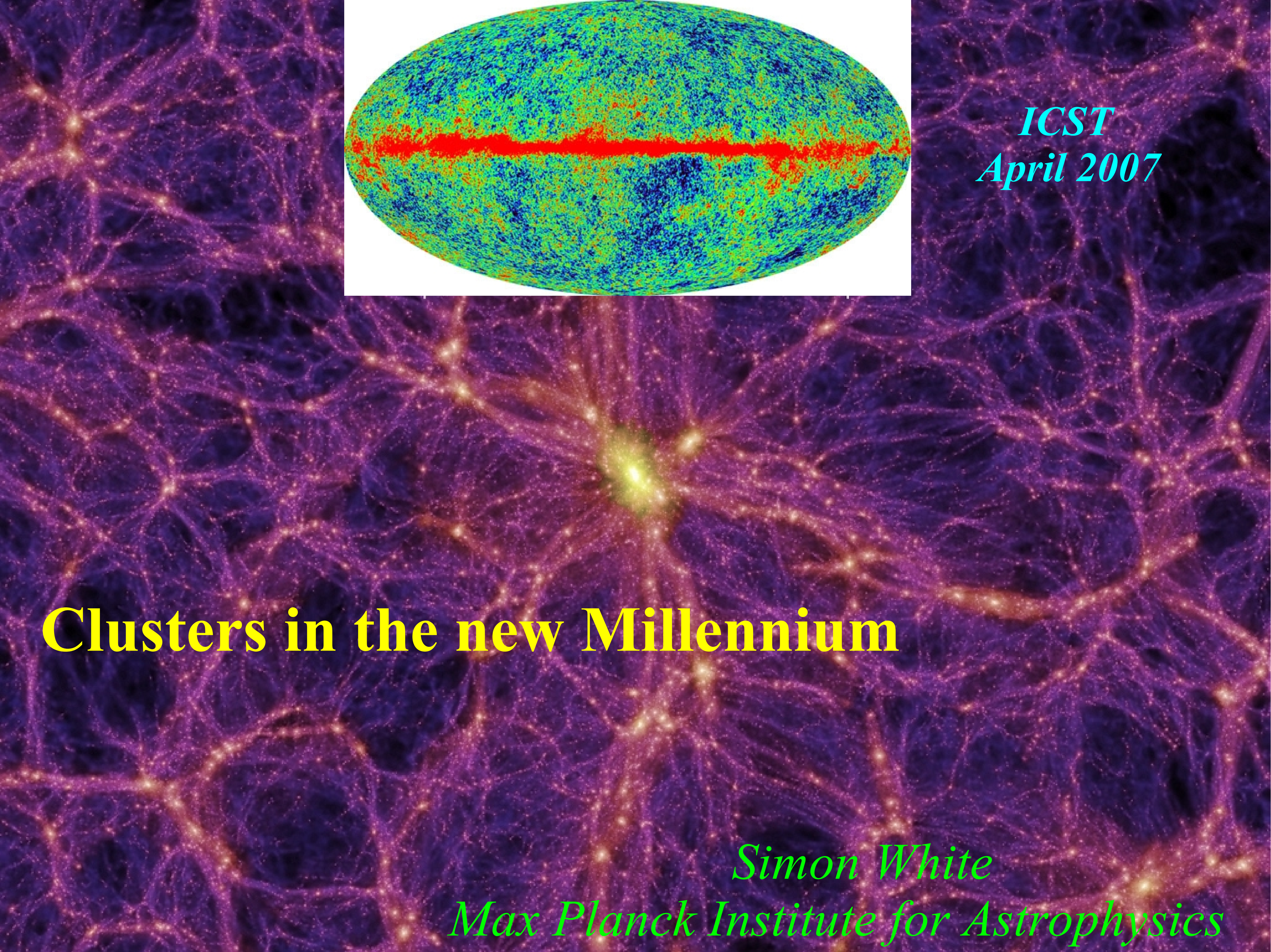


ICST
April 2007

Clusters in the new Millennium

Simon White
Max Planck Institute for Astrophysics

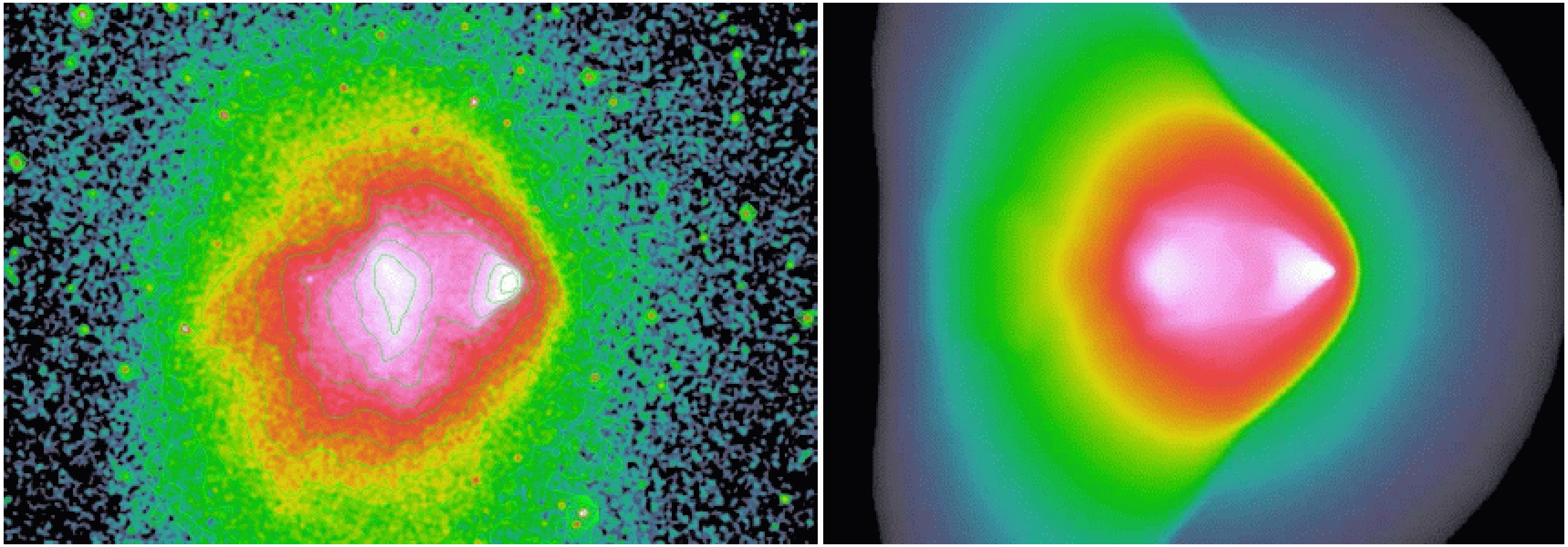
Simulation input to cluster studies

- Simulations of individual clusters can address
  - -- Evolution of internal density/temperature/metallicity
  - -- Effects of feedback, B-fields, relativistic components
    - -- Constrain nature of DM, extra physics
      e.g. 1E0657-56 "The bullet cluster"

- Simulations of large cluster samples can address
  - -- Cluster abundances as functions of M, z, L_X, T_X, Y...
  - -- Cluster clustering as functions of M, z, L_X, T_X, Y...
  - -- Estimation of uncertainties in Dark Energy projects

1E0657-56 – the “Bullet” cluster

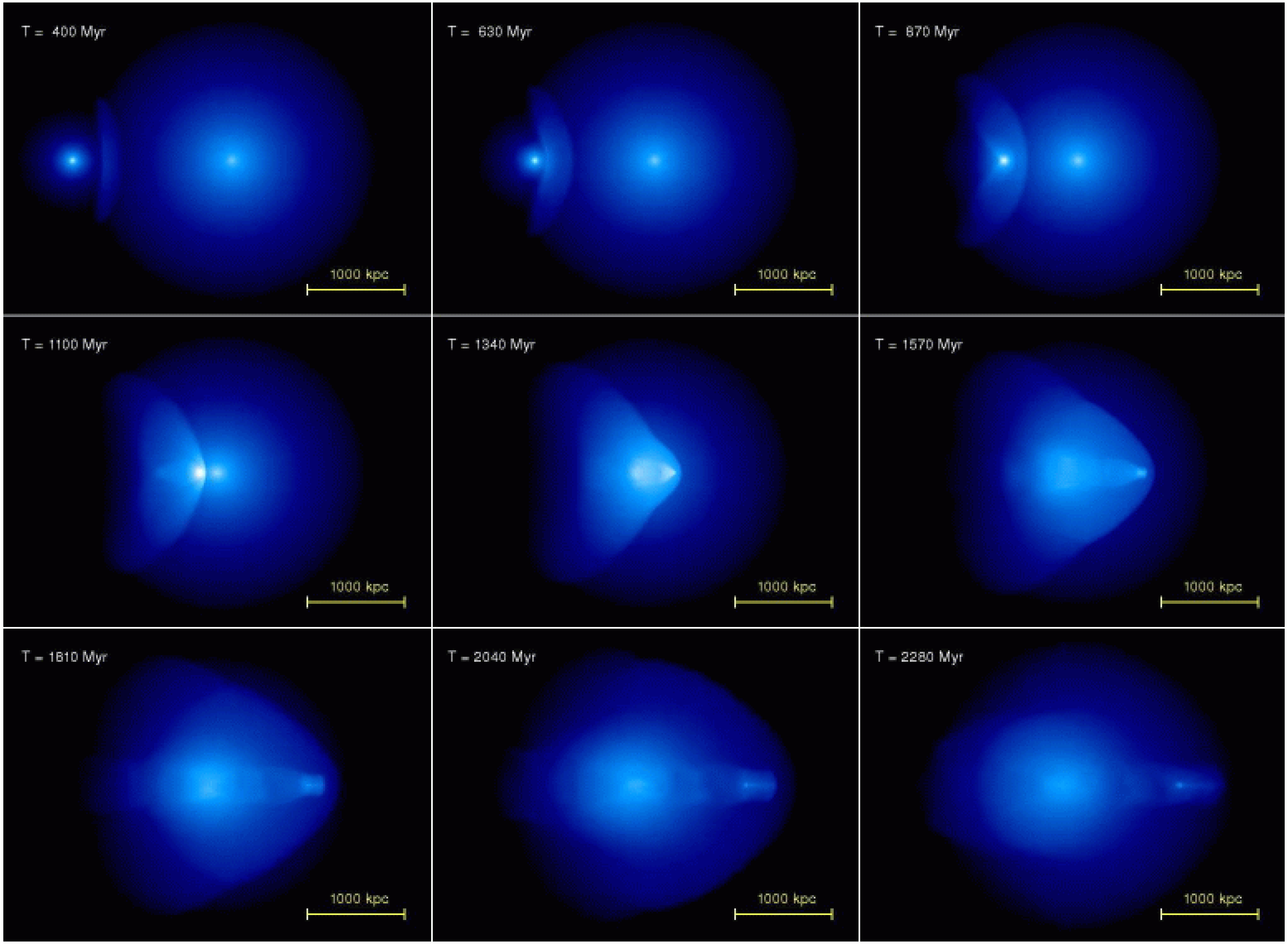
Springel & Ferrar 2007



- One of the most luminous and hottest clusters known
- $z=0.296$, lensing masses are 10^{15} and 10^{14} $M_\odot/h$
- Shock geometry gives $M \sim 3$ and upstream gas has T ~ 10 keV
  $\longrightarrow$ $V_{shock} = 4700$ km/s --- implausibly high for ΛCDM?

