Small-scale cosmology with satellite galaxies in the era of large sky surveys

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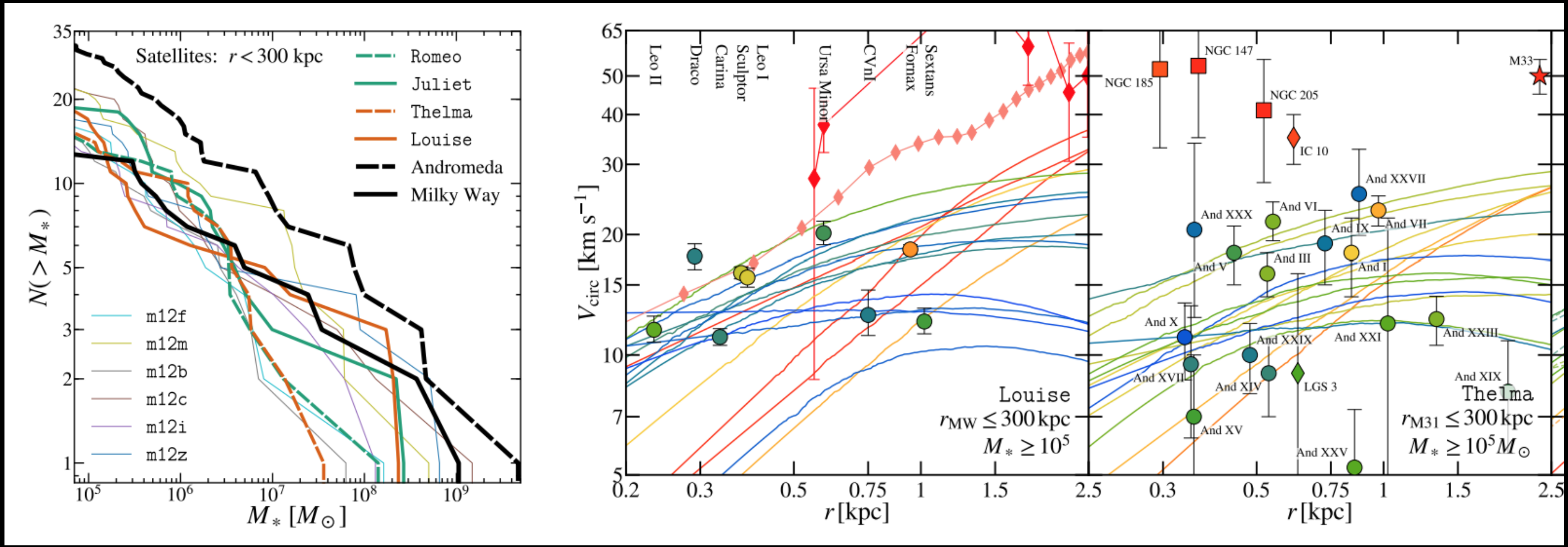
Supported by
NSF-AST 2007065
HST-GO-17158
NASA grant NNG16PJ28C (WINGS)

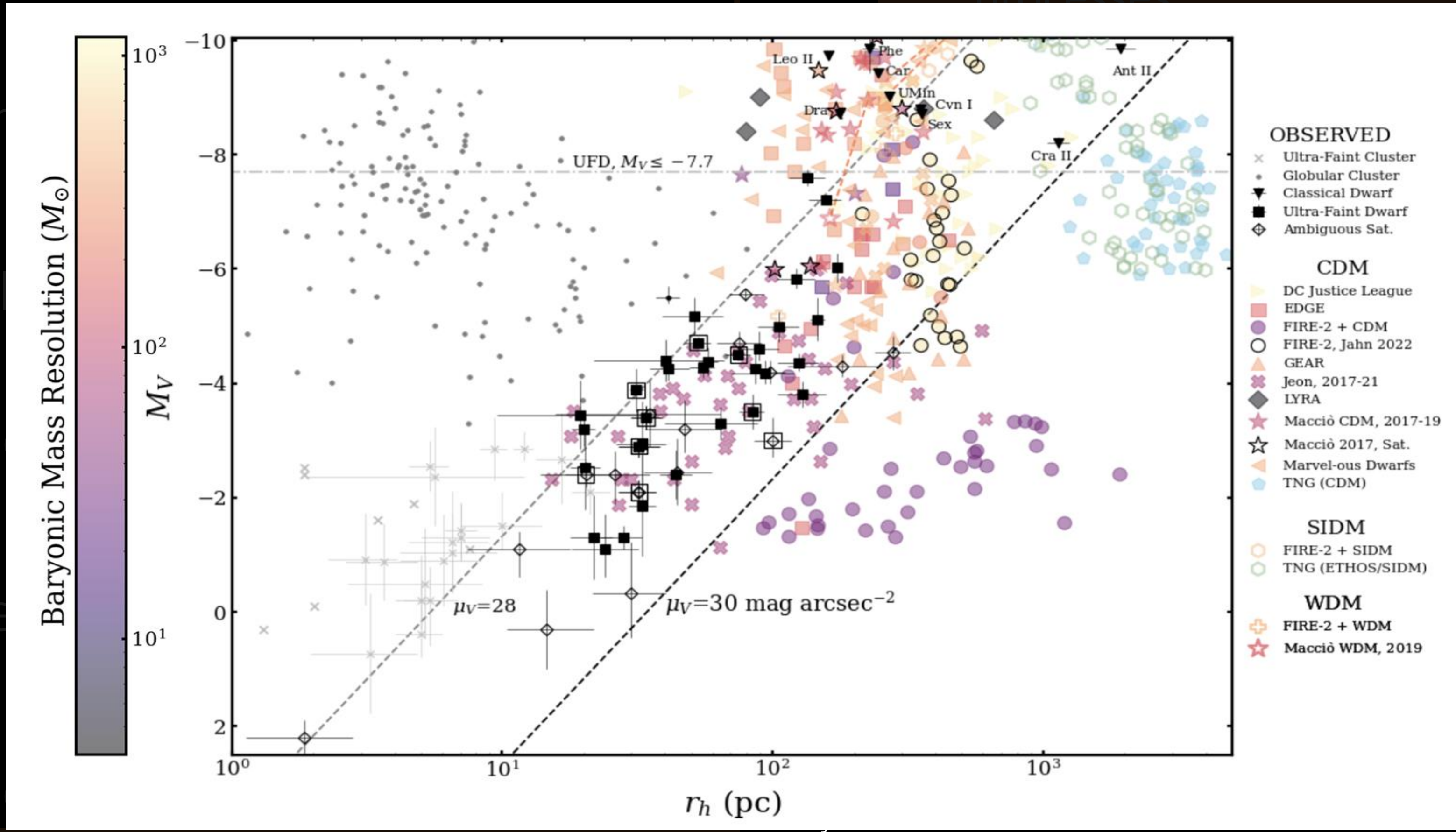
The faint and ultra-faint satellites of the Local Group are our prime source of intuition about galaxy formation and small-scale cosmology.

FIRE : Garrison-Kimmell et al. 2019, MNRAS, 487, 1380



Number of satellites vs. mass velocity scales of satellites vs. half-light radius

The structures of the faint and ultrafaint galaxies in the Local Group sensitively test model resolution, feedback and reionization.

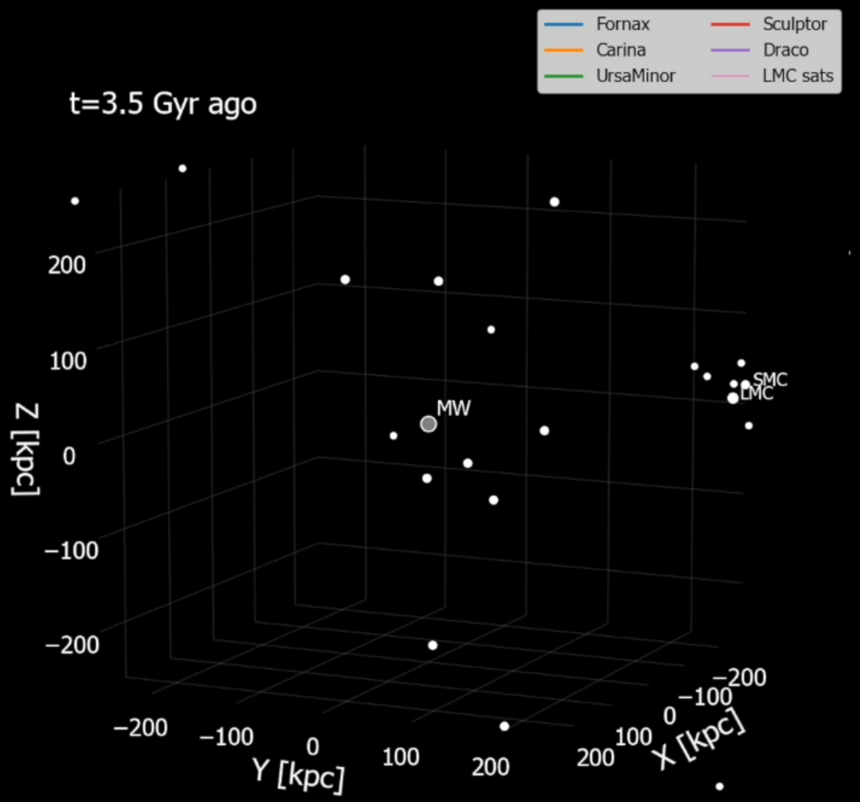


Observations

Simulations w/ different dark matter prescription

Richstein+2024

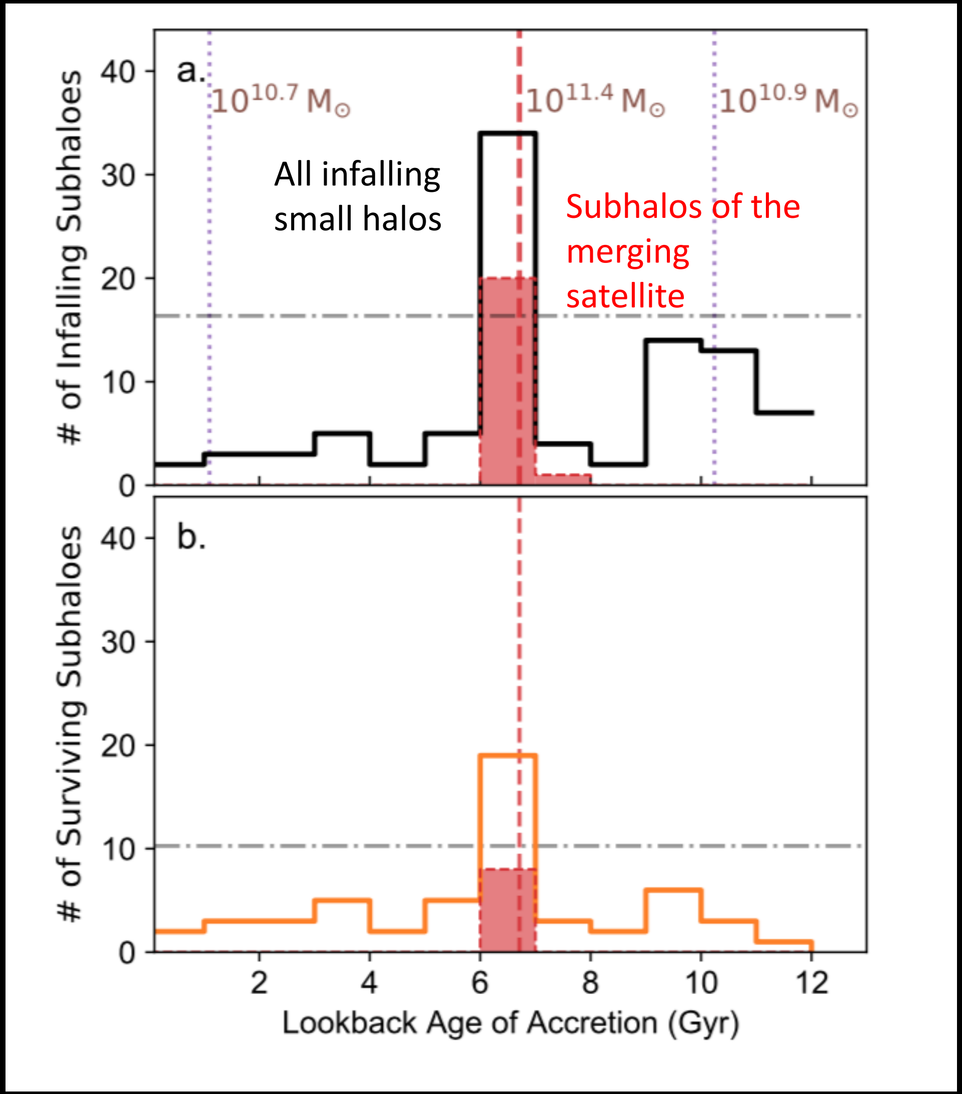
Satellite infall makes generalizing from the MW and M31 dangerous.



Because satellites have fallen in with the LMC and SMC, and each MW-mass galaxy has its own merger history, satellite numbers will depend on the growth history of each MW-mass galaxy.

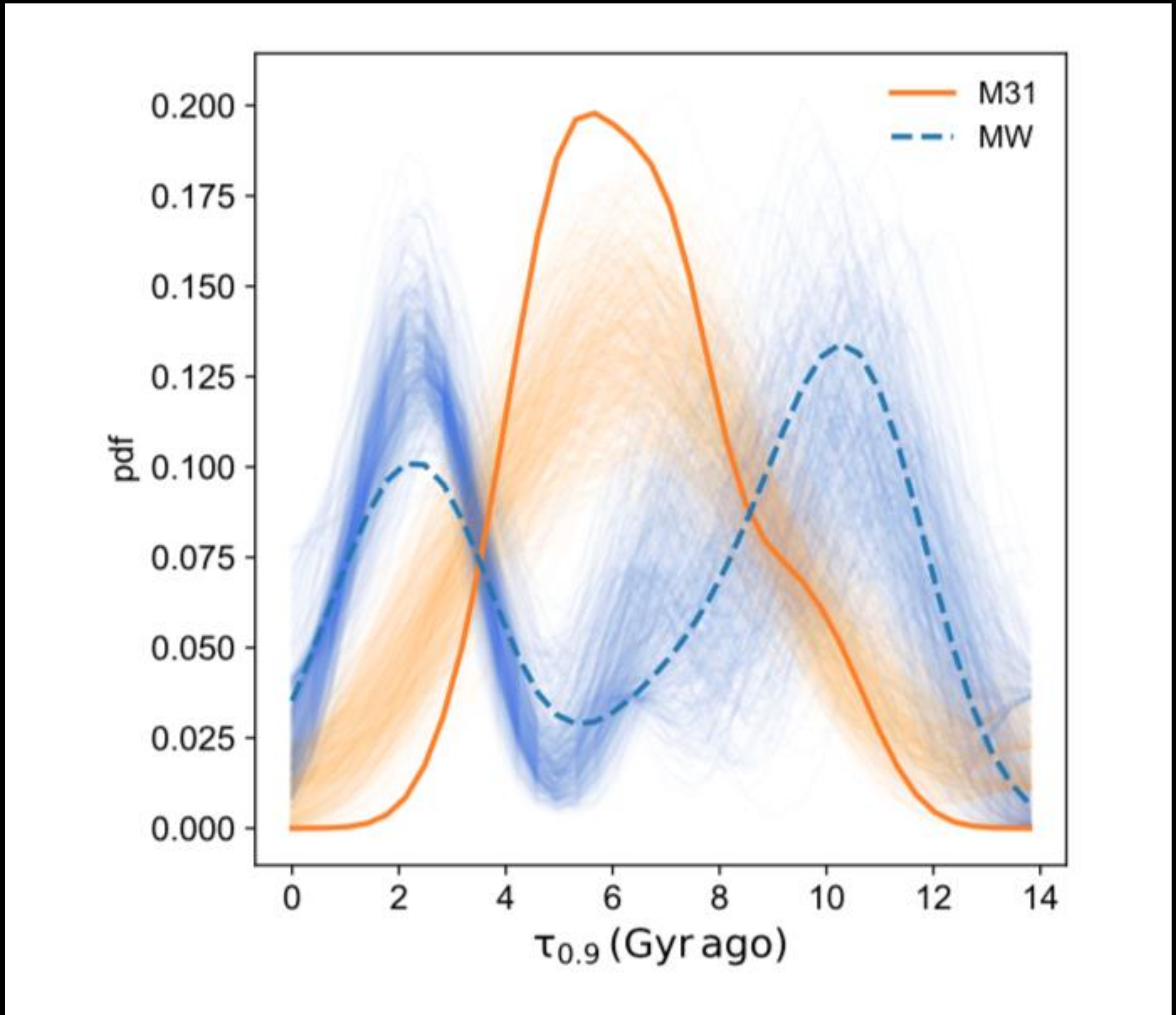
Patel et al. 2020, ApJ, 893, 121

Satellite infall should influence satellite number…



D’Souza & Bell 2021
ELVIS simulation
iLincoln halo (M31-like accretion history)

...and star formation shutoff time (from ram pressure) shows prominent peaks when groups first fell in. In M31's case, most satellites(!) show a peak 6 Gyr ago.

