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Searching for Ultra-Faint Milky Way Satellites with the DELVE Survey

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New Perspectives 2020

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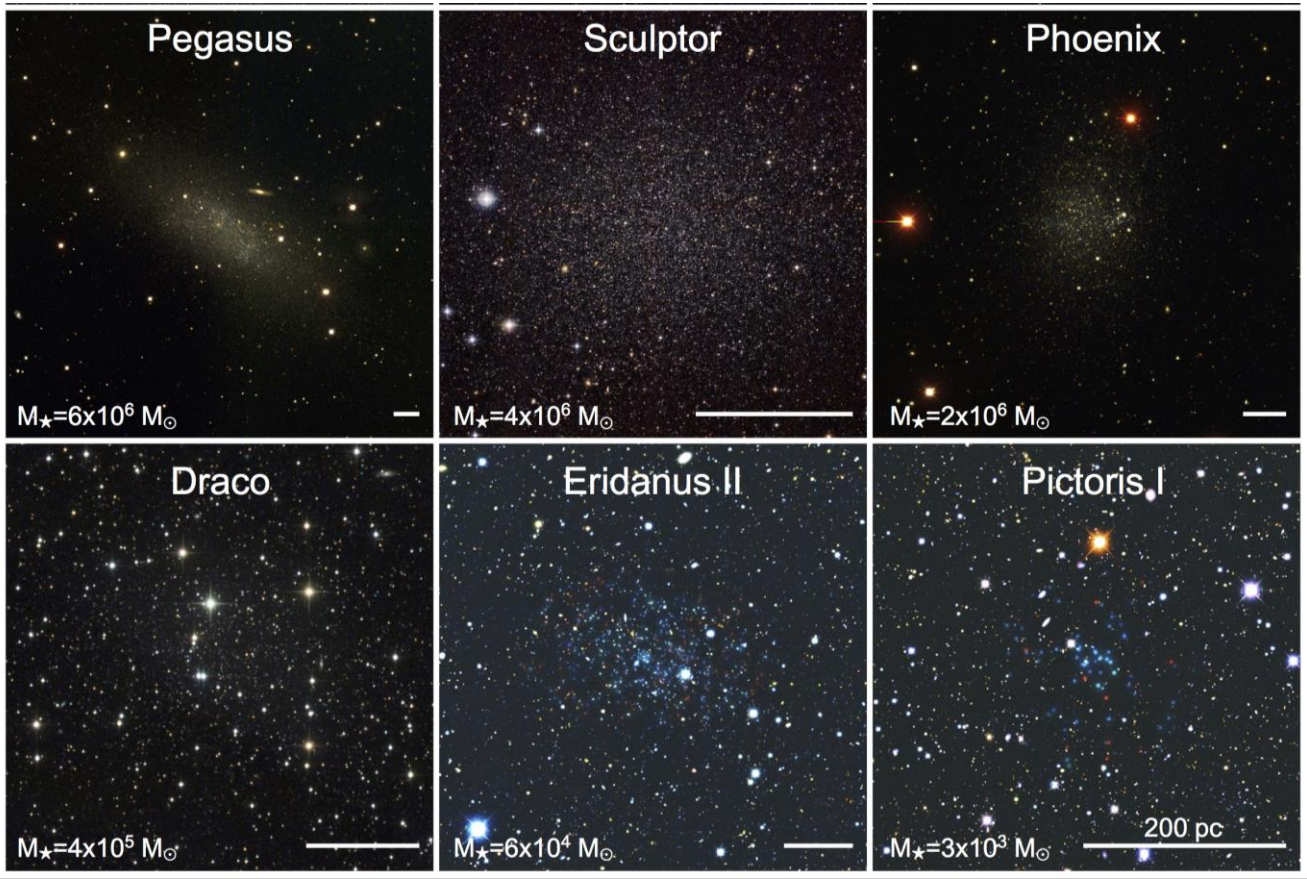
The Universe's Least Luminous Galaxies

