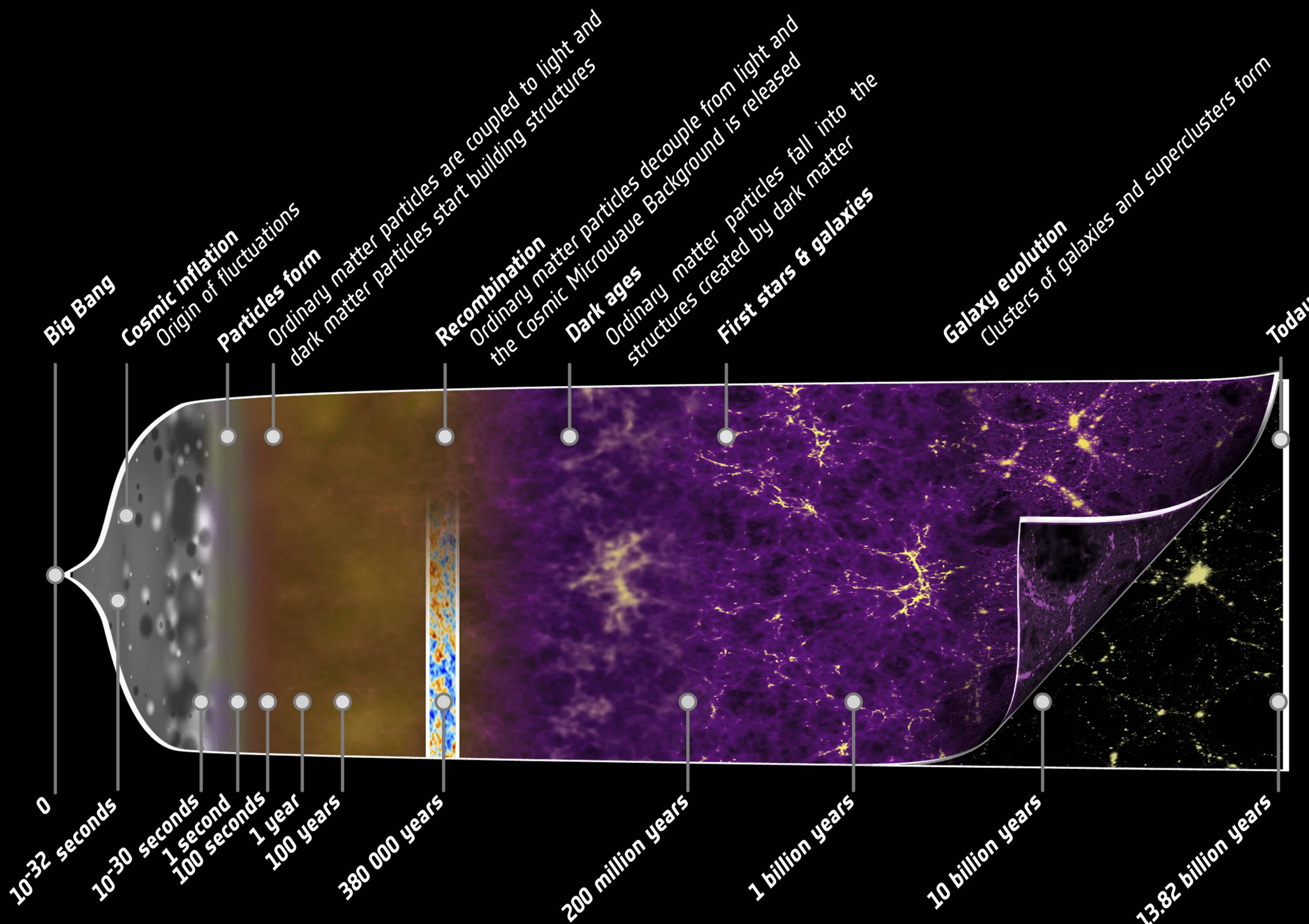
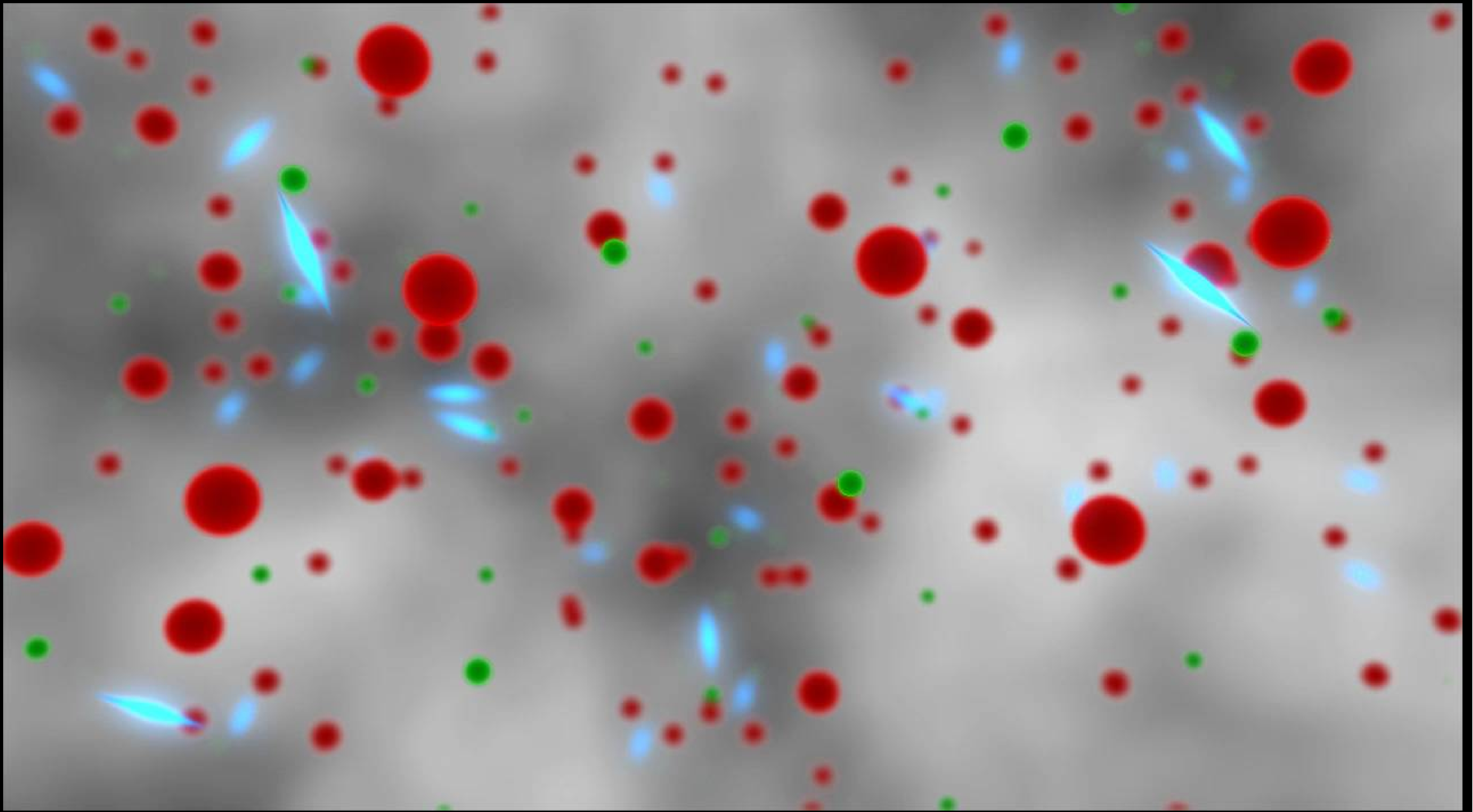
Cosmological constraints on neutrinos

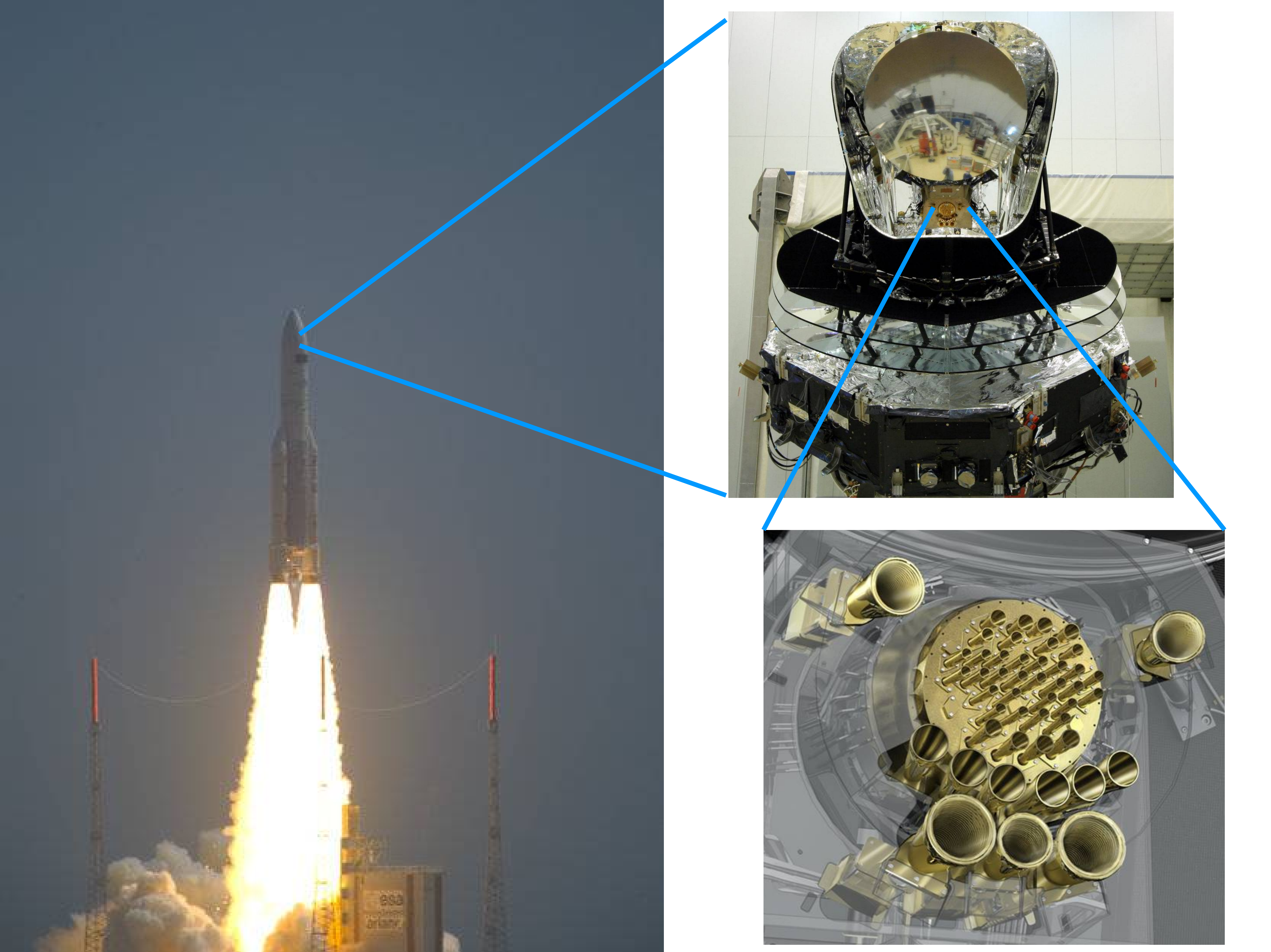
Zhen Hou (UC Davis), 侯臻
on behalf of the *PLANCK* collaboration



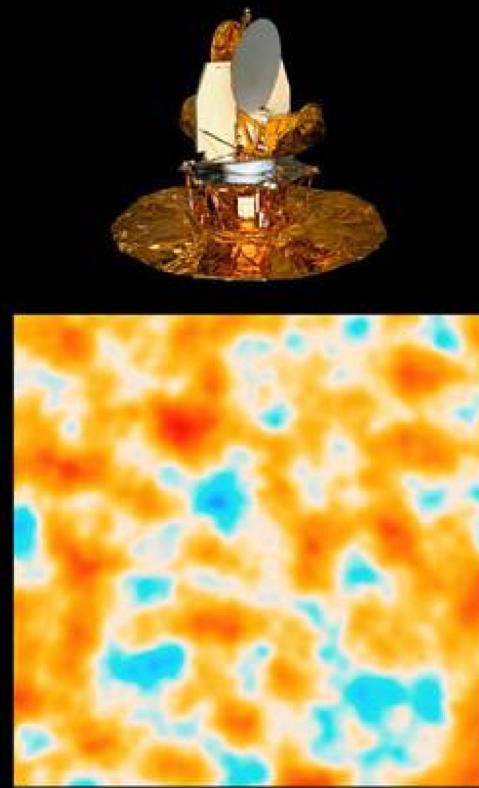
Big Bang
Cosmic inflation
Origin of fluctuations
Particles form
Ordinary matter particles are coupled to light and dark matter particles start building structures
Recombination
Ordinary matter particles decouple from light and the Cosmic Microwave Background is released
Dark ages
Ordinary matter particles fall into the structures created by dark matter
First stars & galaxies
Galaxy evolution
Clusters of galaxies and superclusters form
Today
0
10-32 seconds
10-30 seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years

