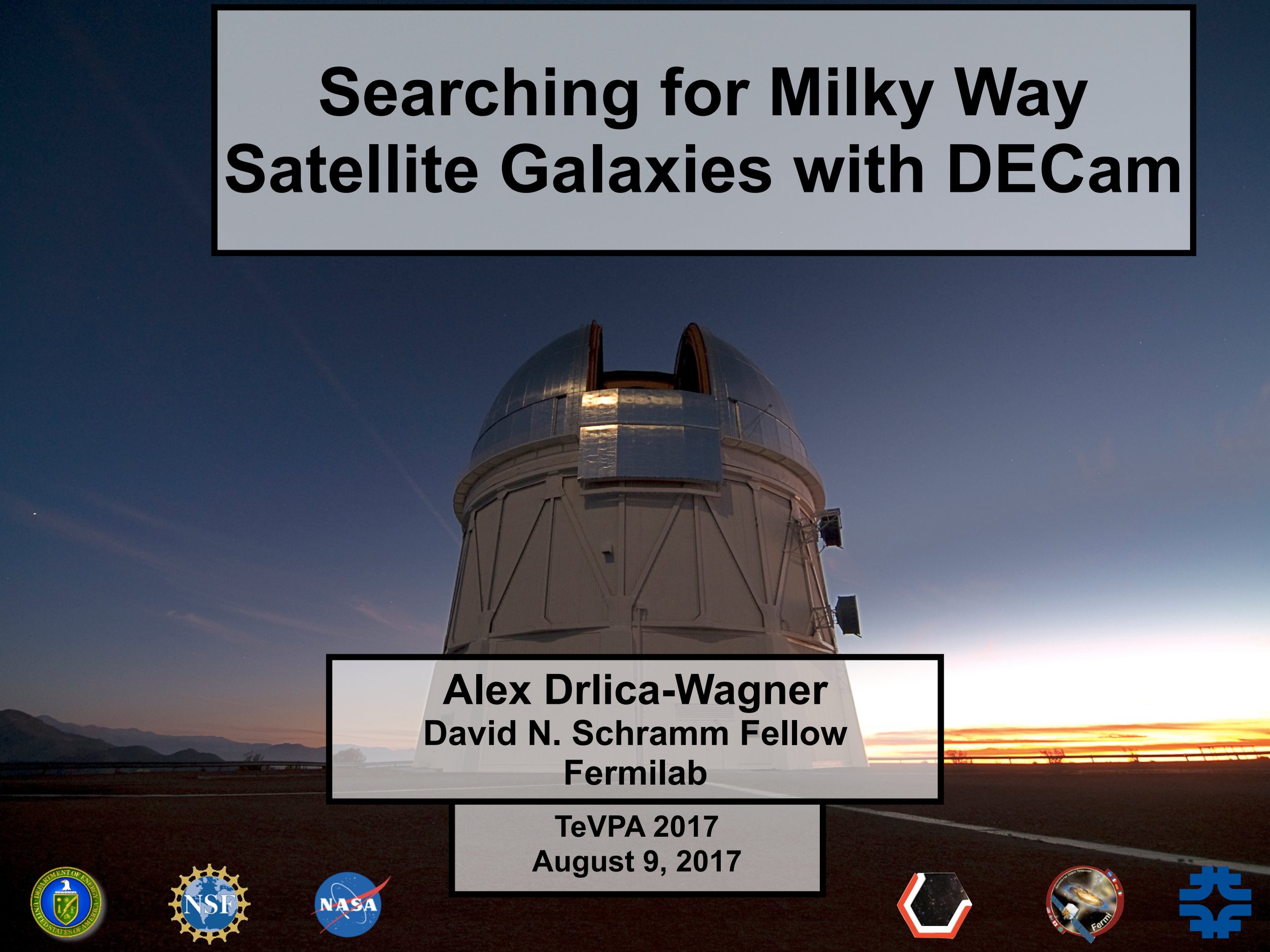
Searching for Milky Way Satellite Galaxies with DECam



Alex Drlica-Wagner
David N. Schramm Fellow
Fermilab

TeVPA 2017
August 9, 2017

What are Dwarf Galaxies?

Fermilab

UGC 10214 - "The Tadpole"

Disturbed spiral galaxy with a very long tail
Distance : 420,000,000 LY
Total length : 390,000 LY

NGC 1316 - "Fornax A"

Dusty elliptical galaxy
Distance : 62,000,000 LY
Diameter : 220,000 LY

NGC 908

arbursting galaxy with
sturbed spiral arms
stance : 65,000,000 LY
ameter : 75,000 LY

Hercules A

Giant elliptical galaxy with powerful radio jets
(shown in pink) powered by a supermassive
black hole at the galaxy's center
Distance : 2,100,000,000 LY
Diameter : 1,500,000 LY (jets)

M87

A giant elliptical at the center of the Virgo Cluster.
At its center, material falling onto a supermassive
black hole is emitting powerful jets
Distance : 53,000,000 LY
Diameter : 980,000 LY

NGC 4921

A spiral galaxy in the Coma Cluster, it has lost much
of its gas and can no longer form many new, blue stars,
giving it an unusually pale appearance
Distance : 320,000,000 LY
Diameter = 230,000 LY

Arp 81

Two merging galaxies
Distance : 280,000,000 LY
Diameter : 200,000 LY

M100

Spiral galaxy in the Virgo Cluster
Distance : 55,000,000 LY
Diameter : 160,000 LY

The Milky Way

Hoag's Object

Elliptical galaxy surrounded by a ring of blue stars
Distance : 600,000,000 LY
Diameter : 120,000 LY (of outer ring)

NGC 6670

Two interacting galaxies seen edge-on
Distance : 400,000,000 LY
Diameter : 120,000 LY

The Milky Way

It's us !
Diameter about 100,000 LY
Artist's impression (Nick Risinger)

M31 - "Andromeda"

Nearby spiral in our Local Group
About as massive as the Milky Way
It's headed straight for us ! Collision in about 4 billion years
Distance : 2,500,000 LY
The main stellar disc is about the same size as the Milky Way
but an extended, fainter disc spans about 220,000 LY

NGC 1365

Barred spiral galaxy in the Fornax Cluster
Distance : 61,000,000 LY
Diameter : 200,000 LY

M33 - "Triangulum"

Smaller spiral in our Local Group
Distance : 2,700,000 LY
Diameter : 50,000 LY

M104 - "Sombrero"

Spiral galaxy with a prominent
bulge and dust ring
Distance : 28,000,000 LY
Diameter : 50,000 LY

Malin 1

Arguably the largest spiral
Normal stellar disc embedded in a huge, very faint halo
Distance : 1,400,000,000 LY
Diamteter : 30,000 LY (inner disc)
Diameter : 650,000 LY (outer disc)
(image is an original artist's impression, not a real observation
of Malin 1)

ESO 350-40 - "Cartwheel"

Everyone's favourite ring galaxy
(well, probably)
Distance : 500,000,000 LY
Diameter : 150,000 LY

NGC 7049

Elliptical galaxy with an unusual dust ring
Distance : 90,000,000 LY
Diameter : 150,000 LY

Centaurus A

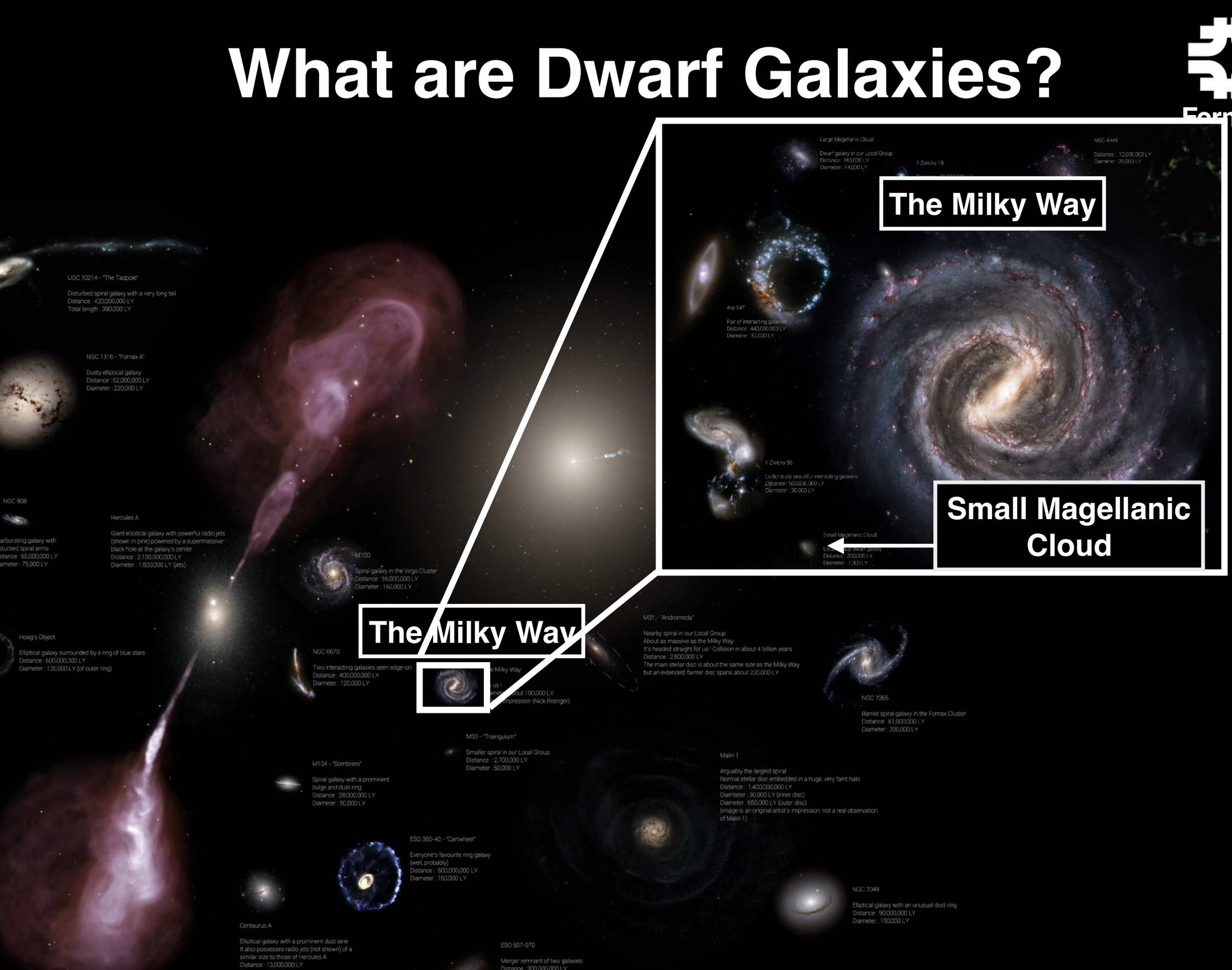
Elliptical galaxy with a prominent dust lane
It also possesses radio jets (not shown) of a
similar size to those of Hercules A
Distance : 13,000,000 LY

ESO 507-070

Merger remnant of two galaxies
Distance : 300,000,000 LY

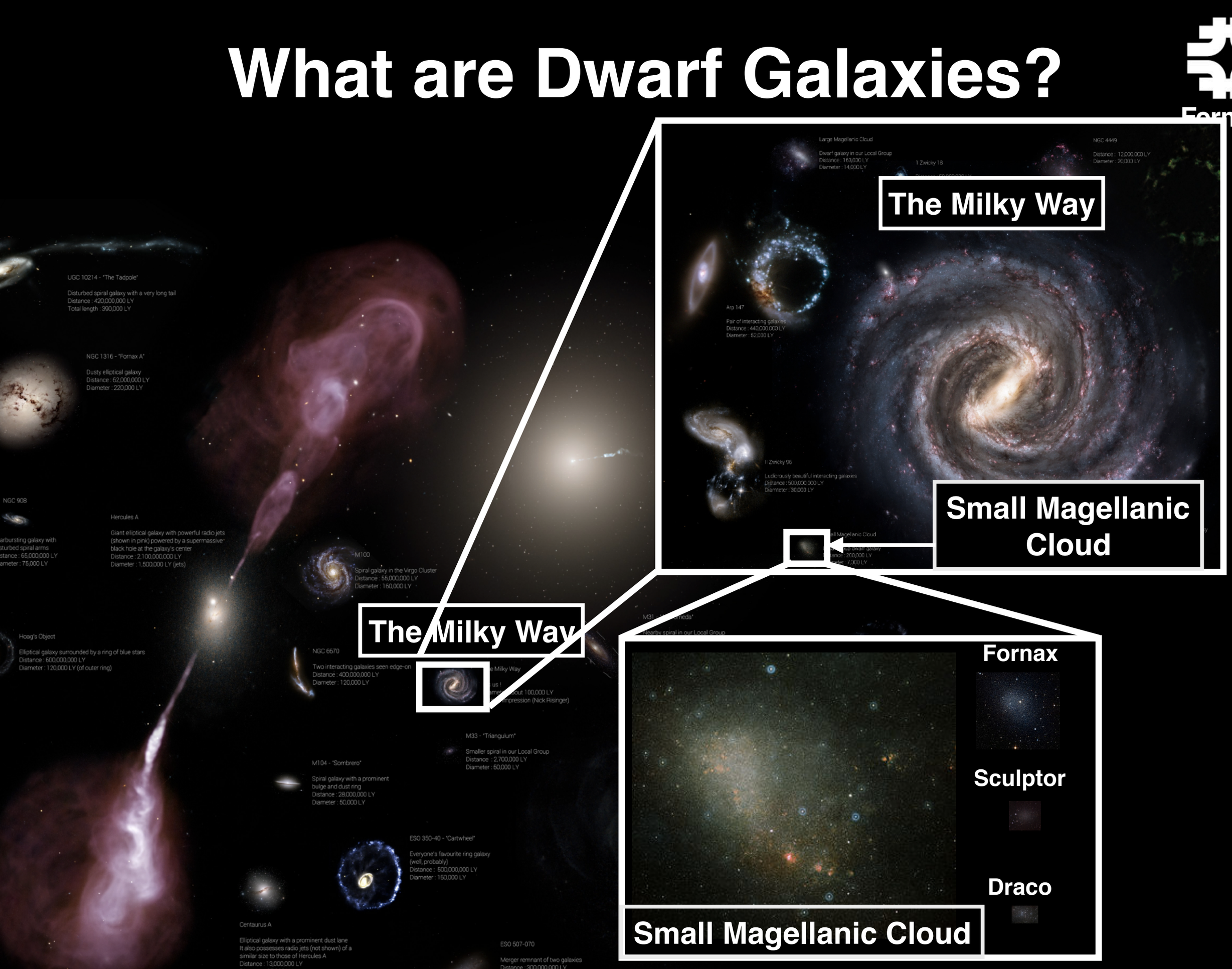
What are Dwarf Galaxies?

