Massive galaxies with RAMSES

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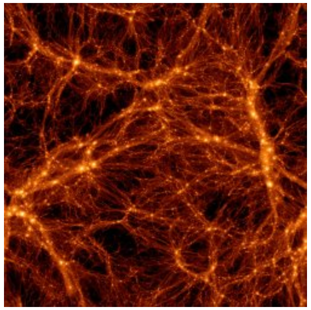
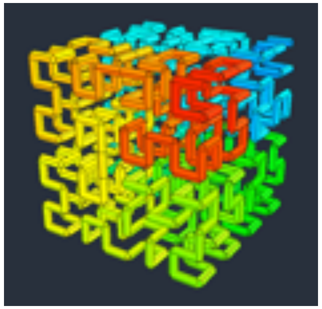
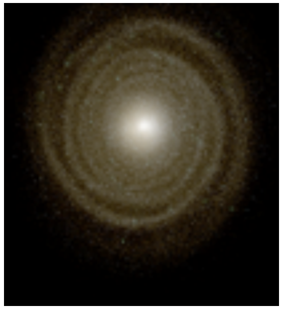






University of Zurich

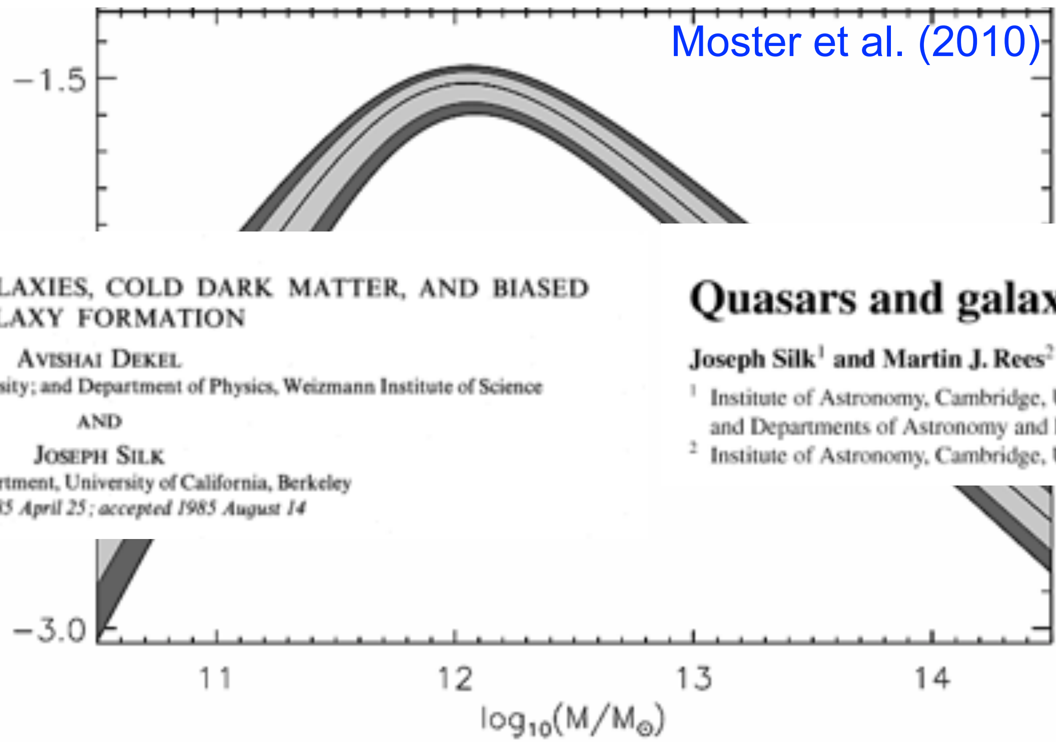
Massive galaxies: the realm of AGN feedback

Very low efficiency of gas conversion into star.

Small mass galaxies are dominated by stellar feedback.

Large mass galaxies are governed by AGN feedback.

Stellar-to-halo mass ratio



Dekel & Silk (1986)

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

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Silk & Rees (1998)

Quasars and galaxy formation

Joseph Silk[1] and Martin J. Rees[2]
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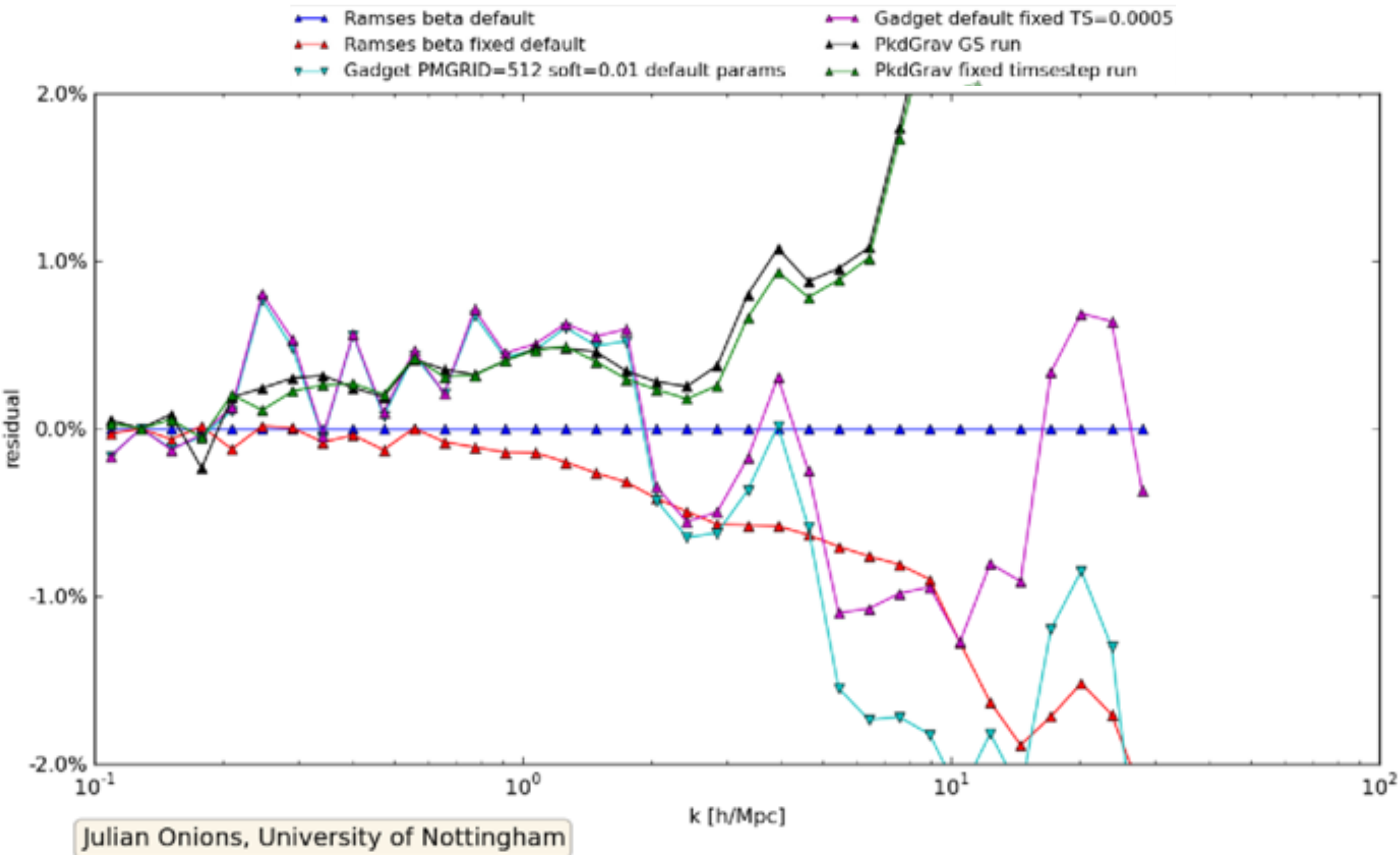
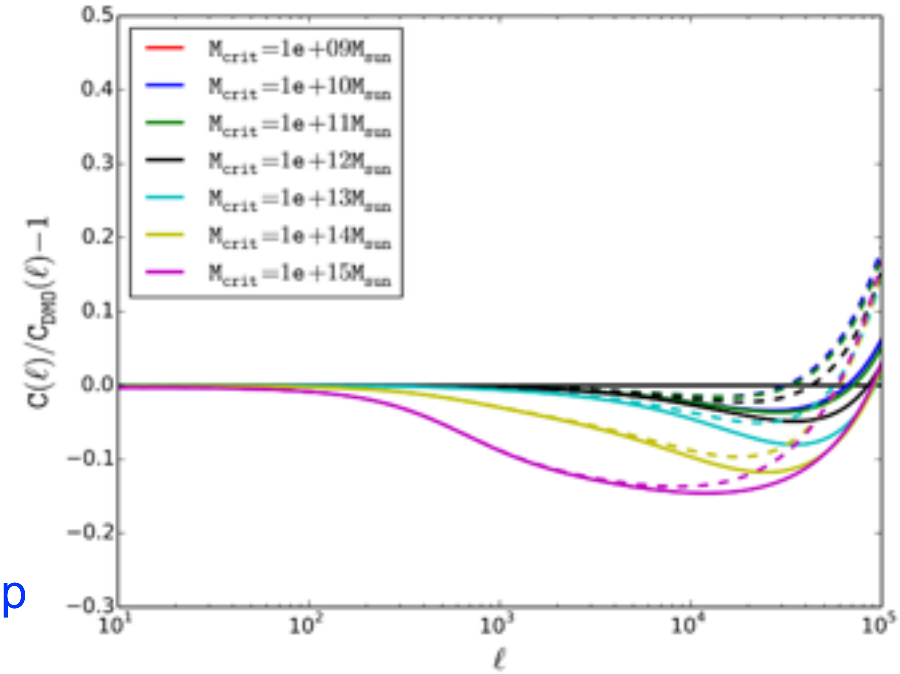
[2] Institute of Astronomy, Cambridge, UK

Precision computational cosmology



Cosmological Simulation Working Group (Euclid Consortium)

