Searching for Ultra-faint Galaxies in Three Years of Data from the Dark Energy Survey

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(LSST)
on behalf of the DES Collaboration

TeV Particle Astrophysics
8 August 2017

THE DARK ENERGY SURVEY

LSST

DES Year 1 Cosmology Results

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See talk by Elisabeth Krause Wednesday morning

Dark Energy Survey Year 1 Results: Photometric Data Set for Cosmology
Drlica-Wagner et al. 2017

Dark Energy Survey Year 1 Results: Redshift distributions of the weak lensing source galaxies
Hoyle et al. 2017

Dark Energy Survey Year 1 Results: Weak Lensing Shape Catalogues
Zuntz et al. 2017

Dark Energy Survey Year 1 Results: The Impact of Galaxy Neighbours on Weak Lensing Cosmology with im3shape
Samuroff et al. 2017

Dark Energy Survey Year 1 Results: Curved-Sky Weak Lensing Mass Map
Chang et al. 2017

Dark Energy Survey Year 1 Results: Galaxy-Galaxy Lensing
Prat et al. 2017

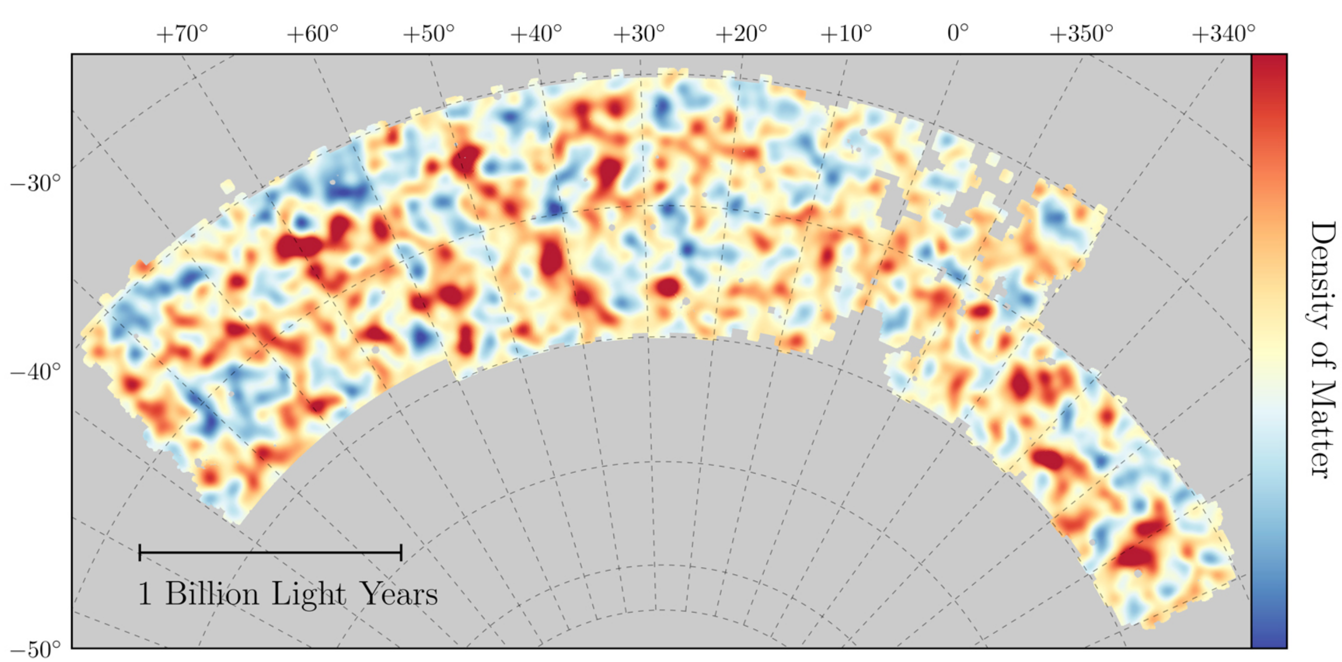
Dark Energy Survey Year 1 Results: Cosmological Constraints from Cosmic Shear
Troxel et al. 2017

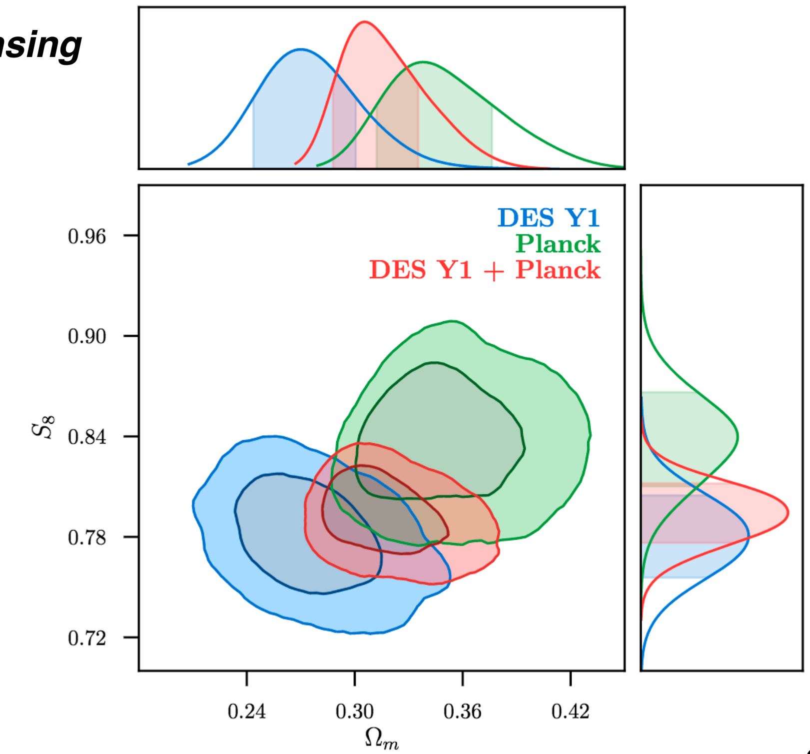
Dark Energy Survey Year 1 Results: Galaxy clustering for combined probes
Elvin-Poole et al. 2017

Dark Energy Survey Year 1 Results: Multi-Probe Methodology and Simulated Likelihood Analyses
Krause et al. 2017

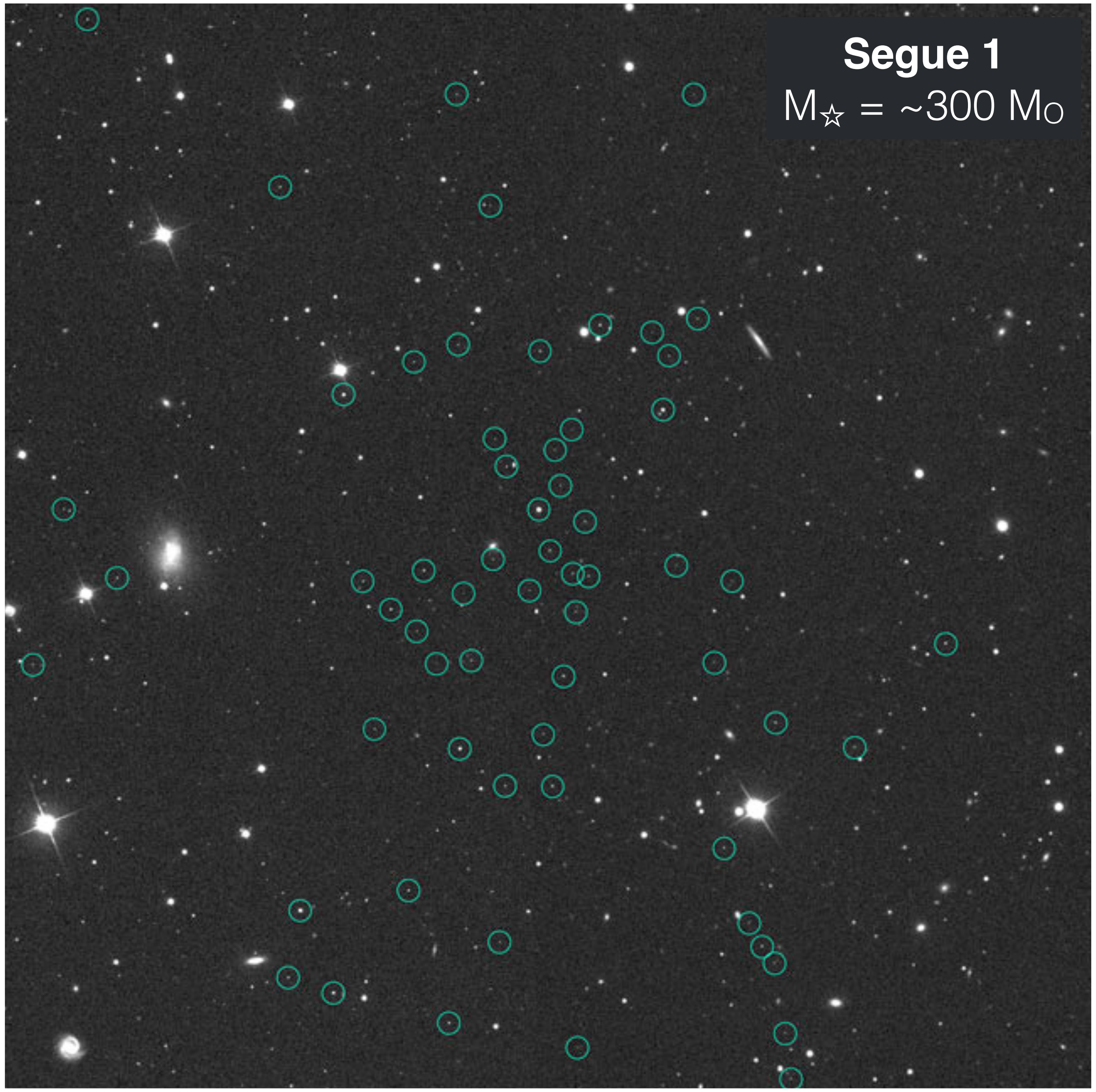
Dark Energy Survey Year 1 Results: Cosmological Constraints from Galaxy Clustering and Weak Lensing
DES Collaboration 2017

Onward to DES Y3 and beyond!

