Co-Evolution of Central Black Holes and Nuclear Star Clusters

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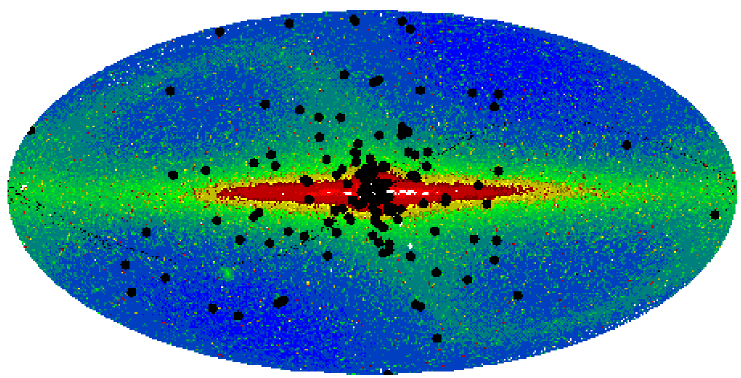
Resolved star cluster

highest known density of stars



Globular clusters in the Galaxy

median distance from the center is 5 kpc

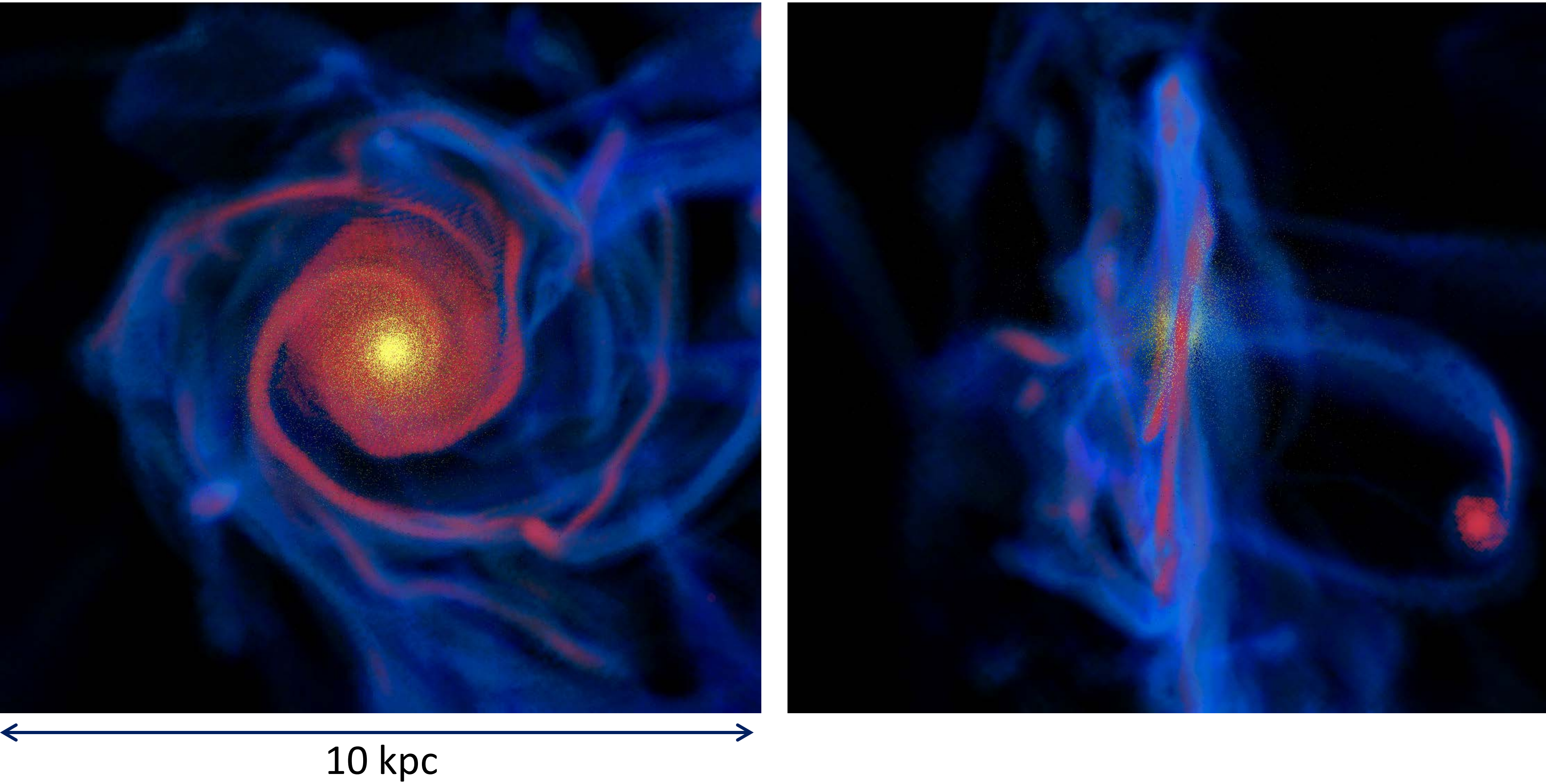
Black hole

Nucleated galaxy FCC277

nuclear star cluster is a sharp density enhancement over field stars

Hydrodynamic cosmological simulations of galaxy formation predict very high gas density at galaxy center ($\rho \propto r^{-2}$ or steeper) $\rightarrow$ NSC.

