Milky Way and Local Volume Constraints on the Particle Nature of Dark Matter with LSST

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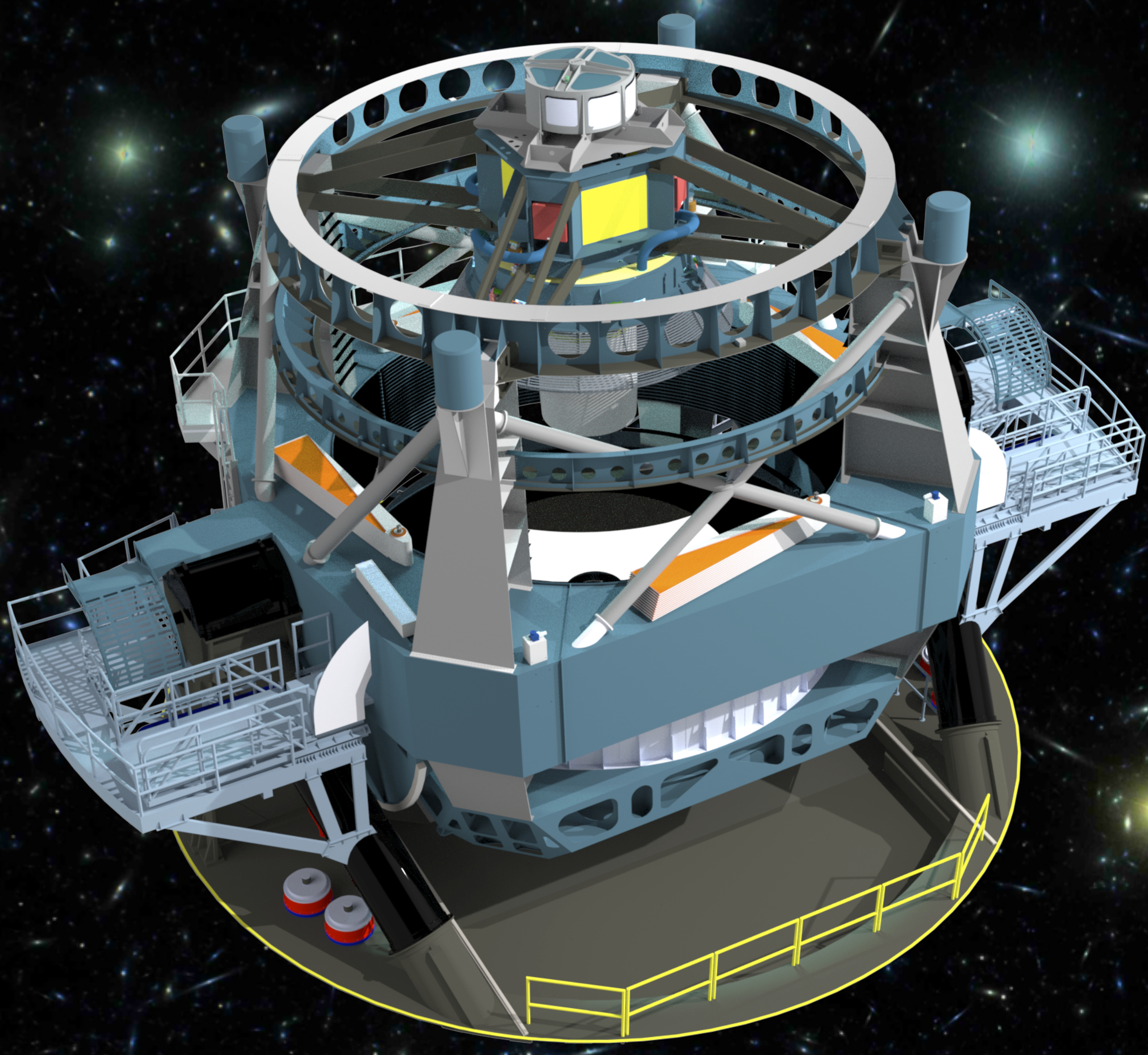
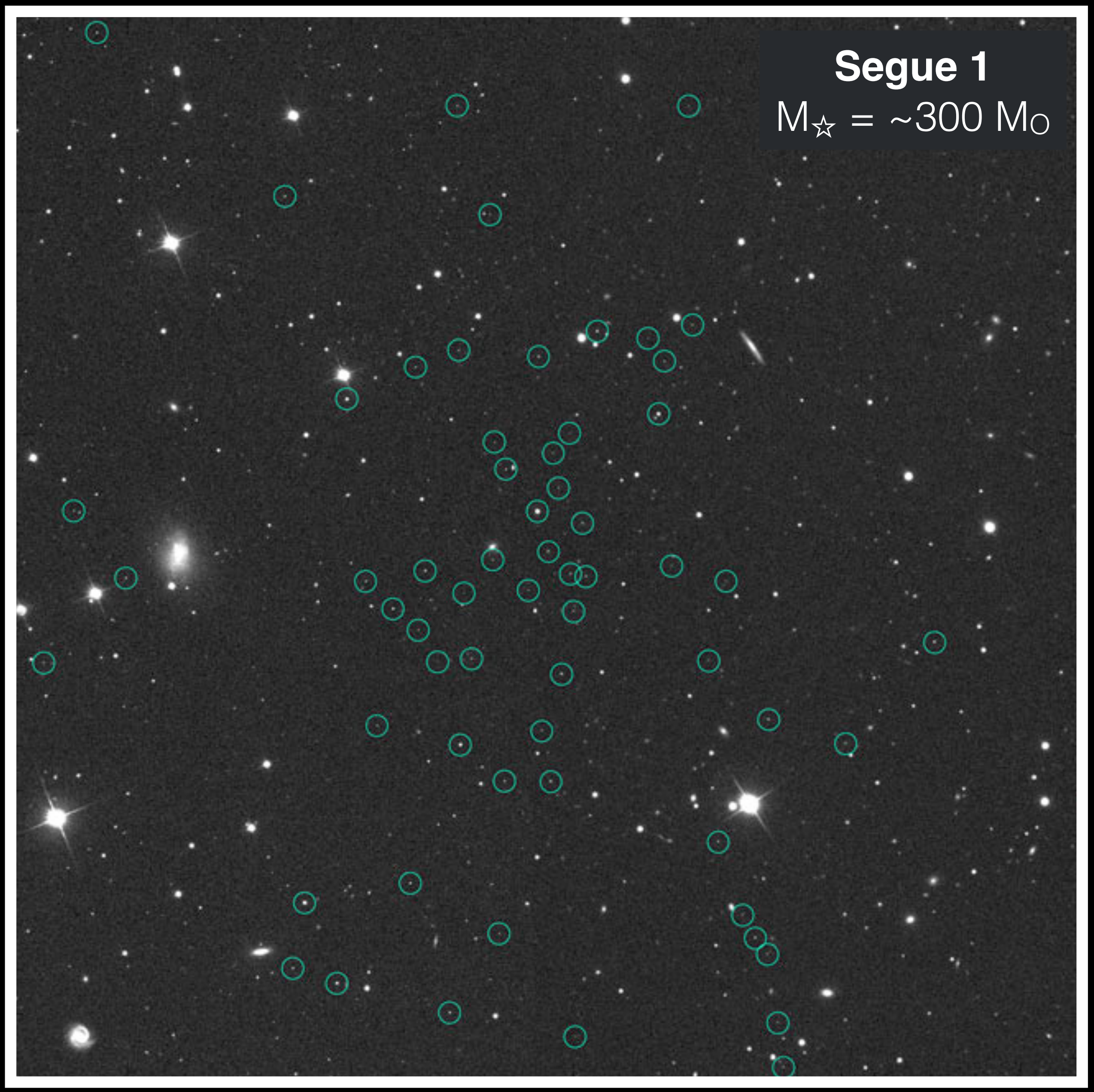
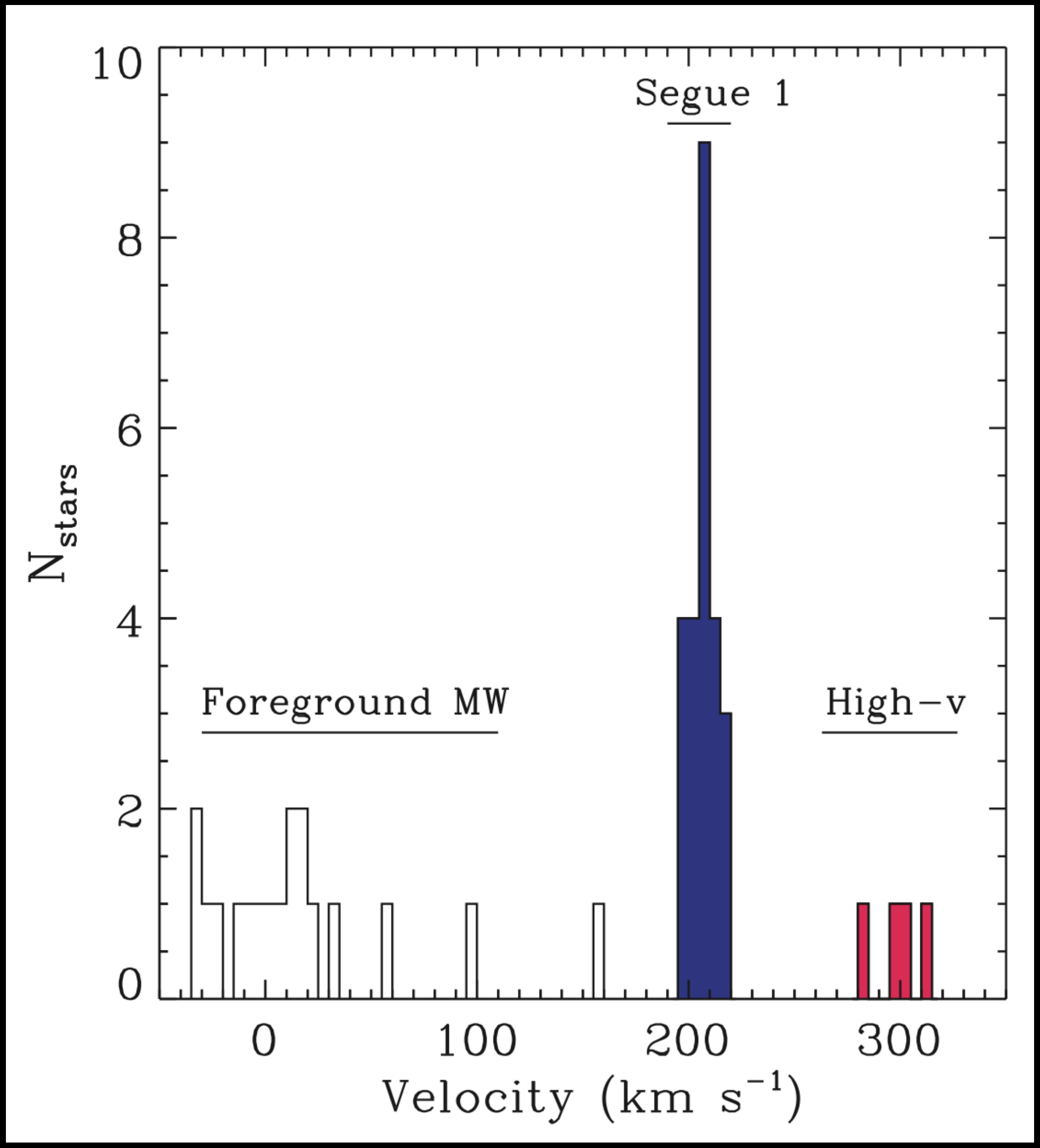
LSST Project and Community Meeting
16 August 2017



