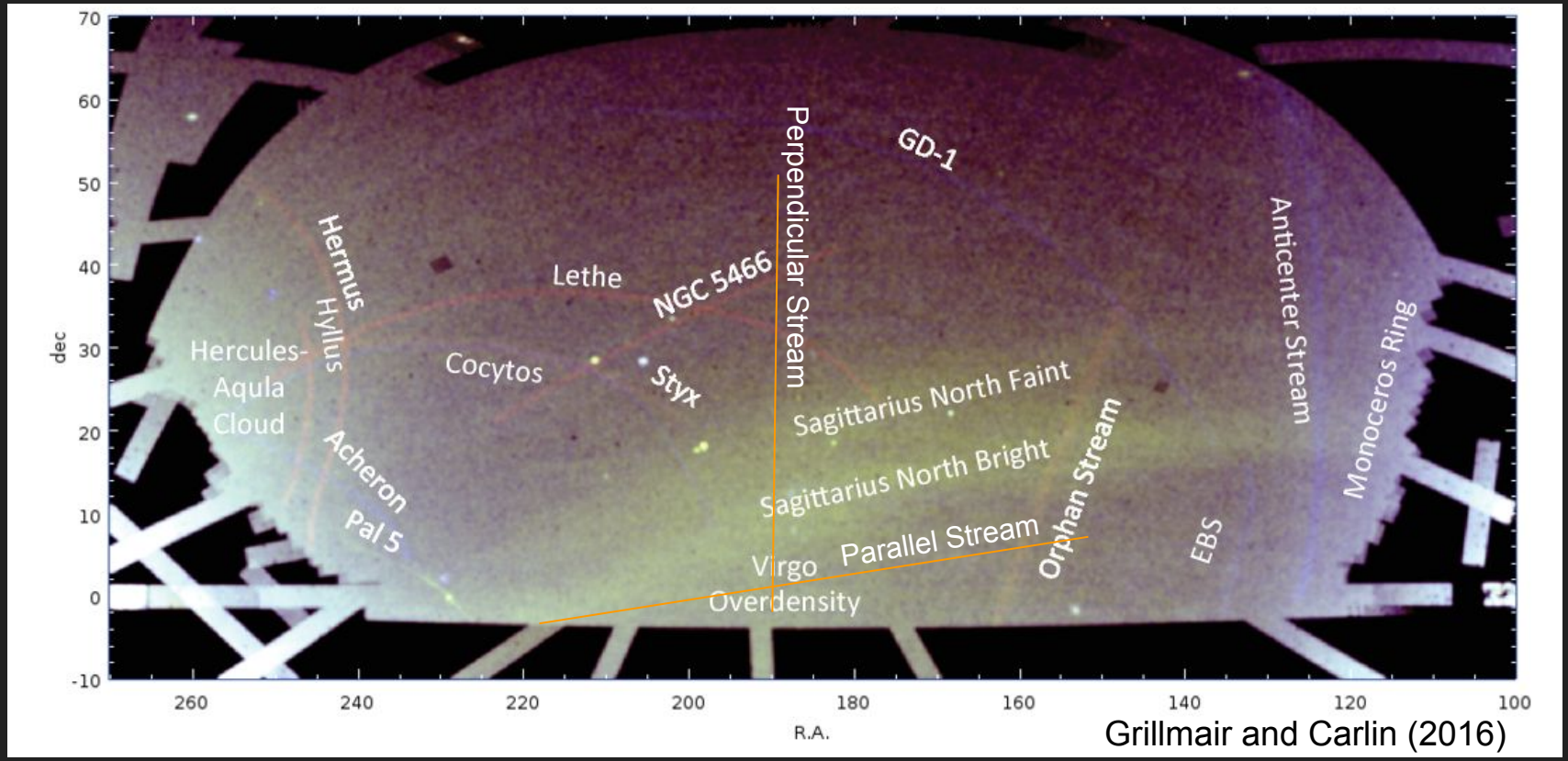
Fitting the Density of the Milky Way using Statistical Photometric Parallax

Jake Weiss
Rensselaer Polytechnic Institute

Overview

- Fitting Halo Stellar Density with MilkyWay@home
- Exploring Virgo in 6D Phase Space
- Putting the Pieces Together - The Virgo Radial Merger (VRM)

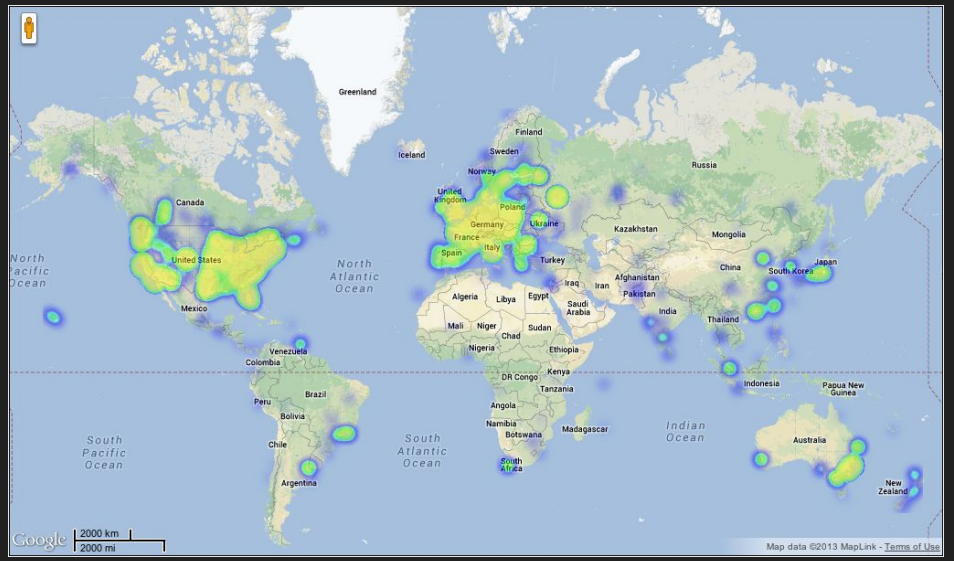
SDSS North Galactic Cap



Grillmair and Carlin (2016)

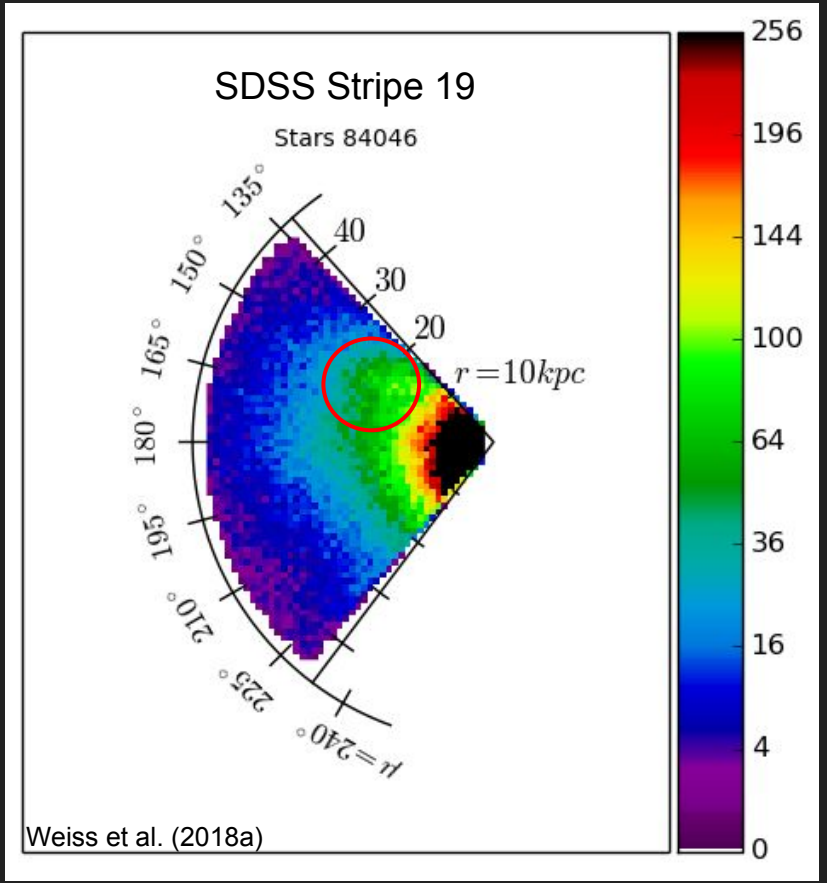
Background - MilkyWay@home

- Massive distributed volunteer computing network
- Uses the Berkeley Open Infrastructure for Network Computing (BOINC)
- Designed to tackle large scale optimization problems
- 20,000 active volunteers
- 30,000 active computers
- Power equivalent to ~1 PetaFLOPs
- Sign up at: https://milkyway.cs.rpi.edu



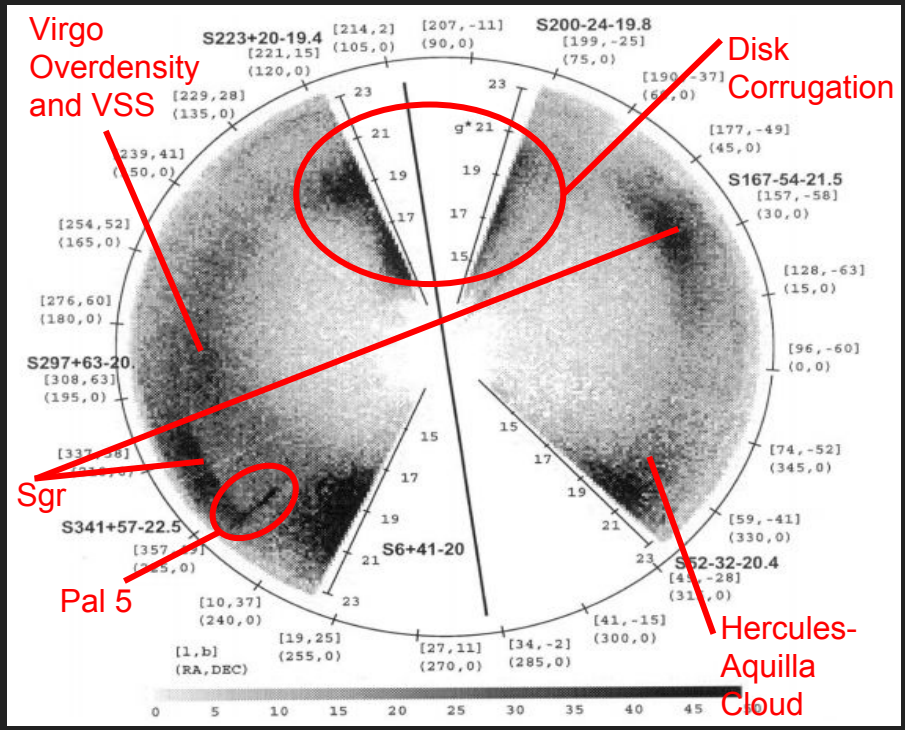
Background - SDSS Wedge

- Main Sequence Turnoff Stars (MSTO)
- SDSS Wedge Coordinate System
  - μ - angular position along great circle
  - v - angular position above or below great circle
  - r - Heliocentric distance



