Relationship between the CMB, SZ cluster counts and local Hubble parameter measurements in a simple void model

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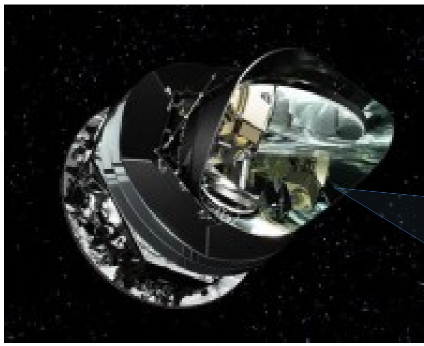
KI, C-M. Yoo and M. Oguri, PRD93, 2016

Outline

- Concordant cosmology in 2013 & 2016
  - Low density fluctuations and large Hubble parameter in the local universe
- Planck SZ and a simple void model
- MCMC analysis and results
- Summary and Conclusion

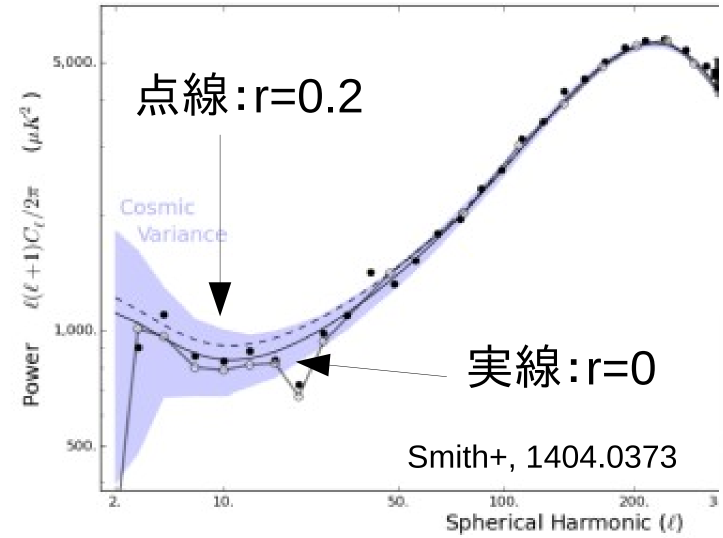
There were several tensions back in 2013

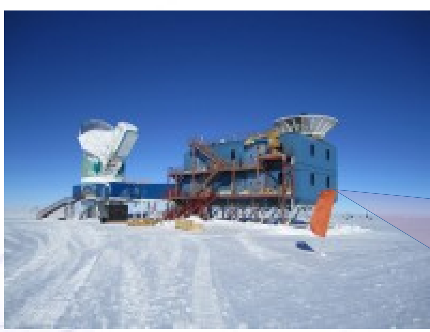
tension 1: r=0.2?



Planck衛星 2013

$$r \lesssim 0.11$$





BICEP2 2014

$$r = 0.2^{+0.07}_{-0.05}$$

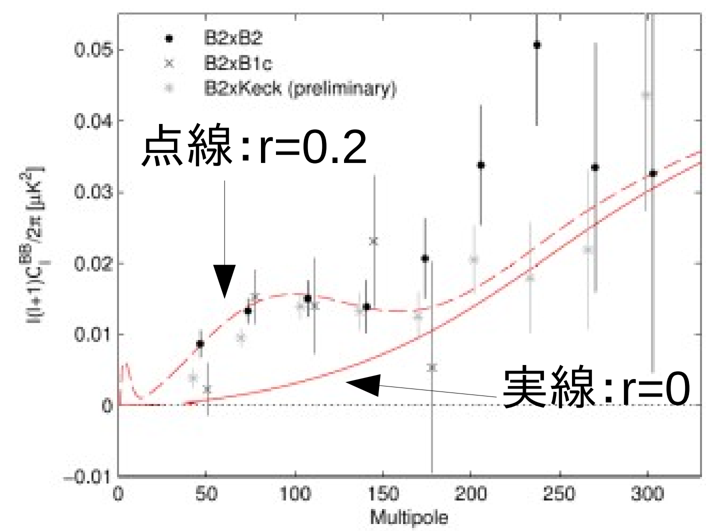
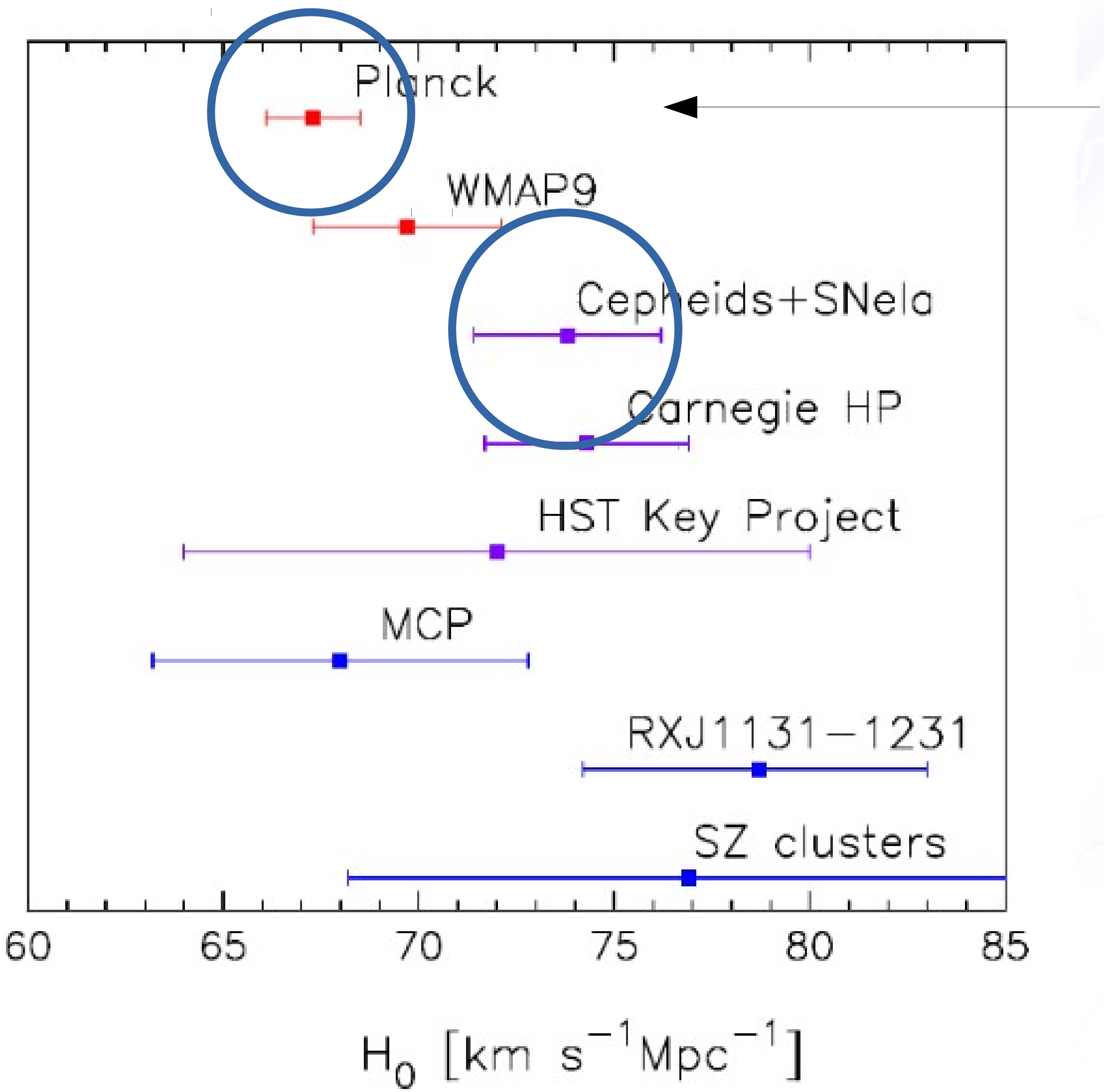


FIG. 9.— Comparison of the BICEP2 *BB* auto spectrum and cross spectra taken between BICEP2 and BICEP1 combined, and BICEP2 and *Keck Array* preliminary. (For clarity the cross spectrum points are offset horizontally and the BICEP2×BICEP1 points are omitted at $\ell > 200$.)

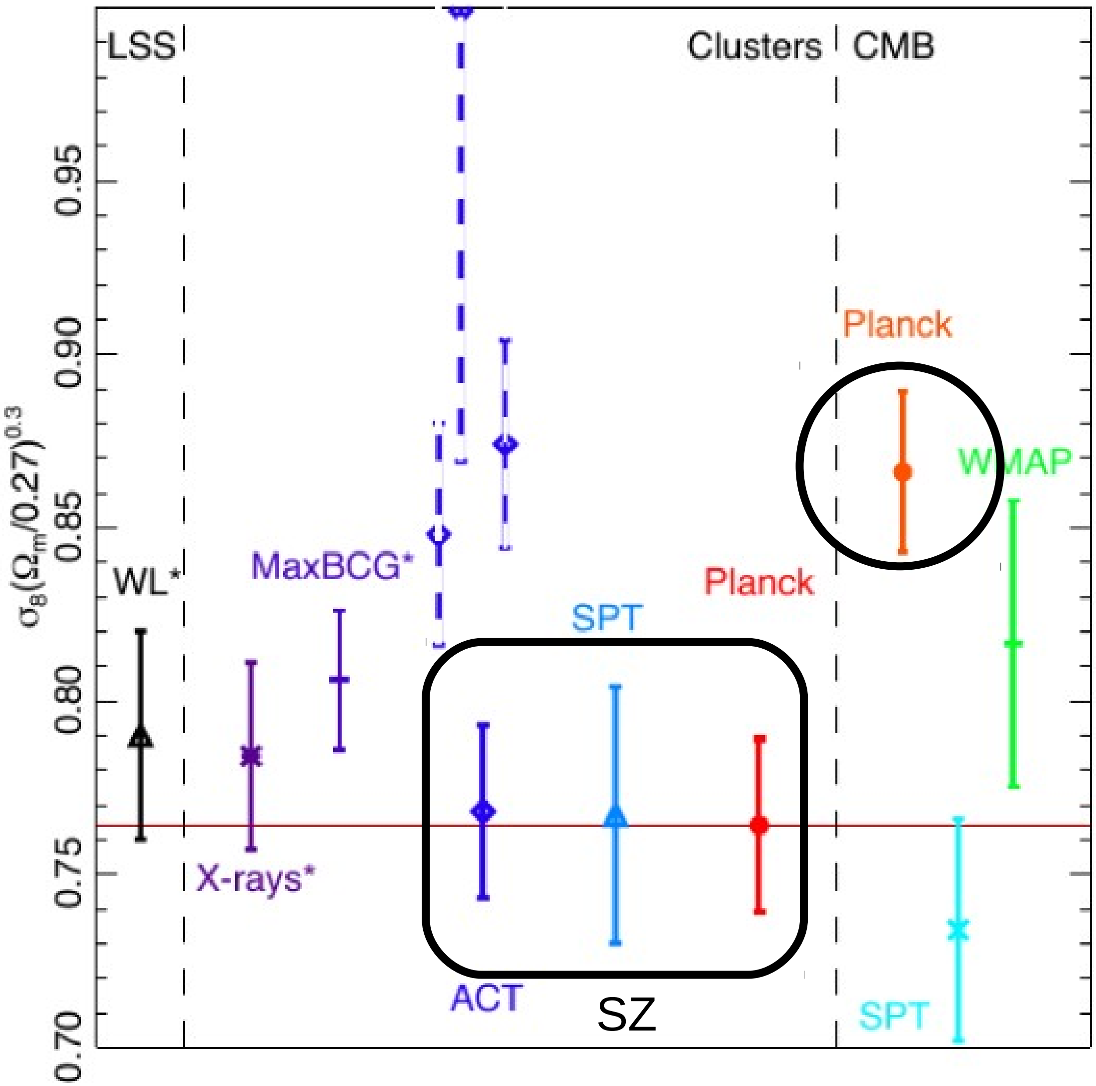
Tension 2: H_0 (Hubble)



