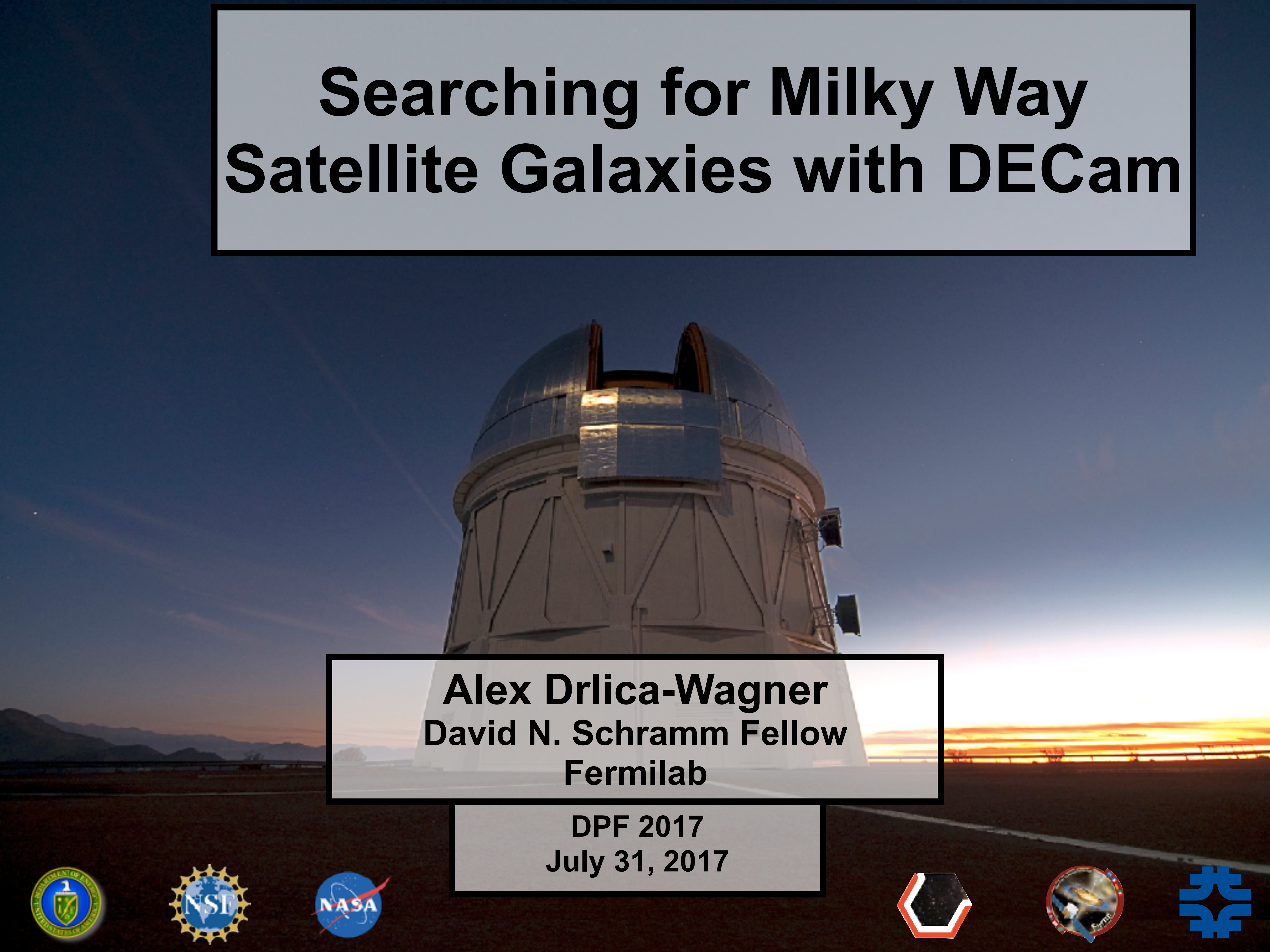


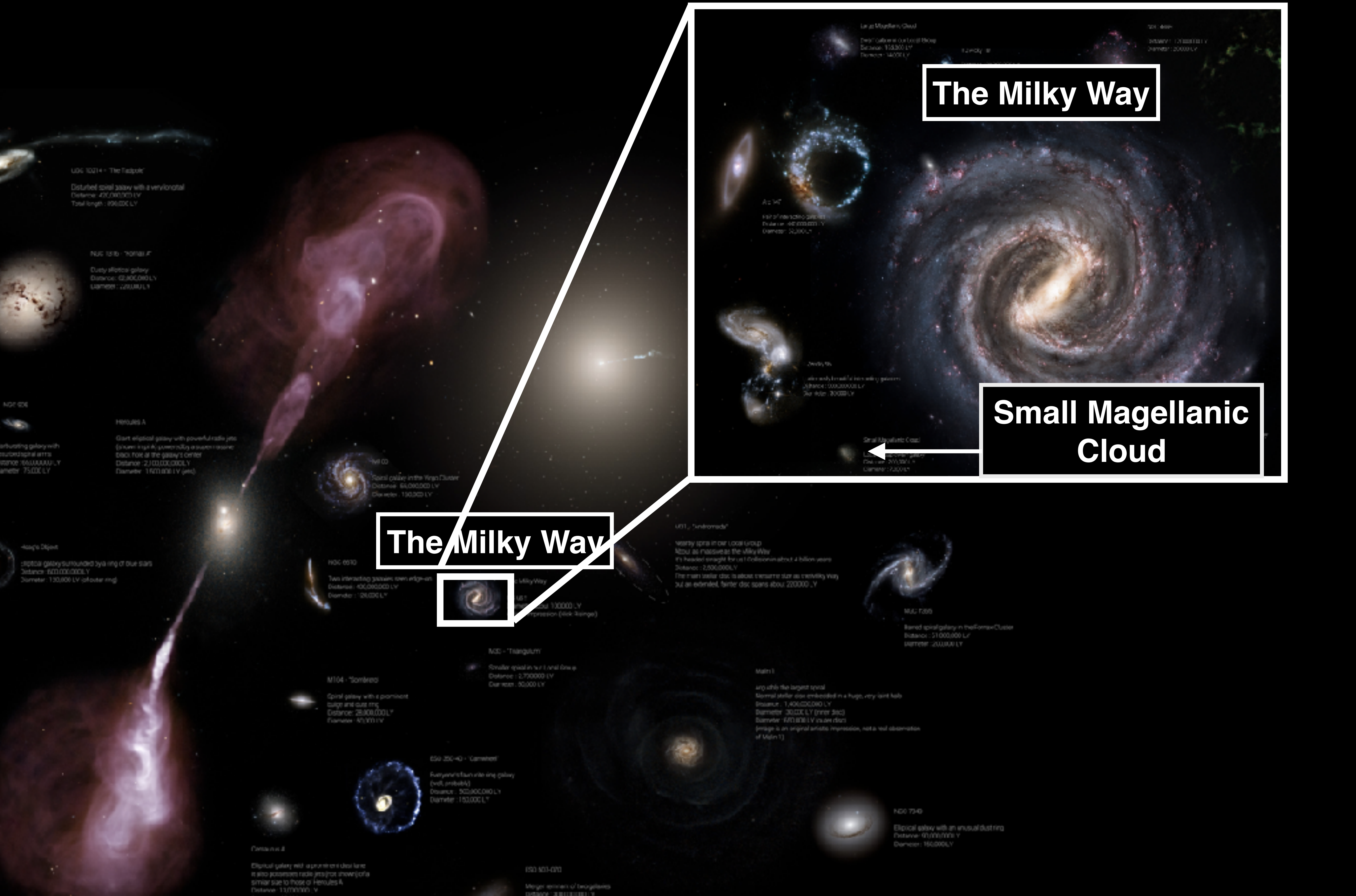
Searching for Milky Way Satellite Galaxies with DECam

Alex Drlica-Wagner
David N. Schramm Fellow
Fermilab

DPF 2017
July 31, 2017

What are Dwarf Galaxies?

What are Dwarf Galaxies?

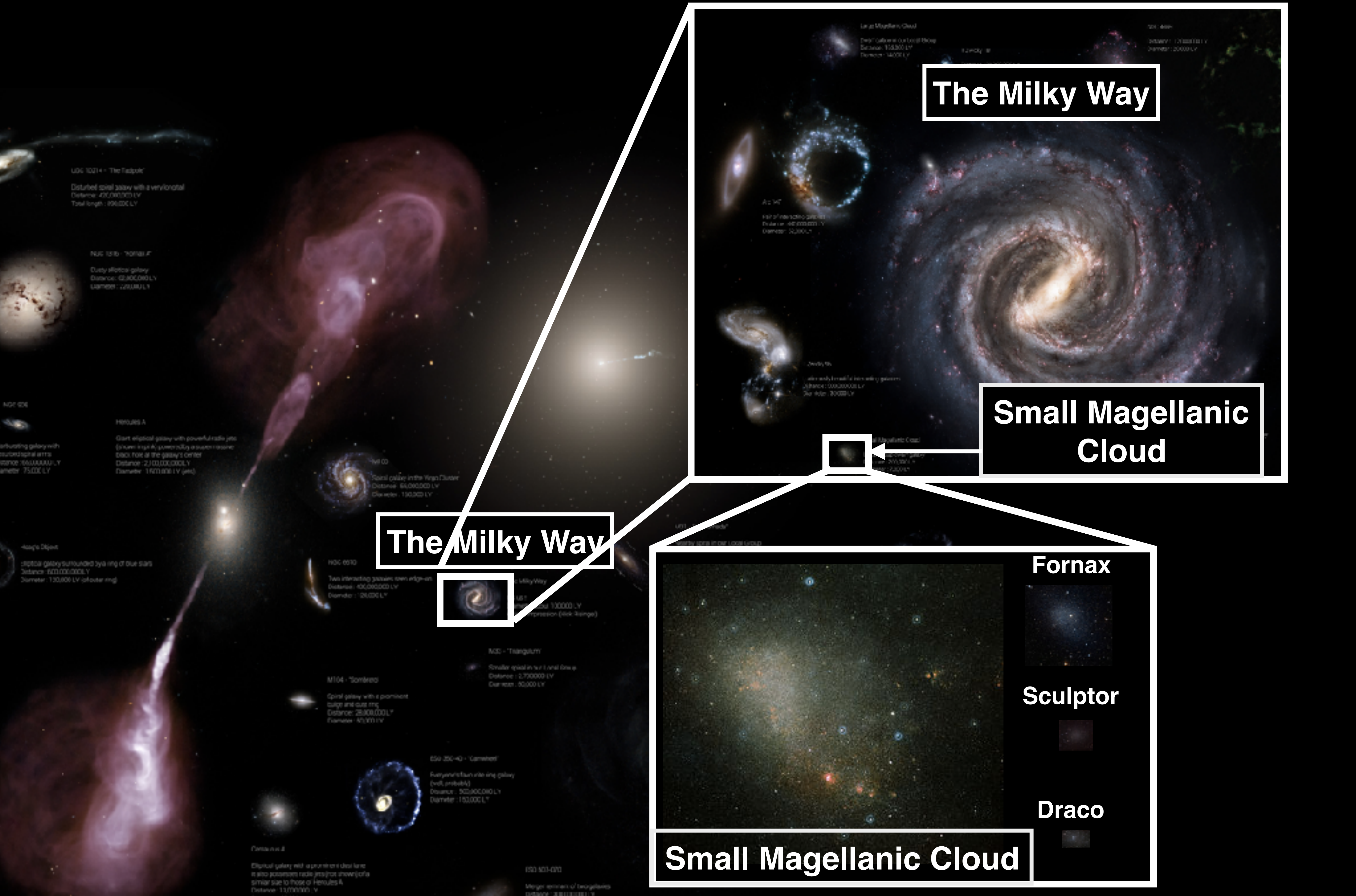


The Milky Way

The Milky Way

Small Magellanic Cloud

What are Dwarf Galaxies?



The Milky Way

The Milky Way

Small Magellanic Cloud

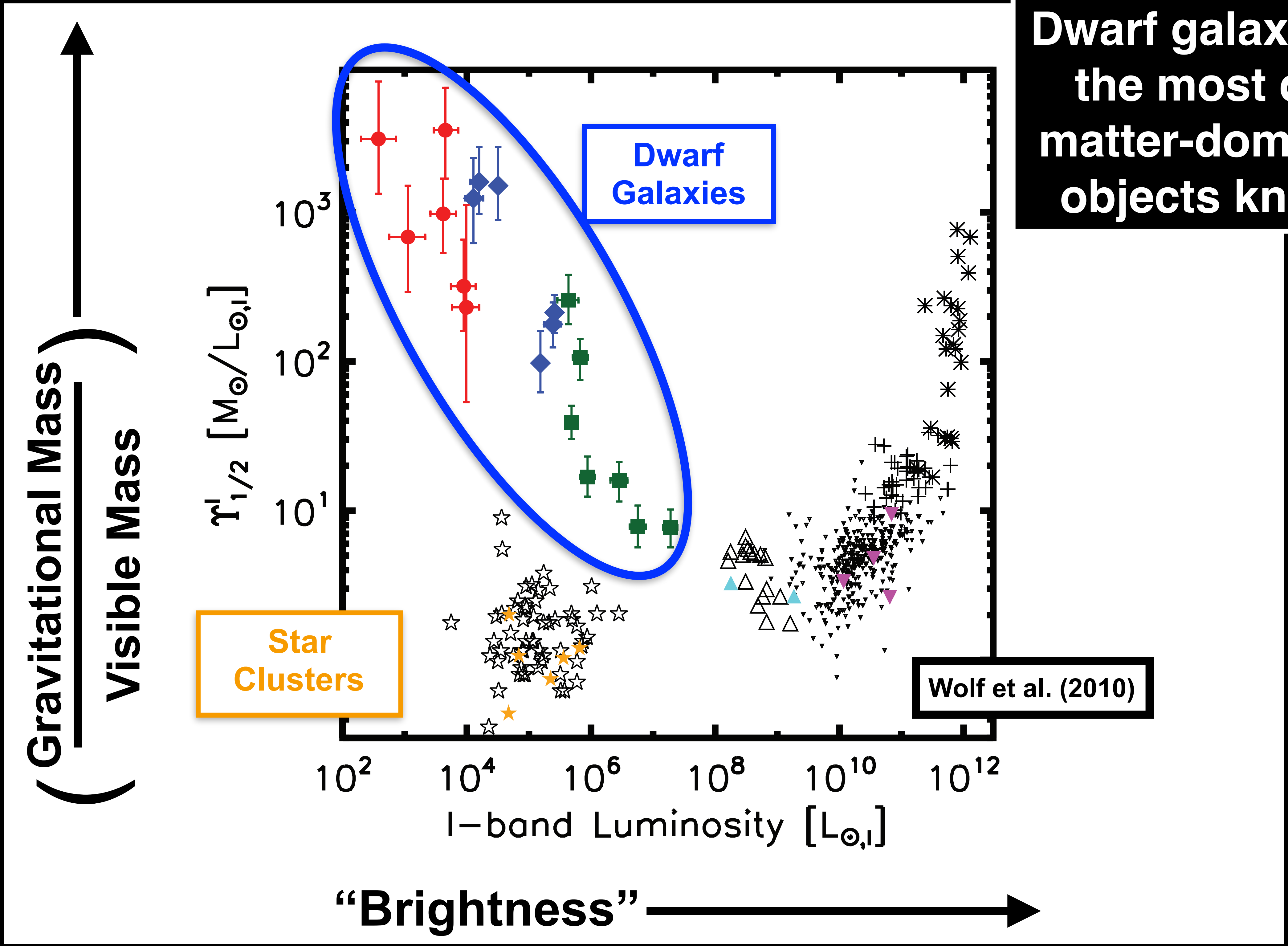
Fornax

Sculptor

Draco

Small Magellanic Cloud

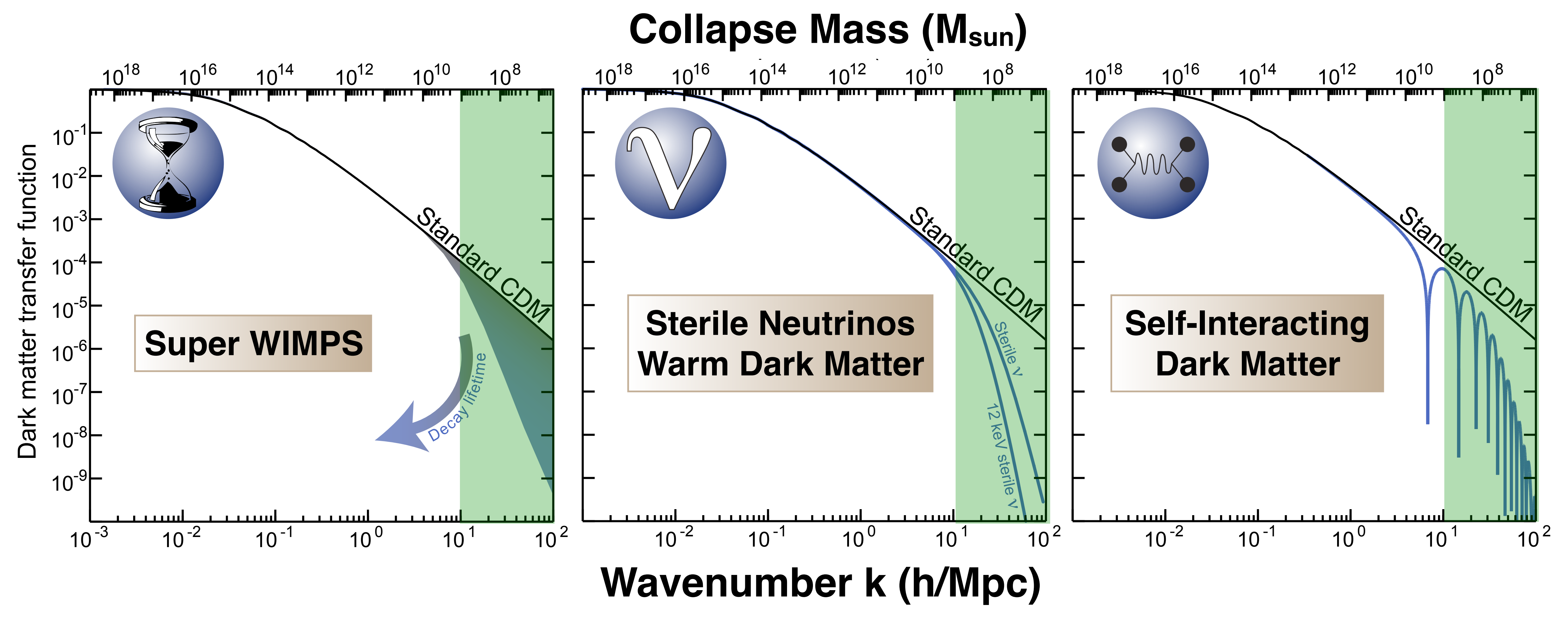
Why are dwarf galaxies important?



Wolf et al. (2010)

Dwarf galaxies are the most dark-matter-dominated objects knowns

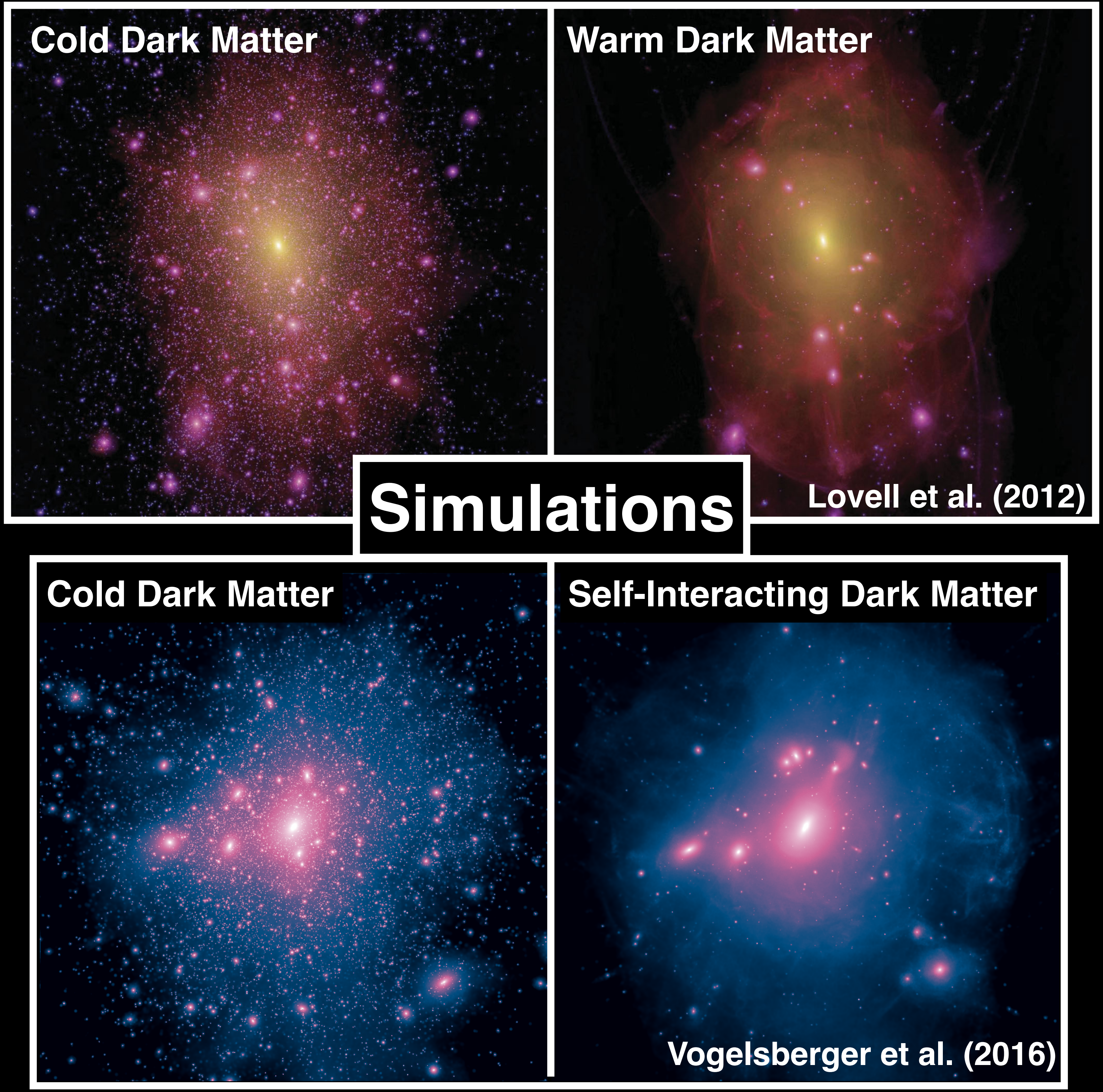
Smallest Structures Probe Fundamental Characteristics of Dark Matter



Deviations from Cold Dark Matter could be detected in the abundance and densities of the smallest structures.

