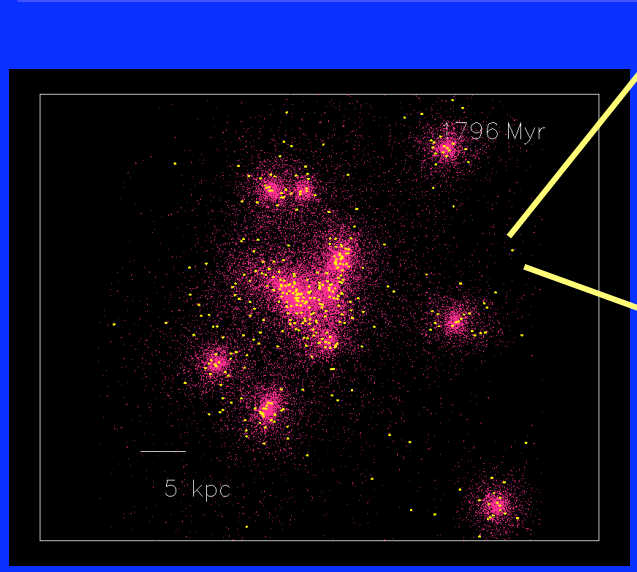
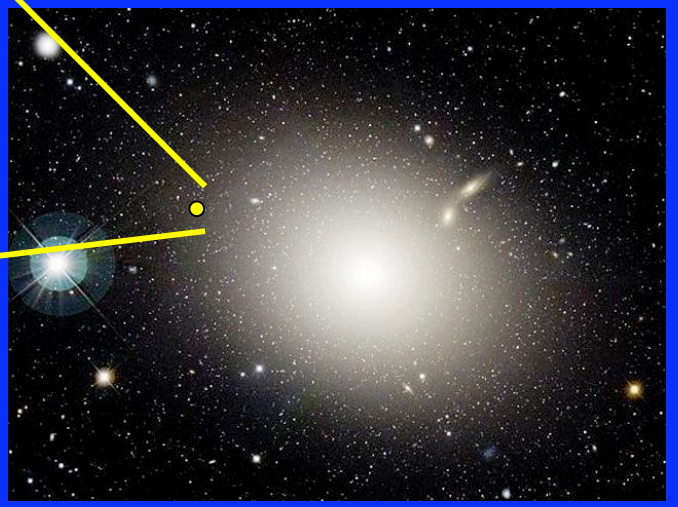
Globular Cluster – Galaxy Connections in Old Early-type Galaxies



GC



Z=10 (Simulation)

Evolution ?

Z=0 (M87)

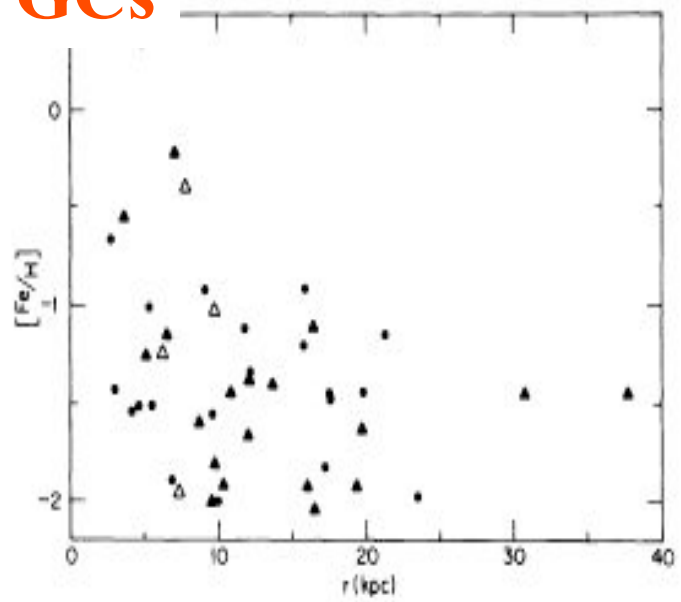
Kenji Bekki (UNSW, Australia)

Globular cluster systems (GCSs) as fossil records of galaxy formation and evolution.

(1) Possible age spread and no/little metallicity gradient of the Galactic GCS → The Galaxy formation via accretion events (e.g., Searle & Zinn 1978).

(2) GCS-host relations → GCS formation in the context of hierarchical clustering scenarios (e.g., Brodie & Strader 2006).

[Fe/H] of GCs



Distance from the Galaxy

(Searle & Zinn 1978)

What do we learn about galaxy formation and evolution ?

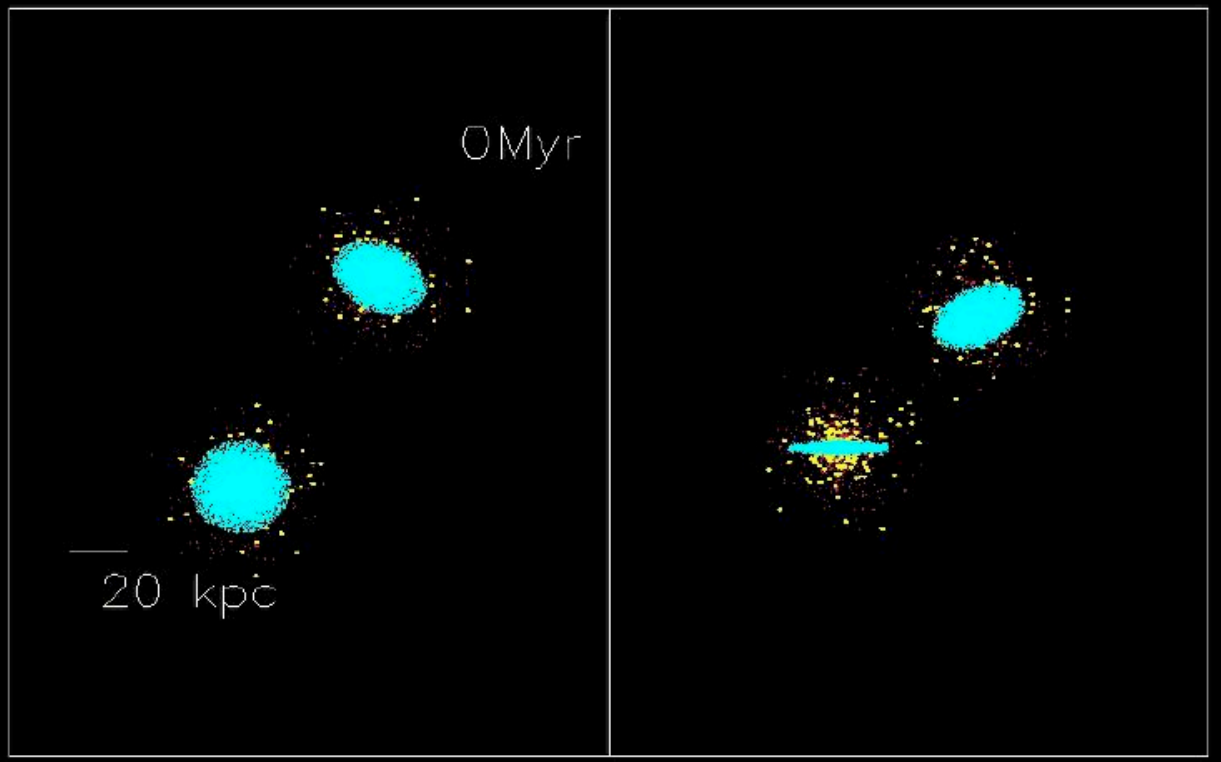
For example...

(1) Elliptical galaxies with GCSs having large V/σ → E formation via major merging ? (Bekki et al. 2005)

(2) GC streams (``GC necklaces'') in galactic halos → Galaxy growth via accretion of low-mass dwarfs (Bekki and Chiba 2004) ?

Major mergers and E formation (m_2=1.0).

