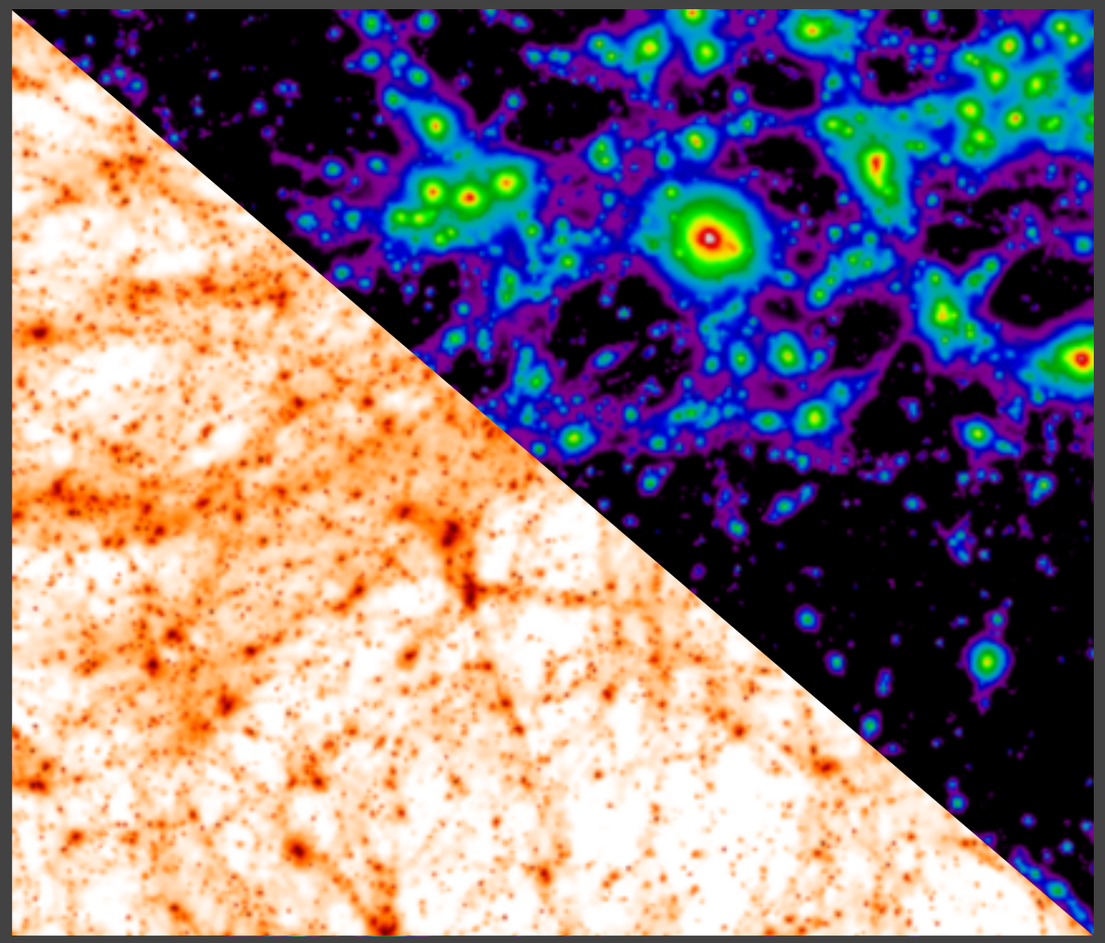
Cross-Correlation Prospects for CMB Secondary Anisotropies and LSST

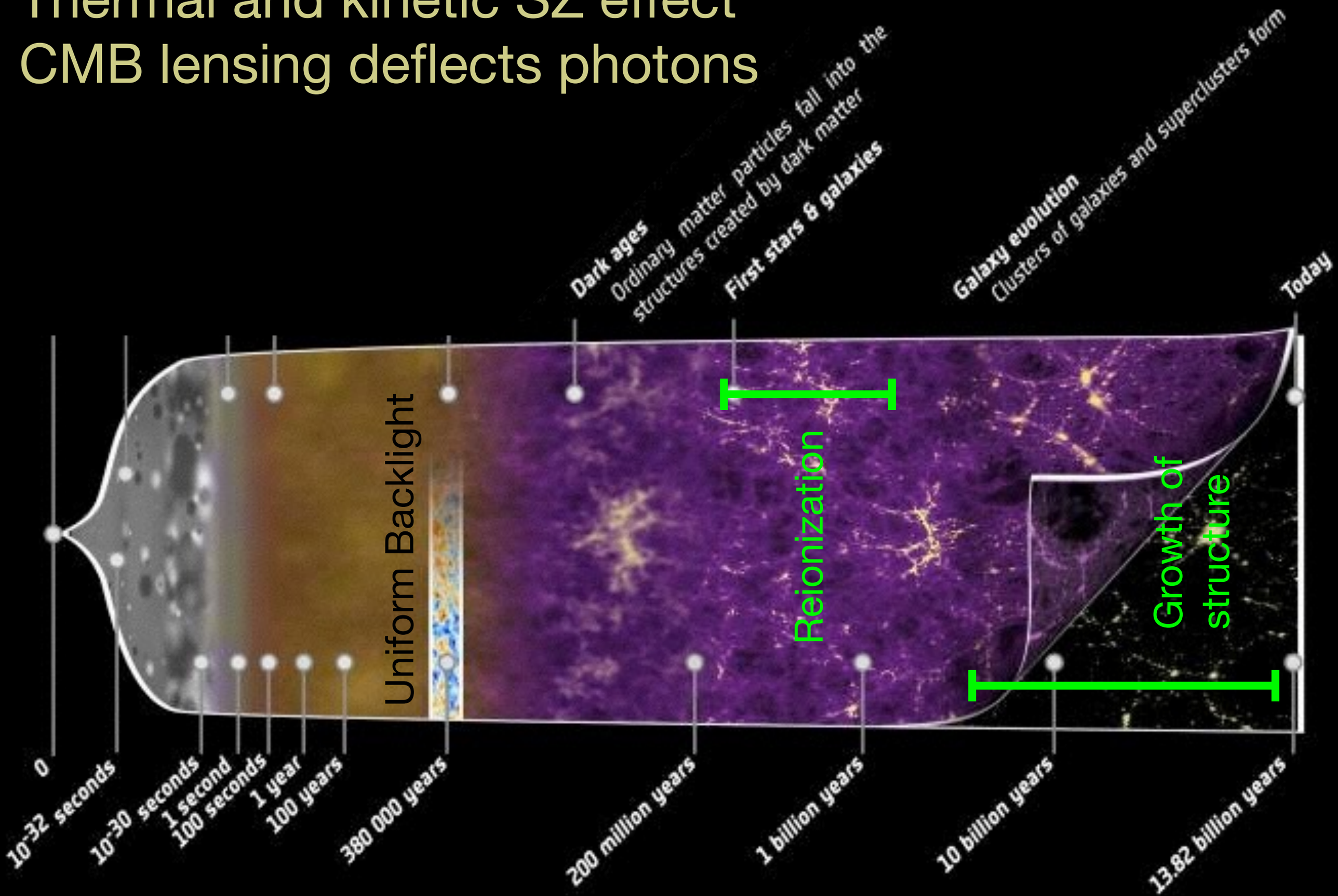


Nick Battaglia
Lyman Spitzer Fellow
Princeton University

Emmanuel Schaan (Princeton), Colin Hill (Columbia), Simone Ferraro (Berkeley),
Christoph Pfrommer (HITS), Jon Sievers (UKZN), Amir Hajian (Industry)
Dick Bond (CITA), David Spergel (Princeton), Norm Murray (CITA)

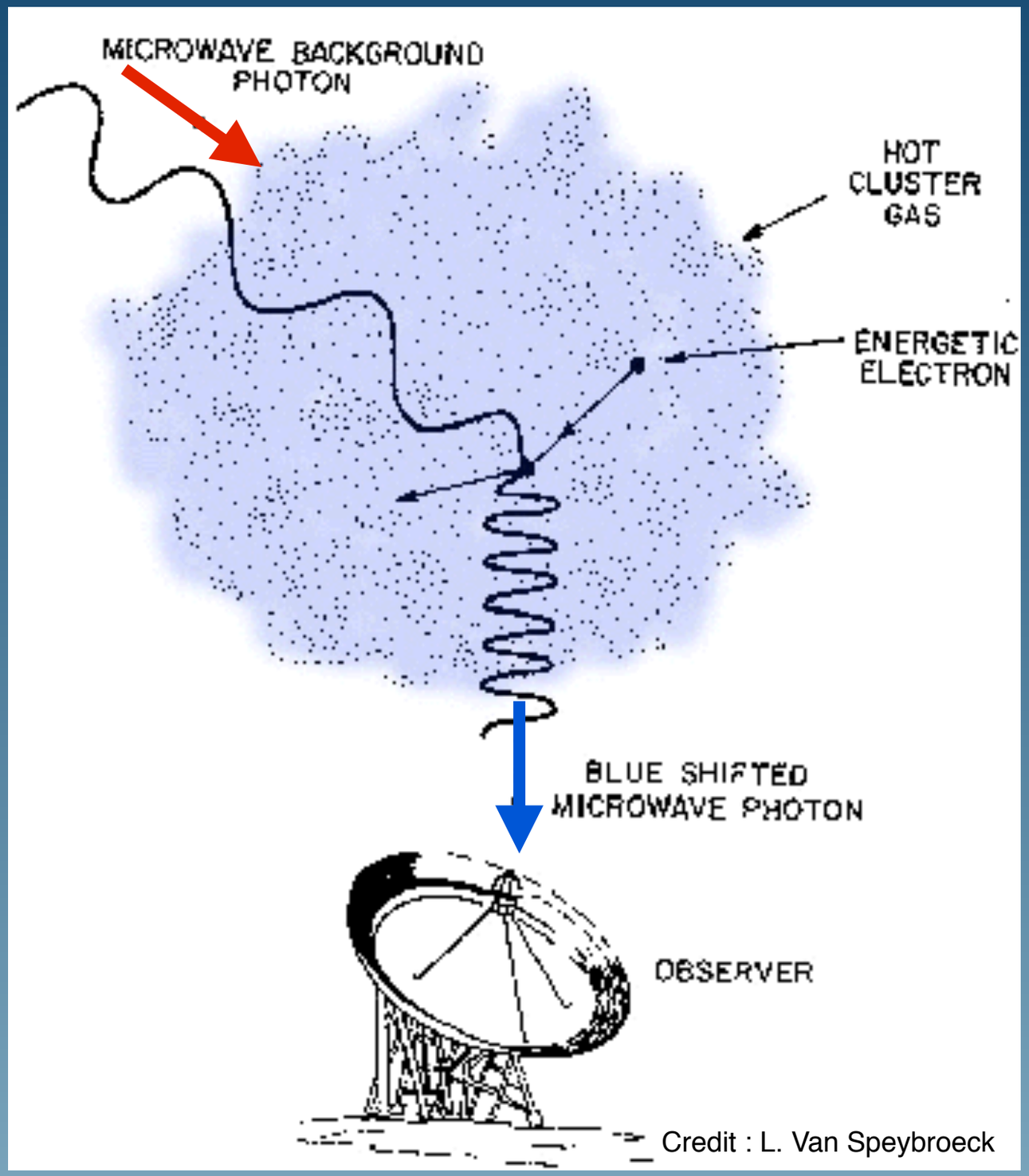
LSST Spectacular
May 23 2016

CMB scattering sources (secondaries):
Thermal and kinetic SZ effect
CMB lensing deflects photons

