planck

esa

Reviewing tensions between Planck and other data

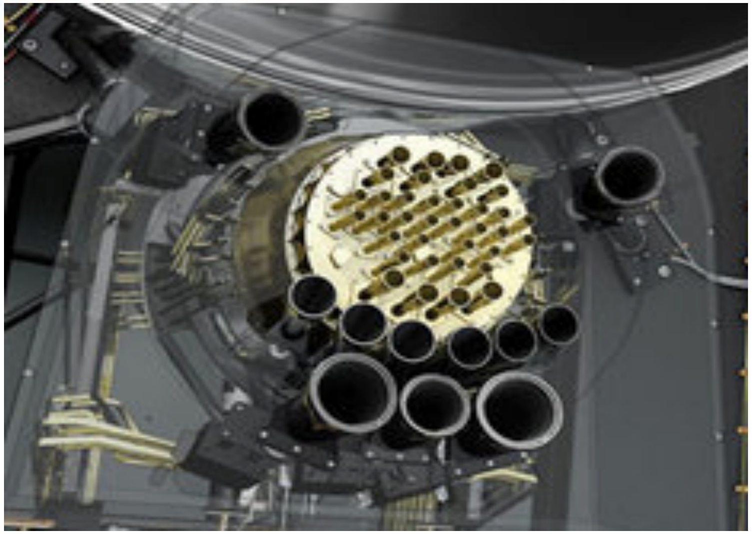
Silvia Galli
IAP-Paris

with Marius Millea, Lloyd Knox, Ali Narimani, Douglas Scott, Martin White and the rest of the Planck collaboration

“Planck 2016 intermediate results. LI. Features in the cosmic microwave background temperature power spectrum and shifts in cosmological parameters ”
arXiv:1608.02487

Sydney, 30/11/2016

The Planck satellite



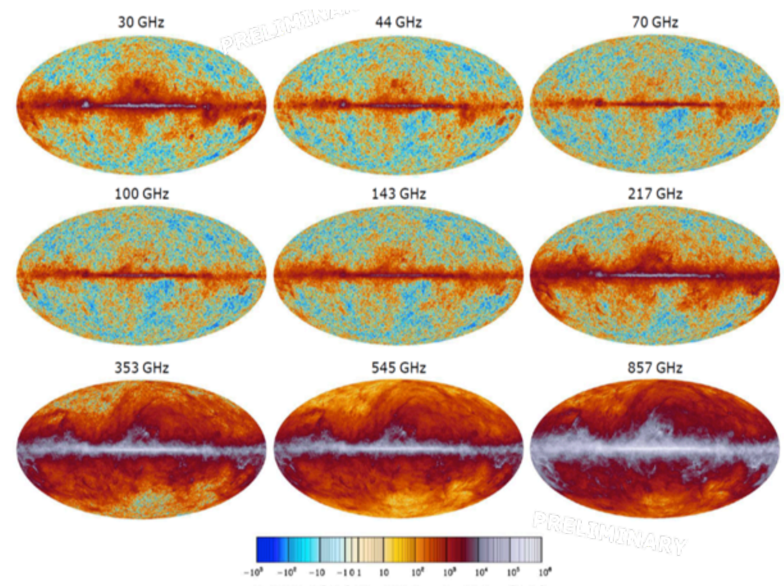
Launched in 2009, operated till 2013.
2 Instruments, 9 frequencies.

LFI:

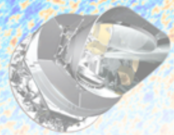
- 22 radiometers at **30, 44, 70 Ghz.**

HFI:

- 50 bolometers (32 polarized) at **100, 143, 217, 353, 545, 857 Ghz.**
- **30-353 Ghz polarized.**



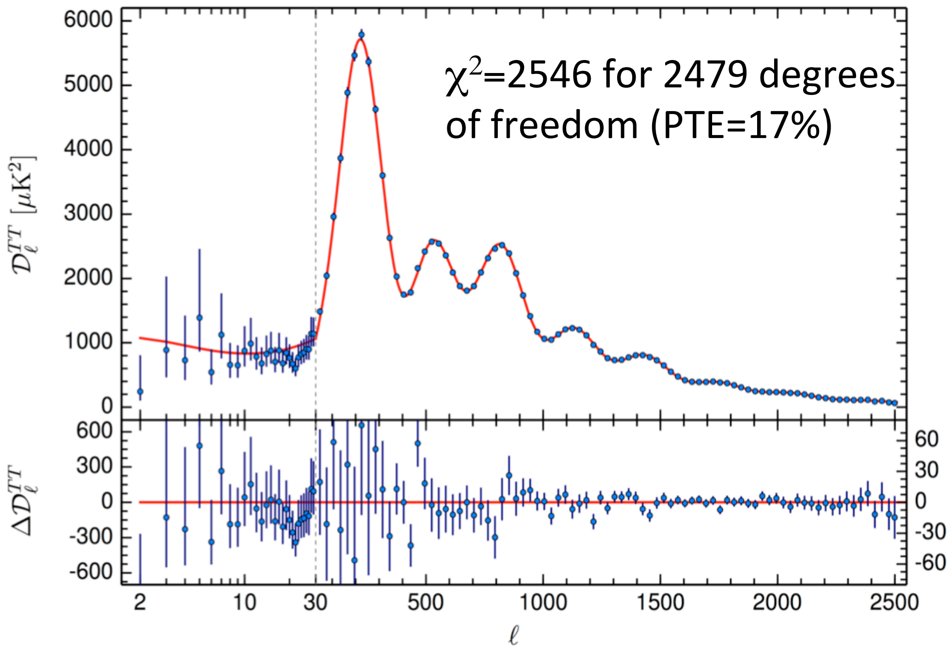
- **1st release 2013: Nominal mission**, 15.5 months, Temperature only.
- **2nd release 2015: Full mission**, 29 months for HFI, 48 months for LFI, Temperature + Polarization



ΛCDM and Planck

General relativity+standard model particles. Homogeneous and isotropic universe.
Cold dark matter, dark energy, baryons, radiation (photons+3 neutrinos).
Basic ΛCDM controlled by 6 parameters: ω_m, ω_b, A_s, n_s, τ, θ

Excellent fit to the data



Most of parameters at the ~1% level.

No significant deviation from ΛCDM in extended models

Curvature:
Compatible with flatness at the level of 10^{-3}

$$\Omega_K = 0.000 \pm 0.005 \ (95\%)$$
(PlanckTT+lowP+Lensing+BAO)

Sum of neutrino masses:
Bound already stronger than what achievable by Katrin (tritium beta decay)

$$\sum m_\nu < 0.23 \text{ eV}$$
(PlanckTT+lowP+Lensing+ext)

Number of relativistic species:
Compatible with standard predition N_{eff}=3.046 with 3 active neutrinos

$$N_{\rm eff} = 3.13 \pm 0.32$$
(PlanckTT+lowP)

Helium abundance
Good agreement with measurements of primordial abundances and BBN predictions

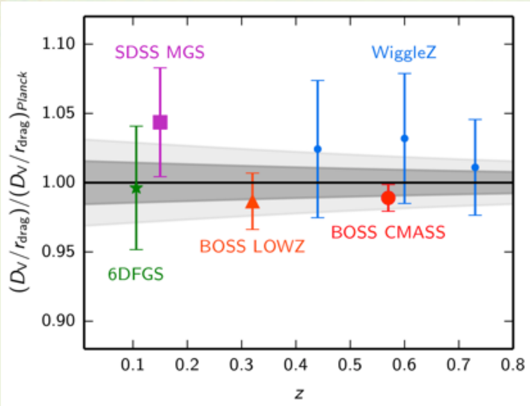
$$Y_P^{\rm BBN} = 0.253 \pm 0.021$$
(PlanckTT+lowP)

