Exploring Neutrino Physics with the Cosmic Microwave Background

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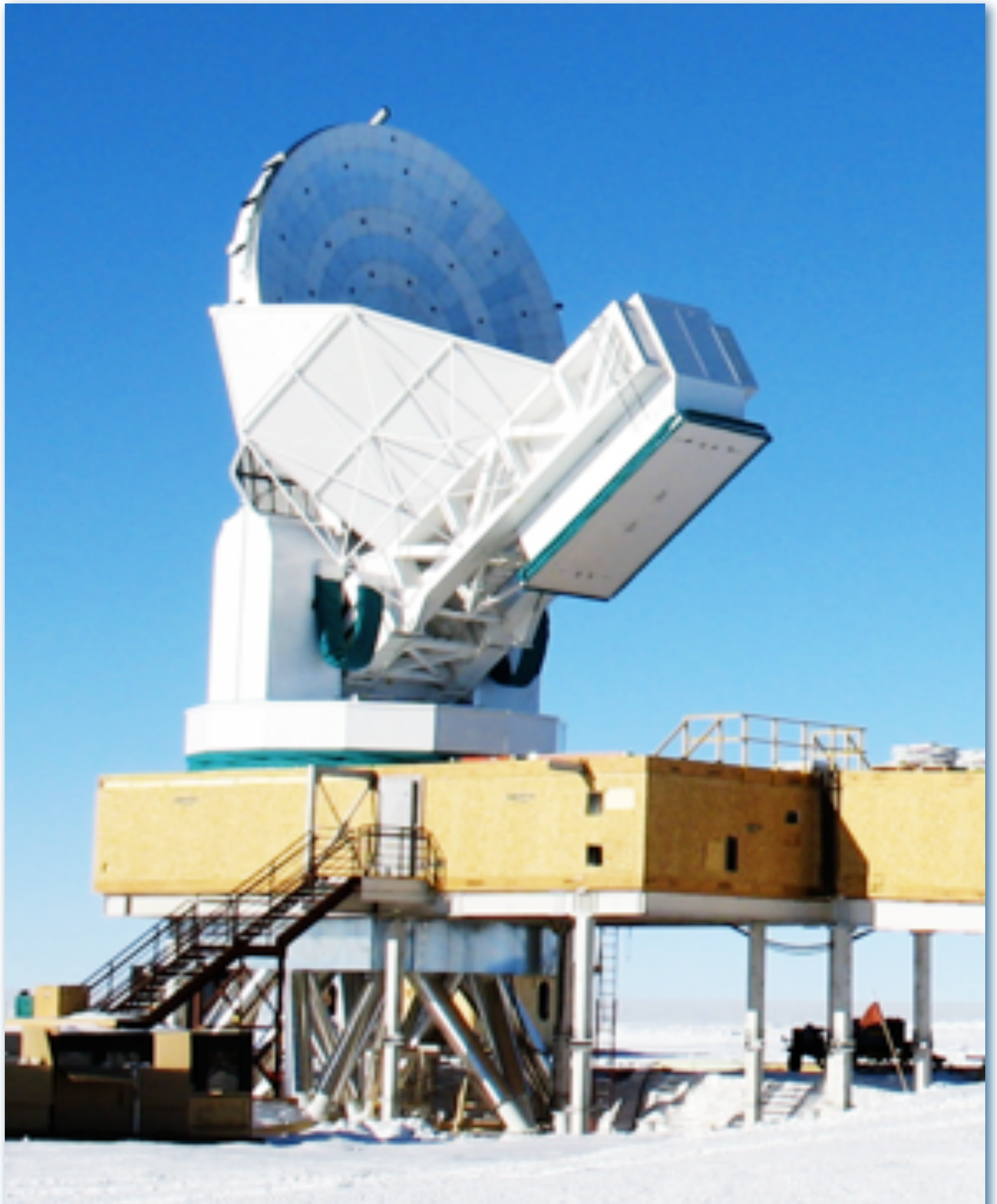
The South Pole Telescope (SPT)



Sub-millimeter Wavelength Telescope:

- 10 meter telescope (1.1’ FWHM beam)
- Off-axis Gregorian optics design
- Fast scanning (up to 2 deg/sec in azimuth)
- 2” pointing accuracy

Funded by NSF


SPT Collaboration

arXiv:1210.7321

A MEASUREMENT OF THE COSMIC MICROWAVE BACKGROUND DAMPING TAIL FROM THE 2500-SQUARE-DEGREE SPT-SZ SURVEY

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Submitted to ApJ

arXiv:1104.2333

CONSTRAINTS ON COSMOLOGY FROM THE COSMIC MICROWAVE BACKGROUND POWER SPECTRUM OF THE 2500-SQUARE DEGREE SPT-SZ SURVEY

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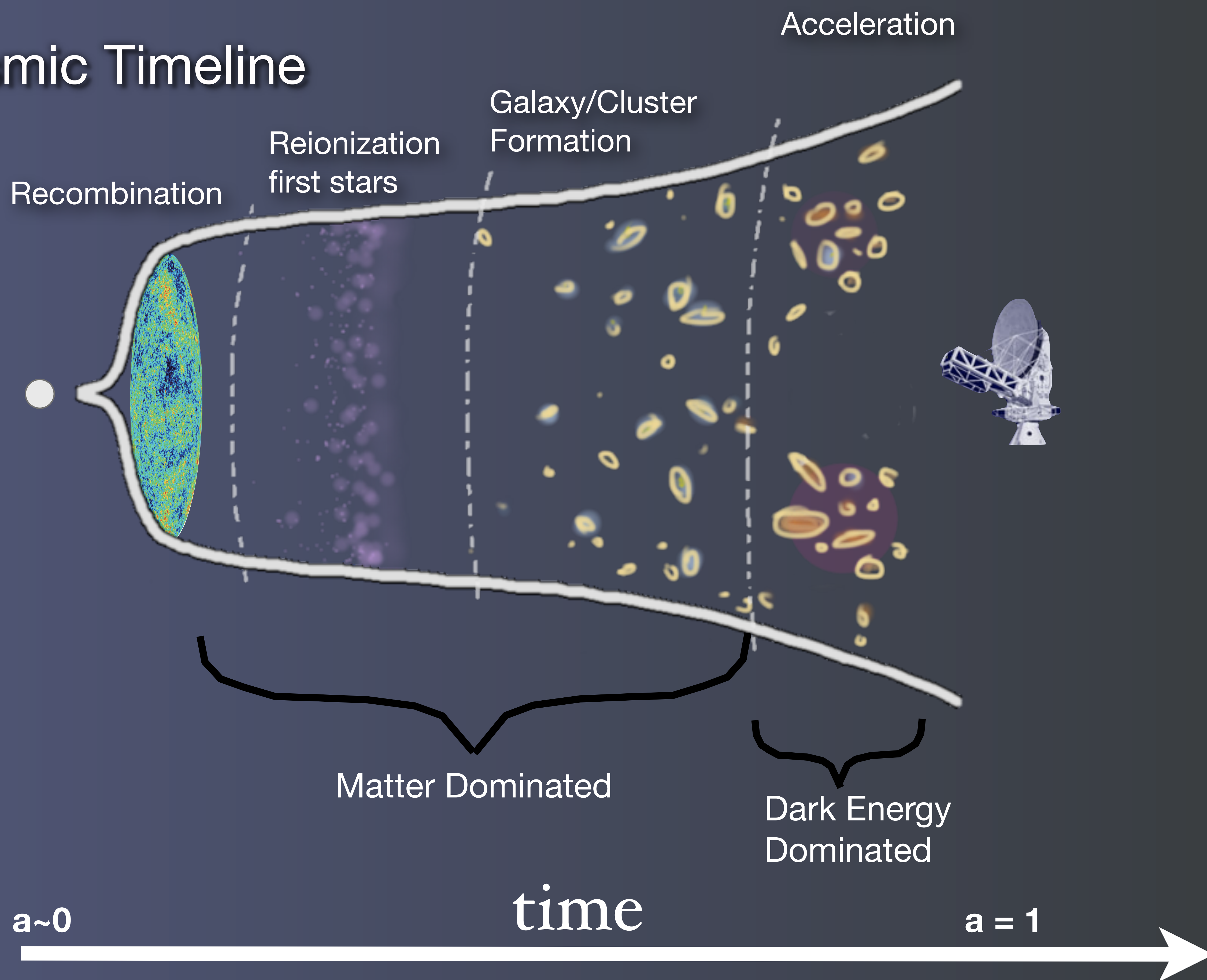
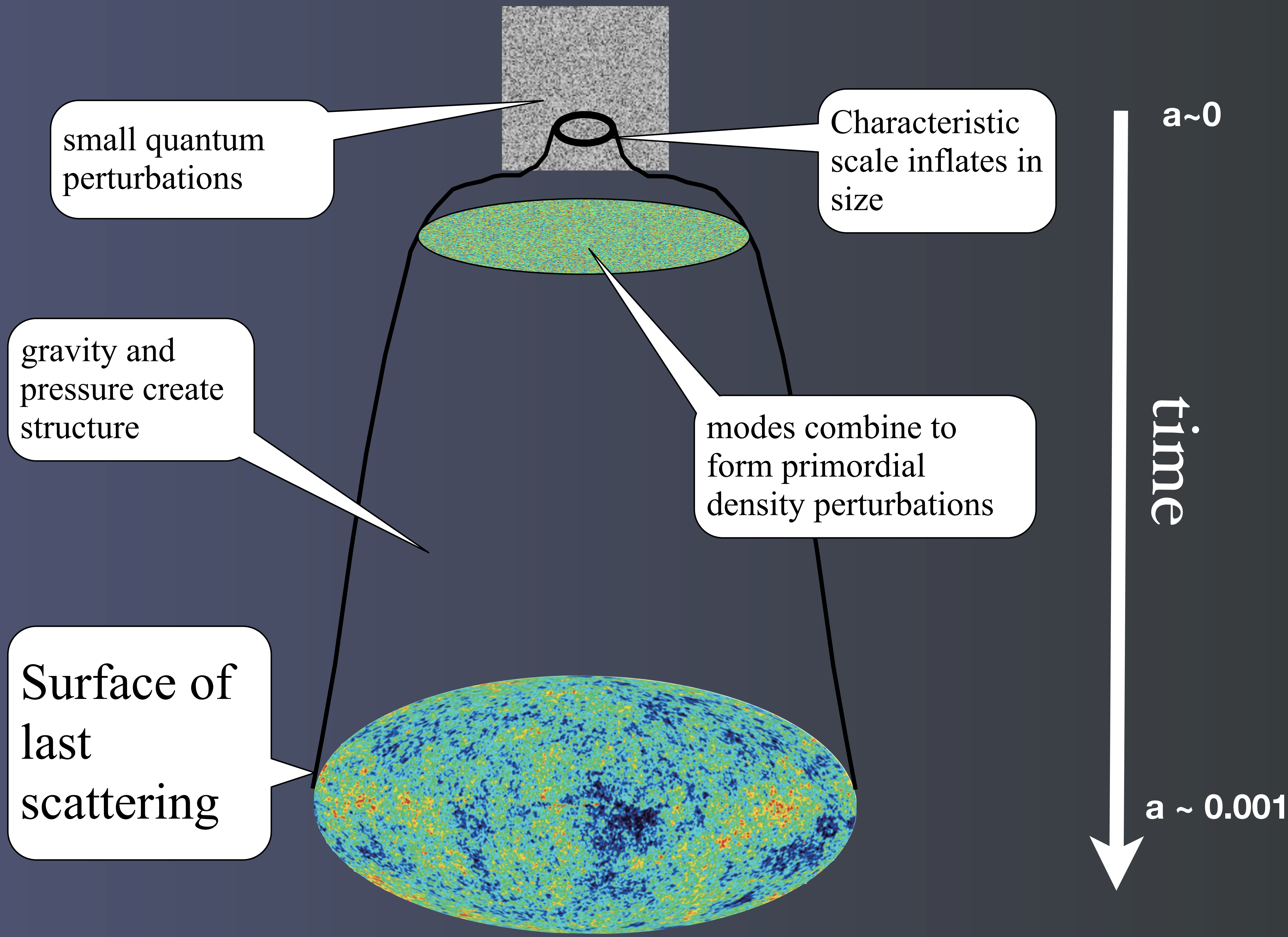
Submitted to ApJ

