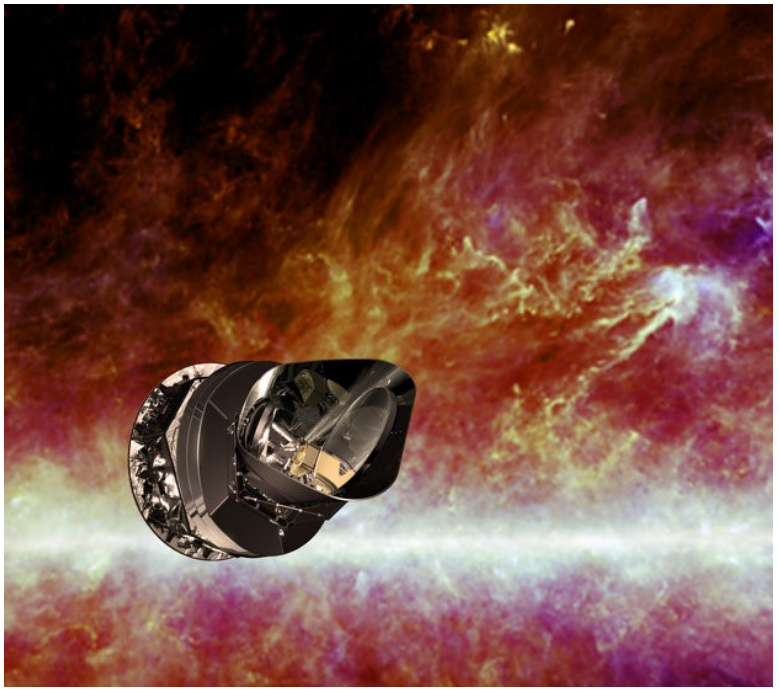
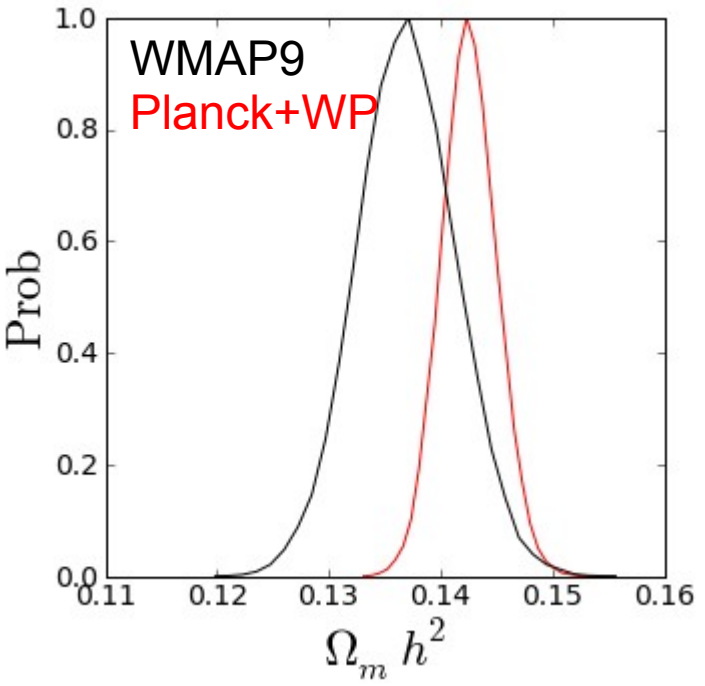
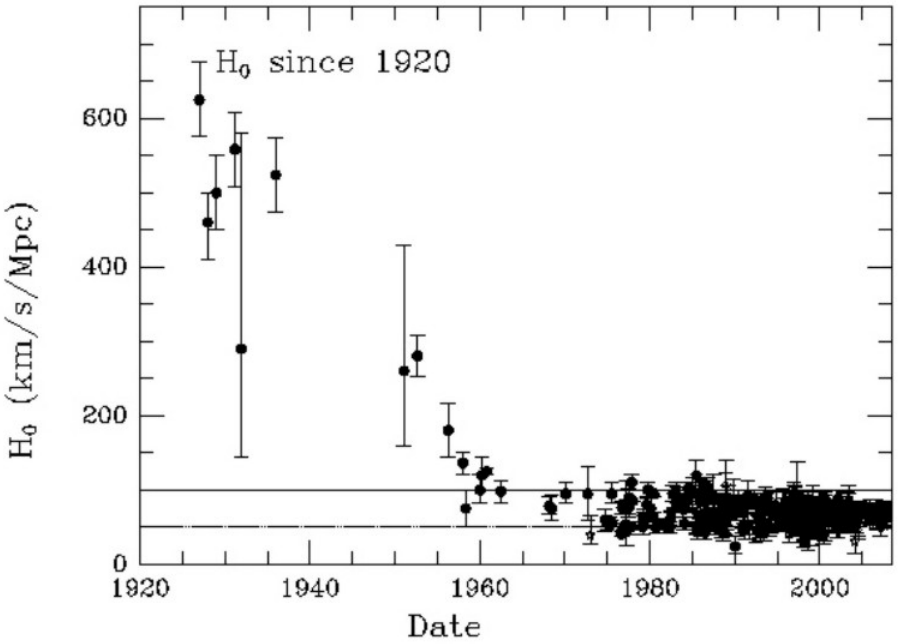
Planck LCDM and Extensions

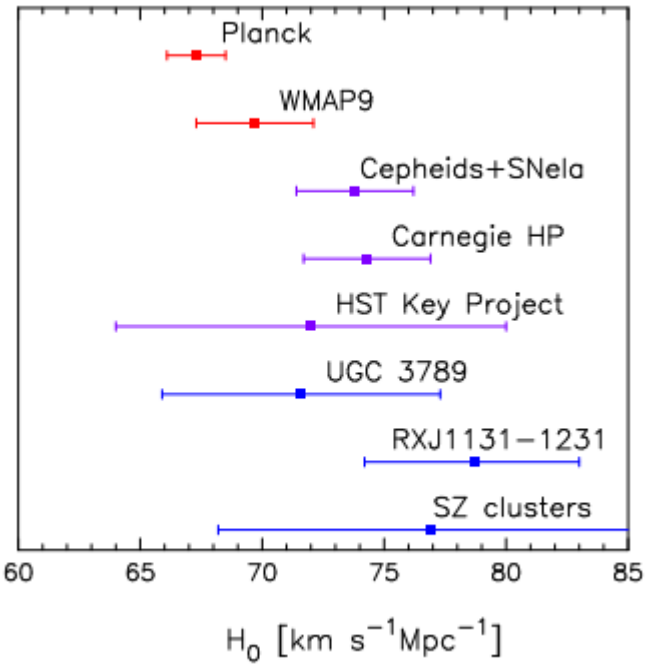
Planck Collaboration
Marius Millea
UC Davis Graduate Student
Planck, SPT member



Intro


WMAP9
Planck+WP
Prob
$\Omega_m h^2$

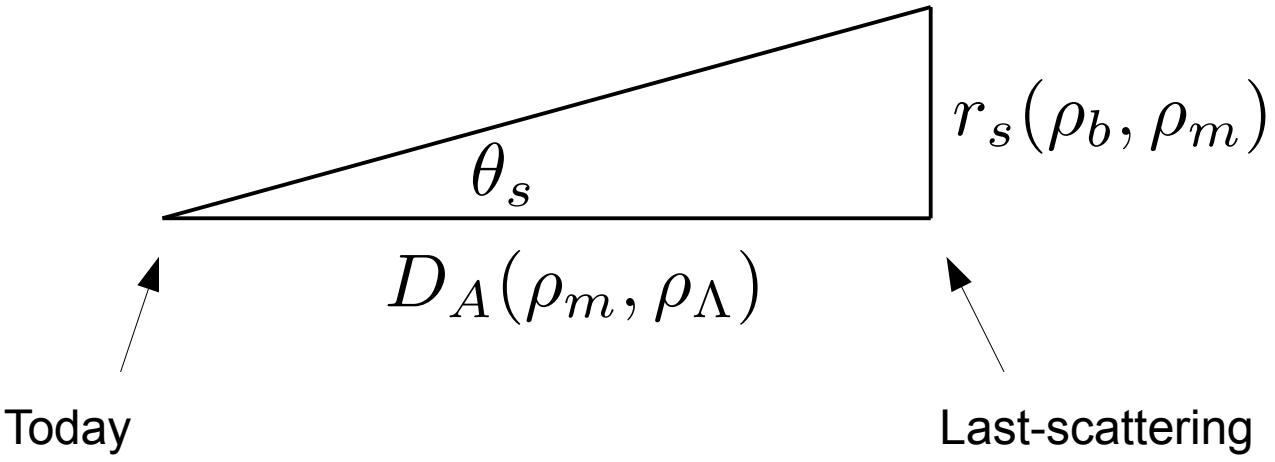

H_0 since 1920
H_0 (km/s/Mpc)
Date


Planck
WMAP9
Cepheids+SNela
Carnegie HP
HST Key Project
UGC 3789
RXJ1131−1231
SZ clusters
H_0 [km s^{-1}Mpc^{-1}]

How CMB measurements of ρ_m provide an inference of H_0

$$H_0^2 = \frac{8\pi G}{3}\left(\rho_m + \rho_\Lambda\right)$$

R=0.95 $\rho_m \uparrow$ $H_0 \downarrow$



In particular, assuming $\sum m_\nu = 0.06\mathrm{eV}$

lowers H_0 by 0.6 km/s/Mpc (50% sigma)