Running of the scalar spectral index
Compatible with no running

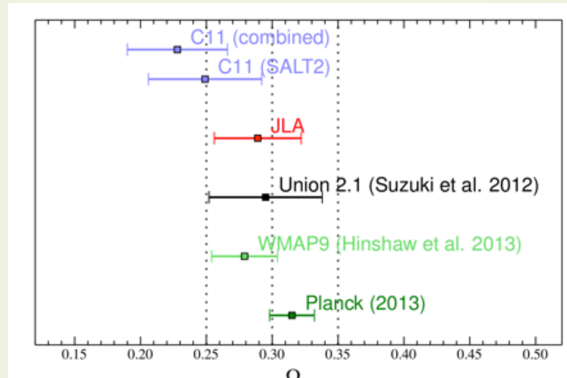
$$\frac{dn_s}{d\ln k} = -0.0084 \pm 0.0082$$
(PlanckTT+lowP)

Comparison with other datasets:

BAO

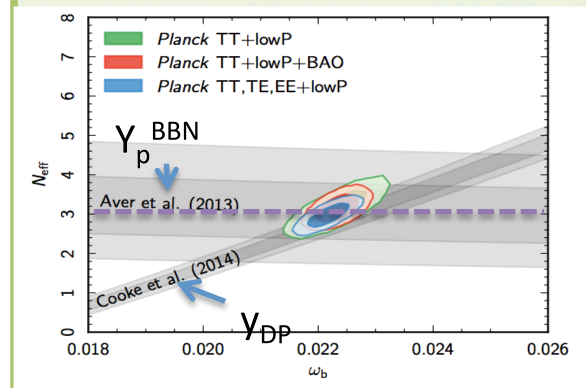


Supernovae (Ω_m)

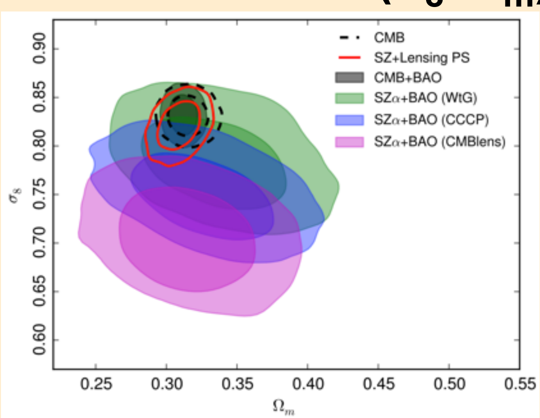


Betoule et al. 2014

BBN

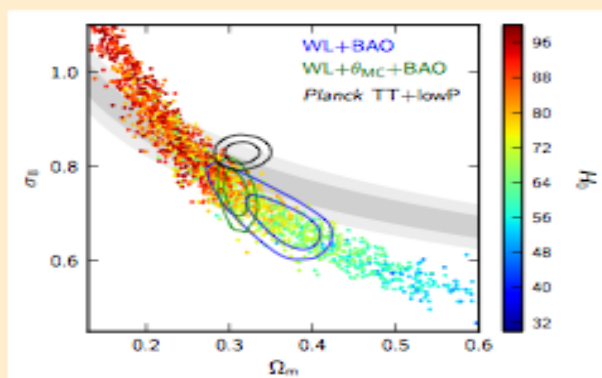


Cluster counts (σ_8-Ω_m)



Planck collaboration XXIV

Weak Lensing (σ_8-Ω_m)



Direct measurements H_0

H_0=67.8±0.92 [in Km/s/M
(PlanckTT+lowP+lensing)

H_0=72.8±2.4 **[2σ tension]**
(Riess+11)

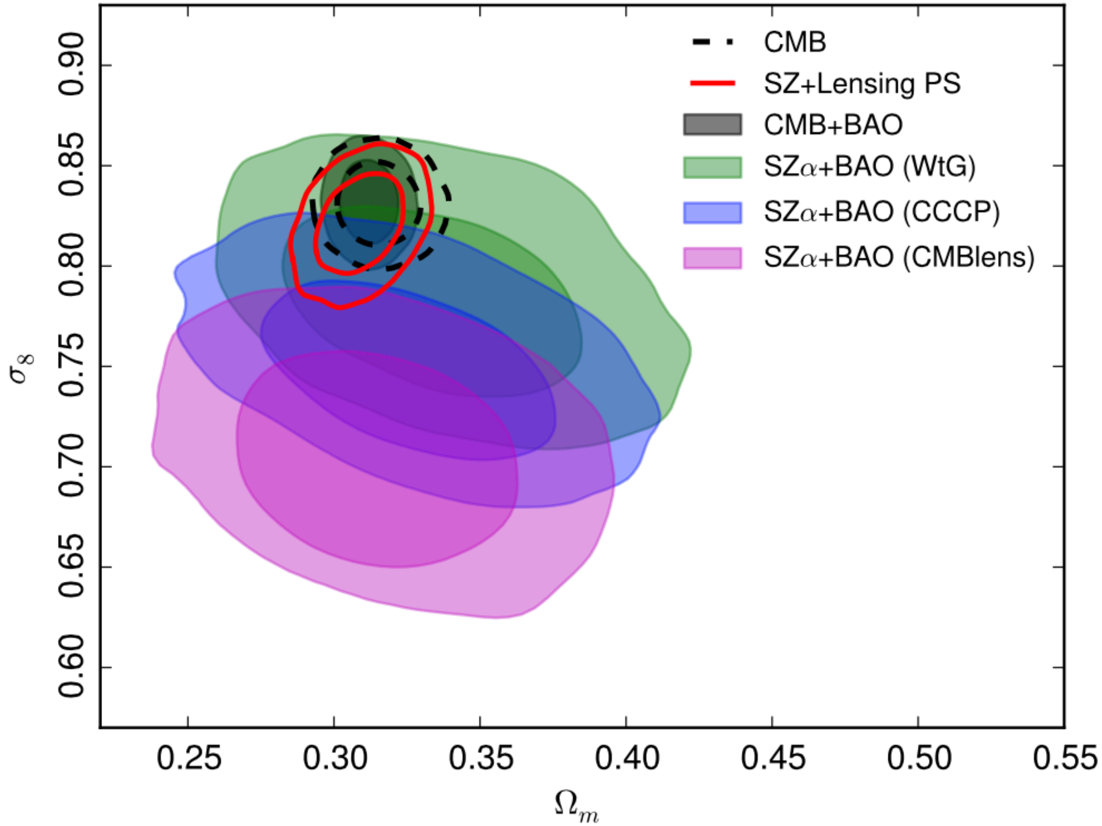
H_0=70.6 ± 3.3 **[1σ tension]**
(Efstathiou+14)

H_0=74.3 ± 2.6 **[2.5σ tension]**
(Freedman+12)

H_0=73.±1.8 **[2.7σ tension]**
(Riess+16)

Cluster counts with Planck 2015

- **Number of clusters** as a function of **z** sensitive to cosmology.
- Detected through **Sunyaev-Zeldovitch effect in CMB** surveys.
- Need to know the **mass** of the observed clusters -> Need Ysz-mass relation-> Calibrated with X-ray observations-> Assume hydrostatic equilibrium-> **mass bias!**
- Mass bias can be measured from lensing measurements.