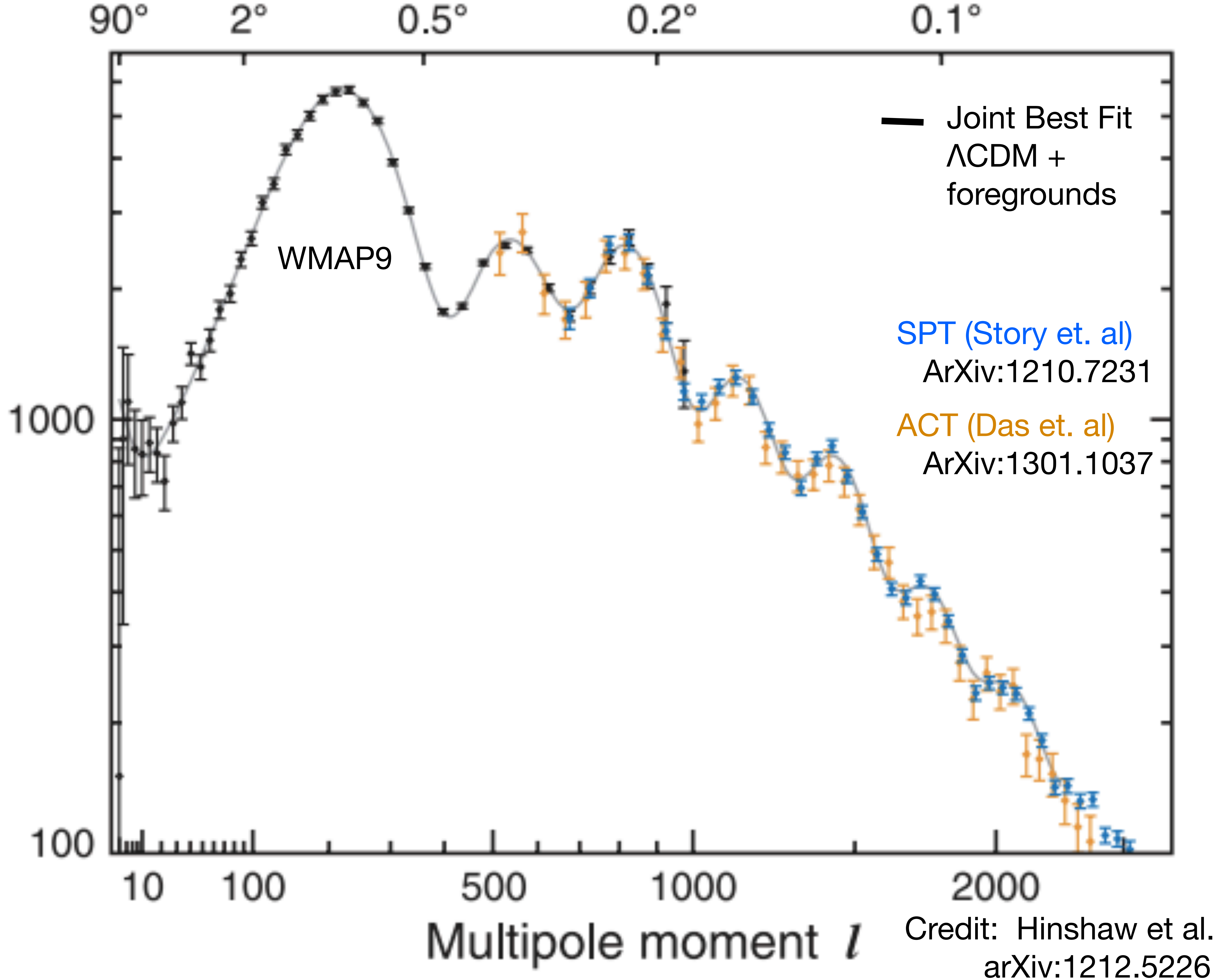
Outline

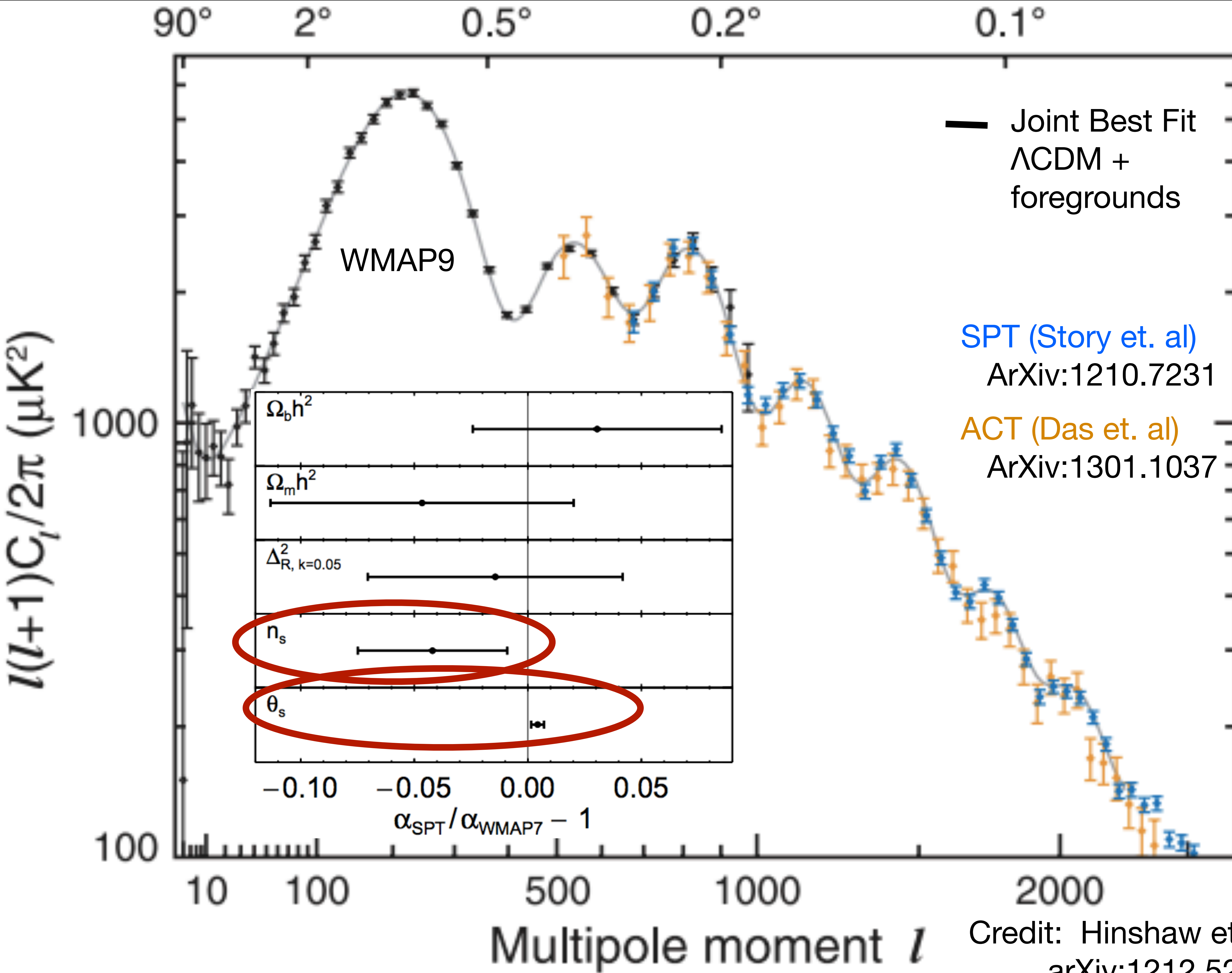
- Background
- Additional neutrino-like species
- Weighing the neutrinos with cosmology
- Future results

Cosmic Timeline




small quantum perturbations
Characteristic scale inflates in size
a~0
gravity and pressure create structure
modes combine to form primordial density perturbations
time
Surface of last scattering
a ~ 0.001


90° 2° 0.5° 0.2° 0.1°
Joint Best Fit
ΛCDM +
foregrounds
WMAP9
SPT (Story et. al)
ArXiv:1210.7231
ACT (Das et. al)
ArXiv:1301.1037
$l(l+1)C_l/2\pi$ (μK²)
1000
100
10 100 500 1000 2000
Multipole moment l
Credit: Hinshaw et al.
arXiv:1212.5226

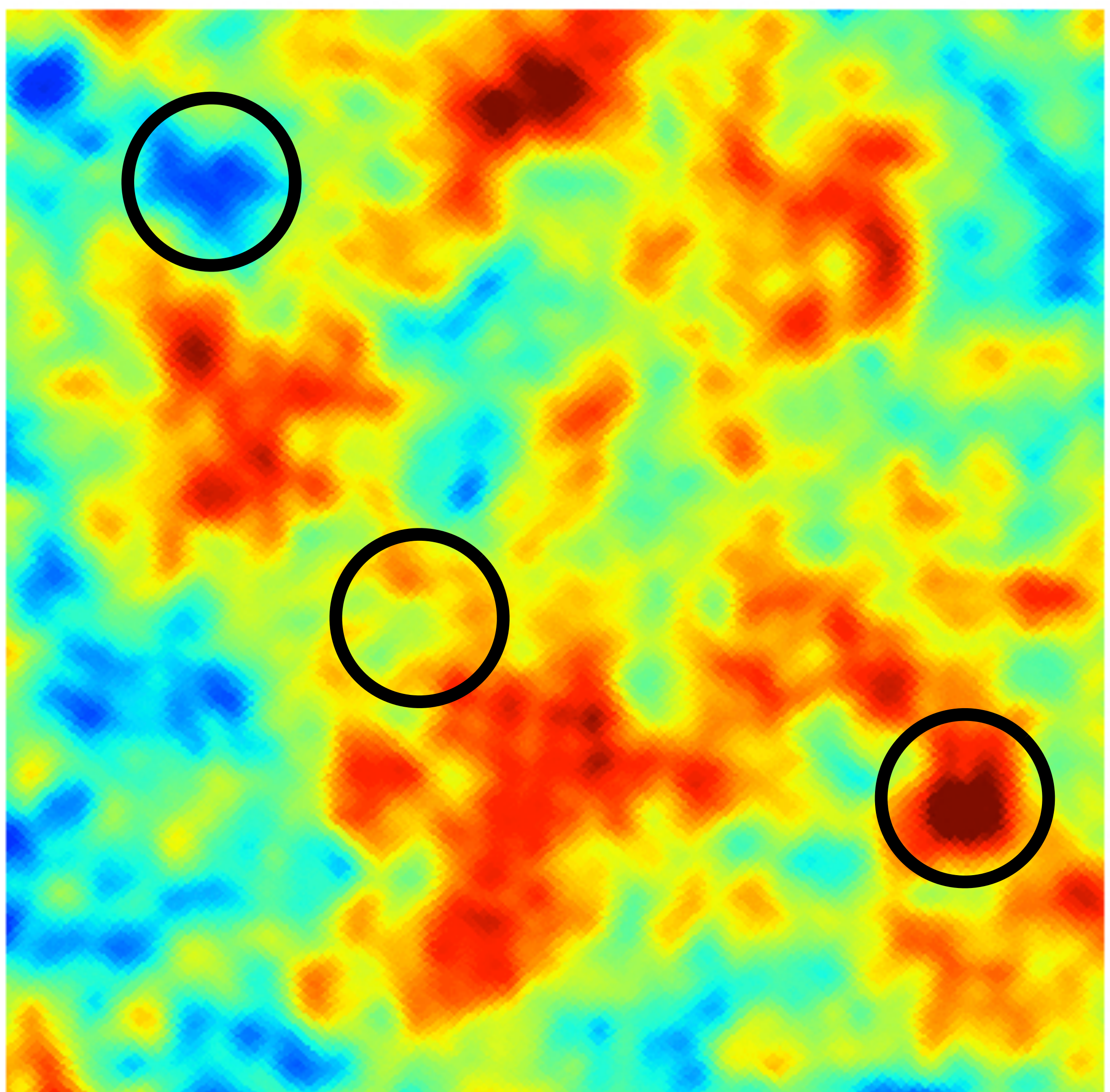


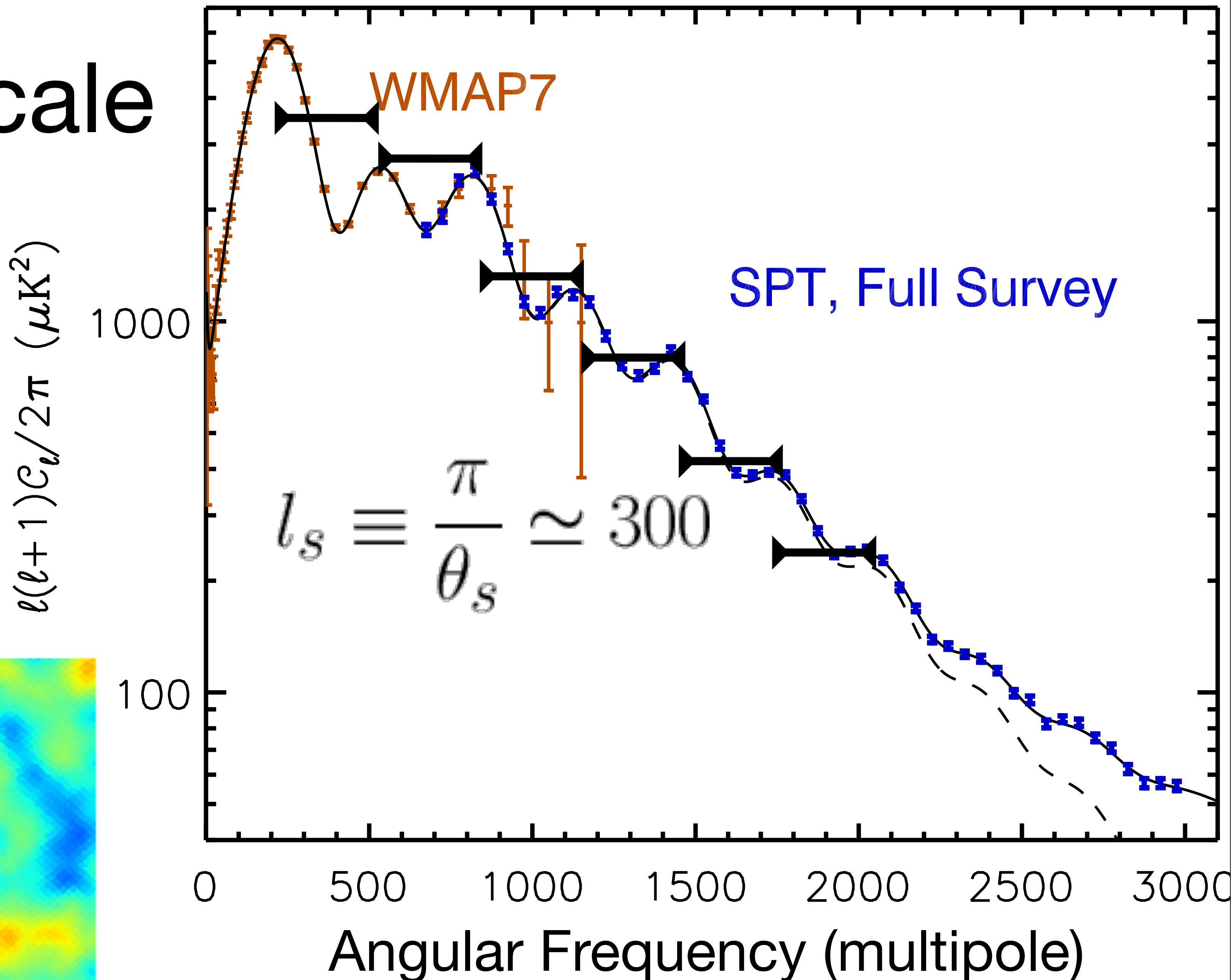
Credit: Hinshaw et al.
arXiv:1212.5226

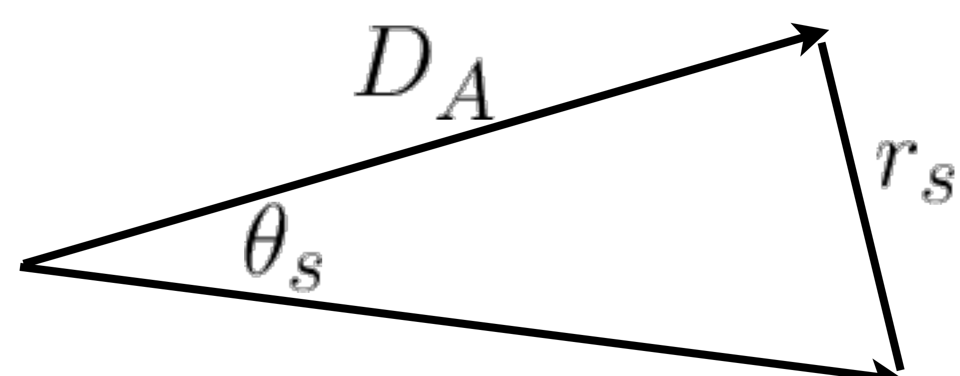
Sound Horizon Scale

standing waves in the matter fluid when photons decouple gives characteristic distance scale on last scattering surface

