Formation Efficiencies of Globular Clusters

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13 faculty, 4 postdocs, 25 students
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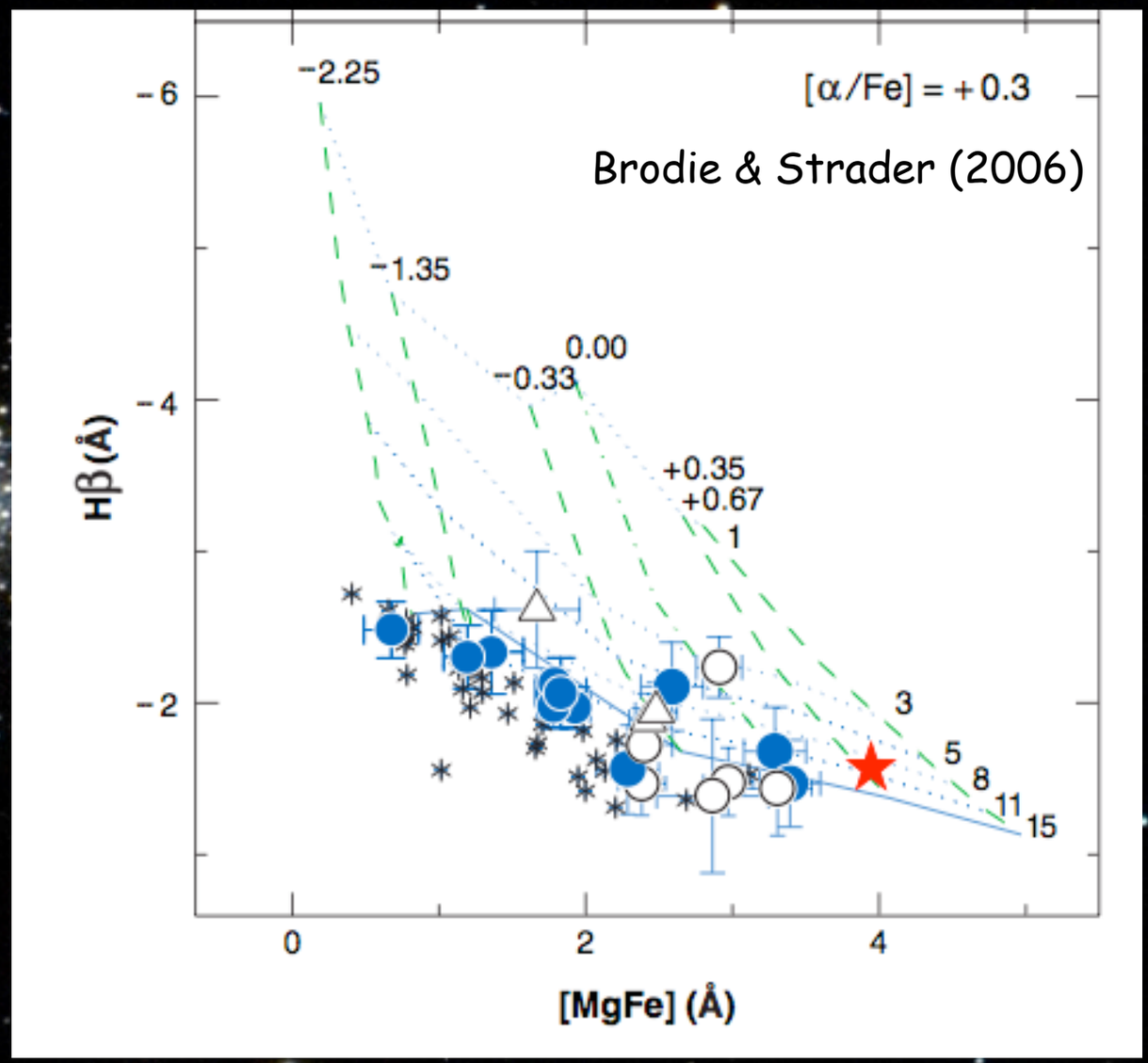
Emphasis on small workshops
and visitor programs at KIAA

Please come visit!

Do Globular Cluster Systems Mirror Their Host Galaxies? Not really...

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



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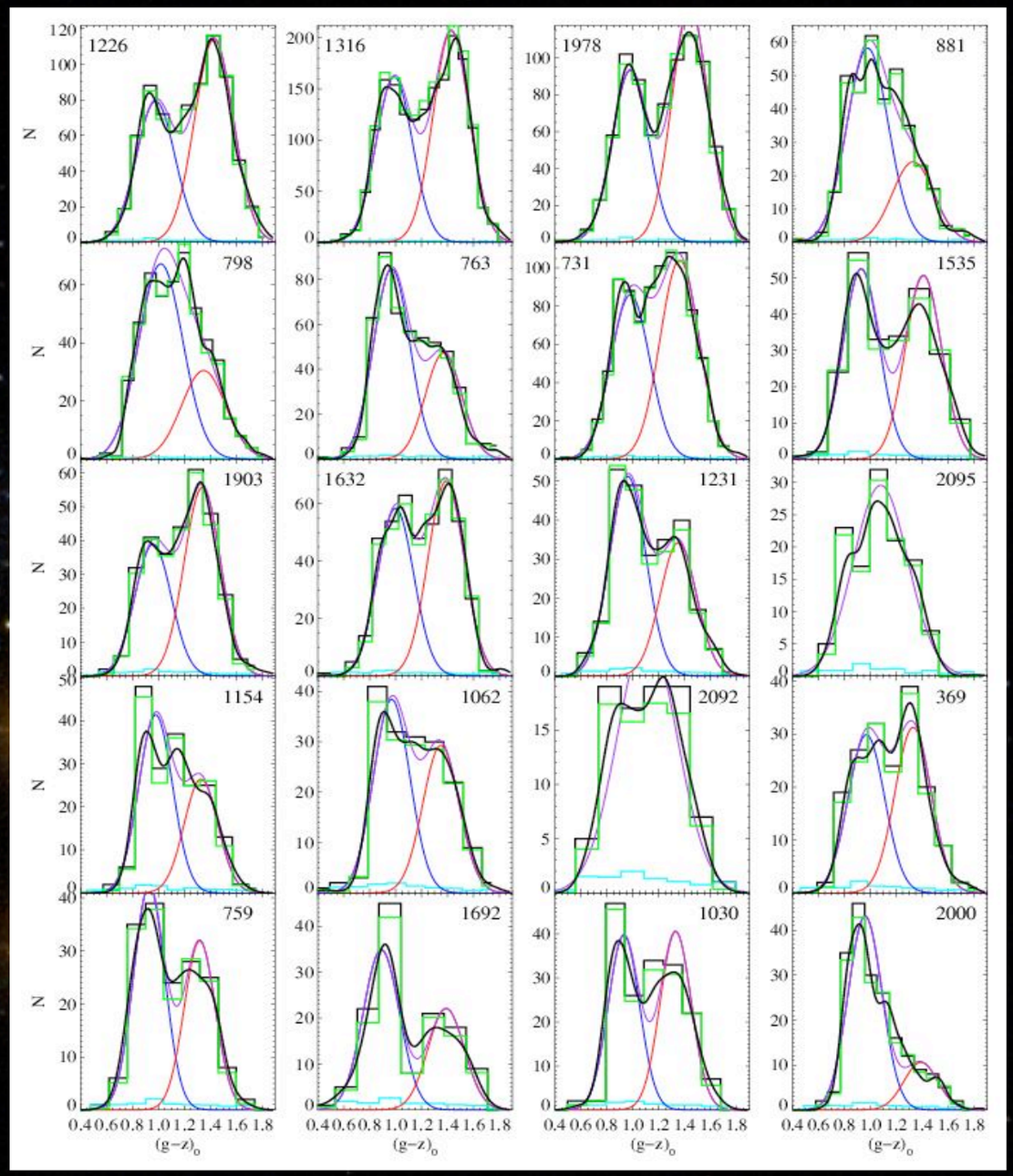

Peng et al. (2006)

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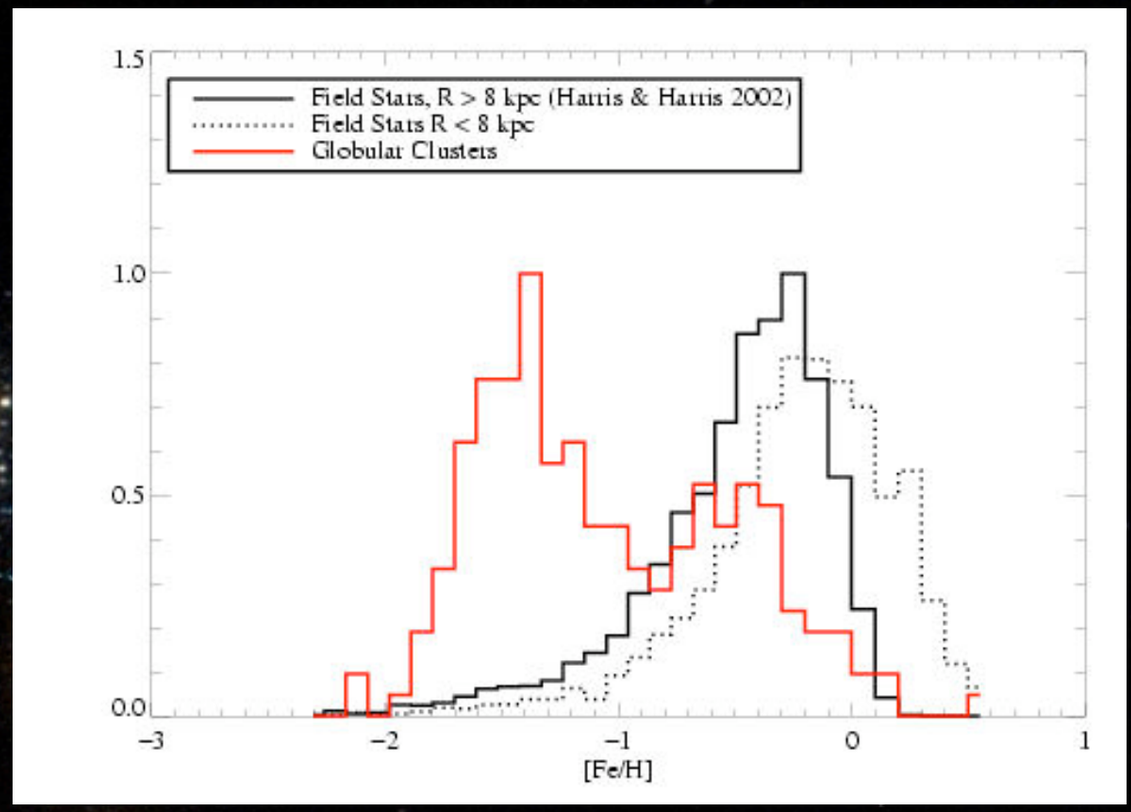

Peng et al (2004); Harris & Harris (2002)

Issue #1: Globular cluster formation efficiency is not constant across metallicity and age

Do Globular Cluster Systems Mirror Their Host Galaxies? Not really...

