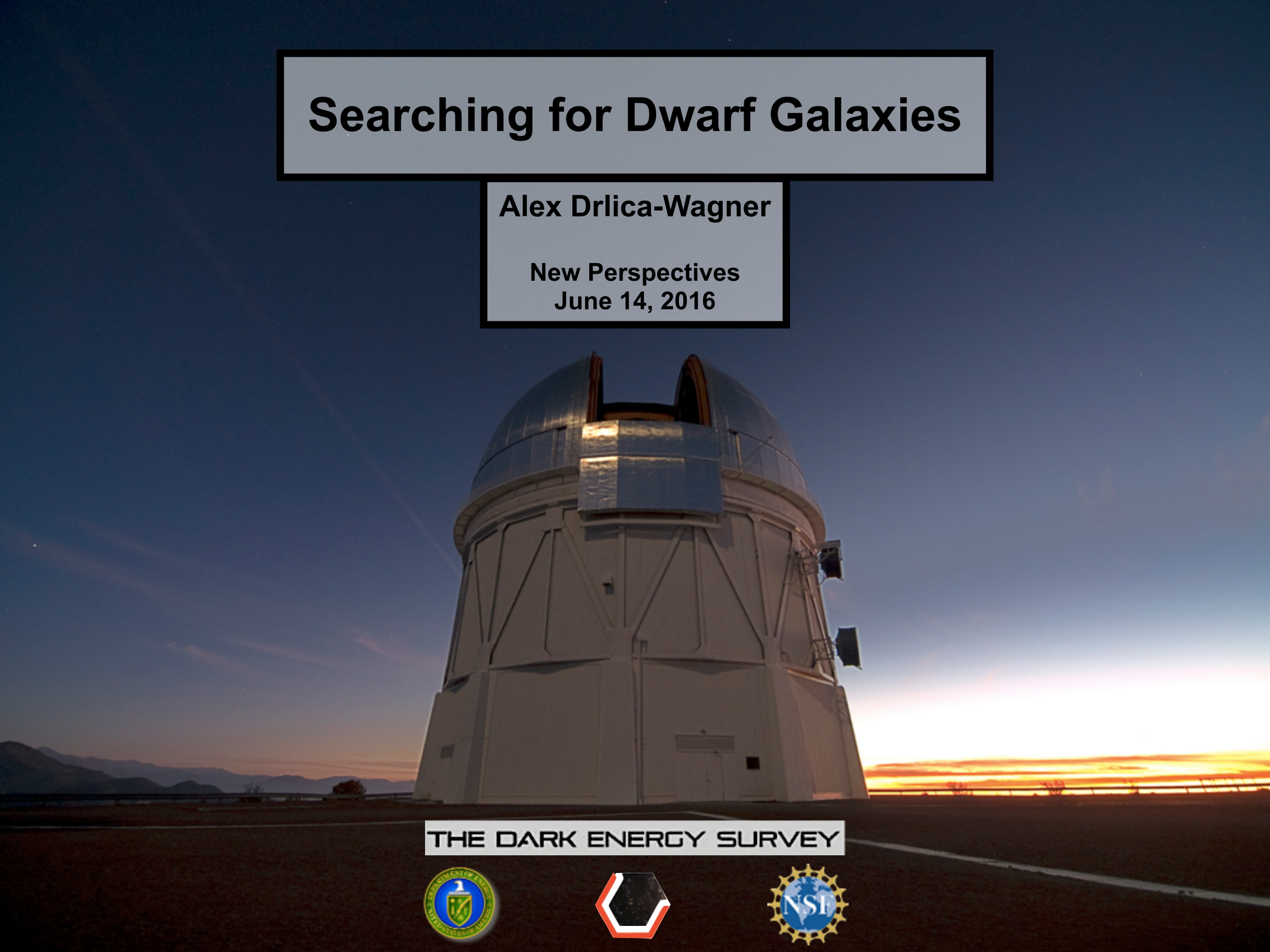
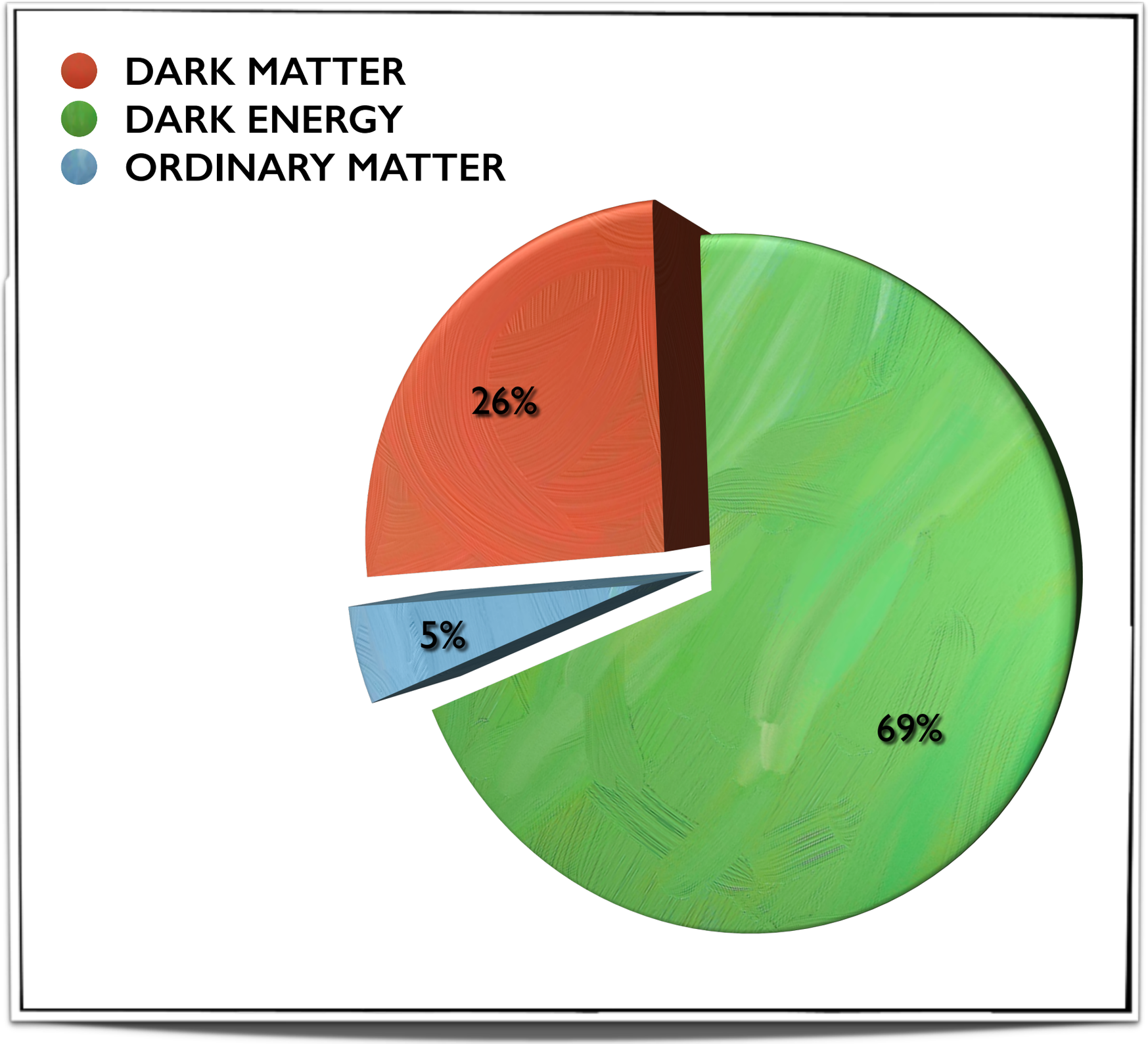
Searching for Dwarf Galaxies

