The role of galaxy cluster simulations in the current cosmological paradigm

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LSS ESO MPA
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ACT-CL J0102-4915, z=0.870

Menanteau+12

Galaxy Clusters

Rare peaks in the density field, sensitive to cosmological parameters (σ_8 & Ω_M)

Trace the growth of structure at late times.

Potential is there to constrain Σm_ν, w…

Optical + IRAC 3.6μm and 4.5μm

1'

Crossroads of Cosmology & Astrophysics

"LSS we choose cosmology or astrophysics" -Peacock

"Baryons are scary" -Senatore

Simulations with calibrated sub-grid models are now in pretty good agreement with some observations

Unlike most areas LSS, we do not need more clusters

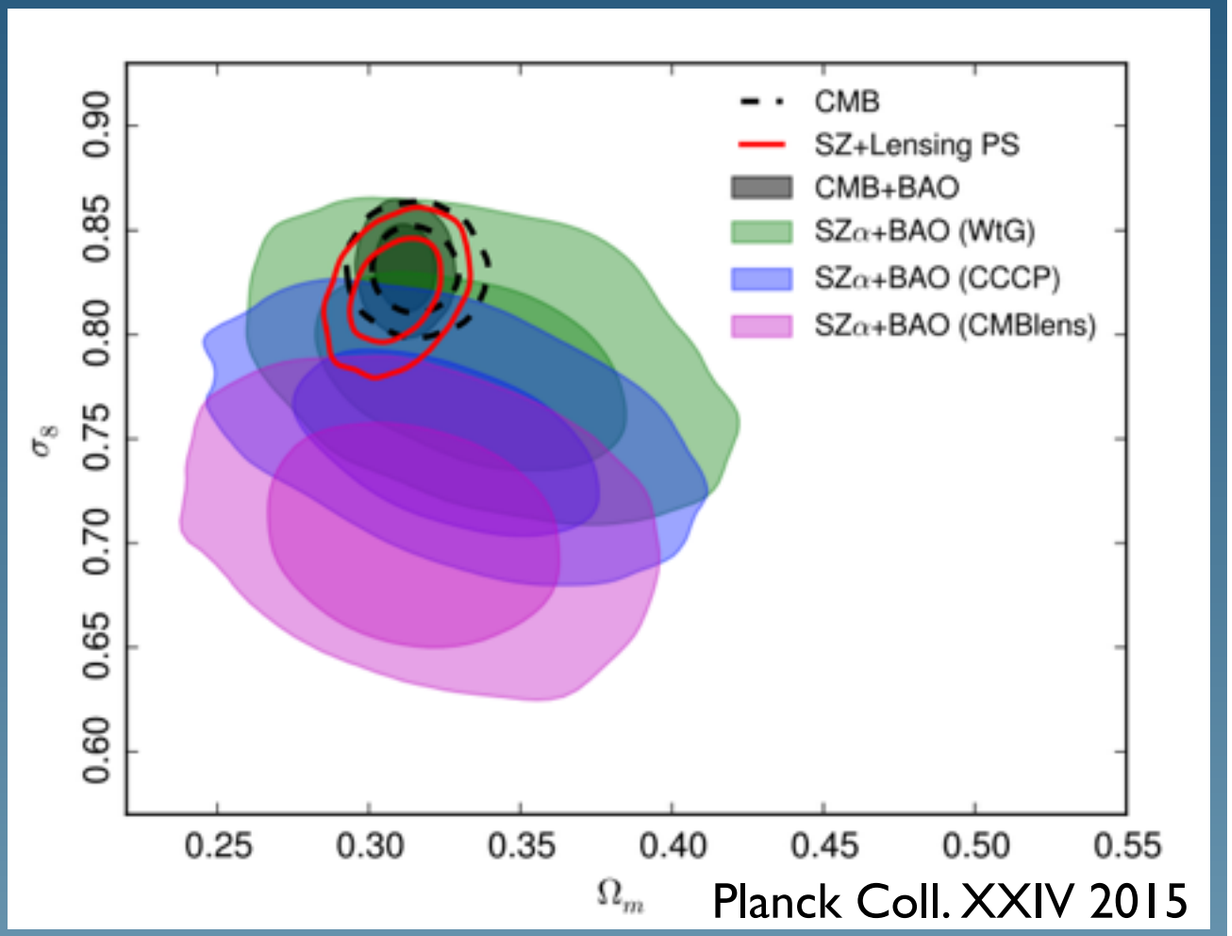
Systematics dominated (astrophysical uncertainties)

Focus mostly on the tSZ cluster cosmology

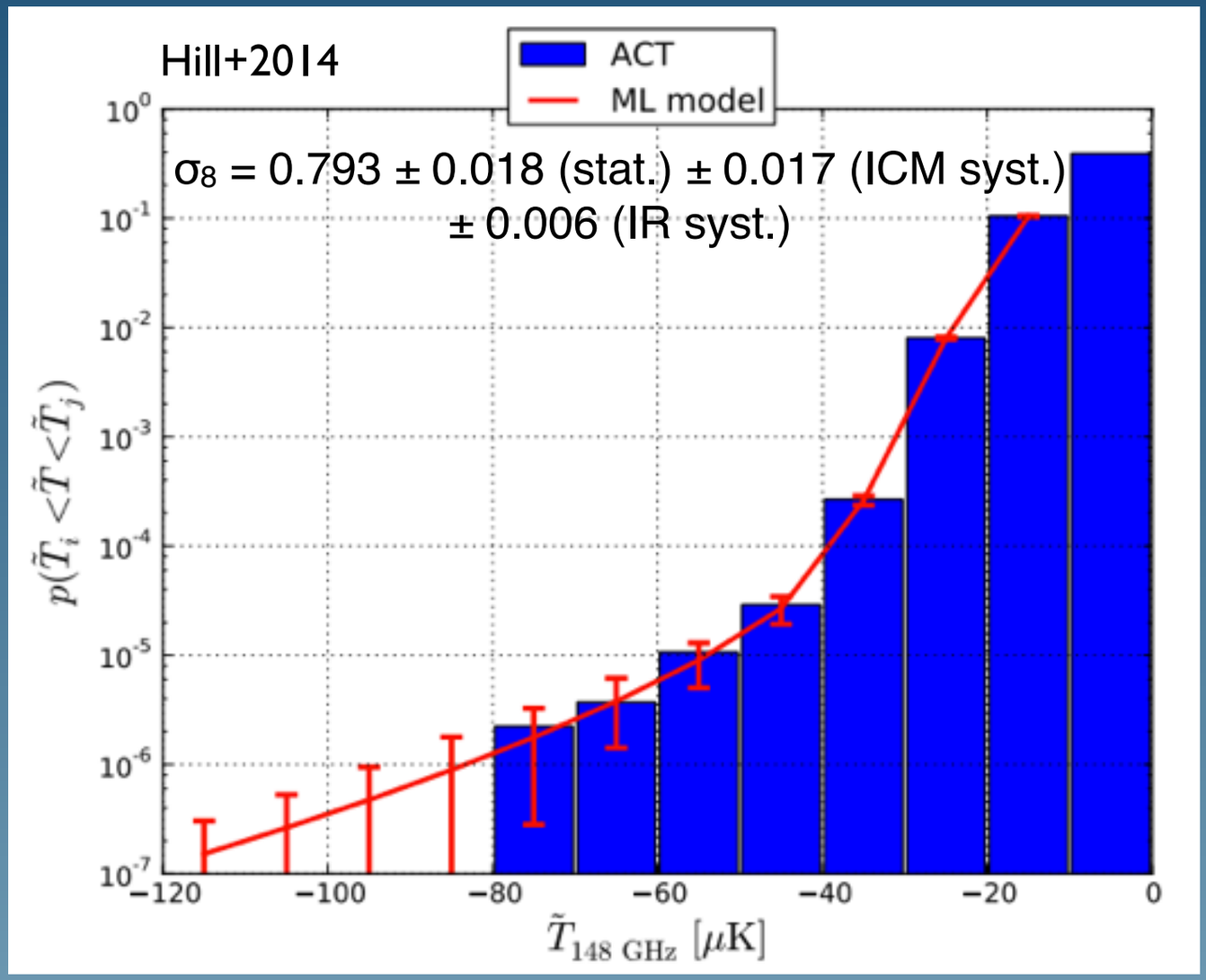
Simulations are a tool for understanding and quantifying the important gastrophysics, biases, and scatter in surveys

Systematics!

Prior to planck reached the systematics limit
e.g., Vikhlinin+2009, Vanderlinde+2010, Sehgal+2011…



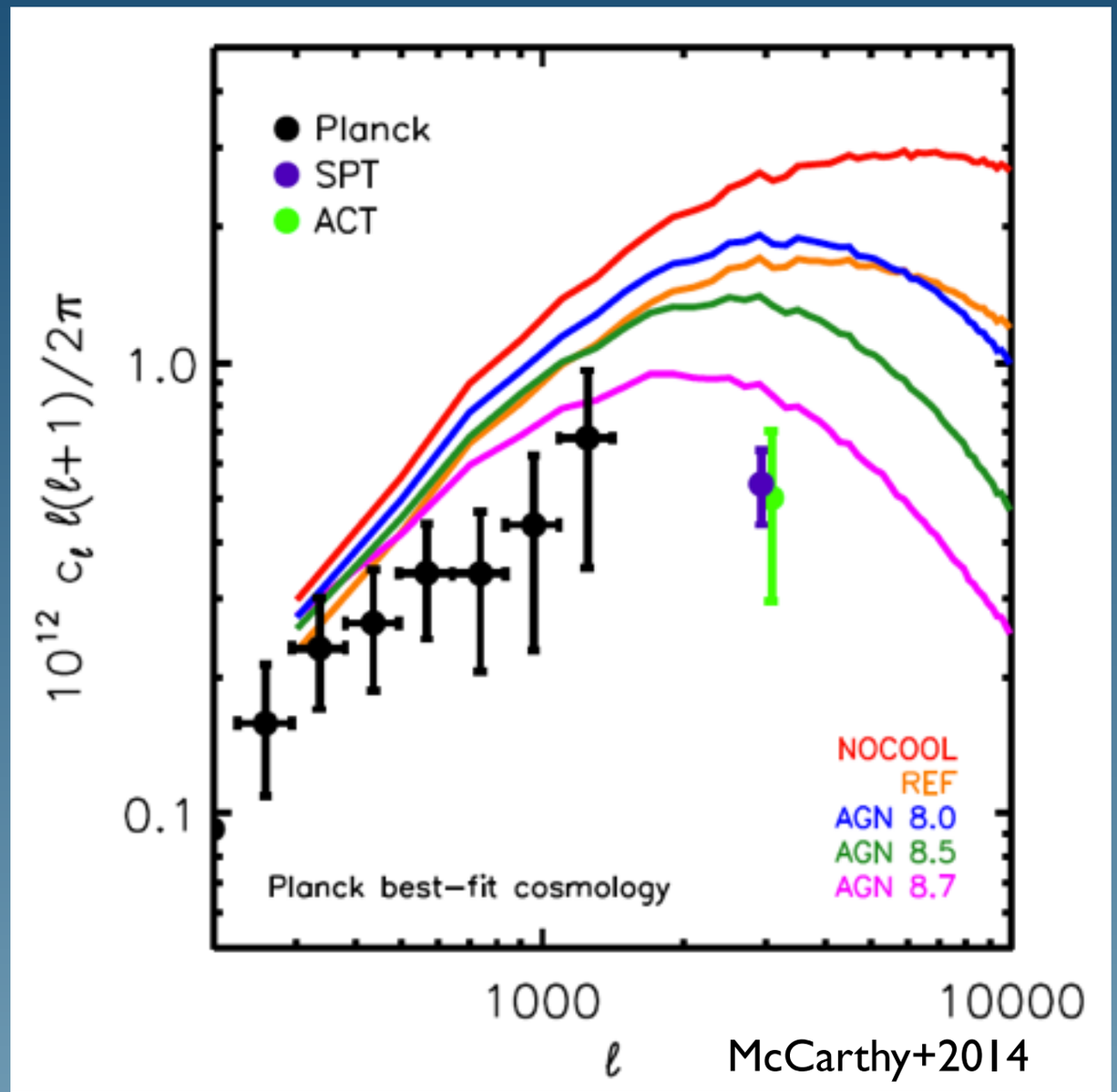
Planck Coll. XXIV 2015



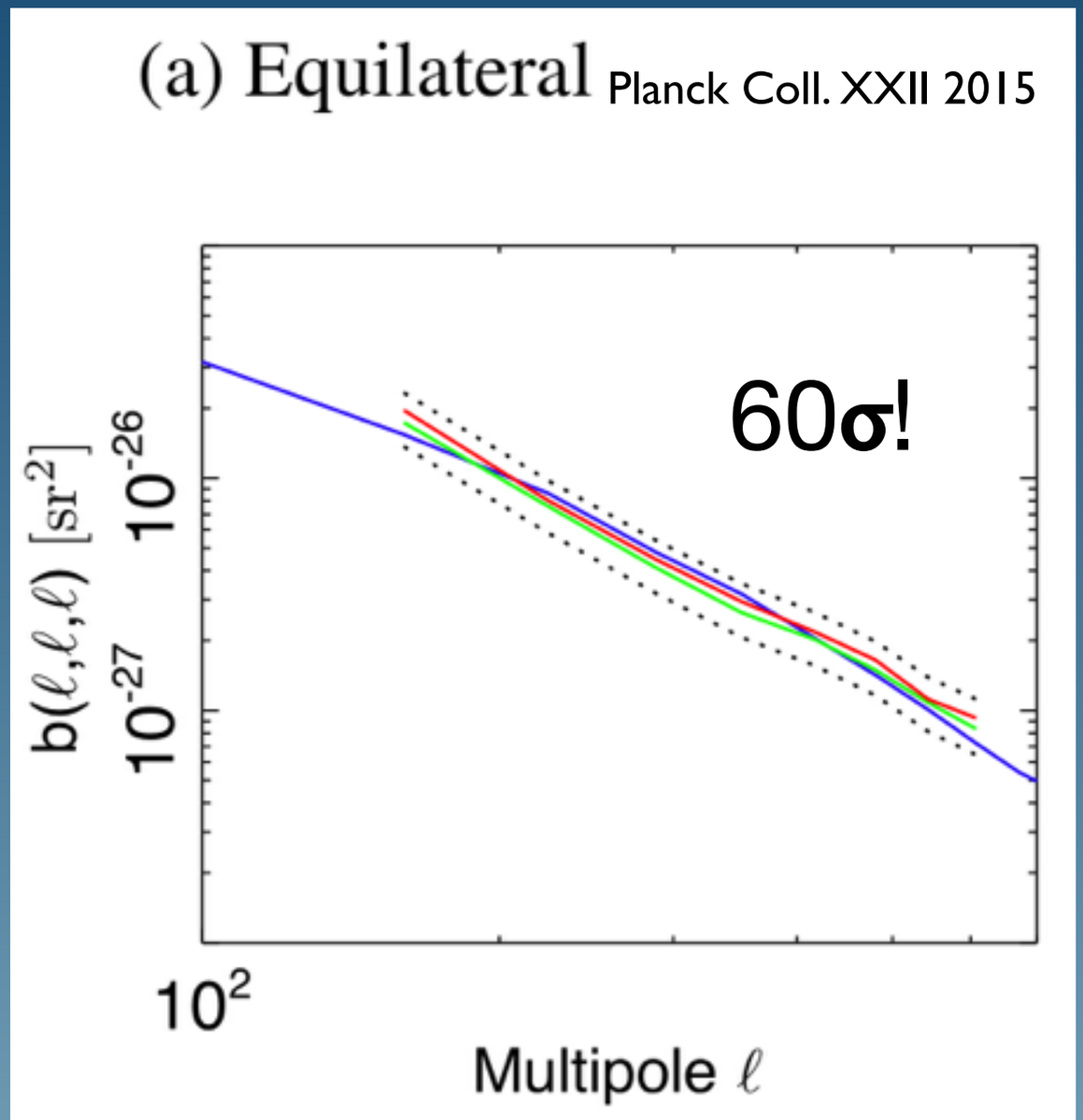
Cluster counts and the PDF

Systematics!