Fermilab

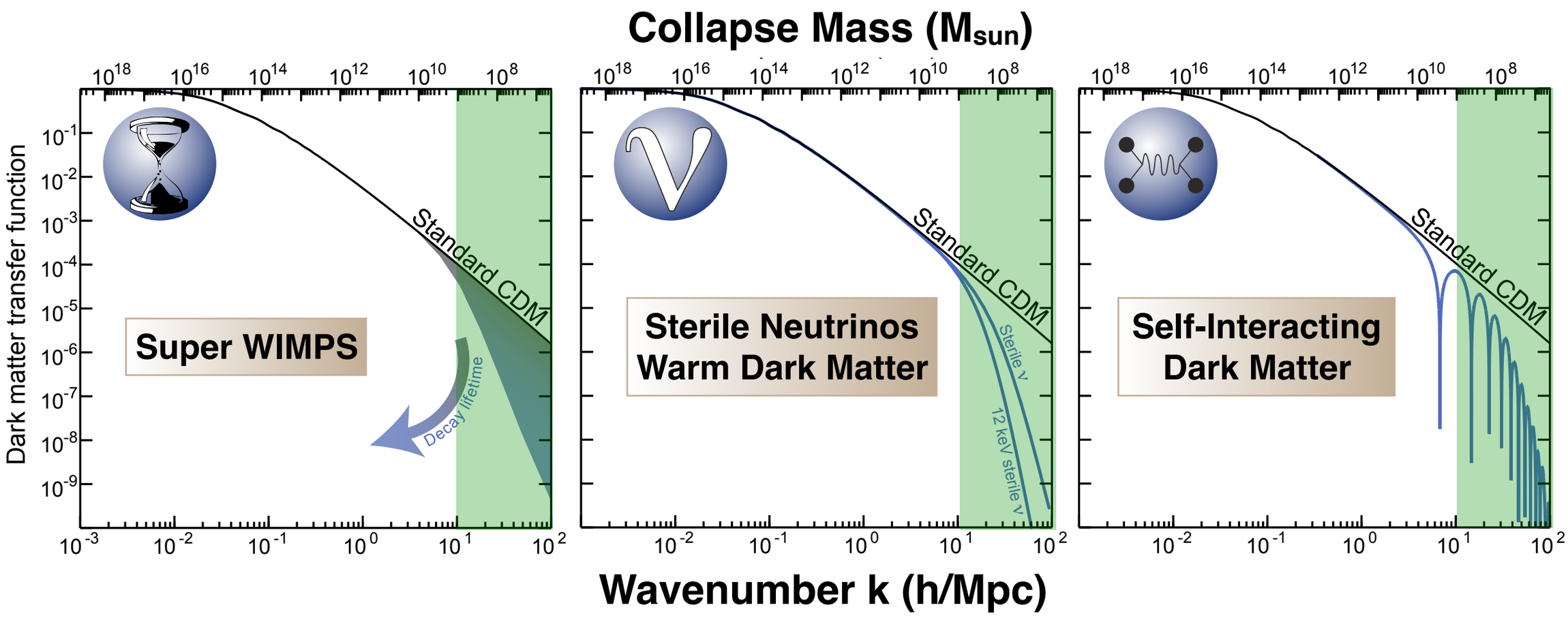


What are Dwarf Galaxies?

Fermilab

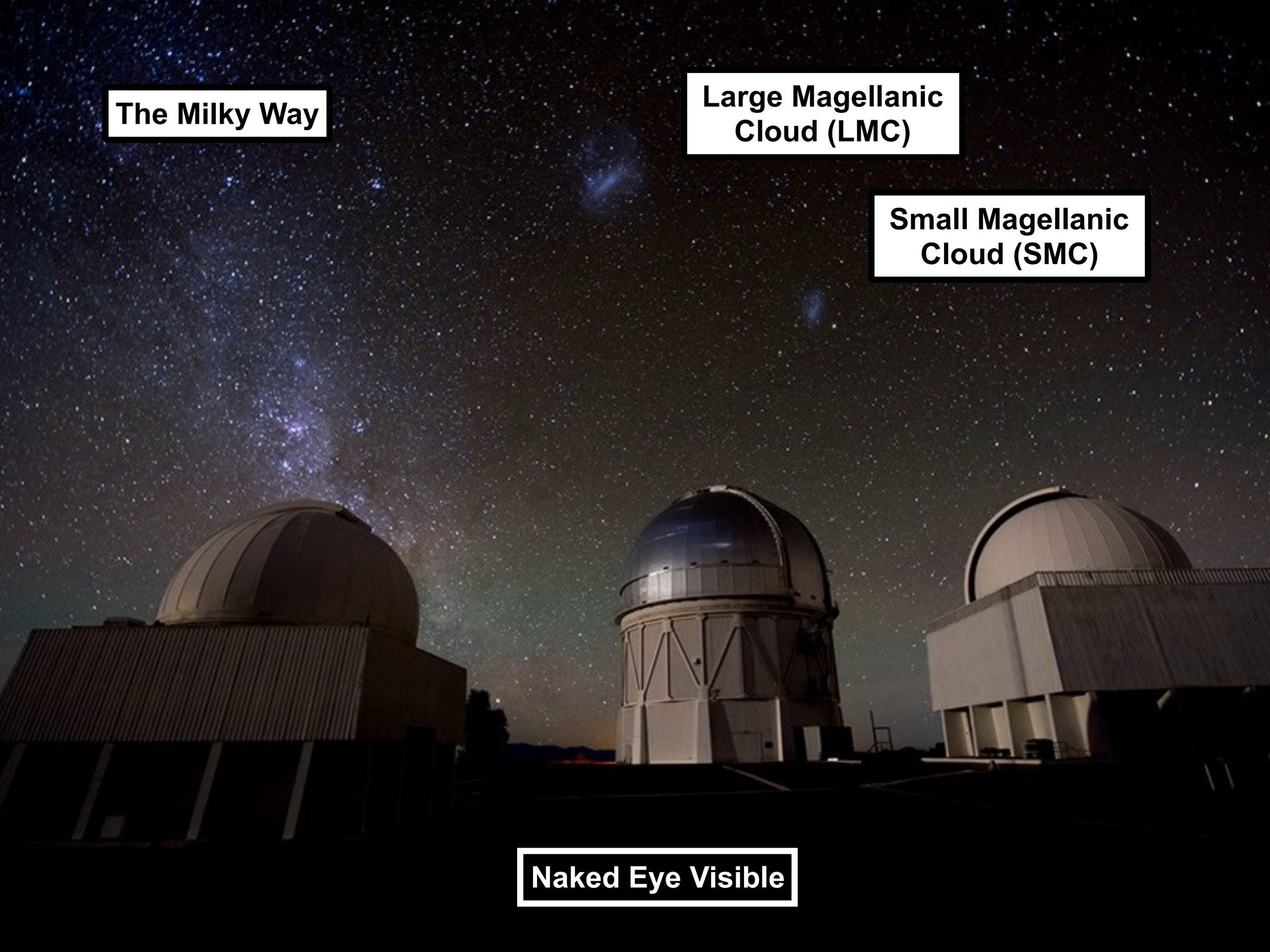


Smallest Structures Probe Fundamental Characteristics of Dark Matter

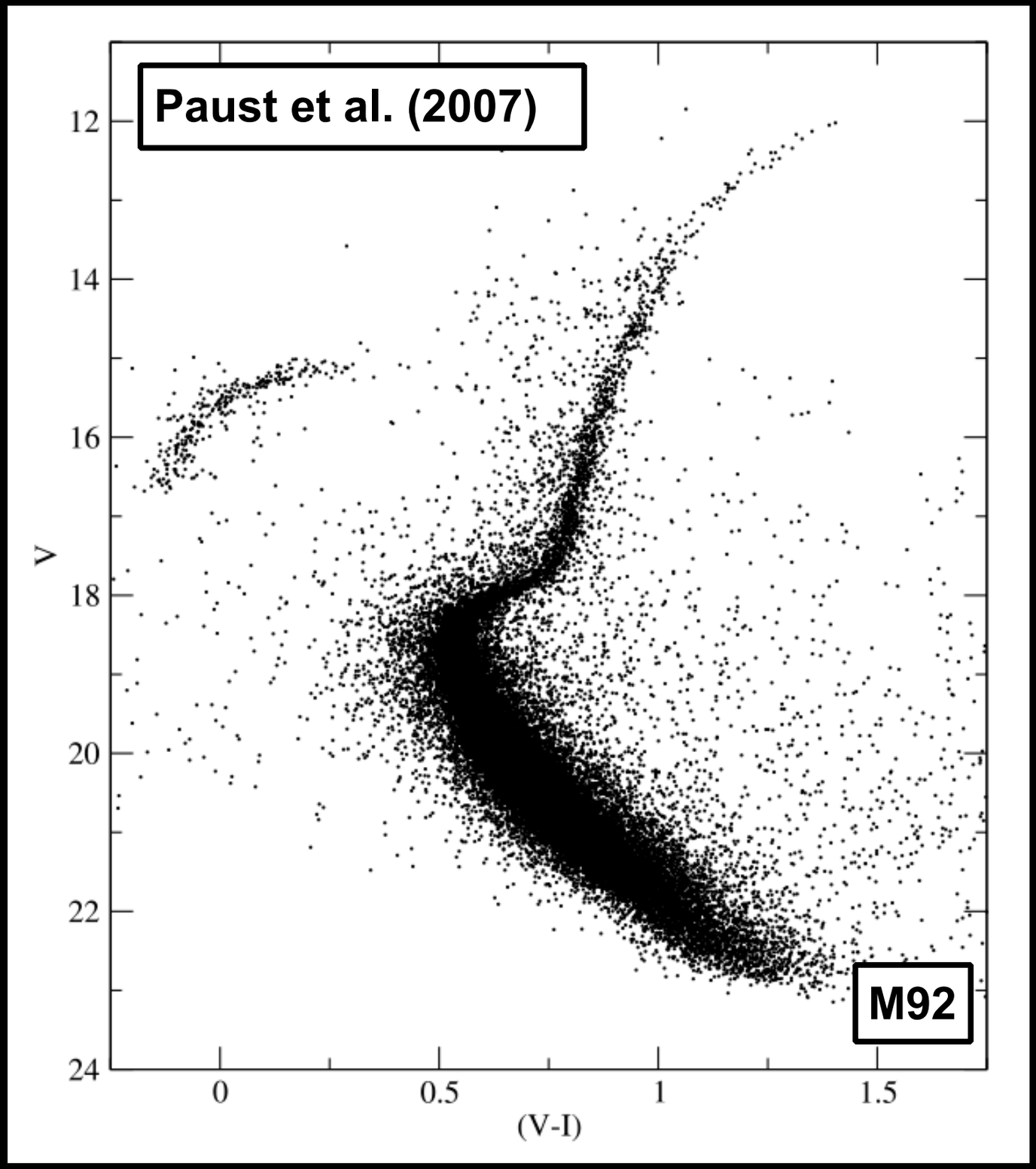


Deviations from Cold Dark Matter could be detected in the abundance and densities of the smallest structures.

Image Credit: Massey & Moustakas


The Milky Way
Large Magellanic Cloud (LMC)
Small Magellanic Cloud (SMC)
Naked Eye Visible

