State of the art in numerical simulations of galaxy formation

Romain Teyssier

University of Zurich

cea

Outline

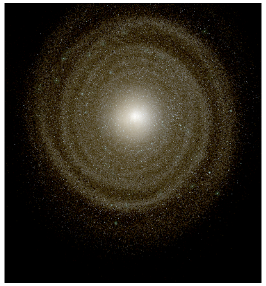
- Galaxy formation in dwarf haloes
- Galaxy formation in MW-like haloes
- Galaxy formation in a Virgo-like cluster

Ben Moore, Lucio Mayer, Davide Martizzi (Zürich)
Oscar Agertz (Chicago)
Yohan Dubois, Julien Devriendt, Adriane Slyz (Oxford)

Simulations performed at the Swiss Supercomputing Center CSCS, Manno
and at the French Supercomputing Center CCRT, Bruyères

Cosmological simulations of galaxy formation

Disks are getting larger: 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)...

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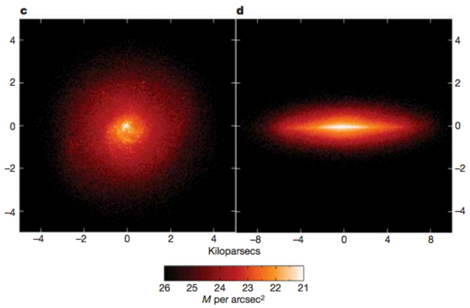
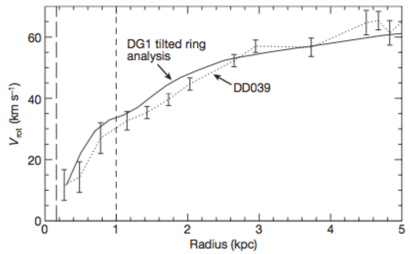
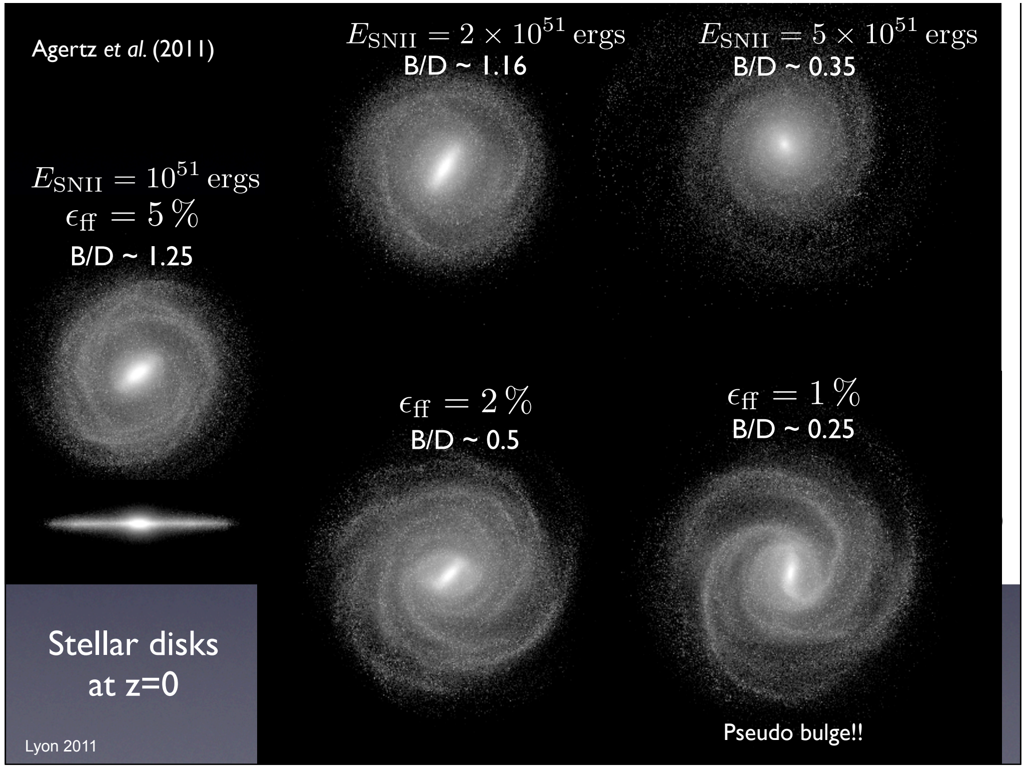
LETTERS

Bulgeless dwarf galaxies and dark matter cores from supernova-driven outflows

F. Governato[1], C. Brook[2], L. Mayer[3], A. Brooks[4], G. Rhee[5], J. Wadsley[6], P. Jonsson[7], B. Willman[9], G. Stinson[6], T. Quinn[1] & P. Madau[8]





