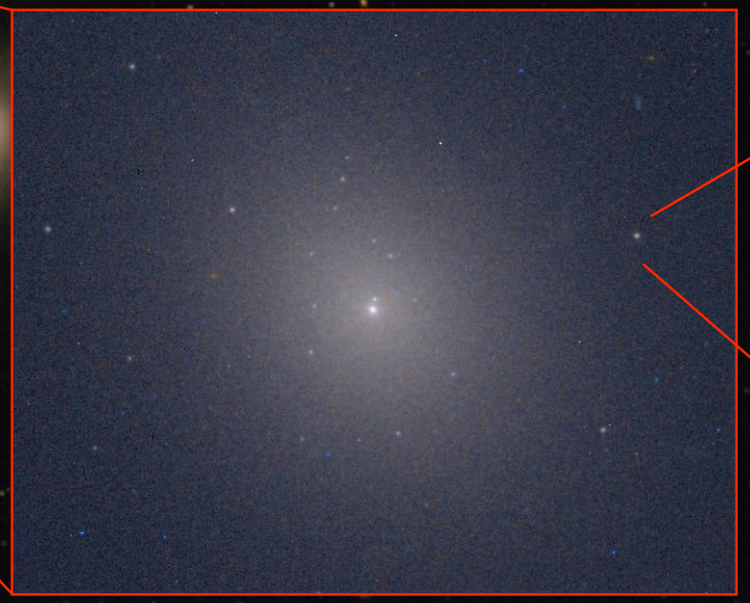
Environment and the Formation of Globular Cluster Systems



Eric Peng
Peking University, Dept of Astronomy
Kavli Institute for Astronomy and Astrophysics

Peking University (PKU) in Beijing, China
China's oldest modern university (1898)

Dept of Astronomy and
Kavli Institute for Astronomy and Astrophysics (KIAA)
13 faculty, 4 postdocs, 25 students
Plans to expand to ~30 total faculty

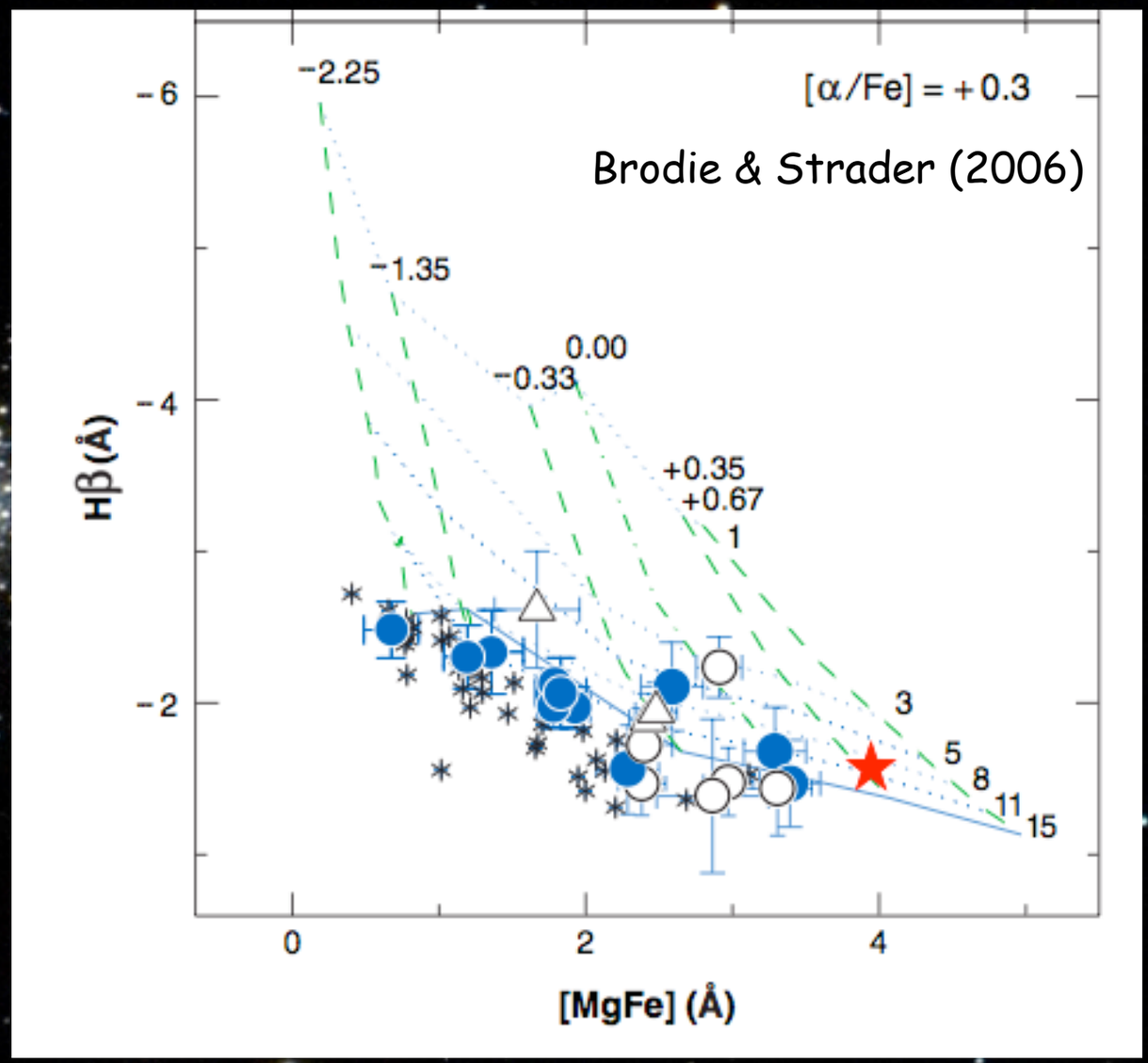
北京大学
PEKING UNIVERSITY

Emphasis on small workshops
and visitor programs at KIAA

Please come visit!

What do Globular Cluster Systems tell us about Galaxy Evolution?

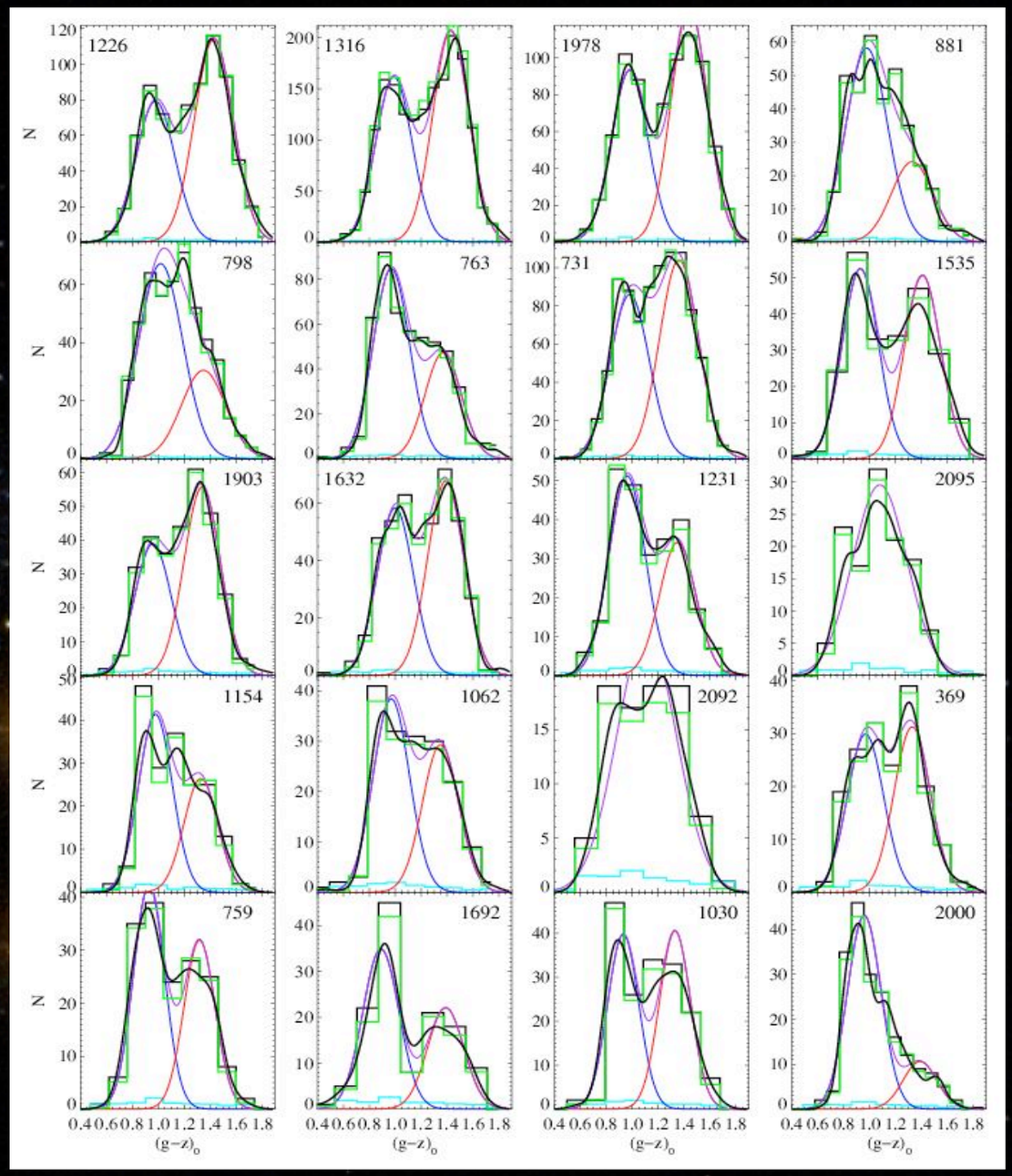
- Globular cluster are predominantly old (> 8 Gyr) and metal-poor



What do Globular Cluster Systems tell us about Galaxy Evolution?

- Globular cluster are predominantly old (> 8 Gyr) and metal-poor

- Globular cluster metallicity distributions in massive galaxies are often bimodal, unlike underlying field star metallicity distributions
- Metal-poor (halo), metal-rich (bulge)



Peng et al. (2006)

What do Globular Cluster Systems tell us about Galaxy Evolution?

- Globular cluster are predominantly old (> 8 Gyr) and metal-poor

- Globular cluster metallicity distributions in massive galaxies are often bimodal, unlike underlying field star metallicity distributions
- Metal-poor (halo), metal-rich (bulge)

GCs

Gray (2009)

Galaxies

[Fe/H] ⟶

Globular cluster formation efficiency is not constant across metallicity and age

What do Globular Cluster Systems tell us about Galaxy Evolution?

Specific Frequency: number of GCs normalized to M_V=-15

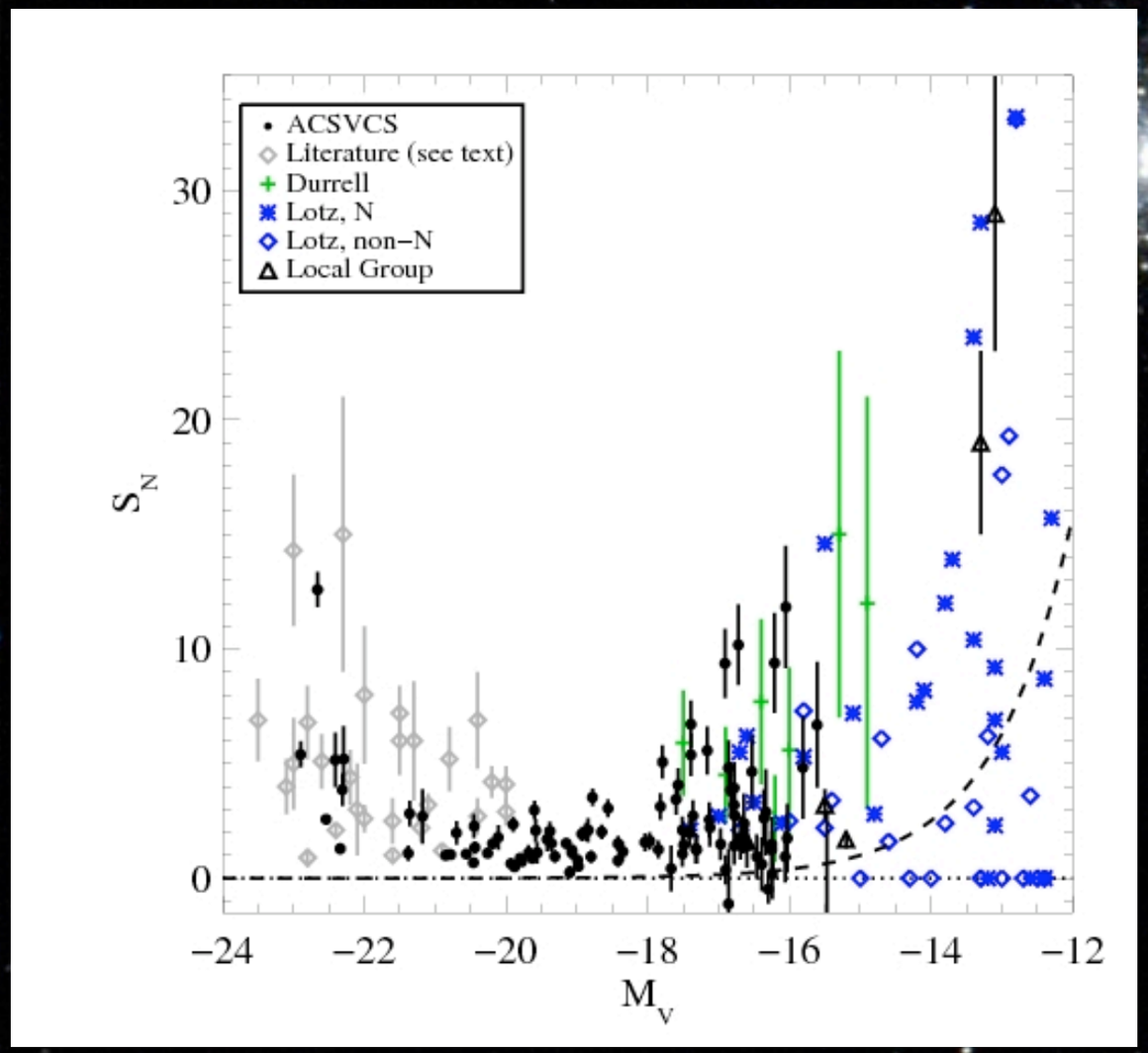
$$S_N = N_{GC}\, 10^{\,0.4(M_V+15)}$$

Purpose: "To investigate whether there is in fact a 'universal' and uniform capability for globular cluster formation." (Harris & van den Bergh 1981)

What do Globular Cluster Systems tell us about Galaxy Evolution?

Specific Frequency: number of GCs normalized to M_V=-15

$$S_N = N_{GC}\, 10^{\,0.4(M_V+15)}$$



Peng et al. (2008)

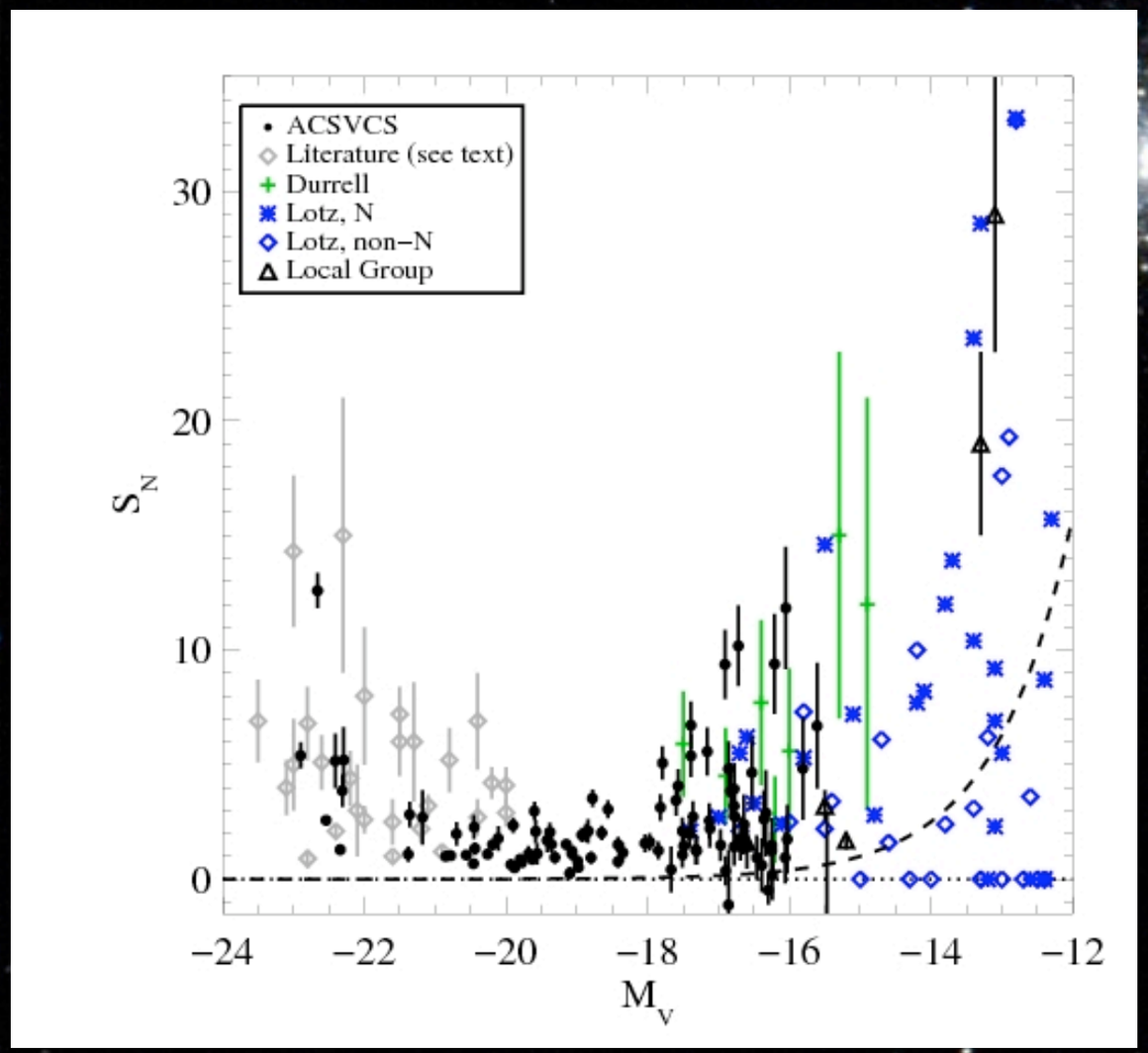
Purpose: "To investigate whether there is in fact a 'universal' and uniform capability for globular cluster formation." (Harris & van den Bergh 1981)

Globular cluster formation efficiency is not constant across galaxy mass

What do Globular Cluster Systems tell us about Galaxy Evolution?