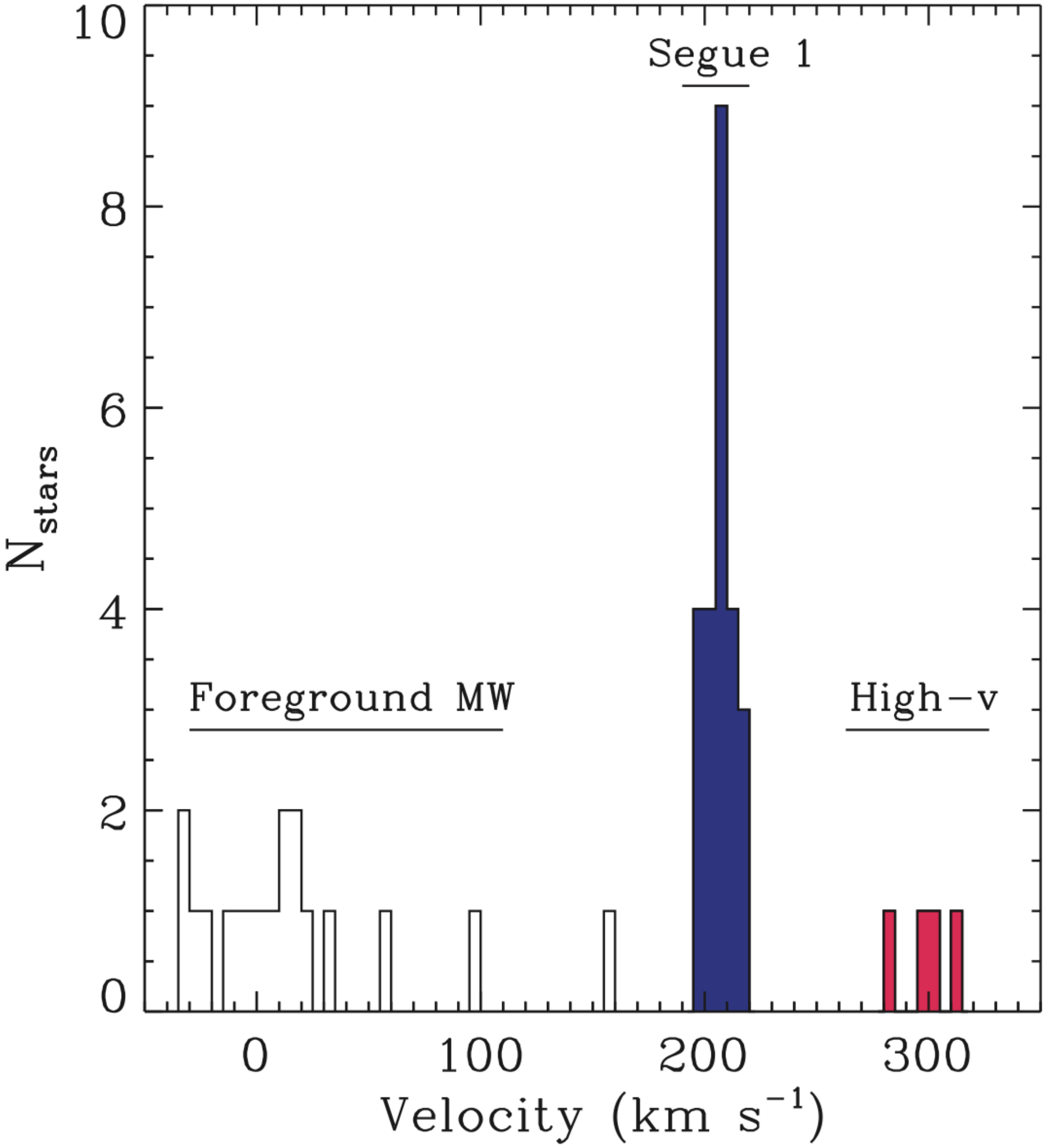




Ultra-faint Galaxies: Observer's Perspective



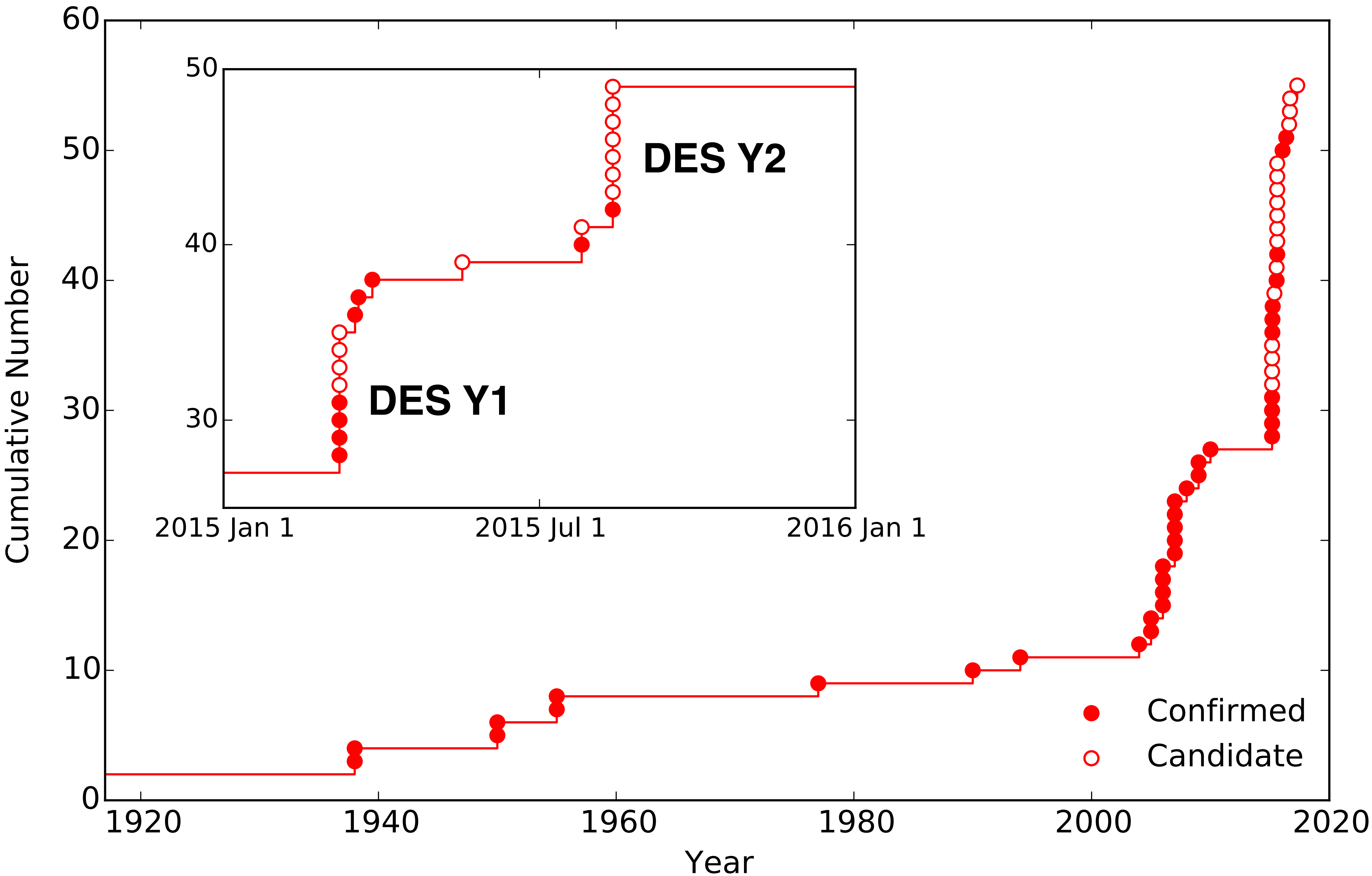
Geha et al. 2009, ApJ, 692, 1464



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)

Milky Way Satellite Galaxy Discovery Timeline



See **back-up slides** for highlights from ongoing spectroscopic campaign to confirm new stellar overdensities as **dark-matter-dominated** galaxies

Hundreds of Milky Way Satellites??

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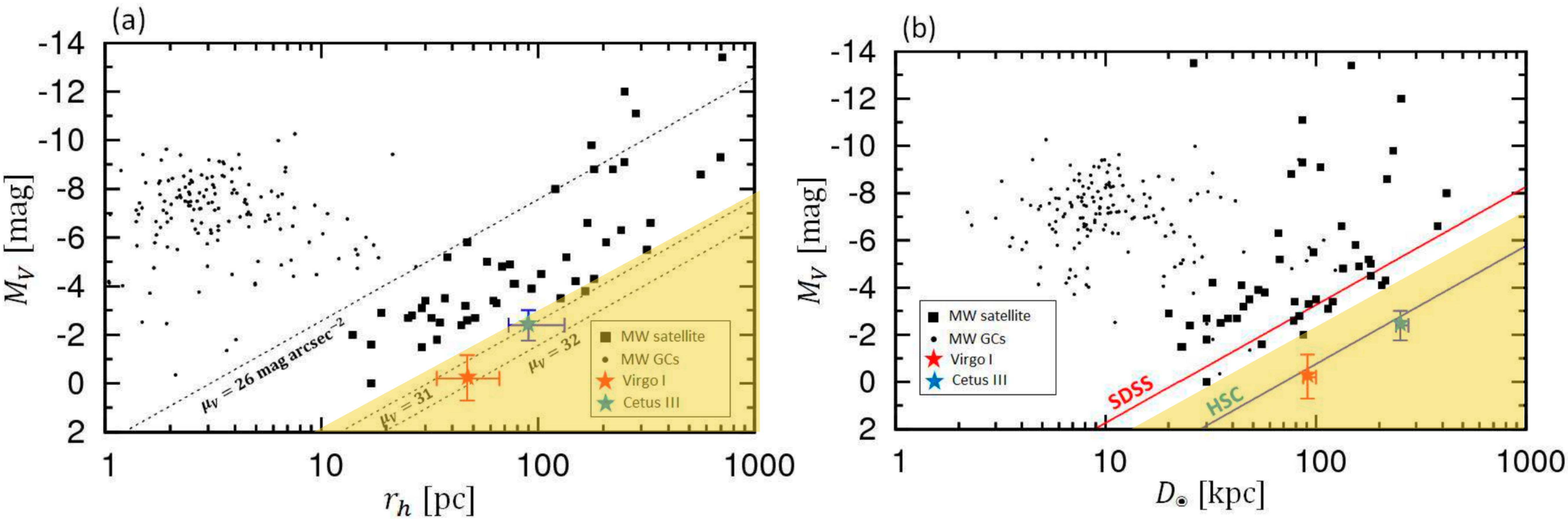
Two new ultra-faint galaxy candidates found in first 300 deg^2 of Hyper-Suprime Cam SSP data (<1% of 4π celestial sphere) that are likely undetectable in any previous survey

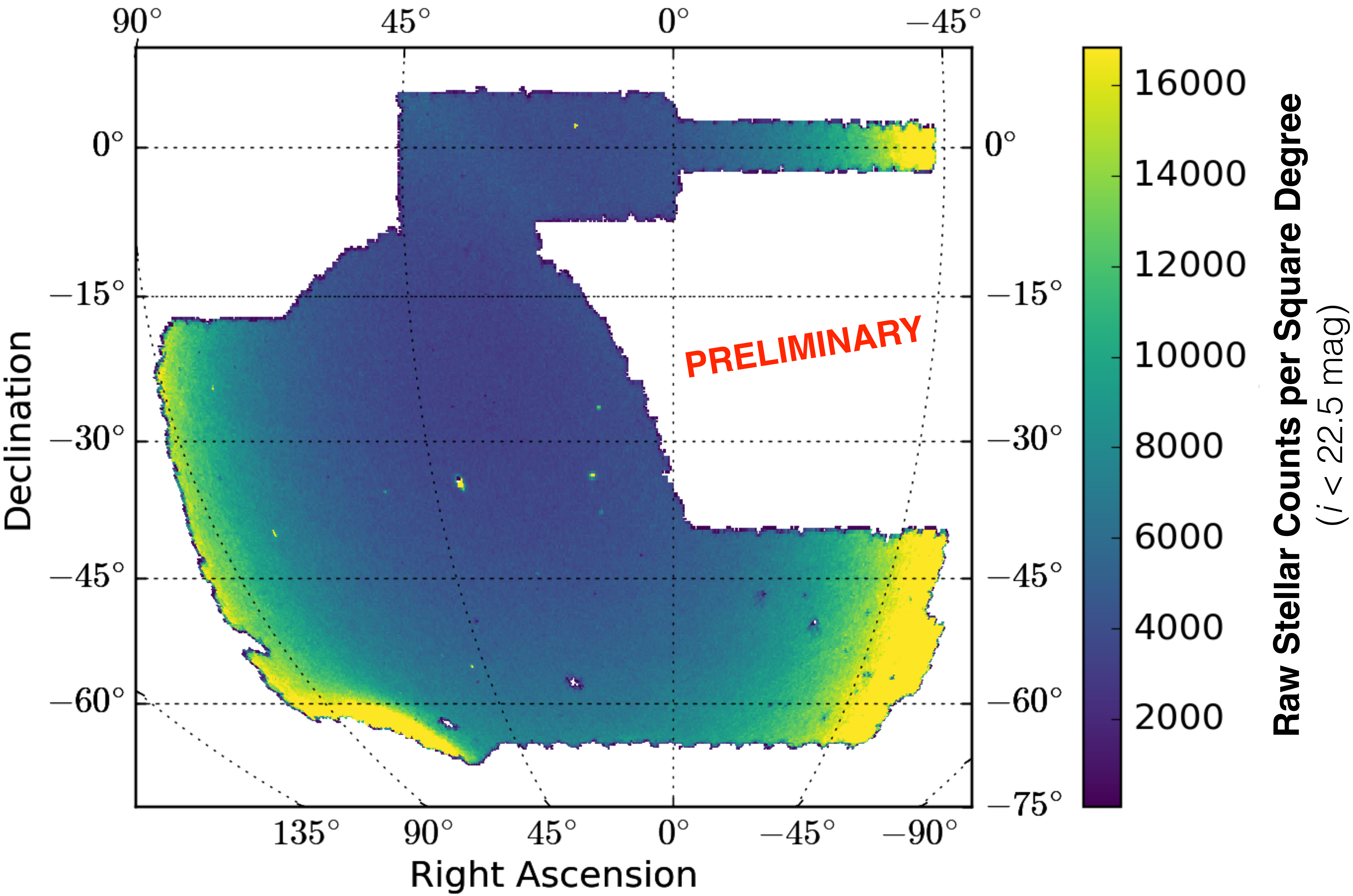


Homma et al. 2017

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

DES Y3 Footprint: ~5000 deg^2



DES Y3 Data Quality Improvements

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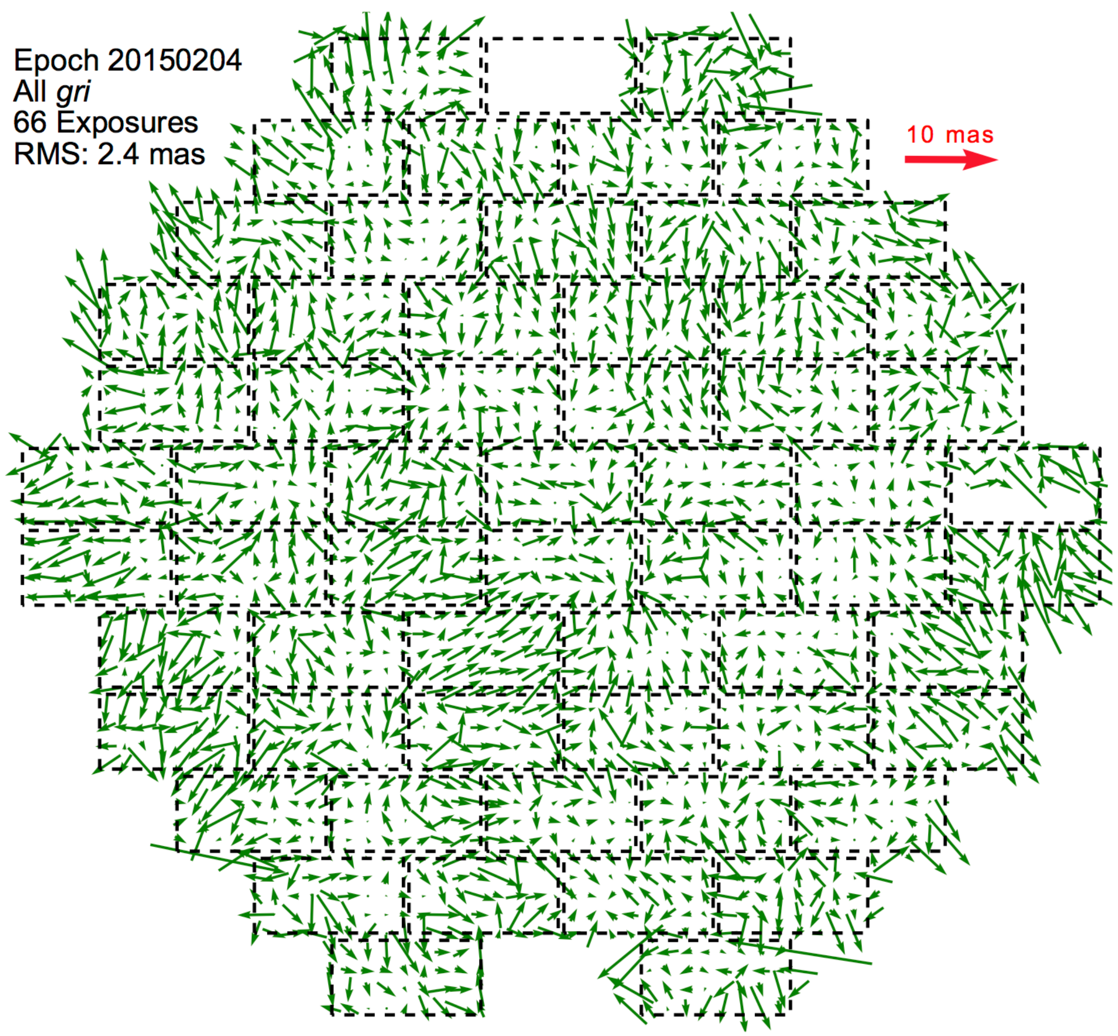
- Complete reprocessing of SV, Y1, Y2, and Y3 data
- Improved image detrending (Bernstein et al. 2017a)
- Improved instrument signature removal (Drlica-Wagner et al. 2017)
- Improved astrometric solution (Bernstein et al. 2017b)
- Photometric calibration
  - Forward Global Calibrations Module (Rykoff et al. 2017)
  - Updated DECam standard bandpass
  - Chromatic corrections and SED-dependent interstellar extinction corrections
- Multi-object, multi-epoch fitting (NGMIX + MOF)