Background - Statistical Photometric Parallax

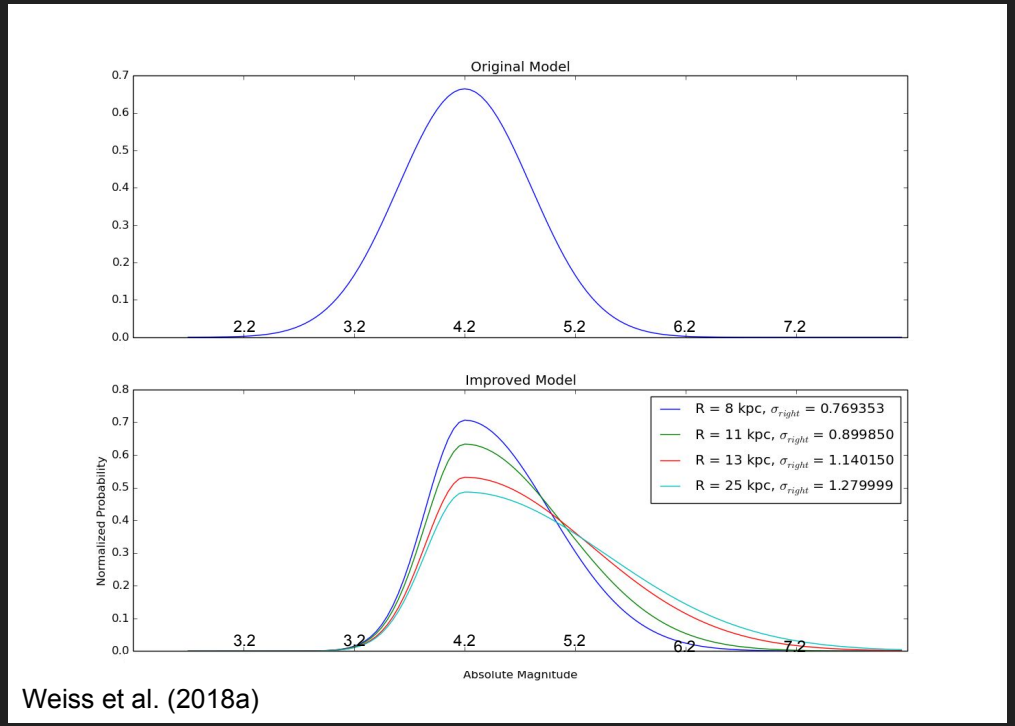
- Main Sequence Turnoff Stars (MSTO)
- Stars are spread over a 2 magnitude range in absolute magnitude
- Fit the MSTO absolute magnitude distribution
- Convolve our stellar density model to match our data
- Apply observational effects
- Fit the parameters of our density model to learn about the underlying density of stars



Newberg et al. (2002)

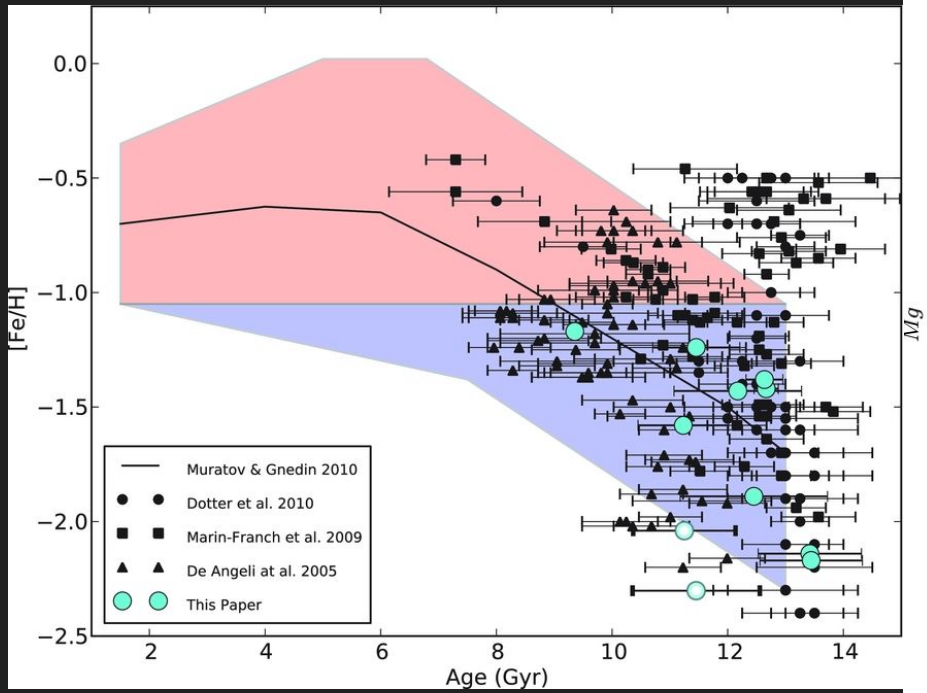
Model - Main Sequence Turn Off Stars

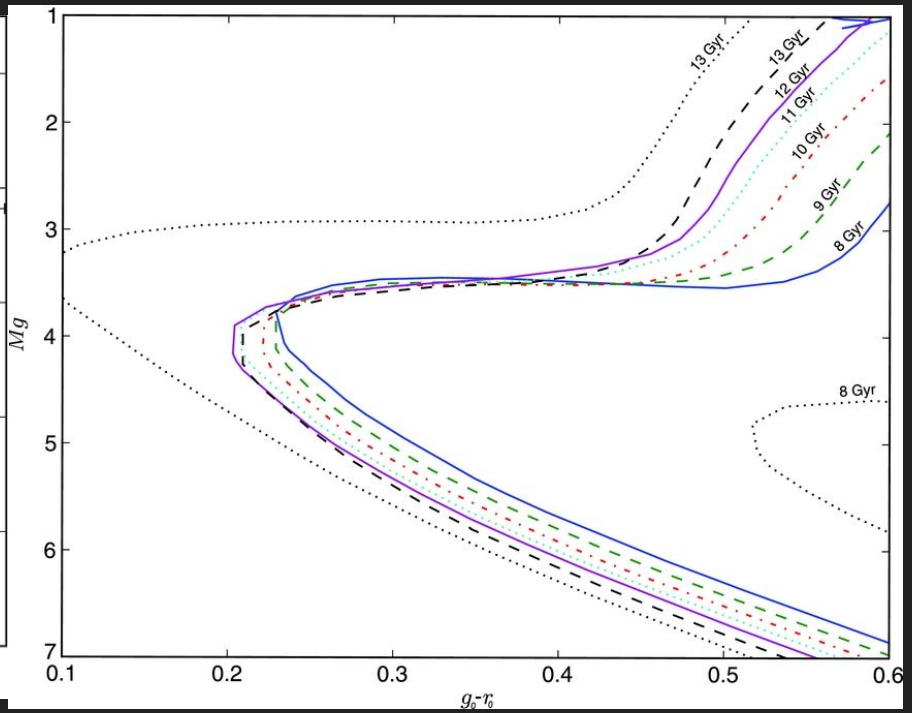
- Originally used Gaussian (standard deviation 0.6)
- Newby et al. (2011) modeled turnoff for globular clusters
- Determined 2 half Gaussians with distance dependant faint standard deviation was best.



Weiss et al. (2018a)

The Age-Metallicity Conspiracy

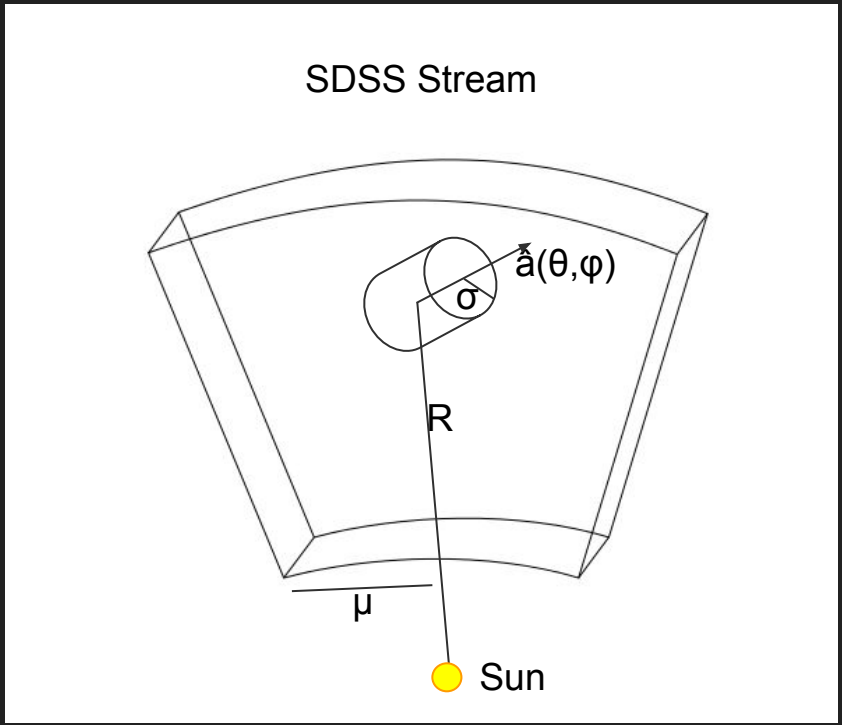




Newby et al. (2011)