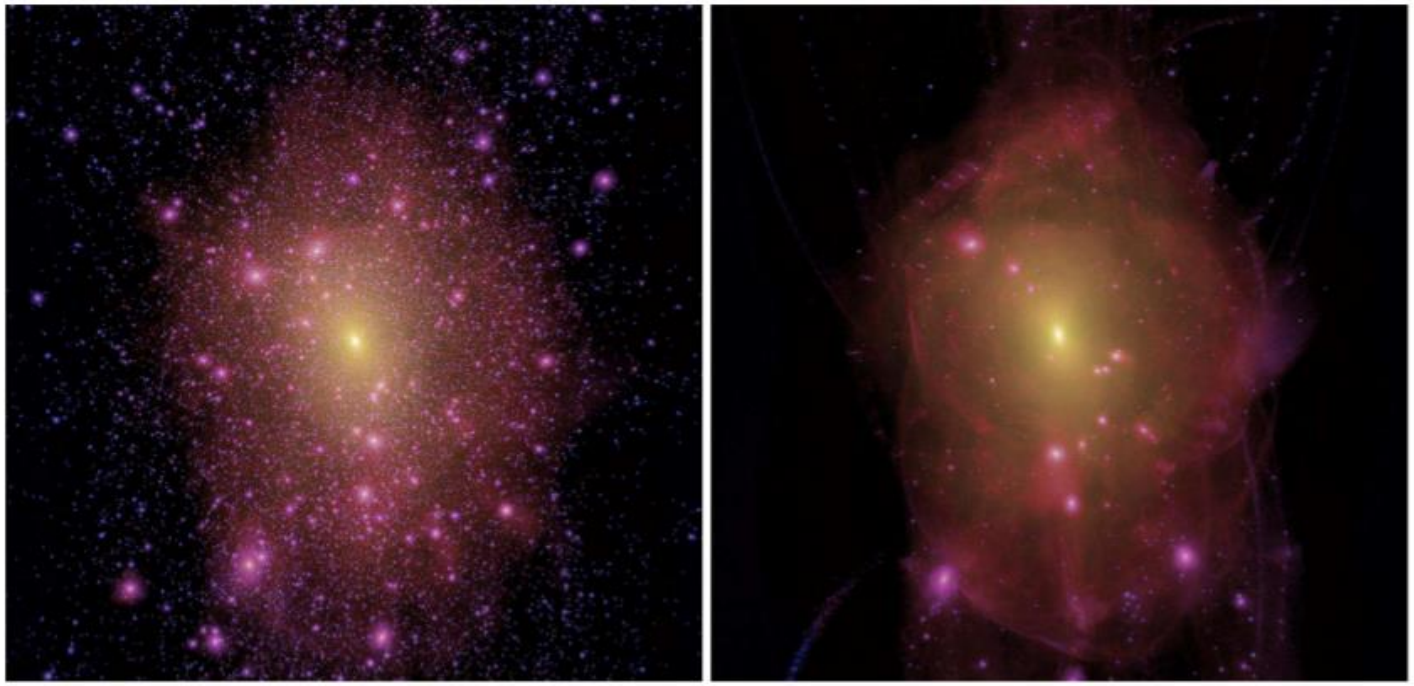


Adapted from Bullock & Boylan-Kolchin (2017)

- Diffuse and Low Surface Brightness -> hard to detect!
  - Less compact and much fainter than globular star clusters
  - Only ~60 known Milky Way satellite dwarf galaxies
- Old, metal poor stellar populations
  - Often only tens to hundreds of detectable member stars
- Dark Matter Dominated: ~99% dark matter
  - Inhabit substructure in MW halo
  - Masses typically up to 100x bigger than what would be measured from luminous matter alone

Why Study Dwarf Galaxies?

Test Dark Matter Particle Models



Cold Dark Matter Simulation | Warm Dark Matter Simulation

Image credit: Lovell et al. (2012)

Probe Galaxy Formation

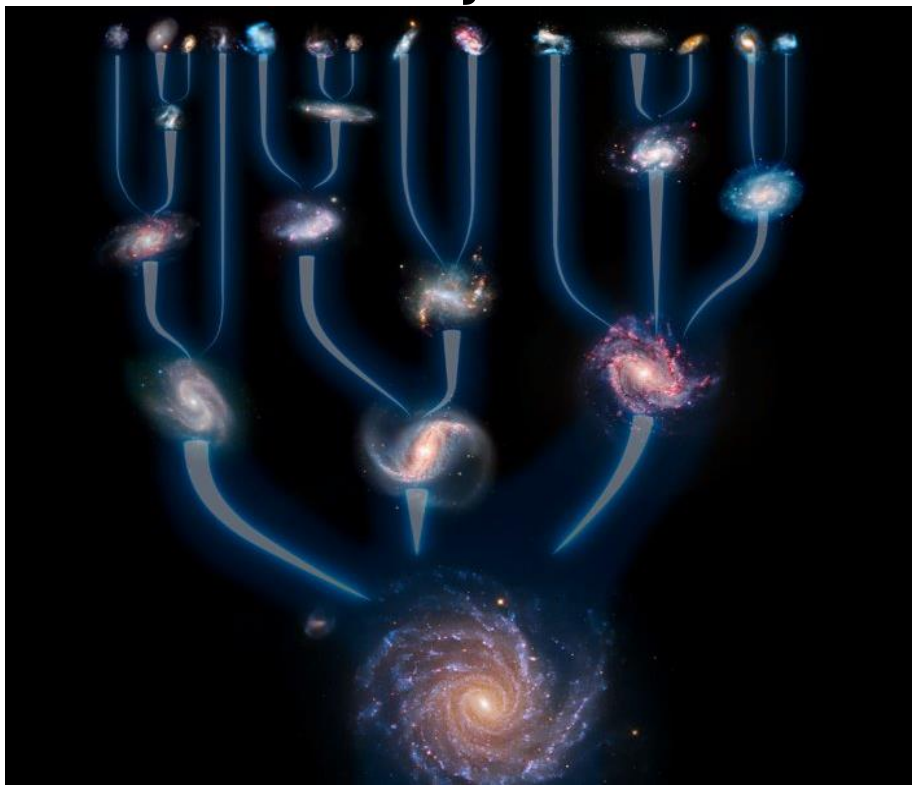


Image credit: ESO

+ search for dark matter annihilation, study reioniziation physics, and uncover the history of the Milky Way

The Dark Energy Camera

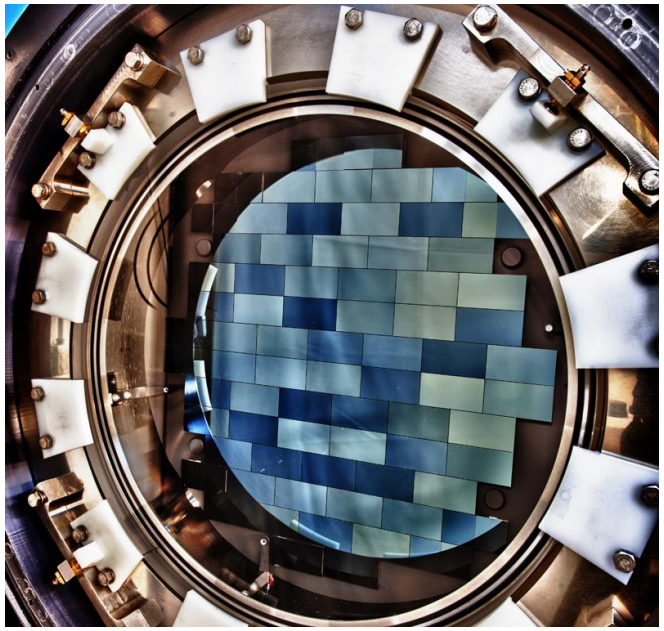
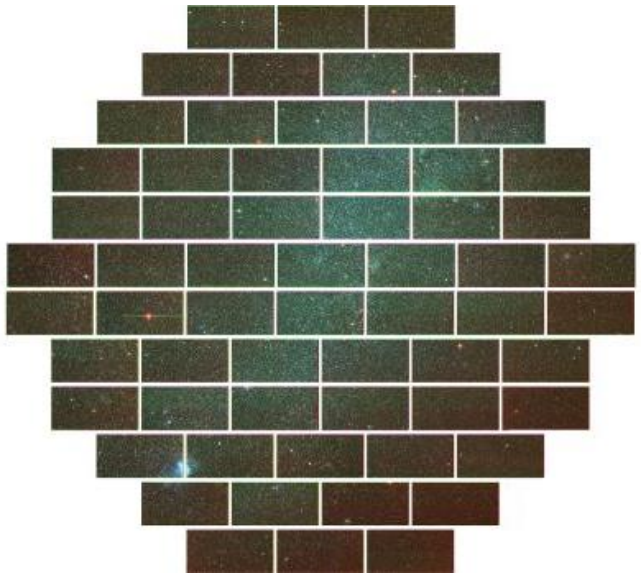


