Exploring the Structure of the Milky Way with WFIRST

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Simulation: Stefan Gottlöber/AIP

Image Credit: Heidi Newberg

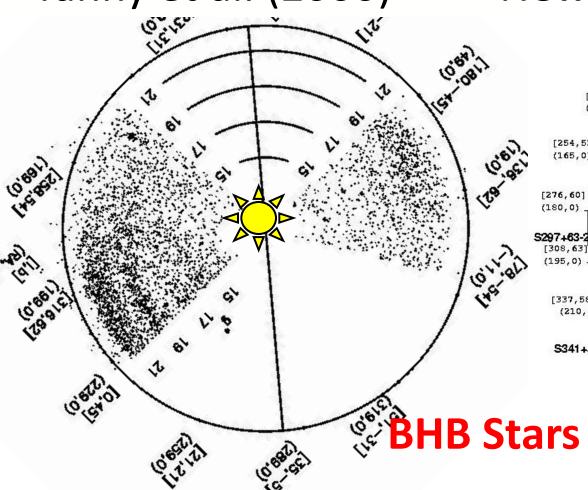
Milky Way Structure – we want it all:

- The Milky Way covers the entire sky (need large area).
- It is the only galaxy we can see in full 6D phase space (angular position, distance, proper motion, line-of-sight velocity. Star velocities are ~200 km/s, and substructure is ~10 km/s
- We also want type of star, metallicities (all elements), stellar populations/ages.

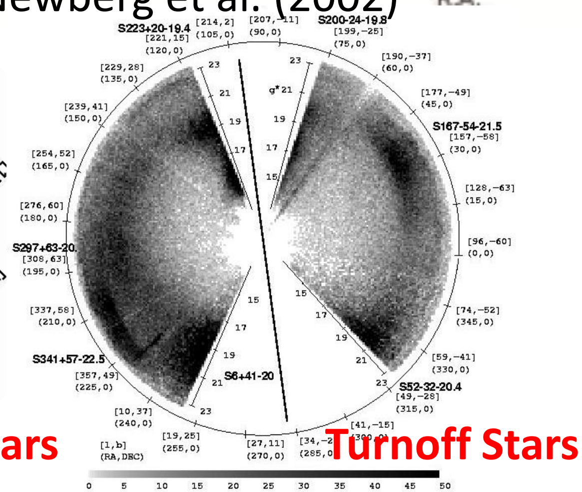
Next up: Why do we want it?

Grillmair & Carlin (2016)

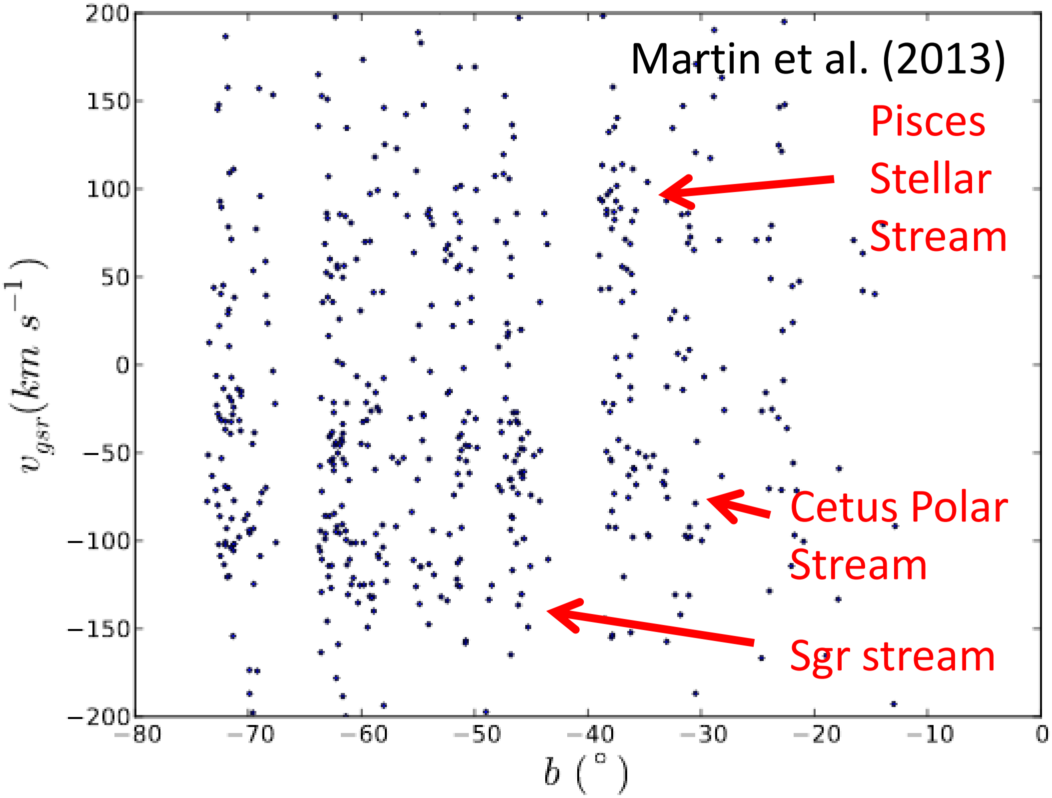
Yanny et al. (2000)



Newberg et al. (2002)



Having higher density stellar tracers, and having tracers that are present in all populations, makes a big difference.



