Prospects for Galaxy Cluster Research with eROSITA

Hans Böhringer (MPE)

With help from Gayoung Chon and Martin Mühlegger (MPE)

Overview

- Galaxy clusters as astrophysical laboratories

  -- and probes to test cosmological models

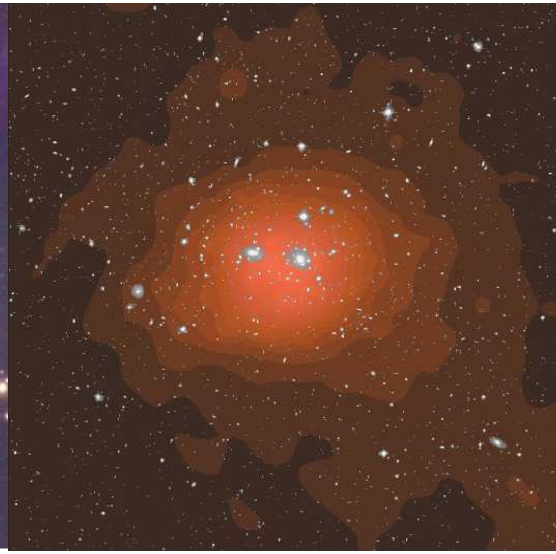
- Statistics of galaxy cluster detections in eROSITA

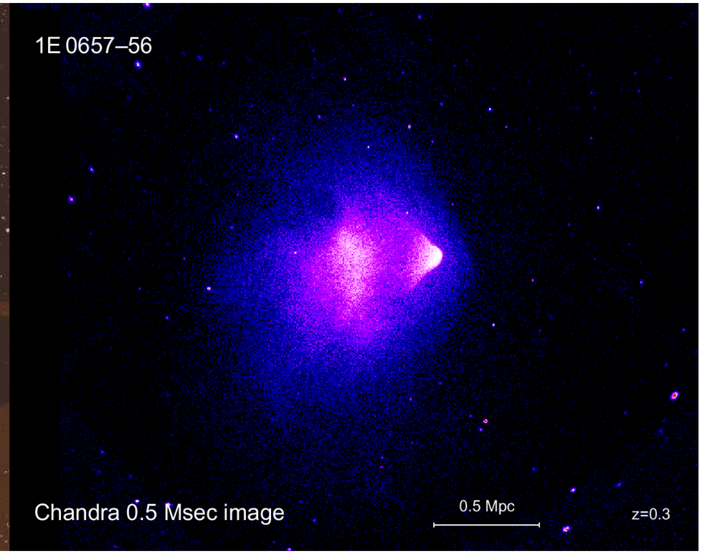
- Dependence of cluster number counts on astrophysics and cosmology

- Studies with eROSITA clusters

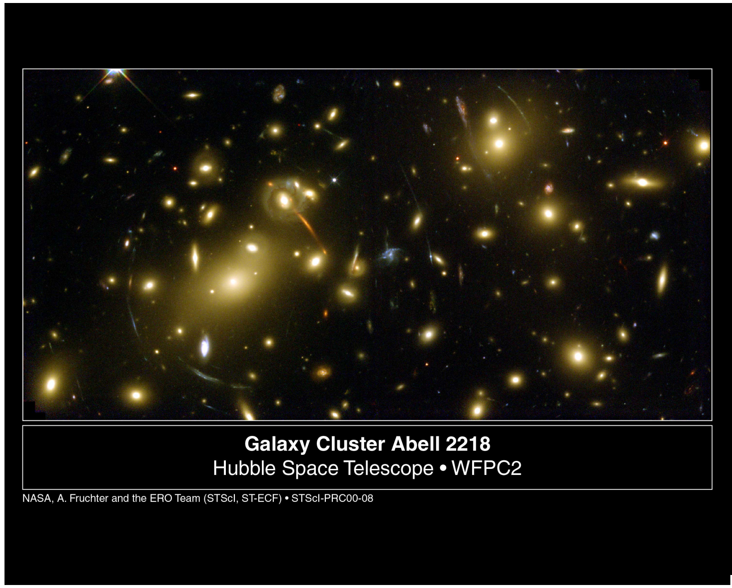
Galaxy Clusters as Laboratories

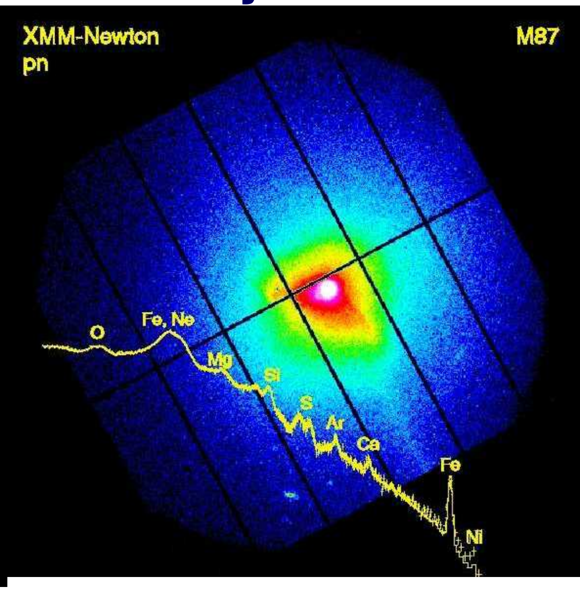
For: galaxy population intergalactic plasma cluster dynamics

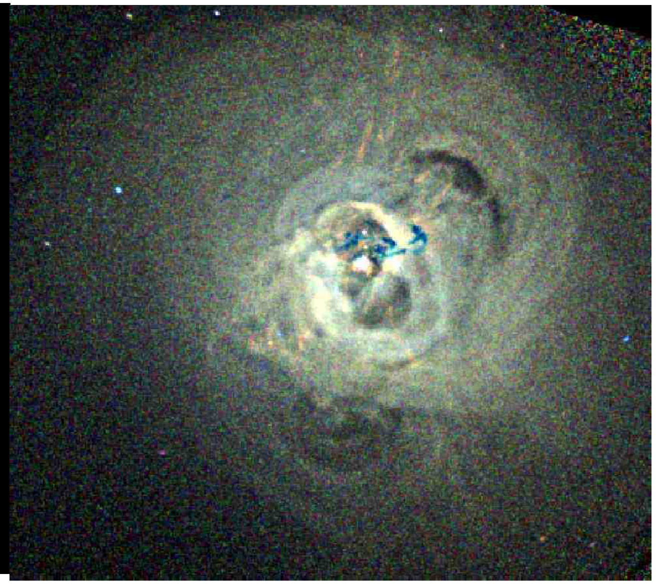




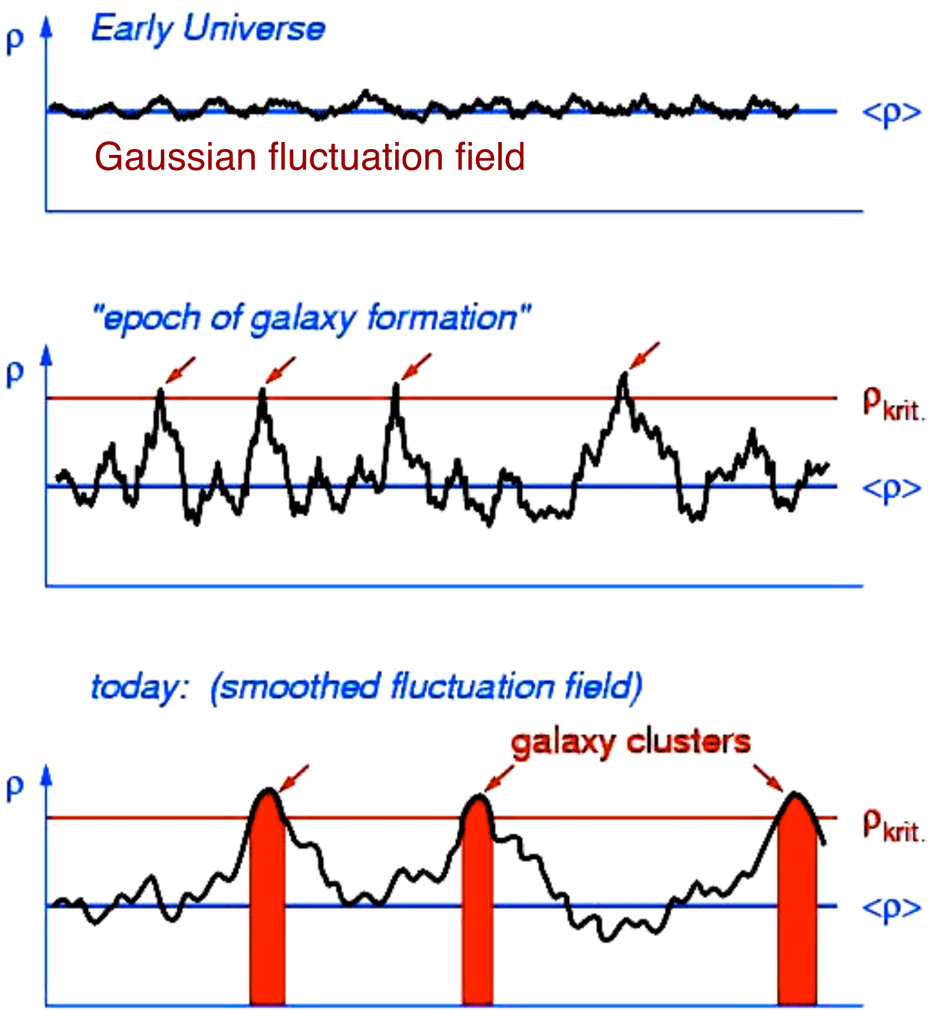
dark matter distribution nucleosynthesis AGN feedback







The Role of Galaxy Clusters in the Hierarchy of Large-Scale Structure



mass of galaxy clusters ~ $10^{14} – 10^{15}$ M_{sun}

From the cluster population:

1) Fluctuation amplitude and shape of $\mathbf{P(k)_{DM}}$ (over few Mpc range) by cluster **abundance**
2) Large-scale cluster density distribution $\mathbf{P(k)_{CL}}$ and its **bias** above $P(k)_{DM}$
3) The **evolution** of the cluster population – testing the growth of structure
4) Evolution of internal cluster properties

Cosmological model
H_0 Ω_m Ω_Λ Ω_B (w)

← **cosmological parameters**

↓

Generation of density fluctuations
σ_8 $P_0(k)$

← **primordial P(k)**
Test of inflation

↓

Nature of the Dark Matter
CDM (HDM) ? (transfer fct.)

← **form of DM (e.g. neutrinos)**

↓

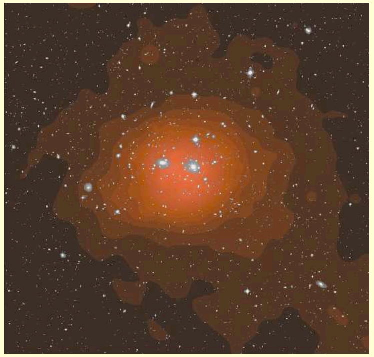
Structure evolution
(gravitational effect)