Baryonic effects on weak lensing



Mohammed+, in prep

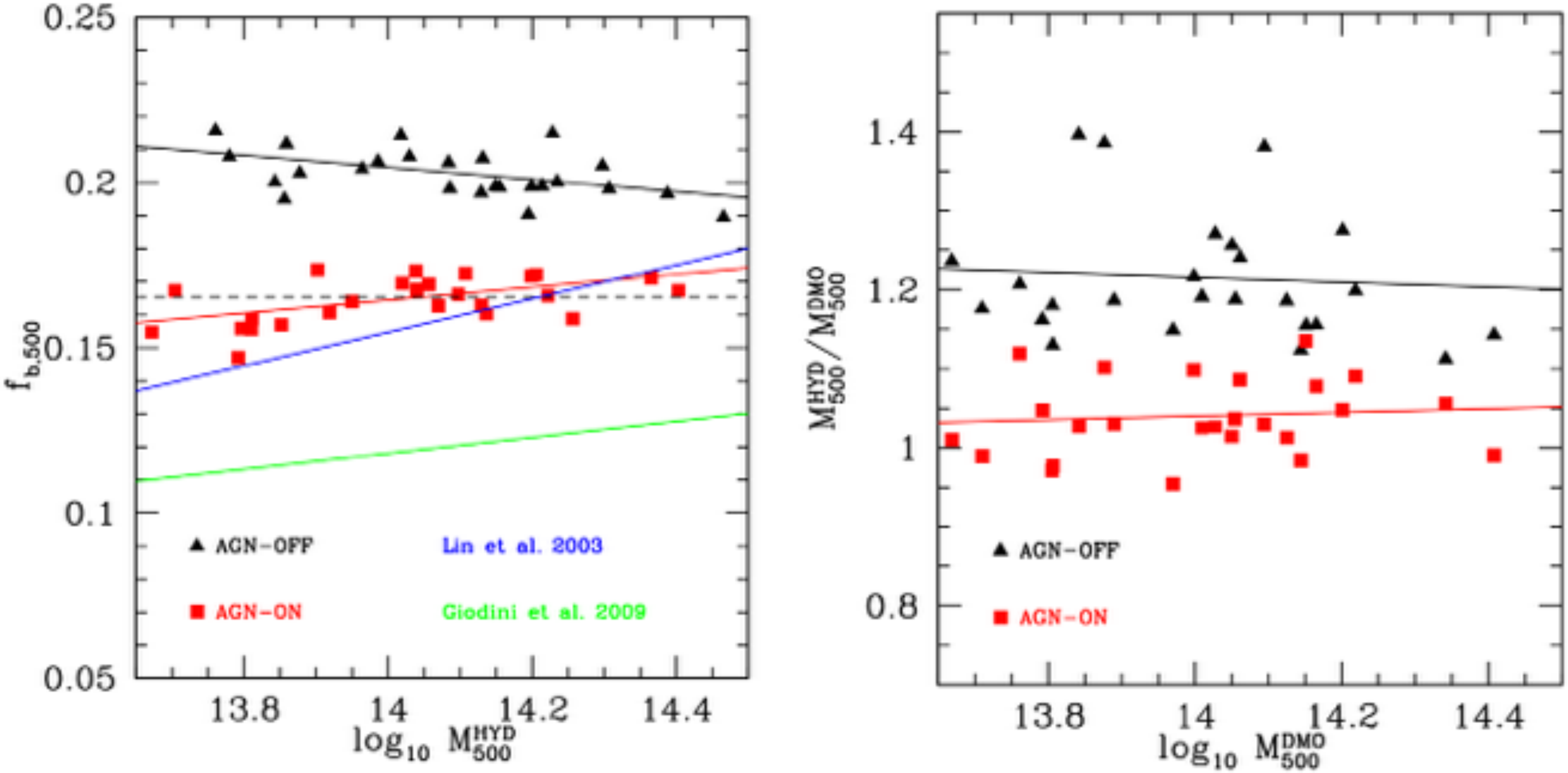
Model AGN feedback by removing gas below M_{crit}

Measuring the matter power spectrum using a pure dark matter theoretical model leads to a bias on the cosmological parameters. This bias could be as high as 10%, for a target precision < 1%.

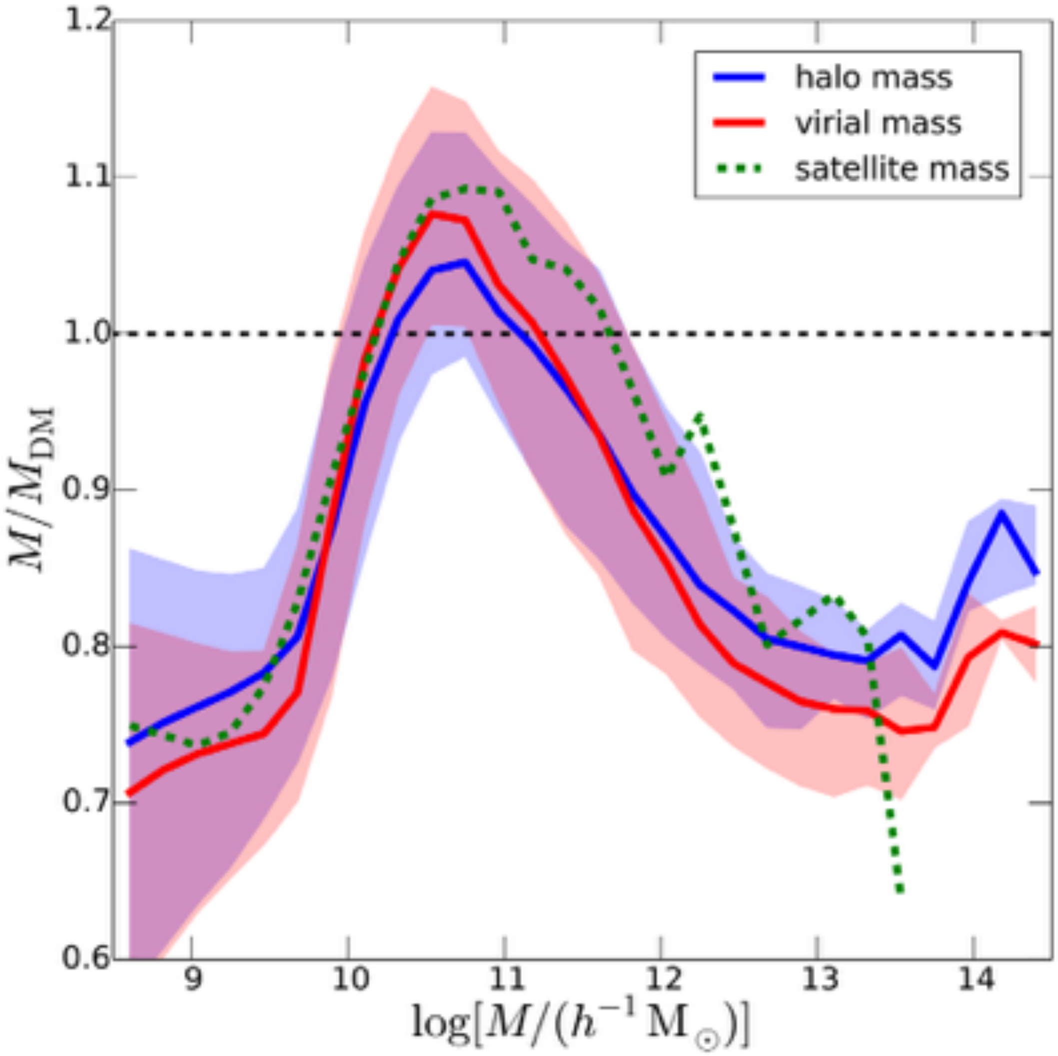
Solution: use a theoretical model that includes baryonic effect. Error bars are increased but the bias is removed.

Scaling properties for massive haloes with RAMSES

Martizzi+14



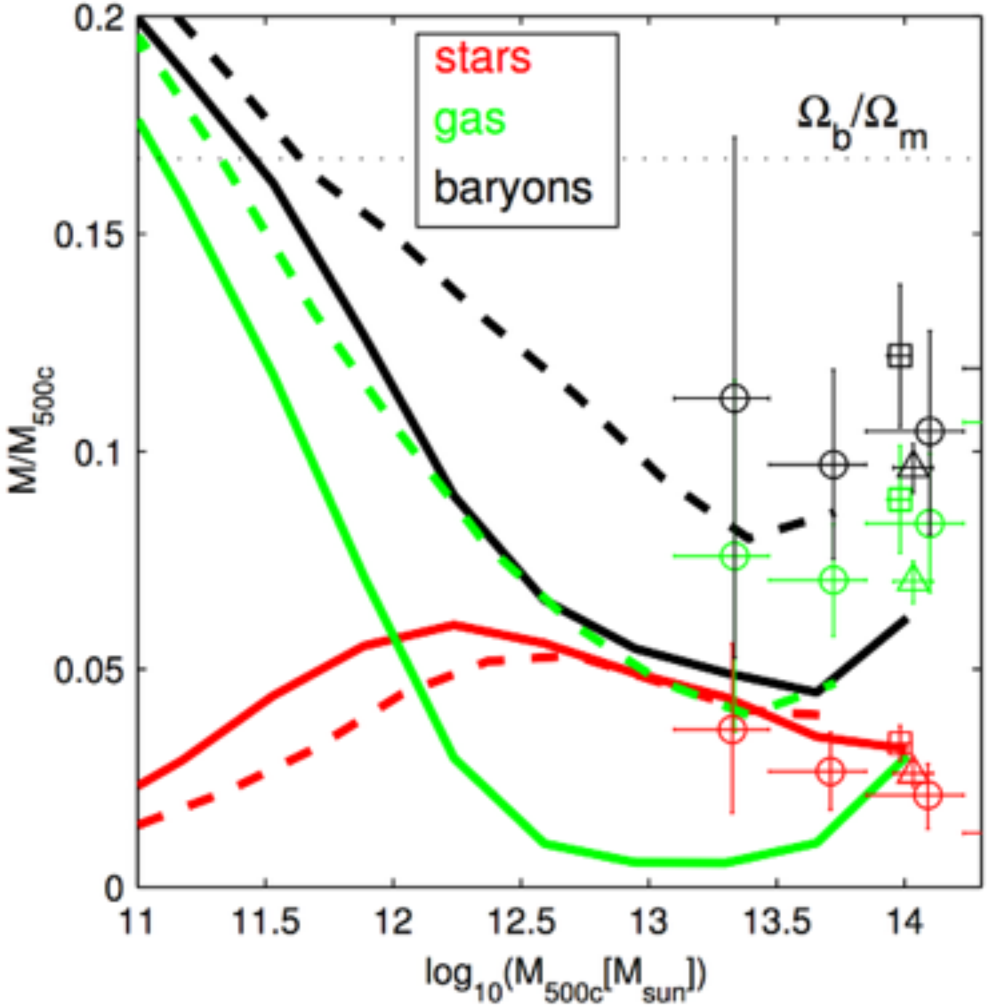
Scaling properties for massive haloes with AREPO



