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The formation and evolution of central cluster and group galaxies

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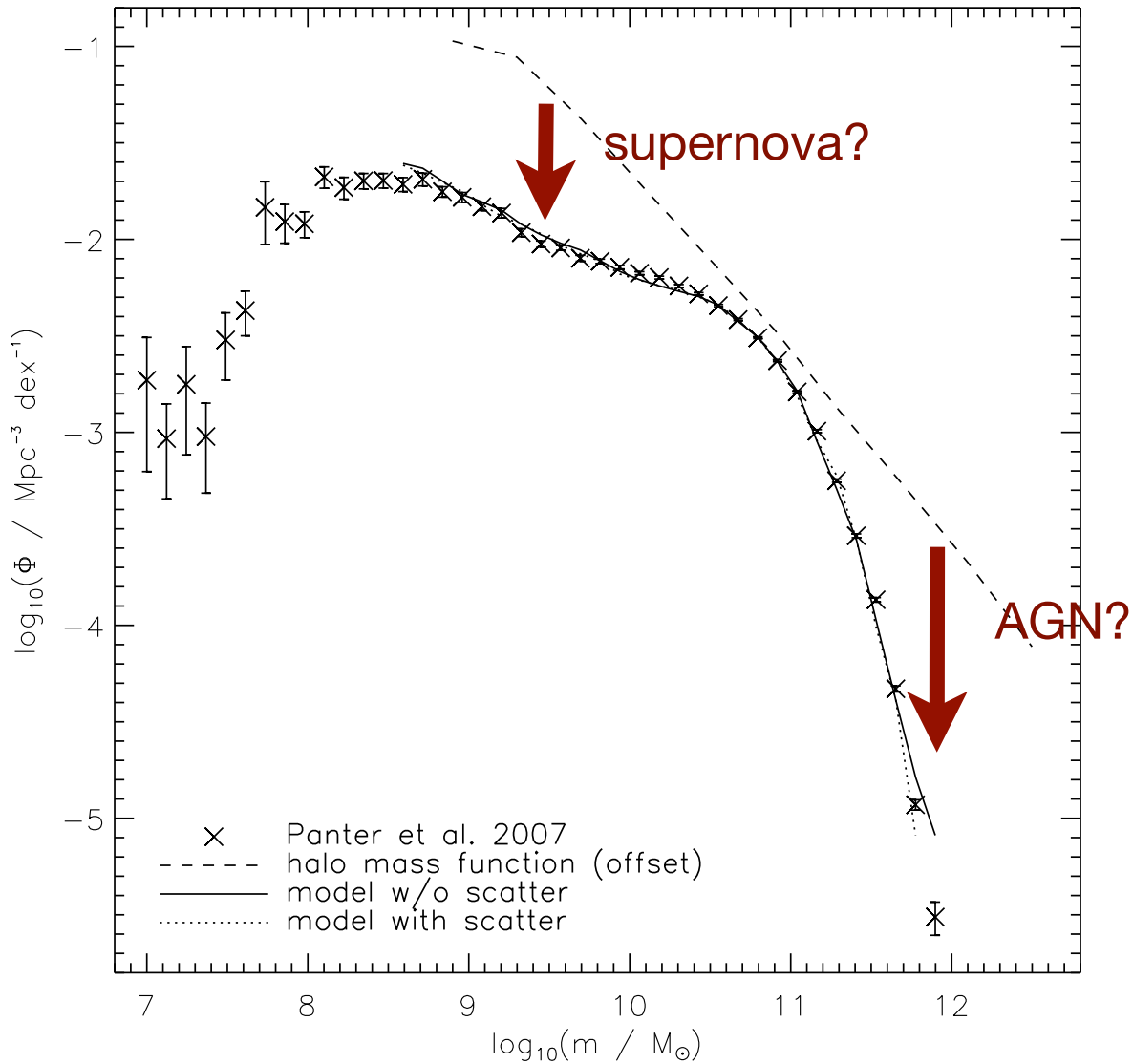
The main problem of galaxy formation

- different shape of halo mass function & galaxy stellar mass function (GSMF)
- can the difference be explained by supernova (SN) and AGN driven winds?
- can this be modeled in hydro simulations?



Moster et al. 2010

Simple kinetic galactic wind models in hydrodynamical simulations

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- e.g., Springel & Hernquist 2003 model:
  - available supernova energy = $\epsilon_{\mathrm{SN,w}} \dot{M}_*$
  - wind velocity and mass loading

$$\frac{1}{2} \dot{M}_{\mathrm{w}} v_{\mathrm{w}}^2 = \epsilon_{\mathrm{SN,w}} \dot{M}_* \qquad \eta \equiv \dot{M}_{\mathrm{w}} / \dot{M}_*$$

  - for Salpeter IMF & constant $\eta = 2$ => constant $v_w \sim 484$ km / s
  - particles are stochastically selected from star forming phase and receive kick

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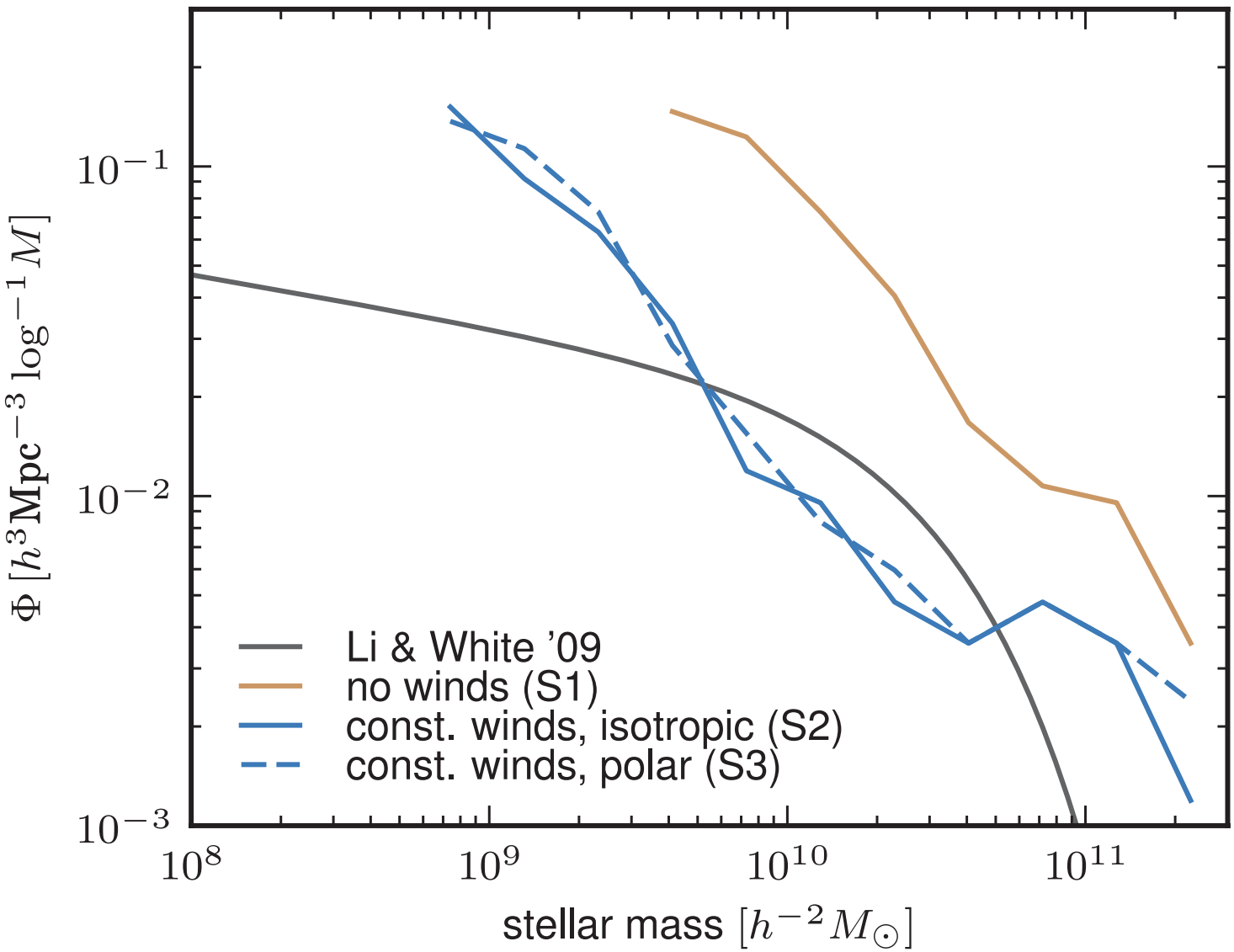


