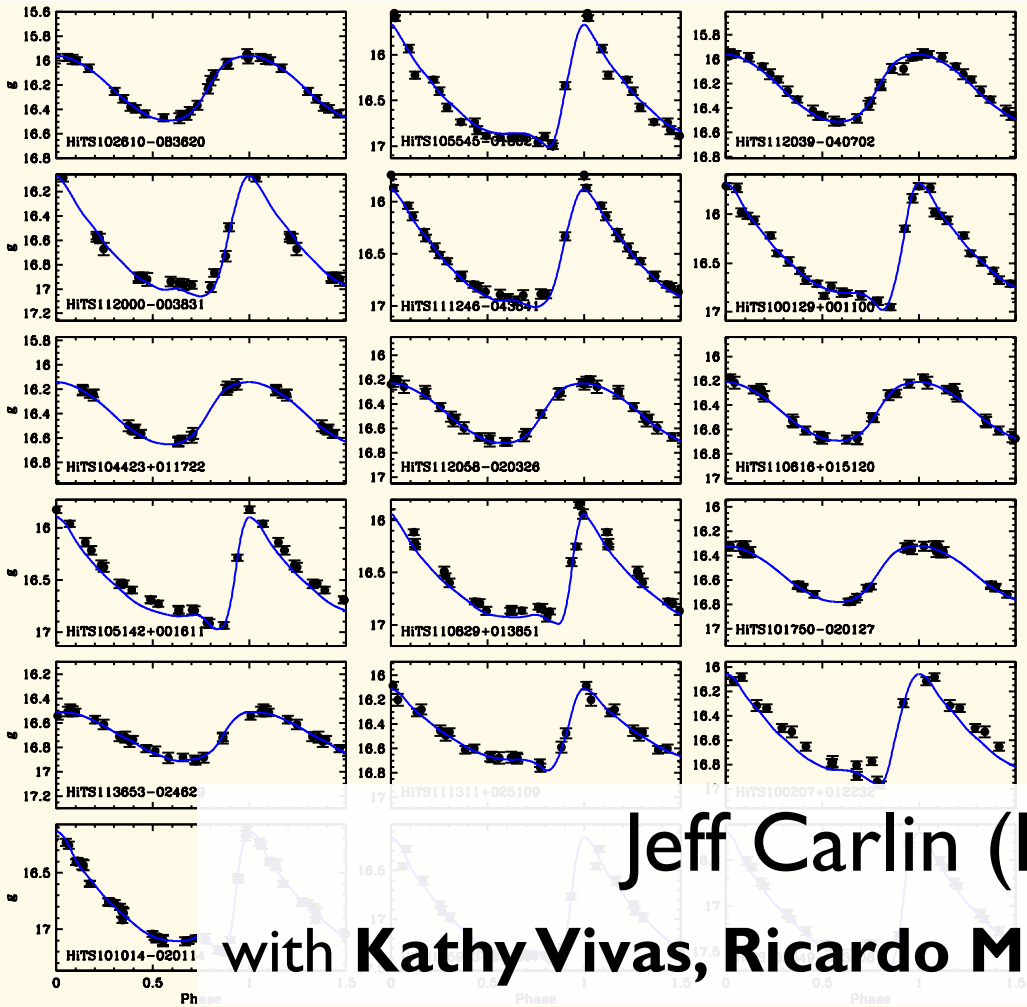
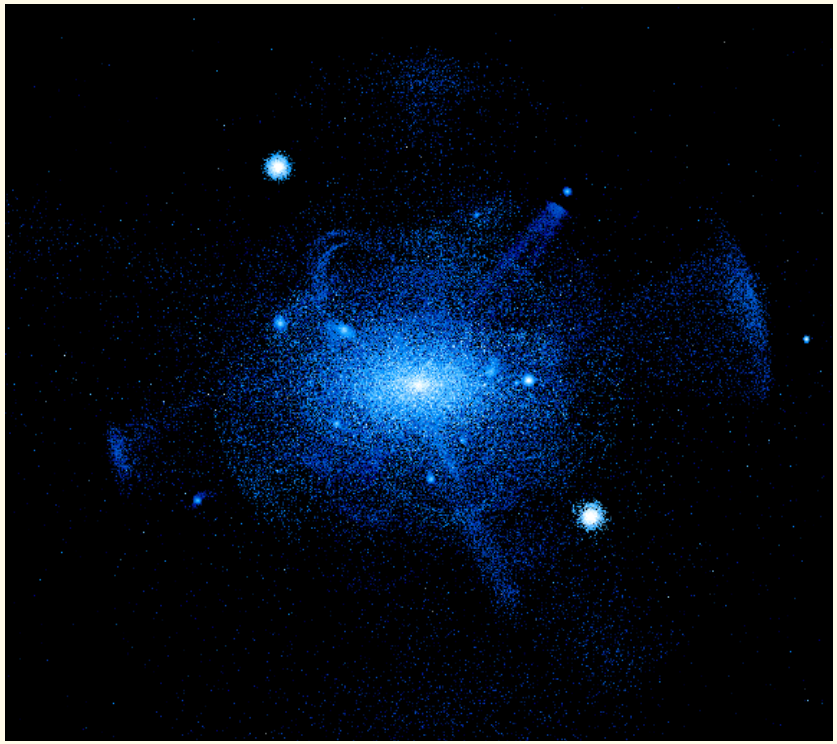
Probing the halo of the Milky Way beyond 100 kpc with RR Lyrae stars





Jeff Carlin (LSST)

with **Kathy Vivas, Ricardo Muñoz**, Gustavo Medina

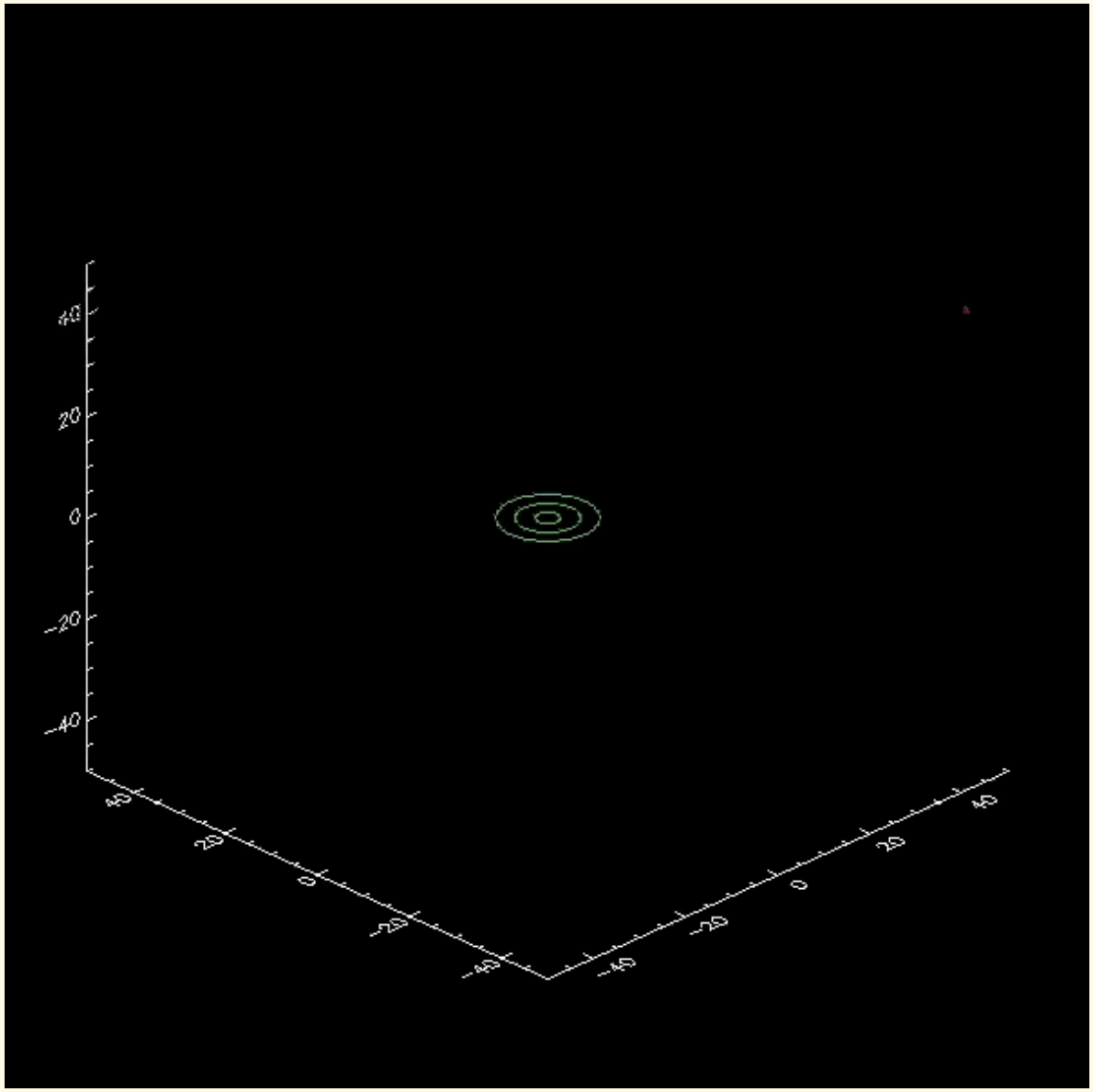
Why distant RR Lyrae stars?

- Outer halo should contain *lots* of faint dwarf galaxies
- Every dwarf that has been searched contains at least one RR Lyrae star
- Stellar density of the halo probes the accreted population of satellites
- Mass modeling of the Milky Way is constrained most strongly by the outermost probes