Vogelsberger+14

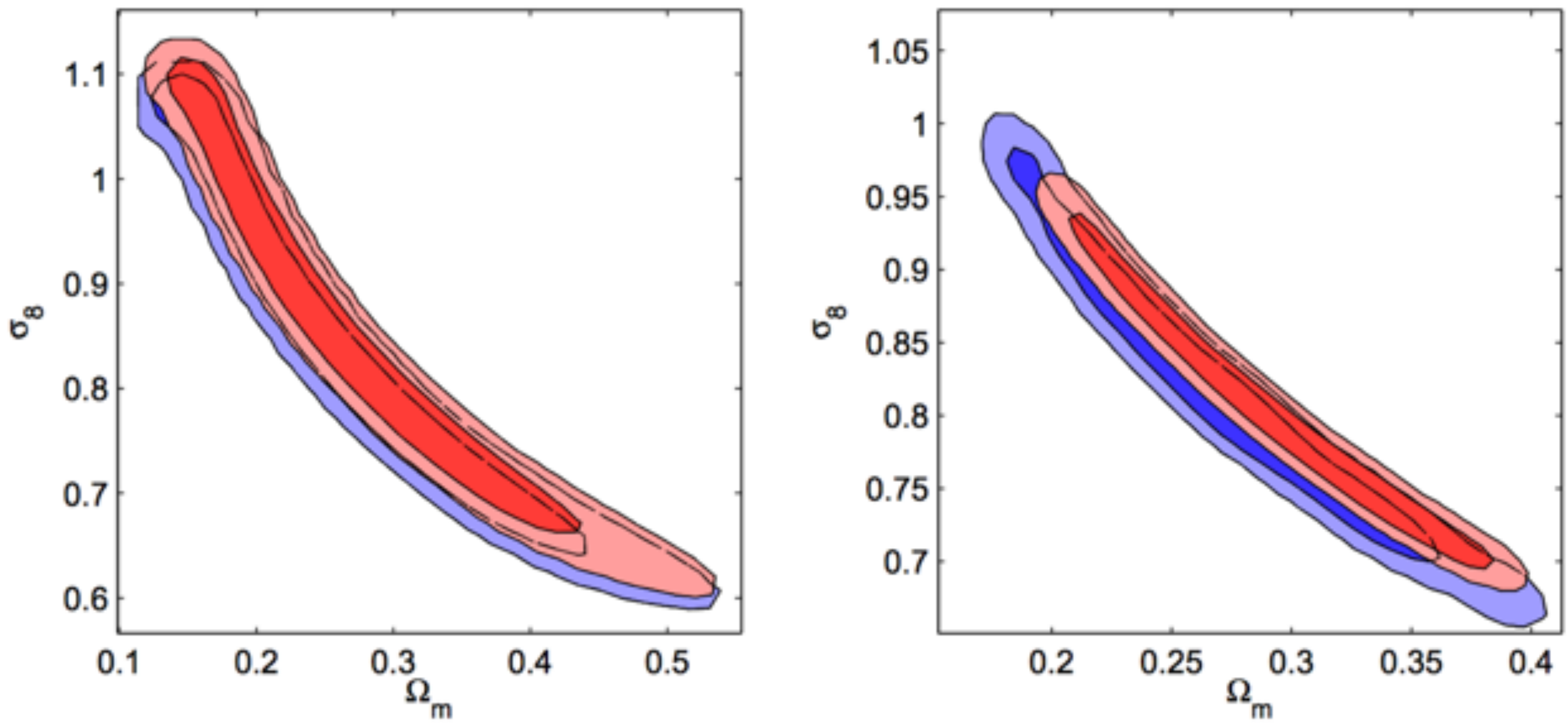
Scaling properties for massive haloes with AREPO

Genel+14



Baryonic effects on the mass function

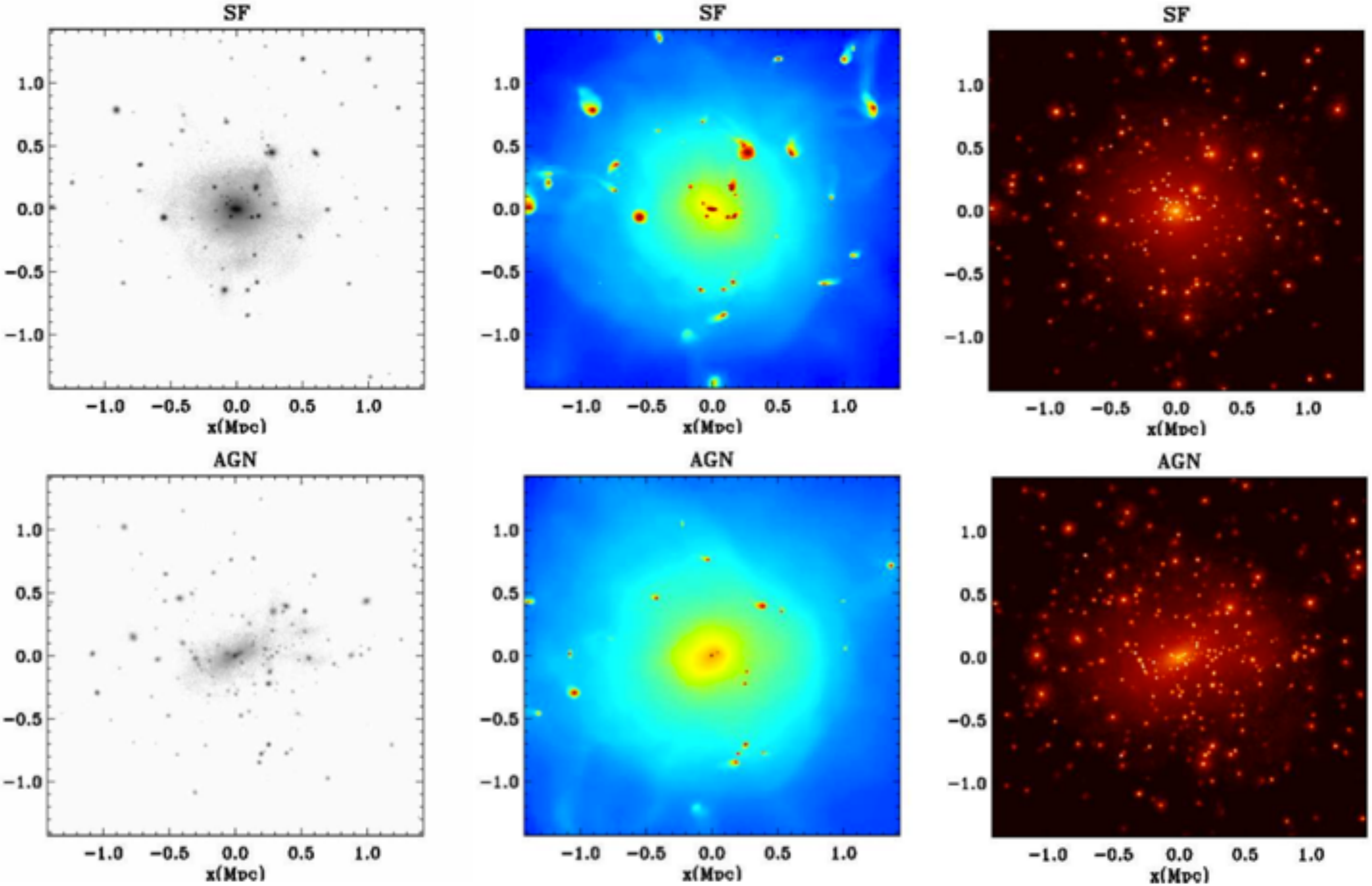
Martizzi+14



Max-BCG or REFLEX
0.5 (Gpc/h)^3

eROSITA or EUCLID
500 (Gpc/h)^3

Galaxy formation on cluster scales



Feedback models from SMBH in massive ellipticals

- Thermal feedback (Sijacki et al. 2007; Booth & Schaye 2010; Teyssier et al. 2010): “thermal bombs”
- Radiative feedback (Choi et al, 2012, 2014; Vogelsberger et al. 2013): dust-absorbed UV radiation from the accretion disk.
- Jet feedback (Omma et al., Cattaneo & Teyssier, Dubois et al. 2010, Choi et al. 2014): injection of momentum in a jet-like geometry.
- Cosmic ray feedback (Pfrommer at al. 2010; Oh et al, 2013): heating from Alfven waves excited by CR-induced instabilities.
- Bubble feedback (Sijacki et al. 2007): buoyantly rising bubble with initial radius close to 50 kpc

These models are related to the quasar mode (thermal, radiative) or to the radio mode (jet, CR, bubbles) of AGNs.

Class of simulations: cosmological simulations with zoom-in or periodic boxes and around 1 kpc resolution.

The thermal feedback model in RAMSES.

Numerical implementation in cosmological simulations: 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}.

Accretion on a sink particle 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 $$\dot{M}_{\rm ED} = \frac{4\pi G M_{\rm BH} m_{\rm p}}{\epsilon_r \sigma_{\rm T} c}$$

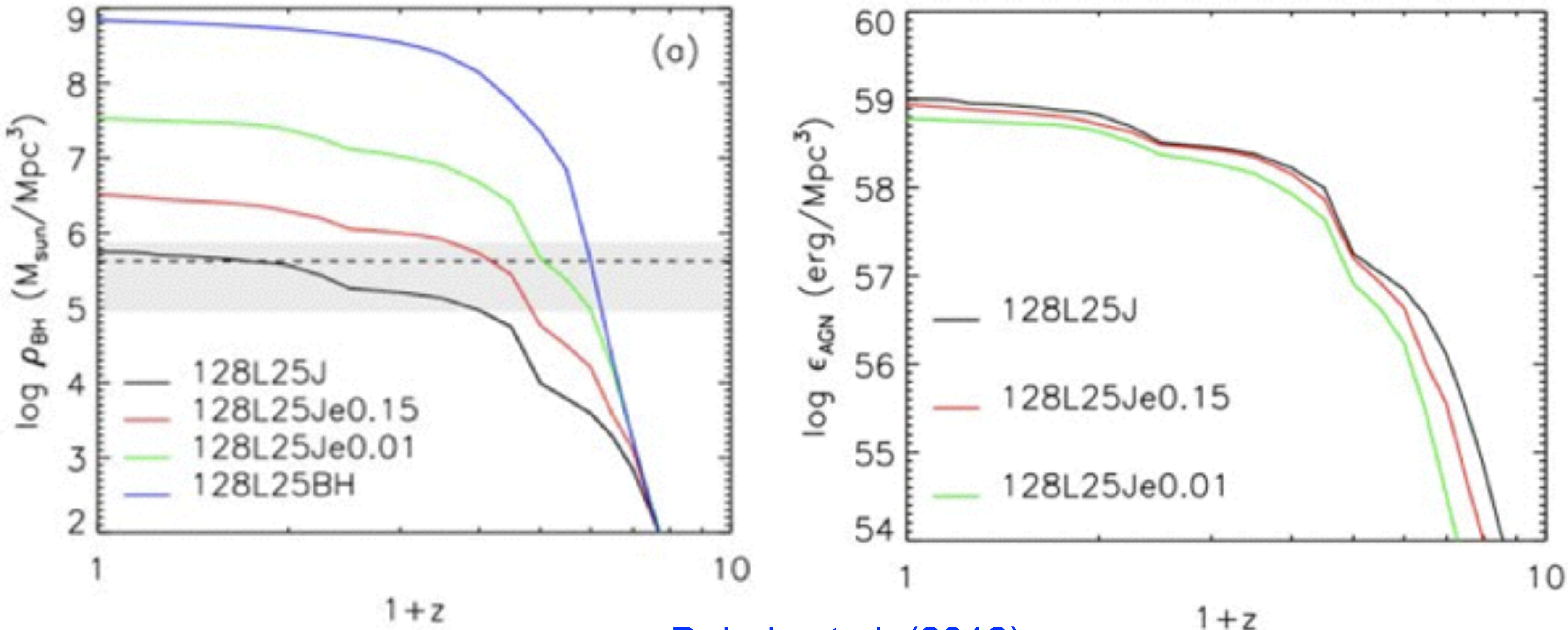
Feedback performed using a thermal dump $$\Delta E = \epsilon_c \epsilon_r \dot{M}_{\rm acc} c^2 \Delta t.$$