Ultra-faint Milky Way Satellite Galaxies



Geha et al. 2009, ApJ, 692, 1464



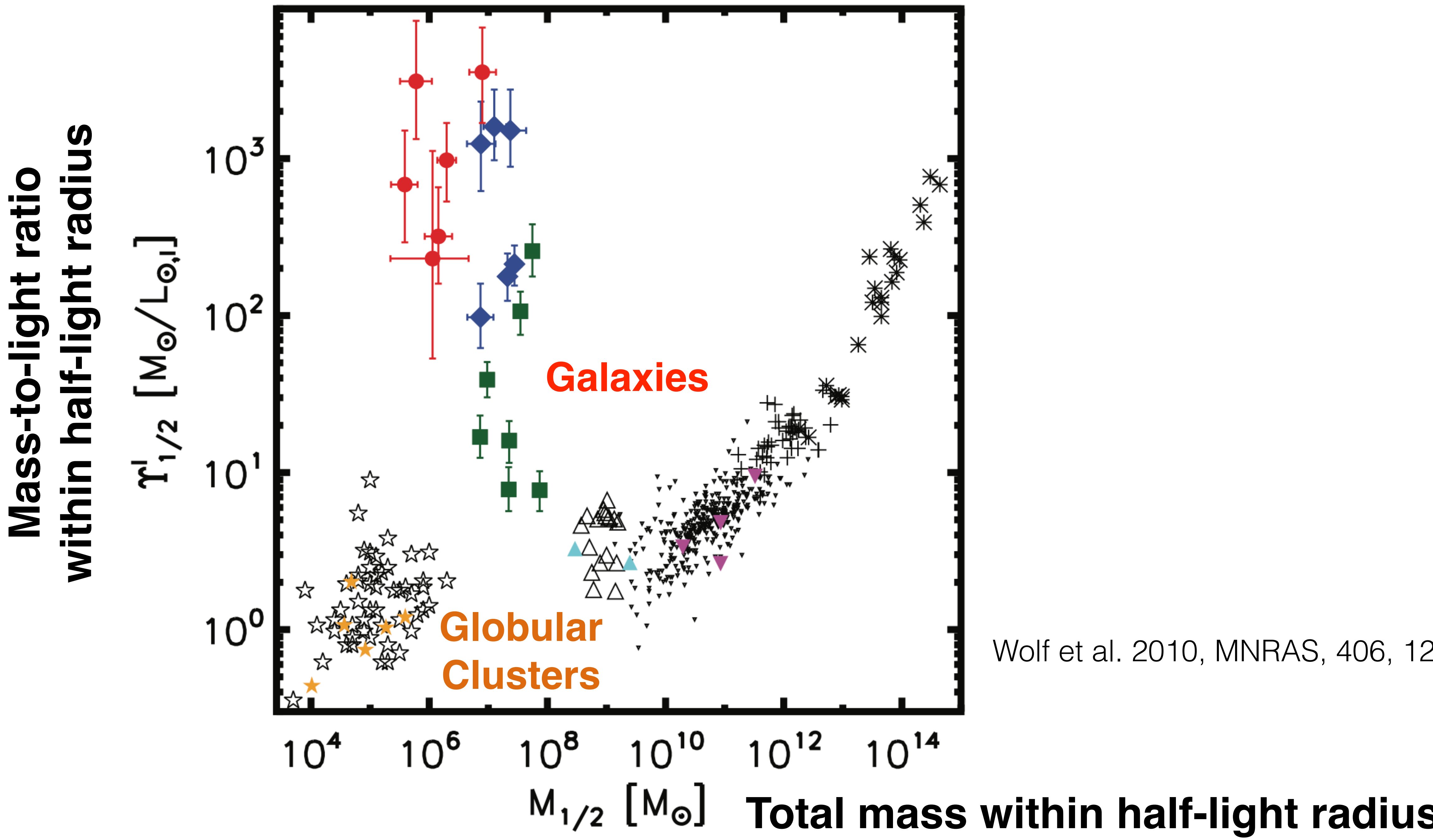
Discovered as arcminute-scale statistical overdensities of individually resolved stars

Confirmed as dark-matter-dominated galaxies via spectroscopic follow-up (line-of-sight velocity dispersion)

Galaxy “Defined”

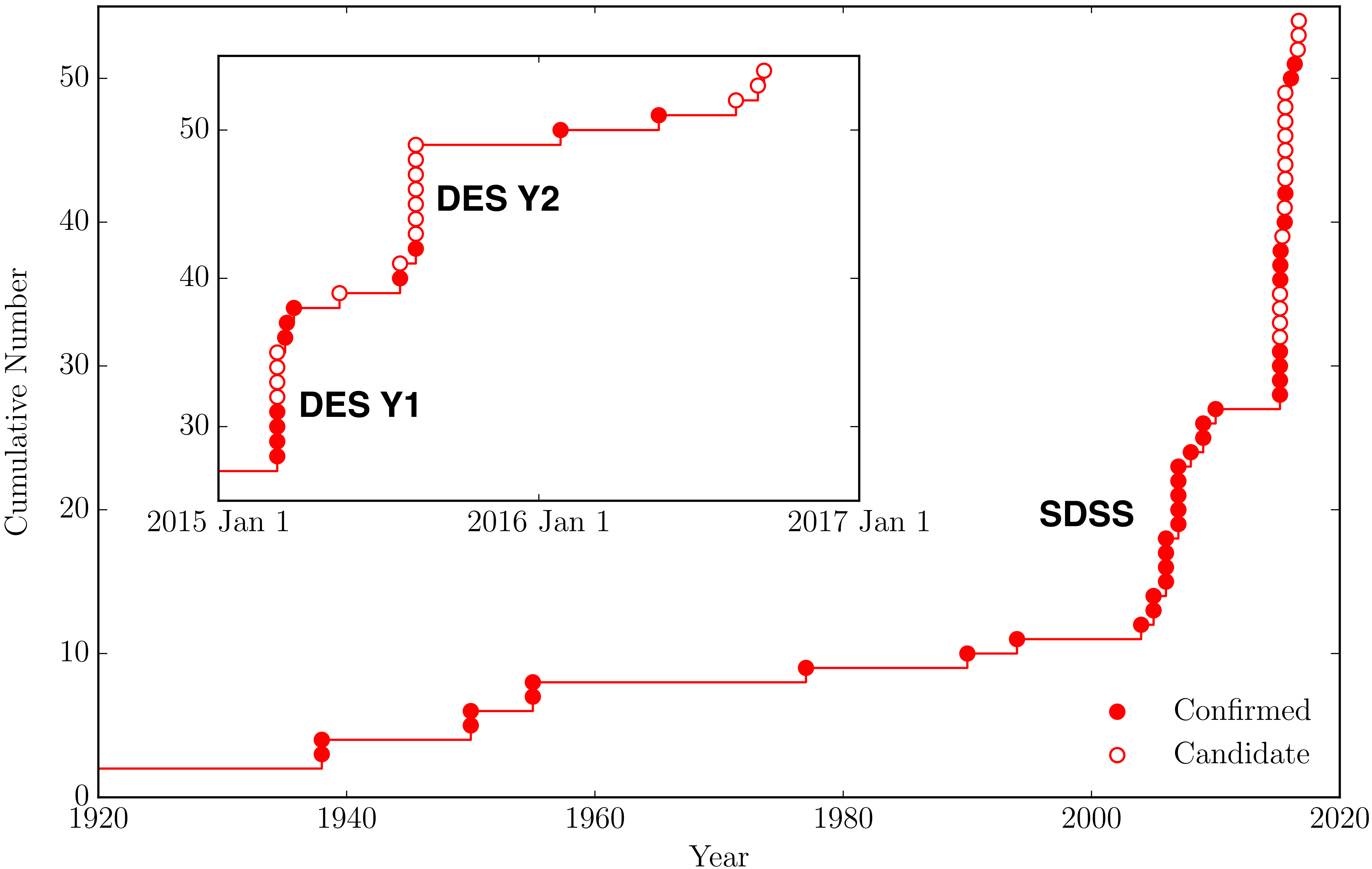
A galaxy is a gravitationally bound collection of stars whose properties cannot be explained by a combination of baryons and Newton's laws of gravity.

Willman & Strader 2012, AJ, 144, 76



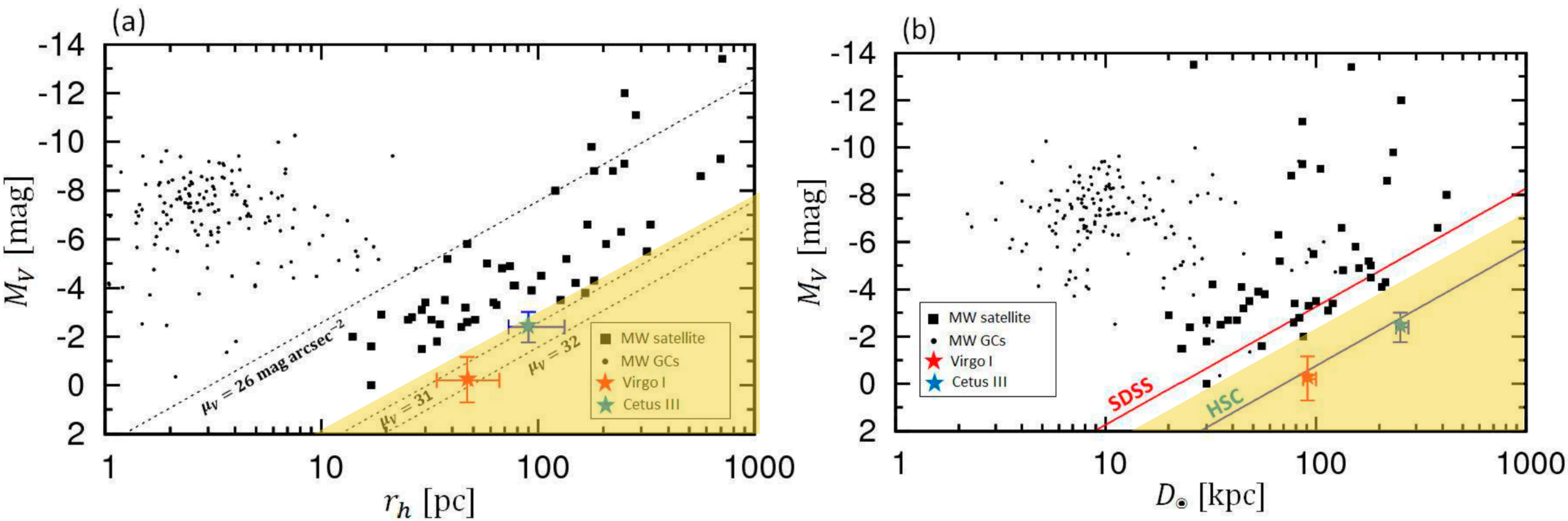
Wolf et al. 2010, MNRAS, 406, 1220

Discovery Timeline for Milky Way Satellite Galaxies



Current census is highly incomplete

Two new ultra-faint galaxy candidates found in first 300 deg^2 of HSC SSP data (<1% of 4π celestial sphere) that are likely undetectable in any previous survey

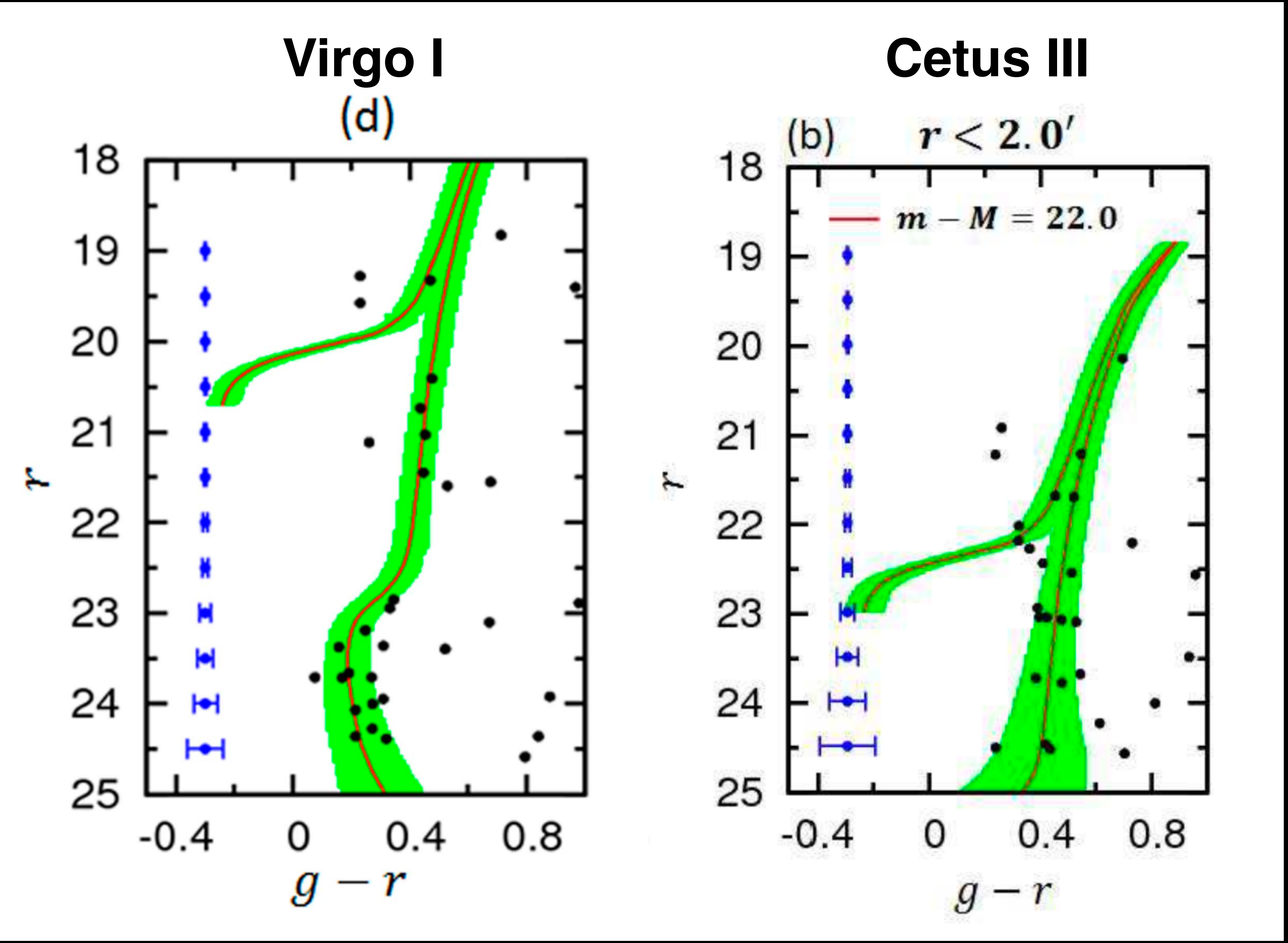


Homma et al. 2017

Similarly, we estimate that ~half of the ultra-faint galaxy candidates found with DES would not have been detected in a survey of SDSS depth