← **effect of Dark Energy**

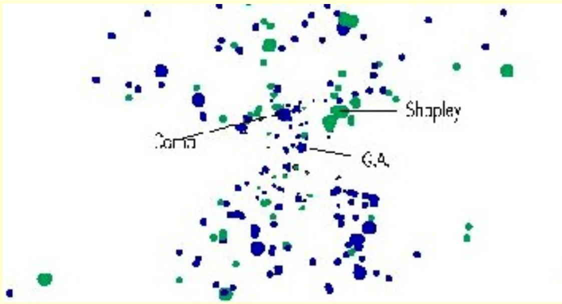
↓

Galaxy clusters mass function

Large-scale galaxy/cluster distribution



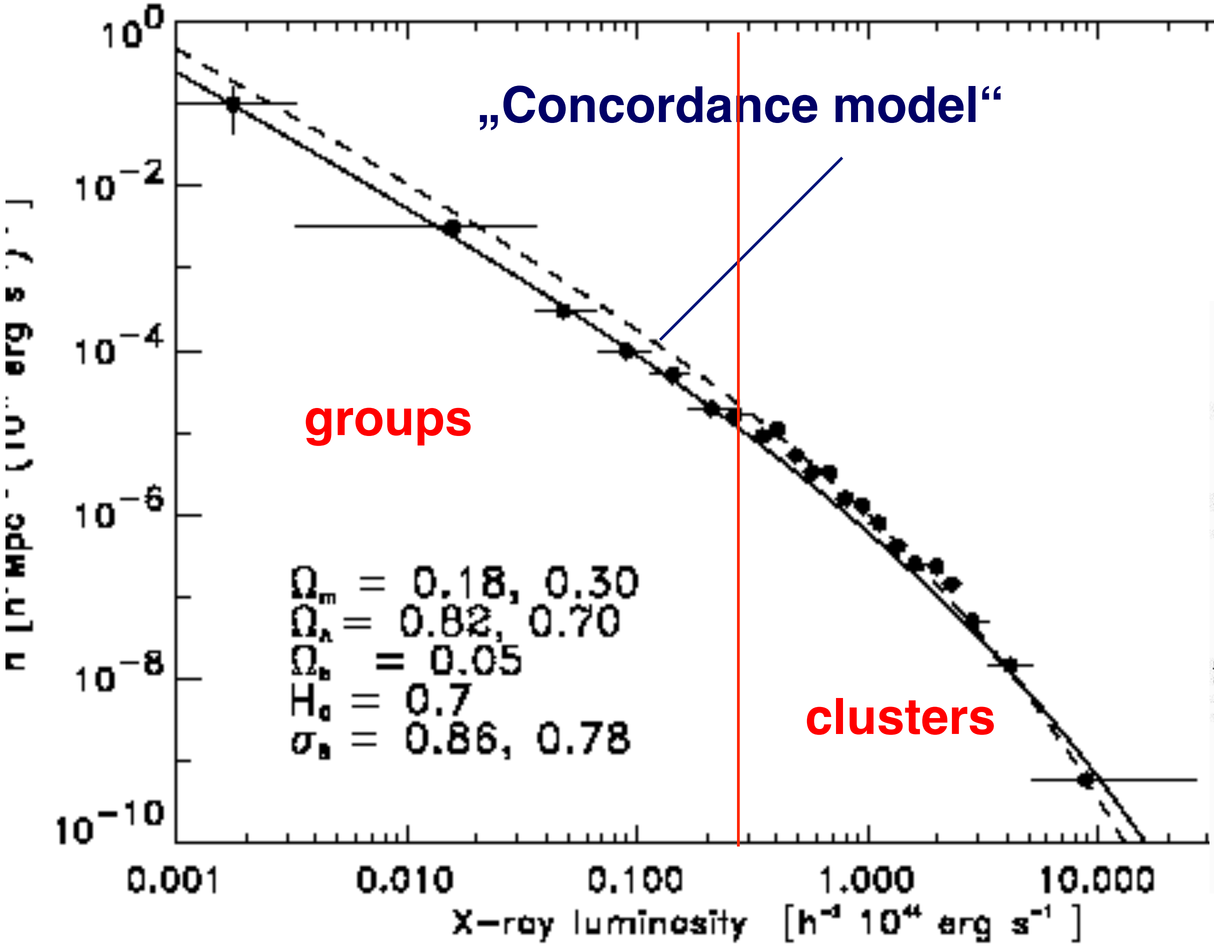
$$\frac{dN^2}{dMdz}$$

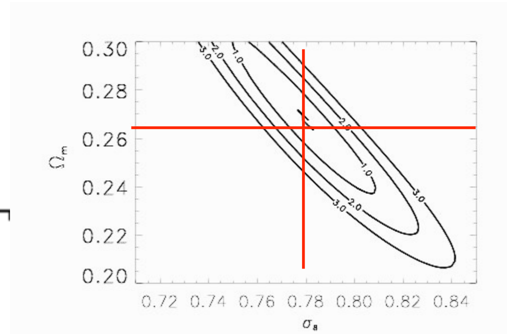


$P(k)_{clus}$

From cosmological model predicted and observed X-ray luminosity function

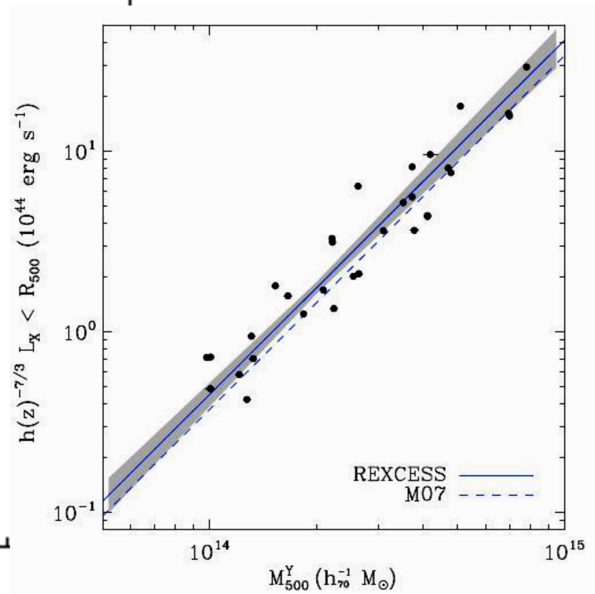
REFLEX I survey (Böhringer et al. 2002)





Ω_m = 0.27 +- 0.05

σ_8 = 0.78 +- 0.04



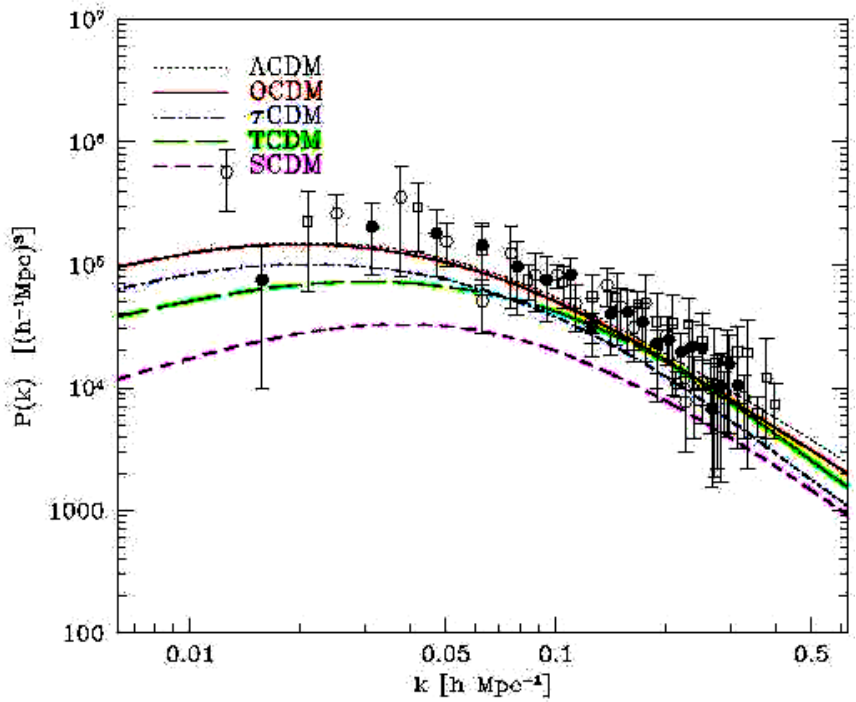
Lx – mass relation

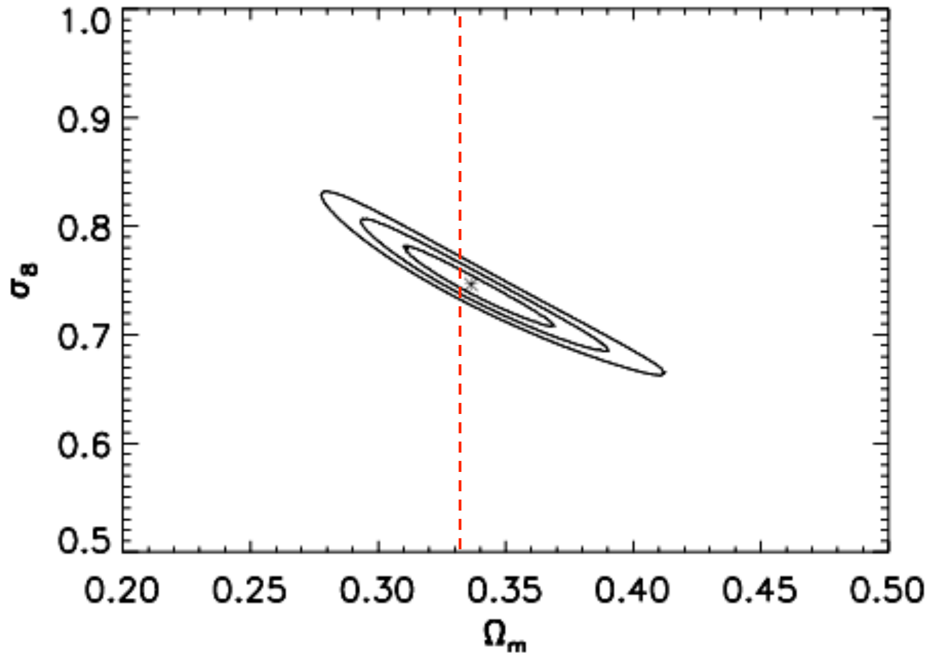
(REXCESS) Pratt et al. 09

Constraints on Cosmological Models and Ω_m from the REFLEX Cluster Survey

REFLEX power spectrum

Volume-limited samples with boxlength of: 300, 400, 500 h^{-1} Mpc

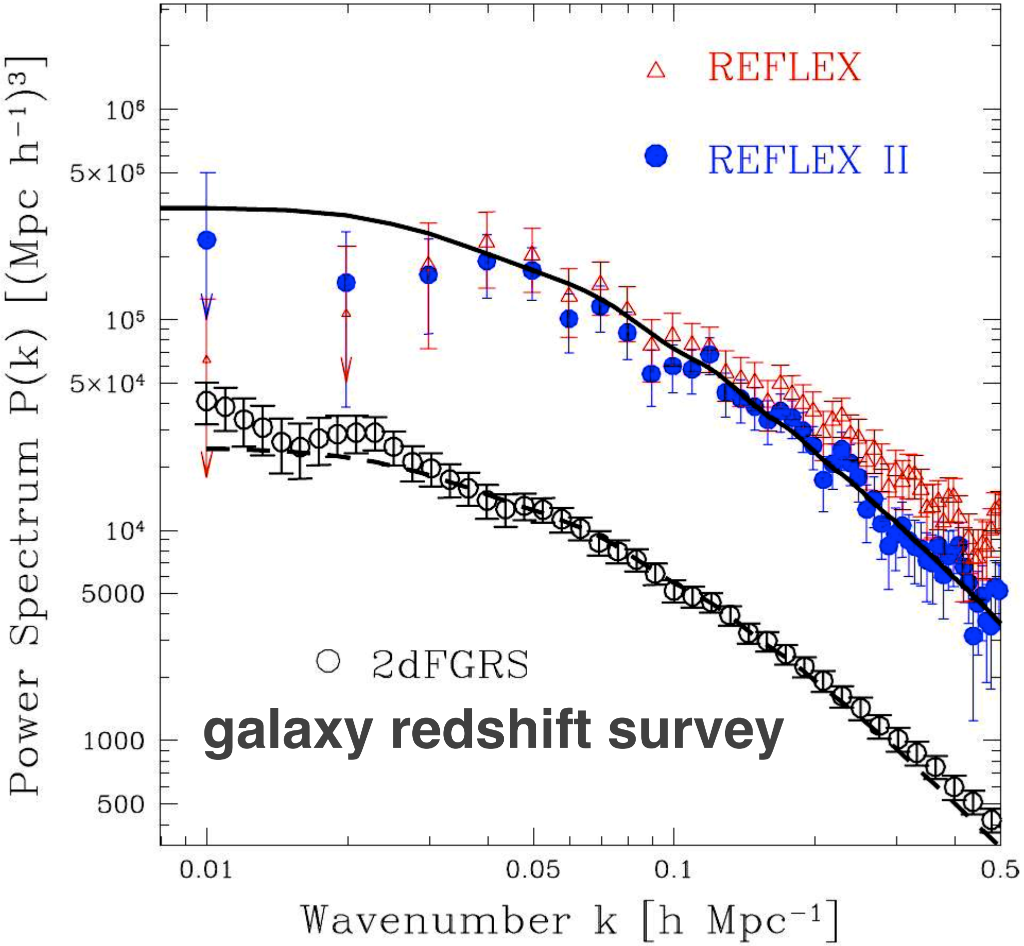




$\Delta\Omega_m$ ~ 0.34 +-0.05 (+ syst. errors +-0.05) 2σ !

[Schuecker et al. 2002, 03]

REFLEX II Power Spectrum (ΛCDM-Cosmology)

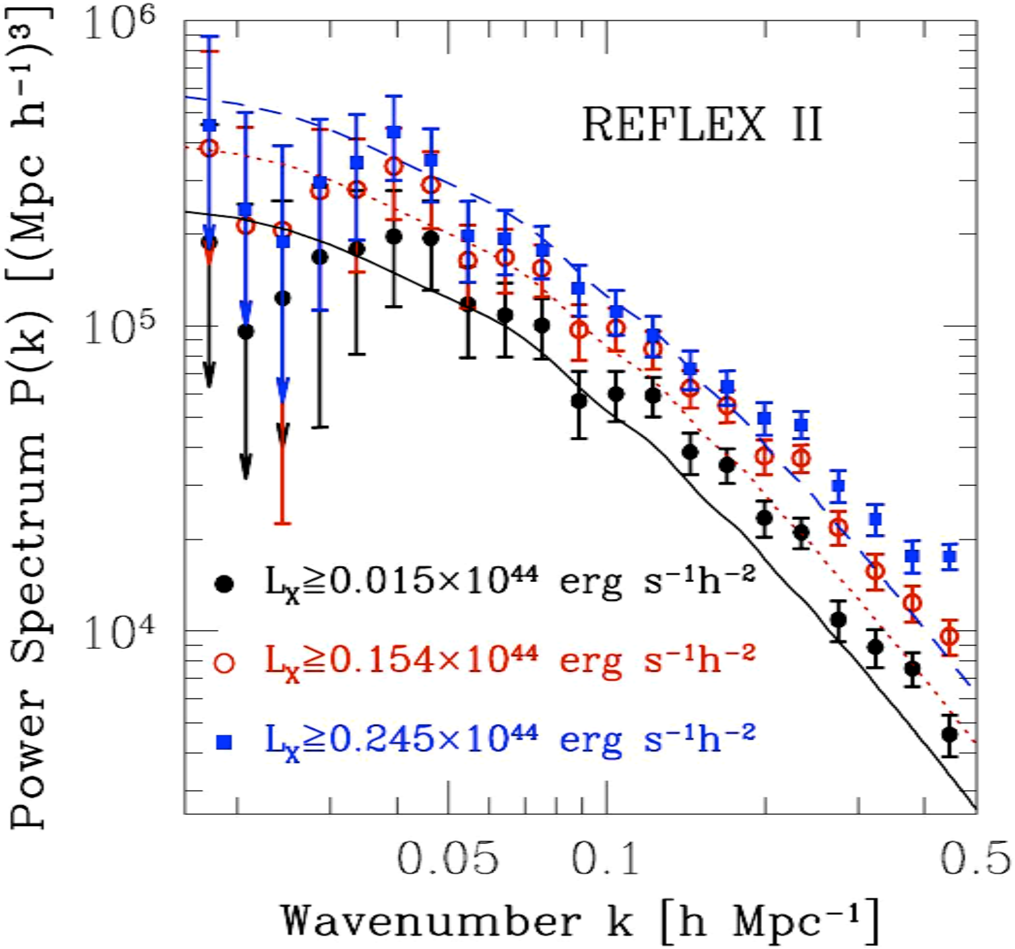


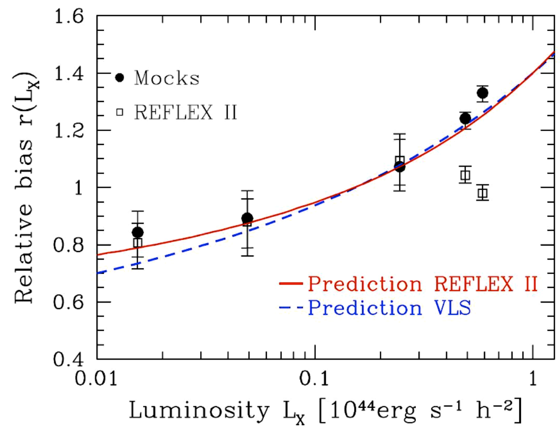
The lines give the prediction of the Concordance Cosmological Model with WMAP 5yr parameters