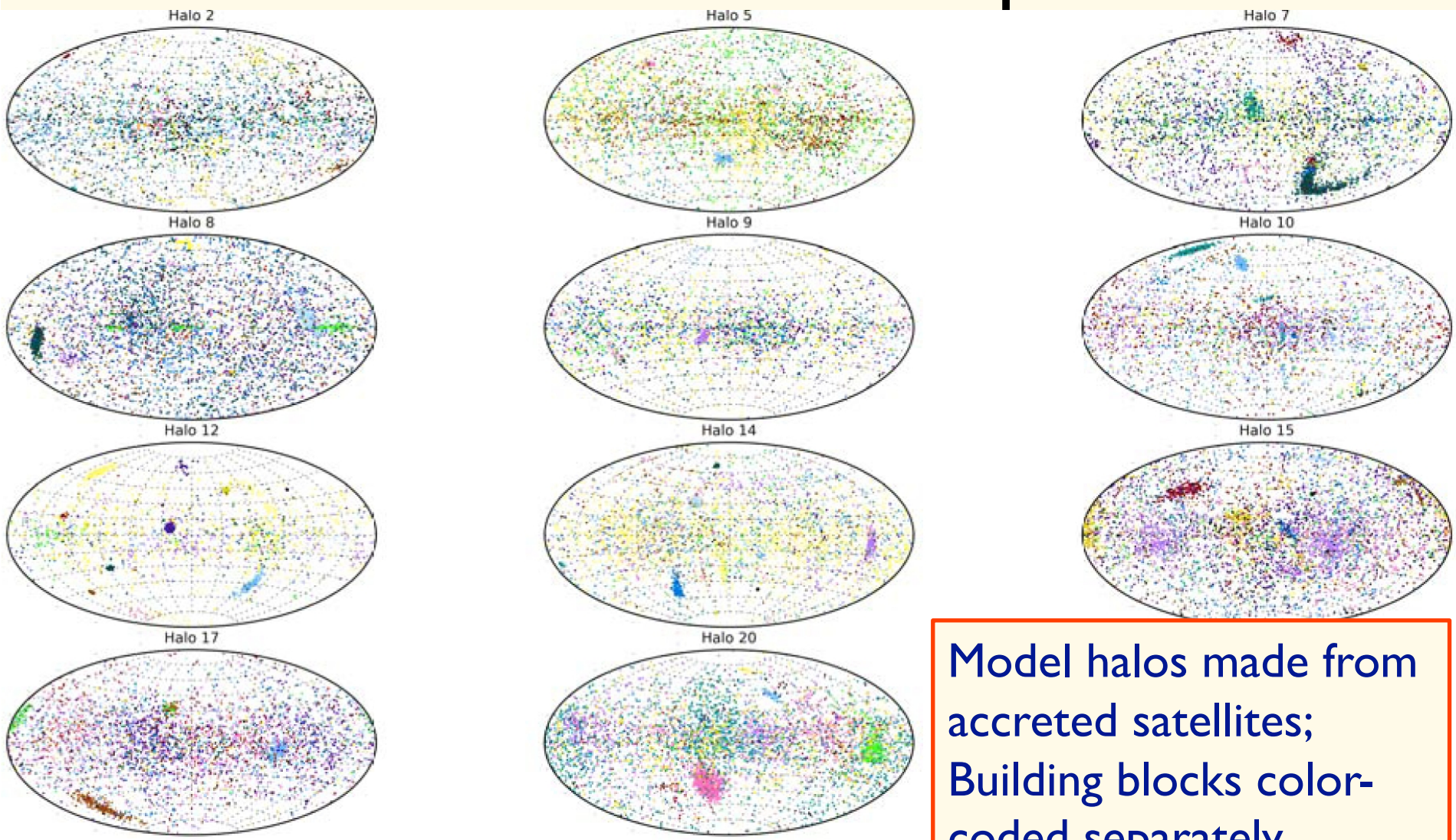
Building up the Milky Way halo

Models predict that the Milky Way should have accreted and subsequently tidally destroyed hundreds of low-mass galaxies in the past ~12 Gyr.

(e.g. Bullock & Johnston 2005, ApJ, 635, 931)



Simulated (accreted) stellar halos at d > 100 kpc

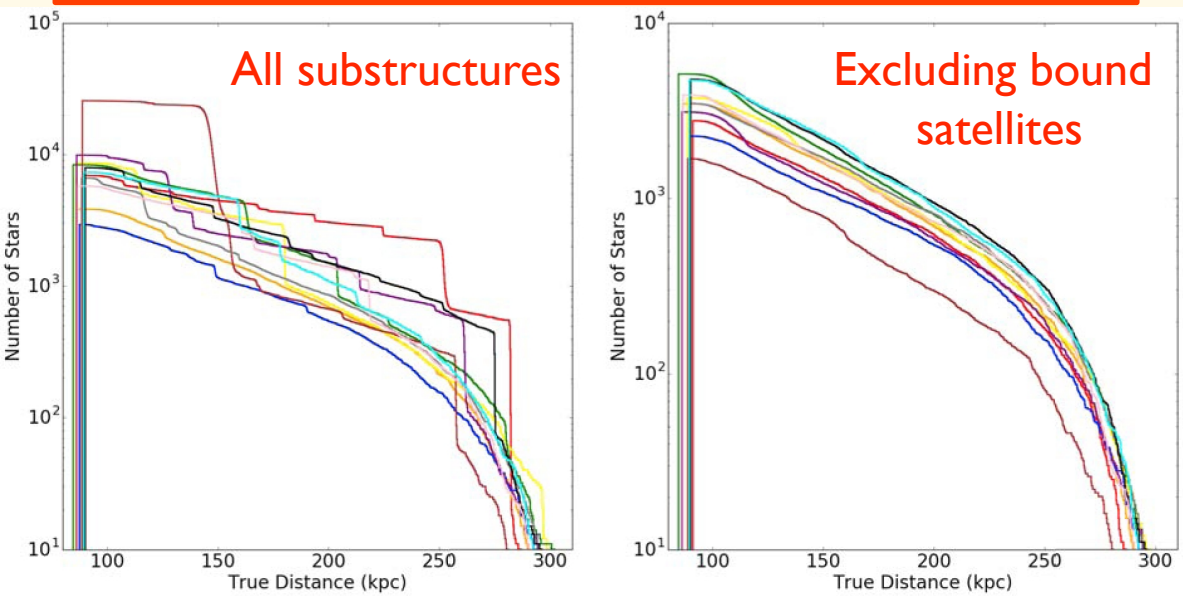


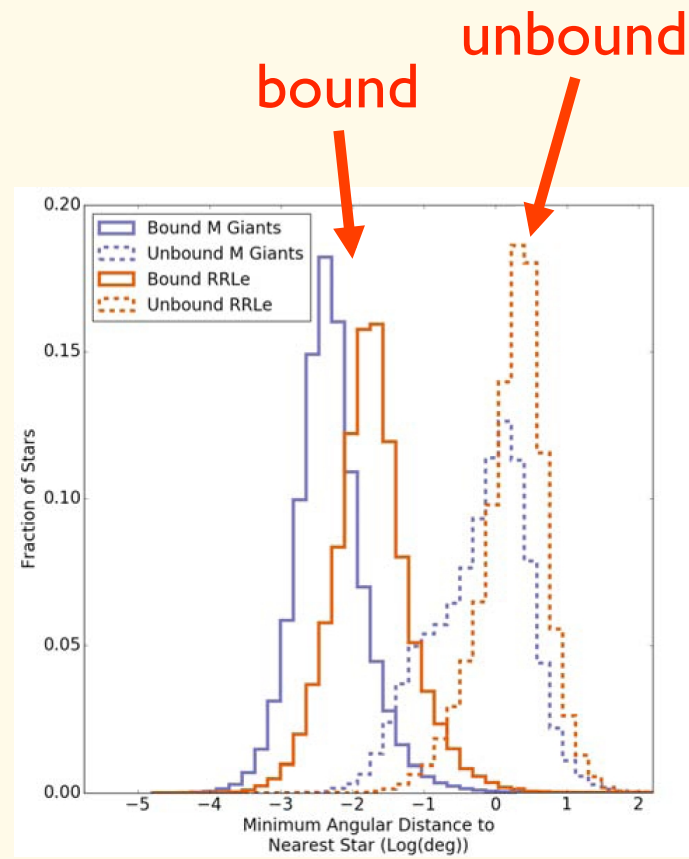
Model halos made from accreted satellites; Building blocks color-coded separately

Sanderson+2017 (MNRAS, 470, 5014)

Simulated (accreted) stellar halos

Expect ~2,000-10,000 RR Lyrae stars between 100 < d < 282 kpc:



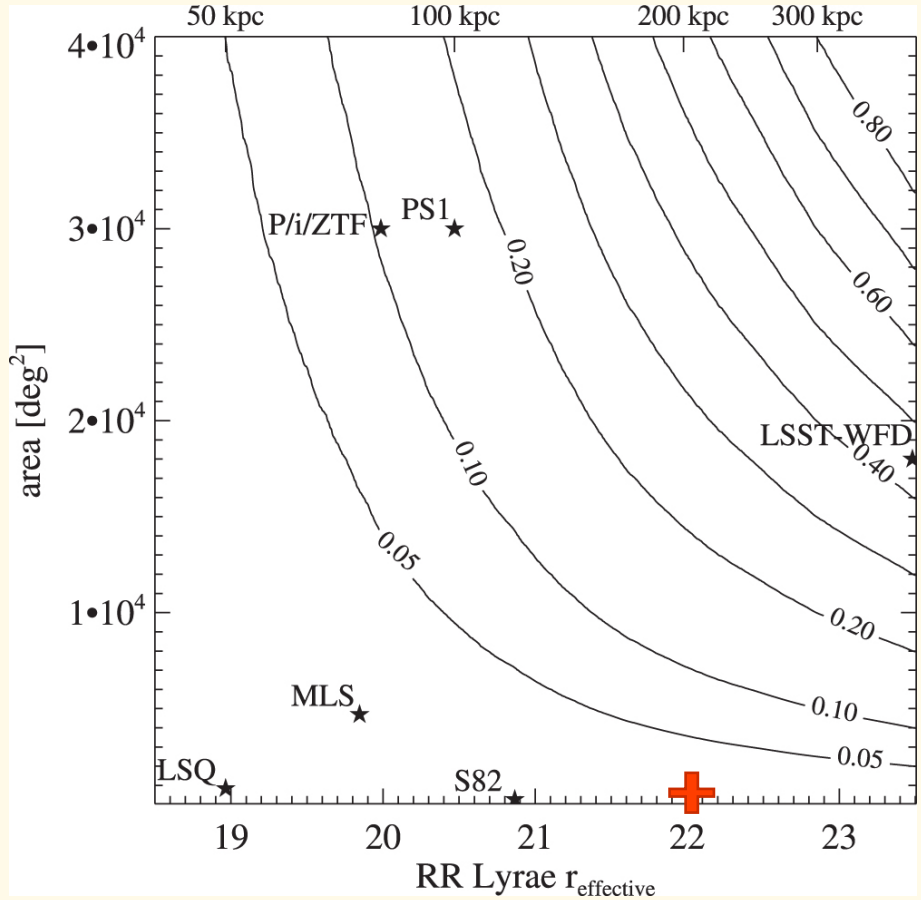


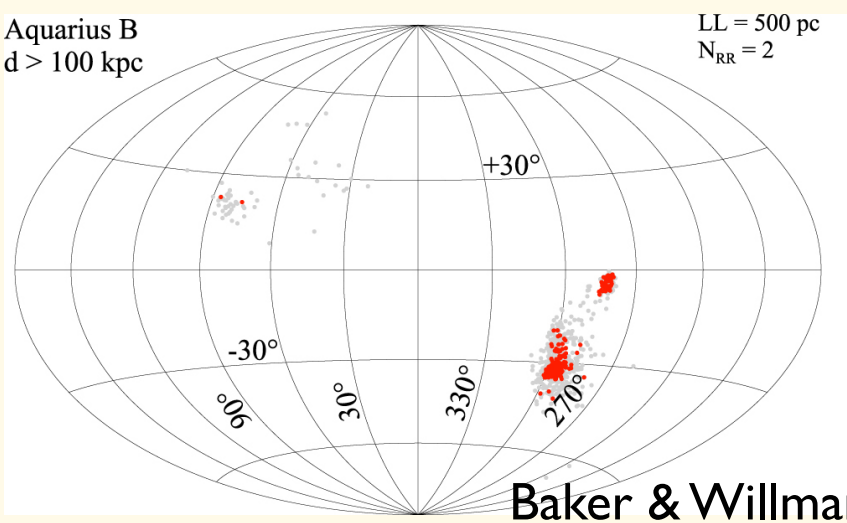
Stars in bound satellites will be ~1 arcmin from nearest star

