The Overdensity in Virgo, Sagittarius Debris, and the Asymmetric Spheroid

Heidi Jo Newberg

Rensselaer Polytechnic Institute

Brian Yanny, Nate Cole, Timothy C. Beers, David Martinez-Delgado, Paola Re Fiorentin, Donald P. Schneider, Ron Wilhelm

Overview

- The overdensity in the Virgo constellation: S297+63-20.5, VSS, VOD, Sgr tidal tails, triaxial spheroid
- The Sgr leading tidal tail appears to arc through the NGC, over (not through) the overdensity in Virgo and misses the Sun by more than 15 kpc.
- The stars in the central part of the S297+63-20.5 overdensity have $V_{gsr}=130\pm10$ km/s.
- S297+63-20.5 is not associated with the Sgr dwarf galaxy, but probably is associated with the VSS and VOD.
- Some of the 2MASS M giants associated with the Sgr leading tidal tail might not be part of the leading tidal tail.
- The stellar spheroid is asymmetric.
- There are lumps in the spheroid everywhere we look, in density and velocity.

Overdensities Identified in Virgo

The next four slides illustrate four substructures that have been previously identified in Virgo, some of which may describe the same stellar populations.

#1 – The Virgo Stellar Stream

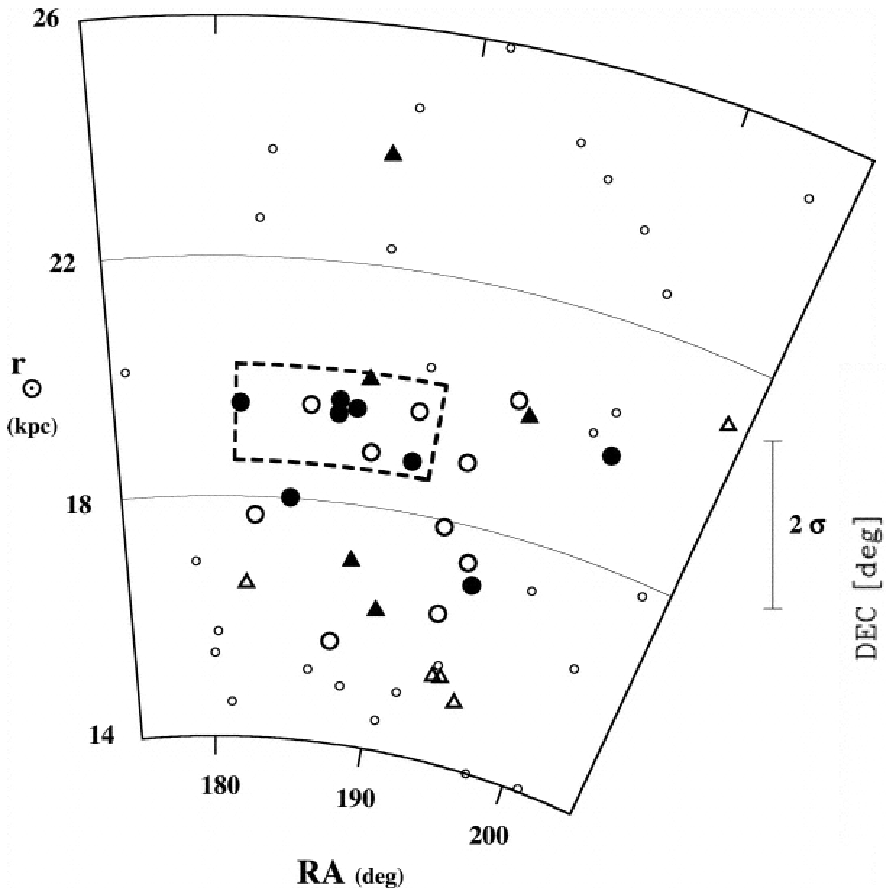
#2 – S297+63-20.5

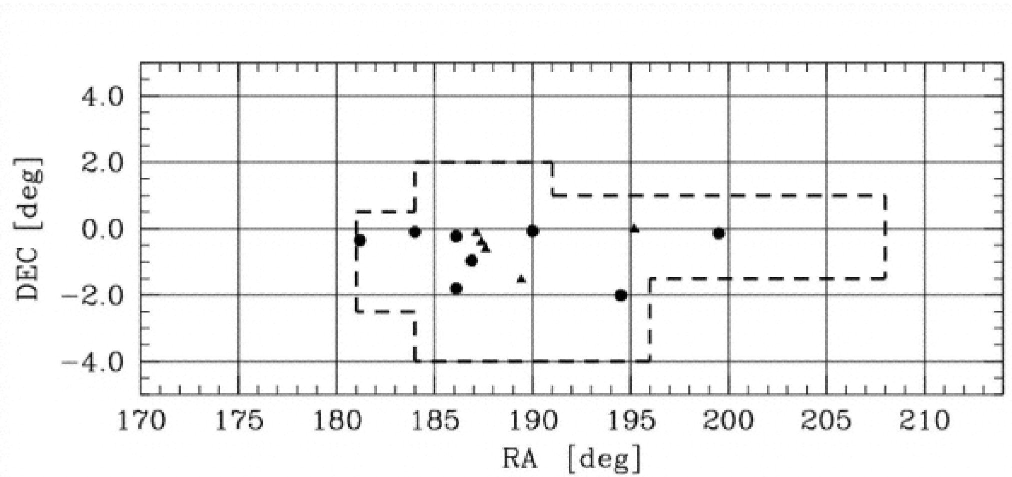
#3 – The Virgo Overdensity

#4 – The Triaxial Spheroid

#5 – Suggestion that the Virgo Overdensity is really the Sgr dwarf spheroidal leading tidal tail

The Virgo Stellar Stream (VSS)





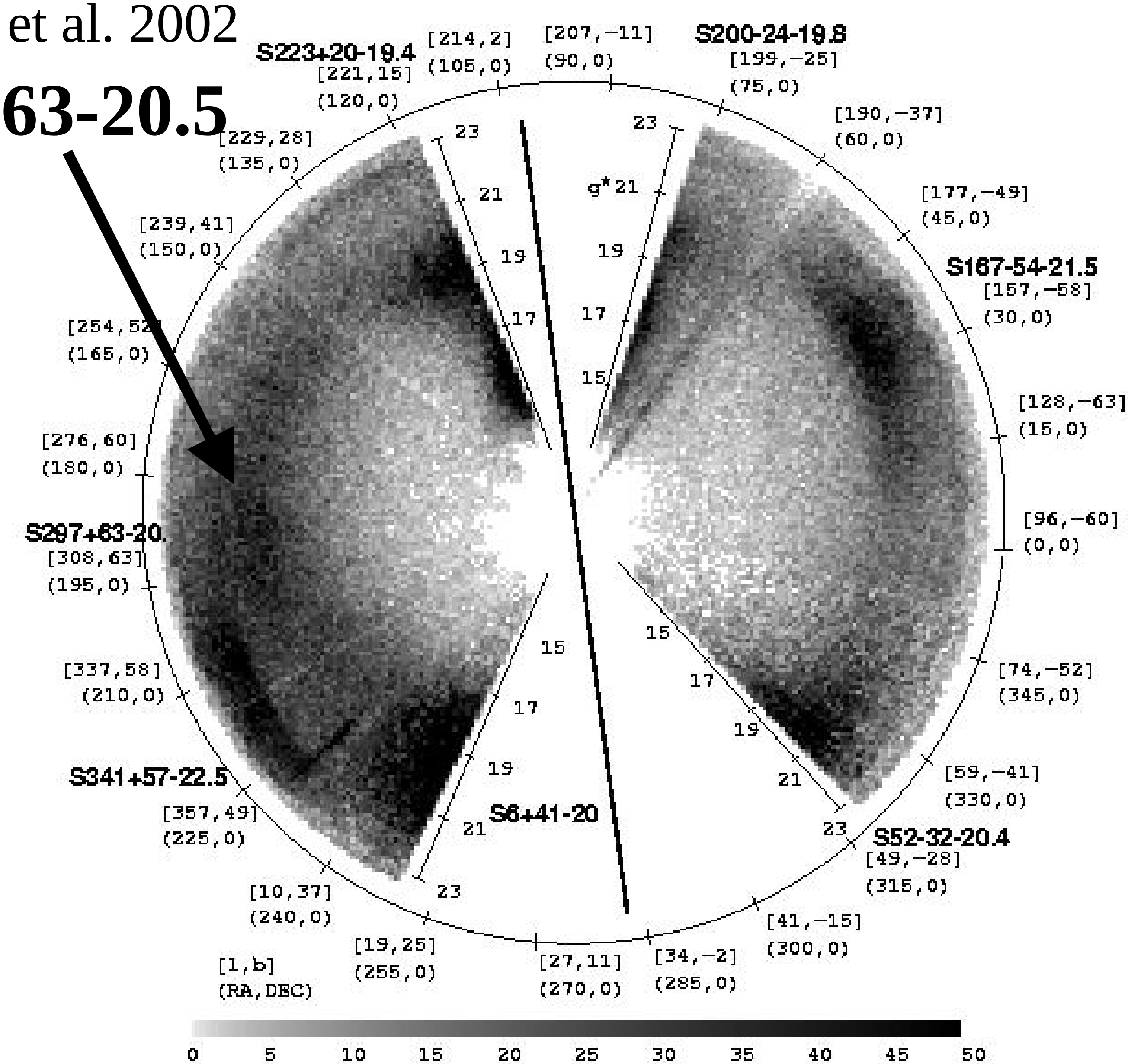
The central knot is at (l,b)=(288°,62°),
18 kpc from the Sun, V_{gsr}=100 km/s.