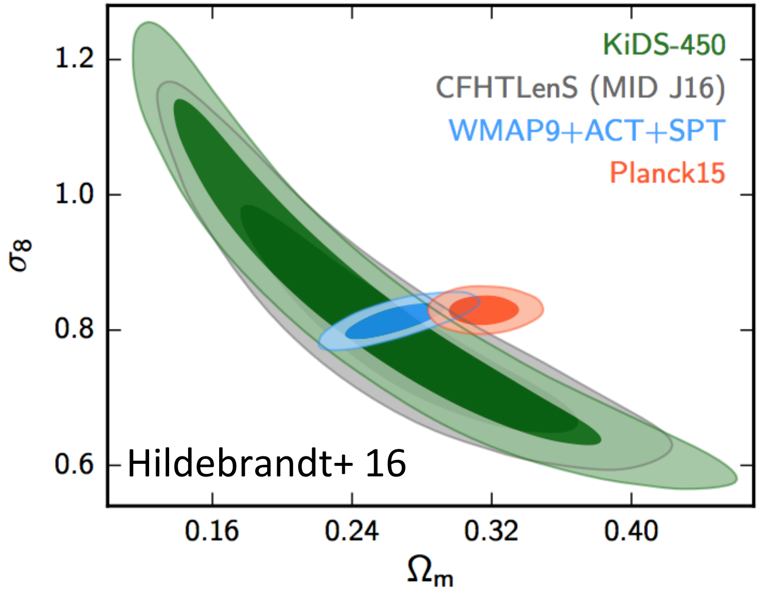


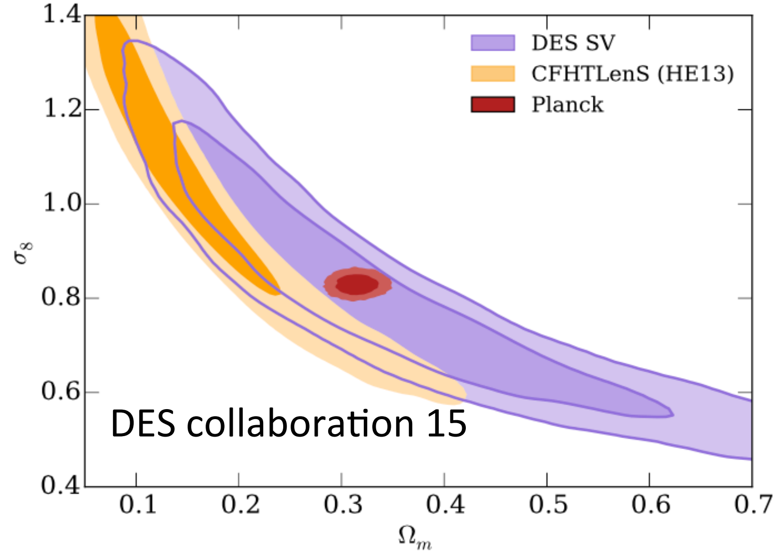
Prior name	Quantity	Value & Gaussian errors
Weighing the Giants (WtG)	$1-b$	0.688 ± 0.072
Canadian Cluster Comparison Project (CCCP)	$1-b$	0.780 ± 0.092
CMB lensing (LENS)	$1/(1-b)$	0.99 ± 0.19

- For perfect agreement with CMB, $(1-b) = 0.58 \pm 0.04$. 1σ lower than WtG.
- Tension can be relieved with non-zero neutrino mass, but detection disappears if BAO data is also included.

Weak Lensing: CFHTLenS, KIDS and KiDS

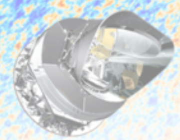
Cosmic shear correlation functions sensitive to the combination $\sim\sigma_8\Omega_m^{0.5}$



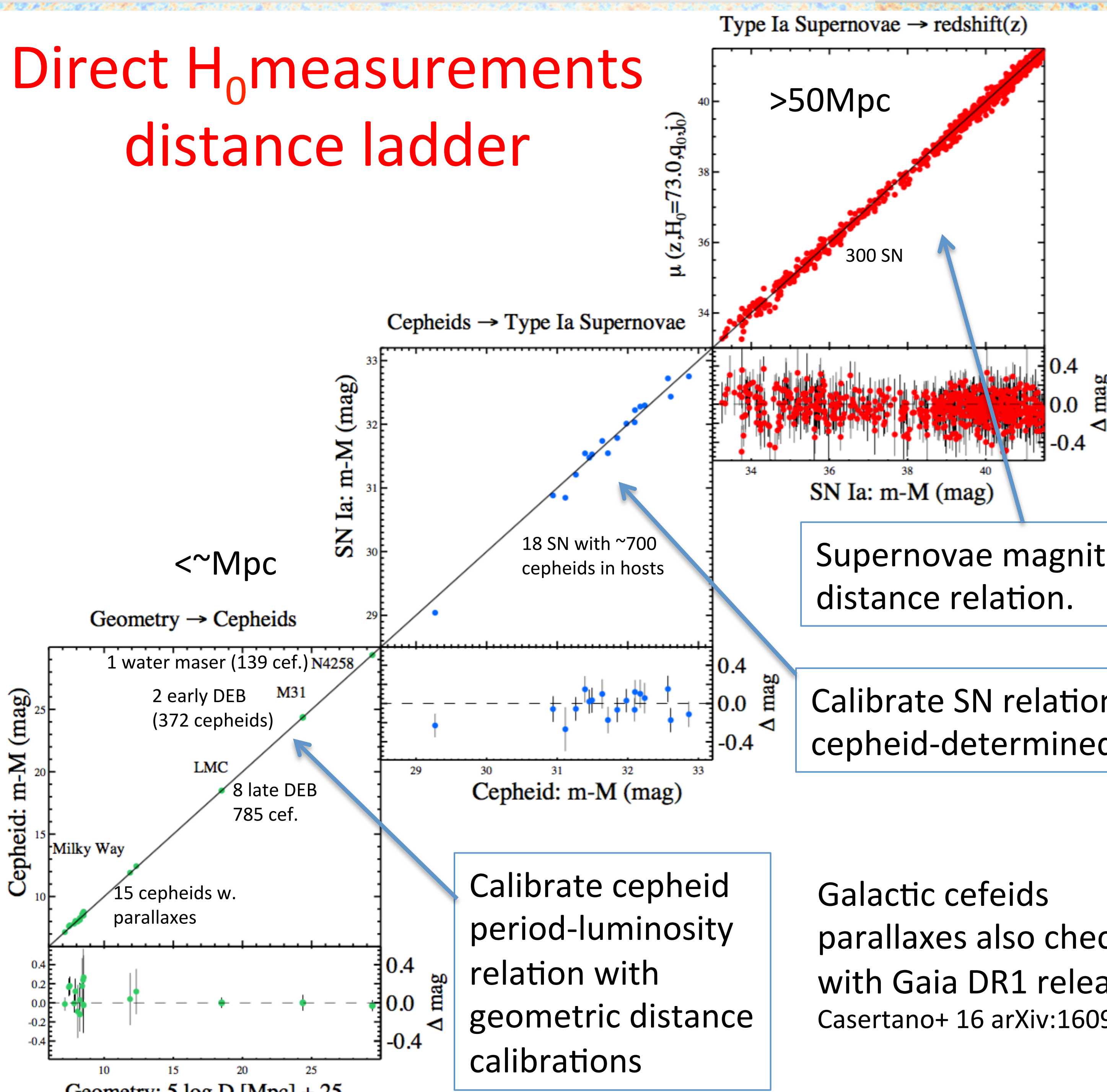


- CFHTLenS and KiDS in agreement, ~2.3σ discrepancy on $\sigma_8\Omega^{0.5}$ with Planck.
- Can be relaxed if one adds one sterile neutrino. (2σ detection).
- DES Science Verification results not enough constraining yet.

For CFHTLenS, see also Heymans+ 13, Kitching+ 14, Joudaki +16 (CFHTLenS), Joudaki +16 (KiDS). Recent reanalisys from Kitching+ 2016 of CFHTLenS.



Direct H_0 measurements distance ladder



Supernovae magnitude-distance relation.

