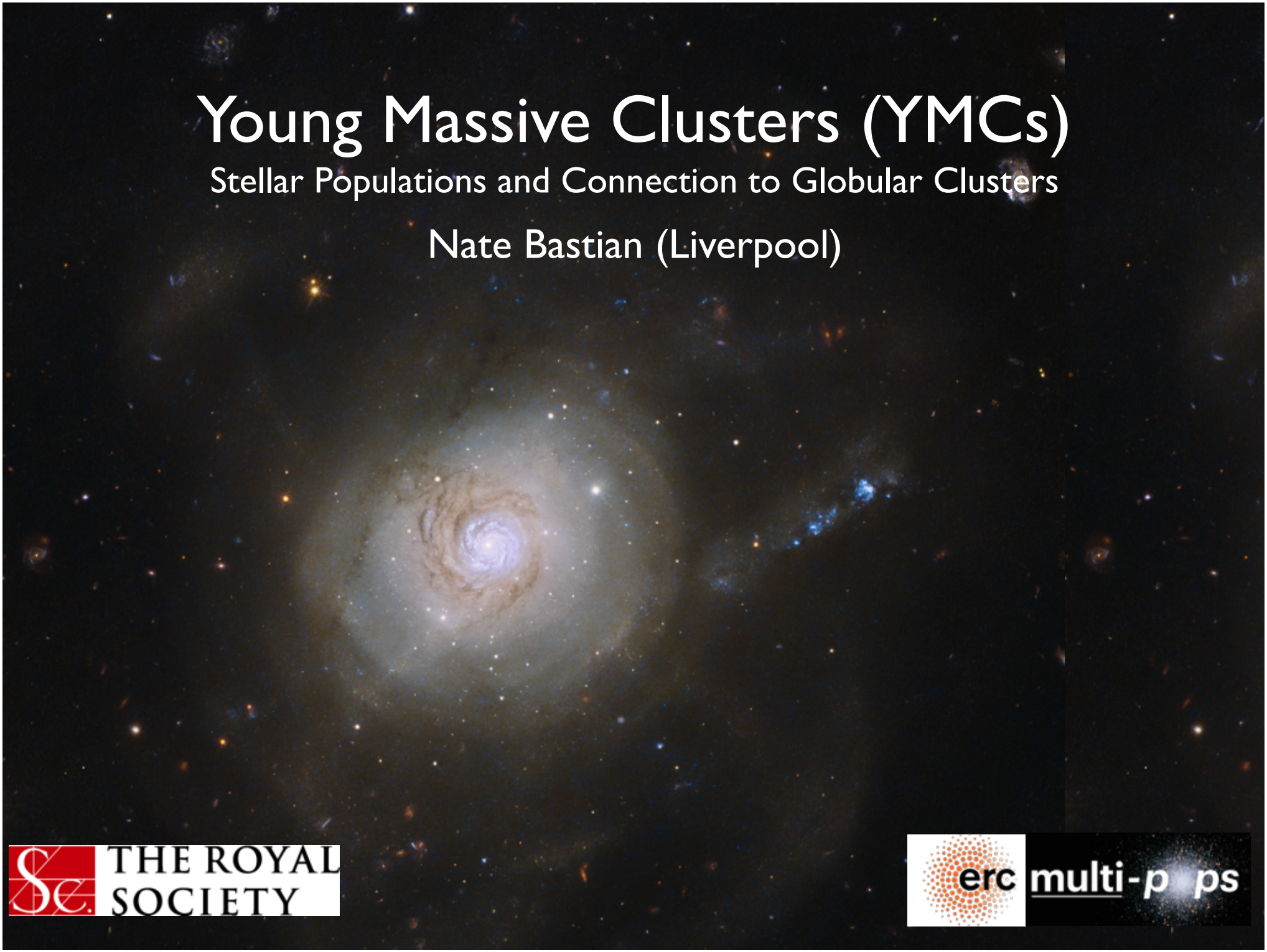
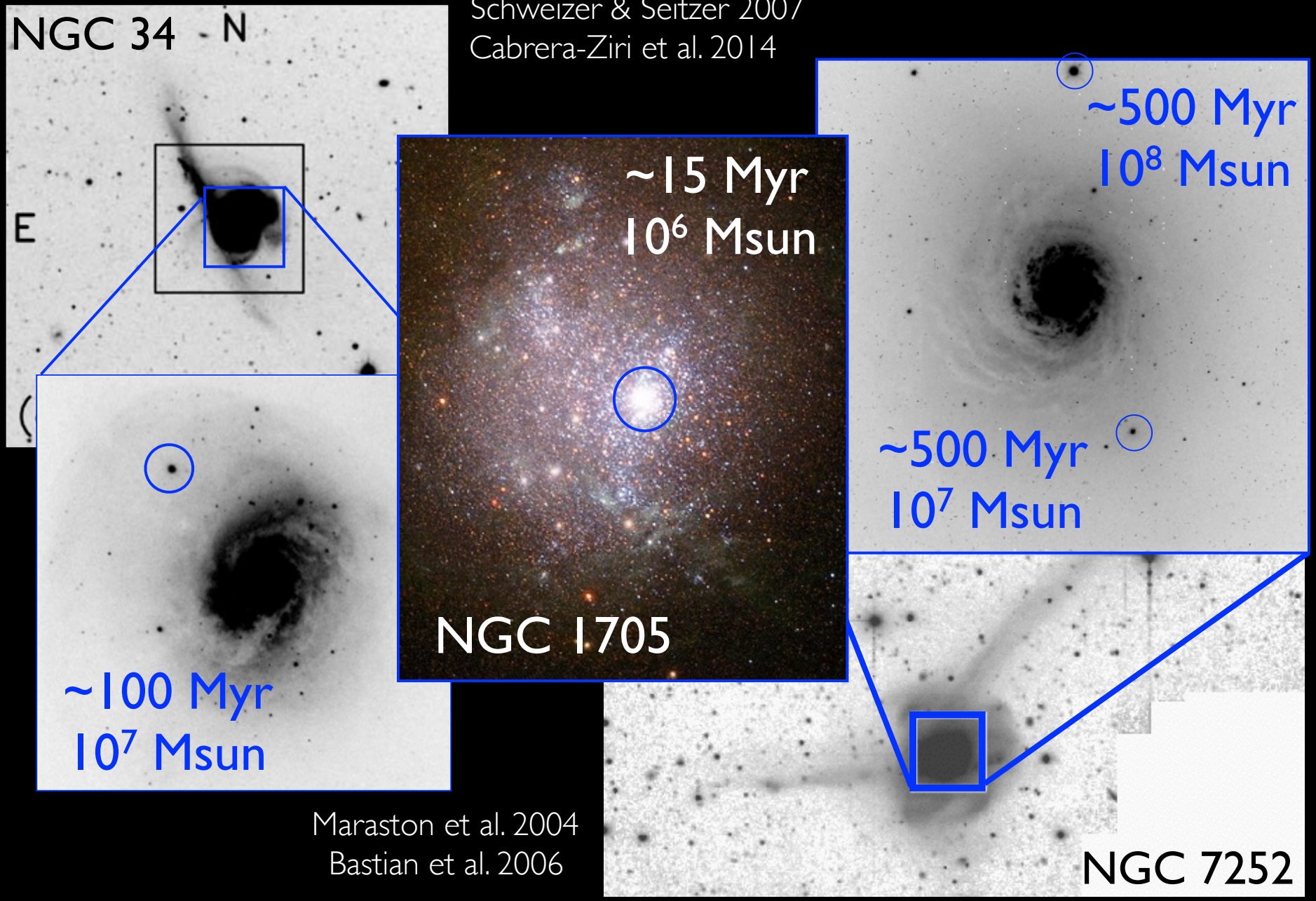

Young Massive Clusters (YMCs)
Stellar Populations and Connection to Globular Clusters
Nate Bastian (Liverpool)
THE ROYAL SOCIETY
erc
multi-p ps

Introduction to Stellar Clusters

Open Clusters
few - 10^4 Msun
few Myr - few Gyr
~solar metallicity
disk of the Galaxy

Globular Clusters
10^4 - 10^6 Msun
10 - 13 Gyr
low metallicity
bulge/halo of the Galaxy

Young Massive Clusters (YMCs)