Fermilab



Brighter

Magnitude

Fainter

Color

Bluer

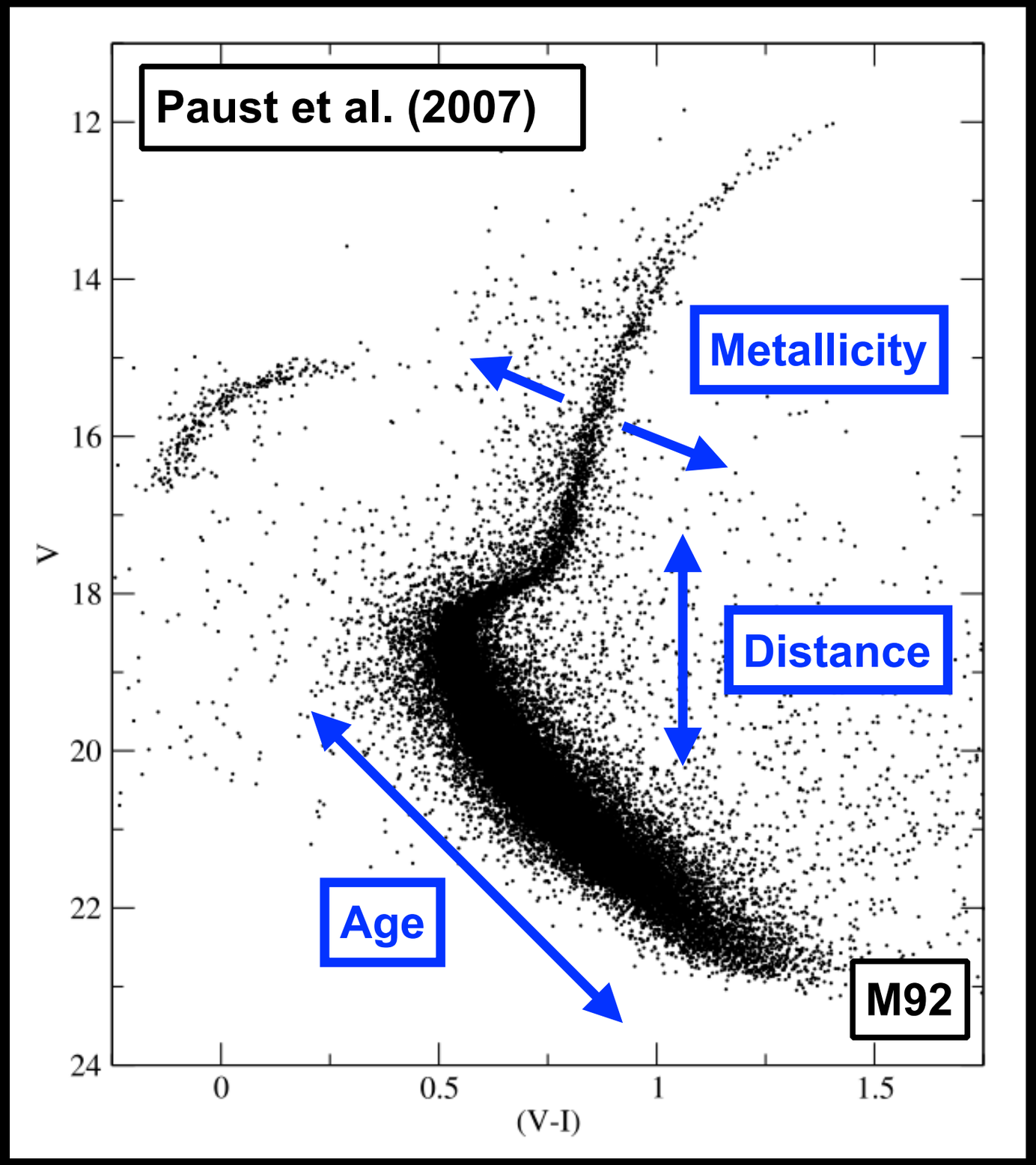
Redder

Fermilab

Brighter

Magnitude

Fainter



Color

Bluer ⟷ Redder

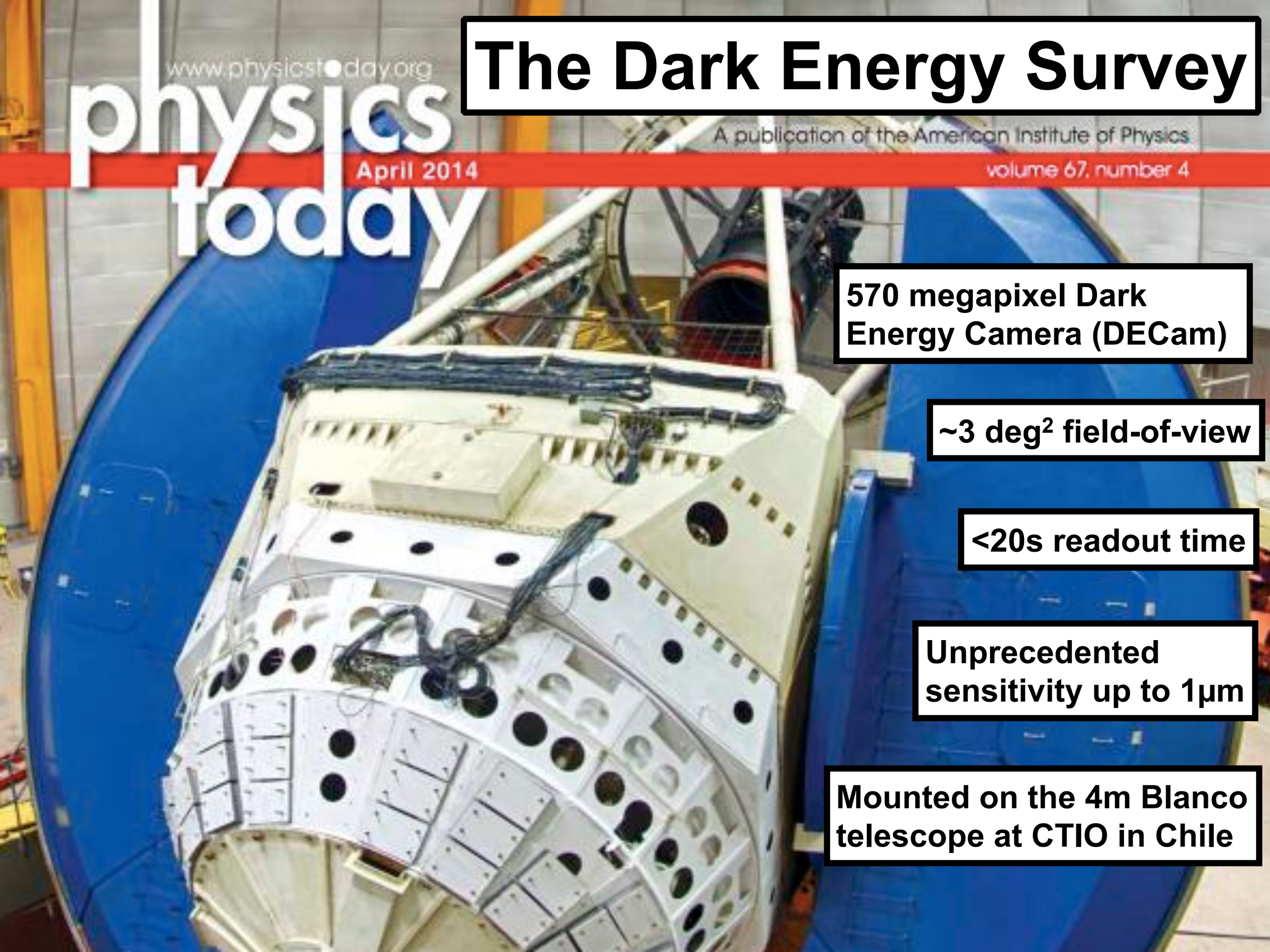
Measure:
- Age
- Metallicity
- Distance

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

Spectroscopic campaign required!

www.physicstoday.org
physics today
April 2014
A publication of the American Institute of Physics
volume 67, number 4

The Dark Energy Survey



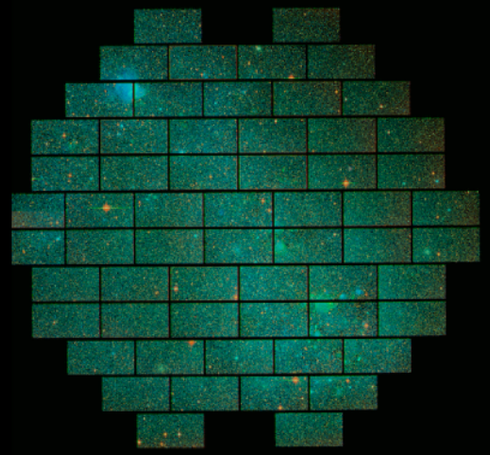
570 megapixel Dark Energy Camera (DECam)