Planck 2013 results

PLANCK CMB shows smaller H_0 values

Tension 3: σ_8



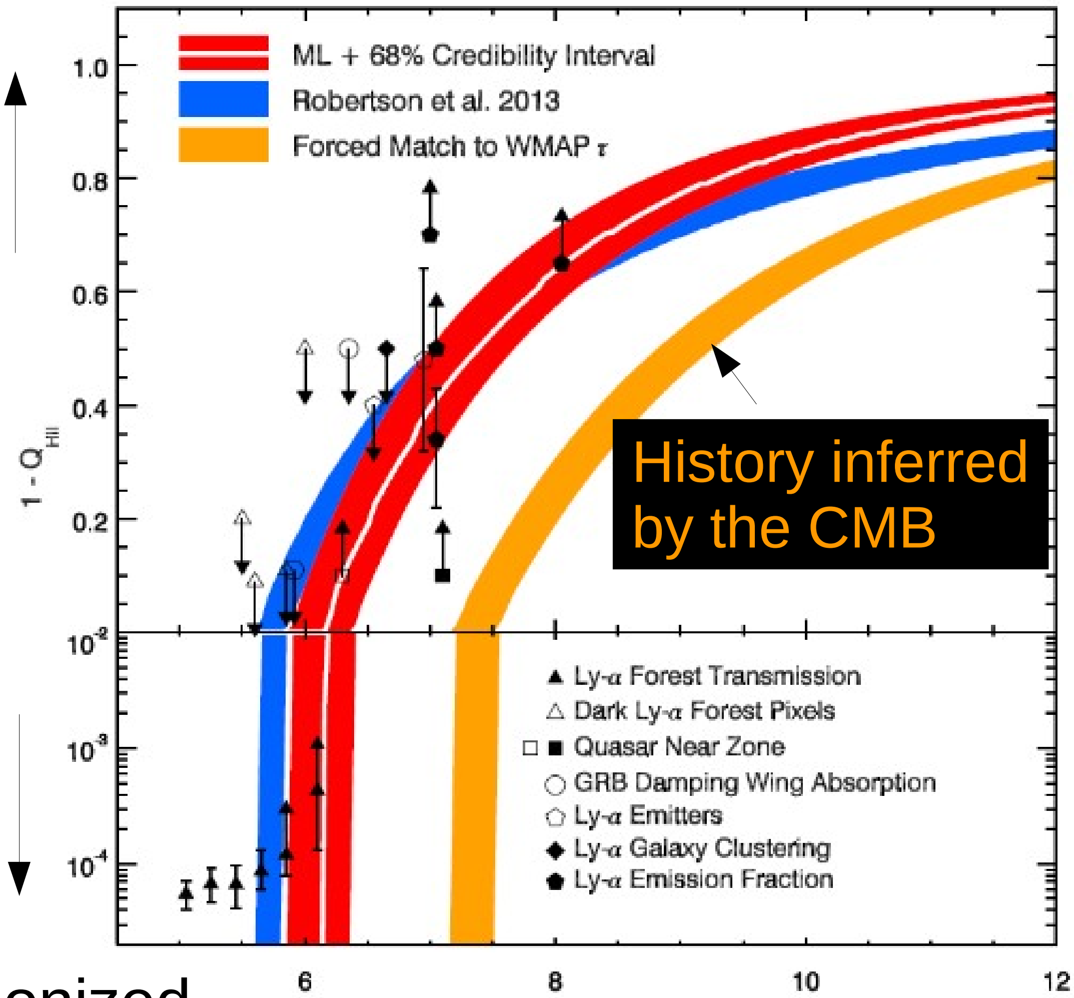
Planck 2013 results

σ_8: mass variance on $8h^{-1}$ Mpc scale

PLANCK CMB shows larger σ_8 values

tension 4: τ (reionization)

neutral



ionized

Redshift z

B. E. Robertson et al., arXiv:1502.02024

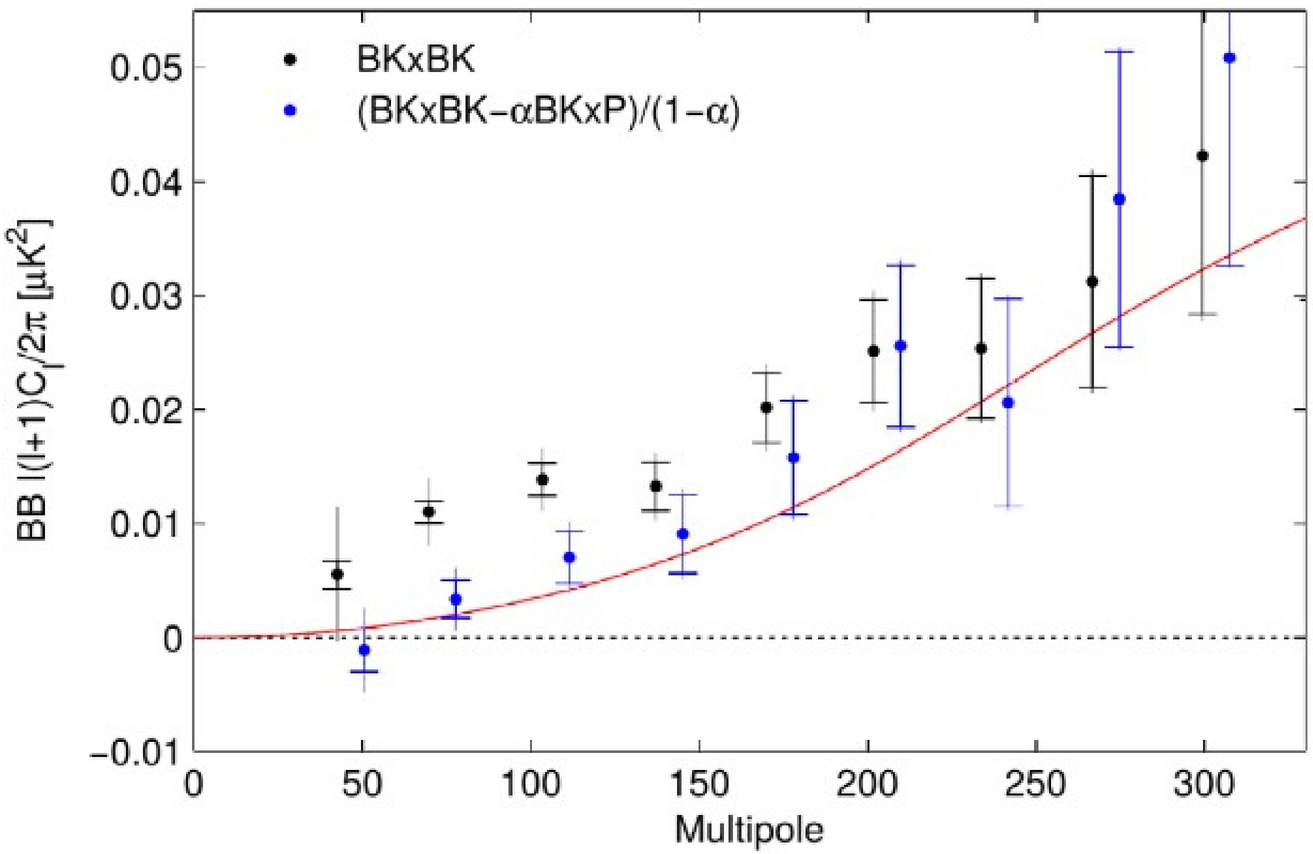
τ: optical depth to the CMB surface

Distant galaxies seem not to emit enough UV photons for the early reionization that CMB predicts

How does it go after PLANCK 2015 results ?

How does it go after 2015 ?

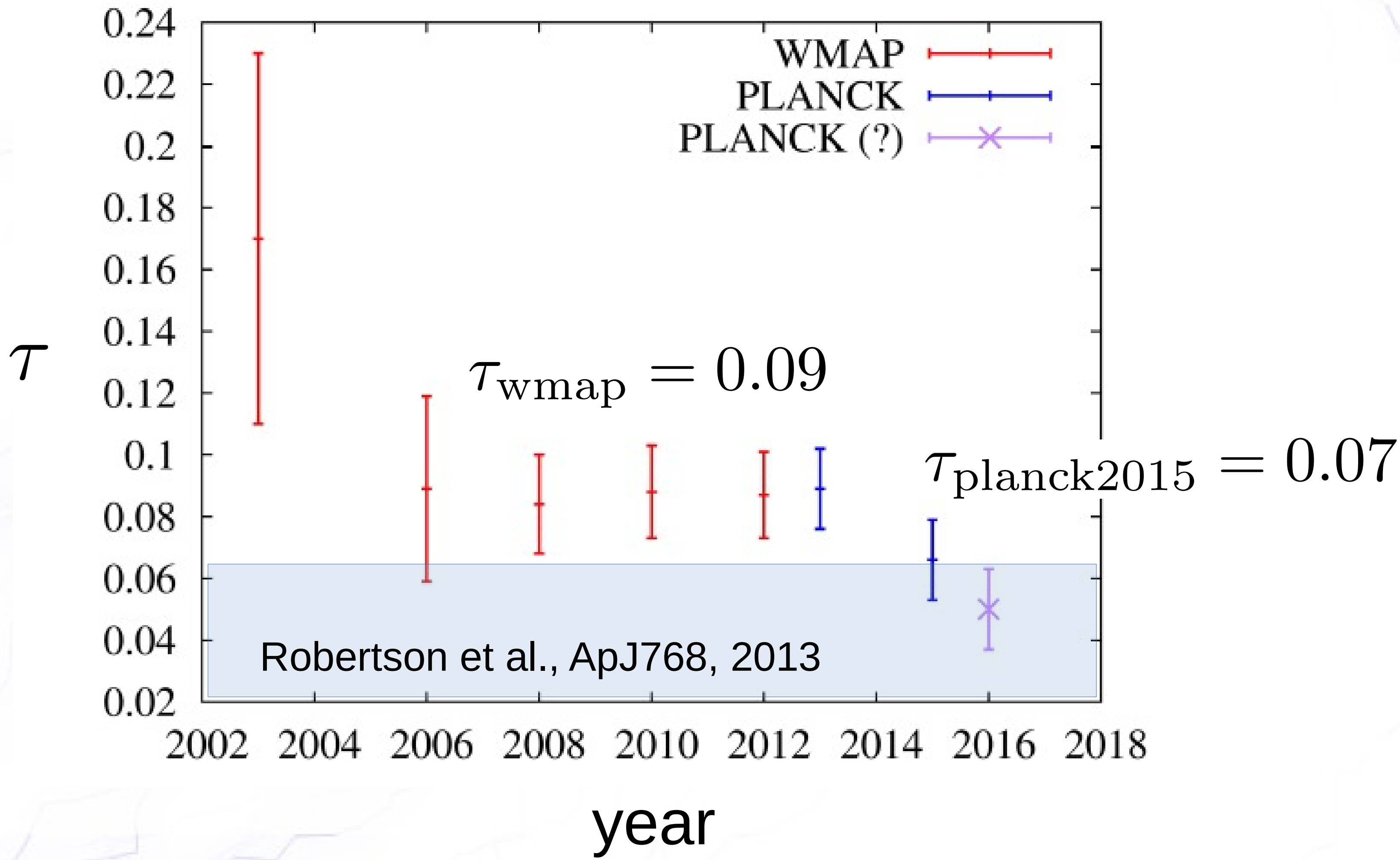
- **tension 1 (r) ... resolved (dust)**



Joint analysis of BICEP2/Keck & Planck; PRL114, 2015

How does it go after 2015 ?

- **tension 4 (τ) ... resolved (CMB was wrong)**



How does it go after 2015 ?

- **tension 2 (H_0)… marginally remains**
  - $H_0^{2013} = 67.3 \pm 1.2 \longrightarrow H_0^{2015} = 67.26 \pm 0.98$
  - **Efstathiou reanalysed Riess et al. data**

$$H_0^{\rm Riess} = 73.8 \pm 2.4 \longrightarrow$$

$$H_0 = 70.6 \pm 3.3$$

NGC 4258 (maser distance)

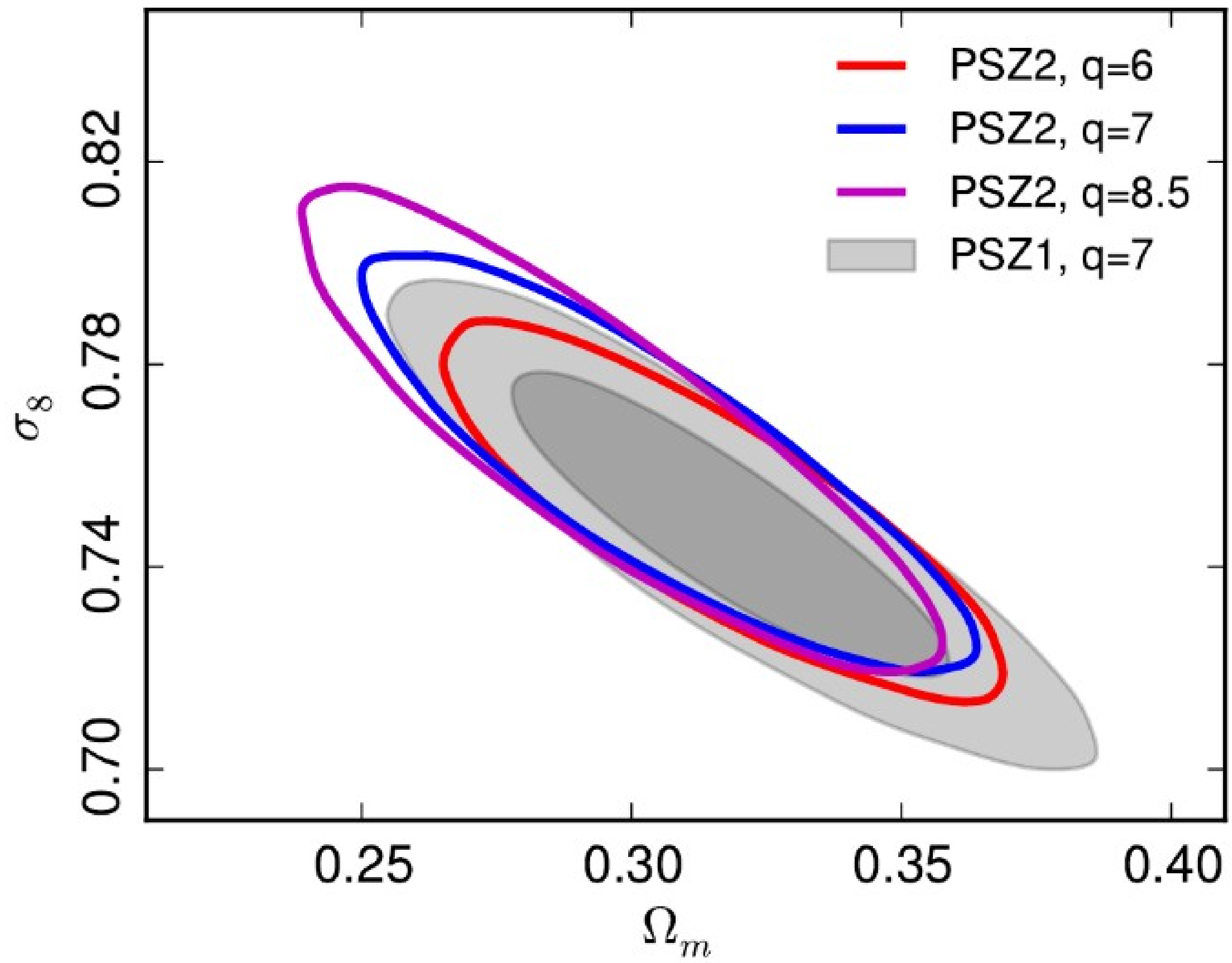
$$H_0 = 73.9 \pm 2.7$$

LMC+MW (parallax)