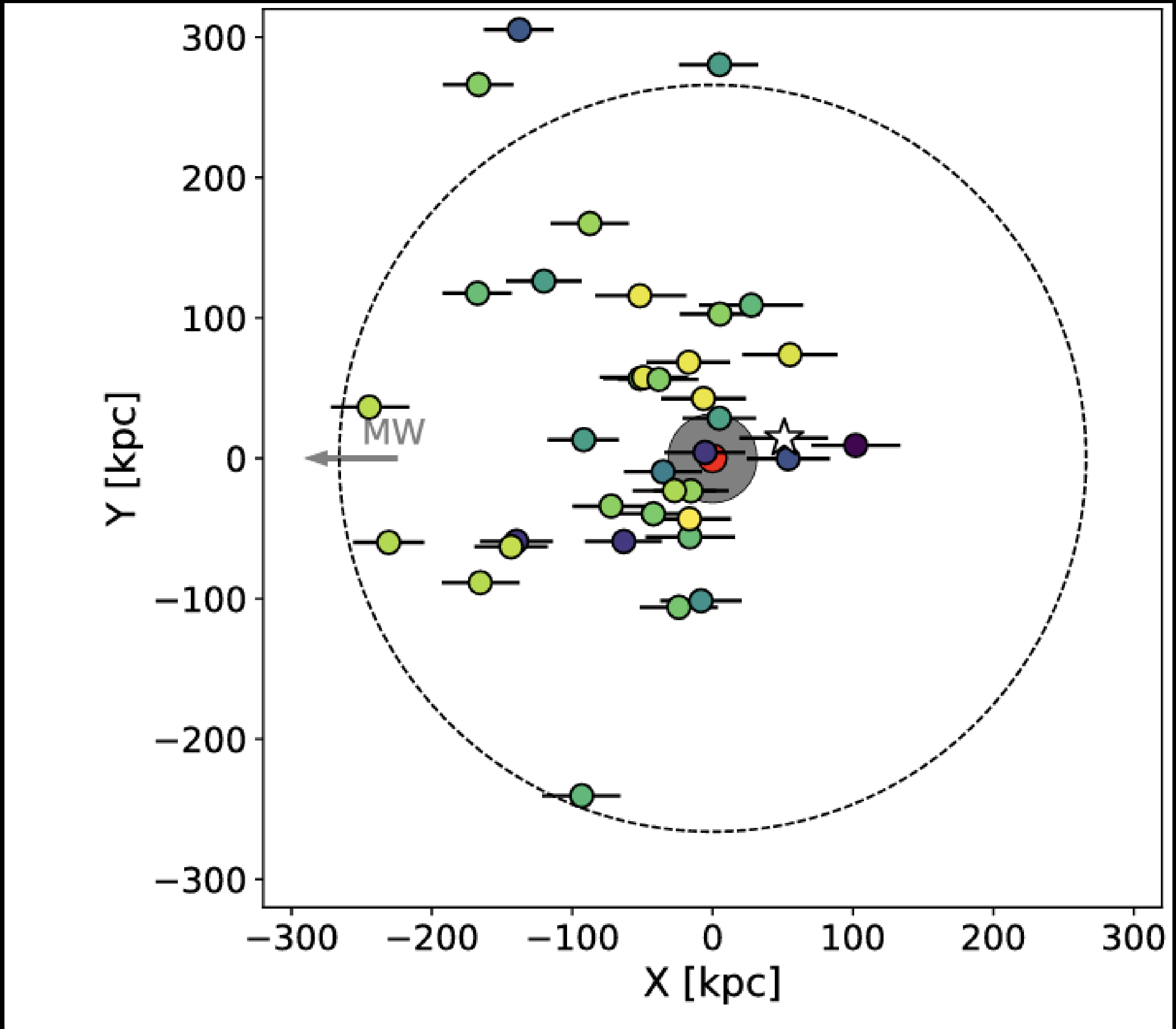


M31's massive merger
- infall ~6Gyr ago
- merger ~2Gyr ago

MW
Gaia-Enceladus ~10Gyr ago
LMC group Infall ~2Gyr ago

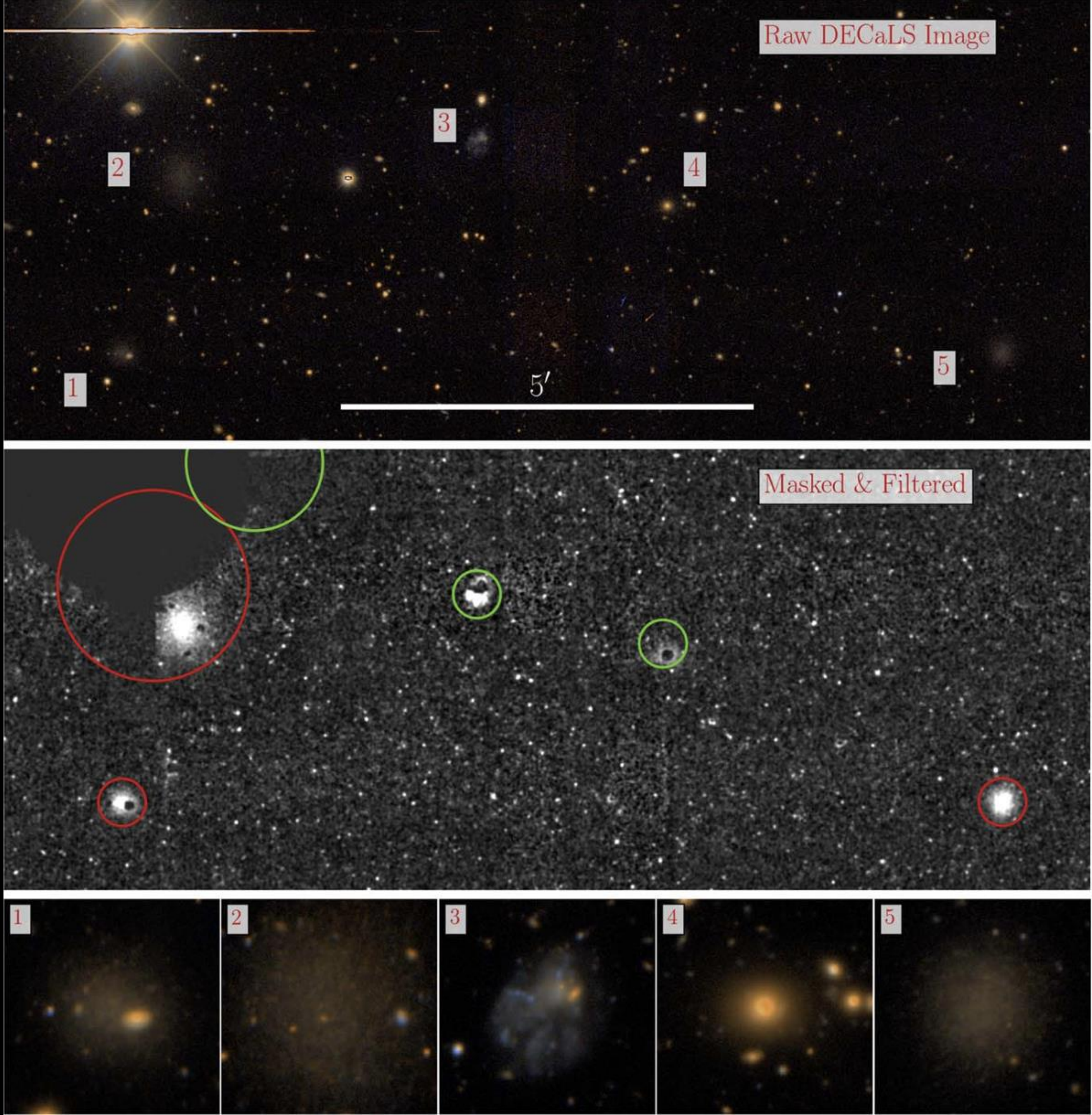
D'Souza & Bell 2021

Indeed, these satellites aren’t phase mixed yet, most are on one side (ours!) of M31!

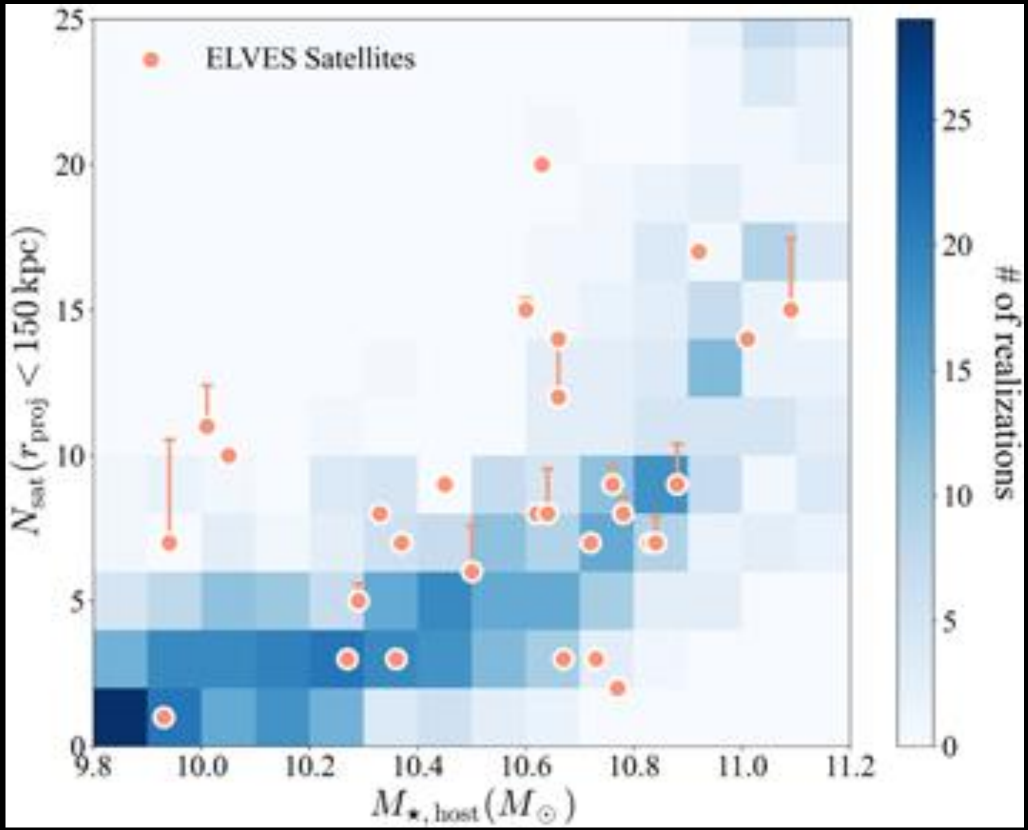


Savino et al. 2022

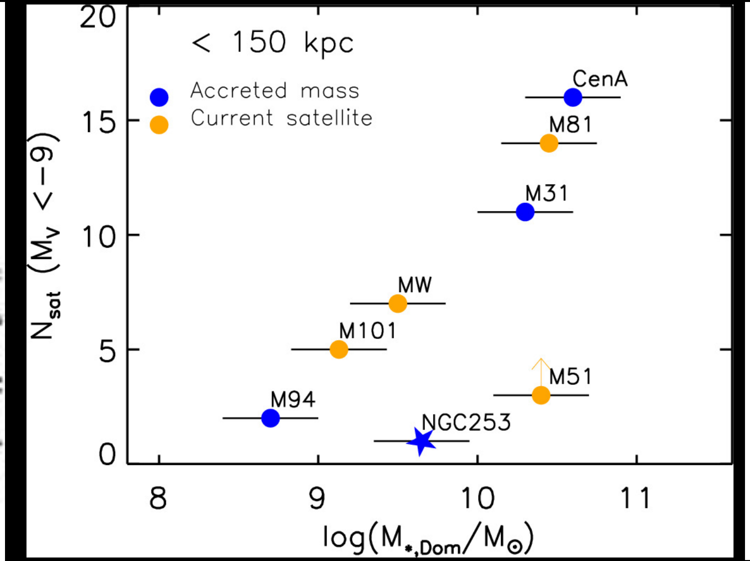
This motivated searches for ~classical dwarf galaxies in nearby galaxy groups, generally using integrated light with resolved or semi-resolved follow-up. (e.g., Müller+2015; Smercina+2018; Carlsten+2022).

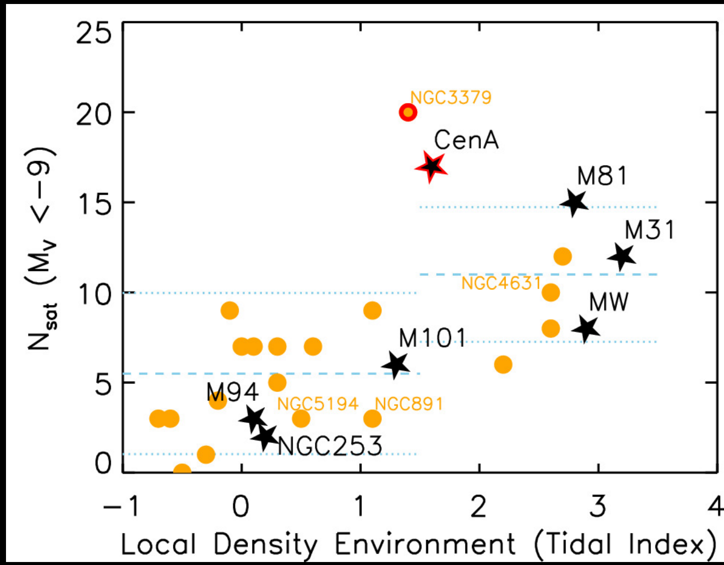


The number of satellites scales with host luminosity (assumed to trace halo mass) with scatter; scatter observed to vary with measures of merger history or environment.