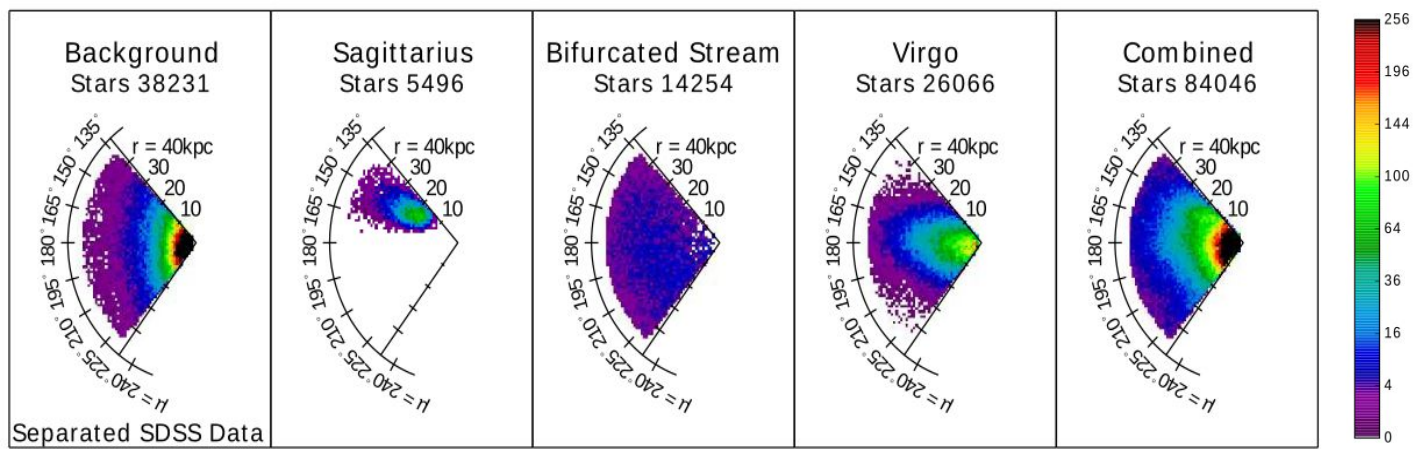
Model - Parameters

- Smooth background (Hernquist plus exponential thick disk)
  - Fit 2 parameters
- Fit 3 streams per wedge
  - Fit 6 parameters each
  - Gaussian cylinders



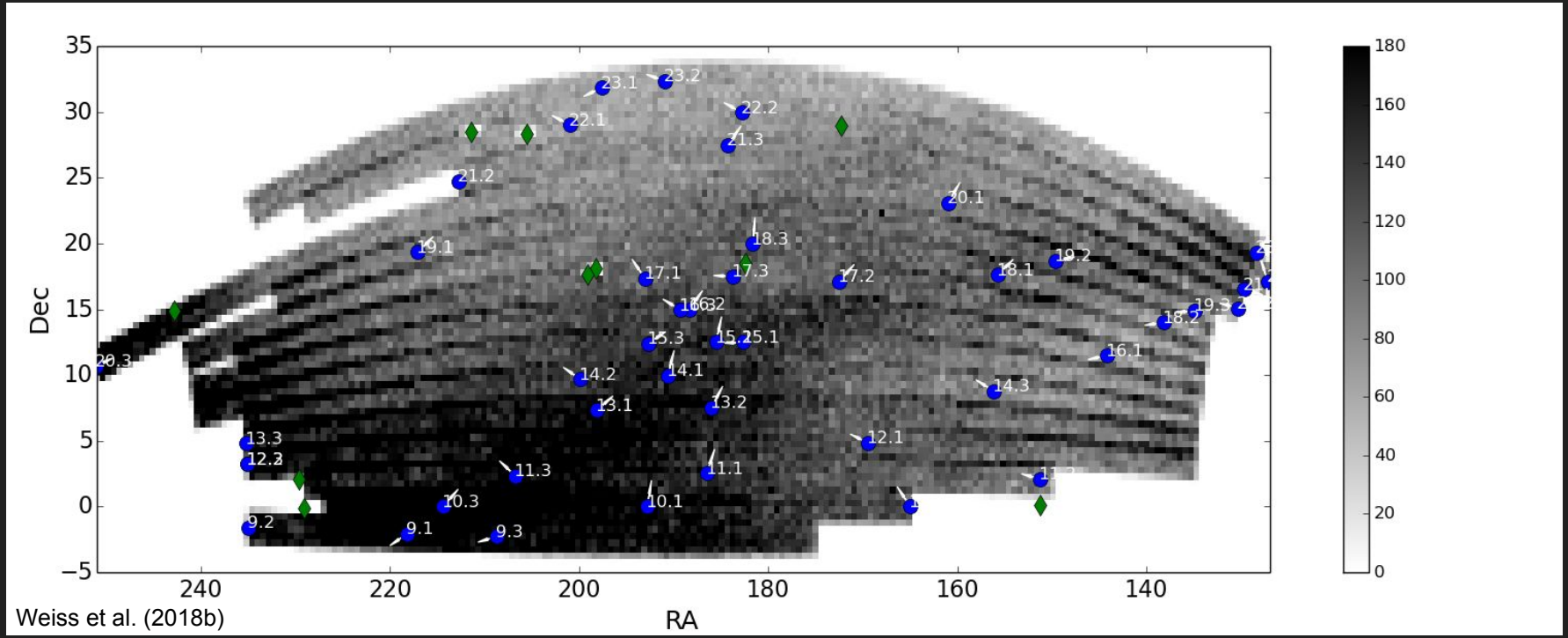
Density Fitting Results - Smooth Background

- Average Halo Flattening of 0.58
- Dispersion of Flattening was 0.04
- Average Background Fraction of 52%
- Dispersion of Background Fraction was 6.6%



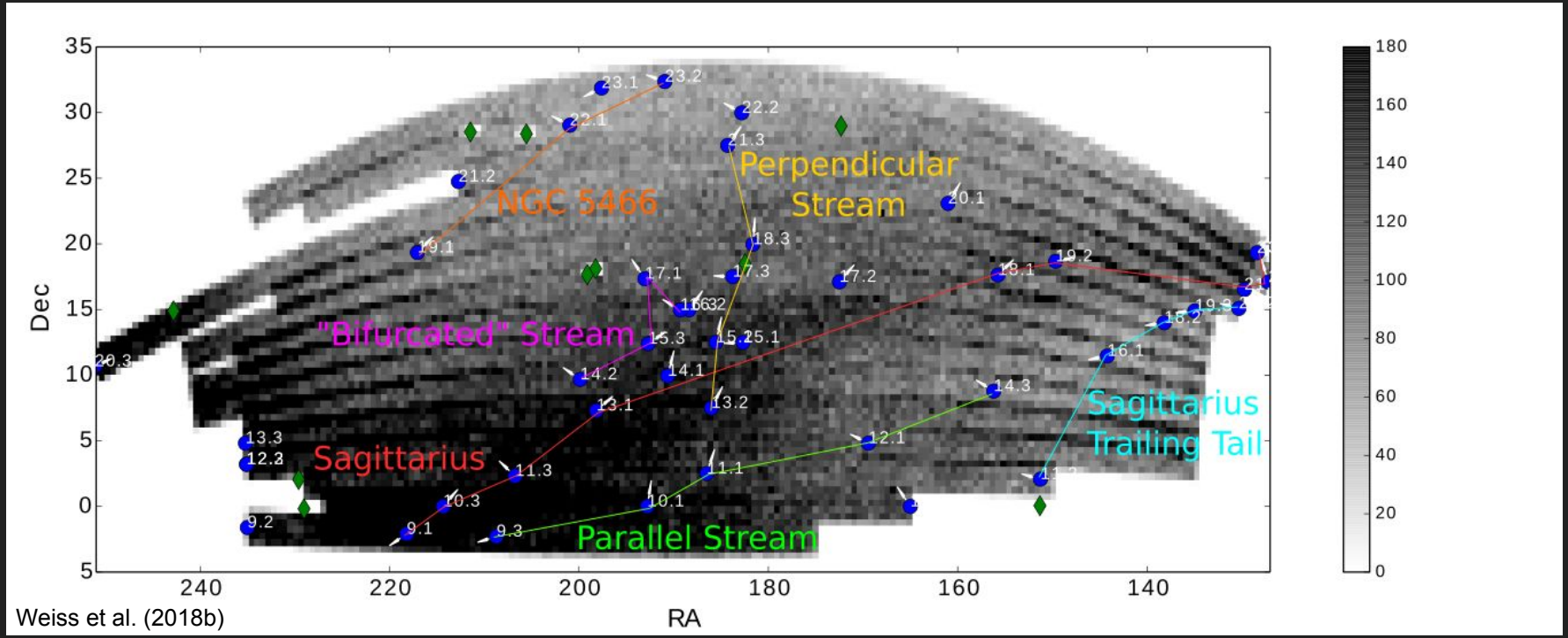
Weiss et al. (2018a)