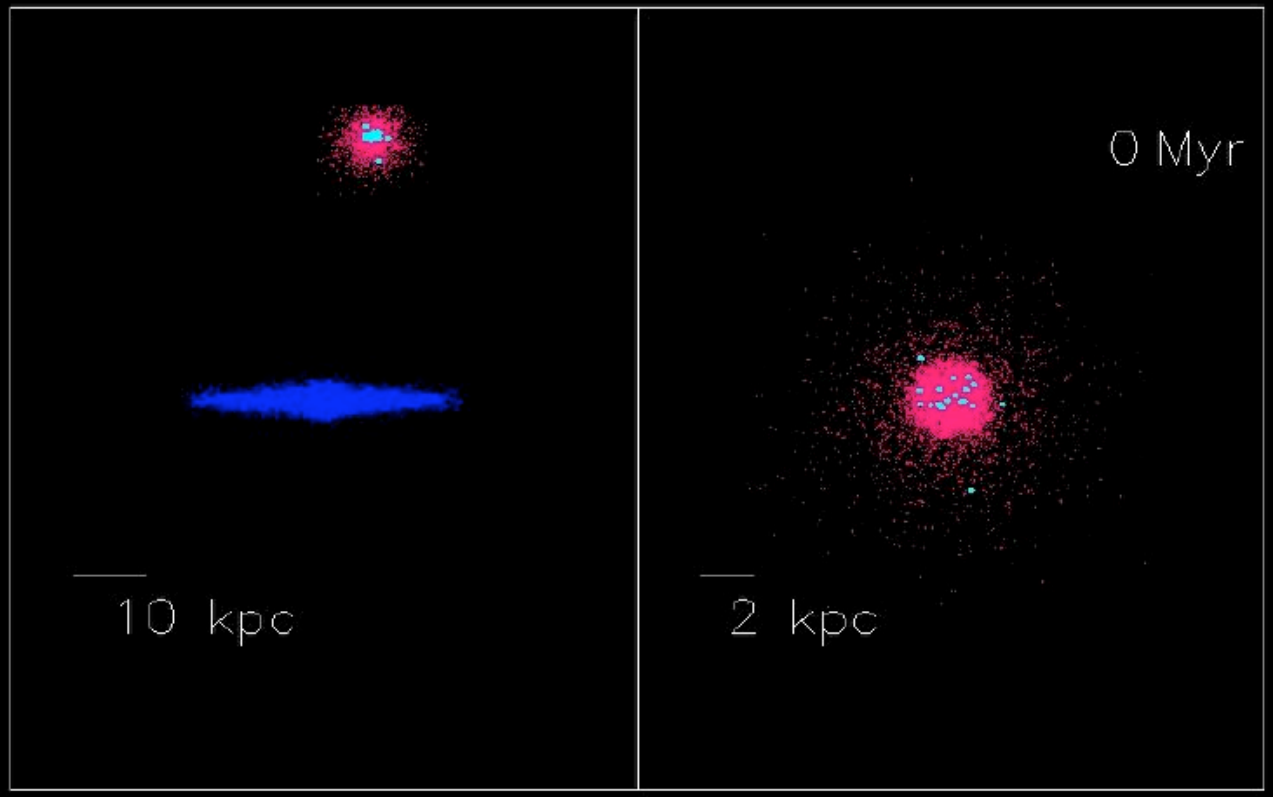
XY



XZ

GCS:V/σ=0→0.5-1

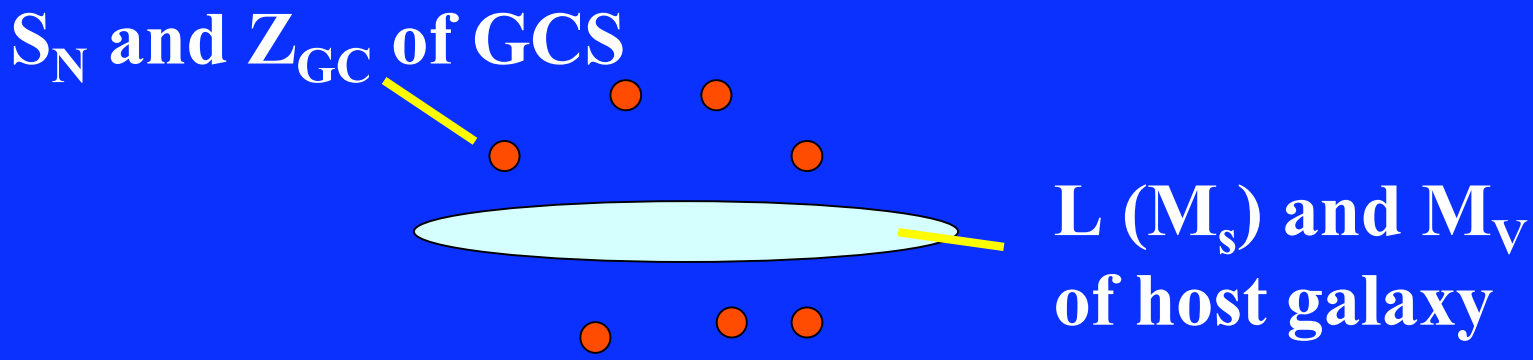
GC stripping during dE destruction (Bekki & Chiba 2004)



Larger scale **Smaller scale**

Today's topics: GCS-host relations.

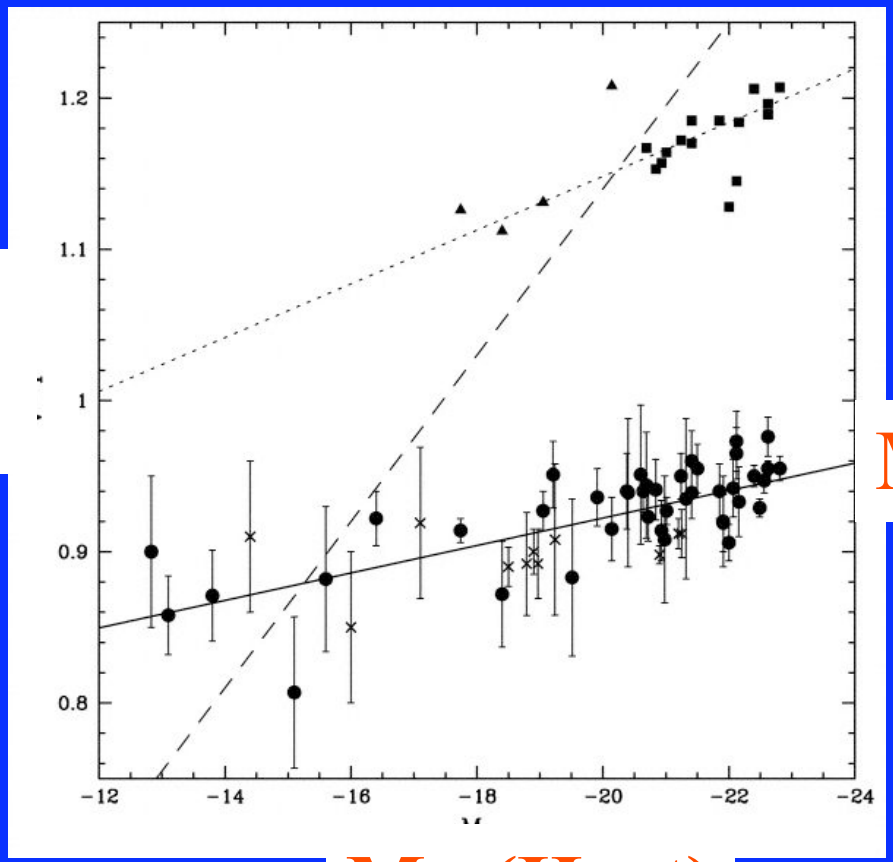
- L-Z_{GC} relation (Strader et al. 2004; Peng et al. 2006).
- S_N-M_V relation (Harris 1991; Forbes 2005).



