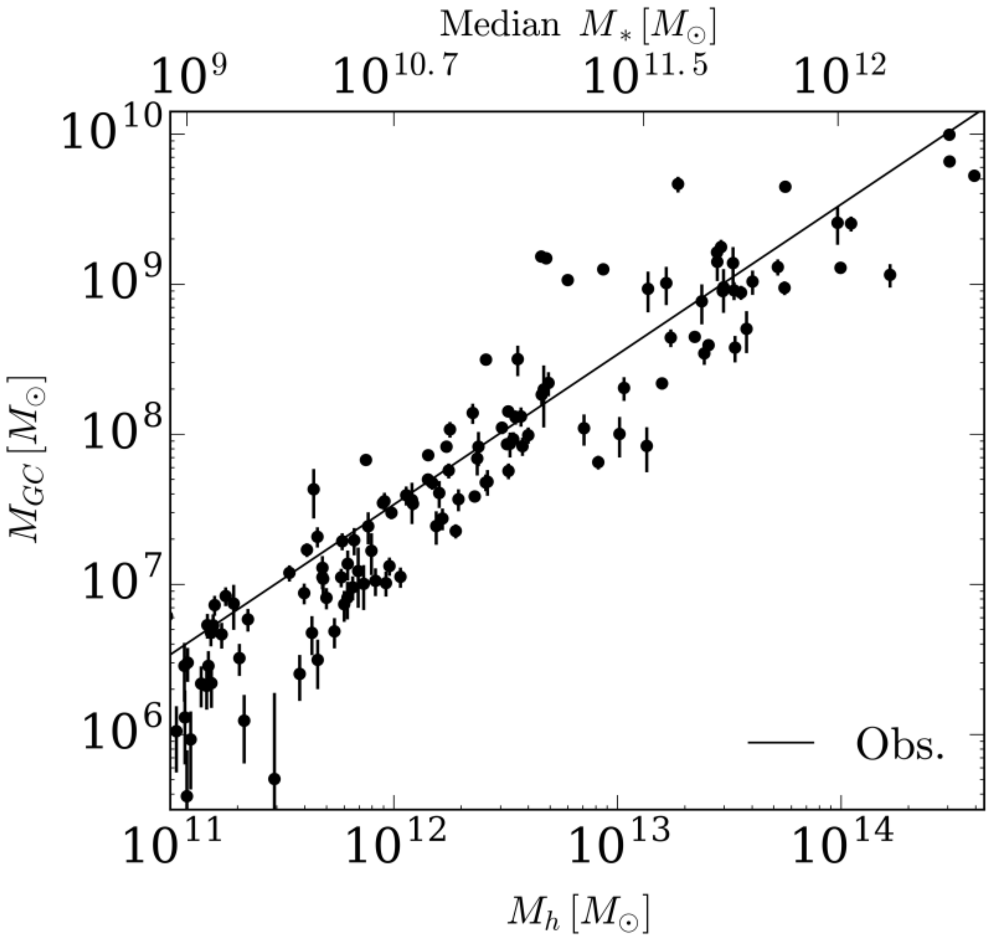
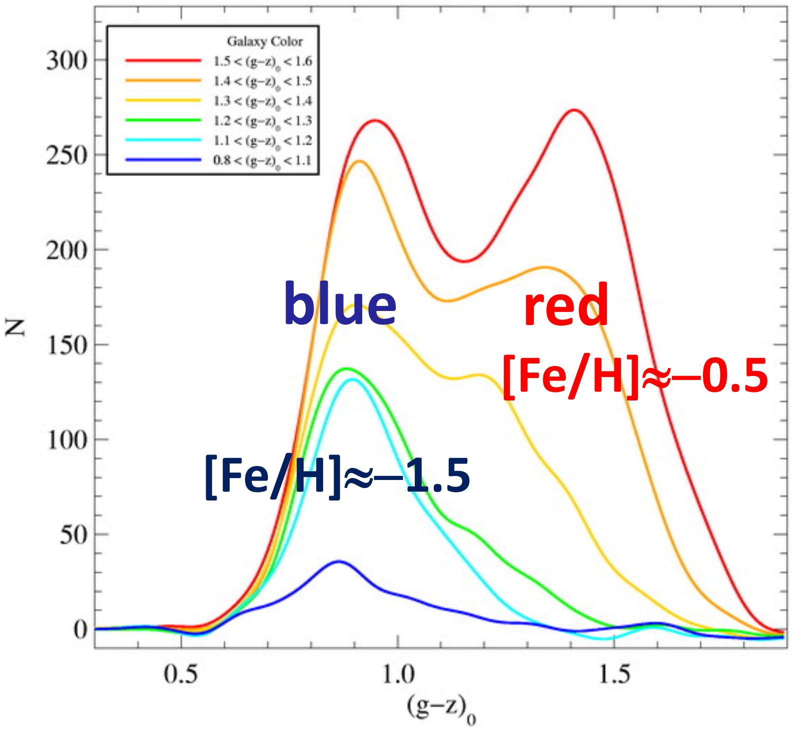
On the origin of the correlation between halo mass and its globular cluster system mass