- **tension 3 (σ_8) … remains**
  - $\sigma_8^{2013} = 0.829 \pm 0.012 \longrightarrow \sigma_8^{2015} = 0.829 \pm 0.015$

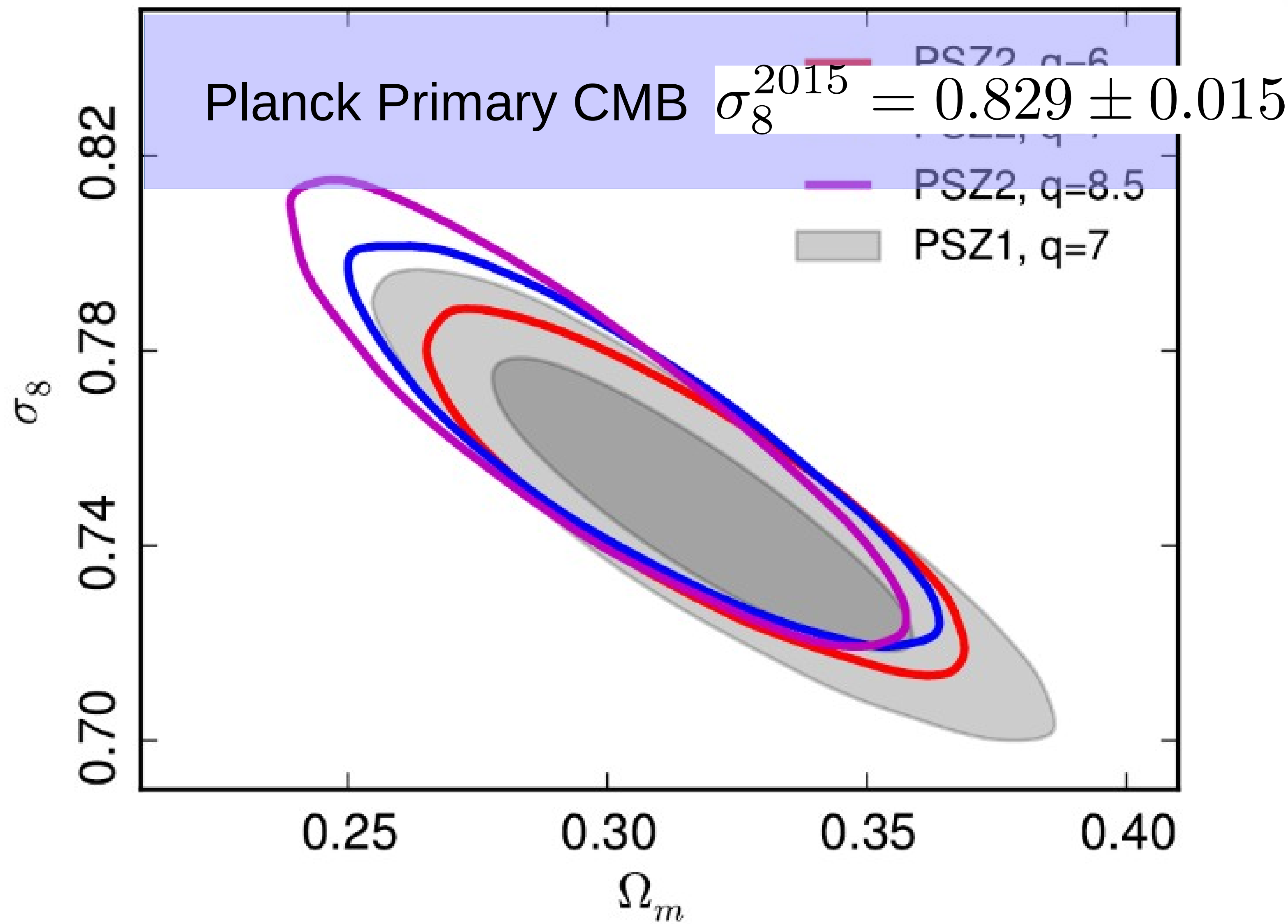
How does it go after 2015

Planck SZ cluster cosmology result 2015

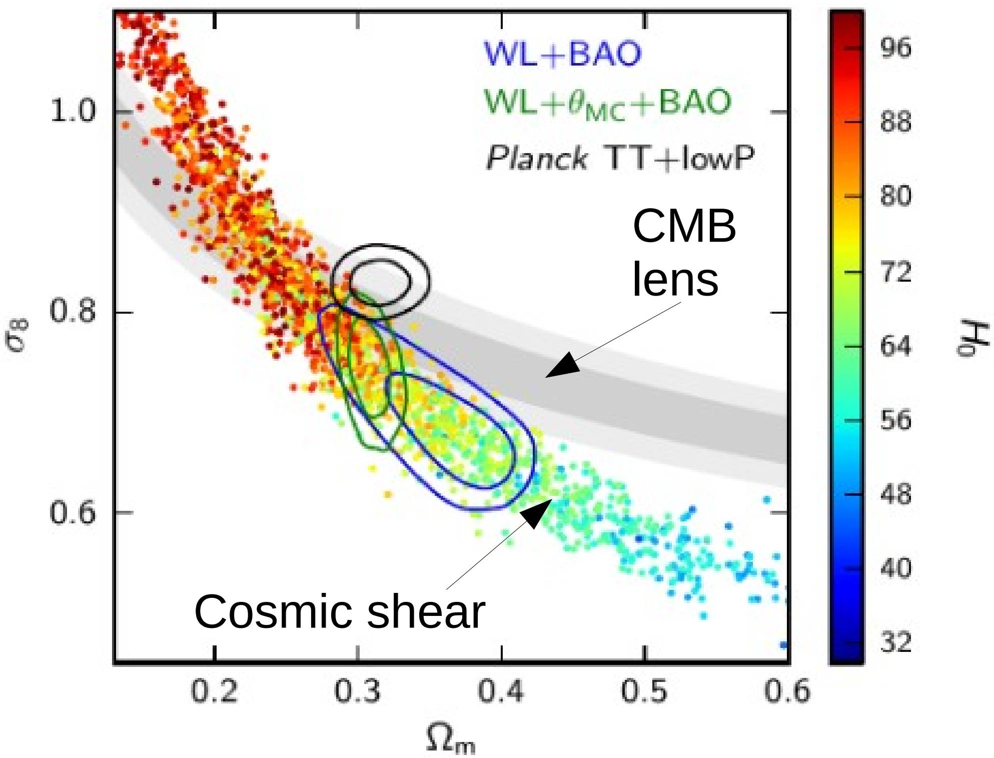


How does it go after 2015

Planck SZ cluster cosmology result 2015

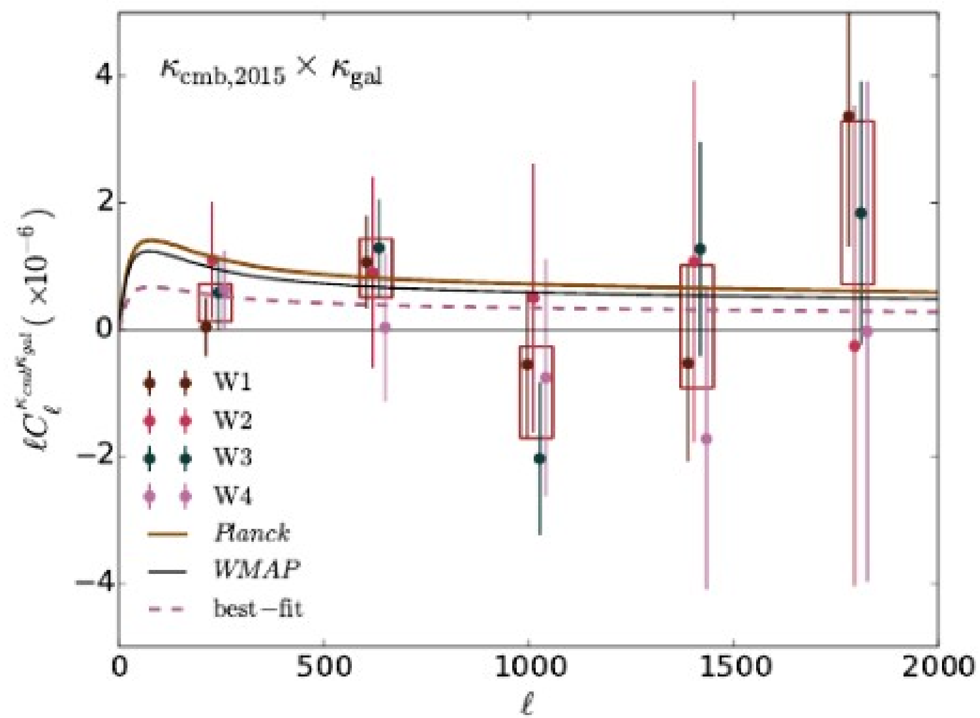


low density fluctuations at low-z



Planck 2015 results XIII

Liu & Hill, PRD92, 2015



$$A = 0.44 \pm 0.22$$

"A" should be unity for the Planck LCDM

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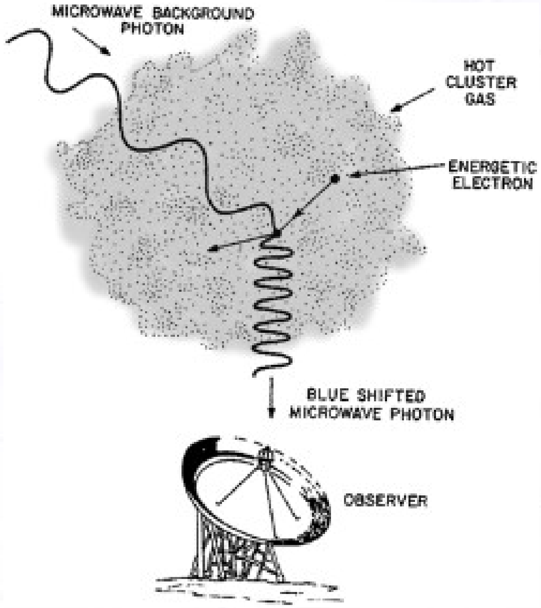
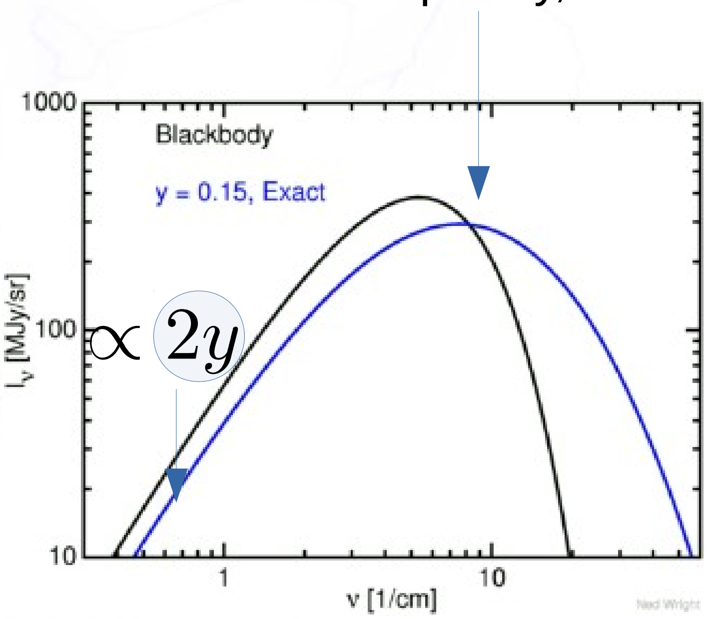
SZ effect

- Some of the CMB photons are Compton-scattered by hot electrons in clusters of galaxies, leading to a distortion of the Blackbody spectrum
- A good way to detect cluster of galaxies



