Bright Cluster Galaxy formation and the role of AGN feedback

Romain Teyssier

Outline

- Feedback and galaxy formation
- The role of AGN feedback in Milky Way halos
- Cosmological simulation of a Virgo-like cluster
- The role of AGN feedback in BCG formation

Ben Moore (Zürich), George Lake (Zürich)
Davide Martizzi (Zürich), Christine Moran (Zürich)
Oscar Agertz (Zürich→Chicago)

Simulations performed at the Swiss Supercomputing Center CSCS, Manno

Abundance matching

For each dark matter halo and sub-halo, assign a galaxy with mass m.

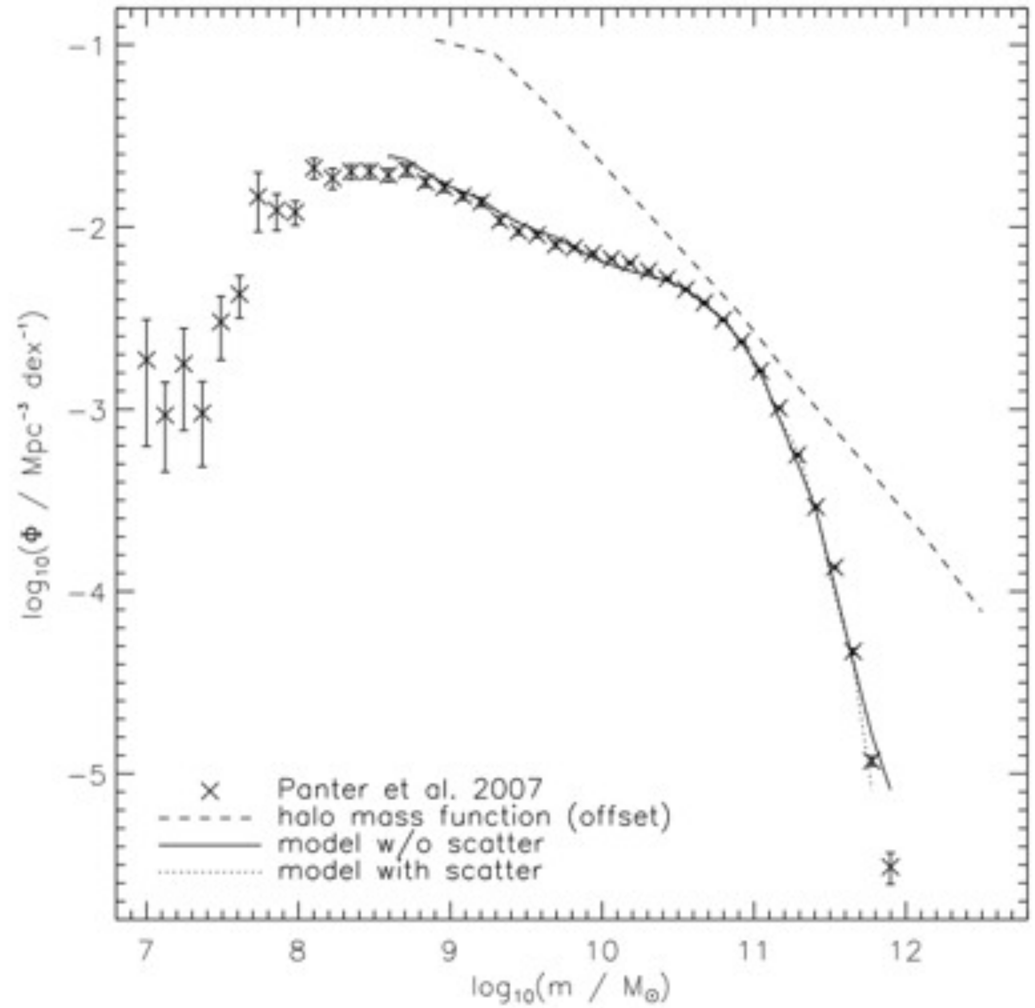
Determine the **stellar-to-halo mass fraction** m/M=f(M) with

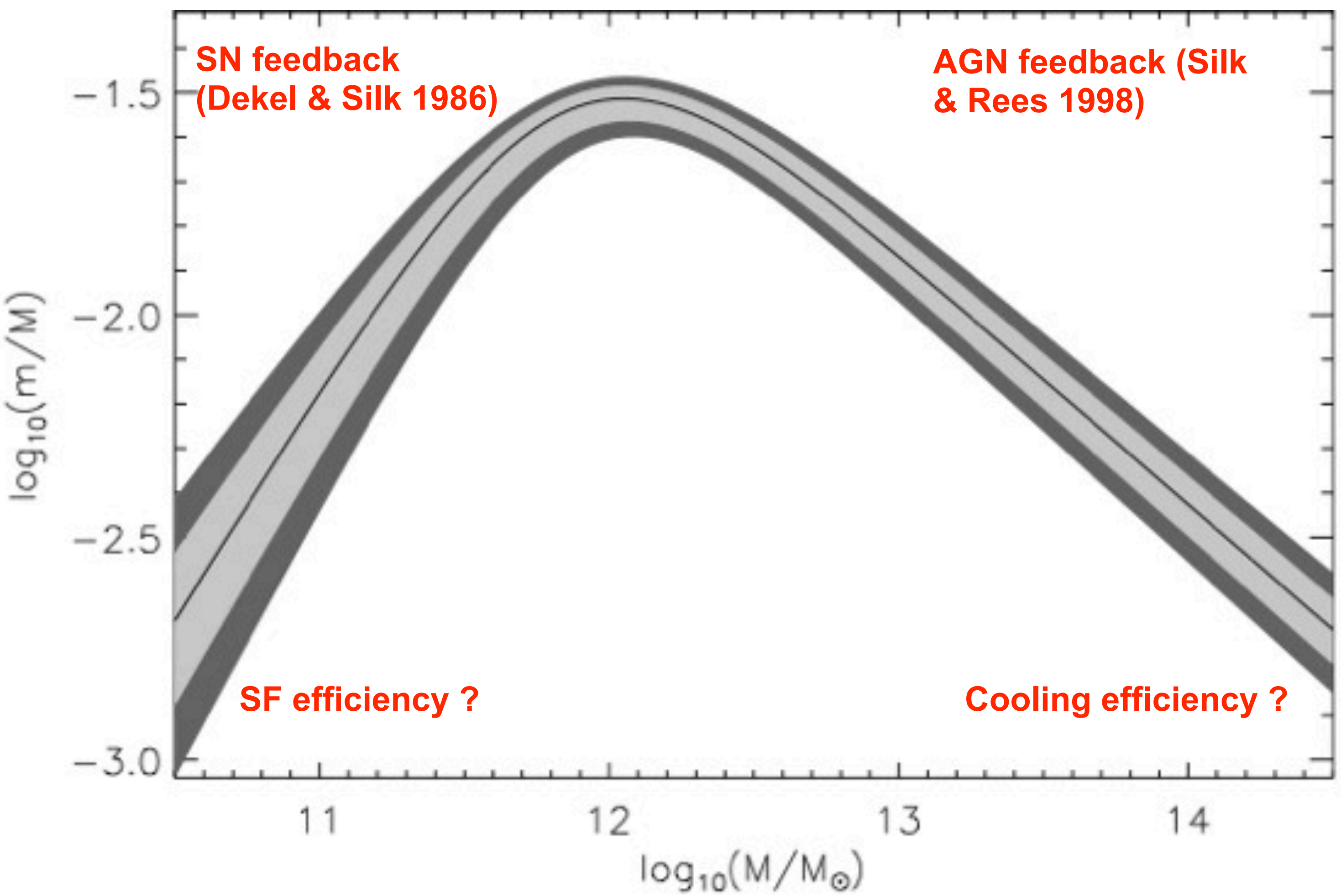
$M=M_{vir}$ for central galaxies

$M=M_{max}$ for satellite galaxies

by fitting directly the galaxy luminosity function:

Moster et al. (2010)

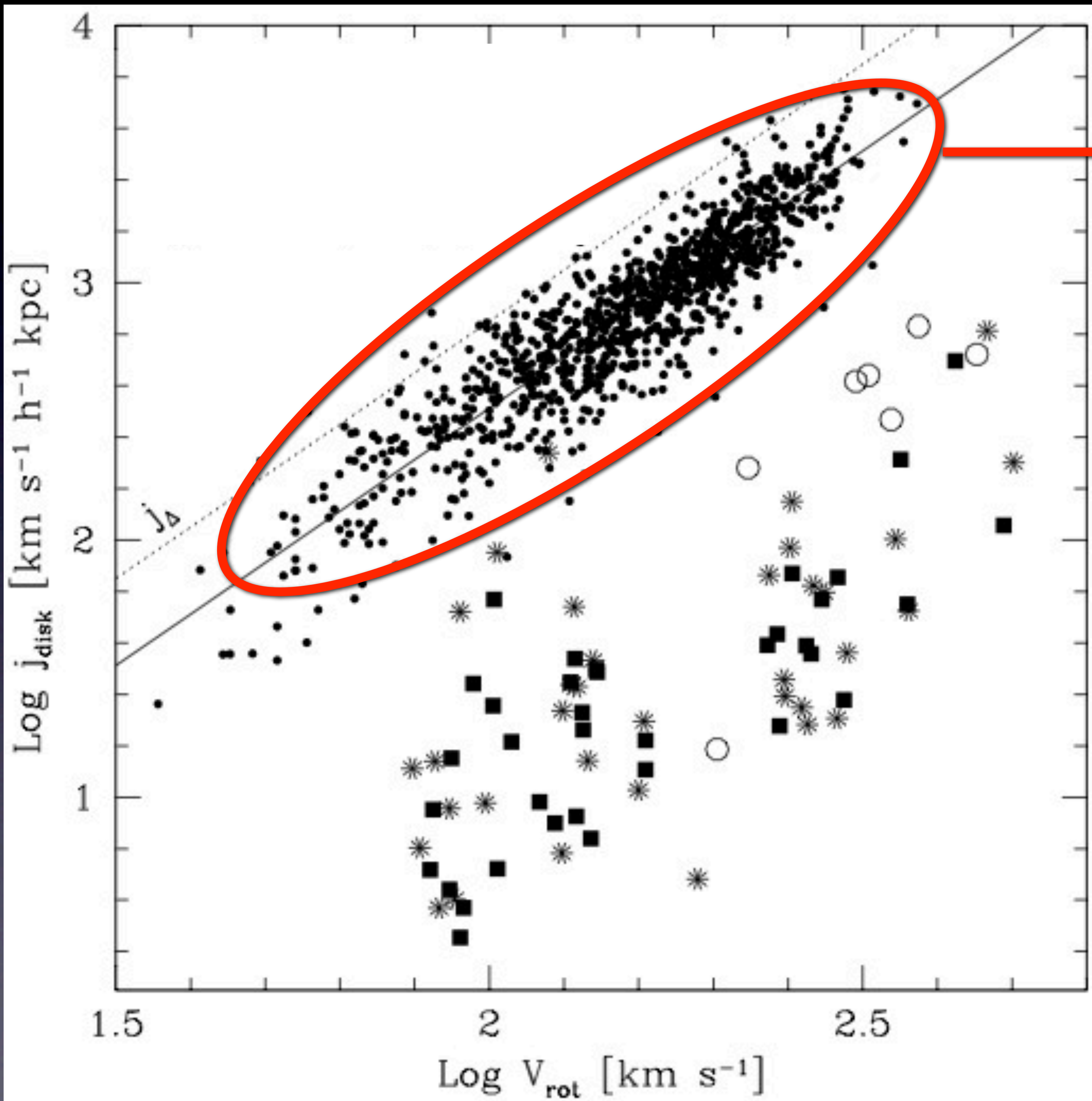




Guo et al. (2010), Moster et al. (2010)

Similar conclusions from SAM: Croton et al. 2006; Cattaneo et al. (2006, 2008, 2009)

First galaxy formation simulations



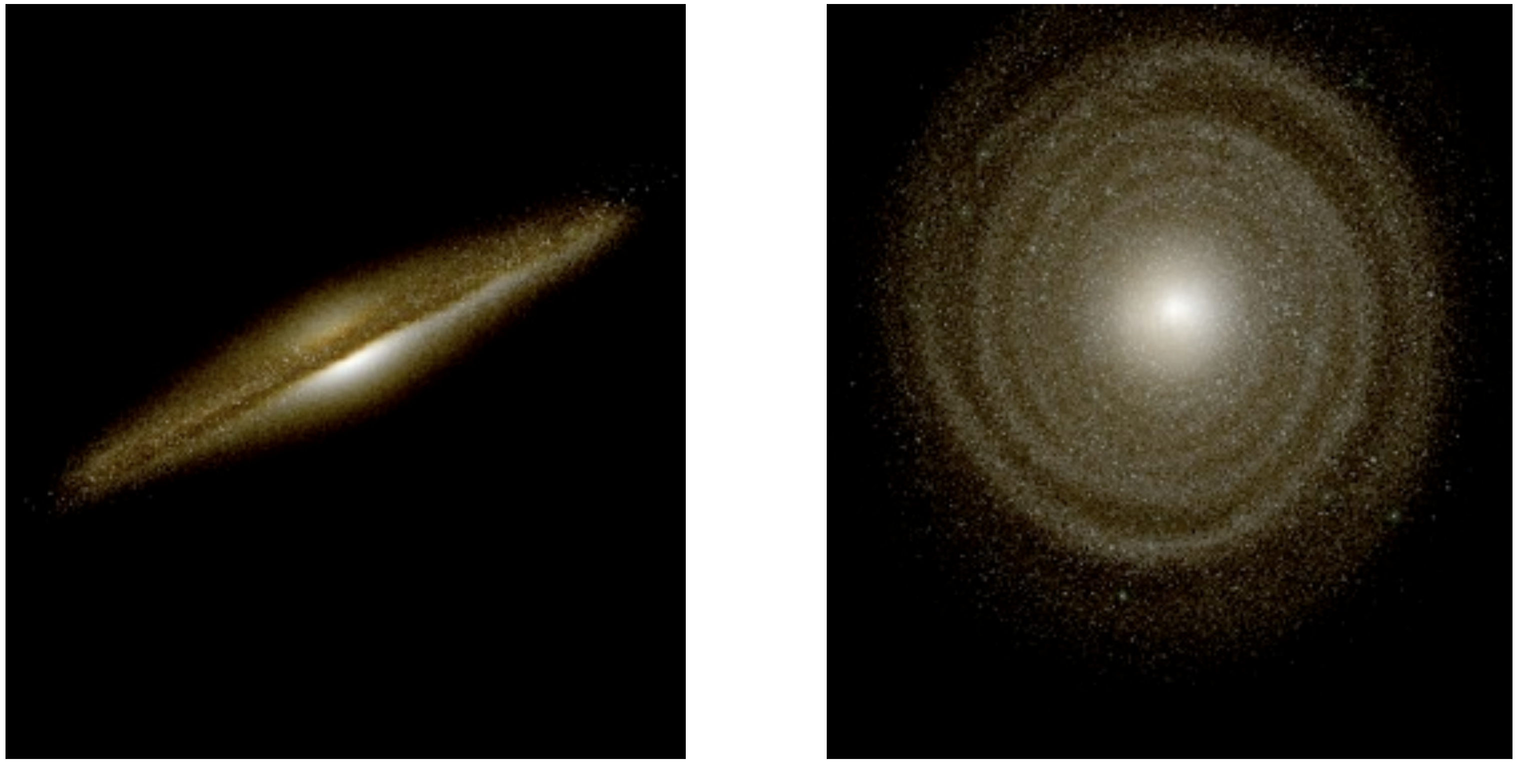
Courteau (1997)
Sb-Sc galaxies

The angular momentum problem

Navarro & Steinmetz 2000

Modern galaxy formation simulations

Disks get larger because of increased resolution and more powerful SN feedback.