Alex Drlica-Wagner

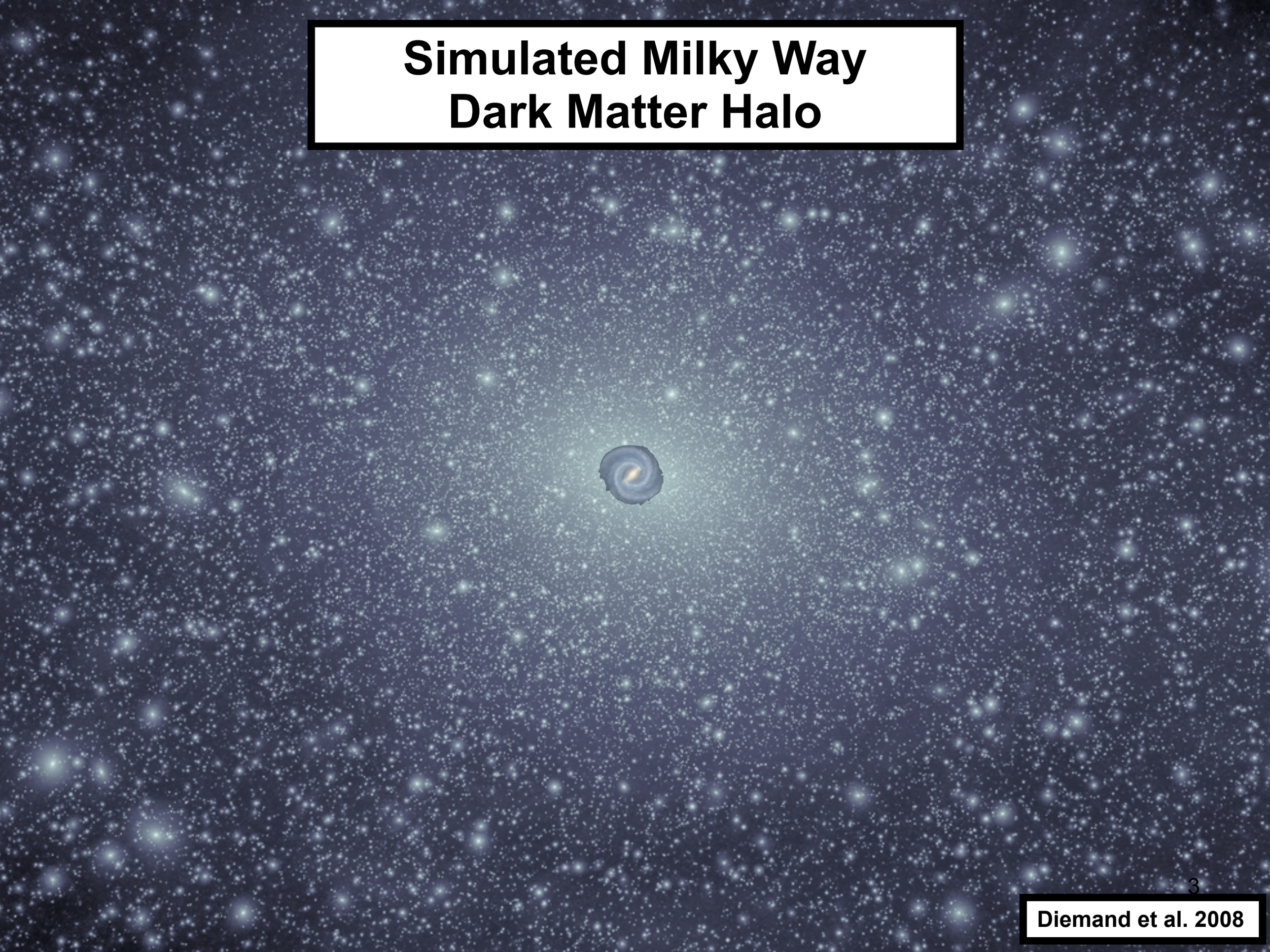
New Perspectives
June 14, 2016



Composition of the Universe

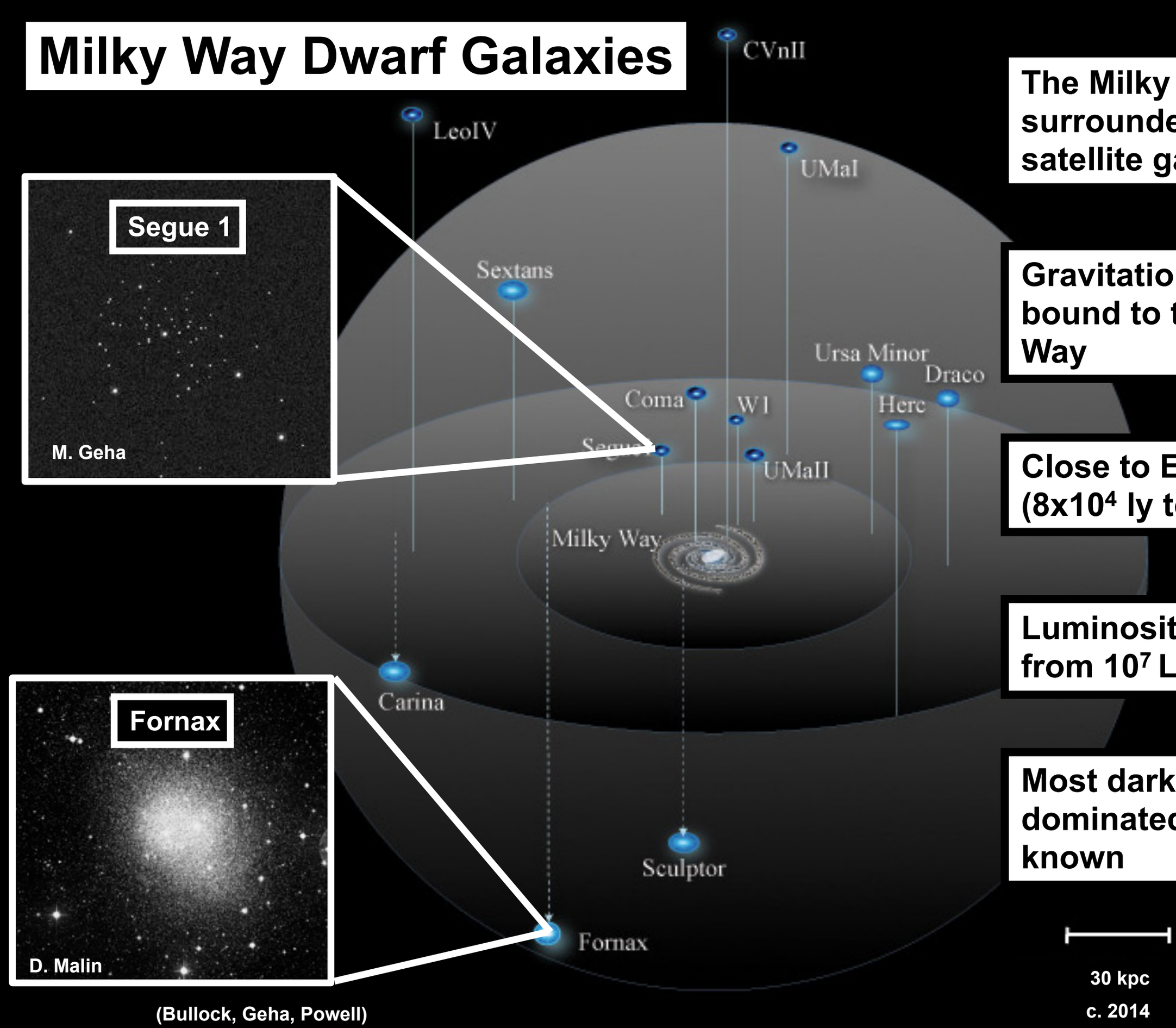


Simulated Milky Way Dark Matter Halo



Diemand et al. 2008

Milky Way Dwarf Galaxies



The Milky Way is surrounded by small satellite galaxies

Gravitationally bound to the Milky Way

Close to Earth (8×10^4 ly to 8×10^5 ly)

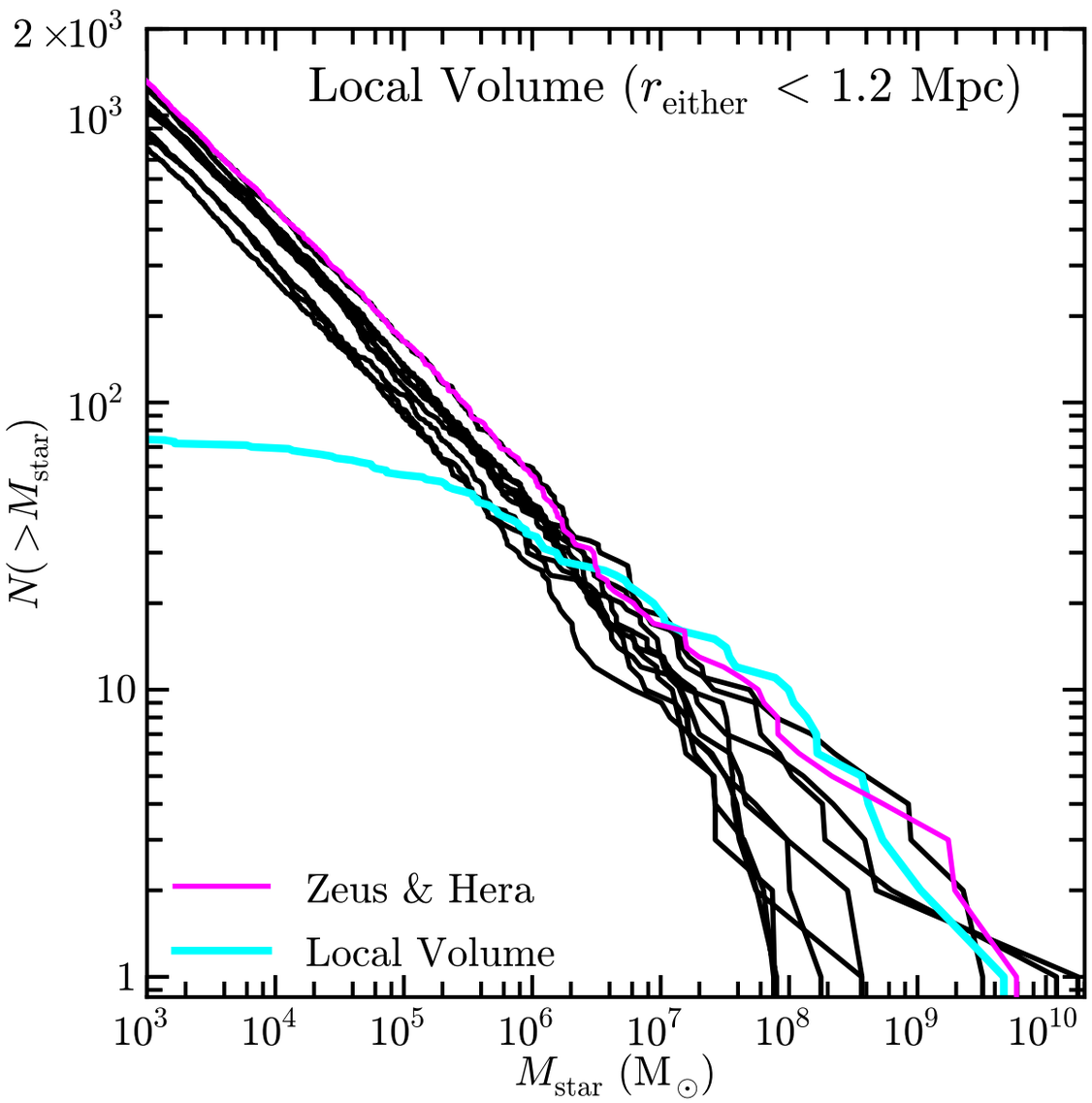
Luminosities range from $10^7\ L_\odot$ to $10^3\ L_\odot$

Most dark matter dominated objects known

(Bullock, Geha, Powell)

c. 2014

Missing Satellites Problem



- **Simulations predict ~10^4 dark matter subhalos bound to the Milky Way**
- **Observationally, we see < 10^2 satellite dwarf galaxies**
- **Where are the "missing satellites"?**
  - ✓ **Observational incompleteness: faint dwarf galaxies are hard to find and our observational coverage is largely incomplete**
  - ✓ **Galaxy formation: Only massive subhalos retain enough gas to form stars and galaxies**
  - ? **Dark matter characteristics: Warm or self-interacting dark matter will suppress subhalos formation**