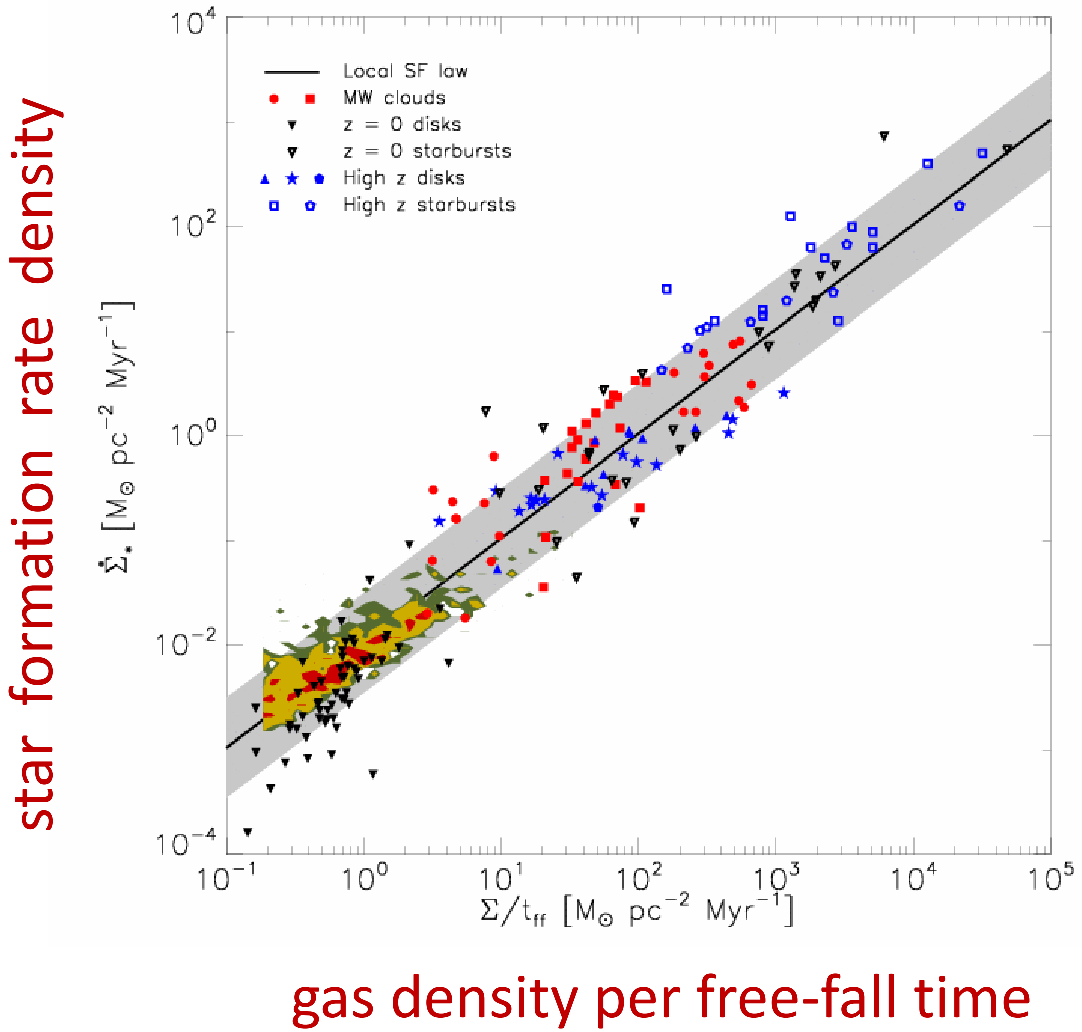
It may be reduced by stellar feedback and massive black hole mergers.



Disk galaxy at z=3: stars, molecular gas, atomic gas

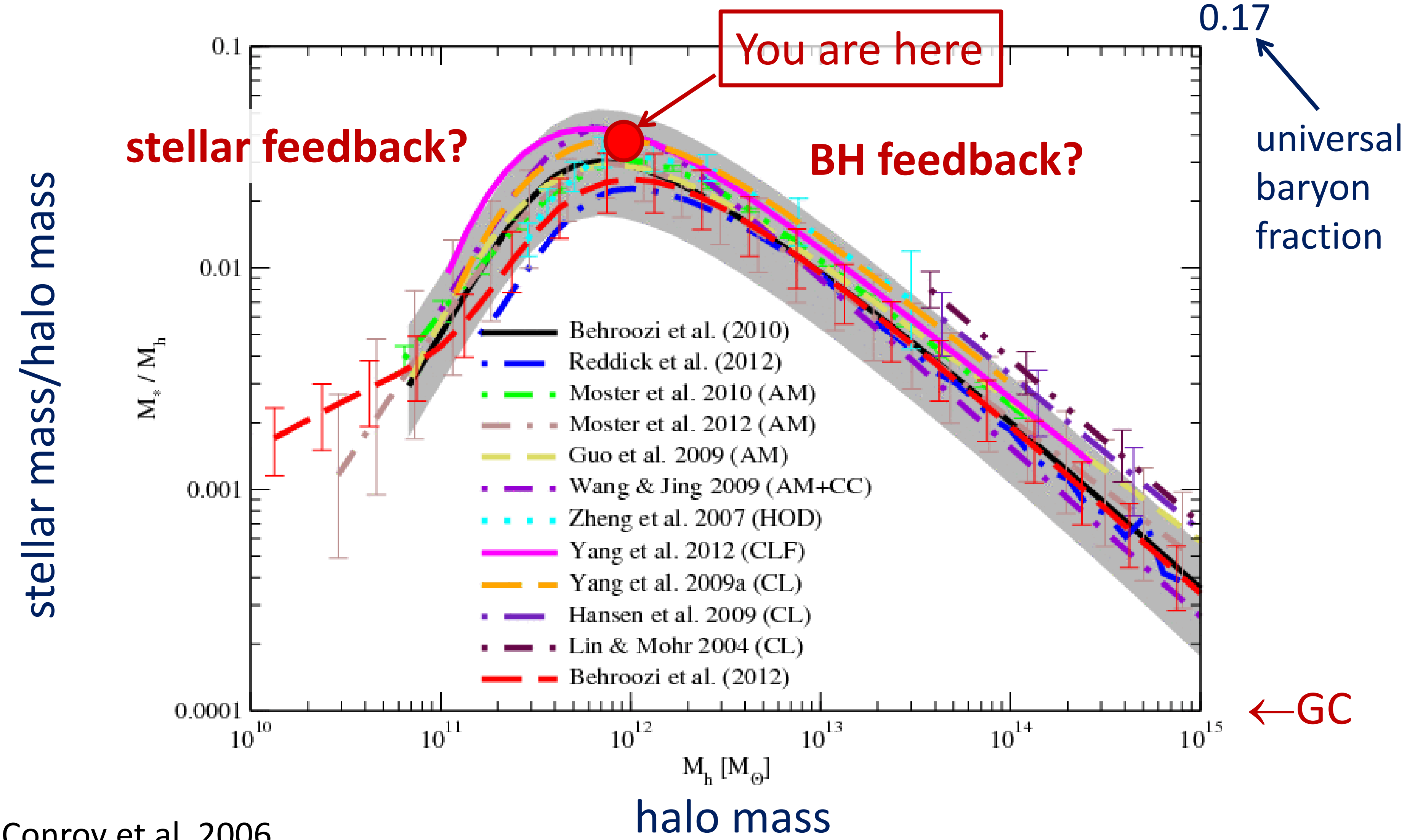
Zemp, OG, N. Gnedin, Kravtsov (2012)

In most galaxies at low and high redshift, efficiency of star formation on small scales is low: only ≈ 1% of cold gas is converted into stars in one dynamical time