Specific Frequency: number of GCs normalized to M_V=-15

$$S_N = N_{GC}\, 10^{\,0.4(M_V+15)}$$



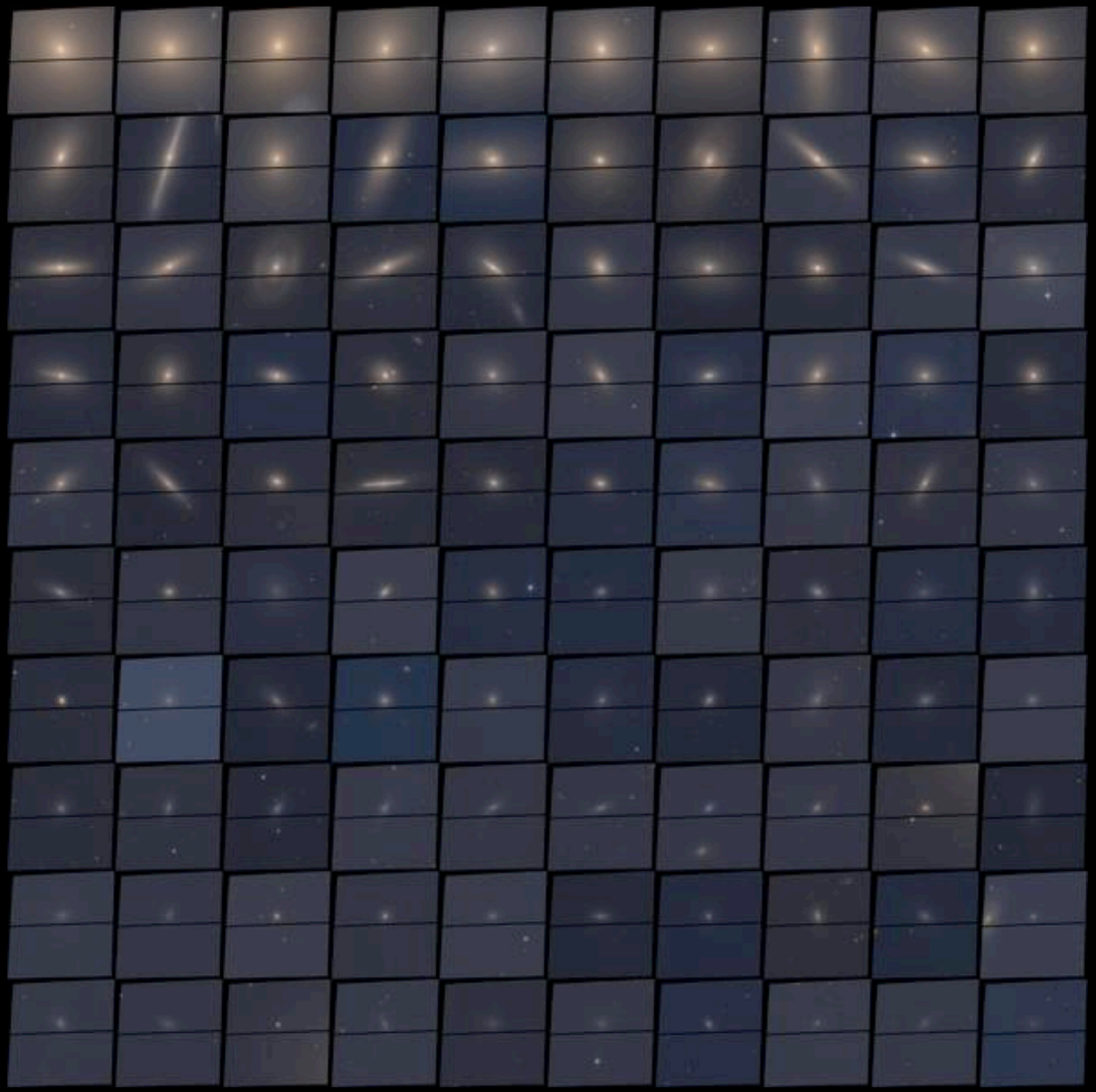
Peng et al. (2008)

Purpose: "To investigate whether there is in fact a 'universal' and uniform capability for globular cluster formation." (Harris & van den Bergh 1981)

Globular cluster formation efficiency is not constant across galaxy mass

GC systems offer a unique and complementary view on galaxy formation: Environment may be the key.

The ACS Virgo Cluster Survey



- HST/ACS imaging survey in *g* and *z*
- 100 early-type galaxies
- $-22 < M_B < -15$, giants to dwarfs
- Depth: 90% of *GC* population
- 16 control fields

The ACS Virgo Cluster Survey

- HST/ACS imaging survey in *g* and *z*
- 100 early-type galaxies
- $-22 < M_B < -15$, giants to dwarfs
- Depth: 90% of GC population
- 16 control fields

A homogeneous survey across the mass spectrum of "surviving progenitors" and "merger products"

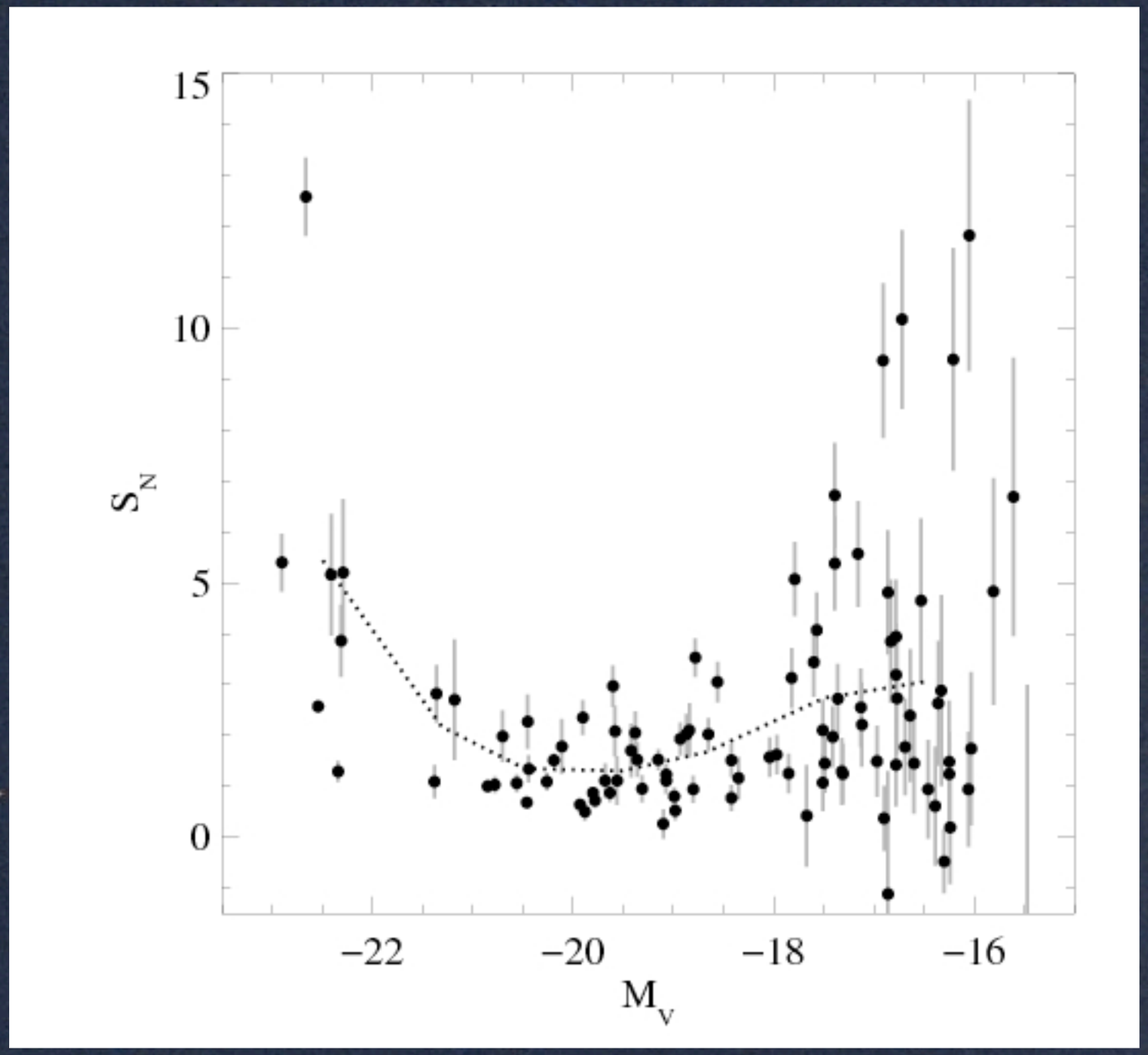
The ACS Virgo Cluster Survey

Patrick Côté (PI: Virgo)
Andrés Jordán (PI: Fornax)
John Blakeslee
Laura Ferrarese
Simona Mei
Chin-Wei Chen
Marianne Takamiya
Michael West

- HST/ACS imaging survey in *g* and *z*
- 100 early-type galaxies
- $-22 < M_B < -15$, giants to dwarfs
- Depth: 90% of GC population
- 16 control fields

A homogeneous survey across the mass spectrum of "surviving progenitors" and "merger products"

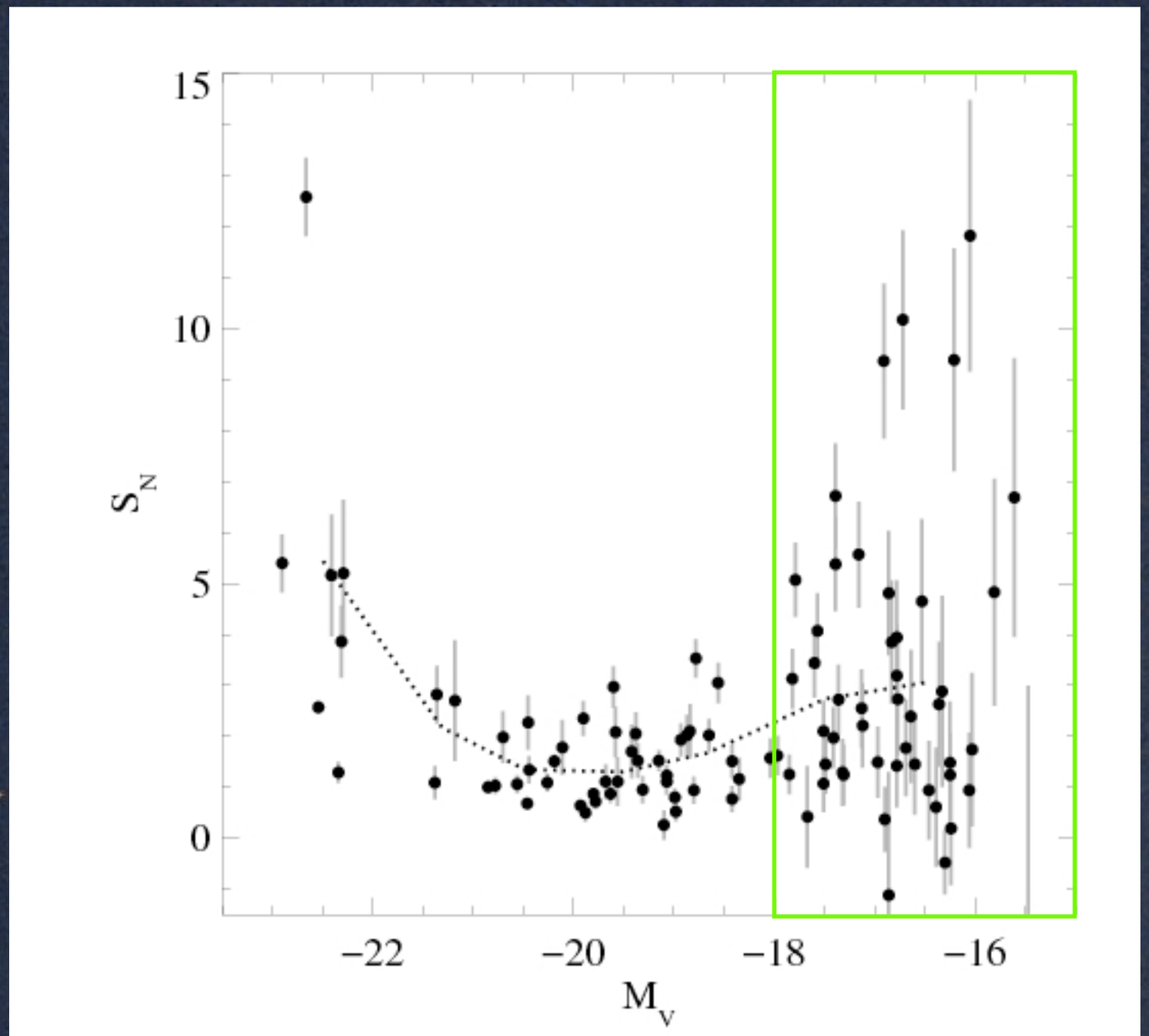
How does GC fraction behave across galaxy mass?



Peng et al. (2008)

- Narrow range of S_N at intermediate L
- High S_N values for both giants and dwarfs

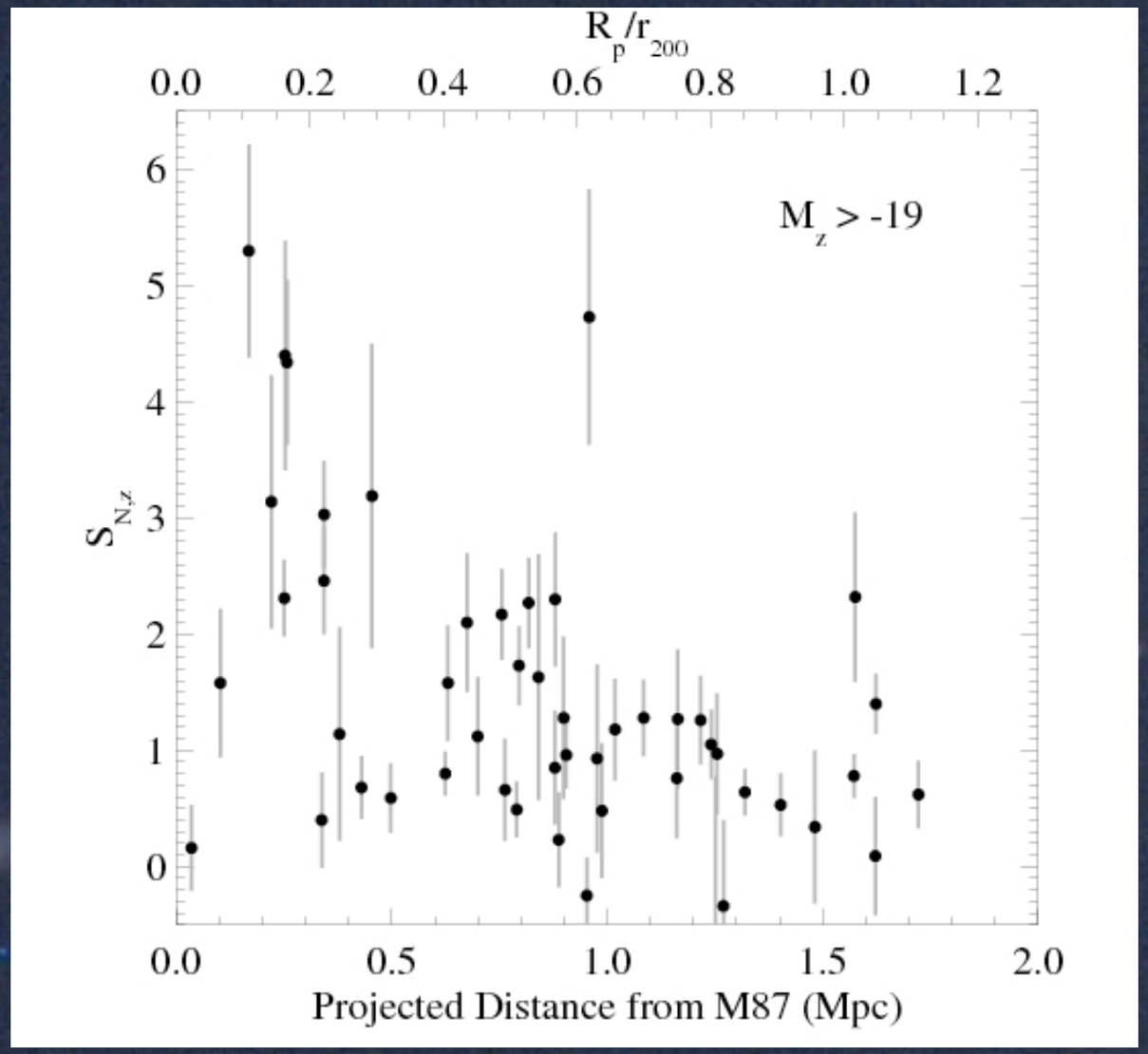
How does GC fraction behave across galaxy mass?



