Danieli et al. 2022 [arXiv: 2111.14851 (ApJL)]

Bar, Danieli & Blum 2022 [arXiv:2202.10179 (ApJL, submitted)]

NGC5846-UDG1:

WHAT CAN WE LEARN ABOUT CLUSTER FORMATION AND DARK MATTER FROM ITS GLOBULAR CLUSTERS?

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with Pieter van Dokkum, Sebastian Trujillo-Gomez, Diederik Kruijssen, Aaron Romanowsky, Scott Carlsten, **Zili Shen**, Jiaxuan Li, Roberto Abraham, **Jean Brodie**, Charlie Conroy, Jonah Gannon, Johnny Greco, Nitsan Bar, Kfir Blum

STAR AND CLUSTER FORMATION

- Star formation in the Milky-Way typically proceeds in molecular clouds with sizes of 10-100 pc
- Two scales/structures/modes:
  - Protostellar Cores - the birth sites of individual or binary stars
  - Clumps (concentrations) - the birthplace of clusters within giant molecular clouds

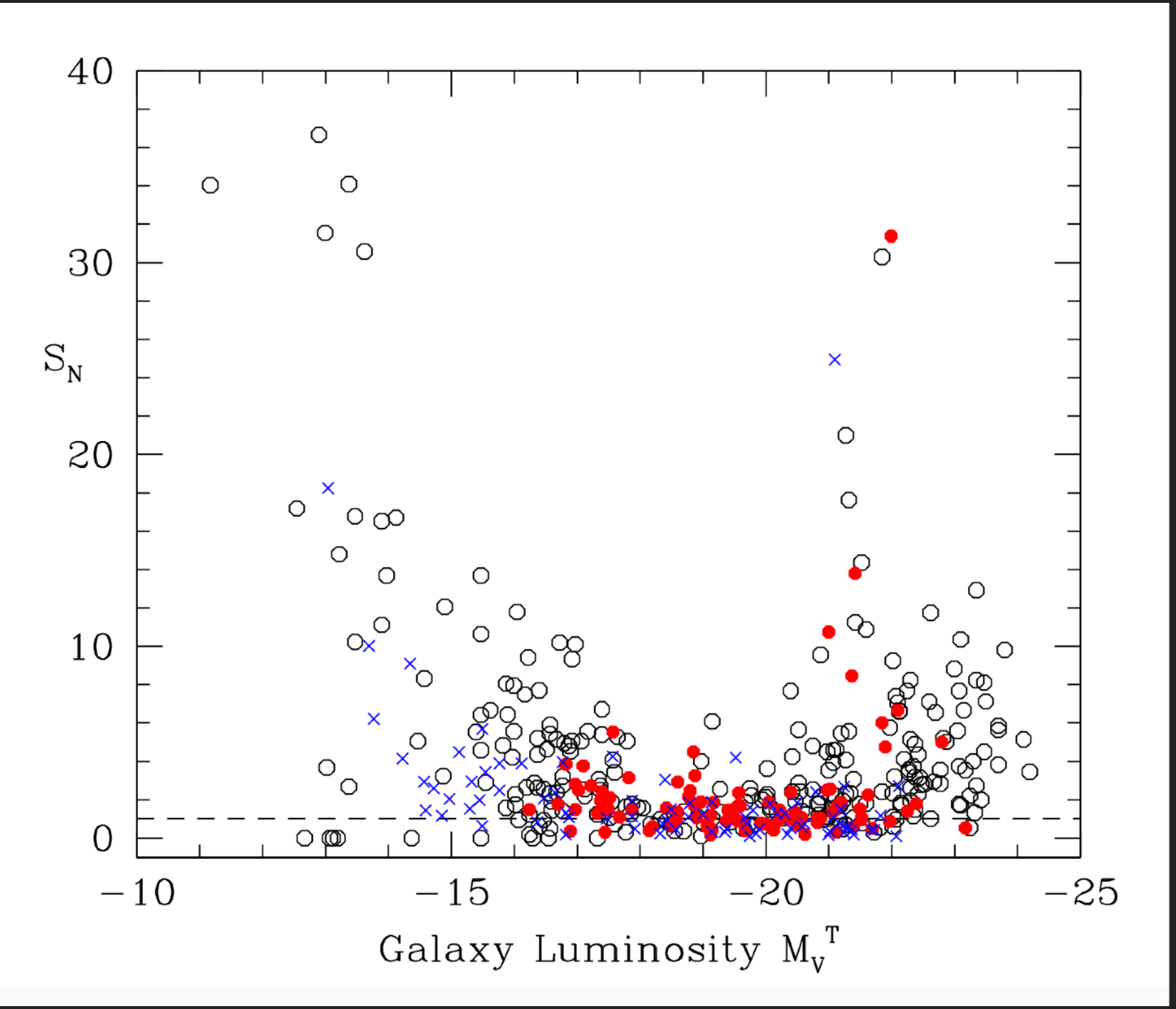
First 100 Myr: some clusters disperse through tidal shocks by dense molecular structures

After ~100 Myr: clusters lose mass via two-body relaxation and shocks by GMCs, shaping the cluster mass function to appear on ~ 1 – 10 Gyr timescales

OBSERVED GLOBULAR CLUSTERS COUNTS IN GALAXIES

The specific frequency (S_N) can differ by a factor of ~40-50 between different galaxies

U-shaped distribution –
– intermediate-luminosity galaxies in a "valley"
– dwarfs and supergiants - large scatter and higher mean S_N



Harris et al. 2013

ULTRA DIFFUSE GALAXIES

R_{eff} >1.5 kpc

μ_g > 24 mag arcsec^{-2}

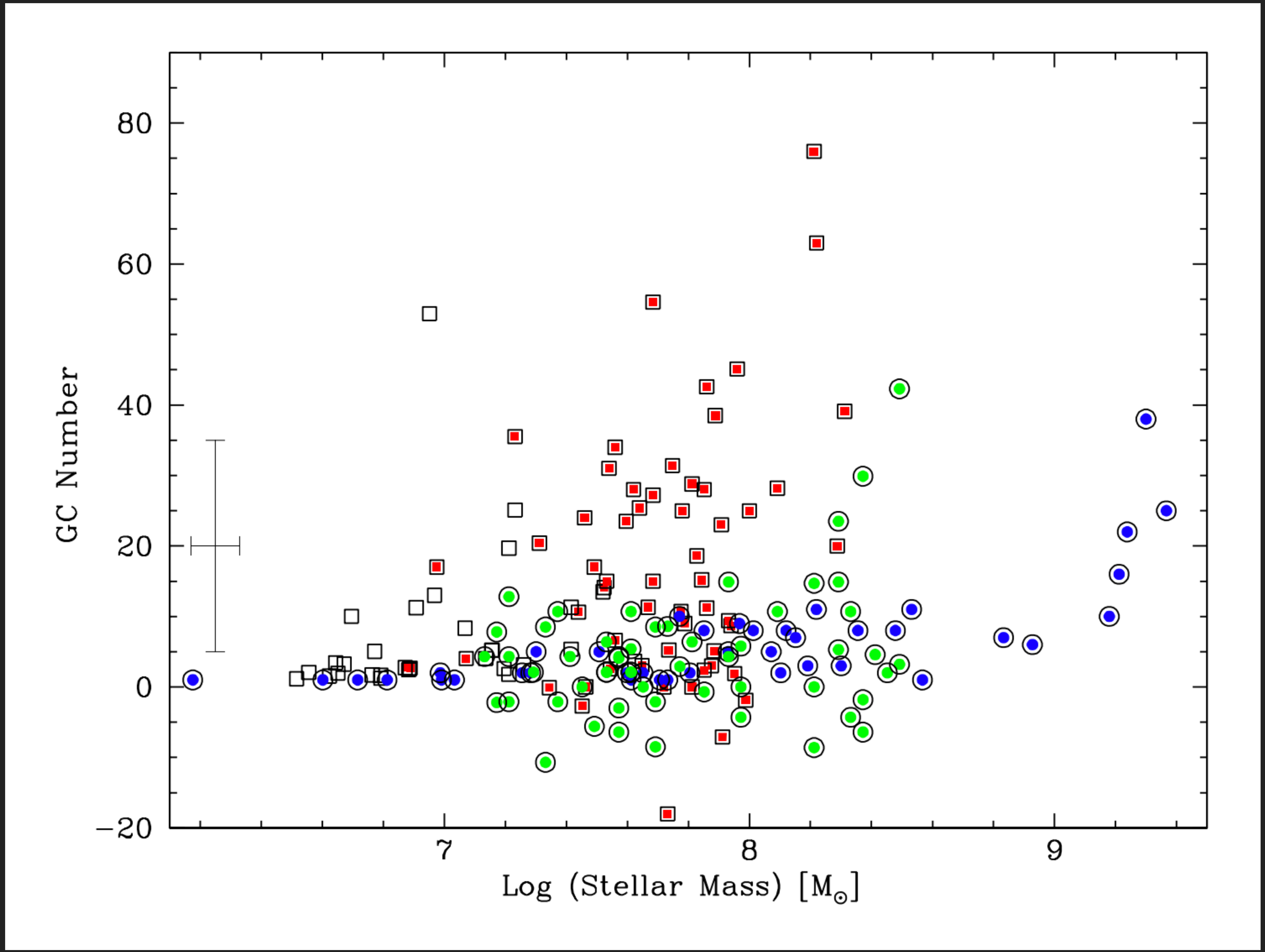
more on Zili Shen's talk tomorrow!