$$100\theta_s = 1.0441 \pm 0.0012$$







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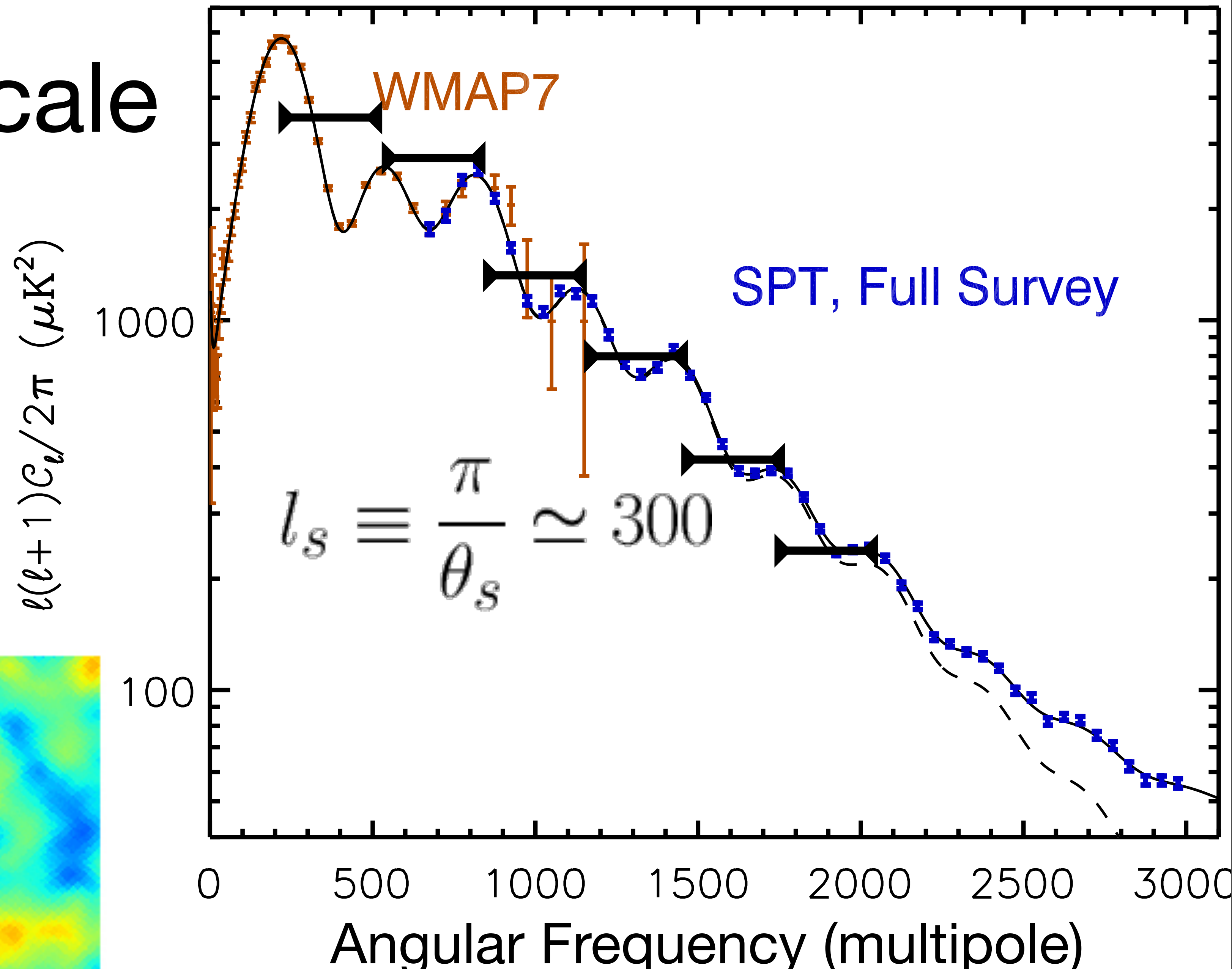
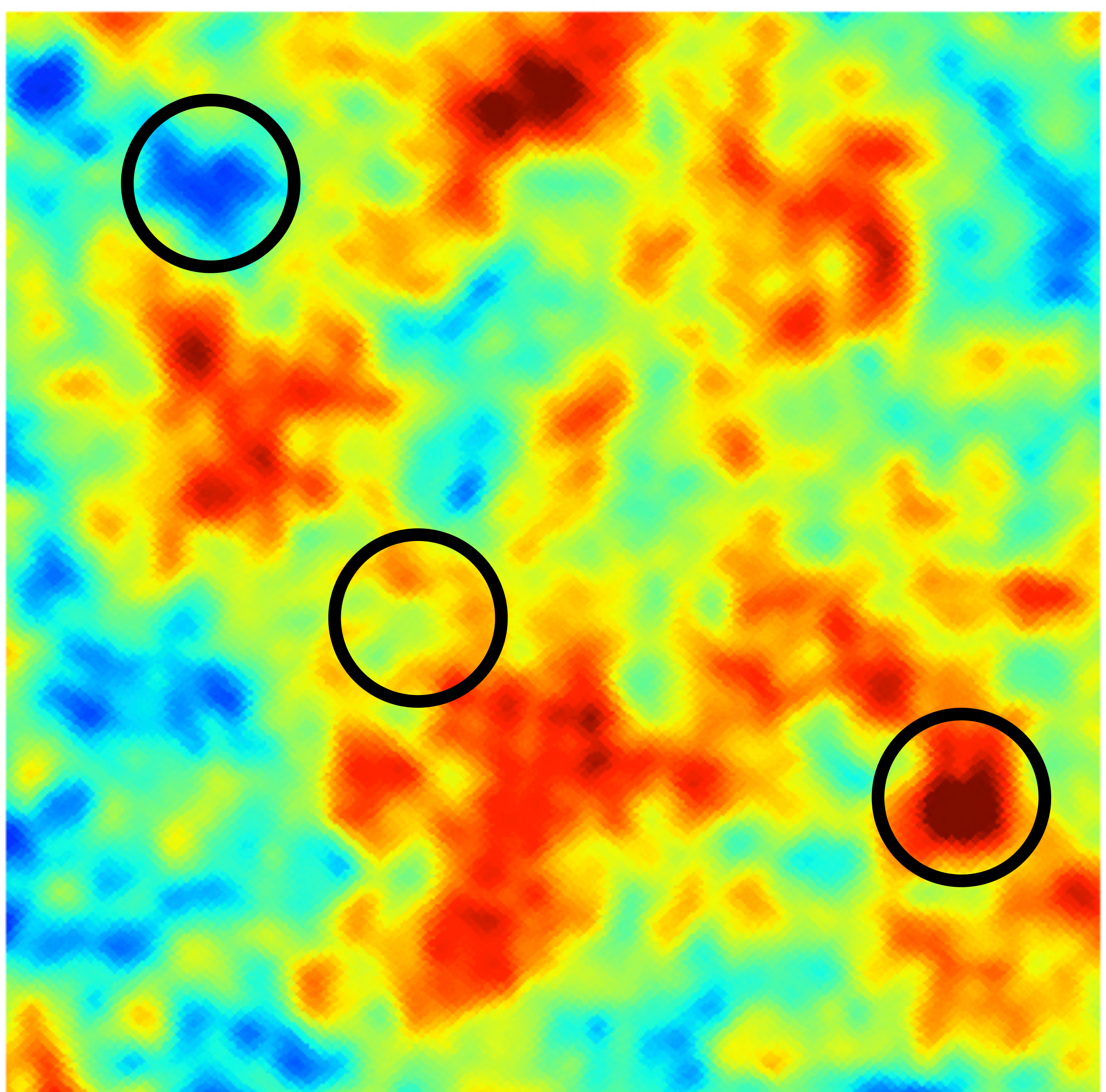
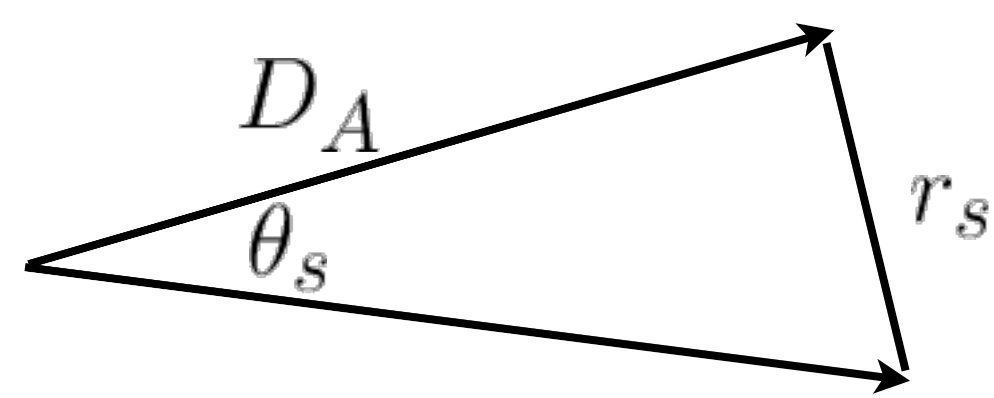


$$l_s \equiv \frac{\pi}{\theta_s} \simeq 300$$



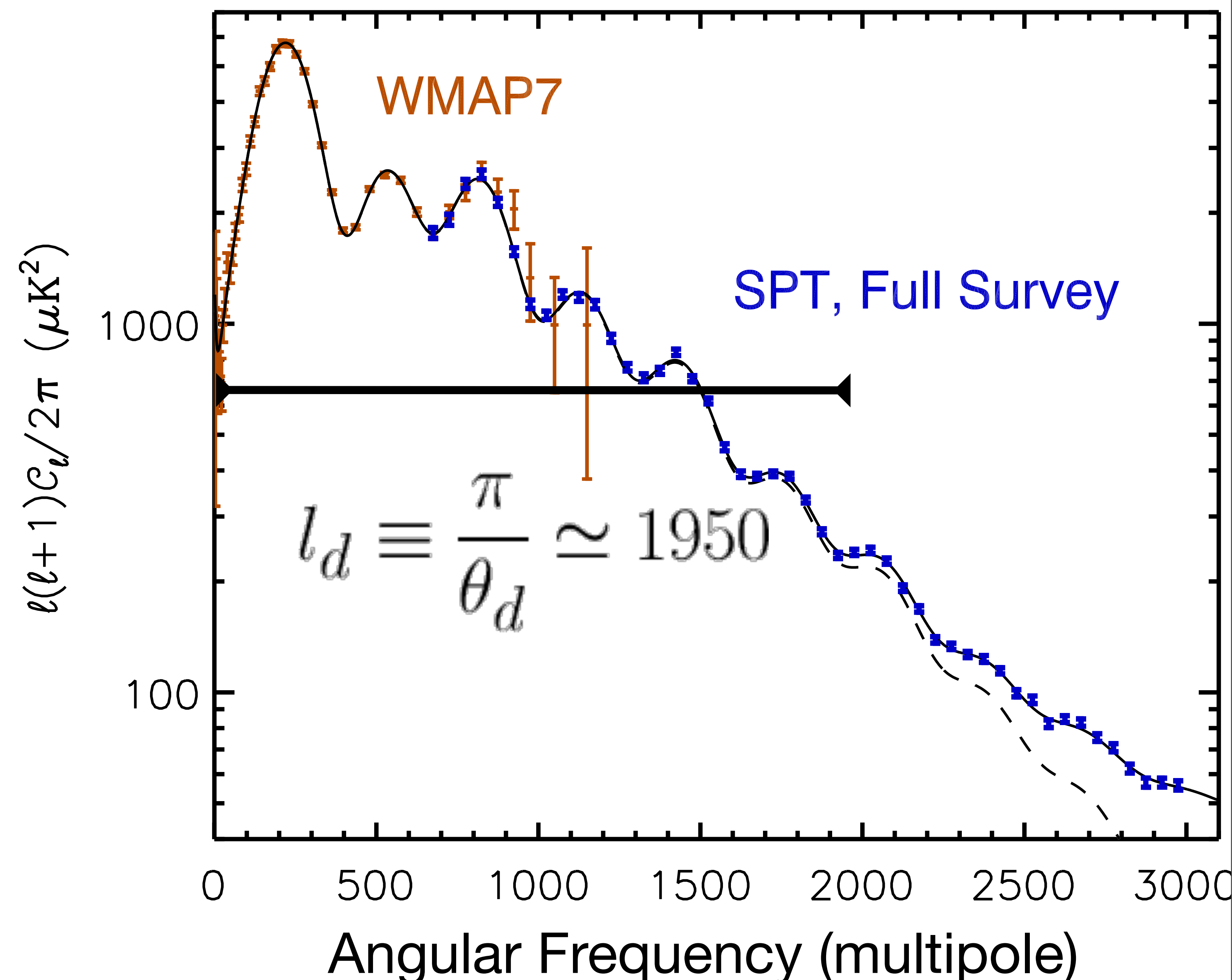
$$H^2(a) = H_0^2\left(\frac{\Omega_m}{a^3} + \frac{\Omega_\gamma}{a^4} + \frac{\Omega_\nu}{a^4} + \Omega_\Lambda\right)$$

