Mapping the Hot Gas in the Universe

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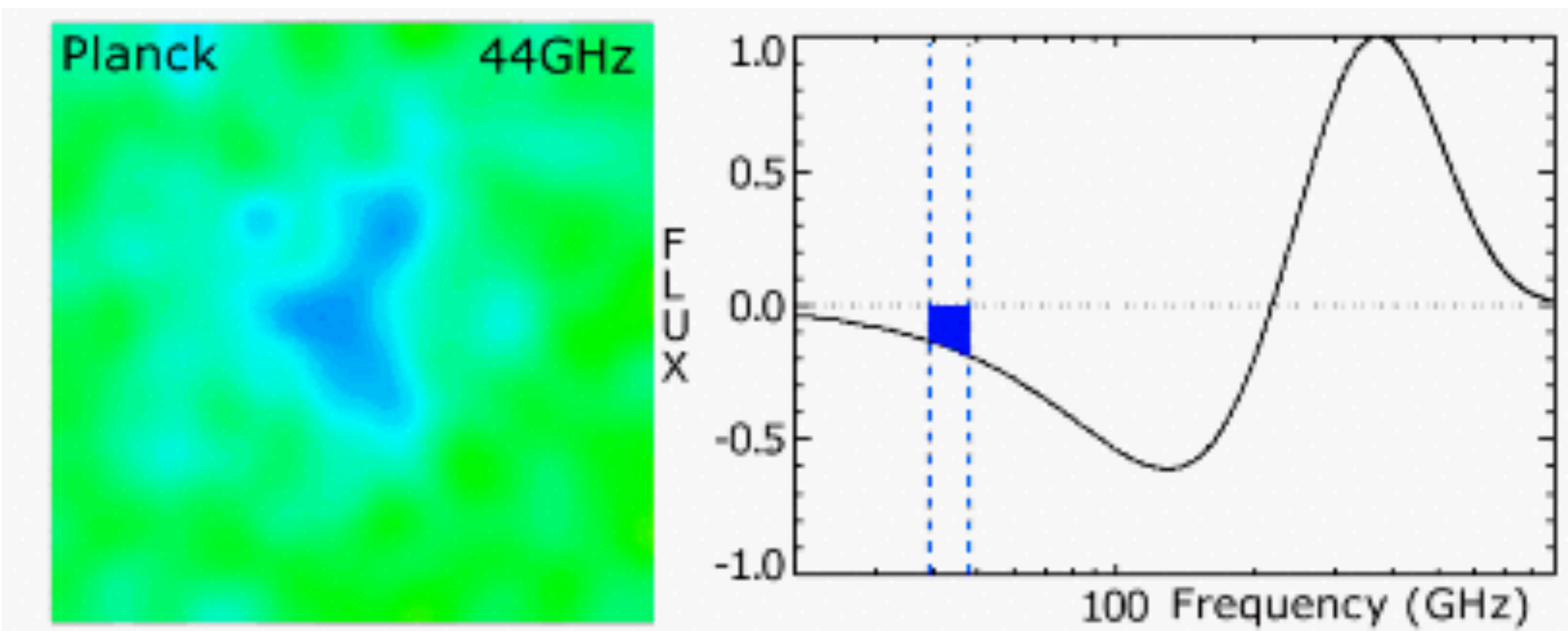
Thermal SZ (tSZ) Effect

- Thermal SZ effect (in the non-relativistic limit) enables us to map thermal pressure in the universe

$$Y_{\mathrm{tSZ}}(\boldsymbol{\theta}) = \frac{k_B \sigma_T}{m_e c^2} \int \mathrm{d}l \, n_e(\boldsymbol{\theta}, l) \, T(\boldsymbol{\theta}, l)$$

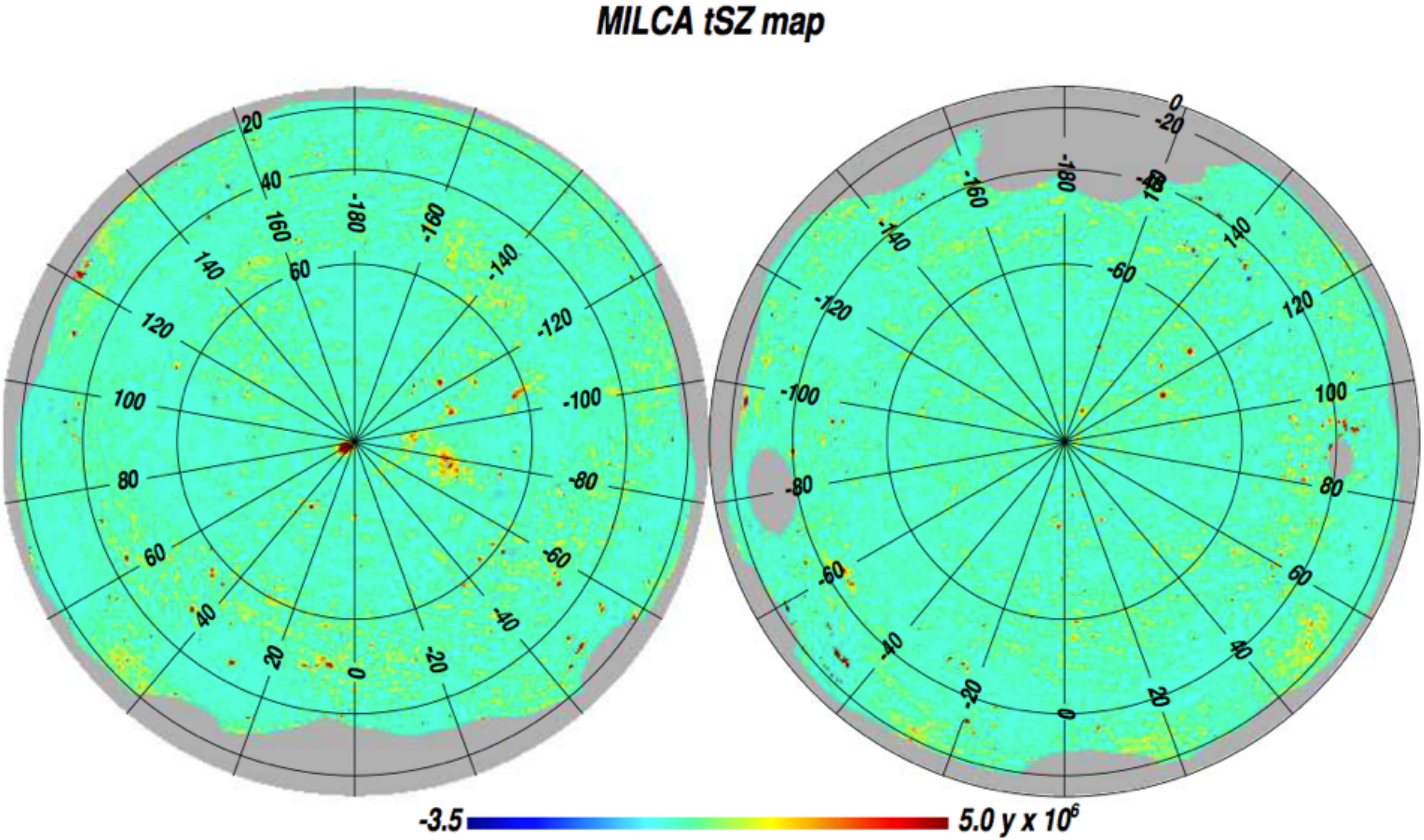
Thermal SZ (tSZ) Effect

- The unique frequency dependence of tSZ: we can make a map of Y_{tSZ}



Planck Collaboration

Compton Y from Planck



- Planck did a great job!

We can simulate this

arXiv:1509.05134

SZ effects in the Magneticum Pathfinder Simulation: Comparison with the Planck, SPT, and ACT results

