Galaxy formation: big and small

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Outline

1- Galaxy formation and feedback

2- AMR simulations of a dwarf galaxy with stellar feedback

arxiv/1206.4895

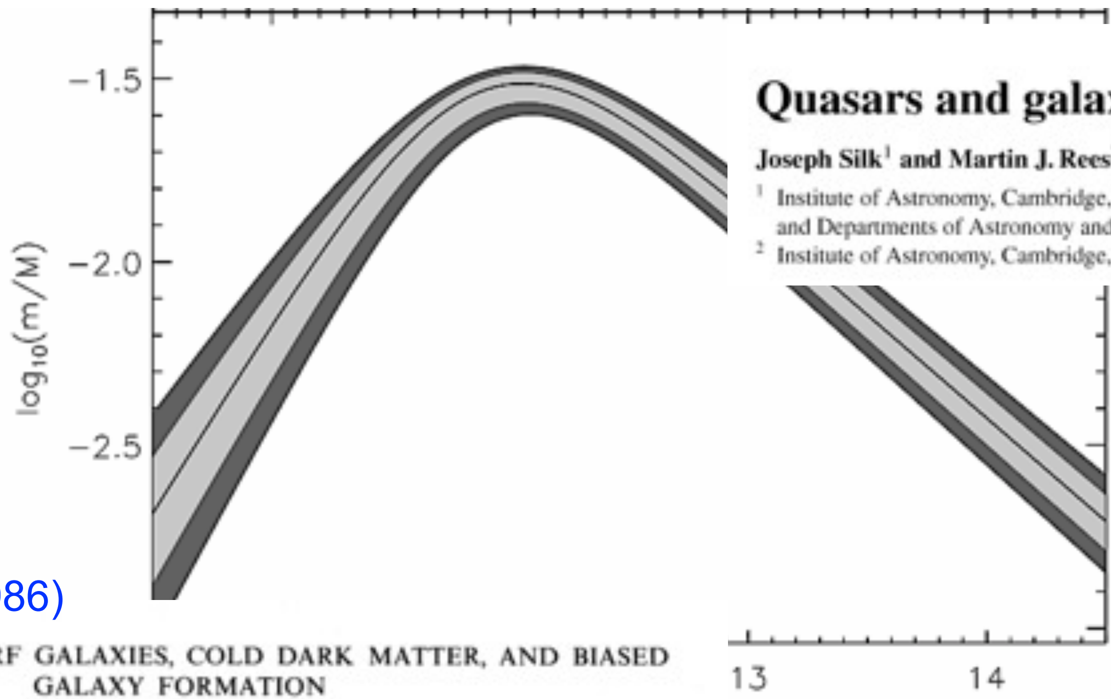
3- AMR simulations of a massive elliptical with AGN feedback

Davide Martizzi's PhD work

Feedback processes in galaxy formation

Moster et al. (2010)

Stellar-to-halo mass ratio



Silk & Rees (1998)

Quasars and galaxy formation

Joseph Silk[1] and Martin J. Rees[2]

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Dekel & Silk (1986)

THE ORIGIN OF DWARF GALAXIES, COLD DARK MATTER, AND BIASED GALAXY FORMATION

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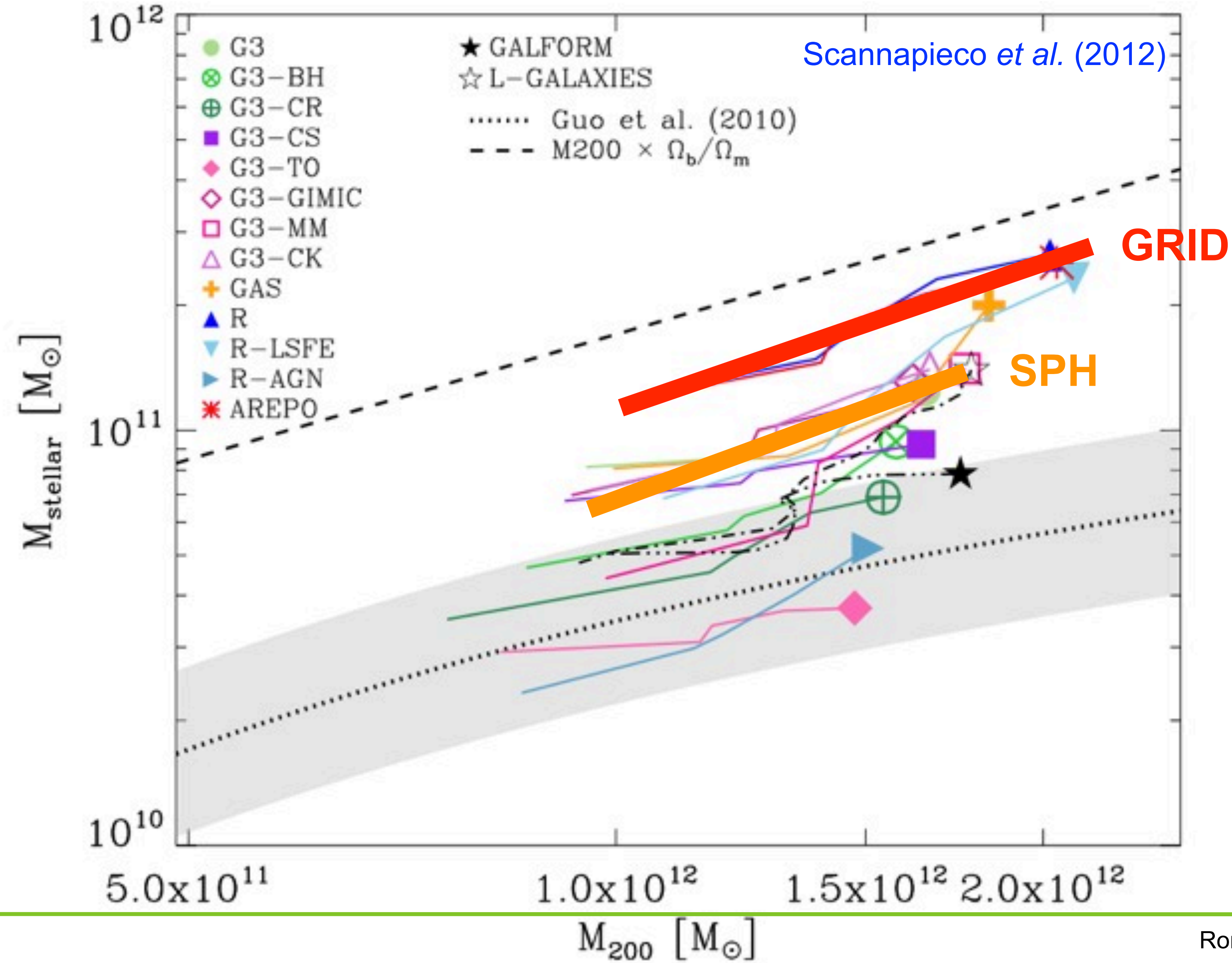
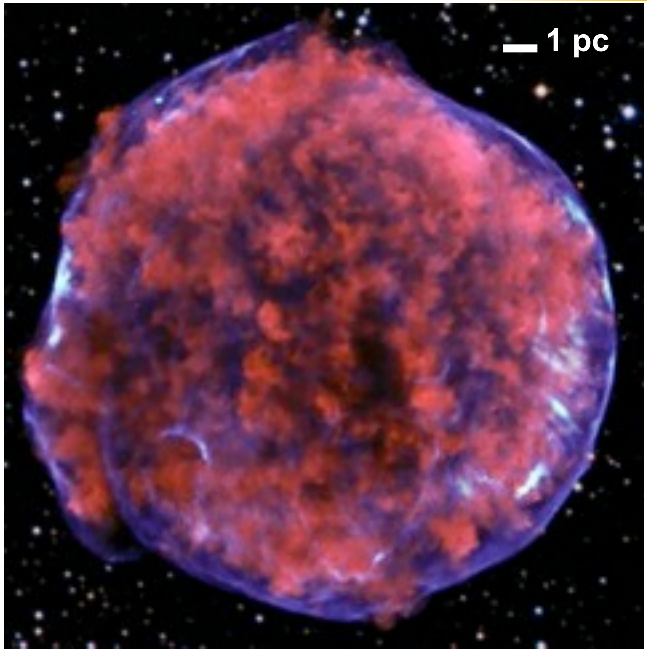
Simulated MW properties dominated by feedback



Stellar feedback with delayed cooling



Chandra image of Tycho

Stellar winds, supernovae remnants are highly turbulent environment, filled with cosmic rays and magnetic field.

Thermal energy dissipates almost instantaneously through cooling. Non-thermal processes dissipate much more slowly.

Hanasz et al. 2009 ; Scannapieco & Brüggen 2010; Wadepuhl & Springel 2011 and others...

Here, we capture the non-thermal energy as:

$$\rho \frac{D\epsilon_{turb}}{Dt} = \dot{E}_{inj} - \frac{\rho \epsilon_{turb}}{t_{diss}} \qquad \epsilon_{turb} = \sigma_{turb}^2$$

The total dynamical pressure is $P_{tot} = P_{thermal} + P_{turb}$

Maximal feedback scenario: $\dot{E}_{inj} = \dot{\rho}_* \eta_{SN} 10^{50} \text{ erg/M}_\odot \qquad t_{diss} \simeq 10 \text{ Myr}$

We mimic slow dissipation of non-thermal energy using delayed cooling for the thermal energy:

$$\rho \frac{D\epsilon_{thermal}}{Dt} = \dot{E}_{inj} - P_{thermal} \nabla \cdot \mathbf{v} - n_H^2 \Lambda \quad \text{with} \quad \Lambda = 0 \text{ if } \sigma_{turb} > 10 \text{ km/s}$$

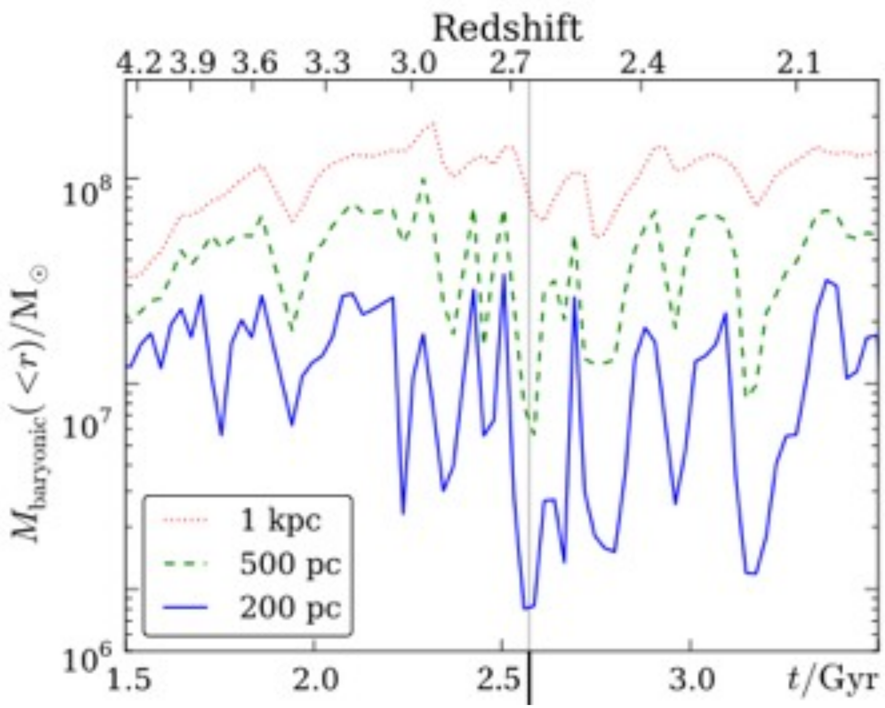
High density threshold SF in dwarf galaxies

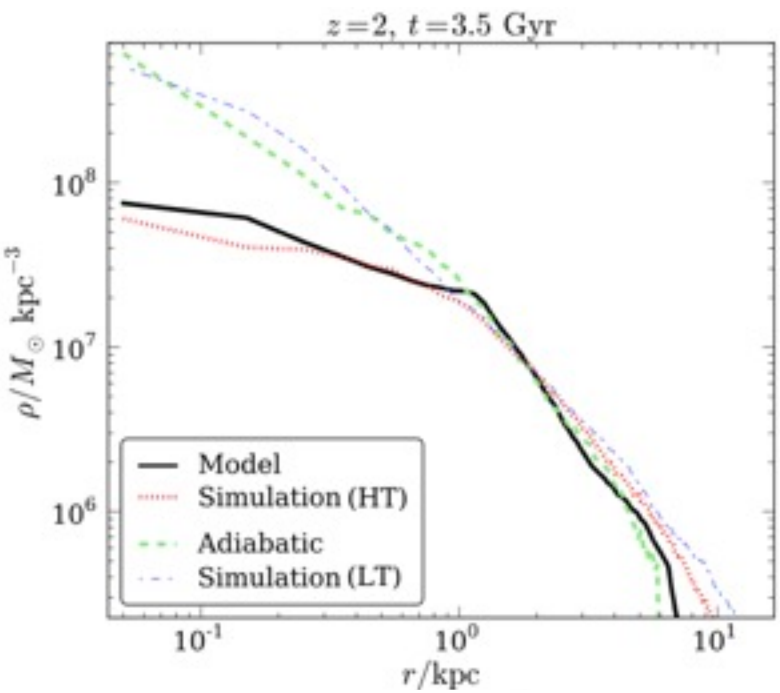
High-resolution SPH simulations with dense clumps and strong feedback result in very strong and very fast potential variations.

