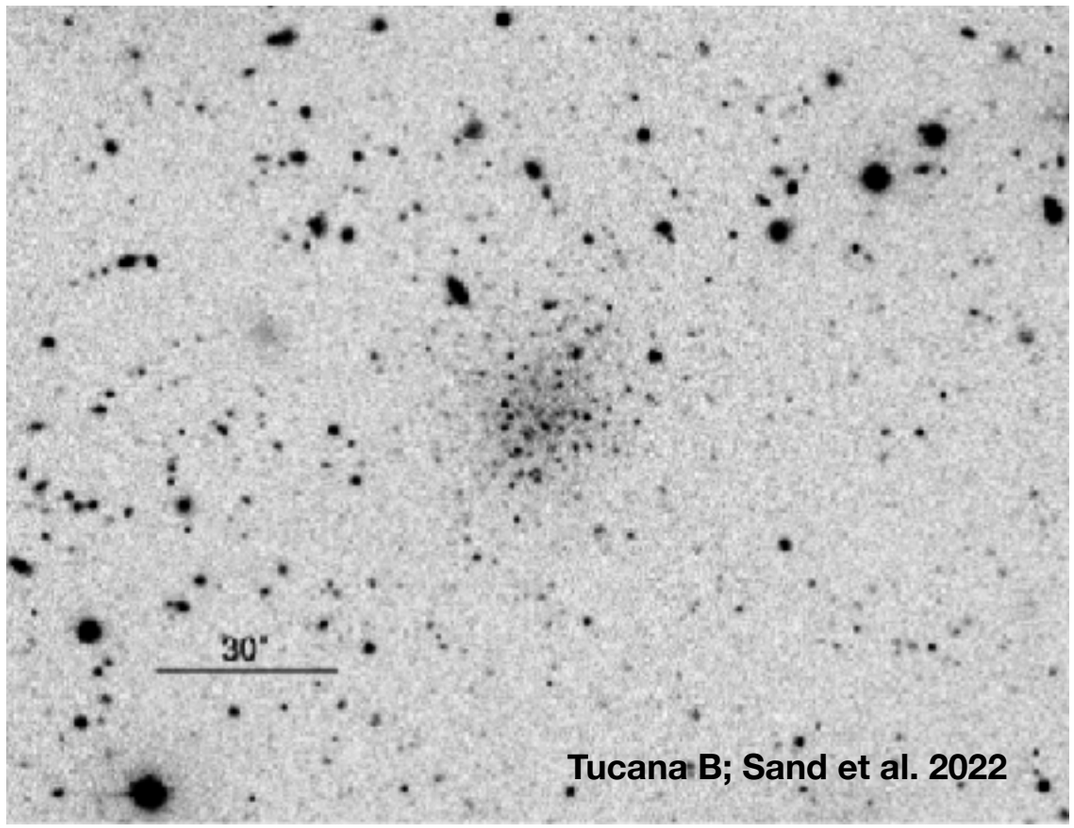
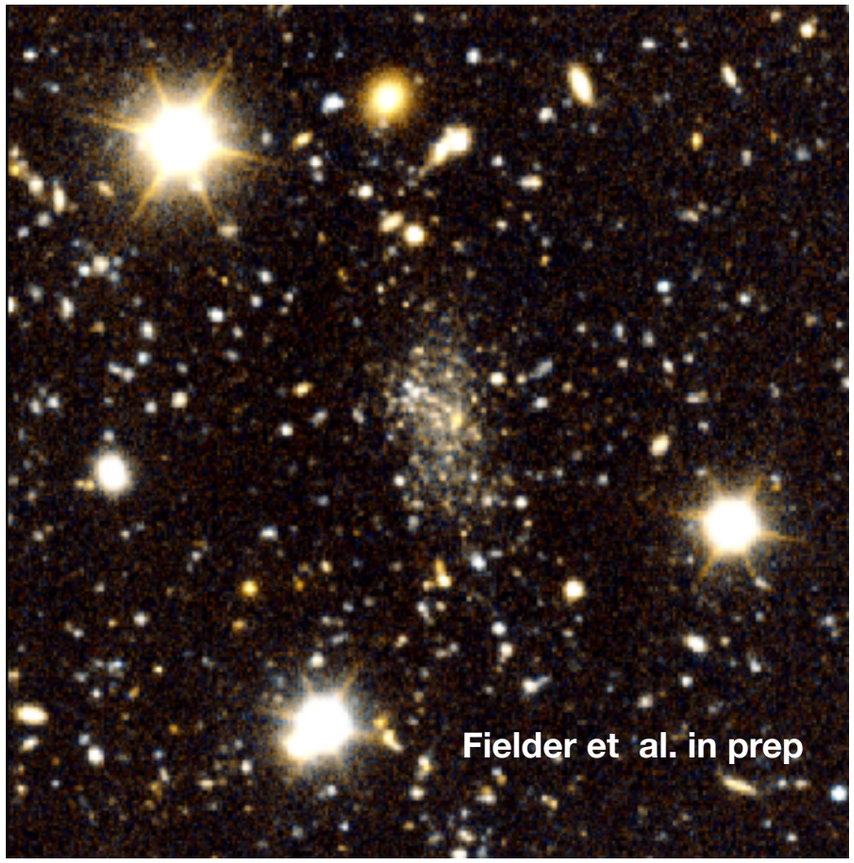
Quenched Ultra-Faint Dwarf Galaxies in the Field and Low-Density Environments



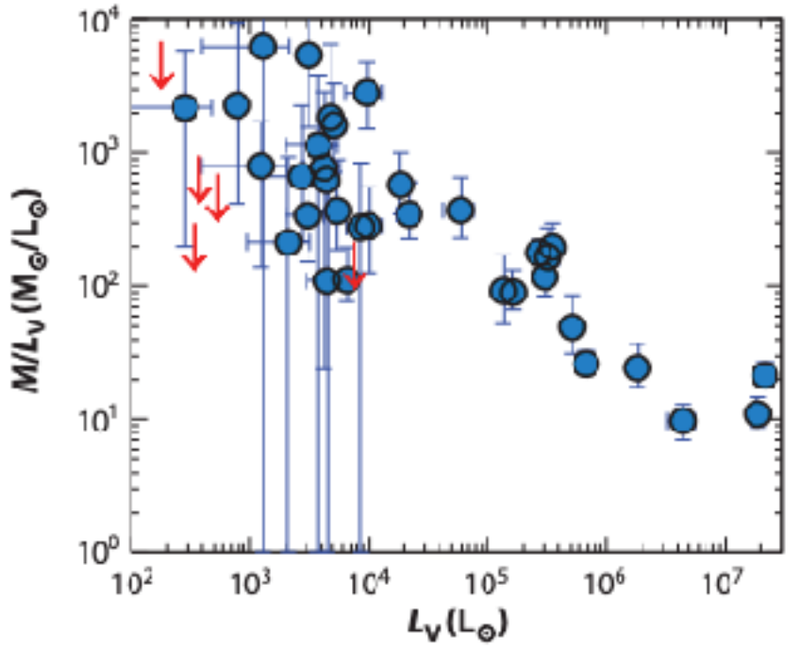


D. Sand (U of Arizona)
C. Fielder, M. Jones, P. Bennet, D. Crnojevic, A. Drlica-Wagner, A. Karunakaran, B. Mutlu-Pakdil, K. Spekkens
KICP Dwarf/Star Cluster/Stream Meeting; July 2024

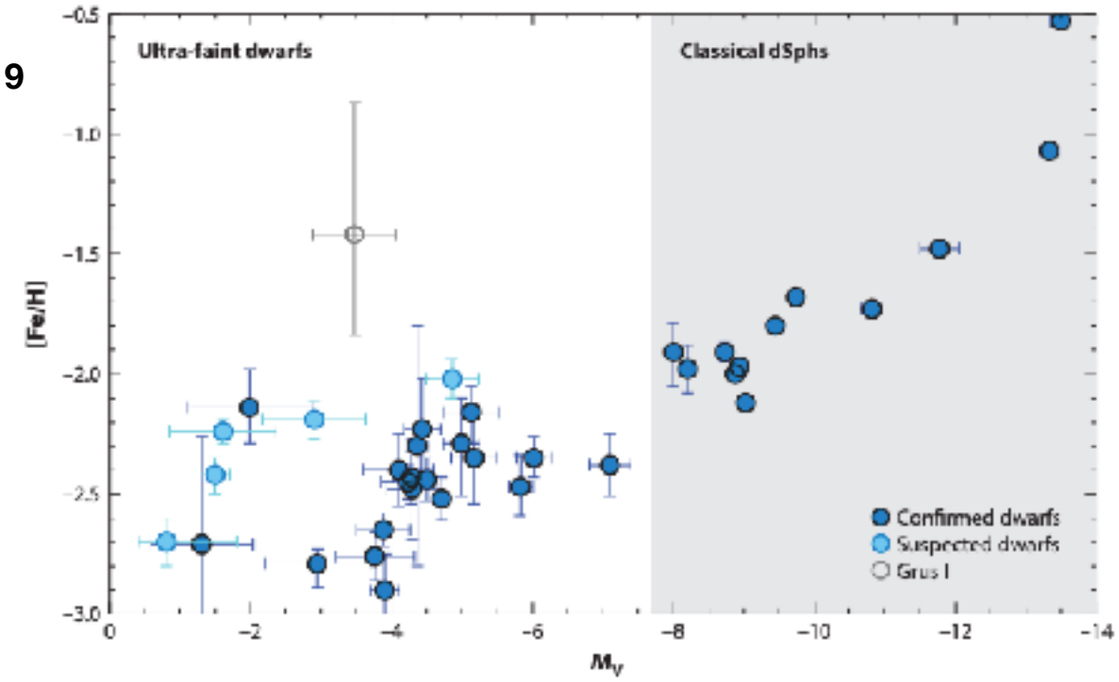
Outline

- The Significance of the Faintest Dwarf Galaxies
- Baryonic Physics shapes their properties
- We are just about to discover many ultra-faints at the edge of the Local Group and new environments
- Tucana B and (near) future JWST observations down to the oldest MSTO
- New faint and ultra-faint dwarfs in the direction of NGC300 (an LMC-mass galaxy)

Significance of the Faintest Dwarf Galaxies



Simon+19

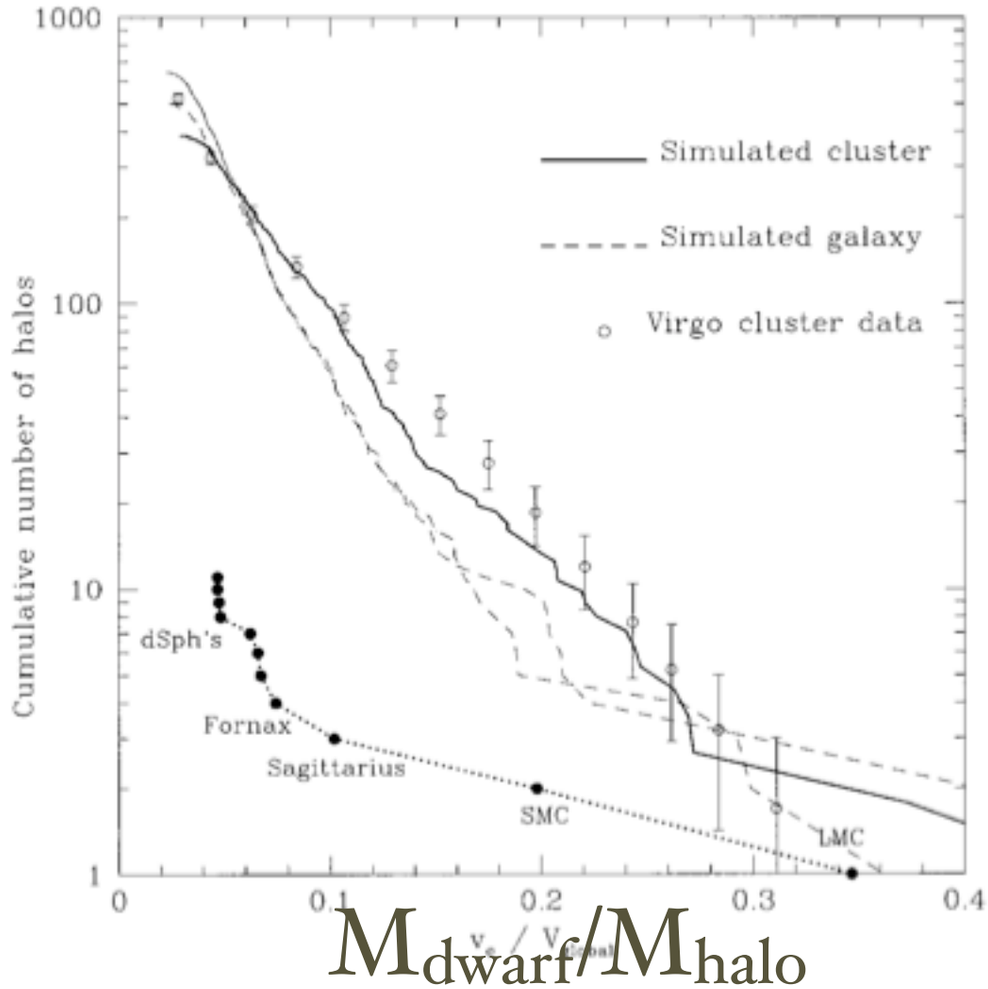


- In the smallest dark matter halos we know of ($\lesssim 10^9$ Msun).
- Most dark matter dominated systems
- Floor of galaxy formation? Lowest metallicities, smallest sizes, smallest stellar masses, simplest assembly history of all galaxies (paraphrased from Simon+19).
- Because they are the smallest stellar systems known to host dark matter halos, a great laboratory to understand internal (SN & star formation feedback) and external (tidal & ram pressure stripping) influences. Reionization likely also leaves an imprint.

Cold Dark Matter Simulations -- Number & Distribution of Subhalos-- the 'Missing Satellites' Problem

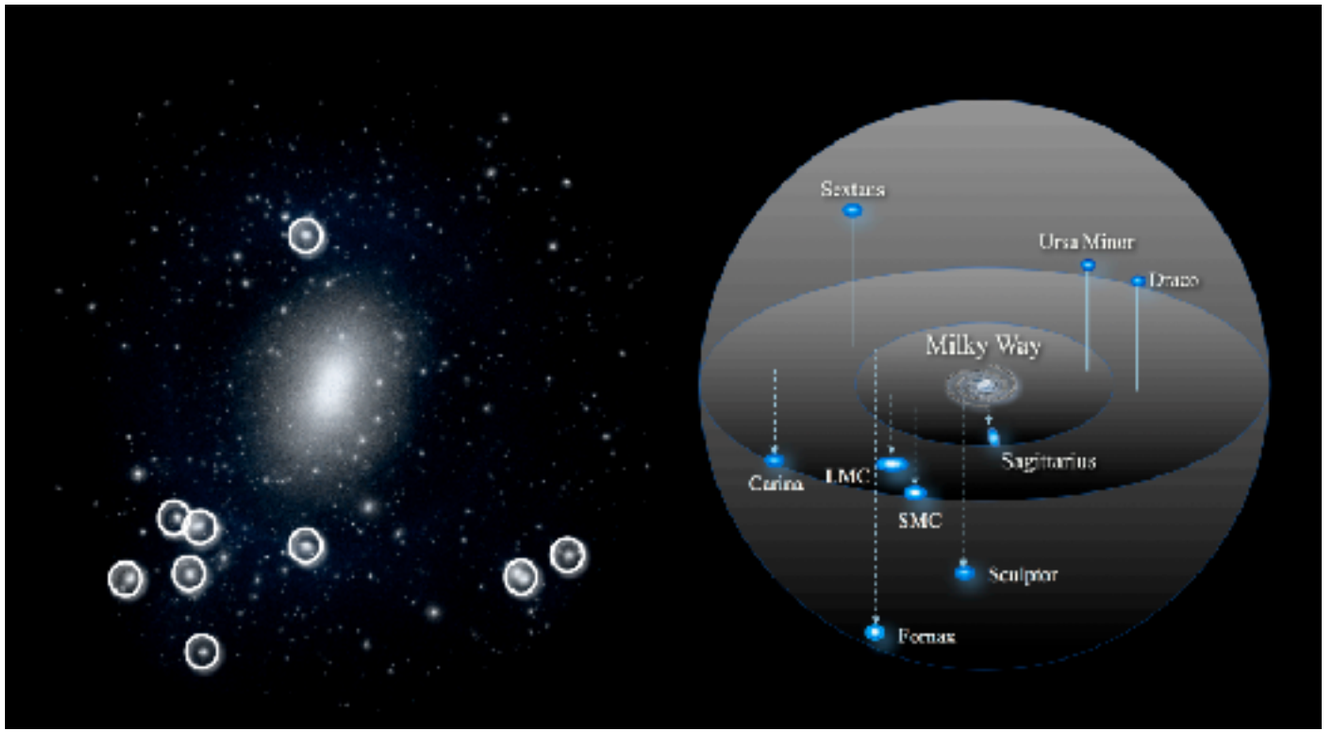
- As originally posed: Within the virial radius, the Milky Way should contain ~500 halos larger than Draco

- The galaxy cluster satellite function could reproduce numerical predictions, but not for a halo the size of the MW!

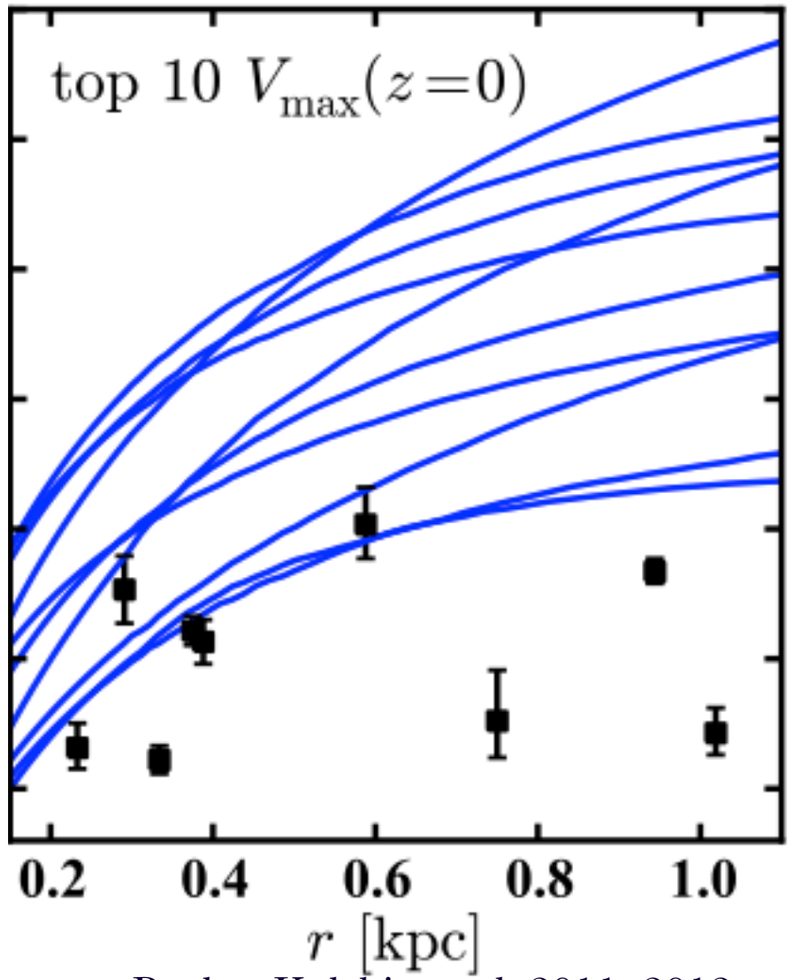


Moore et al. 1999; Clear lack of MW satellites, pre-SDSS

Too Big to Fail



Vcirc (km/s)



Boylan-Kolchin et al. 2011, 2012

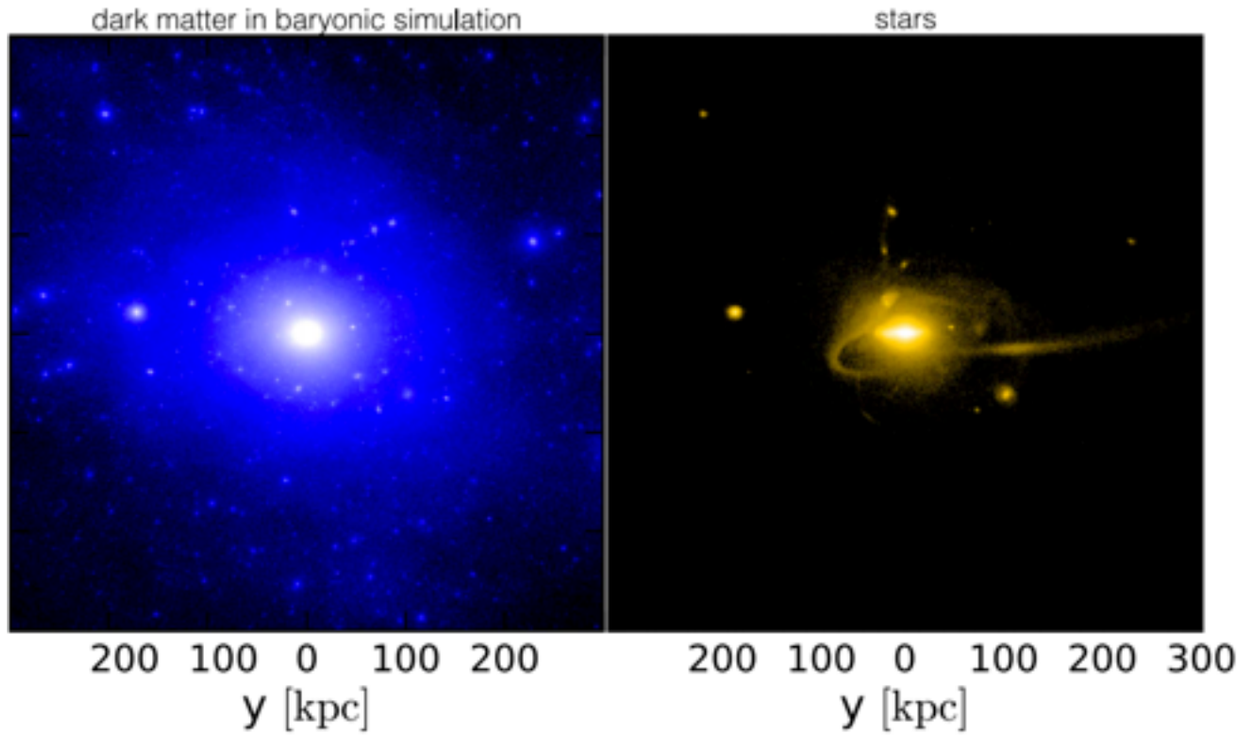
- Dark matter only simulations predict too many massive dense subhalos compared with satellites around the MW.