Substantial improvements in nearly every aspect of data processing relative to DES Y1 and Y2 Milky Way satellite searches

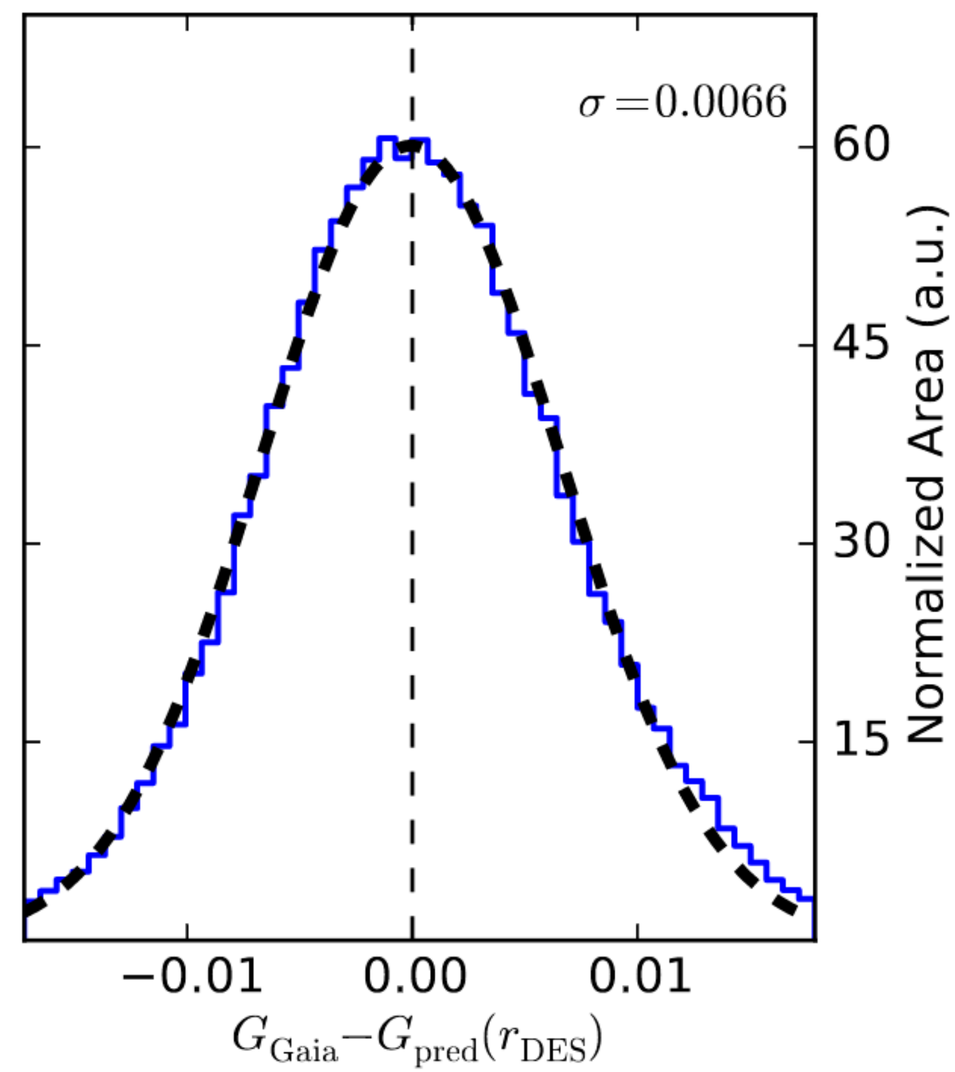
Precision Astrometry and Photometry

DECam astrometric model registered to *Gaia* has RMS errors below 10 mas
(limited by shot noise
and atmospheric turbulence)



Bernstein et al. 2017
arXiv:1703.01679

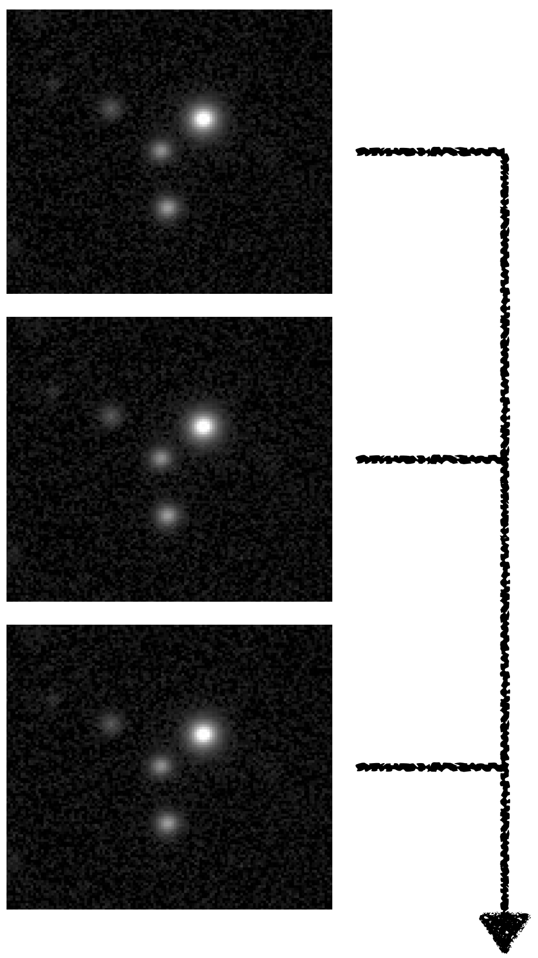
6.6 mmag (<1%) flux calibration relative to *Gaia*