Peng et al. (2008)

- Narrow range of S_N at intermediate L
- High S_N values for both giants and dwarfs

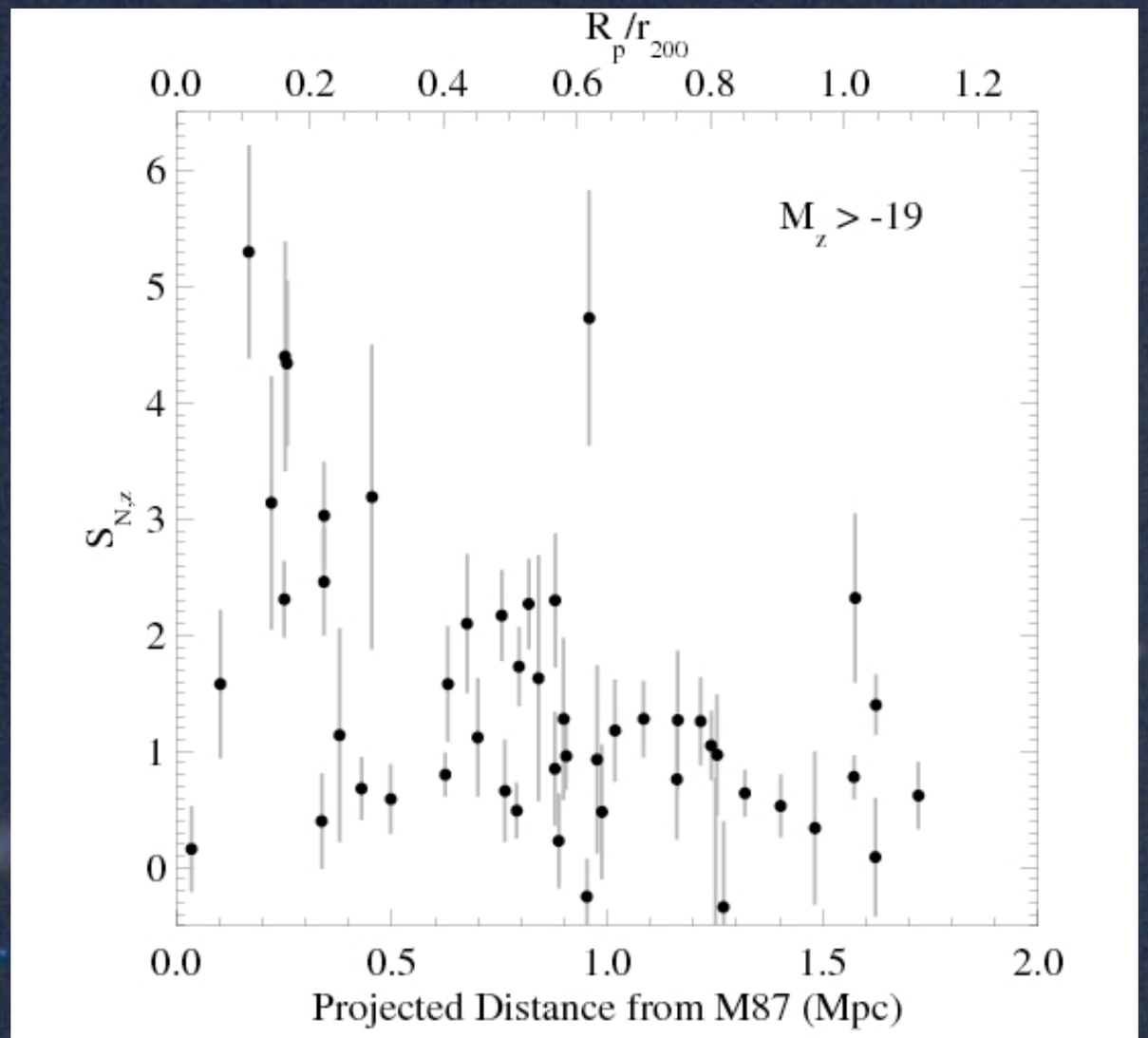
Globular Clusters in dEs: The Role of Environment



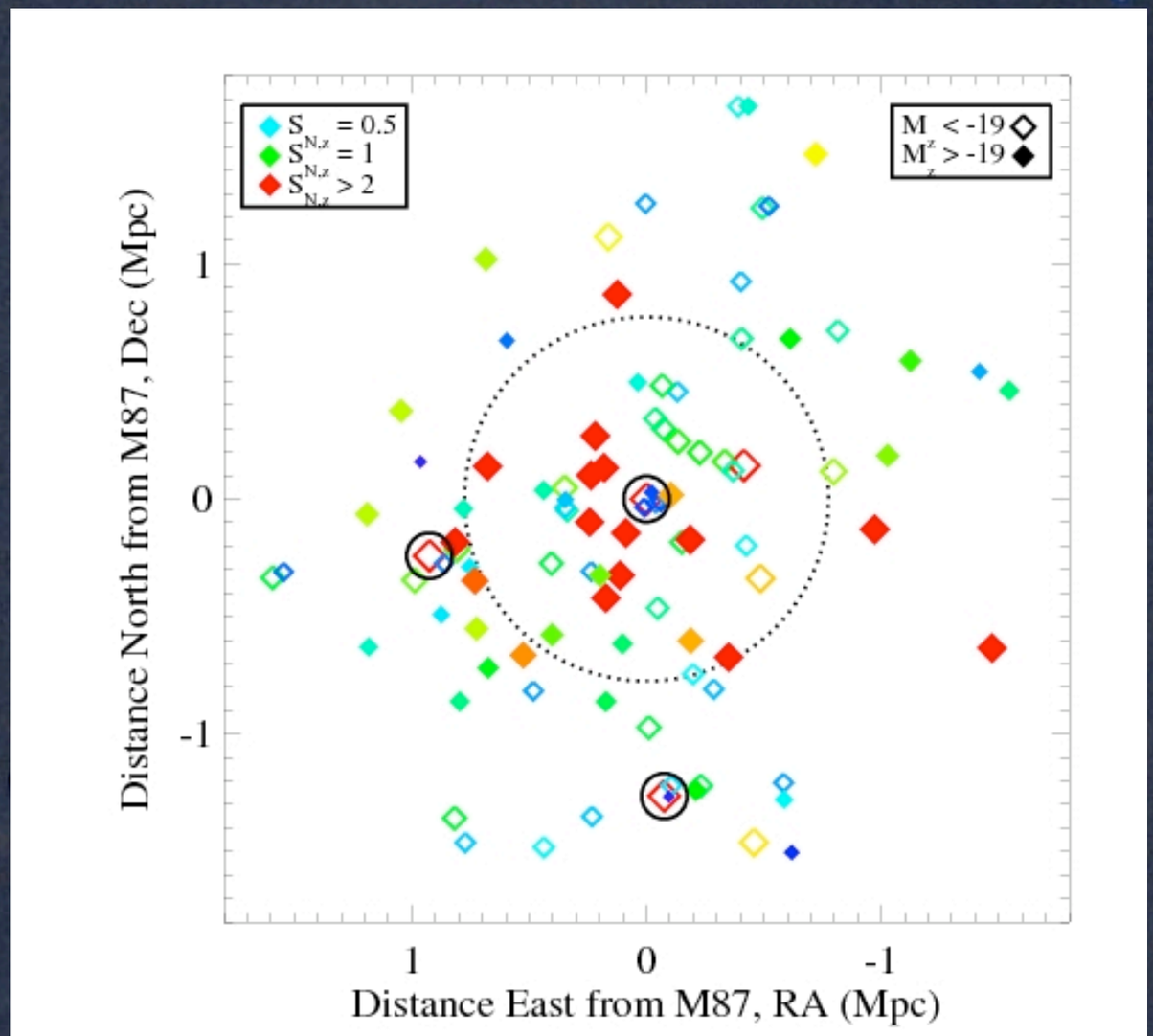
- Dwarfs only: $M_z > -19$
- S_N vs clustercentric distance

Peng et al. (2008)

Globular Clusters in dEs: The Role of Environment



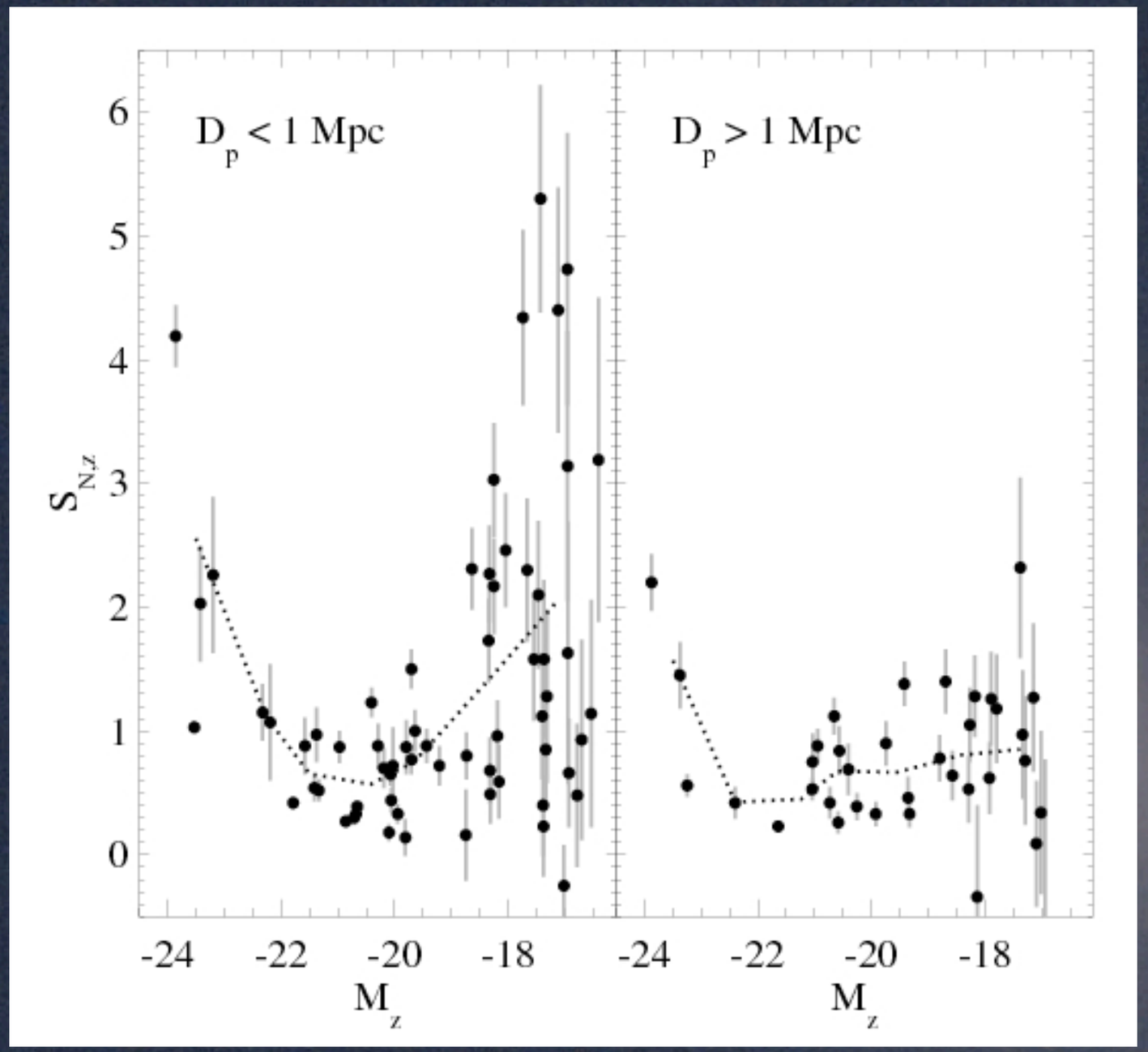
- Dwarfs only: $M_z > -19$
- S_N vs clustercentric distance



- dEs with high GC fractions are within $D_p < 1$ Mpc
- dEs within 100 kpc, stripped of GCs

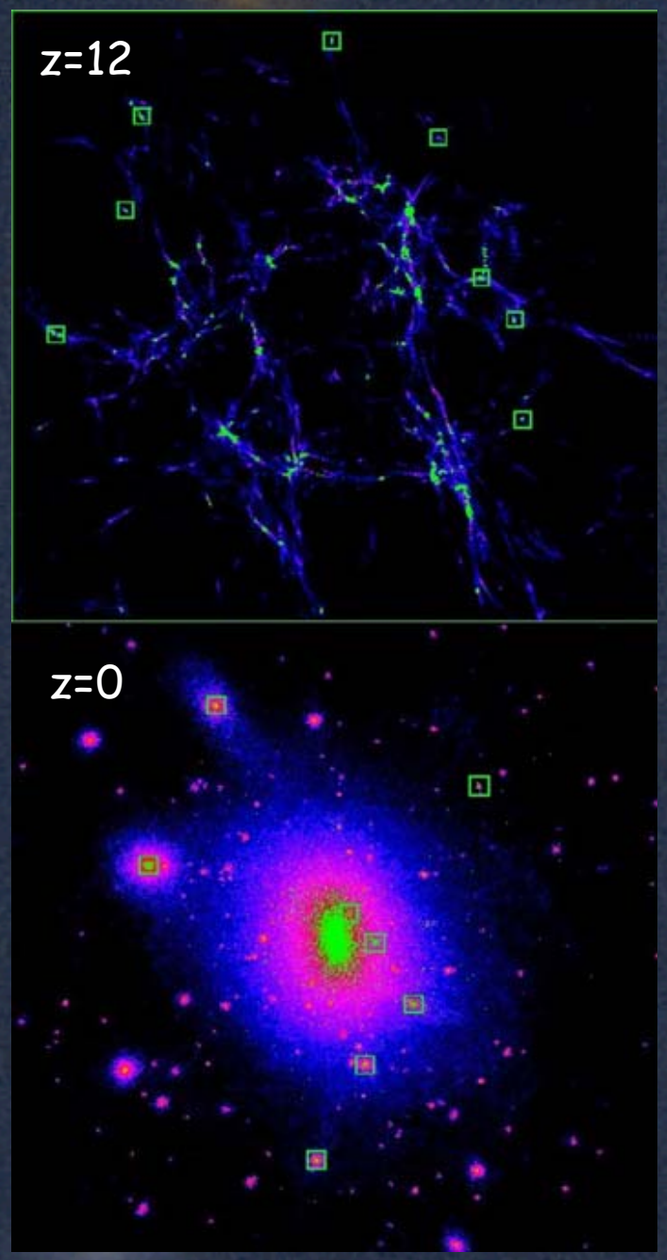
Peng et al. (2008)

Globular Clusters in dEs: The Role of Environment



Peng et al (2008)