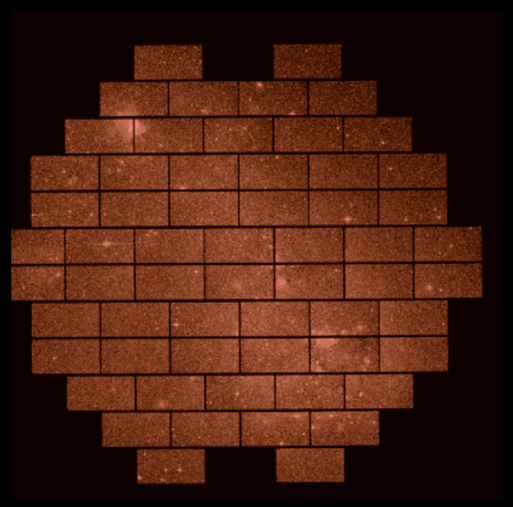
~3 deg^2 field-of-view

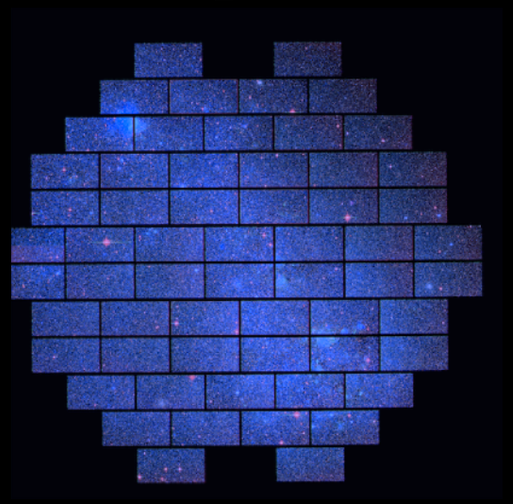
<20s readout time

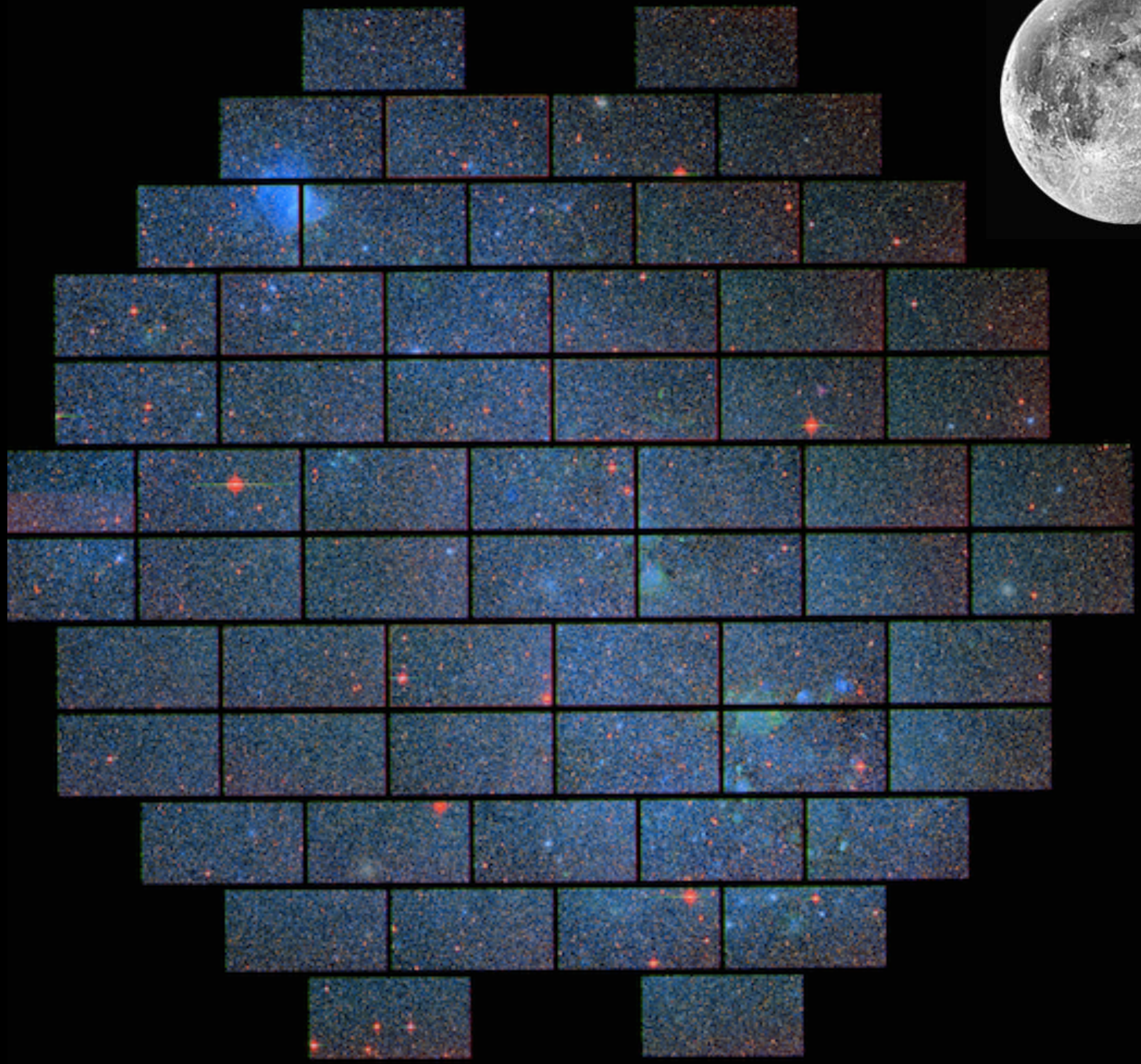
Unprecedented sensitivity up to 1μm

Mounted on the 4m Blanco telescope at CTIO in Chile







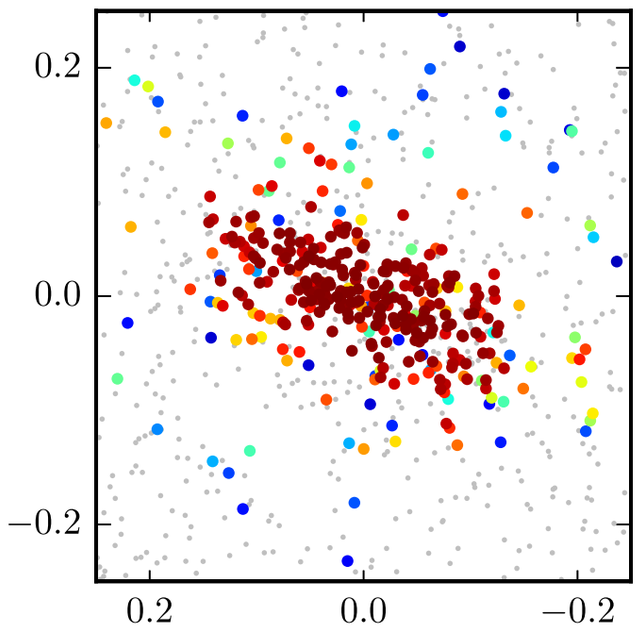


Maximum-Likelihood Searches

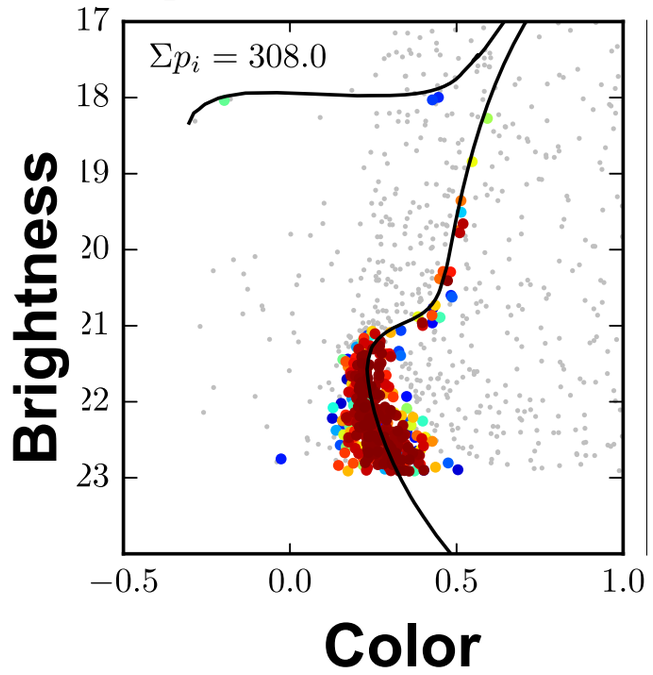
THE DARK ENERGY SURVEY

Fermilab

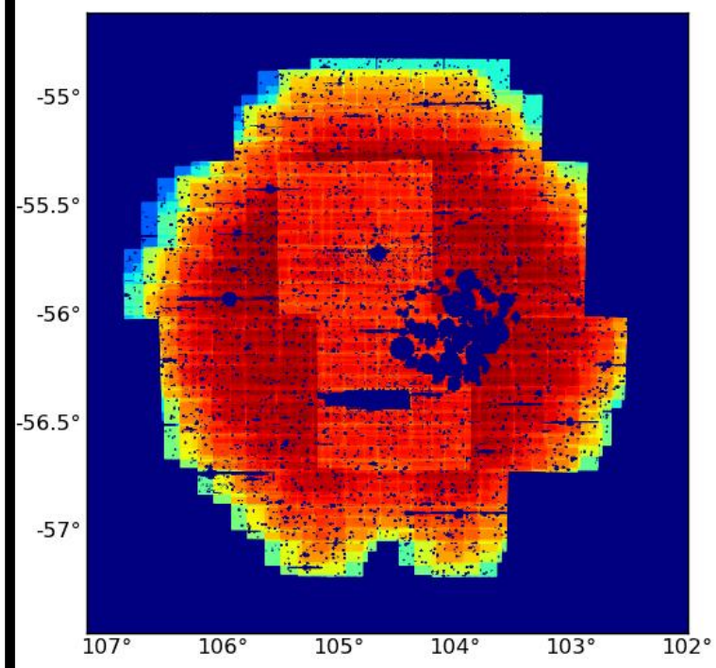
Spatial Model



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 combine spatial and spectral information

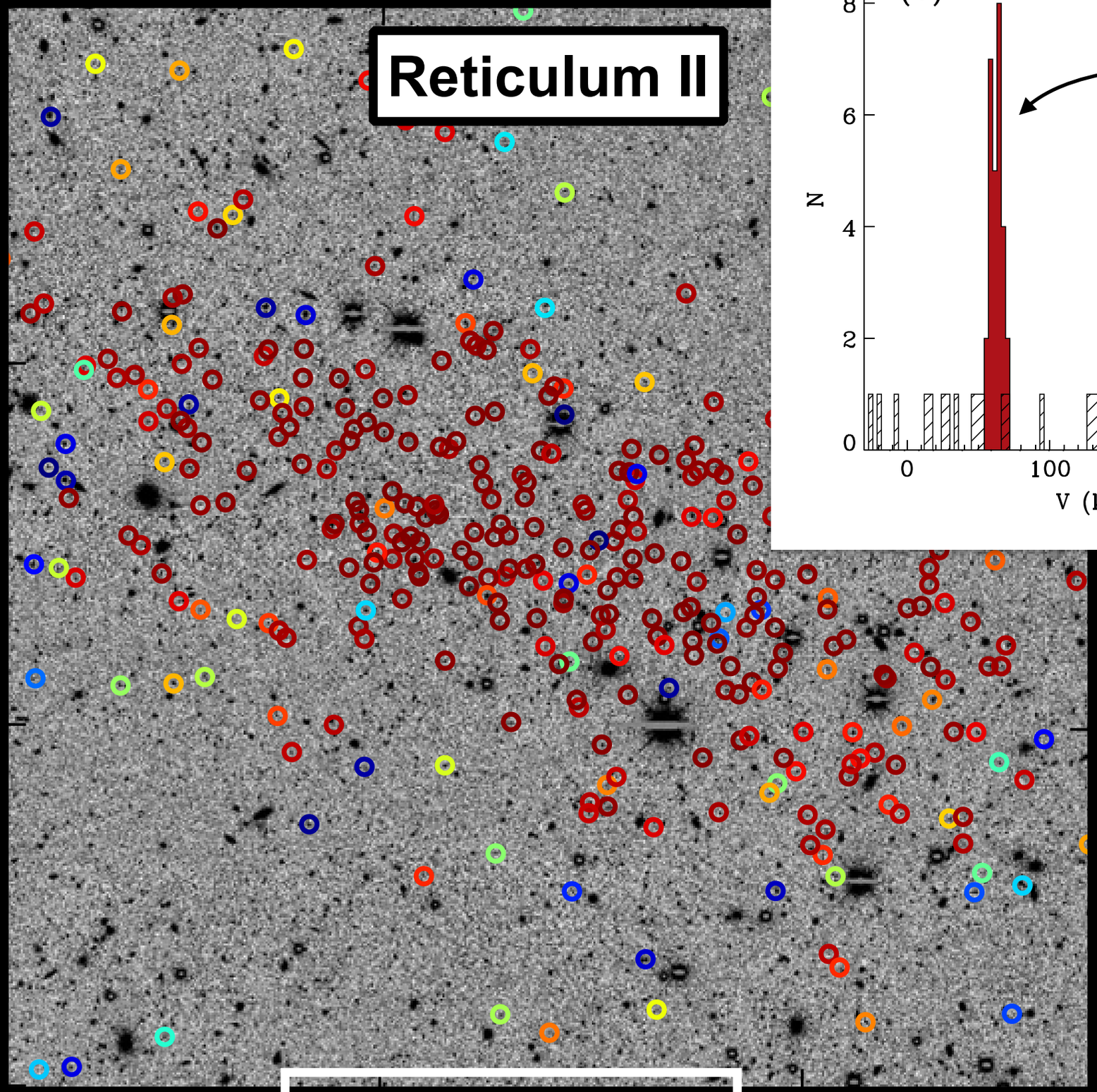
u_i **= signal probability**

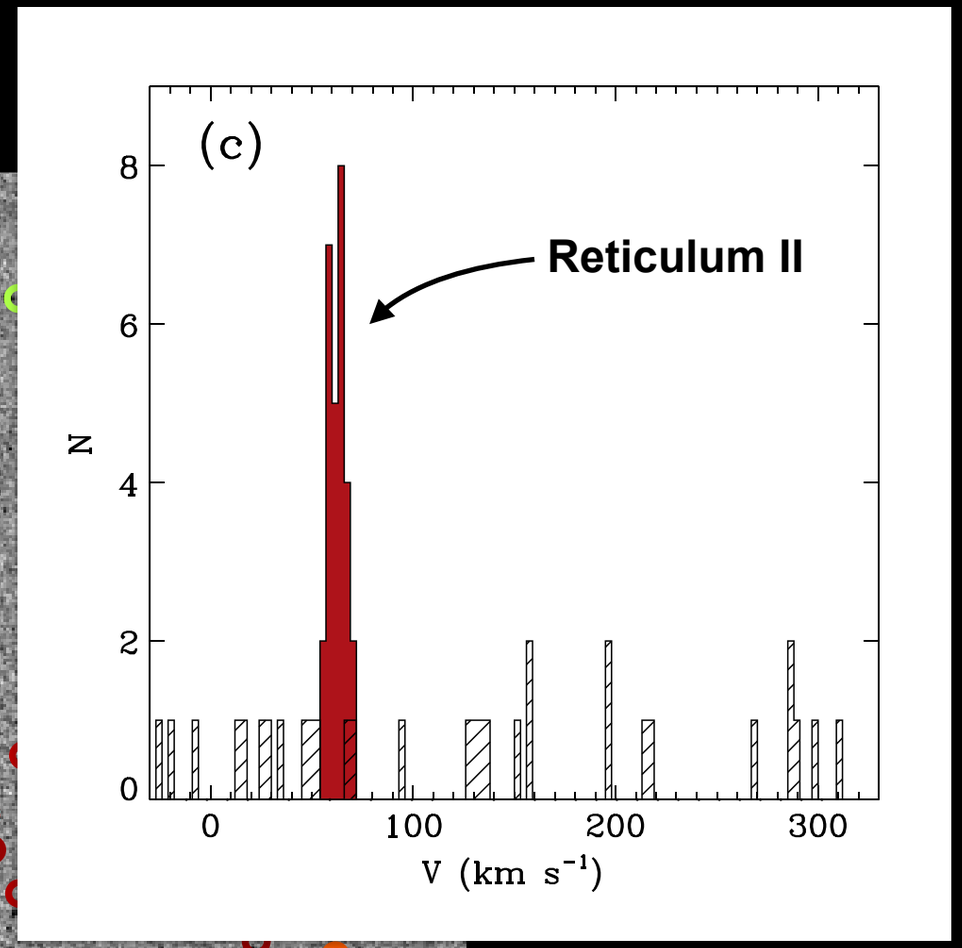
b_i **= background probability**

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



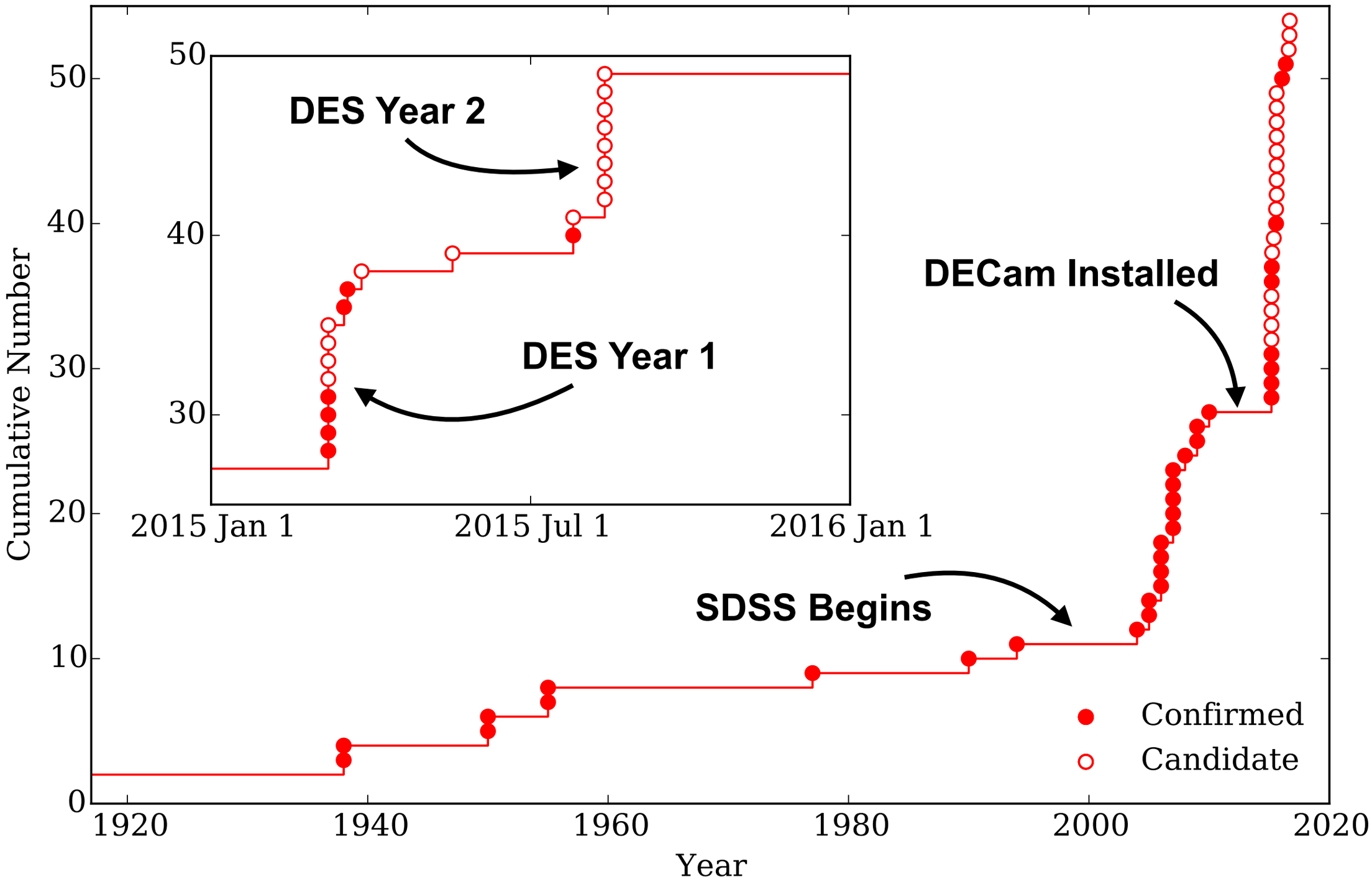


Colors correspond to the membership probability assigned to each star by the likelihood analysis