1E0657-56 – the “Bullet” cluster

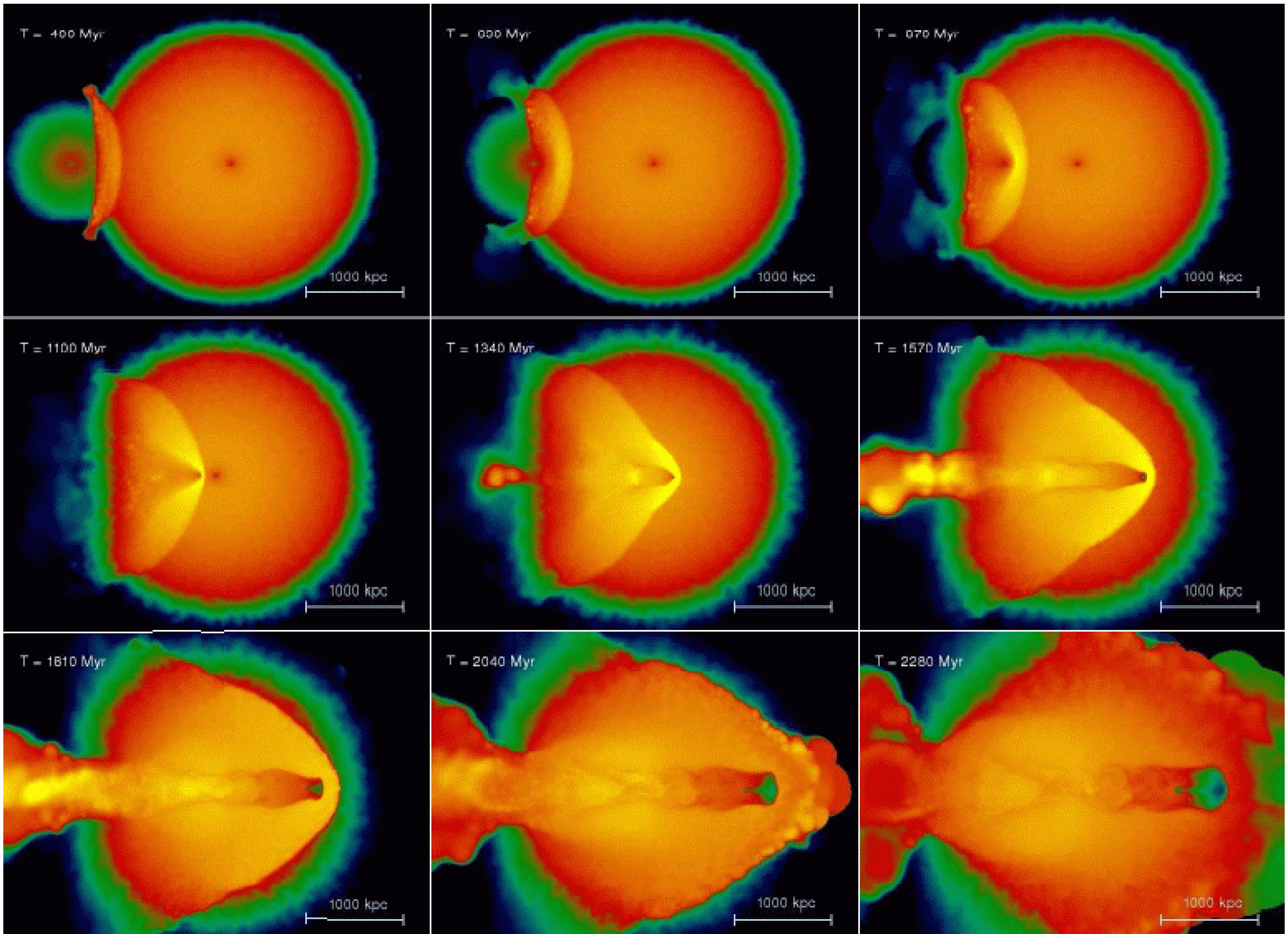
Springel & Ferrar 2007



X-ray surface brightness

1E0657-56 – the “Bullet” cluster

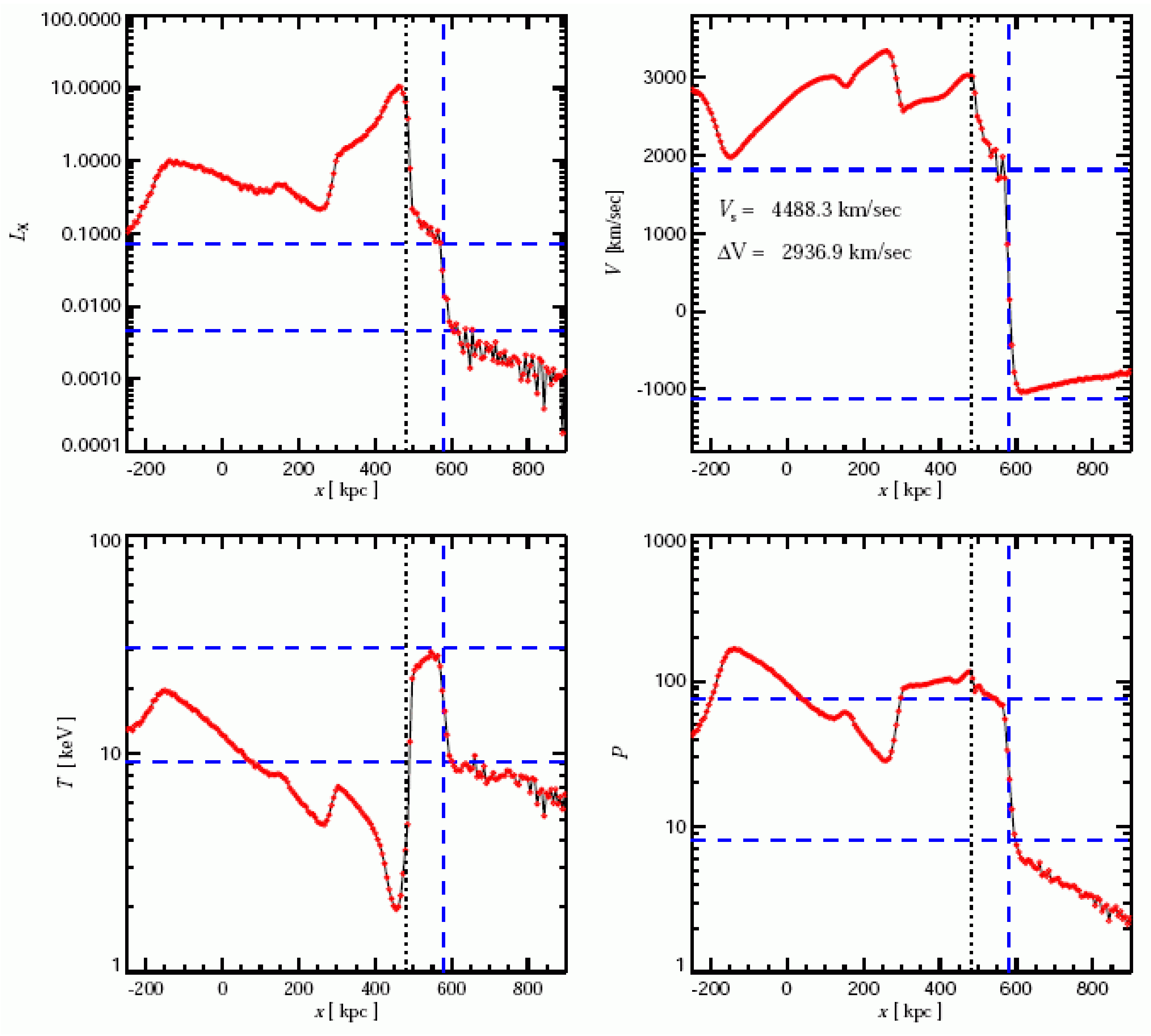
Springel & Ferrar 2007



mean X-ray temperature

1E0657-56 – the "Bullet" cluster

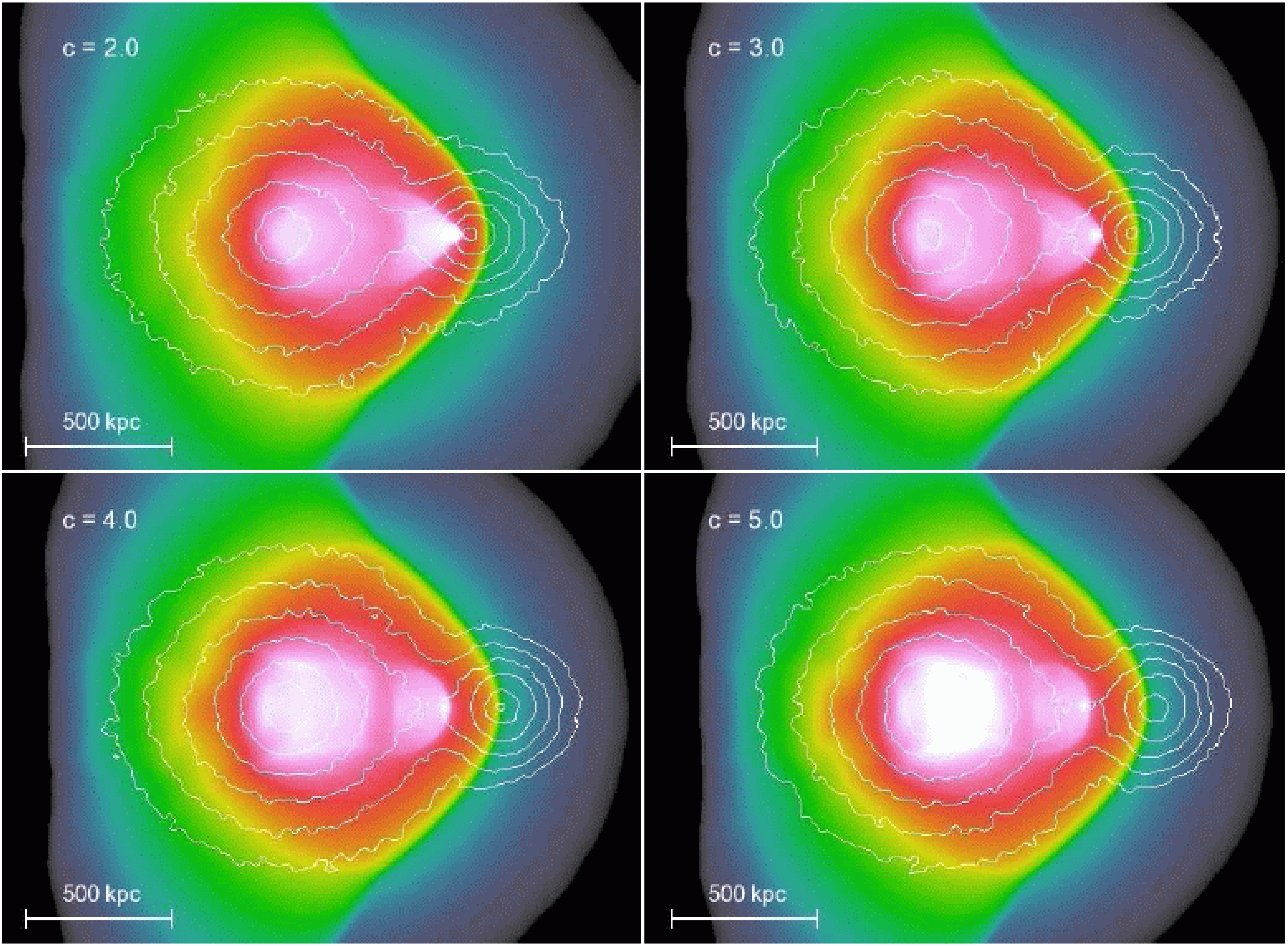
Springel & Ferrar 2007



Properties along symmetry axis

1E0657-56 – the “Bullet” cluster