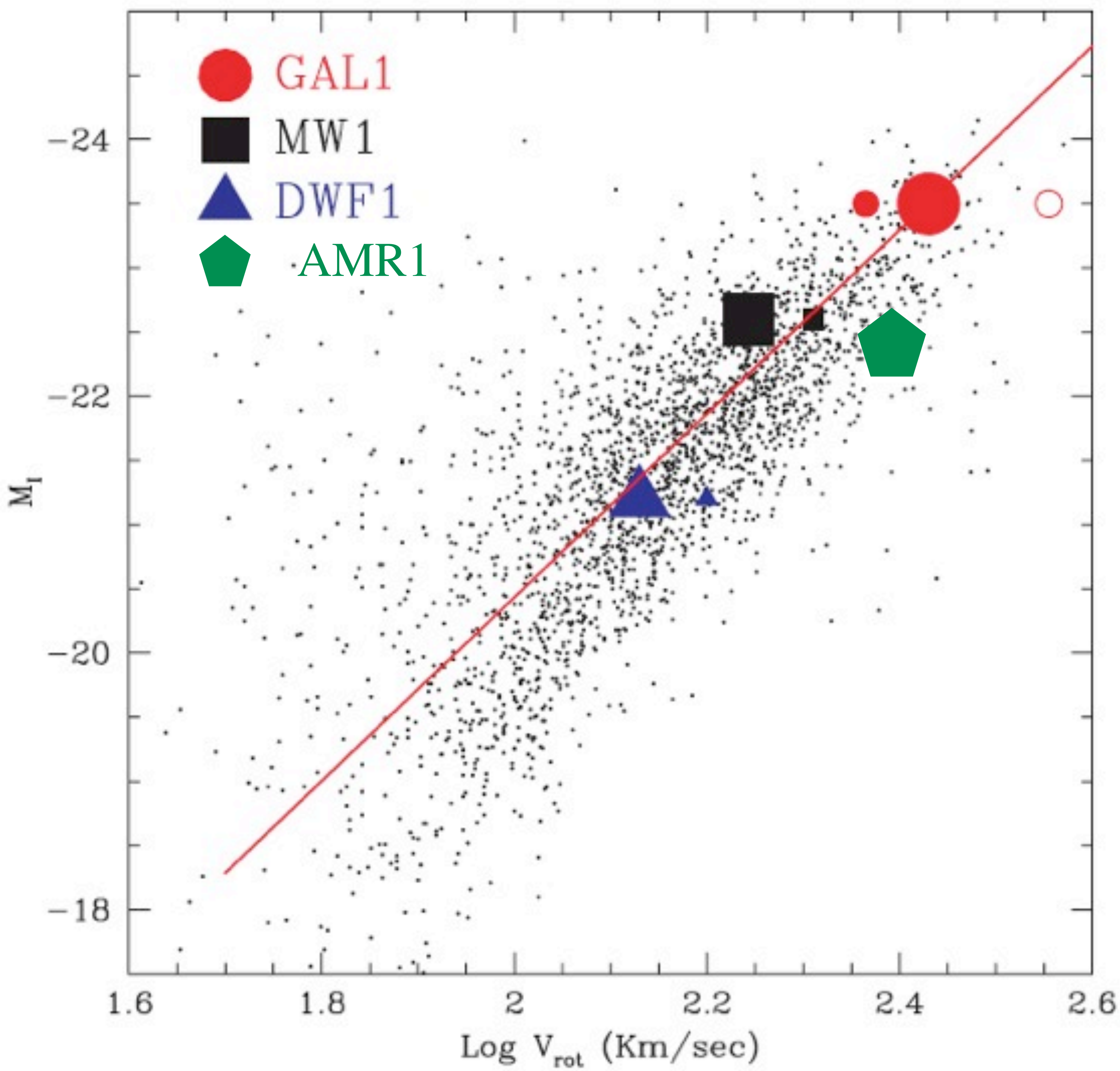


Mock gri SDSS composite image with dust absorption based on Draine opacity model from a RAMSES cosmological simulation.

NGC4622 as seen from HST

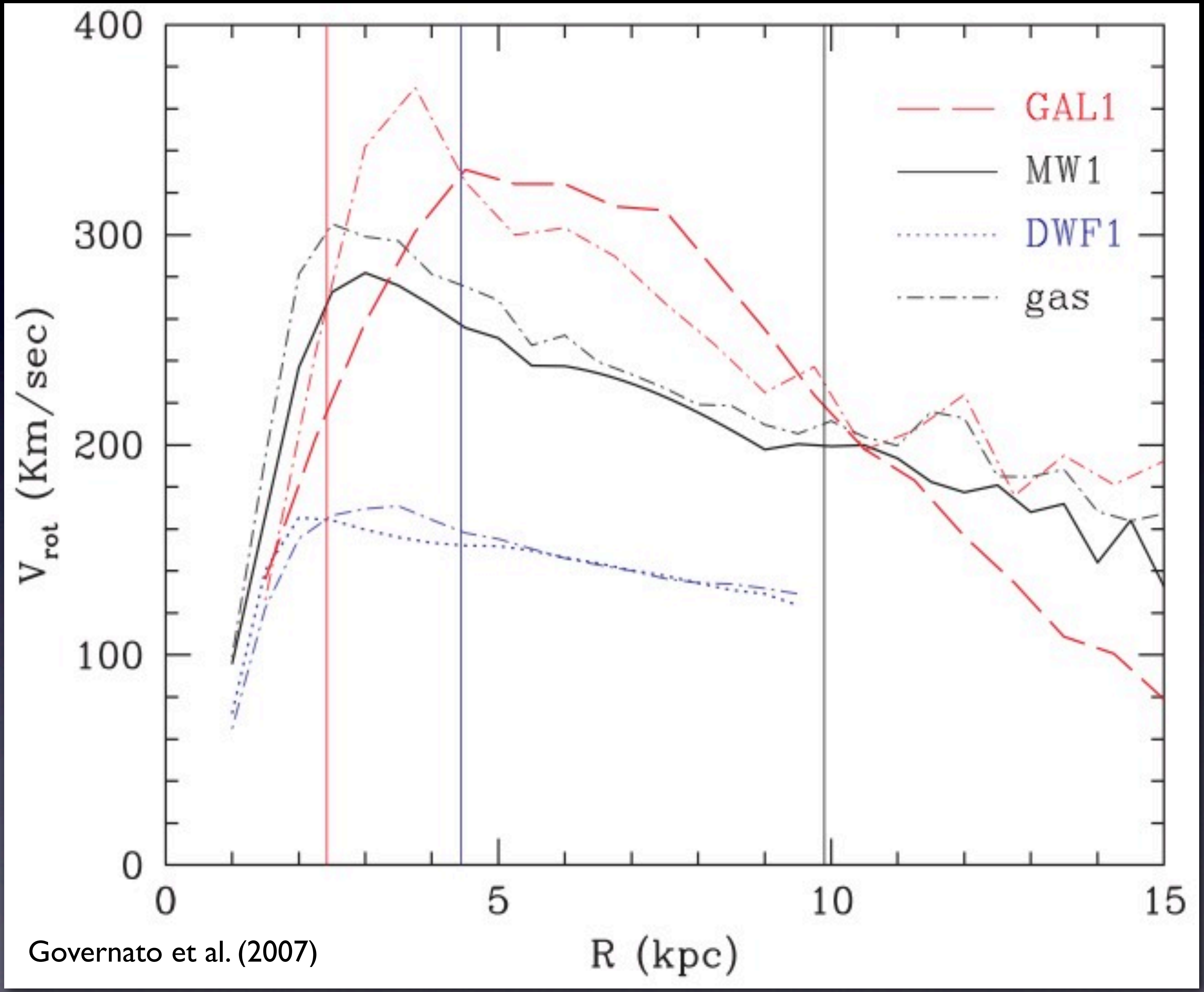
Okamoto et al. (2009), Governato et al. (2007, 2009, 2010), Piontek & Steinmetz (2009), Scannapieco et al. (2008, 2009); Agertz et al. (2010); Wadephul & Springel (2010)

Stronger feedback, higher resolution



I Band Tully-Fisher relation
GASOLINE data from Governato et al. 2007, Mayer et al. 2008

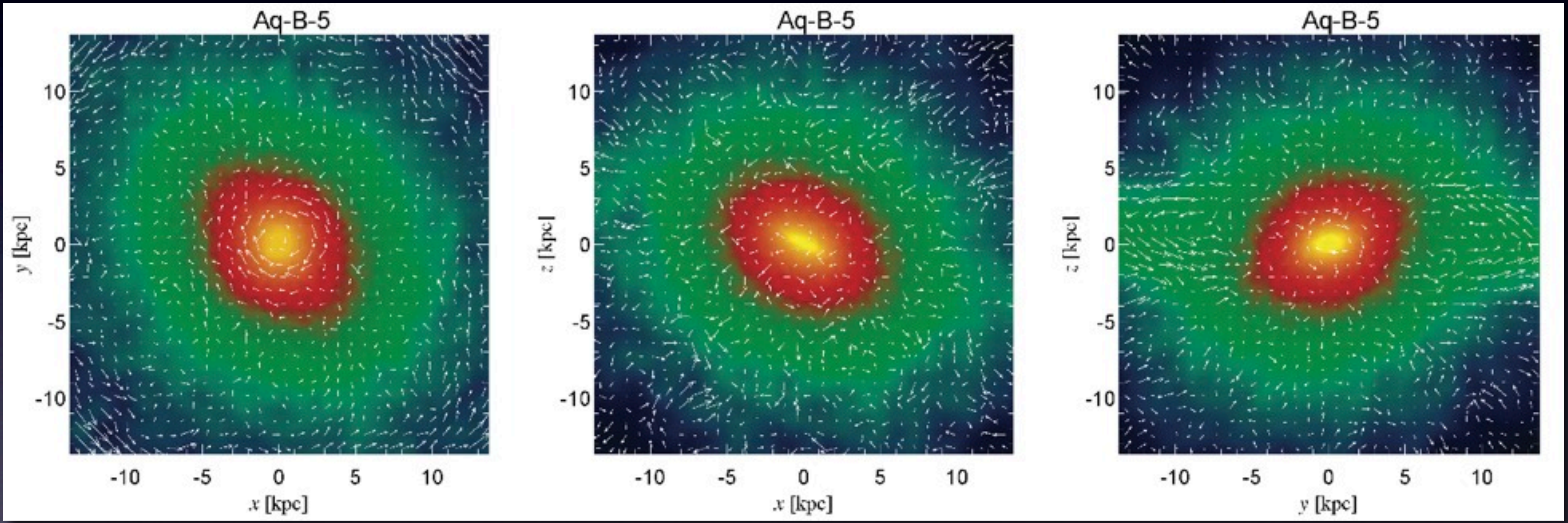
Rotation curves are still strongly peaked !



Governato et al. (2007)

Disks in large haloes are still too small

Galaxy formation in 8 Milky Way haloes (Scannapieco et al. 2009)
(Hydro + N-body simulations of the Aquarius halos)
Sophisticated models of SNe feedback, winds lead to largest D/T ~ 2



Disk are small in size or in mass:
Small disk dominated galaxies (weak feedback)
or bulge dominated galaxies (strong feedback)

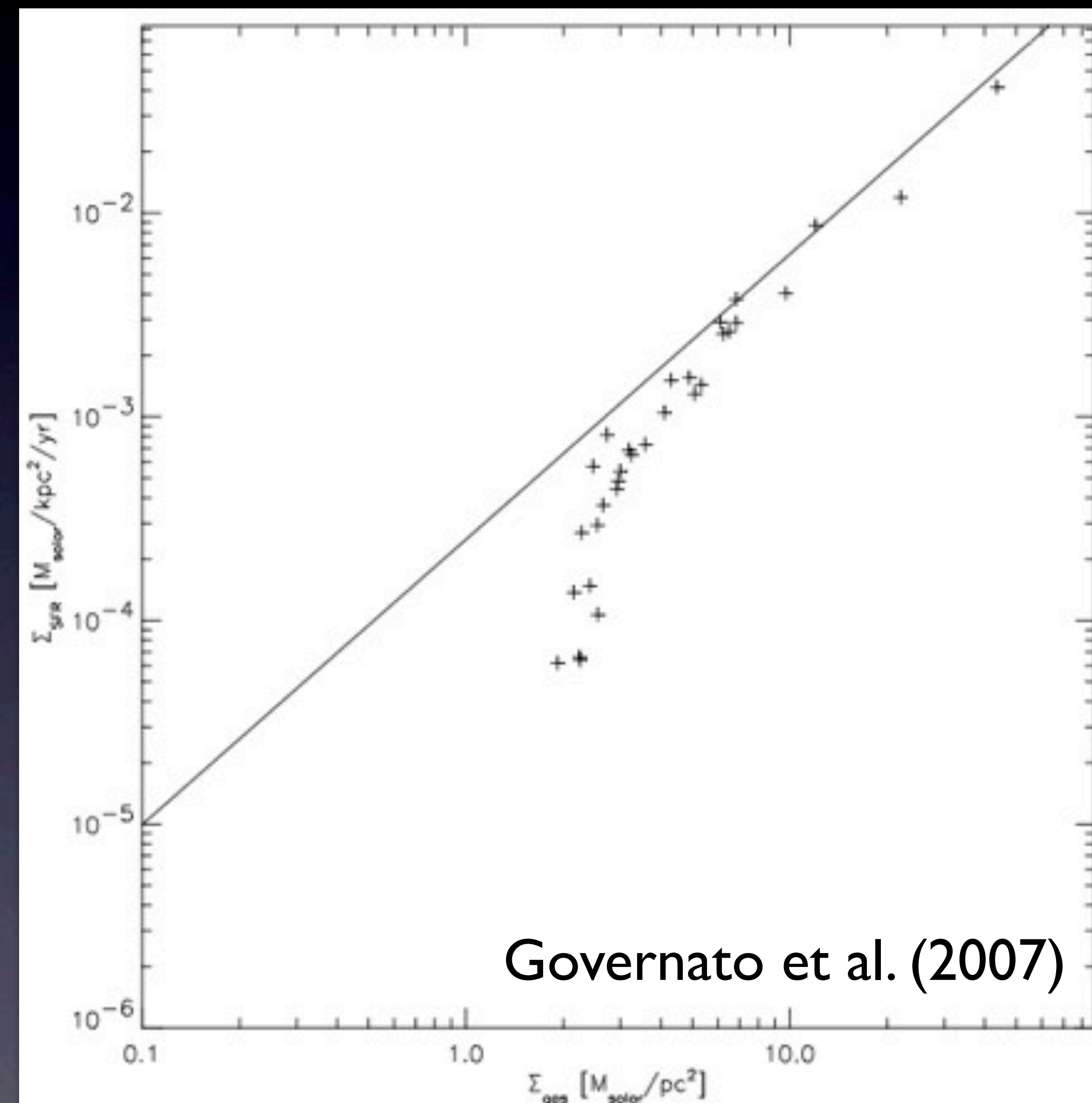
Standard practice of star formation and feedback in simulations of galaxy formation...

1. Tune the star formation efficiency and supernovae feedback to the Kennicutt-Schmidt relation (Kennicutt 1998), using an isolated disk.

$$\dot{\rho}_* = \epsilon_{\rm ff} \frac{\rho_{\rm g}}{t_{\rm ff}} \text{ for } \rho > \rho_0$$

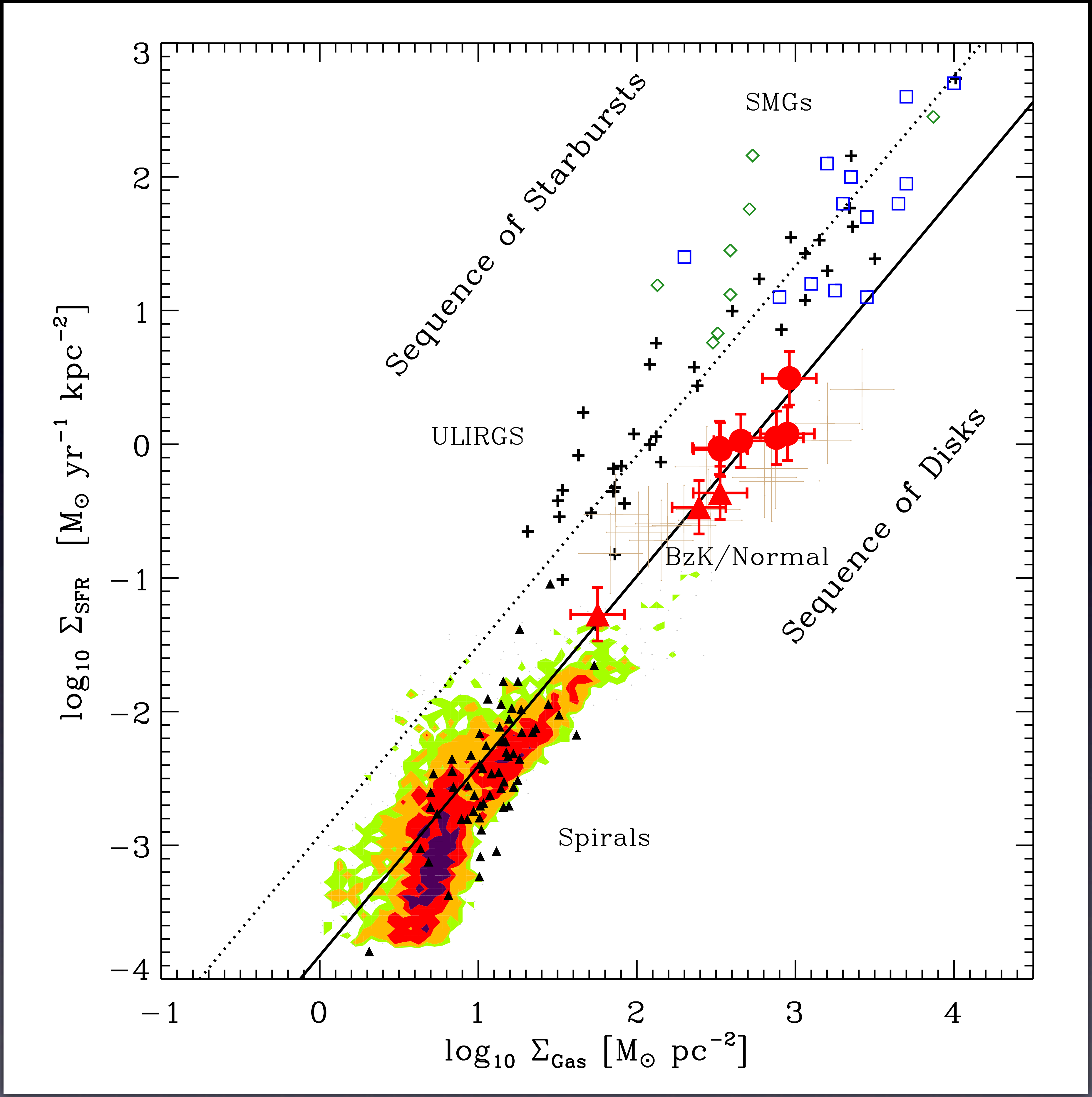
$\downarrow$

$$\Sigma_{\rm SFR} = (2.5 \pm 0.7) \times 10^{-4} \left(\frac{\Sigma_{\rm gas}}{\rm M_\odot pc^{-2}} \right)^N$$



Governato et al. (2007)

2. Assume star formation is regulated by supernovae explosions at high-z. Dump $E_{\rm SNII}$ into the ISM (kinetic, thermal, cooling shutoff etc).



