Globular Cluster Systems - Steps to Understanding Formation

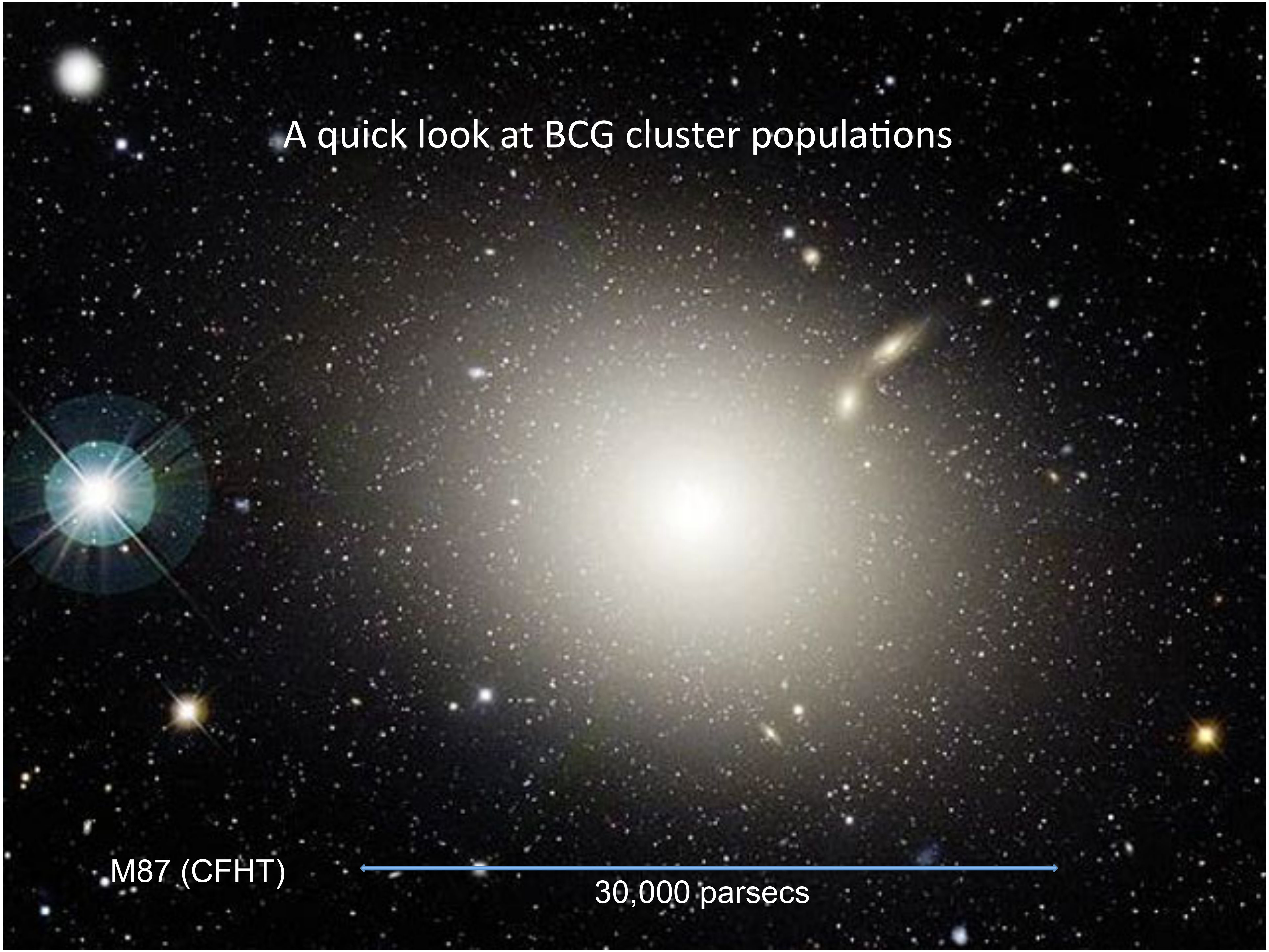
Bill Harris
Sexten, June 2019

Massive star clusters are fundamental components of galactic evolution.

D.Cohen et al. 2018, ApJ 860, 47

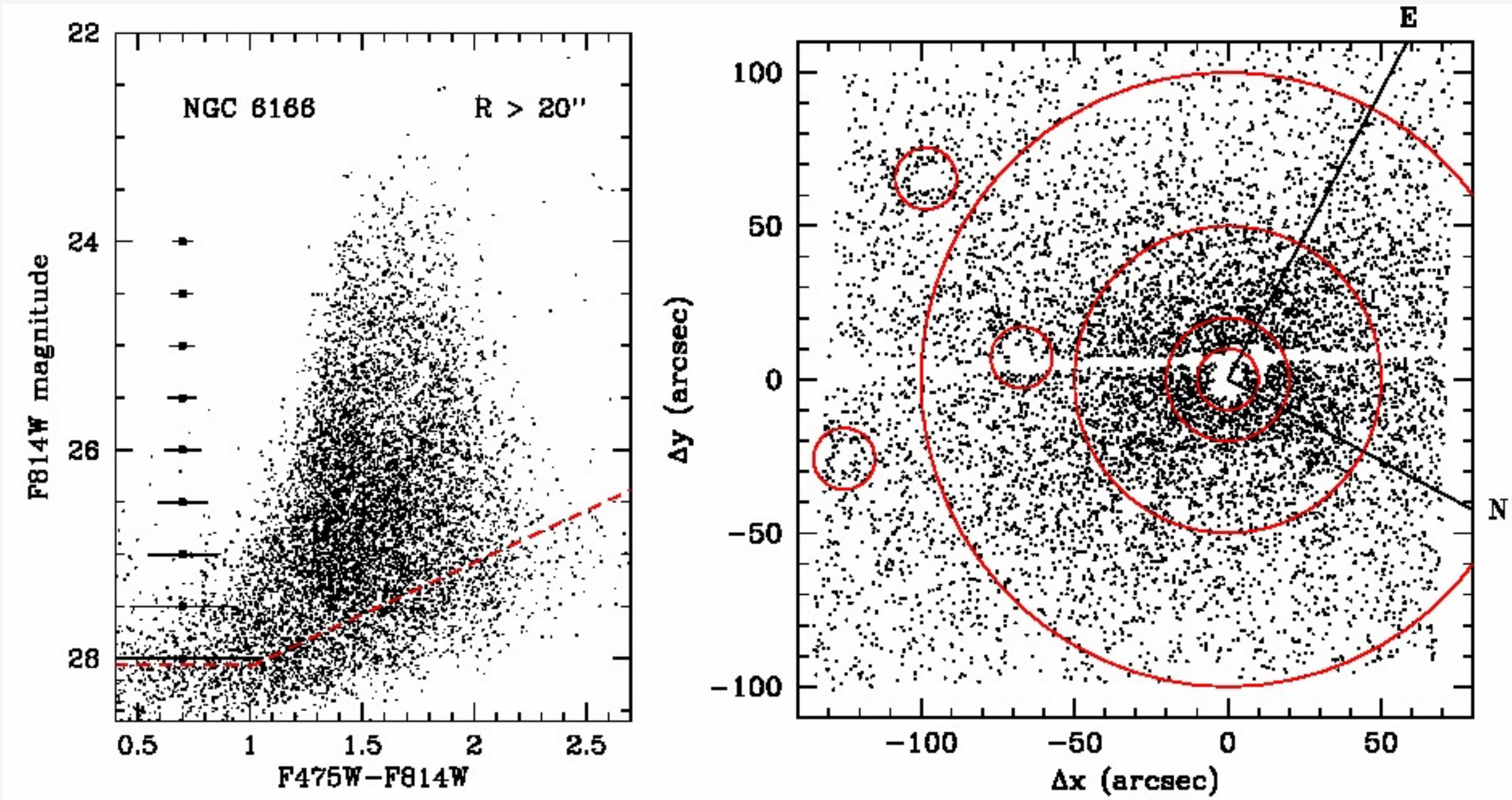
One of the major goals of modern astronomy is an understanding of galaxy formation. An ideal tool for this study would be a witness which was both present at the long-since-vanished first epoch when most galaxies formed, and yet still survives today to tell us its story.

Geisler, Lee, & Kim 1996, AJ 111, 1529


A quick look at BCG cluster populations
M87 (CFHT)
30,000 parsecs

Color-magnitude distribution for GCs

Harris et al. 2016



Classic bimodality is not so obvious here

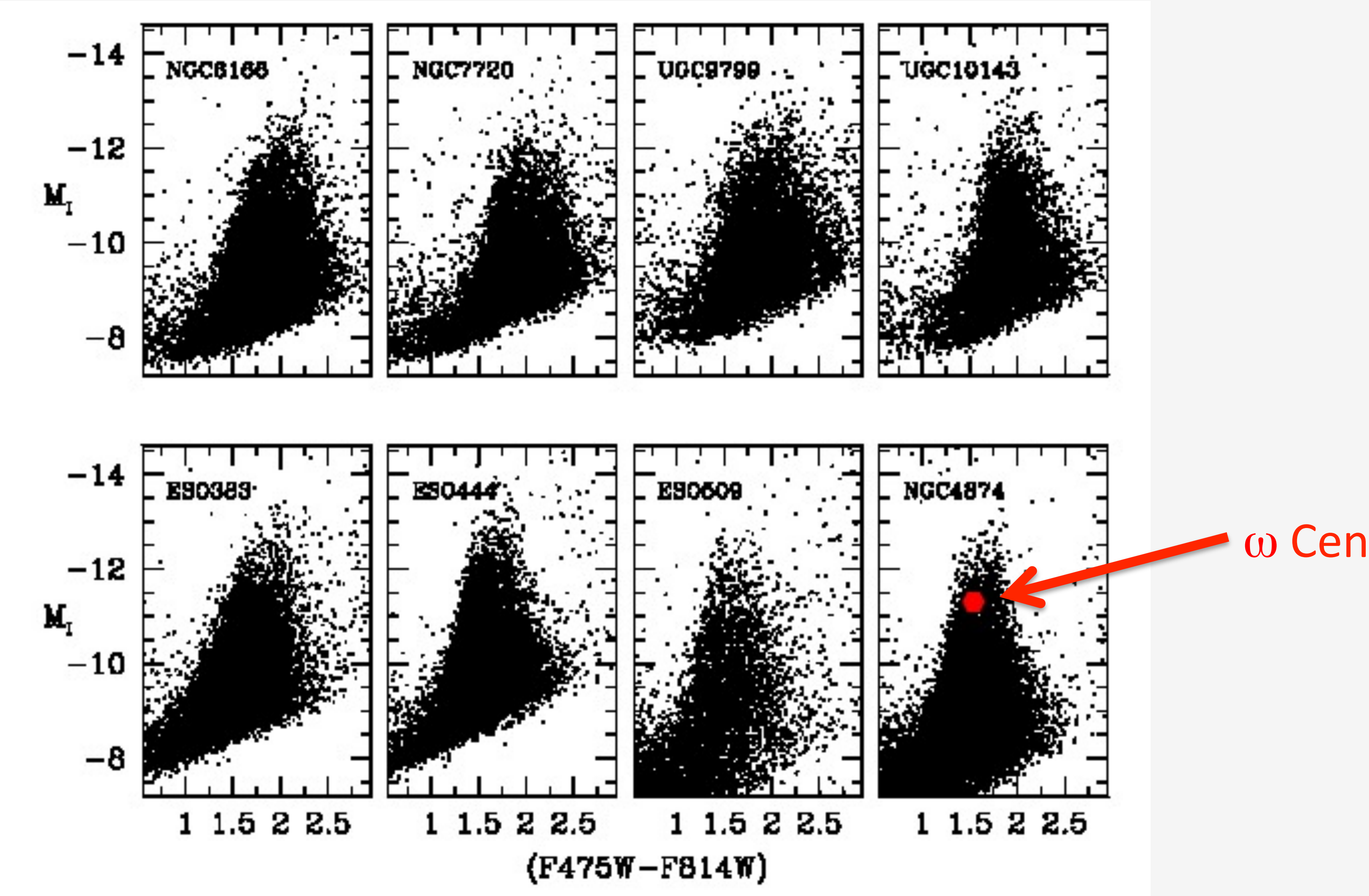
100 kpc

In nearby galaxies, resolved-star photometry of halo stars can provide the ***metallicity distribution function*** of the halo at any point