Springel & Ferrar 2007



Effect of the concentration of the main cluster on the lag between gas and DM.

Simulation input to cluster studies

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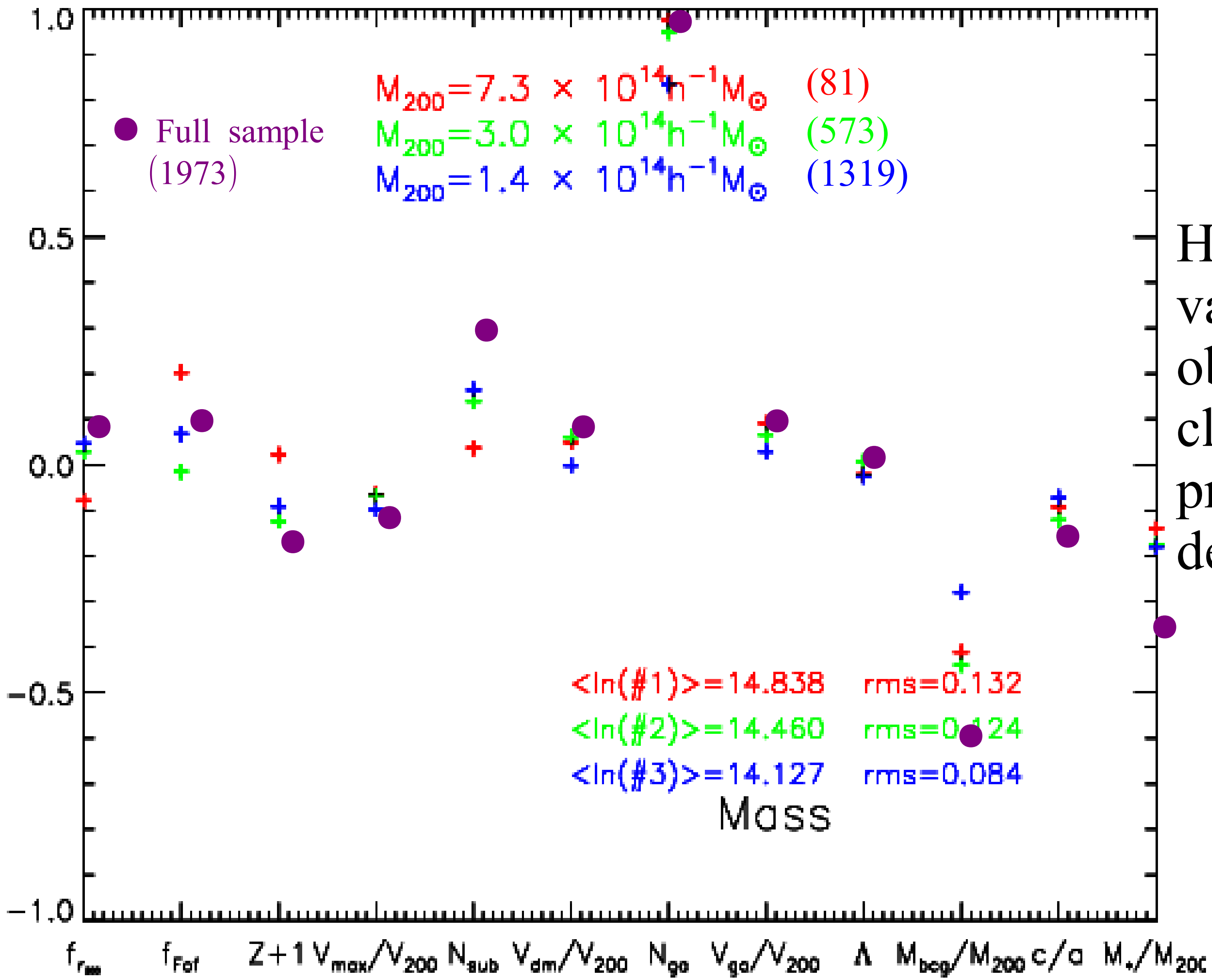
Correlations between cluster properties

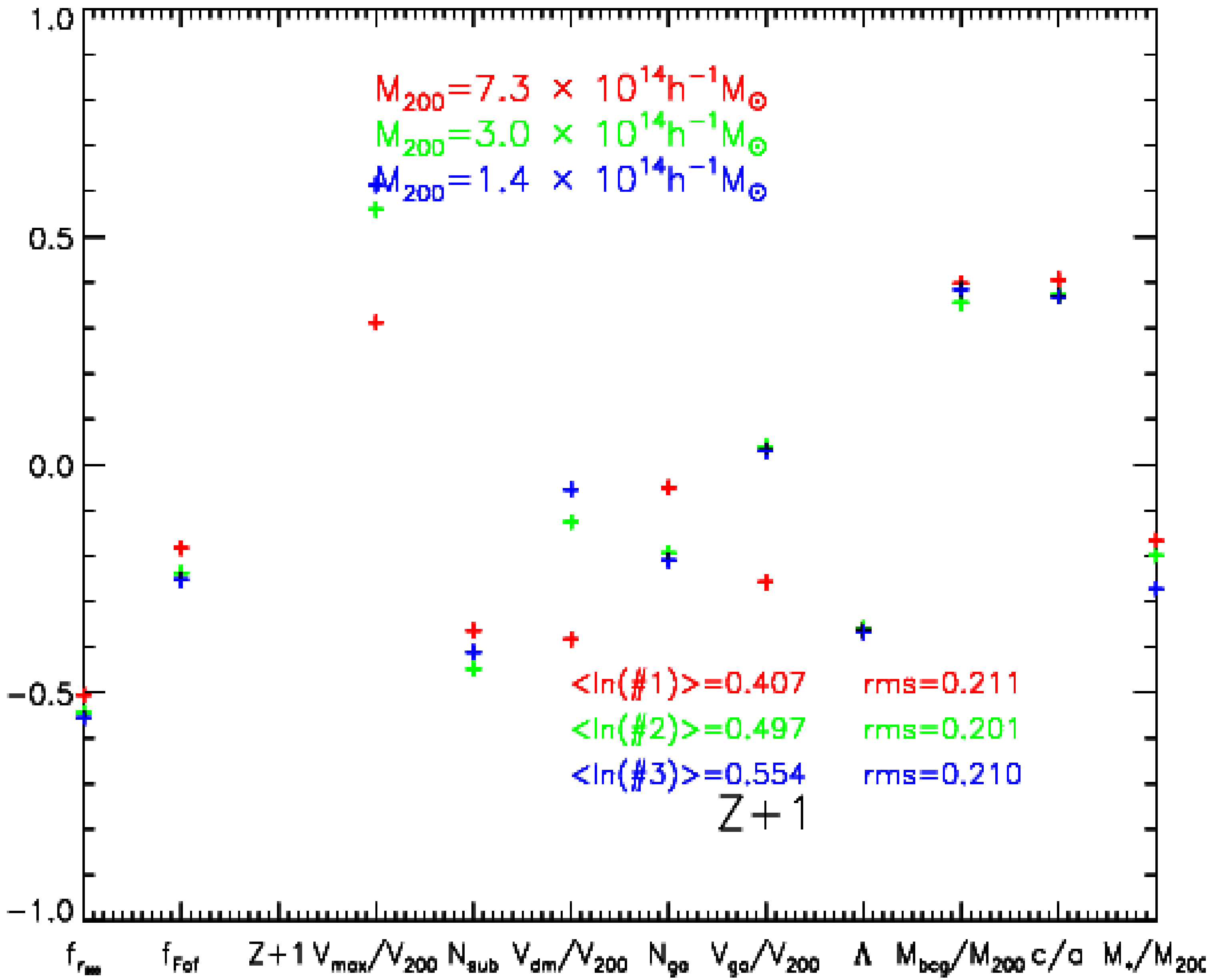
Gao & White 2007



How many variables do observable cluster properties depend on?