Daddi et al. 2010
Genzel et al. 2010

The way gas is converted into stars is observed to vary *among* different galaxies, *within* galaxies and at different cosmic epochs!

Various feedback numerical models

Supernovae driven feedback

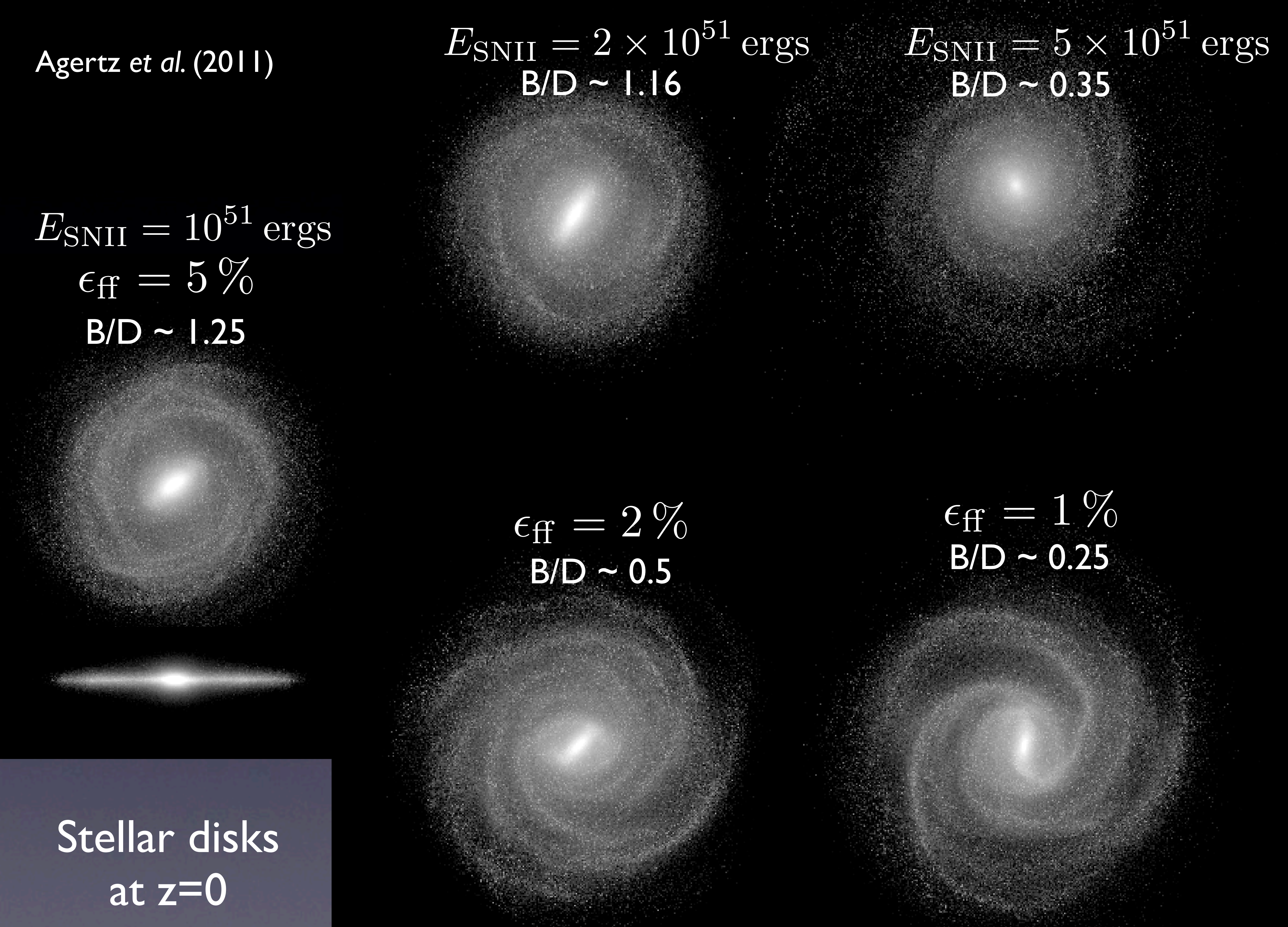
- thermal dump with delay cooling (Stinson *et al.* 2008)
- thermal dump at high resolution (Ceverino & Klypin): gas temperature reaches $T>10^7$ K
- runaway stars
- kinetic feedback: momentum kick with velocity $\mathbf{v}_{\mathbf{wind}} \propto 500 - 1000 \ \mathrm{km/s}$
- WARNING: positive feedback due to metal enrichment !

Momentum driven feedback (Dave & Oppenheimer, Genel *et al.* 2010)

- kinetic feedback with velocity $\mathbf{v}_{\mathbf{wind}} \propto \mathbf{v}_{\mathbf{esc}} \simeq 3V_{\mathrm{vir}}$

AGN feedback (Sijacki *et al.*; Booth & Schaye 2010)

- SMBH growth model
- thermal dump of jet-driven kinetic feedback

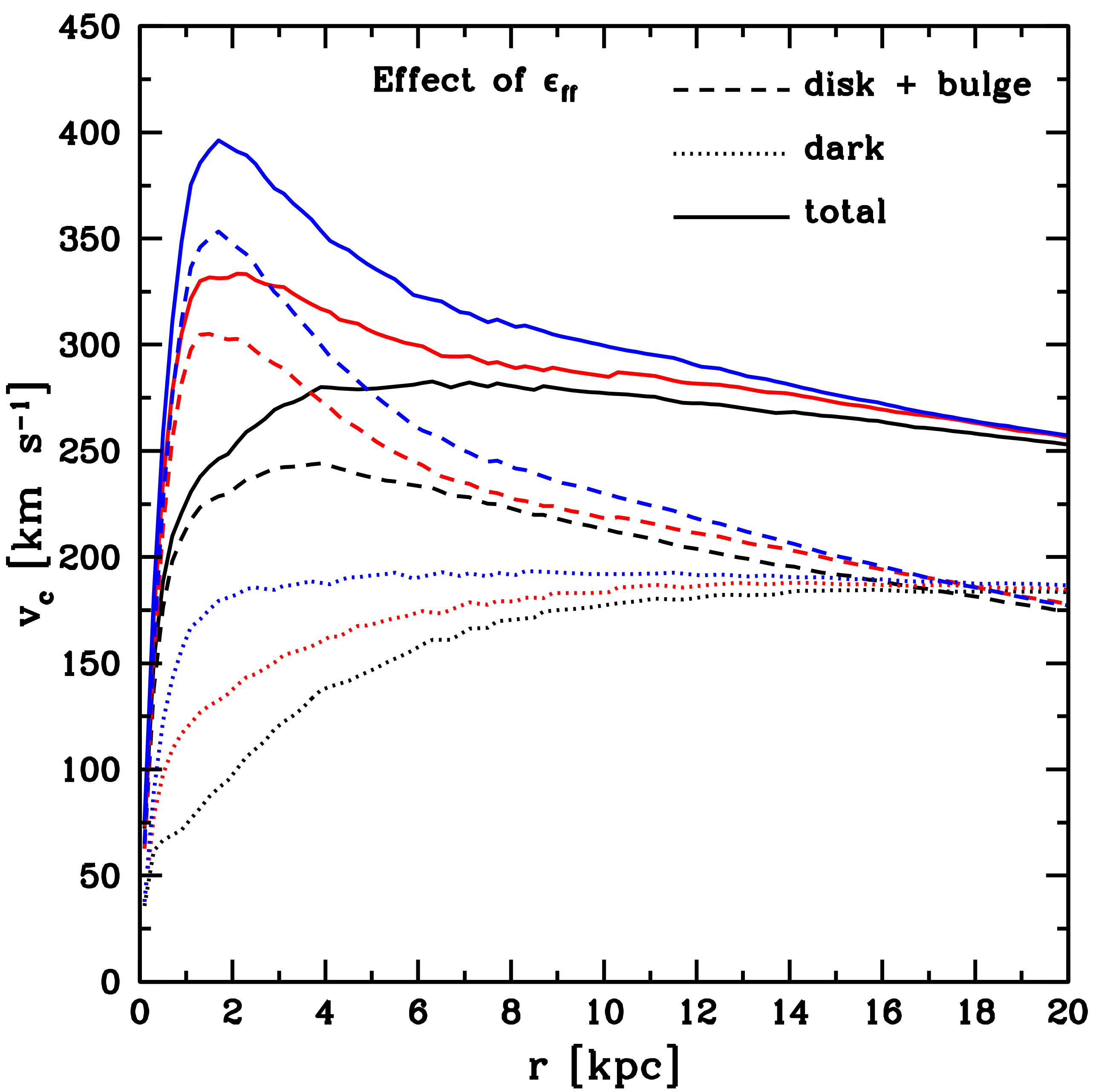


Stellar disks at z=0

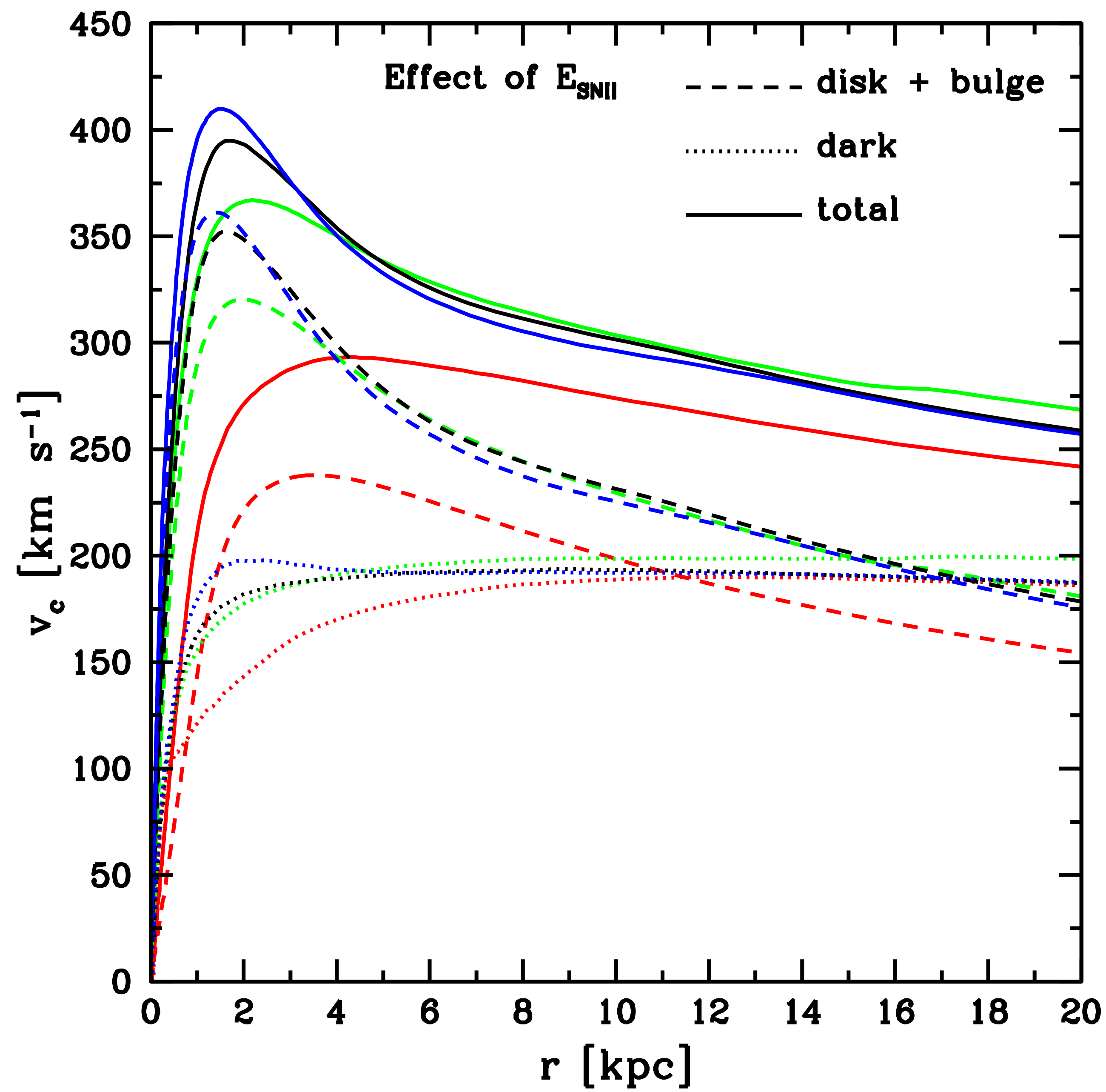
Agertz *et al.* (2011)

Circular velocities

Effect of SFE



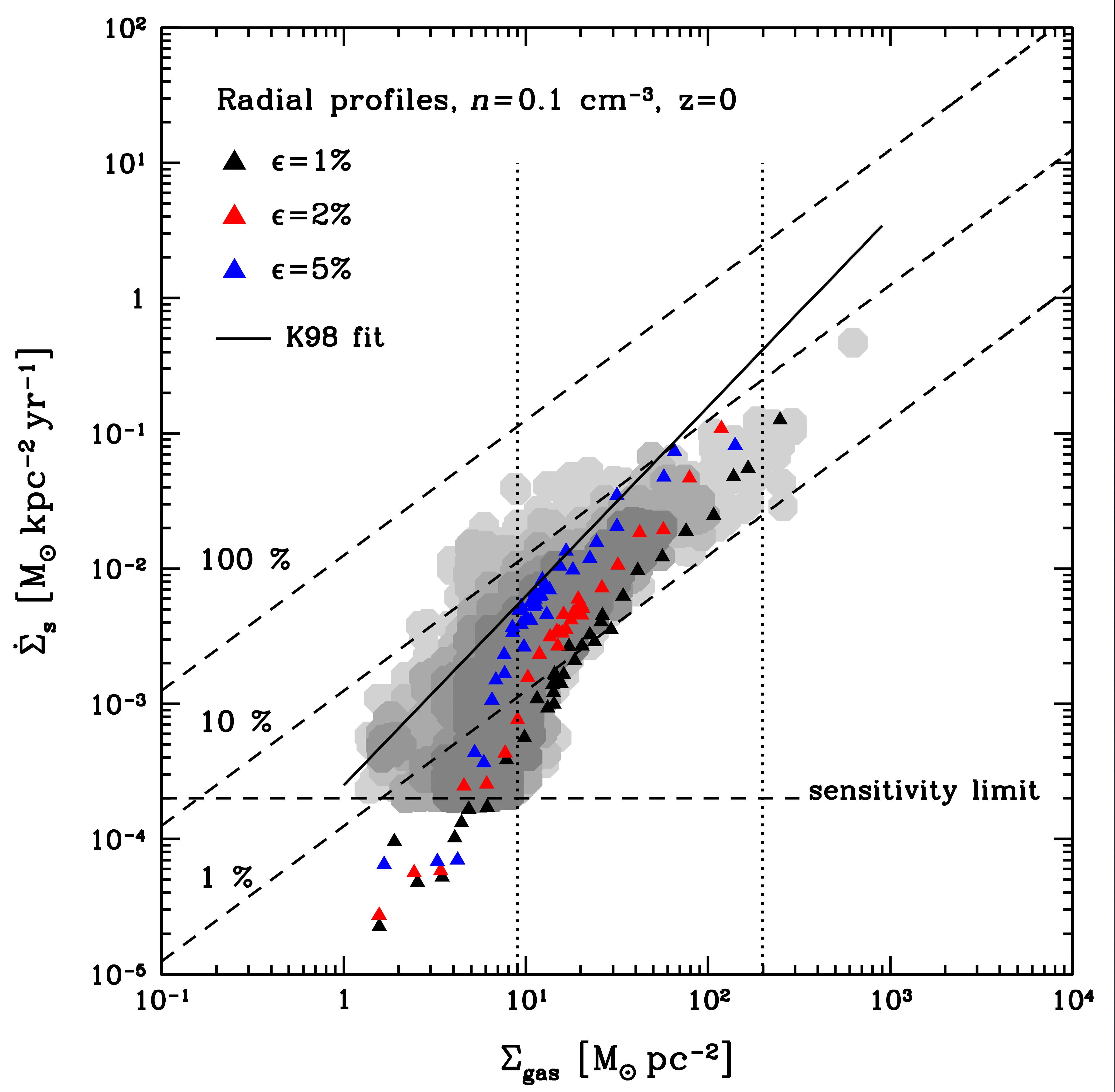
Effect of SNe feedback



10-20% scaling recovers the Milky Way

MW models with small halo mass (~ 7×10^{11} Msol) are required

Agertz *et al.* (2011)



Observe simulated disks @ z=0

Kennicutt-Schmidt relation + THINGS data (Bigiel et al. 2008)

The baryon fraction problem

Using abundance matching with dark halos, one can relate the stellar mass to the halo mass.