Life of a photon

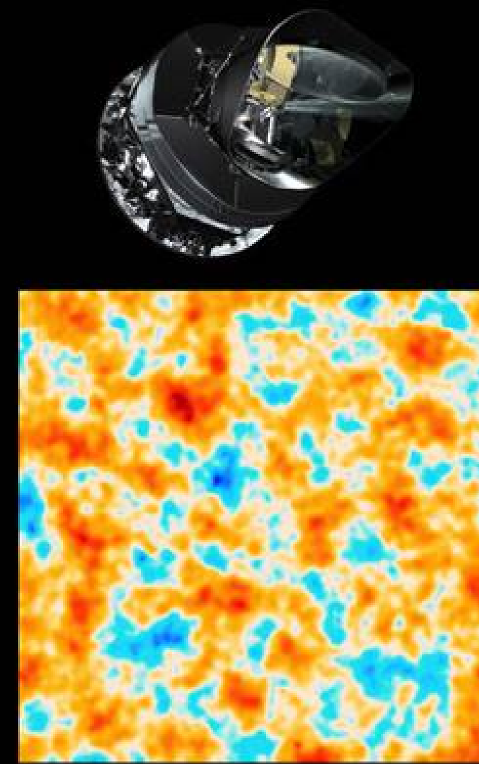




COBE



WMAP

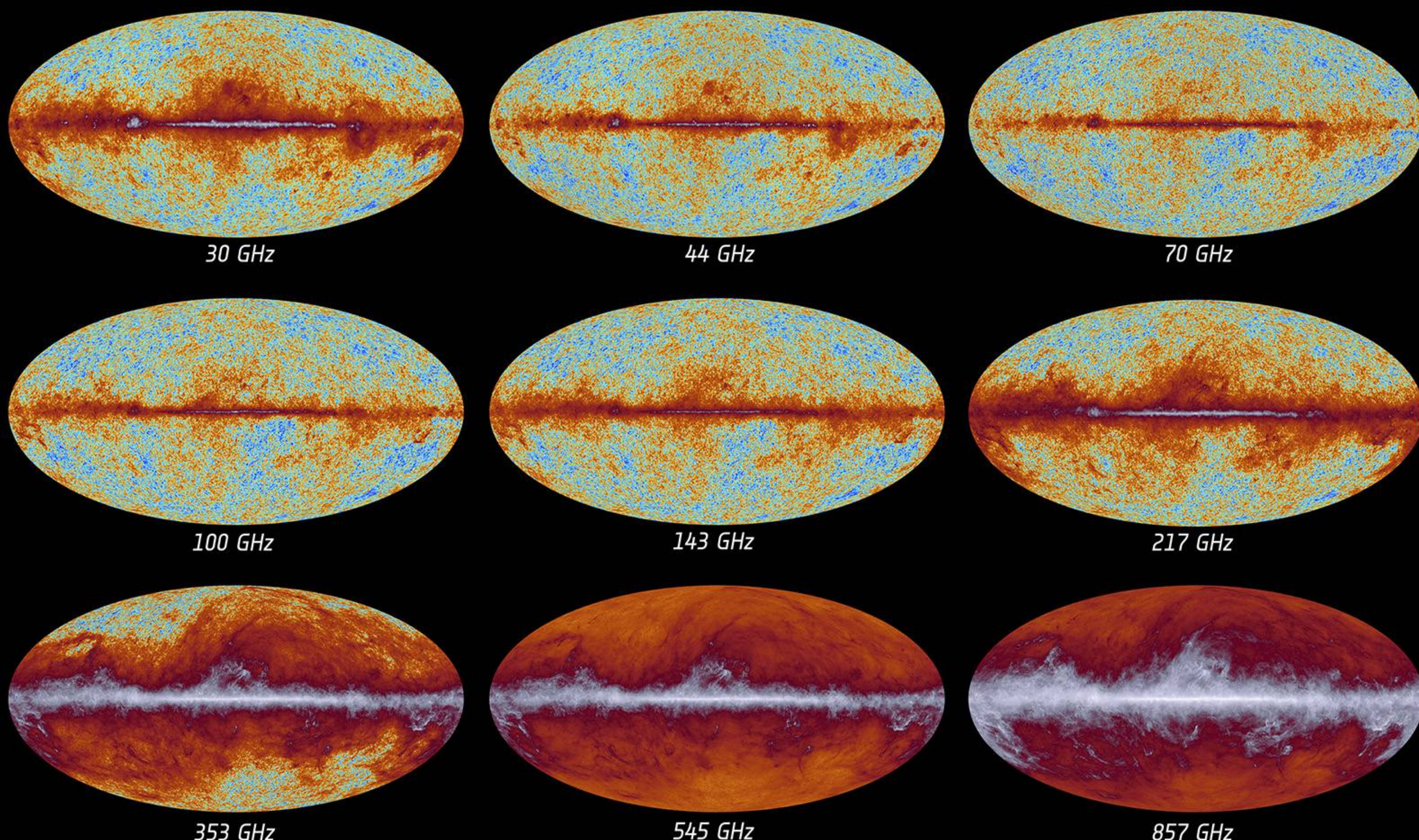


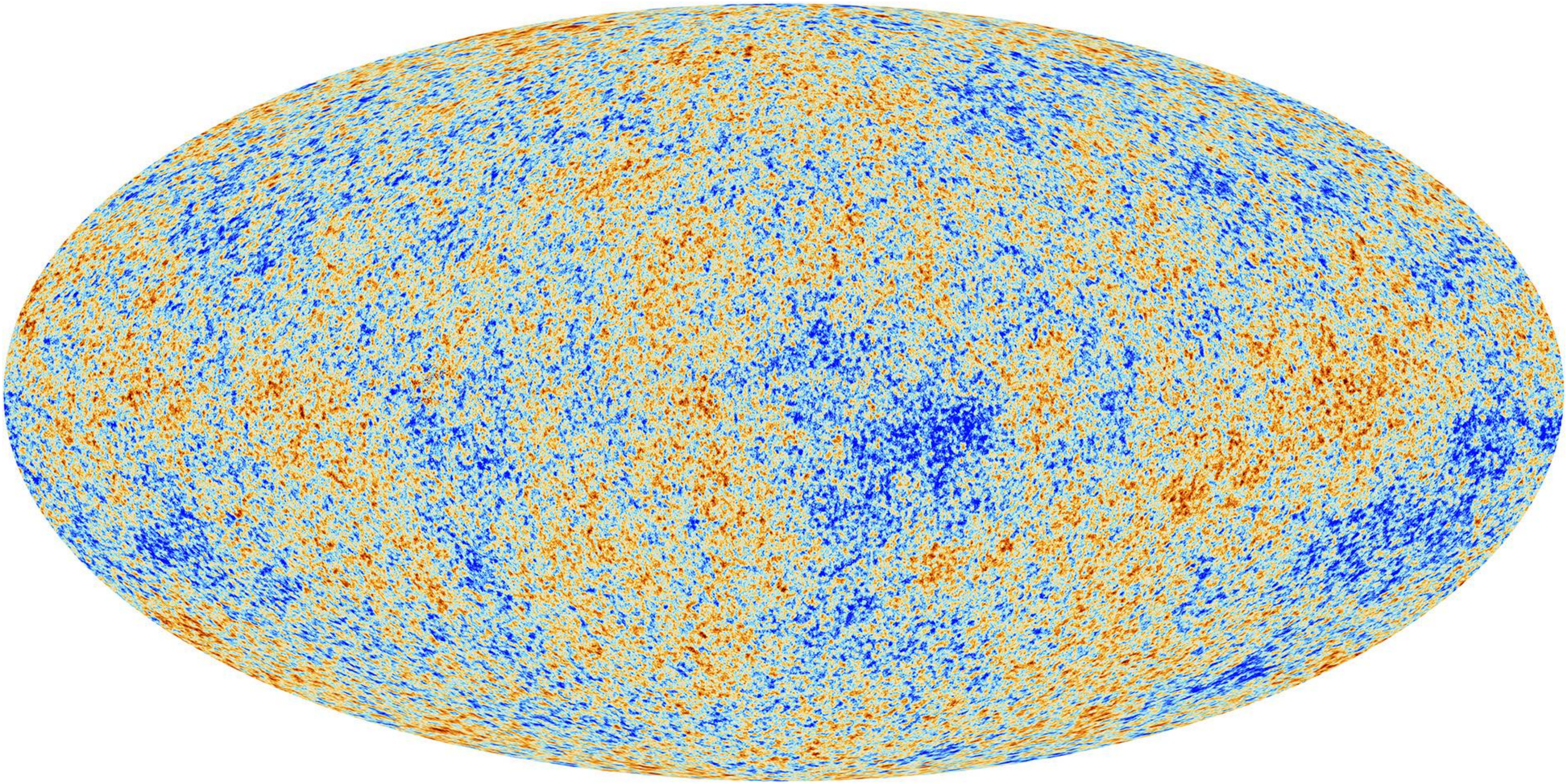
Planck

South Pole Telescope (SPT)

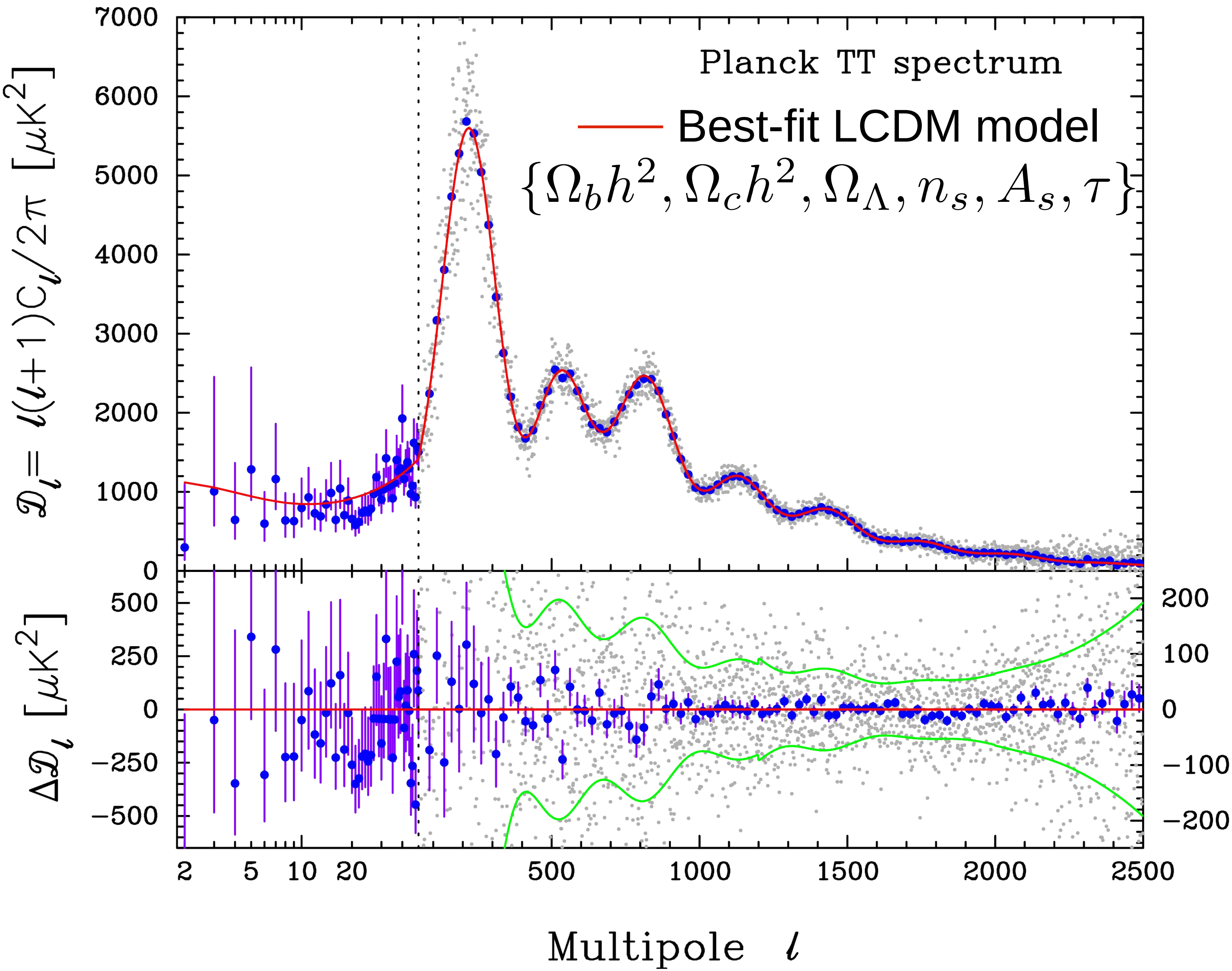
Atacama Cosmology Telescope (ACT)

The sky as seen by Planck





The power spectrum



Planck TT spectrum
Best-fit LCDM model
$\{\Omega_b h^2, \Omega_c h^2, \Omega_\Lambda, n_s, A_s, \tau\}$
$\mathcal{D}_\ell = \ell(\ell+1)C_\ell/2\pi\ [\mu K^2]$
$\Delta\mathcal{D}_\ell\ [\mu K^2]$
Multipole ℓ
7000
6000
5000
4000
3000
2000
1000
0
500
250
0
−250
−500
200
100
0
−100
−200
2
5
10
20
500
1000
1500
2000
2500