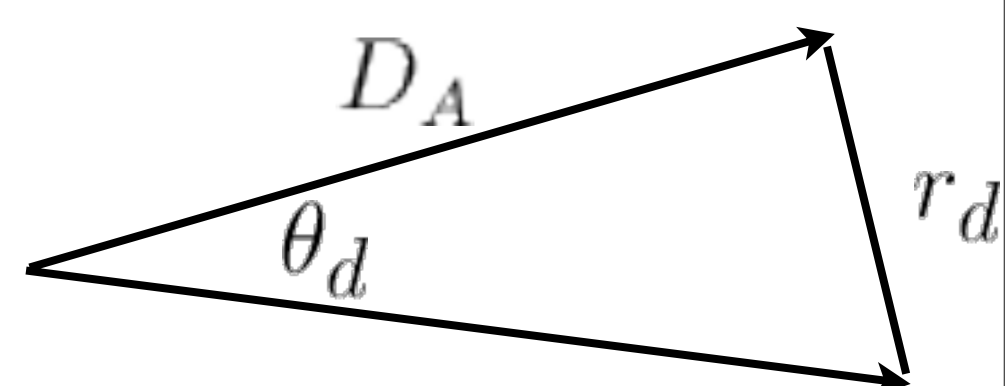


Photon Diffusion Damping Scale

Streaming photons isotropize local volume, damping anisotropy on scales smaller than the photon diffusion scale

$$\frac{\theta_d}{\theta_s} = 0.1562 \pm 0.0011$$





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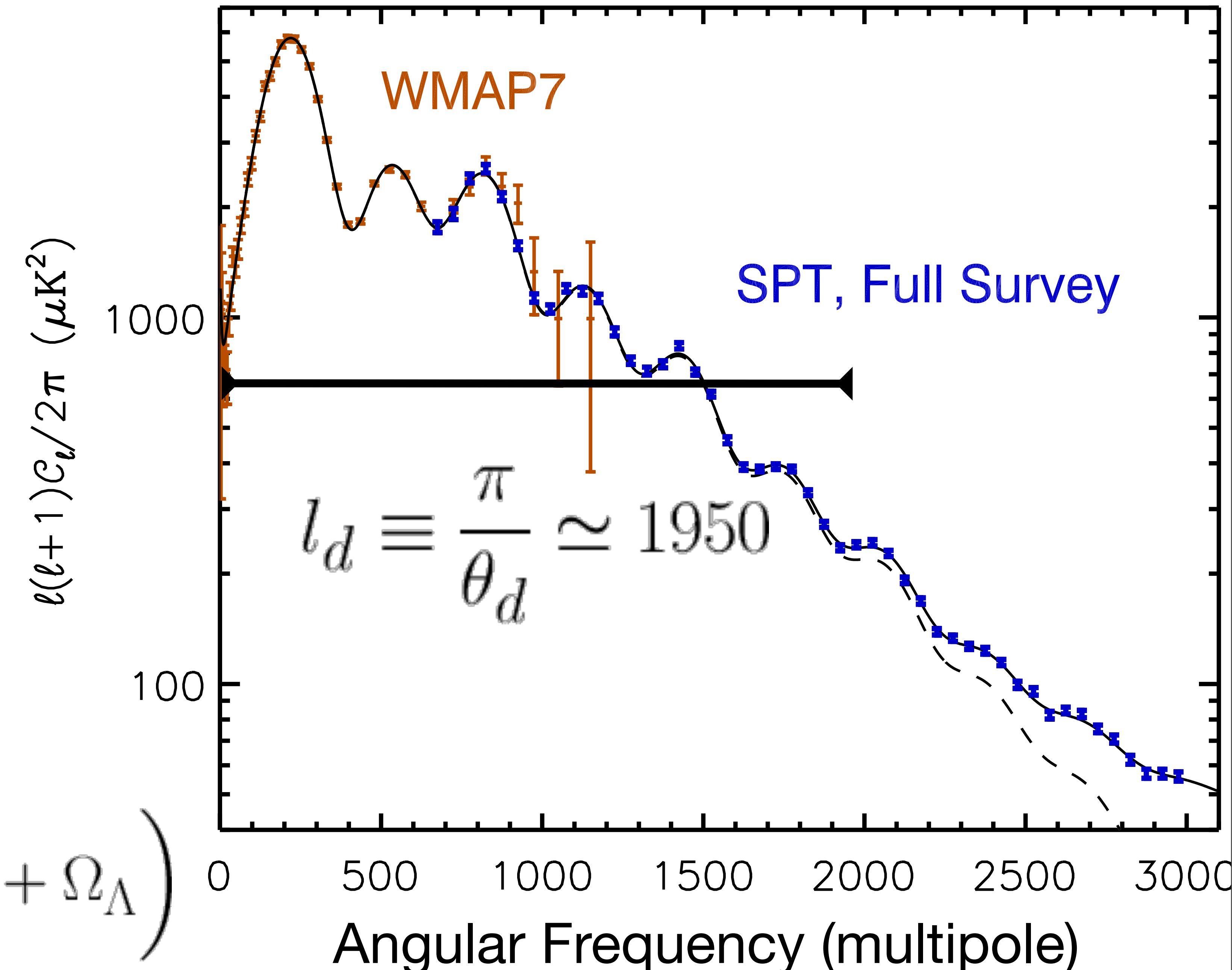
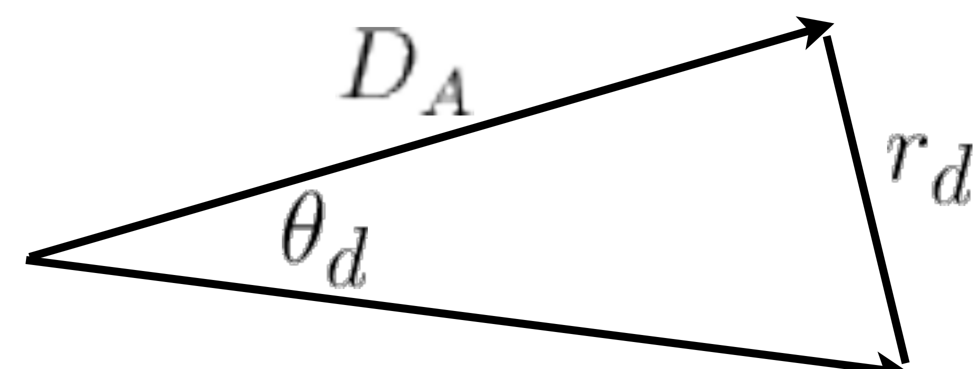
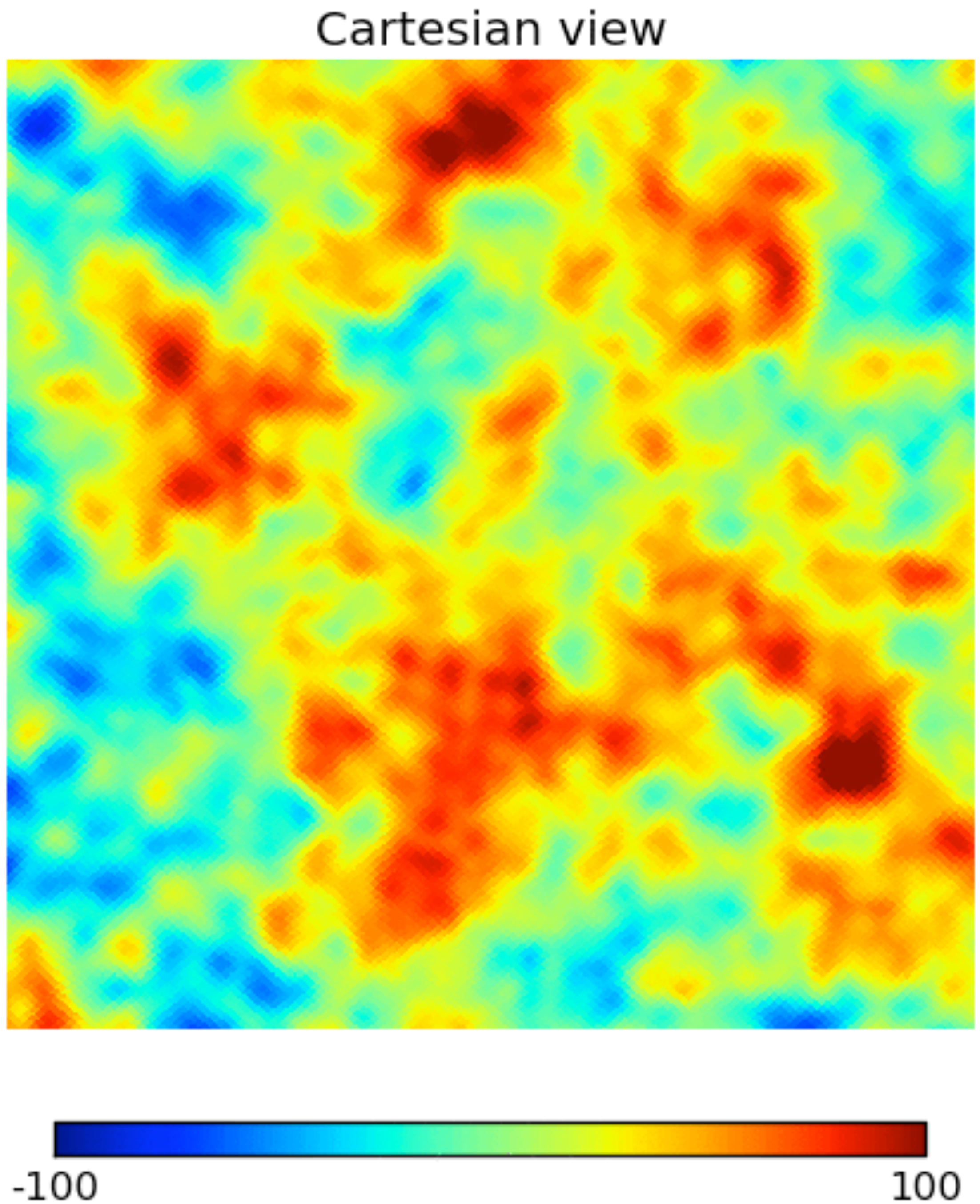
$$r_s \propto H^{-1} \qquad \frac{\theta_d}{\theta_s} \propto \sqrt{H}$$

$$r_d \propto H^{-1/2}$$







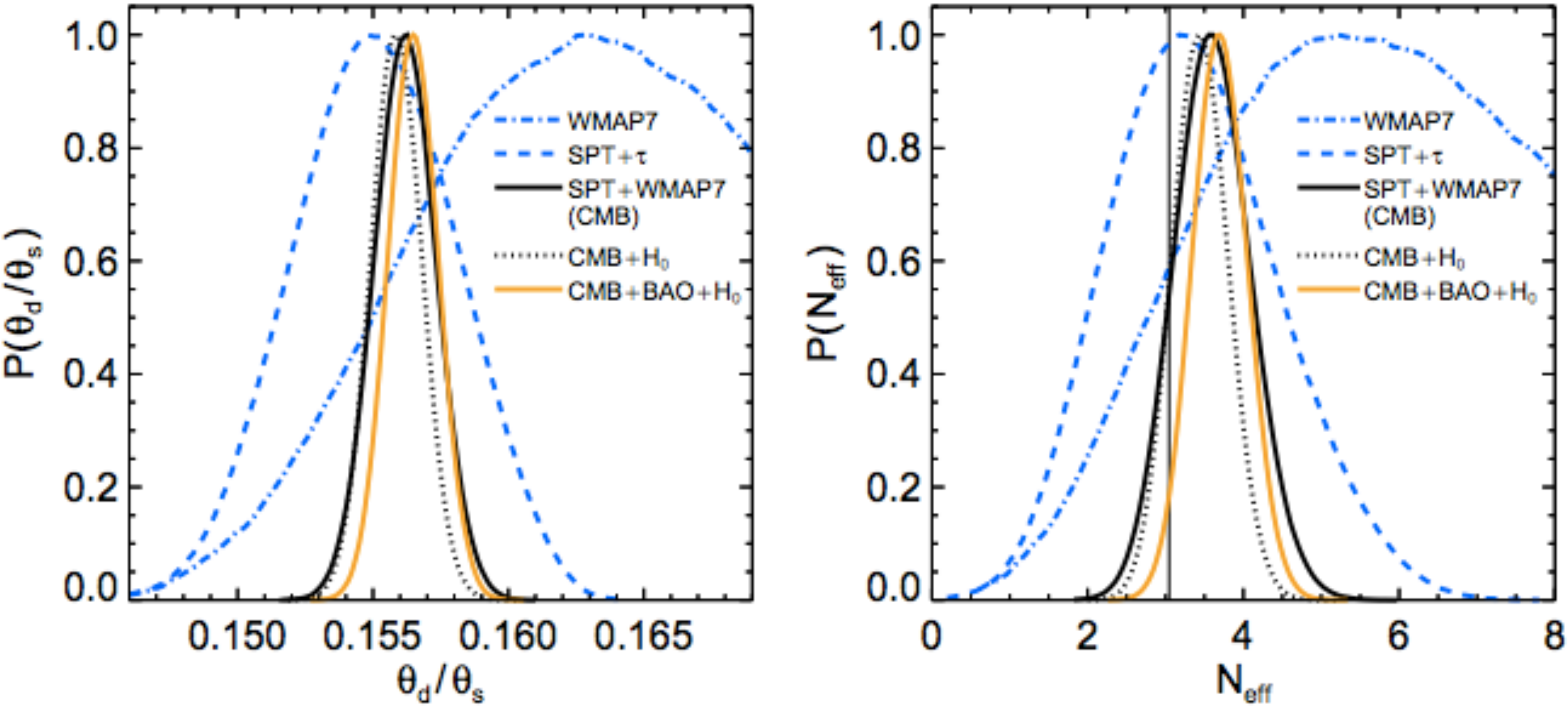
credit: Marius Millea

Panel 1: Number of neutrino-like species = 2

Panel 2: Number of neutrino-like species = 6

increasing neutrino mass washes out small scale power, by increasing damping scale

Number of Neutrino-like Species (N_{eff})