CDM problems could be (mostly) fixed by baryonic processes

- Ultraviolet heating from **reionization** can keep gas from cooling in small halos, and so no stars form.

- SN feedback -- a first generation of stars goes supernova, and drives out remaining gas in shallow potential well of low-mass DM halo.

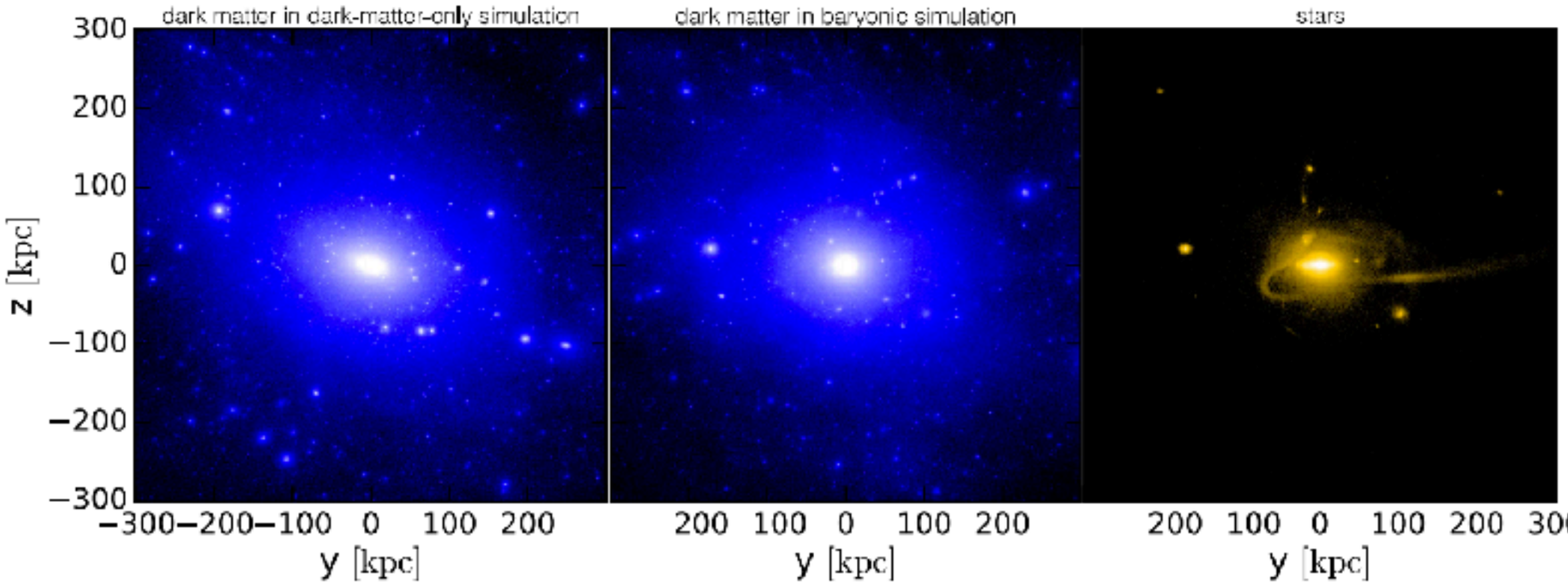
- Tidal/ram pressure stripping of gas. Fewer visible dwarfs today, and/or greatly influenced.



Latte simulations; Wetzel et al. 2016

Mapping between number of stars and DM halo mass is stochastic at low mass end.

Realistic inclusion of baryons significantly reduces CDM's 'problems'



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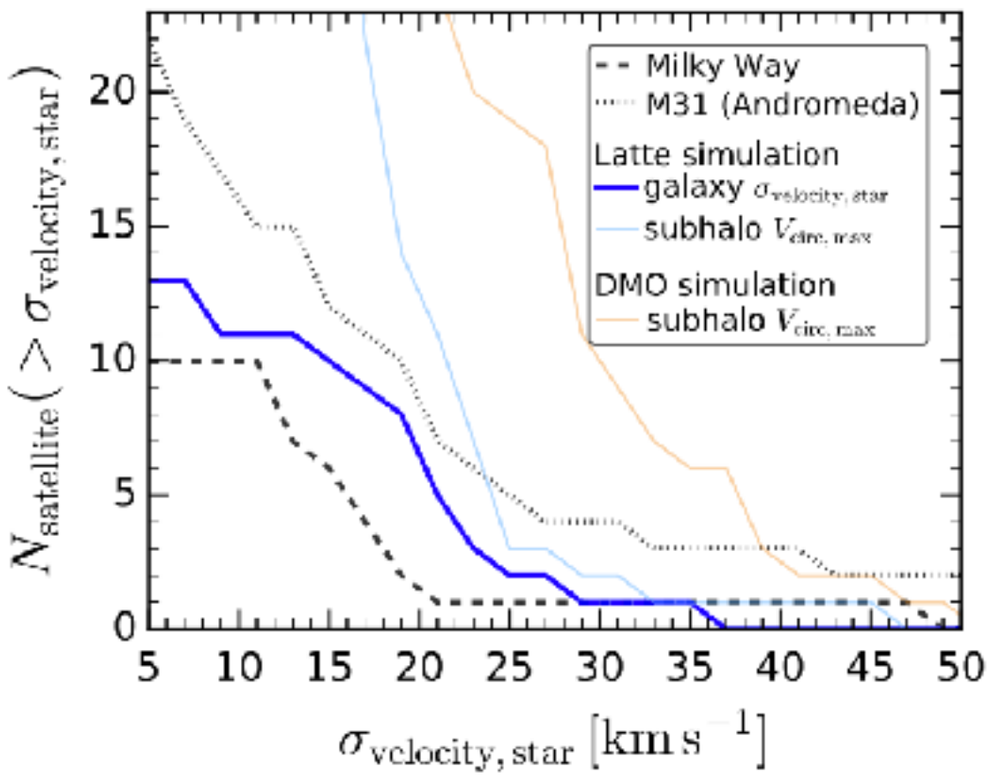
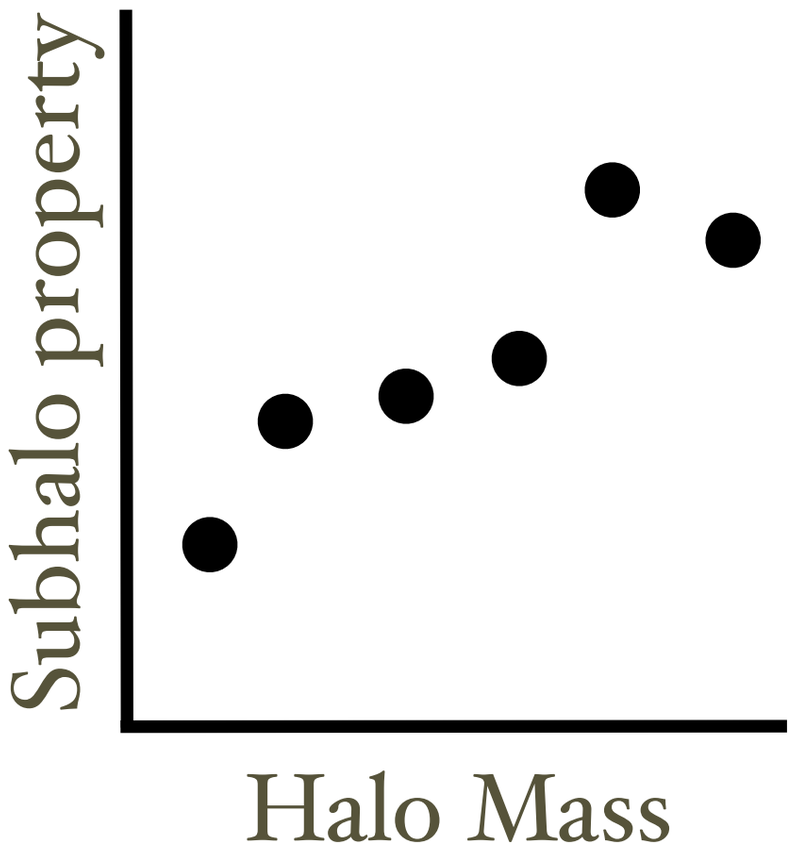
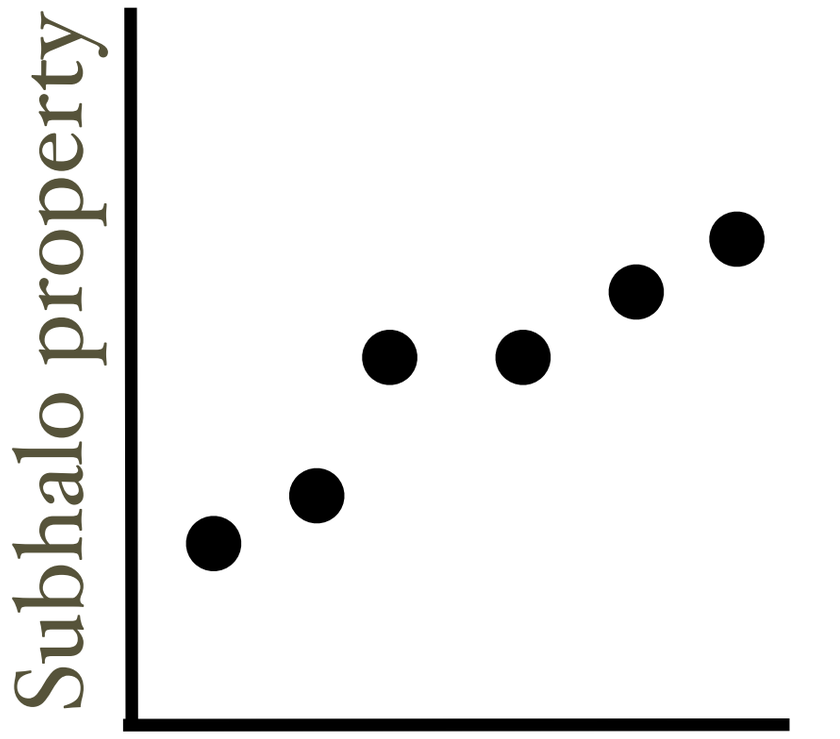


Theory + Observations converging in the Local Group.

Where do we go from here? The Local Group is nice, but....
What we want:





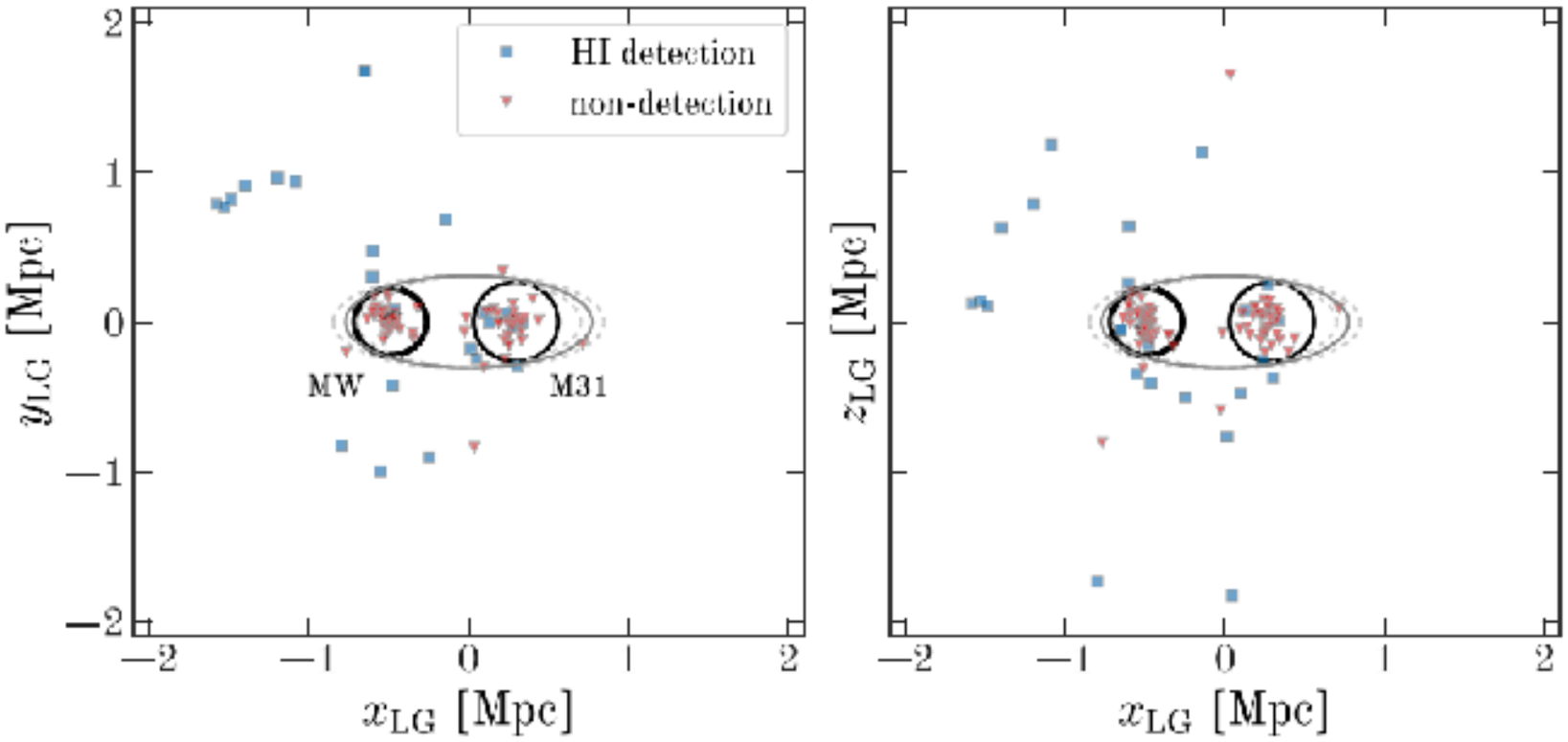
Subhalo property can be dwarf luminosity function, stream richness, you name it.

Many Interesting Areas of Parameter Space Not Yet Explored

Can stress-test or expand our views of the interplay between baryonic physics & DM

- Dwarfs at edge of Local Group: backsplash galaxies and gas stripping/quenching.
- Truly quenched ‘field dwarfs’ that have never interacted with a larger galaxy and may have been quenched by reionization, supernova/stellar feedback, stripping by cosmic web

In the Local Group, environment seems to matter — no HI, no more star formation



Widely interpreted as ram-pressure stripping of dwarfs by the hot halos of the MW/M31

Putman+21

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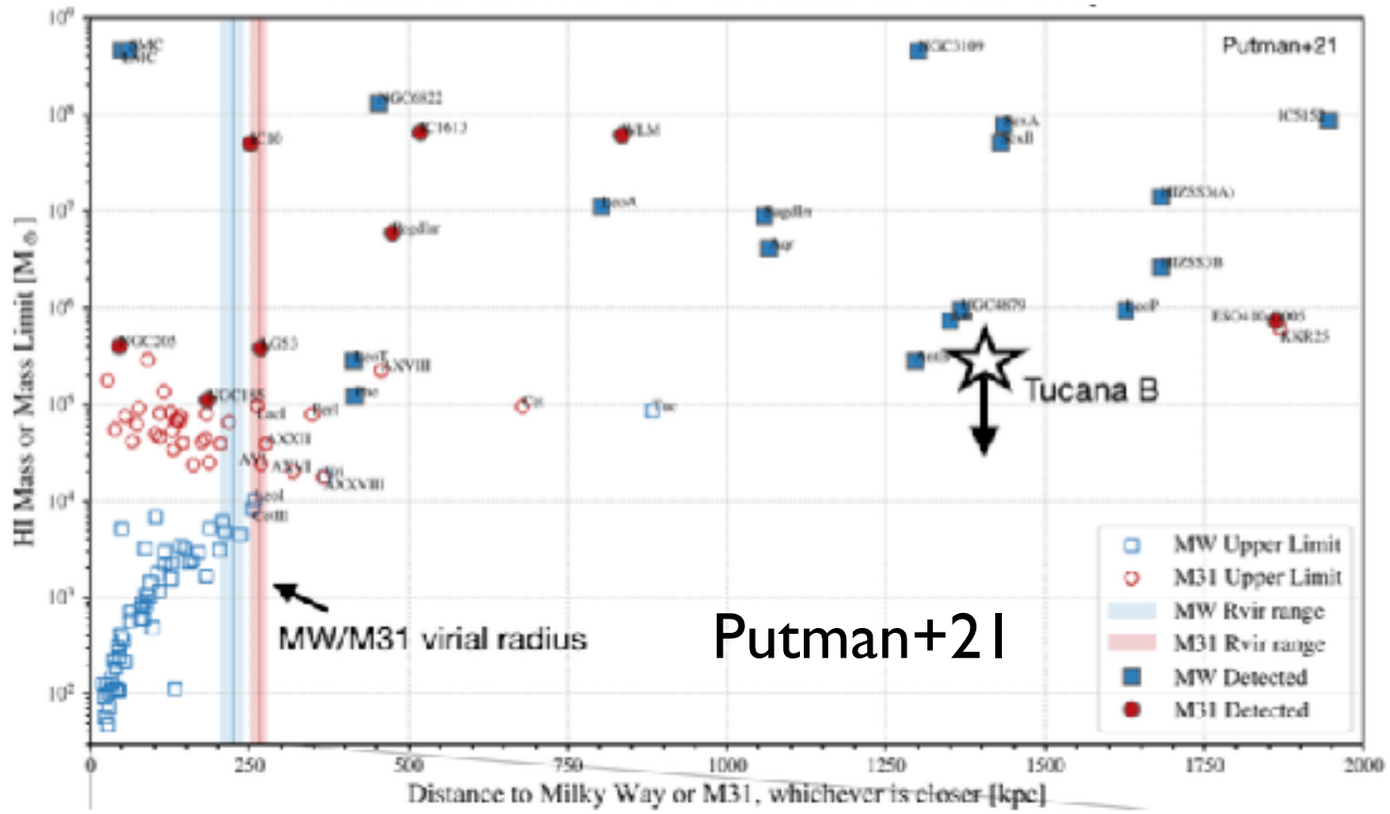