Cosmological (Non-standard) parameters for neutrinos

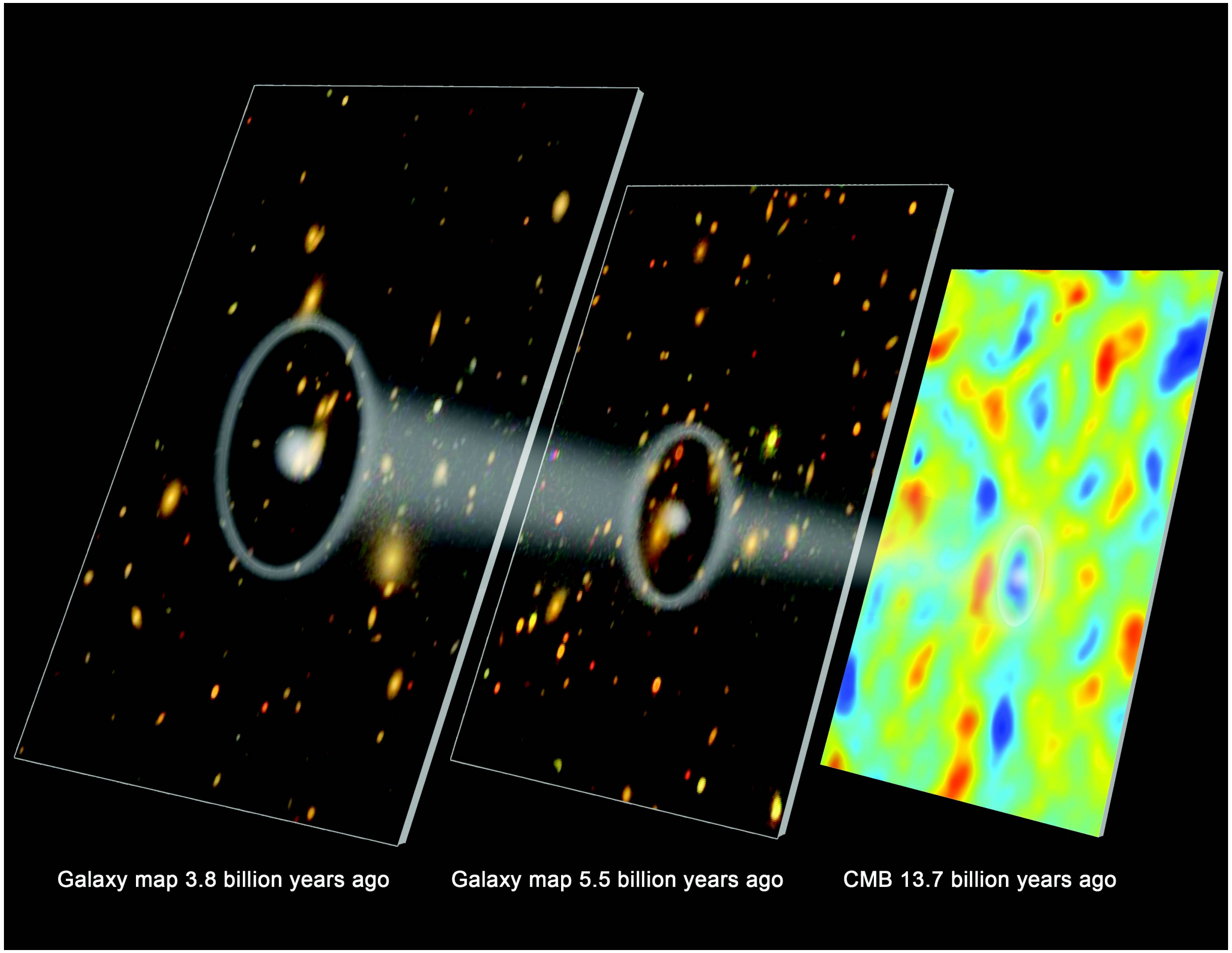
- N_{eff}

  $$\rho_{\mathrm{rad}} = \left[1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N_{\mathrm{eff}}\right]\rho_\gamma$$

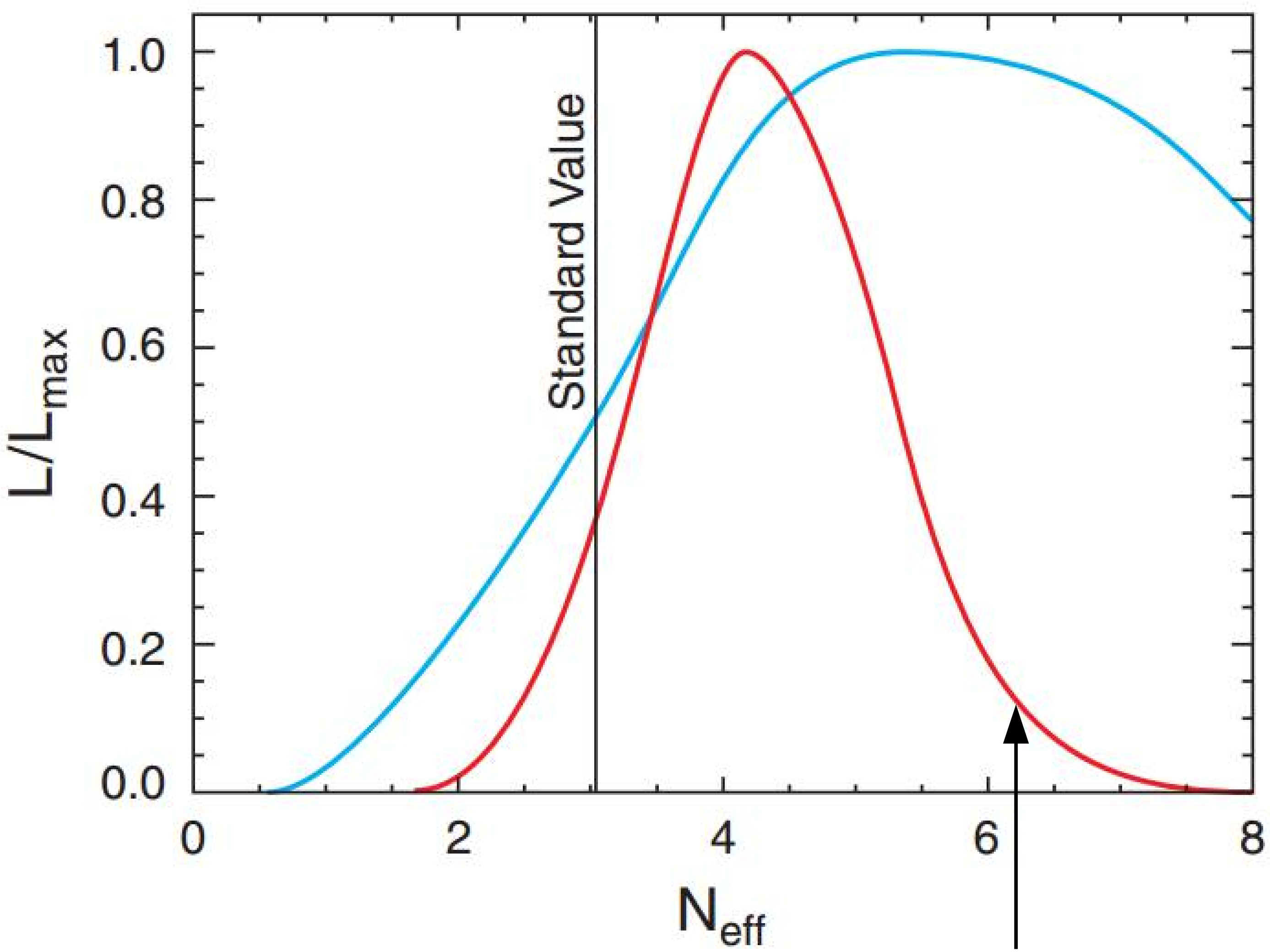
- $\sum m_\nu$
- $c^2_{\mathrm{vis}},\ c^2_{\mathrm{eff}}$
- $m^{\mathrm{eff}}_{\mathrm{sterile}}$

Other cosmological measurements

- Baryon acoustic oscillation
- H_0



Cosmological constraints on $N_{\rm eff}$ since WMAP7



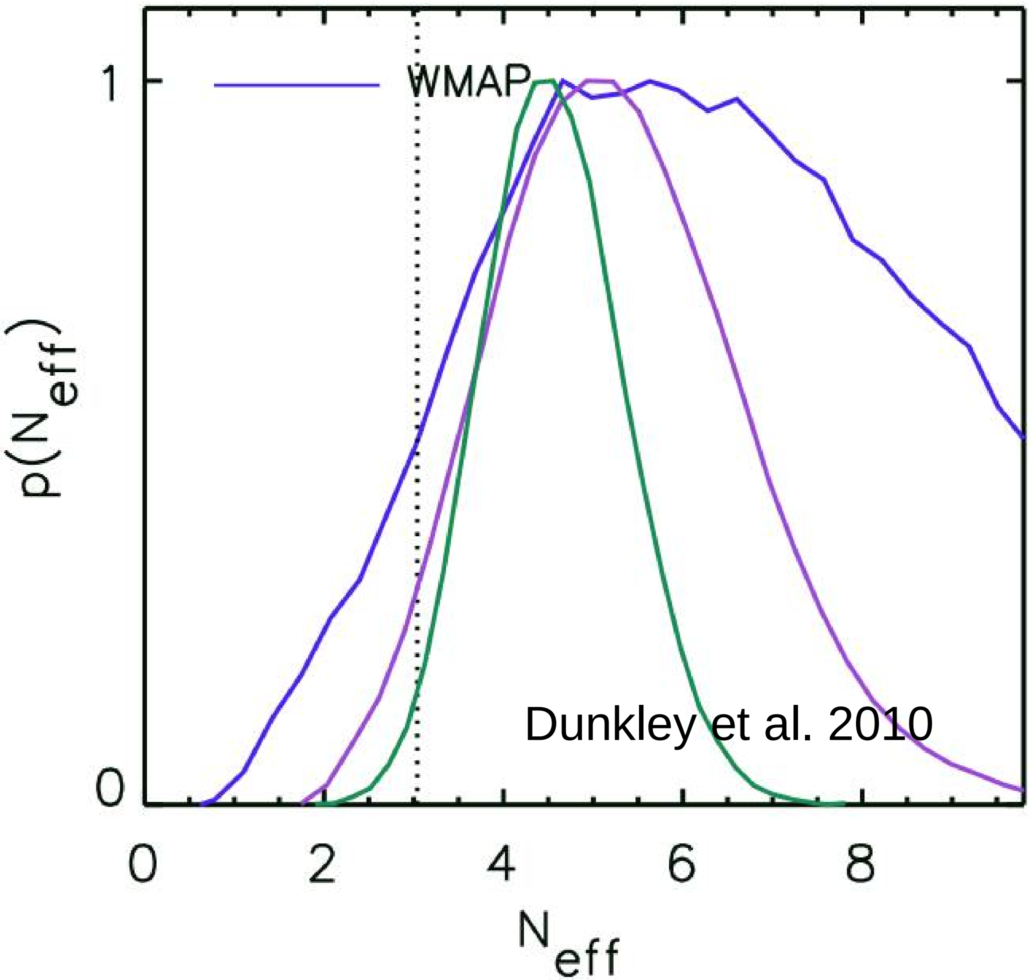
$$N_{\rm eff} = 4.34^{+0.86}_{-0.88} (68\%{\rm CL})$$