Limited by our knowledge of the pressure profile



McCarthy+2014



Power spectrum and higher order statistics

"Standard" Measurements

Number counts or power spectrum

Also higher order meas.

e.g. Wilson+13, Hill+13, Bhattacharya+13, Crawford+13

f_{gas} e.g. Mantz+10

Cluster counts Selection function & Mass proxy

$$N = \int_0^{z_{\max}} dz \frac{dV}{dz} \int dM \frac{dn(M,z)}{dM}$$

$$p(\mathbf{s}|\mu, z)$$

$$\mu = \ln M$$

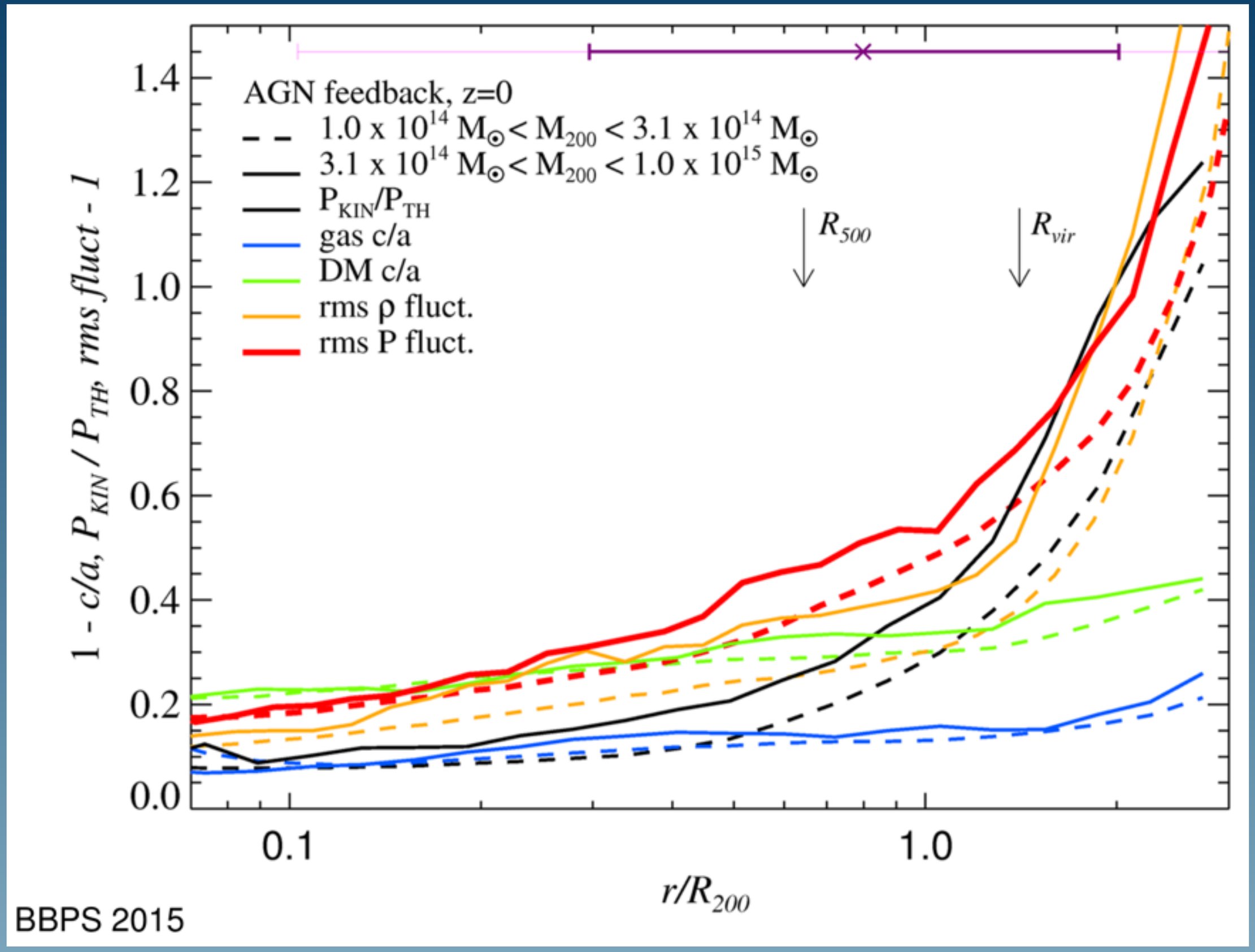
Gastrophysics

tSZ power spectrum $A_{tSZ} \propto \sigma_8^8$

$$C_l = g_\nu^2 \int_0^{z_{\max}} dz \frac{dV}{dz} \int dM \frac{dn(M,z)}{dM} \left|\tilde{y}_l(M,z)\right|^2$$

+ Clustering of clusters (Sub-dominant)

Summary of astrophysical effects

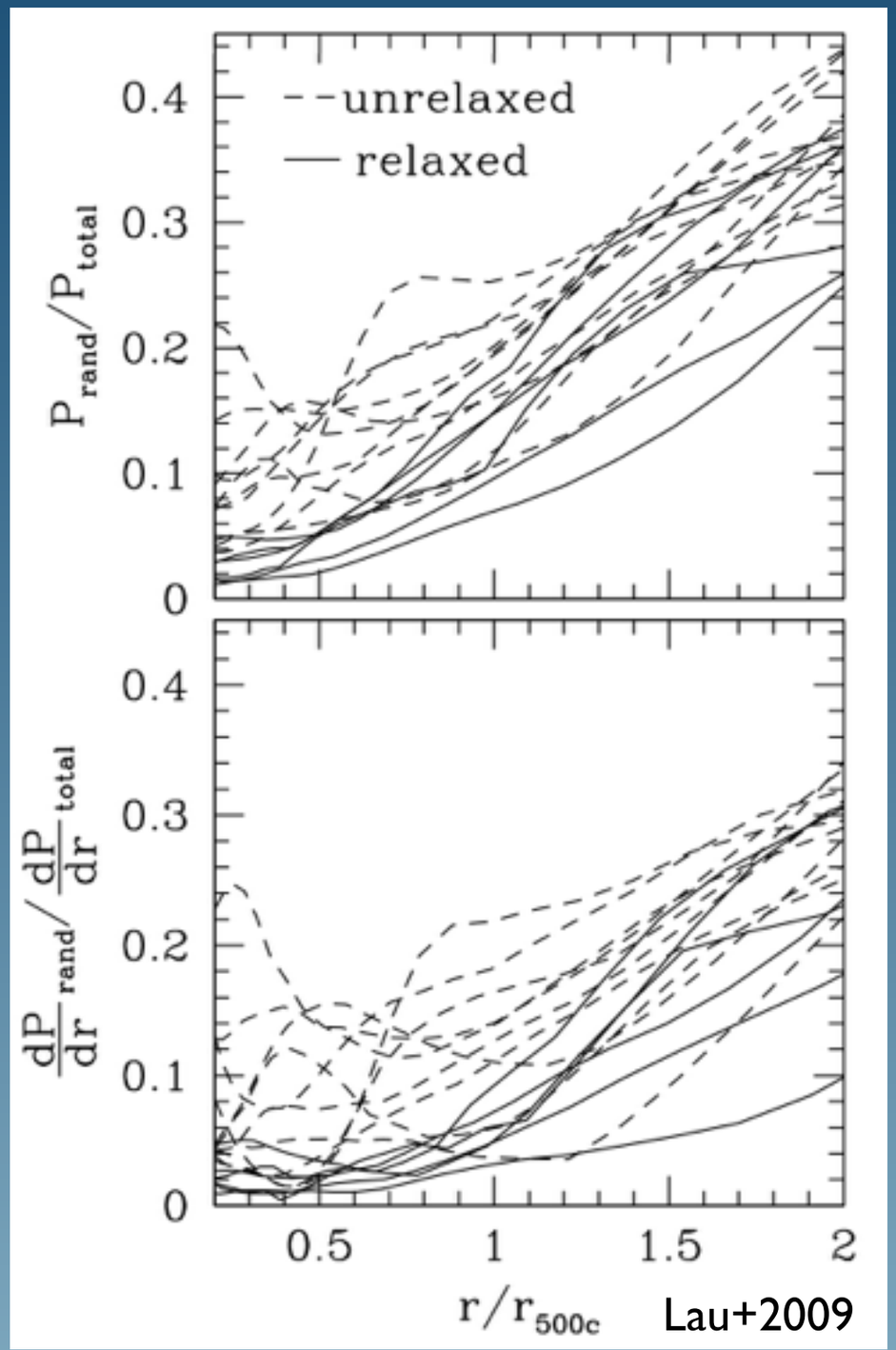


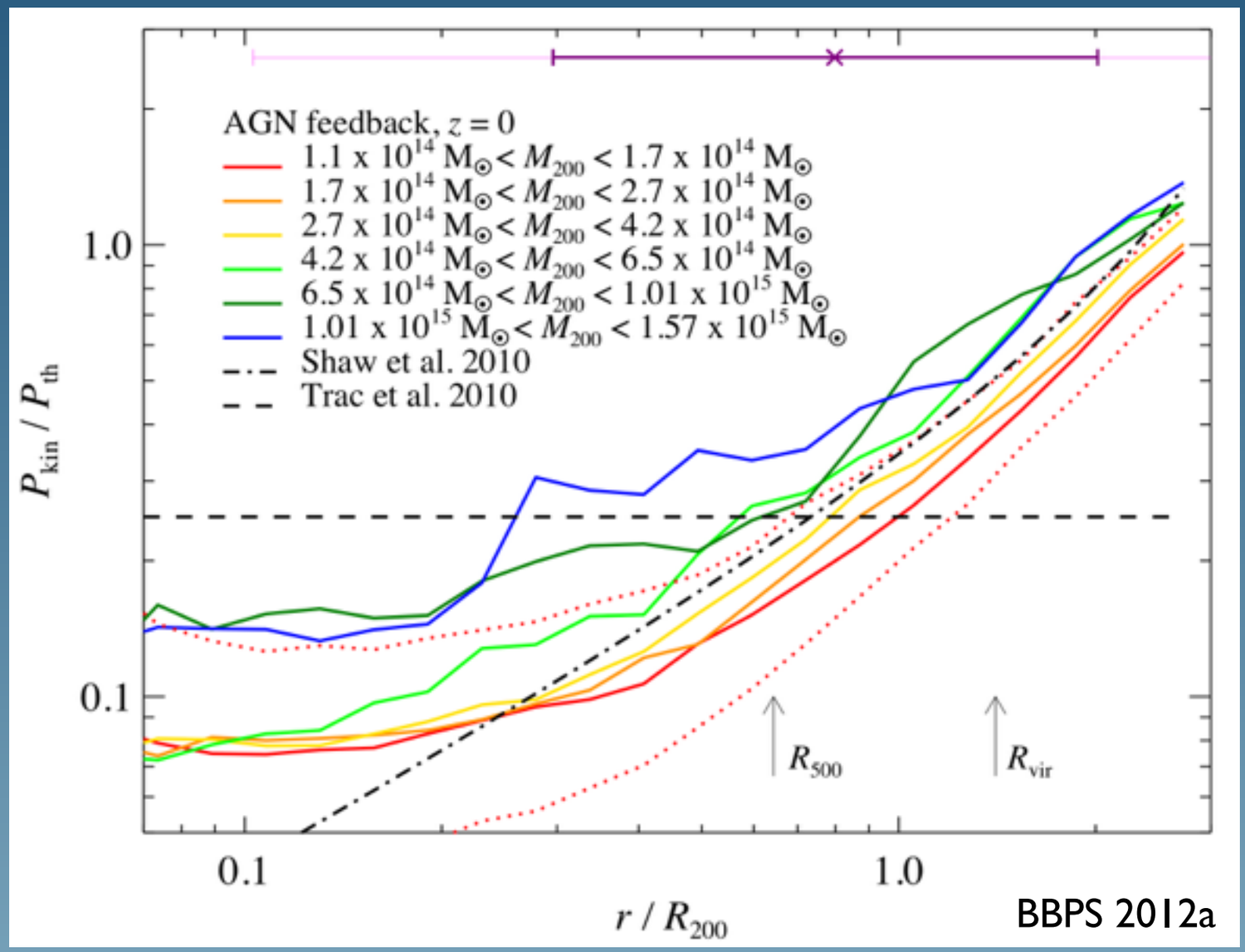
BBPS 2015

Non-thermal pressure support

$$\nabla P = \rho \boldsymbol{g} \rightarrow -\rho G M(<r)\hat{\boldsymbol{r}}/r^2$$