Duffau et al. 2006, originally suggested in Vivas et al. 2001

Newberg et al. 2002

#2

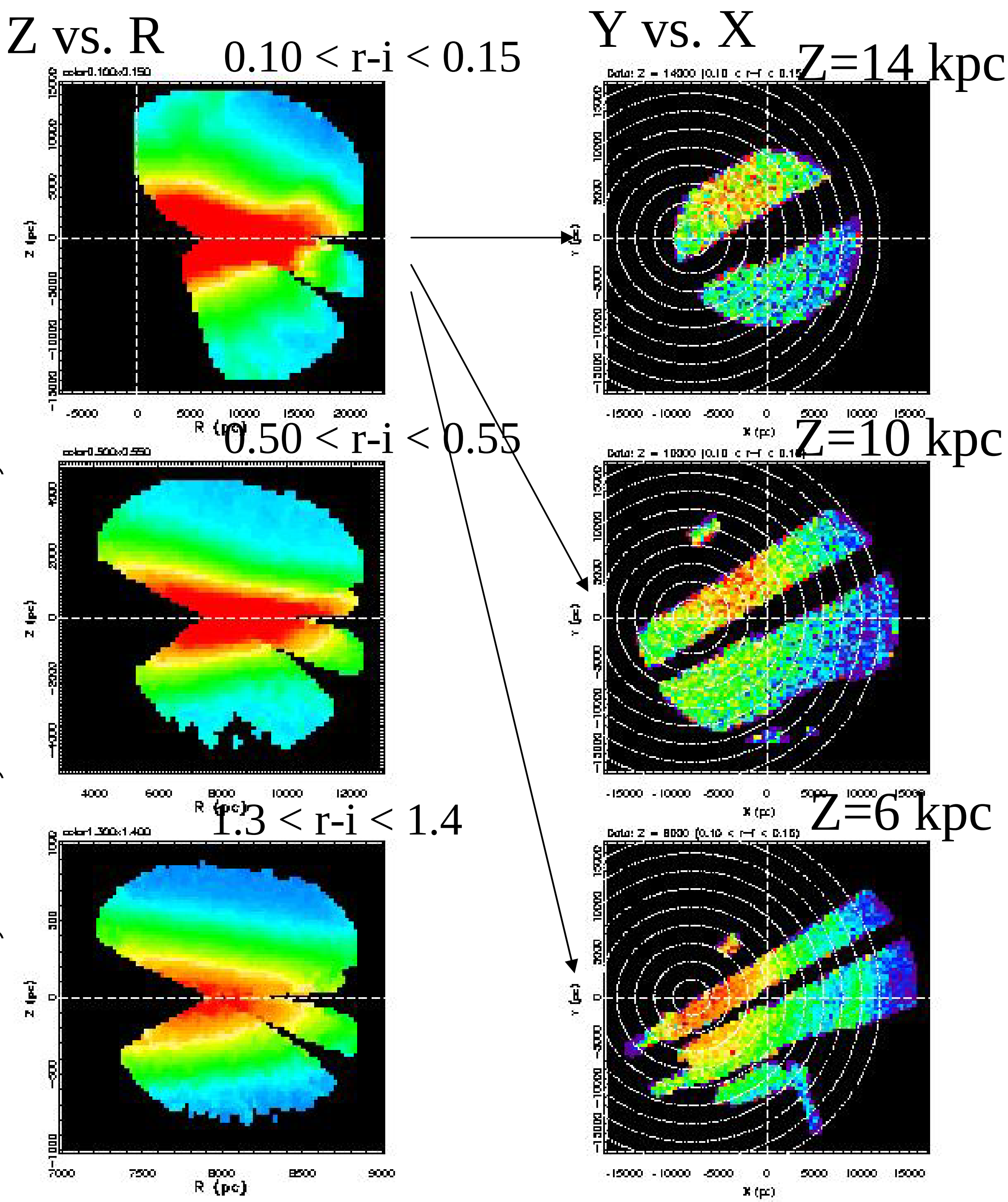
S297+63-20.5



(l,b)=(297,63), g=20.5 → ~18 kpc from the Sun, slightly offset but same position as VSS

#3

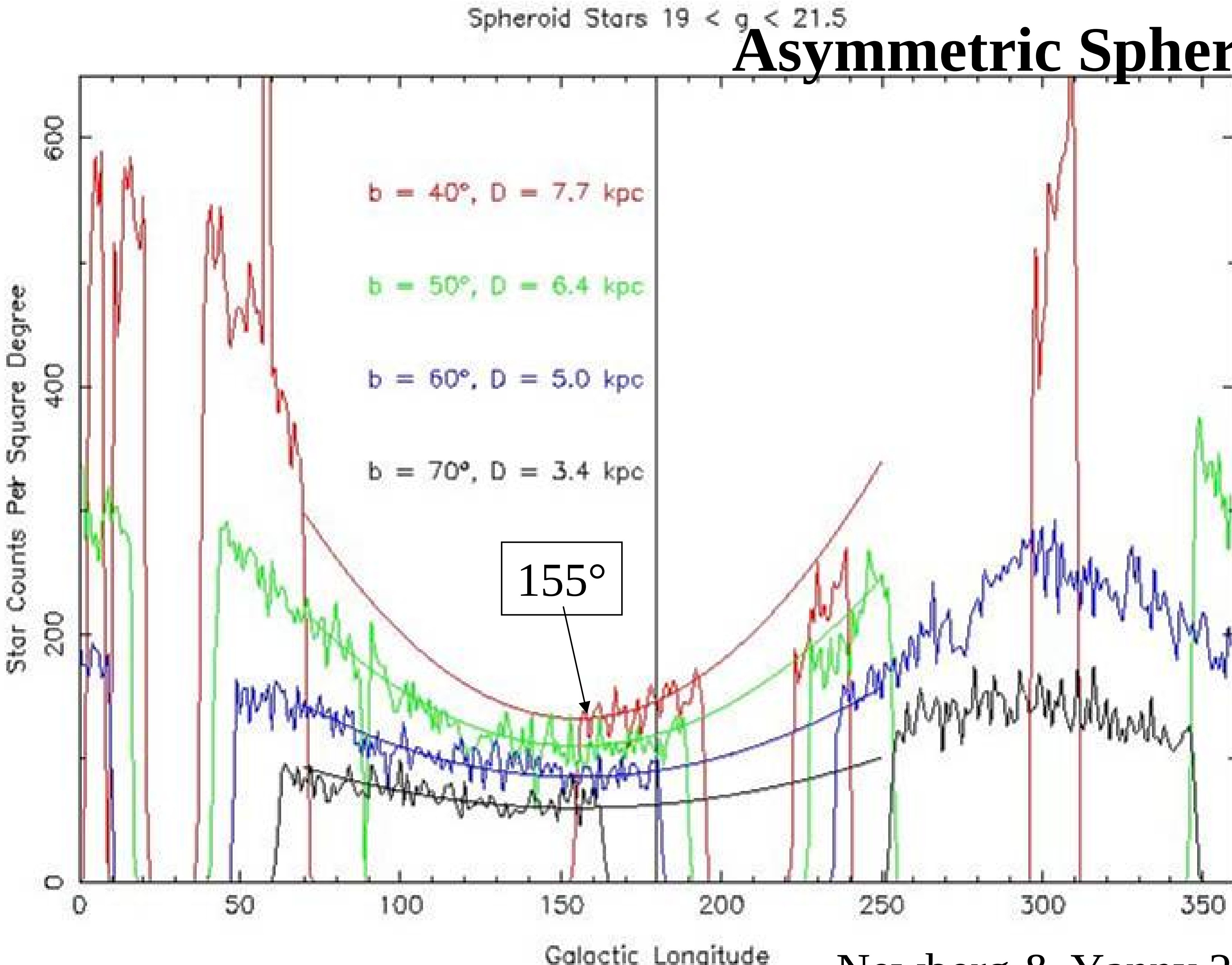
Juric, Ivezic, Brooks et al., submitted



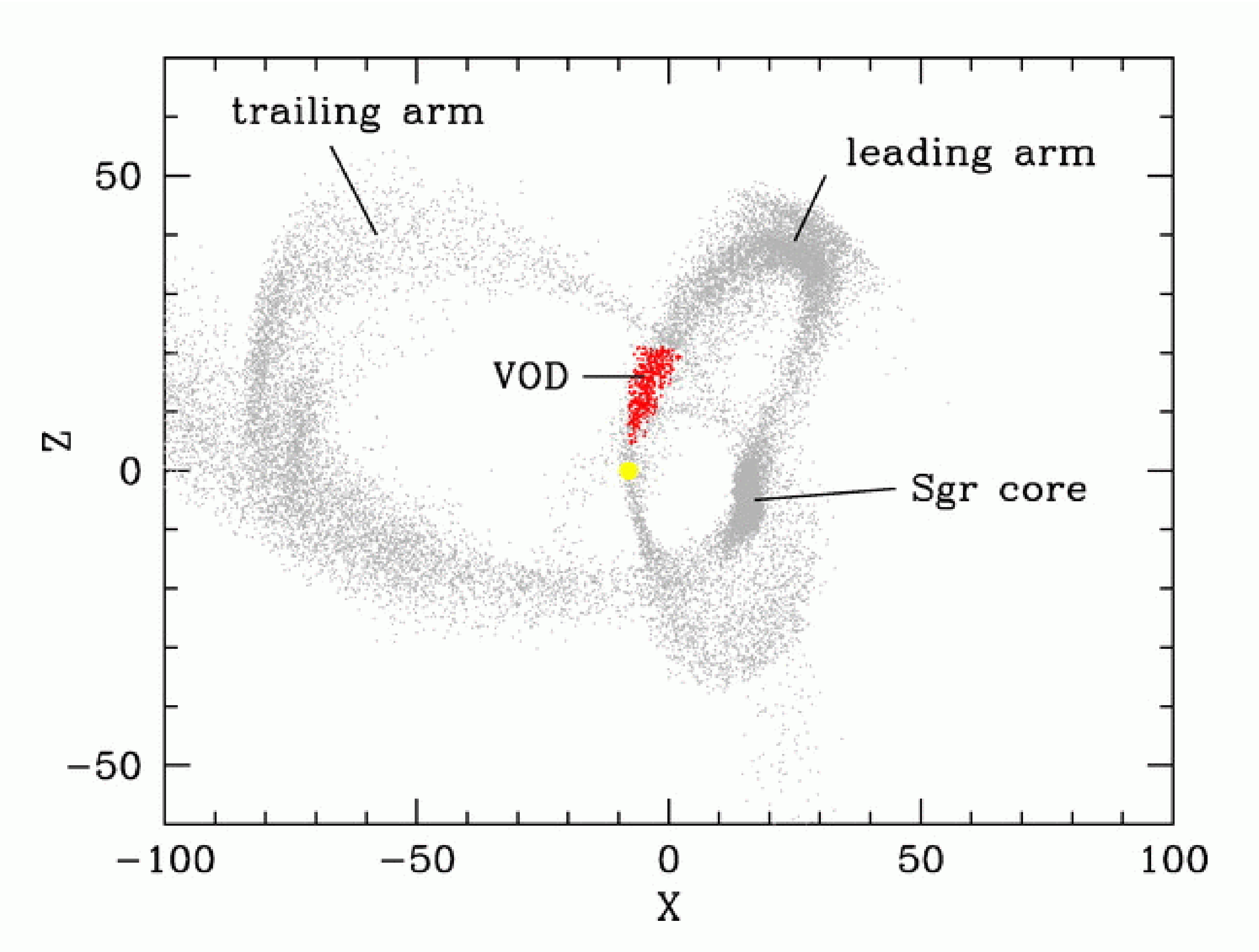
The Virgo Overdensity (VOD)

5-15 kpc from the Sun, factor of two more stars than the smooth speroid, possibly large invading galaxy