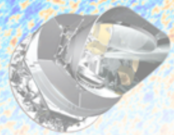
Calibrate SN relation with cepheid-determined distances

Calibrate cepheid period-luminosity relation with geometric distance calibrations

Galactic cefeids parallaxes also checked with Gaia DR1 release

Casertano+ 16 arXiv:1609.05175

Riess+ 16



Direct measurements H_0

Direct measurements H_0

H_0=67.8±0.92 [in Km/s/Mpc]
(PlanckTT+lowP+lensing)

H_0=73.±1.8 **[2.7σ tension]**
(Riess+16)

Anchor(s)	Value [km s^{-1} Mpc^{-1}]
One anchor	
NGC 4258: Masers	72.39 ± 2.56
MW: 15 Cepheid Parallaxes	76.09 ± 2.41
LMC: 8 Late-type DEBs	71.93 ± 2.70
M31: 2 Early-type DEBs	74.45 ± 3.34
Two anchors	
NGC 4258 + MW	73.85 ± 1.97
Three anchors (preferred)	
NGC 4258 + MW + LMC	**73.02 ± 1.79** km s^{-1} Mpc^{-1}
Four anchors	
NGC 4258 + MW + LMC + M31	73.24 ± 1.75
Optical only (no NIR), three anchors	
NGC 4258 + MW + LMC	71.19 ± 2.55

Riess+ 16

H_0 can be also measured from multiply-imaged quasar systems with measured gravitational time delays. H0licow project from 3 lenses: $H_0 = 71.9^{+2.4}_{-3.0}\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$

Bonvin et al.arXiv:1607.01790

Not only a Planck tension

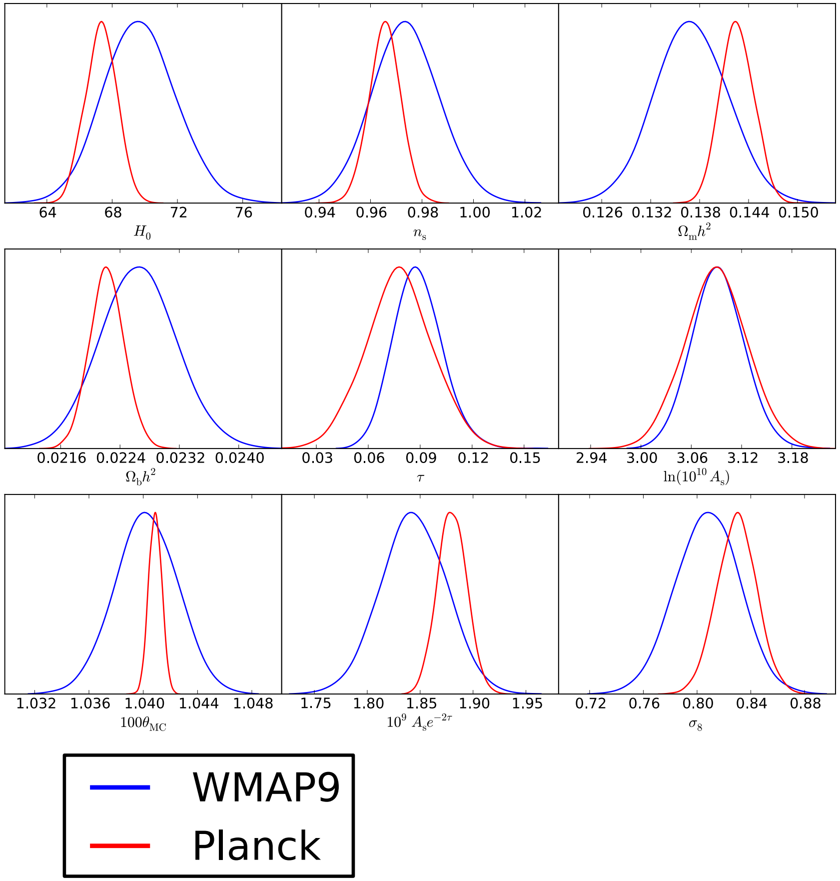
Planck15	H_0=67.3±0.9	2.8σ tension
Riess+ 2016	H_0=73.02±1.79	
WMAP	H_0=69.7±2.1 [Km/s/Mpc]	

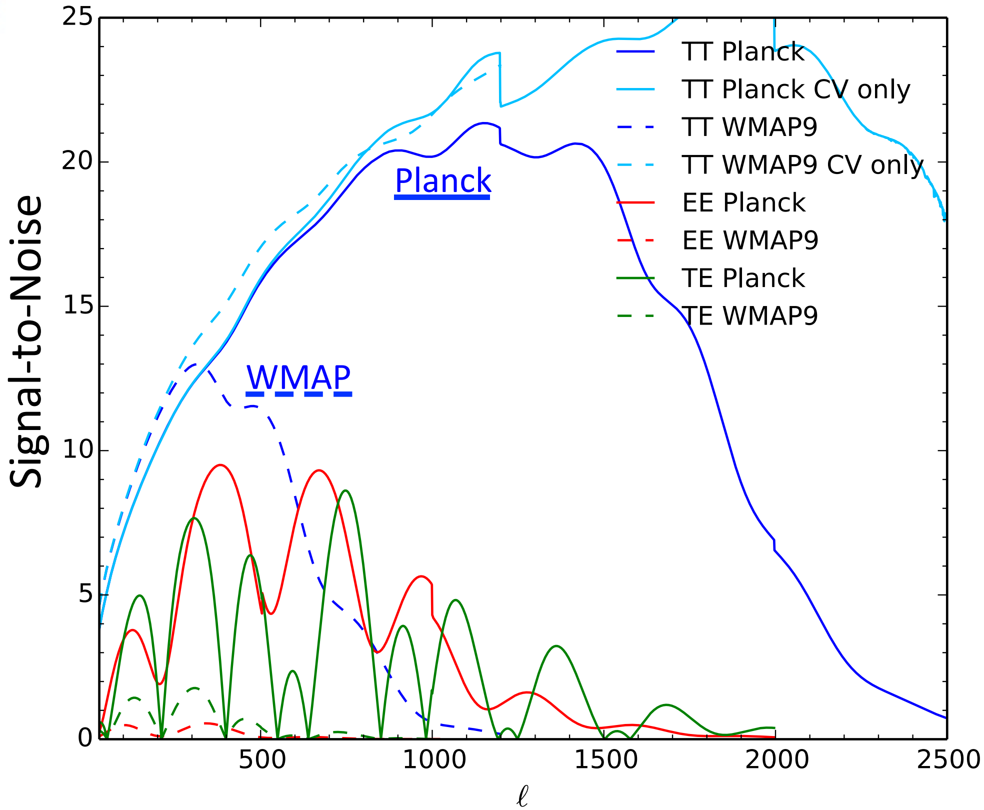
*The direct measurement tension is *NOT only* a Planck problem:

- WMAP9+BAO (BOSSDR11+6dFGS+Lyman α)+high-z Sne
  H_0= 68.1 ± 0.7 (2.5σ tension) (Aubourg+ 2015)

- WMAP9+ACT+SPT + BAO (BOSSDR11+6dFGS)
  H_0 = 69.3 ± 0.7 (1.9s tension) (Bennet+ 2014)

Planck and WMAP



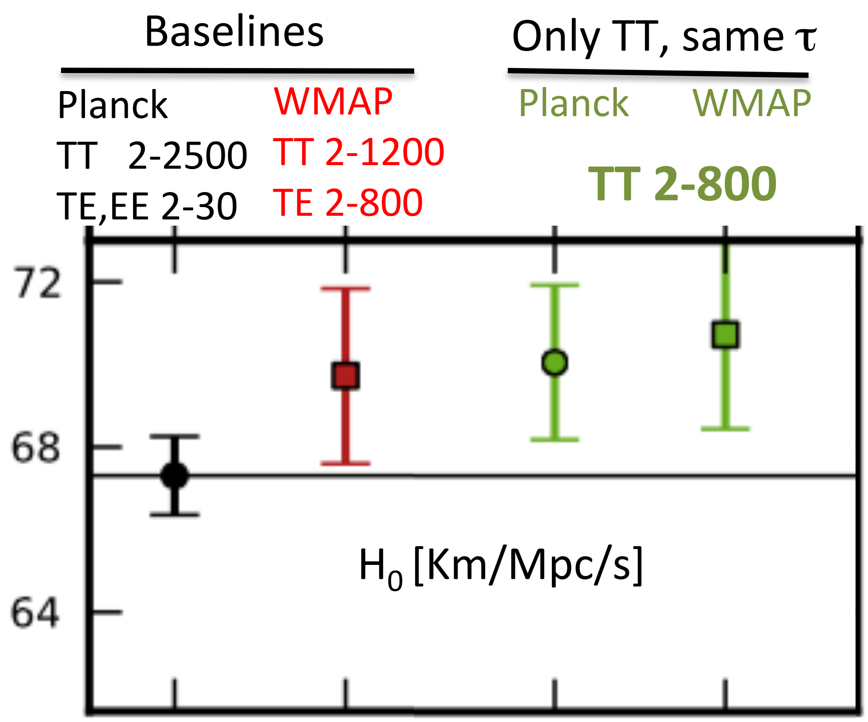


Planck sample variance limited till **l~1600** (data points till ~2500, fsky~40-70%)

WMAP sample variance limited till **l~600** (data points till l~1200)

Compare apples to apples

- Same prior on the optical depth, temperature only, same multipole region (although noise properties and fsky are still different).