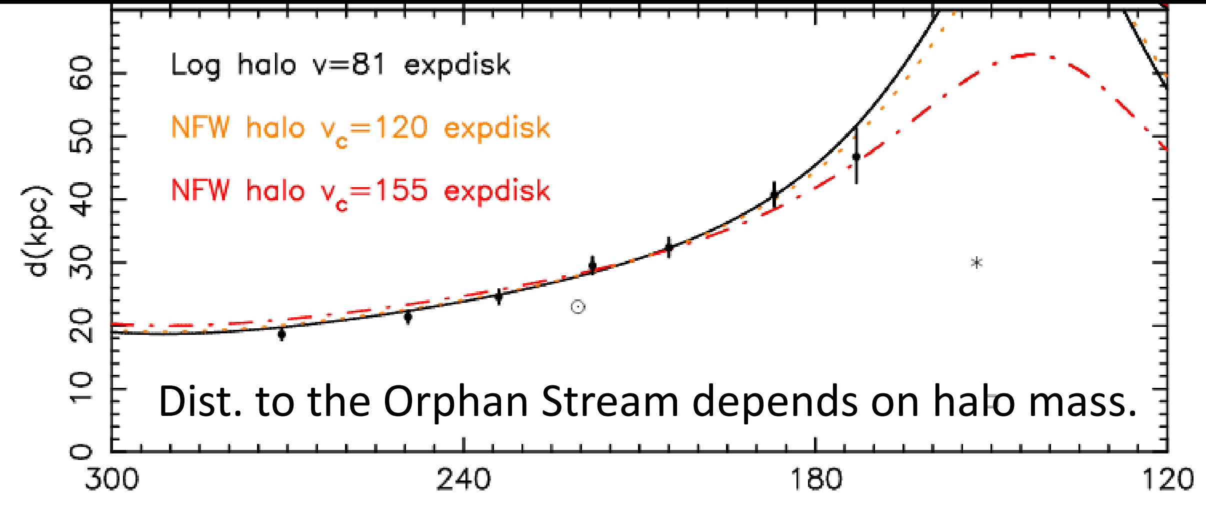
Metal-poor giant stars in SDSS, showing two large streams, and the discovery of a new stream that is elongated in Galactic longitude, and thus looks compact in this figure.

When velocities are available (with accuracies of 10 km/s or better), smaller tidal streams can be identified.

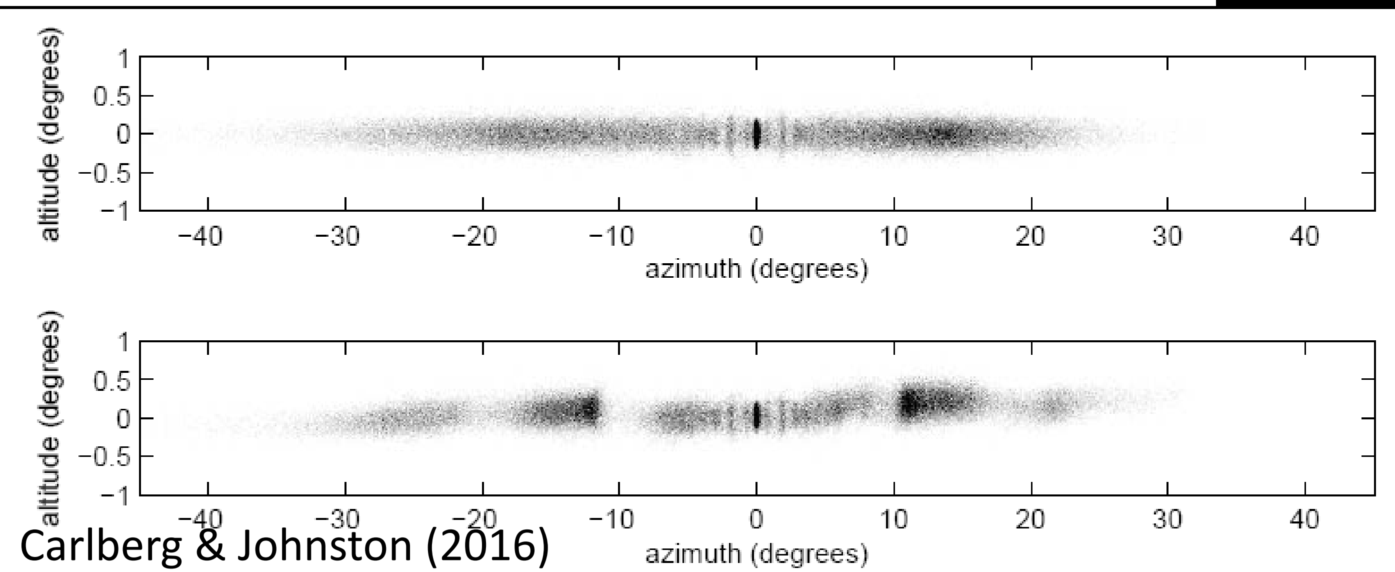
Note: We find streams with fewer than ten stars with spectra.

Getting at Dark Matter:

The orbits of the stream stars depend on the Galactic potential, and the widths and gaps depend on the lumpiness of the halo.

