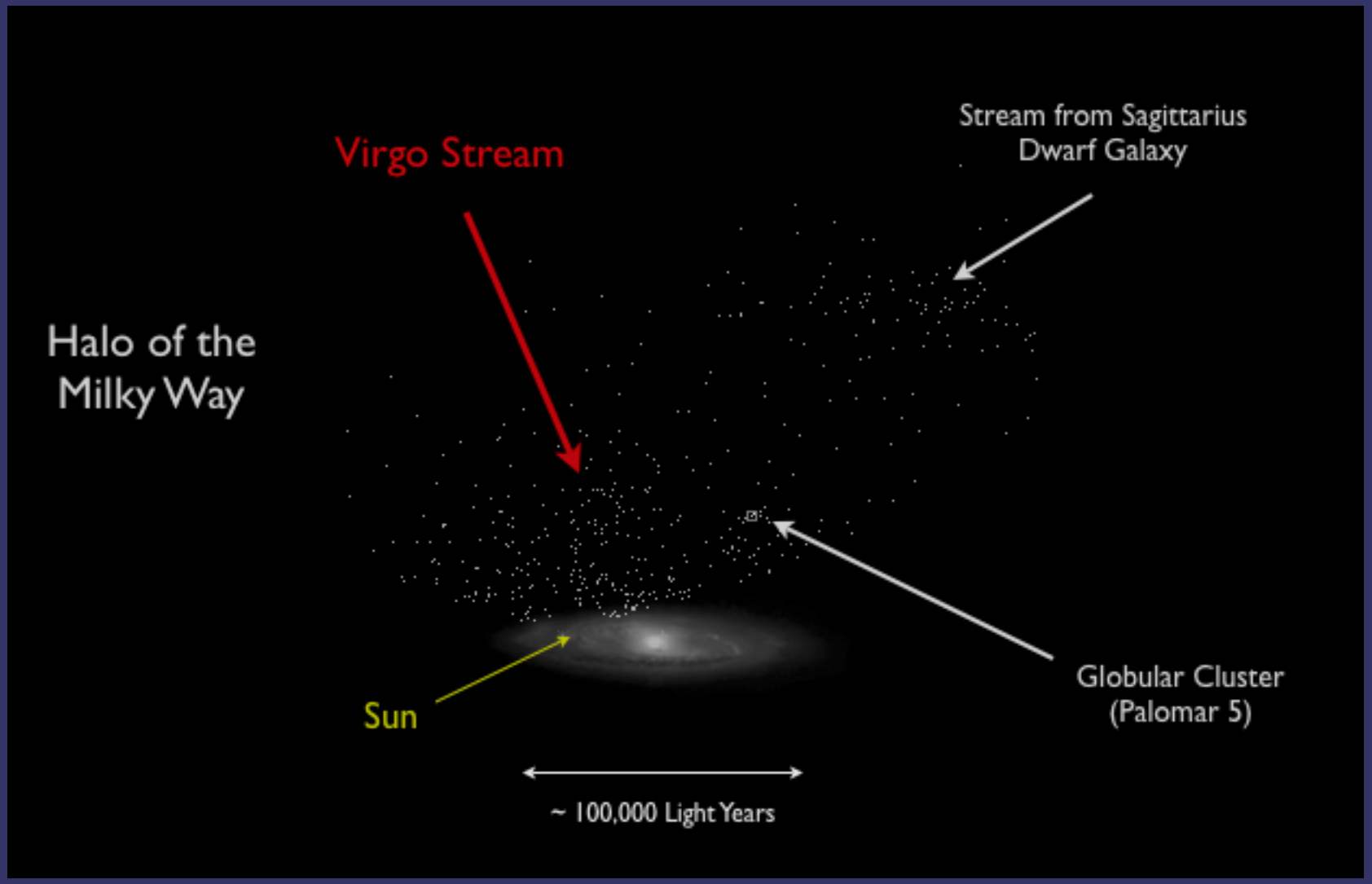


THE QUEST RR LYRAE SURVEY AND HALO SUB-STRUCTURE

Kathy Vivas (CIDA, Venezuela), Bob Zinn (Yale U., USA), Sonia Duffau (U. de Chile), Yara Jaffé, Jesús Hernández, Yolimar Subero (CIDA, Venezuela), G. Carraro (Padova, Italy), R. Méndez (U. de Chile), C. Gallart (IAC, Spain), R. Winnick (Yale U., USA)

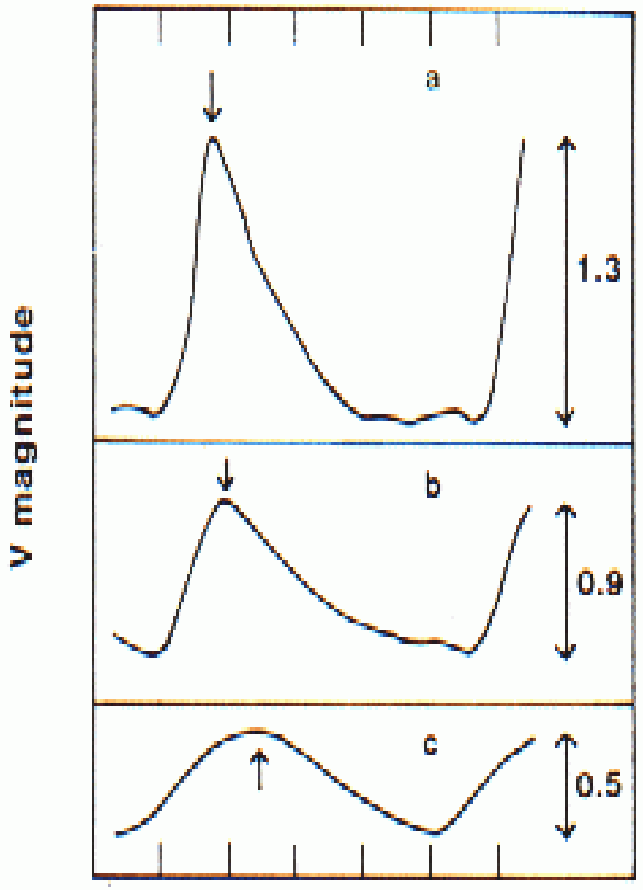
How Good of a Tracer are the RR Lyrae Stars?

RR Lyrae stars are powerful probes of the halo because:

- They are excellent STANDARD CANDLES
- They are old stars (Age> 9Gyr)
- They are giant, bright stars
- They are easy to recognize by their large variability and characteristic light curves.

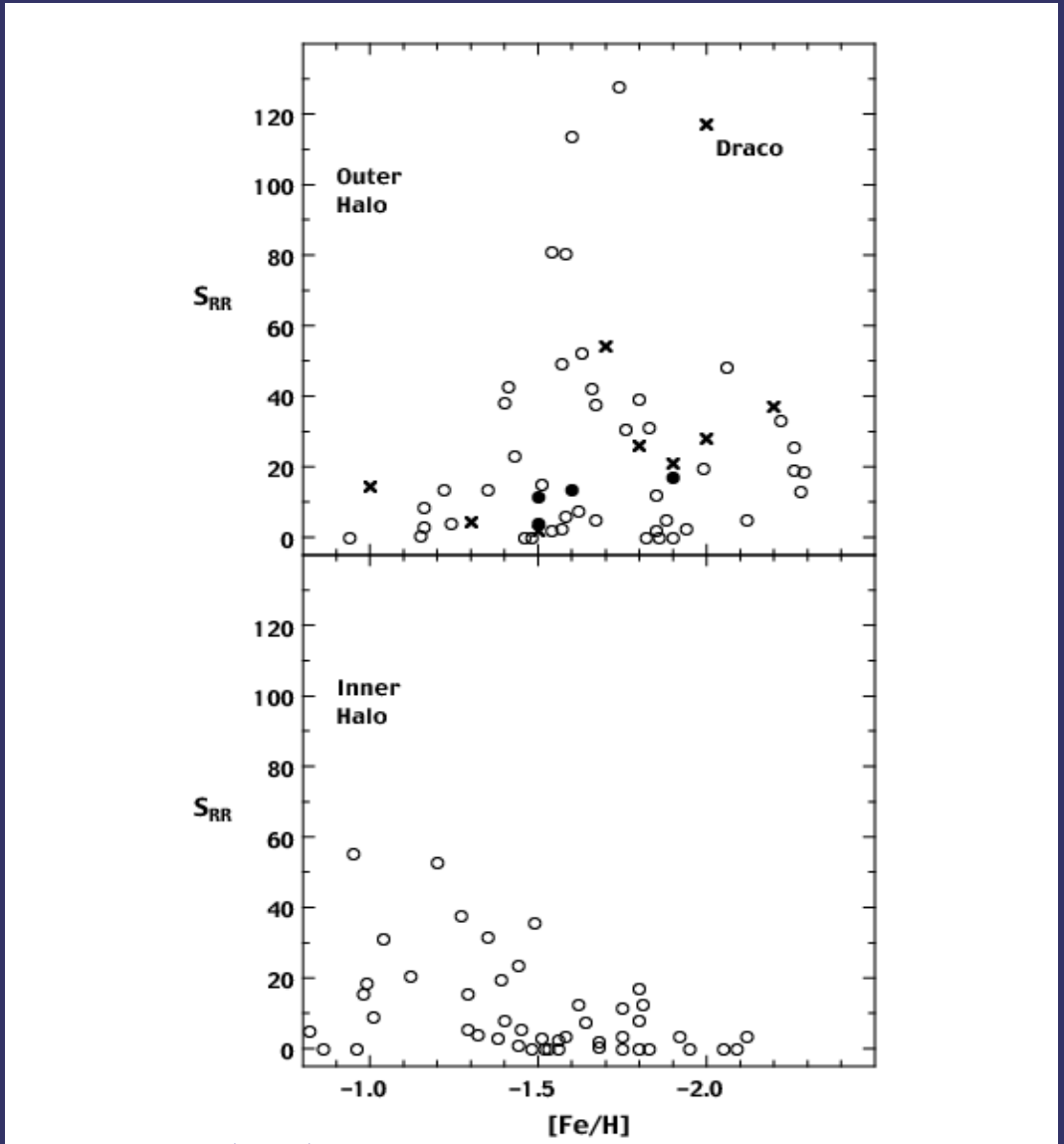
But...

The population of RR Lyrae stars depends on the morphology of the horizontal branch



Smith (1995)

How Good of a Tracer are the RR Lyrae Stars?