- Planck and WMAP agree very well when compared properly.
- This confirms the findings of comparison at map/power spectrum level.
- **Still need to prove that shifts between lmax=800 and lmax=2500 for Planck itself are consistent with expectations!**

Simulations

- We simulate ~5000 TT power spectra and estimate cosmological parameters from each different l-ranges (e.g. l<800 and l<2500).

- We only use **TT data** and use a prior on the optical depth τ=0.07+-0.02 as a proxy of the large scale polarization data (but we also tested the a prior τ=0.055+-0.01, compatible with the latest HFI results 2016).

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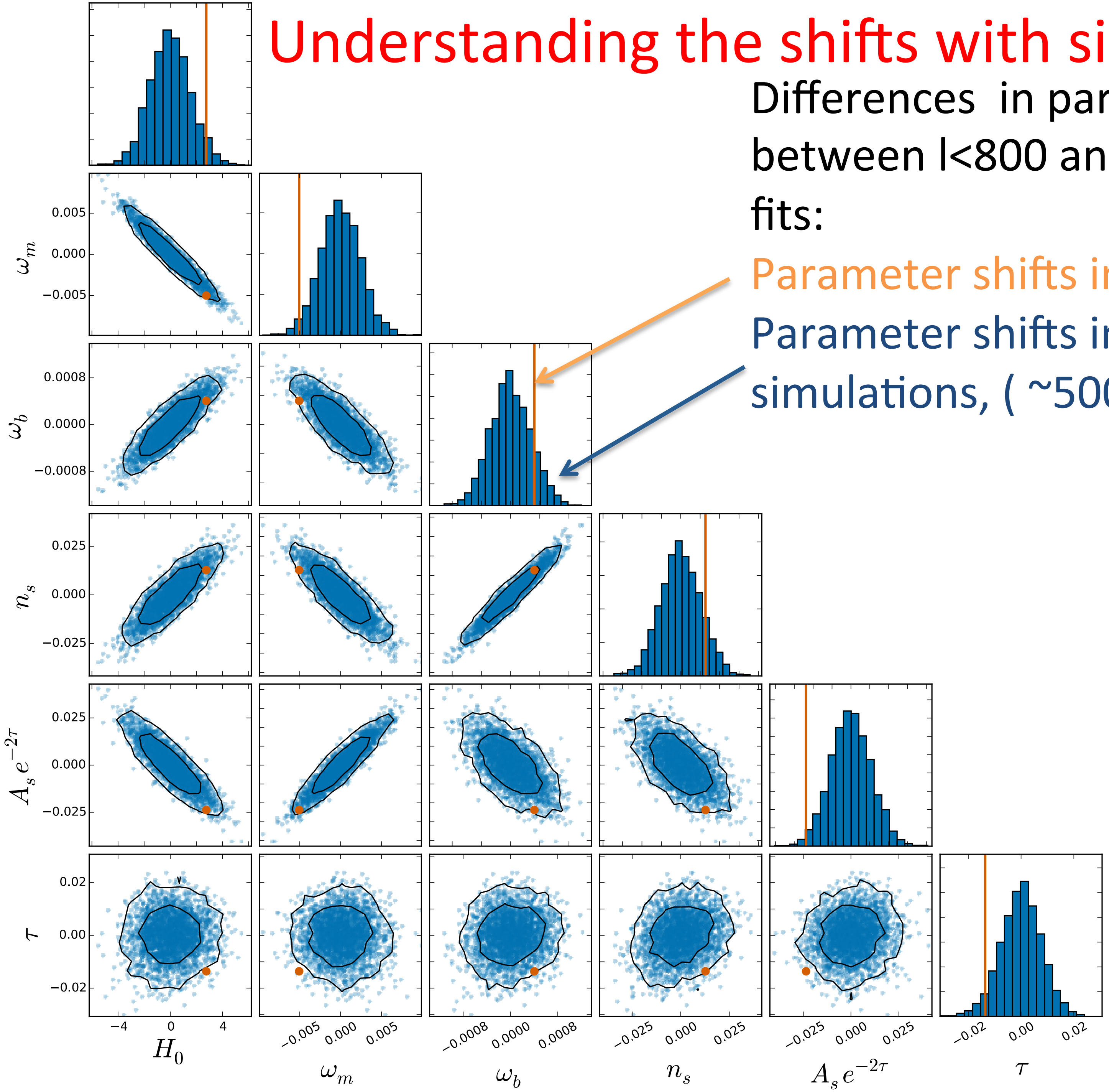
Understanding the shifts with simulations



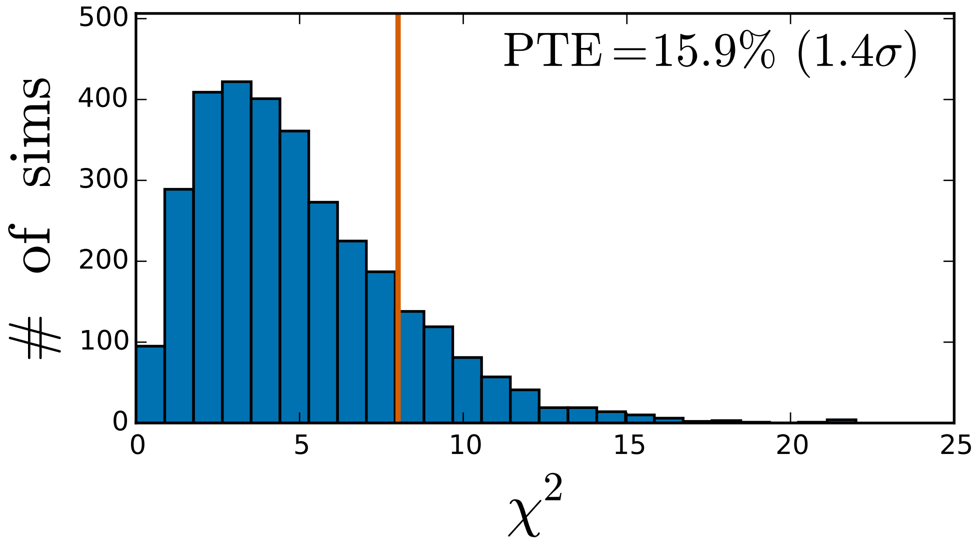
Differences in parameters between l<800 and l<2500 best-fits:

Parameter shifts in the data

Parameter shifts in the simulations, (~5000 sims)

Planck collaboration LI 2016

Parameter shifts and their statistical significance



PTE=15.9%, equivalent to 1.4σ.

i.e. 15.9% of the sims exceed the data. Corresponds to the number of outliers larger than 1.4σ for a 1D gaussian.

The difference is **not** statistically very significant.