Bechtol et al. 2015, Drlica-Wagner et al. 2015

Ultra-faint Galaxies Discovered with HSC

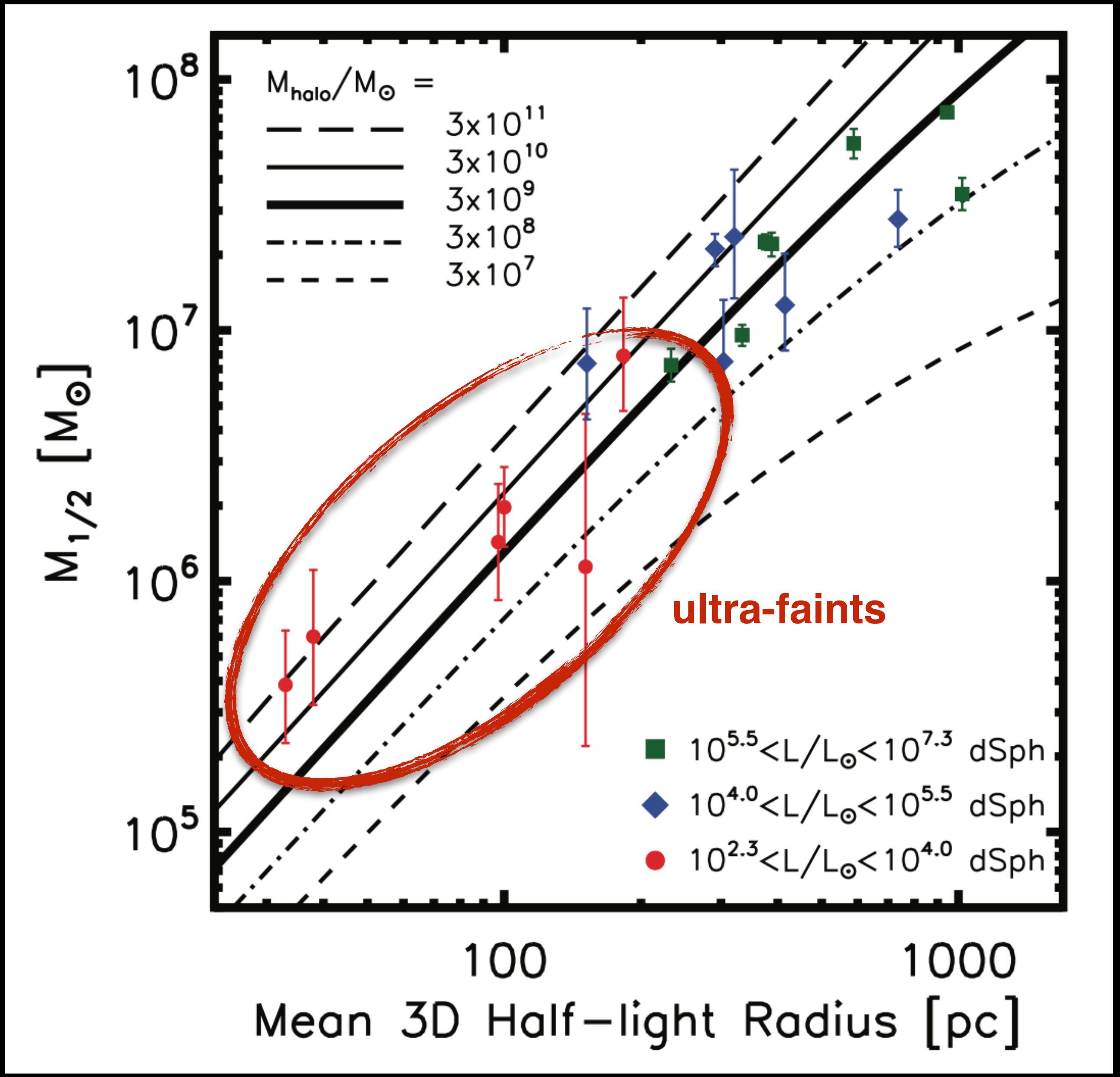


Homma et al. 2016

Homma et al. 2017

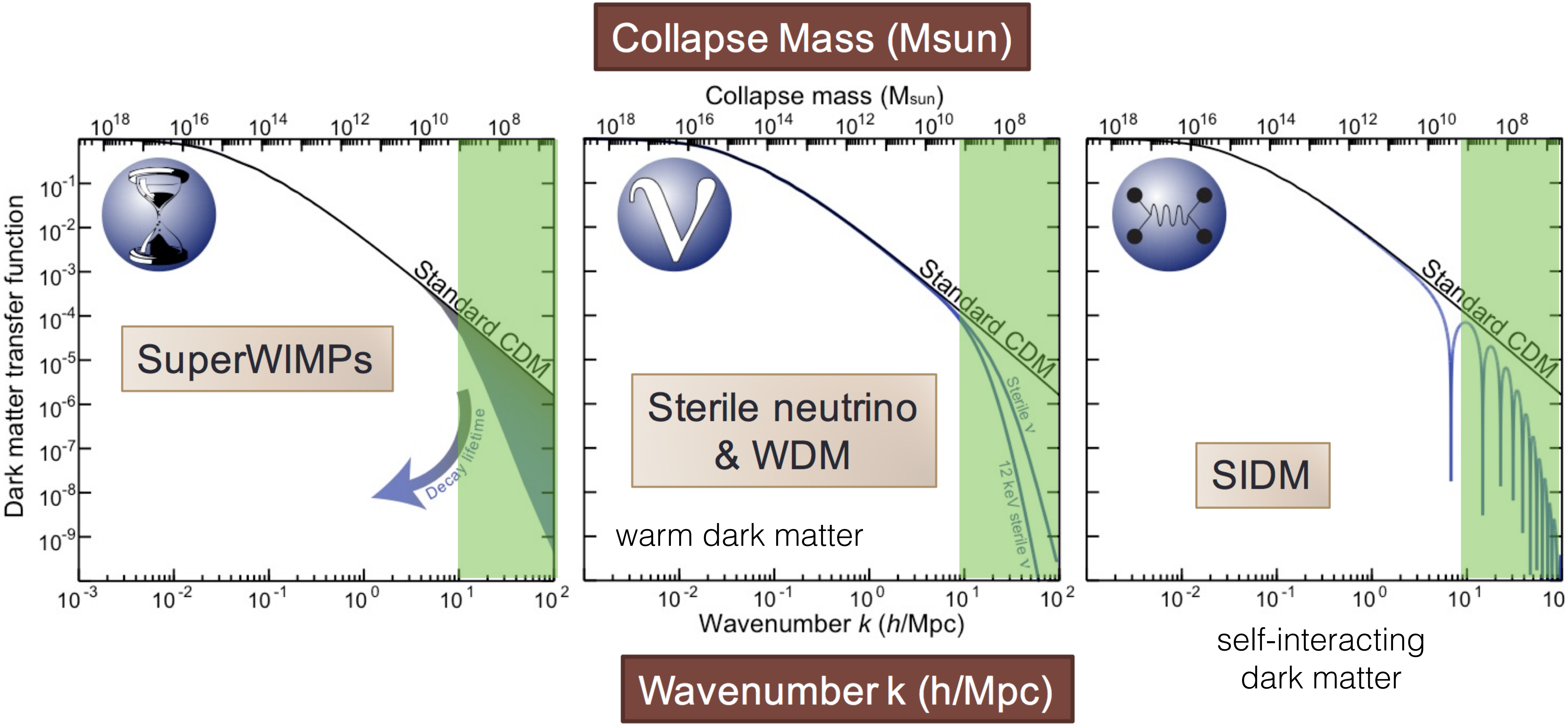
What exactly do we measure from the census of Milky Way satellites?

For galaxies with a small number of velocity measurements (tens), the most robustly constrained quantity is the total mass within the stellar 3D half-light radius — a small fraction of the total halo mass



This is an example of where more theoretical work is needed to compare with the information gained from other probes of small scale structure …

Sensitivity of small-scale structure to the particle identity of dark matter

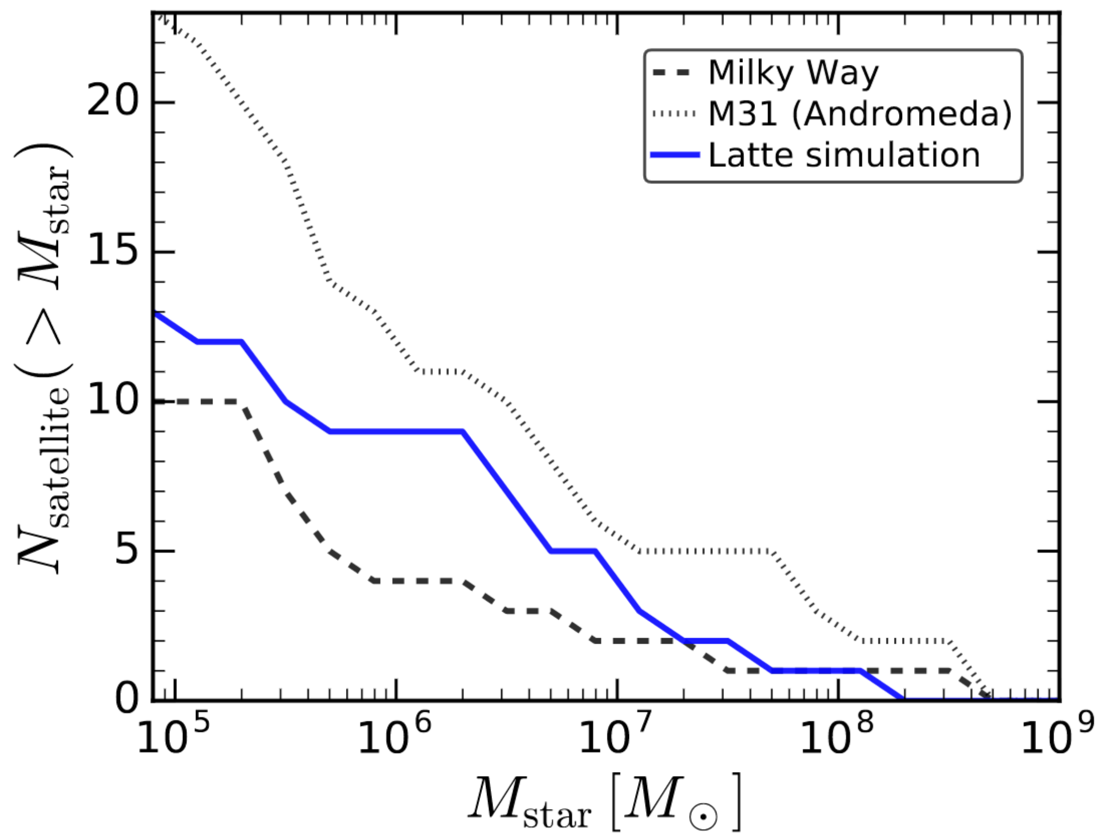


Deviations from Cold Dark Matter would be detected at the smallest scales explored with **dwarf galaxies**, strong lensing, and the Lyman-alpha forest

Image Credit: Leonidas Moustakas

Example Theoretical Predictions

"Missing Satellites"