Vivas & Zinn (2006)

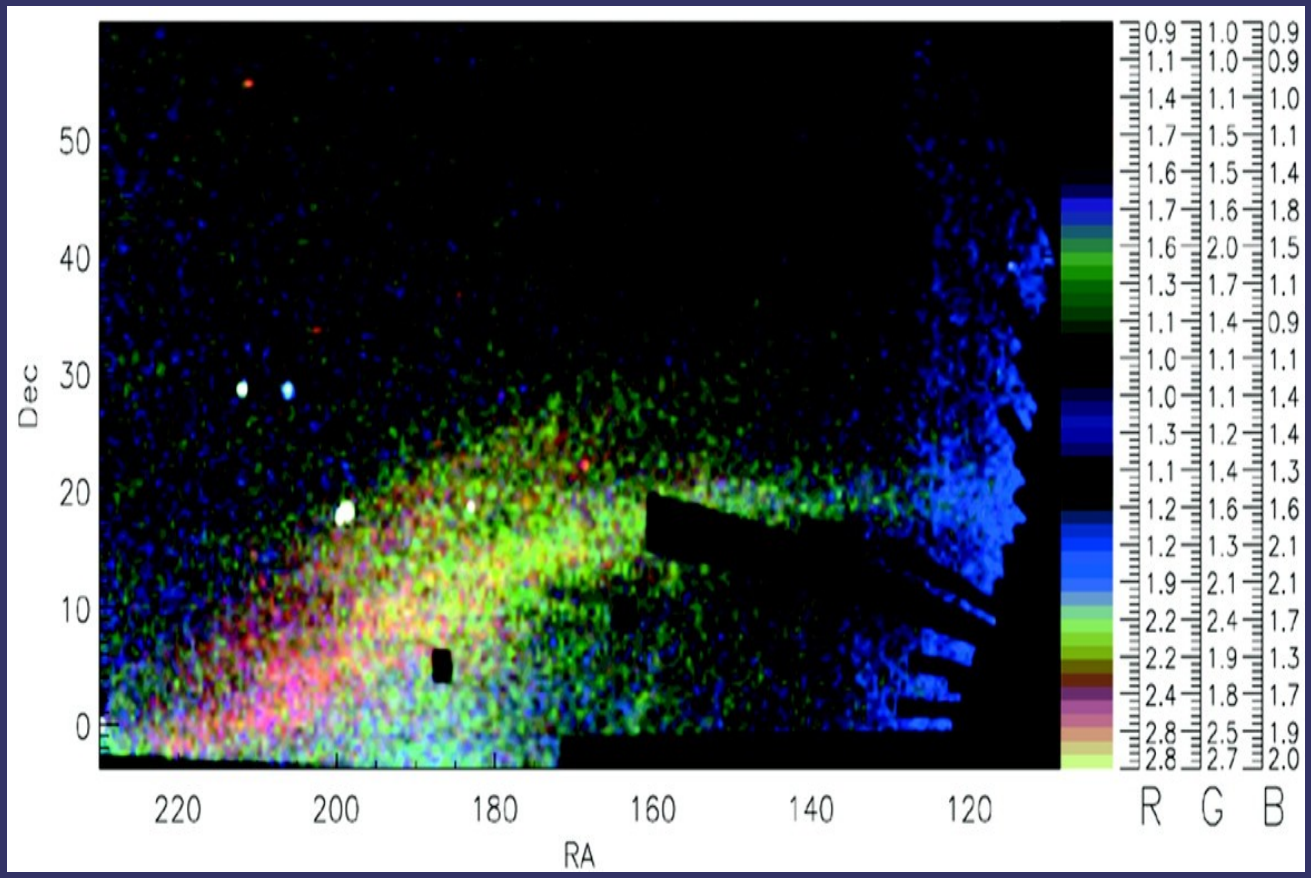
Specific frequency of RR Lyrae stars as a function of the metallicity

o -- Globular Clusters
x -- MW dSph Galaxies
• -- M31 dSph Galaxies

All dSph galaxies have $S_{RR}>0$

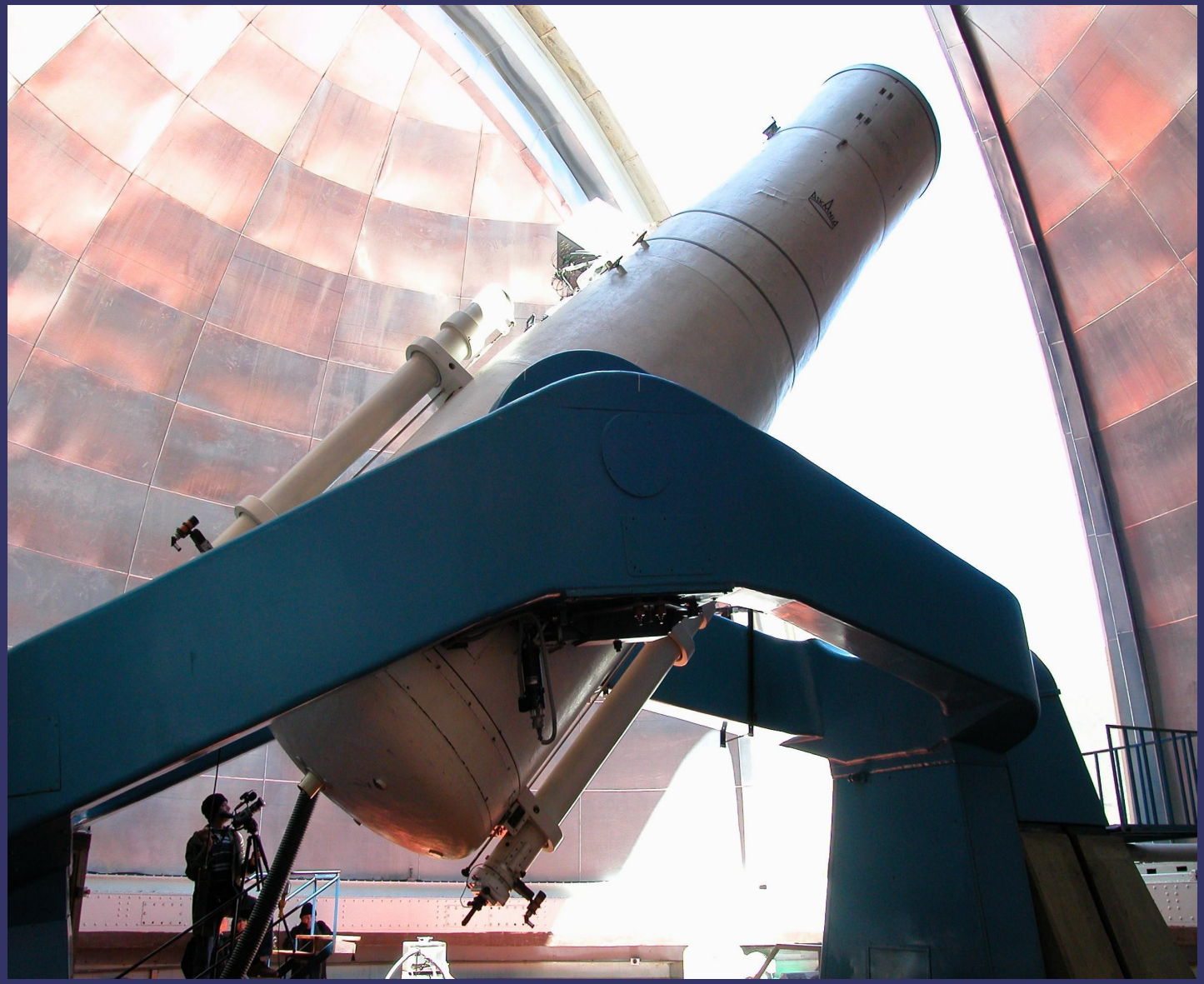
Surveys for RR Lyrae stars in the halo are good for detecting stellar streams or debris from destroyed satellite galaxies.

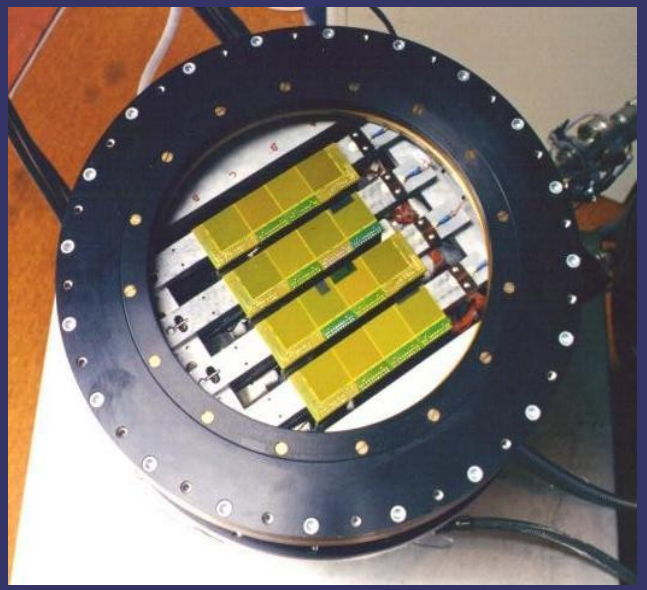
Other surveys, other tracers



SDSS upper main sequence and turnoff stars (Belokurov et al 2006)

The QUEST Survey

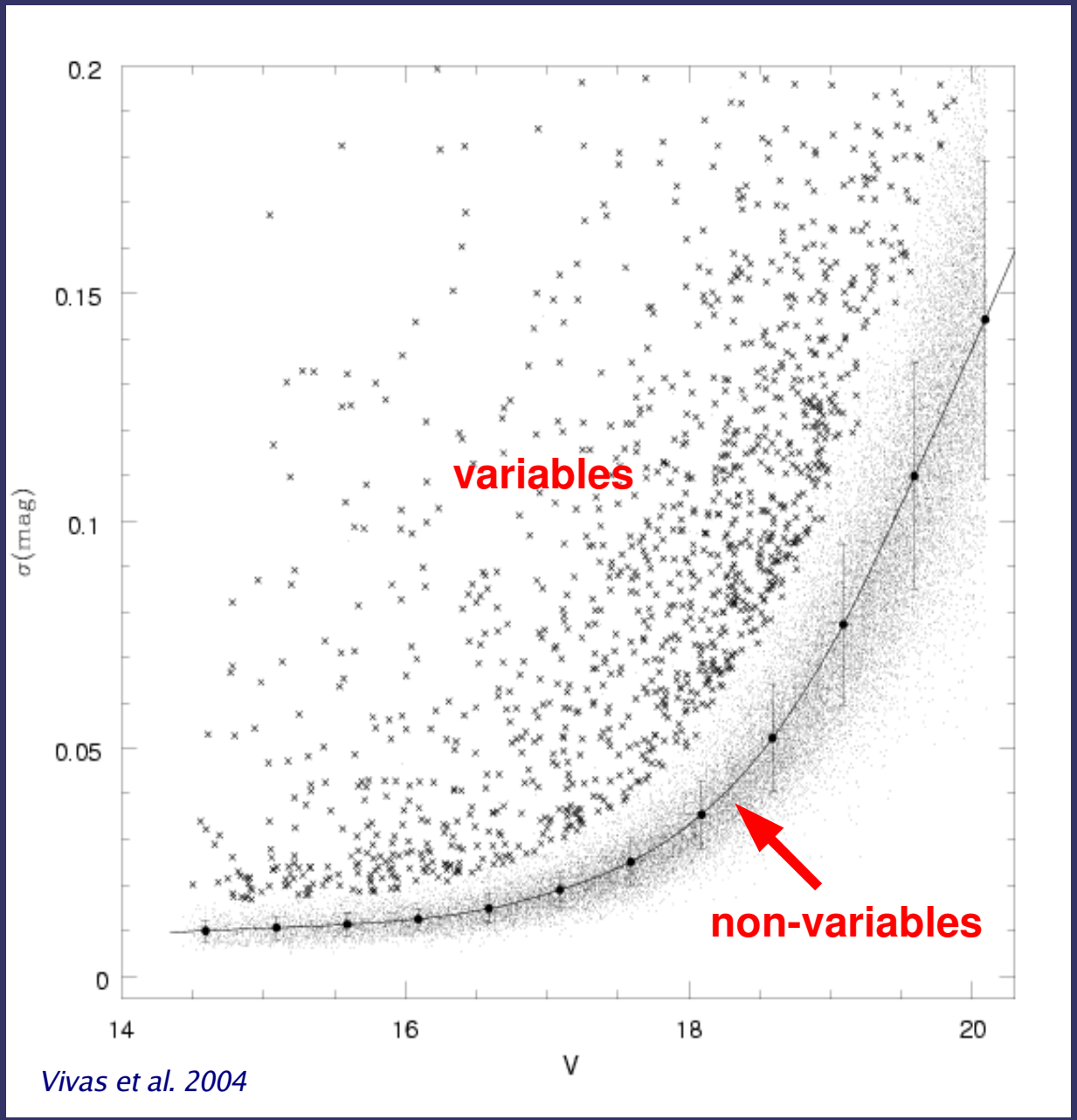




The 64 megapixel QUEST camera (built by Yale, CIDA and Indiana, *Baltay et al. 2002*)

The 1m. Jürgen Stock Telescope at the Venezuelan National Observatory of Llano del Hato