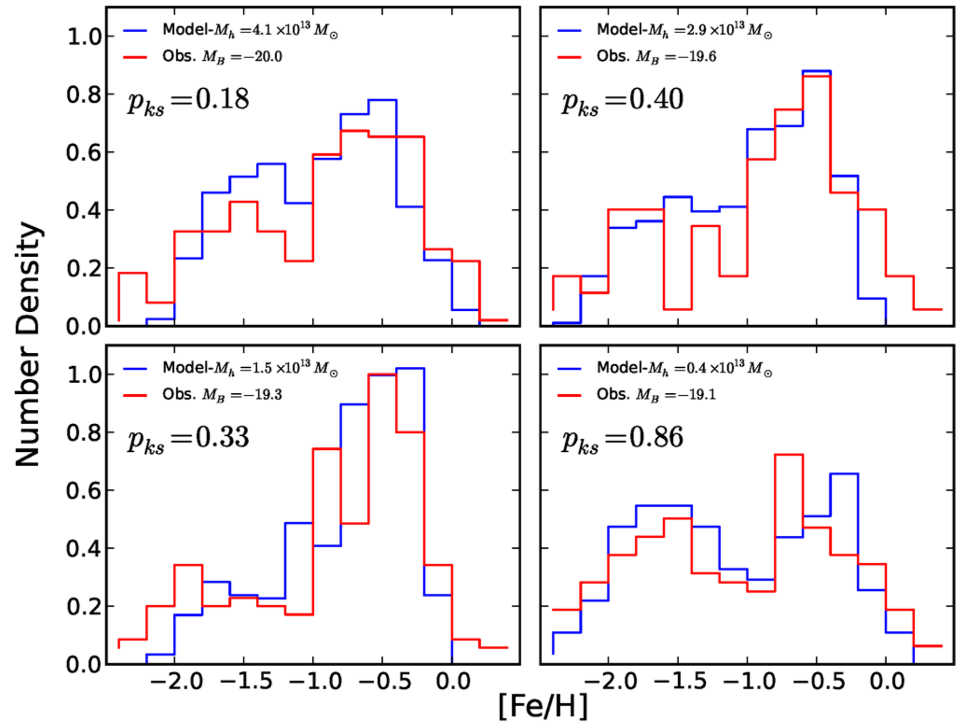
Oleg Gnedin
(University of Michigan)

Nick Choksi
(UC Berkeley)

It started with bimodality of the metallicity distribution, then came unimodality, multimodality…