Carlsten et al. 2022; Danieli et al. 2023

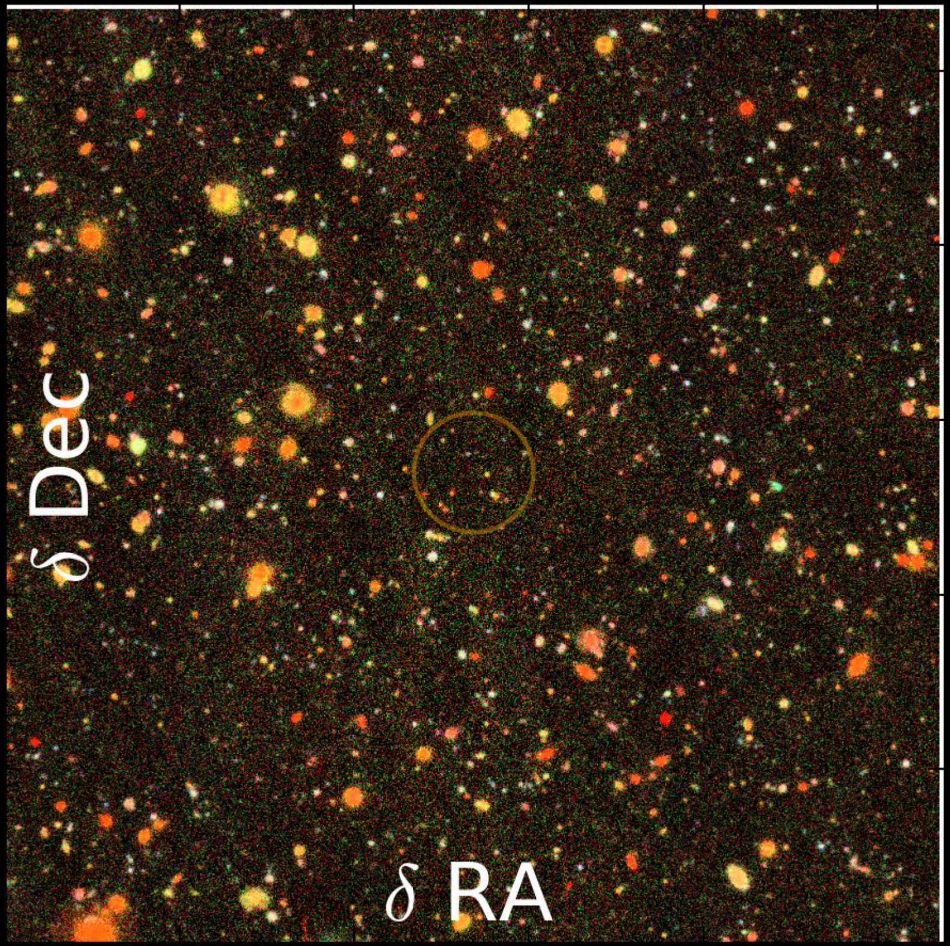




Number of satellites larger for larger past mergers and denser environments.

Bennet et al. 2019; Smercina et al. 2022; Mutlu-Pakdil 2024

But ultra-faint galaxies are so faint and low surface brightness that they require discovery with resolved star techniques (e.g., Mutlu-Pakdil, Crnojevic, Sand).



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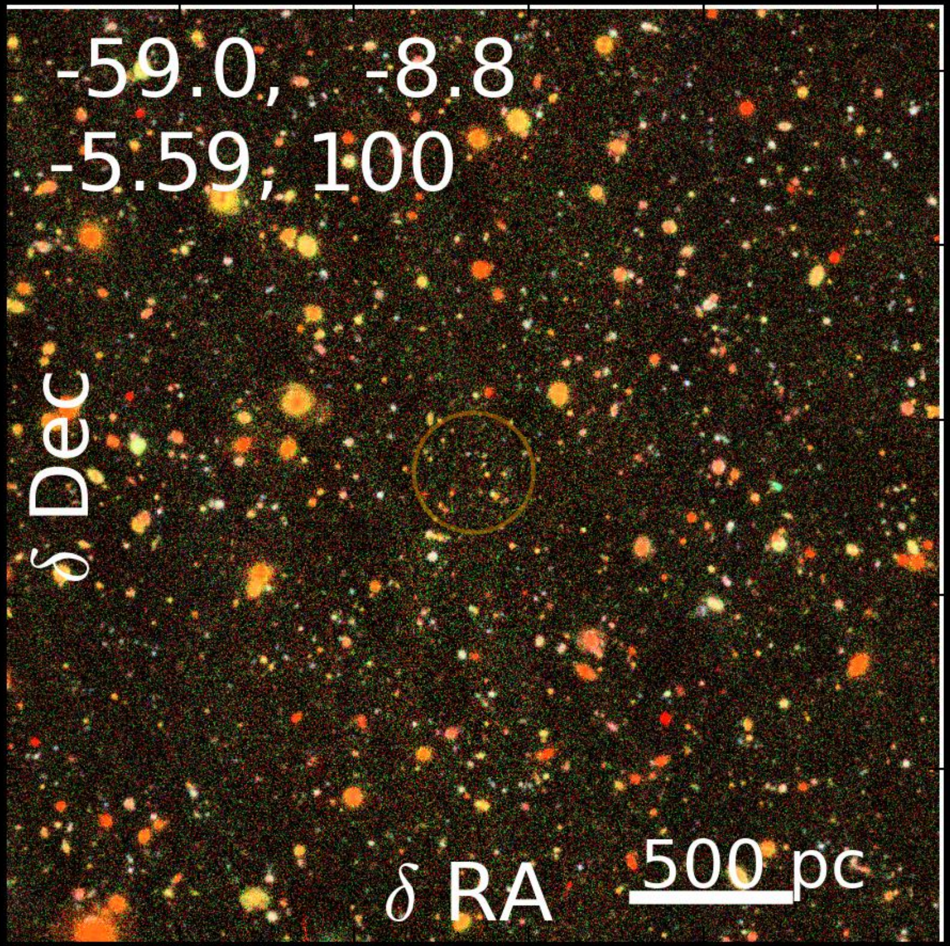

Mock UFD
M_V = -5.6
r_{hl} = 100pc

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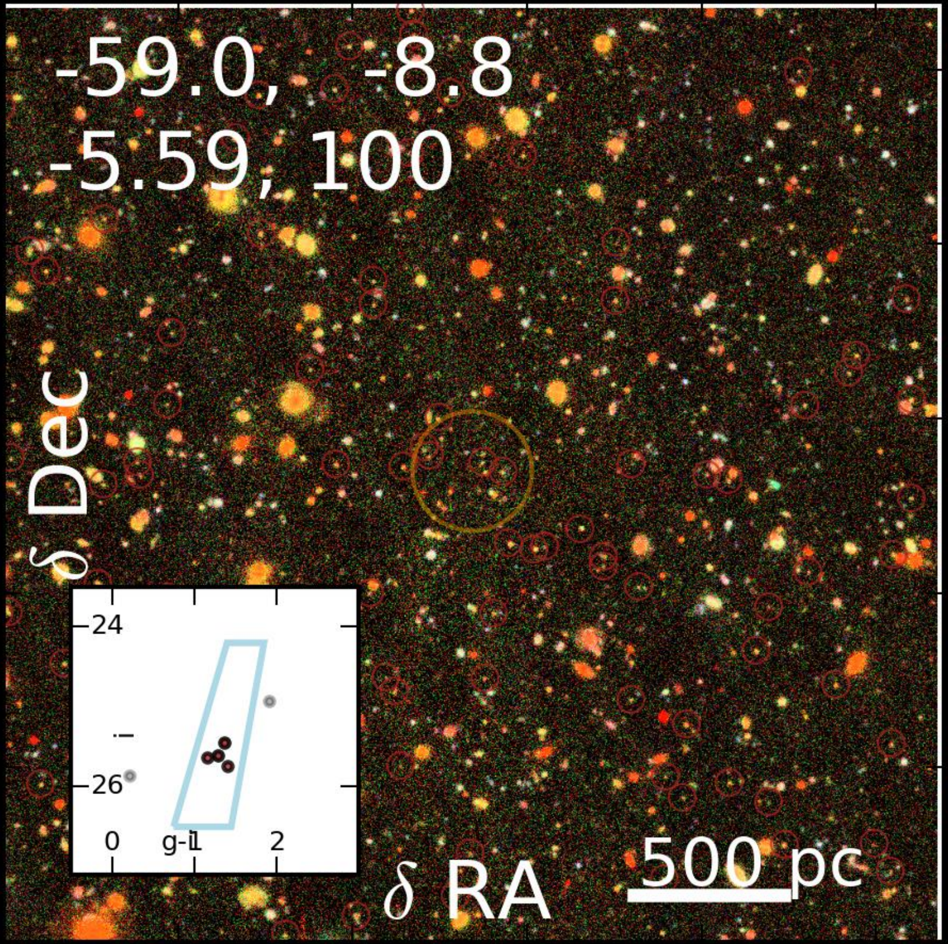
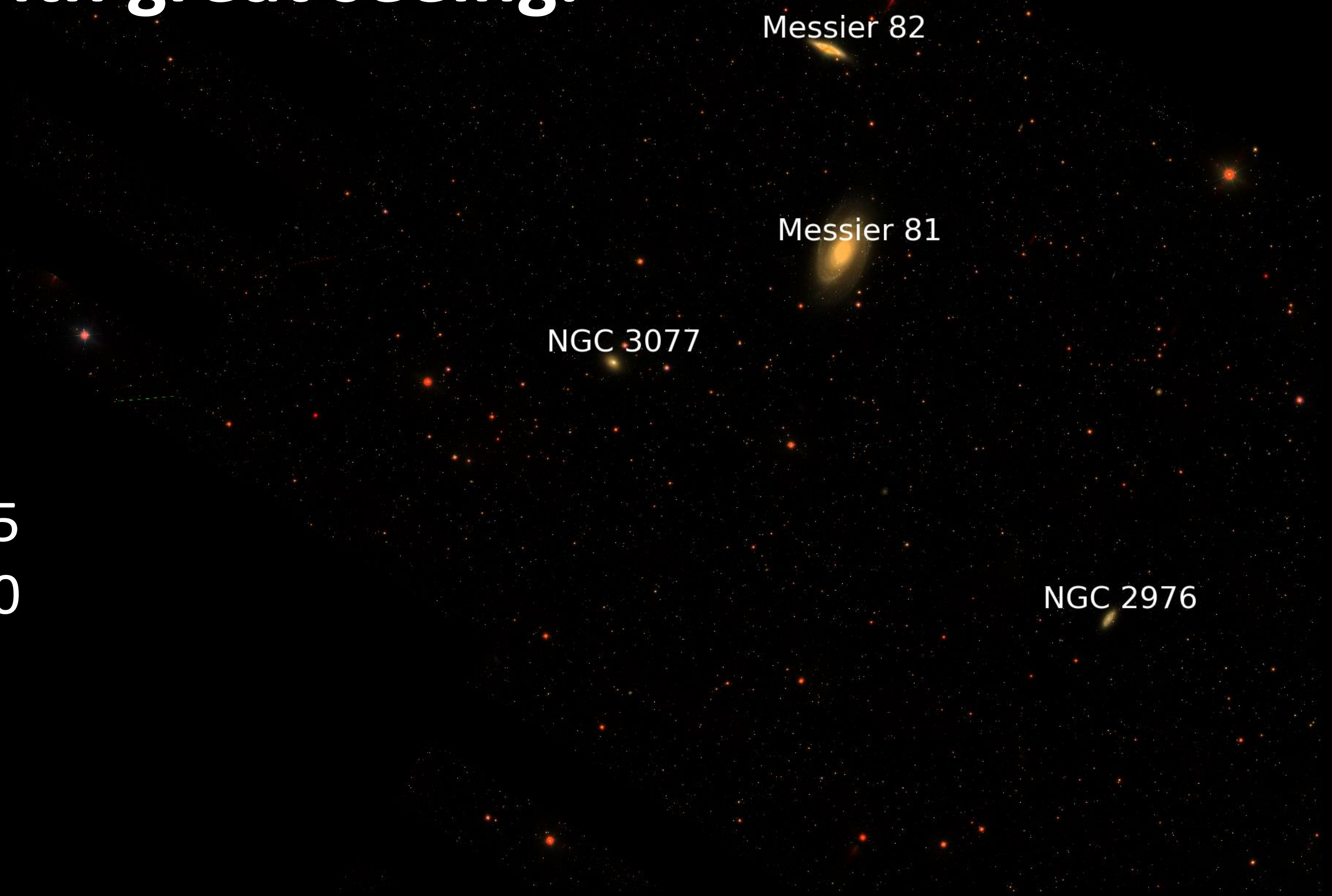


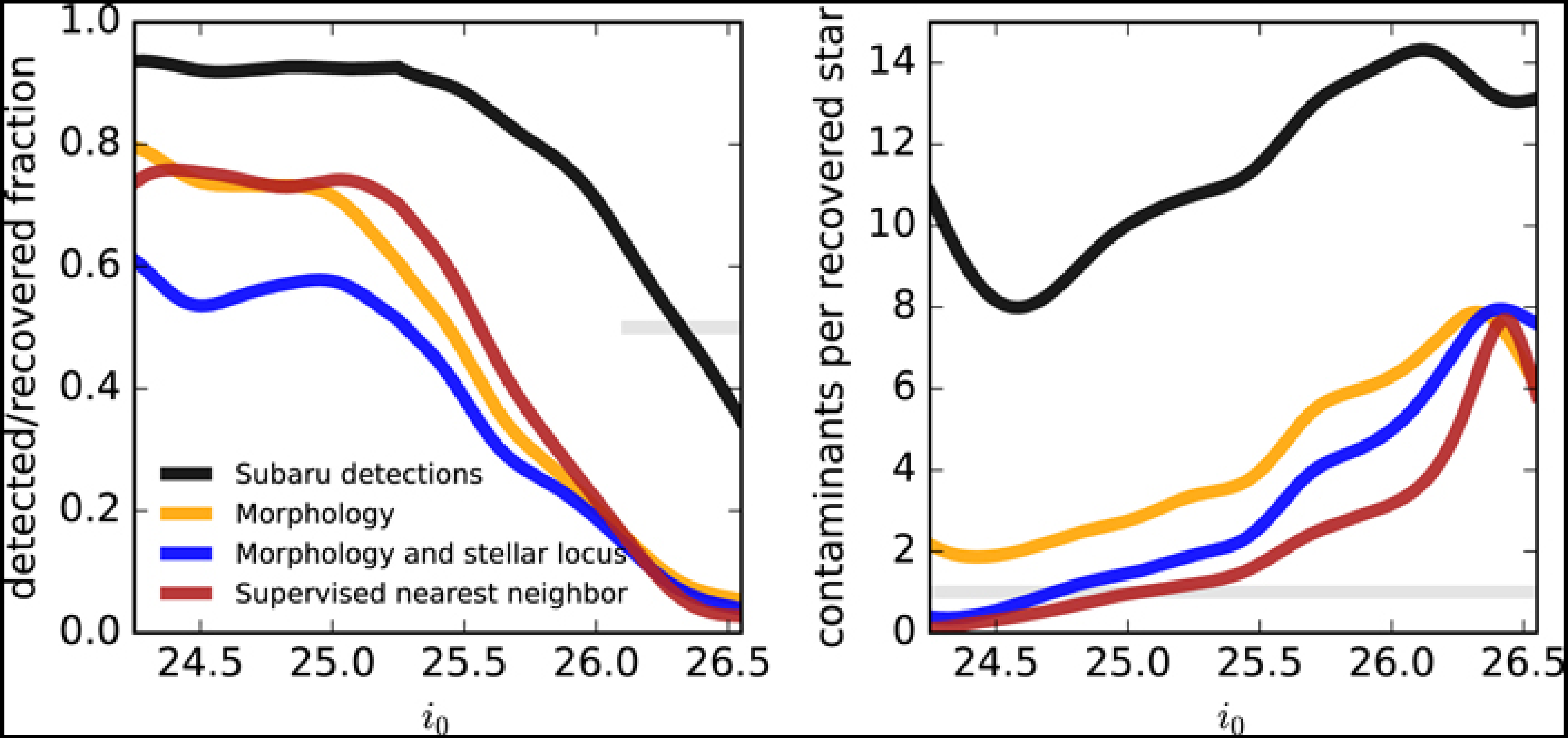
Mock UFD
M_V = -5.6
r_{hl} = 100pc

Our and other groups have been surveying the stellar halos and satellites of nearby Milky Way mass galaxies in resolved stars with Subaru’s HSC – these datasets are LSST 10-year stack depth with great seeing.