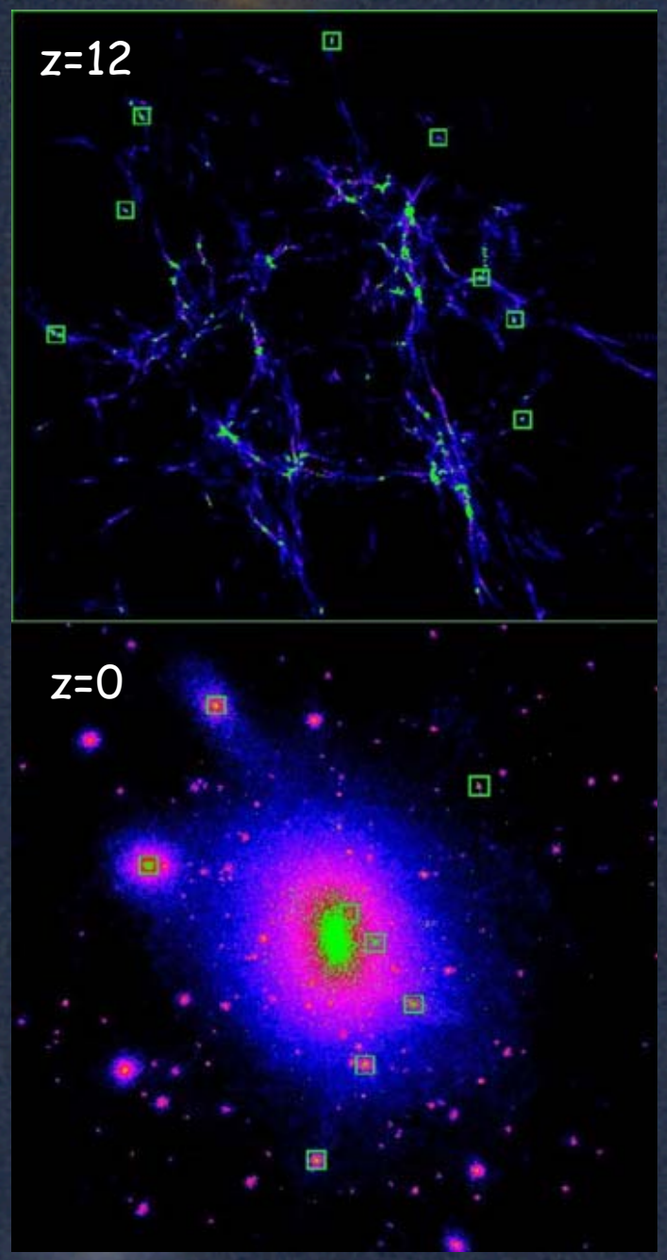
Implications



Moore et al (2006)

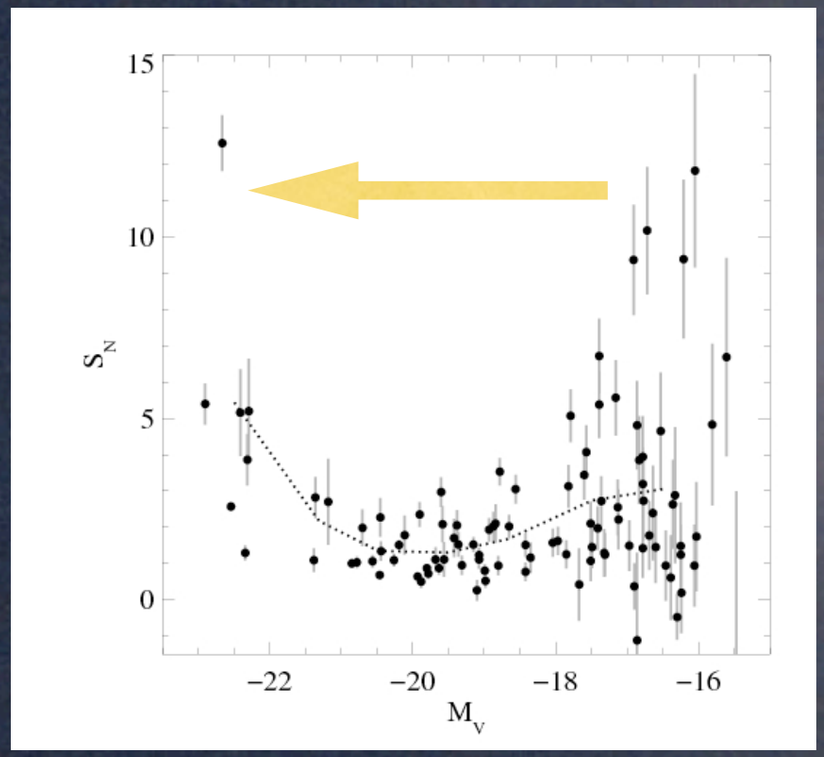
- GC formation in dEs is most efficient in dense regions (biased)
- Low mass halos in dense regions collapse earlier, and are perhaps more efficient at producing GCs
- Earliest collapsing low mass halos in densest regions could build metal-poor GC populations in giants

Implications



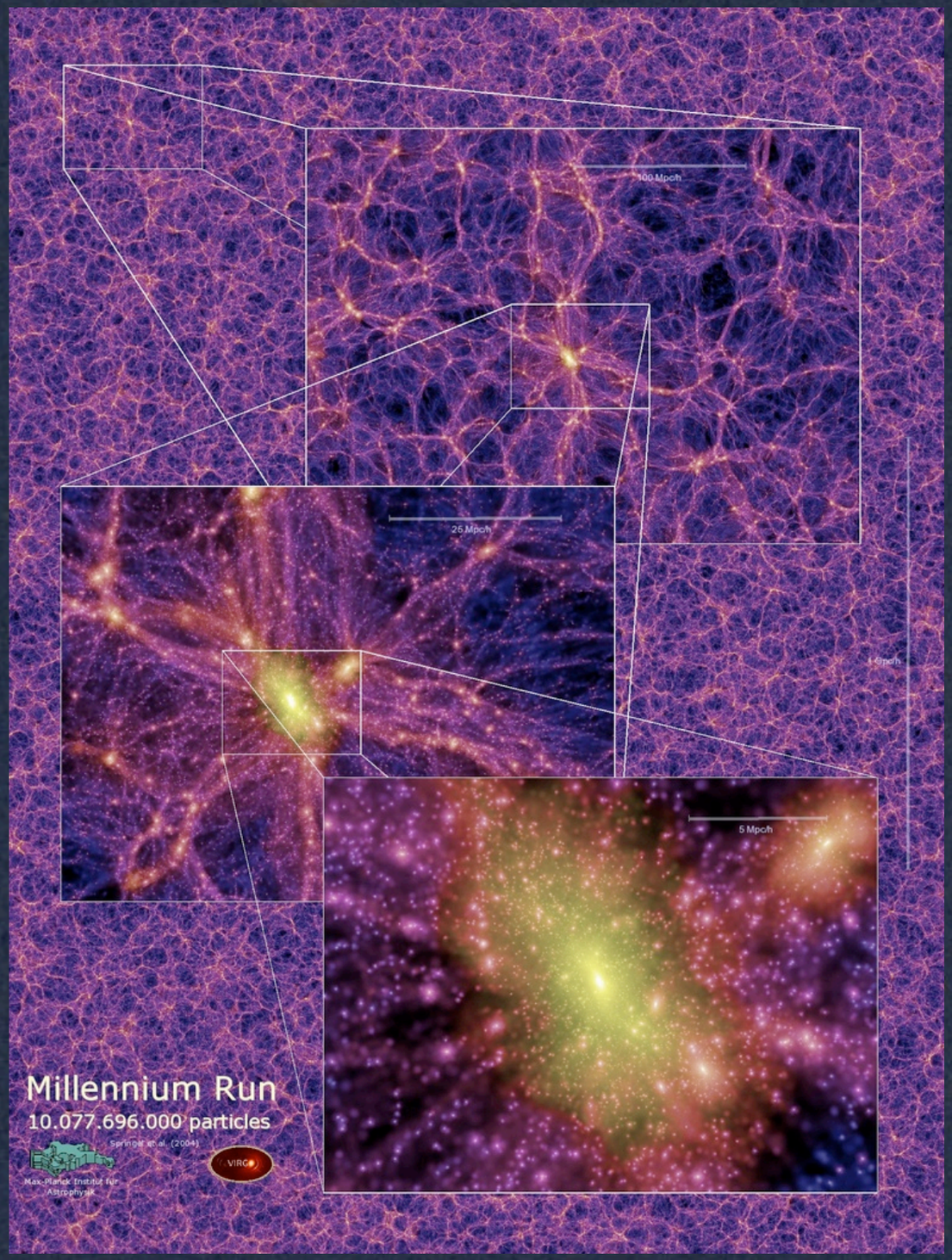
Moore et al (2006)

- GC formation in dEs is most efficient in dense regions (biased)
- Low mass halos in dense regions collapse earlier, and are perhaps more efficient at producing GCs
- Earliest collapsing low mass halos in densest regions could build metal-poor GC populations in giants



The Millennium Simulation

(Springel et al 2005, De Lucia et al 2006)



- 2160^3 dark matter particles
- 500^3 h^{-1} Mpc volume
- z=127 to present
- Galaxies with stellar mass > $3x10^8$

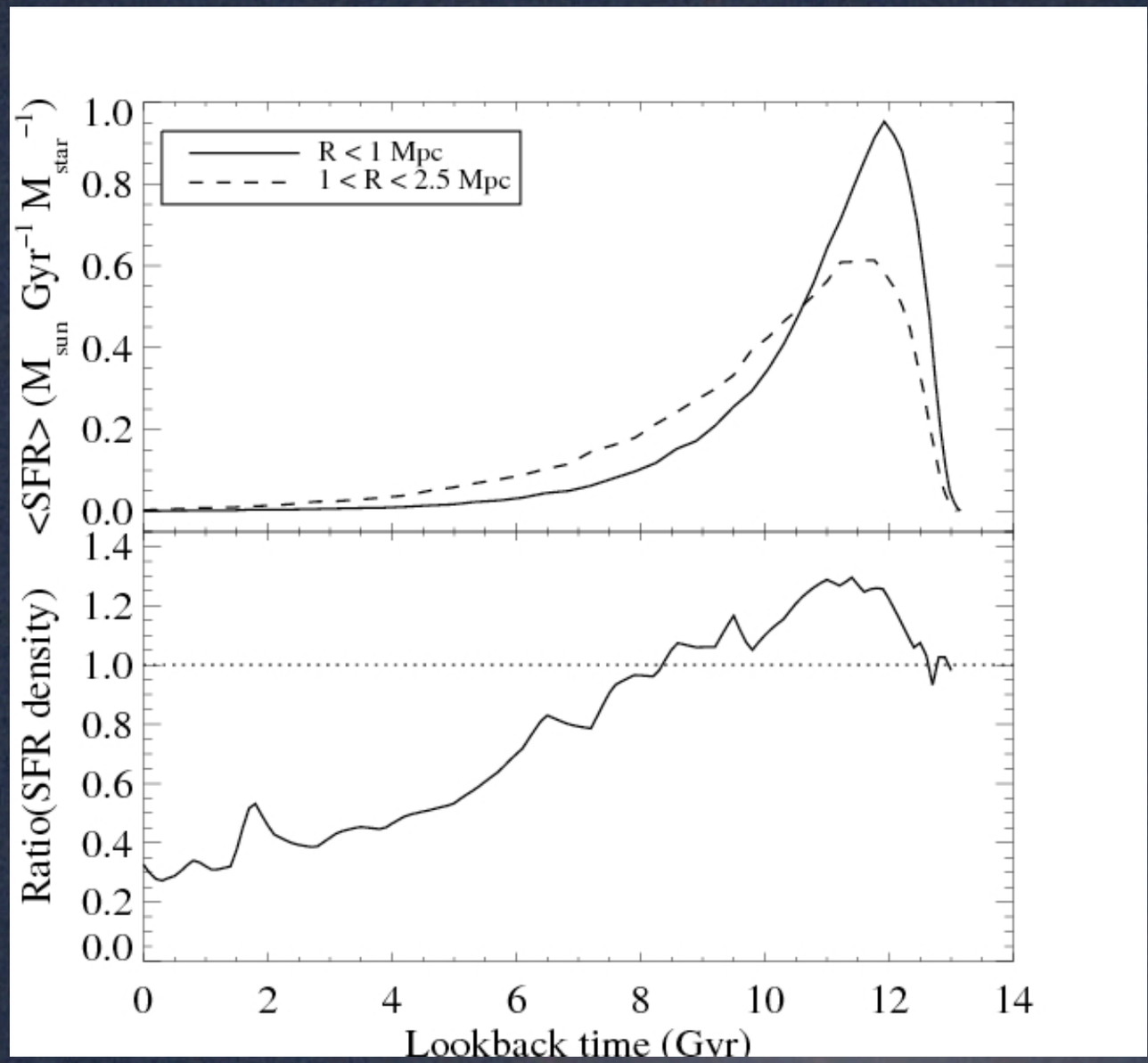
- 126 massive galaxy clusters
- Select 15,506 simulated early-type dwarfs (M_z>-19 at z=0) and their progenitors
- 63 snapshots from z=12

What are the properties and star formation histories of simulated early-type cluster dwarfs?

The Millennium Simulation:
Early-type cluster dwarfs

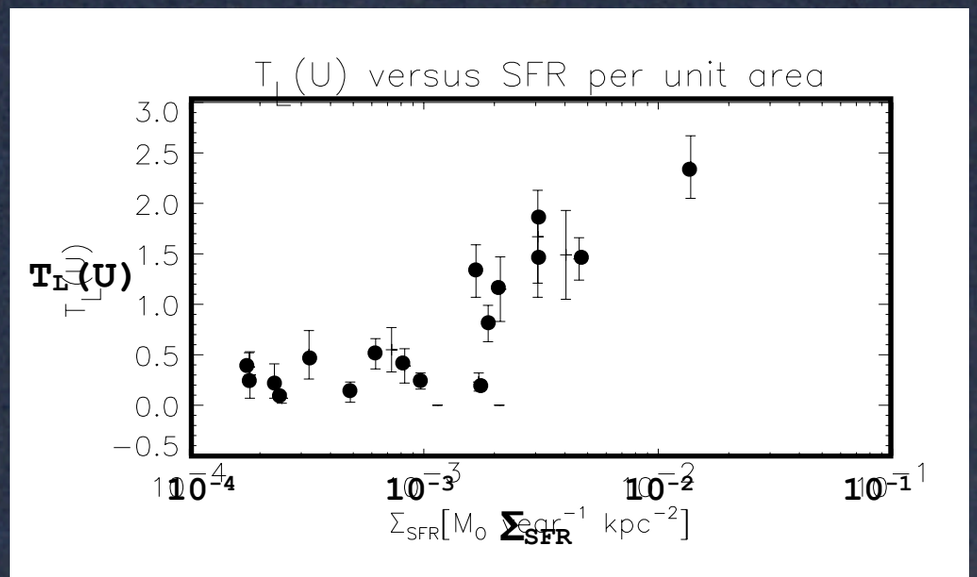
Average star formation rate of central dwarfs more peaked with rapid falloff

Star formation in central dwarfs occurs at higher star formation rate **density**



The Millennium Simulation:
Early-type cluster dwarfs

In local star forming galaxies, higher SFR surface density means a larger fraction of stellar luminosity/ mass in massive star clusters

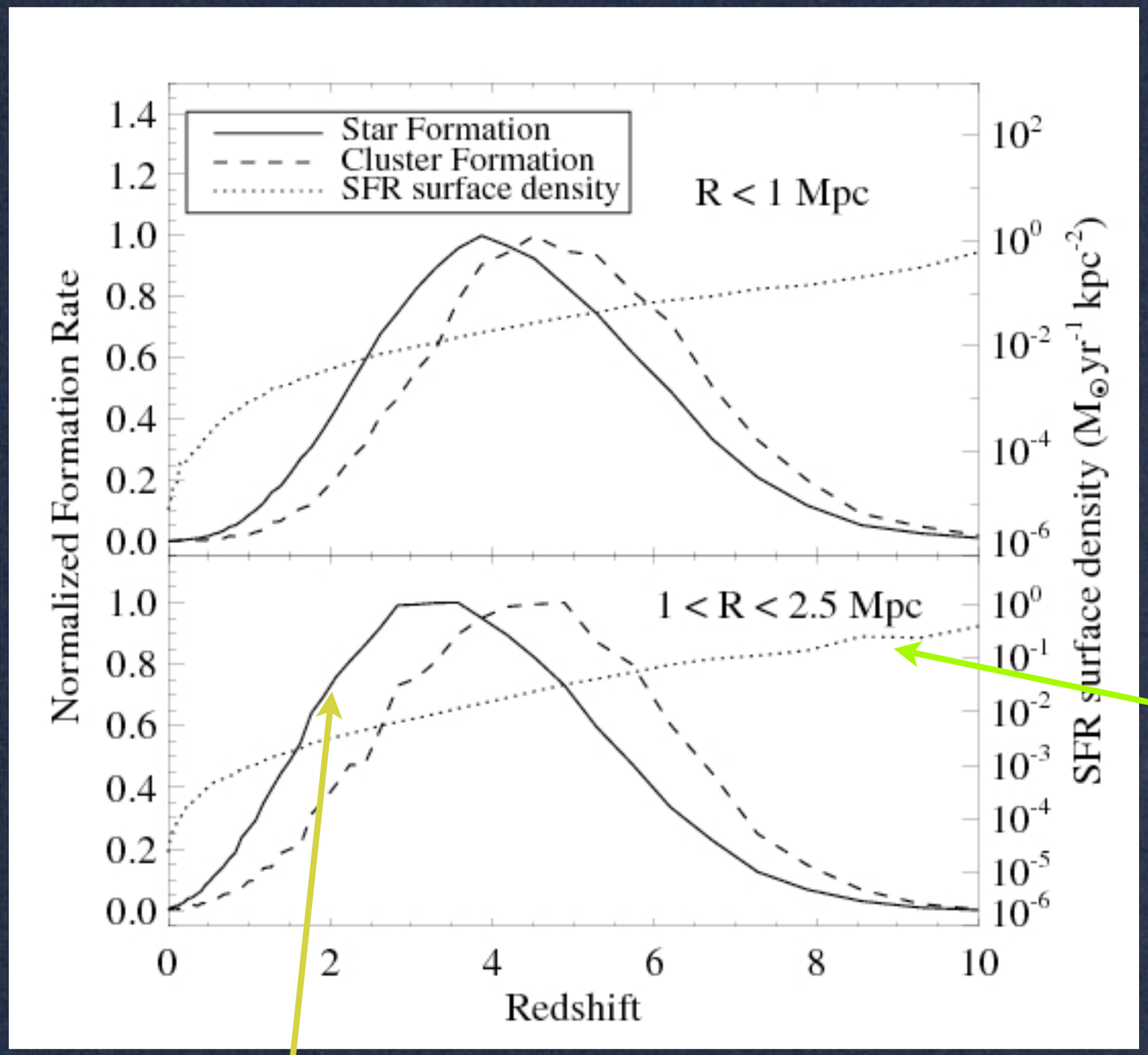


Larsen & Richtler (2000)