Peng et al. 2006 – HST Virgo Cluster Survey

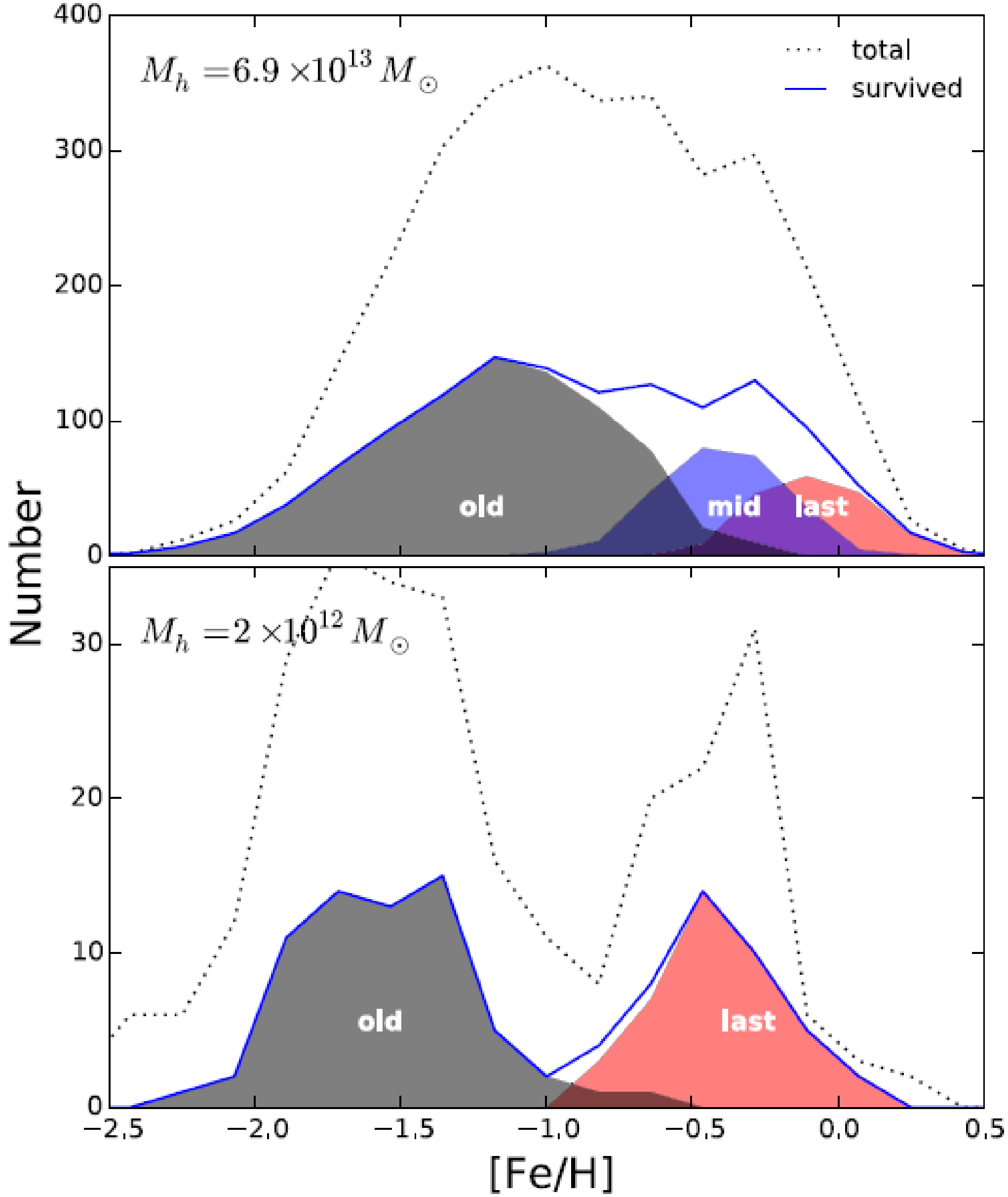


Muratov & OG 2010
Li & OG 2014

Color/metallicity distribution of GCs in most galaxies is multimodal

Each metallicity group tells us about distinct episodes of cluster formation

Model for GC formation in gas-rich galactic mergers, metallicity assigned from observed M_*-Z relation for host galaxies



