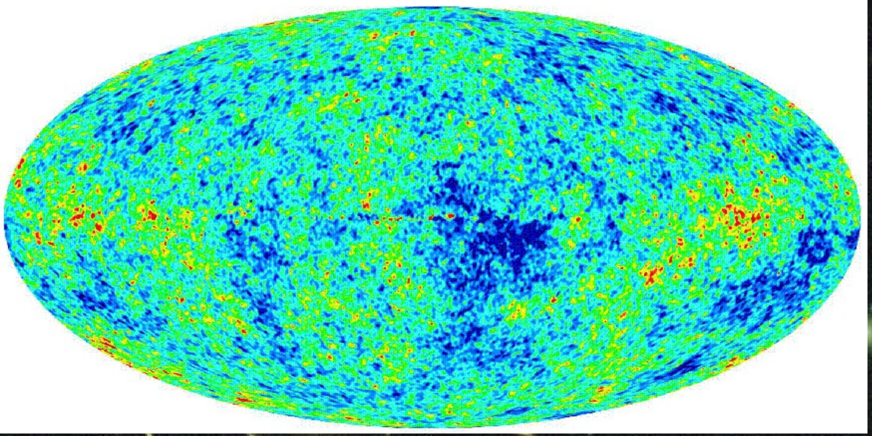
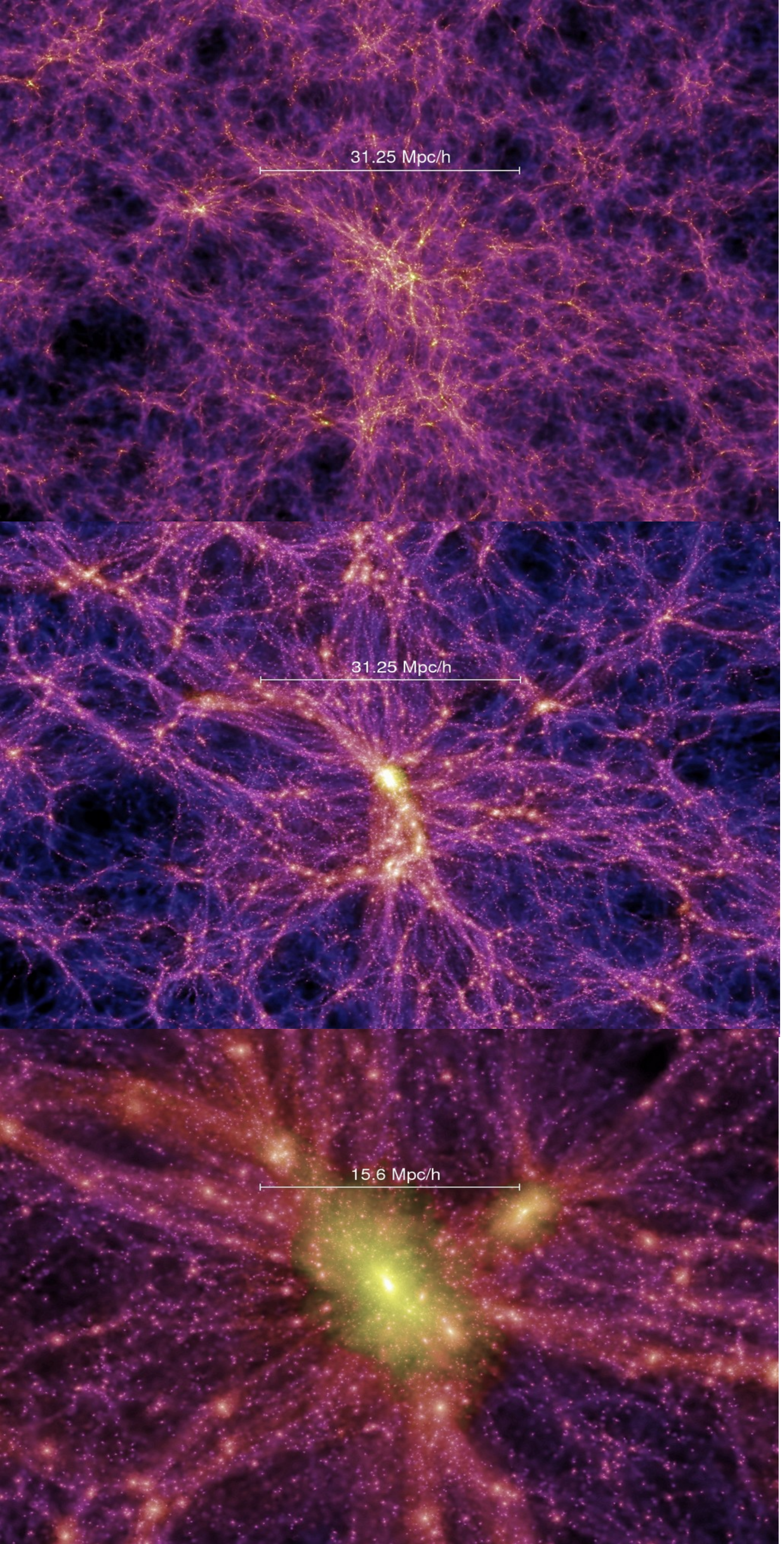


CIFAR/AGM Whistler 2012

The Millennium-XXL Simulation: resolving the Planck SZ cluster-stacking puzzle

Simon White
Max Planck Institute for Astrophysics



The standard cosmic structure formation model reproduces :

-- the linear initial conditions
-- IGM structure during galaxy formation
-- large-scale structure today

Simulating this model predicts precise

-- abundances
-- internal structures
-- assembly histories
-- spatial/peculiar velocity distributions
-- merger rates

for DM halos at all redshifts

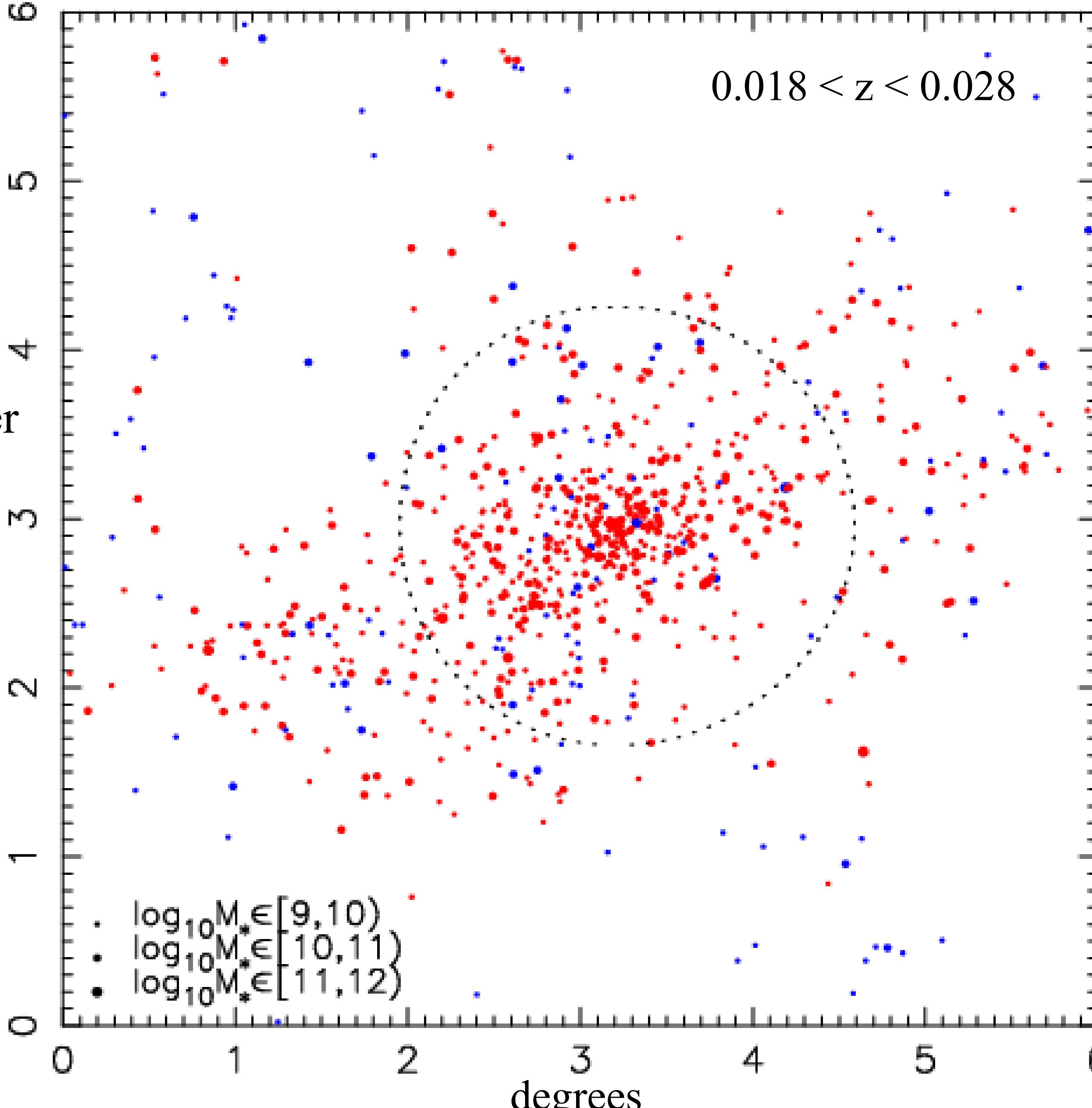
How do galaxies & clusters form and evolve within this model?

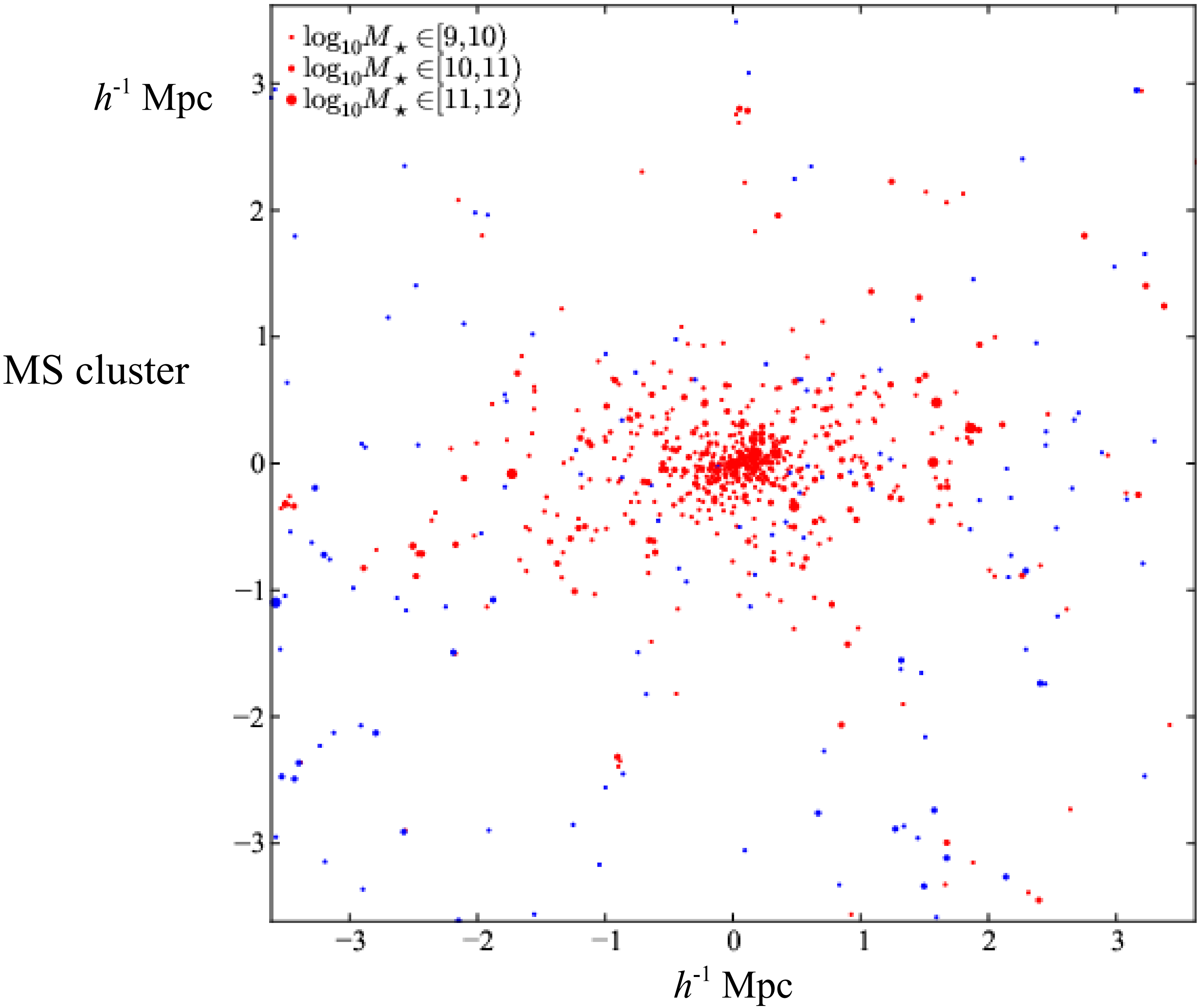
Can this be understood well enough to test the model/measure its parameters?