χ^2 of the parameter differences

$\chi^2 = \Delta p^T \Sigma^{-1} \Delta p$

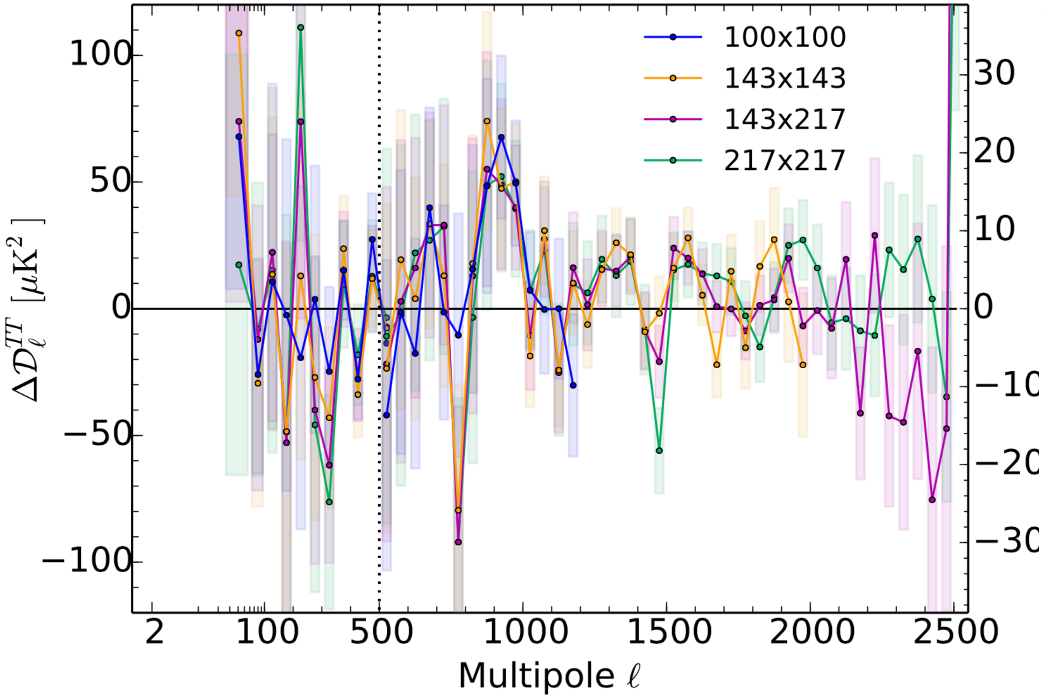
$\Delta p = p[2\text{-}2500] - p[2\text{-}800]$

Significances

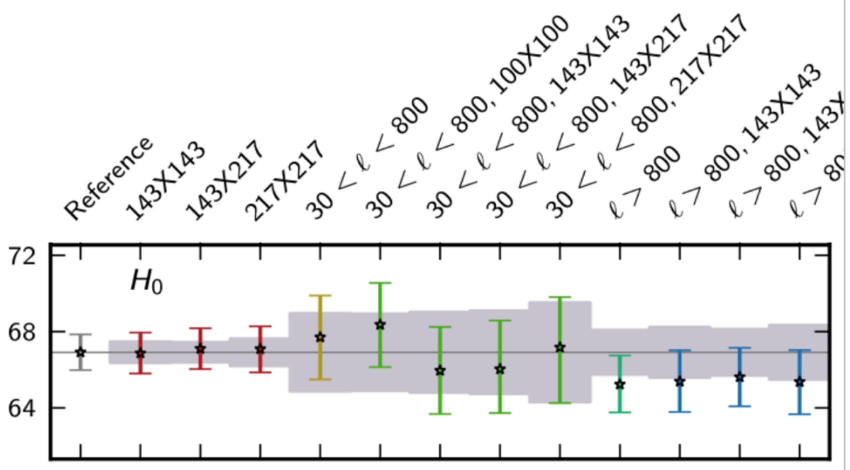
Data set 1	Data set 2	Test	
		χ^2	max-param
$\ell < 800$	$\ell < 2500$	$1.4\,\sigma^\dagger$	$1.7\,\sigma$ $(A_s e^{-2\tau})$
$\ell < 800$	$\ell > 800$	$1.6\,\sigma$	$2.1\,\sigma$ $(A_s e^{-2\tau})$
$\ell < 1000$	$\ell < 2500$	$1.8\,\sigma^\dagger$	$1.5\,\sigma$ $(A_s e^{-2\tau})$
$\ell < 1000$	$\ell > 1000$	$1.6\,\sigma$	$1.6\,\sigma$ (ω_m)

The differences are not statistically very significant.

Consistency between frequencies



Power spectrum features are very similar across frequencies. Cosmological parameters inferred from different frequencies are in very good agreement.

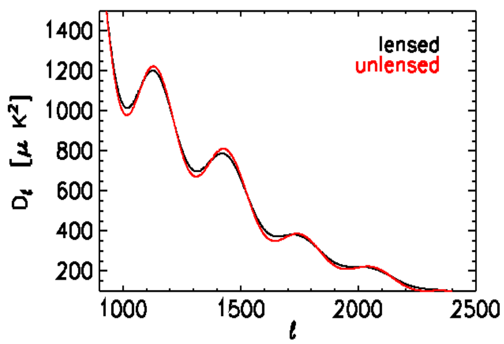


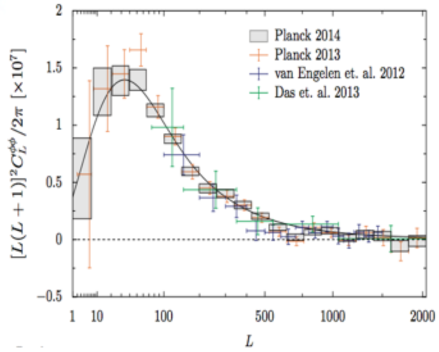
What is driving the shifts between lmax=800 and lmax=2500?

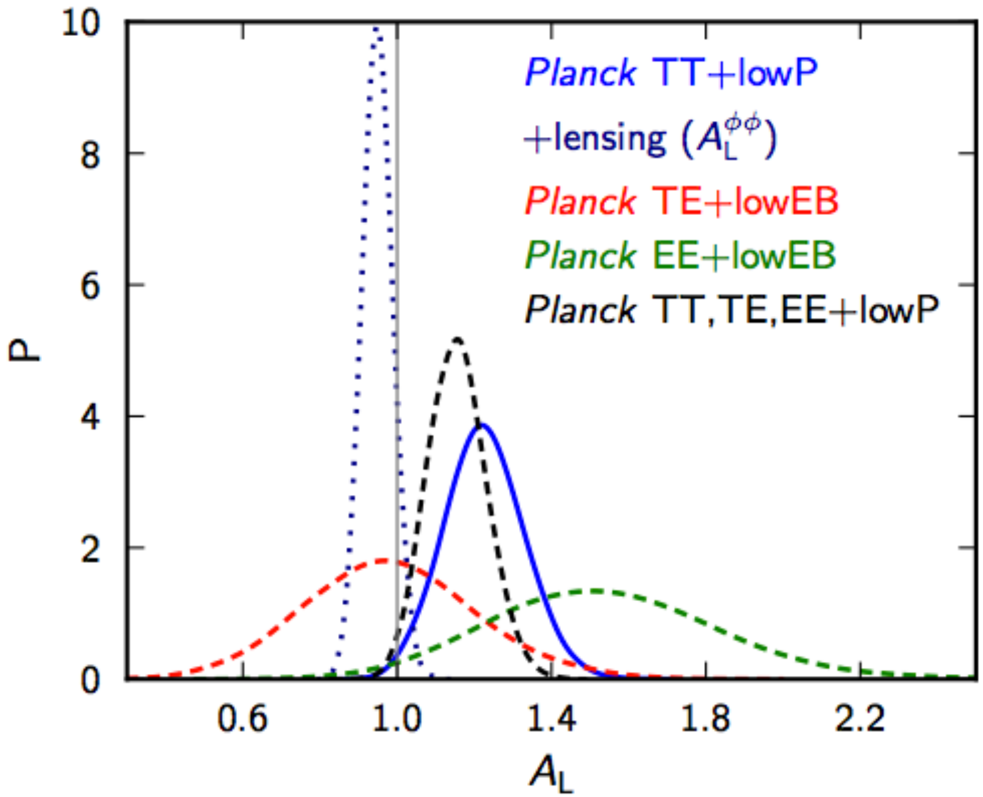
1. Is there a preference for extra-lensing?