Image credits: Dark Energy Survey Collaboration



- Originally built for the Dark Energy Survey Collaboration, centered here at Fermilab
- Mounted on 4-meter Blanco Telescope at Cerro Tololo Inter-American Observatory (CTIO) in Chile
- Extremely-well suited for wide-field sky surveys:
  - Large field of view (~3.4 deg^2)
  - High Resolution: 62 4,000x2000 pixel CCDs
    - 570 Megapixel camera!
- Used to discover 20+ dwarf galaxies to date

Milky Way Satellite Discovery Timeline

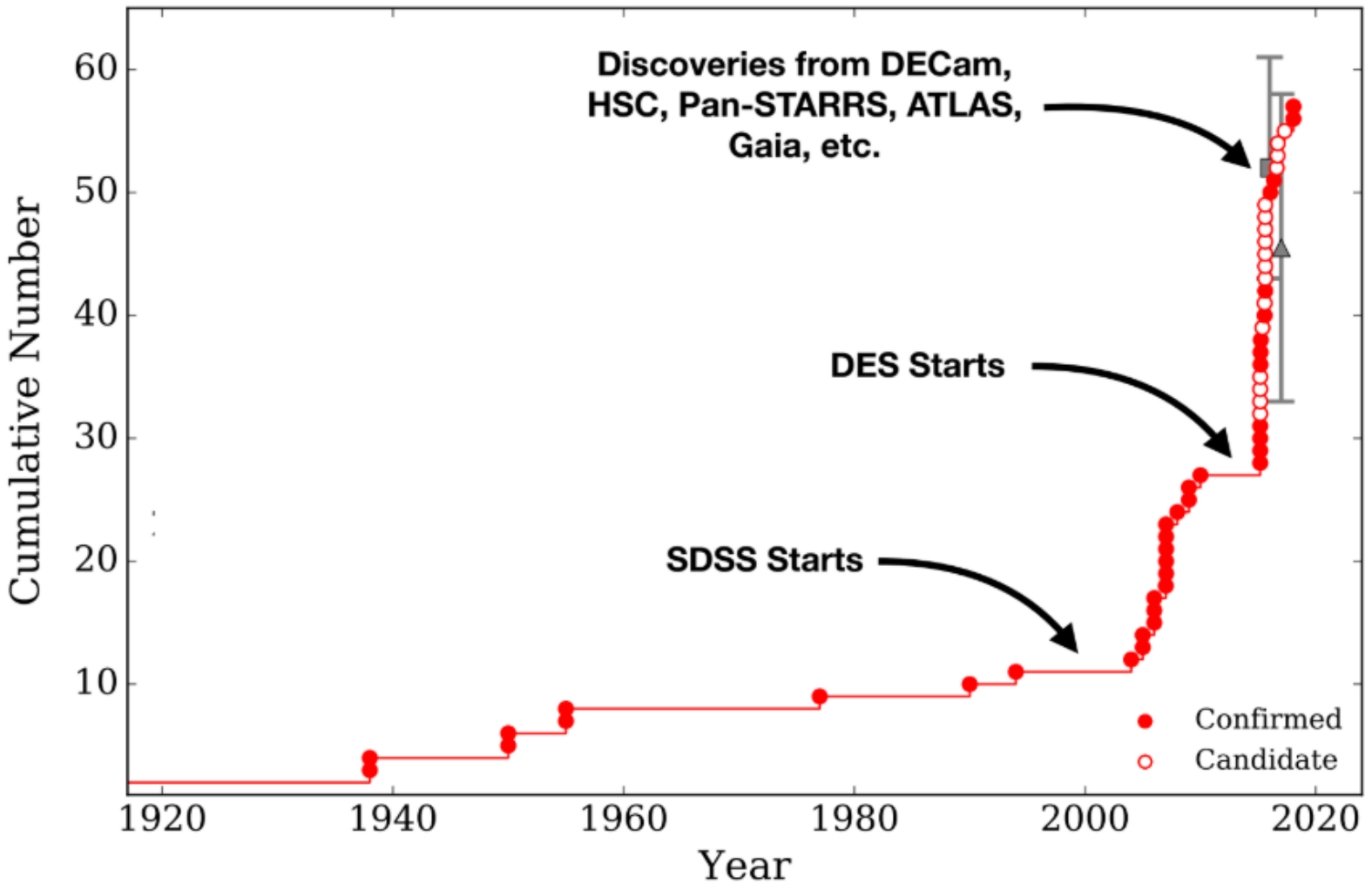


Image credit: Alex Drlica-Wagner

DECam Local Volume Exploration (DELVE)

- Aiming to complete uniform, contiguous coverage of the Southern Sky on the Dark Energy Camera (DECam)

- Combines 126 nights of new g- and i- band observations across 3 years with thousands of publicly available exposures taken on the same instrument from the community

- Perfect for conducting a census of Milky Way dwarf galaxies! (among many other science cases)