degrees

Coma cluster with R_{200}

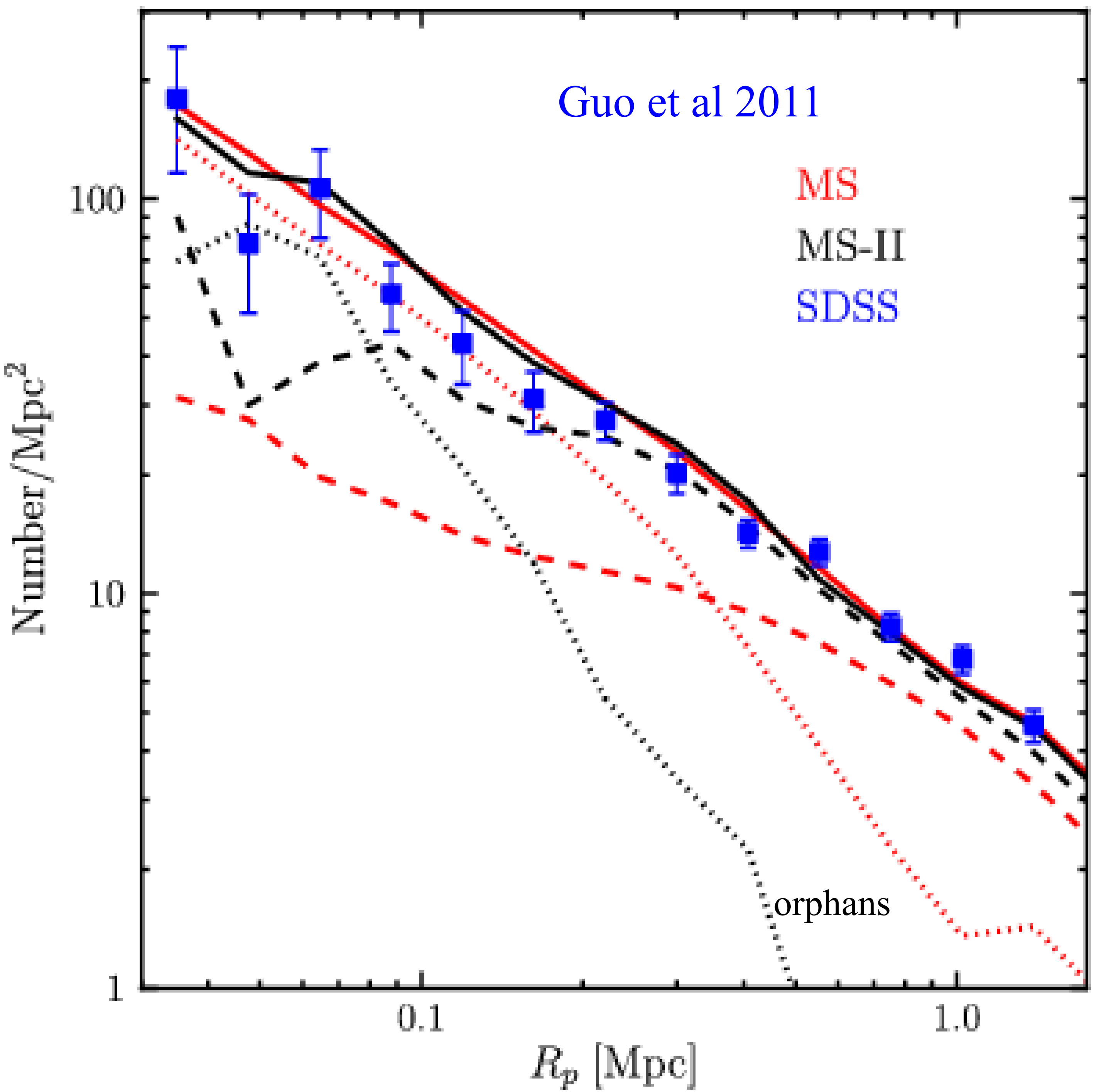
SDSS data





$\log_{10} M_\star \in [9,10)$
$\log_{10} M_\star \in [10,11)$
$\log_{10} M_\star \in [11,12)$
h^{-1} Mpc
MS cluster
3
2
1
0
−1
−2
−3
−3
−2
−1
0
1
2
3
h^{-1} Mpc

Projected galaxy number density profiles of clusters



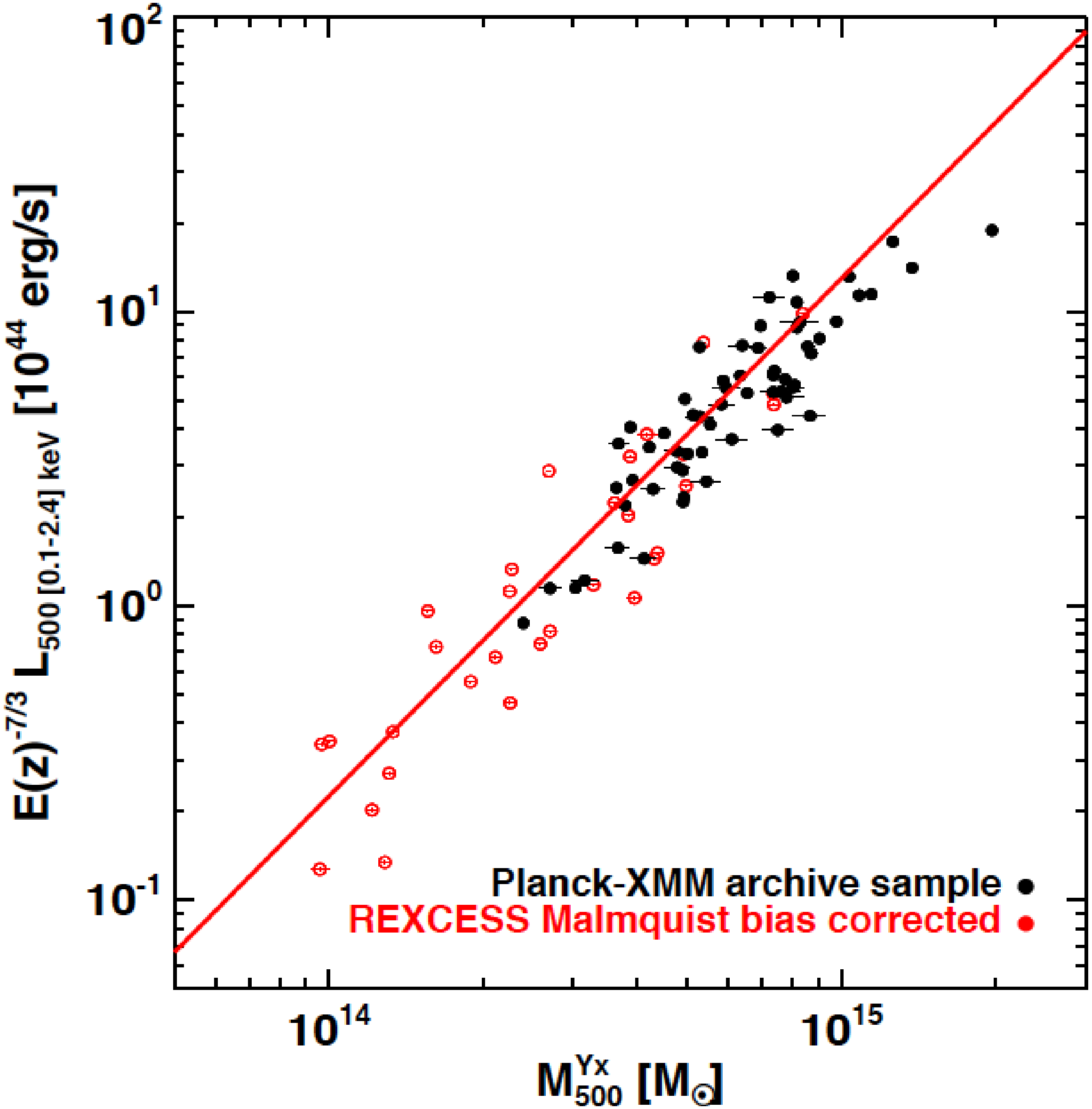
$\log M_{gal} > 10.0$

$14.0 < \log M_{clus} < 14.3$

Note: good agreement of MS with MS-II is *only* when orphans are included

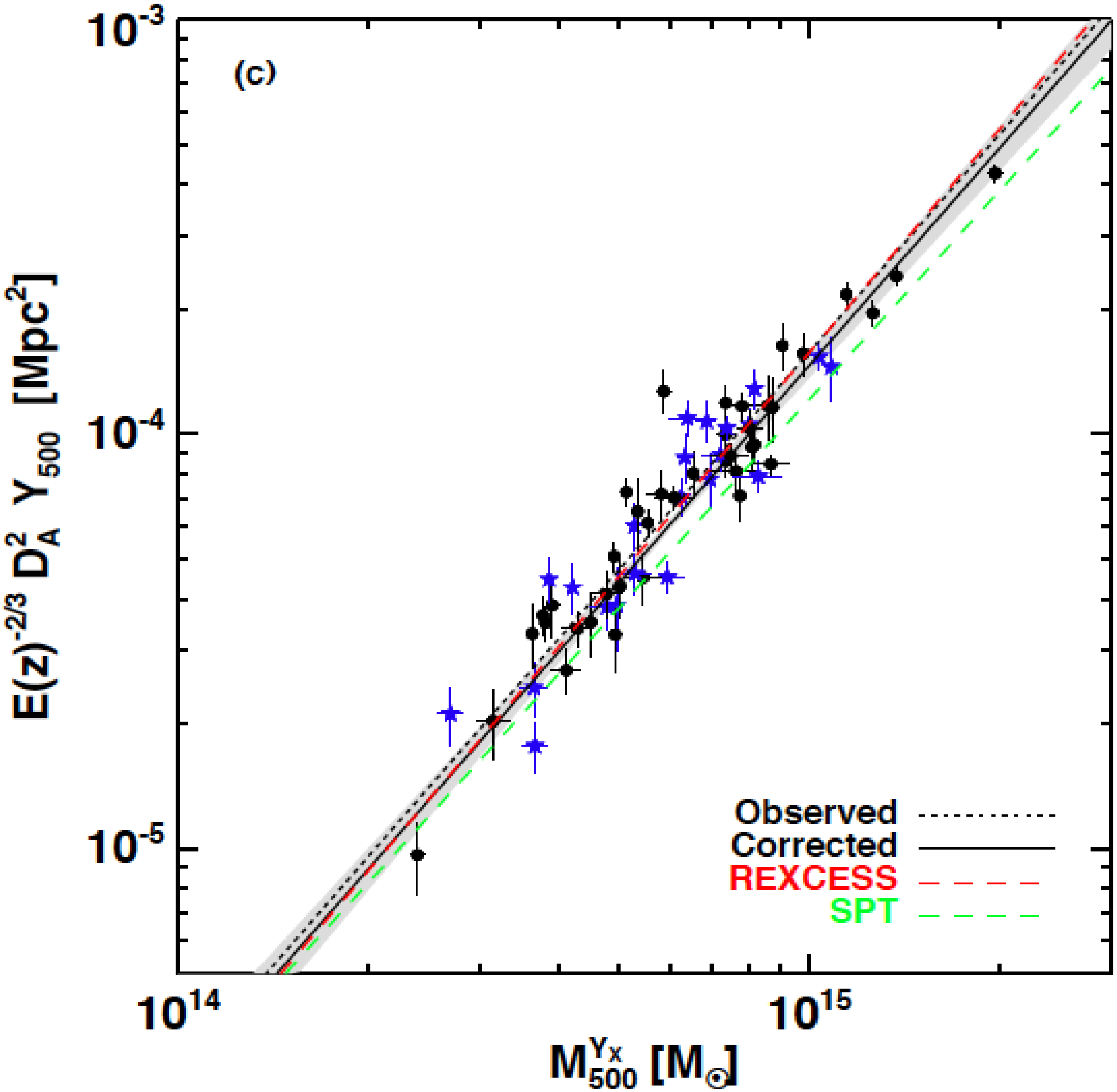
Orphan treatment is physically consistent and needed to fit SDSS

The Planck SZ cluster-stacking puzzle



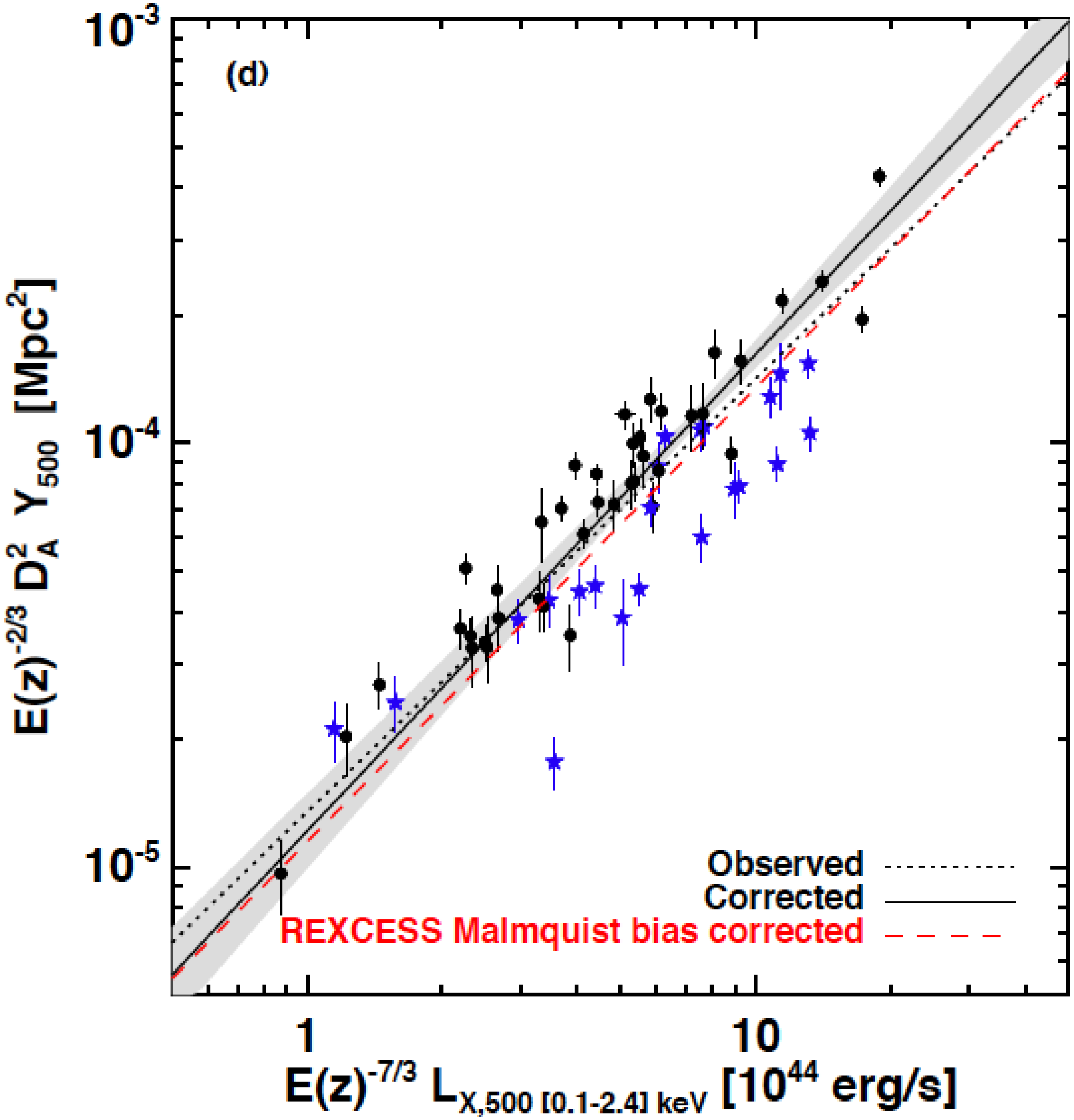
X-ray selected clusters show a tight relation between X-ray luminosity and X-ray estimated mass