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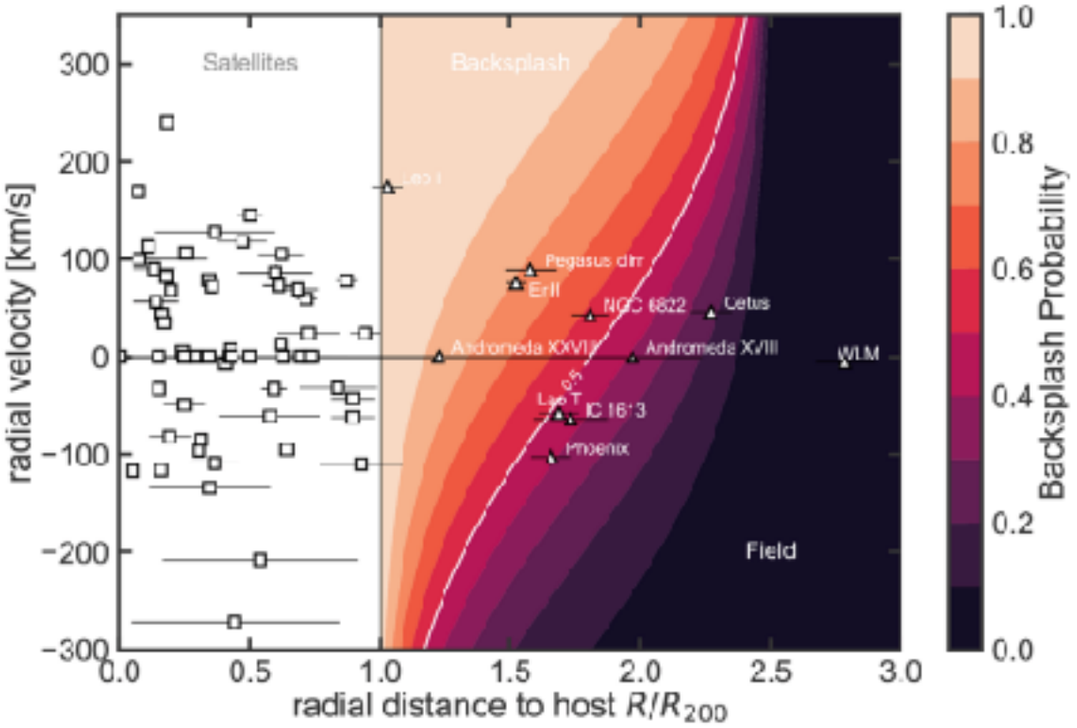
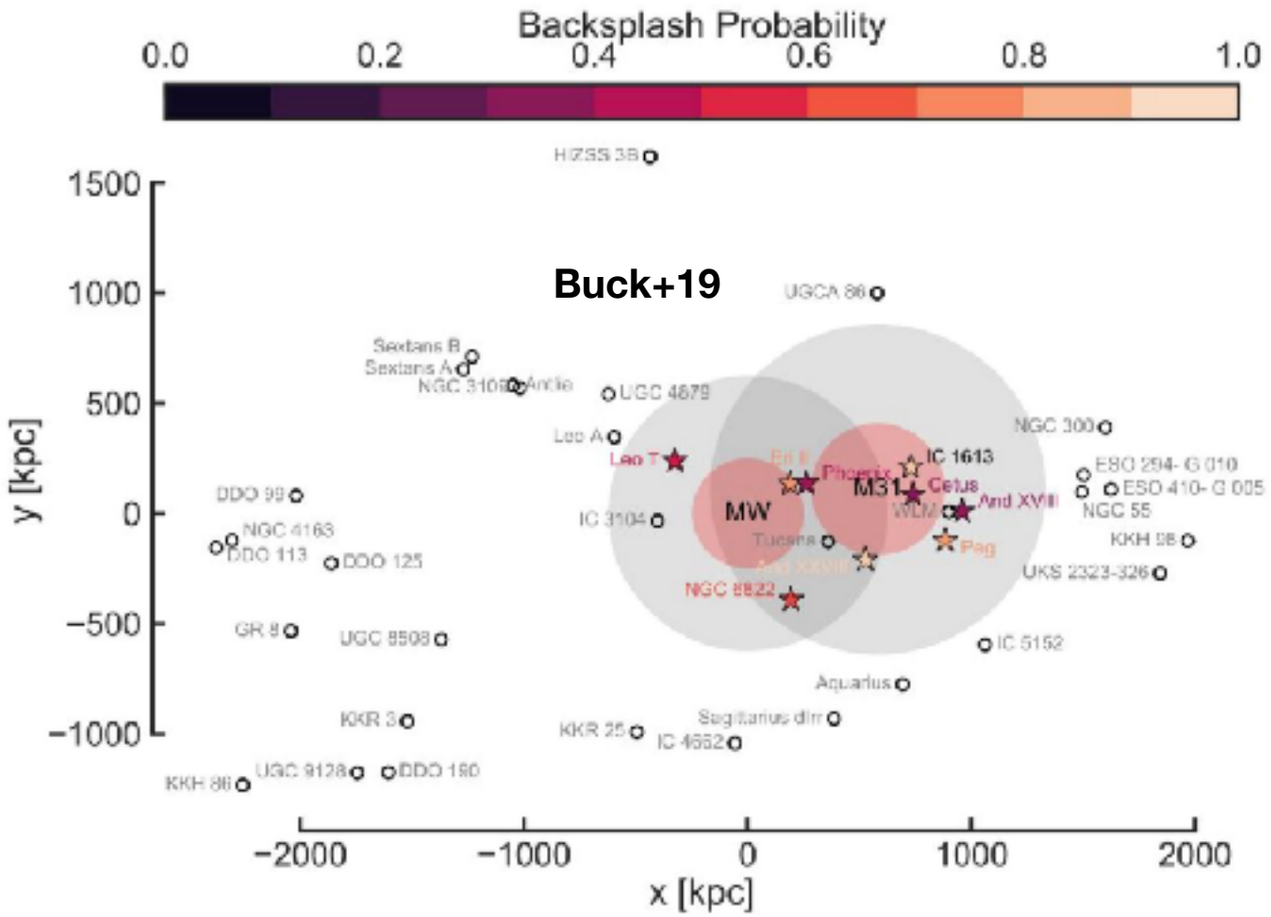
- Dwarfs within virial radius are mostly gas free
- Dwarfs at ~1-2 r_{vir} are a mix of gas rich and gas-free
- Dwarfs out in the 'field' are nearly always gas-rich [Geha+12]. With no hot halo to interact with, can retain gas and continue SF.

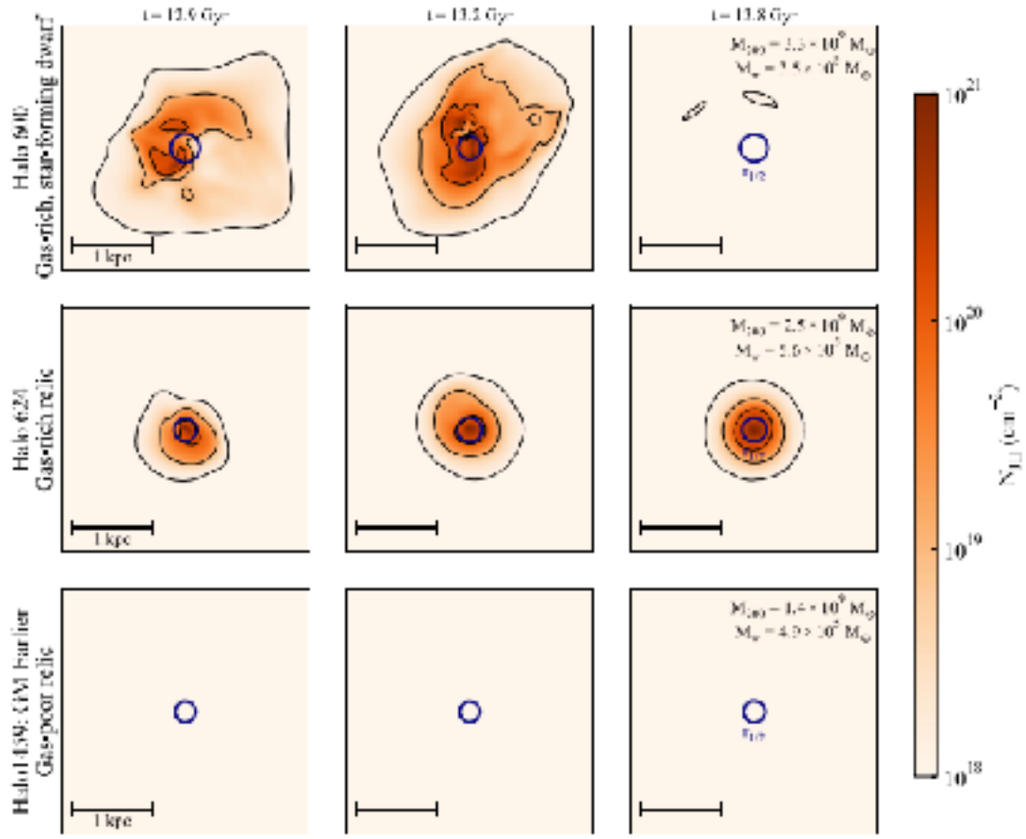
Backsplash Galaxies





- Tricky to identify with radial velocities and distances. May improve with proper motions.
- Teach us about orbital history of satellite system, and quenching.
- Now accessible around other nearby galaxy systems (e.g. NGC253, CenA, M81 etc)

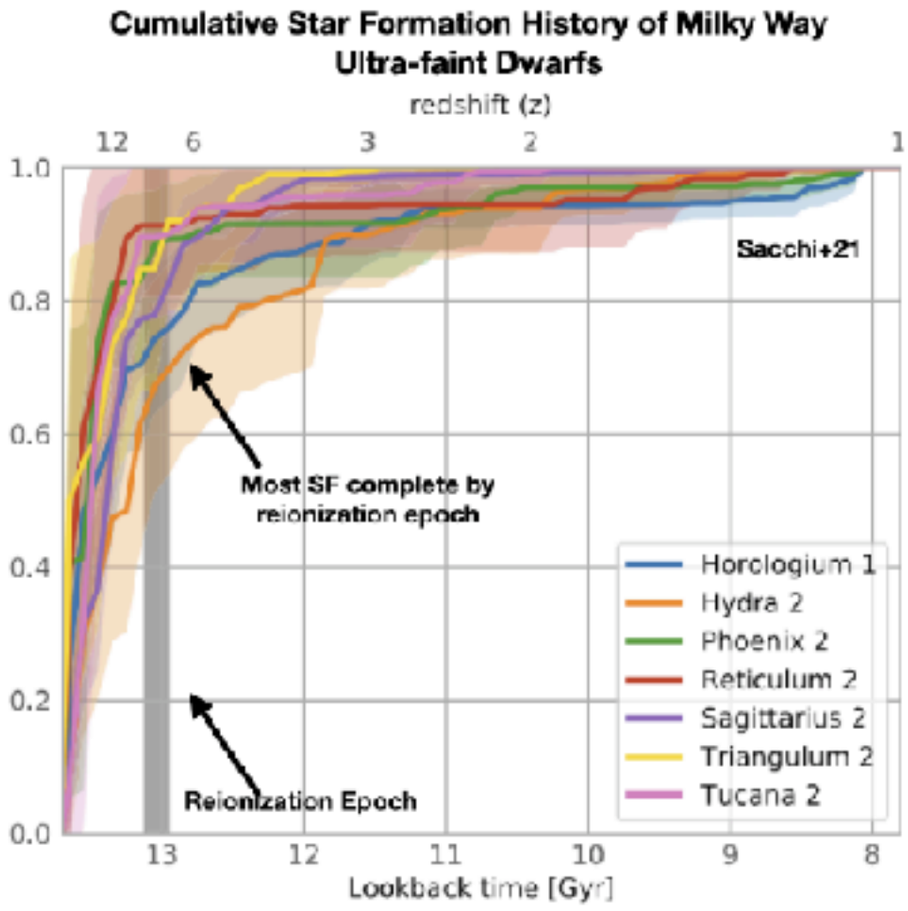
Reionization may quench the faintest dwarfs

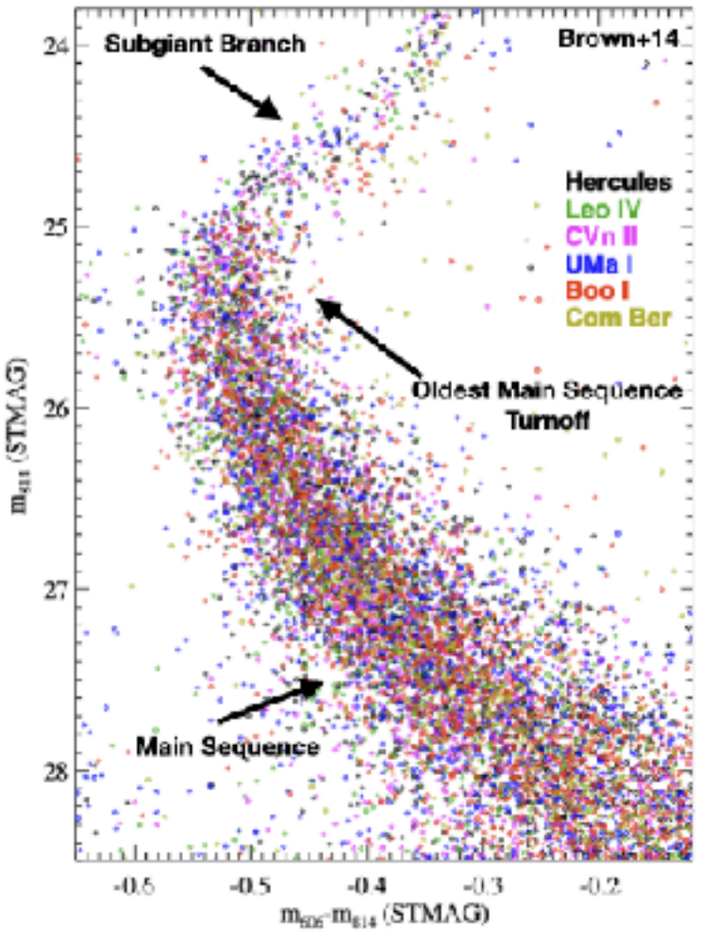


Rey+22

- Ultra-faint dwarfs are the most sensitive to reionization. The UV photons that reionize hydrogen also heat it up, effectively 'boiling' out the gas in the smallest DM halos (e.g. Jeon+17; Rey+20; Applebaum+21).
- Dwarfs with M_{star} <$10^{5\text{-}6}$ M_{sun} most sensitive (although measuring this is important!). Bullock+01; Ricotti & Gnedin+05, Rey+20, Pereira Wilson+22
- Dwarfs may re-accrete gas and even form stars again (Rey+22)
- Would be a strong verification of galaxy formation models at small scales.

Reionization may quench the faintest dwarfs





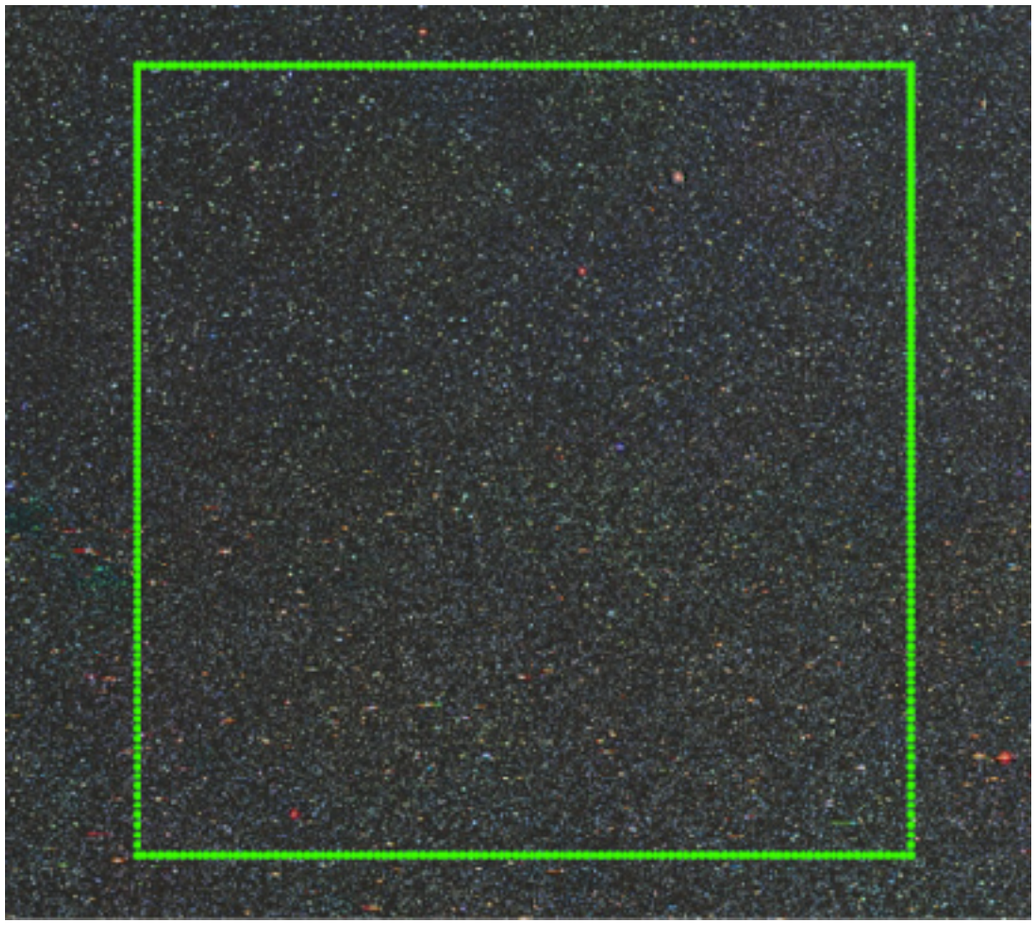
- Those dwarfs associated with the LMC seem to have an 'extended' early epoch of star formation with respect to the MW (Sacchi+21). Patchy reionization? (Kim+23). May be differences with M31 as well (Savino+23)
- Disentangling the effects of environment and reionization are difficult in the Local Group (see Miyoshi+20, but see Rodriguez Wimberley+19). Ultra-faint dwarfs in the 'field' are necessary for verification and to sample a variety of environments, etc
- We can now observe down to the oldest main sequence turnoff within ~2-3 Mpc with NWST+NIRCam! (Weisz+19)

Many Interesting Areas of Parameter Space Not Yet Explored

Can stress-test or expand our views of the interplay between baryonic physics & DM

- Edge of Local Group (McQuinn, DELVE, HSC-SSP)
- 'Floor is Lava' approach that helped lead directly to new ML/CNN searches like SEAMLESS (see Jones talk earlier).

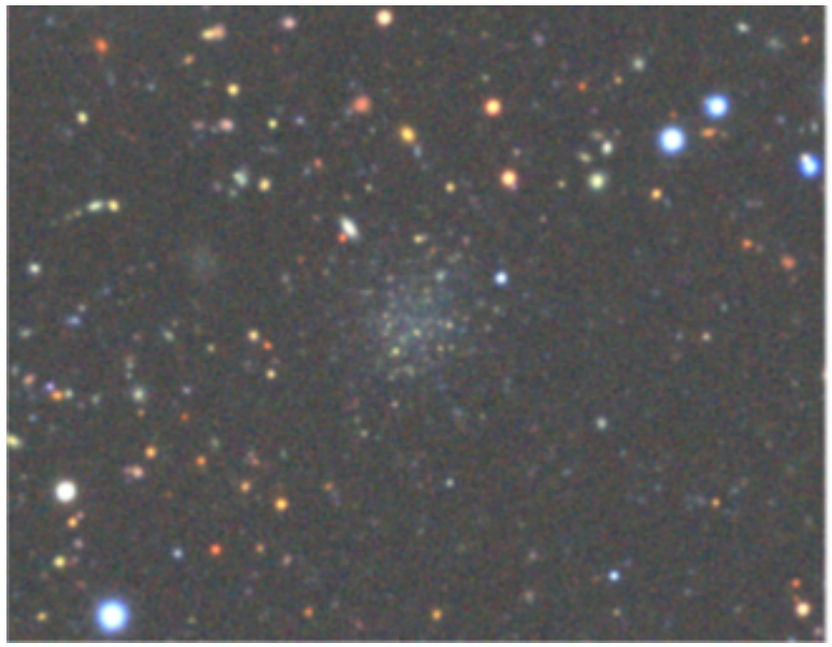
Dwarfs at the Edge of the Local Group *should* have their own satellites

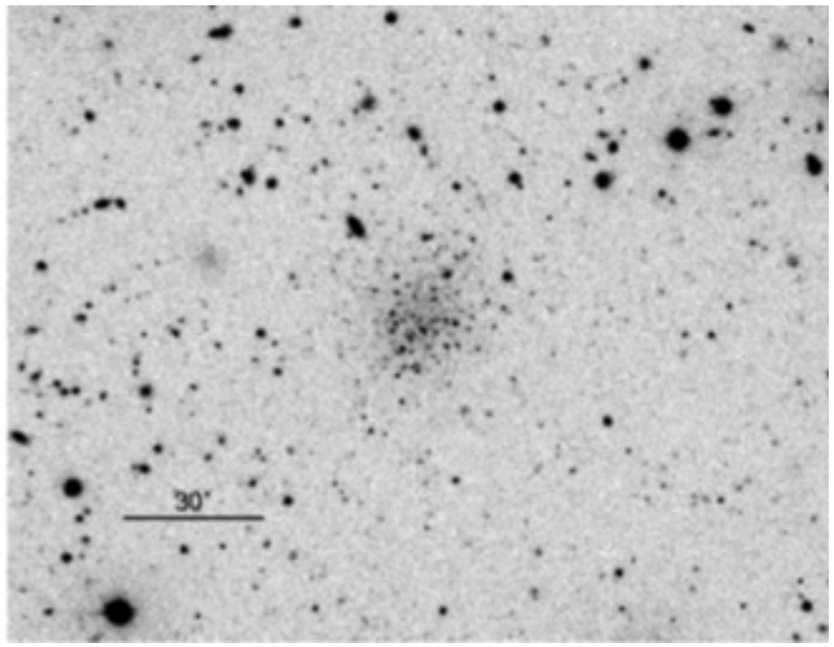


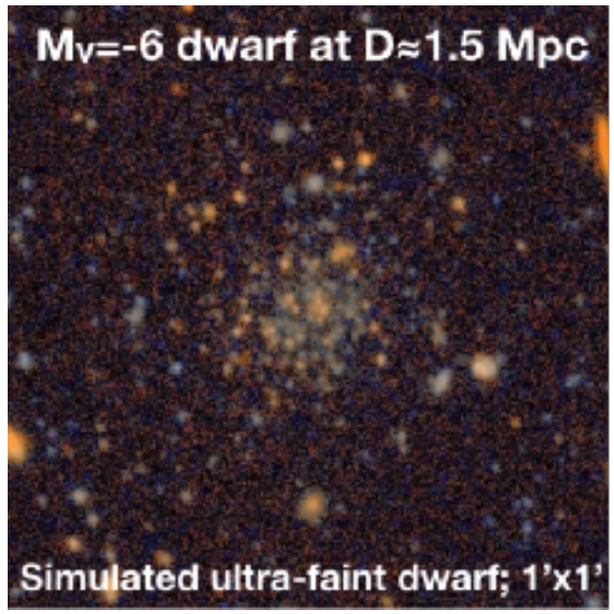
- Tucana dwarf spheroidal, at edge of Local Group
  - D=900 kpc
  - M_V=-9.5
- Quenched, likely backsplash galaxy.
- Search by eye in the wonderful Legacy Viewer, marking off 200x200 kpc^2 region: https://www.legacysurvey.org/viewer

Tucana B:

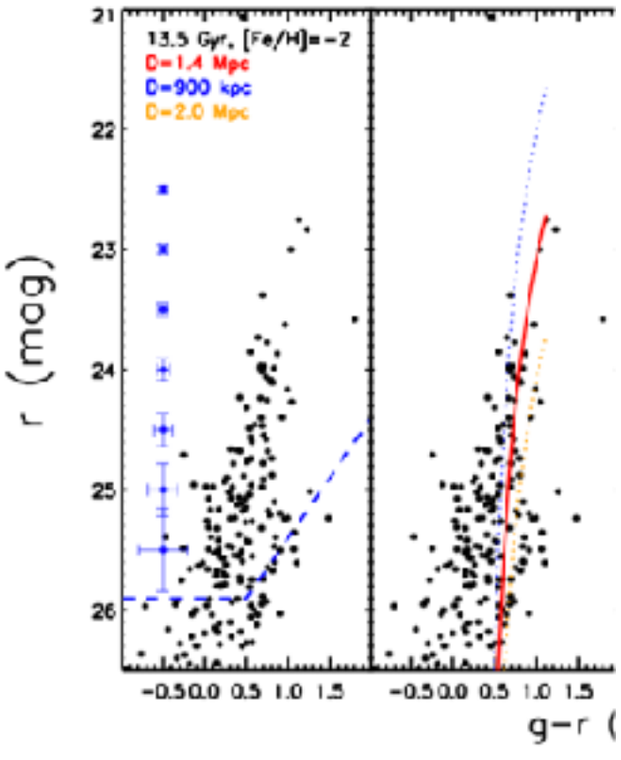
A real candidate to be a ‘reionization fossil’ (Sand et al. 2022). Not associated with Tucana!