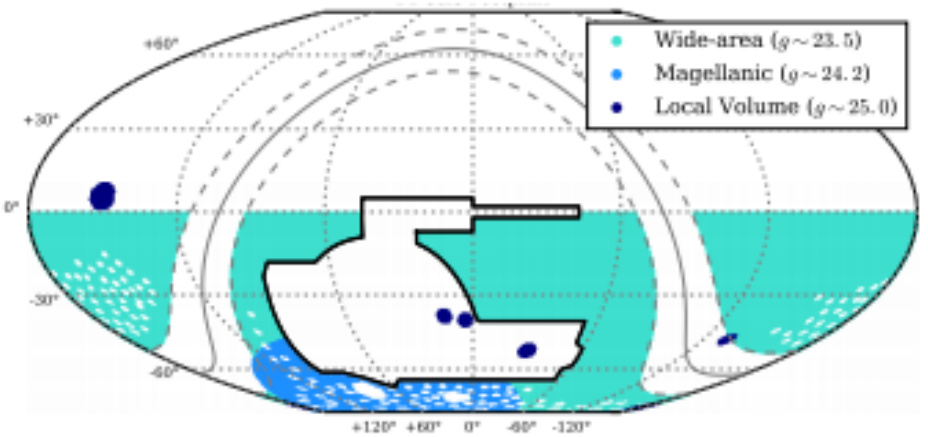
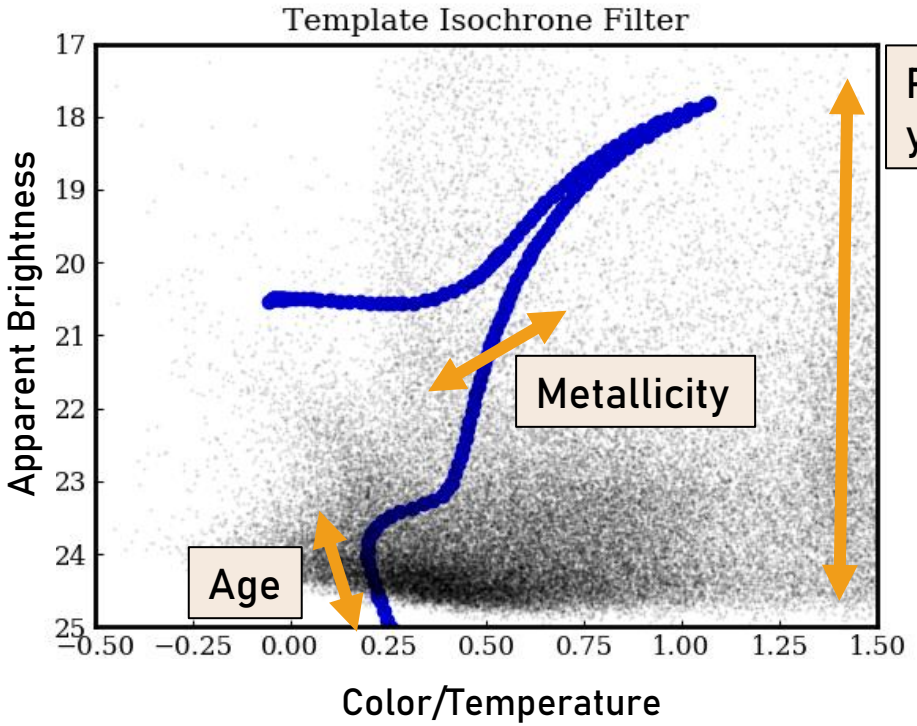