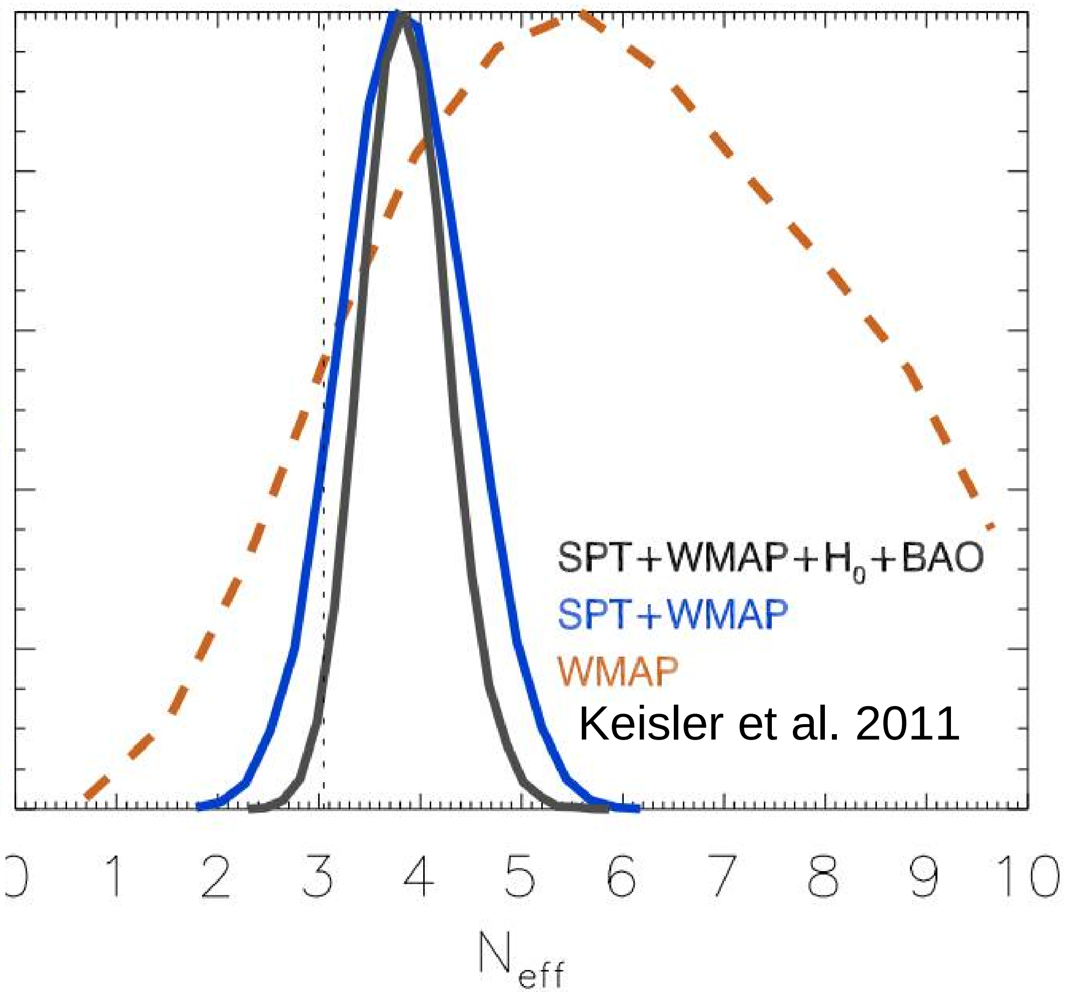
Komatsu et al., 2010, arXiv:1001.4538

Blue – WMAP7 only

Red – WMAP7+BAO+H_0

Constraints on $N_{\rm eff}$ from the first results from ACT and SPT



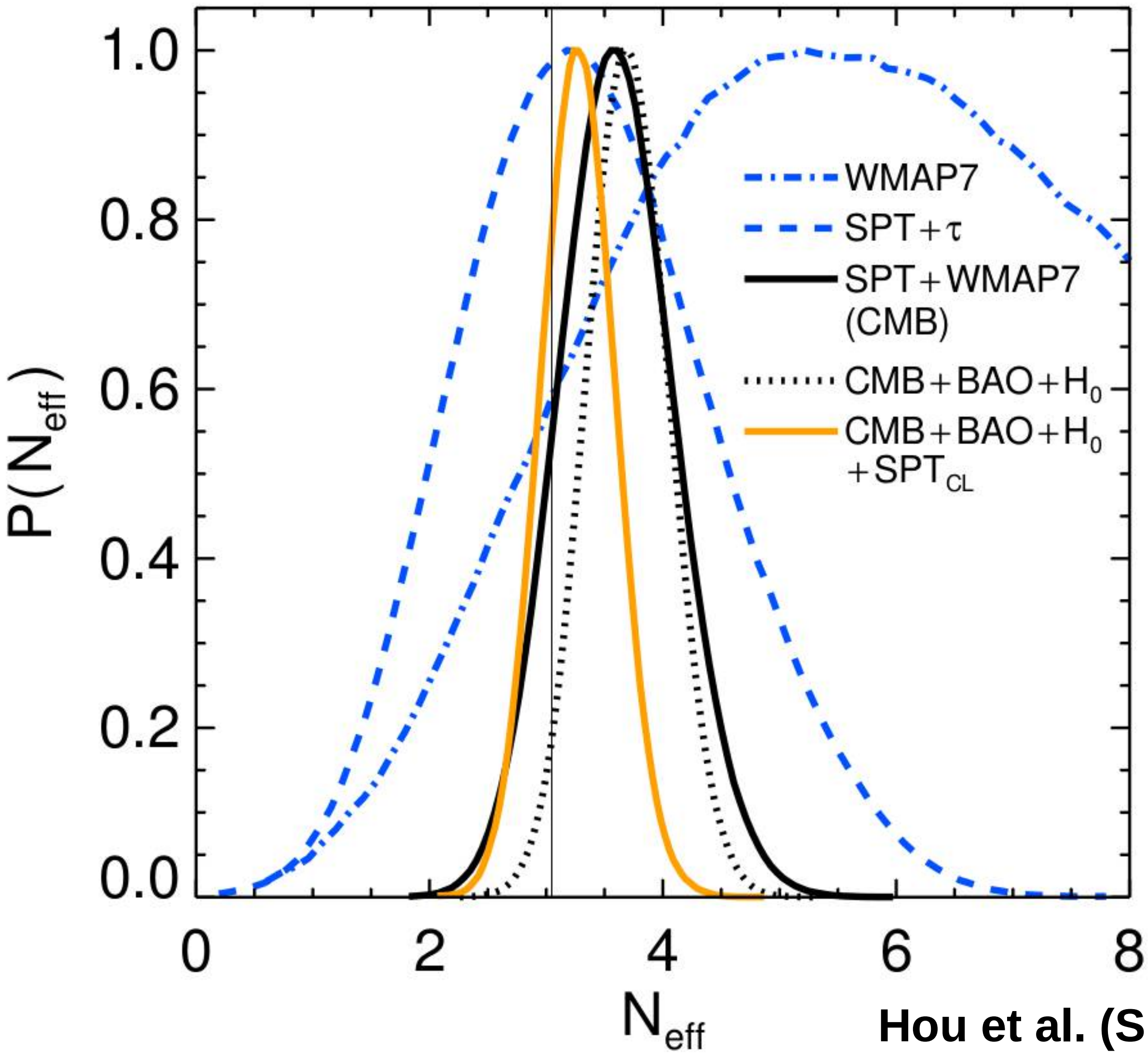


$$\mathrm{WMAP7{+}ACT{+}BAO{+}}H_0$$
$$N_{\rm eff} = 4.56 \pm 0.75 (68\%\mathrm{CL})$$

$$\mathrm{WMAP7{+}SPT{+}BAO{+}}H_0$$
$$N_{\rm eff} = 3.86 \pm 0.42 (68\%\mathrm{CL})$$

$+SPT_{CL}$

Constraints on $N_{\rm eff}$ from $2500\ \rm deg^2$ SPT survey



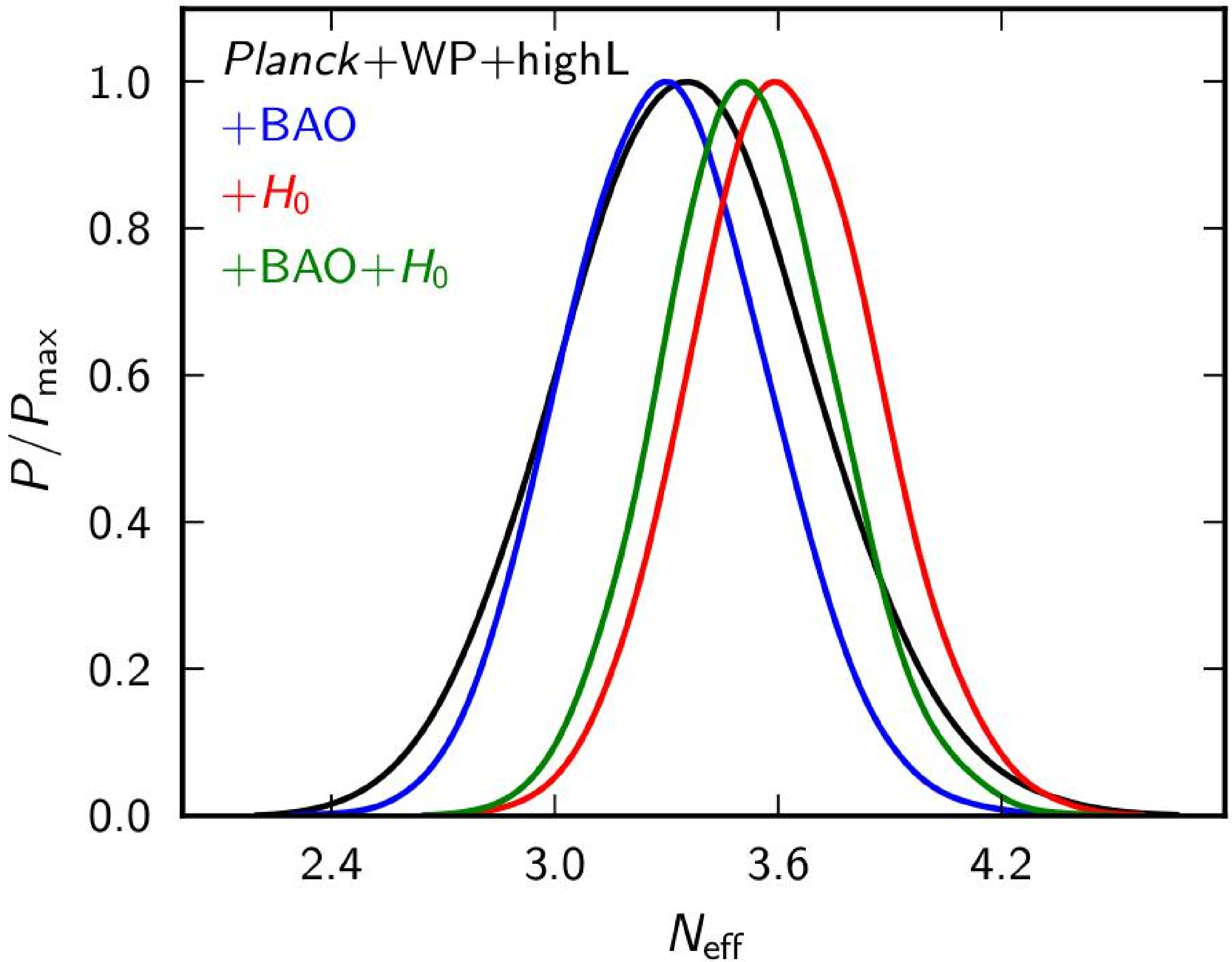
WMAP7+SPT
$N_{\rm eff} = 3.62 \pm 0.48$

WMAP7+SPT+BAO+H_0
$N_{\rm eff} = 3.71 \pm 0.35$

WMAP7+SPT+BAO+H_0 $+SPT_{CL}$
$N_{\rm eff} = 3.29 \pm 0.31$

Hou et al. (SPT collaboration), 2012 arXiv:1212.6267

Constraints on $N_{\rm eff}$ from PLANCK



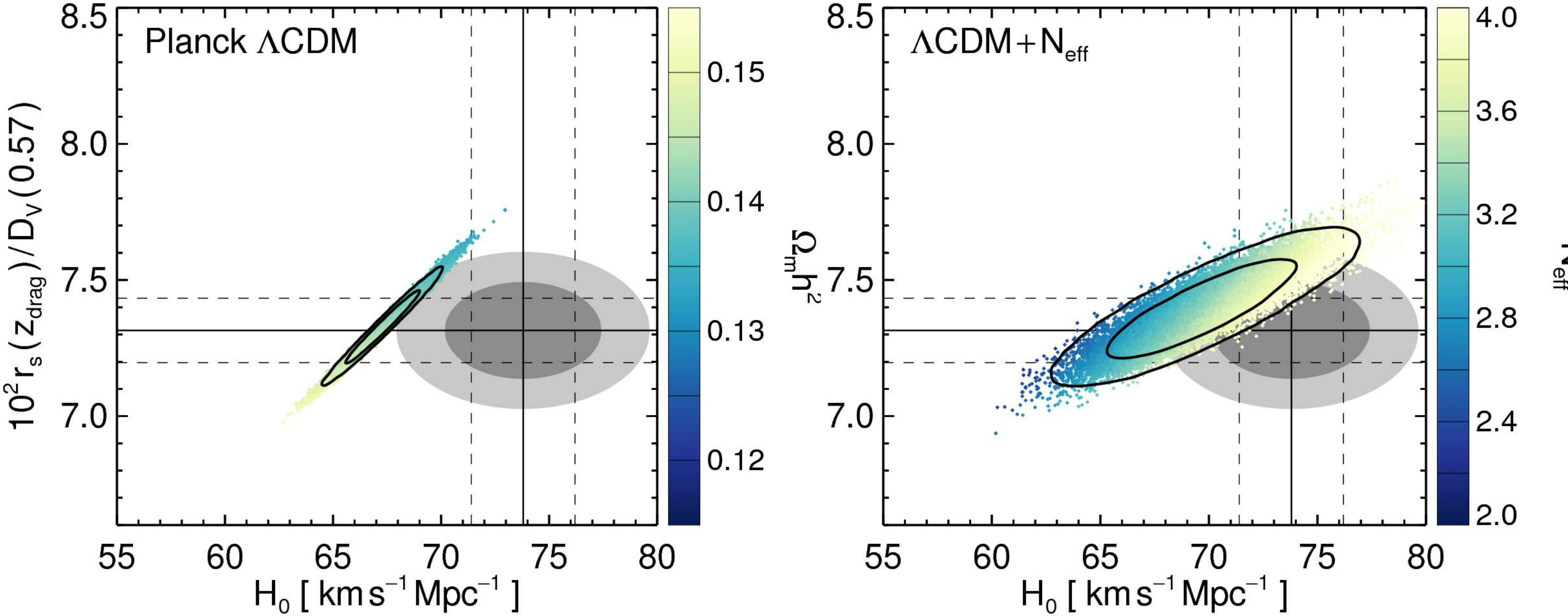
Planck
$N_{\rm eff} = 3.36 \pm 0.34$

Planck+BAO
$N_{\rm eff} = 3.30 \pm 0.26$

Planck+H_0
$N_{\rm eff} = 3.62 \pm 0.25$

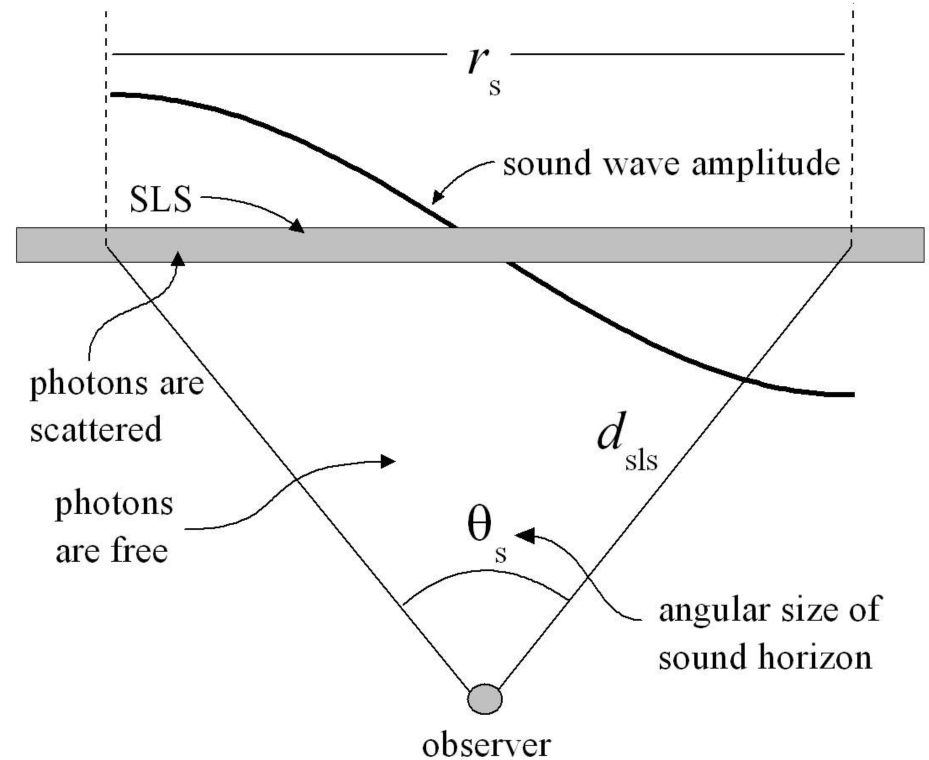
PLANCK collaboration, 2013
arXiv:1303.5076