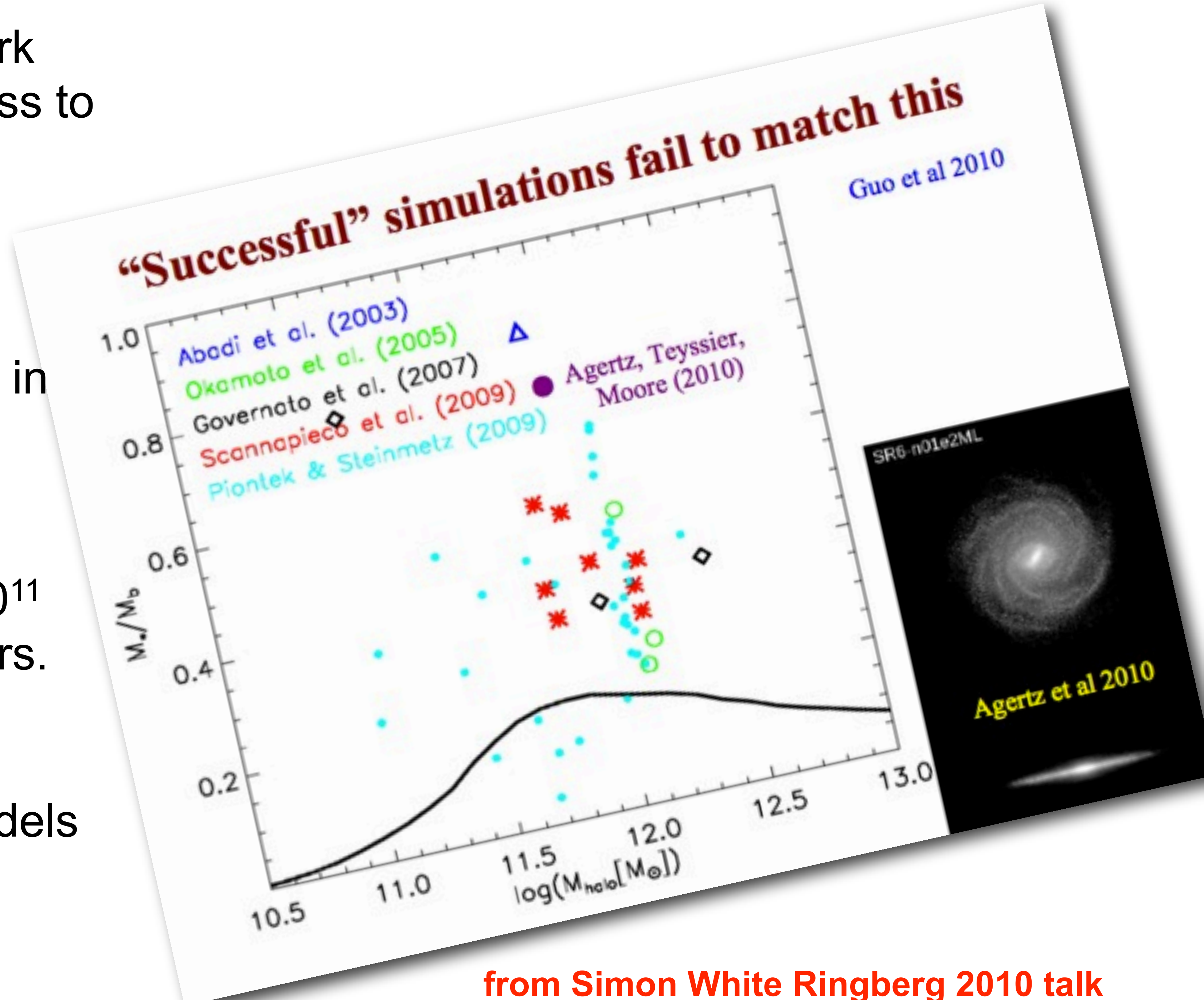
This gives $M_{halo}=2\times10^{12}$ M_{sol} for the Milky Way and 20% baryon fraction in stars !

Our simulation suggests $M_{halo}=7\times10^{11}$ M_{sol} with 80% baryon fraction in stars.

Low star fraction in current MW models requires very efficient feedback.

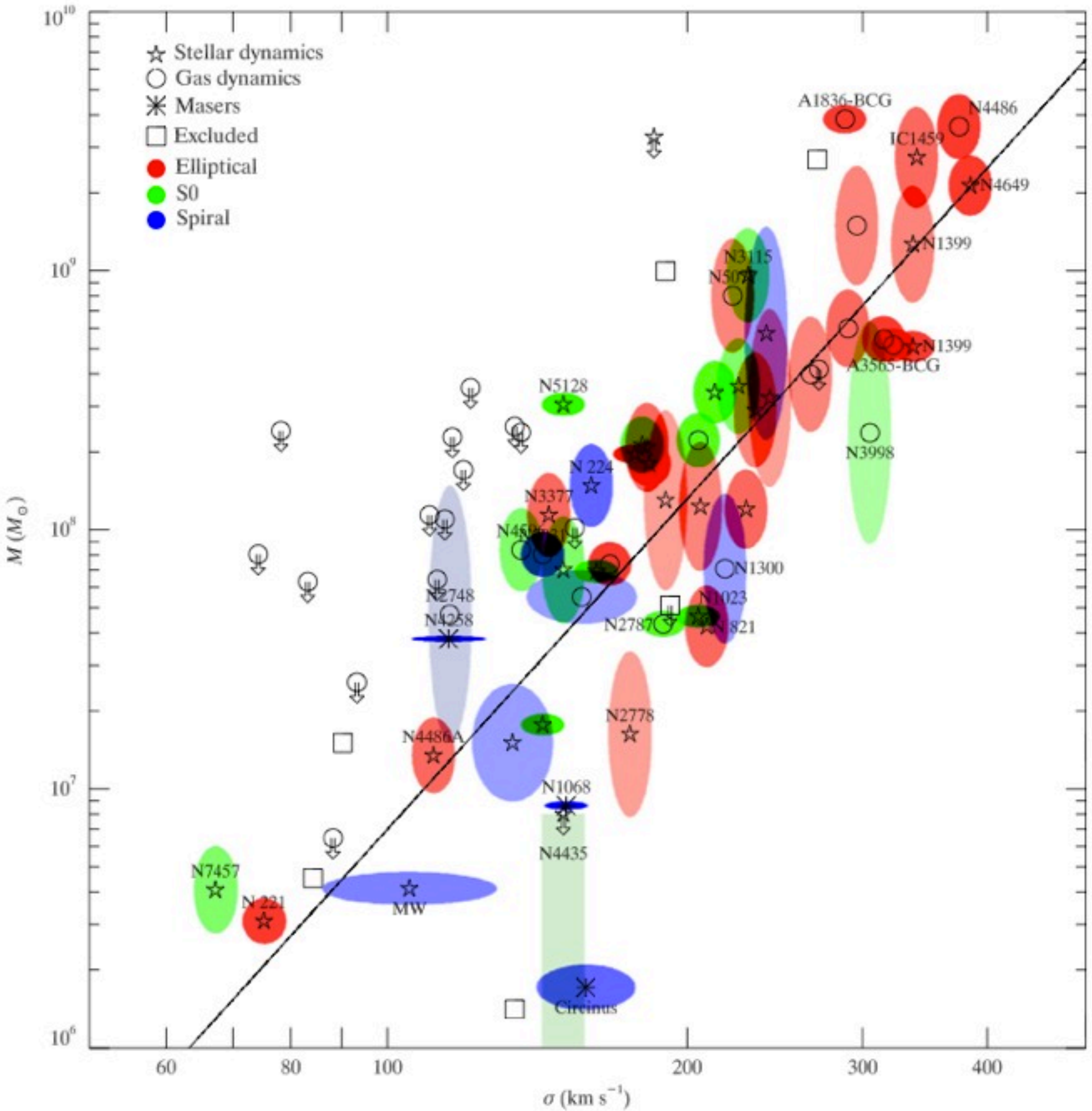
Need for AGN feedback ?

Transition from late to early type galaxies around the Milky Way halo mass.



from Simon White Ringberg 2010 talk

SMBH and galaxy co-evolution



Gültekin *et al.* (2009)

A simple model for SMBH growth and feedback

The original idea: see e.g. Silk & Rees (1998).The numerical implementation in cosmological simulations: Sijacki et al. 2007; **Booth & Schaye 2010.**

In high density regions with stellar 3D velocity dispersion > 100 km/s, we create a seed BH of mass 10^5 M_{sol}.

Accretion is governed by 2 regimes:

Bondi-Hoyle limited $$\dot{M}_{\rm BH} = \alpha_{\rm boost} \frac{4\pi {\rm G}^2 M_{\rm BH}^2 \rho}{(c_{\rm s}^2 + u^2)^{3/2}}$$

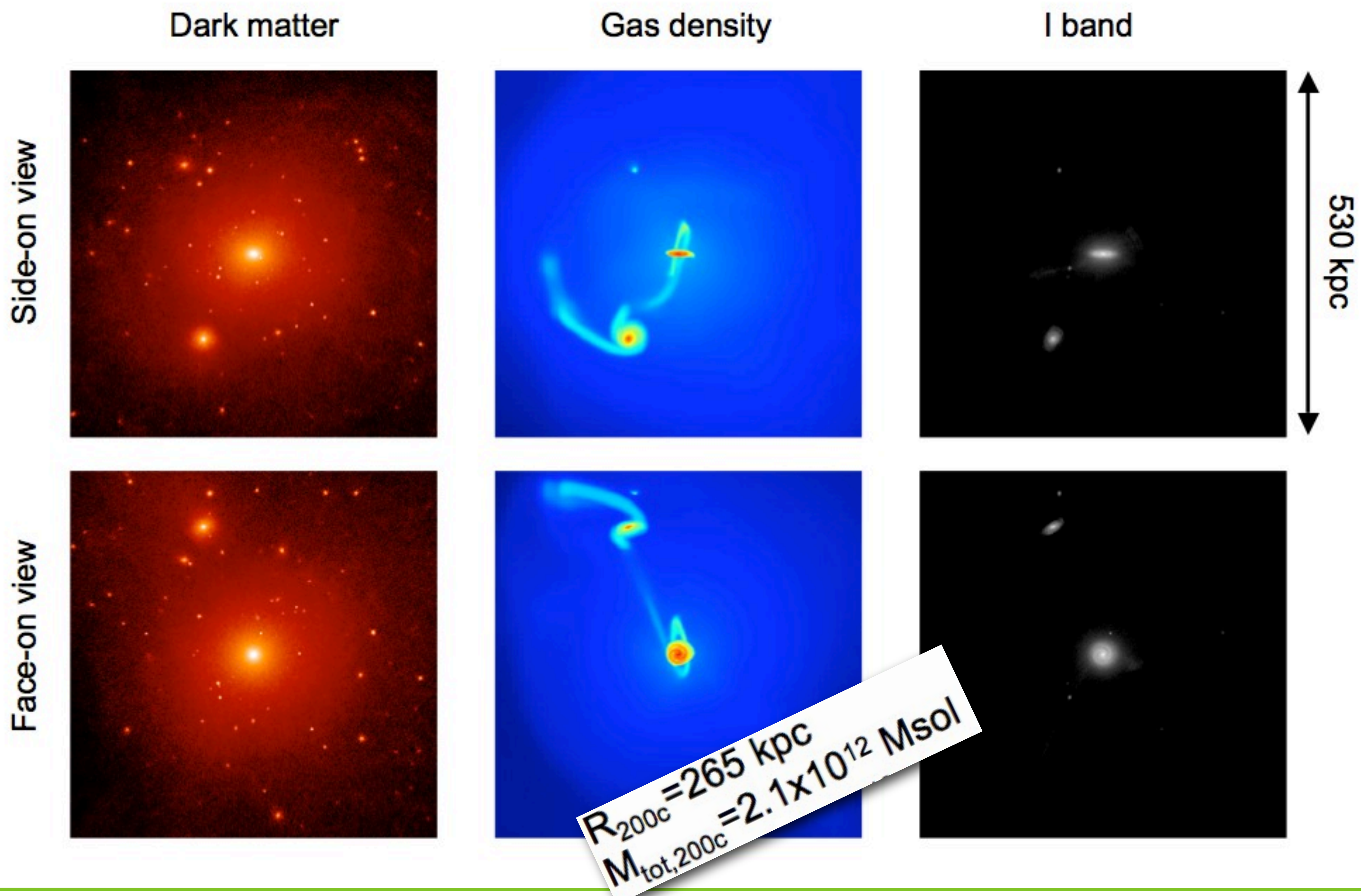
Eddington limited $$\dot{M}_{\rm ED} = \frac{4\pi {\rm G} M_{\rm BH} m_{\rm p}}{\epsilon_r \sigma_{\rm T} c}$$

Feedback performed using a thermal dump $\Delta E = \epsilon_{\rm c} \epsilon_{\rm r} \dot{M}_{\rm acc} c^2 \Delta t.$

with following trick to avoid overcooling: $E_{\rm AGN} > \frac{3}{2} m_{\rm gas} k_B T_{\rm min}$ $\quad T_{\rm min} = 10^7$ K

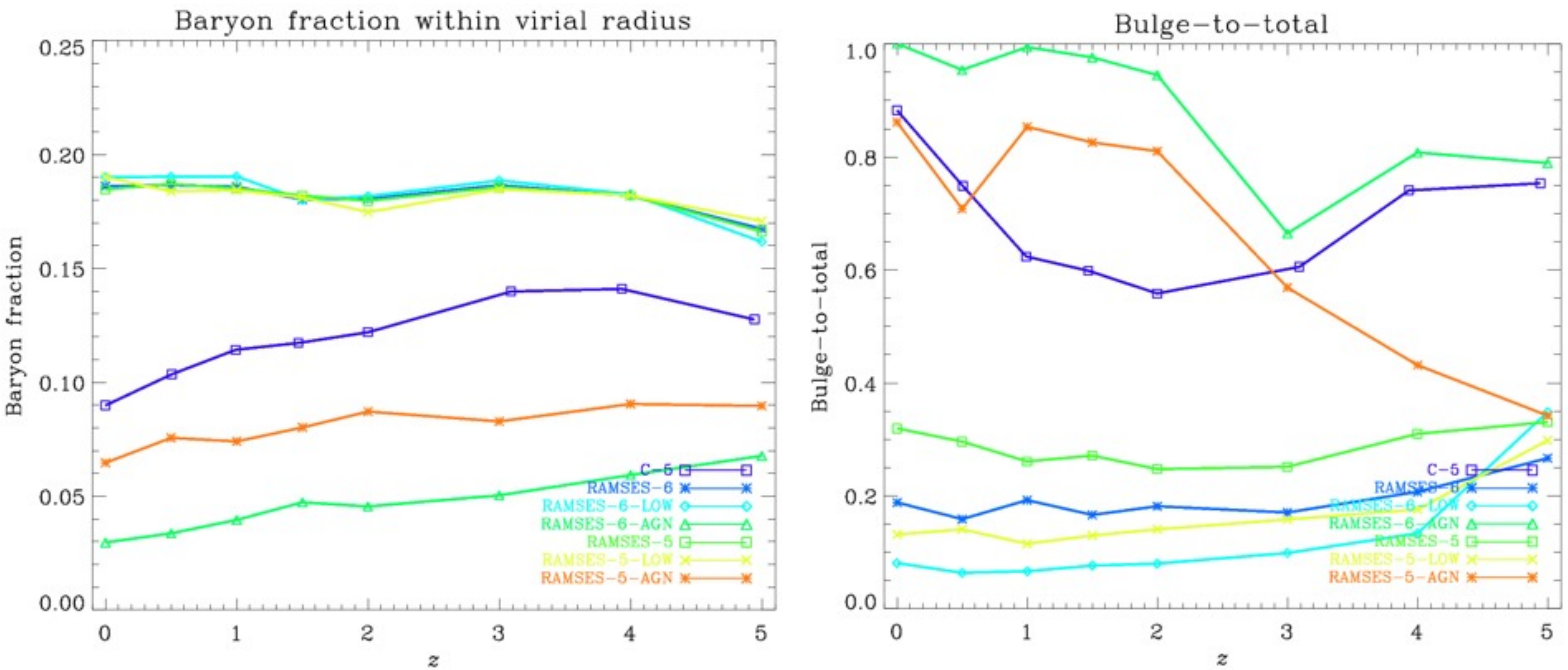
Free parameter ε_c calibrated on the M-σ relation.