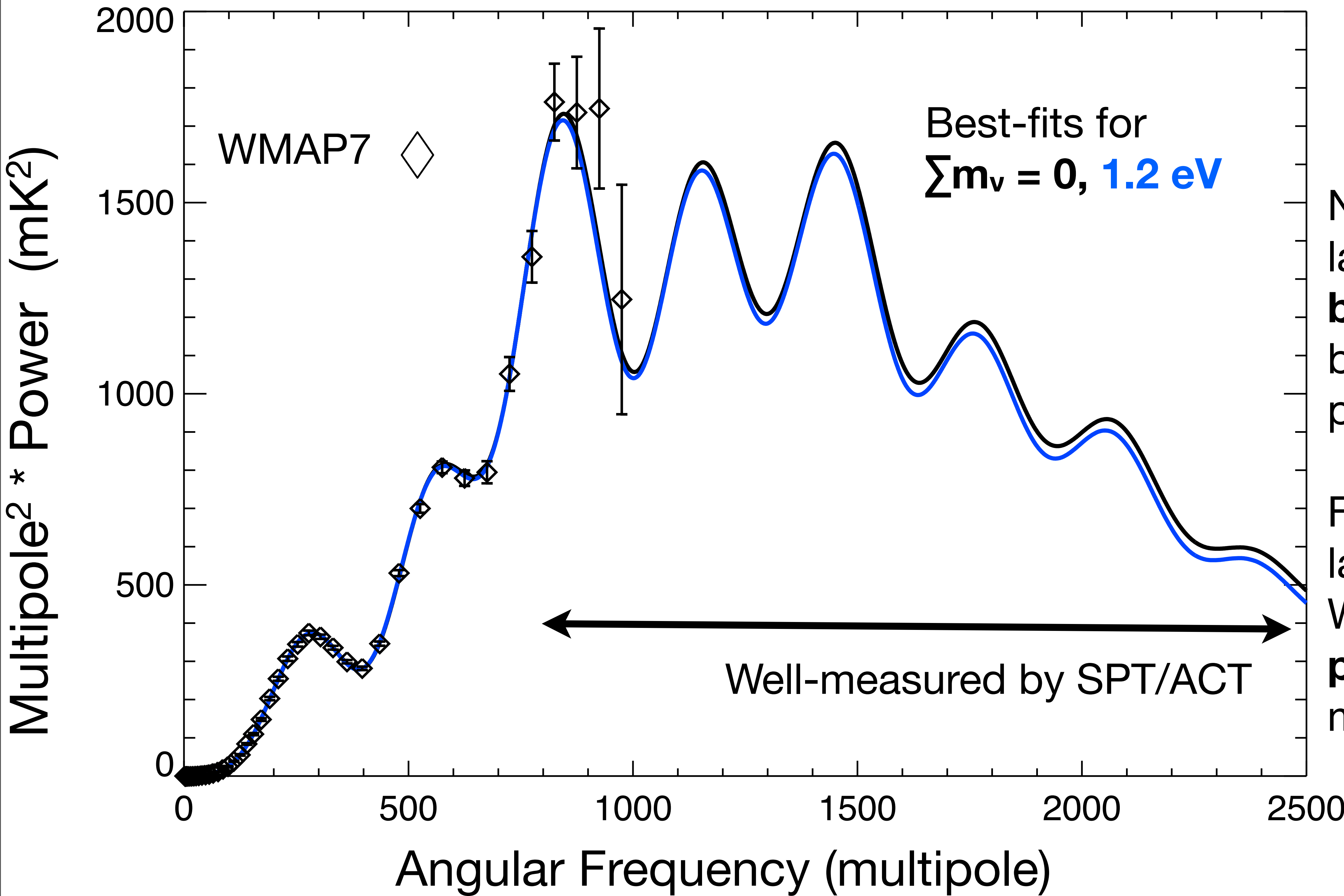


- N_{eff} = 3.62 ± 0.48 (SPT+WMAP7)
- N_{eff} = 3.71 ± 0.35 (SPT+WMAP7+H_0+BAO) (1.9 σ higher than 3.046)
- N_{eff} = 2.97 ± 0.56 (ACT+WMAP7)
- N_{eff} = 3.50 ± 0.42 (ACT+WMAP7+H_0+BAO)

Outline

- Background
- Additional neutrino-like species
- Weighing the neutrinos with cosmology
- Future results

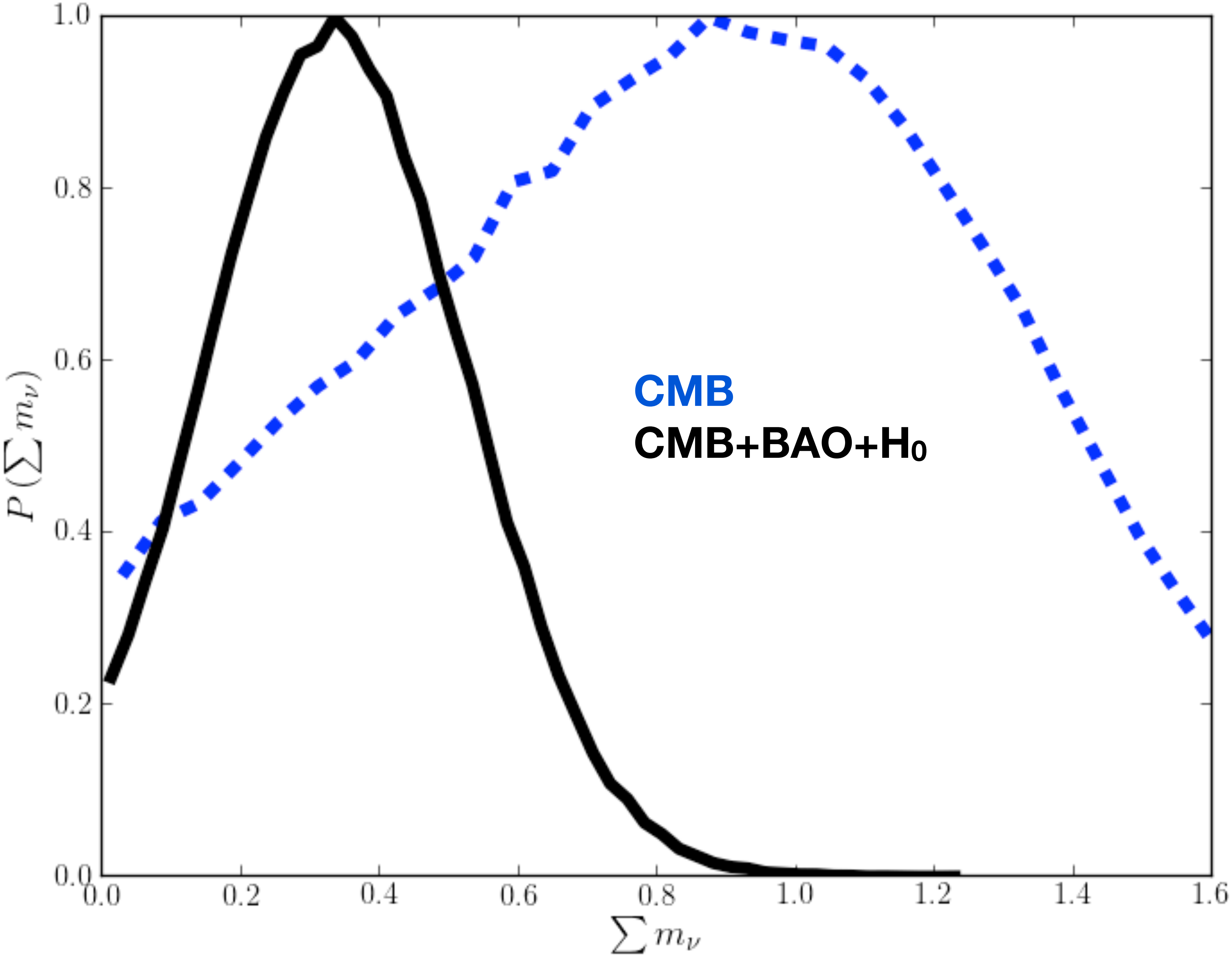
Massive neutrinos from the CMB



Neutrino mass affects largest scales, but **can be compensated for** by changing other parameters

Fixing the power at large scales to match WMAP gives **lower power** at small scales measured by **SPT/ACT**

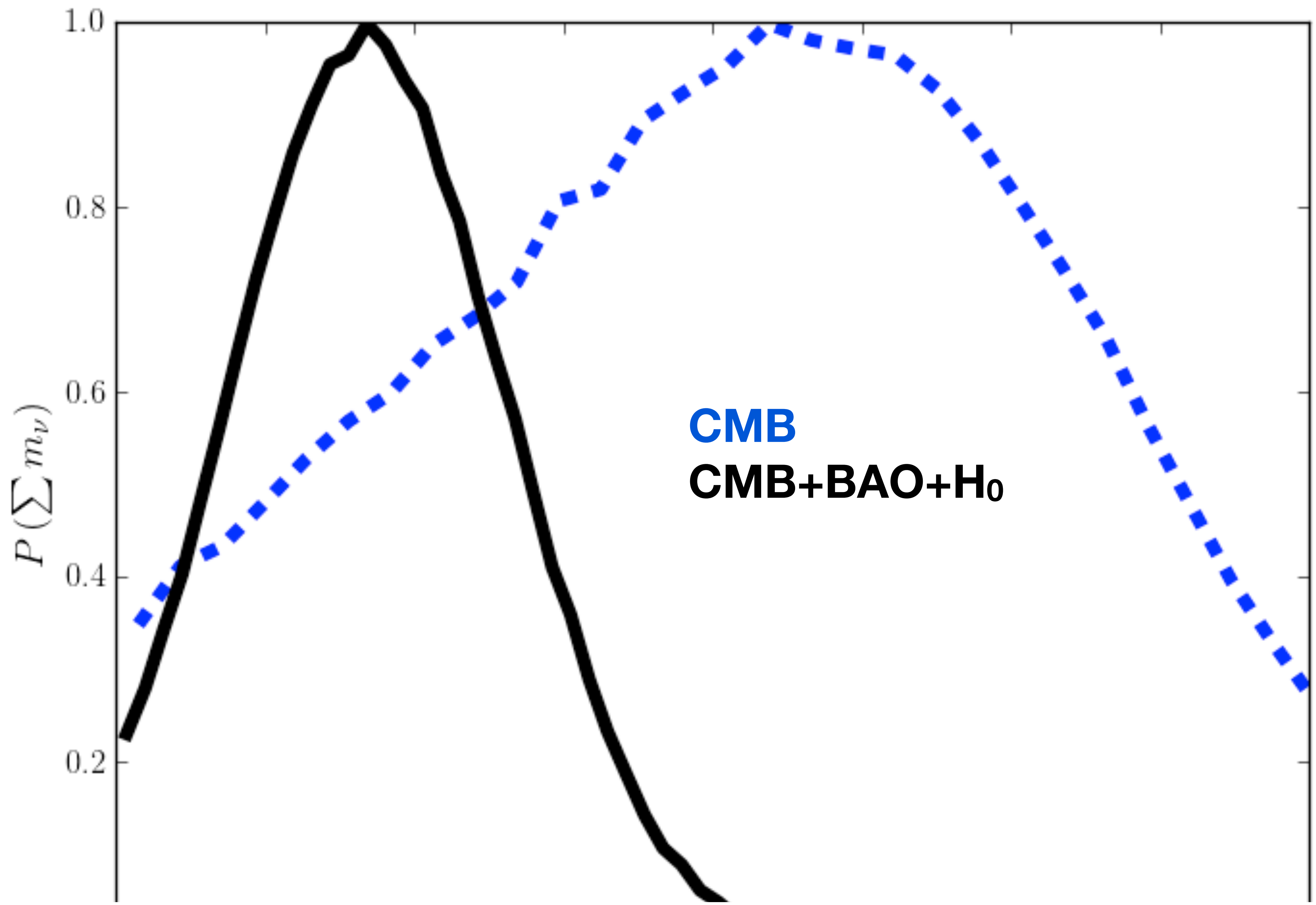
Mass constraints from the CMB



BAO and **H_0** measurements provide low-redshift information on the hubble rate at recent times

CMB is consistent at < 2 σ with massless neutrinos--**not very satisfying!**

Mass constraints from the CMB



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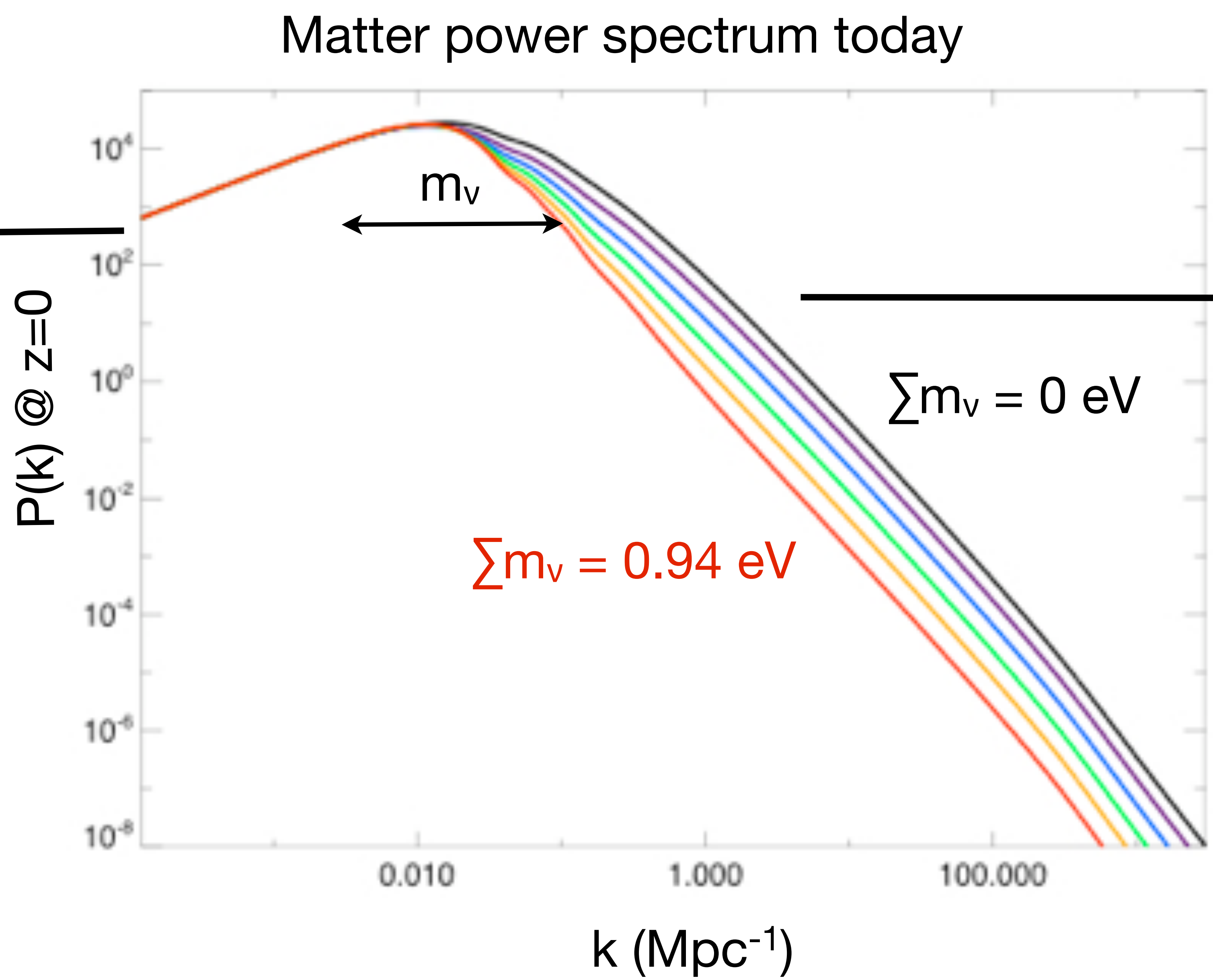
SOLUTION: add lower redshift probes, like galaxy cluster counts