1. L-Z_{GC} relation of metal-poor GCs (MPCs).

Redder

V-I (GCS)



MPCs

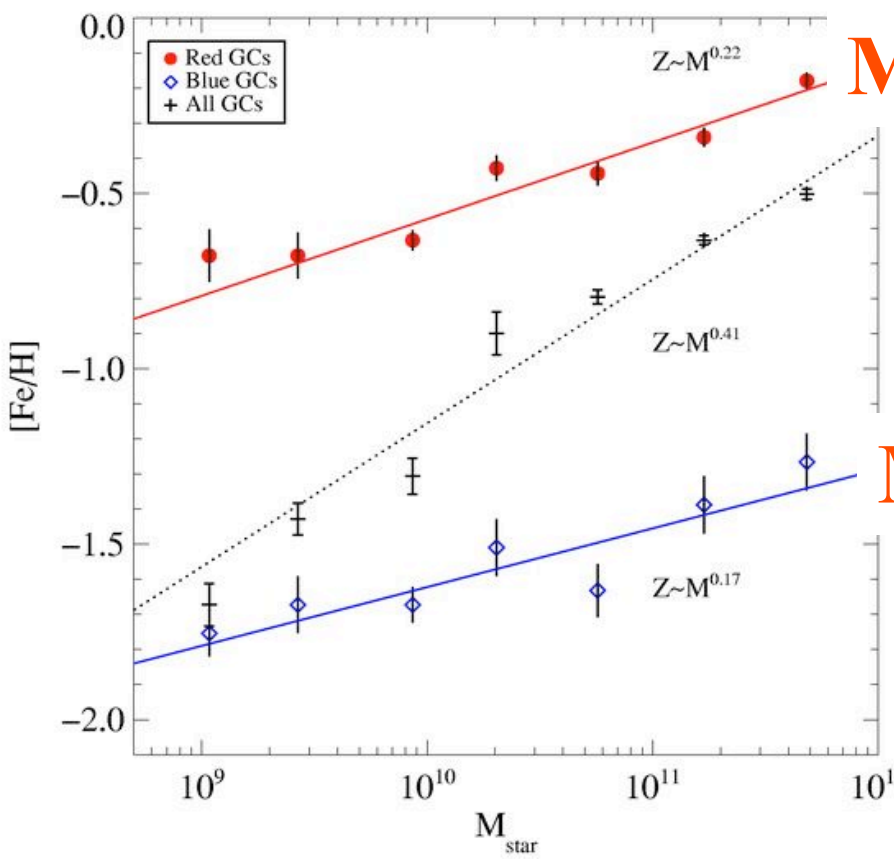
M_V (Host) → **Brighter**

(Strader et al. 2004)

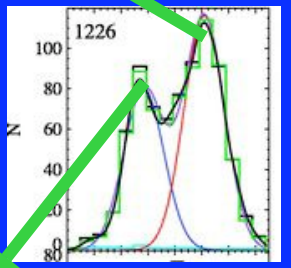
1. L-Z_{GC} relation.

More metal-rich

[Fe/H] (GCS)



MRCs

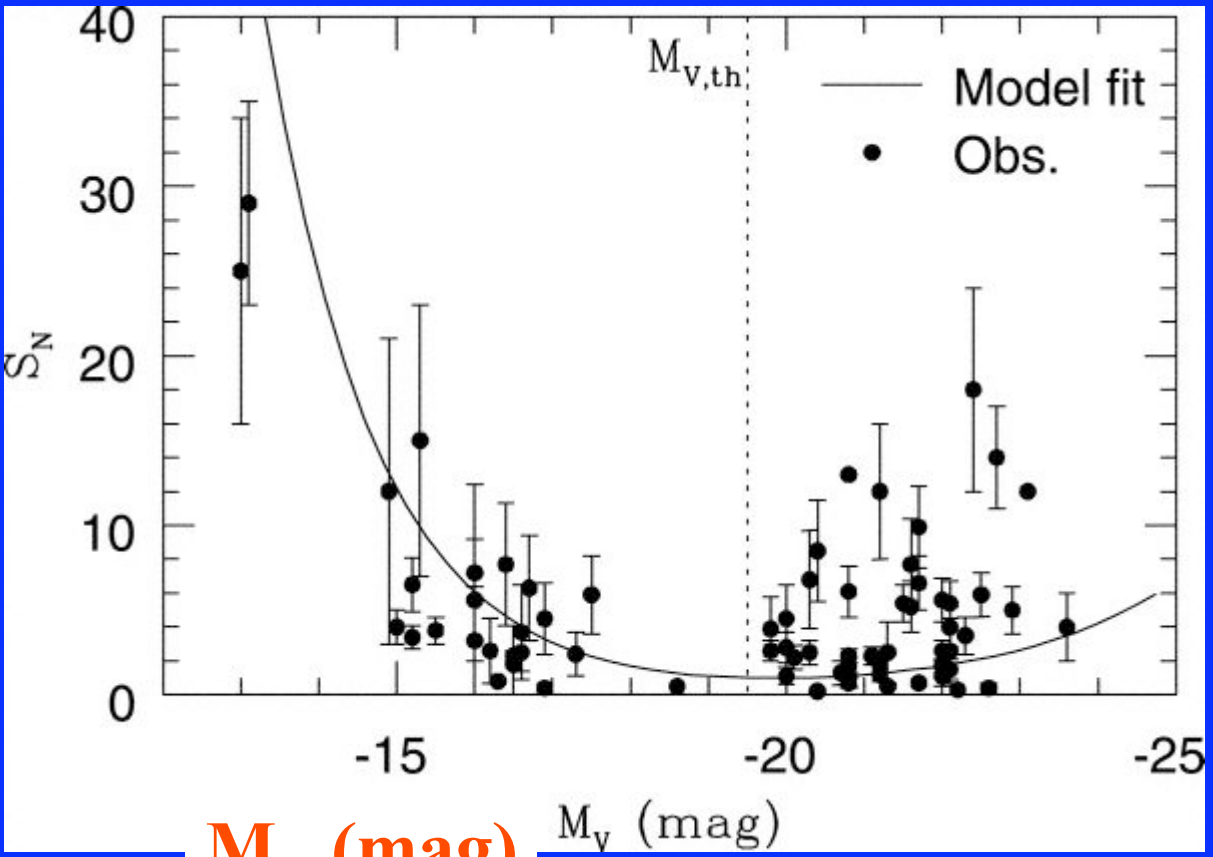


MPCs

M_s (Host) → **More massive**

(Peng et al. 2006)

2.The bimodality in the M_V-dependence of S_N in galaxies.