Lau+2013 for more details





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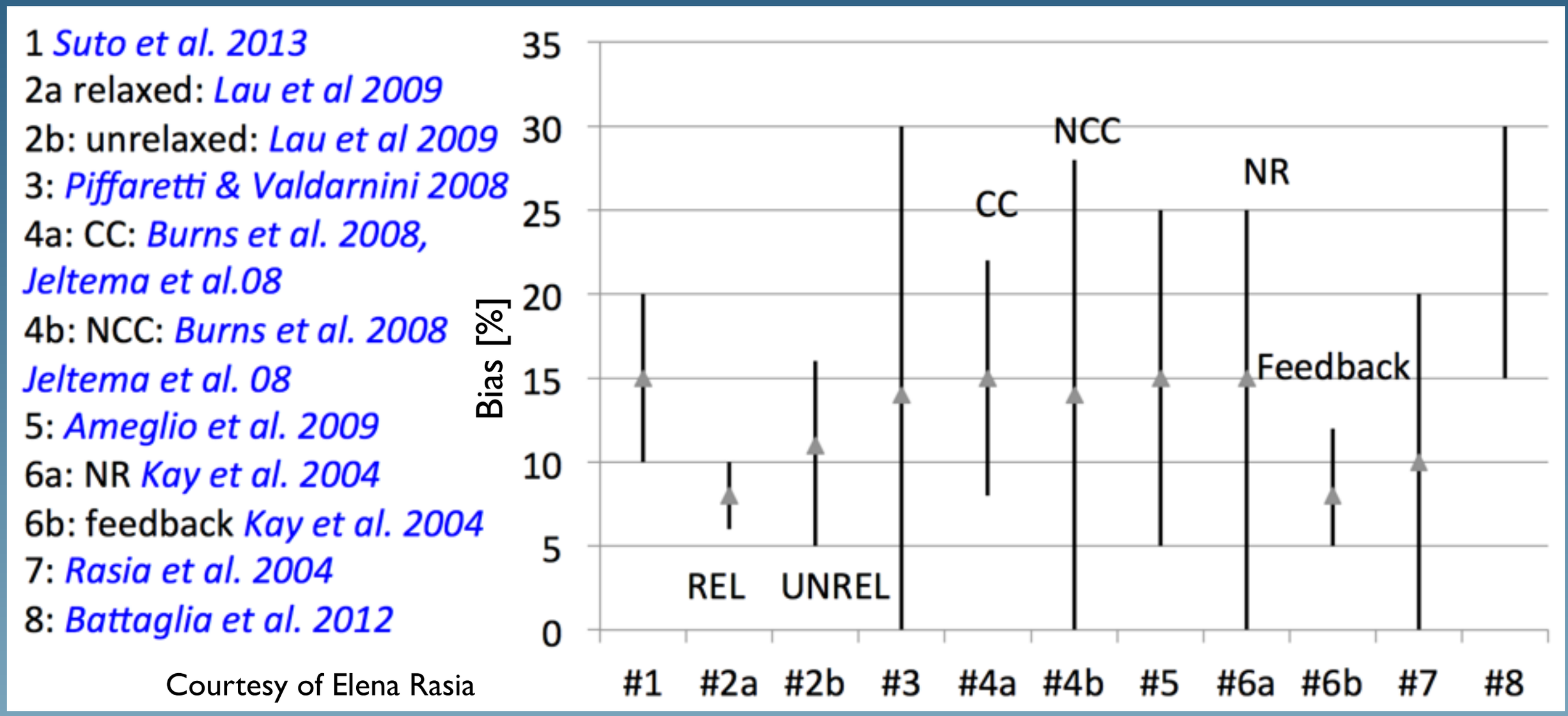
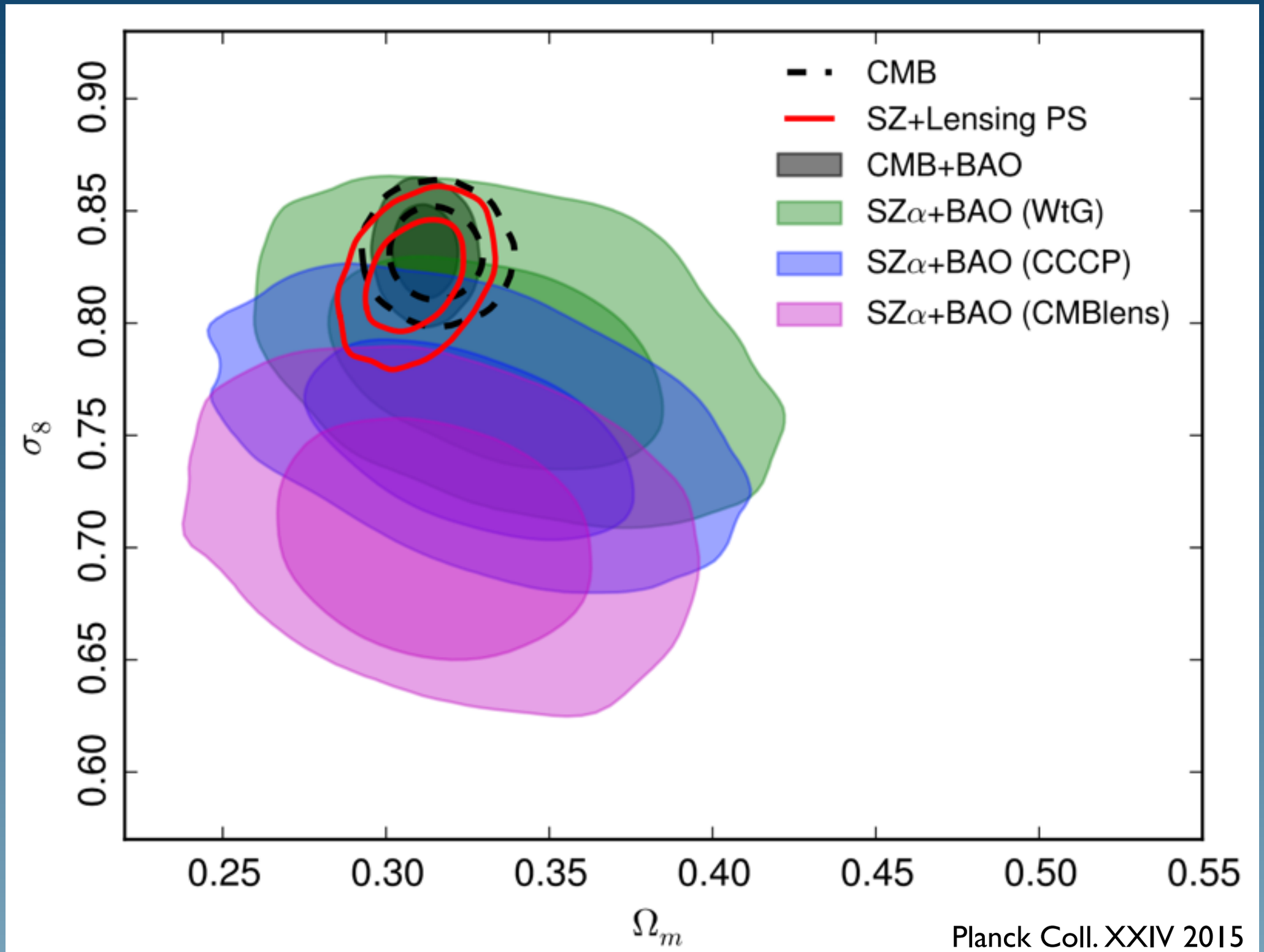