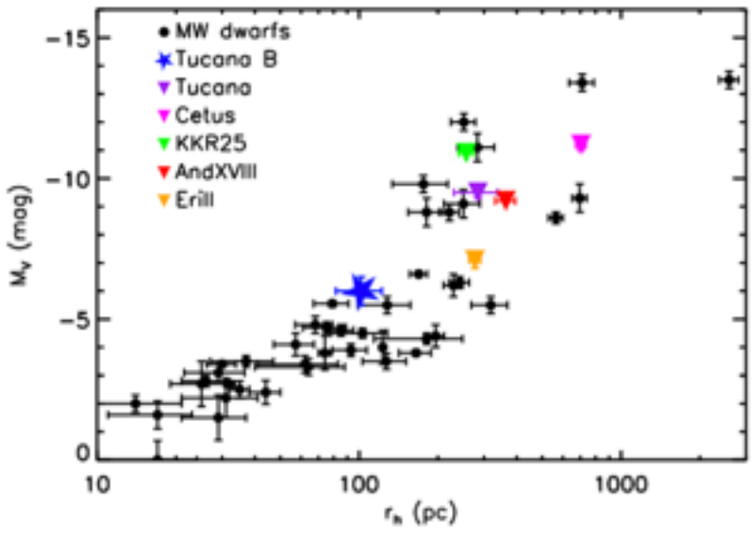


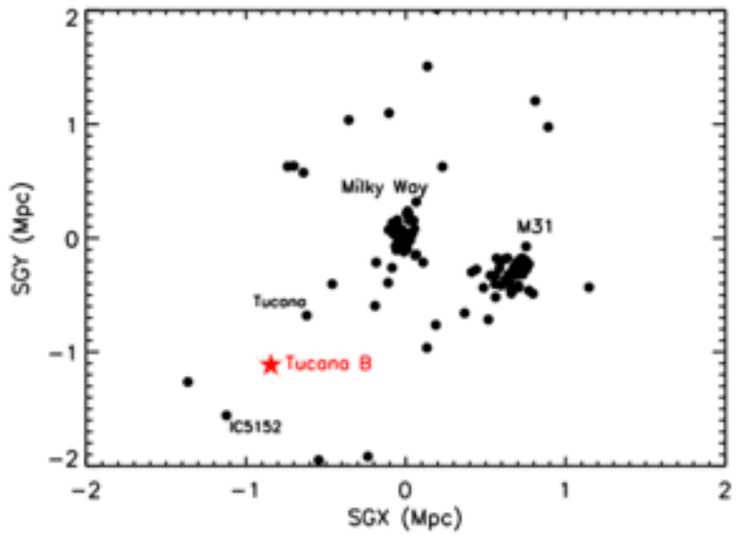




Tucana B; an isolated M_V=-6.9 dwarf at 1.4 Mpc. No GALEX UV emission: $\log(\mathrm{SFR}/\mathrm{M}_\odot\ \mathrm{yr}^{-1})<-6.0$ (based on the FUV band).







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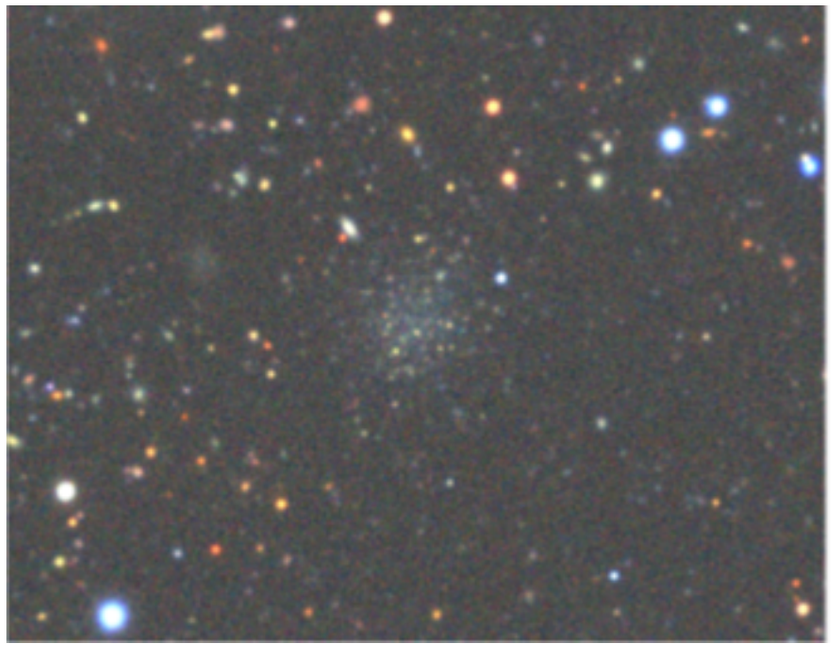

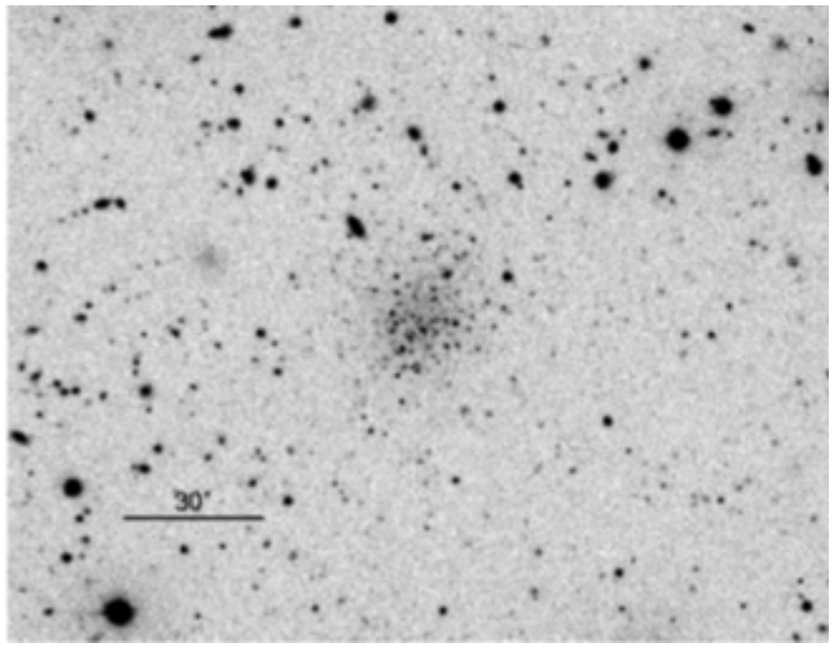

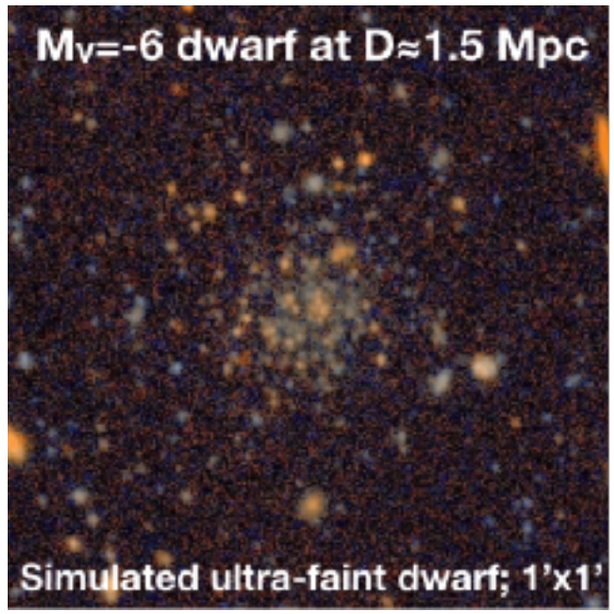

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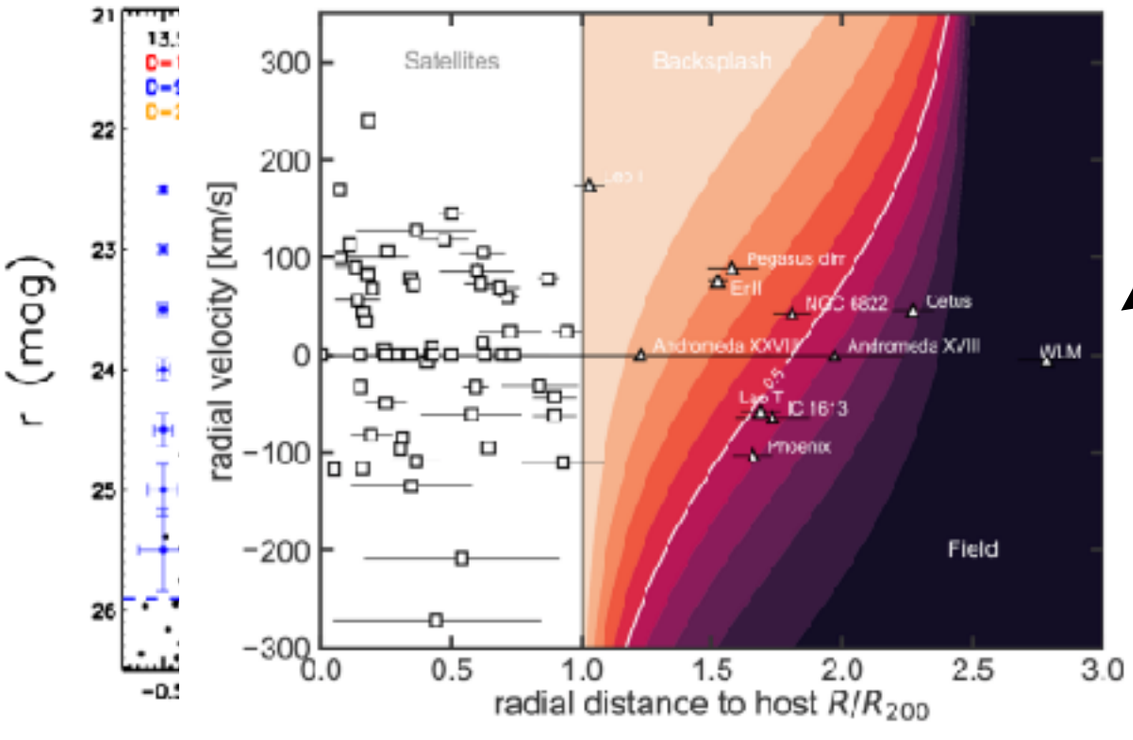
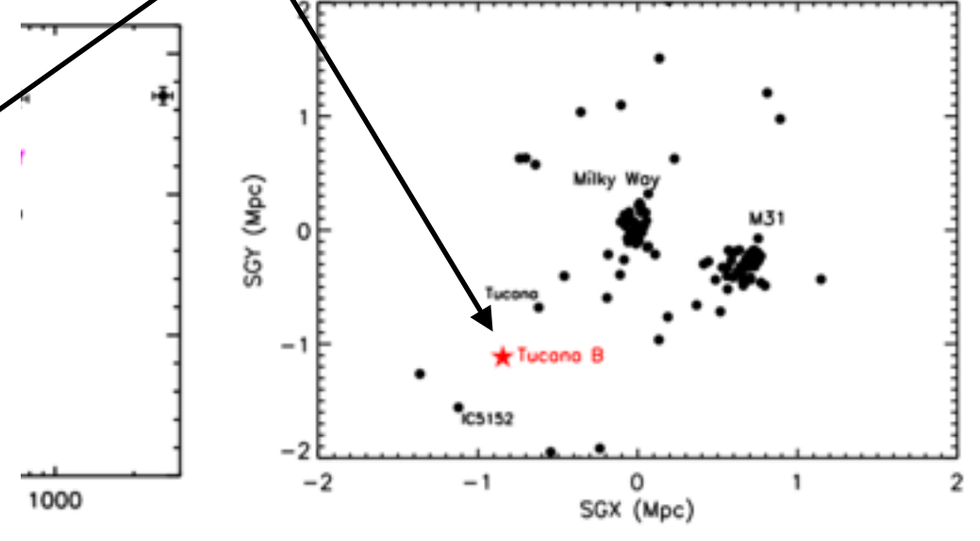


Tucana B is ~4-5 rvir! Very unlikely to be a splashback galaxy



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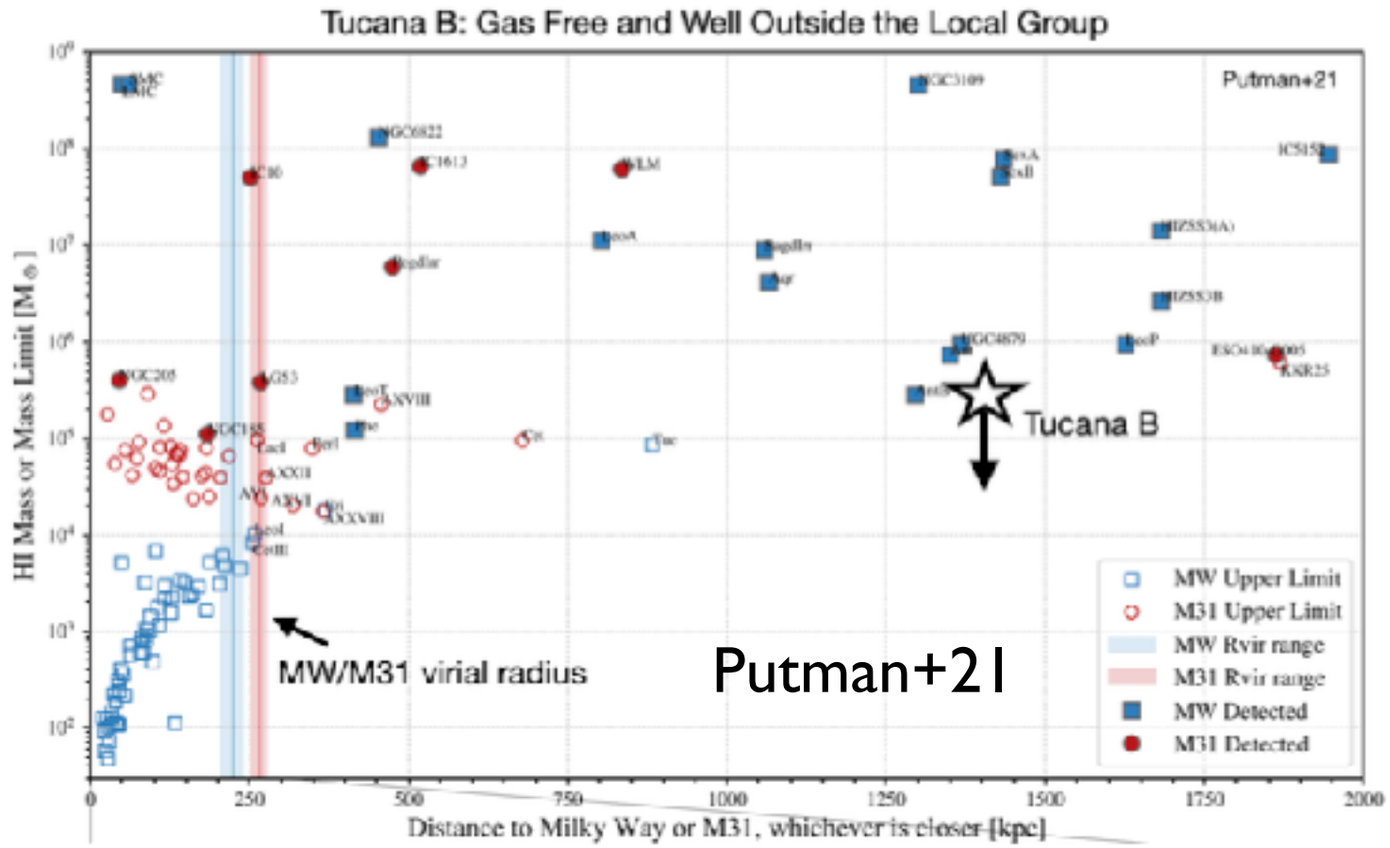

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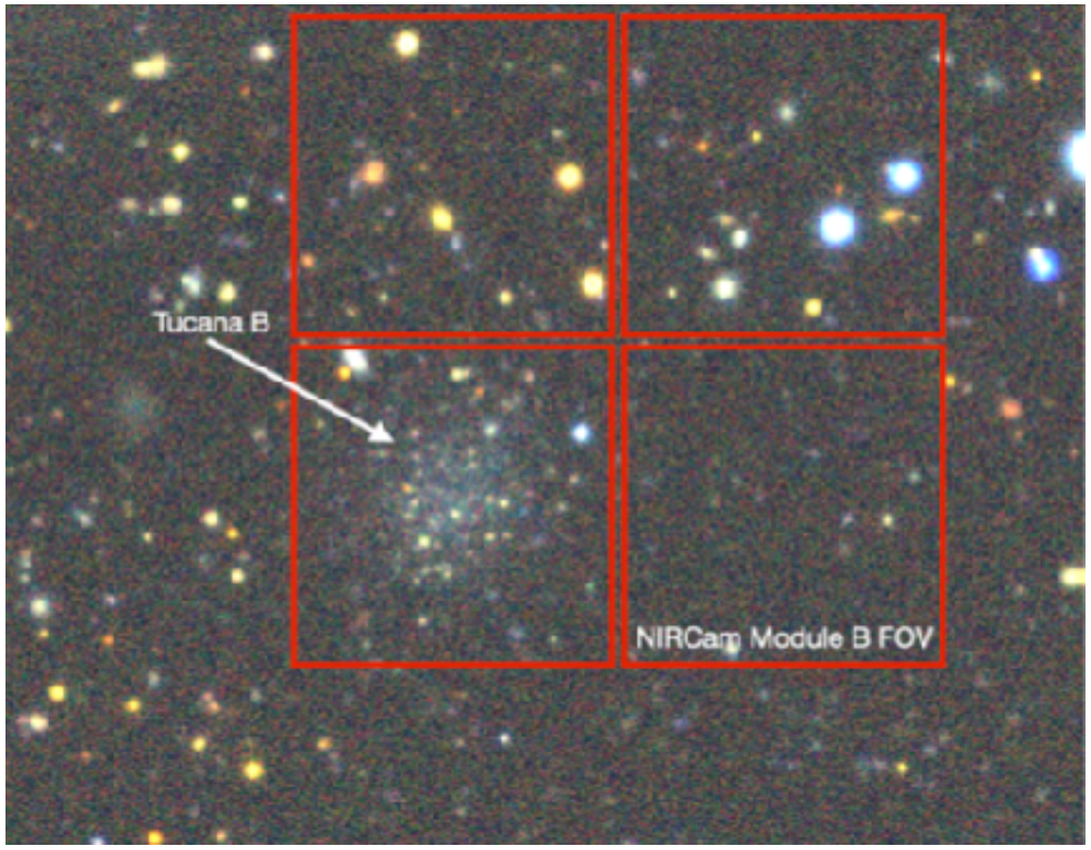
A real candidate to be a ‘reionization fossil’ (Sand et al. 2022)



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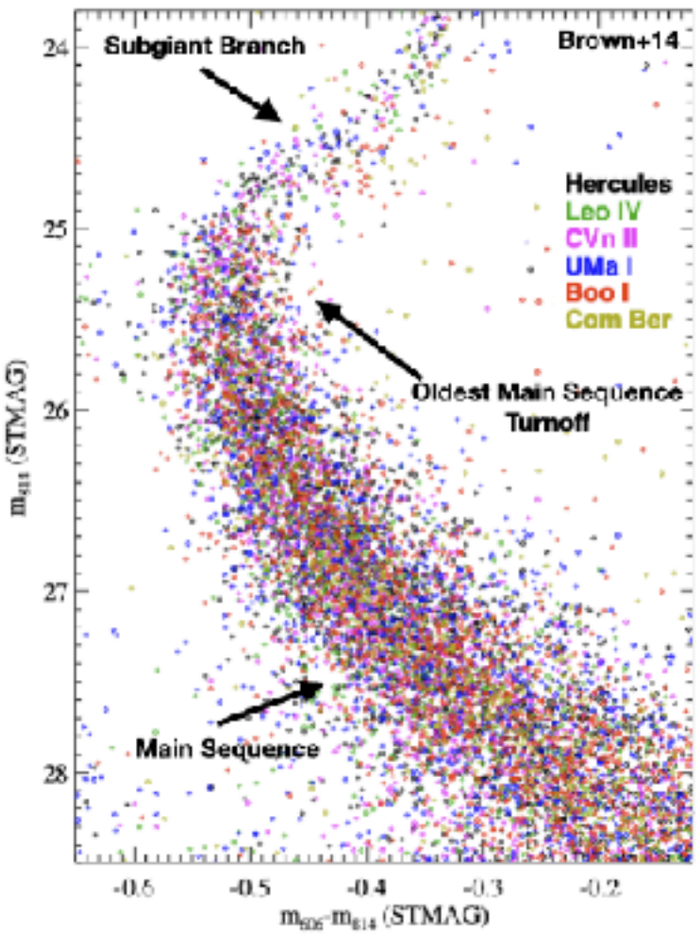