Pivot frequency, 217 GHz

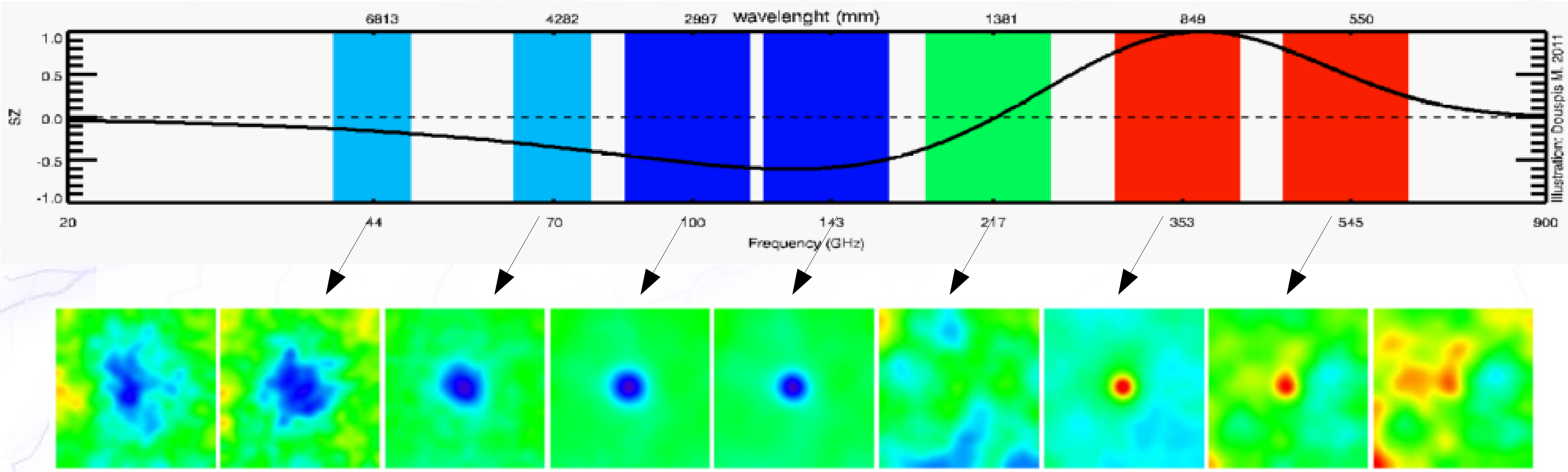


Weisskopf arXiv:1003.1990

SZ signal from Planck

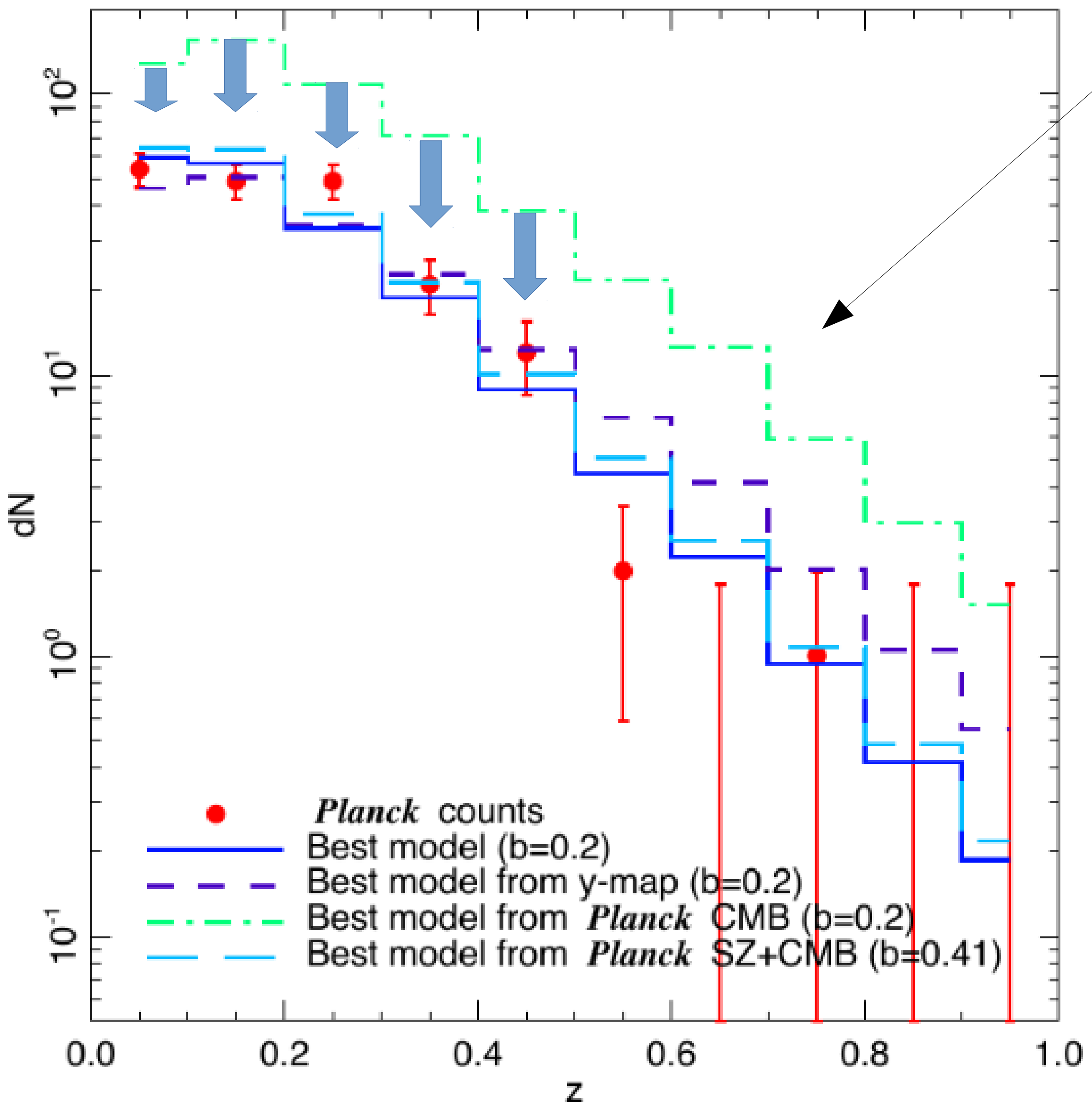
$$Y = \int y d\Omega = \frac{\sigma_T}{d_A^2} \frac{dV n_e k_B T_e}{m_e c^2}$$

- **Total thermal energy → unbiased mass-limited selection**
- **Number of clusters highly depends on the fluctuation amplitude**
- **All-sky survey → rarest clusters → cosmology (DE, ν-mass)**
- **Can probe high-z clusters**



Stacked signal from PLANCK

Cluster counts from 2013 Planck Results



Less clusters than predicted are actually found

why?

Possible explanations

- **Assumed mass bias is wrong:**
  - Eddington bias correction   Battaglia+, ArXiv:1509.08930
  - Gas effects   Bocquet+, ArXiv:1502.07357
- **Assumed cosmology is wrong:**
  - Massive neutrinos, Decaying dark matter
    Battye&Moss, PRL112, '14; Berezhiani+, ArXiv:1505.03644
  - Dark energy with w =/ -1
  - Non-Gaussianity   Trindade, MNRAS435, '13
  - void   Lee, MNRAS440, '14; Marra+, PRL110, '13

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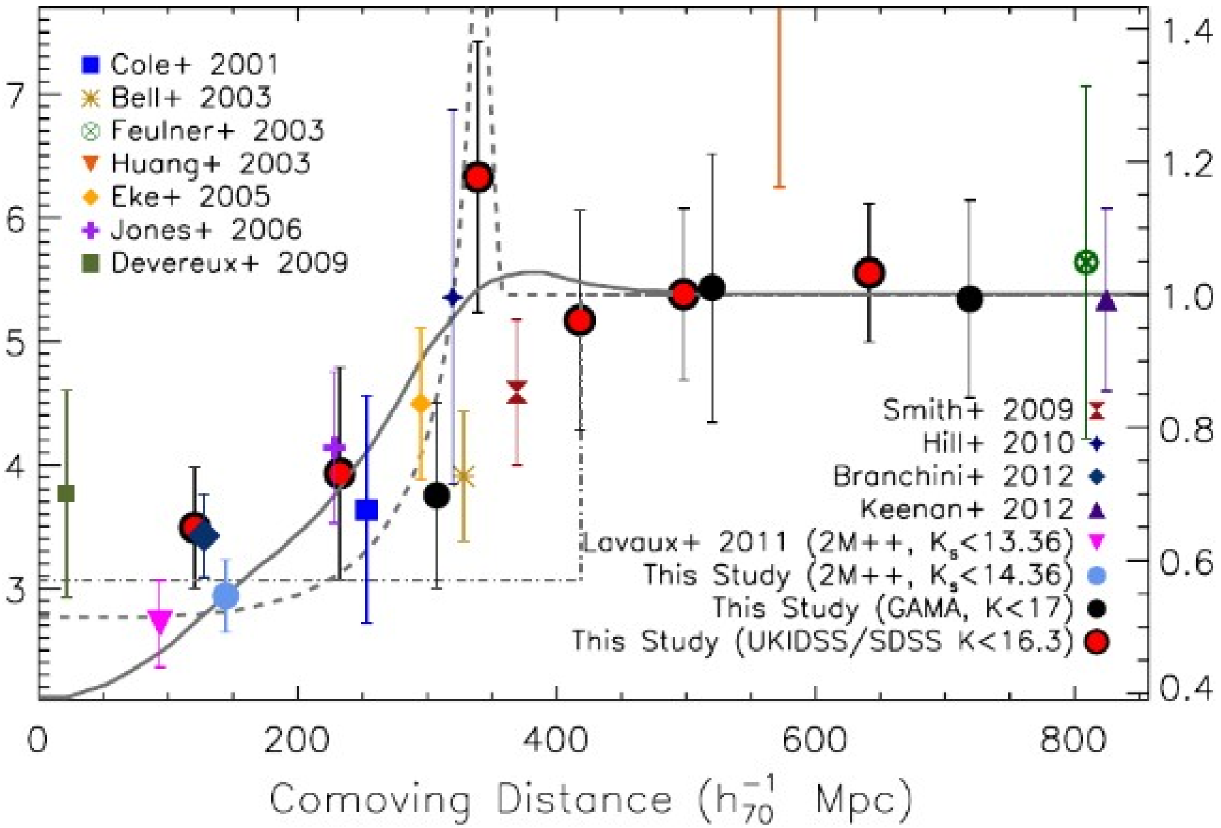
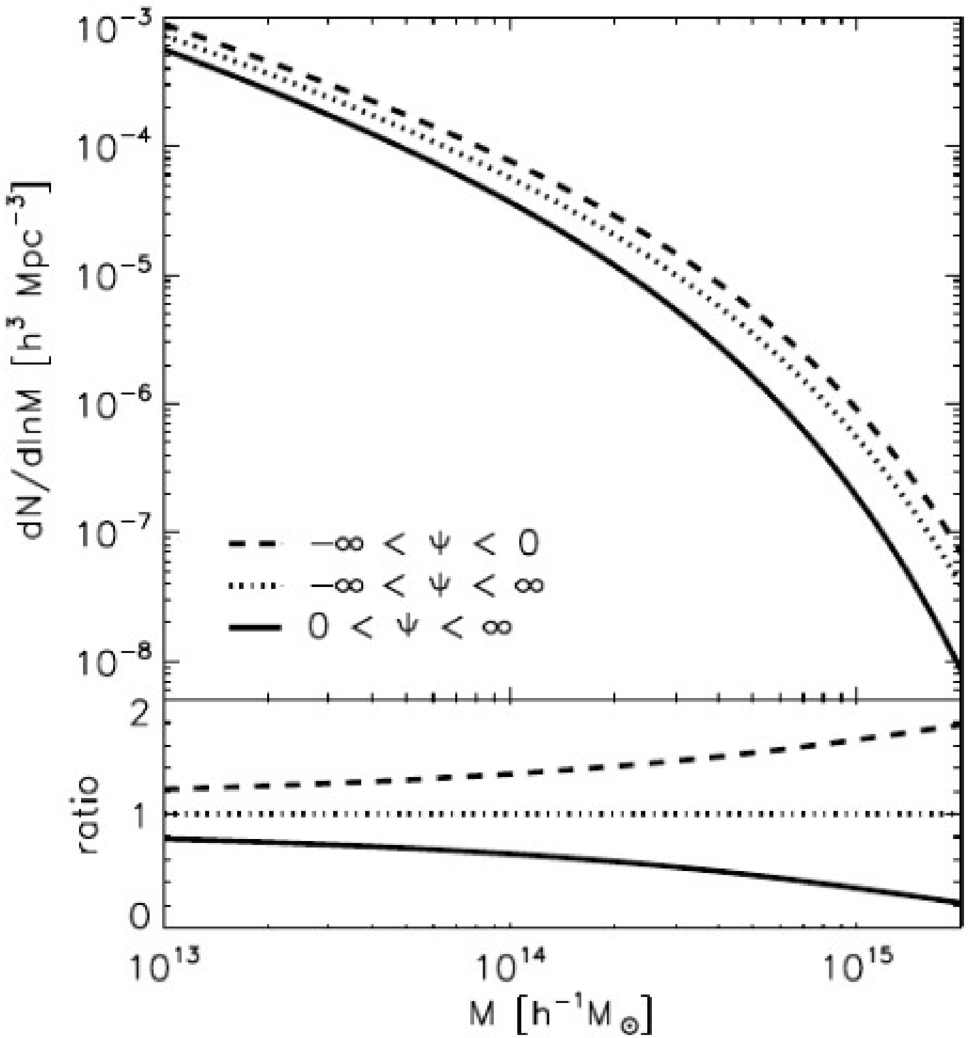
They do not explain σ_8 and H_0 simultaneously

We live in a void?