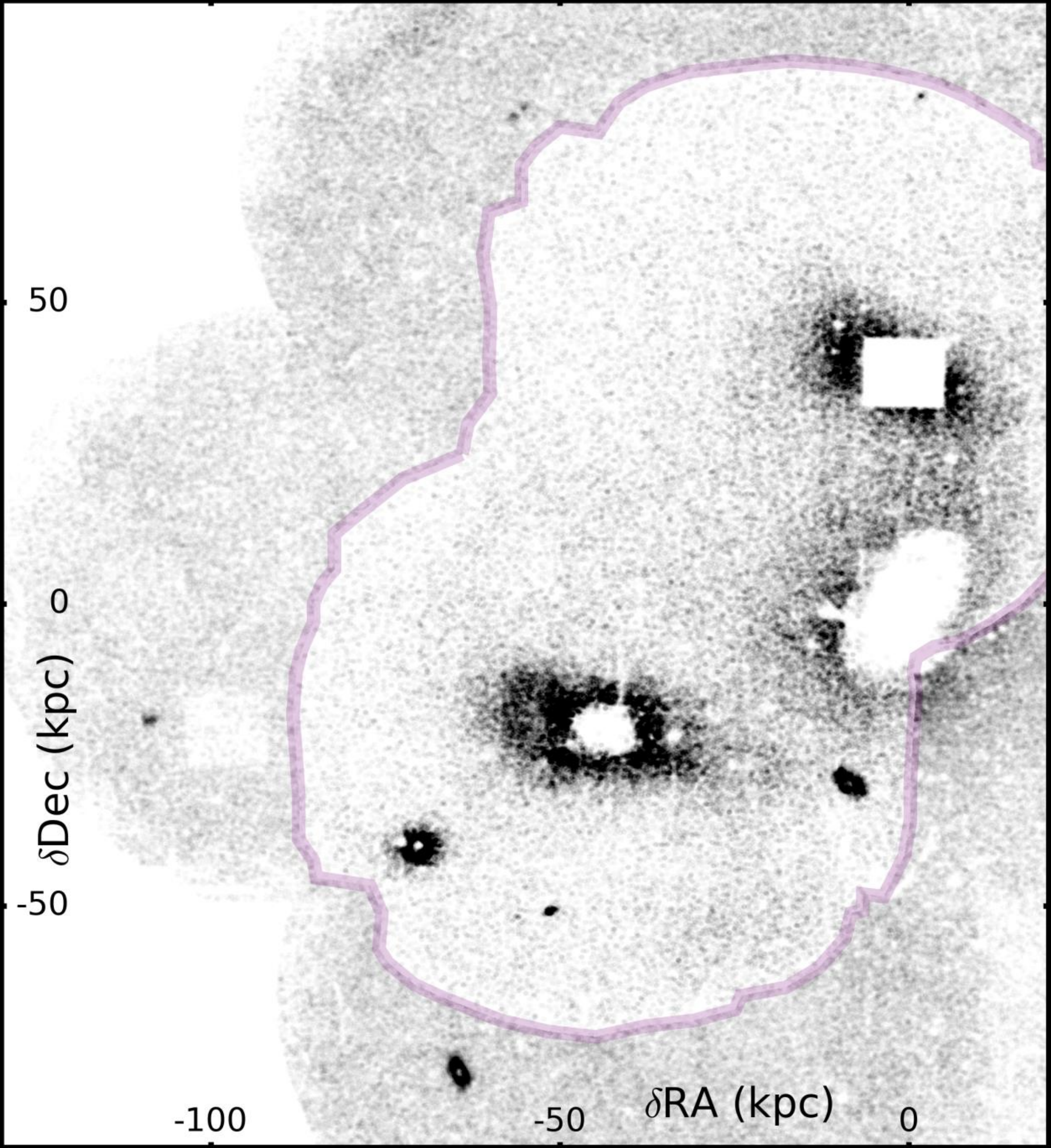


Mature dataset in
the M81 group:
Okamoto et al. 2015
Smercina et al. 2020

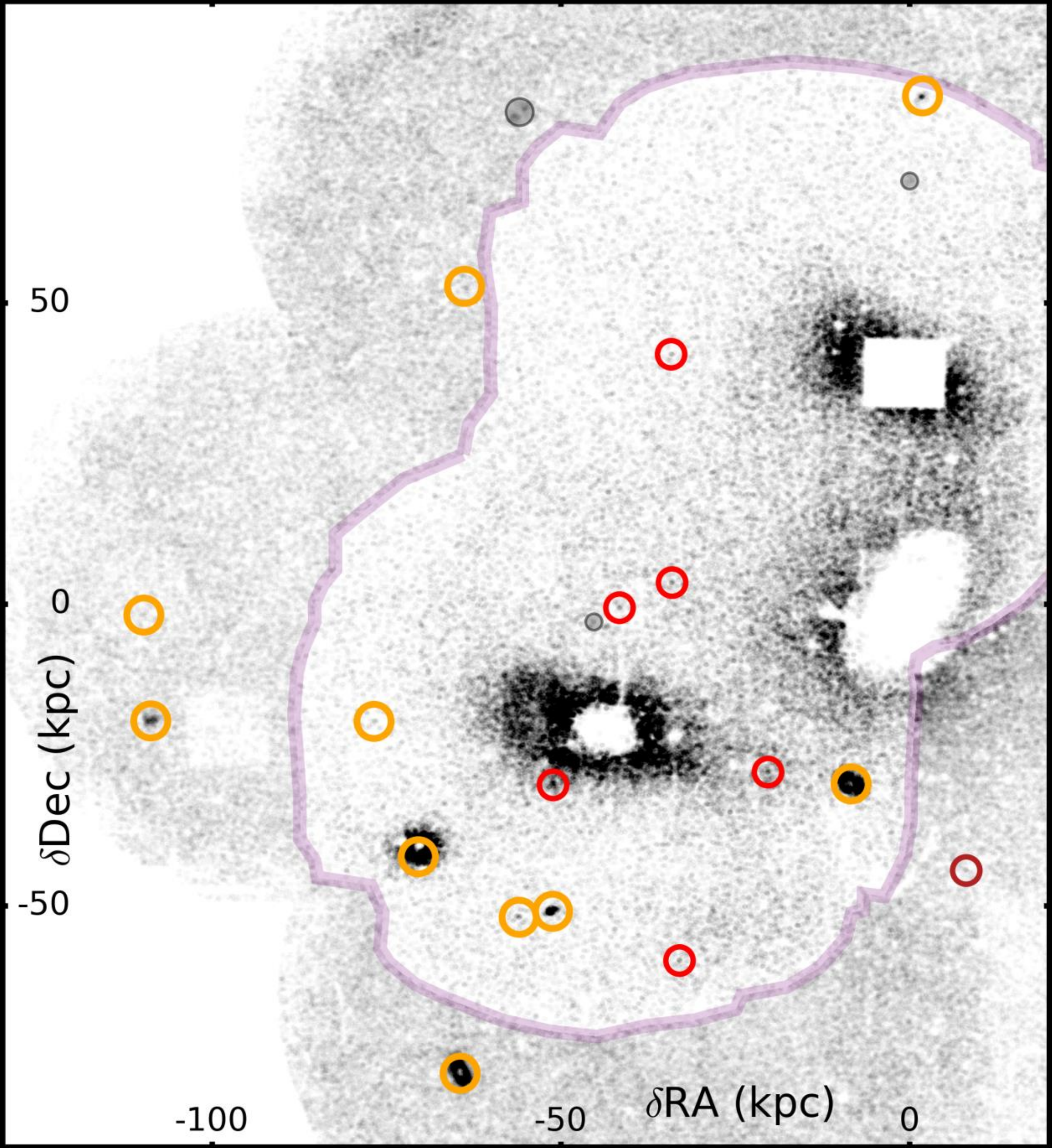
Because galaxies dramatically outnumber stars, star-galaxy separation to i=26.5(!) needed to discover UFDs ☹



Seek KDE overdensties with P<3x10^{-7} from chance alone – expect <~1 false positive from blank field calibrations.



In addition to all **known M81 dwarfs** in the survey footprint, we find one **definite dwarf** and some **low surface brightness candidates**



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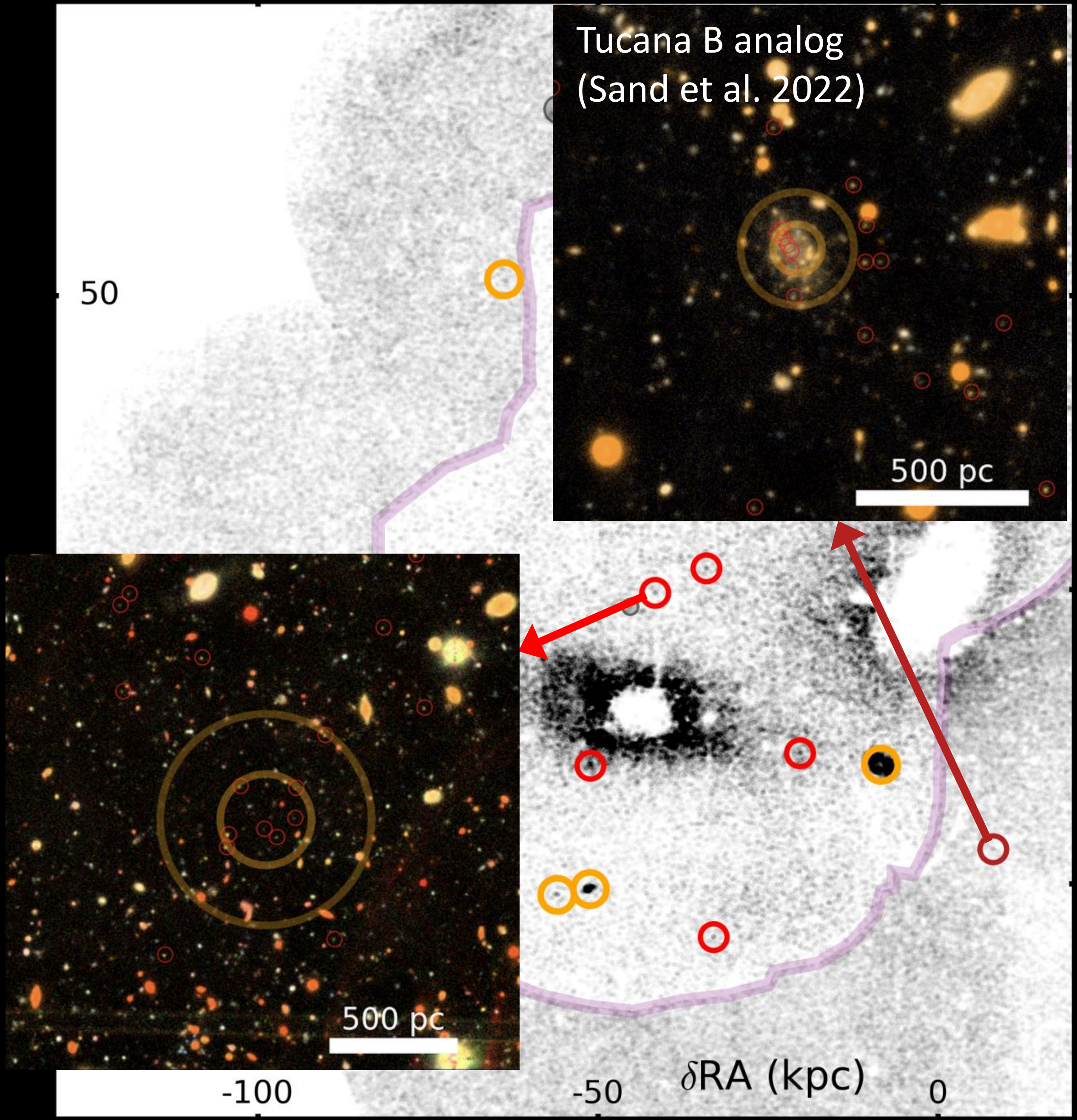
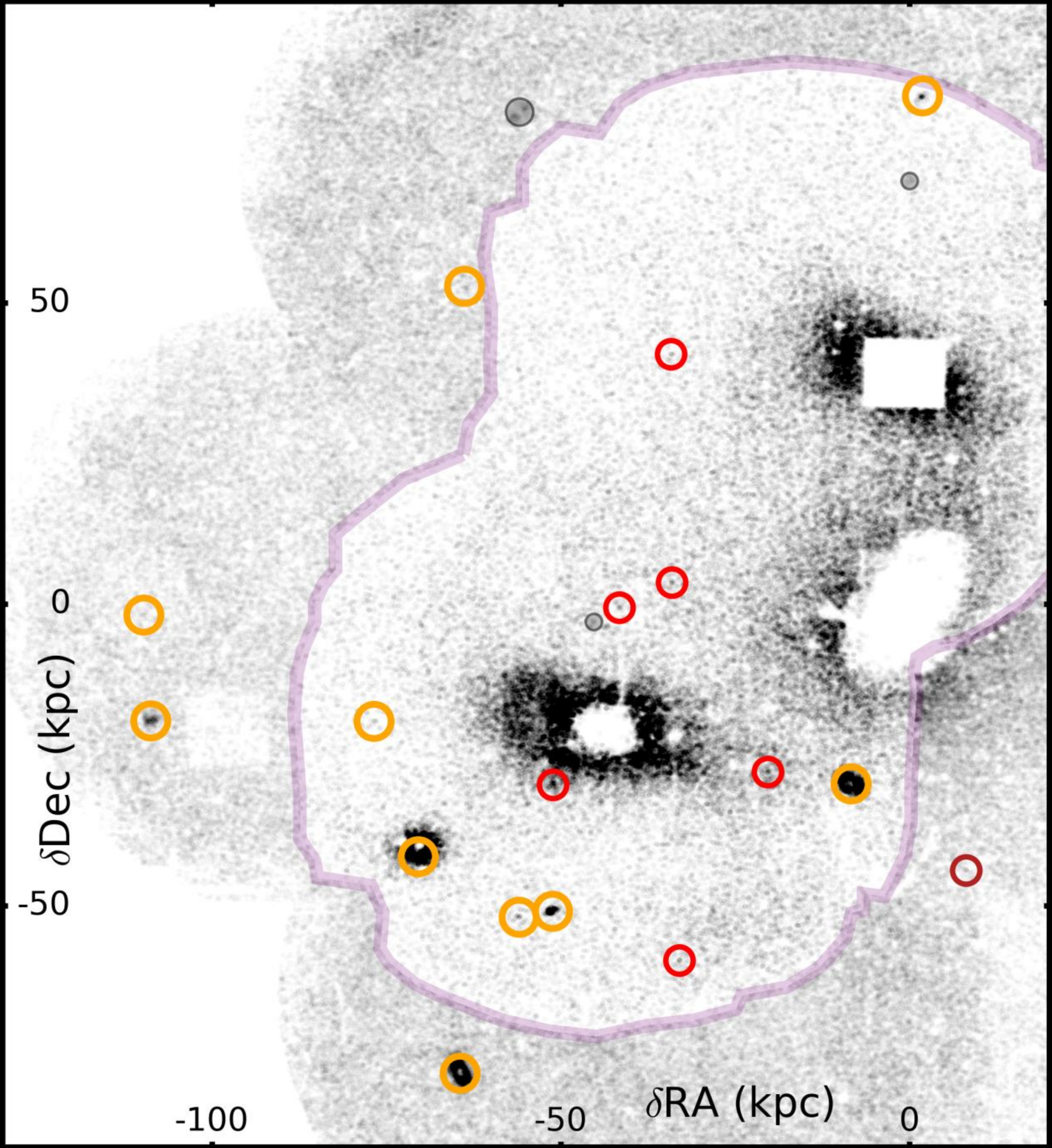


HST follow-up rules out all LSB candidates, but confirms 4 UFDs with $-7.7<M_V<-6.5$, as diffuse as $\mu \sim 30$ mag/□"