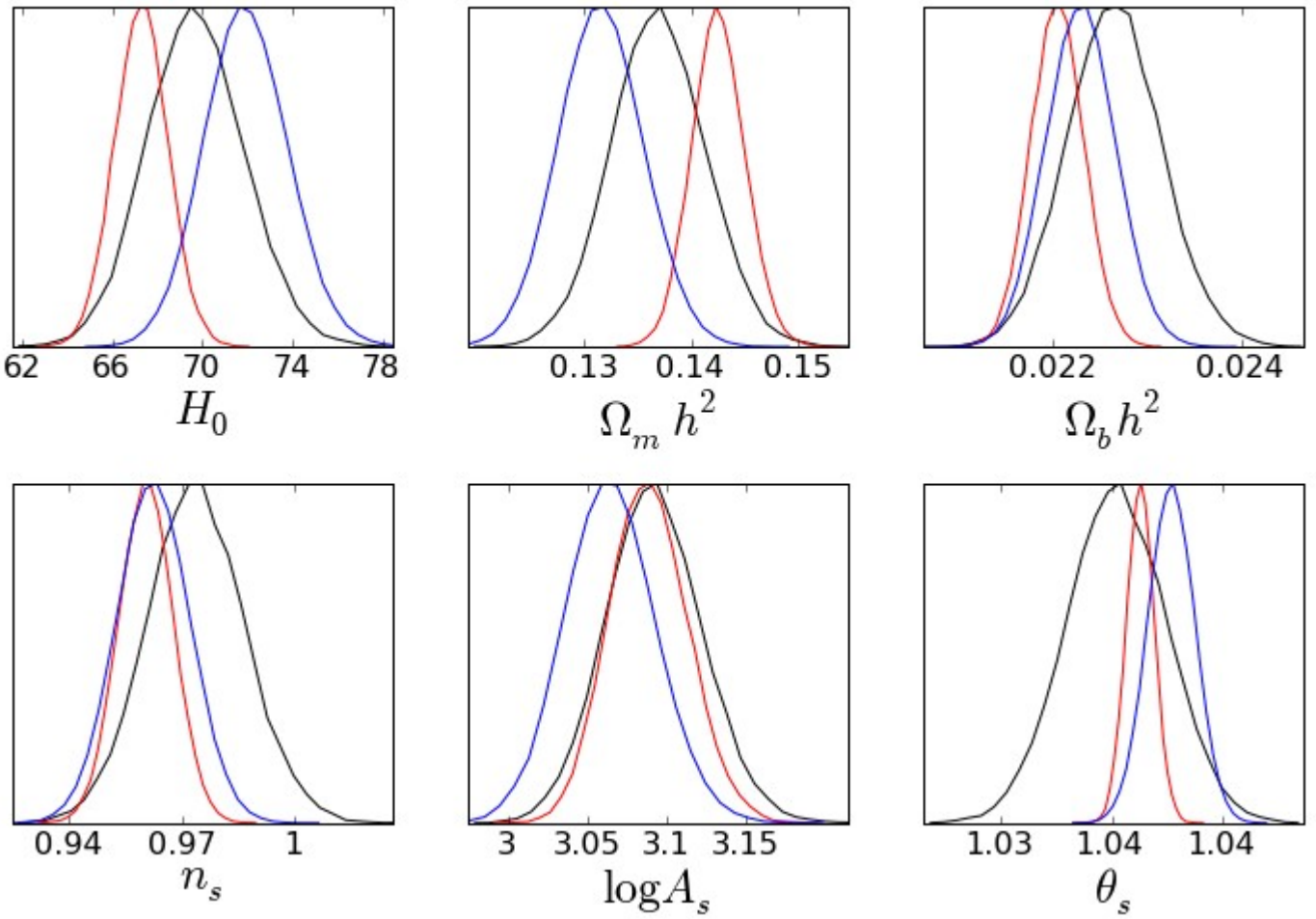
Outline

- LCDM
  - Planck-WMAP
  - Lensing
  - Damping
  - Robustness tests
  - Planck-SPT
- LCDM+Extensions

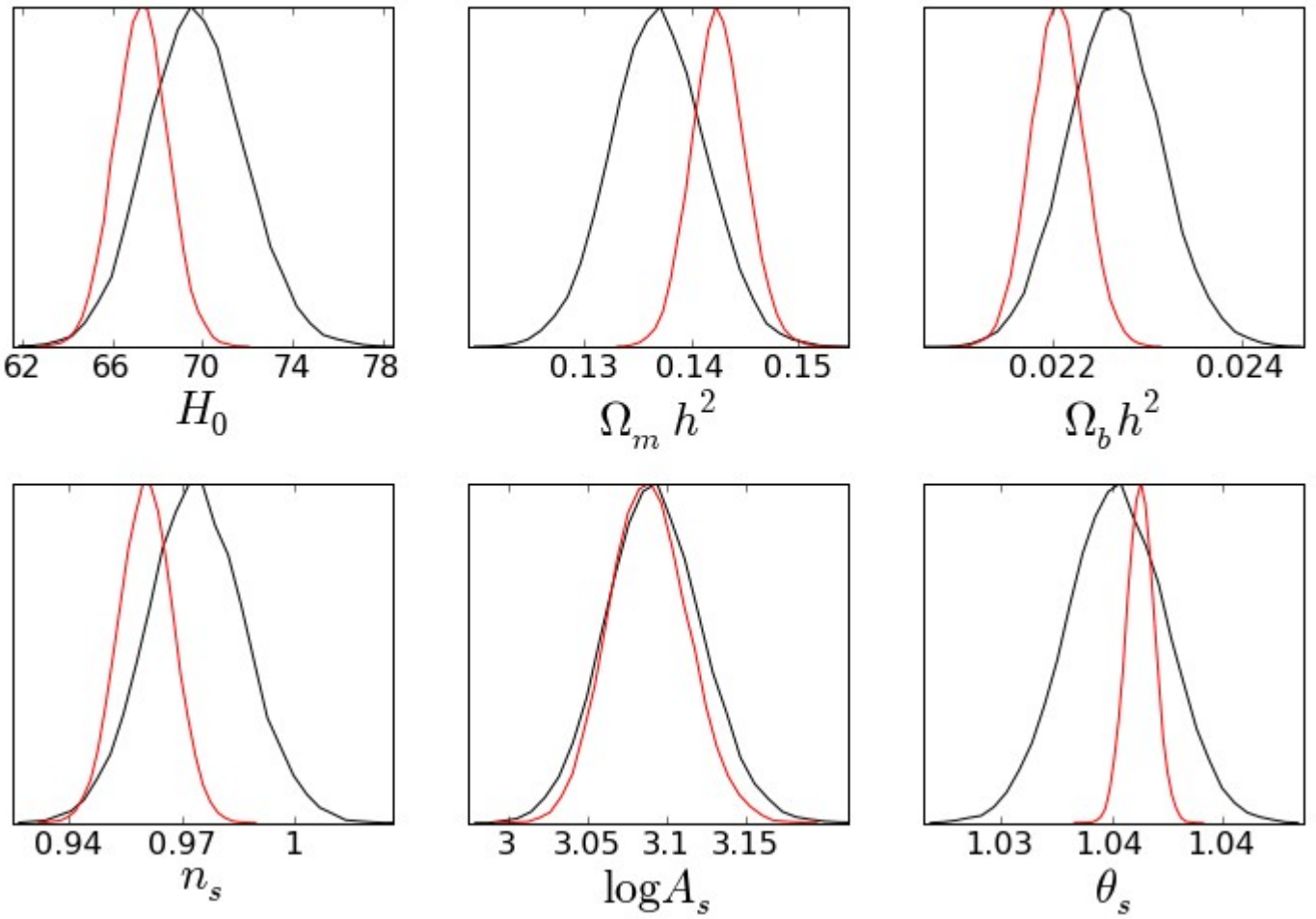
Outline

- LCDM
  - Planck-WMAP
  - Lensing
  - Damping
  - Robustness tests
  - Planck-SPT
- LCDM+Extensions