The Planck SZ cluster-stacking puzzle



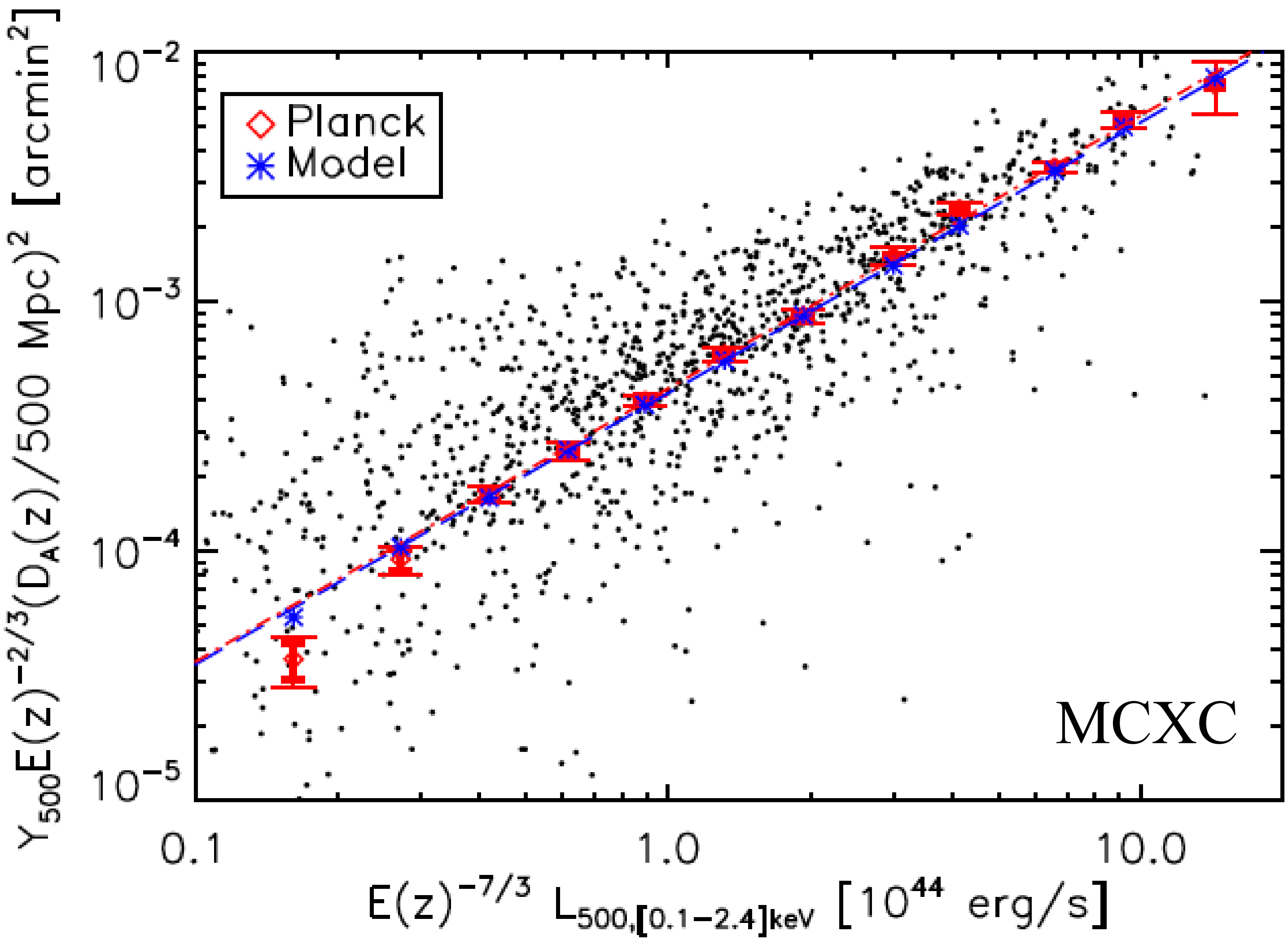
X-ray selected clusters also show a tight relation between SZ "luminosity" and X-ray estimated mass

The Planck SZ cluster-stacking puzzle



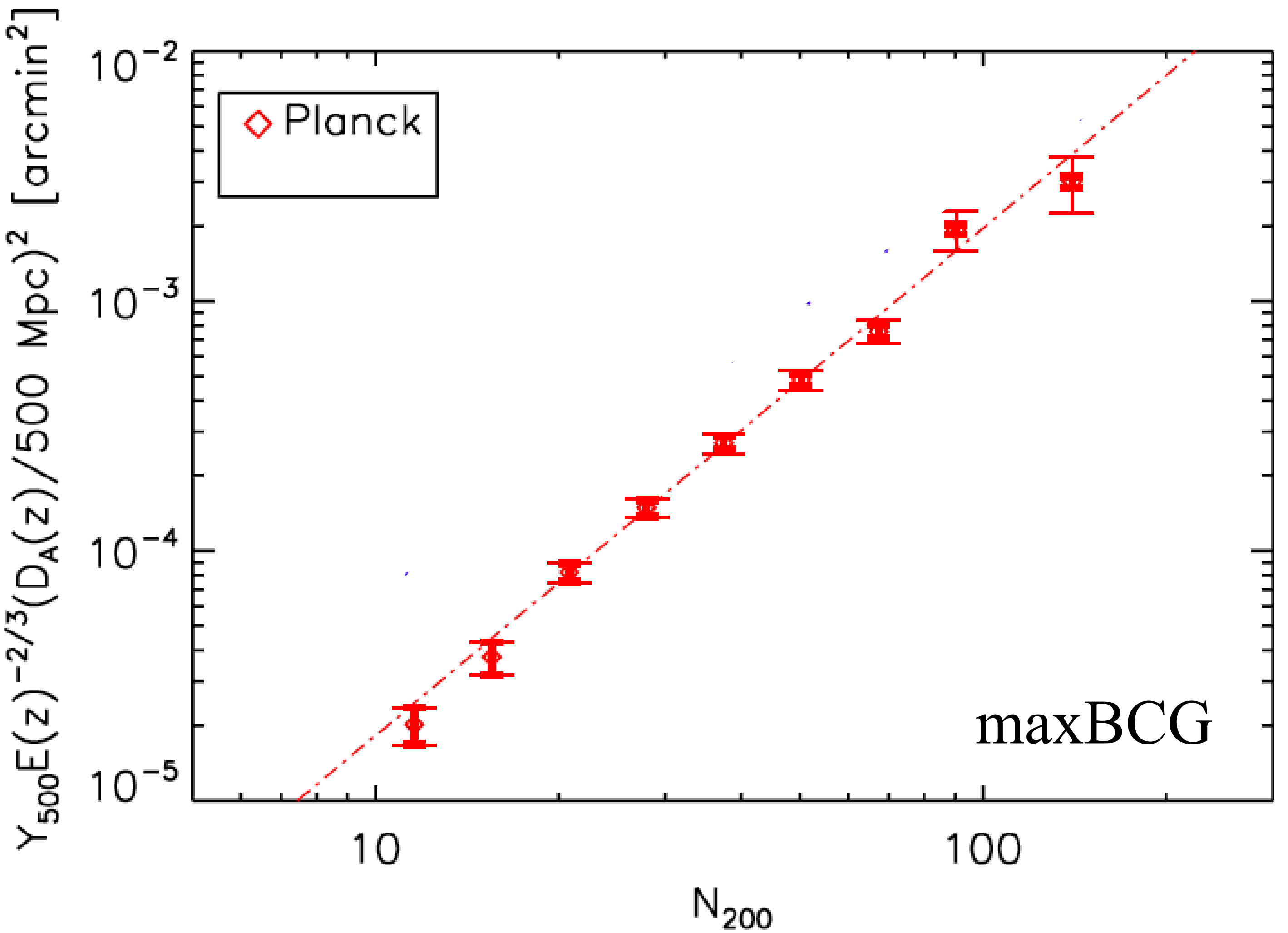
For X-ray selected clusters the $Y - L_X$ relation is less tight because cool core clusters are overluminous

The Planck SZ cluster-stacking puzzle



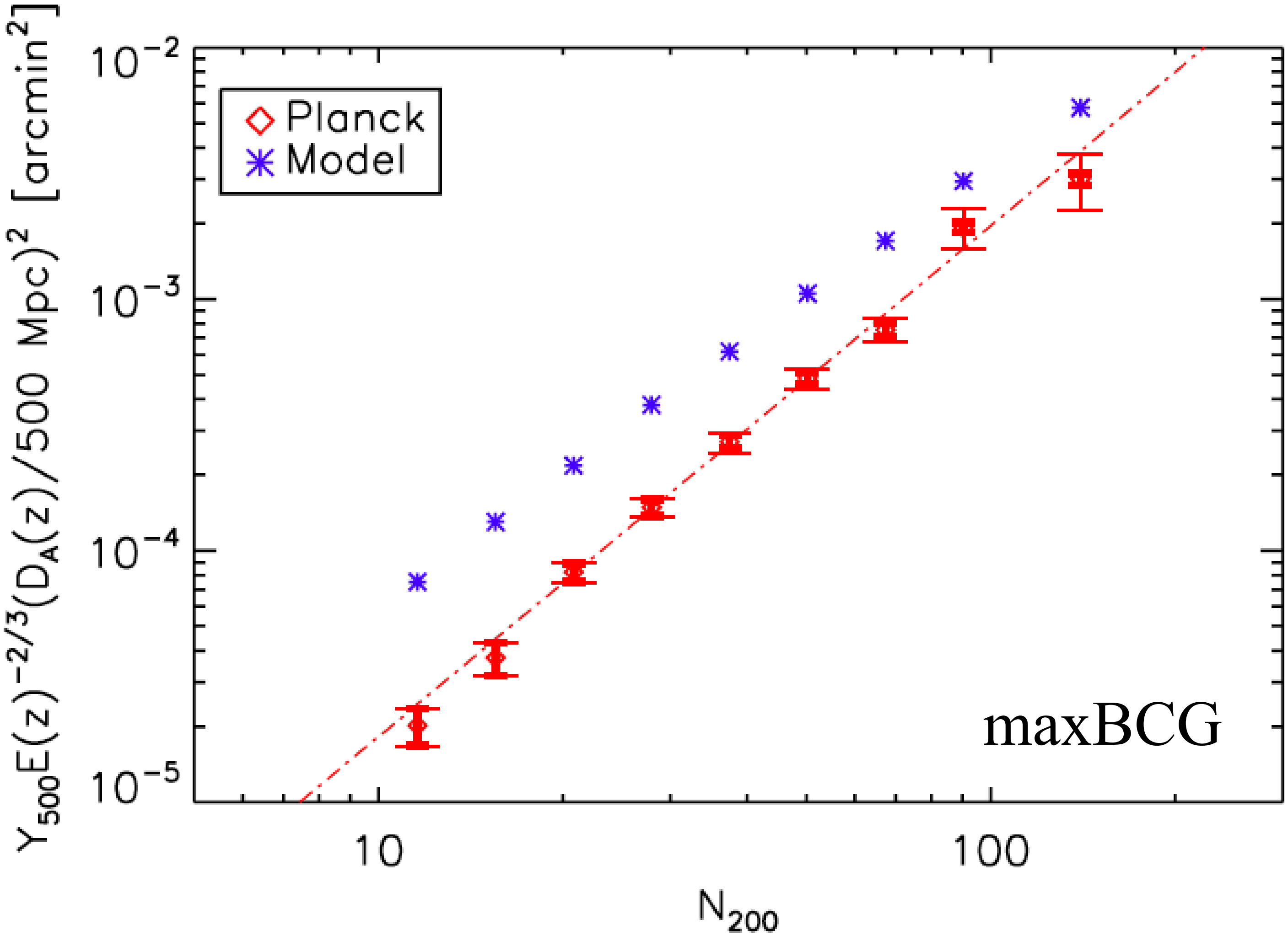
For stacked X-ray selected clusters, the $Y - L_X$ relation is a power law and fits well a model $L_X \rightarrow M \rightarrow Y$ based on scaling relations

The Planck SZ cluster-stacking puzzle



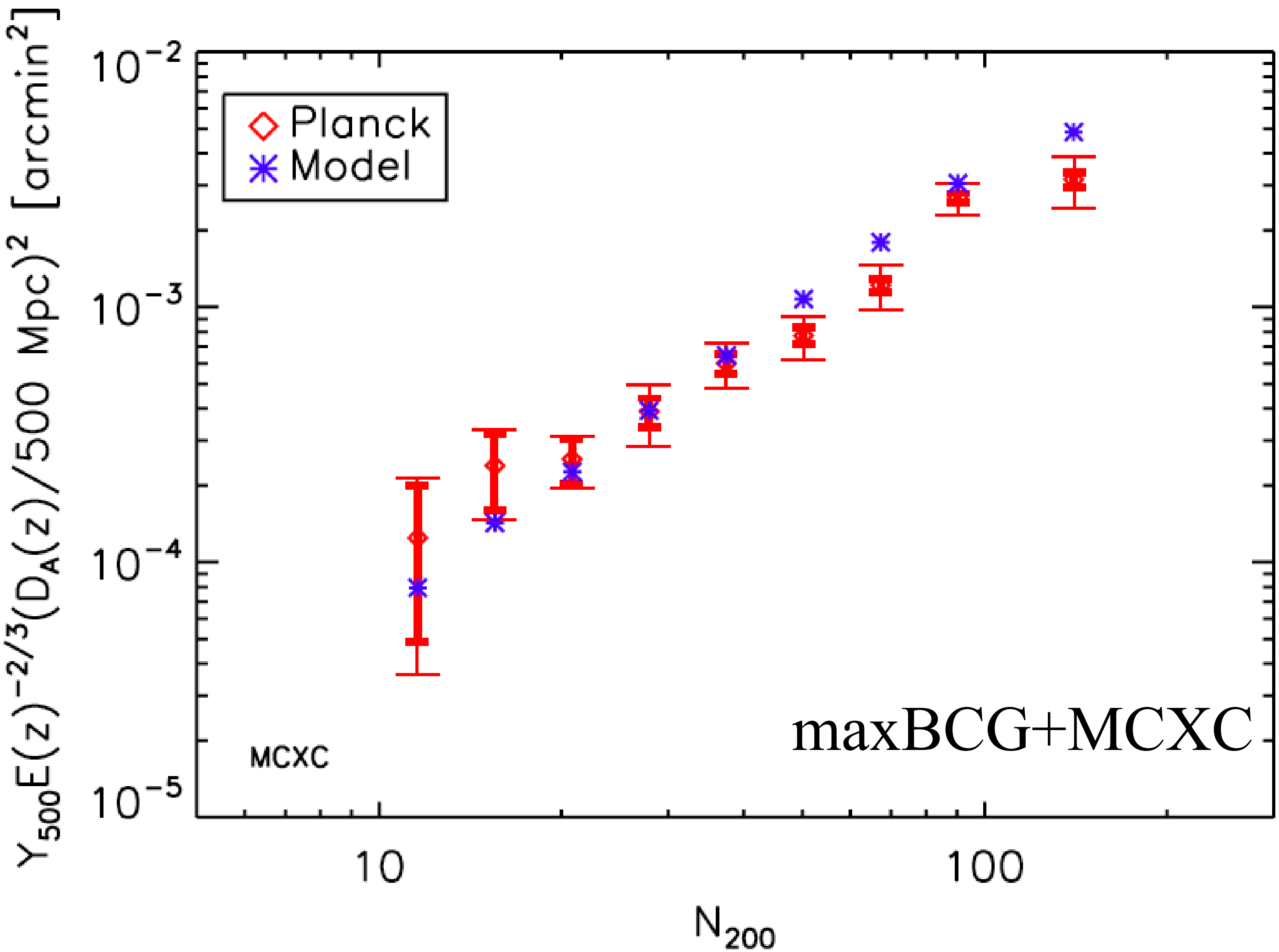
For stacked optical clusters, the $Y - N_{200}$ relation is also a power law