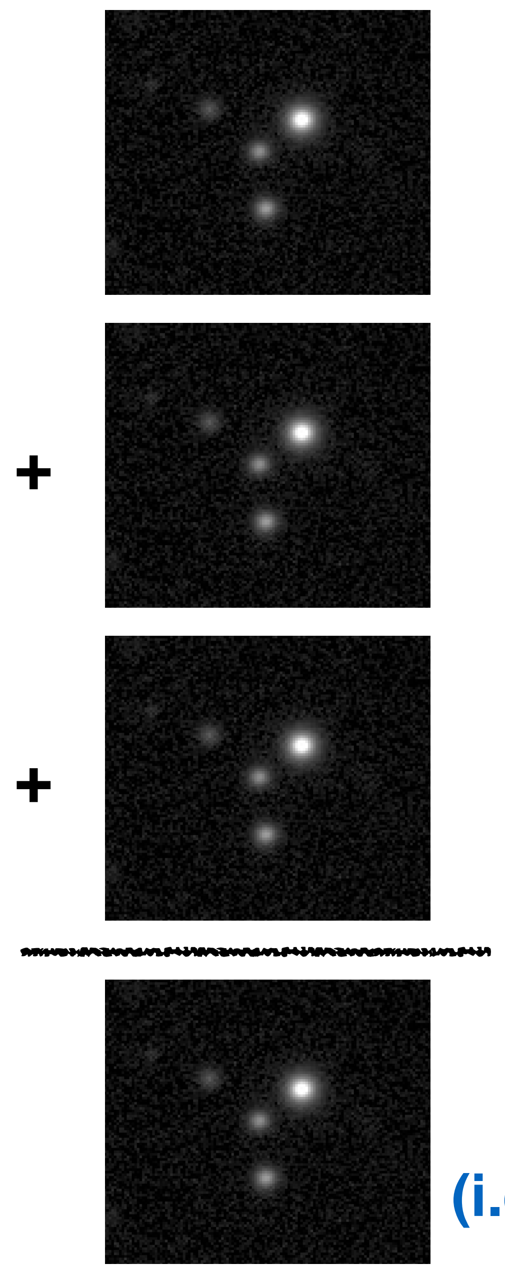
Burke et al. 2017
arXiv:1706.01542

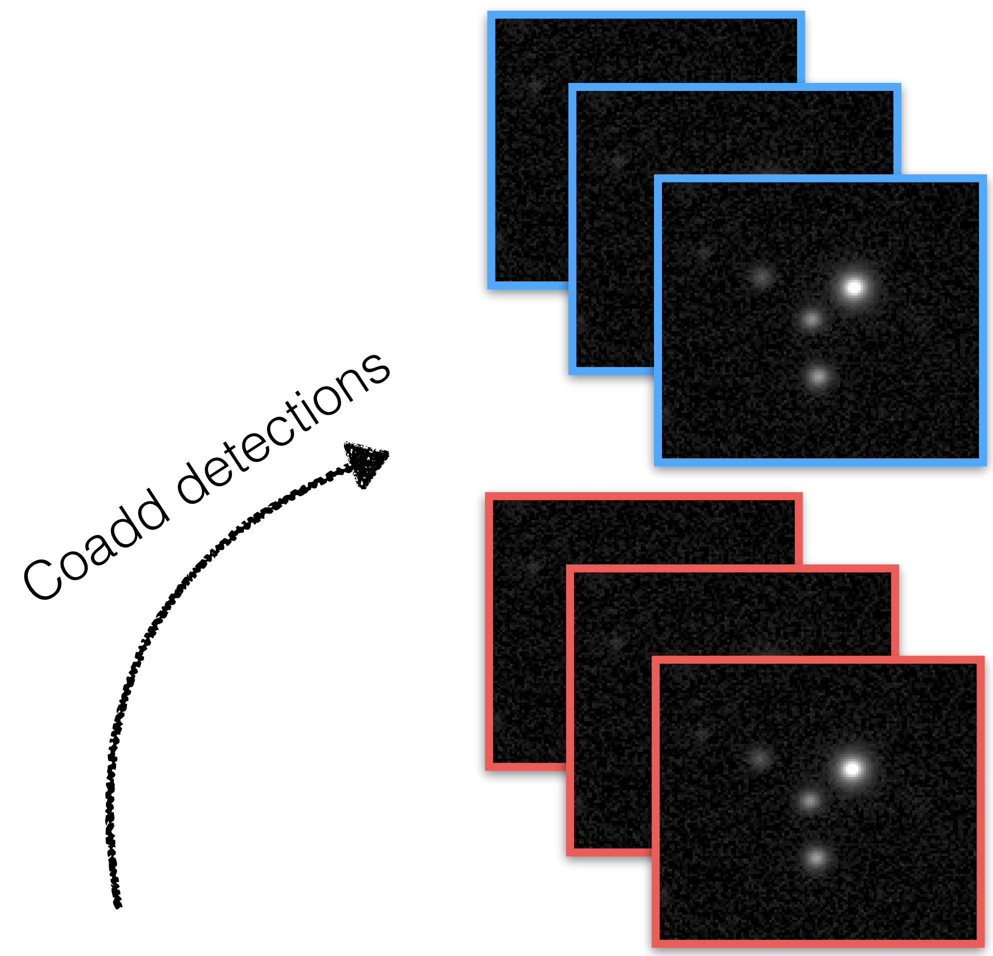
Source Measurement Strategies

Weighted Average	Coadd	Multi-Epoch Multi-Band



Average single-epoch measurements





Measurements from stacked (i.e., coadded) image

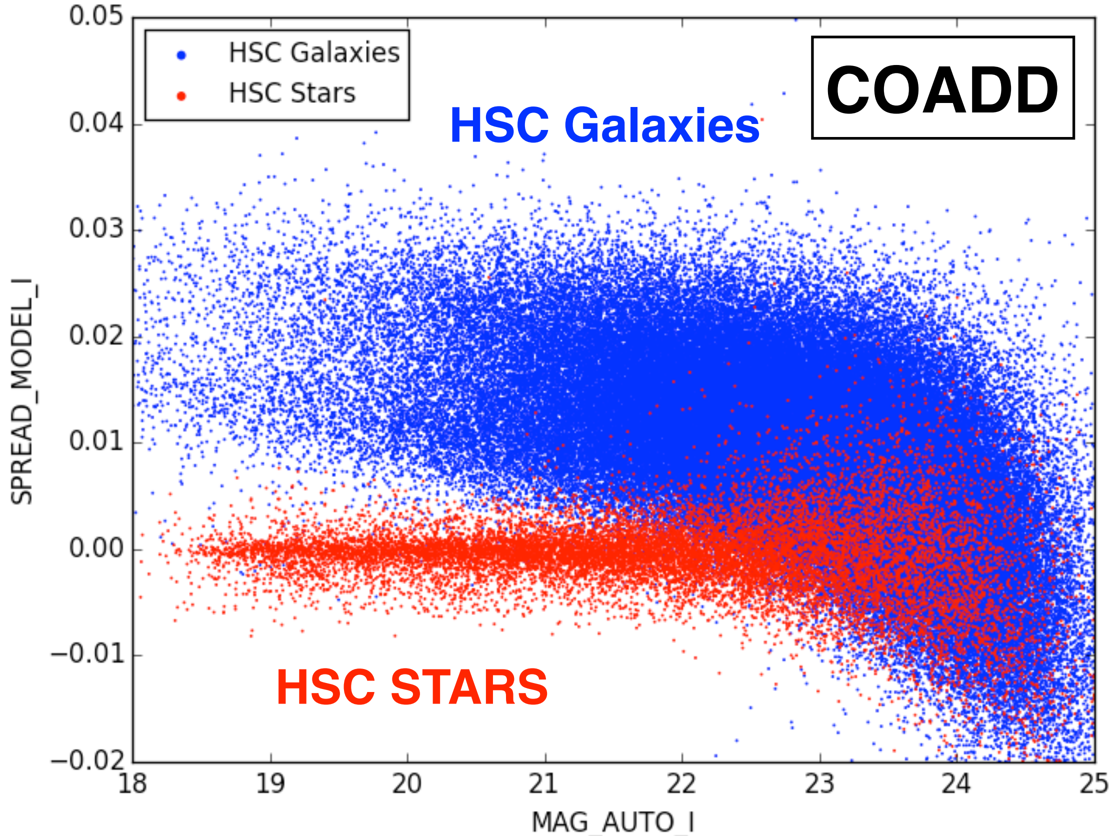
Joint fit

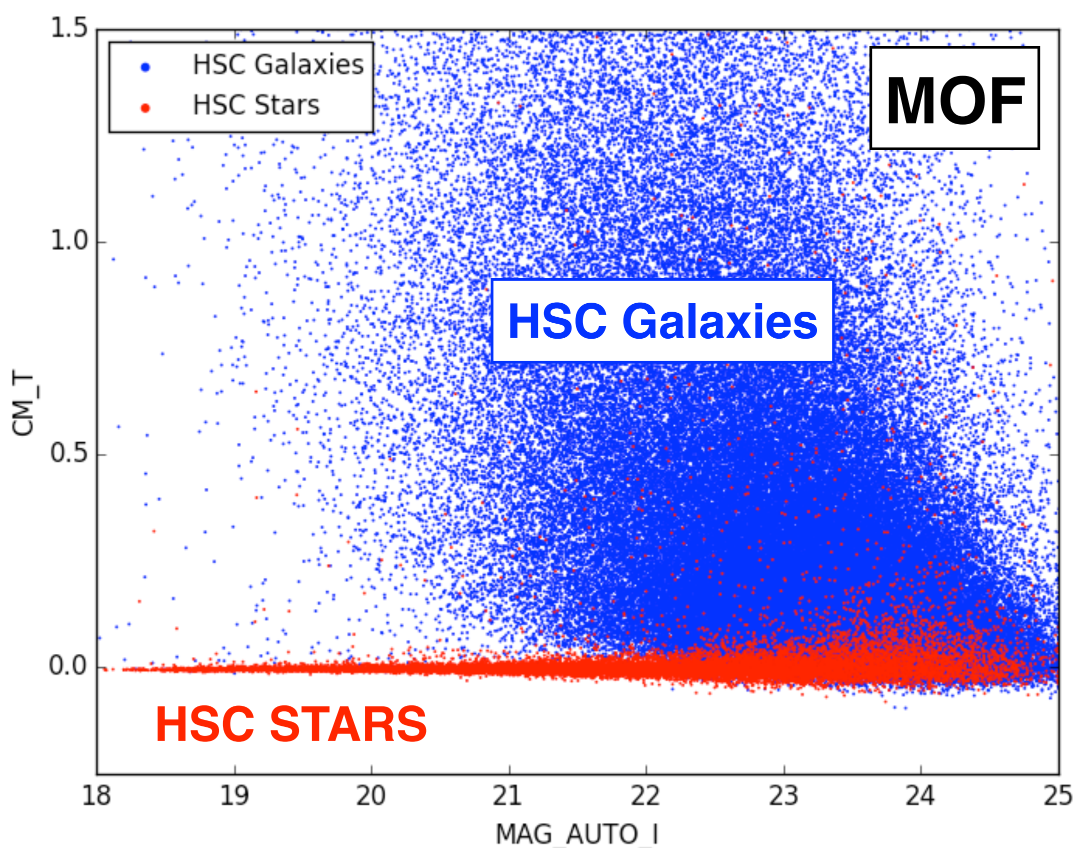
DES Y2Q1
Satellites Search

DES Y1A1
Satellites Search

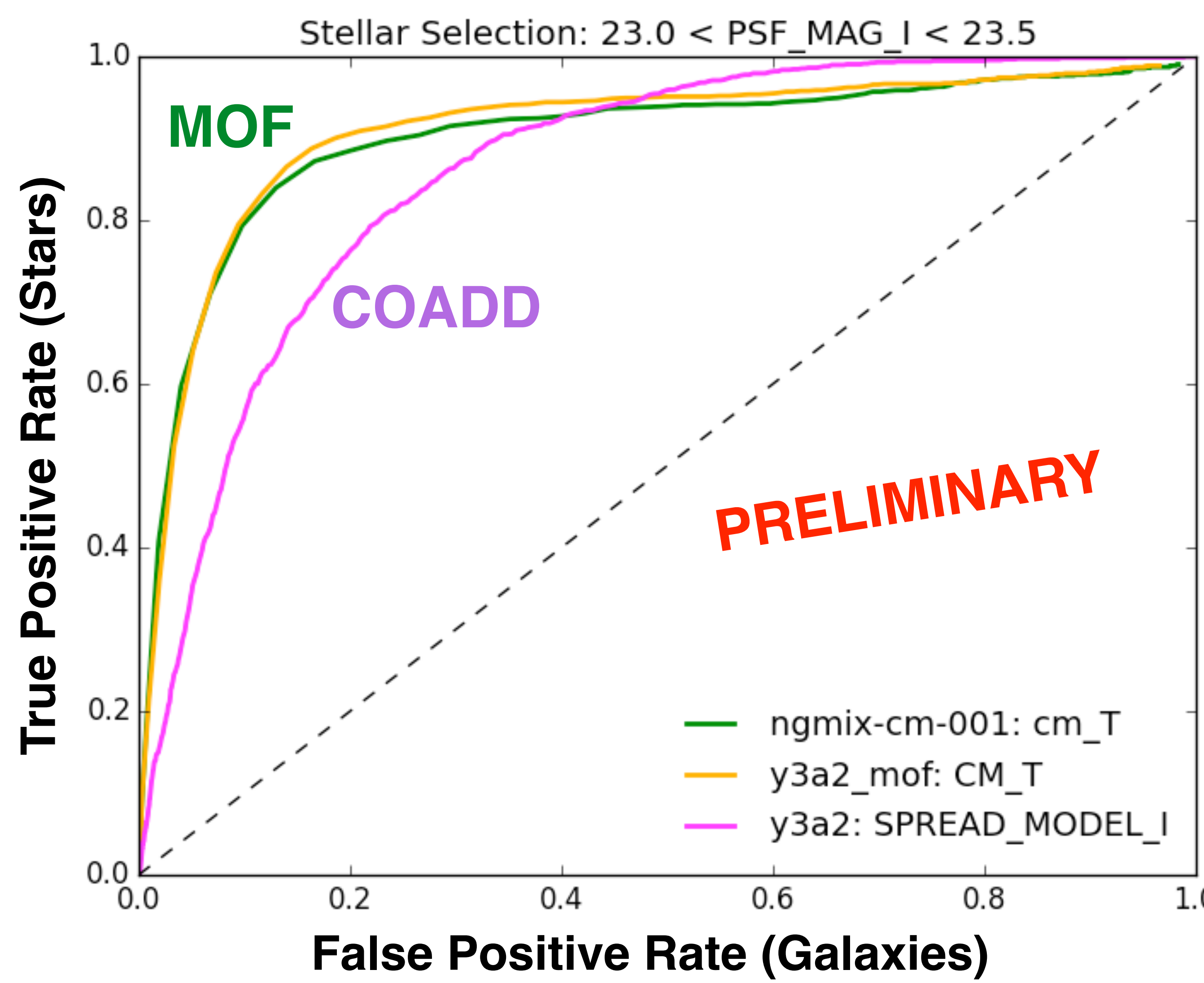
DES Y3A2
Satellites Search

Improved Object Classification





Star-Galaxy Separation at Faint Magnitudes



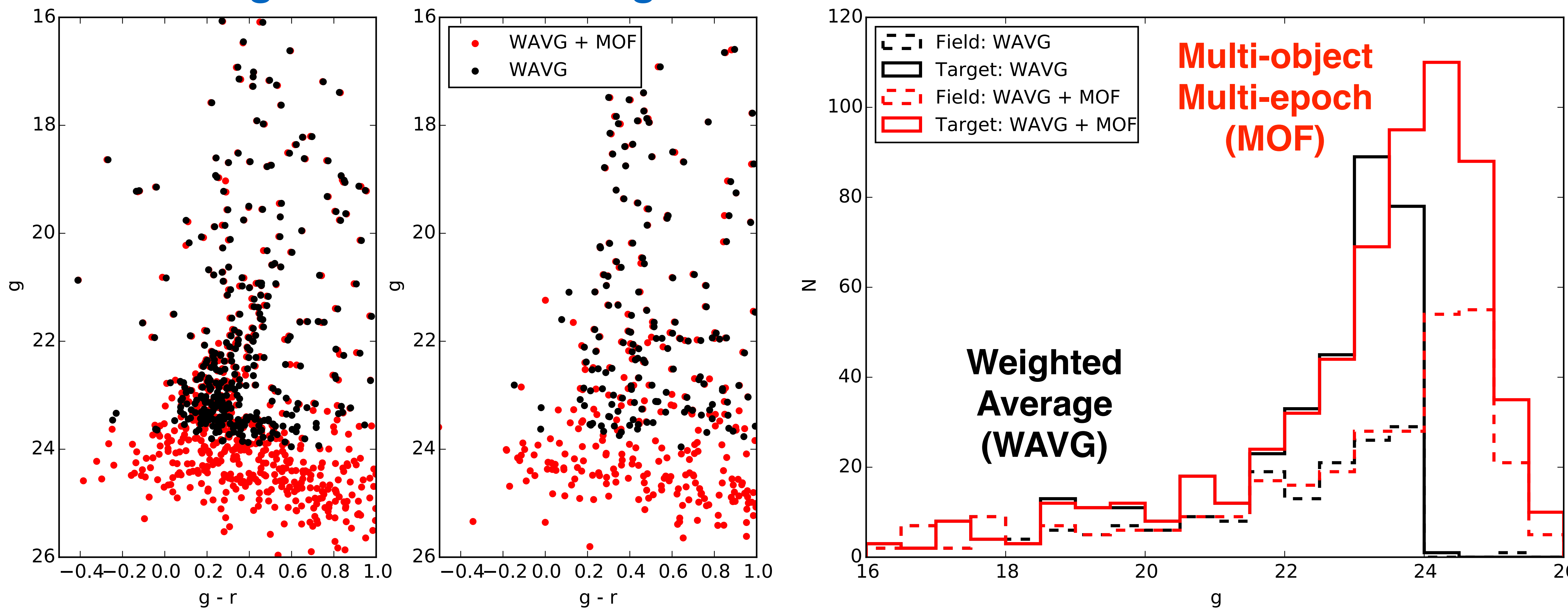
Improved handling of PSF enables more accurate and robust classification

Increasing Depth

Example for Grus II

discovered in DES Y2Q1 dataset using weighted-average measurements

On-target | **Off-target** | **Flux distribution of *detected* stars**

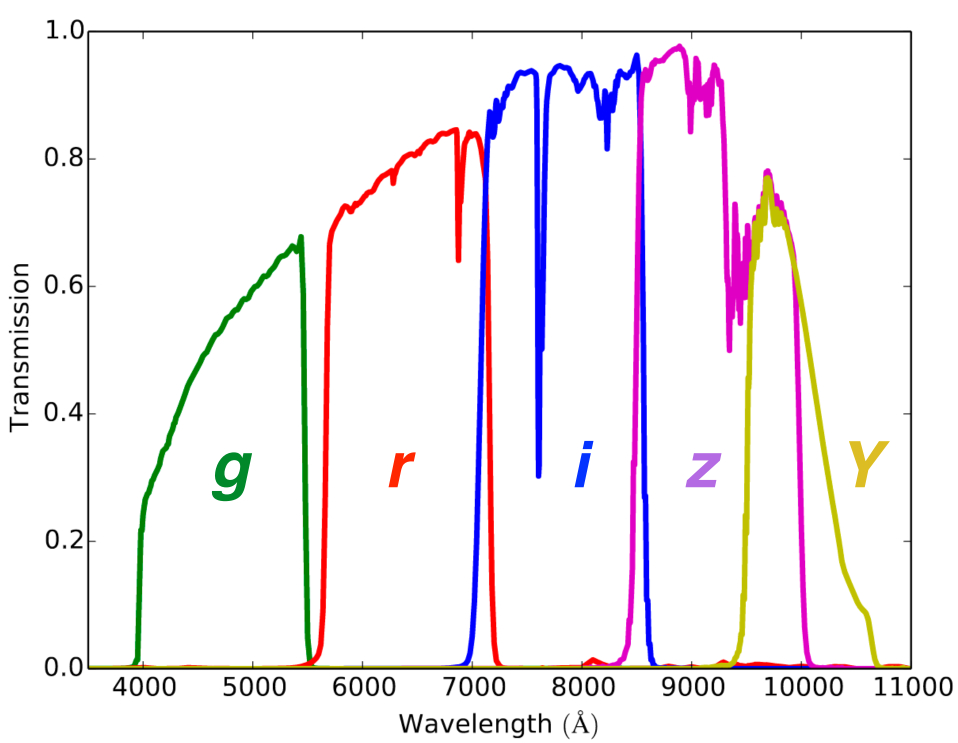


Significant excess of unresolved (PSF-like) objects observed
even in faint regime where star-galaxy confusion becomes a challenge

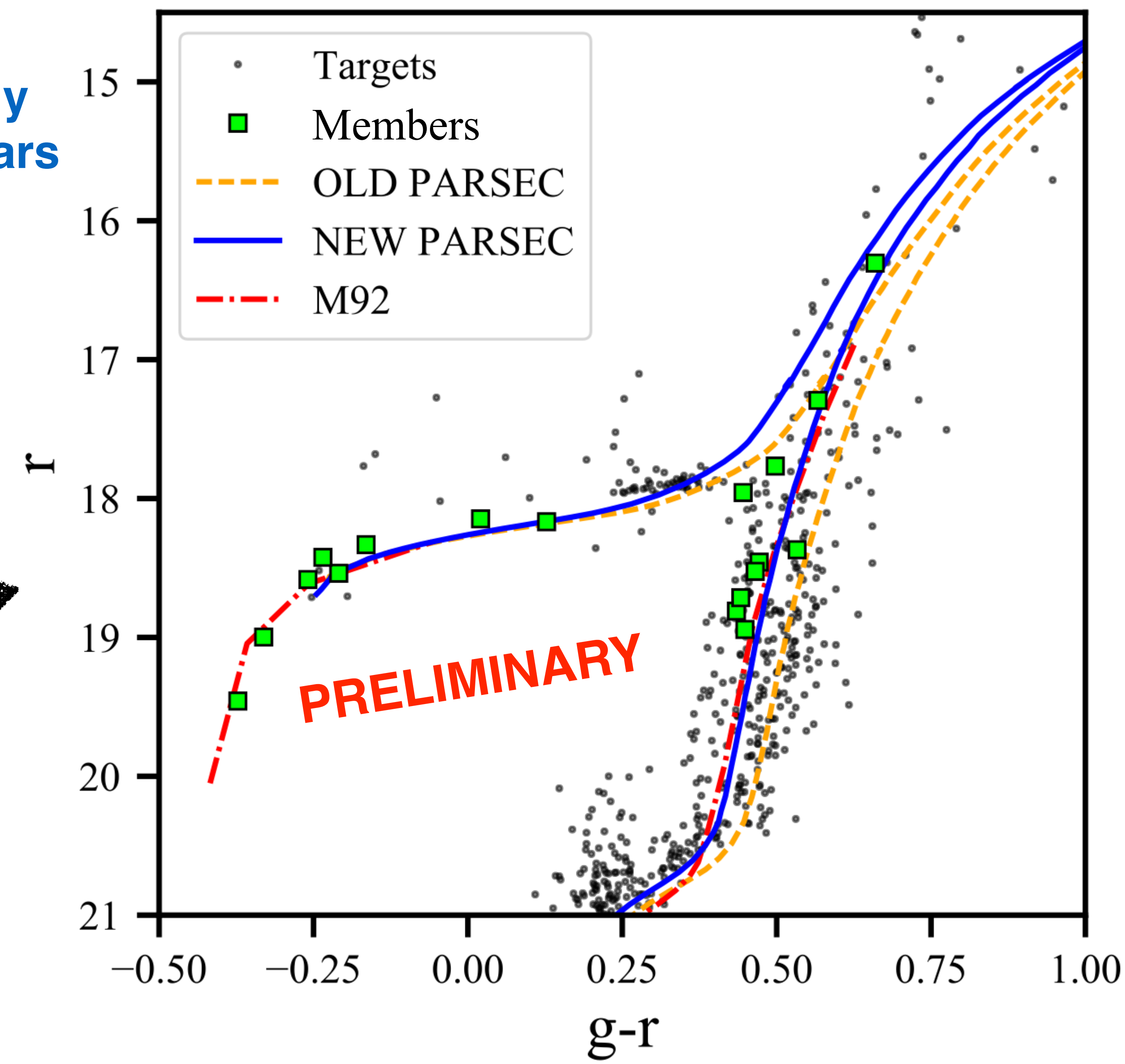
Improved Isochrone Modeling

A population of stars born with a range of initial masses follows a distinct locus in color-flux space called an **isochrone**. Improved measurement of the DECam bandpass has resulted in more accurate transformation of theoretical stellar spectra to observed colors.

