Multiple Populations and Globular Cluster Formation in Dwarf Galaxies

Aaron J. Maxwell
PhD Candidate, McMaster University

Collaborators: James Wadsley, Hugh Couchman, Sergey Mashchenko, Alison Sills

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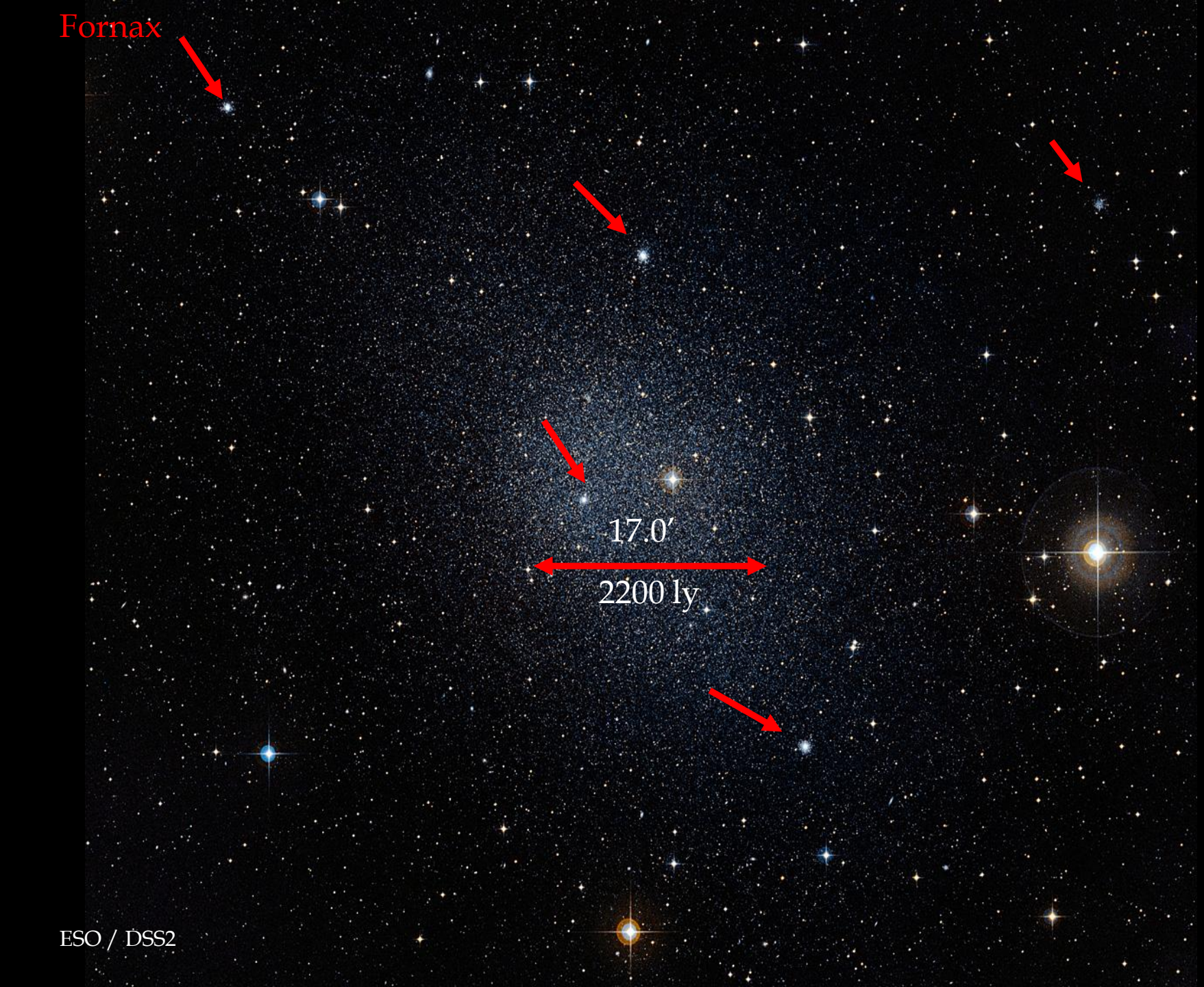
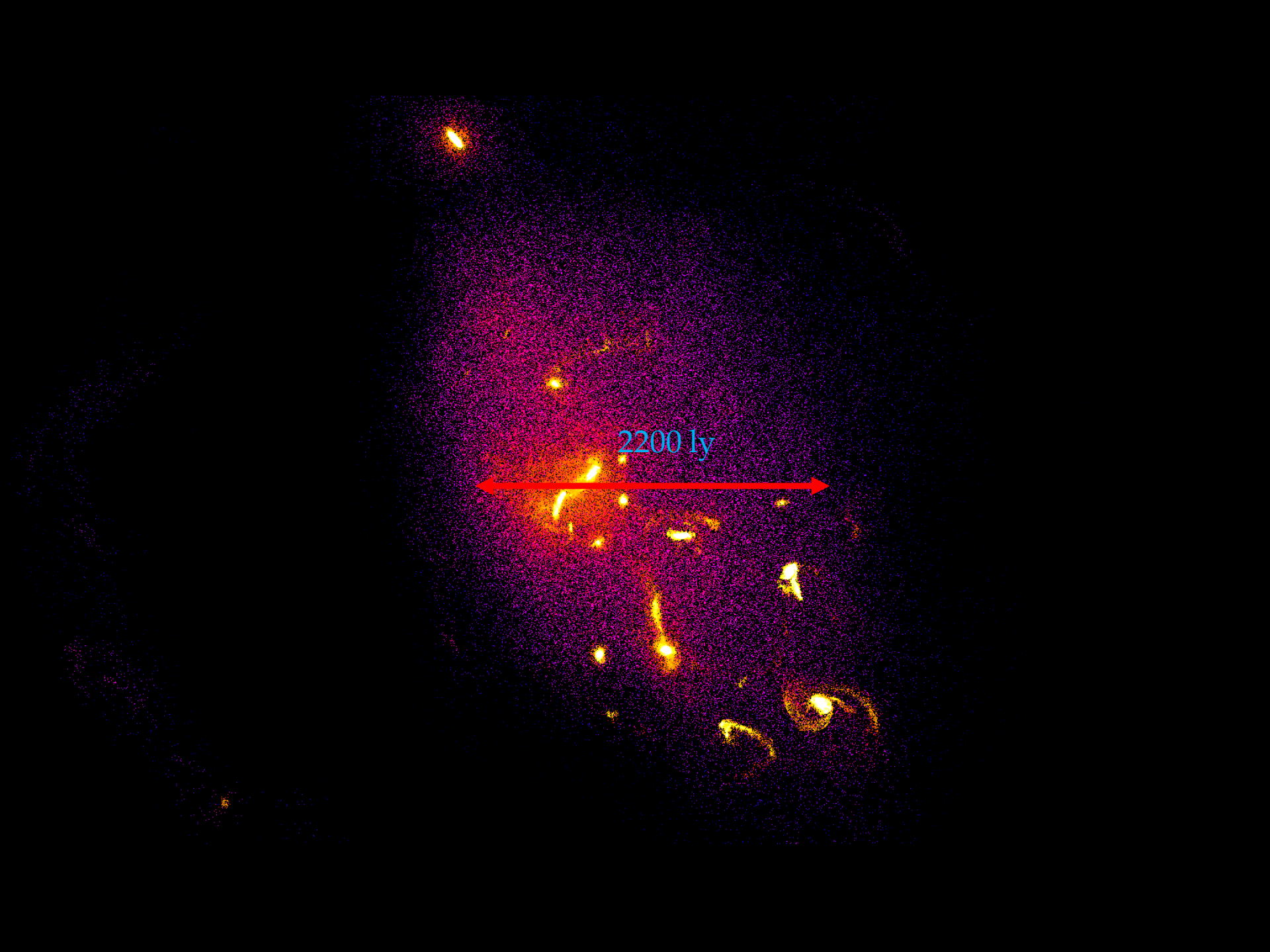
Dwarf Galaxies as Star Formation Laboratories