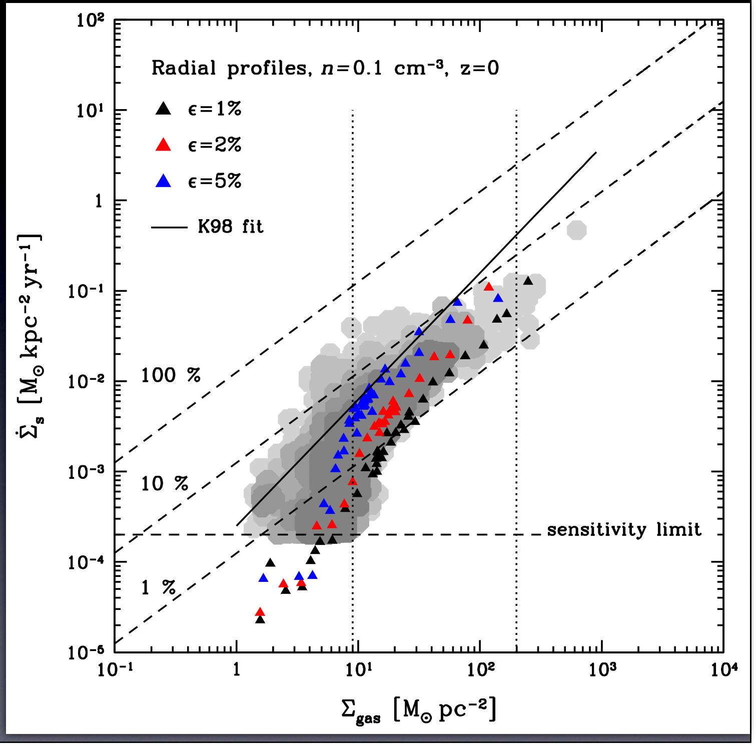


Agertz et al. (2011)
$E_{\rm SNII} = 10^{51}$ ergs
$\epsilon_{\rm ff} = 5\,\%$
B/D ~ 1.25
$E_{\rm SNII} = 2 \times 10^{51}$ ergs
B/D ~ 1.16
$E_{\rm SNII} = 5 \times 10^{51}$ ergs
B/D ~ 0.35
$\epsilon_{\rm ff} = 2\,\%$
B/D ~ 0.5
$\epsilon_{\rm ff} = 1\,\%$
B/D ~ 0.25
Pseudo bulge!!
Stellar disks
at z=0
Lyon 2011

Agertz *et al.* (2011)

Observe simulated disks @ z=0

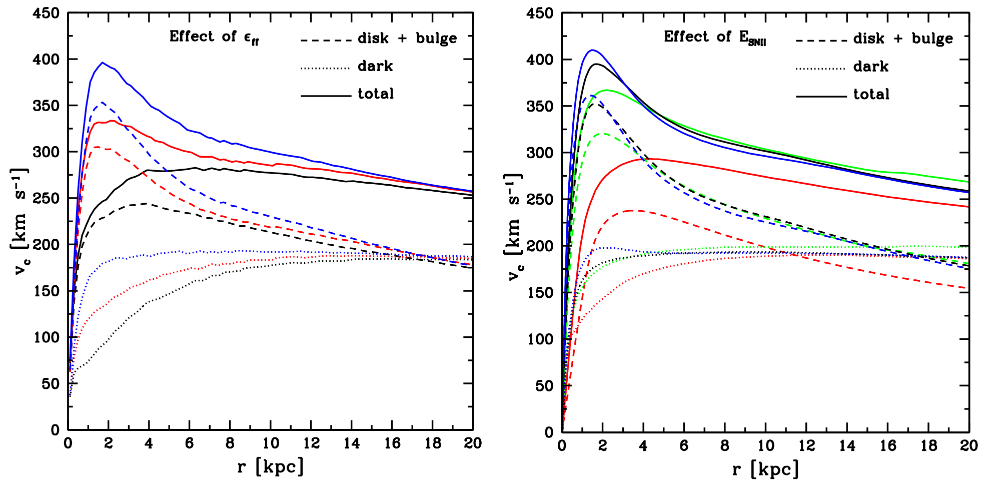
Kennicutt-Schmidt relation + THINGS data (Bigiel et al. 2008)



Agertz *et al.* (2011)