S_N

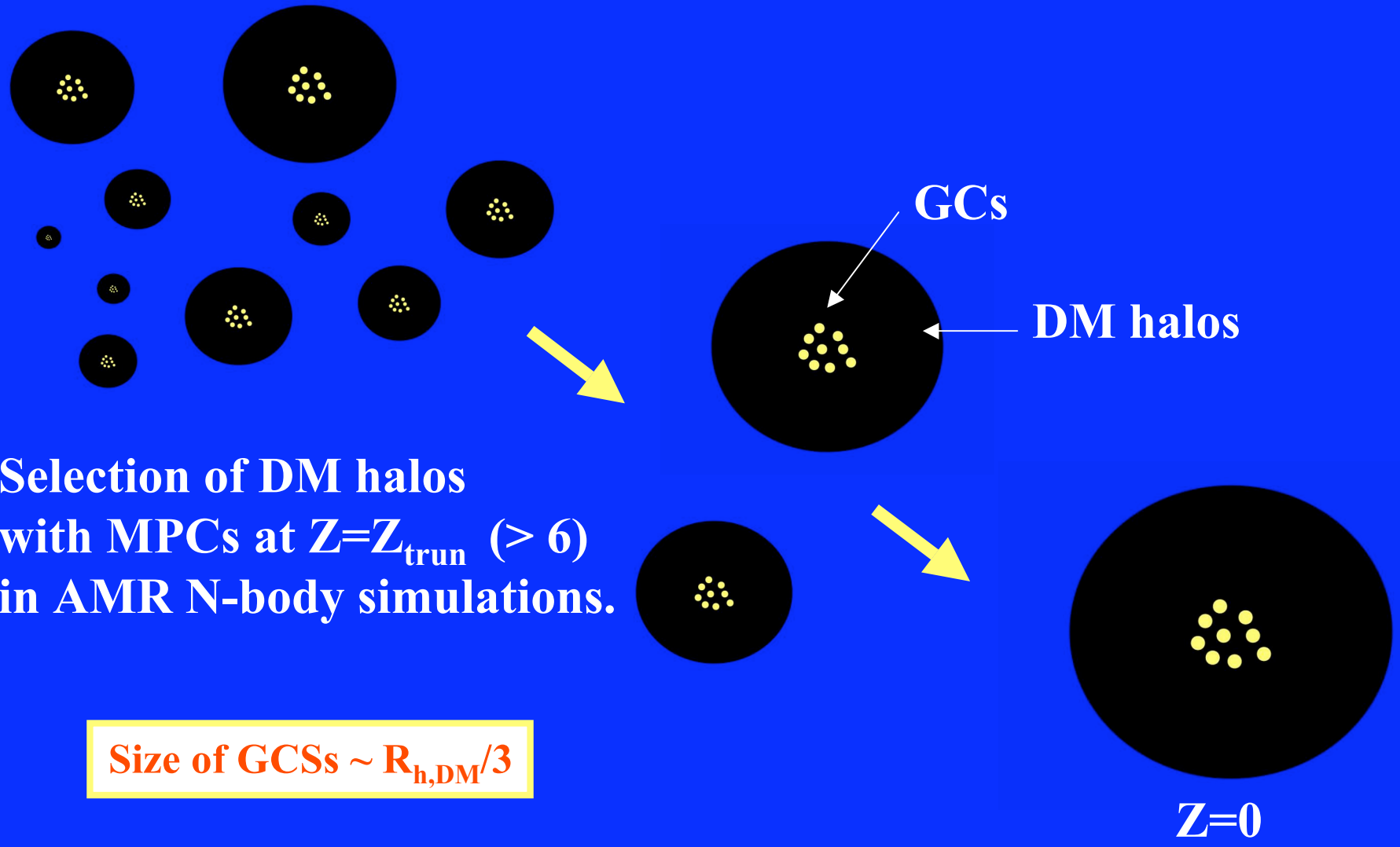
M_V (mag)

Bekki et al. (2006) reproduced from Data by Harris (1991) and Durrell et al. (1996).

A big question:

How do we understand the origin of these GCS-Host connetctions in the context of hierarchical clustering scenarios of galaxy formation ?

Numerical studies of GCS formation (Yahagi & Bekki 2005; Bekki,Yahagi, & Forbes 2006)



The model for MPC formation in a ΛCDM universe (e.g., Yahagi & Bekki 2005).

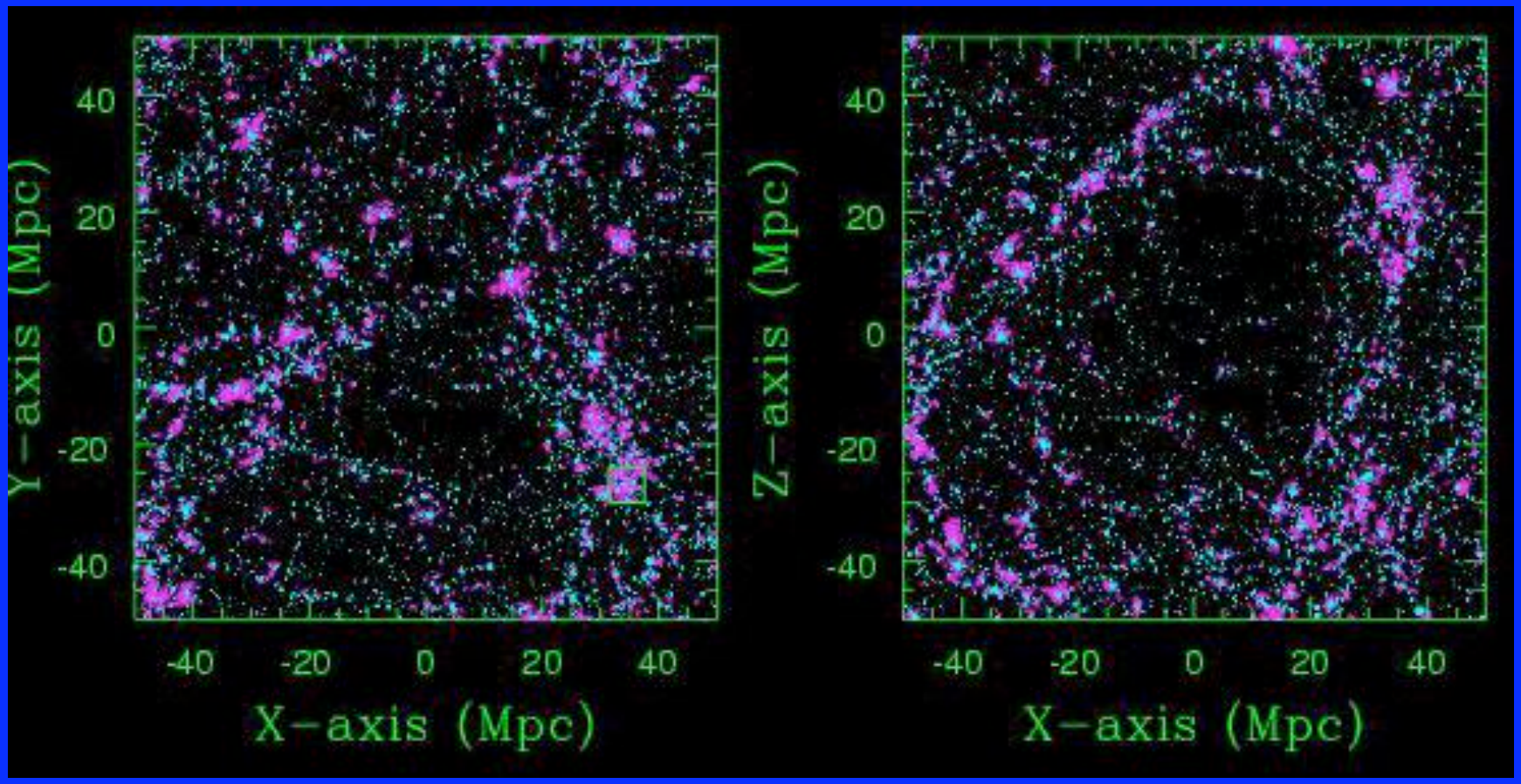
(1) MPC formation in halos virialized before z_{trun} (e.g., suppression of star formation at the reionization epoch; Susa & Umemura 2004).

(2) L-Z_{GC} relation and M/L at $z=z_{trun}$ (=6-15).

(3) MRCs formation during later dissipative merging is *not* modeled.