#4
Asymmetric Spheroid



Newberg & Yanny 2005



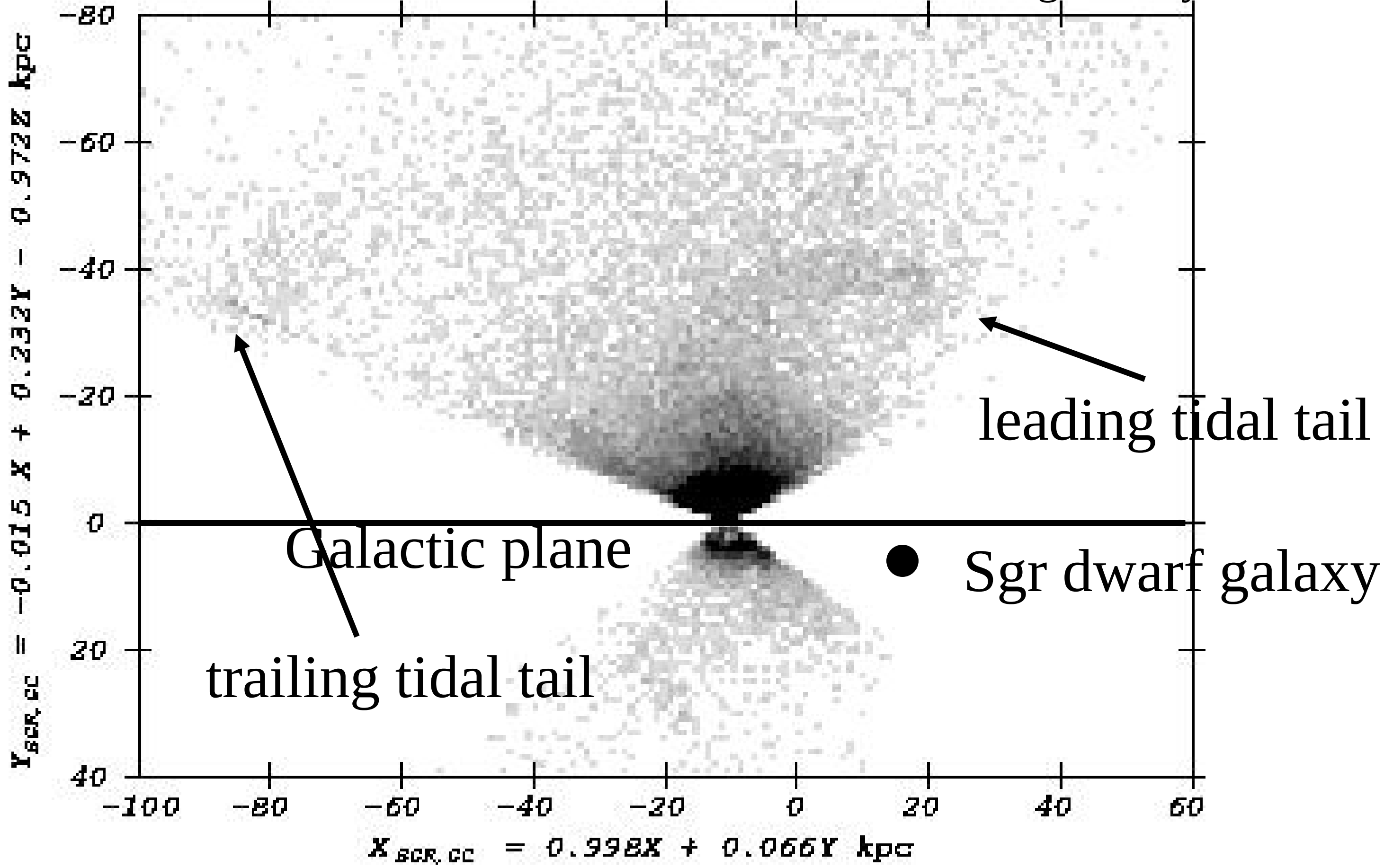
Martinez-Delgado et al. 2007

The Sgr dwarf leading tidal tail might go through the Virgo structure. Highly negative V_{gsr} velocities are predicted in Virgo.

The Sgr tidal tails

The next four slides show the leading and trailing tidal tails of the Sgr dwarf as seen in SDSS BHB stars (first three diagrams) and F turnoff stars (fourth diagram). There is an extra closer lump that we originally thought was in Virgo, but it is on the wrong side of the Galaxy. The spheroid is lumpy.

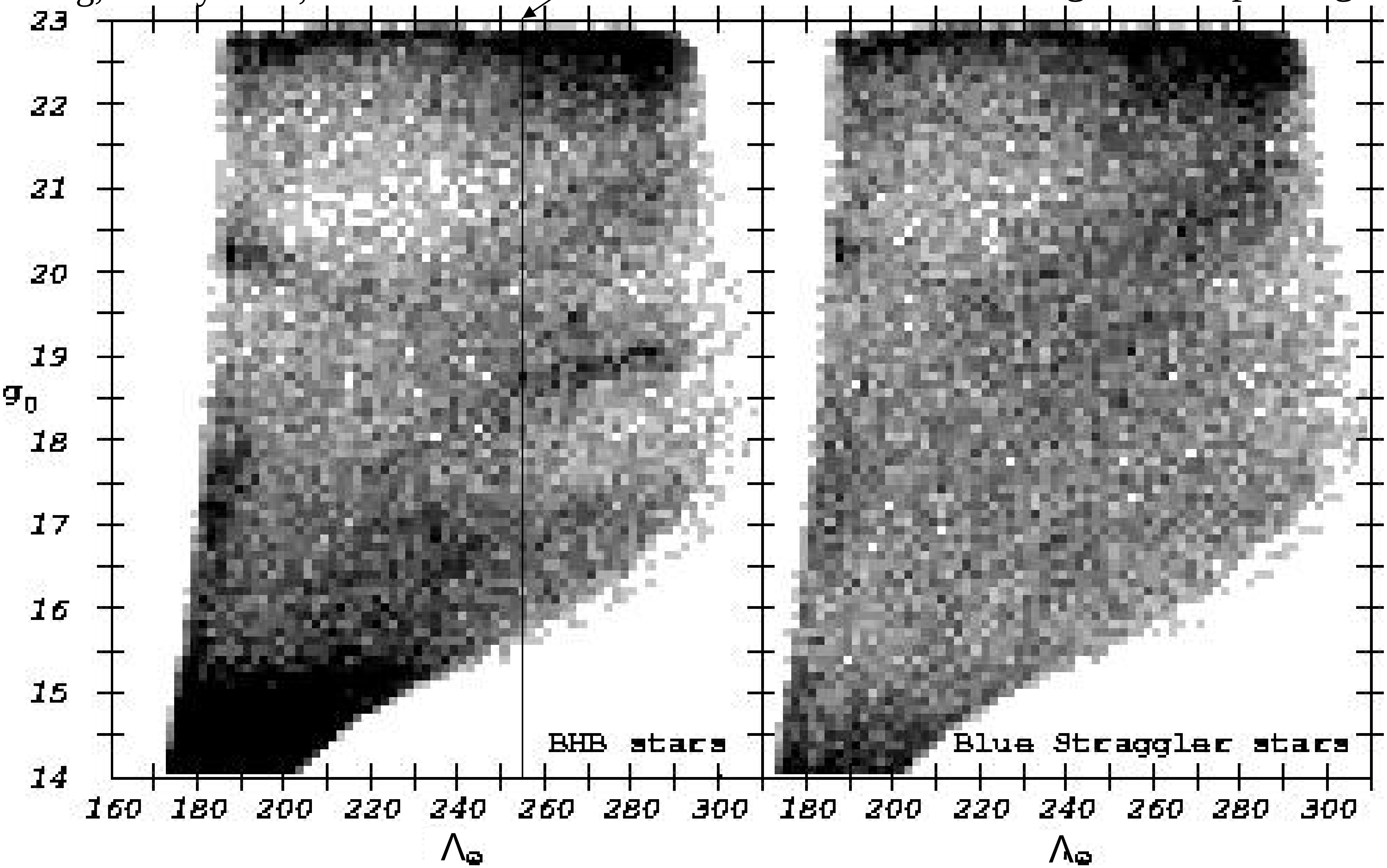
Newberg, Yanny et al., submitted



Color-selected SDSS BHB stars within 15 kpc of the Sgr dwarf orbital plane. Positions assume all BHB stars have M_g=0.7. All stars within 0.2° of the GCs M53, NGC 5053, NGC 4147, and NGC 5466 are excluded.