Li & OG 2014

Analytical model for the build-up of globular cluster systems from *gas-rich mergers* and *accretion of galaxies*:

begin with cosmological simulations of halo formation

supplement halos with cold gas mass based on observations

use $\dot{M}_{GC}$ - M_{gas} relation from hydro simulations of galaxy formation

metallicity from observed M_* - Z relation for host galaxies, including evolution with time

tidal disruption leaves only a small fraction of clusters at z=0

New model with updated galaxy scaling relations circa 2017
(cold gas fraction, metallicity evolution, new halo catalogs)

Model has two adjustable parameters:

$$M_{\rm GC} = 1.8 \times 10^{-4} p_2 M_g$$

GCS rate scales with cold gas mass

$$R_m \equiv \frac{M_{h,2} - M_{h,1}}{t_2 - t_1} \frac{1}{M_{h,1}}.$$

GC form when halo is actively growing (often due to mergers)

Cluster formation is triggered if $R_m > p_3$

The rest are published galactic scaling relations:

Lilly+13, Genzel+2015, Tacconi+2017

$$\frac{M_g}{M_*} \equiv \eta(M_*, z) = \eta_9 \left(\frac{M_*}{10^9 \, M_\odot} \right)^{-n_m} (1+z)^{n_z}$$

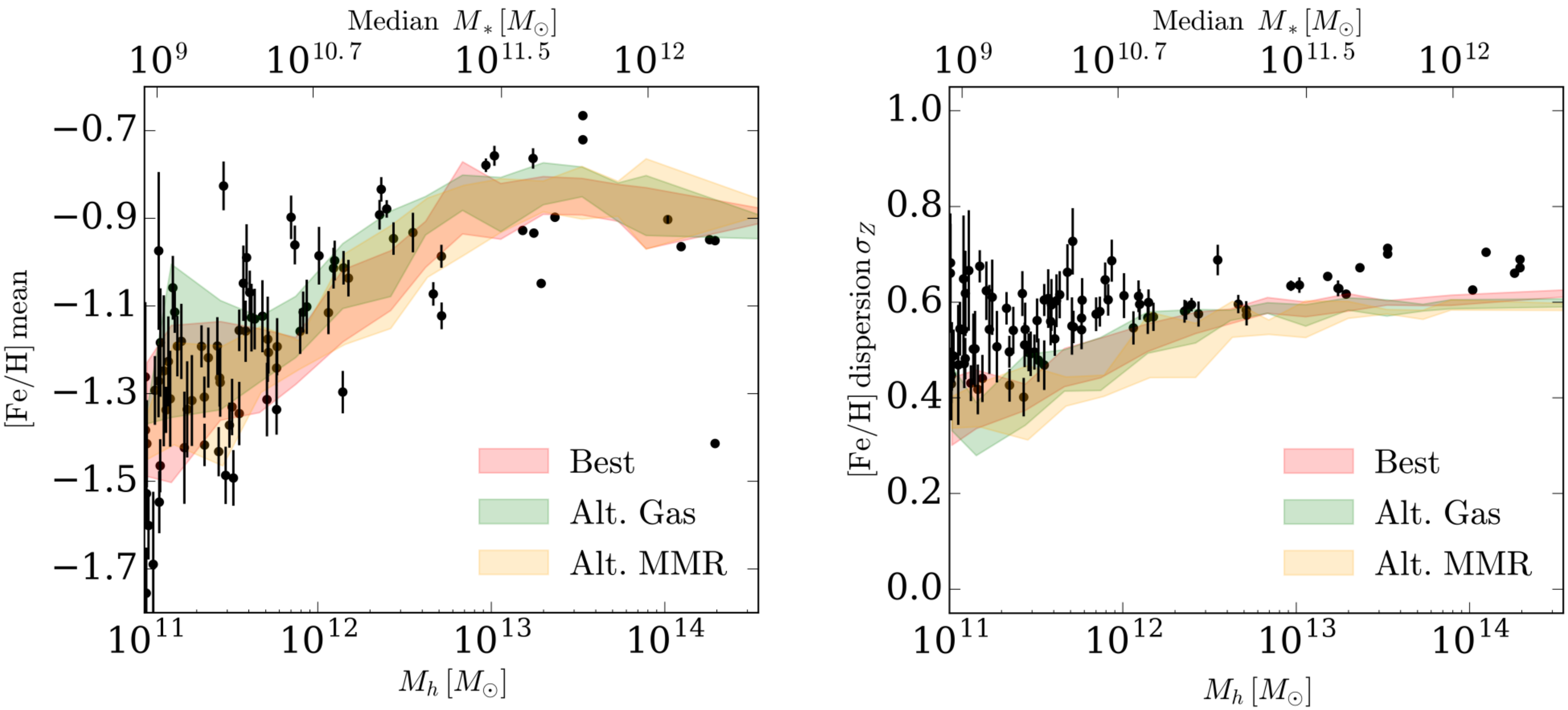
Mannucci+2009, Kirby+13, Ma+16

$$[\mathrm{Fe/H}] = \log_{10} \left[\left(\frac{M_*}{10^{10.5} M_\odot} \right)^{\alpha_m} (1+z)^{-\alpha_z} \right]$$

+ alternative versions for evolution of gas fraction and mass-metallicity relation (MMR)

New model with updated galaxy scaling relations circa 2017

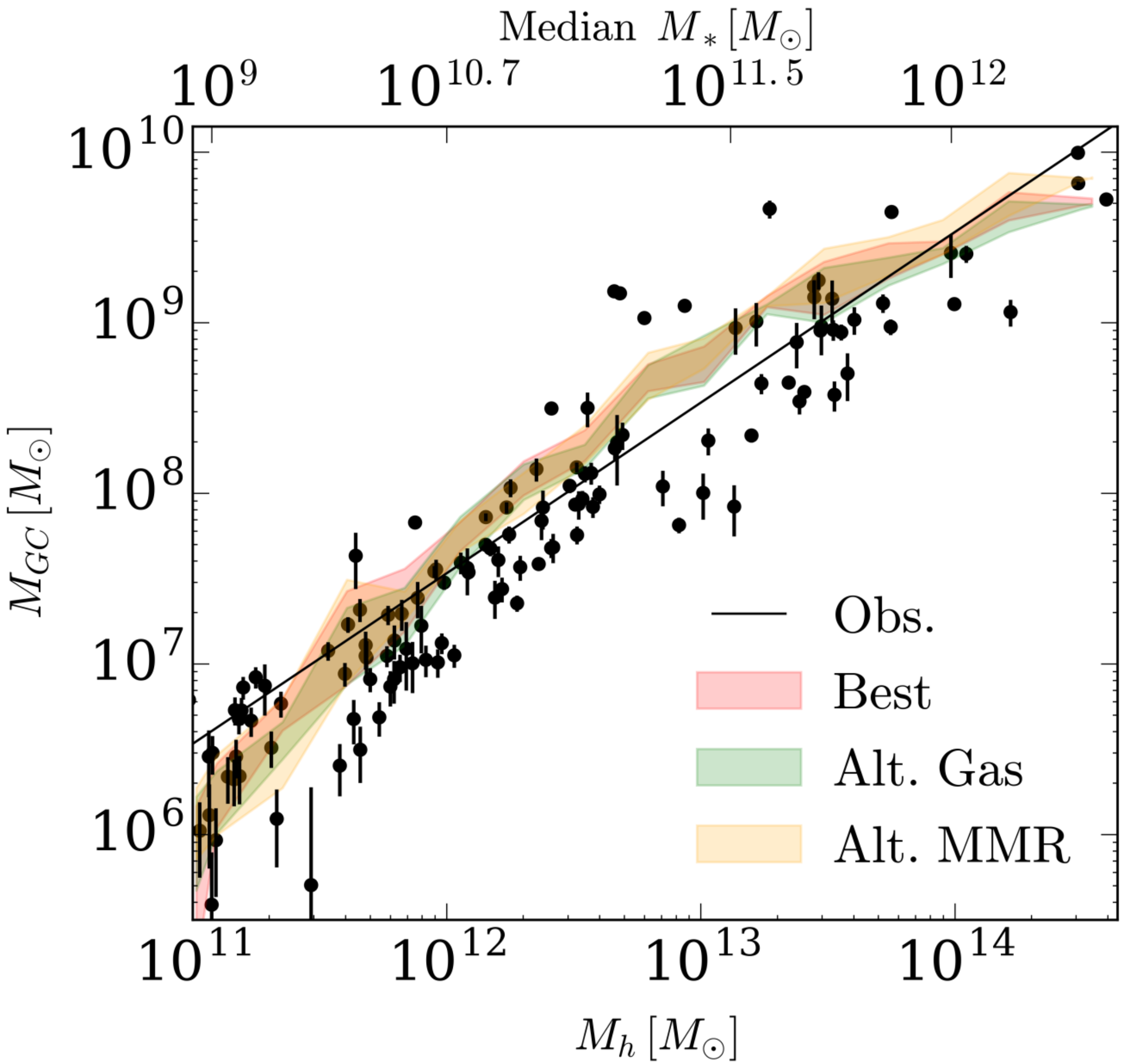
(cold gas fraction, metallicity evolution, new halo catalogs)