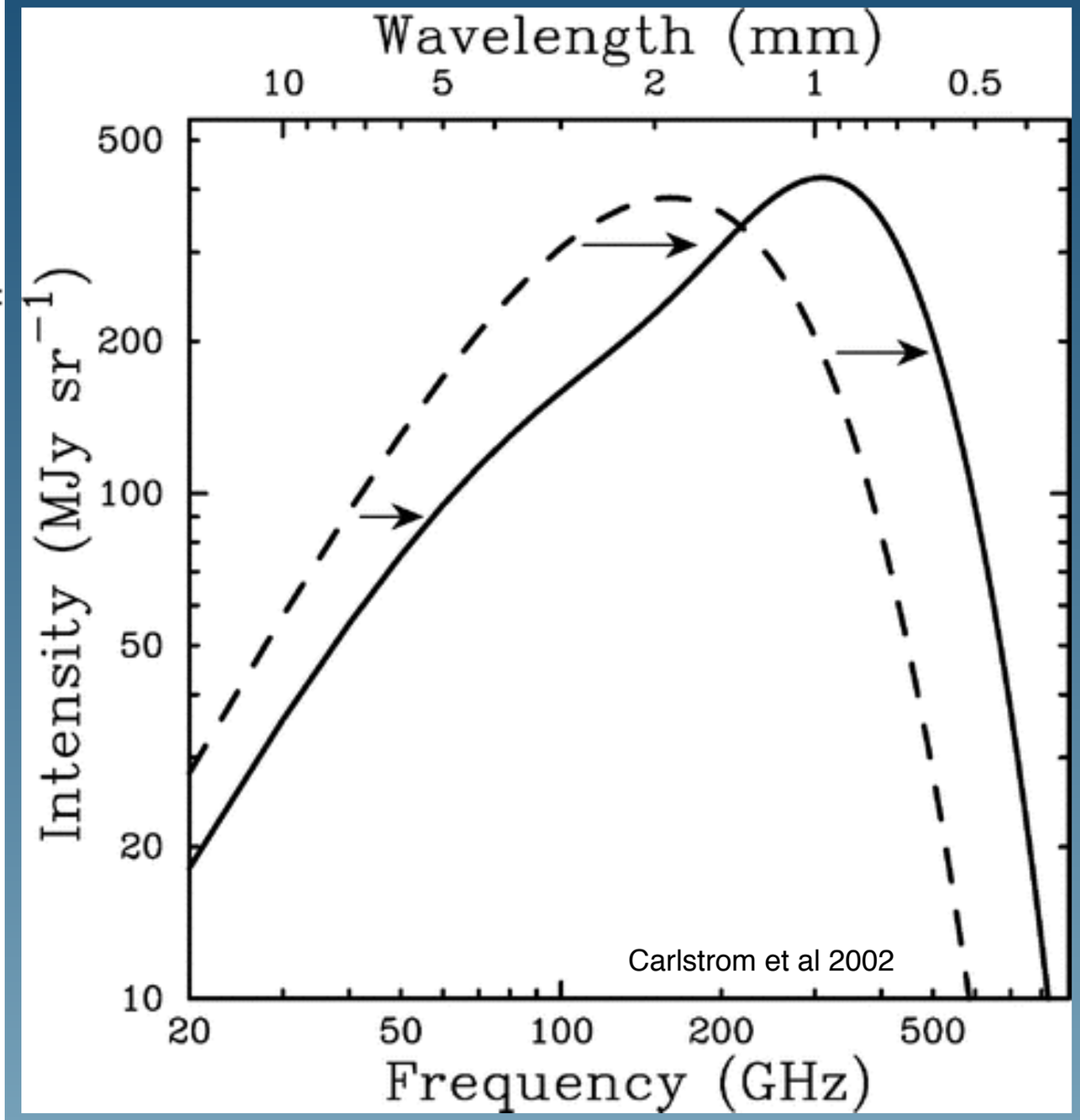


Thermal Sunyaev-Zel'dovich Effect

- Inverse Compton scattering of CMB photons



Credit : L. Van Speybroeck



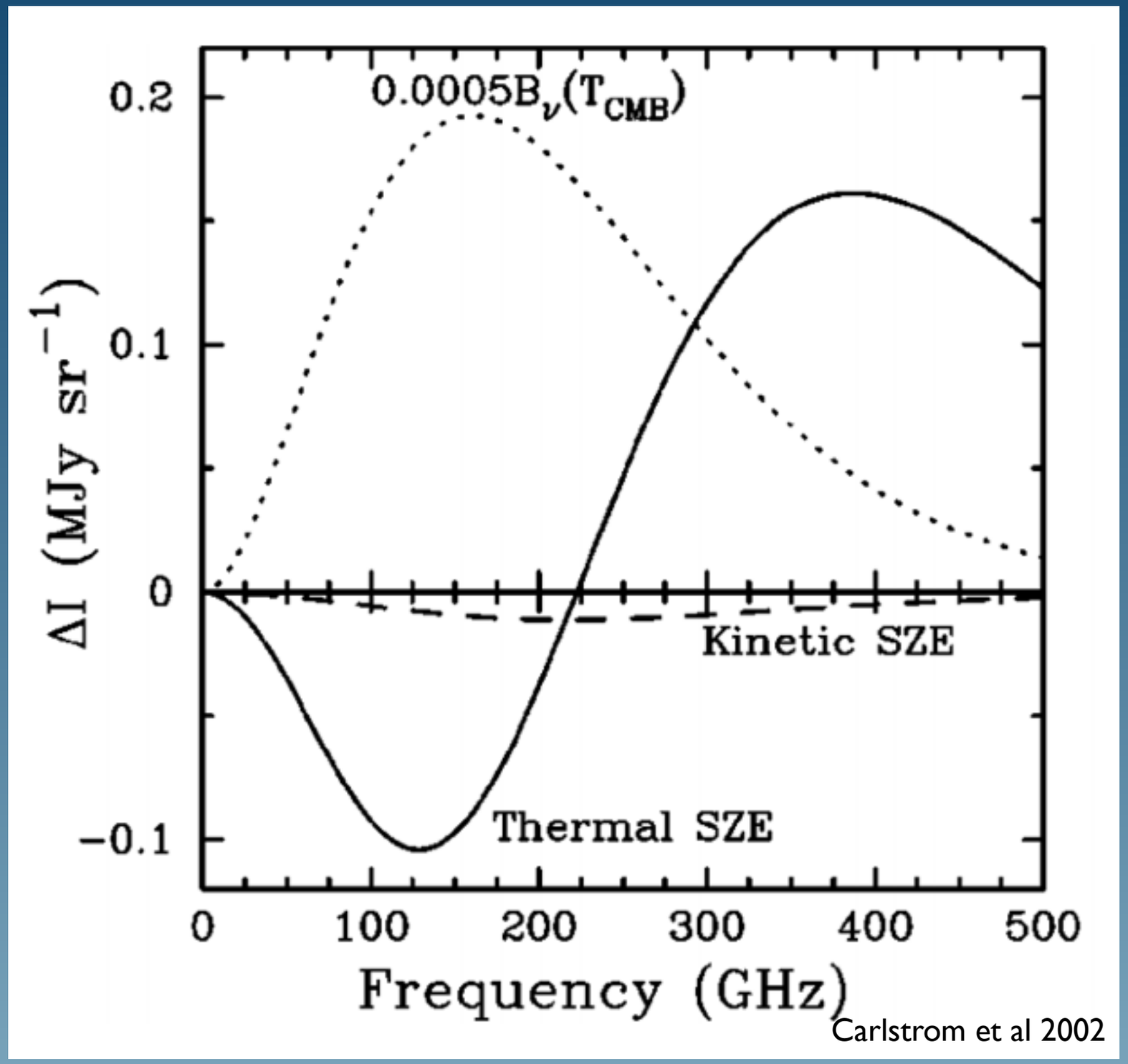
Thermal Sunyaev-Zel'dovich Effect

- Secondary anisotropies in the CMB

$$\frac{\Delta T}{T_{CMB}} = g_\nu \, y$$

$$y = \frac{k_b \sigma_T}{m_e c^2} \int n_e T_e dl$$

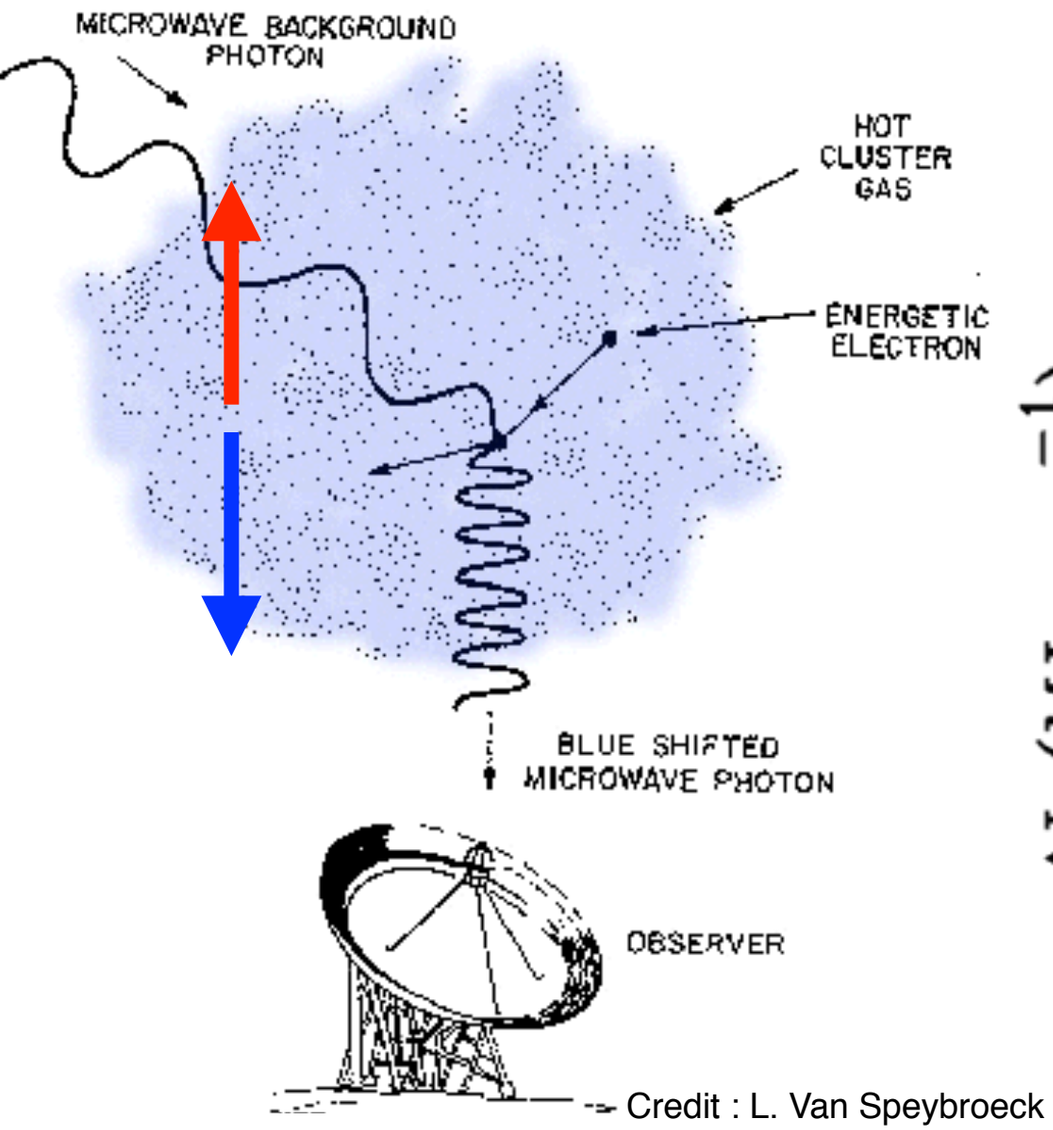
Integrated pressure



Carlstrom et al 2002

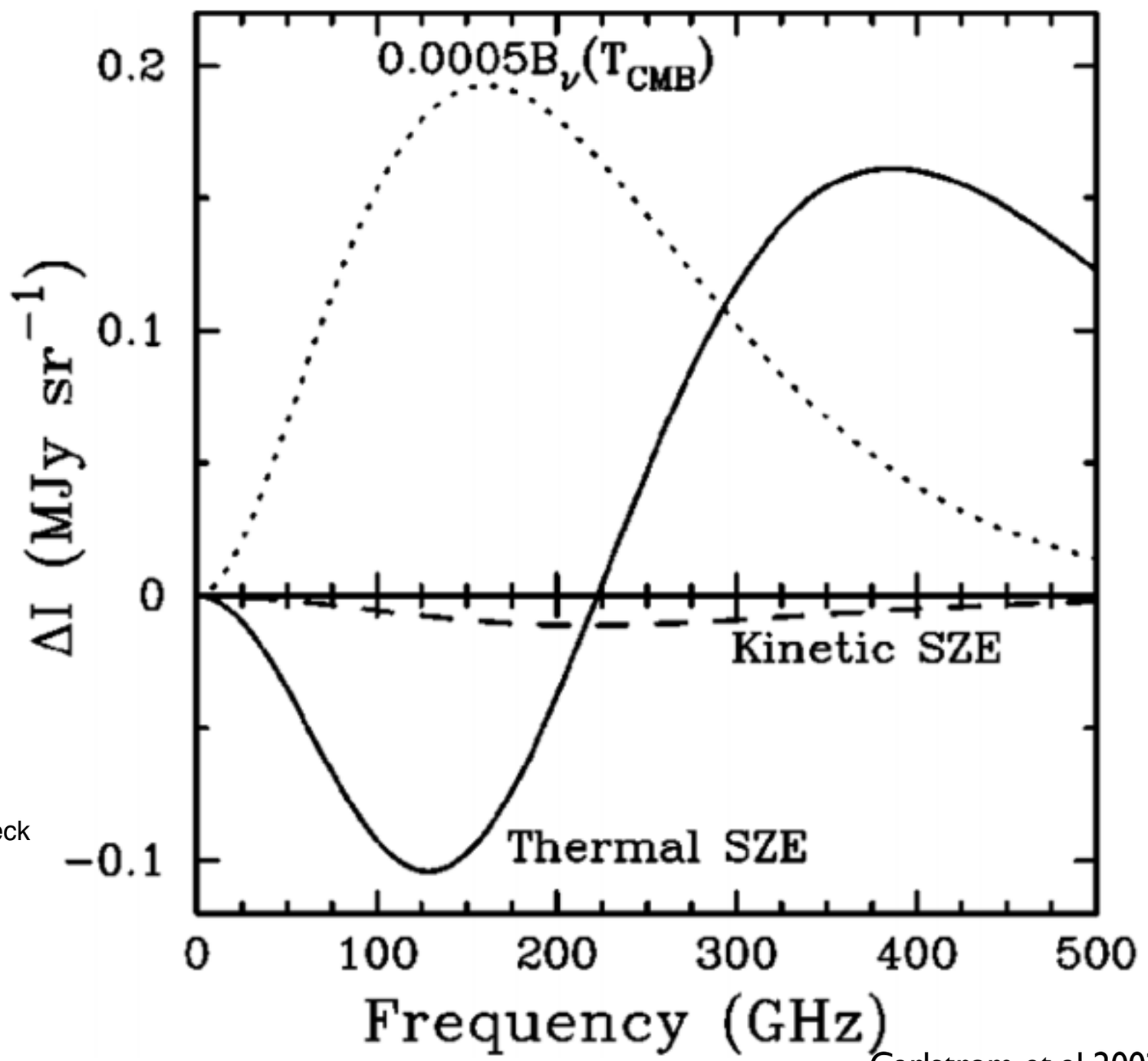
Kinetic Sunyaev-Zel'dovich Effect

- Doppler boosting of CMB photons



Credit : L. Van Speybroeck

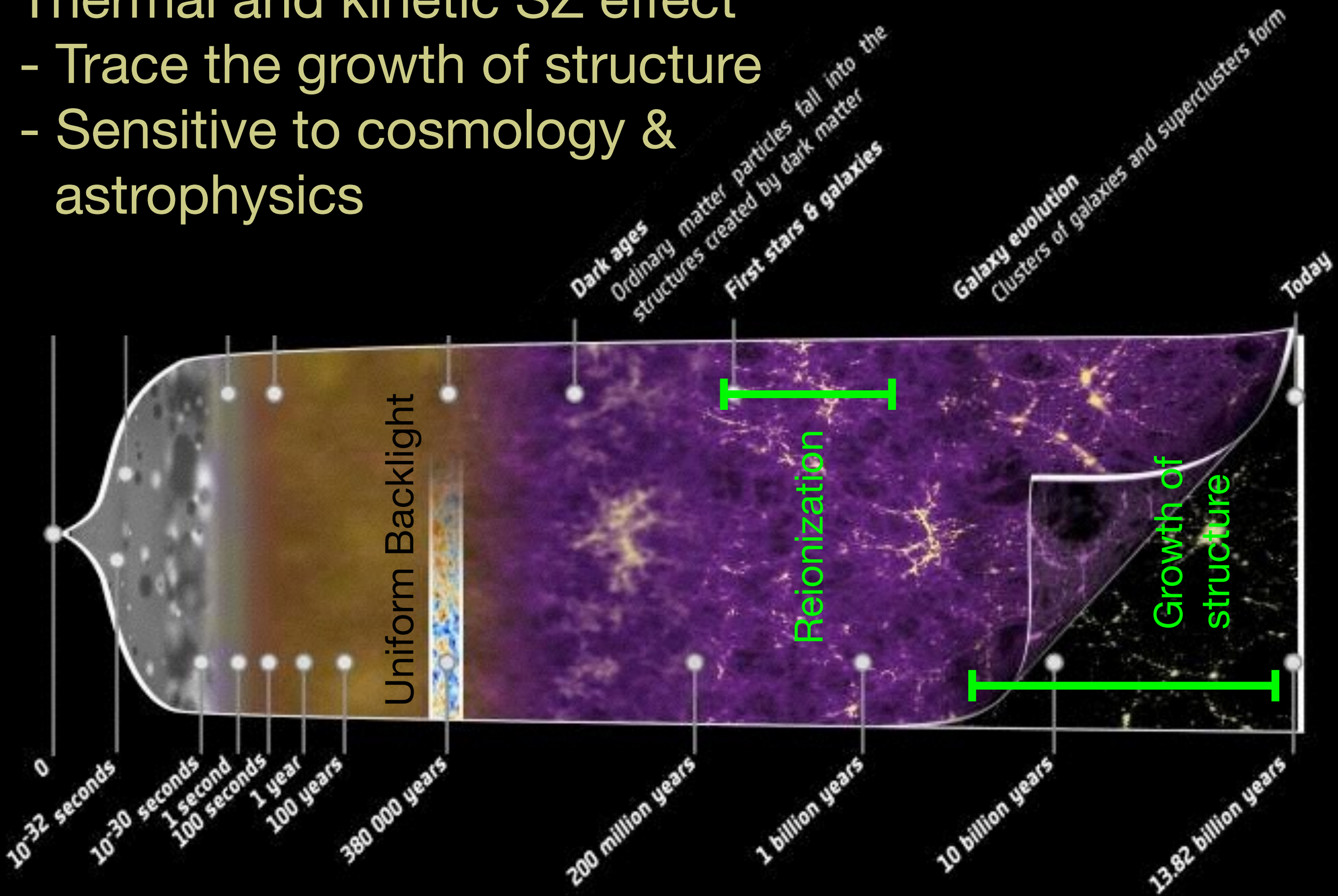
$$b \equiv \frac{\sigma_T}{c} \int n_e v_{los} dl$$



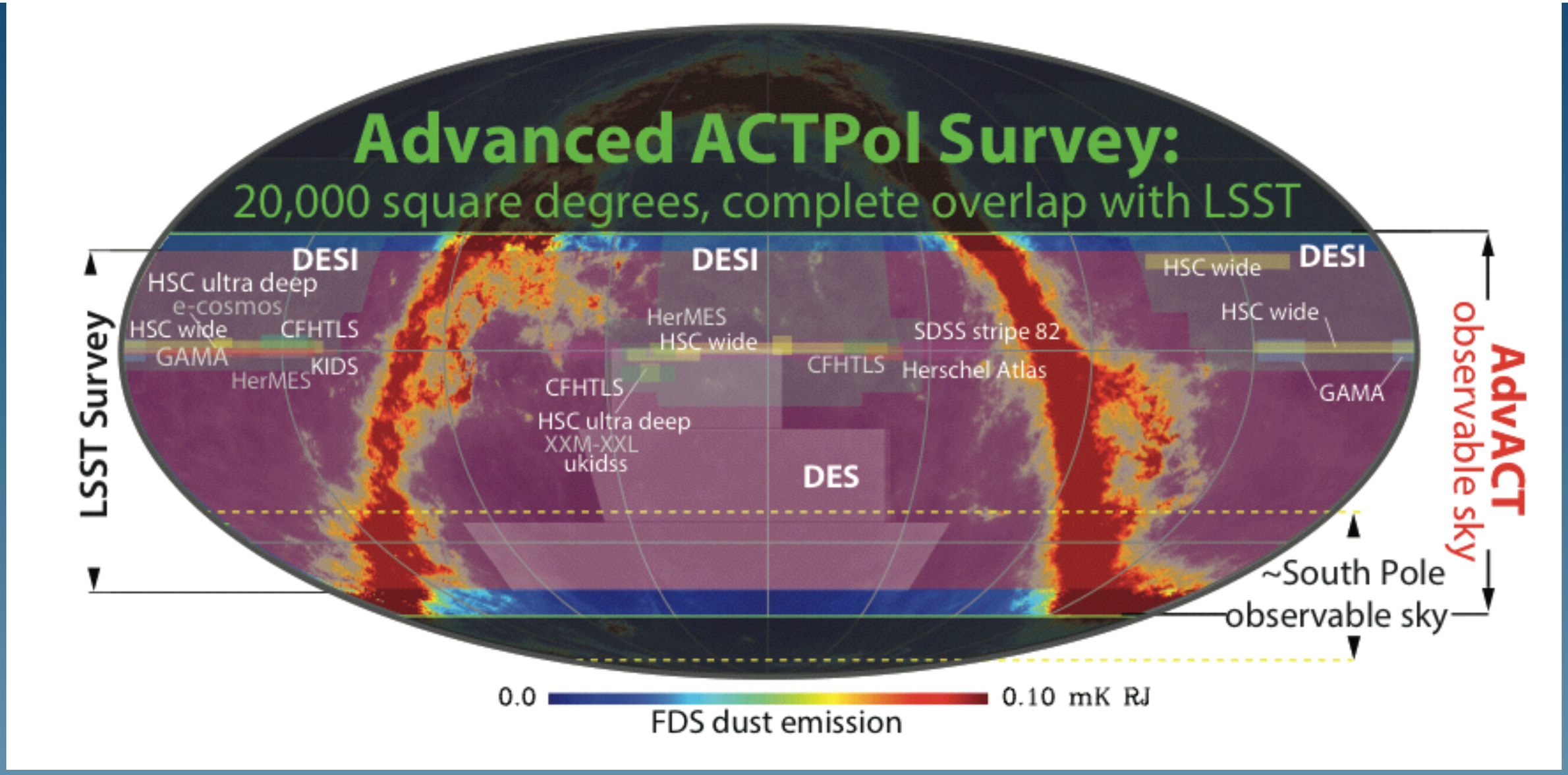
Carlstrom et al 2002

CMB scattering sources (secondaries): Thermal and kinetic SZ effect

- Trace the growth of structure
- Sensitive to cosmology & astrophysics



AdvACT + LSST



Funded, large area, multiple frequency bands
Potential for cross correlations is yuuuge!
Looking further ahead there will be CMB S4

The Simons Observatory

http://simonsobservatory.org

ALMA

- A five year, $45M+ program to pursue key Cosmic Microwave Background science targets, and advance technology and infrastructure in preparation for CMB-S4.

- Merger of the ACT and POLARBEAR/Simons Array teams.

- Tentative plans include:
  - Major site infrastructure
  - Technology development (detectors, optics, cameras)
  - Demonstration of new high throughput telescopes.
  - CMB-S4 class receivers with partially filled focal planes.
  - Data analysis

POLARBEAR/Simons Array

ACT

BERKELEY LAB CONICYT HEISING-SIMONS FOUNDATION NSF Penn PRINCETON UNIVERSITY SIMONS FOUNDATION

Auto & Cross spectra
(ignoring clustering)