Circular velocities

Effect of SFE | Effect of SNe feedback



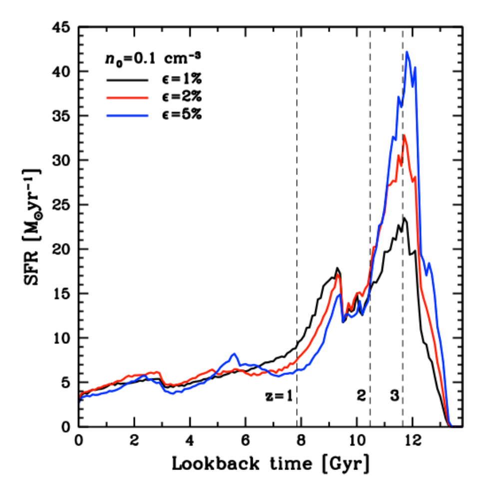
10-20% scaling recovers the Milky Way

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

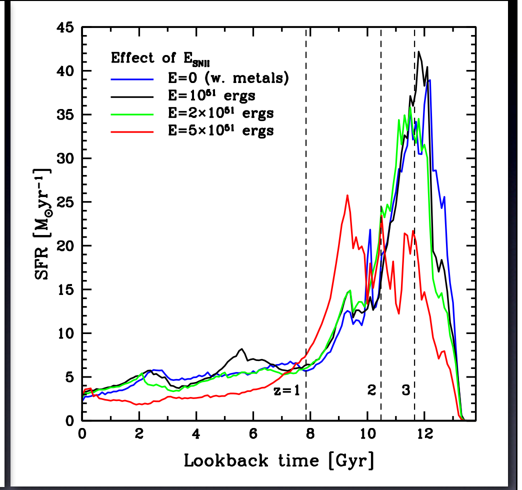
Agertz *et al.* (2011)