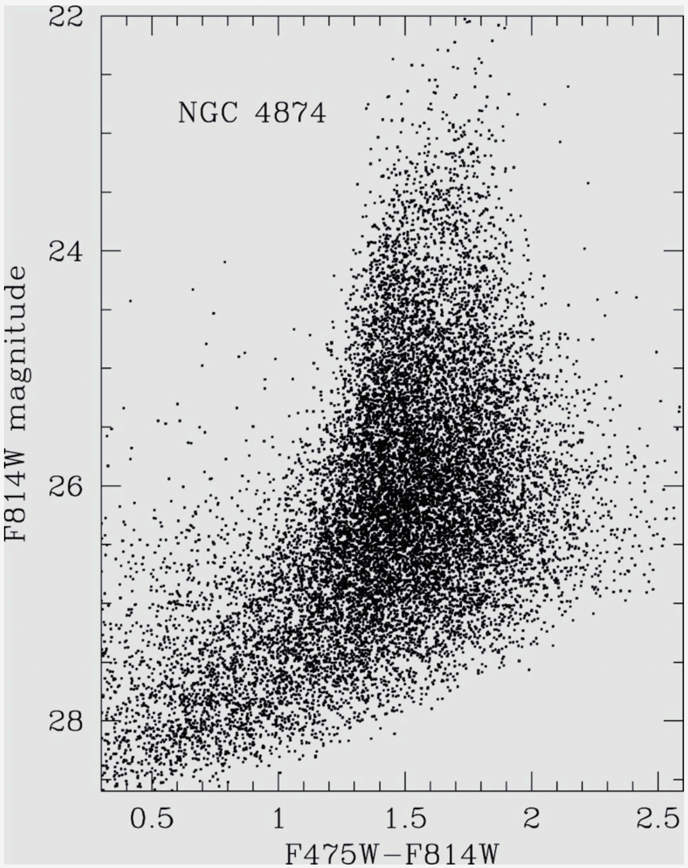
For somewhat more distant galaxies (out to 300 Mpc), ***globular clusters*** can do the same thing: explicitly obtain the MDF.

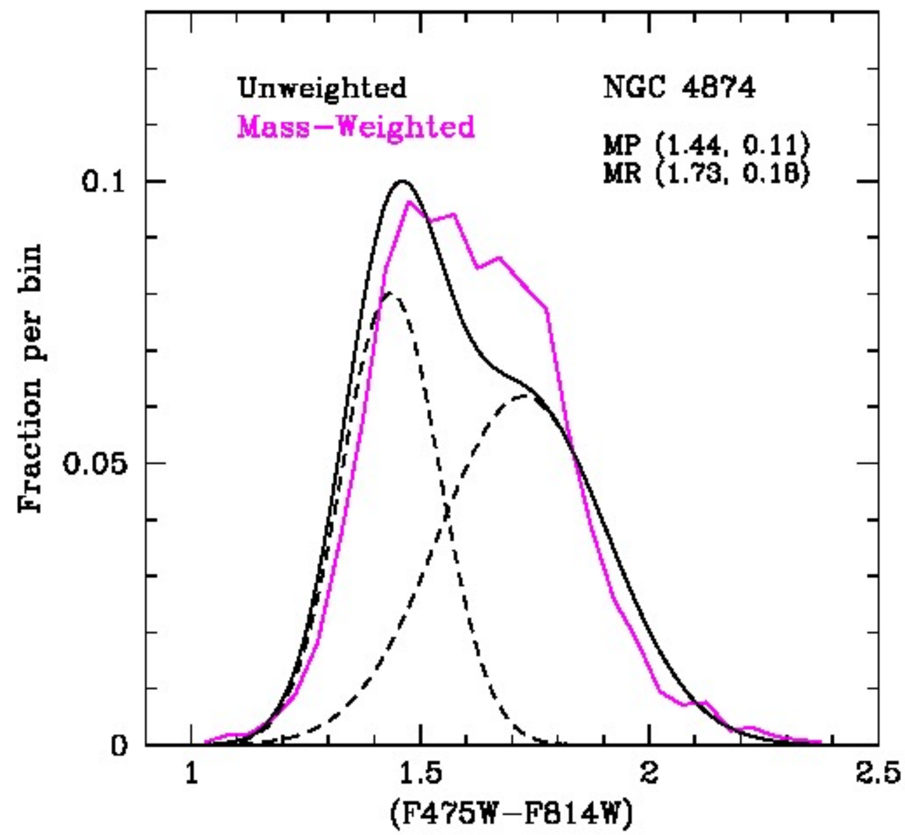
Much larger distance range than RGB halo stars can reach, but concerns about bias: how representative are the GCs?
Red GCs → track halo light well, usually
Blue GCs → more extended; closer to DM profile

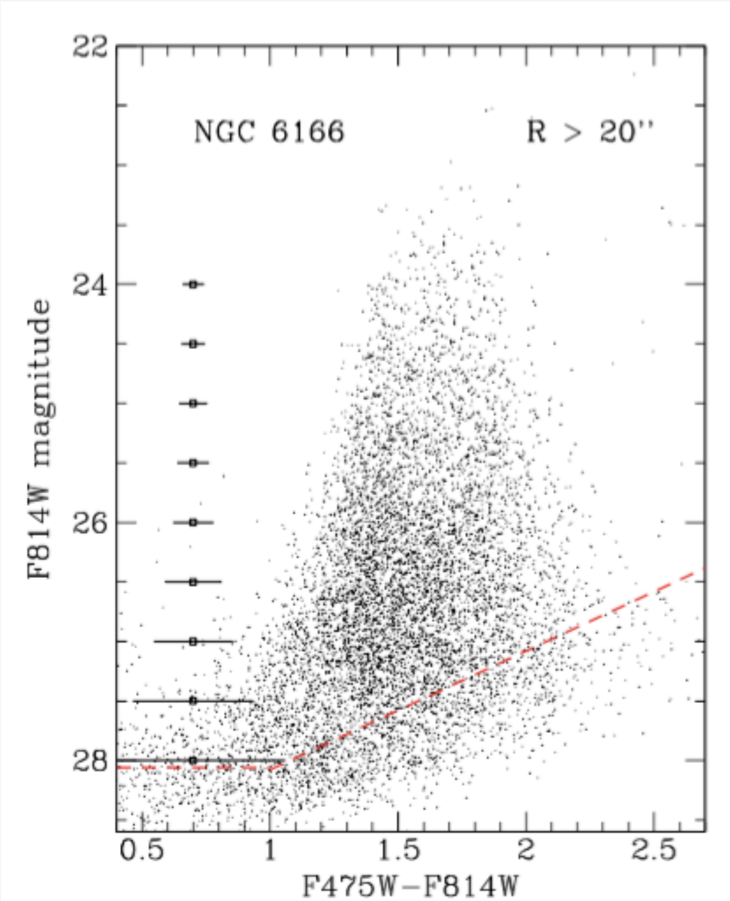
Recent results from HST photometry of BCGs within 250 Mpc:
Harris et al. 2014, 2016, 2017, 2019



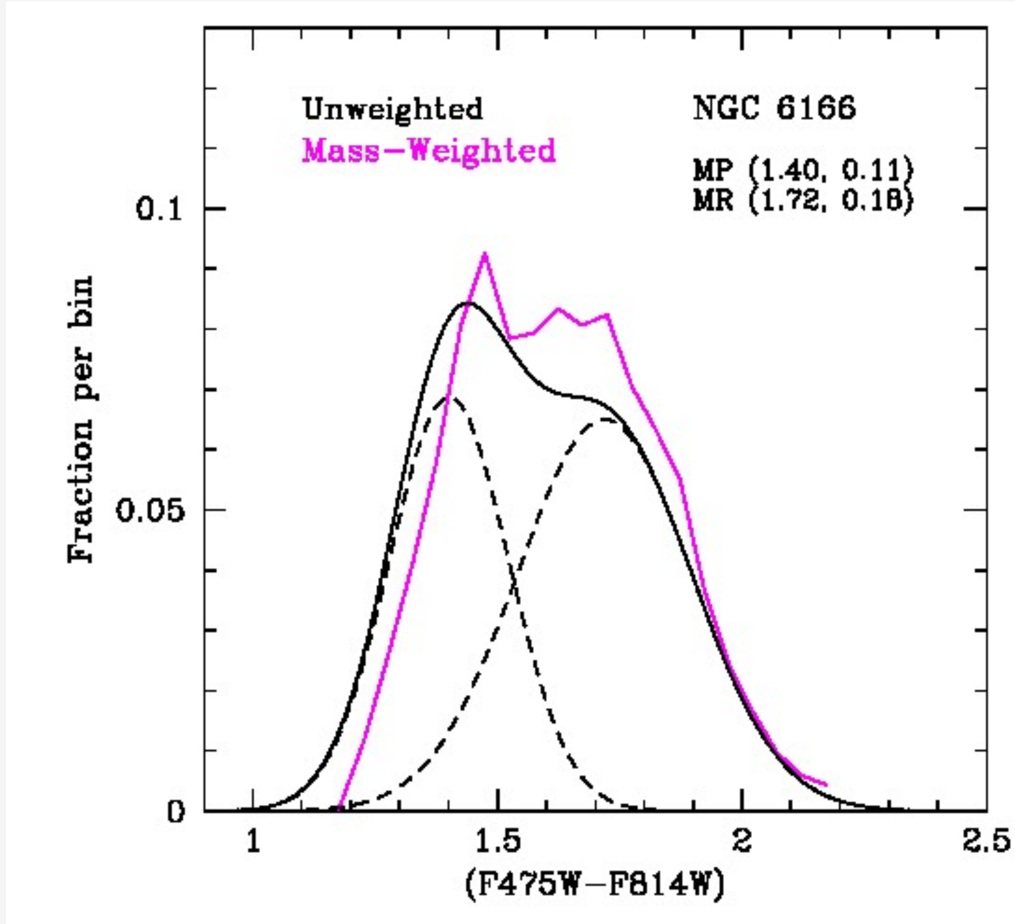
Mass-weighted MDFs compared with "normal" unweighted version



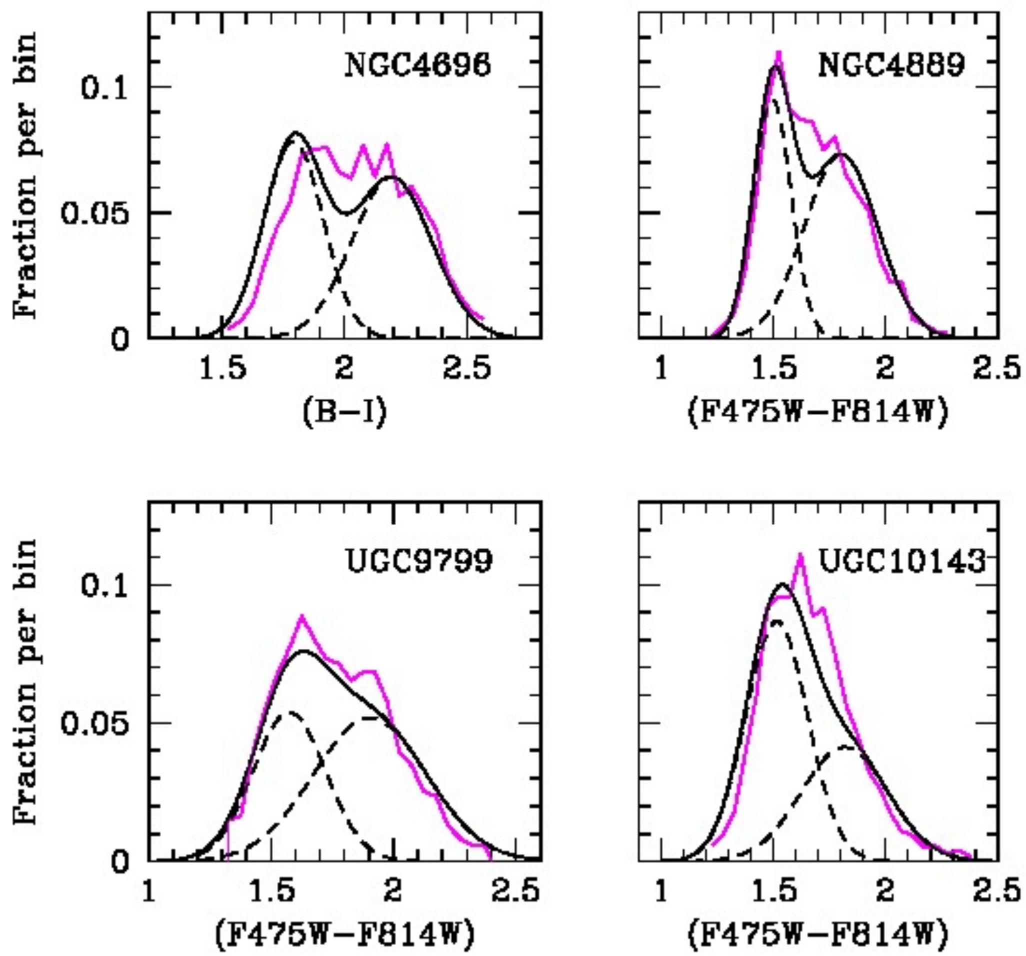




NGC 6166
R > 20''
F814W magnitude
F475W−F814W
22
24
26
28
0.5
1
1.5
2
2.5



Unweighted
Mass−Weighted
NGC 6166
MP (1.40, 0.11)
MR (1.72, 0.18)
Fraction per bin
(F475W−F814W)
0
0.05
0.1
1
1.5
2
2.5