2. Is it the low-l anomaly?

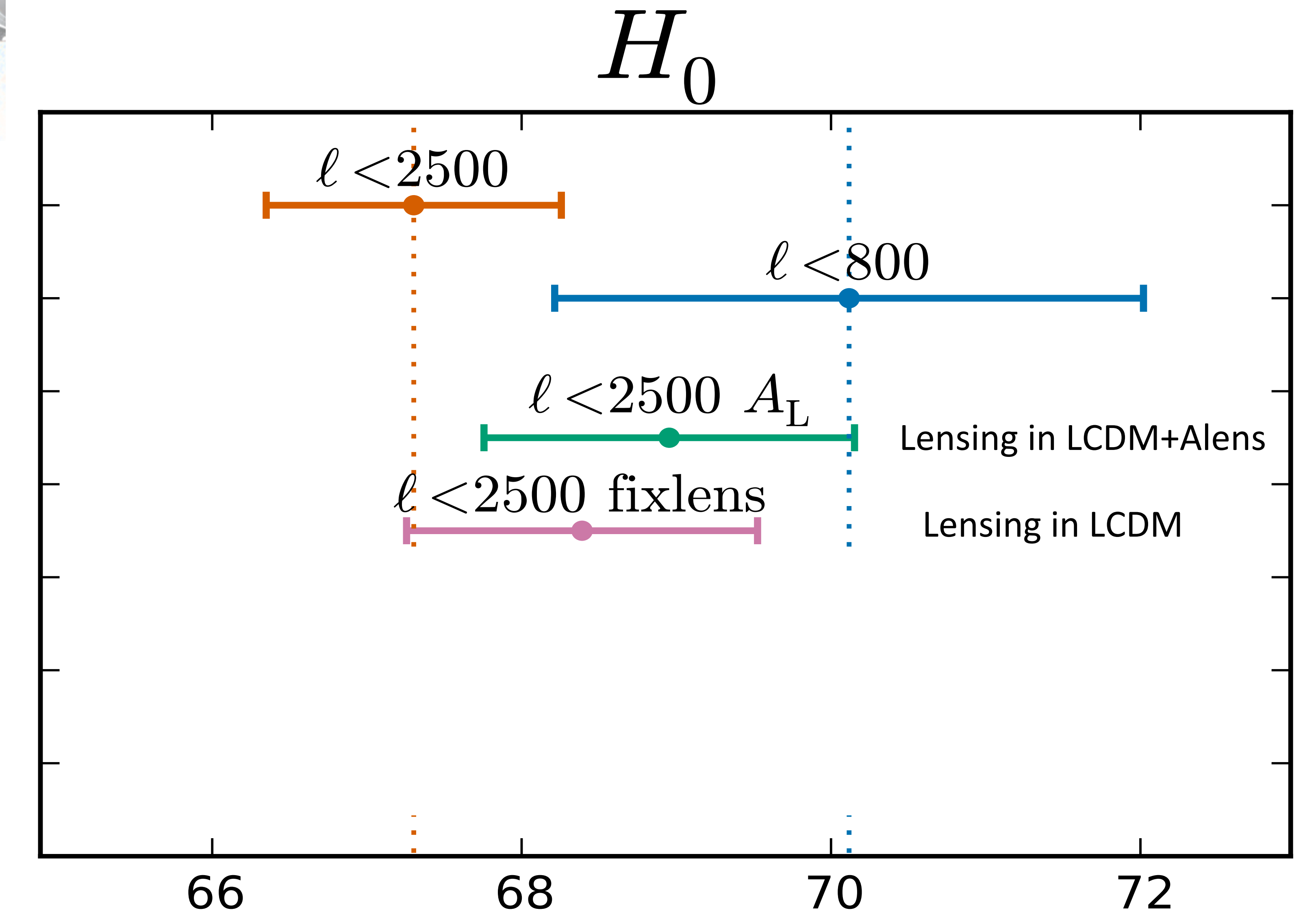
A slight preference for high lensing in the power spectrum