Schweizer & Seitzer 2007
Cabrera-Ziri et al. 2014

Maraston et al. 2004
Bastian et al. 2006

few million Msun
~12 Gyr

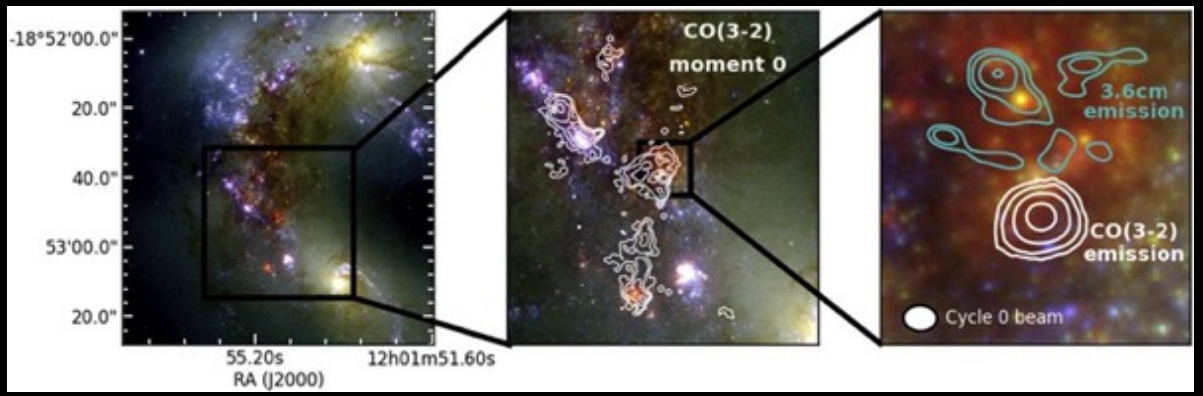
globular clusters are still forming in the local universe

few million Msun
~7 Myr

Omega Cen - ESO

Antennae colliding galaxies - HST

10 million solar mass clusters

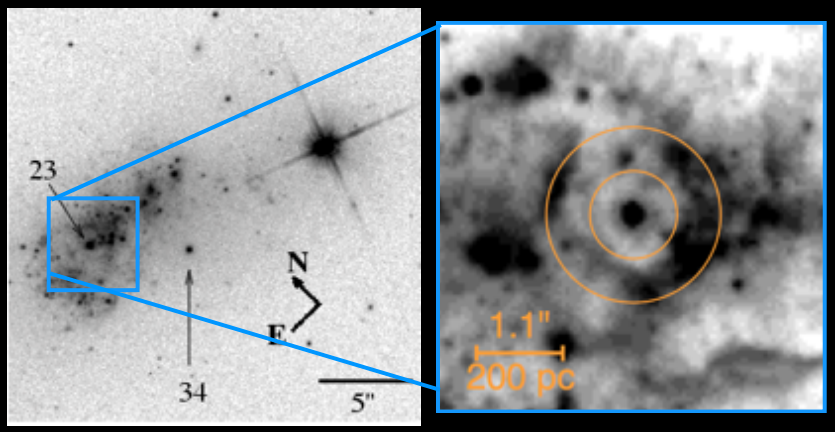


Antennae galaxies

≲1 Myr

R_{eff} < 25 pc

Johnson et al. 2015



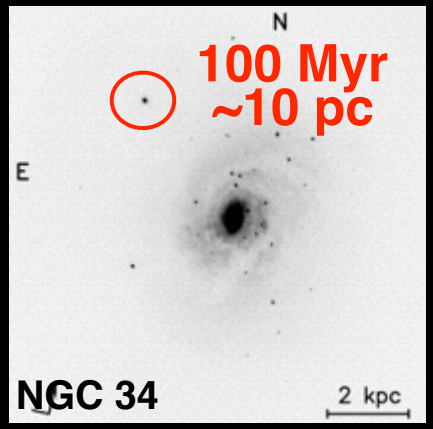
ESO 338-IG04

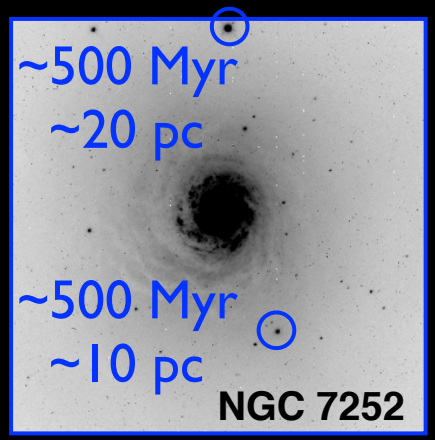
6 Myr

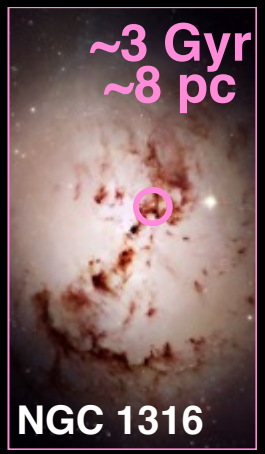
R_{eff} ~ 5 pc

Ostlin et al. 2007
Bastian et al. 2014

We have examples of 10^7 M_o at all stages of their evolution







What do we know about YMCs?

- Power-law mass function (index of -2 from ~100 to 10^8 Msun)
- High pressure environments conducive to forming high mass clusters

  Elmegreen & Efremov 1998, Kruijssen 2015
- Single bursts of star-formation (no significant age spreads)

  Bastian et al. 2013, Cabrera-Ziri et al. 2014, 2016
- Extremely efficient at removing gas/dust within them (<4 Myr)

  Hollyhead et al. 2015, Longmore 2015, Cabrera-Ziri et al. 2015
- In tension with all predictions from multiple populations scenarios

  Bastian & Lardo 2018 ARA&A

Models for multiple populations do not agree with observations of YMCs

Are multiple populations detected in YMCs?

- Clusters younger than ~2 Gyr, none spectroscopically detected

  Mucciarelli et al. 2008, 2012, 2014

- YMCs show complex CMDs. However, not likely connected to multiple populations (instead stellar rotation is the cause)

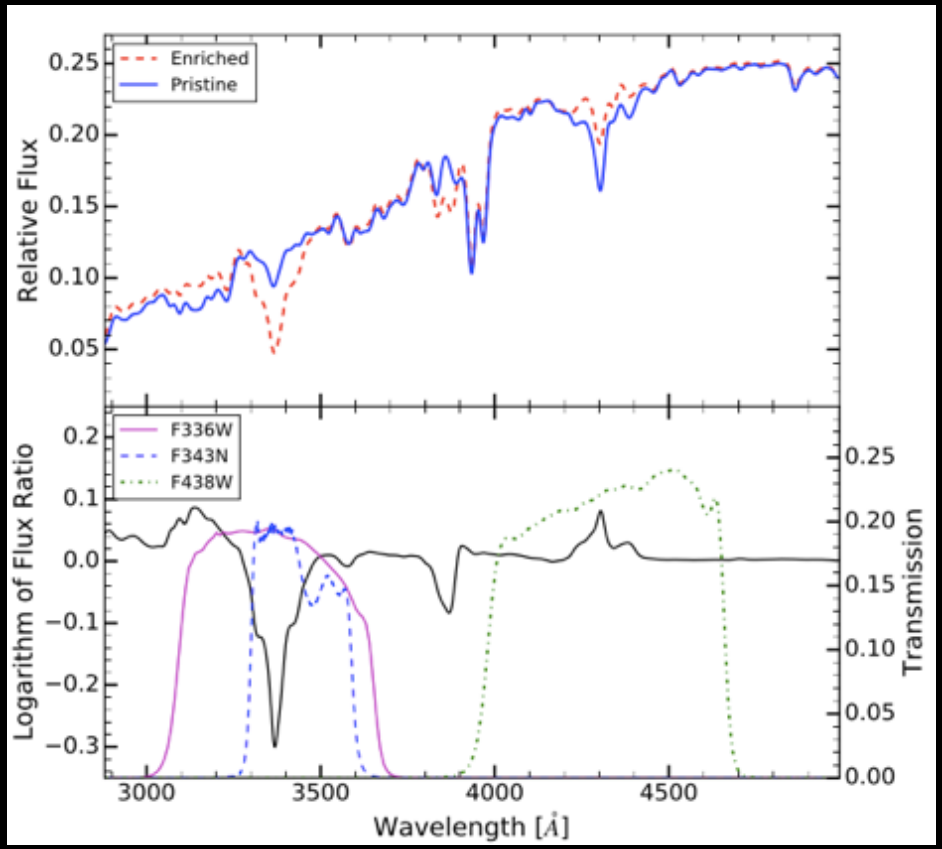
  Milone et al. 2015, 2017; D'Antona et al. 2015,2017; Bastian et al. 2015, 2017

- See upcoming Annual Review of Astronomy & Astrophysics

  Bastian & Lardo 2018

Are Multiple Populations Restricted to Old GCs?