Fornax dSph on same scale

van Dokkum et al. 2017

Danieli & van Dokkum 2019

HIGH GLOBULAR CLUSTER SPECIFIC FREQUENCY IN ULTRA DIFFUSE GALAXIES



Coma UDGs

Coma LSBs dwarfs

Coma early-type dwarfs

Local dwarfs

Forbes et al. 2020

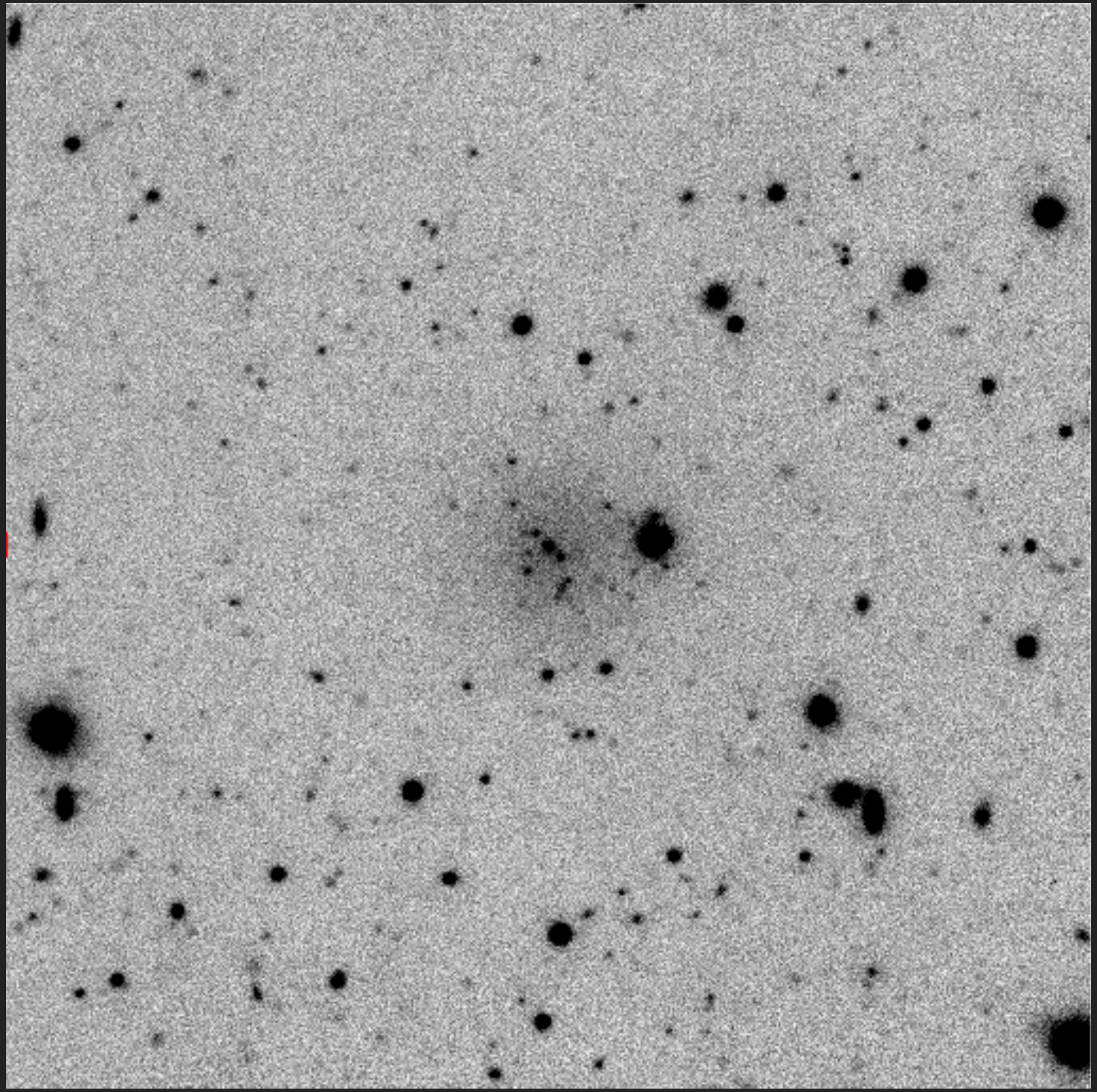
NGC5846-UDG1

First cataloged in a survey targeting the the NGC5846 group with the CFHT telescope (Mahdavi et al. 2005)

Recently re-identified in the VEGAS survey (OmegaCAM on the VST; Forbes et al. 2019)

Likely part of the NGC5846 group at ~25 Mpc

Forbes et al. 2019, 2020 and Muller et al. 2021 pointed out of a potential over-abundance of globular clusters

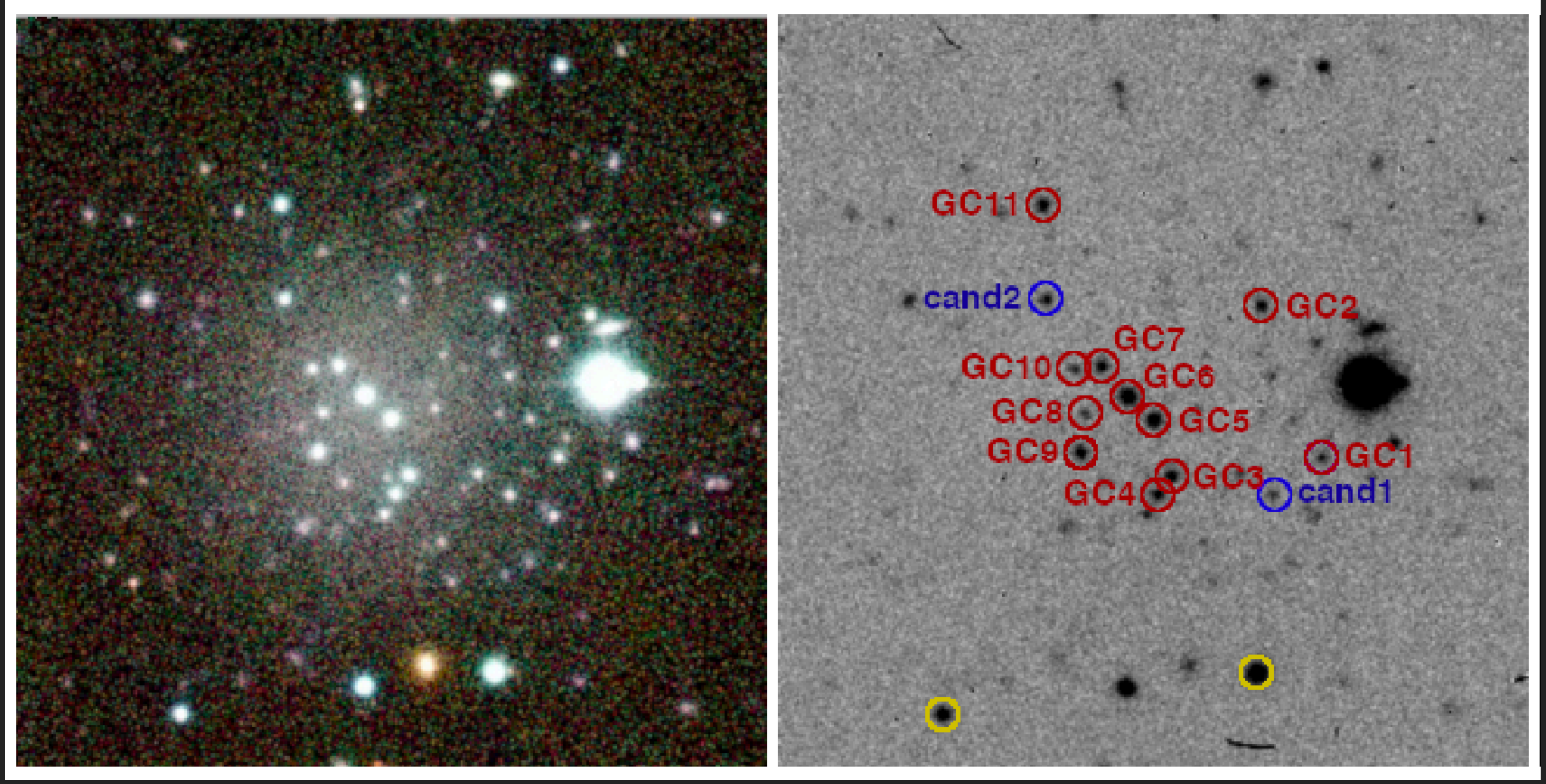


Forbes et al. 2019

HUBBLE SPACE TELESCOPE IMAGING (CYCLE 28, PI: DANIELI)