K-band luminosity density
(Keenan+, ApJ '13)

We conclude that if the observed trend in *K*-band luminosity density as a function of distance is indicative of a similar trend in the underlying total mass density, then the local universe may be under-dense on a scale and amplitude sufficient to introduce significant biases into local measurements of cosmological observables. Leaving aside considerations of whether or not such an unusual local structure could obviate the need for dark energy, it appears that the observed under-density is roughly the right scale and amplitude (given the analysis of Marra et al. 2013a) to explain the apparent tension between local measurements of the Hubble constant ($H_0 = 73.8 \pm 2.4$ km s^{-1} Mpc^{-1}; Riess et al. 2011) and the recent results from Planck ($H_0 = 67.3 \pm 1.2$ km s^{-1} Mpc^{-1}; Planck Collaboration 2013b).



Here, we set up a hypothesis that the present local universe have formed in a primordial potential crest with $\psi > 0$ rather than in a trough with $\psi < 0$ in the early universe. This hypothesis naturally leads to an expectation that the cluster number densities measured in the local universe would be lower than the global counterparts for a given background cosmology. The intriguing question is whether or not this hypothesis can explain away the tension between the local and the Planck measurements of the key cosmological parameters, especially, Ω_m and σ_8, on which the cluster number densities are most strongly dependent.

(Lee, MNRAS '14)

Our idea and motivation

- A local void may make H_0 and σ_8 observations concordant
- Let us use a simple void model to explain the lower σ_8 and predict H_0
- We do not fit σ_8 and predict H_0 simultaneously.

A simple void model

- **Separate universe approach** (e.g., Li, Hu, Takada, PRD '14)
  - The mean density fluctuation δ_b is absorbed into the background density $\bar{\rho}_m(1+\delta_b) = \bar{\rho}_{m,\mathrm{void}}$
  - So that the separate universe parameters obey

$$\frac{\Omega_{m,\mathrm{cmb}} h^2_{\mathrm{cmb}}}{a^3}(1+\delta_b) = \frac{\Omega_{m,\mathrm{void}} h^2_{\mathrm{void}}}{a^3_{\mathrm{void}}}$$

  - assume a growing mode $\lim_{a\to 0} a_{\mathrm{void}} = a \quad \lim_{a\to 0} \delta_b = 0.$
  - so

$$\Omega_{m,\mathrm{cmb}} h^2_{\mathrm{cmb}} = \Omega_{m,\mathrm{void}} h^2_{\mathrm{void}}$$

A simple void model

- **Separate universe approach** (e.g., Li, Hu, Takada, PRD '14)
  - Introduce f_{void} parameter

$$h_{\rm void} = {\color{red} f_{\rm void}} h_{\rm cmb} \quad \begin{cases} f_{\rm void} > 1 & \text{underdence} \\ f_{\rm void} < 1 & \text{overdence} \end{cases}$$

  - Local universe is described by a FRW

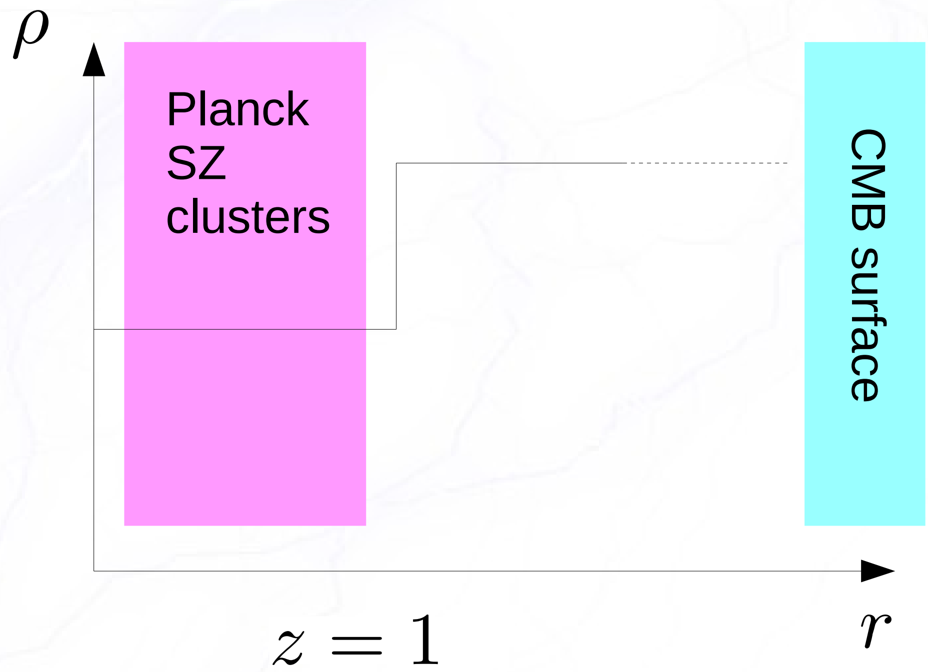
$$\Omega_{\rm k,void} = 1 - \sum_i \Omega_{\rm i,void}$$

$$\Downarrow$$

$$\Omega_{\rm k,void} > 0 \ \text{ if } \ f_{\rm void} > 1 \ \text{(and } \Omega_{\rm k,cmb} = 0)$$

A simple void model

- One assumption: The distance to the LSS remains same as the standard LCDM.



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Likelihood calculation

- **Use Tinker mass function** $\dfrac{dn}{dM_{500}dV}$
- **Consider completeness**

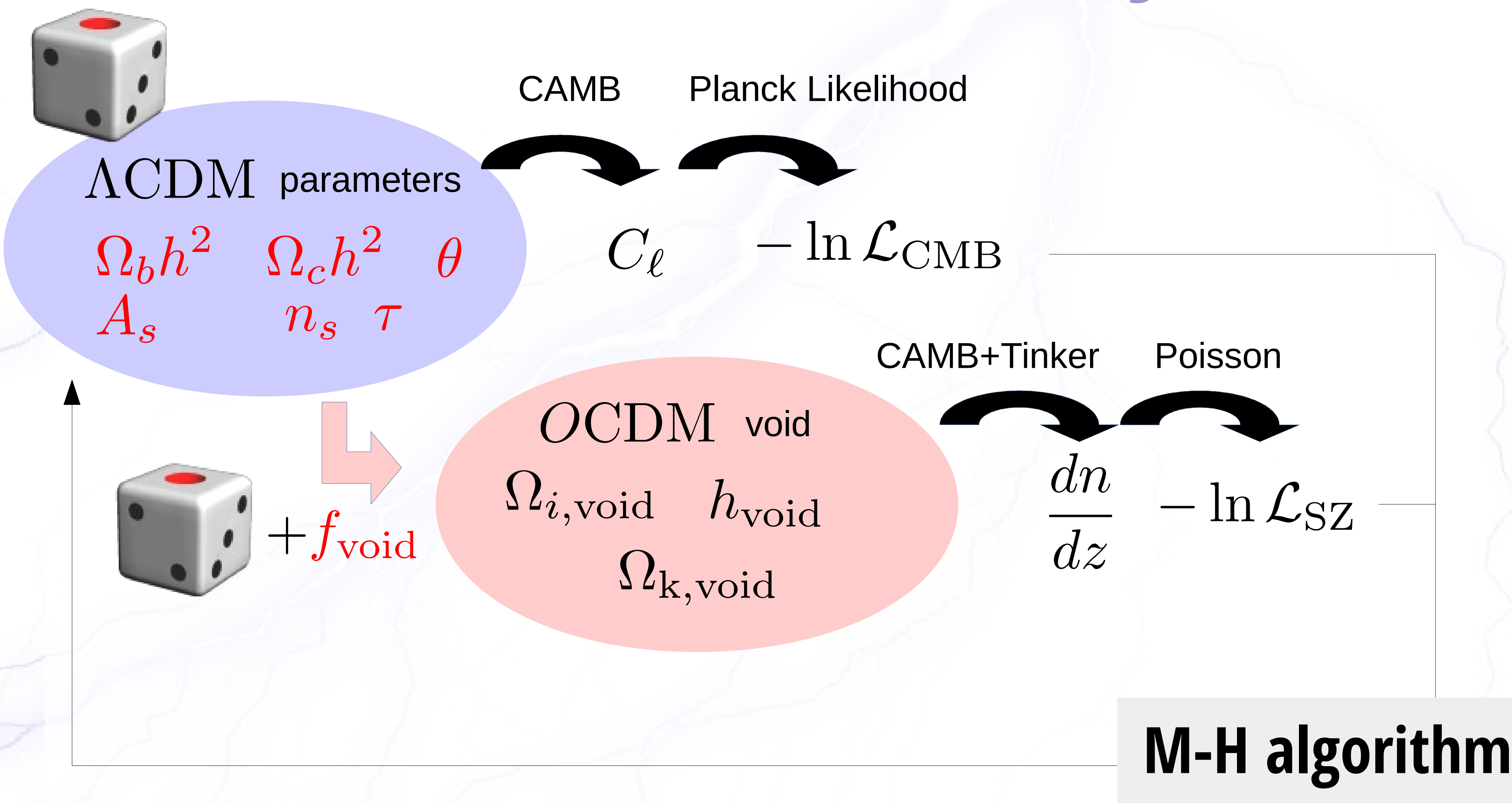
$$x(M,z) = \int_{M_{\mathrm{lim}}(z)}^{\infty} d\ln M^{\mathrm{obs}} p(M^{\mathrm{obs}}|M)$$

$$p(M^{\mathrm{obs}}|M) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{(\ln M^{\mathrm{obs}} - \ln M)^2}{2\sigma^2}\right]$$

- **Calculate expected cluster number**

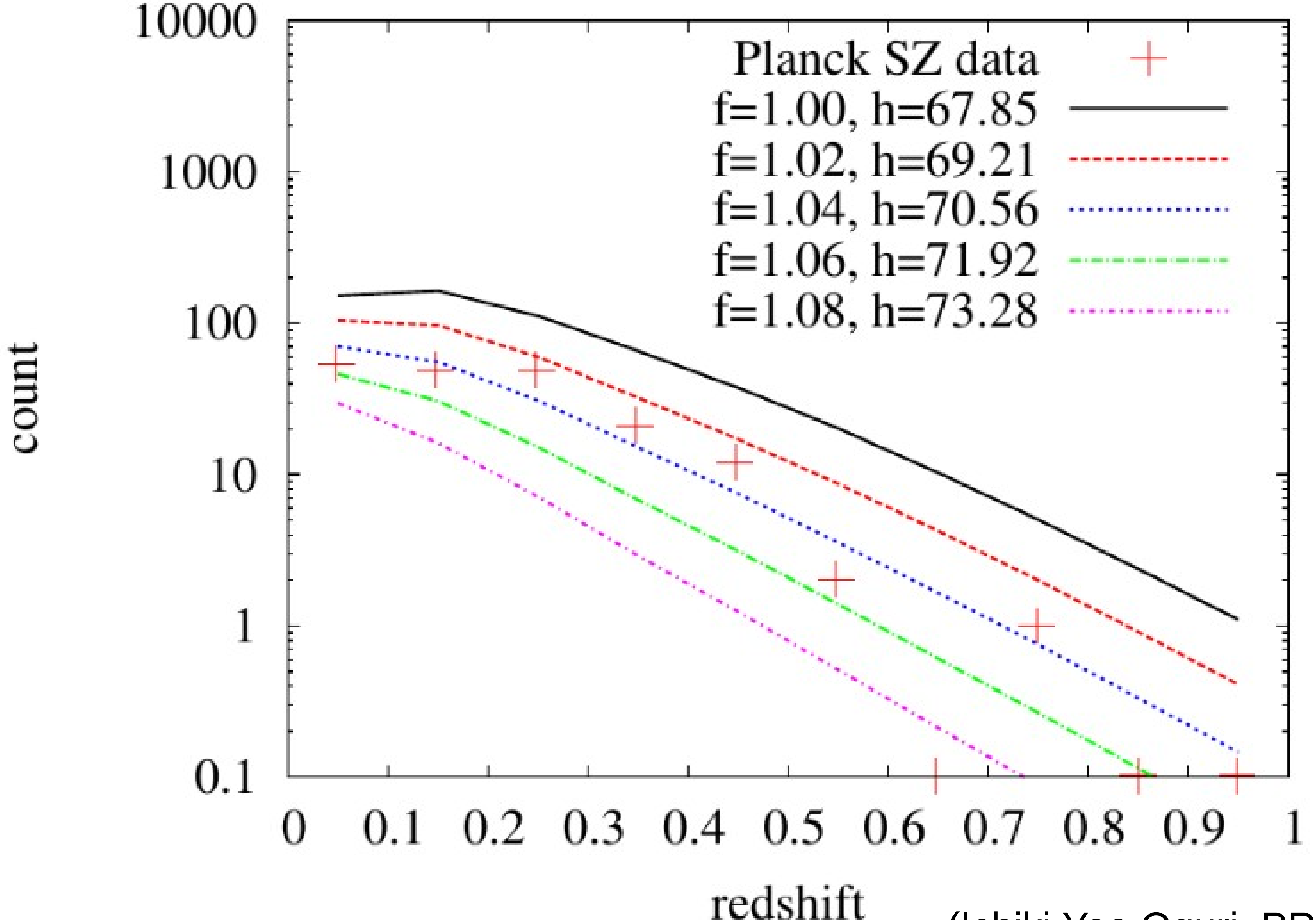
$$dN_{\mathrm{cluster}} = \int_{z_i}^{z_i+\Delta z} dz \int_0^{\infty} dM \frac{dn}{dMdV} x(M,z) \frac{dV}{dz}$$