Krumholz et al. 2012

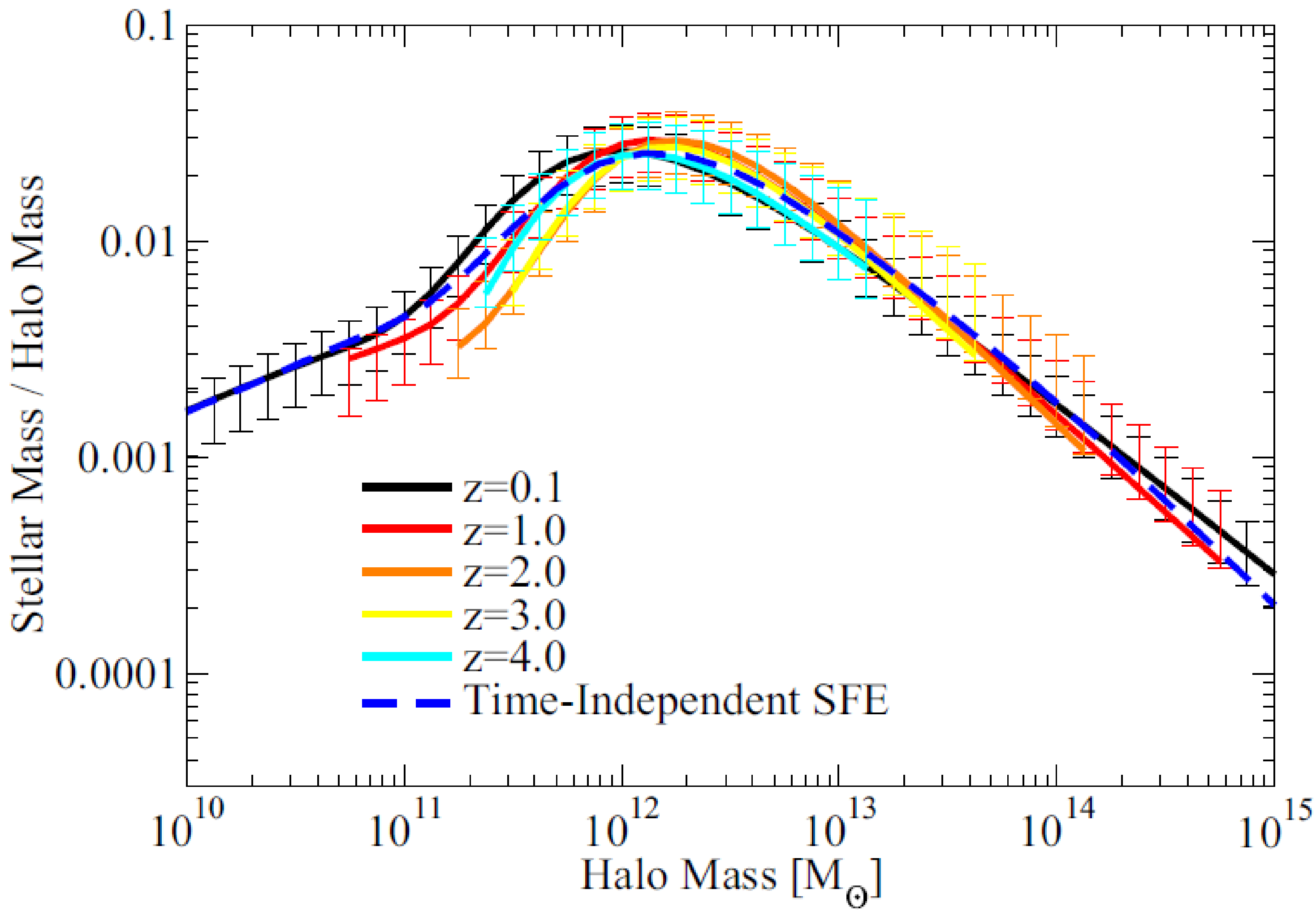
Matching numbers of halos and galaxies indicates that star formation is also globally inefficient, especially at low and high galaxy masses



Conroy et al. 2006,
Behroozi et al. 2012

Matching numbers of halos and galaxies indicates that star formation is also globally inefficient, at all redshifts up to $z \approx 4$:

early star formation has to wait until galaxies get big

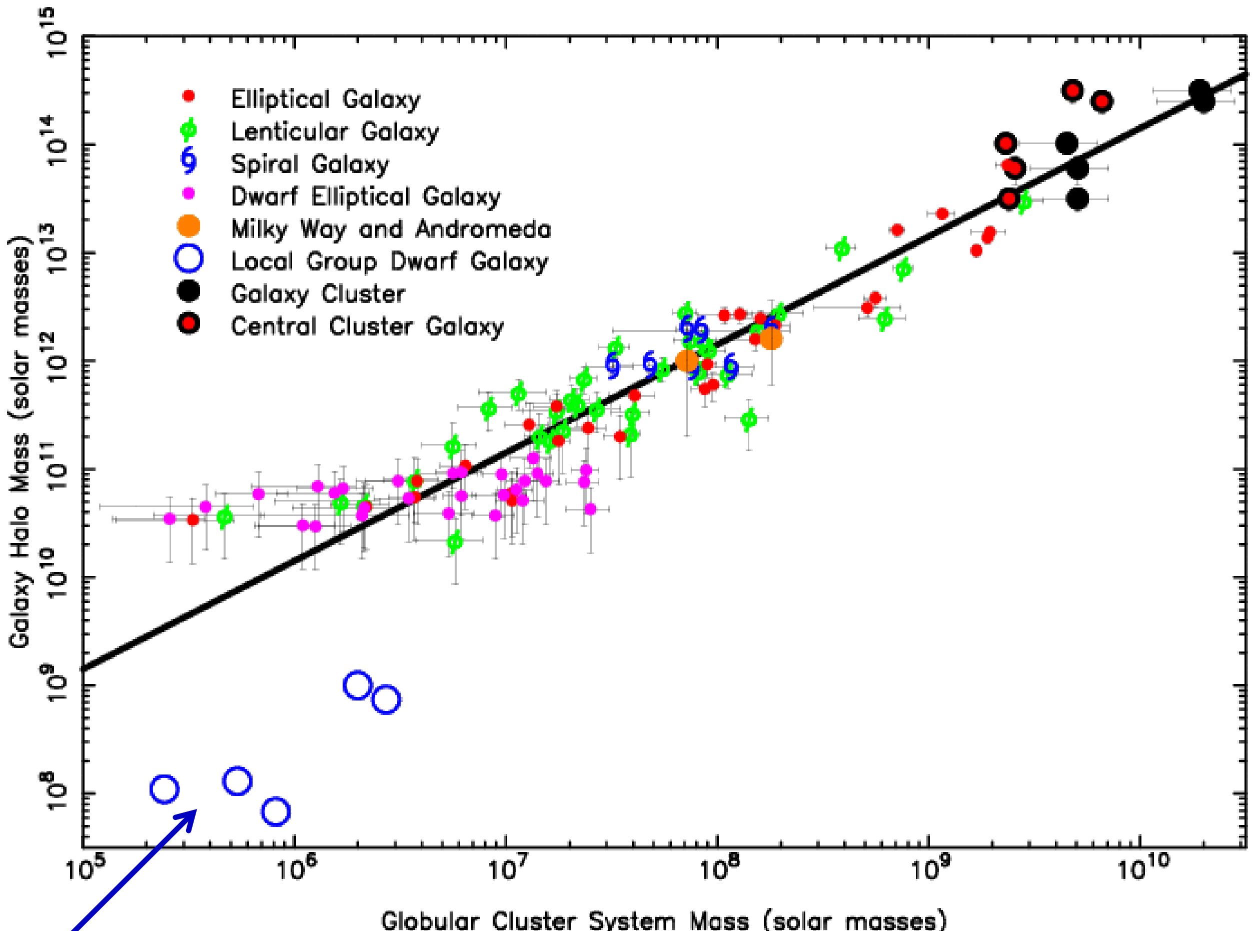


Behroozi et al. 2013

BUT: fraction of galaxy mass in the globular cluster system is similar in galaxies of (almost) all type and environment, over 5 orders of magnitude in mass

group environment

single galaxy environment



Spitler & Forbes (2009)

Georgiev at al. (2010)

Harris et al. (2013)

Hudson et al. (2014)

dwarfs are problem

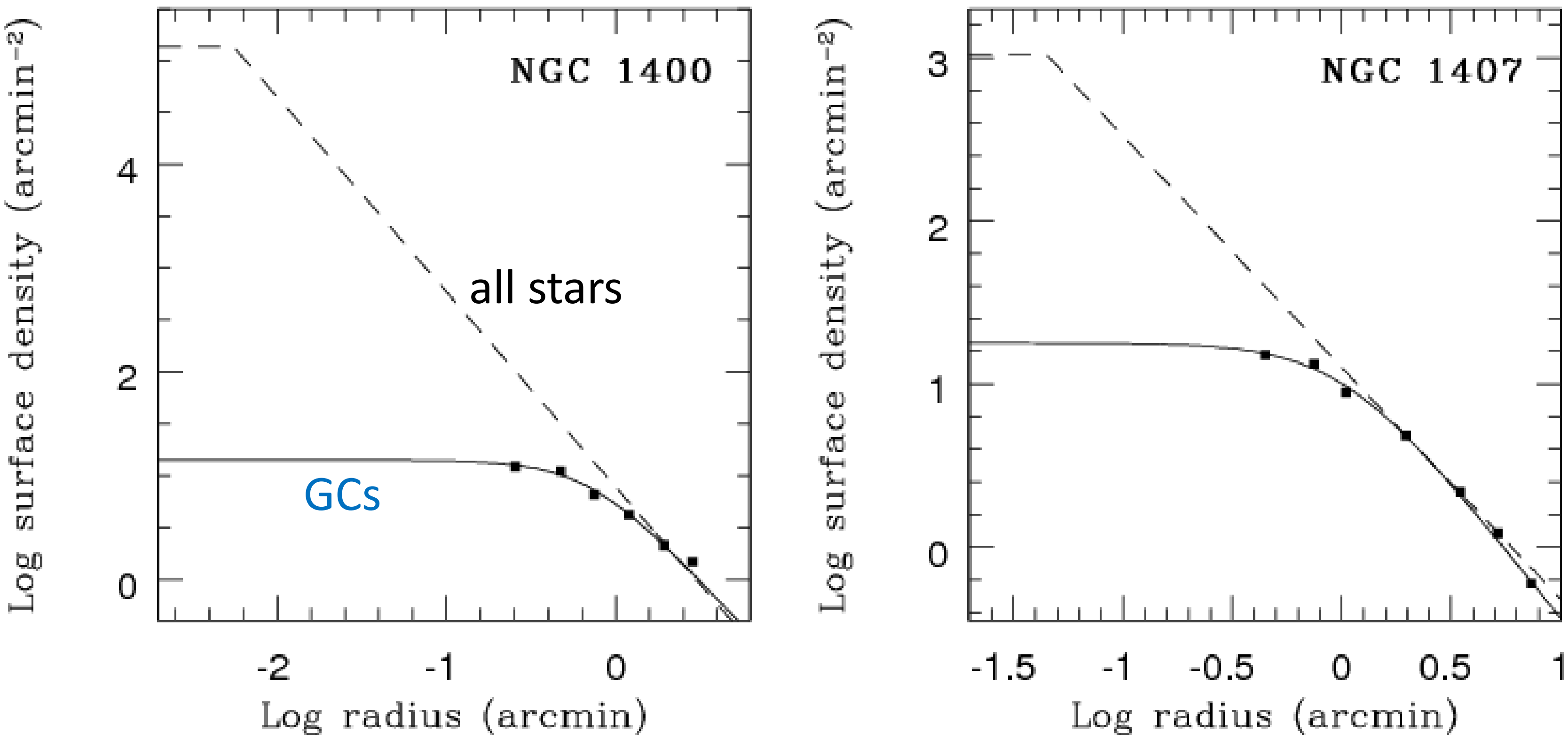
$$M_{GC} \approx (1\text{-}5)\times10^{-3}\, M_{*} \approx 10^{-4}\, M_{host}$$

In addition to in-situ star formation, a nuclear star cluster can be assembled from globular clusters inspiraling towards the galaxy center by dynamical friction.

Why? There is a deficit of GCs relative to field stars near the center.

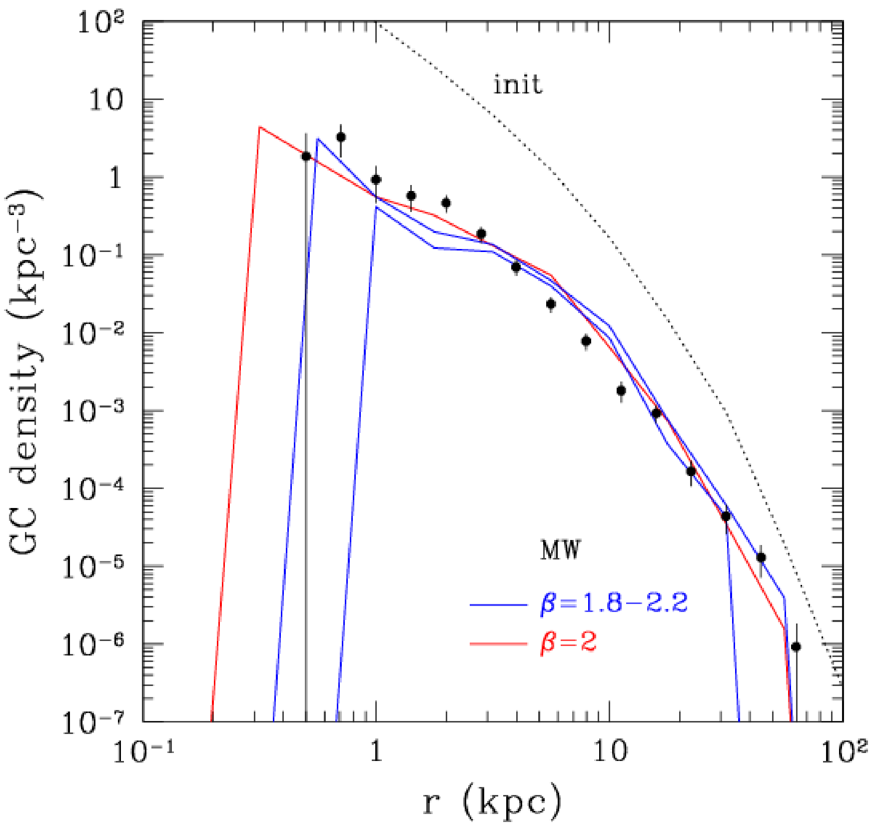
Tremaine et al. 1975
Capuzzo-Dolcetta 1993
Lotz et al. 2001
Capuzzo-Dolcetta & Miocchi 2008
Agarwal & Milosavljevic 2011
Antonini 2013 and 2014
and many more…