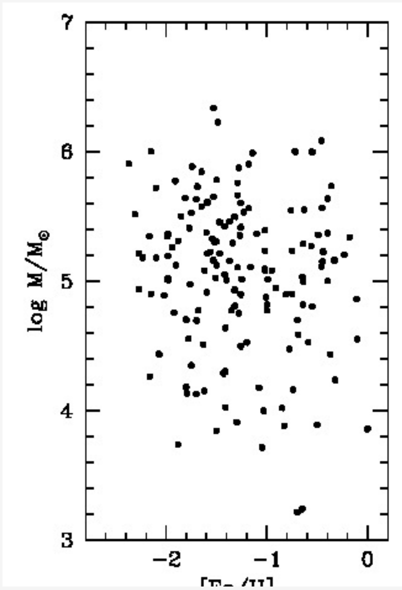


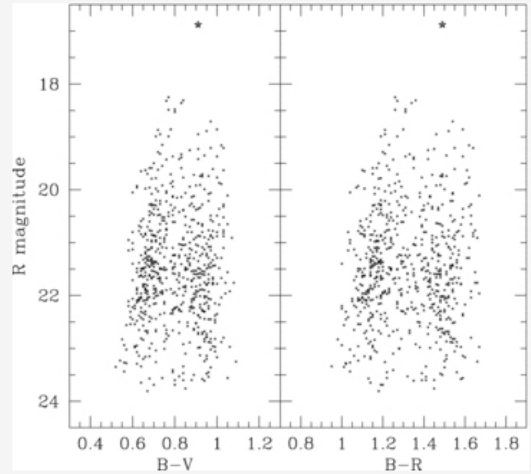
In the BCGs the *mass* in clusters is *more continuously distributed with metallicity*

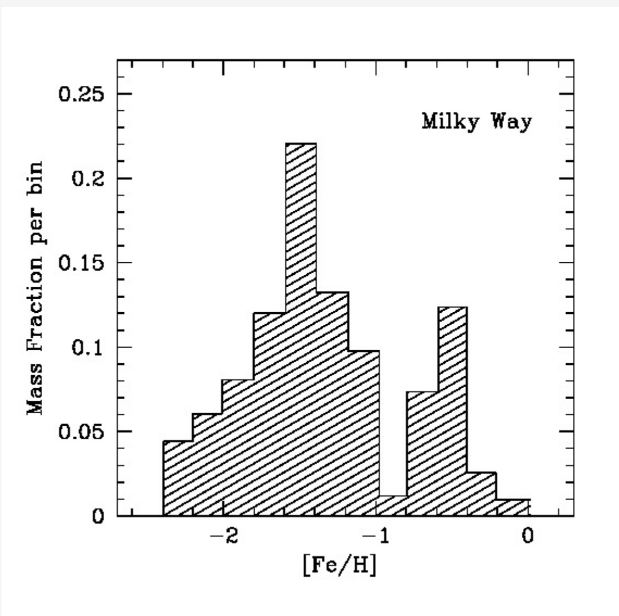
Very high-mass, very low-metallicity GCs are missing – their formation in small, metal-poor halos is unlikely. See:

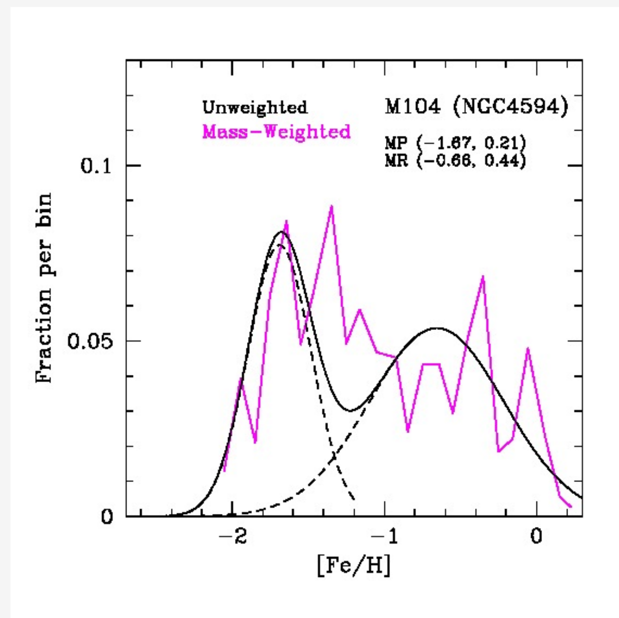
- Harris && 2006
- Choksi, Gnedin. & Li 2018
- Usher && 2018

Mass-weighted MDF less useful for smaller N!