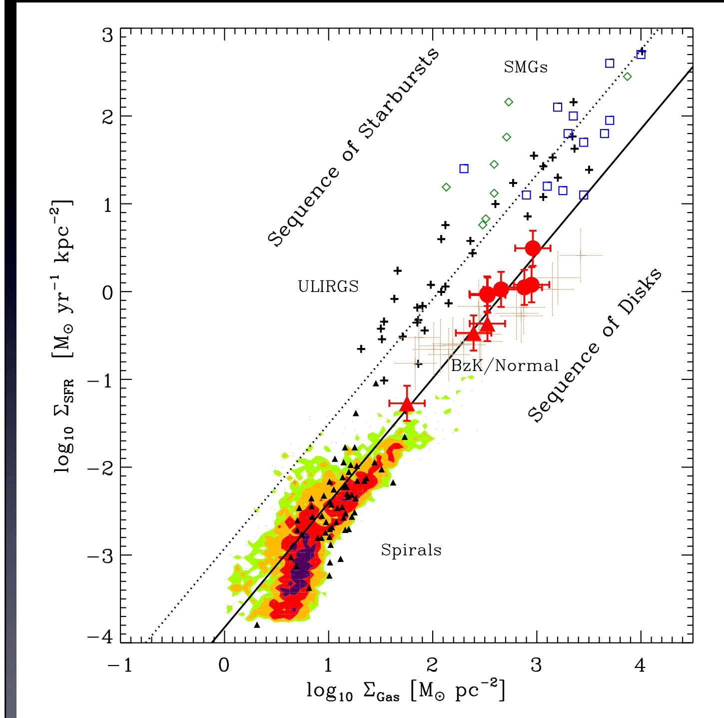
Star formation histories

Effect of SFE

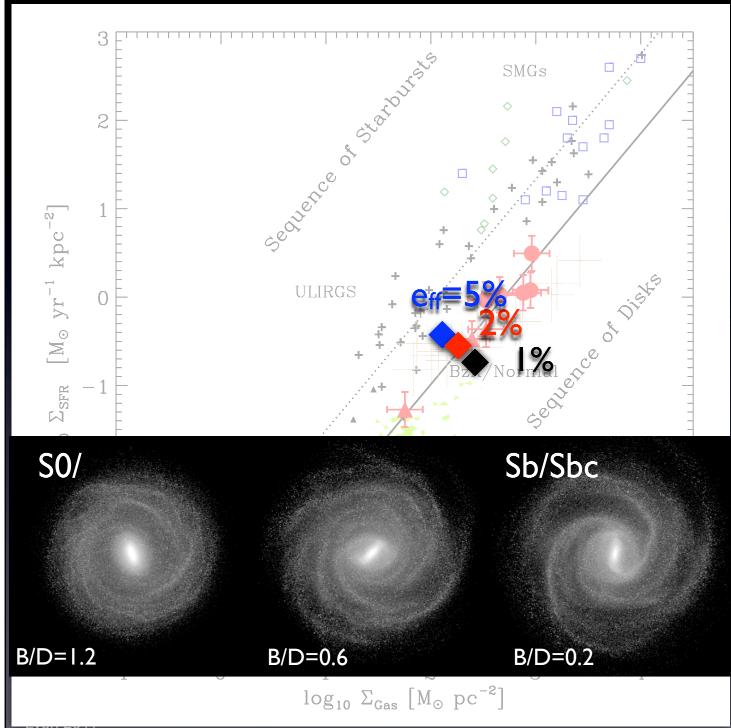


Effect of SNe feedback





Daddi et al. 2010
Genzel et al. 2010



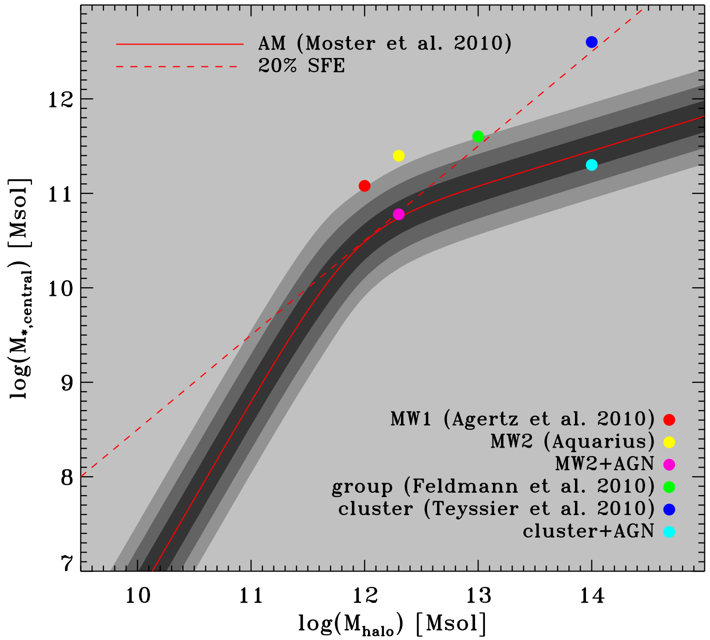
Daddi et al. 2010
Genzel et al. 2010

Observe simulated disks @ z=3

The simulated disks with a low B/D @ z=0 correspond to lower Σ_{SFR} @ z=3 in the discs' sequence.

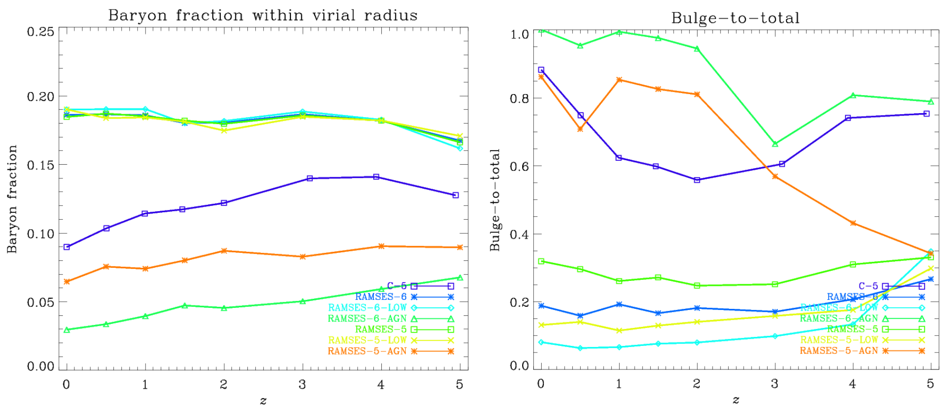
Romain Teyssier

Constraints from abundance matching



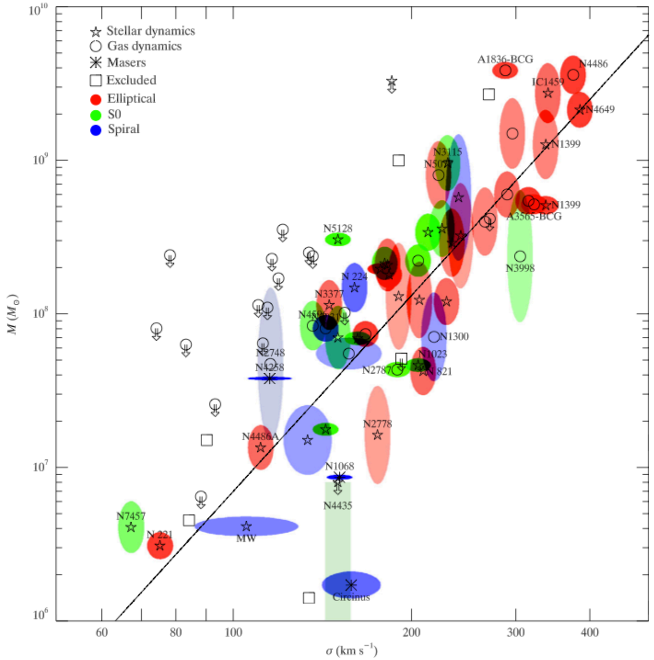
Strong feedback remove baryons from the halo...