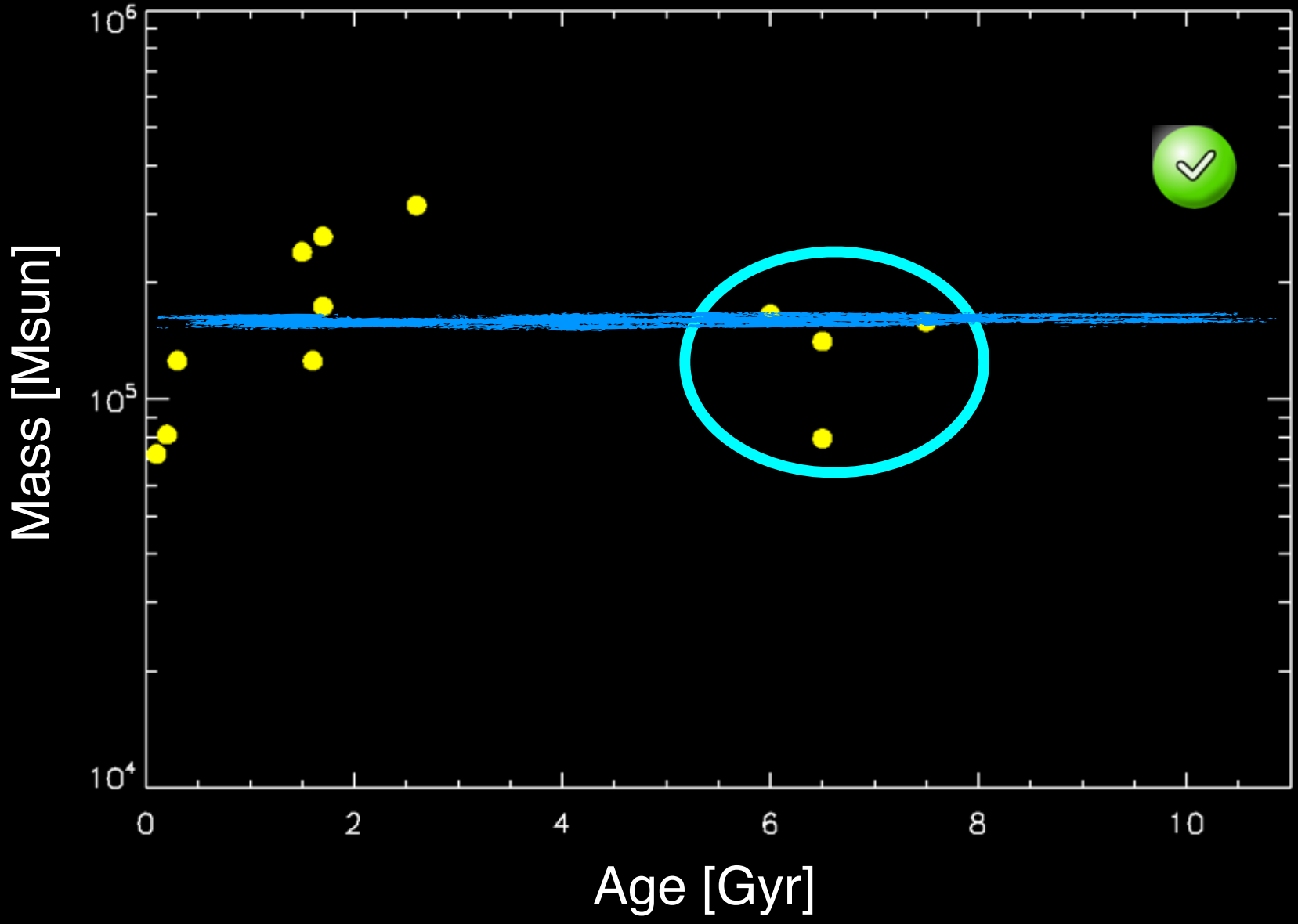
- HST study to search for multiple populations in massive (>10^5 M_o) clusters in the LMC/SMC, from 100 Myr - 11 Gyr
- VLT survey to search for N, C and O variations directly



The chosen filters pick up variations in N and O

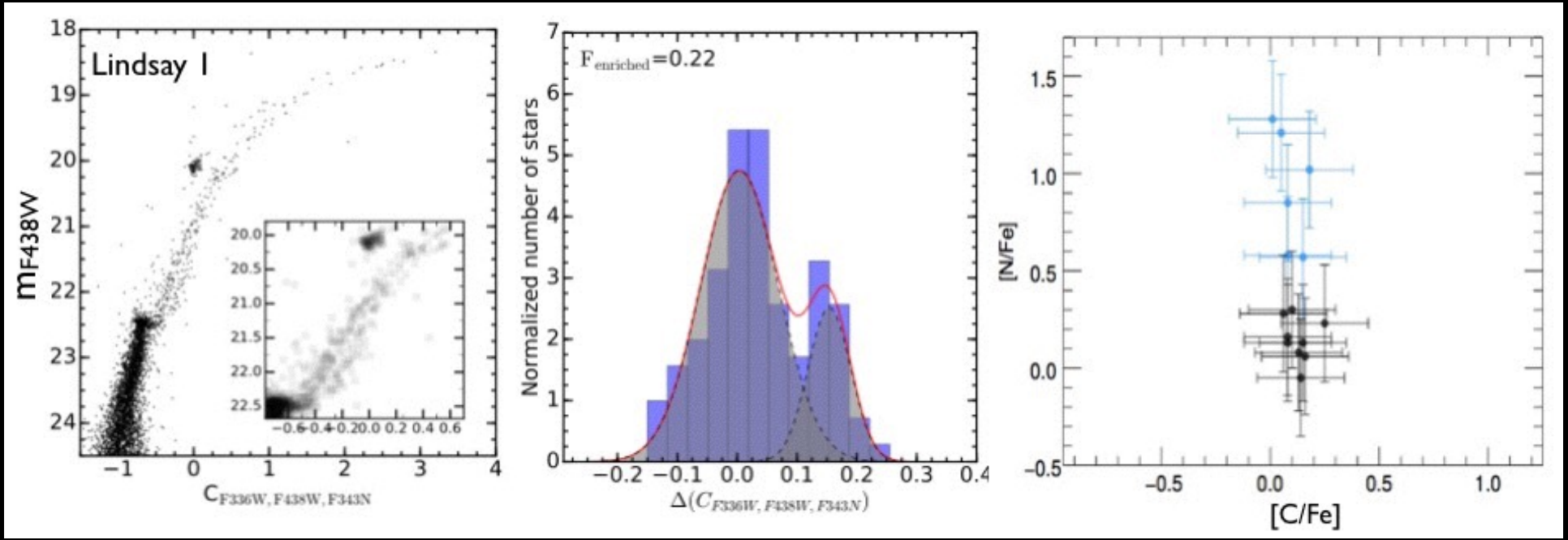
Niederhofer, NB, et al. 2016a,b
Hollyhead et al. 2016, 2017
Martocchia, NB et al. 2017

Are Multiple Populations Restricted to Old GCs?



Are Multiple Populations Restricted to Old GCs?

i.e. are YMCs and GCs really the same thing?



Linsday I - SMC cluster

~7.5 Gyr

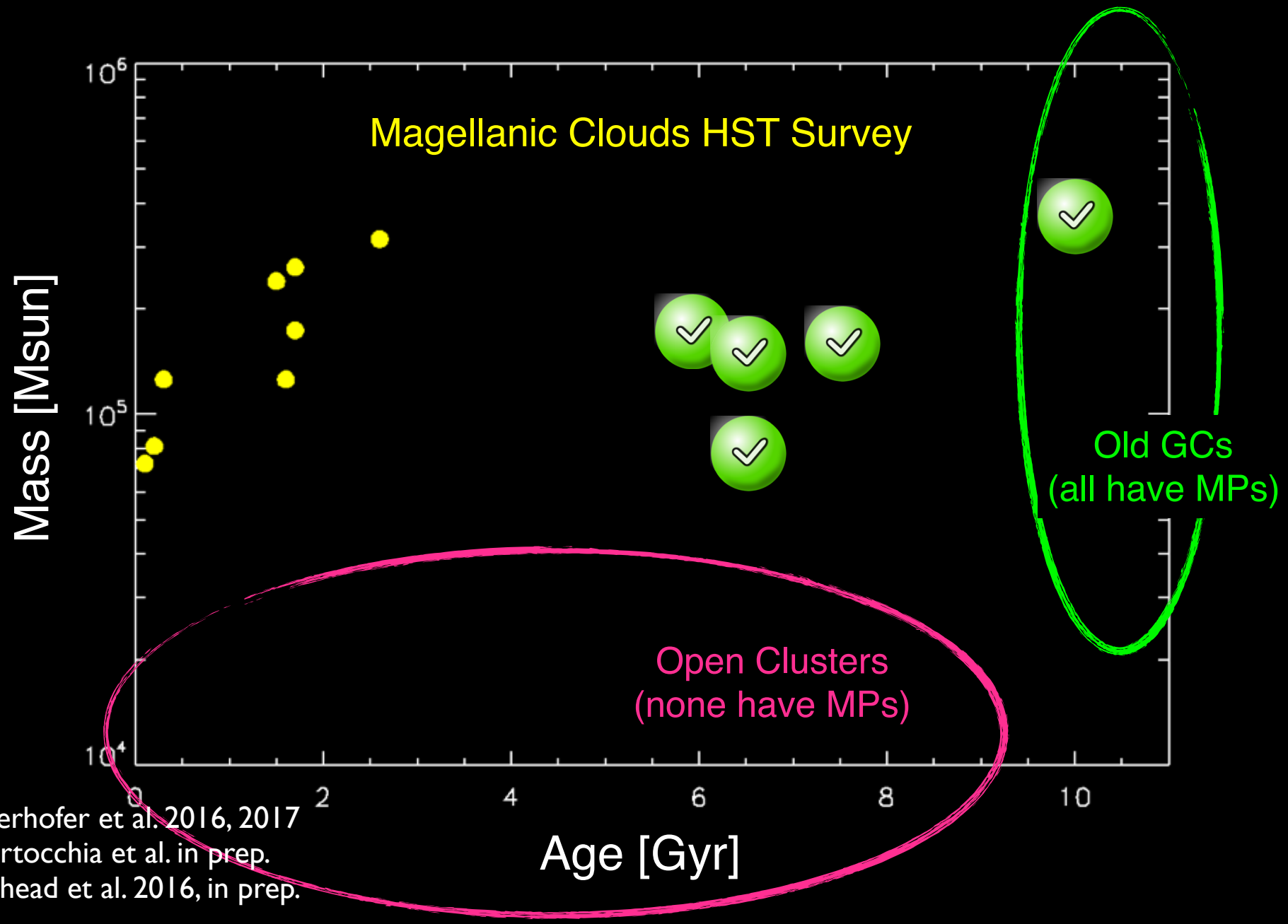
~10^5 $M_\odot$

z_{form} ~ 1

Hollyhead et al. 2016

Niederhofer, NB et al. 2017

Are Multiple Populations Restricted to Old GCs?