We can scale the SFR and SFR densities in Millennium semi-analytic models to predict star cluster formation rates

Cluster Formation Rate $\propto$ SFR x SFR surface density

The Millennium Simulation:
Early-type cluster dwarfs



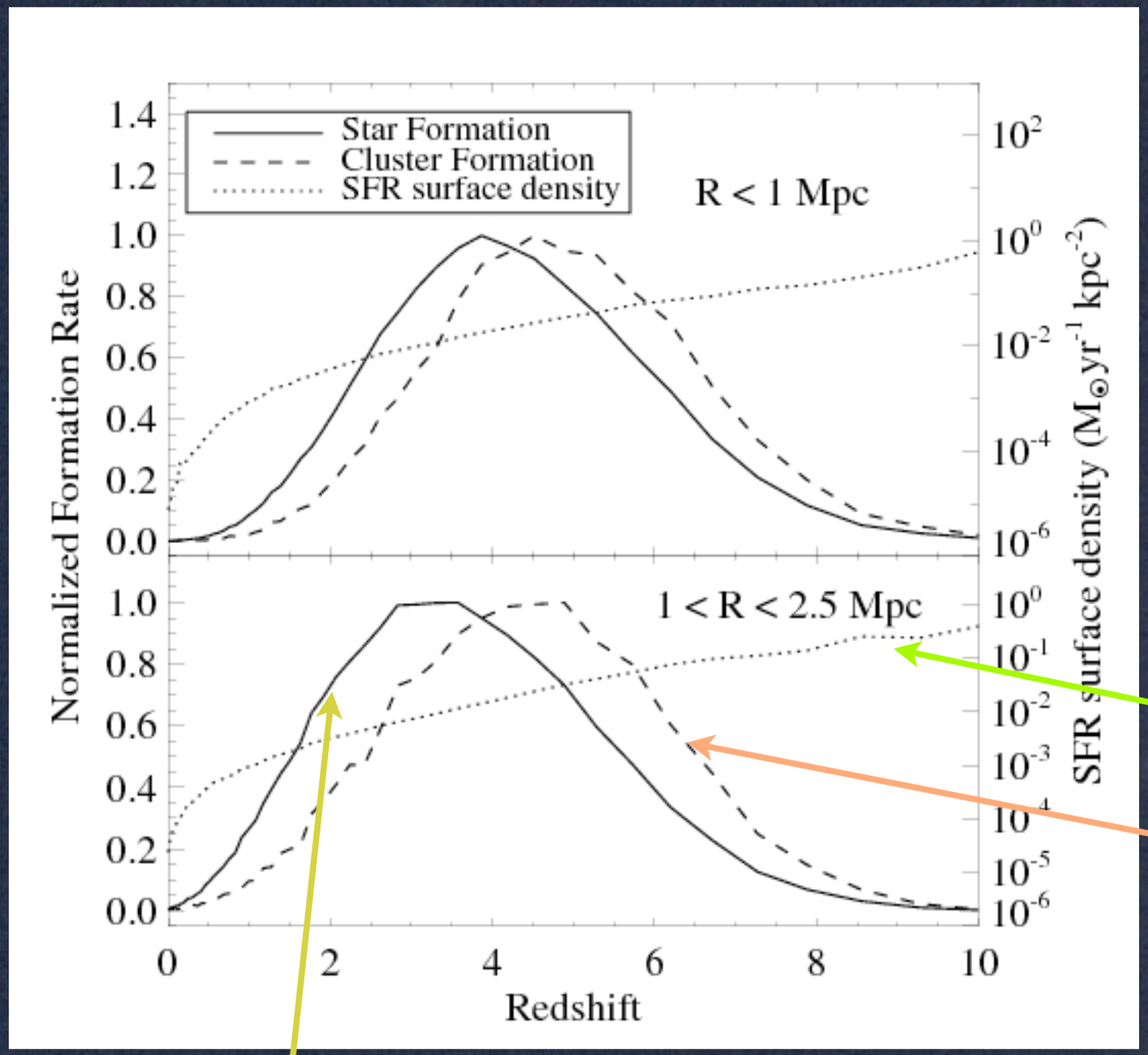
Peng et al. (2008)

Peak formation of massive star clusters is naturally earlier than peak SFR

SFR surface density

Star Formation Rate

The Millennium Simulation:
Early-type cluster dwarfs



Peng et al. (2008)

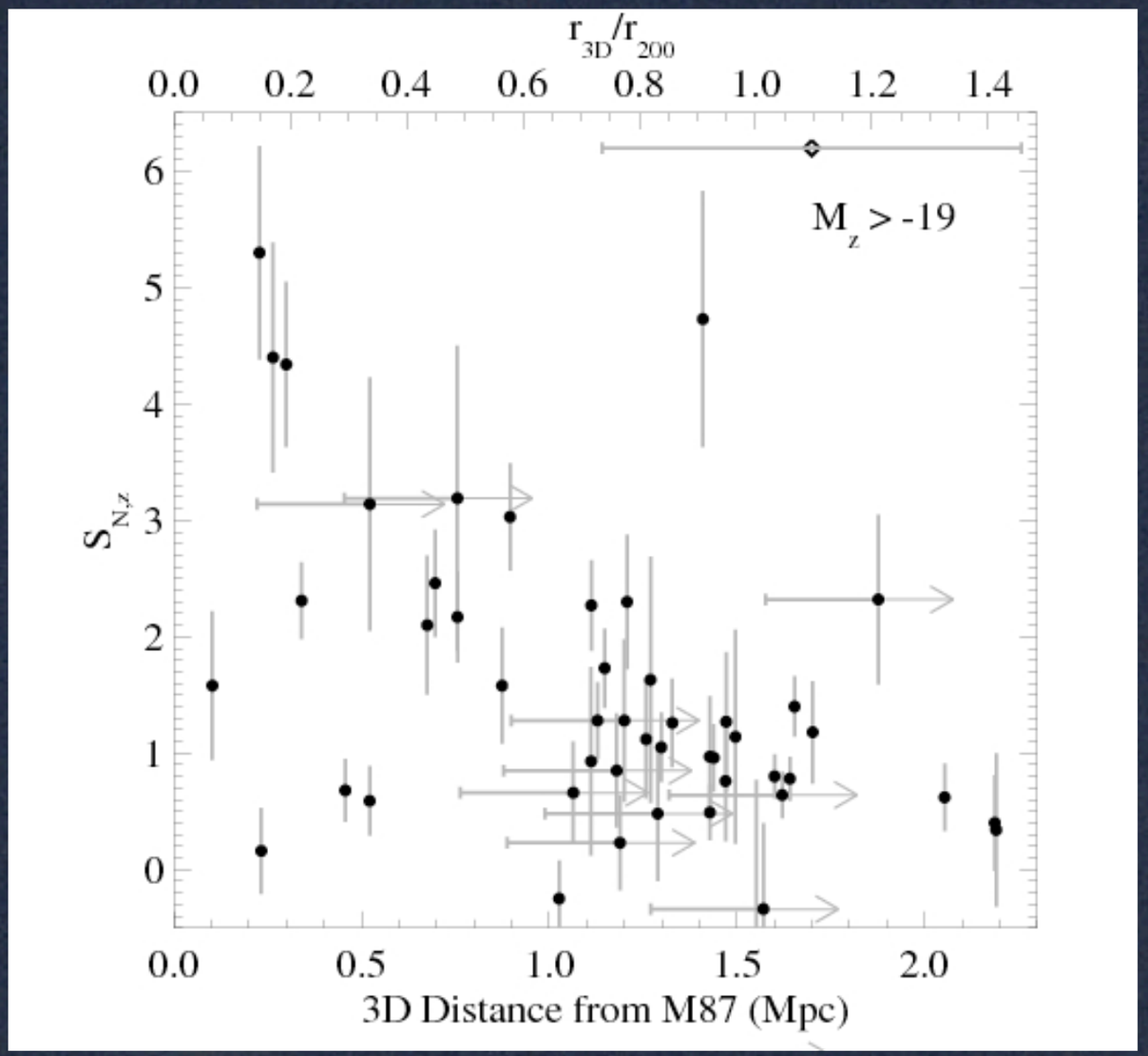
Peak formation of massive star clusters is naturally earlier than peak SFR