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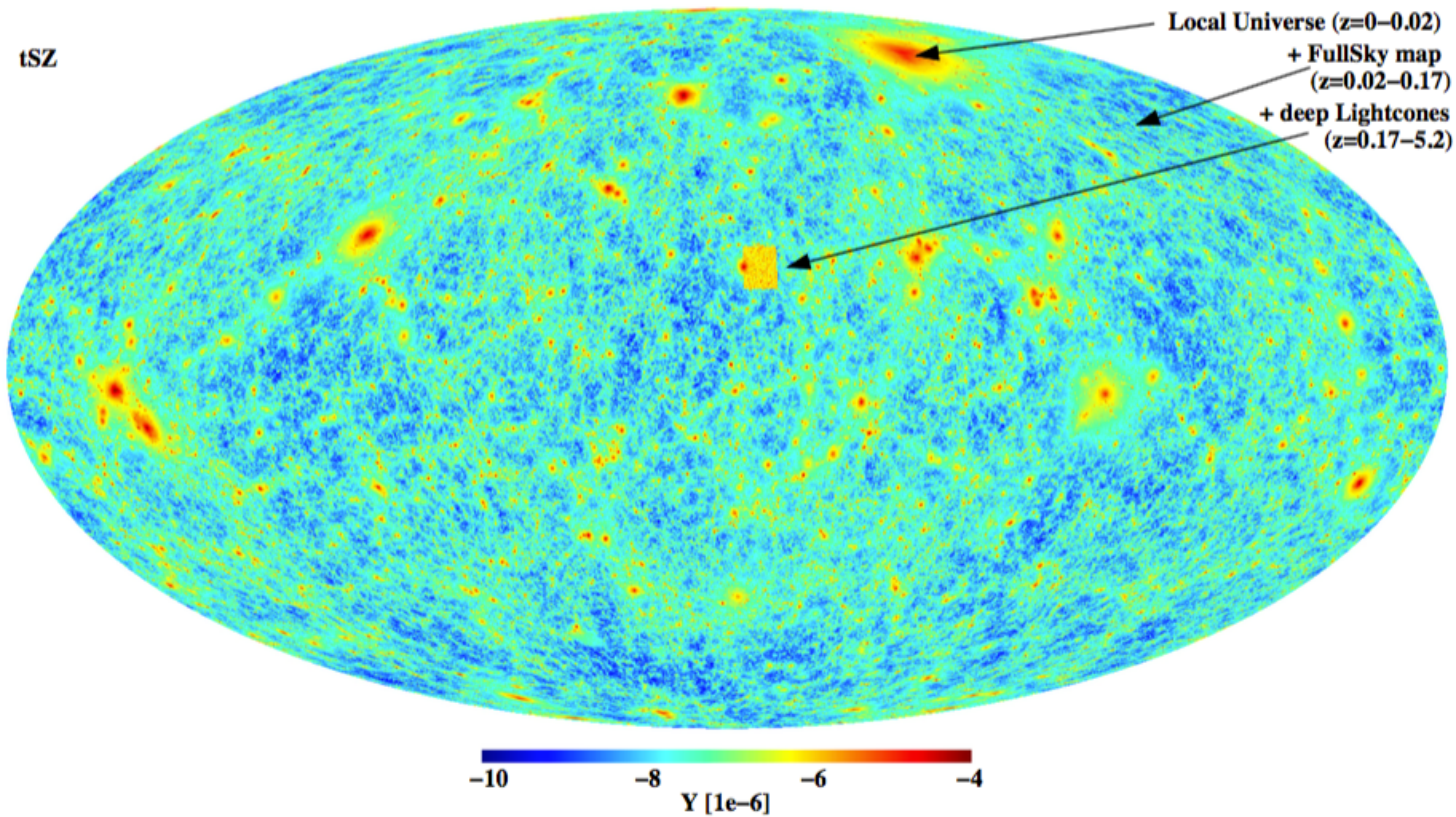
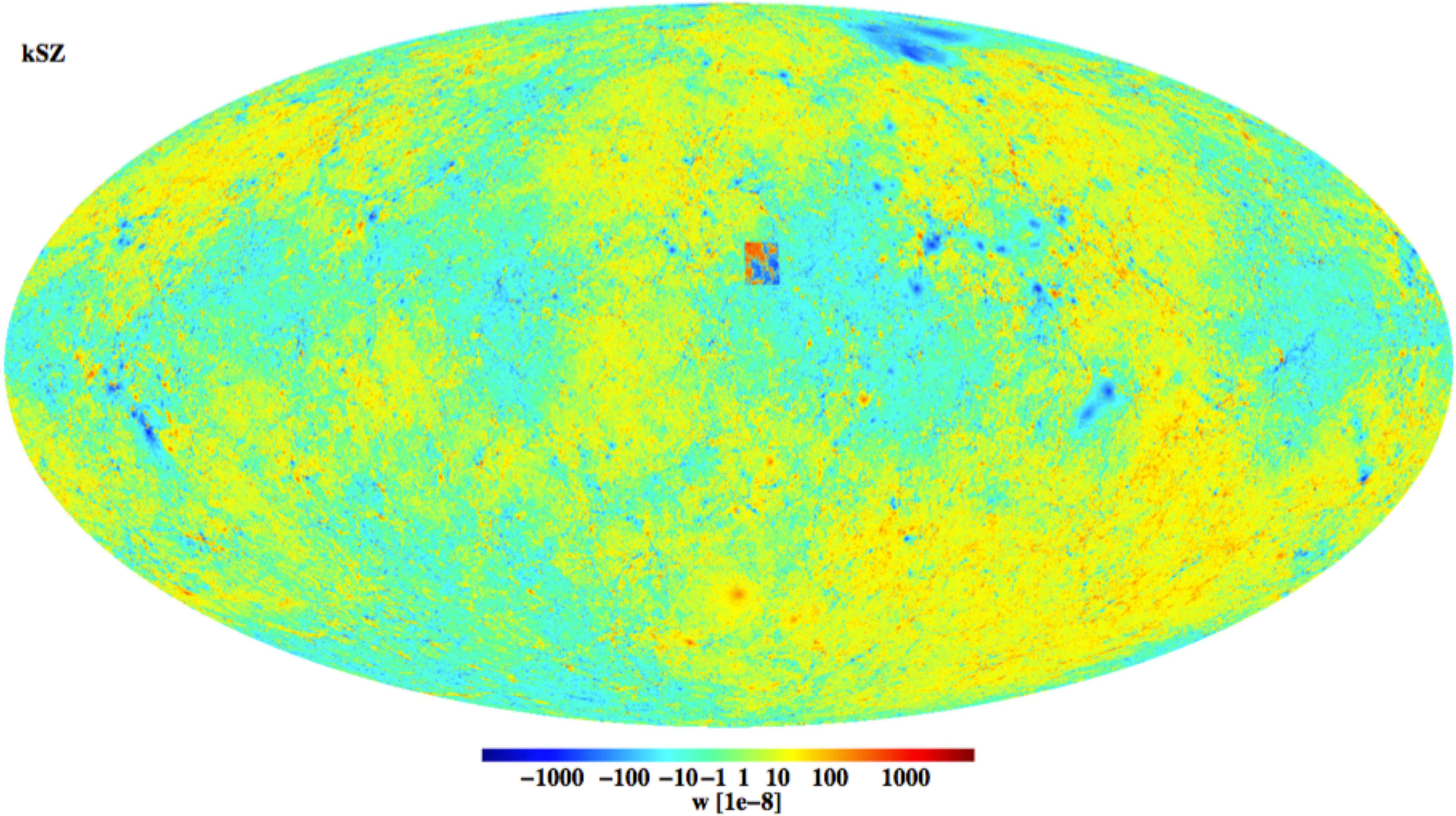
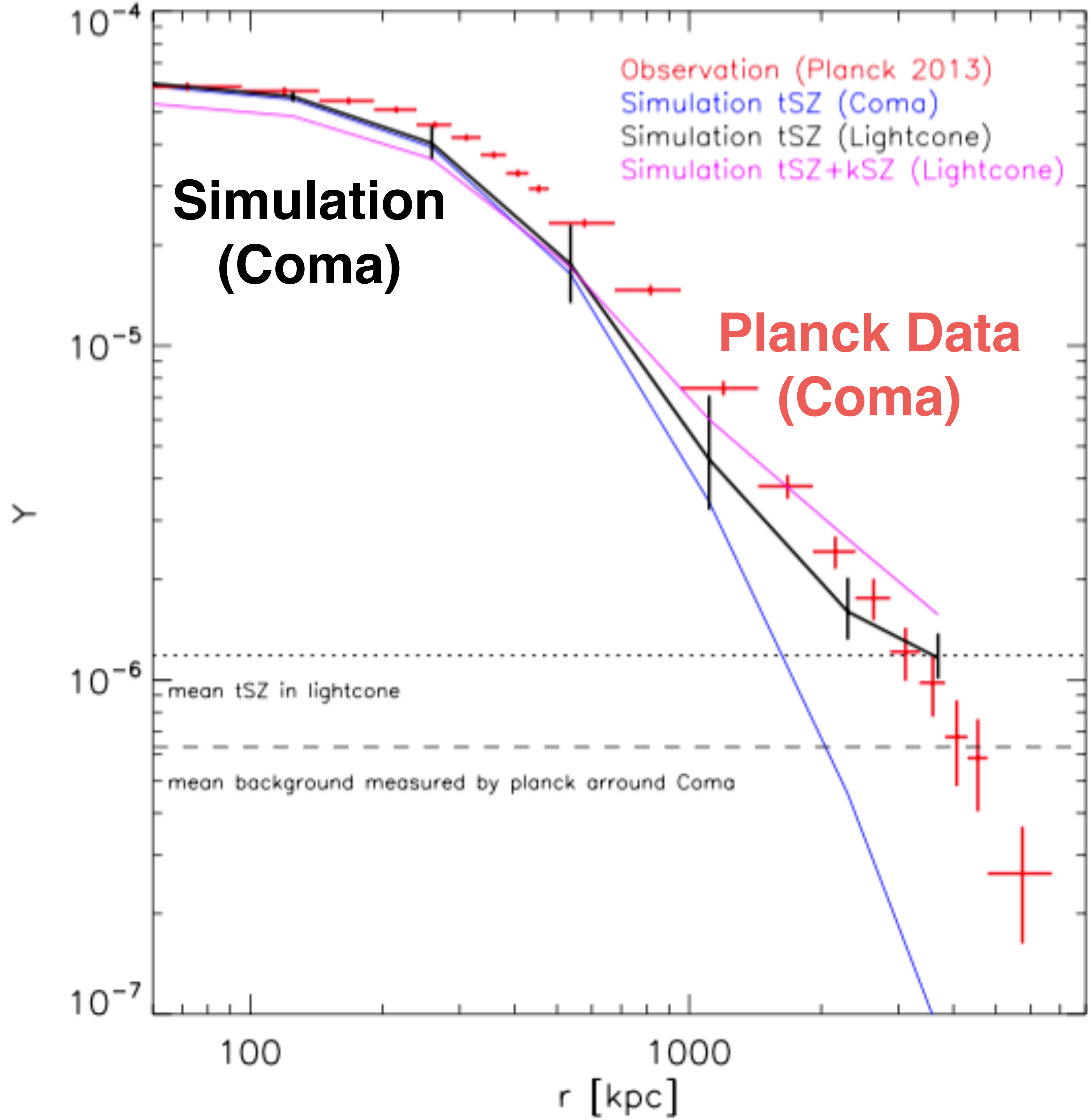
- Volume: $(896\ \mathrm{Mpc/h})^3$
- Cosmological hydro (P-GADGET3) with star formation and AGN feed back
- 2 x 1526^3 particles ($m_{DM}=7.5\times10^8\ M_{sun}/h$)