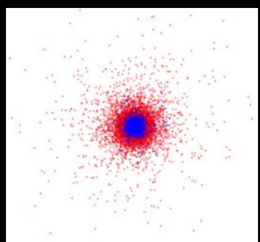


Newberg et al. (2010)

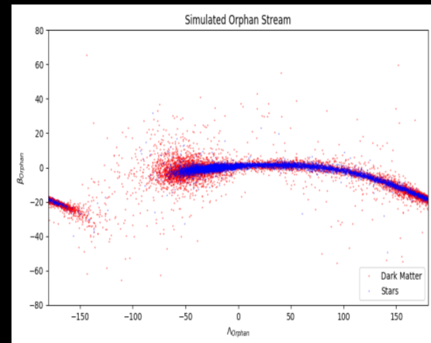


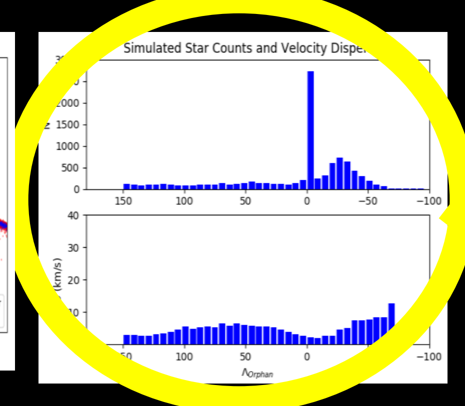
Carlberg & Johnston (2016)

Next: My group is gearing up to measure the dark matter distribution within the Milky Way using MilkyWay@home!

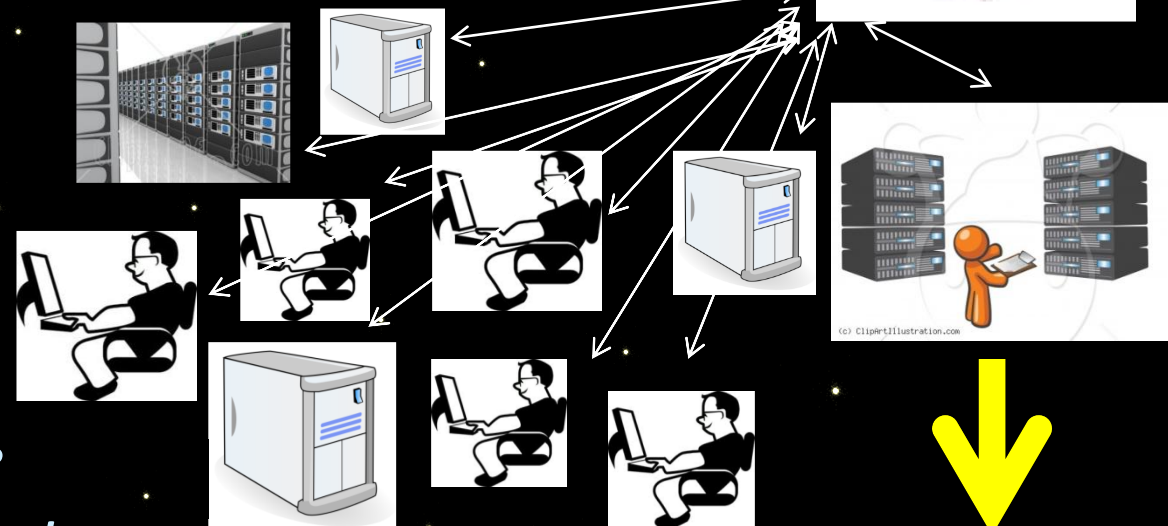


3.95 Gyr





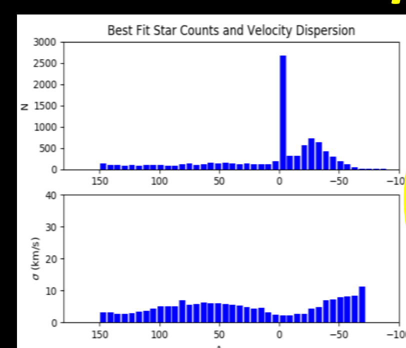
Simulated data

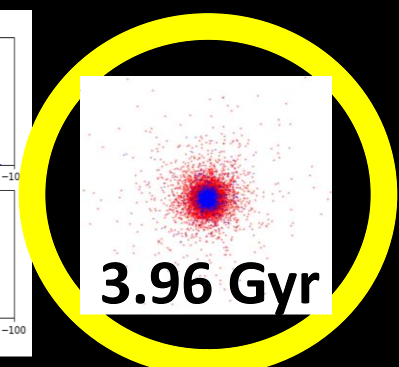


MilkyWay@home

also fits the mass and radial profile of both the dark matter and stars in the dwarf galaxy progenitor of a tidal stream (four parmeters plus time), given the density and velocity dispersion along the stream.