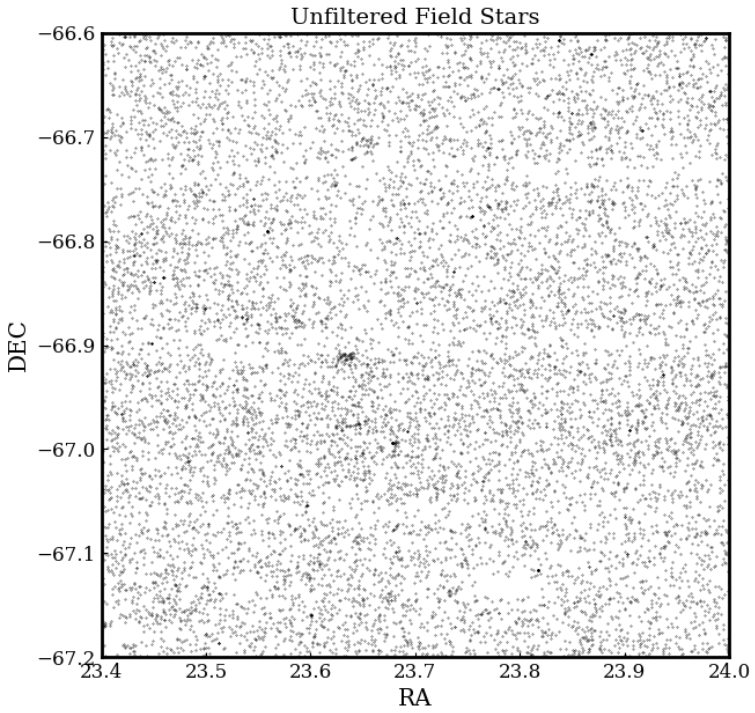
Image credit: Alex Drlica-Wagner

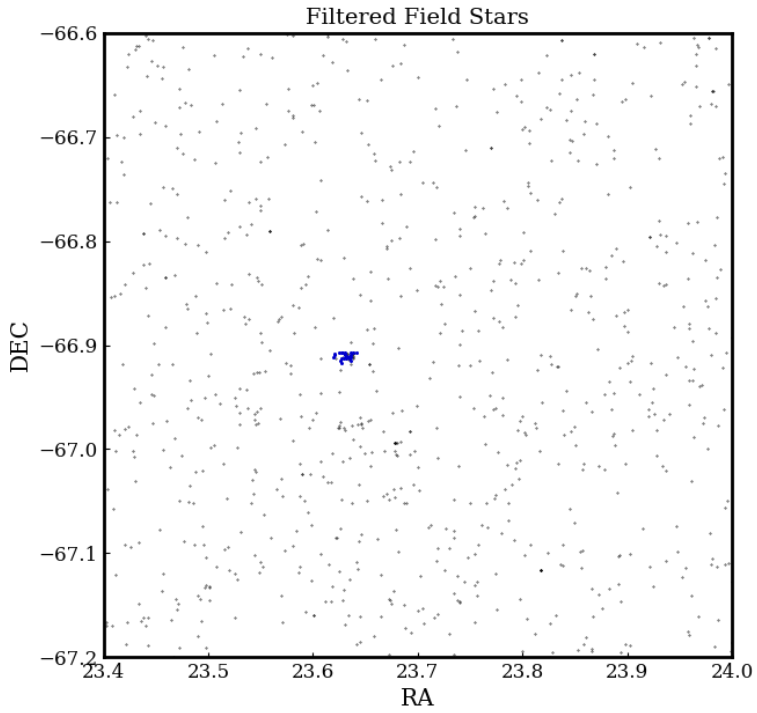
DELVE Collaboration:
~85 members across 10 countries!