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

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

Gastrophysics

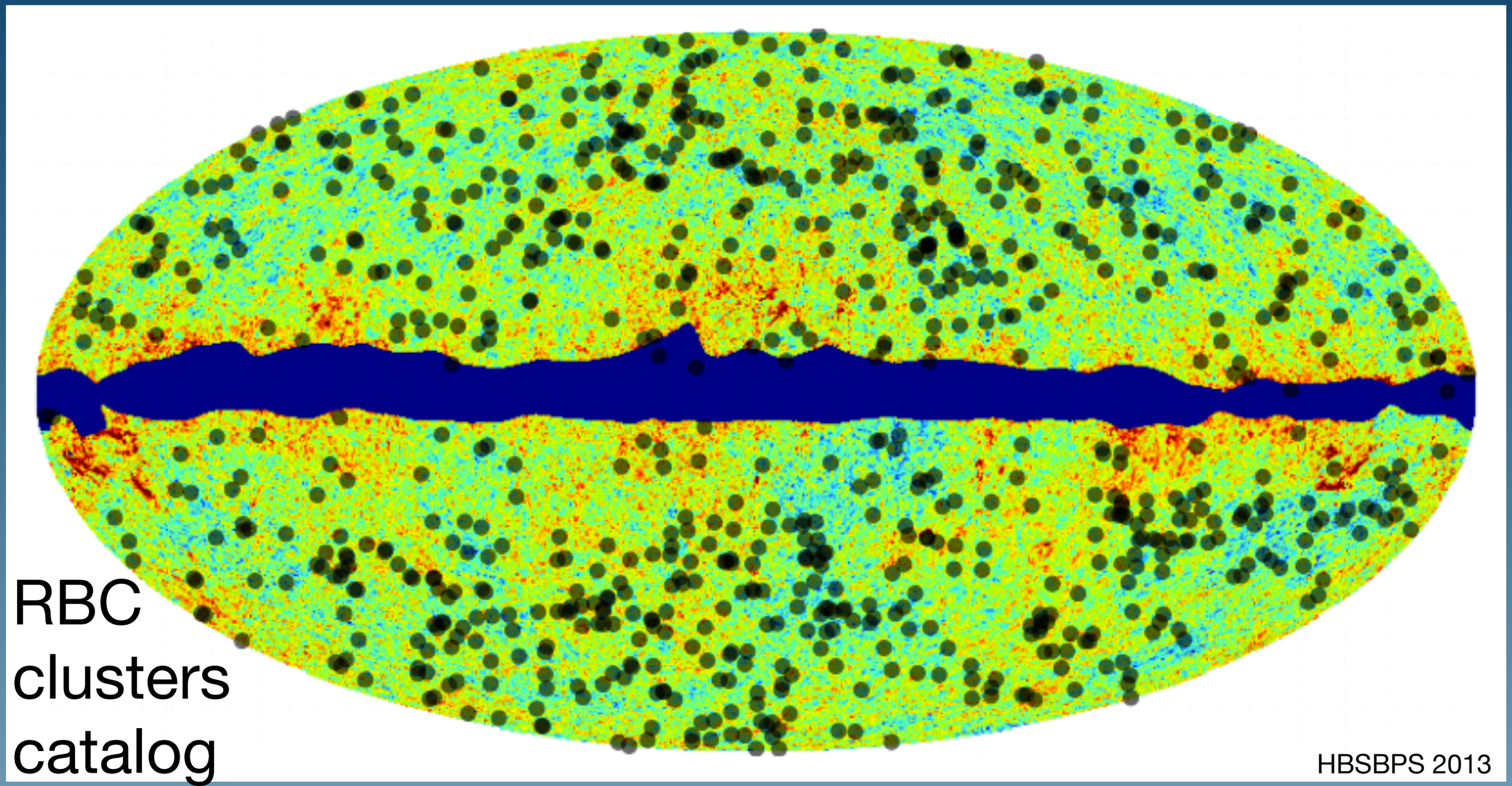
tSZ cross power spectrum

$$C_\ell^{SZ\times n} = f_\nu \int_{0.04}^{\infty} \frac{\mathrm{d}V}{\mathrm{d}z} \mathrm{d}z \int_0^{\infty} \frac{\mathrm{d}n(M,z)}{\mathrm{d}M} \tilde{y}_\ell(M,z) \Theta(M,z) \mathrm{d}M,$$

$A_X \propto \sigma_8^{7.4}\, \Omega_M^{1.9}$
High mass, low redshift clusters

Selection function
(Gastrophysics)

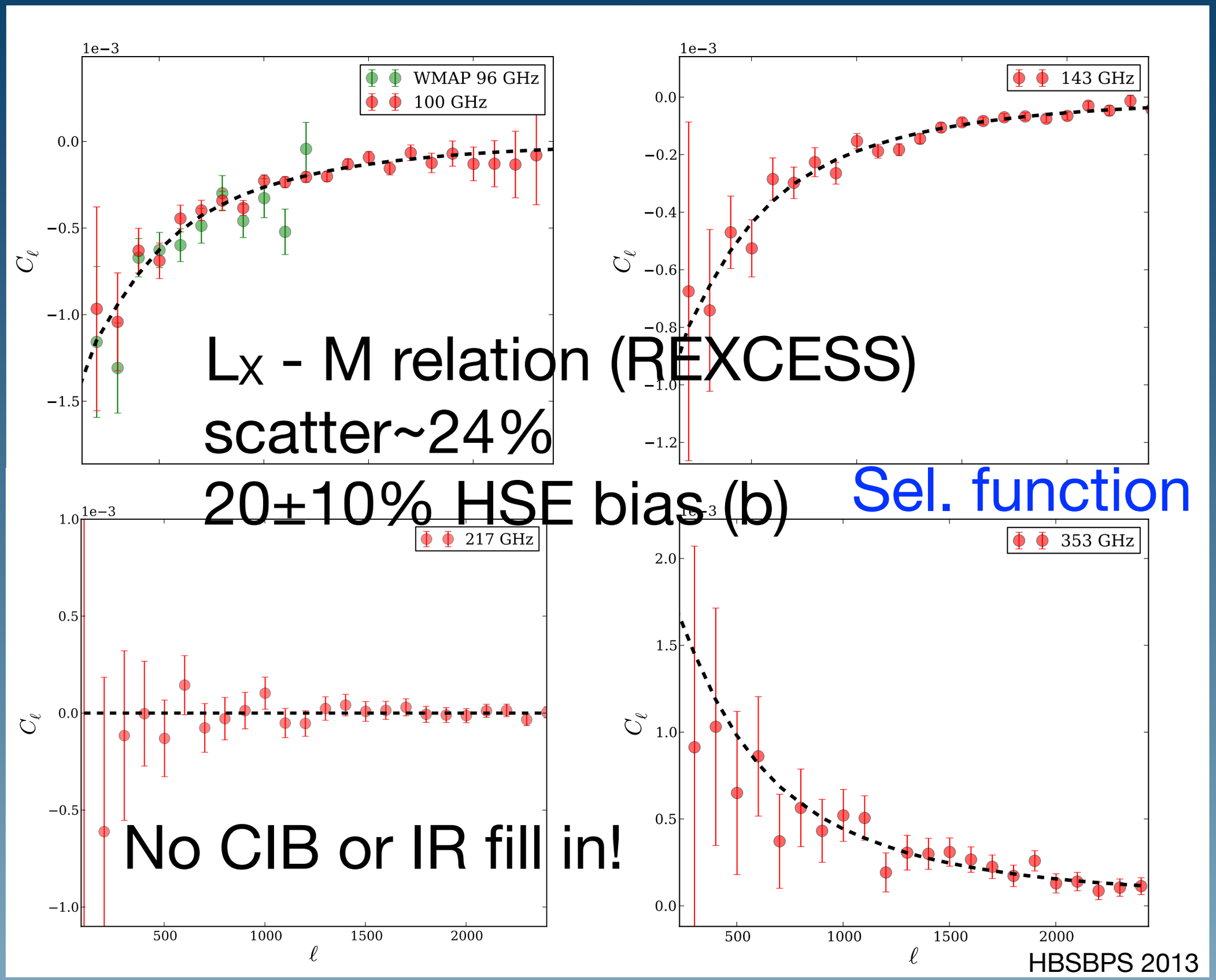
Cross Correlation with X-ray clusters



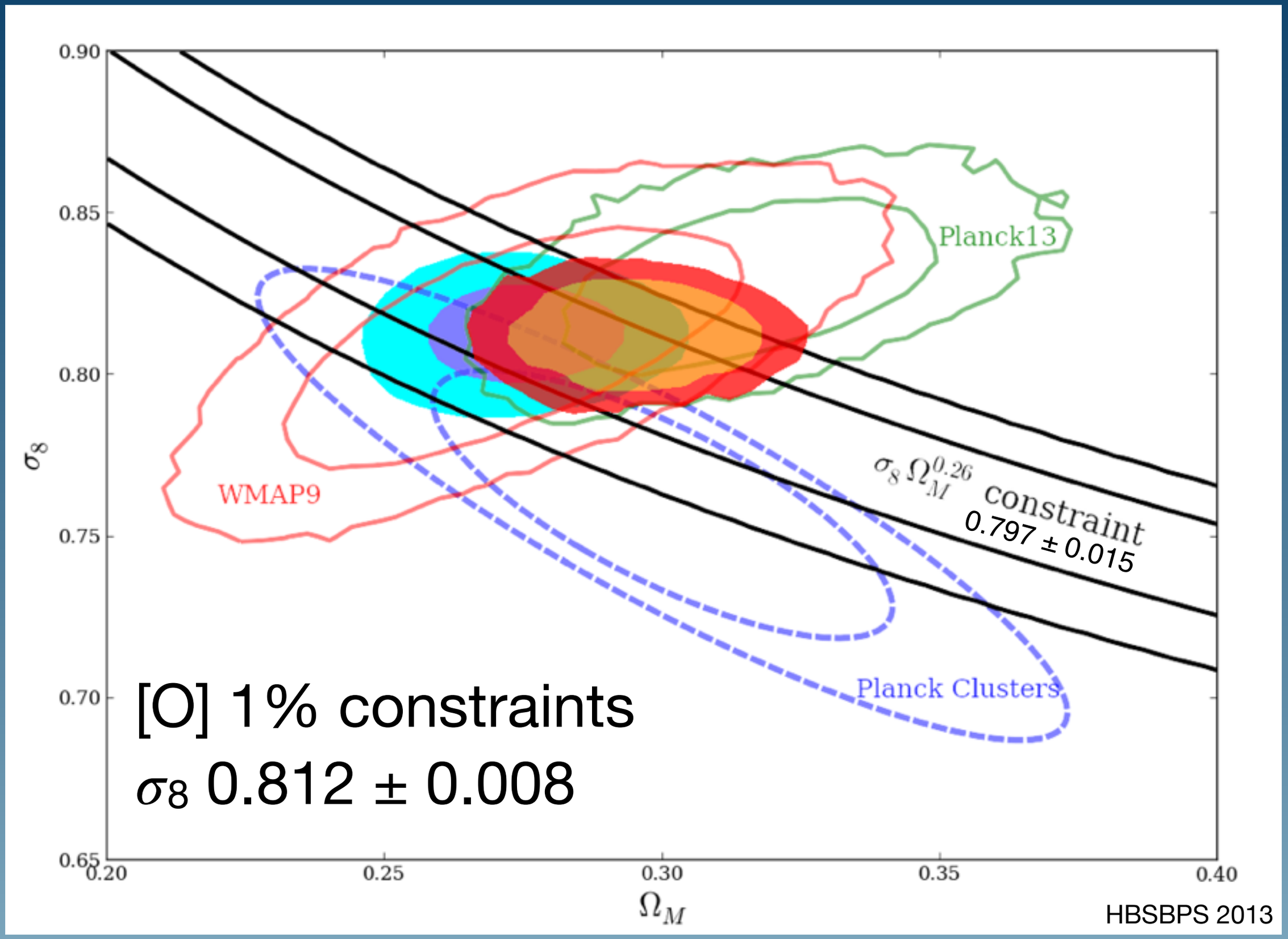
Used the raw Planck at 100-857 GHz

Also used the WMAP9 94 GHz

Cross spectra



Cross spectra constraints



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

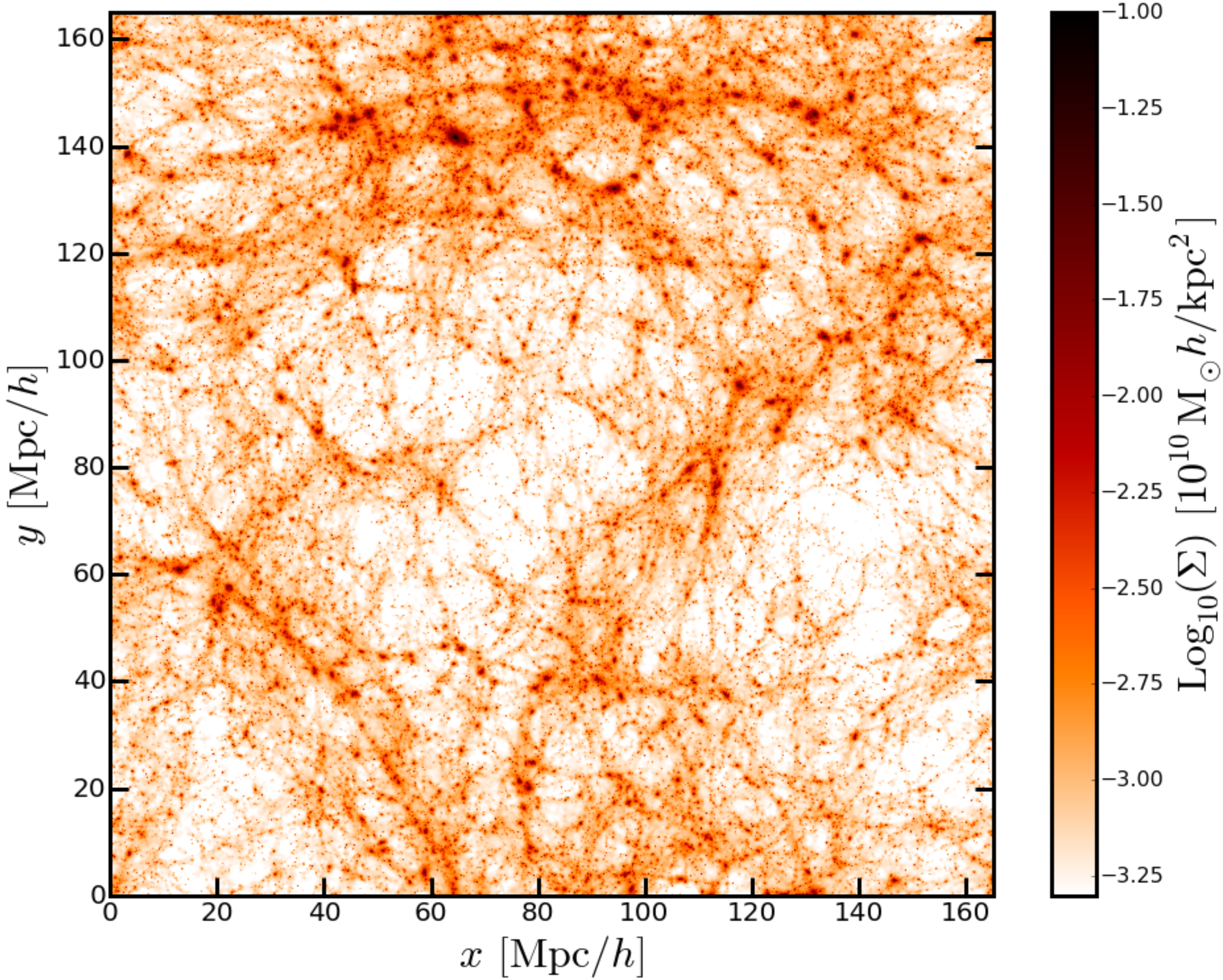
PHYSICAL REVIEW D **89**, 023508 (2014)