The Aquila project (Navarro *et al.* in prep)



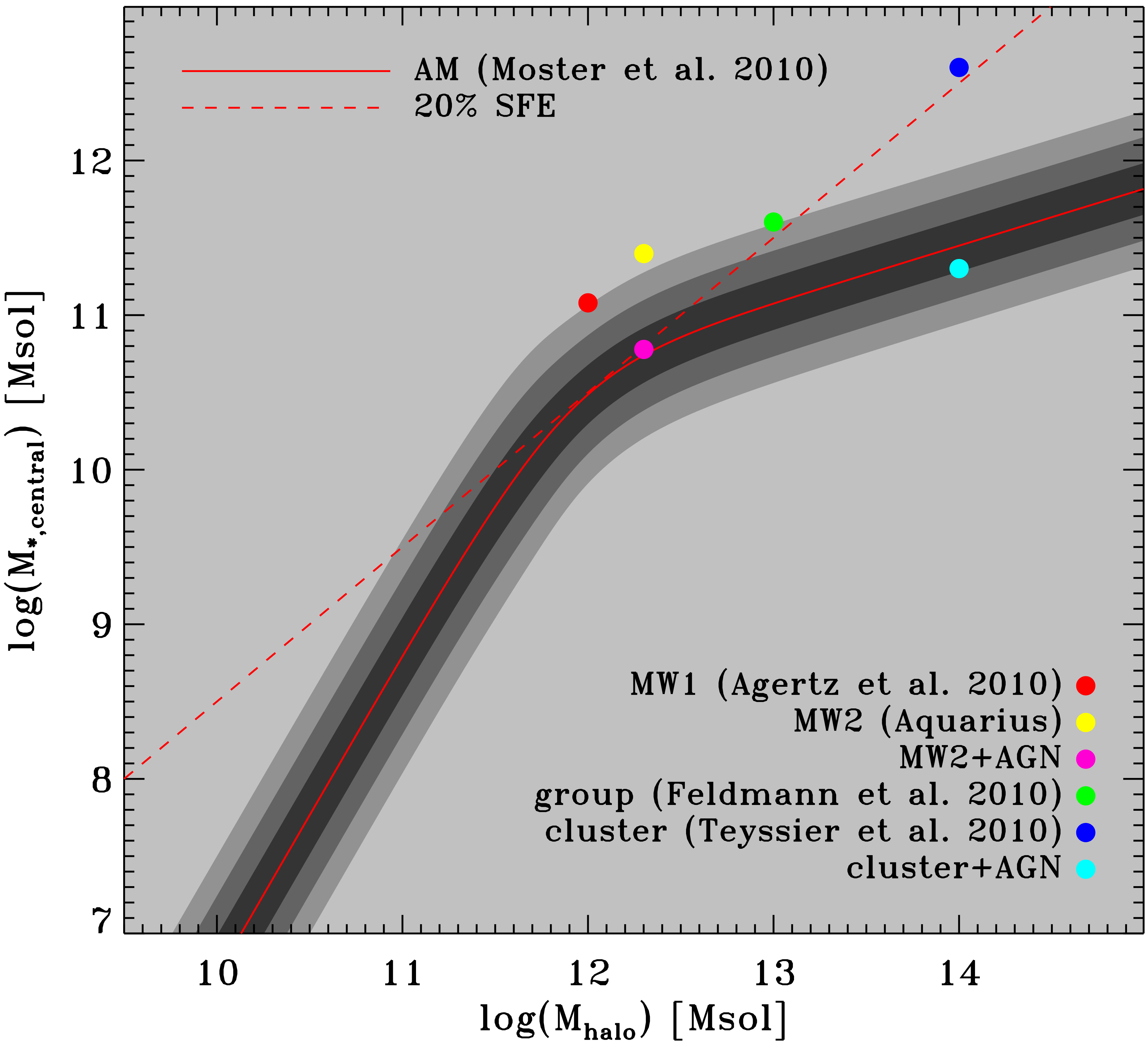
Strong feedback remove baryons from the halo...

We adapted to AMR the AGN feedback model of Booth & Schaye (2010).

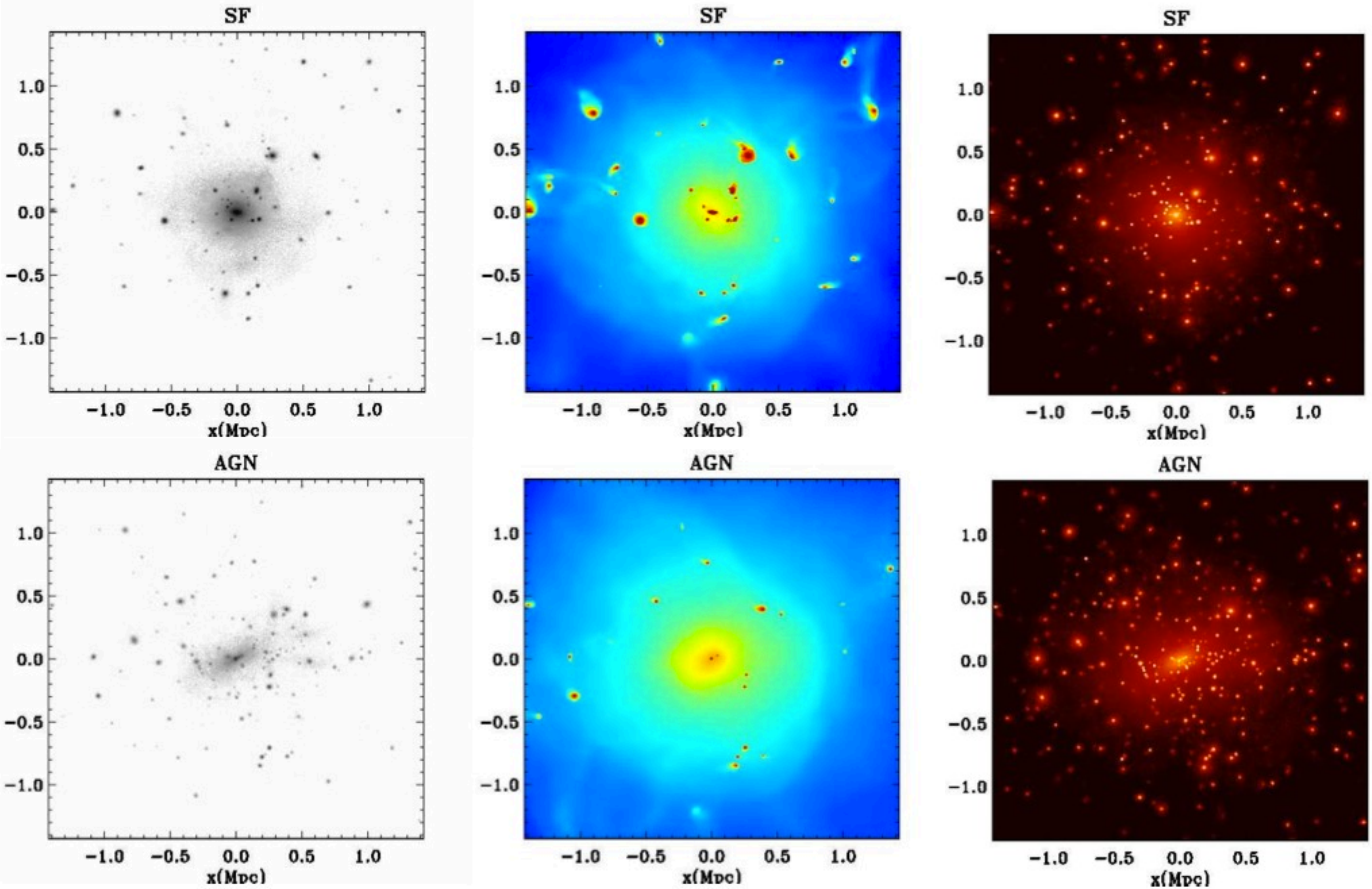


...but lead to the formation of dead spheroids.

Constraints from abundance matching

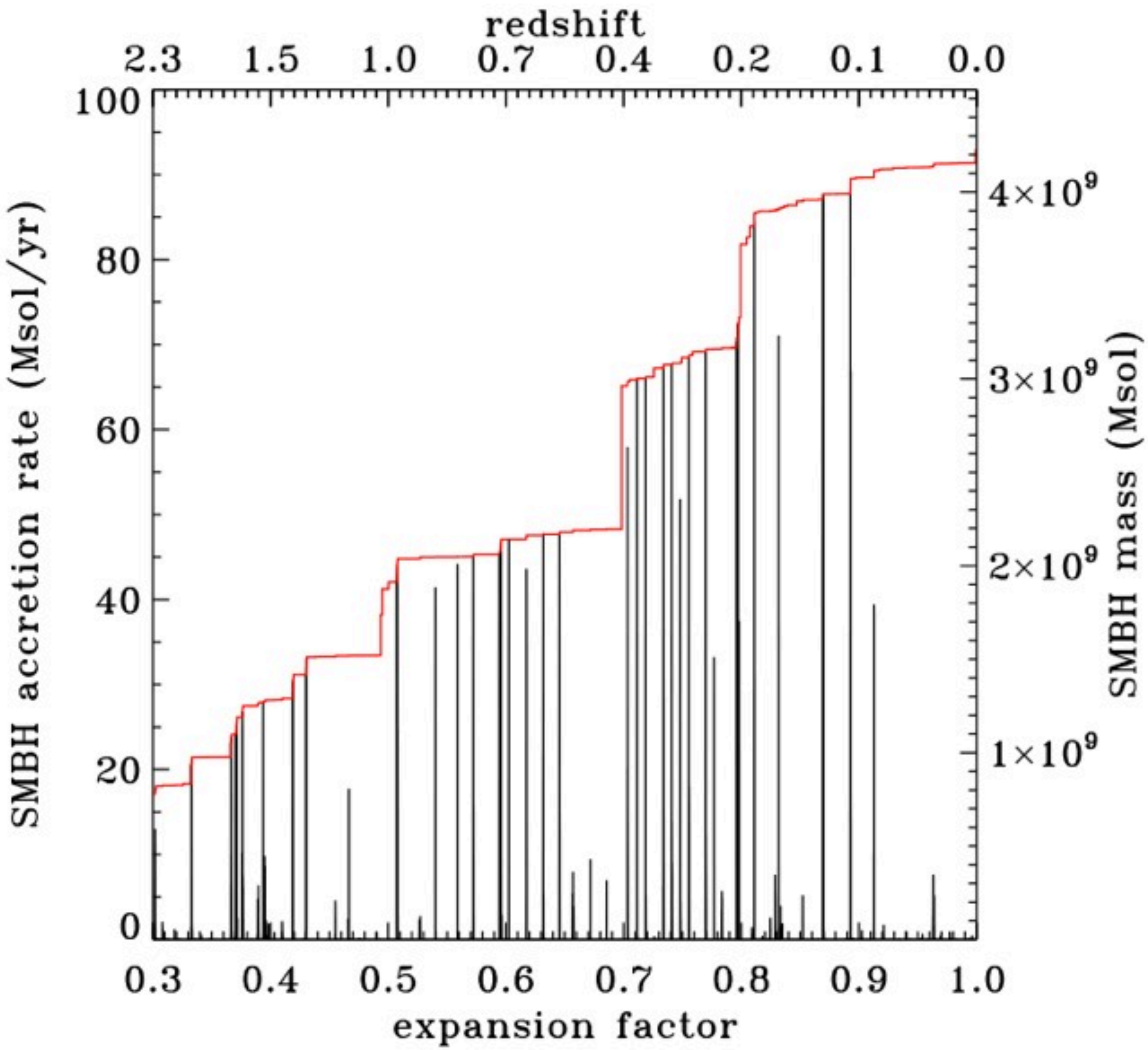


Galaxy formation on cluster scales



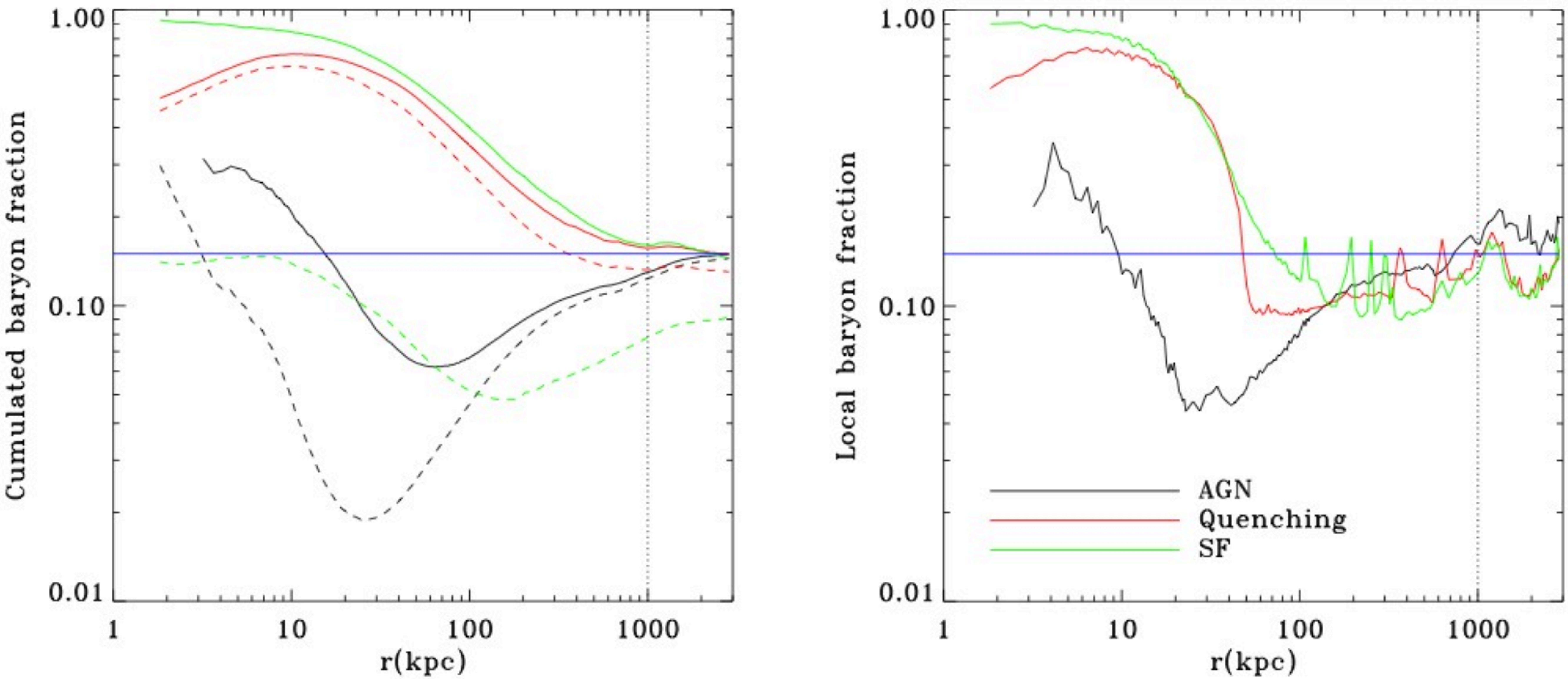
Teyssier *et al.* 2010, in press, arxiv.1003.4744