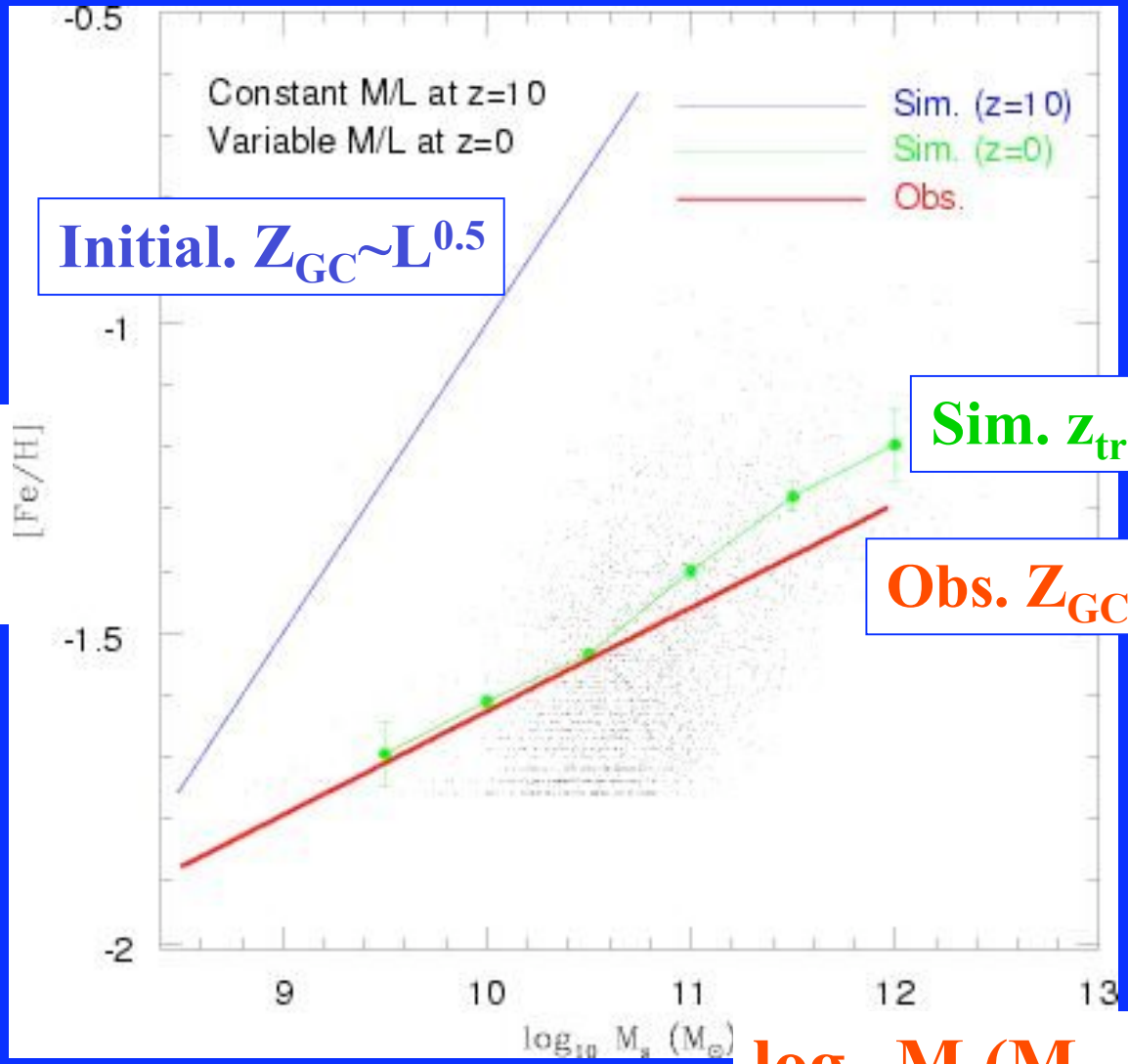
The large-scale structure of MPCs (z_{trun}=6)

● = GCs within halo ● = Inter-galactic GCs (not within any halos)

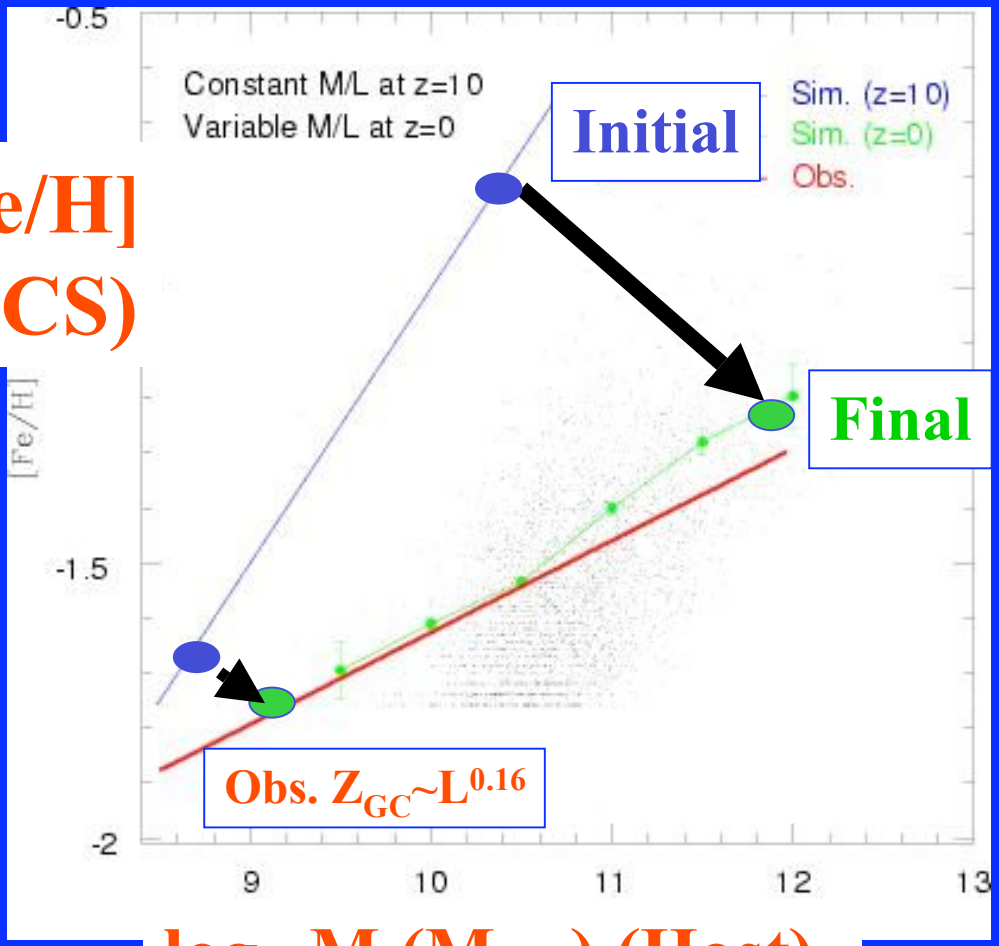


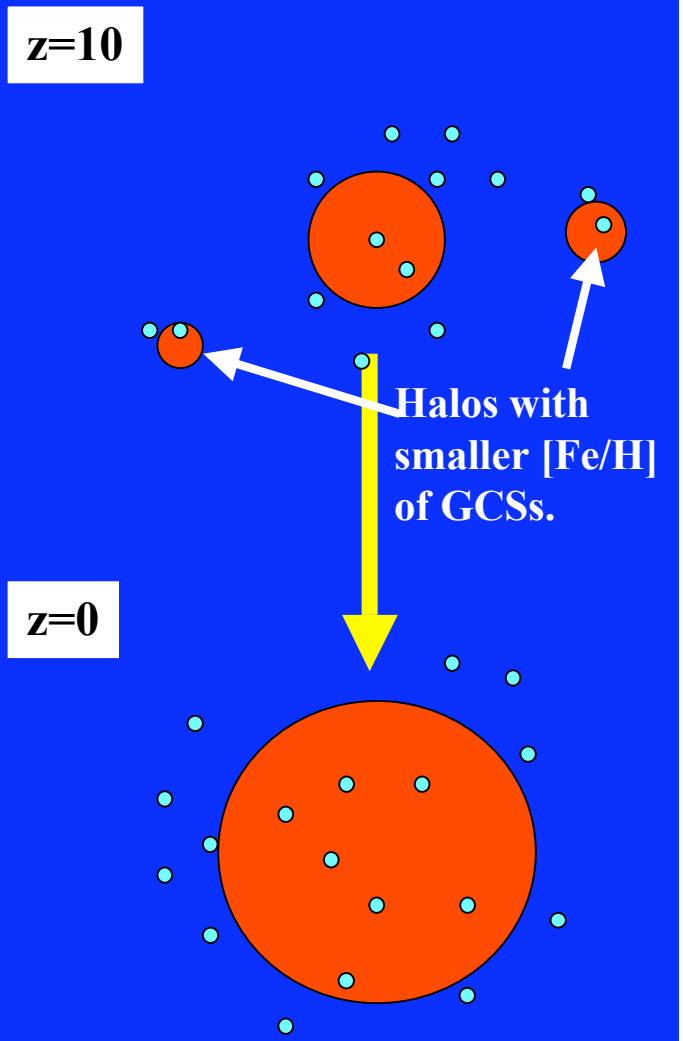
N=512^3, 70/h Mpc, Ω=0.3, Λ=0.7, σ_8=0.9, M_T=4.08*10^{16}M_{sun} in a ΛCDM model.