Image Credit: Massey & Moustakas

Smallest Structures Probe Fundamental Characteristics of Dark Matter



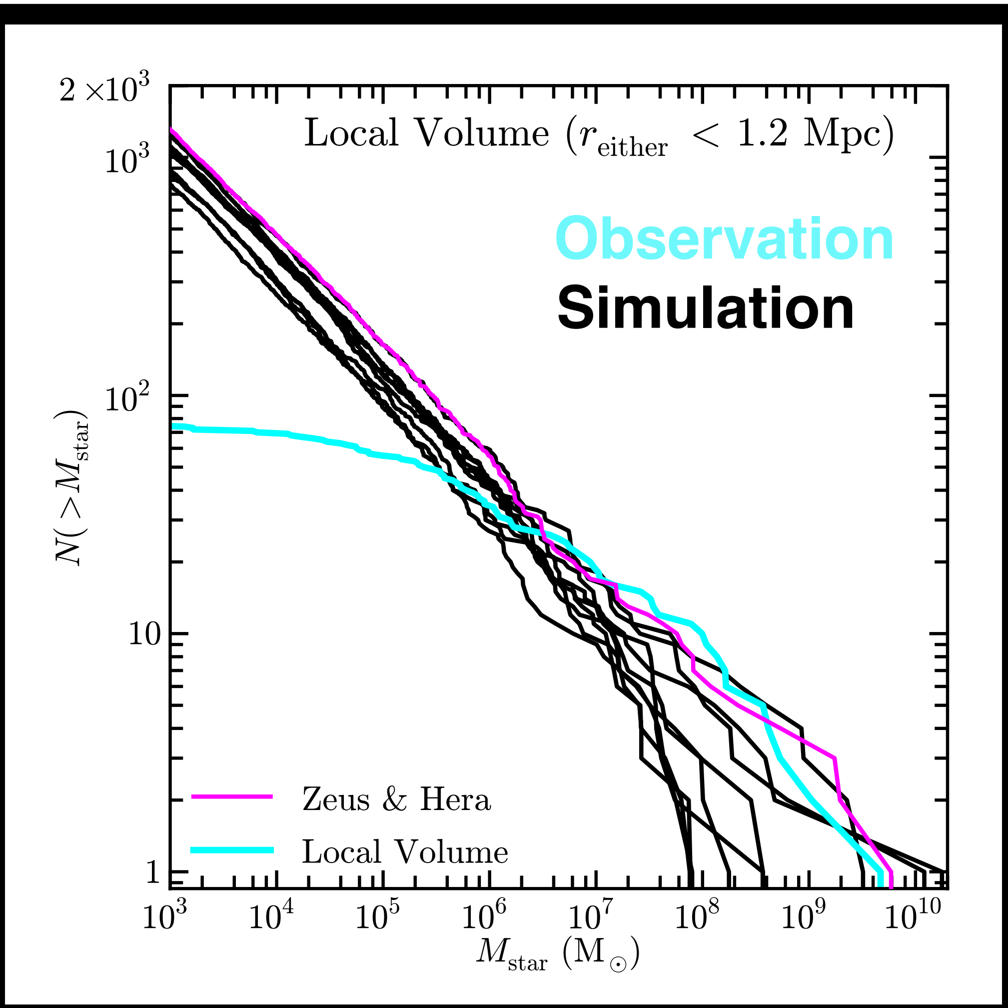
Simulations

Lovell et al. (2012)

Vogelsberger et al. (2016)

Observational Challenges to Cold Dark Matter

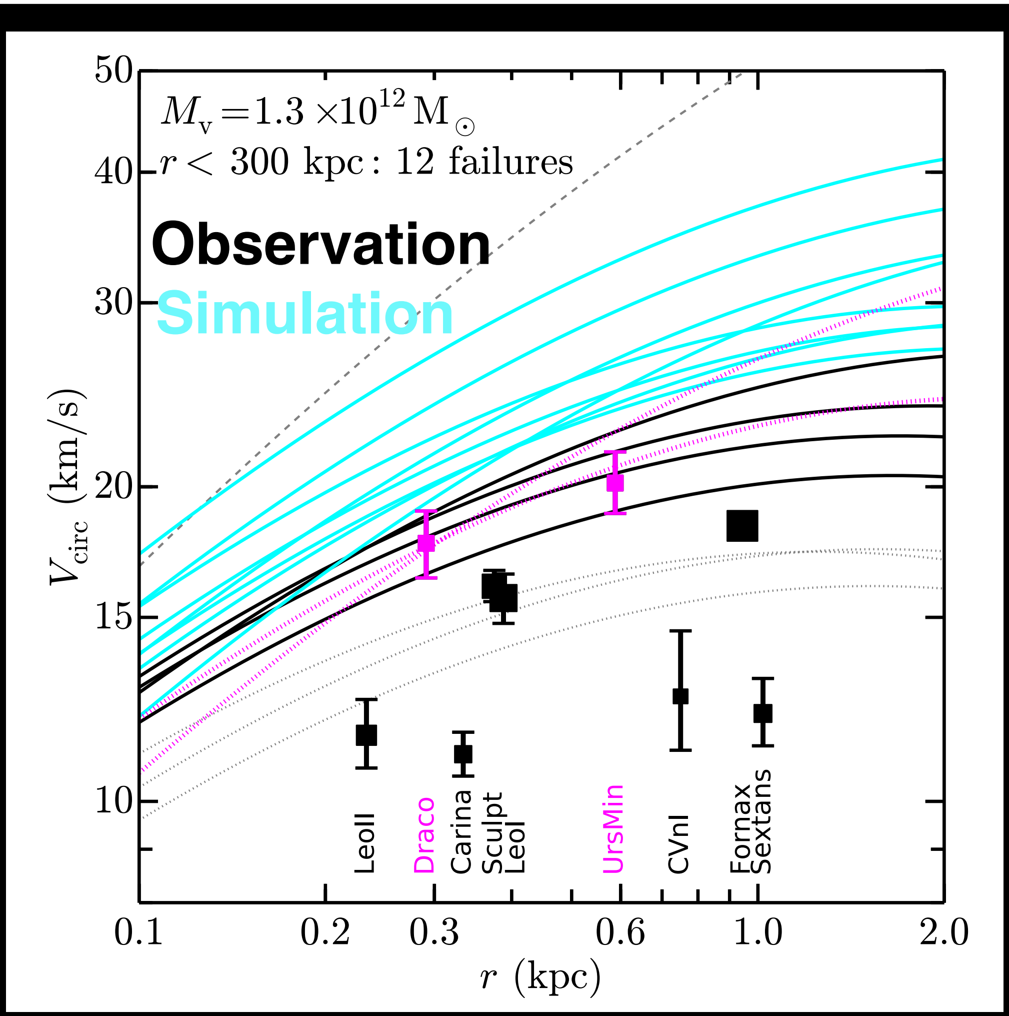
The “Missing Satellites” Problem



Garrison-Kimmel et al. (2014)

Fewer satellites are observed compared to simulations

The “Too Big to Fail” Problem

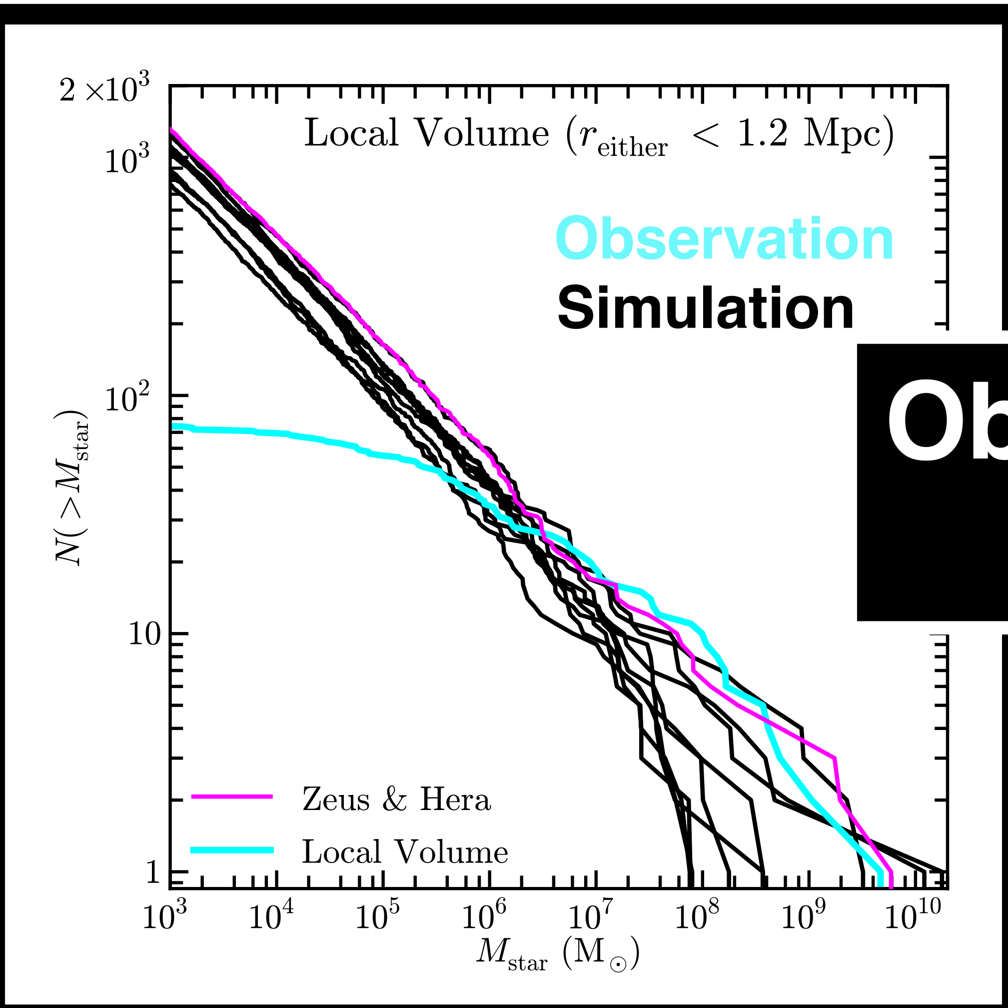


Garrison-Kimmel et al. (2014)

Observed satellites are under-dense compared to simulations

Observational Challenges to Cold Dark Matter

The “Missing Satellites” Problem

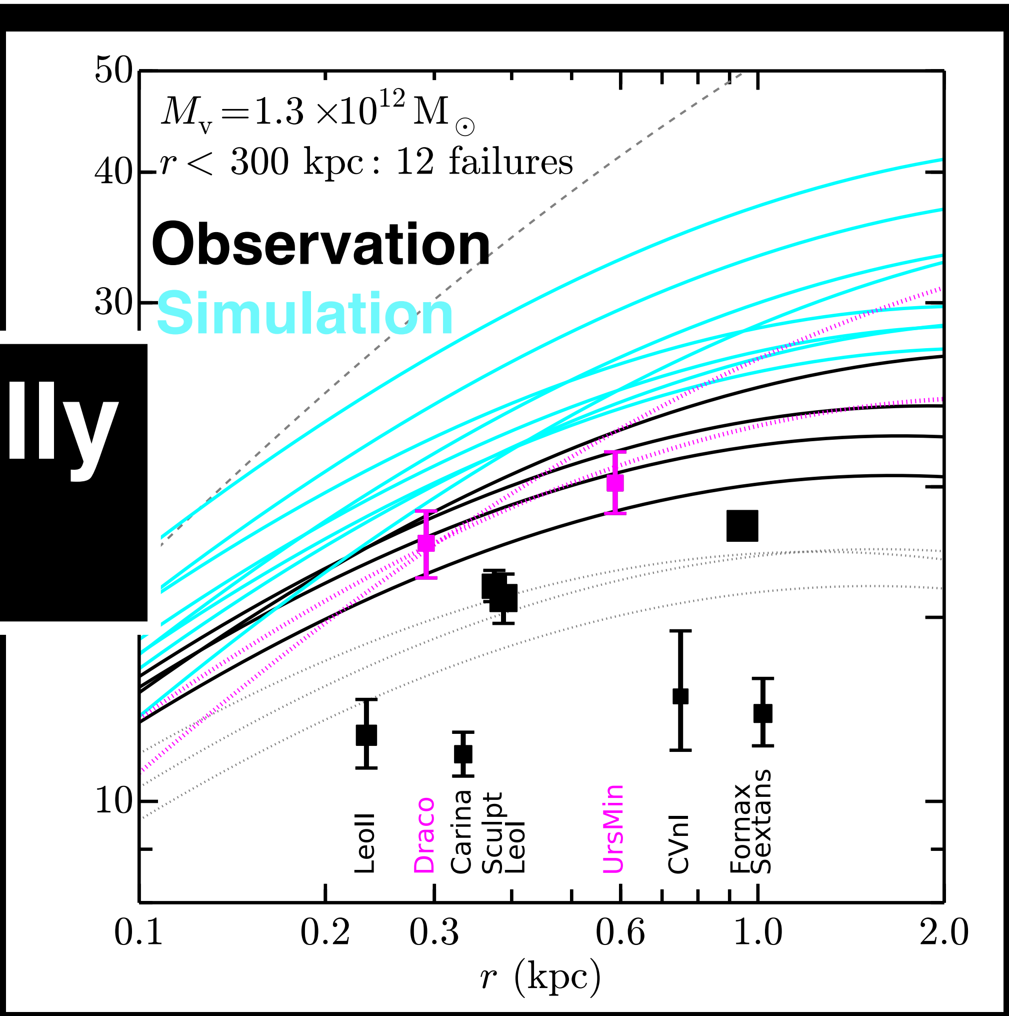


Garrison-Kimmel et al. (2014)

Fewer satellites are observed compared to simulations

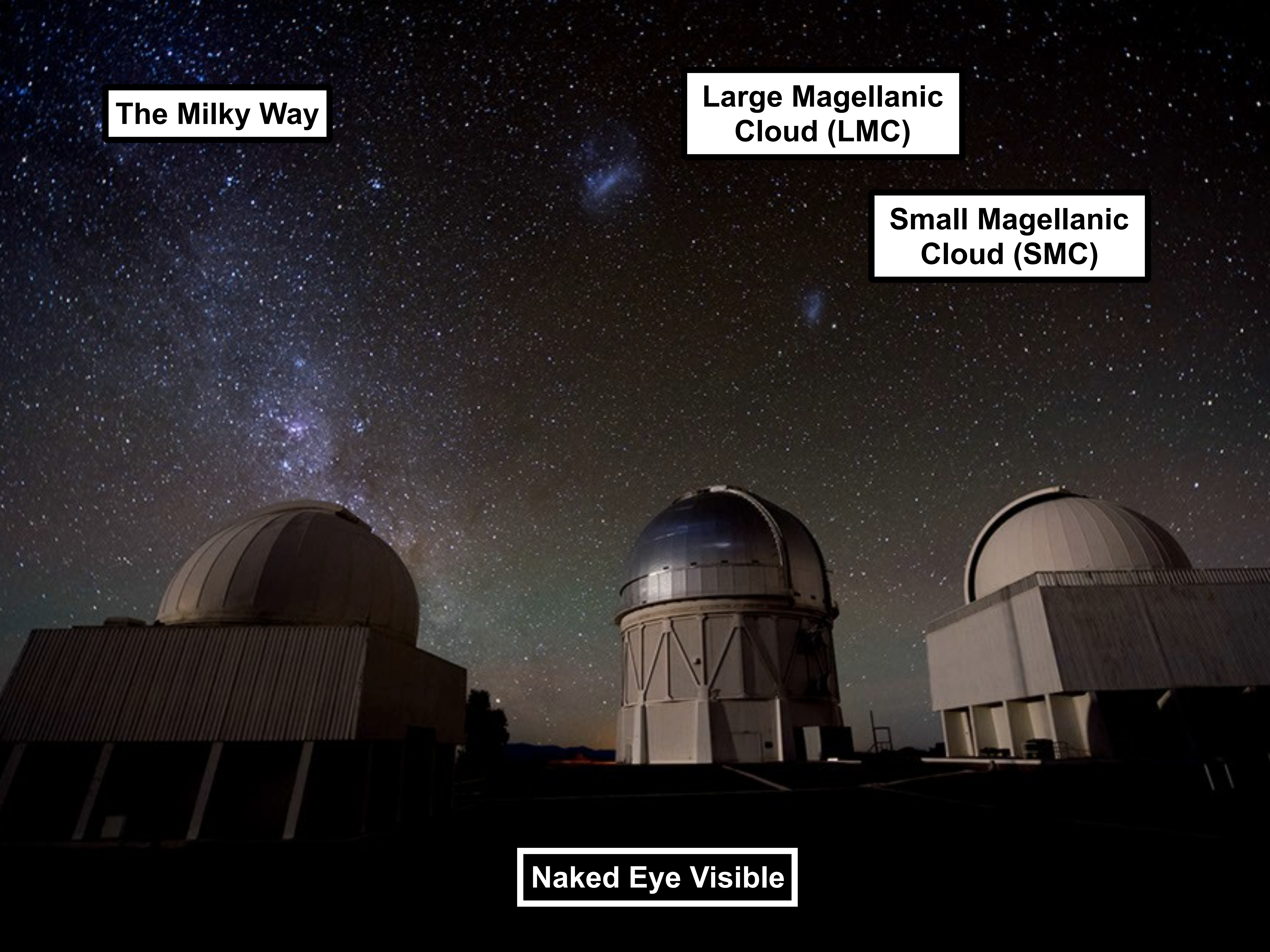
Observationally Limited!