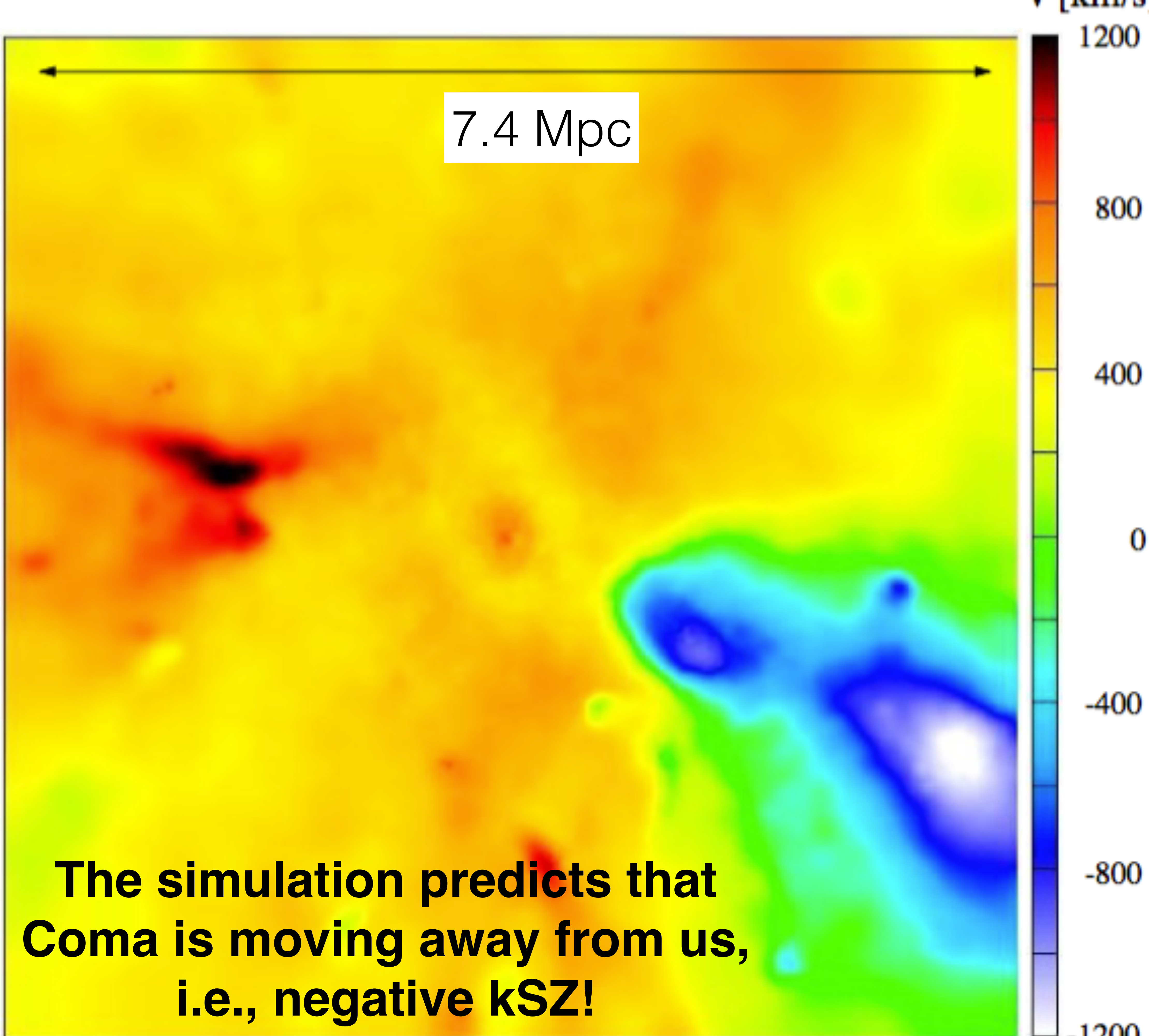
$$Y_{\mathrm{tSZ}}(\boldsymbol{\theta}) = \frac{k_B \sigma_T}{m_e c^2} \int \mathrm{d}l \, n_e(\boldsymbol{\theta}, l) \, T(\boldsymbol{\theta}, l)$$

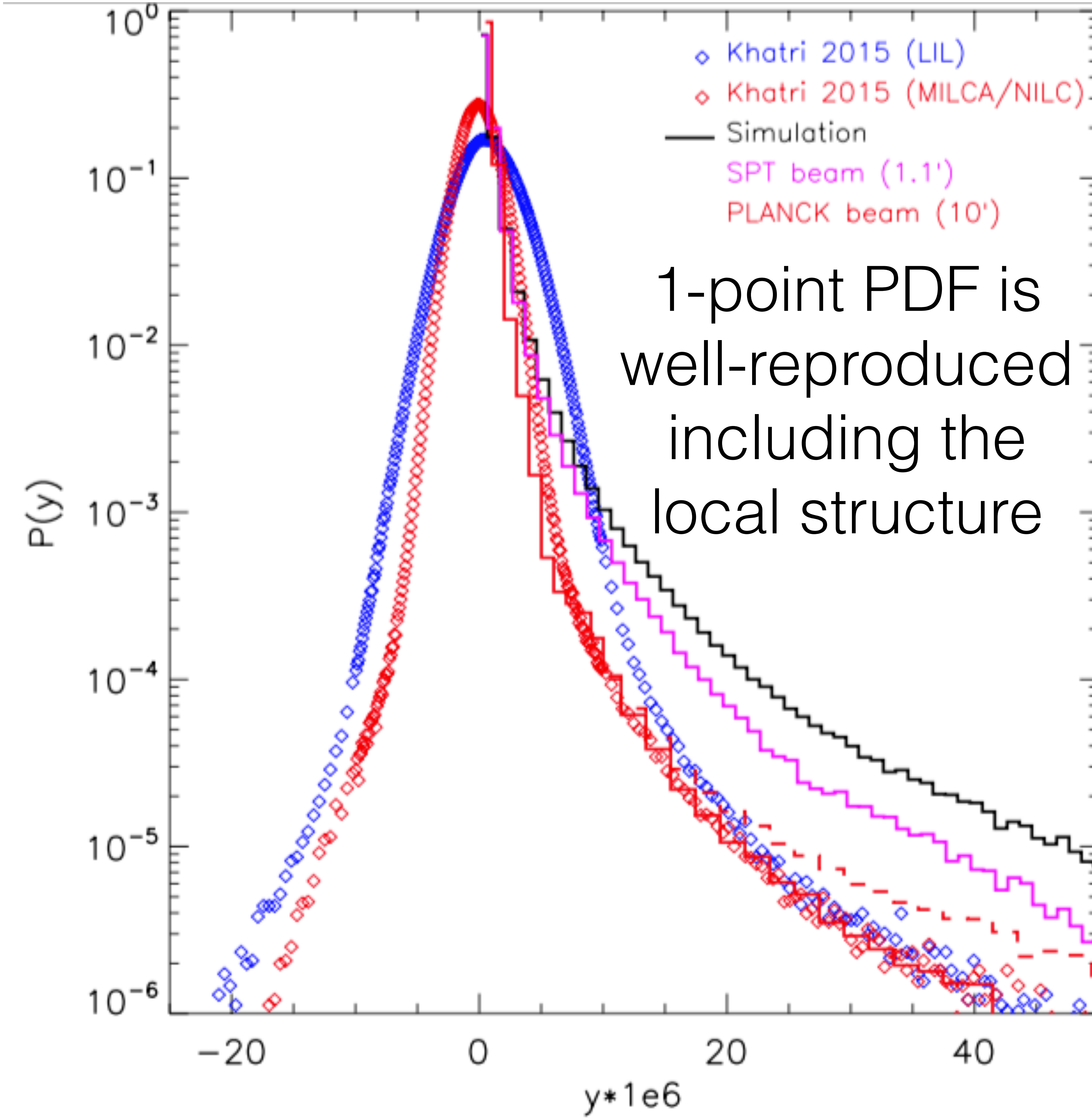


$$w_{\rm kSZ}(\boldsymbol{\theta}) \equiv \frac{\delta T_{\rm kSZ}}{T_{\rm cmb}} = -\frac{\sigma_T}{c}\int {\rm d}l\, n_e(\boldsymbol{\theta},l)\, v_r(\boldsymbol{\theta},l)$$