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)

Spirals	S_N~1
Ellipticals	S_N~5
Dwarf Ellipticals	S_N~0-30
M87	S_N~14

Issue #2: Globular cluster formation efficiency is not constant across galaxy mass and morphology

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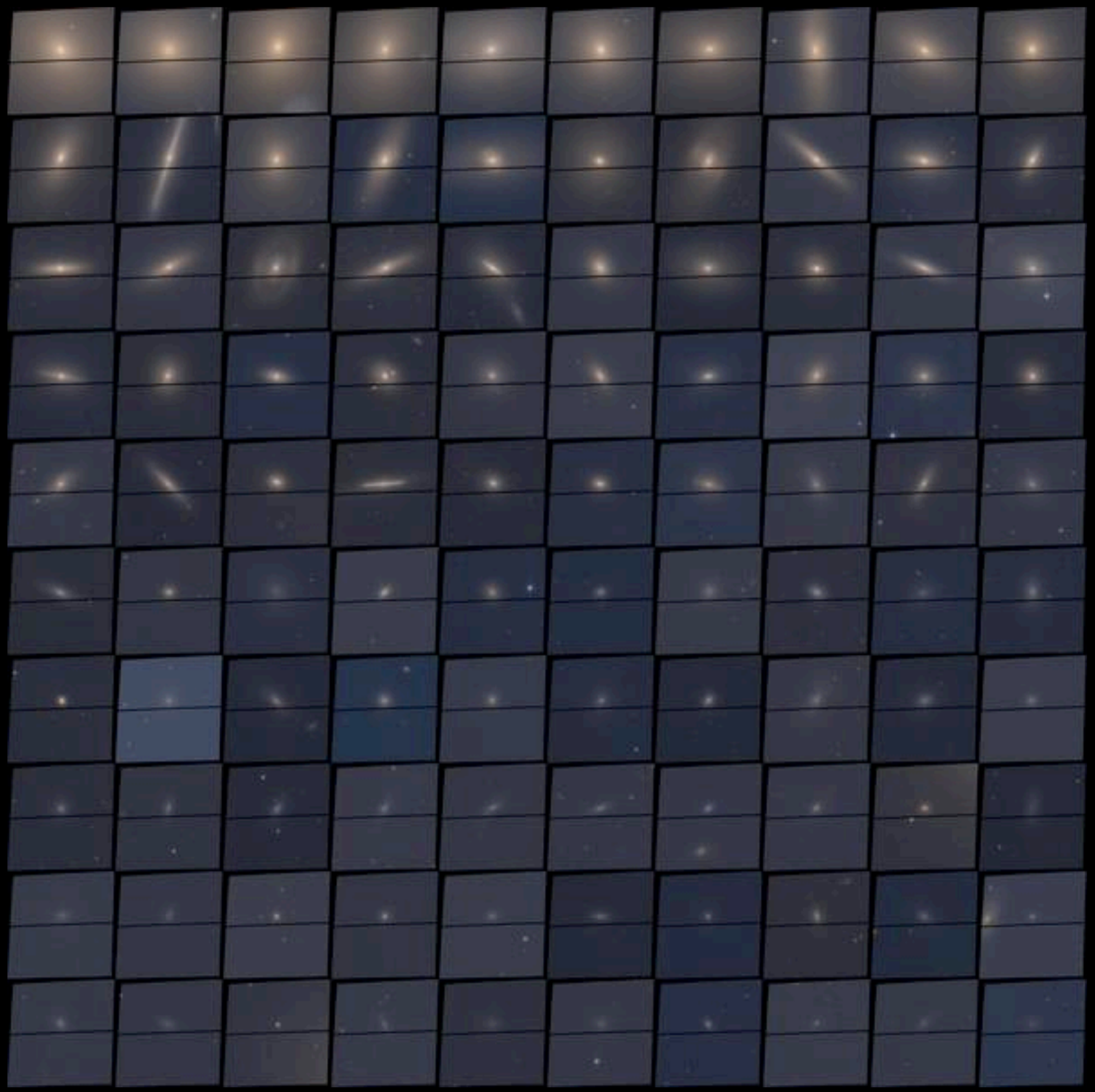
Issue #2: Globular cluster formation efficiency is not constant across galaxy mass and morphology

A problem? No! GC systems offer a unique and complementary view on galaxy formation.

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 for *GC* identification and background subtraction

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

The ACS Virgo Cluster Survey

Patrick Côté (PI: Virgo)
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Laura Ferrarese
Andrés Jordán (PI: Fornax)
Simona Mei
Eric Peng
John Tonry
Michael West

Chin-Wei Chen
Elena Dalla Bontá
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Monica Haşegan
Dean McLaughlin
Steffen Mieske

Chris Onken
Slawomir Piatek
Thomas Puzia
Marianne Takamiya
Andrew West

The ACS Virgo Cluster Survey
Data and Analysis

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- Model underlying galaxy
- Identify GC candidates
- Fit with PSF-convolved King models
- Compare with customized control fields
- Select clean sample of GCs in g and z

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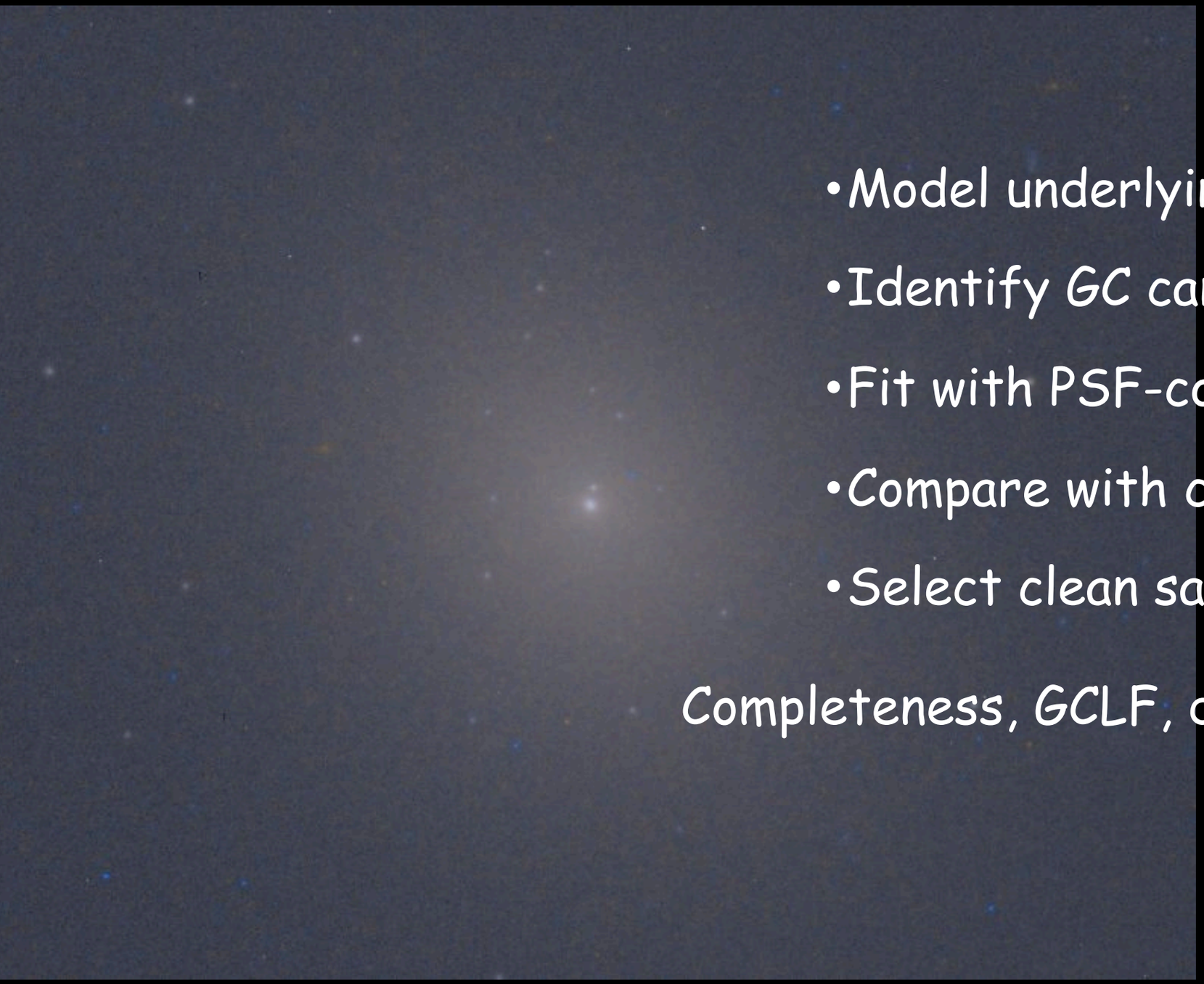

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Completeness, GCLF, distances, total magnitudes

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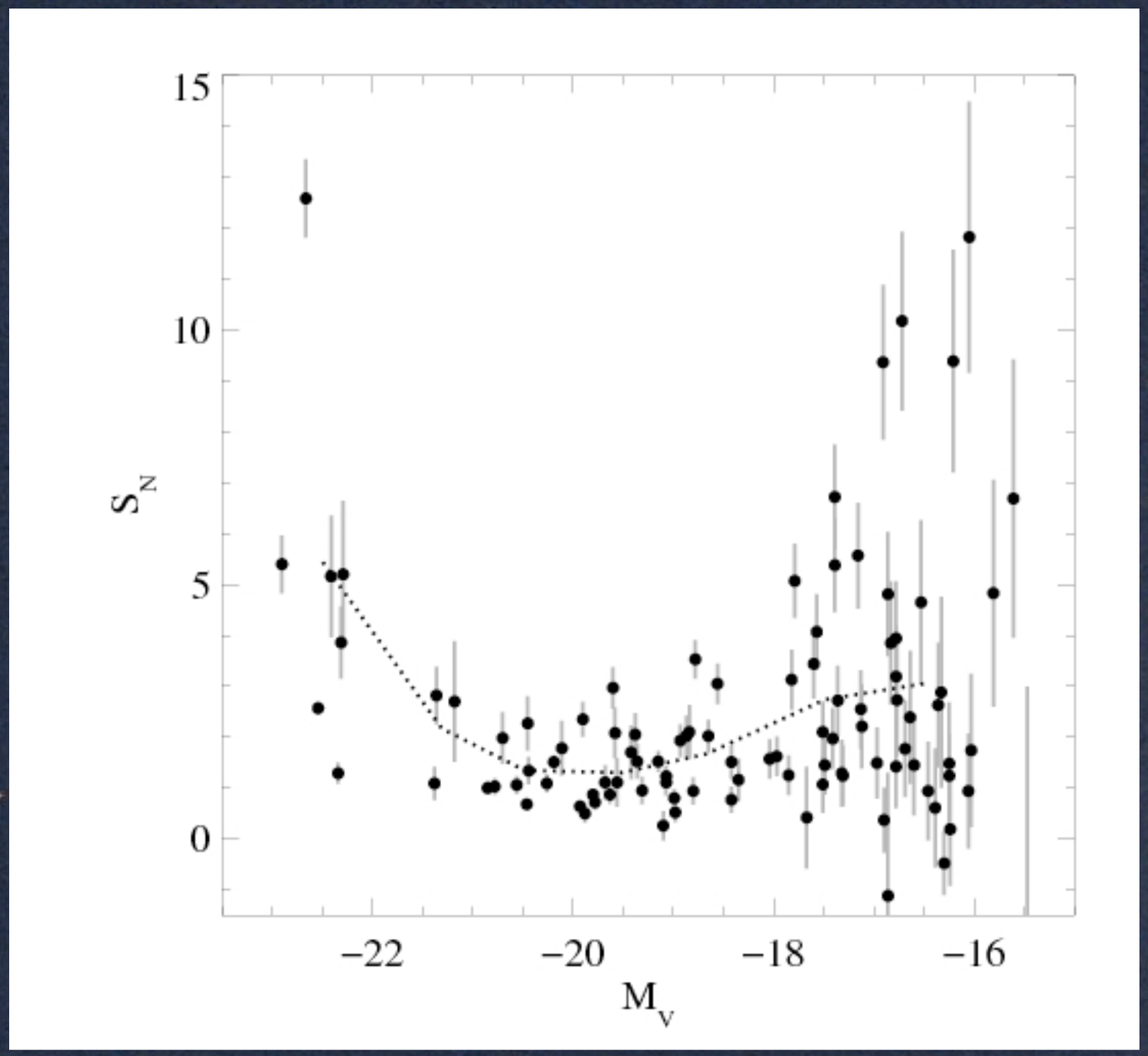
Over 11,000 GCs detected in 100 galaxies
Jordan, Peng, et al (2009)

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
- Reminiscent of M/L vs galaxy mass