The Planck SZ cluster-stacking puzzle



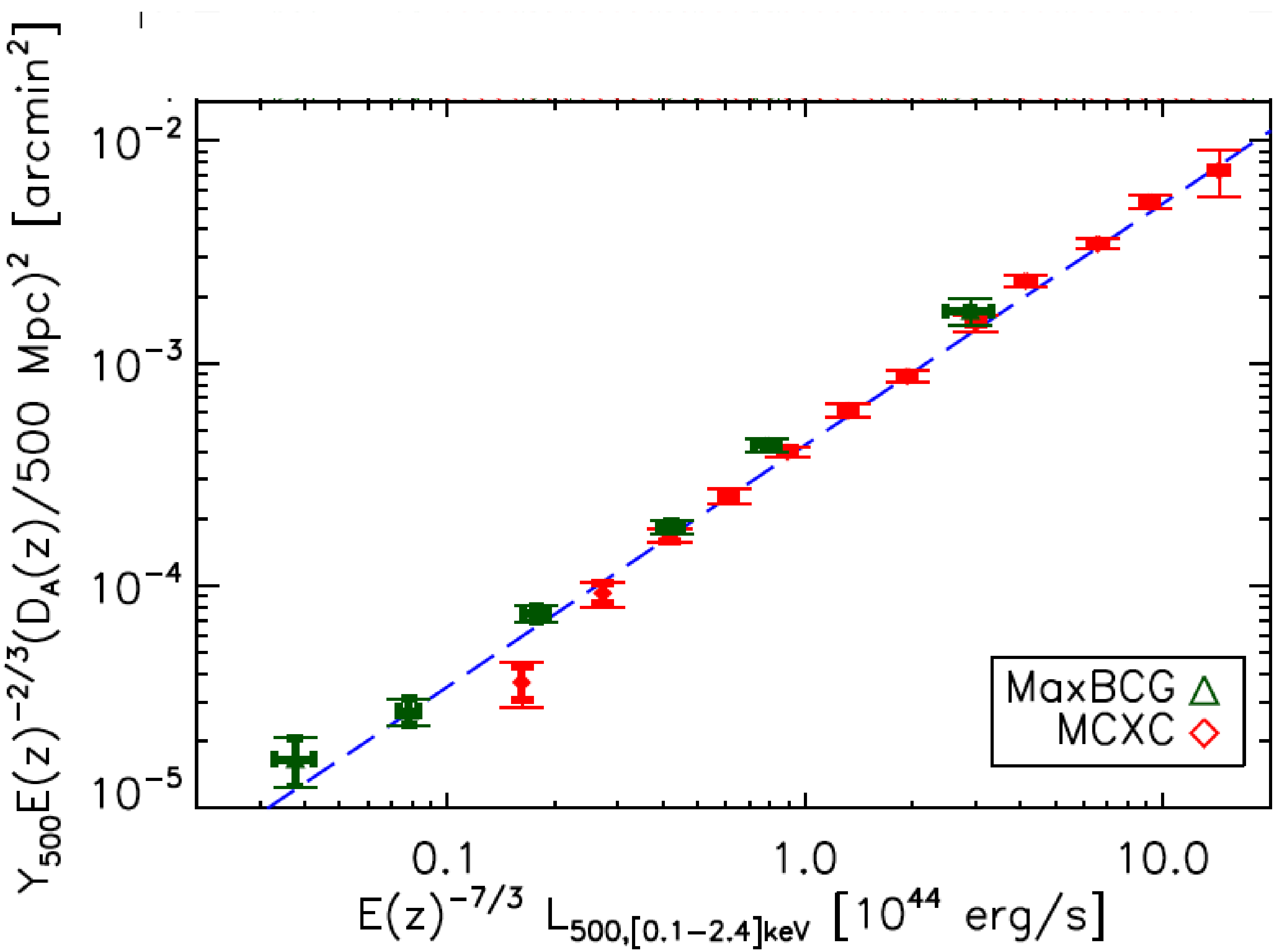
For stacked optical clusters, the $Y - N_{200}$ relation is also a power law but does NOT fit a model $N_{200} \rightarrow M \rightarrow Y$ based on scaling relations

The Planck SZ cluster-stacking puzzle



The model DOES fit the subset of maxBCG clusters which are also in the MCXC X-ray catalog

The Planck SZ cluster-stacking puzzle



Stacks of optical and of X-ray clusters nevertheless have almost the same $Y - L_X$ relation, so the model $N_{200} \rightarrow L_X \rightarrow Y$ works well

Millennium-XXL was successfully executed on JUROPA in 2010

PARAMETERS OF FINAL RUN

6720^3 ~ 303 billion particles

3000 Mpc/h box, Millennium cosmology

12288 cores: 3072 MPI-task / 4 threads (70% of Juropa)

9216^3 FFT mesh

86 trillion force calculations

Cost: 2.7 million CPU hours (~300 years), corresponding to 9.3 days wallclock time (including FOF+SUBFIND)

Peak memory usage: 29 TB
(105 bytes/particle)

700 million halos at z=0 (44% of particles)

About 25 billion (sub)halos in merger trees

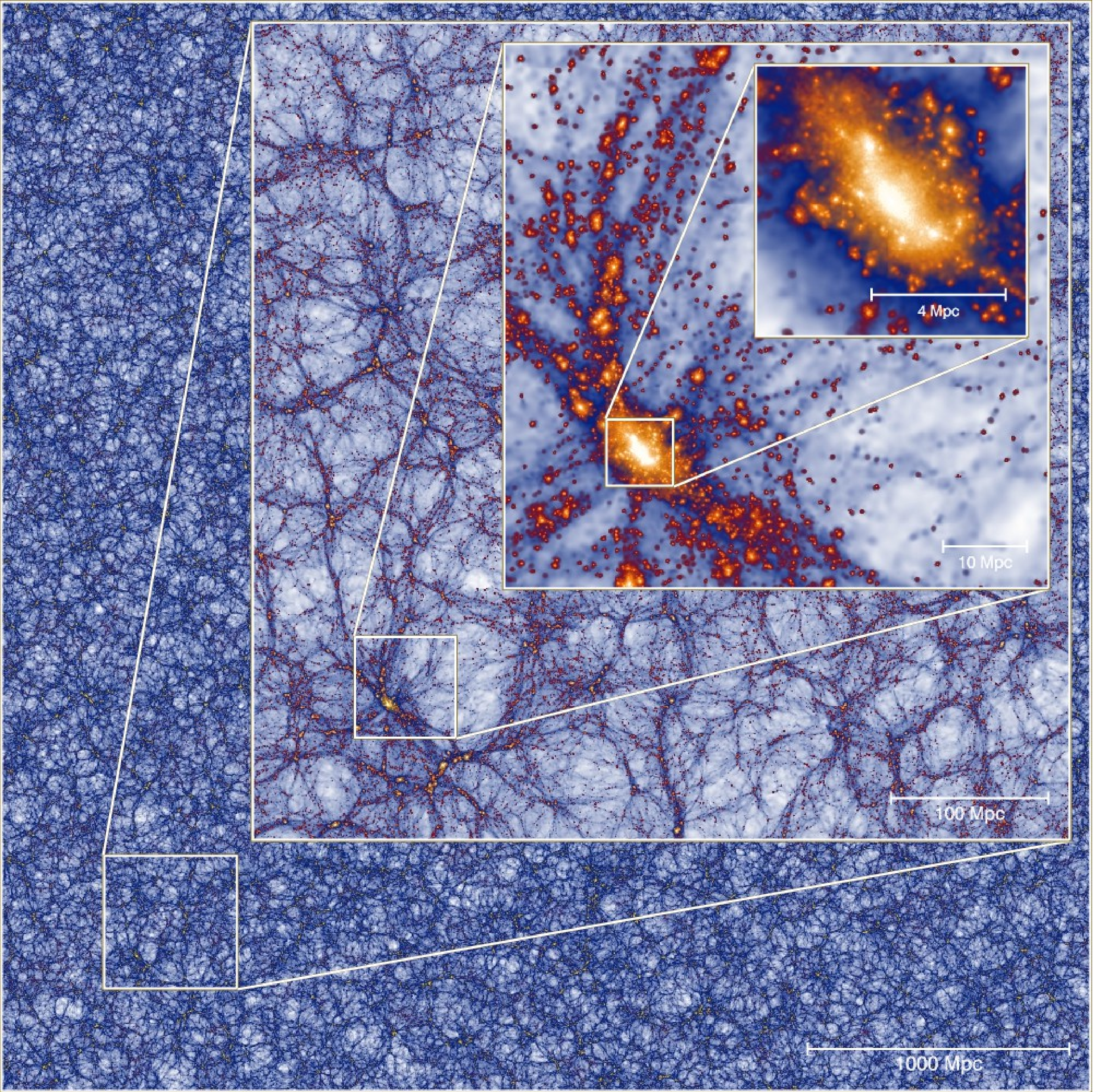
Largest cluster has $9 \times 10^{15}\ M_{\odot}$