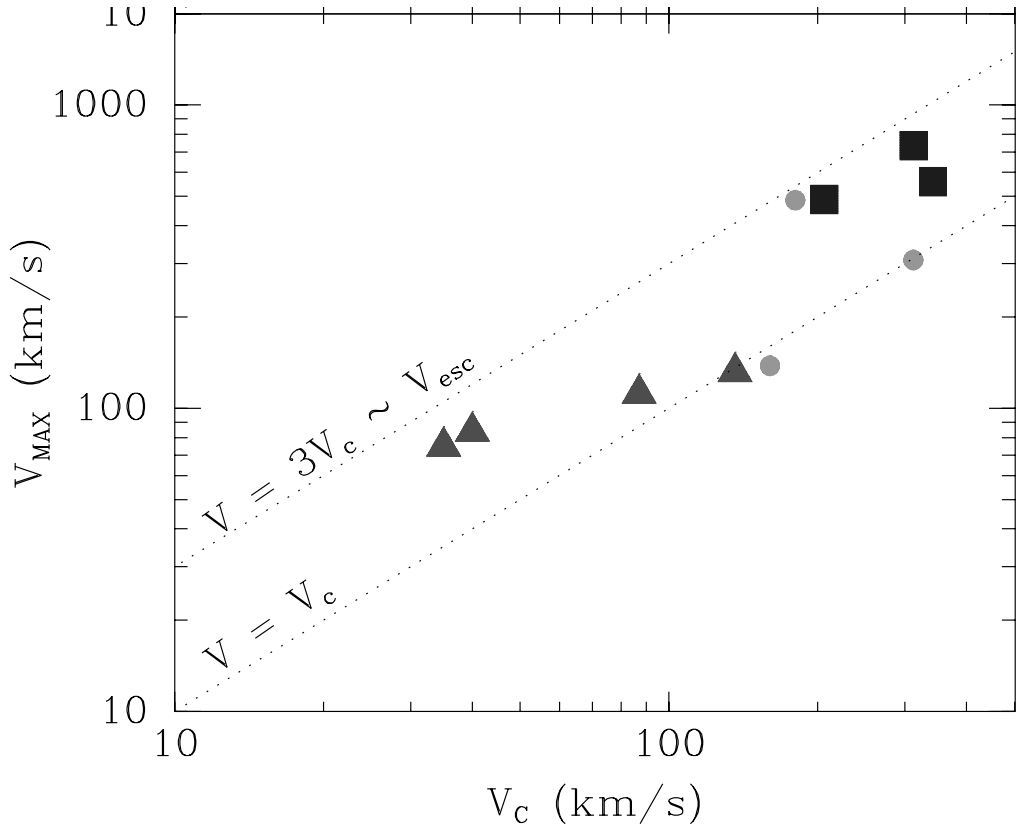
EP & Springel 2012

Wind velocity

- wind velocity & mass loading:

$$\eta \sim v_{\mathrm{w}}^{-2}$$

- decreasing wind velocity to 0.6 x v_{esc} boosts mass loading



Martin 2005

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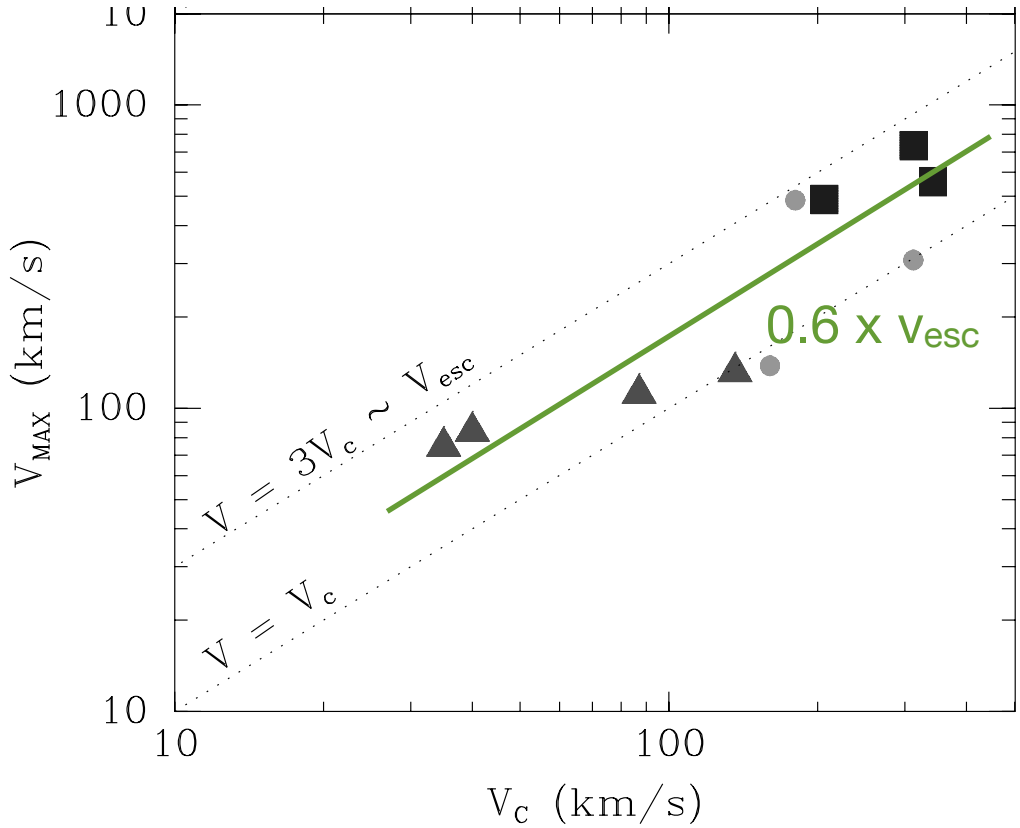

Martin 2005

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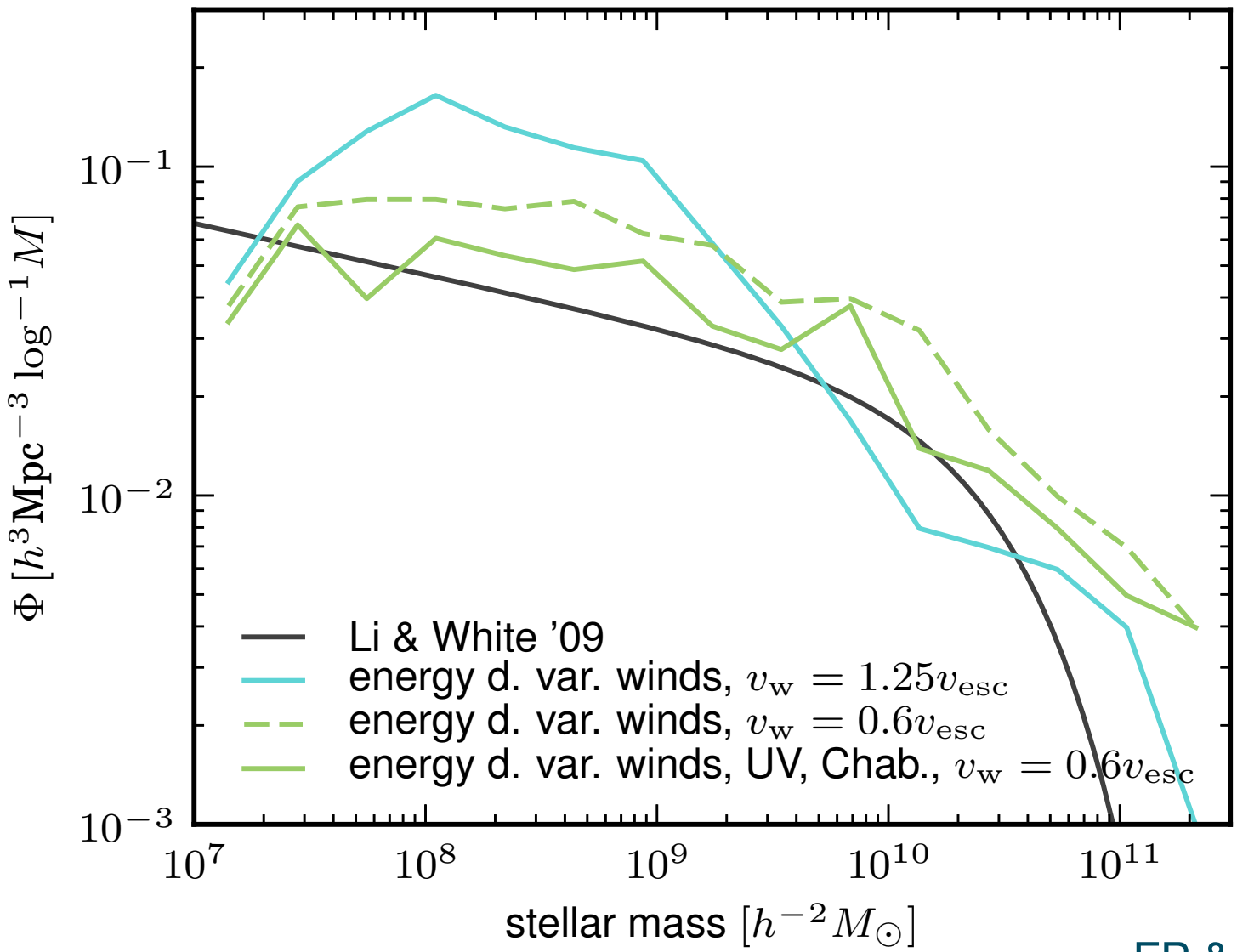
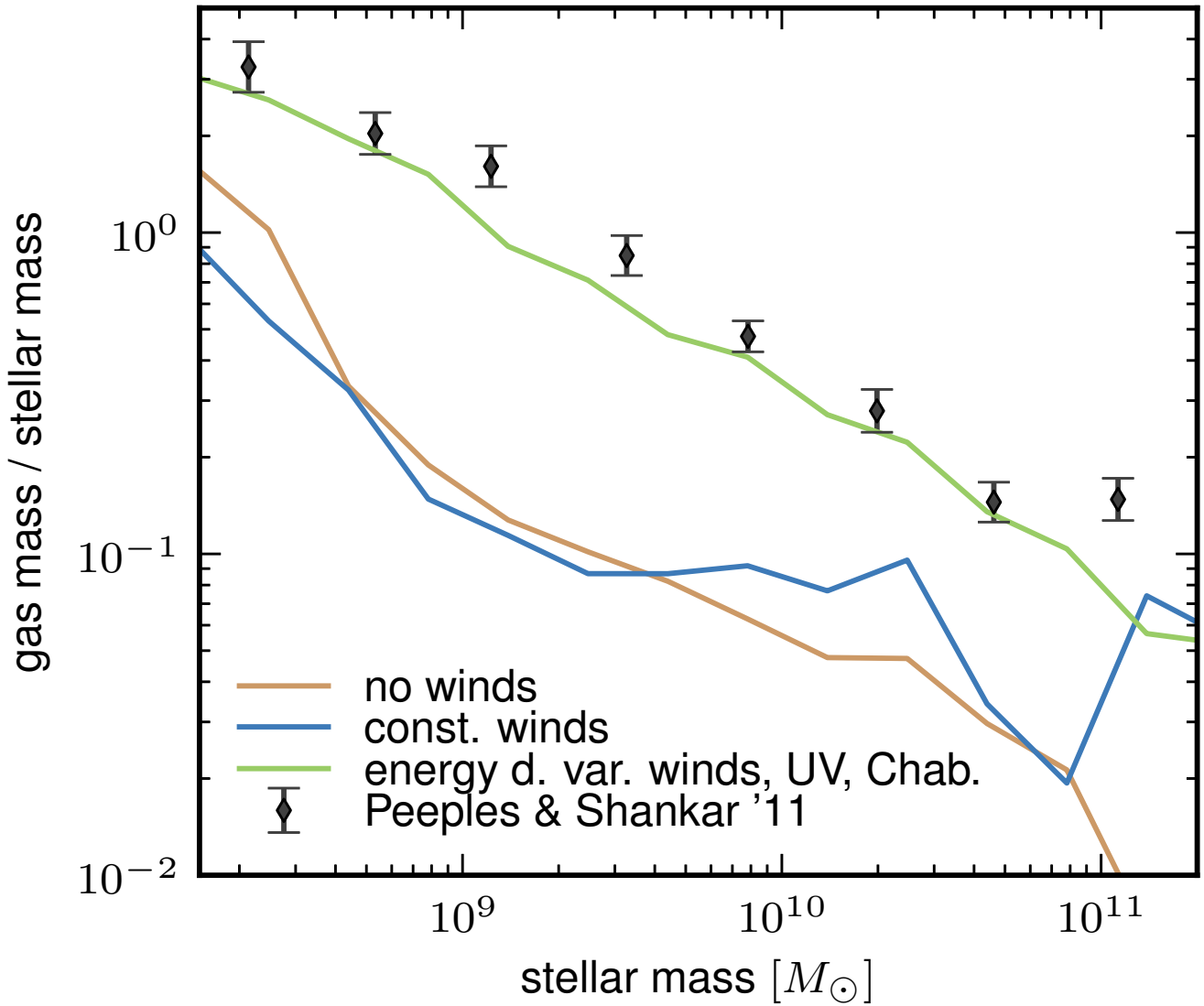