Read & Gilmore (2005); Mashchenko et al. (2008); Governato et al. (2010)

Irreversible «heating» of the dark matter cusp into a core.

Pontzen & Governato (2011)





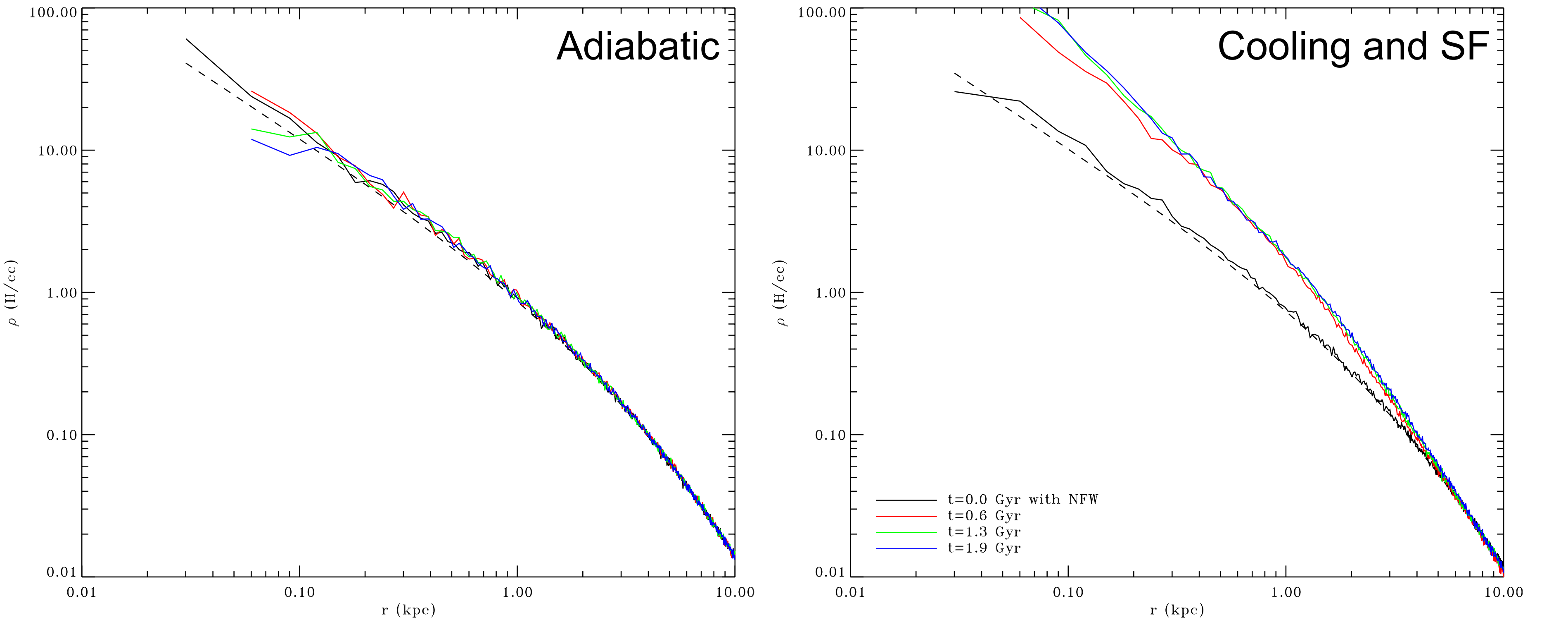
Feedback in dwarf galaxies: a controlled experiment

We consider an equilibrium NFW halo (dark matter + 15% gas).

parameters: $N_{DM}=10^6$, $\Delta x=20$ pc, $V_{200}=35$ km/s, $M_{200}=10^{10}$ M_{sol}

3 runs with the RAMSES code: 1- pure adiabatic hydrostatic case

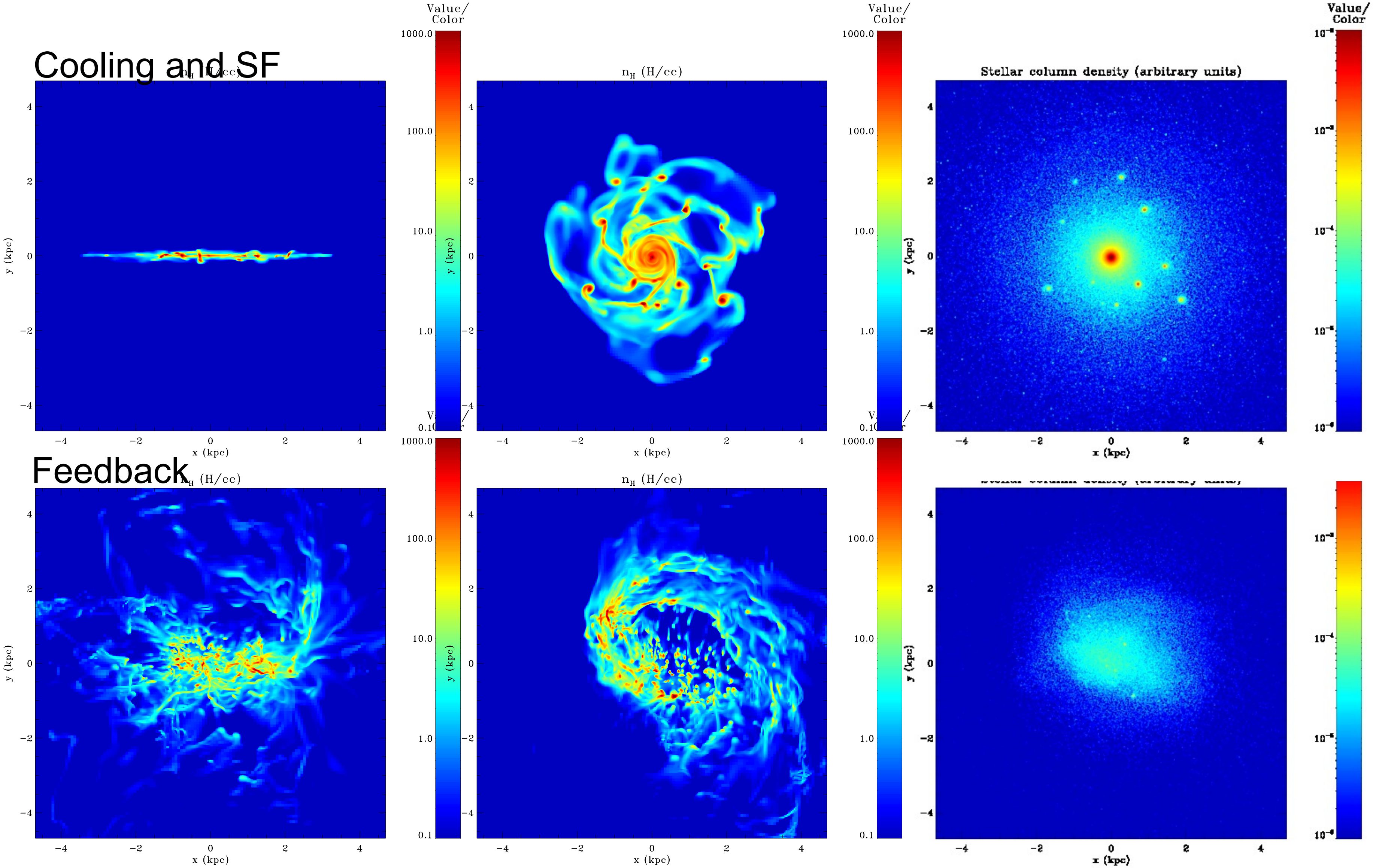
2- pure cooling and star formation (no feedback) versus 3- stellar feedback