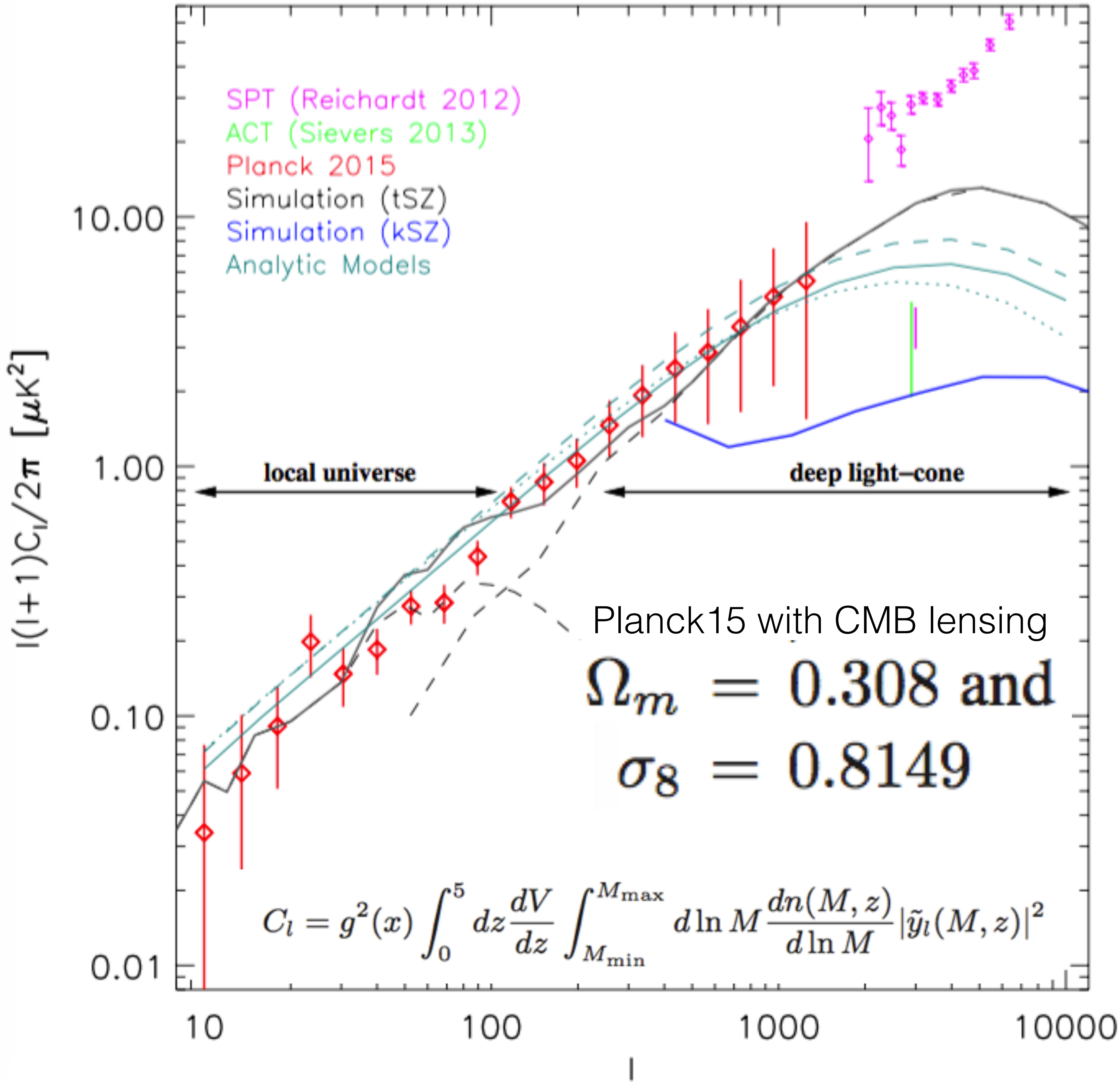


Observation (Planck 2013)
Simulation tSZ (Coma)
Simulation tSZ (Lightcone)
Simulation tSZ+kSZ (Lightcone)
Simulation (Coma)
Planck Data (Coma)
mean tSZ in lightcone
mean background measured by planck arround Coma
Y
r [kpc]