The “Too Big to Fail” Problem



Garrison-Kimmel et al. (2014)

Observed satellites are under-dense compared to simulations



Naked Eye Visible

Sculptor Dwarf Galaxy

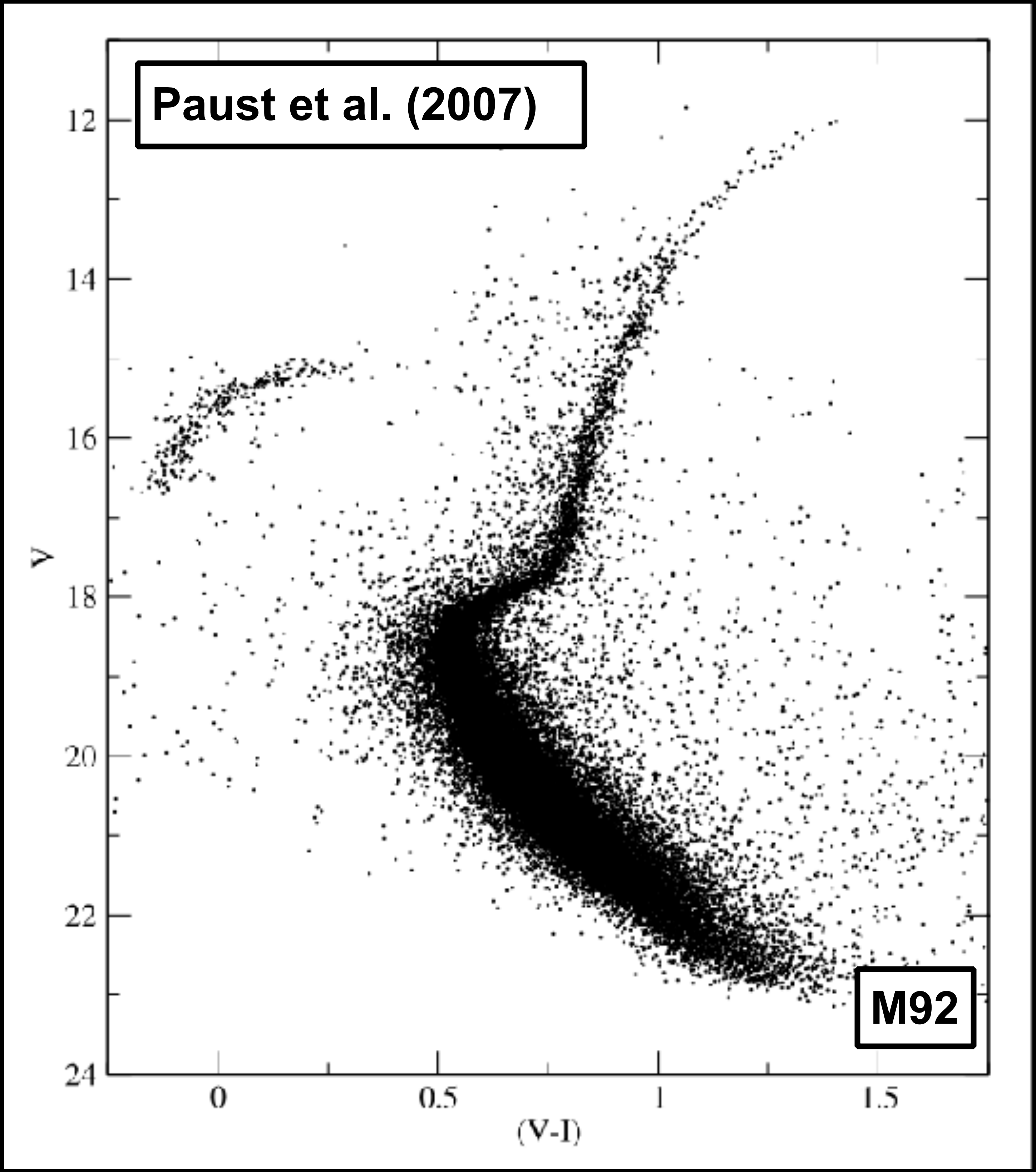
ESO/DSS2

1.2m Telescope
Photographic Plates

Brighter

Magnitude

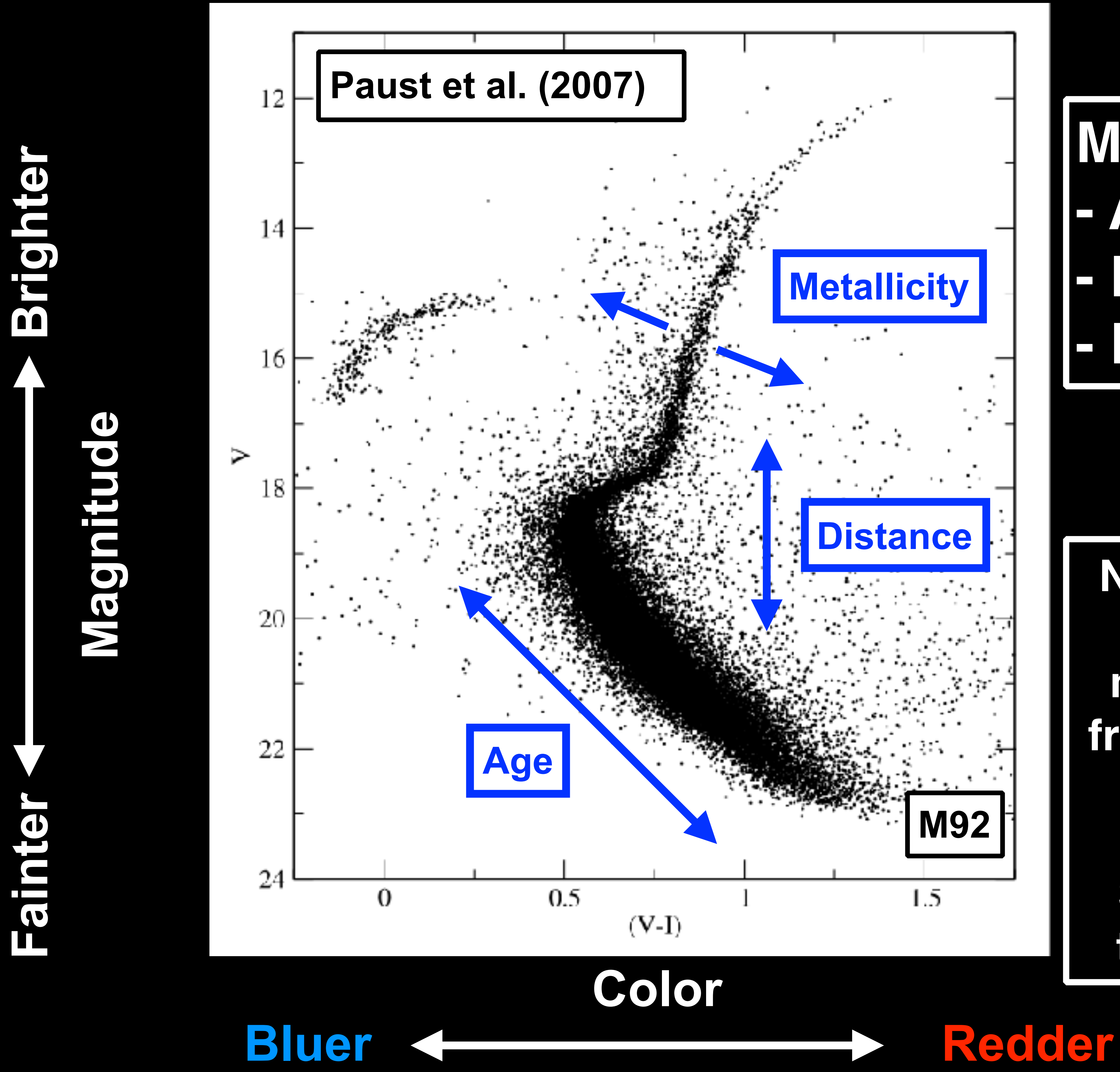
Fainter



Color

Bluer

Redder

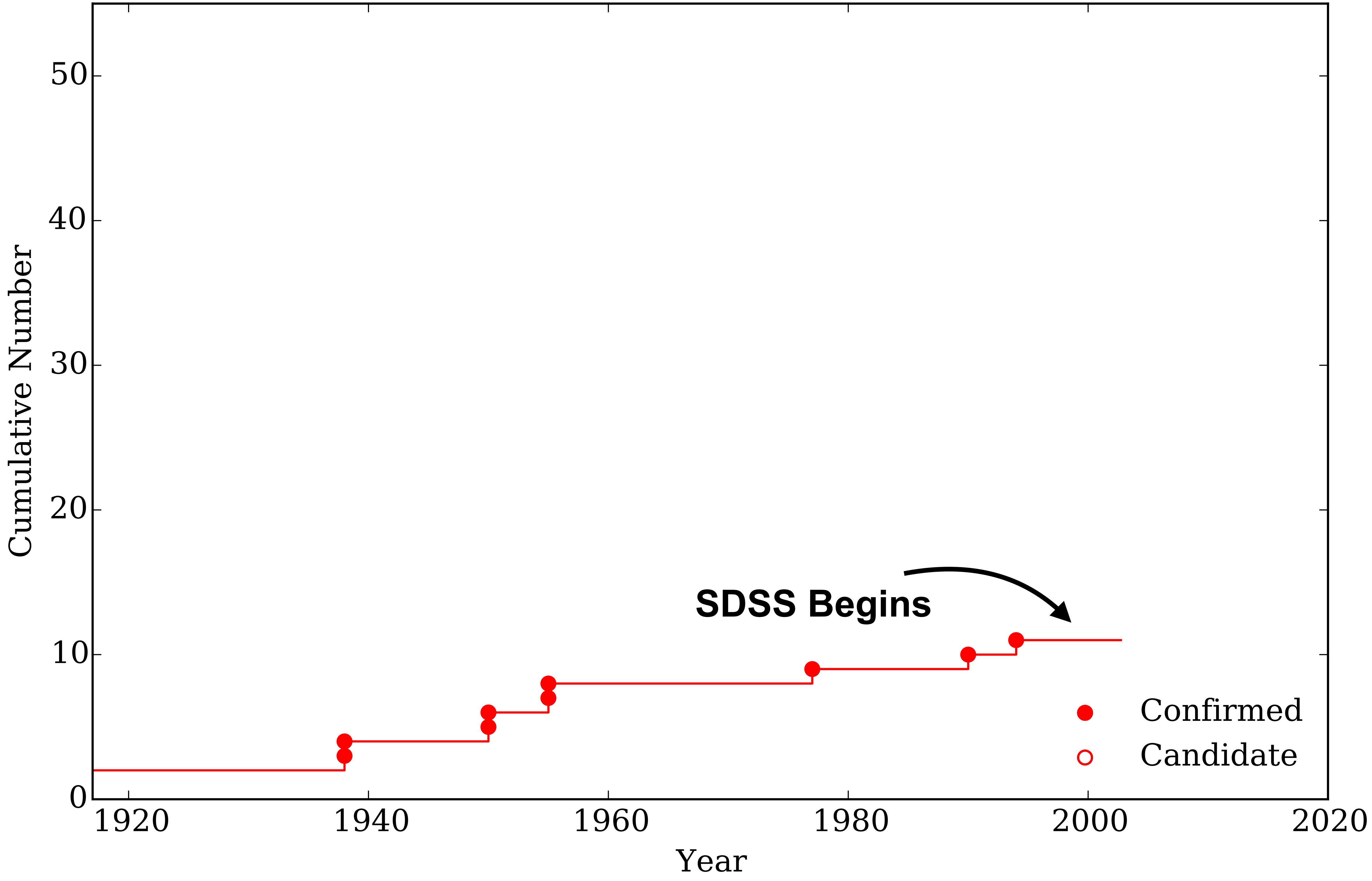


Measure:
- **Age**
- **Metallicity**
- **Distance**

NOTE: We can't measure dark matter content from photometry alone…

Spectroscopy talk by Ting Li

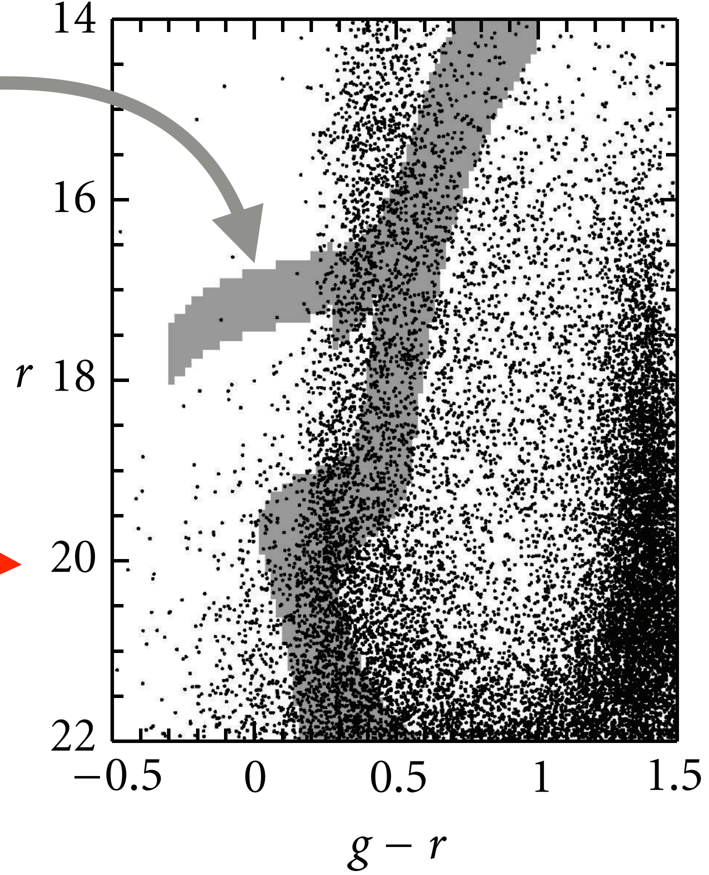
Dwarf Galaxy Discovery Timeline



Matched-Filter Searches

Koposov et al. (2008)
Walsh et al. (2009)
Willman et al. (2010)