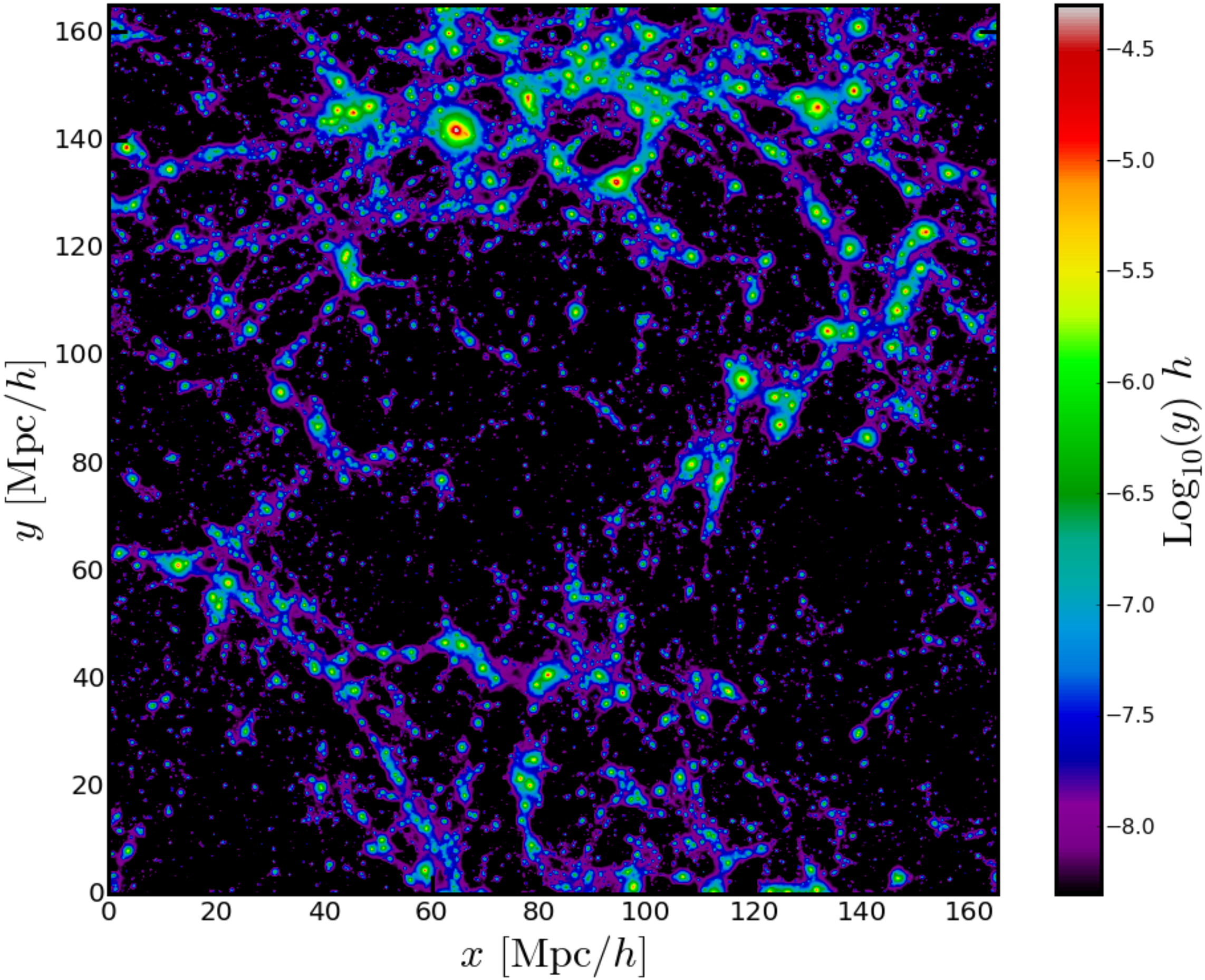
Detection of warm and diffuse baryons in large scale structure from the cross correlation of gravitational lensing and the thermal Sunyaev-Zeldovich effect

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

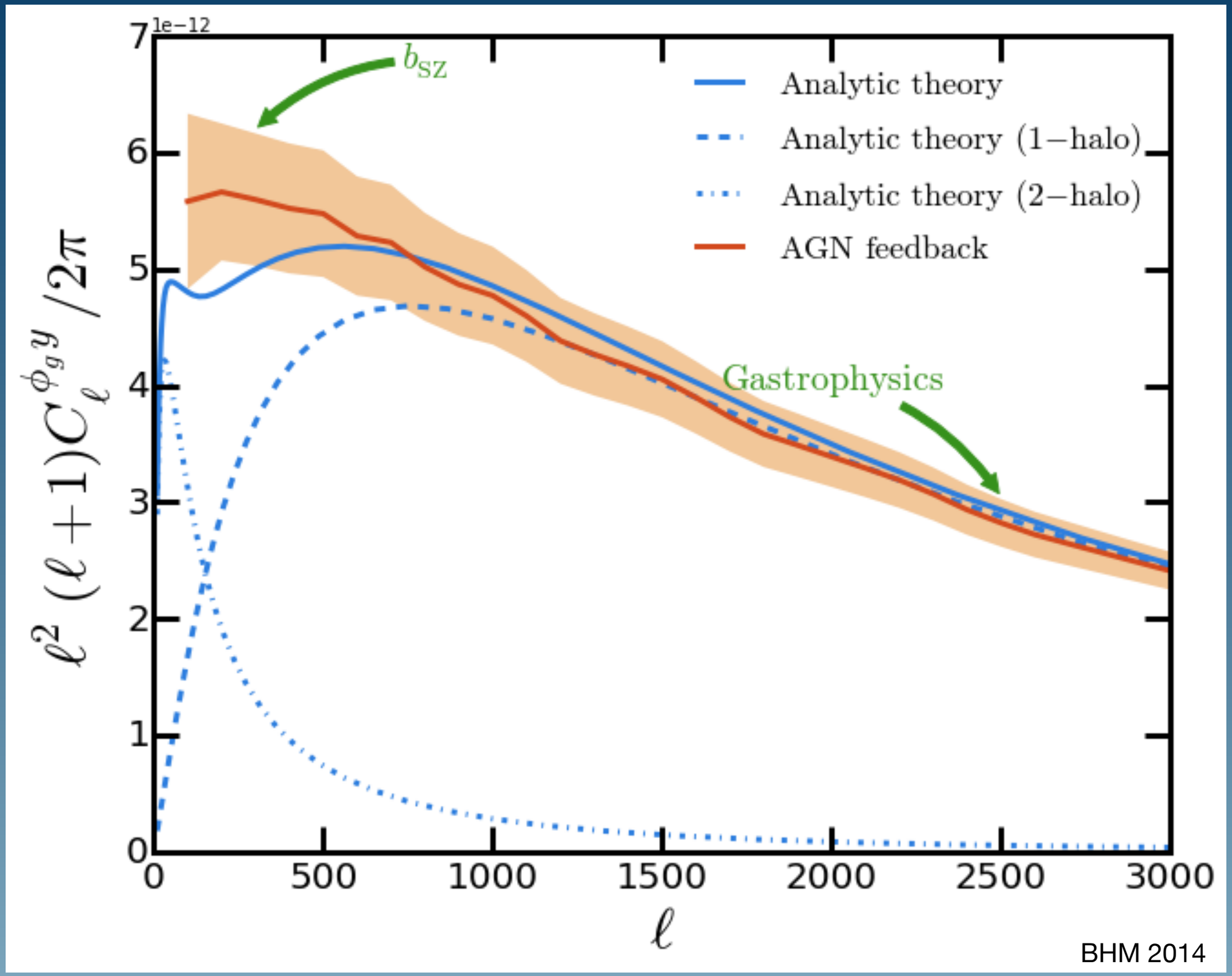
Ma+2014 & Hojjati+2014 - Interpretation of results

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


160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
y [Mpc/h]
x [Mpc/h]
−1.00
−1.25
−1.50
−1.75
−2.00
−2.25
−2.50
−2.75
−3.00
−3.25
$\mathrm{Log}_{10}(\Sigma)$ $[10^{10}\mathrm{M}_{\odot}h/\mathrm{kpc}^2]$

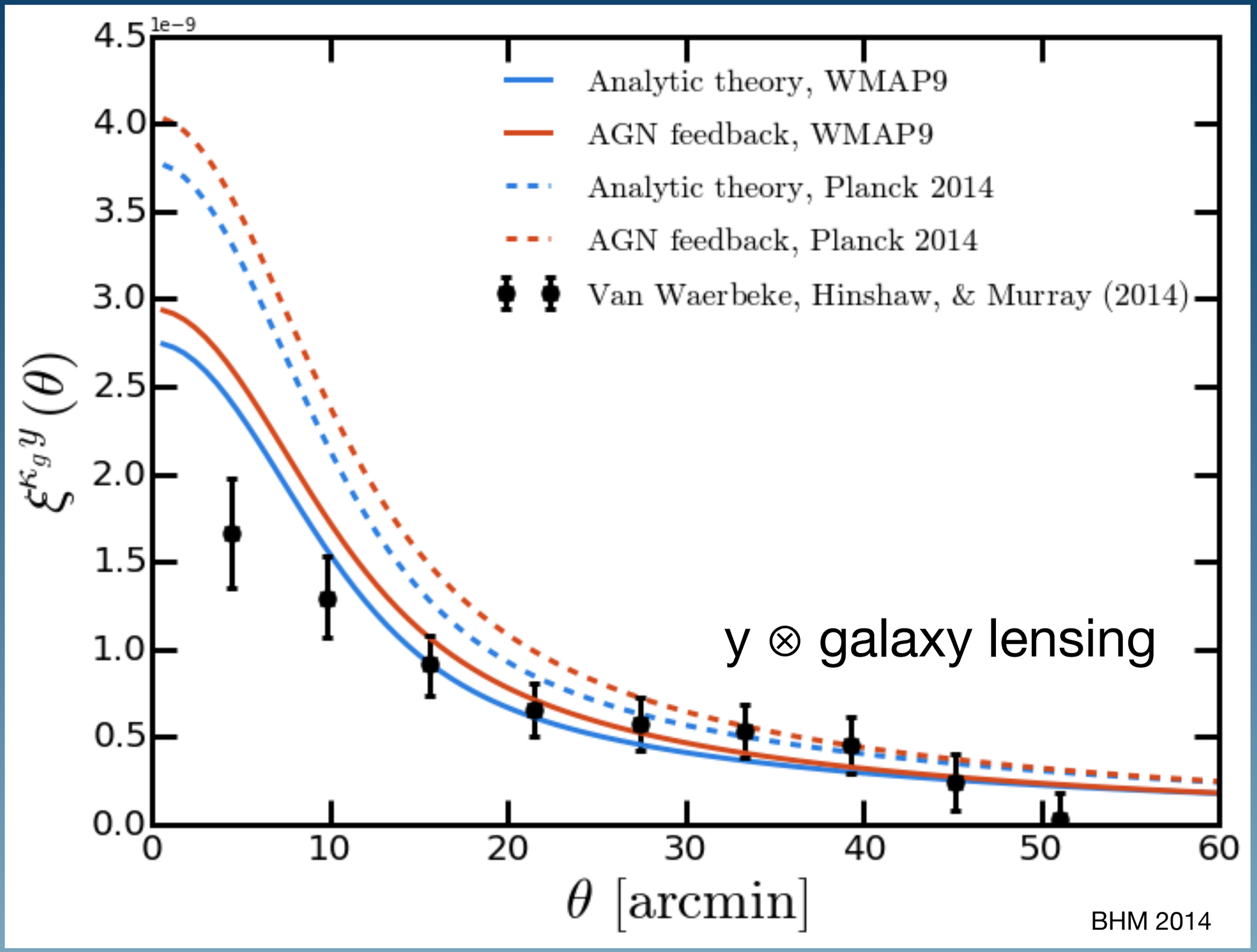

160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
y [Mpc/h]
x [Mpc/h]
−4.5
−5.0
−5.5
−6.0
−6.5
−7.0
−7.5
−8.0
$\mathrm{Log}_{10}(y)\ h$