(Capuzzo-Dolcetta & Mastrobuono-Battisti 2009)

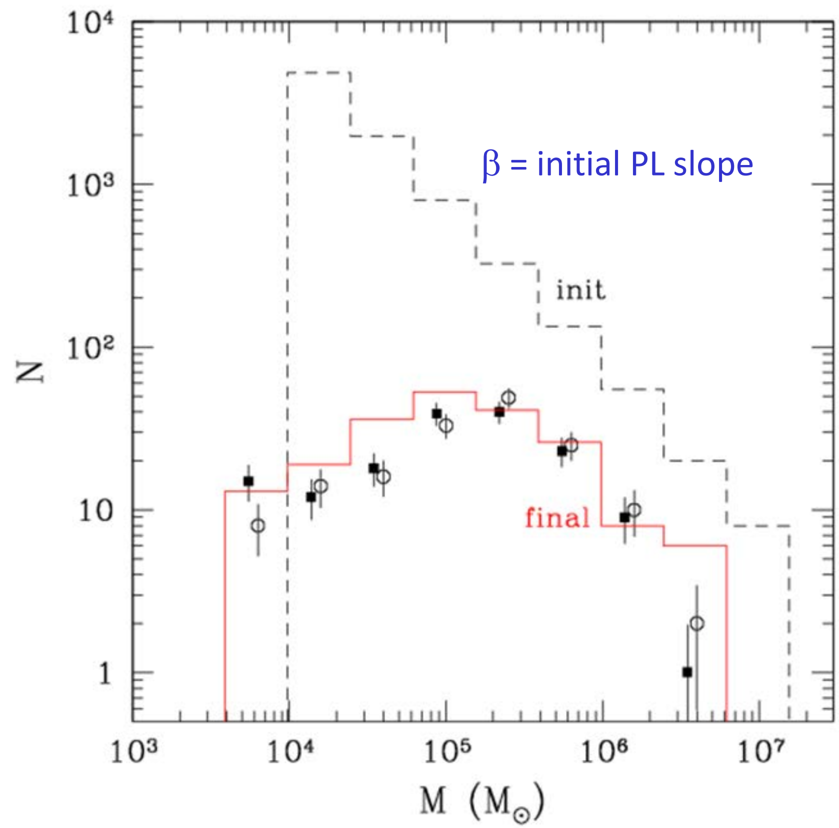


How many globular clusters could merger into a NSC?

Simple model: assume globular clusters in the Galaxy initially follow stellar density, migrate inward by dynamical friction, and tidally disrupt along the way.



Choose normalization such that surviving clusters match the observed density profile of Galactic clusters

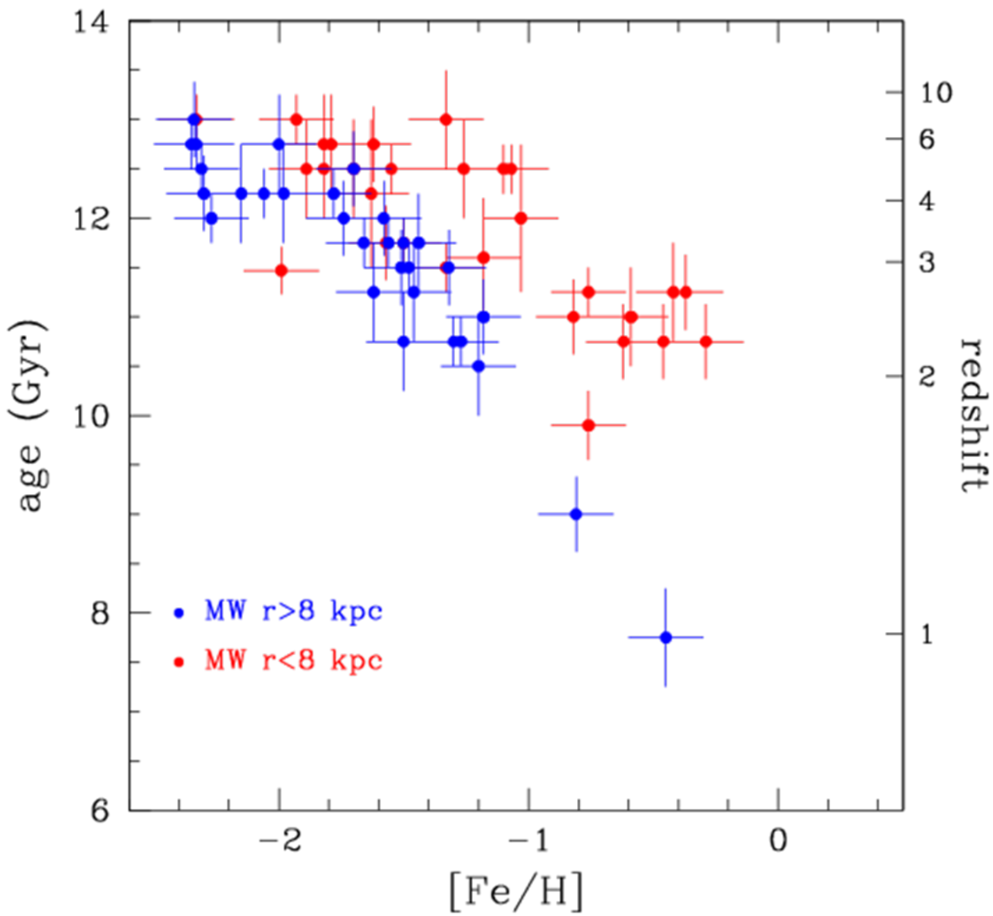


…and reproduce the observed cluster mass function

(OG, J. Ostriker & S. Tremaine 2014)

Do all clusters form at the same (early) time?