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



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

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

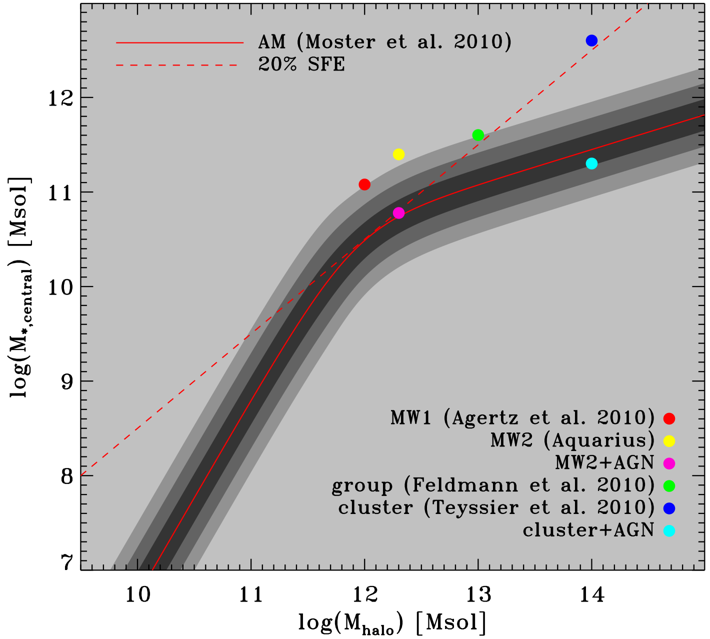
Eddington-limited $$\dot{M}_{\rm ED} = \frac{4\pi {\rm G} M_{\rm BH} m_{\rm p}}{\epsilon_r \sigma_{\rm T} c}$$

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

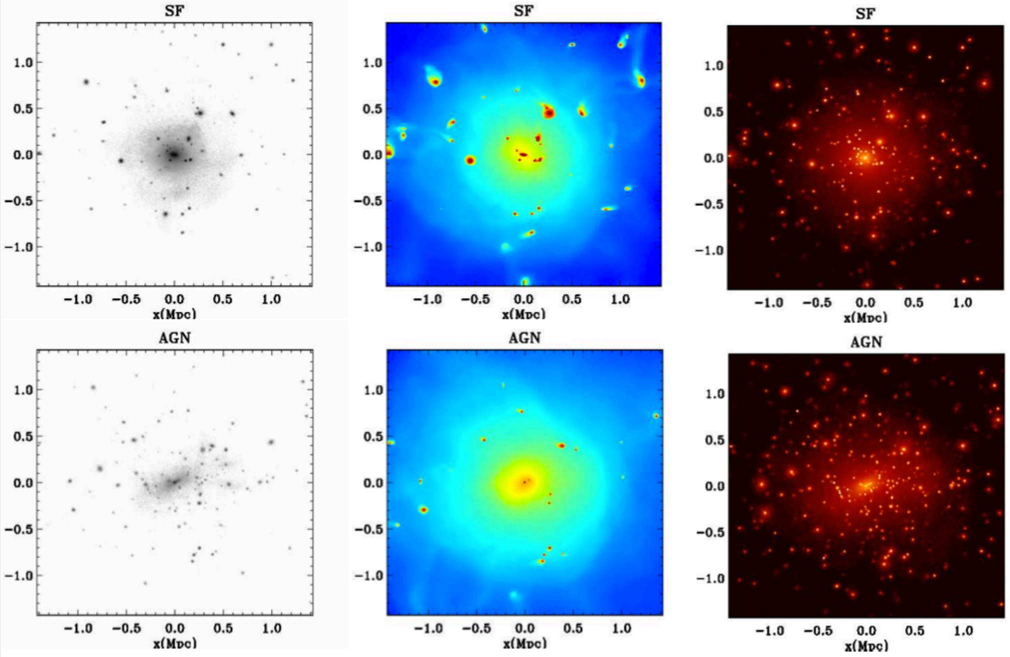
with following trick to avoid overcooling: $E_{\rm AGN} > \frac{3}{2} m_{\rm gas} k_B T_{\rm min}$ $\quad T_{\rm min} = 10^7$ K

Free parameter $\varepsilon_{\rm c}$ calibrated on the M-σ relation.