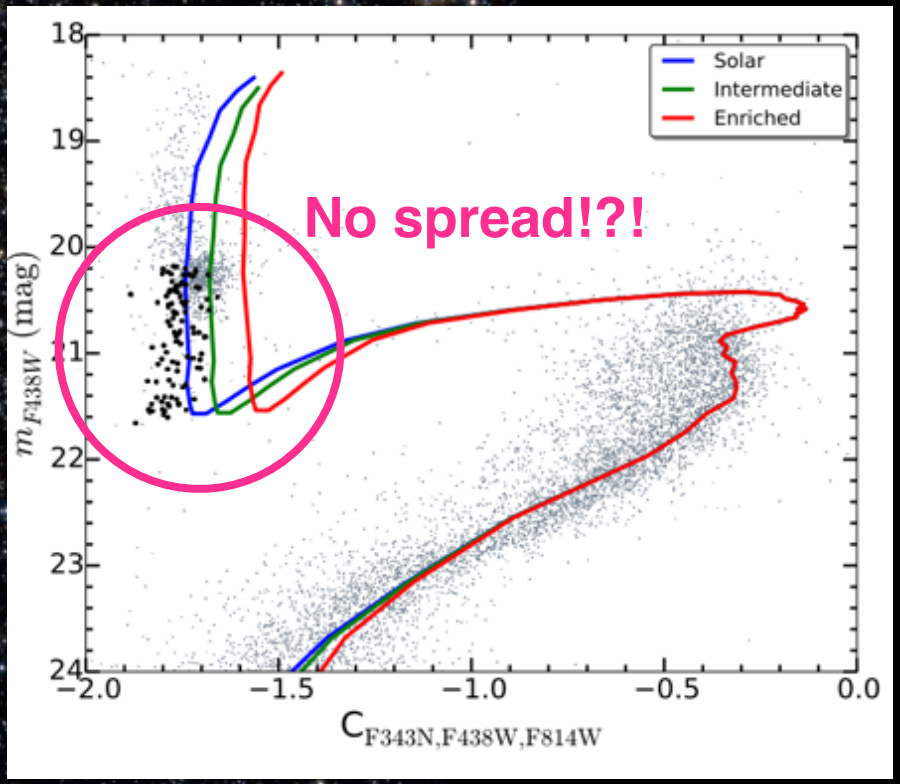
Niederhofer et al. 2016, 2017
Martocchia et al. in prep.
Hollyhead et al. 2016, in prep.

Are Multiple Populations Restricted to Old GCs?