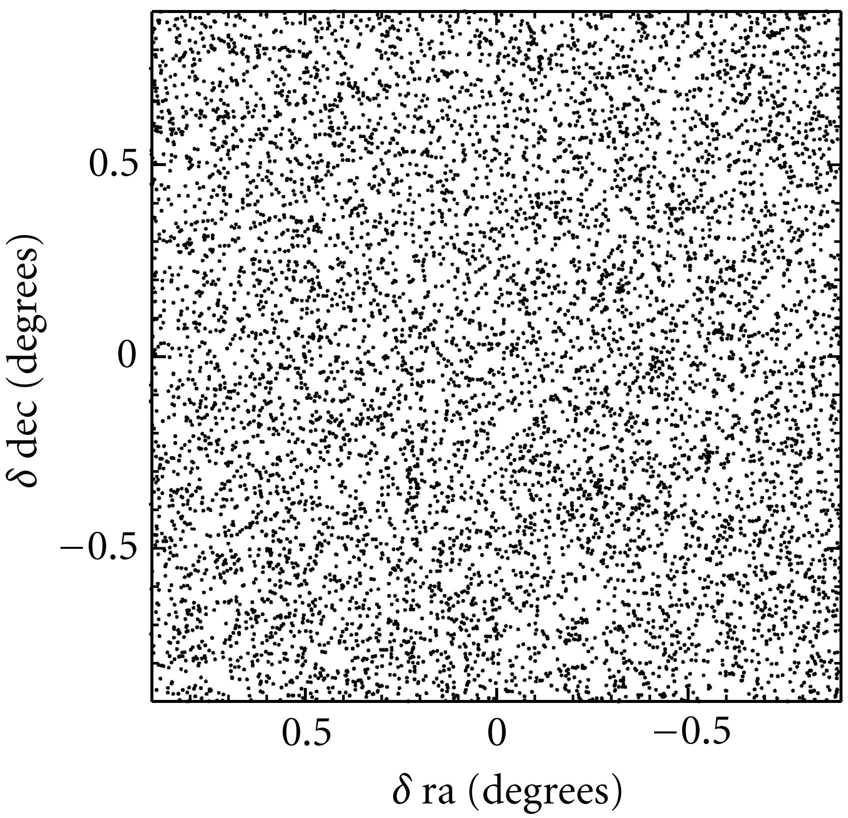
1) Start with a large catalog of stars

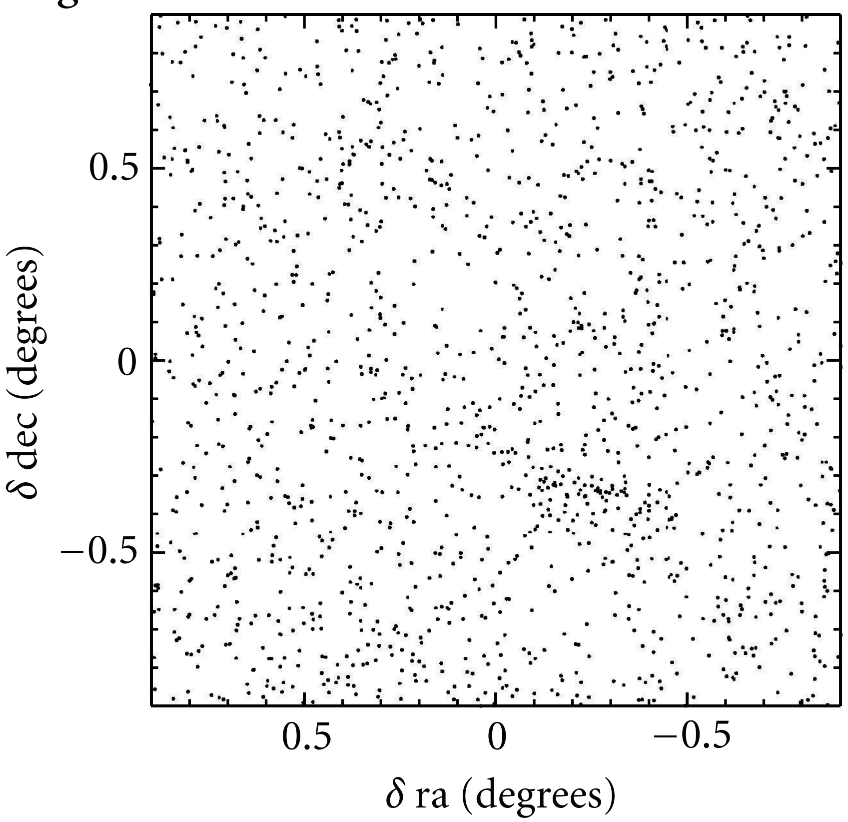


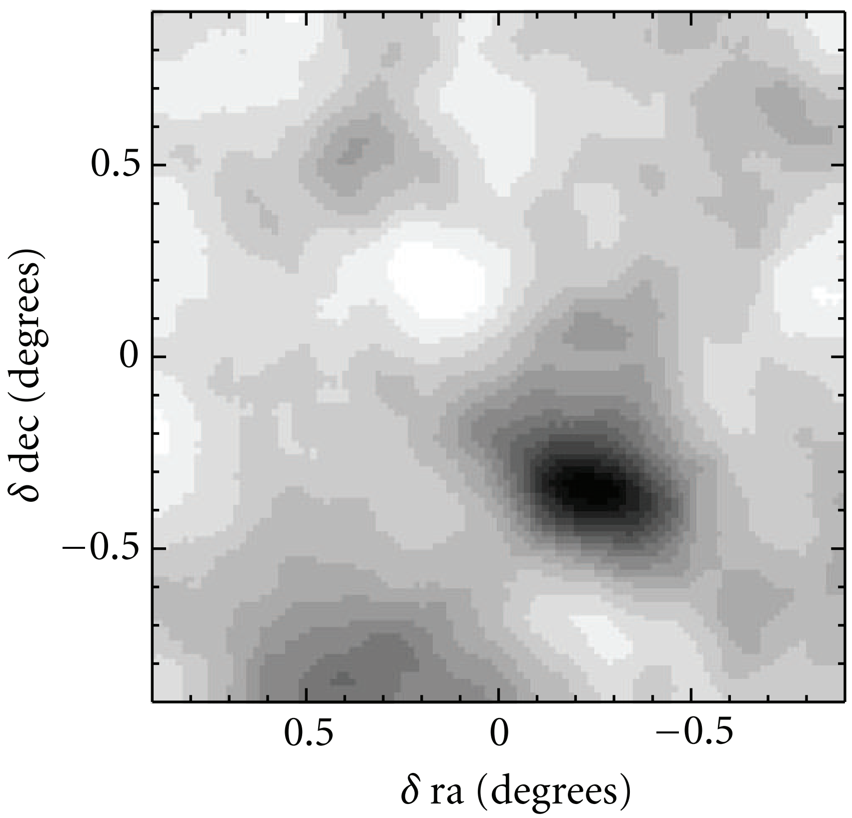
Stellar Isochrone

2) Apply a selection in color-magnitude space based on a stellar isochrone

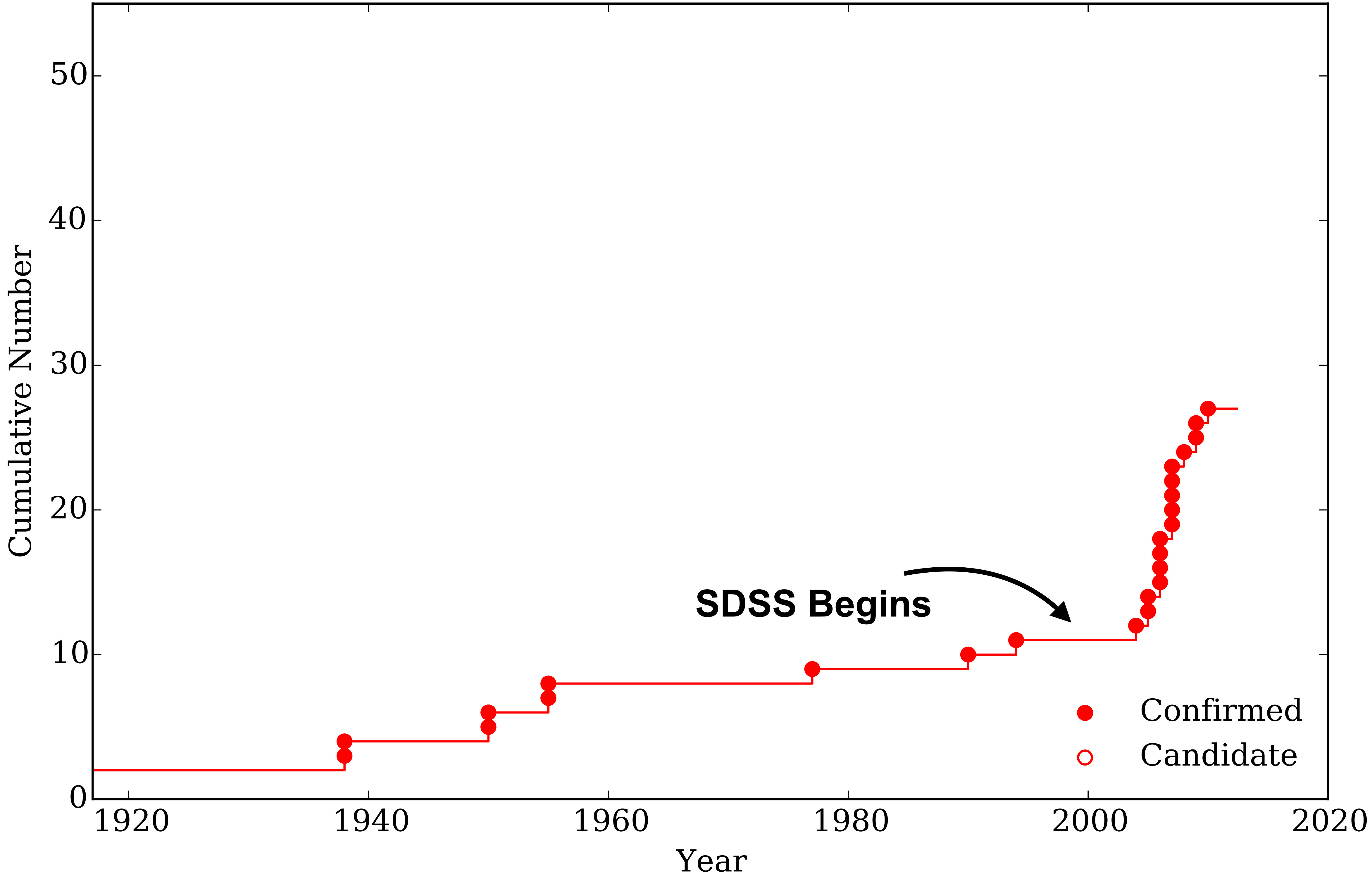
3) Convolve with a spatial kernel



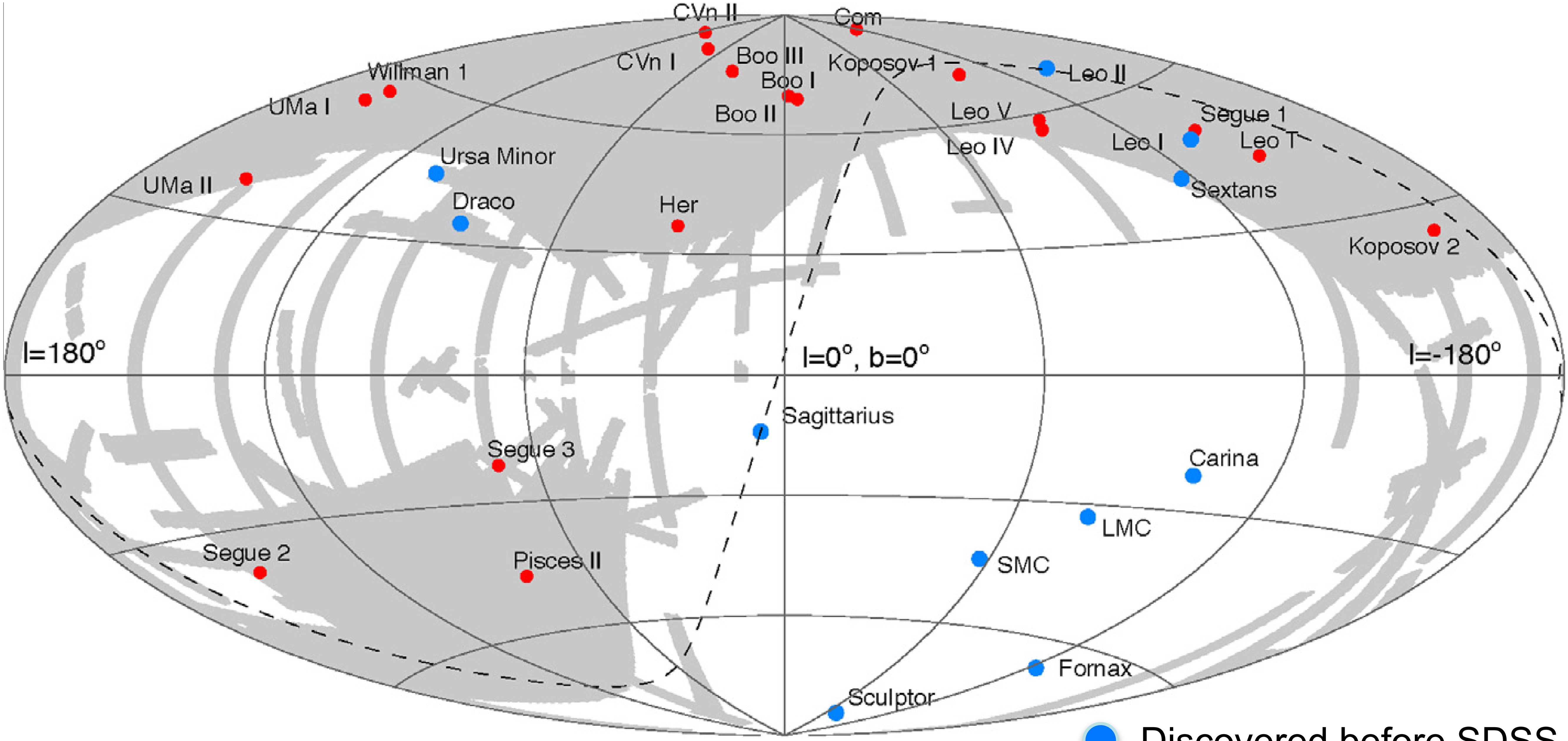




Dwarf Galaxy Discovery Timeline



SDSS Sky Coverage



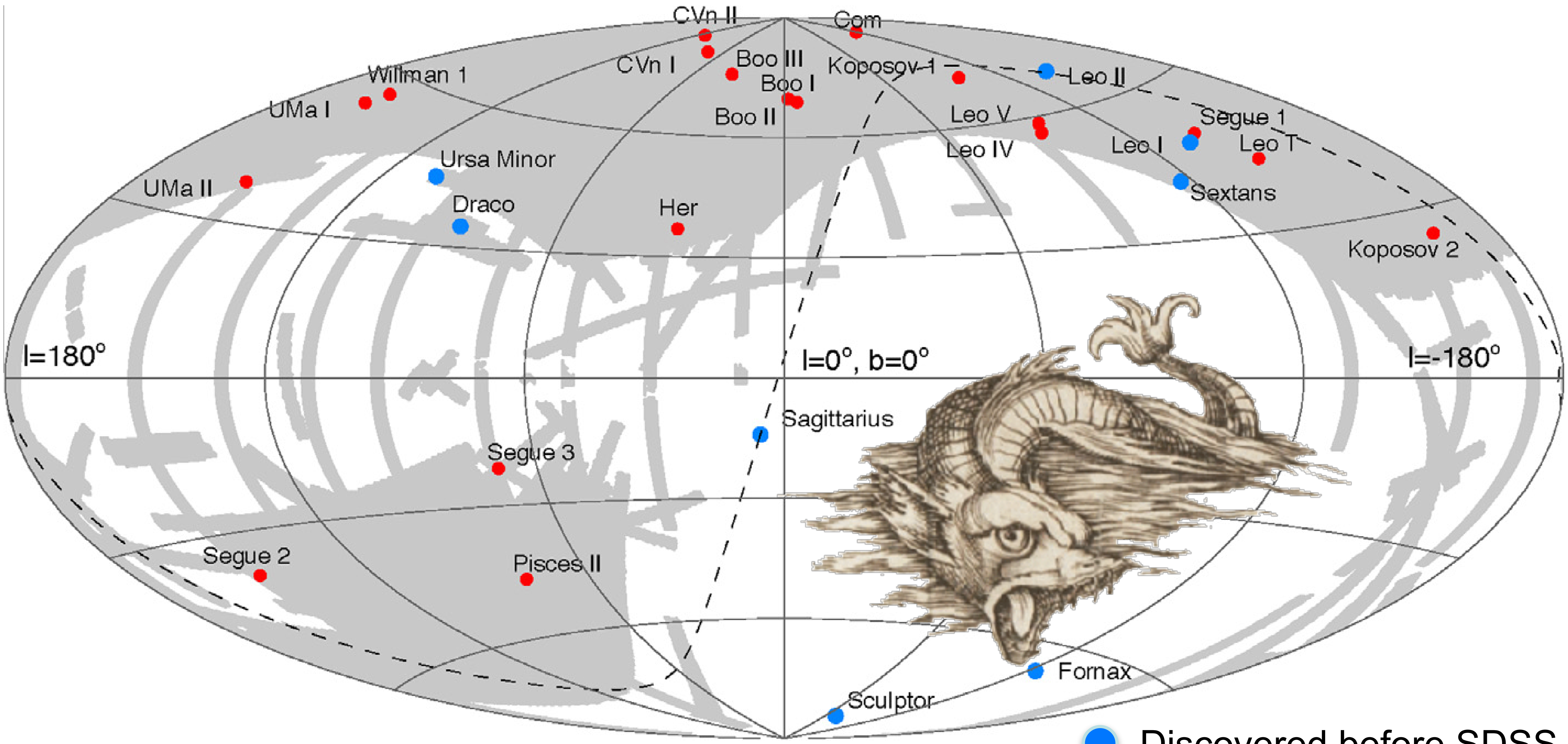
▨ Sky Covered by SDSS

● Discovered before SDSS (classical dwarfs)

● Discovered with SDSS (ultra-faint dwarfs)

(Belokurov 2013)

SDSS Sky Coverage



▨ Sky Covered by SDSS

● Discovered before SDSS (classical dwarfs)

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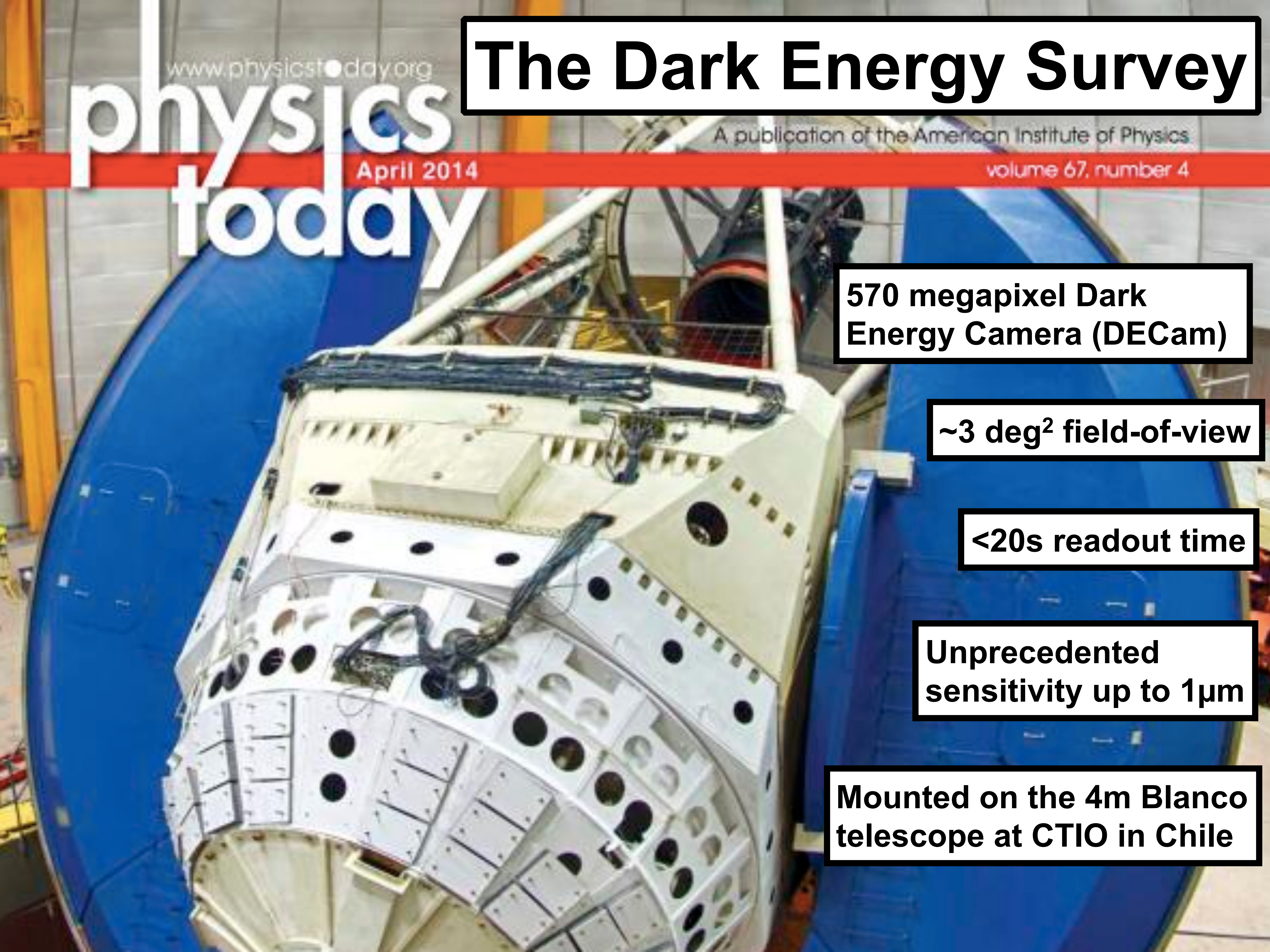
(Belokurov 2013)

The Dark Energy Survey



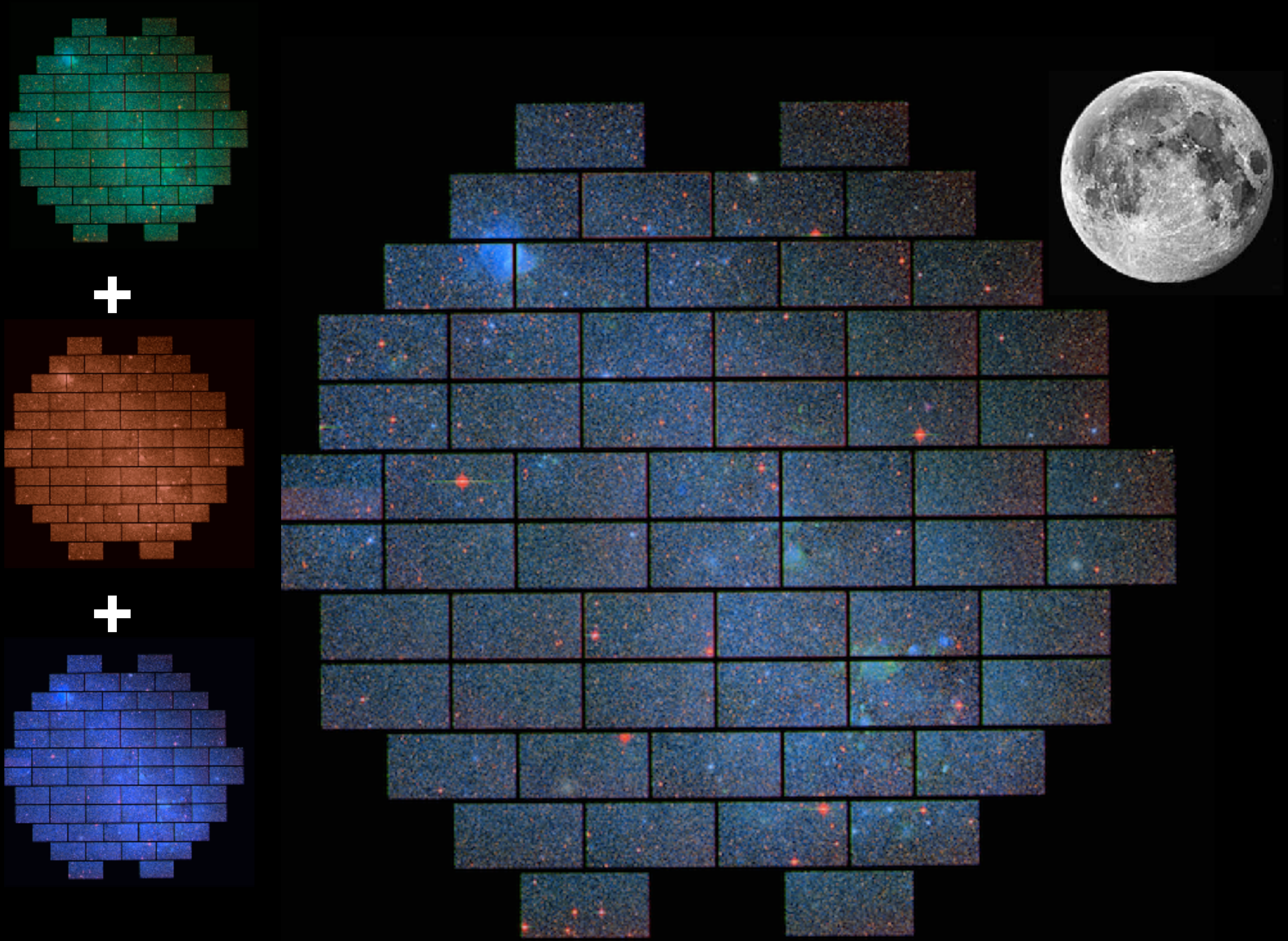
570 megapixel Dark Energy Camera (DECam)

~3 deg^2 field-of-view

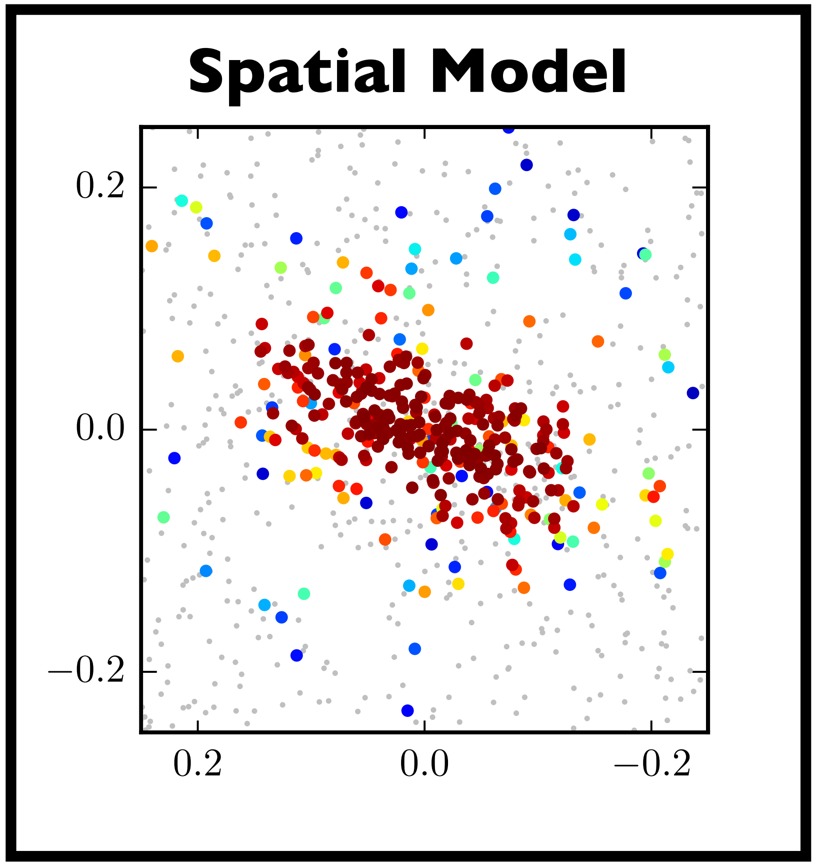
<20s readout time

Unprecedented sensitivity up to 1μm

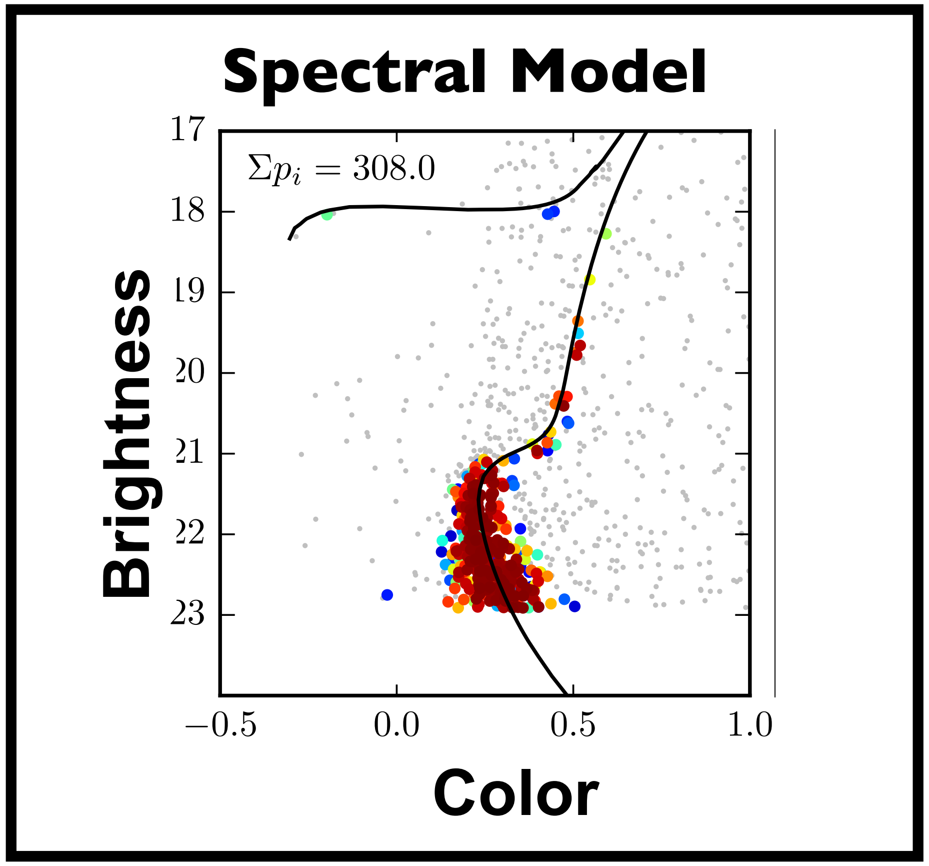
Mounted on the 4m Blanco telescope at CTIO in Chile