WMAP9
Planck+WP
WMAP7+SPT

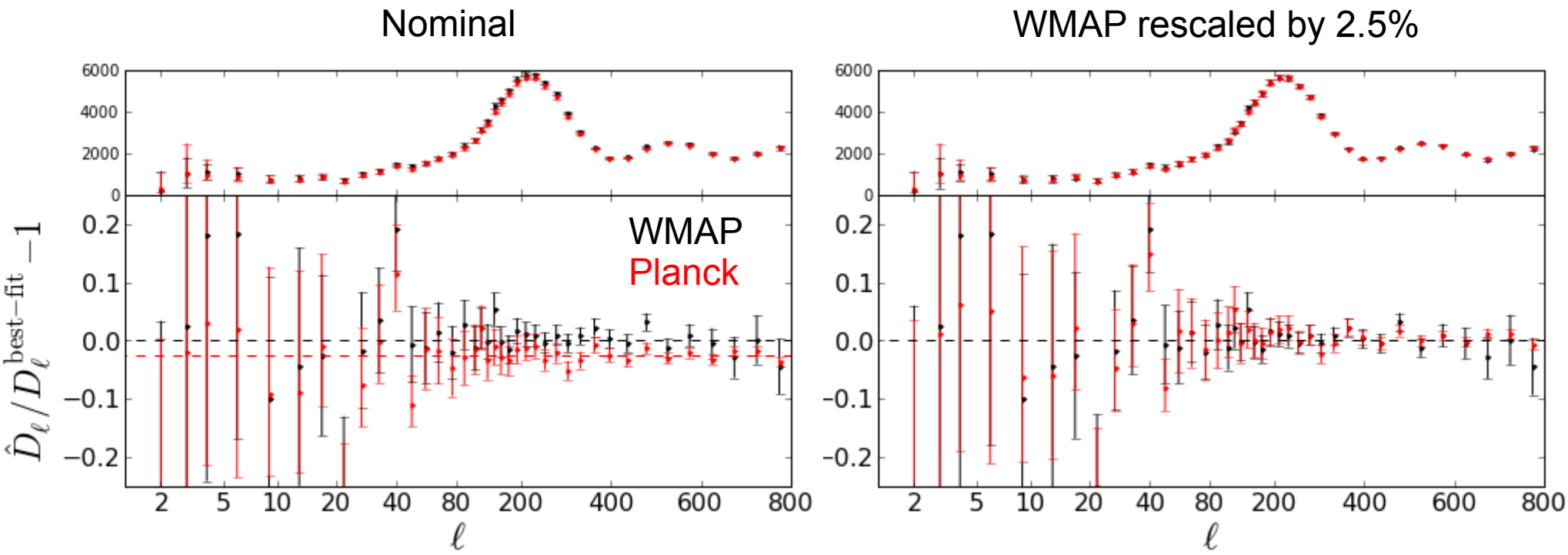


WMAP9
Planck+WP



WMAP-Planck Agreement

- A 2.5% rescaling removes most of the differences between WMAP and Planck

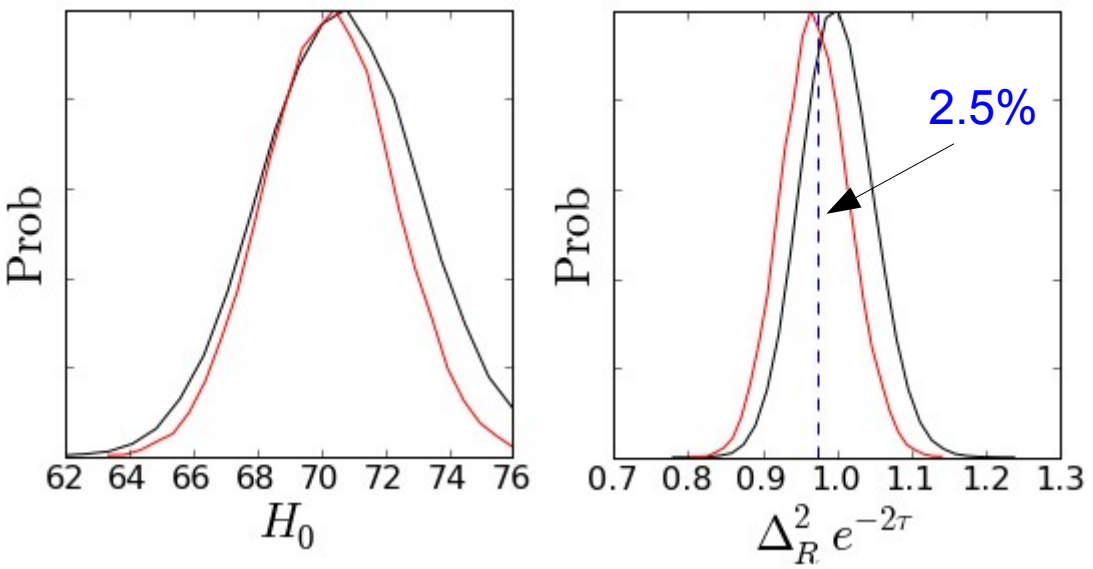


Note: different masks, beam uncertainties not included in error bars

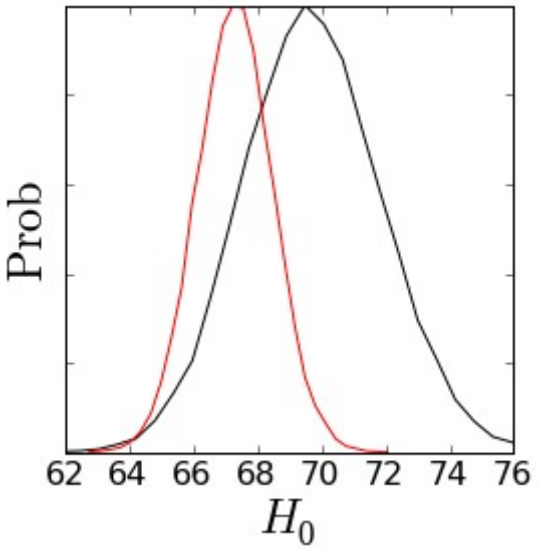
WMAP-Planck

L<800 only

WMAP
Planck



Full L range



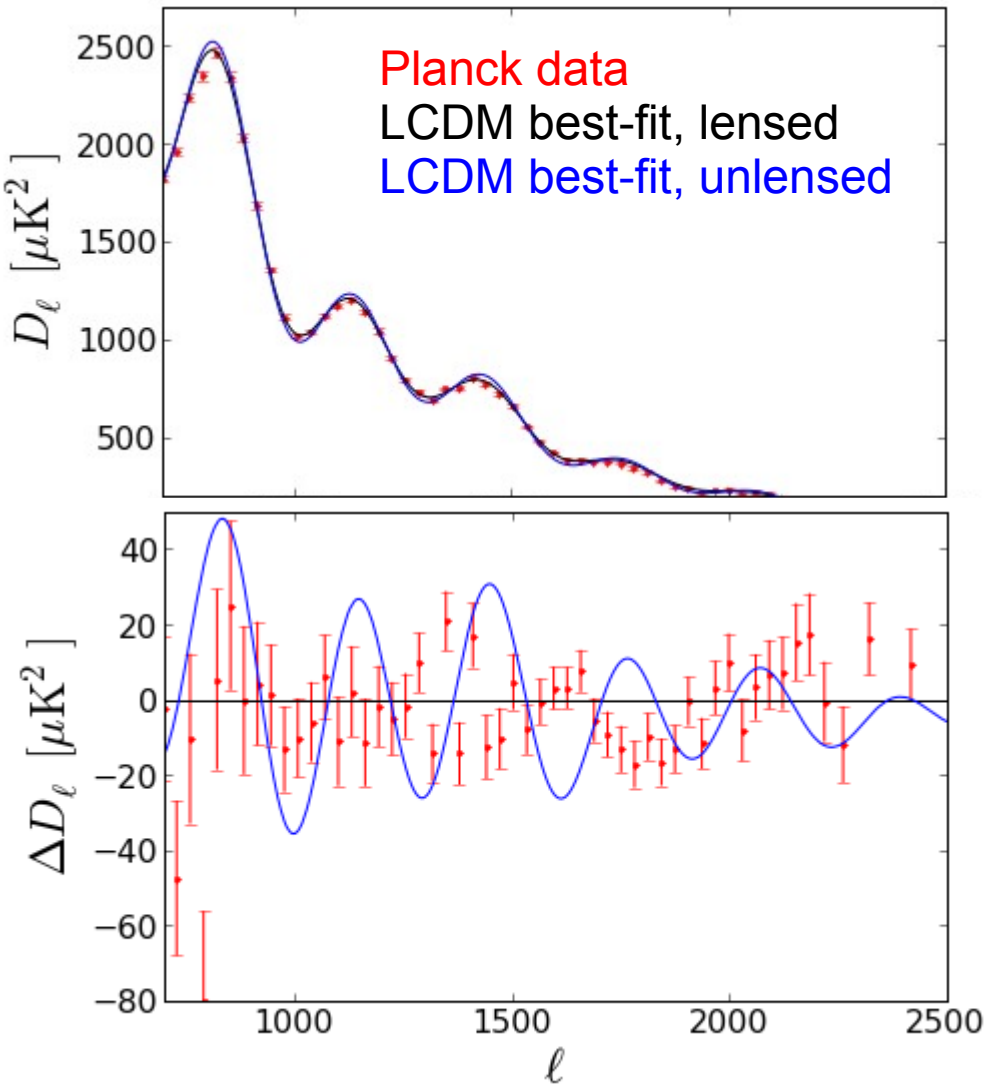
To understand WMAP/Planck differences, we need to understand Planck L<800 vs. L>800 differences

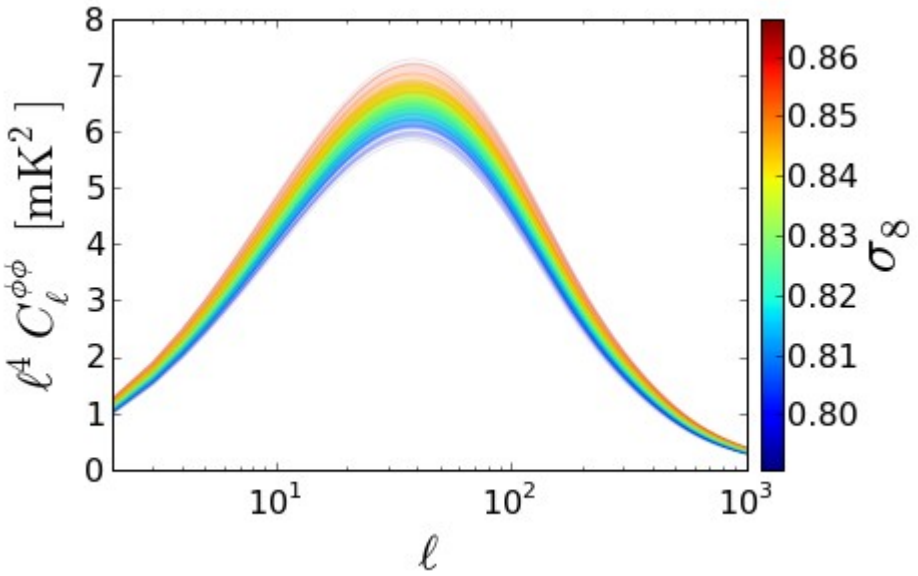
Outline

- LCDM
  - Planck-WMAP
  - Lensing
  - Damping
  - Robustness tests
  - Planck-SPT
- LCDM+Extensions

Lensing

$$C_\ell^{TT,\mathrm{lensed}} \approx C_\ell^{TT,\mathrm{unlensed}} * C_\ell^{\phi\phi}$$