SMBH growth and associated feedback



Teyssier *et al.* 2010

AGN feedback regulates the baryon fraction

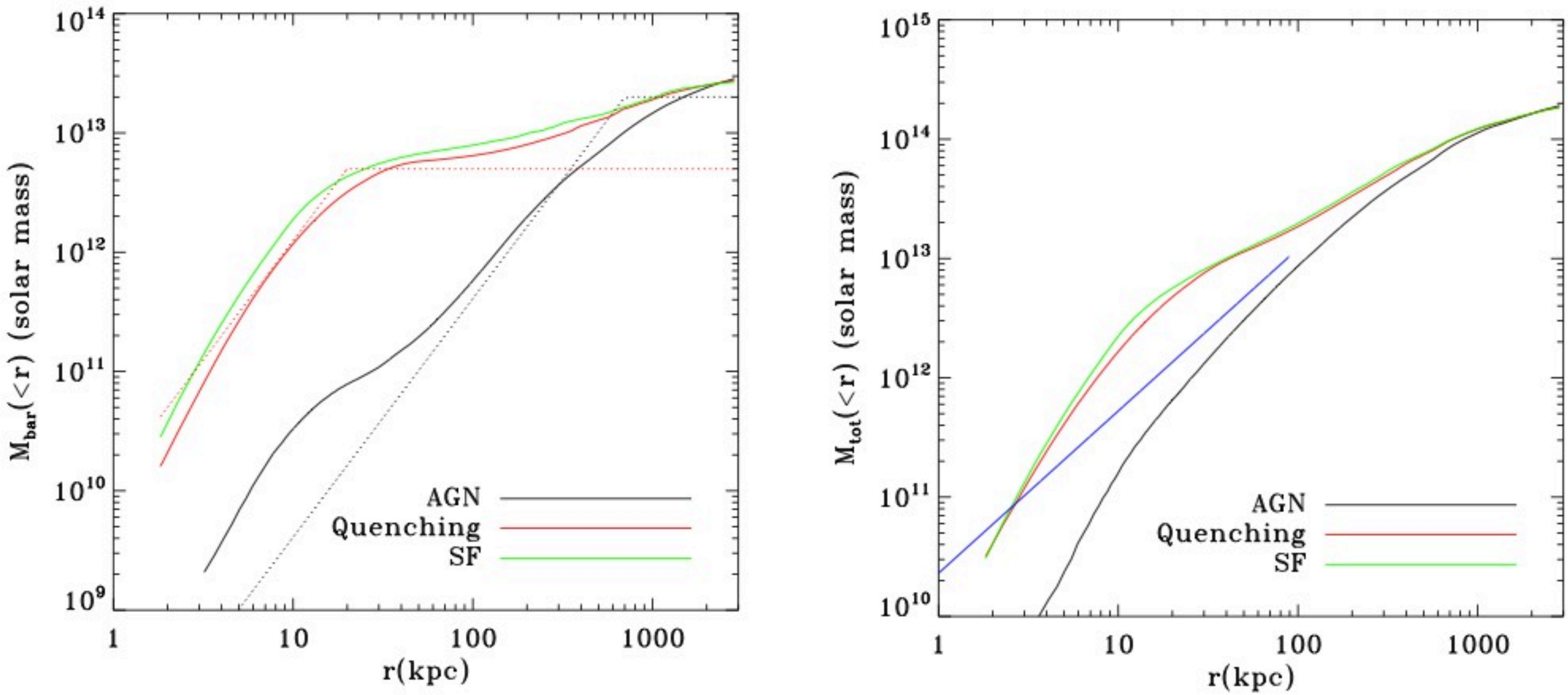


Small baryon deficit (10%) due to shocks and buoyant motions.

Mission baryons accumulate between 1 and 2 R_{200}.

Teyssier *et al.* 2010

AGN feedback regulates the mass distribution

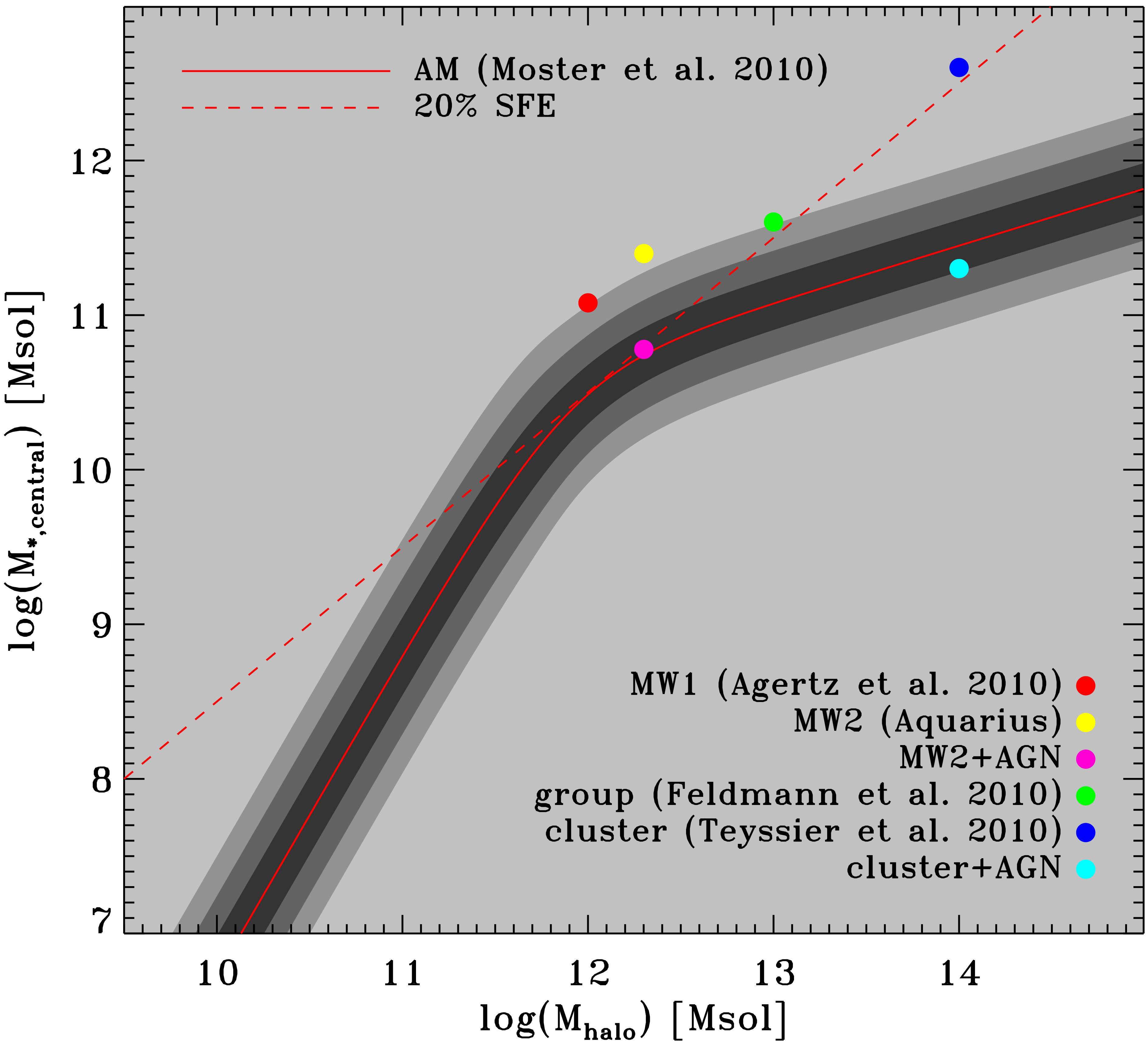


Without AGN feedback, overcooling leads to a strong mass concentration in the center.

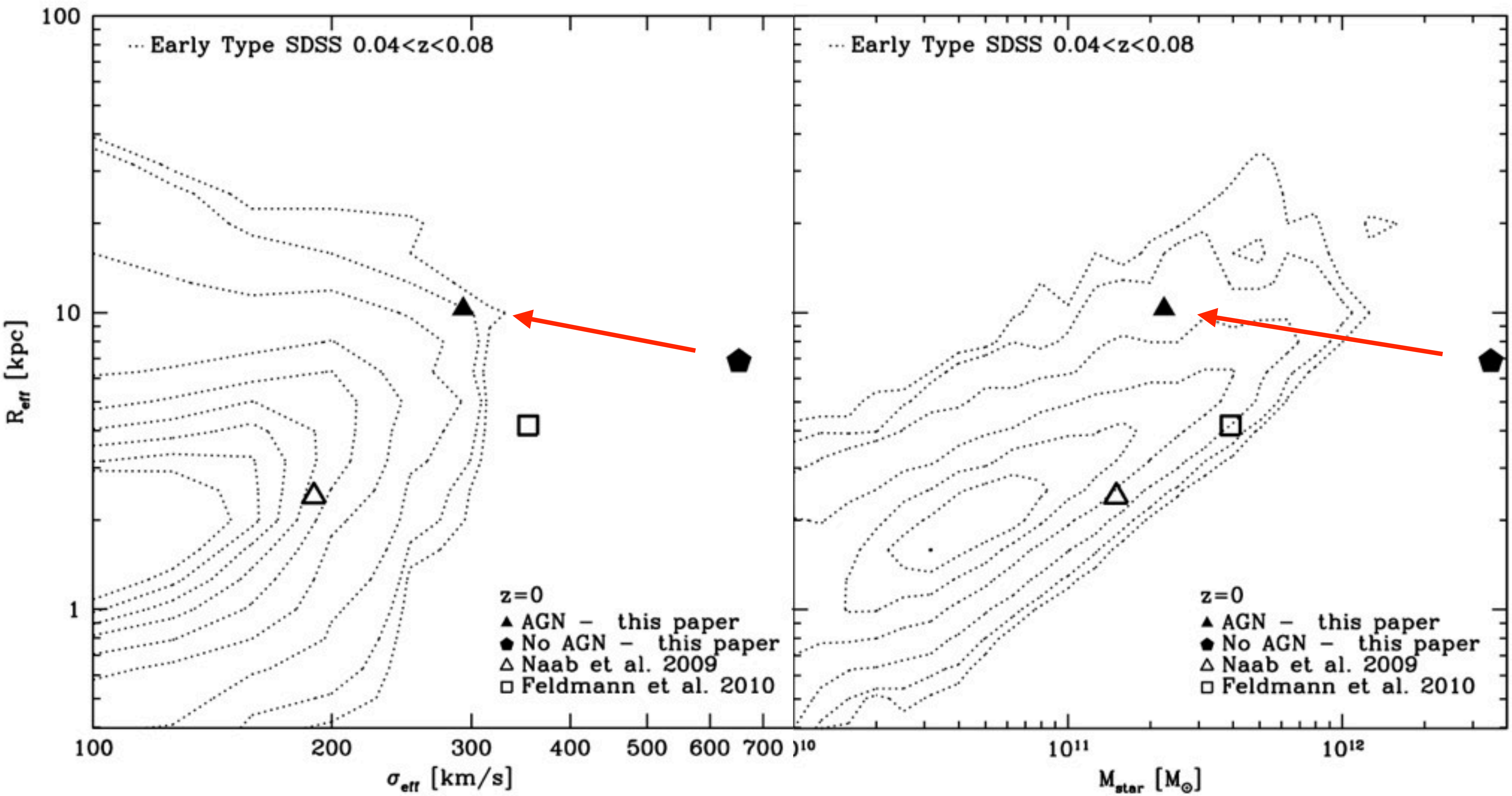
With AGN feedback, we see a small adiabatic expansion of the dark halo.

Teyssier *et al.* 2010

Constraints from abundance matching

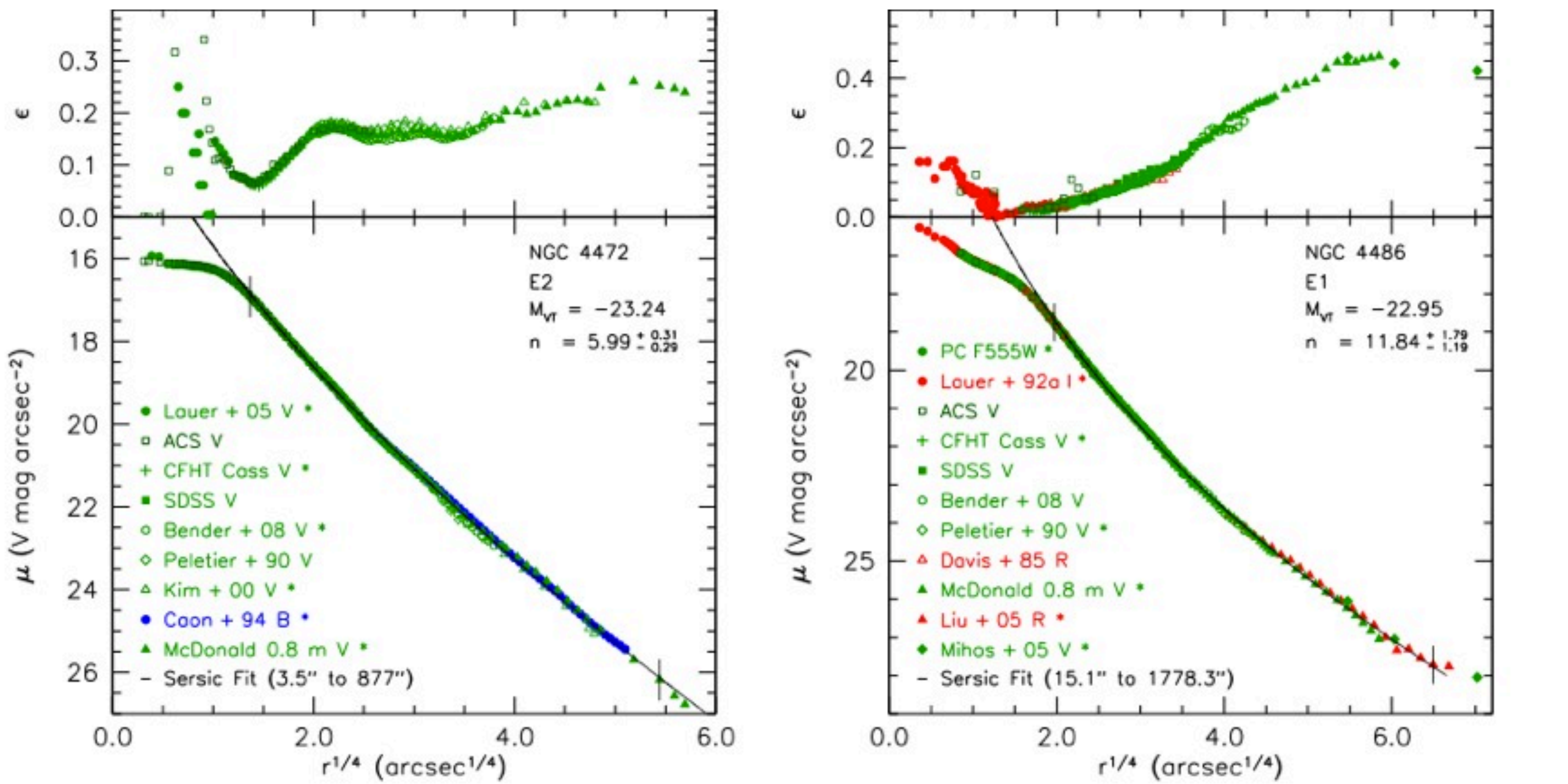


AGN feedback modifies the BCG properties



A dichotomy in the structure of elliptical galaxies

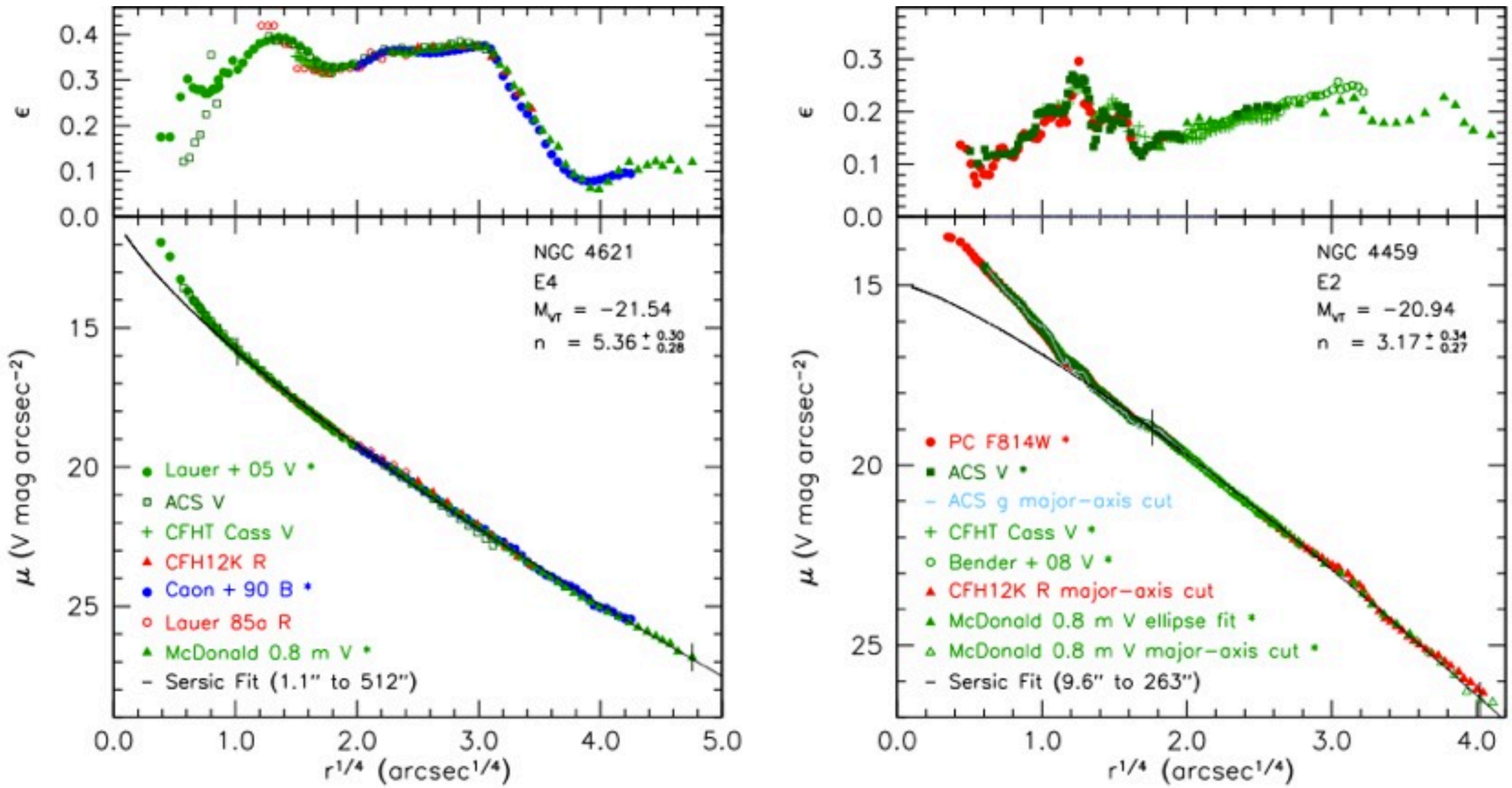
«Core» elliptical: light deficit, low ellipticity, slow rotator