EP & Springel 2012

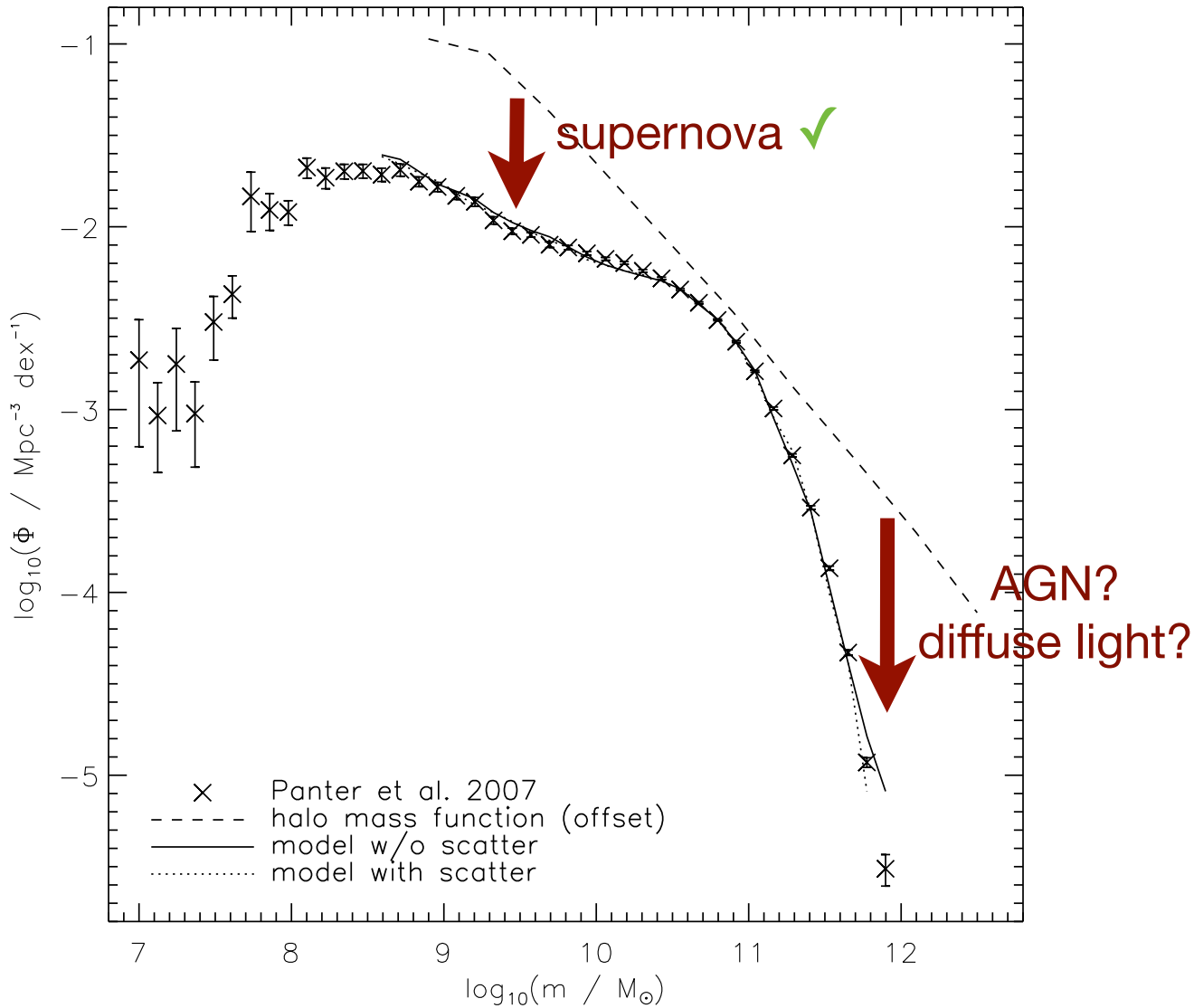
The gas / stellar mass ratio



EP & Springel 2012

The high-mass end of the GSMF

- can the overproduction of massive galaxies be prevented by AGN feedback?
- what about diffuse light?



Moster et al. 2010

The overcooling problem

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- cooling flow problem, overcooling in cluster cores

  ➡ unrealistically bright and blue BCGs

- cluster scaling relations incompatible with observations

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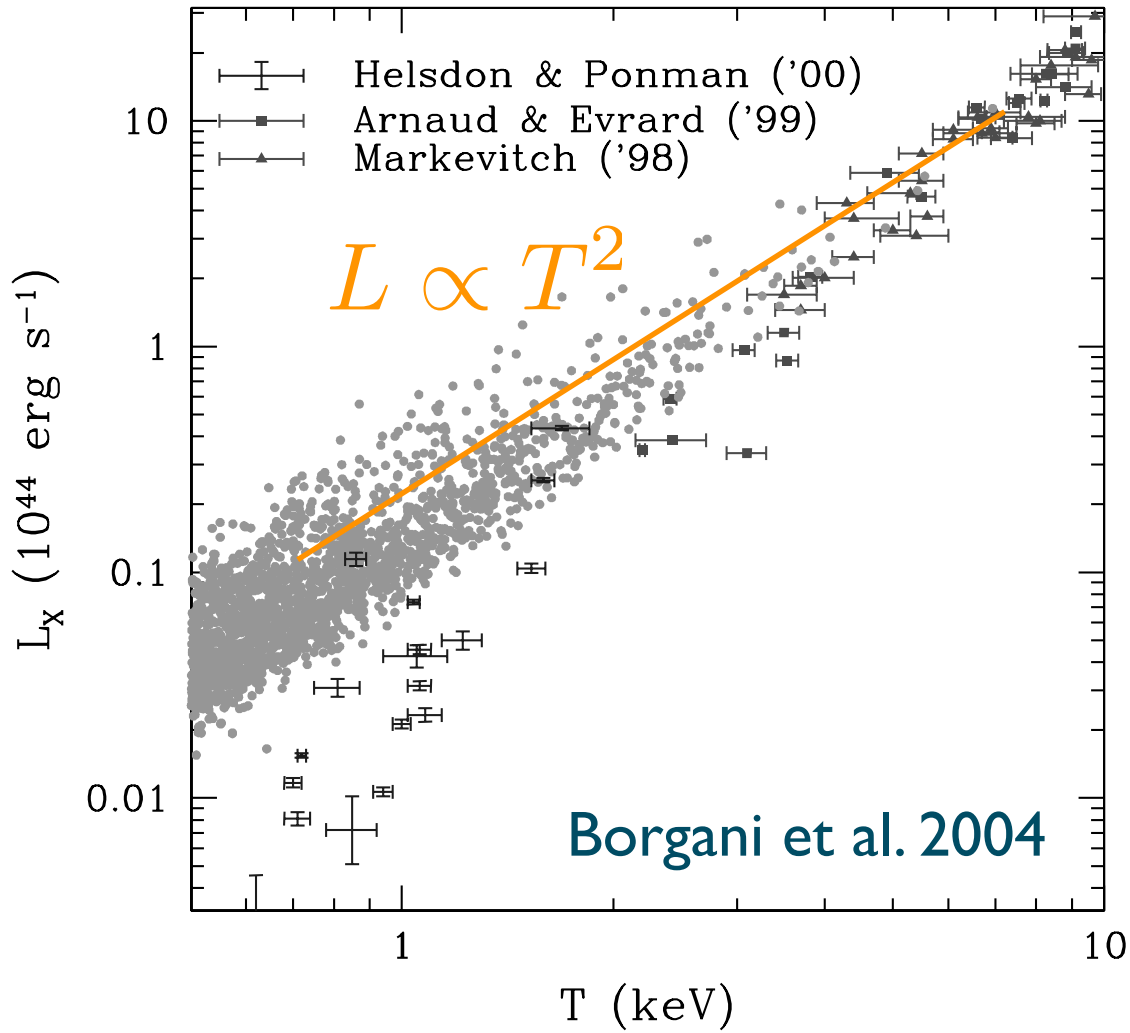
The Lx - T relation