Courtesy of Elena Rasia

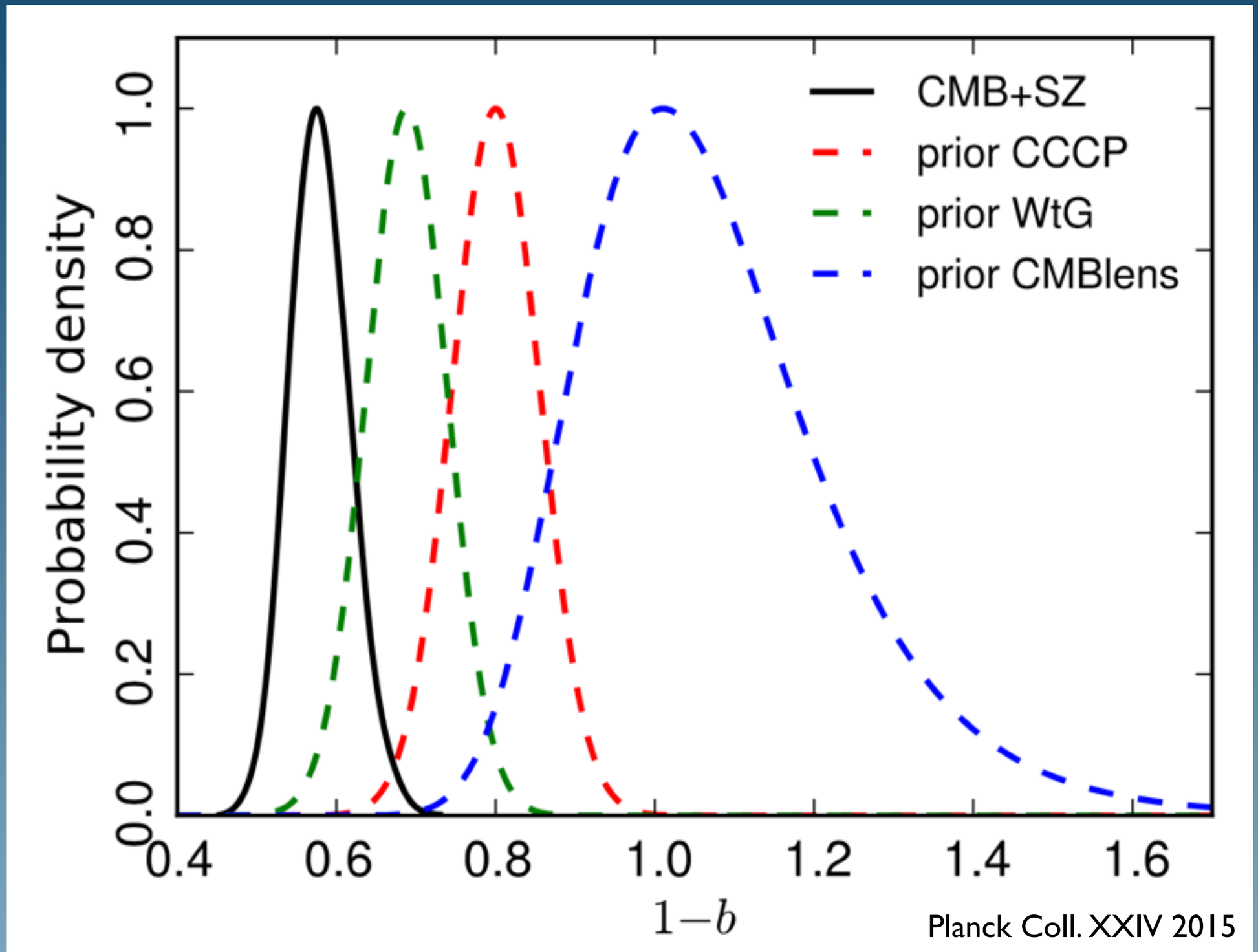
Example - Planck Cluster Cosmology



Planck Coll. XXIV 2015

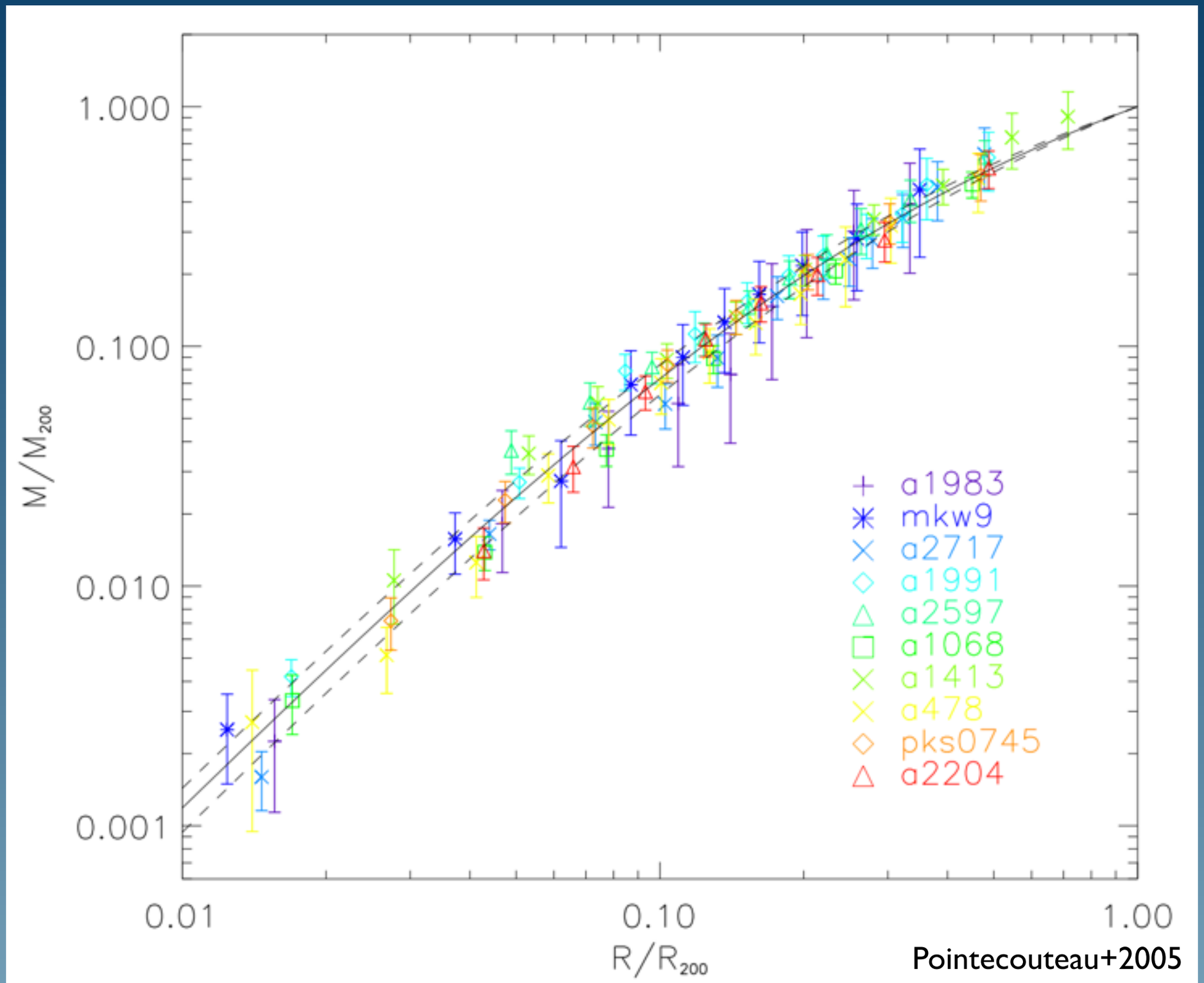
Example - Planck Cluster Cosmology

Parametrized our ignorance



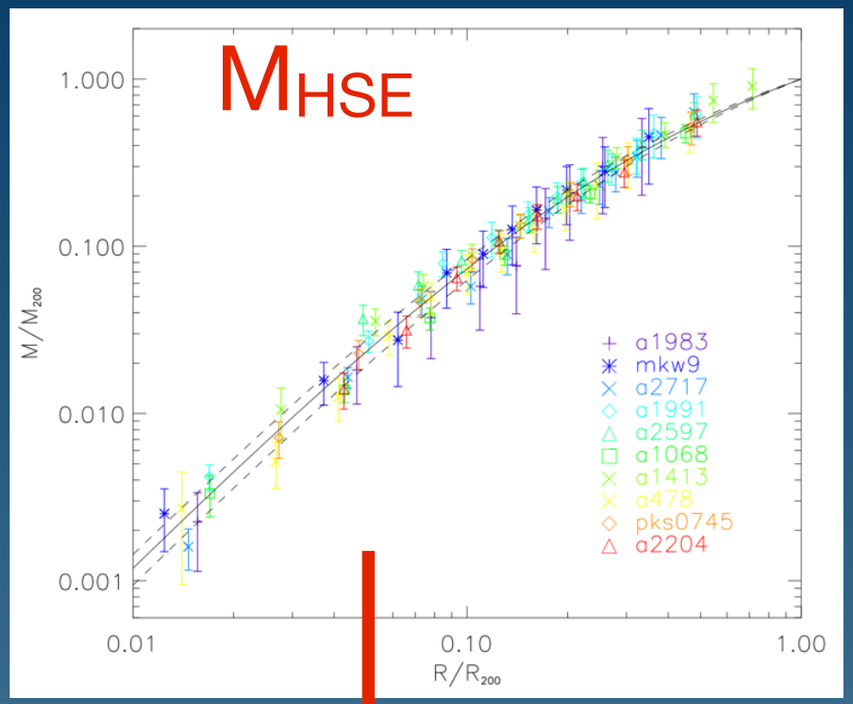
Planck Coll. XXIV 2015

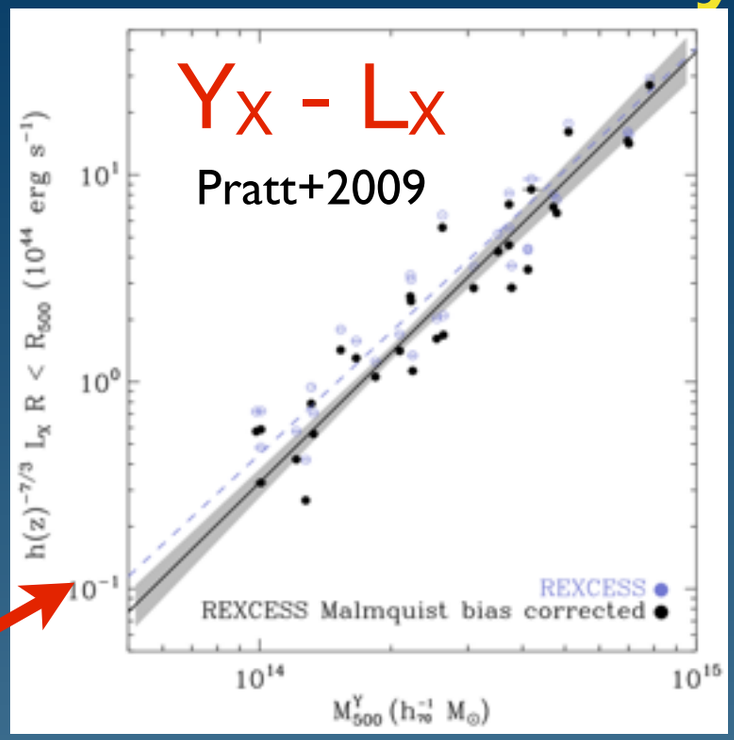
Planck Y_{SZ} Mass Calibration History

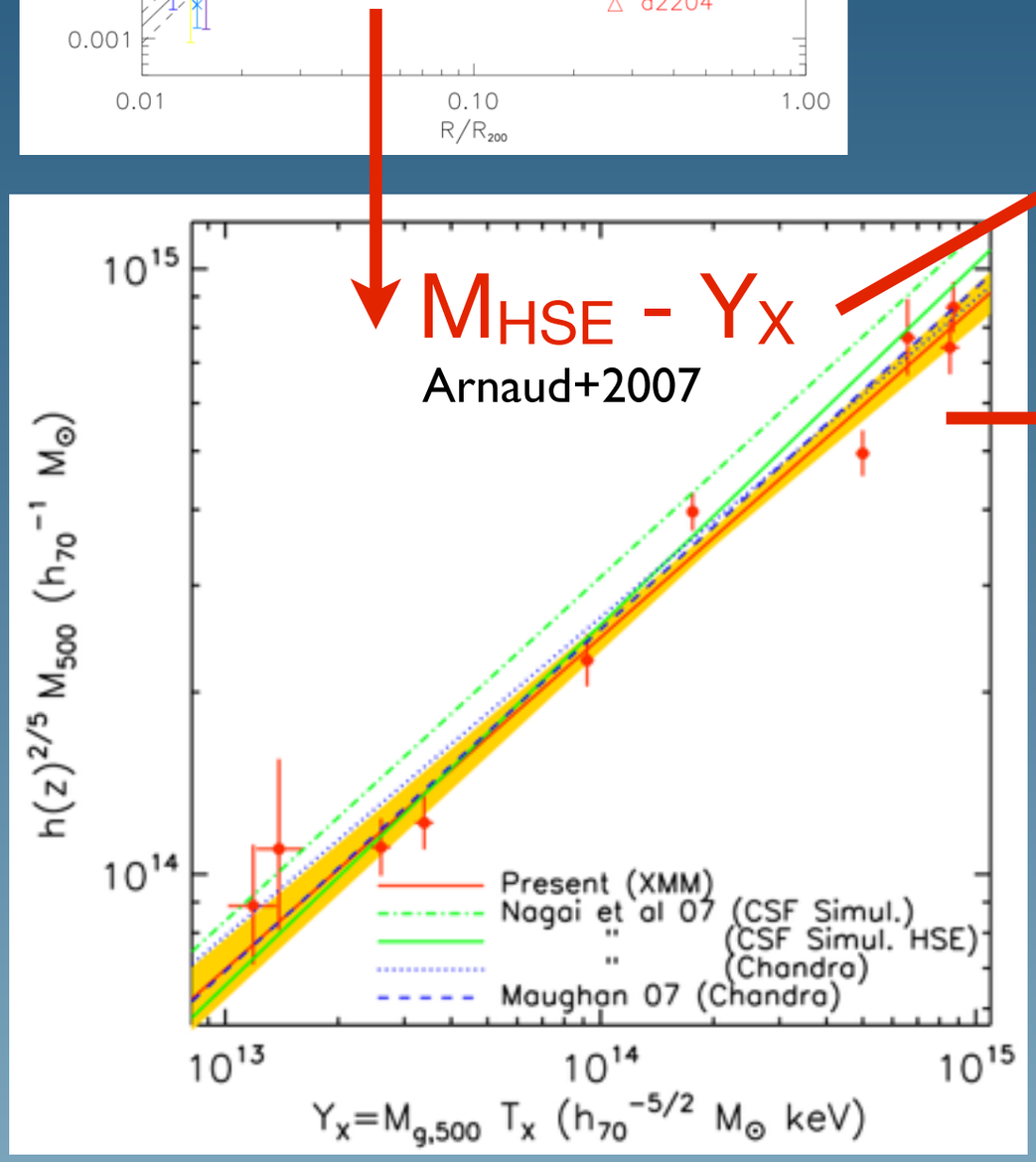


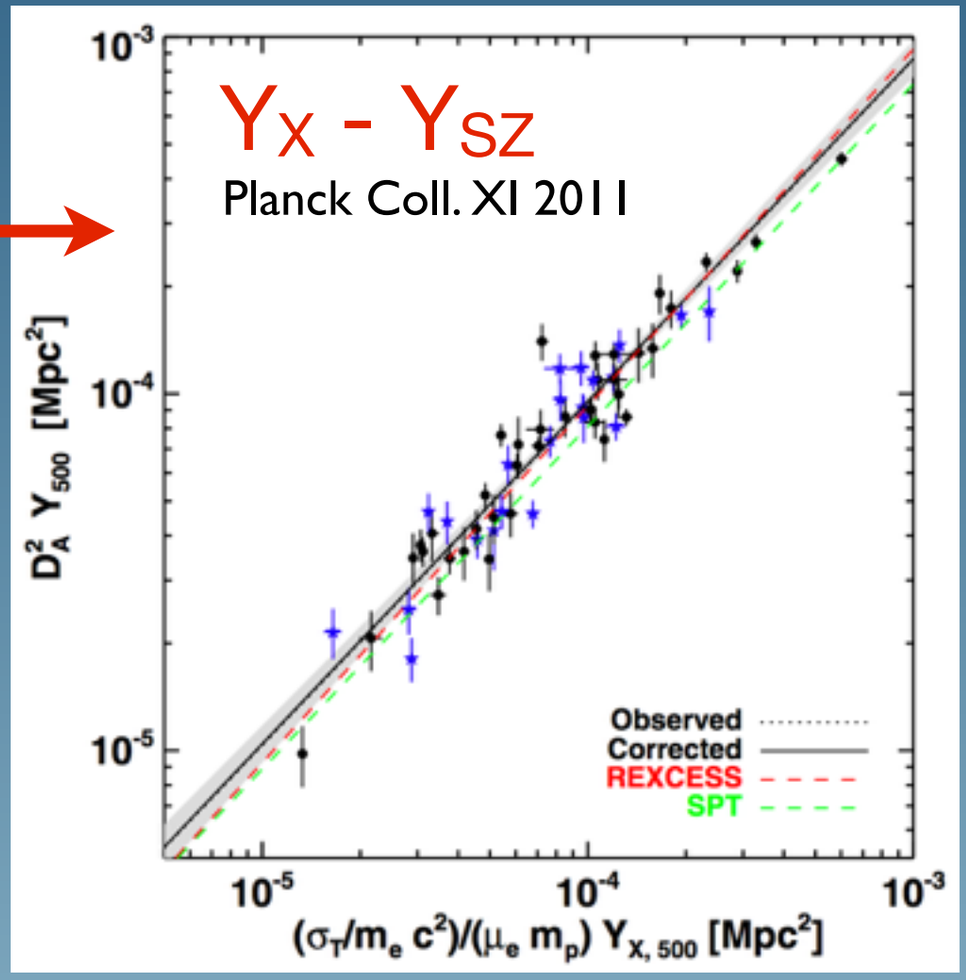
Pointecouteau+2005

Planck Y_{SZ} Mass Calibration History









Cluster Catalog

Subsample of the MCXC (flux lim.)

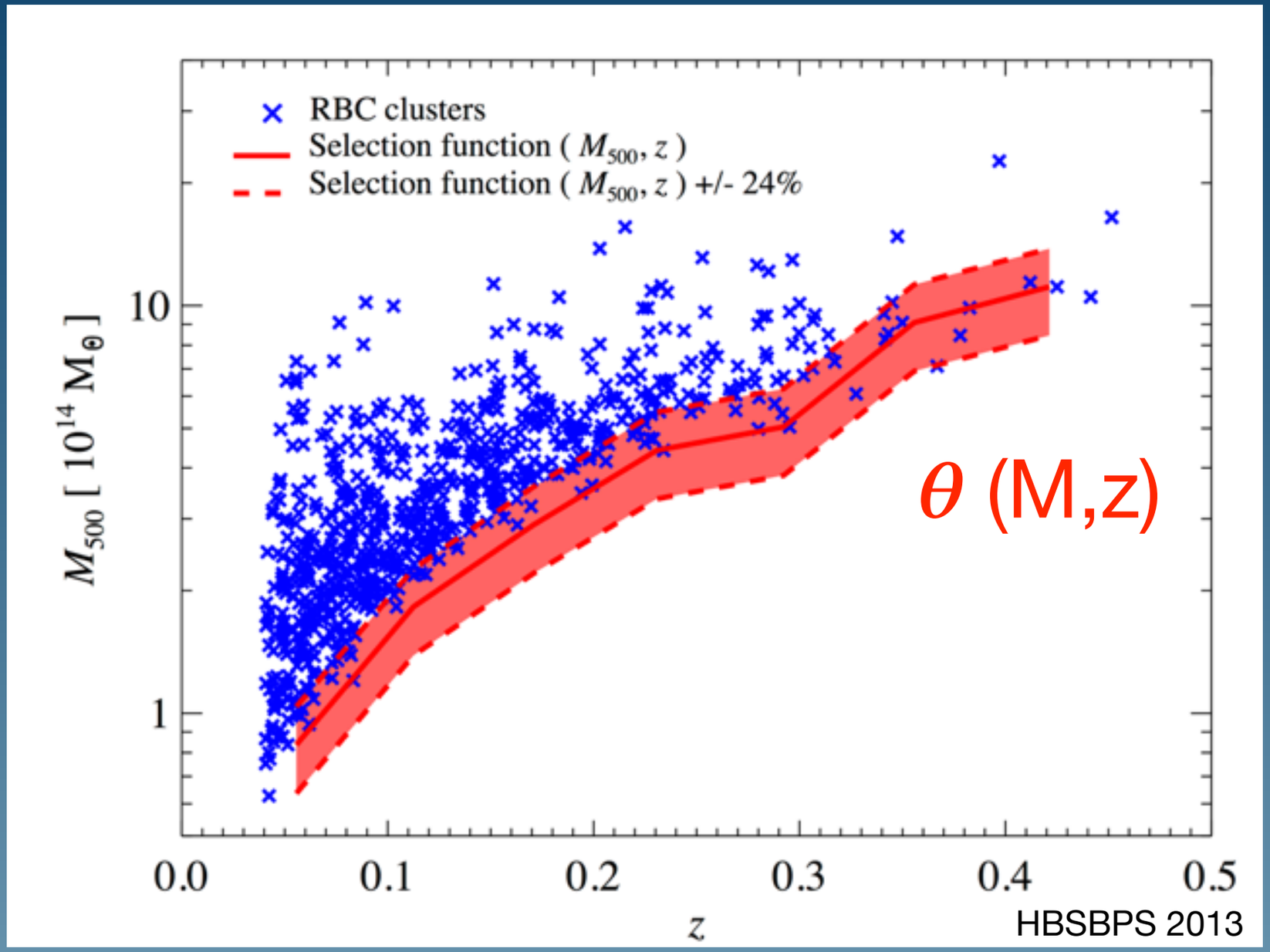
REFLEX

BCS

CIZA

RBC

~800 clusters



$M_{500} \rightarrow L_X$ - M relation calibrated from the REXCESS sample (not core excised ~24% scat.)