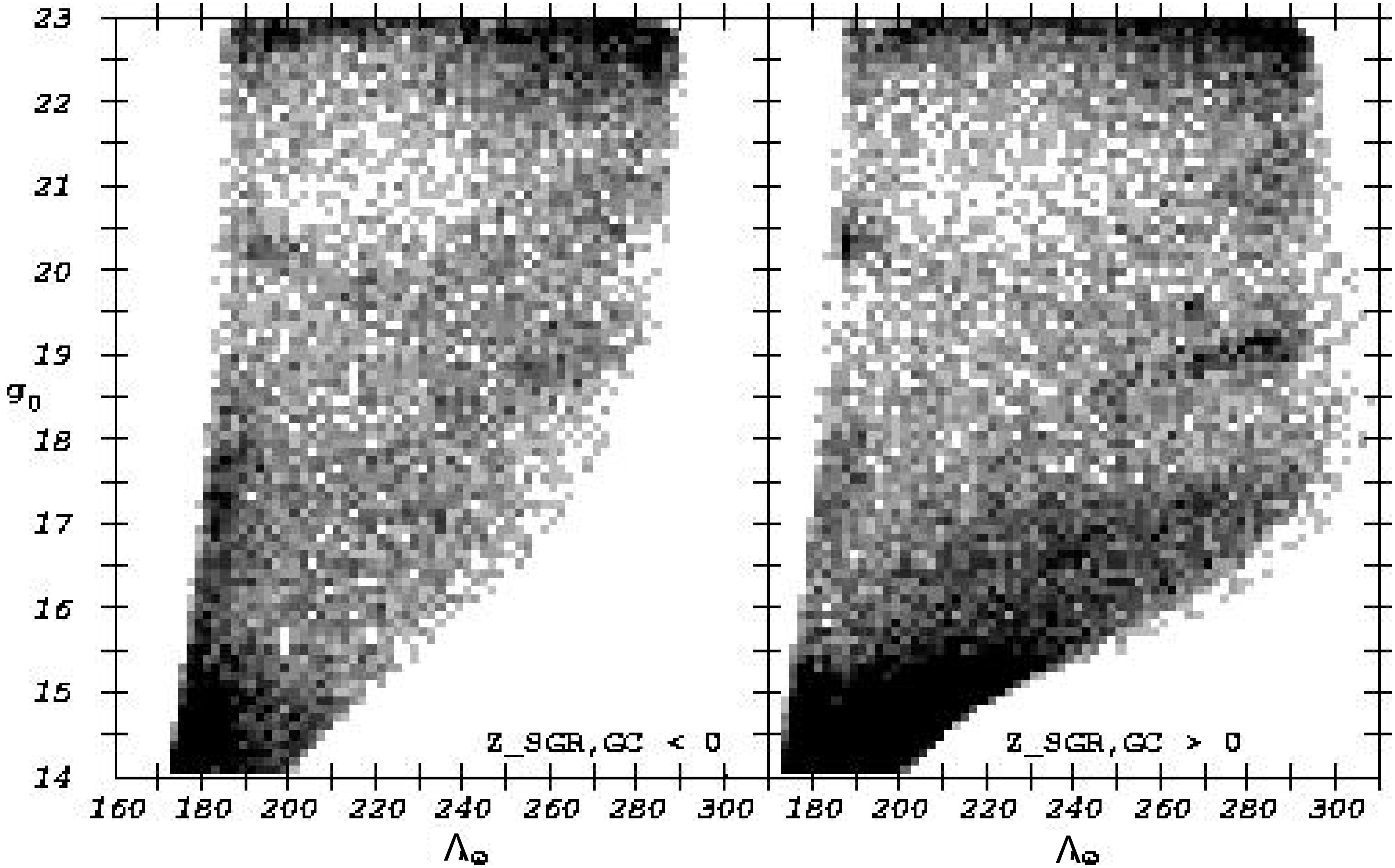
Newberg, Yanny et al., submitted

As close the the NGP as the Sgr orbital plane gets



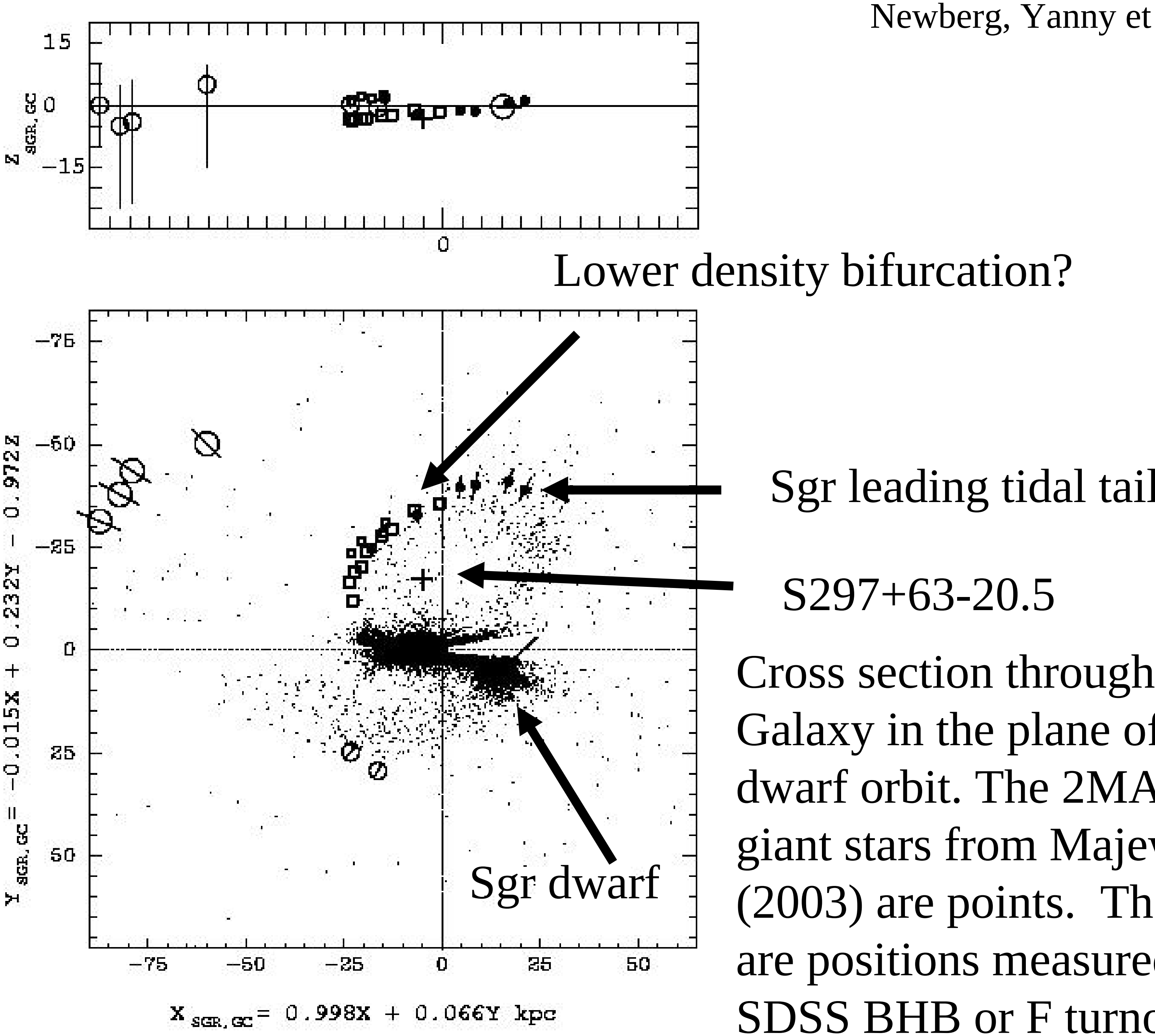
BHB and BS stars within 10 kpc of Sgr dwarf orbital plane – apparent magnitude vs. angle from the Sgr dwarf galaxy. If the leading tidal tail of Sgr came down on the solar position, it would come from $\Lambda_\odot$=256°.

Newberg, Yanny et al., submitted



If we divide the BHB stars up by which side of the Sgr dwarf orbital plane they are on, we see that the apparent lump at g=16.5 is on the wrong side to be associated with any of the identified overdensities in Virgo.

Newberg, Yanny et al., submitted

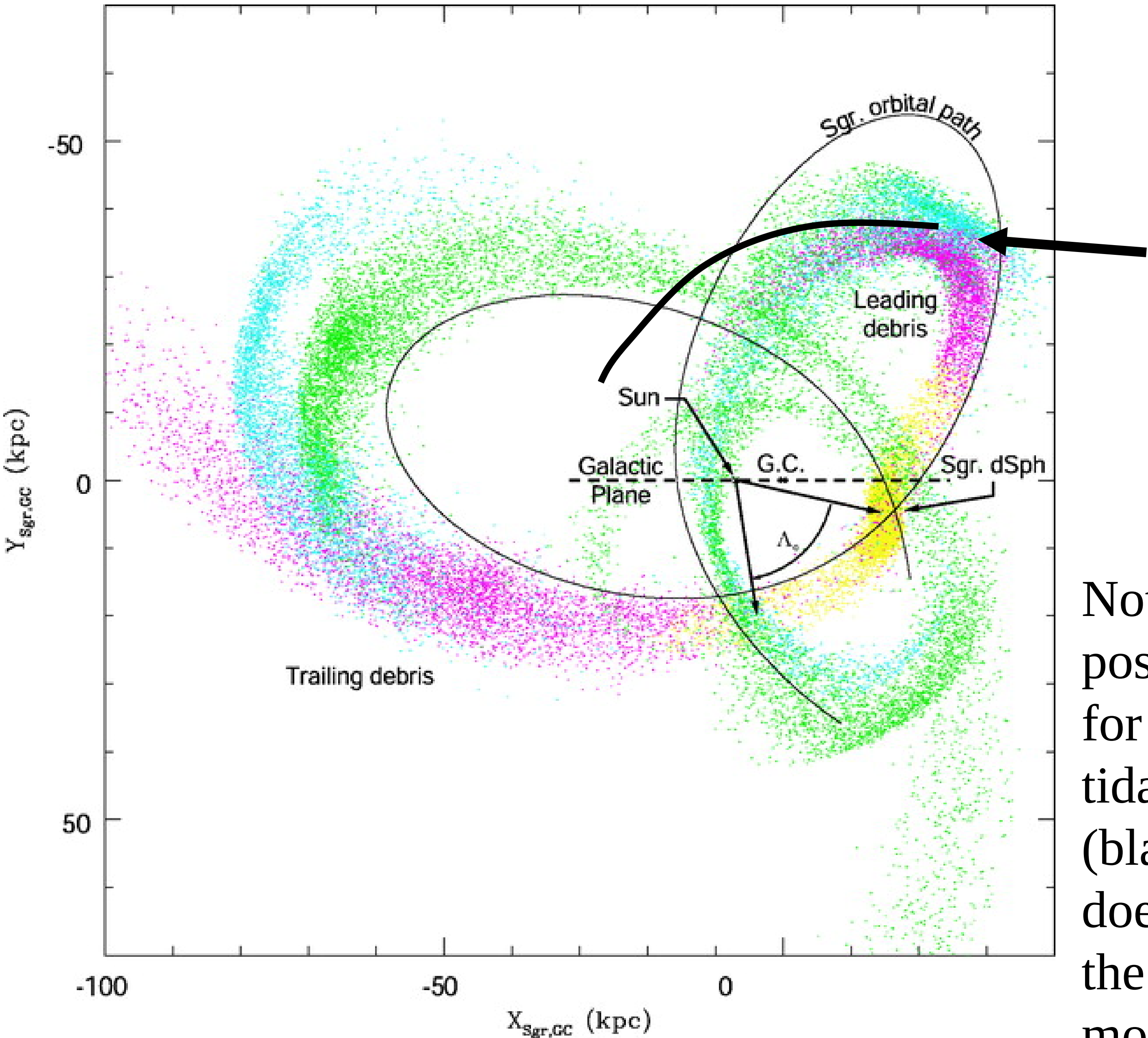


Cross section through the Galaxy in the plane of the Sgr dwarf orbit. The 2MASS M giant stars from Majewski et al. (2003) are points. The symbols are positions measured from SDSS BHB or F turnoff stars.

Comparison with LJM Model

The next plot shows that our leading tidal tail positions do not line up with the Law, Johnston, and Majewski 2005 model of the Sgr stream. The one after that shows that the M giant stars with velocities that don’t fit the oblate spheroid model are not at the same distance as the Sgr stream.