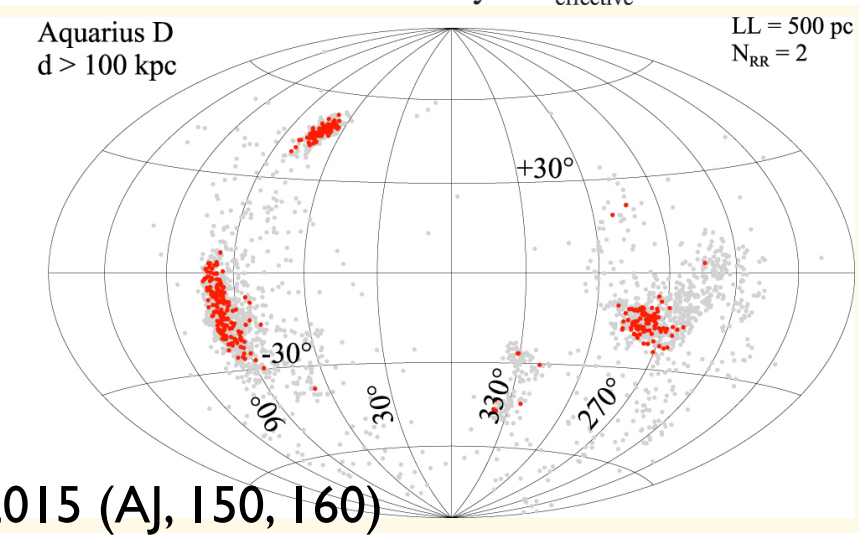
Sanderson+2017 (MNRAS, 470, 5014)

Simulated (accreted) stellar halos

Using Aquarius model stellar halos; ~1,000-6,000 RR Lyrae expected at d>100 kpc



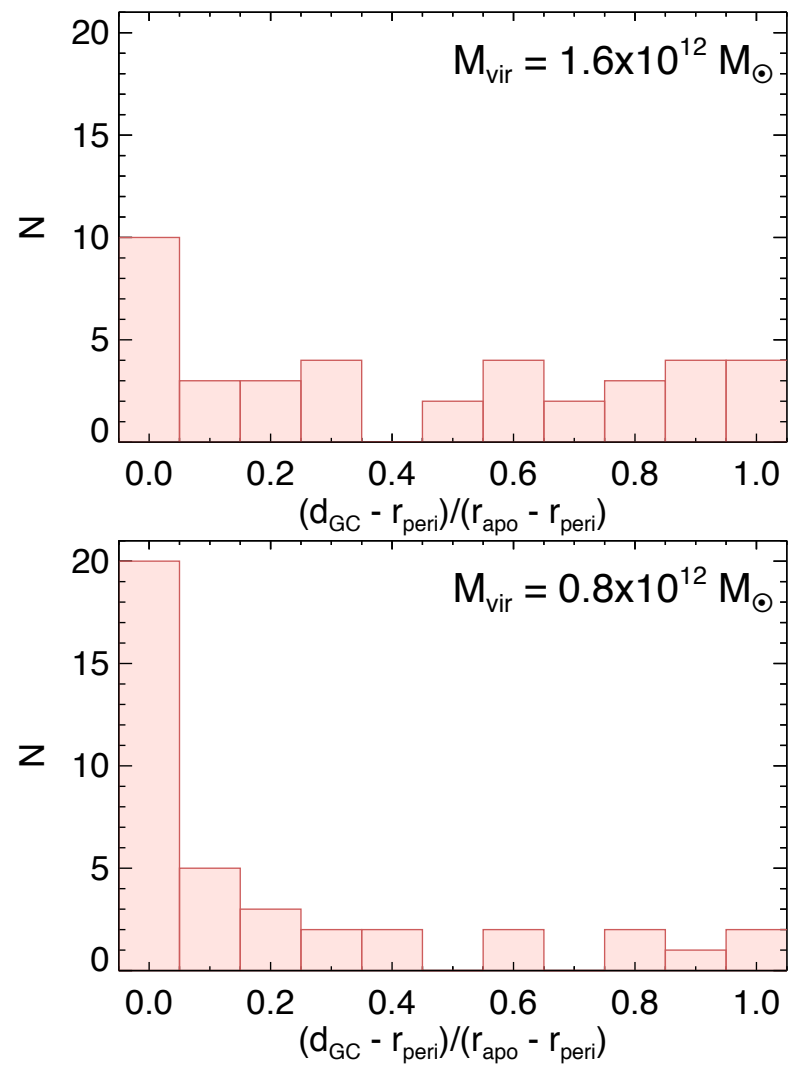


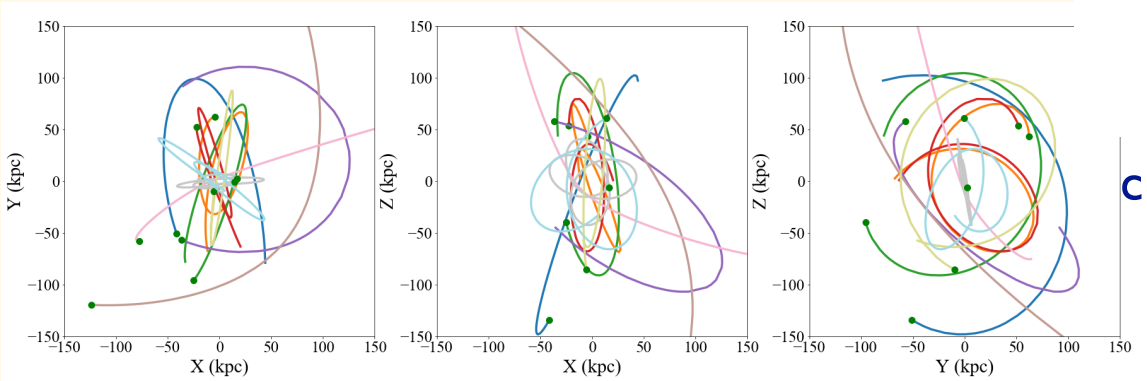


Baker & Willman 2015 (AJ, 150, 160)

Gaia DR2 orbits of MW satellites: More dwarf galaxies found near pericenter than apocenter – many more to be discovered?

Fritz+2018 (arXiv:1805.00908)

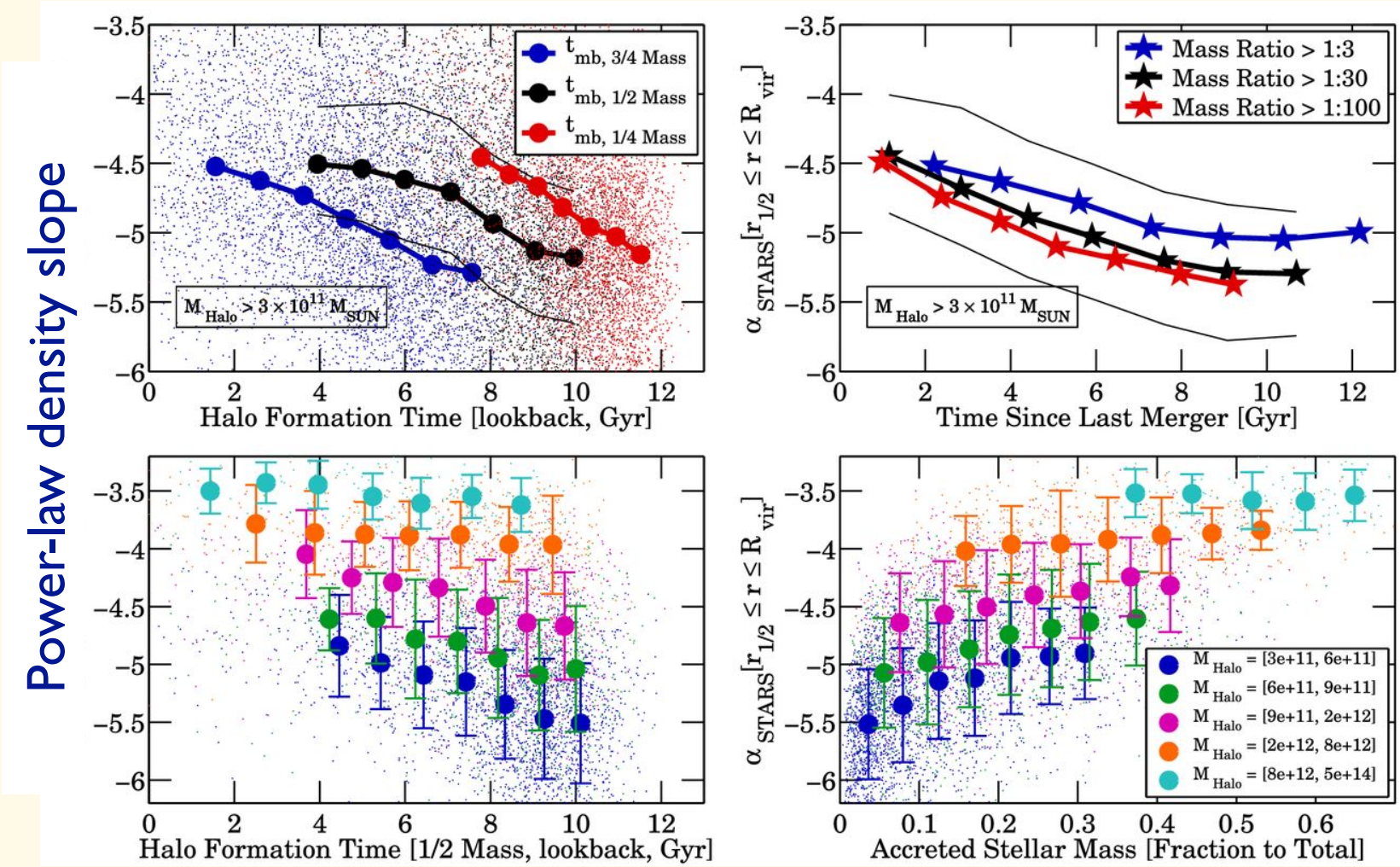




closer to peri ⟷ closer to apo

dSph orbits from Helmi+2018 (arXiv:1804.09381)

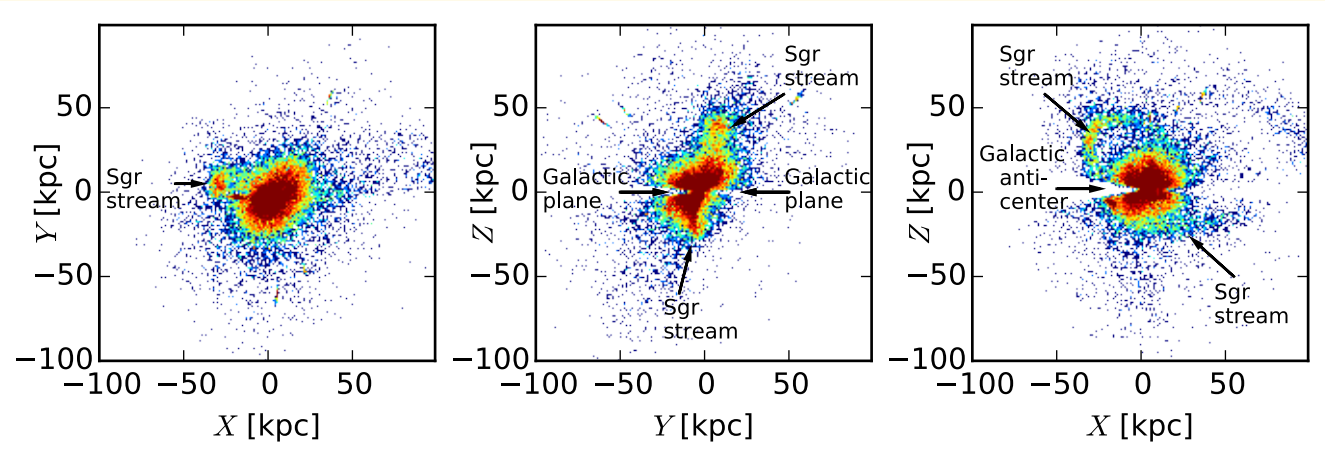
The slope of the halo density profile is sensitive to the host's mass and its accretion history