Density Fitting Results - RA and Dec



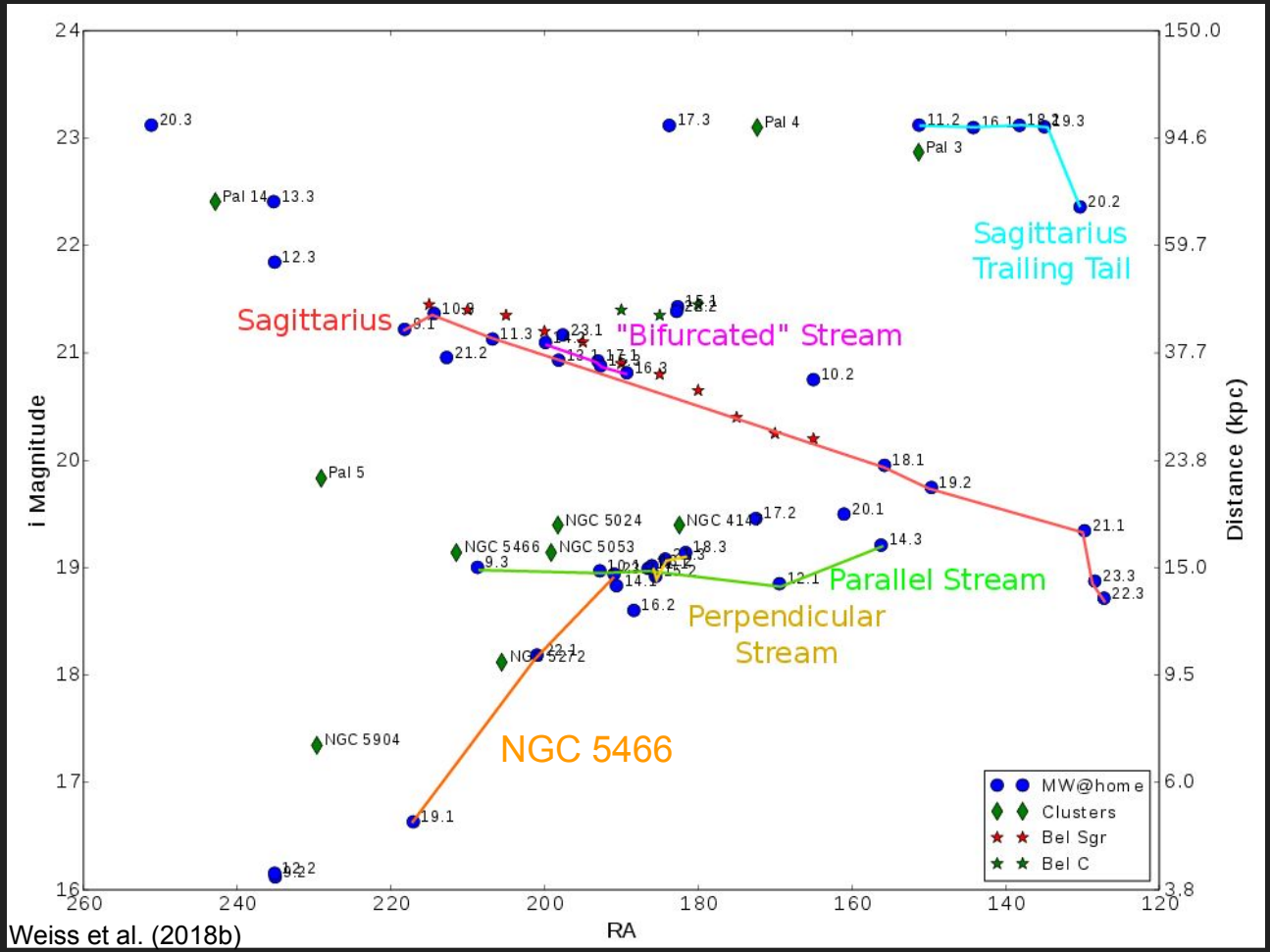
Weiss et al. (2018b)

Density Fitting Results - RA and Dec



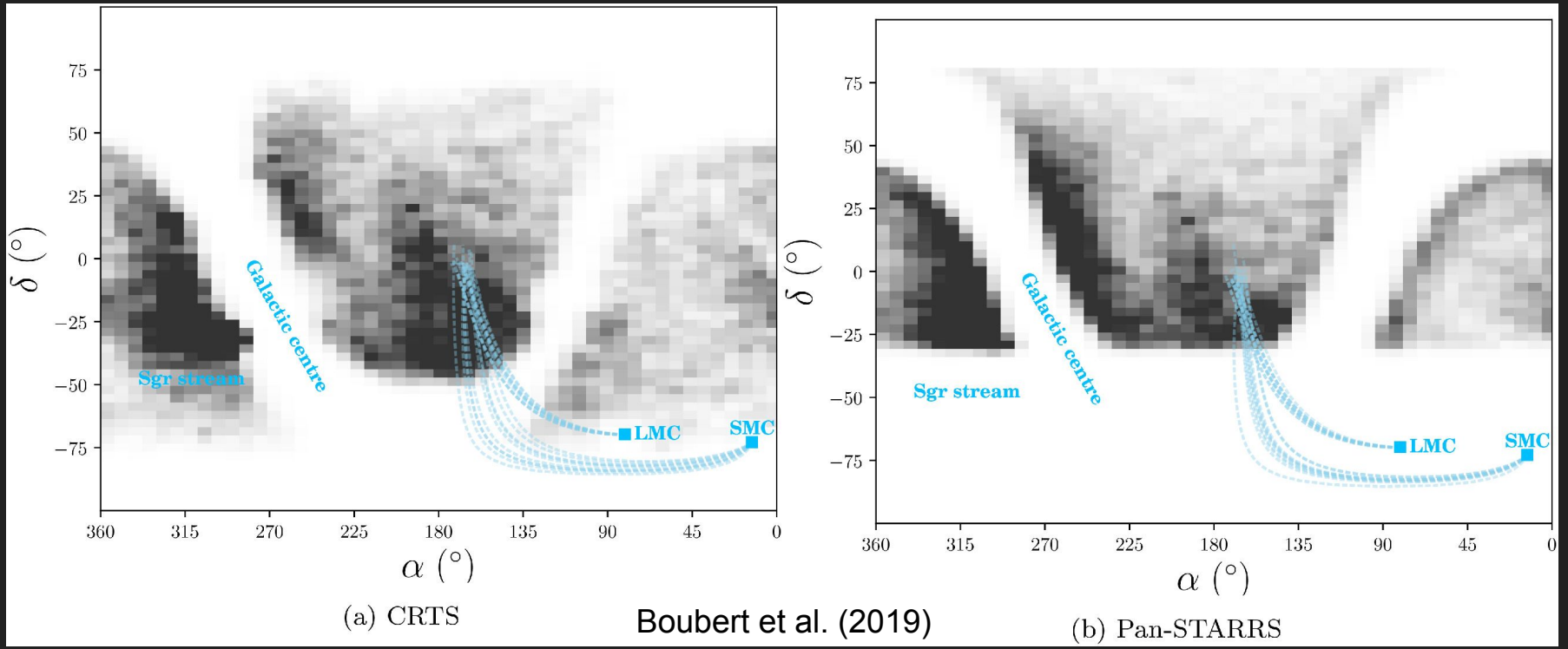
Weiss et al. (2018b)

Density Fitting Results - RA and Magnitude



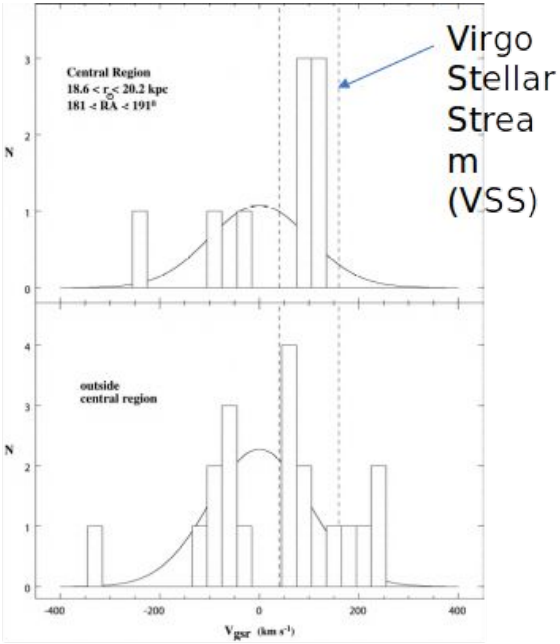
Weiss et al. (2018b)

Perpendicular Stream in RR Lyraes



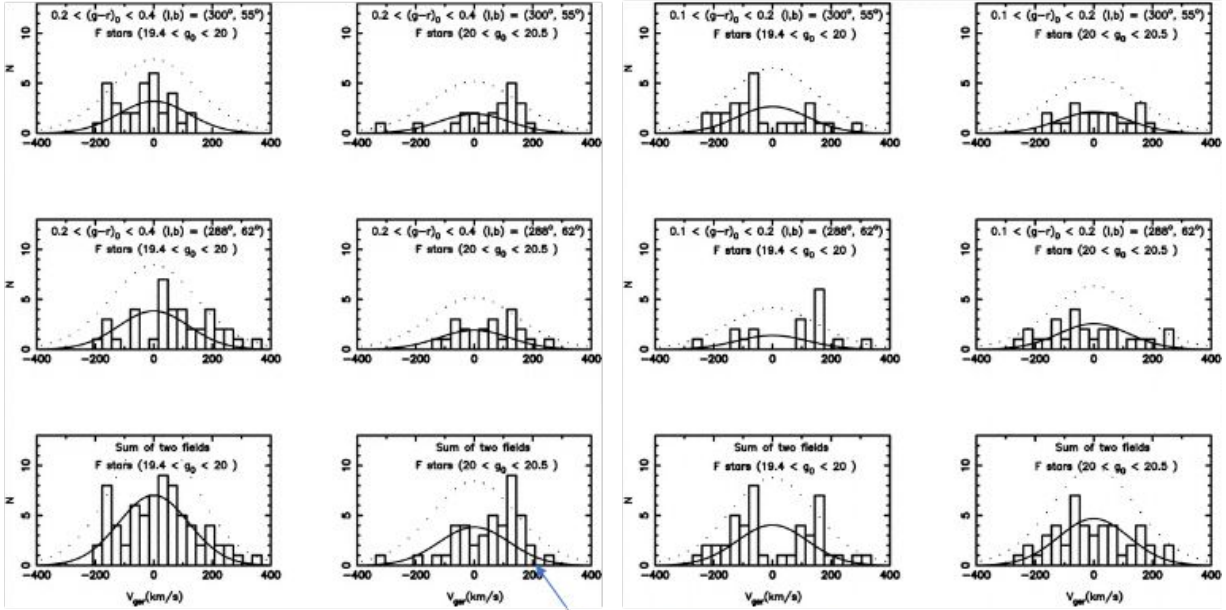
Boubert et al. (2019)

The Virgo Overdensity - The Horns of Virgo



Virgo Stellar Stream (VSS)