7.4 Mpc
1200
800
400
0
-400
-800
-1200
The simulation predicts that
Coma is moving away from us,
i.e., negative kSZ!

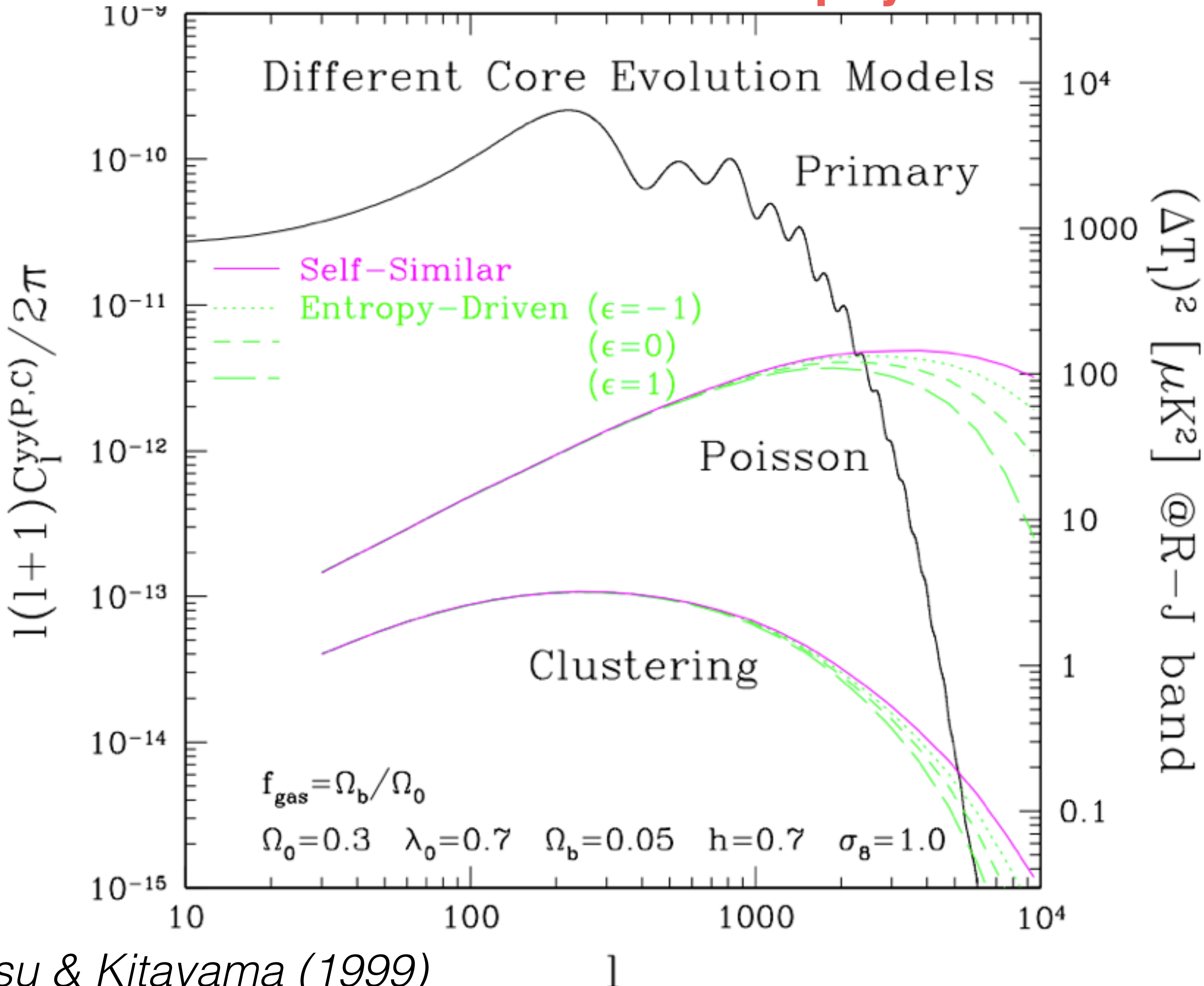


1-point PDF is well-reproduced including the local structure



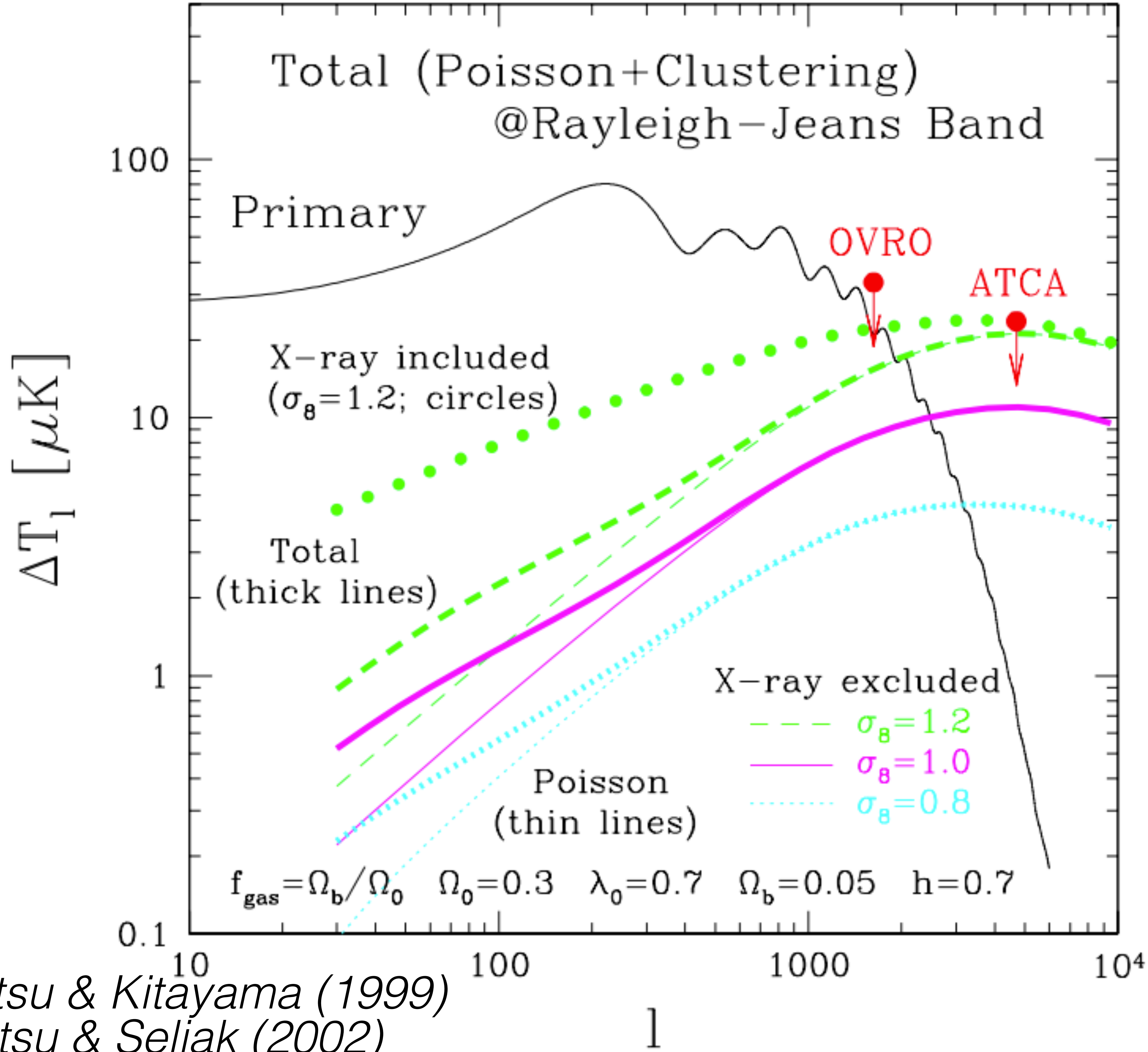
SPT (Reichardt 2012)
ACT (Sievers 2013)
Planck 2015
Simulation (tSZ)
Simulation (kSZ)
Analytic Models
local universe
deep light–cone
Planck15 with CMB lensing
$\Omega_m = 0.308$ and
$\sigma_8 = 0.8149$
$C_l = g^2(x) \int_0^5 dz \frac{dV}{dz} \int_{M_{\min}}^{M_{\max}} d\ln M \frac{dn(M,z)}{d\ln M} |\tilde{y}_l(M,z)|^2$
$l(l+1)C_l/2\pi$ [μK^2]
10.00
1.00
0.10
0.01
10
100
1000
10000
l

Degree-scale Compton Y power spectrum is less sensitive to astrophysics

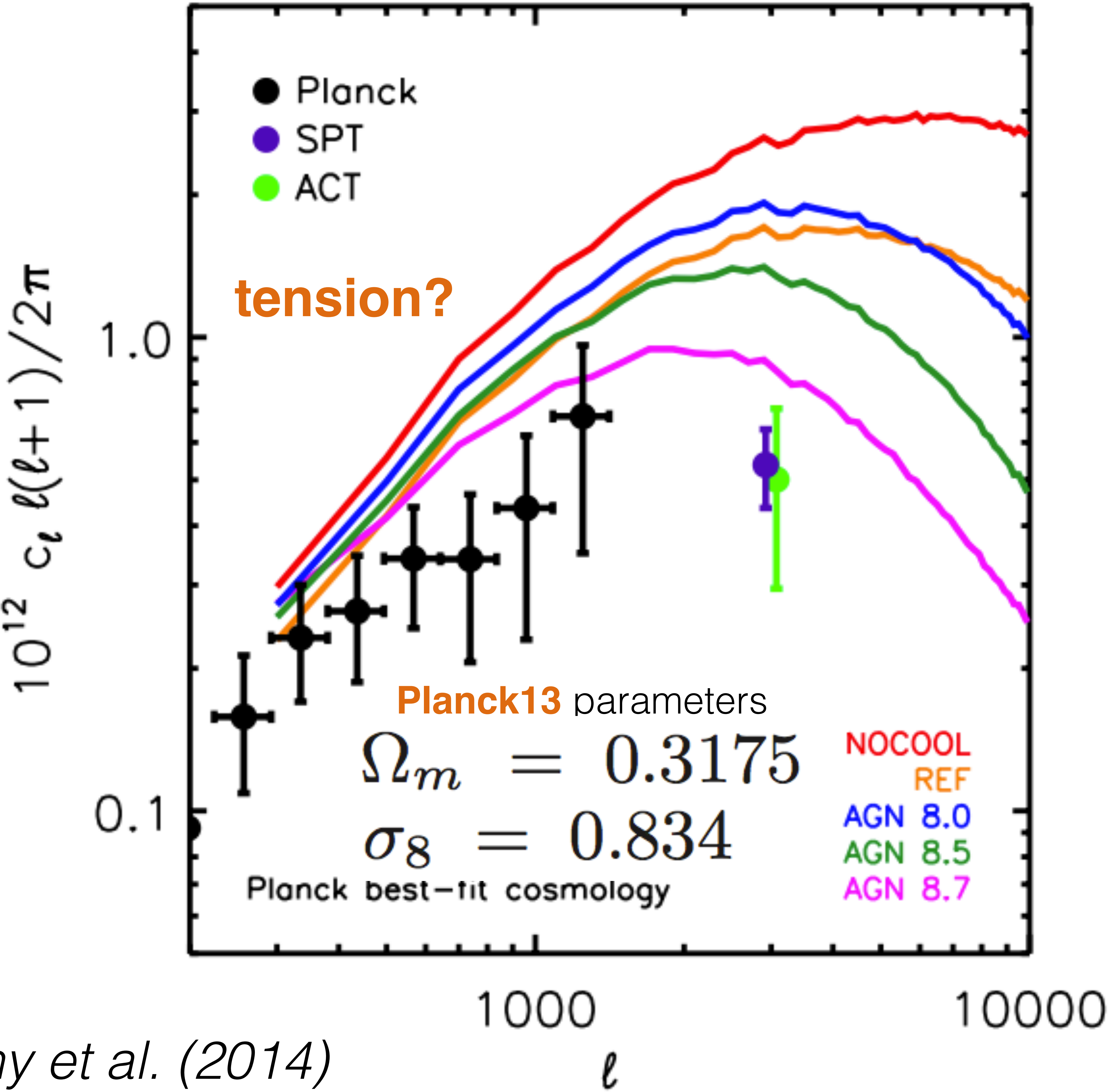


Komatsu & Kitayama (1999)