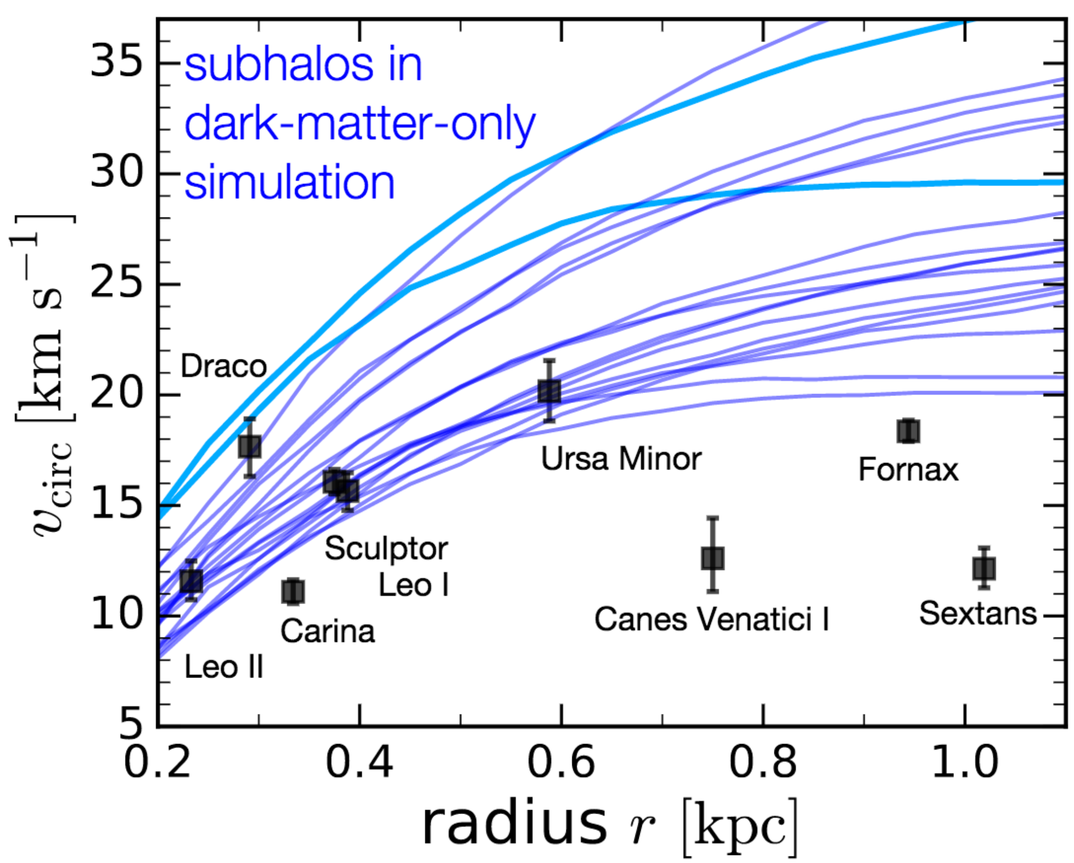
Simulations including **redshift-dependent ultraviolet background** (reionization) and **stellar feedback** (radiation pressure, local photoionization and photoelectric heating, stellar winds, supernovae)

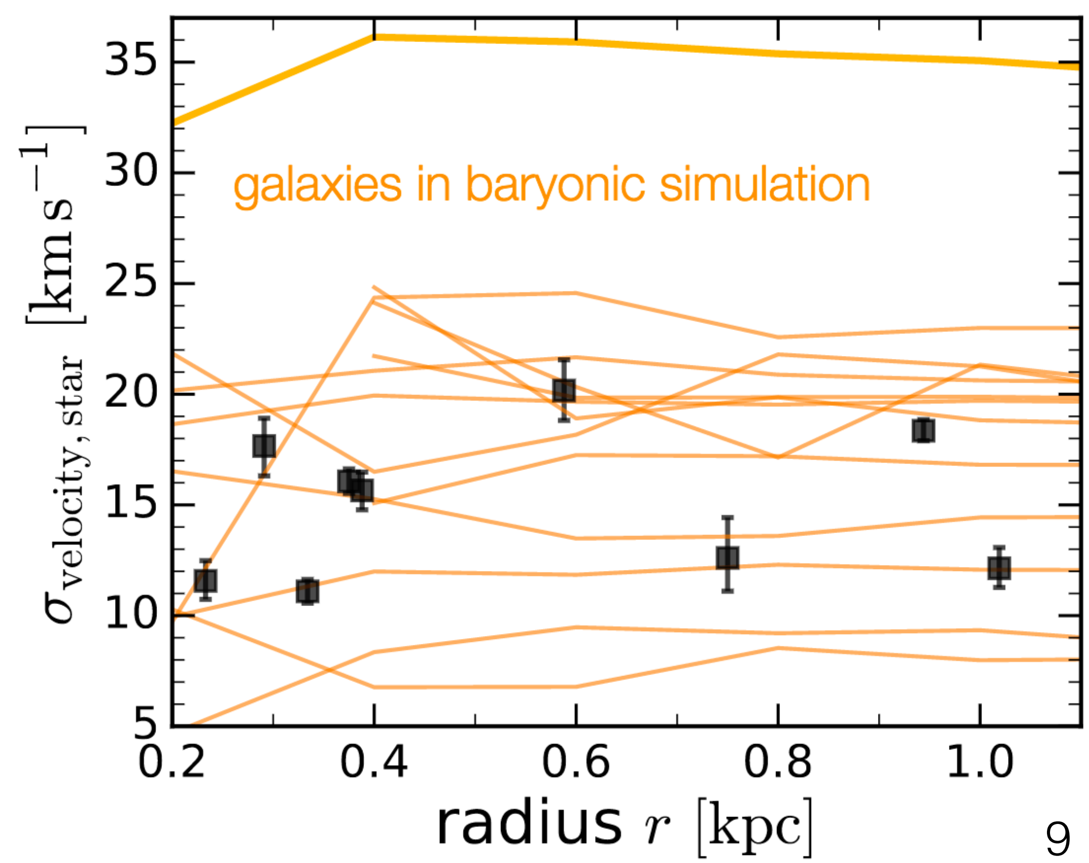
Resolve galaxies with $M_\star > 10^5\ M_\odot$

For comparison, we now detect galaxies with $M_\star \sim 10^2\ M_\odot$

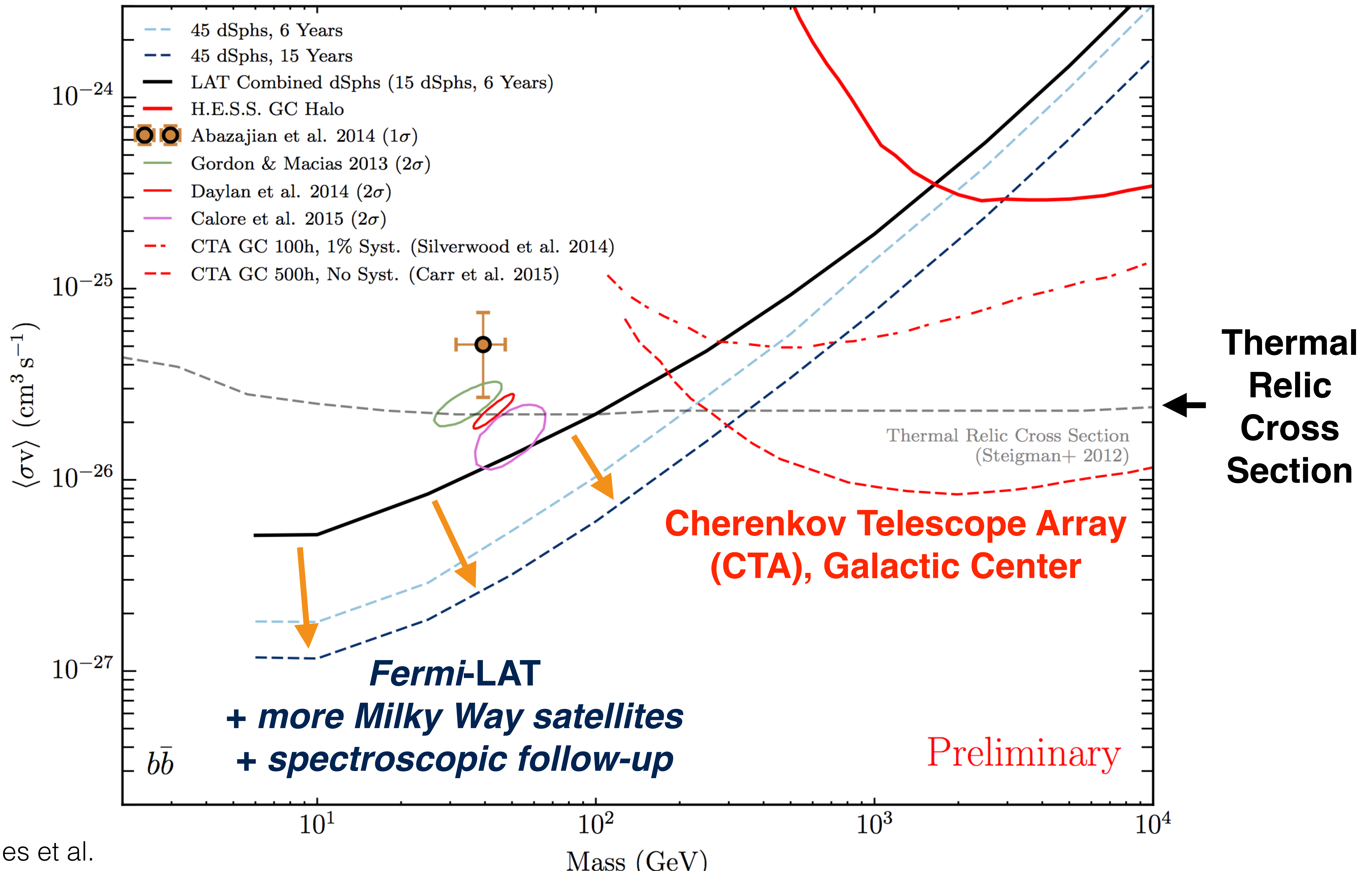
Wetzel et al. 2016

"Too Big to Fail"

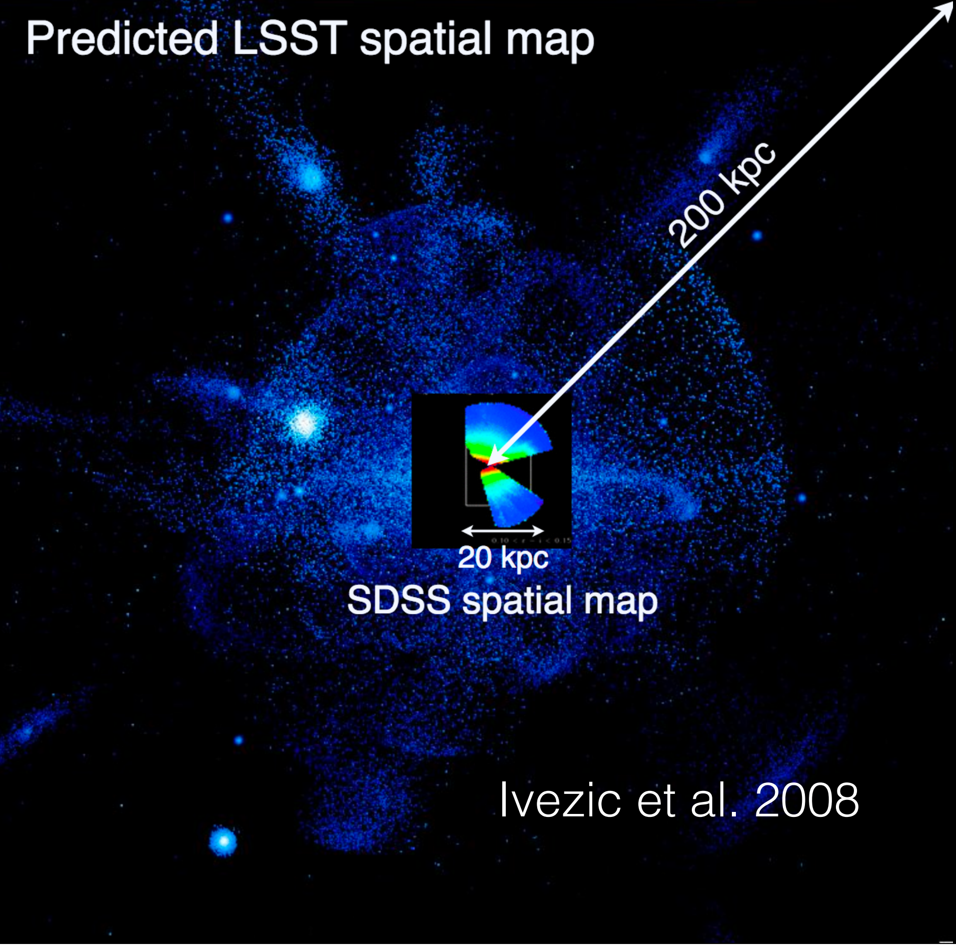




Leading Targets for Indirect Dark Matter Searches (Annihilation)