- At M_{star}=5x10^4 M_{sun} in the regime where reionization is important (Bullock+01; Ricotti & Gnedin+05)
- Likely did not interact with Milky Way
- Near enough that you can go down to the oldest MSTO to measure the shutoff of early SF (but let’s find out)

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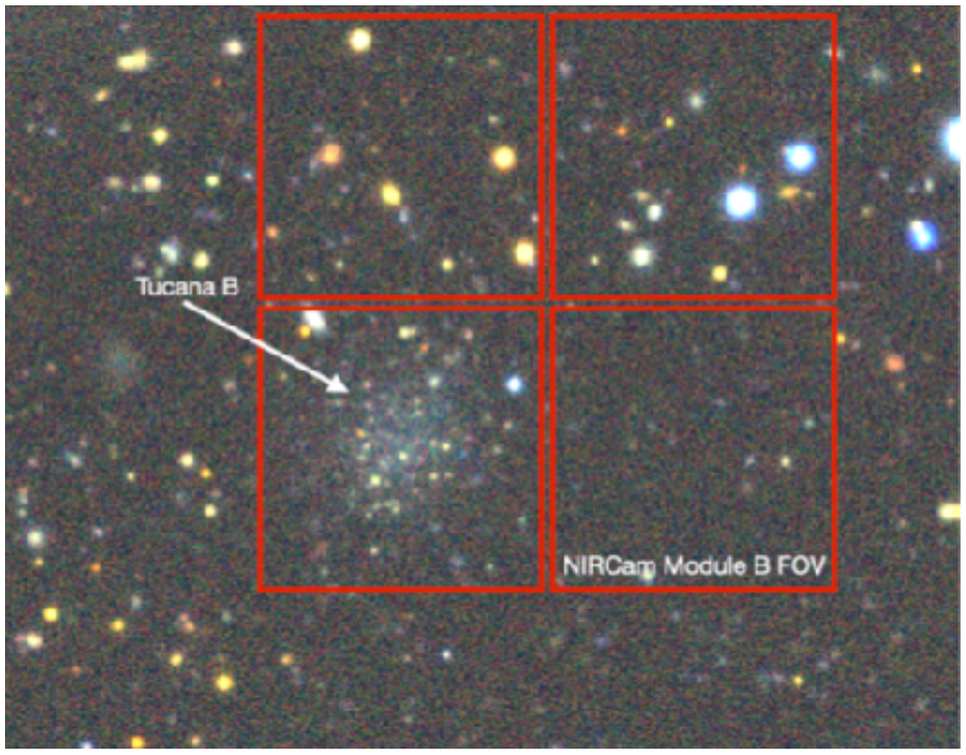
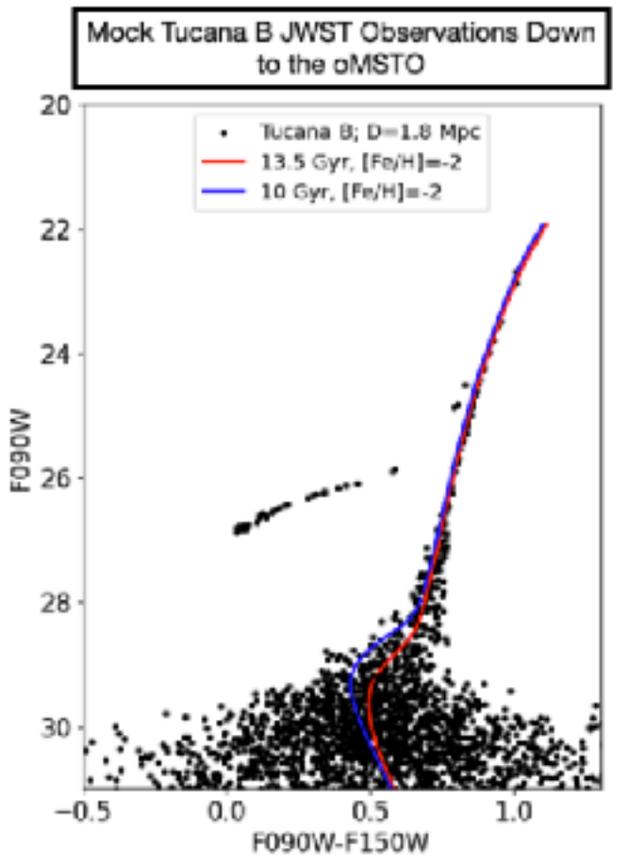
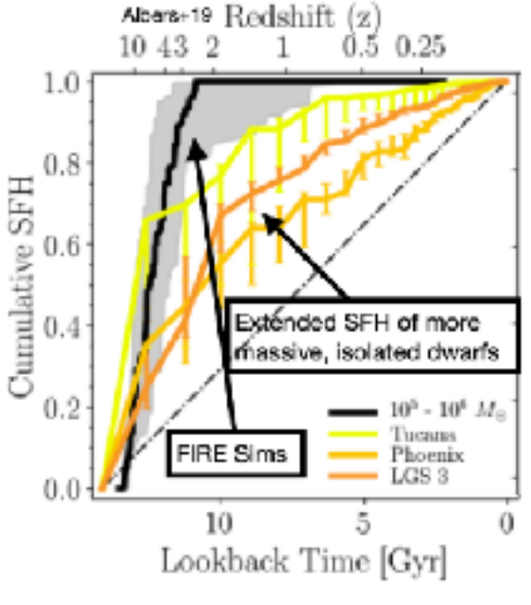




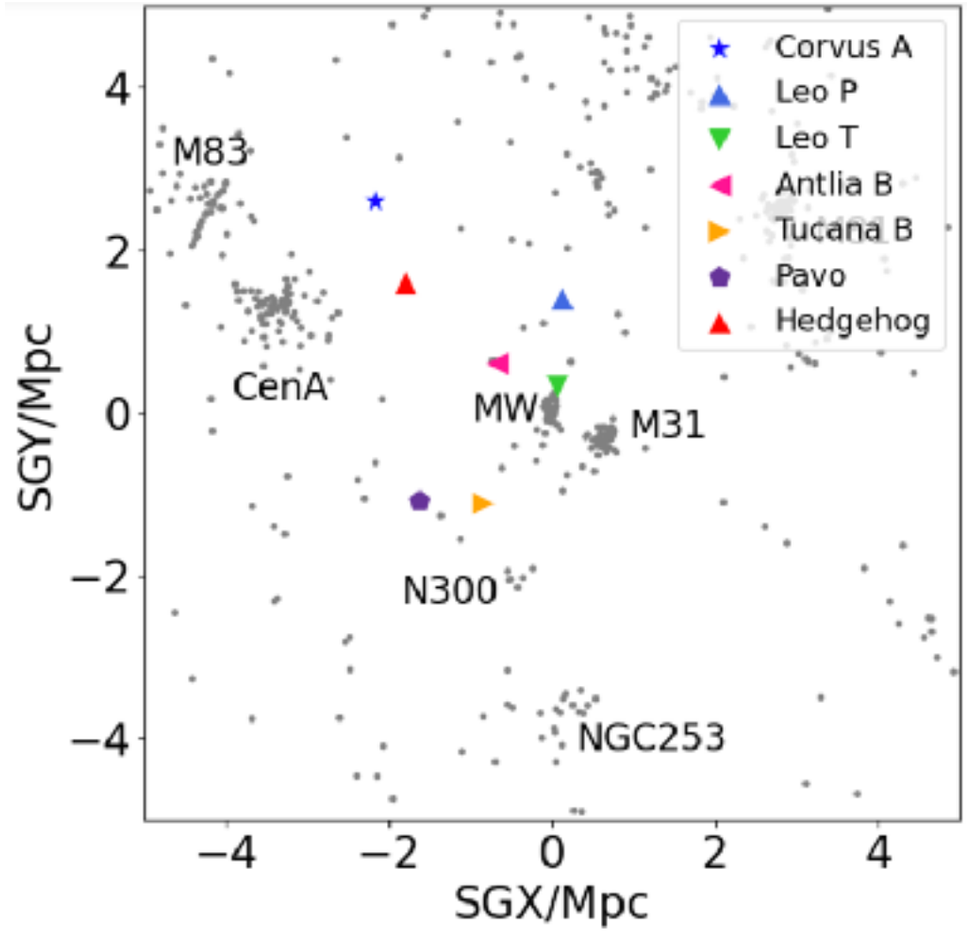
- Mock Observations are ‘Worst Case’ if we got the distance wrong. F090W=29.8 at S/N=5.

- Cycle 3 observations coming Summer 2025. Don’t forget PMs.

- One system will not be enough to understand reionization’s role, or other feedback processes!

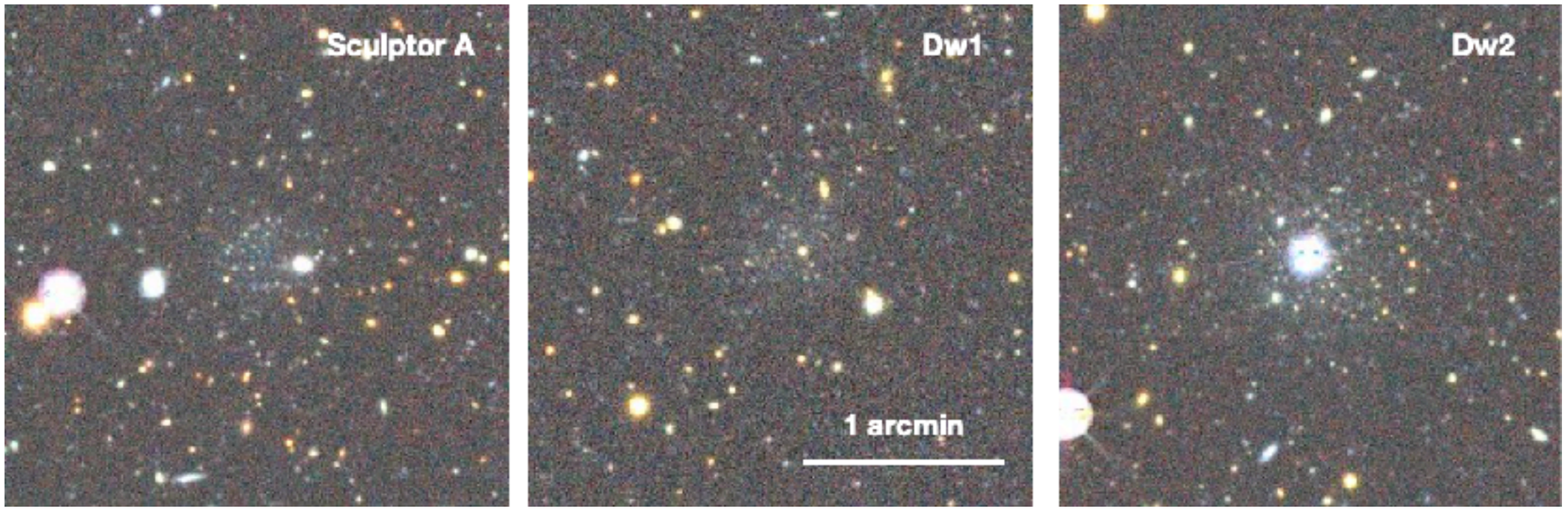


Search for dwarfs around NGC300



- NGC300: SA Spiral galaxy.
  - D=2 Mpc
  - $\log(L_K/L_{sun})$=9.4 [almost identical to LMC]
  - r_{vir}~120 kpc
- Searched out to ~200 kpc
- What effect do LMC-like galaxies have on their satellite population? Will have a weaker tidal field, and will lack the hot coronae necessary for ram pressure stripping (Keres+09).

Search for dwarfs around NGC300: Three Strong Candidates



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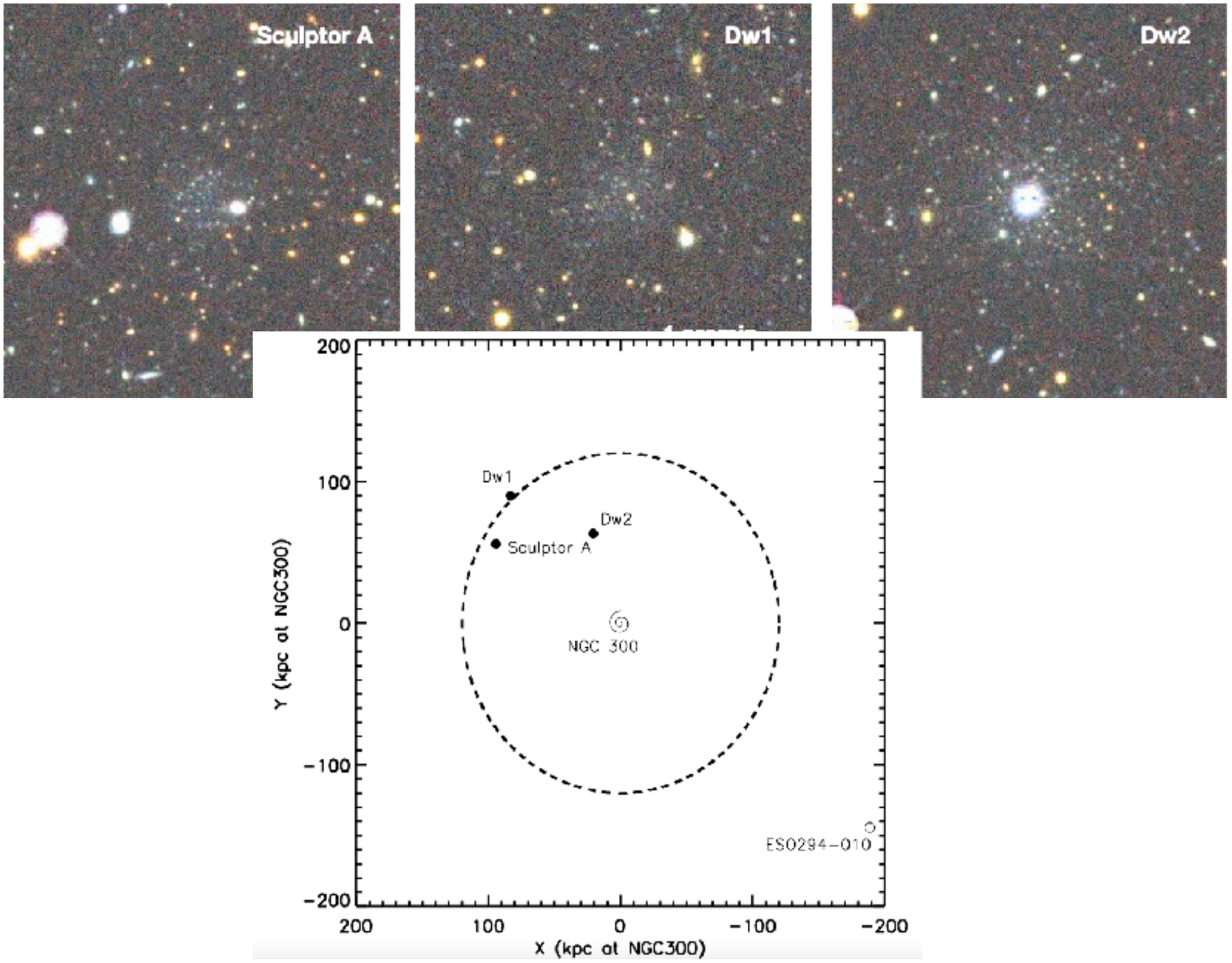

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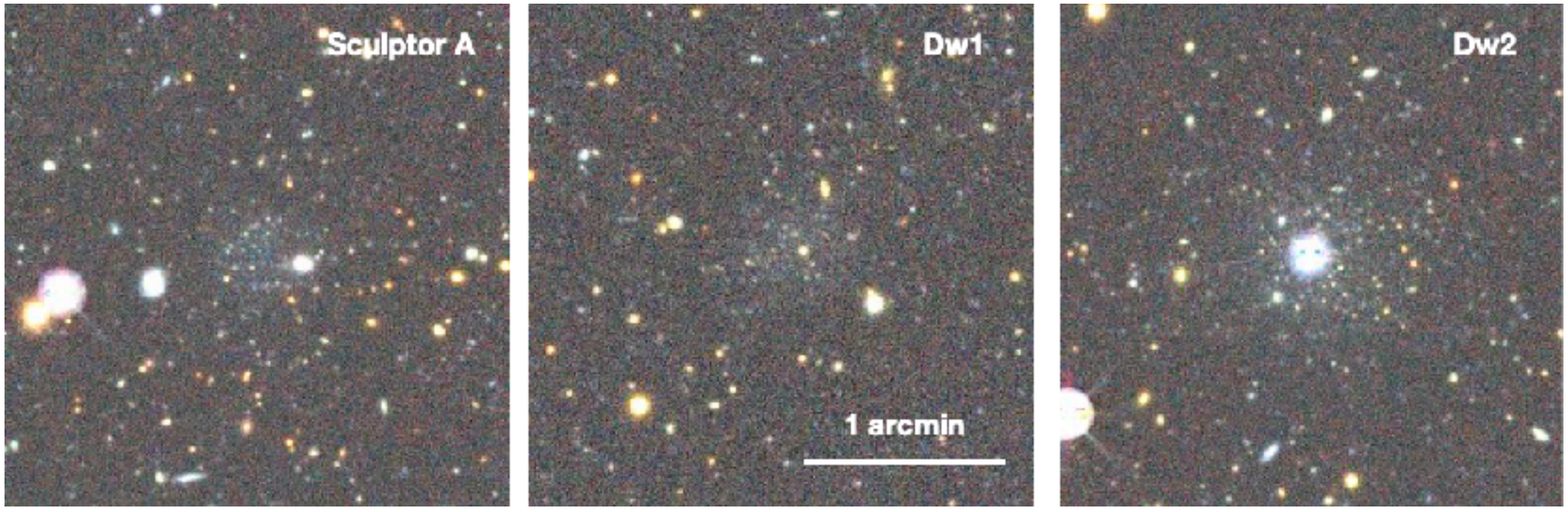
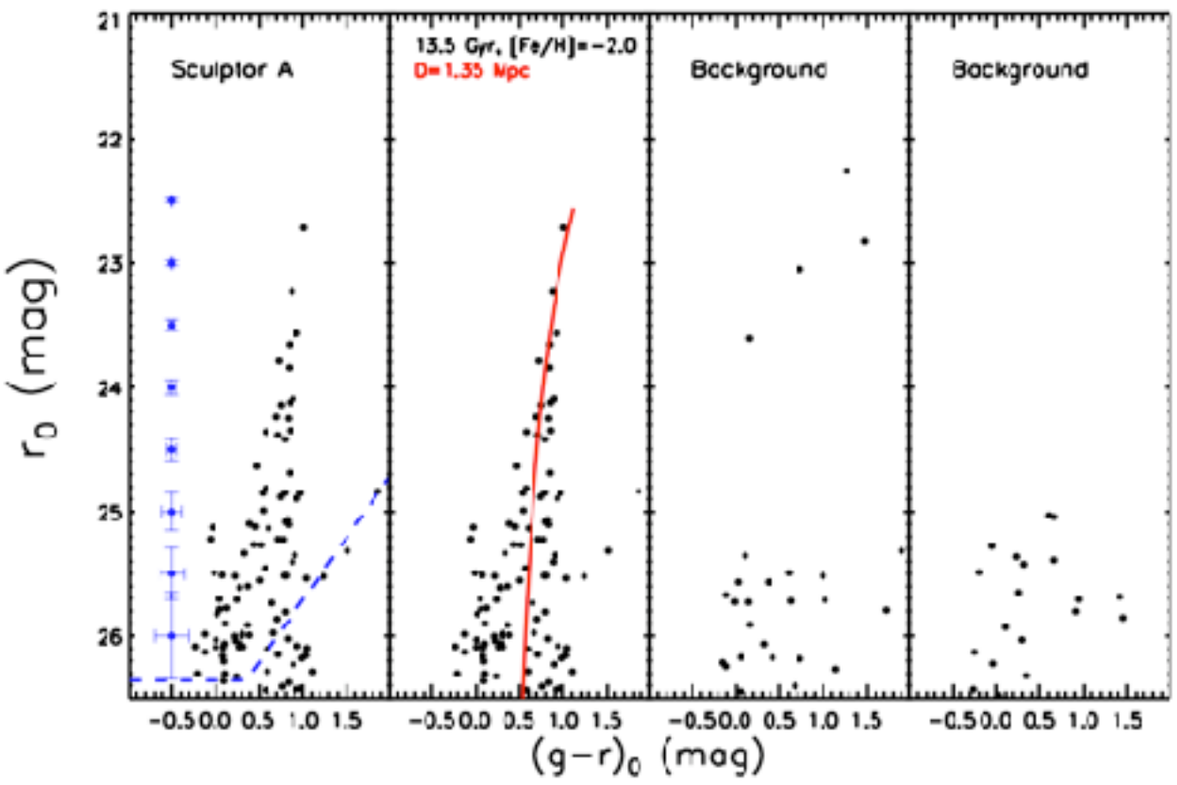


Gemini Fast Turnaround Imaging (*excellent* conditions)