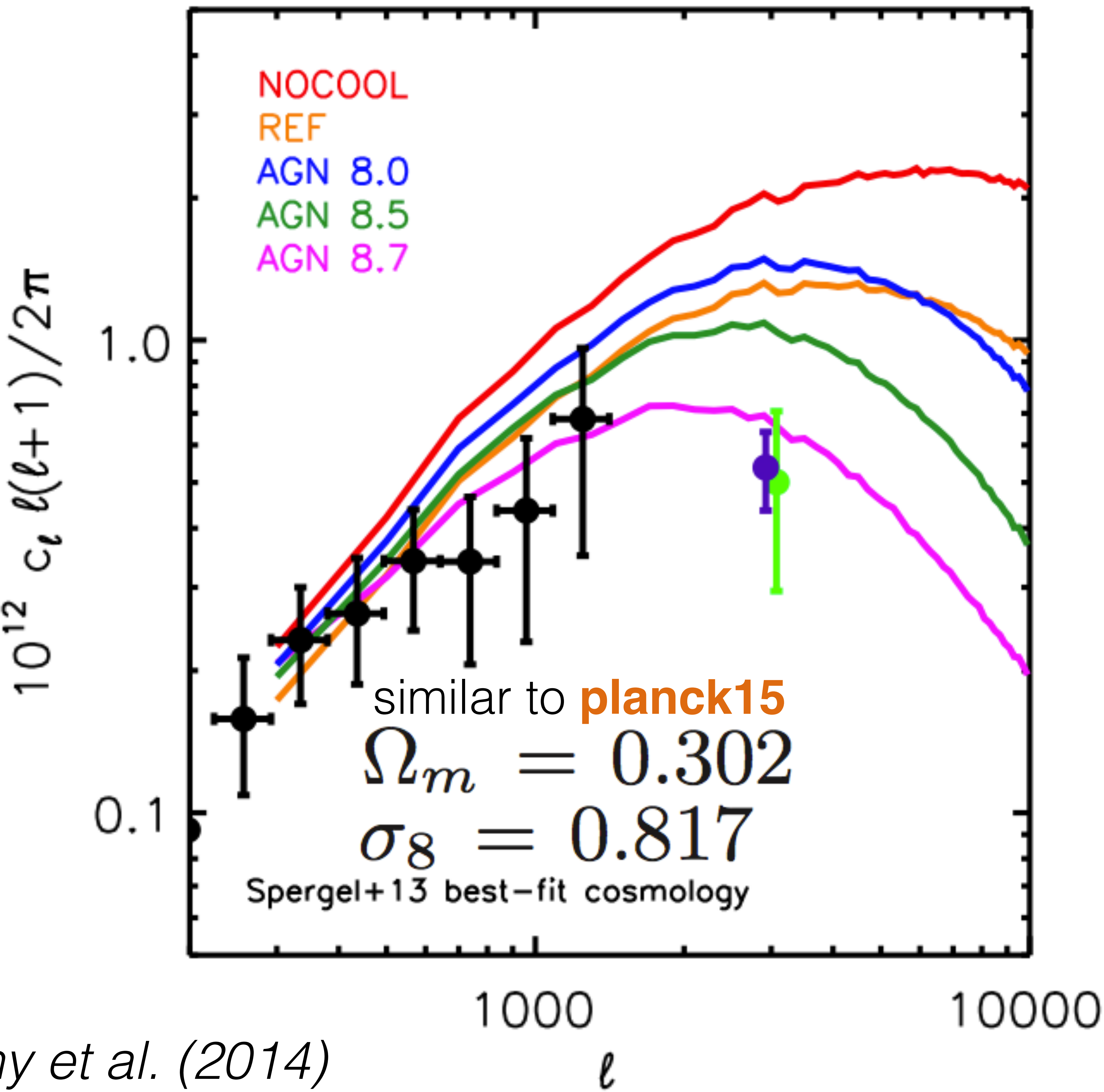
It is very sensitive to the amplitude of fluctuations



Komatsu & Kitayama (1999)
Komatsu & Seljak (2002)



McCarthy et al. (2014)



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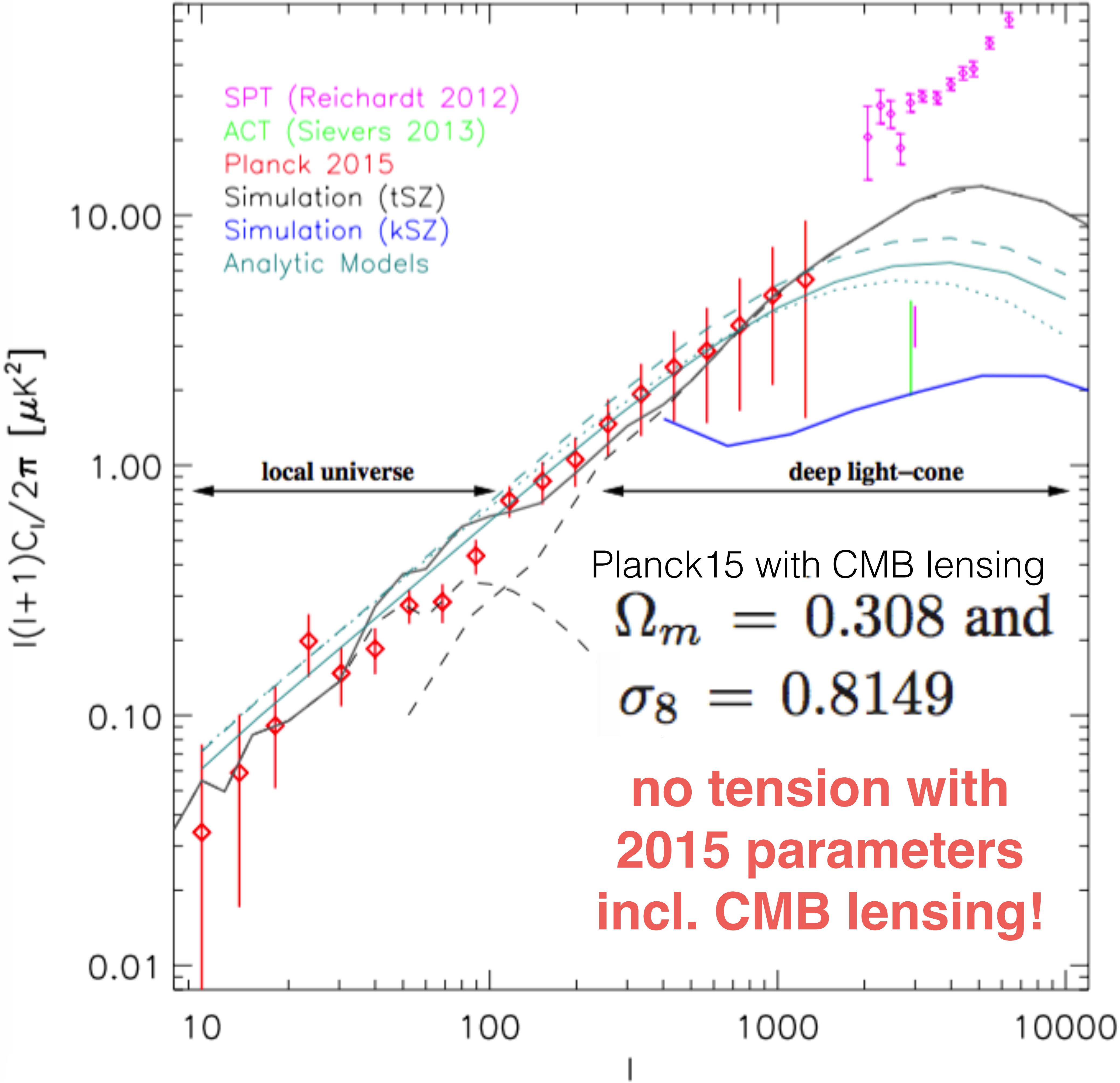
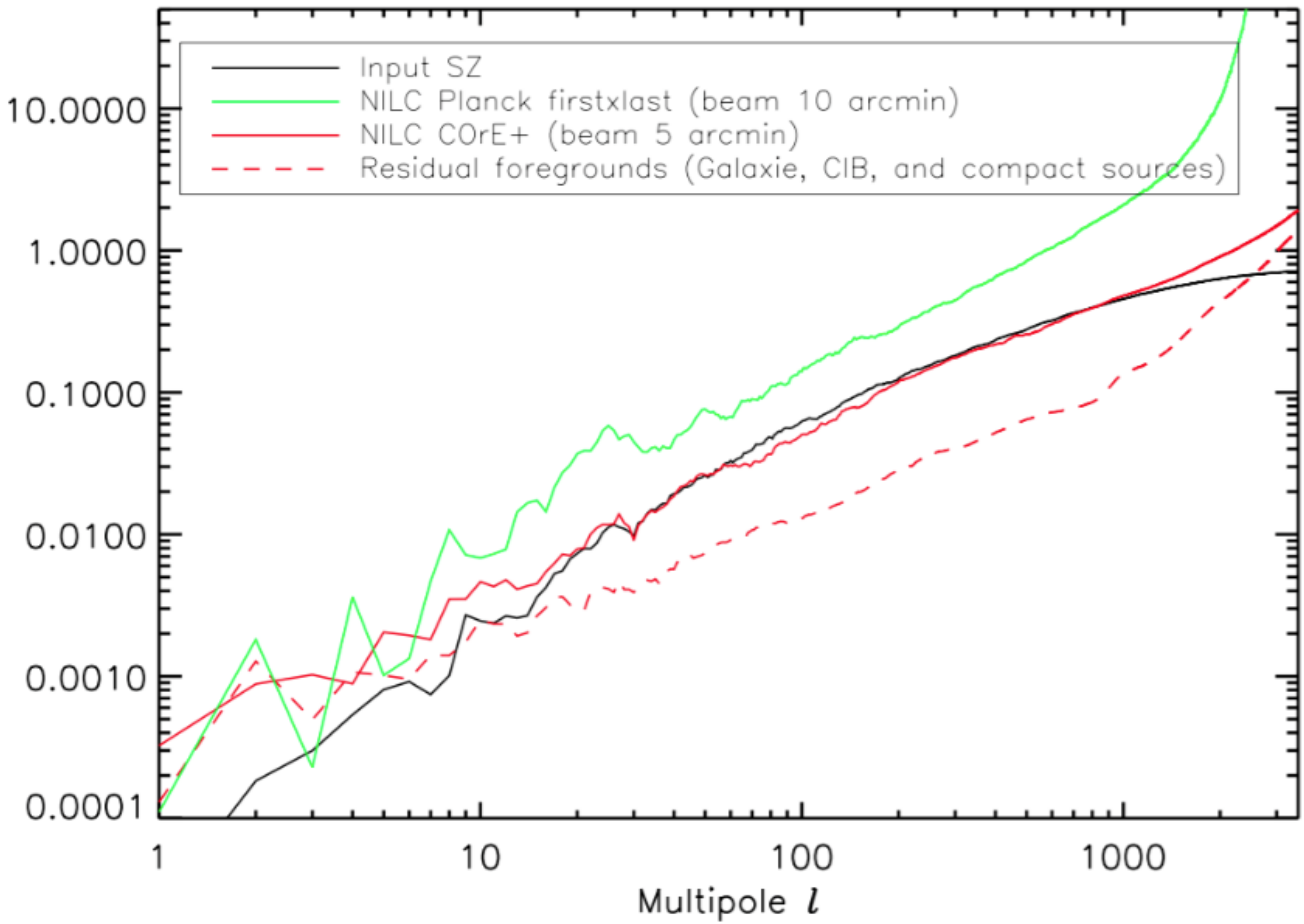


Planck15 with CMB lensing

$$\Omega_m = 0.308 \text{ and}$$
$$\sigma_8 = 0.8149$$

no tension with 2015 parameters incl. CMB lensing!