Results: (I) L-Z_{GC} (M_S-Z_{GC}) relation for z_{trun}=10.

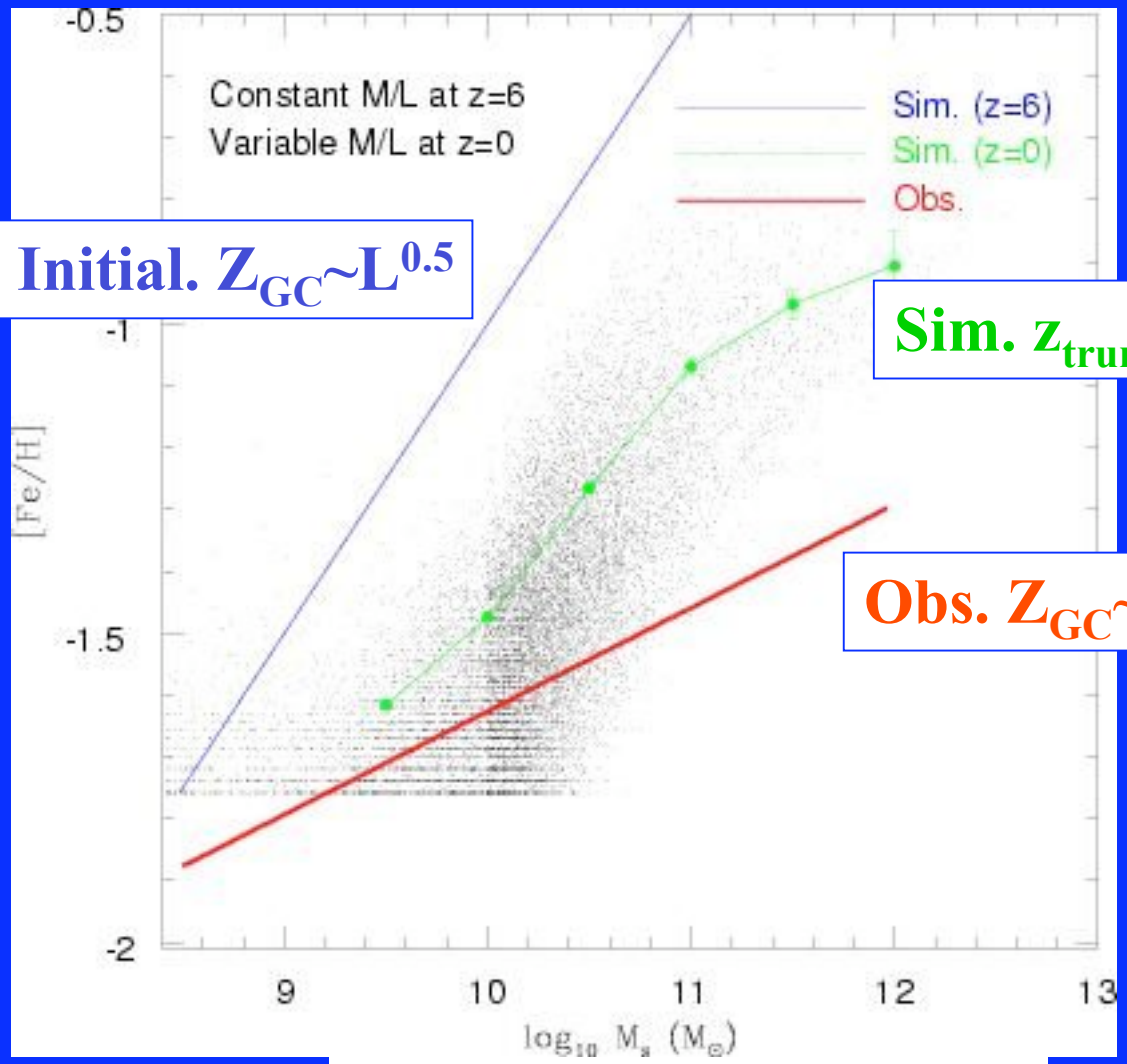


Flattening of the M_S-Z_{GC} relation due to hierarchical galaxy growth.





$z_{trun}=6$



Initial. $Z_{GC}\sim L^{0.5}$

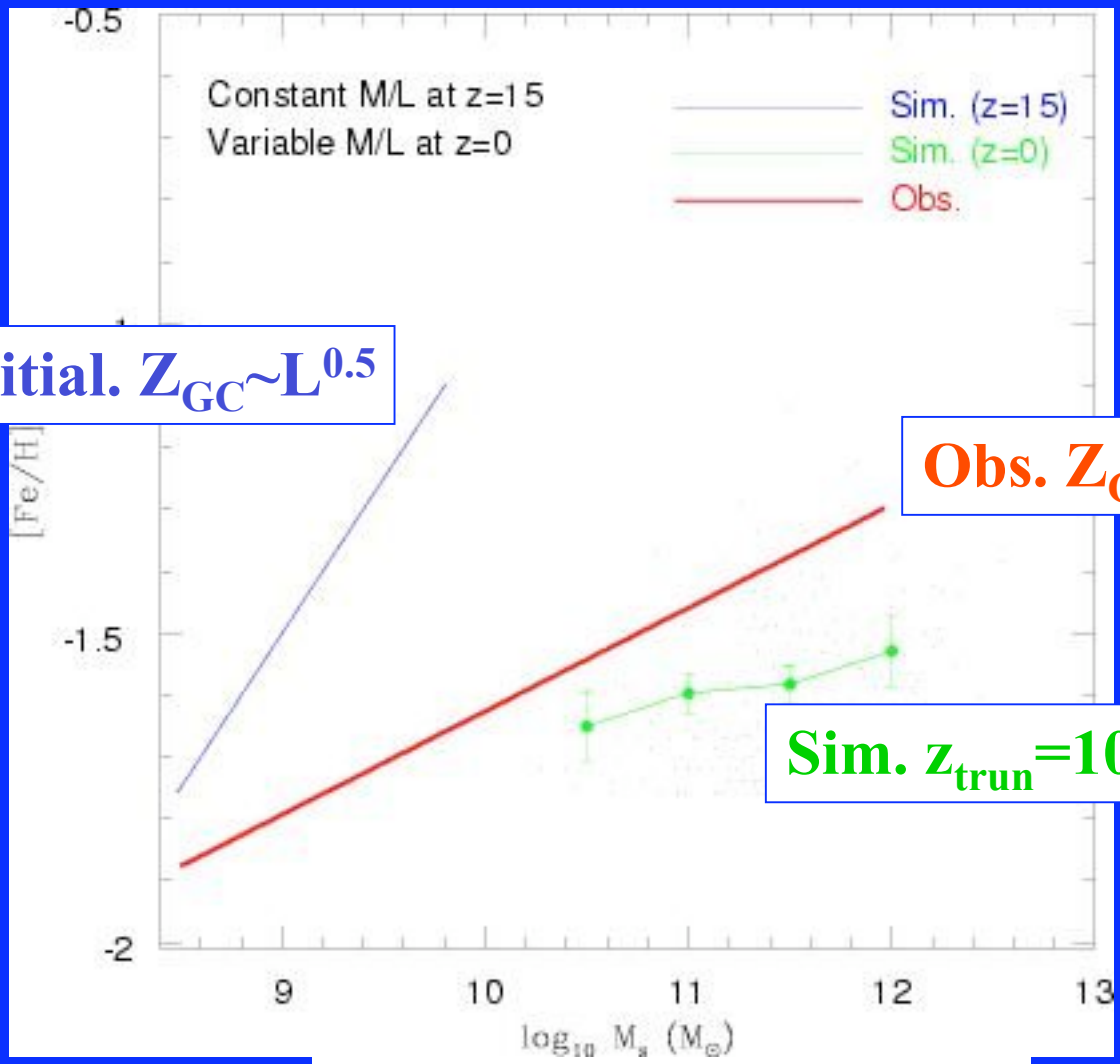
Sim. $z_{trun}=6$

[Fe/H] (GCS)