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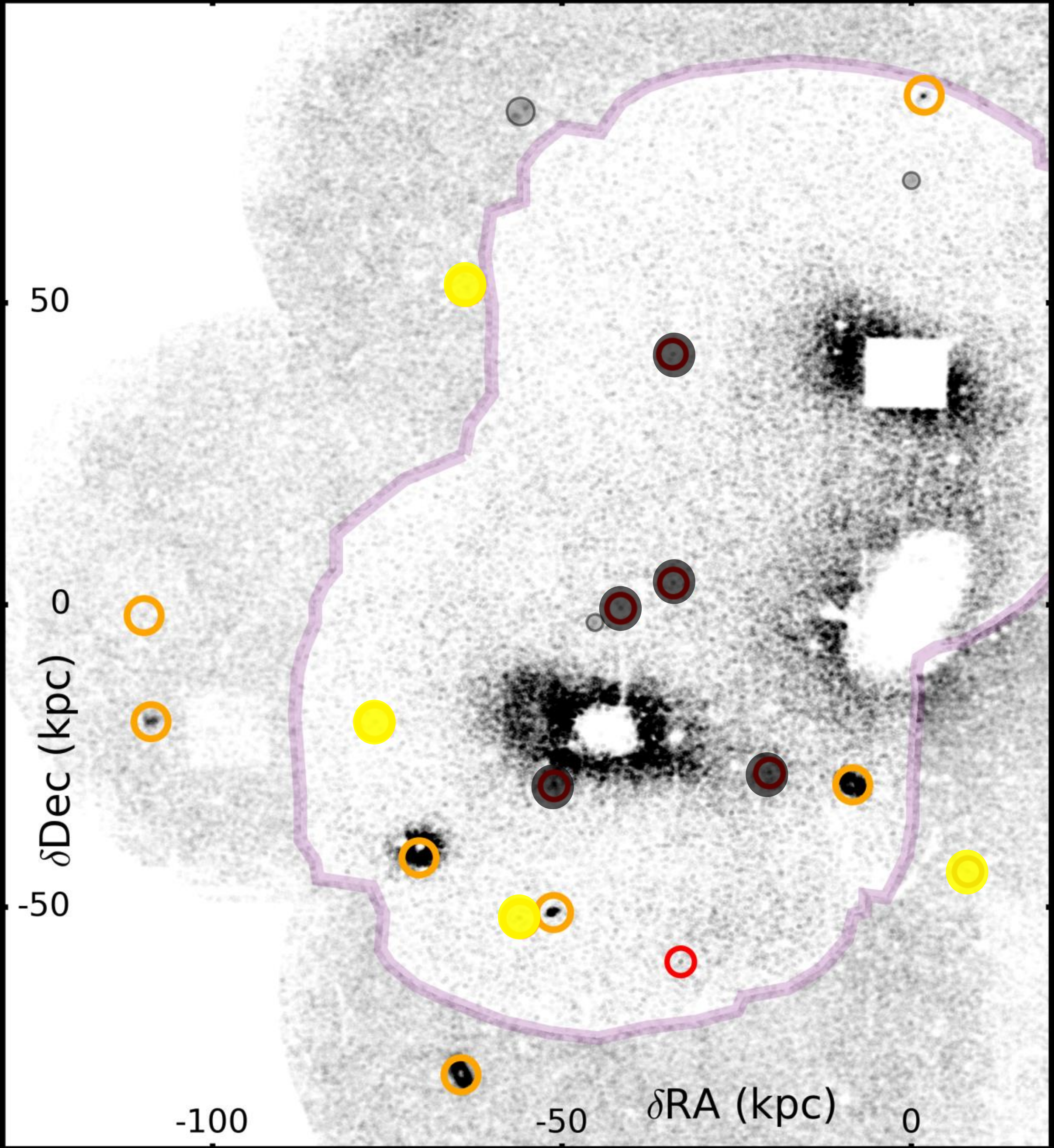
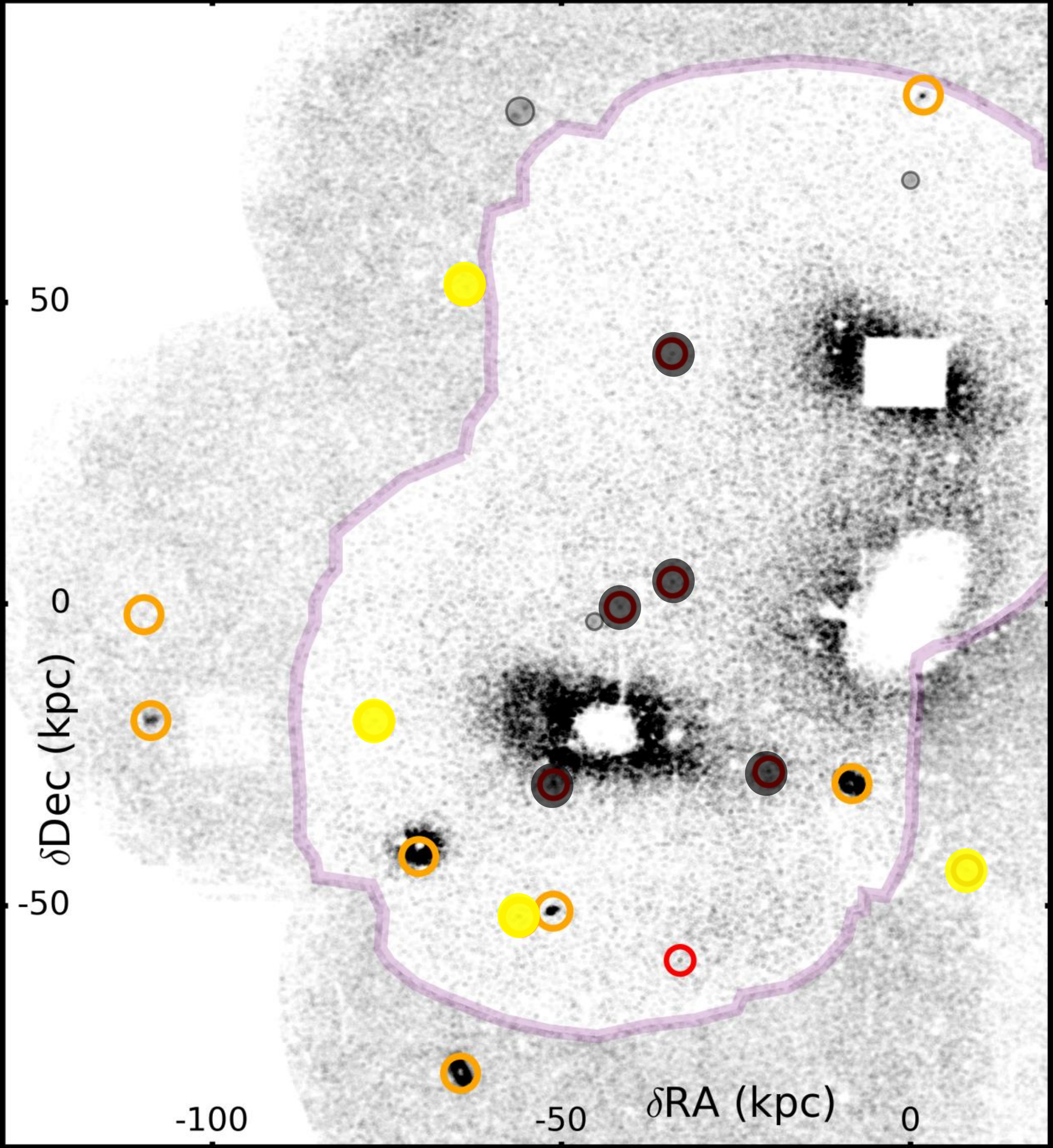


What led to false positives?

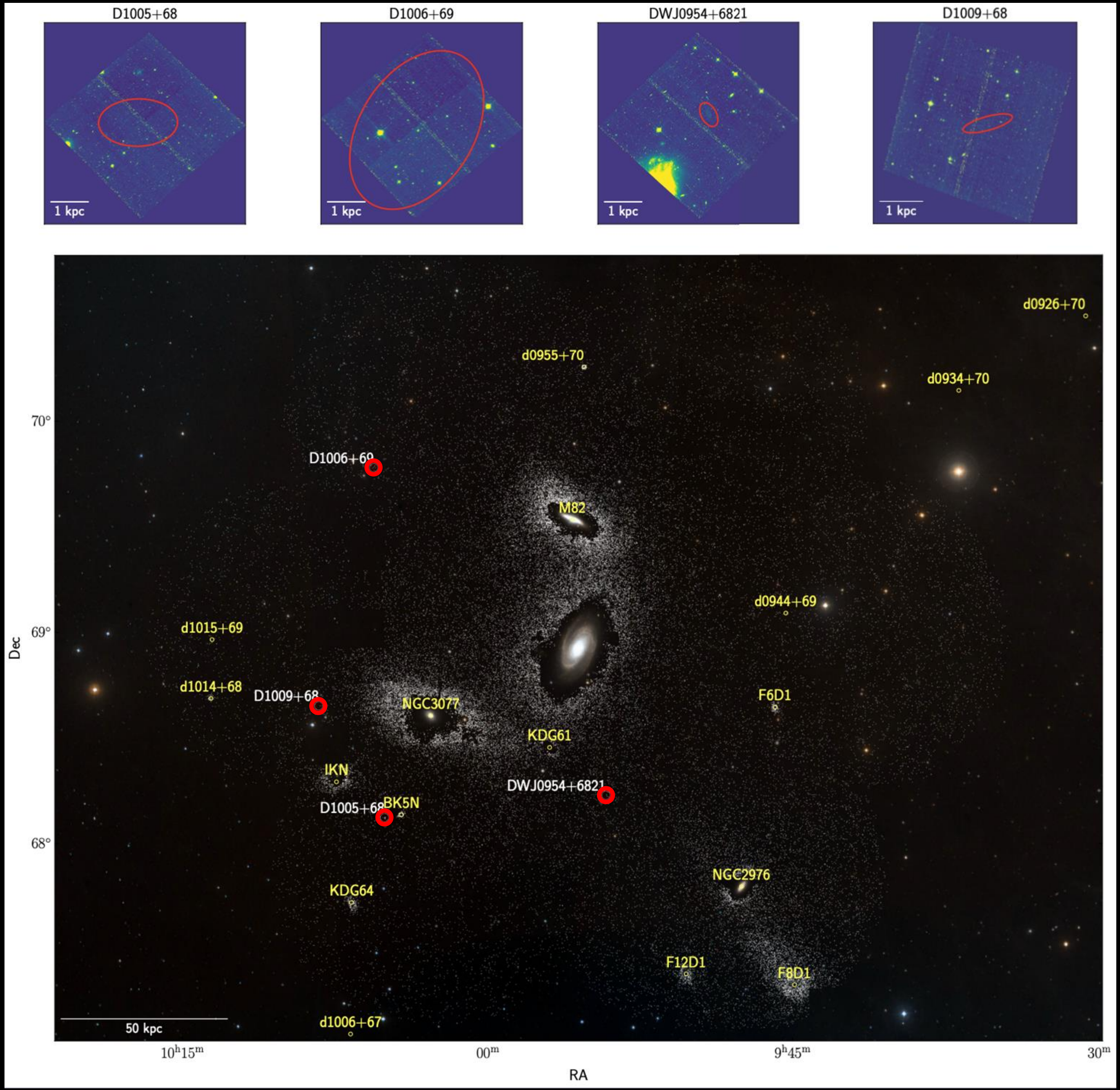
Background galaxy groups (at density suggested by empty fields)

Blue helium-burning stars with Subaru colors placing them in metal-poor RGBs

Edge effects (My fault - I needed a better background model)

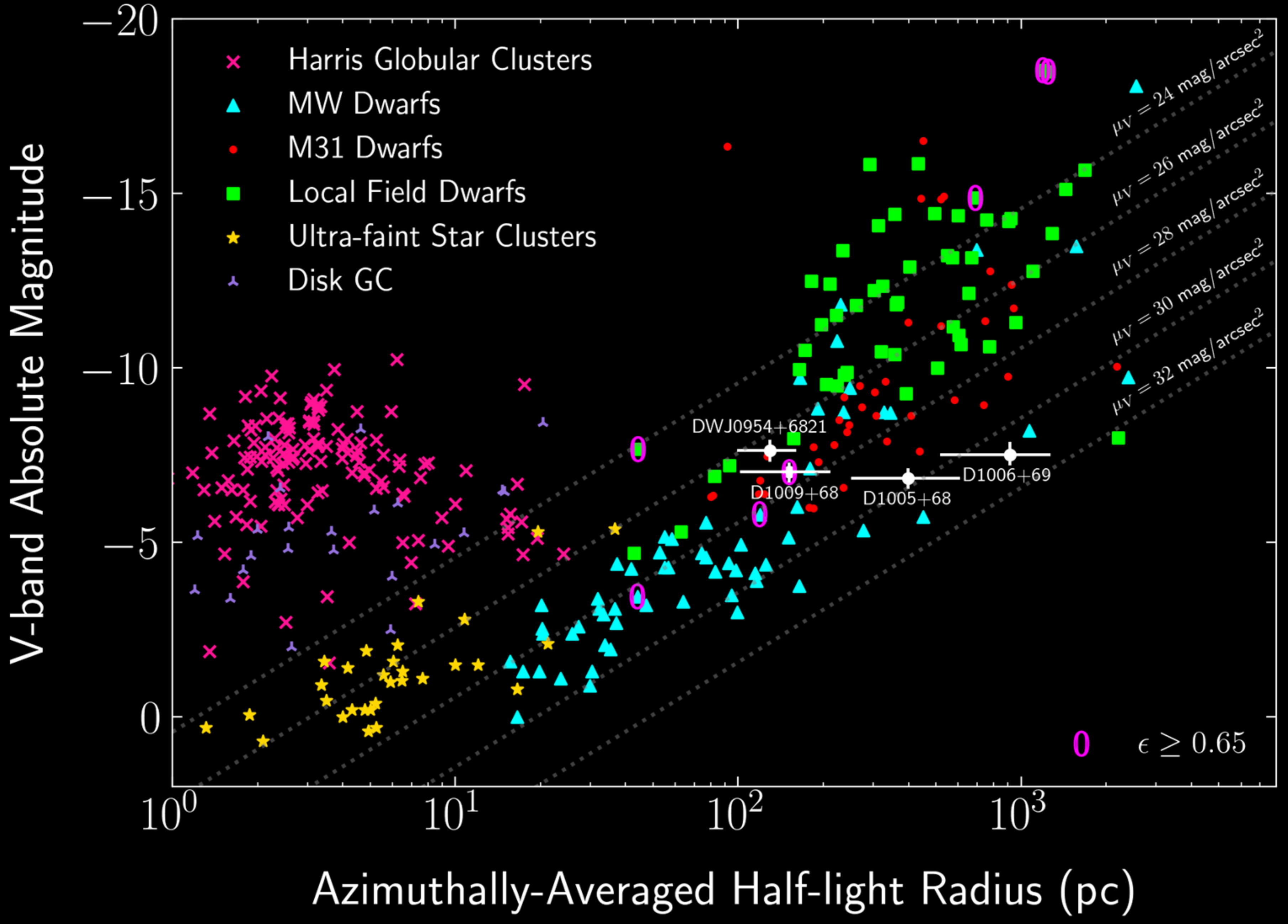


But, we confirm four UFDs – faintest galaxies in M81 group, and amongst faintest ever found outside Local Group.