Constraints from abundance matching

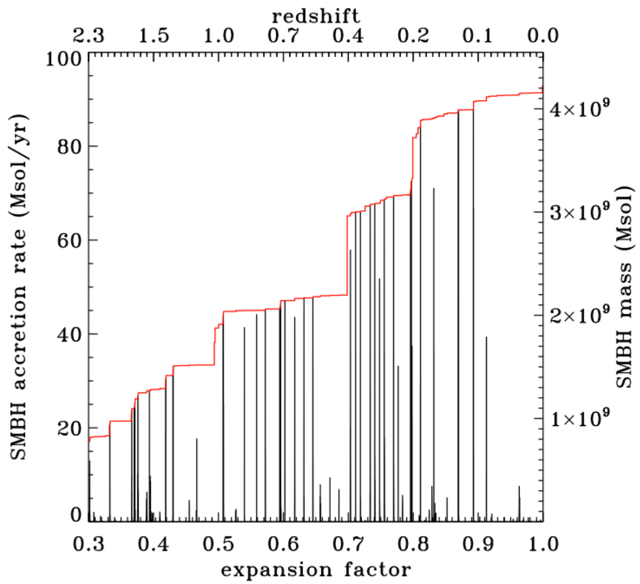


Galaxy formation on cluster scales



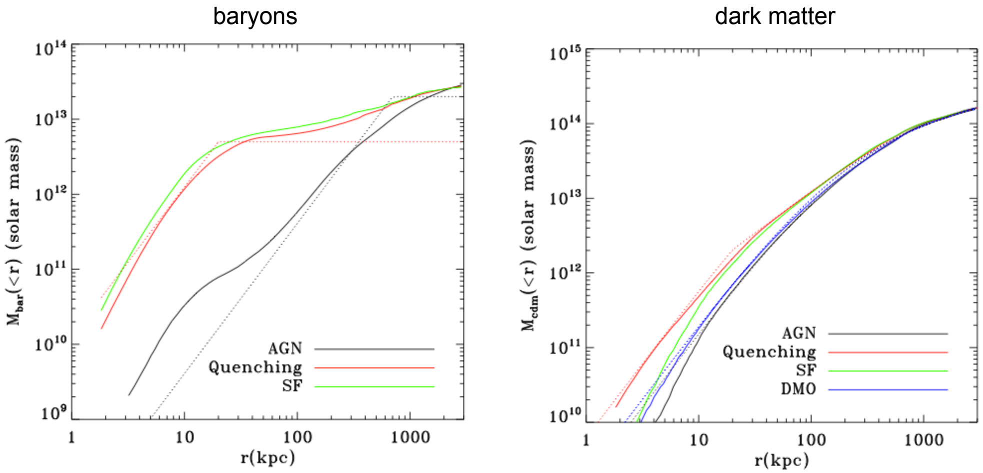
Teyssier *et al.* 2011, MNRAS, 414, 195

SMBH growth and associated feedback



Teyssier *et al.* 2010

AGN feedback regulates the mass distribution

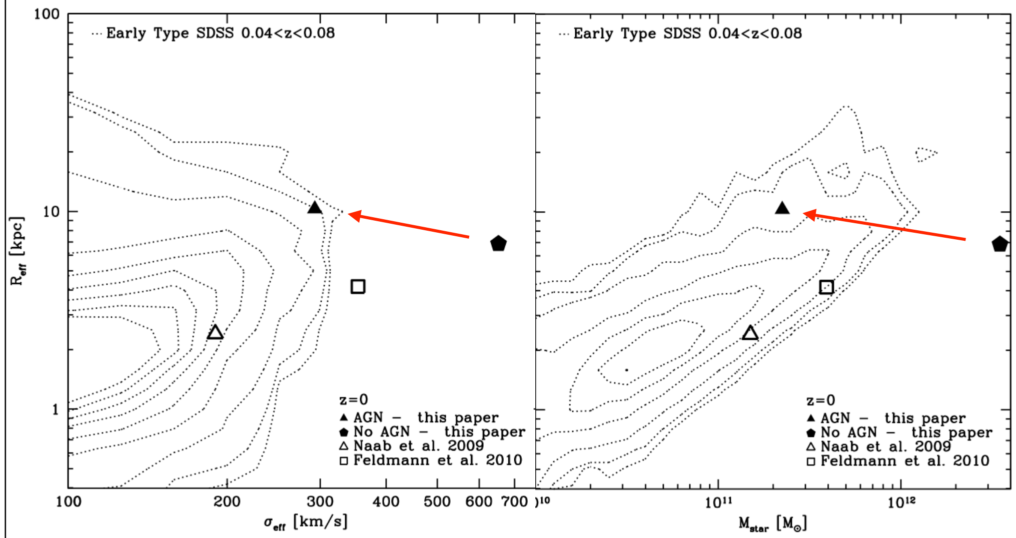


Without AGN feedback, overcooling leads to a strong mass concentration in the center.

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

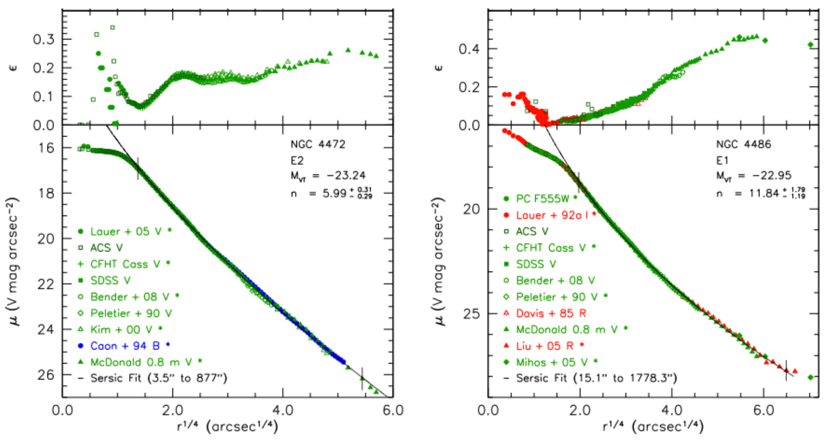
See talk by Yohan Dubois.