DECam standard bandpass



Colors of spectroscopically confirmed dSph member stars

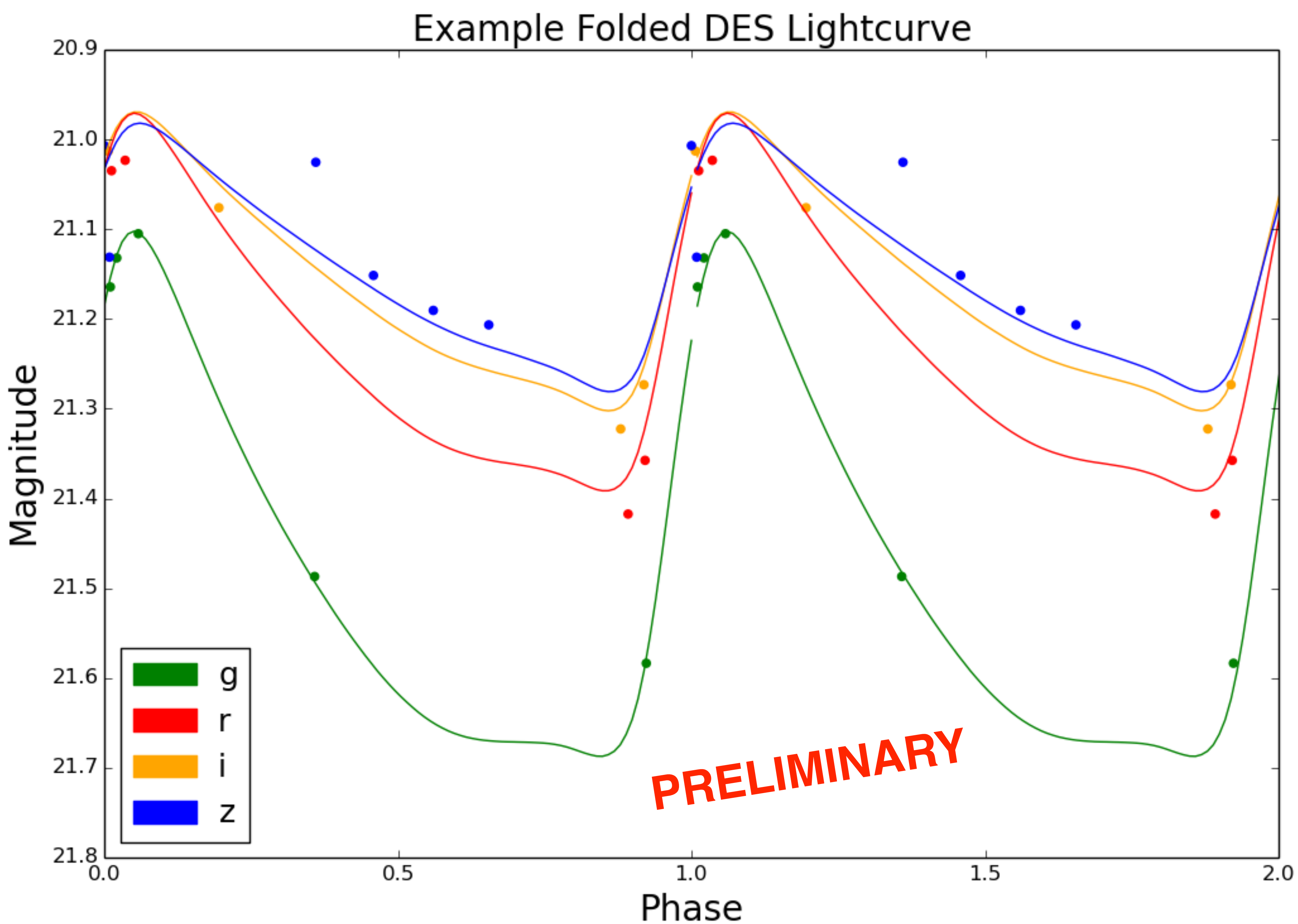


Burke et al. 2017
arXiv:1706.01542

Using RR Lyrae to Identify Substructures in the Milky Way Halo

At least one RR Lyrae (variable star standard candle) has been identified in *every* dSph with published time-series observations

Baker & Willman 2015



Sparse sampling: total of ~50 DES observations distributed across 5 bands over 5 years (typical pulsation periods range from 0.25 to 0.8 days)

Using RR Lyrae to Identify Substructures in the Milky Way Halo

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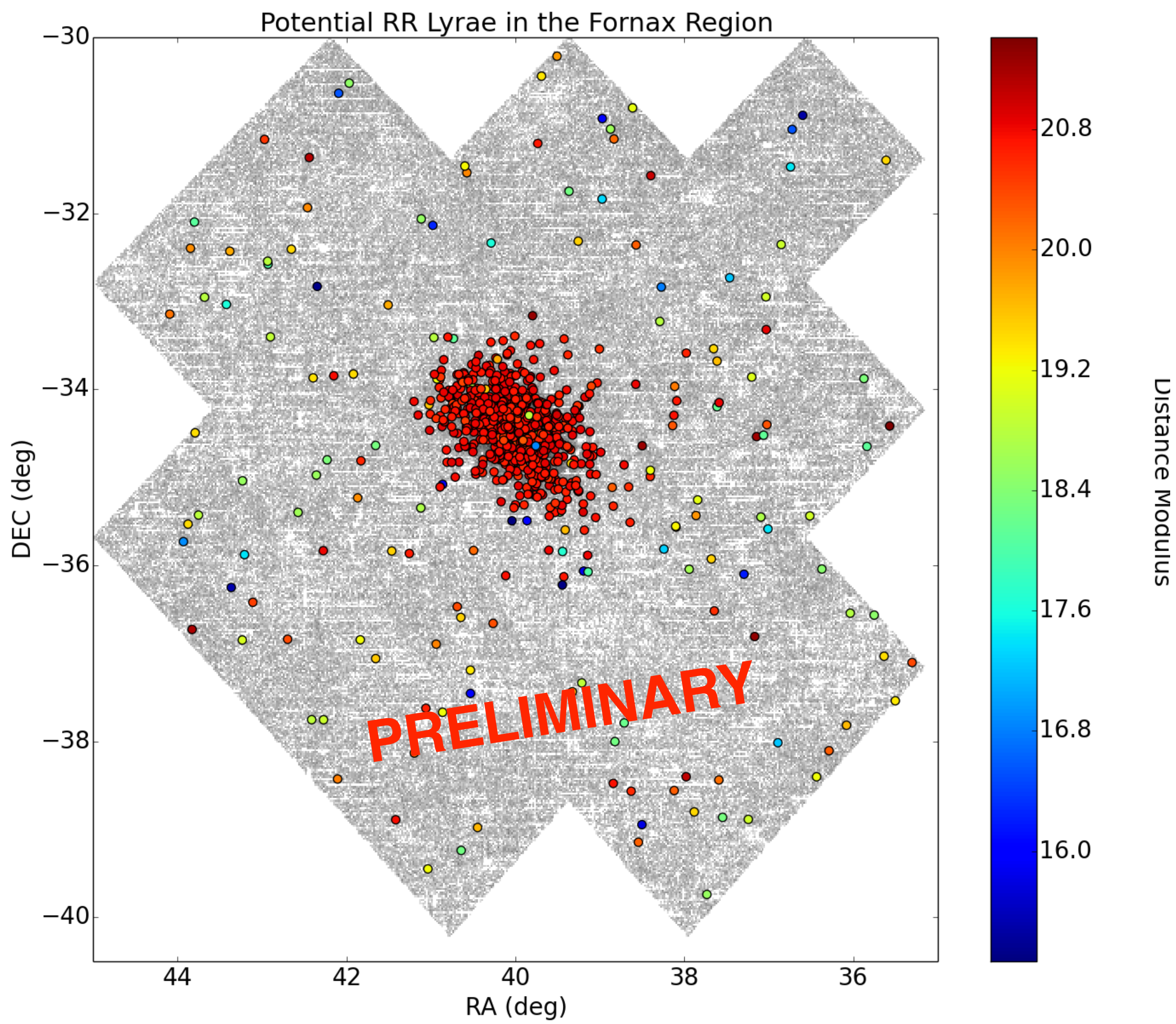
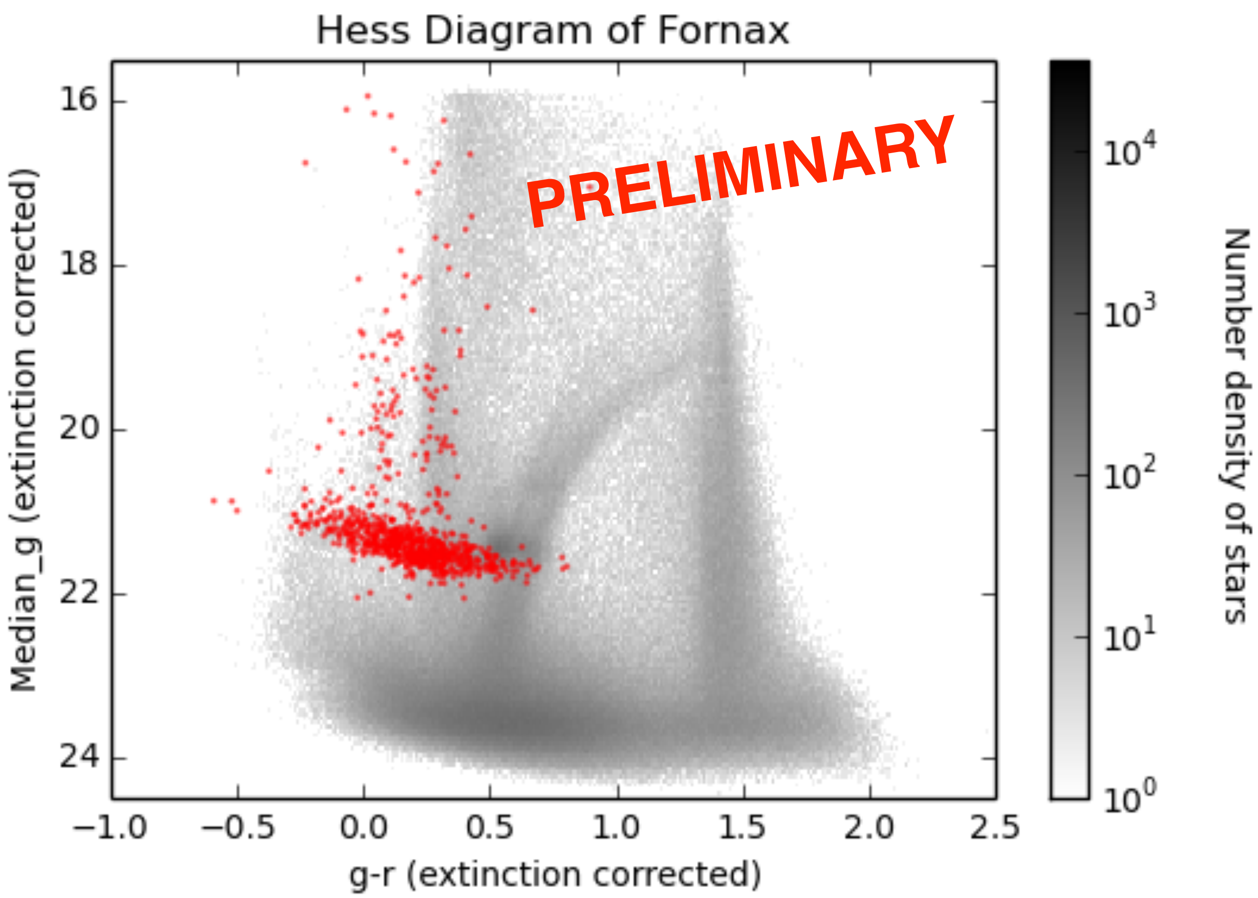
Baker & Willman 2015