Consistency between CMB, BAO and H_0



http://ned.ipac.caltech.edu/level5/Sept02/Reid/Figures/figure3.jpg

Two angular scales

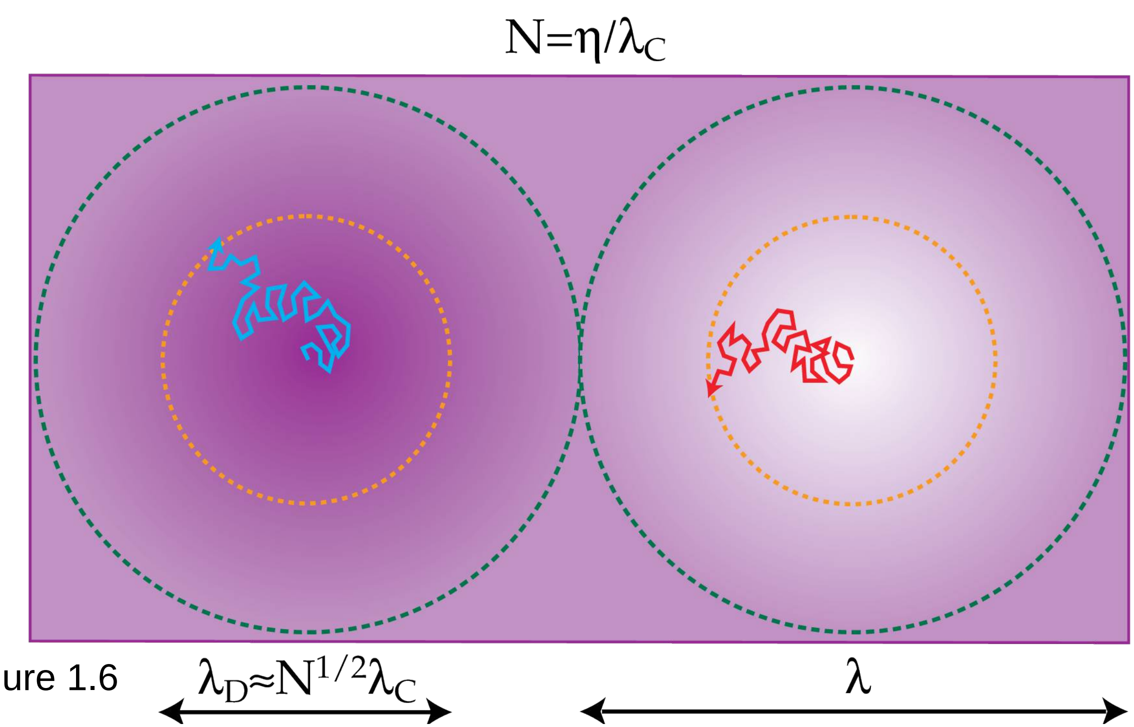


- Sound horizon scale

  Very precisely measured by the locations of acoustic peaks (0.06% from Planck in LCDM)