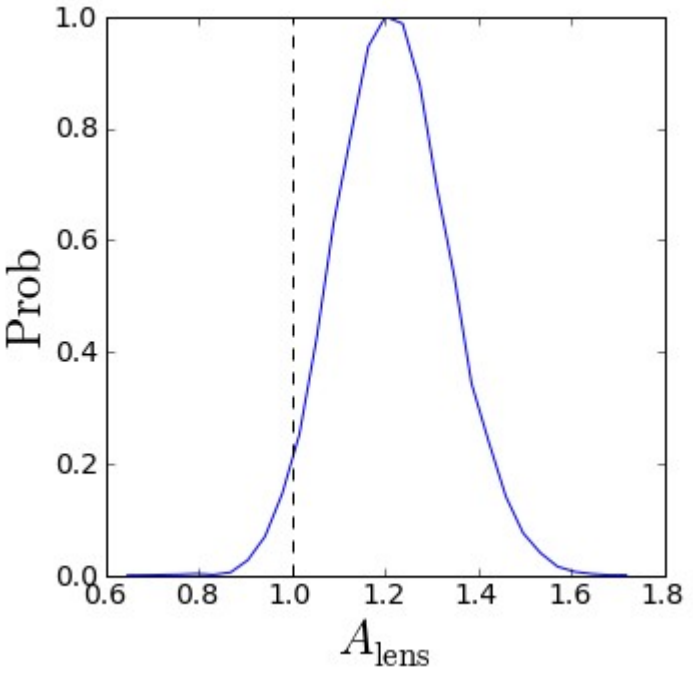


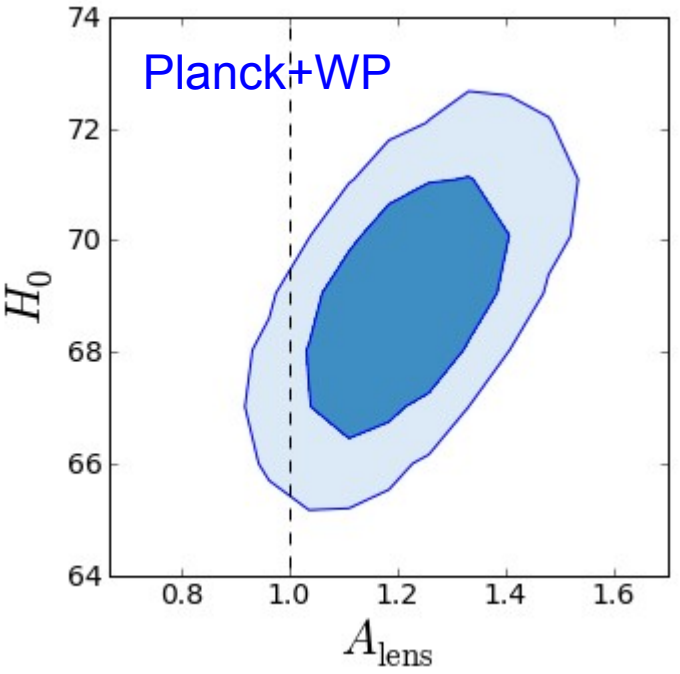


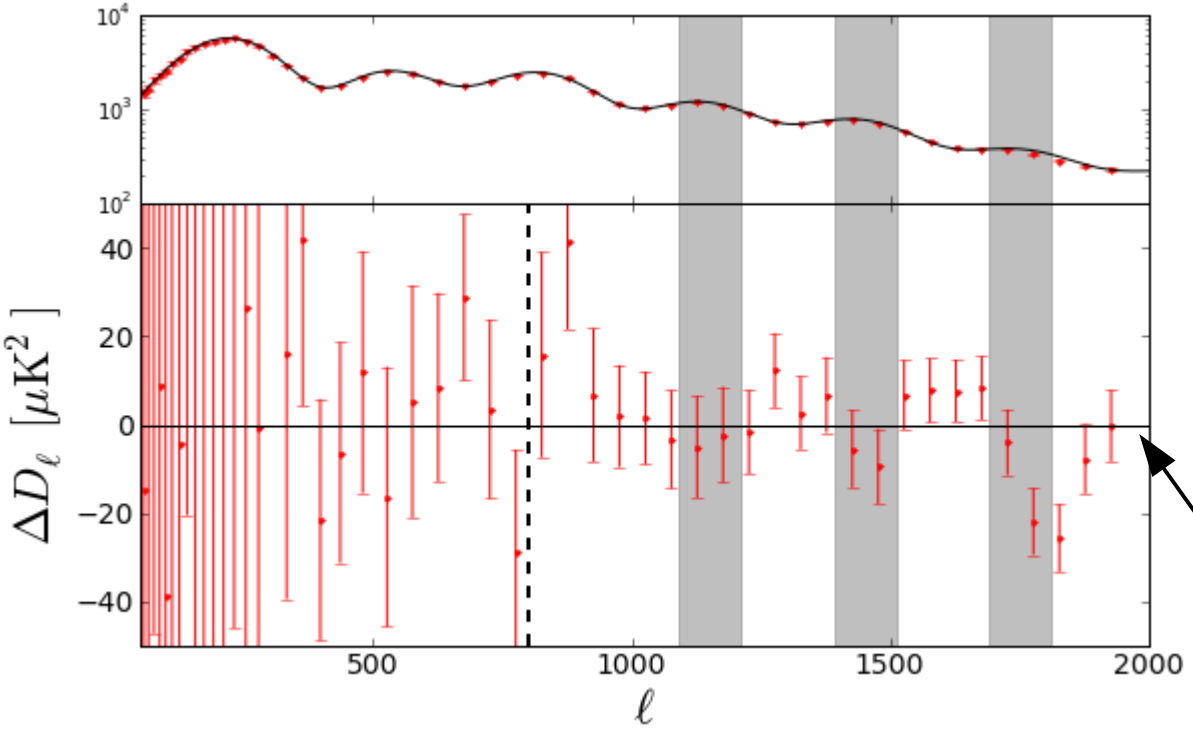
$\rho_m \uparrow$ $\sigma_8 \uparrow$

$$C_\ell^{\phi\phi} \rightarrow A_{\rm lens} C_\ell^{\phi\phi}$$

- No preference for high Alens in the lensing reconstruction
- Lensing reconstruction is consistent with LCDM best fit





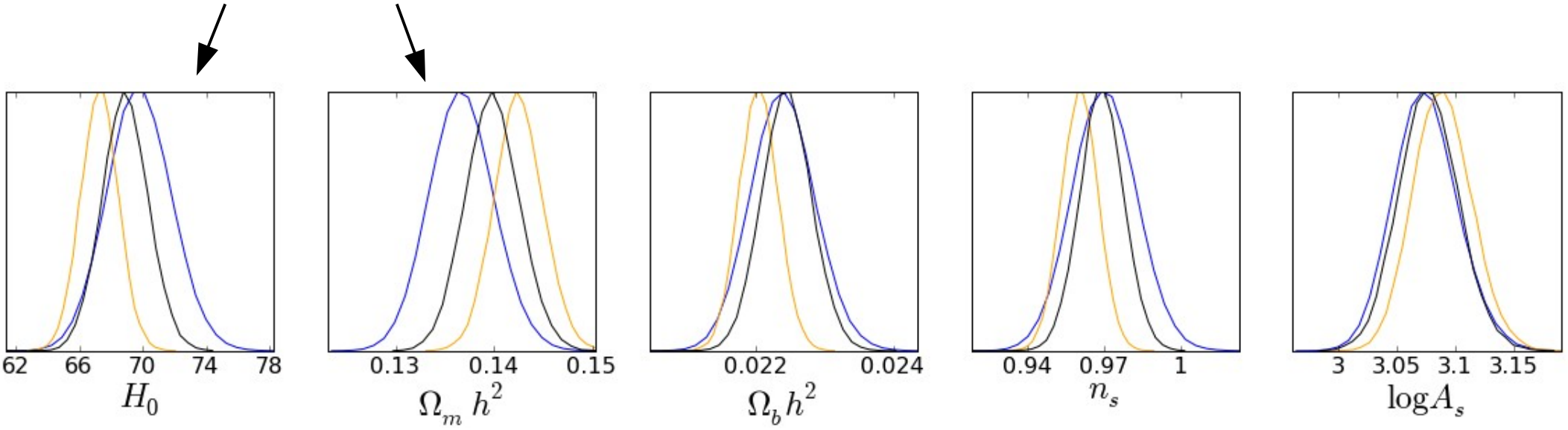


Planck 217-only data

Planck L<800 best fit LCDM

Removing lensing information returns you significantly towards L<800 constraints

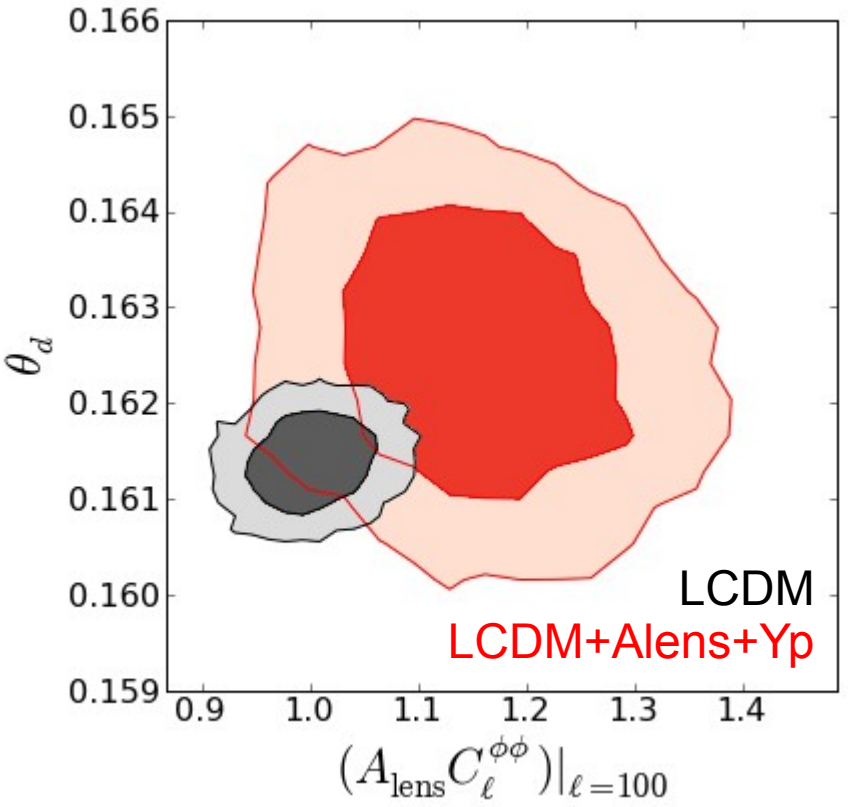
What else at L>800 is driving this remaining shift?