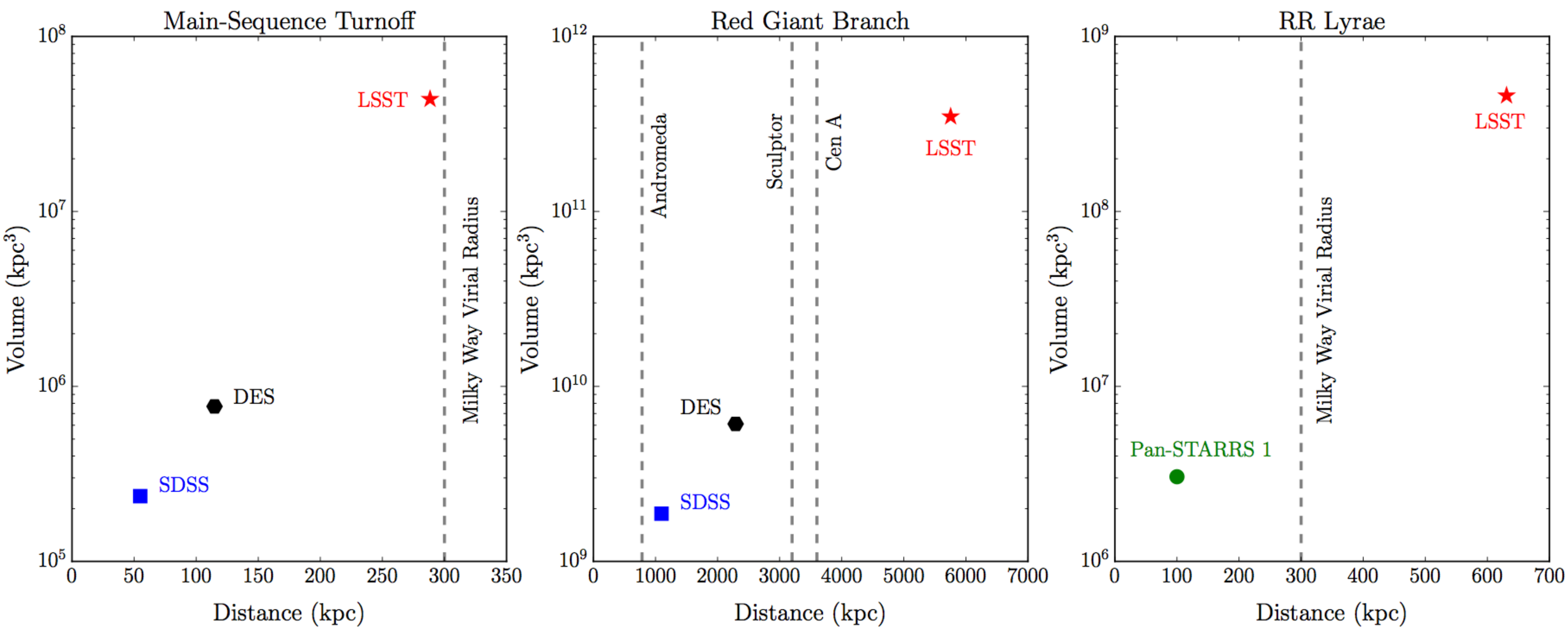


See Charles et al.
arXiv:1605.02016



LSST will enable a comprehensive search for Local Volume dwarf galaxies out to a few Mpc, including isolated dwarfs in the field

Likely to be limited by star-galaxy confusion
at faint magnitudes for some stellar populations



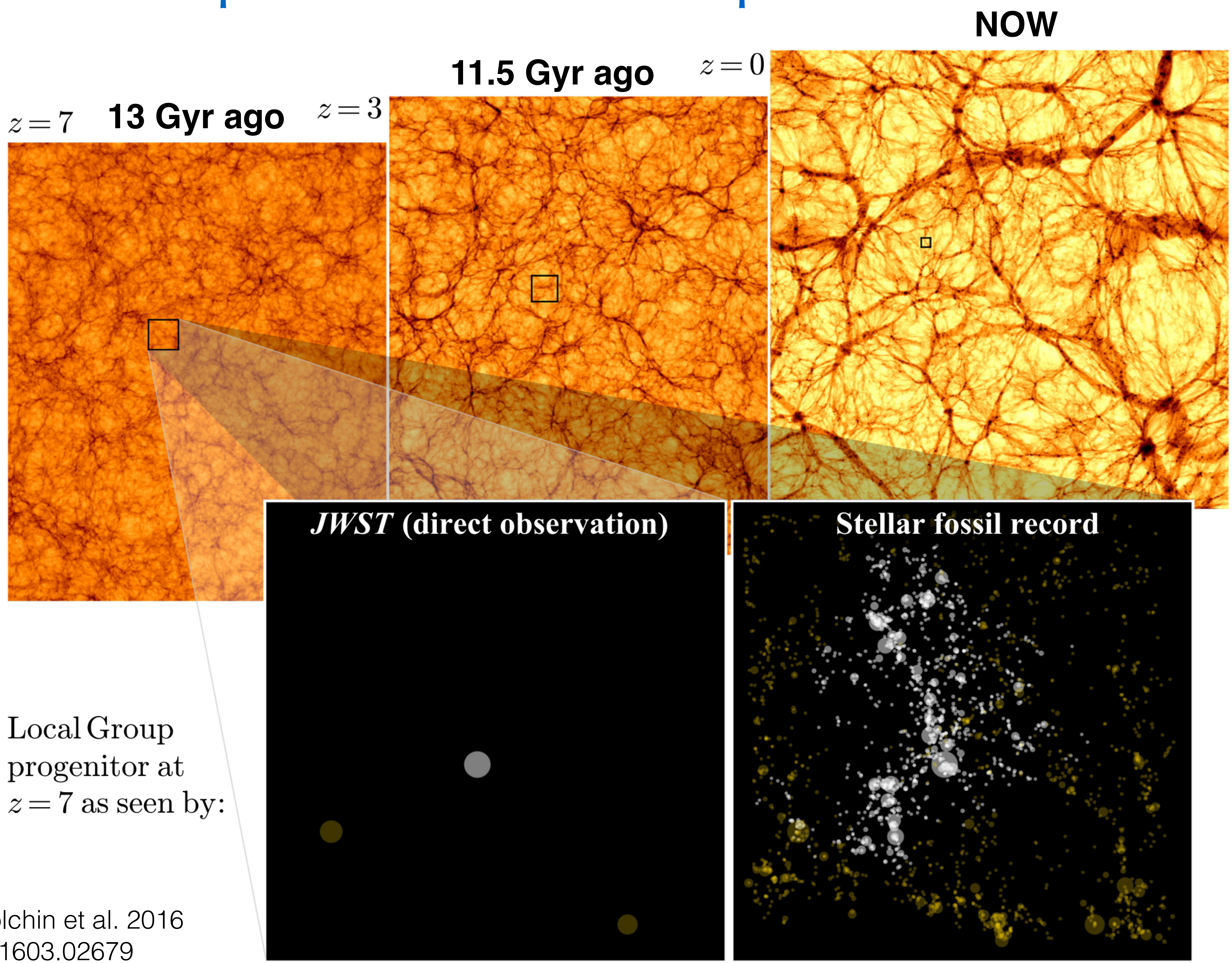
Predictions for LSST Yield of Milky Way Satellite Galaxies

TABLE 1
PREDICTED NUMBER OF DWARF GALAXIES FOR LSST AND DES

	DES ($\pm$ 10/90)	LSST ($\pm$ 10/90)
$L > 10^3 L_\odot$, $r_{lim} = 23.8$		
Massive in the past	7^{+2}_{-2}	28^{+6}_{-5}
Pre-reionization Fossils	7^{+3}_{-2}	30^{+11}_{-5}
Earliest Infall	5^{+4}_{-2}	23^{+11}_{-6}
$L < 10^3 L_\odot$, $r_{lim} = 23.8$		
Massive in the past	10^{+9}_{-6}	40^{+29}_{-15}
Pre-reionization Fossils	10^{+14}_{-6}	43^{+36}_{-19}
Earliest Infall	8^{+9}_{-5}	35^{+32}_{-15}
$L > 10^3 L_\odot$, $r_{lim} = 25.8$		
Massive in the past	8^{+3}_{-3}	33^{+8}_{-6}
Pre-reionization Fossils	9^{+4}_{-3}	37^{+16}_{-8}
Earliest Infall	6^{+4}_{-3}	25^{+14}_{-7}
$L < 10^3 L_\odot$, $r_{lim} = 25.8$		
Massive in the past	42^{+31}_{-18}	171^{+117}_{-60}
Pre-reionization Fossils	56^{+43}_{-27}	179^{+128}_{-84}
Earliest Infall	20^{+17}_{-11}	81^{+60}_{-28}

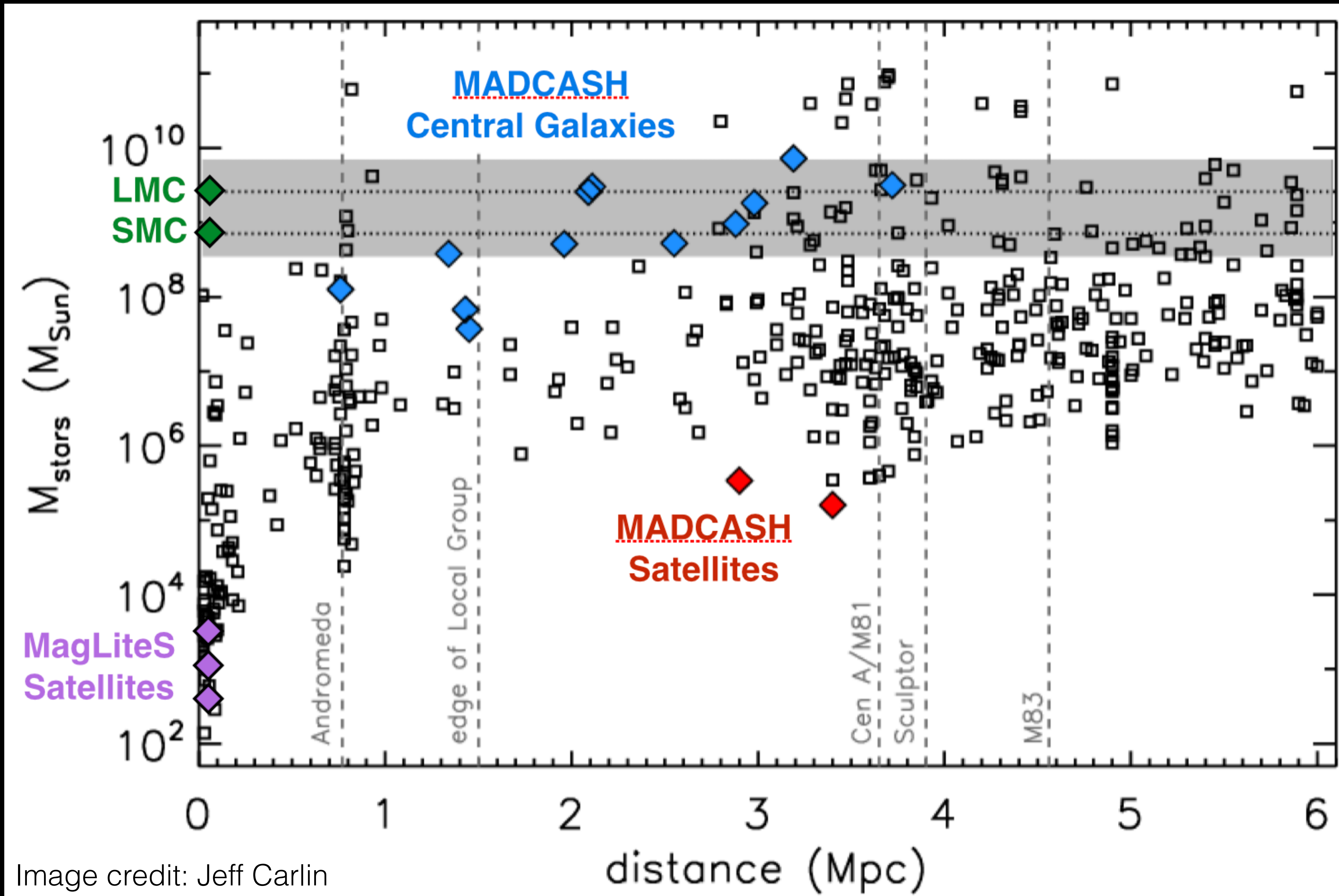
Hargis et al. 2014, ApJL, 795, L13

Local Group as “Ultimate Deep Field”