Dark matter profiles

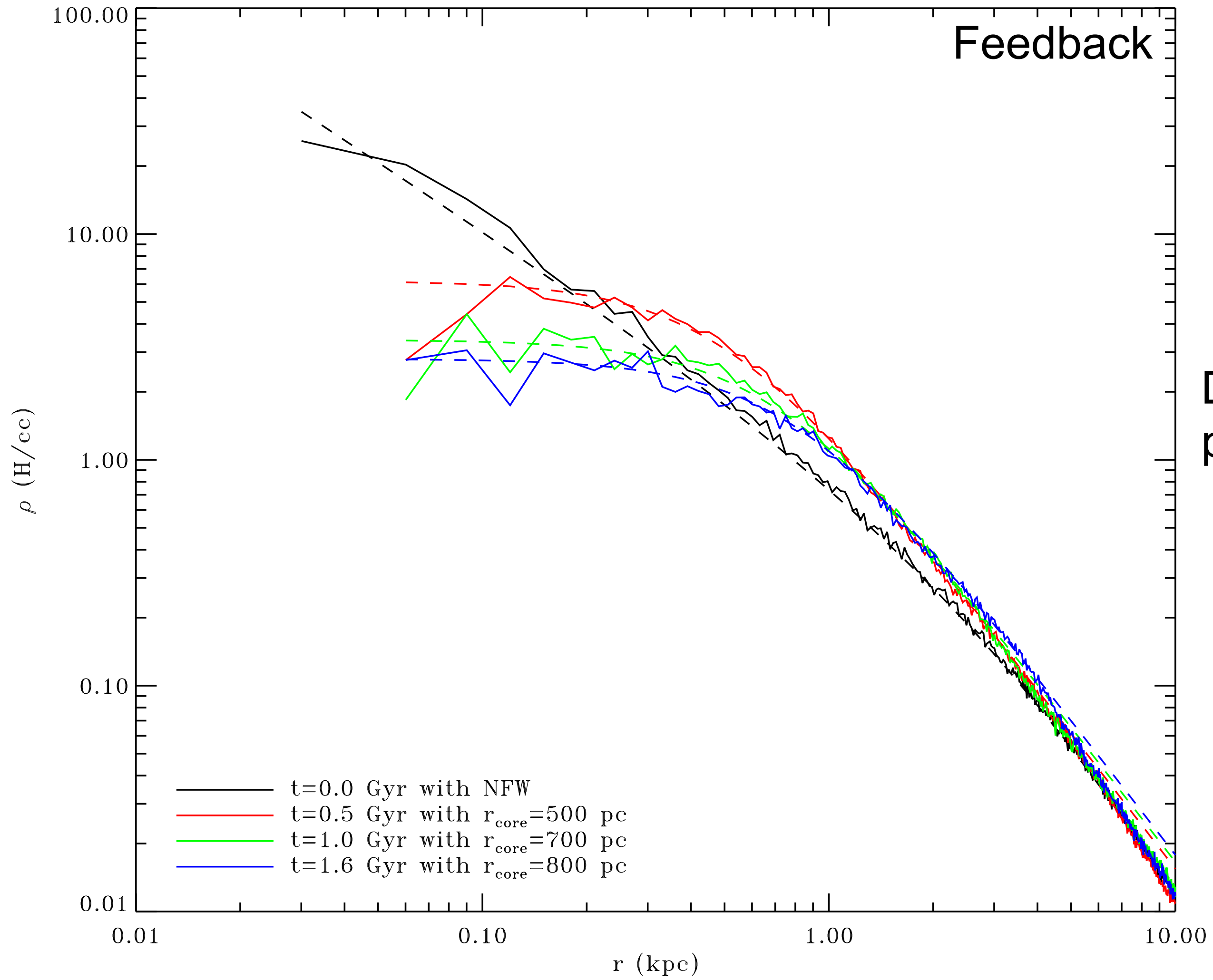
Romain Teyssier

Widely different galaxy properties



Dark matter core out of an initially cuspy profile

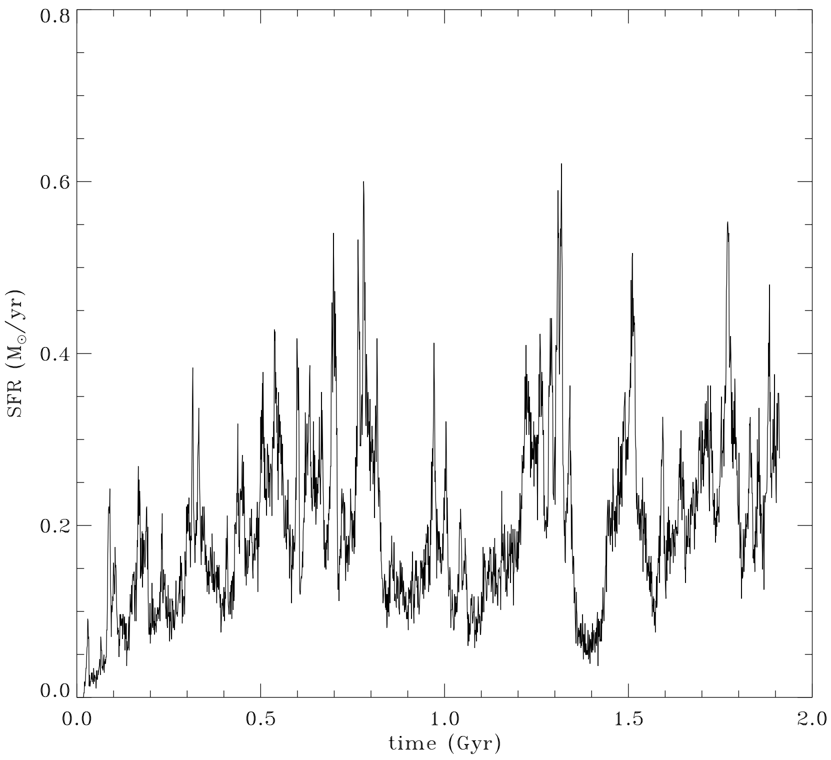
Excellent fit with a pseudo-isothermal profile $$\rho \propto \frac{1}{1+(r/r_{core})^2}$$



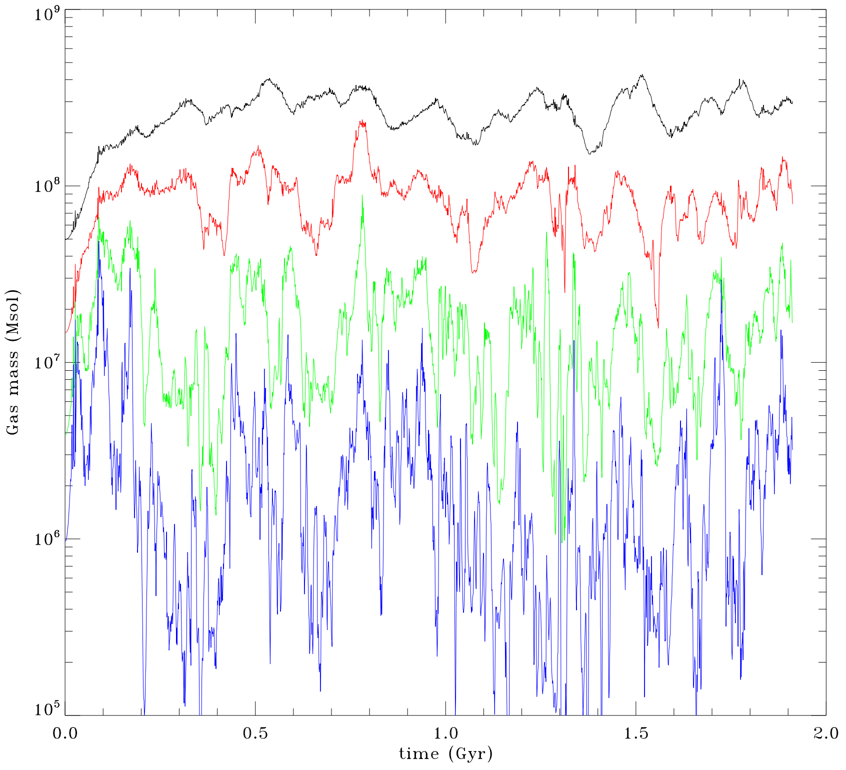
Dark matter profile

Fluctuations in the gravitational potential...

