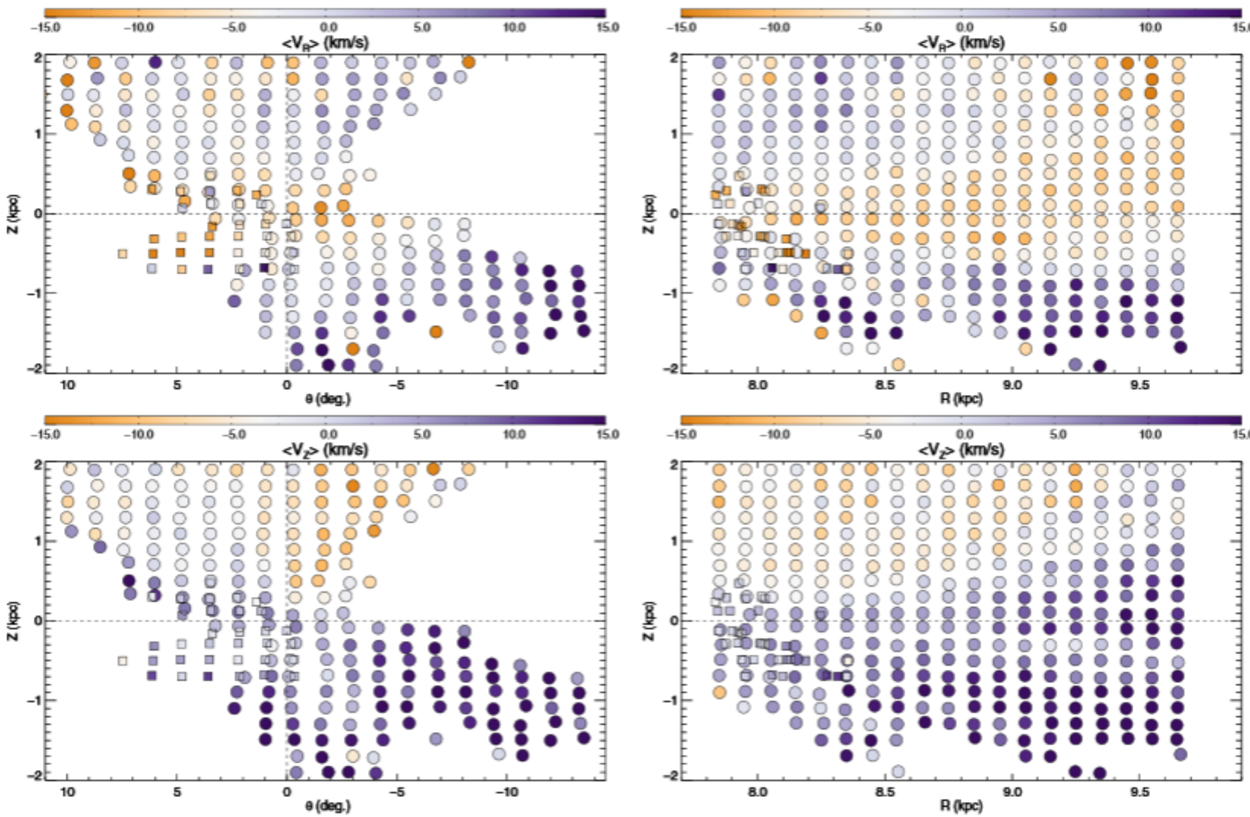


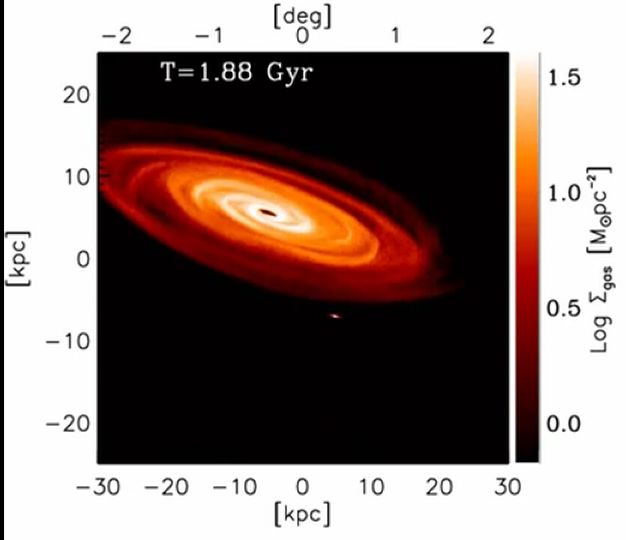
Figure 2. Radial (V_R, upper panels) and vertical (V_Z, lower panels) components of the Galactocentric velocities of stars between $7.8 < R_{GC} < 9.8$ kpc as a function of positions in Z and θ (left column) and Z, R (right column). Circles denote LAMOST data, and small squares are derived from RAVE velocities. Each colored point represents the mean value of all stars within a bin 200 pc wide in R and Z, and 13 in θ. All bins contain at least 50 stars, and some contain many thousands of stars. The dots are centered at the mean position of the stars within each subsample, and color encodes the mean V_R or V_Z according to the scale given by the color bar at the top. Apparent radial features in the right panels are artifacts consistent with ~20%–30% errors in the distances.

Carlin et al. (2013)

- Williams et al. (2013) find velocity substructure in RAVE data
- Widrow et al. (2012) find velocity substructure in SDSS data
- Carlin et al. (2013) find velocity substructure in LAMOST data
- Yanny and Gardner (2013) find, at the Sun's position, more stars above the disk than below the disk at a scale height of 1 kpc, and more below the disk at 300 pc.

Evidence from Andromeda

Screenshot from simulation of Dierickx, Blecha & Loeb (2014) – Andromeda spiral/rings caused by collision with M32



Andromeda's NE clump (40 kpc from the galaxy center) thought to be disk stars, possibly tossed out by an encounter with the dwarf galaxy progenitor for the Giant Stellar Stream (Ibata et al. 2005, Richardson et al. 2008, Bernard et al. 2015)

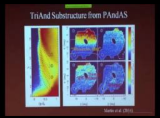
And this just in:

Price-Whelan et al. (2015) just posted an article to ArXiv saying the M giant to RR Lyrae ratio in the Triangulum-Andromeda ring is characteristic of a disk population and not any known dwarf galaxy.

Conclusions

- We identify and asymmetry in the disk that oscillates from the north to the south to the north to the south, thus extending the disk radius to at least 25 kpc.
- The "Near North" structure is 10.5 kpc from the Galactic center, and is perturbed approximately 70 pc above the plane. The "South Middle" structure is 14 kpc from the Galactic center and 170 pc below the plane. The next oscillations coincide with the Monoceros and TriAnd "Rings."
- The rings open in the direction of the Milky Way's spiral arms.
- Oscillations induced by infalling dwarf galaxies or dark subhalos could produce vertical displacements like the ones we see.

For more information, search "heidi newberg corrugated milky way" on youtube.com:

 non-scientists (1 min)  public (20 min) 

astronomers (50 min)

Read the paper on ArXiv,

Or invite me to give a talk at your institution. I will be on sabbatical and not teaching next year.

I am interested in organizing a conference on this for summer 2016. If you have a suggested venue or would like to help, let me know.