Modified MCMC analysis



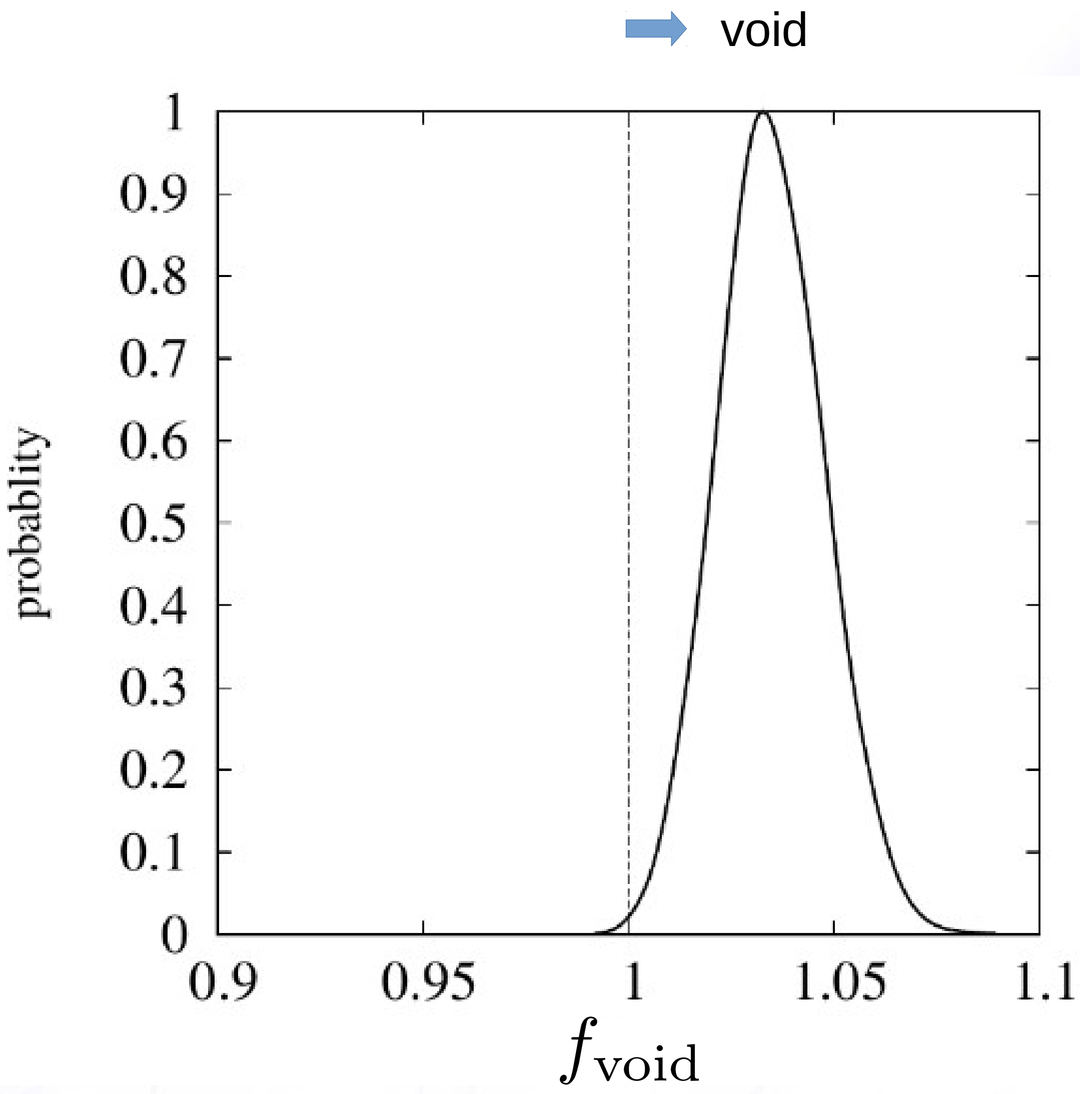
cosmomc (http://cosmologist.info/cosmomc/)

fvoid parameter & SZ counts



(Ichiki,Yoo,Oguri, PRD '16)

Constraints on fvoid

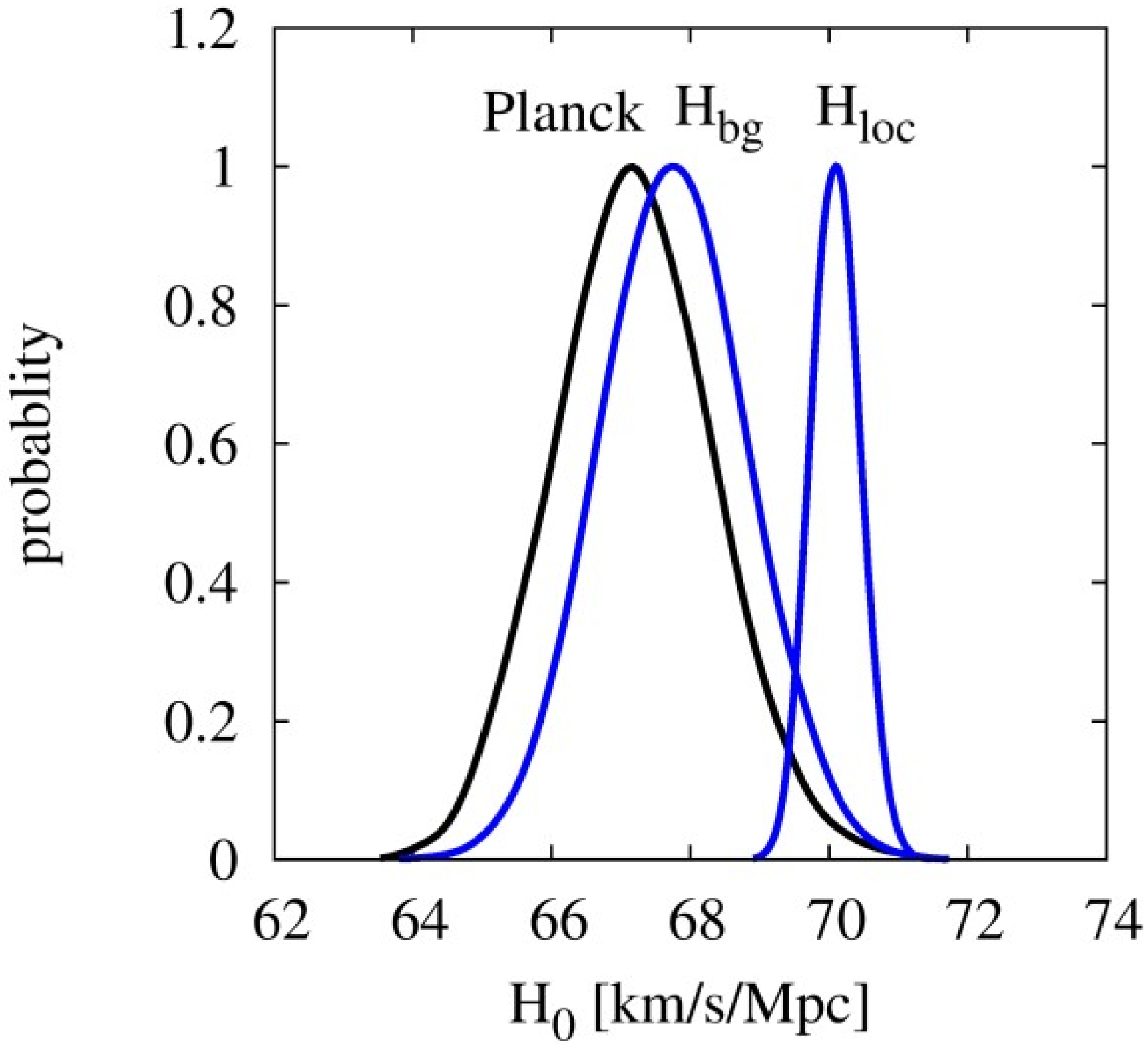


$$f_{\rm void} = 1.03 \pm 0.01245$$

$$\Delta\chi^2 = -8.44$$

Void reduces the number of clusters and makes the fit better

Hubble parameter's'



summary

- Precise measurements bring tensions in the concordant cosmology
- The σ_8 and h_0 tensions found in 2013 still remain in 2016.
- If you consider a local void, these tensions will be resolved away.

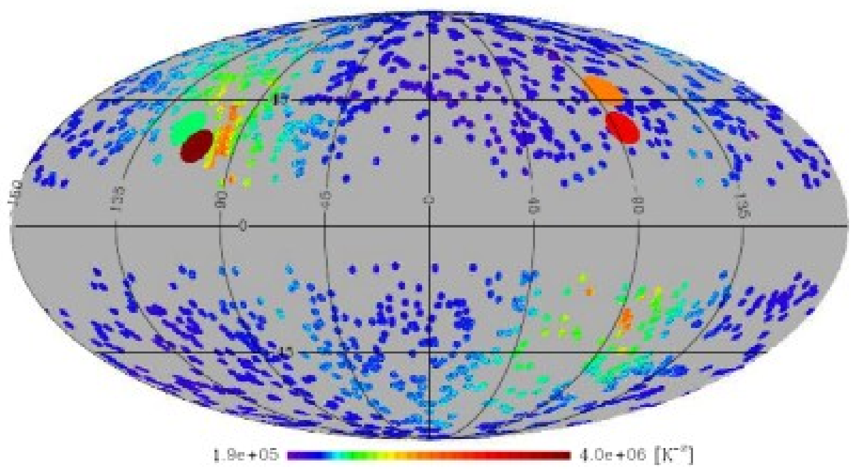
Conclusion

- If you solve the σ_8 problem by introducing a local void, the local Hubble parameter will be

$$H_0 = 70.0 \pm 1$$

One strong constraint: kSZ

- Inhomogeneous universe generally leads to large bulk velocities ... which can be constrained by the kinematic SZ effect



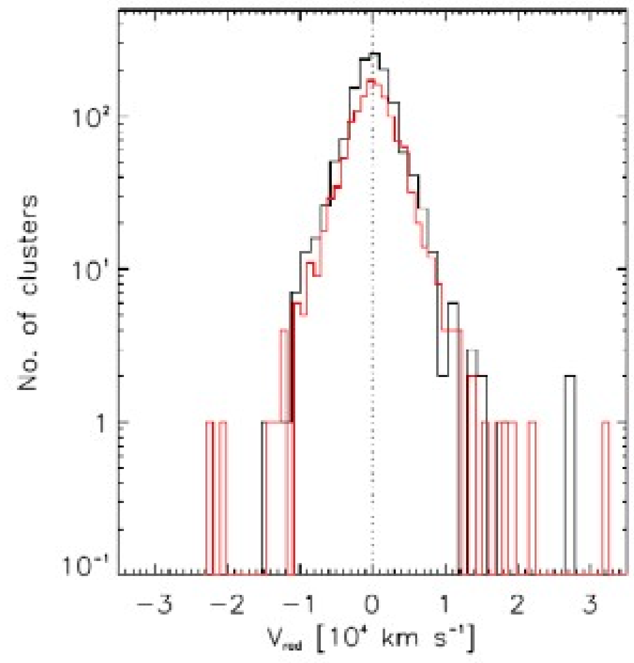


Fig. 5. Histogram of recovered radial peculiar velocities as estimated by the uMMF (black) and AP (red) implementations on HFI frequency maps.