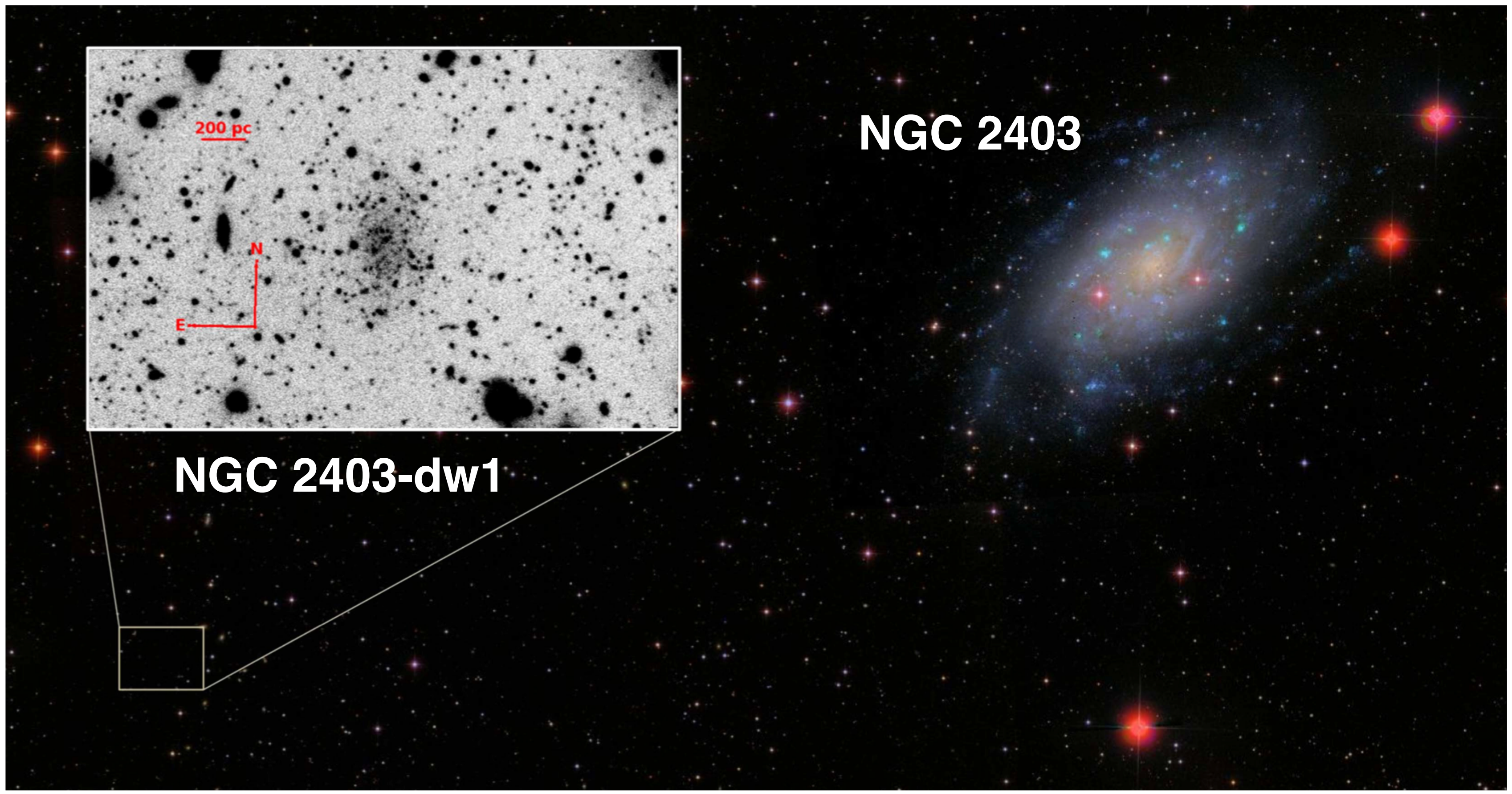
Boylan-Kolchin et al. 2016
arXiv:1603.02679

Beyond the Milky Way



Access to low luminosity galaxies around dwarfs and in the field avoids many of the baryonic effects and disruption effects associated with large neighbor galaxies

(see predictions from Dooley et al. 2017, arXiv:1703.05321)



NGC 2403:

D ~ 3.2 Mpc

$M_\star$ ~ 7 x 10^9 $M_\odot$

~ 2.5 $M_{\star,LMC}$

Dwarf:

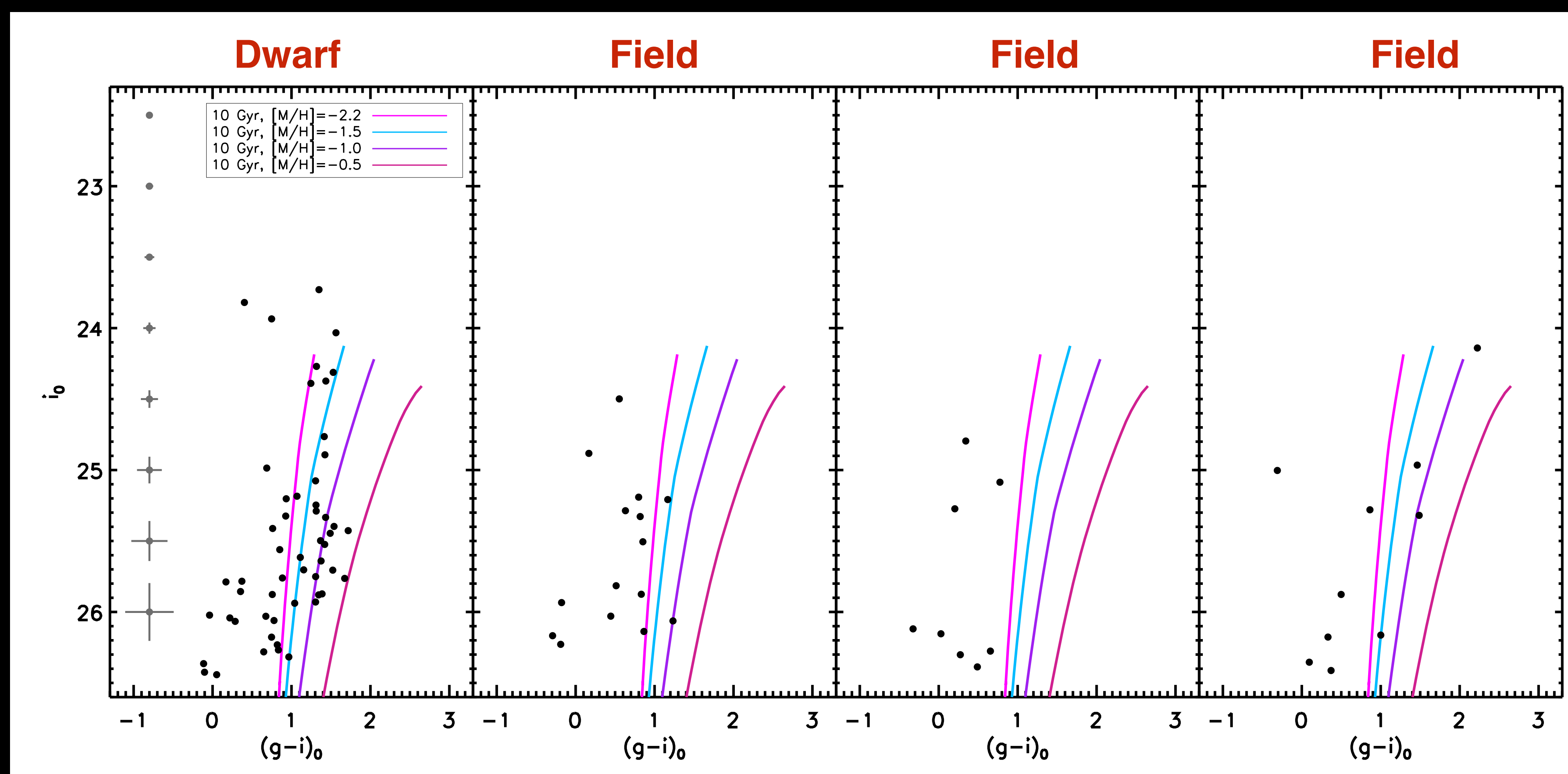
M_V ~ -7.7

r_{half} ~ 200 x 70 pc

R_{proj} ~ 35 kpc from NGC 2403

Carlin et al. 2016
arXiv:1608.02591

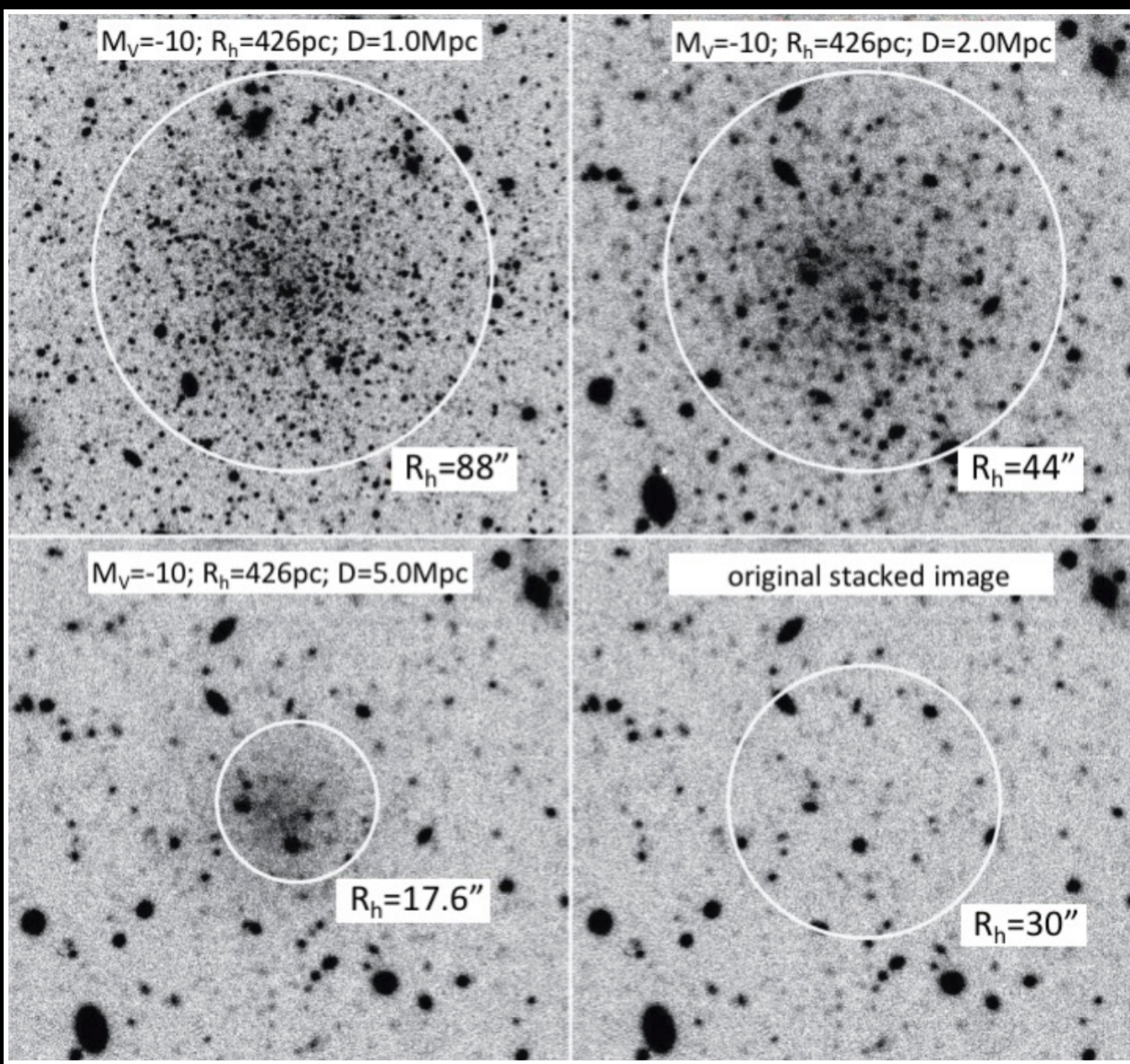
HSC images reduced using a branch of the LSST proto-pipeline (dwarf identified by visual inspection)