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

Free parameter epsilon_c calibrated on the M-sigma relation.

AGN feedback: calibrating the coupling efficiency

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



Dubois at al. (2012)

BHs deposit the same energy / independant of the AGN efficiency

BCG properties

Brightest cluster galaxies in cosmological simulations: achievements and limitations of AGN feedback models

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Brightest Cluster Galaxies in Cosmological Simulations with Adaptive Mesh Refinement: Successes and Failures

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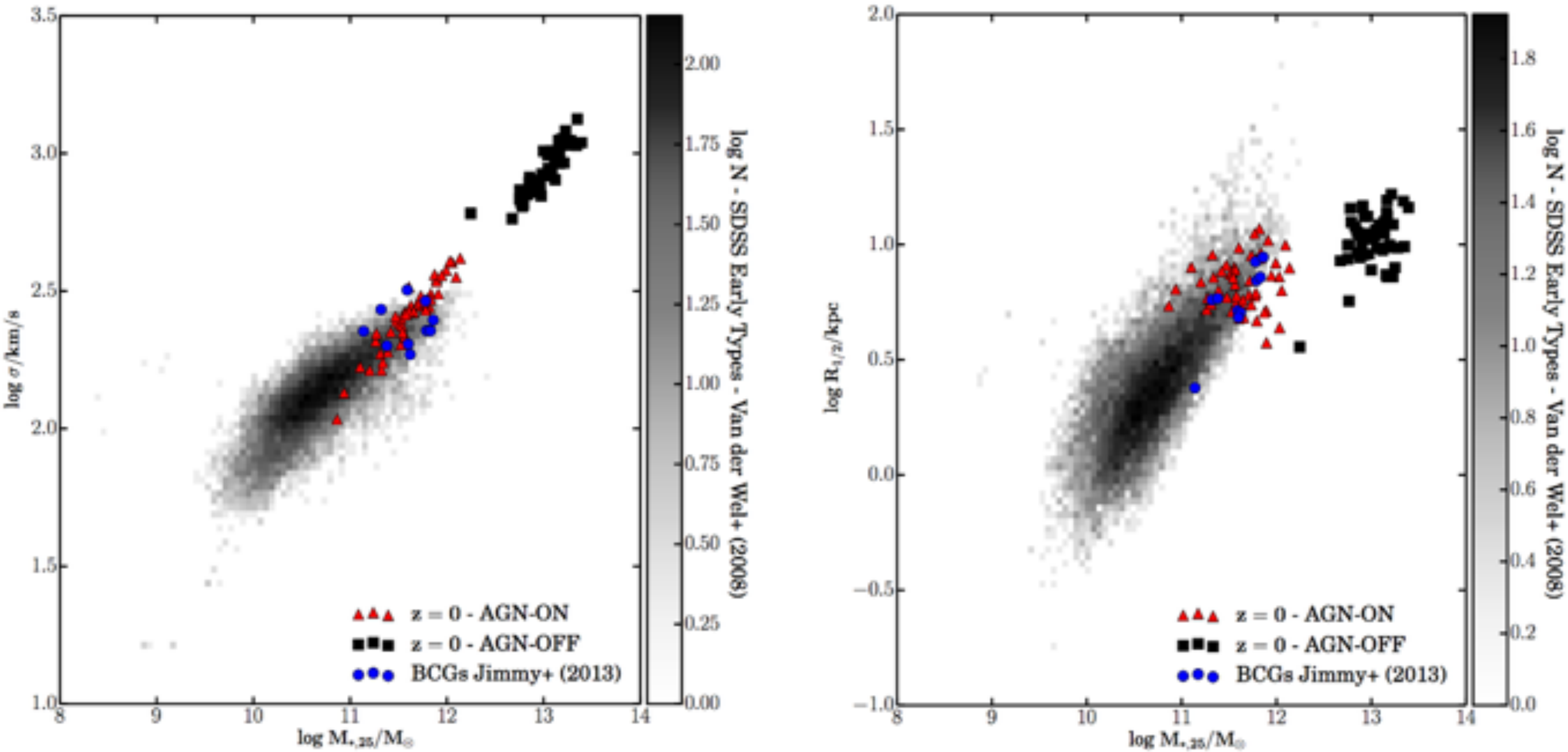
[2] *Institute for Computational Science, University of Zurich, CH-8057 Zürich, Switzerland*

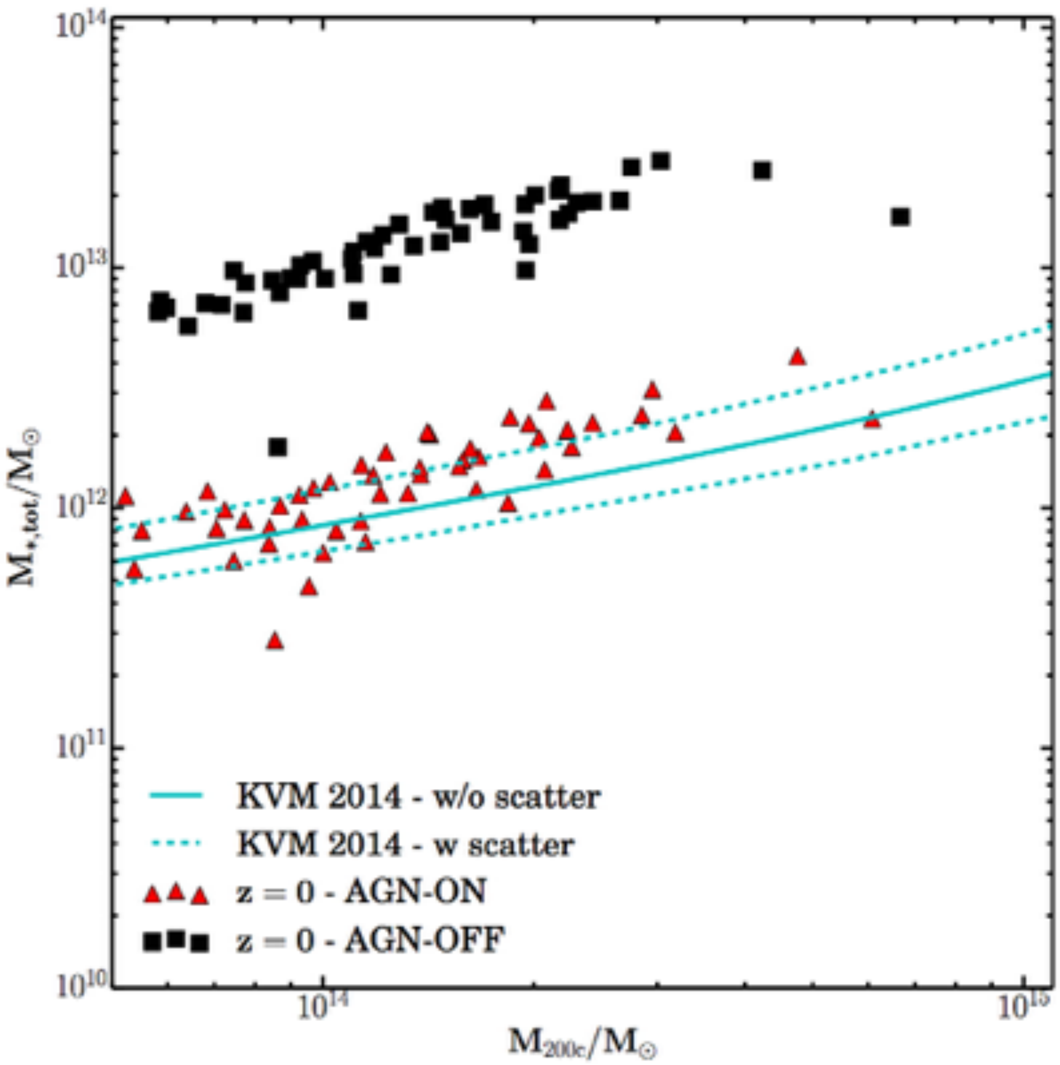
AGN feedback modifies the BCG properties