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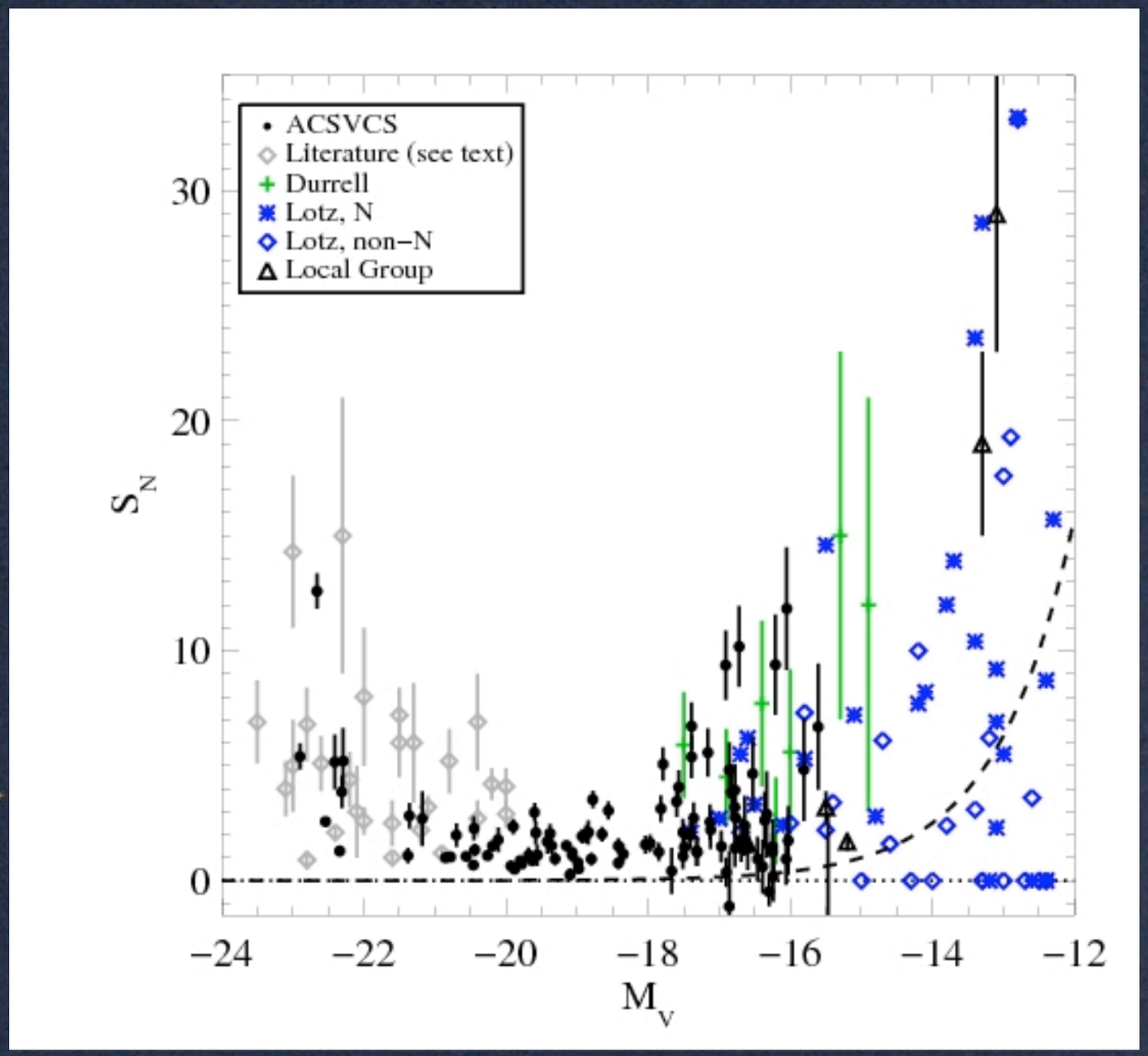

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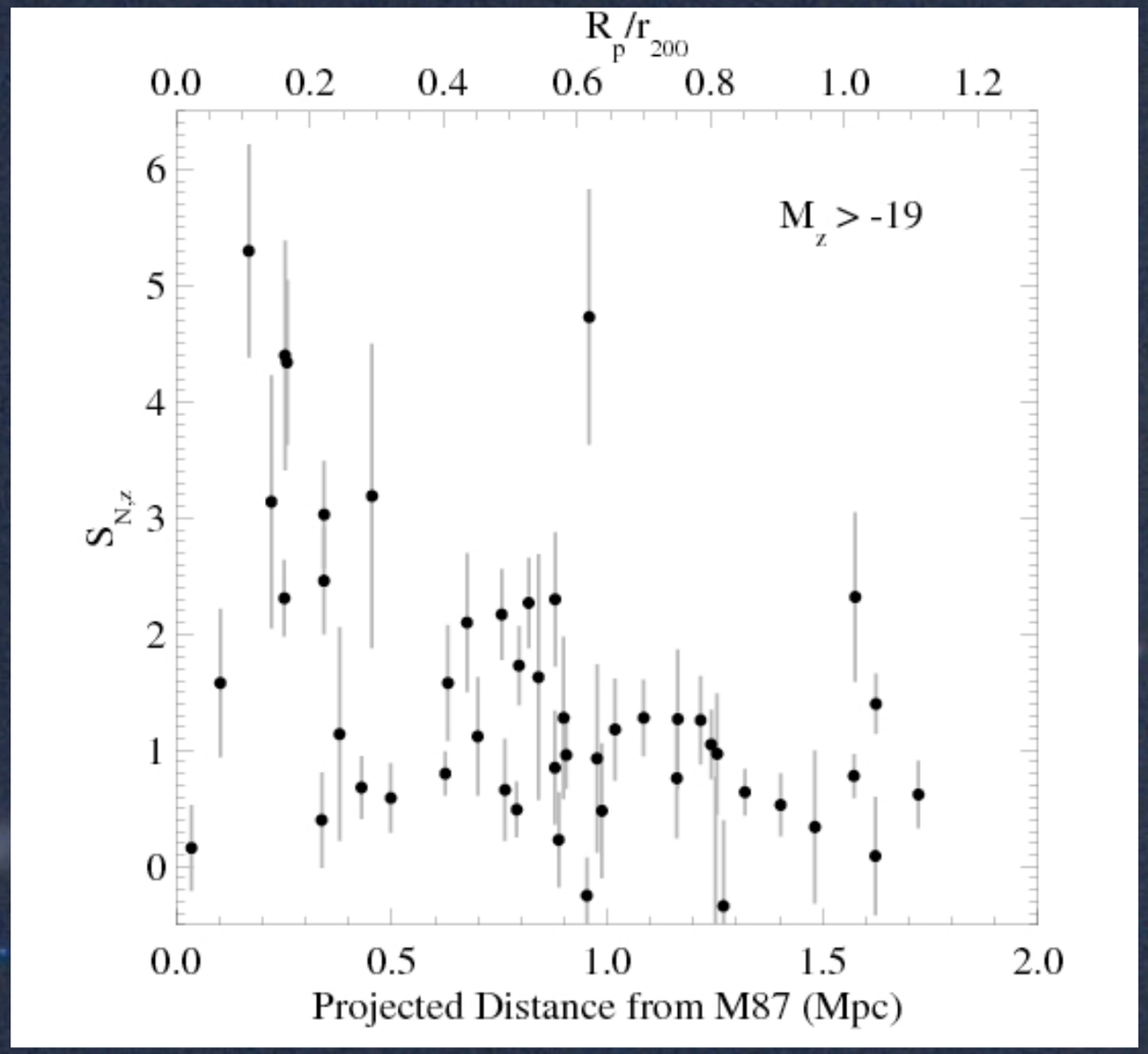
Globular Clusters in dEs: The Role of Environment



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

Peng et al. (2008)

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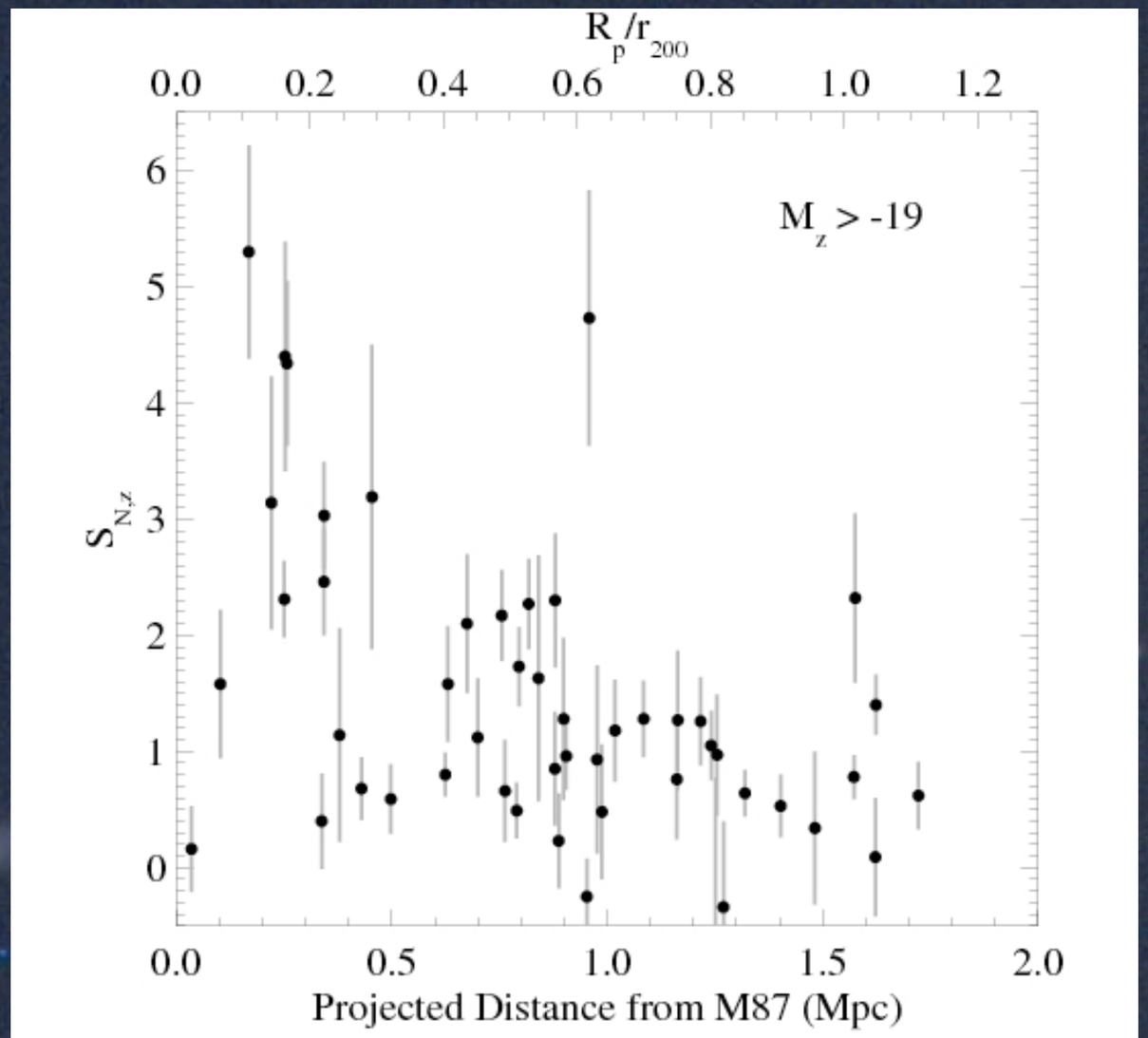