The AGN feedback model (Sijacki et al. 2007)

- BHs are seeded in all halos when they exceed a threshold mass
- BHs grow by mergers and accretion:

$$\dot{M}_{\rm BH} = \frac{4\pi\alpha G^2 M_{\rm BH}^2 \rho}{\left(c_{\rm s}^2 + v^2\right)^{3/2}},$$

- two modes of AGN feedback:

➡ QUASAR MODE: for large accretion rates, less efficient

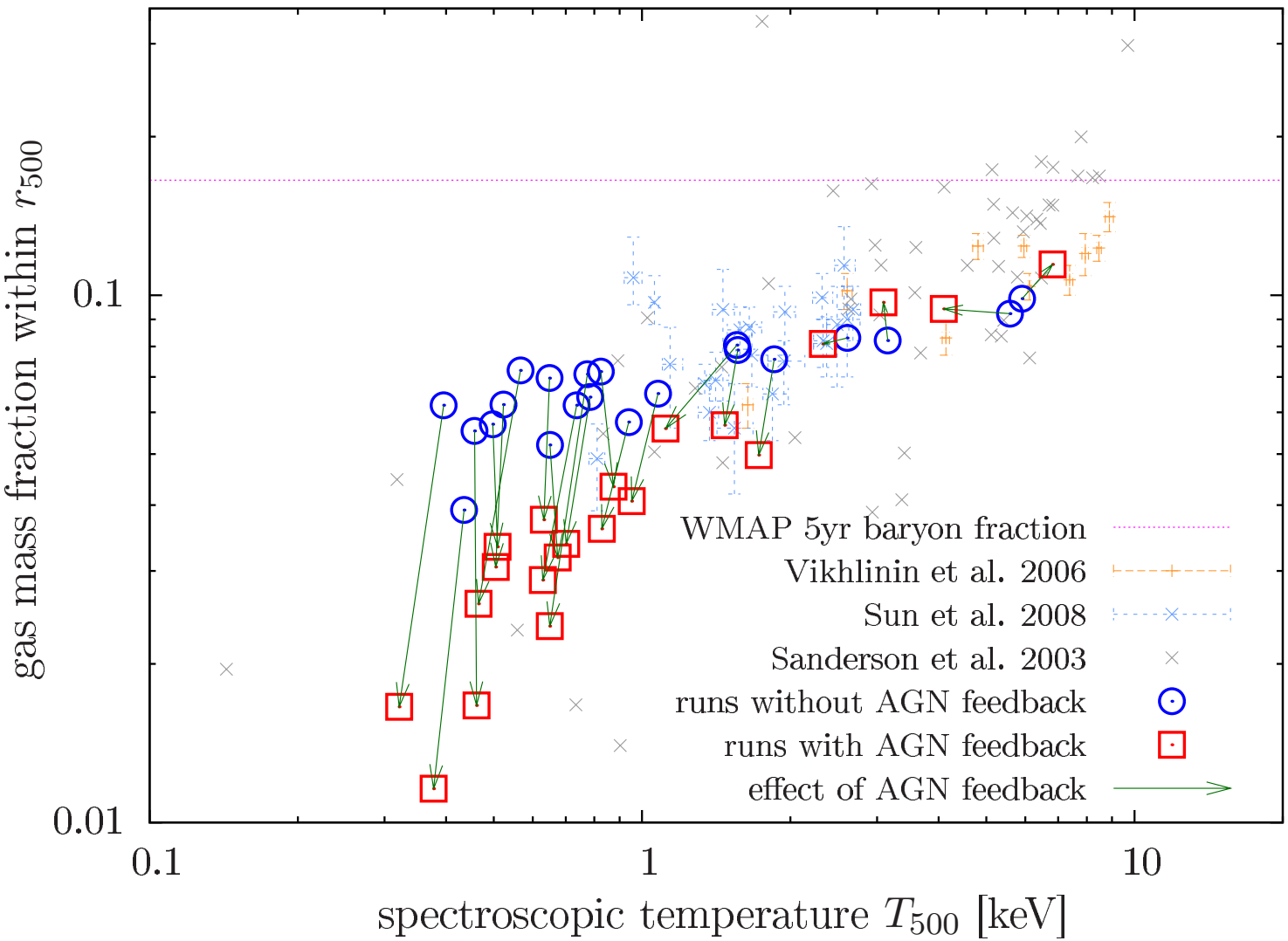
$$\dot{M_{BH}} > 0.01 \times \dot{M}_{EDD} \Rightarrow E = 0.005 \times \Delta M_{BH} c^2$$

➡ RADIO MODE: for small accretion rates, larger efficiency

$$\dot{M_{BH}} < 0.01 \times \dot{M}_{EDD} \Rightarrow E = 0.02 \times \Delta M_{BH} c^2$$