The QUEST Survey



Vivas et al. 2004

Photometric errors:
~0.01 @ V=14-17
~0.1 @ V=19.5

Distances from 4 to 60 kpc

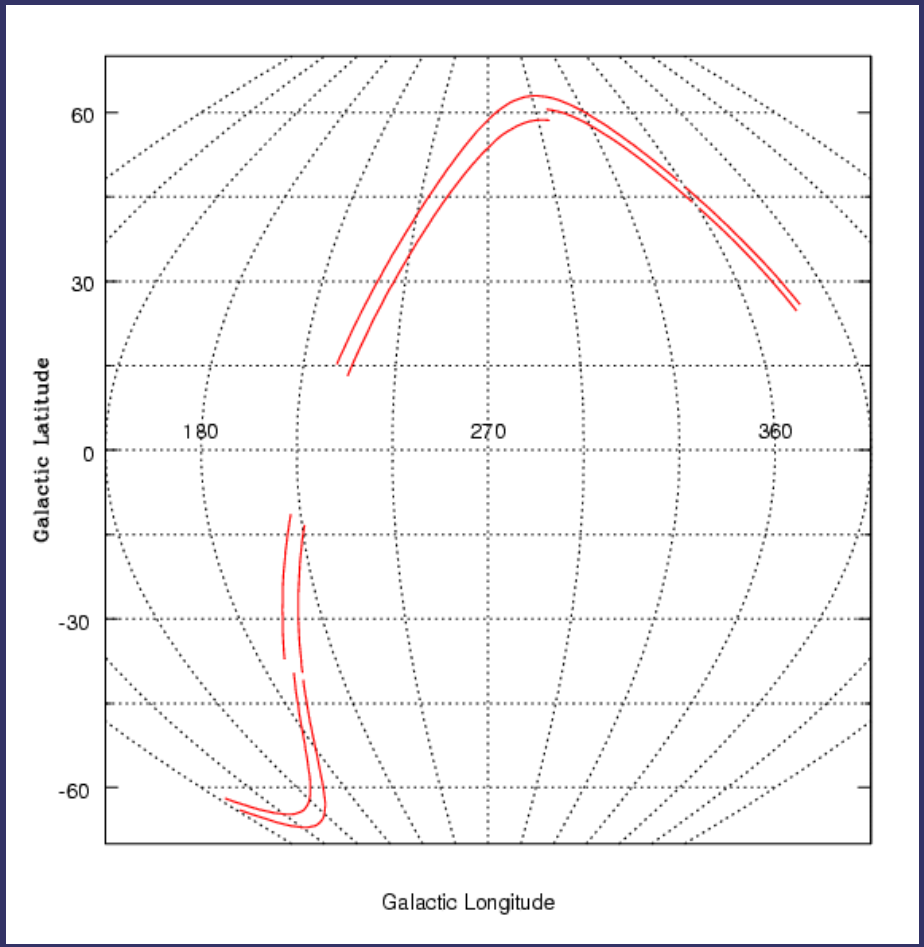
30 to 60 epochs in ~3 years

RR Lyrae stars are recognized by their light curves

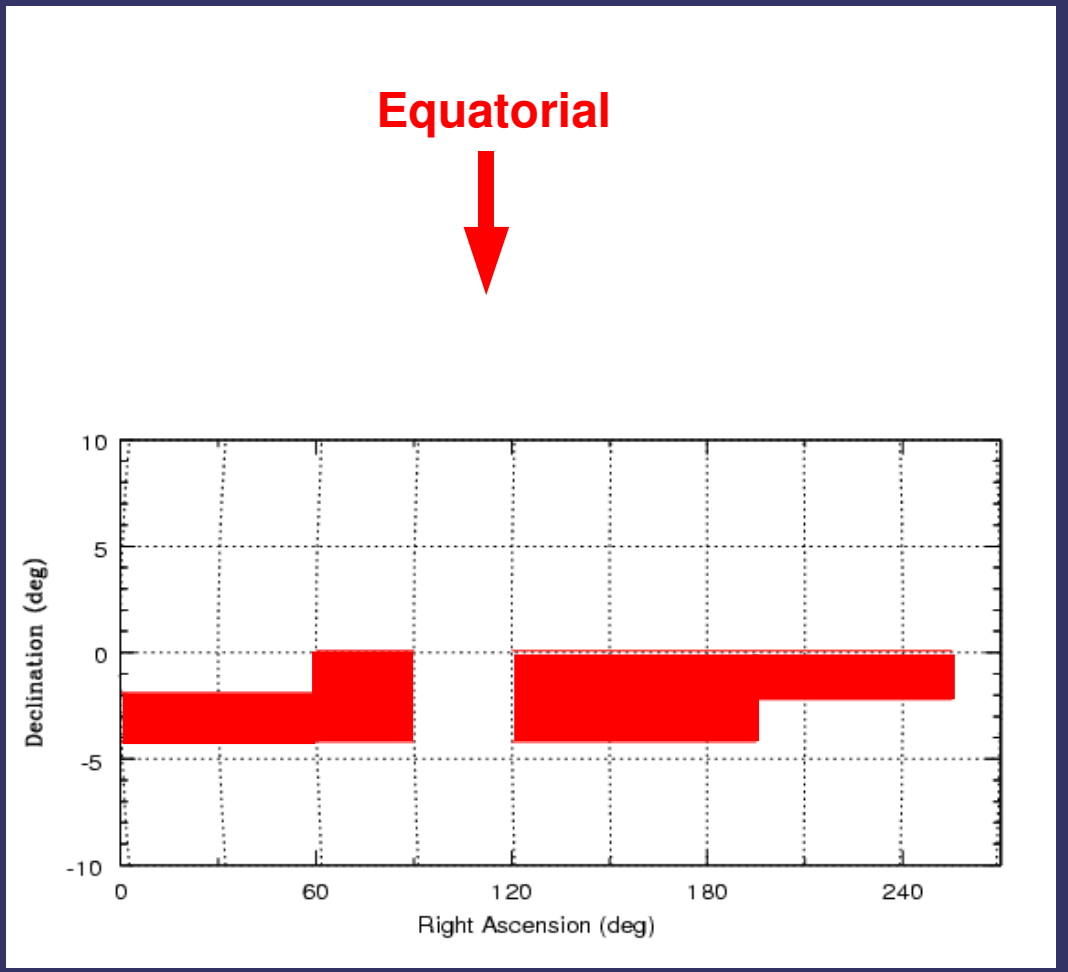
The Observed Region

700 sq degrees of the equatorial sky

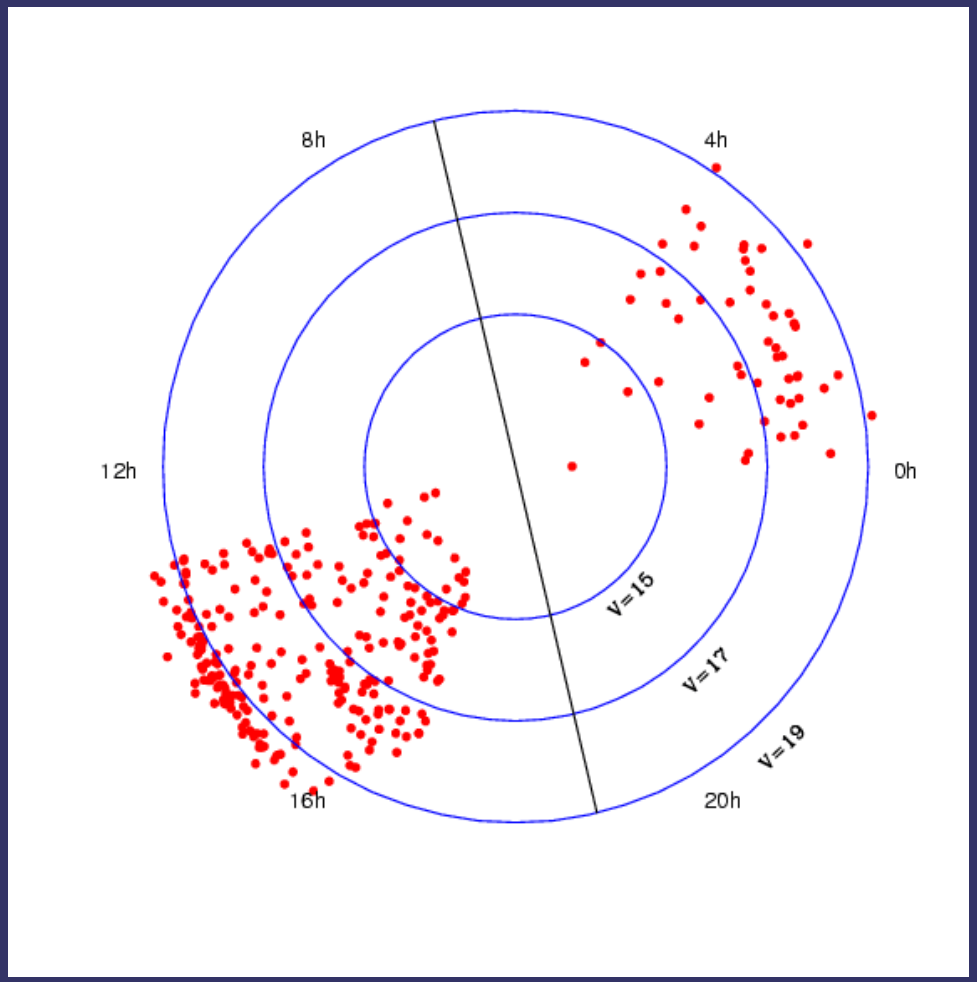
Galactic



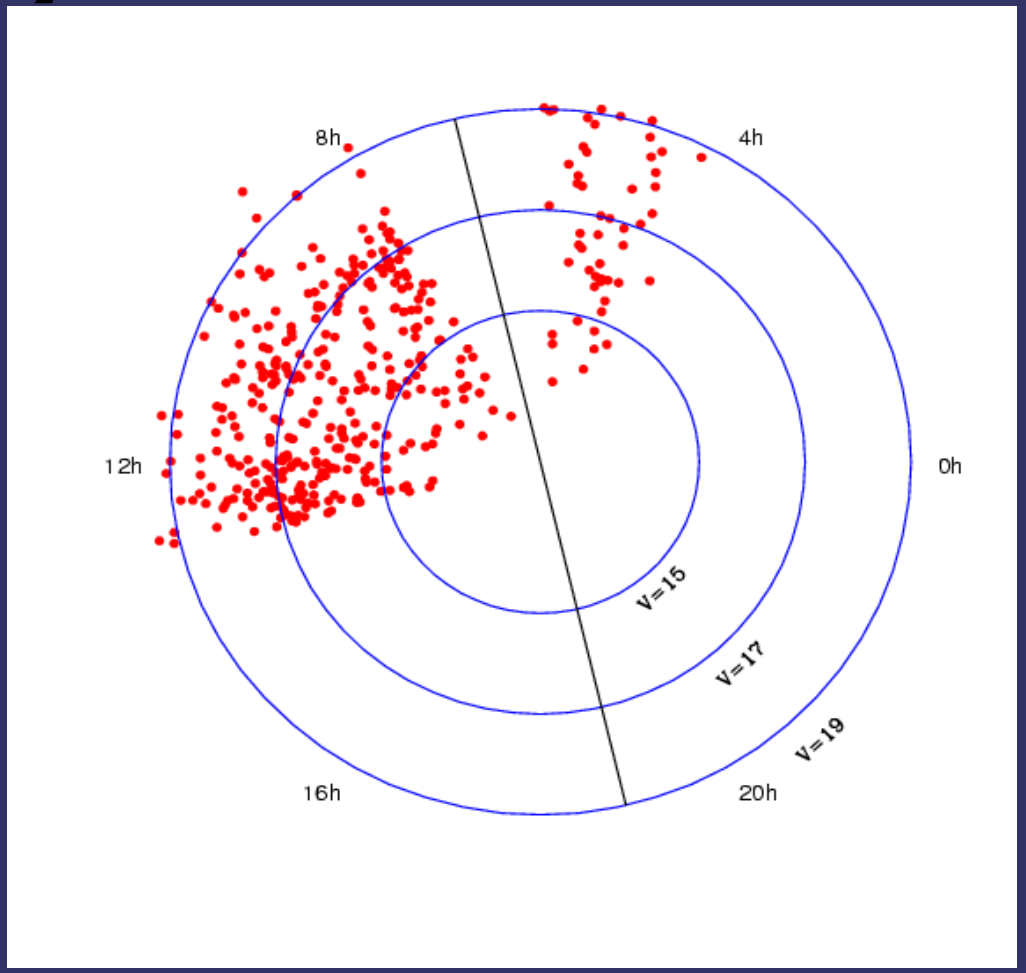
Equatorial



Results from the Photometric Survey

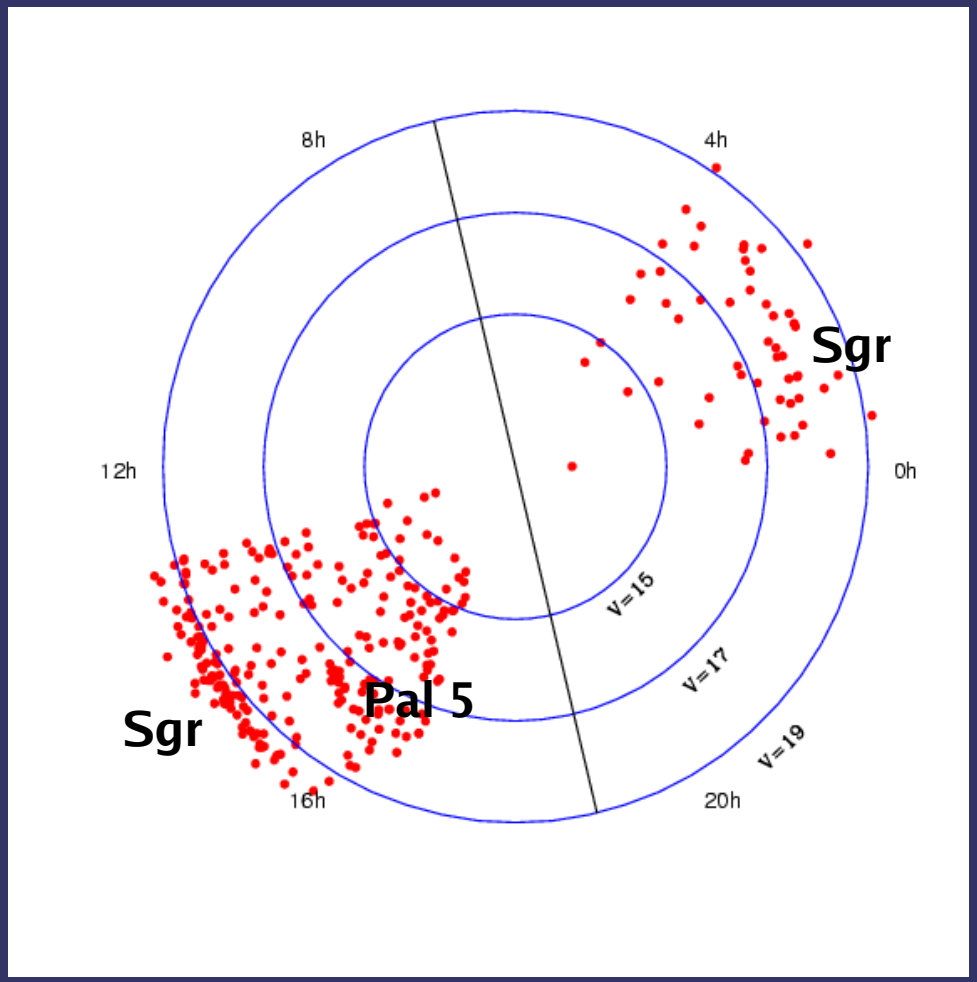