Observations include:

- Milky Way, M31
- Virgo Cluster galaxies
- Brightest Cluster Galaxies

GCS mass – Galaxy mass relation: beyond linear

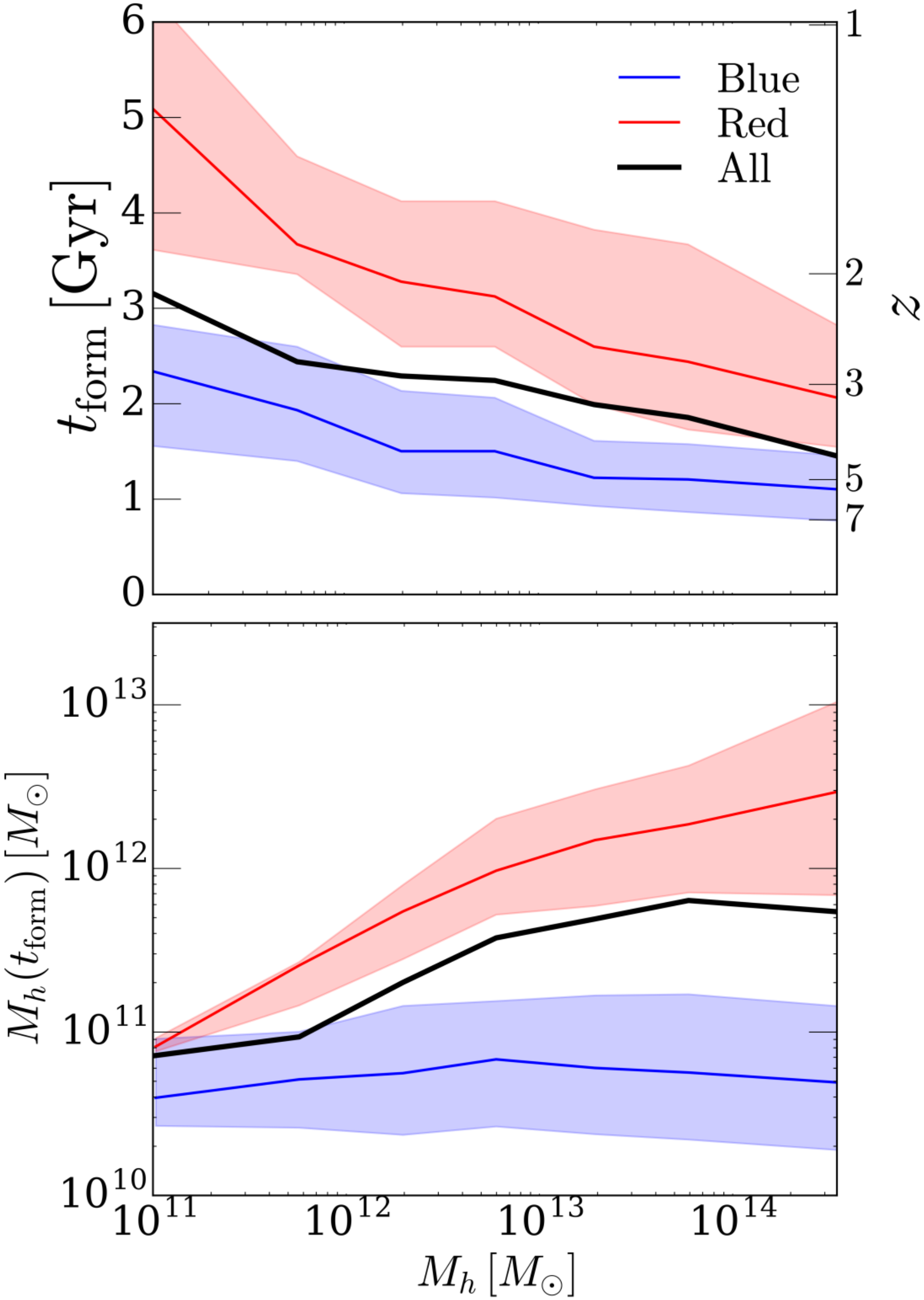


Spitler & Forbes (2009)