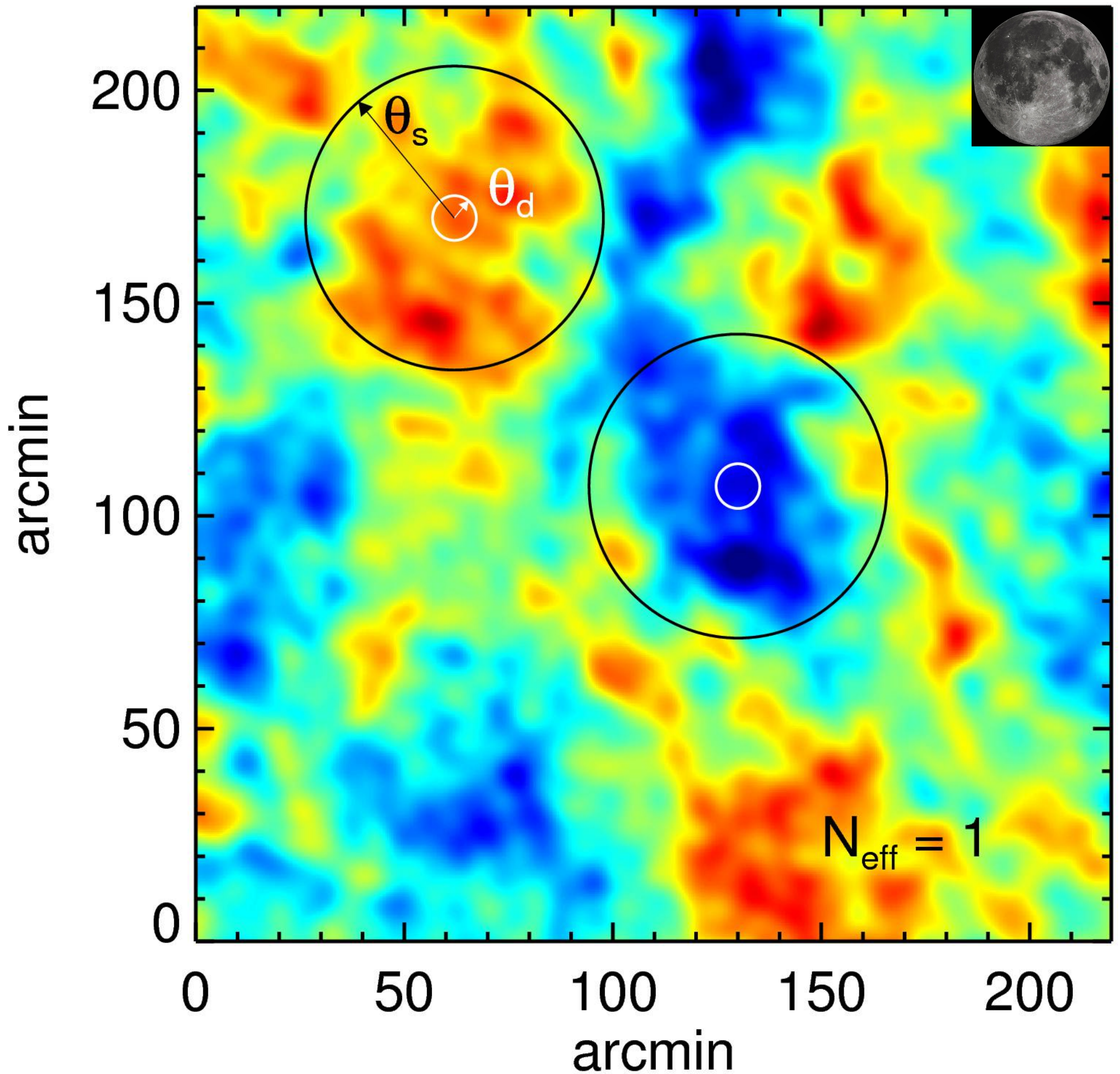
- Photon diffusion damping scale

  0.2% precision from Planck in LCDM

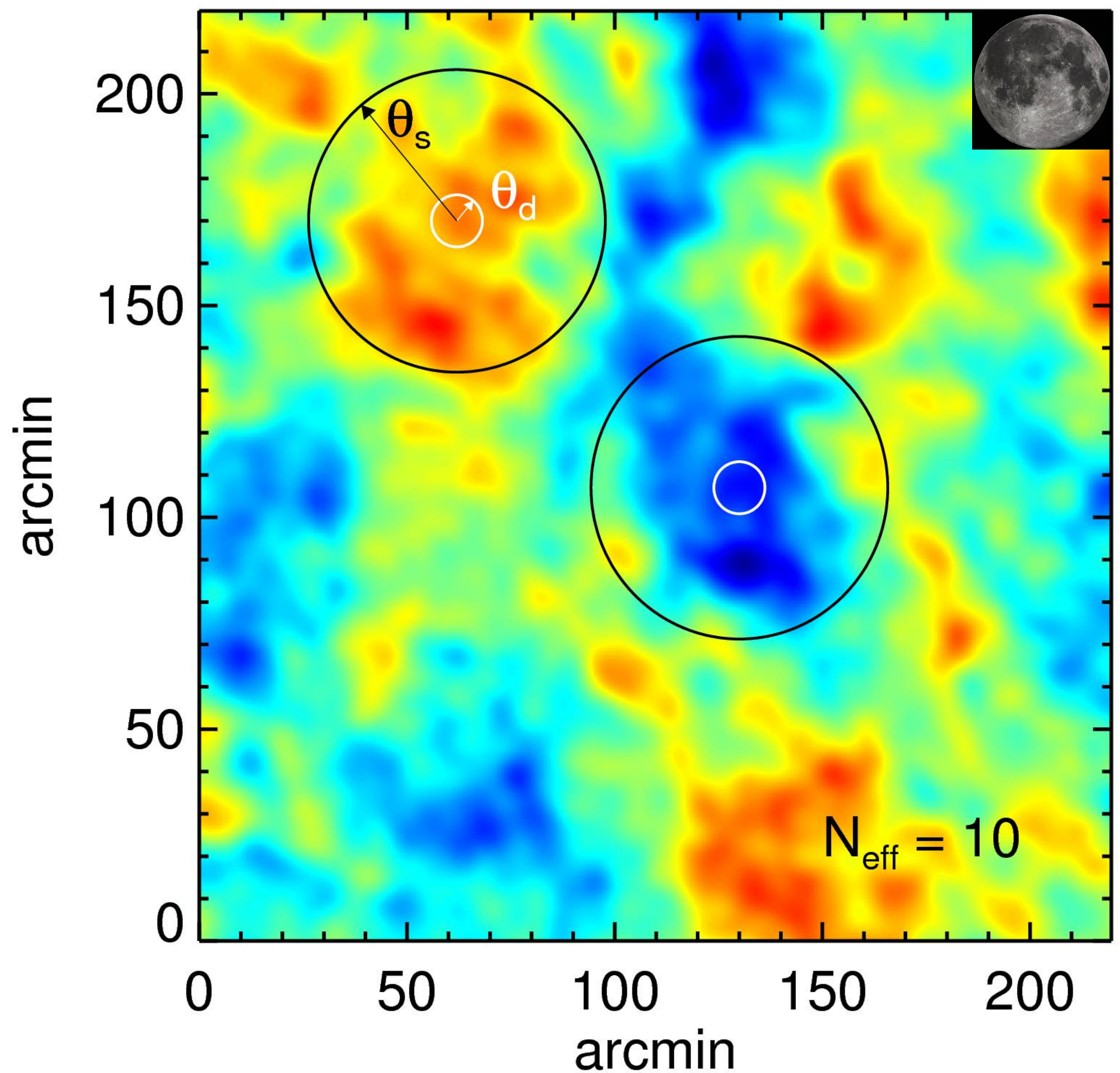


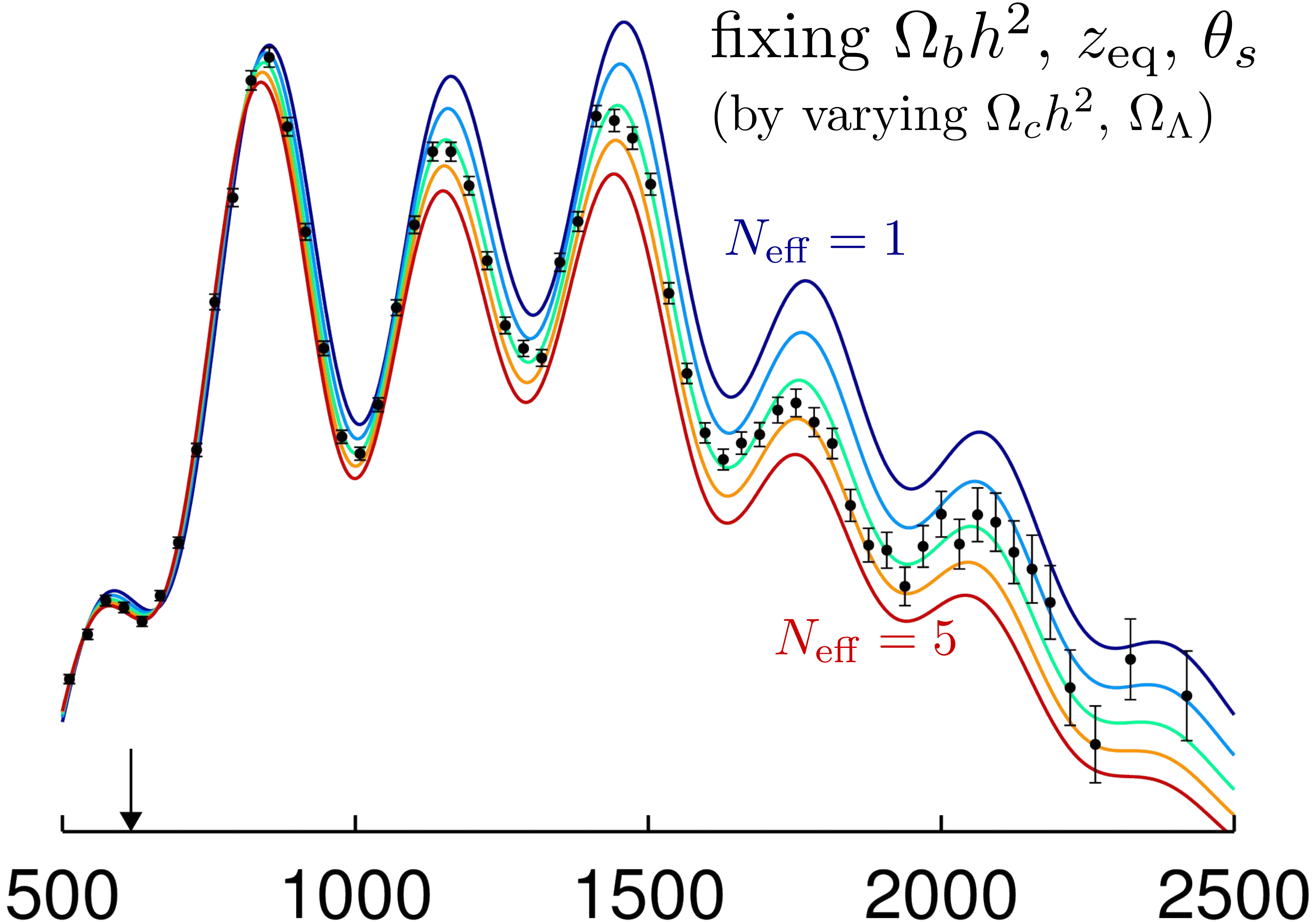
Wayne Hu
PhD Thesis Figure 1.6

Two angular scales

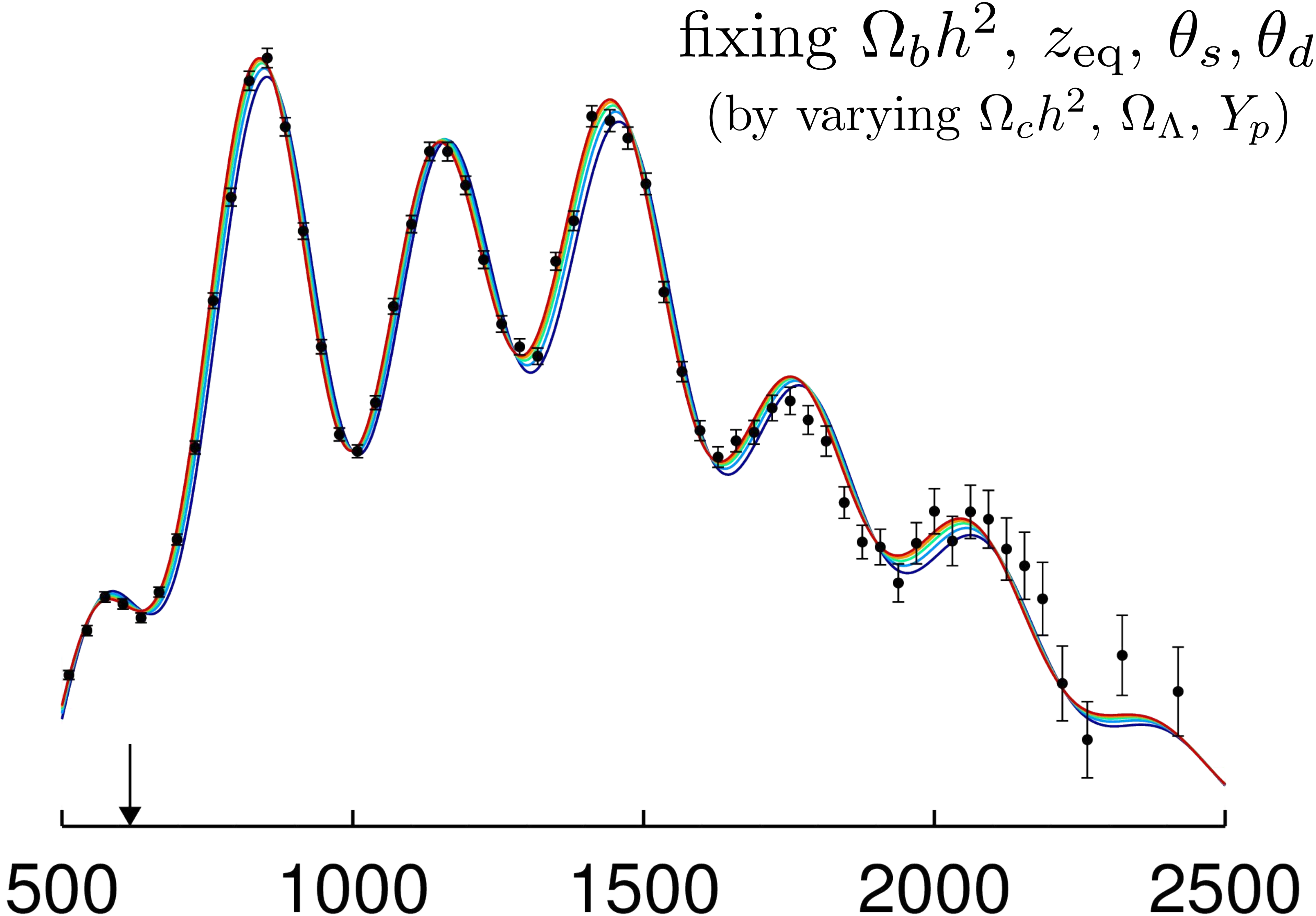


Two angular scales

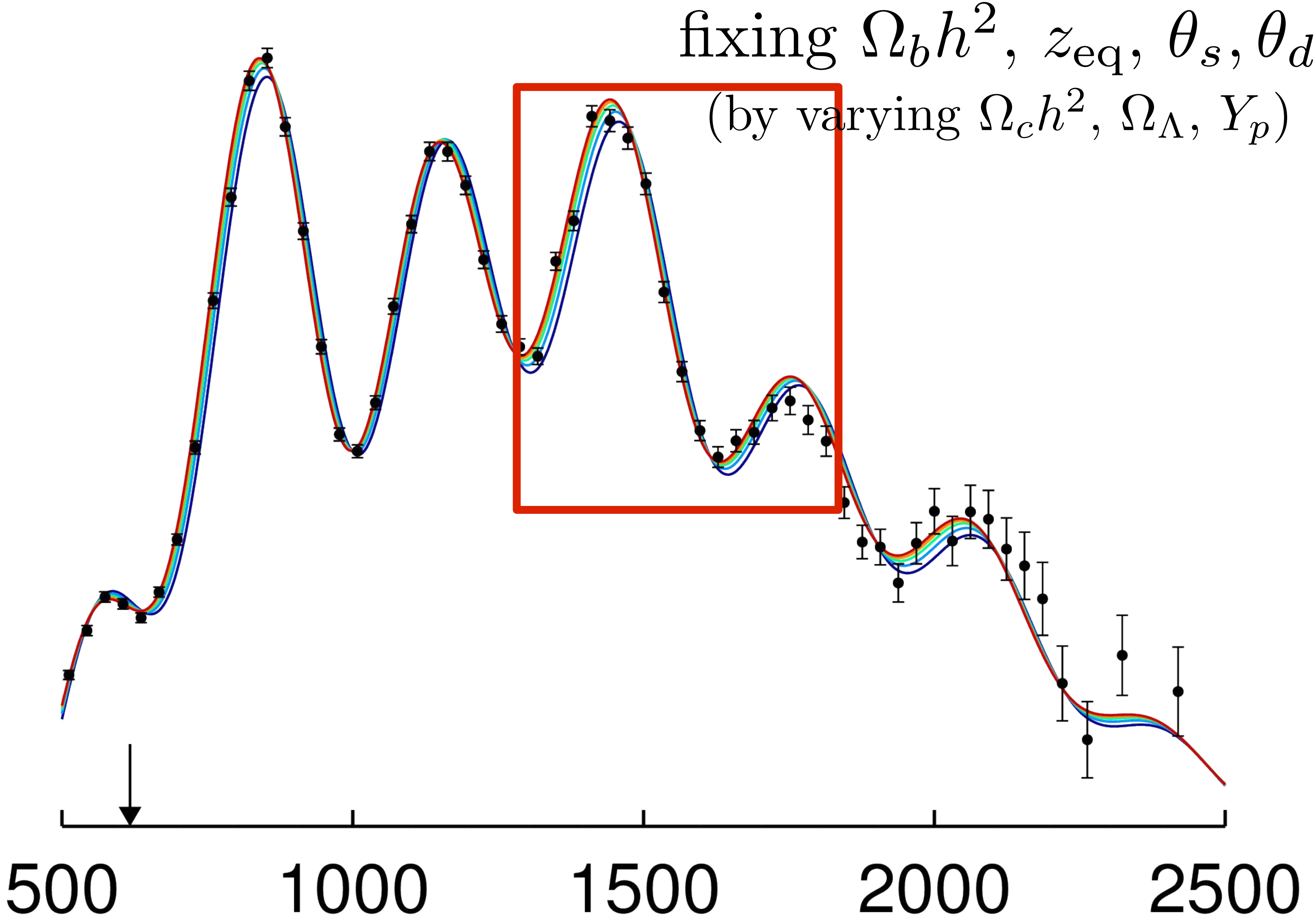




Hou et al., arXiv:1104.2333



Hou et al., arXiv:1104.2333

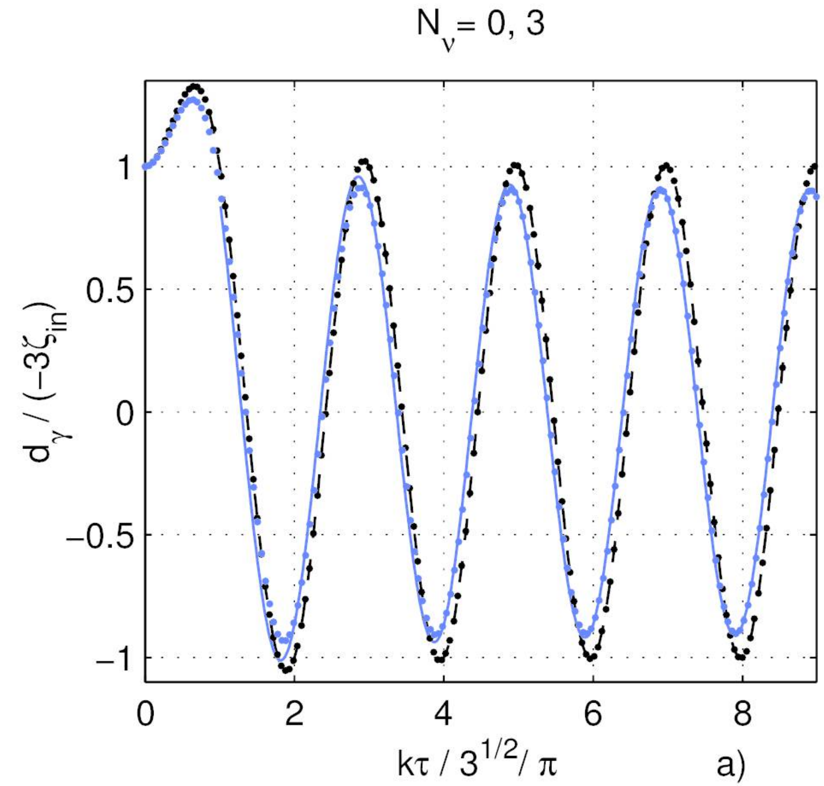


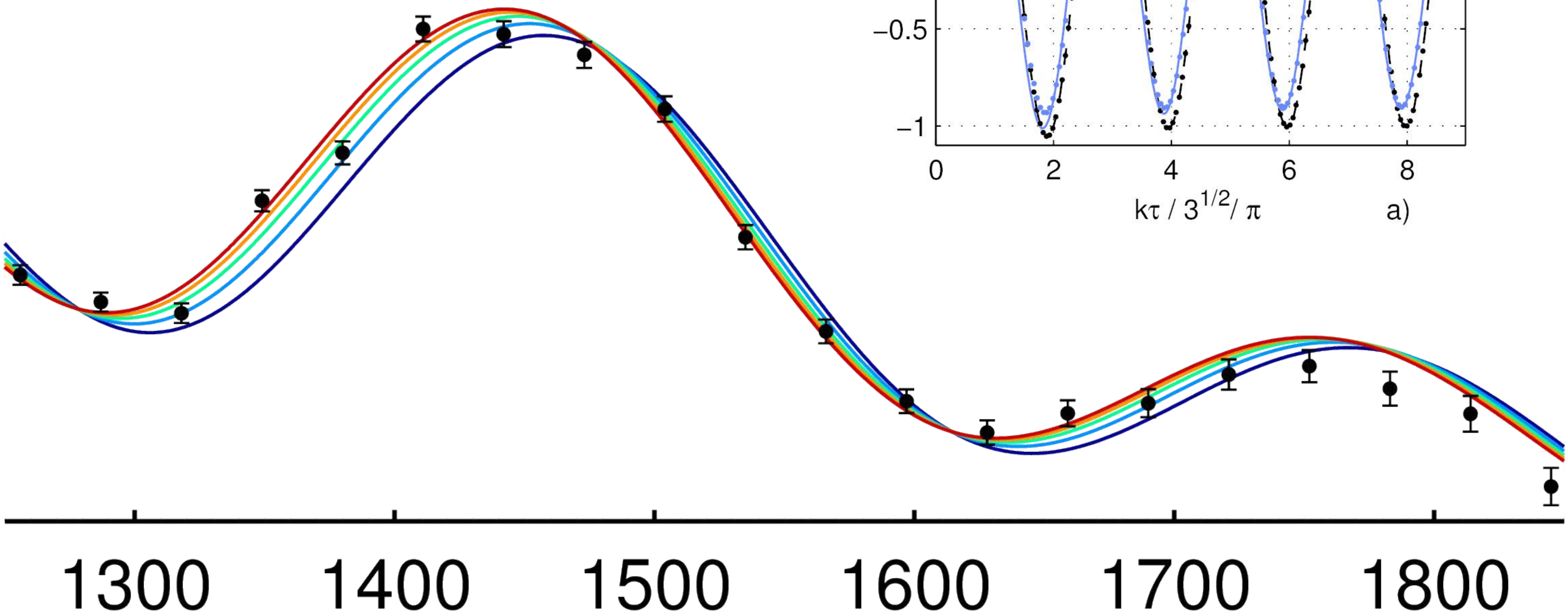
fixing $\Omega_b h^2$, $z_{\rm eq}$, θ_s, θ_d
(by varying $\Omega_c h^2$, Ω_Λ, Y_p)
500
1000
1500
2000
2500