Galactic globular clusters show a systematic Age - Metallicity relation: metal-rich clusters are younger by a few Gyr



Data: resolved CMD with HST

[red circles: within 8 kpc of MW center

blue circles: outside 8 kpc]

Marín-Franch et al. (2009)

Dotter et al. (2011)

Vandenberg et al. (2013)

Leaman et al. (2013)

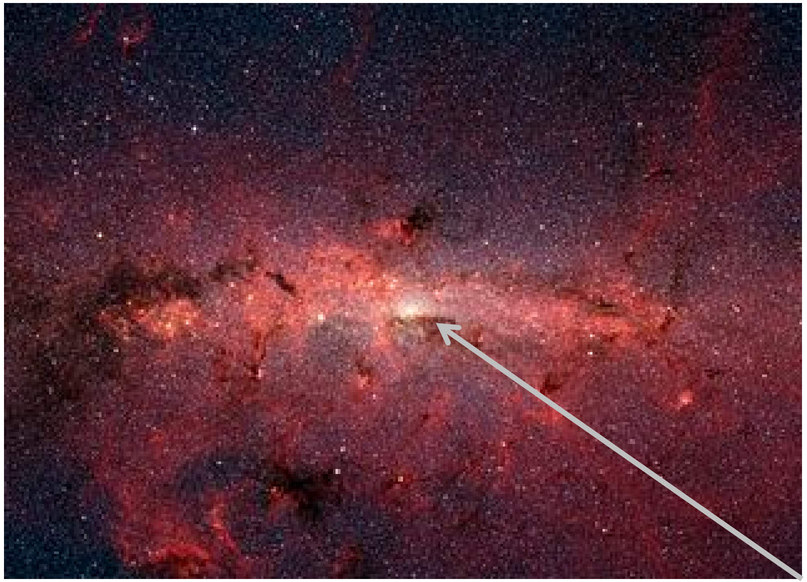
Model that explains the age and metallicity distributions:

Muratov & OG 2010

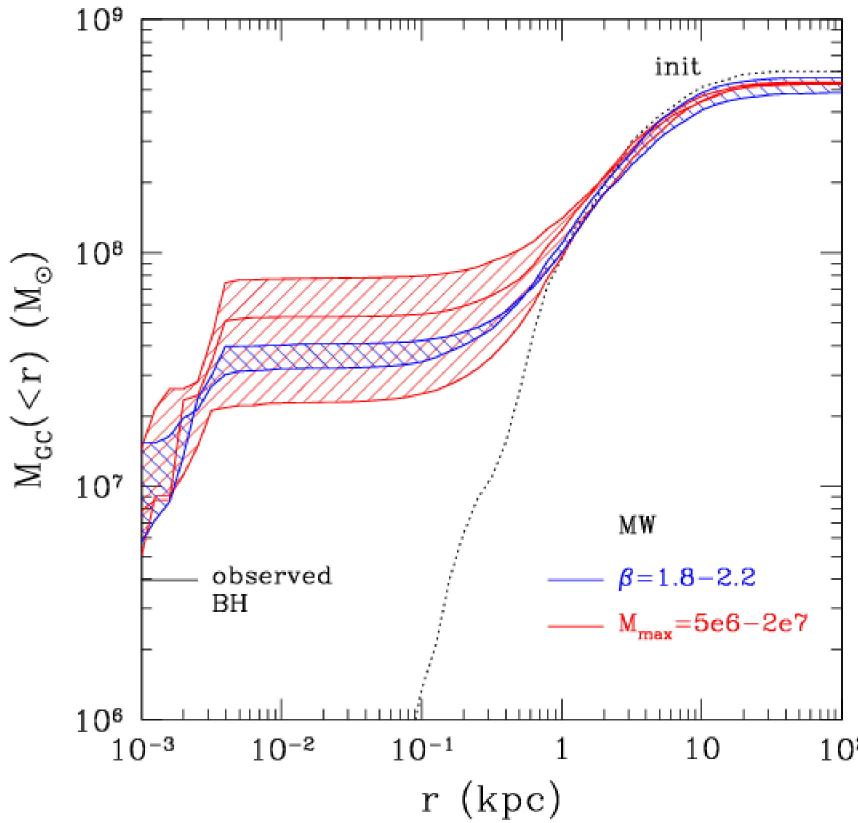
Li & OG 2014

GCs form in gas-rich galaxy mergers

Now we can check how many clusters accumulate at the Galactic center. *Are they more massive than the central black hole now?*