- Present day dwarf galaxies represent the fossil remains of early galaxy formation
- Their early evolution can only be studied through simulations
- We can resolve the size scales important to star formation
- Star formation can dramatically redistribute the mass within dwarf galaxies

Clustered Star Formation

- Can drive huge variations in potential, which redistributes dark matter and forms a core (Mashchenko et al. 2008, Governato et al. 2012, Pontzen et al. 2012, Teyssier et al. 2013)
- Stars and star clusters follow suit, filling the dwarf halo even though they formed within the centre of the galaxy (Maxwell et al. 2012)


Fornax
17.0′
2200 ly
ESO / DSS2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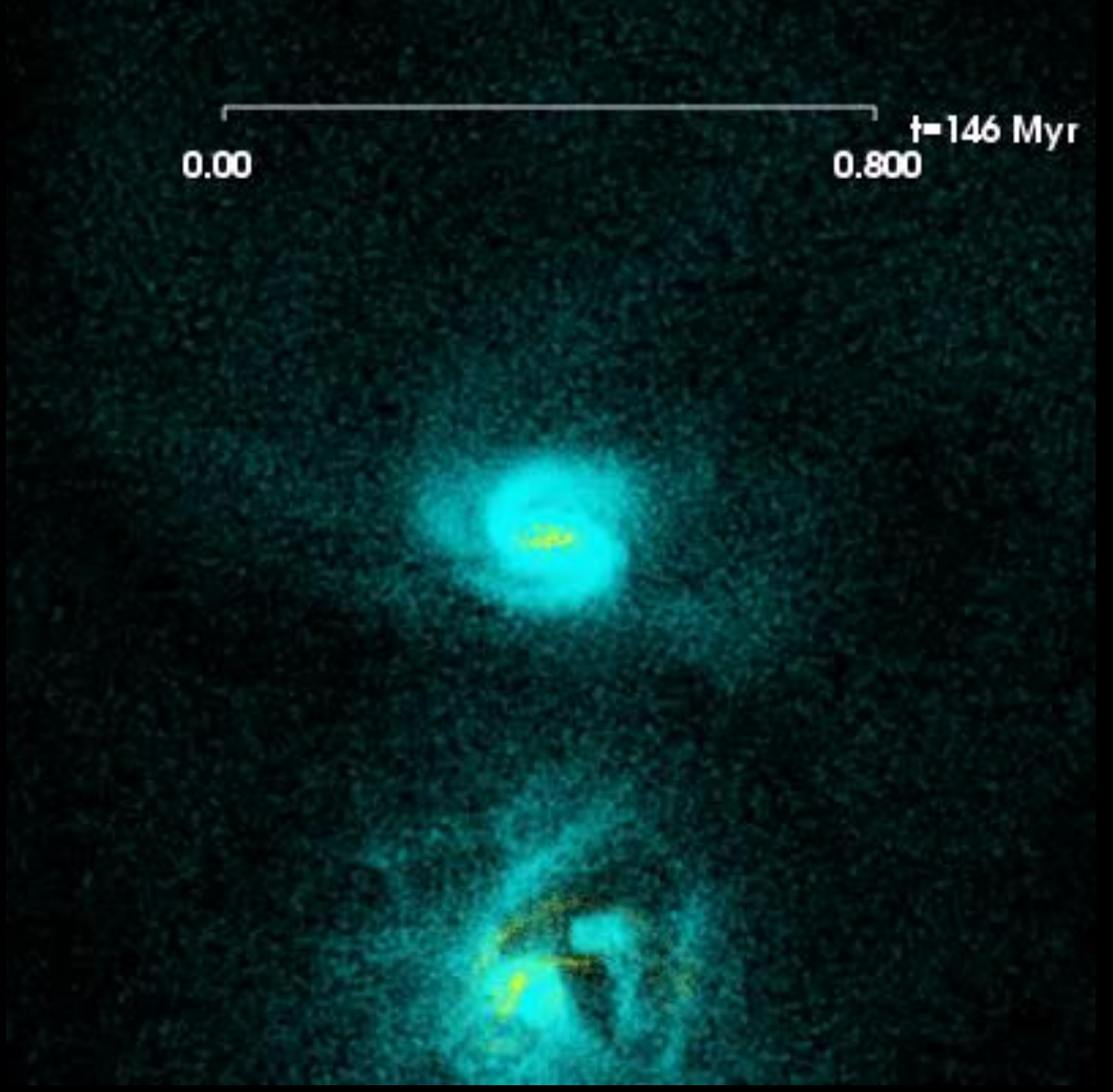
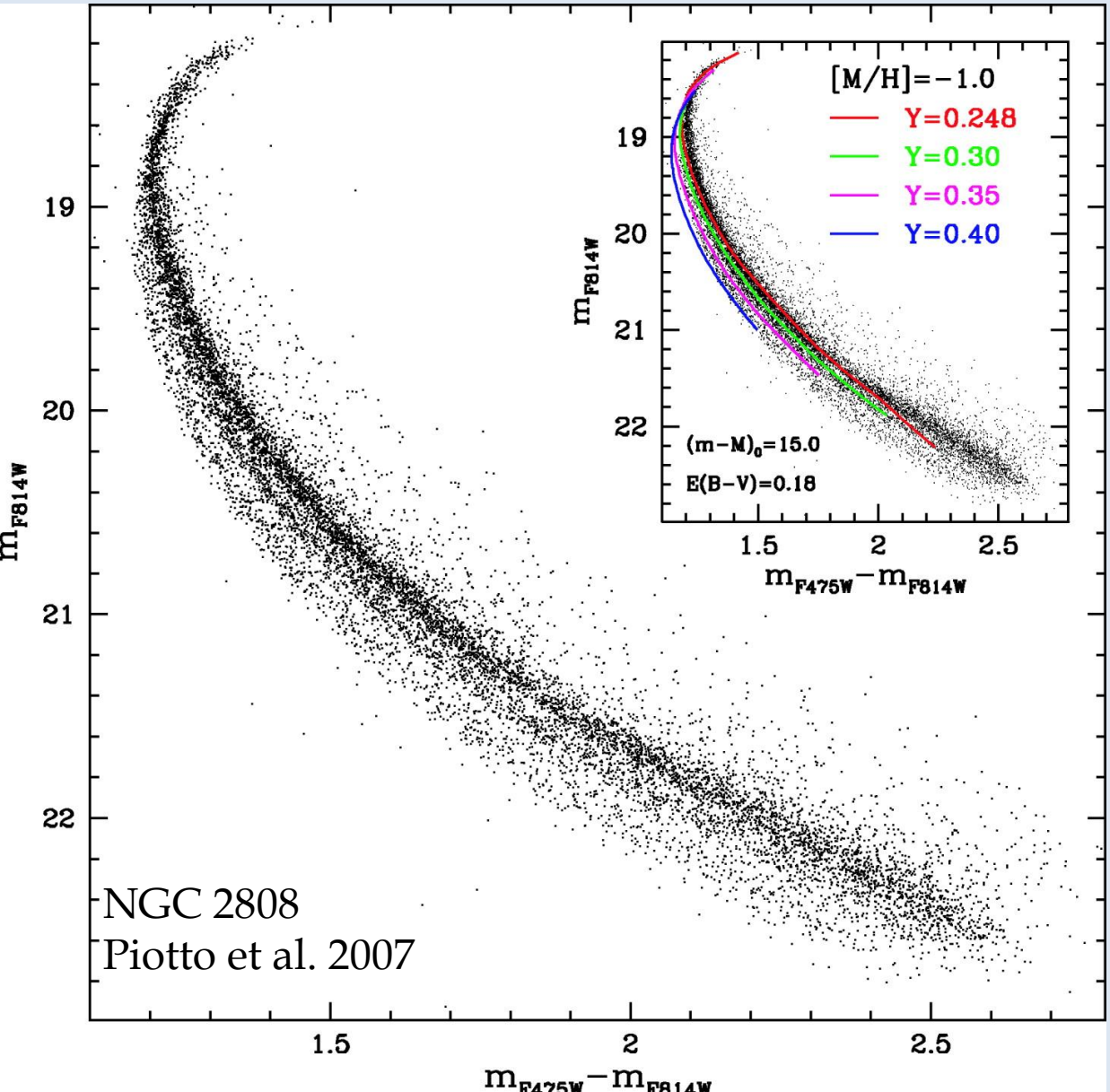
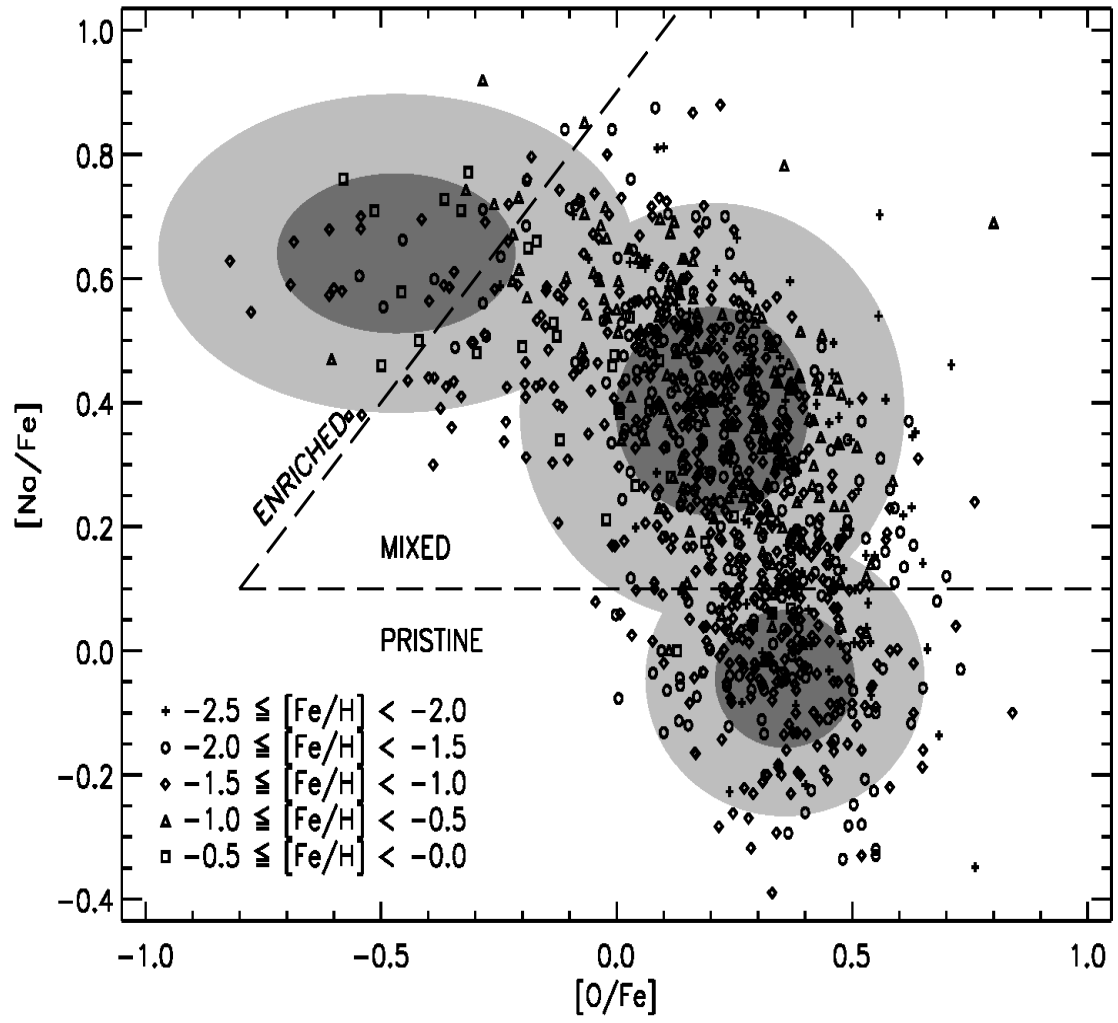