Finding Milky Way Satellite Galaxies

Visual Searches

- **First objects discovered by visual scans of photographic plates**

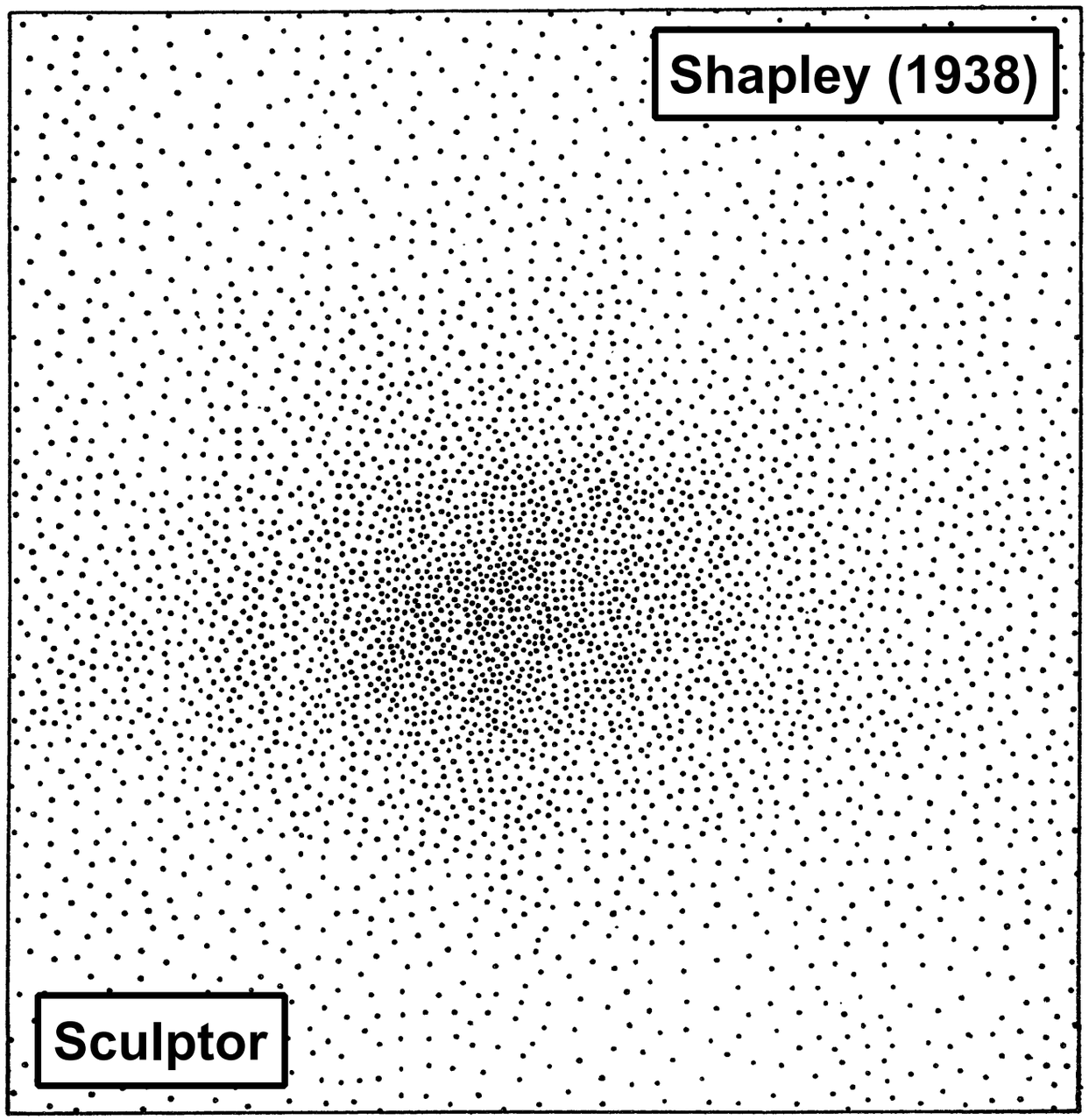


FIGURE 2.— DISTRIBUTION OF STARS IN CENTRAL SQUARE DEGREE

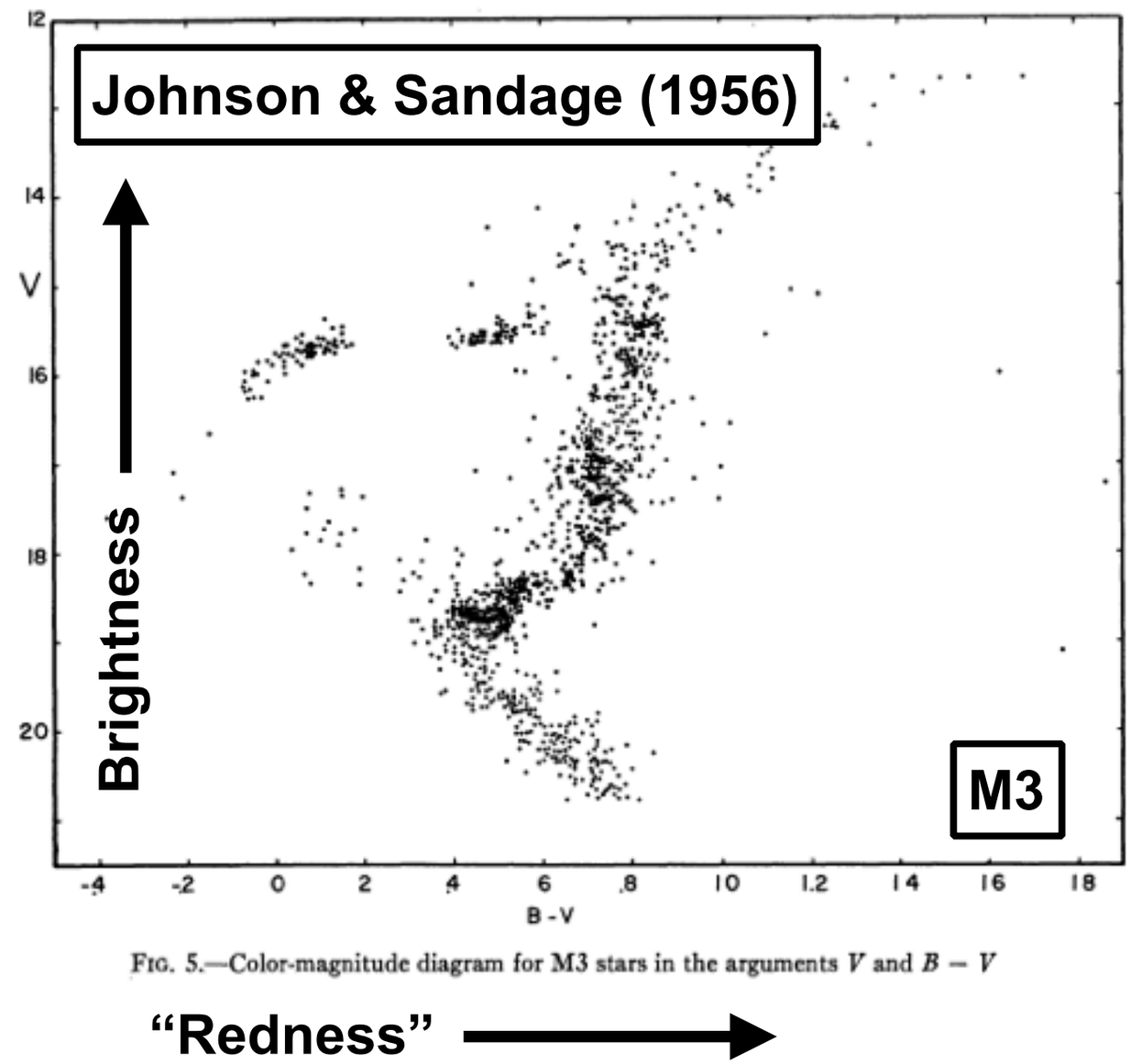
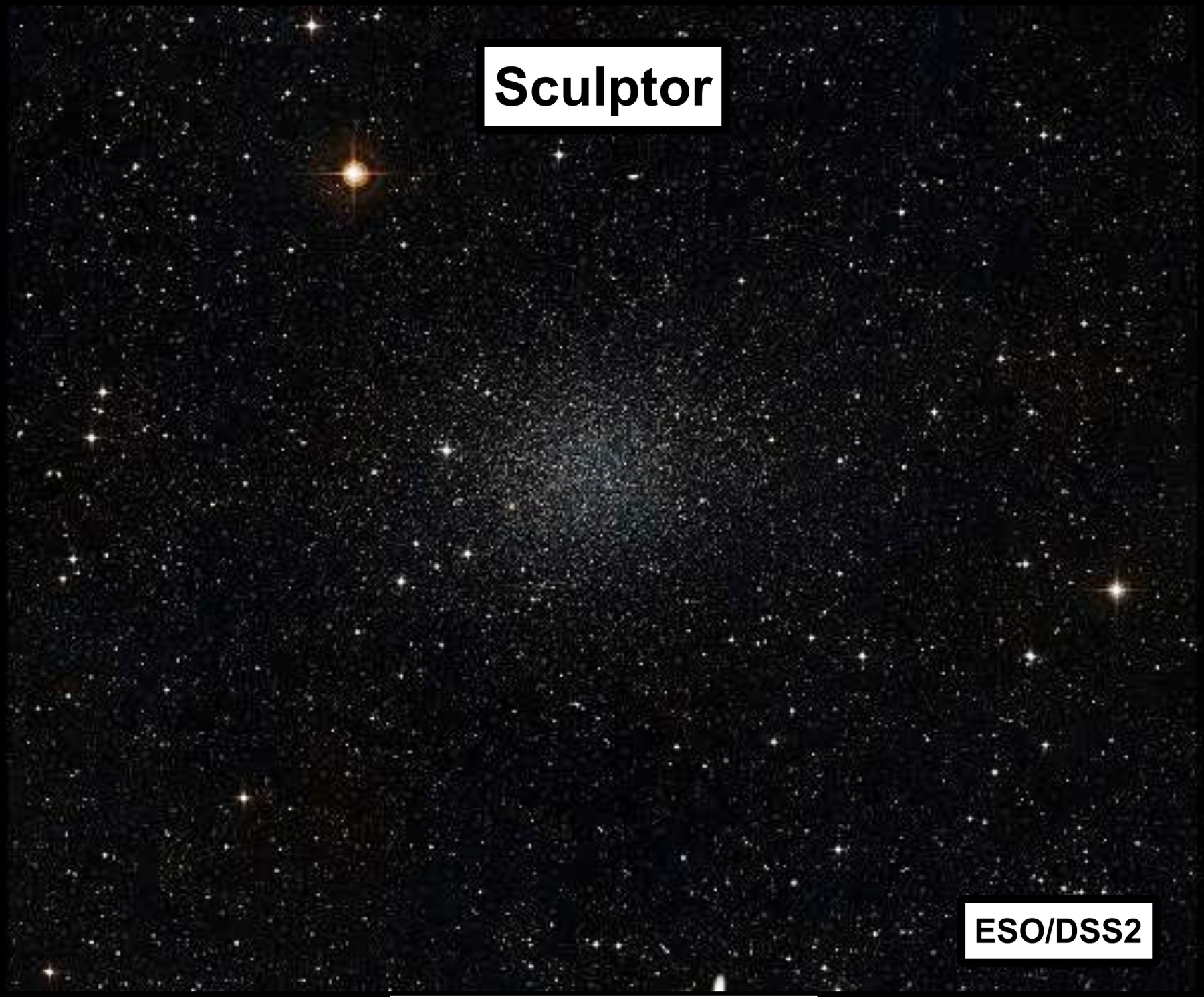
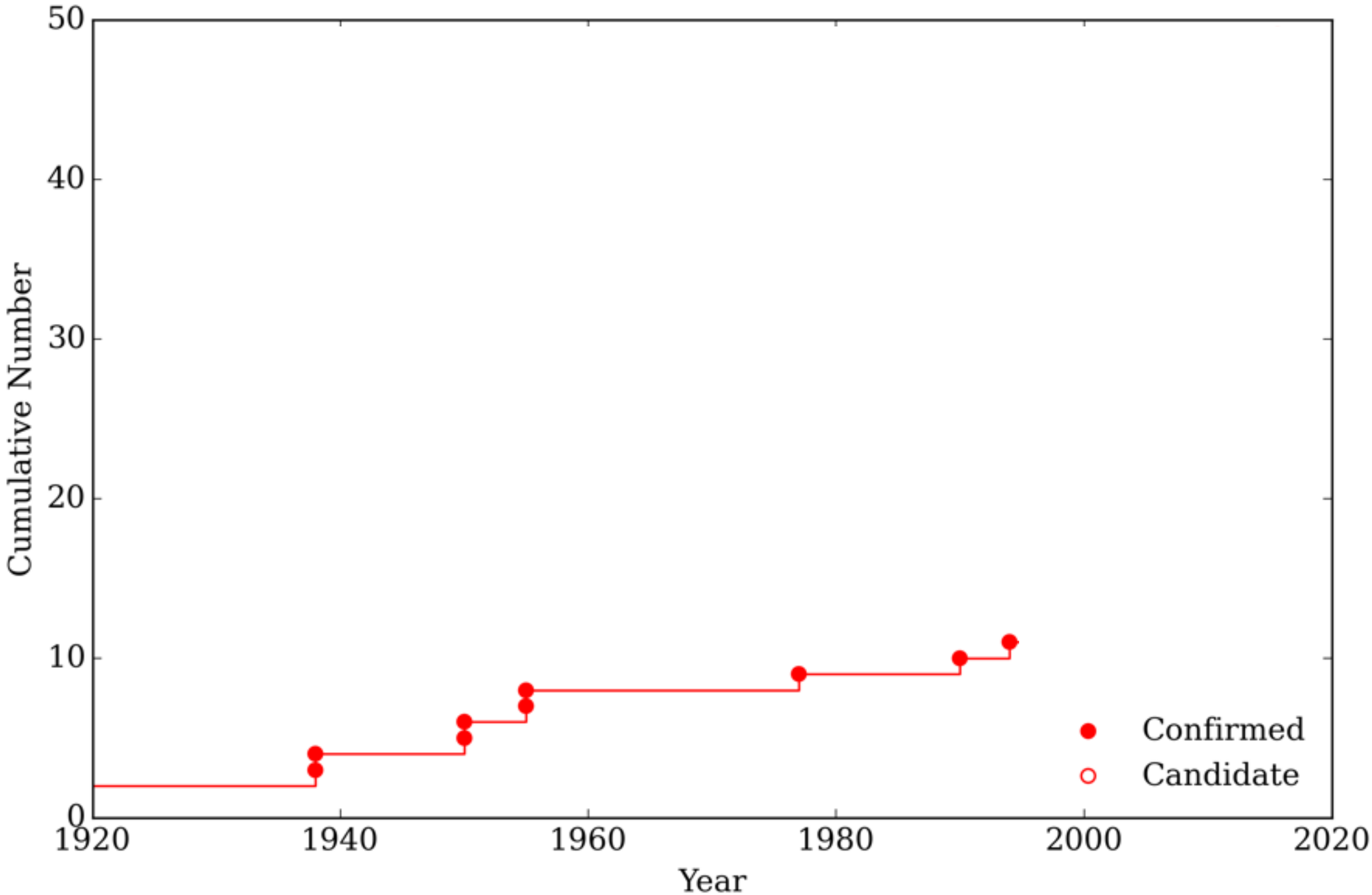