Balaguera-Antolinez et al. 2010

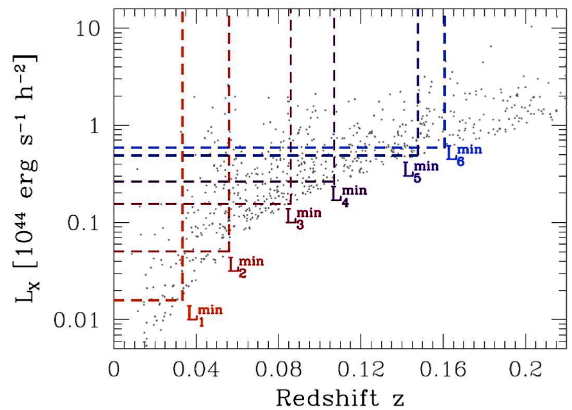
REFLEX II Power Spectrum (biasing)

The amplitude of the P(k) increases with increasing lower mass limit

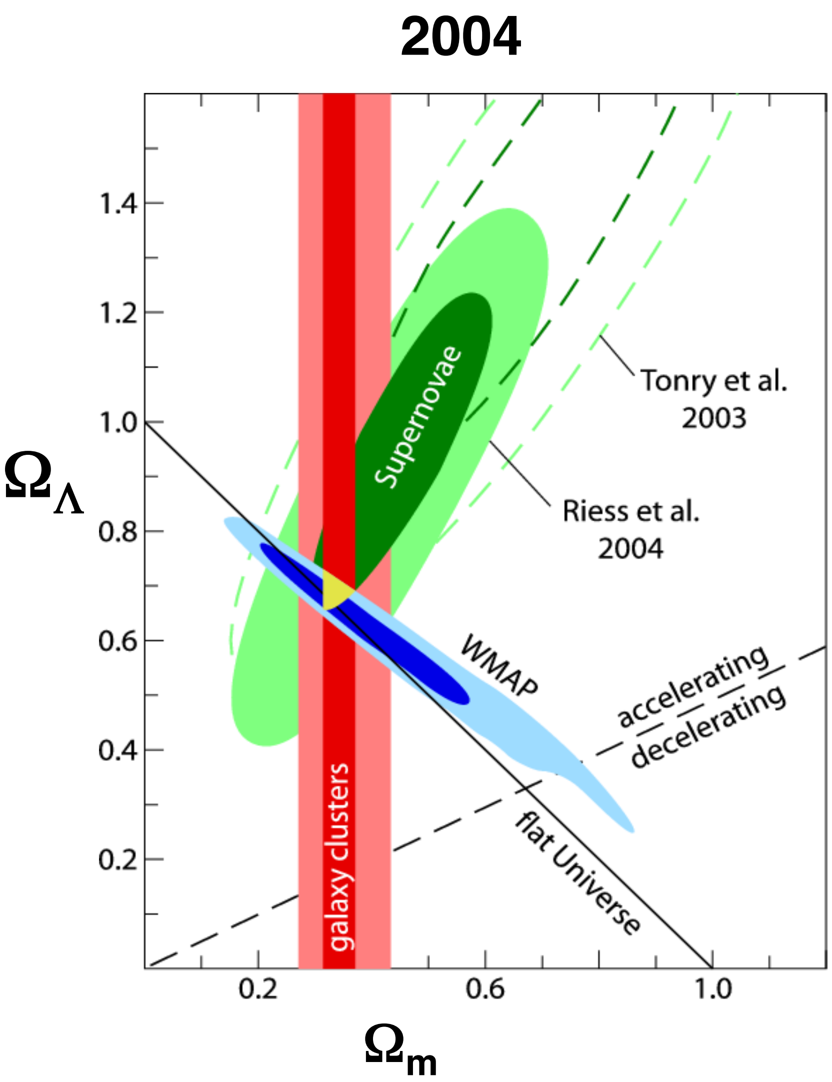


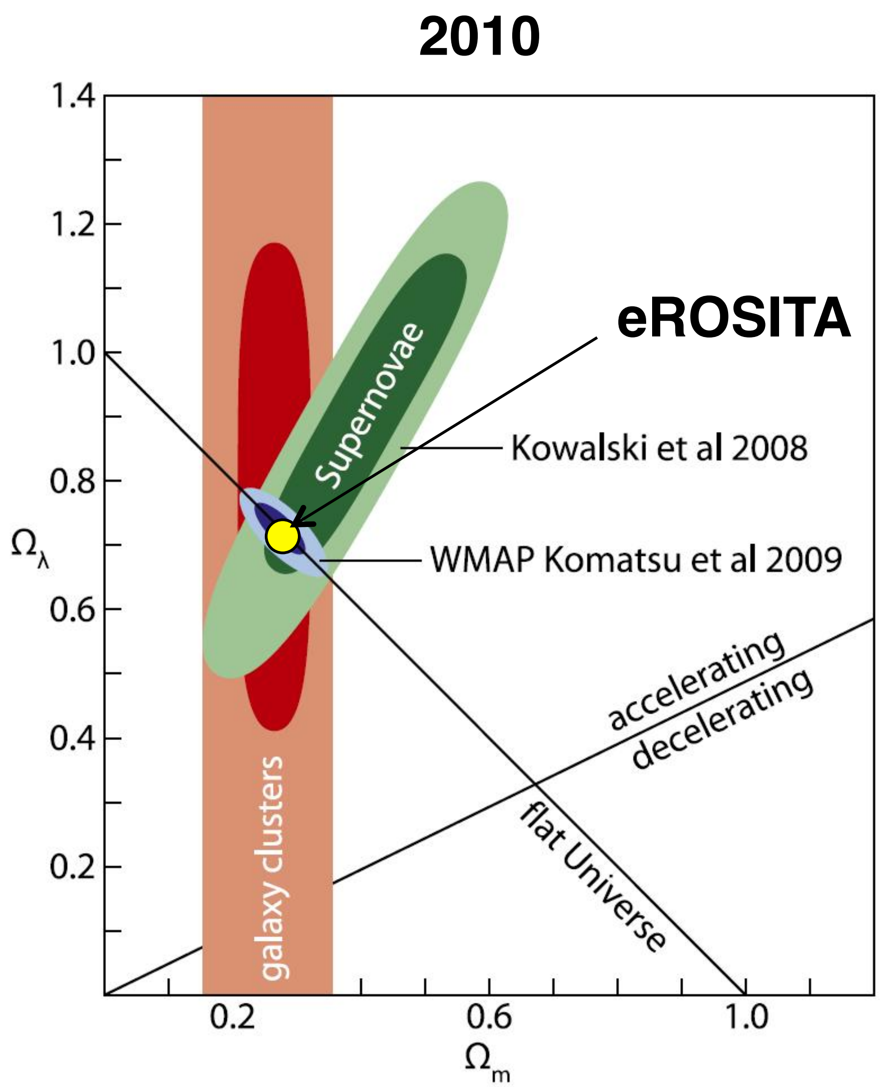


Increase of the amplitude (above) for 6 volume limited subsamples



Comparison of Observational Model Constraints





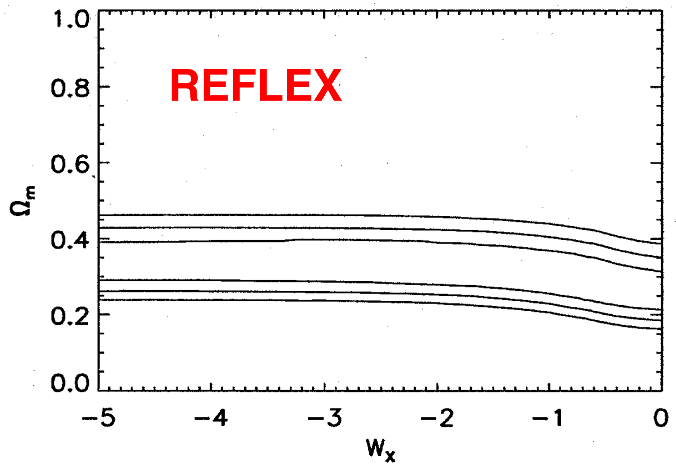
WMAP results (1 yr)
REFLEX I results

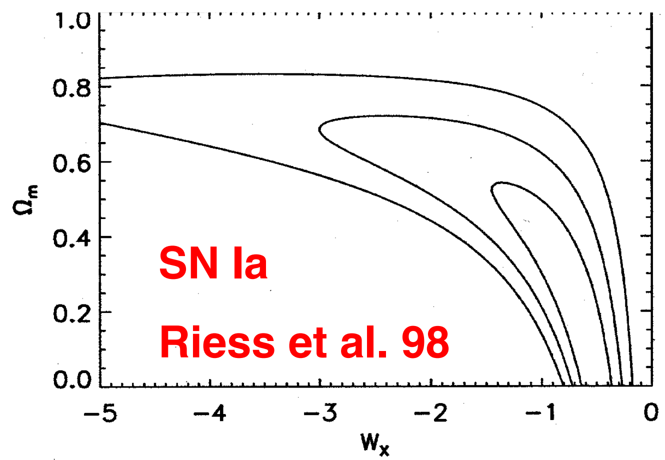
Constraints strongest from WMAP
But WMAP does not constrain w(DE) !

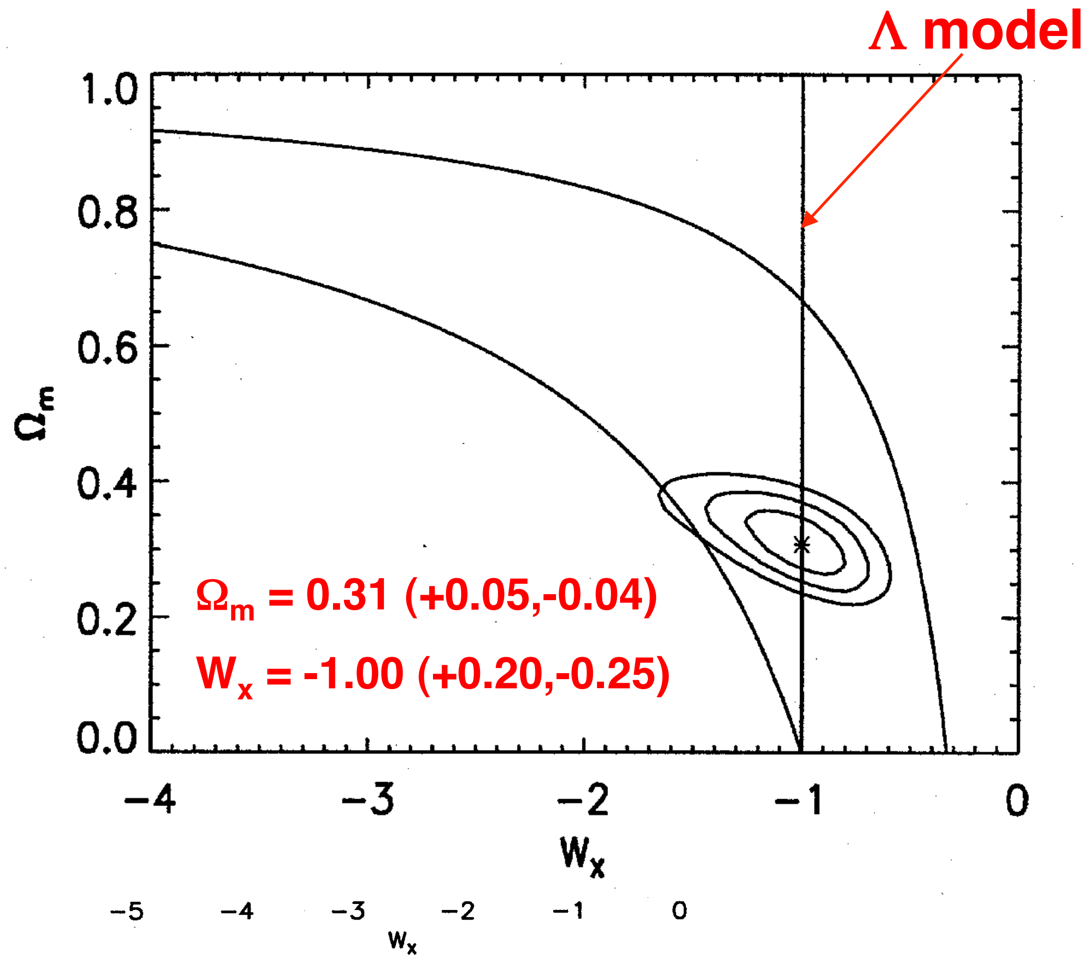
Combined Constraints REFLEX & SN Ia on Ω_m and W_x