0.00
0.800
t=146 Myr

Photometry: Multiple Main Sequences



- Deep HST data reveals the presence of multiple MS in a single globular cluster
- Stellar evolution models explain this as stars with varying of amounts of helium

Spectroscopy: Abundance Dispersion



Ramirez et al. 2002, 2003; Cohen et al. 2005a, 2005c; Carretta et al. 2006, 2007a, 2007b, 2007c, 2009a, 2009b

- light elements (Na, O, N, C, Al, Mg) show significant abundance spreads within the same cluster down to the MS
- no evidence of similar spread in heavy elements (Fe, e.g. Ramirez et al. 2001, Carretta et al. 2009c) or field stars (e.g. Gratton et al. 2006, 2007)

GCs are *not* Simple Stellar Populations

- GCs studied show evidence of multiple star formation episodes
- Multiple MS suggest significant helium enrichment
- The most plausible source of enrichment are AGB stars
- However, previous theories required a modified IMF (e.g. D'Antona & Caloi 2004, D'Antona et al. 2005) or an order of magnitude increase in initial mass (e.g. D'Antona & Caloi 2008, D'Ercole et al. 2010) to provide enough ejecta (Cohen et al. 2005) but then have these stars disappear …

Globular Cluster Dine & Dash!

Globular clusters can form multiple populations as they accrete matter on each passage through the gas rich galaxy centre (Maxwell et al., in prep)

- Star clusters form near the centre
- Star formation creates feedback which pumps energy into cluster orbits
- Supernovae clear out gas within inner few hundred pc (no Fe enrichment!)
- AGB winds, however, can be held within this same region (He, O, Na, …)
- Globular Clusters experience a couple passages through the gas rich centre
- Eventually, SNII ejecta and fresh gas resets the cycle

Exploring The Mechanism

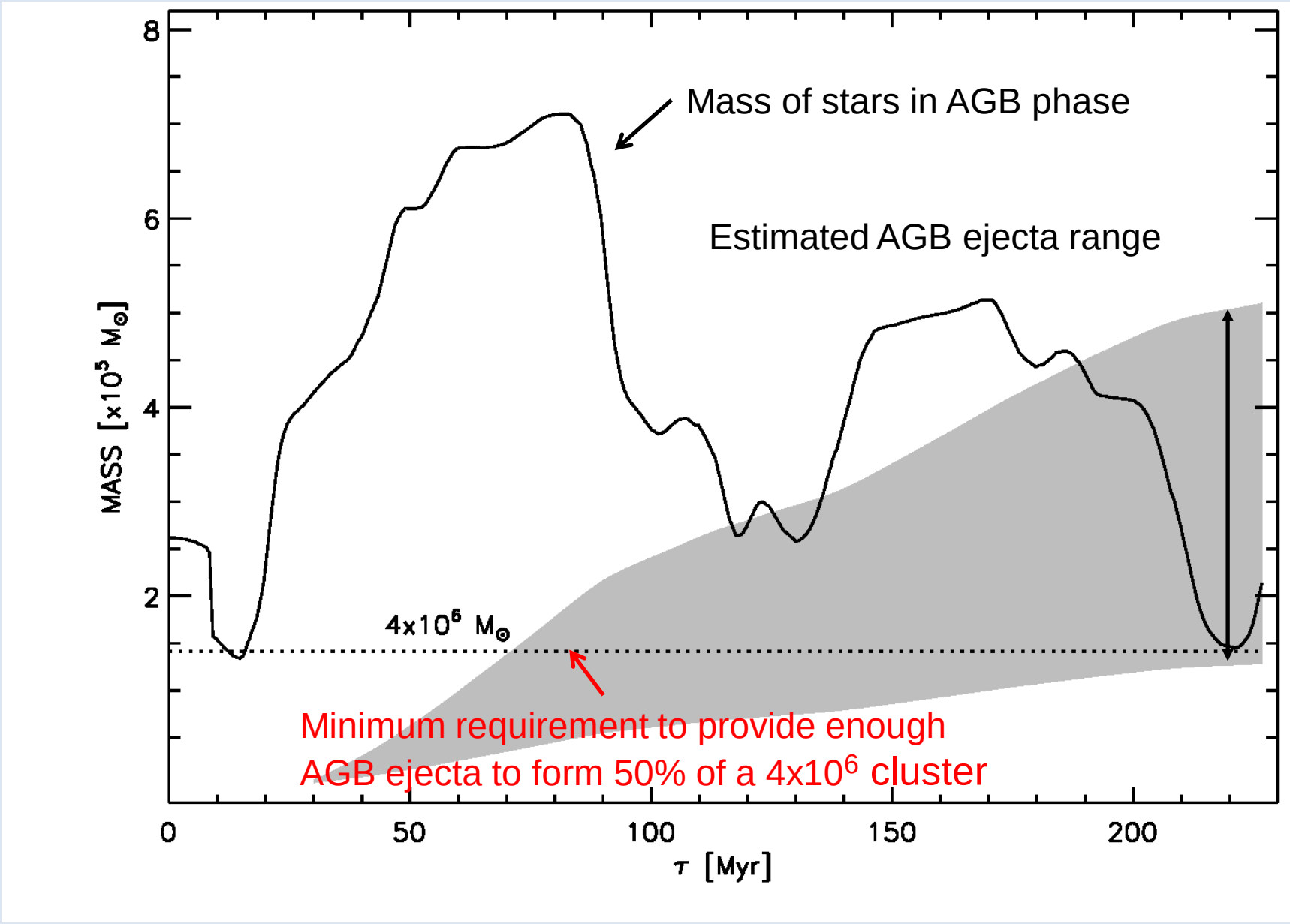
Looked at the Mashchenko et al. 2008 simulation for globular cluster orbits (Maxwell et al. 2012)

Mashchenko et al. 2008

- Designed to look at the cusp-core problem
- High resolution cosmological simulation of a dwarf galaxy (10^9 $M_\odot$)
- 12 pc spatial resolution, and 110 $M_\odot$ per star particle
- Four long lived dense star clusters