Georgiev at al. (2010)

Harris et al. (2013, 2015, 2017)

Hudson et al. (2014)



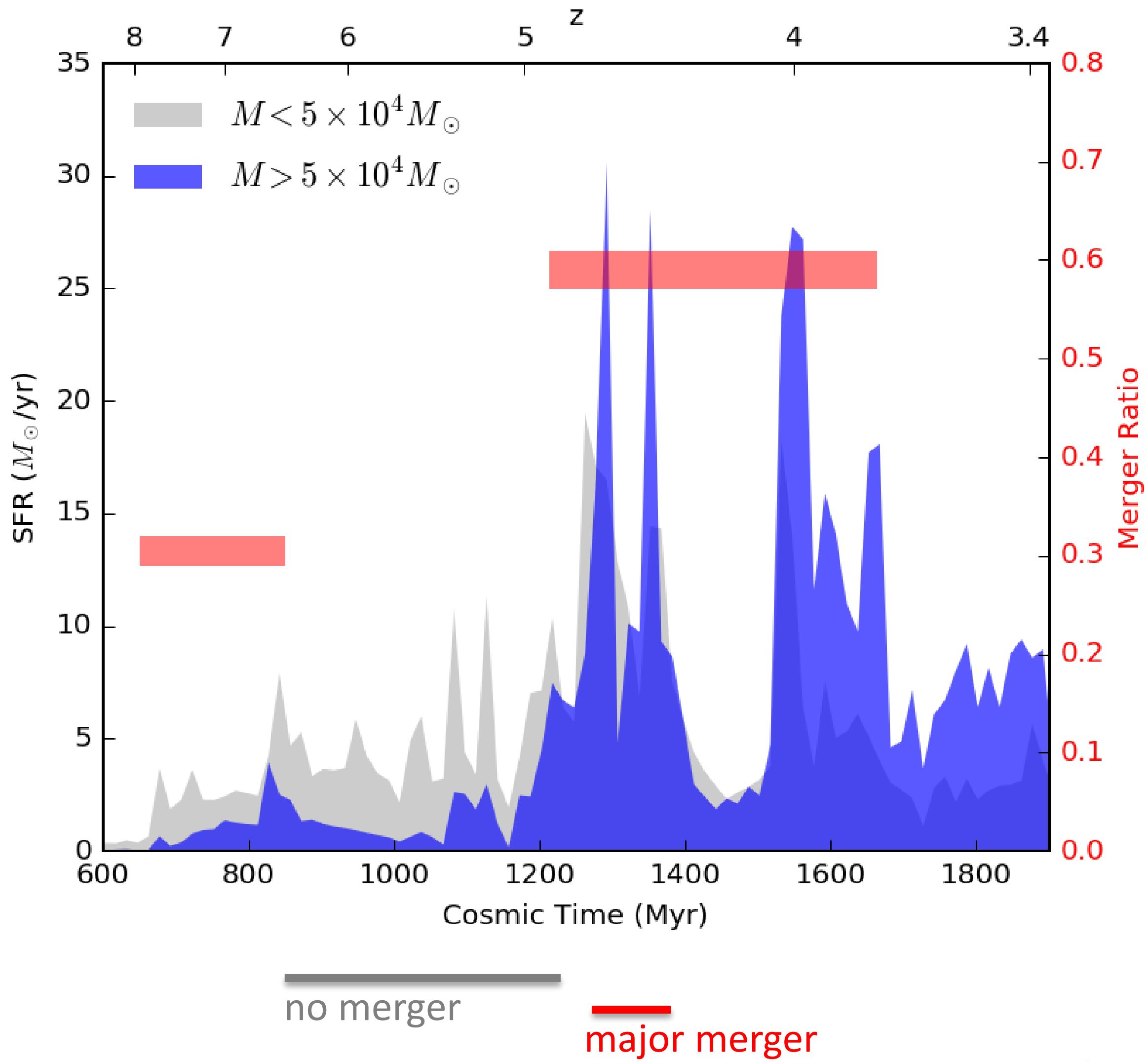
Most blue clusters form when halo mass is $2\times10^{10} - 10^{11}$ $M_\odot$ at redshifts *z = 3-7*