Martizzi+13,14



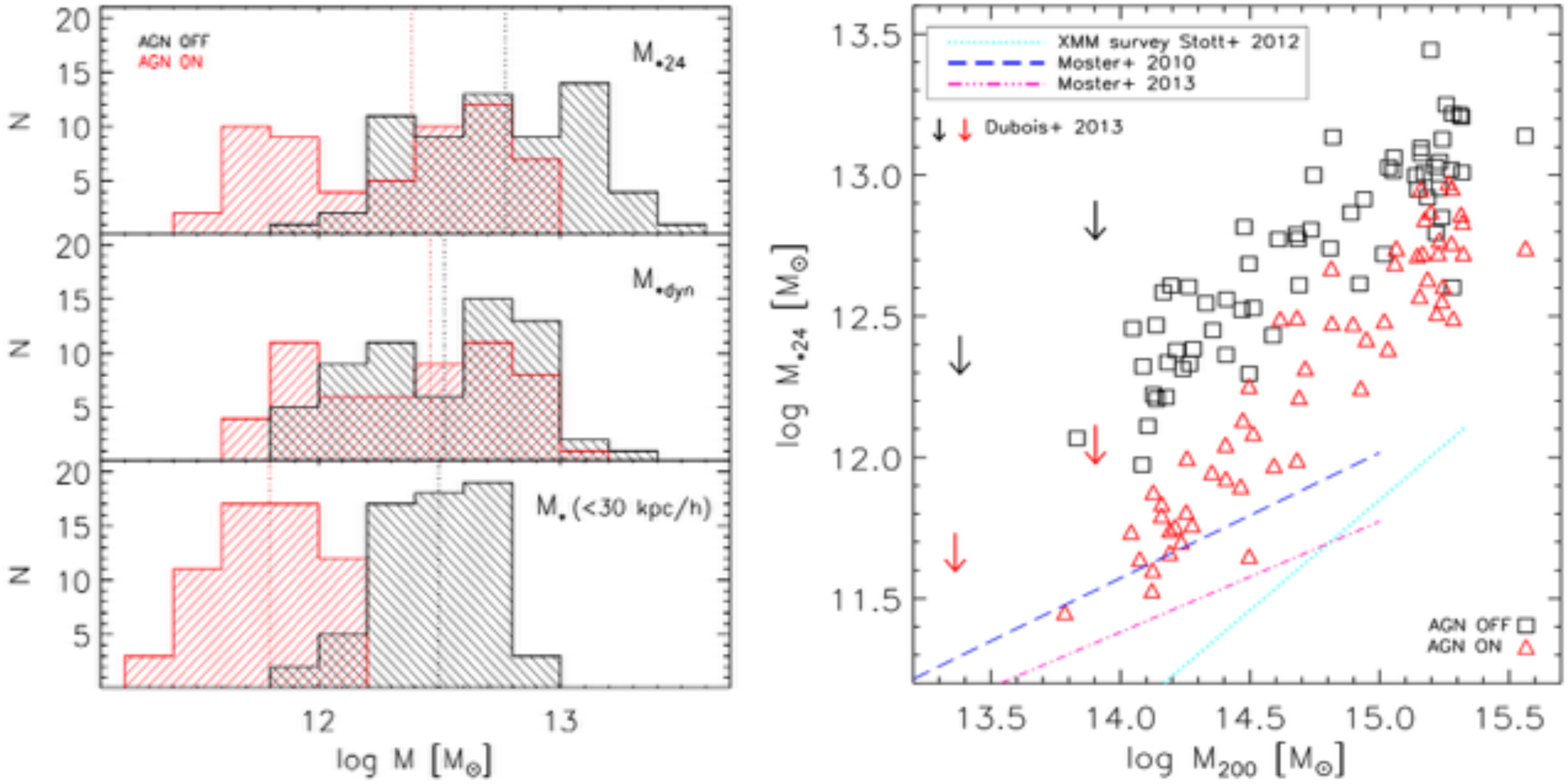
Booth & Schaye 10; Teyssier+10; Sembolini+11; Dubois+10,11; Martizzi+11

Stellar conversion efficiency with RAMSES



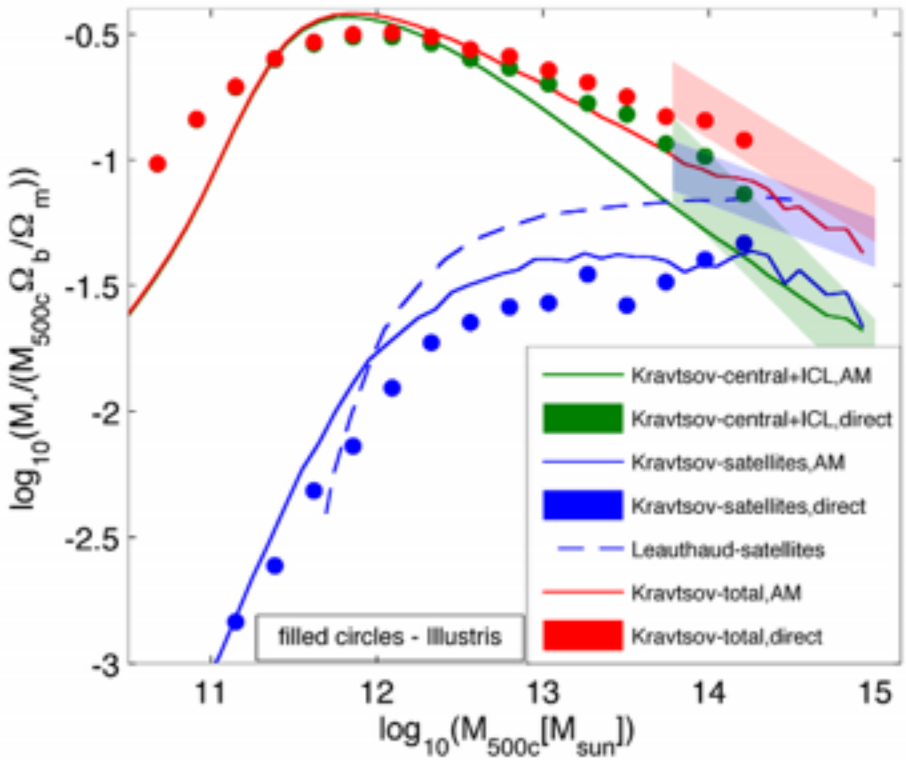
Martizzi+14

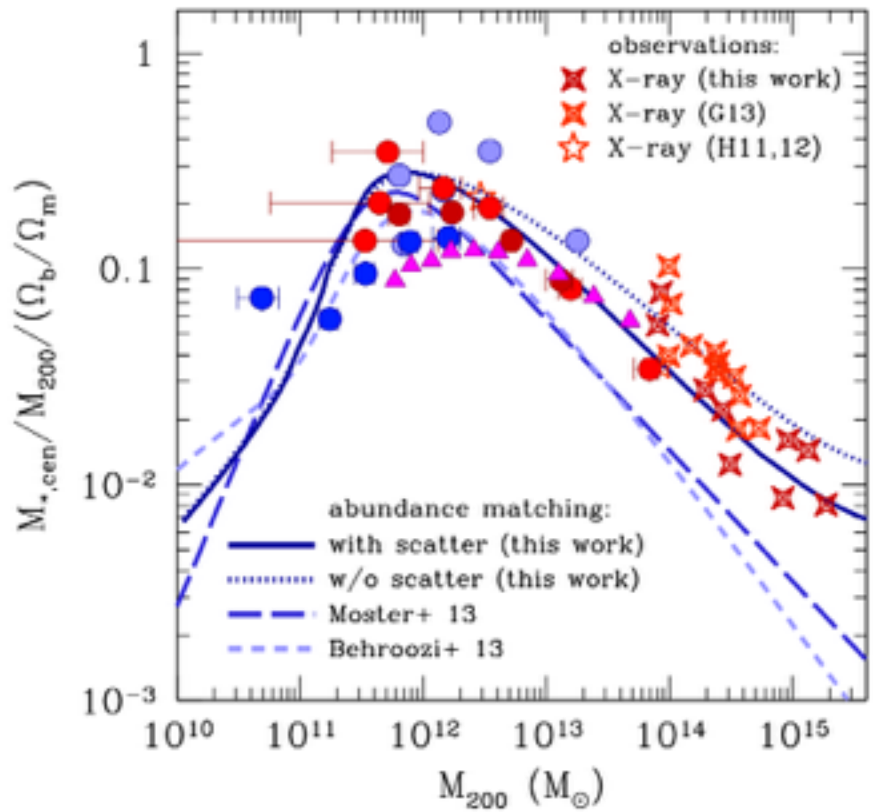
Stellar conversion efficiency with GADGET