FIG. 5.—Color-magnitude diagram for M3 stars in the arguments V and $B - V$



1.2m Telescope
Photographic Plates

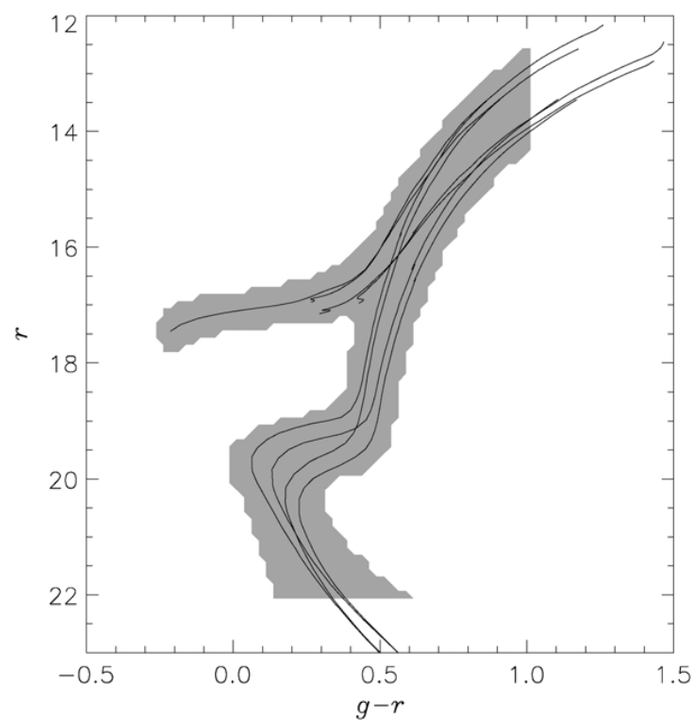
Discovery Timeline

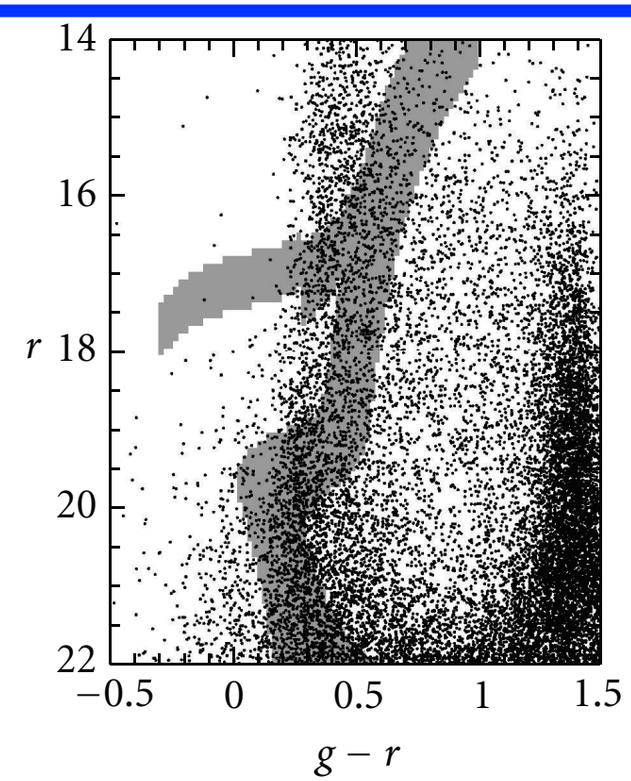


Matched-Filter Searches

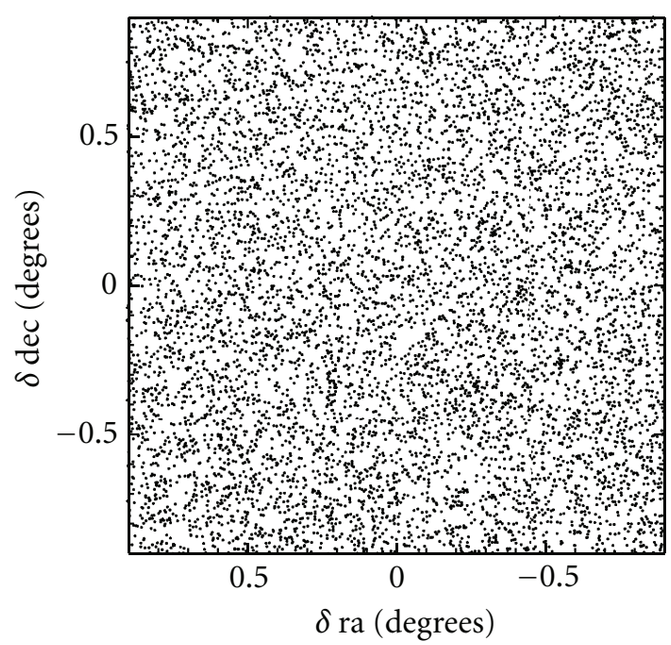
Koposov et al. (2008)
Walsh et al. (2009)
Willman et al. (2010)