Cross correlate with lensing

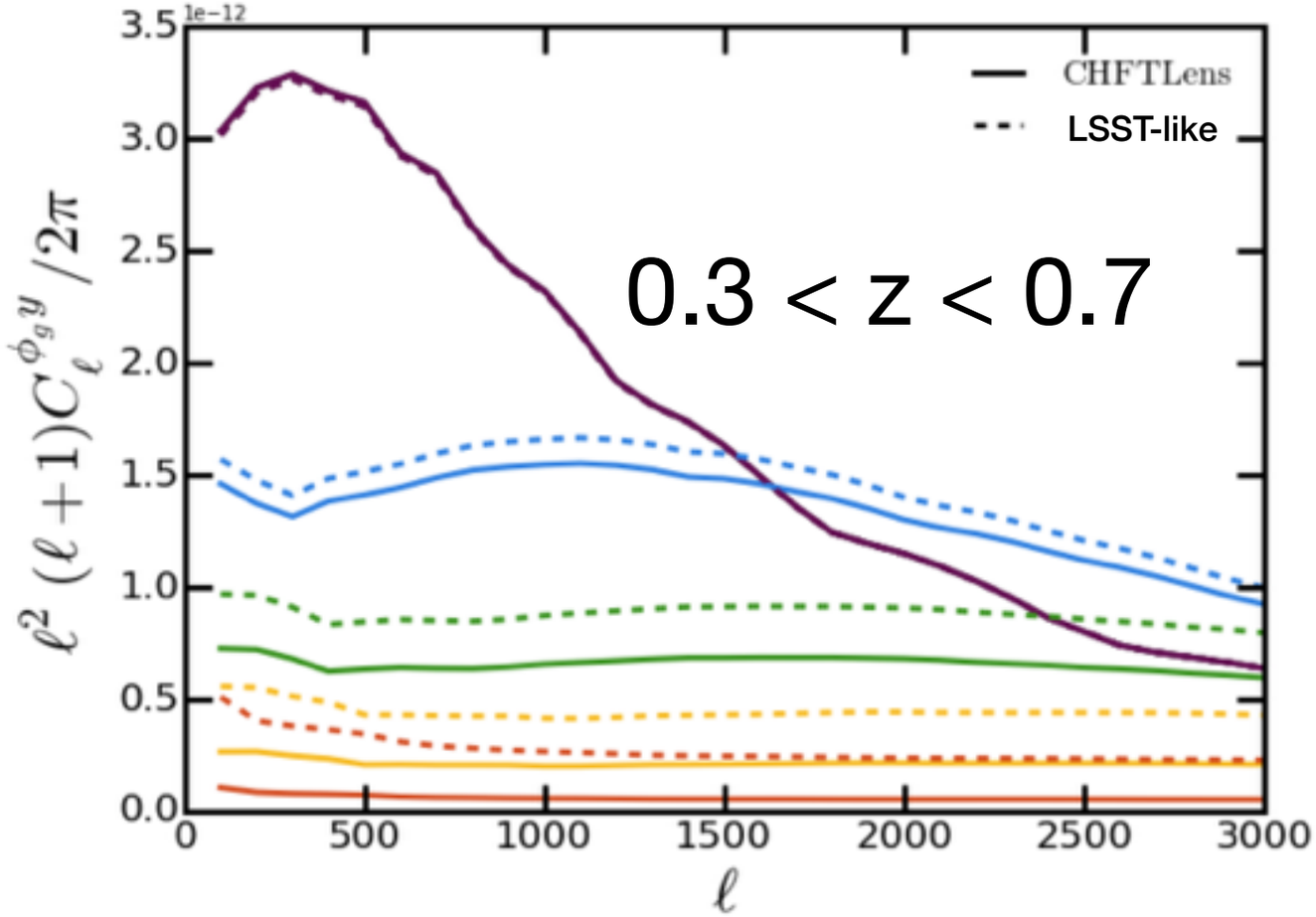


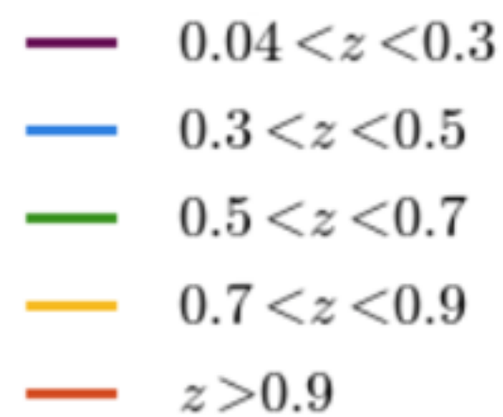
BHM 2014

Cross correlate with lensing



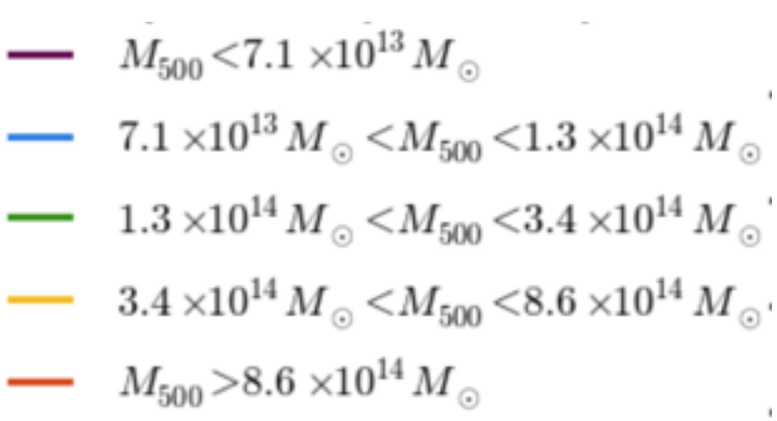
Cross correlate with lensing

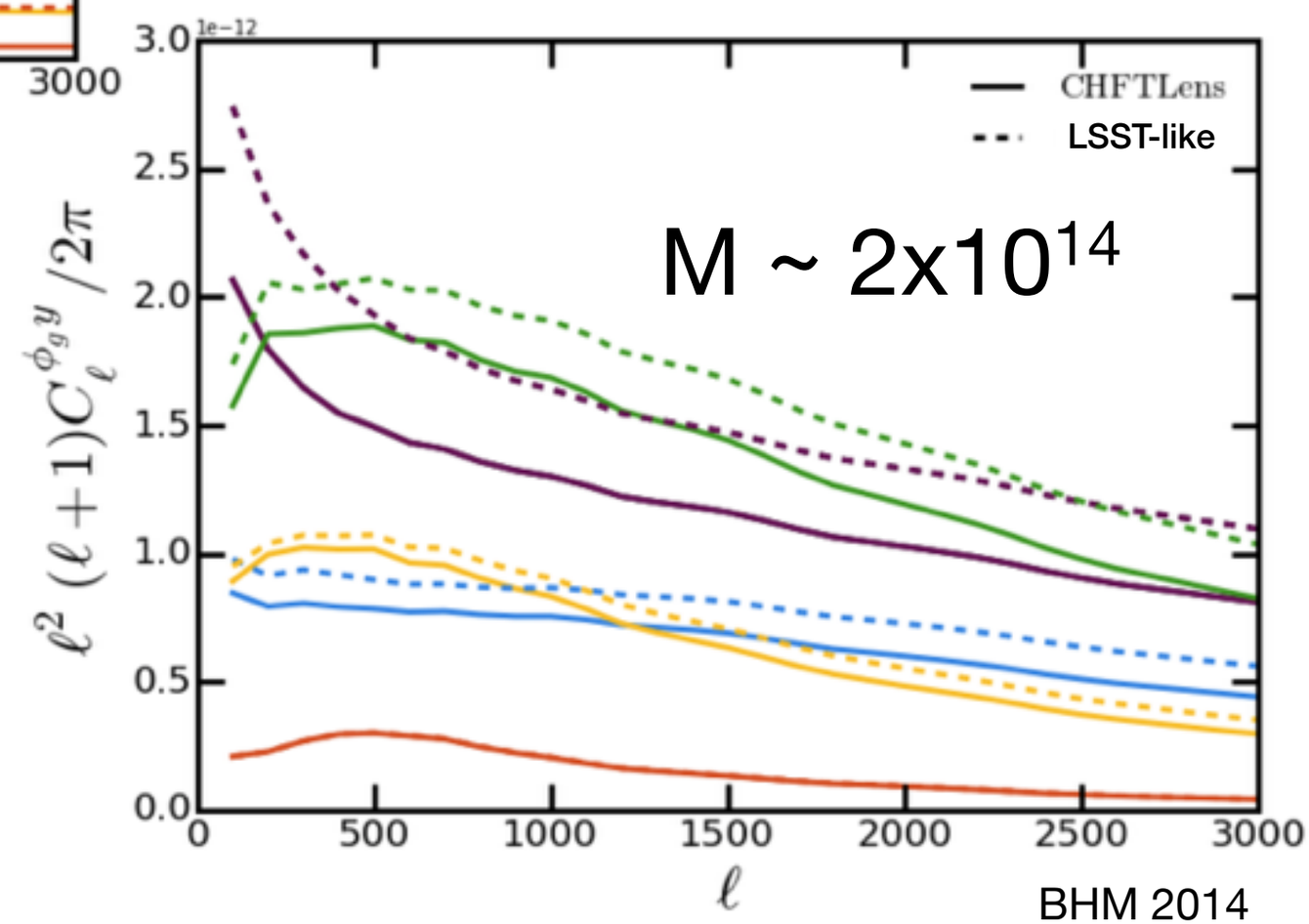




Intermediate redshifts

Intermediate mass halos





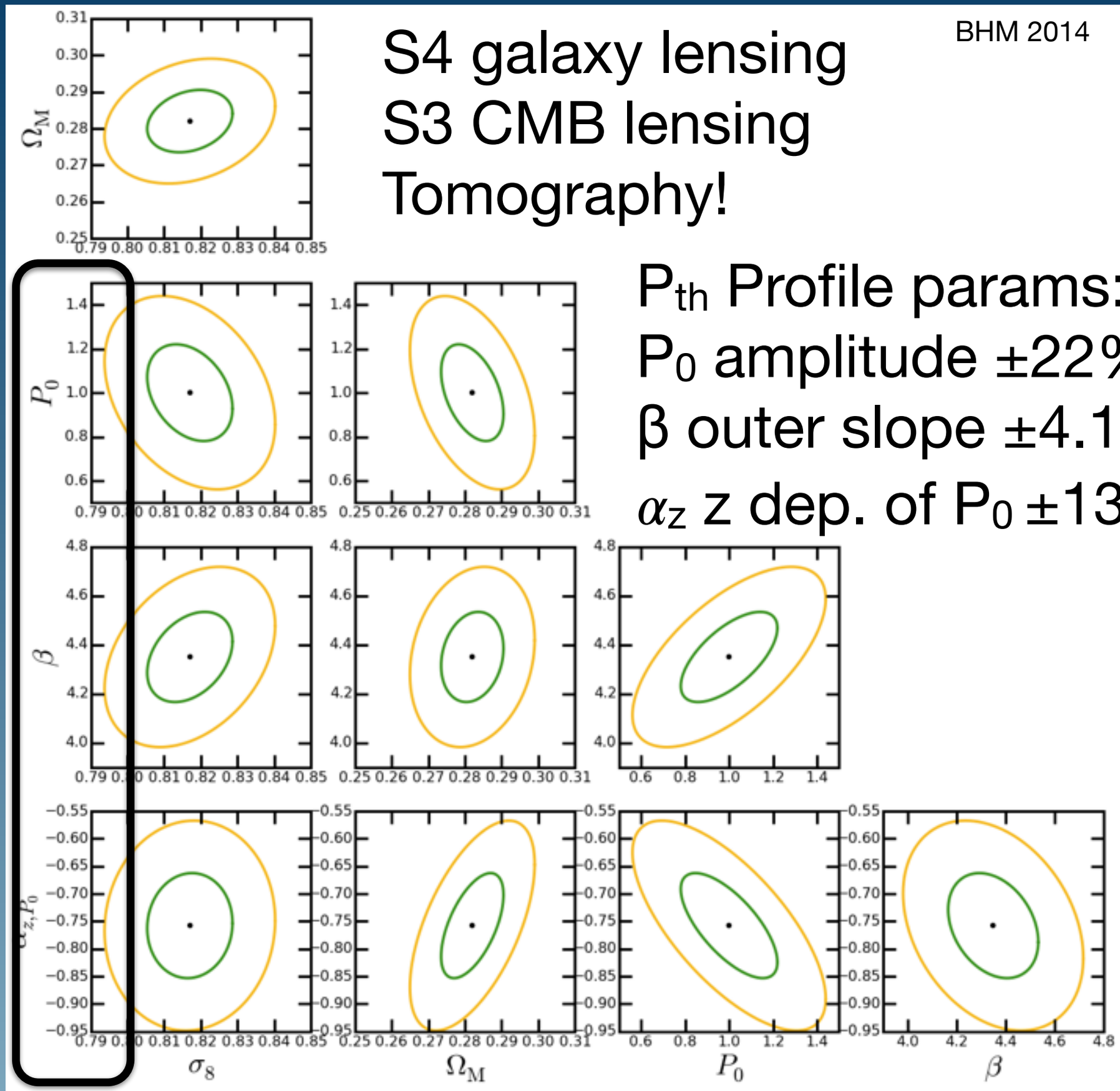