Ragone-Figueroa+ 2013

Stellar conversion efficiency with AREPO



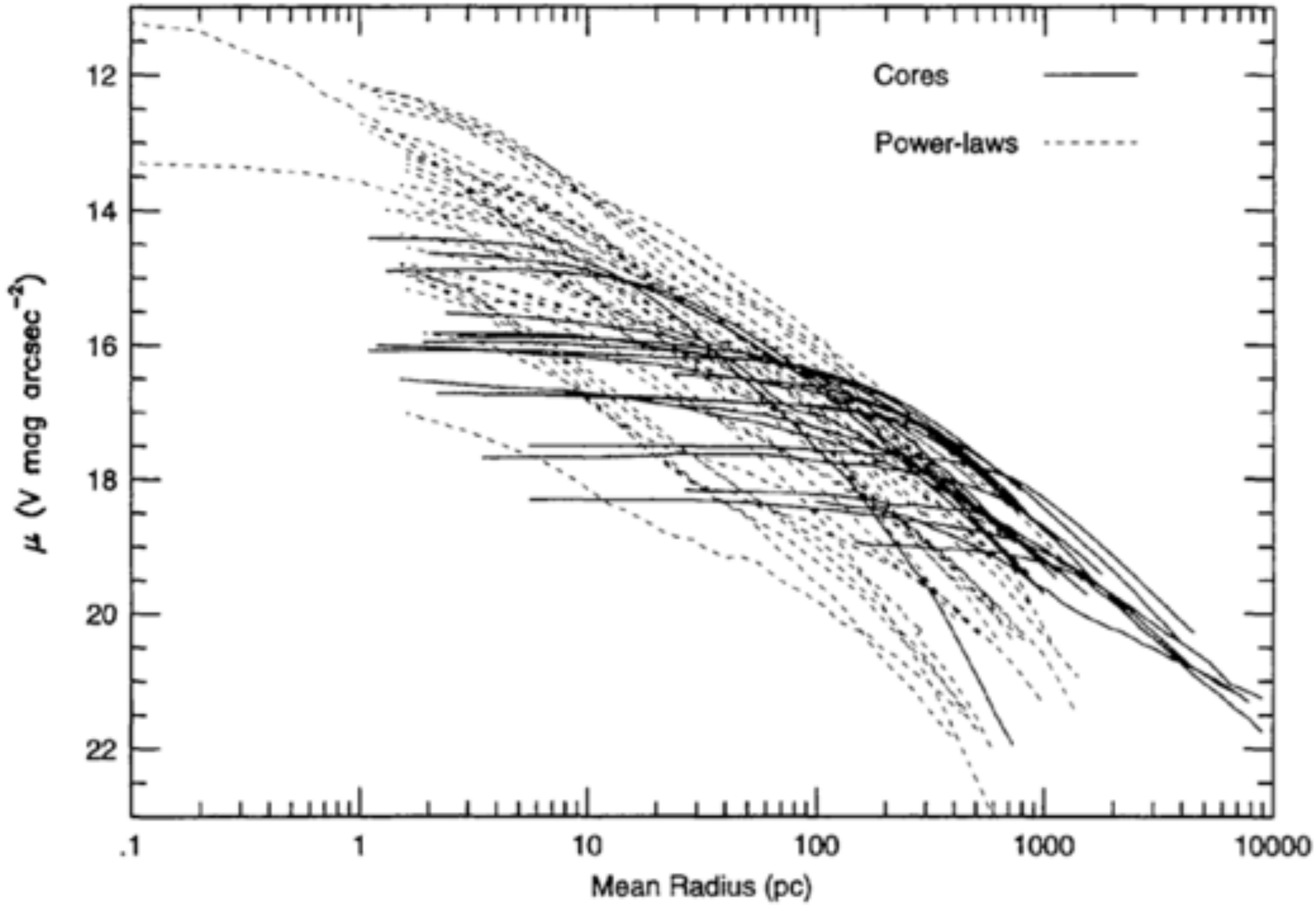


Genel+ 2014

Kravtsov+2014

The structure of elliptical galaxies

1774 FABER *ET AL*.: EARLY-TYPE GALAXIES. IV.

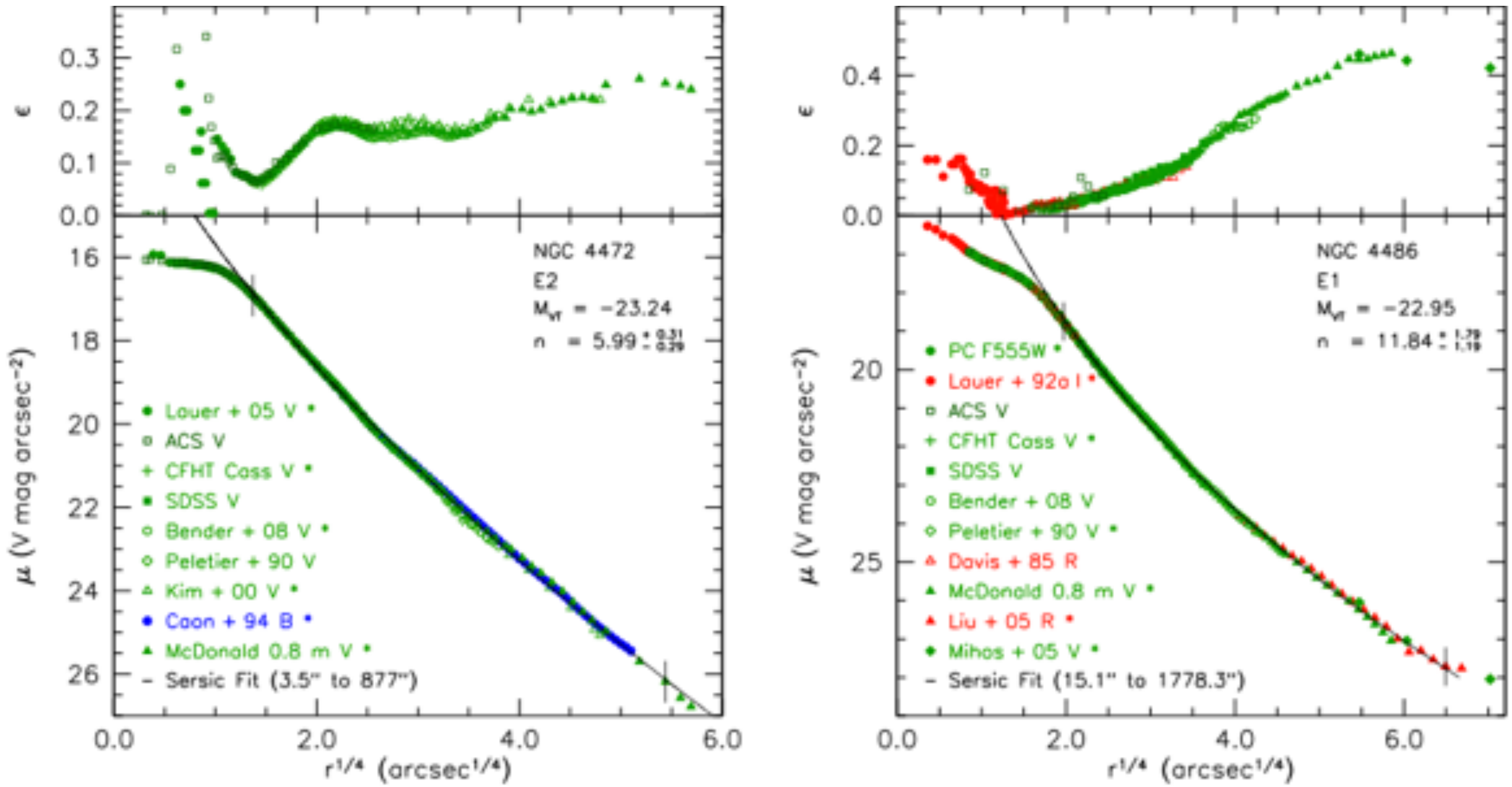


Faber et al. 1997

A stellar core in massive elliptical galaxies ?