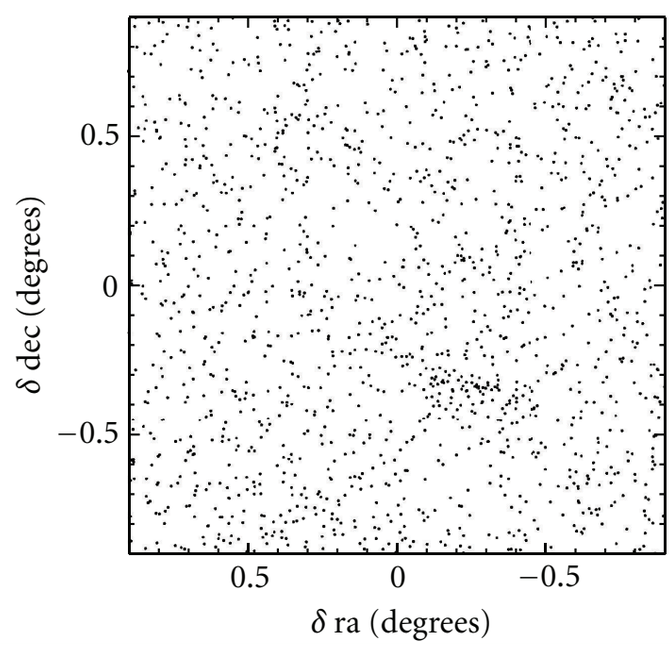
Color-Magnitude Domain

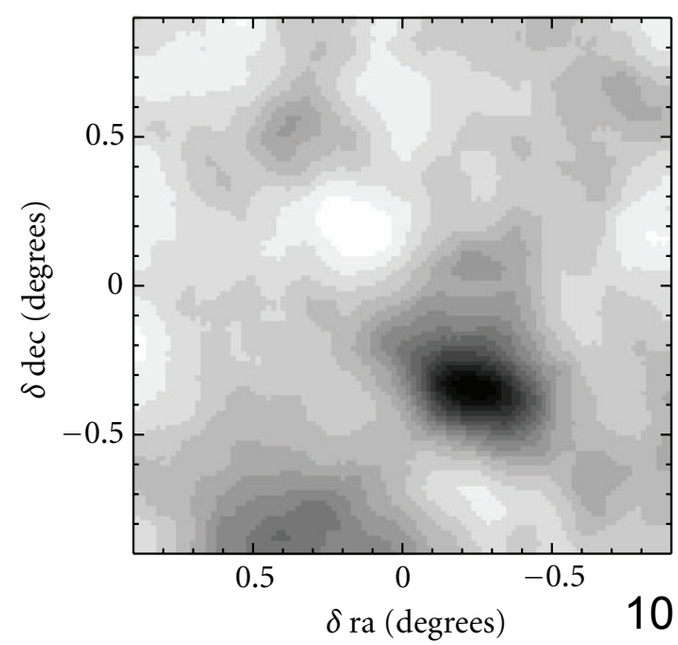


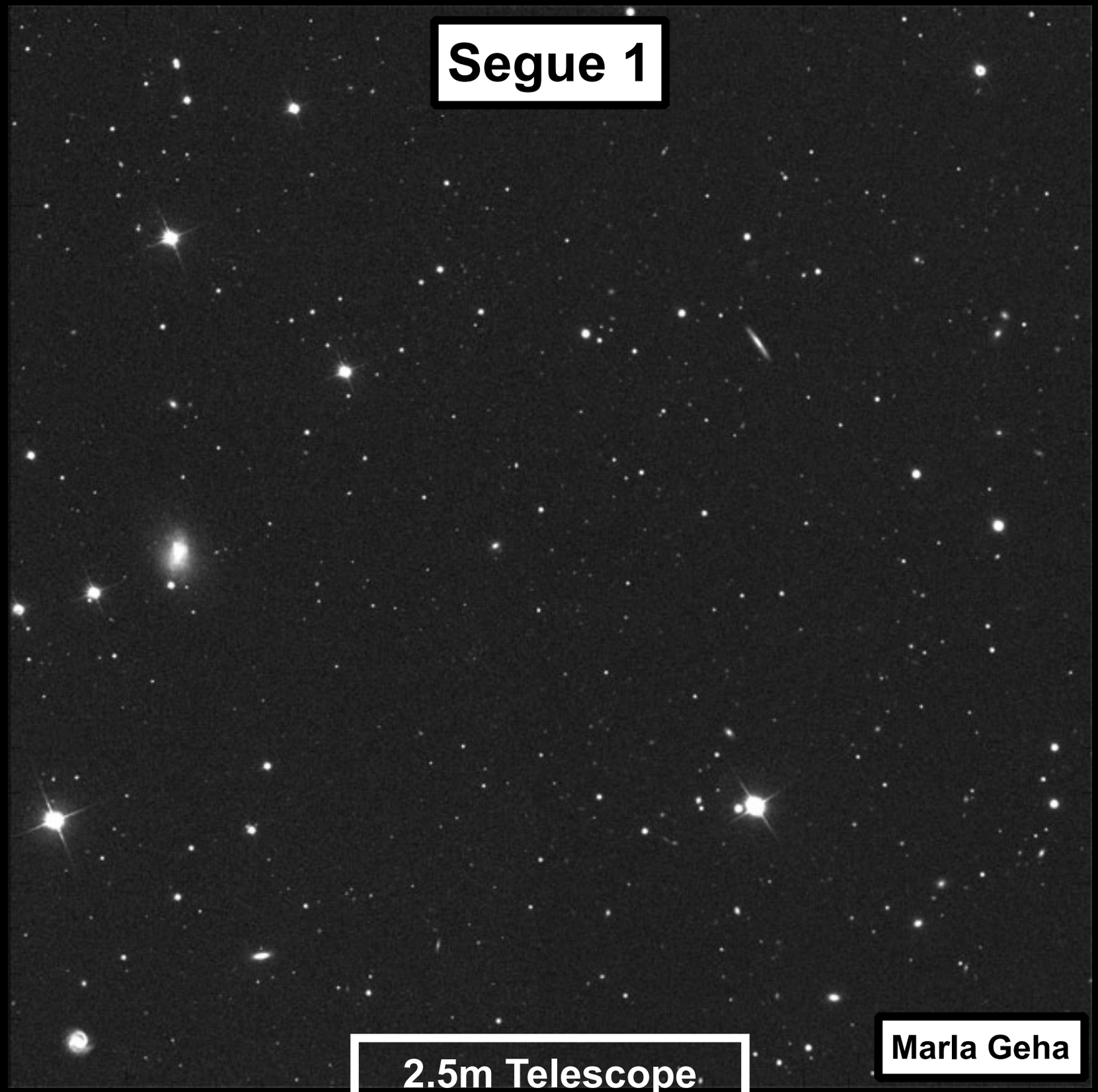


Spatial Domain

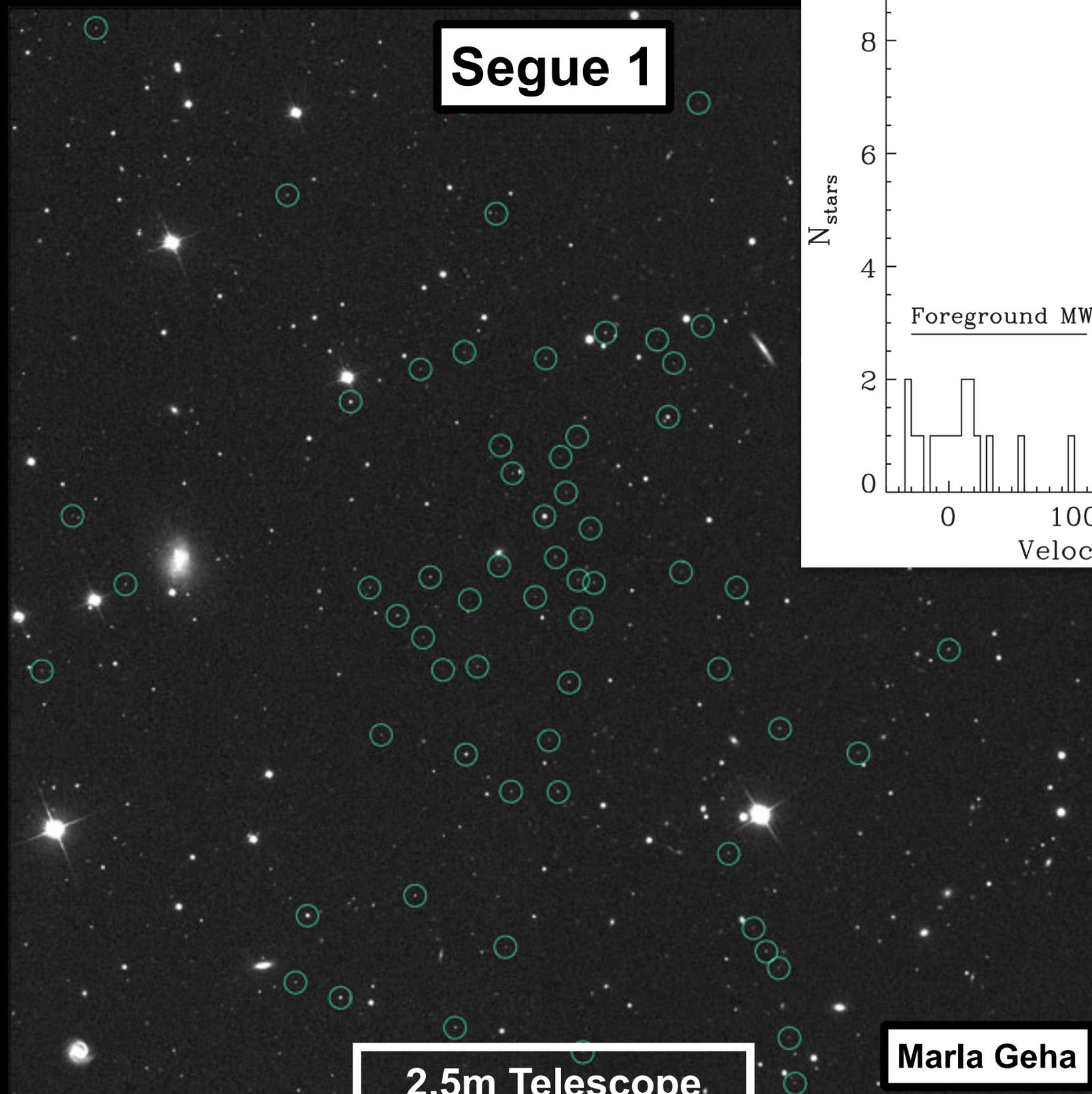


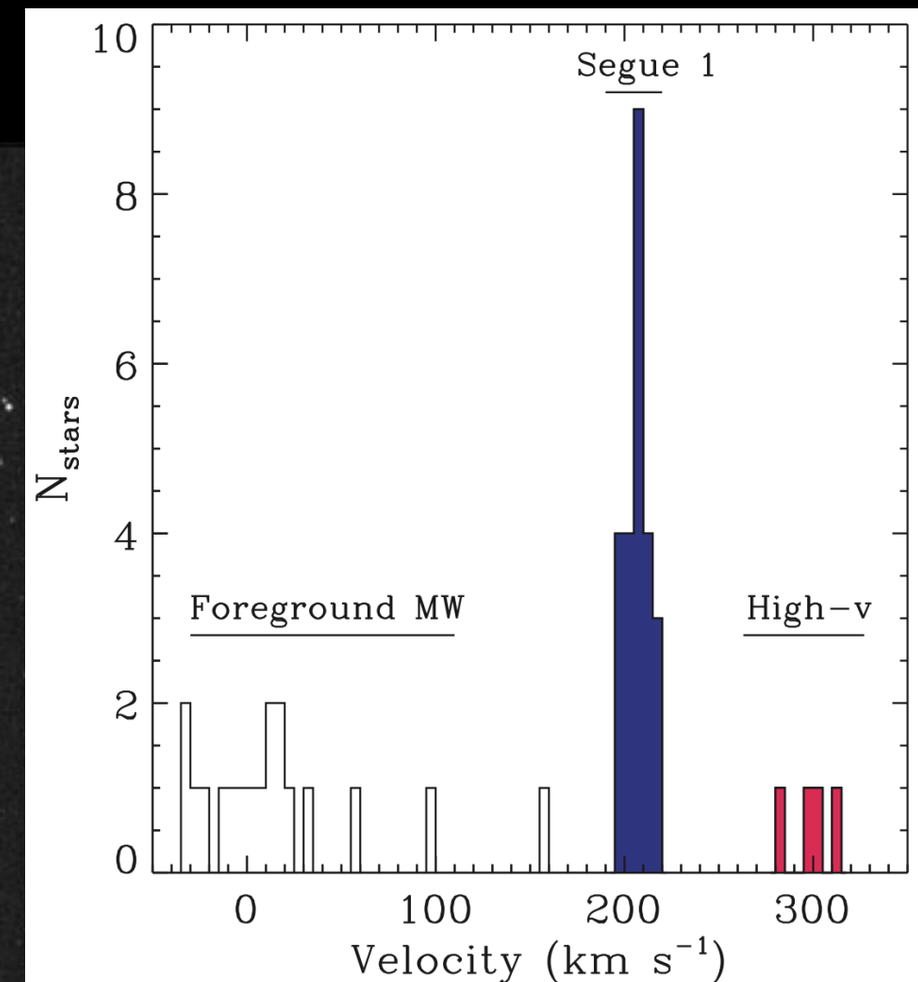






2.5m Telescope
SDSS CCD Camera





2.5m Telescope
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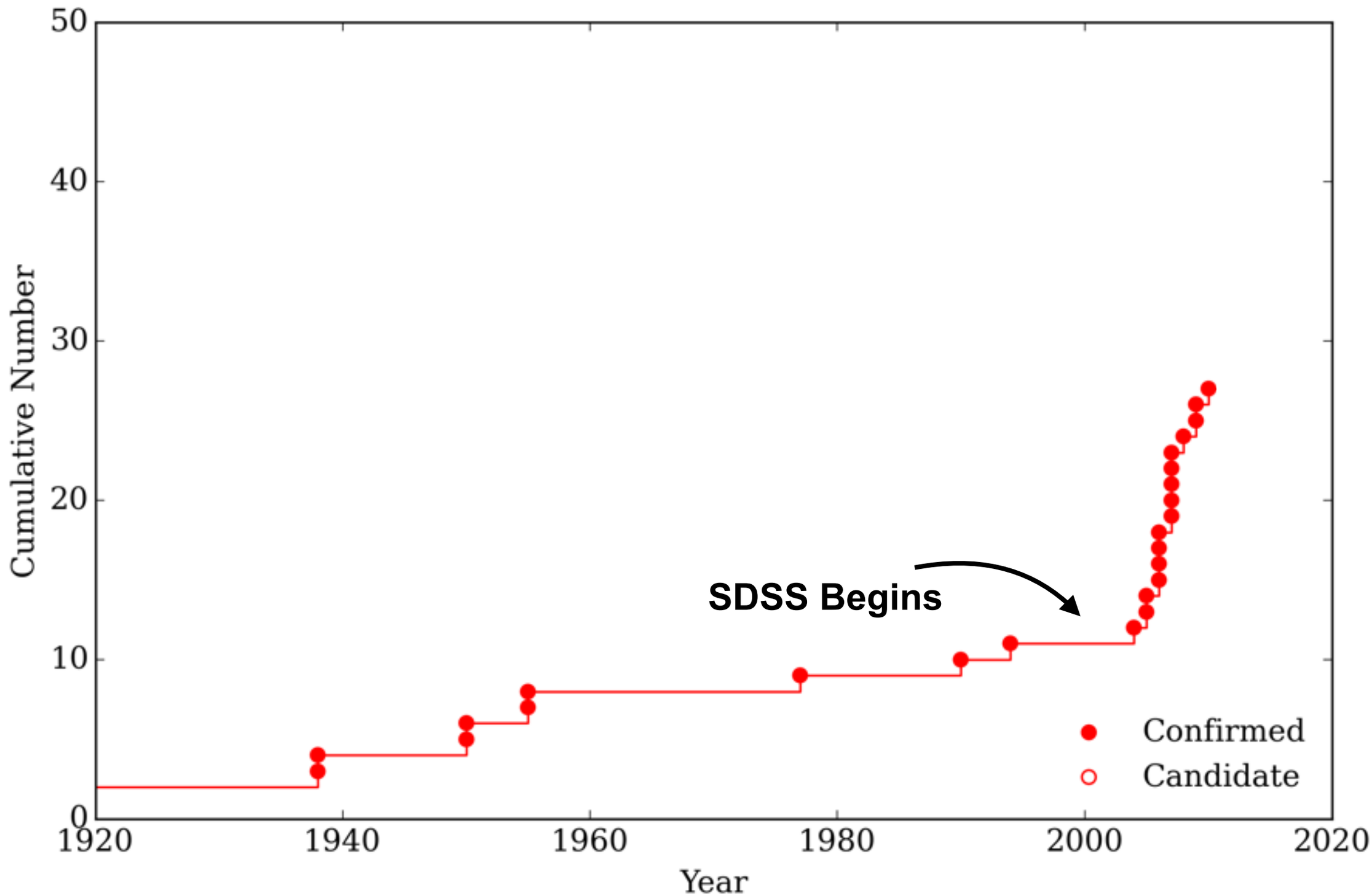
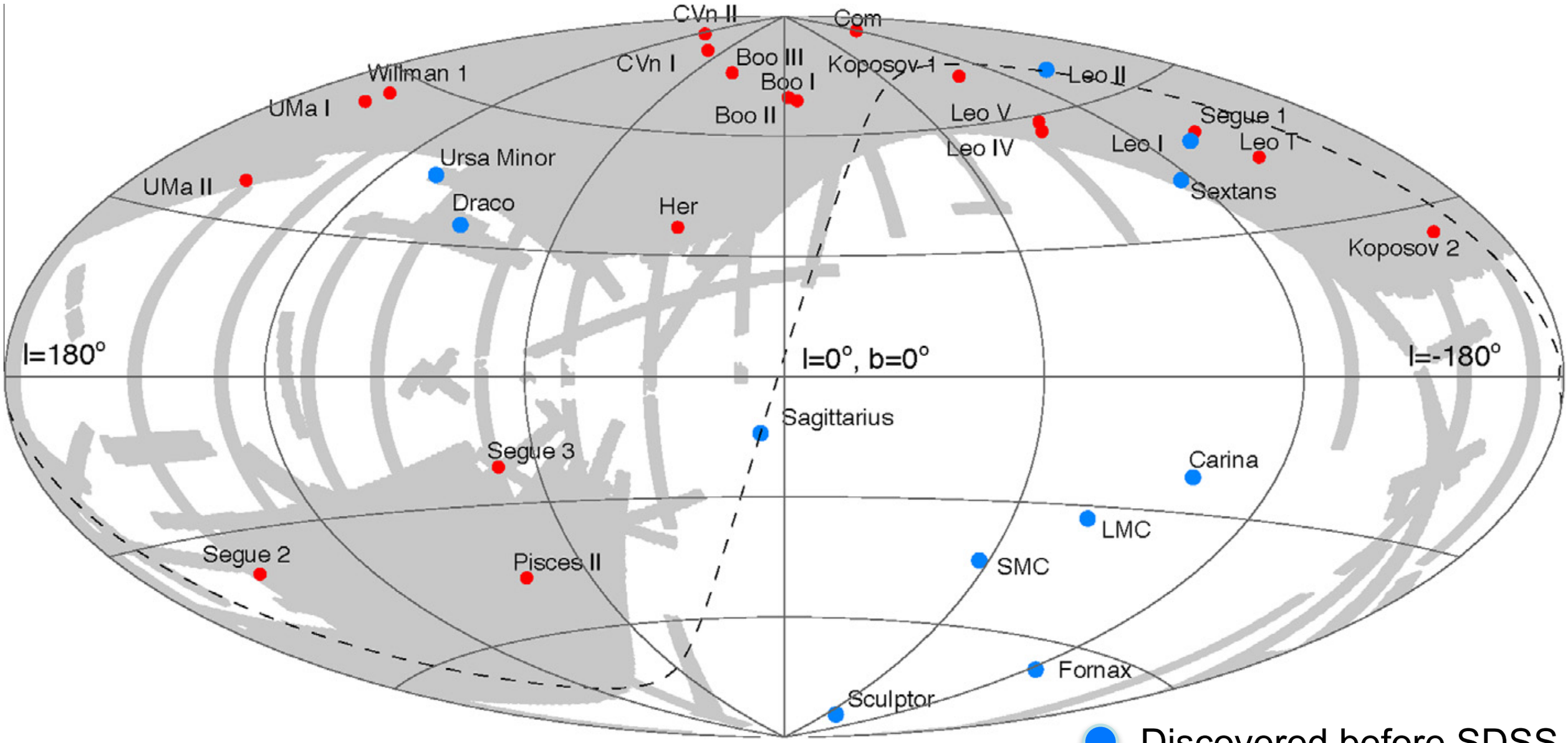
Discovery Timeline