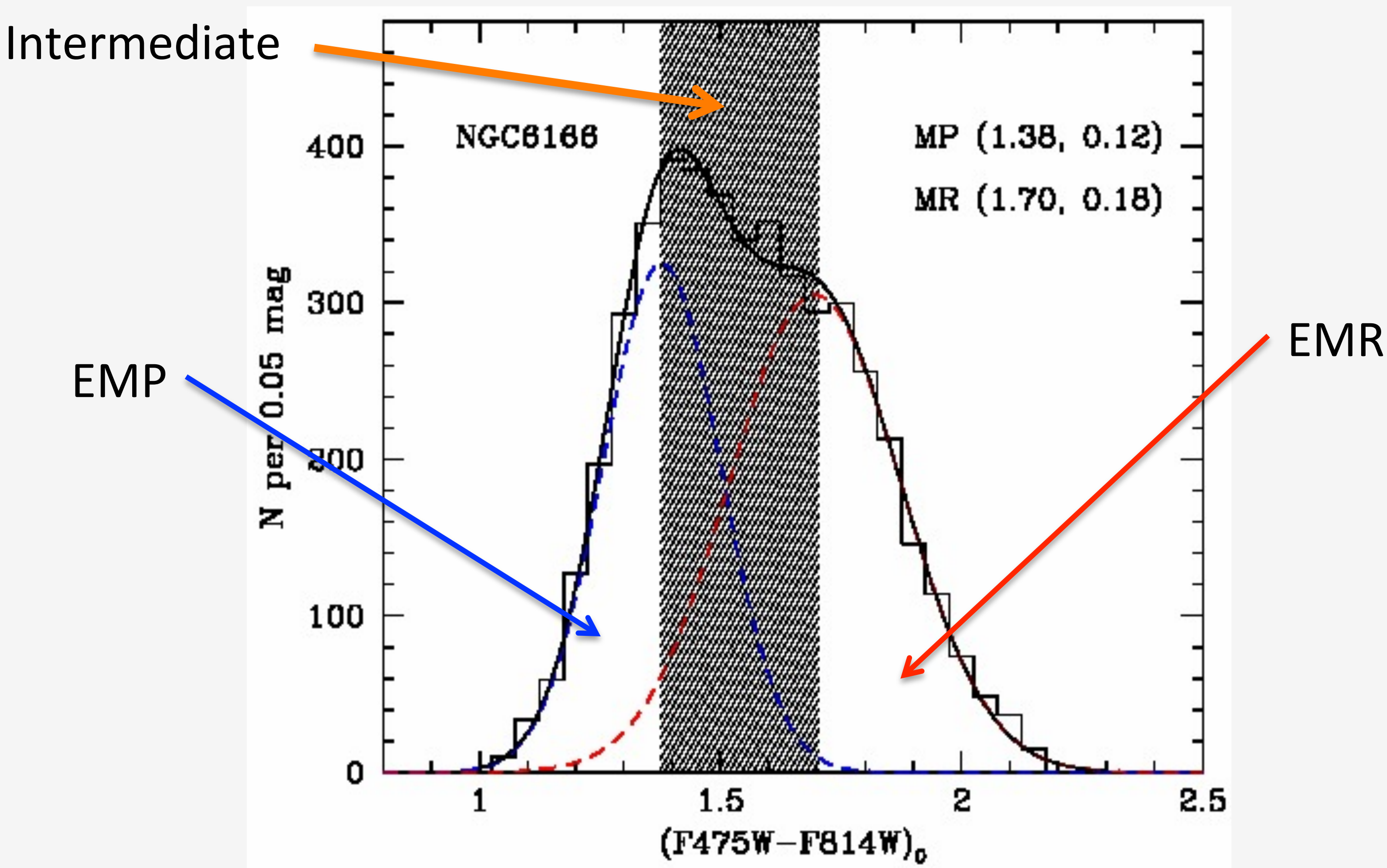


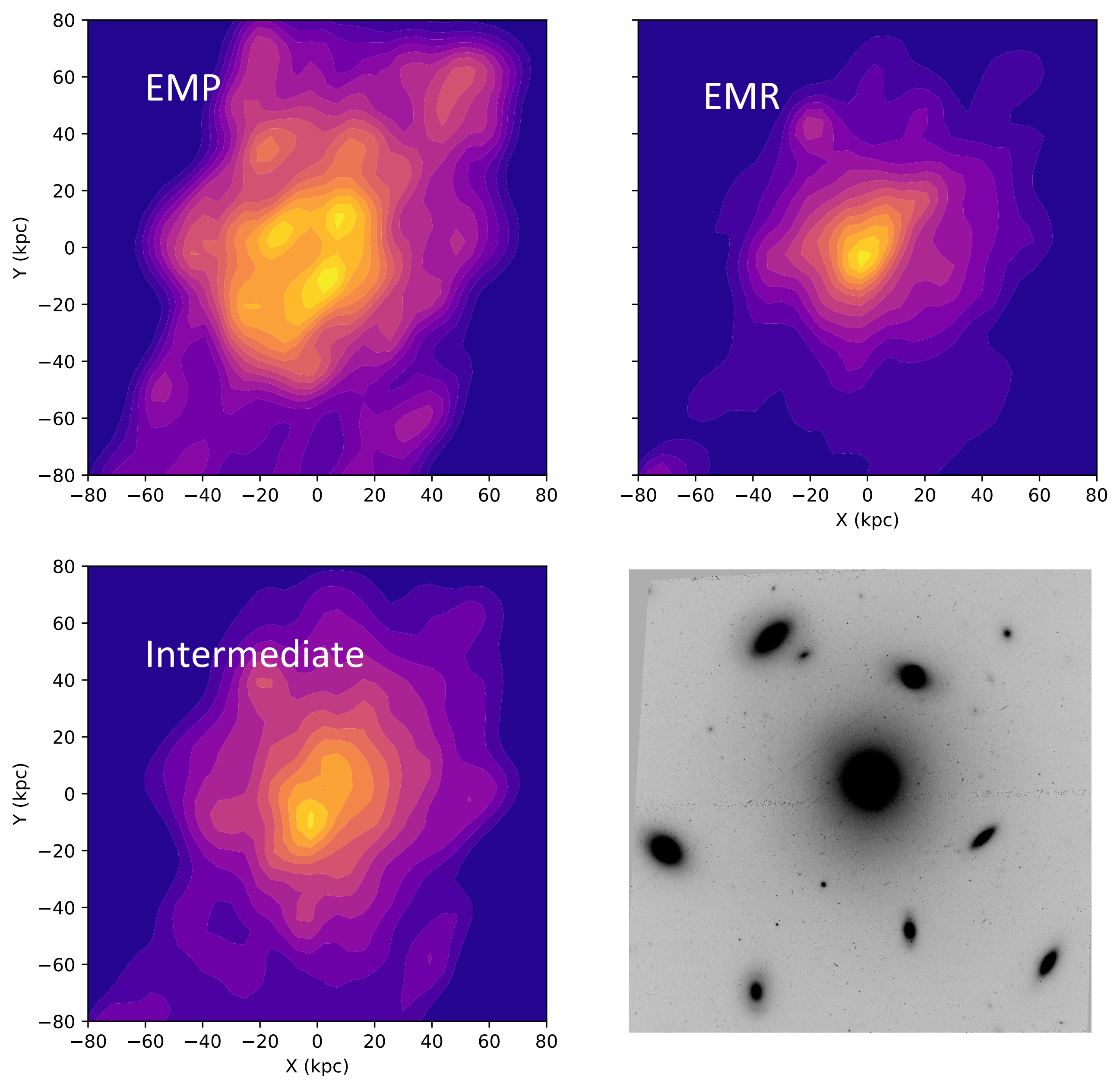
Define subcomponents

EMP = GCs bluer than the blue peak

EMR = GCs redder than the red peak

Intermediate = in between

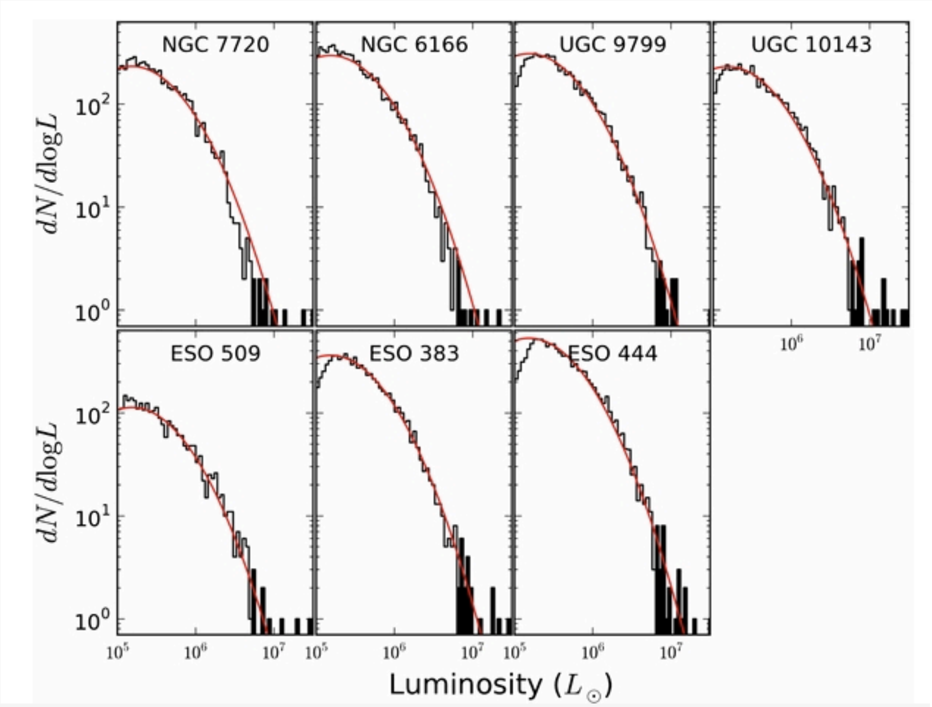




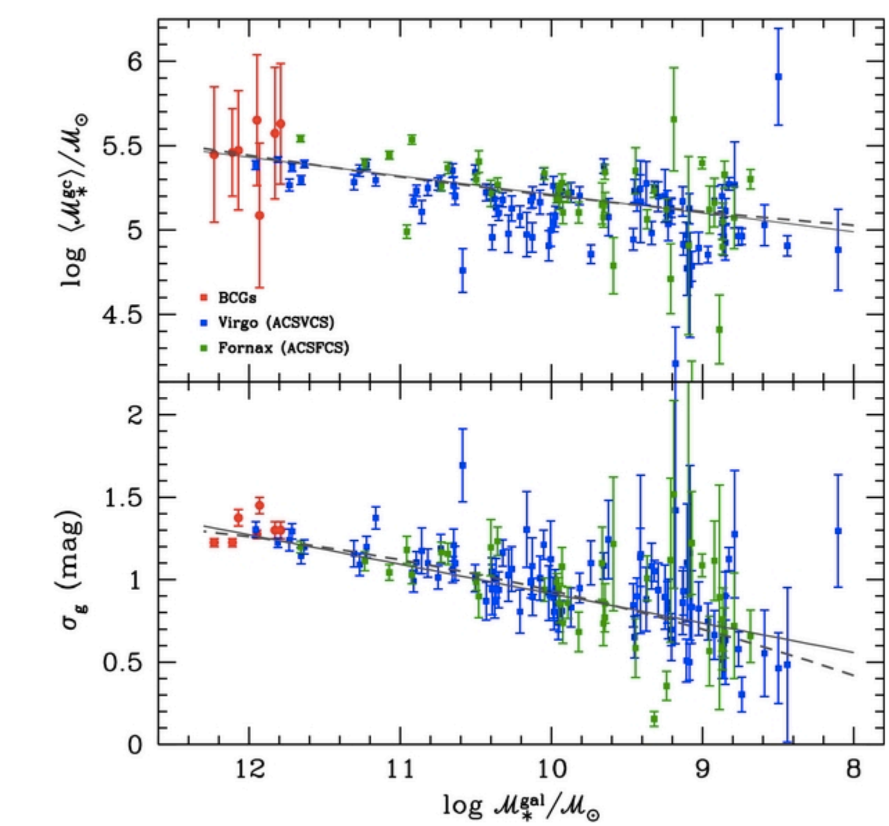
NGC 4874 (Coma)

Spatial distributions

GCLFs extremely similar!



Trends in GCLF peak and dispersion, defined by smaller galaxies, continues smoothly upward

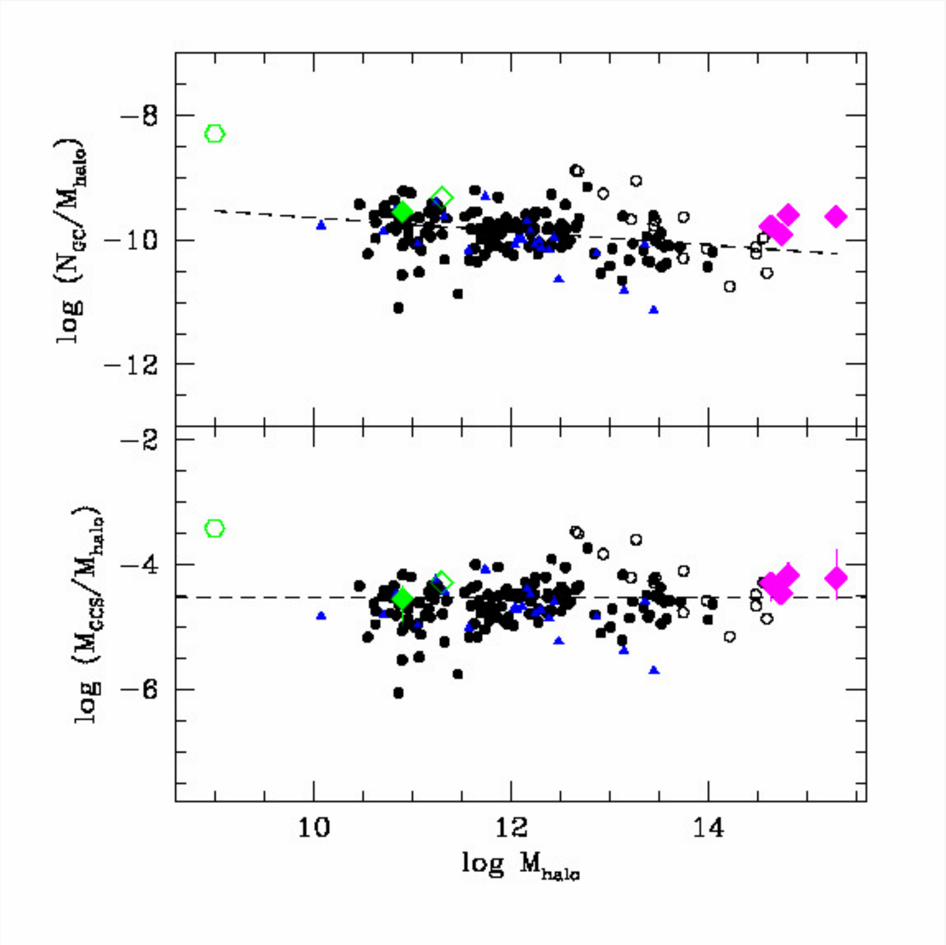


Harris et al. 2014
Villegas et al. 2010

Extremely simple correlation between GCS and total mass M_h of a galaxy (where $M_h = M_{bary} + M_{DM}$)

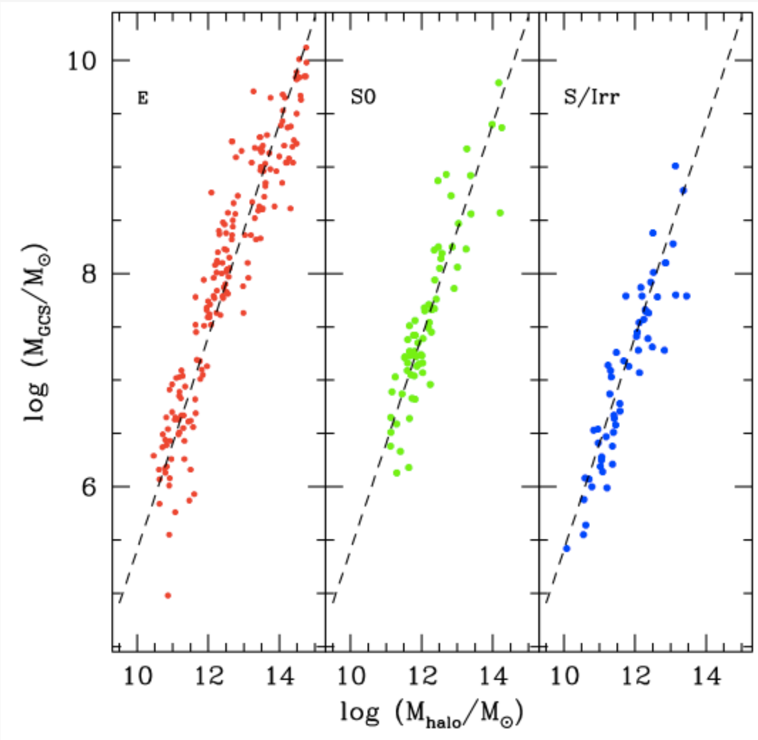
$$\eta_N = N_{GC} / M_h$$
$$\Rightarrow N_{GC} \sim M_h^{0.9}$$

$$\eta_M = M_{GCS} / M_h$$
$$\Rightarrow M_{GCS} \sim M_h^{1.0}$$



Harris, Blakeslee, & Harris 2017

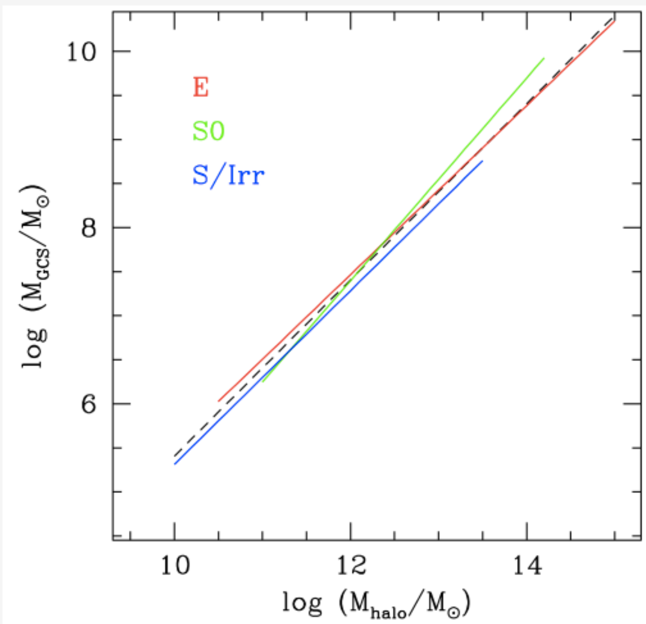
What about host galaxy type (morphology)?