Obs. $Z_{GC}\sim L^{0.16}$

$\log_{10}M_s(M_{sun})$ (Host)

$z_{trun}=15.$



Initial. $Z_{GC}\sim L^{0.5}$

Obs. $Z_{GC}\sim L^{0.16}$

Sim. $z_{trun}=10$

[Fe/H] (GCS)

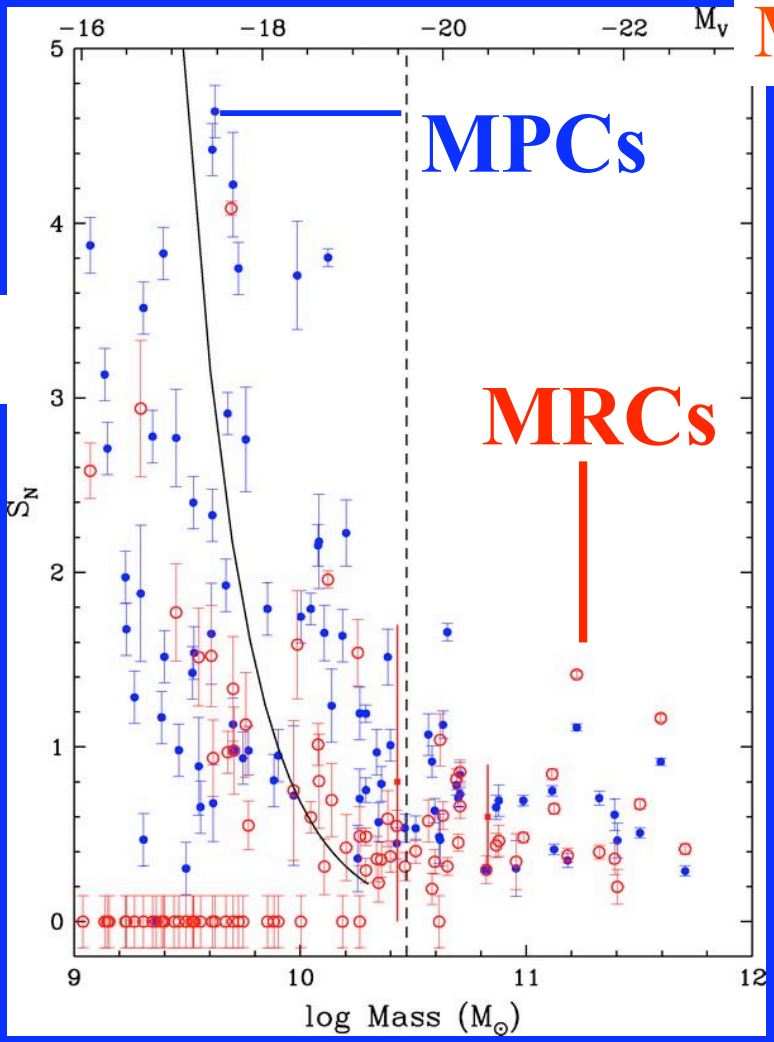
$\log_{10}M_s(M_{sun})$ (Host)

A key result:

Models with $z_{trun} \sim 10$ are the most consistent with observations: $z_{reion} \sim 10.9$ in WMAP results (Page et al. 2006).

Results: (II) The S_N-M_V relation.

Observations:
Forbes (2005) from ACS data.



M_V (mag)

MPCs

MRCs

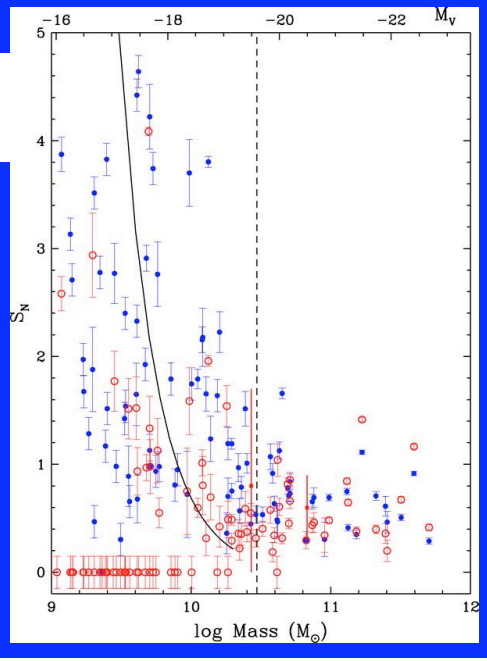
S_N

Results: (II) The S_N-M_V relation.

Observation

$\delta S_N \sim 5$ over 1 order of mag.

S_N

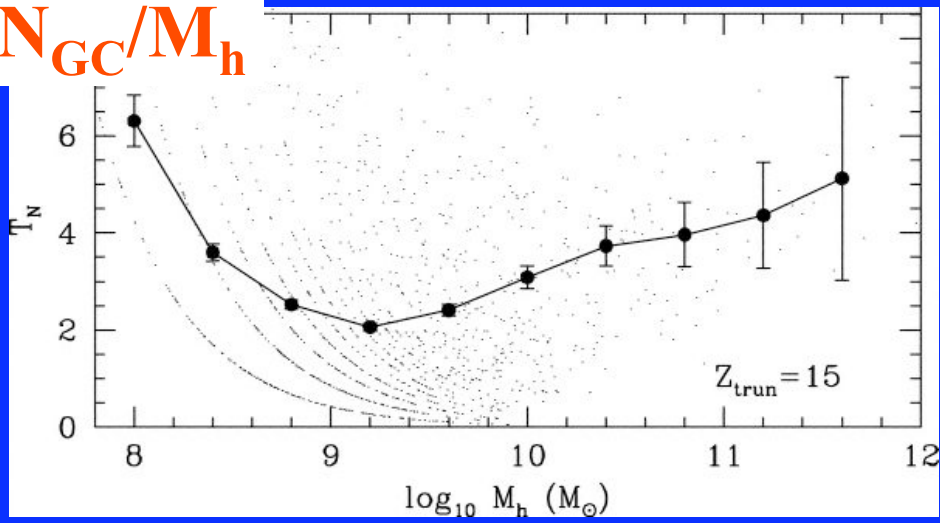


$\log_{10} M_s (M_{sun})$

Simulation

$\delta T_N \sim 3$ over 3 orders of mag.