IDENTIFICATION OF GLOBULAR CLUSTERS

MUSE IFU spectroscopy confirmed 11 globular clusters + 2 candidates (Müller et al. 2020)



Müller et al. 2020

All spectroscopically confirmed clusters are old and metal-poor

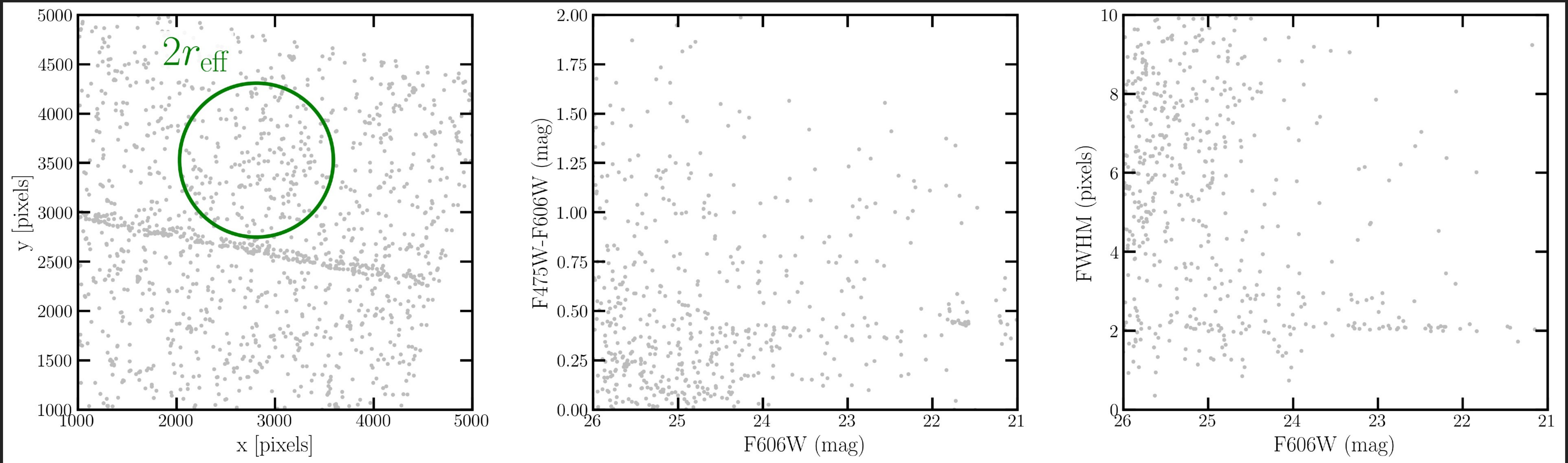
Limited to the most luminous clusters!

IDENTIFICATION OF GLOBULAR CLUSTERS

Photometric selection based on the HST images

Color

Size

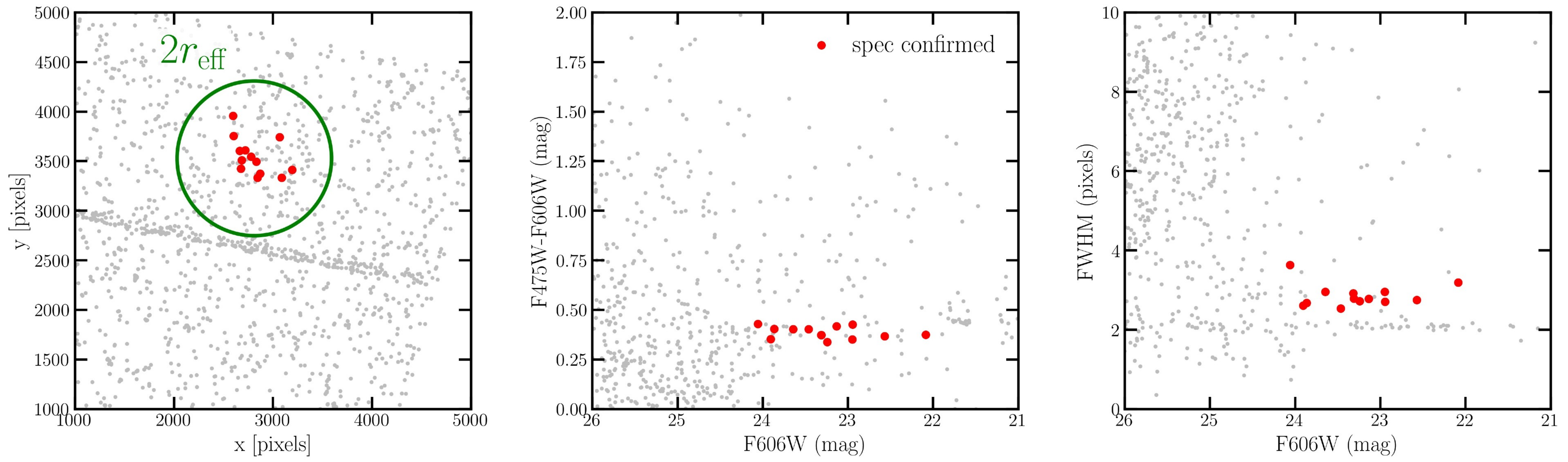


IDENTIFICATION OF GLOBULAR CLUSTERS

11 spec-confirmed clusters span a narrow range in color and size

Color

Size



IDENTIFICATION OF GLOBULAR CLUSTERS

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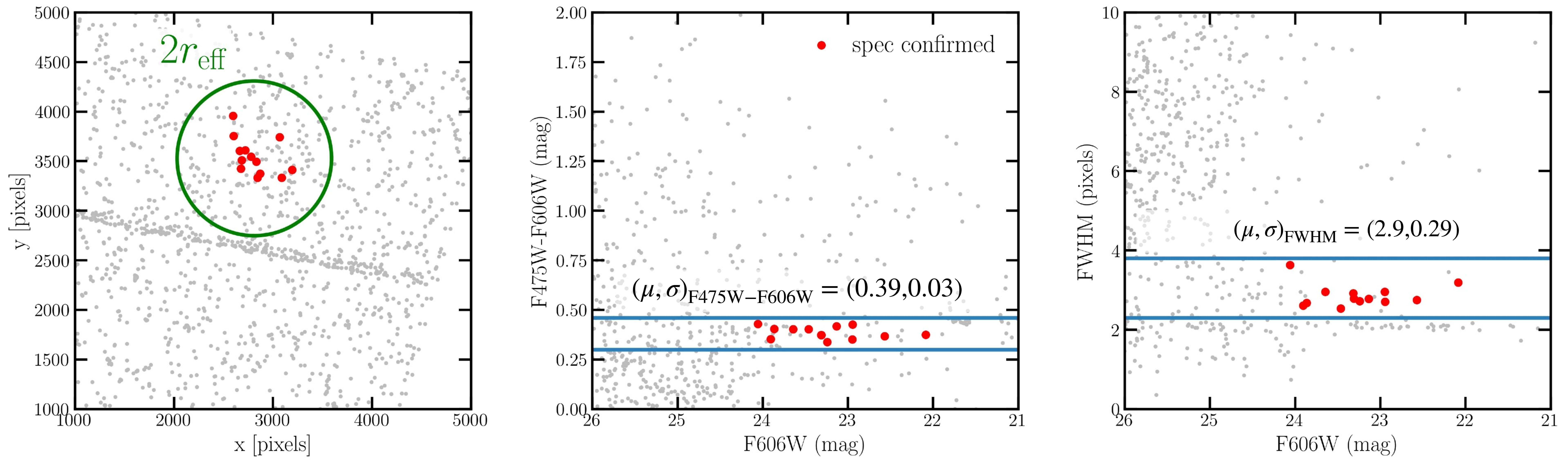
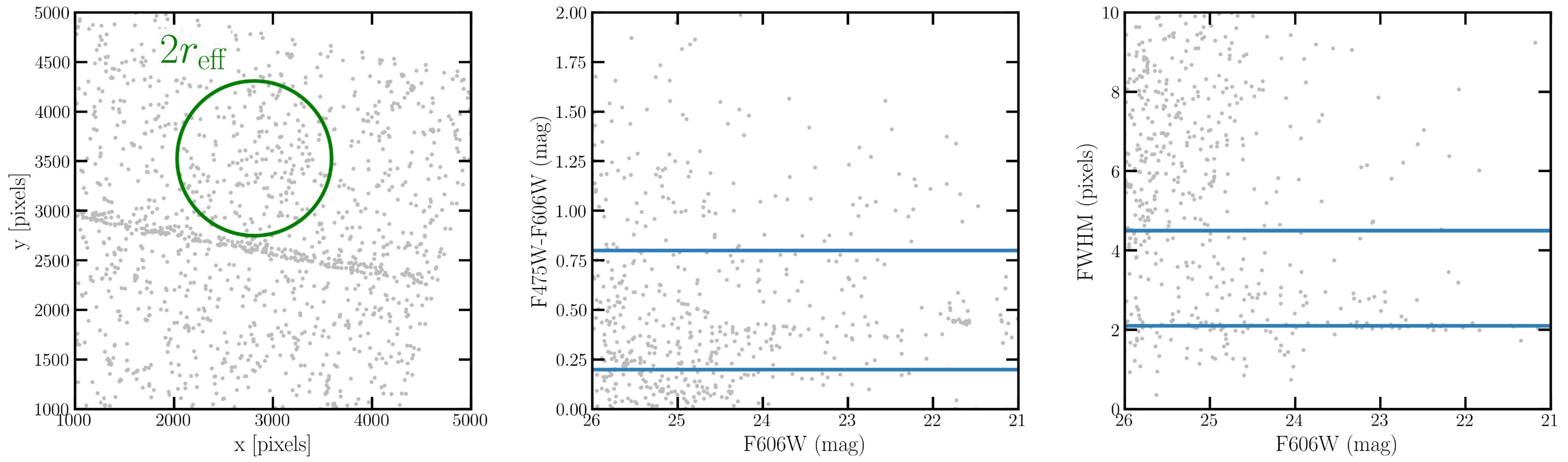