As seen by structure growth

Large scales: Faster expansion & clustering cancel (no net change)

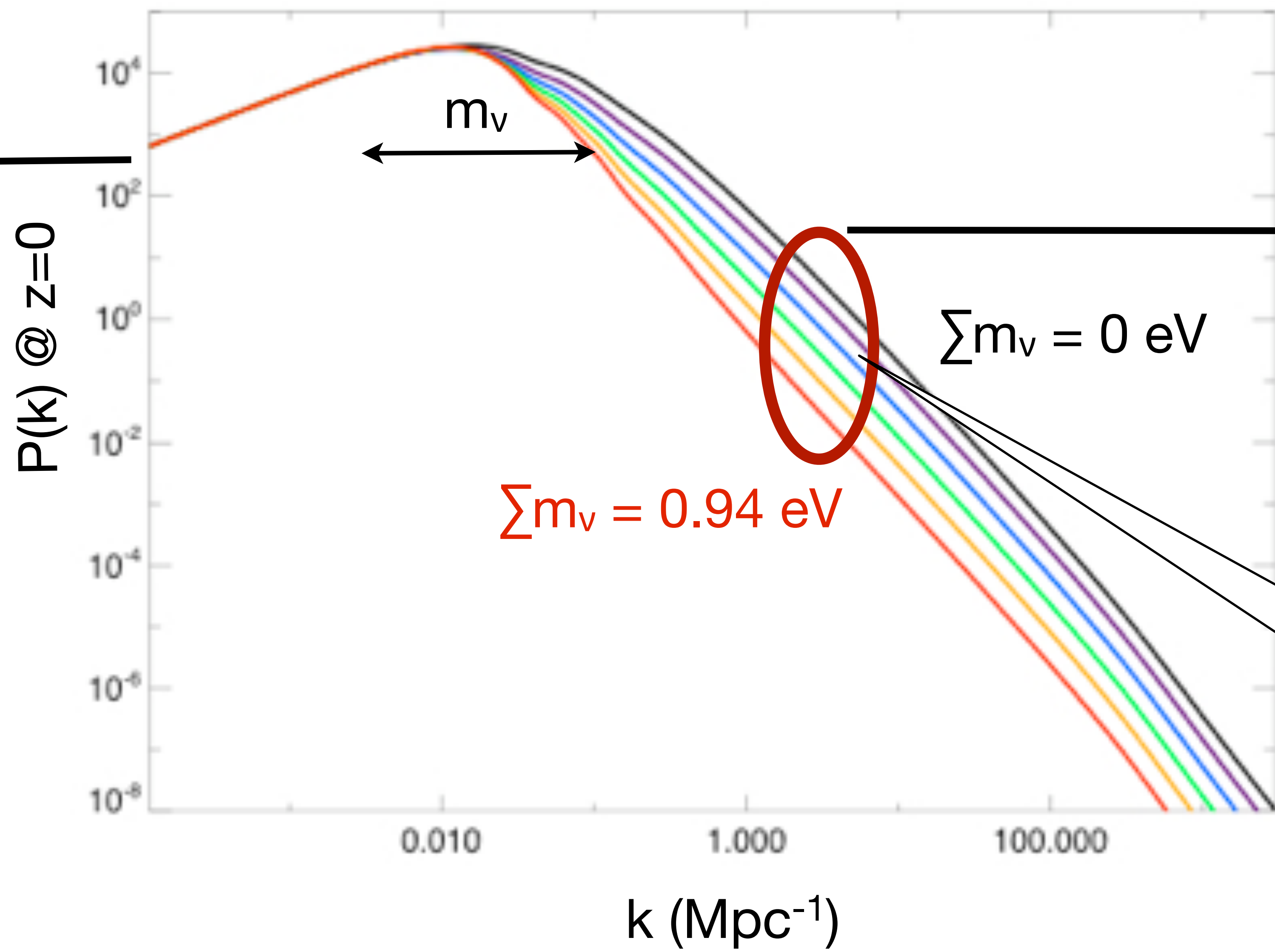


Small scales: Faster expansion suppresses structure

As seen by structure growth

0.1 eV changes cluster abundance by **25%**

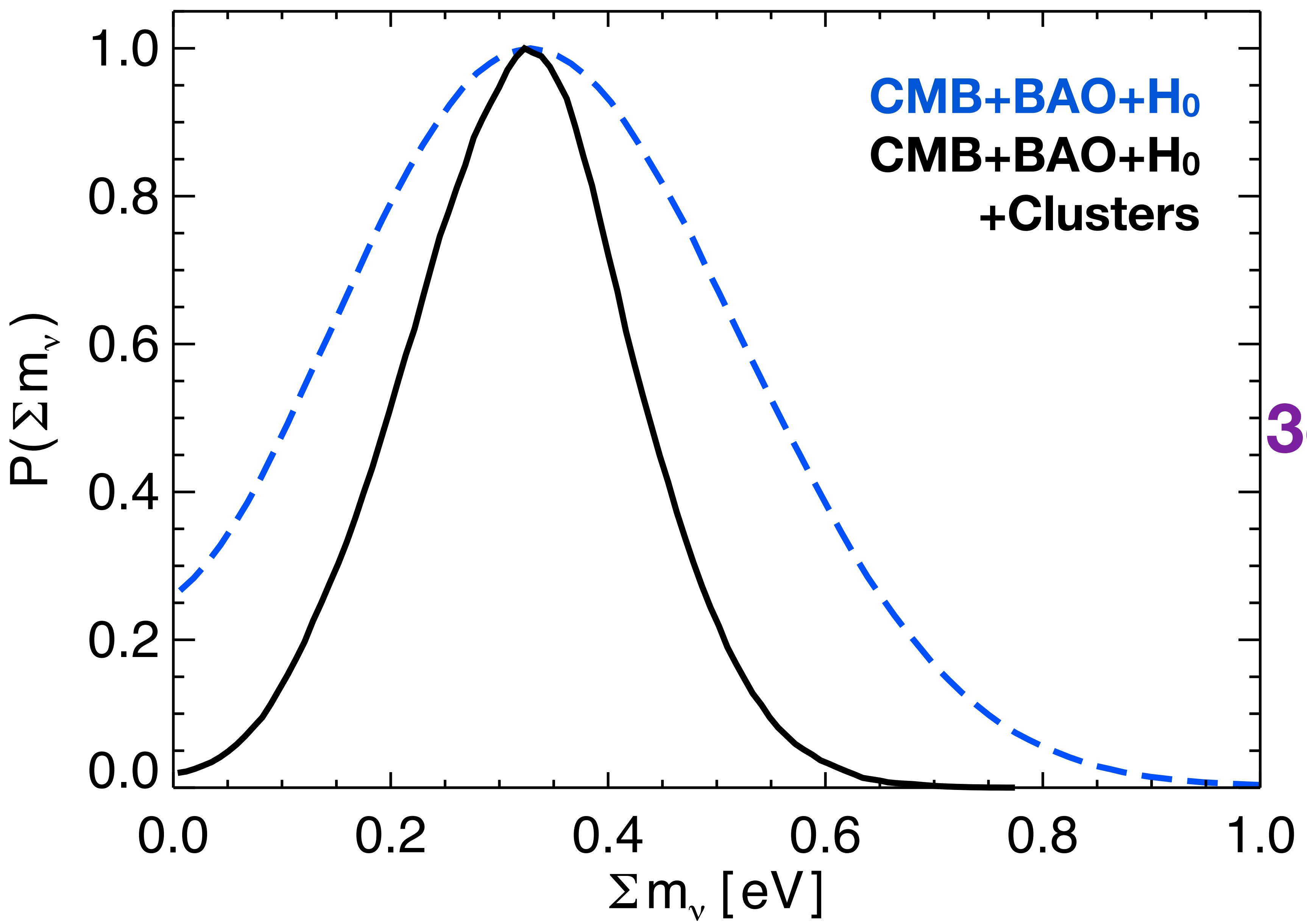
Large scales: Faster expansion & clustering cancel (no net change)



Small scales: Faster expansion suppresses structure

Determines the number and mass of clusters

Hints of massive neutrinos

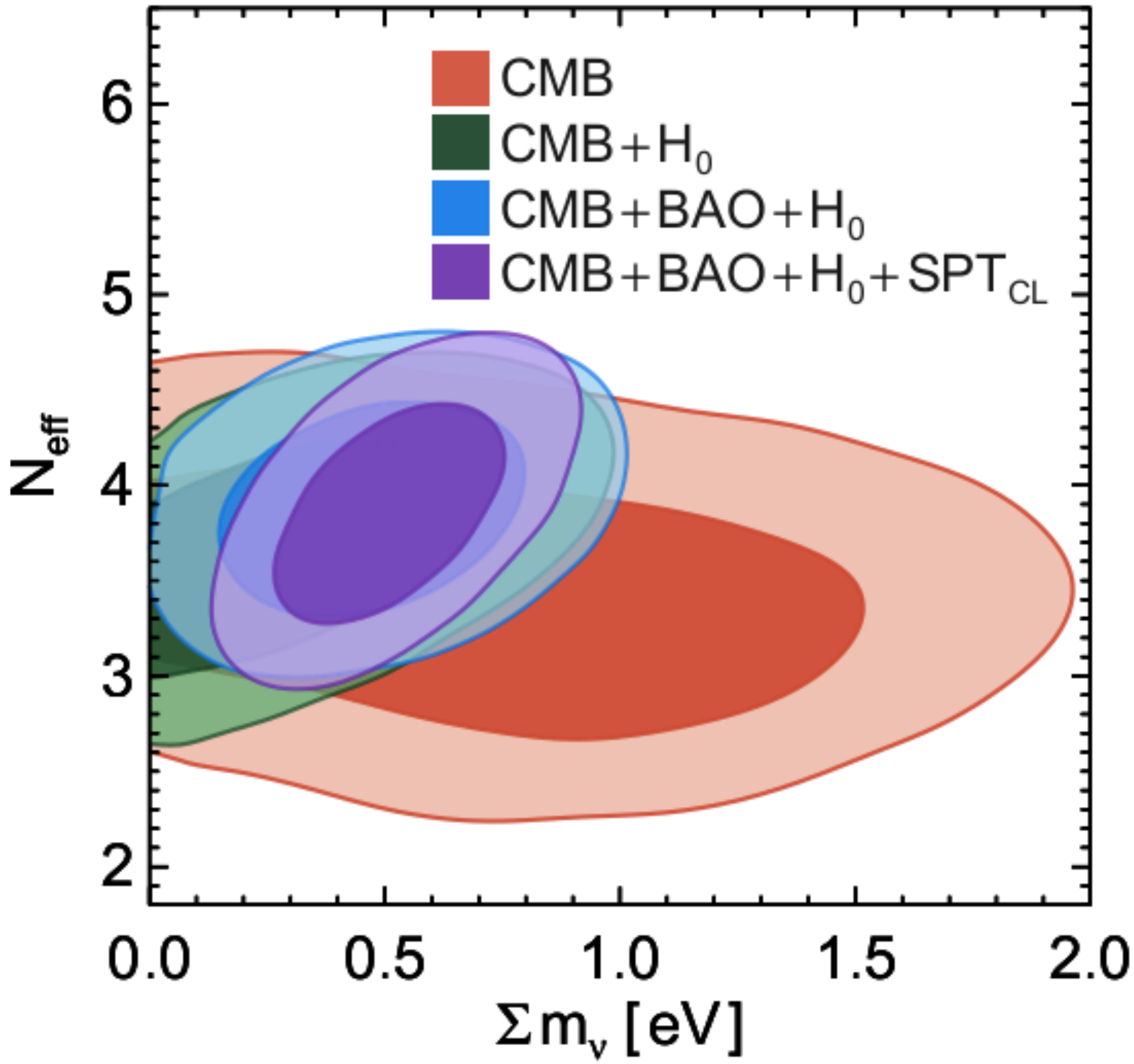


Including everything:

$\sum m_\nu = 0.32 \pm 0.11$ eV

3σ preference for $\sum m_\nu > 0$

Extra massive neutrinos



CMB + low redshift geometry:

$$N_{eff} = 3.89 \pm 0.37$$

$$\sum m_\nu = (480 \pm 210)\ \mathrm{meV}$$

CMB+low redshift geometry
+ Large Scale Structure:

$$N_{eff} = 3.86 \pm 0.37$$

$$\sum m_\nu = (510 \pm 150)\ \mathrm{meV}$$

Future Experiments

- Neff: greater power spectrum sensitivity, lensing
- mass: cluster abundance measurements (SZ effect)
- Planck+BOSS (next several years)
  - 25x sky area than SPT, much lower noise than WMAP, **will resolve damping scale**
  - Neff to within 0.14*, mass to within 120* meV
- 3rd Gen (SPT3G)+PLANCK+BOSS (2016-2019)
  - **10 times deeper than SPT**, 1/10 the noise of Planck
  - Neff to within .08*, mass to within 40* meV

*9 parameter LCDM+r+Neff+mnu cosmology

Source: SPT-3G proposal

Summary

– Number of neutrino-like species is constrained geometrically by the CMB at ~10% level