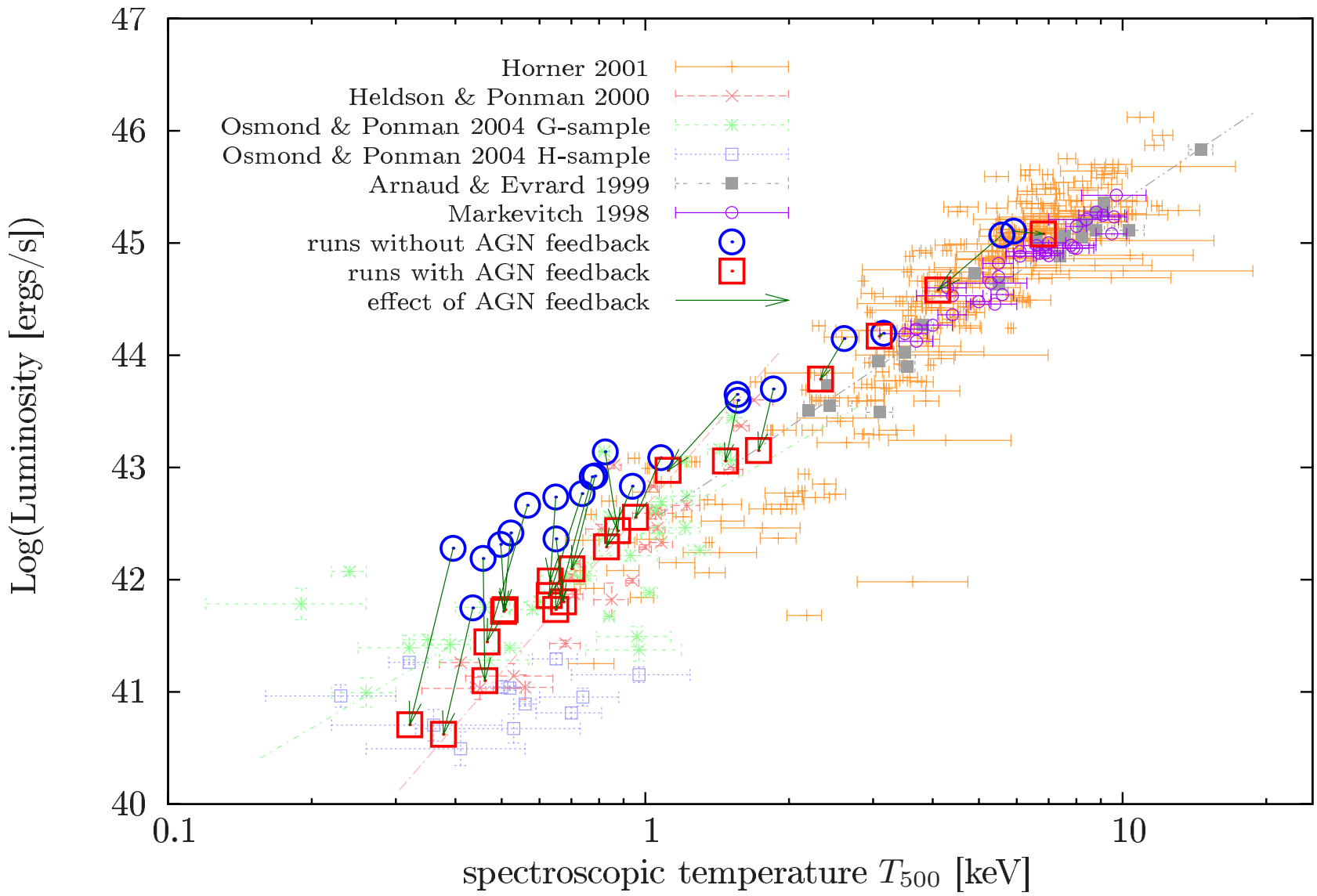
Gas fractions within $r_{500,\,crit}$

zoom-simulations of 21 clusters and groups with/without AGN feedback



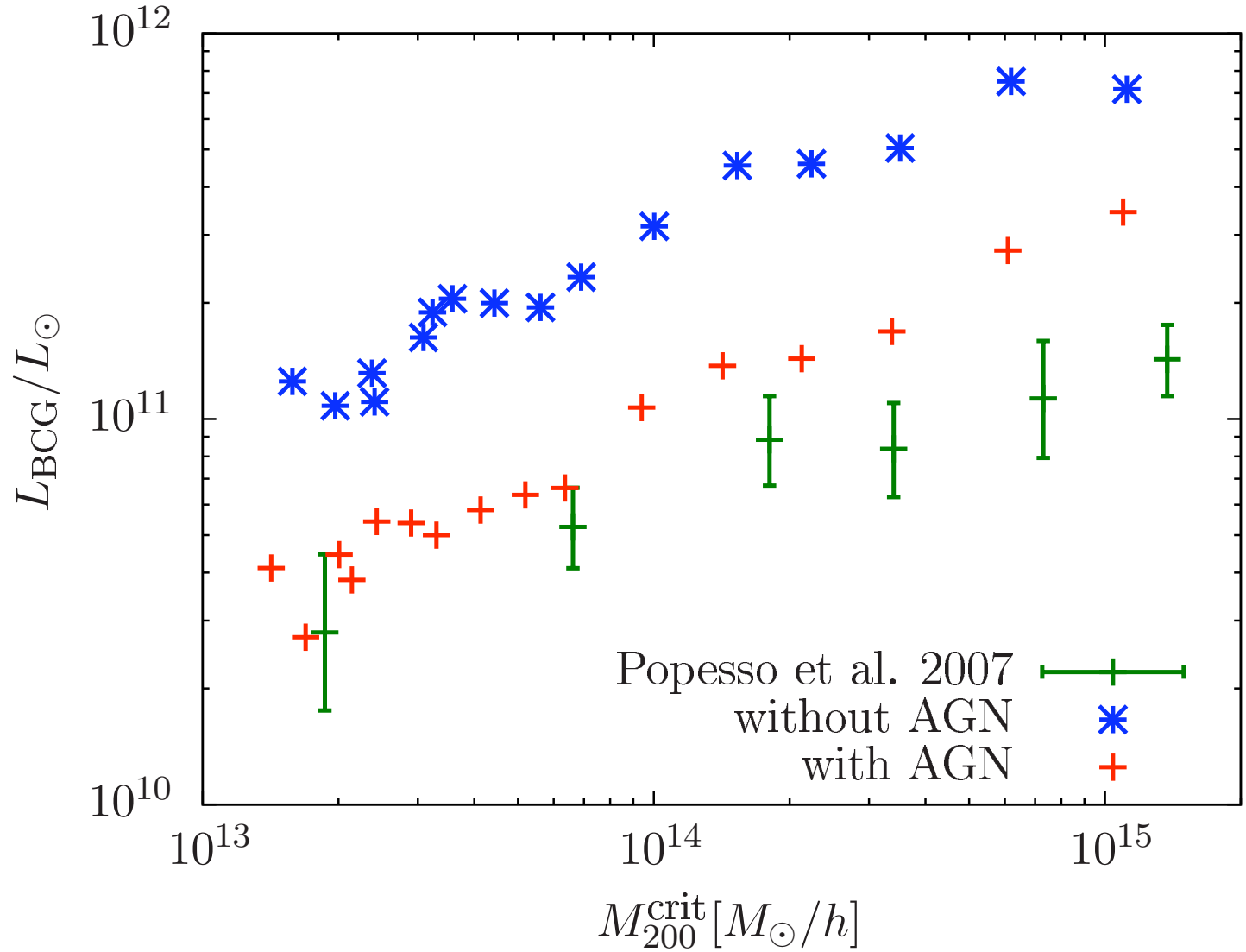
EP, Sijacki, Springel 2008

The L_X-T relation



EP, Sijacki, Springel 2008

BCG luminosities



EP, Springel, Sijacki, Dolag 2010

The high-mass end of the GSMF

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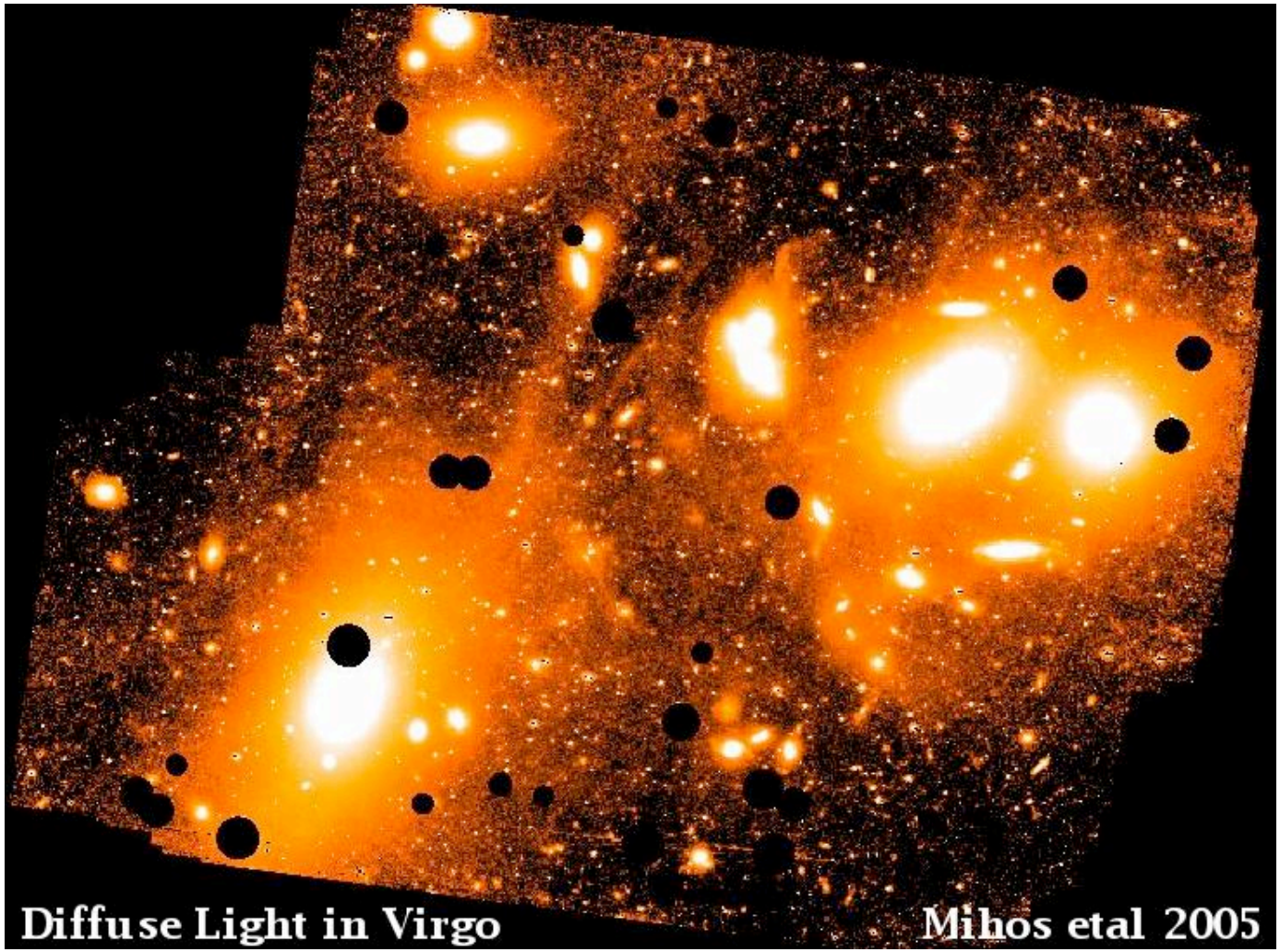

=> need to make sure that the same galaxy vs. ICL accounting is done in observations and simulations