Star formation rate

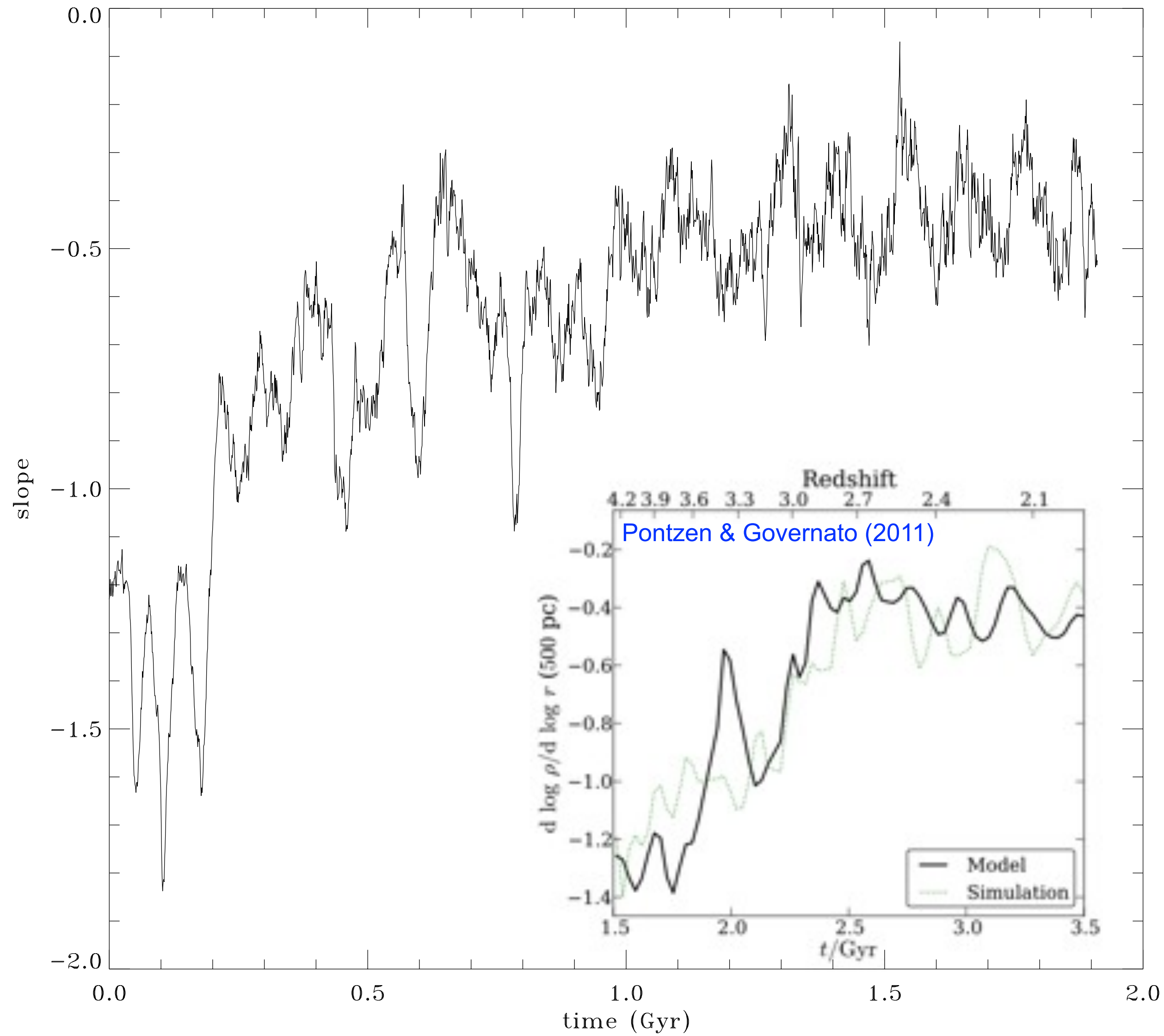


Enclosed gas mass

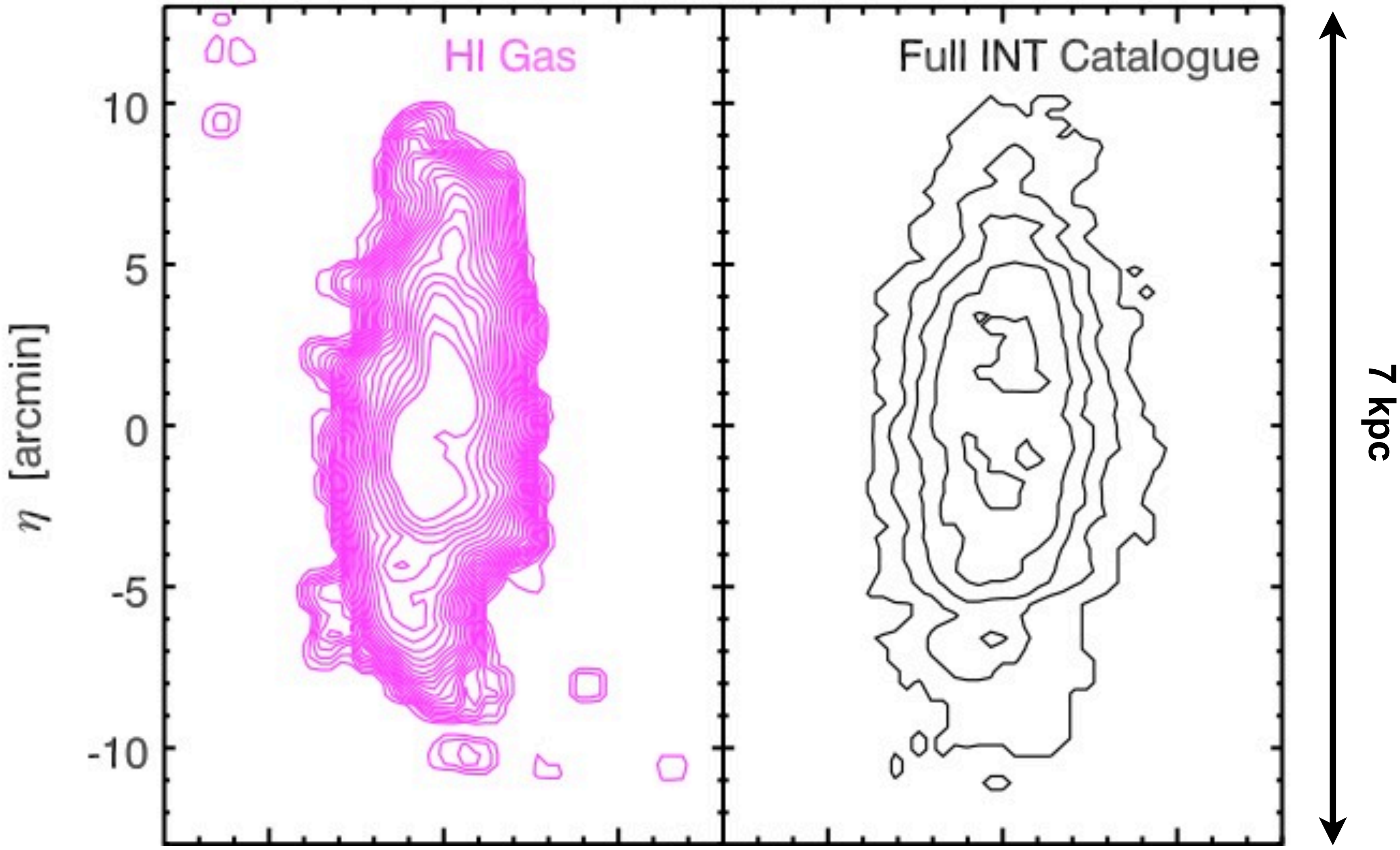


r<1600 pc
r<800 pc
r<400 pc
r<200 pc

...lead to an irreversible flattening of the cusp

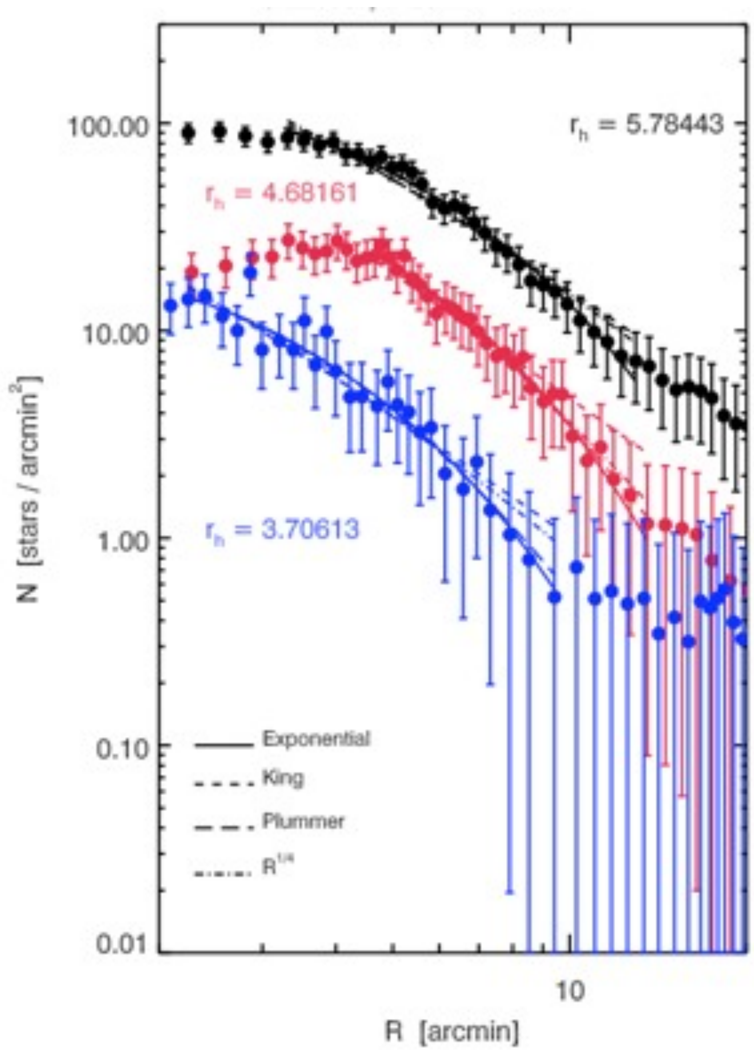


Comparison to WLM (Leaman et al. 2012)