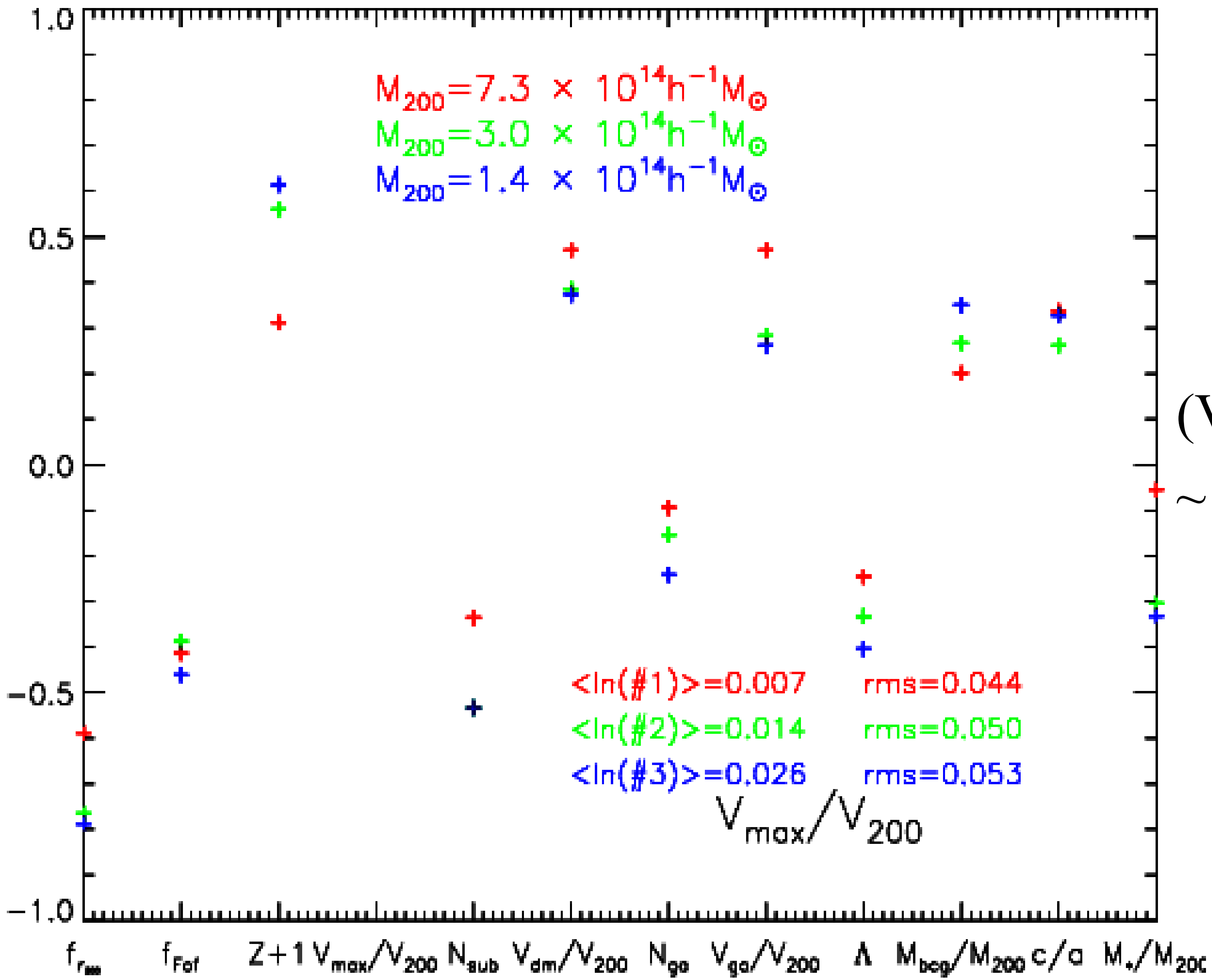
Correlations between cluster properties

Gao & White 2007



Correlations between cluster properties

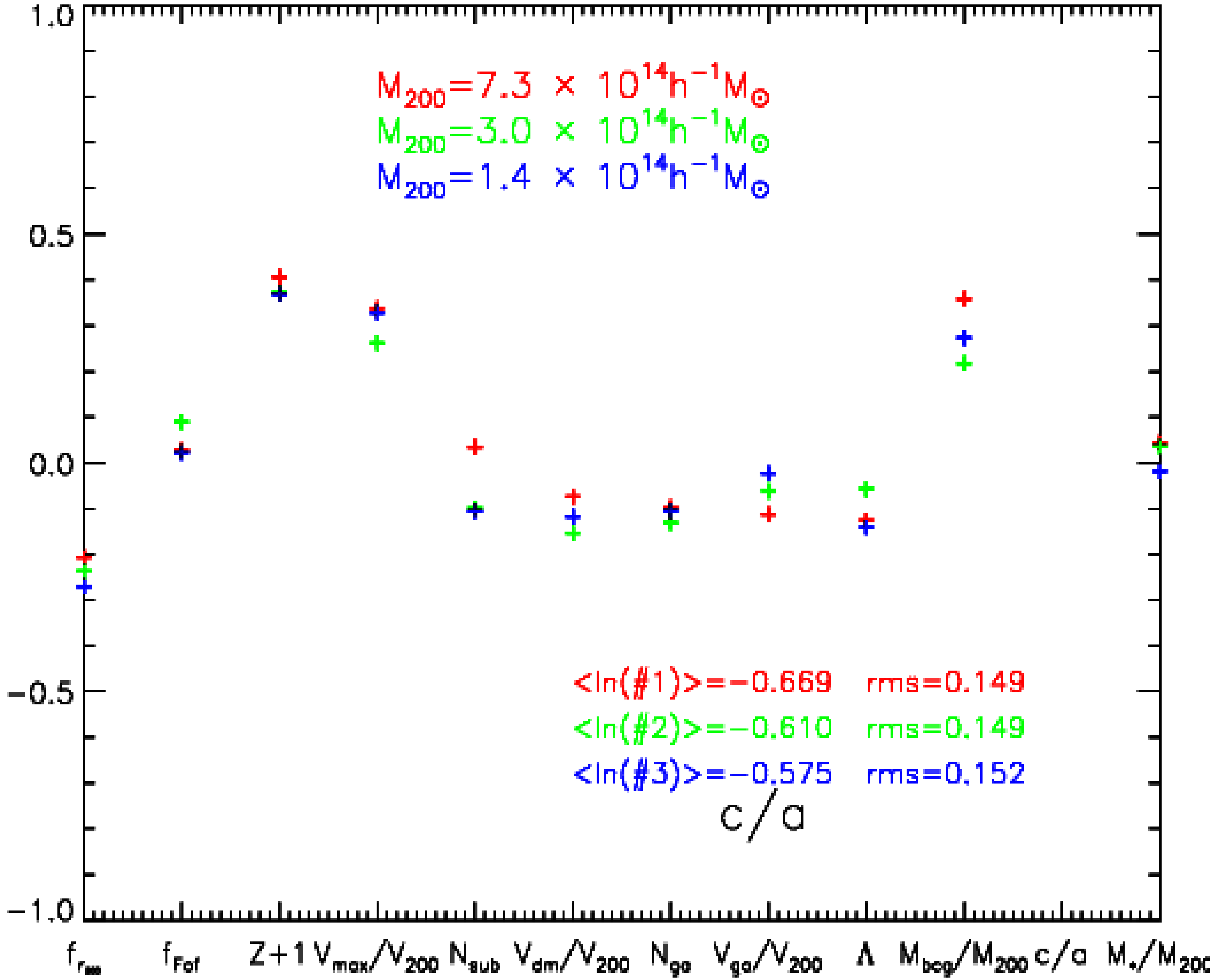
Gao & White 2007



$(V_{max}/V_{200})^2 \sim T_X/M_{200}^{2/3}$

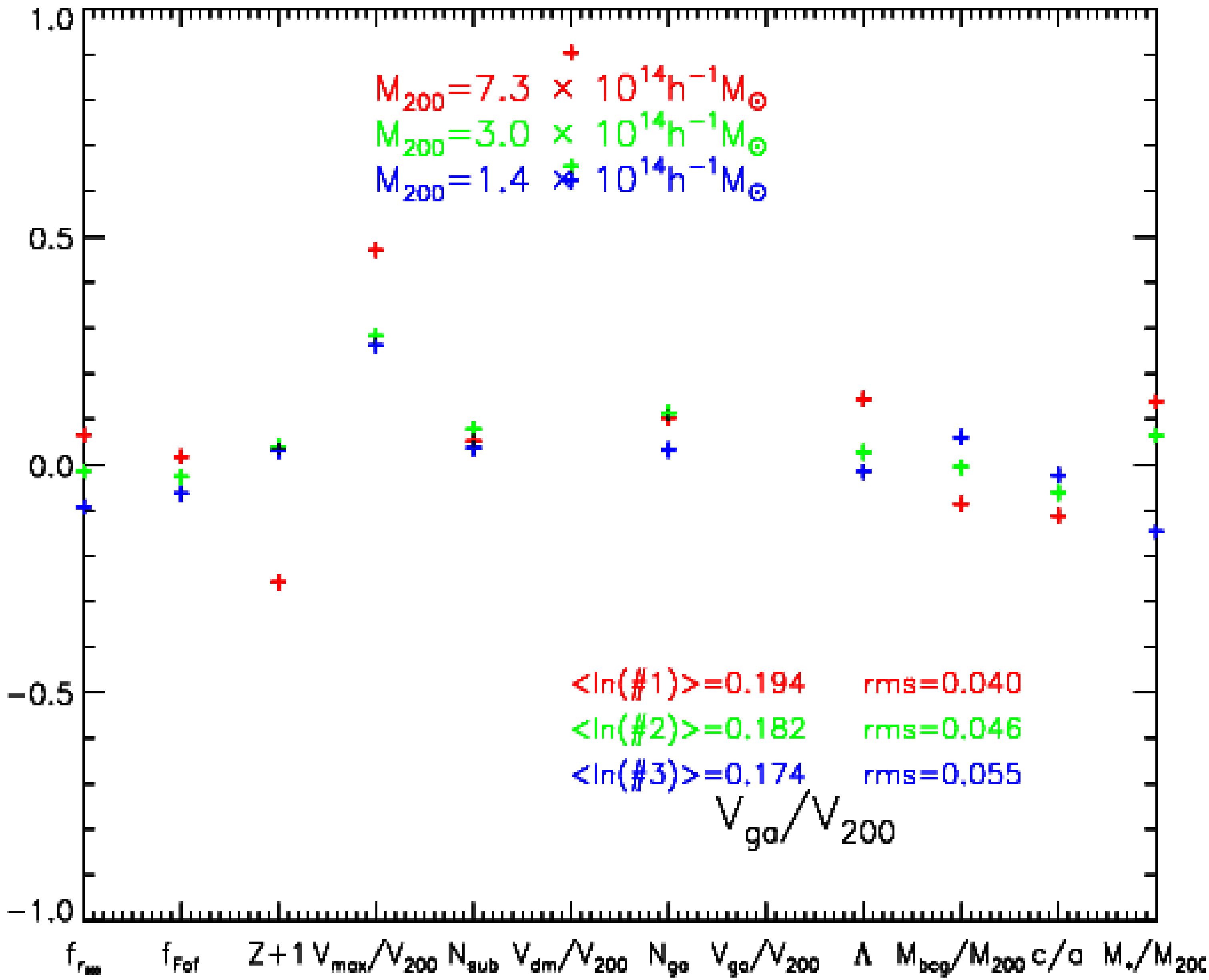
Correlations between cluster properties

Gao & White 2007



Correlations between cluster properties

Gao & White 2007



Correlations between cluster properties

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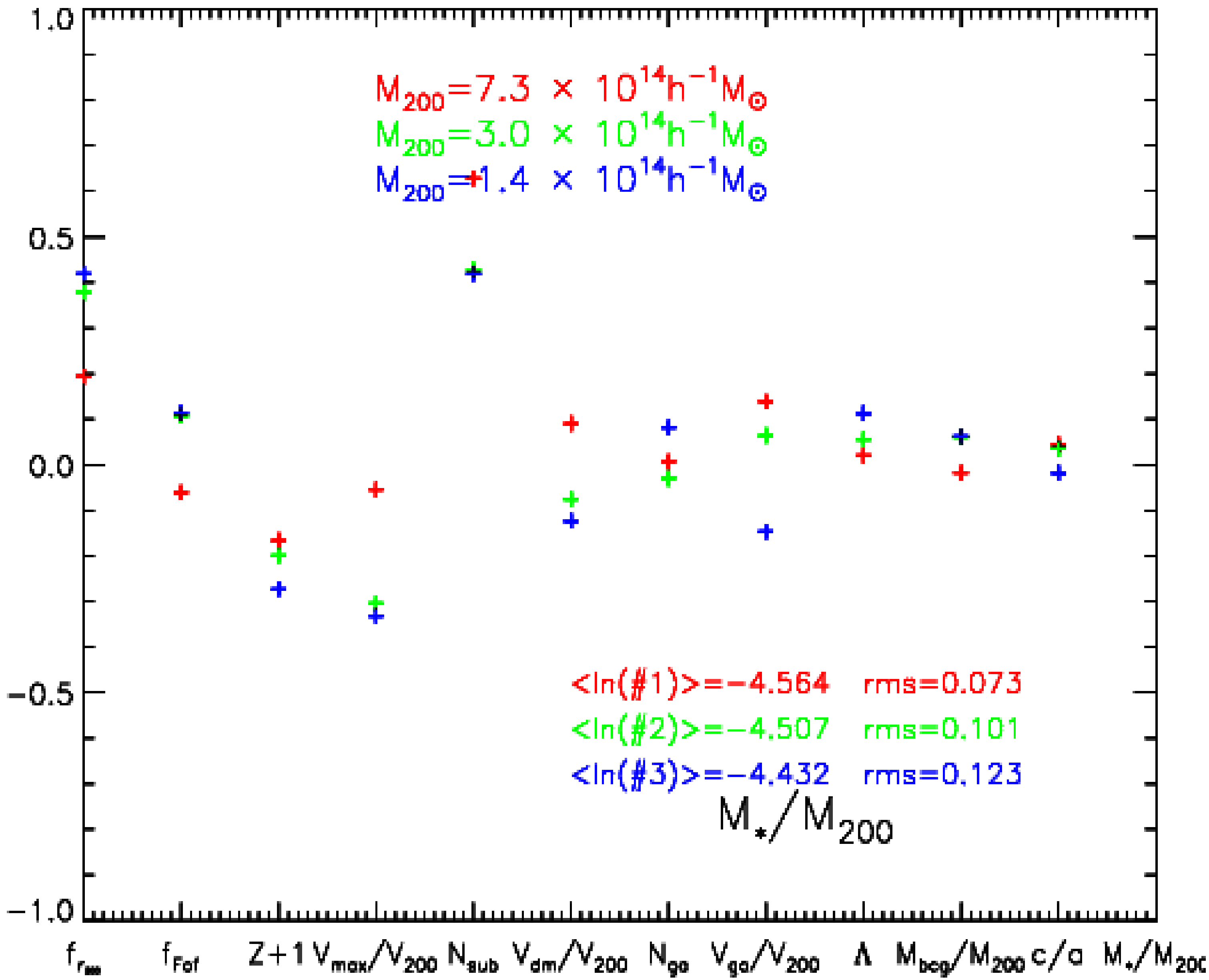

Correlations between cluster properties

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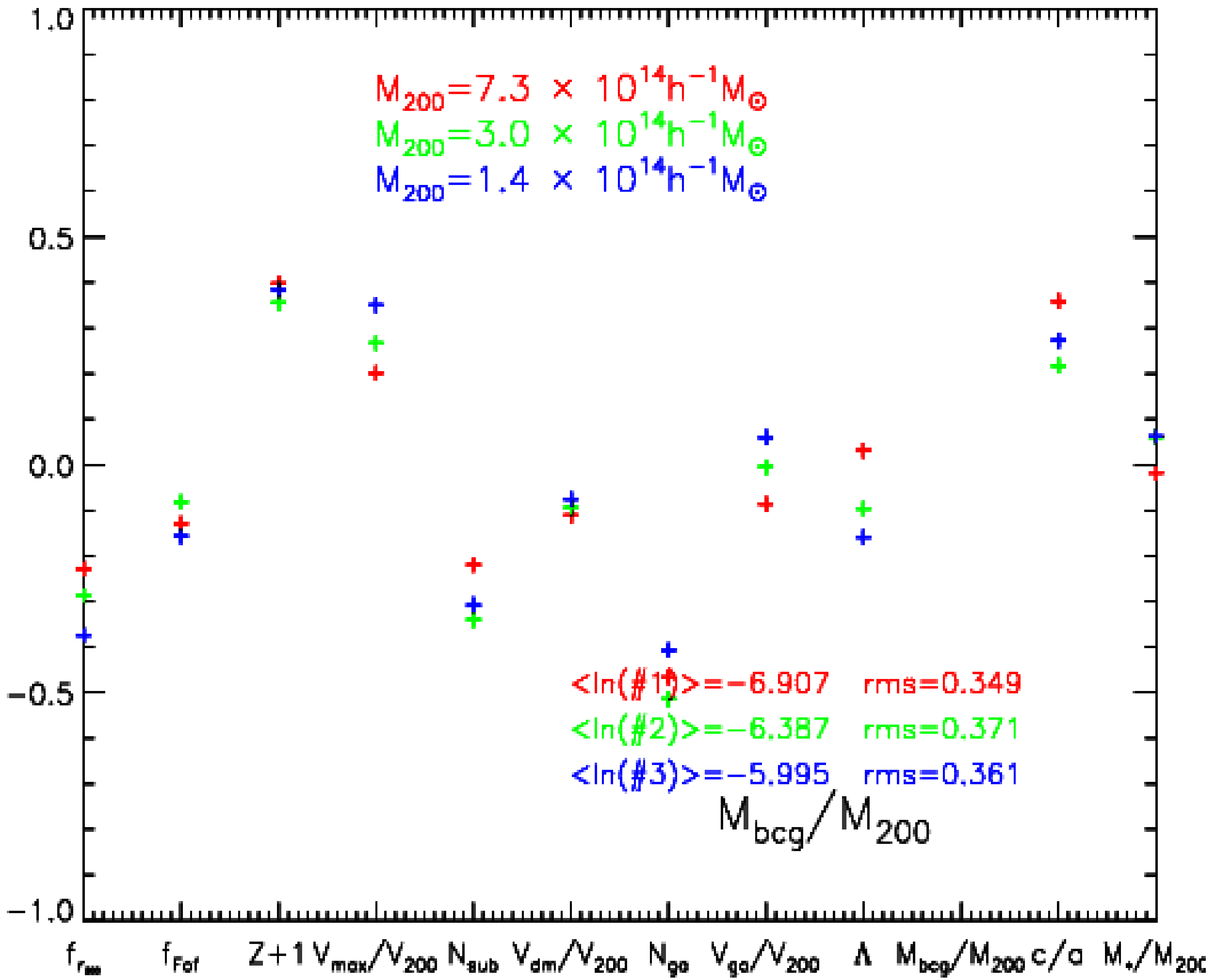
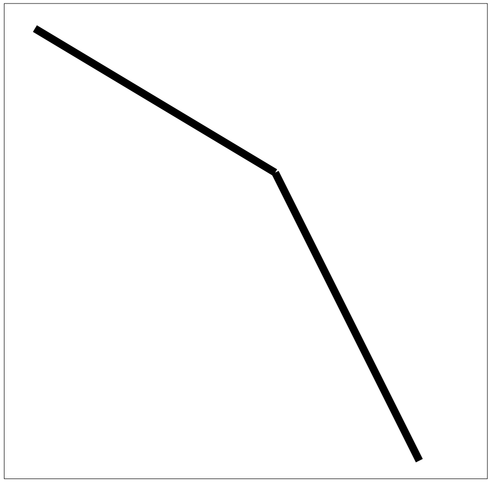


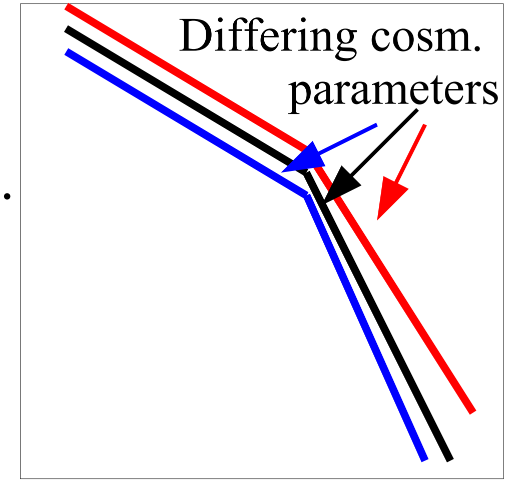
Using cluster abundances to constrain cosmology

Obs. # /squ. deg./unit z



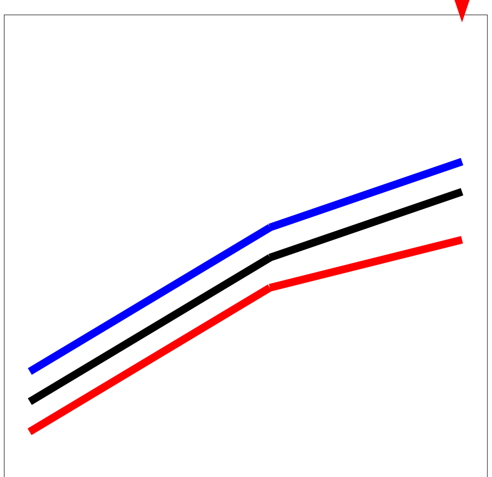
Obs. flux

Pred. # /squ. deg./unit z



Mass (e.g. M_{200})

L_X



Mass (e.g. M_{200})

- Comparison of observed cluster density at given z with prediction for a given model
  $\longrightarrow$ a mass-luminosity relation at z
- Requiring consistency at various z with expected behaviour constrains cosmology
- Expected behaviour must be sufficiently well understood to get a result

Using cluster abundances to constrain cosmology

- Cluster abundance can be <u>measured</u> as a function of L_X, T_X, Y, L_{opt}, M_{lens}, σ_{gal}, .. to a level determined by observational precision and Poisson statistics

- Cluster abundances can be <u>predicted</u> as a function of M_{200}, σ_{dm}, c/a, conc., substr., spin... to a level determined by modelling uncertainties

- Typically each well observed quantity (e.g. L_X) depends on a number of well predicted quantities (e.g. M_{200}, σ_{dm}, c/a, conc.) <u>and</u> on redshift

- Cosmological information can be extracted *only* if these dependences and their redshift variation are sufficiently well understood -- XEUS!

Can clustering information help?