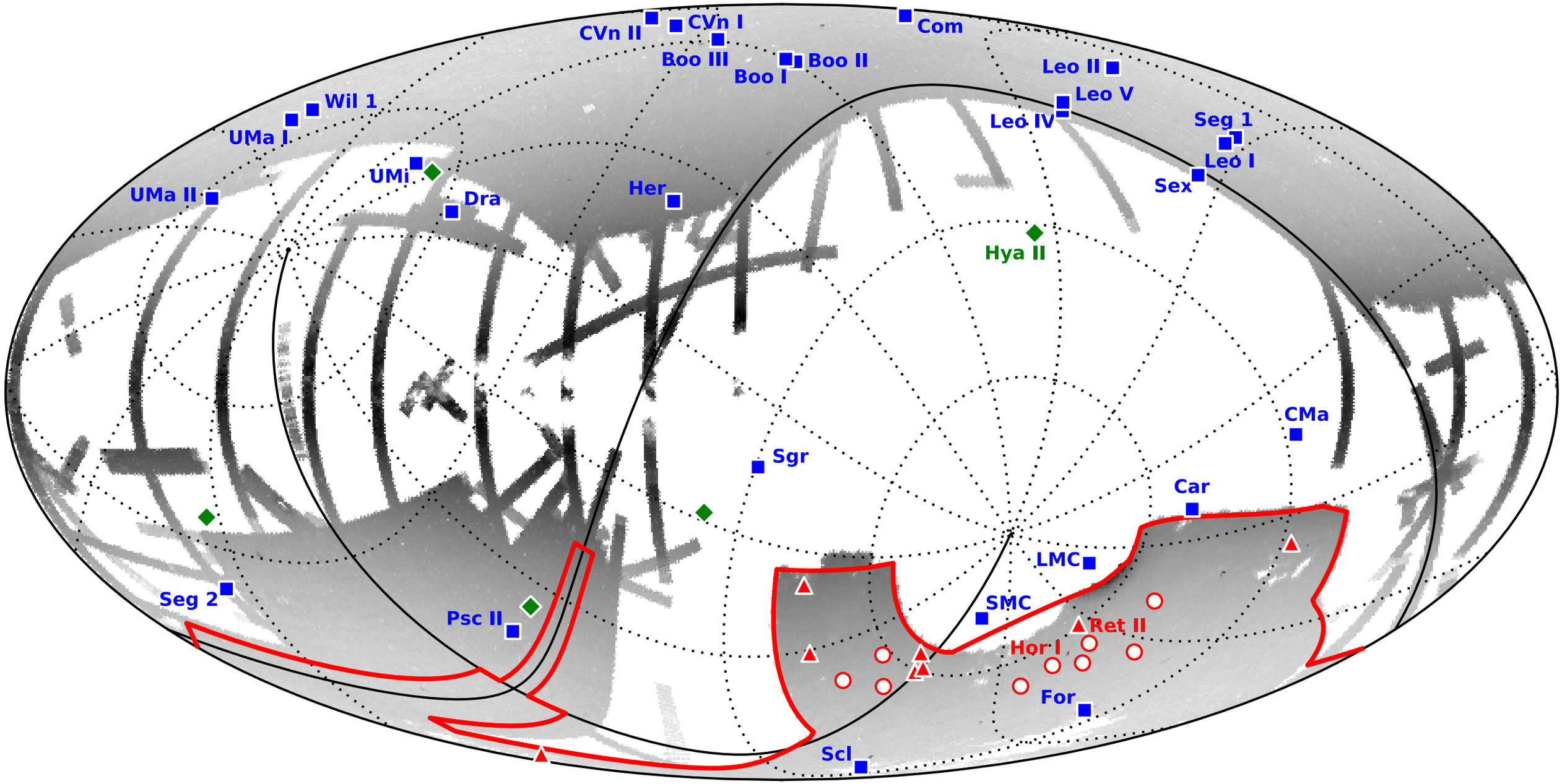
4m Telescope
DECam CCD Camera

Bechtol, ADW et al. (2015)

Dwarf Galaxy Discovery Timeline



SDSS + DES Sky Coverage

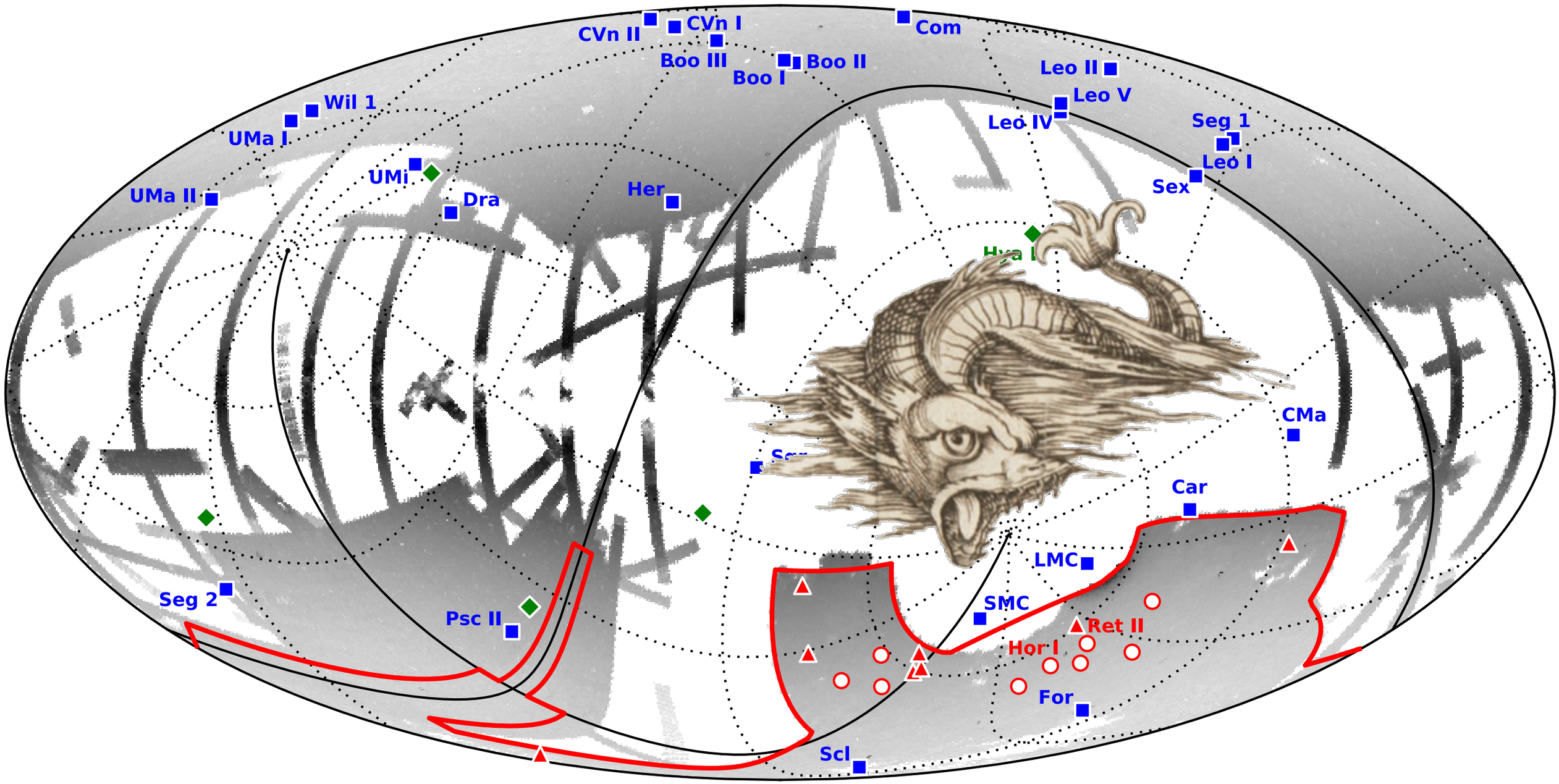


Blue - Previously discovered satellites
Green - Discovered in 2015 with PanSTARRS, SDSS, etc.

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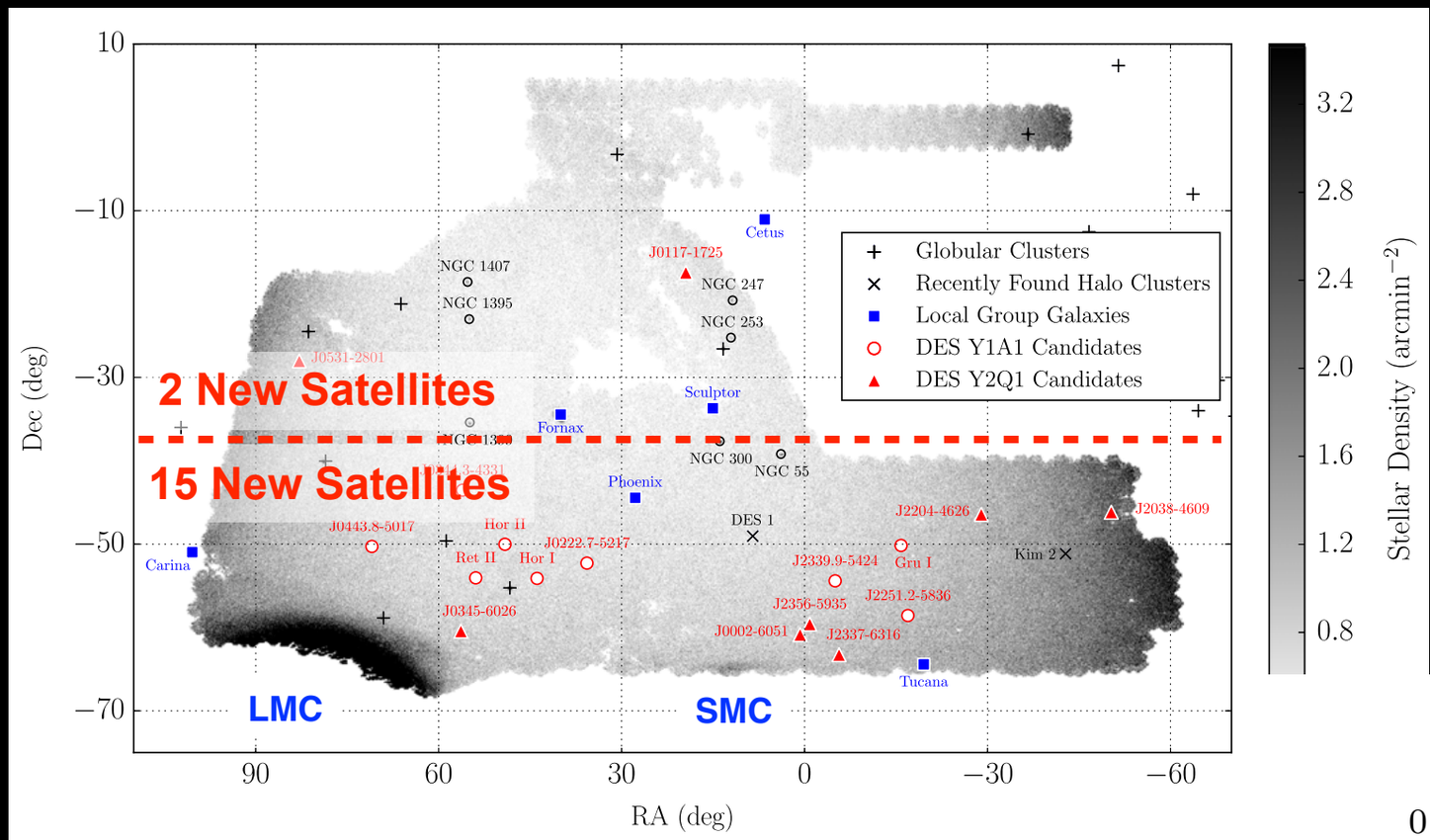
ADW, et al. ApJ 813, 109 (2015)

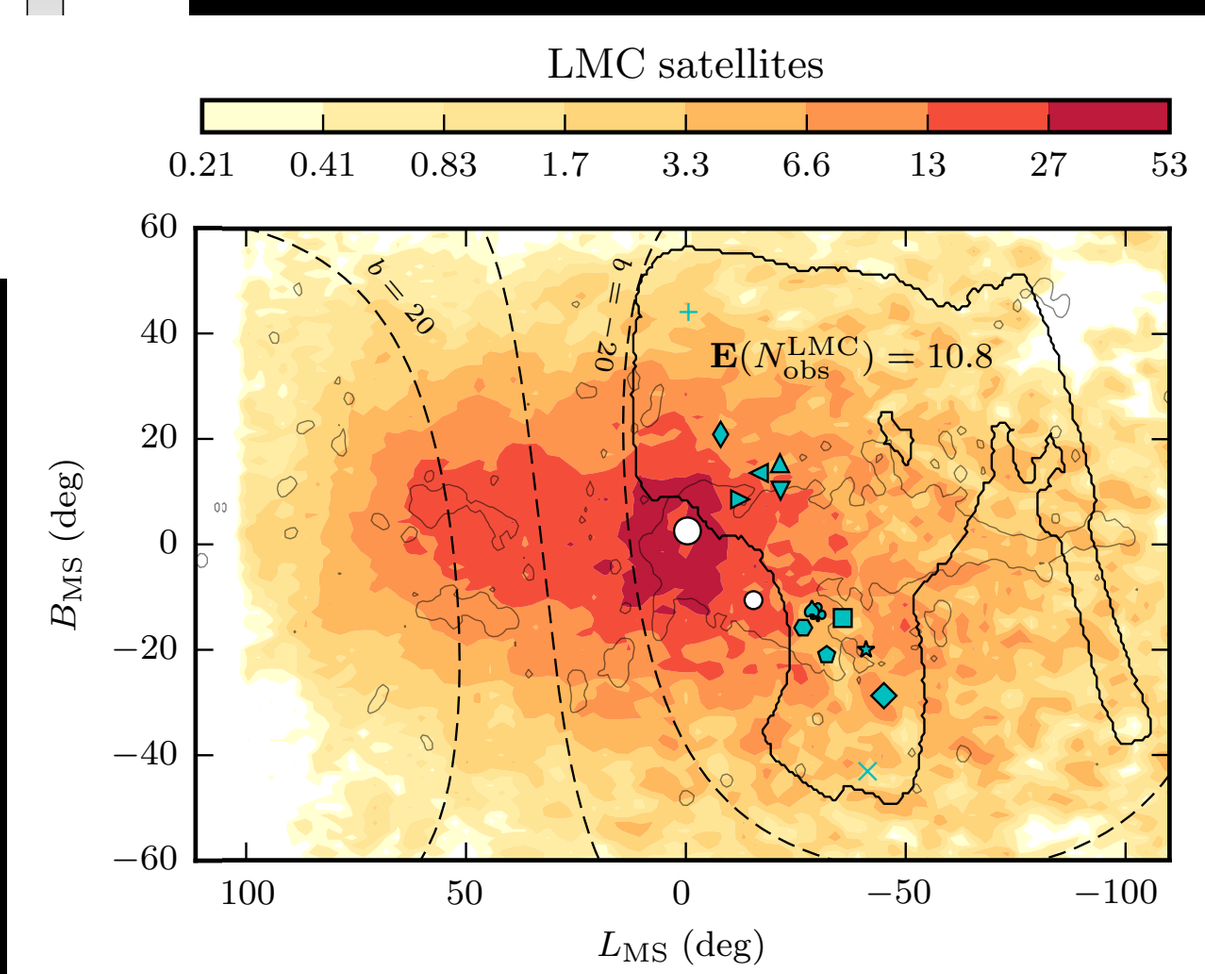
Satellites of the Magellanic Clouds?