BHM 2014

Cross correlate with lensing forecast

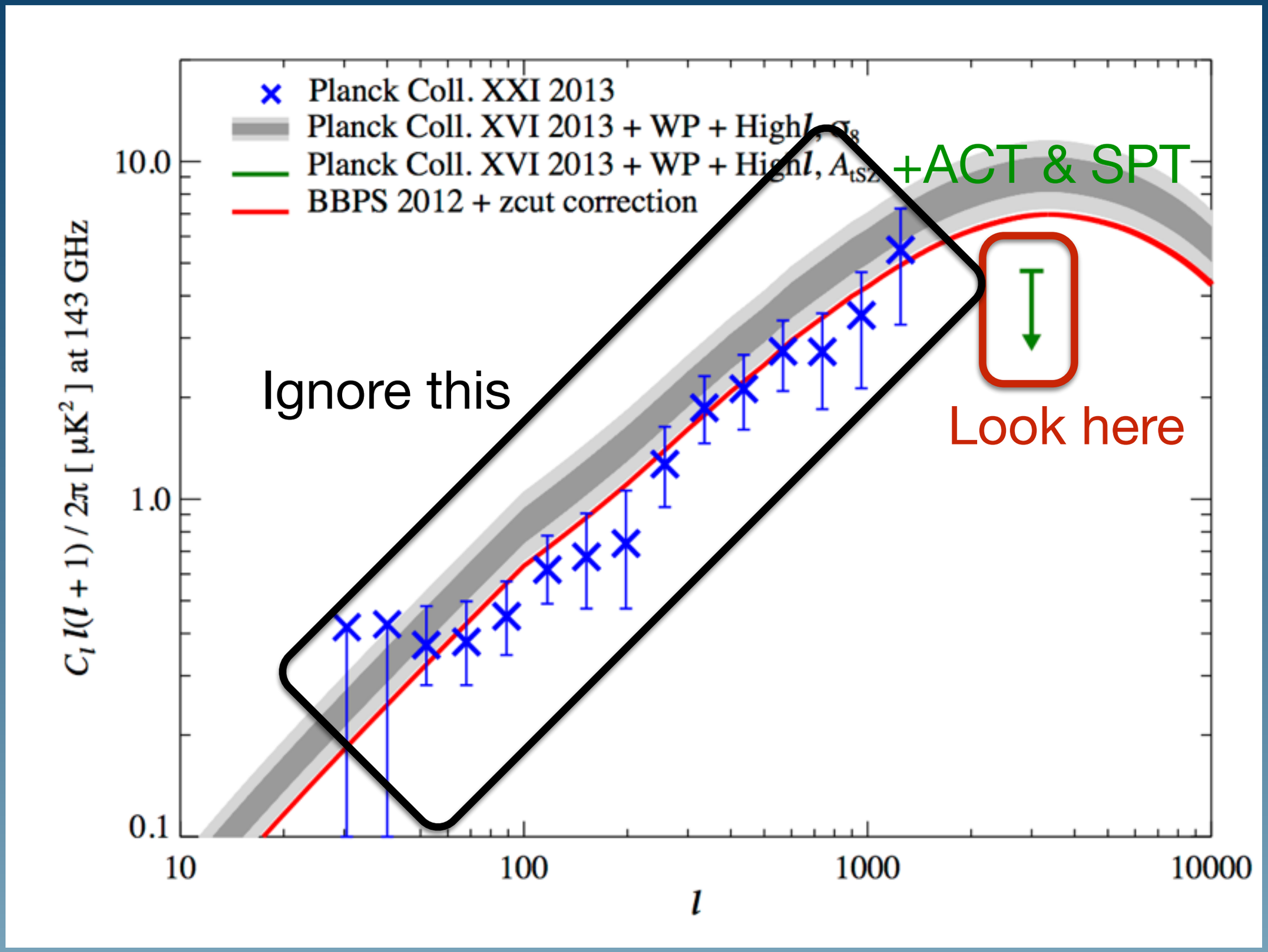
BHM 2014

S4 galaxy lensing
S3 CMB lensing
Tomography!

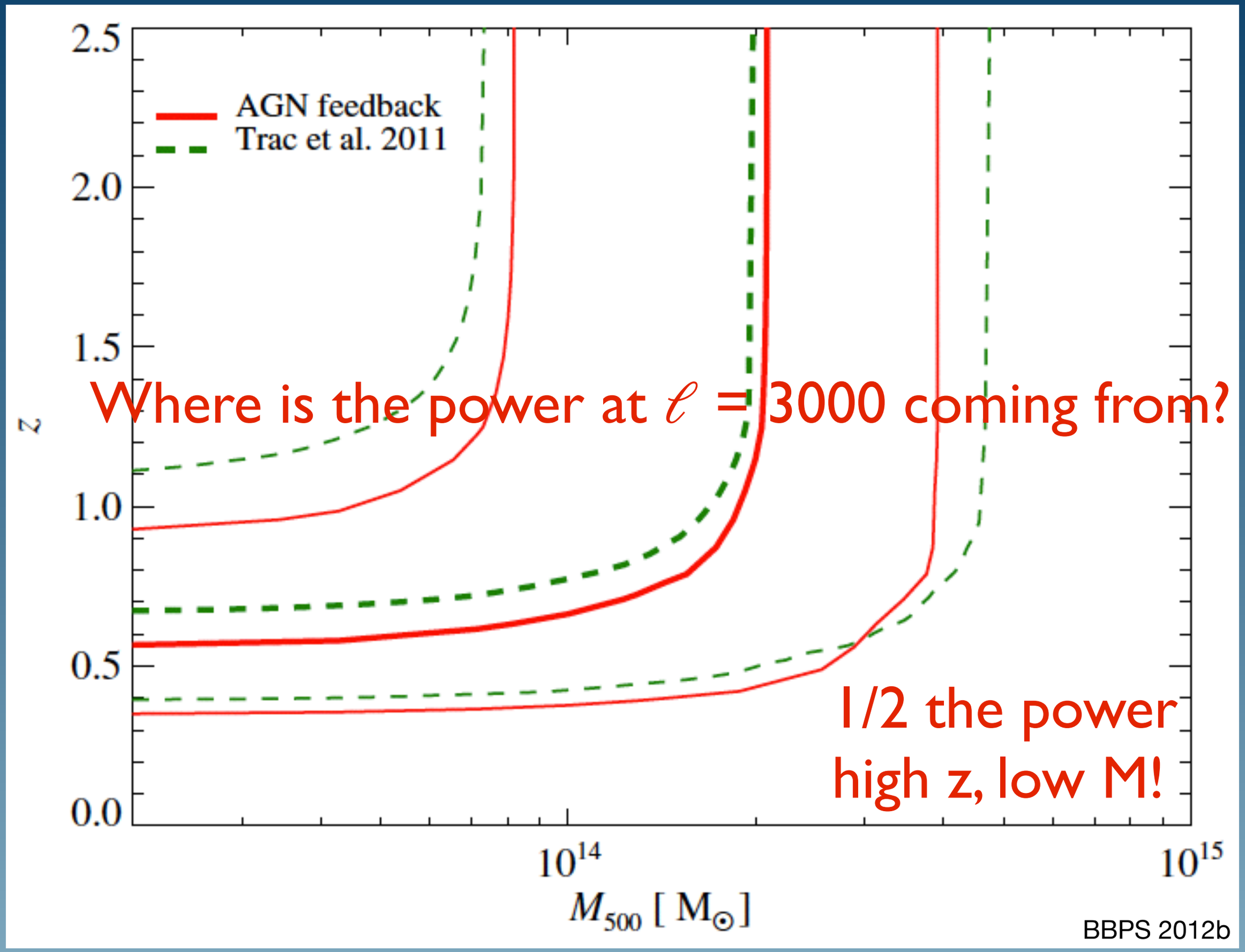
P_{th} Profile params:
P_0 amplitude ±22%
β outer slope ±4.1%
α_z z dep. of P_0 ±13%



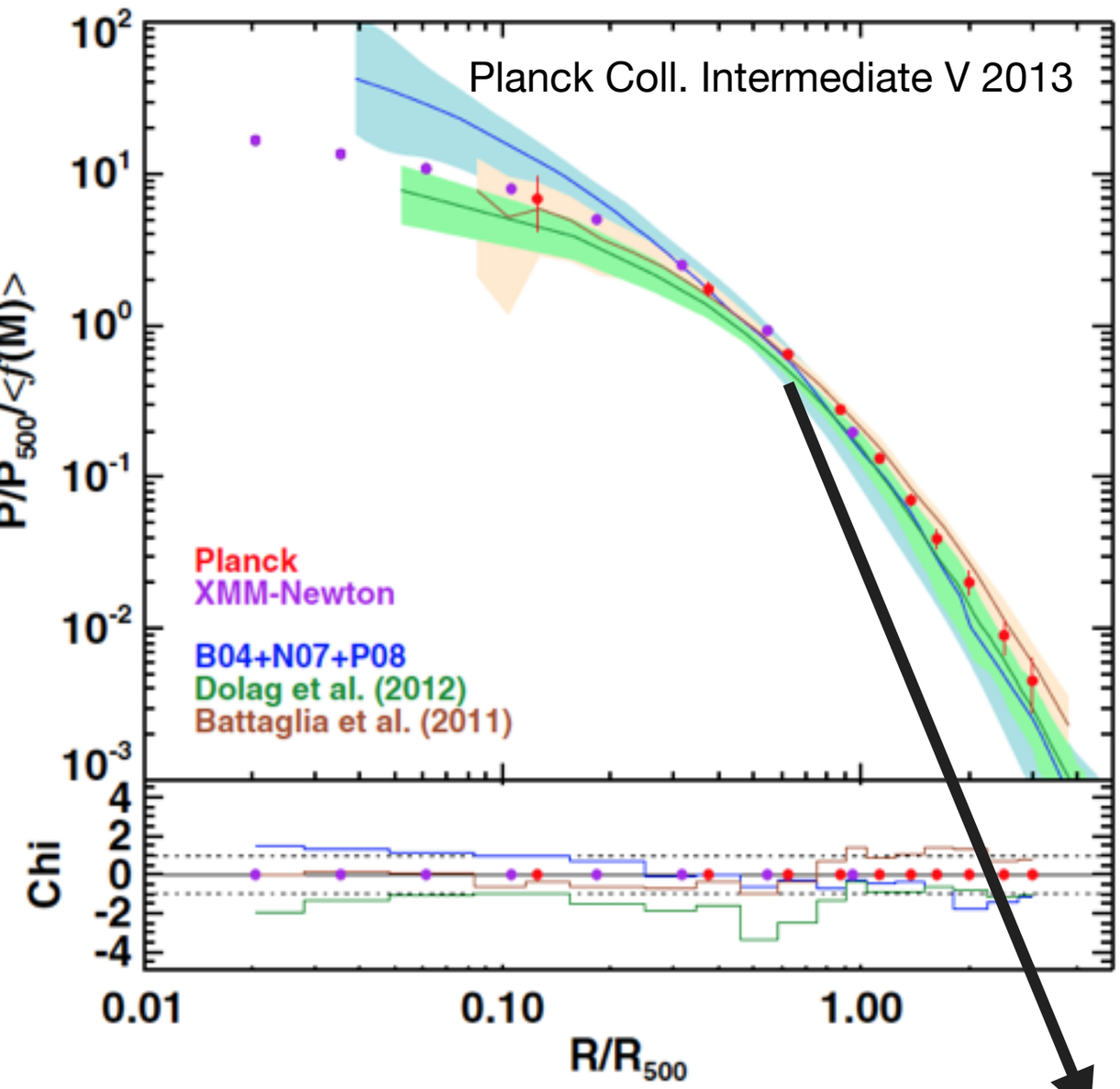
Discrepancy at ℓ = 3000?