Using clustering to constrain cosmology

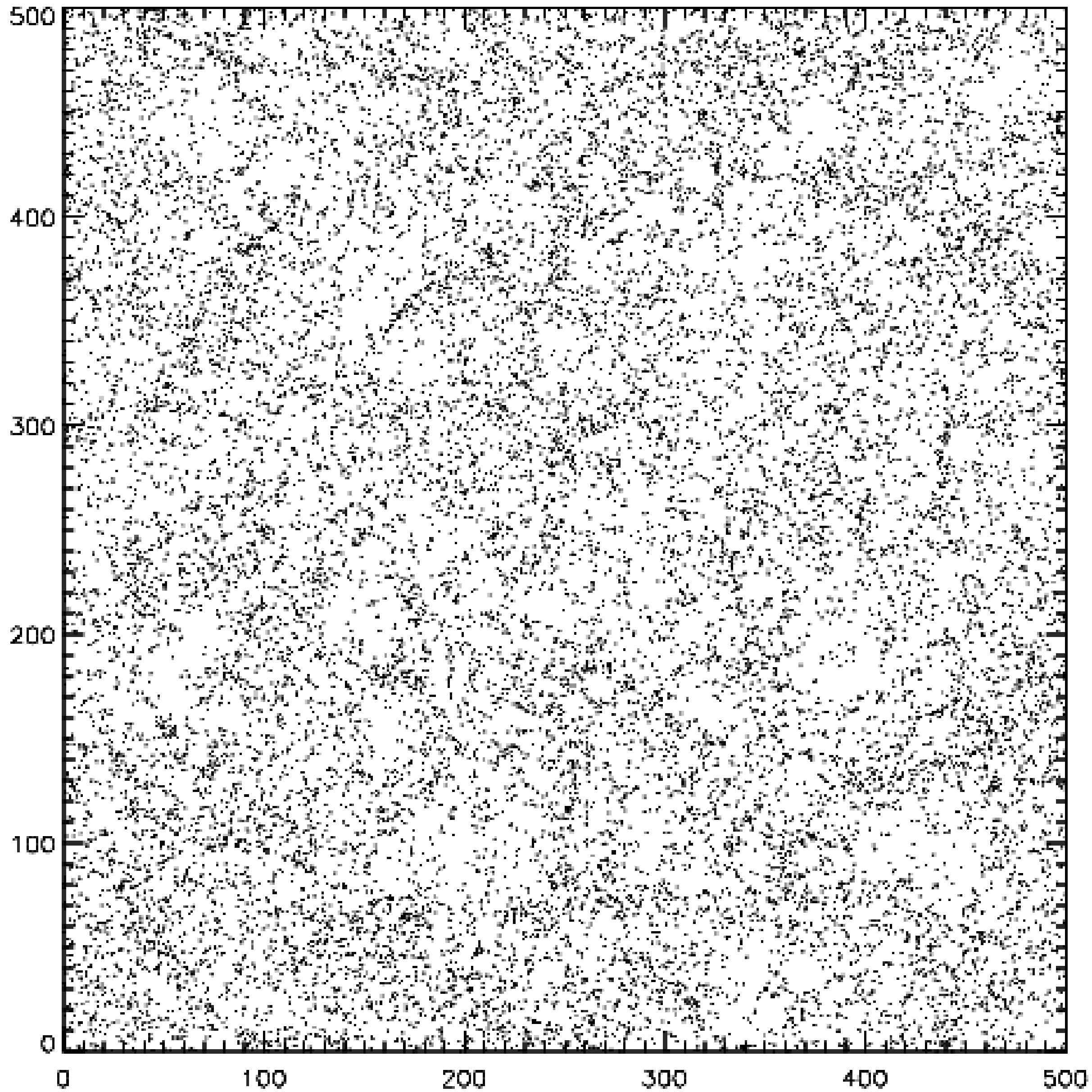
- Observationally one can measure clustering at z as a function of angular scale for clusters with specific properties (L_X, L_X, Y..)

- Theoretically for given cosmology one can predict clustering both for the mass and for clusters with specific properties (M_{200}, c/a..)

- Thus one can compare the two provided the relation between observables and theoretical quantities is well enough known

- This comparison constrains cosmological parameters *provided* the bias can be well enough predicted

Does halo clustering depend on formation history?

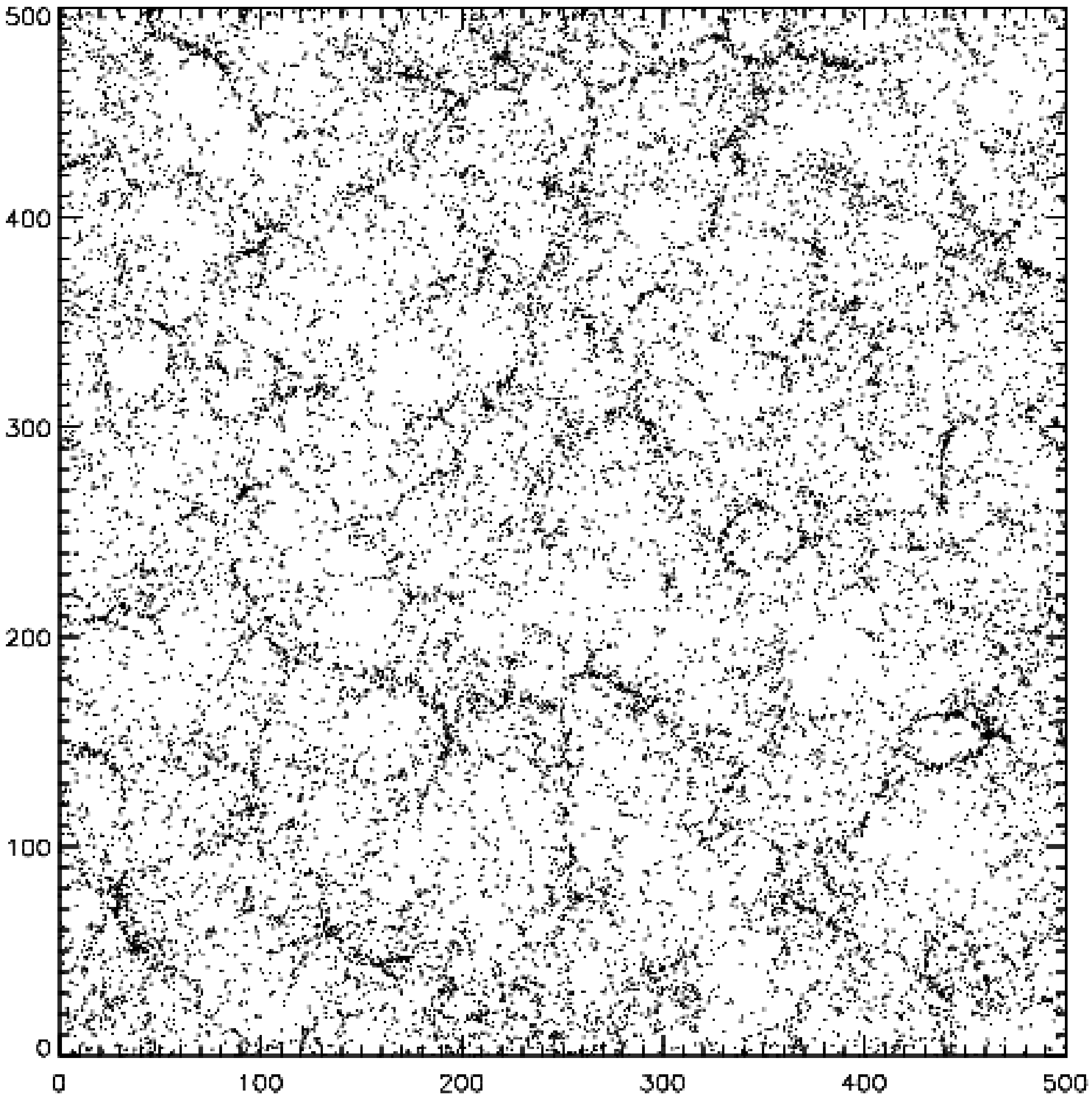


Gao, Springel & White 2005

The 20% of halos with the *lowest* formation redshifts in a 30 Mpc/h thick slice

$$M_{halo} \sim 10^{11} M_{\odot}$$

Does halo clustering depend on formation history?



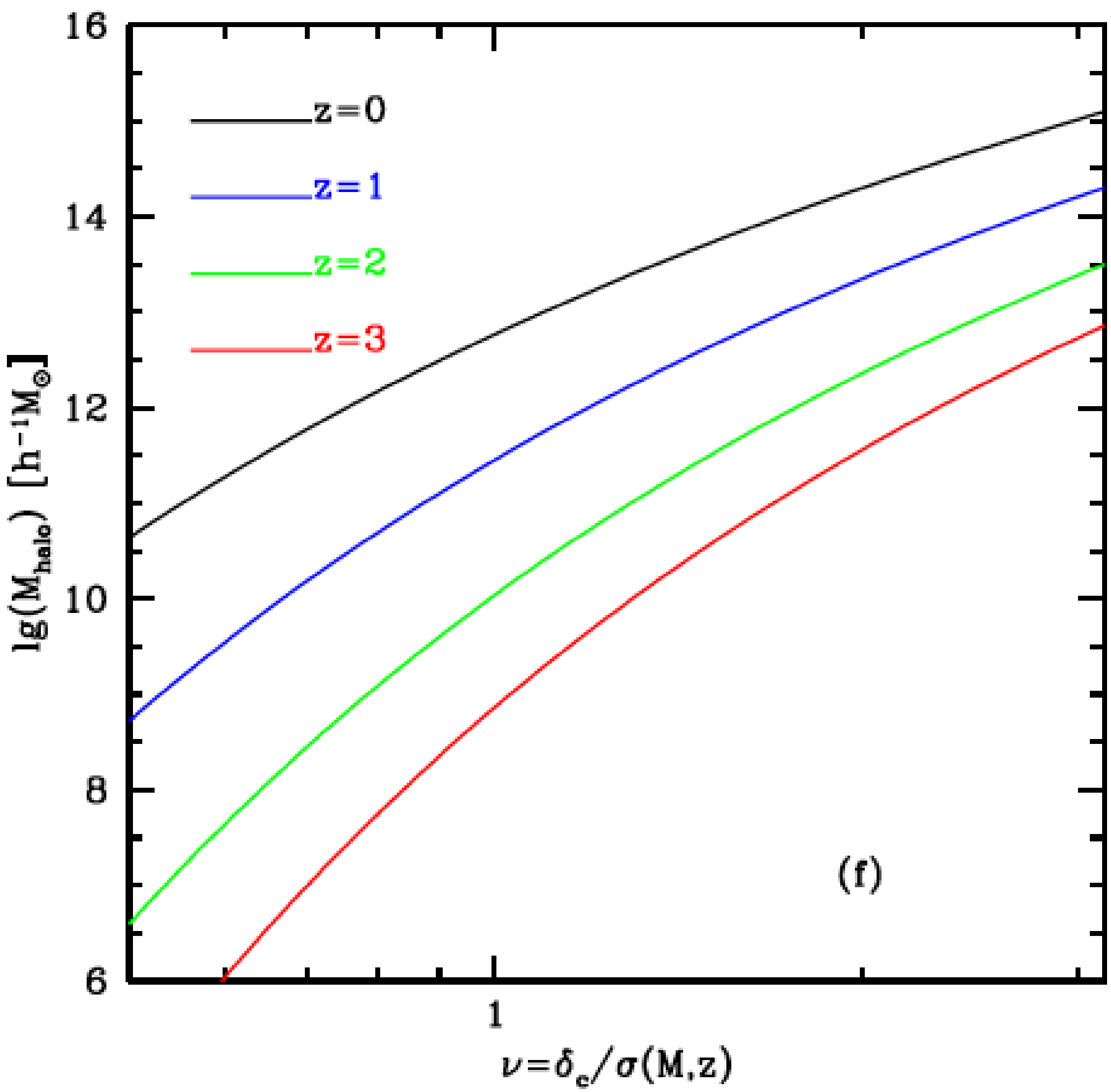
Gao, Springel & White 2005

The 20% of halos with the ***highest*** formation redshifts in a 30 Mpc/h thick slice