Cluster Catalog

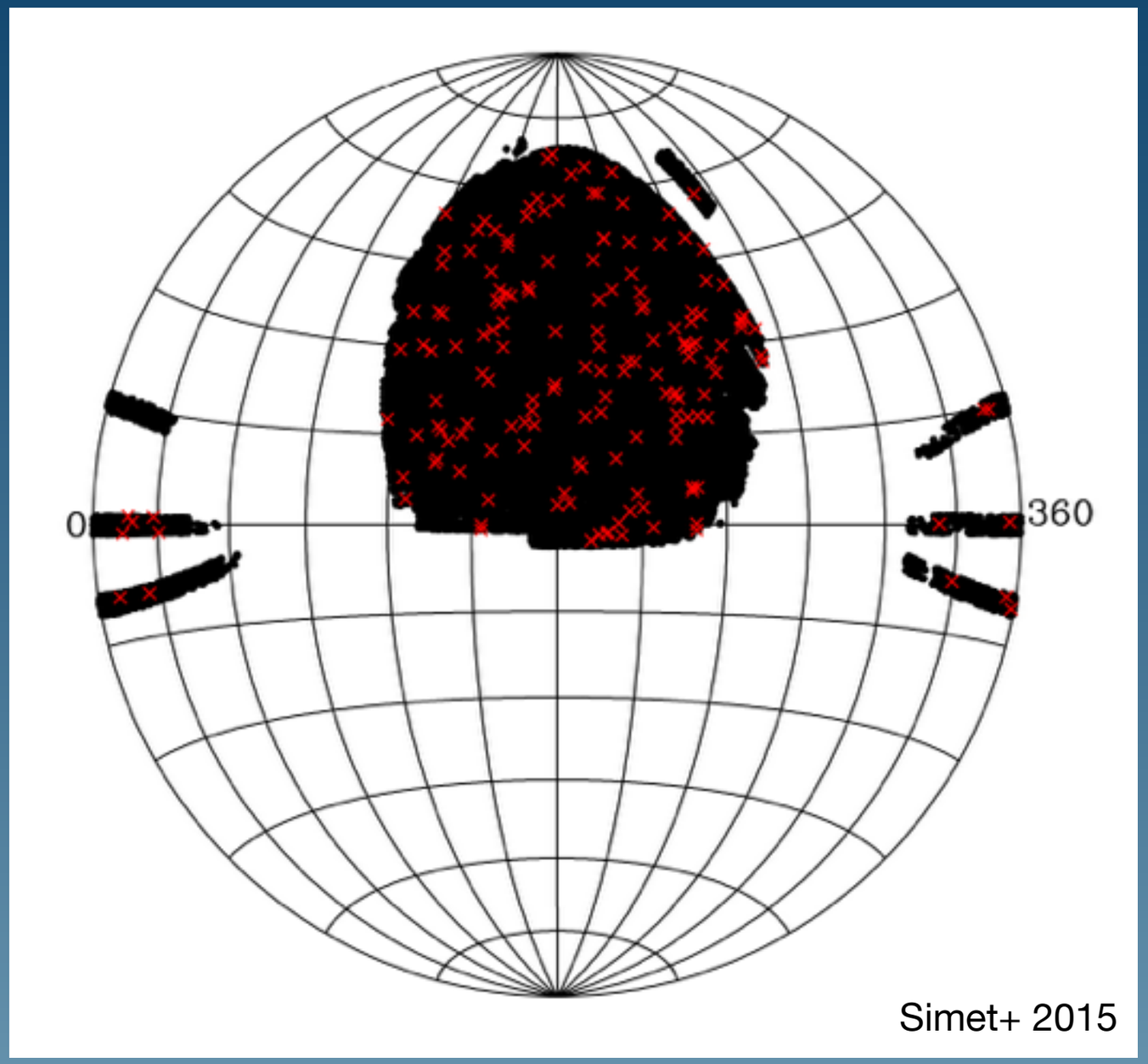
Reyes+2012 shape catalog (SDSS)

166 clusters

Stacked

Model the selection function

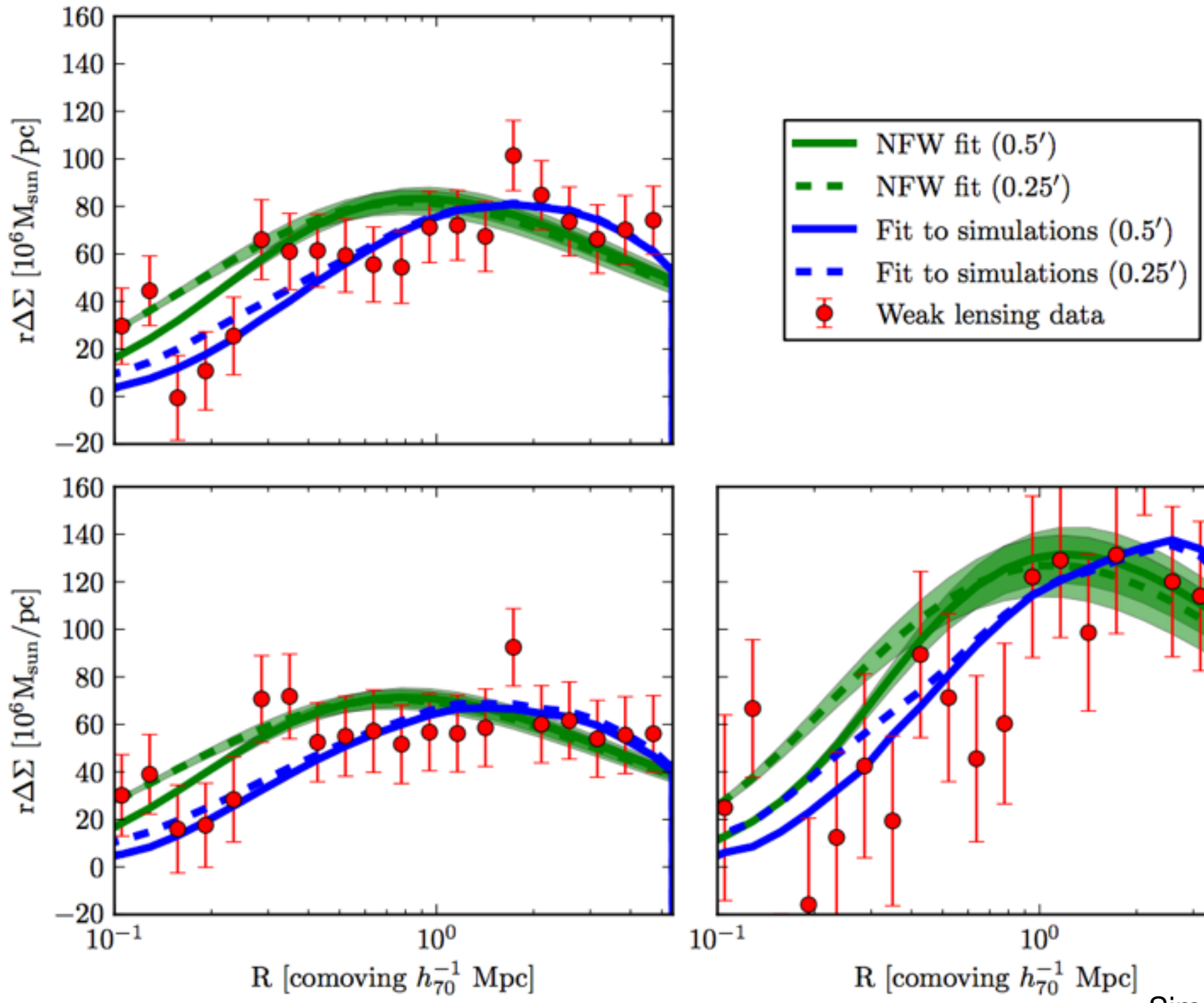
Miscentering



Simet+ 2015

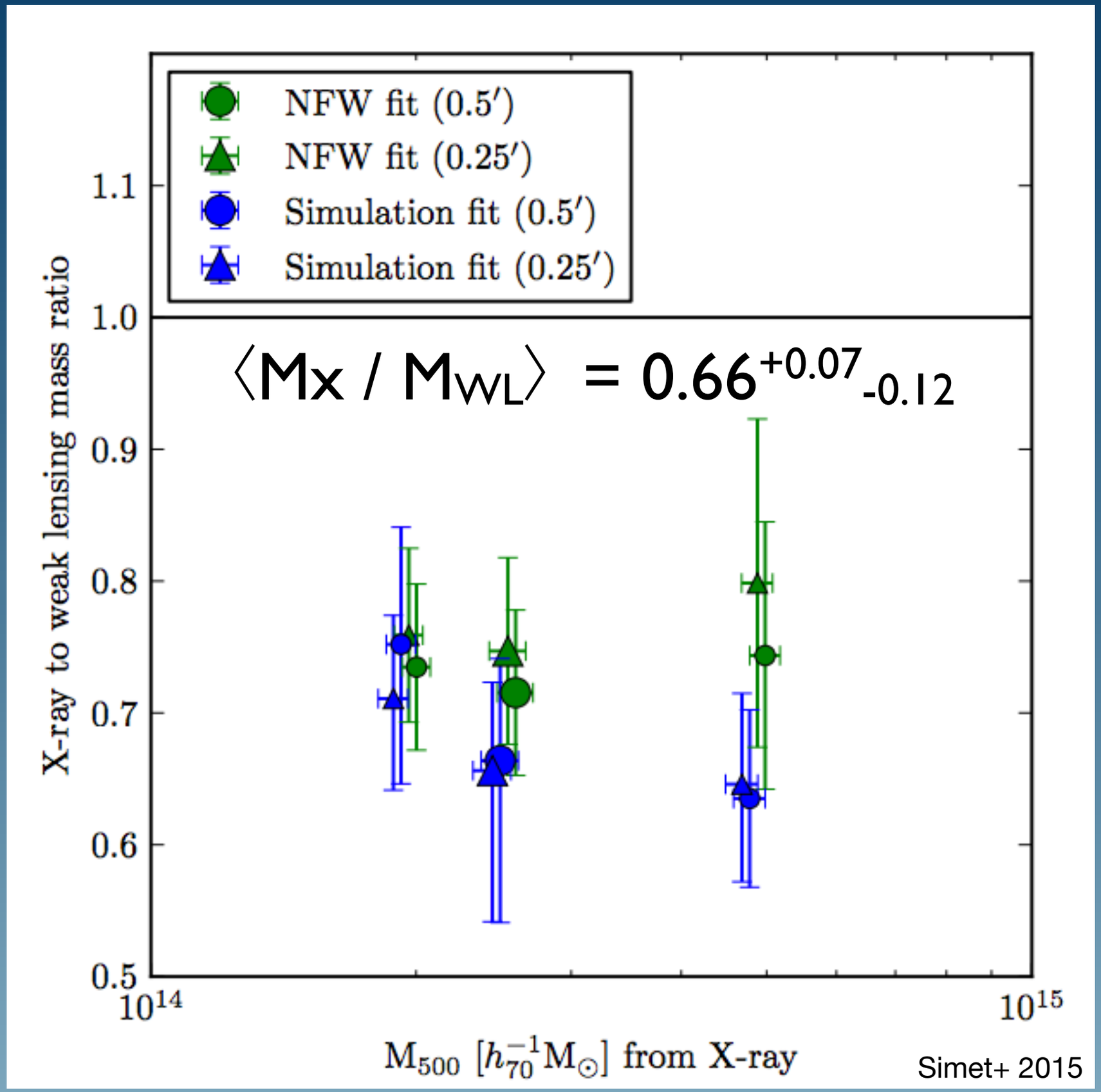
Make mock WL signals from simulated clusters, fit for the mass (also fit NFW)