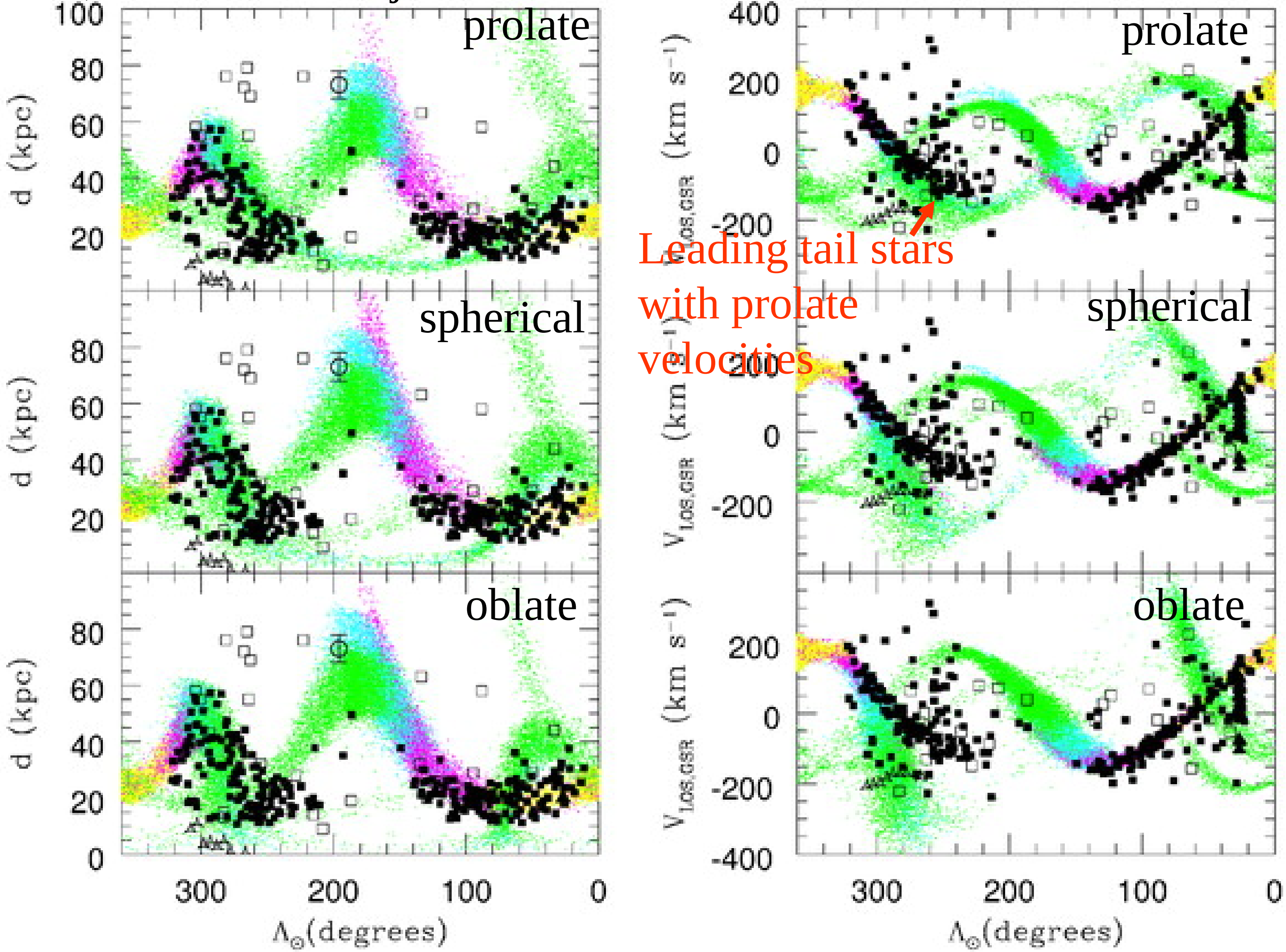
Law, Johnston & Majewski 2005



Leading tidal tail in A/F stars

Notice that the position we find for the leading tidal tail of Sgr (black curve) does not follow the LJM 2005 model.

Law, Johnston & Majewski 2005



Polar plots of F turnoff stars

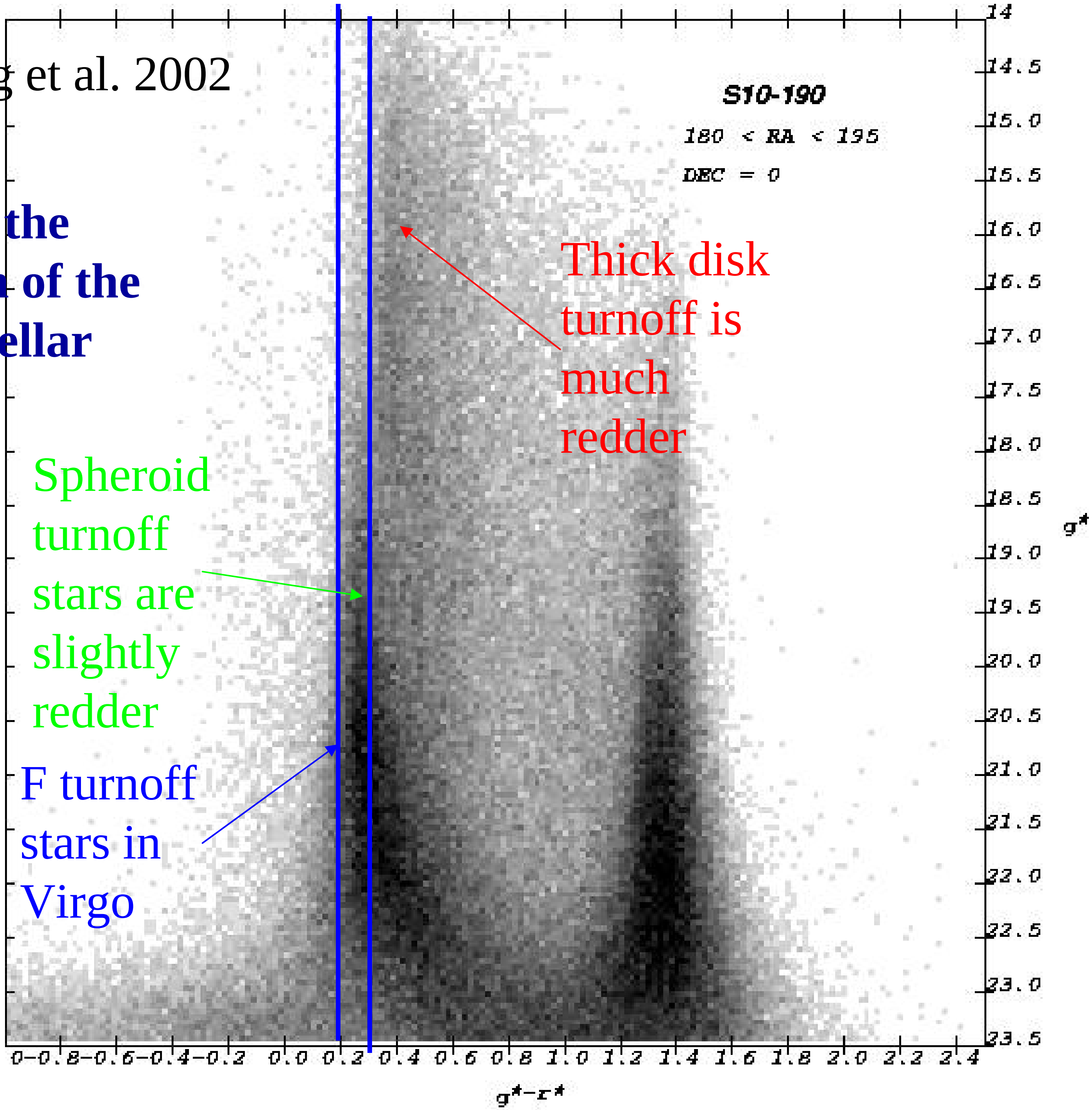
The next slide shows that we select turnoff stars that are bluer than the turnoff of the thick disk. The following slide shows three polar plots of those stars, each in a different apparent magnitude (and therefore distance from the Sun) range. Notice that we see the Sgr stream in the direction of the anticenter for 20<g<21 – so it is not raining down on us.

Also, we do not see the VOD in the brighter (19<g<20) polar plot, which is where it should be if it were really a closer structure than the VSS.

The VSS is most prominent for 20<g<21. In that direction in the sky, the Sgr dwarf tidal stream is more prominent for 21<g<22 (farther away).

Newberg et al. 2002

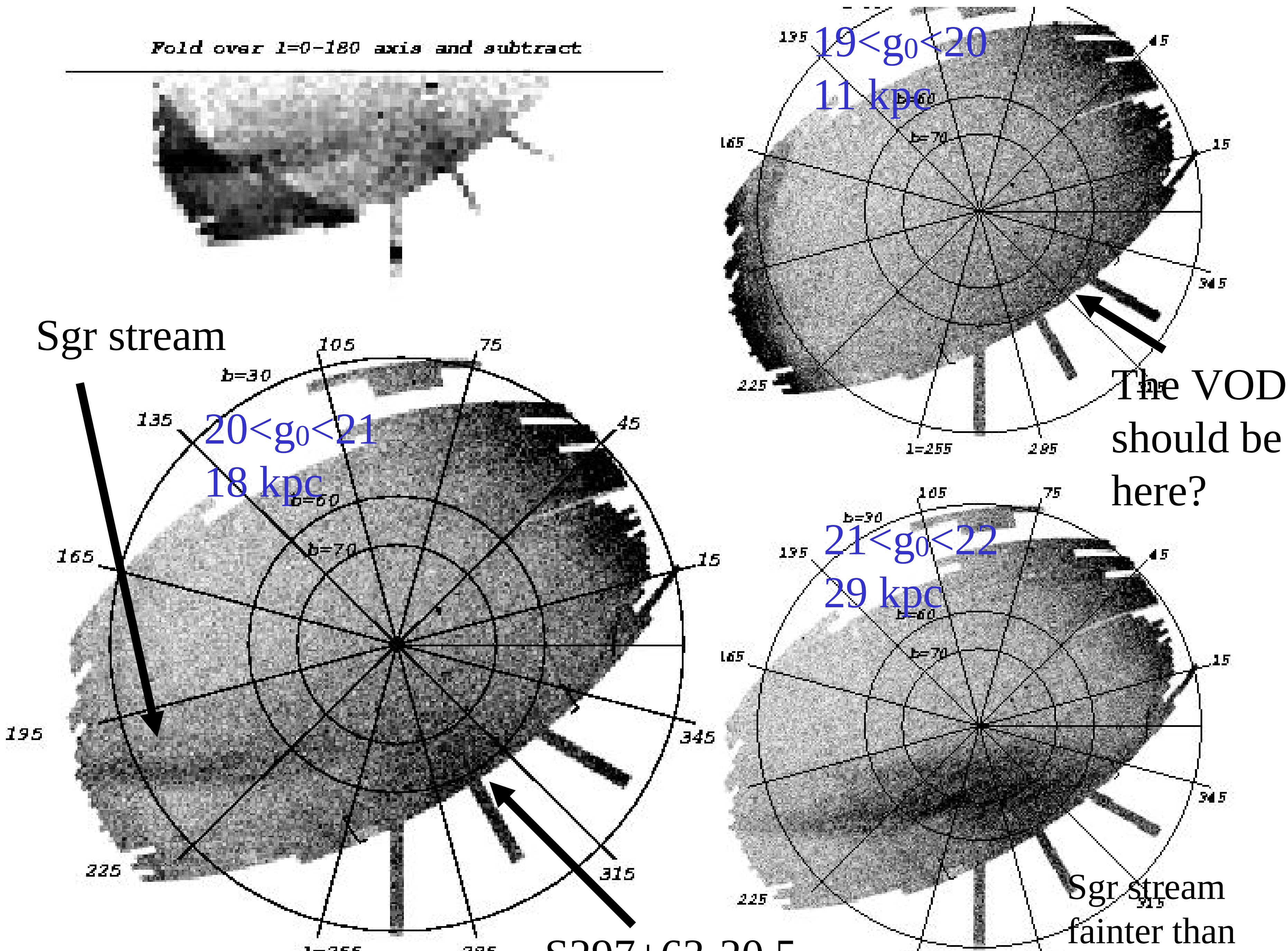
CMD in the direction of the Virgo Stellar Stream