ADW et al. ApJ 813, 109 (2015)

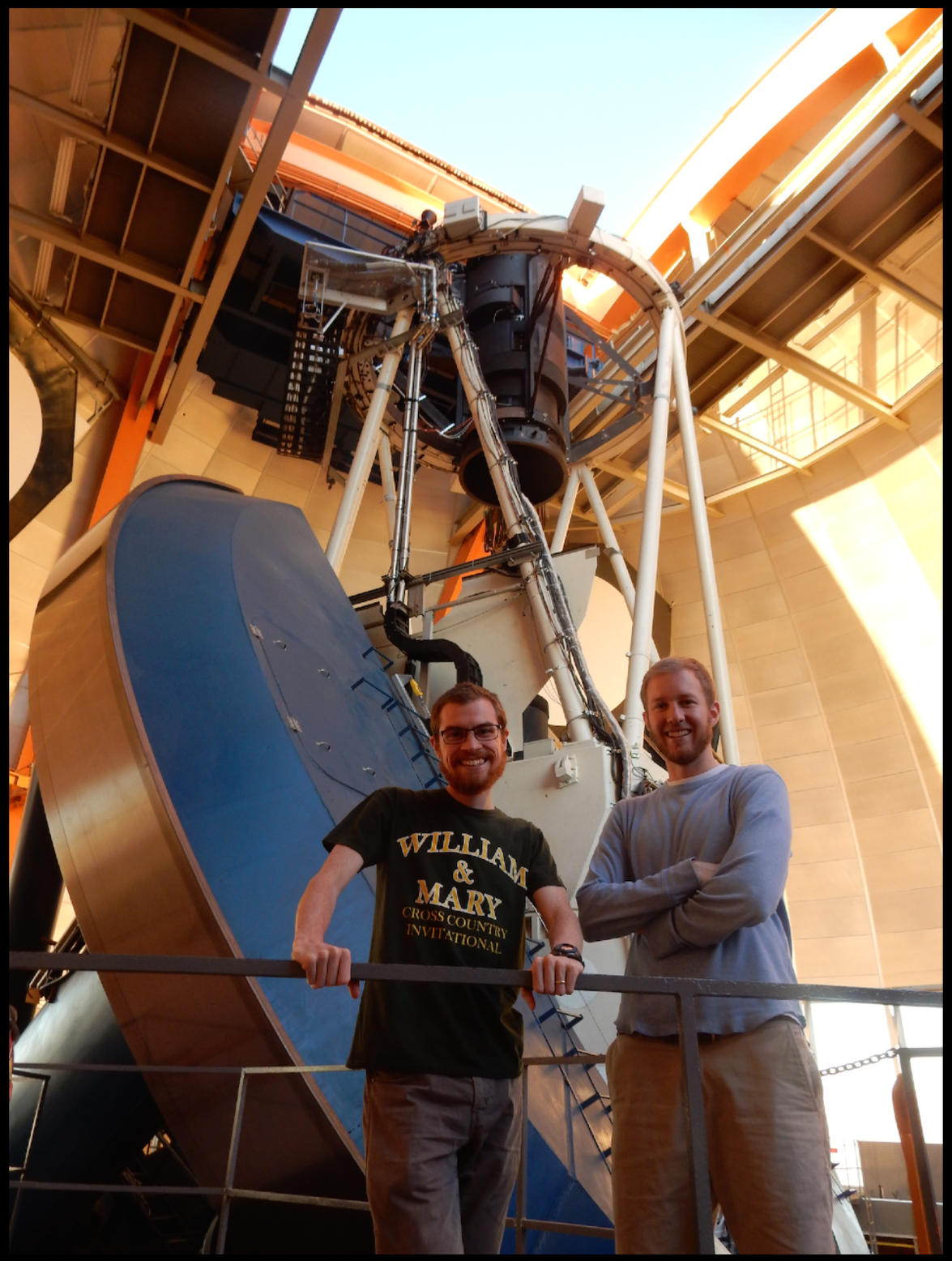
There is ~3σ evidence that DES satellites are not isotropically distributed.

Jethwa et al. MNRAS 461, 2 (2016)



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

Magellanic Satellites Survey



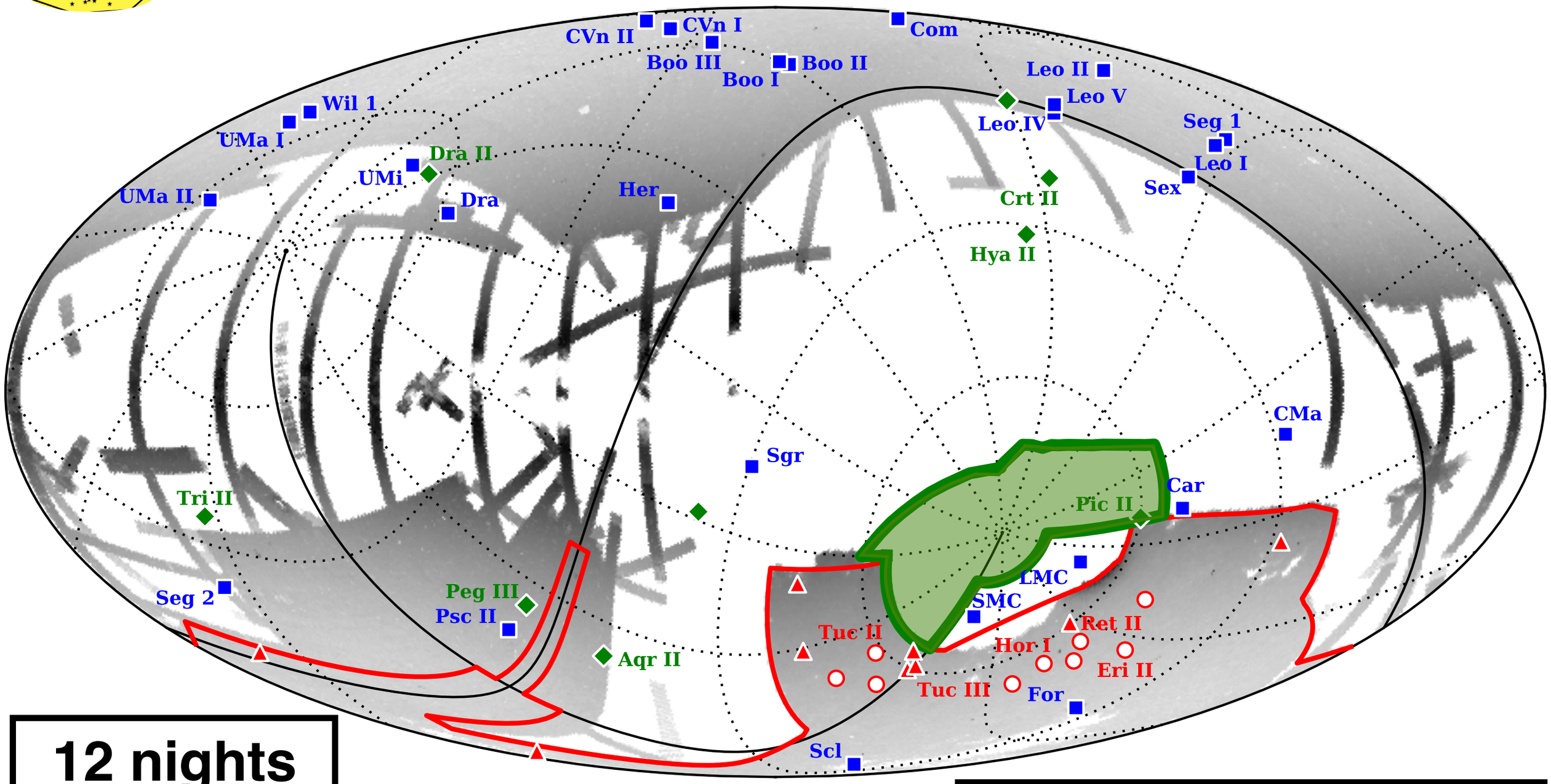
(MagLiteS)

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)