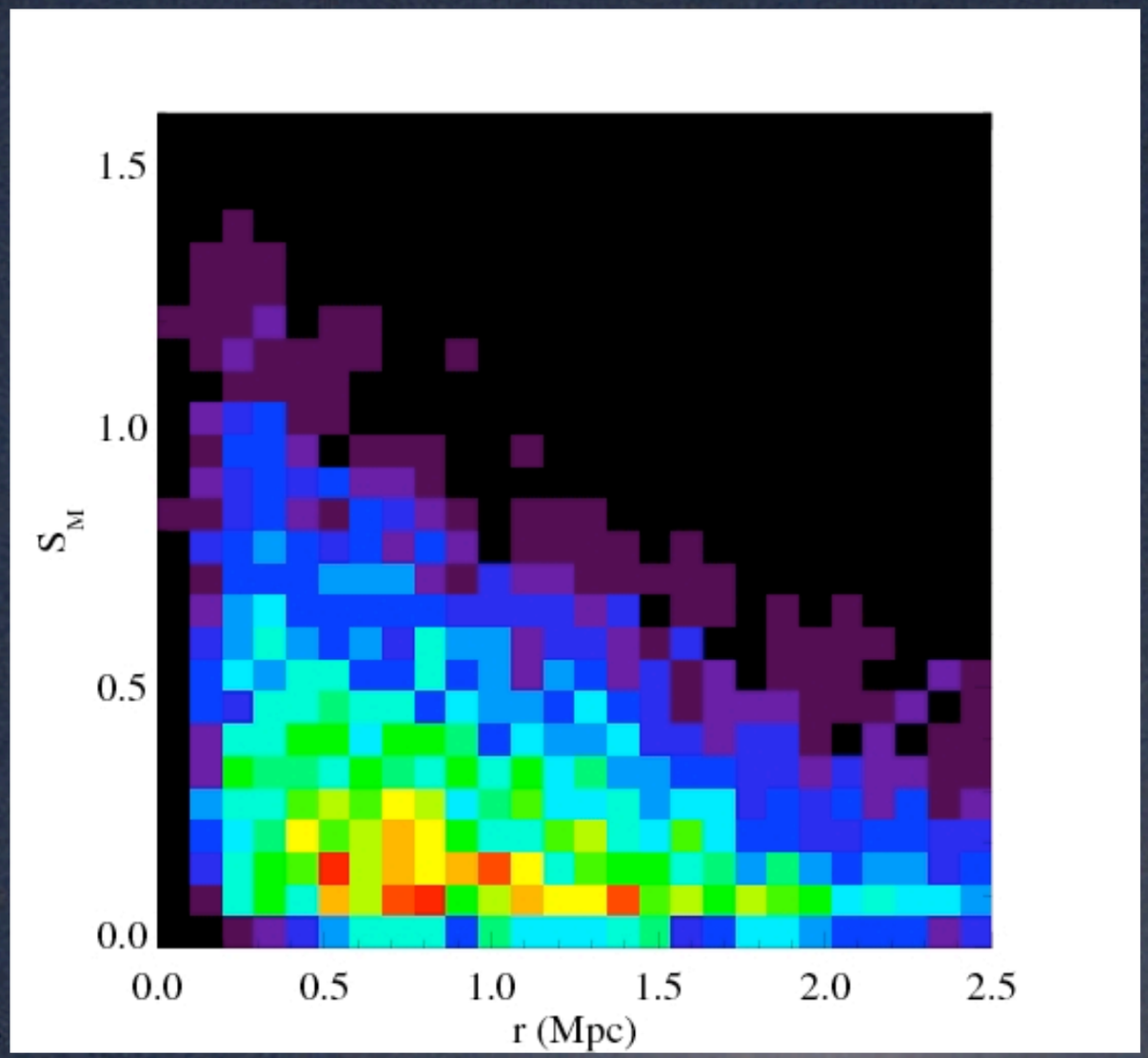
SFR surface density

Cluster Formation Rate

Star Formation Rate

The Millennium Simulation:
Early-type cluster dwarfs



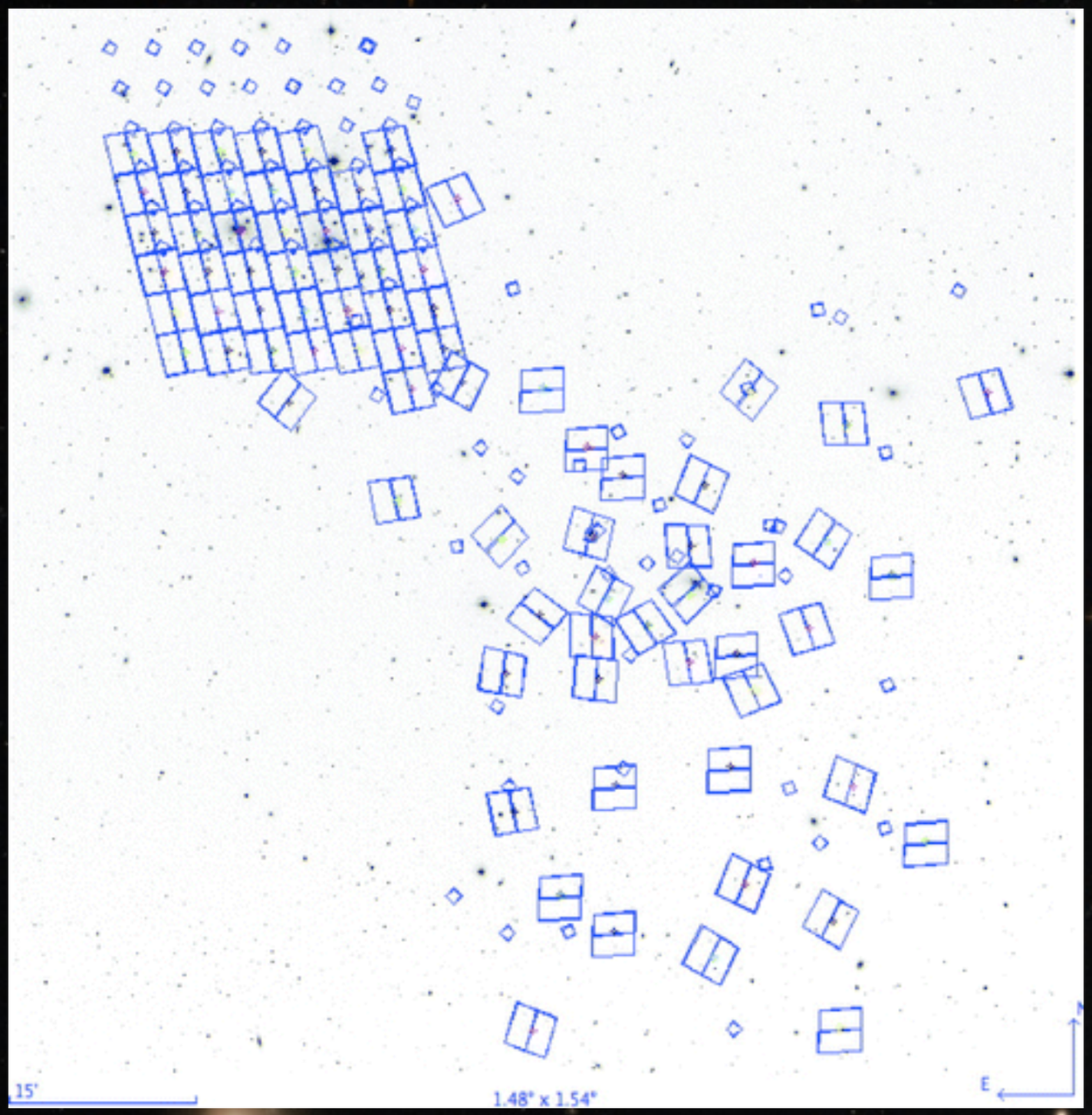


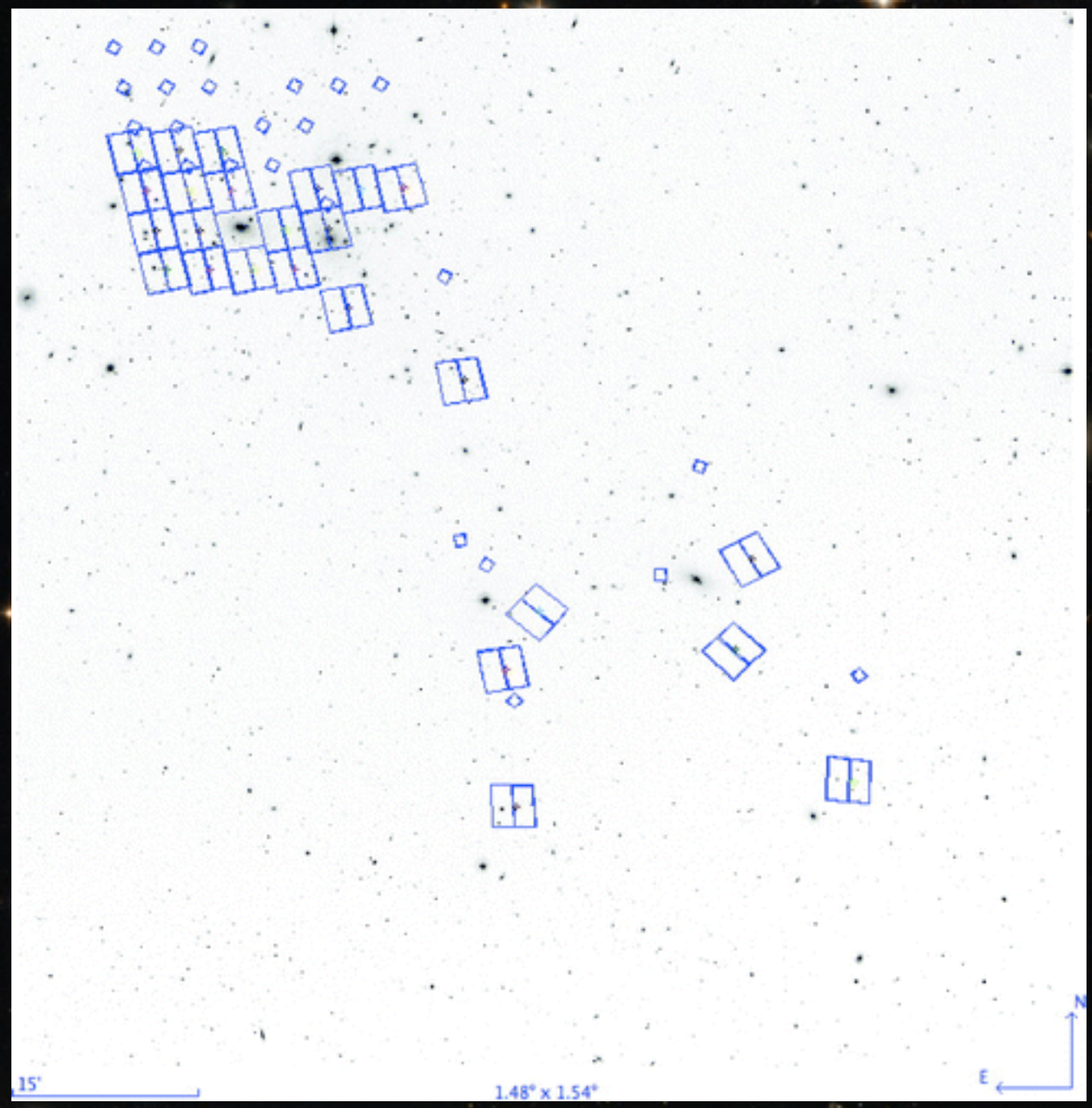
Oldest dwarfs are at cluster center and formed GCs at high efficiency.

The HST/ACS Coma Treasury Survey

- Nearest rich, dense cluster environment (100 Mpc)
- HST/ACS Treasury survey to observe 82 pointings in g and I in cluster core and outskirts. Only 25 completed.
- D. Carter (PI), H. Ferguson, P. Goudfrooij, T. Puzia, et al.

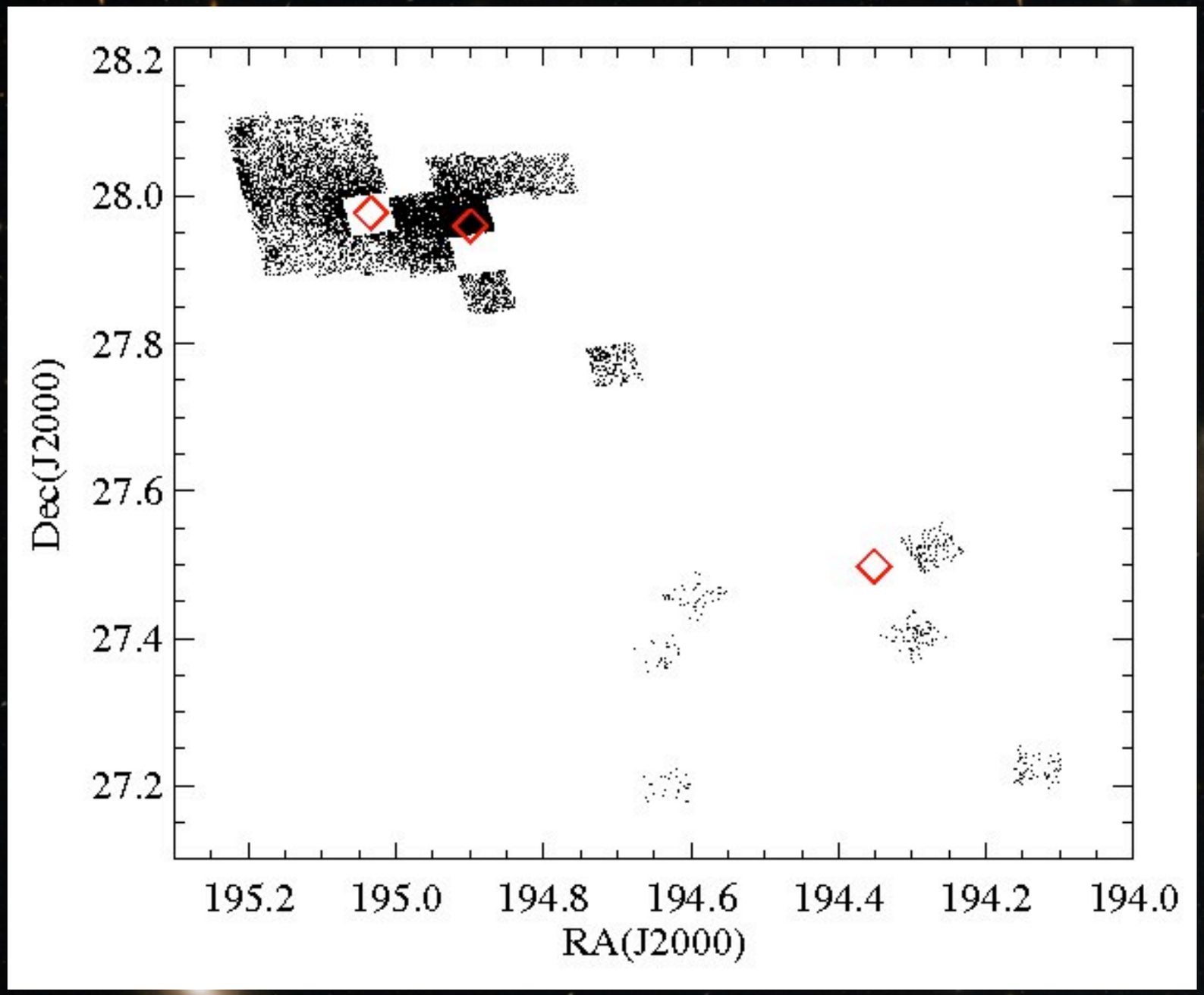
The HST/ACS Coma Treasury Survey





Can still do interesting GC and galaxy science!
(See talks and posters by M. Hudson, R. Smith, A. Graham)

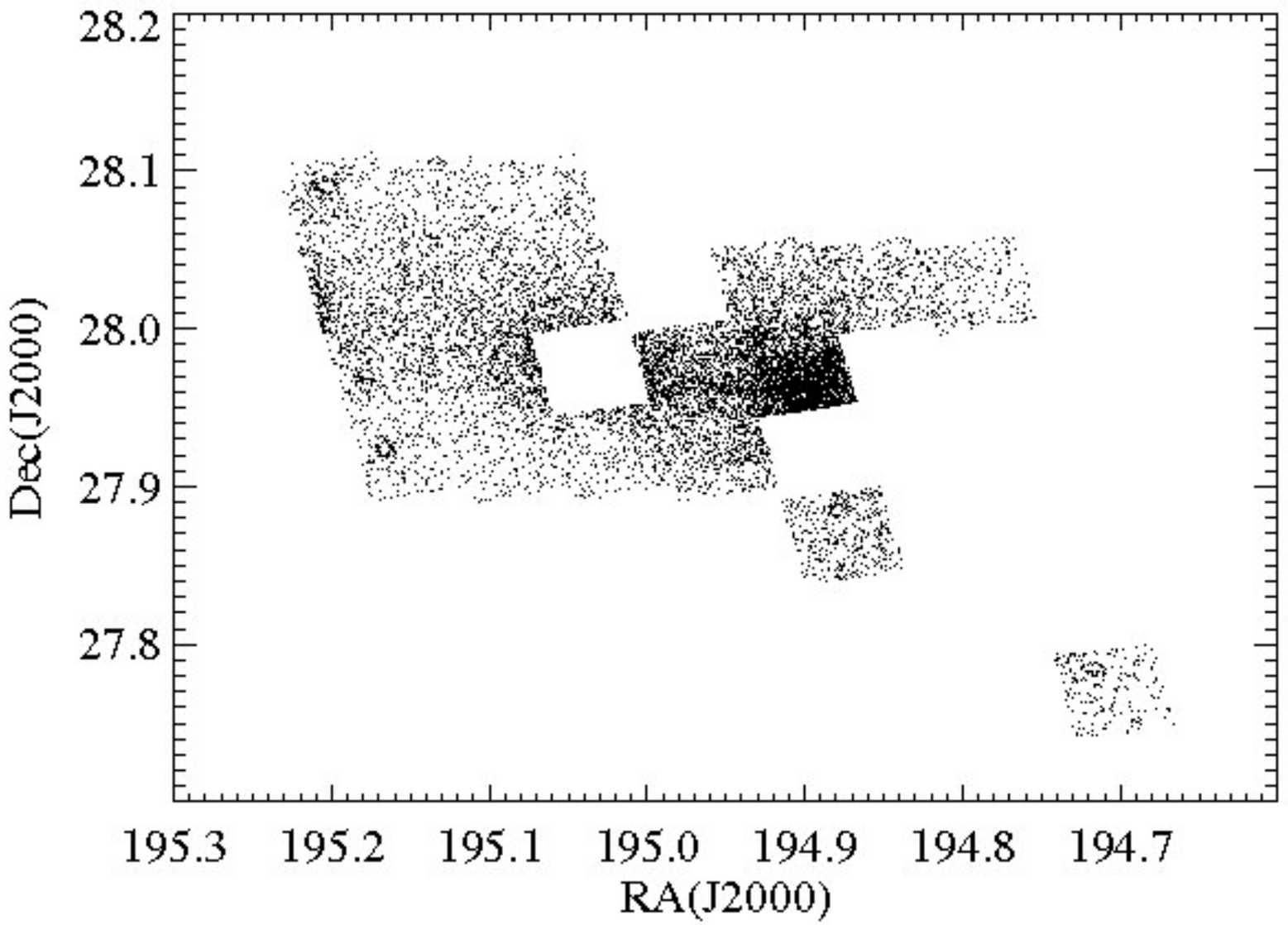
The HST/ACS Coma Treasury Survey



- GCs are point sources
- Entire cluster core is filled with GCs
- Intergalactic population
- Most are metal-poor (2:1)
- Spatial structure in GCs

Peng et al. (in prep)

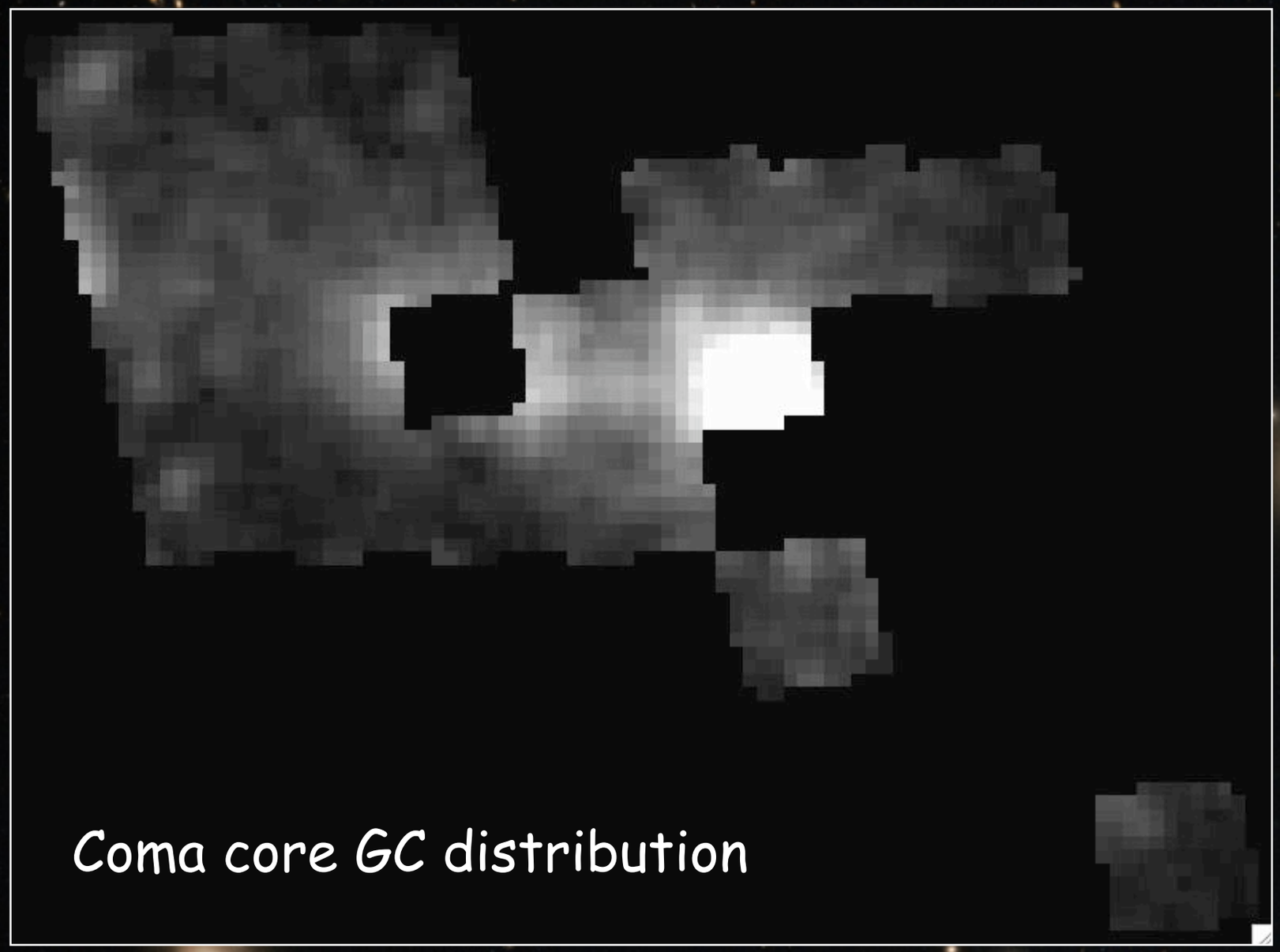
The HST/ACS Coma Treasury Survey



- GCs are point sources
- Entire cluster core is filled with GCs
- Intergalactic population
- Most are metal-poor (2:1)
- Spatial structure in GCs

Peng et al. (in prep)