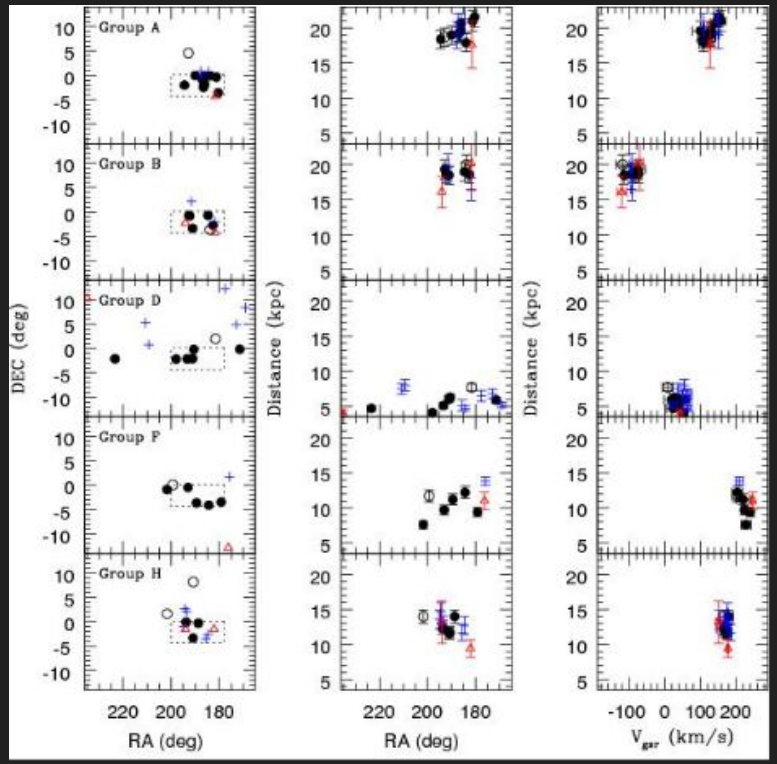
Duffau et al. (2006)



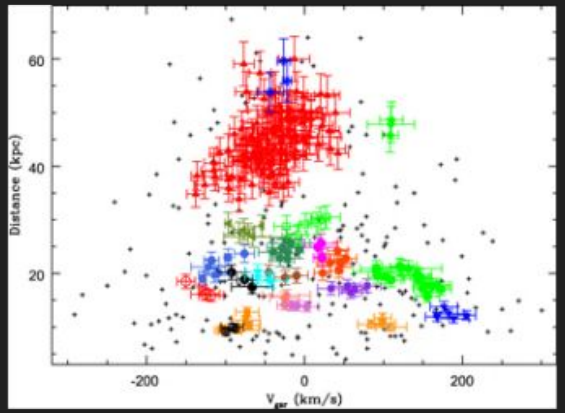
Newberg et al. (2007)

Virgo Overdensity

Moving Groups in Virgo



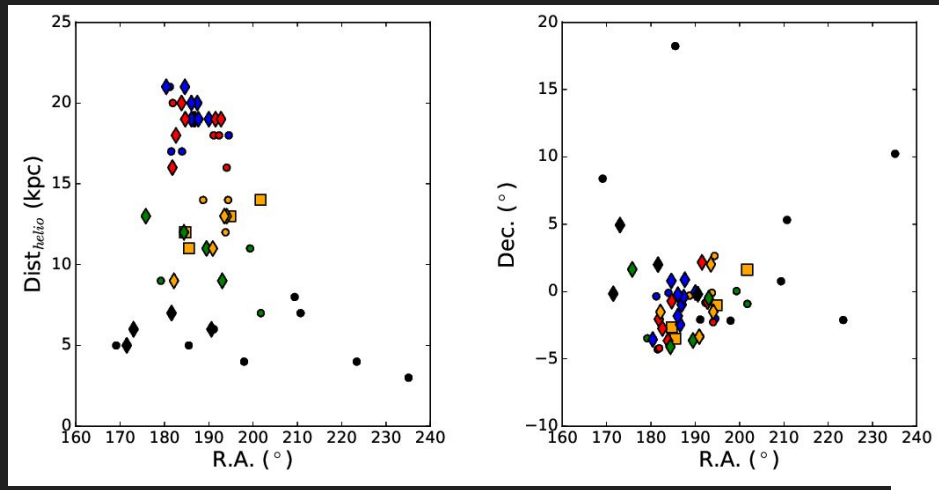
Duffau et al. (2014)

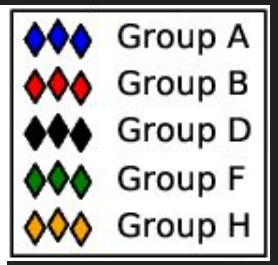


Vivas et al. (2016)

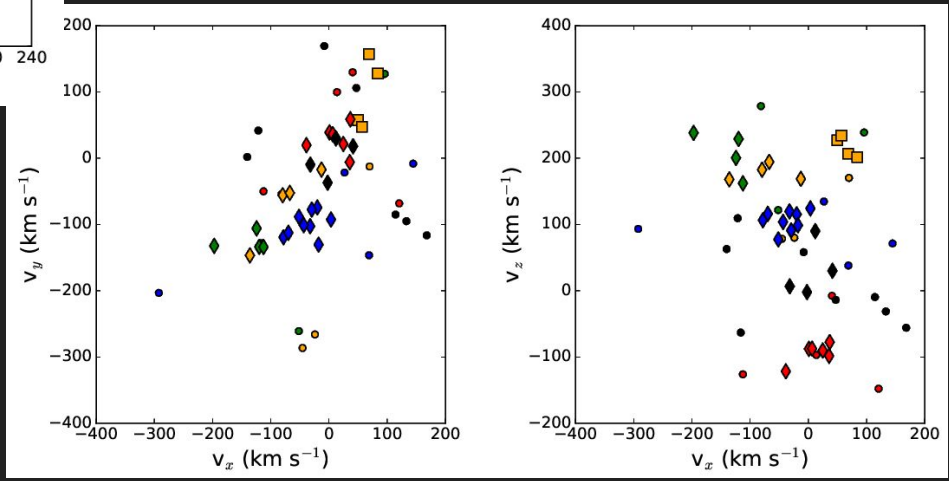
Duffau finds five moving groups in the Virgo region in RRL/BHB stars. Vivas et al (2016) finds 22 groups but only 6-10 of the groups are thought to be significant.

Moving Groups in Virgo

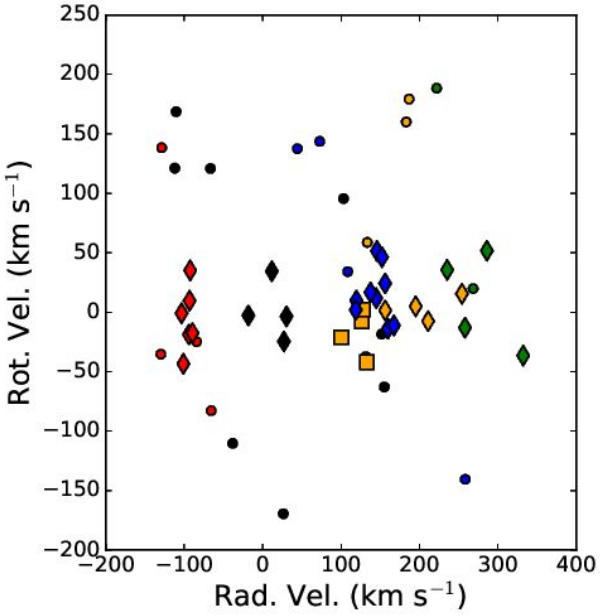


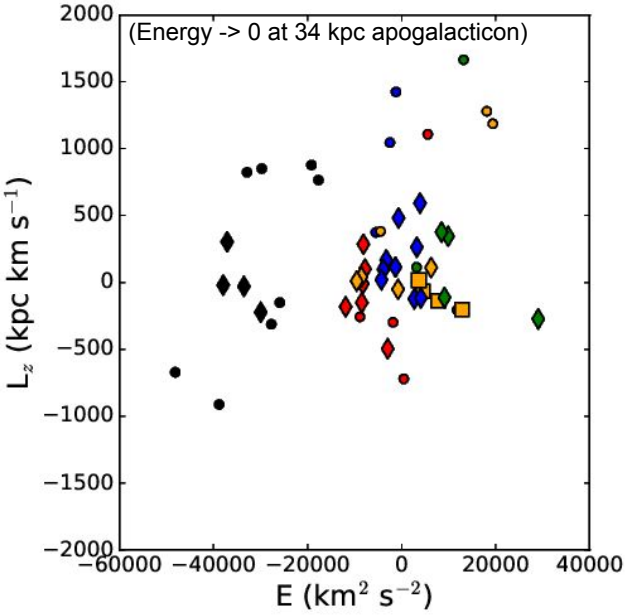


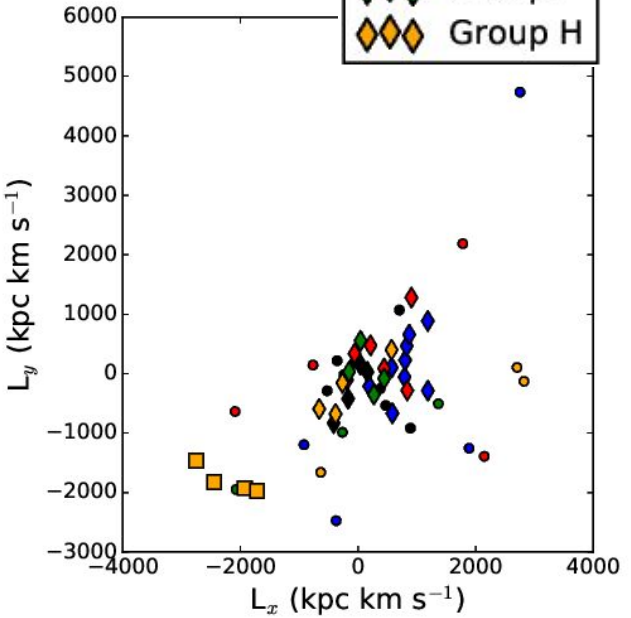
Donlon et al. (Submitted)