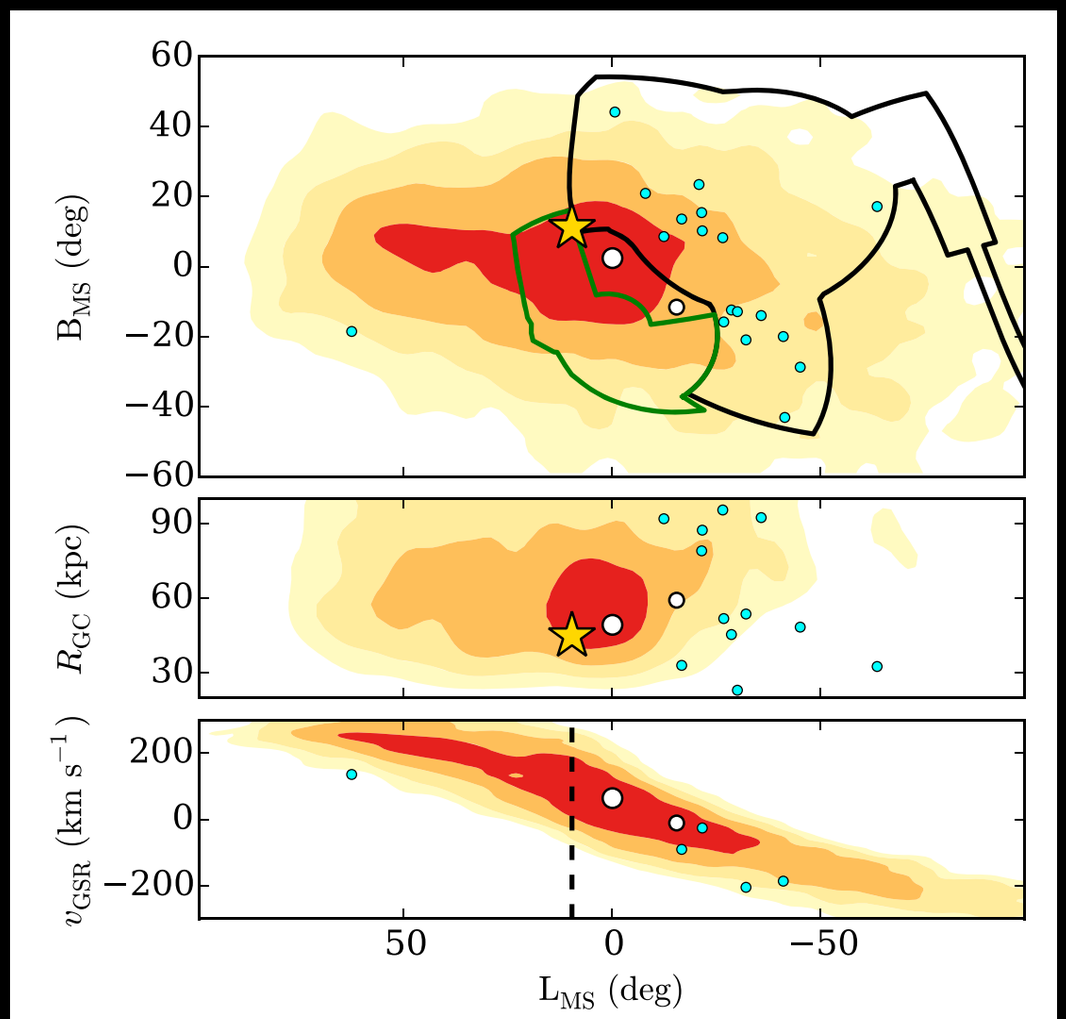


12 nights
~1300 deg²
3 tilings

Roughly comparable in depth to the DES Y2 satellite search

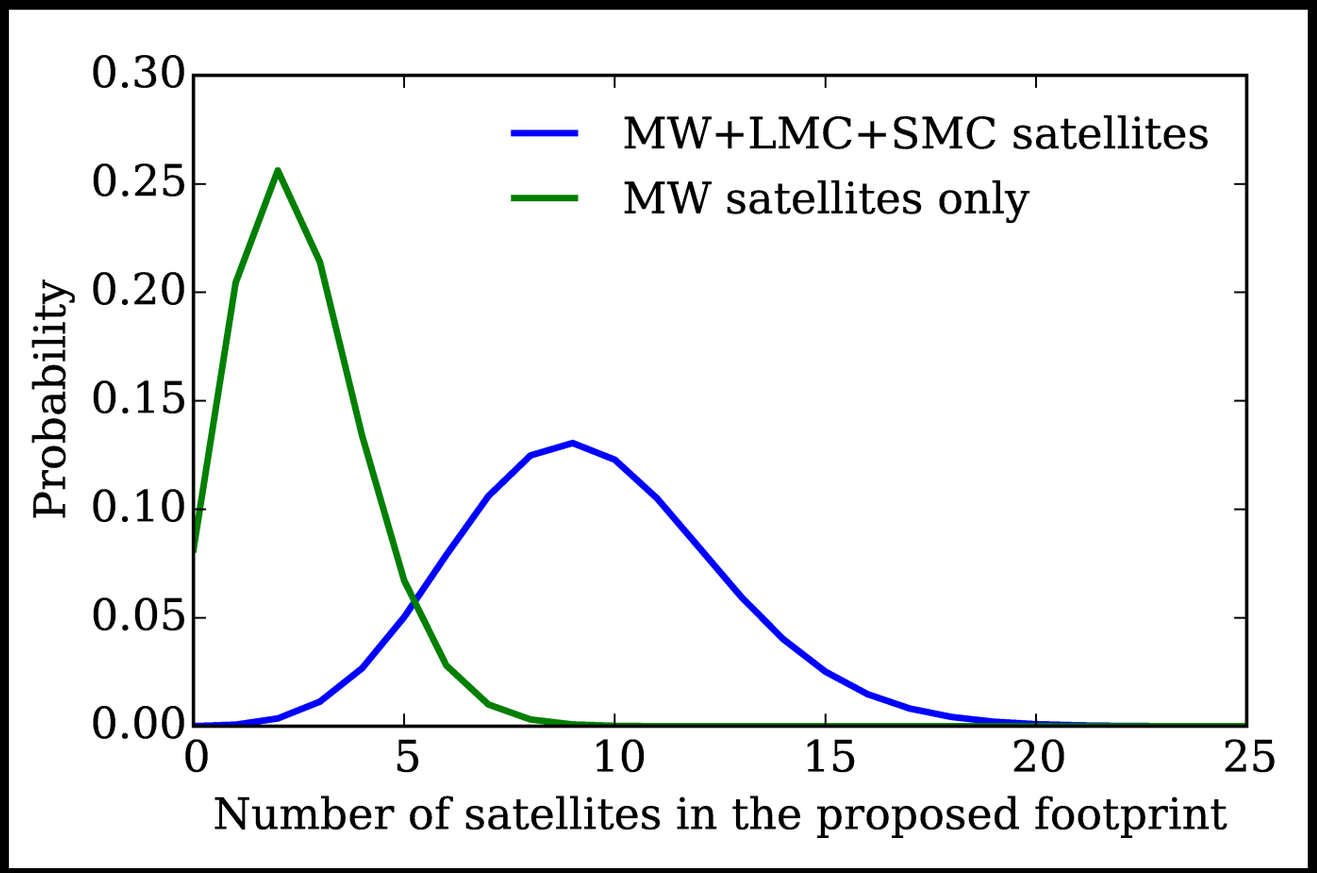
Alex Drlica-Wagner | Fermilab

Satellites of the Magellanic Clouds?



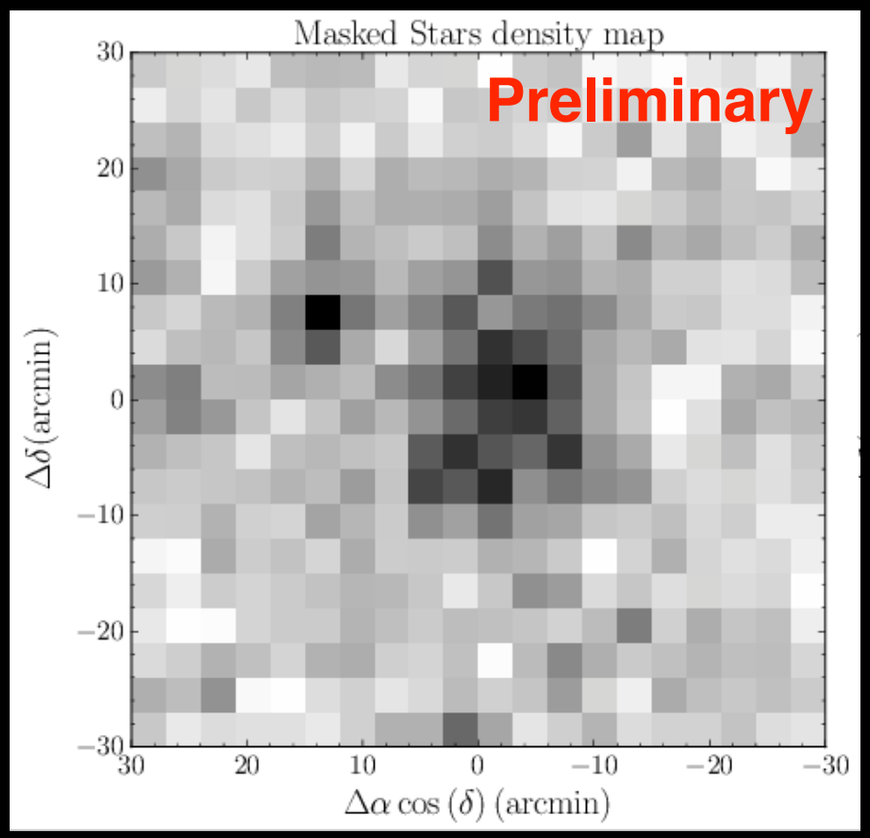
ADW et al. ApJL 833, 5, 2016

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

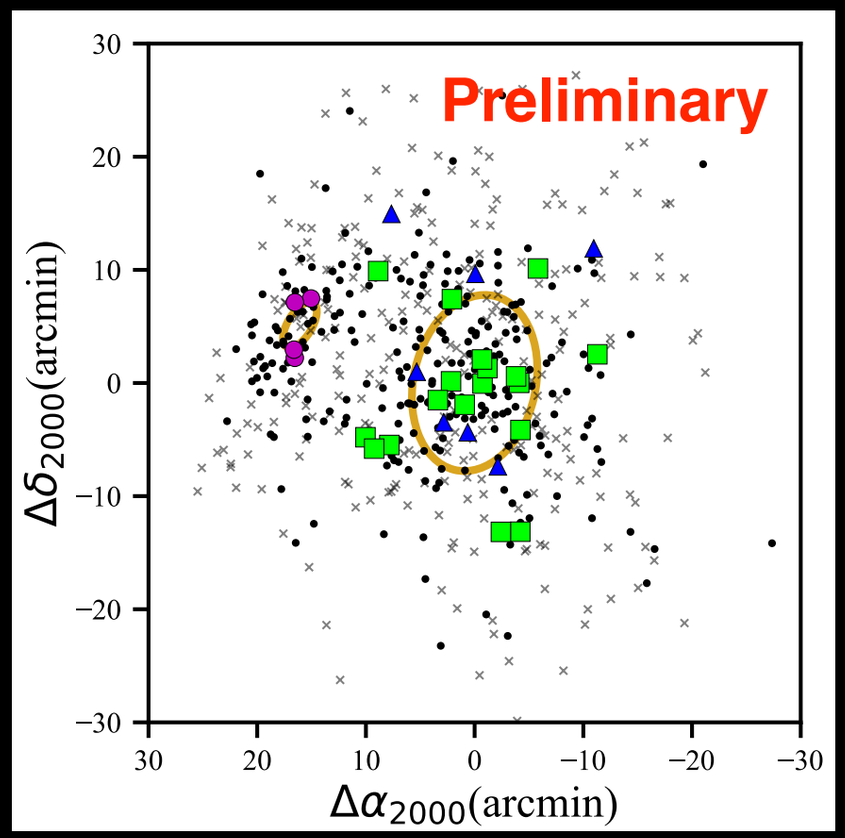


First 1/4th of MagLiteS:
1) One satellite that may still be bound to the LMC
2) Tight pair of satellites located close to the LMC…

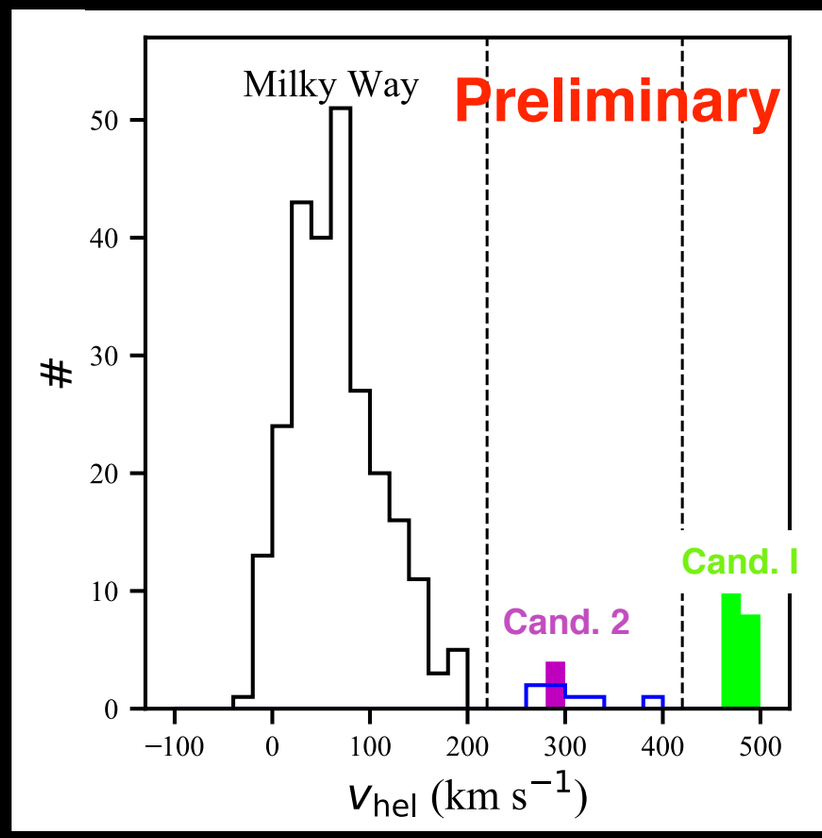
New Candidates from MagLiteS



Torrealba et al. (in prep)



Li et al. (in prep)



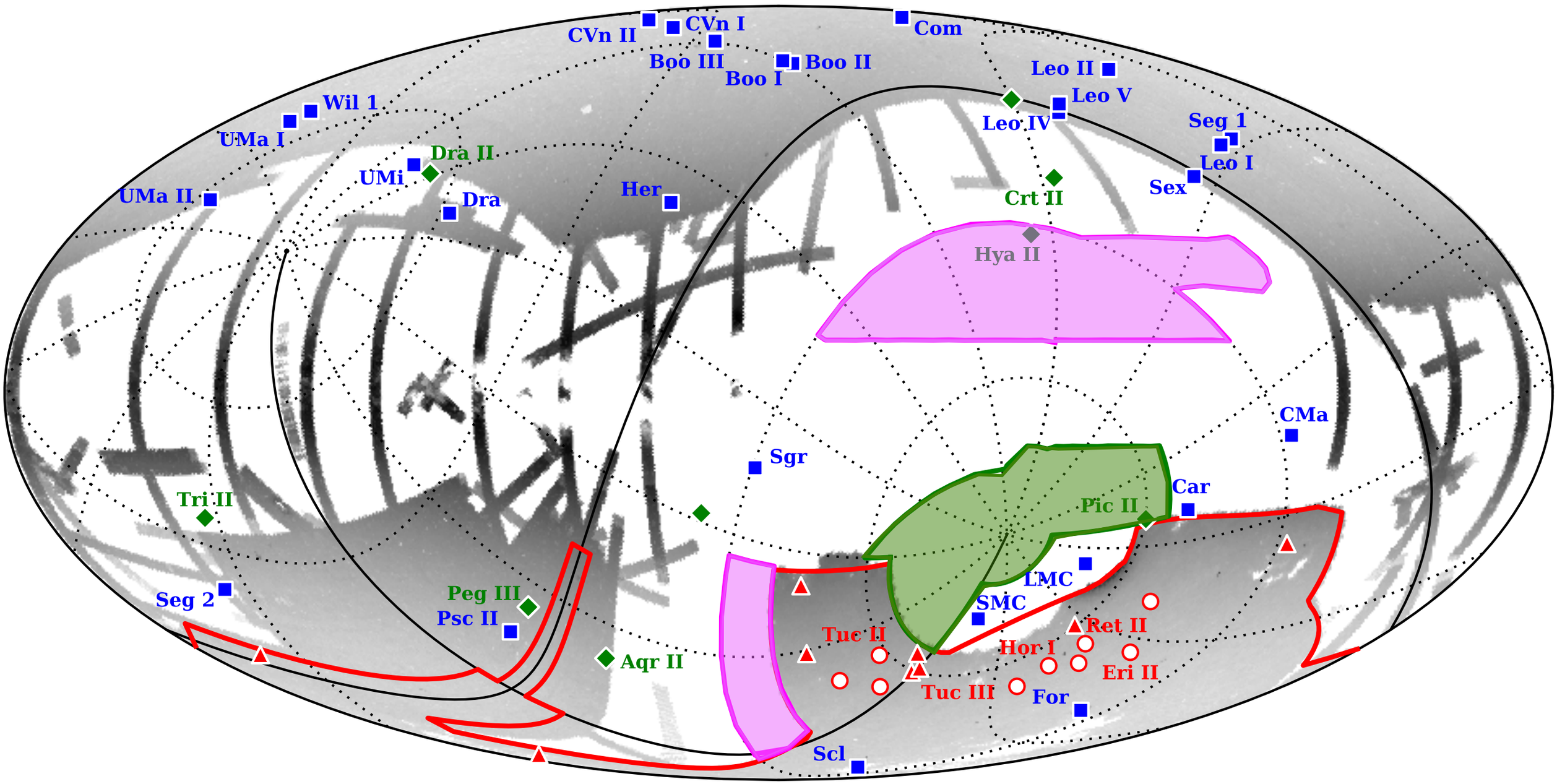
Li et al. (in prep)

Two candidates found separated by ~17’

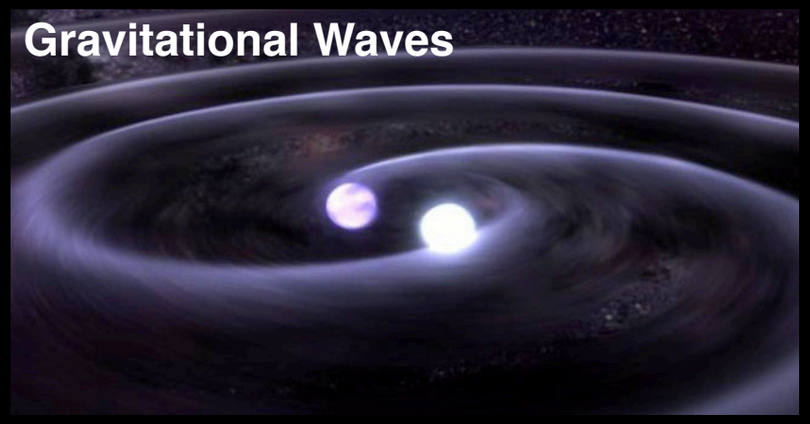
Larger candidate at a distance of ~36 kpc
Smaller candidate at a distance of ~28 kpc