DES Candidate RR Lyrae in Fornax region



Color-coded by distance

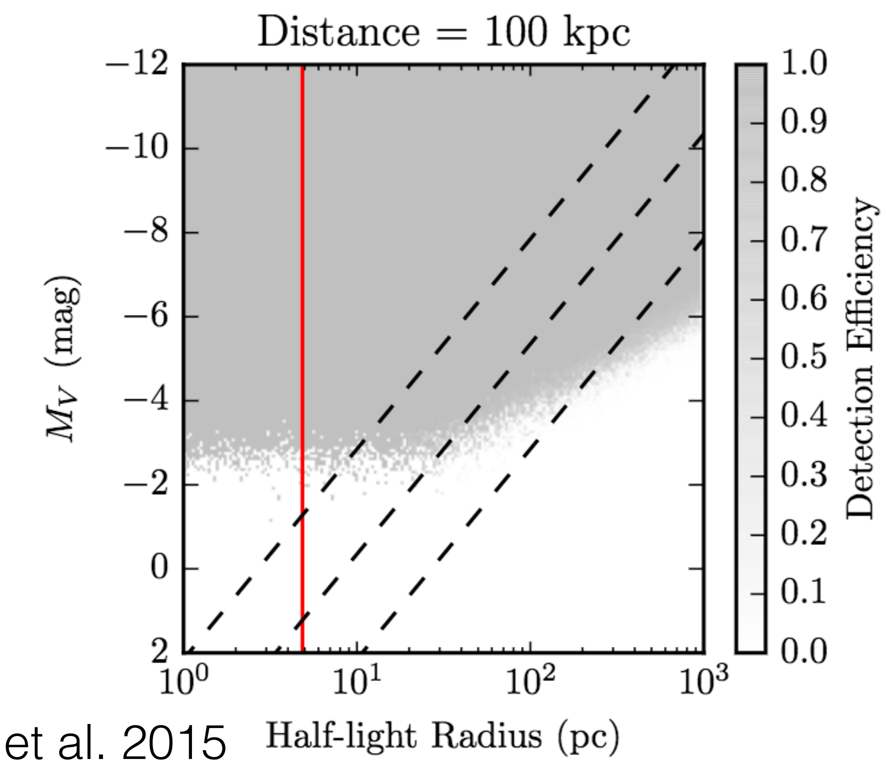
Location in Color-Flux Space



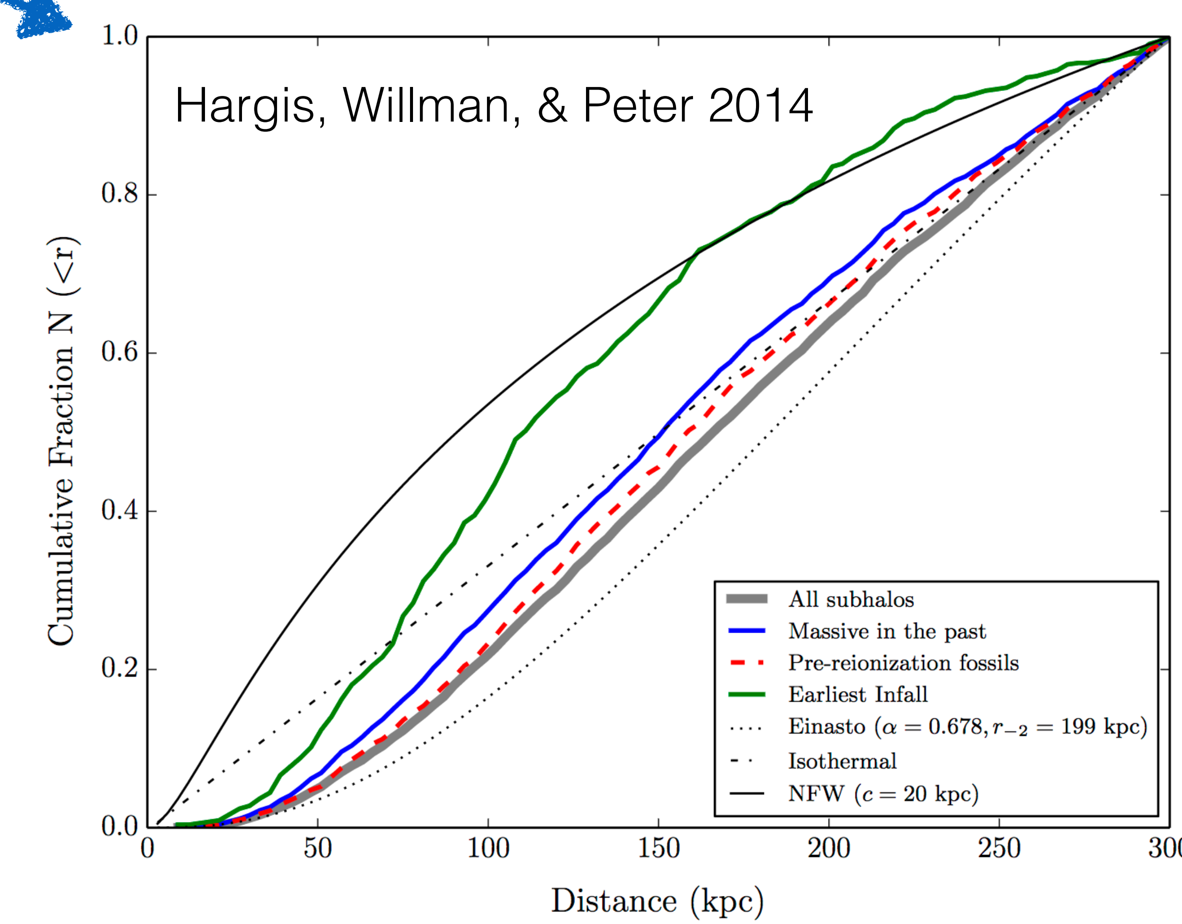
Candidates are concentrated in specific region of color-flux space consistent with being RR Lyrae at the distance of Fornax

DES Y3 Milky Way Satellites Analysis Projects

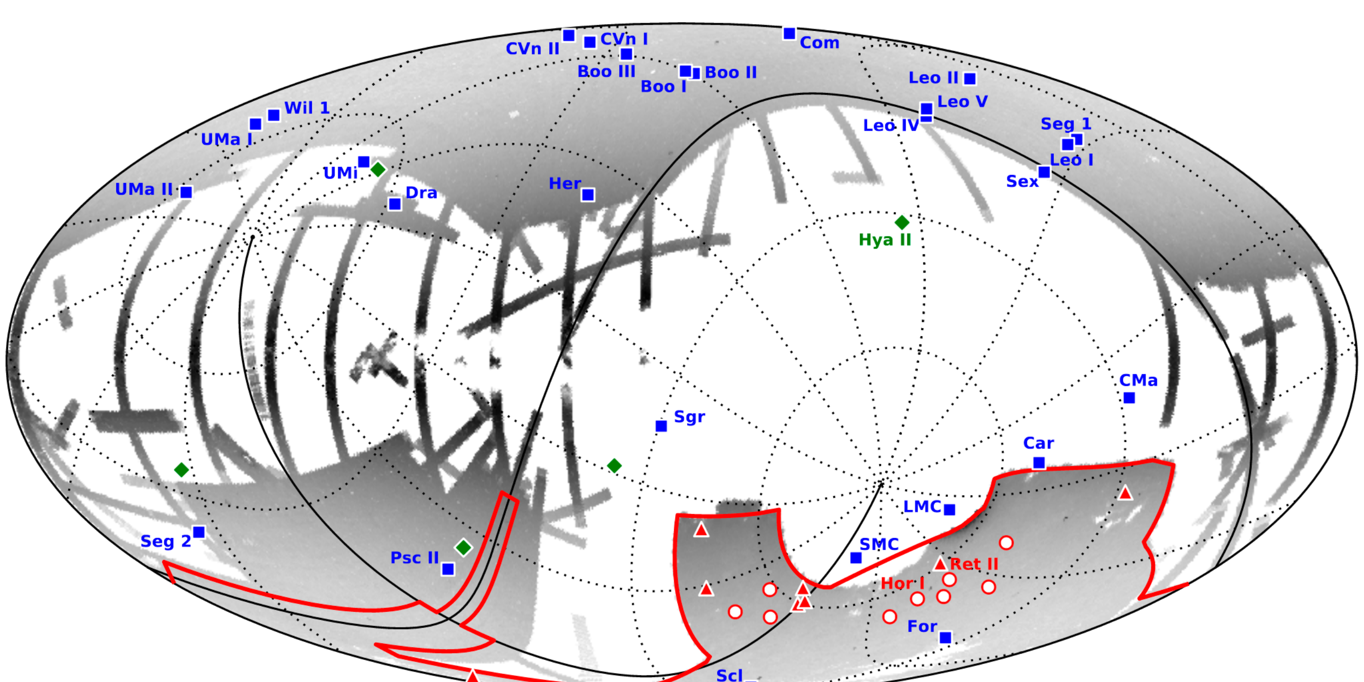
- Search and discovery!
- Characterizing the luminosity function:
  - ➡ Selection function
  - ➡ Radial distribution?
  - ➡ Anisotropy?



Bechtol et al. 2015



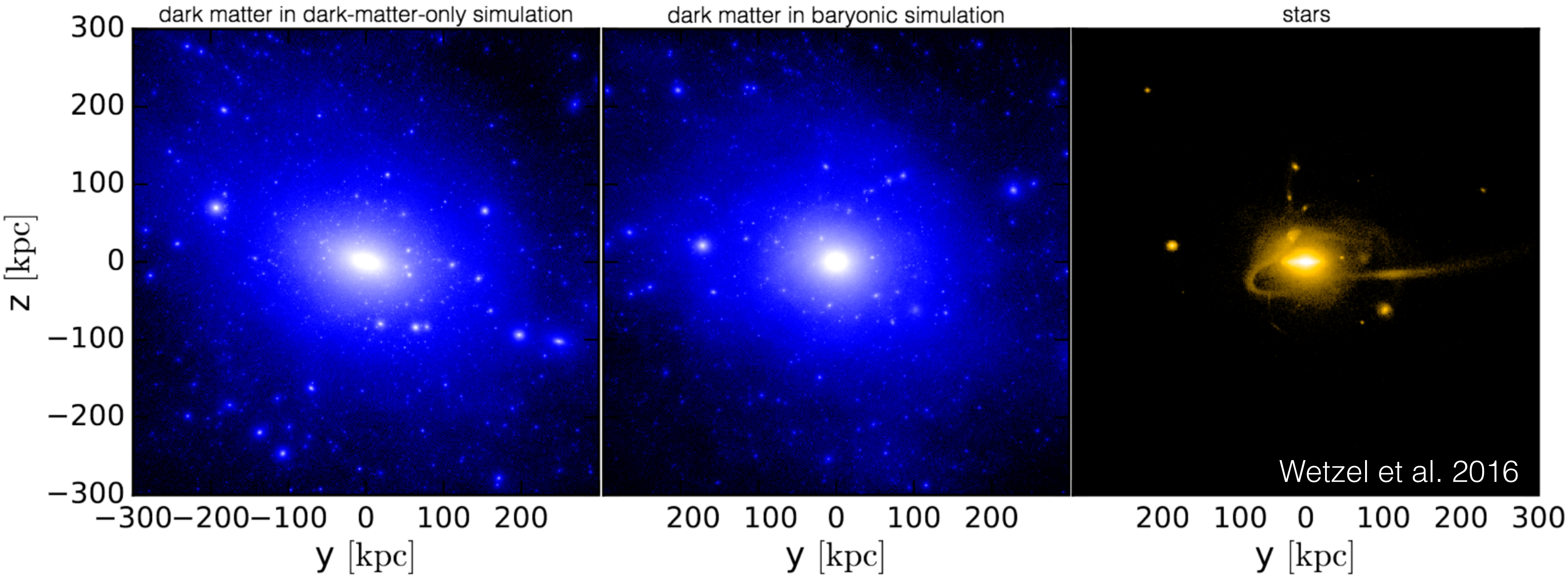
Hargis, Willman, & Peter 2014



Drlica-Wagner et al. 2015

DES Y3 Milky Way Satellites Analysis Projects

Perhaps the most challenging part will be mapping observations to theory predictions to constrain dark matter microphysics



See talks by Alex Drlica-Wagner for indirect dark matter searches and additional DECam searches

Drlica-Wagner et al. 2015

Bonus Slides

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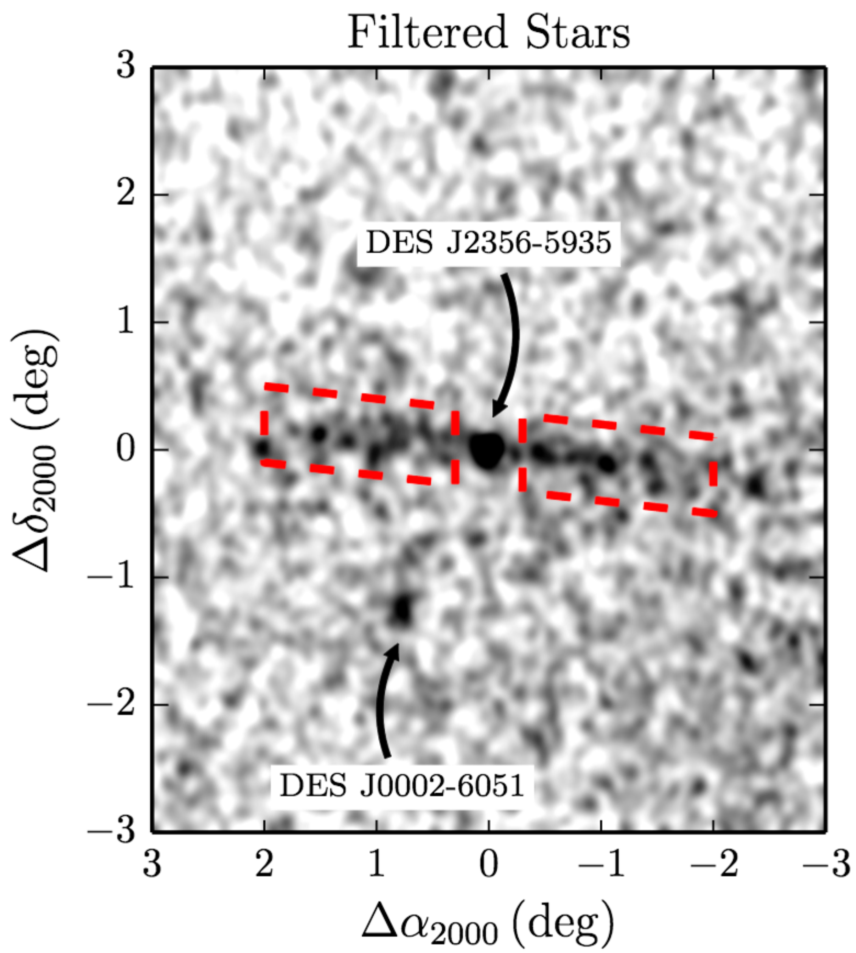
Spectroscopic Follow-up Results: Dynamics