RBC weak lensing mass calibration



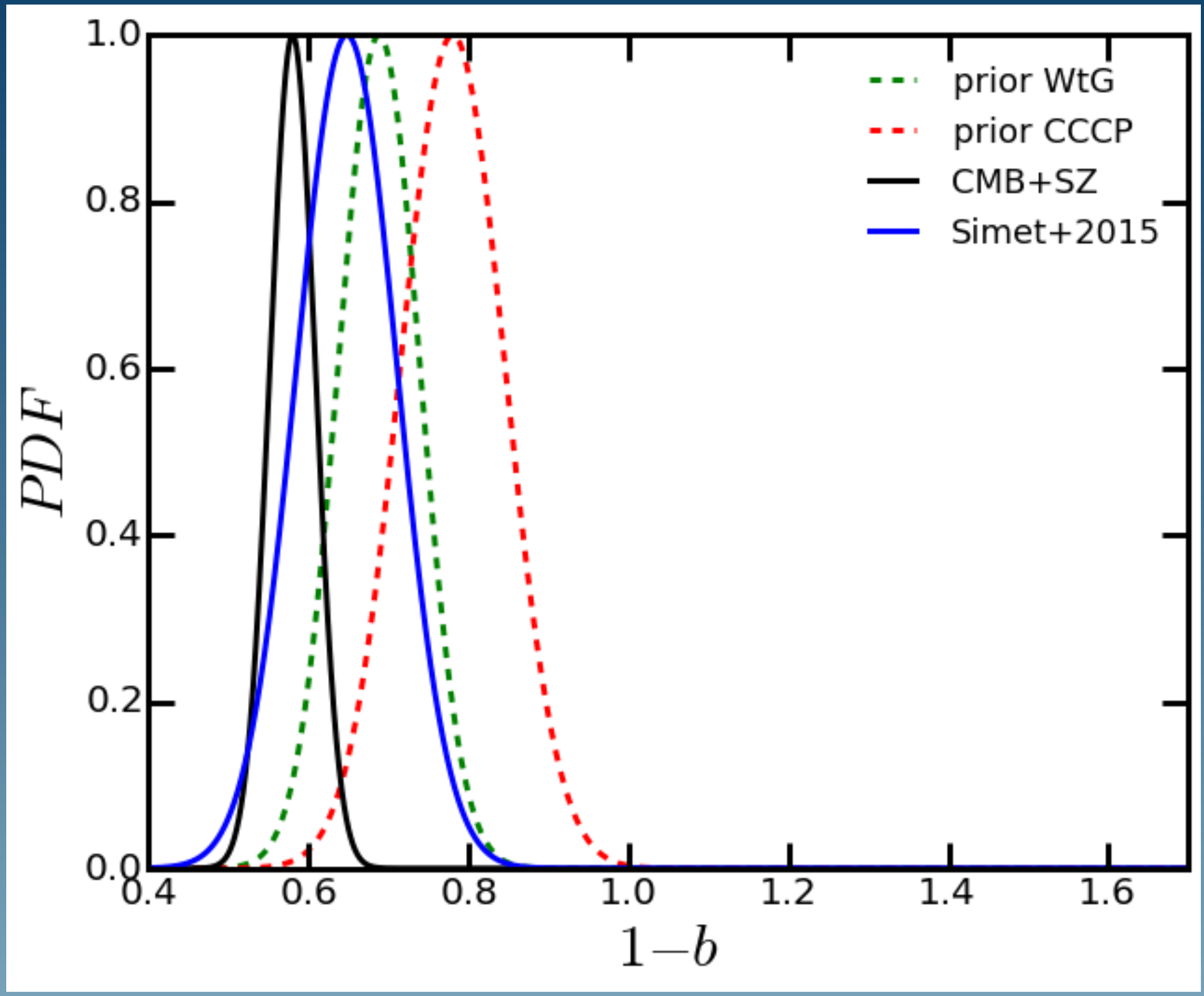
Simet+ 2015

RBC weak lensing mass calibration

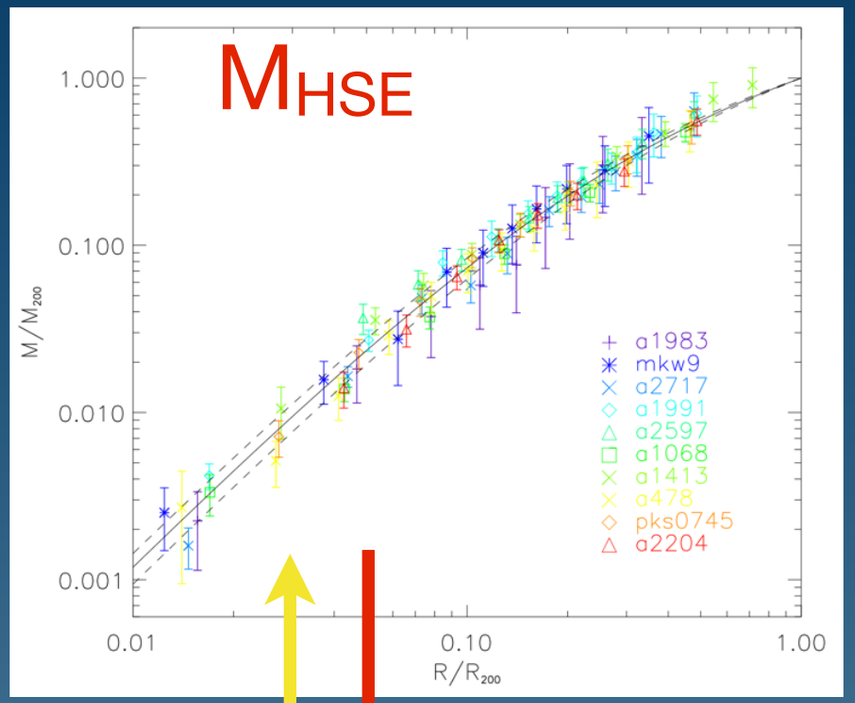


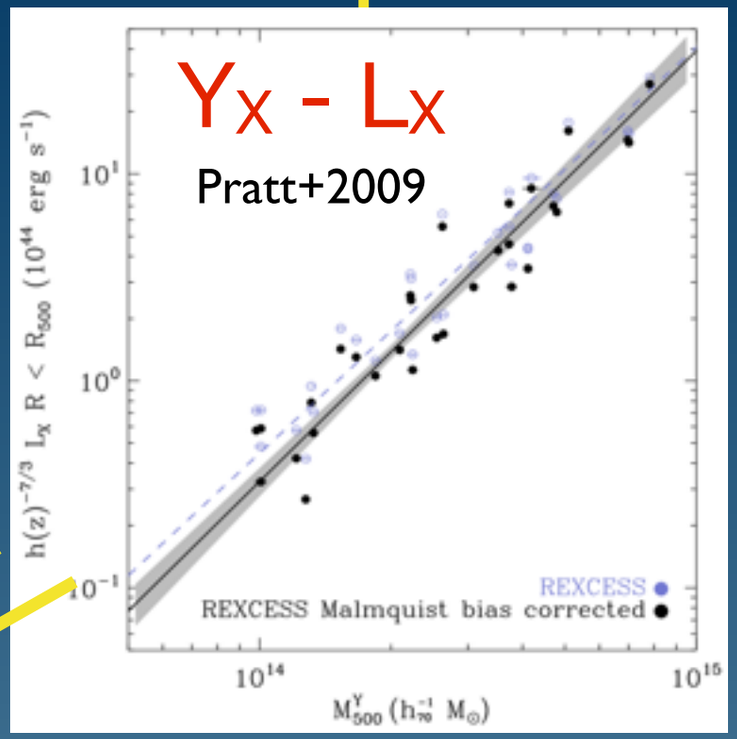
Simet+ 2015

Caution!

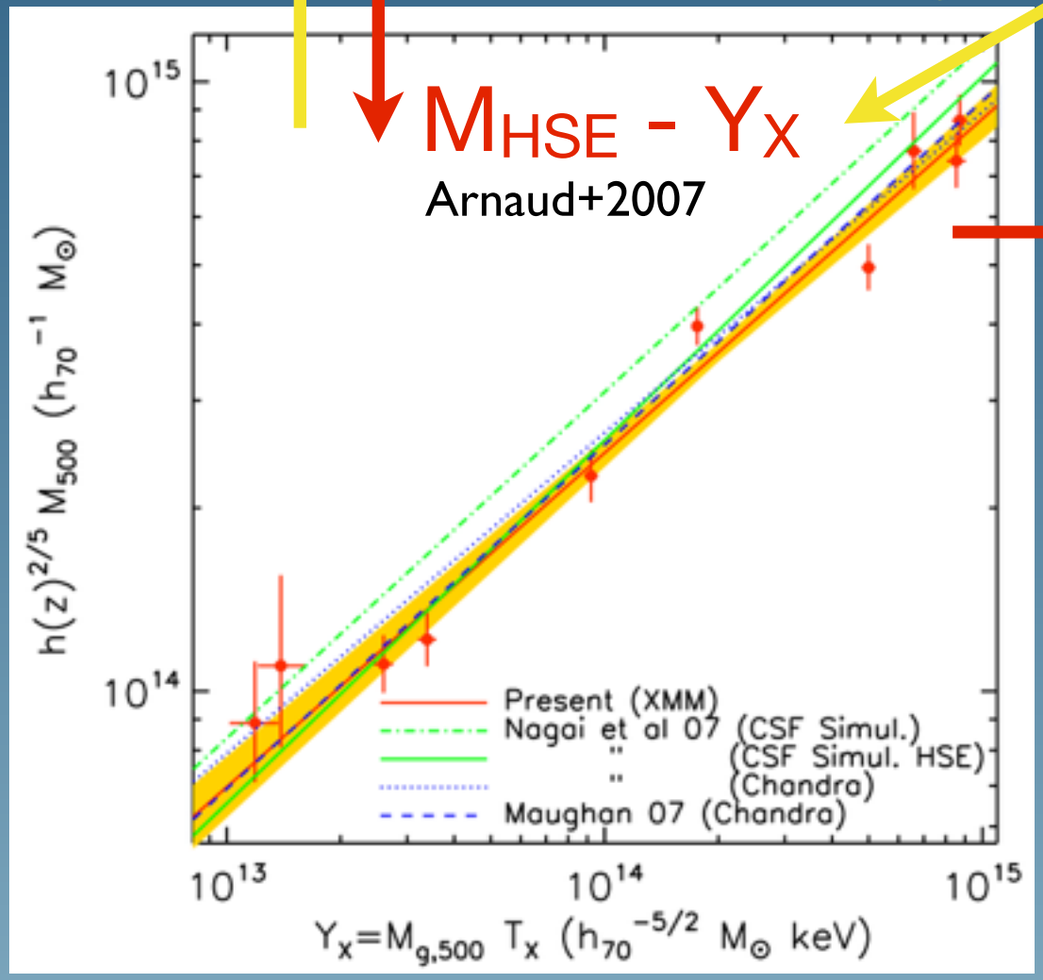

1.0
0.8
0.6
0.4
0.2
0.0
PDF
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1−b
prior WtG
prior CCCP
CMB+SZ
Simet+2015