NGC 419 - SMC cluster

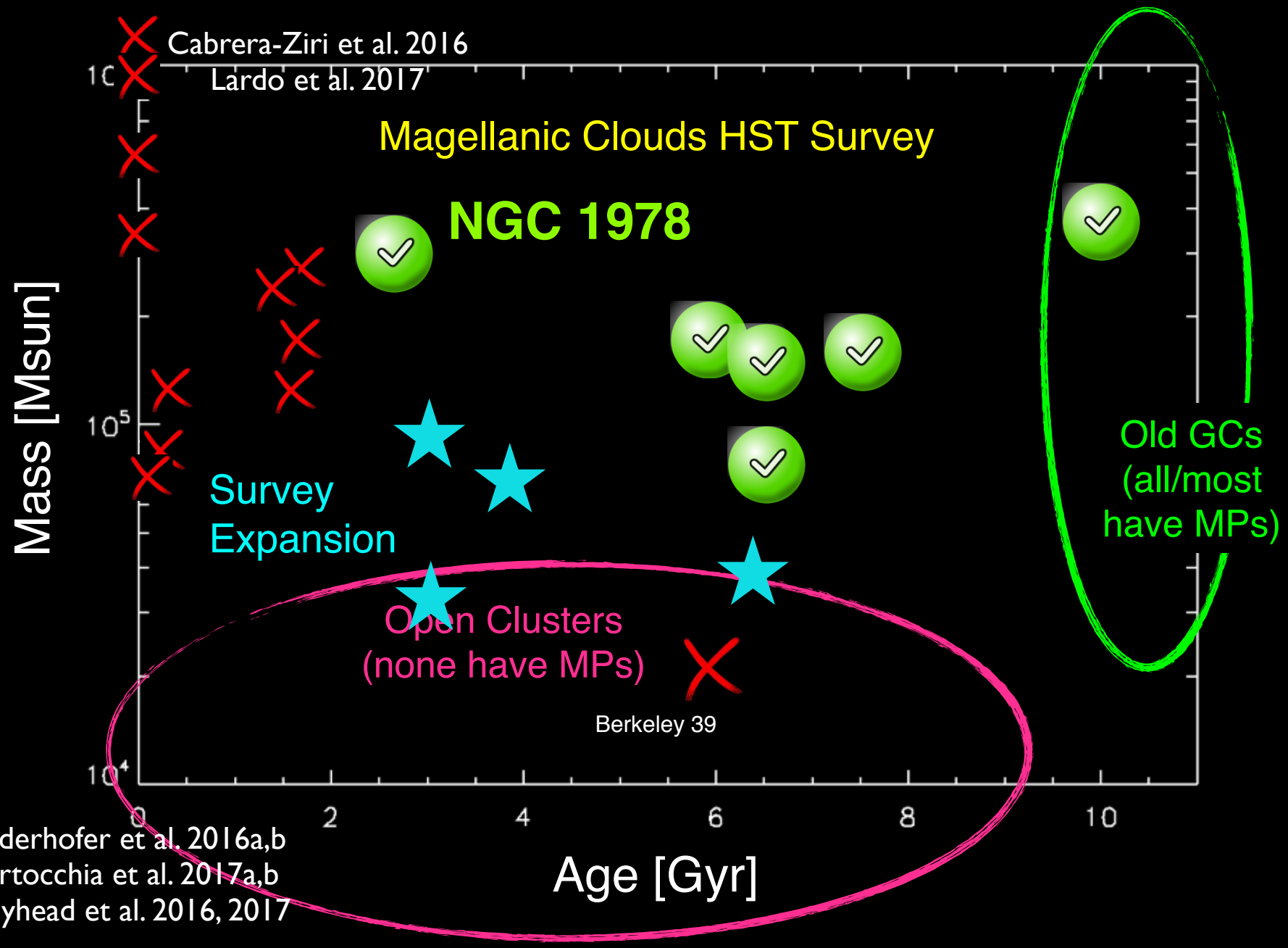
~1.5 Gyr

~$2*10^5$ $M_\odot$

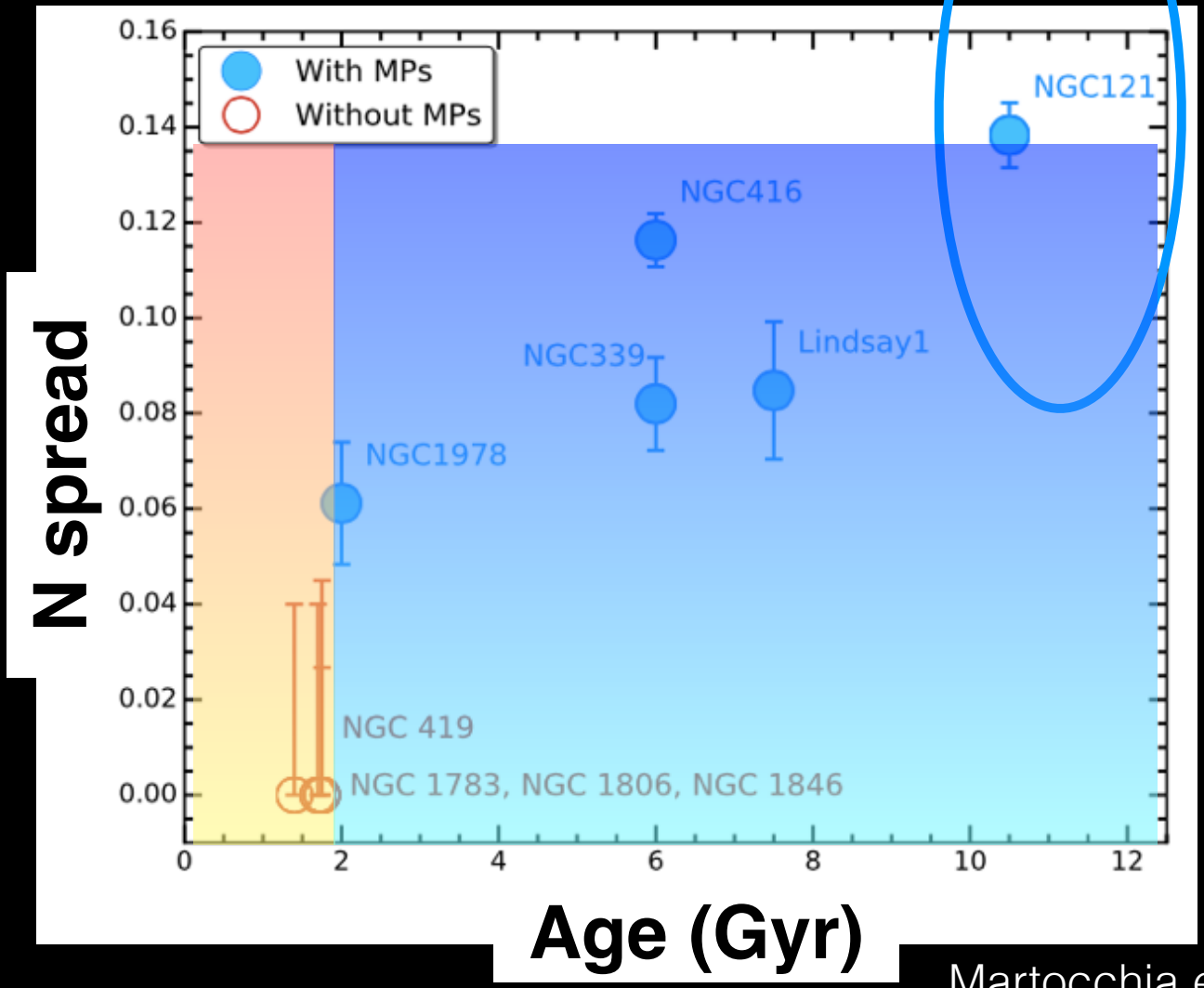


Martocchia, NB et al. 2017

Are Multiple Populations Restricted to Old GCs?