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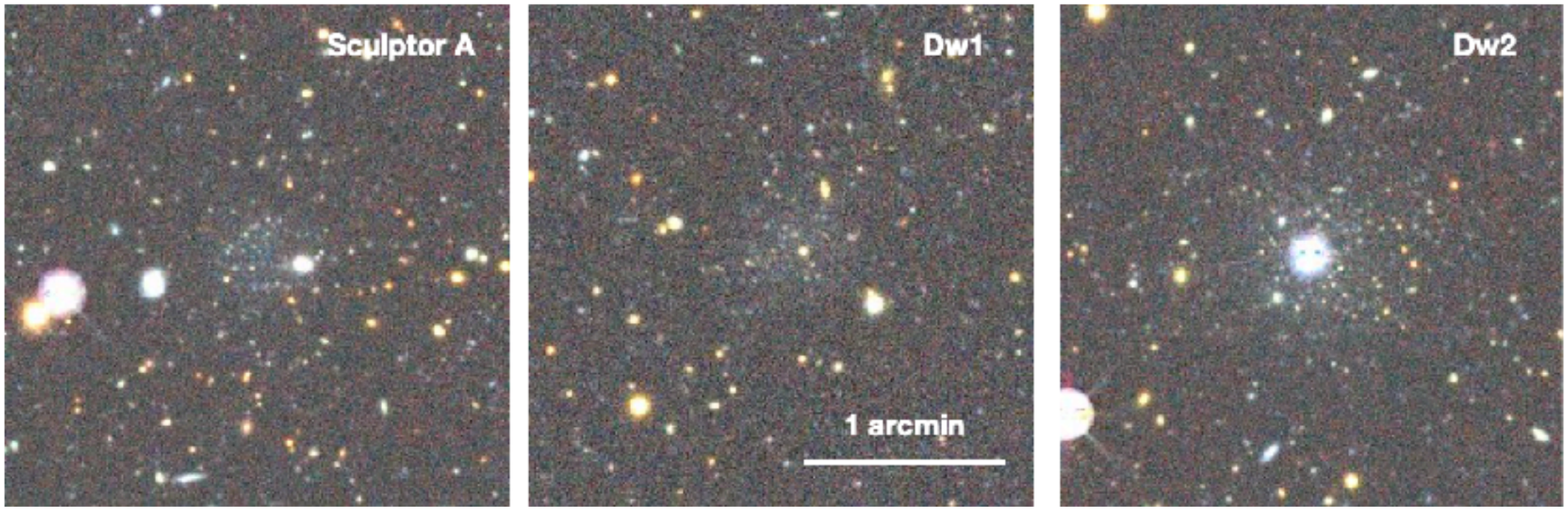

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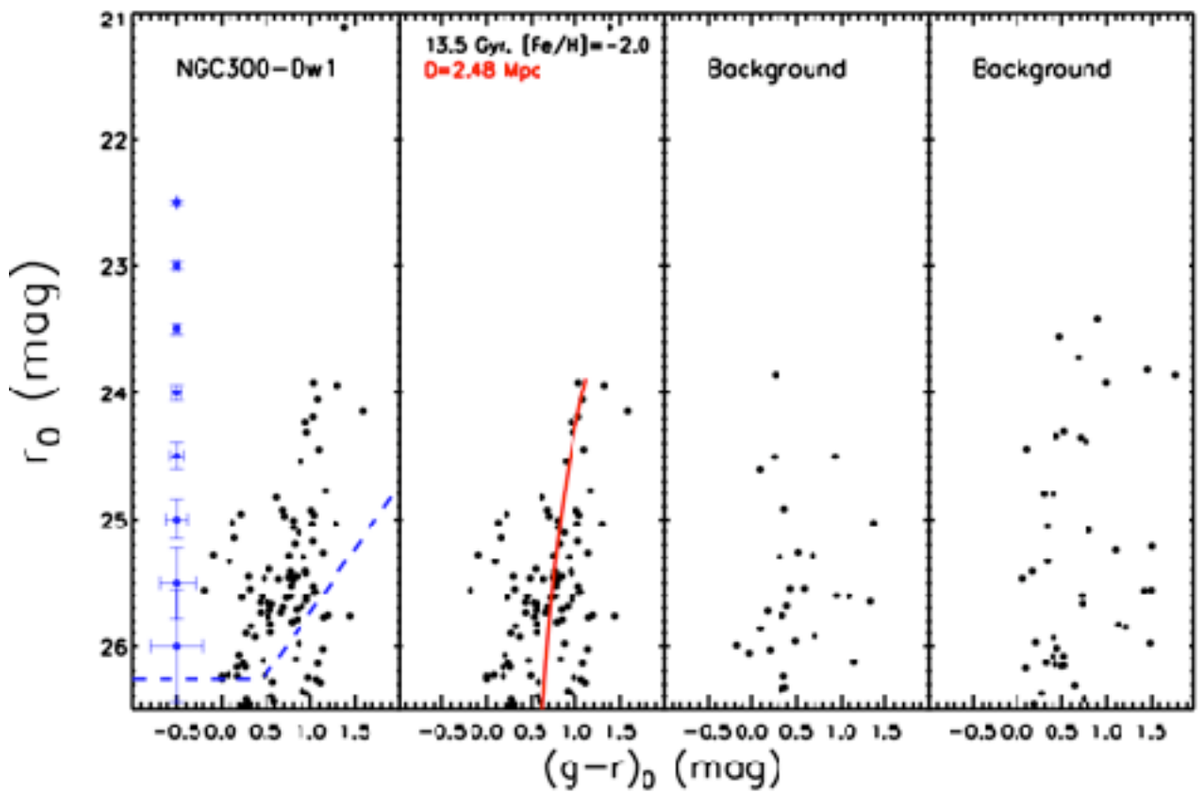

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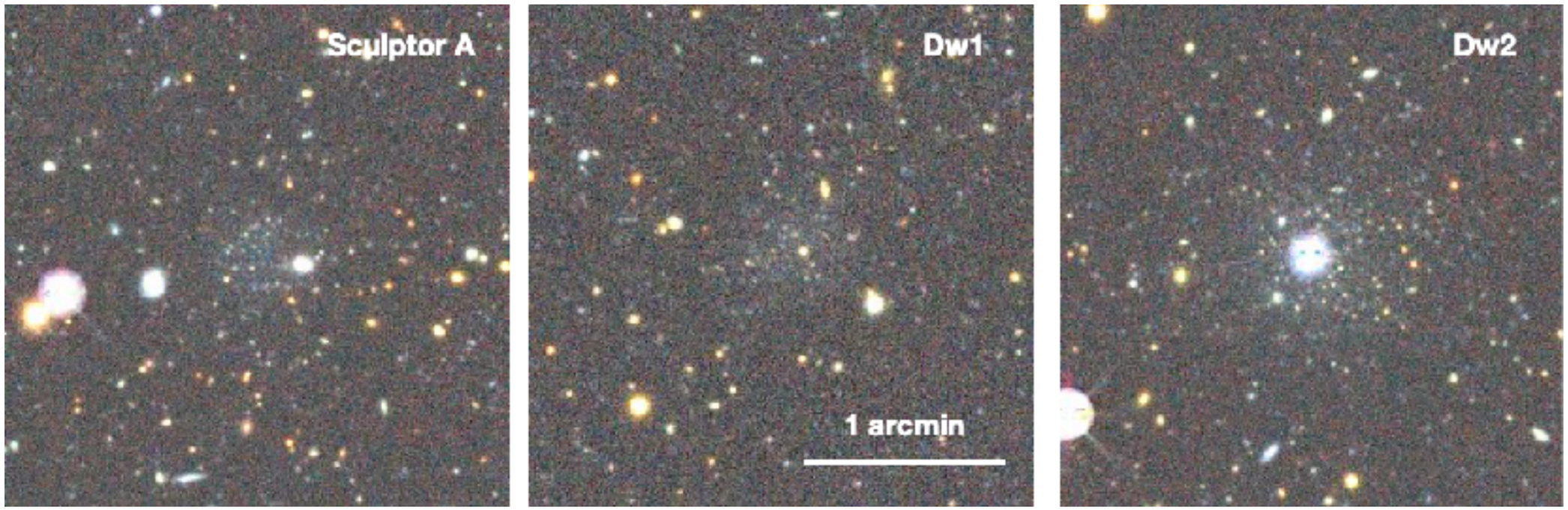
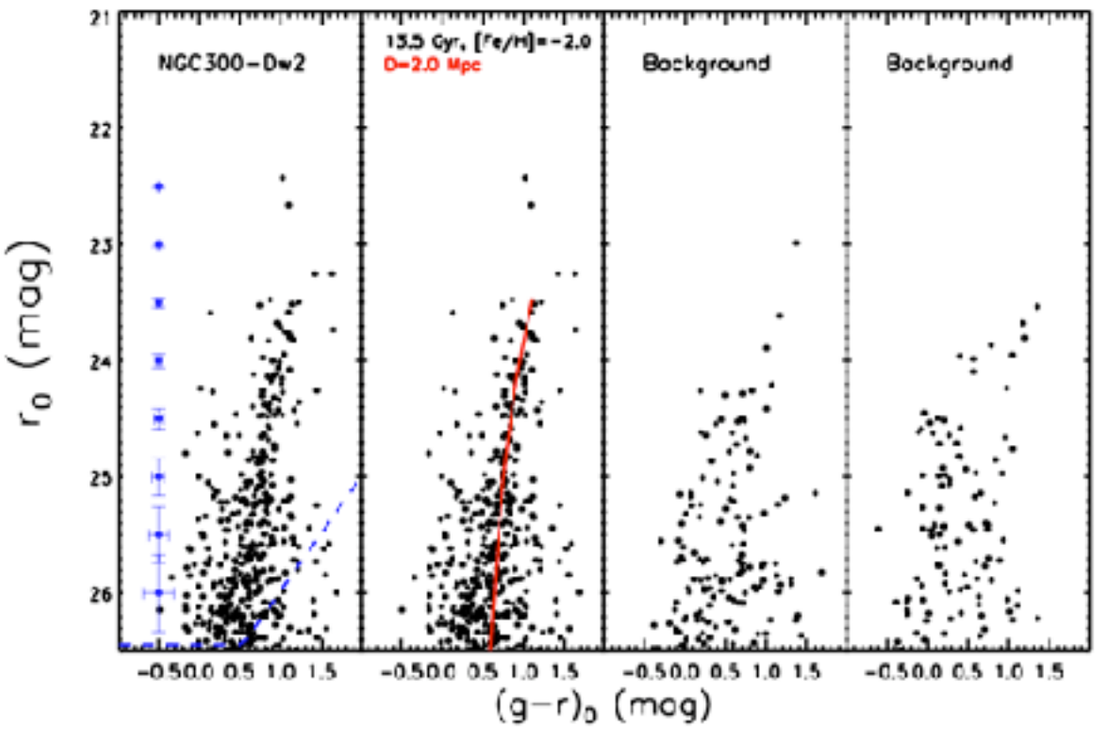
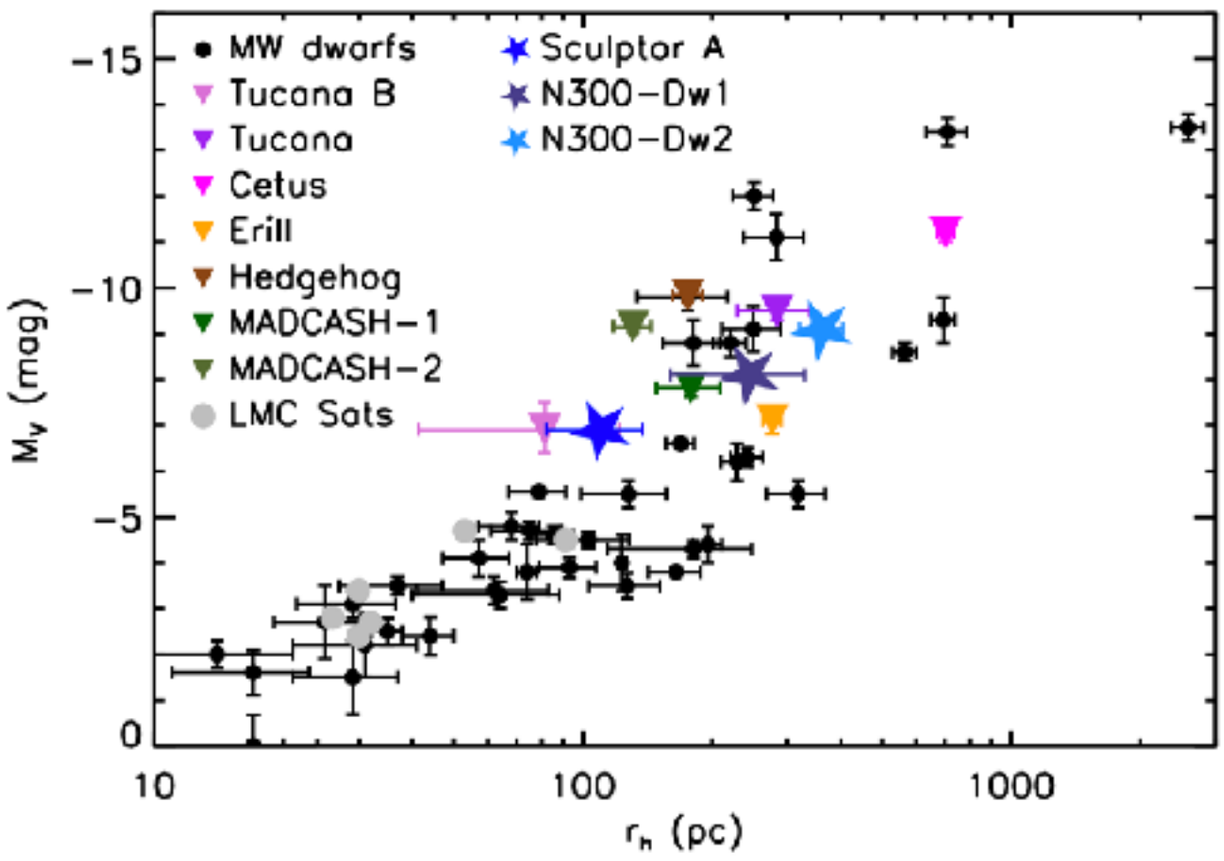
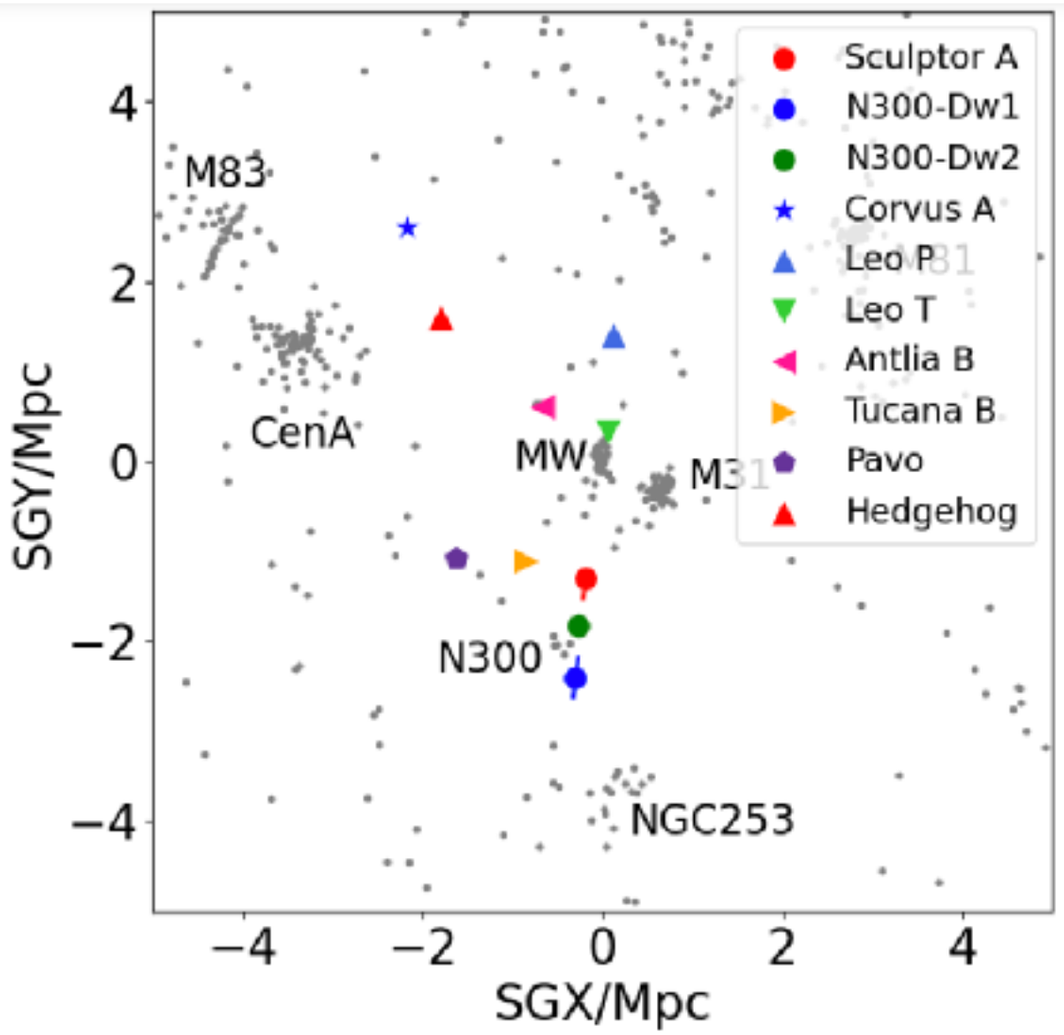


Gemini Fast Turnaround Imaging (*excellent* conditions)



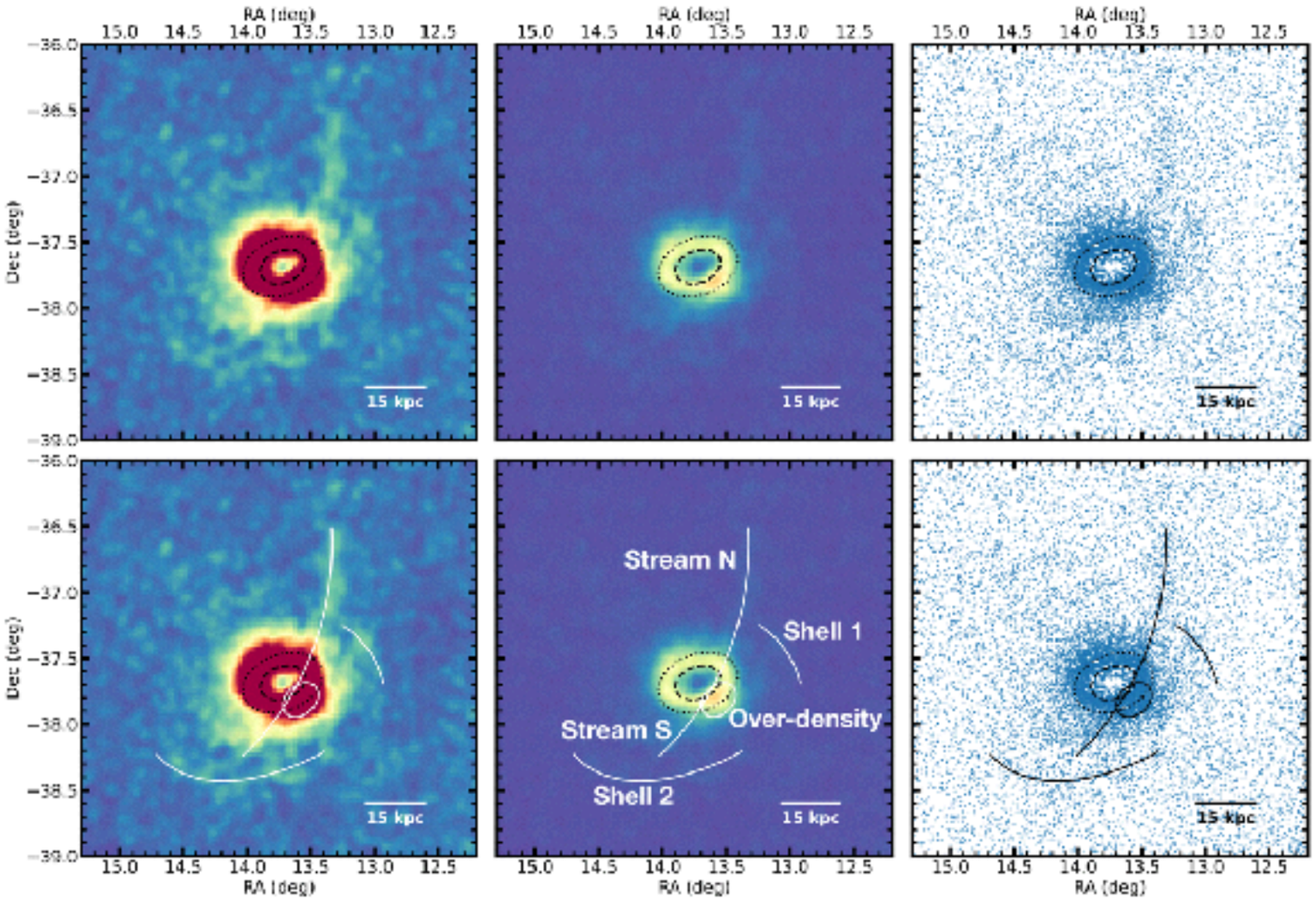
Ultra-faint and faint dwarfs in direction of NGC300

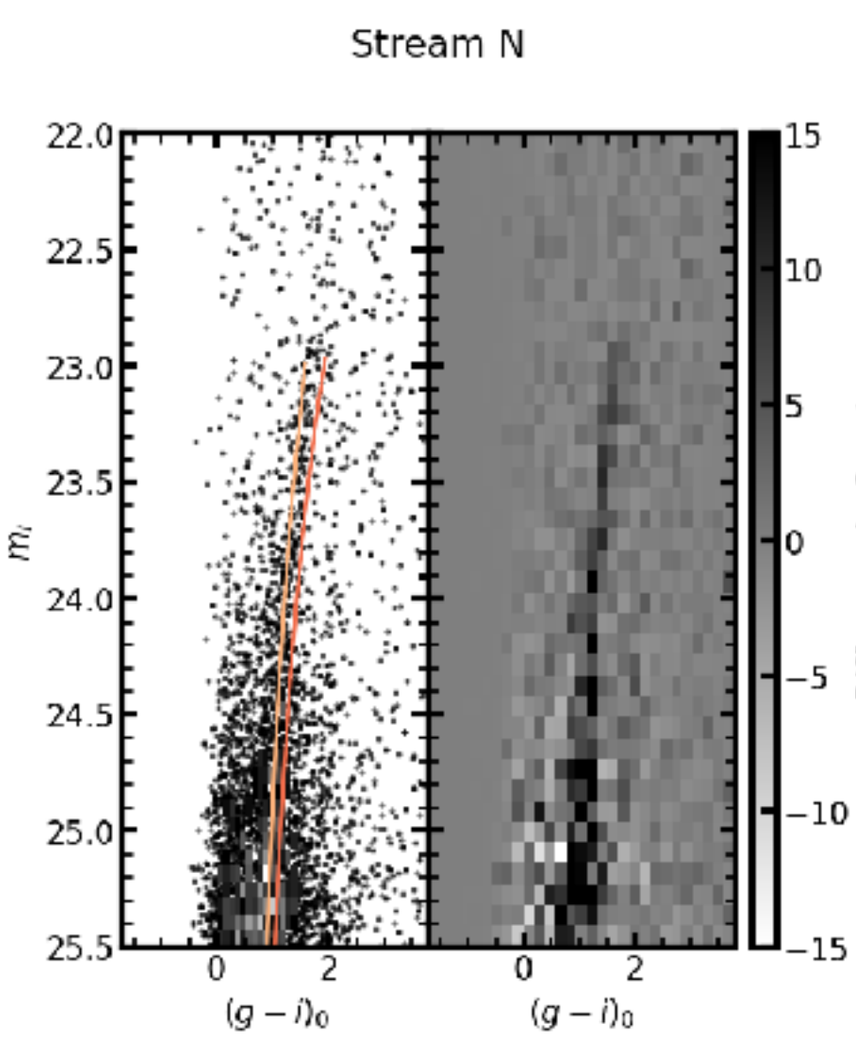




- Sculptor A very similar to Tucana B. Nearest neighbor is WLM, ~600 kpc.
- N300-Dw1 and Dw2 may be loosely associated with NGC300.
- Similar to other LMC-like satellites, but still brighter than the LMC's satellites.