$$\Lambda \Rightarrow \rho_x(z) \quad ; \; w = \frac{P_x}{\rho_x}$$

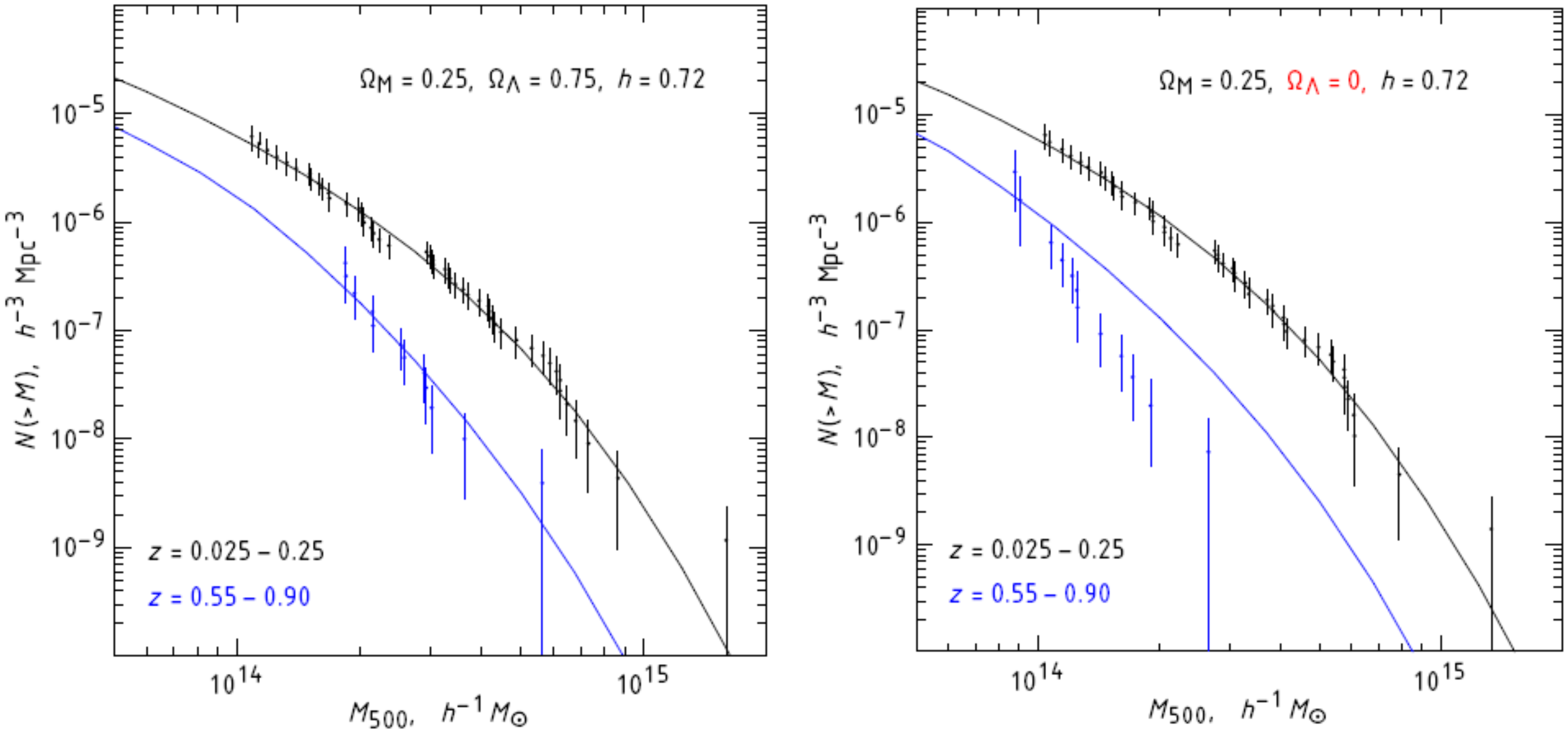
Data from REFLEX and SN observations



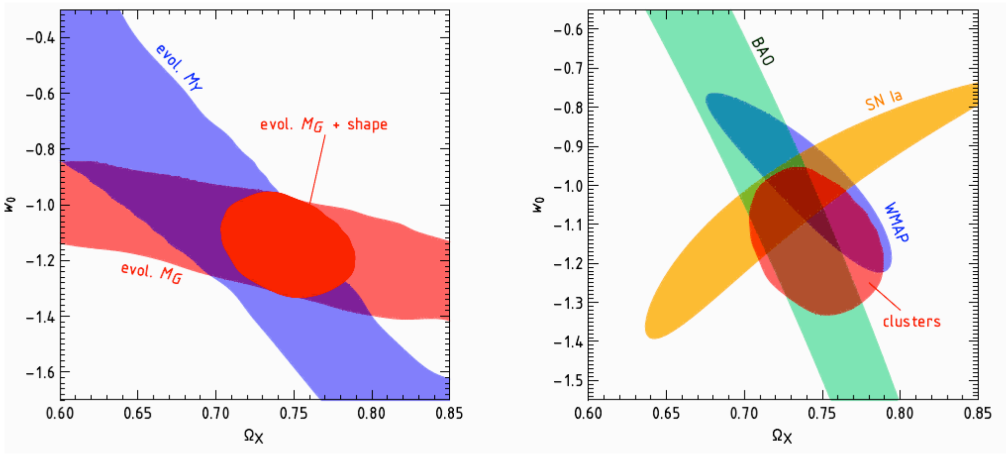




Evolution of the Cluster Mass Function



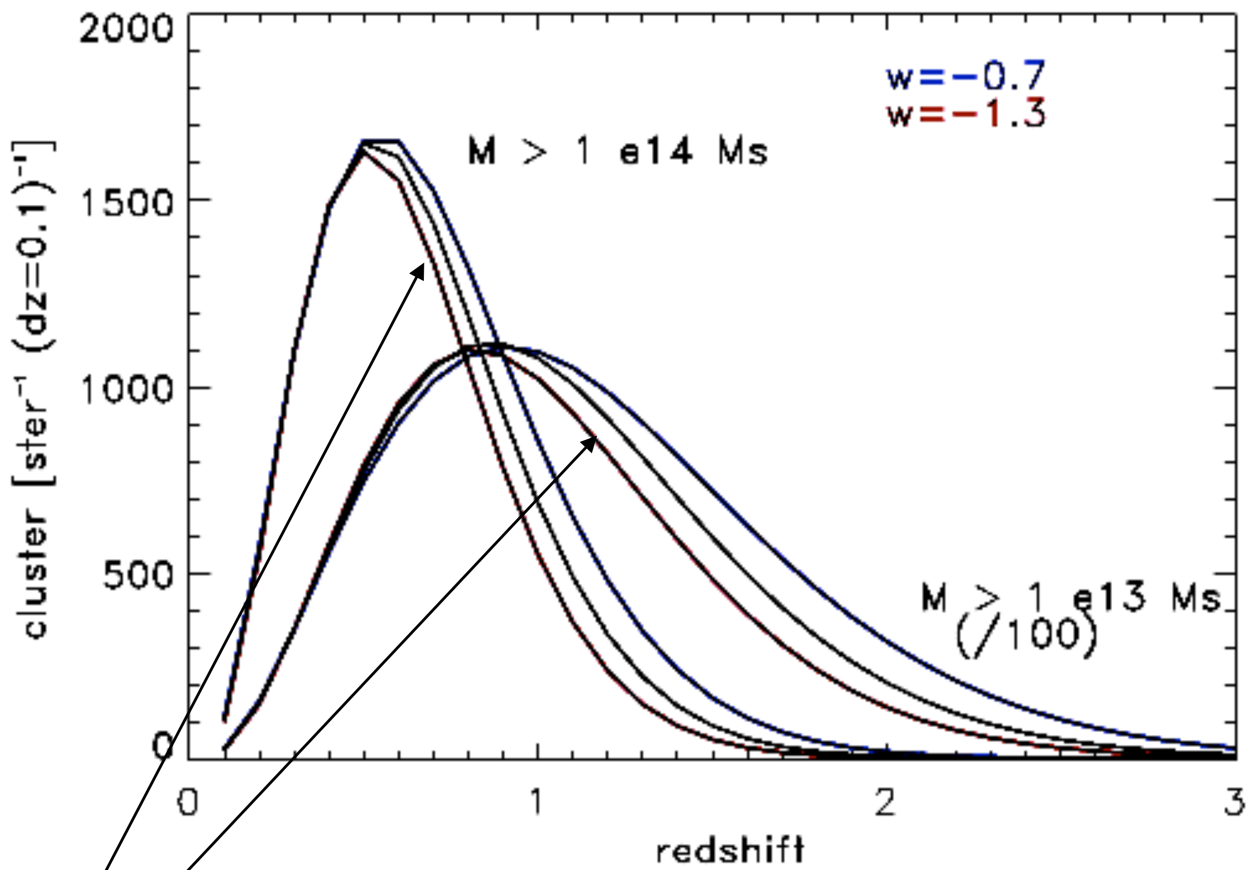
Model constraints from the observation of the cluster mass function evolution: gas mass and Yx parameter as alternative observables (proxies)



Vikhlinin et al. , Astro-ph 2008

Evolution of the Cluster Mass Function

Differential comoving cluster abundance (> $Mass_{limit}$) $ster^{-1}$ $dz=0.1^{-1}$



$$w = \frac{P_{DE}}{\rho_{DE} c^2}$$

→ There are more distant clusters for small -w !

Number count variation ~ 30% dlogN/dlogM at this point ~ 3
→ the accuracy needed in the mass measurement is a few %

Assumptions for the Modelling for eROSITA

- Cosmological parameters: H_0 = 70 km/s/Mpc Ω_b = 4.5%
  Ω_m = 0.30 Ω_Λ = 0.70 σ_8 = 0.80   + standard P(k)

- M – L relation used – see later

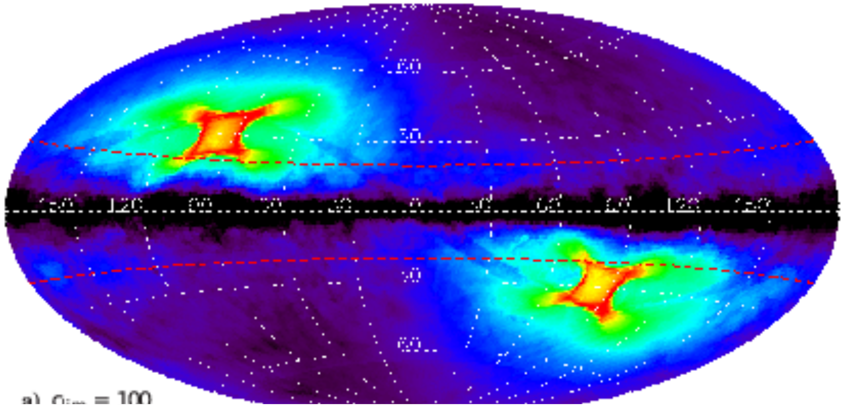
- Exposure maps for eROSITA Survey (from Robrade)

- Minimal count limit of 100 source counts
  (ROSAT >20-30 cts   XMM-Surveys > 100 cts)

- Calculation of the detection limit per sky pixel & redshift shell

- For Galaxies: richness – L_X relation (SDSS)
  - cluster galaxy luminosity function
  - evolutin of L* involving mostly passive evol.