IDENTIFICATION OF GLOBULAR CLUSTERS

Color and size selection informed by spectroscopic sample

Color

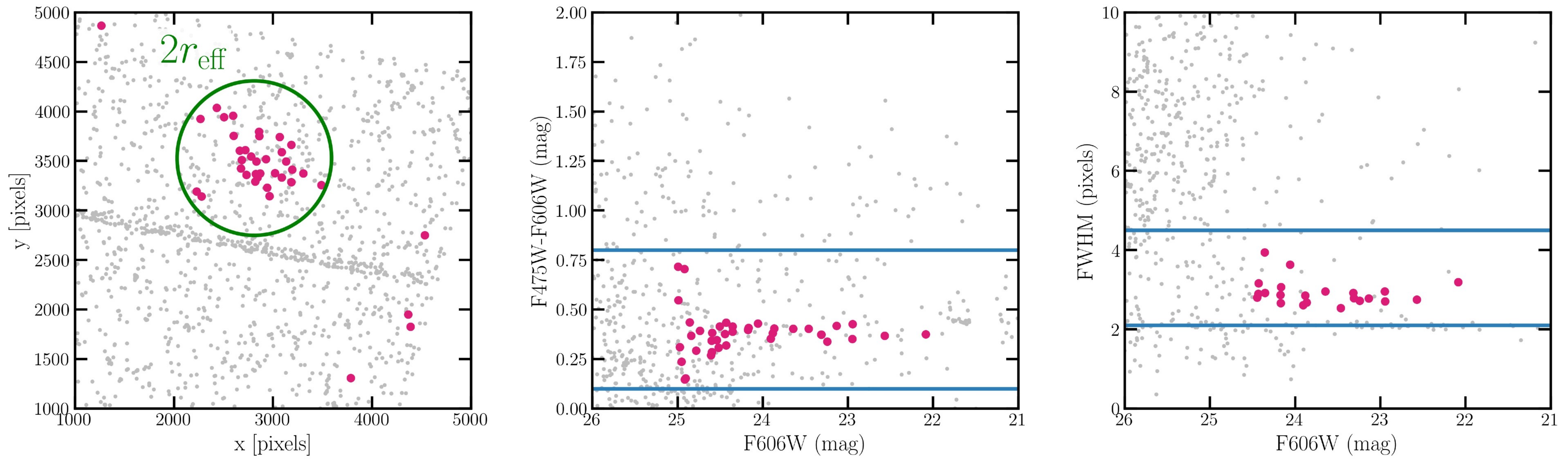
Size



For $m_V < 25$ mag, using these color and size criteria, we find **33 objects** within $2xr_{eff}$ and **one object** in an "empty" field with a comparable area

Color

Size



IDENTIFICATION OF GLOBULAR CLUSTERS

$m_V < 25$ mag:

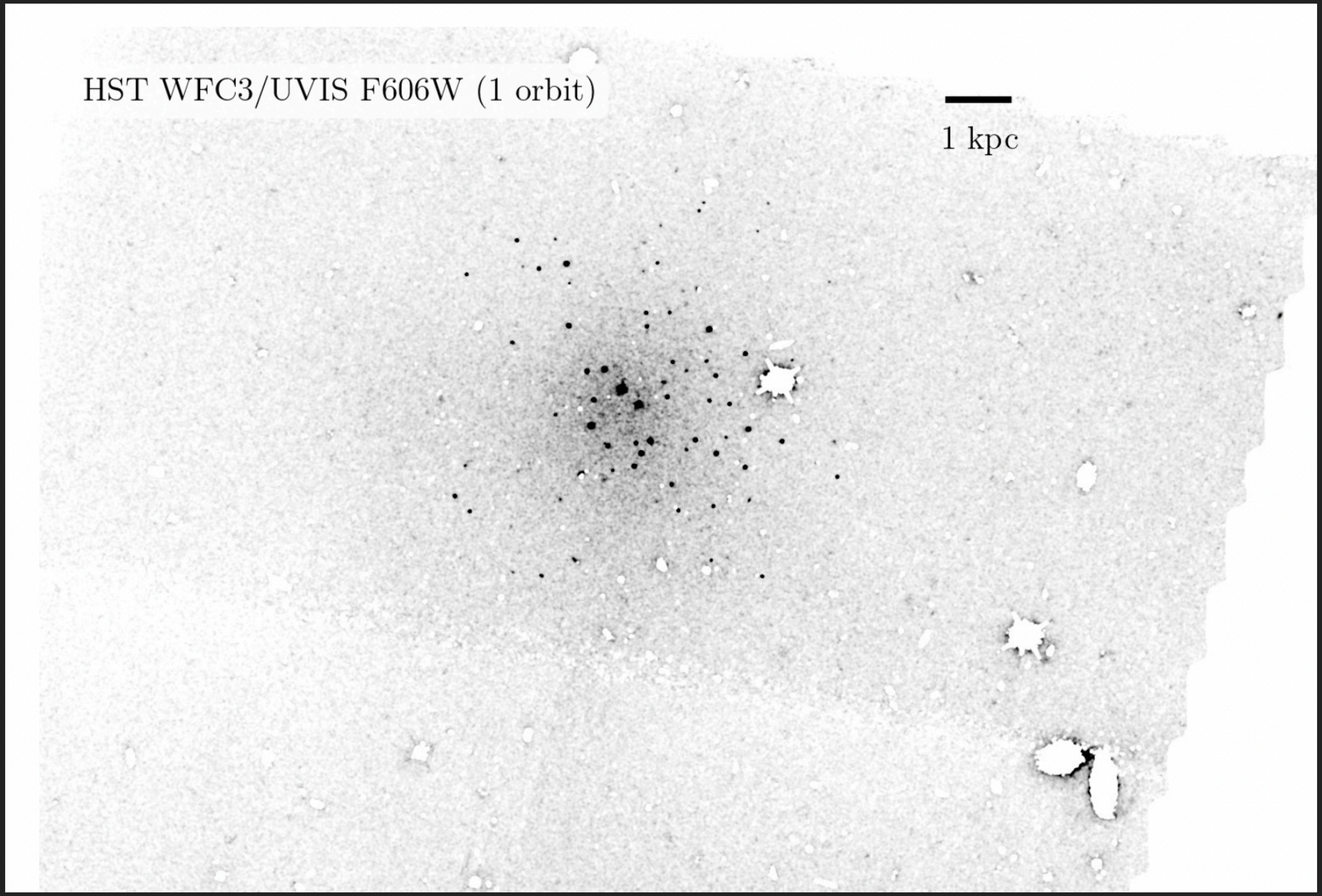
33 “in” and 1 “out" –> 32 GCs

$25 < m_V < 26.5$ mag:

43 “in” and 24 “out” –> 19 GCs

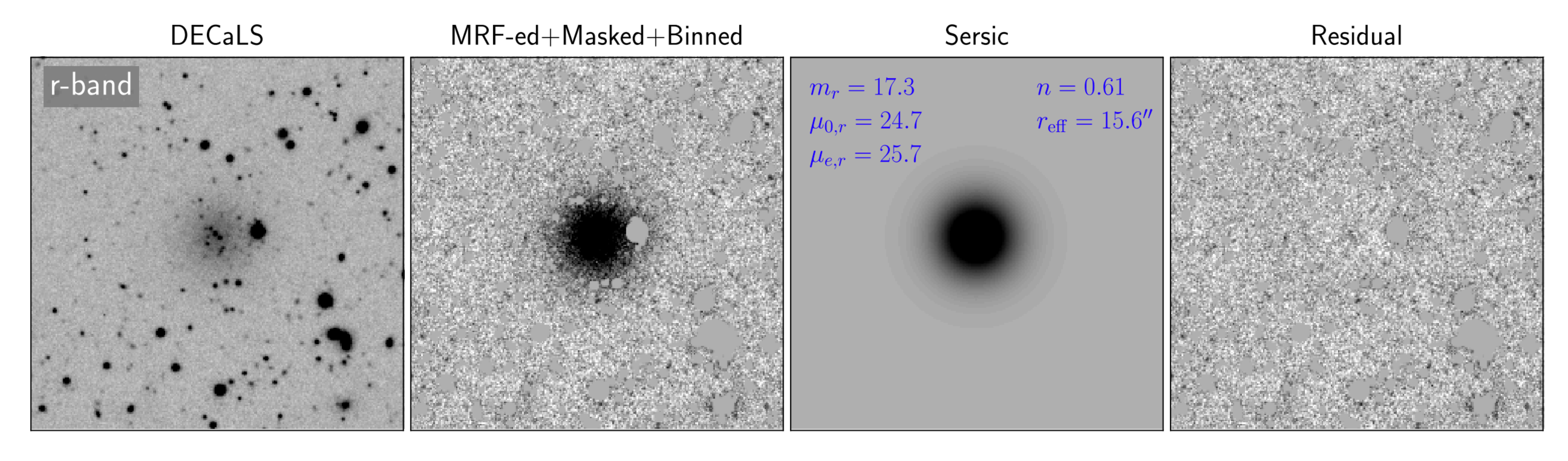
We find that NGC5846-UDG1 hosts 54 ± 9 globular clusters

($M_* = 1.2 \times 10^8\ M_\odot$)

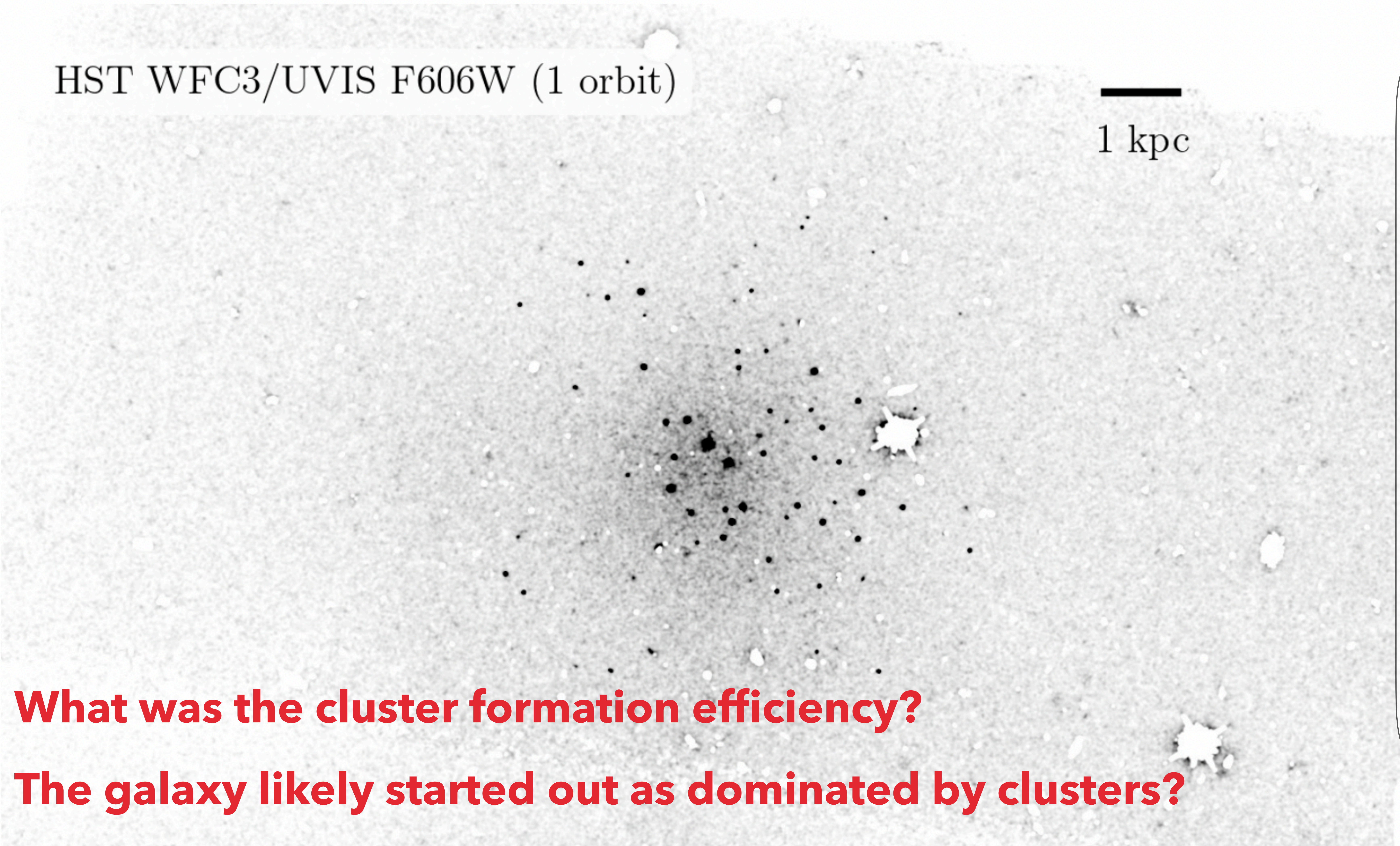


STRUCTURAL AND PHYSICAL PARAMETERS OF UDG1

DECaLS + HST/WFC3 data



FRACTION OF STARS IN GLOBULAR CLUSTERS



What was the cluster formation efficiency?

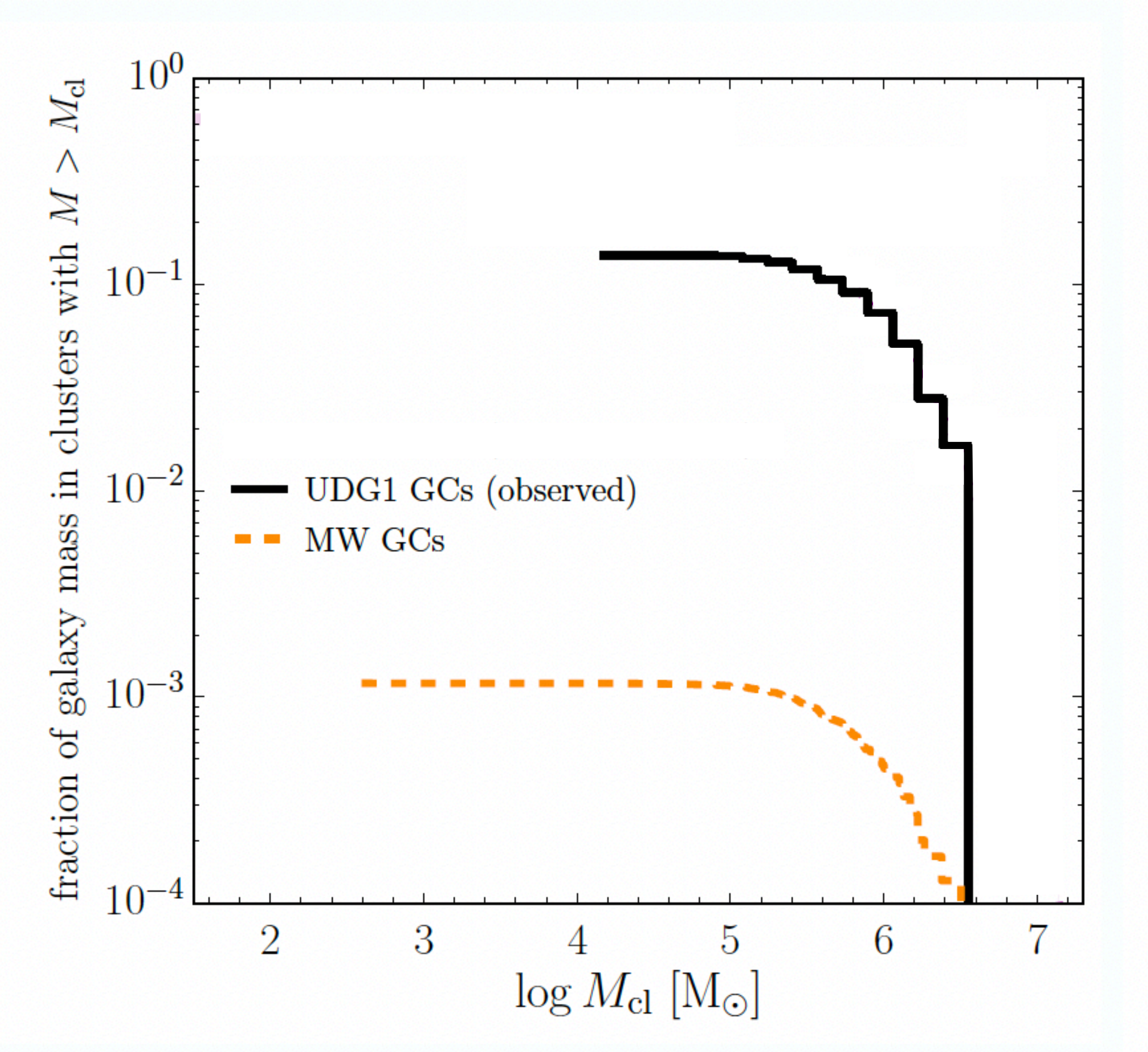
The galaxy likely started out as dominated by clusters?