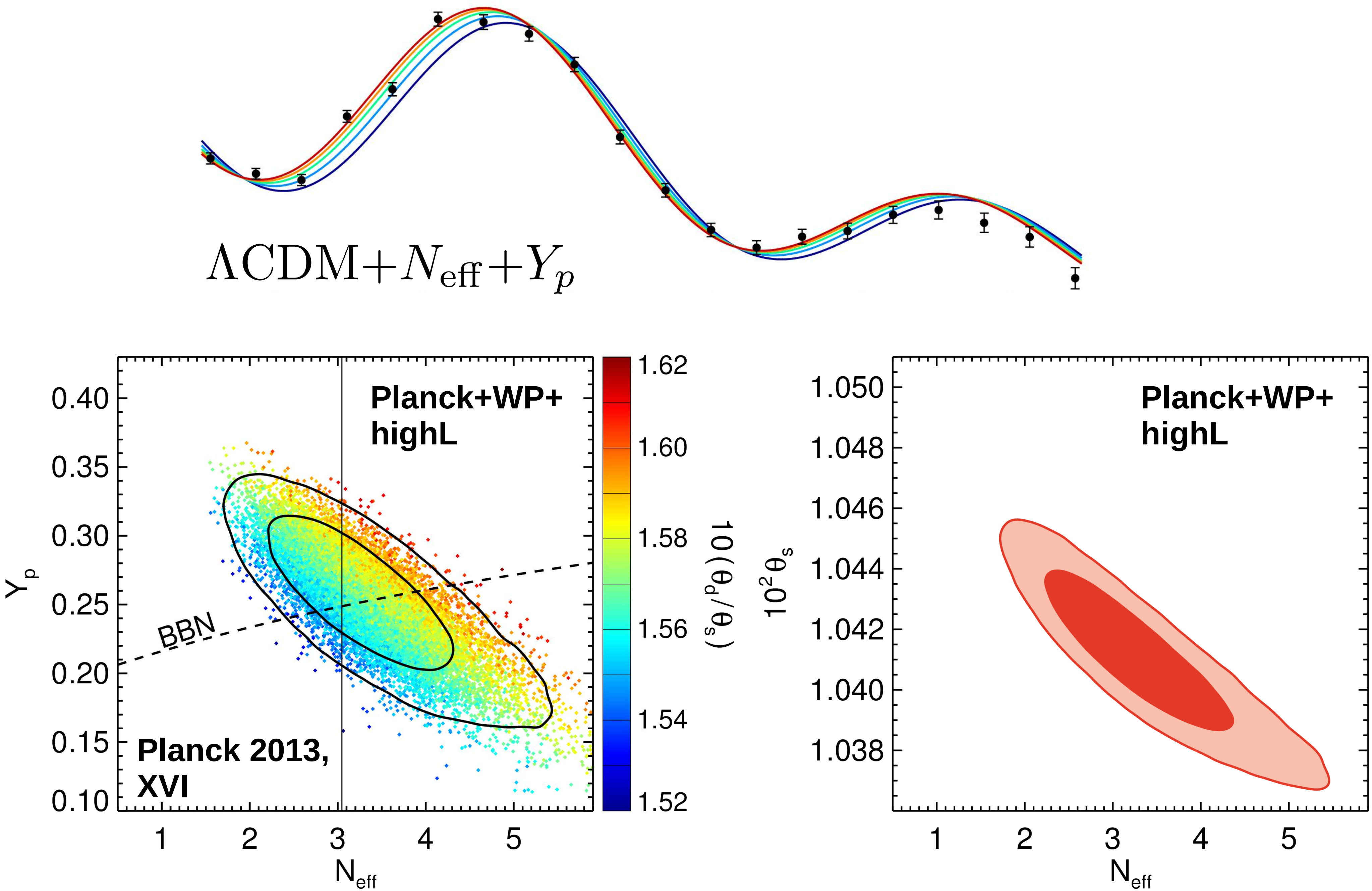
fixing $\Omega_b h^2$, $z_{\rm eq}$, θ_s, θ_d

(by varying $\Omega_c h^2$, Ω_Λ, Y_p)

Bashinsky & Seljak, 2004



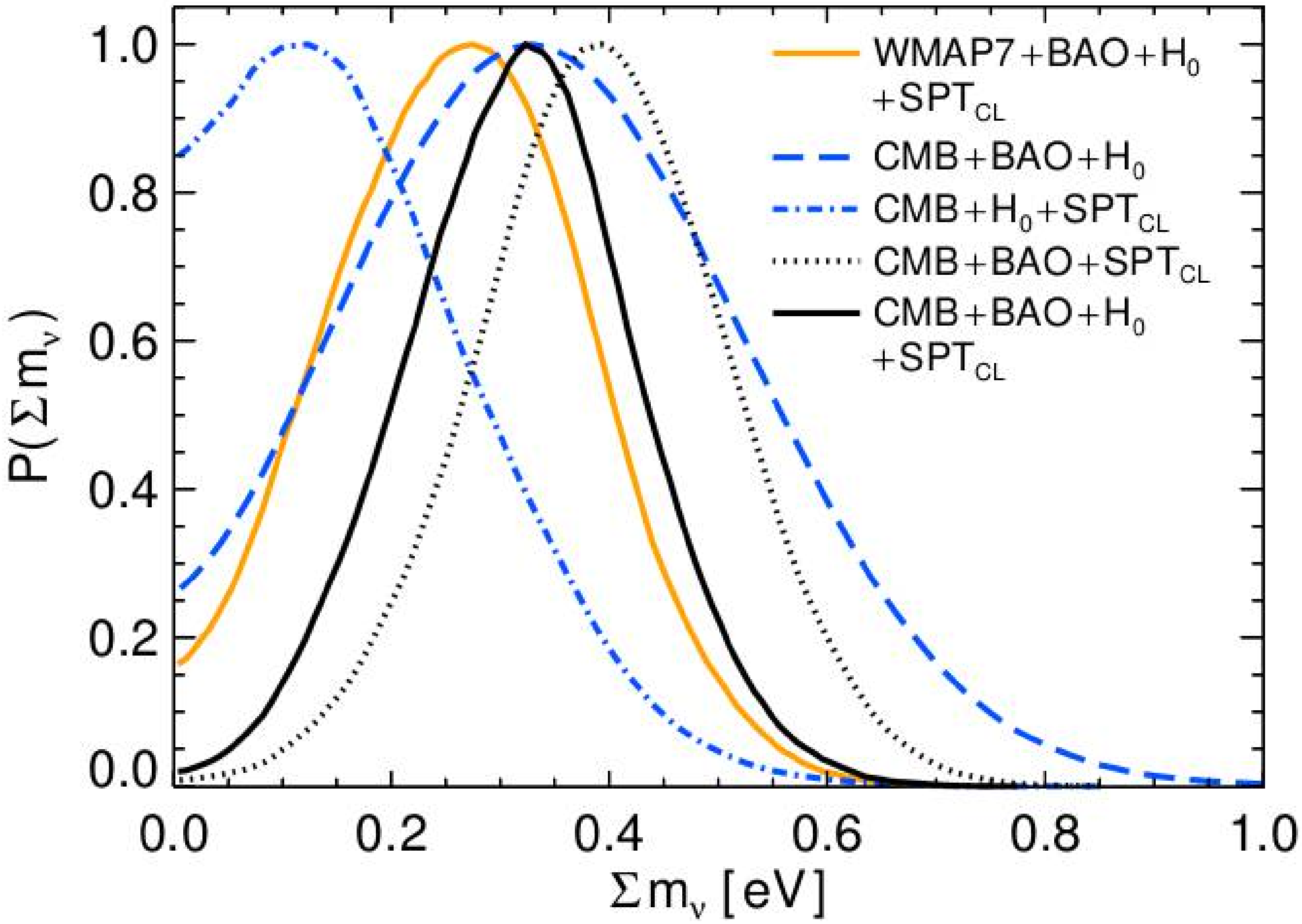




ΛCDM+N_eff+Y_p
Planck+WP+highL
Planck 2013, XVI
BBN
Y_p
0.40
0.35
0.30
0.25
0.20
0.15
0.10
N_eff
1
2
3
4
5
10(θ_d/θ_s)
1.62
1.60
1.58
1.56
1.54
1.52
Planck+WP+highL
10^2θ_s
1.050
1.048
1.046
1.044
1.042
1.040
1.038
N_eff
1
2
3
4
5

$\sum m_\nu$

Constraints on $\sum m_\nu$ from SPT $2500\ \mathrm{deg}^2$ survey



(for CMB+BAO+H_0+SPT$_{\rm CL}$):

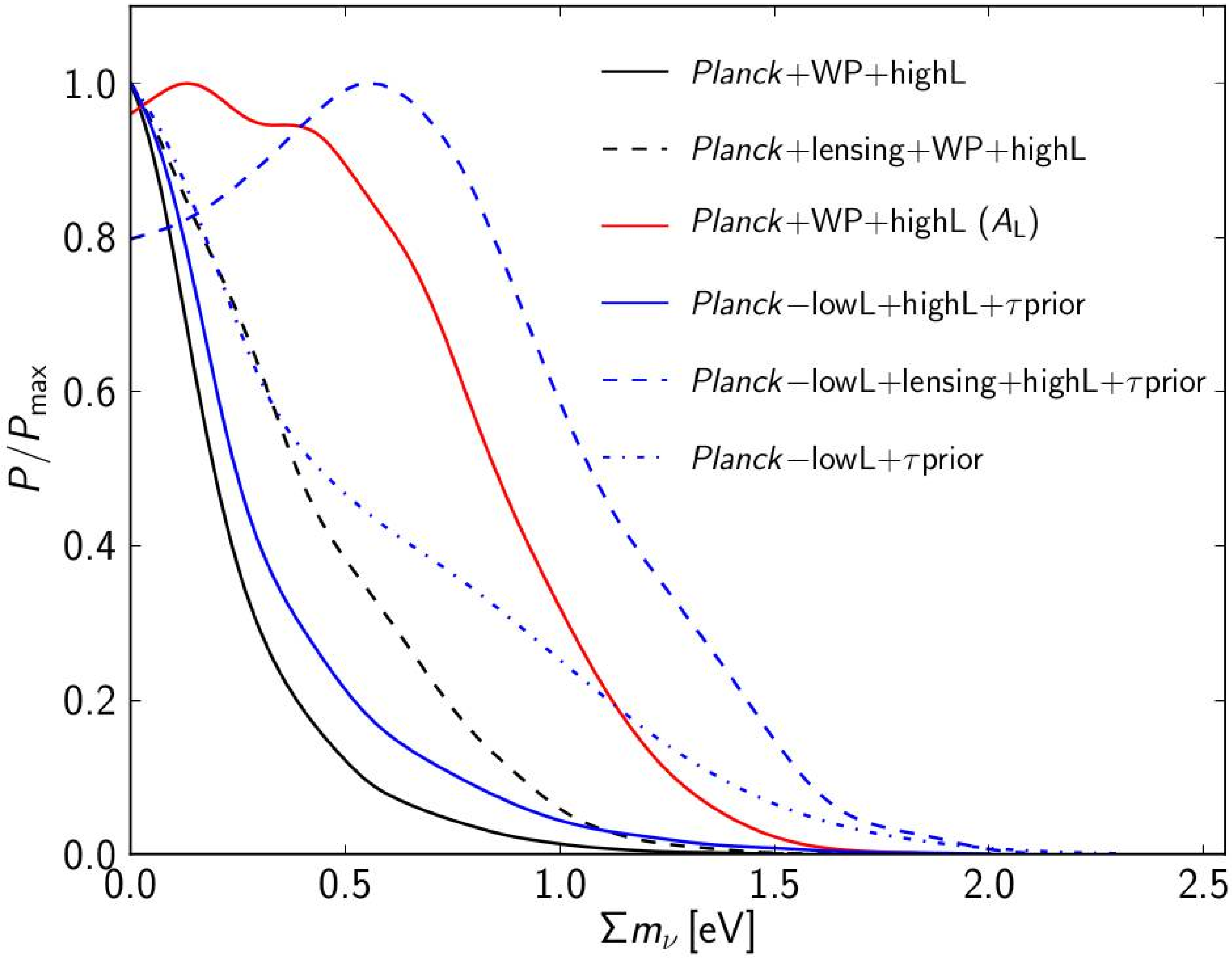
Hou et al. (SPT collaboration), 2012
arXiv:1212.6267