Galaxy Cluster Number Counts in the eROSITA Survey

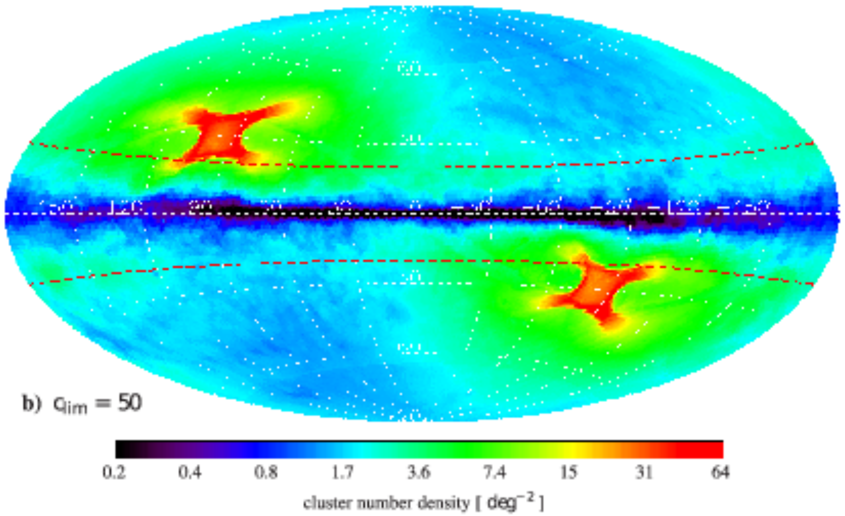


$N_{phot.}$	all sky	extragal. Sky
50	~300 000	~240 000
100	~140 000	~105 000
500	~ 20 000	~ 15 000
1000	~ 9 000	~ 6 700

M. Mühlegger Ph.D. Thesis

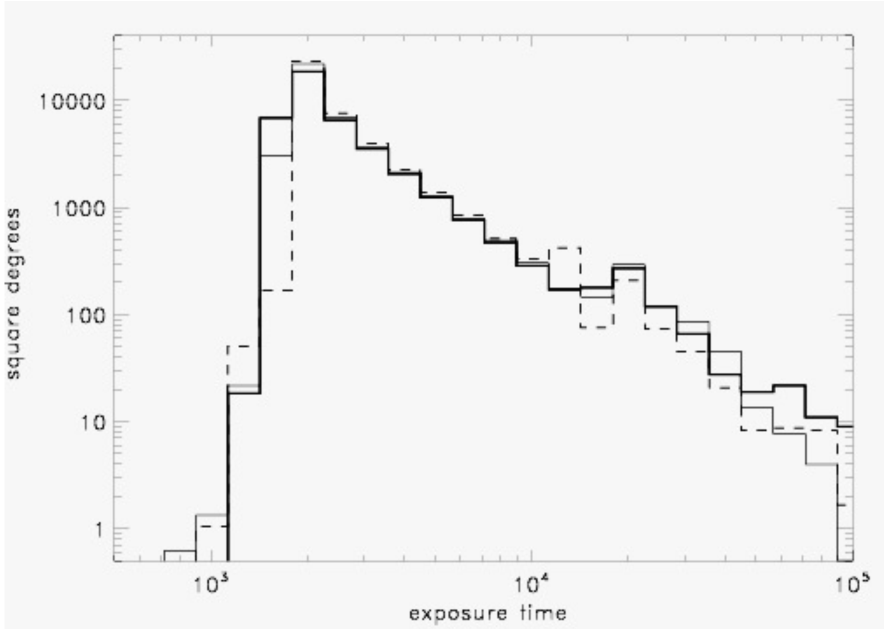
Redshift	extragal. Sky > 100 cts
> 0.3	~ 50 000
> 0.6	~ 10 000
> 0.8	~ 3 500
> 1.0	~ 900

M. Mühlegger, G. Chon,
H. Böhringer



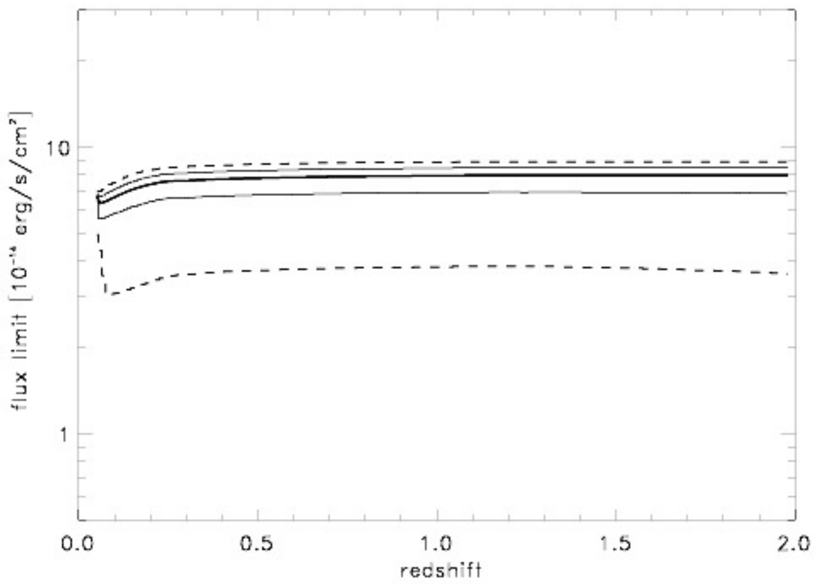
Number Counts of Clusters in the eROSITA Survey

Exposure distribution all-sky



Sun-pointing, 0.7°, 7° circles

Effective flux limit

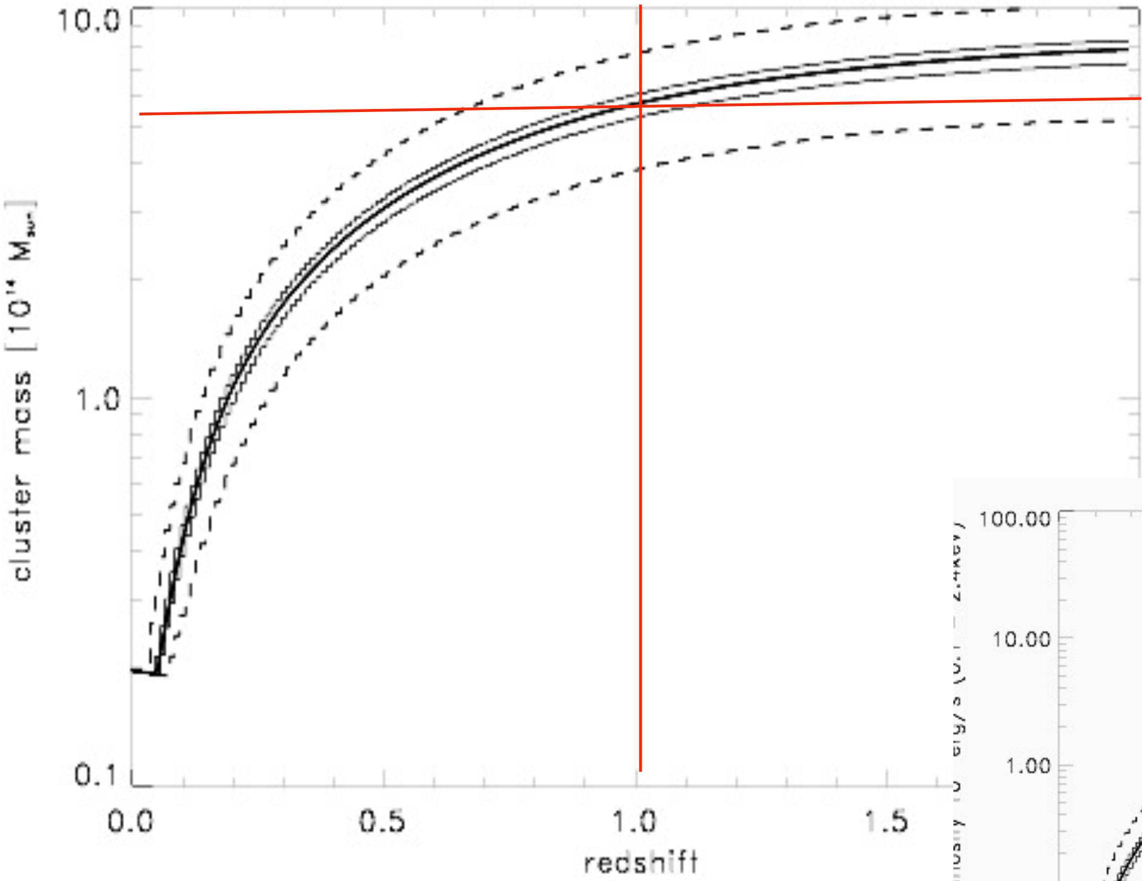


10%, 30%, 50%, 70% and 90% limits

$F_{lim} \sim 8\ 10^{-14}$ erg s^{-1} cm^{-2}

Mass Limit of the Detected Clusters

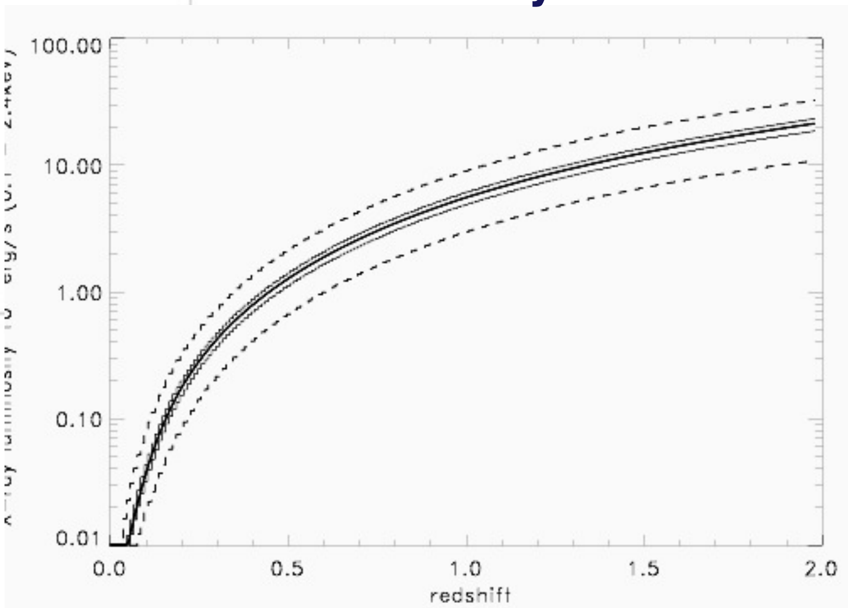
Mass limit as function of redshift



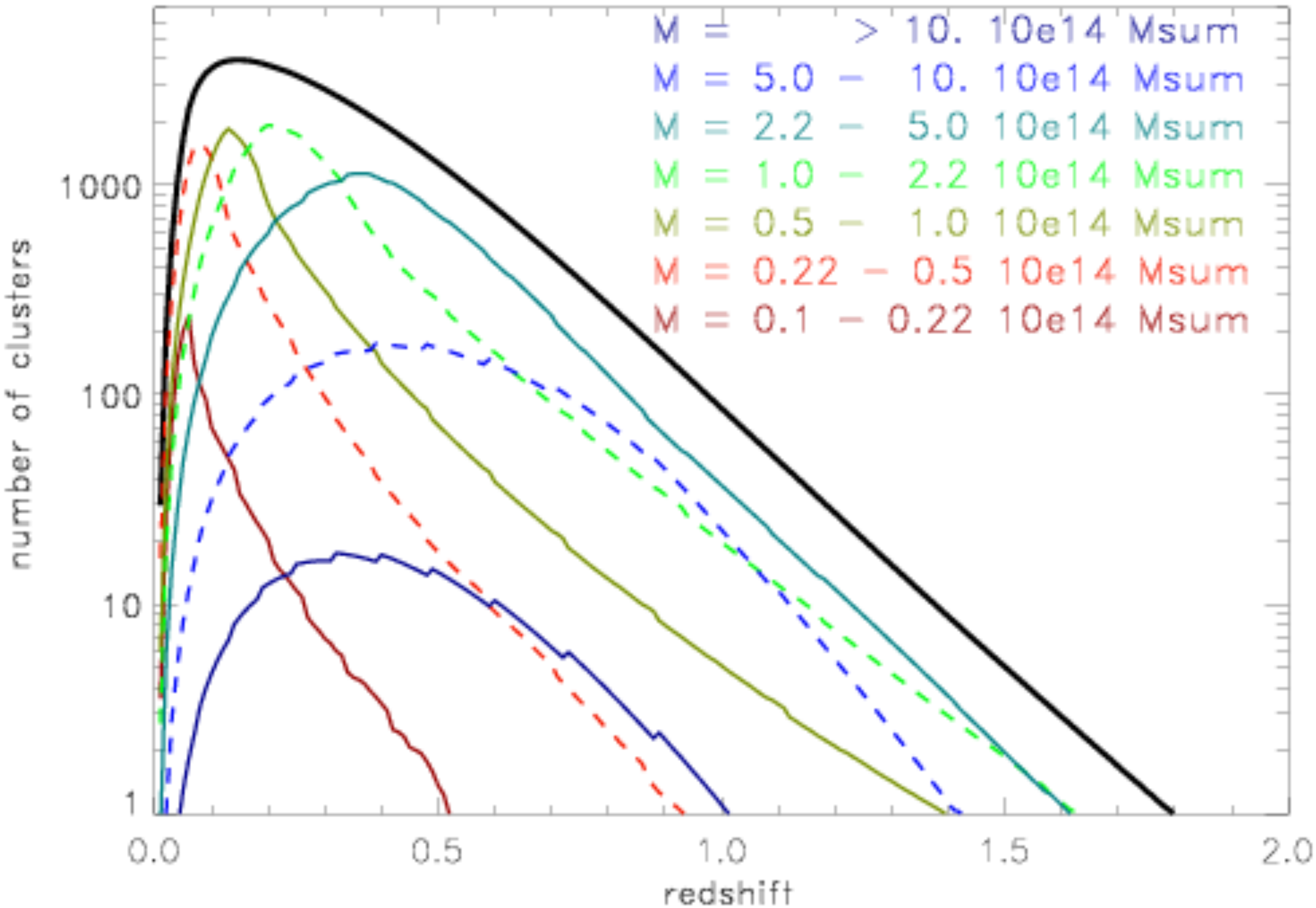
typical cluster at redshift 1:

Mass = 5 10^{14} M_{sun}

Luminosity limit

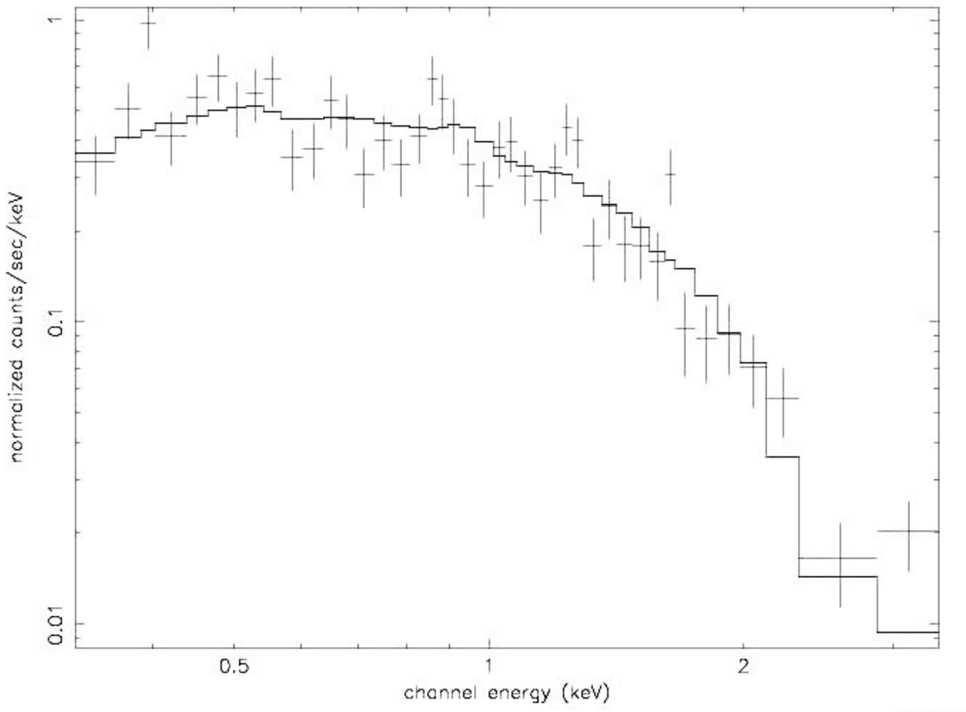


Mass and Redshift Distribution of the Clusters



Böhringer et al. (in prep.)

Temperature measurements of eROSITA Clusters



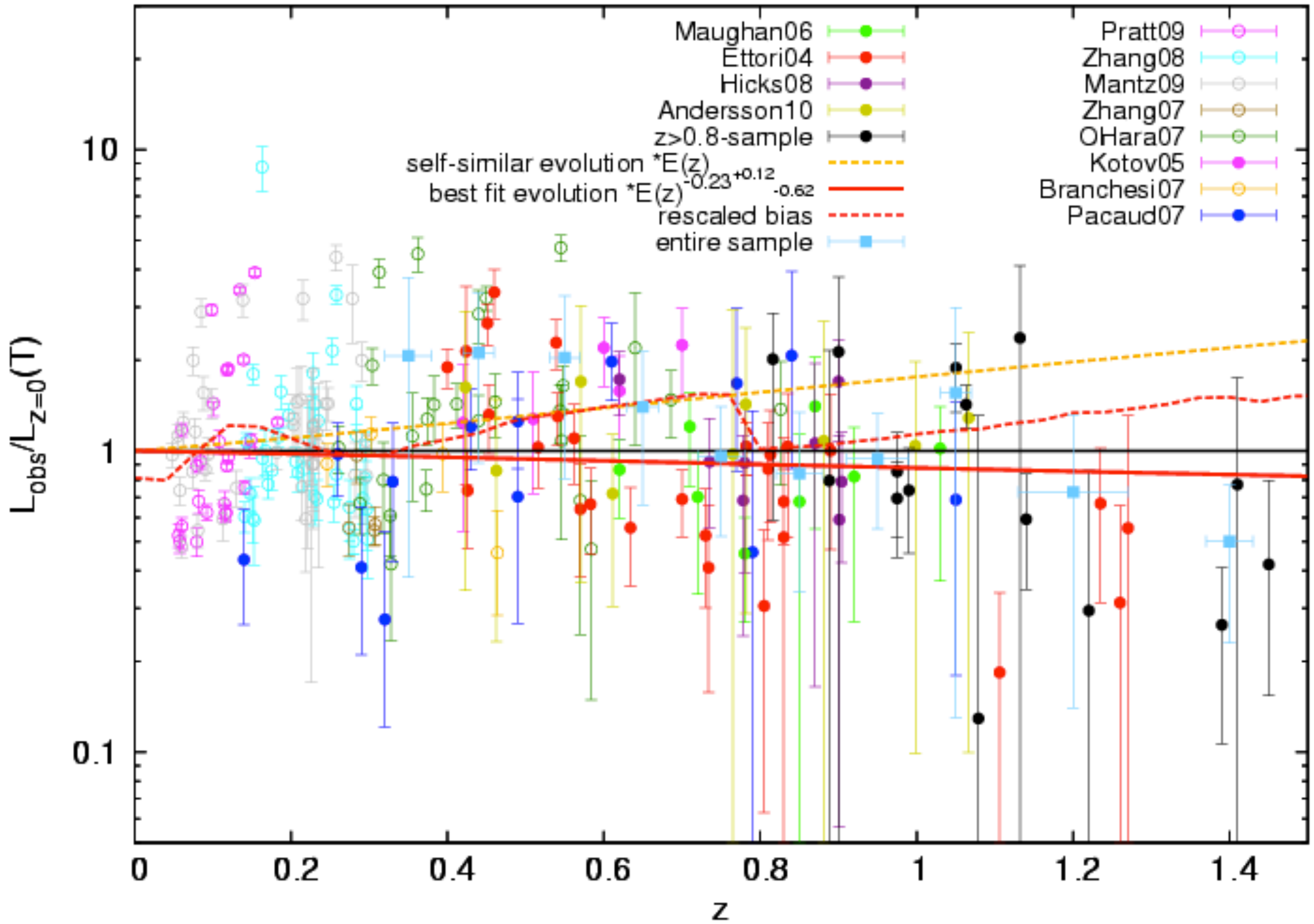
Simulated spectrum of an eROSITA detected cluster at z = 0.2 T = 4 keV

Detected with **1000** cts

Simulation includes subtracted background

Temp.	**2**	**3**	**4**	**5**	**6 keV**
accur.	**10%**	**16%**	**19%**	**21%**	**30%**

Evolution of the L – T Relation

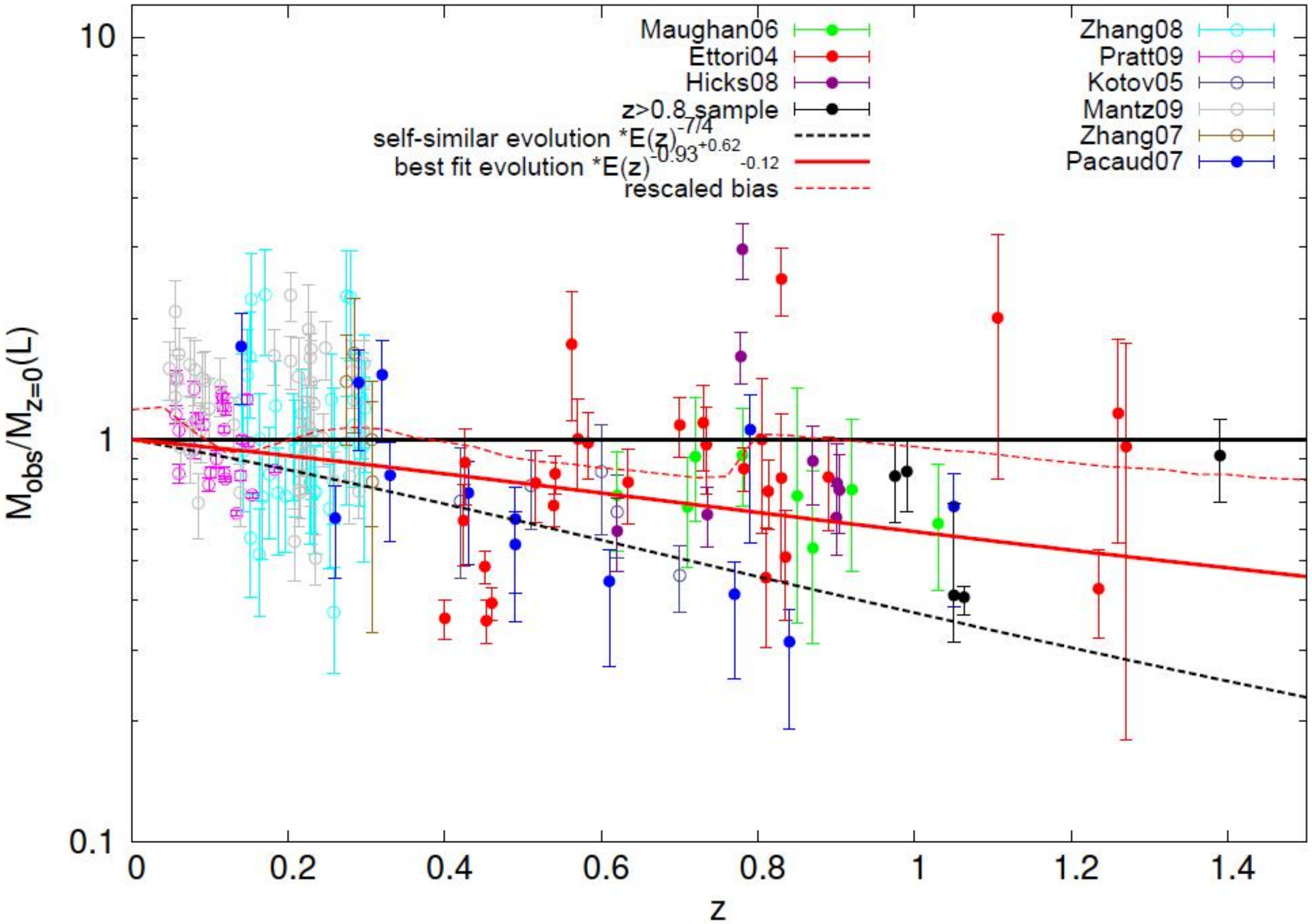


$$L_X = 0.079\ (\pm 0.008) \cdot T_{keV}^{2.70\pm0.24} \cdot E(z)^{-0.23\ (+0.12-0.62)} \times 10^{44}\ \mathrm{erg/s}$$

expected: L prop. T^a $E(z)^1$

Reichert, Böhringer et al. 2011

Observed Evolution of the M - L Relation

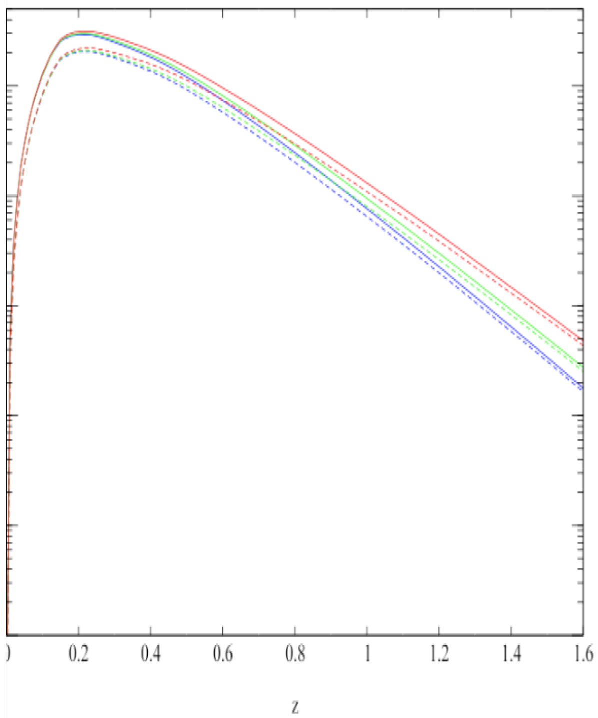


X-ray luminosity for given cluster mass does not increase as fast with redshift as assumed in self-similar models !