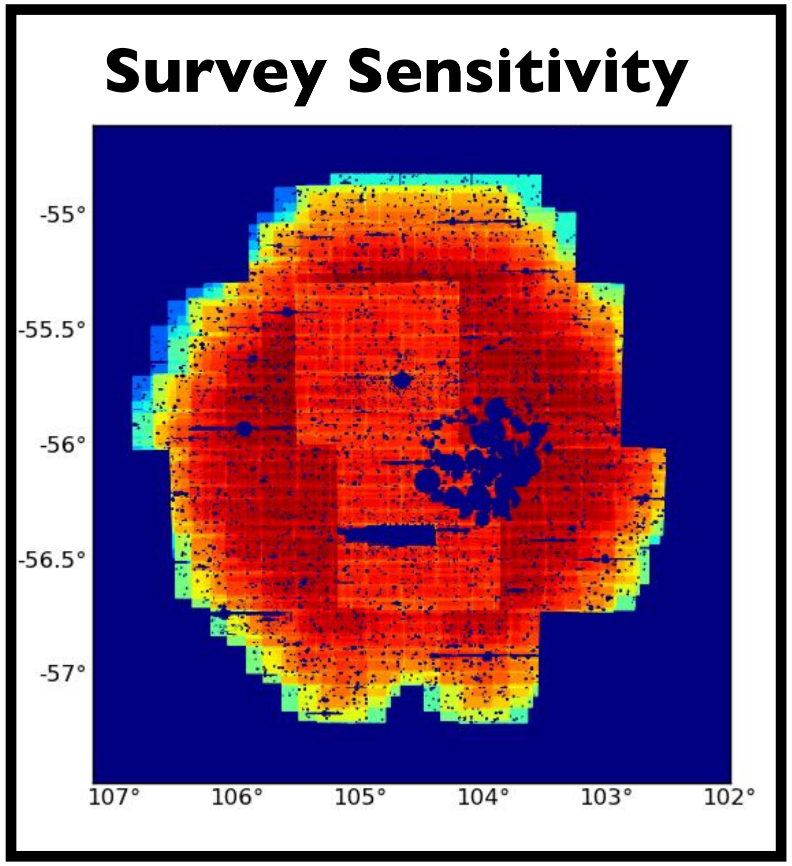
Maximum-Likelihood Searches



Spatial Model



Spectral Model



Survey Sensitivity

$$p_i = \frac{\lambda u_i}{\lambda u_i + b_i}$$

$$\lambda = \frac{1}{f} \sum_{i \in \mathrm{Stars}} p_i$$

$$\log L = -\sum_{i \in \mathrm{Stars}} \log(1 - p_i) - f\lambda$$

A likelihood analysis to simultaneously combine spatial and spectral information

u_i = **signal probability**

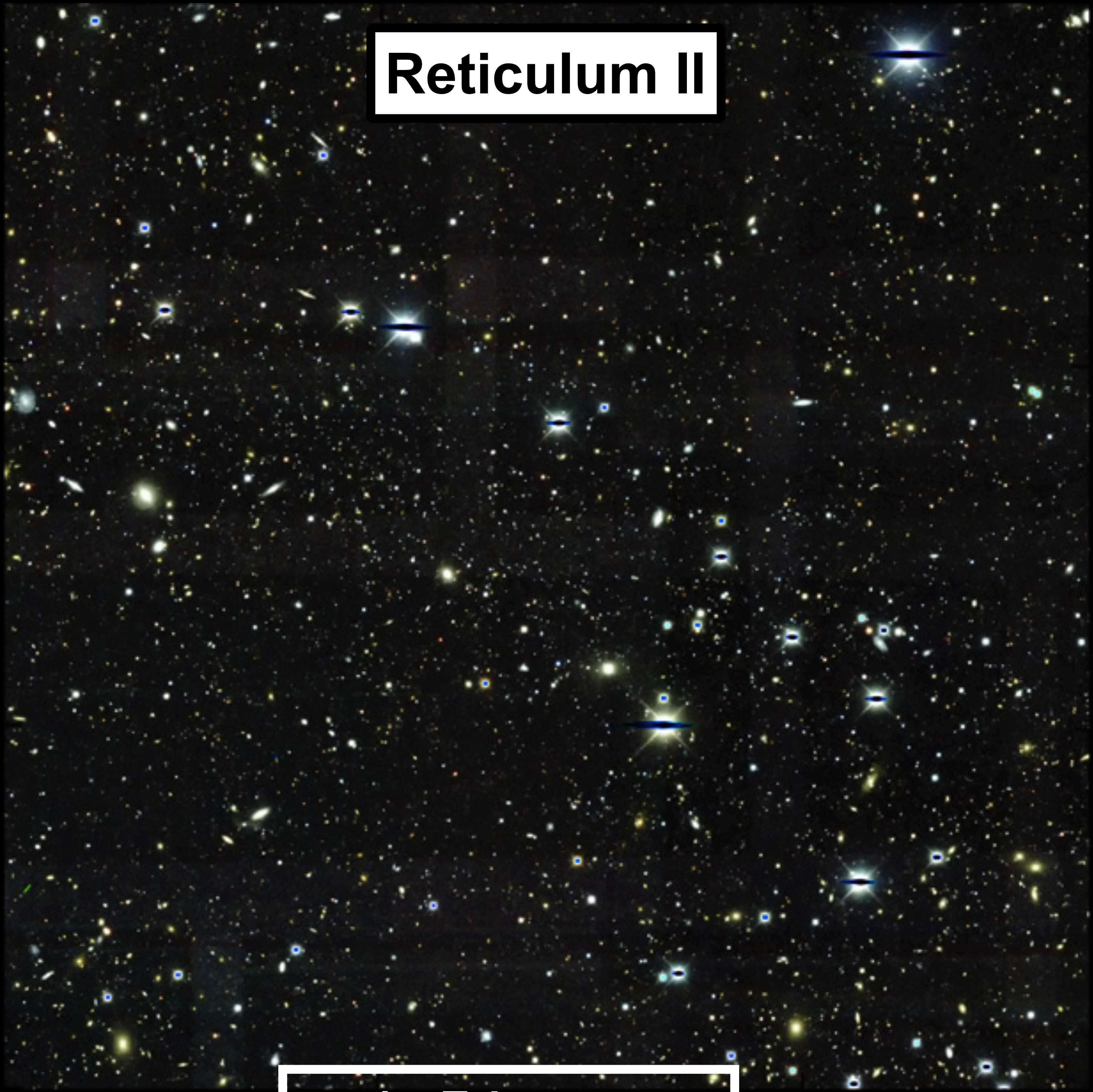
b_i = **background probability**

λ = **number of stars in the dwarf**

f = **observable fraction of stars**

This technique naturally yields a membership probability for each star; important for spectroscopic targeting

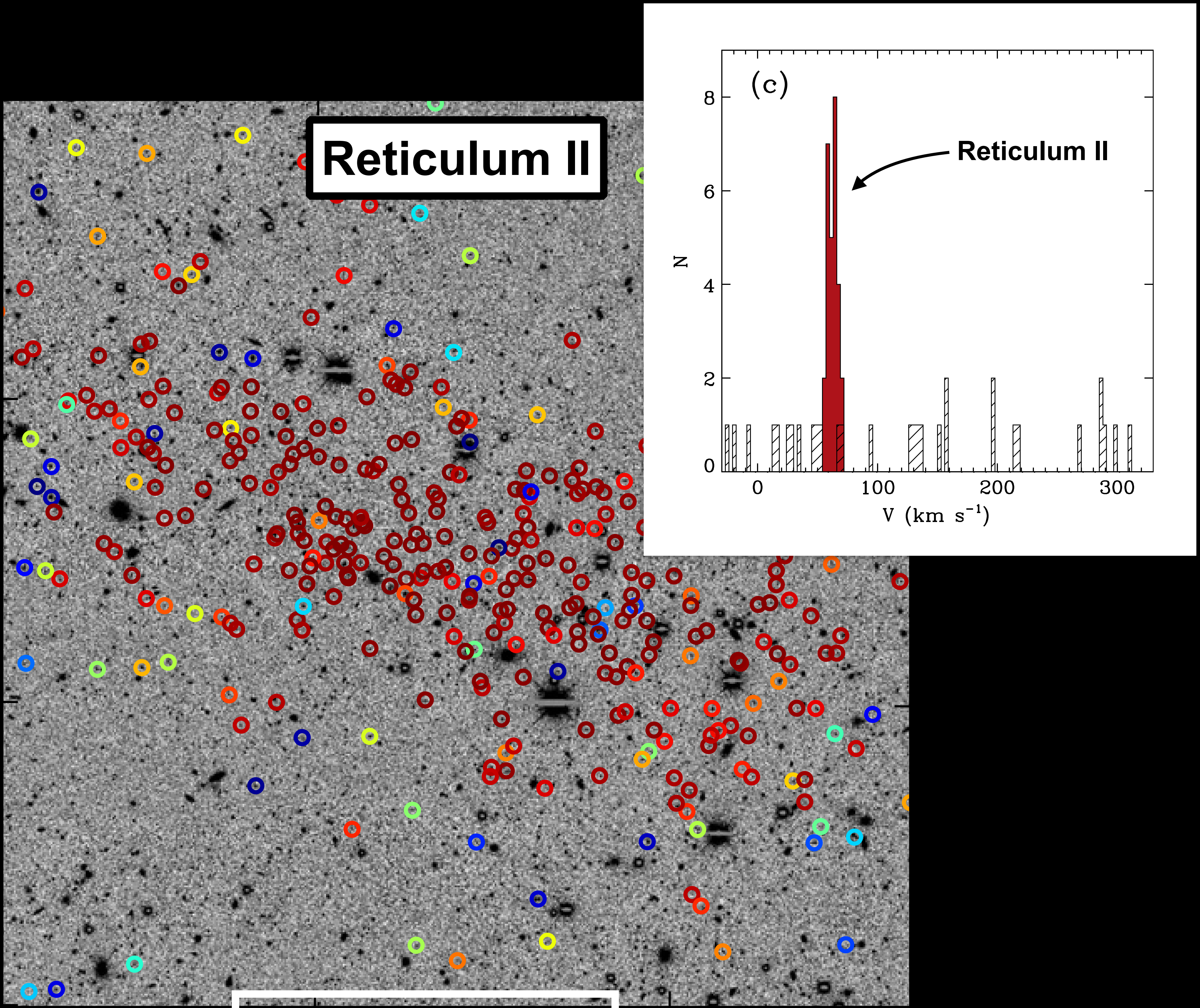
Reticulum II



4m Telescope
DECam CCD Camera

Bechtol, ADW et al. (2015)

Colors correspond to the membership probability assigned to each star by the likelihood analysis



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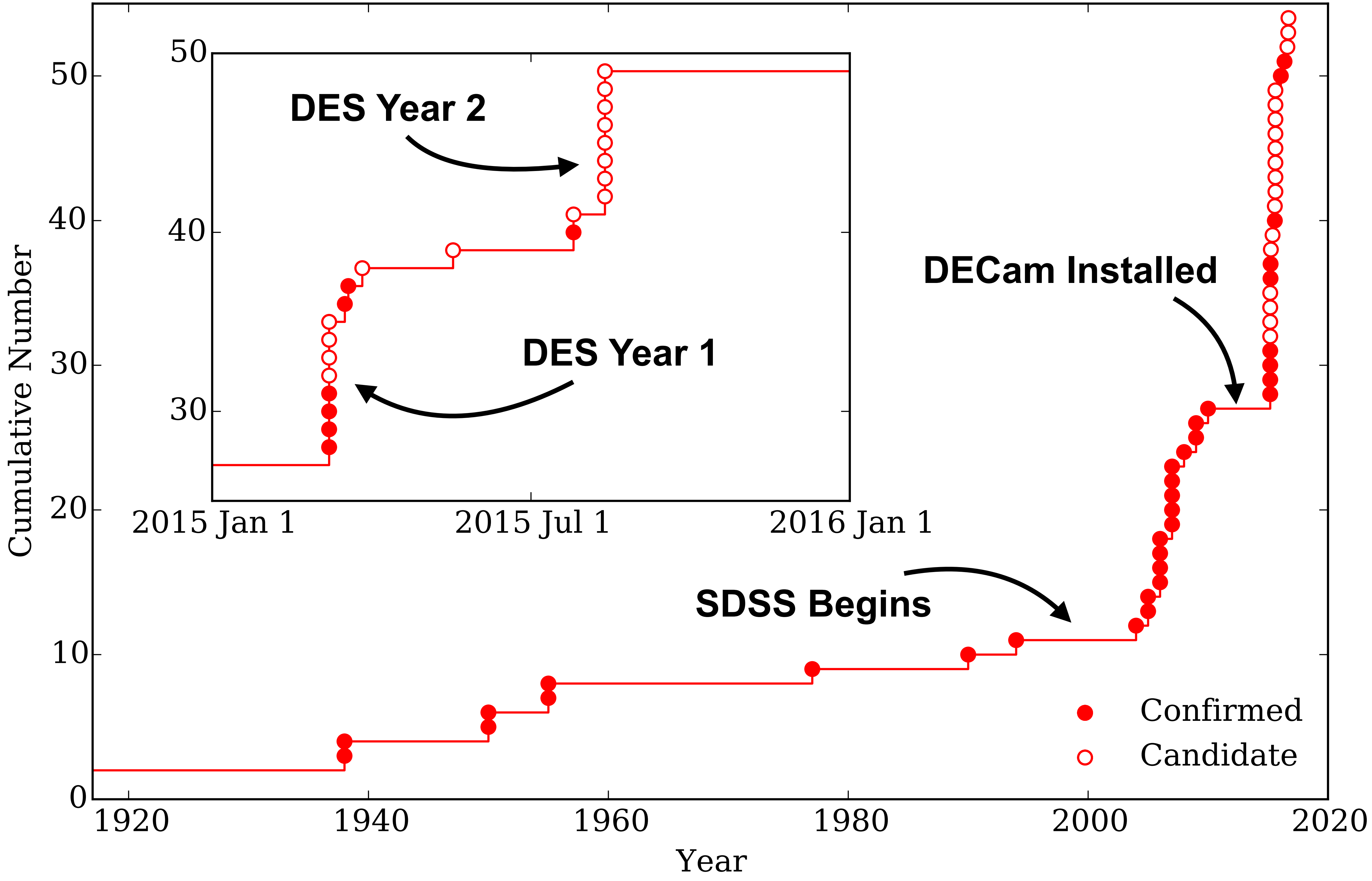
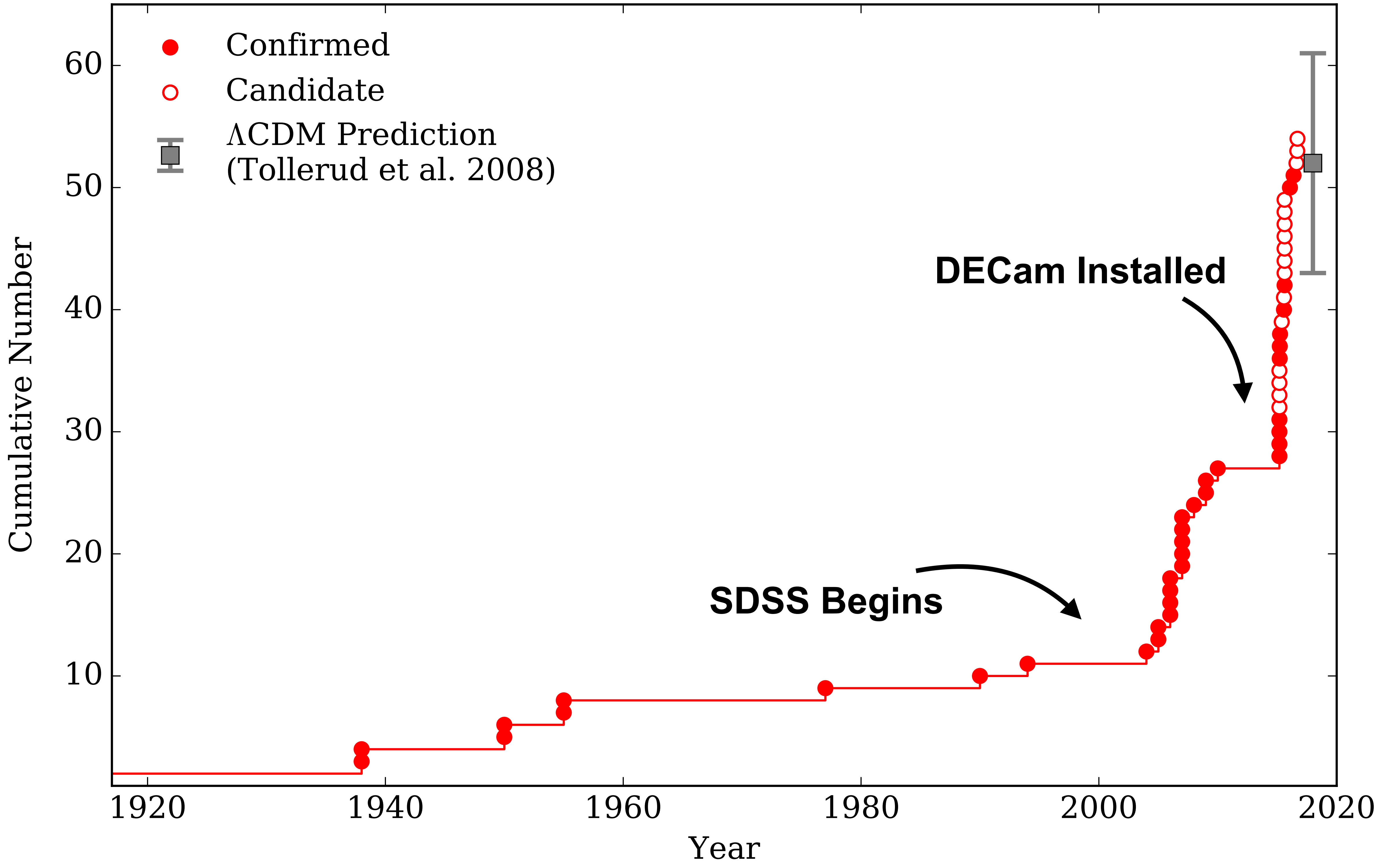
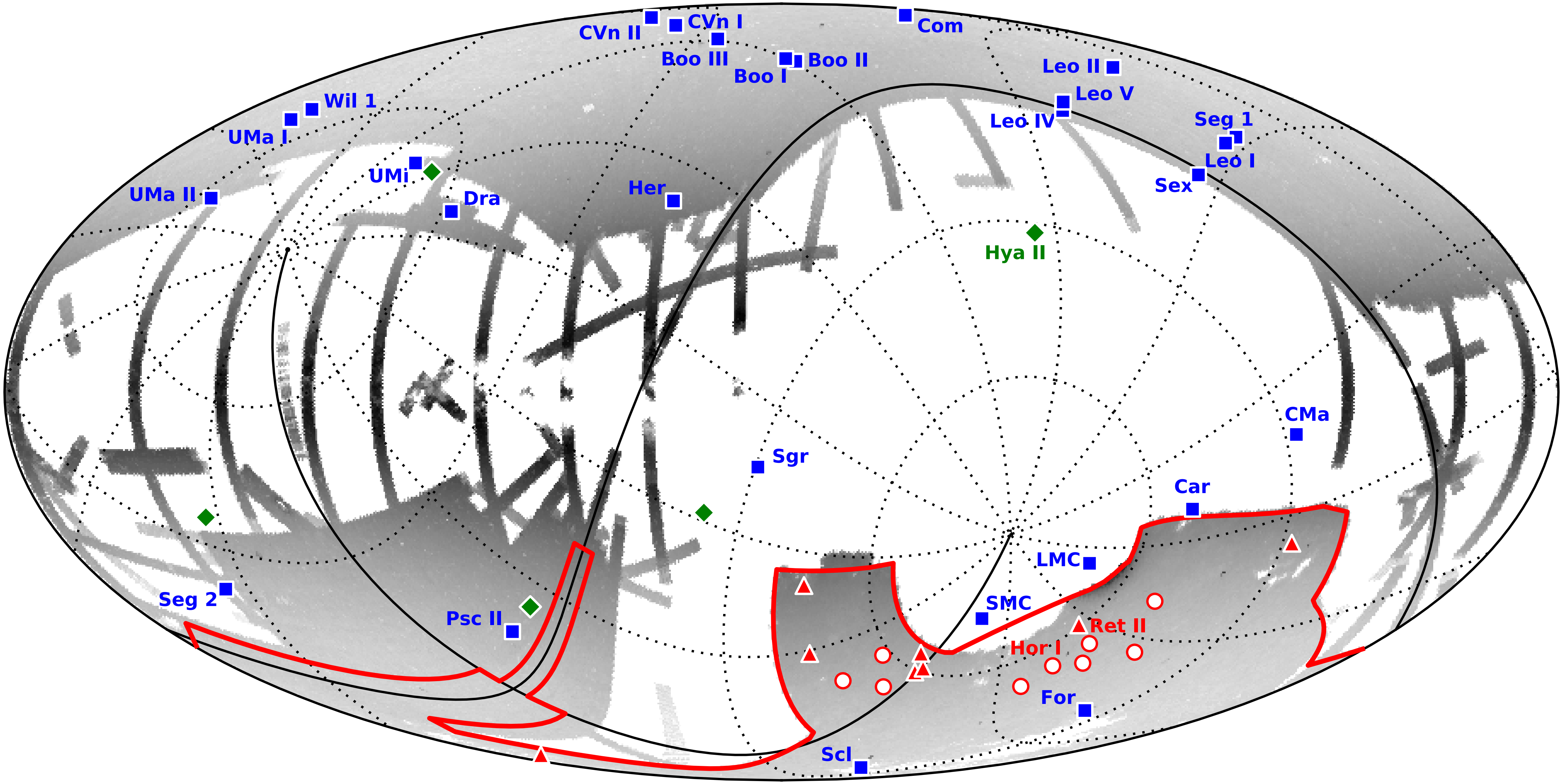
Dwarf Galaxy Discovery Timeline