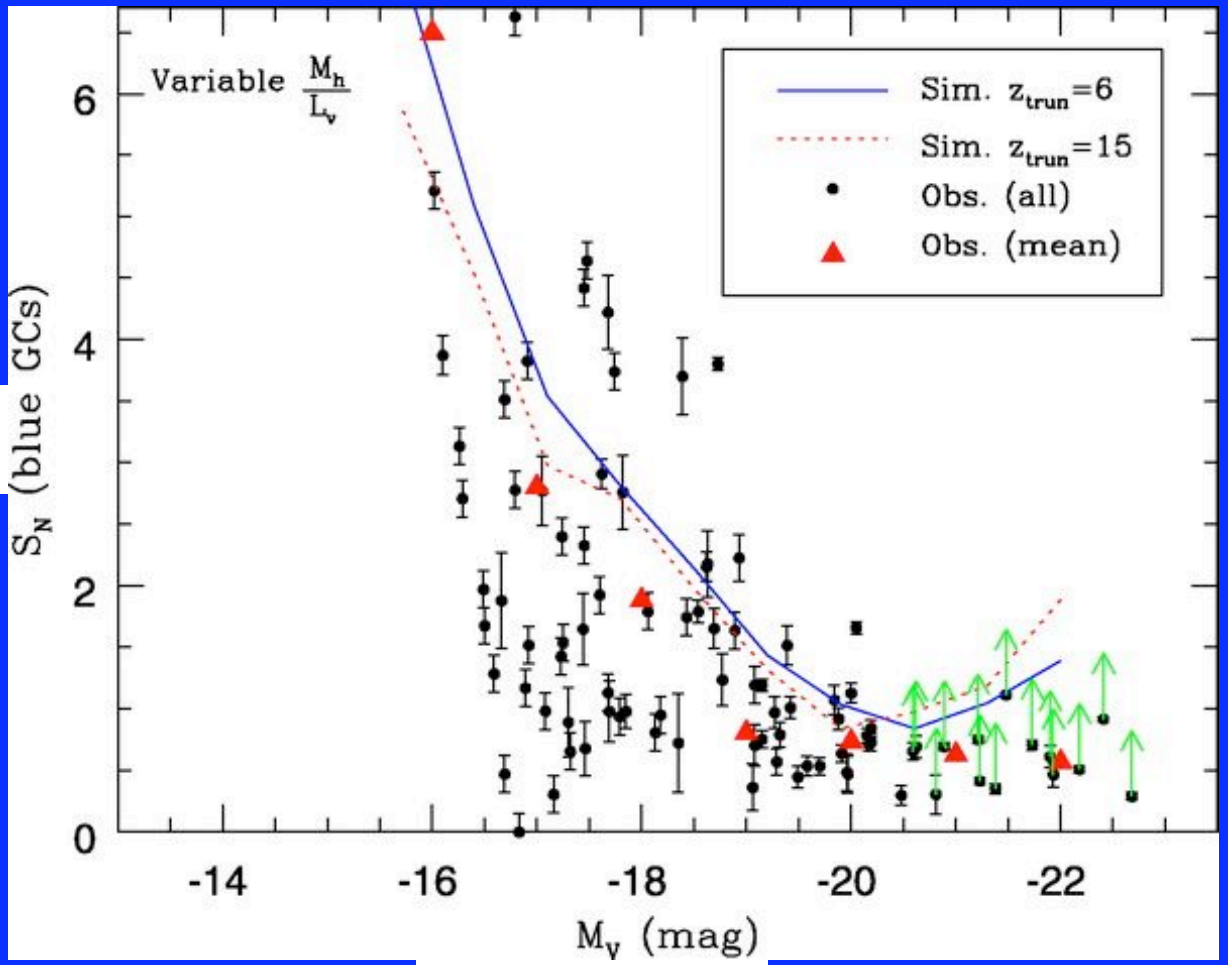
$T_N \sim N_{GC}/M_h$



$\log_{10} M_h (M_{sun})$

Results: (II) The S_N-M_V relation.

Variable M/L models ($M_h/L_v \sim M_h^{-1}$ for lower L_v).

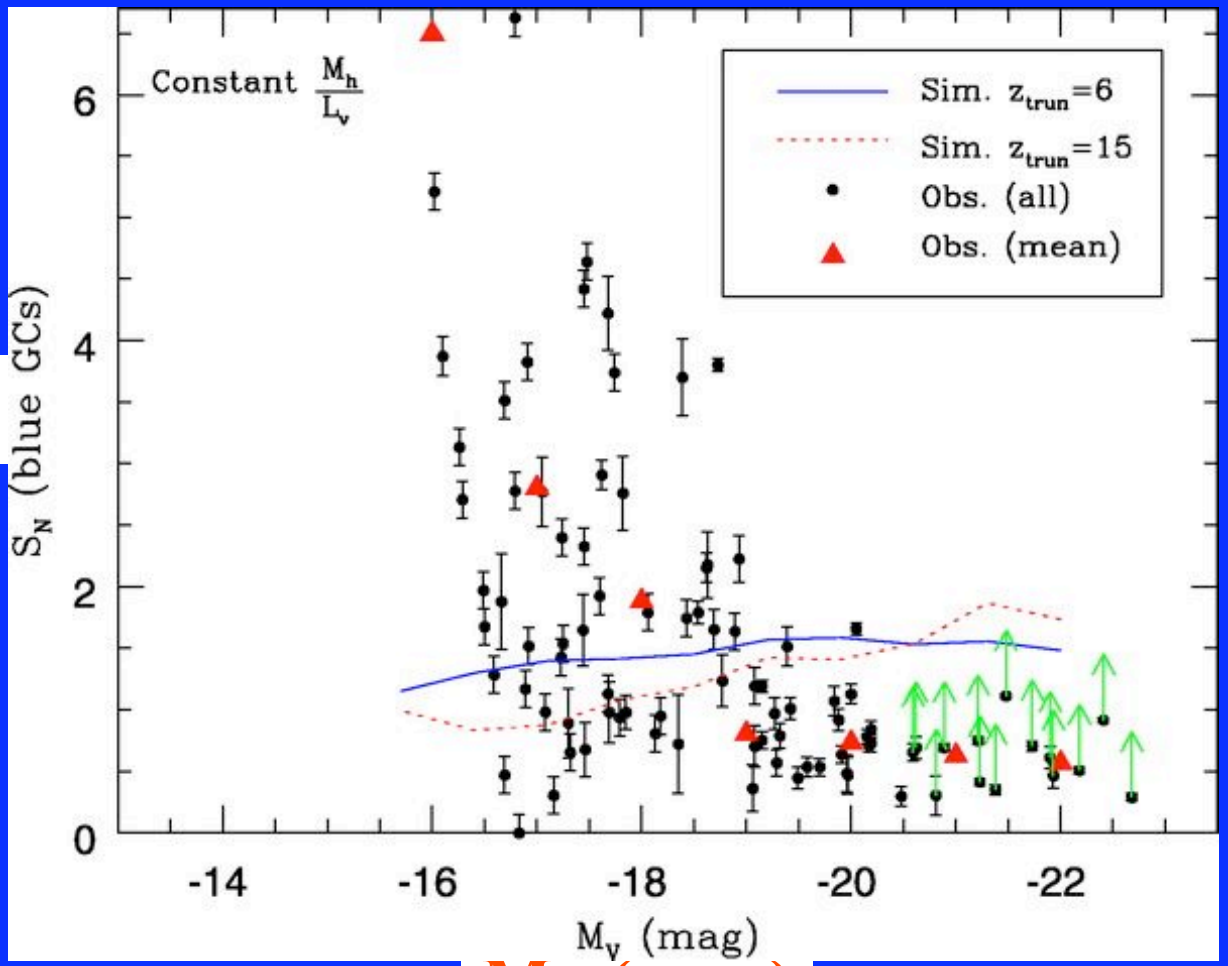


S_N

M_V (mag)

Results: (II) The S_N-M_V relation.

Constant M/L models (M_h/L_v~10 for lower L_v).



S_N

M_V (mag)

Implication:

Less luminous galaxies need to have higher M/L for M_V>-19.5 mag: M-dependent M/L due to supernovae feedback effects (e.g., Dekel & Silk1986) ?

Summary

- The flat L-Z_{GC} relation is consistent with hierarchical galaxy growth with $z_{trun} \sim 10$.
- The steep S_N-M_V relation for M_V>-19.5 mag can be due to M-dependent M/L in galaxies.