Planck L<800 LCDM
Planck L<2500 LCDM
Planck L<2500 LCDM+Alens

Damping

Freeing Y_p (helium fraction) is to damping as freeing A_{lens} is to lensing



- Unlike freeing A_{lens}, freeing Y_p does not return you closer to L<800 values
- Its not clear if there is actually a preference for *less power* at high L, because n_s increases to compensate increased damping
- Need to understand degeneracies

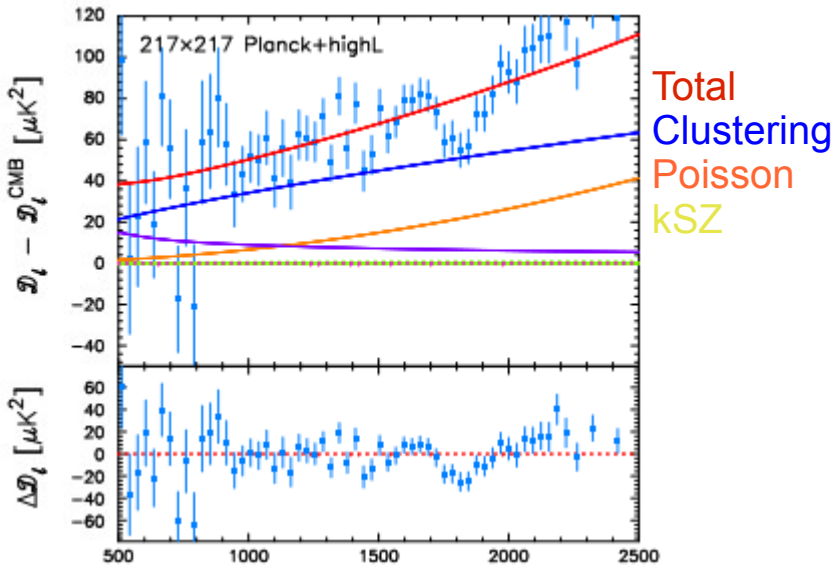
Outline

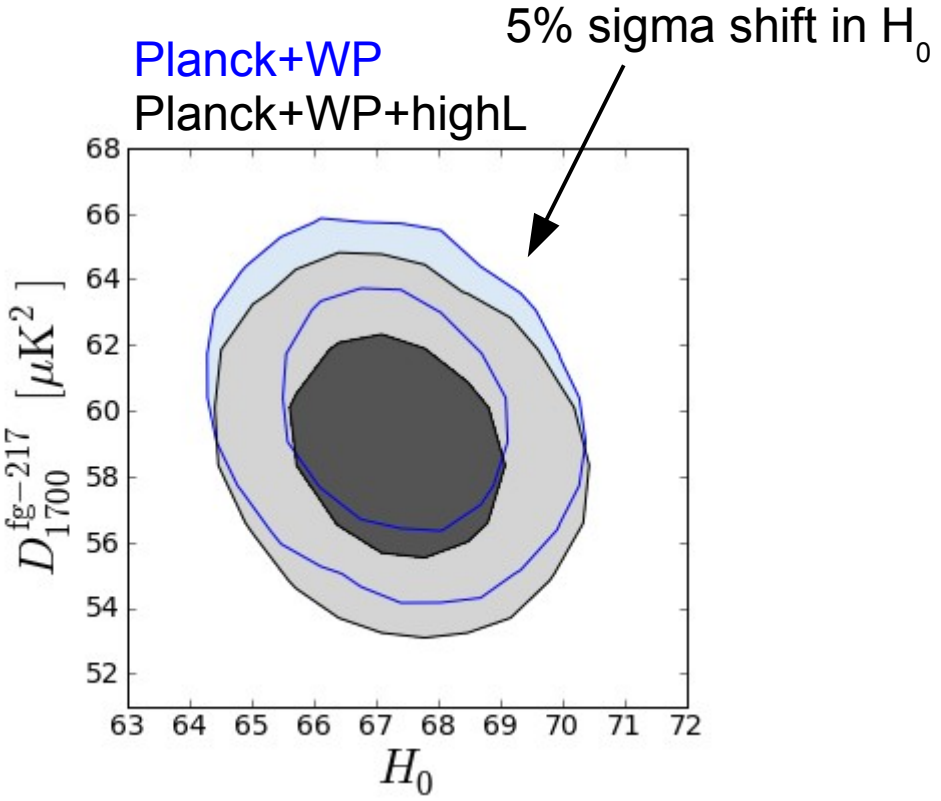
- LCDM
  - Planck-WMAP
  - Lensing
  - Damping
  - Robustness tests
  - Planck-SPT
- LCDM+Extensions

Extra-galactic Foregrounds

Emission from external galaxies and Sunyaev-Zeldovich effects contribute anisotropy power at high L

Planck Collaboration XVI 2013



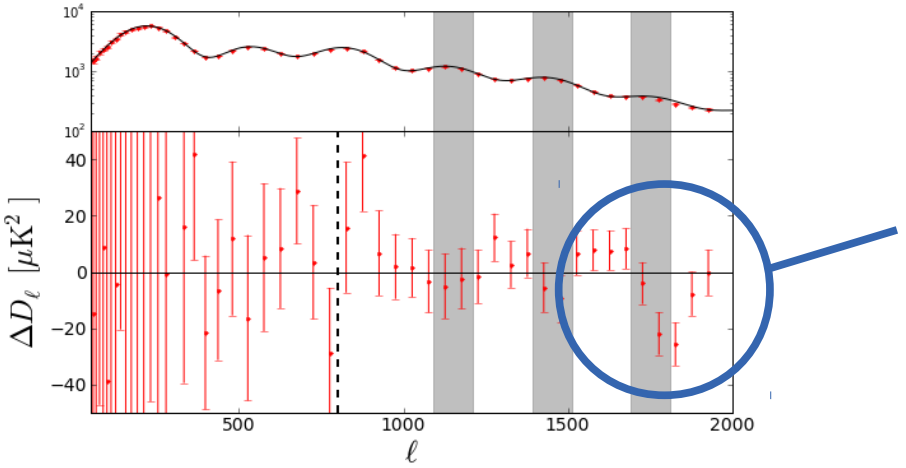


- Internal tests showed that the choice extra-galactic foreground model at most shifted H_0 by 20% sigma.

"low" H0 is robust to extra-galactic foreground modeling

L=1800 feature

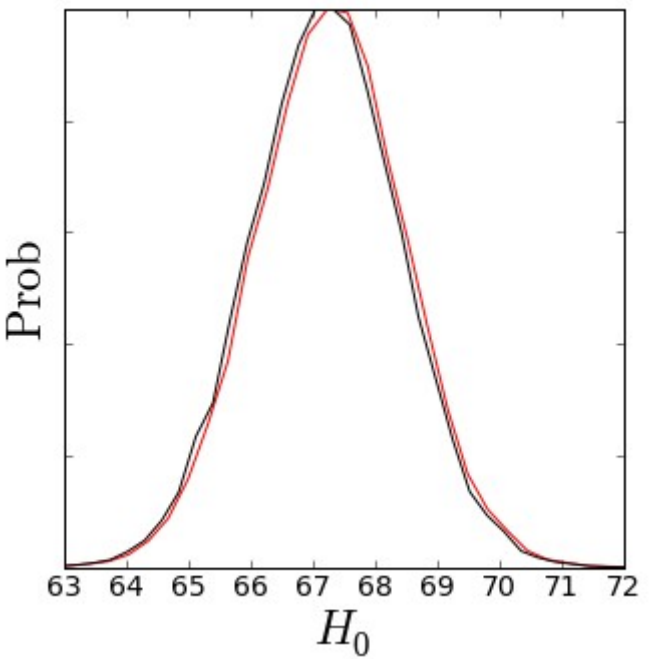
Planck 217-only data



- Pulling towards higher Alens
- Identified in the Inflation paper as the source of a local feature in the primordial power-spectrum reconstruction
- Not present in 143GHz, SPT or ACT

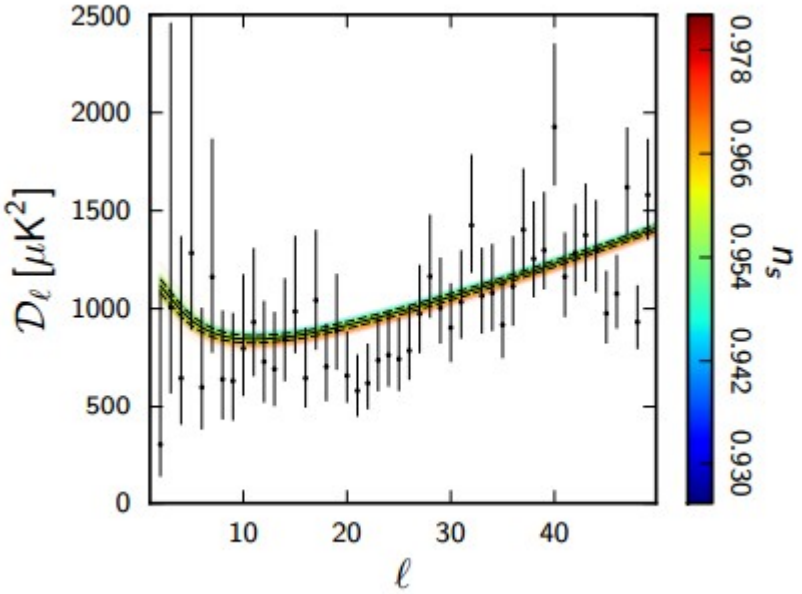
Planck+WP

Planck+WP 1700<L<1900 removed



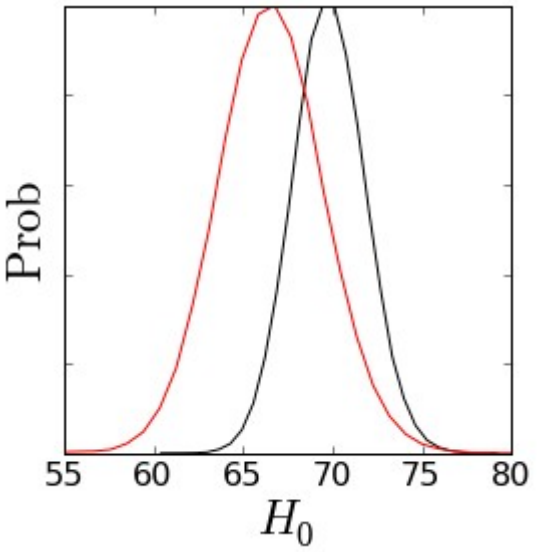
Low-L “anomaly”