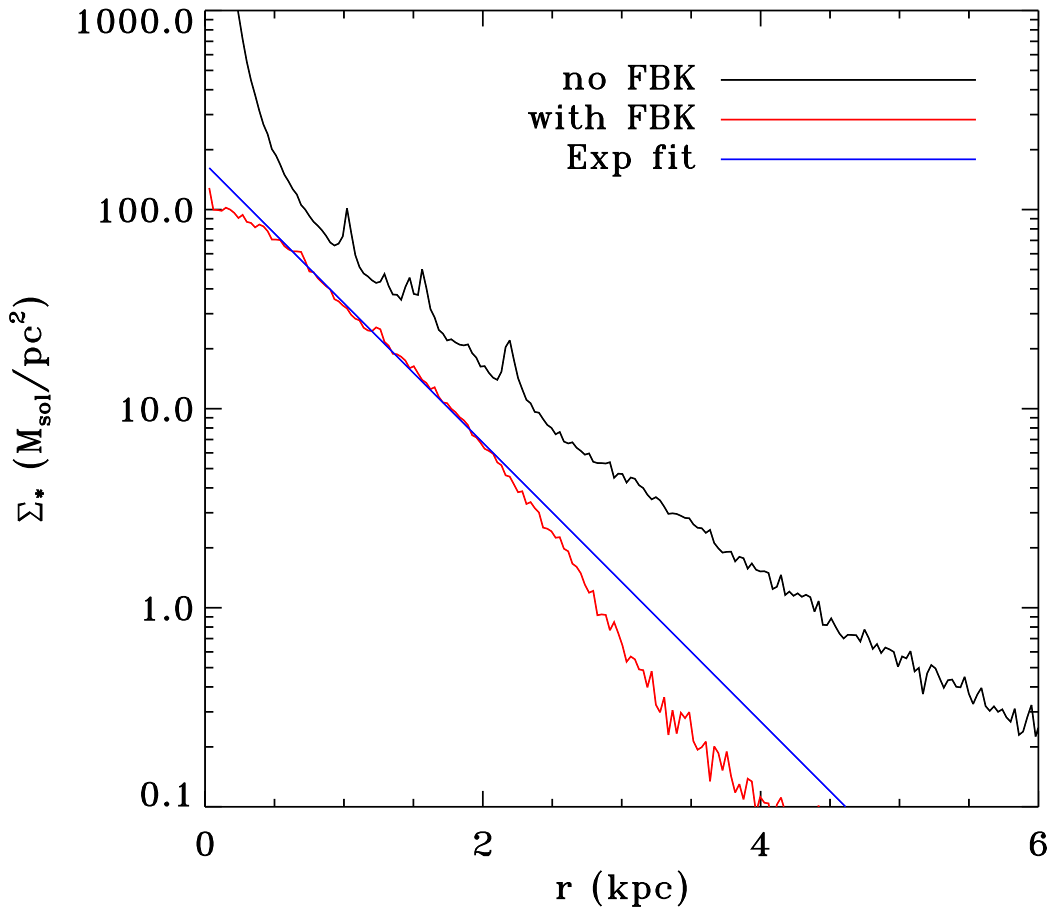


A (cored ?) exponential profile

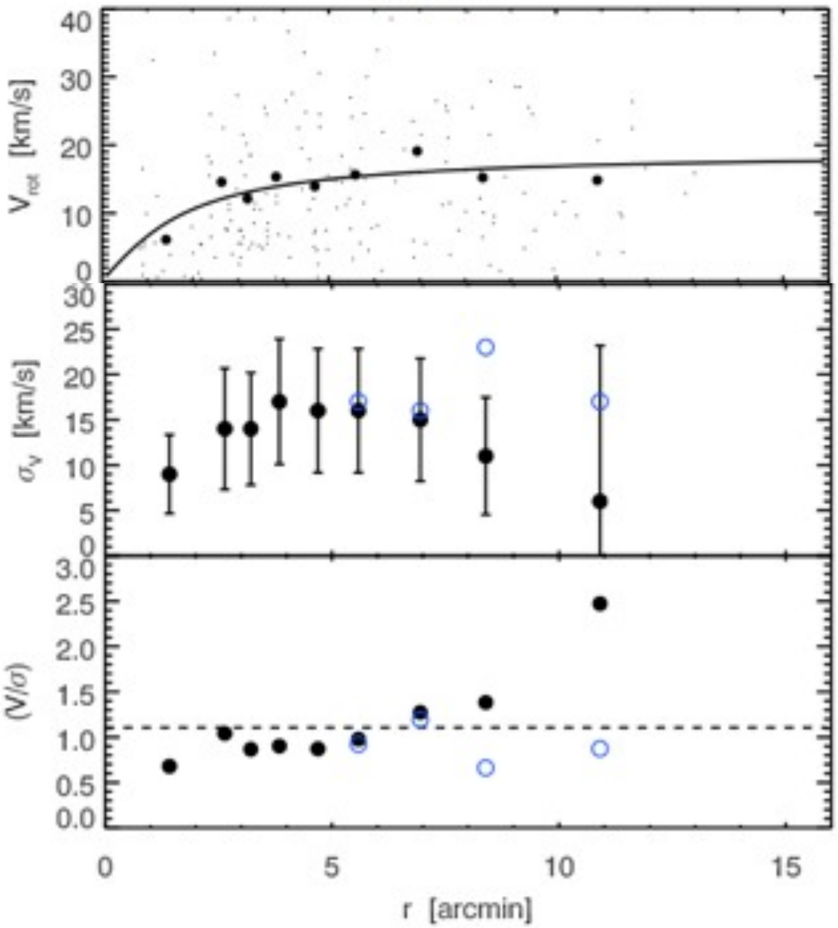
R_d=1 kpc

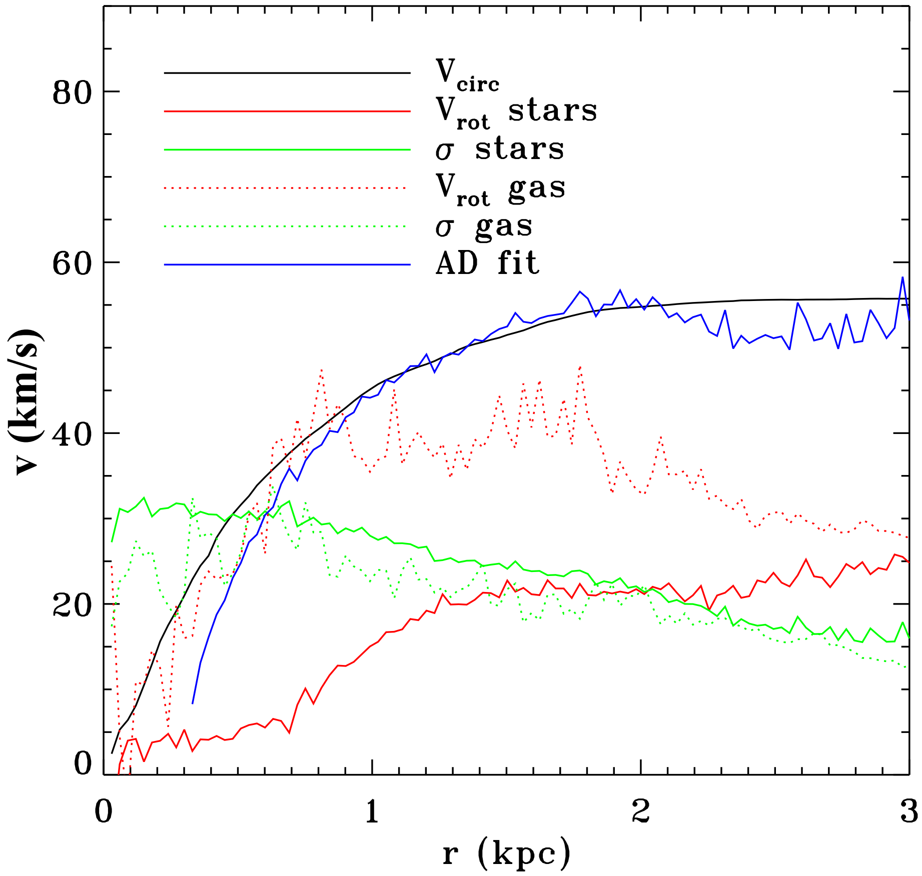


R_d=1.1 kpc

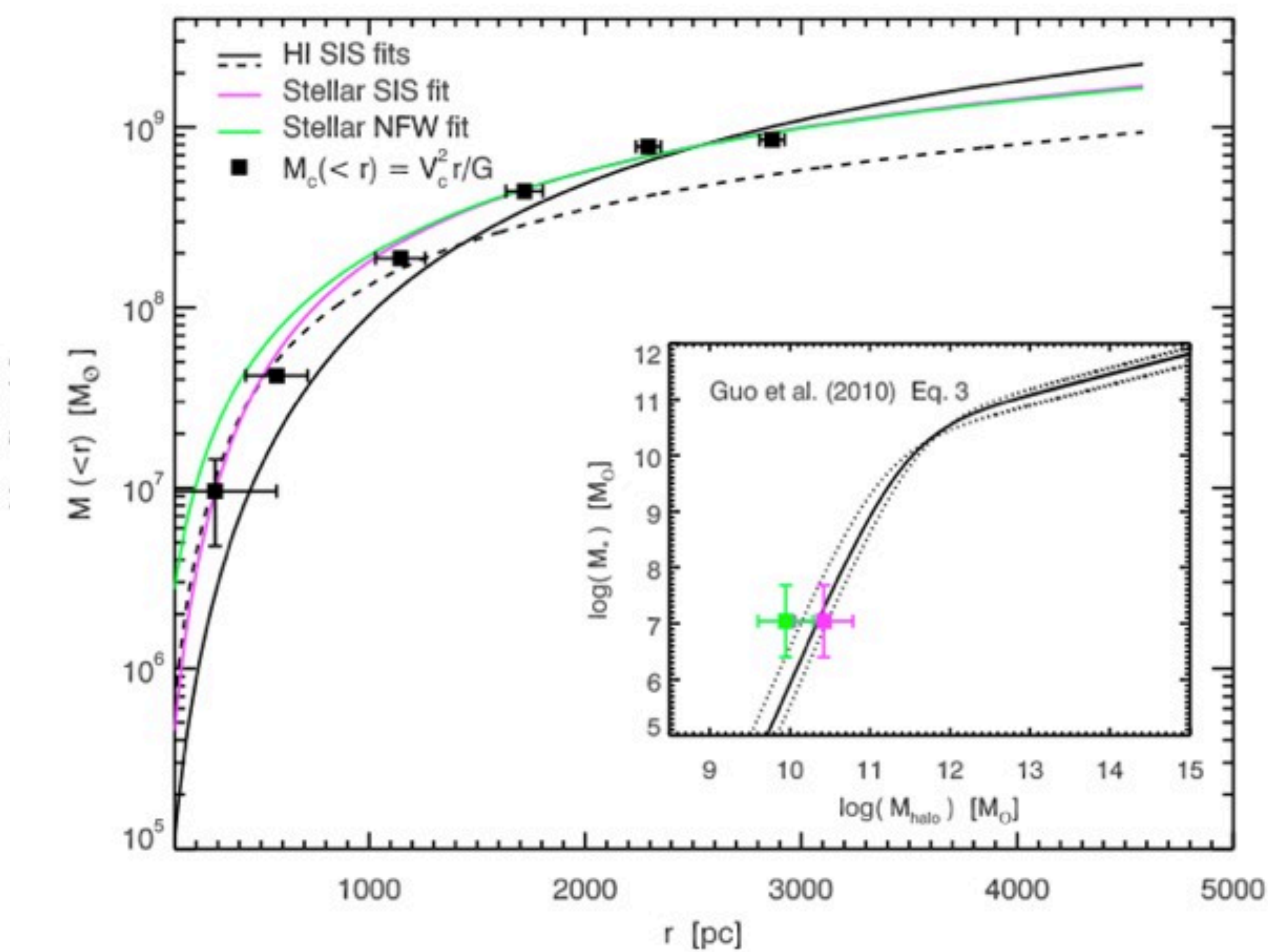


A thick rotating disc





Mass profile of WLM



Still too many baryons in stars

Solution:

Early radiative stellar feedback with 10x the fiducial supernovae energy.

Brook et al. 2012

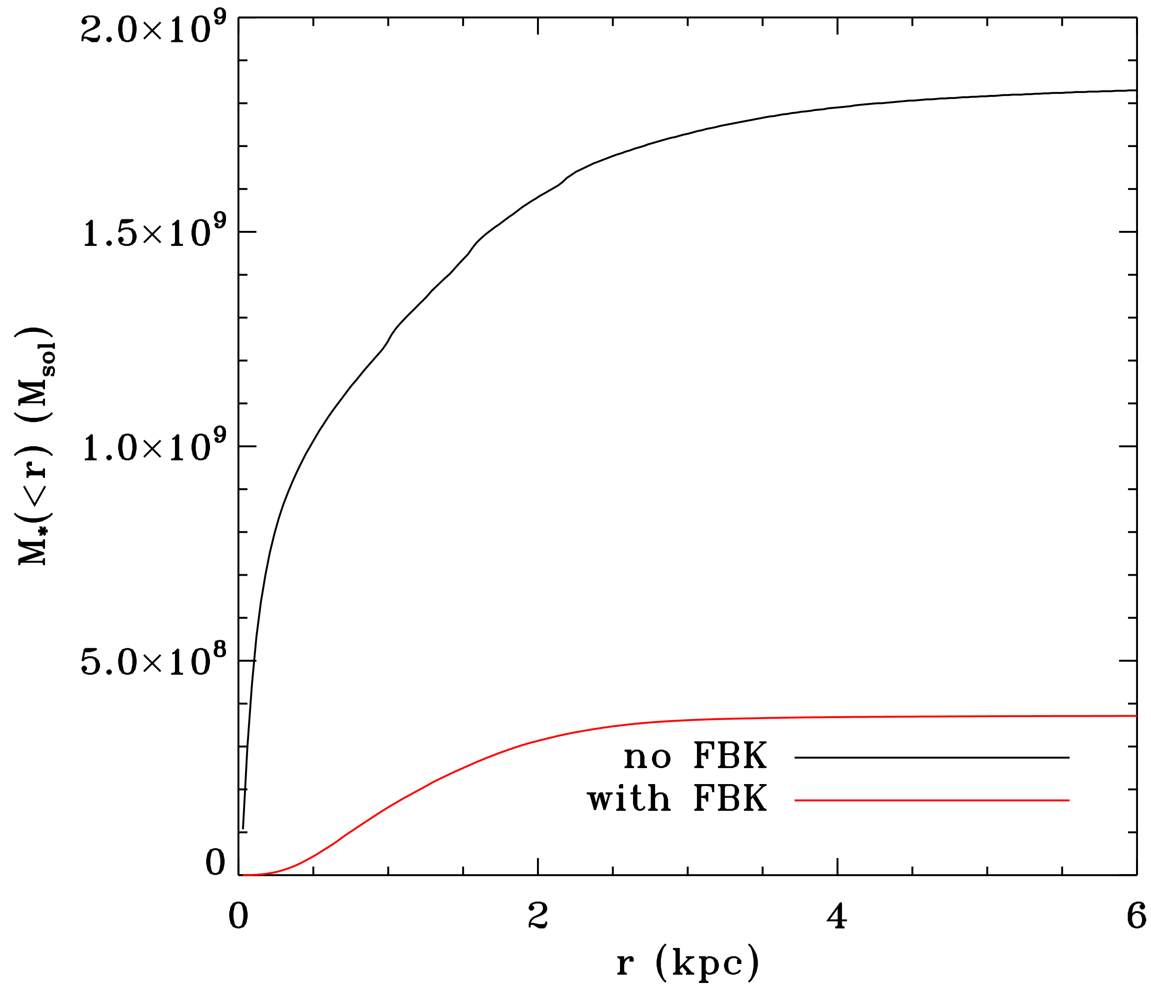
Another solution:

Lower the SF efficiency by 10 (low metallicity induces low H2 formation efficiency ?)

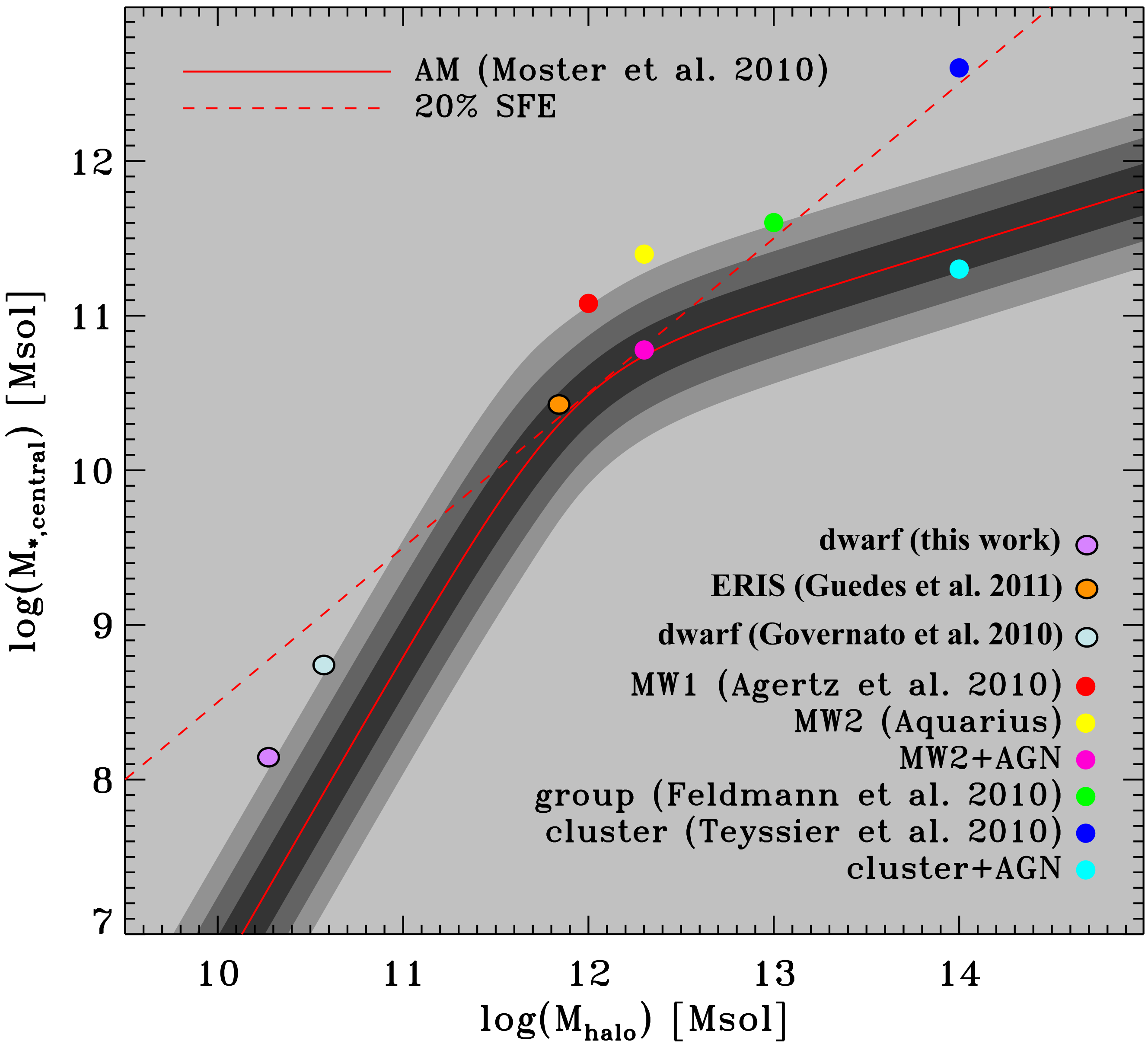
Krumholz & Dekel 2011

AND use a top-heavy IMF (boost the mass fraction in massive star by 10)

Marks et al. 2012



Constraints from abundance matching

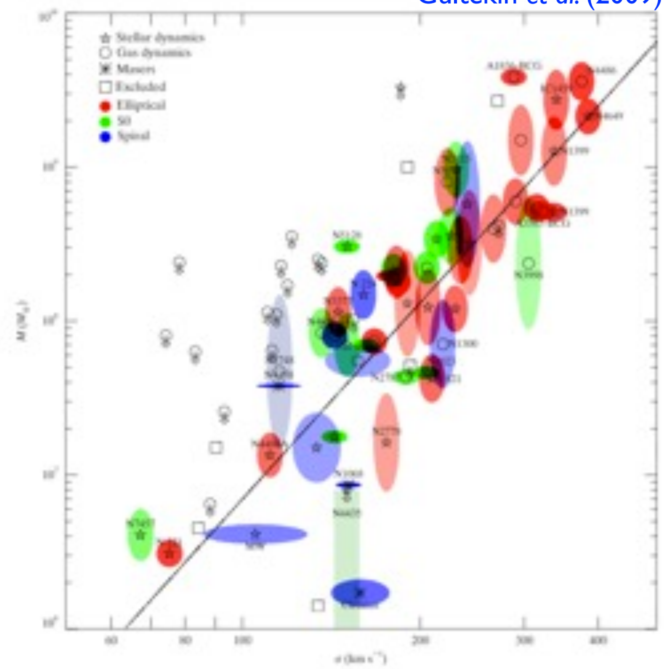


A simple model for SMBH growth and feedback

Numerical implementation in cosmological simulations: Di Matteo et al. 2005, Sijacki et al. 2007; Booth & Schaye 2010 and many others...