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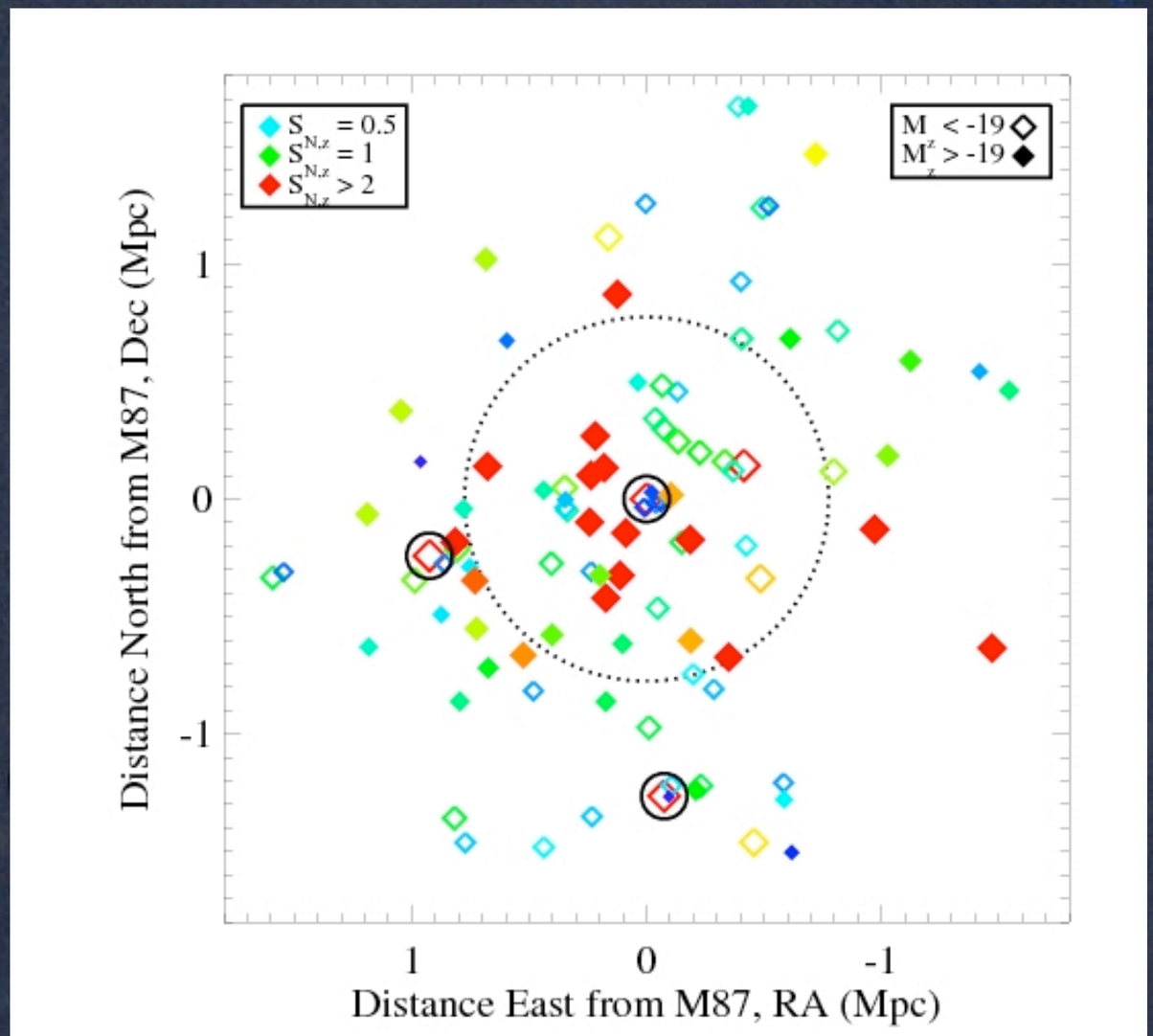

- dEs with high GC fractions are within $D_p < 1$ Mpc
- dEs within 100 kpc, stripped of GCs

Peng et al. (2008)

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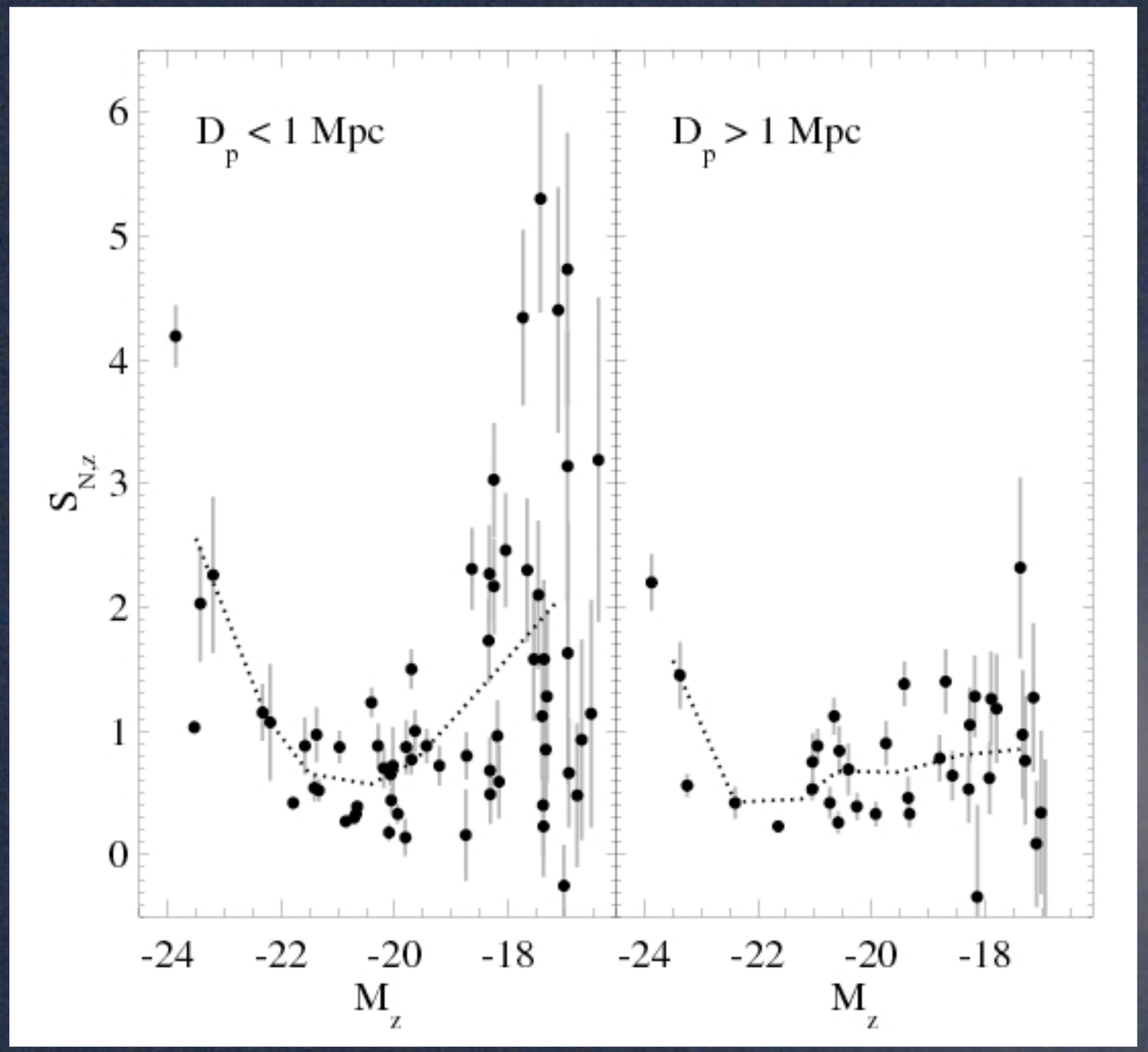
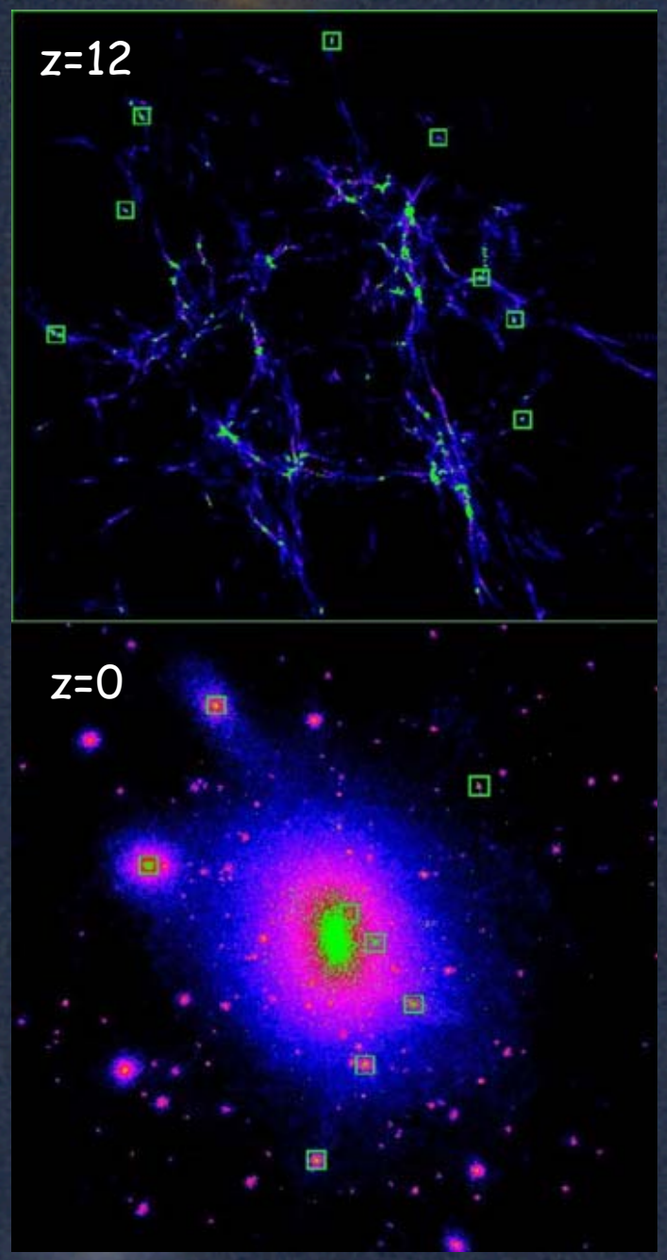


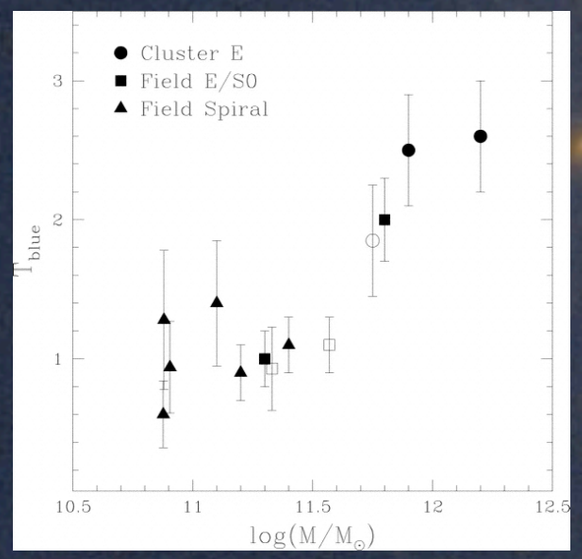
Peng et al (2008)

Implications



Moore et al (2006)