SDSS DR10



Sky Covered by SDSS

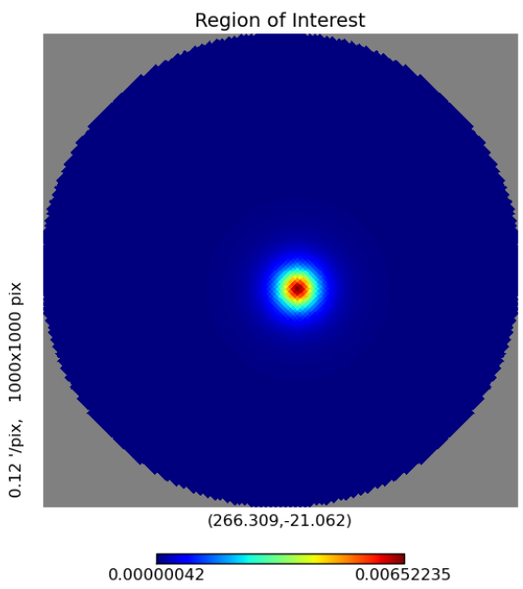
Discovered before SDSS (classical dwarfs)

Discovered with SDSS (ultra-faint dwarfs)

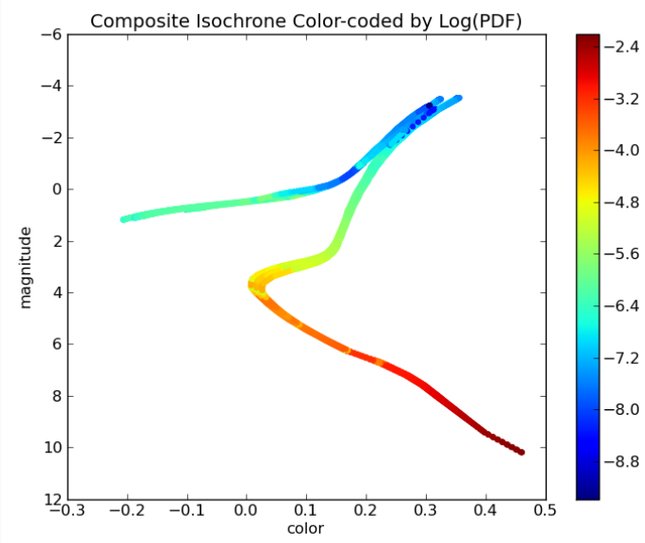
(Belokurov 2013)

Maximum-Likelihood Searches

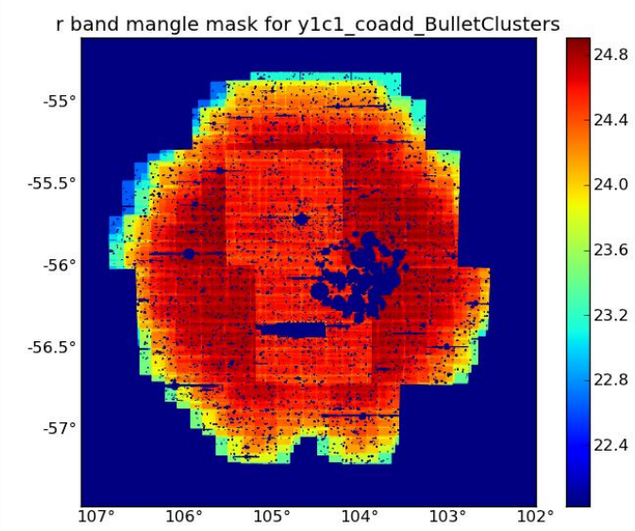
Spatial Model



"Spectral" Model



Survey Sensitivity



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

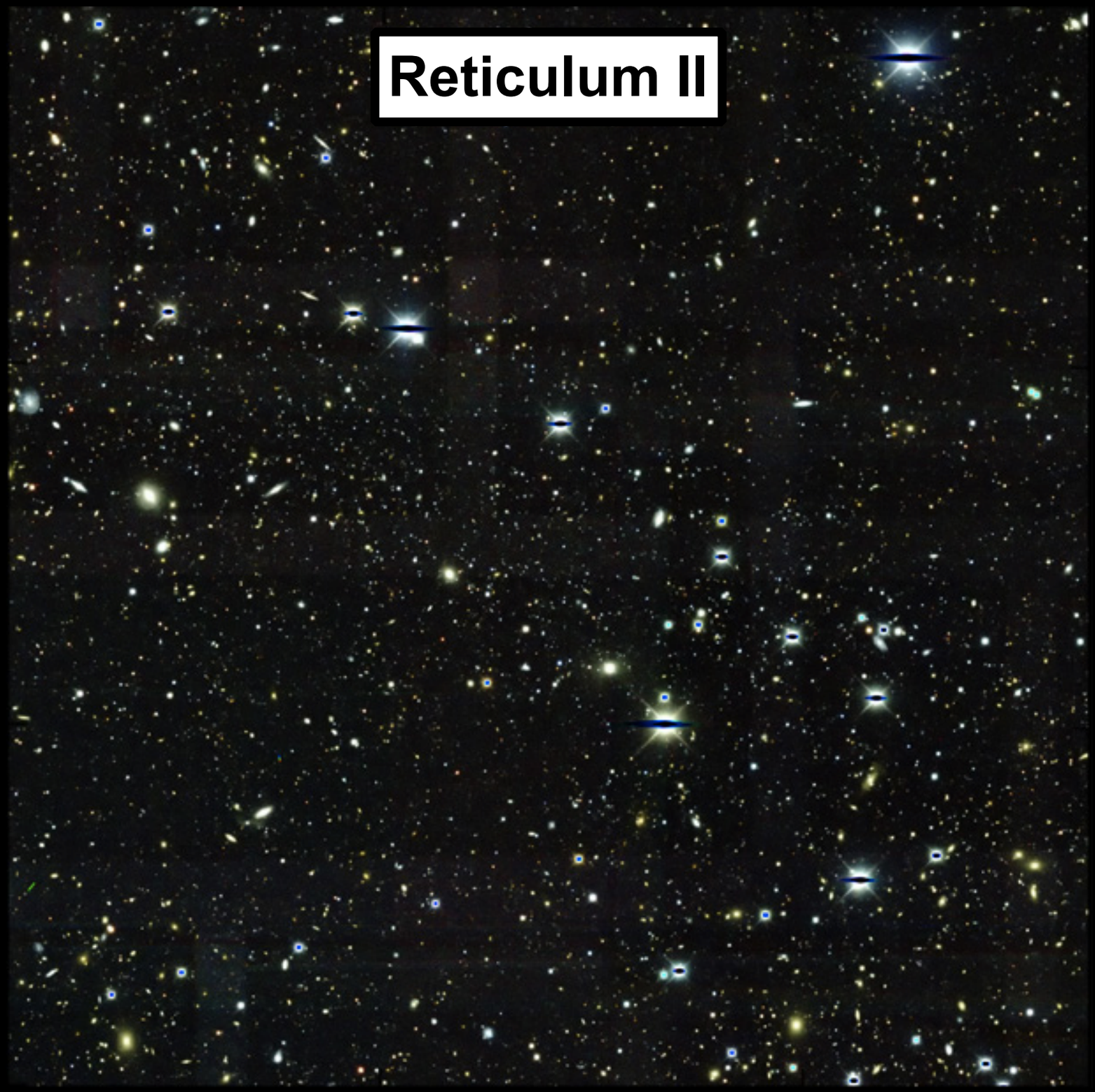
$$\lambda = \frac{1}{f} \sum_{i \in \text{Stars}} p_i$$

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

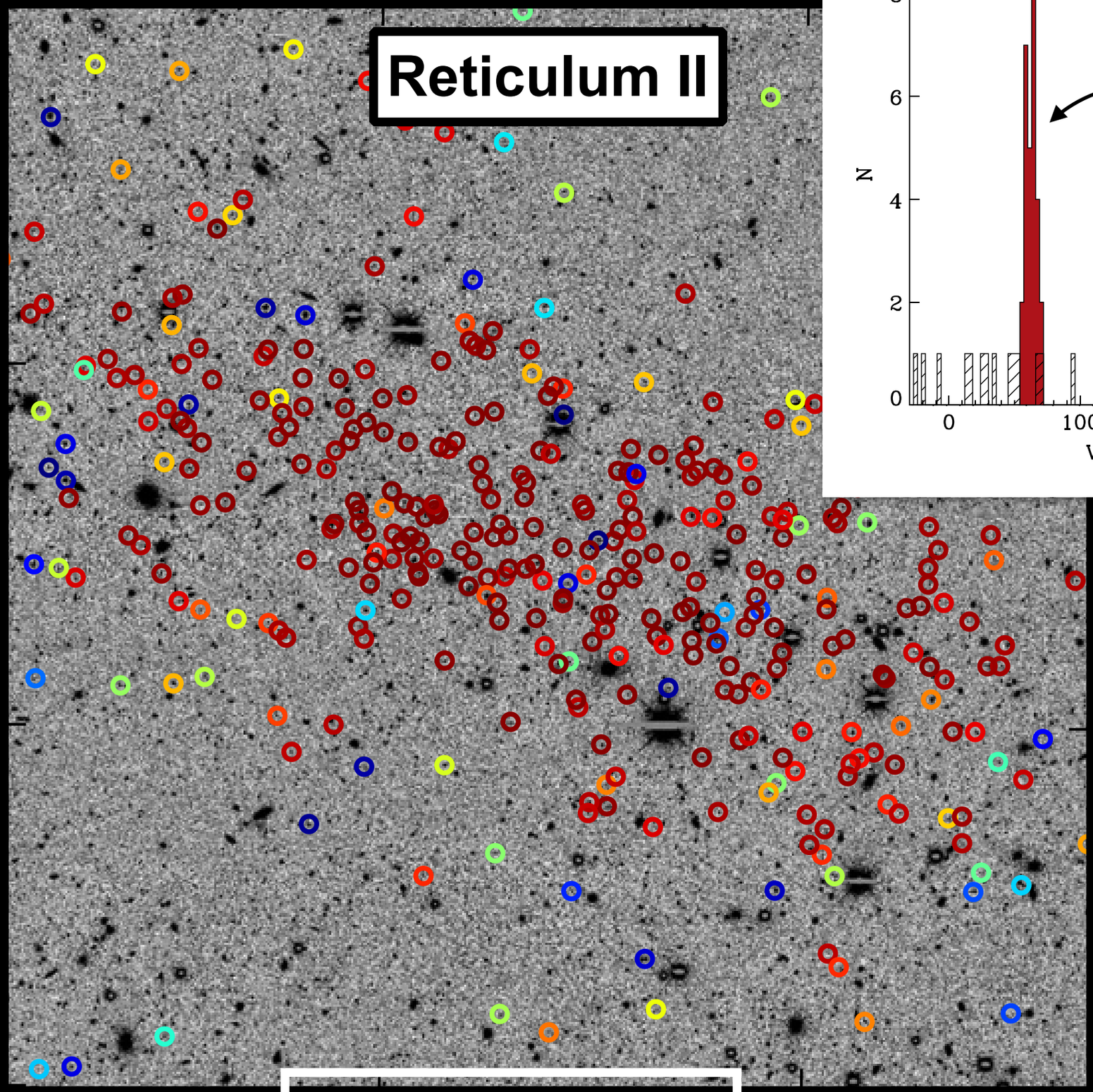
A likelihood analysis to simultaneously combines spatial and spectral information