Spatial distribution of QUEST RR Lyrae stars in a **2.4-wide** strip of the sky

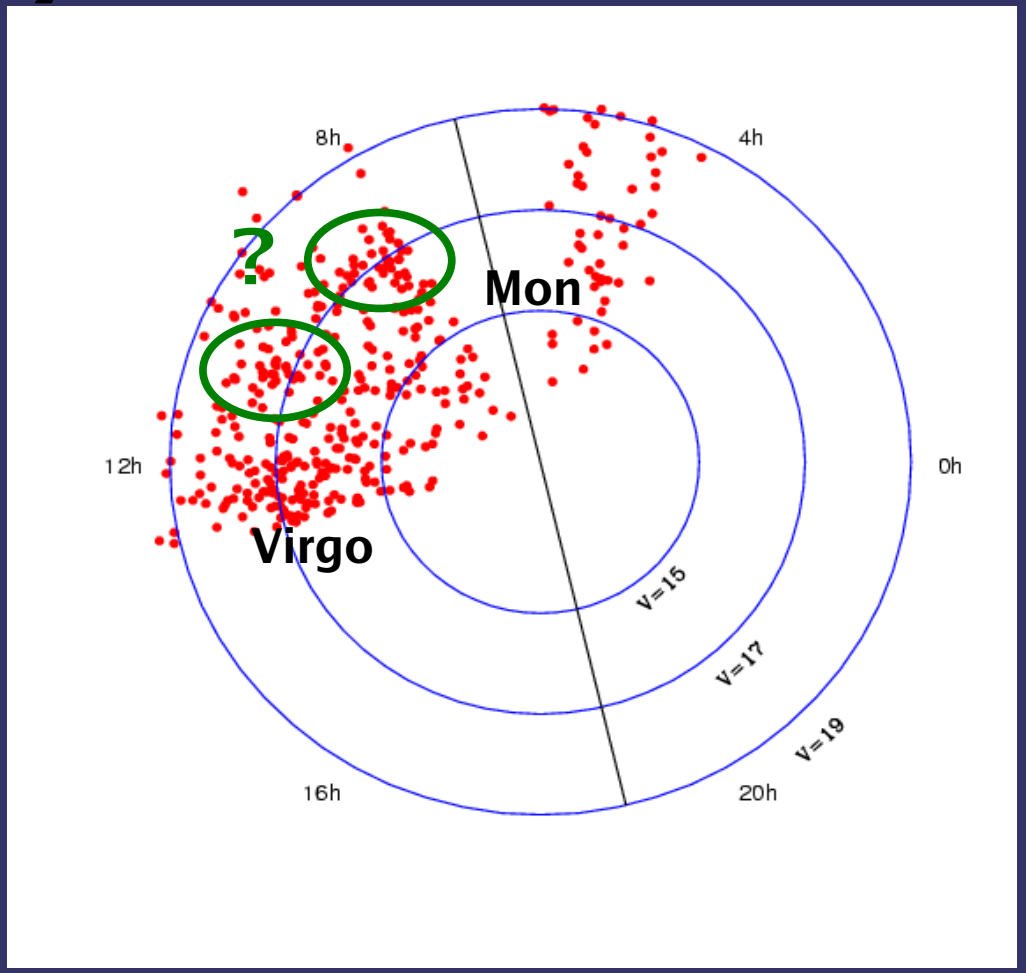


4.2-wide strip of the sky

Results from the Photometric Survey



Spatial distribution of QUEST RR Lyrae stars in a **2.4-wide** strip of the sky

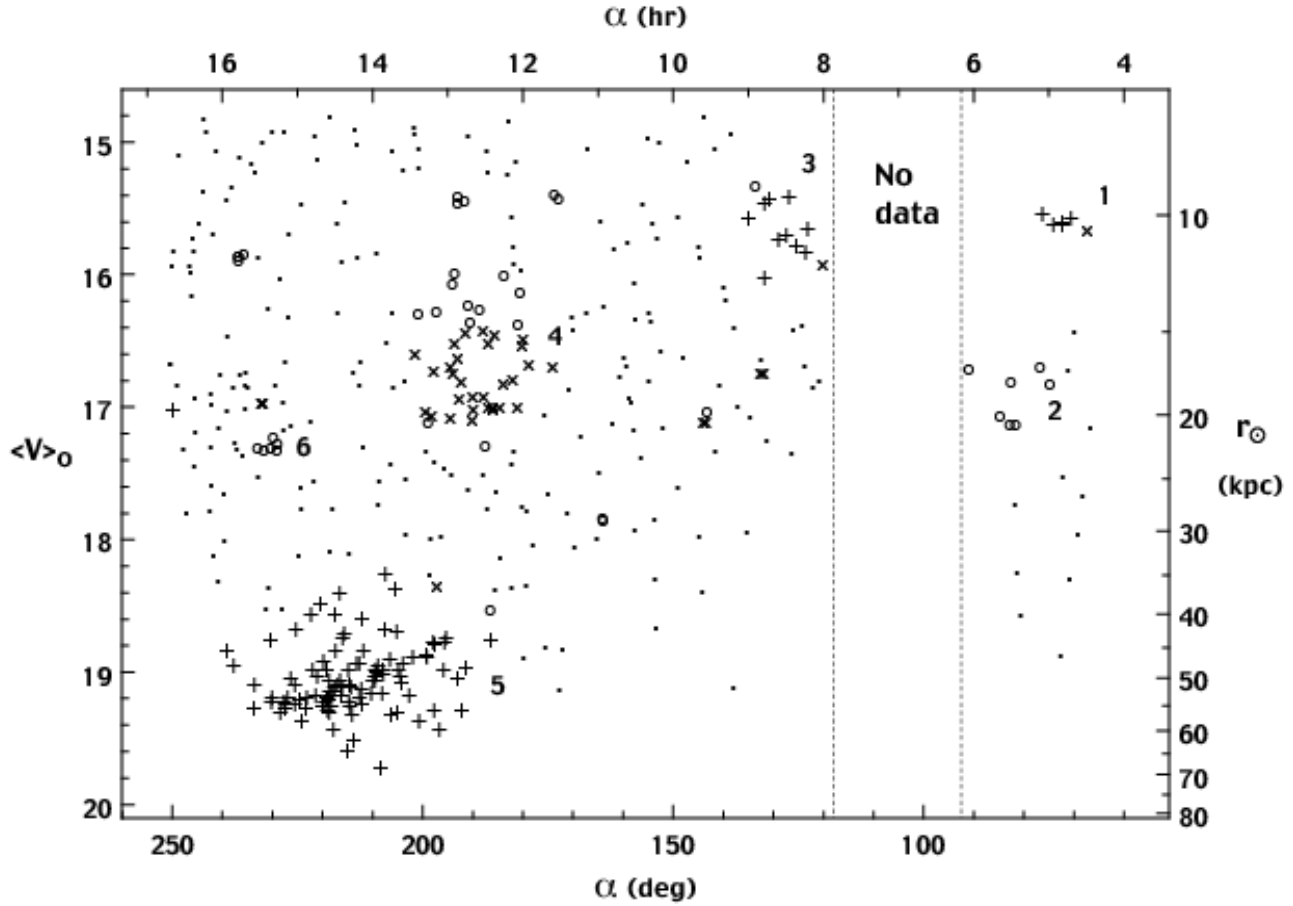


4.2-wide strip of the sky

Detecting Structures in the Halo

In the first part of the survey, several groups were recognized as statistically significant.

The different symbols indicate high (+), medium (x) and low (o) probability of being a real group.