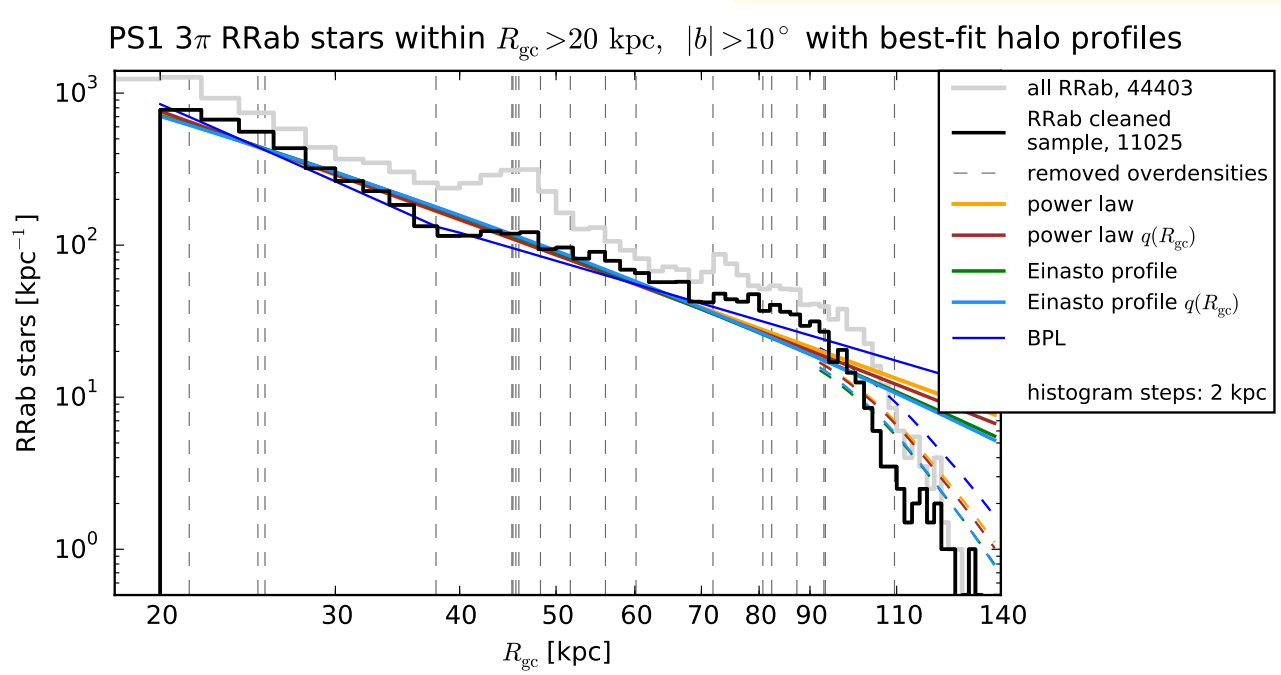
Based on Illustris simulations

Pillepich+2014 (MNRAS, 444, 237)

Measuring the MW halo density profile



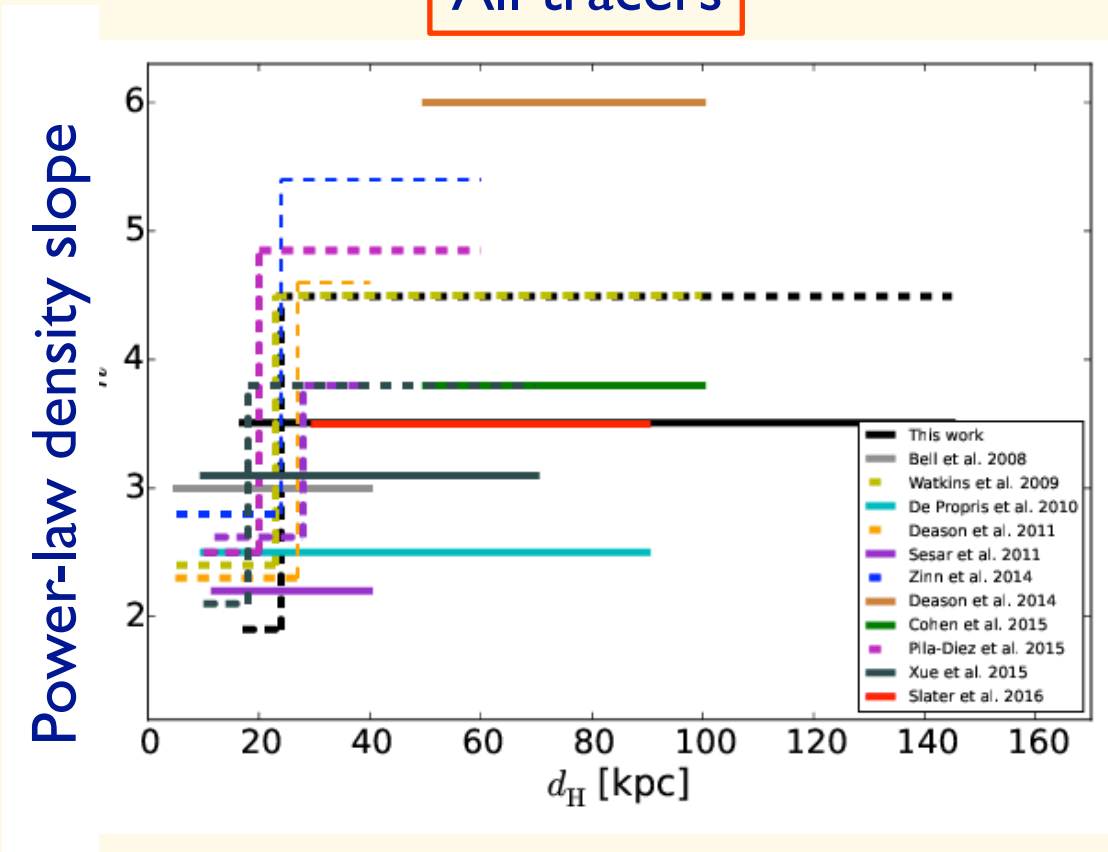
~44,000 RR Lyrae from PanSTARRS1



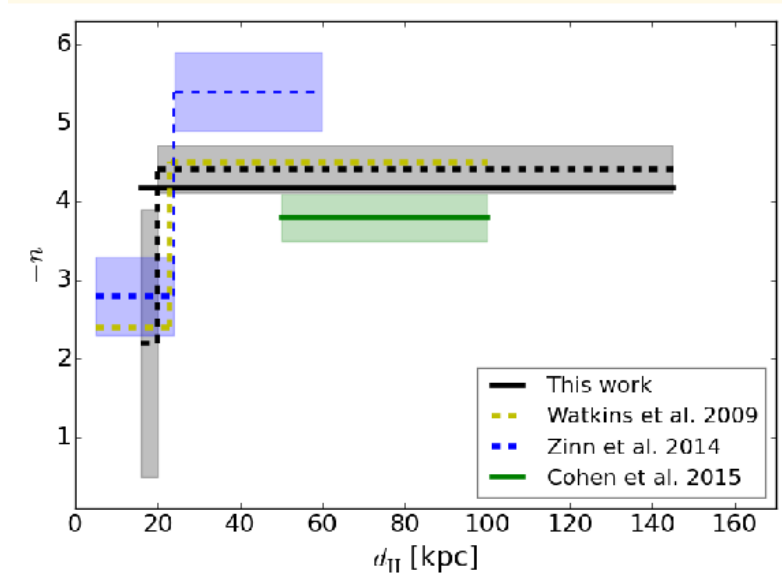
Hernitschek+2018 (arXiv:1801.10260)

Measured slope of the MW halo density profile

All tracers



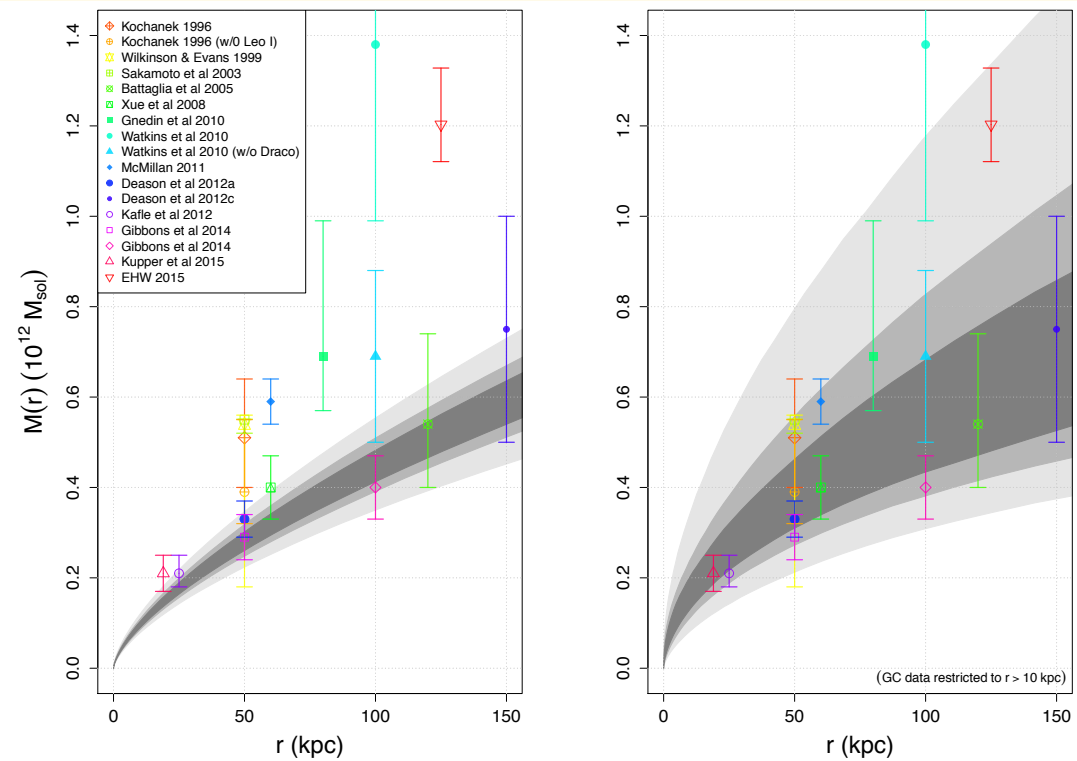
RR Lyrae only



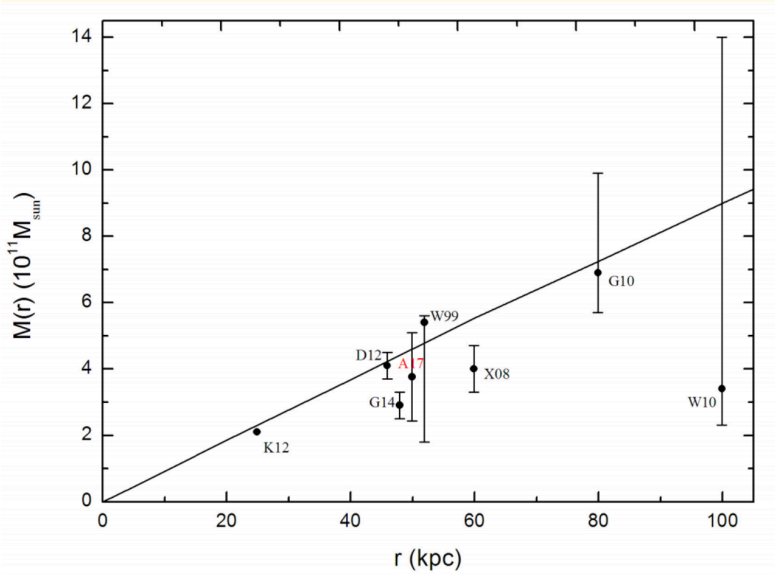
See summary table in Medina+2018 (ApJ, 855, 43)