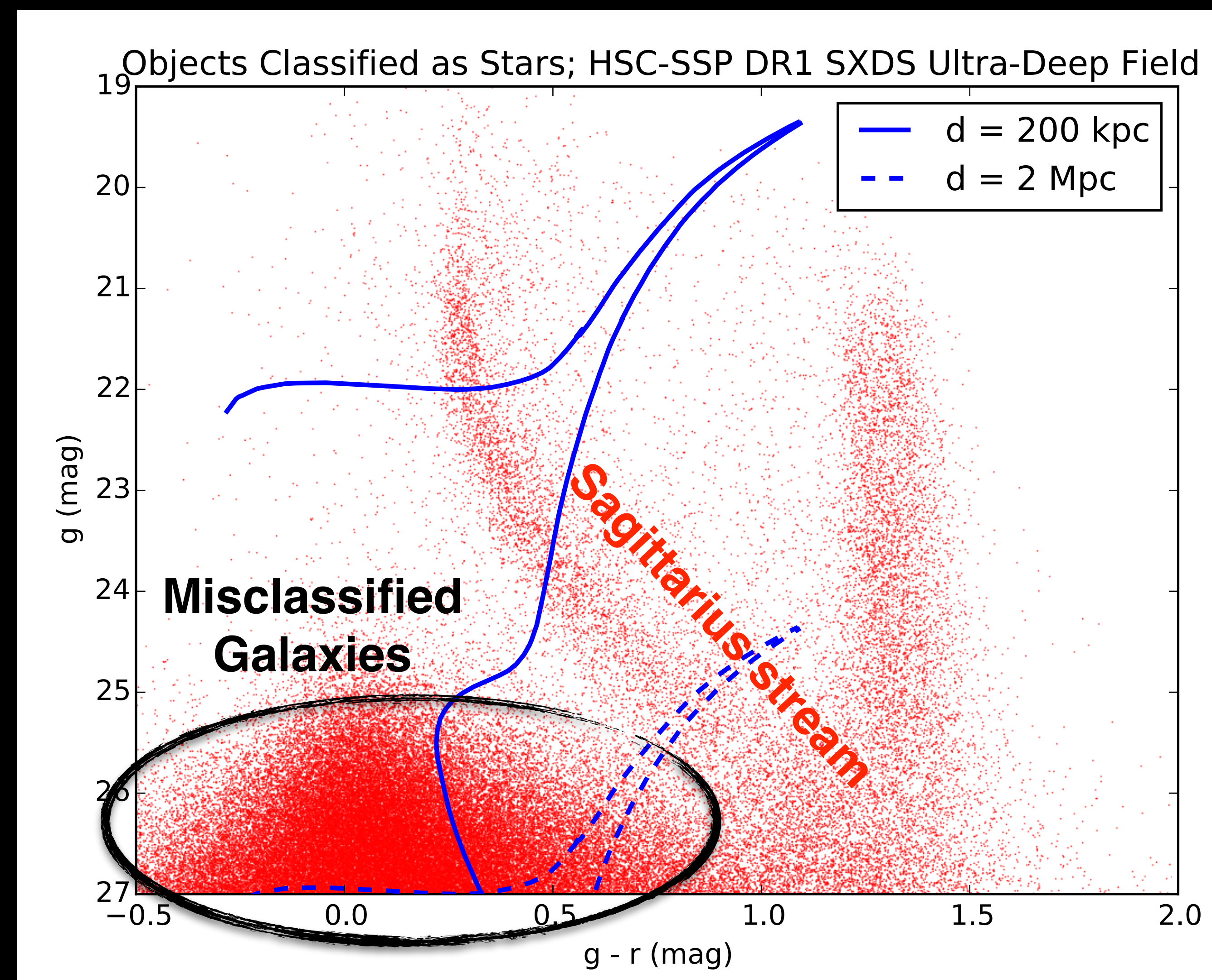
Data Analysis Opportunities

Star-galaxy separation (PSF characterization), diffuse light / deblending, proper motions, variable stars, …

Simulations from Beccari et al. 2016

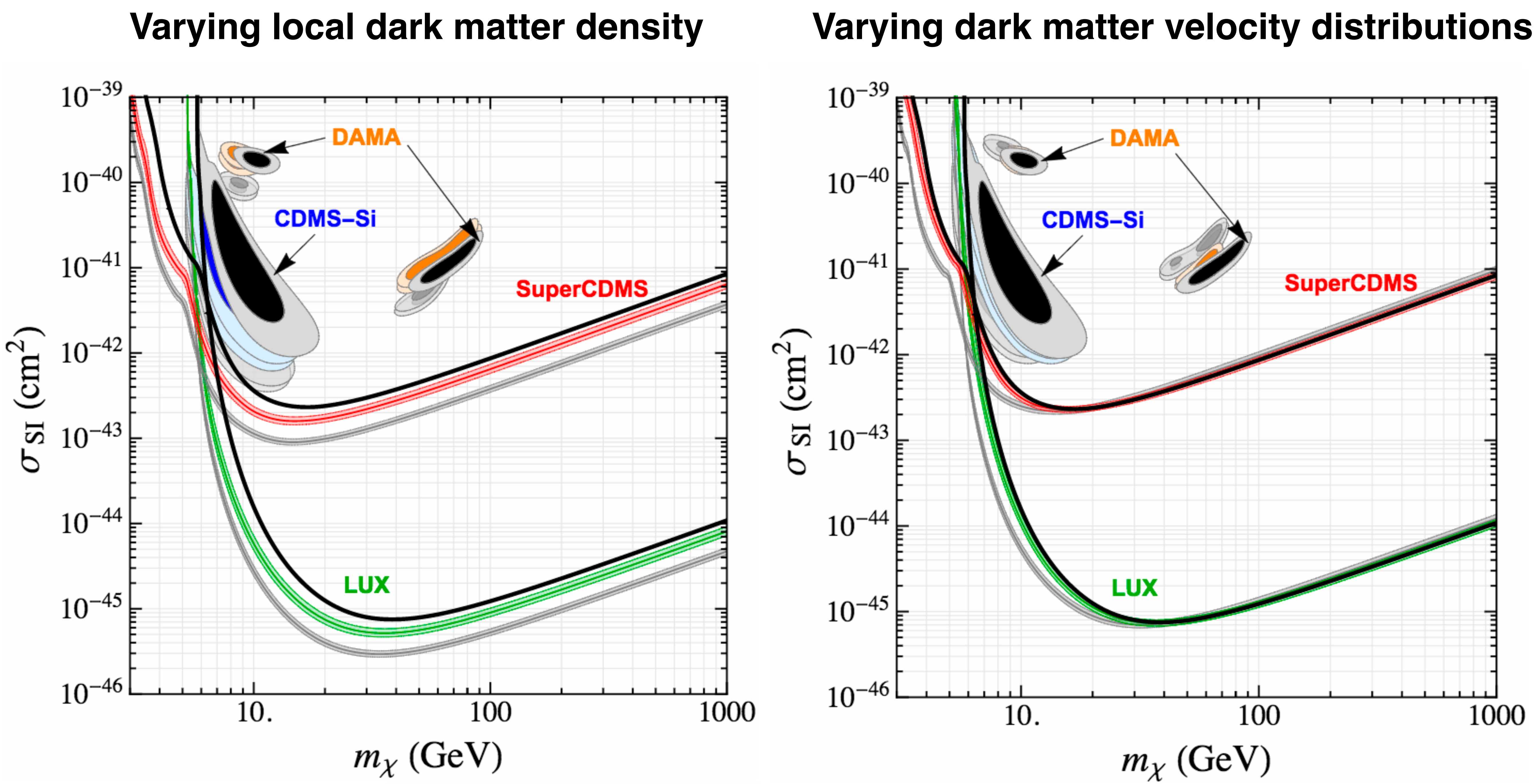


Comparable to LSST Wide-Fast-Deep 10 yr depth (27th mag), 0.6" seeing



HSC-SSP DR1 SXDS Ultra-Deep Field

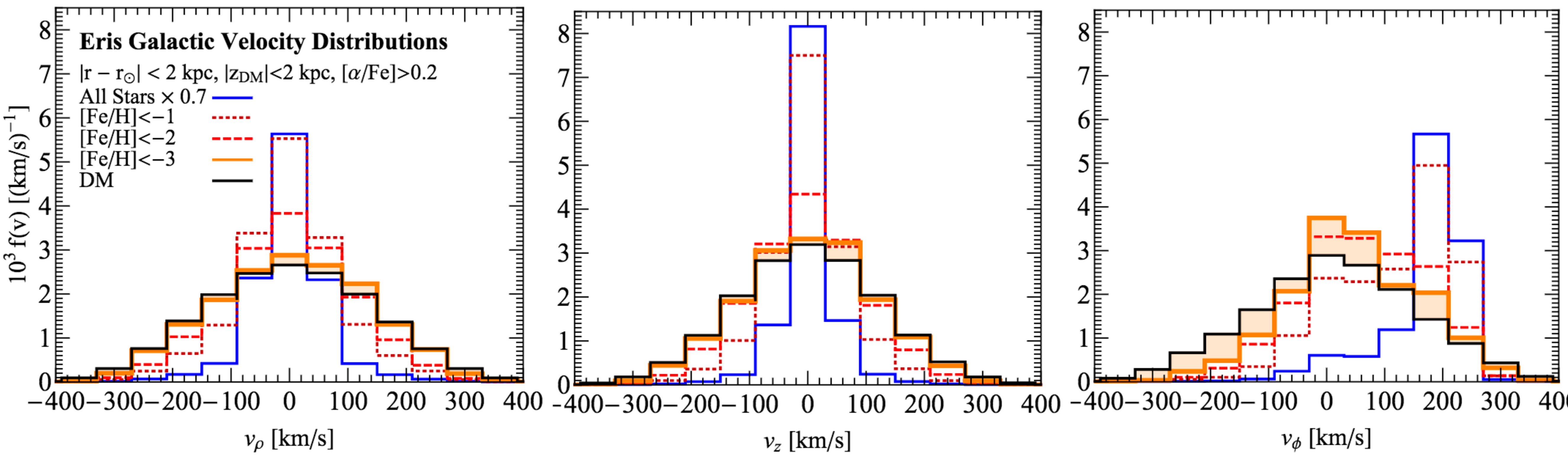
Impact of Galactic Halo Uncertainty on Direct Detection Searches



Bozorgnia et al. 2016, arXiv:1601.04707
See also
Kelso et al. 2016, arXiv:1601.04725
Sloane et al. 2016, arXiv:1601.05402

Using stellar kinematics to probe dark matter

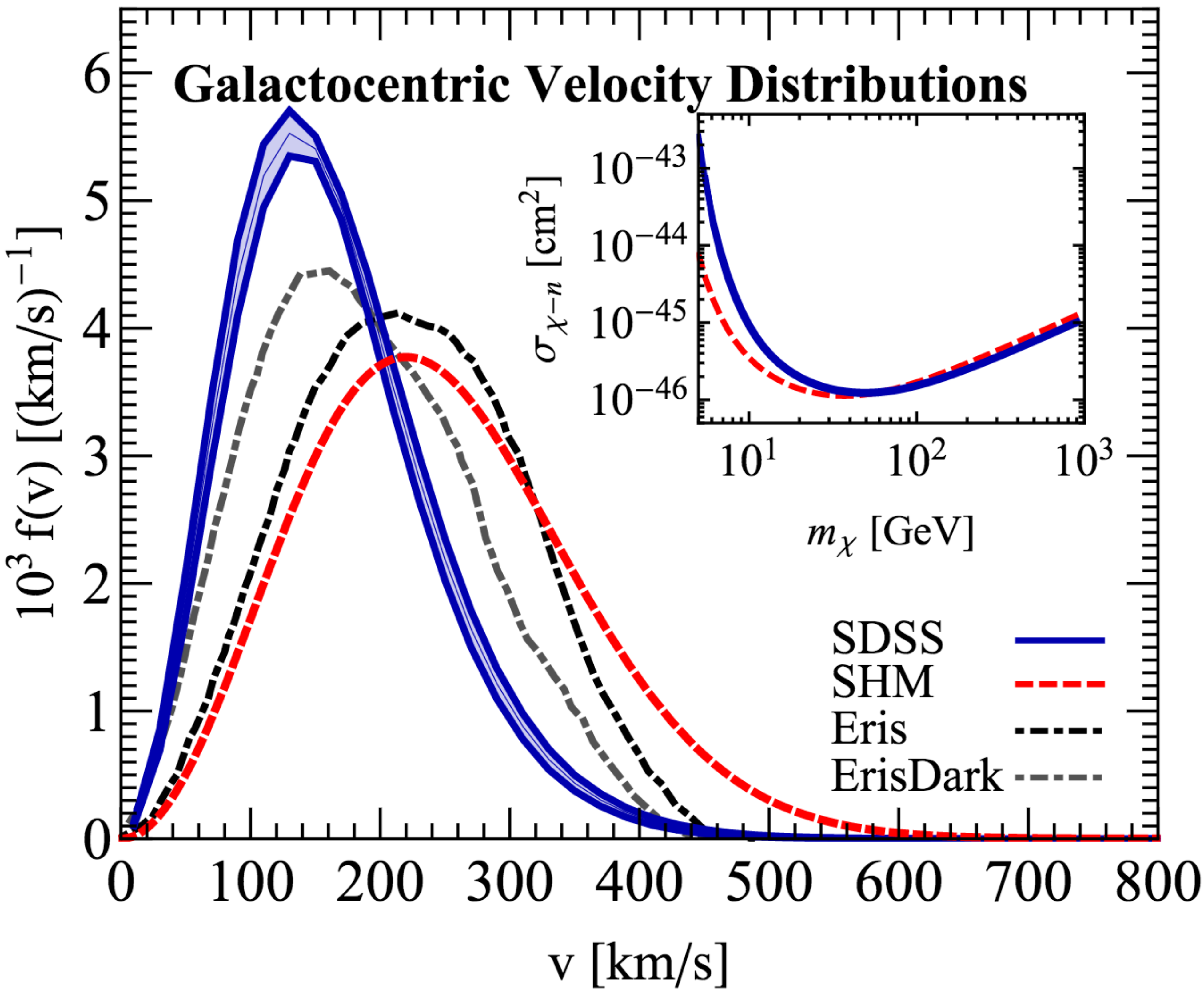
Idea: dark matter halos and their associated stars are accreted together during Milky Way assembly. Substructures persist in velocity space even after being mixed in positional space.