Dwarf Galaxy Discovery Timeline



SDSS + DES Sky Coverage

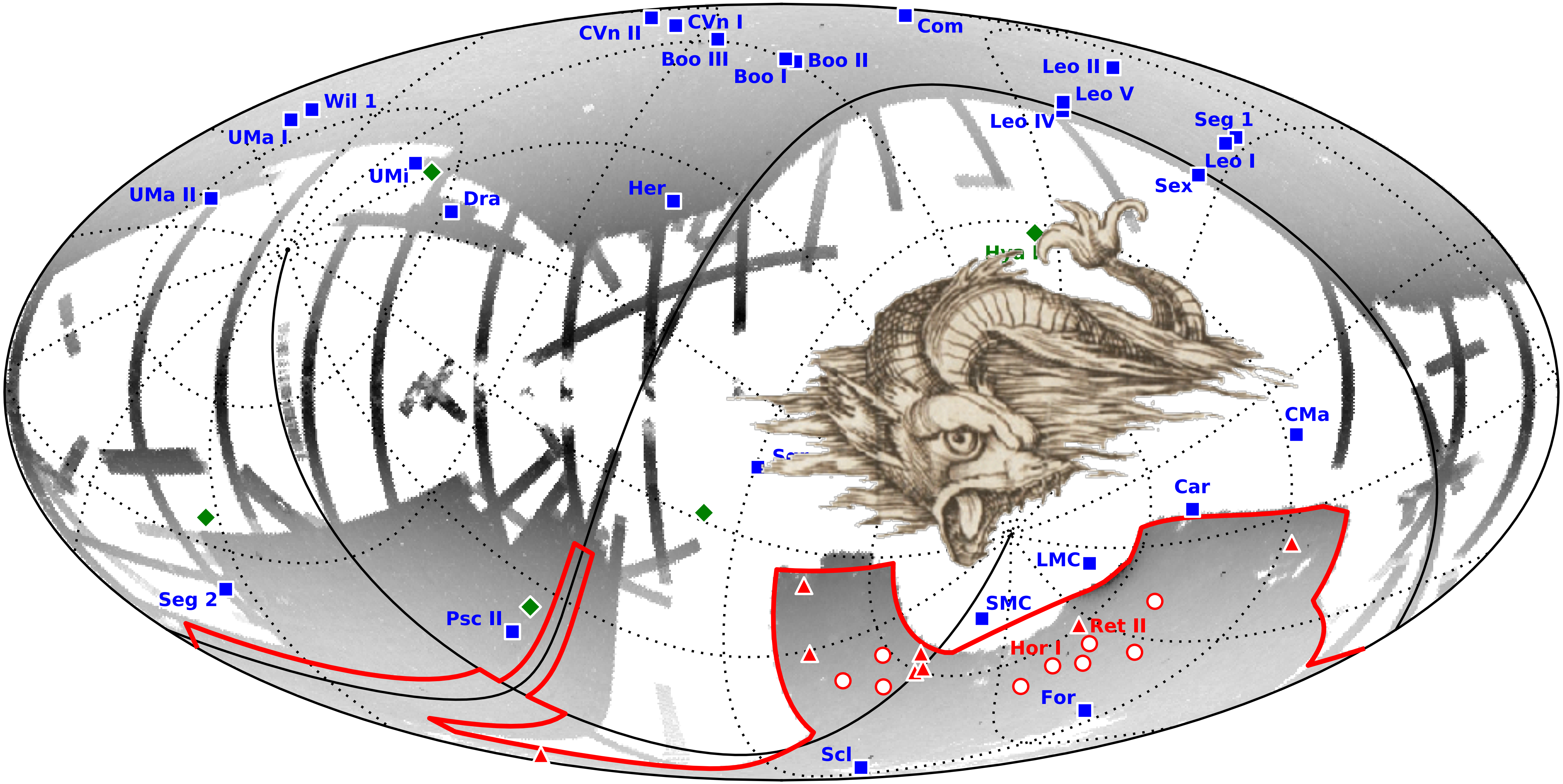


Blue - Previously discovered satellites
Green - Discovered in 2015 with
PanSTARRS, SDSS, etc.

Red outline - DES footprint
Red circles - DES Y1 satellites
Red triangles - DES Y2 satellites

ADW, et al. ApJ 813, 109 (2015)

SDSS + DES Sky Coverage



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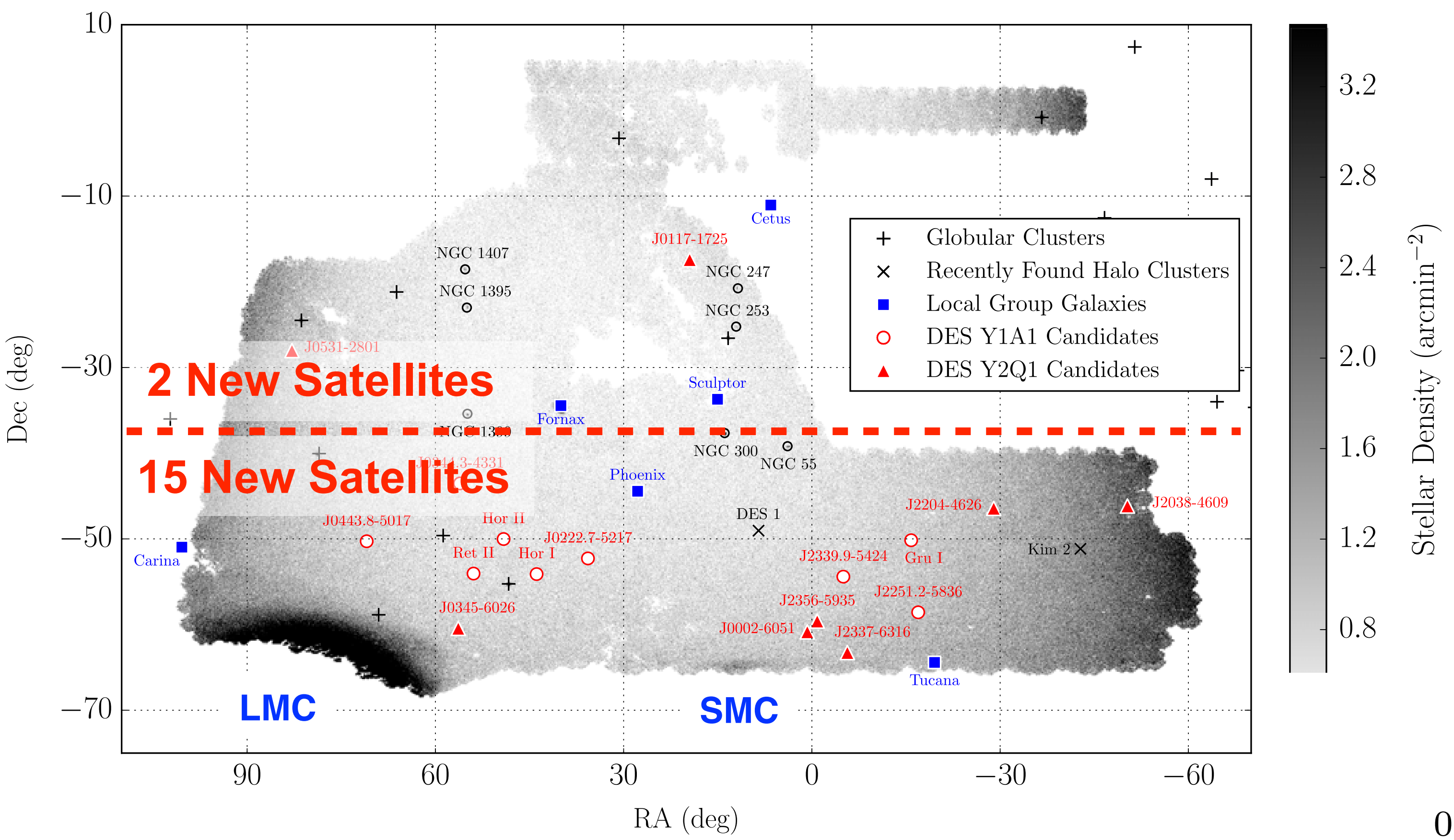
ADW, et al. ApJ 813, 109 (2015)

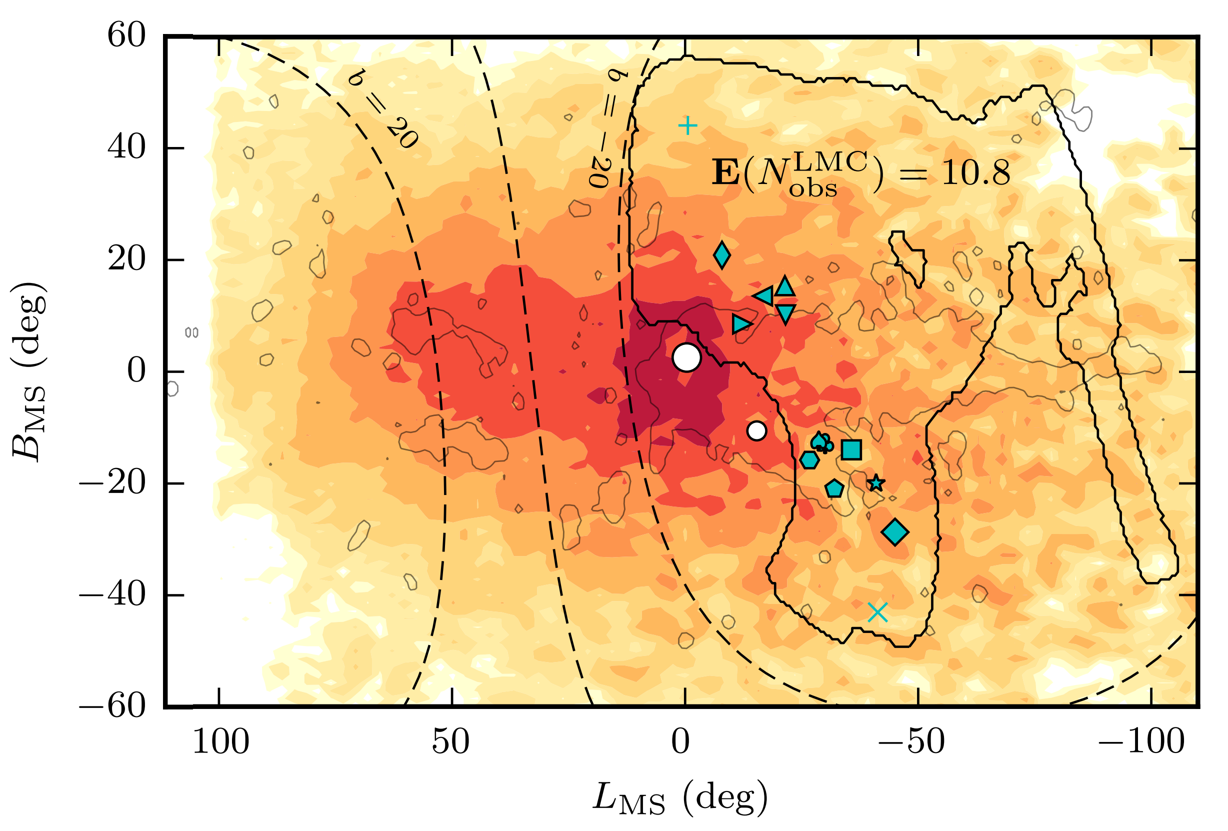
Satellites of the Magellanic Clouds?



ADW et al. ApJ 813, 109 (2015)

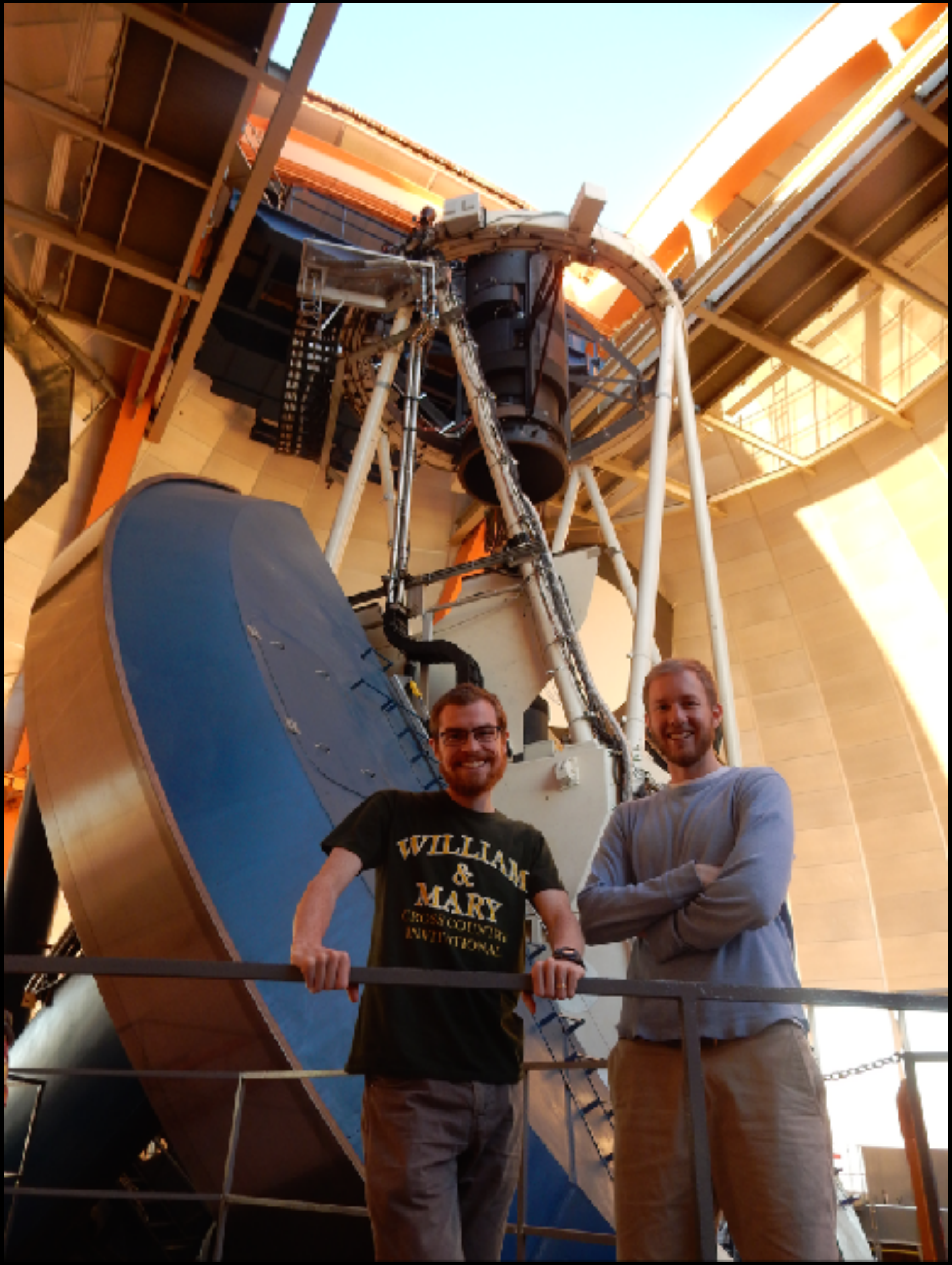
There is ~3σ evidence that DES satellites are not isotropically distributed.

Jethwa et al. MNRAS 461, 2 (2016)



This anisotropy could be explained by an association with the Magellanic Clouds

Magellanic Satellites Survey



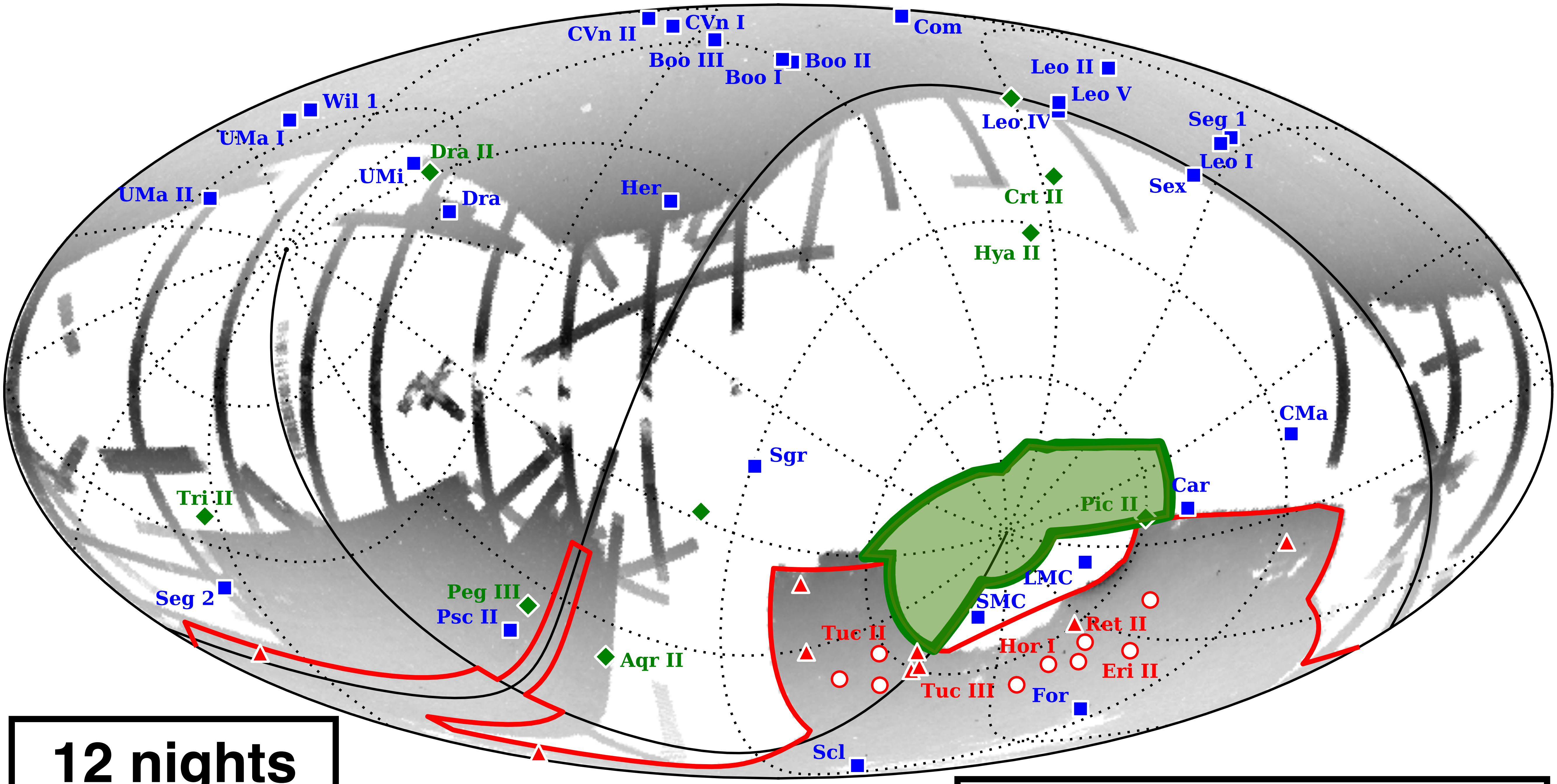
(MagLiteS)

DECam Program for 12 nights
in 2016-2017
PI: Keith Bechtol
Deputy PI: ADW

Funding through the NASA
Guest Investigator Program
PI: ADW

Collaboration of ~45 members
across ~20 institutions

Magellanic Satellites Survey (MagLiteS)