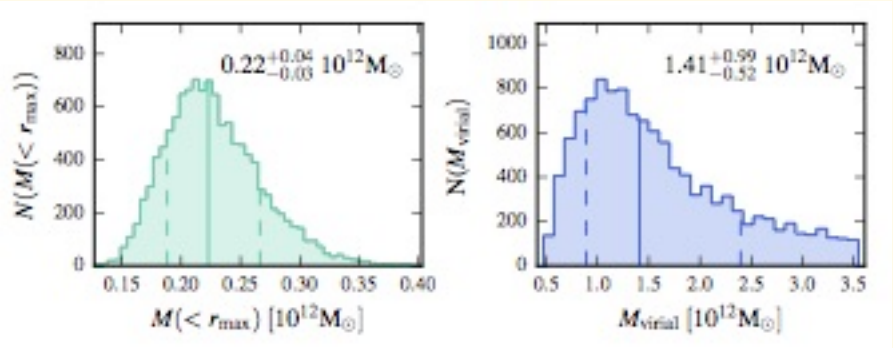
Milky Way mass estimates vary by a factor of ~2

MW mass estimated using globular cluster orbits
Eadie & Harris (2016, ApJ, 829, 108)



using RR Lyrae circular velocity curve:
Ablimit & Zhao (2017, ApJ, 846, 10)

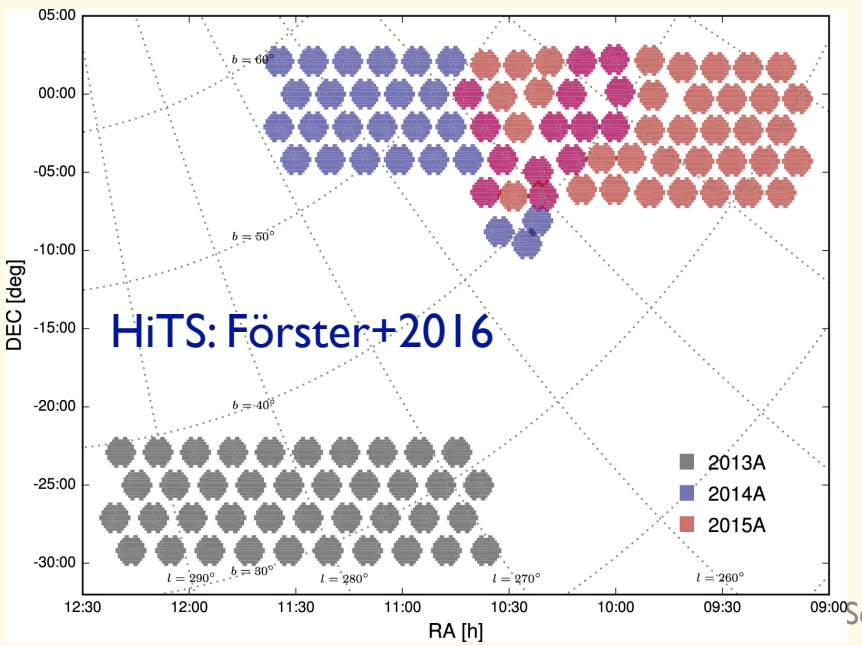




Gaia DR2 globular cluster orbits (R_{GC} < 40 kpc)
Watkins+2018 (arXiv:1804.11348)
(see also Posti & Helmi 2018 (arXiv:1805.01408)

Searching for outer halo RR Lyrae stars

- DECam's FOV makes mapping large areas efficient
- Started with archival data from the HiTS supernova survey (Förster+2016)
- ~20-30 epochs per field
- Have been awarded 7 nights (3 in 2017B, 4 in 2018A) via NOAO/CNTAC proposals (PIs: Carlin, Muñoz)



Status of survey/data

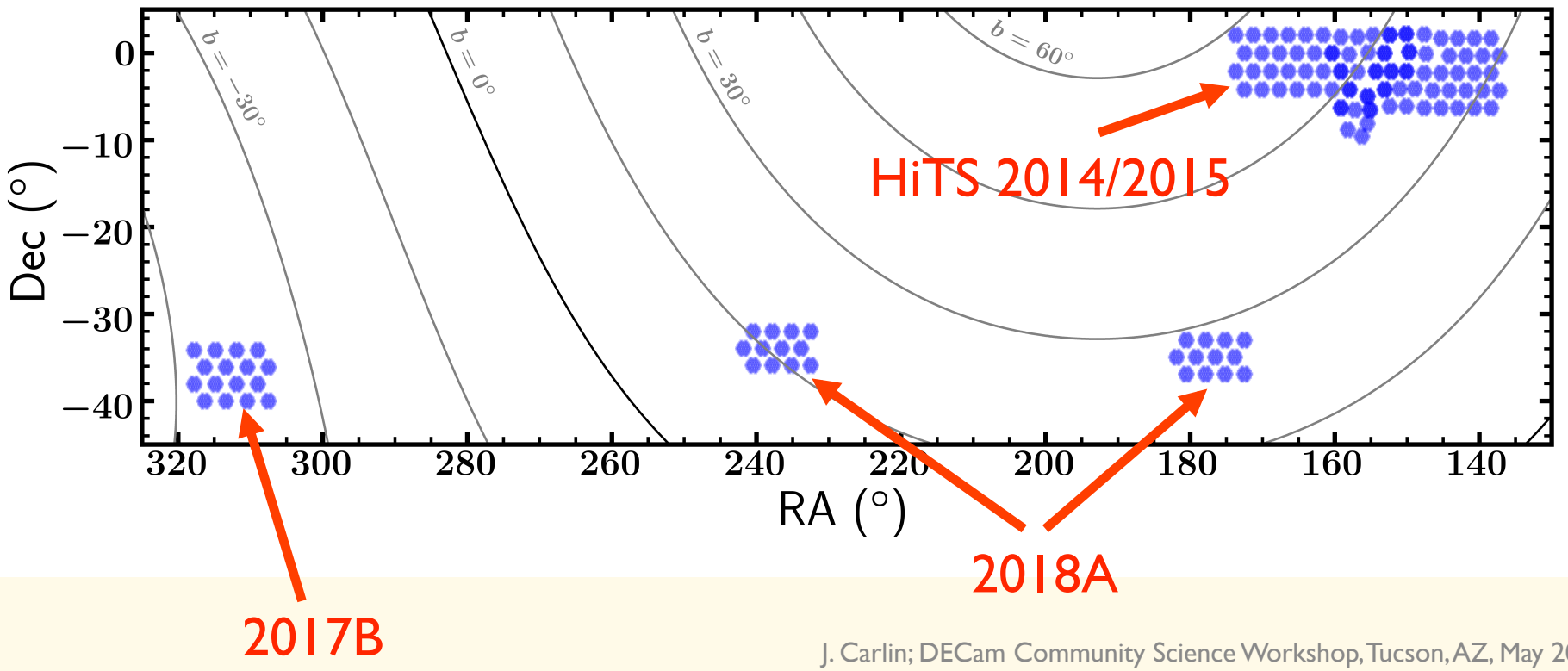
HiTS:

- 2014 campaign results published (Medina+2018, ApJ, 855, 43; Medina+2017, ApJL, 845, 1) ~120 deg^2
- 2015 analysis in progress ~110 deg^2

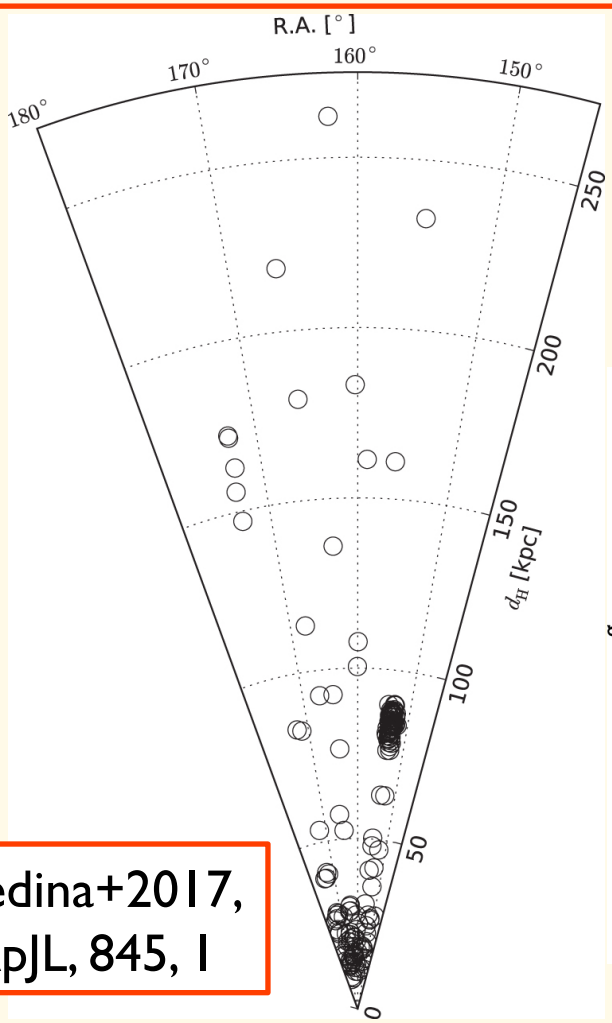
New DECam observing program (PIs Carlin, Muñoz):

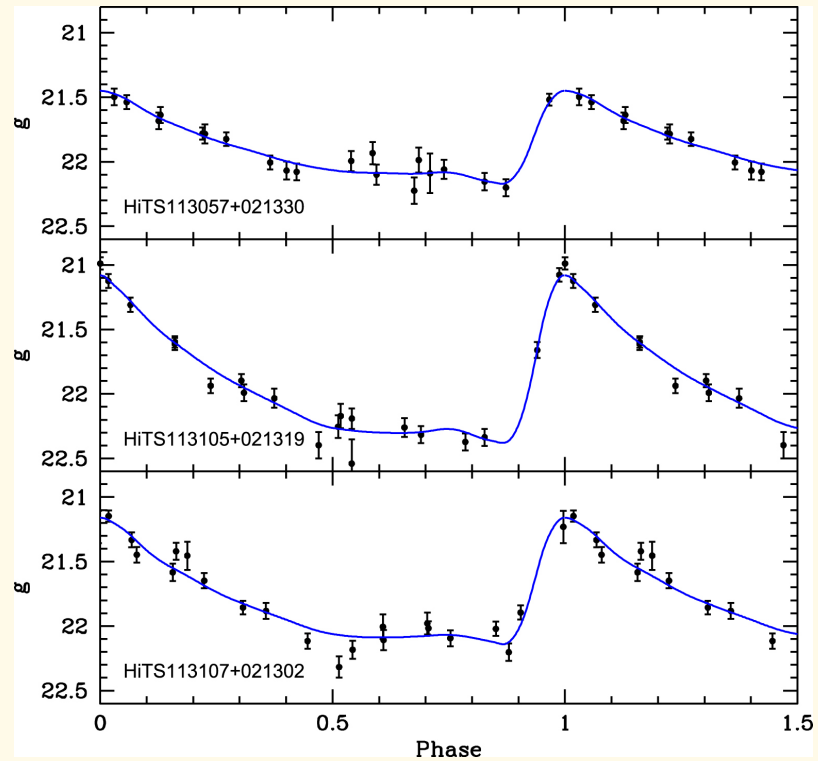
- 2017B: 16 DECam fields, 20-30 visits ~50 deg^2
- 2018A: 24 DECam fields, ~20 visits ~70 deg^2