QUEST data

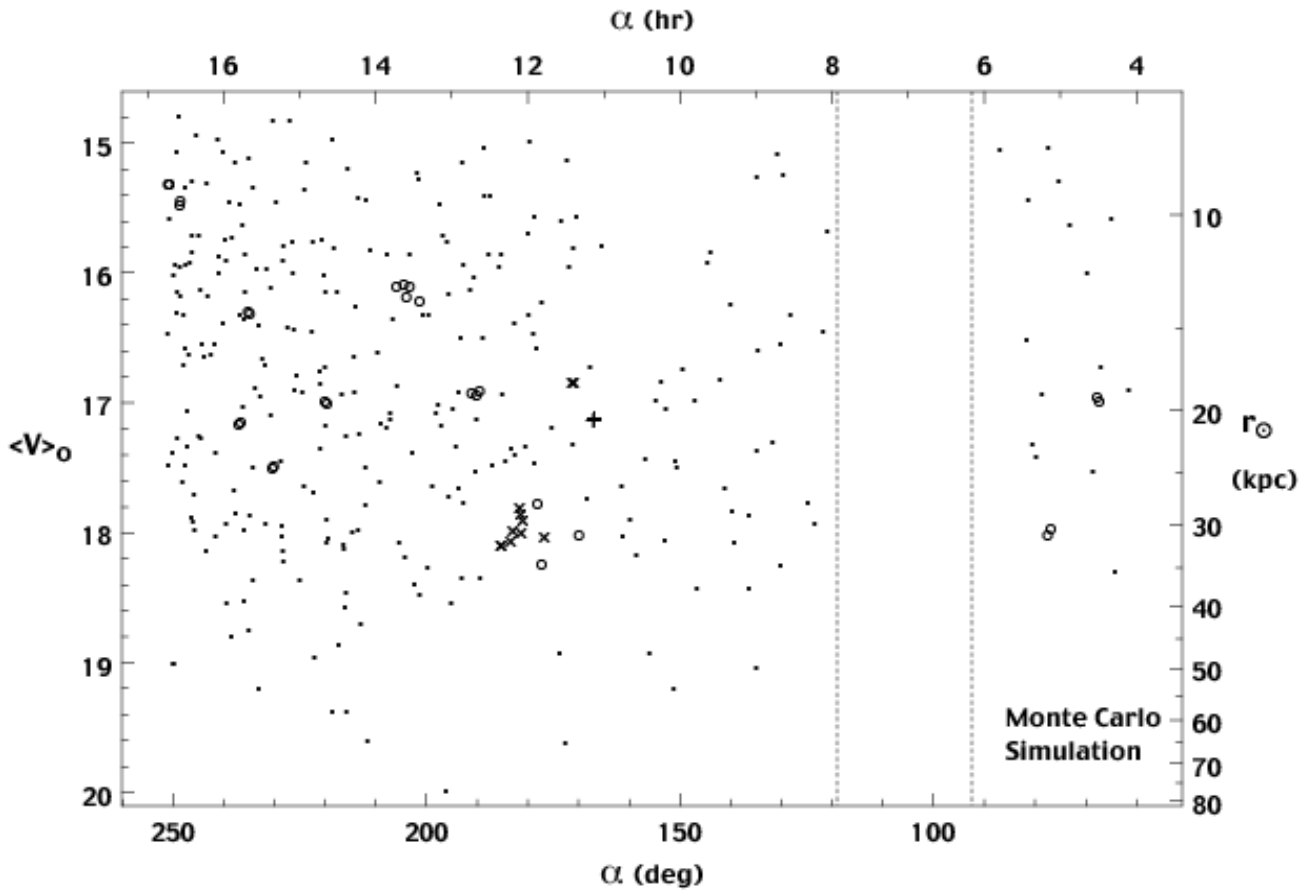
Vivas & Zinn (2006)

The Need for an Additional Parameter

Random fluctuations alone may produce significant groups.

Radial velocities are needed to confirm the smaller groups.

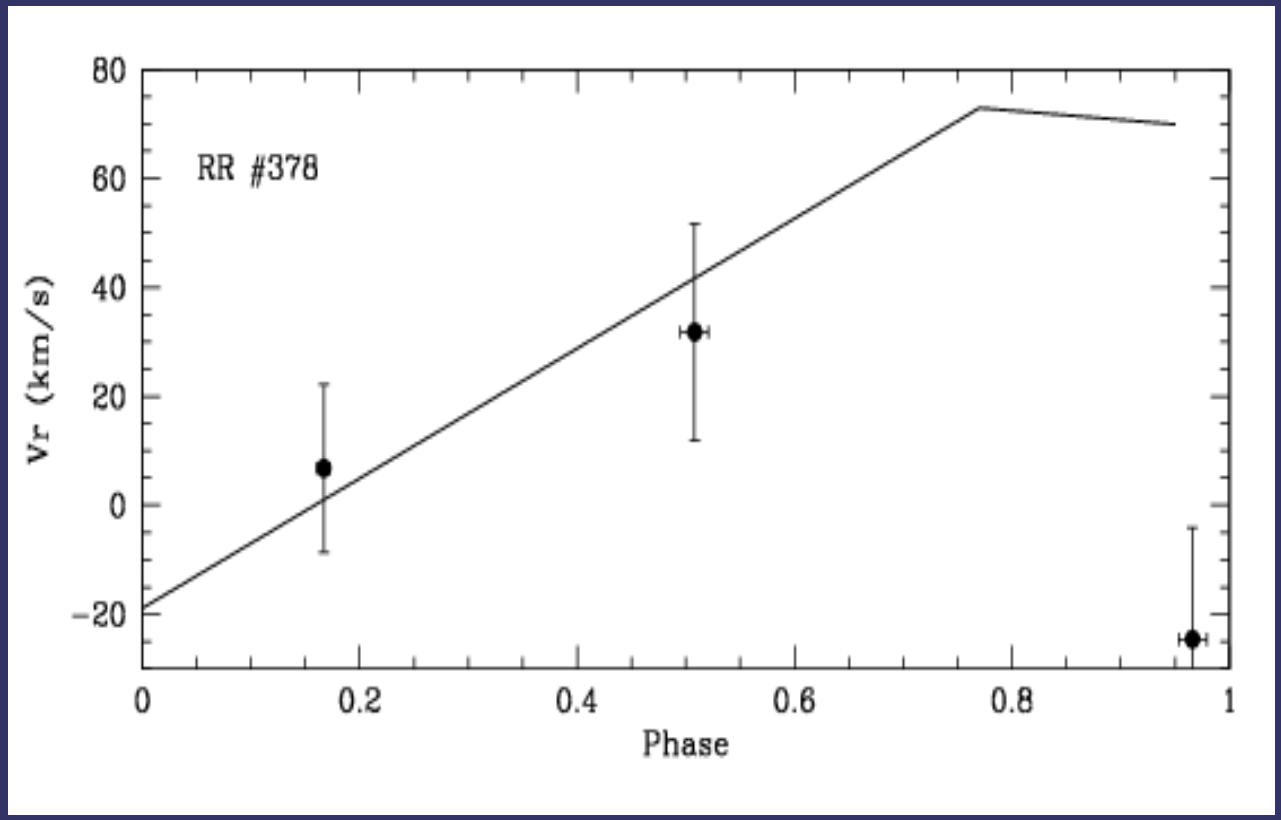
In addition, spectroscopy provides metallicities, which may give some insight on the origin of the groups.



Monte Carlo Simulation

Vivas & Zinn (2006)

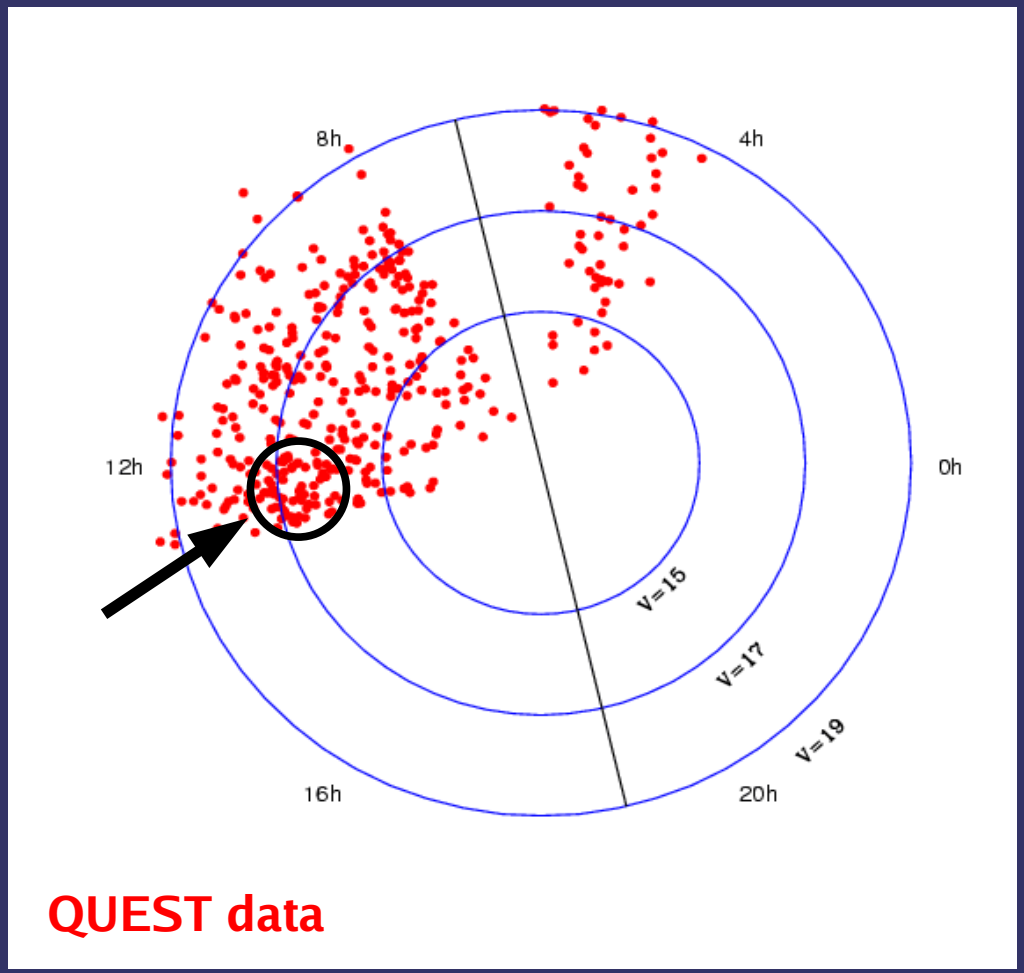
Radial Velocities



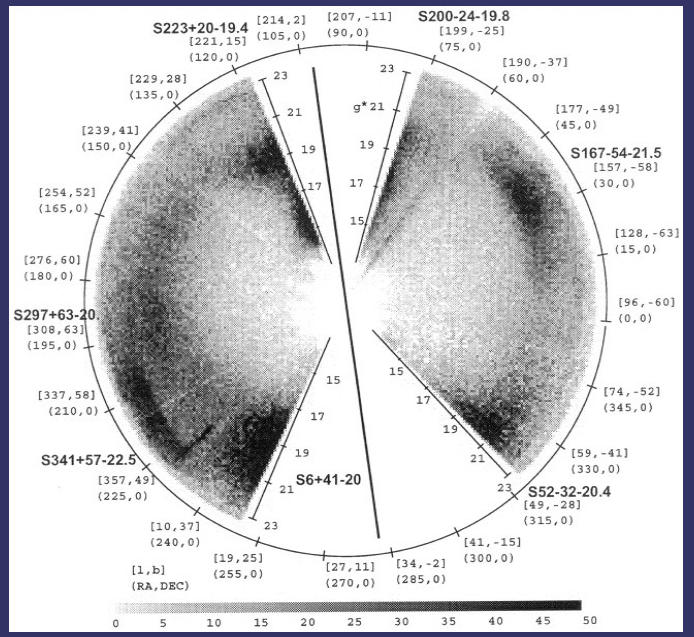
A large number of QUEST RR Lyrae stars have been observed spectroscopically using telescopes in Chile and the US.

The pulsation of the RR Lyrae stars changes the velocity of the star for up to 100 km/s . It is necessary to fit a radial velocity curve to isolate the systemic velocity.