Red clusters form at *z = 2-4* in most massive galaxies, and at *z = 1-2* in dwarfs *(downsizing effect)*

Mass of hosts of red clusters scales with final galaxy mass

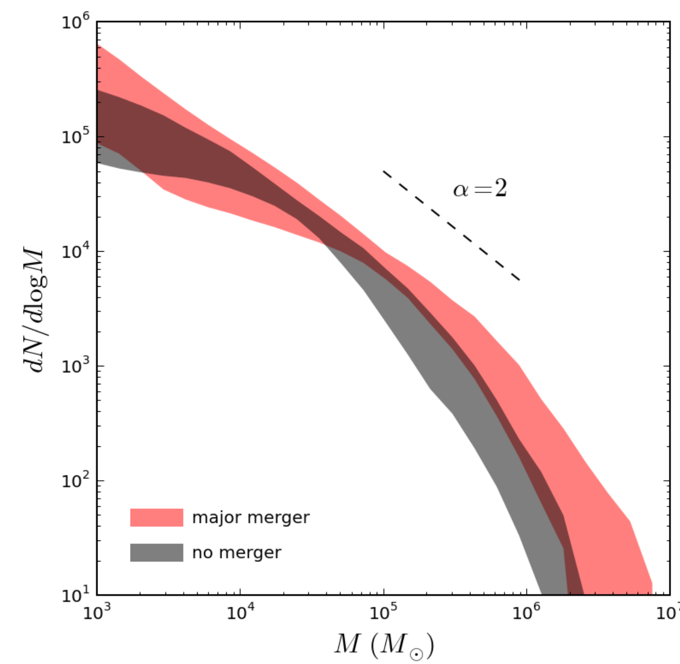
25% - 75% range of all clusters formed (and survived to z=0) within a galaxy of mass M_h

Gas-rich mergers of massive galaxies trigger cluster formation



Cosmological simulations at 5 pc resolution, with cluster formation model

Li, OG et al. 2017, 2018



Cluster MF is more strongly truncated between mergers

Summary

- Analytical model for cluster formation and disruption, based on halo assembly from cosmological simulations and observed galactic scaling relations

- Matches the number of GCs, mean and width of the metallicity distribution for galaxies from $M_* = 10^9\ M_\odot$ to $10^{12.5}\ M_\odot$

- Mergers of gas-rich galaxies may trigger/enhance formation rate of massive star clusters

- Halo mass – GC mass relation is non-linear, the averaging effect is not perfect