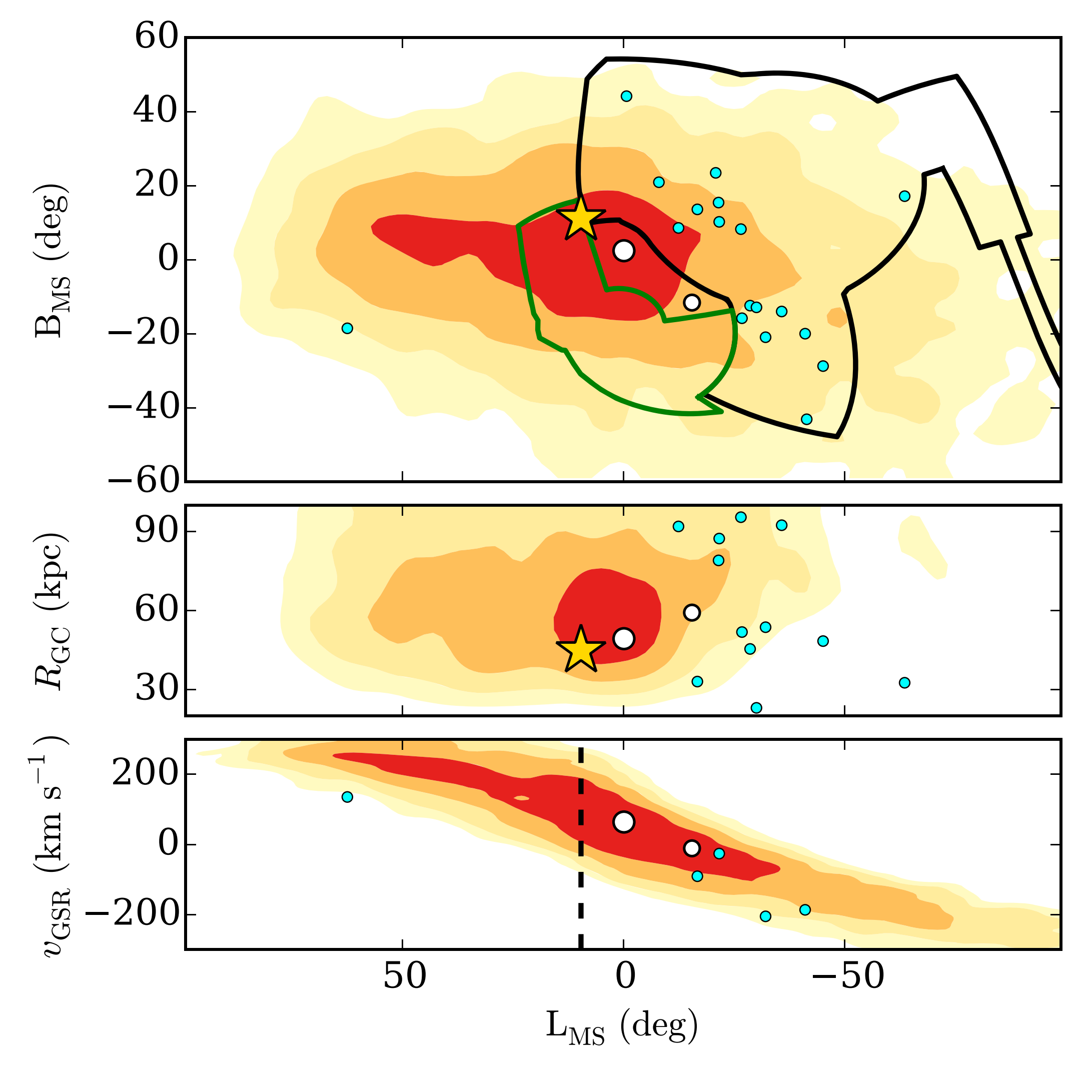


12 nights
~1300 deg²
3 tilings

Roughly comparable in depth to DES Y2 in g and r-bands

Alex Drlica-Wagner | Fermilab

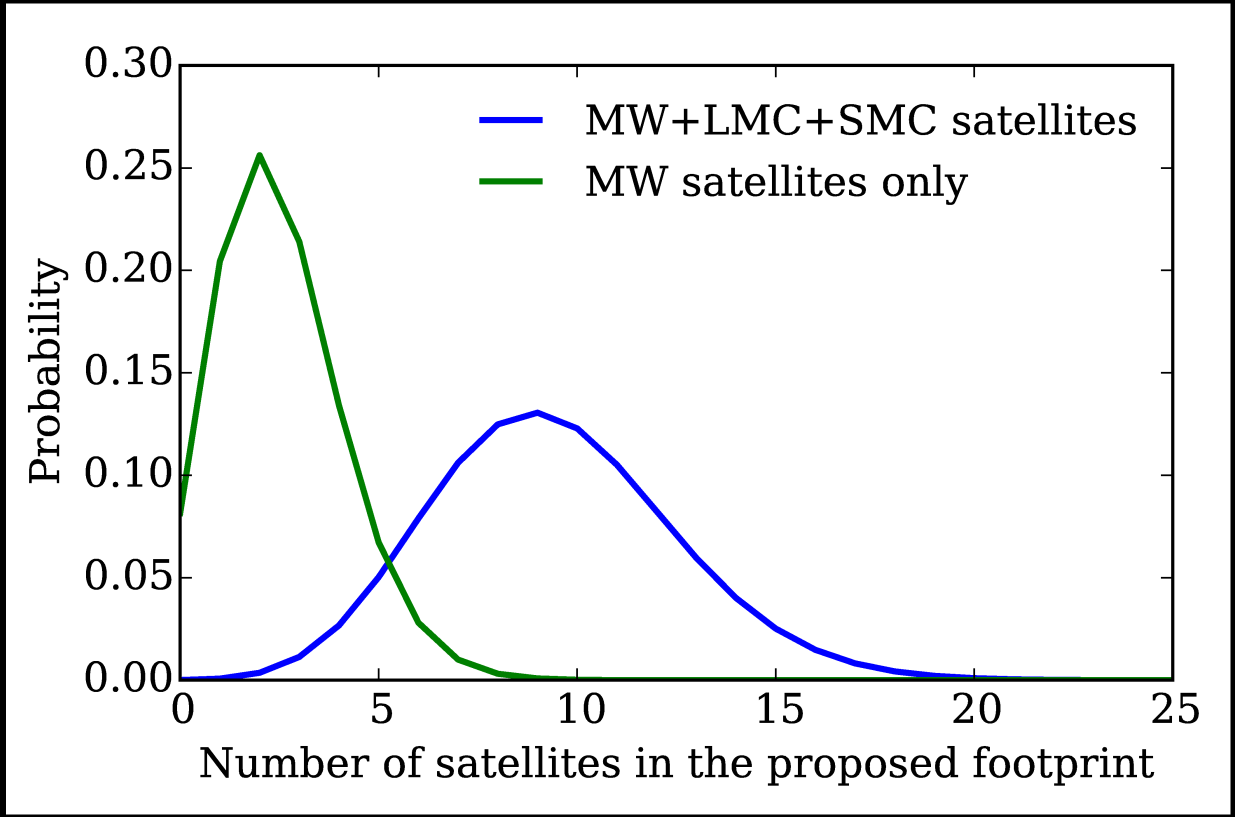
Satellites of the Magellanic Clouds?



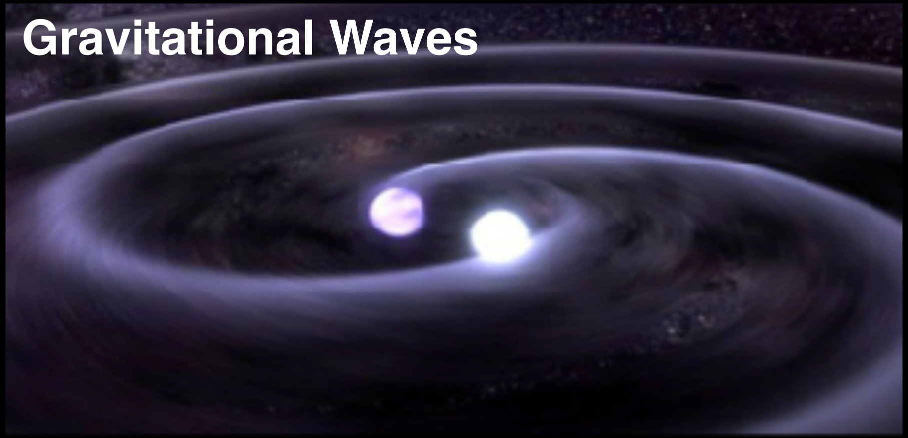
ADW et al. ApJL 833, 5, 2016

Simulations predict ~3 dwarf galaxies for an isotropic distribution and ~10 galaxies for a Magellanic Cloud association.

First satellite found in a 1/4th of the MagLiteS data; other candidates being investigated.



Blanco Imaging of the Southern Sky



NOAO DECam Program for 12 nights in 2017A
Co-PIs: Soares-Santos & ADW

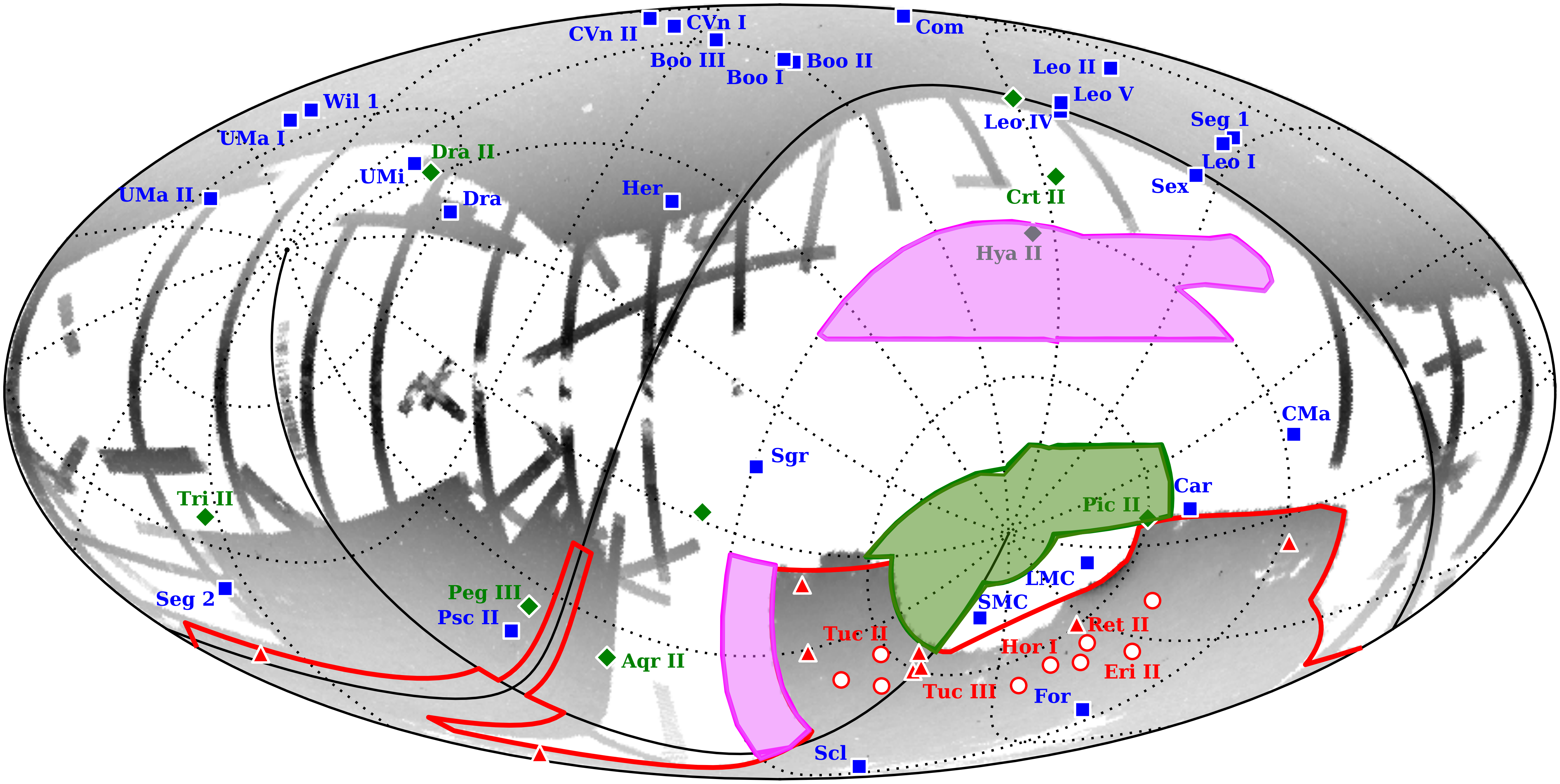
3 Science Drivers:

- Dwarf Galaxy Searches
- Gravitational Wave Follow-up
- Search for Planet 9

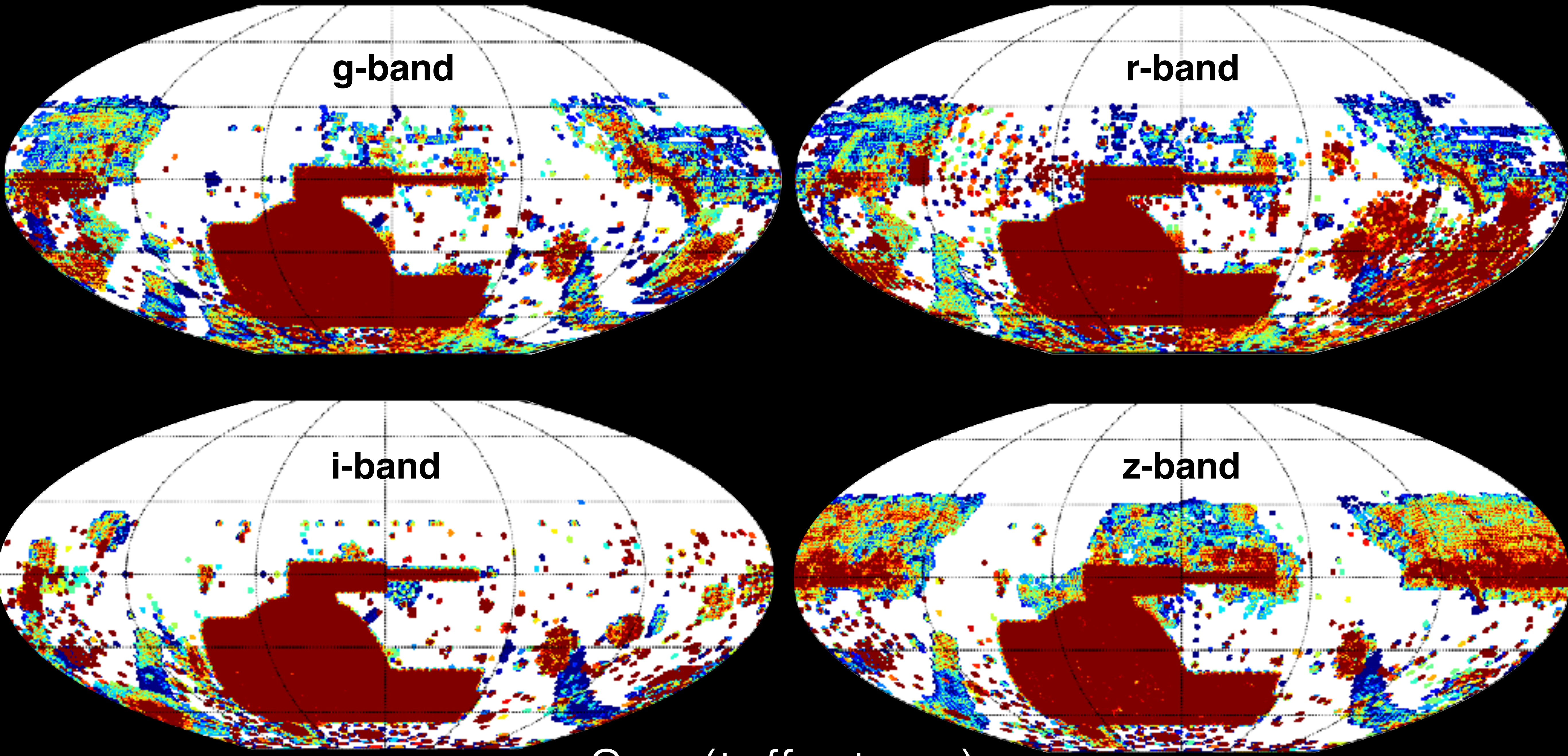
Cover ~2000 deg^2 in 2017; eventually cover the entire sky in g,r,i,z bands

Collaboration of ~35 members across ~10 institutions

Blanco Imaging of the Southern Sky (BLISS)

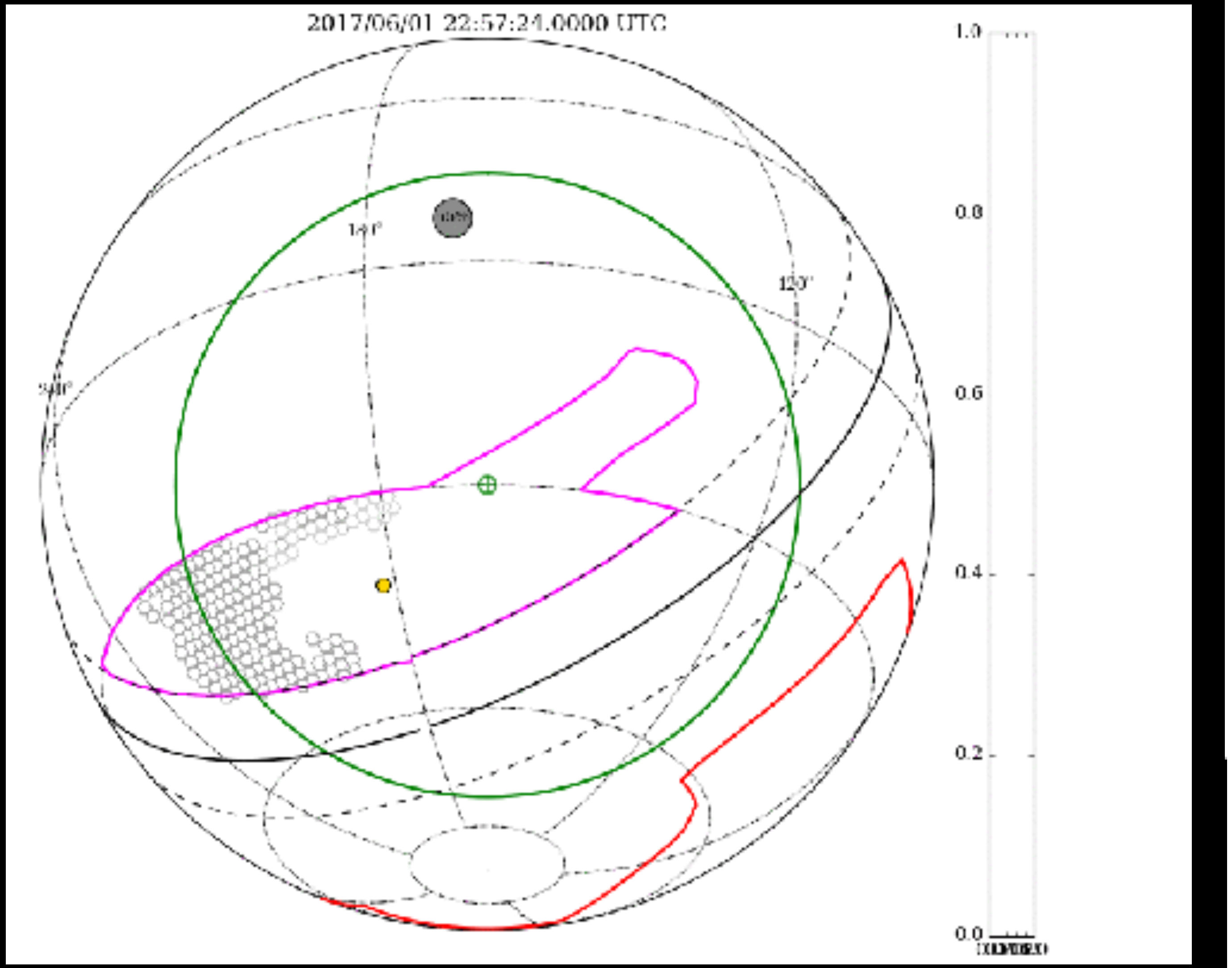


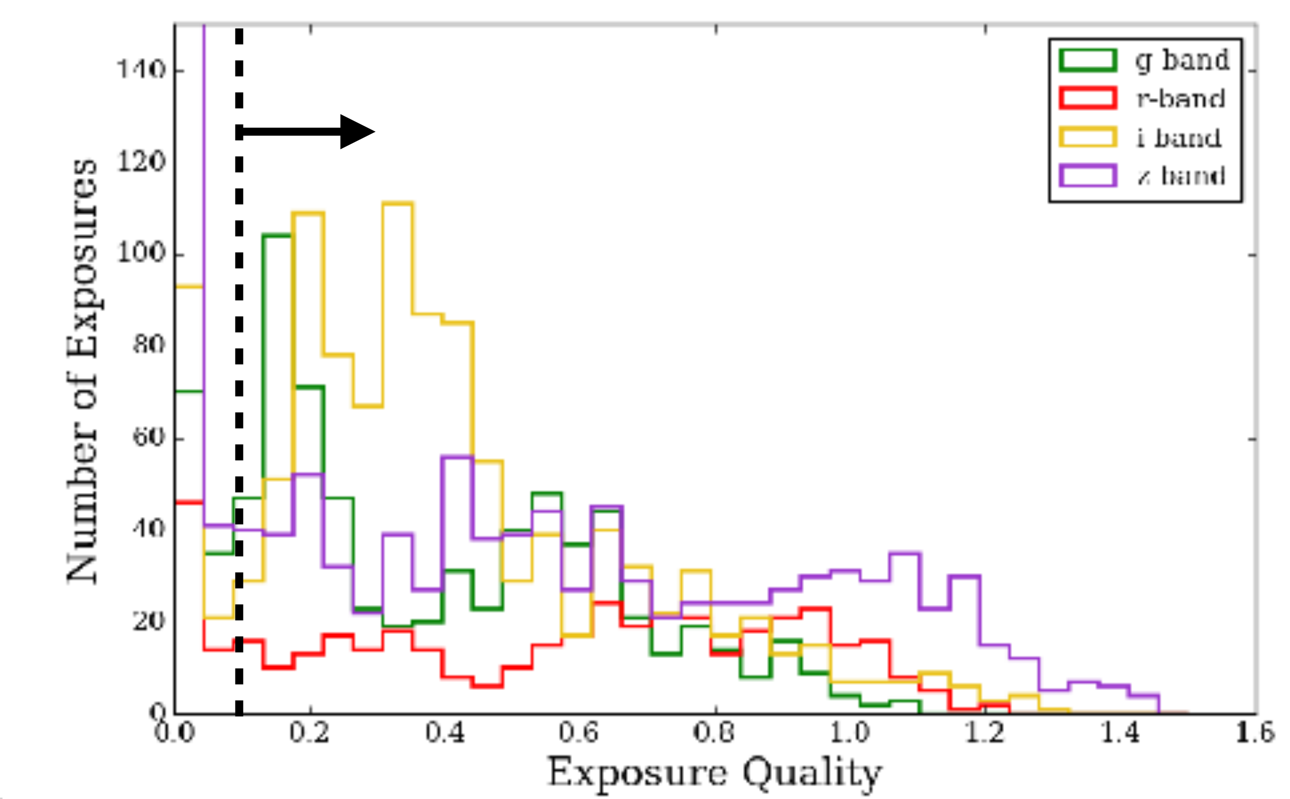
BLISS also uses all pre-existing DECam Data