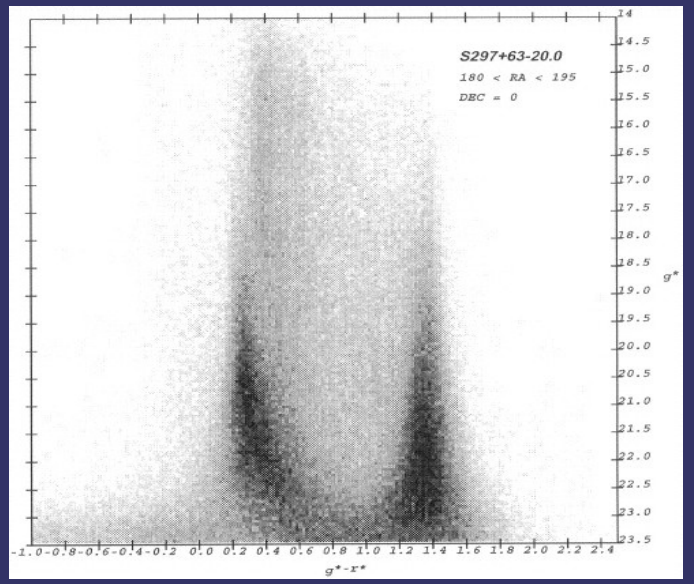
The Virgo Stellar Stream



QUEST data



SDSS Data

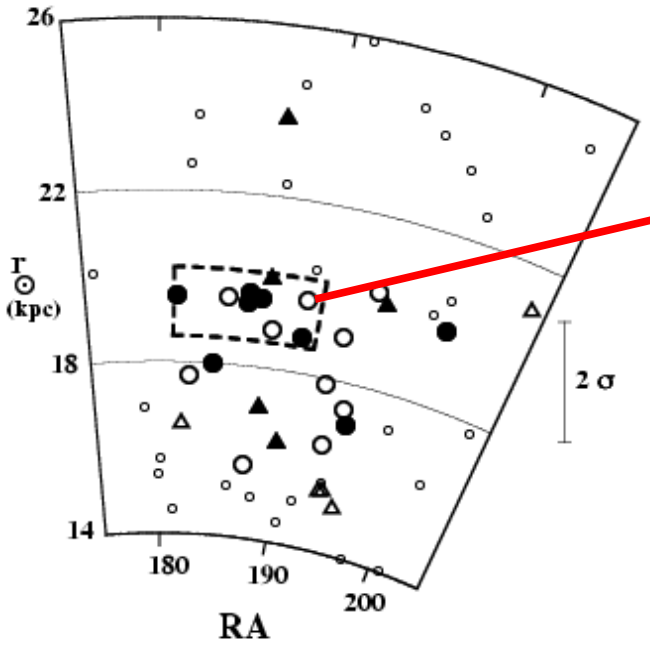


Overdensity of RR Lyrae stars (also seen with SDSS turnoff stars) at ~20 kpc from the Sun, in the direction of Virgo.

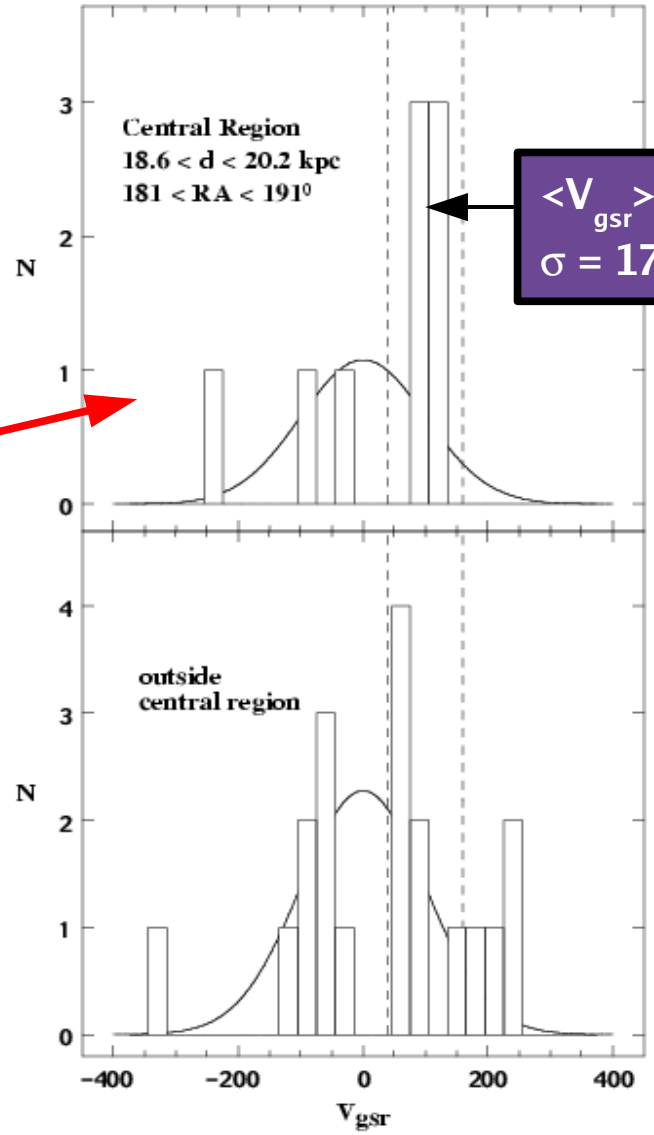
Newberg et al (2002)

The Virgo Stellar Stream

QUEST RR Lyrae (circles) and SDSS BHB (triangles) in the region of the overdensity.
Large symbols have spectra.



Velocity Distribution



<V_{gsr}>=100 km/s
σ = 17 km/s

BHB stars from Sirko et al. (2004)
Plots from Duffau et al. (2006)

The Virgo Stellar Stream

Mean metallicity of 7 RR Lyrae (type ab) in the group:

[Fe/H] = -1.86

σ = 0.40

- The dispersion in metallicity is too large for being a destroyed globular cluster
- The SDSS CMD (*Newberg et al 2002*) does not show any sign of significant intermediate age population
- There are no carbon stars associated with this structure
- Although models of the Sgr tidal tails (*Law et al. 2005, Martínez-Delgado et al. 2004*) predict stars in this region, neither the density of RR Lyrae stars nor the velocity of the group are compatible

Likely, the VSS is debris from a destroyed galaxy whose population was mostly old

Is the VSS = VOD?

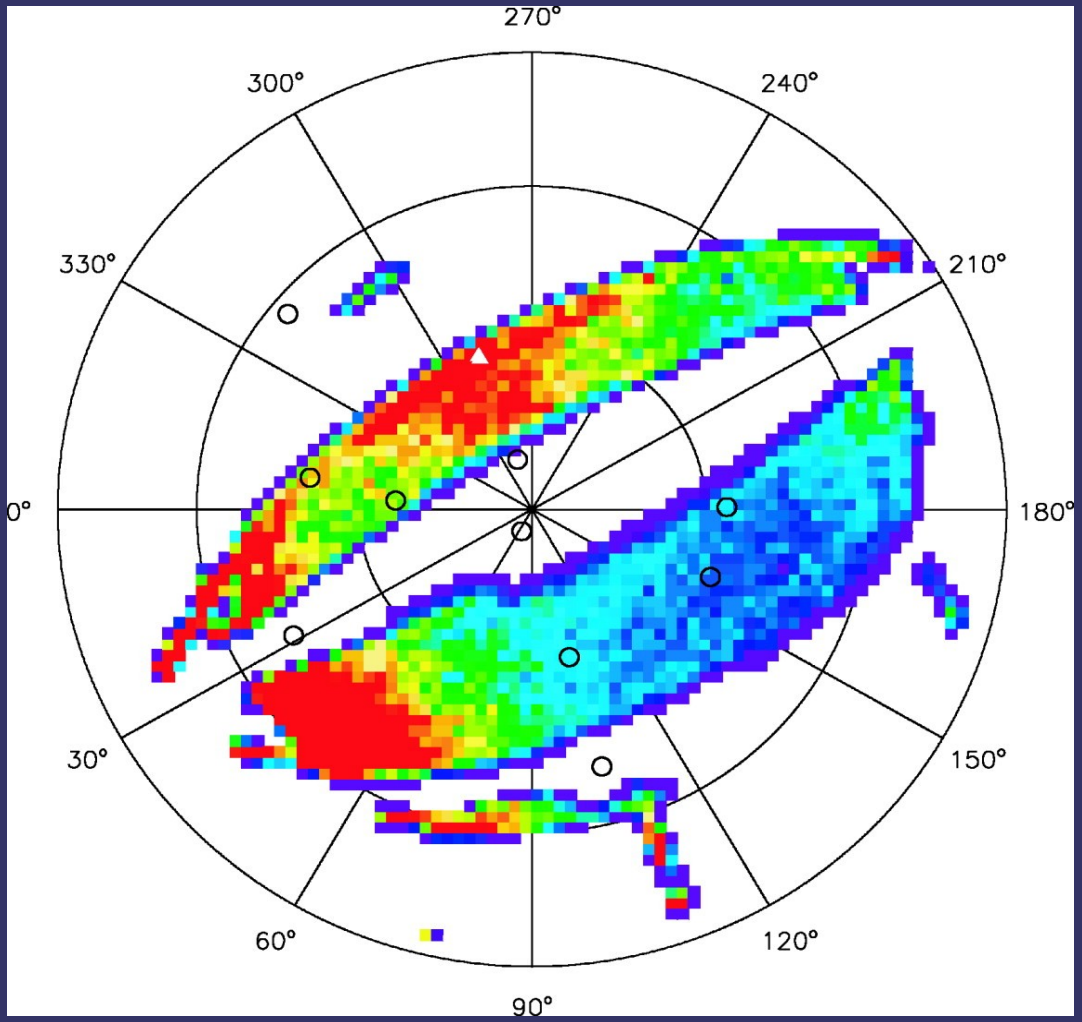


Figure from Martínez-Delgado (2007)

Juric et al (2005) found a high density of main sequence stars, toward Virgo, in a range of distances from 5 to 15 kpc, and covering more than 1,000 sq. degrees.
They interpreted it as a dwarf galaxy merging with the MW

Is the VOD = Sgr debris?