Nuclear star cluster at Galactic center

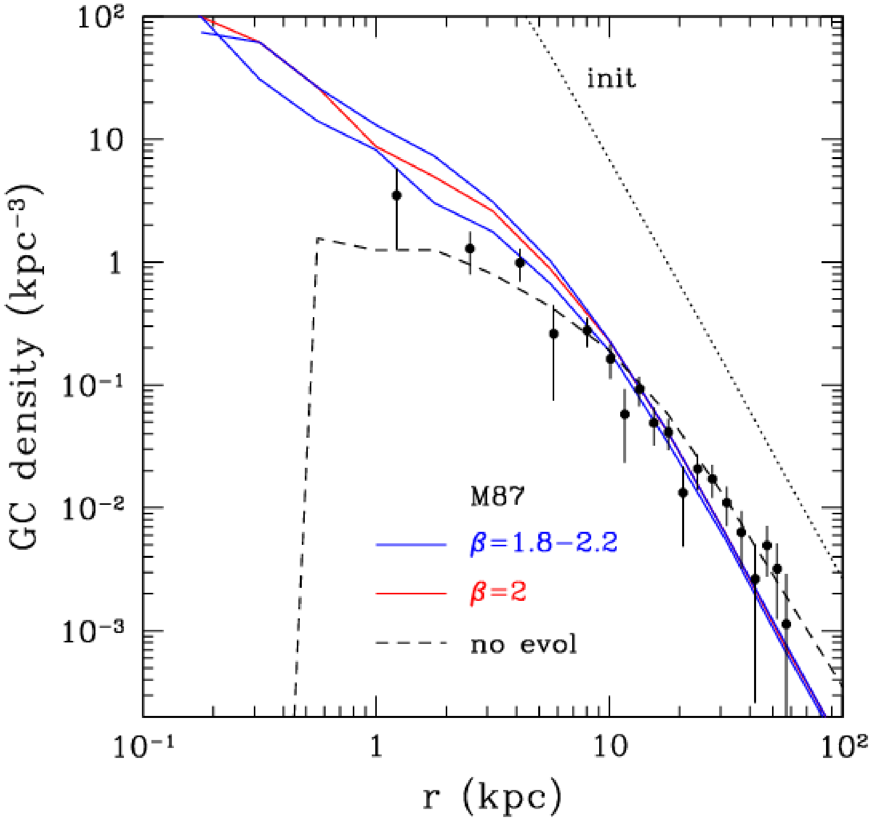


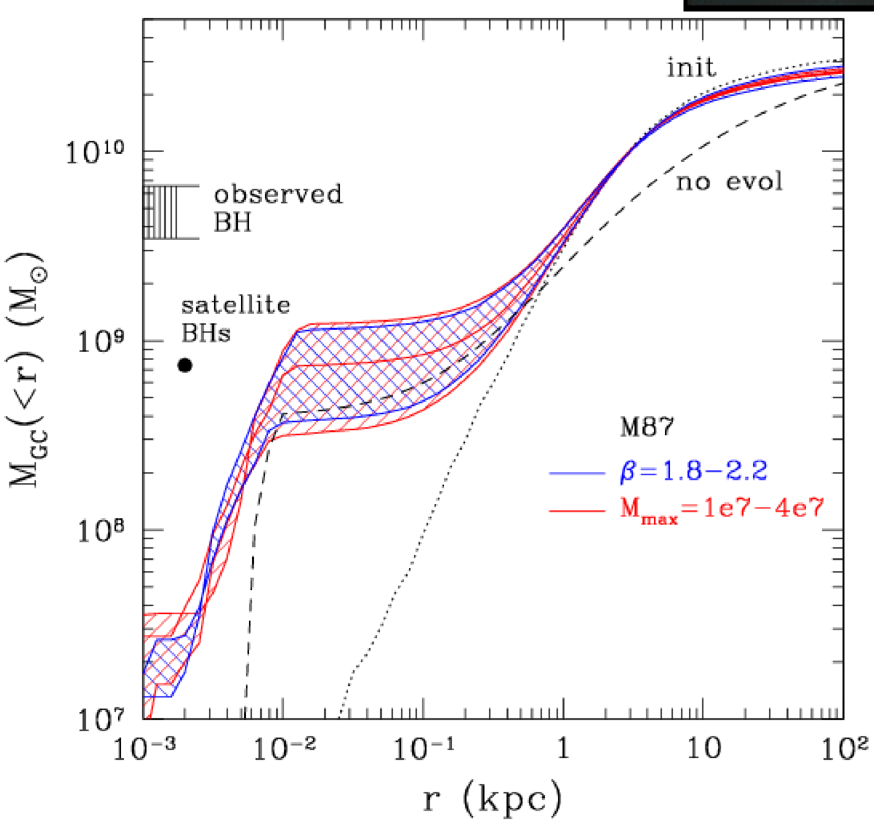
Stellar mass of disrupted clusters at the Galactic center is more than enough to form our NSC (~10^7 $M_\odot$) and SMBH (4×10^6 $M_\odot$)

(OG, Ostriker & Tremaine 2014)

What about other galaxies? A similar model for M87 (giant elliptical) with continuous formation of clusters predicts significantly less mass than the observed SMBH.

In lower-mass ellipticals NSC mass is closer to SMBH mass.