Planck Collaboration XVI 2013



Low-L deficit was noted in WMAP, and grew worse in Planck because the best-fit model changed

Planck+WP L<800
Planck+taup 50<L<800



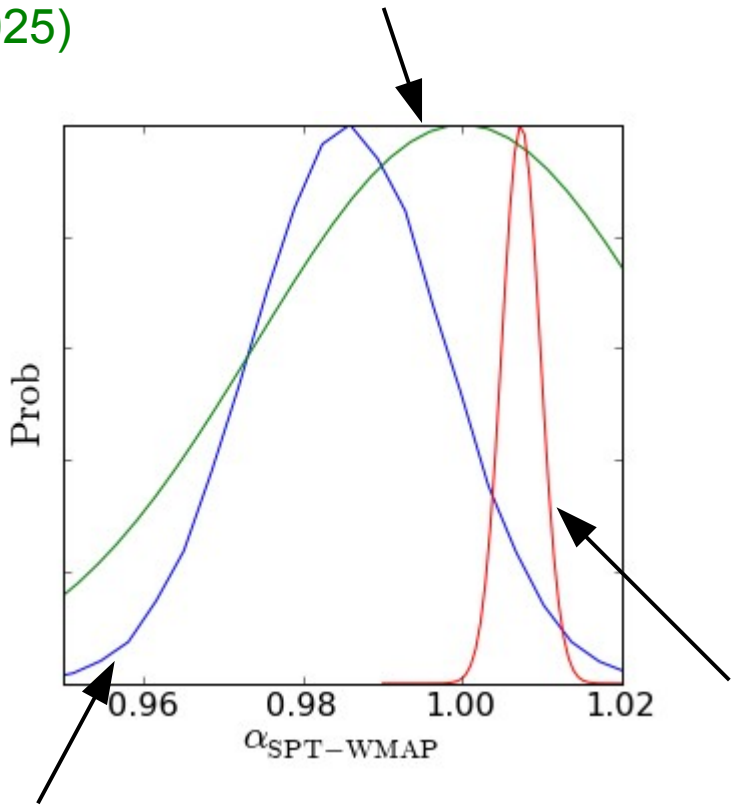
Outline

- LCDM
  - Planck-WMAP
  - Lensing
  - Damping
  - Robustness tests
  - Planck-SPT
- LCDM+Extensions

Planck-SPT

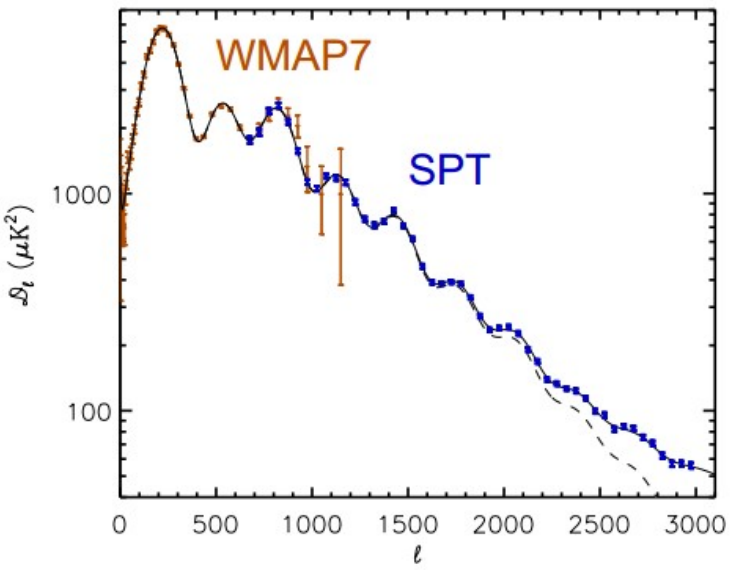
- SPT also measured the damping tail so why did H0 go up from WMAP?

Calibration prior from matching to WMAP7
(1.00 +/- 0.025)



Posterior from chain
(0.985 +/- 0.012)

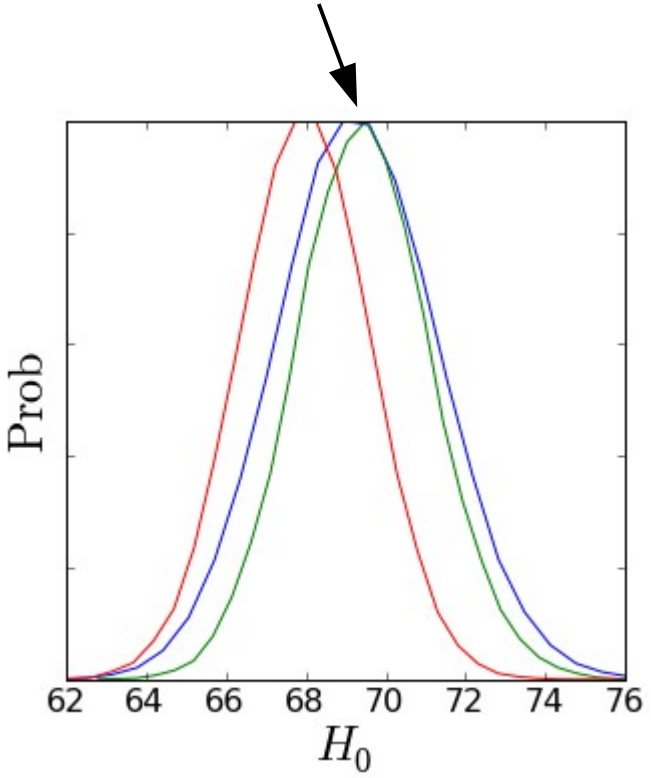
Story et al. 2012



Using Planck to calibrate WMAP7 and SPT to each other

Planck-SPT

No desire for significantly larger H0



SPT calibrated to Planck

LCDM	Planck L<800
LCDM	Planck L<800 + SPT S12
LCDM+Alens	Planck L<800 + SPT S12

SPT prefers low Alens, thus freeing Alens *lowers* H0
as pointed out in Hou et al. 2012

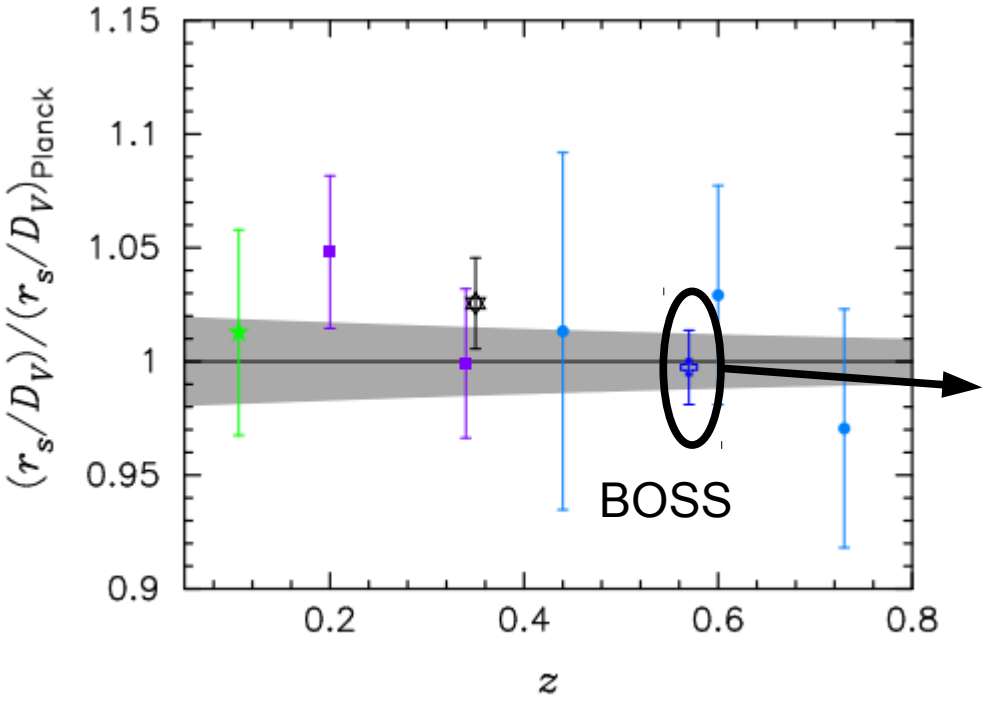
This also explains why SPT-WMAP calibration was driven to <1. SPT prefers lower matter density which predicts a lower third peak, and SPT calibration was matching that.