Kormendy et al. (2009)

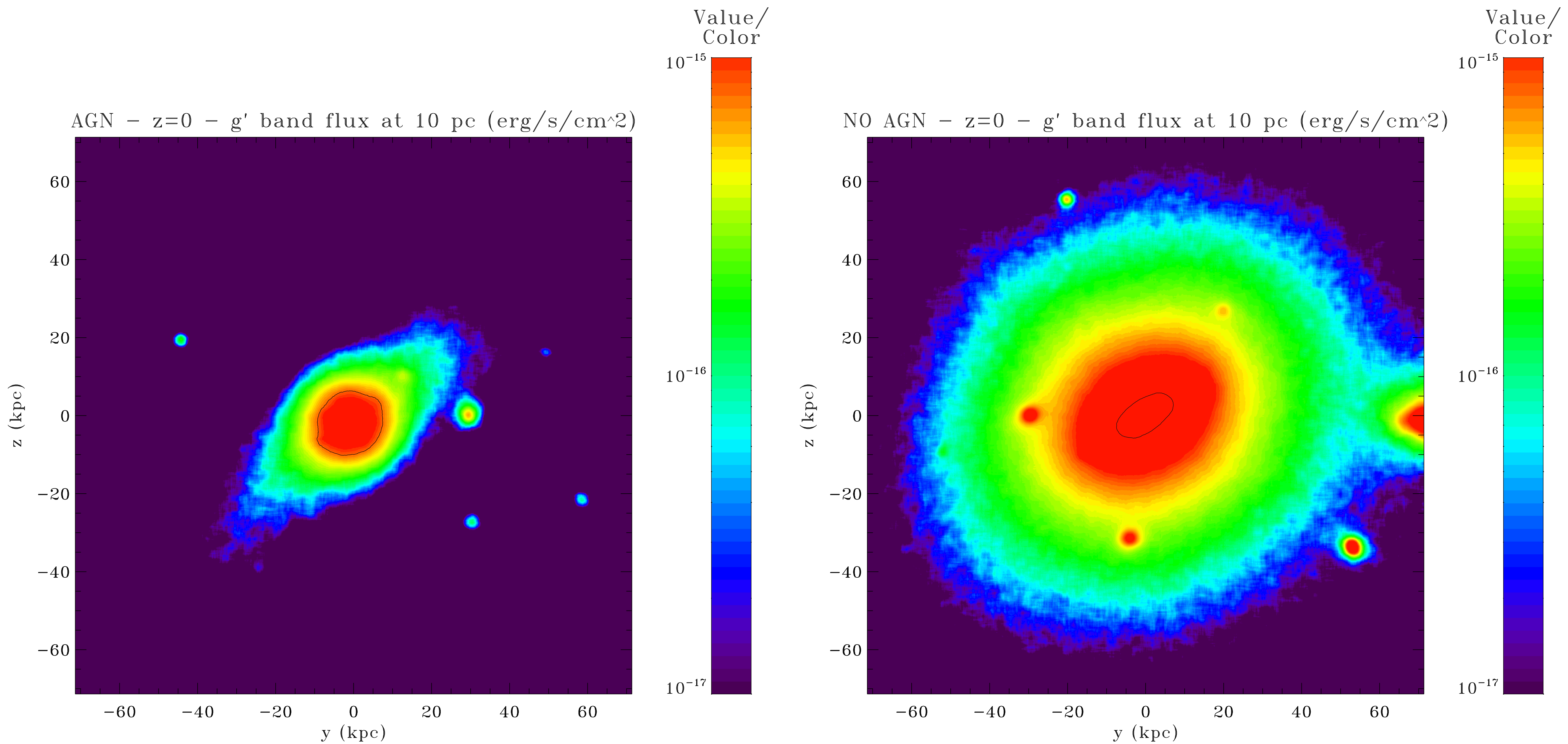
A dichotomy in the structure of elliptical galaxies

«Extra light» elliptical: light excess, high ellipticity, fast rotator



Kormendy et al. (2009)