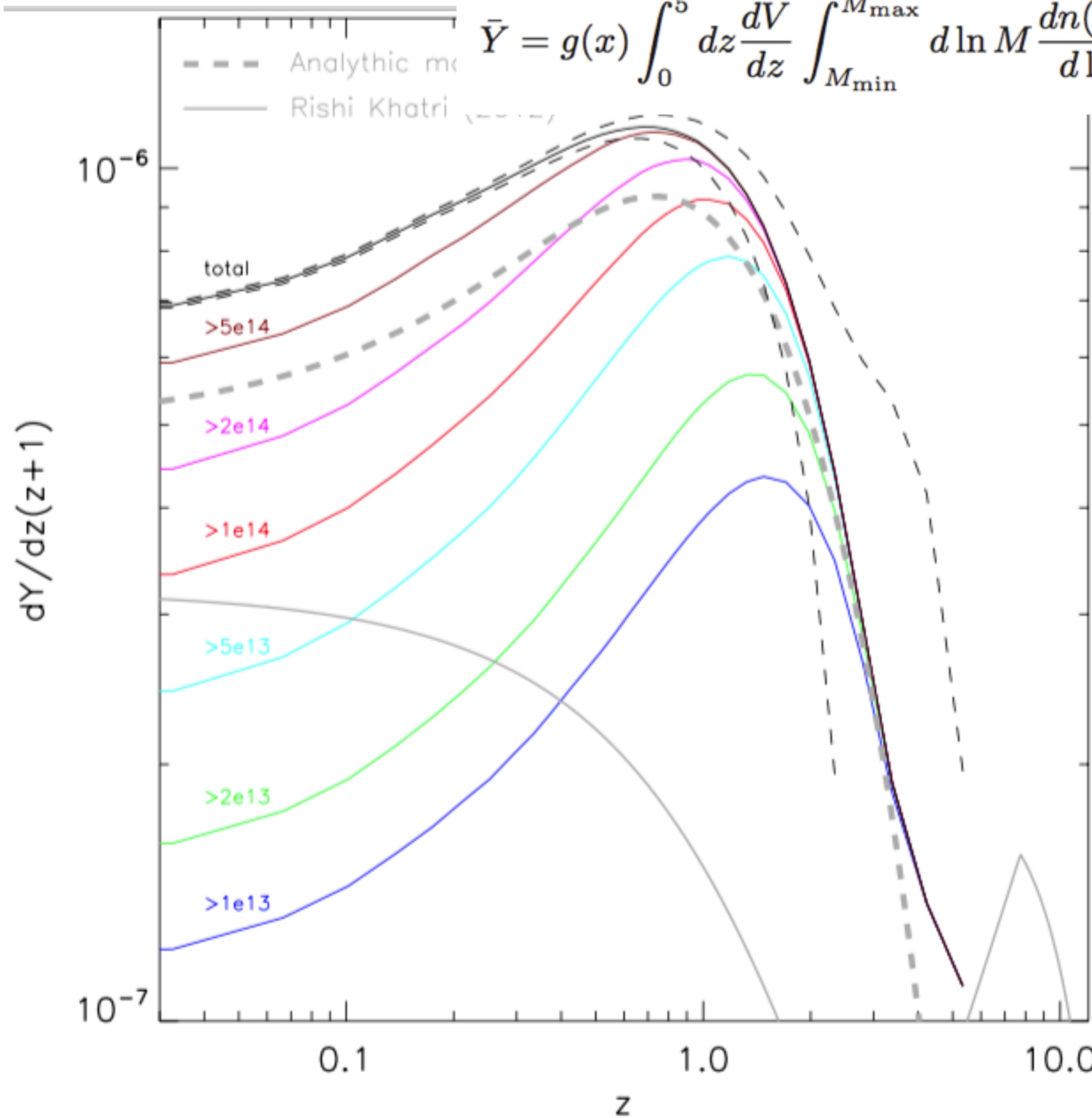
COrE+ improves fidelity



Mean Y

- The sky-averaged fluctuating component of the Compton Y measures the total thermal energy content of the universe
    - Seems like a fundamental quantity that we should know!
    - Planck is not sensitive to the uniform component of Y, but the fluctuating component can still be constrained

$$\bar{Y} = g(x) \int_0^5 dz \frac{dV}{dz} \int_{M_{\min}}^{M_{\max}} d\ln M \, \frac{dn(M,z)}{d\ln M} \tilde{y}_0(M,z)$$