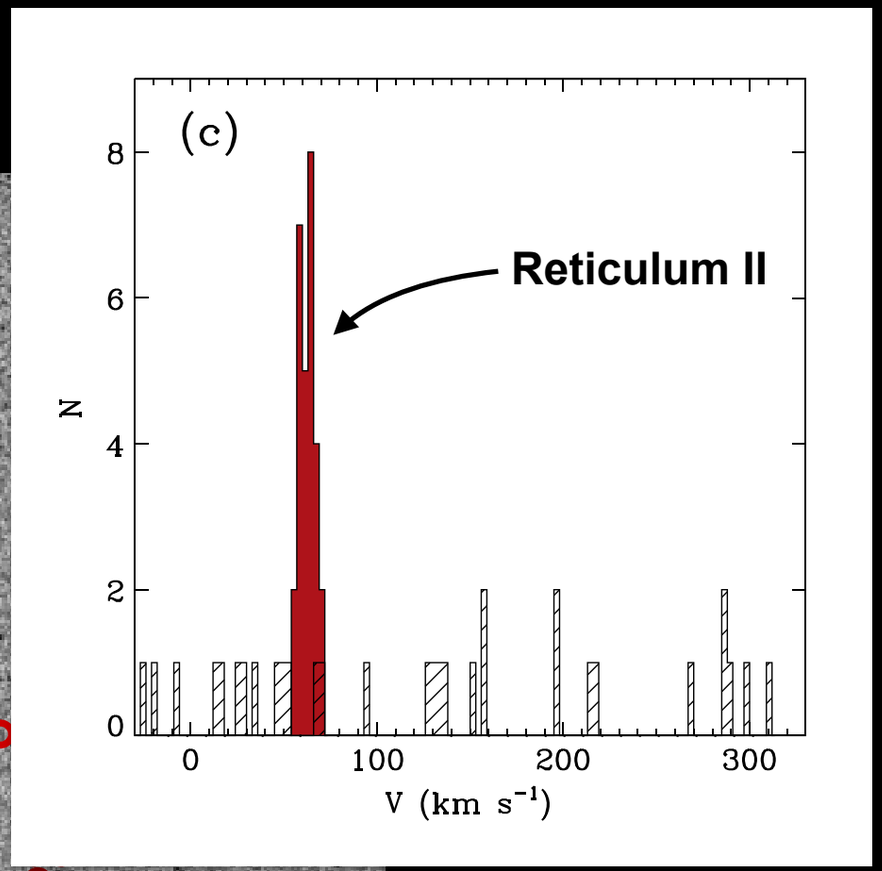
u_i = sig prob
b_i = bkg prob
λ = normalization = number of stars
f = observable fraction

This approach naturally yields a membership probability for each star; important for spectroscopy