$$M(GCS) \sim M_h^{0.96\pm0.02} \quad Ellipticals$$

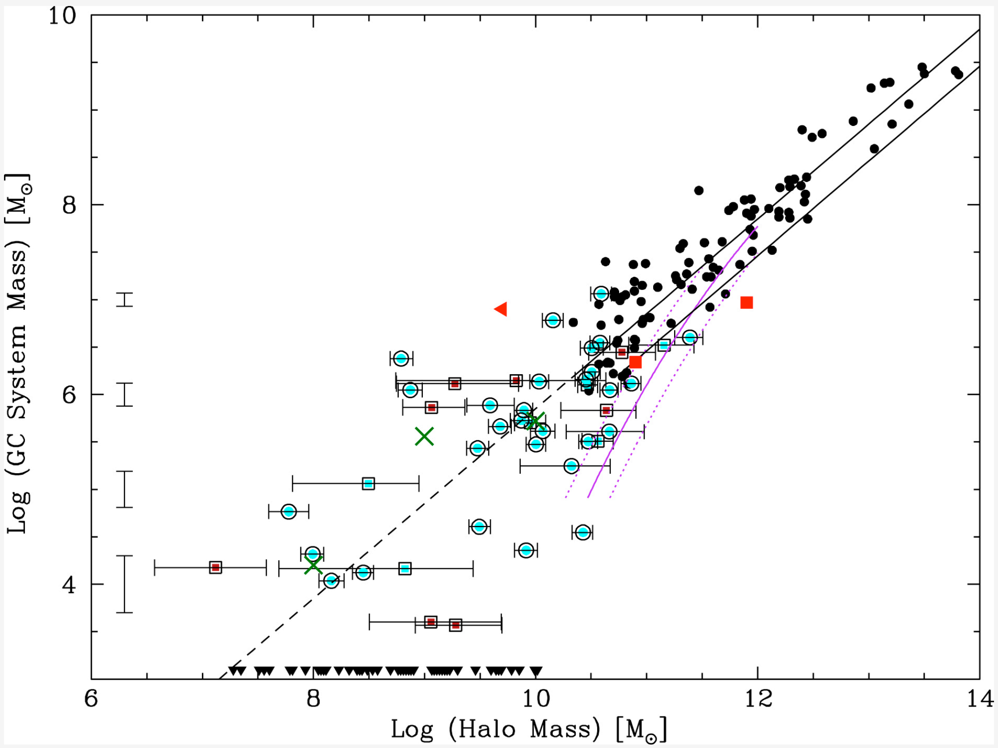
$$M(GCS) \sim M_h^{1.15\pm0.05} \quad S0's$$

$$M(GCS) \sim M_h^{0.99\pm0.08} \quad S/Irr$$



S/Irr offset (0.18 +- 0.06) dex below E/S0 types. Globally "less efficient" at forming GCs? (by 30-40% nominally)

Extending the correlation to < 10^{10} $M_{\odot}$ (dwarf regime) reveals huge scatter, with many small galaxies having no GCs



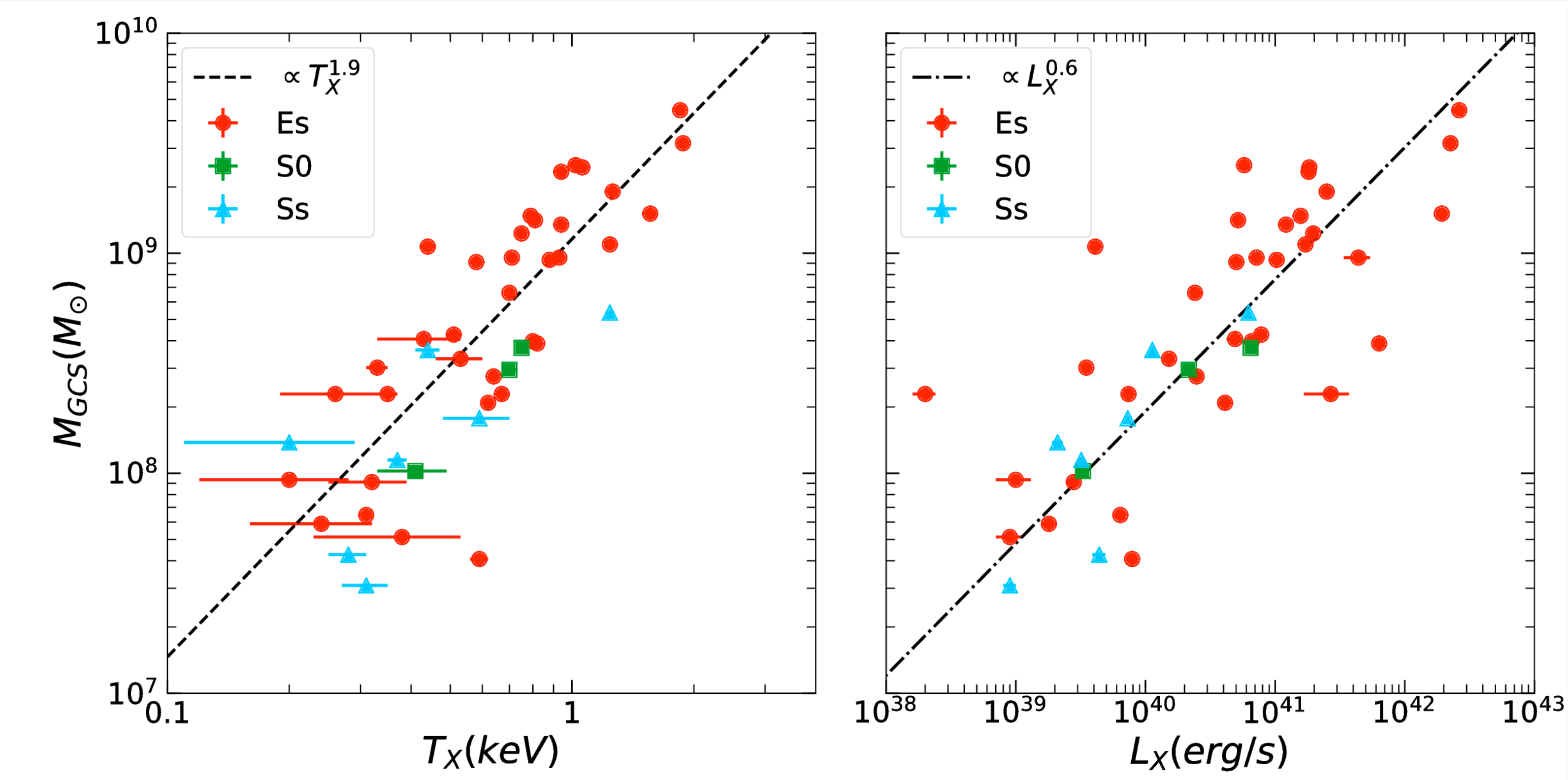
Forbes && 2018

Hierarchical merging → roughly linear correlation for larger galaxies, as observed

Kravtsov & Gnedin 2005, ApJ 623, 650
Choksi et al. 2018, MNRAS 480, 2343
Choksi & Gnedin 2019, 1905.05199
El-Badry et al. 2019, MNRAS 482, 4528
Forbes et al. 2018, MNRAS 481, 5592

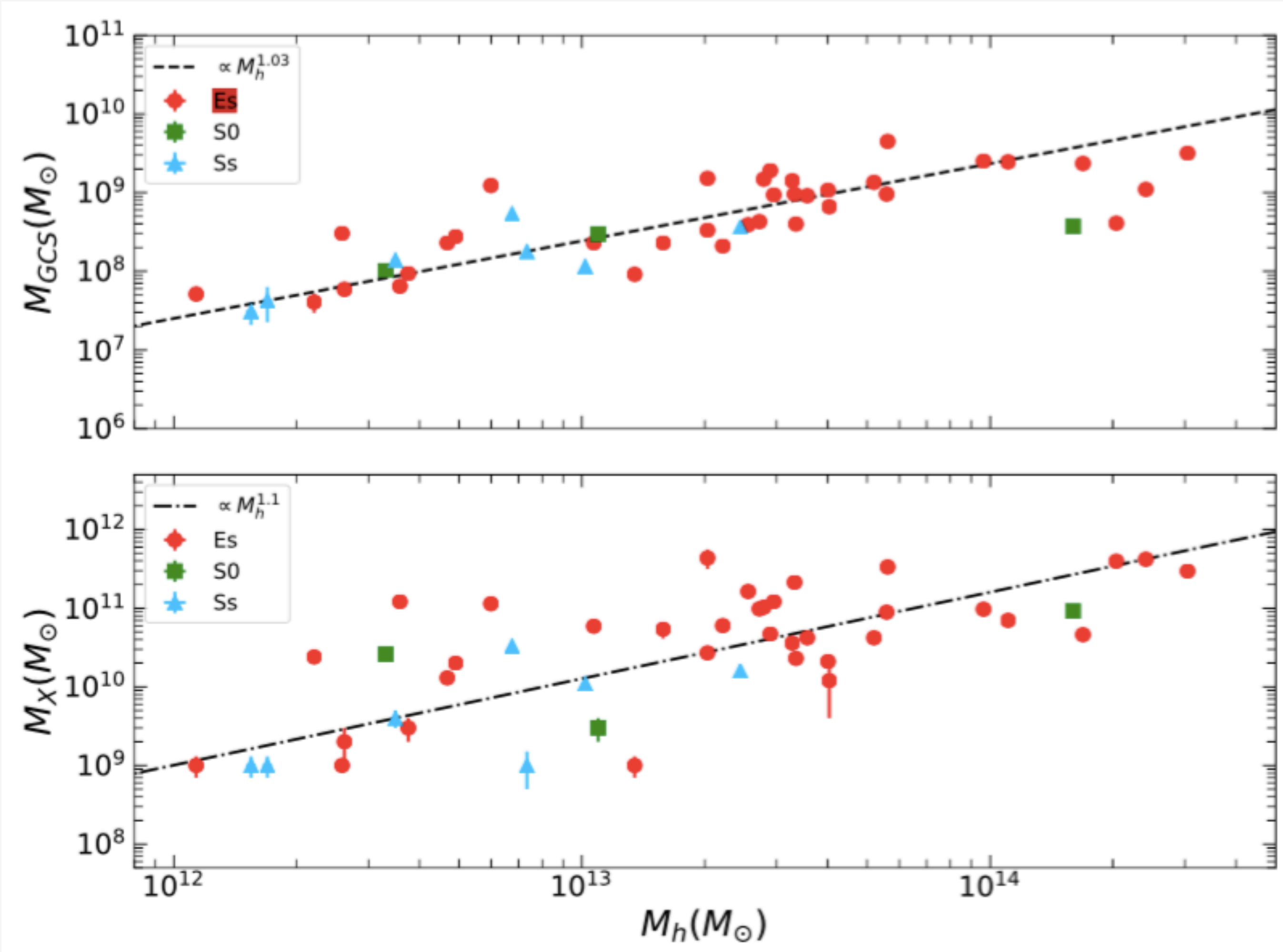
Some new correlations of GCS mass with X-ray halo mass (for galaxies > 10^{12} $M_\odot$)

T_X , M_{GCS} both indicate total depth of galaxy's potential well



G.Harris et al. 2019, ApJ submitted

See also James && 2018 (1810.09475)