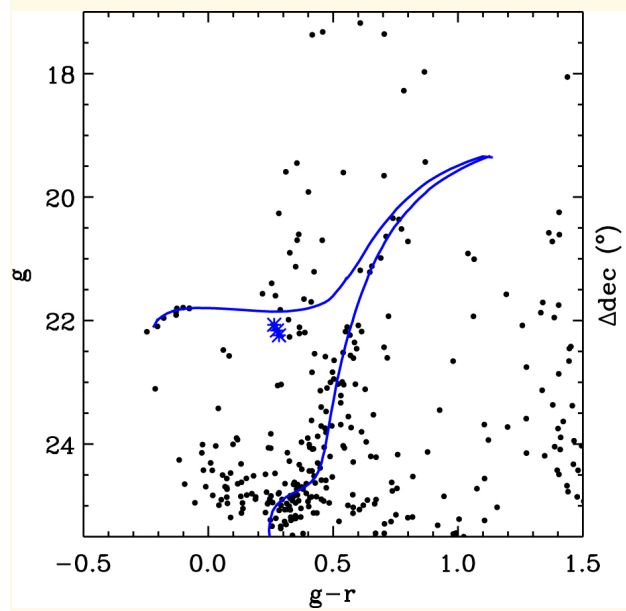
TOTAL: ~350 deg^2

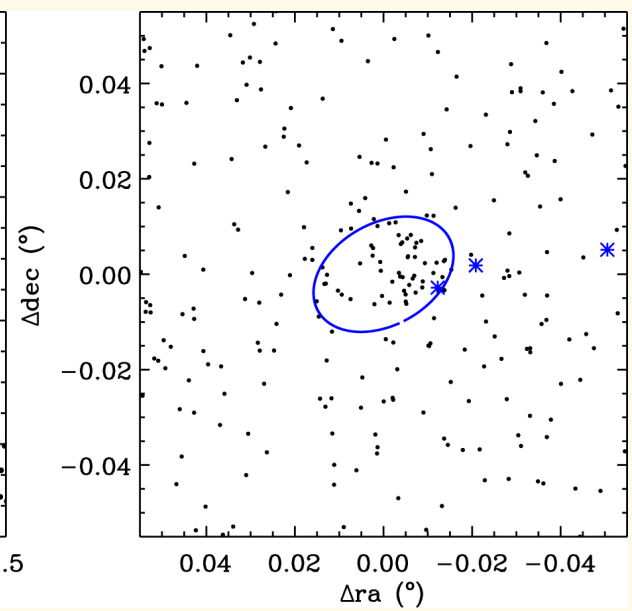


RESULTS:
"Serendipitous" (re-)discovery of Leo V dSph with HiTS (2014) RR Lyrae stars



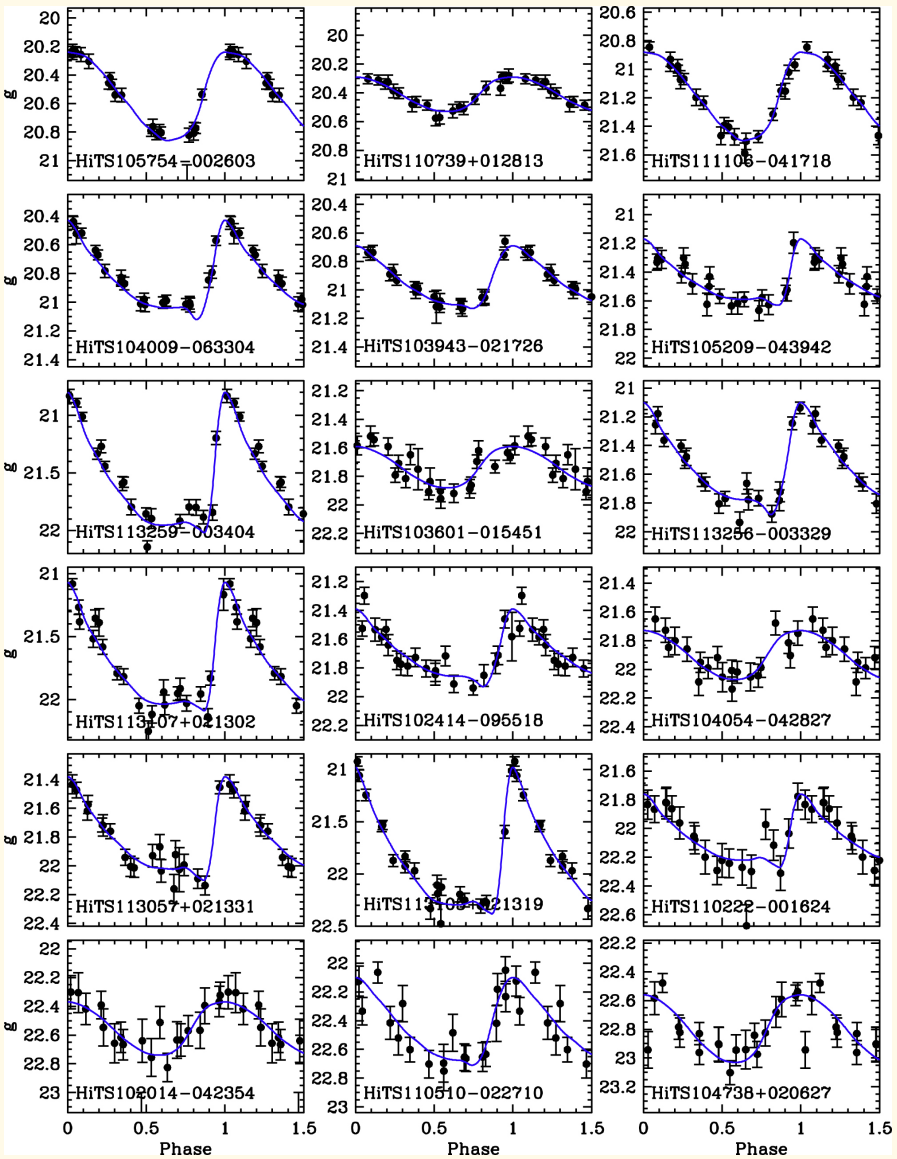




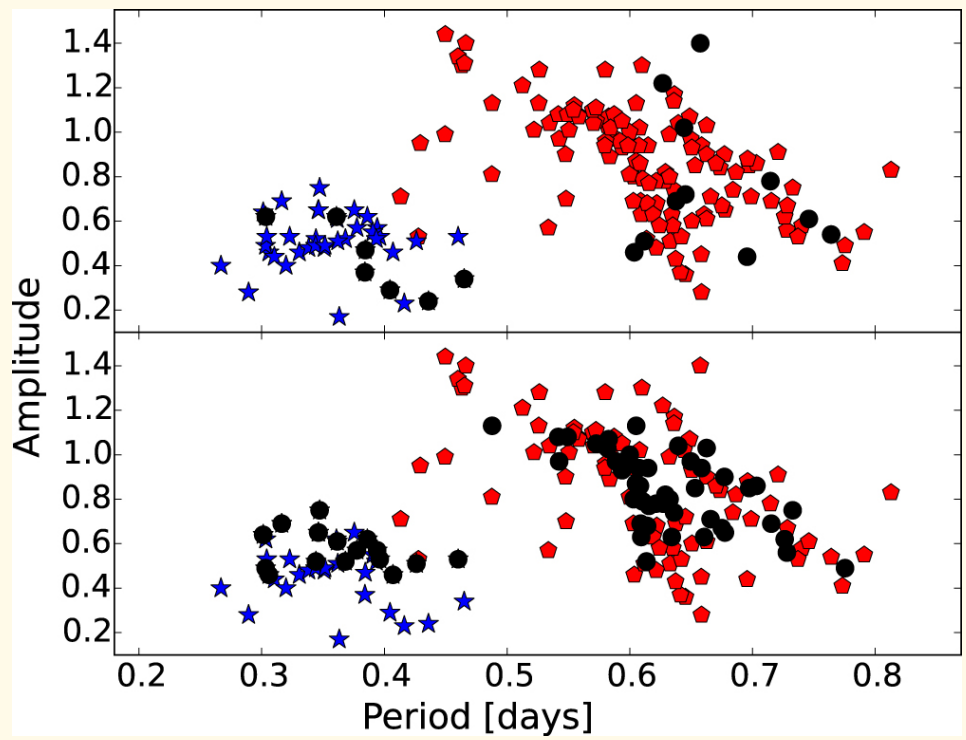


Medina+2017, ApJL, 845, 1

Full HiTS (2014) results (Medina+2018, ApJ, 855, 43):



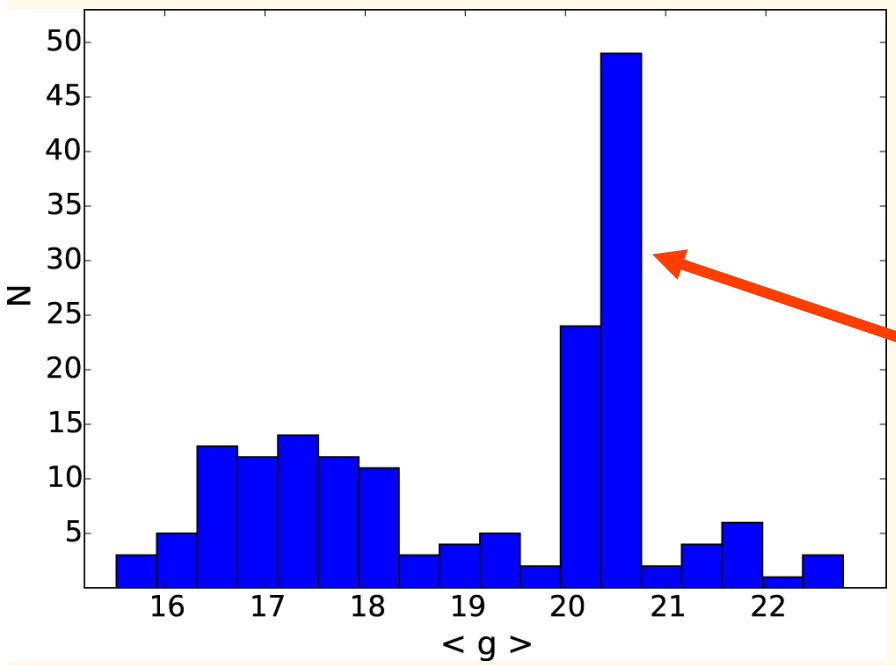
173 RR Lyrae stars, including 18 at d > 90 kpc