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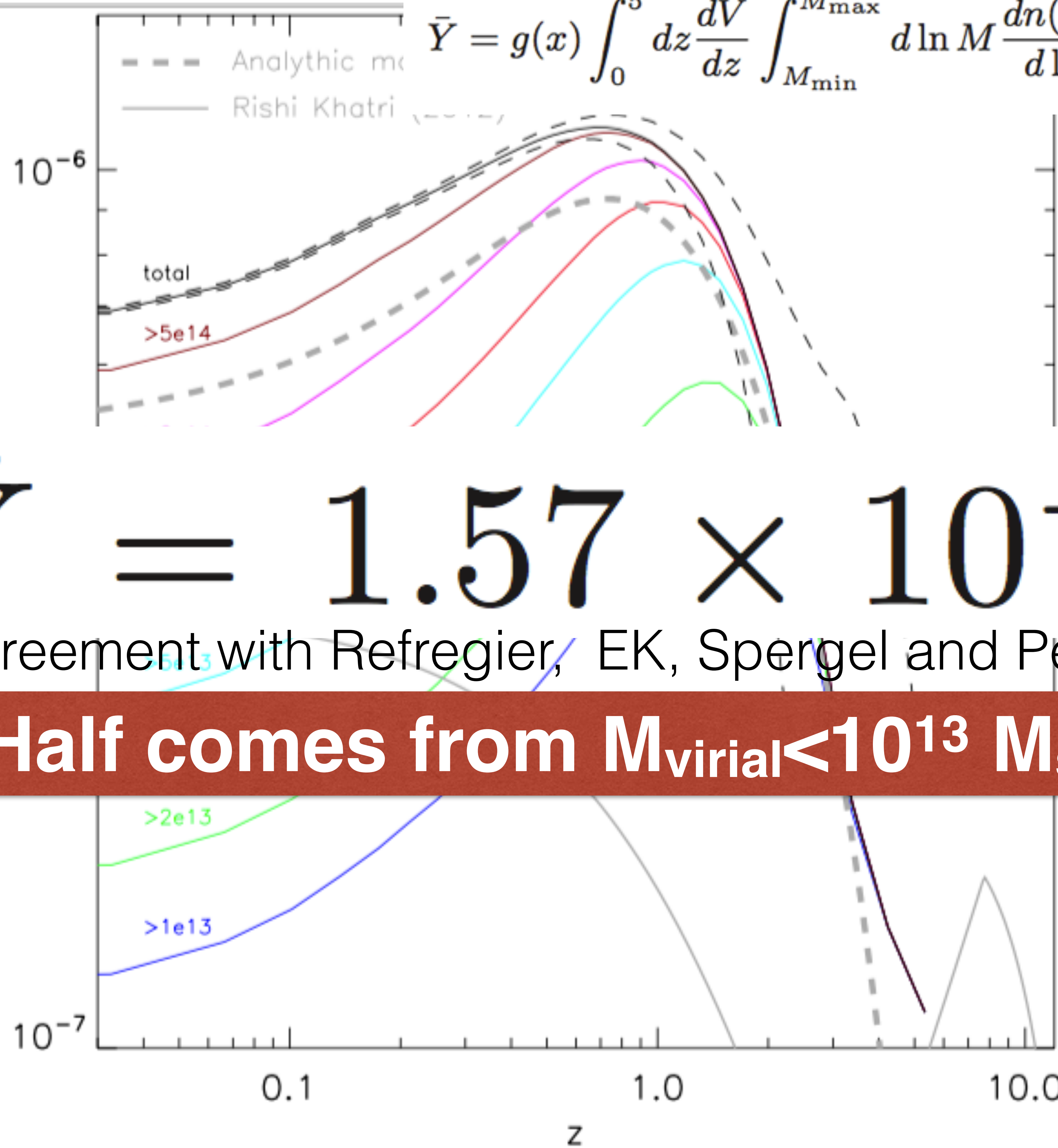
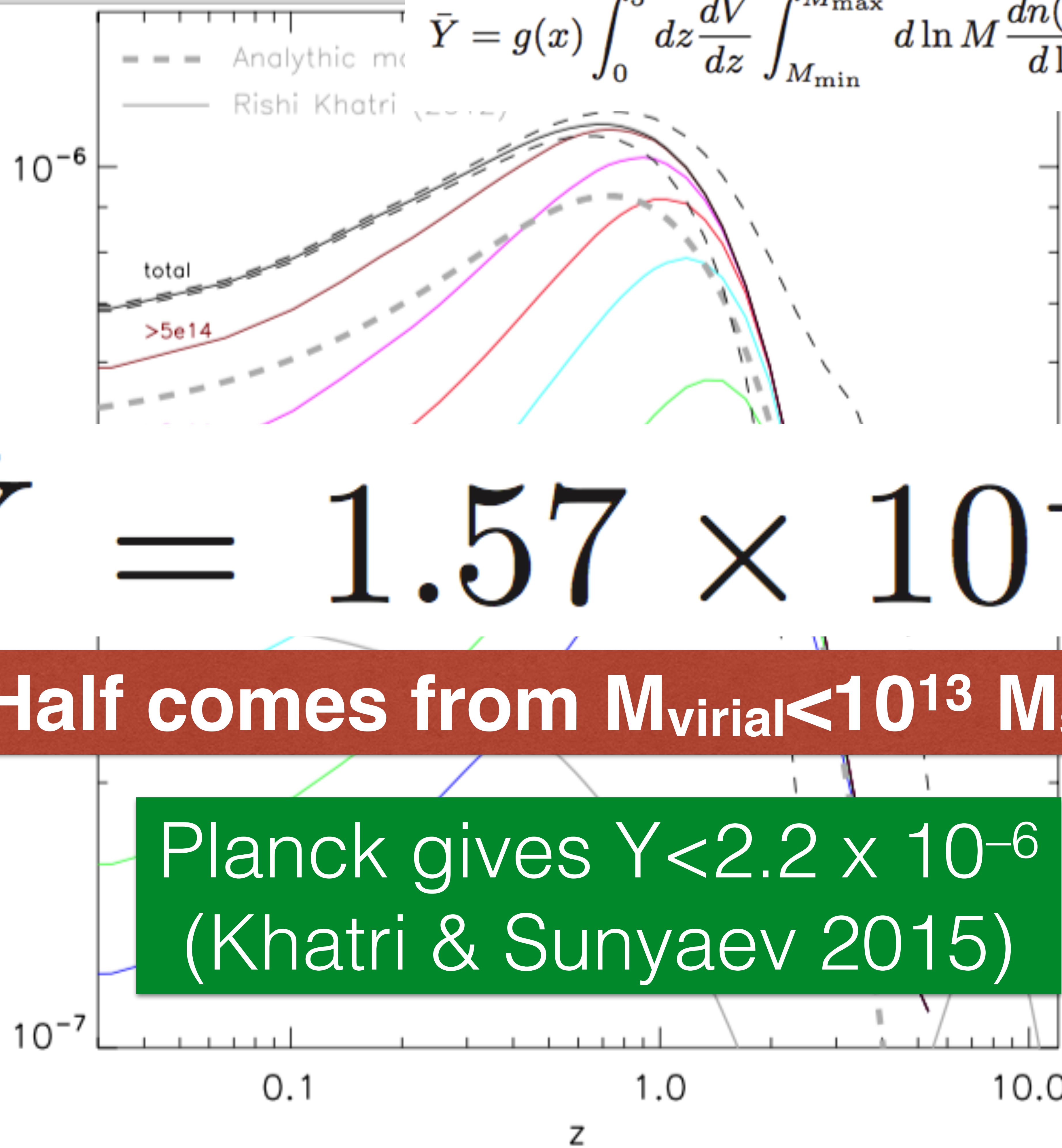


$$\bar{Y} = 1.57 \times 10^{-6}$$

in agreement with Refregier, EK, Spergel and Pen (2000)

Half comes from $M_{virial} < 10^{13}$ M_{sun}/h

$$\bar{Y} = g(x)\int_0^5 dz\,\frac{dV}{dz}\int_{M_{\rm min}}^{M_{\rm max}} d\ln M\,\frac{dn(M,z)}{d\ln M}\tilde{y}_0(M,z)$$

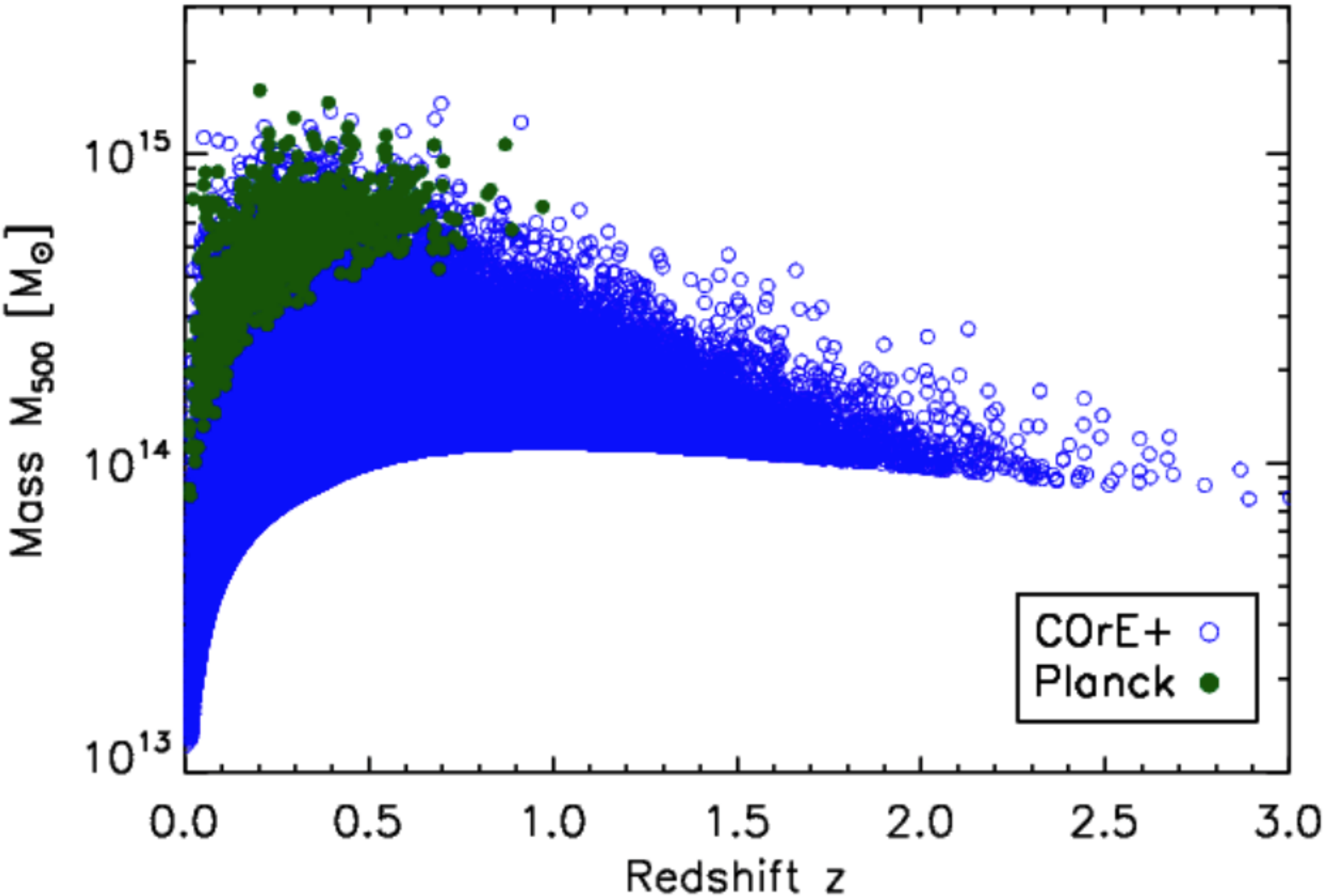


$$\bar{Y} = 1.57\times 10^{-6}$$

Half comes from $M_{virial}<10^{13}\ M_{sun}/h$

Planck gives $Y<2.2 \times 10^{-6}$
(Khatri & Sunyaev 2015)

Y map gives us lots of clusters



Summary

- With tSZ, we are really mapping out all the hot gas in the universe
    - Statistical properties of the Compton Y map from the Planck data are reproduced in the simulation
    - **COrE+ can take this to the next level of fidelity - incredible legacy data set**
- With COrE+, we can find all massive ($M_{500}>10^{14}\ M_{sun}/h$) galaxy clusters out to high redshifts as long as they exist
- Other interesting science: relativistic correction to tSZ providing temperature; kSZ measurements