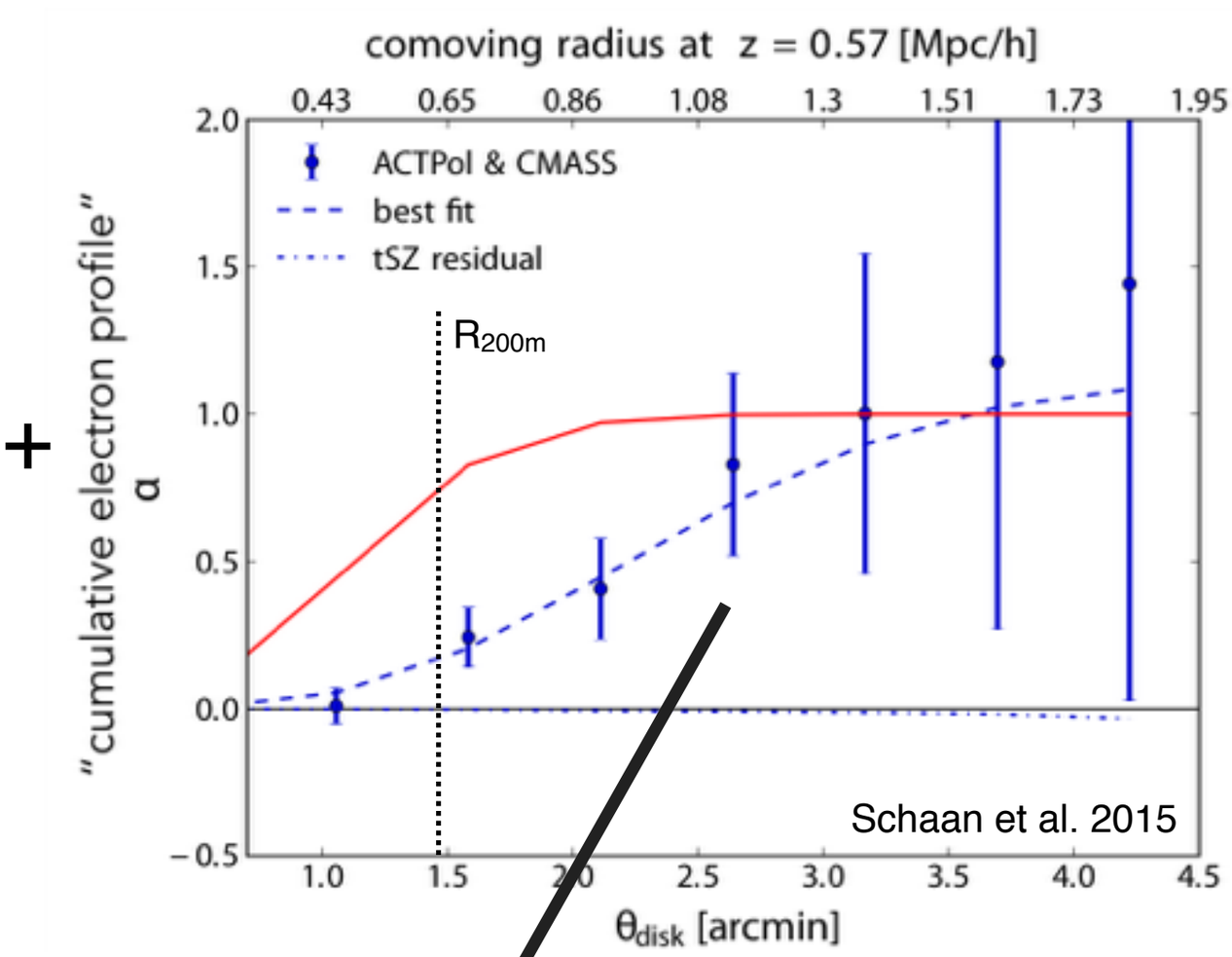
$C_\ell(M,z)$


AGN feedback
Trac et al. 2011
2.5
2.0
1.5
1.0
0.5
0.0
z
10^{14}
10^{15}
M_{500} [$M_\odot$]
Where is the power at ℓ = 3000 coming from?
1/2 the power
high z, low M!
BBPS 2012b

Combining tSZ & kSZ measurements (if there's time)

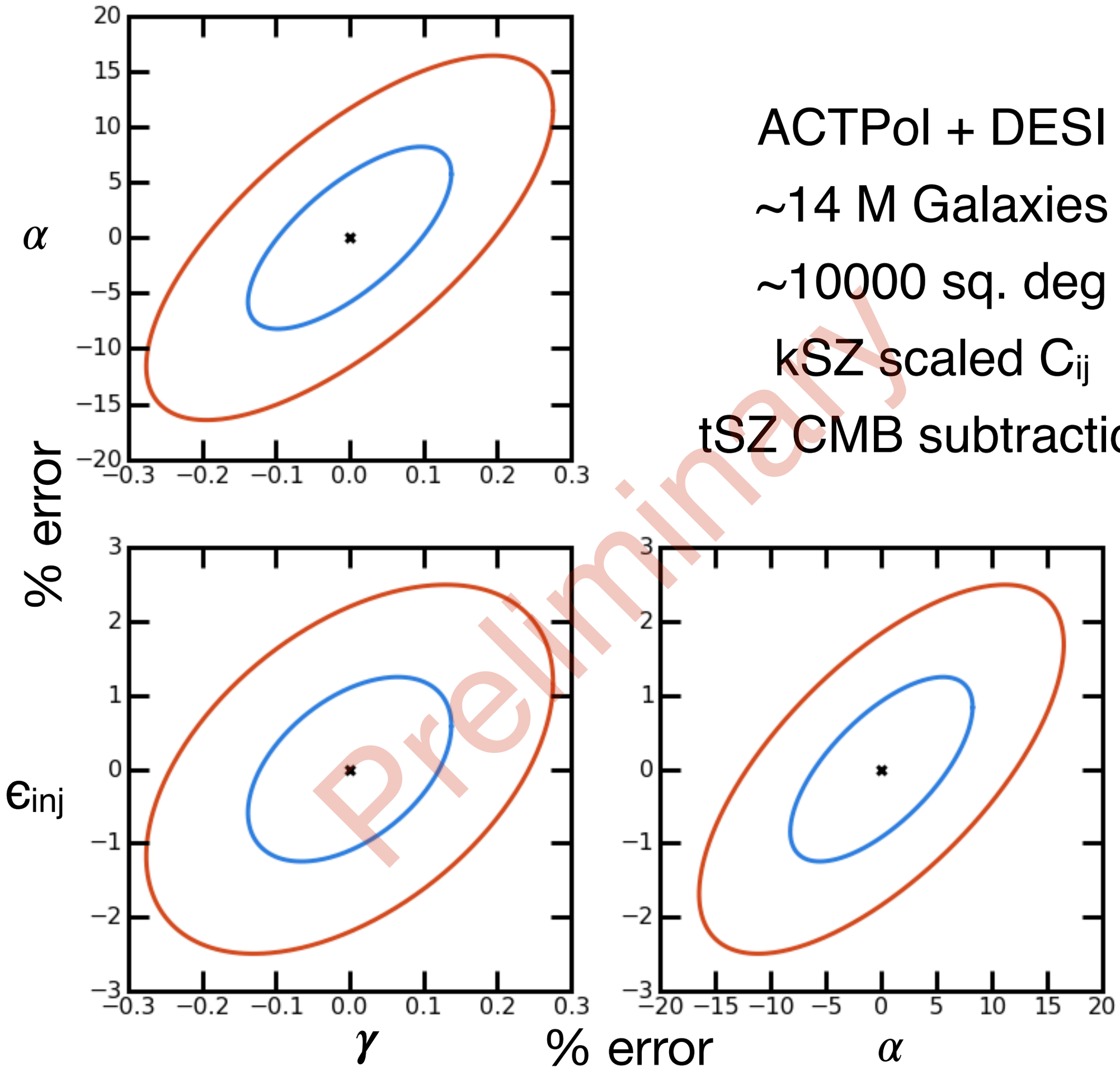


+



Given $P_{th}(r)$ and $\rho(r)$

Can we constrain γ, α & E_{inj} ?



ACTPol + DESI

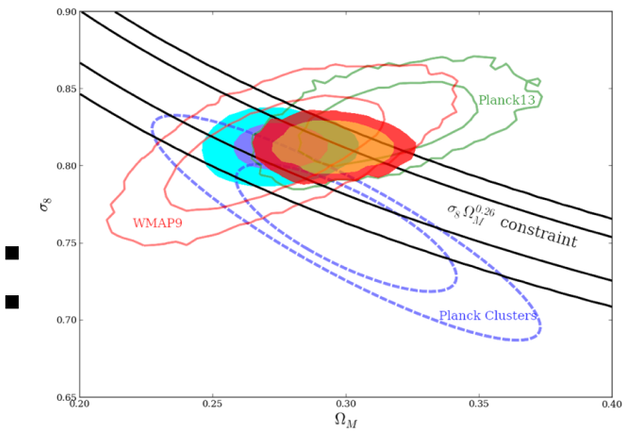
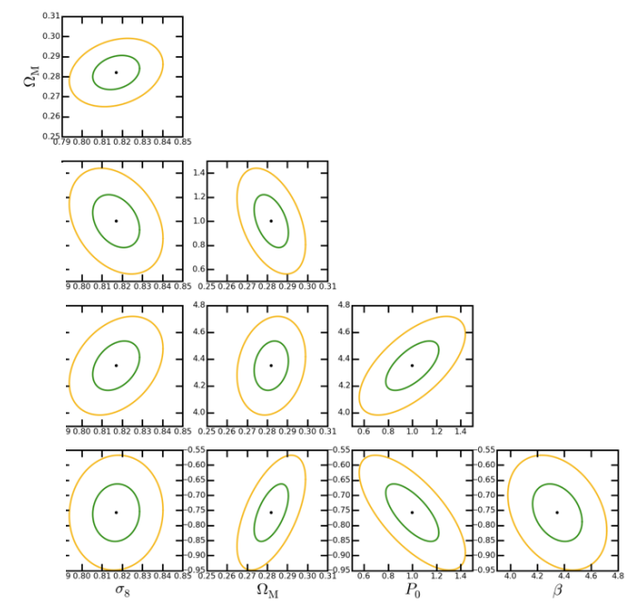
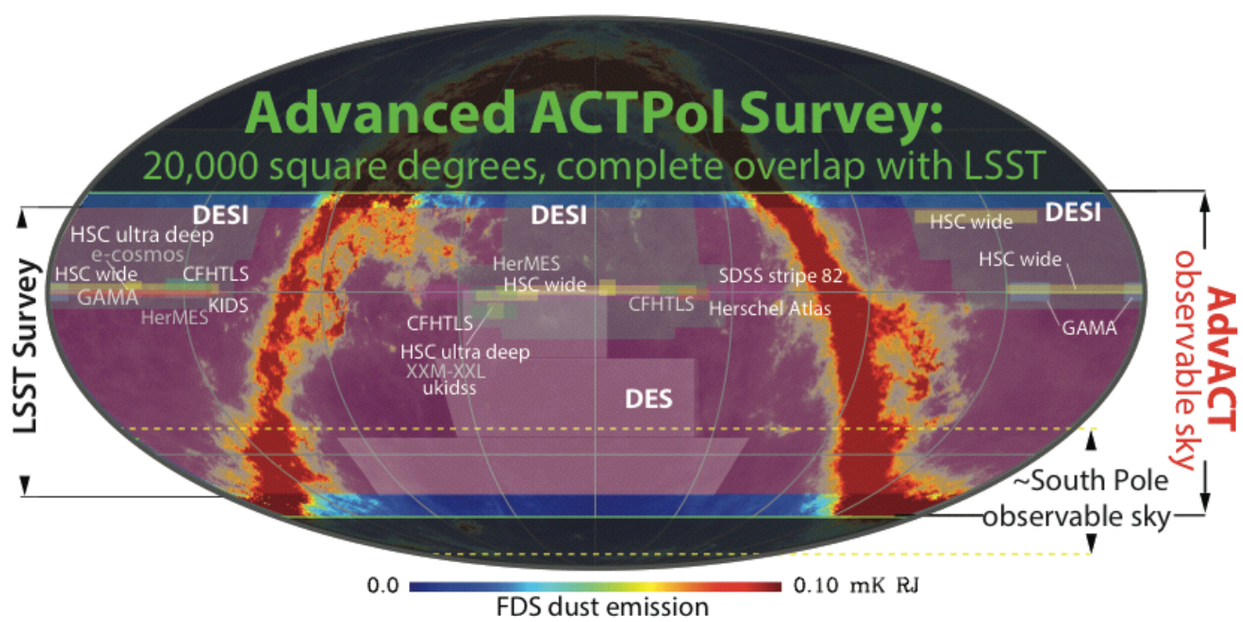
~14 M Galaxies

~10000 sq. deg

kSZ scaled C_{ij}

tSZ CMB subtraction

Summary

Cross correlations with CMB secondaries are great tools for: Constraining astrophysics & cosmology

Looking forward CMB secondaries is already a data-rich field and is only going to grow