$L_{V,gal} = 6 \times 10^{7}\ L_{\odot}$

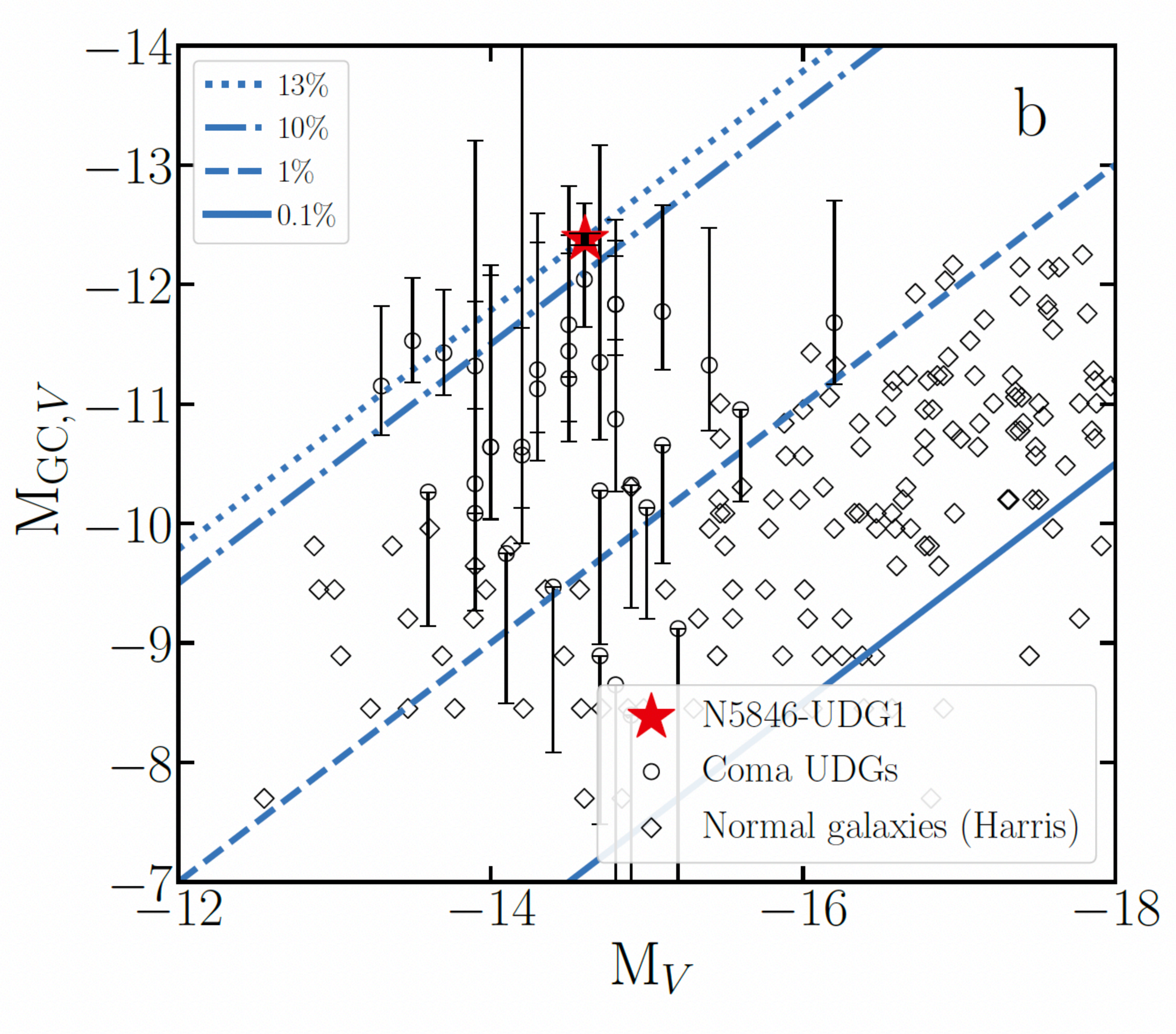
$L_{V,GCs} = 7.6 \times 10^{6}\ L_{\odot}$

the clusters currently comprise 13% of the total light

NGC5846-UDG1 IN CONTEXT



NGC5846-UDG1 IN CONTEXT



What could have led to the formation of a galaxy such as NGC5846-UDG1?

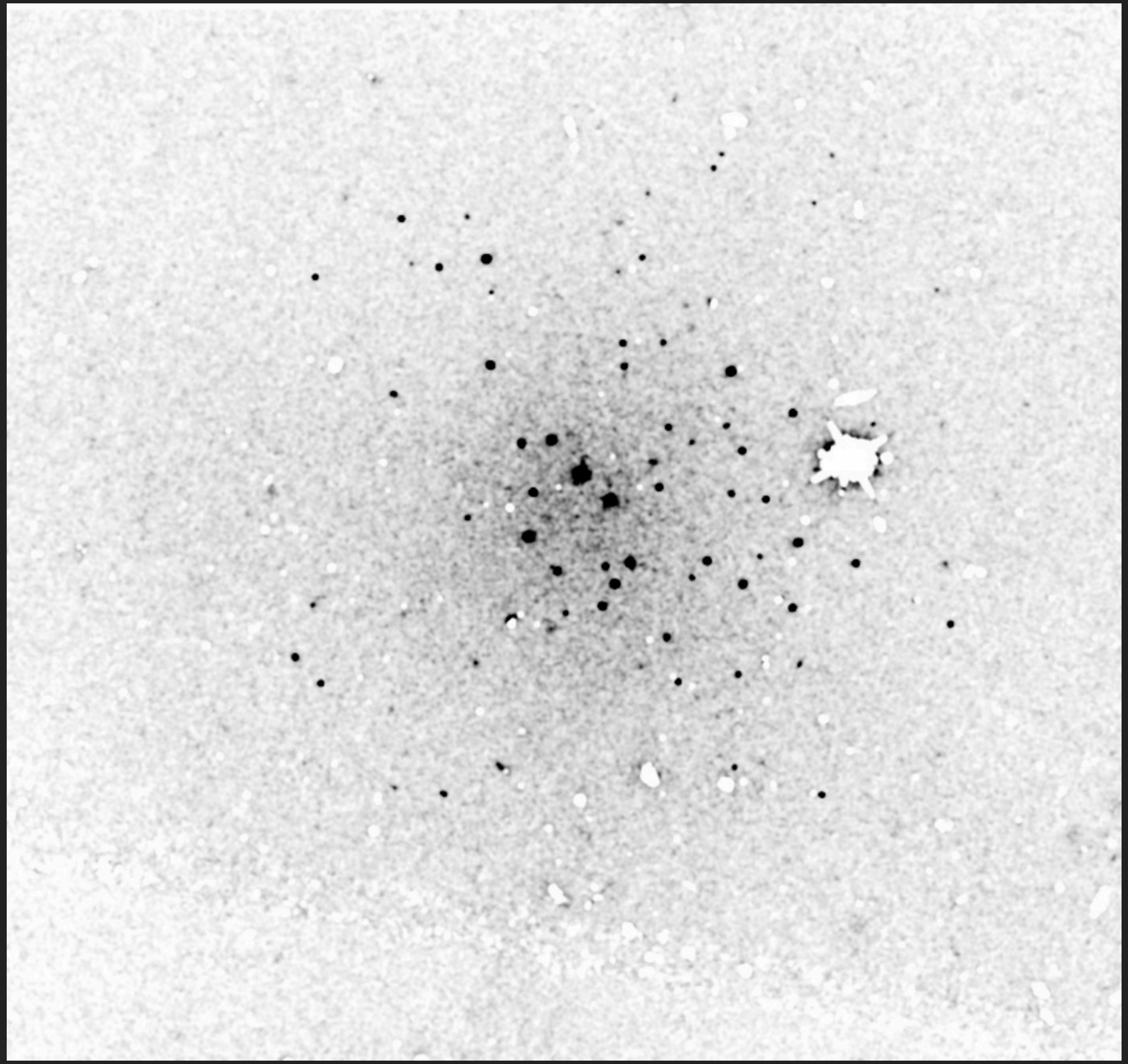
Trujillo-Gomez et al. 2021: early collapsing dark matter halos with high gas surface densities formation model

Such conditions give rise to massive cluster formation with a high CFE, resulting in an elevated number of globular clusters for its stellar mass.