Moving Groups in Virgo



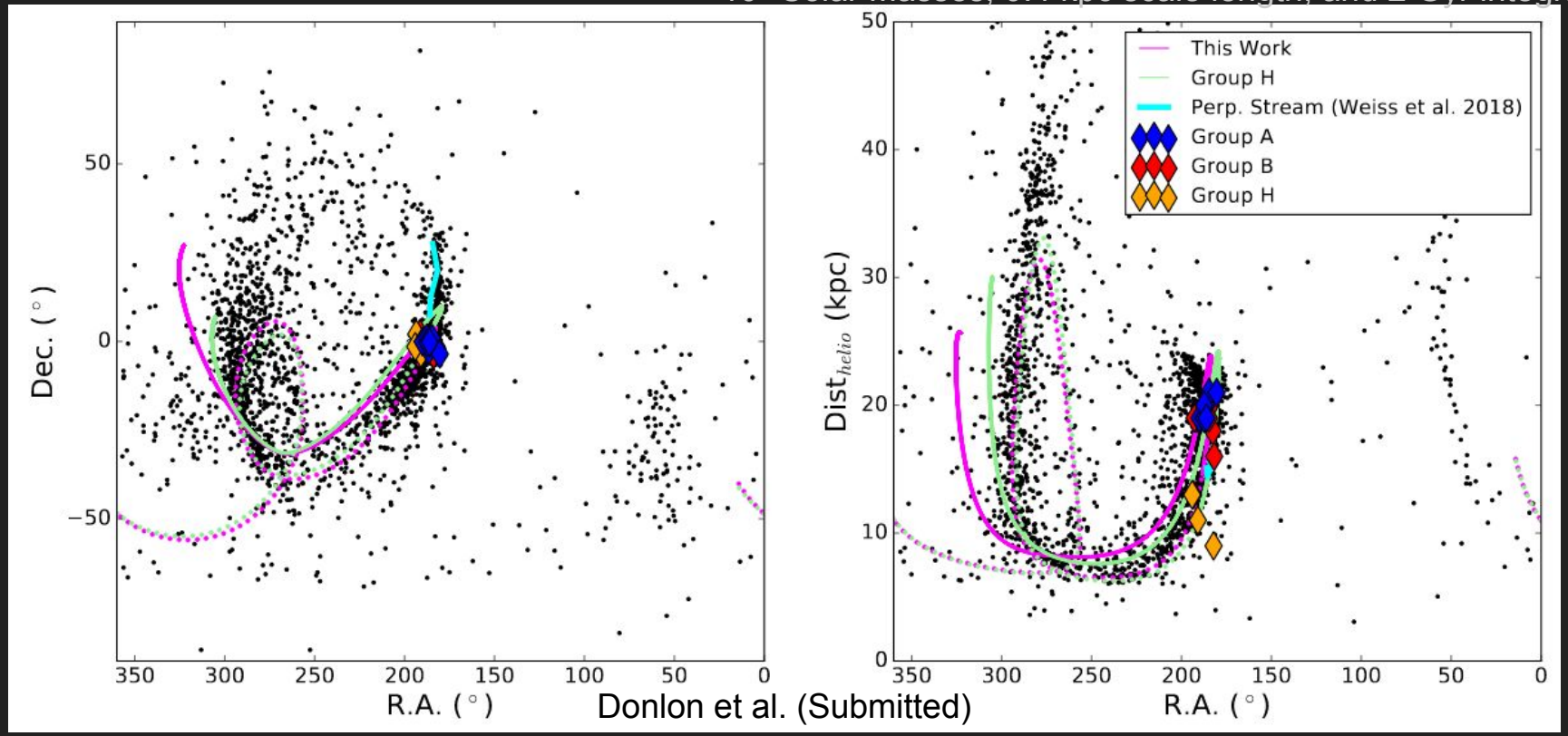




Donlon et al. (Submitted)

Orbits & N-bodies: Perpendicular Stream

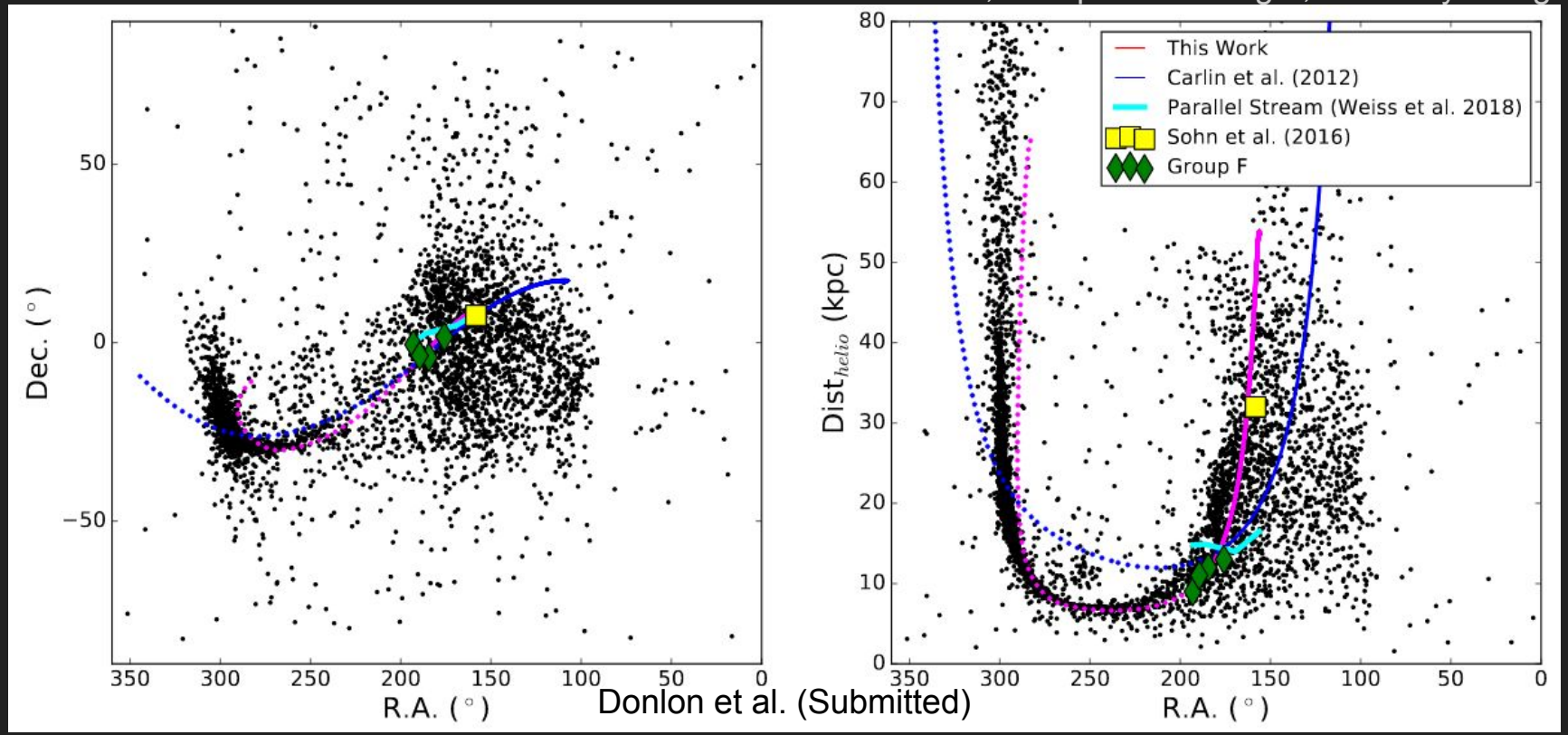
10^7 Solar Masses, 0.4 kpc scale length, and 2 Gyr integration



Donlon et al. (Submitted)

Orbits & N-bodies: Parallel Stream

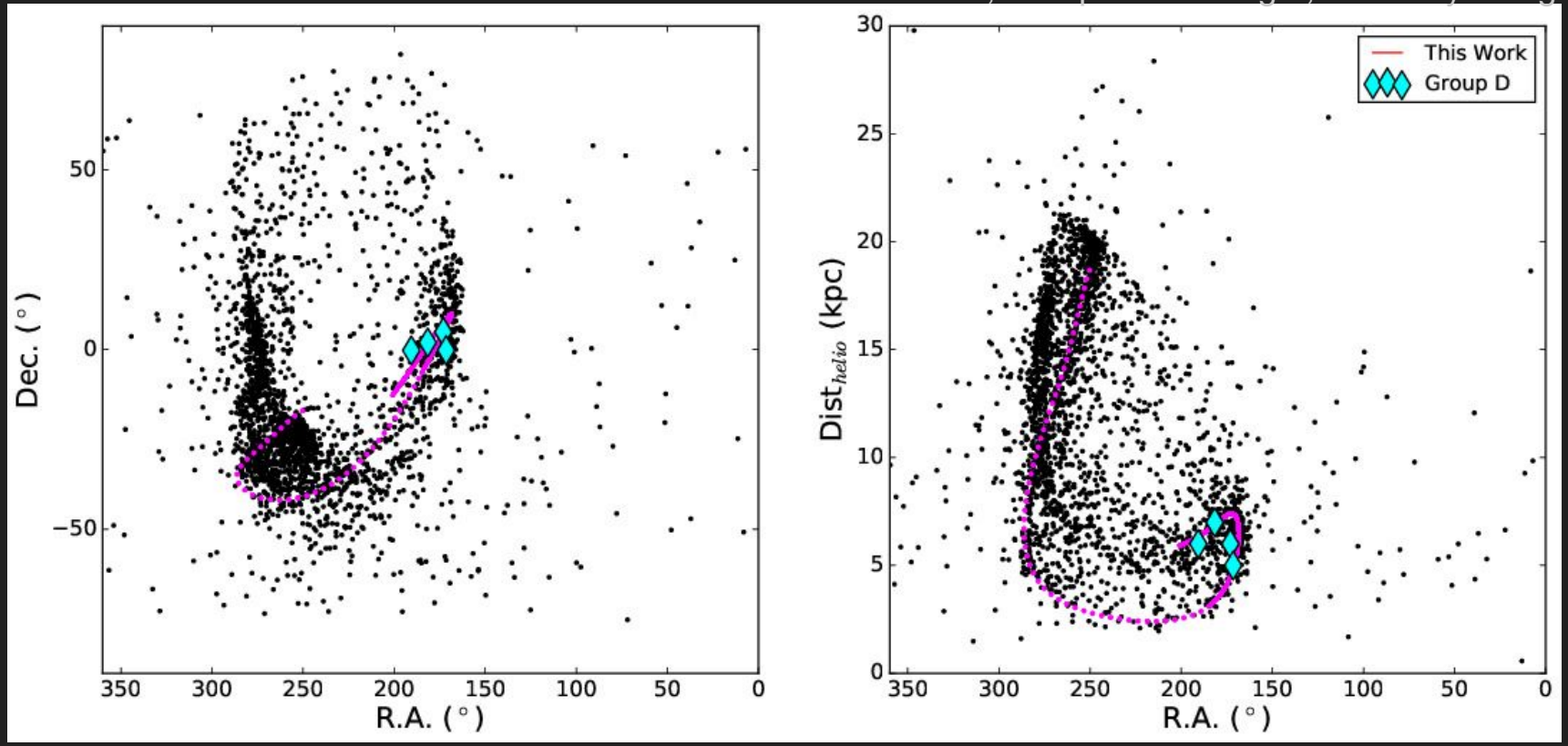
10^7 Solar Masses, 0.4 kpc scale length, and 2 Gyr integration