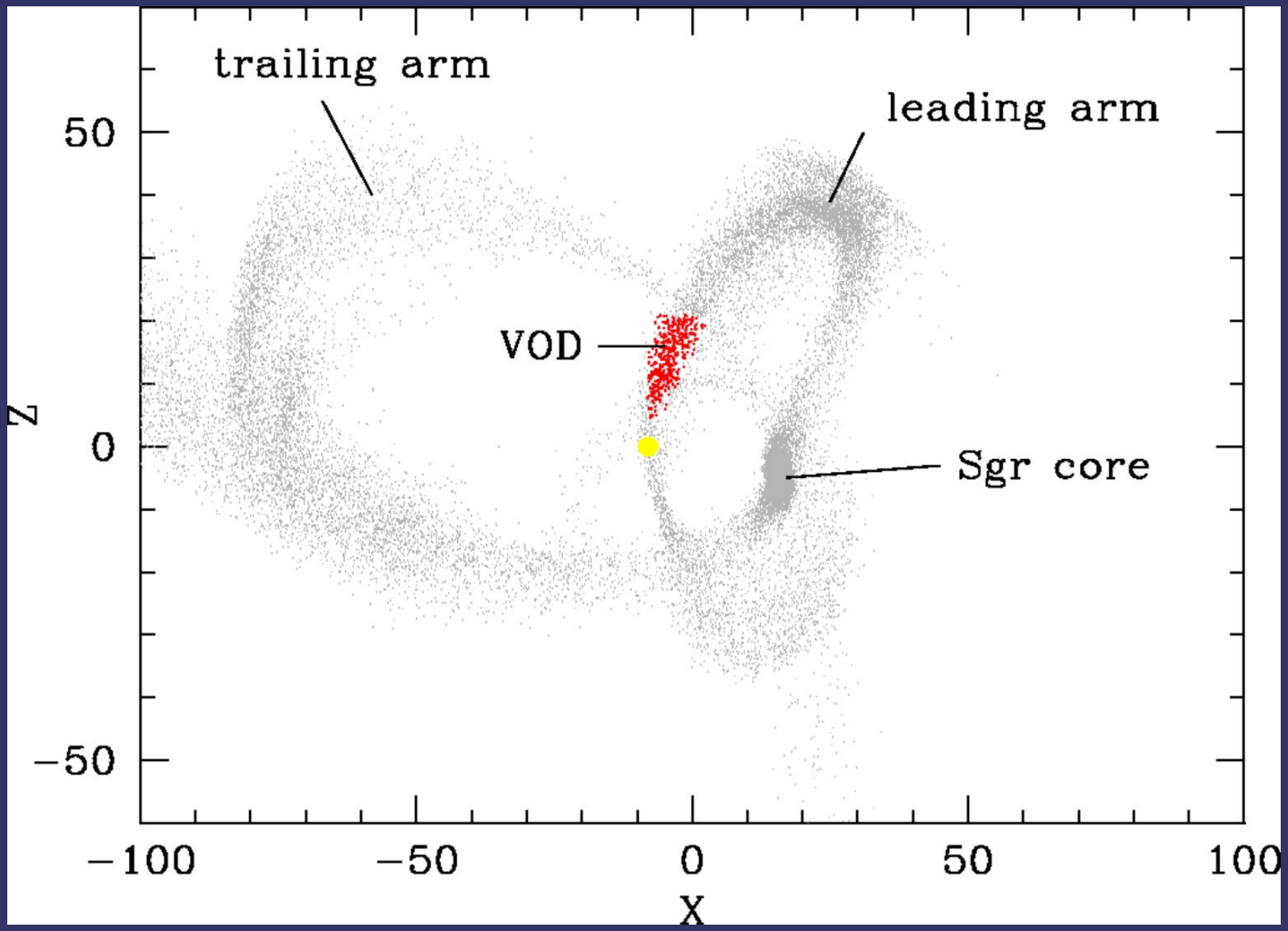
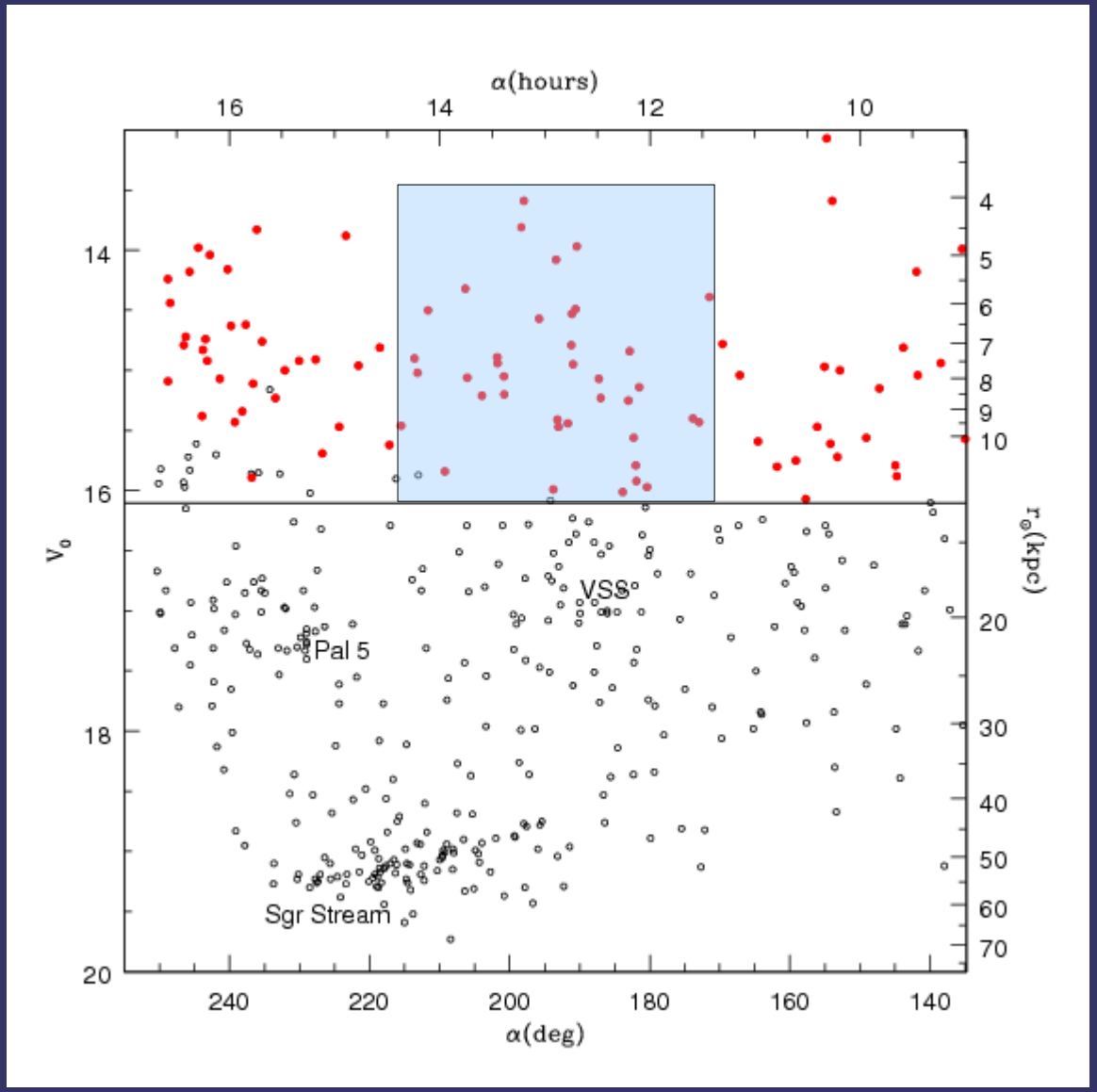
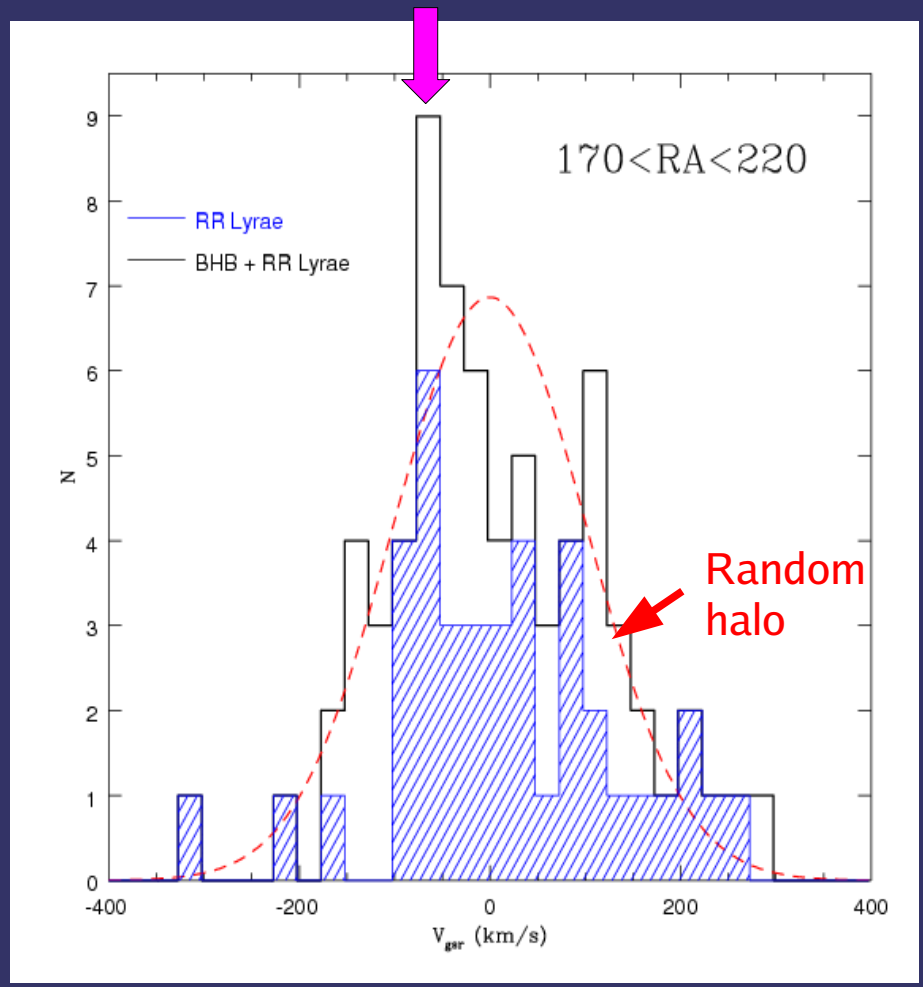


Figure from Martínez-Delgadoet al. (2007)

Martínez-Delgado et al (2007) interpreted the VOD as part of the Sgr leading stream, which is falling onto the solar neighborhood. They also suggest that the VSS is part of the Sgr trailing tail.

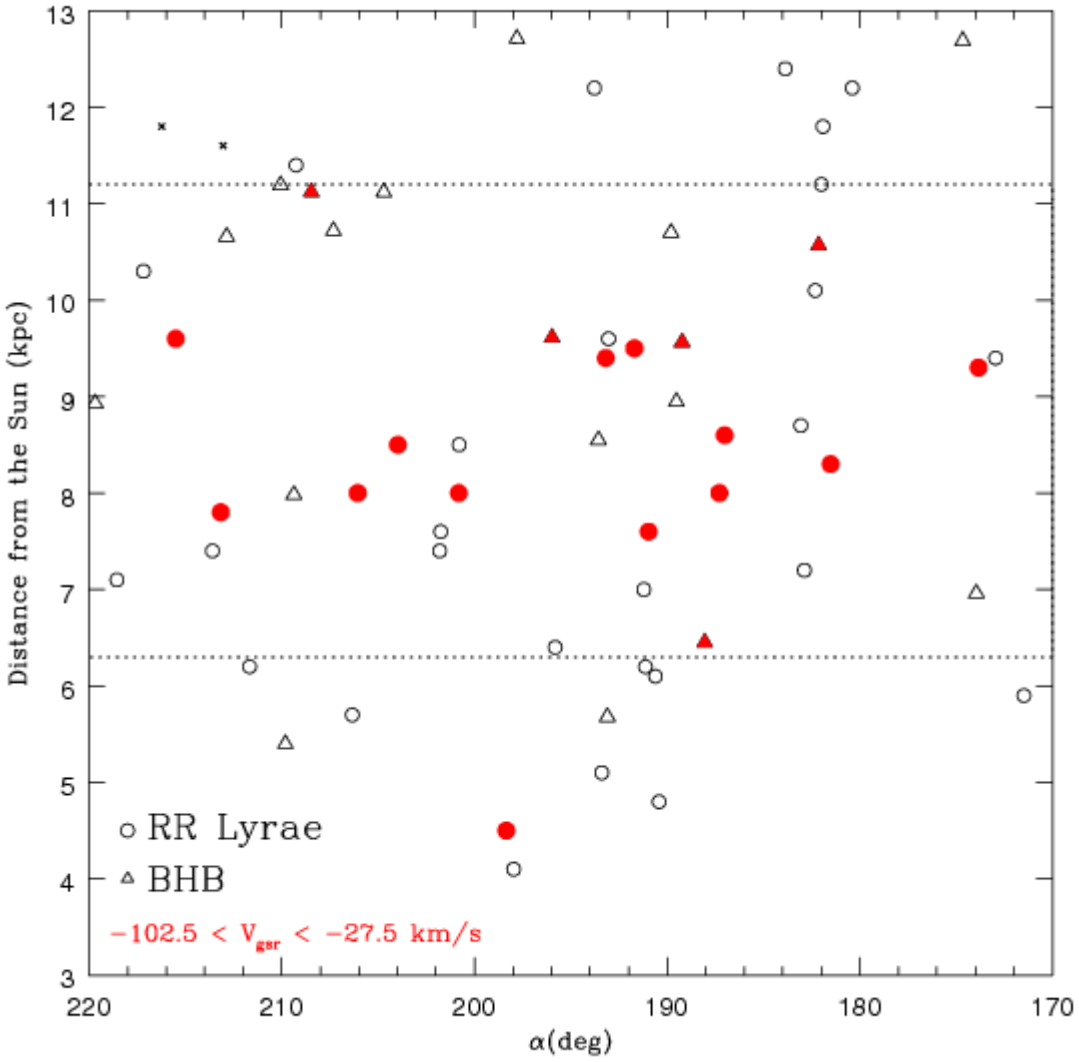
Spectroscopy of the Bright QUEST RR Lyrae stars





Is the peak at V_{gsr} ~ -65 km/s significant?