Size of a full snapshot: ~10 TB

More than 120 TB stored for science

JUROPA
Jülich
Forschungszentrum

Carried out by Raul Angulo and Volker Springel within the Virgo Consortium



The MXXL

Angulo, Springel
et al 2012

Bigger than the Millennium Run by factors of

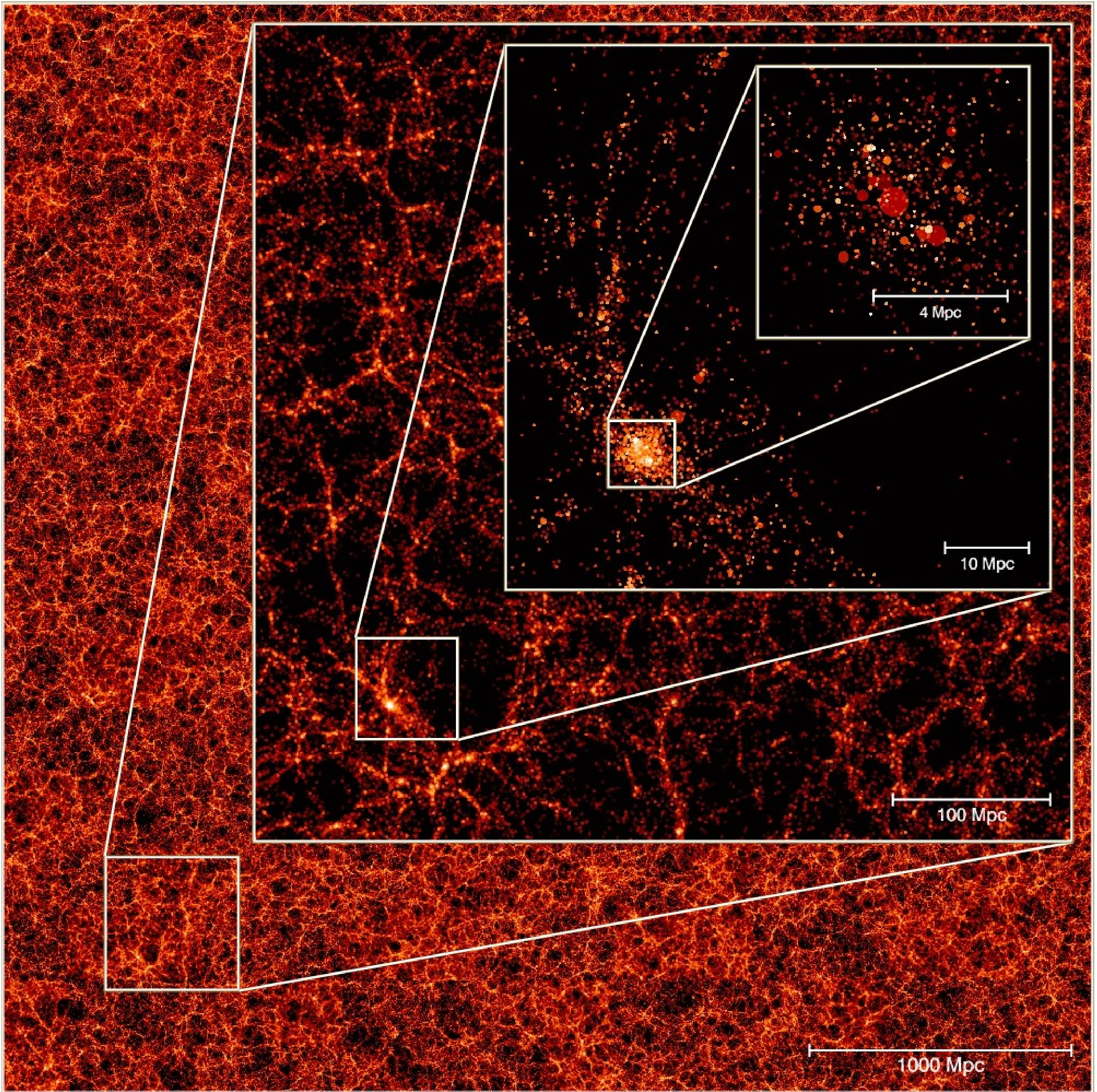
30 in $N_{particle}$

200 in Volume

6 in $m_{particle}$

The MXXL

Angulo, Springel et al 2012



Bigger than the Millennium Run by factors of

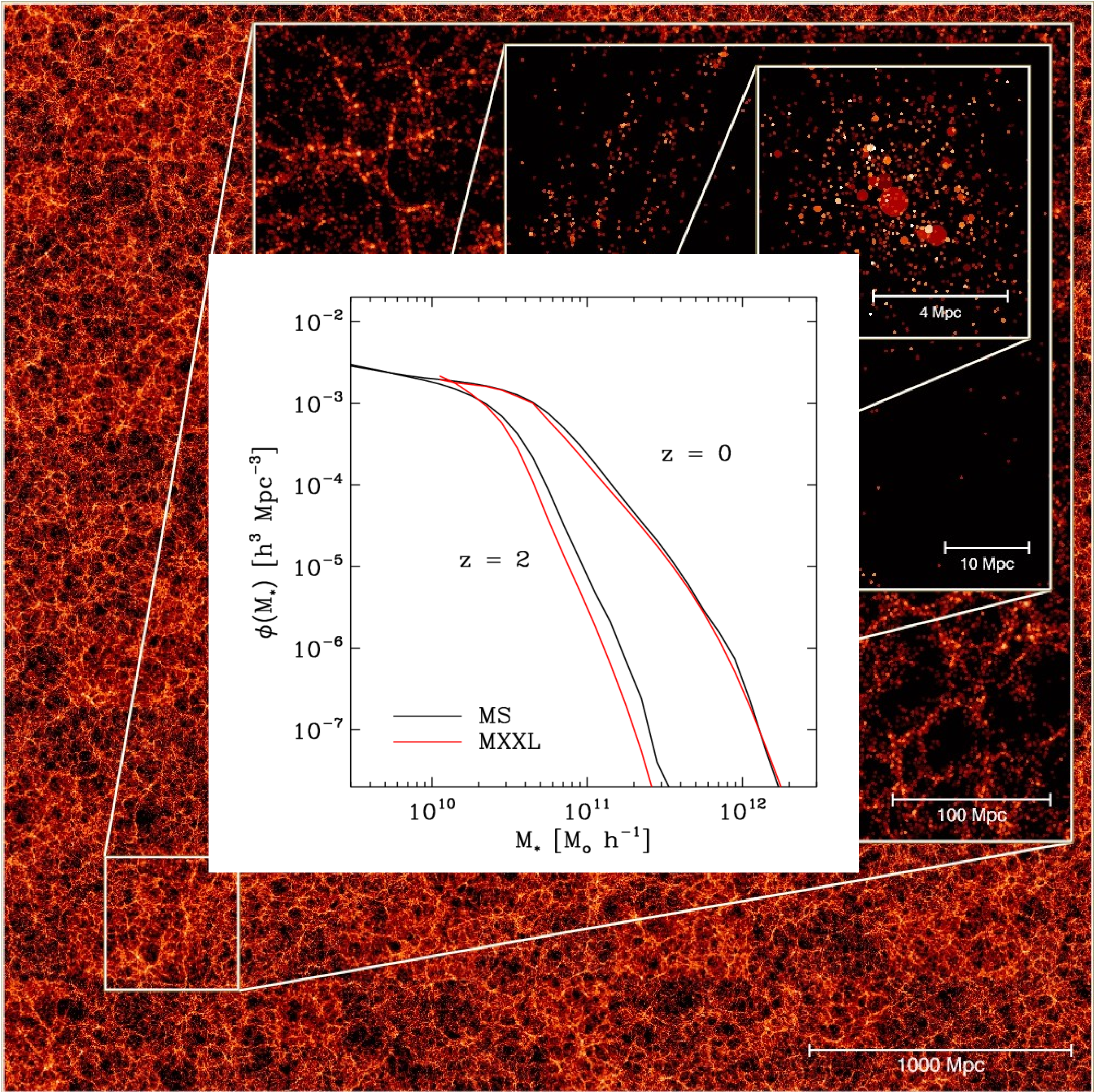
30 in $N_{particle}$

200 in Volume

6 in $m_{particle}$

3×10^8 galaxies
$\log M_*/M_\odot > 10$

3×10^5 clusters
$\log M_*/M_\odot > 14$



The MXXL

Angulo, Springel et al 2012

Bigger than the Millennium Run by factors of

30 in $N_{particle}$

200 in Volume

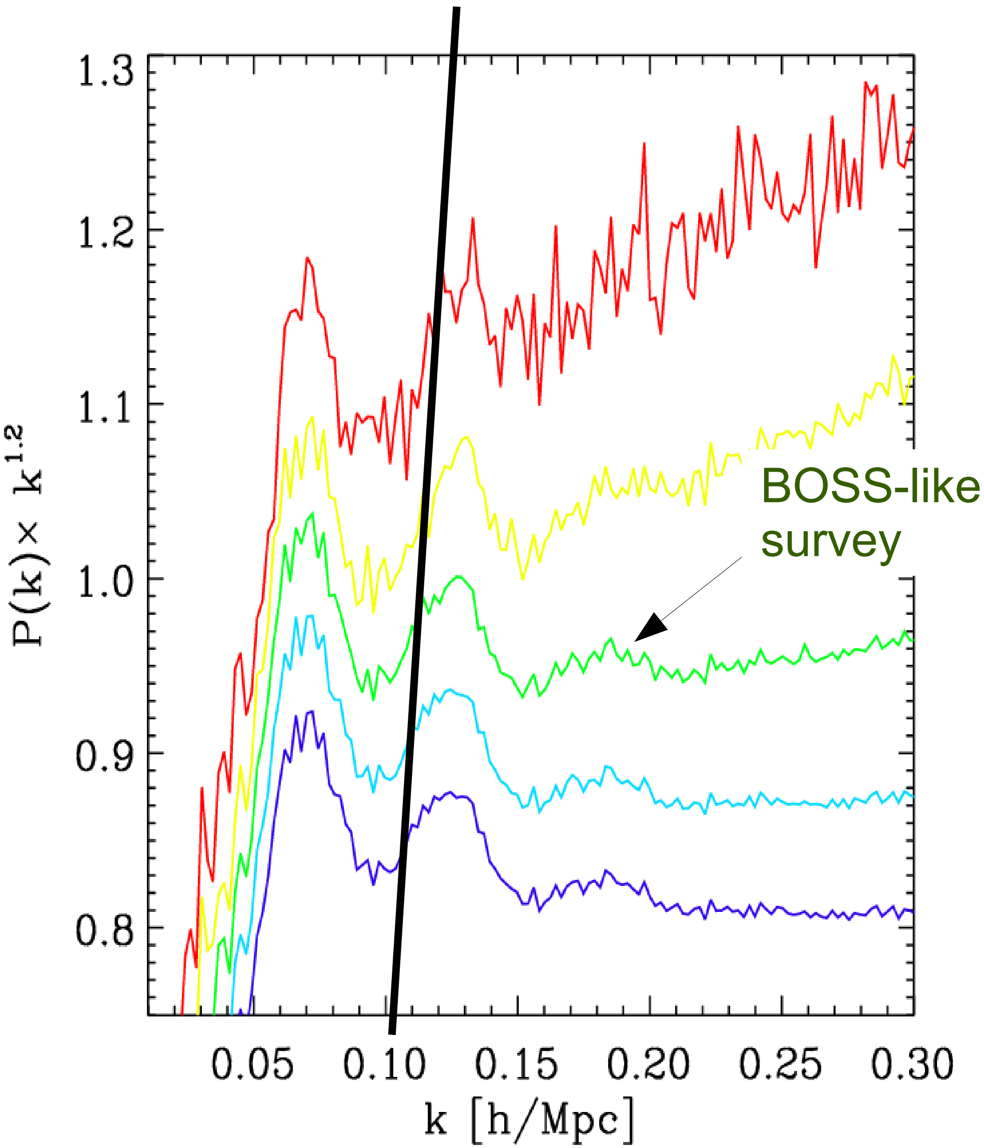
6 in $m_{particle}$

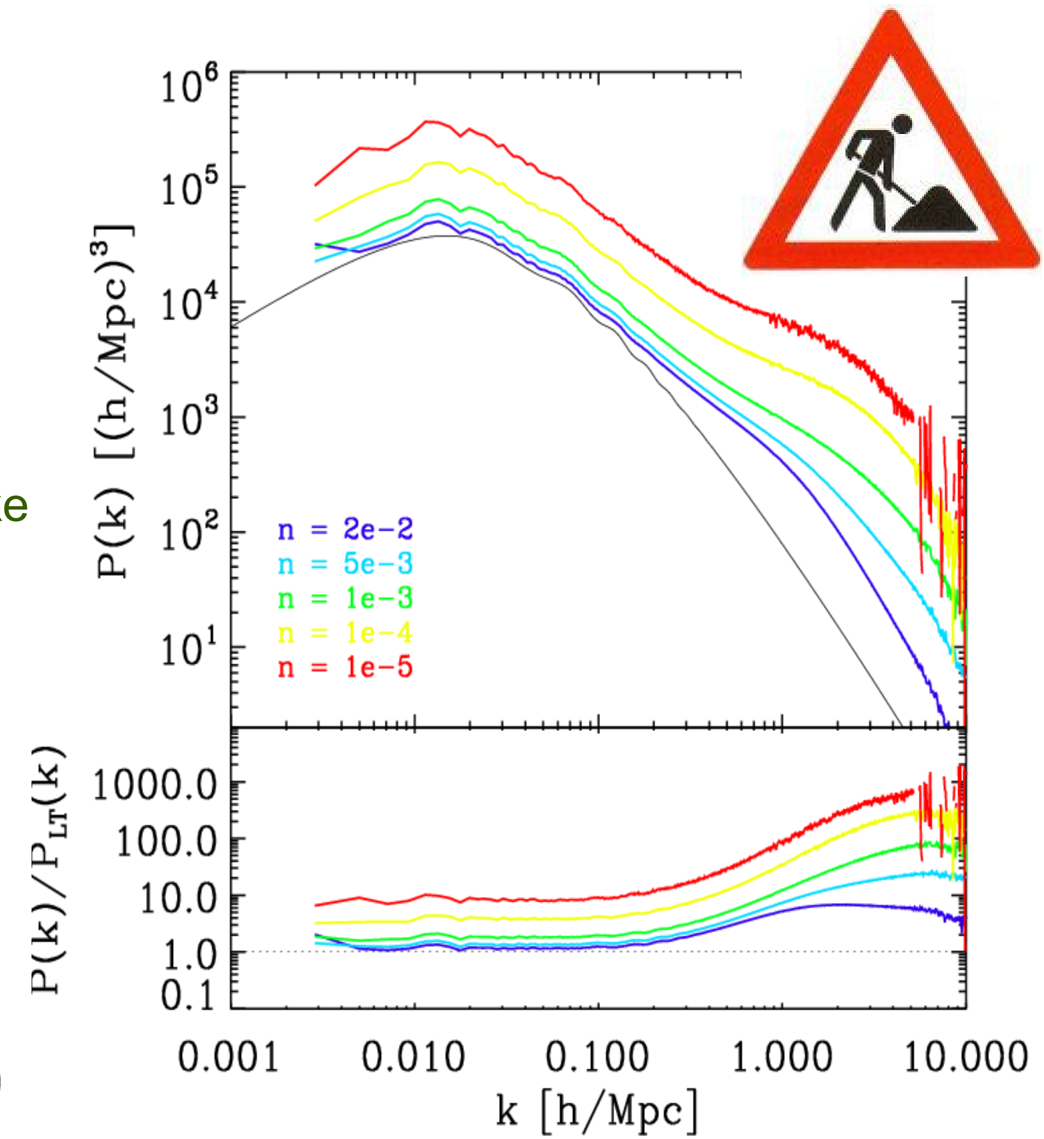
3×10^8 galaxies
$\log M_*/M_\odot > 10$

3×10^5 clusters
$\log M_*/M_\odot > 14$

Different galaxy catalogues in the MXXL simulation trace the BAO features with a <u>mass- and scale-dependent</u> bias