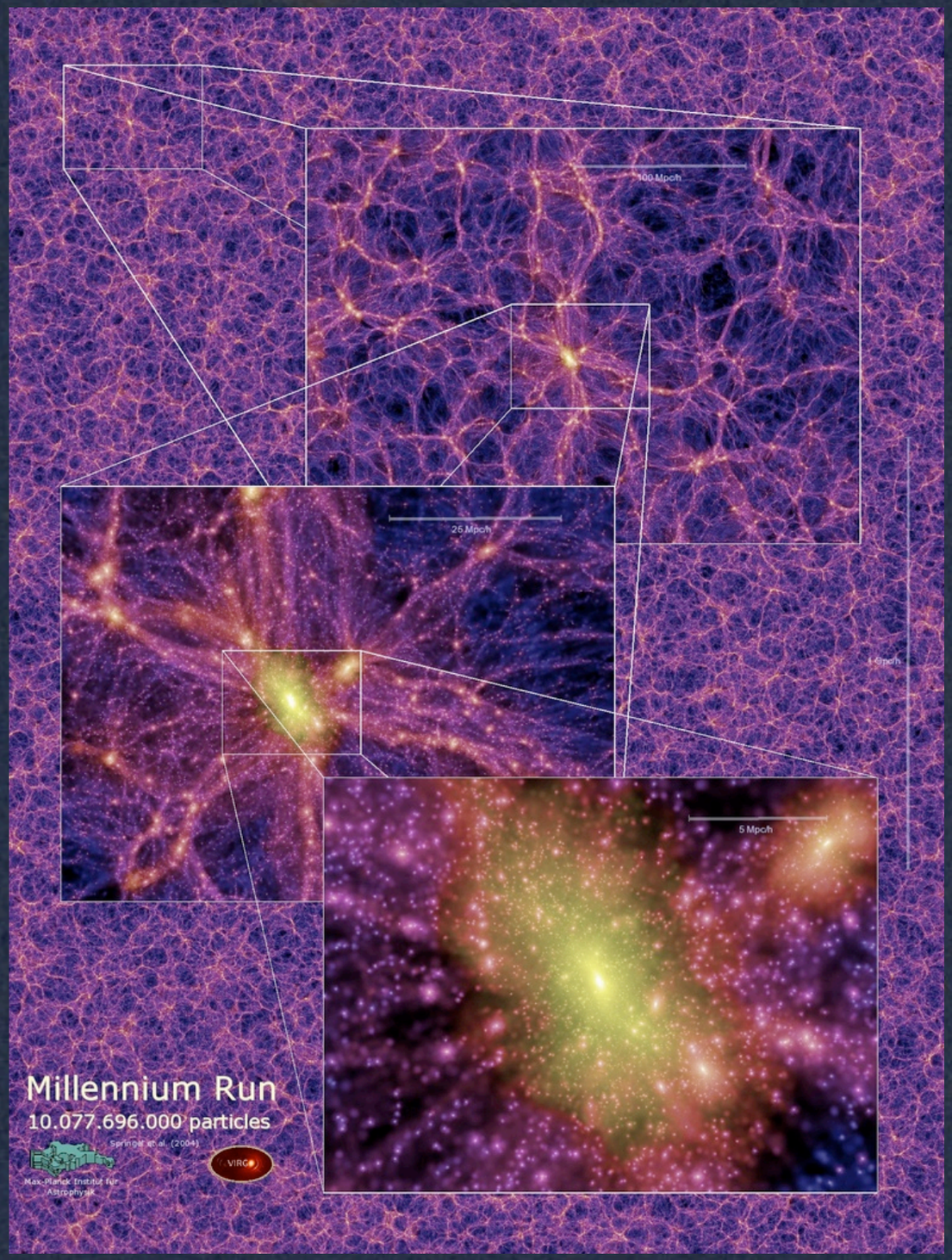
- GC formation in dEs is most efficient in dense regions (biased)
- Low mass halos in dense regions collapse earlier, and are perhaps more efficient at producing GCs
- Earliest collapsing low mass halos in densest regions could build metal-poor GC populations in giants



Rhode, Zepf & Santos 2005
also West (1993)

The Millennium Simulation

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



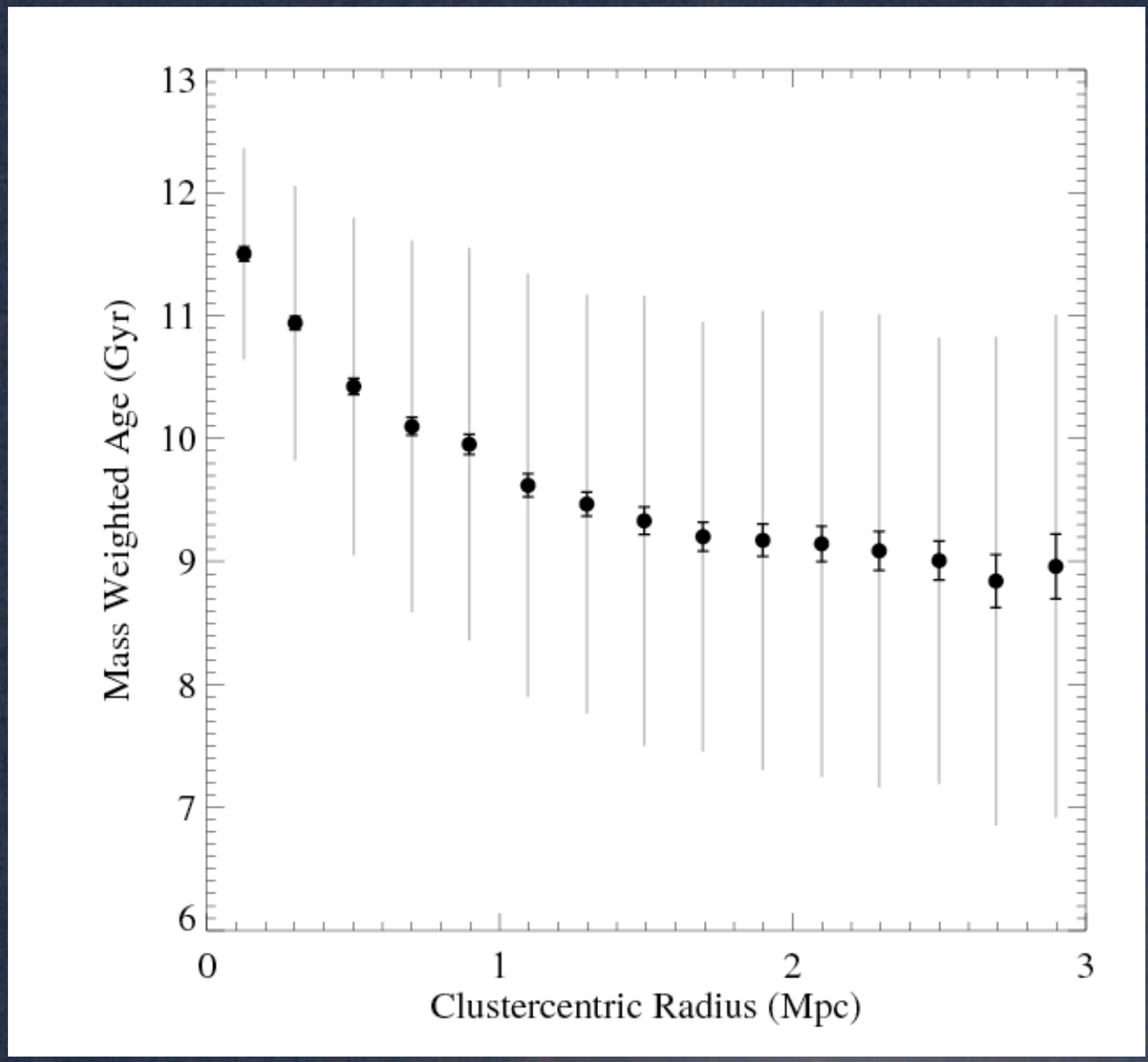
- 2160^3 dark matter particles
- 500^3 h^{-1} Mpc volume
- z=127 to present
- Galaxies with stellar mass > $3x10^8$

- 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

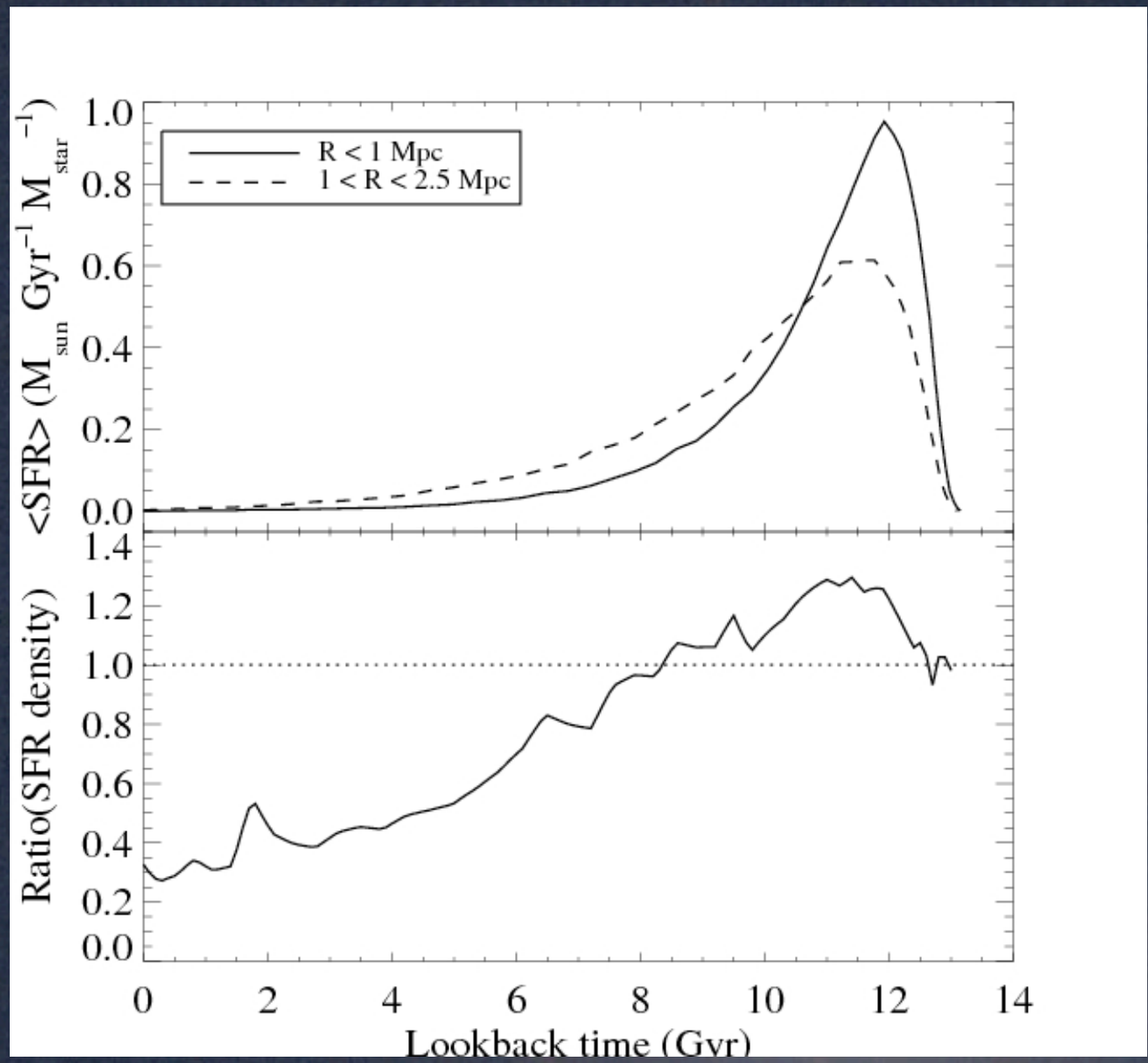
Mass-weighted age of central dEs is older



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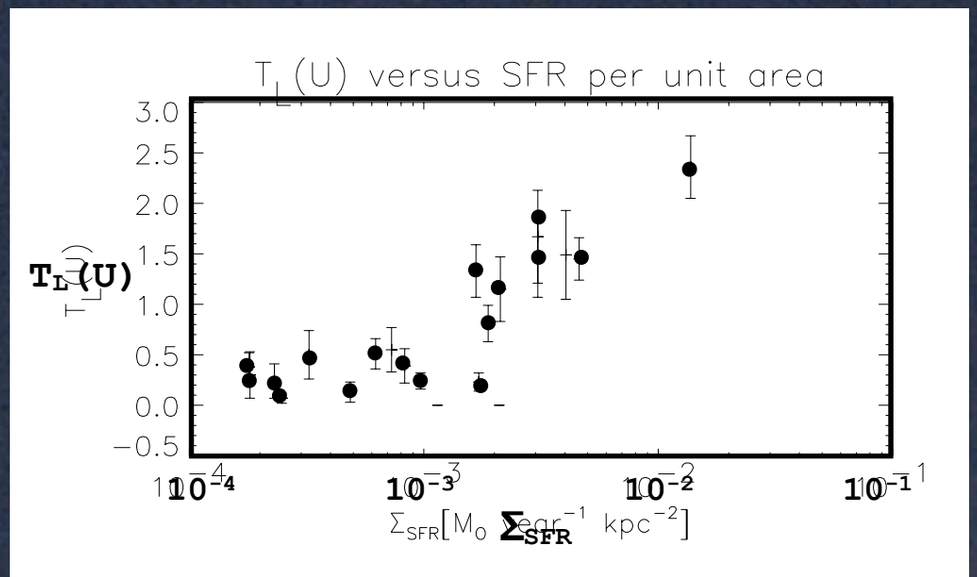
In local star forming galaxies, higher SFR surface density means a larger fraction of stellar luminosity/ mass in massive star clusters