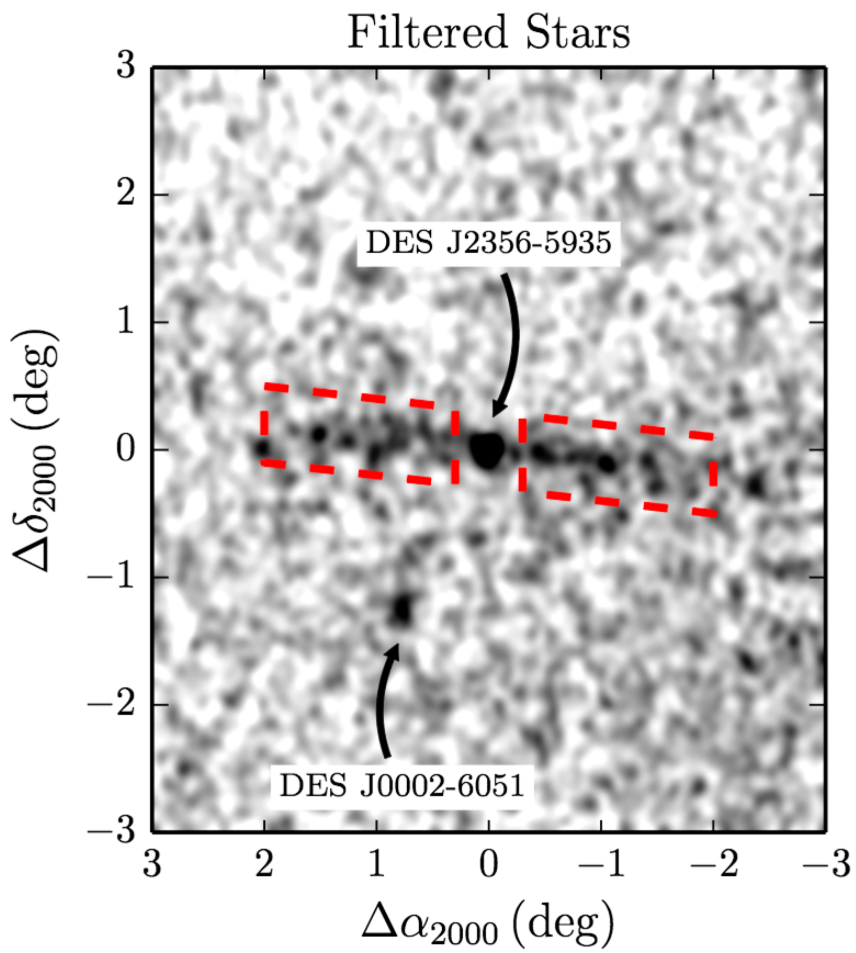
Tucana III tidal tails



Drlica-Wagner et al. 2015
arXiv:1508.03622

Spectroscopic Follow-up Results: Dynamics

Tucana III tidal tails



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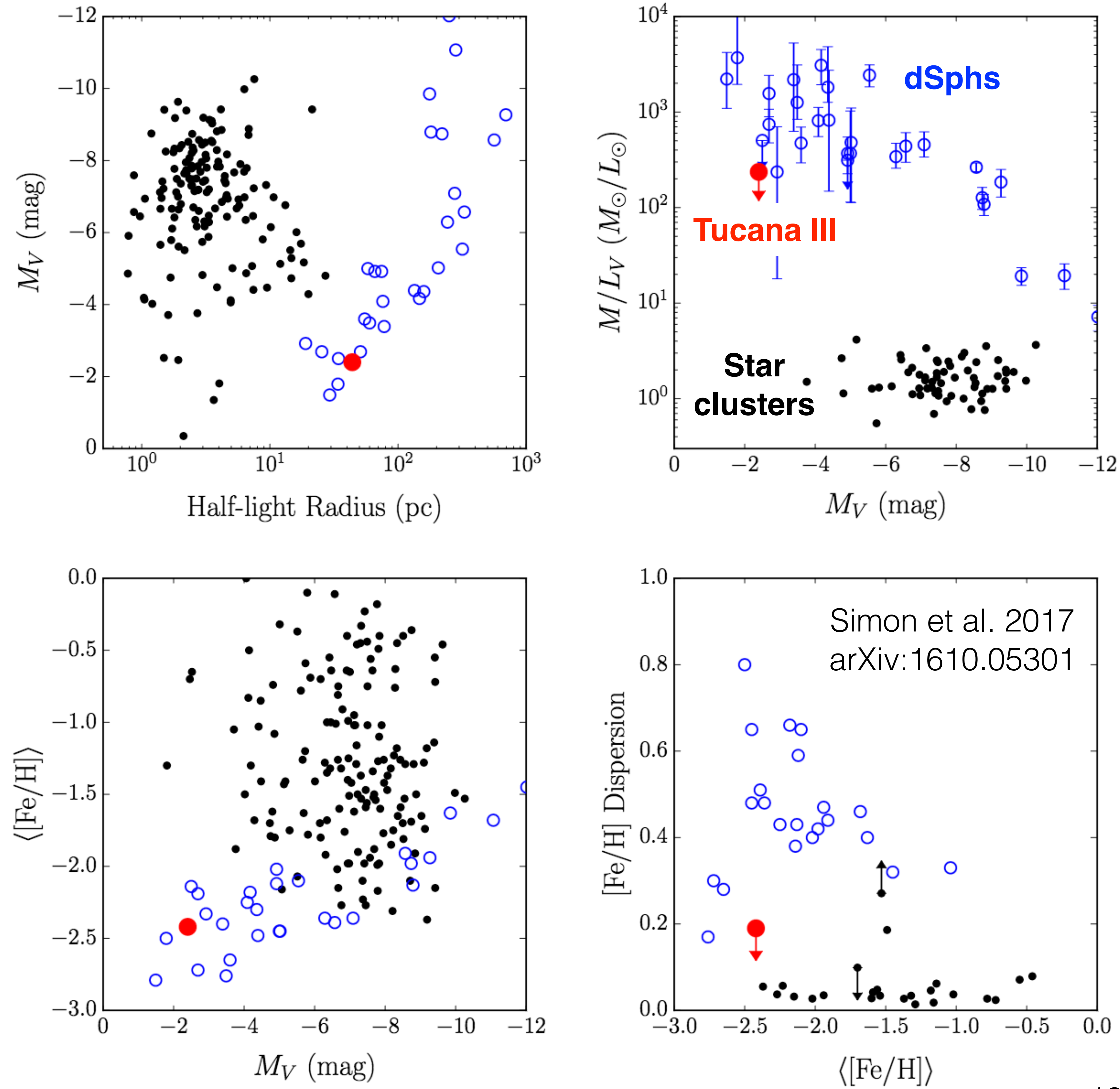
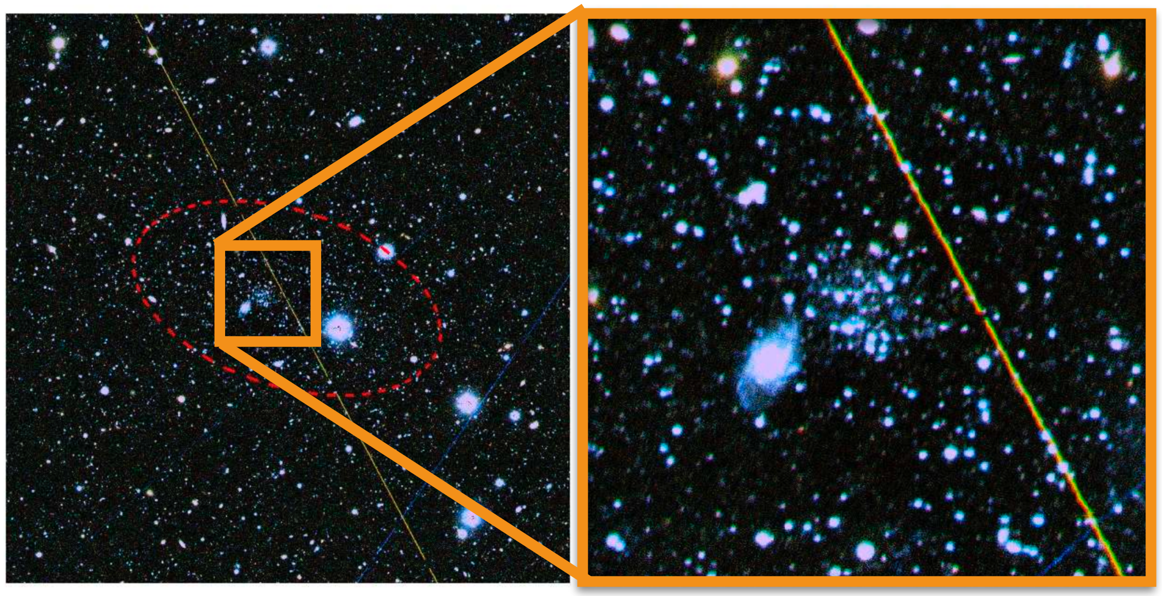


Upper bound on velocity dispersion
(mass-to-light ratio < 240 $M_\odot / L_\odot$)

A tidally stripped dwarf galaxy?

Spectroscopic Follow-up Results: MACHO Dark Matter constraints



Dwarf galaxy Eridanus II (discovered w/ DES) has it's own small star cluster.

Crnojevic et al. 2016
arXiv:1604.08590

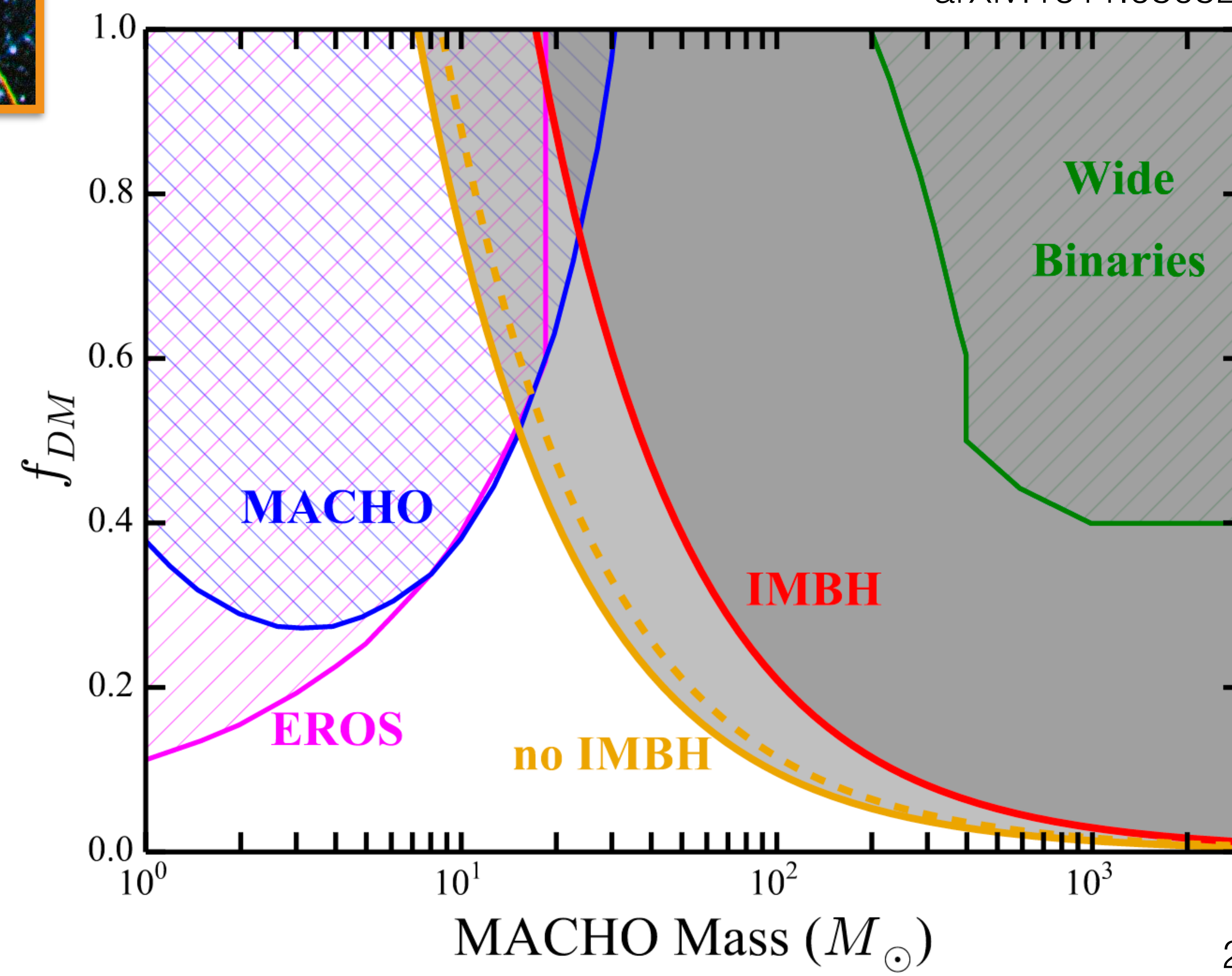
With follow-up spectroscopy, we infer a large mass-to-light ratio in the central regions of Eridanus II

$$M / L_V = 420^{+210}_{-140}\ M_{sol} / L_{sol}$$

(i.e., large dark matter density)

We can use the survival of this star cluster to place upper limits on the mass of individual dark matter particles. High-mass dark matter particles would disrupt the cluster.