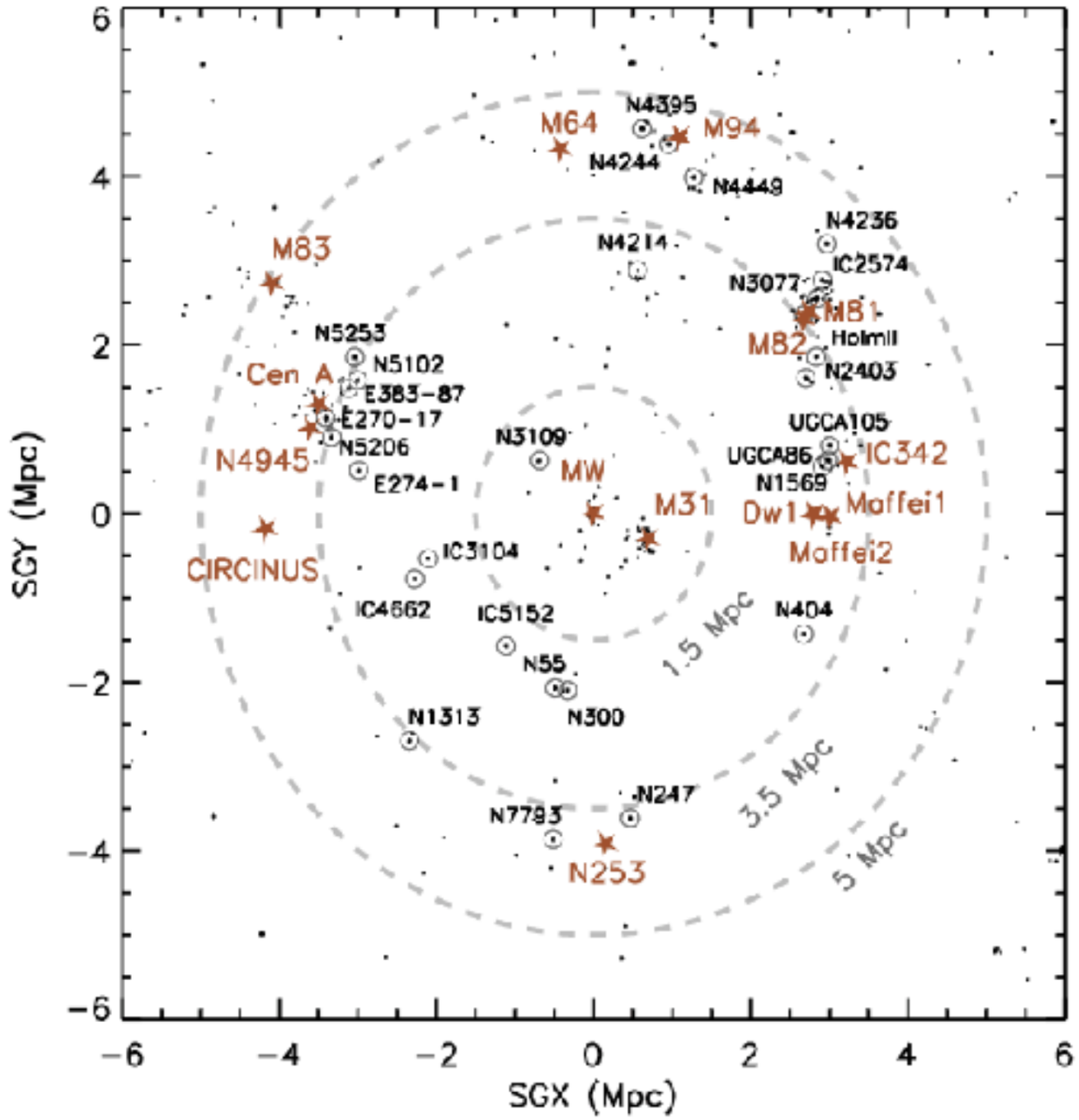
More to come in NGC300





- DELVE Deep will quantify the satellite luminosity function of NGC300
- A red giant branch map shows clear signs of an accreted stellar halo (Fielder+ in prep) — understanding the origins of dwarf galaxy halos will be a core goal of DELVE Deep. See poster!

Where Can We Go From Here?
Lets think about resolved stars from the ground with LSST
D<5 Mpc Roughly



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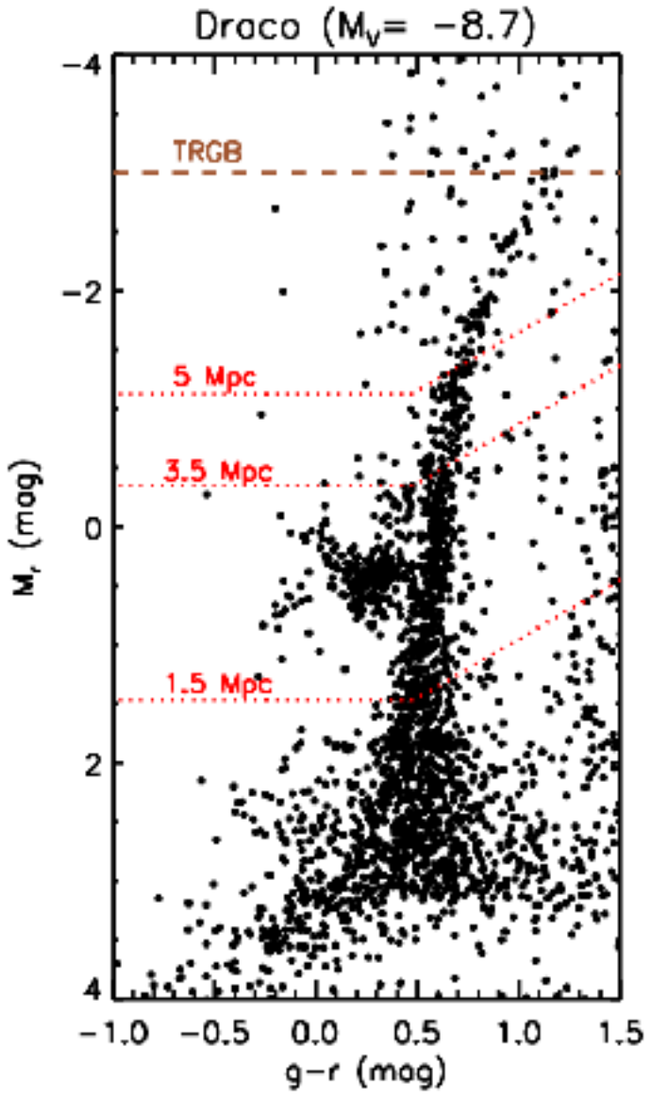
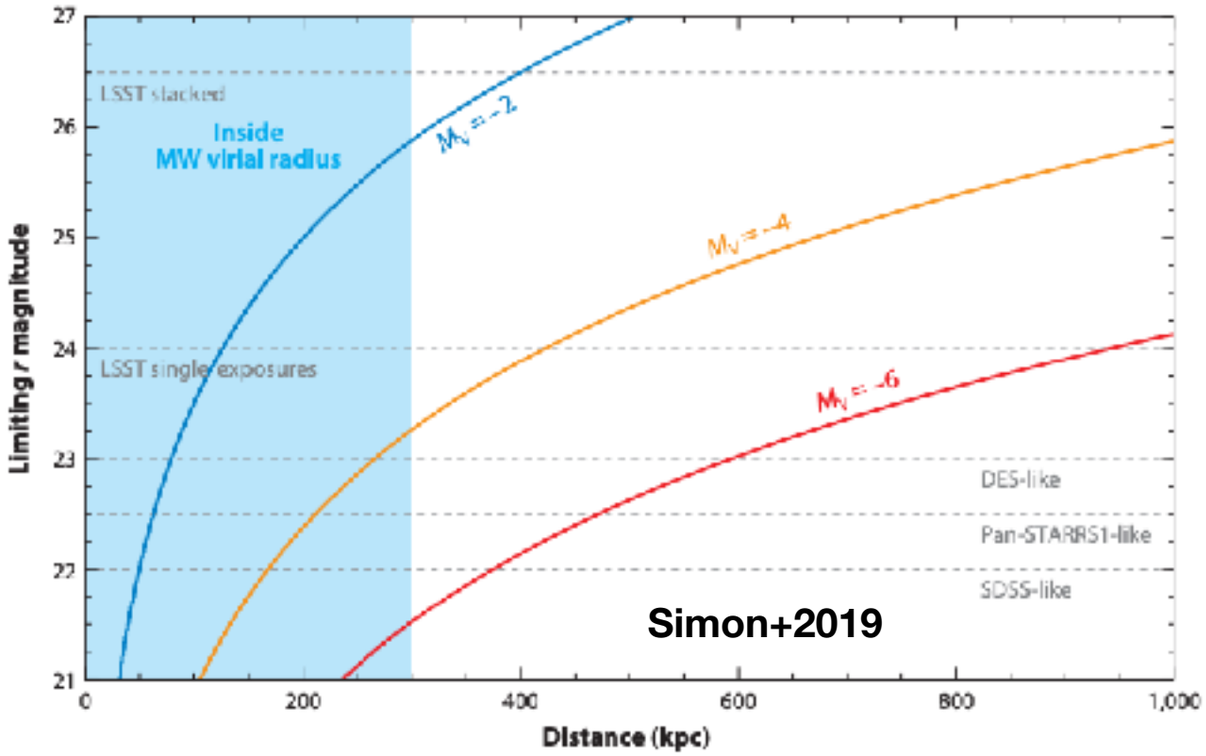


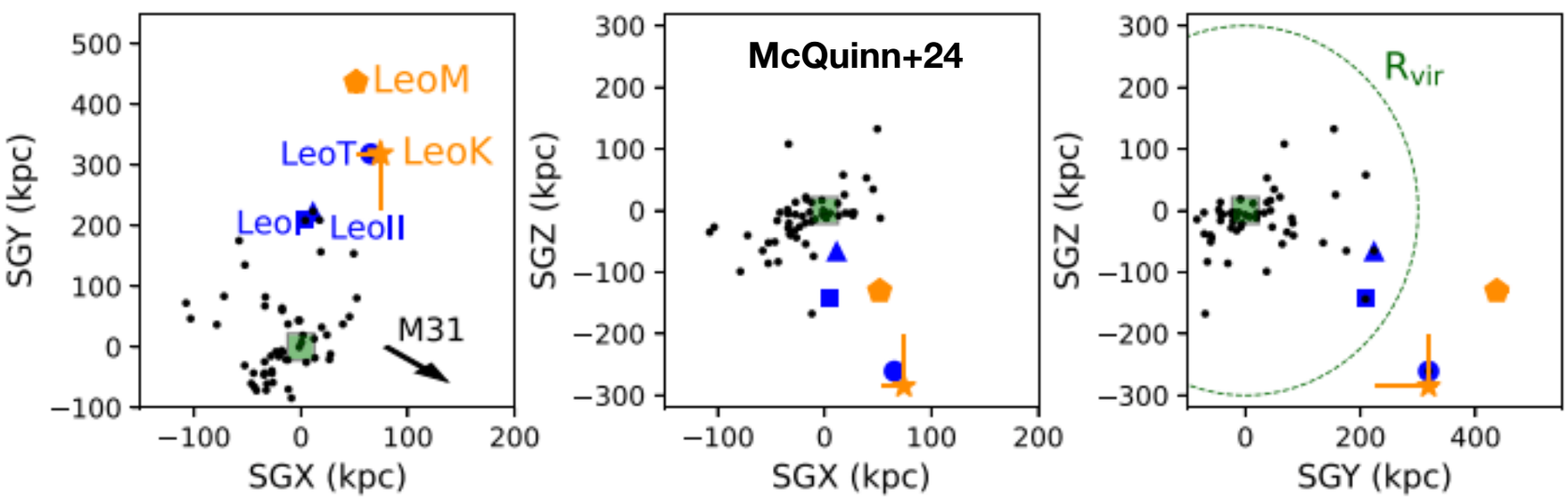
Red corresponds to r~27.4, g~27.8 at 50% comp — close to LSST 10-yr depth HSC data (Carlin et al. 2016, 2019)

Dwarfs at the edge of the Local Group

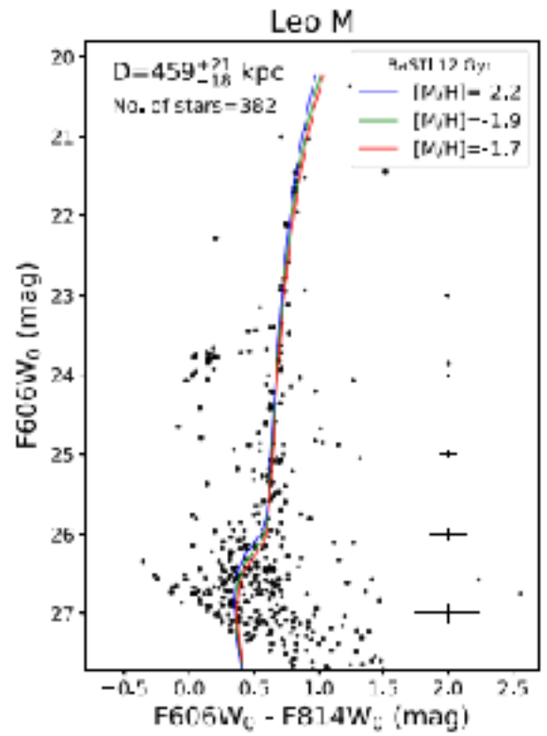


Simon+2019

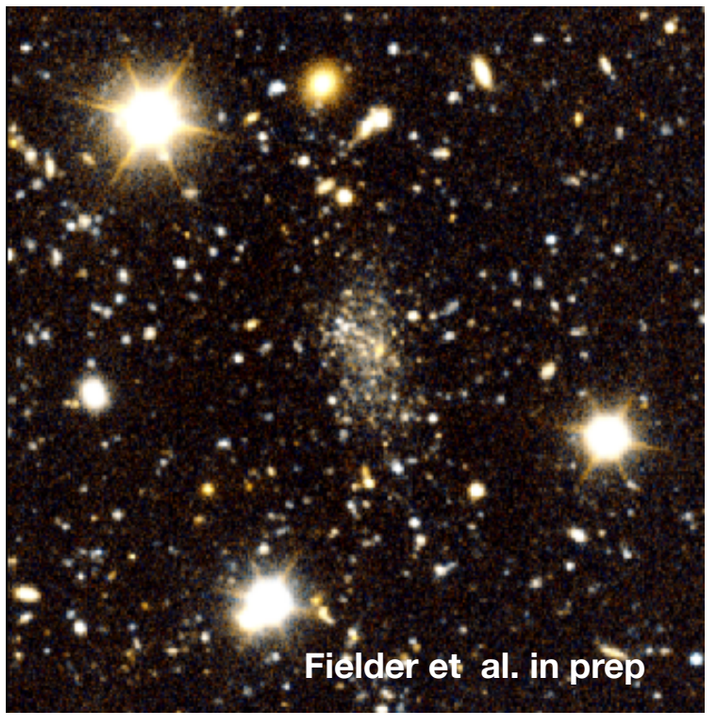
DECam data over much of southern sky is pretty close to LSST single exposure depth.

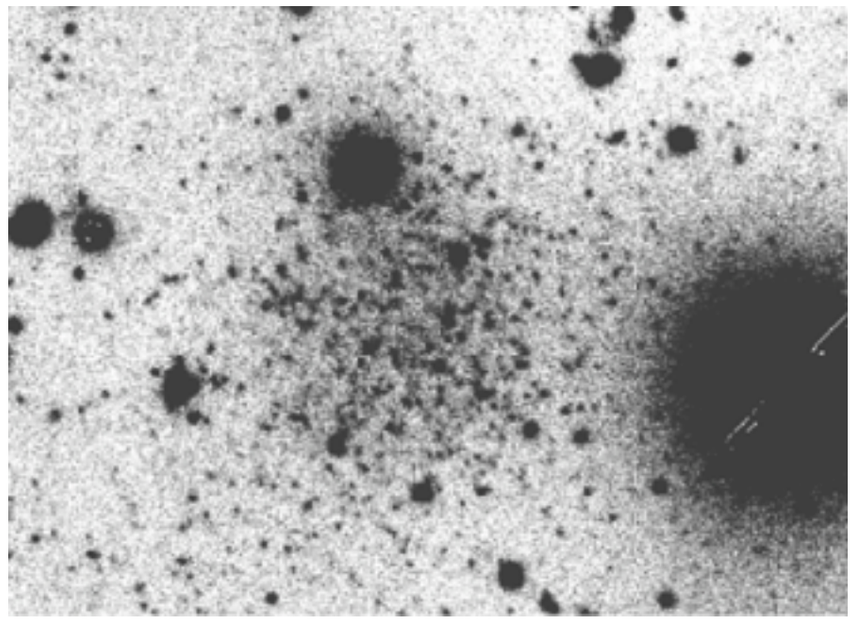


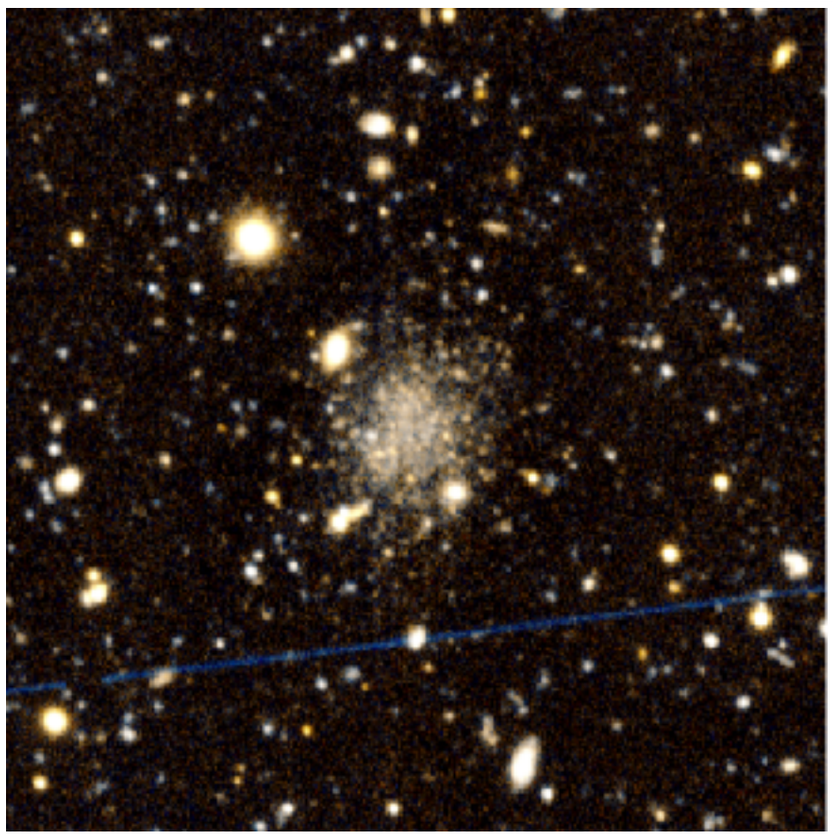
McQuinn+24



SEAMLESS — Semi-automated CNN search is finding many more candidate quenched, isolated and backsplash dwarfs