Fit Parameters



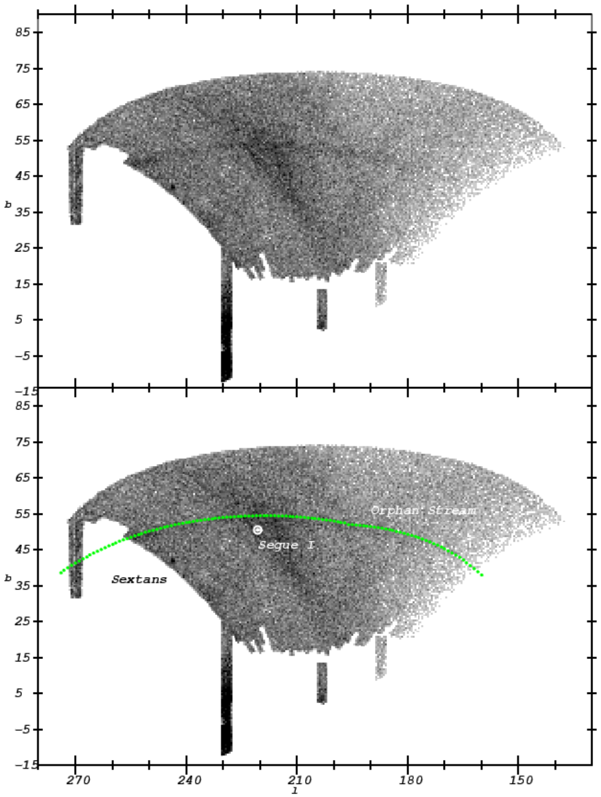


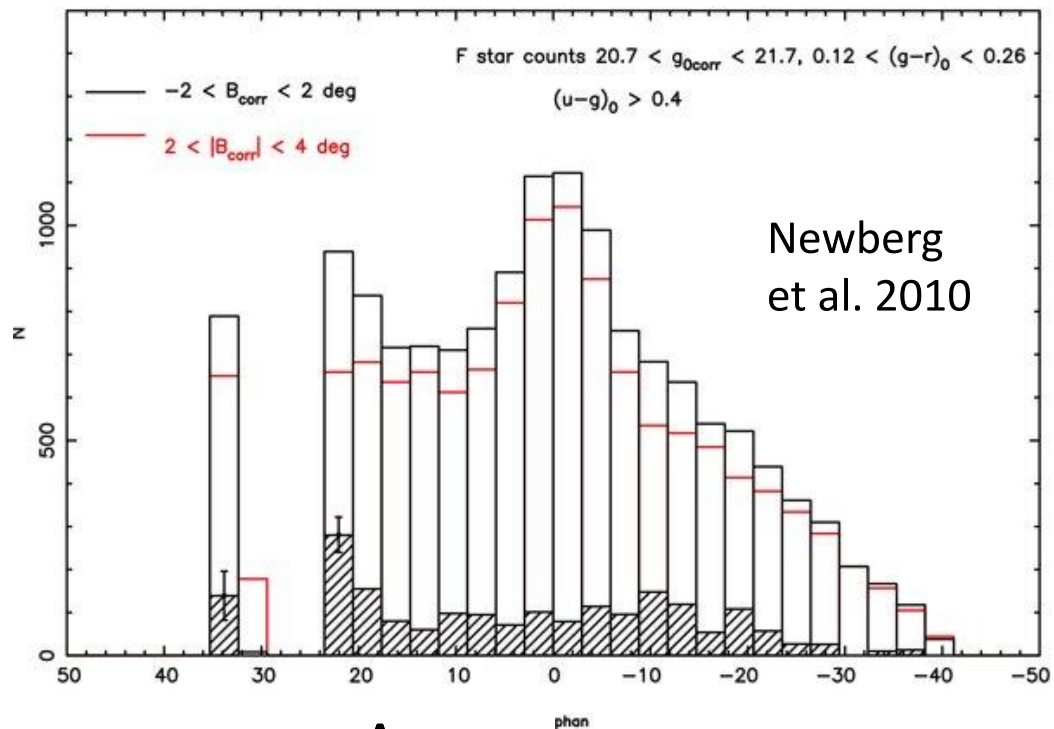
3.96 Gyr

Additional things to model….

- Simultaneous fitting of orbit, Milky Way potential, and progenitor properties
- Different density profiles/properties of the dwarf galaxy progenitors
- Milky Way potential could vary radially, be triaxial or lumpy, and change with time
- Dynamical friction affects dwarf galaxy orbits

This is in principle tractable because there are very many parameters that could be constrained by an enormous number of stream stars from multiple streams.