DES Collaboration

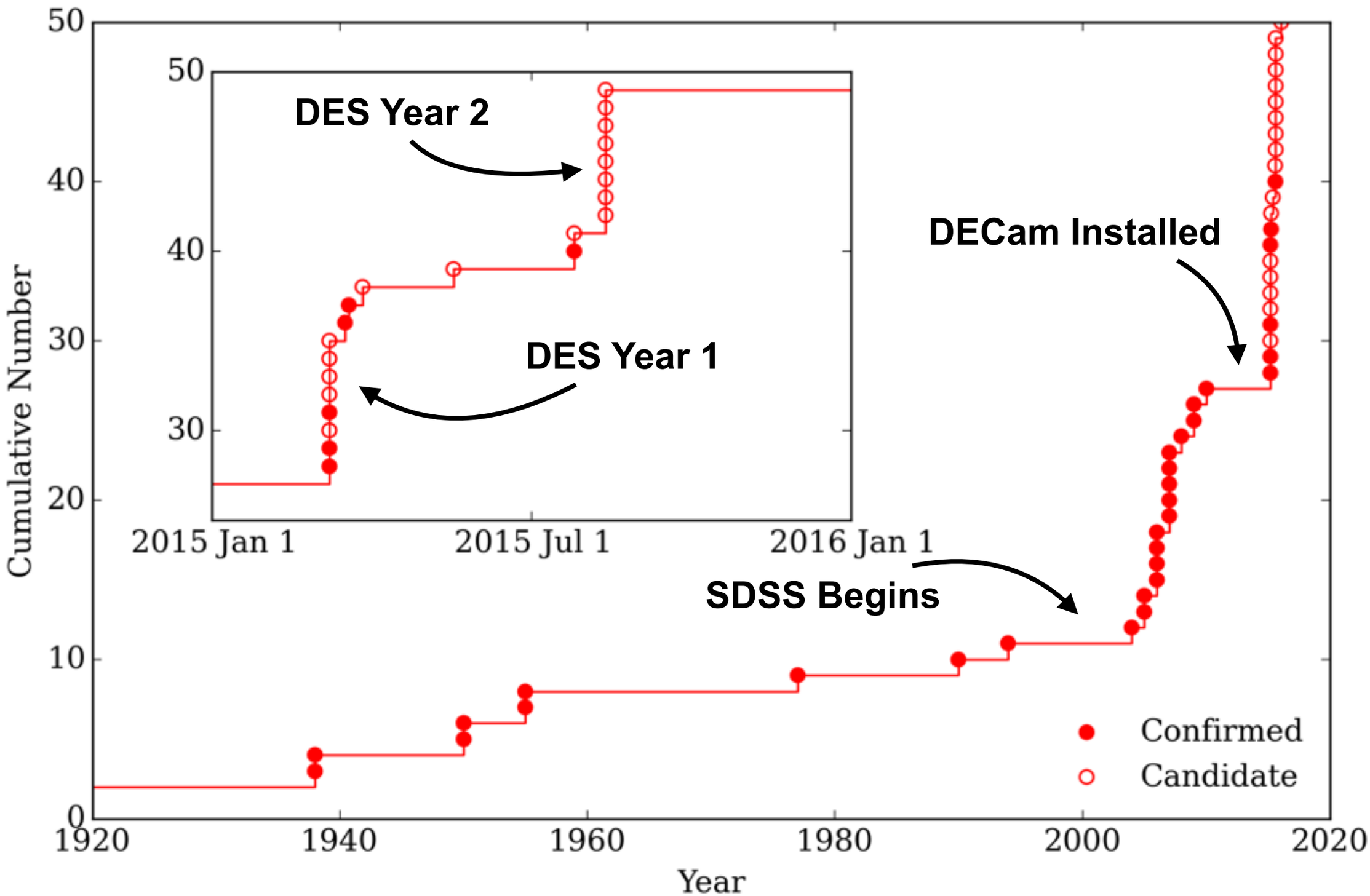




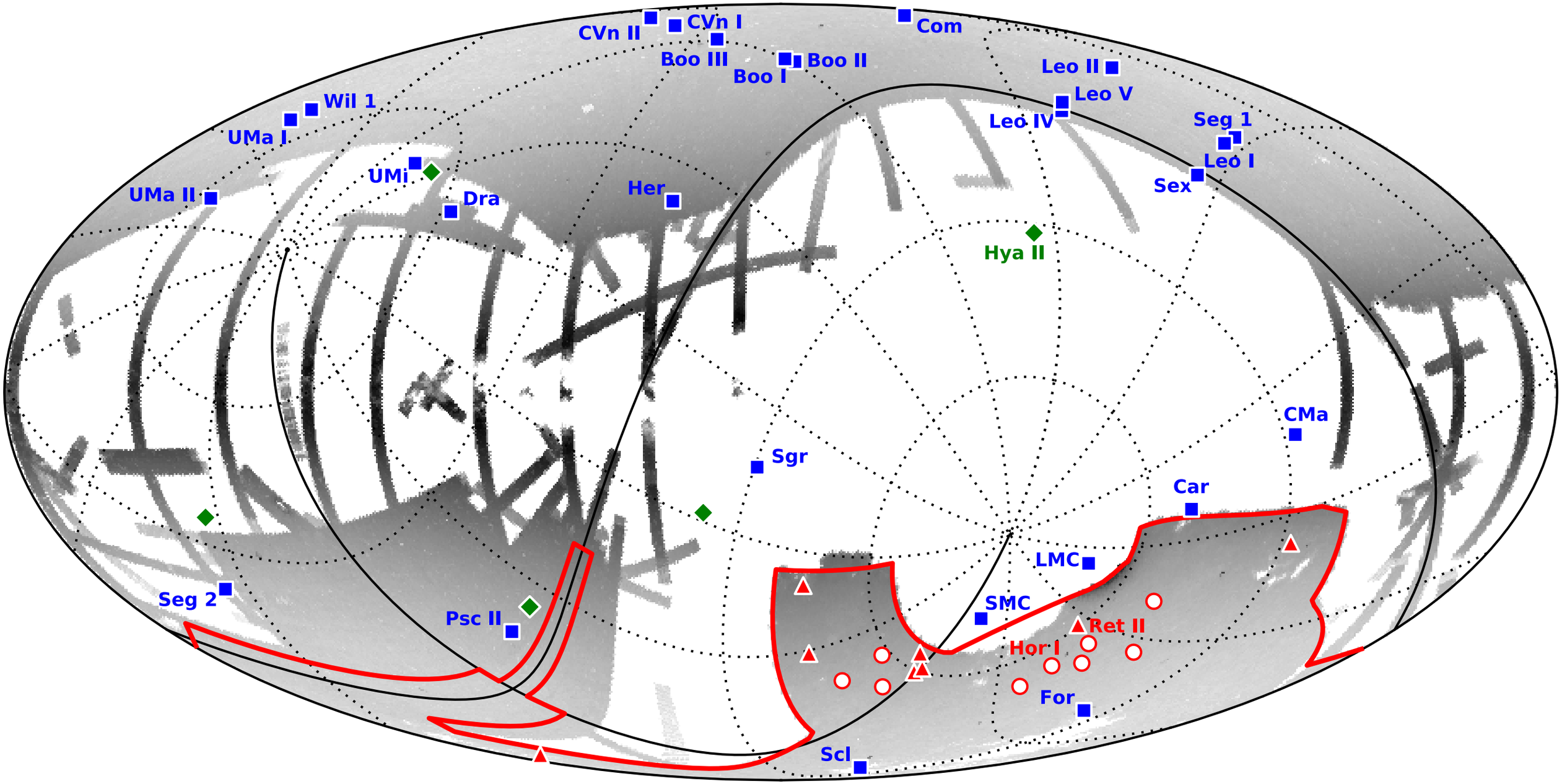
4m Telescope
DECam CCD Camera

DES Collaboration

Discovery Timeline



SDSS DR10 + DES Y2

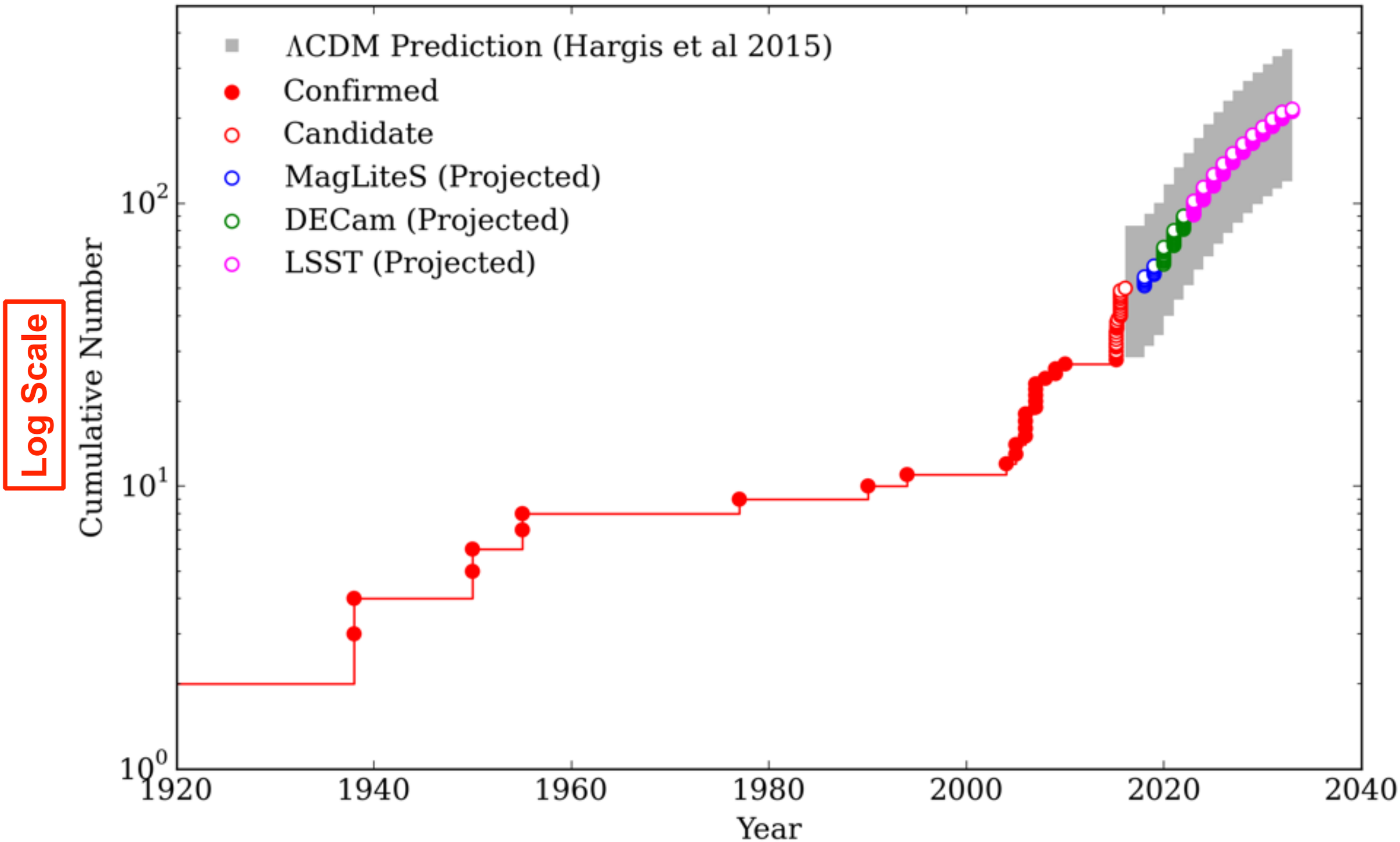


Blue - Previously discovered satellites
Green - Discovered in 2015 with PanSTARRS/SDSS

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

DES Collaboration, ApJ 813, 109 (2015)

Projected Timeline



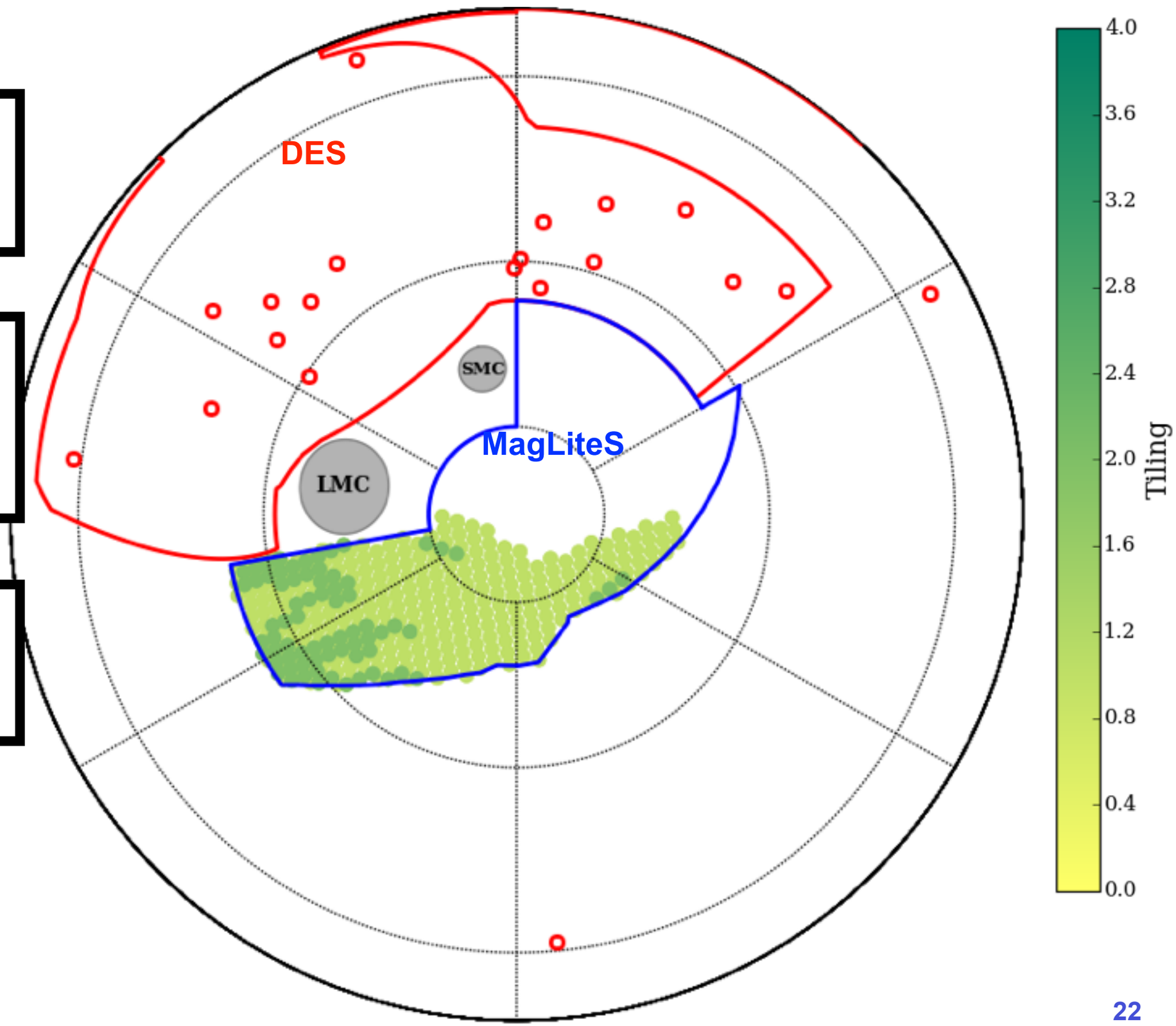
Backup Slides

Magellanic Satellites Survey

Two-year survey with DECam outside of the DES area

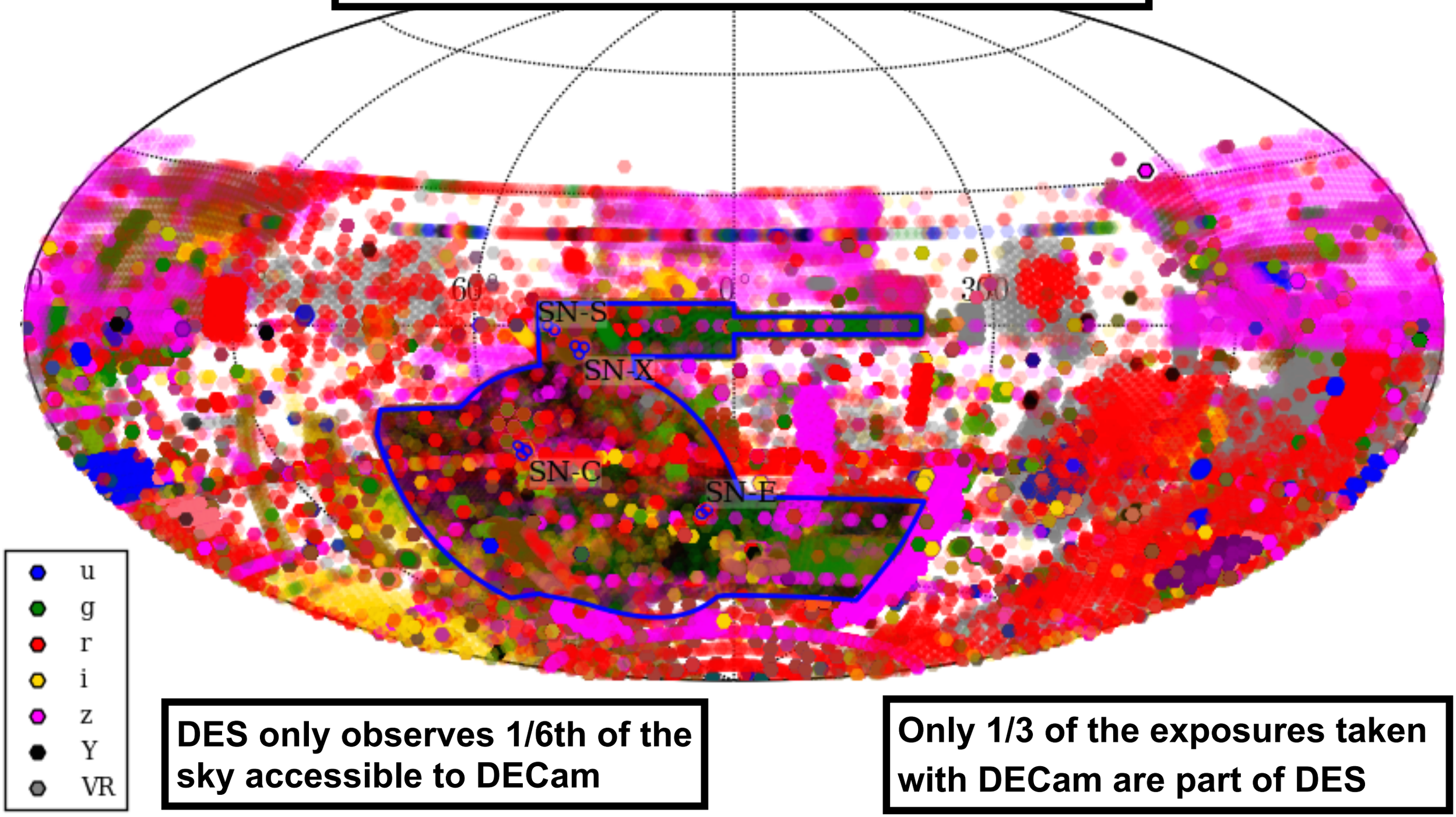
Image ~1300 deg^2 at roughly the same depth as the first two years of DES

Test for a spatial association with the Magellanic Clouds



DECam Sky Coverage

All-Sky Map of DECam Coverage (Feb 26, 2016)



DES only observes 1/6th of the sky accessible to DECam

Only 1/3 of the exposures taken with DECam are part of DES