Planck intermediate results XIII

One strong constraint: kSZ

- Inhomogeneous universe generally leads to large bulk velocities ... which can be constrained by kinematic SZ effect

felt for the same period in conformal time. The dipole anisotropy at clusters is then given by

$$\frac{\Delta T}{T} \approx 1 - \frac{R(\eta_*)}{a(\eta_*)} , \quad (8)$$

where $a(\eta_*)$ and $R(\eta_*)$ denote the scale factors of the background and void regions when the incoming photon enters into the void, and follow the Friedmann equations in flat and open ΛCDM models, respectively. For our

Planck 2015 constraints

$$\frac{\Delta T}{T} < 6.4 \times 10^{-4}$$

Our simple void model gives

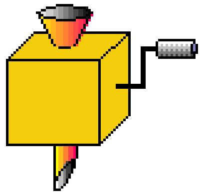
$$\frac{\Delta T}{T} \approx 7 \times 10^{-4} \quad (a_* = 0.01)$$

$$9 \times 10^{-3} \quad (a_* = 0.1)$$

Fairly large void is necessary

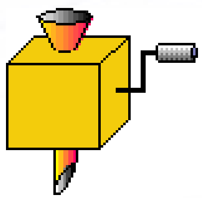
KI, Yoo, Oguri, PRD, 2016

- **Boltzmann equation** $f(\omega)$



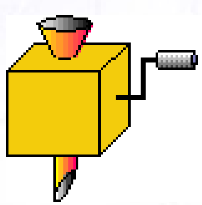
← Isotropic distribution
small energy transfer

$$\frac{\partial f}{c\partial t} \approx n_e \sigma_T \left(\frac{kT_e}{mc^2}\right) \frac{1}{\omega^2} \frac{\partial}{\partial \omega} \left(\omega^4 \frac{\partial f}{\partial \omega}\right)$$



← Optically thin

$$\Delta f \approx y \frac{1}{\omega^2} \frac{\partial}{\partial \omega} \left(\omega^4 \frac{\partial f}{\partial \omega}\right) \qquad y = \int dr \frac{n_e \sigma_T kT_e}{m_e c^2}$$



$f(\omega)$ をBlack bodyで近似して温度変化に直すと

$$\frac{\Delta T}{T} = -y\left[4 - x\coth(x/2)\right] \longrightarrow -2y$$

$$x \equiv \omega/T \ll 1$$

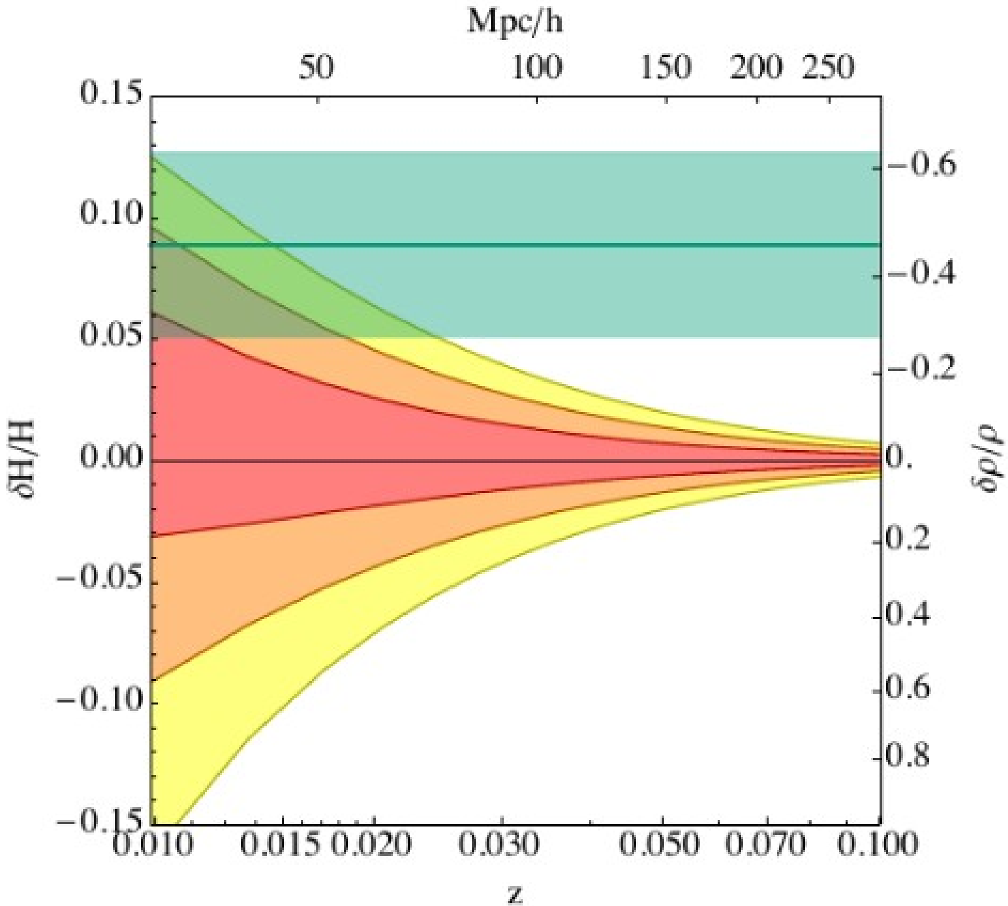


Figure 3. The 68%, 95% and 99.7% confidence-level probabilities of log-normally distributed matter fluctuations (right vertical axis) and consequently of the local Hubble parameter (left vertical axis), as a function of co-moving size of the matter fluctuation (top ticks) or, equivalently, redshift (bottom ticks). As in Fig. 2 we show the 1-σ band relative to the value $H_0^{\rm local}/H_0^{\rm CMB} - 1$.

Case	Density Contrast Distribution	$z_{\rm min}$	$\sigma^+_{H_0}$	$\sigma^-_{H_0}$	$\delta H_0^+ \left(\frac{\rm km/s}{\rm Mpc}\right)$	Adding errors linearly	Adding errors in quadrature
I	$p_{\rm gau}$ of Eq. (3)	0.010	2.1%	2.1%	1.58	$\Delta H = 1.6\sigma$	$\Delta H = 2.1\sigma$
II	$p_{\rm logn}$ of Eq. (4)	0.010	2.4%	1.7%	1.79	$\Delta H = 1.5\sigma$	$\Delta H = 2.1\sigma$
III	$p_{\rm gau}$ of Eq. (3)	0.023	1.2%	1.2%	0.90	$\Delta H = 1.9\sigma$	$\Delta H = 2.4\sigma$
IV	$p_{\rm logn}$ of Eq. (4)	0.023	1.3%	1.1%	0.97	$\Delta H = 1.8\sigma$	$\Delta H = 2.4\sigma$

(Marra+, PRL '13)

Samples for cosmology (2013)

- A sample of 187 clusters with S/N>7
  - 1227 clusters & candidate
    - 683 previously known
    - 178 new clusters
    - 366 candidates
- Important inputs:
  - Mass function
  - Scaling relation
  - completeness

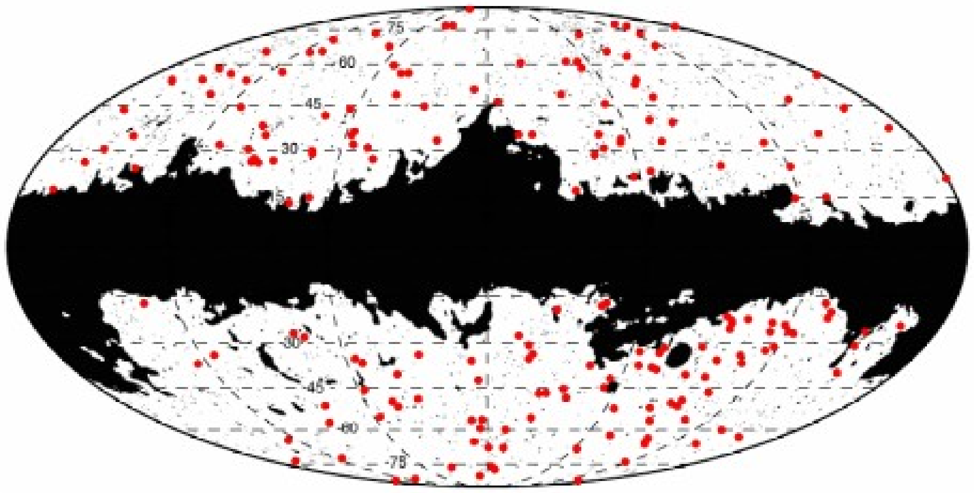
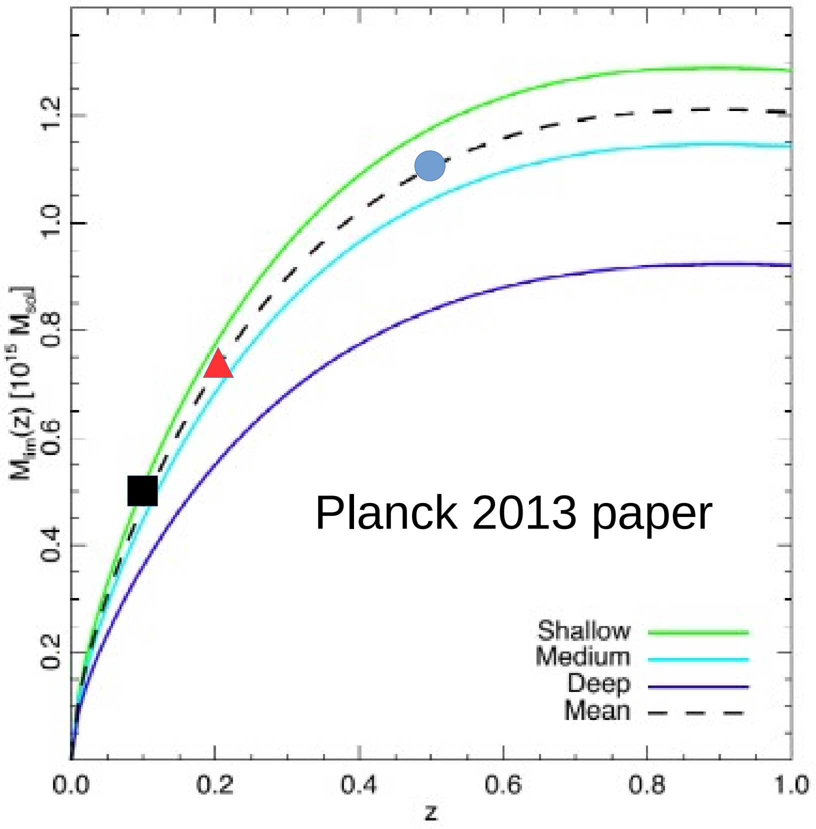
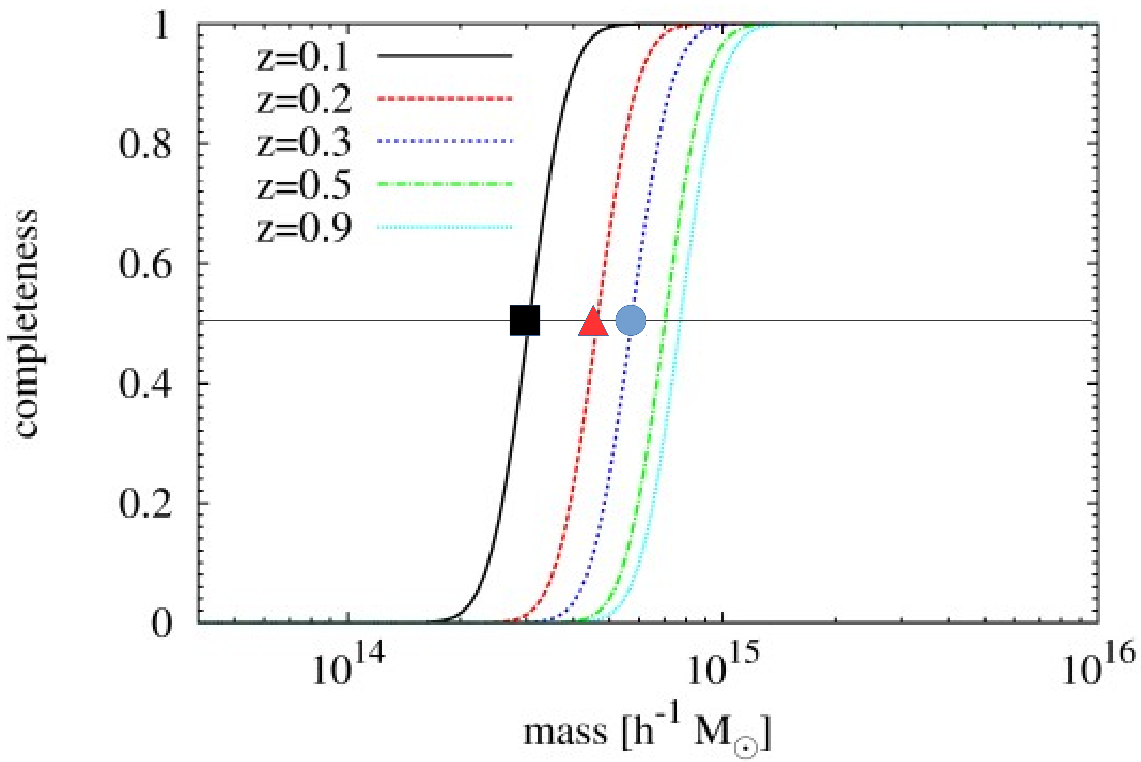
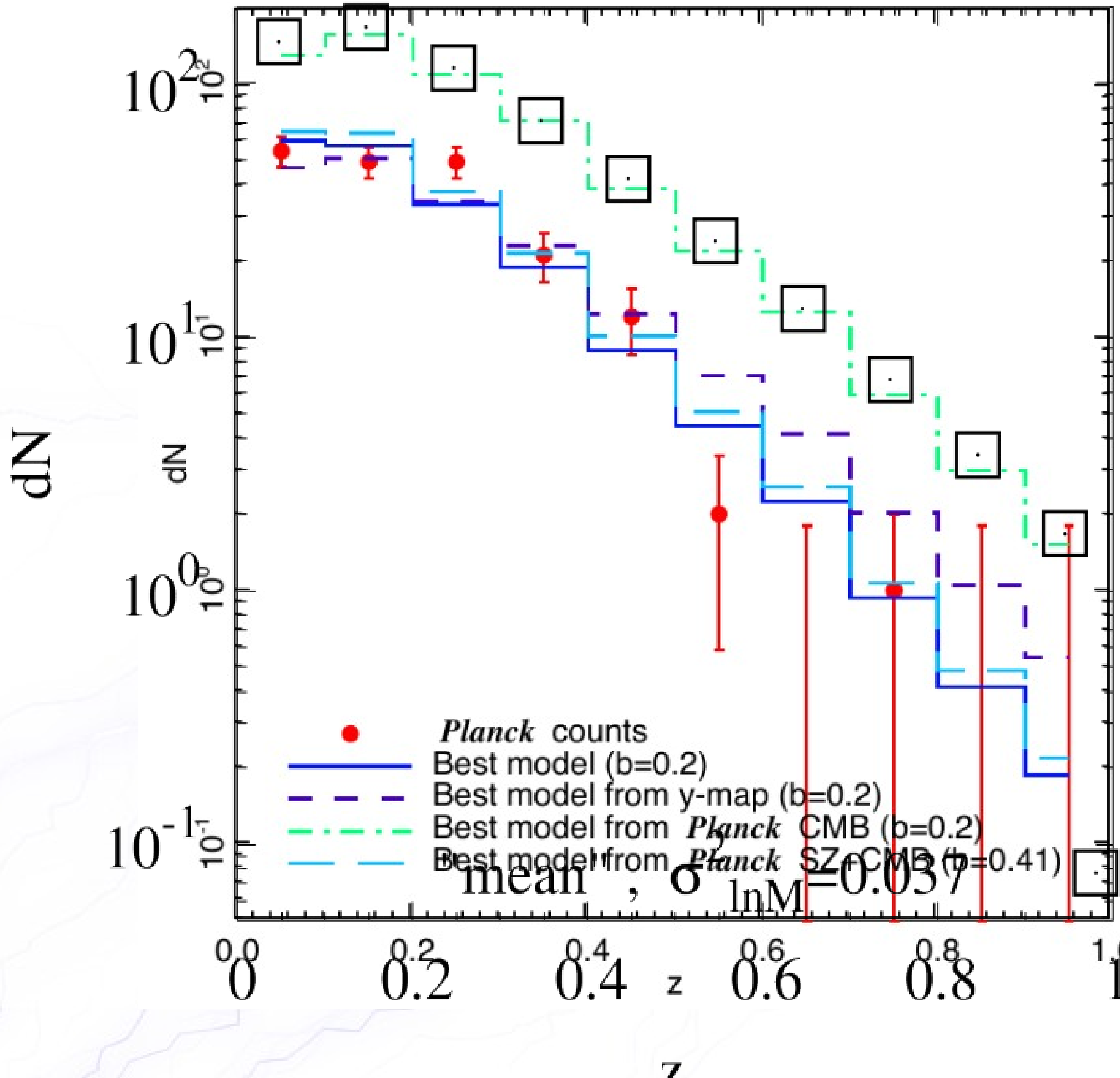