POWER SPECTRA OF THE GALAXY DISTRIBUTION AT Z=0 FOR DIFFERENT SPACE DENSITIES

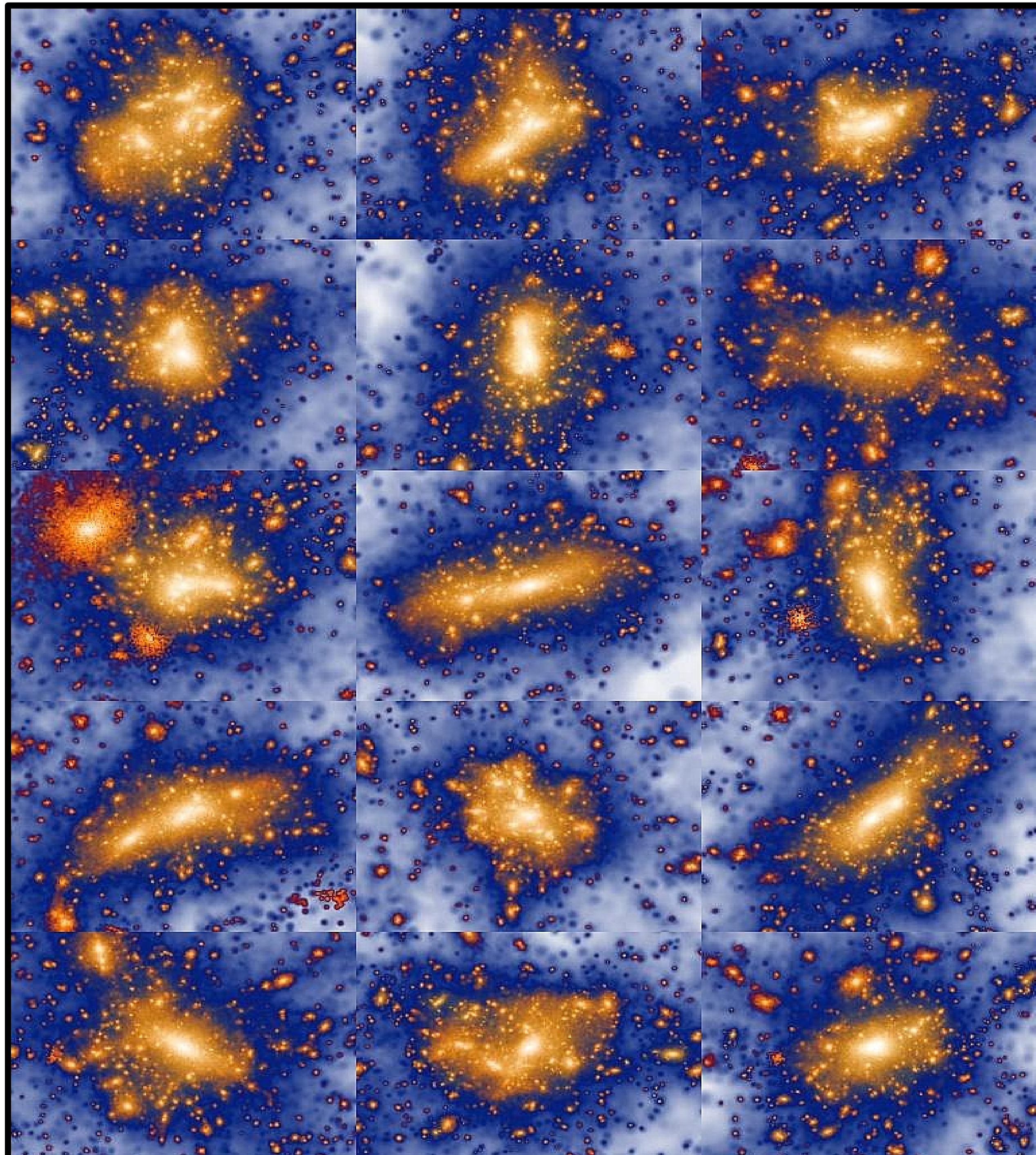


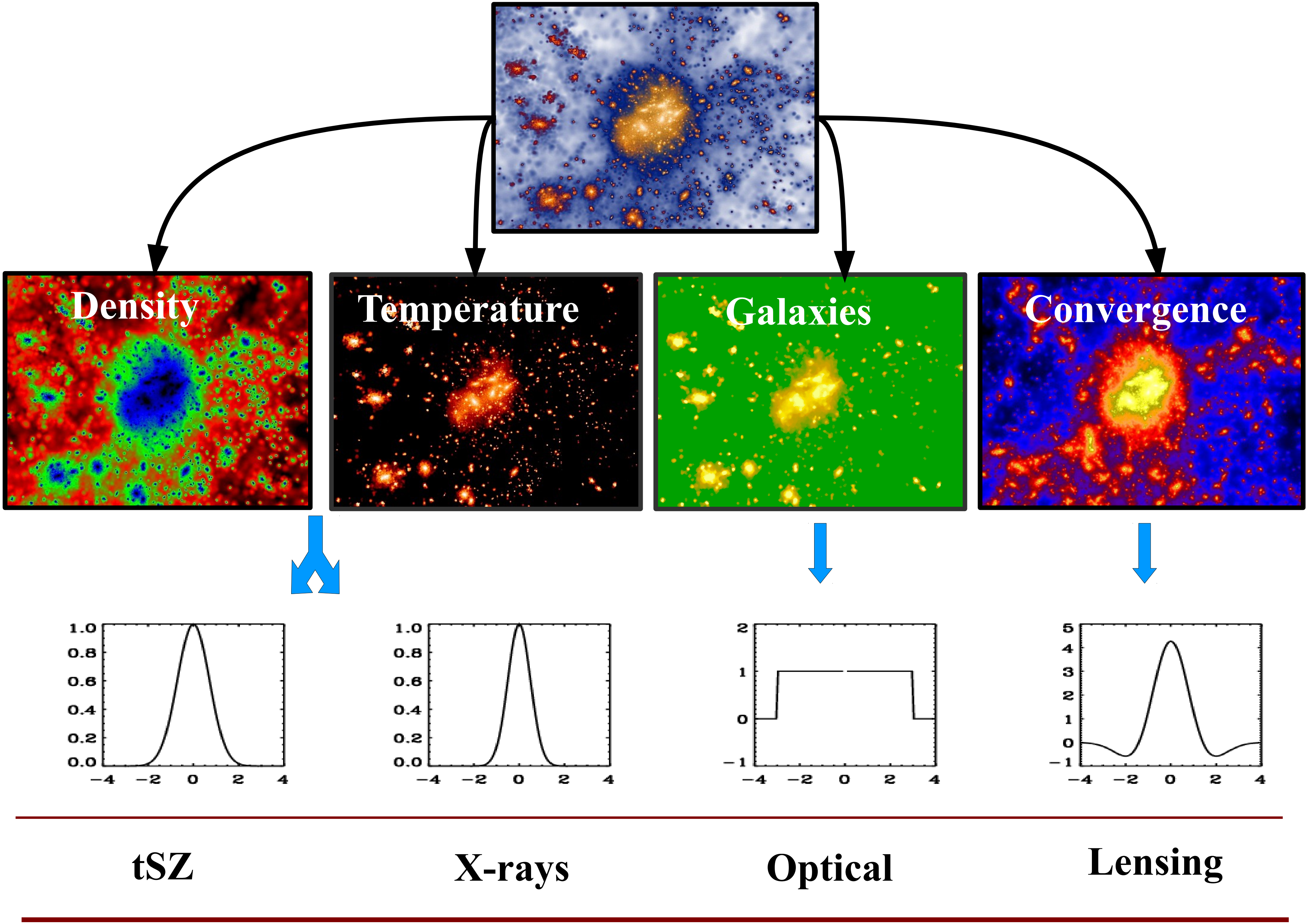


Angulo et al. (2011)

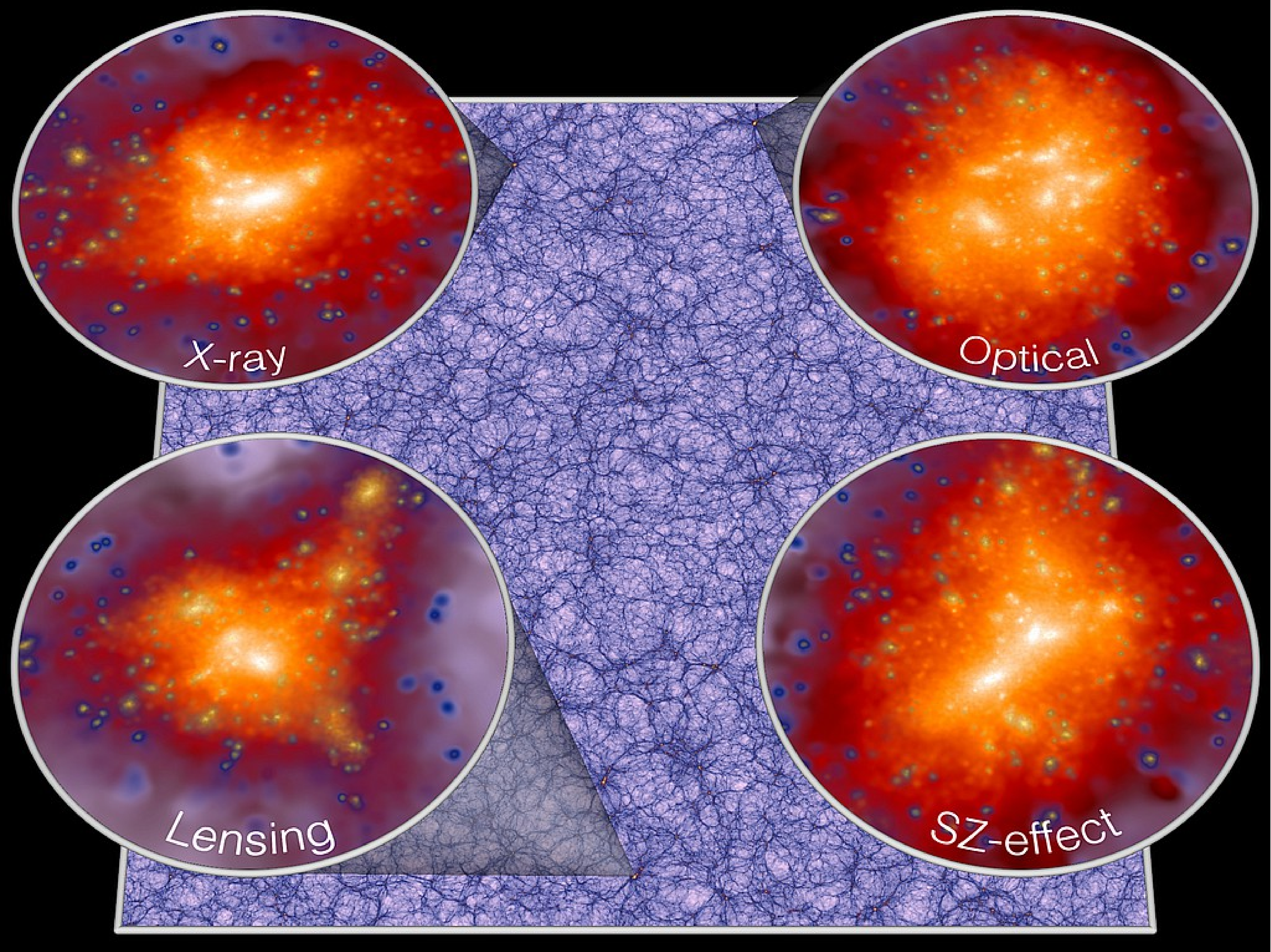
Massive clusters aren't a homogenous population and are often irregular

Snapshot z=0.32
15 most massive clusters
according to M_{200}
$M = [2.5 – 4] \times 10^{15}\ M_{\odot}/h$



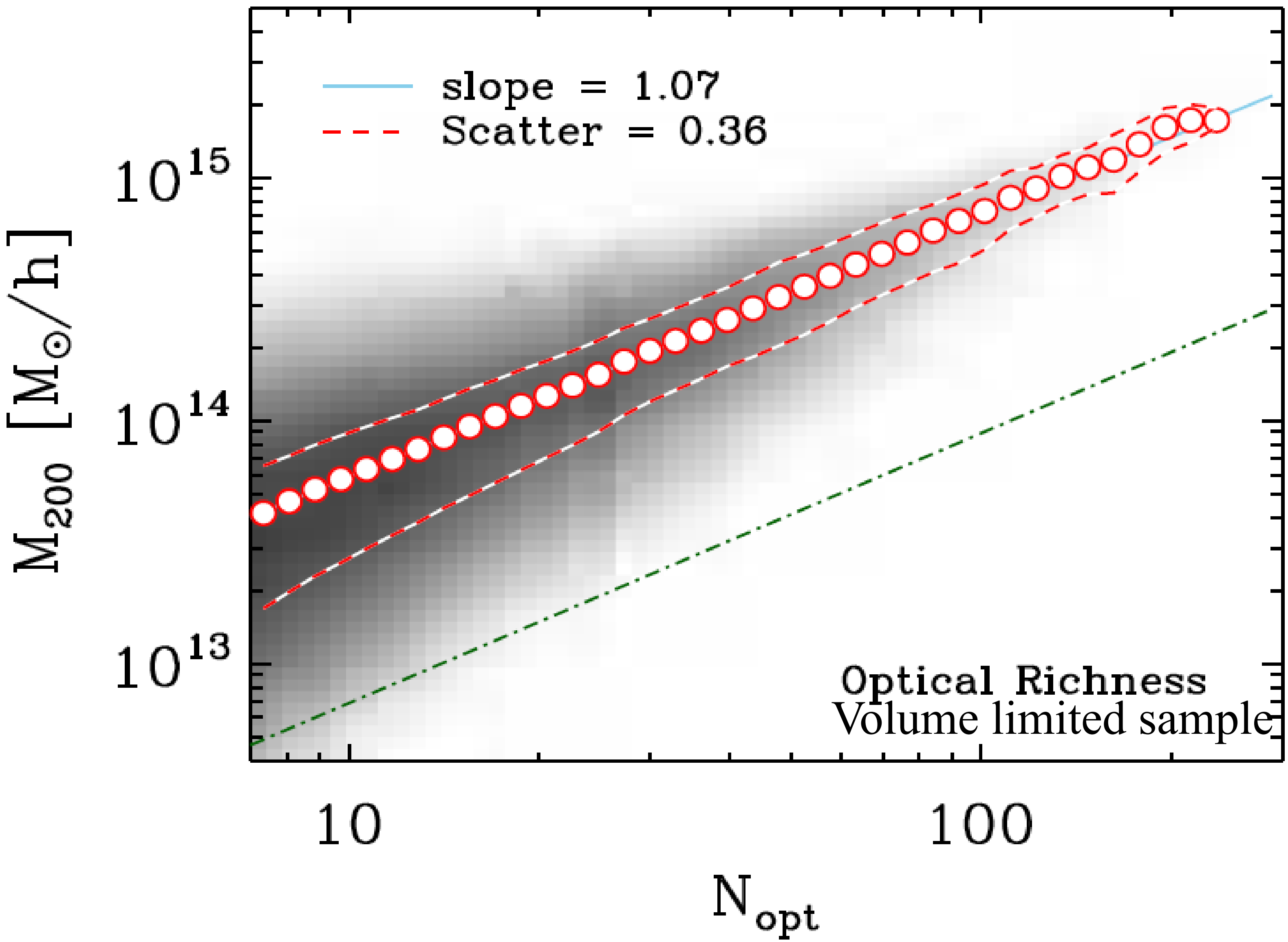


Density
Temperature
Galaxies
Convergence
1.0
0.8
0.6
0.4
0.2
0.0
−4
−2
0
2
4
5
3
1
−1
tSZ
X-rays
Optical
Lensing


X-ray
Optical
Lensing
SZ-effect

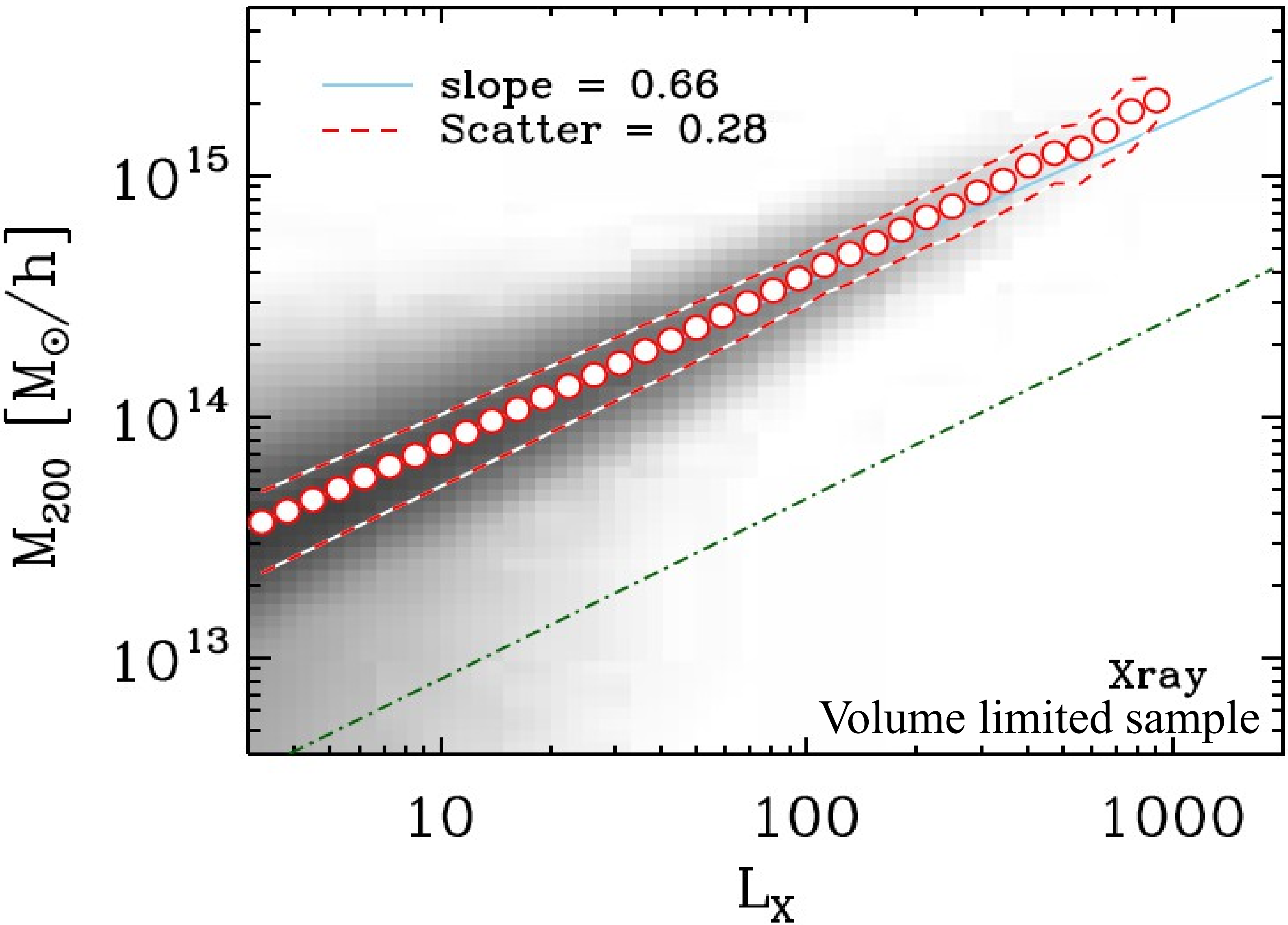
True virial mass as a function of maxBCG richness