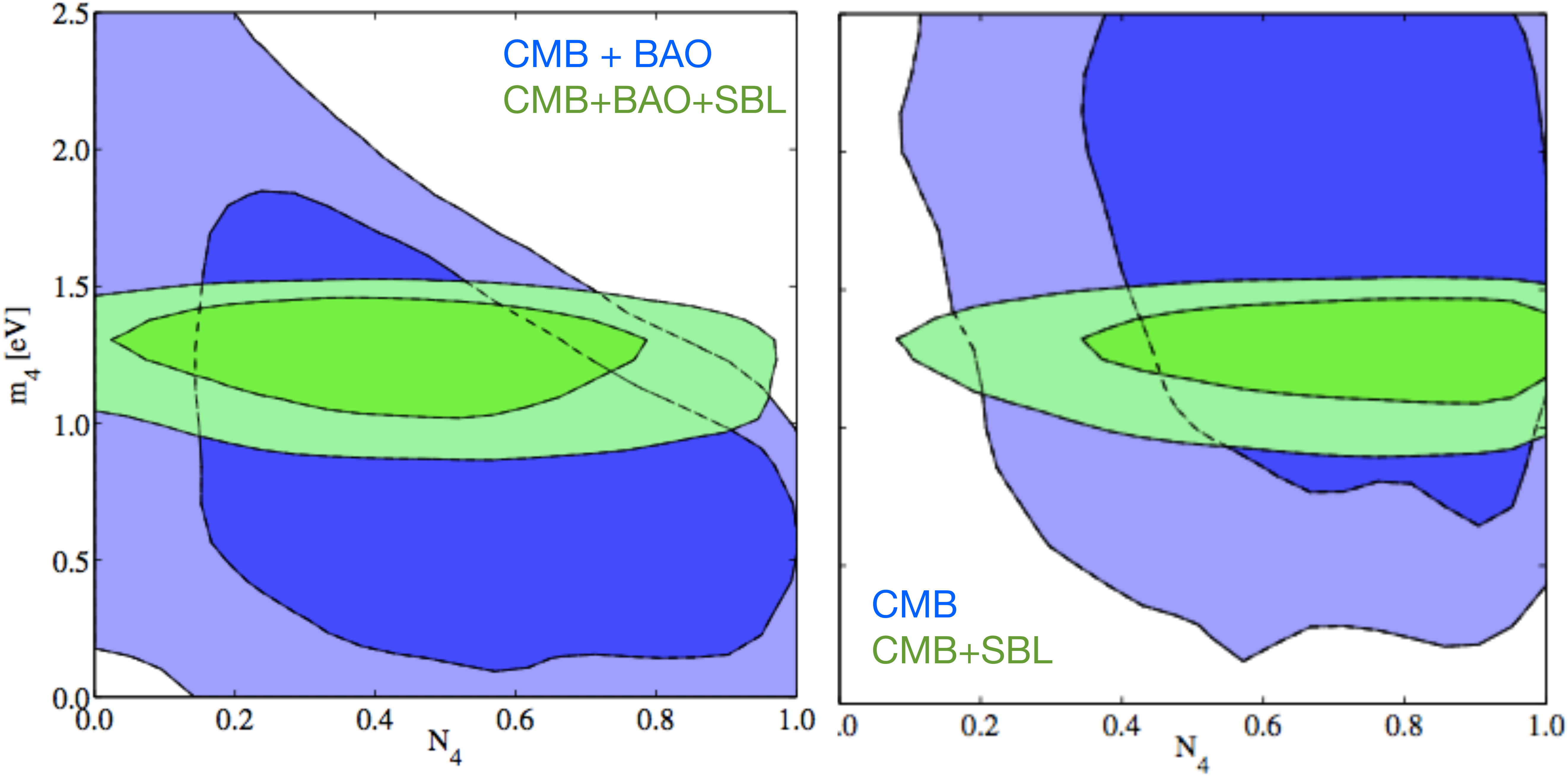
– Mass of neutrinos depends crucially on additional cosmological probes, like late-time geometry constraints (**BAO, H_0**) and **cluster abundances.** Current sensitivity of ~100meV/3.

– Future experiments through better measurements of lensing effect and additional cluster probes will reach ~2-5% sensitivity on the number of species and probe the 10meV scale for neutrino mass.