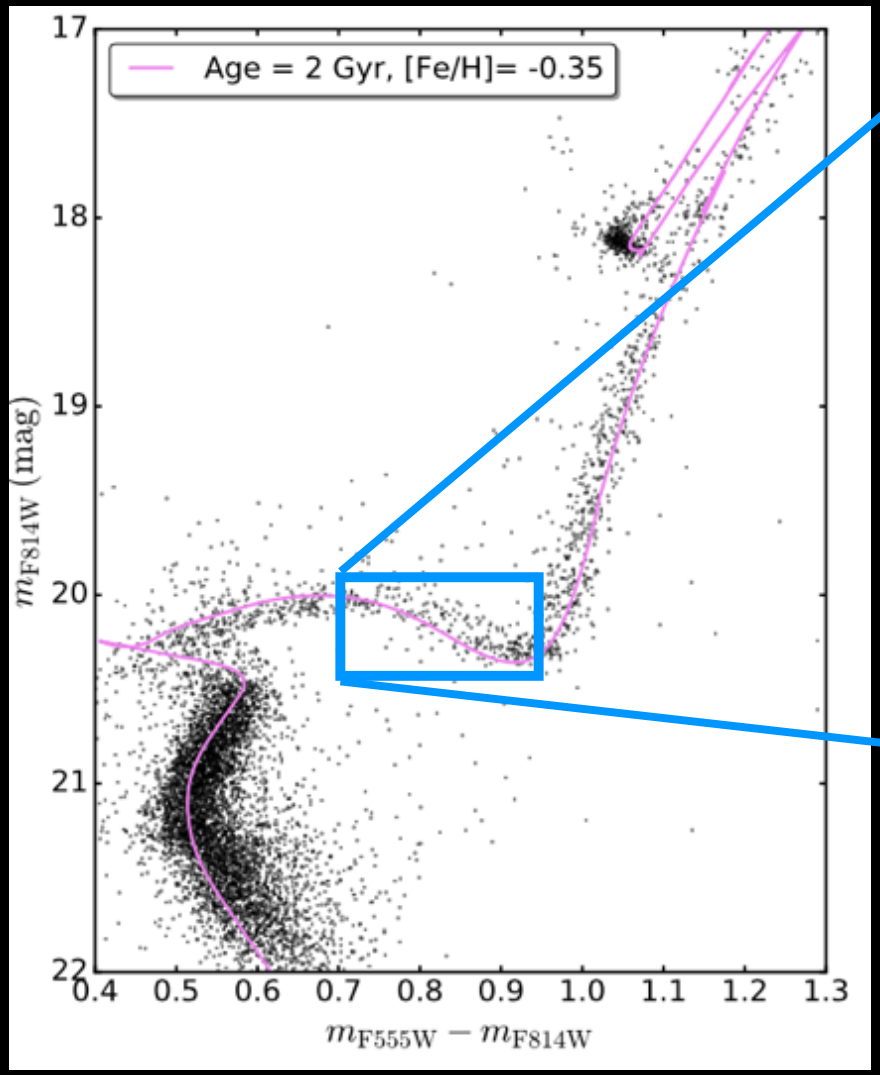
Role of cluster age

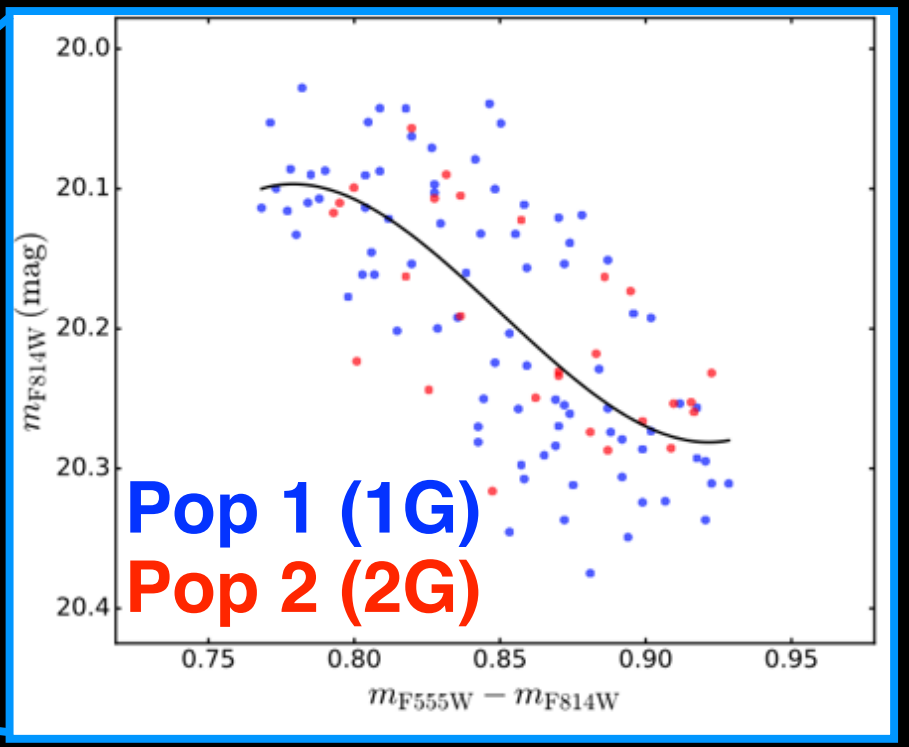


Milky Way GCs

Martocchia et al. 2017a,b
Niederhofer et al. 2017a,b
Hollyhead et al. 2017

NGC 1978
Direct Constraints on Age



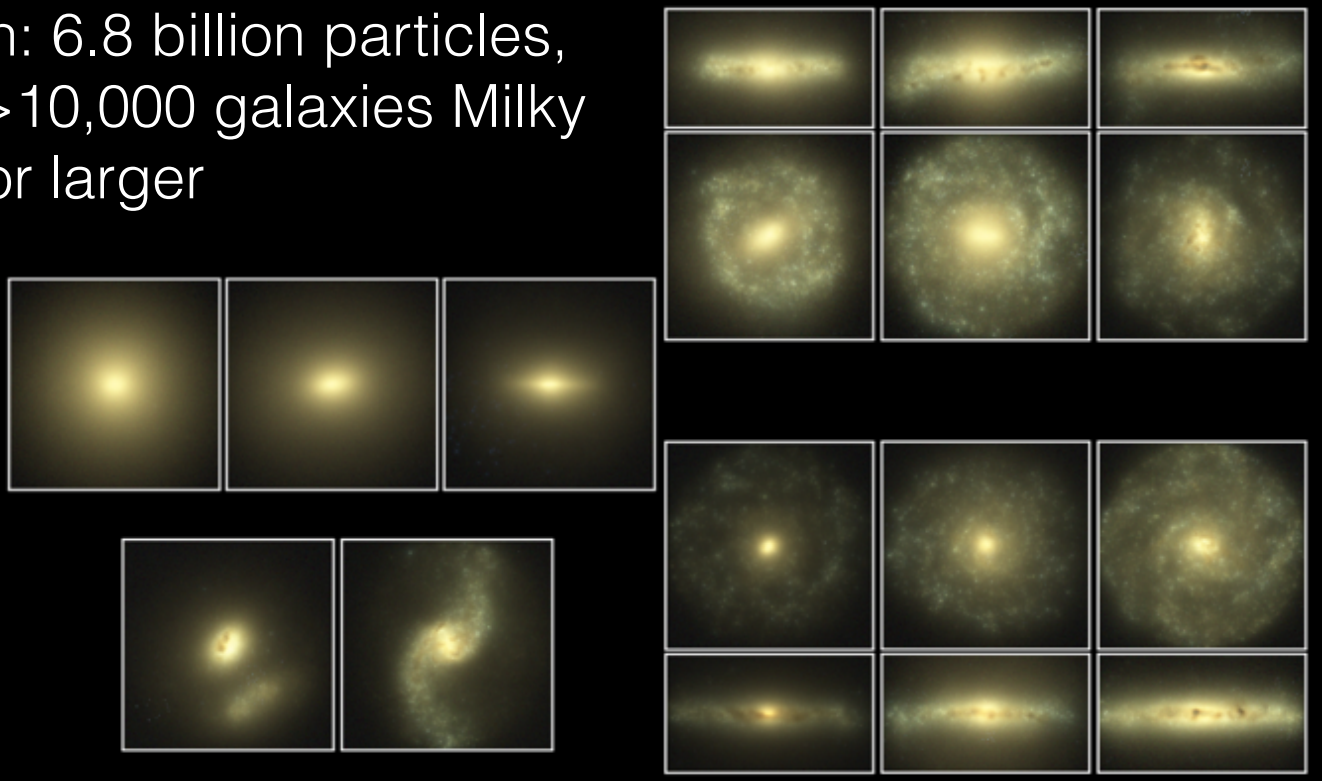


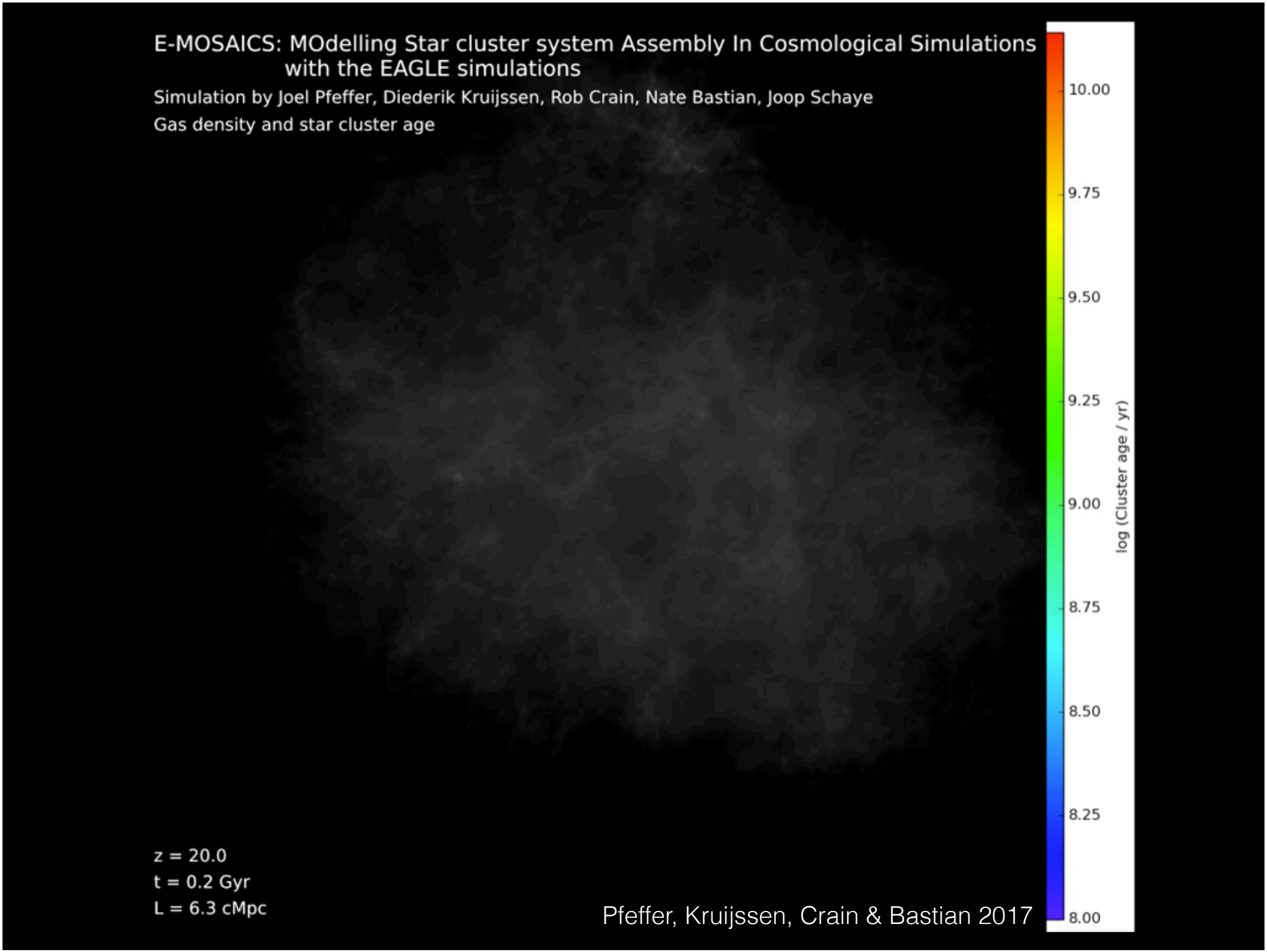
Δ(age) = 6 ±17 Myr

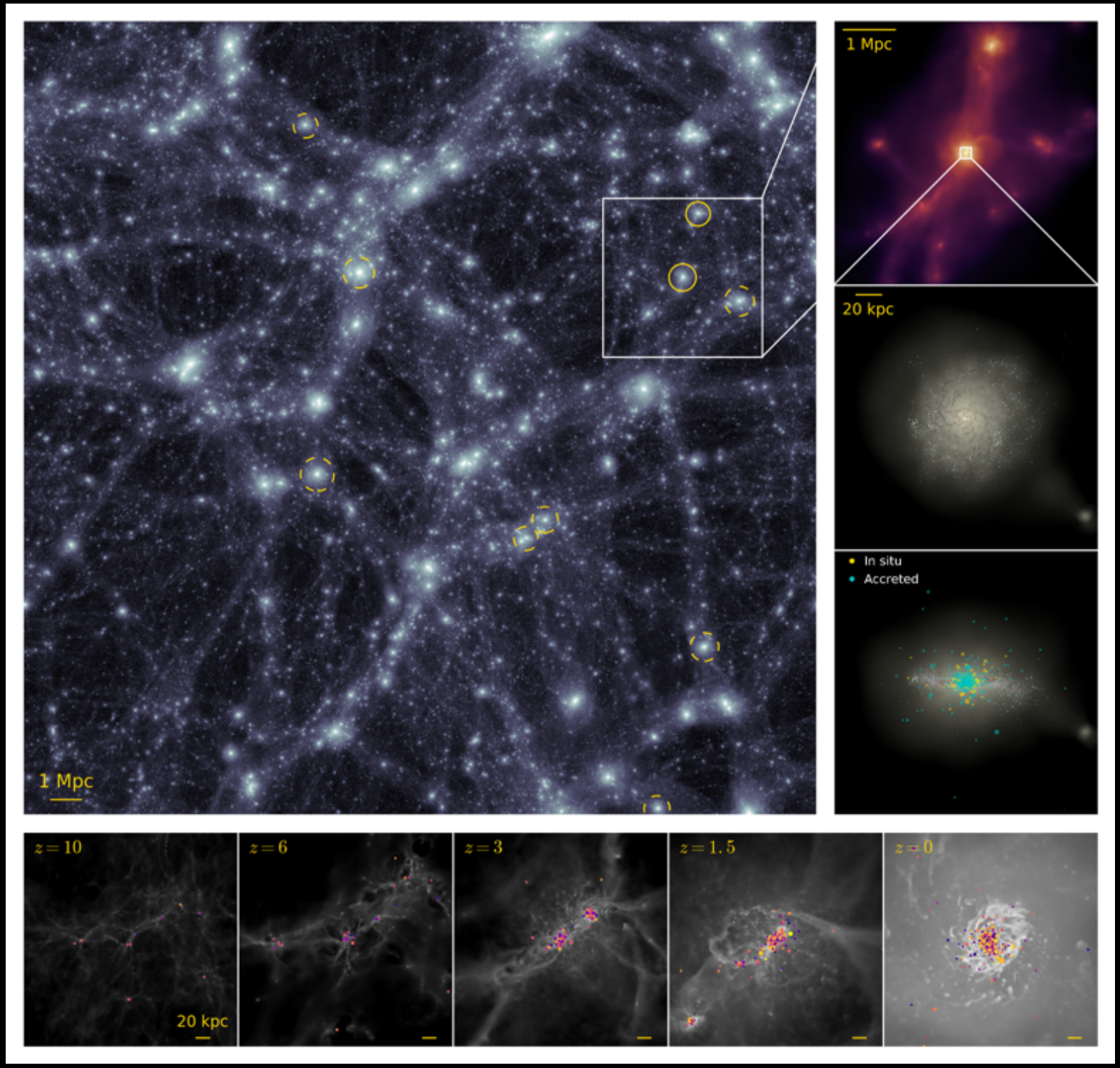
Bastian & Lardo ARA&A 2018

E-MOSAICS: MOdelling Star cluster system Assembly In Cosmological Simulations with the EAGLE simulations