Thick disk turnoff is much redder

Spheroid turnoff stars are slightly redder

F turnoff stars in Virgo

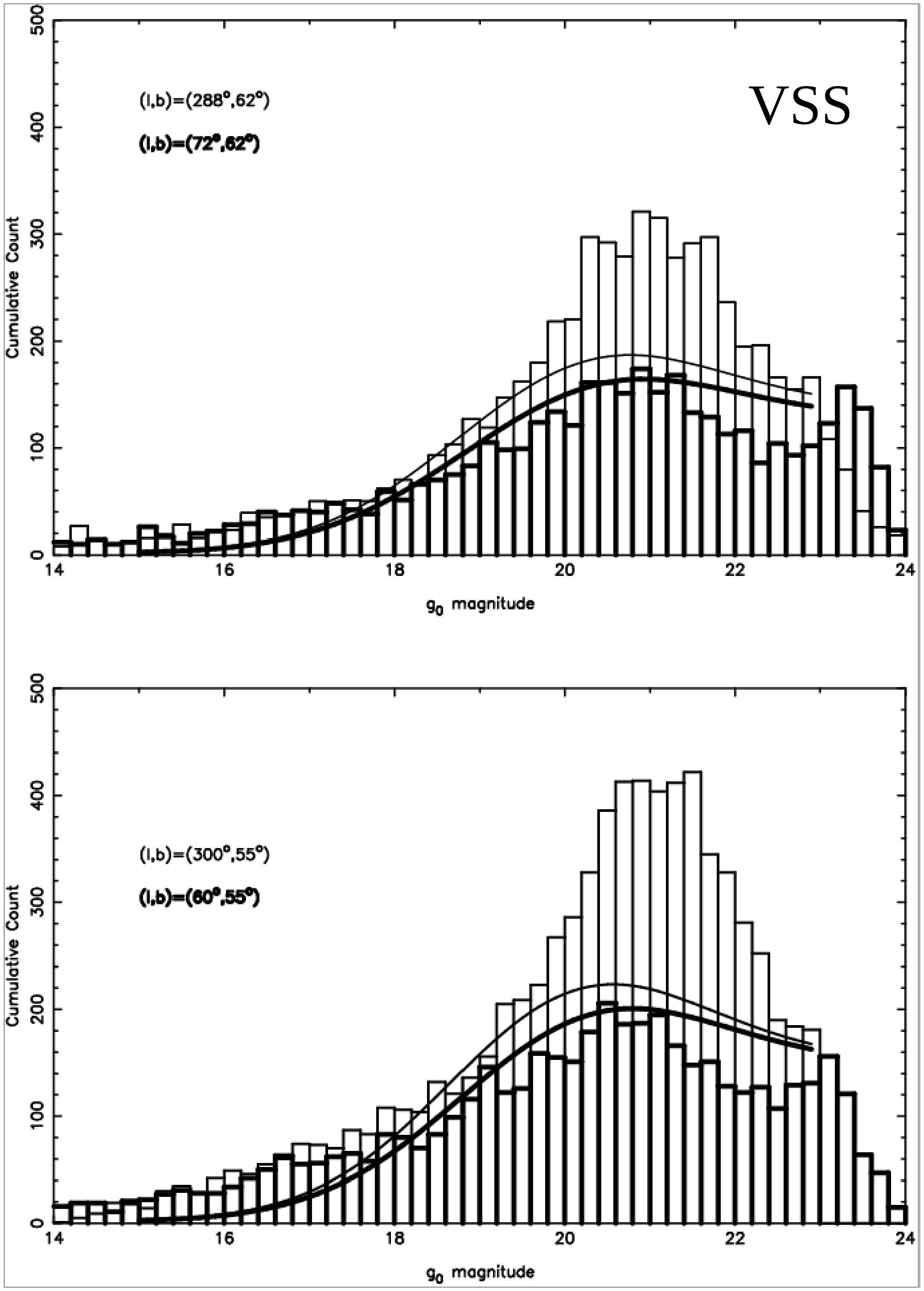


Newberg, Yanny et al., submitted

Asymmetry of Spheroid

The next three slides show the magnitude distribution of F turnoff stars in two directions in Virgo compared to directions with the same Galactic latitude but with Galactic longitude that is symmetric about the Galactic center. In a smooth symmetric spheroid the number counts in these directions should be the same.

We show that the current asymmetric spheroid models do not fit S297+63-20.5, but they can explain the wings of the S297+63-20.5 distribution that extend over many magnitudes and half the sky. We will later show that spectroscopy identifies a moving group in the center of S297+63-20.5, and supports that the asymmetry at brighter magnitudes is not due to this moving group.



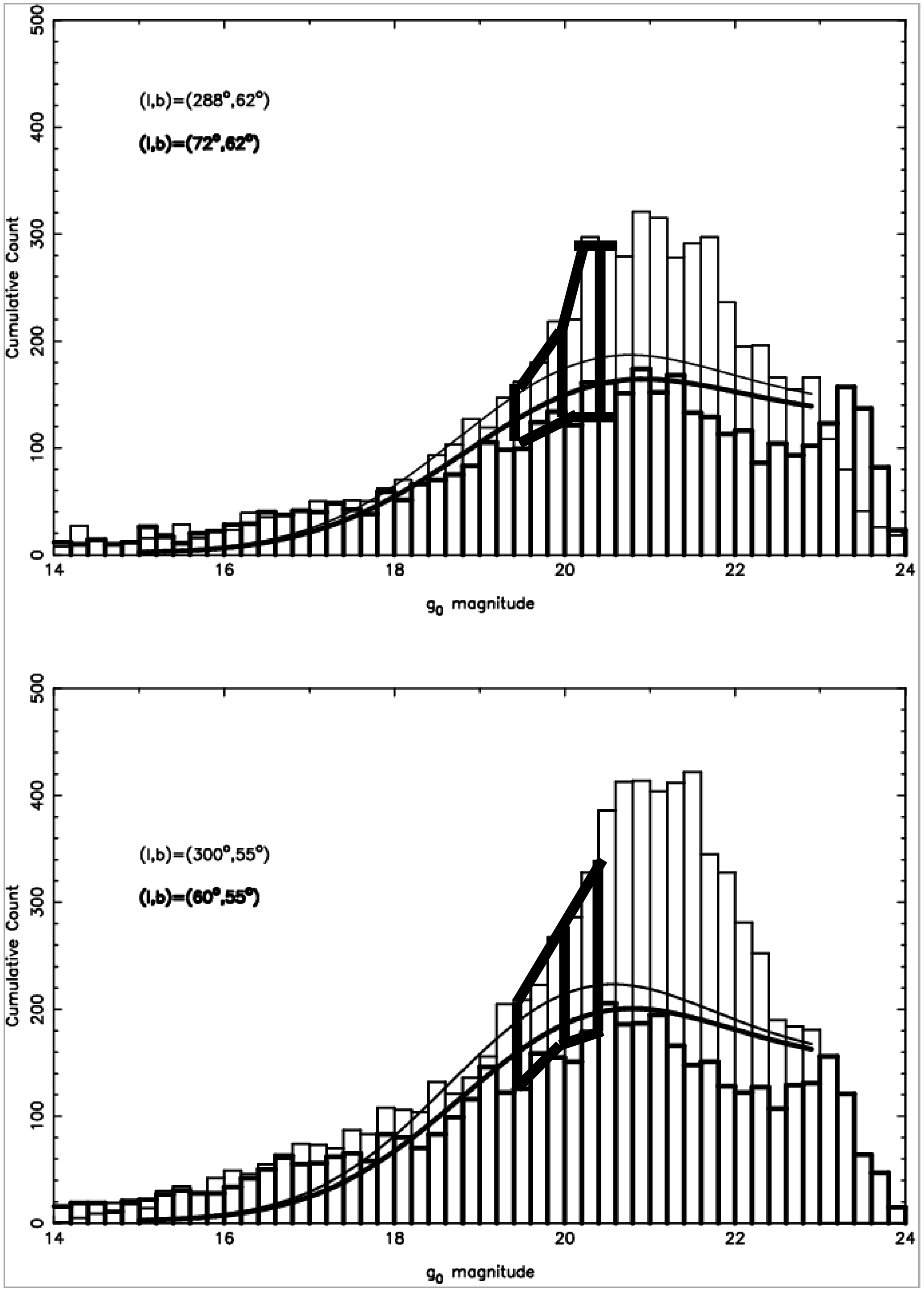
Newberg, Yanny et al., submitted

Counts of F turnoff stars with $0.2<(g-r)_0<0.4$.

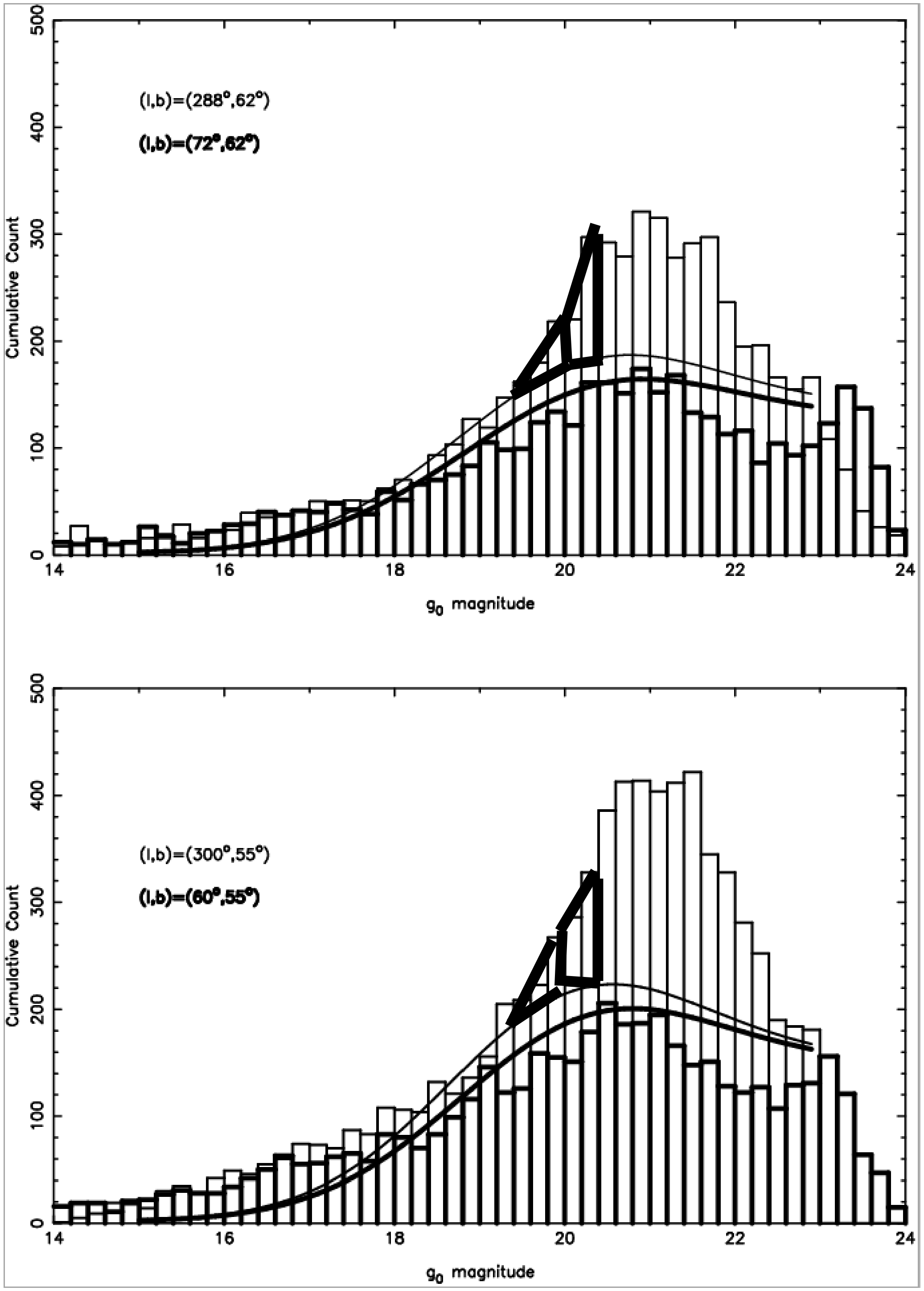
We compare one sight line in Virgo with the symmetric point with respect to the Galactic center. In a symmetric spheroid, the star counts in the two directions should be the same.