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

Gültekin *et al.* (2009)



Accretion is governed by 2 regimes:

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

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

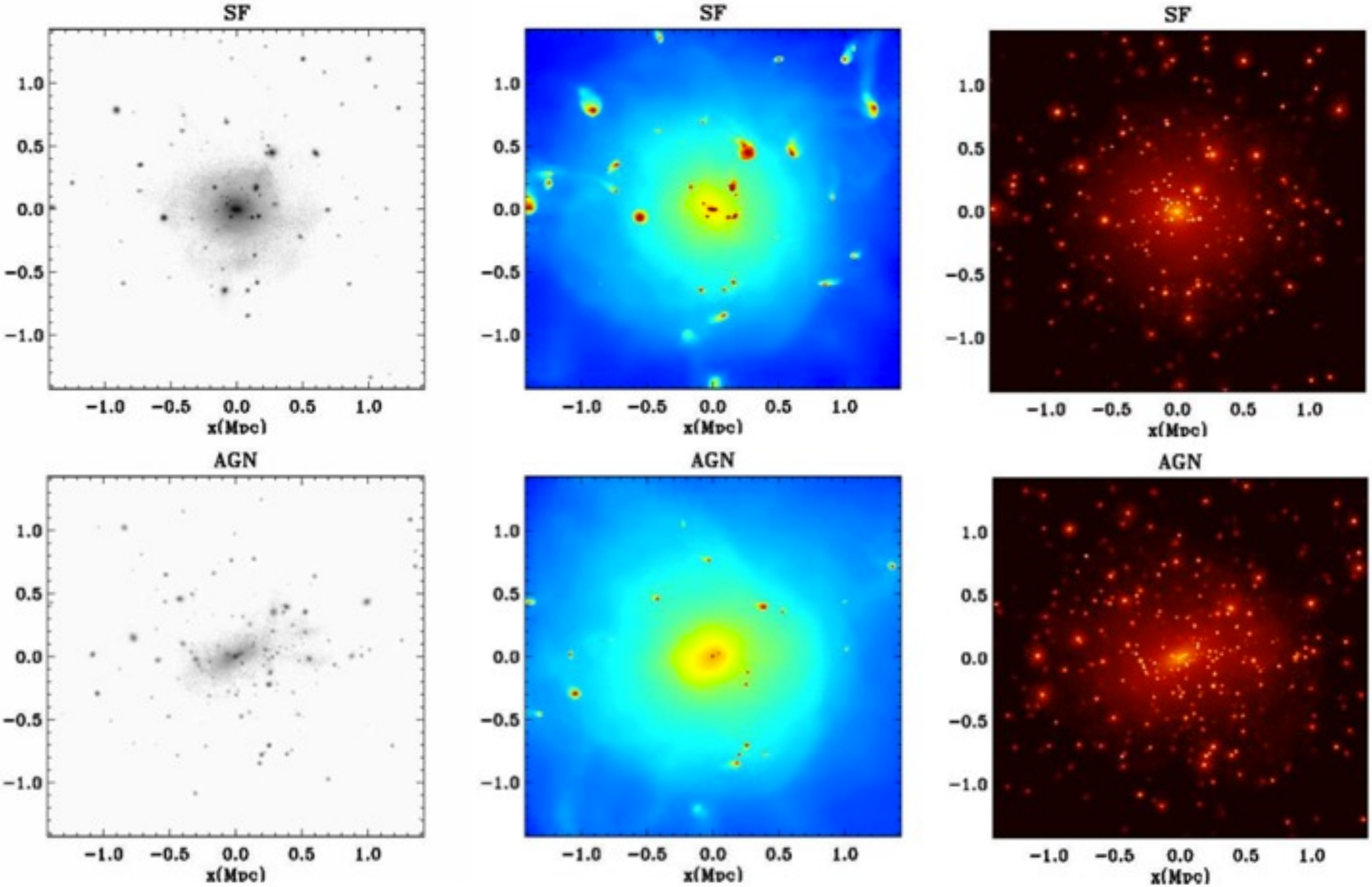
Feedback performed using a thermal dump

$$\Delta E = \epsilon_c \epsilon_r \dot{M}_{\rm acc} c^2 \Delta t.$$

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

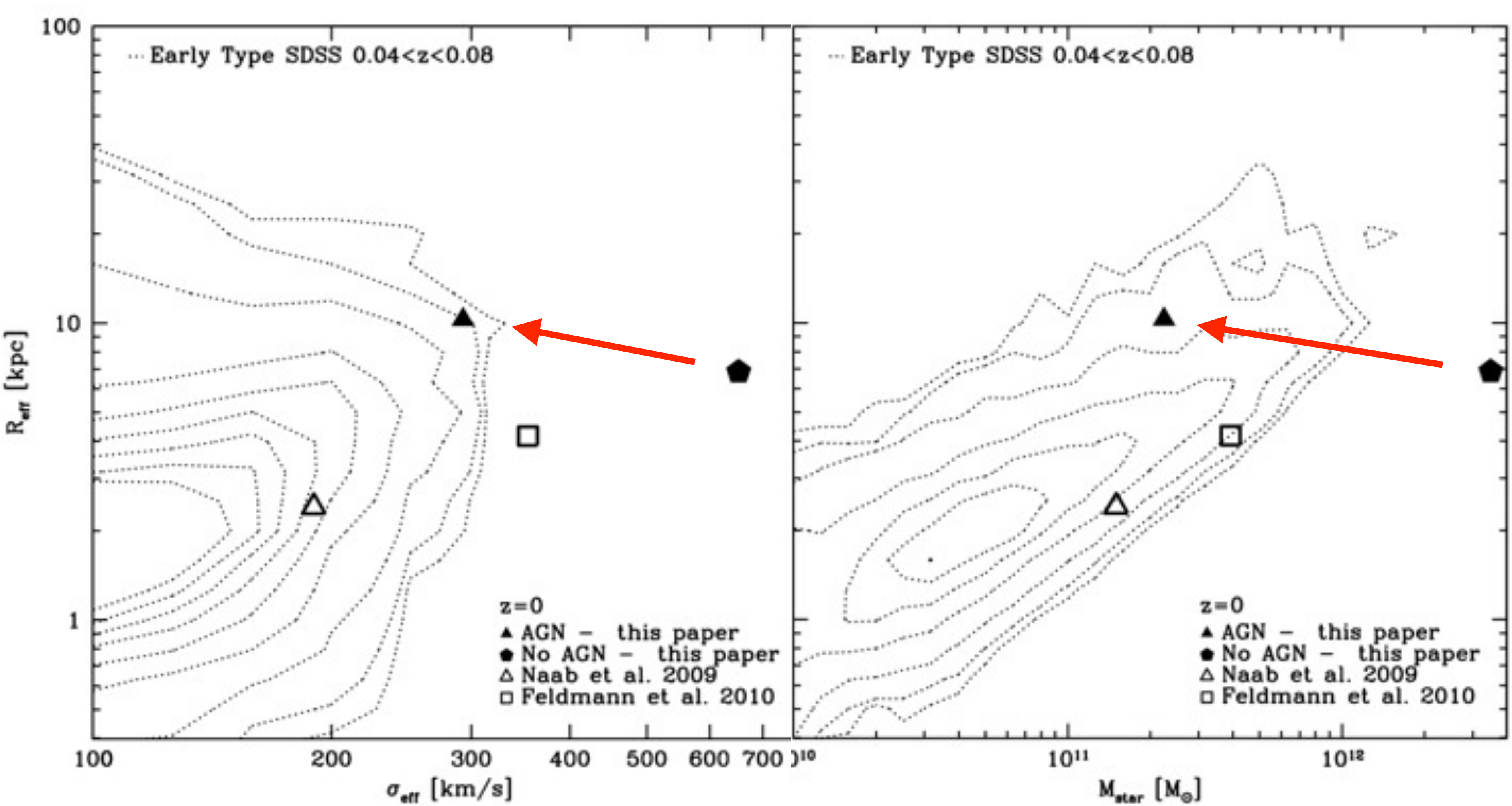
Free parameter ε_c calibrated on the M-σ relation.