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

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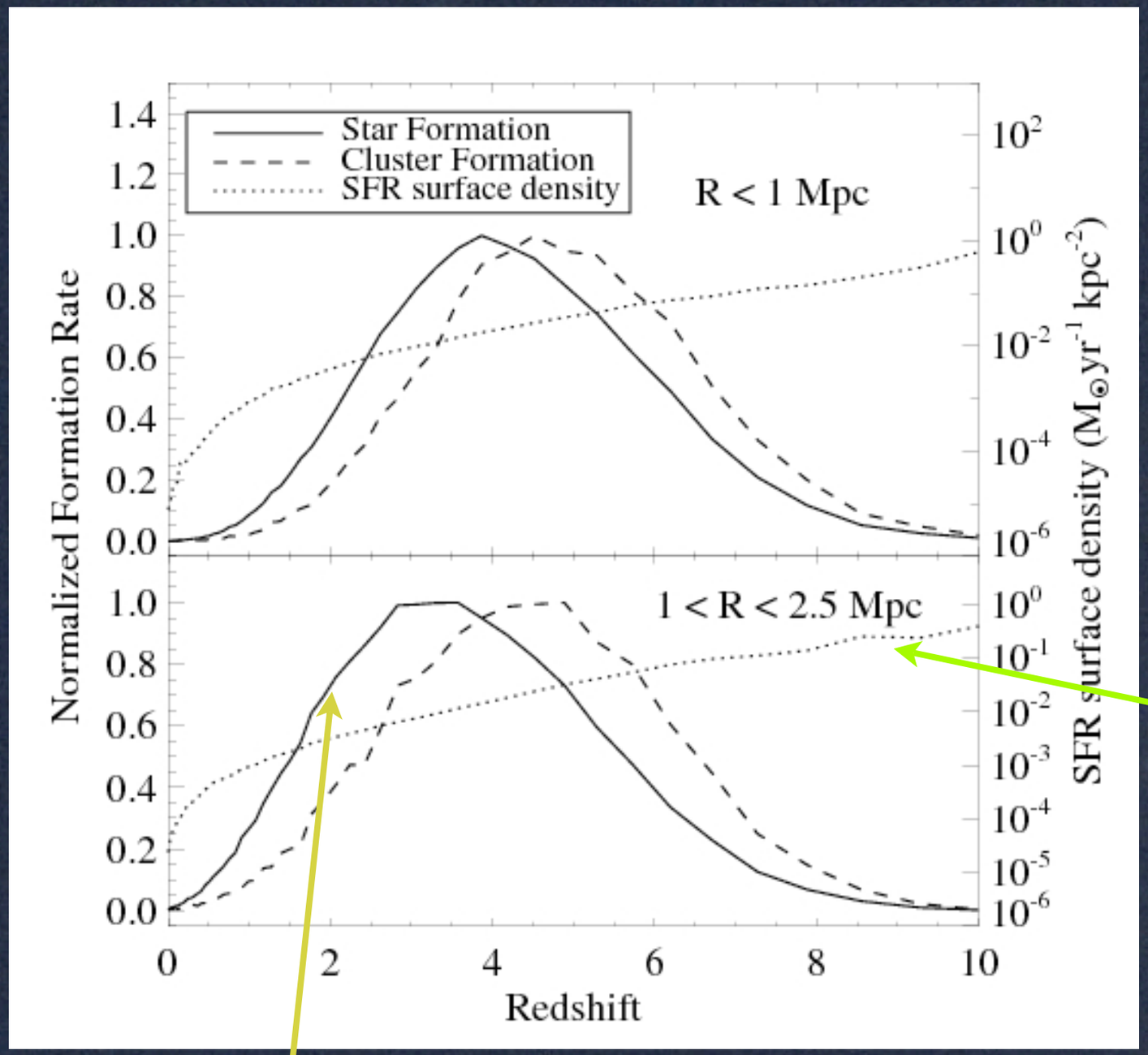
Early-type cluster dwarfs



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

SFR surface density

Star Formation Rate

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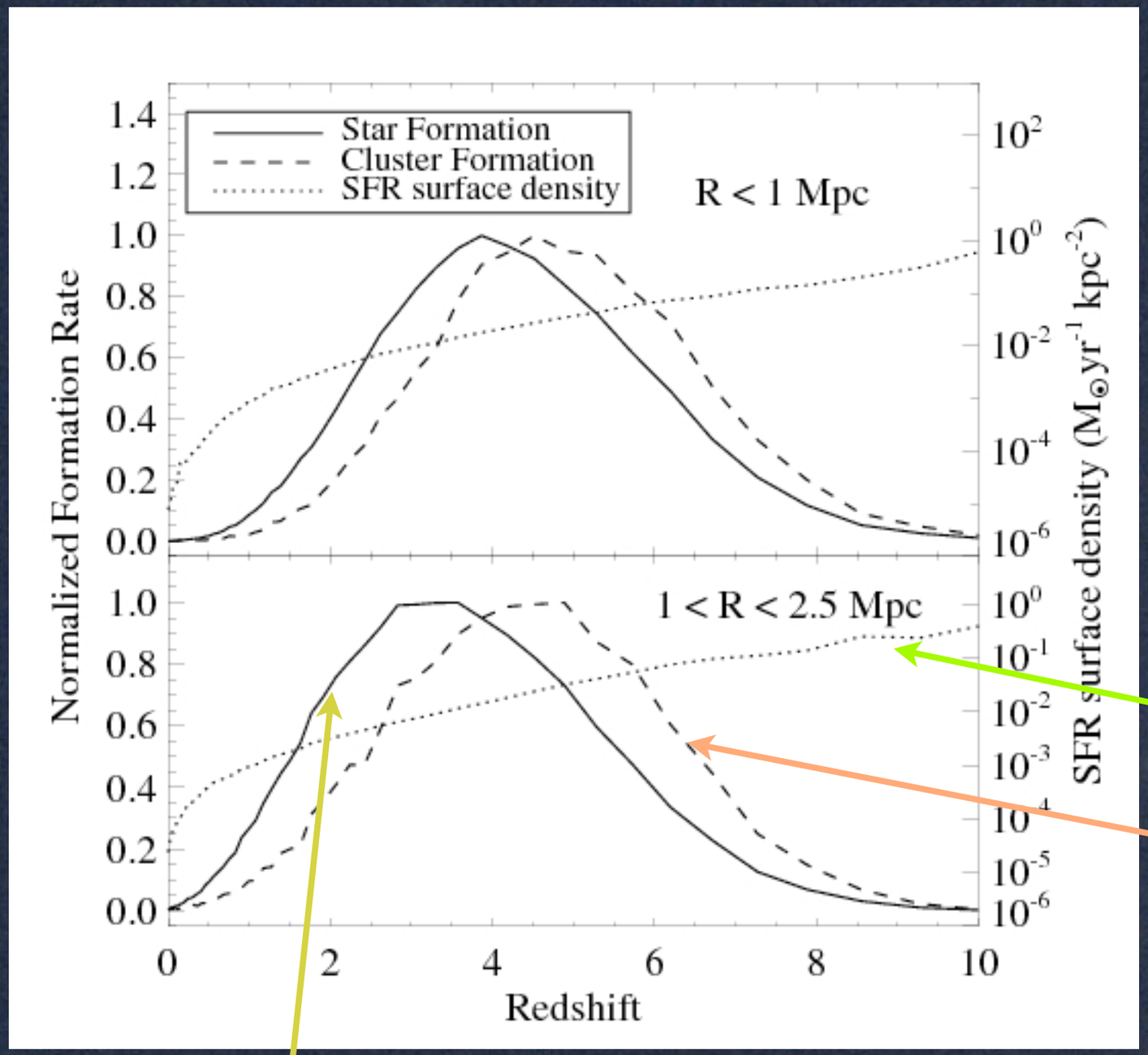

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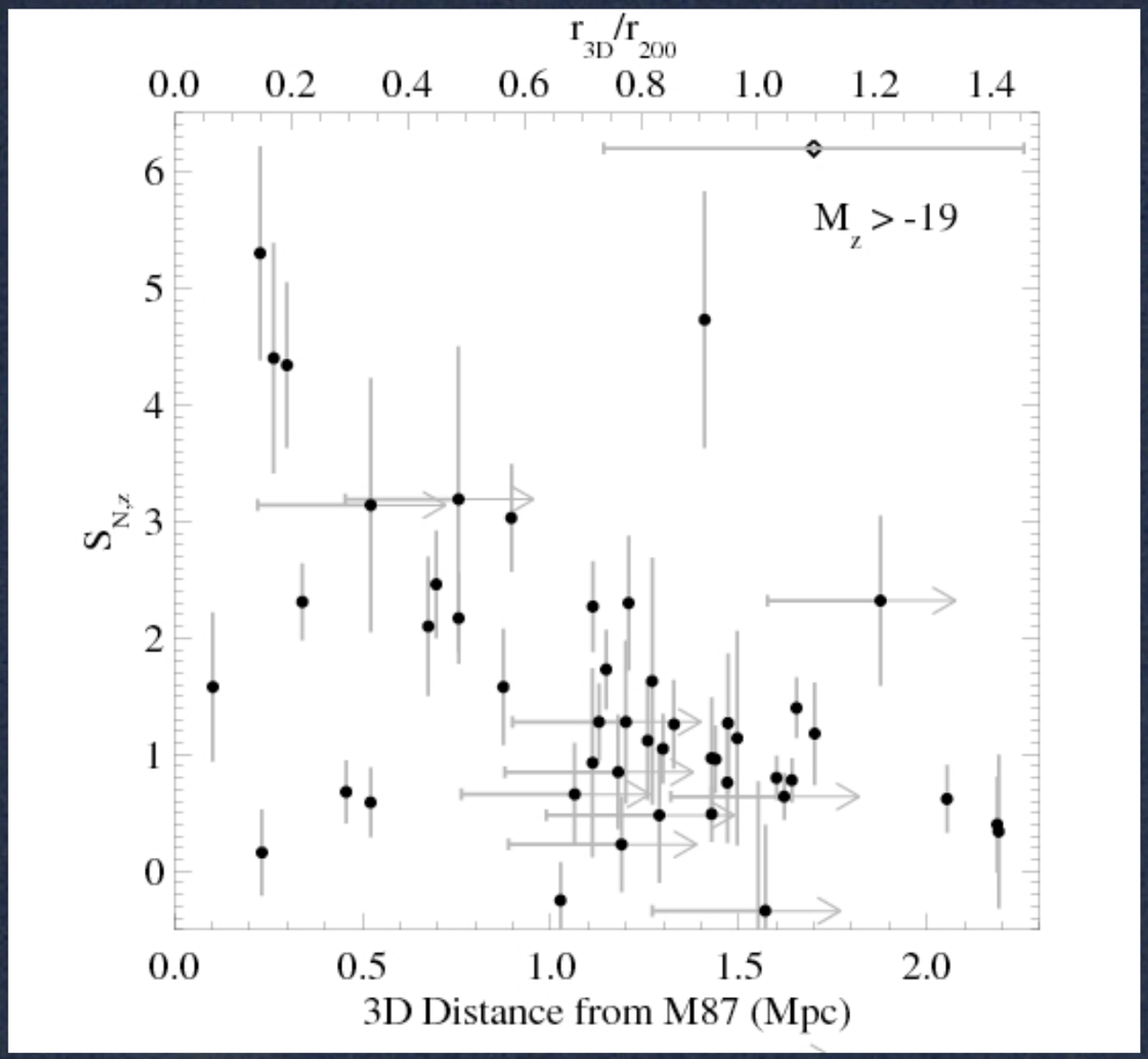