Models are Galactocentric triaxial Hernquist profiles.

Newberg, Yanny et al., submitted



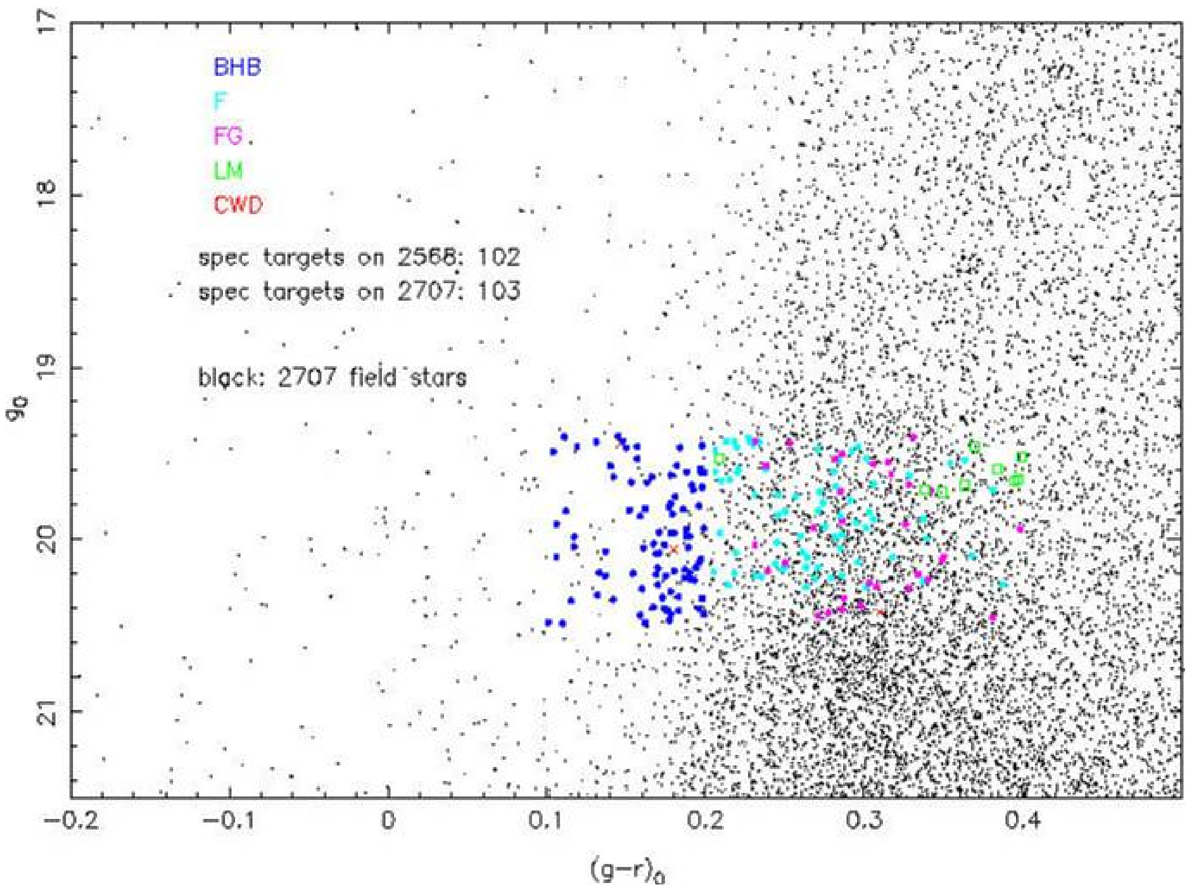
In a symmetric spheroid, we expect **37±4%** of the stars with $19.4<g_0<20.0$ to have coherent velocities, an **46±5%** of the stars with $20.0<g_0<20.3$ to have coherent velocities.



Newberg, Yanny et al., submitted

In a triaxial spheroid, we expect **11%** of the stars with $19.4<g_0<20.0$ to have coherent velocities, an **36%** of the stars with $20.0<g_0<20.3$ to have coherent velocities.

Newberg, Yanny et al., submitted



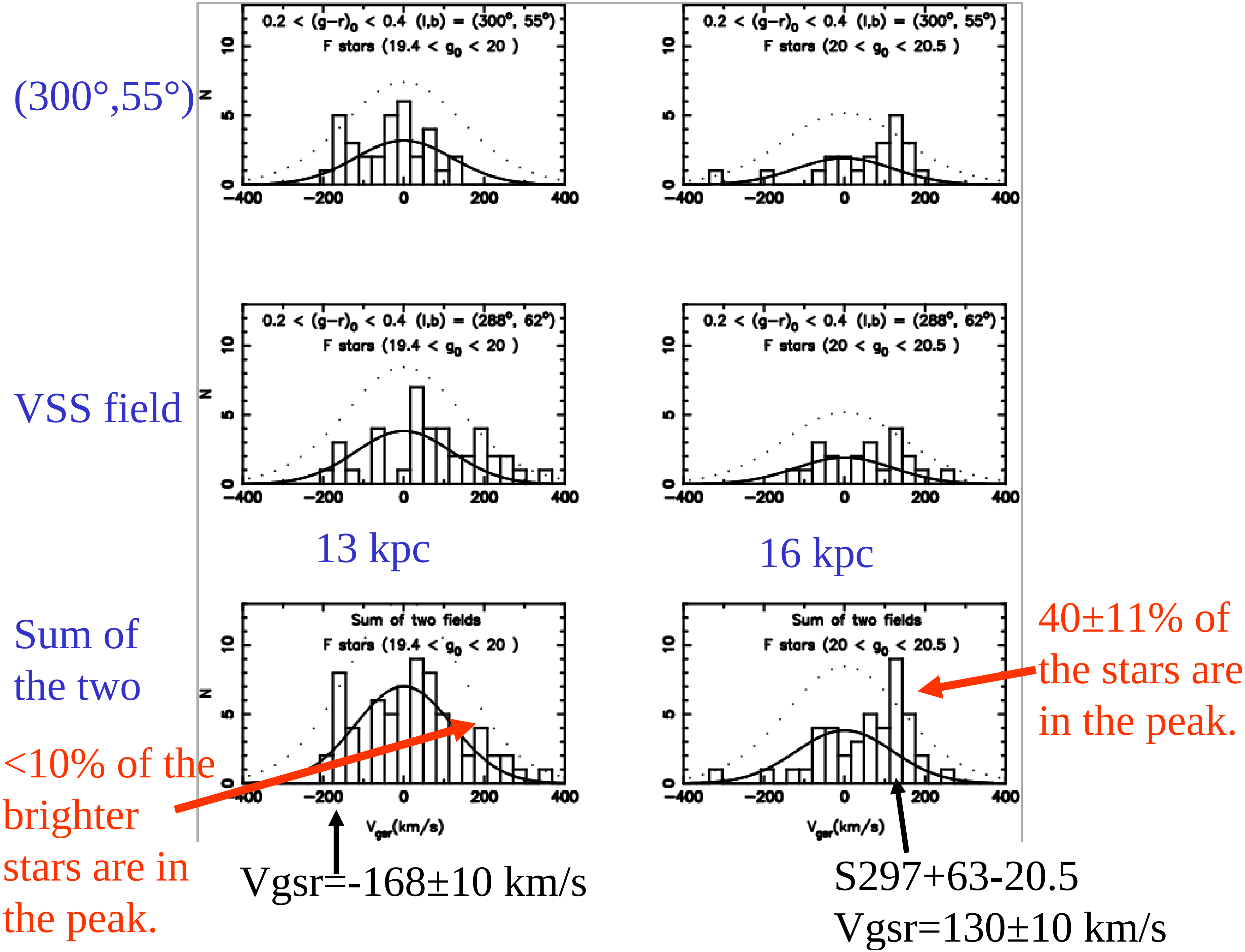
Note that the distribution of SEGUE spectra is uniform over color and magnitude, and does not follow the density of stars in the Galaxy. We have to be careful to select spectra in a narrow color bin, and not rely on the fact that the density at (g-r)=0.3 is much higher than at (g-r)=0.2.

Spectra in Virgo

We show histograms of the Vgsr velocities in two SEGUE plates in the same directions that we just showed apparent magnitude distributions. We identify a strong velocity peak in the fainter, redder set of spectra, that is similar to that of the VSS.

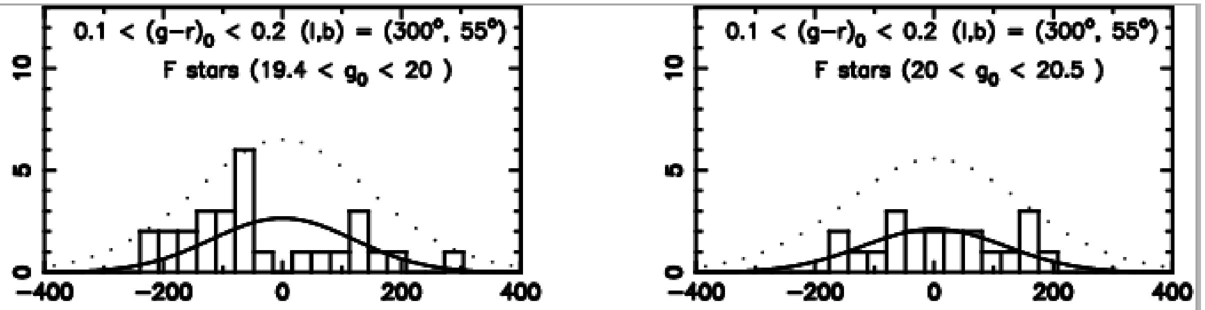
There are a few other smaller peaks, including one for the brighter, bluer stars that is at about the same velocity as the stars LJM 2005 attribute to Sagittarius.

The S297+63-20.5 moving group is not observed in the brighter set of stars, which supports the idea of a non-axisymmetric spheroid.