Li et al. 2016
arXiv:1611.05052



Spectroscopic Follow-up Results: Chemical Abundances

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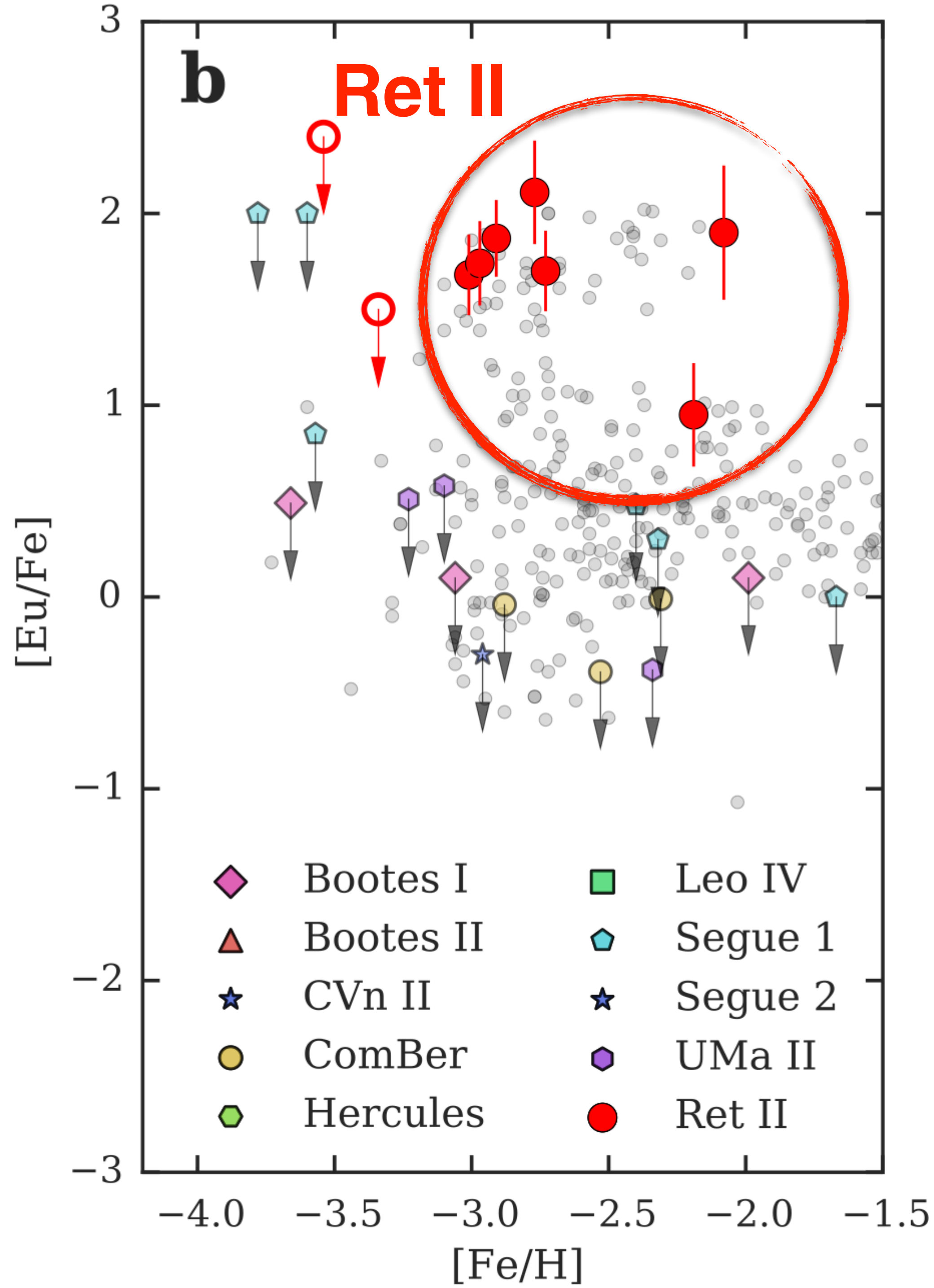
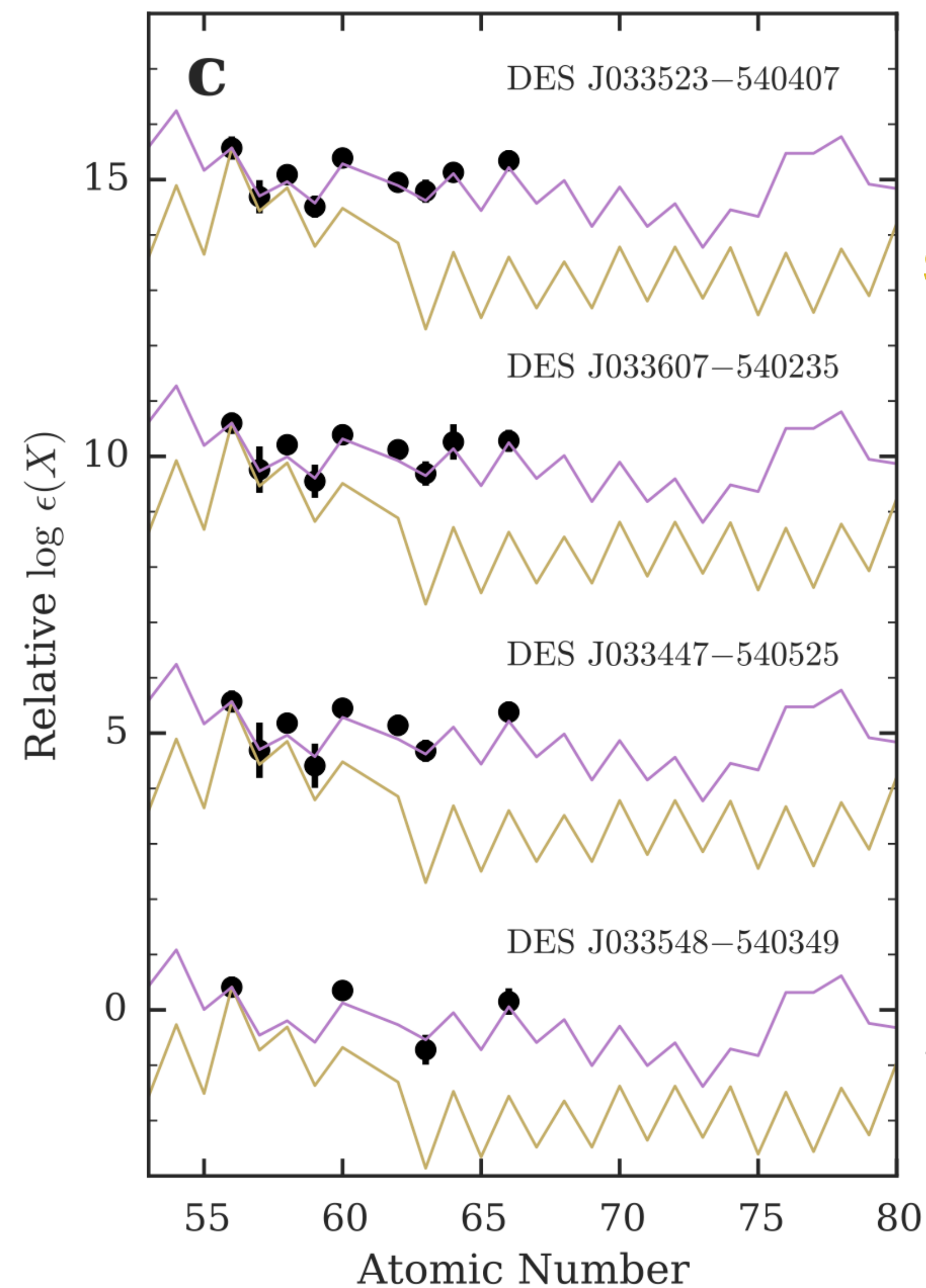
Using europium as representative r-process element



Neutron-capture abundance patterns for 4 brightest Ret II stars



r-process

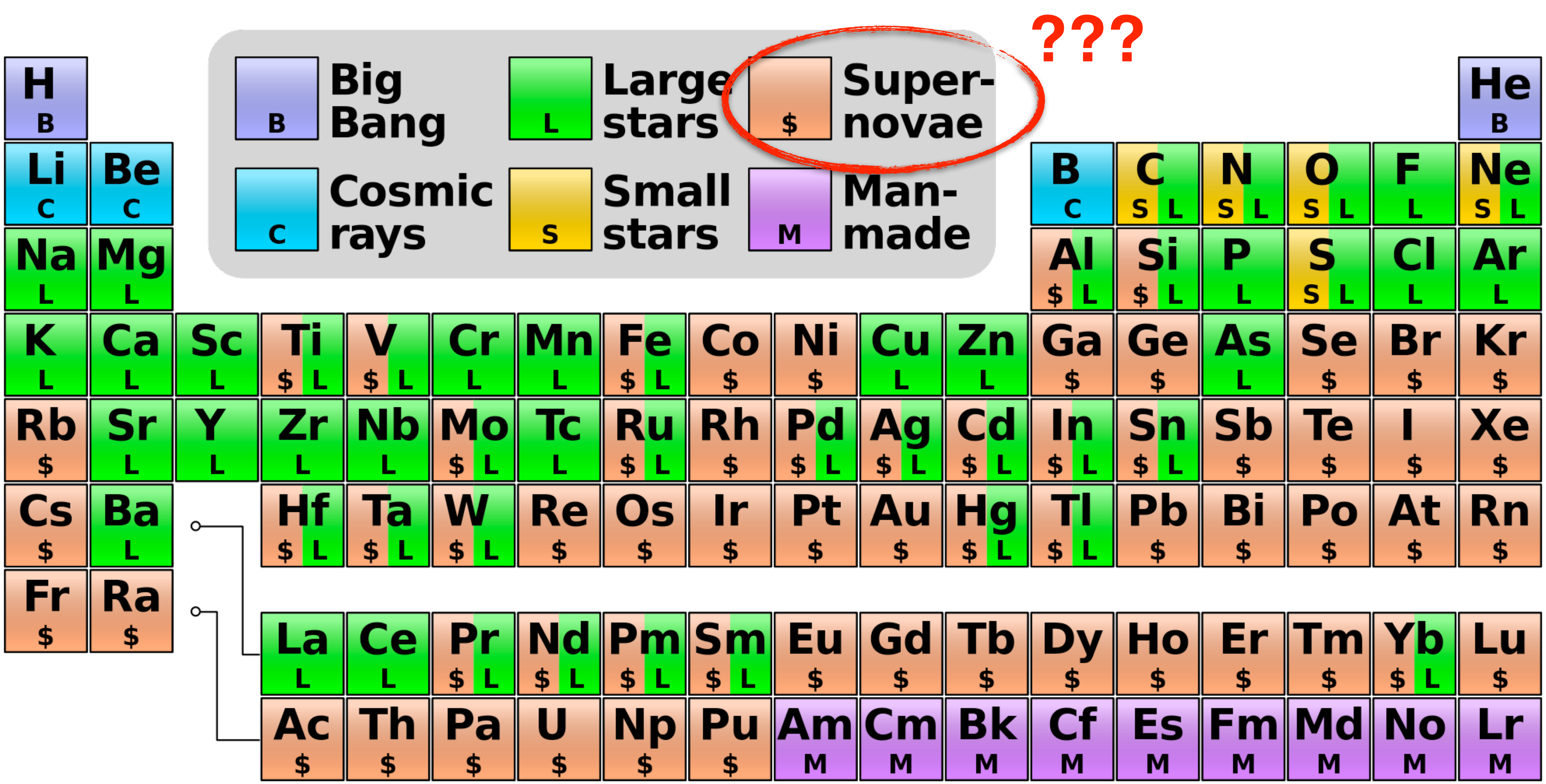
s-process

Ji et al. 2015
arXiv:1512.01558

Spectroscopic Follow-up Results: Chemical Abundances

Rapid absorption of free neutrons during explosive event
Proposed sites: **core-collapse supernovae, neutron star mergers**

Observed excess of r-process elements in Ret II relative to other ultra-faint dwarfs (by factor >100) suggests **enrichment by a single (rare) event**
→ Consistent with neutron star merger hypothesis

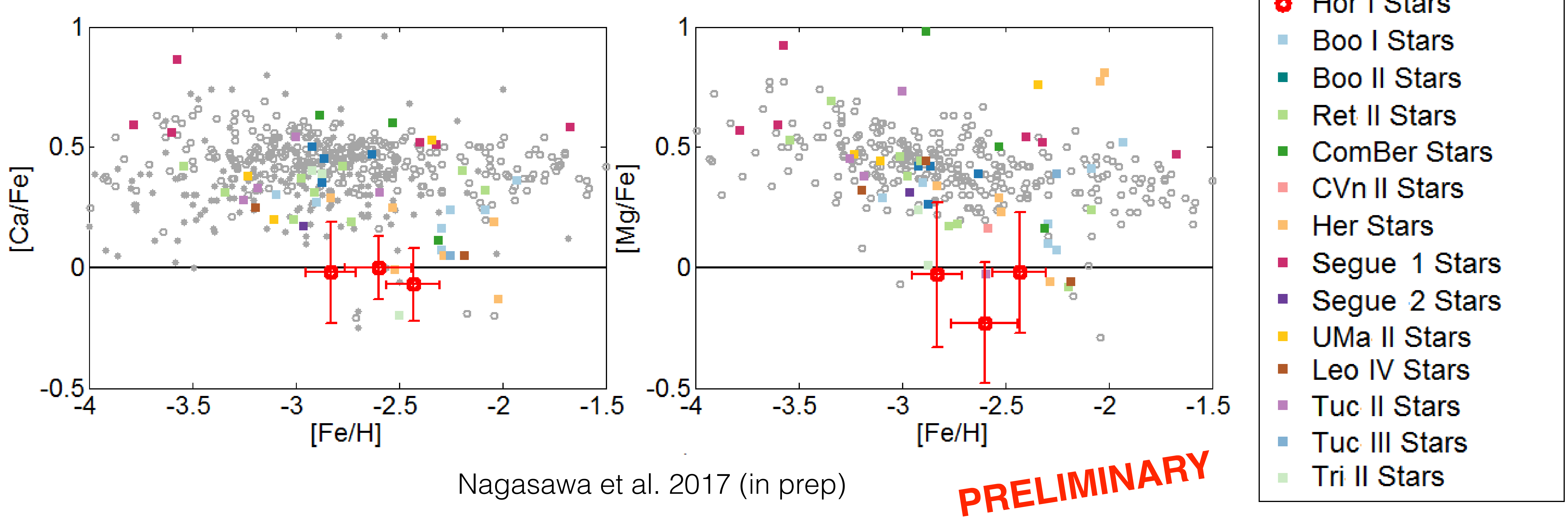


Spectroscopic Follow-up Results: Chemical Abundances

dSphs harbor many of the **oldest** and most **chemically pristine** stars known
→ laboratories for nucleosynthetic processes

Each of the 4 DES-discovered dSphs with detailed chemical analysis exhibit **unique abundance patterns**, suggesting that star formation in the early Universe must have been a stochastic process that was highly variable on the scales of ultra-faint dwarf galaxies.

Ji et al. 2016a, Ji et al. 2016b, Roederer et al. 2016, Hansen et al. 2017



Nagasawa et al. 2017 (in prep)