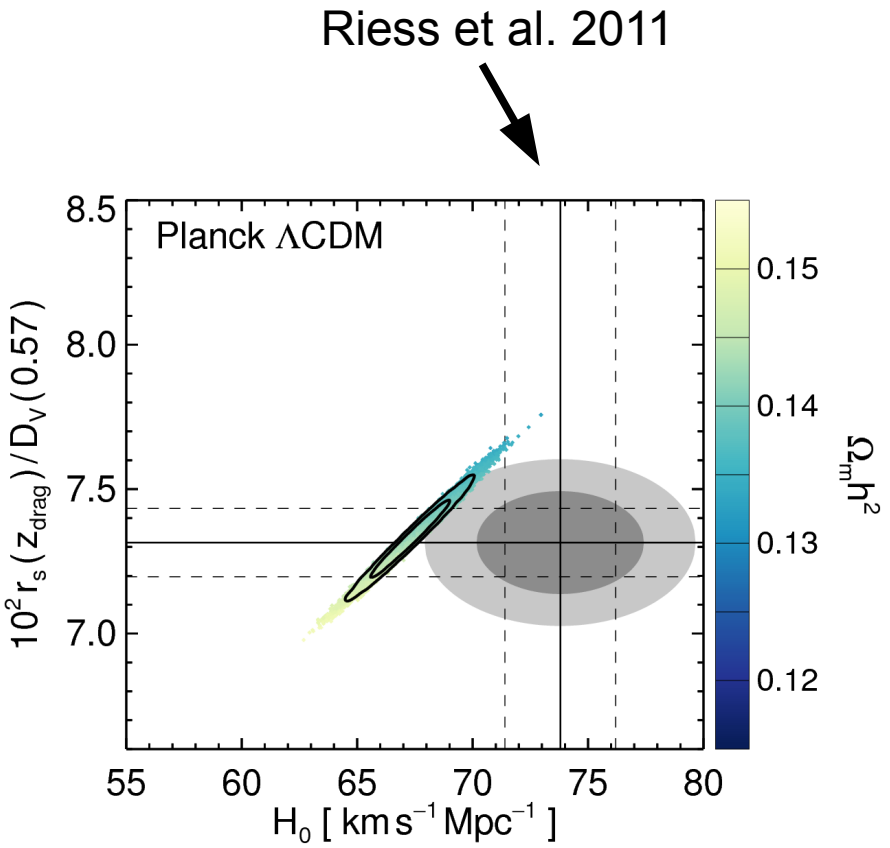
Outline

- LCDM
  - Planck-WMAP
  - Lensing
  - Damping
  - Robustness tests
  - Planck-SPT
- LCDM+Extensions

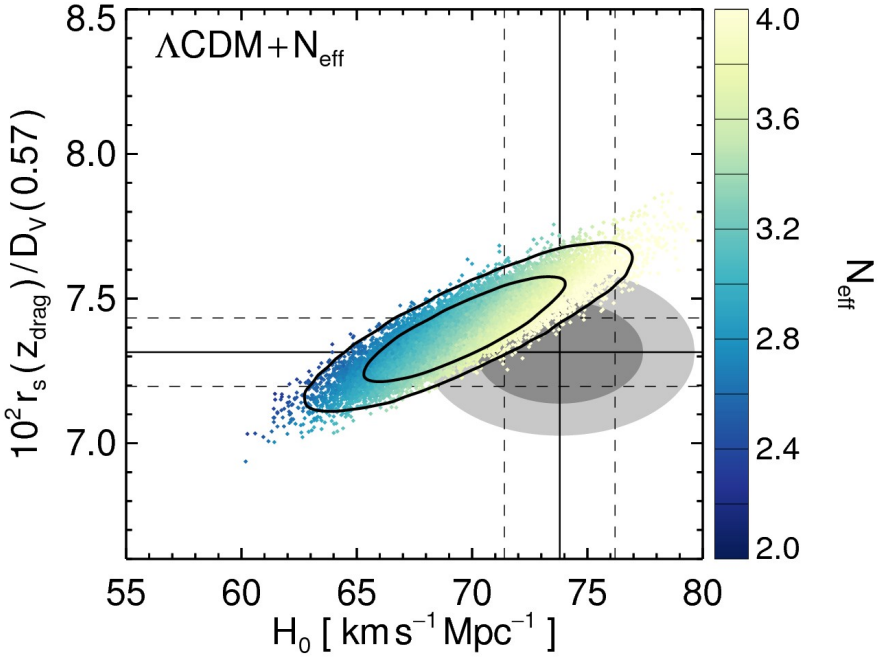
LCDM+Extensions

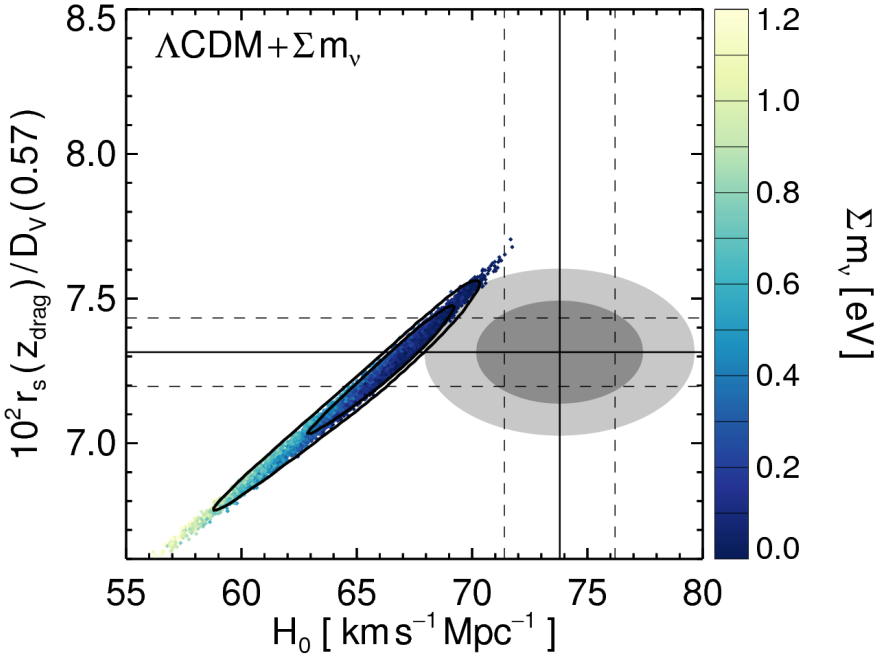
- Since LCDM is already a good fit to the data, let's talk about extension in the context of Planck + external data sets