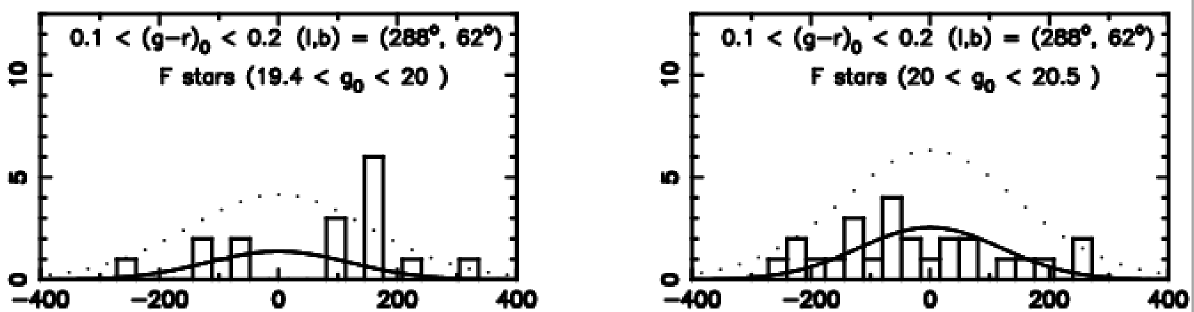


(300°,55°)
VSS field
Sum of the two
0.2 < (g−r)0 < 0.4 (l,b) = (300°, 55°)
F stars (19.4 < g0 < 20)
F stars (20 < g0 < 20.5)
0.2 < (g−r)0 < 0.4 (l,b) = (288°, 62°)
13 kpc
16 kpc
Sum of two fields
Vgsr(km/s)
N
40±11% of the stars are in the peak.
<10% of the brighter stars are in the peak.
Vgsr=-168±10 km/s
S297+63-20.5
Vgsr=130±10 km/s

(300°,55°)



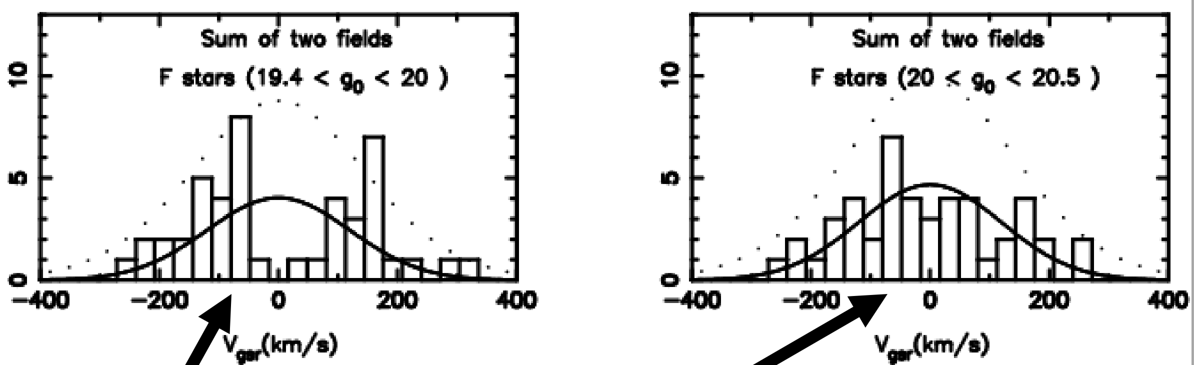
VSS field



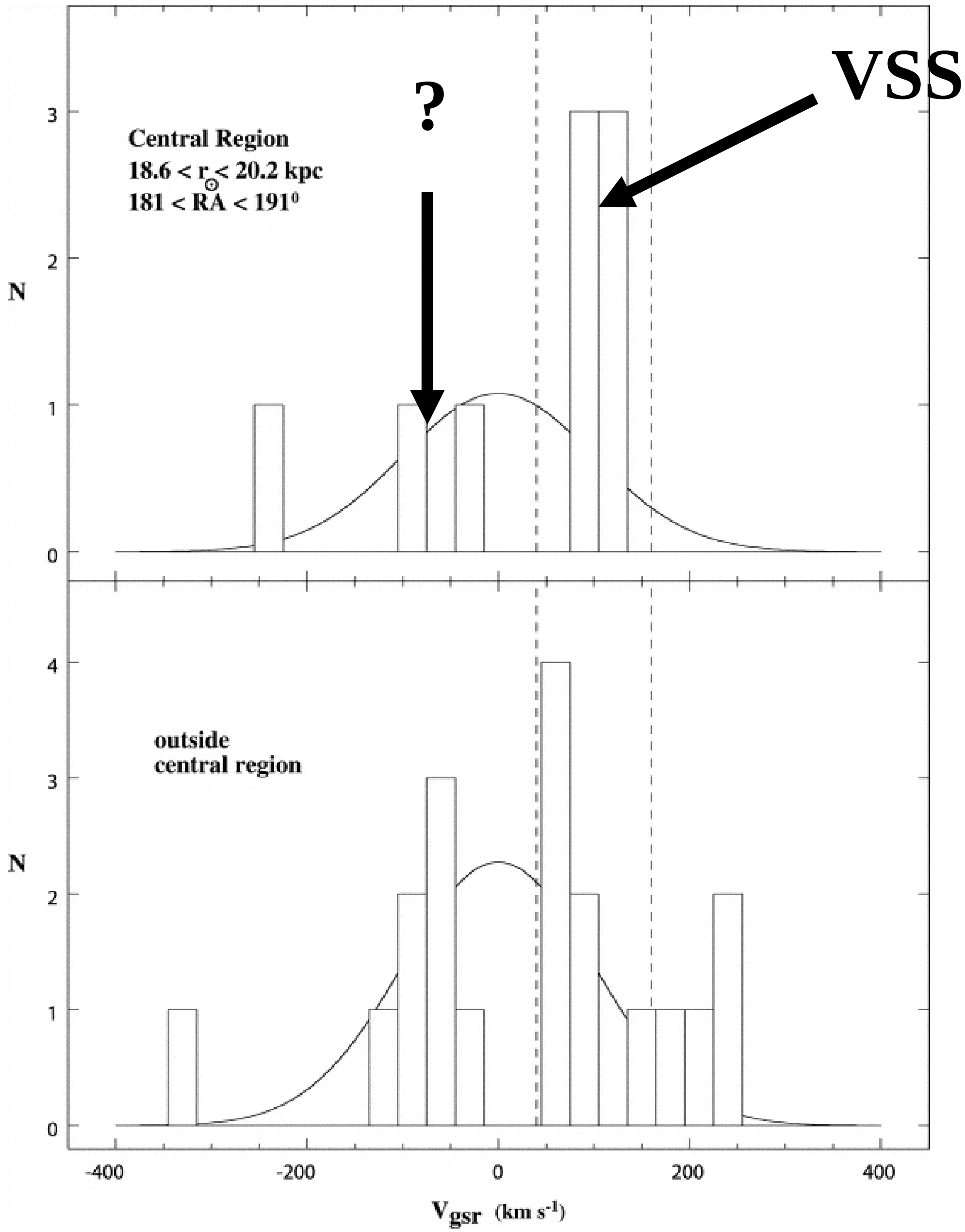
13 kpc

16 kpc

Sum of the two



Vgsr=76±10 km/s

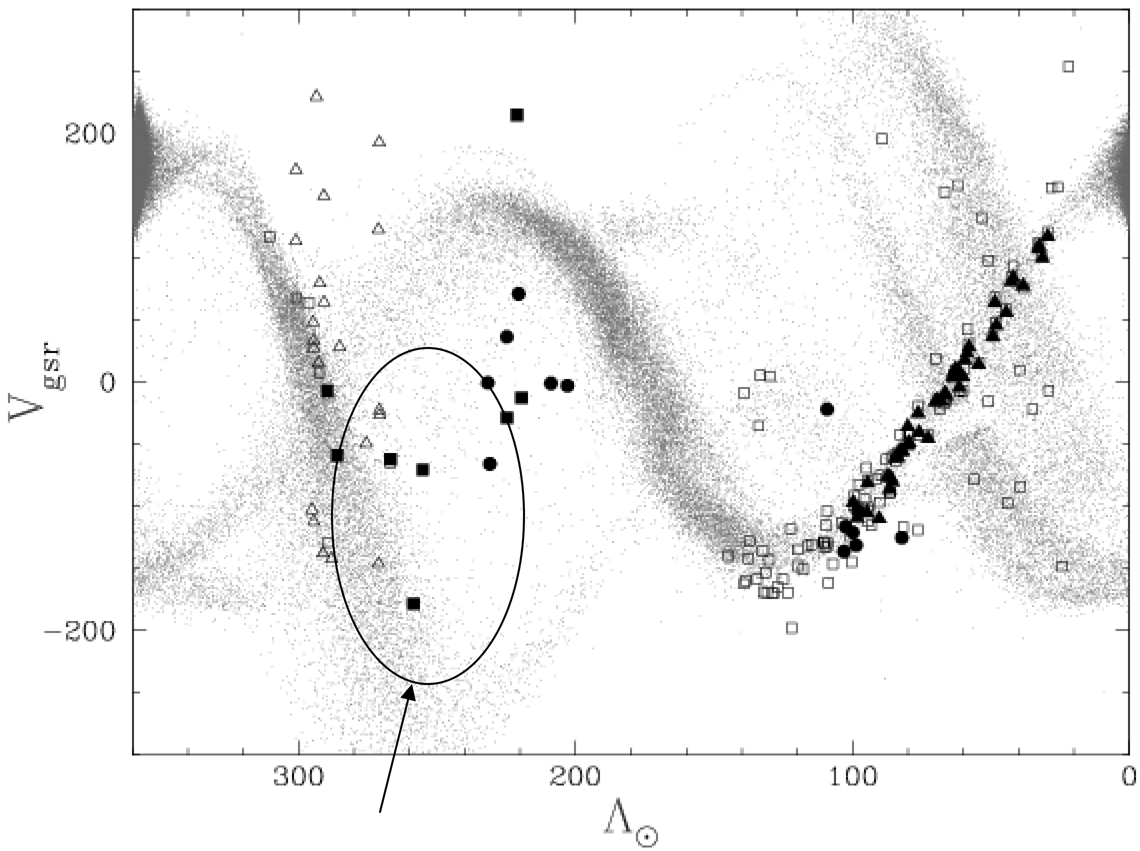


This distribution is not well fit by a Gaussian. It looks more like two peaks. The positive peak at 100 km/s is the VSS, and the negative velocity peak is similar to the velocities of the stars identified in this region by LJM 2005.

Duffau et al. 2006

Monaco et al. 2006

New data (filled symbols) overlaid on
Law et al. oblate halo disruption model



Virgo region

Note that Monaco et al. 2006 identify Sgr stars at substantially lower
Vgsr than LJM (2005) in the Virgo region, along with some stars that are about the
same Vgsr, but do not fit the model.

Conclusion

(1) S297+63-20.5 is probably the same thing as the VOD, probably related to the VSS, and probably not related to the Sgr dwarf tidal tails.

(2) The line-of-sight velocity of S297+63-20.5 is V_{gsr}=130±10 km/s. The velocity width and thickness from photometry is consistent with tidal debris.

(3) The Sgr dwarf leading tidal tail misses the Sun by over 15 kpc. We question whether the closest 2MASS M giant stars that appear to be falling down on the solar position are the same as the Sgr tidal stream models with which they are being compared

(4) The coherent moving group in S297+63-20.5 does not explain the entire surplus of stars in quadrant IV over quadrant I. It is suggested that the spheroid component is asymmetric about the Galactic center.

(5) There is extra structure in all of the density and radial velocity plots that we show.