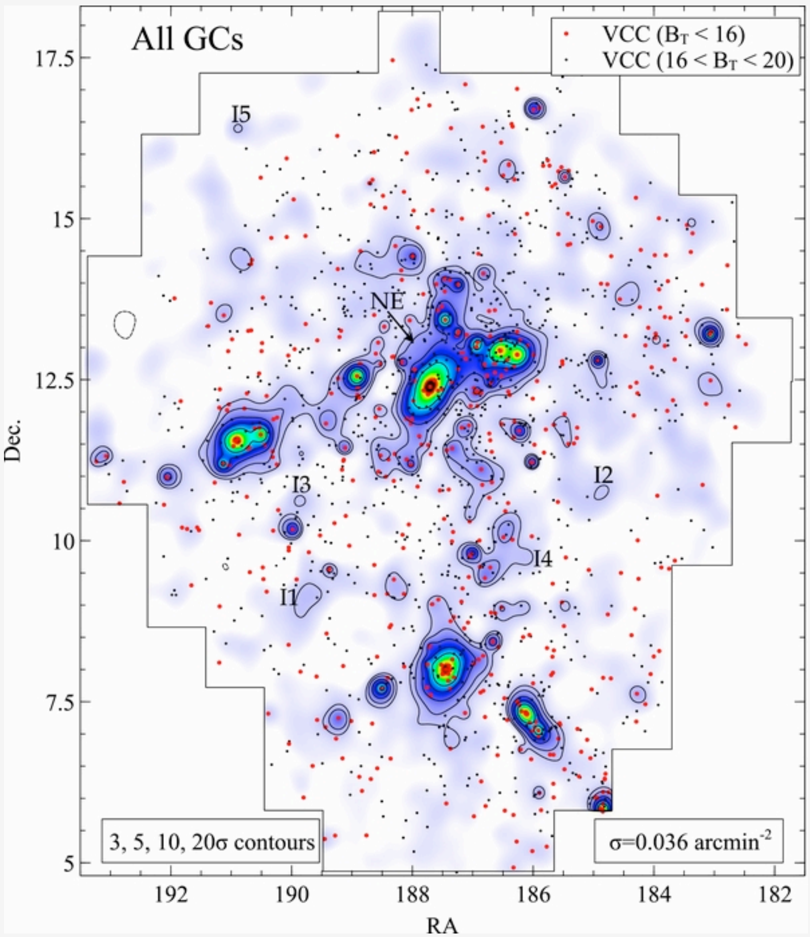


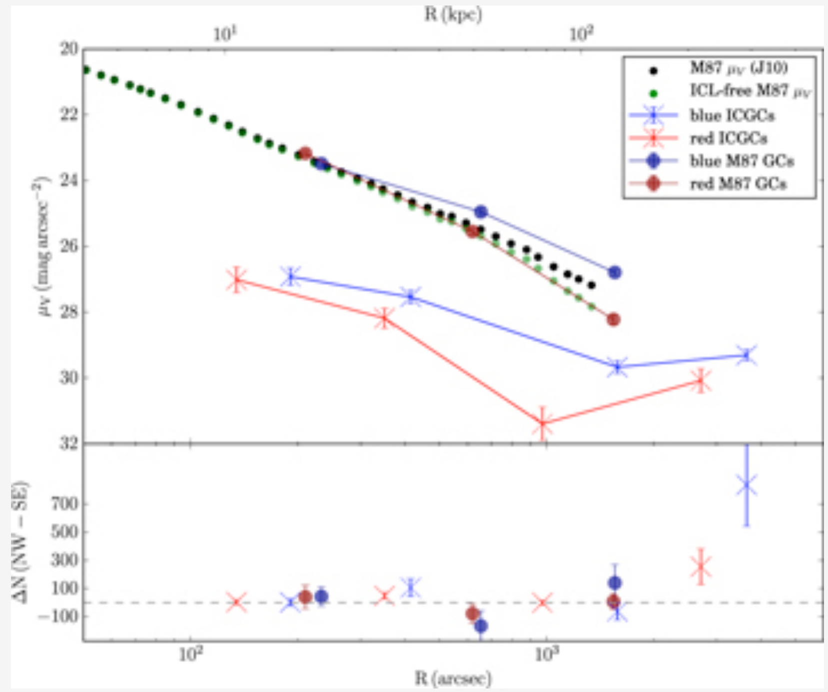
$$M_{GCS} \propto M_h^{1.0}$$
$$M_X \propto M_h^{1.1}$$
$$M_* \propto M_h^{0.35}$$

Role of feedback on inhibiting star formation much stronger – GCs are unaffected once they form

Side effect of hierarchical growth in rich environments: mutual stripping of outer halos
→ production of intracluster light
Measurable with GCs for galaxy clusters: most completely (to date) for Virgo (NGVS)

Durrell et al. 2014
Longobardi et al. 2018

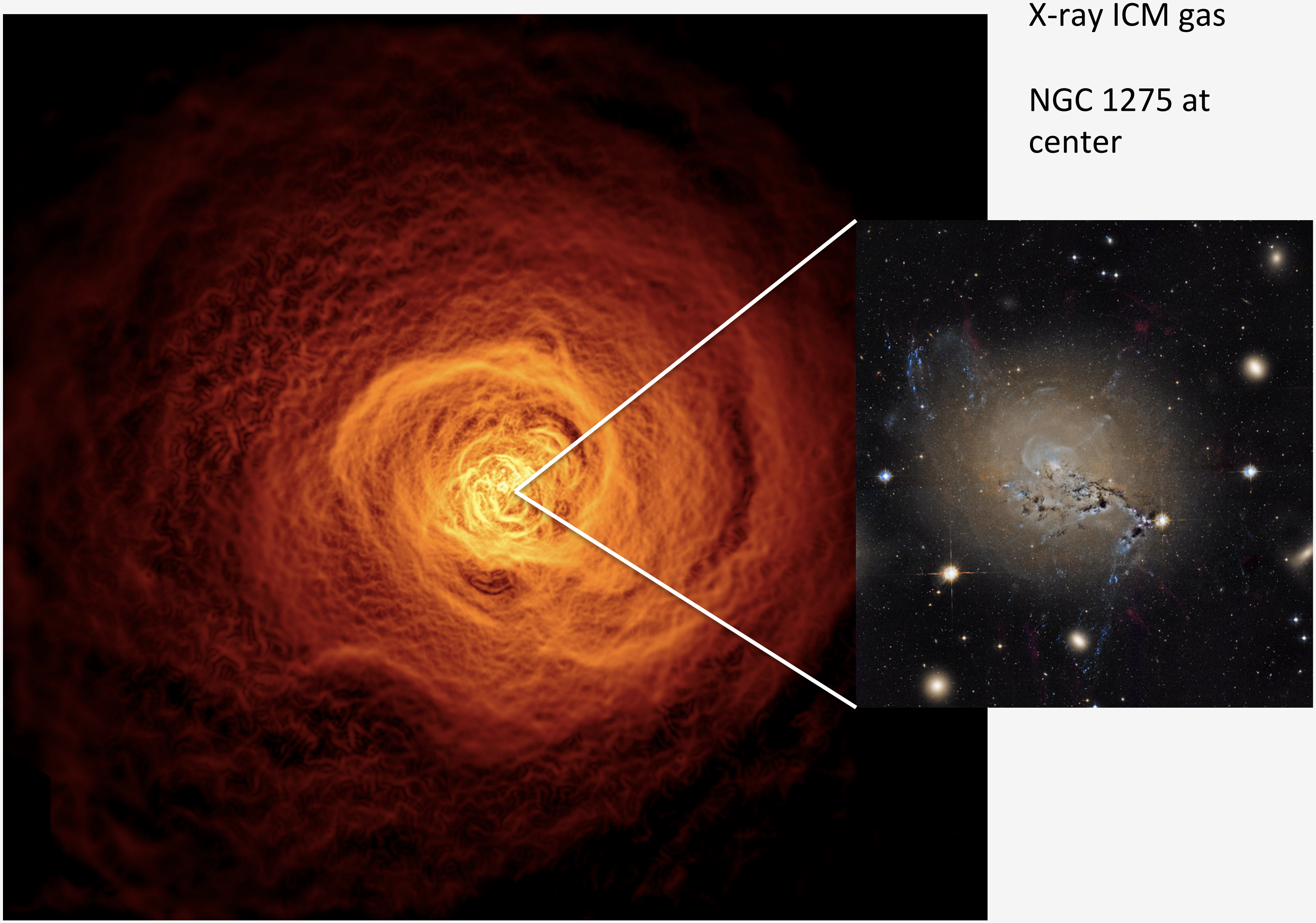




N(ICGC) ~ 5000, S_N = 10

Perseus cluster (Abell 426)

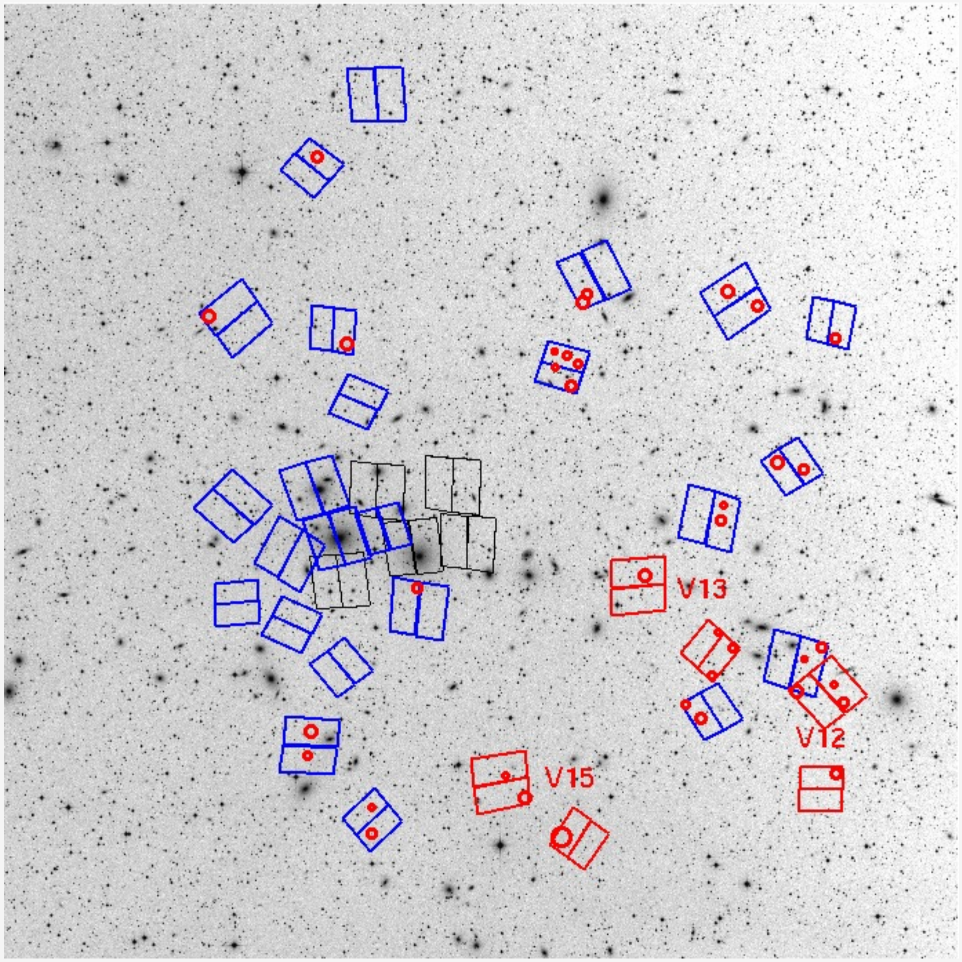
B. Franke (APOD)