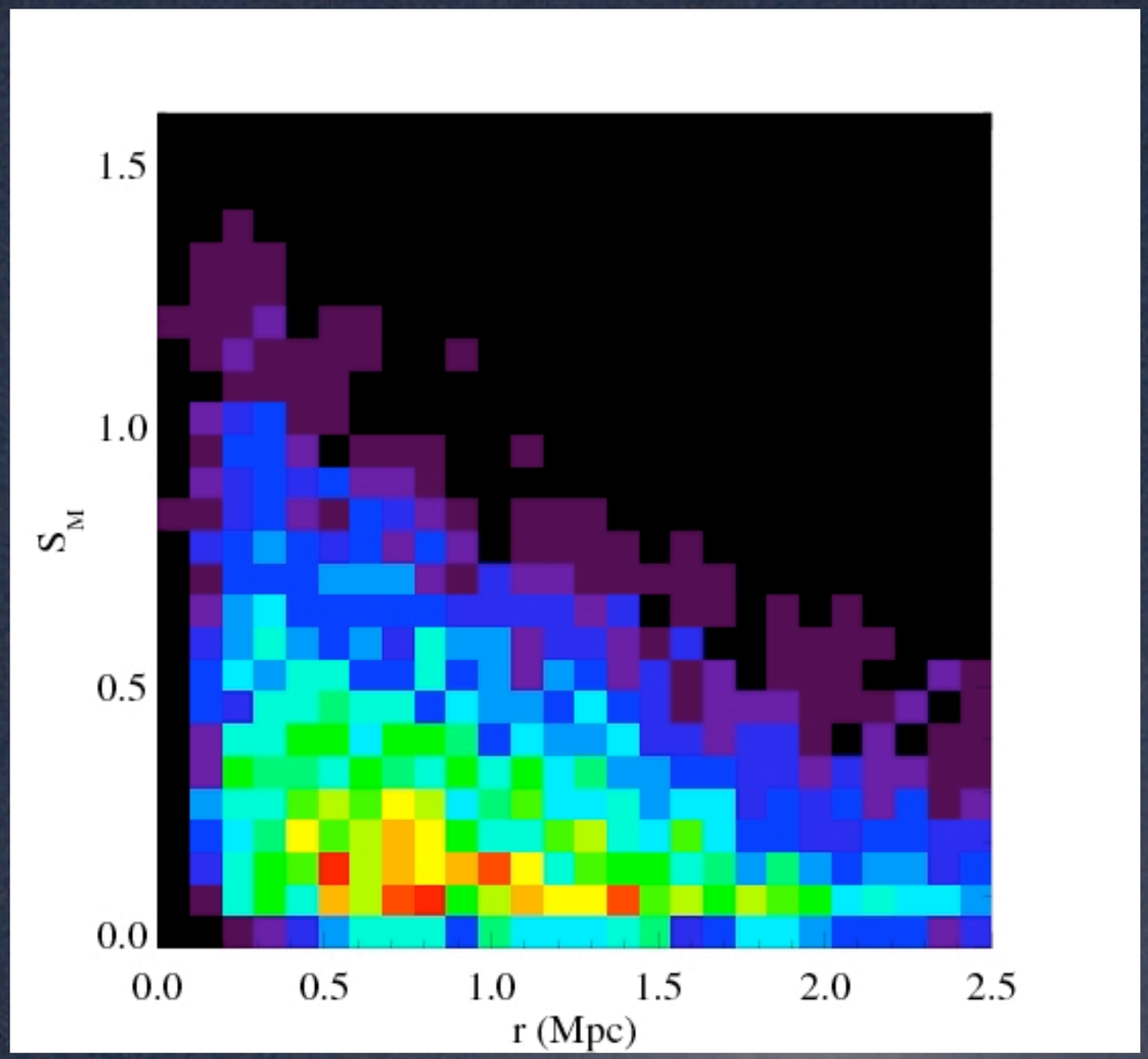

Conclusions

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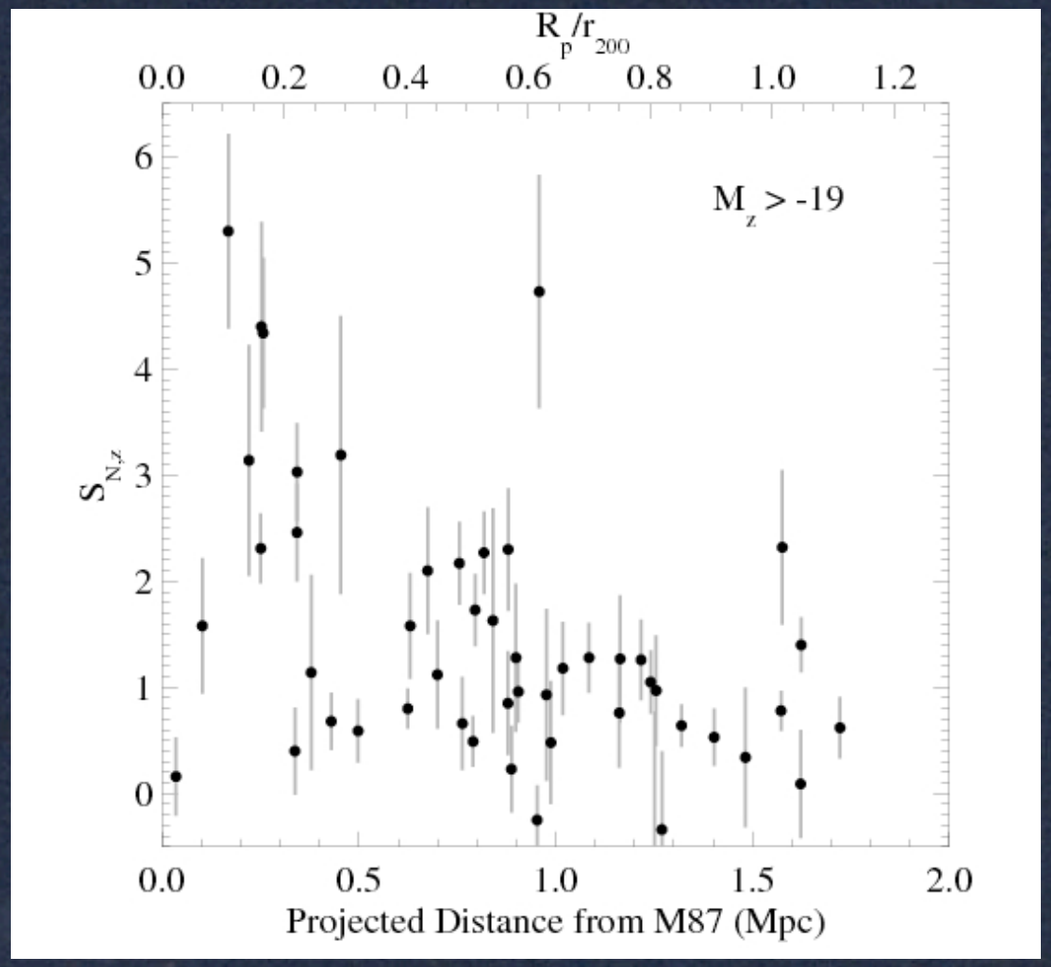

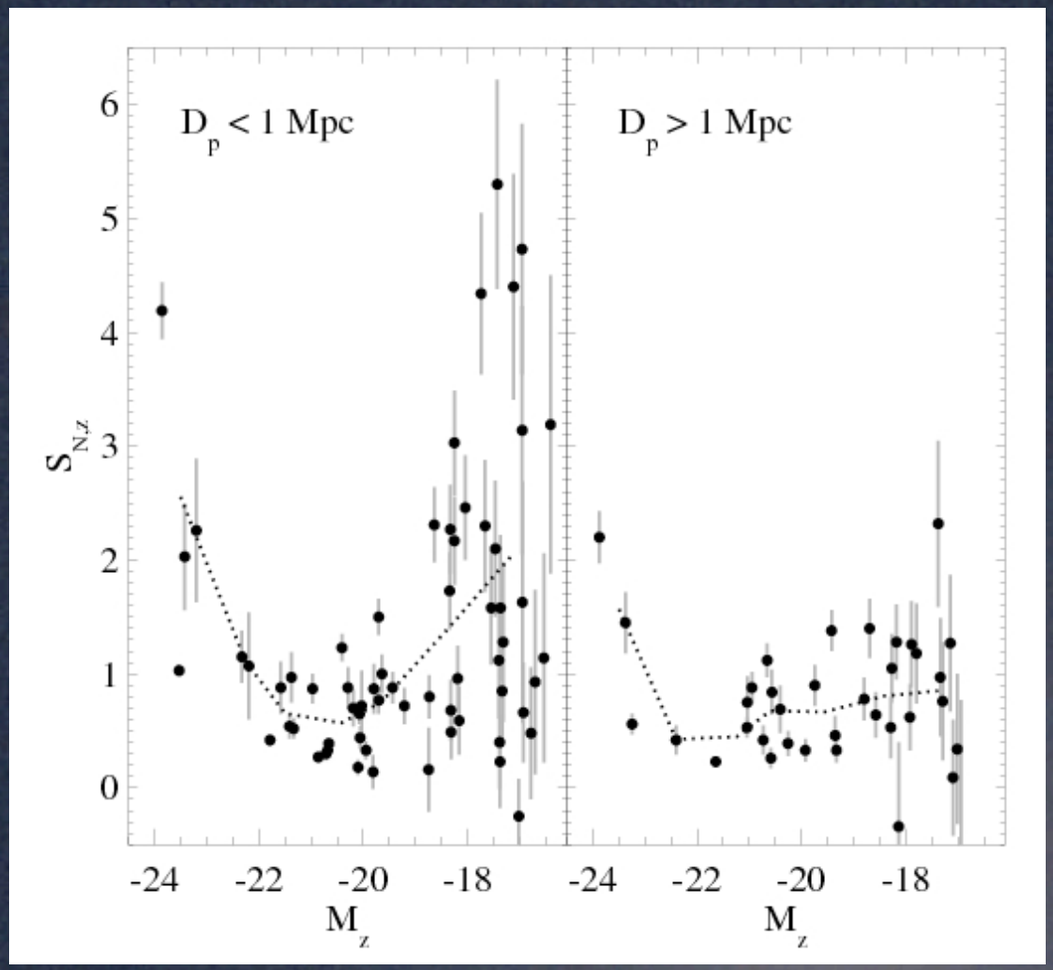

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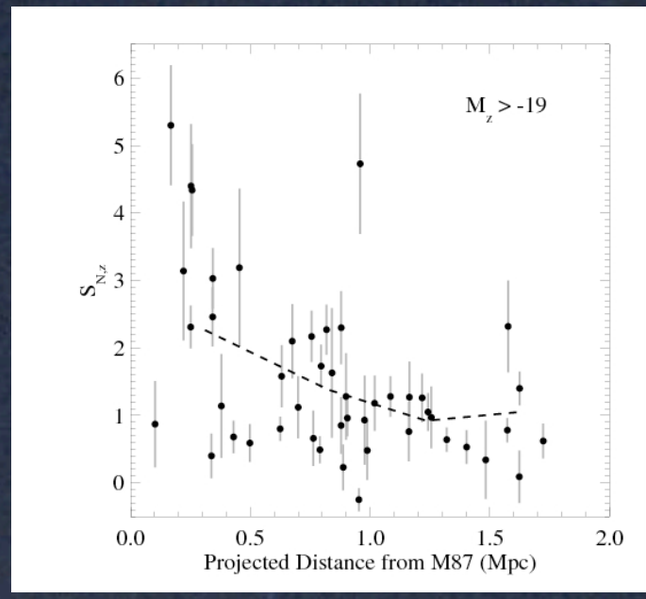