AGN feedback modifies the BCG properties



A dichotomy in the structure of elliptical galaxies

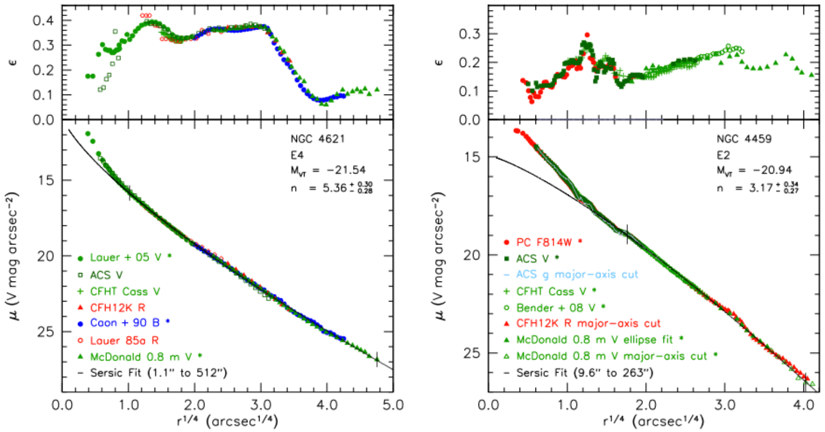
«Core» elliptical: light deficit, low ellipticity, slow rotator



Kormendy et al. (2009)

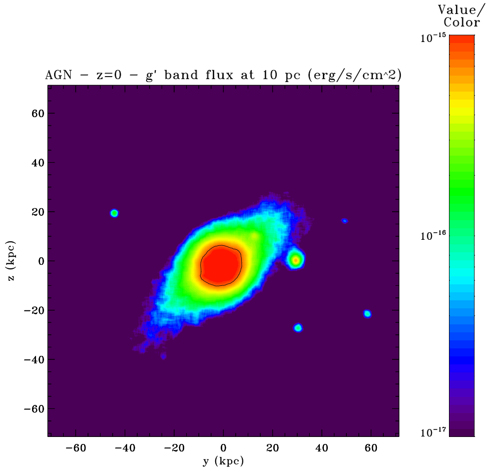
A dichotomy in the structure of elliptical galaxies

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

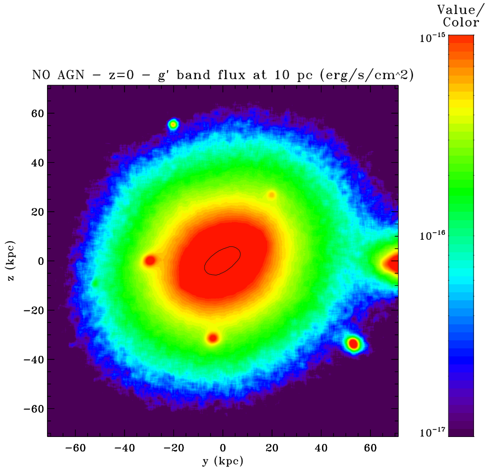


Kormendy et al. (2009)