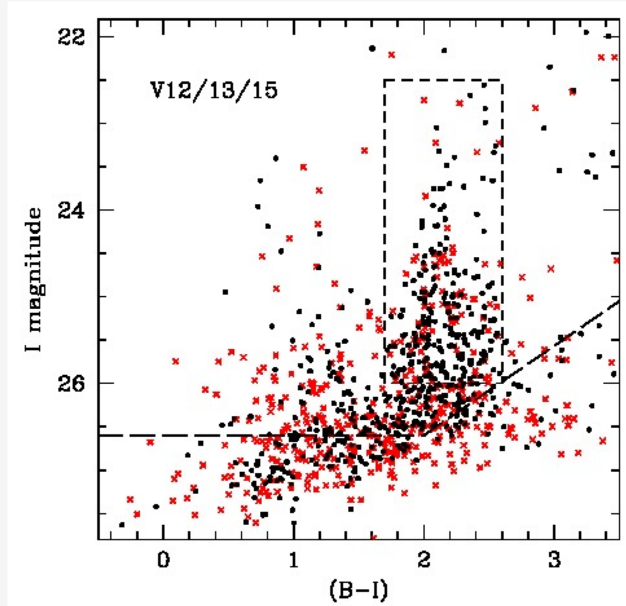


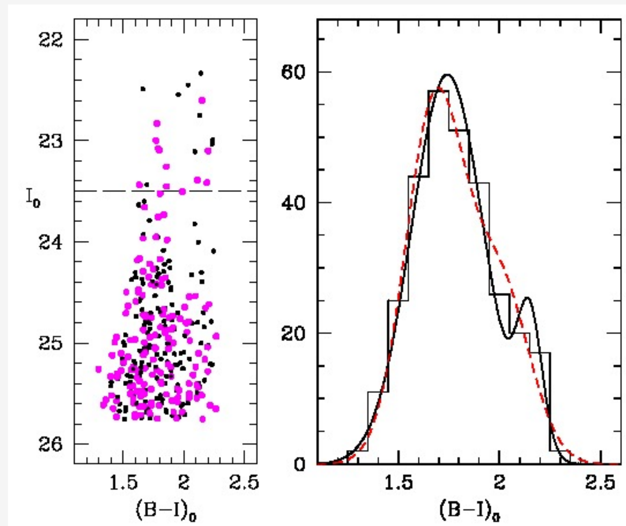
X-ray ICM gas

NGC 1275 at center

HST-based imaging project (PIPER) in progress



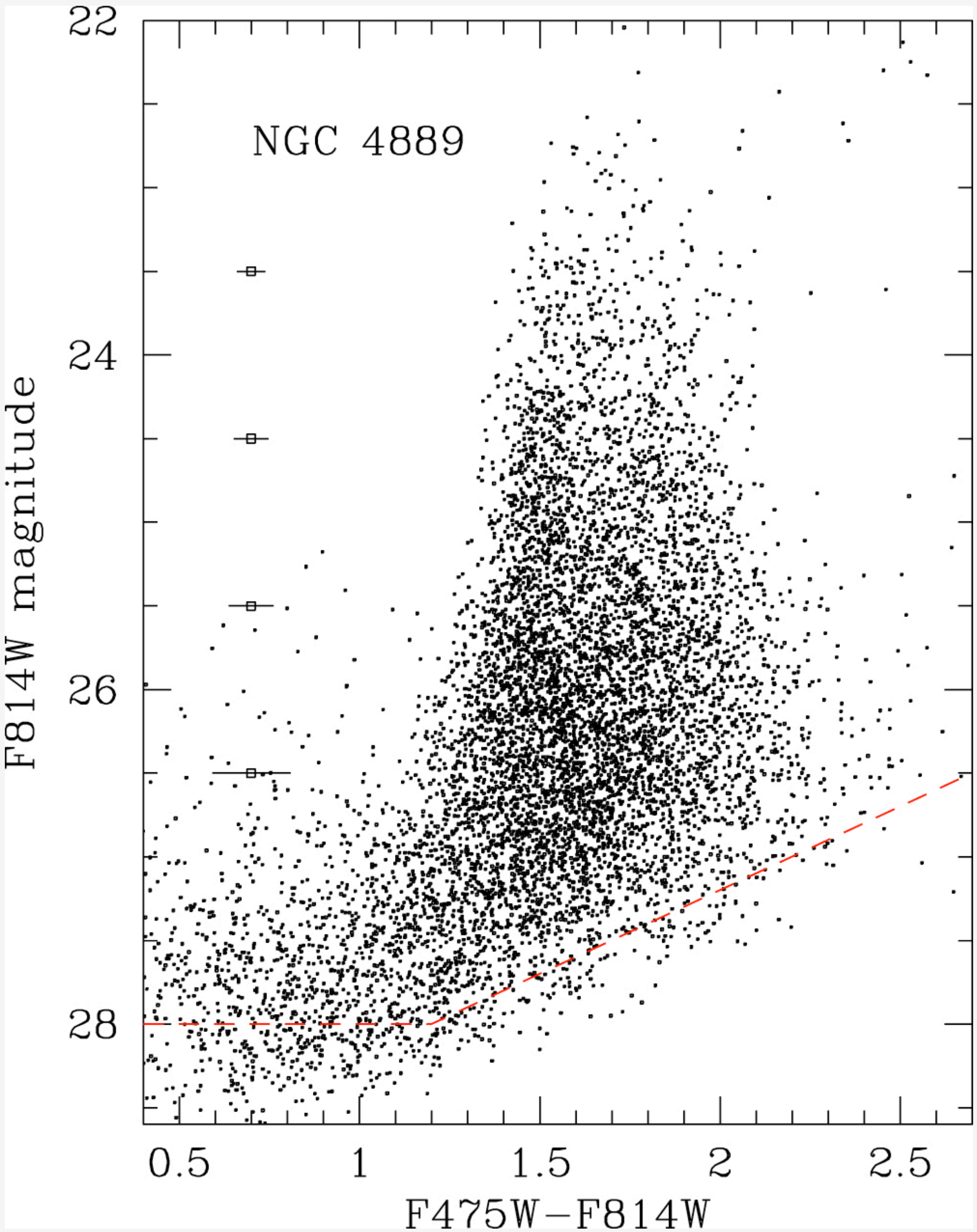




Also: major core galaxies, UDGs, UCDs …

Plus Subaru HSC imaging! Covers entire region


What implications do the observations have for
globular cluster formation?

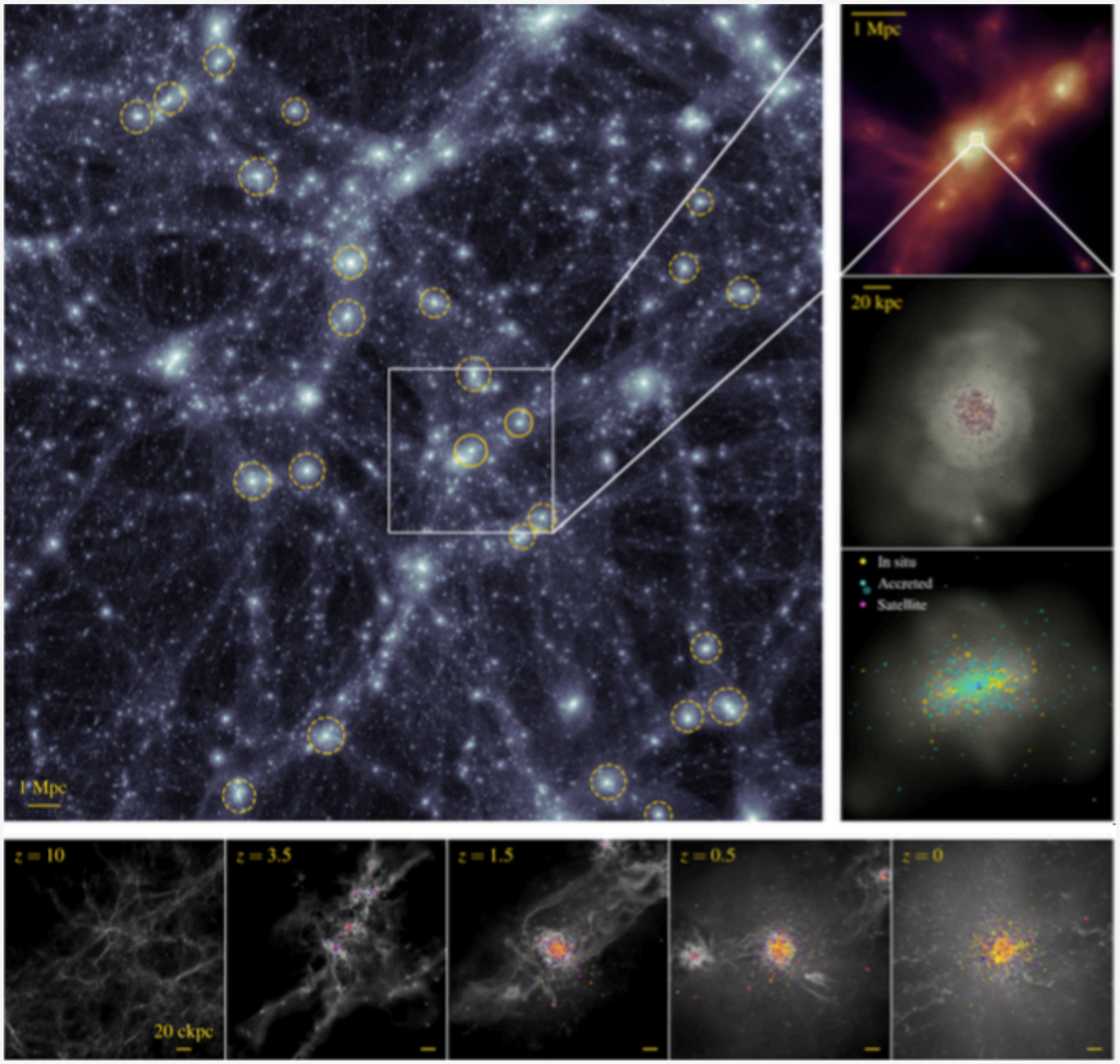


Continuity of properties over factors of 200x in metallicity and 10,000x in mass.

Globular clusters are
unusual
But they are not
special

(Dean McLaughlin)

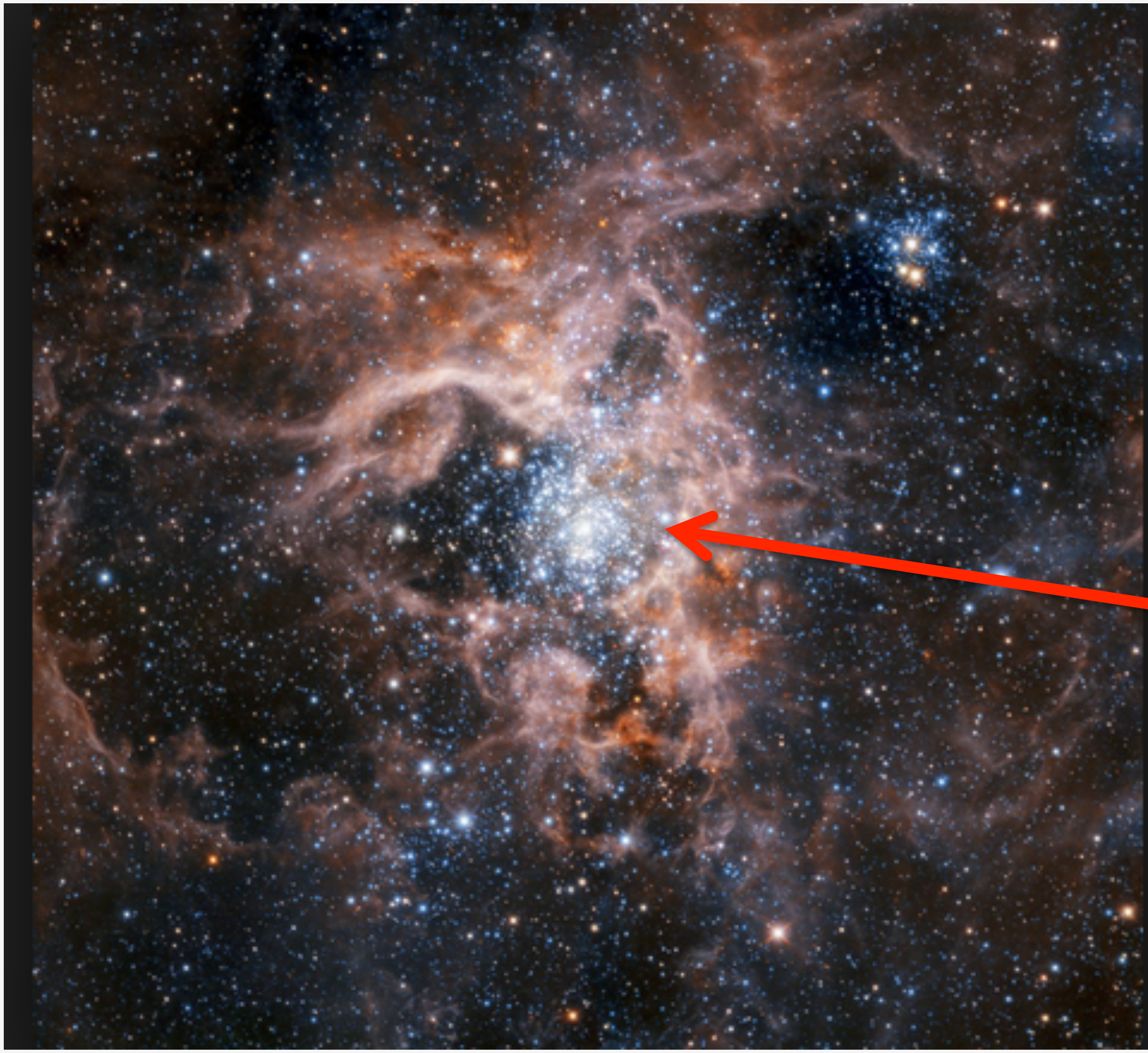
What features of star cluster formation are *different at high mass* that do not occur at low mass? Anything at all?