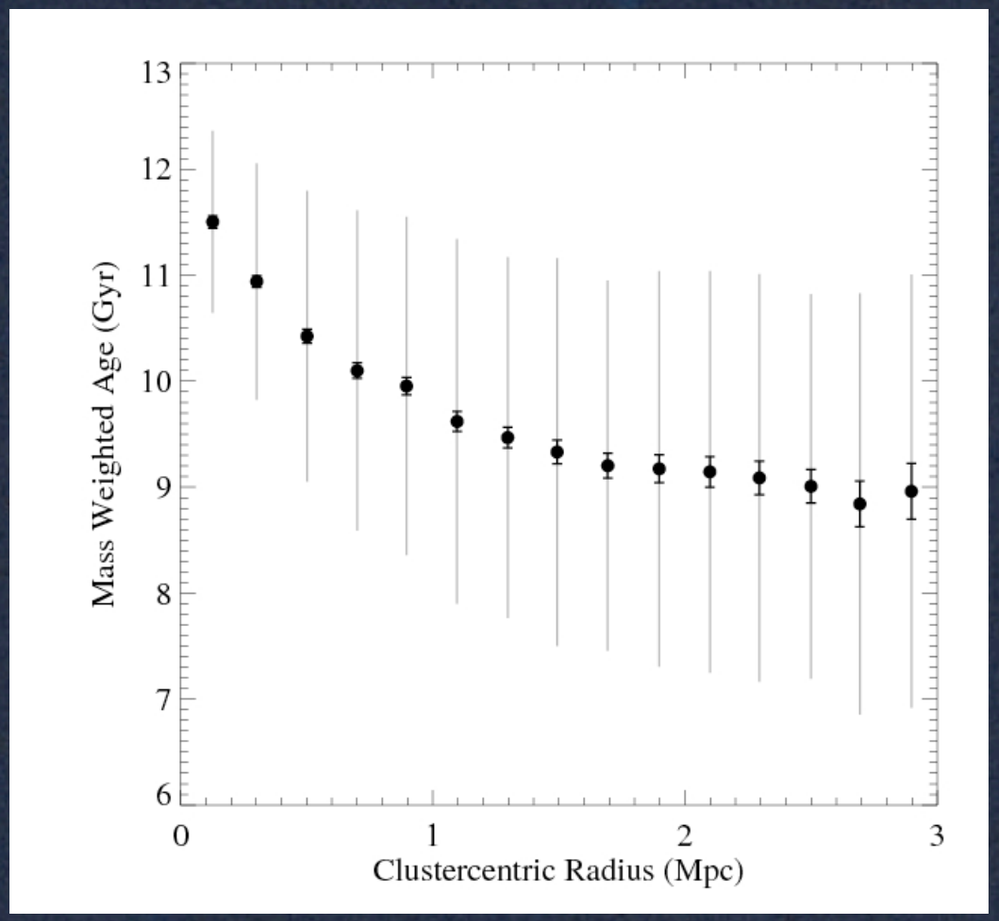

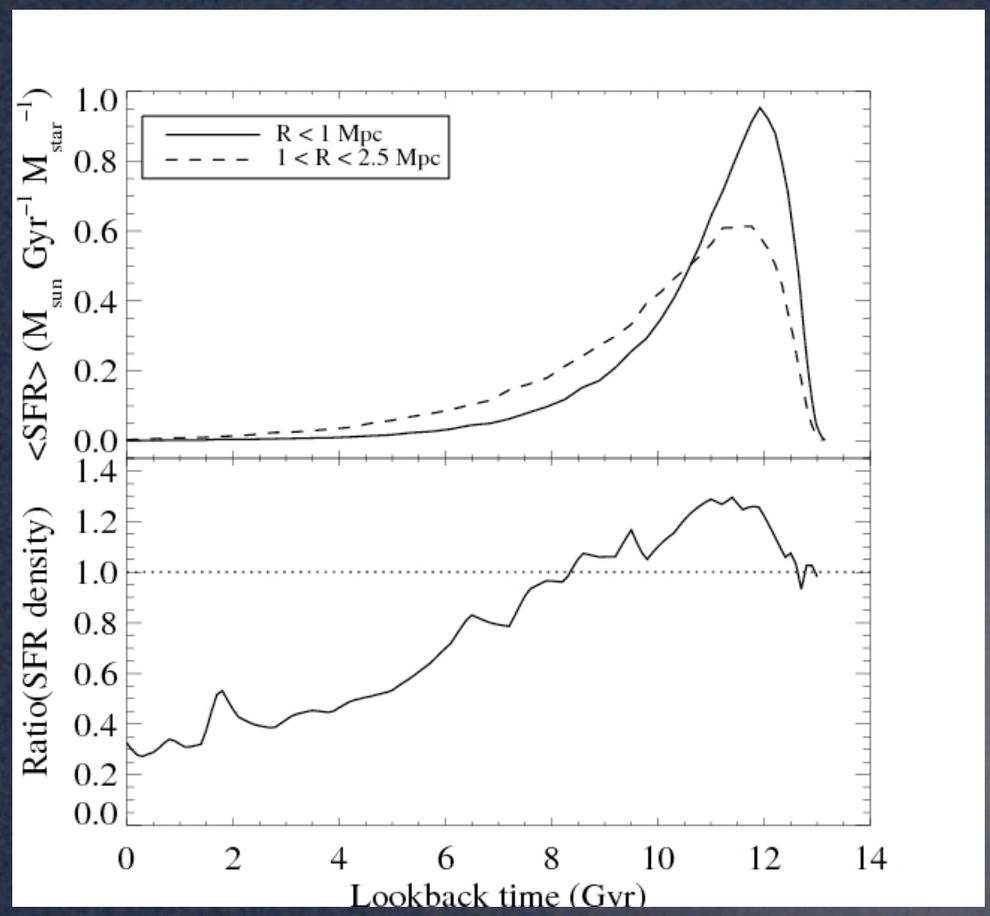

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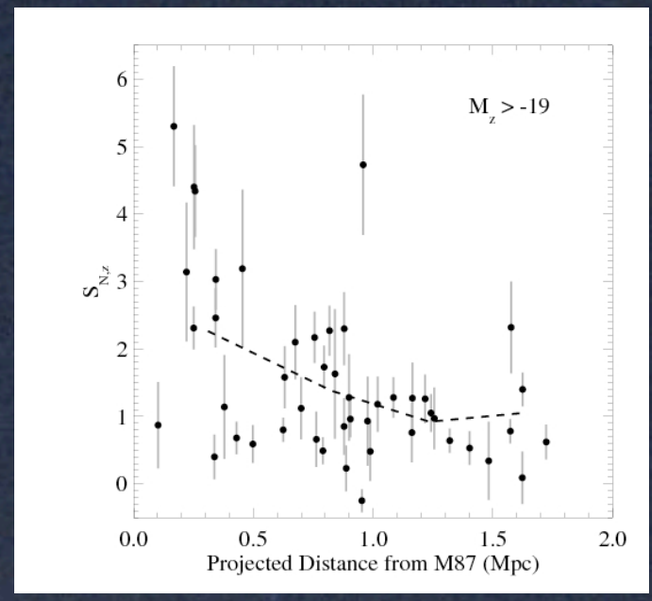

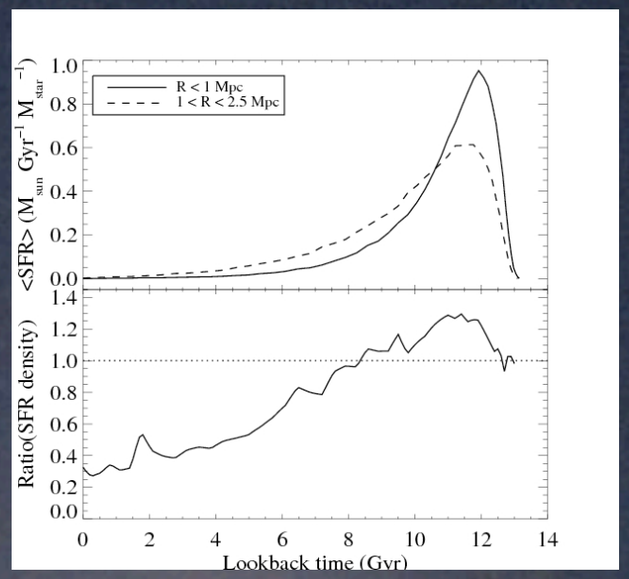

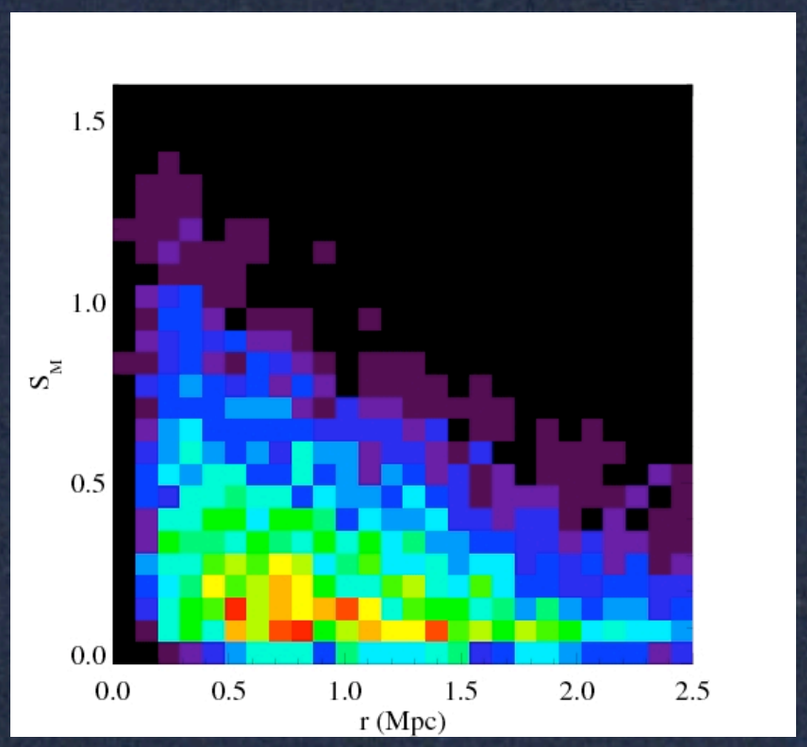

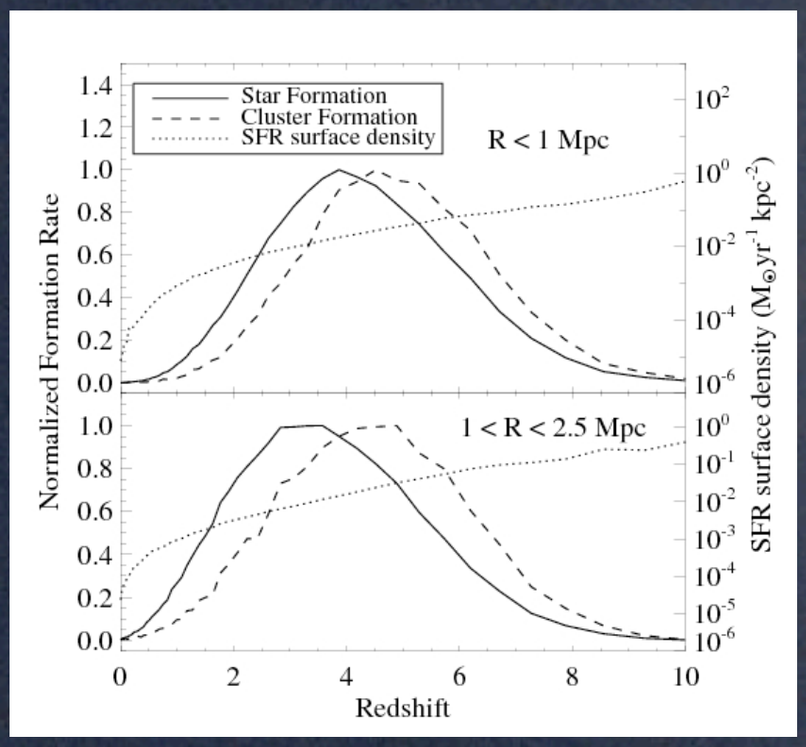

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4. GCs of innermost dEs (D<100kpc) already stripped. Central dwarfs with high GC fractions are survivors most similar to the protogalaxies that assembled the M87 GC system