EAGLE: Largest run: 6.8 billion particles, 100 Mpc box, with >10,000 galaxies Milky Way or larger

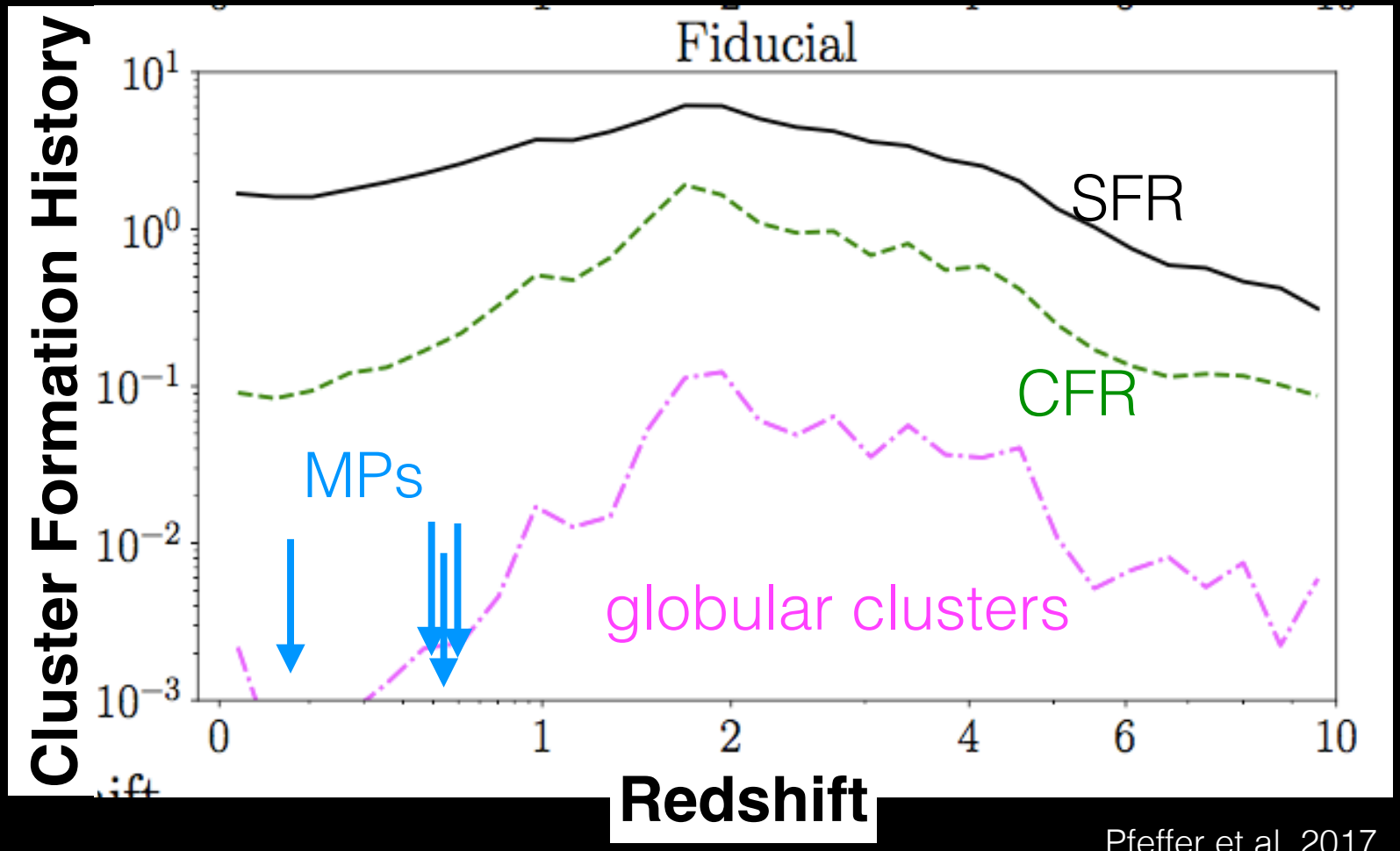



E-MOSAICS: MOdelling Star cluster system Assembly In Cosmological Simulations with the EAGLE simulations
Simulation by Joel Pfeffer, Diederik Kruijssen, Rob Crain, Nate Bastian, Joop Schaye
Gas density and star cluster age
10.00
9.75
9.50
9.25
9.00
8.75
8.50
8.25
8.00
log (Cluster age / yr)
z = 20.0
t = 0.2 Gyr
L = 6.3 cMpc
Pfeffer, Kruijssen, Crain & Bastian 2017



Pfeffer et al. 2017

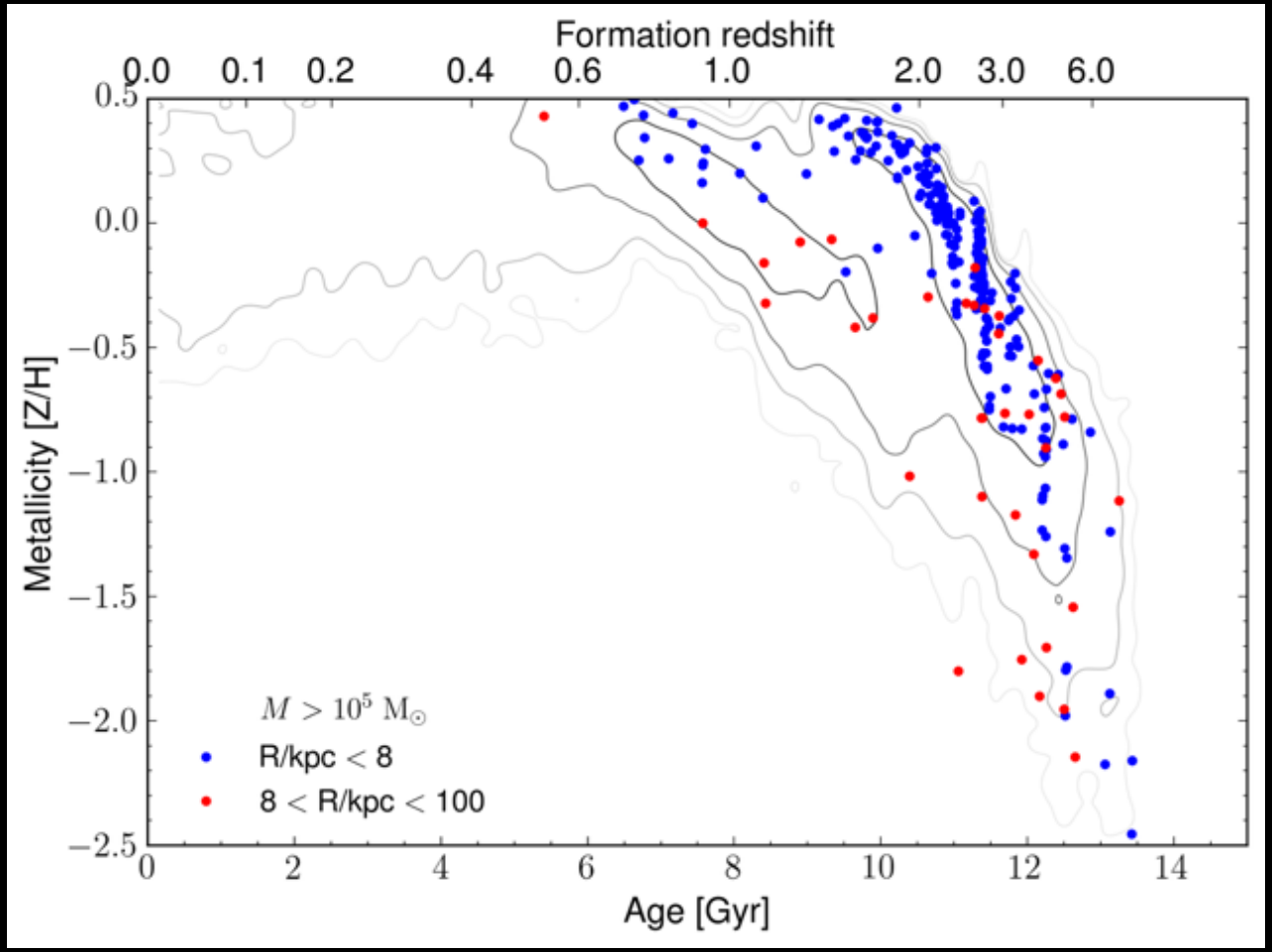
GC and YMC Formation in Cosmological Simulations