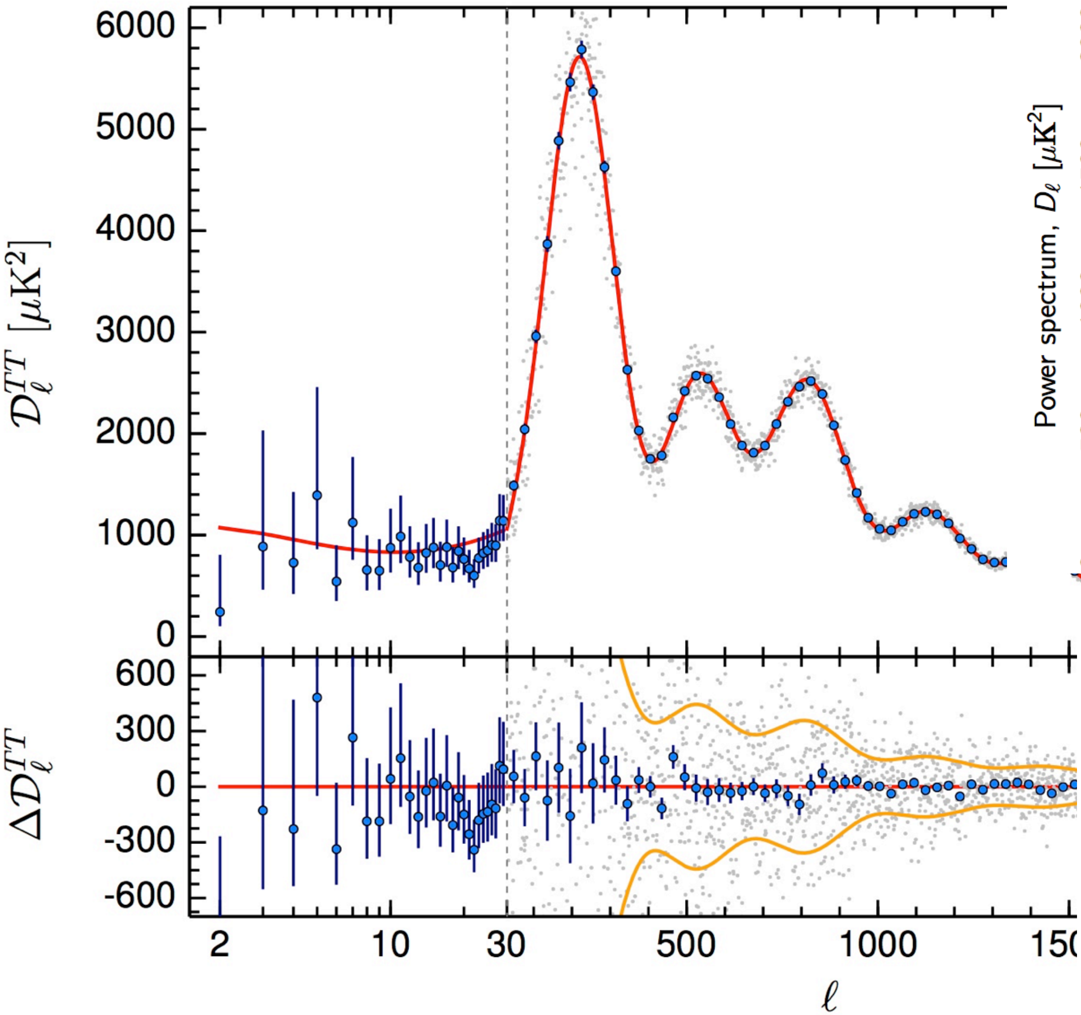


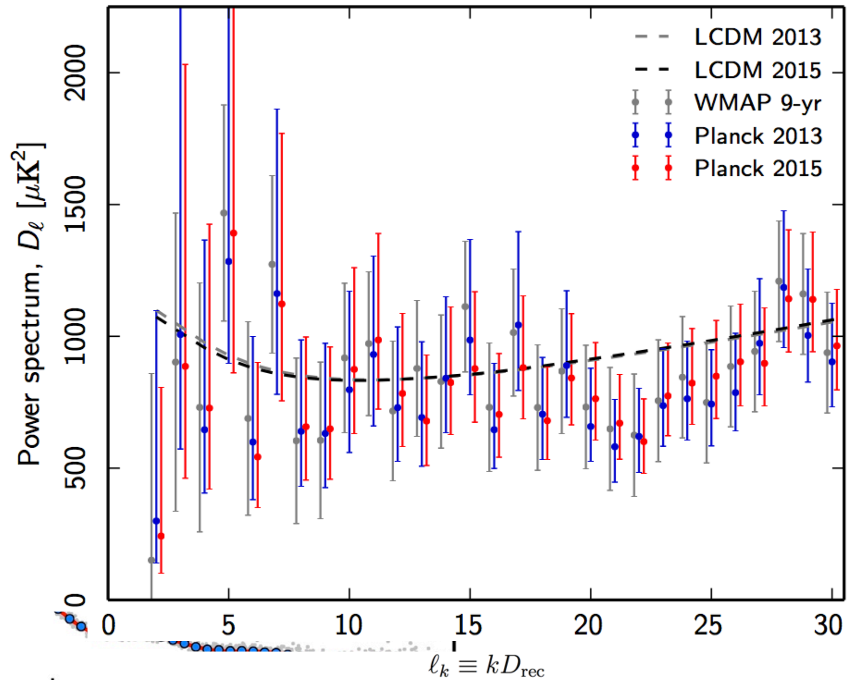
- A_L parametrizes amplitude of lensing power spectrum.
- In LCDM+A_L model, TT power spectrum prefers a ~2-sigma larger lensing amplitude than LCDM prediction.
- We do not think this is physical, because the lensing reconstruction does not share this preference for high amplitude.
- **This could just be a statistical fluctuation in the data.**

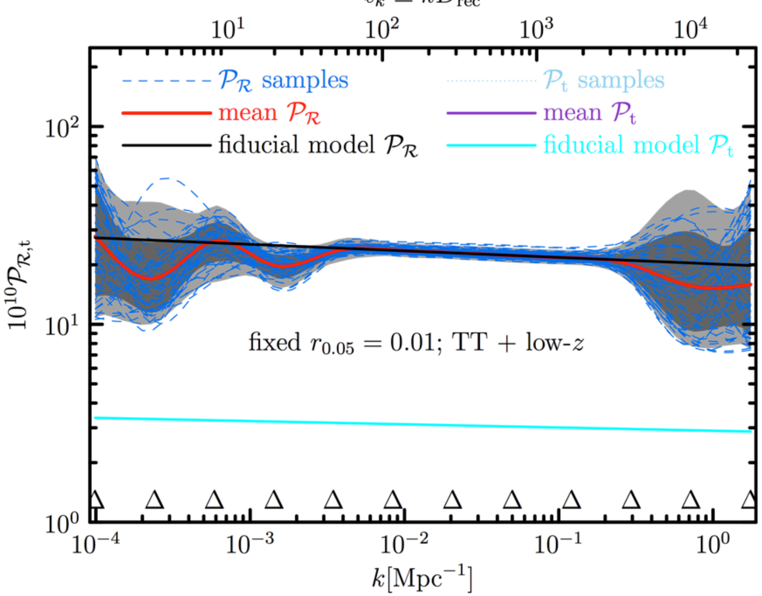


H_0
$\ell < 2500$
$\ell < 800$
$\ell < 2500\ A_L$
Lensing in LCDM+Alens
$\ell < 2500$ fixlens
Lensing in LCDM
66
68
70
72

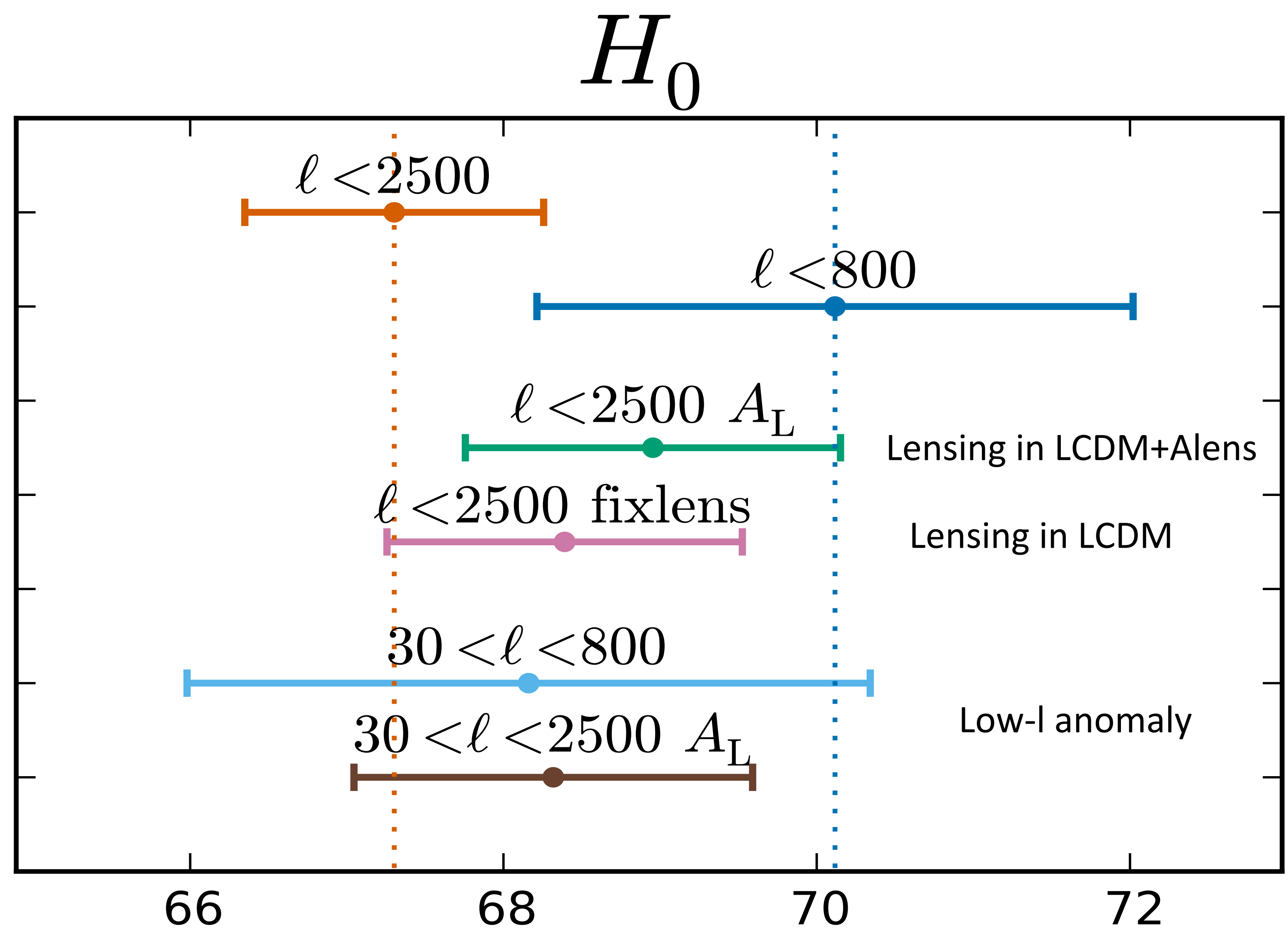
Is it the low-l anomaly?







See also Hannestad 03, Shafieloo 03,
Bennet et al. 2011, Mortonson et al. 2009 and many others



H_0
$\ell < 2500$
$\ell < 800$
$\ell < 2500 \;\; A_L$
Lensing in LCDM+Alens
$\ell < 2500$ fixlens
Lensing in LCDM
$30 < \ell < 800$
$30 < \ell < 2500 \;\; A_L$
Low-l anomaly
66
68
70
72

Conclusions

- Planck consistent with BAO, SN, BBN. Open issue with clusters, weak lensing. Tension with direct measurements of H_0.
- H_0 tension present also in WMAP+BAO+SN.
- WMAP and Planck in very good agreement if compared at same scales.
- WMAP+SPT do not have statistical power of Planck
- Planck low-l Planck high-l in good statistical agreement
- Smoothing of high-l peaks and low-l deficit possibly responsible for shifts between low and high-l.

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada.

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.