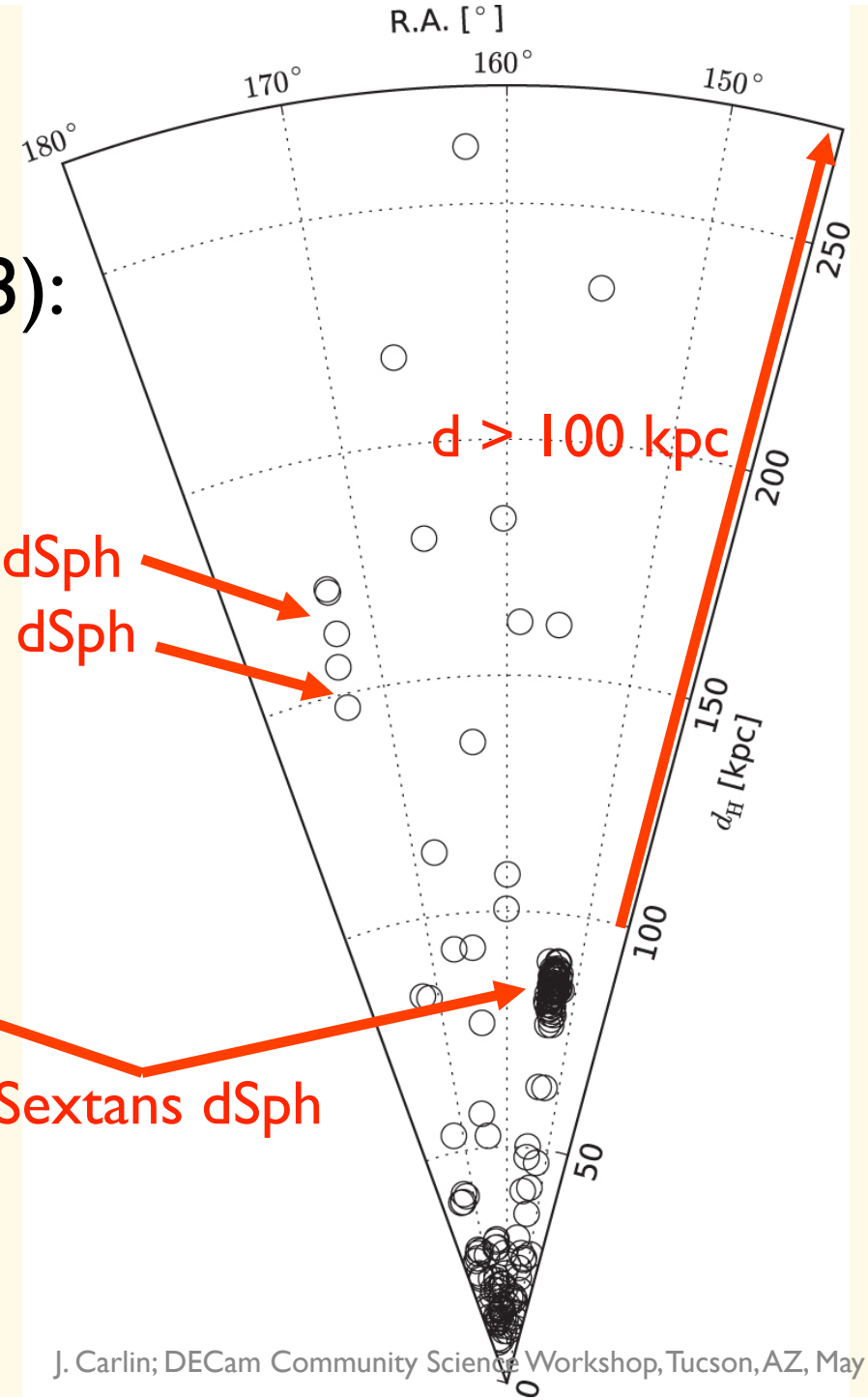


Medina+2018, ApJ, 855, 43

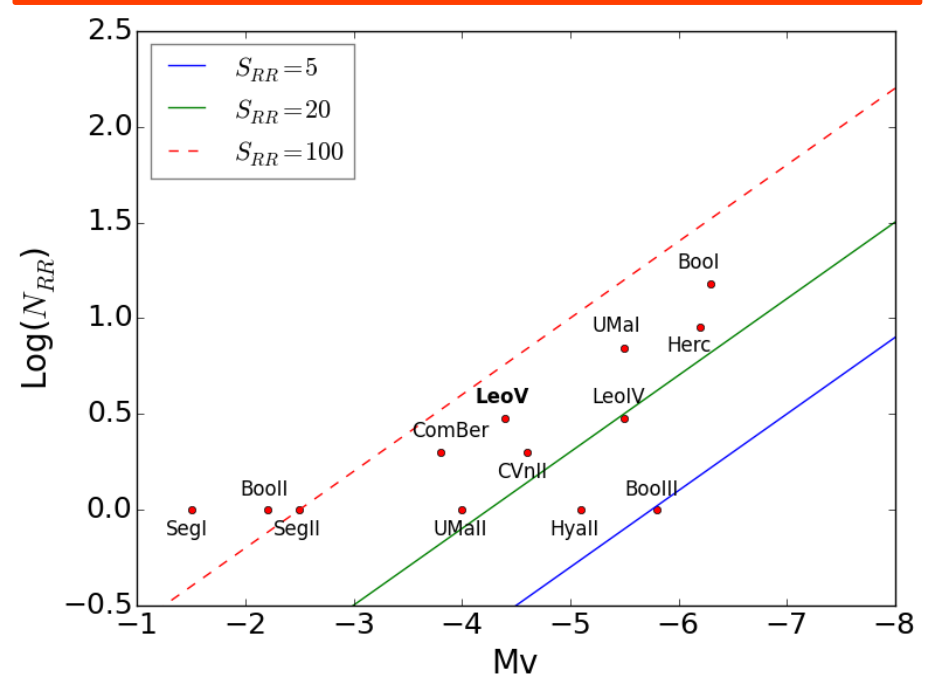
Full HiTS (2014) results (Medina+2018, ApJ, 855, 43):

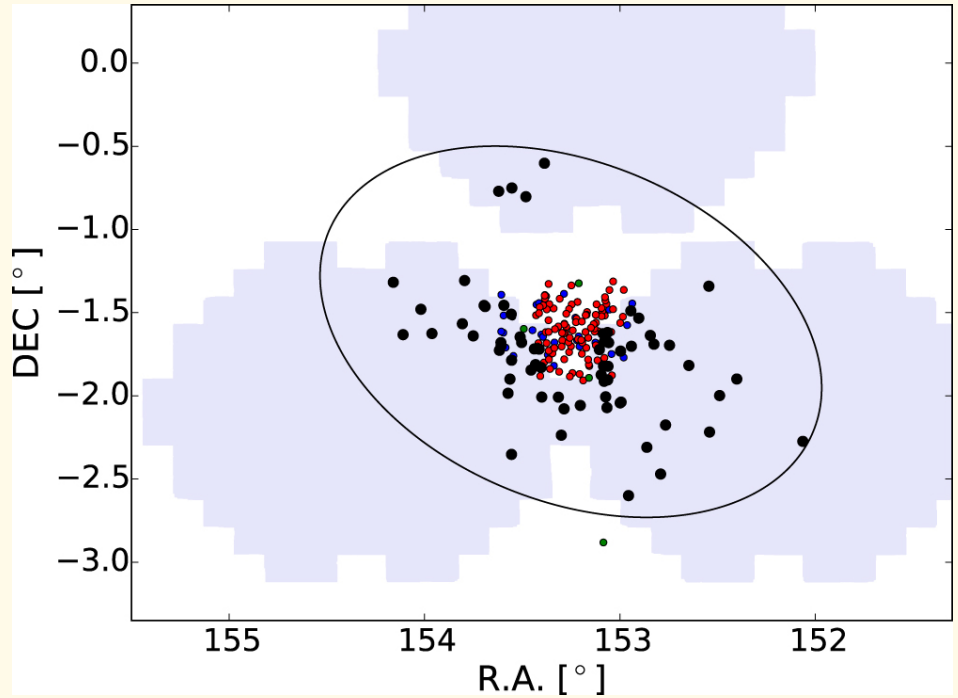
RR Lyrae to <g> > 22
(d > 200 kpc)





Of course we found RR Lyrae in Leo V – all dSphs have them!*

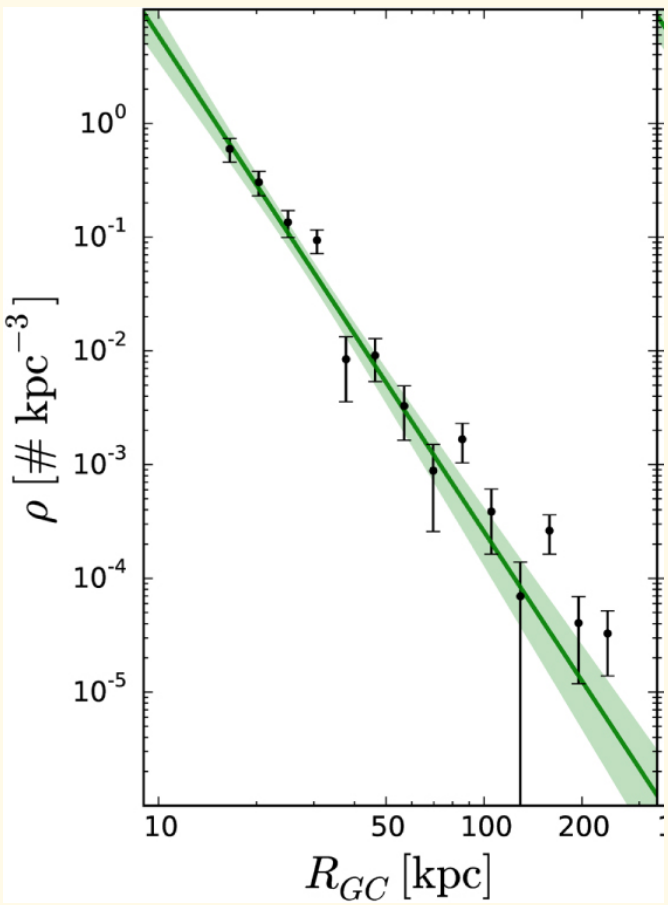




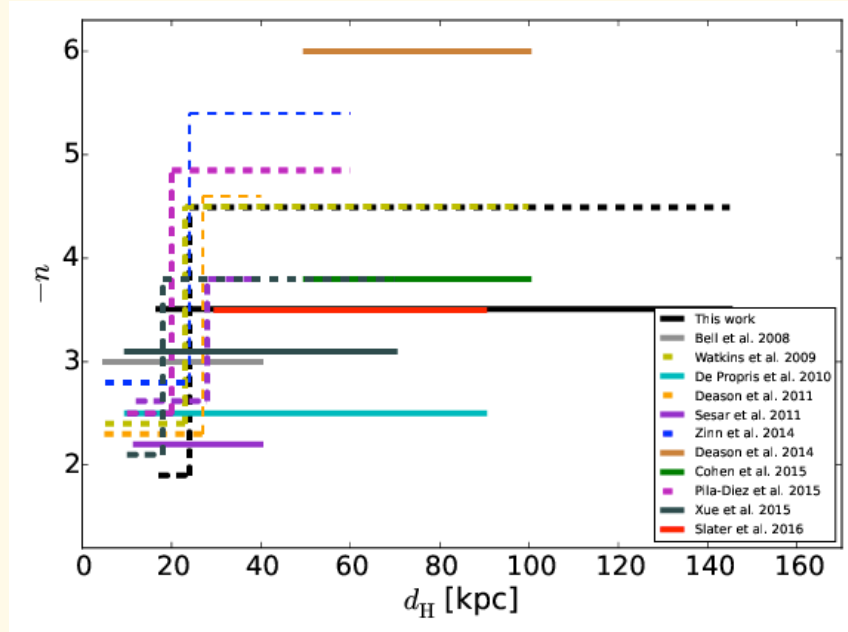
Sextans dSph: 65 RR Lyrae stars (46 prev. unknown)