Pfeffer et al. 2017

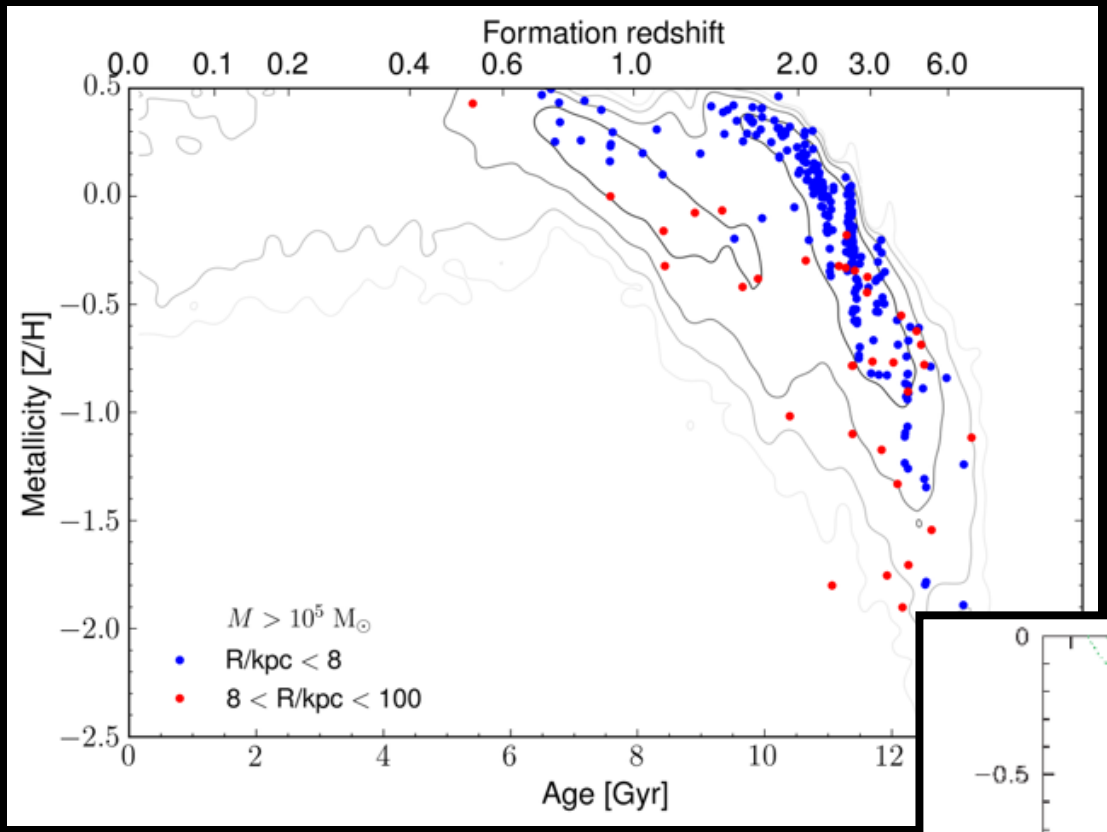
Reina-Campos et al. in prep.

GC and YMC Formation in Cosmological Simulations

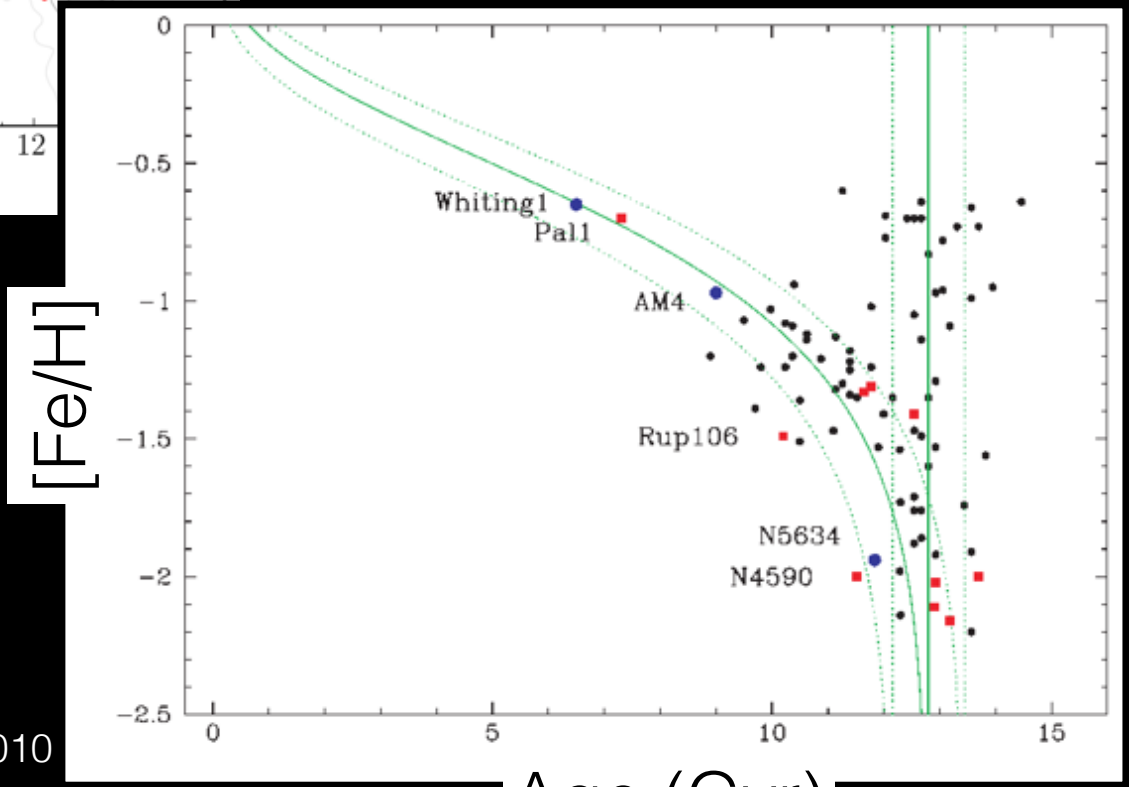


Kruijssen et al. in prep.

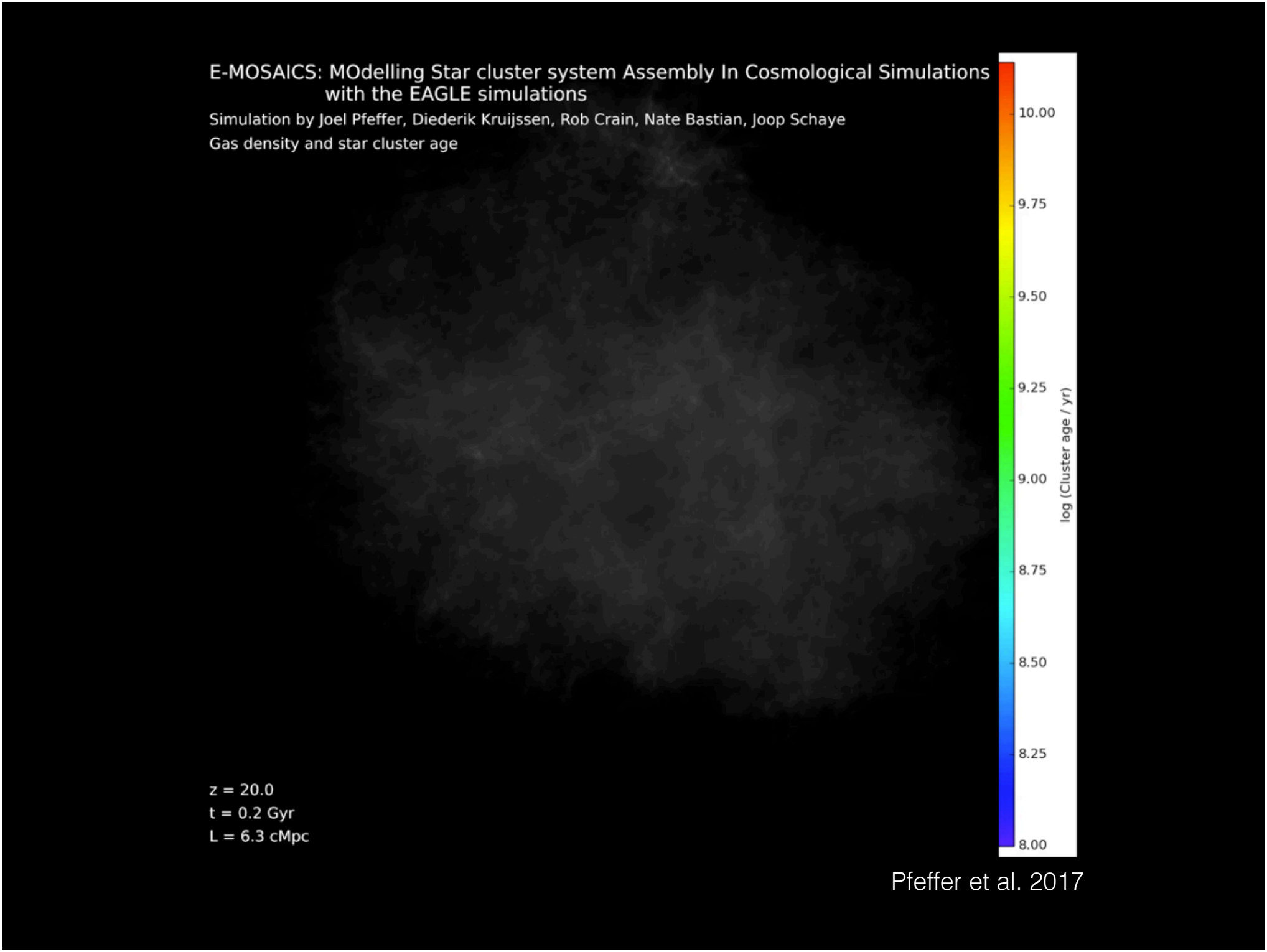
Age-metallicity distribution gives assembly history



Kruijssen et al. in prep.



Forbes & Bridges 2010



Pfeffer et al. 2017