Cosmological simulations: BCG with or w/o AGN



ε~0.1-0.2

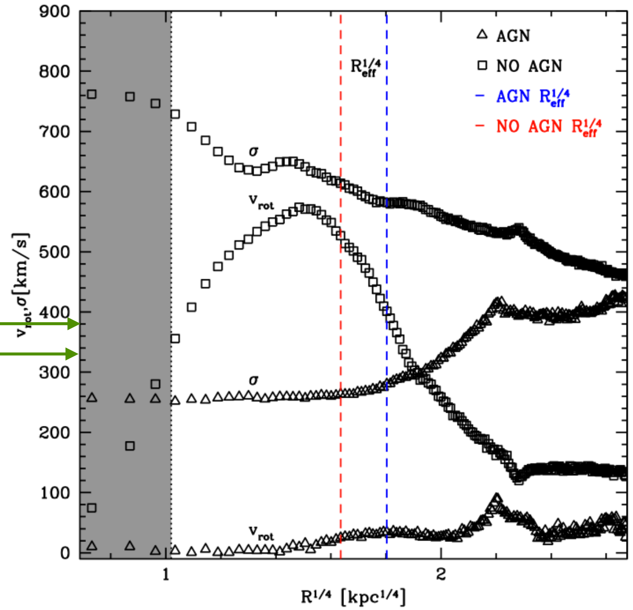


ε~0.2-0.5

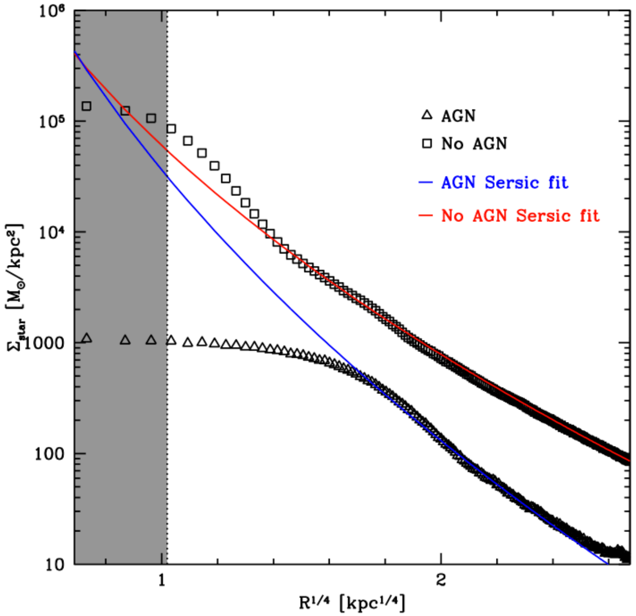
Ellipticities at $r_{1/2}$

Kinematic properties of the BCG

σ in M87
SAURON
HyperLeda

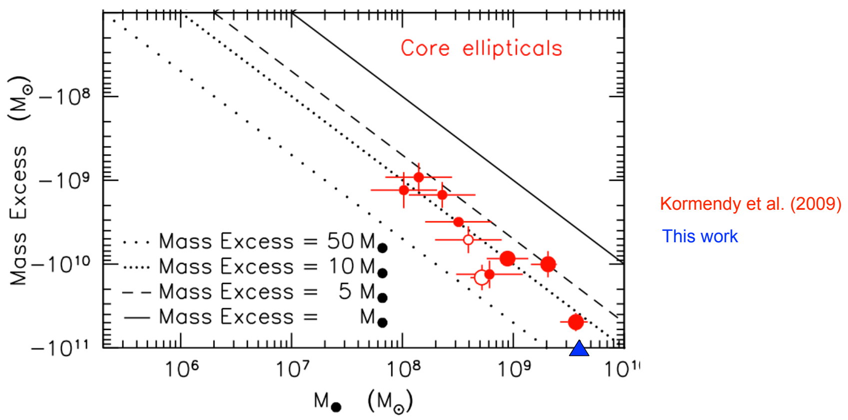


Structural properties of the BCG



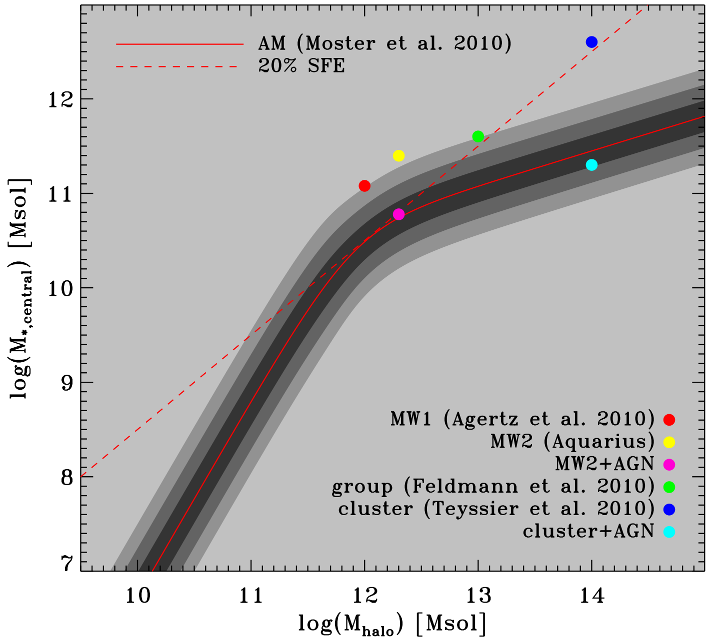
Large mass deficit in the core

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), Goerdt *et al.* (2010) predict $M_{def}/M_{\bullet} \approx 1$ per merger.



See poster by Davide Martizzi for possible origins for the core.

Constraints from abundance matching



Conclusions

- Low star formation efficiency leads to the formation of disc dominated systems.
- At the MW scale, abundance matching is marginally satisfied by standard models. Need for AGN feedback ?
- At the MW scale, strong (AGN?) feedback results in dead spheroids.
- Physical recipes are more important than code types.
- RAMSES and AREPO give strikingly similar results (with however some noticeable differences).
- At clusters scale (BCG formation), strong (AGN?) feedback seems unavoidable.
- BCG formation with or w/o AGN feedback may explain the observed dichotomy in cluster ellipticals.
- We observed the formation of a stellar core