*maybe

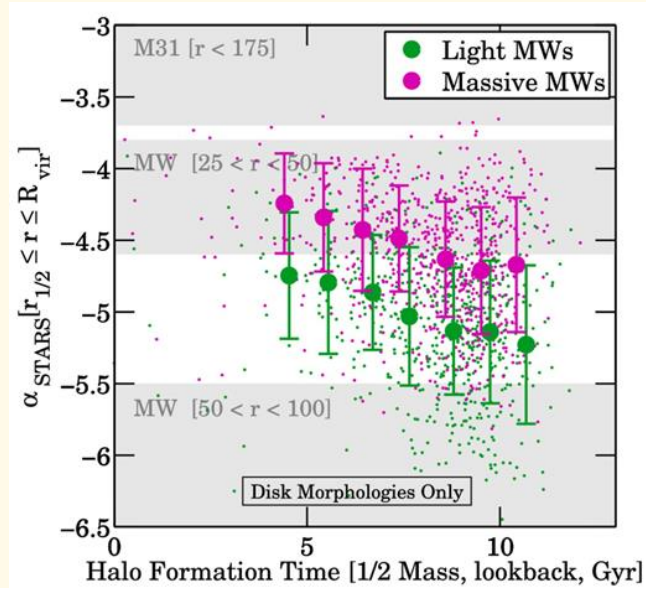
Measured slope of the MW halo density profile: n=-4.17



Medina+2018, ApJ, 855, 43

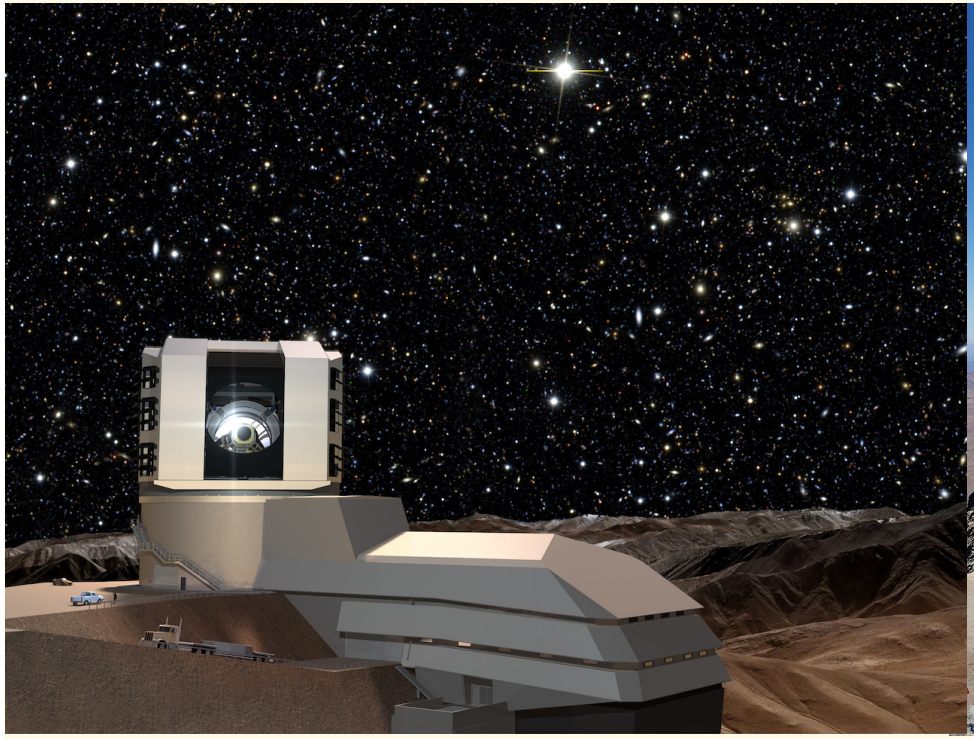


Similar to predictions from Illustris for MW-mass galaxy; Pillepich+2014 (MNRAS, 444, 237)



The Large Synoptic Survey Telescope

will again revolutionize our picture of our own cosmic backyard



(i) an 8.4-meter optical telescope, a 3.5-degree diameter field-of-view, a 3.2 billion pixel camera, and 6 broad-band, optical filters that **will observe more than half the sky hundreds of times over 10 years**

(ii) a data facility that will process, archive, and distribute survey images, associated transient alerts, and calibrated catalogs.

LSST will open ~1,000 times the volume for studying the Local Universe with resolved stars compared to SDSS

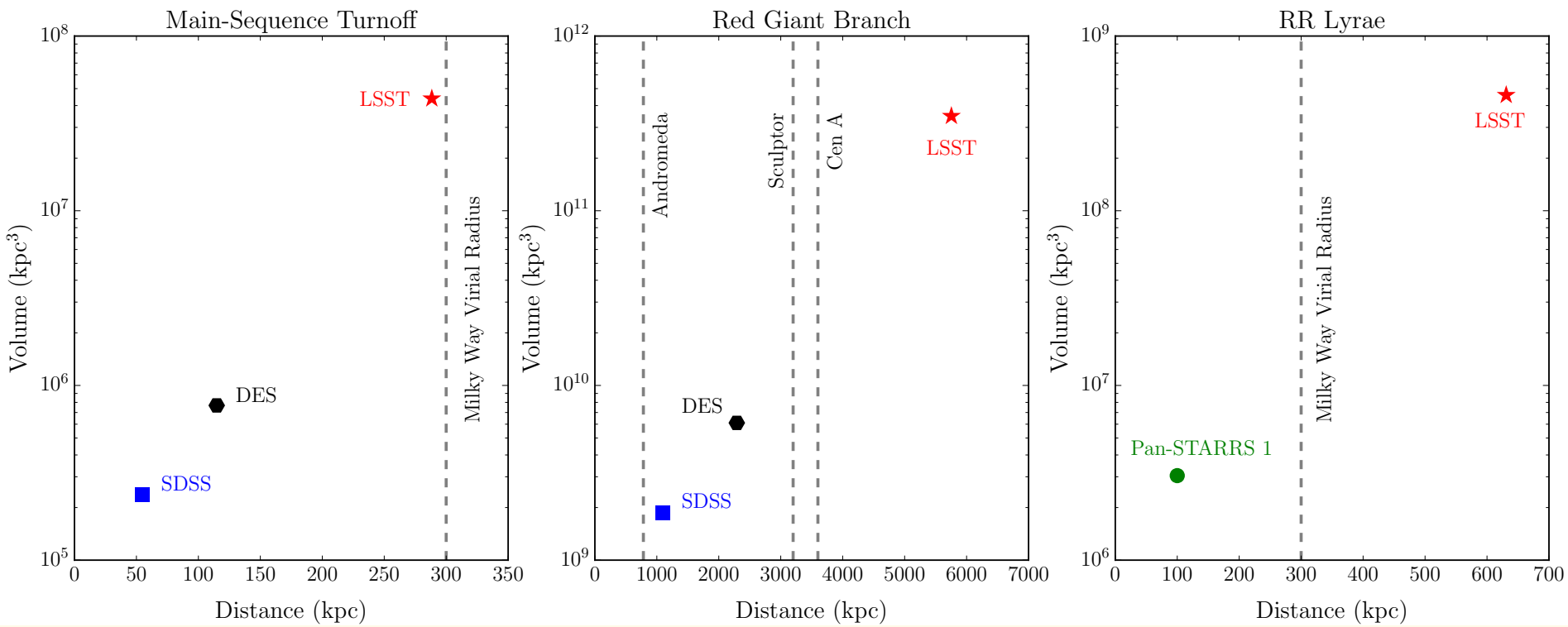


Figure: Keith Bechtol

Conclusions:

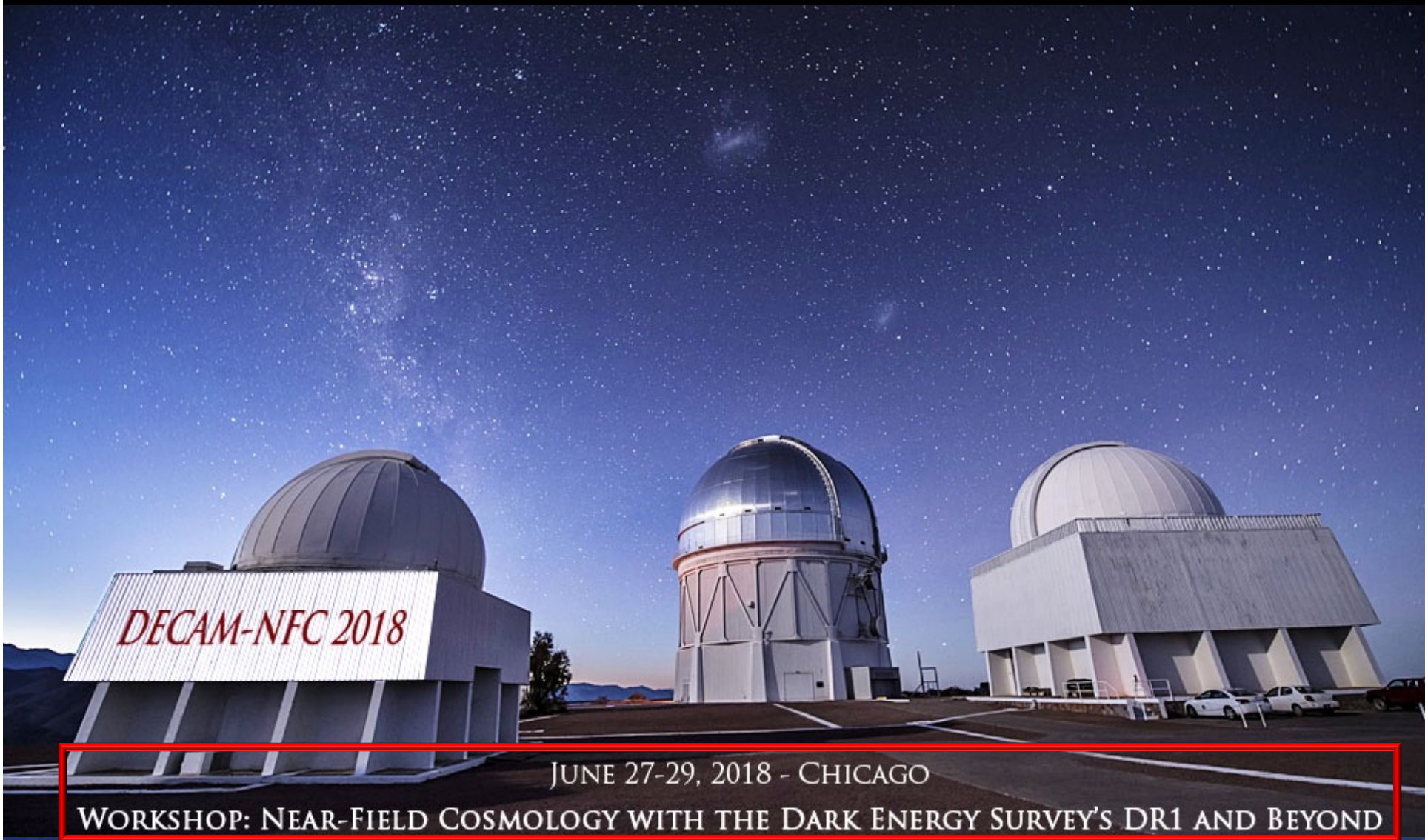
- We (Medina+2017, 2018) have discovered the most distant known RR Lyrae in the Milky Way, with many more to come.
- Serendipitous finding of Leo V RR Lyrae stars: RRLs can be beacons of distant ultra-faint dwarfs.

Next steps:

- HiTS 2015, DECam 2017B, 2018A results soon!
- Spectroscopy (velocities)
- Time-series to more completely fill phase curves.
- Deep imaging (are the distant RRLs in dSphs?
- Survey a larger area?

THANK YOU!

http://kicp-workshops.uchicago.edu/decam-nfc2018/



JUNE 27-29, 2018 - CHICAGO

WORKSHOP: NEAR-FIELD COSMOLOGY WITH THE DARK ENERGY SURVEY'S DR1 AND BEYOND

KICP

THE KAVLI FOUNDATION

THE DARK ENERGY SURVEY

THE UNIVERSITY OF CHICAGO