Some encouraging results …

Surrounding AGB Yield Enough Ejecta



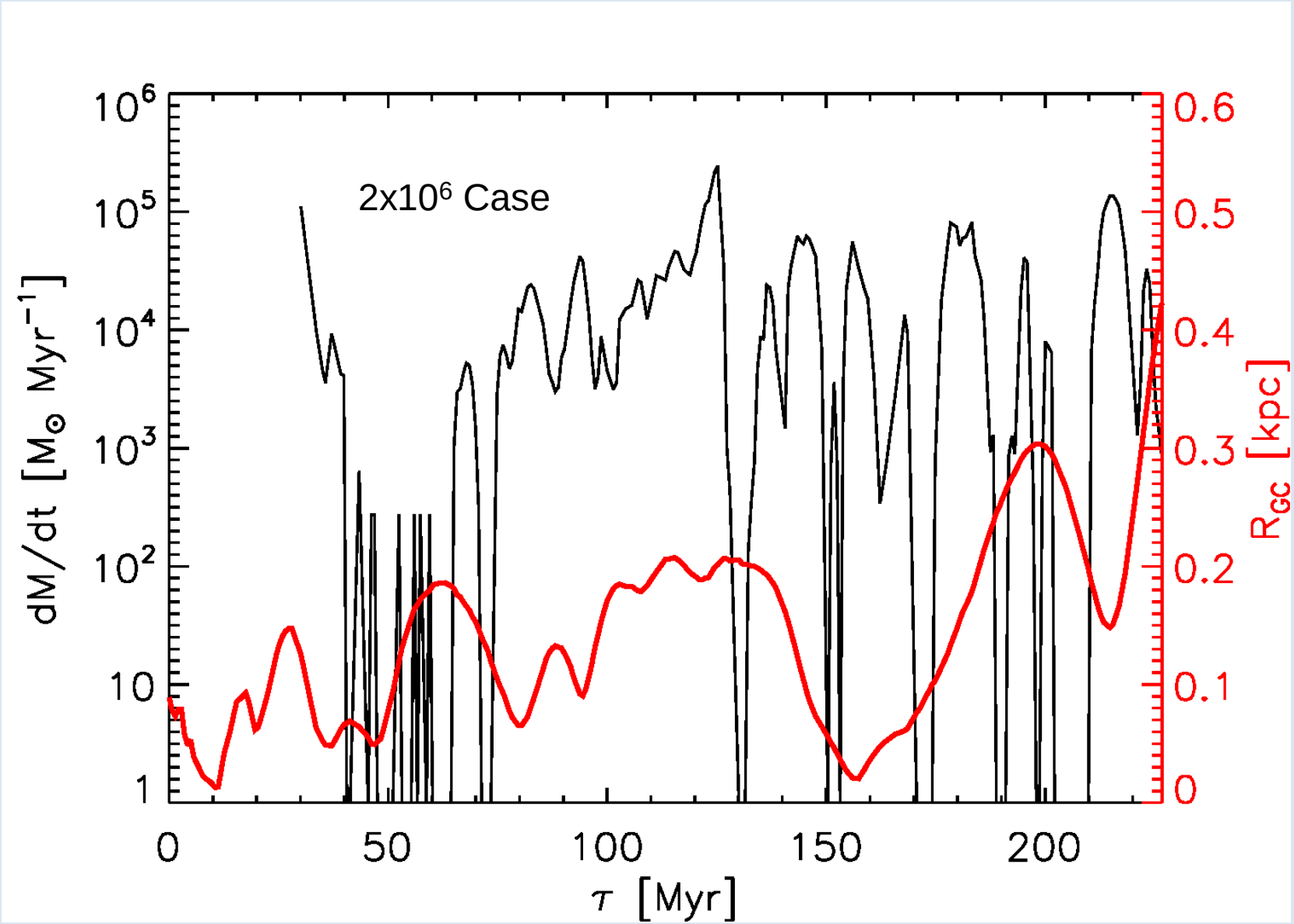
Bondi-Hoyle Accretion on Each Pass

$$\dot{M} \simeq 2\pi \frac{G^2 M_{cl}^2}{(v_{rel}^2 + c_s^2)^{3/2}} \bar{\rho}$$