Angulo et al 2012



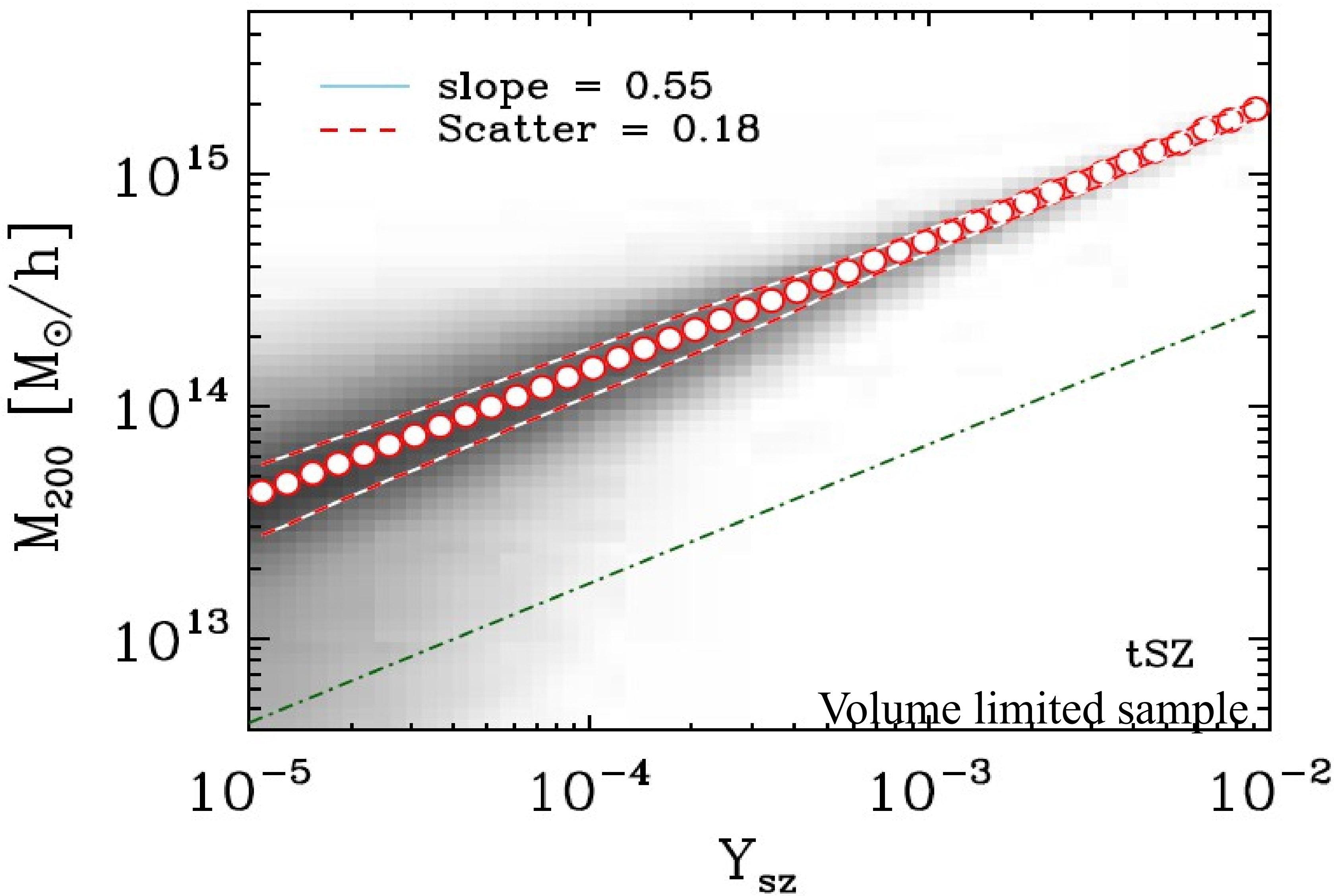
True virial mass as a function of L_X for a "maxBCG" cluster sample

Angulo et al 2012



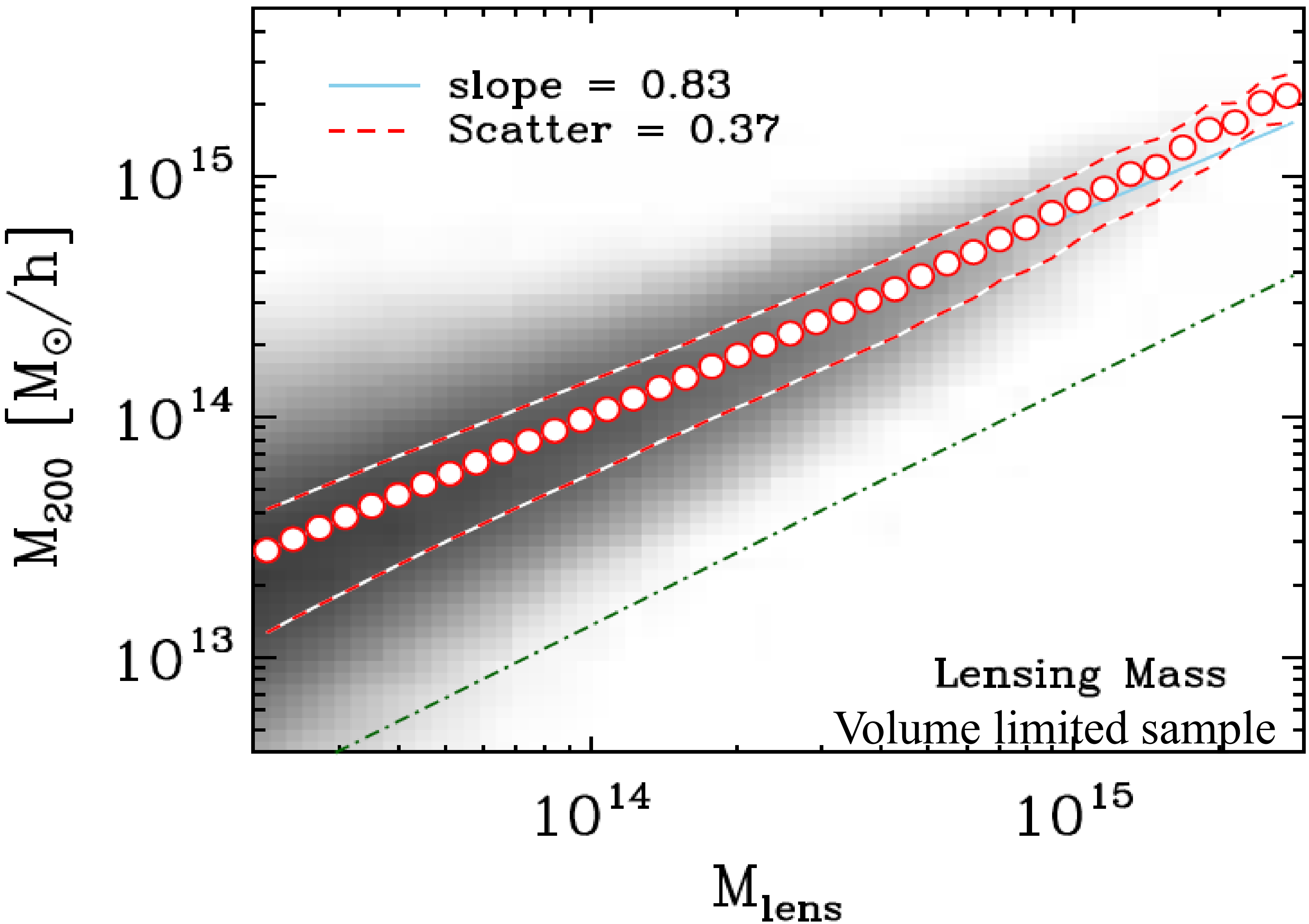
True virial mass as a function of Y_{SZ} for a "maxBCG" cluster sample