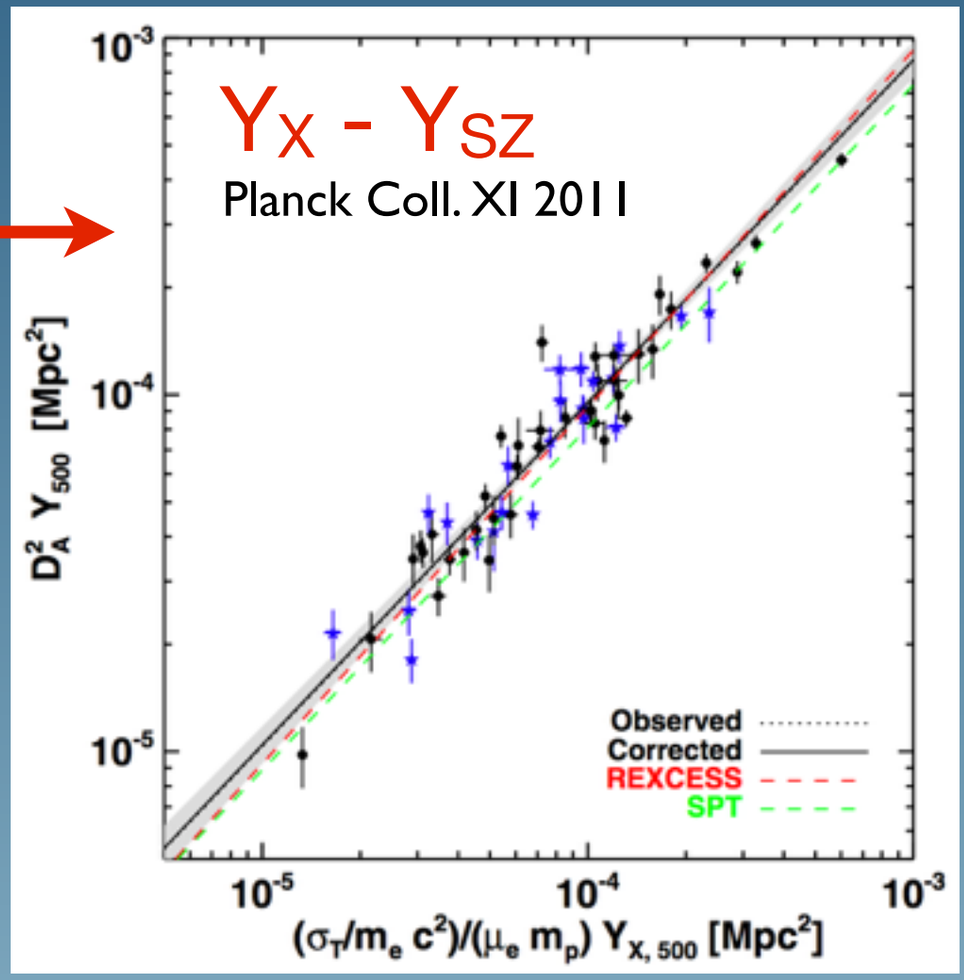
Scatter and sel. func. are important



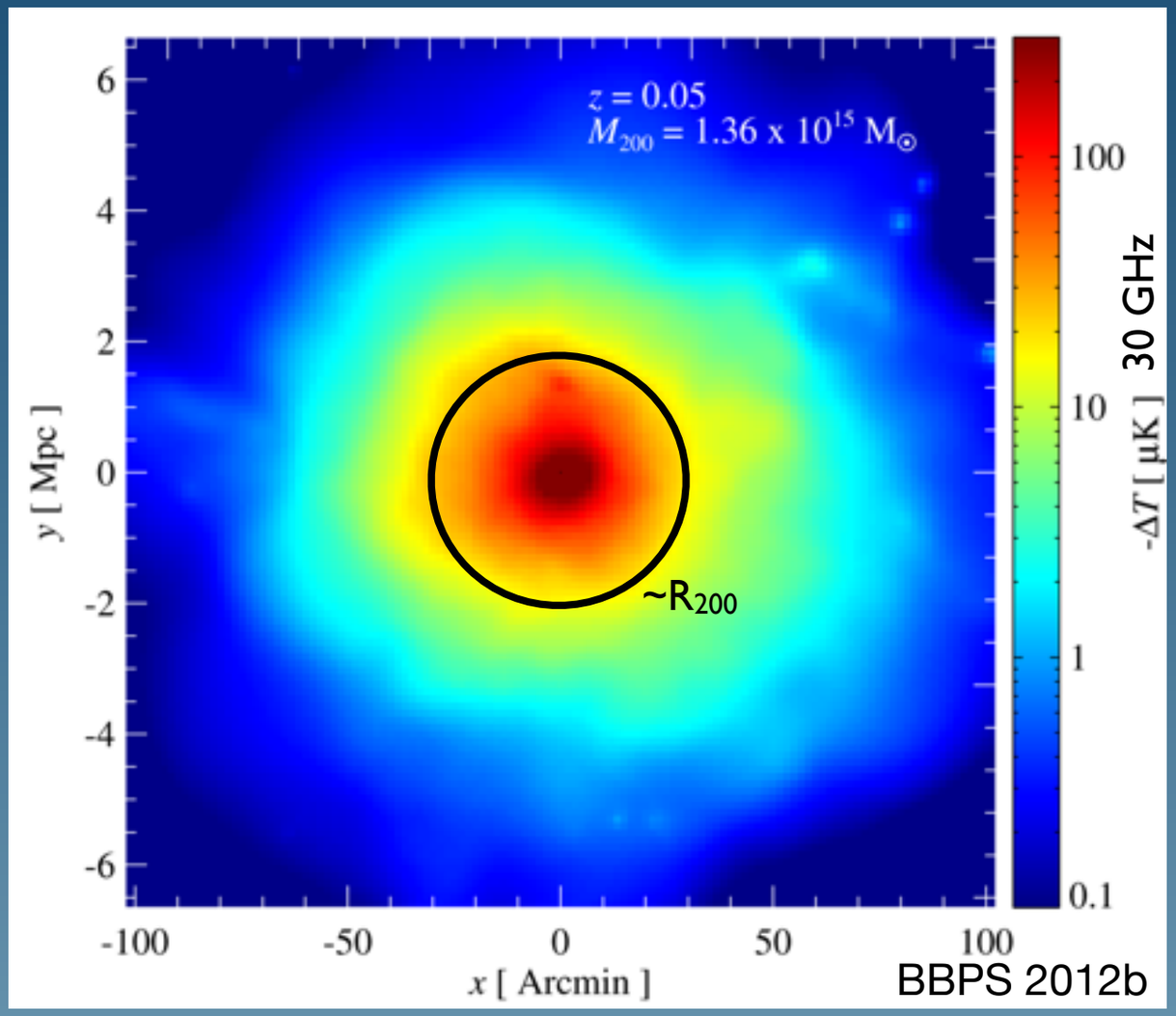


Calibrated

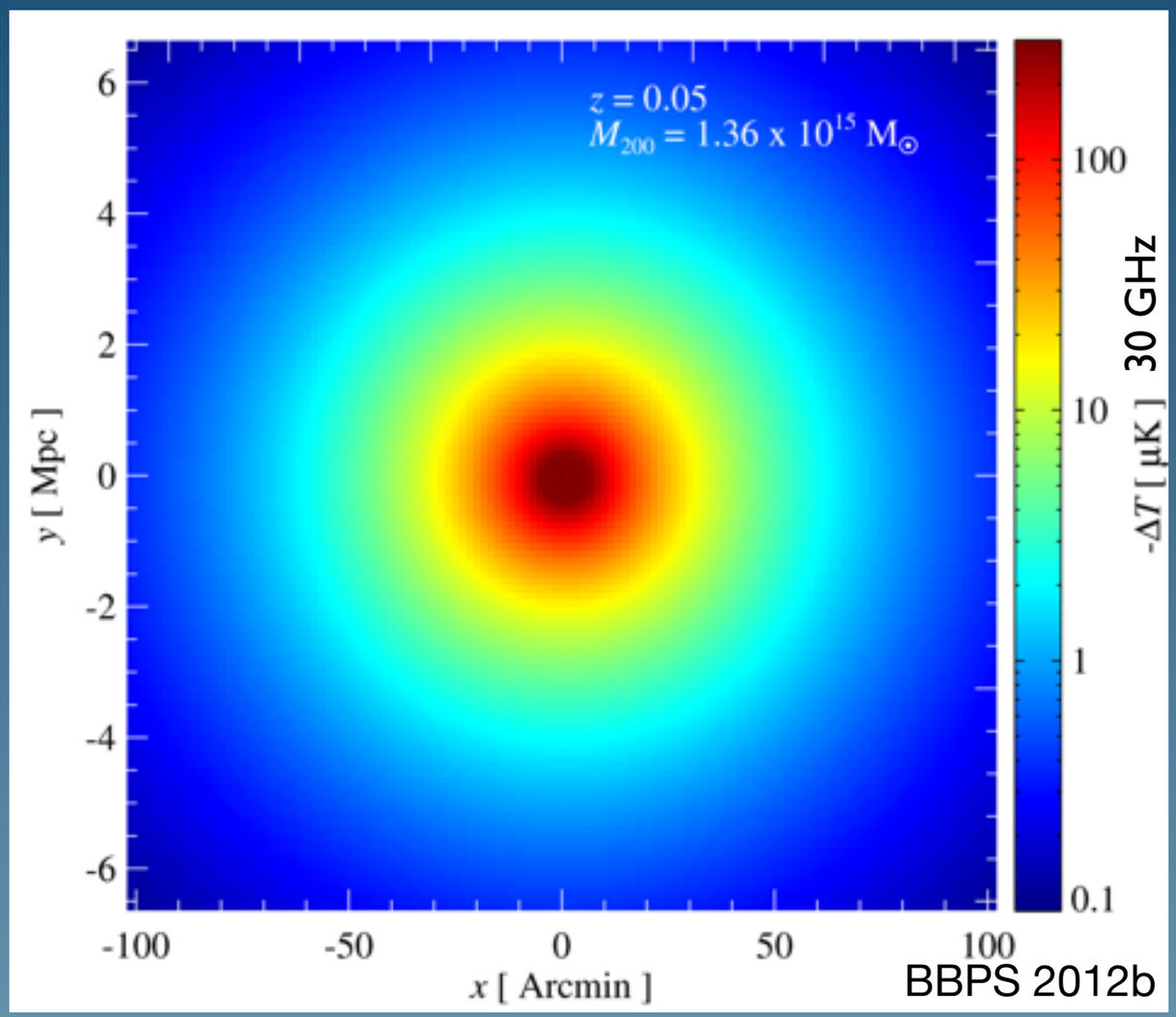




ICM inhomogeneities
Pressure fluctuations

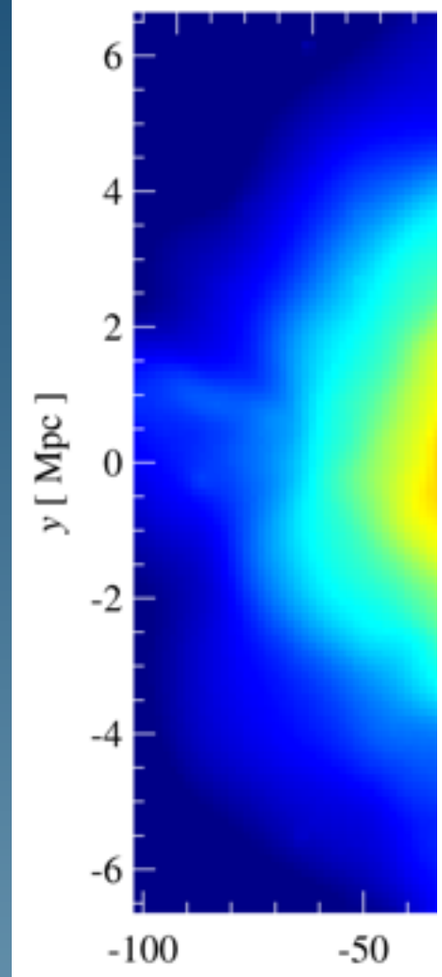


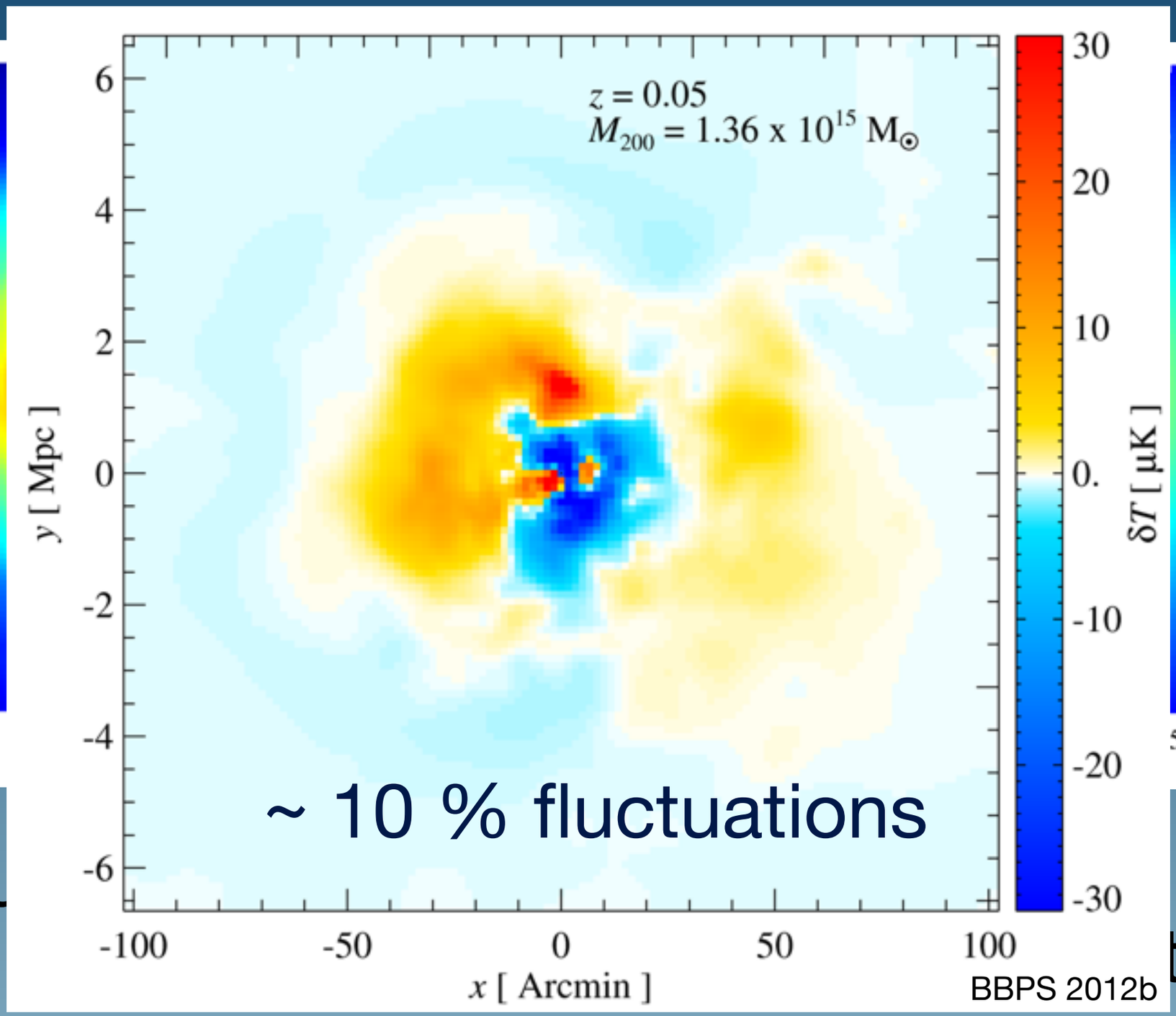
Simulated cluster



Spherical fit
from simulations

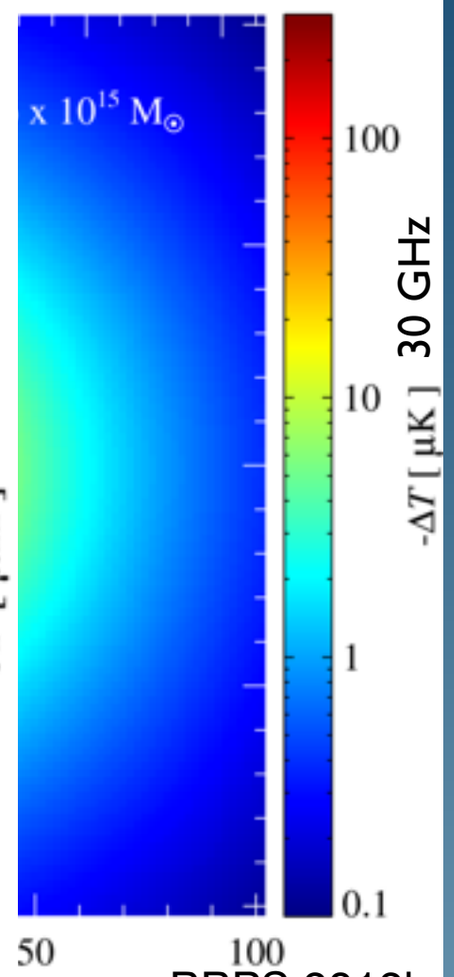
ICM inhomogeneities





~ 10 % fluctuations

BBPS 2012b



BBPS 2012b

Simu fit

tions

ICM inhomogeneities & tSZ PS

$$C_l = g_\nu^2 \int_0^{z_{\max}} dz \frac{dV}{dz} \int dM \frac{dn(M,z)}{dM} \left| \tilde{y}_l(M,z) \right|^2$$

+ Clustering of clusters (Sub-dominant)

Gastrophysics

Self consistently compared tSZ power spectrum methods

- Use the global pressure profile from the simulations:

1) Given a Mass Function: calculate the analytical spectrum

2) Paste the global pressure profile at cluster locations in the simulations

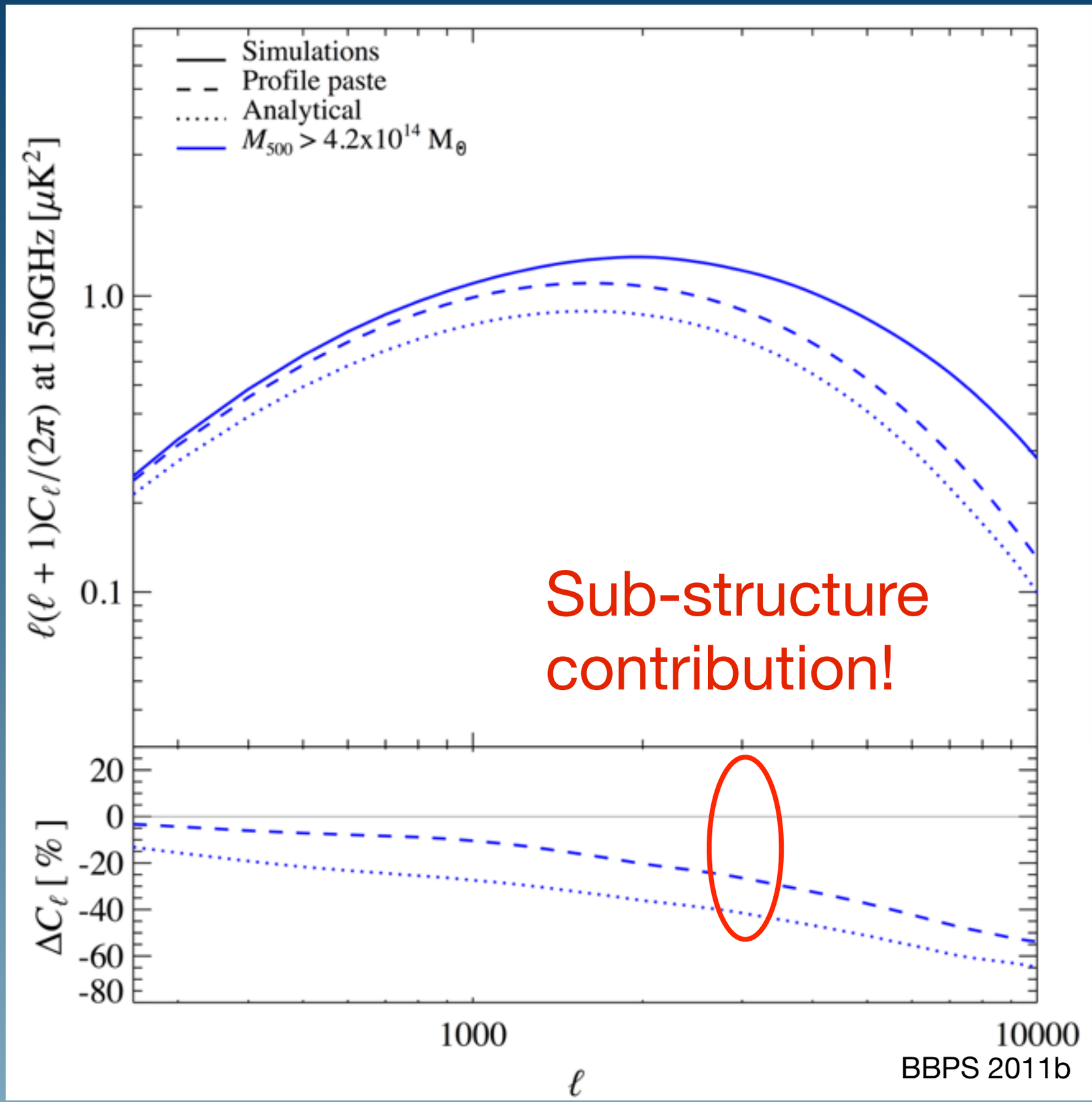
3) FFT the full simulation maps

Determine systematic differences between methods

ICM inhomogeneities & tSZ PS

- High mass halos
  25% at ℓ ~3000
- All masses
  15% at ℓ ~3000
- Additional power from Non-uniformity must be included in Analytic calculations

Can we calibrate P_{th}?