Searching for Dwarf Galaxies



Position of entire isochrone on y-axis is fixed by Distance

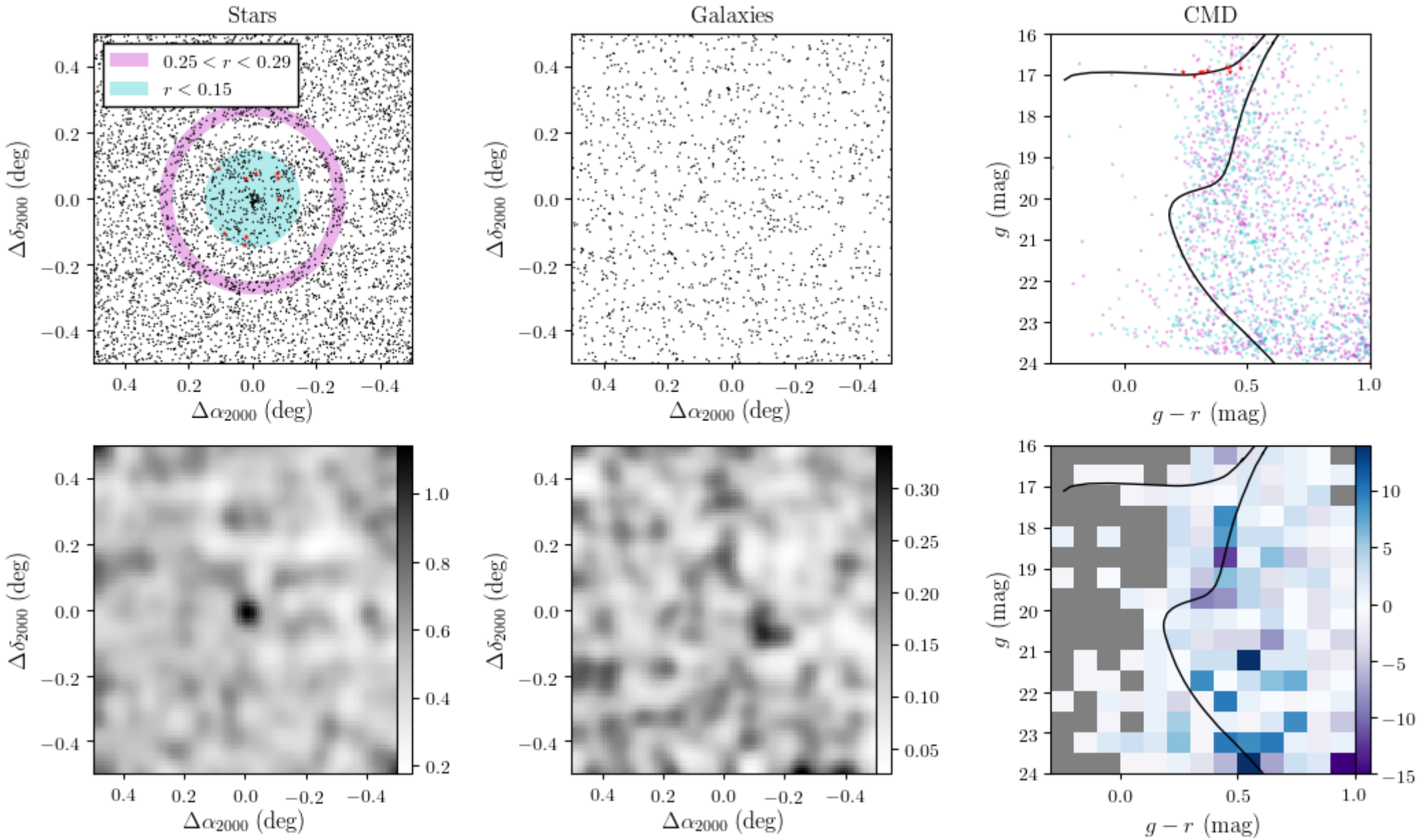




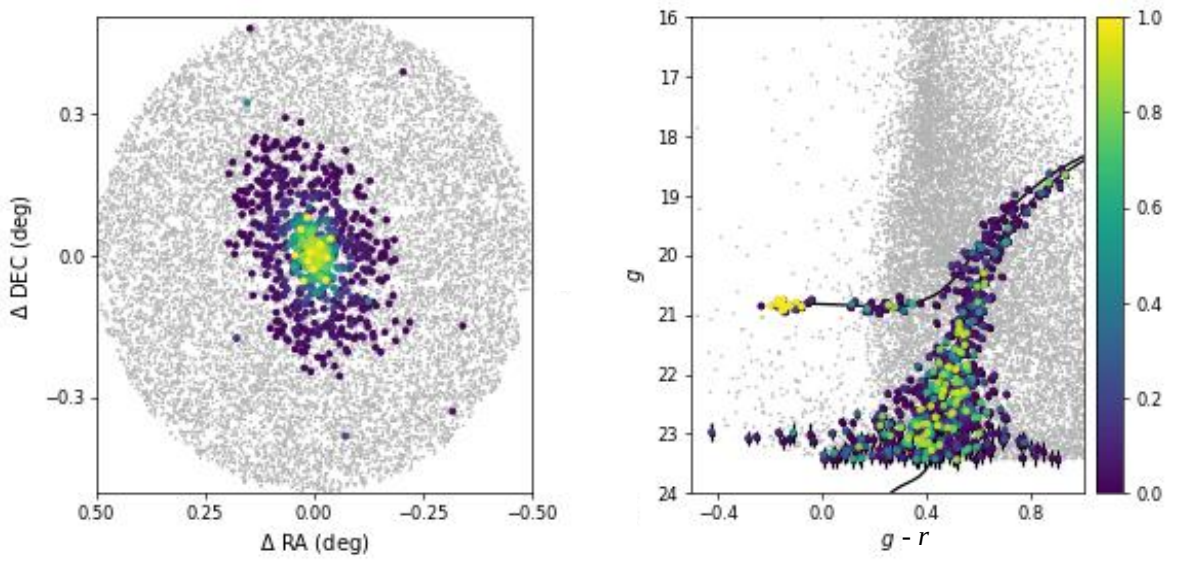
Broad approach:

Use a matched-filter isochrone (stellar evolutionary track) at a range of distances as a “cookie cutter” to filter for overdensities of stars consistent with dwarf galaxy members and increase the density signal relative to foreground/background stars

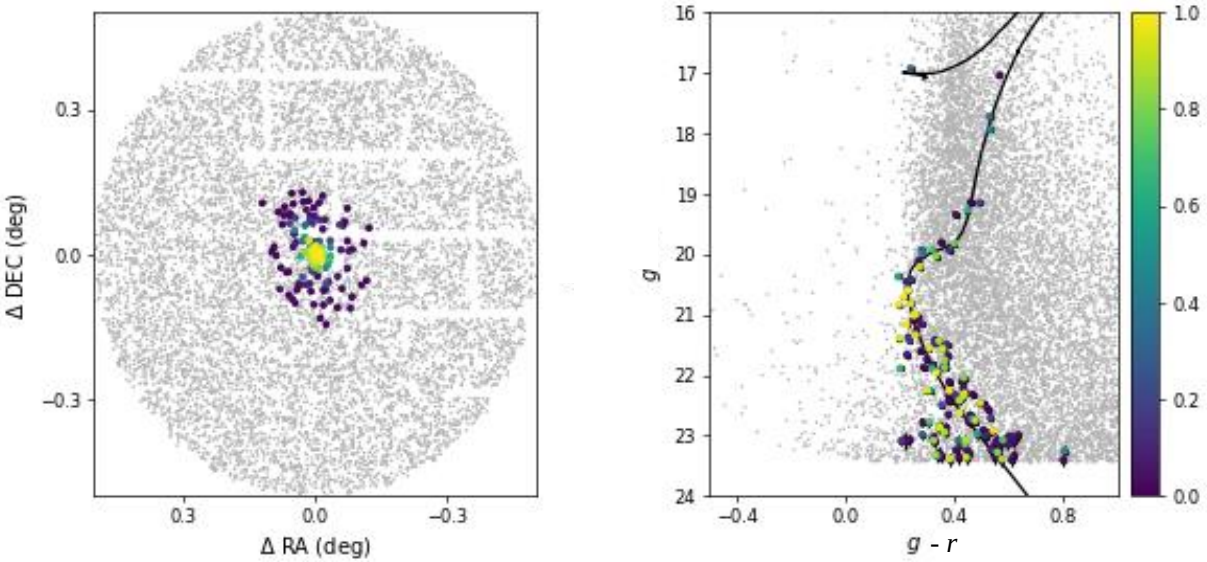
Searching for Dwarf Galaxies: Example Result