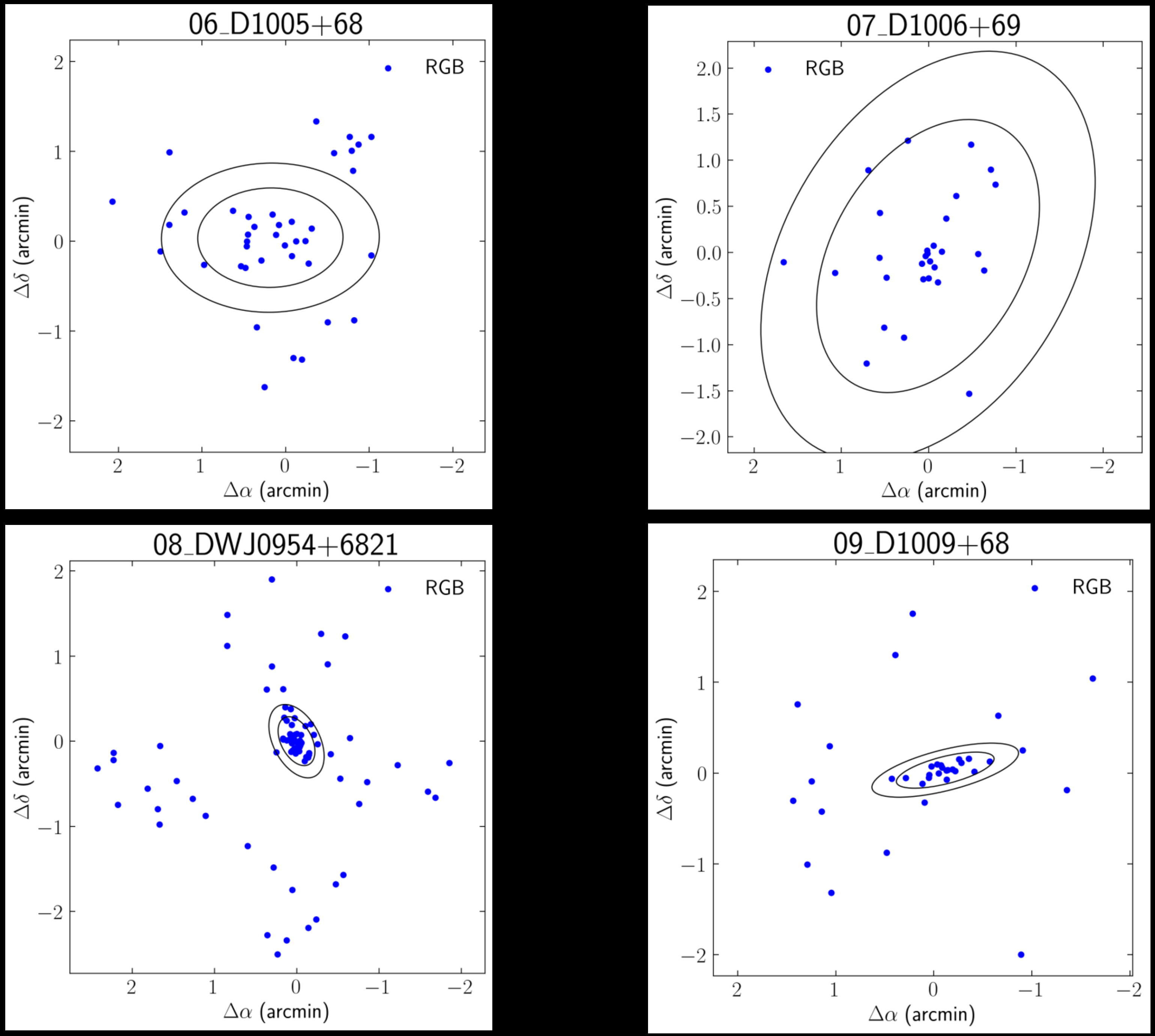


Gozman et al., in prep.

We confirm four M81 ultra-faint galaxies $-7.7<M_V<-6.5$, as diffuse as μ ~ 30 mag/□"



These M81 ultra-faints are *diverse* – x10 range in r_{hl}; one cannot be fit with an exponential and has n~4 (!)



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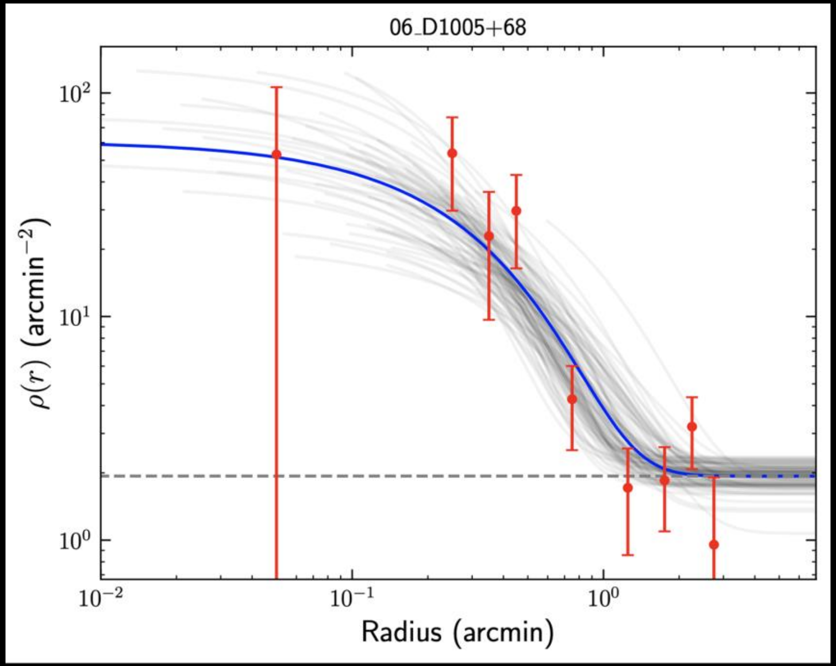
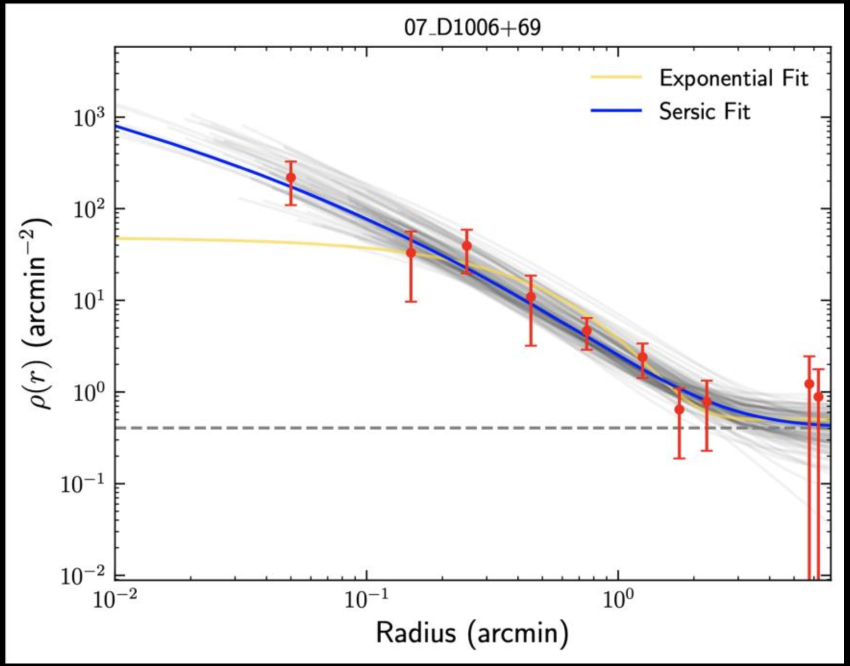
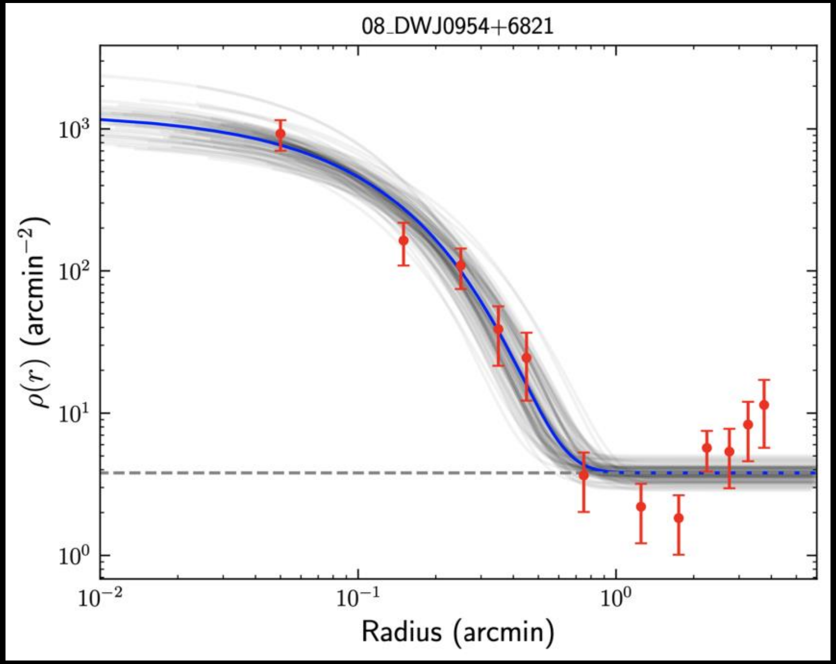
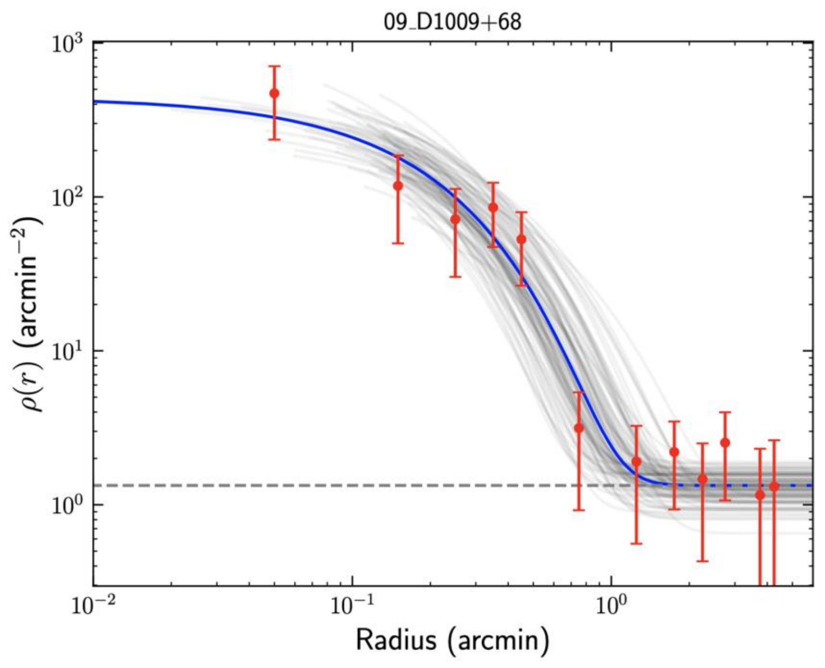
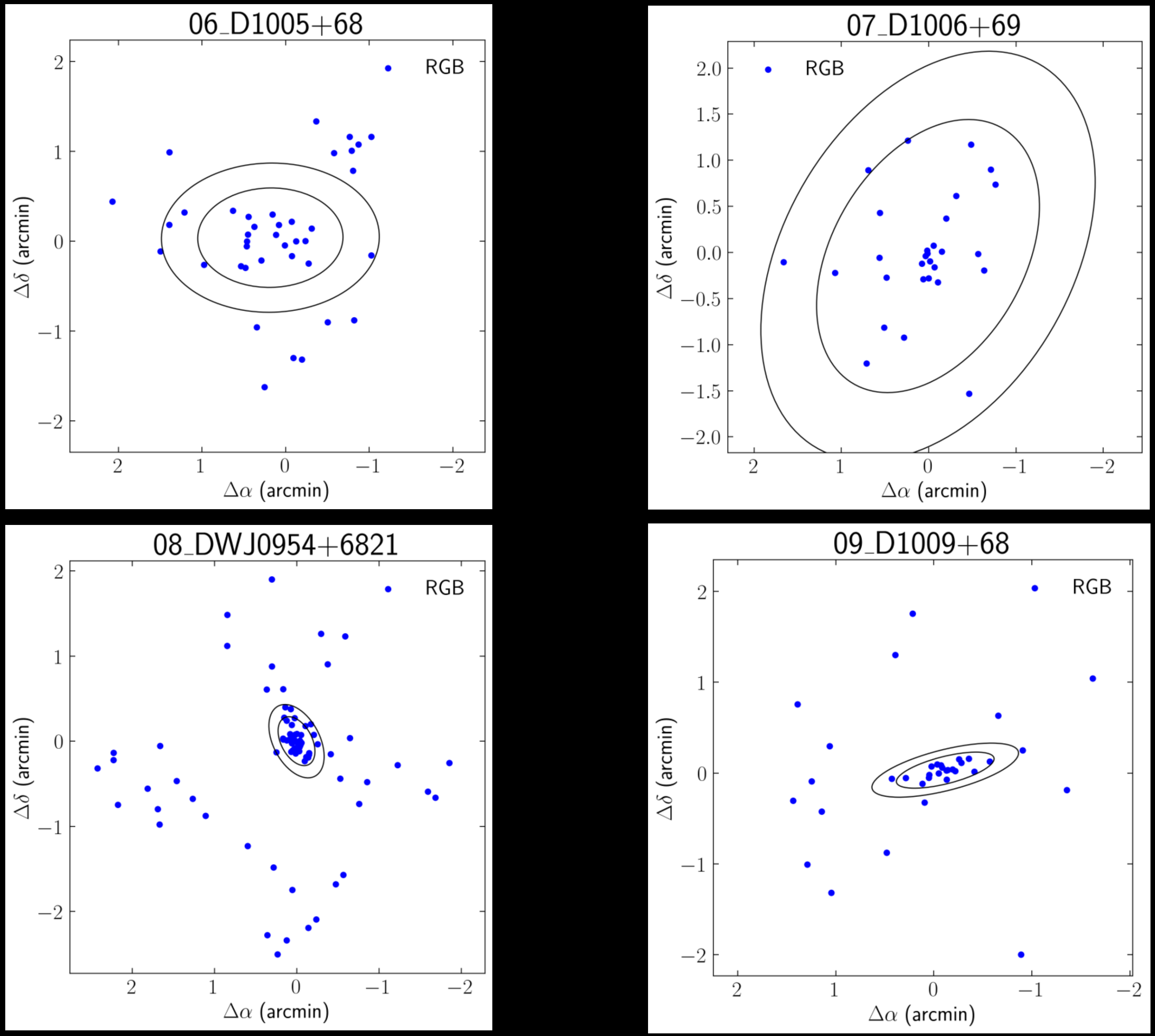






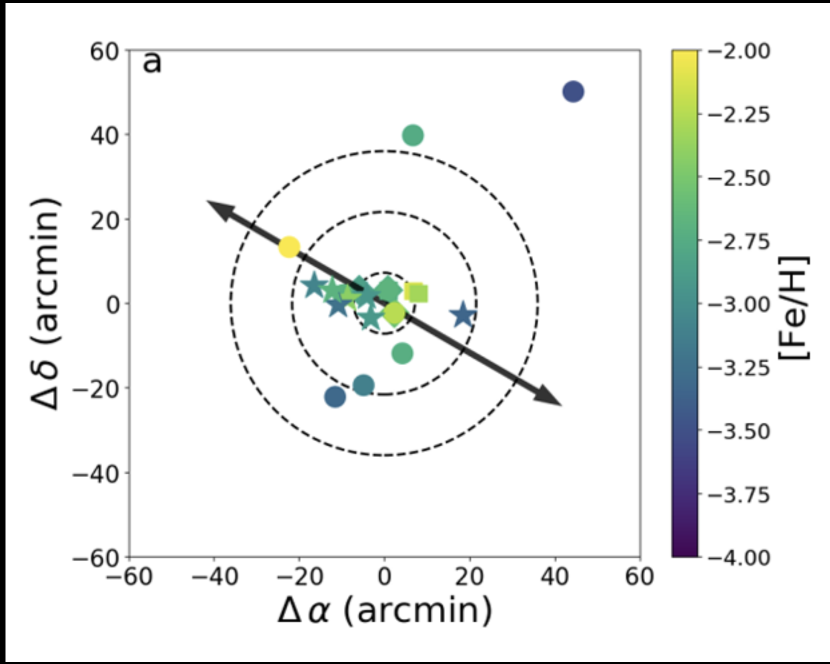


Another has >3:1 axis ratio, reminiscent of Hercules. But like Hercules, none are close to their parent and none are tidally limited (r_{tidal} > few kpc)