Donlon et al. (Submitted)

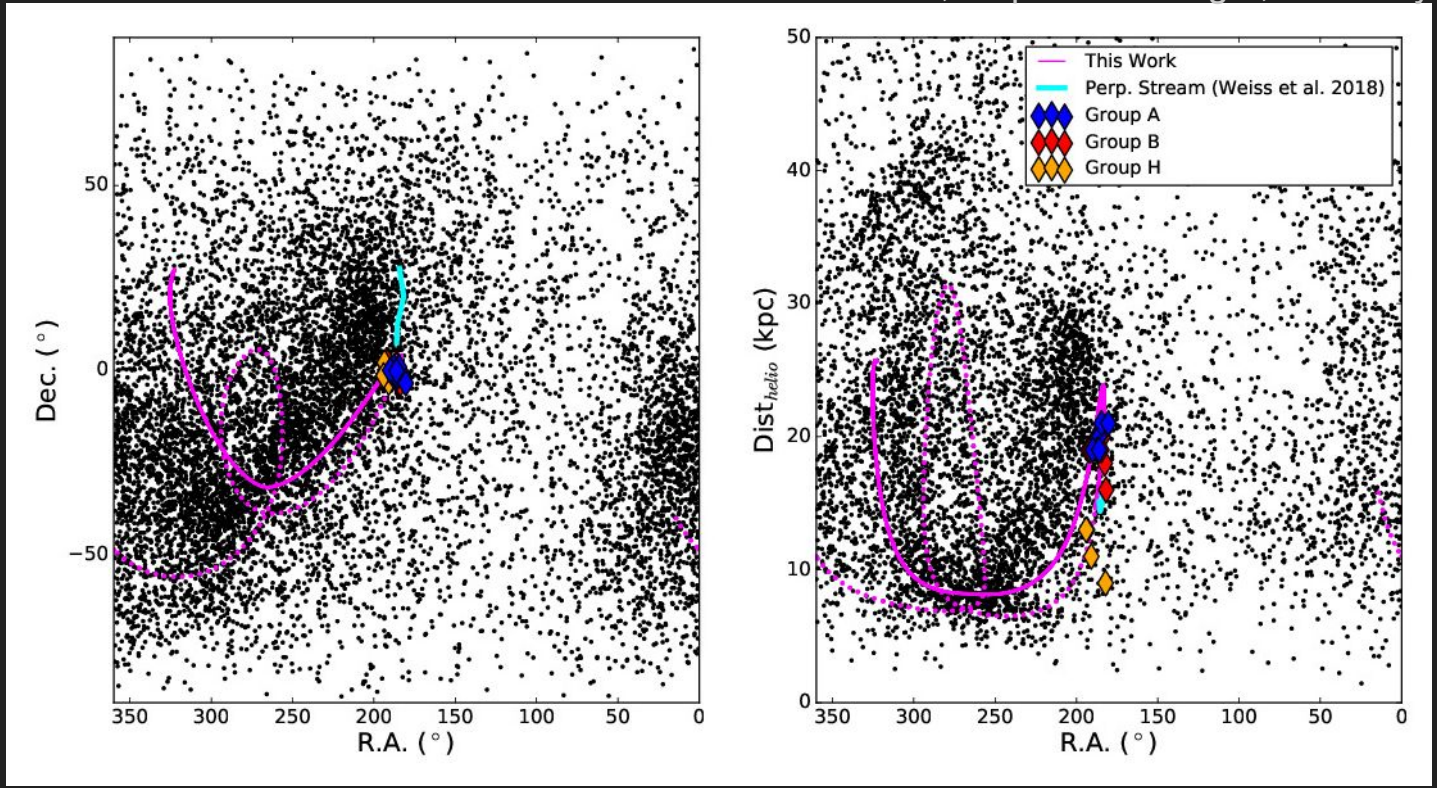
Orbits & N-bodies: Low Energy Stars

10^7 Solar Masses, 0.4 kpc scale length, and 2 Gyr integration



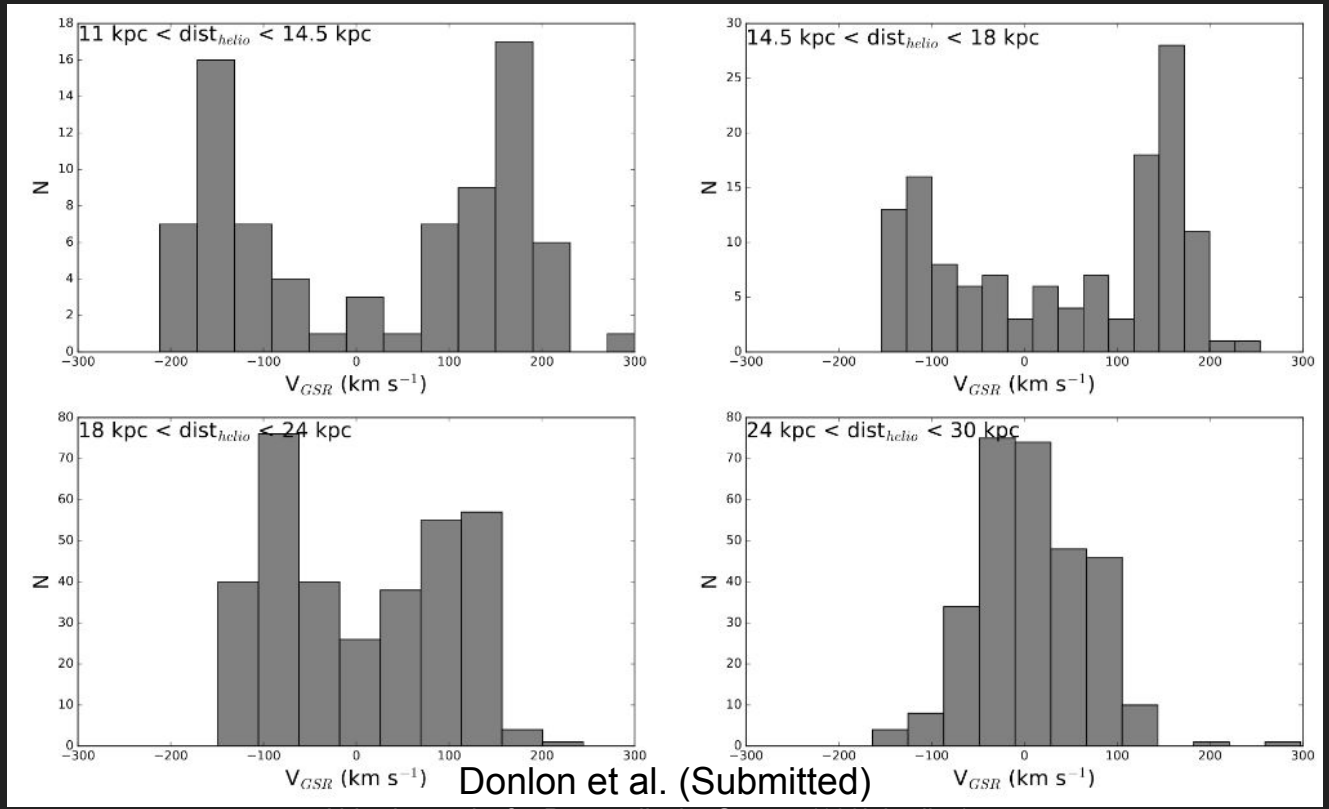
The Virgo Radial Merger (VRM)

10^9 Solar Masses, 3 kpc scale length, and 2 Gyr integration



The Horns of Virgo

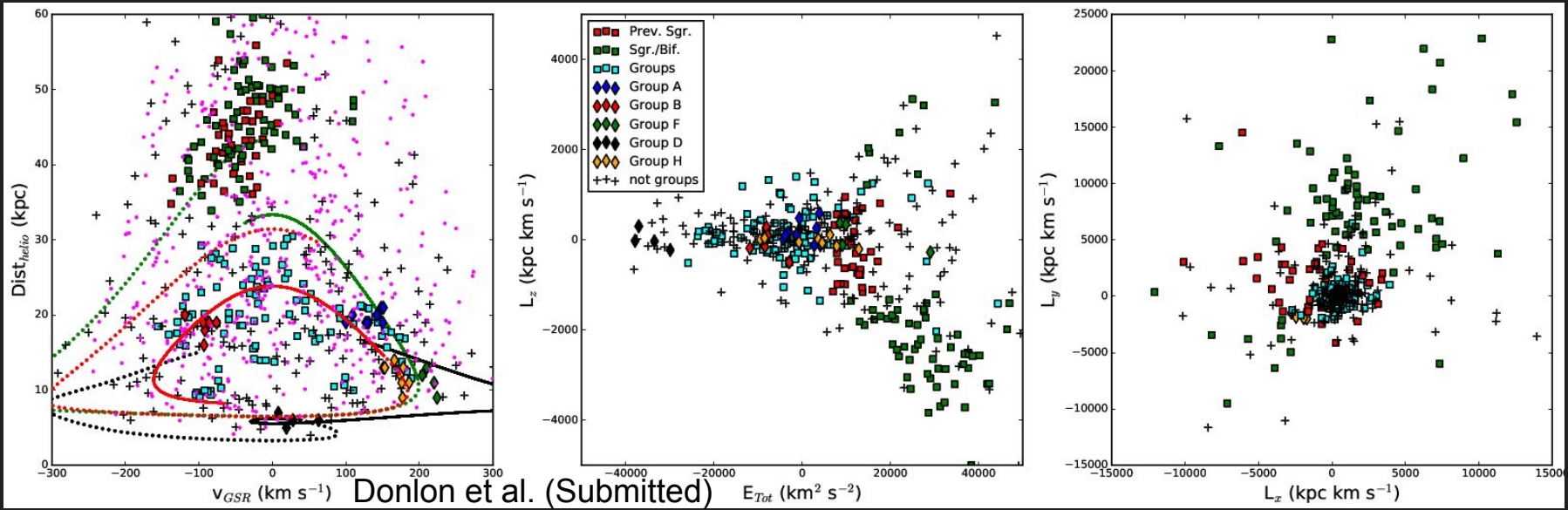
(180◦ < RA < 200◦, -10◦ < Dec < +5◦)