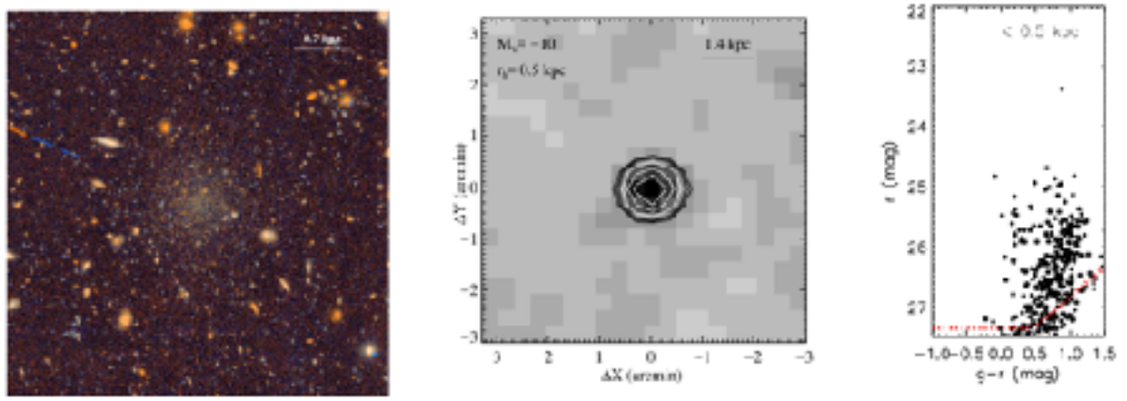




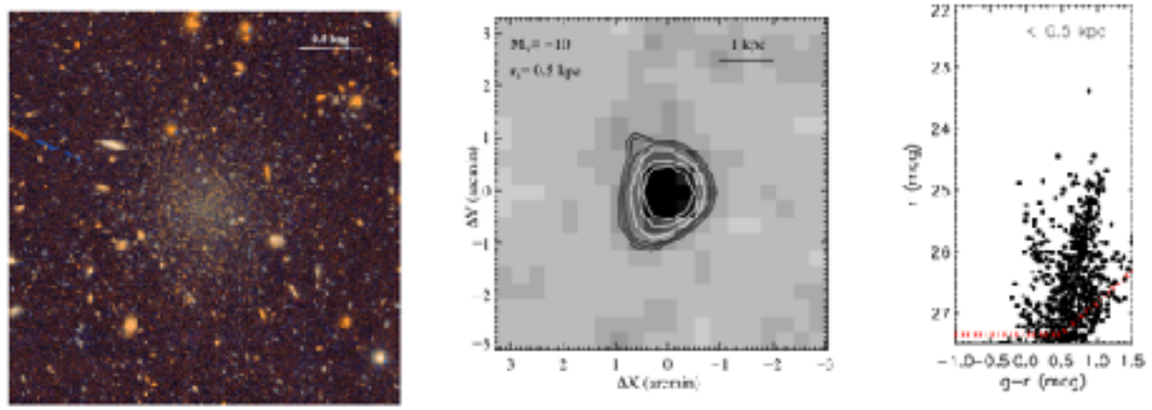


Where Can We Go From Here?
Lets think about resolved stars from the ground with HSC (& VRO)

D=5 Mpc, M_V=-10, r_half=500pc, 1.2 kpc



D=3.5 Mpc, M_V=-10, r_half=500pc, 1.2 kpc



Implanting simulated dwarfs with a range of size, luminosity, ellipticity, stellar background & galactic latitude to forecast resolved dwarf discovery over the next decade from the ground.

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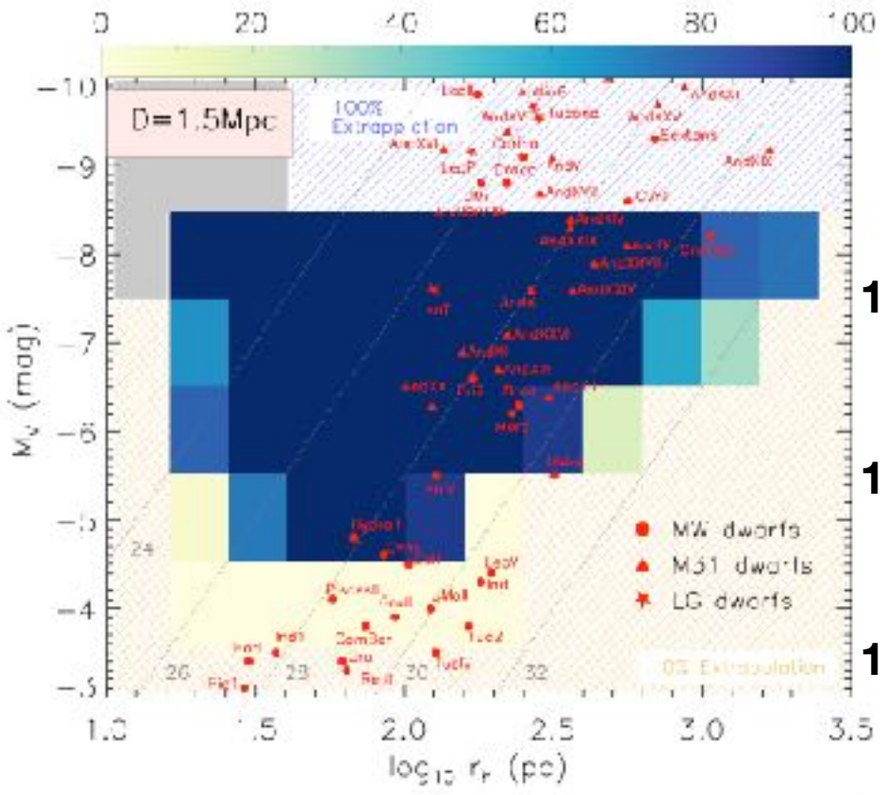
Lets think about resolved stars from the ground with HSC (& VRO)

Results at three fiducial distances

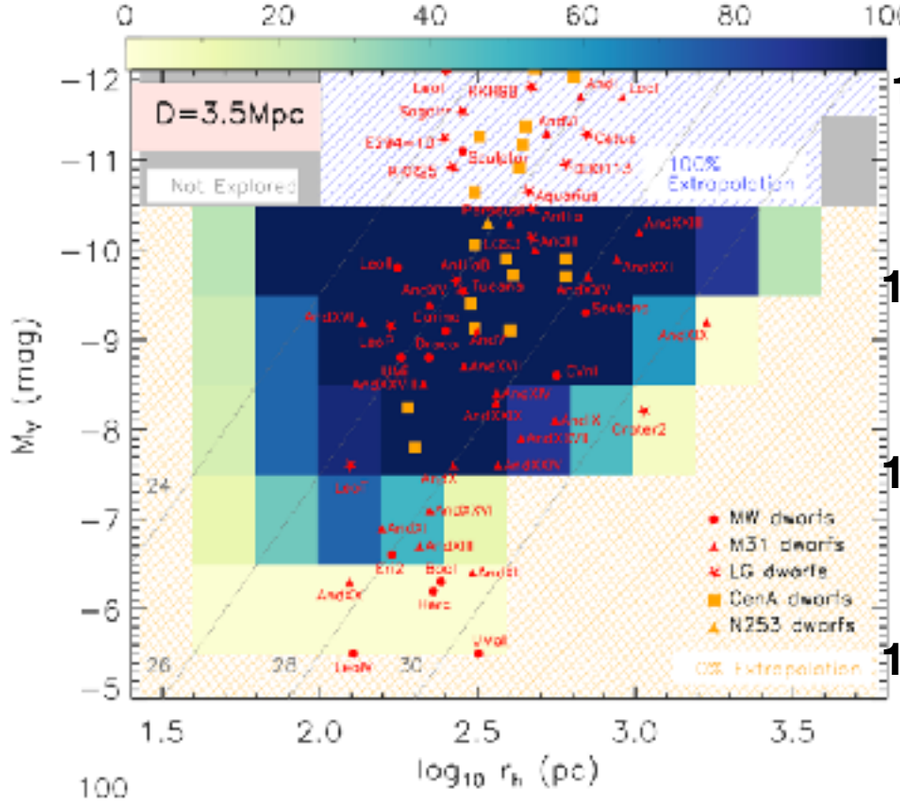


Ultra-faint dwarfs in NGC3109

10^5 Lv

10^4 Lv

10^3 Lv



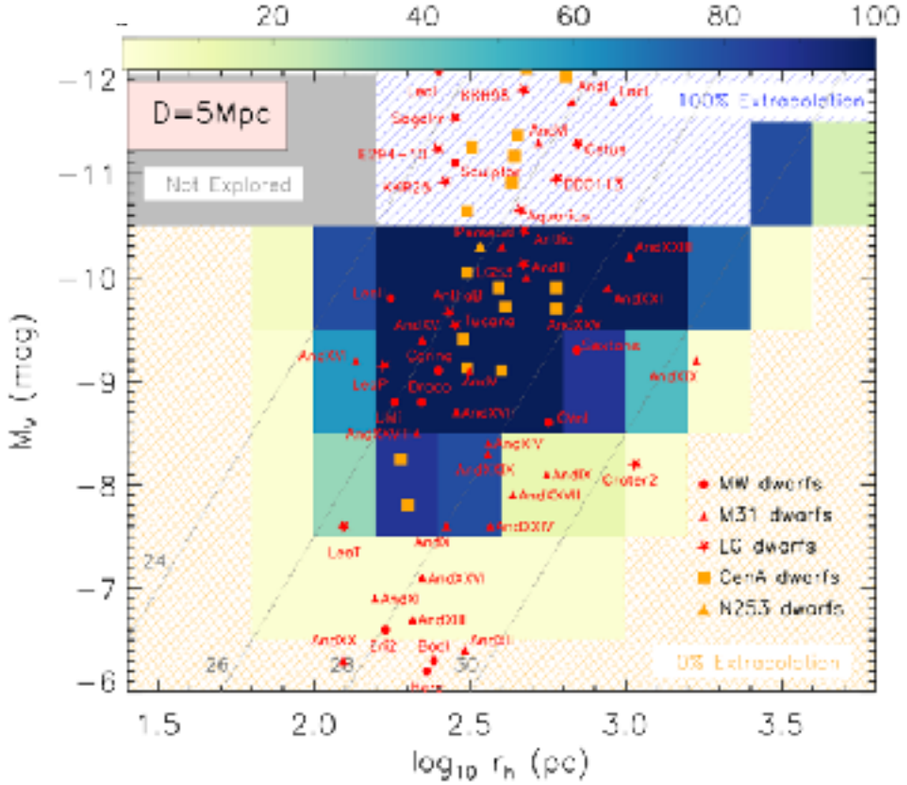
10^7 Lv

10^6 Lv

10^5 Lv

10^4 Lv

M64, M94 and M83 are excellent targets



Fill out the census at D=3.5 Mpc down to M_V=-7 to -8

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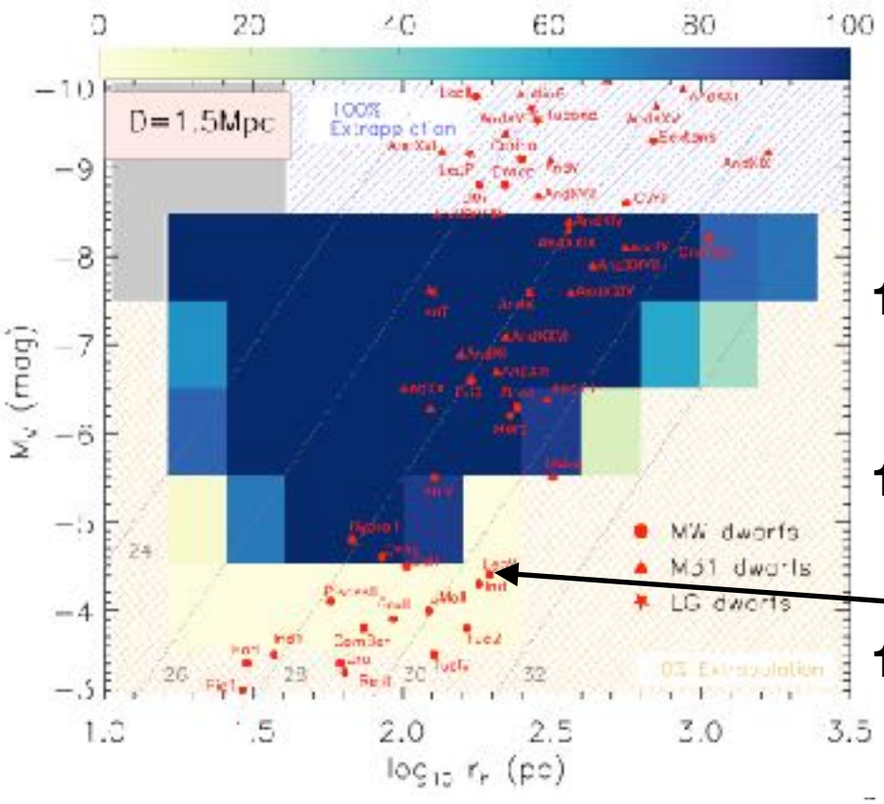
Lets think about resolved stars from the ground with HSC (& VRO)

Preliminary Results at three fiducial distances



Ultra-faint dwarfs in NGC3109

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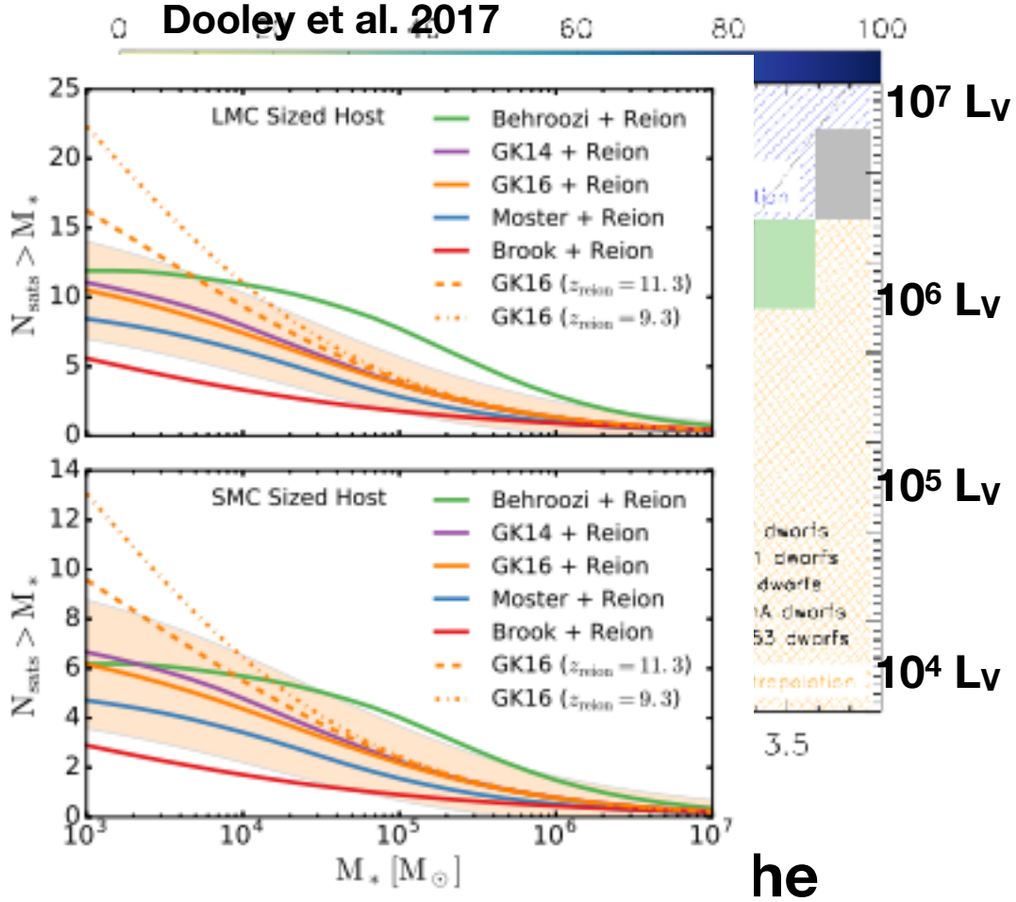

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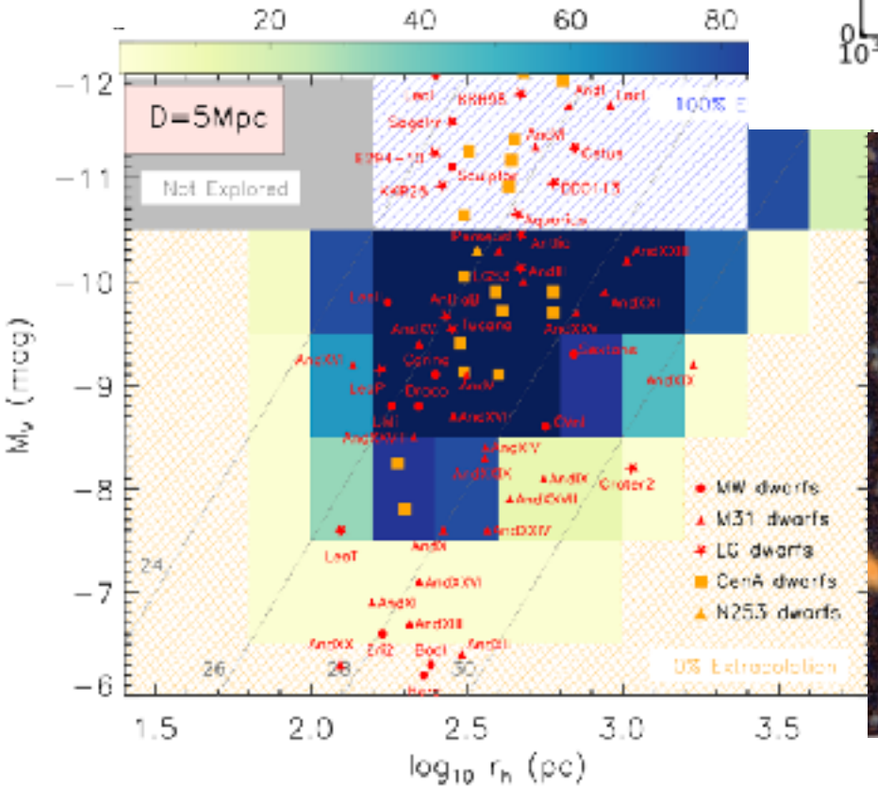
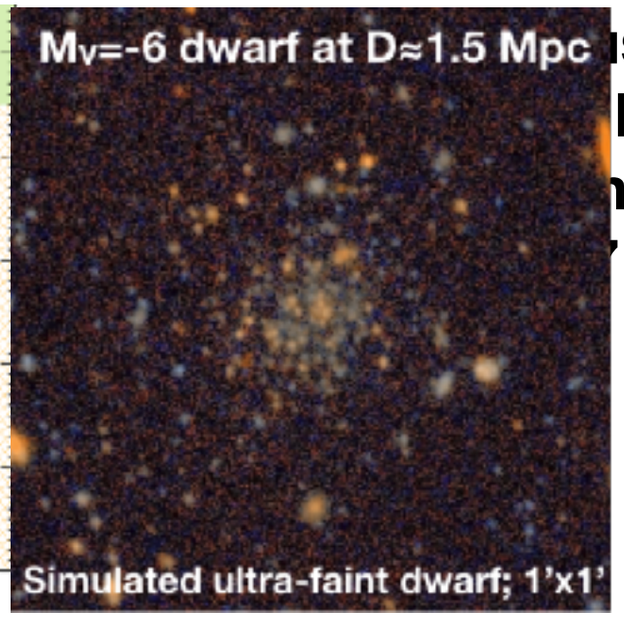




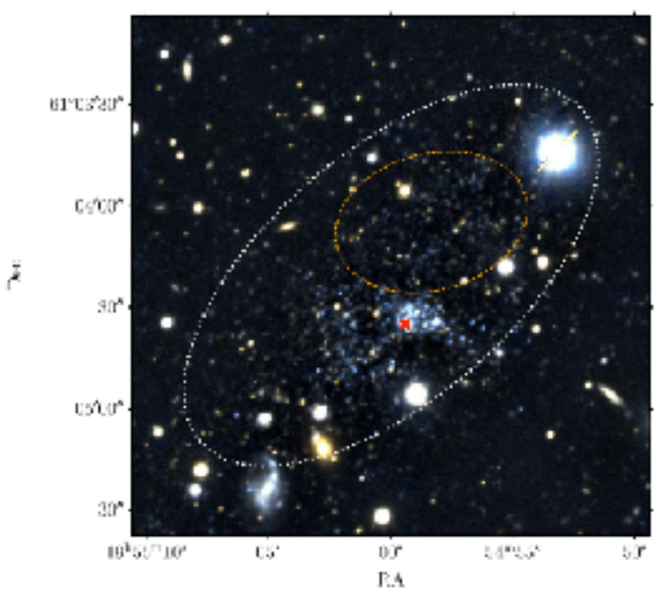
Mutlu-Pakdil, Sand, et al. 2021

Summary

- The least massive dwarf galaxies are an excellent laboratory for testing dark matter/galaxy formation right at the intersection where astrophysics matter.

- Moving beyond the Local Group is key. Field dwarfs and those in backsplash regions will inform us about reionization, internal feedback and potentially satellite orbital history. Keep an eye out for more SEAMLESS results

- The next decade will be bright, with VRO and Roman.



Jones+23,24