Recent models bridge cosmological simulations to sub-galaxy scales and star formation

Kruijssen et al. 2018

Drill down to smaller scales! Bridge to GMCs and ultimately star formation within clusters at sub-parsec scales



GMCs (of the right size and mass) are ultimately the sites of GC formation

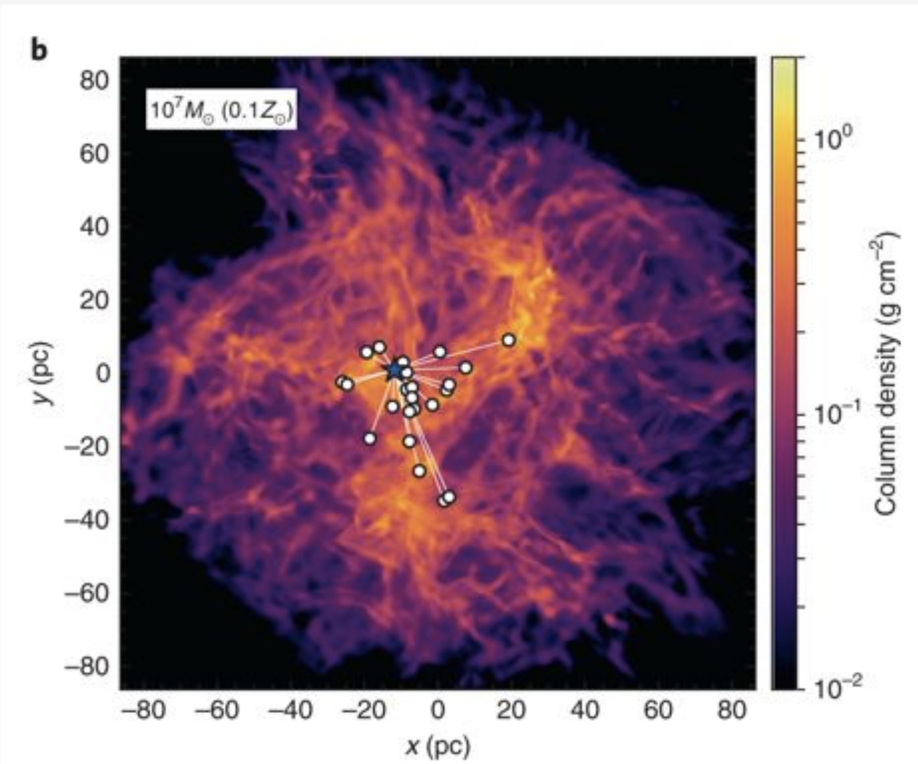
30 Dor
Complex

R136

ESO

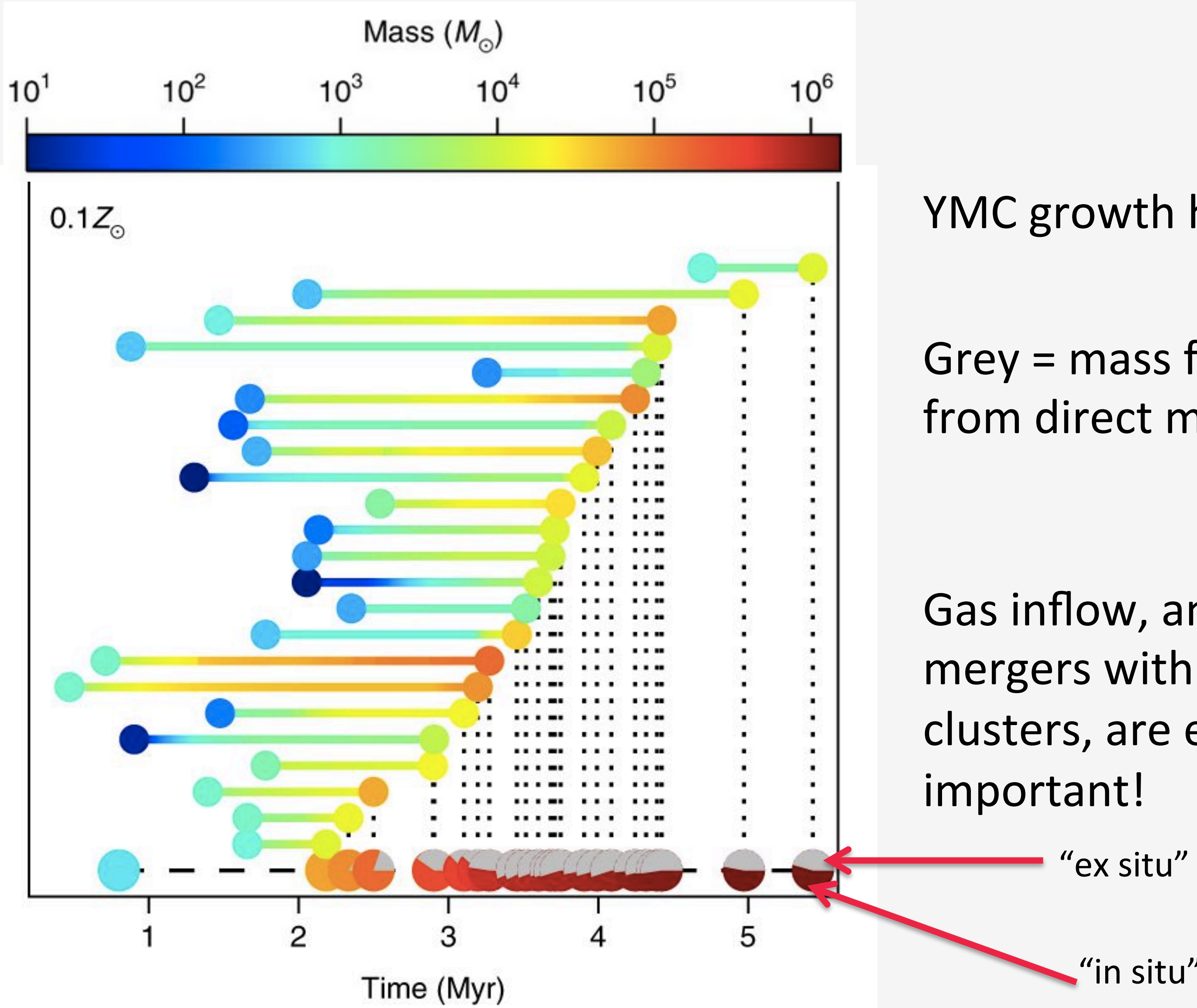
Radiative hydrodynamic (RHD) simulation of turbulent GMCs with FLASH2.5: suite of models covering $10^4 - 10^7\ M_\odot$, metallicities 1 and 0.1 $Z_\odot$, and range of virial parameters

Covers first ~5 My of GMC's history (before SNe)
Traces radiative and ionizing feedback from SF on the surrounding GMC



Young star clusters represented by high-density, gravitationally bound spots along the gaseous filaments

See:
Howard et al. 2017, 2018, 2019

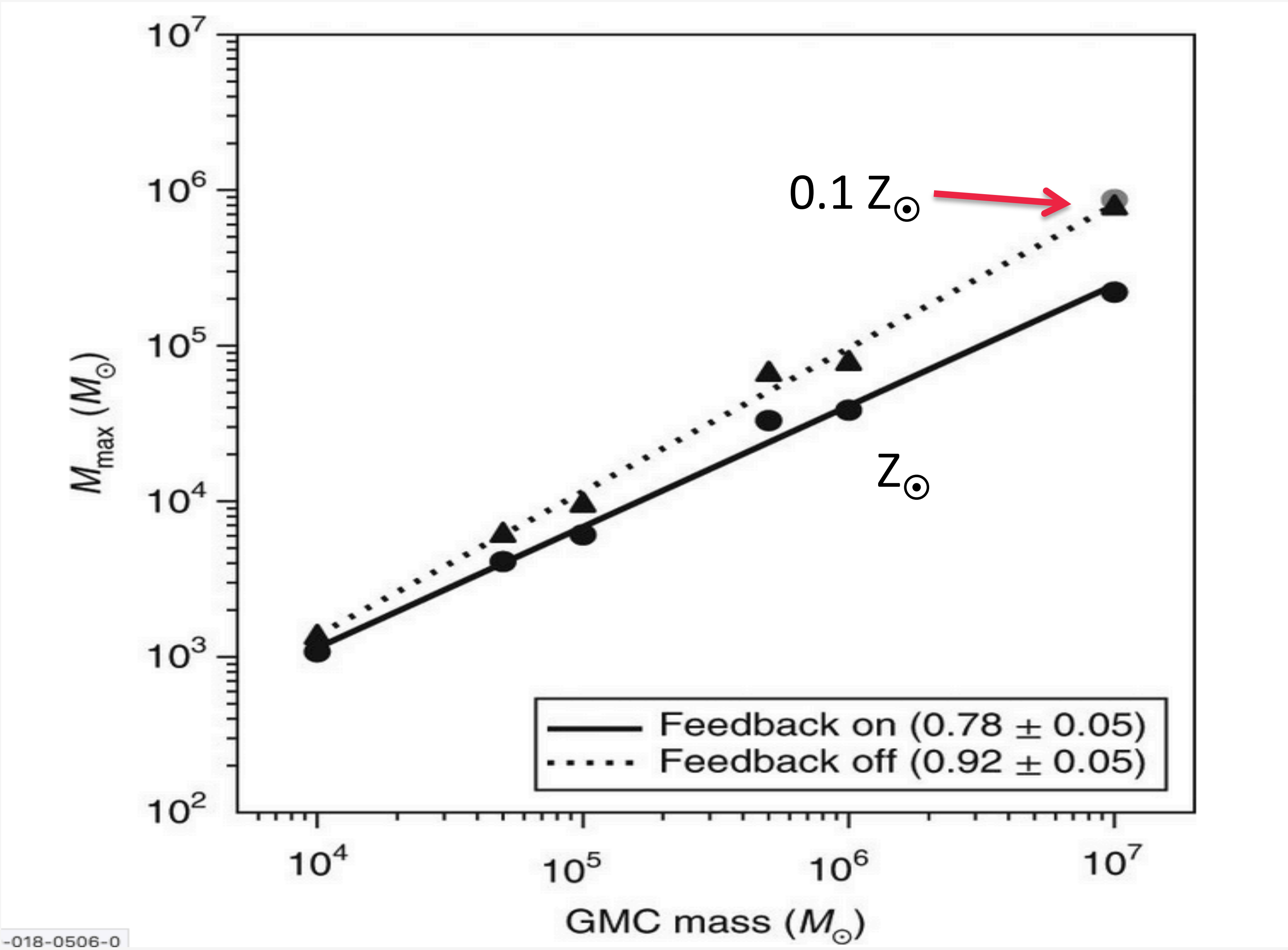


YMC growth history

Grey = mass fraction from direct mergers

Gas inflow, and mergers with smaller clusters, are equally important!

Mass of biggest central YMC is nearly proportional to GMC mass



More material to come! Works in progress

- HST-based BCG survey for GC populations
- Further exploration of M(GCS) vs M(tot) relation
- Perseus cluster imaging survey; the ICM
- Modelling of YMC growth and evolution

With thanks to my colleagues on the BCG program: John Blakeslee, Oleg Gnedin, Brad Whitmore, Doug Geisler, Pat Cote, Jeremy Bailin, Eric Peng, Barry Rothberg, Elizabeth Wehner, Warren Morningstar, Heather O’Halloran, Regina De Graaff, Stephanie Ciccone, Gwen Eadie