Donlon et al. (Submitted)

N-body results for Perpendicular Stream (100k bodies)

Moving Groups from Vivas et al. (2016)



Donlon et al. (Submitted)

VRM Compared to Gaia-Sausage/GEM

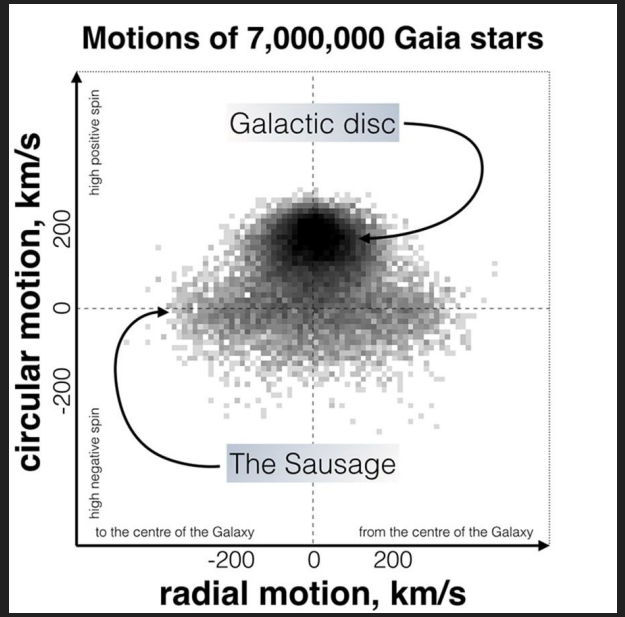
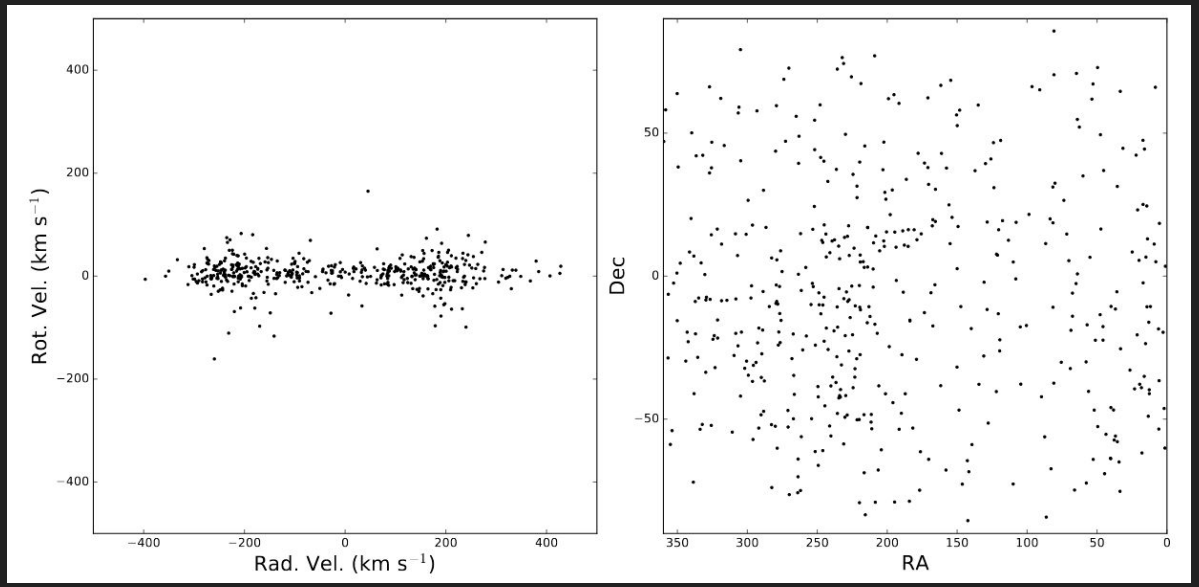
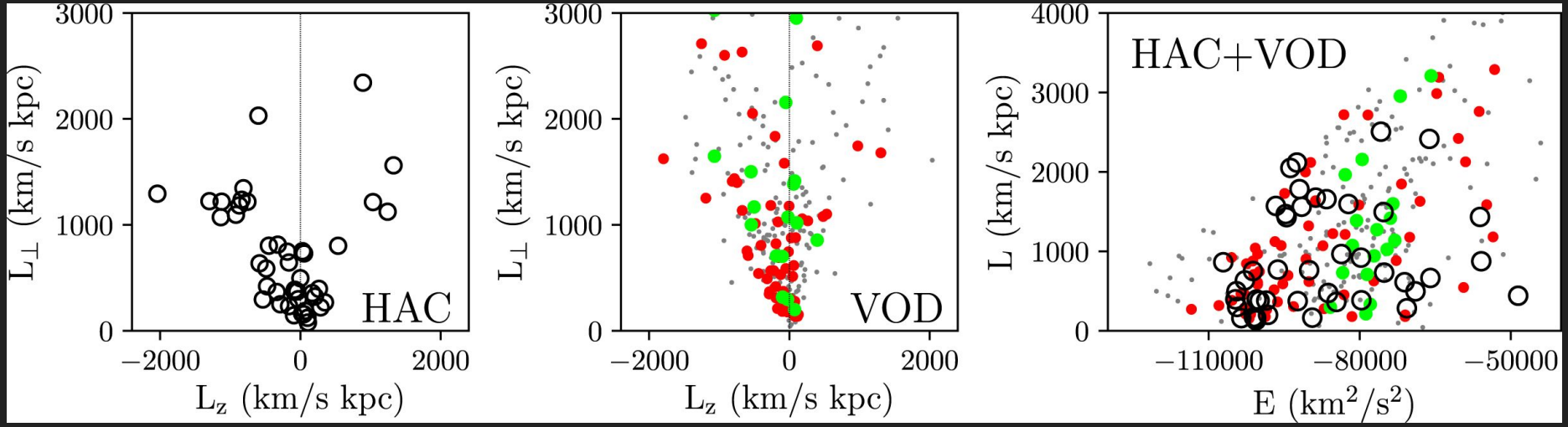


Figure from Belokurov et al. (2018)



N-body results for VRM (100k, cut to local solar region) Donlon et al. (Submitted)

HAC and Virgo being connected is not a new idea.



Simion et al. (2019)

What are the Implications of the VRM?

- What would a 10^9 solar mass merger passing through the Galactic center 2 Gyr ago do to the bulge, bar, and disk?
  - Minchev et al. (2009) and D'Onghia et al. (2016)
- How much does the mass distribution of the Galactic center effect the N-body simulation?
- Is it possible to have a GEM and a VRM or do they have to be from the same merger?

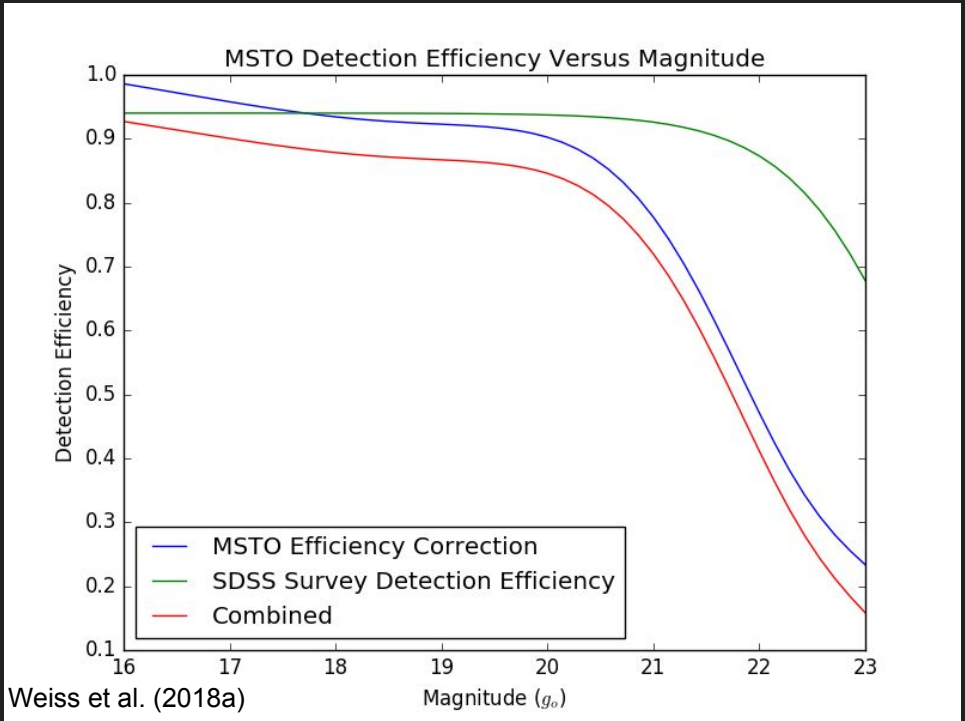
Conclusions

- Statistical Photometric Parallax is capable of discovering new substructure like the Perpendicular Stream.
- We have found strong evidence that the Perpendicular and Parallel streams can account for most moving groups in the Virgo Overdensity.
- We found evidence that might link both the Perpendicular and Parallel streams to each other, HAC, and Eridanus-Phoenix.
- Possible that the Virgo Radial Merger is the same as the Gaia-Sausage/GEM although the reported ages of the two structures do not agree. There is still work to be done here.

Questions?

Model - Detection and Selection Efficiency

- Model SDSS detection efficiency with Sigmoid curve
- Newby et al. (2011) MSTO selection effects on completeness
- Found a correction for the original detection efficiency



Weiss et al. (2018a)