NGC5846-UDG1

The clusters currently comprise 13% of the total light

The observed distribution of globular clusters is suggestive of GC mass segregation



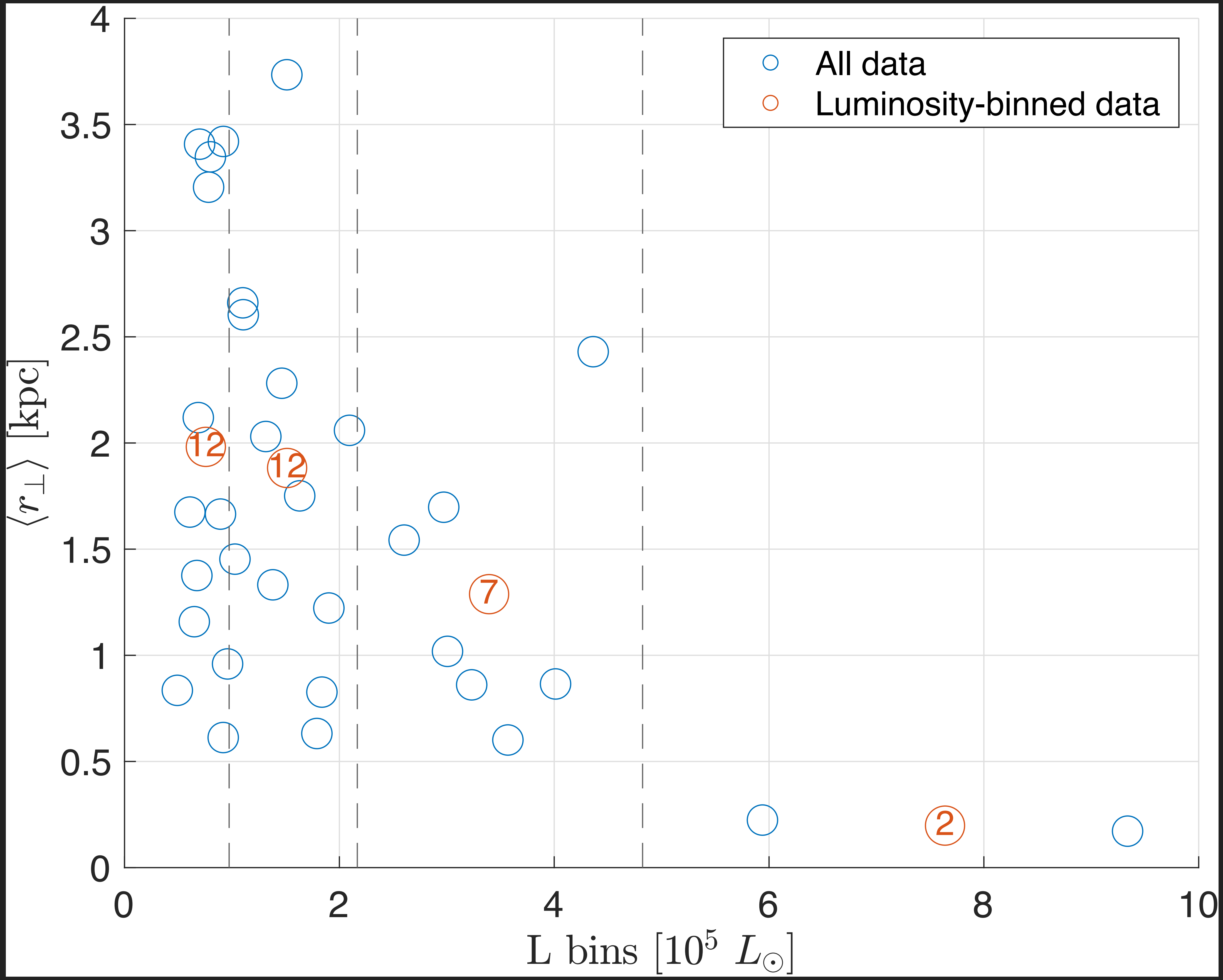
Dynamical friction time-scale:

$$\tau_{\mathrm{DF}} \equiv \frac{v^3}{4\pi G^2 \rho m_{\mathrm{GC}} C}$$
$$\approx 2 \left(\frac{\text{velocity}}{10\frac{\text{km}}{\text{sec}}} \right)^3 \frac{3 \times 10^6 \frac{M_\odot}{\text{kpc}^3}}{\text{medium density}} \frac{3 \times 10^5\ M_\odot}{\text{GC mass}} \text{Gyr}$$

→ dynamical friction effective on globular clusters in ultra-diffuse galaxies

The high quality GC sample provides evidence for mass segregation of GCs across the galaxy

Projected distance from galactic center



Luminosity

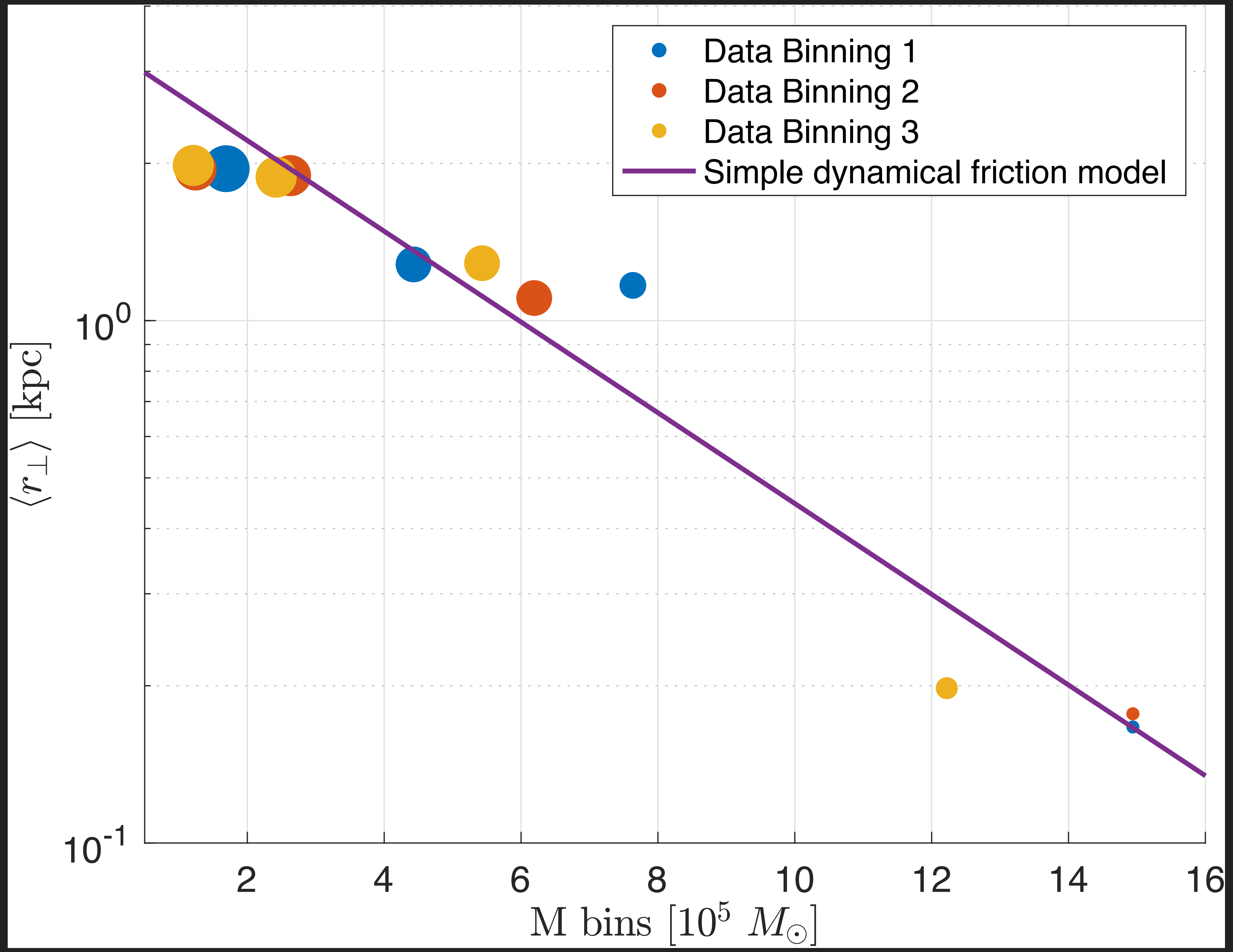
A simple analytical model naturally explains the mass segregation trend with dynamical friction

Since dynamical friction deceleration $\propto m_{\rm GC}$, it is expected to cause mass segregation.