$$\sum m_\nu = (0.32 \pm 0.11)\,\mathrm{eV},$$

$$\sum m_\nu \in [0.01, 0.63]\,\mathrm{eV}\ \ (99.7\%\,\mathrm{CL})\,.$$

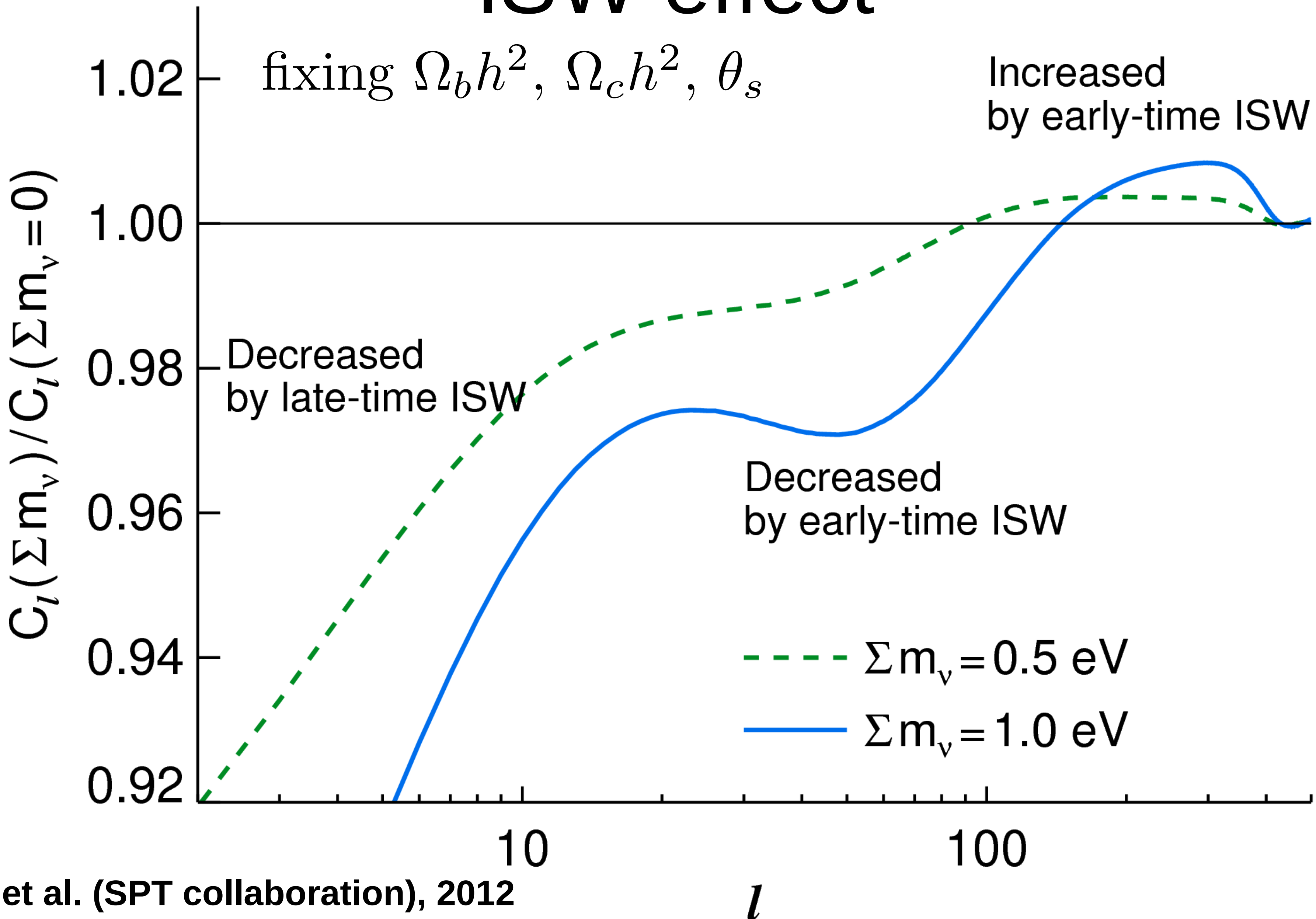
$\sum m_\nu$

Constraints on $\sum m_\nu$ from PLANCK



PLANCK collaboration, 2013
arXiv:1303.5076

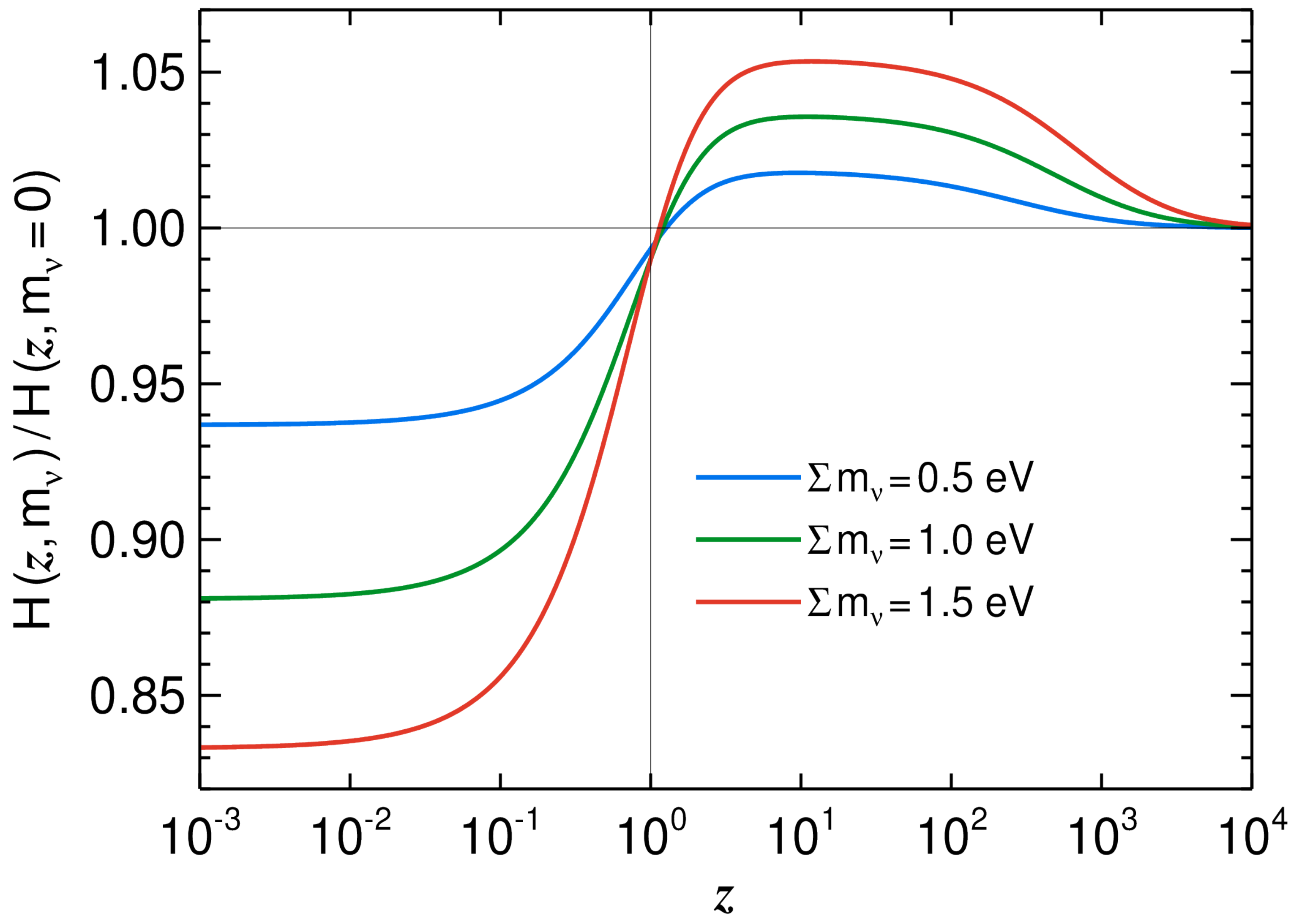
Neutrino mass imprint on CMB by ISW effect



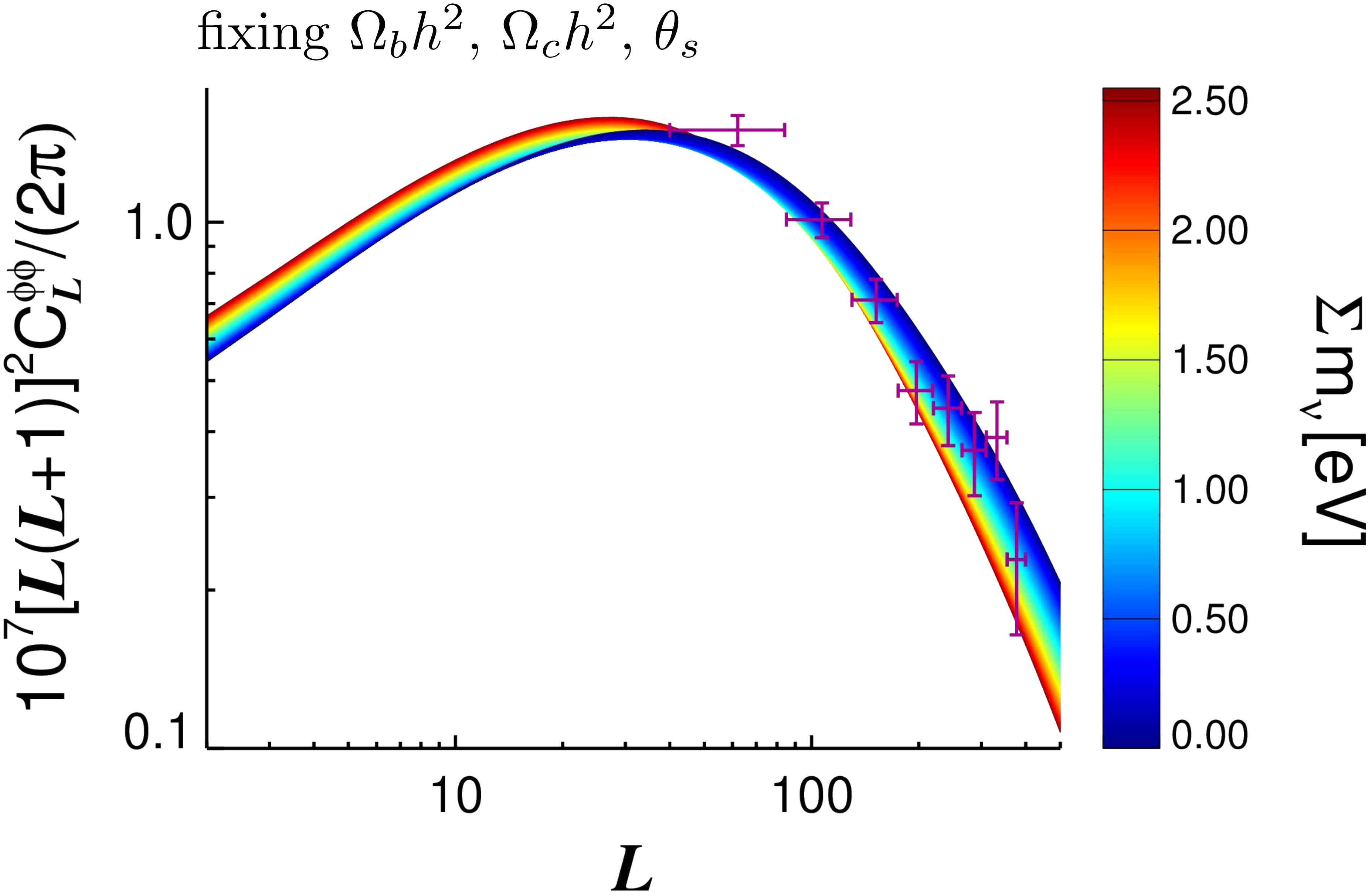
Hou et al. (SPT collaboration), 2012
arXiv:1212.6267

Neutrino mass and expansion rate

fixing $\Omega_b h^2$, $\Omega_c h^2$, θ_s



Neutrino mass and CMB lensing



Summary

- Cosmological or astrophysical signals provide another way of studying neutrino physics

- Current significance of the preference for the non-standard model (Neff > 3) from cosmological signal is weak

- Interpretation of physical stories given the new data is still intriguing

Special thanks to Brendan Crill