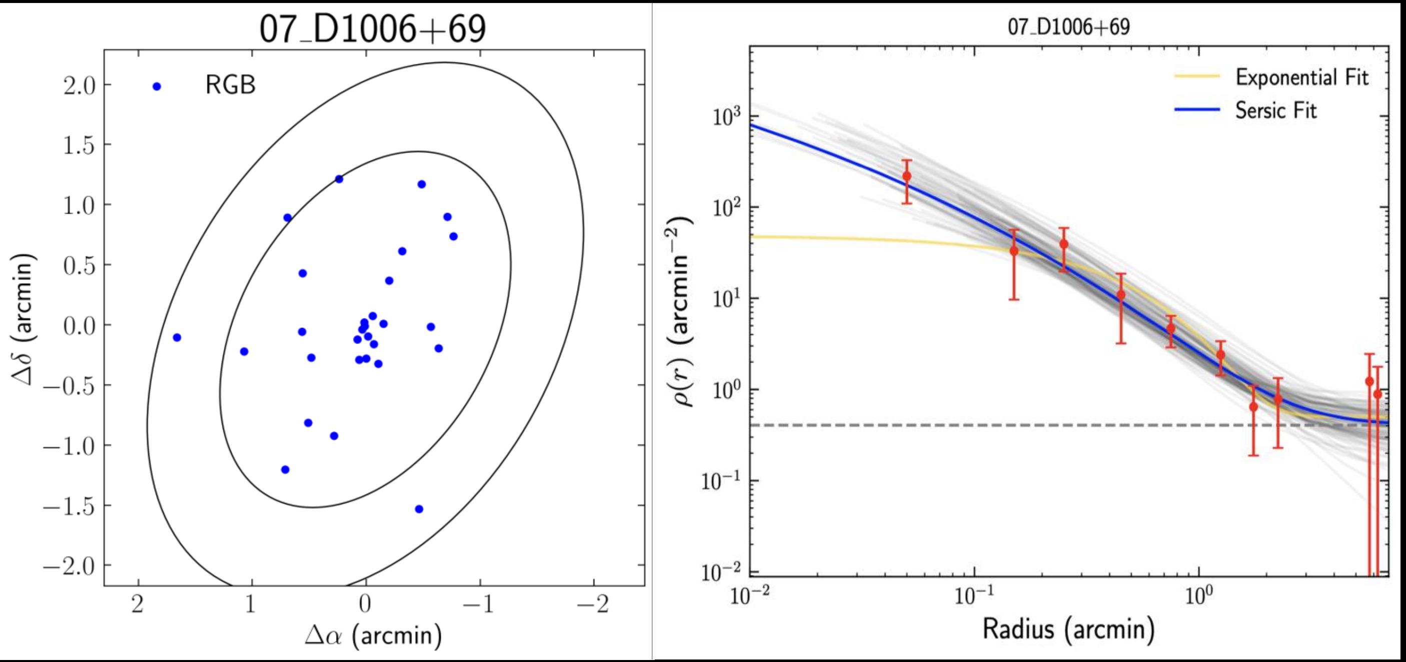
While UFDs with extended envelopes are known at M_V ~ -3.5 (e.g., Tucana II), D1006+69 is unique in its combination of brightness M_V ~ -7.5 and concentration n~4.

Tuc II; M_V~-3.5



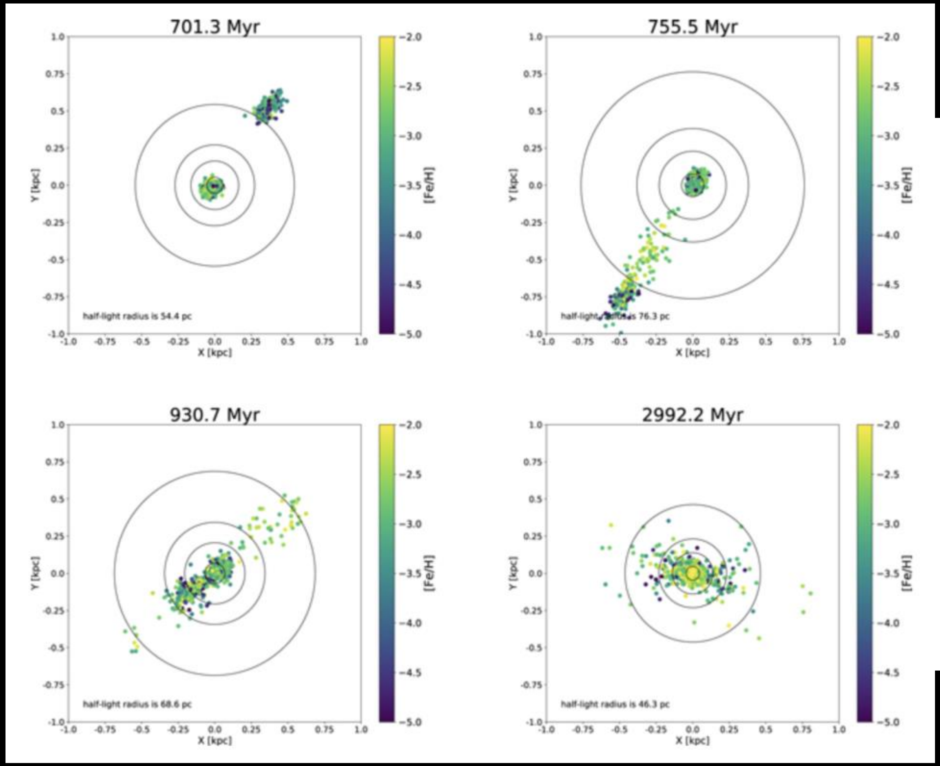
Chiti et al. (2021)

D1006+69; M_V~-7.5

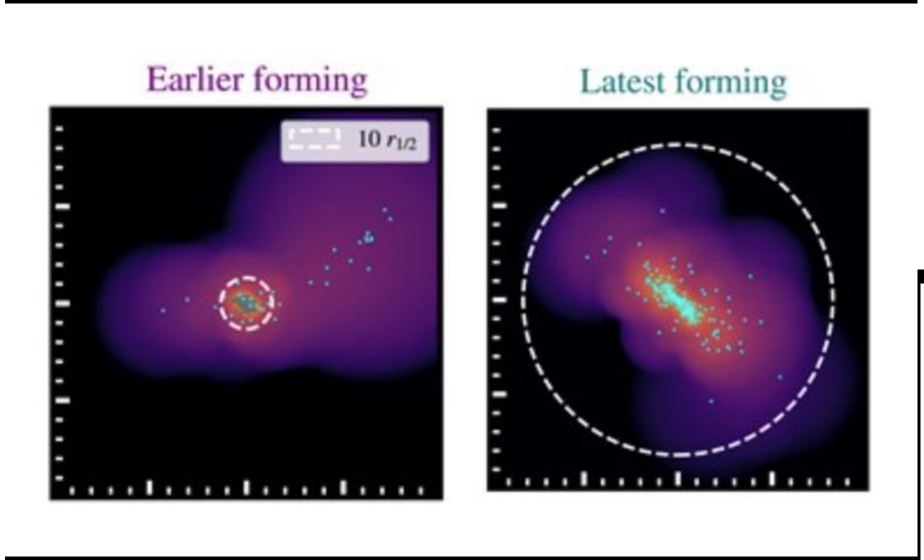


Gozman et al. in prep.

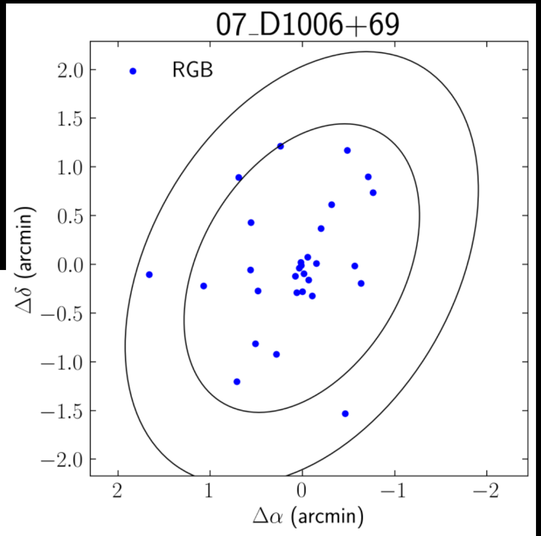
Both extended profiles and highly-flattened UFDs have been suggested to be signs of previous UFD merging – UFD stellar halos that reflect merger time.

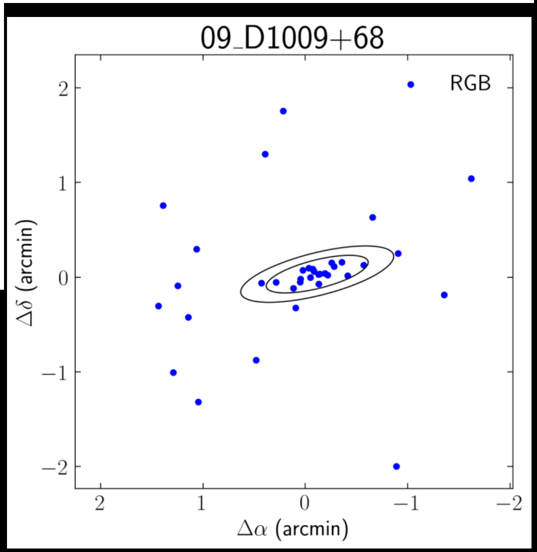


Tarumi et al. 2021

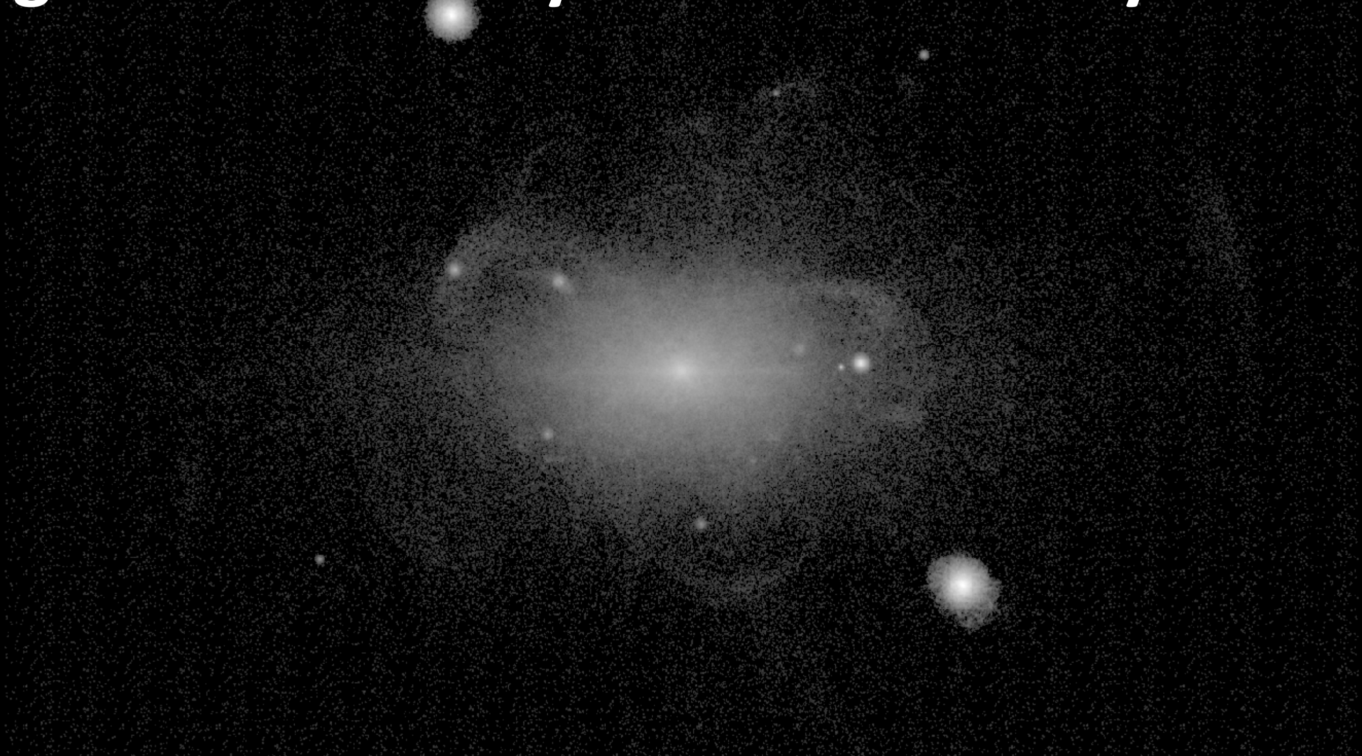


Goater et al. 2024



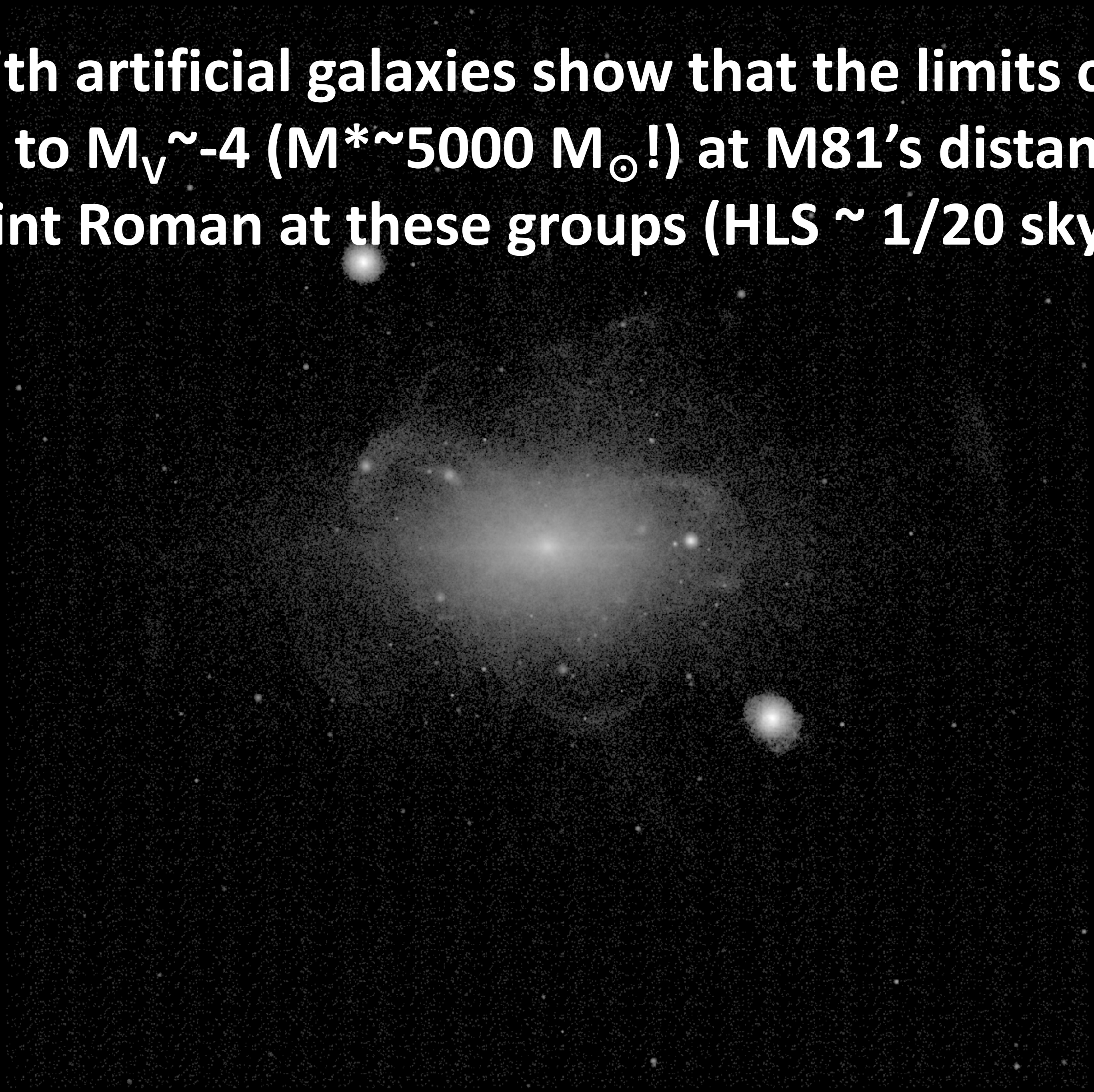


While finding UFDs will be challenging with Rubin, Roman Space Telescope’s wide field, deep point-source detection and star-galaxy separation will give dramatically better sensitivity.