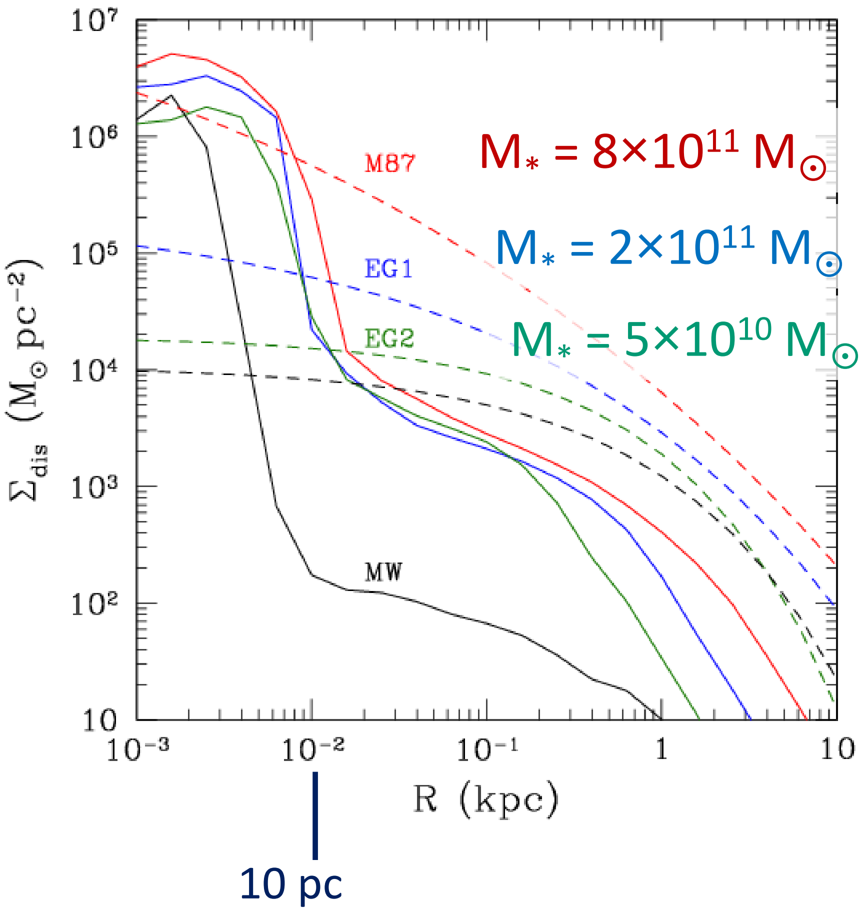


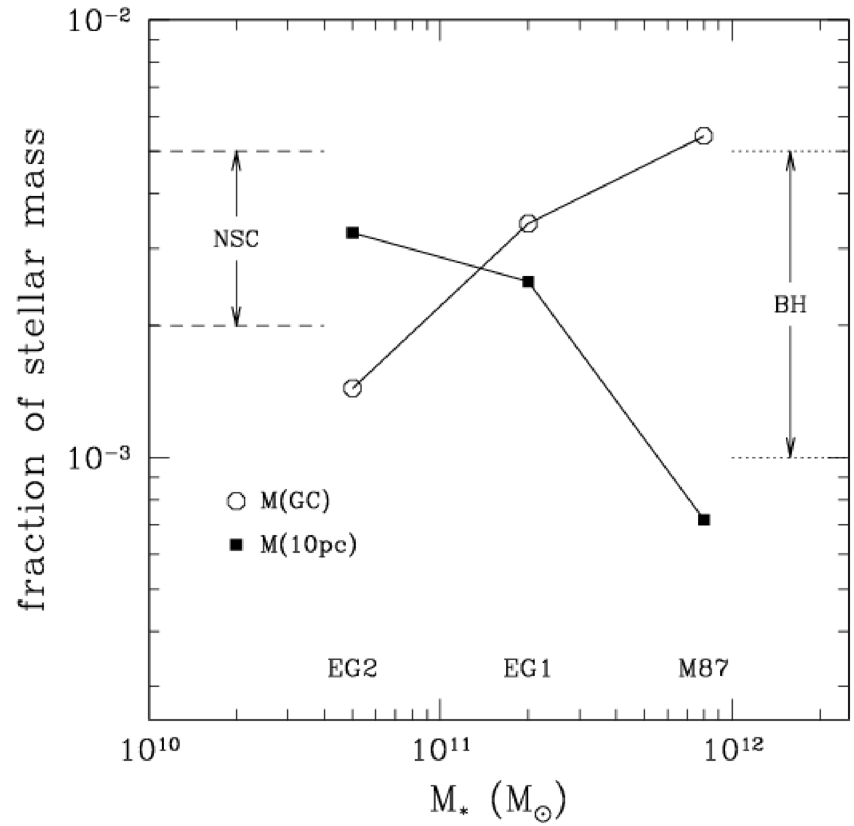


Model includes evolution of the stellar profile of an elliptical galaxy (more compact at high redshift; van Dokkum et al. 2010).

Part of Nuclear Star Cluster built by GCs is higher in lower-mass galaxies (< 10^{11} $M_\odot$) than giant E,

while the in-situ formed part is likely to be higher in more massive galaxies

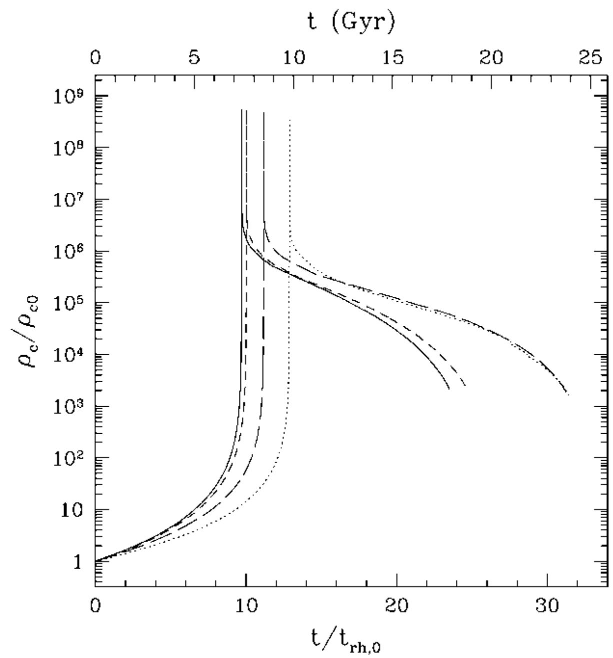




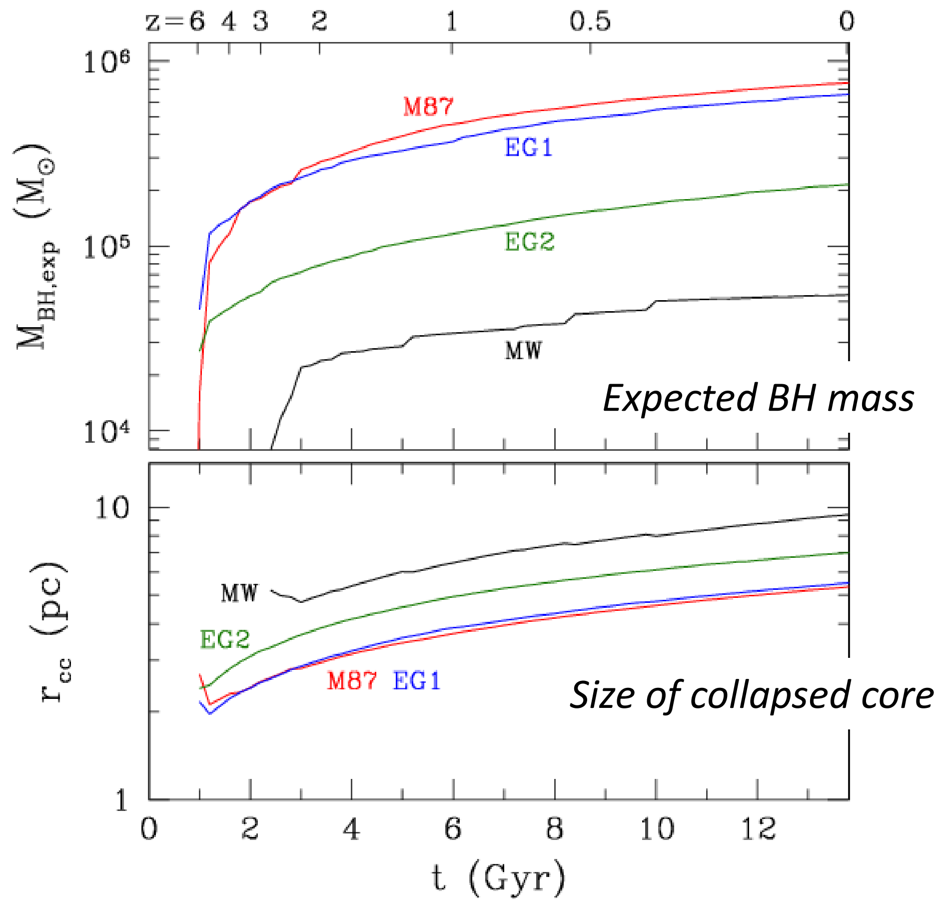
Additional mass from in-situ star formation (50% more, Antonini et al. in prep.)

Remaining GC system is similar to SMBH mass – *coincidence*?

Two-body relaxation may drive the inner 1-10 pc of NSC to collapse into an intermediate-mass black hole



In regular globular clusters, core collapse is reversed by the formation of binary stars that absorb potential energy, until they merge or get ejected. Very dense clusters with σ > 40 km/s cannot absorb enough energy to halt catastrophic core collapse (Miller & Davies 2012).



Core collapse time is shorter than the Hubble time within radius r_{cc}

Summary and Questions for discussion

- All massive galaxies contain systems of globular clusters, with a deficit in the inner region relative to field star surface density: *outcome of evolution or peculiarity of formation?*
- Lower-mass galaxies can build up significant *Nuclear Star Clusters* from disrupted globular clusters: *does this mechanism dominate over in-situ star formation?*
- Catastrophic core collapse could lead to the formation of a central black hole of $\sim 10^5\ M_{\odot}$: *seeds for supermassive BHs?*
- Remaining mass of globular cluster system is similar to the mass of SMBH: *coincidence or not?*