$$M_{halo} \sim 10^{11} M_\odot$$

Halo mass as a function of equivalent peak height

Gao & White 2007



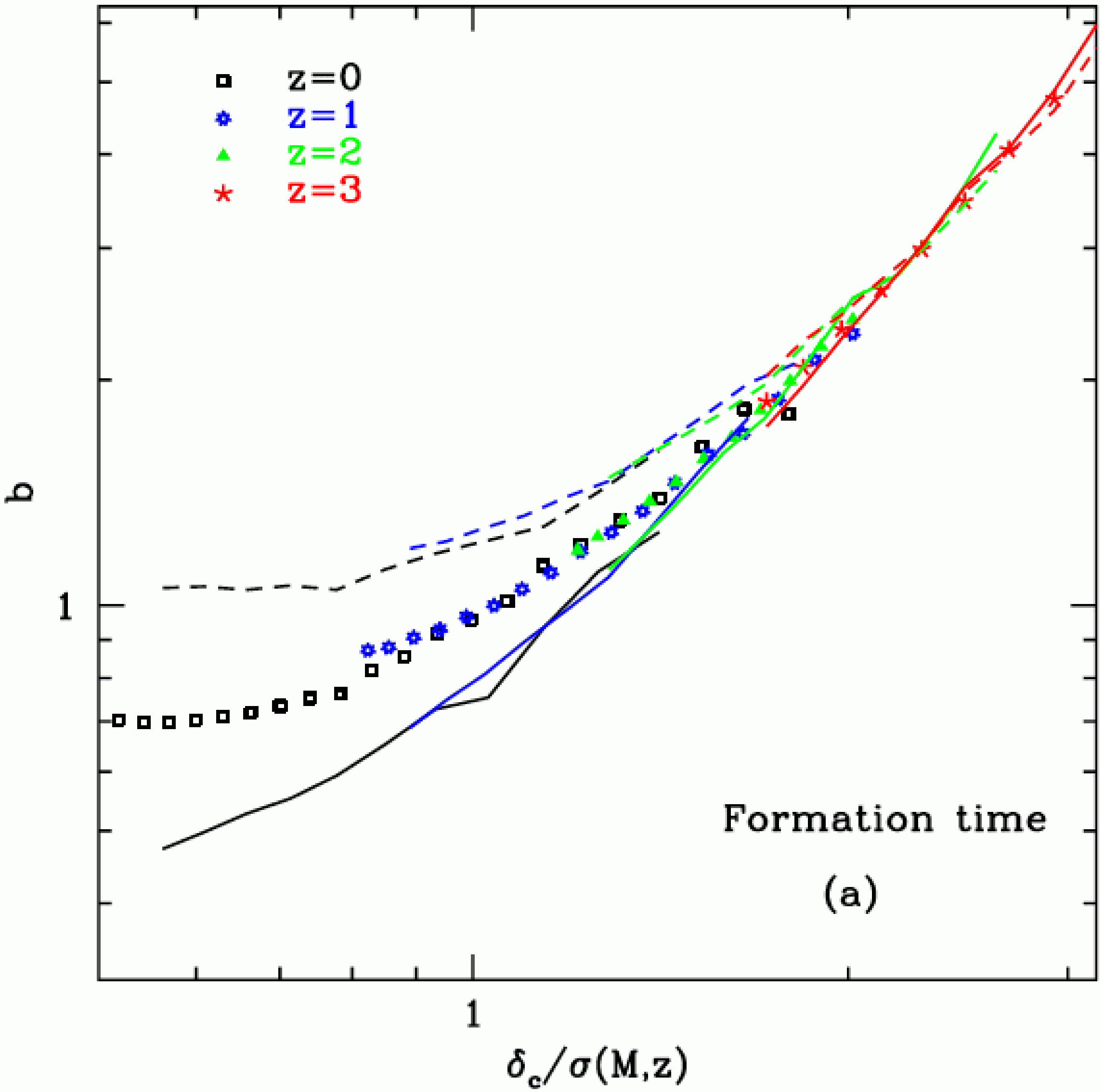
In Press-Schechter models and their extensions both halo abundance and halo bias are functions of the equivalent peak height,

$$\nu(M,z) = \delta_c(z) / \sigma(M),$$

where $\sigma(M)$ is the rms linear fluctuation at z=0 on scale M, and $\delta_c(z)$ is the extrapolated linear present-day overdensity required for collapse at z

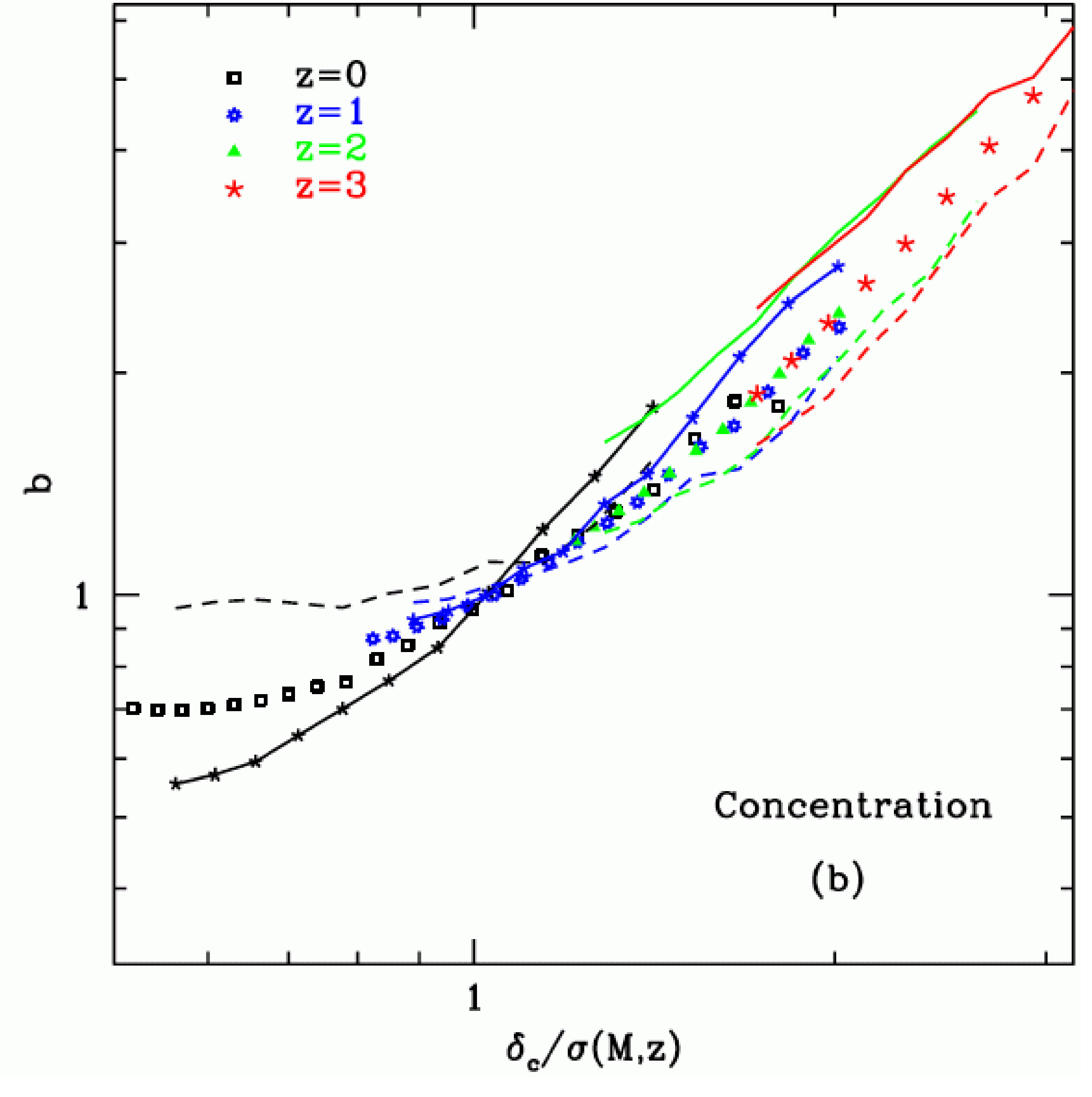
Halo bias as a function of mass and formation time