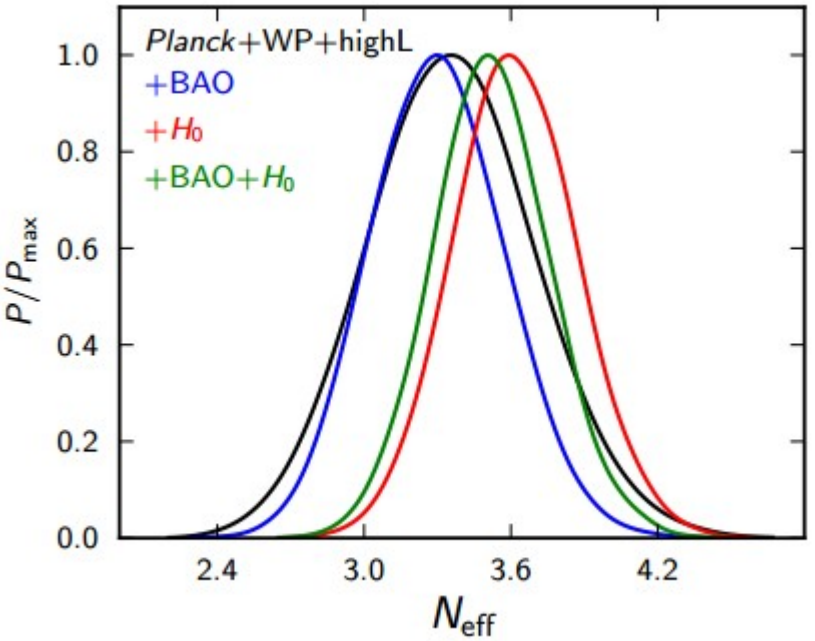


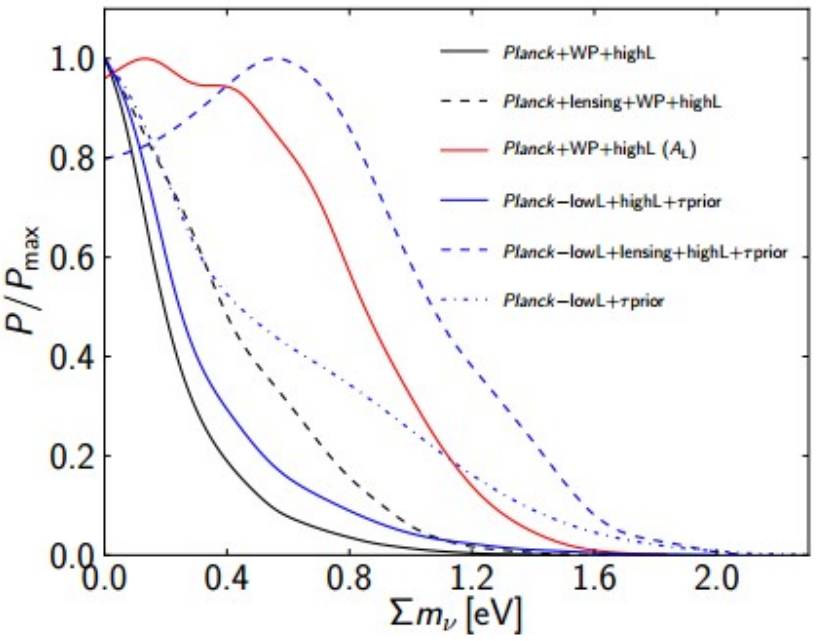


LCDM+Extensions







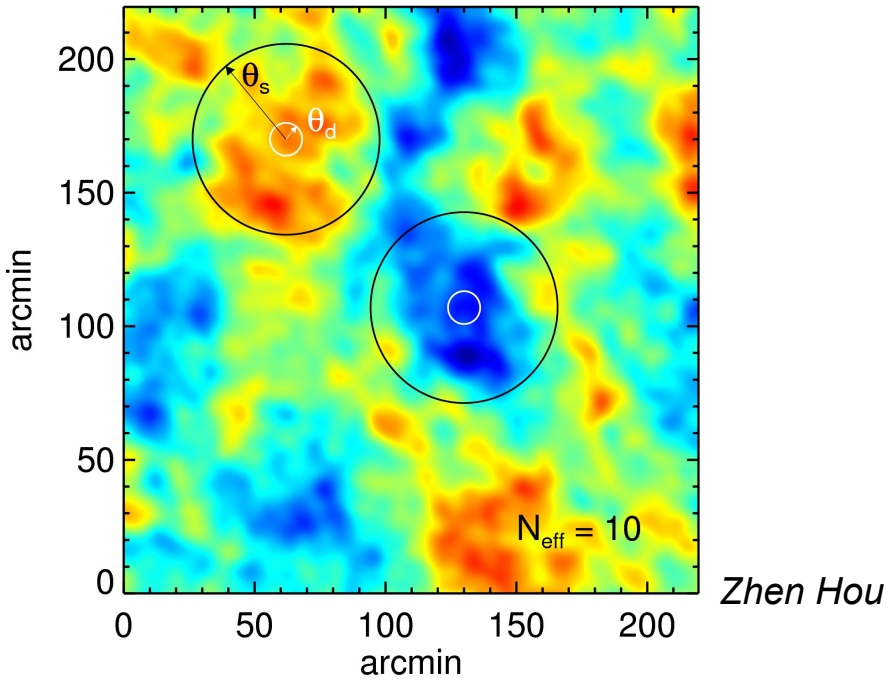


Conclusion

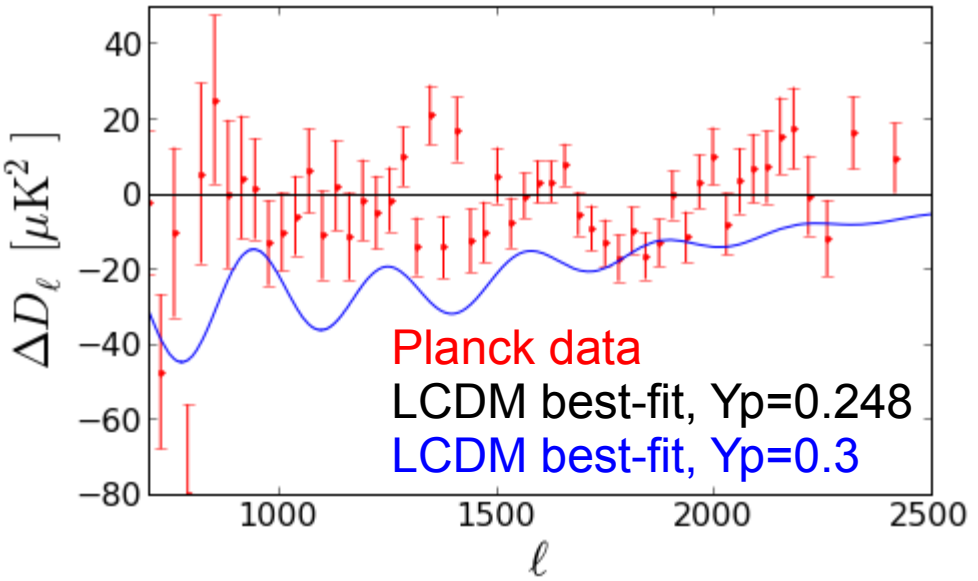
- Lensing is playing an important role in driving the shift from constraints at L<800 to 2<L<2500
  - We will soon learn a lot more about lensing from Planck polarization and other ground based polarization experiments
- 217 GHz plays an important role
- The shifts are robust to foreground modeling
- The L < 800 preference for slightly higher H0 is related to the "low-L anomaly"

Damping

See Zhen Hou's talk on **Wednesday** for an excellent description of the effects of damping



Zhen Hou



Tightly constrained

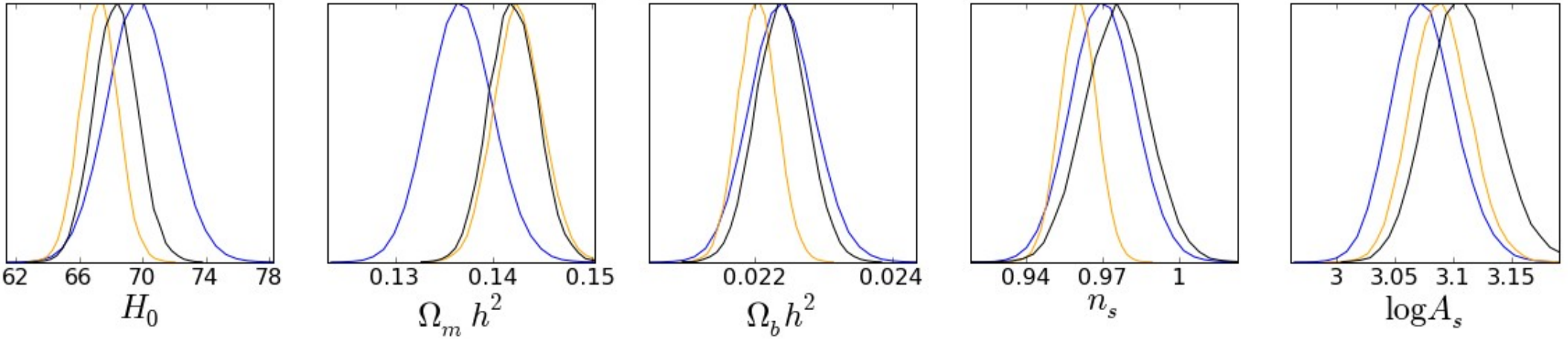
Already constrained by lensing and L<800

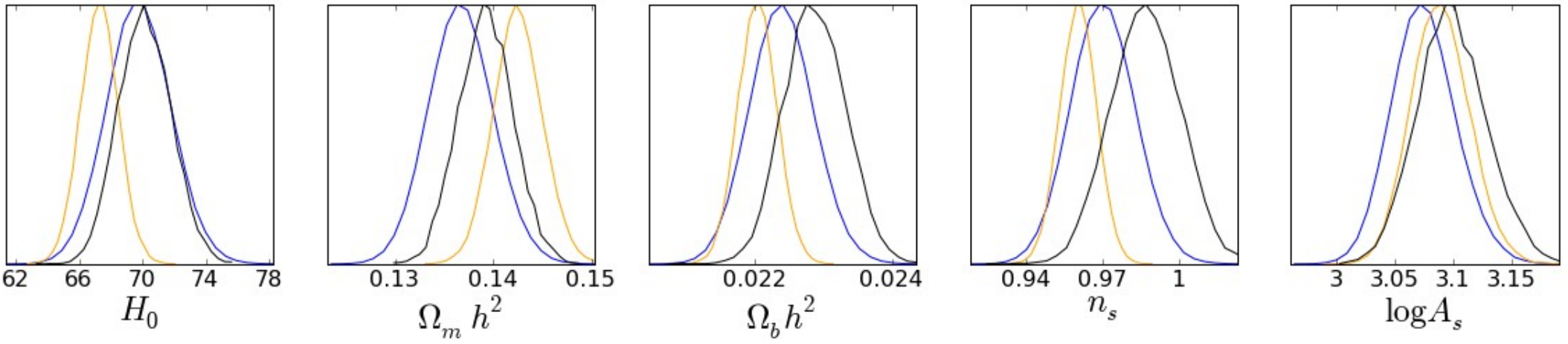
$$\frac{\theta_d}{\theta_s} = \frac{r_d/D_A}{r_s/D_A} = \frac{r_d}{r_s}(\rho_b, \rho_m, Y_p)$$

Not a free parameter in LCDM, analogous to Alens

Damping

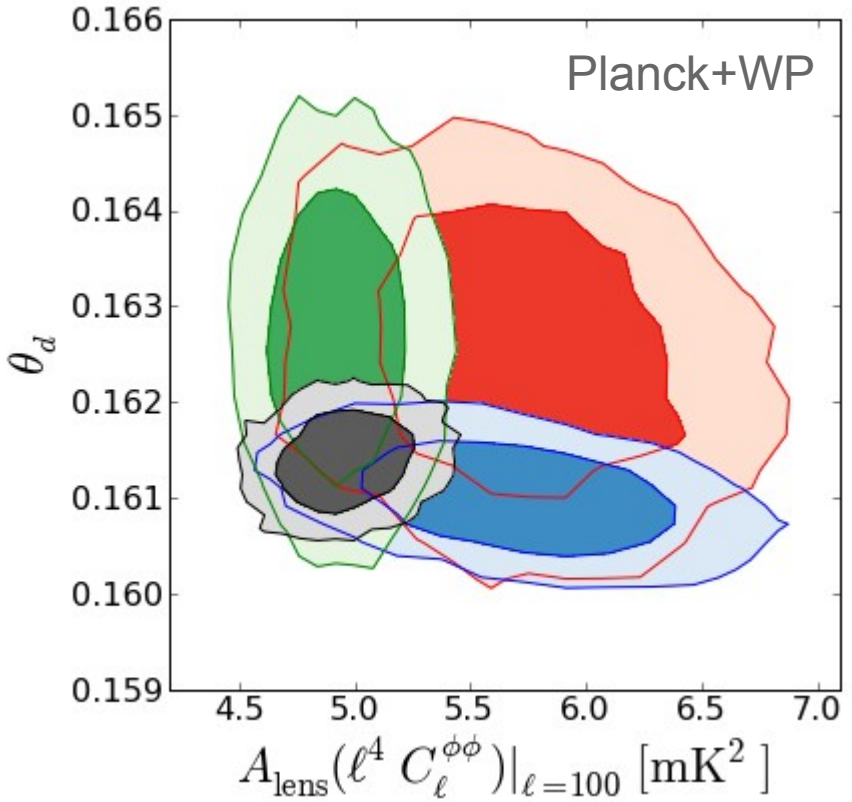
Planck L<800 LCDM
Planck L<2500 LCDM
Planck L<2500 LCDM+Yp





Planck L<800 LCDM
Planck L<2500 LCDM
Planck L<2500 LCDM+Alens+Yp

Lensing and Damping



LCDM
LCDM+Alens
LCDM+Yp
LCDM+Alens+Yp

Just black and red

Degeneracies between thetad and tilt