Cosmological simulations: BCG with or w/o AGN

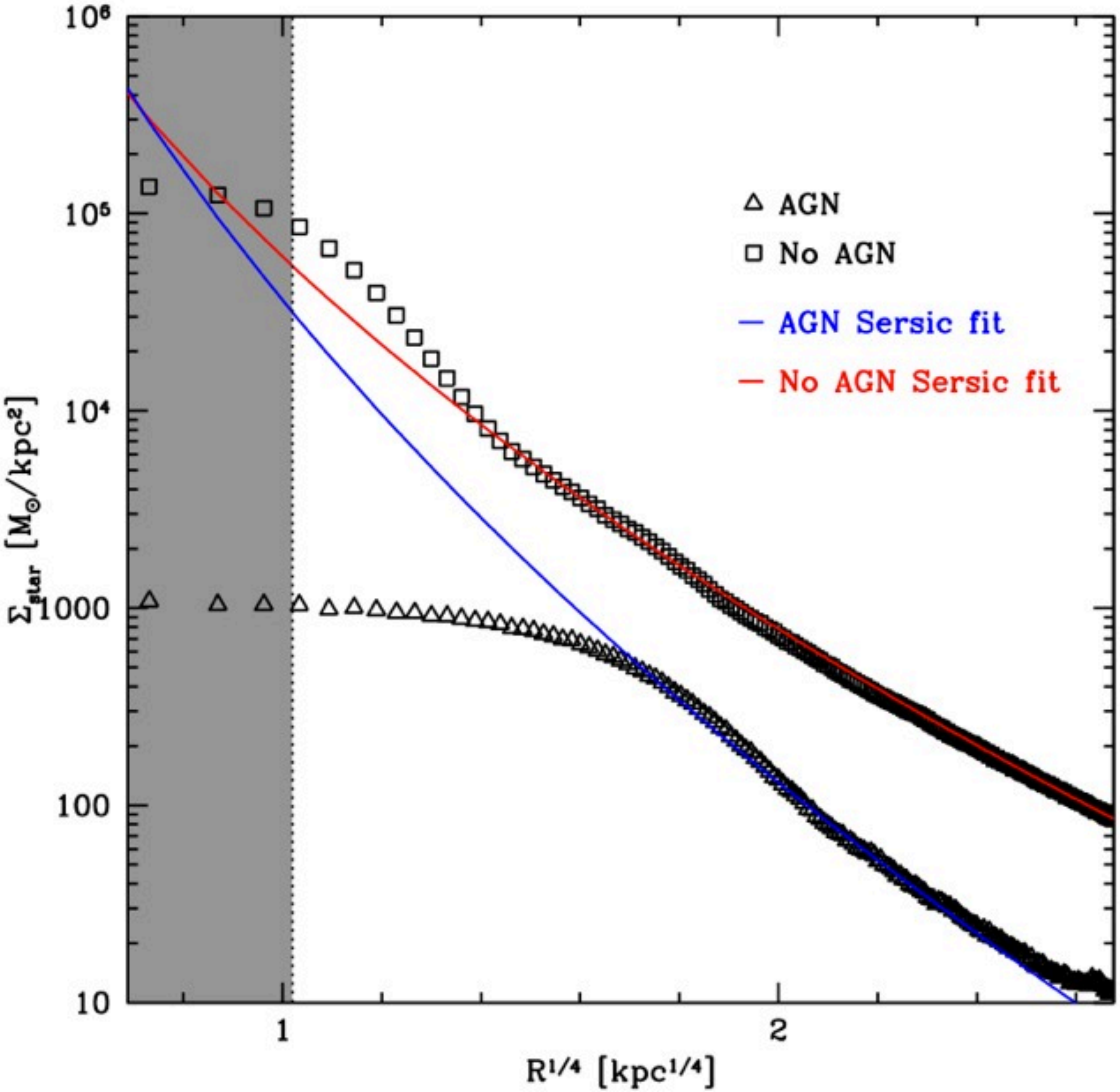


ε~0.1-0.2

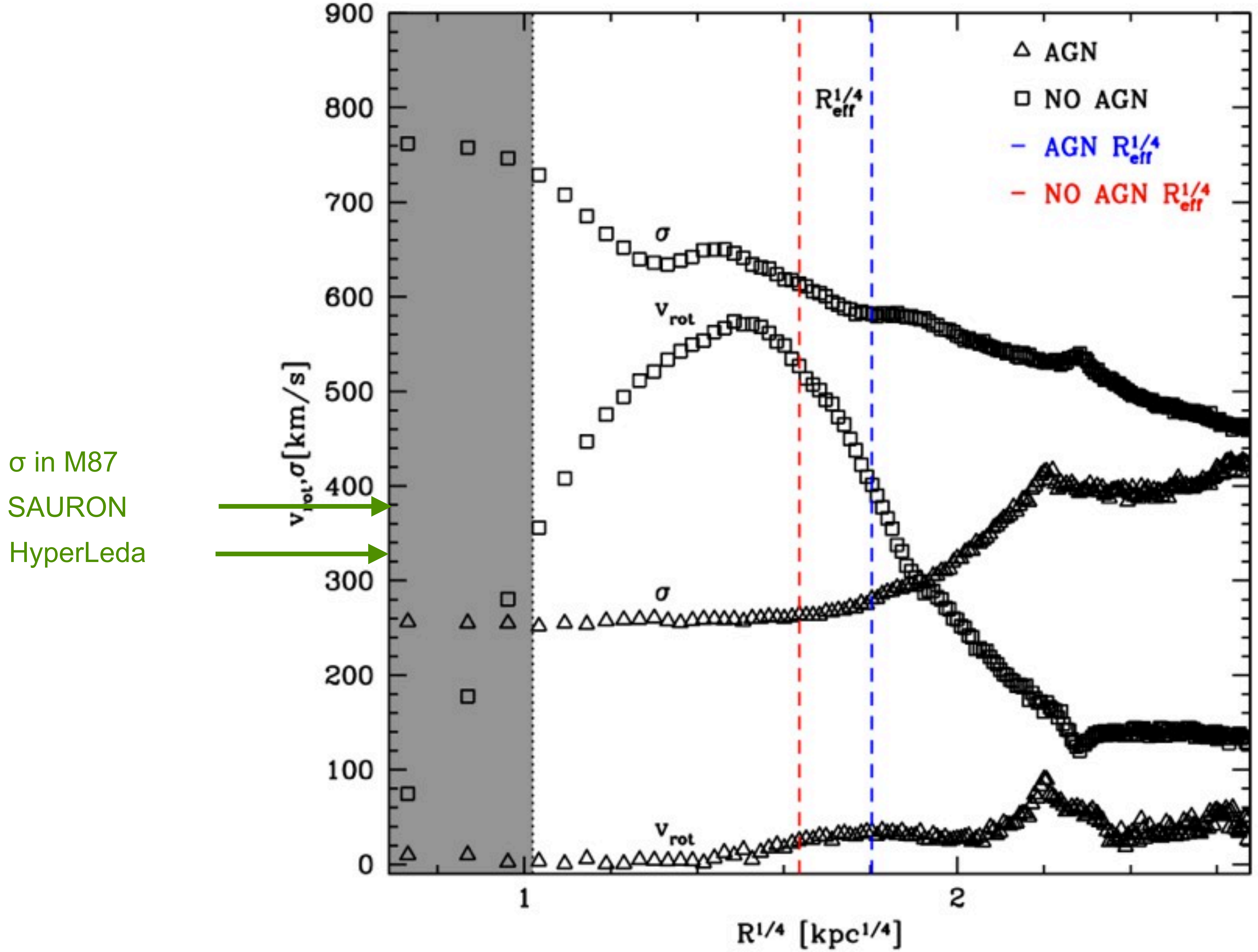
ε~0.2-0.5

Ellipticities at $r_{1/2}$

Structural properties of the BCG

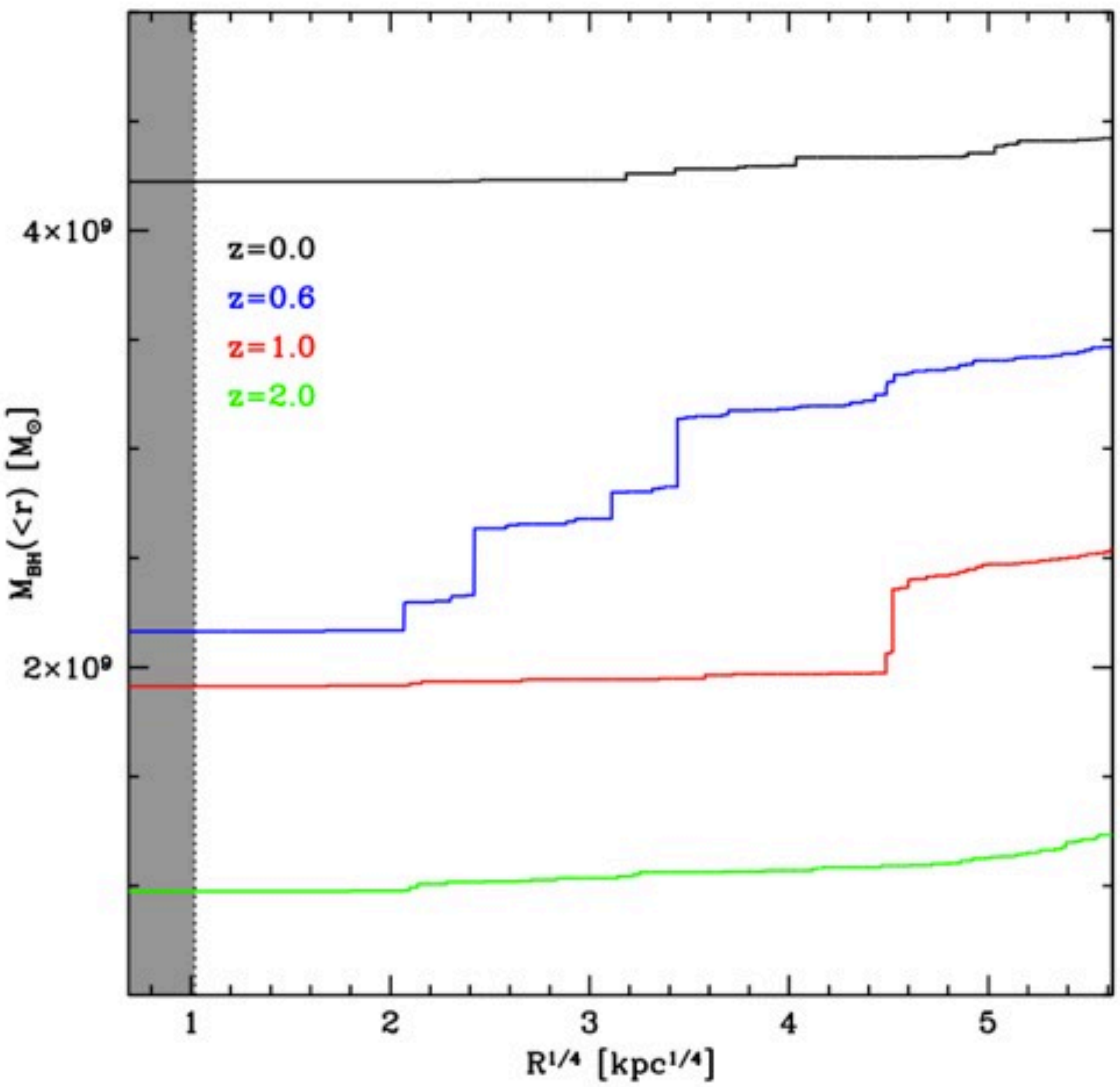


Kinematic properties of the BCG

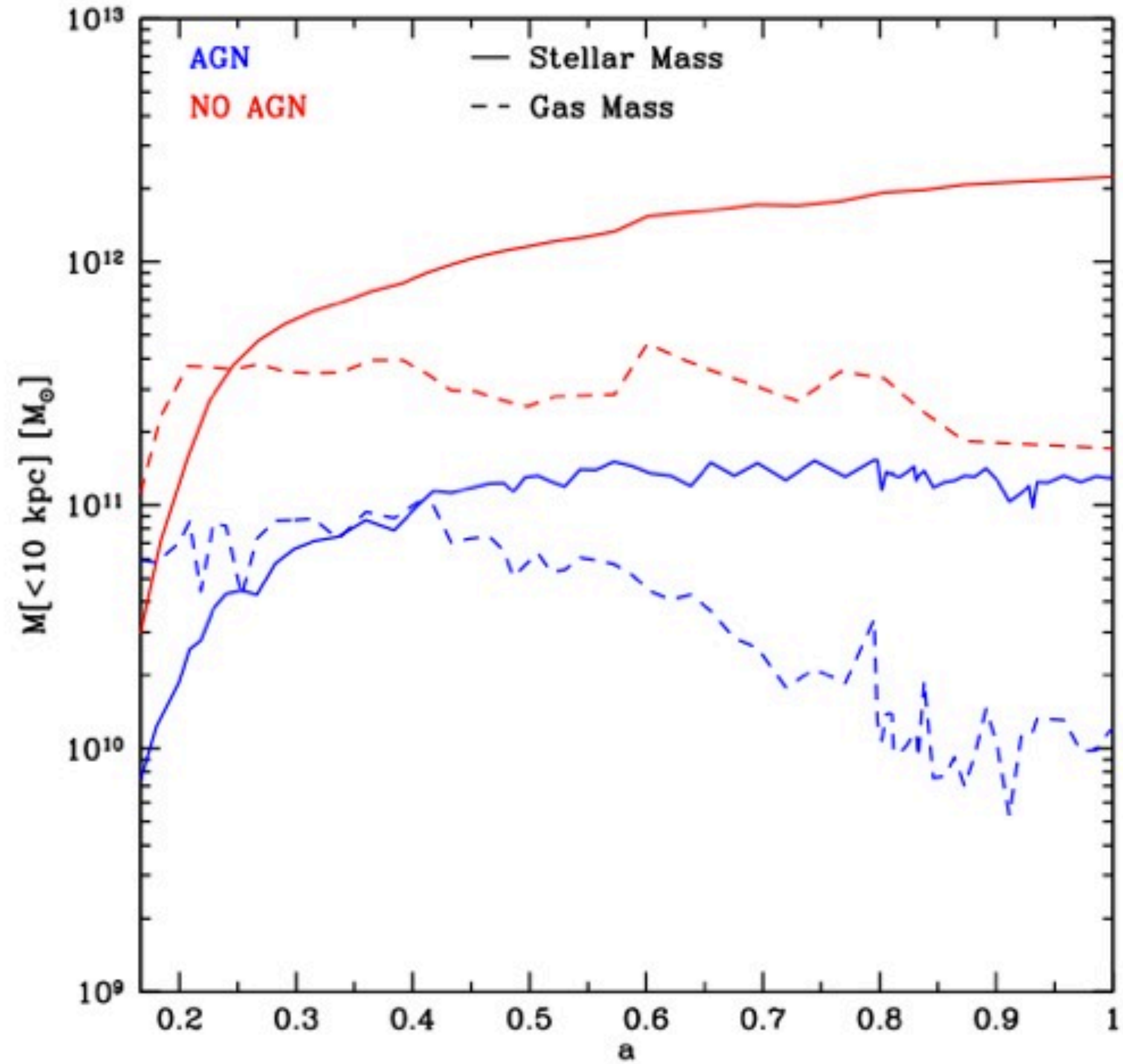


On the origin of «core» ellipticals

Scenario 1: BH scouring



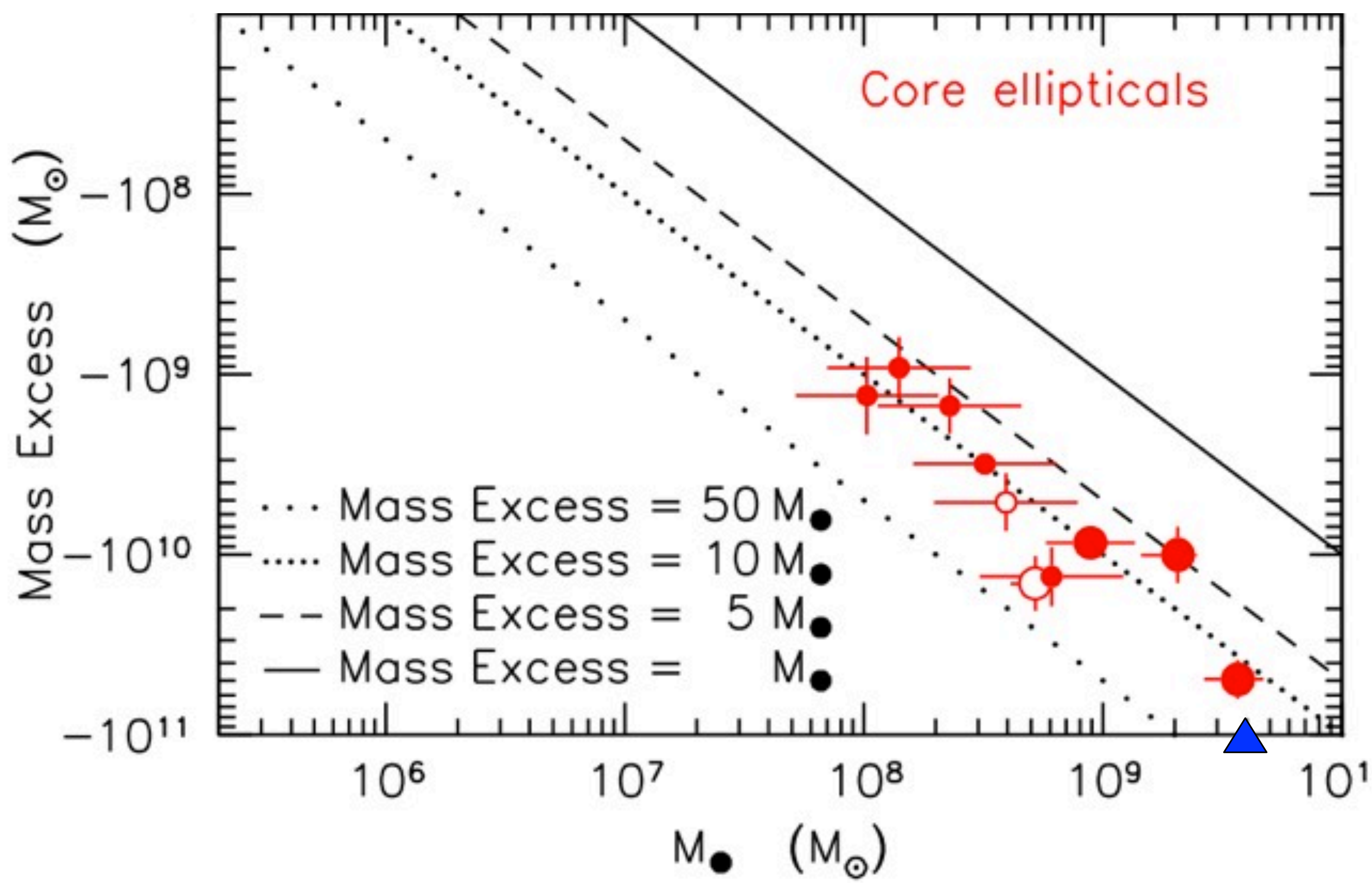
Scenario 2: binding energy removal



Analogy with bulgeless dwarf galaxy formation and dark matter cores ?
(Governato et al. 2010)

Large mass deficit in the core

From the Sersic fit, we infer a mass deficit $M_{def} \sim 10^{11}$ Msol. We have $M_{def}/M_{\bullet} \approx 20$!
Milosljevic & Merrit (2001, 2002) predict $M_{def}/M_{\bullet} \approx 1$ per major merger.

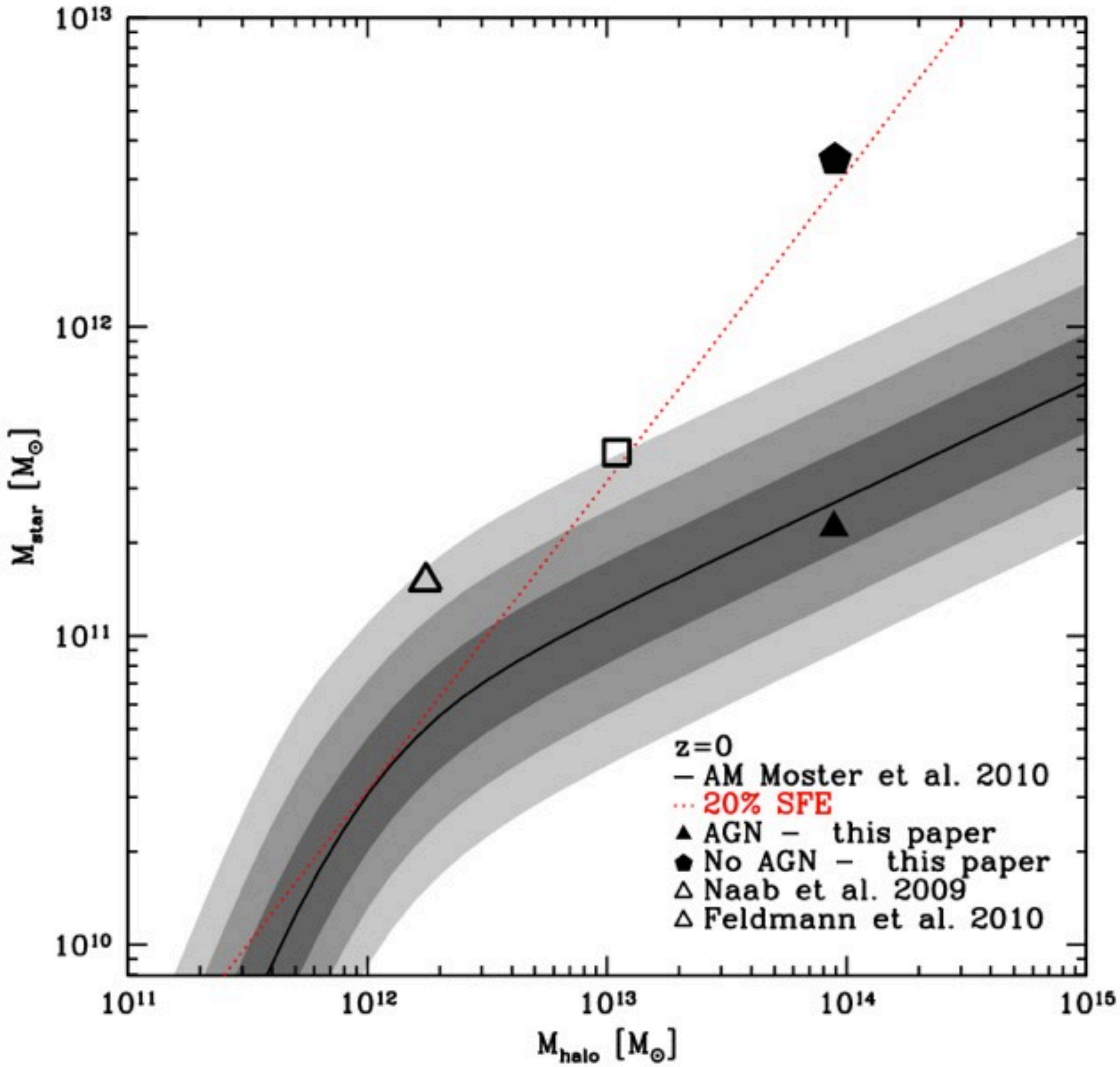


Kormendy et al. (2009)

This work

Both scenario are probably at work.

Cosmological simulations of elliptical galaxies



Conclusions

• Low star formation efficiency leads to the formation of disc dominated systems.

• Low SFEs play the same role as supernova feedback

• At the MW scale, both low SFE and supernovae feedback are borderline. Two alternatives: refute Abundance Matching or use AGN feedback.

• At the MW scale, strong (AGN?) feedback leeds to dead spheroids.

• At clusters scale (BCG formation), strong (AGN?) feedback seems unavoidable.

• BCG formation with AGN feedback may explain in a fully cosmological context the observed dichotomy in cluster ellipticals.

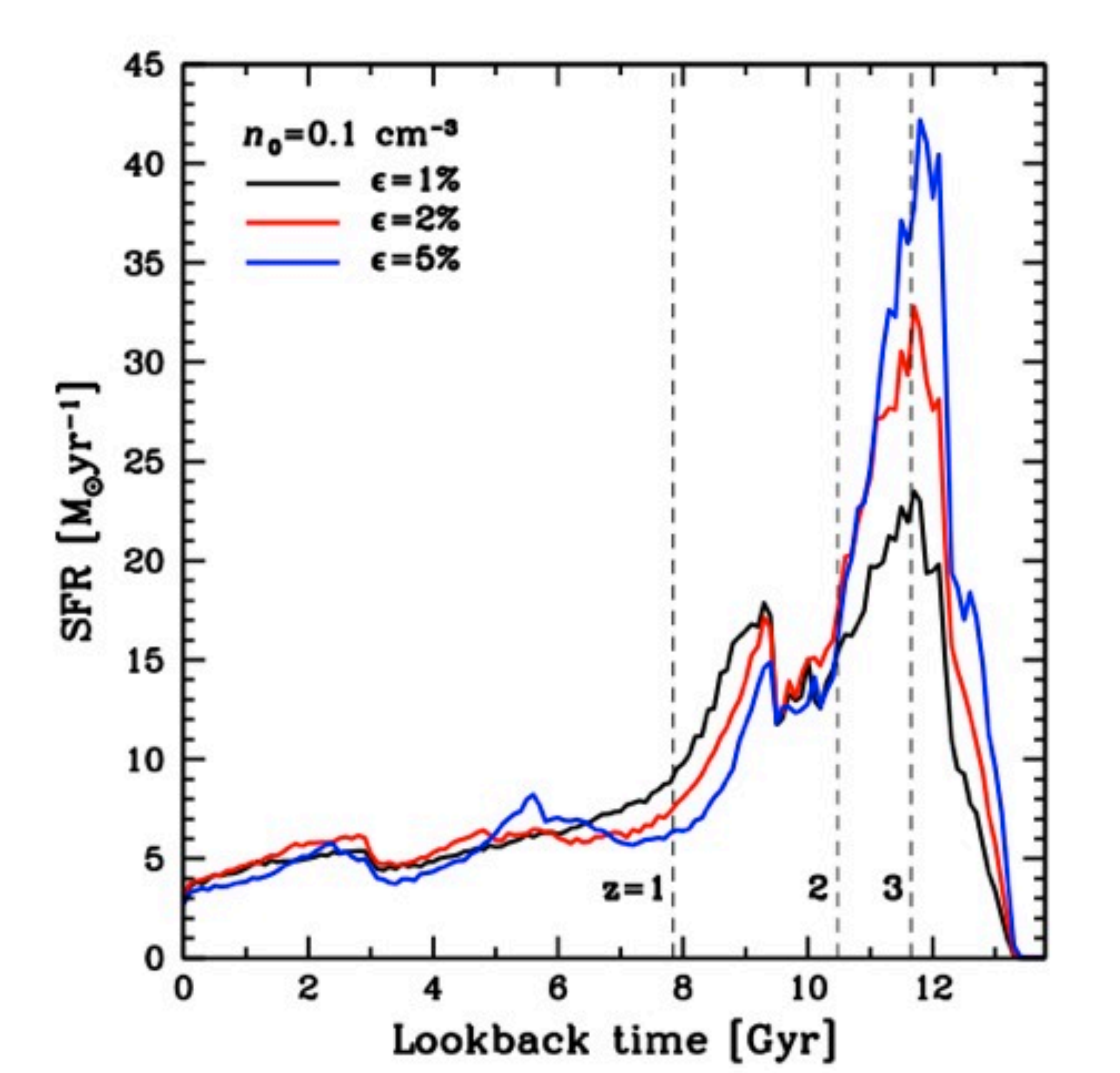
• We observed the formation of a stellar core, but origin still unclear.

• Beware of many numerical issues: mass resolution, softening, cooling length...

Agertz *et al.* (2011)

Star formation histories

Effect of SFE



Effect of SNe feedback