Core elliptical: light deficit, low ellipticity, slow rotator

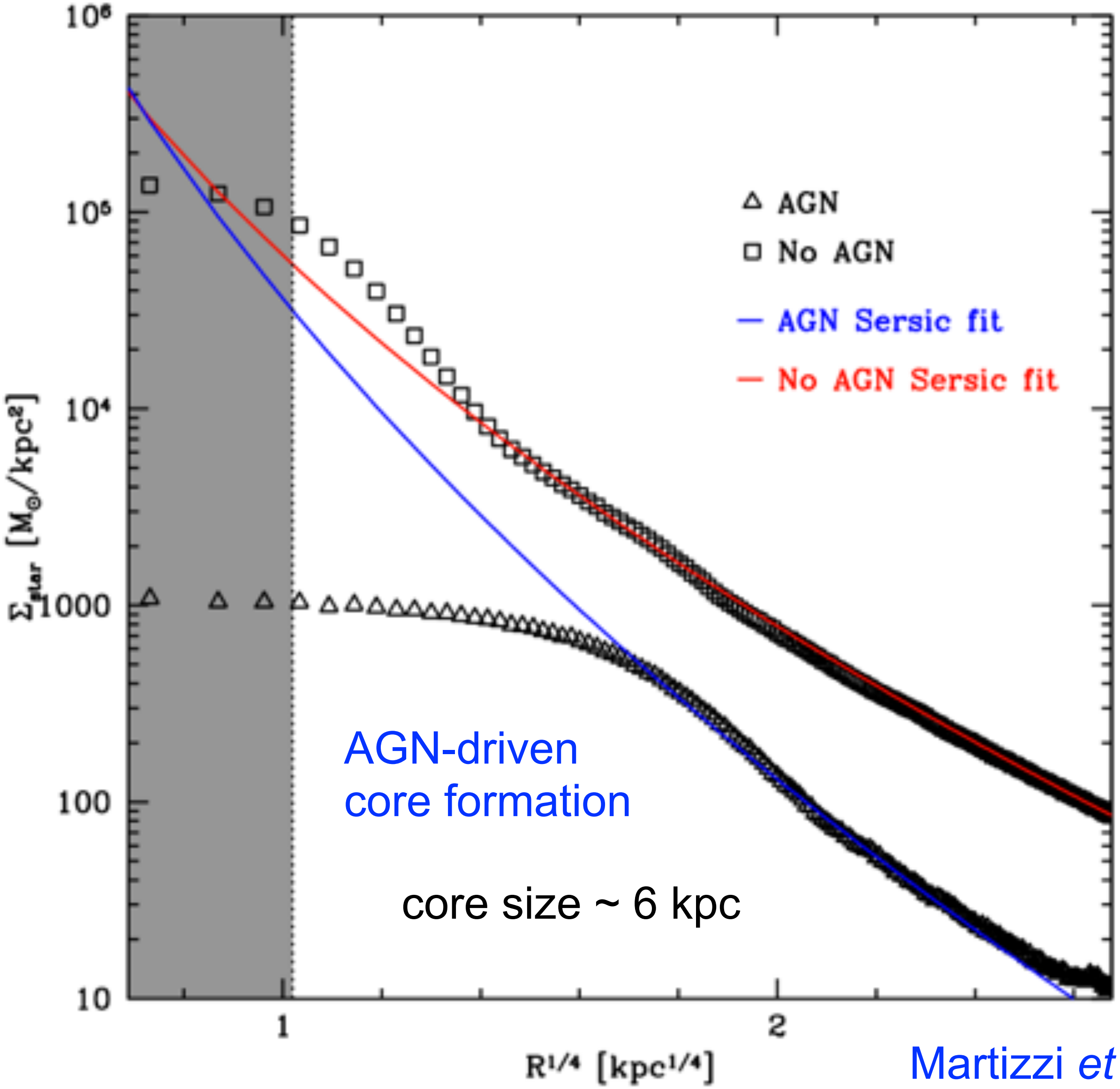
Kormendy *et al.* 2009



core size ~ 0.5 kpc

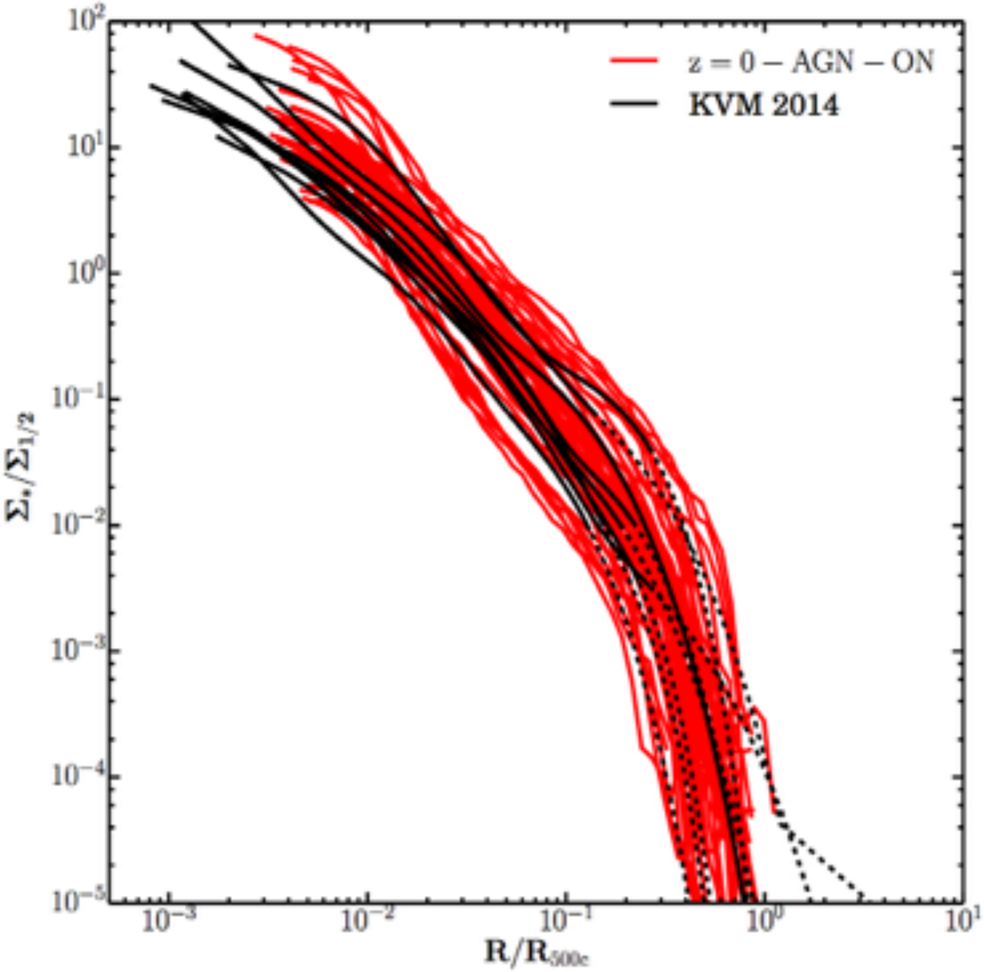
core size ~ 3 kpc

Structural properties of the BCG



Martizzi *et al.* 2011

Structural properties of the BCG

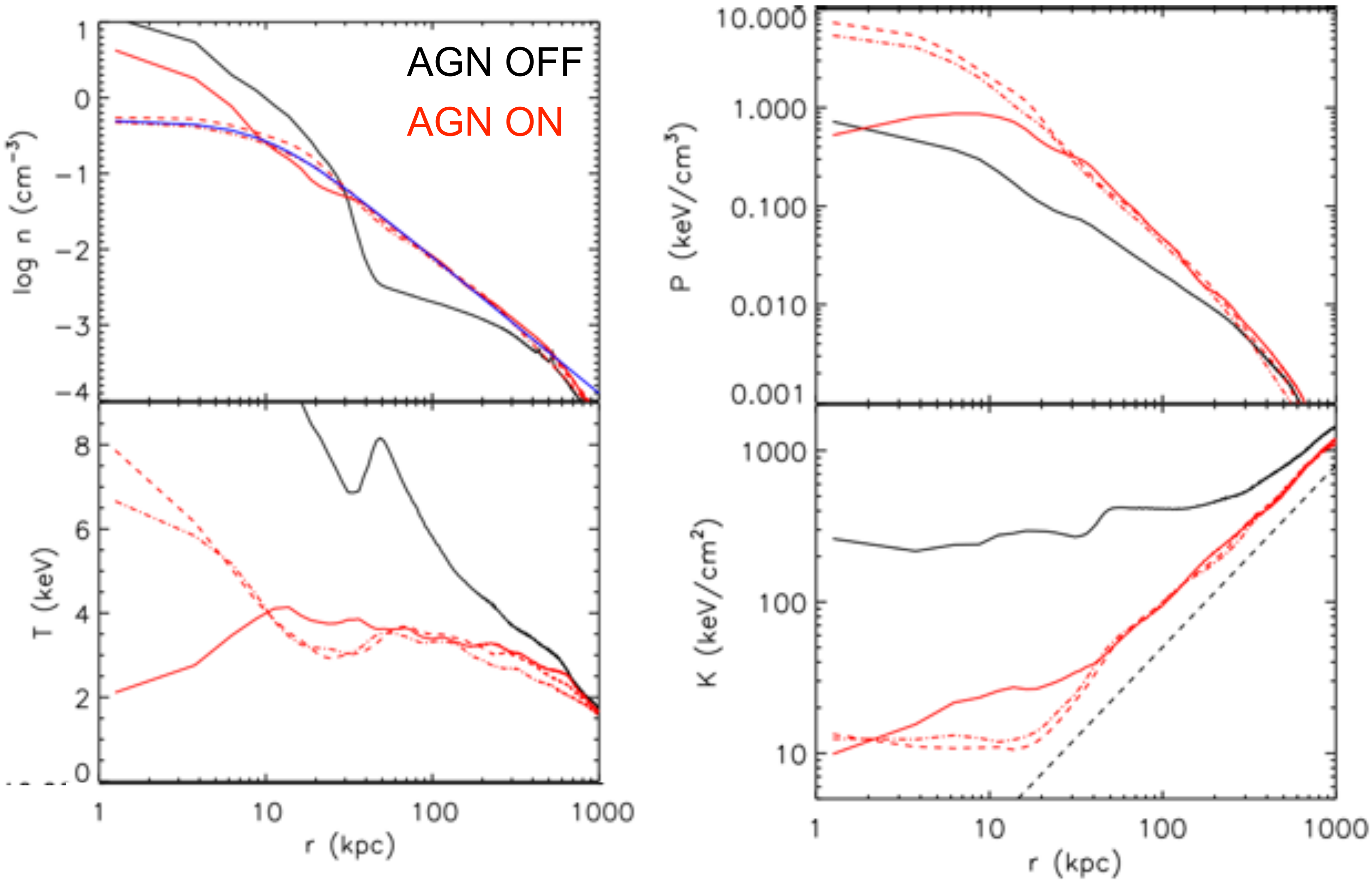


ICL consistent with observations

Martizzi+14

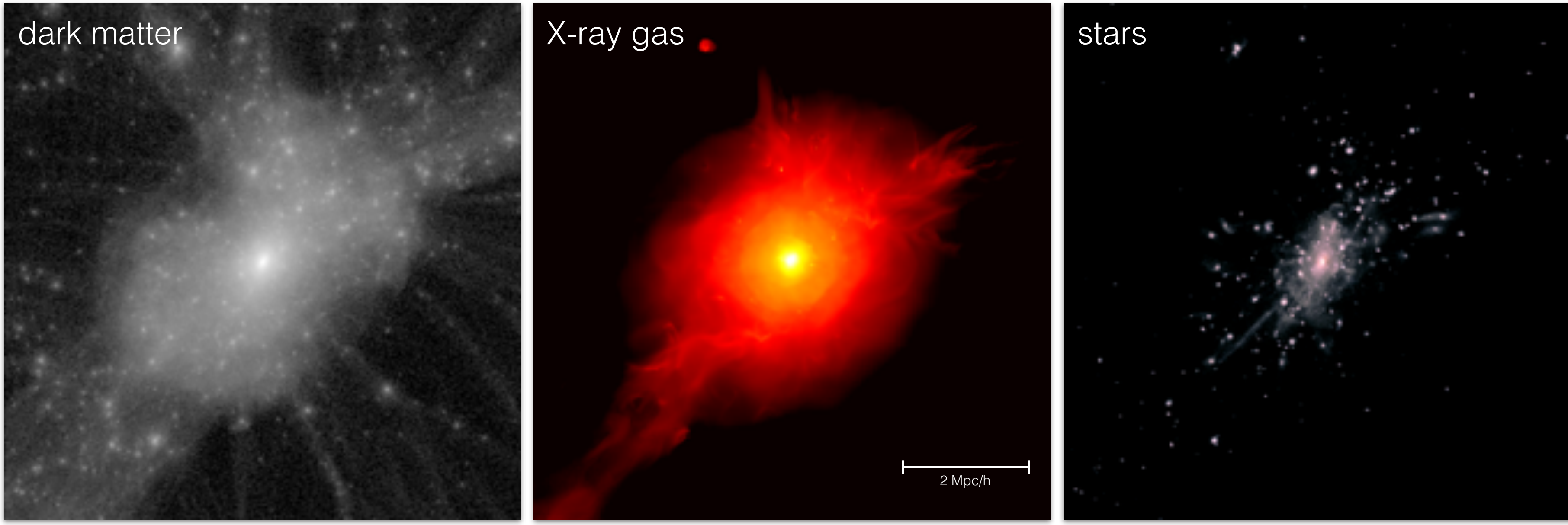
X-ray properties in the core

Dubois+12



Cool core cluster with jet-feedback and zero metallicity cooling

The RAPHSODY-GAS simulation suite



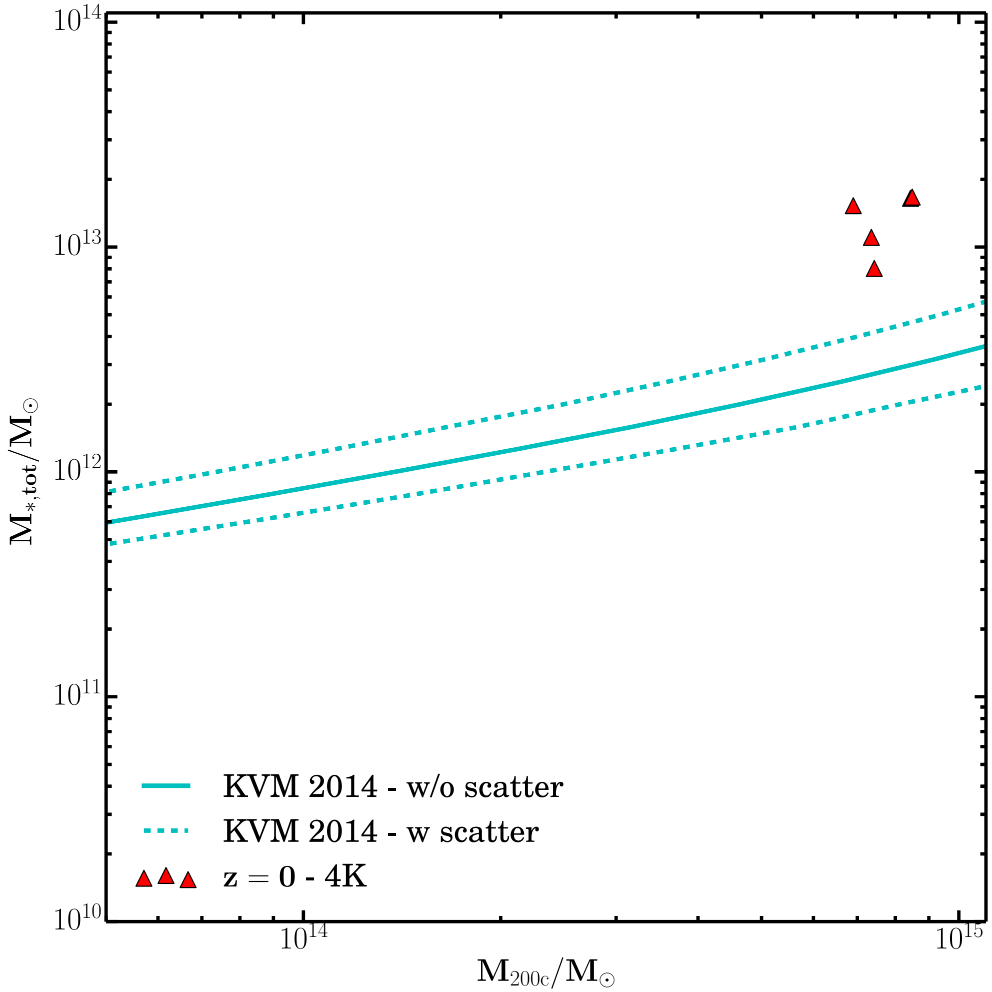
Unique set to address both cosmological observables and the formation of clusters and galaxy members and in its outskirts