In a simplified model:

$$\ln \left\langle r_\perp \right\rangle (m_{\rm GC}) = \ln \left\langle r_{0,\perp} \right\rangle - \frac{\Delta t}{2\tau^{(0)}} \frac{m_{\rm GC}}{m_{\rm GC}^{(0)}}$$

(based on treatment in Bar et al. 2021)



$$\tau_{\rm DF} \approx 5 \frac{5 \times 10^5 \ M_\odot}{\rm GC\ mass} \ {\rm Gyr}$$

$$\left\langle r_{0,\perp} \right\rangle \approx 3 \ {\rm kpc}$$

We construct (simple) simulations for more realistic modeling of the dynamics

- N-body dynamics of GCs in an external potential.
- Dynamical friction processed in semi-analytic approach.
- GC mergers implemented via a prescription of mutual proximity and boundness.

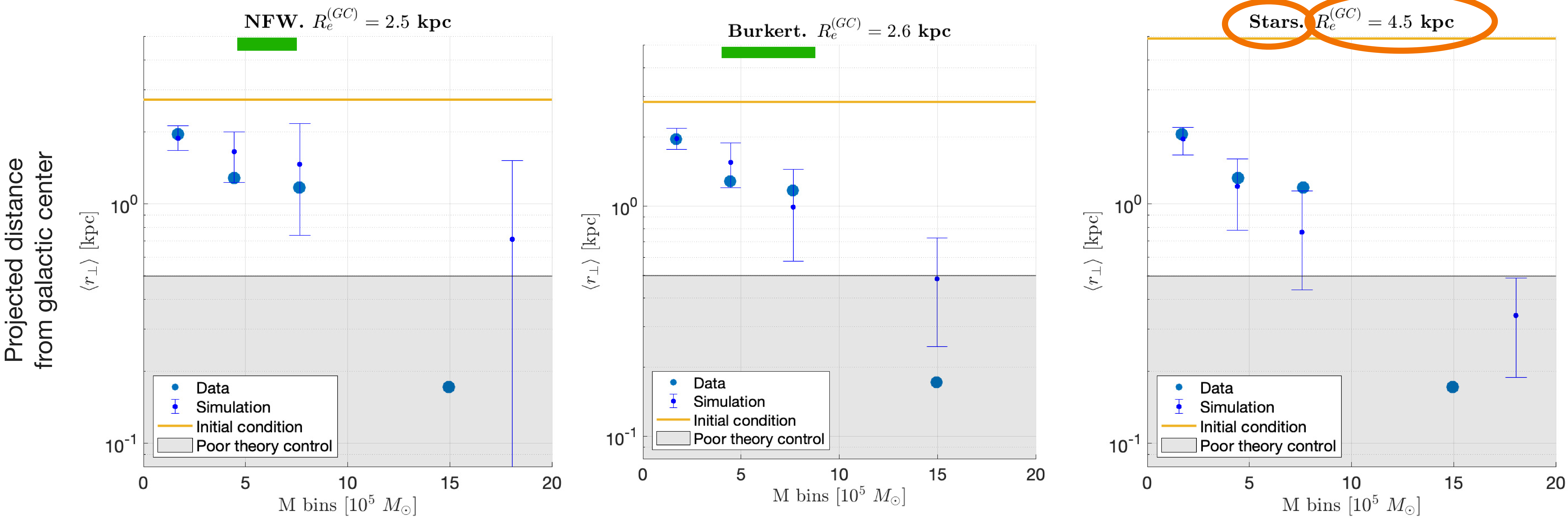
Initial conditions:

- Spherical radial distribution of GCs, similar to the stellar body – though more extended.
- We assume no mass segregation at GC birth.
- GC mass function: will only use the observed mass function in this talk.

Simulations used to ***fit*** initial conditions to observations within a halo model

vs. stellar body $R_e = 1.9$ kpc

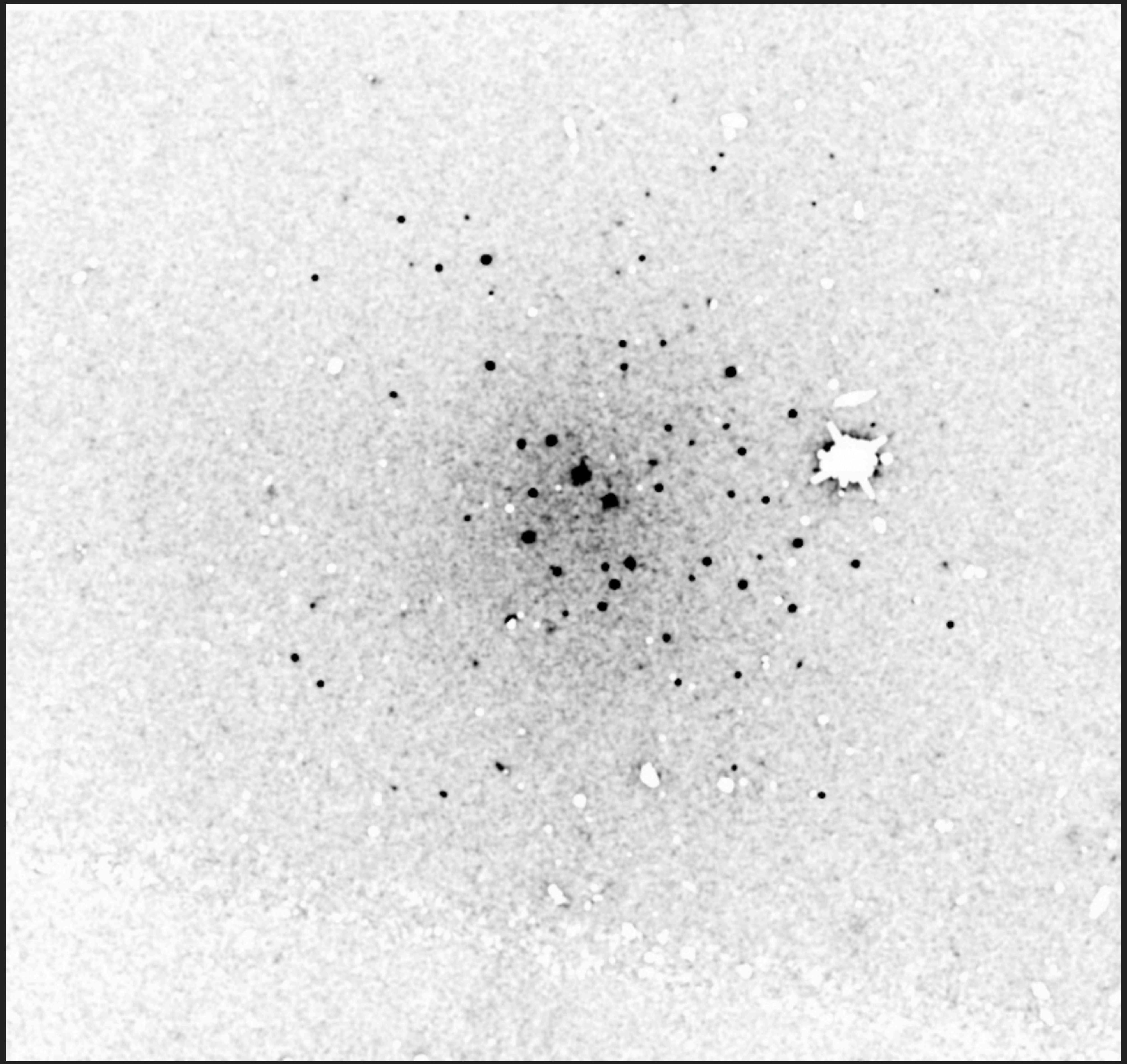
unlikely?



cusp vs. core hard to discriminate

SUMMARY

- NGC5846-UDG1 is a dwarf galaxy that host an extreme GC population
- Its 54 GCs make ~13% of the total light
- It likely started as dominated by star clusters (or at least bound clusters?)
- We find evidence for mass segregation of GCs across NGC5846-UDG1
- We present a proof of concept that dynamical friction alone can naturally explain the mass segregation trend
- Under the assumption that GCs start relatively close to the stellar body, the analysis supports the existence of a massive halo *from photometry only*



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