The high-mass end of the GSMF

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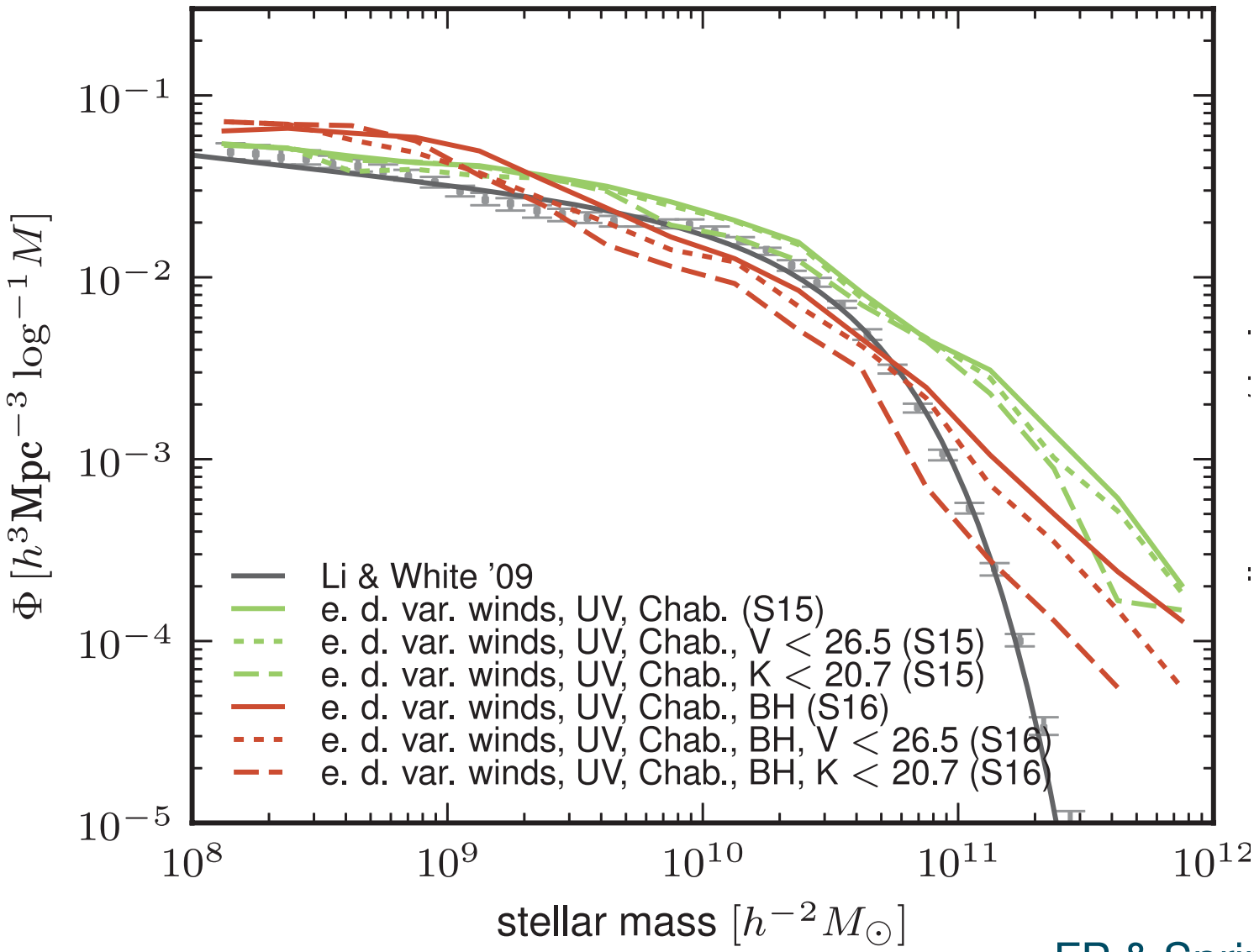
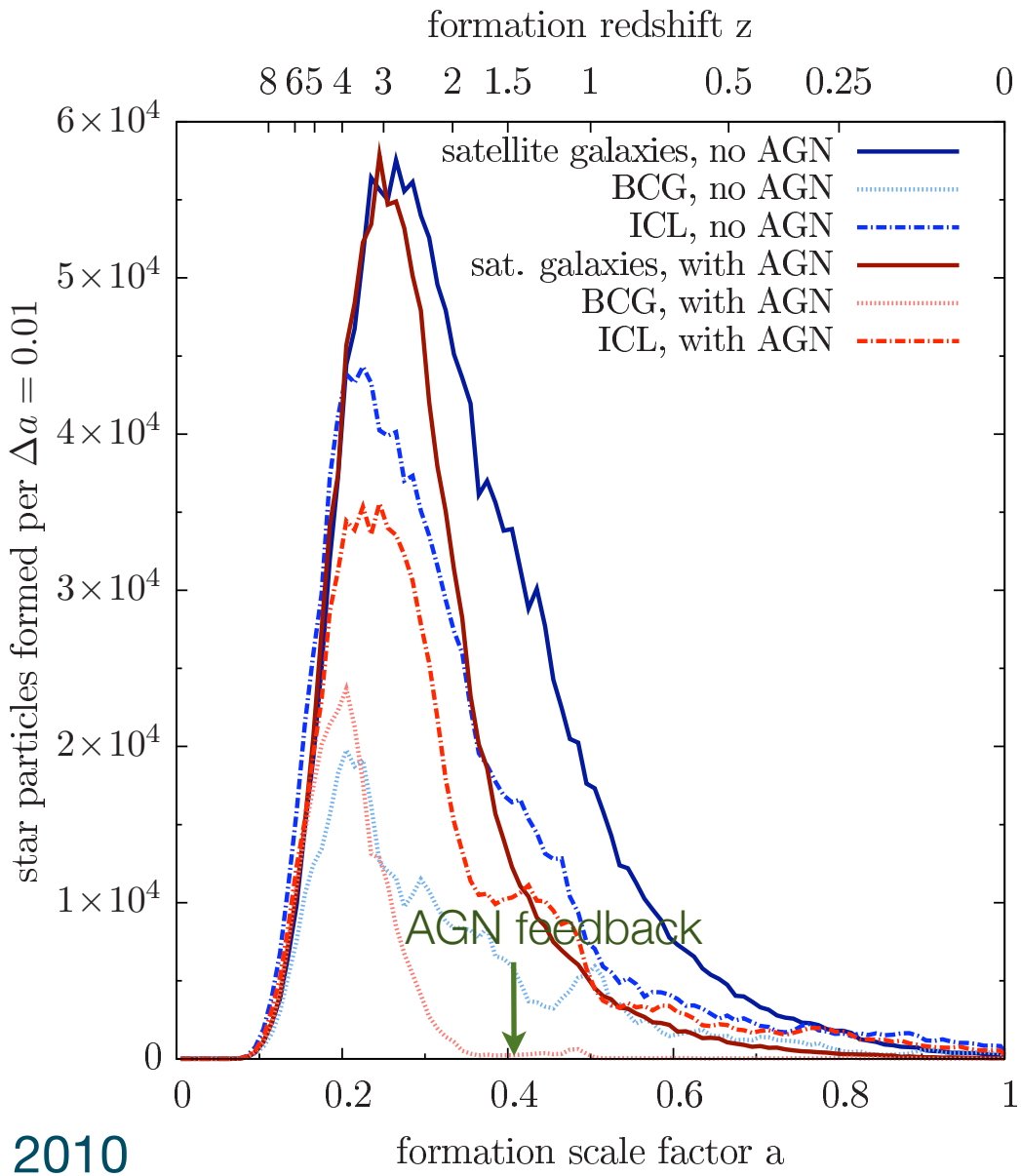


EP & Springel 2012

Star formation histories

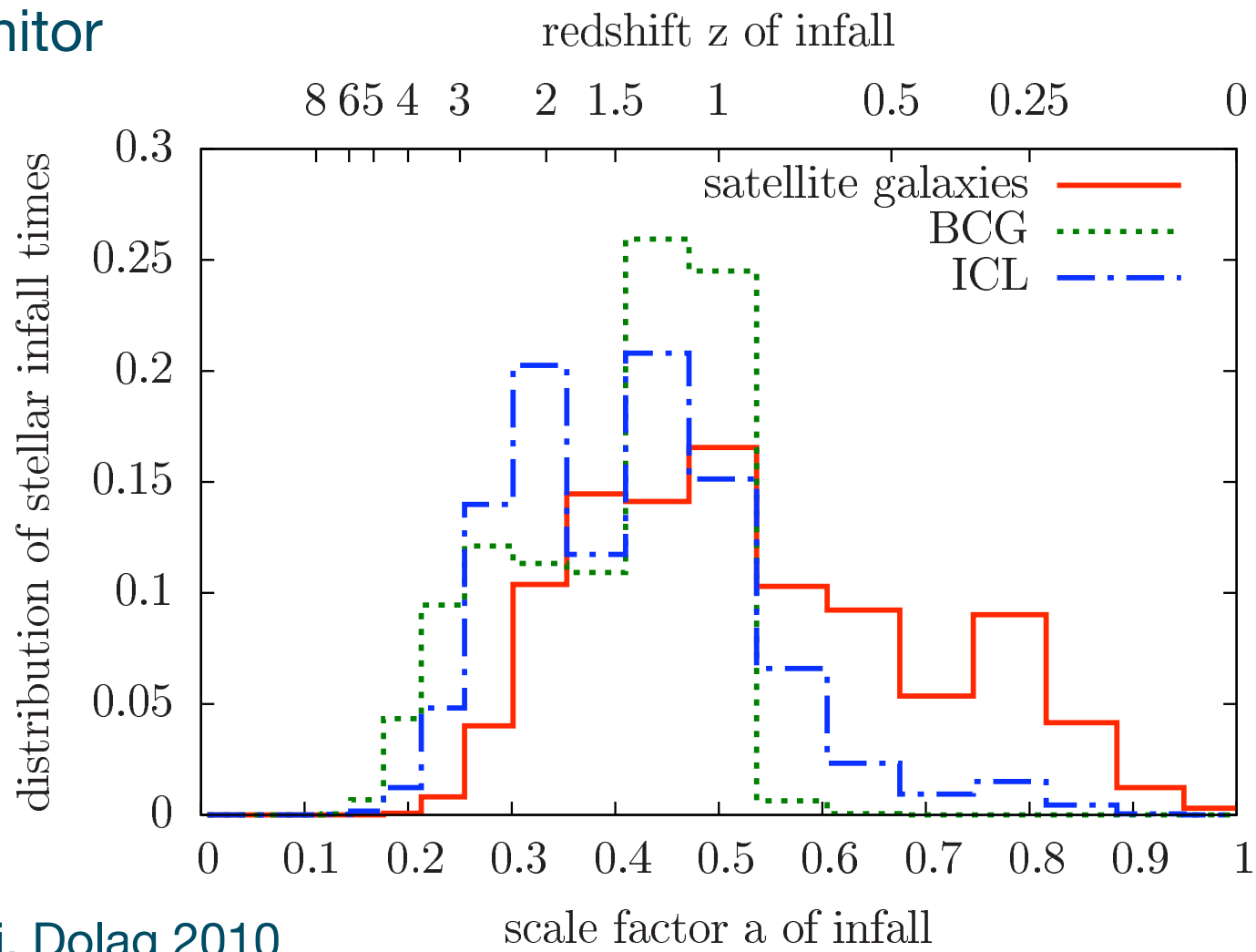
- star formation histories of BCG, ICL & satellites
- AGN feedback suppresses late-time star formation in BCGs
- only ~10-30% of the stars in the BCG form in its main progenitor