Galaxy formation on cluster scales



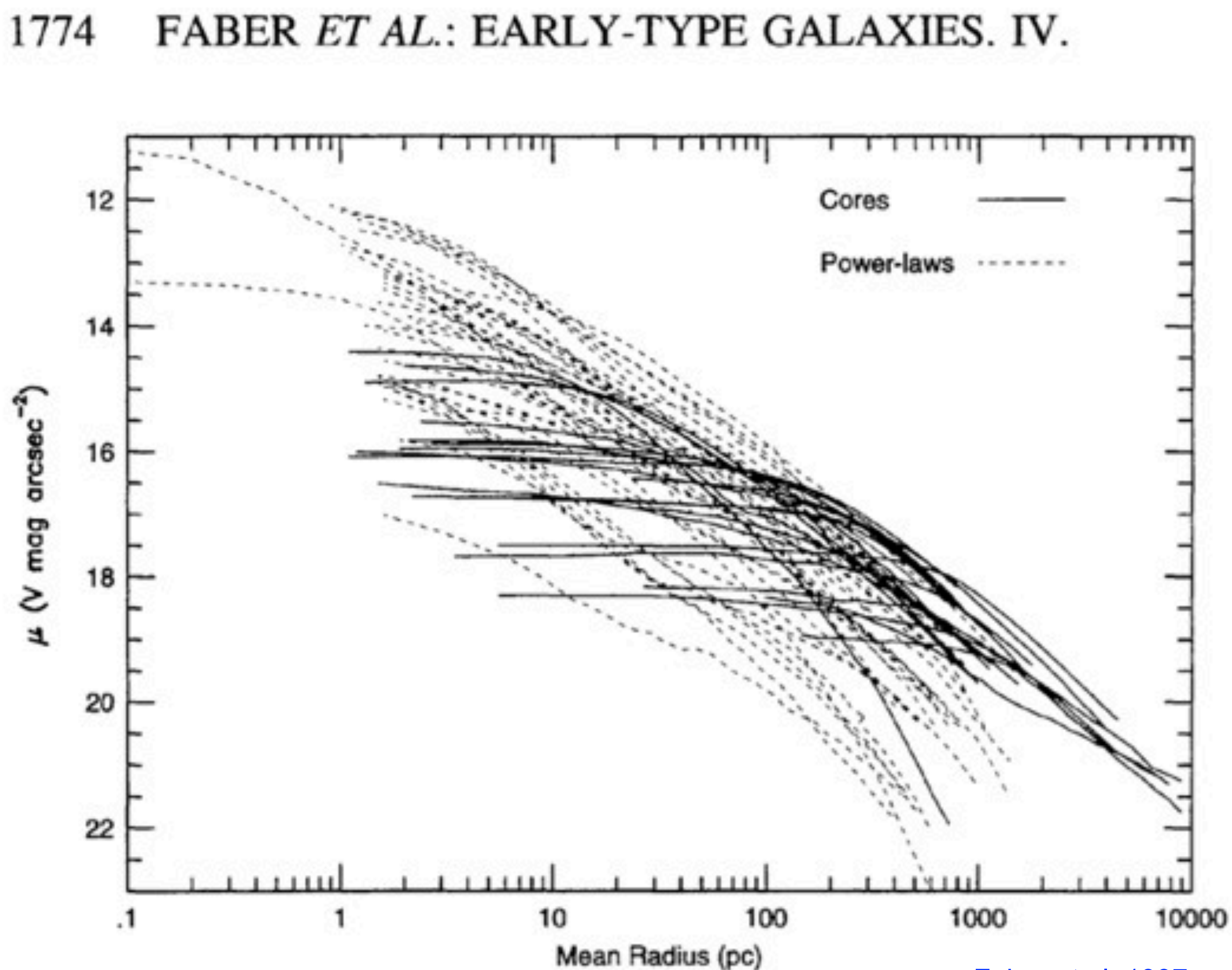
Romain Teyssier

AGN feedback modifies the BCG properties



Booth & Schaye 10; Teyssier+10; Sembolini+11; Dubois+10,11; Martizzi+11

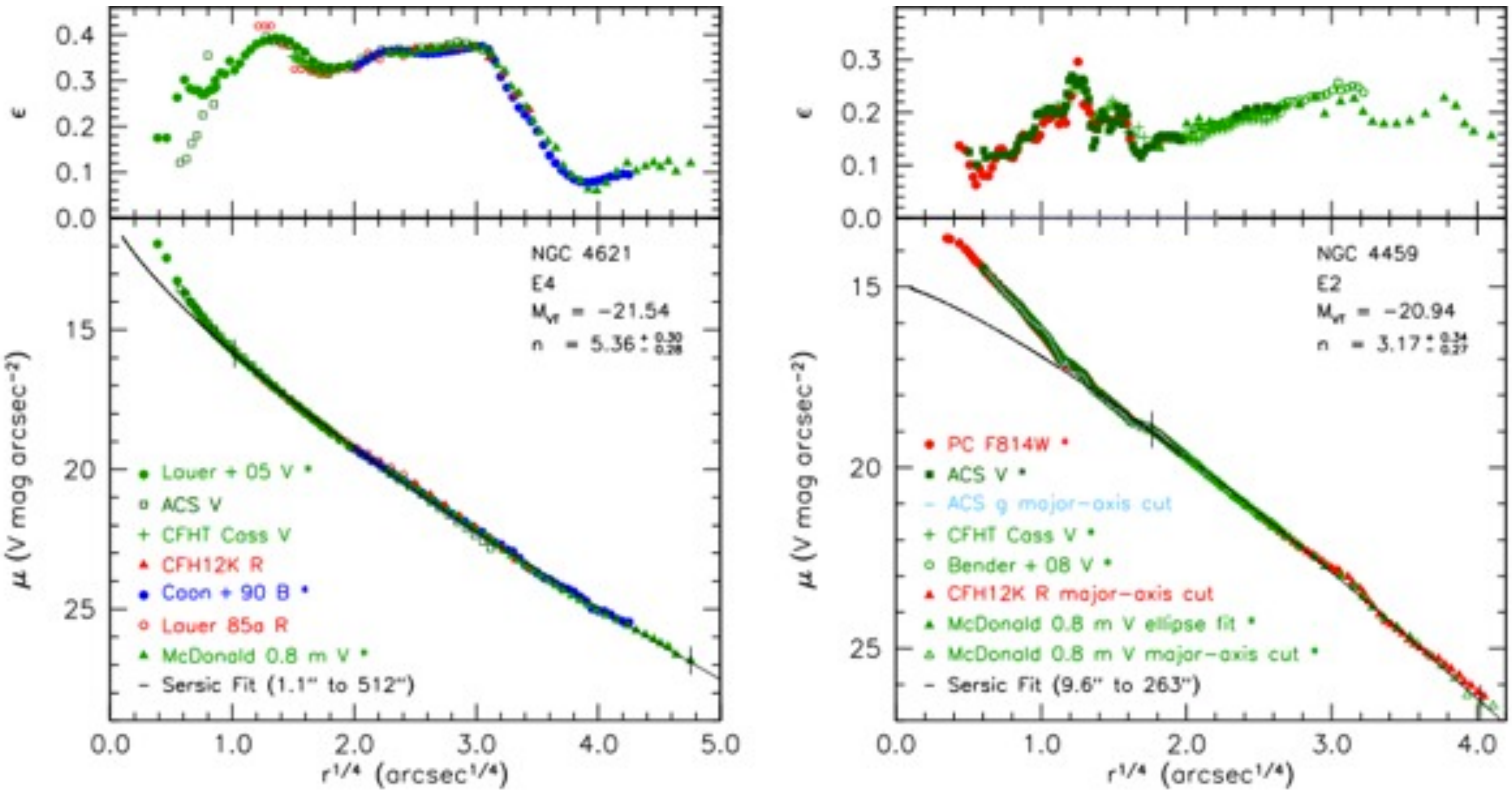
A dichotomy in the structure of elliptical galaxies



Faber et al. 1997

A stellar cusp in low mass elliptical galaxies

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

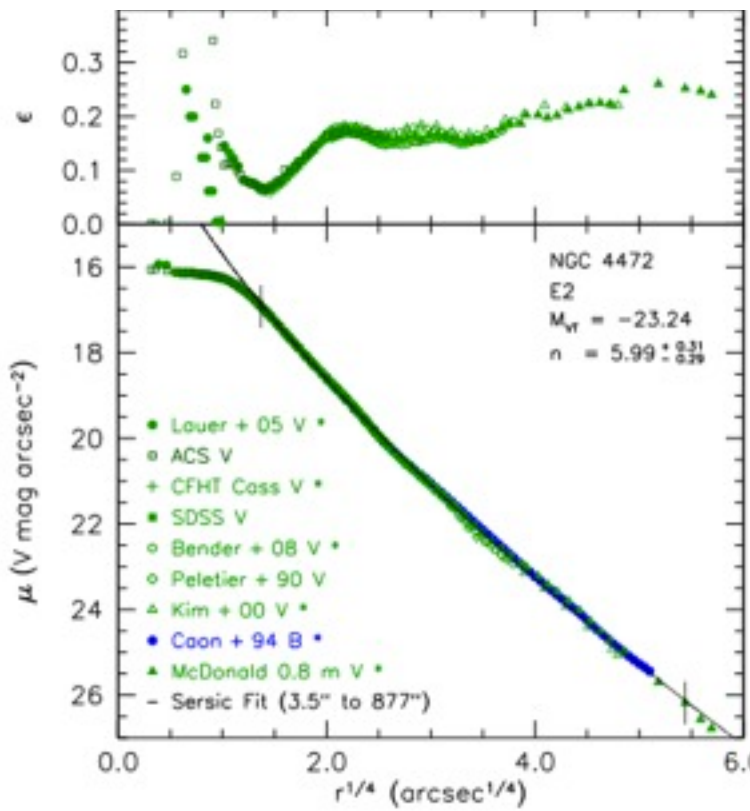


Kormendy *et al.* 2009

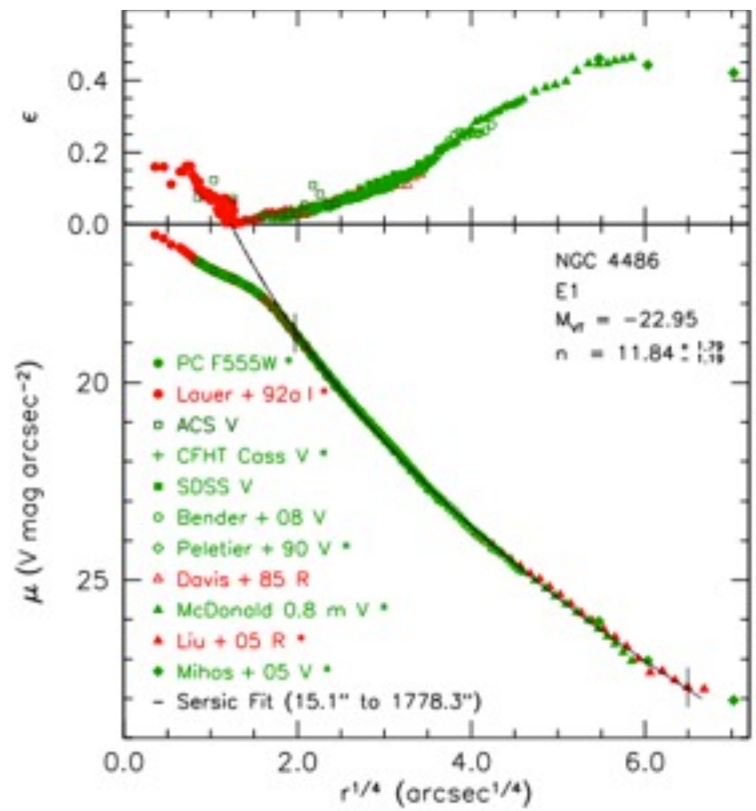
A stellar core in massive elliptical galaxies