RR Lyrae Stars in the VOD Region

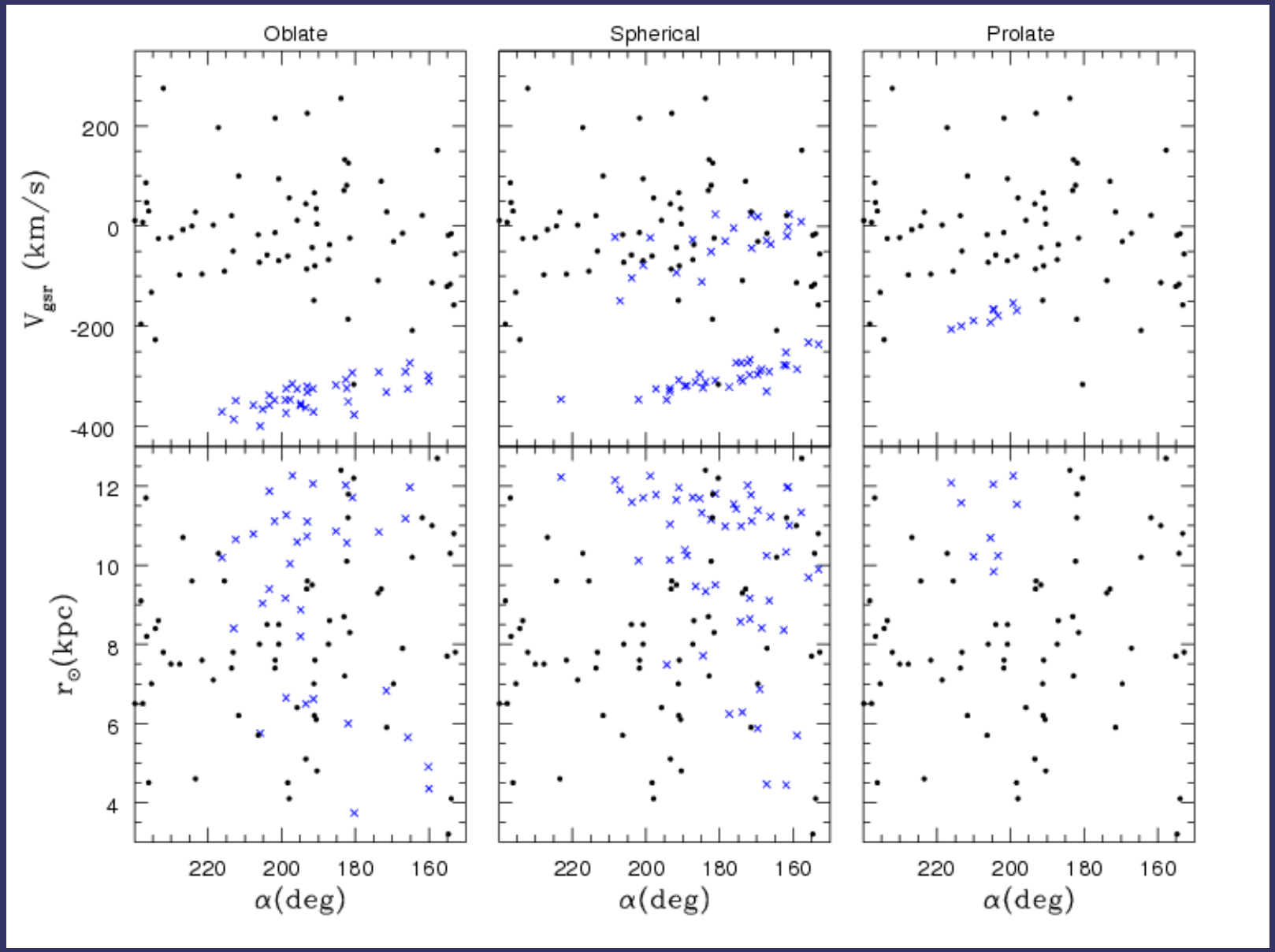


40% of all stars within the lines have velocities between -102 and -27 km/s

Only 1% of our Monte Carlo simulations reproduce a similar velocity distribution

$\langle V_{gsr} = -61$ km/s
$\sigma = 23$ km/s

Sagittarius Debris?



- QUEST RR Lyrae Stars

x Model predictions (Law et al. 2005)

The Virgo Region

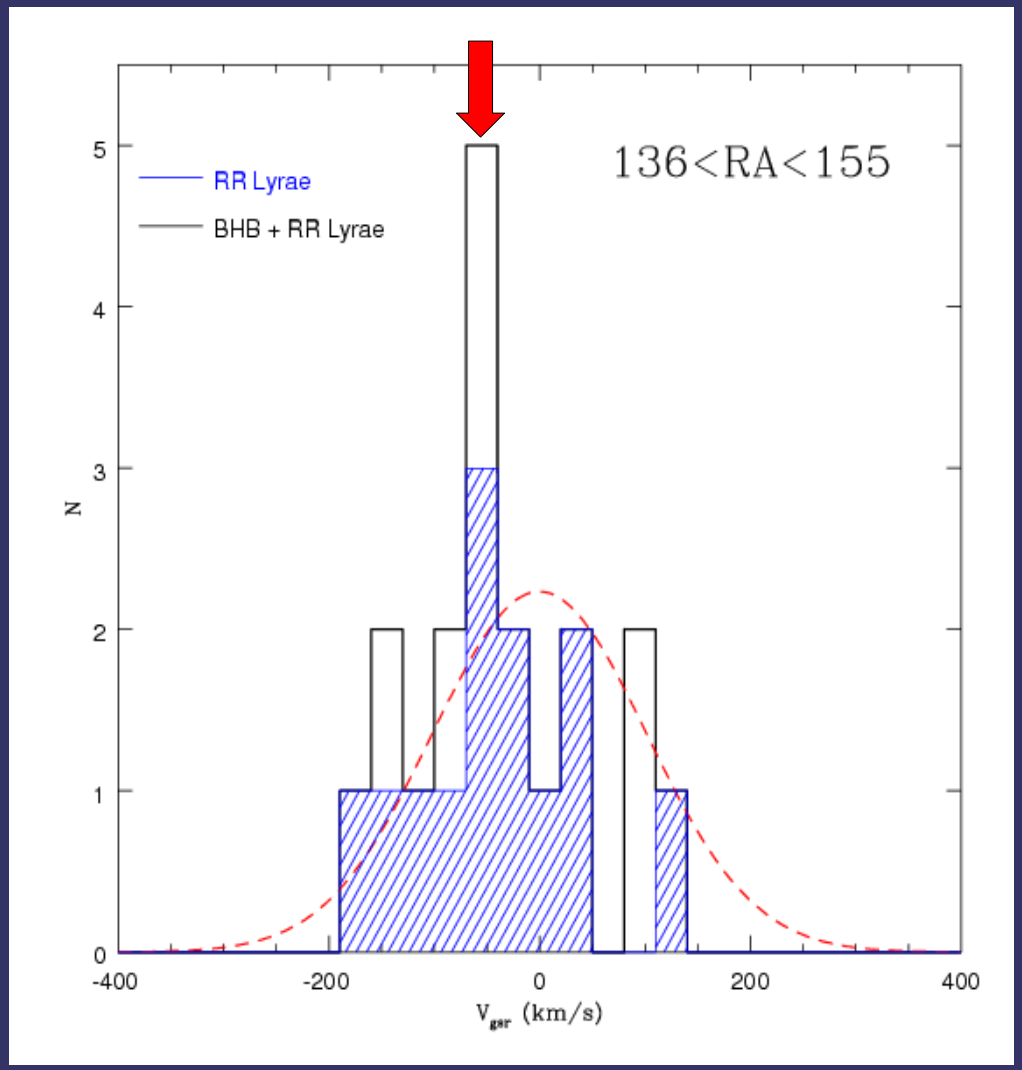
- Two different groups:

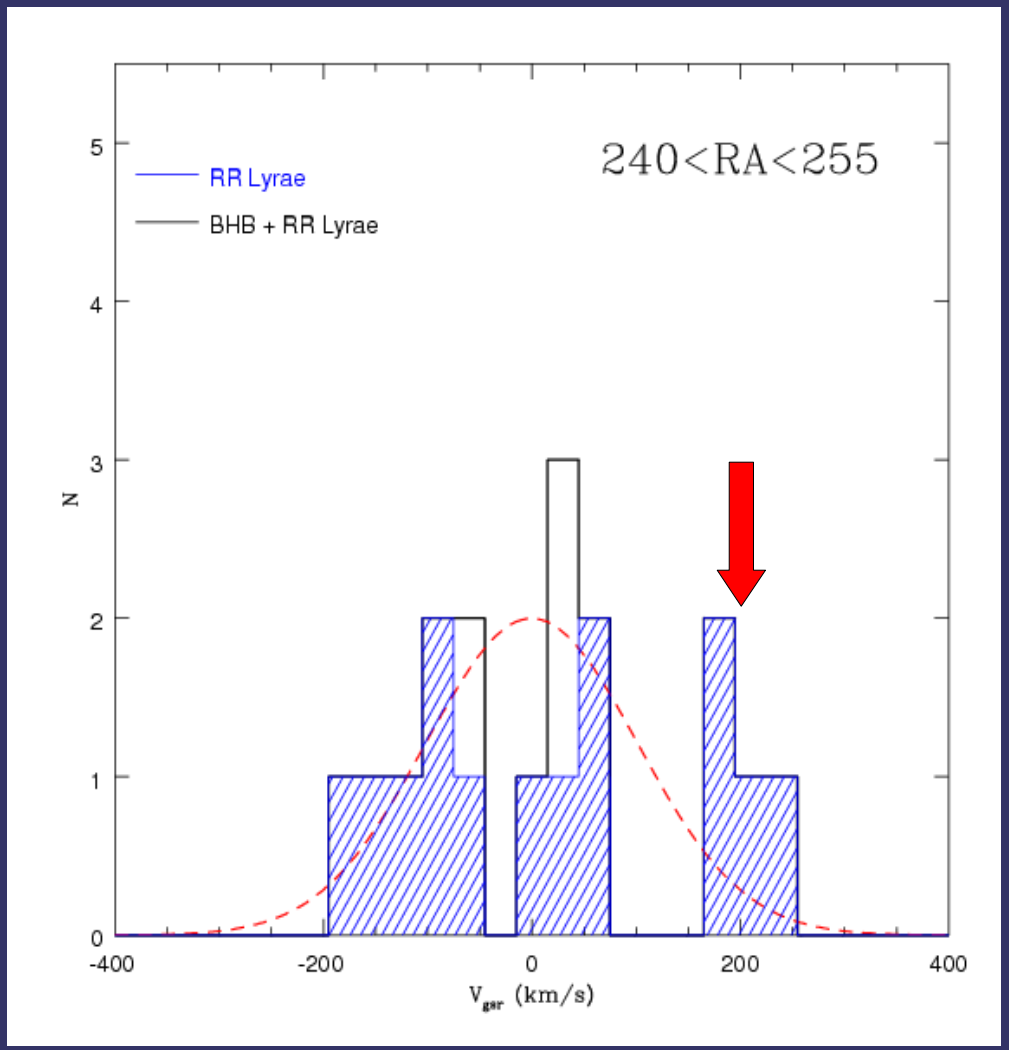
VSS	**-->**	**<Vgsr> = +100 km/s**	**Dist = 20 kpc**
VOD	**-->**	**<Vgsr> = - 61 km/s**	**Dist = 6-11 kpc**

- There are not many stars with high negative velocities as expected if the VOD is part of the Sgr leading tail. A possible implication is that the halo of the MW is prolate, for this model does not predict much Sgr debris in the region.

- Both the VSS and VOD contain a population of old stars.

More Kinematic Groups in the Inner Halo





Conclusion

- The Halo of the Milky Way is filled with sub-structures both spatially and kinematically. The QUEST survey is providing information on the old population of many of these sub-structures.
- Random fluctuations may produce fake groups in many surveys. Each clump must be followed up to confirm its physical association, possible origin and properties.