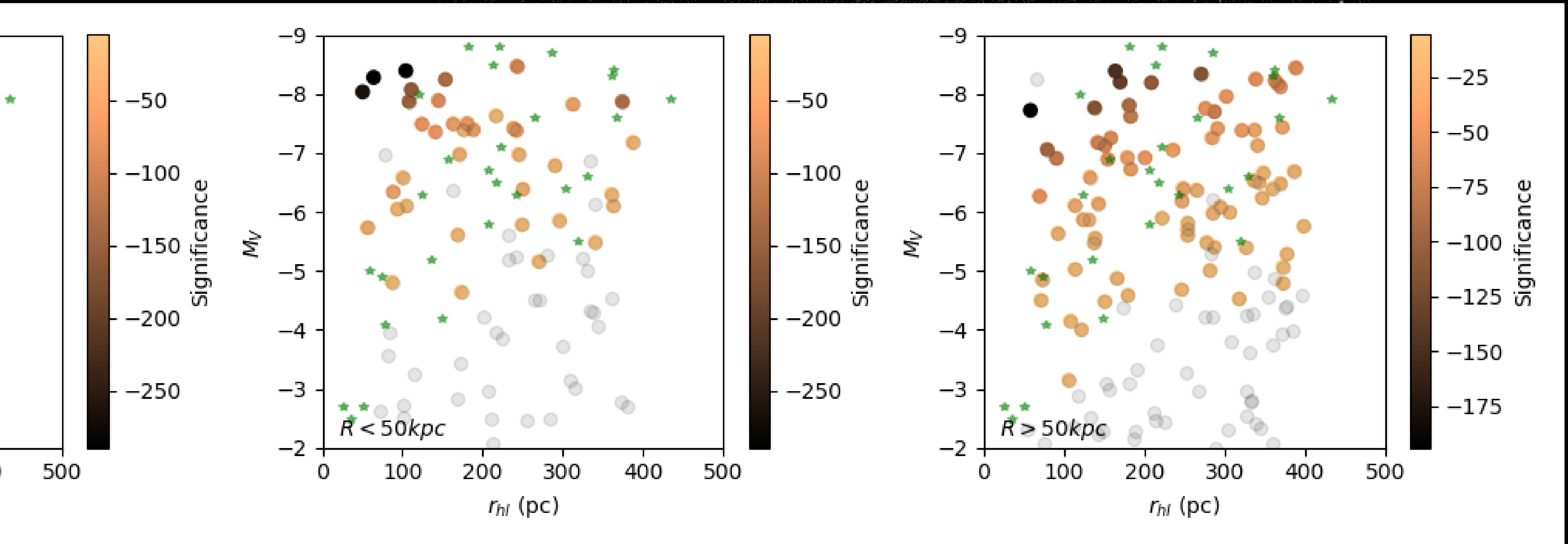


Bullock and Johnston 2005
Simulated 5 sq. degrees(!) at 3.5Mpc distance (J/H ~20h total)
Superimposed on CANDELS UDS unresolved sources x 540(!)

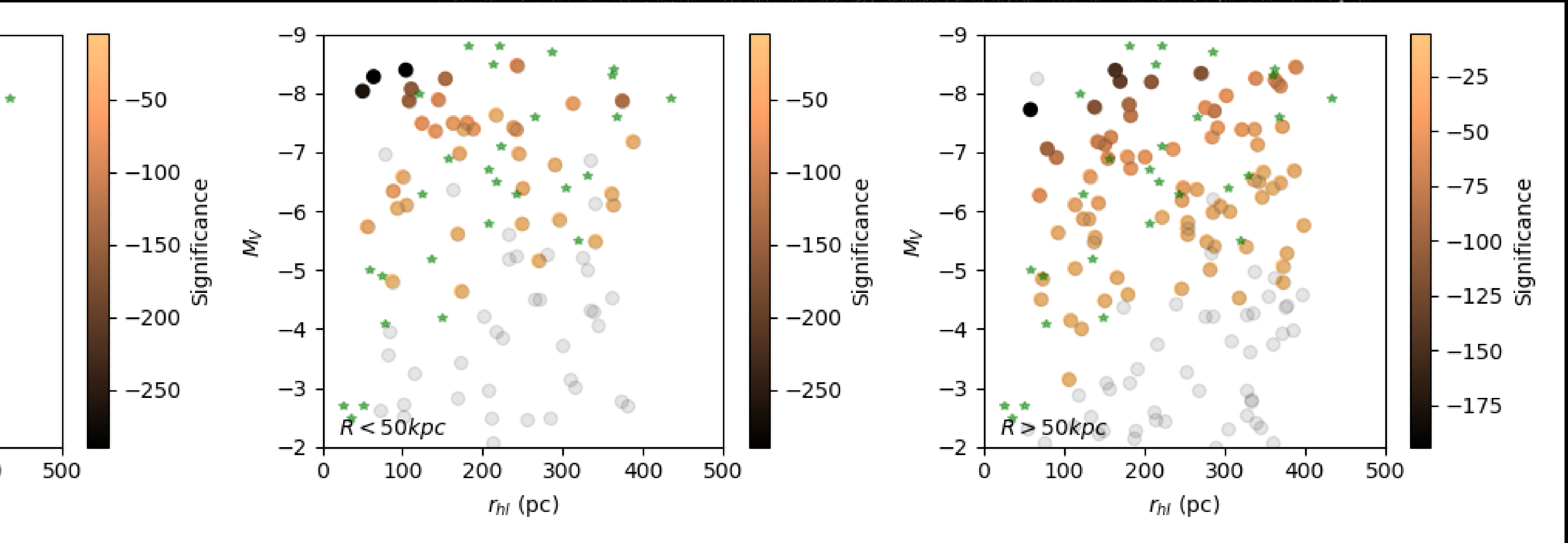
Experiments with artificial galaxies show that the limits can be pushed 10x deeper still to M_V~-4 (M*~5000 $M_\odot$!) at M81's distance. But we will need to point Roman at these groups (HLS ~ 1/20 sky)



At larger distances, one reaches M_V~-4, limited largely by RGB star counting statistics.

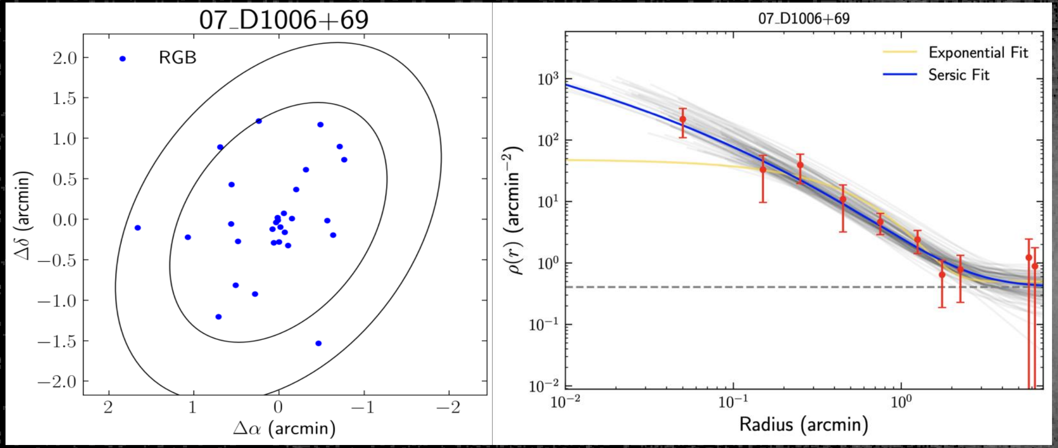


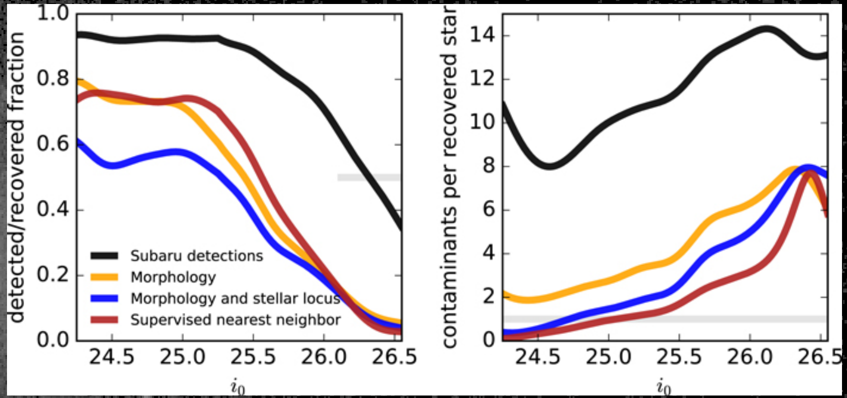
Stellar halo stars limit detection close to the larger galaxies in the group to M_V~-5.5.



Faint and ultra-faint galaxies are our premier constraint on small scale cosmology, but the Local Group can't be generalized.

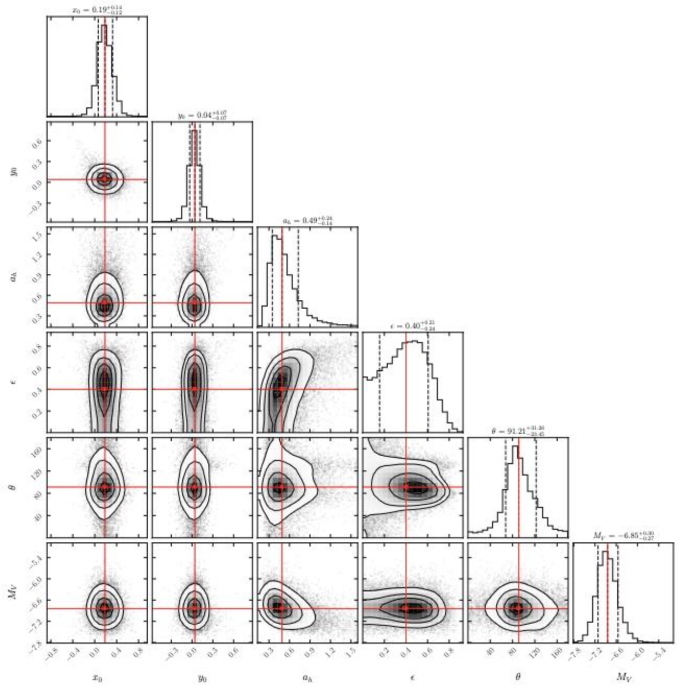
UFDs must be discovered using 'resolved stars' – but compact galaxies are so numerous as to contaminate samples.



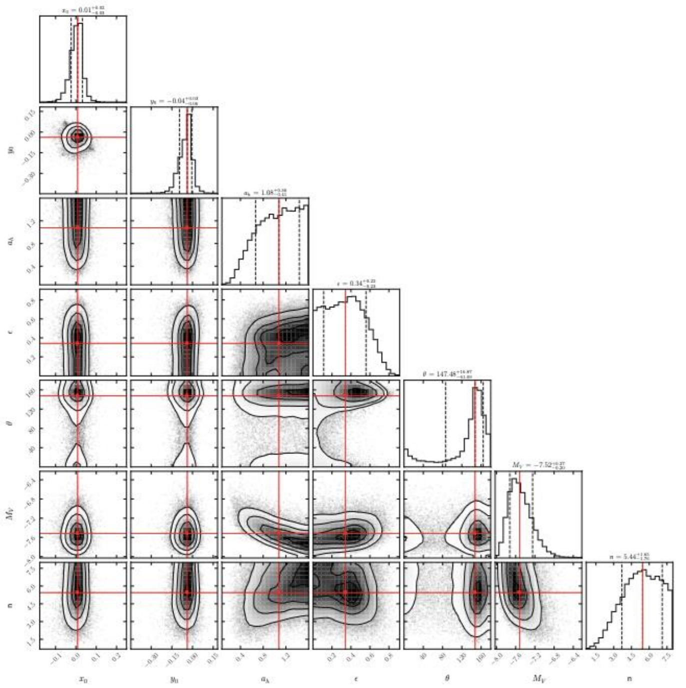


HST follow-up reveals diverse UFDs with unusual structures, possibly reflecting merging.

Discovery of faintest UFDs hard with Rubin; Roman will be very powerful



x_0
y_0
a_h
ϵ
θ
M_V



x_0
y_0
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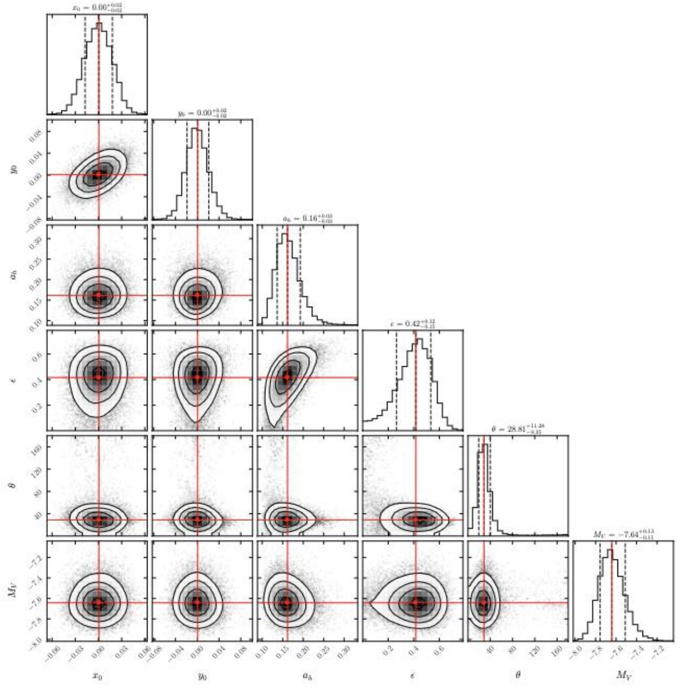
ϵ
θ
M_V
n



x_0
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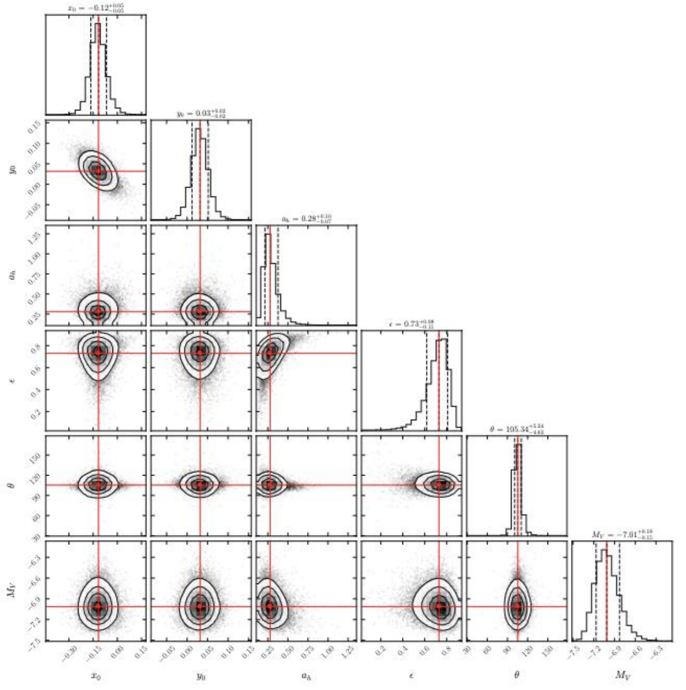

x_0
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