Cross correlate with lensing

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Detection of thermal SZ-CMB lensing cross-correlation in Planck nominal mission data

J. Colin Hill and David N. Spergel

PHYSICAL REVIEW D **89,** 023508 (2014)

Detection of warm and diffuse baryons in large scale structure from the cross correlation of gravitational lensing and the thermal Sunyaev-Zeldovich effect

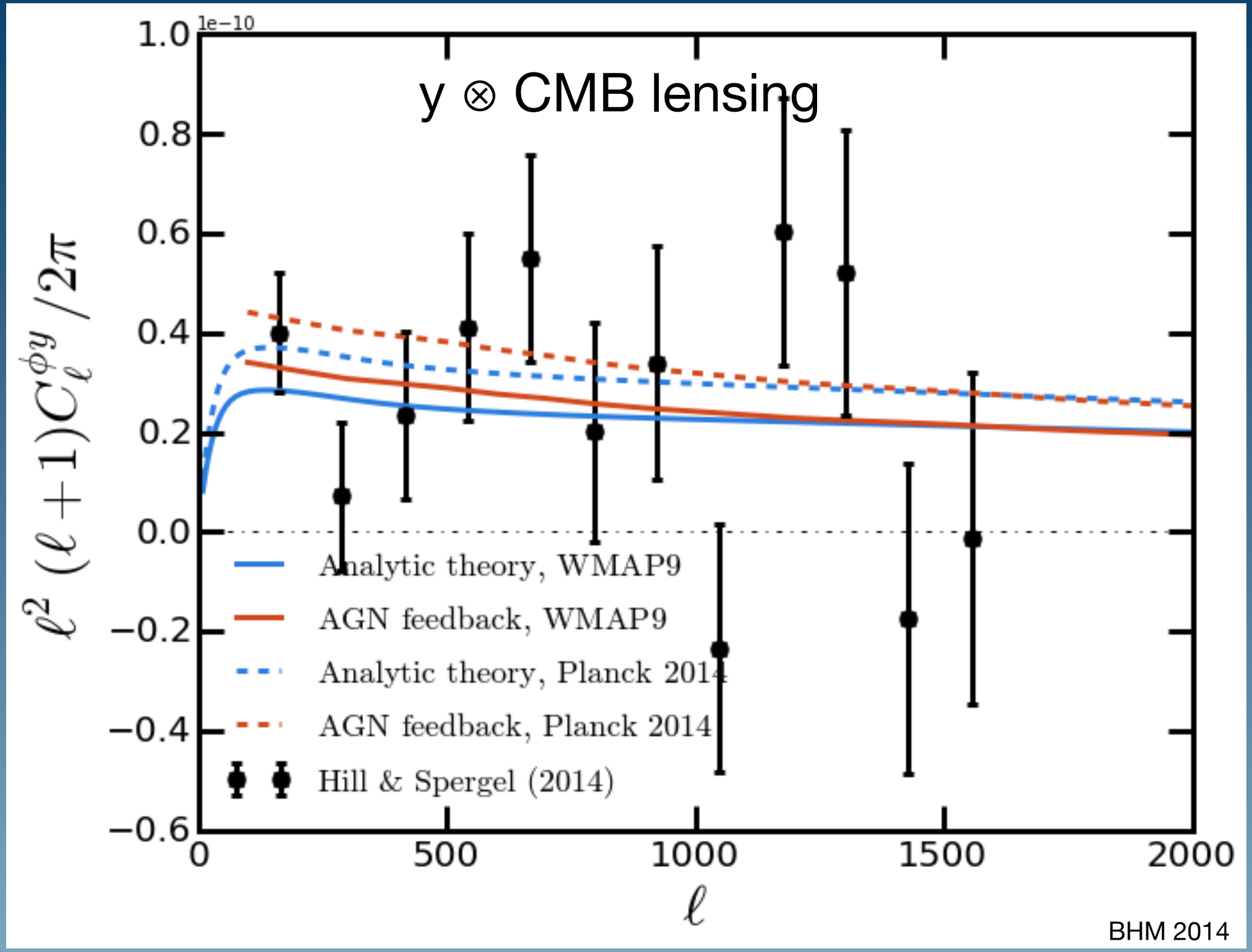
Ludovic Van Waerbeke,[1,*] Gary Hinshaw,[1,2,†] and Norman Murray[3,4,‡]

Ma+2014 & Hojjati+2014 - Interpretation of results

Several sigma detections of the cross correlations (~6σ)

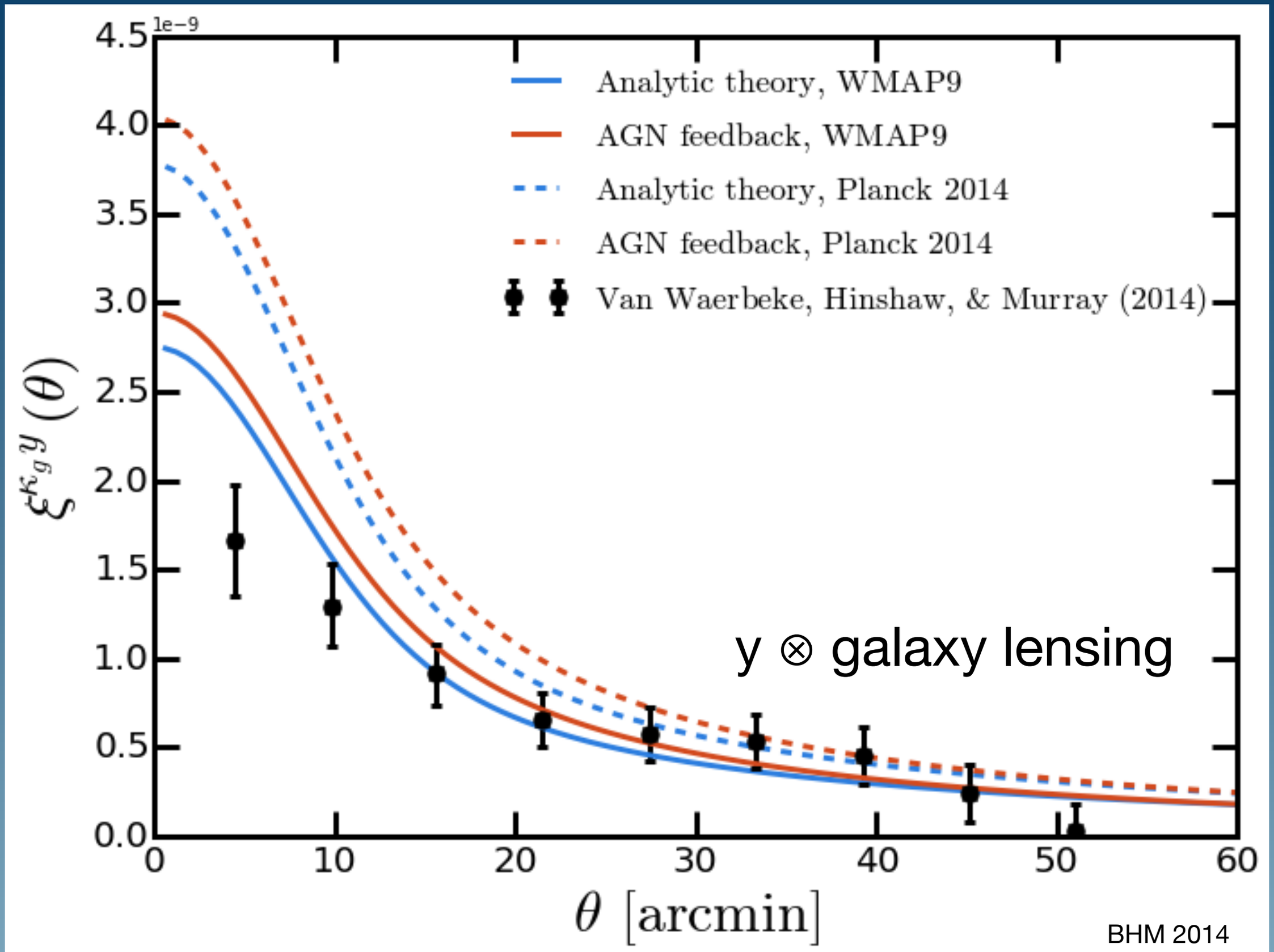
Like tSZ tomography because of the lensing kernels

Cross correlate with lensing



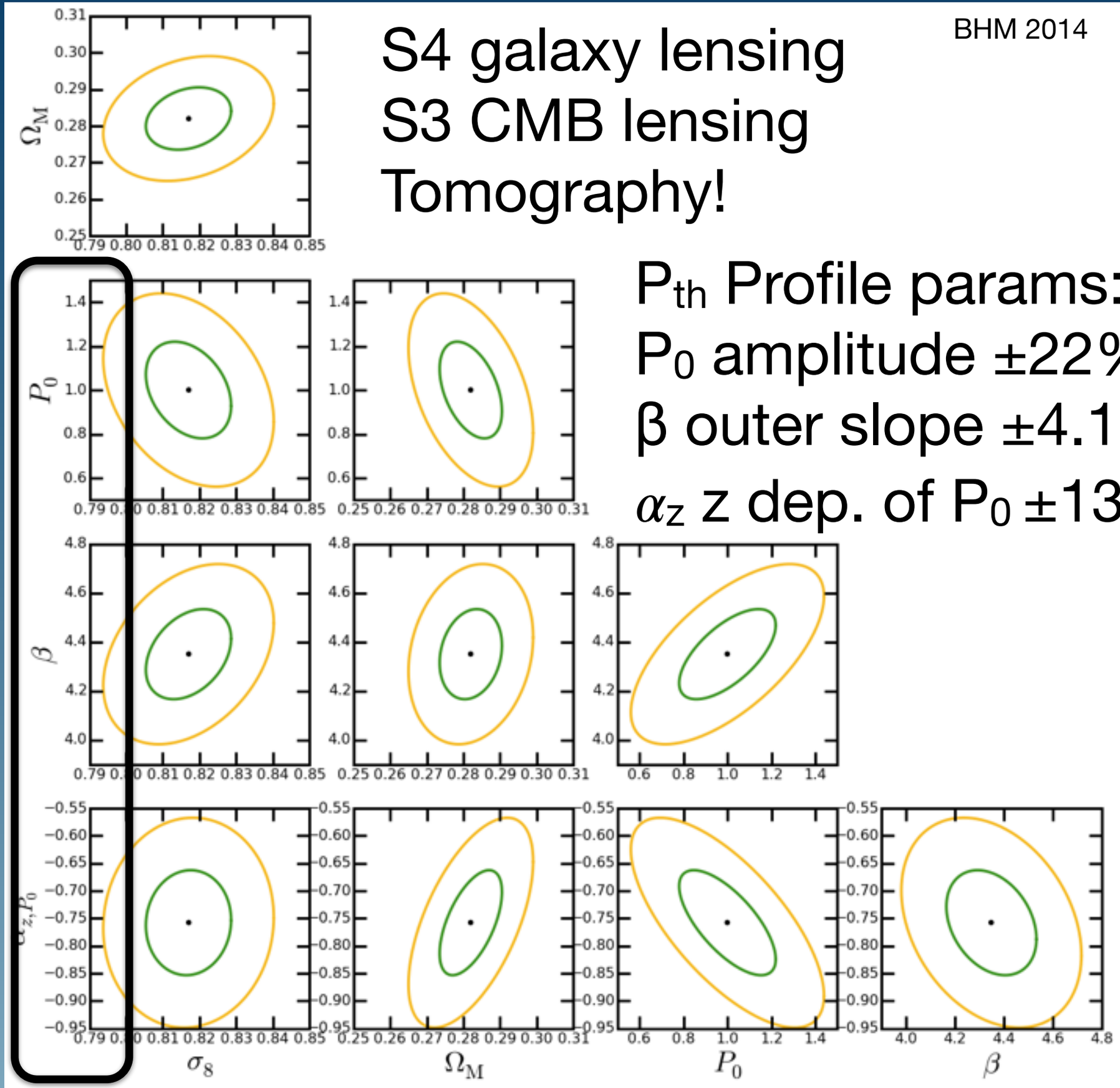
BHM 2014

Cross correlate with lensing



BHM 2014

Cross correlate with lensing forecast



BHM 2014

S4 galaxy lensing
S3 CMB lensing
Tomography!

P_{th} Profile params:
P_0 amplitude ±22%
β outer slope ±4.1%
α_z z dep. of P_0 ±13%

Crossroads of Cosmology & Astrophysics

Simulations are a tool for understanding and quantifying the important gastrophysics, biases, and scatter in surveys

Insight into the many physical processes in clusters that could cause astrophysical biases, e.g., HSE, clumping…

We have calibrated the L_X -M relation used by Planck

Cross correlations are great tools for getting at cluster properties now and in the future

Data rich field, but more clusters are coming:
DES, HSC, KIDS, LSST… AdvACT, SPT3G… eROSTIA…

Thank you