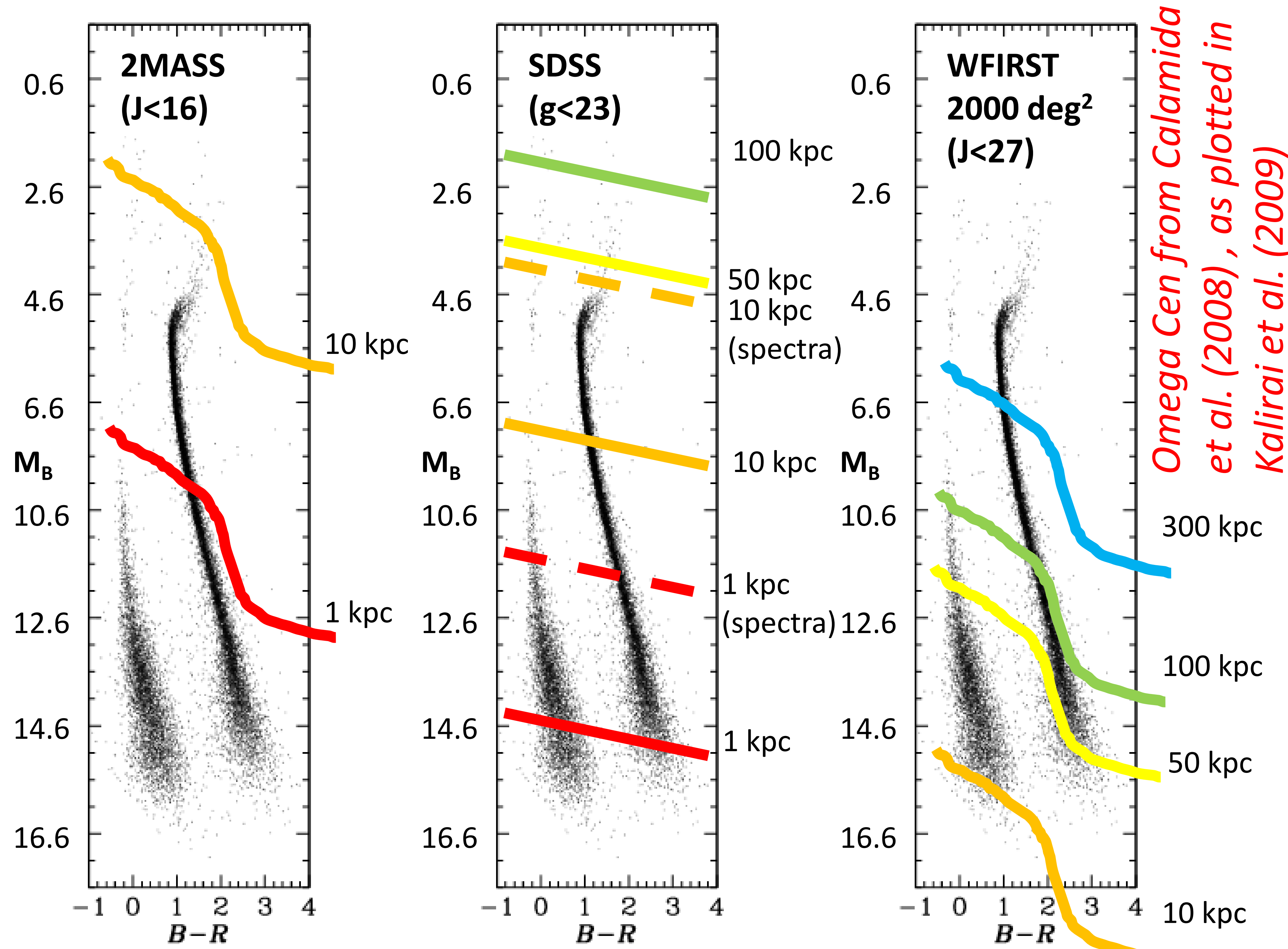


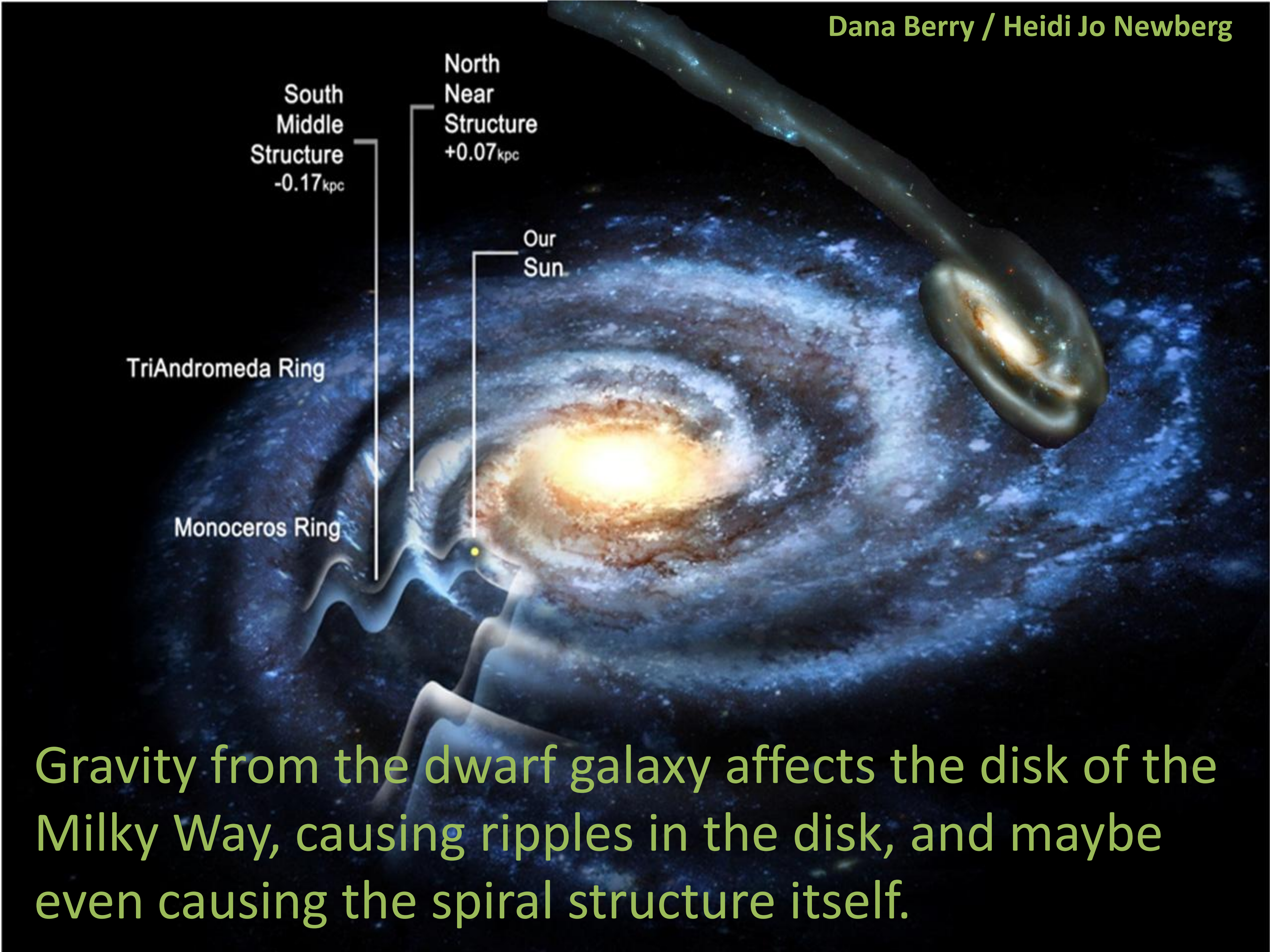


Λ_{Orphan}

Density of F turnoff stars along the actual stream is found by subtracting the density of stars along the stream in the correct magnitude range from the density of stars in an adjacent region in the same magnitude range.