Fig. 1. The distribution on the sky of the *Planck* SZ cluster sub-sample used in this paper, with the 35% mask overlaid.

The Planck SZC likelihood is not public

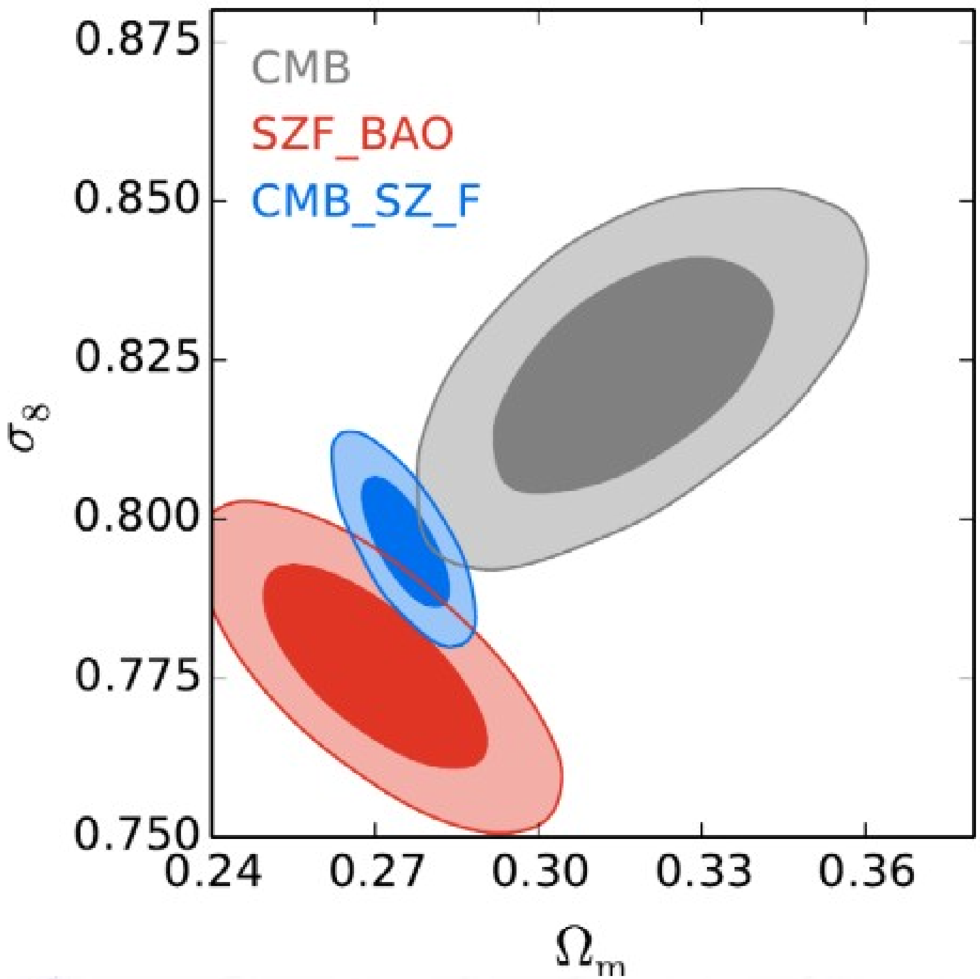






dN
z
10^{-1}
10^{0}
10^{1}
10^{2}
0 0.2 0.4 0.6 0.8 1
0.0 0.2 0.4 0.6 0.8 1.0
Planck counts
Best model (b=0.2)
Best model from y-map (b=0.2)
Best model from *Planck* CMB (b=0.2)
Best model from *Planck* SZ+CMB (b=0.41)
"mean", $\sigma^2_{\ln M}$=0.037

同時にfitすることについて



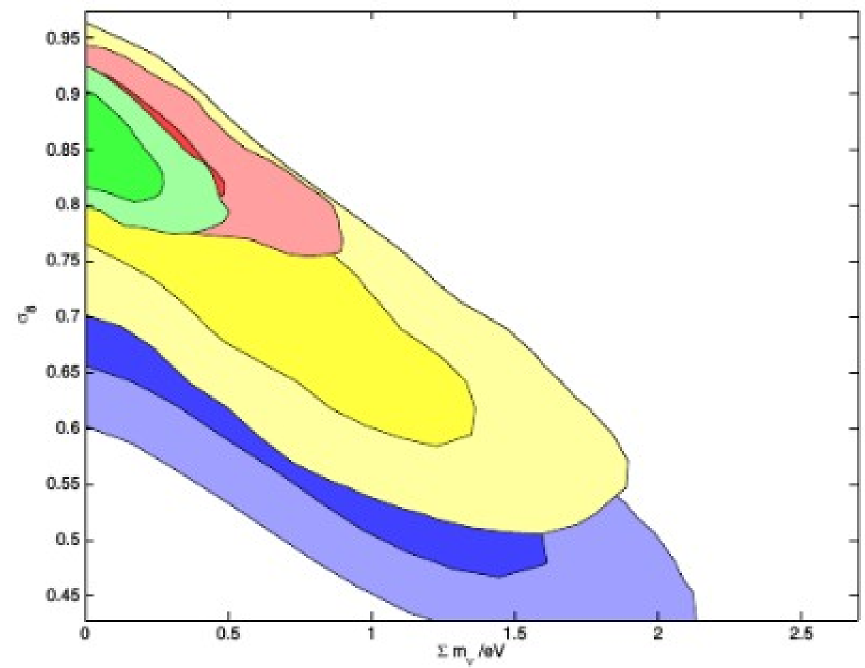
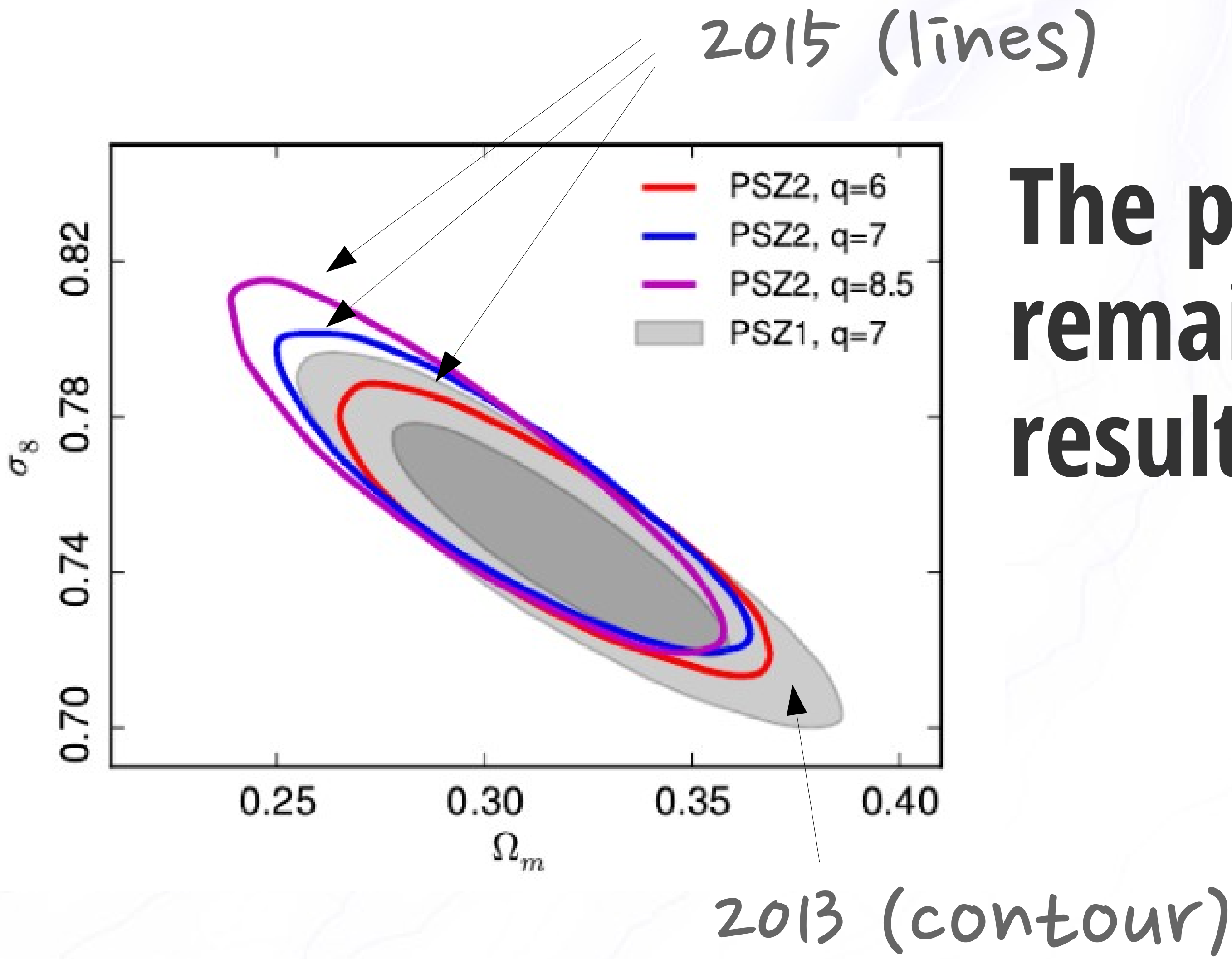


FIG. 2: A 2-D marginalized likelihood contour plot indicating the possible inconsistency of the WMAP and SDSSLYA data. 68% and 95% confidence intervals are illustrated for the following four datasets (from broadest to tightest): blue, WMAP data alone; yellow, "faked" WMAP data alone; green, SDSSLYA and WMAP data; red, SDSSLYA and "faked" WMAP data.

Gratton, Lewis, Efstathiou, PRD77, 08

$\sum m_\nu < 0.17\mathrm{eV}$ は本当か?

2013 (187) → 2015 (439)



The problem remains in 2015 results.

Planck 2015 results XXIV