Gao & White 2007



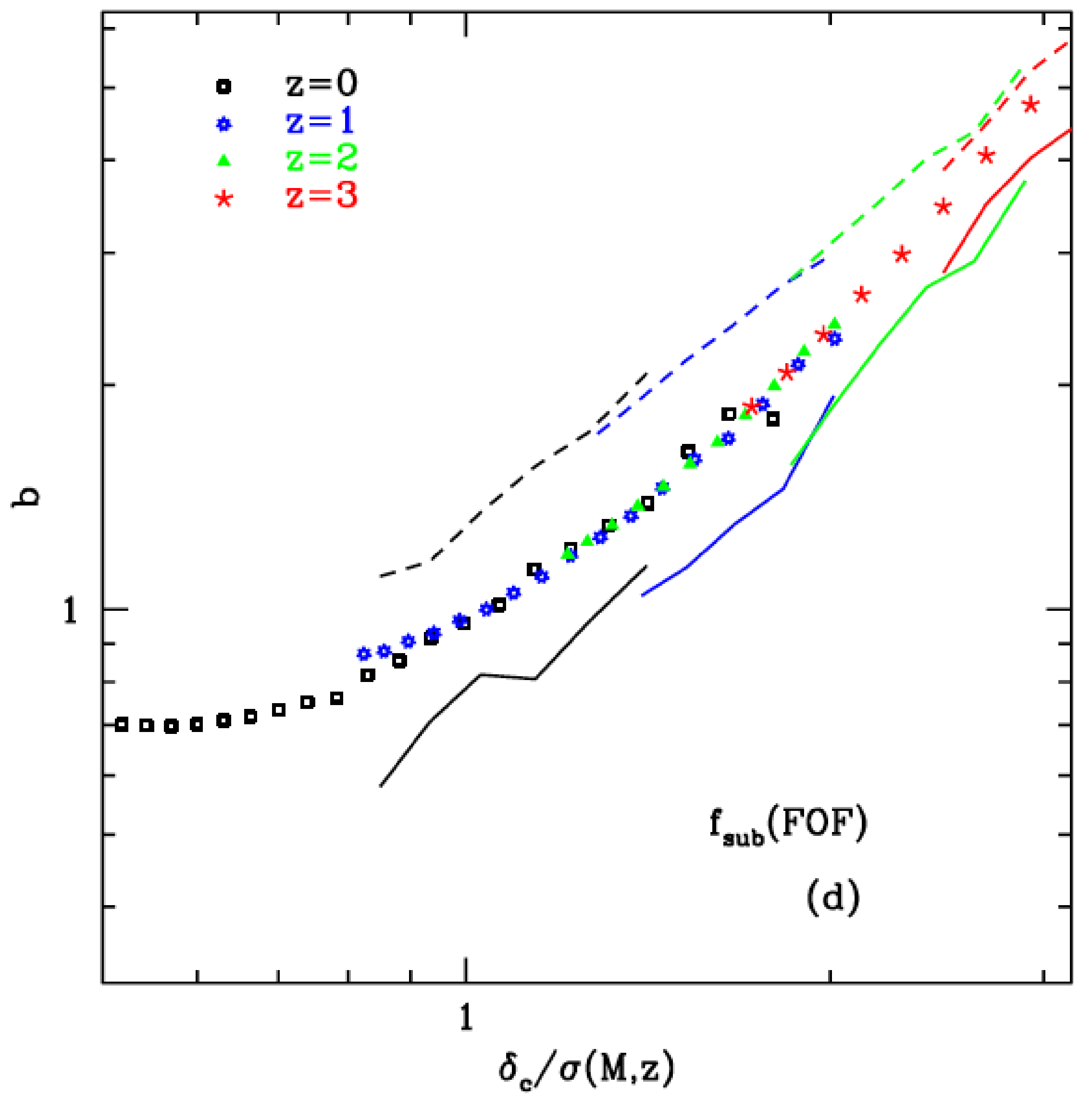
Halo bias as a function of mass and concentration

Gao & White 2007



Halo bias as a function of mass and substructure

Gao & White 2007



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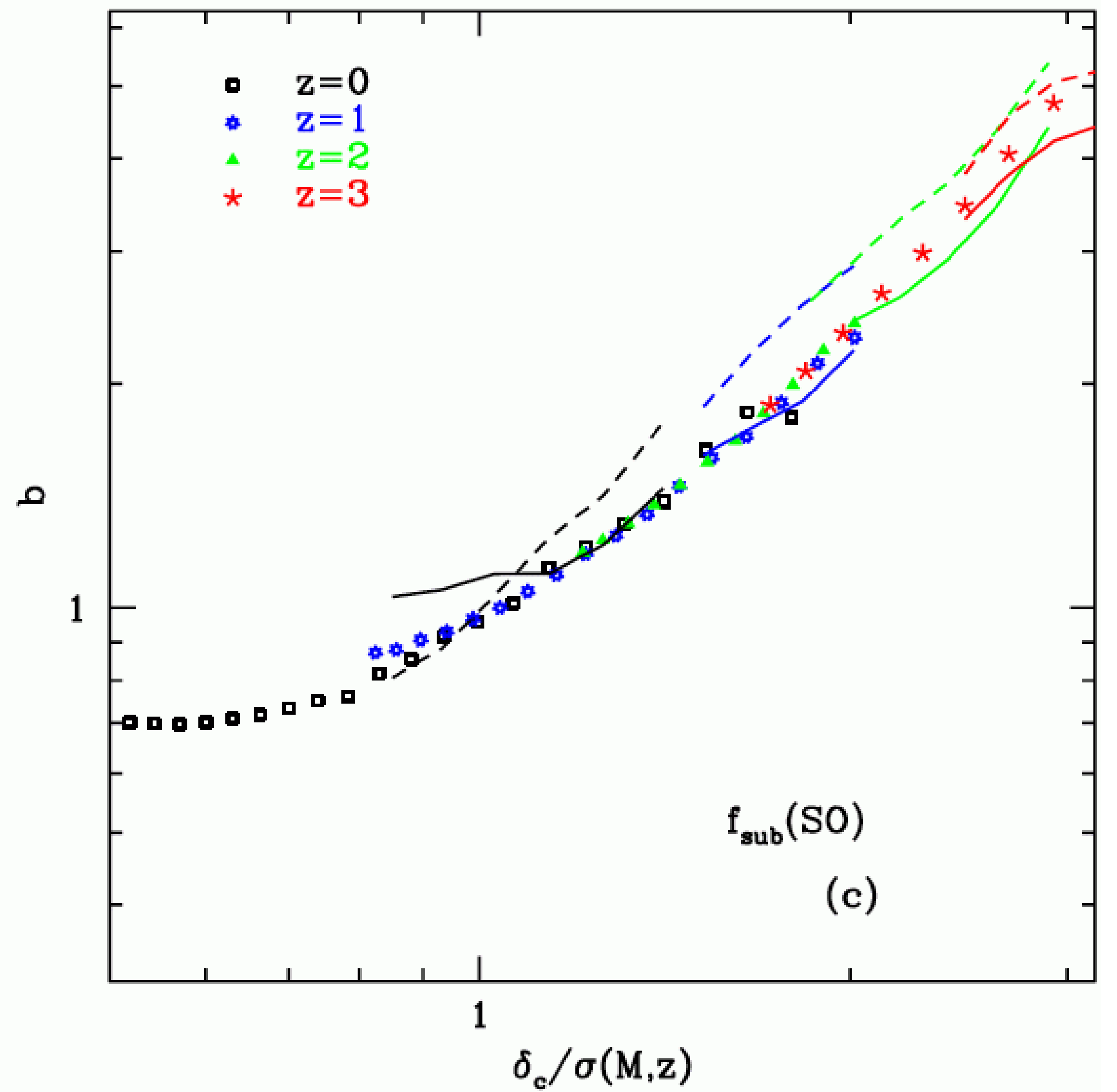
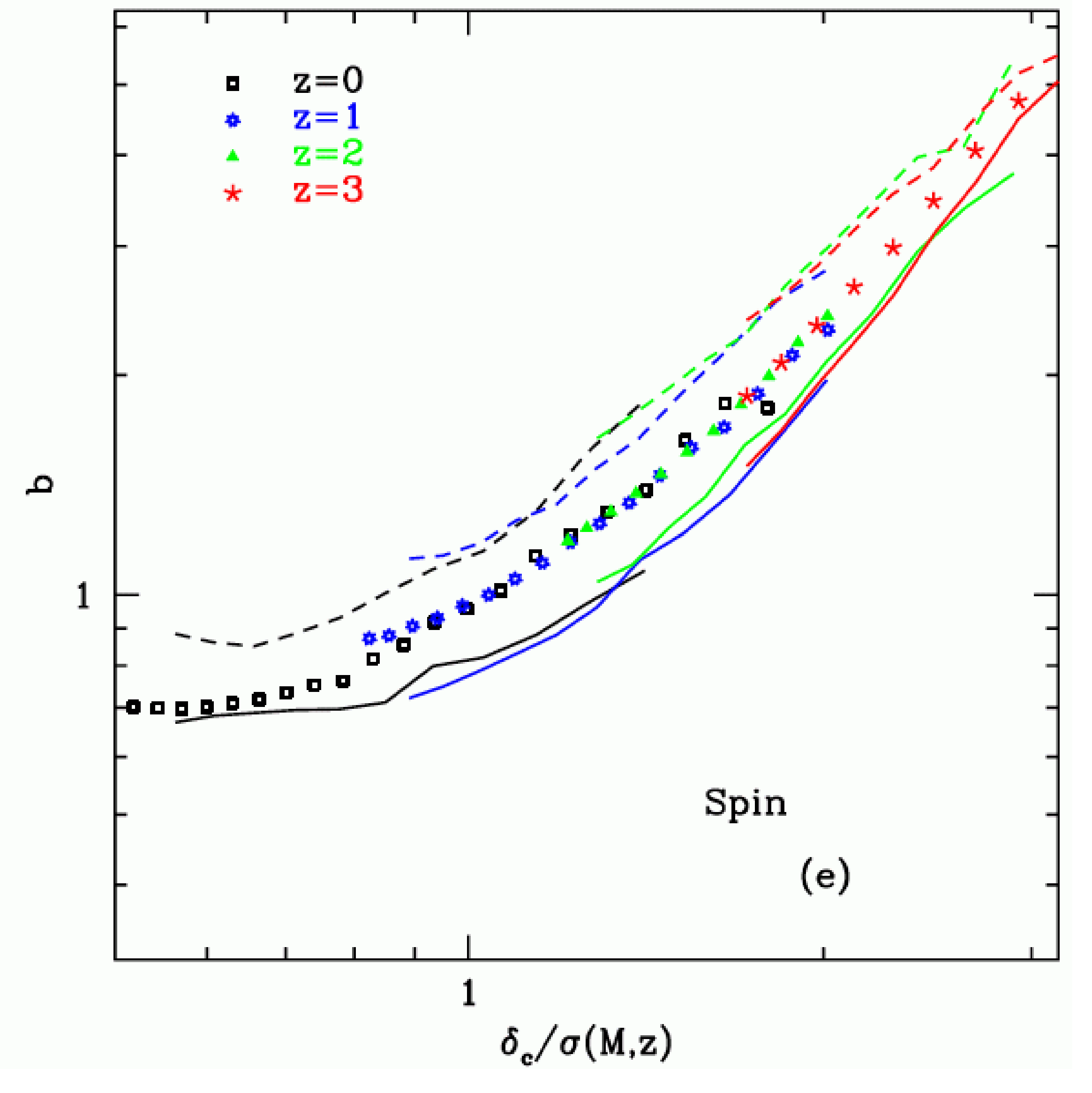
Gao & White 2007



Halo bias as a function of mass and spin

Gao & White 2007



Conclusions?

- Observable cluster properties depend on many cluster variables in addition to mass at the 10 to 20% level

- These dependences and their z-variation must be sufficiently well understood if cluster abundances are to constrain cosmology

- At the 10% level the large-scale bias of cluster populations is a complex function of cluster properties in addition to mass

- Substantial theoretical and numerical work is needed to make cluster abundances and clustering into precise enough tools to constrain Dark Energy. Observational confirmation through studies of cluster structure will be critical to getting a credible result.

  → XEUS!