Herzog-Arbeitman et al. 2017
arXiv:1704.04499

The most metal poor stars in the Milky Way are the oldest and the most likely to reflect accretion history. Simulations with baryons suggest that the most metal poor stars can be used to constrain dark matter velocity distribution.

Using stellar kinematics to probe dark matter



Herzog-Arbeitman et al. 2017
arXiv:1704.04499

Closing Thoughts

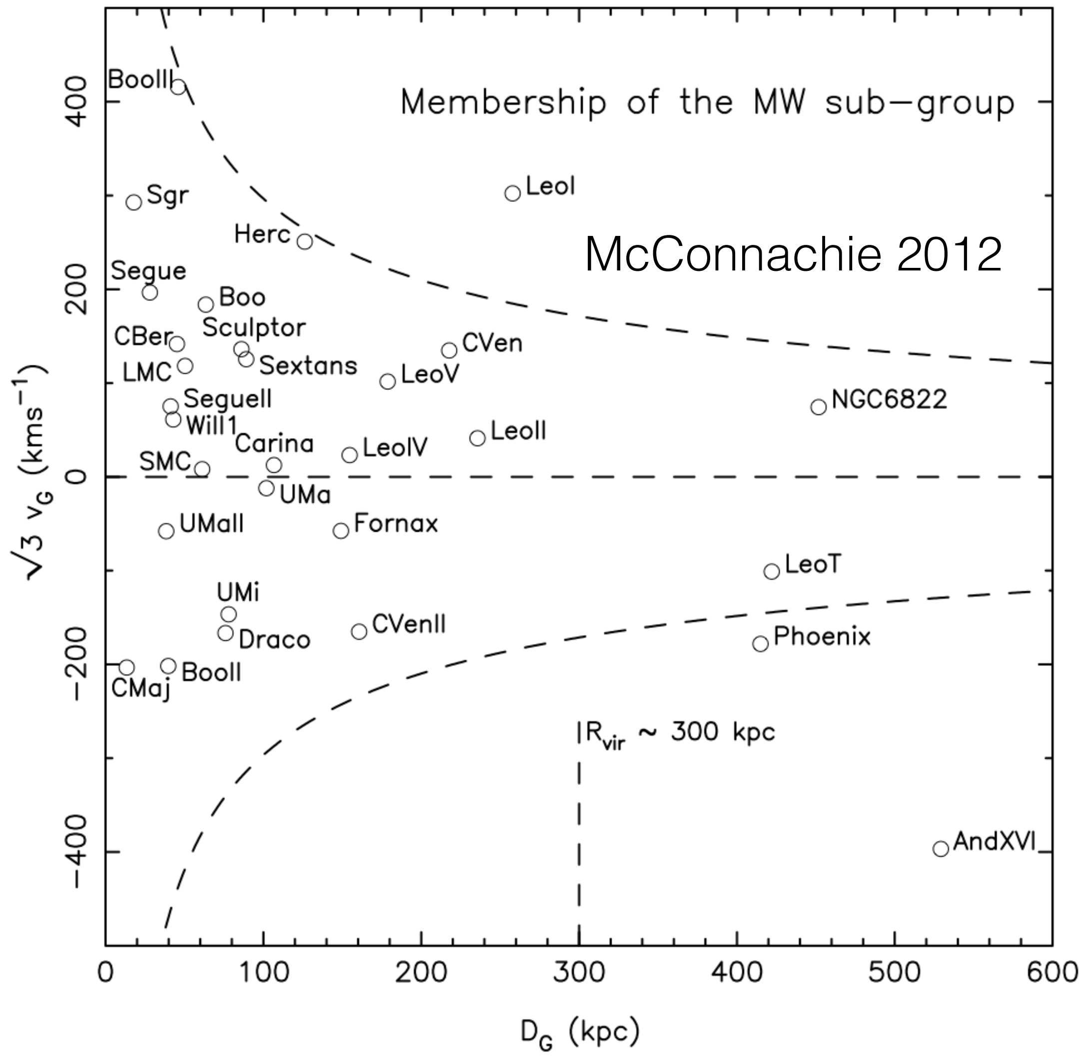
Multiple LSST dark matter probes have been proposed involving observations of resolved stars in the Local Volume

- Gravitational evidence for small-scale structure (dwarf galaxy demographics, stellar stream gaps)
- Targets for indirect searches
- Constraining the profile, shape, and velocity distribution of Milky Way halo — relevant for direct dark matter searches

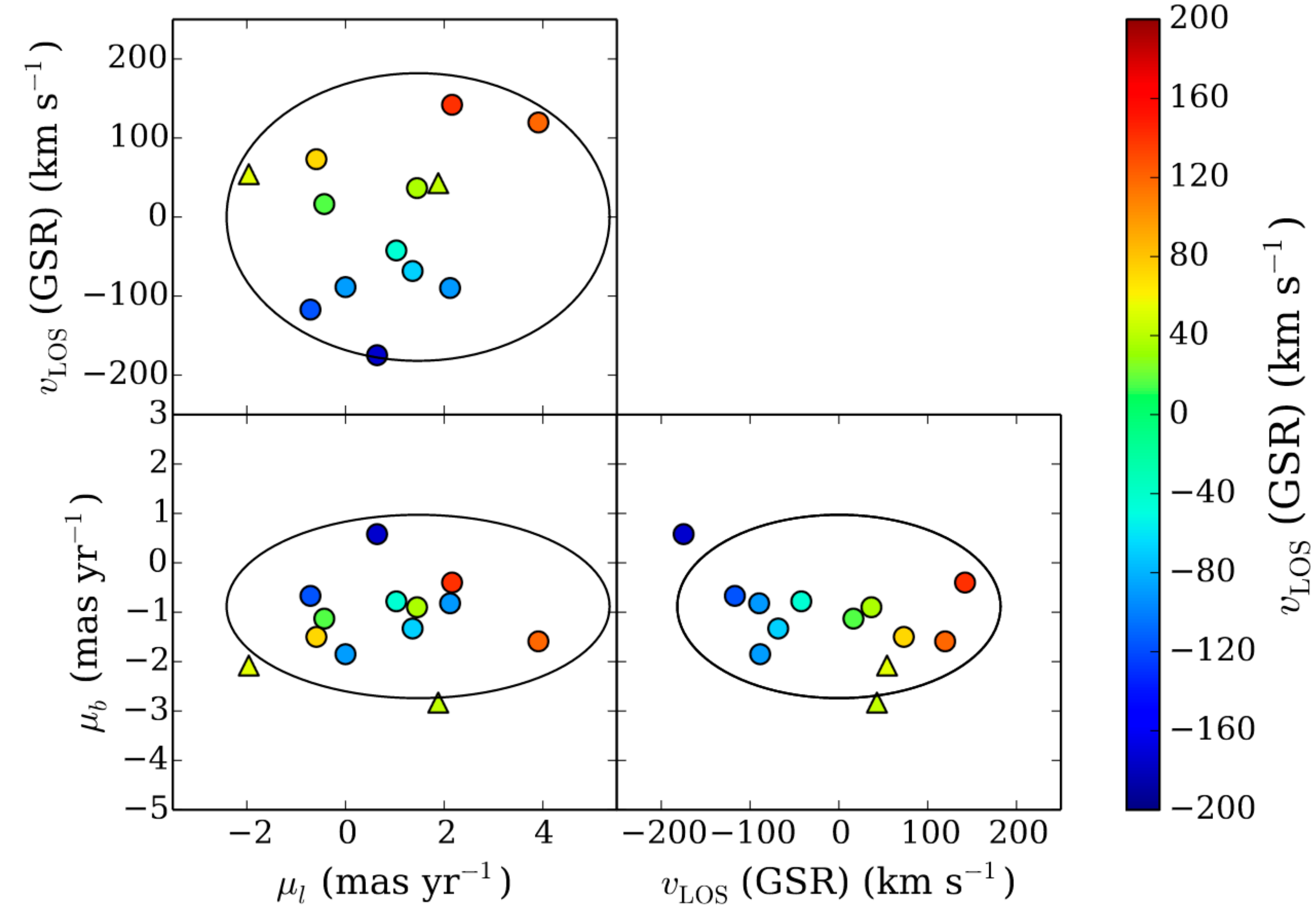
More theoretical work needed to evaluate which probes are most promising and complementary + role of baryonic effects

Many interesting data analysis challenges exercising multiple aspects of LSST data (morphology, colors, variability, proper motions, …)

Proper Motions

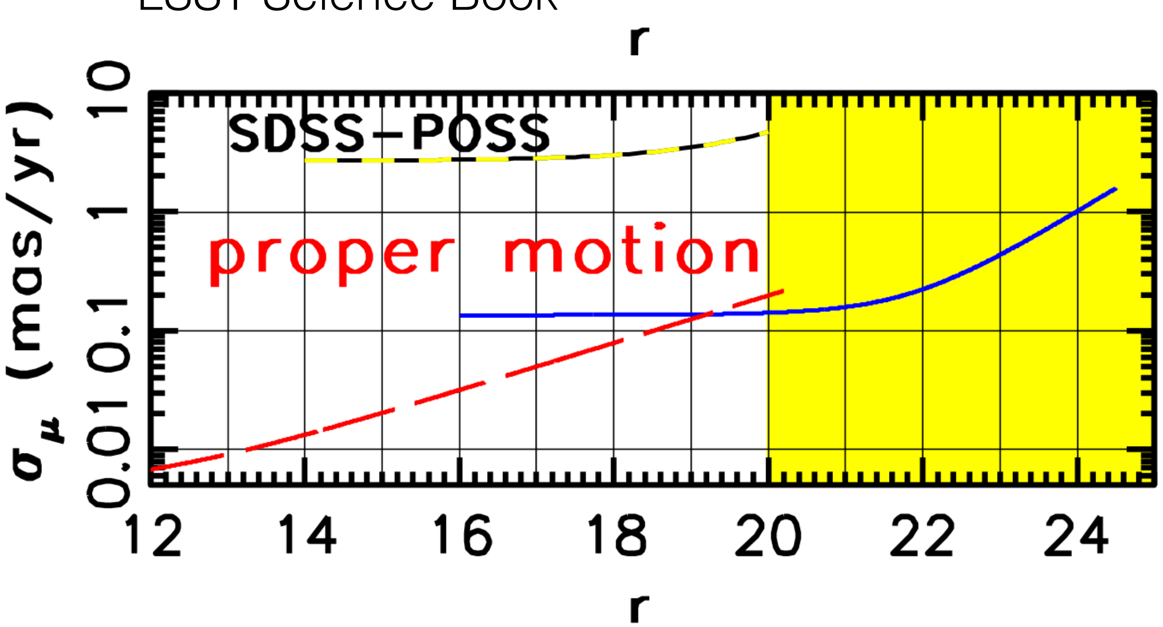


Cunningham et al. 2016
arXiv:1602.03180



First sample of halo stars with measured 3D kinematics outside the solar neighborhood
13 main sequence stars at ~25 kpc

LSST Science Book



$$\mu\ [\text{mas yr}^{-1}] = 0.21\ v_t\ [\text{km s}^{-1}]\ /\ d\ [\text{kpc}]$$