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

Kormendy *et al.* 2009

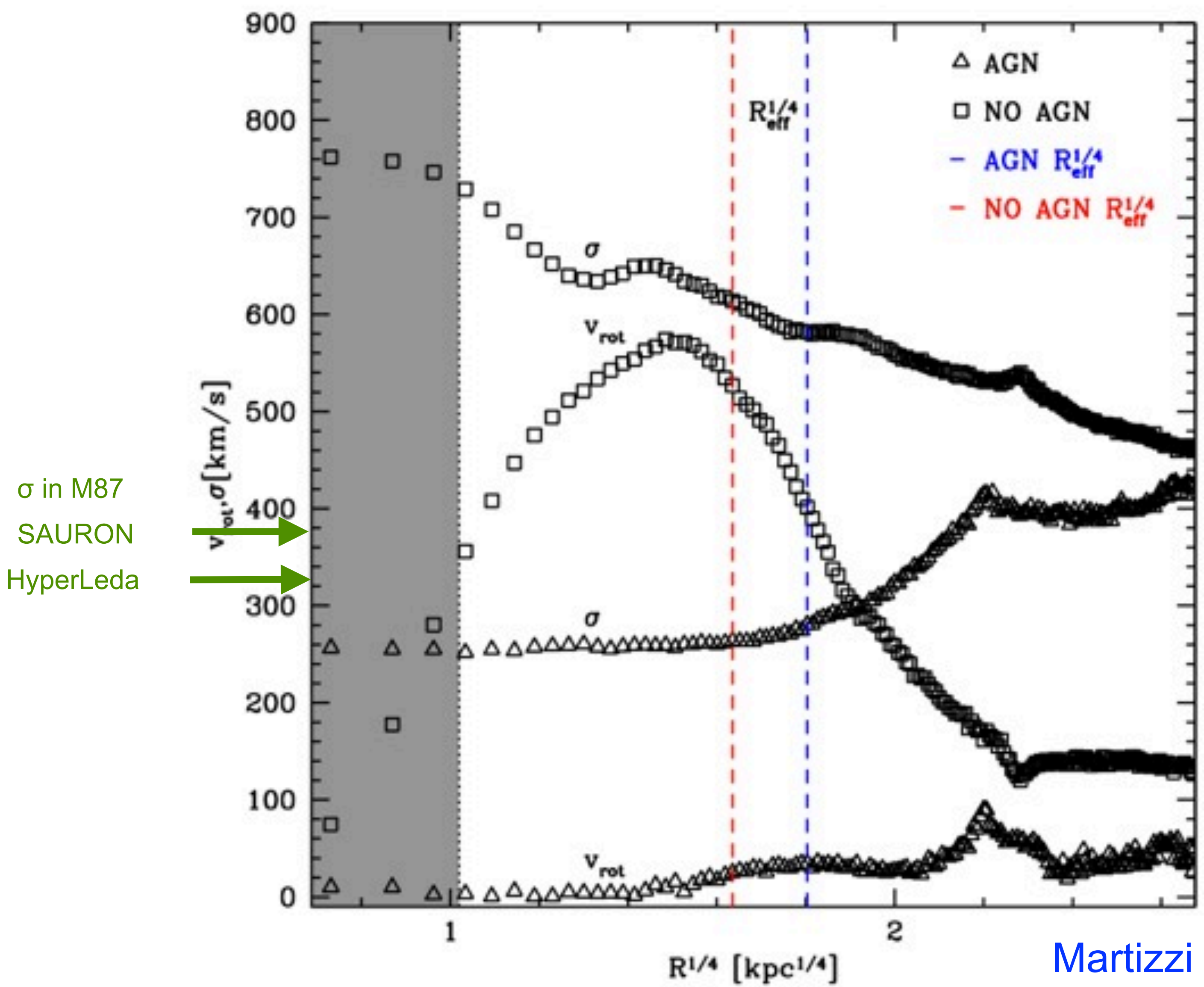


core size ~ 0.5 kpc



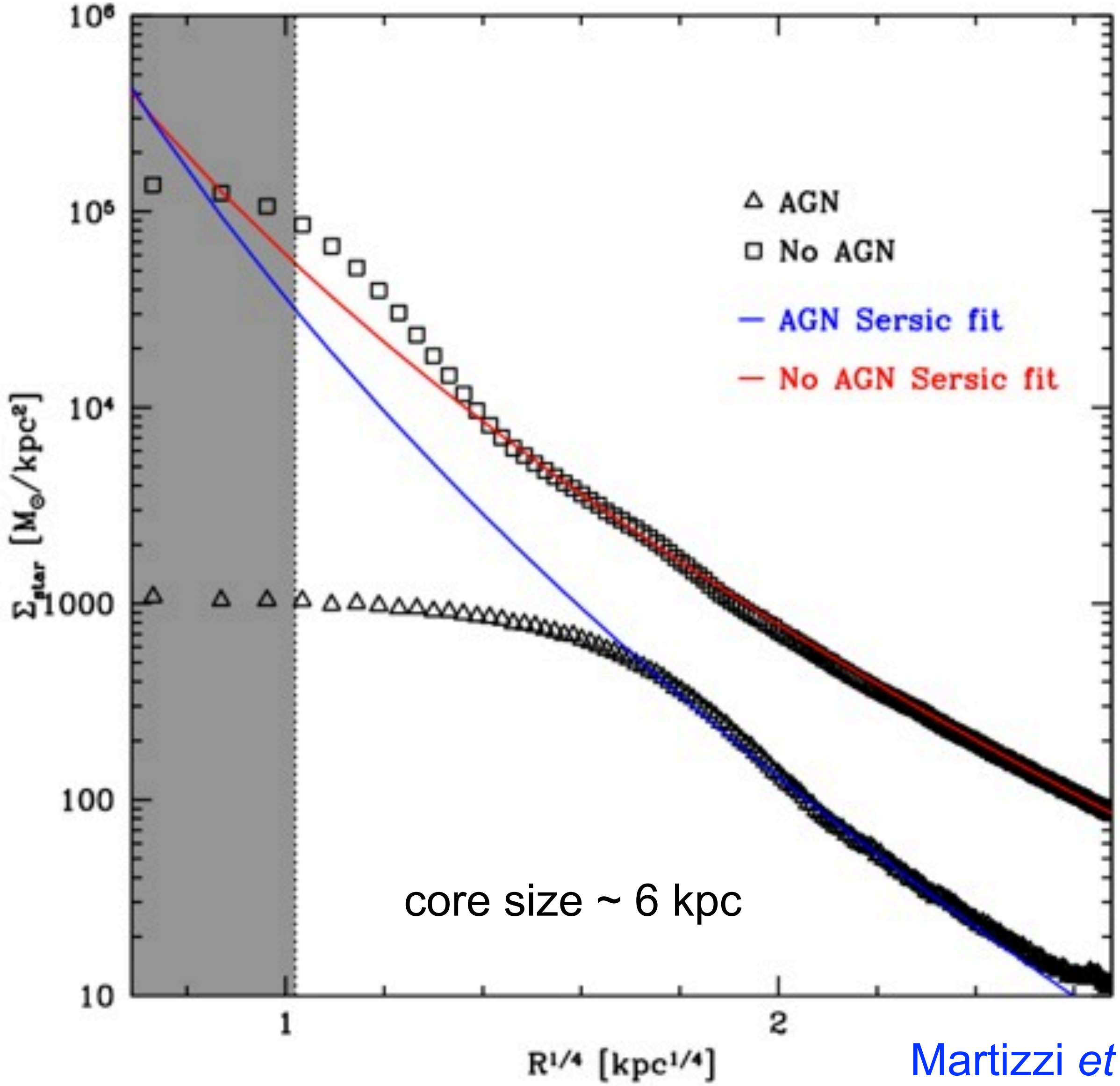
core size ~ 3 kpc

Kinematic properties of the BCG



Martizzi *et al.* 2011

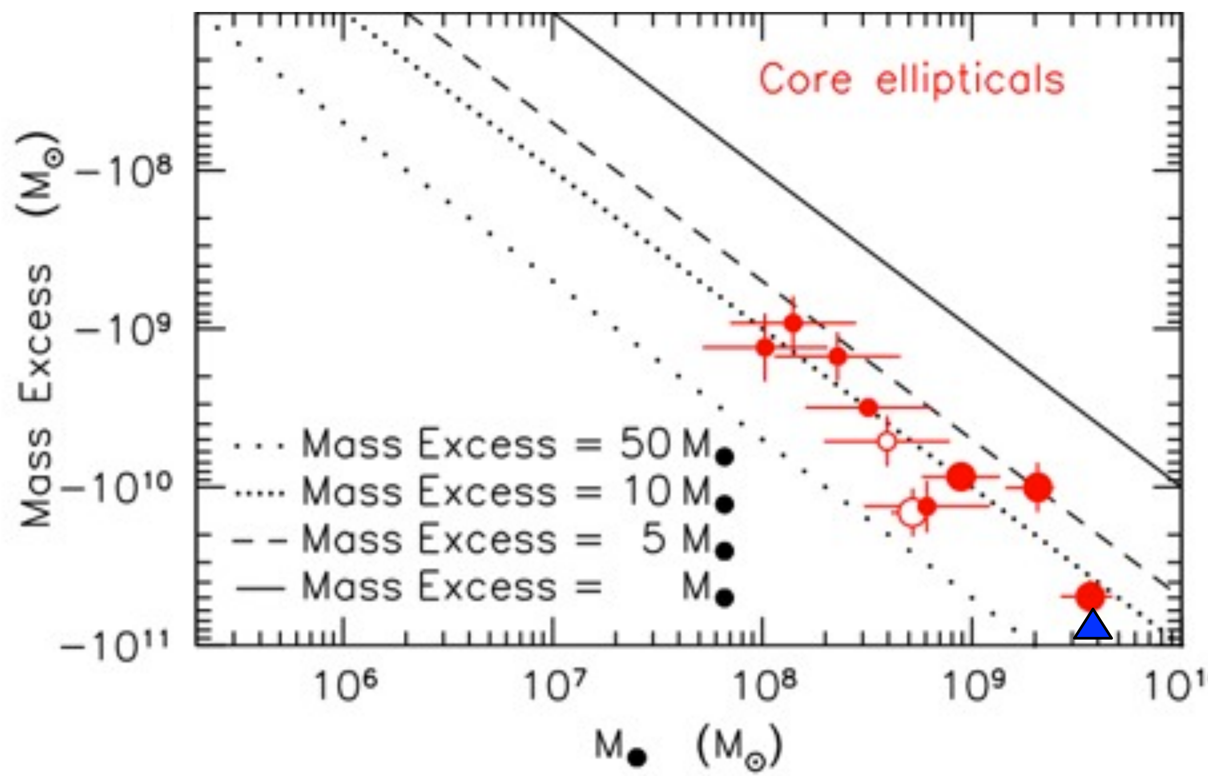
Structural properties of the BCG



Martizzi *et al.* 2011

Large mass deficit in the core

From the Sersic fit, we infer a mass deficit $M_{def}=10^{11}$ M_{sol} or $M_{def}/M_\bullet=20$.

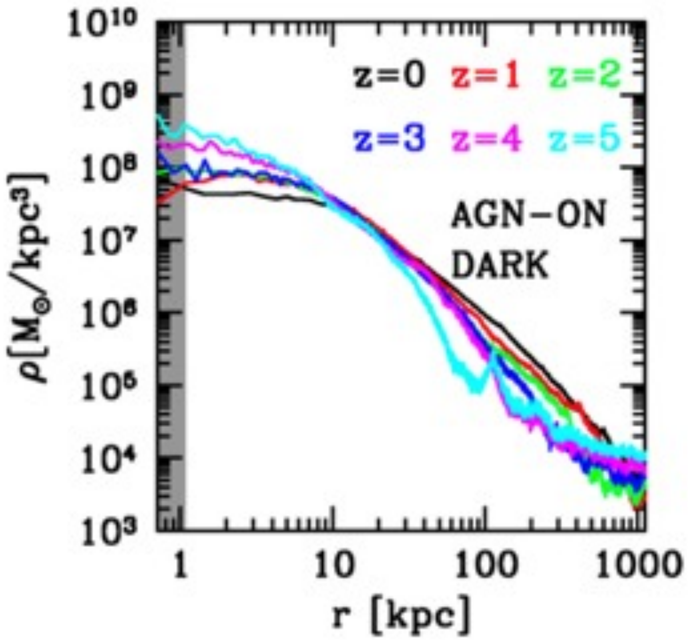


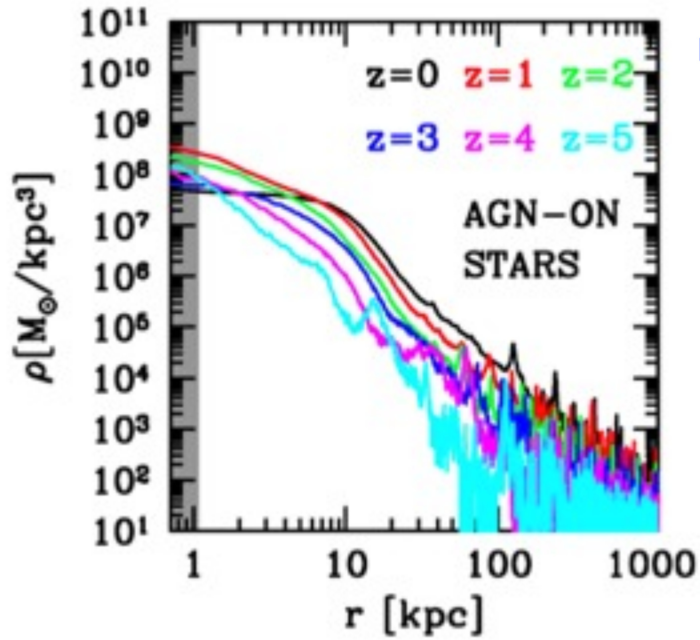
Kormendy *et al.* 2009

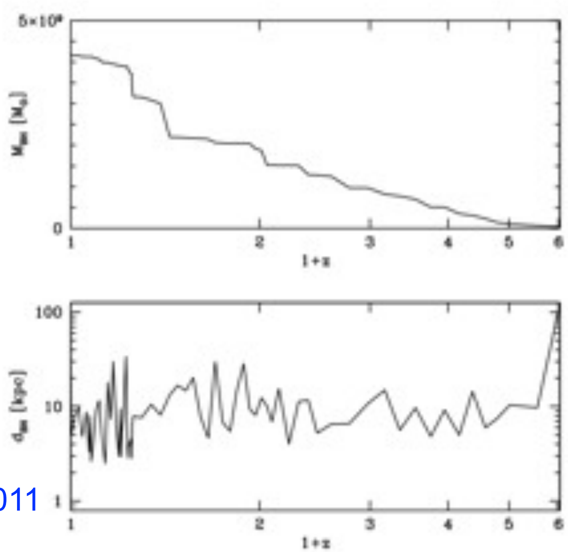
Martizzi *et al.* 2011

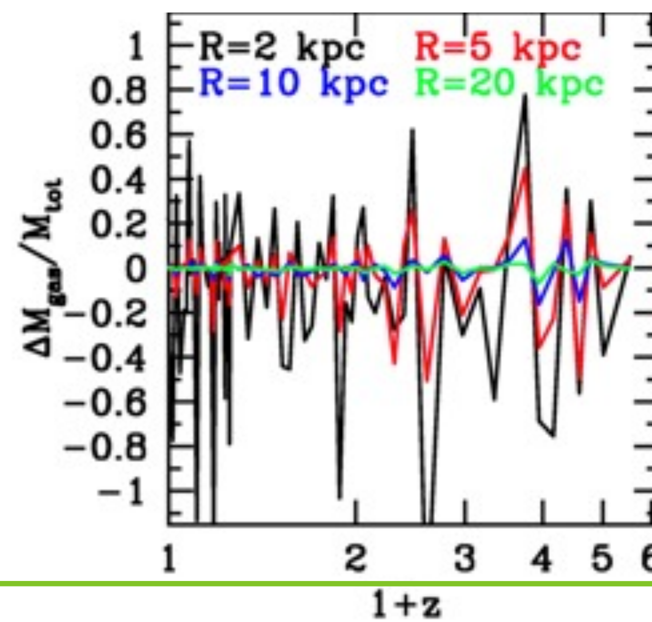
Origin of stellar and dark matter cores in clusters

Martizzi *et al.* 2012









$M_{def}/M_\bullet \approx$ 1 to 5

Goerdt *et al.* 2010

Kulkarni & Loeb 2011

$\Delta\Phi/\Phi$=100%

Pontzen & Governato 2011

Romain Teyssier

Conclusion

A new stellar feedback scheme in RAMSES based on non-thermal processes and implemented as a delayed-cooling scheme.

Dwarf (10^{10} M_{sol}) cooling halo simulations give rise to a cusp-core dark matter profile transition, due to large potential fluctuations within the core.

Kinematic analysis reveals a thick, rotating, exponential disk, in striking agreement with the observed, quasi-isolated dwarf WLM.

Still too many baryons in stars: even stronger feedback required, or non-standard SF efficiencies with a top-heavy IMF (low Z regime ?).

The Booth & Schaye AGN feedback model has been implemented in RAMSES and used in a 10^{14} M_{sol} halo cosmological simulation.

This brings the massive central galaxy properties in agreement with observations (no more overcooling).

Kinematics analysis reveals a massive, slowly rotating elliptical galaxy with a cored Sersic profile.

AGN feedback (high z) and SMBH scouring (low z) give rise to the formation of a dark matter and a stellar core (or broken power law) of similar sizes.