Change of Number of Predicted Distant X-ray Cluster Number Counts

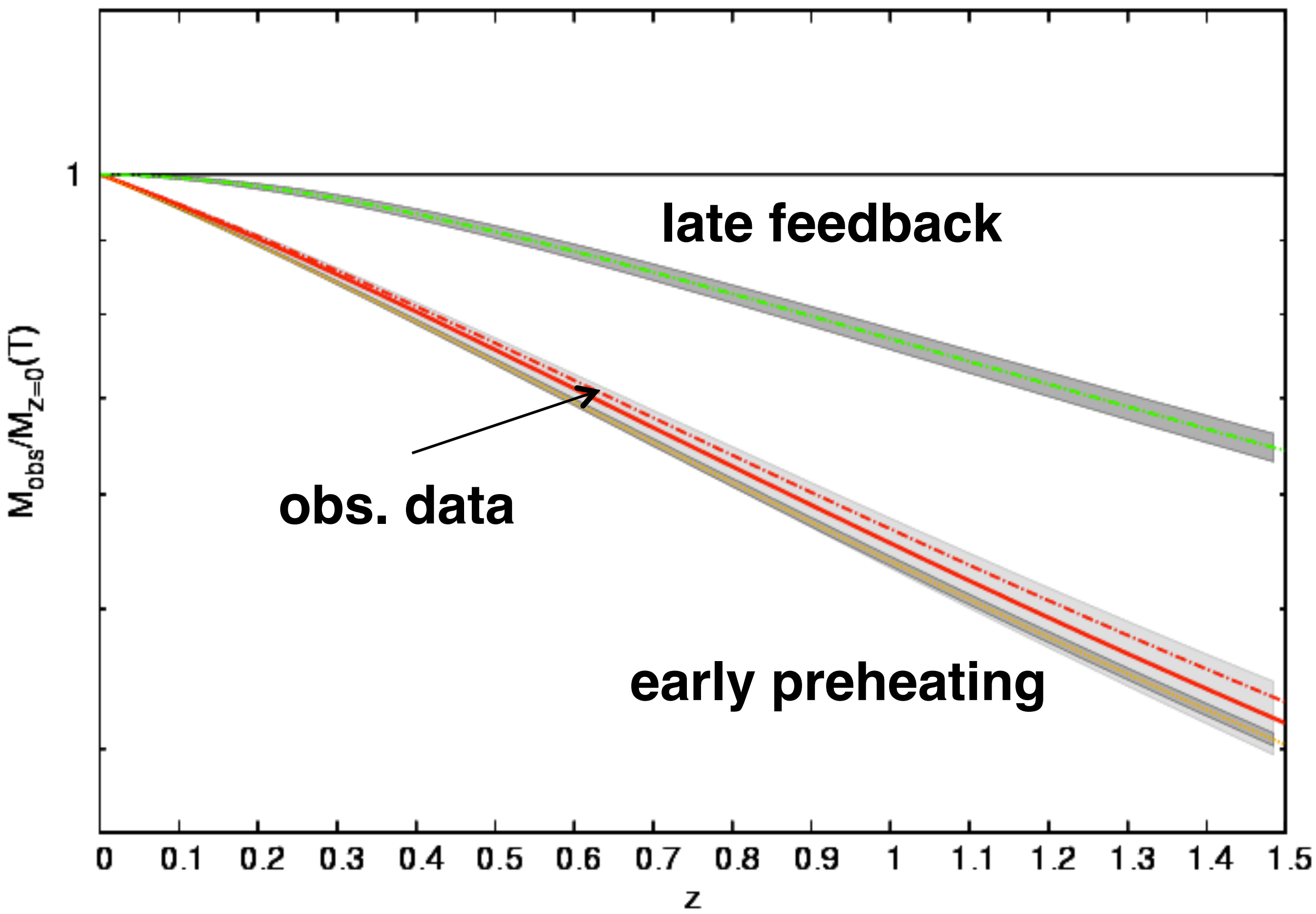
Ratio of clusters above redshift 1 seen by eROSITA:

	ratio to self-similar
Self-similar:	1
no L-T rel. evol.:	0.55
New relation:	0.27



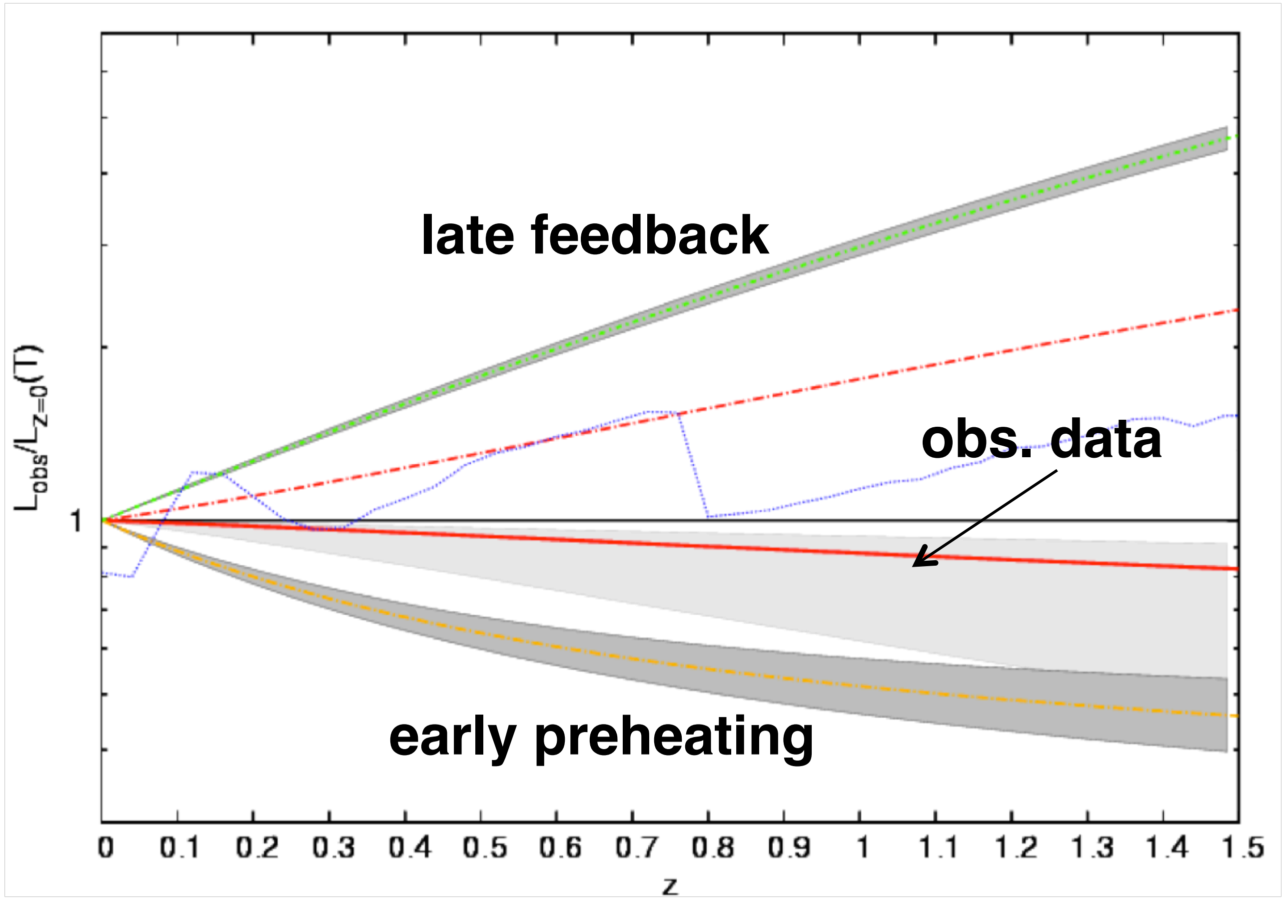
Reichert, Böhringer et al. 2011

Comparison to Simulations: M – T Relation



Simulations: Short et al. 2010 Reichert, Böhringer et al. 2011

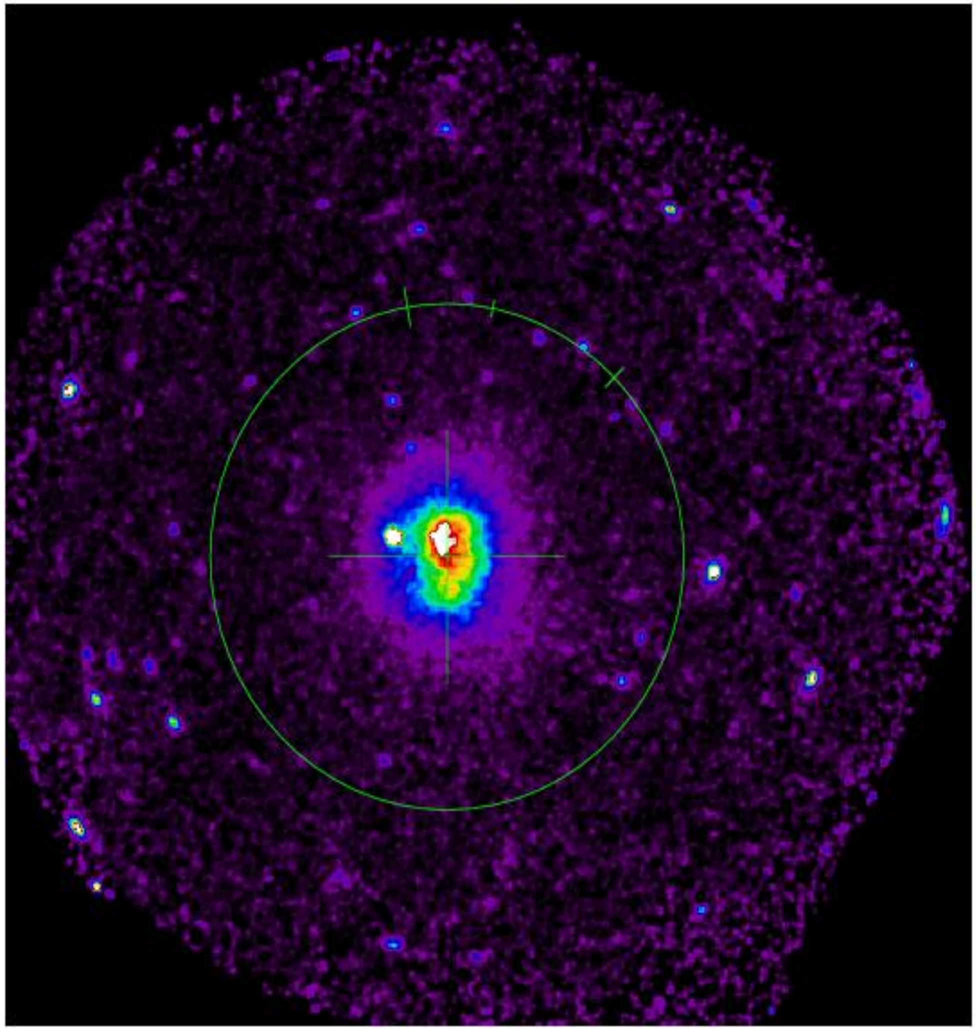
Comparison to Simulations: L – T Relation



Comparison of models and observations favor early preheating

eROSITA will provide very precise data for very stringent comparison

Power Ratio & Center Shift Method



Böhringer et al. 2010

Power ratios are intensity normalized moments:

see Buote & Tsai 1995, 96

P2/P0 quadrupole
P3/P0 hexapole
P4/P0 octopole

$$P_0 = \left[a_0 \ln(R_{ap})\right]^2 \tag{1}$$

$$P_m = \frac{1}{2m^2 R_{ap}^{2m}} \left(a_m^2 + b_m^2\right) \tag{2}$$

where R_{ap} is the aperture radius . The moments a_m and b_m are calculated from

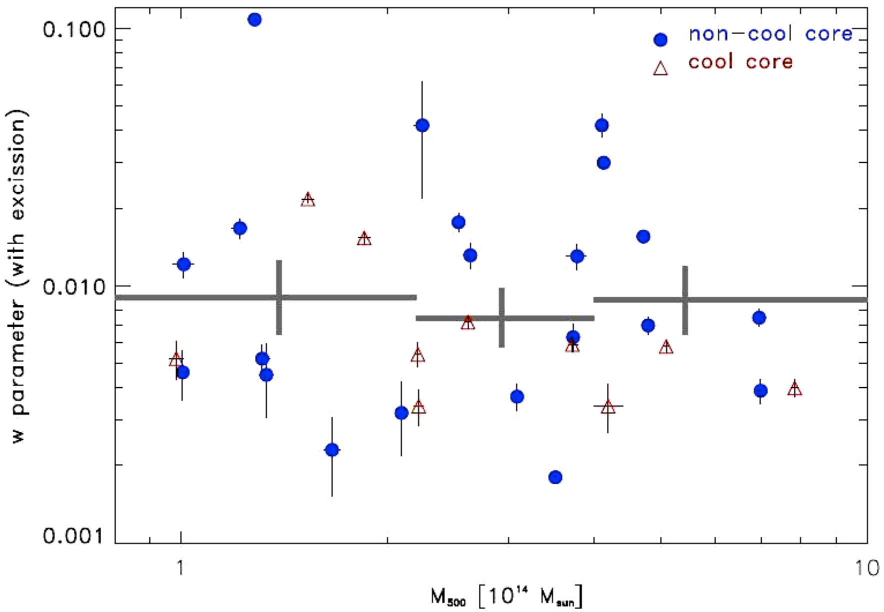
$$a_m(R) = \int_{R' \le R_{ap}} S(x')(R')^m \cos(m\phi')\, d^2x' \tag{3}$$

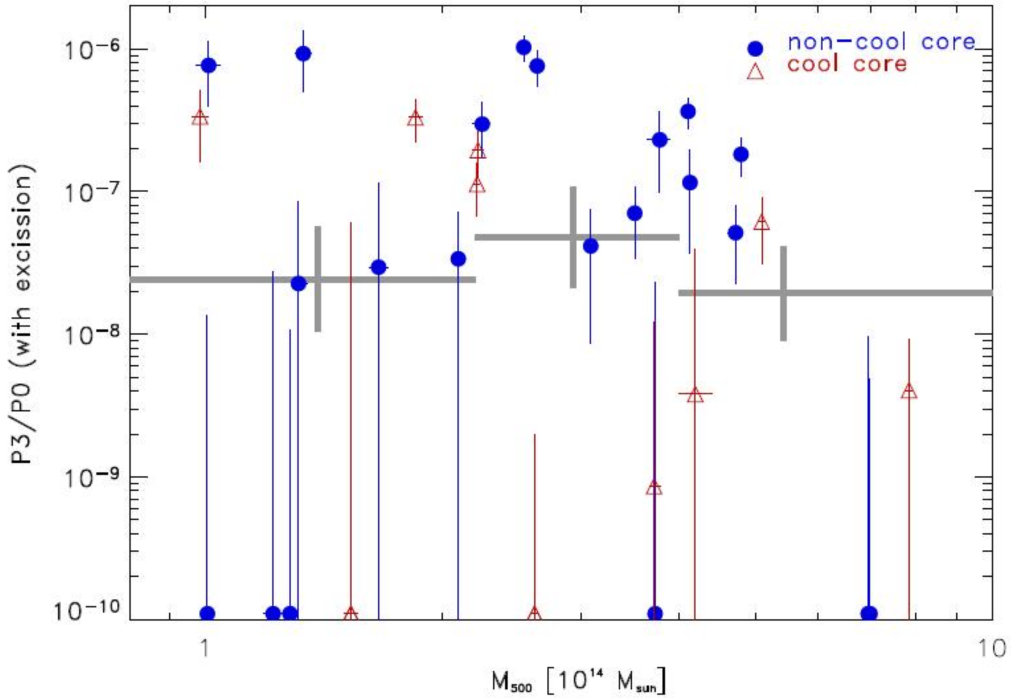
$$b_m(R) = \int_{R' \le R_{ap}} S(x')(R')^m \sin(m\phi')\, d^2x' \tag{4}$$