The HST/ACS Coma Treasury Survey

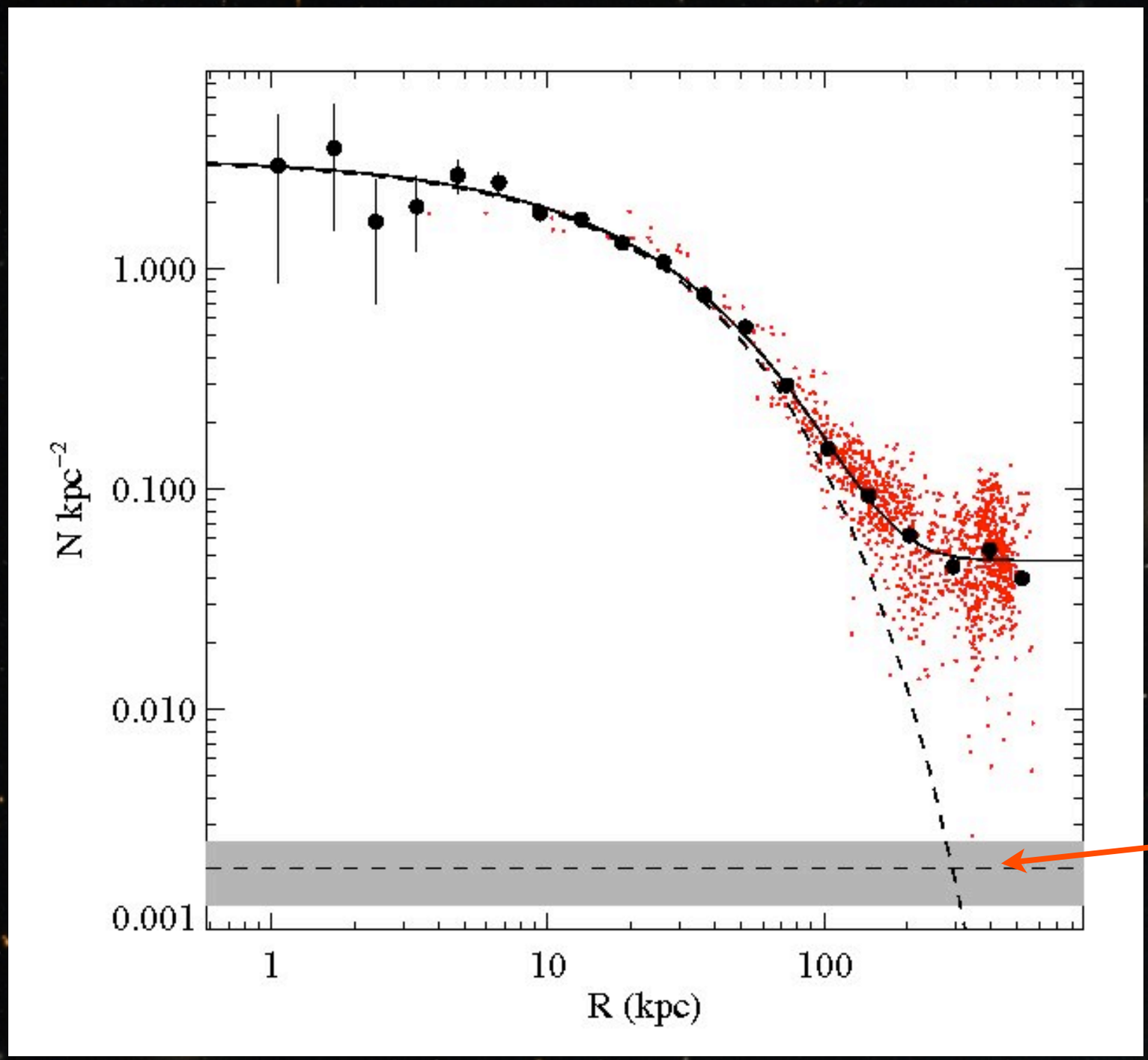


Coma core GC distribution

- GCs are point sources
- Entire cluster core is filled with GCs
- Intergalactic population
- Most are metal-poor (2:1)
- Spatial structure in GCs

Peng et al. (in prep)

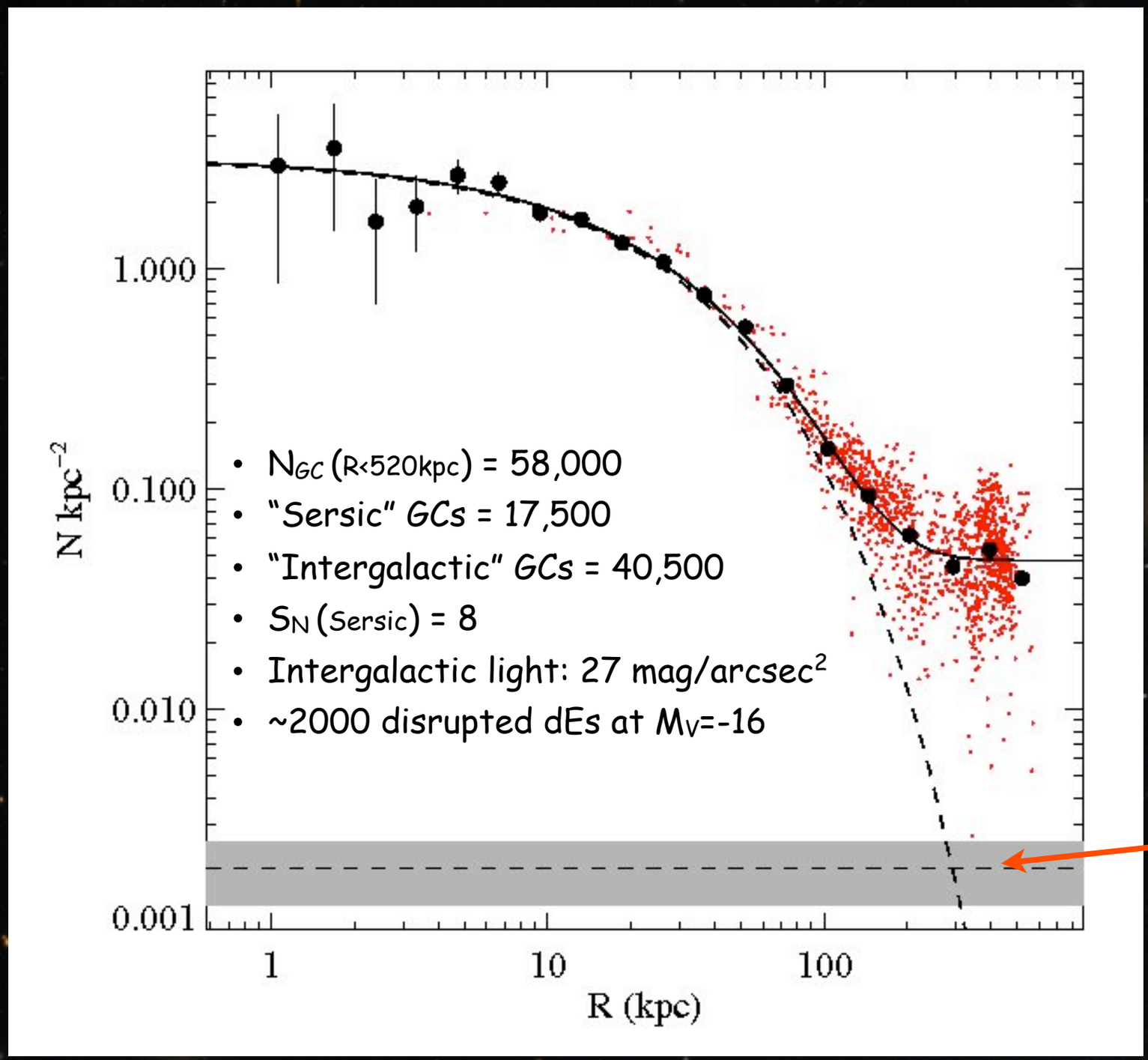
The HST/ACS Coma Treasury Survey



- GC radial profile centered on NGC 4874
- Galaxies masked and their GCs statistically subtracted
- Sersic + constant fits well
- Intergalactic GC density is well above background level

Peng et al. (in prep)

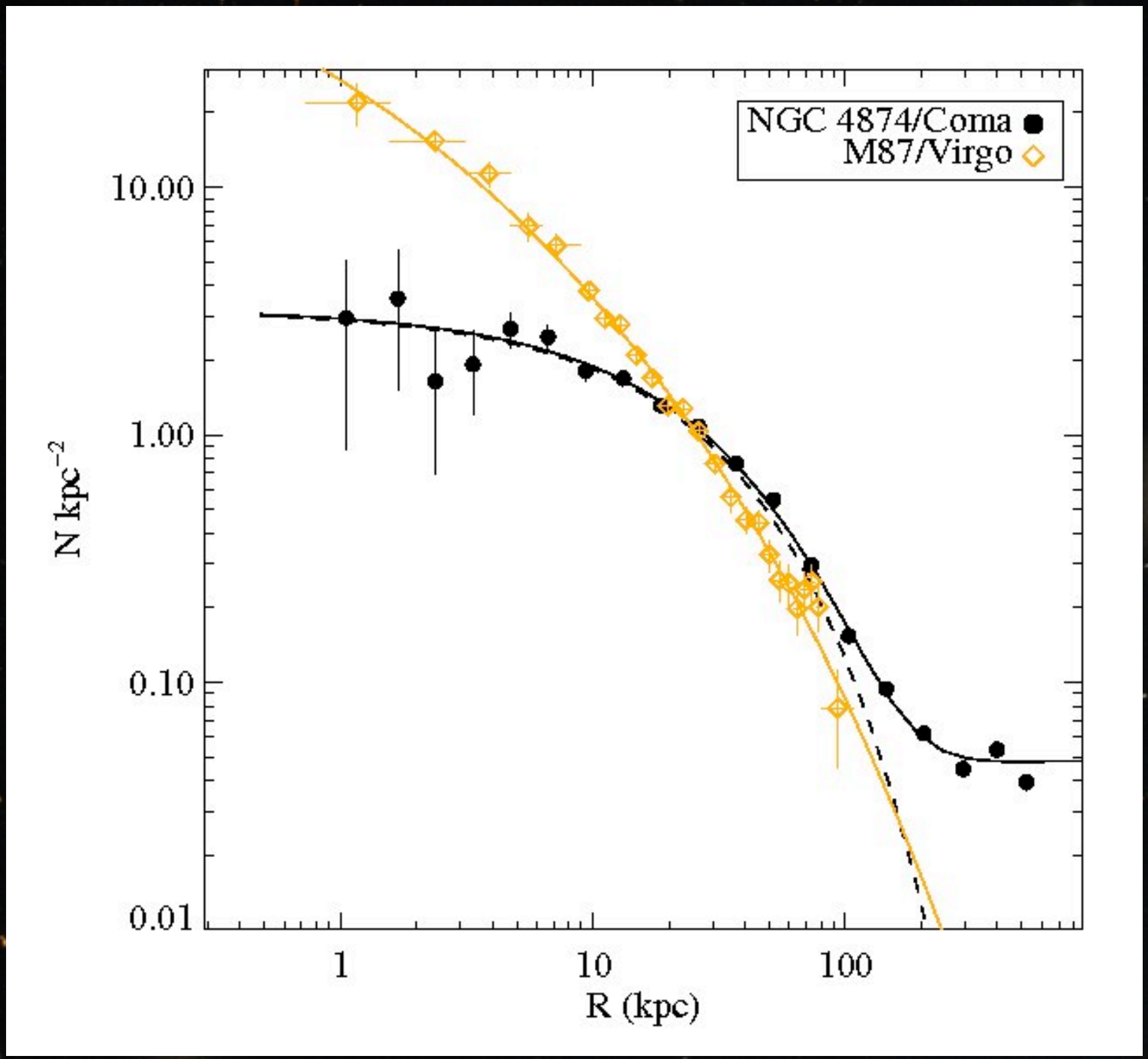
The HST/ACS Coma Treasury Survey



- GC radial profile centered on NGC 4874
- Galaxies masked and their GCs statistically subtracted
- Sersic + constant fits well
- Intergalactic GC density is well above background level

Peng et al. (in prep)

The HST/ACS Coma Treasury Survey

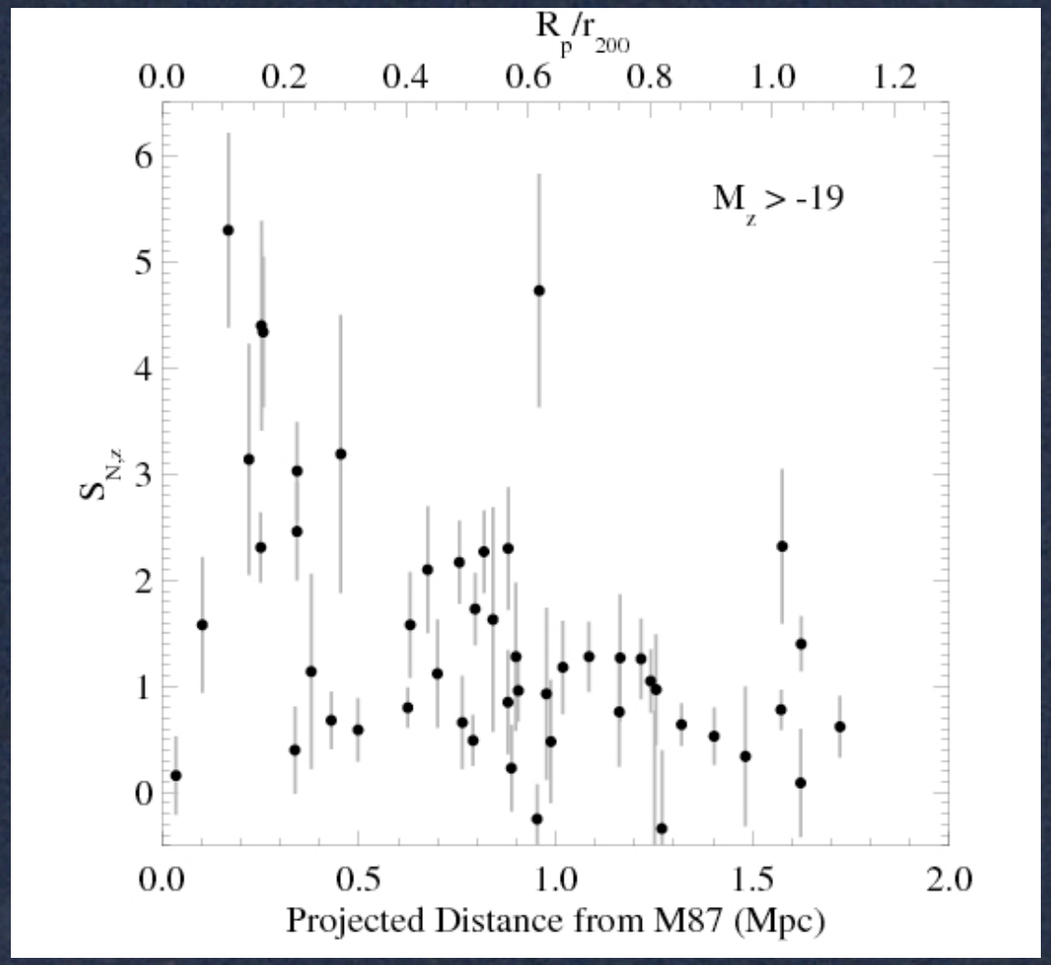


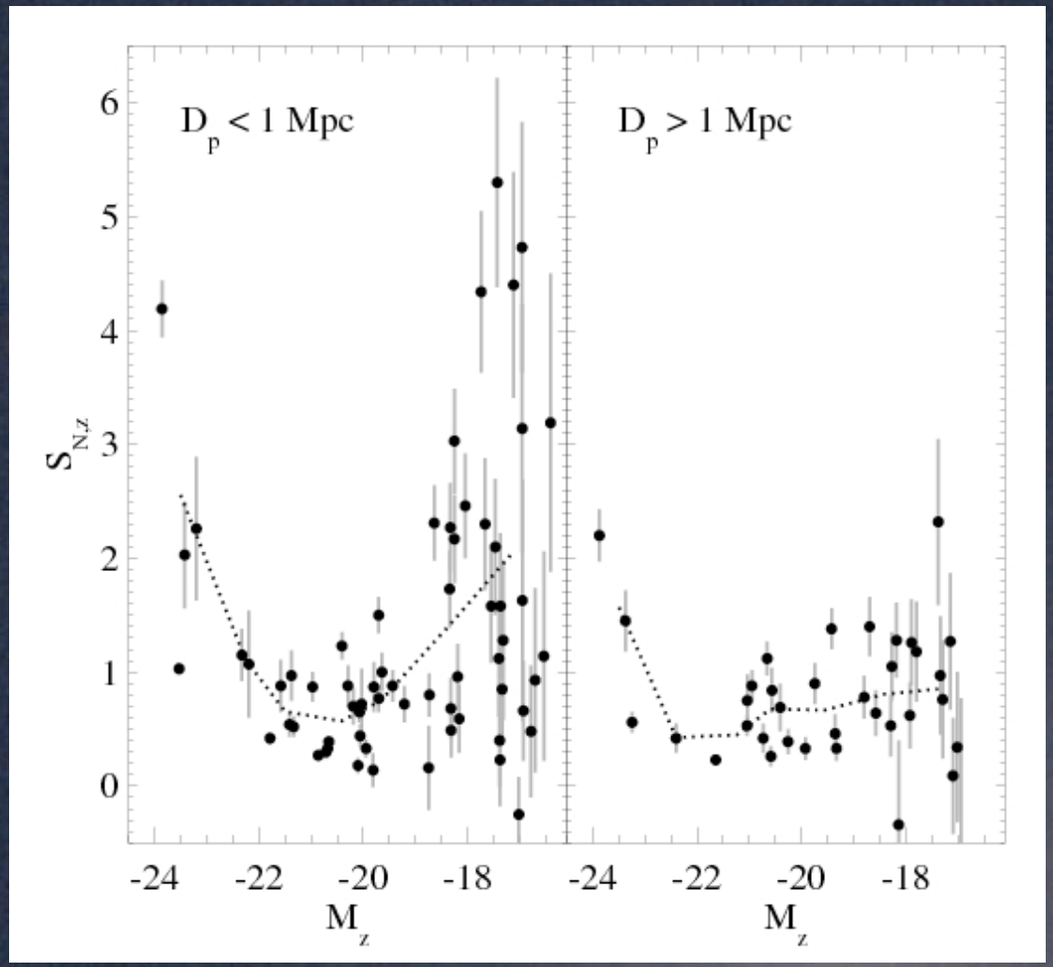
Peng et al. (in prep)