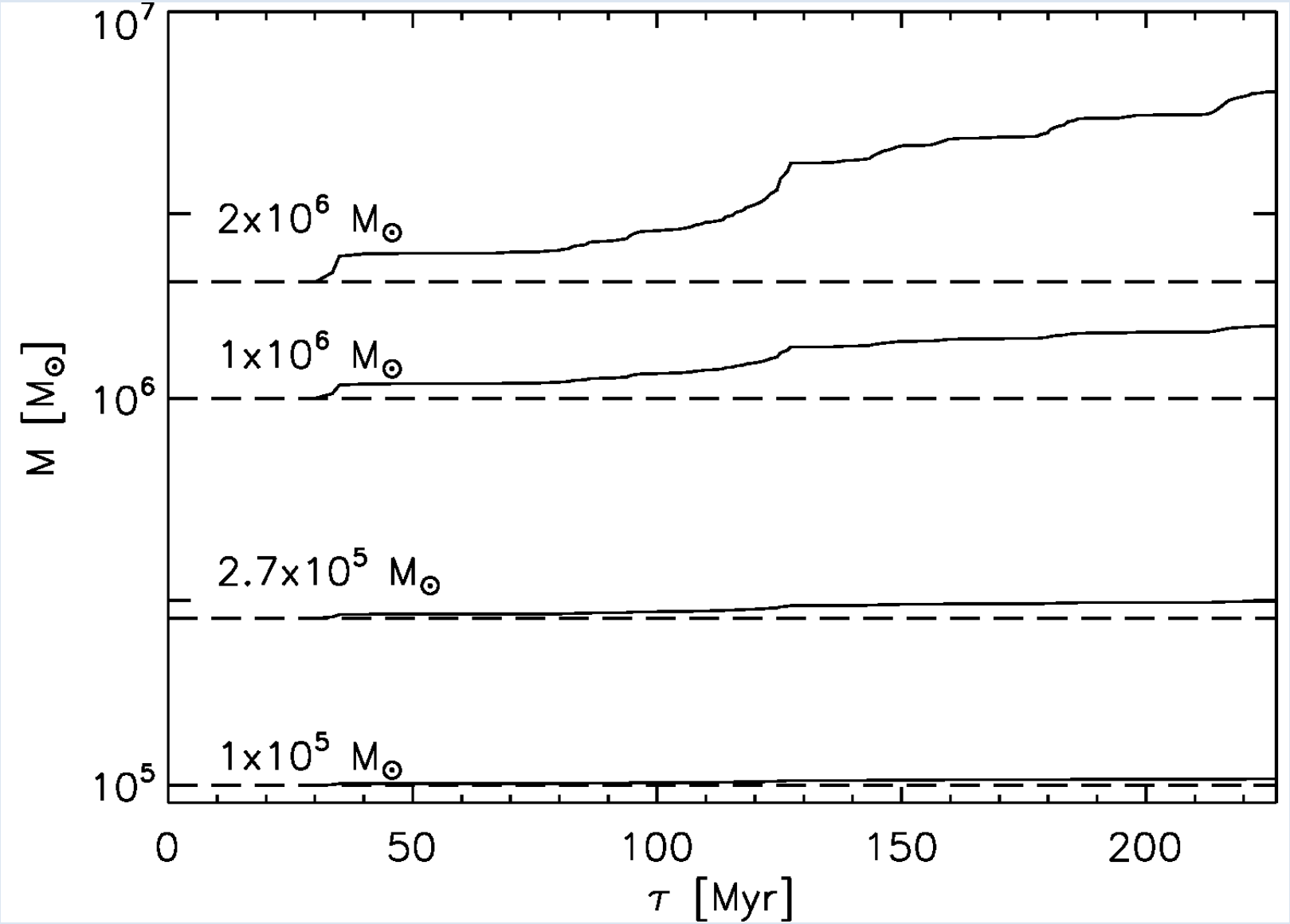
- Mean gas density measured within 35 pc of cluster
- Cluster mass plus accreted mass
- Typical sound speed is 10 km/s

Bondi & Hoyle 1944, Bondi 1952, Conroy & Spergel 2011

Mass Accretion Depends on Orbit



Massive Clusters Double Their Mass



Summary

- Dwarf galaxies can experience significant mass redistribution
- Stars and star clusters can migrate outwards several hundred pc, despite forming in the centre
- Applying this concept to GC formation provides a new way of thinking about multiple population formation – surrounding AGB supply enrichment
- A simple analytic estimate of accretion satisfies a number of observational constraints