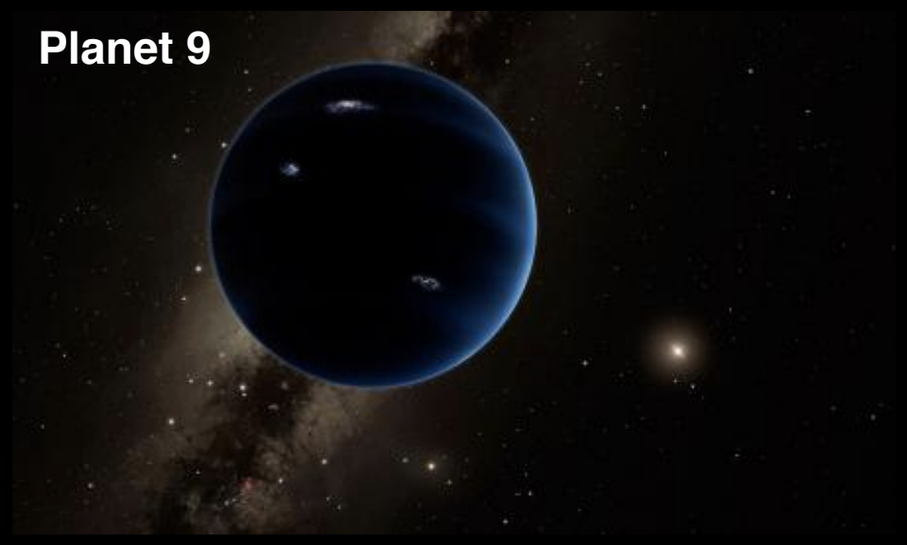
Aligned with axis connecting LMC and SMC

Blanco Imaging of the Southern Sky (BLISS)



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**

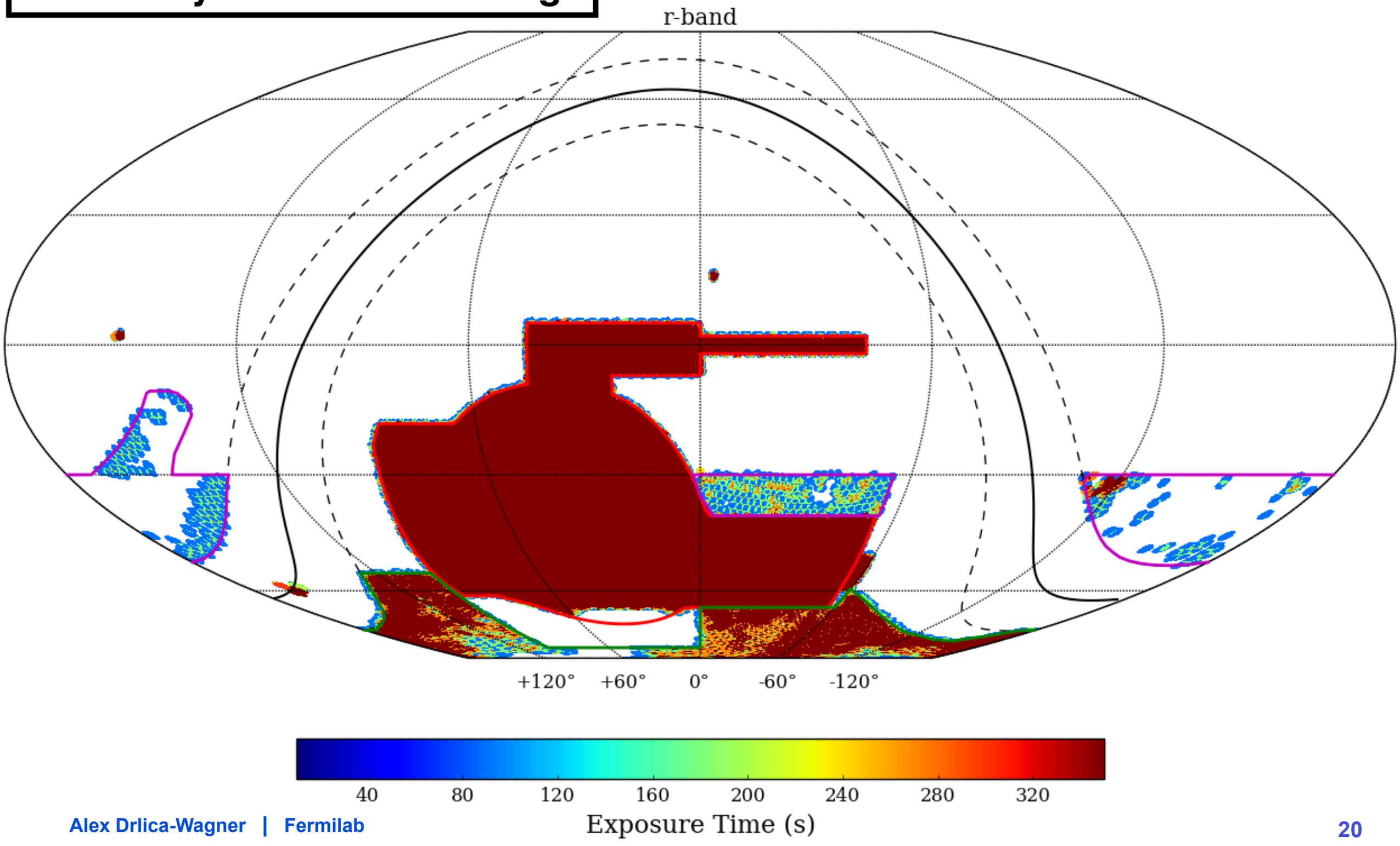
Collaboration of ~35 members across ~10 institutions

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

First-year observations finished on Monday!

DES Sky Coverage

DES *only* covers ~5000 deg²

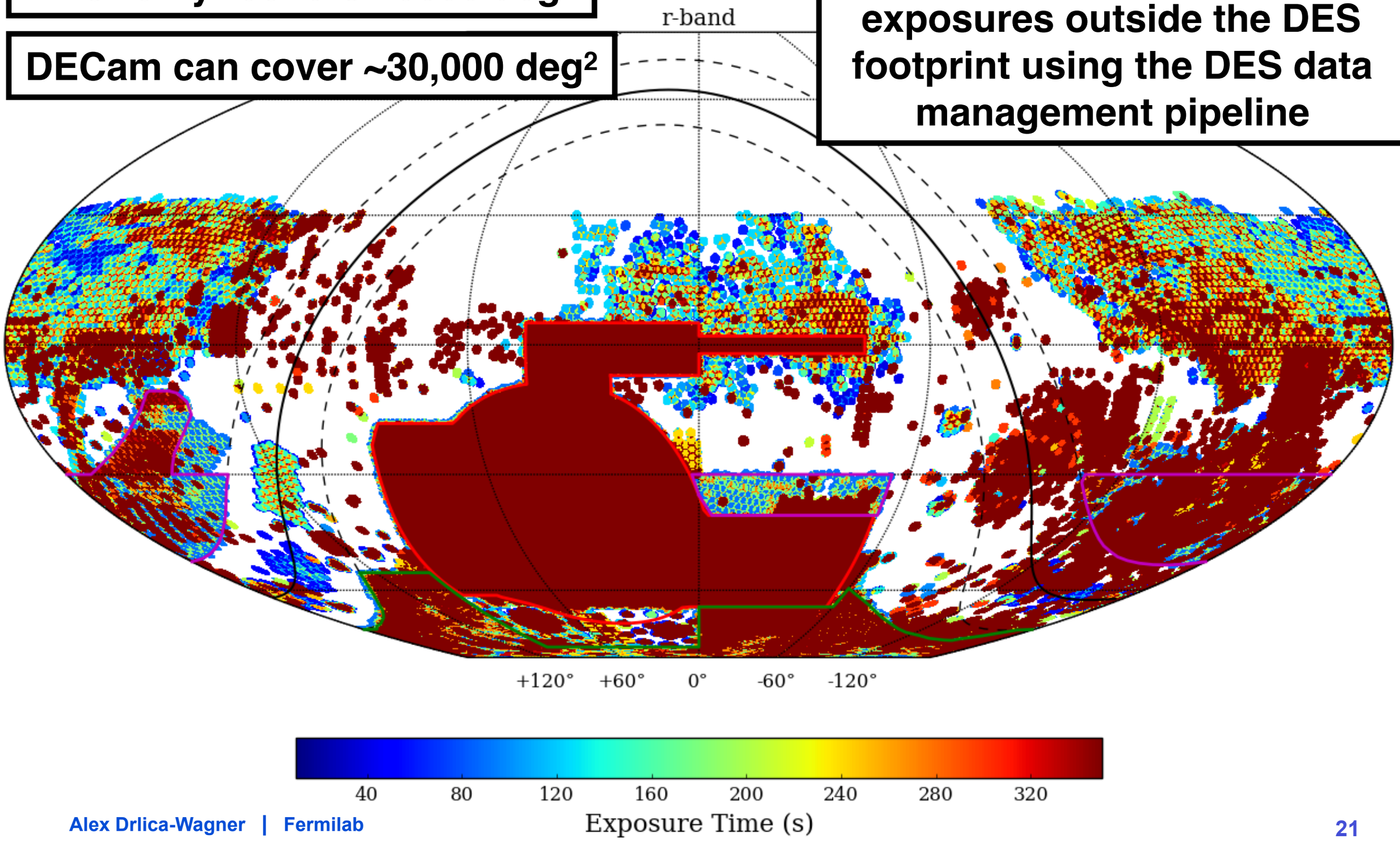


DECam Sky Coverage

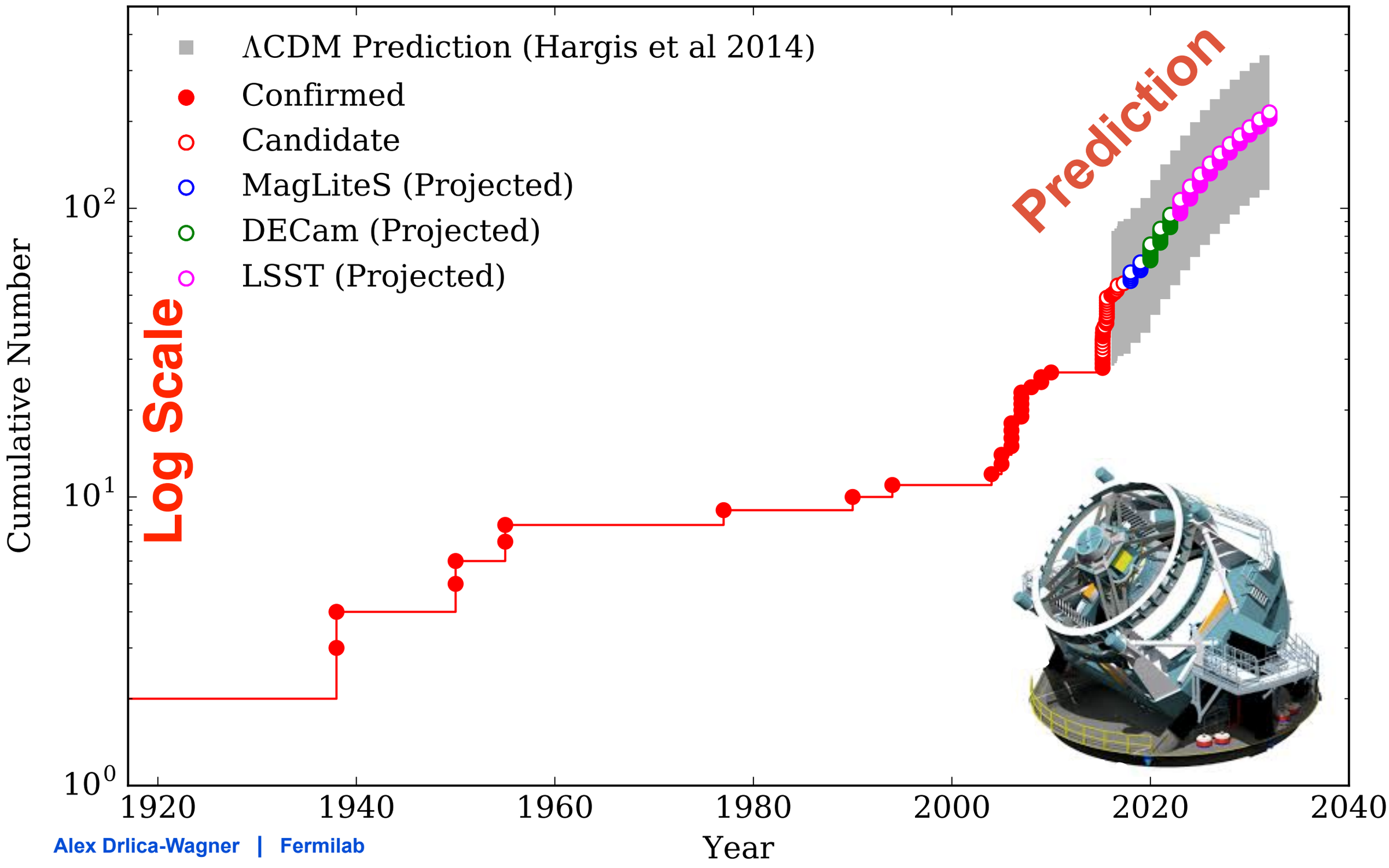
DES *only* covers ~5000 deg²

DECam can cover ~30,000 deg²

We have processed ~100k exposures outside the DES footprint using the DES data management pipeline



LSST is Coming!



LSST is Coming!