- GC radial profile centered on NGC 4874
- Galaxies masked and their GCs statistically subtracted
- Sersic + constant fits well
- Intergalactic GC density is well above background level

Conclusions

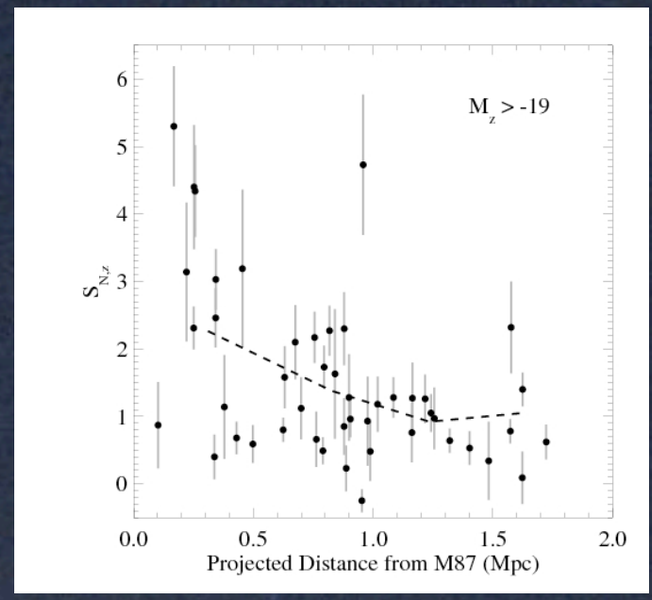
1. GC formation in dEs relative to their field stars is biased toward the cluster center

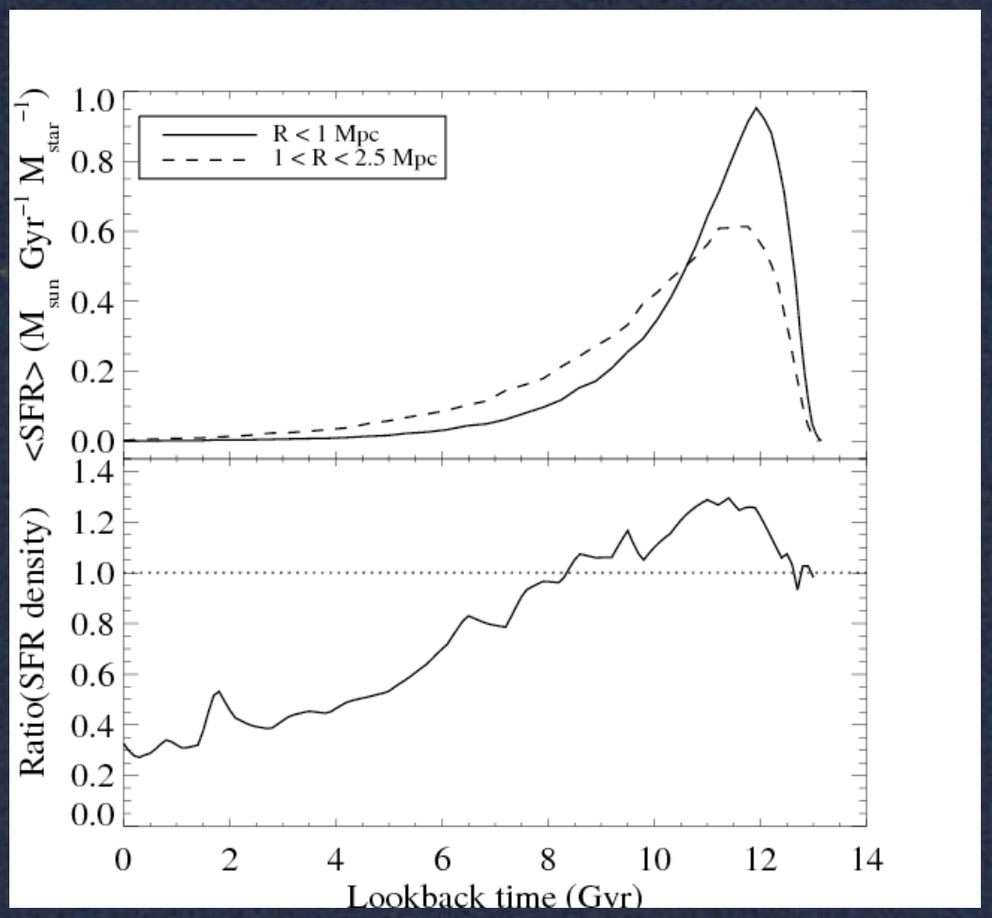


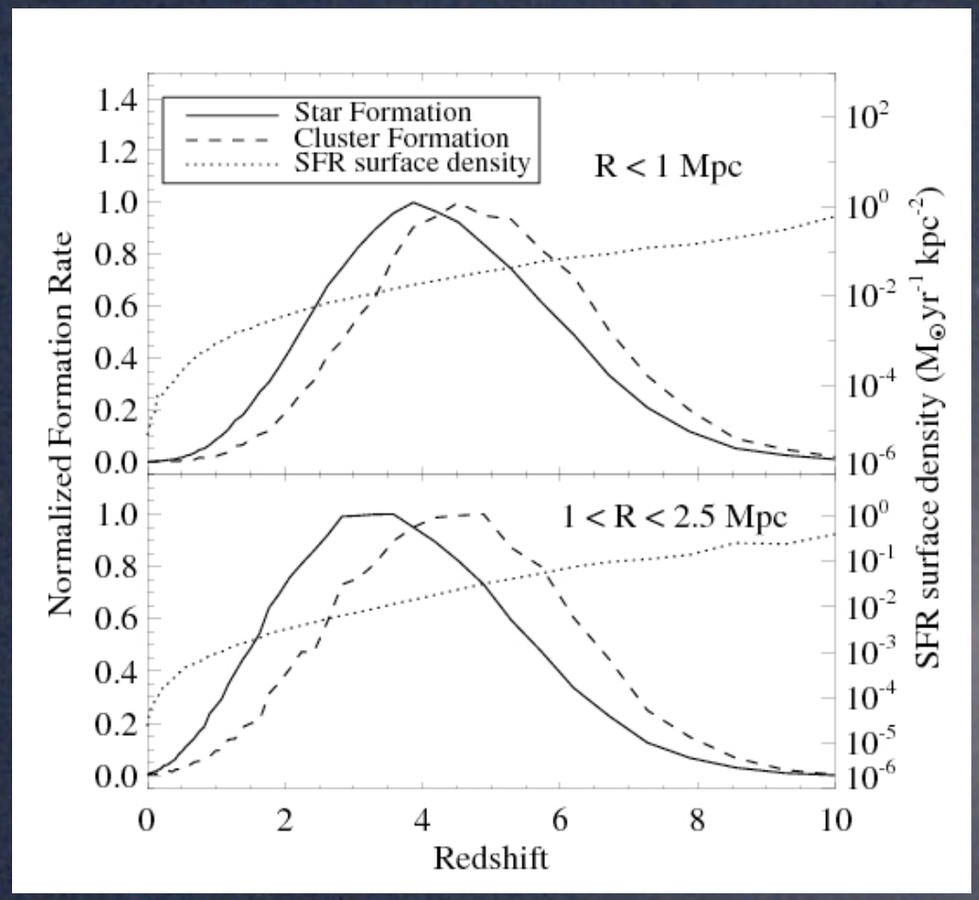


Conclusions

1. GC formation in dEs relative to their field stars is biased toward the cluster center
2. Central dEs form stars and GCs earlier, more intensely, at higher SFR surface densities, naturally producing higher S_N, and leading to GCs that are older, more metal-poor than their hosts.

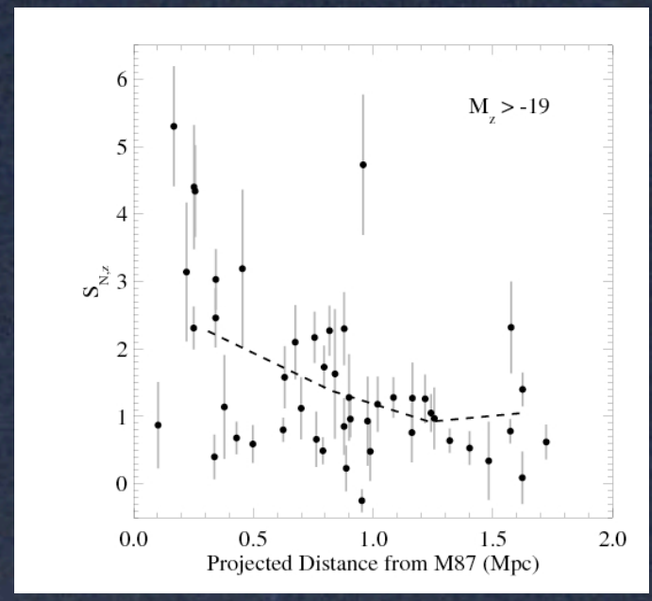


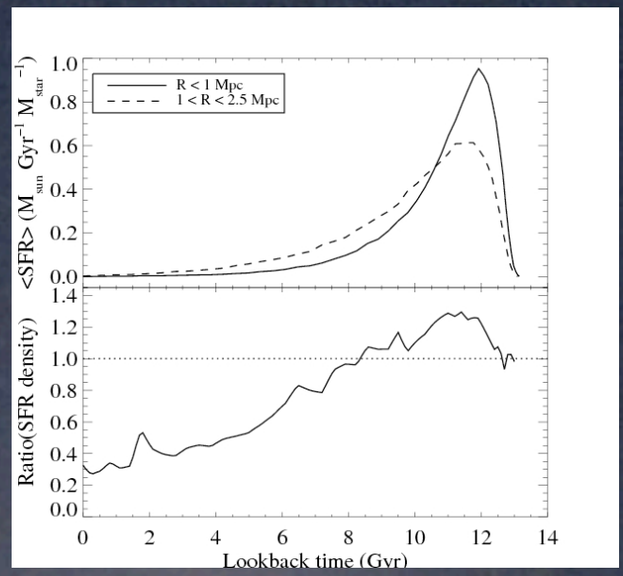


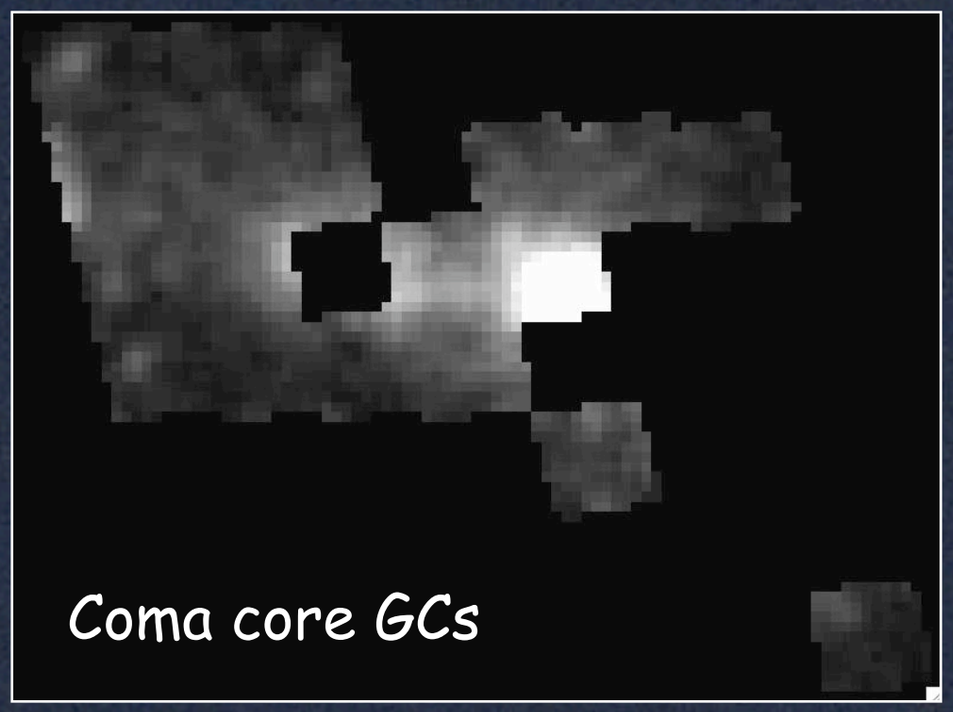


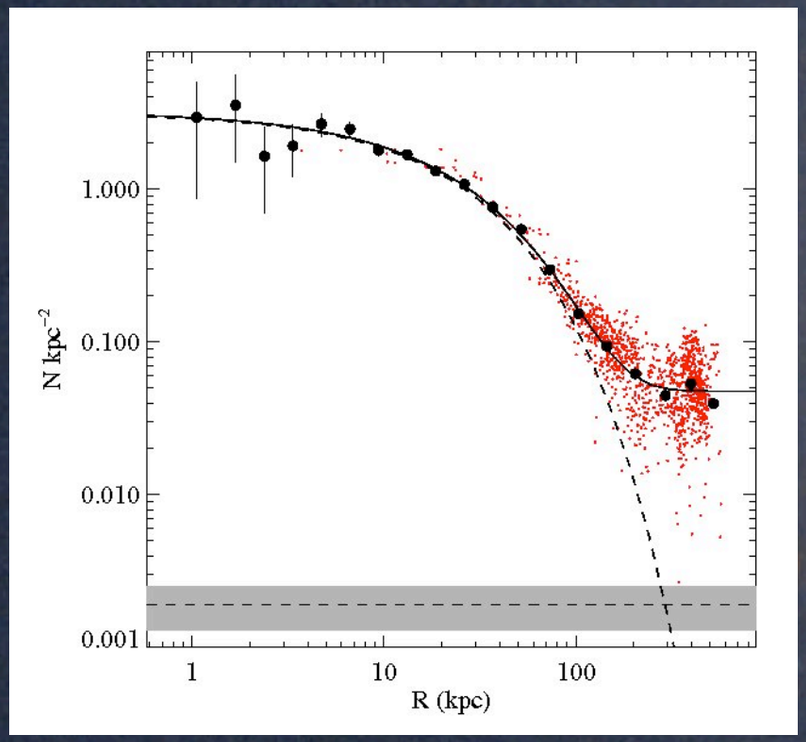
Conclusions

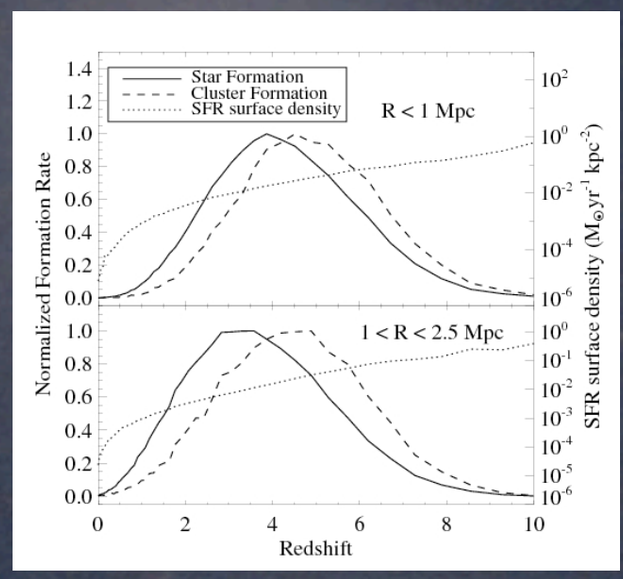
1. GC formation in dEs relative to their field stars is biased toward the cluster center
2. Central dEs form stars and GCs earlier, more intensely, at higher SFR surface densities, naturally producing higher S_N, and leading to GCs that are older, more metal-poor than their hosts.
3. In the Coma cluster core, there exists a large population of intergalactic GCs, possibly corresponding to a large population of disrupted, high-S_N dwarf galaxies.











Conclusions

1. GC formation in dEs relative to their field stars is biased toward the cluster center
2. Central dEs form stars and GCs earlier, more intensely, at higher SFR surface densities, naturally producing higher S_N, and leading to GCs that are older, more metal-poor than their hosts.
3. In the Coma cluster core, there exists a large population of intergalactic GCs, possibly corresponding to a large population of disrupted, high-S_N dwarf galaxies.