Angulo et al 2012

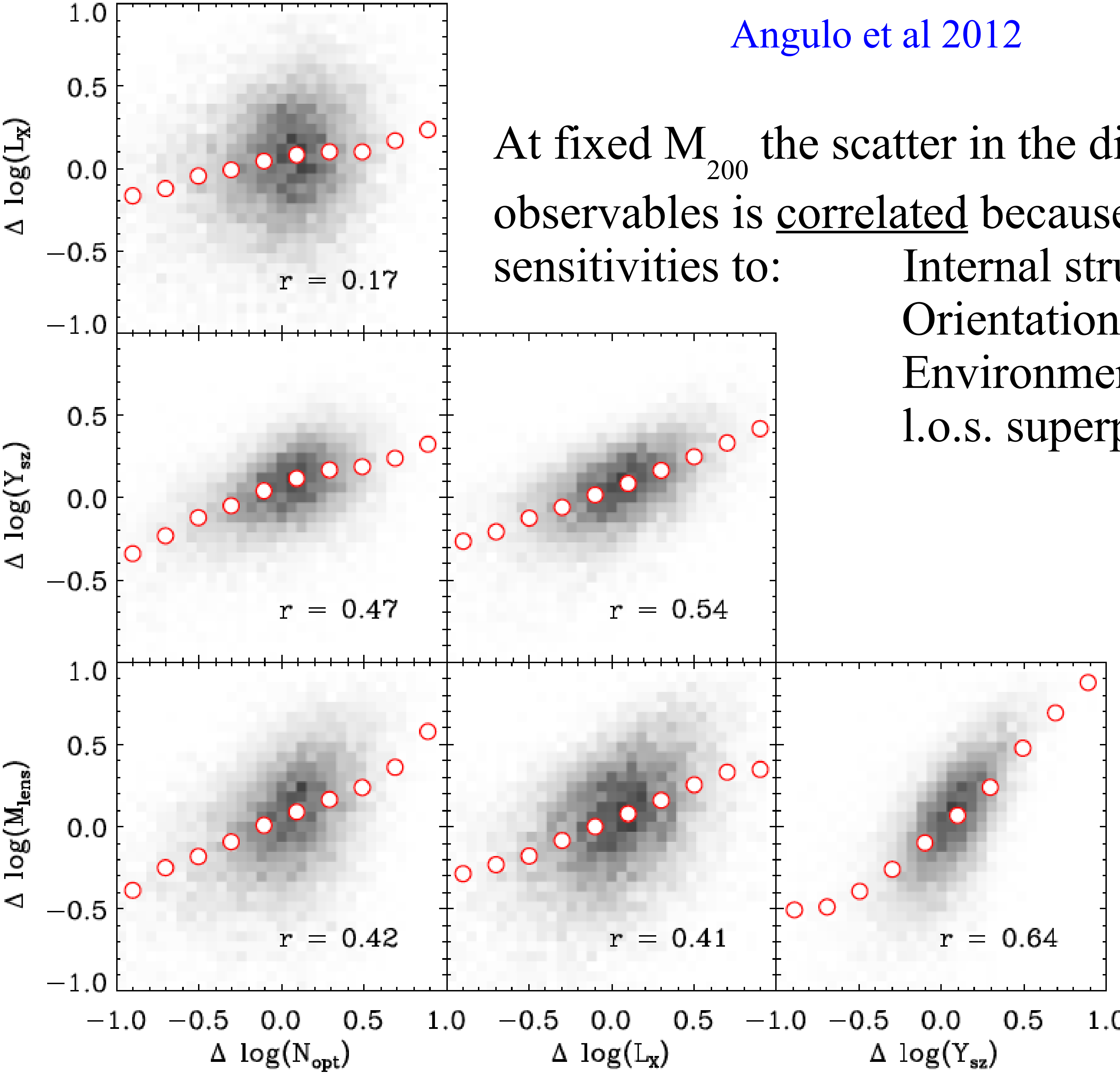


True virial mass as a function of M_{lens} for a "maxBCG" cluster sample

Angulo et al 2012

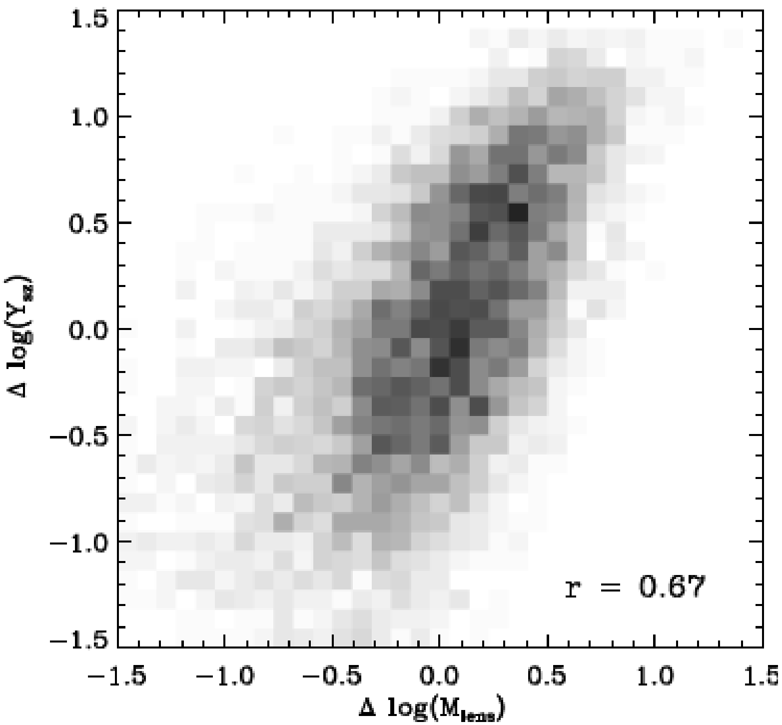


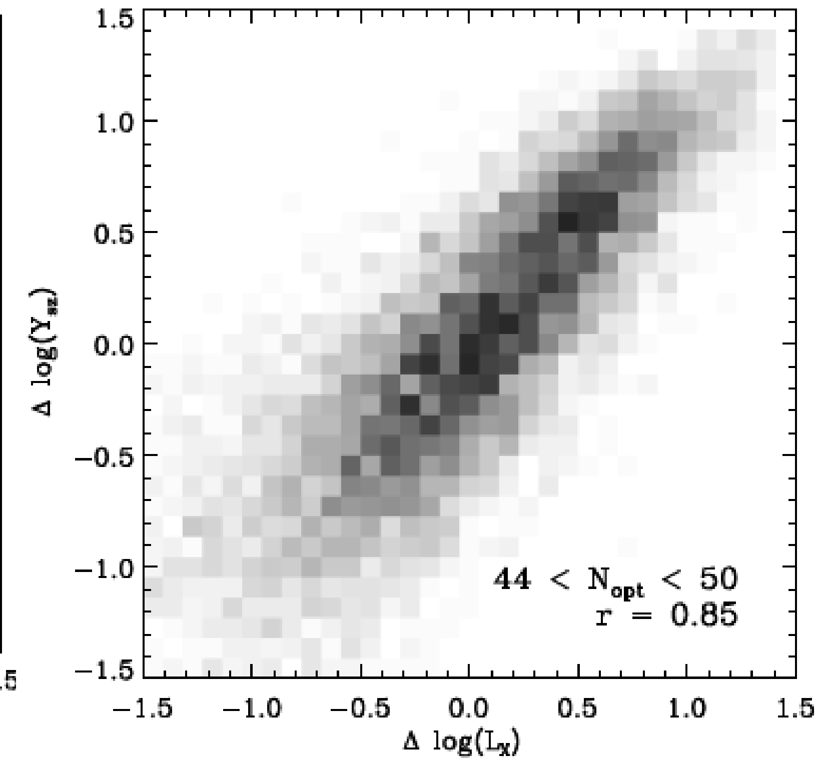
Angulo et al 2012

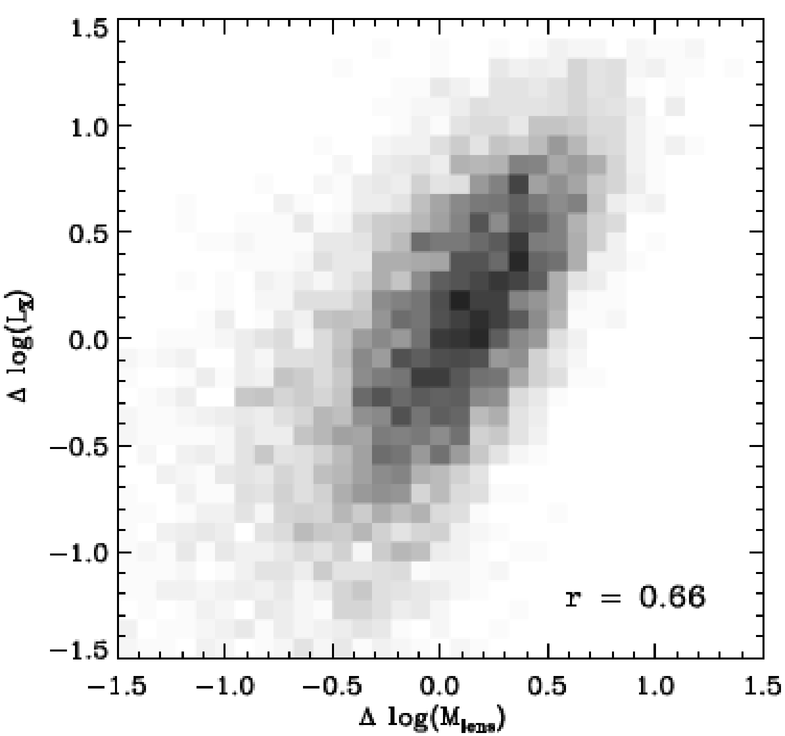


At fixed M_{200} the scatter in the different observables is correlated because of common sensitivities to:

- Internal structure
- Orientation
- Environment
- l.o.s. superpositions

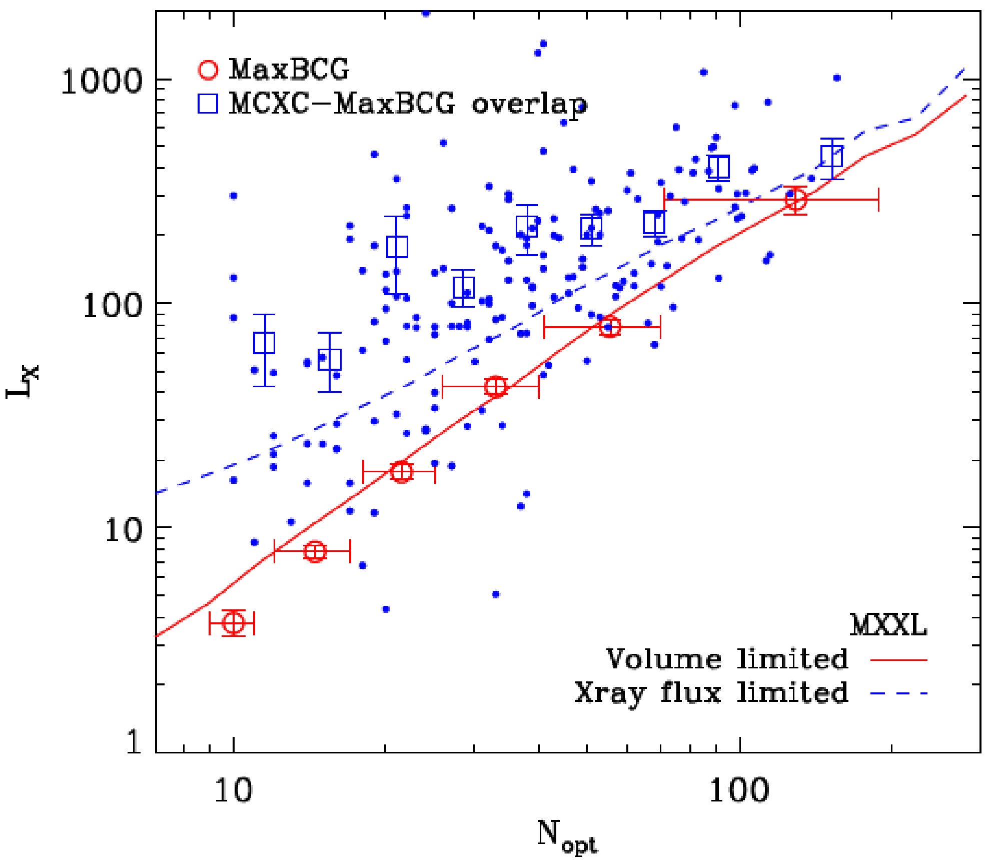


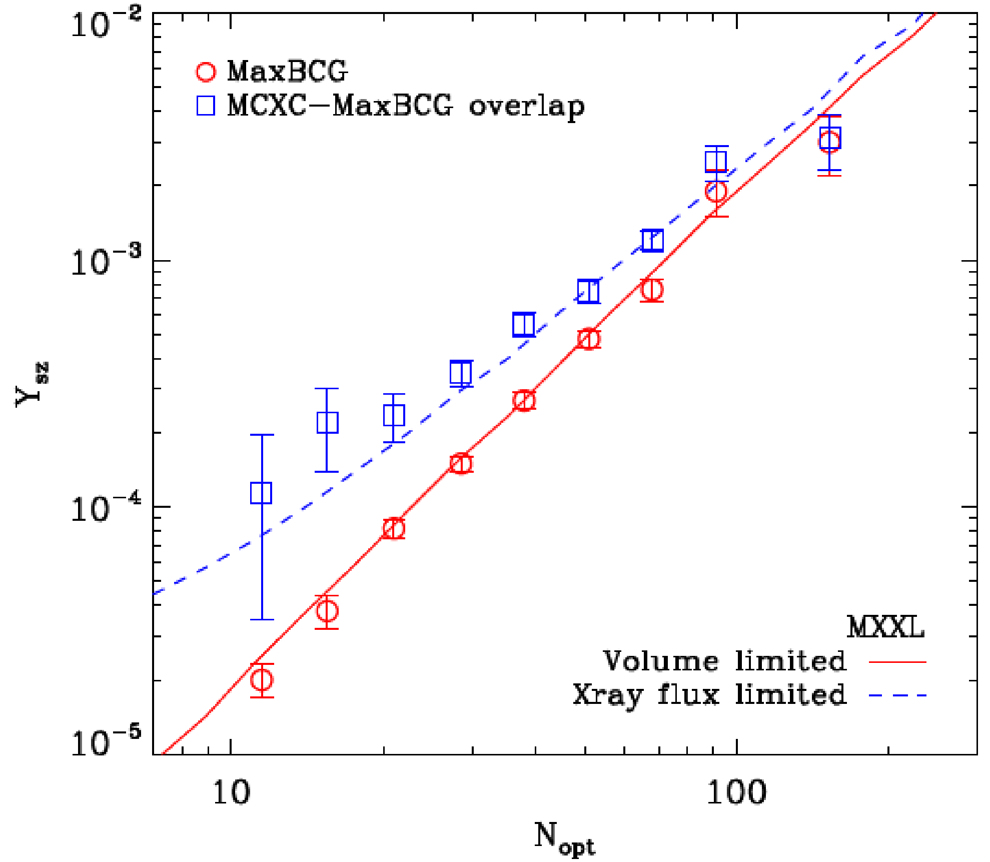




Such correlations are even stronger at fixed optical richness N_{opt}

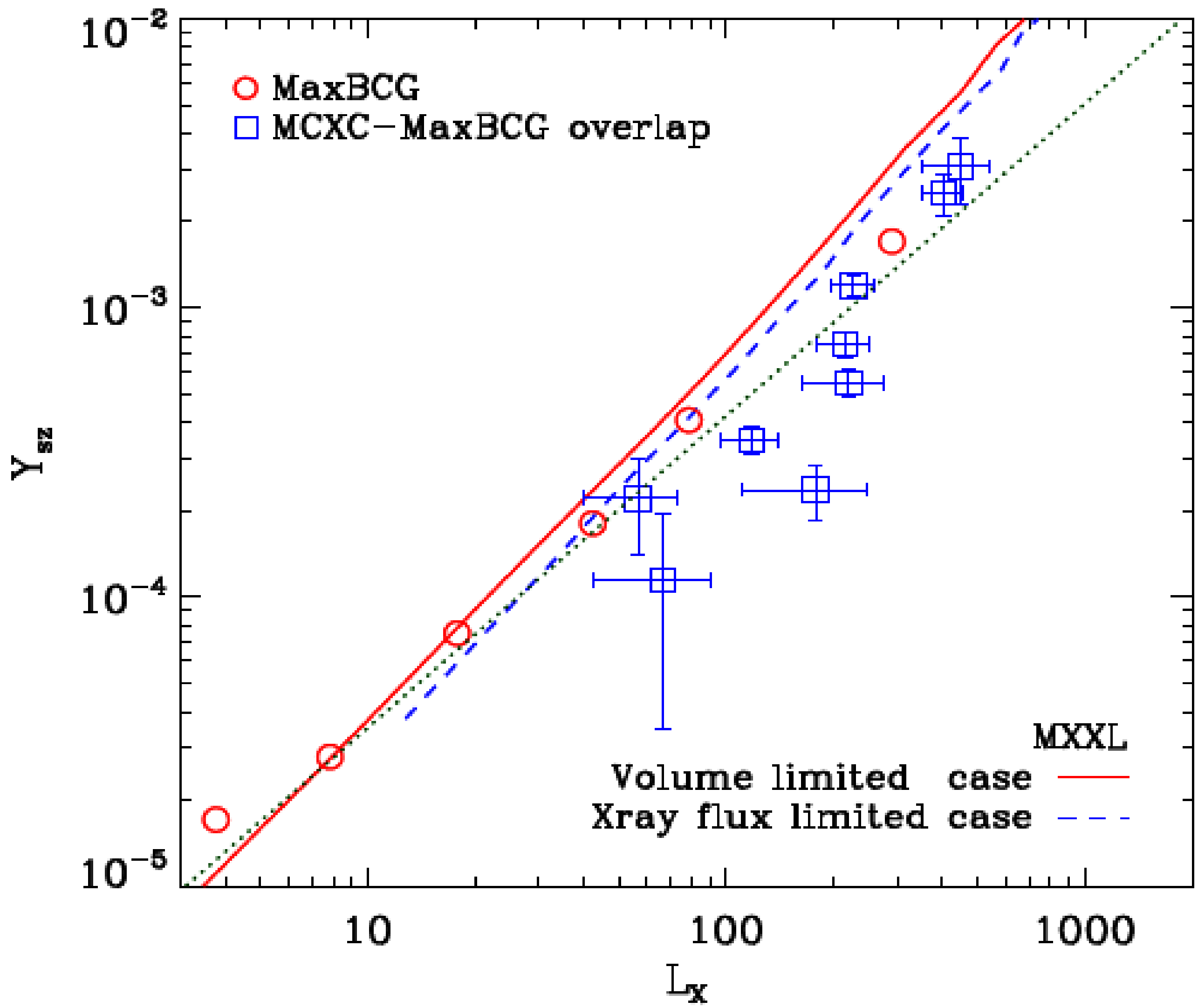
→ Malmquist bias in X-ray selected cluster samples is transferred to their Y distributions.





Surrogate observables are normalised to fit the observed $M_{200} - N_{opt}$, $L_X - N_{opt}$ and $Y - N_{opt}$ for optically selected maxBCG clusters

They then fit the offset relations for the X-ray selected MCXC subset



..and they predict NO difference between the $Y - L_X$ relations of volume- (e.g. maxBCG) and flux- (e.g. MCXC) selected samples

The predicted relation is quite close to that observed

Conclusions

- The ΛCDM cluster population is expected to show almost self-similar scalings but with large scatter
- "Observed" scaling relations depend substantially on survey strategy and on the definition of the observables
- The relations for X-ray selected samples have **less** scatter and are biased **high** compared to volume-limited samples
- At fixed mass or richness the scatter in Y correlates strongly with that in L_X , so Y is **also** biased high in X-ray samples. This (partially?) explains the Planck "problem"
- Precision cosmology with clusters will require purpose-designed surveys with calibration strategies which fully account for the scatter in all relations between observables