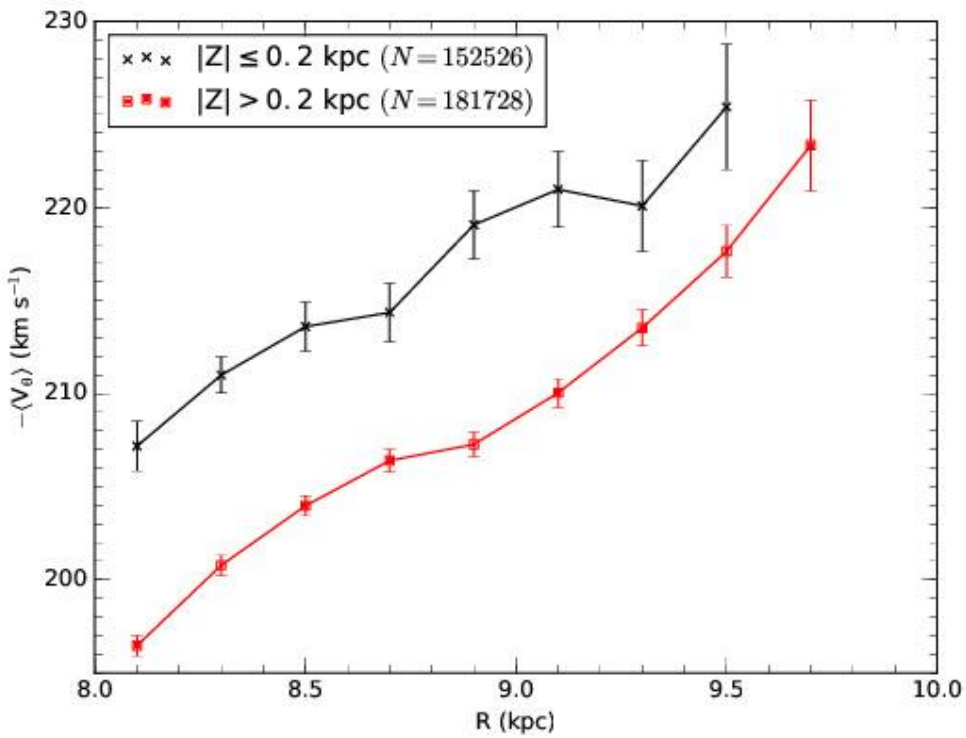
For faint streams the density histogram is quite noisy. The difference in error with larger number of stream stars could be modeled with MilkyWay@home. Proper motions of stream stars (from WFIRST) could also cut down the background. If we could measure the 2D histogram, then velocity dispersions would not be needed.

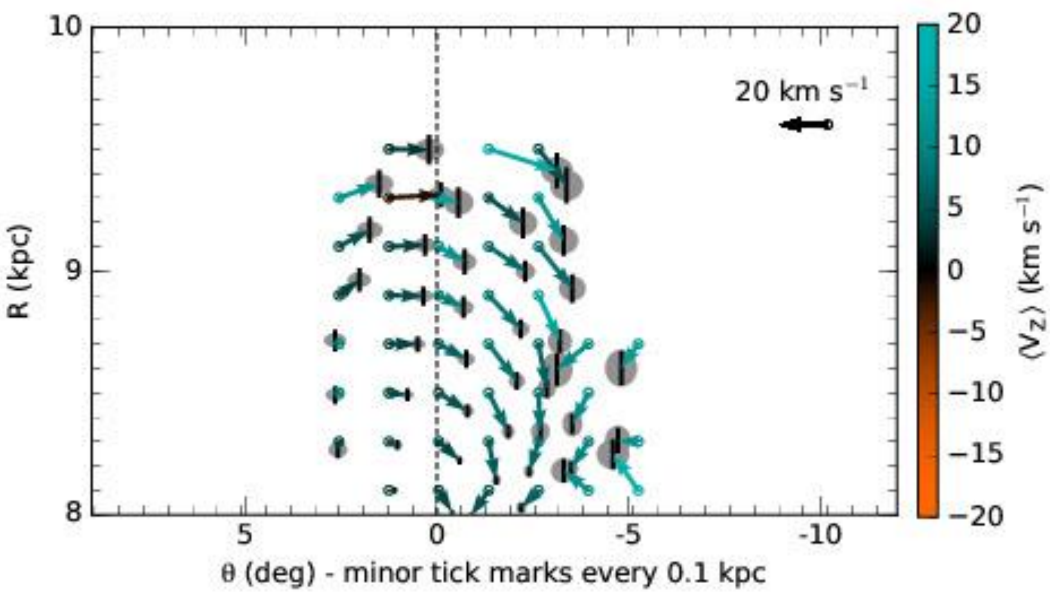

2MASS
(J<16)
SDSS
(g<23)
WFIRST
2000 deg^2
(J<27)
0.6
2.6
4.6
6.6
M_B
10.6
12.6
14.6
16.6
−1 0 1 2 3 4
B−R
10 kpc
1 kpc
100 kpc
50 kpc
10 kpc
(spectra)
10 kpc
1 kpc
(spectra)
1 kpc
300 kpc
100 kpc
50 kpc
10 kpc
Omega Cen from Calamida et al. (2008), as plotted in Kalirai et al. (2009)



Dana Berry / Heidi Jo Newberg

Gravity from the dwarf galaxy affects the disk of the Milky Way, causing ripples in the disk, and maybe even causing the spiral structure itself.