EP, Springel, Sijacki, Dolag 2010

Assembly histories of BCG, ICL & satellites

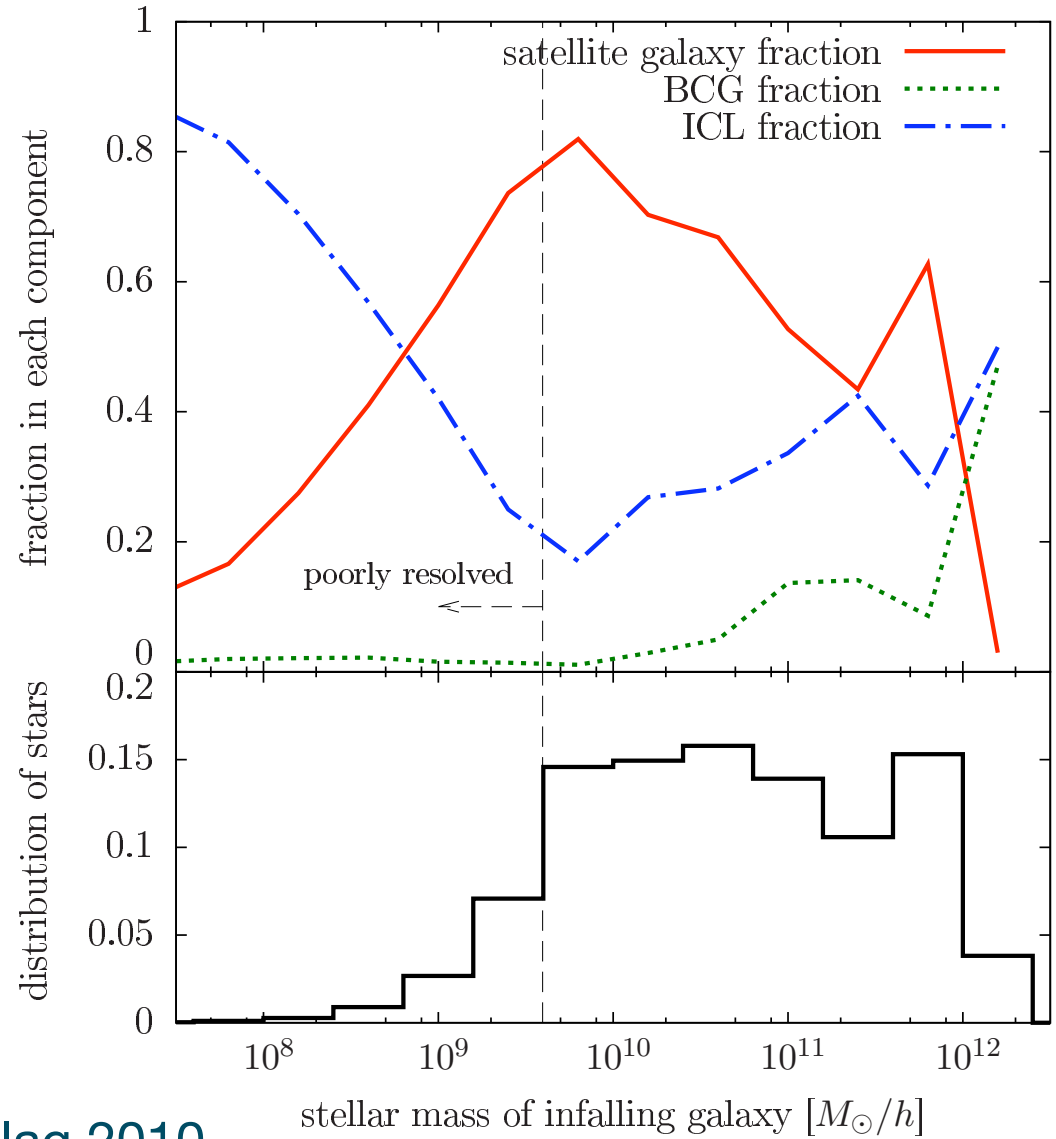
- time of infall into the main cluster progenitor



EP, Springel, Sijacki, Dolag 2010

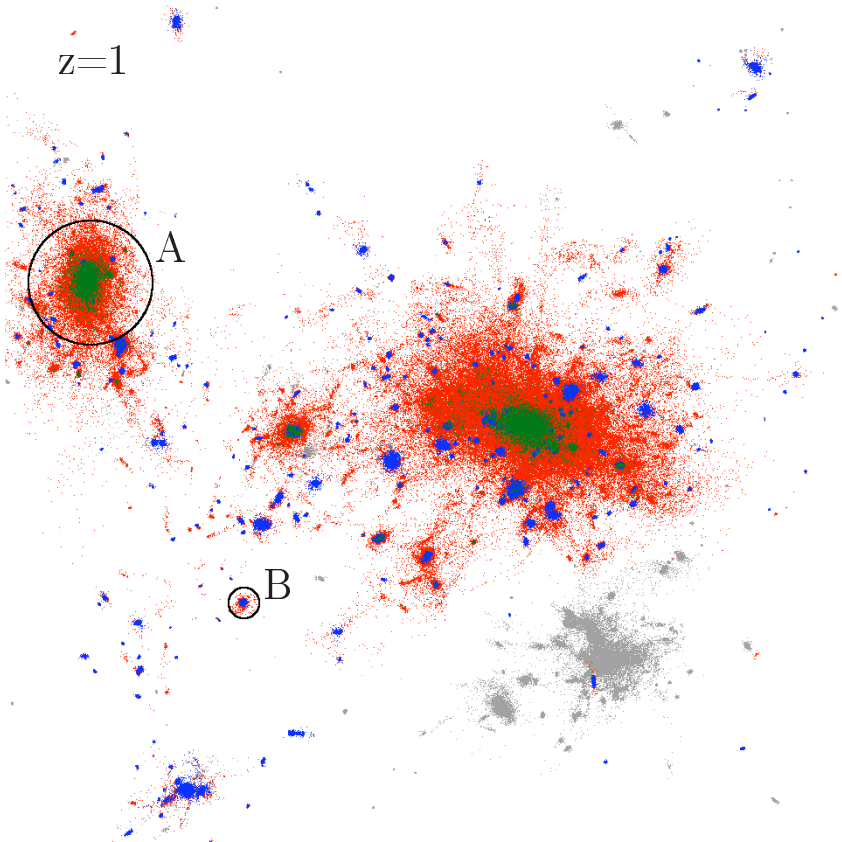
Assembly histories of BCG, ICL & satellites