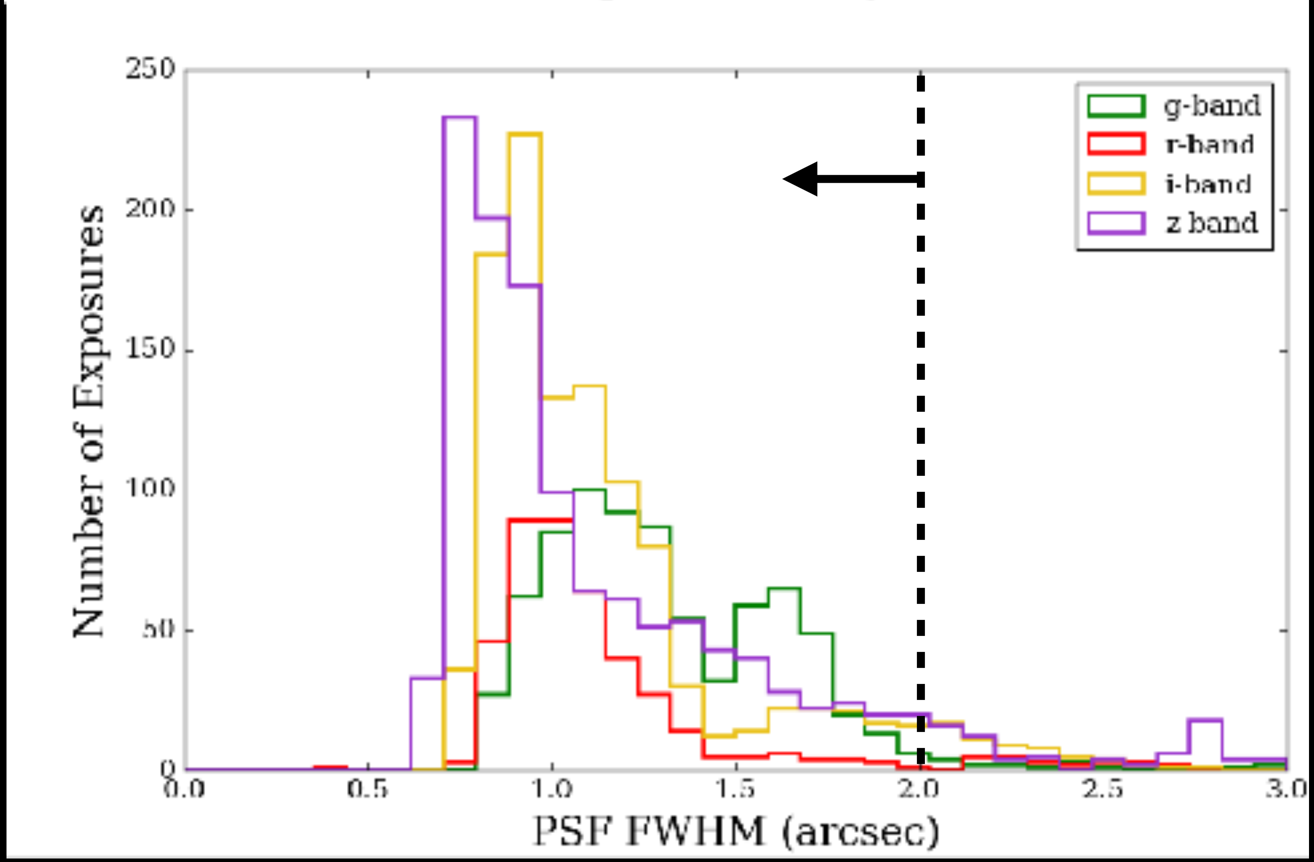


Sum(teff x texp)
log-scale from 30s (blue) to 300s (red)

Blanco Imaging of the Southern Sky

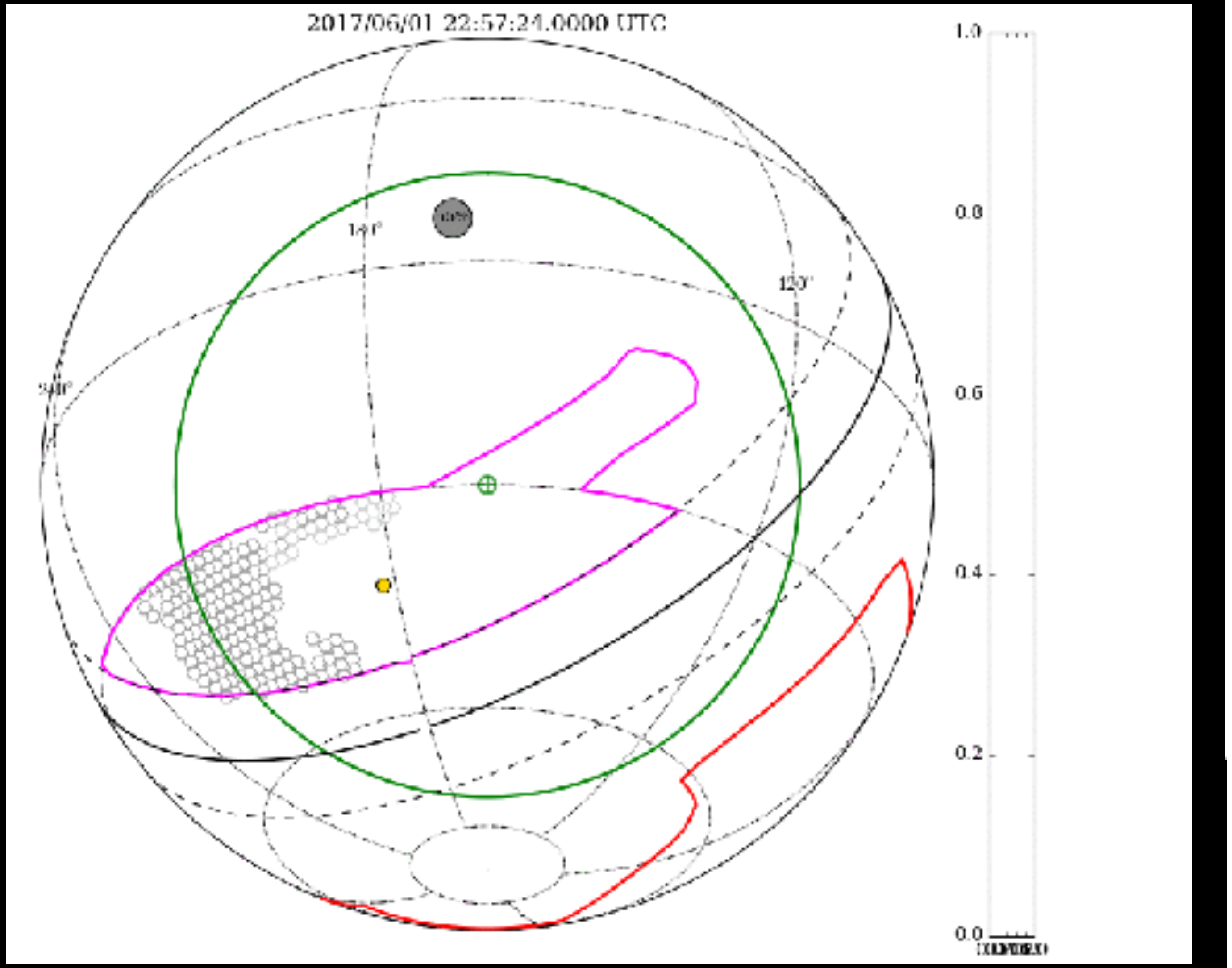


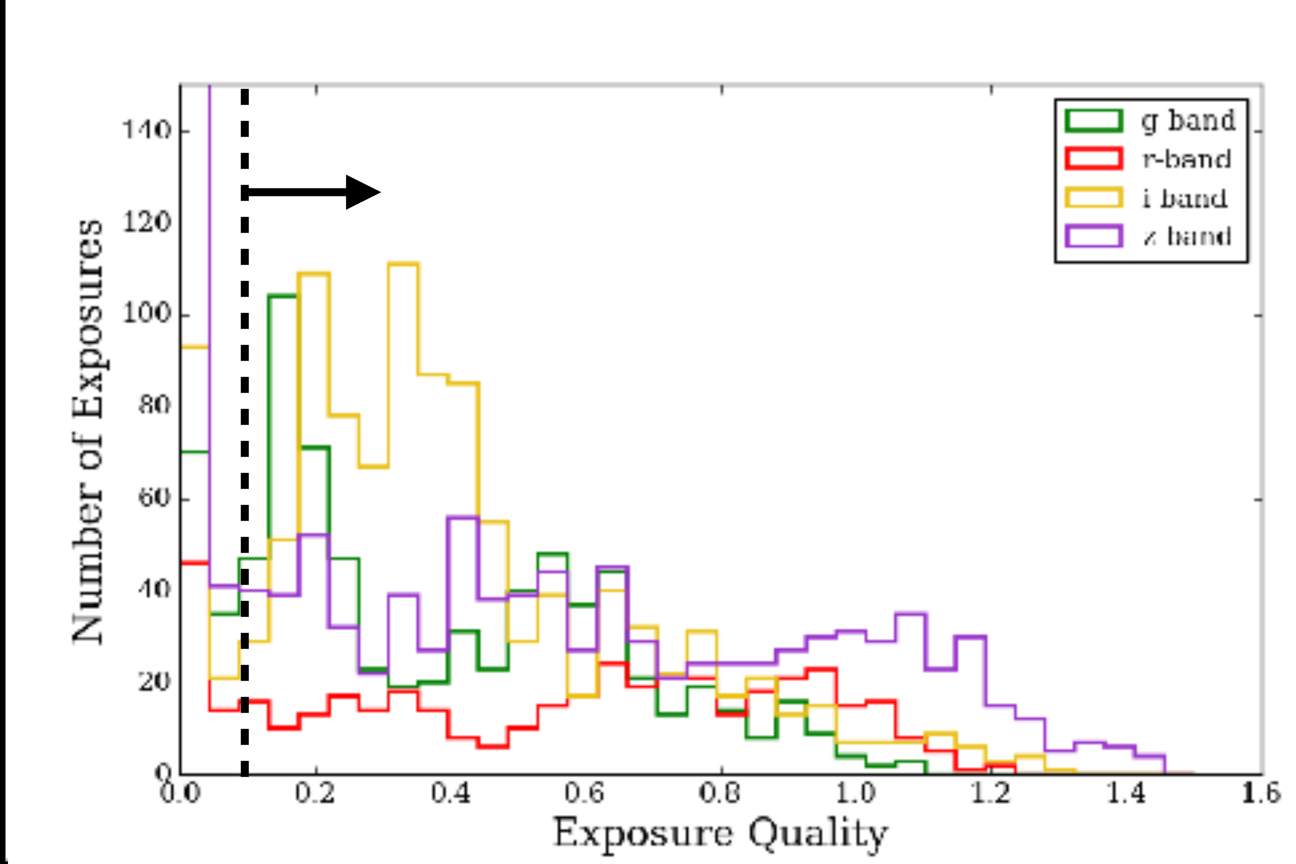


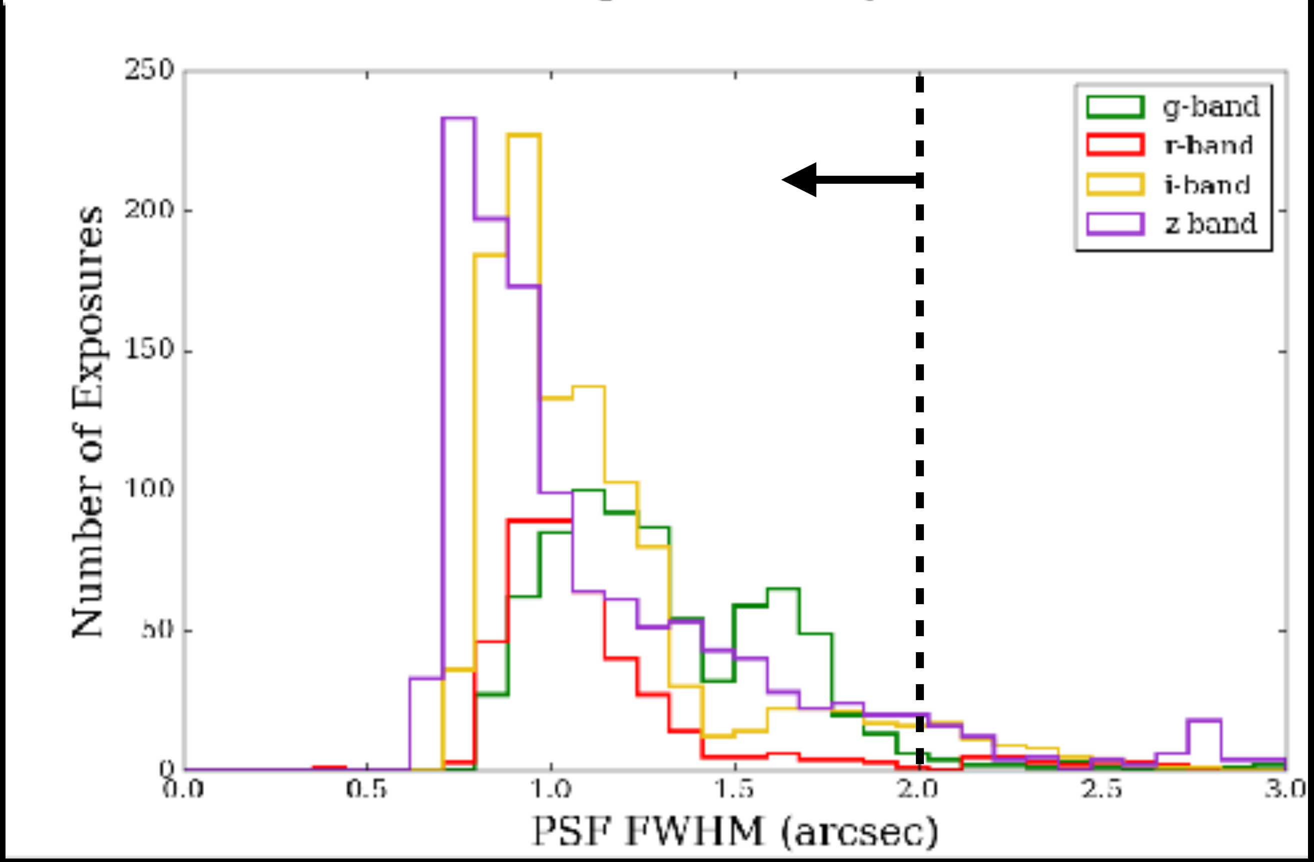


- **Most exposures pass cuts on exposure quality**
- **2017A data covers ~2200 deg^2 in any single band**

Blanco Imaging of the Southern Sky







- Most exposures pass cuts on exposure quality
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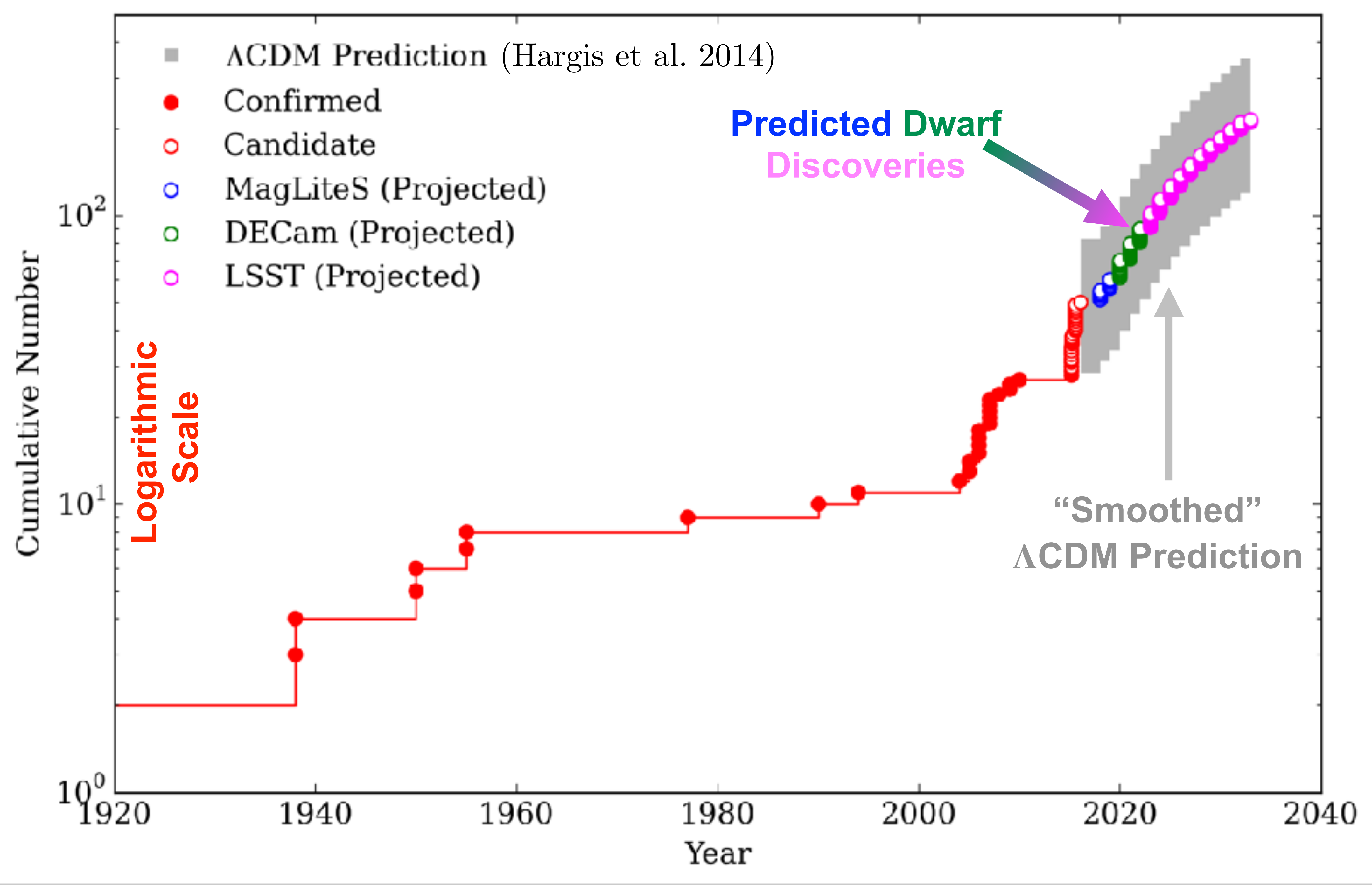
CDM Predictions for Future Dwarf Discoveries



Logarithmic Scale

Predicted Dwarf Discoveries

"Smoothed" ΛCDM Prediction