Characterizing Candidates

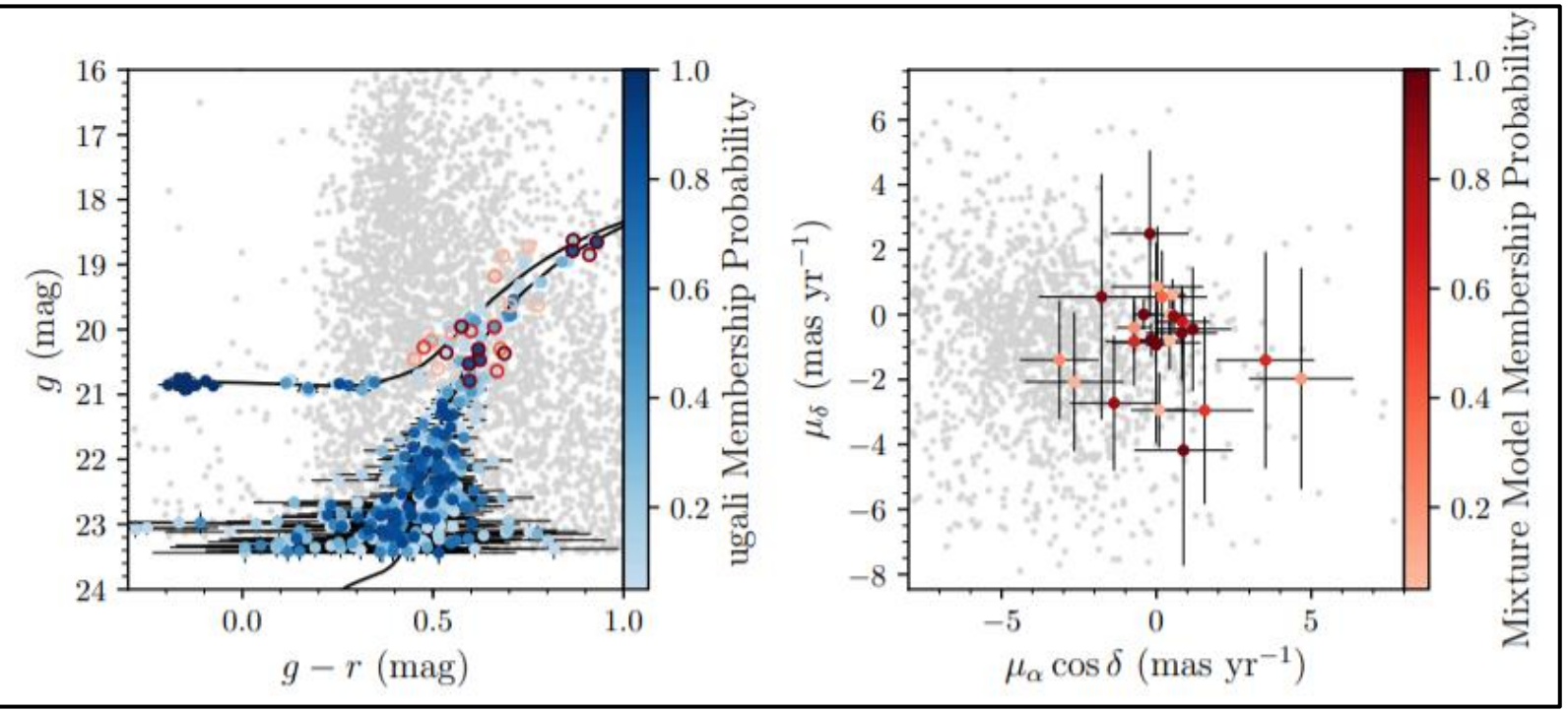


Top: DELVE Discovery of the Centaurus 1 Dwarf Galaxy
Bottom: DELVE Discovery of the DELVE 1 Halo Star Cluster
Color represents Membership Probability



- After candidates are identified, we apply a maximum-likelihood approach to constrain system parameters.
- First, we assume that the system follows a characteristic cluster/dwarf galaxy radial profile, with the isochrone of an old, metal poor system…
- Then, we apply a Markov Chain Monte Carlo approach to simultaneously determine:
  - Structural Parameters (centroid, size, position angle, surface brightness, etc.)
  - Isochrone Parameters (age, metallicity, distance)

Characterizing Candidates, continued



Centaurus 1, from Mau and Cerny et. al (2020)

Cross compare bright member stars to high precision proper motion measurements from the *Gaia* satellite.

Clustering of stars in the right-hand plot suggests bulk motion of Gravitationally bound stars

→ real system!

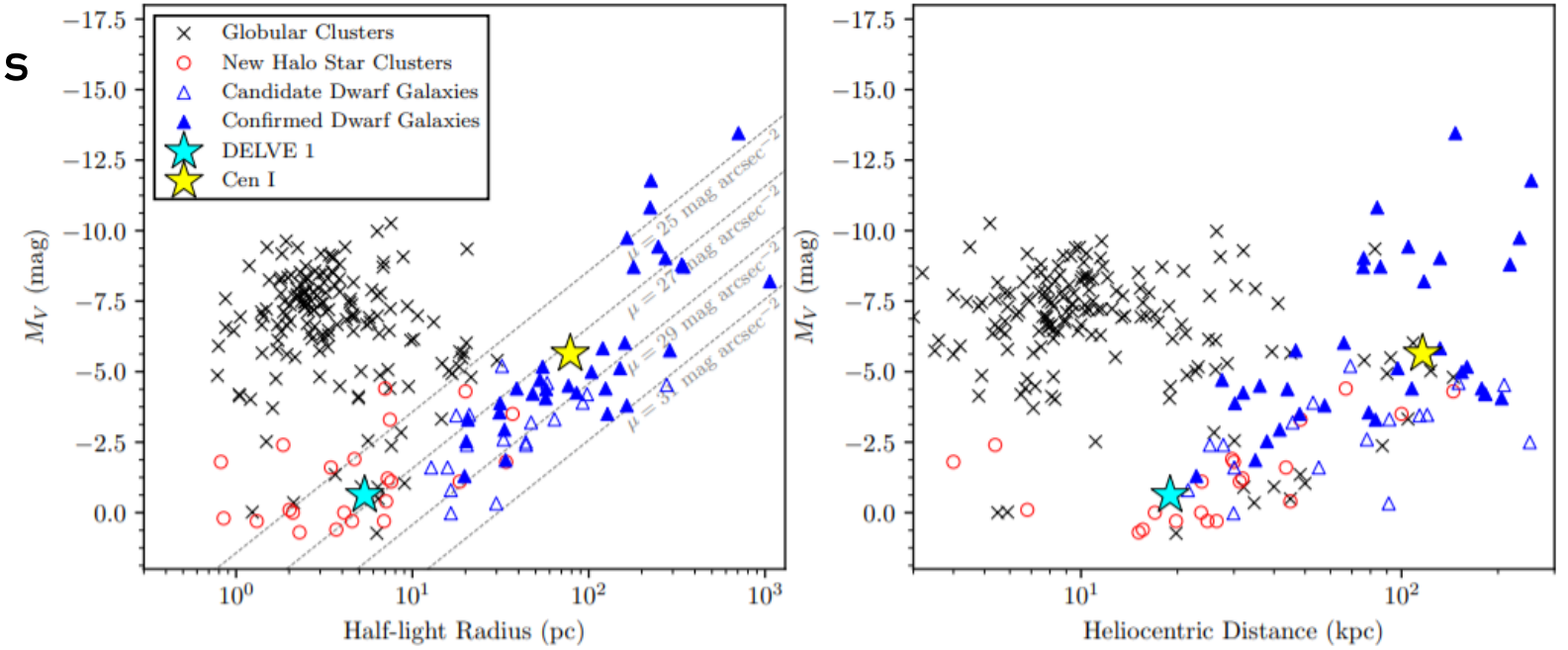
Classifying Candidates

In general, halo star clusters tend to be:

- Higher (brighter) surface brightness
- More compact,
- More metal rich,
- Closer,
- Less elliptical,
- Older, and
- Fainter integrated brightness

compared to known dwarf galaxies.

from Mau and Cerny et. al (2020)

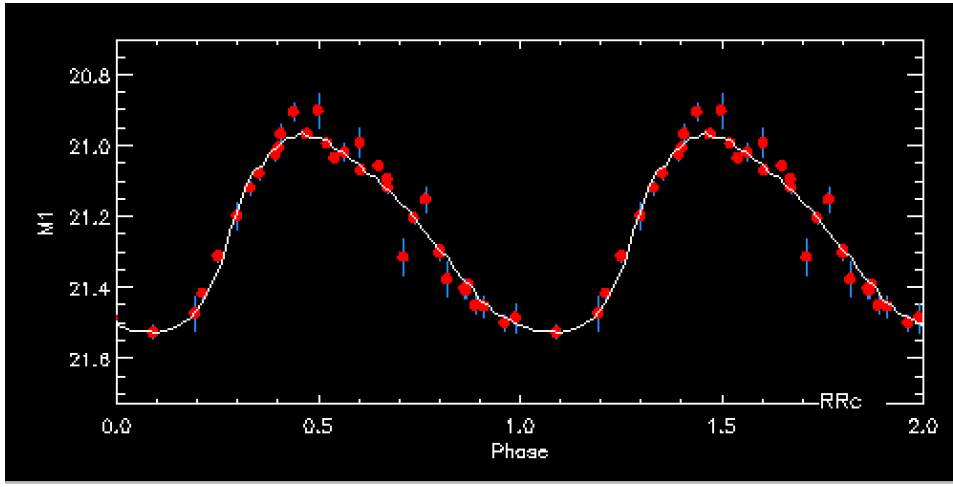


<u>However: the classification of ultra-faint systems is not always clear!</u>

Follow-Up Studies

To maximize scientific insight from dwarf galaxy systems, deeper imaging and spectroscopy is required

Preliminary



Candidate RR Lyrae variable star in Cen I: produces distance consistent with initial discovery results

<u>Deeper + Time-Series Imaging:</u>

- Deeper imaging allows for resolving fainter member stars, leading to better structural parameters
- Time-Series imaging allows for searches for variable stars, especially RR Lyrae → precise distances

<u>Spectroscopy:</u>

- Understanding the elemental abundances within the system can help demystify its origin and history
  - Ex: Large spread of metallicities suggests multiple stellar populations/periods of star formation

- Resolving stellar velocities can allow for estimates of system dynamical mass -> insight into dark matter content

Future Work

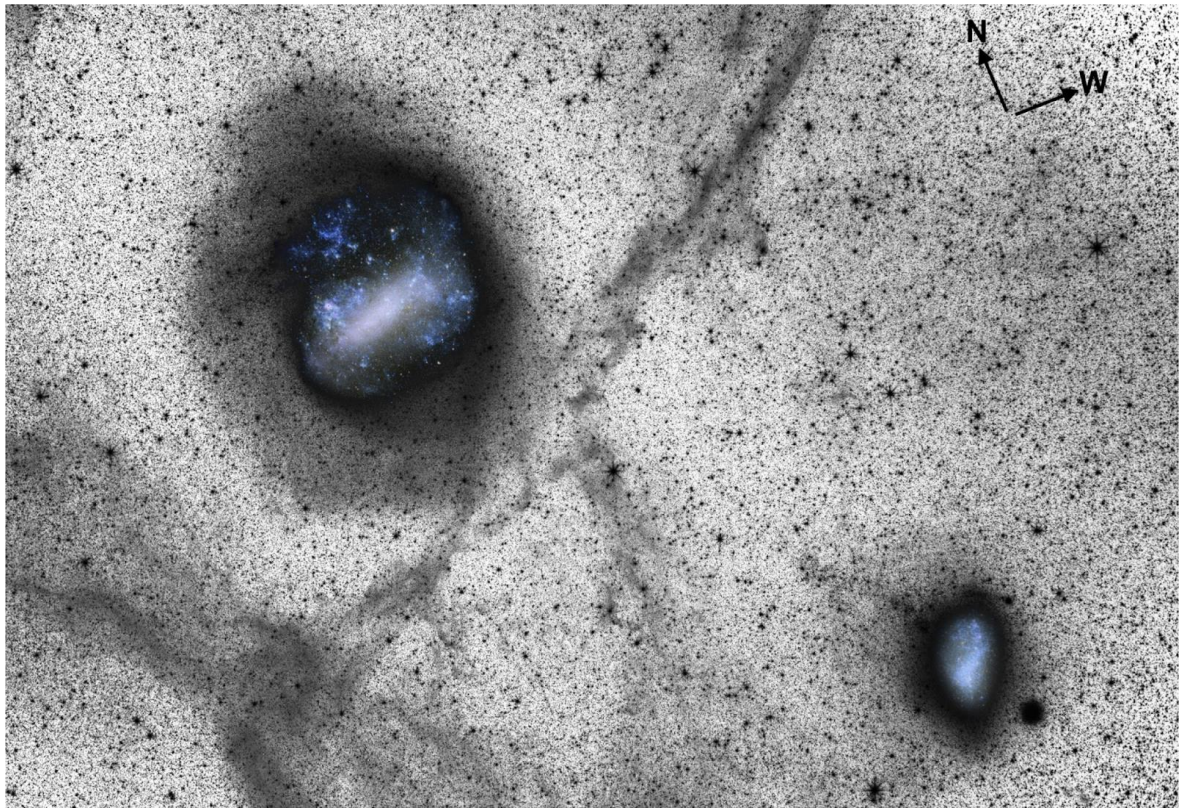


Image Credit: Besla et al (2016).

- Search over different regions of the sky – especially around the Large and Small Magellanic Clouds
- “Hierarchical” galaxy formation suggests that even satellite galaxies can host satellite galaxies
- Growing evidence that the LMC and SMC have “brought in” their own satellites as they infall into the Milky Way