goal: confront astrophysical models with full multi-wavelength data available

ICs will be made public for community comparisons

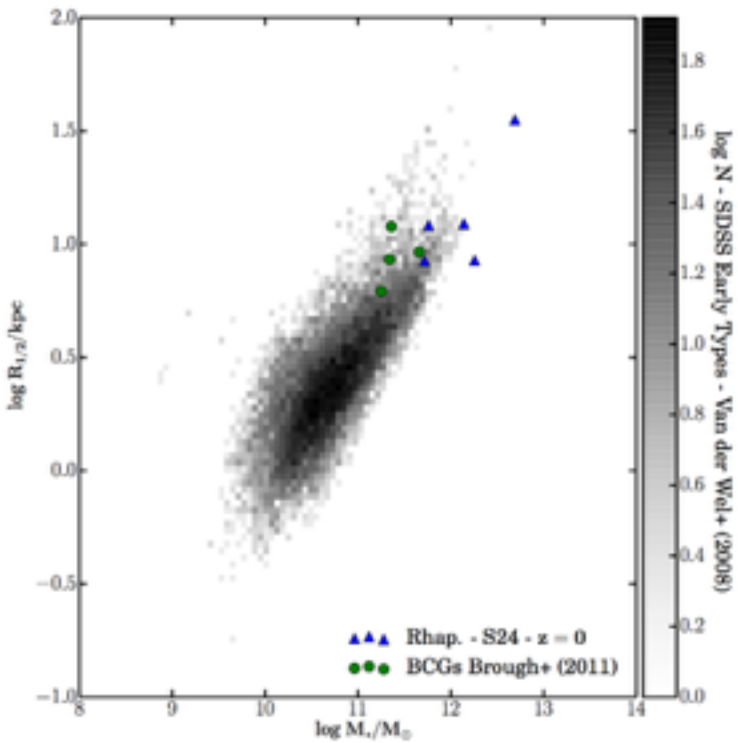
Hahn+(2014, in prep)

Does our AGN recipe fail for very massive galaxies ?



Does our AGN recipe fail for very massive galaxies ?

BCG sizes



BCG velocity disperson

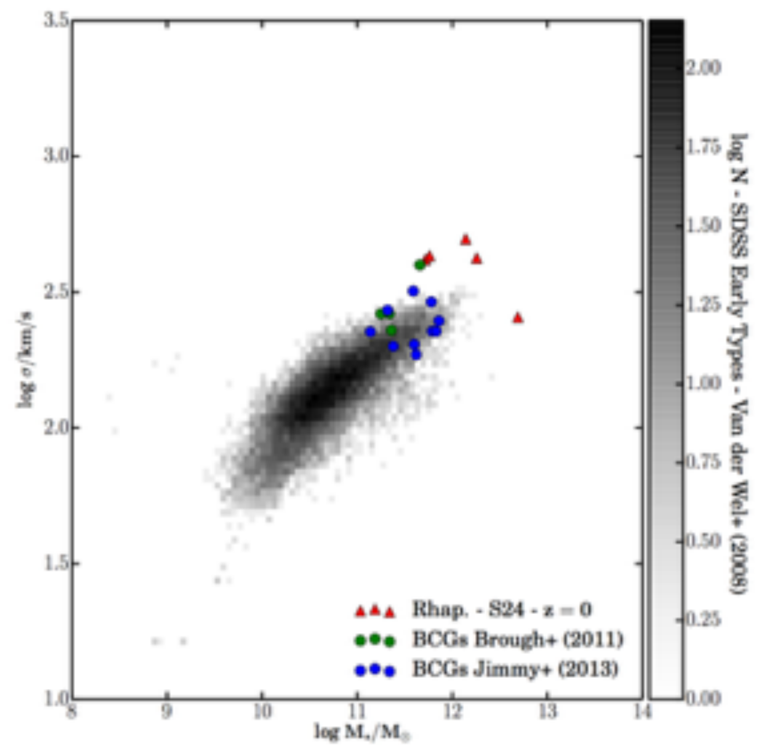
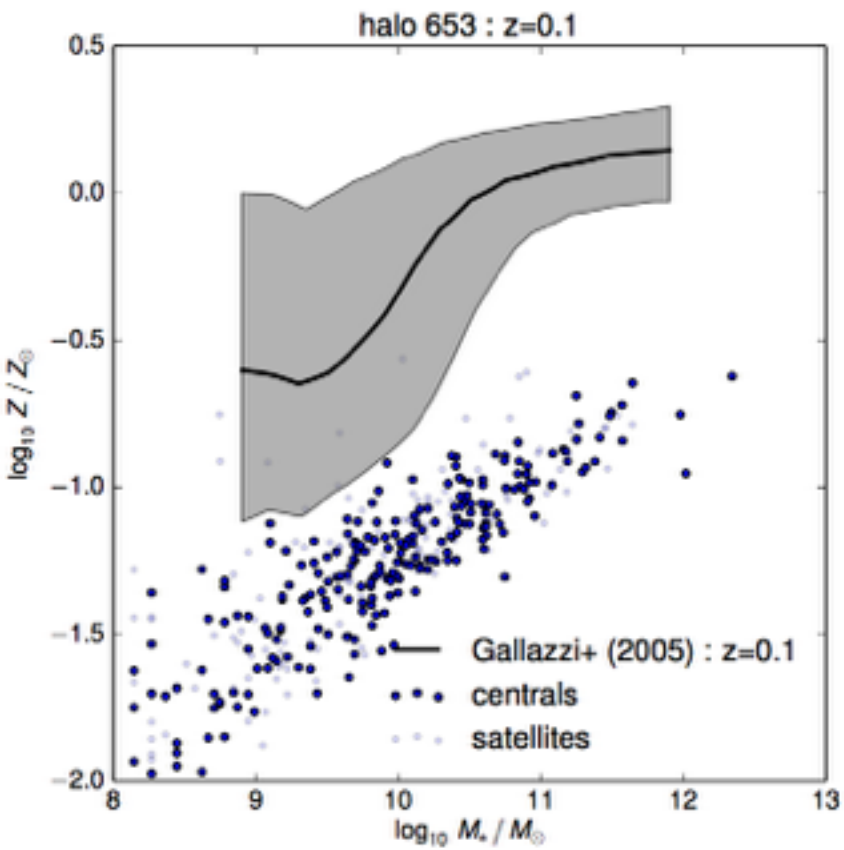


Figure 6: Stellar mass vs. velocity dispersion within half mass radius for the same mass definition of Fig. 1 at $z = 0$. New runs e003rs5.

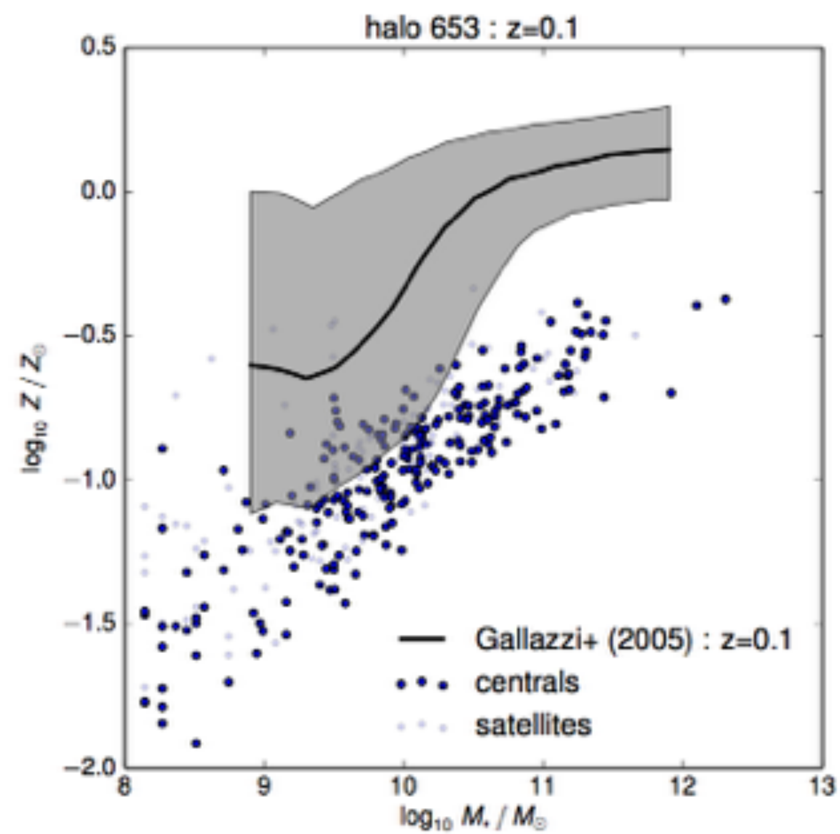
Martizzi, Hahn+(2014, in prep)

Stellar metallicity in massive galaxies

Normal yields



High yields



Stellar metallicities are too low

Conclusions

- AGN feedback regulates the star formation efficiency in massive BCGs
- AGN feedback reproduces scaling relations of BCG and the host clusters (AM, size, vel. disp.) for clusters around 10^14 Msol.
- Is the model failing for massive clusters (M > 10^15 Msol) ?
- AGN feedback reproduces the internal structure of BCG (inner core, Sersic profiles, outer regions and ICL).
- Predicted X-ray properties are not robust (cool core versus entropy floor).
- Key difficulty: efficiency of AGN feedback for various halo masses
- Different implementations of AGN feedback lead to different and sometimes contradictory results: stellar-mass-to-halo-mass relations, gas fraction, effect on the total mass distribution…
- Our AGN feedback models basically push gas out: similar to dwarf galaxies. Resulting metallicity is too low.