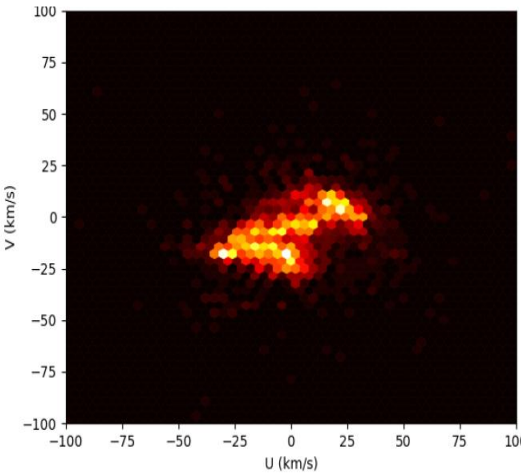




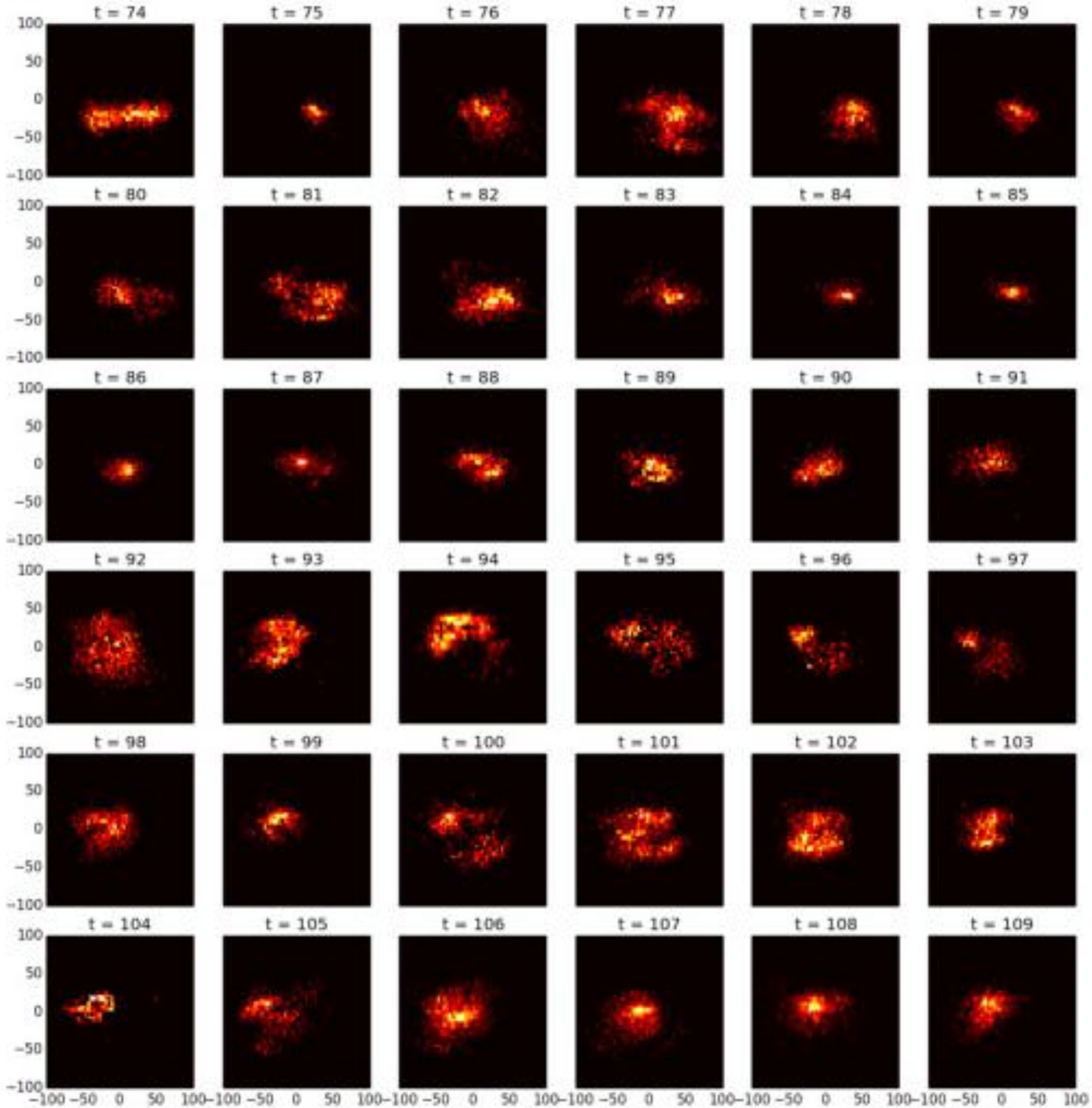
Pearl et al. (2017)

Using LAMOST radial velocities and recalibrated PPMXL for ~340,000 turnoff stars towards the anticenter, show:

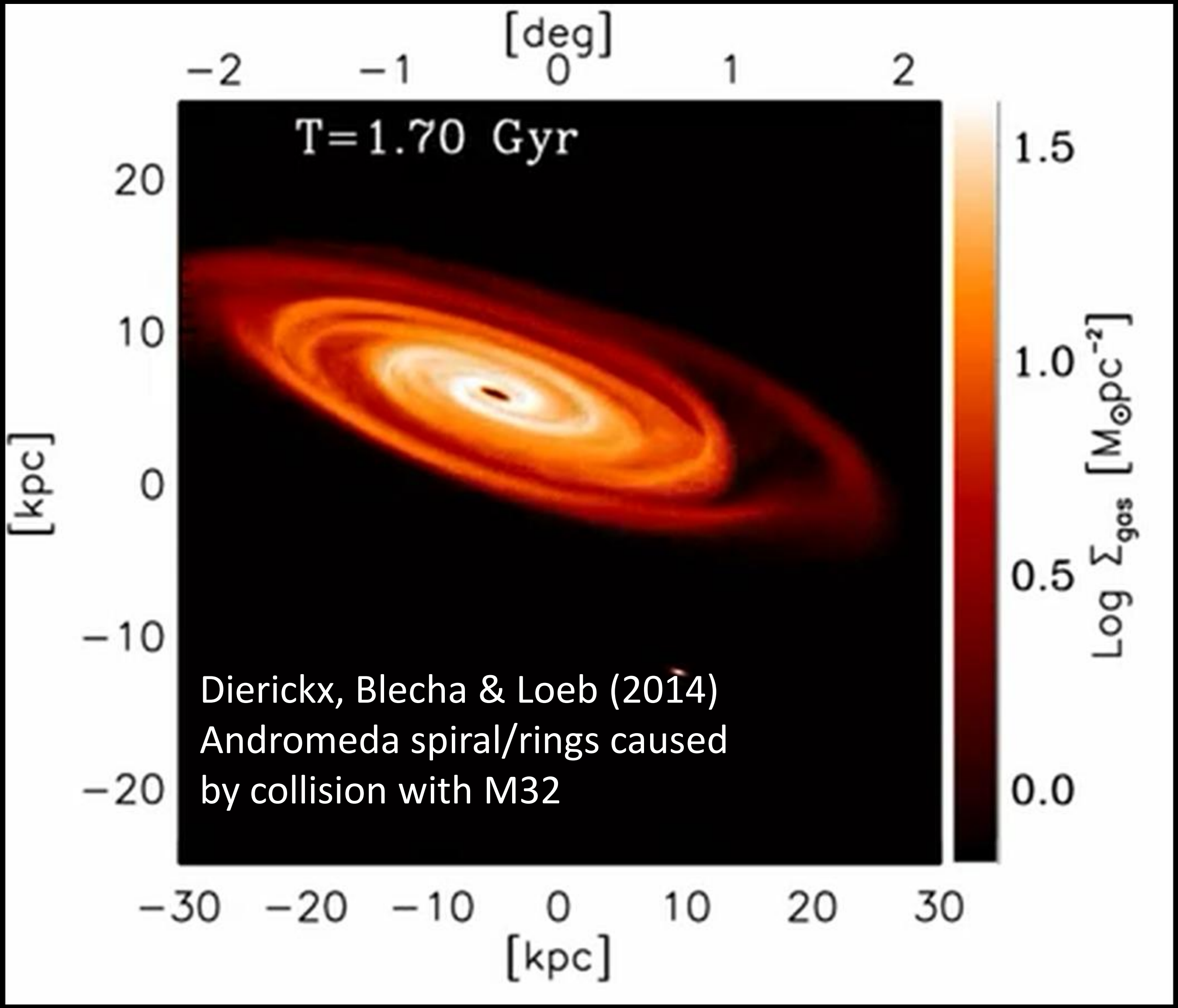
(1) Bulk velocity of order 10 km/s over length scales of 0.5 kpc or less.
(2) Rotation velocity increases with distance from the Galactic center.
(3) looking down on the disk, the stars appear to move in a circular streaming motion



UV plane of local Milky Way from Hipparcos data. Craig et al., in prep



UV plane at Sun-like position in hydrodynamic simulations of Sukanya Chakrabarti.



The disk substructure includes spiral arm-like density substructure that could be investigated with a GO program in WFIRST.

General Observer Science

- **Dwarf galaxies** – proper motions/orbits of known dwarf galaxies would be great. Tracing the structure out much farther than the half light radius make these an obvious project. This would help inform the orbits of known subhalos.

  1 field per DG in four colors for ~25 galaxies x 1 hour x 2 epochs = 200 hours

  Note: the Sgr dwarf galaxy would take 200 pointings to map….

- **Sampling across the width of known tidal streams** – The spread of stars across the stream, especially in the tails, is caused by the interactions with substructure as the stream stars orbit the Milky Way. *A few square degrees on one key stream, up to the entire sky, in one filter. WFIRST provides the proper motion and star/galaxy separation. LSST provides optical photometry and variability. If we could get proper motions (two or more epochs) that would help immensely.*

- **Disk substructure near the anticenter** – One degree is .2 kpc at a distance of 11 kpc. We could look at the velocity substructure of the disk at the distances of Monoceros and TriAnd, and look for stars between the two "rings" and beyond. Observations at the beginning and end of the survey would be important so that we could get 50μas/year proper motion measurements to see velocity substructure out to 20 kpc (or possibly to the edge of the disk). IR and small PSF are key.

  WFIRST would provide the proper motion, star/galaxy separation, infrared photometry in 2? filters. 10 sq. deg. (2 epochs) would help, 100's of sq. deg. Is better. Consider a depth 3 magnitudes brighter than high latitude field?