Variance of the center shift with increasing aperture

$$w = \left[\frac{1}{N-1} \sum (\Delta_i - <\Delta>)^2\right]^{1/2} \times \frac{1}{r_{500}}$$

Substructure as Function of Mass

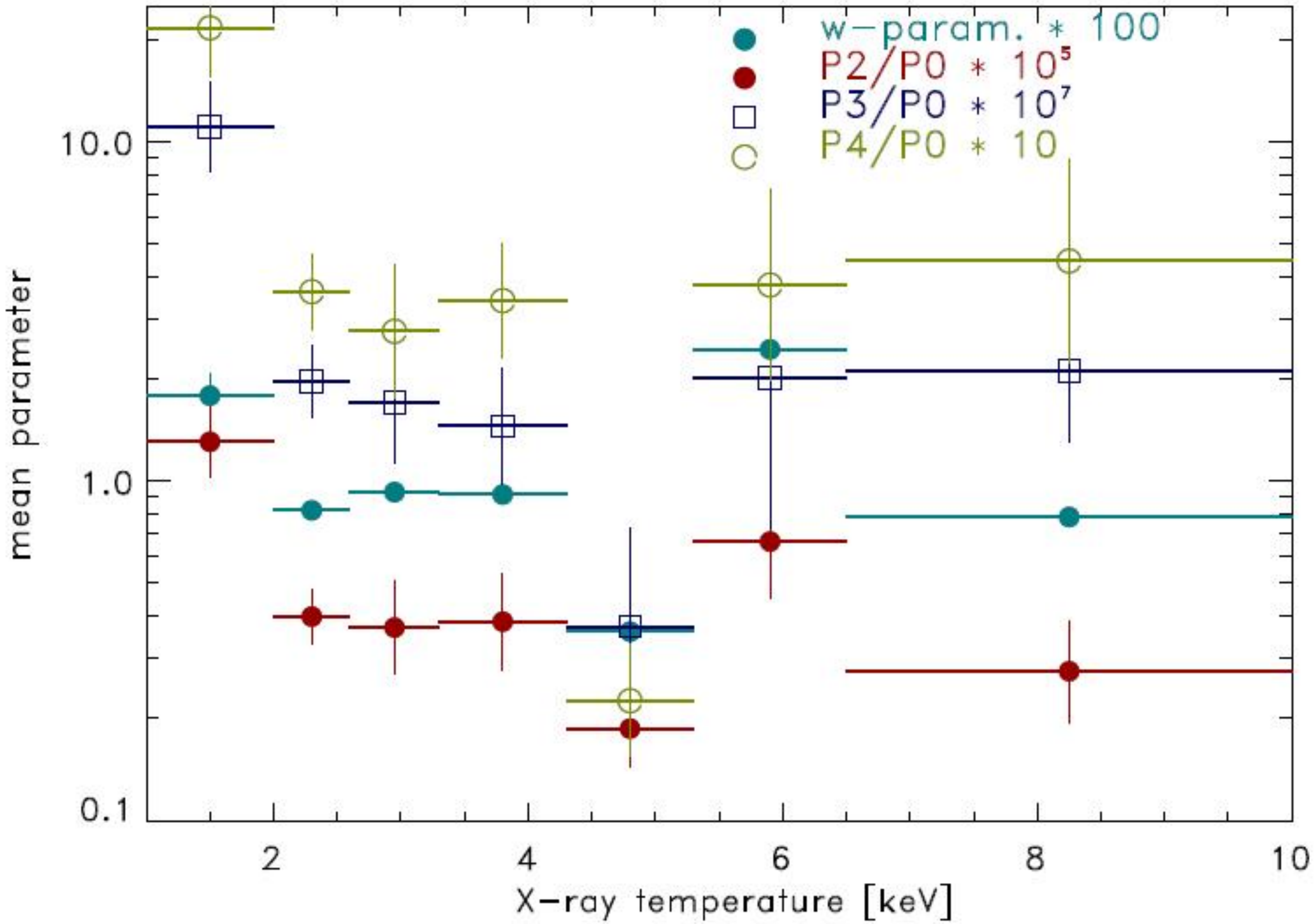




There is no significant change in the substructure statistics with increasing mass of the clusters. - Different from naiv expectations for a hierarchical structure formation scenario.

[Böhringer et al. 2010]

Substructure as Function of Mass in the Simulations

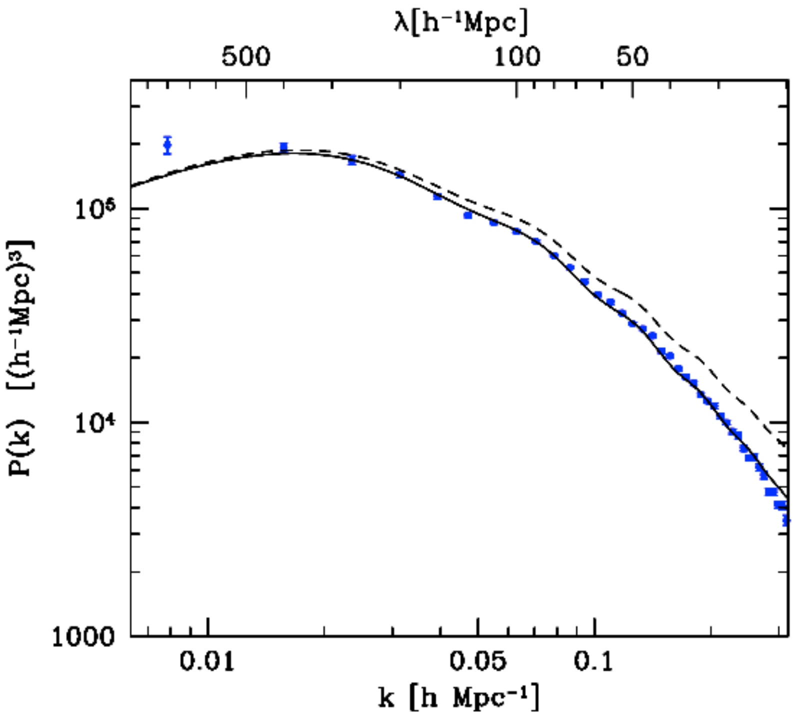


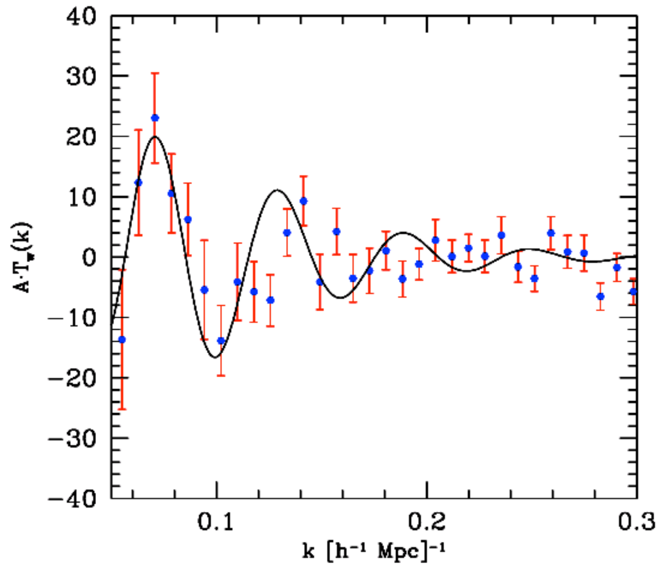
Results of cluster number forecast for different cosmological models

	refer.	σ_8=0.83	Ω_m=0.25	w = -1.3	w = 0.7
z > 0.4	41600	52600	27600	42300	43600
z > 0.8	4800	6900	3200	3900	6300
z > 1.2	490	760	315	327	830

Overall Power Spectrum for 100 000 clusters

Simulations of a eROSITA type Survey with BOA input P(k)

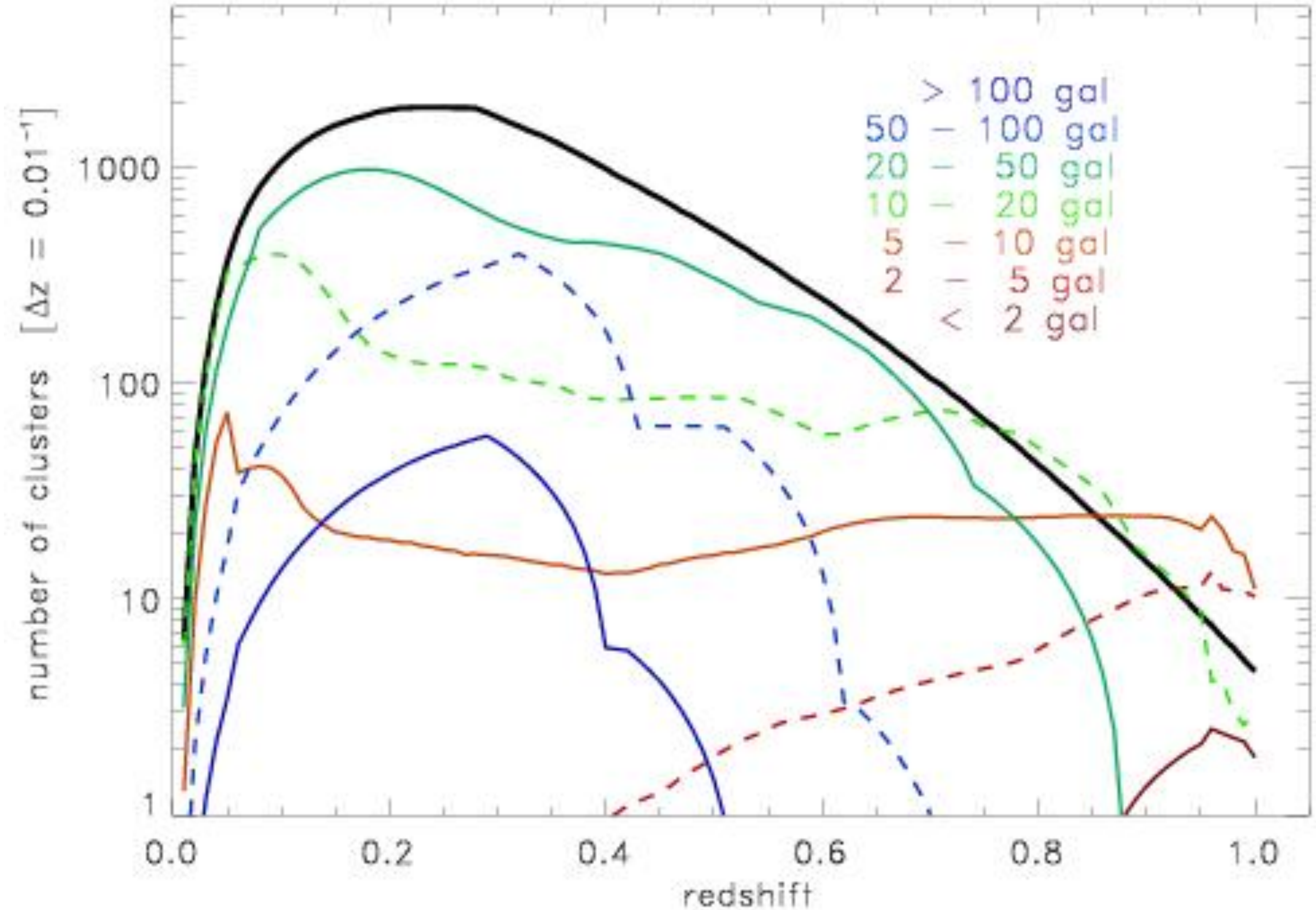




The signal is about 3 – 4 sigma

Observable Galaxies per Clusters

Magnitude range = 18.5 to 20.5 in i-band (< 22 in r-band)



Summary on the Number of Observable Galaxies

For a 15 000 deg^2 Survey   (e.g. 4MOST):

up to   50 000 galaxy clusters

on average 50 galaxies/cluster   =   2.5 Million galaxies
visible for a spectroscopic limit of   r = 22 / I = 20.5

Conclusions

- eROSITA is about 30 times more sensitive for the detection of clusters
  → ~ 100 000 cluster will be detected with > 100 cts

- ~ 7000 cluster with > 1000 cts → temperature, morphology, ..
  wide range of astrophysical studies (e.g. scaling relations and feedback)

- LSS statistics (P(k) for > 10 000 clusters in ten redshift shells out to z = 0.6 (10x more precise than for REFLEX)

- Large potential for constraining cosmological model parameters also for Dark Energy equation of state – and testing more exotic models