- cluster galaxies - merging and stripping



EP, Springel, Sijacki, Dolag 2010

Tracing the stars

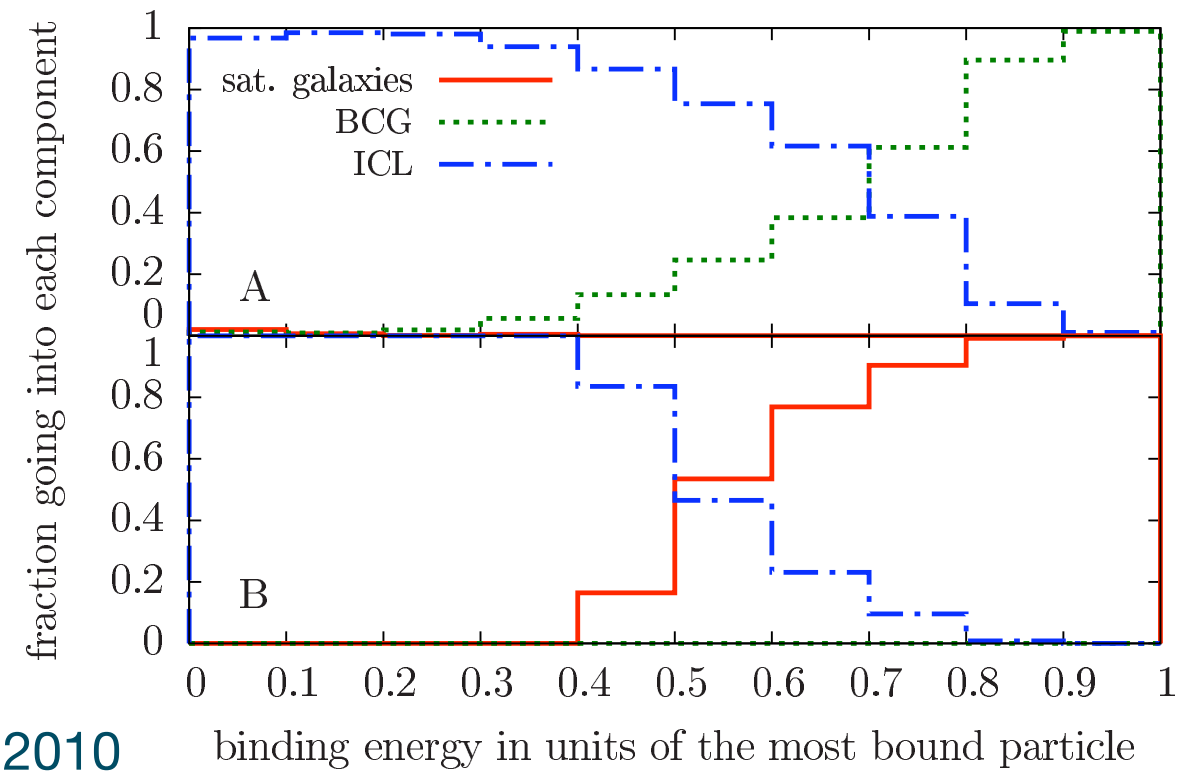


green -> end up in the BCG at z=0

red -> end up in the ICL at z=0

blue -> end up in a satellite galaxy at z=0

gray -> end up outside the cluster at z=0



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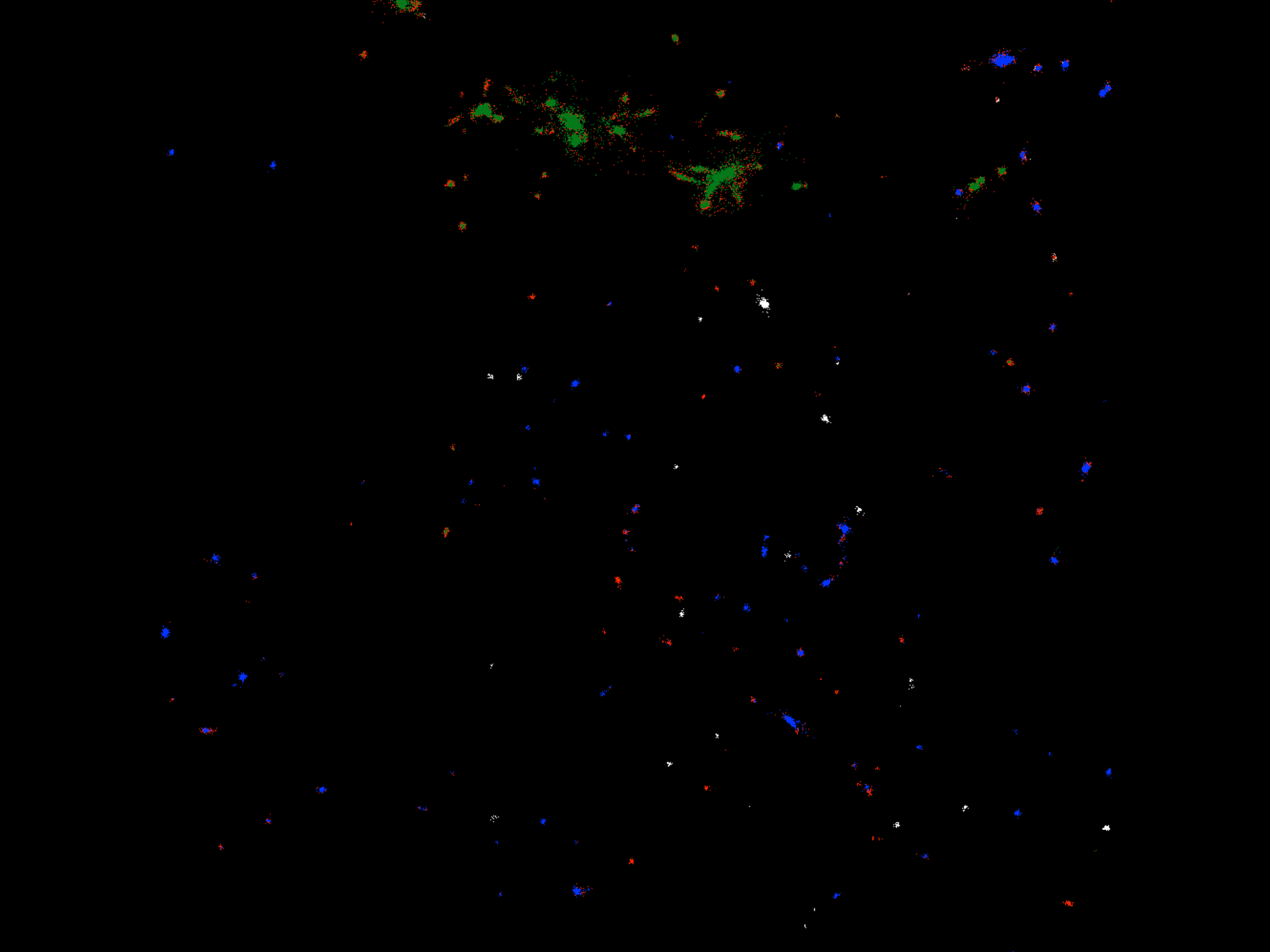

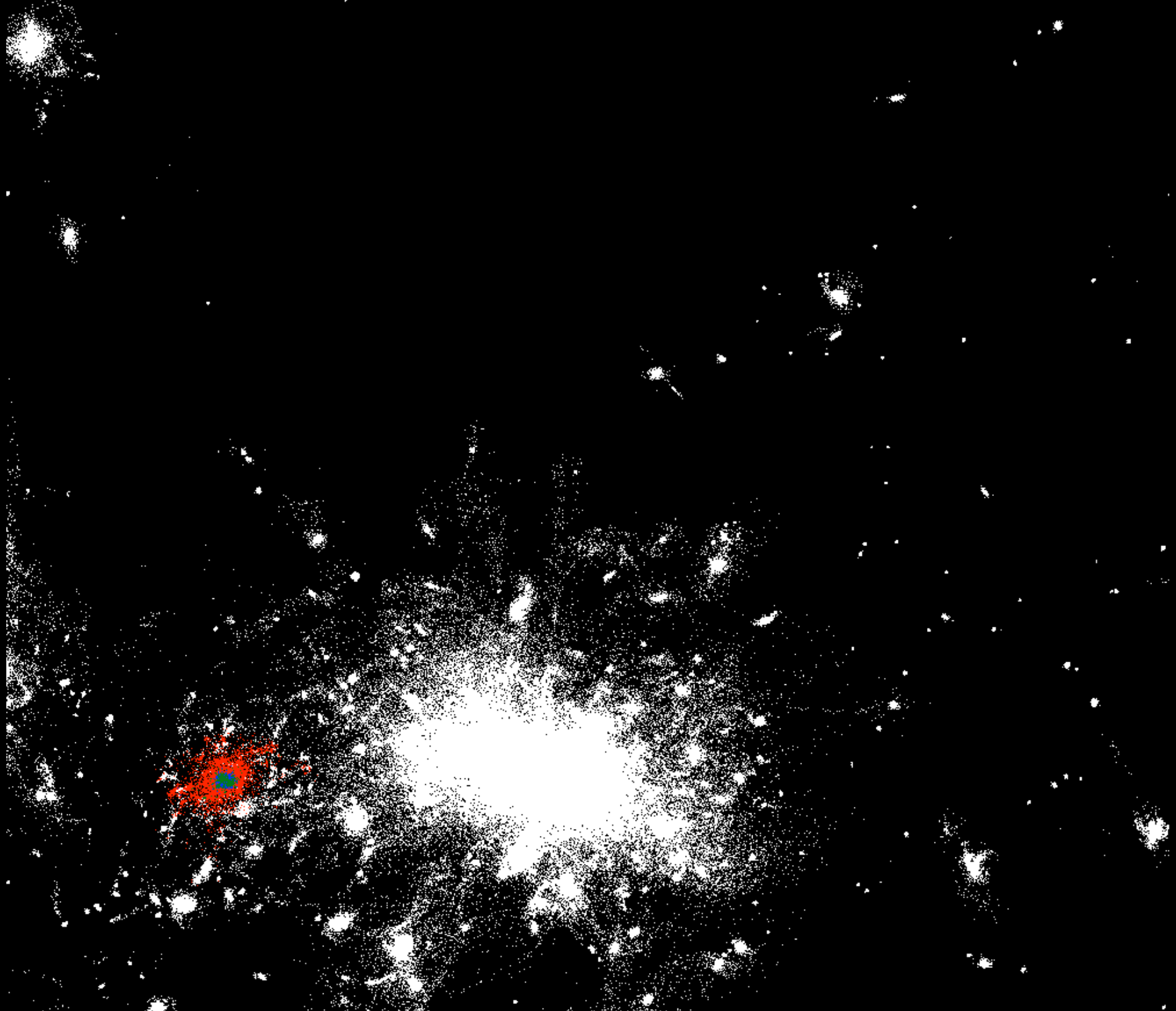

Summary & Conclusions

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- winds in which mass loading & velocity scale with the galaxy escape velocity allow to reproduce the faint-end of the GSMF
- bright end can be recovered much better with AGN feedback and a consistent accounting of diffuse light
- AGN feedback results in BCGs with lower luminosities and old stellar populations
- massive galaxies which are accreted before z~1 preferentially merge into the BCG
- stars that are weakly bound to BCG progenitors end up in the intracluster light