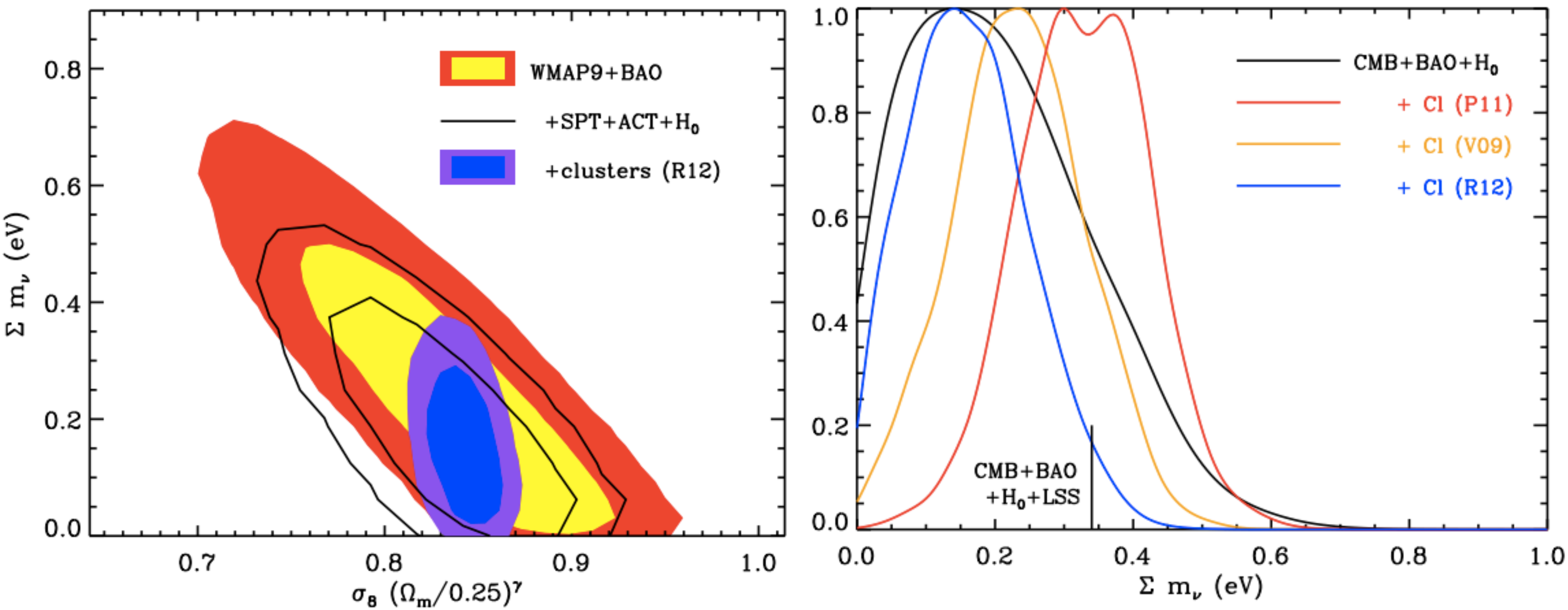
Back-up Slides

(3+1) neutrino model

Archidiacono et. al: **ArXiv:1302.6720**

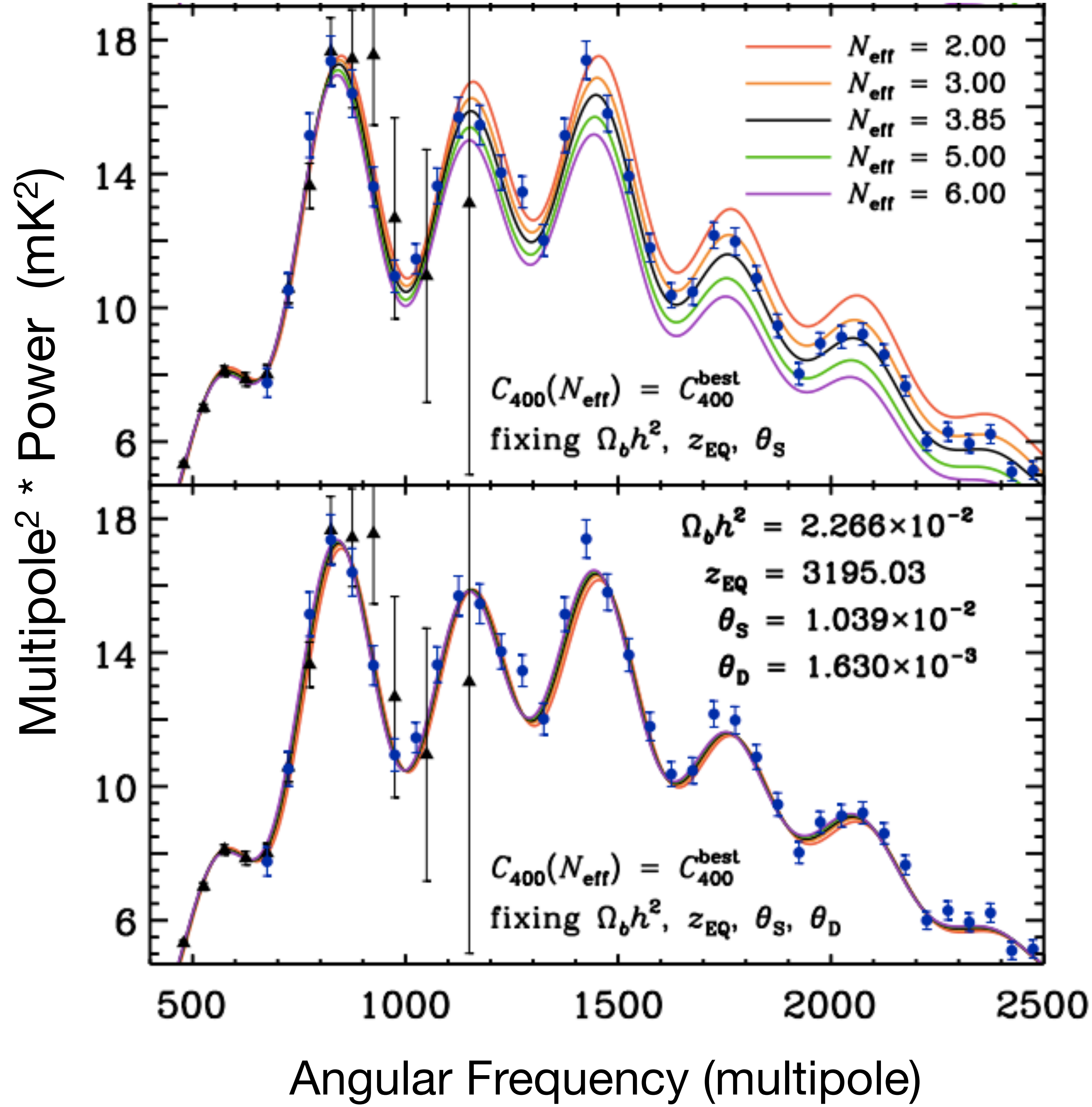


Cluster mass calibrations

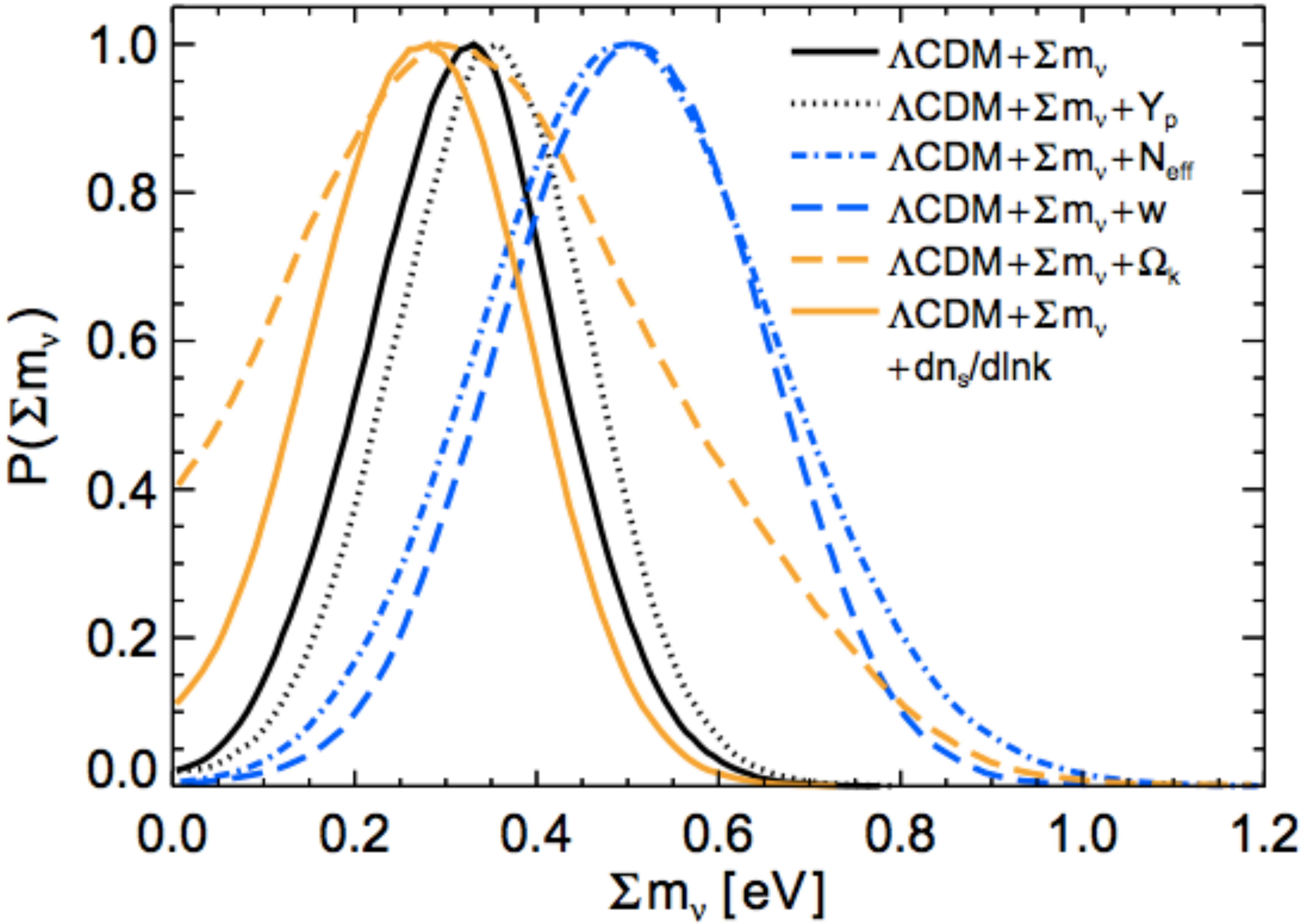


Rozo et. al. arXiv:1302.5086

Best-Fit WMAP spectra

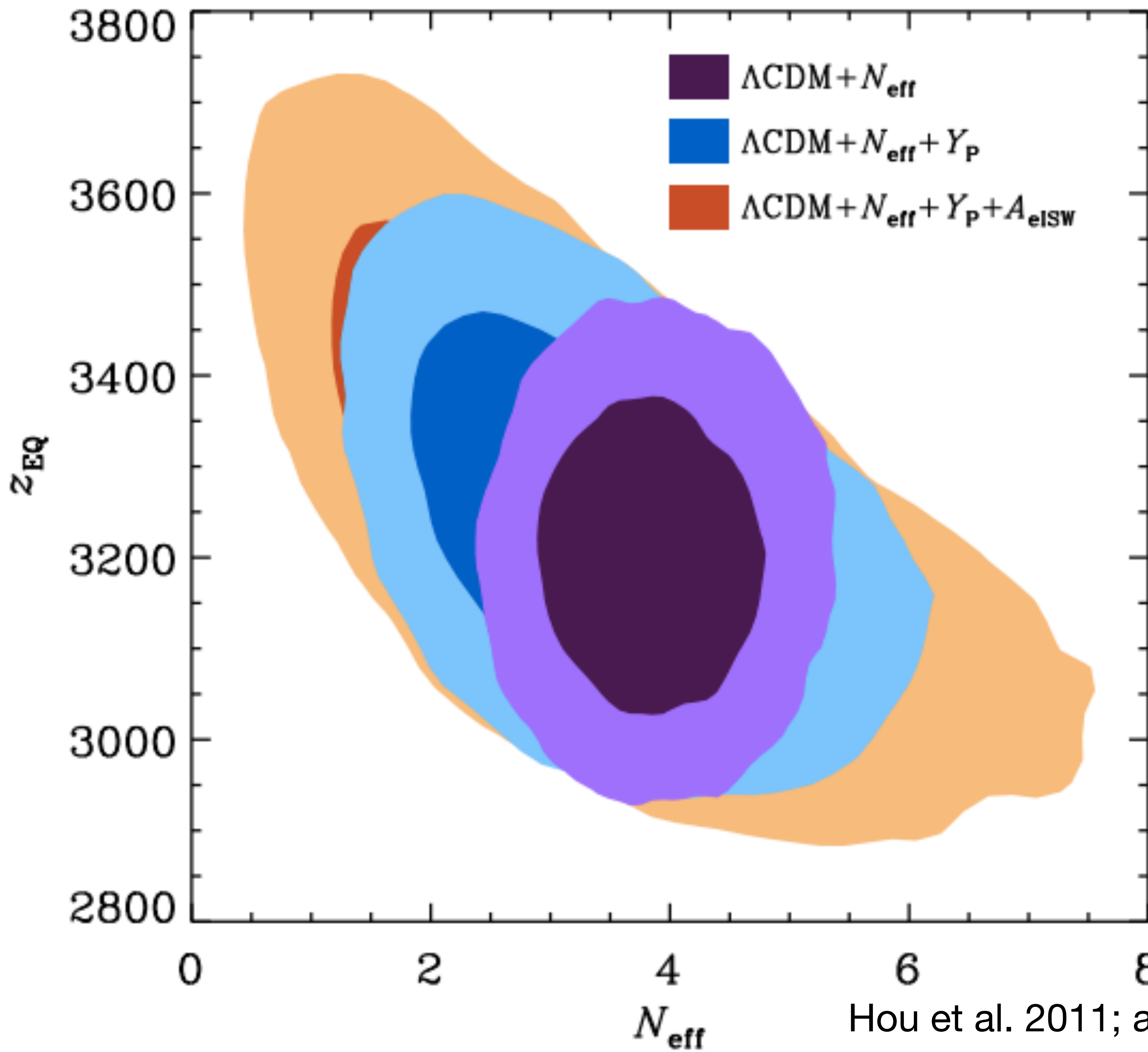


Hou et al. 2011; arXiv:1104.2333



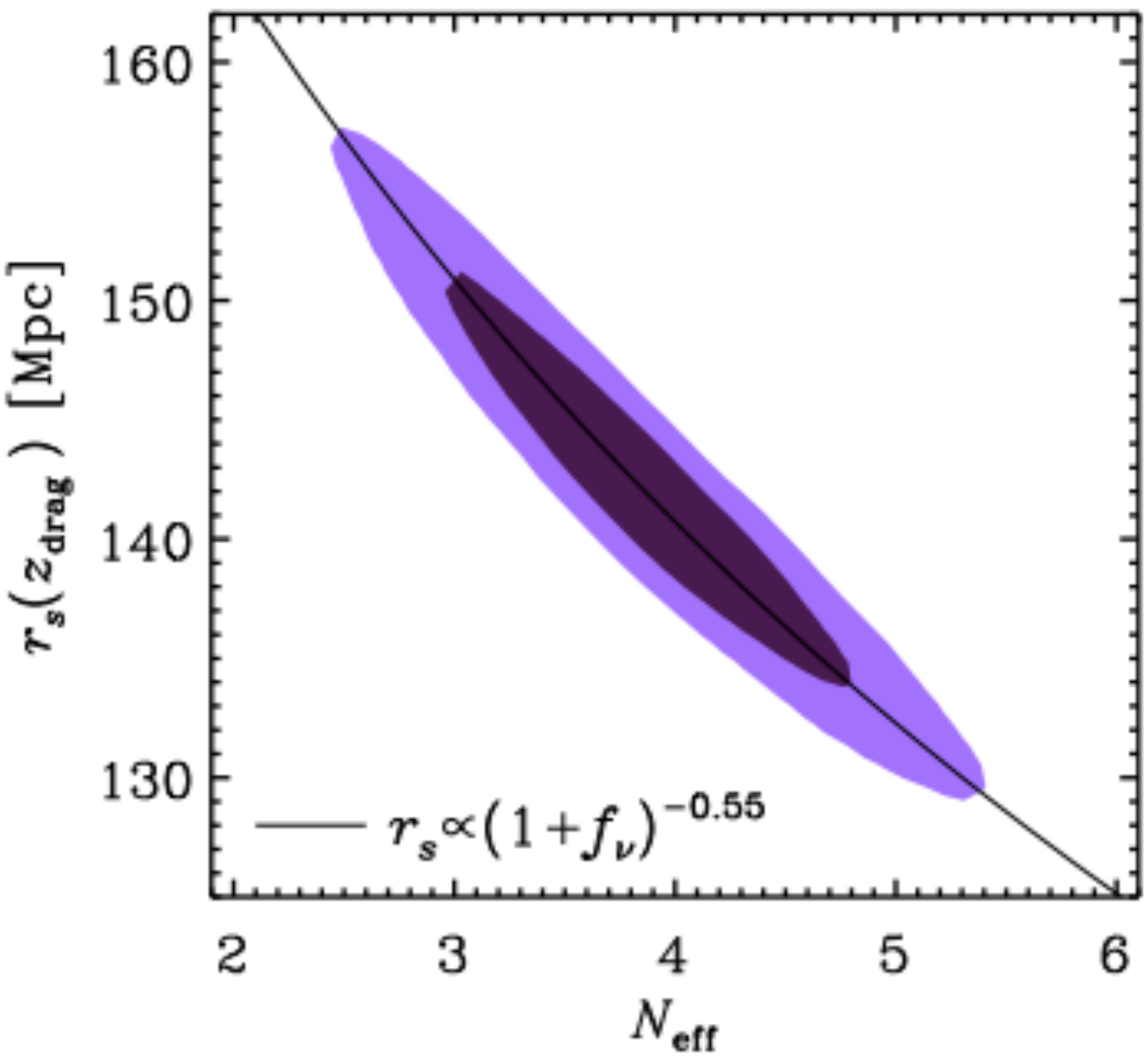
Hou et al. 2012; arXiv:1104.2333

Neff/matter density degeneracy

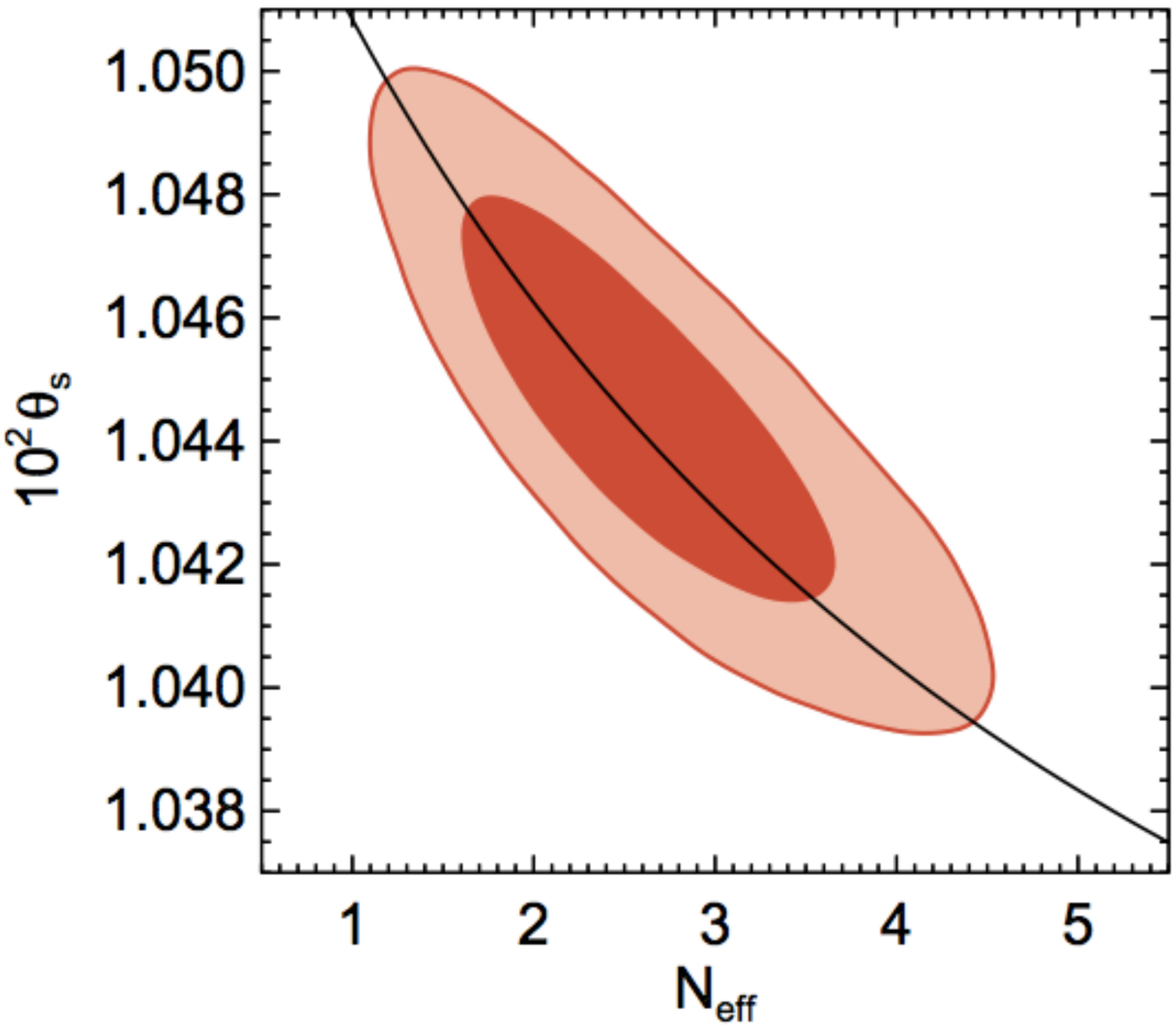


Hou et al. 2011; arXiv:1104.2333

sound horizon versus Neff

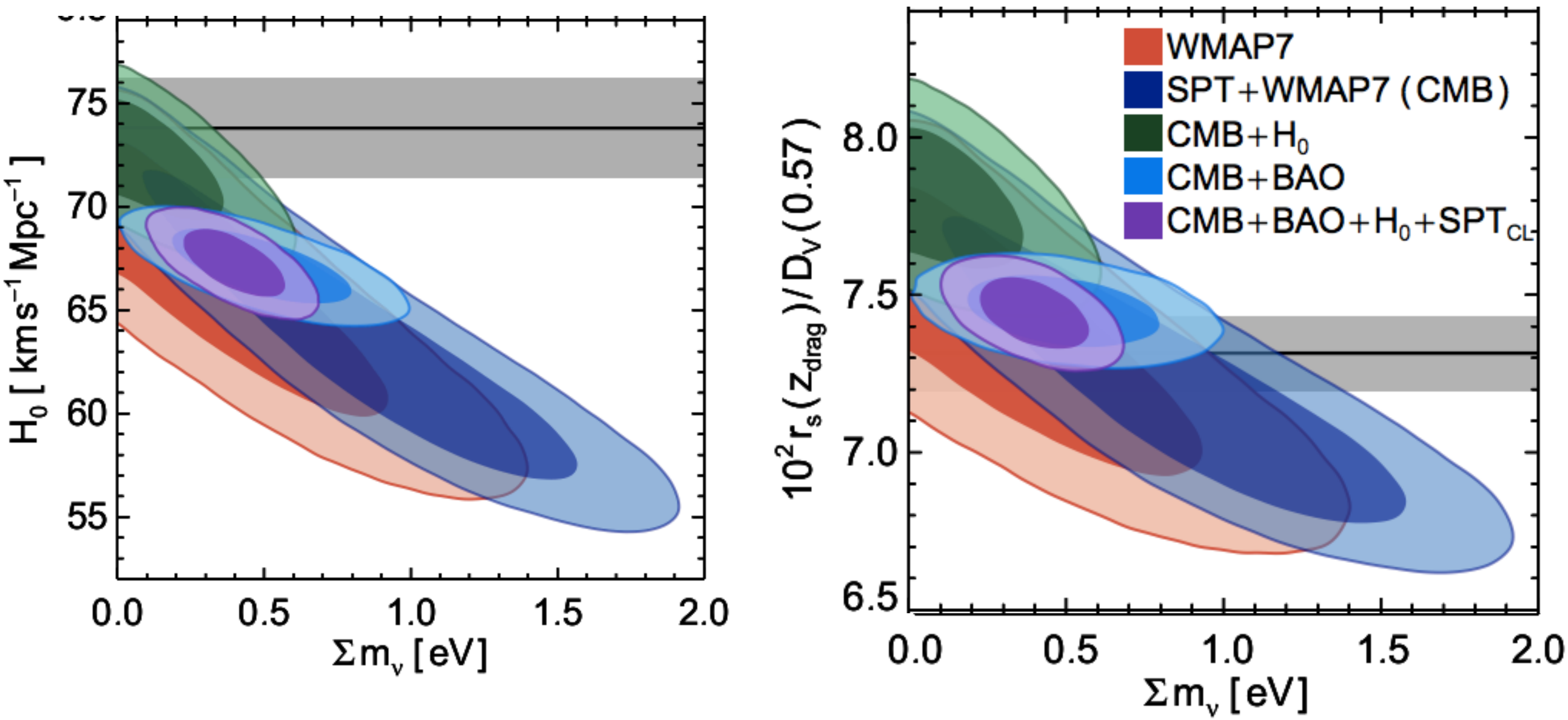


Hou et al. 2011; arXiv:1104.2333

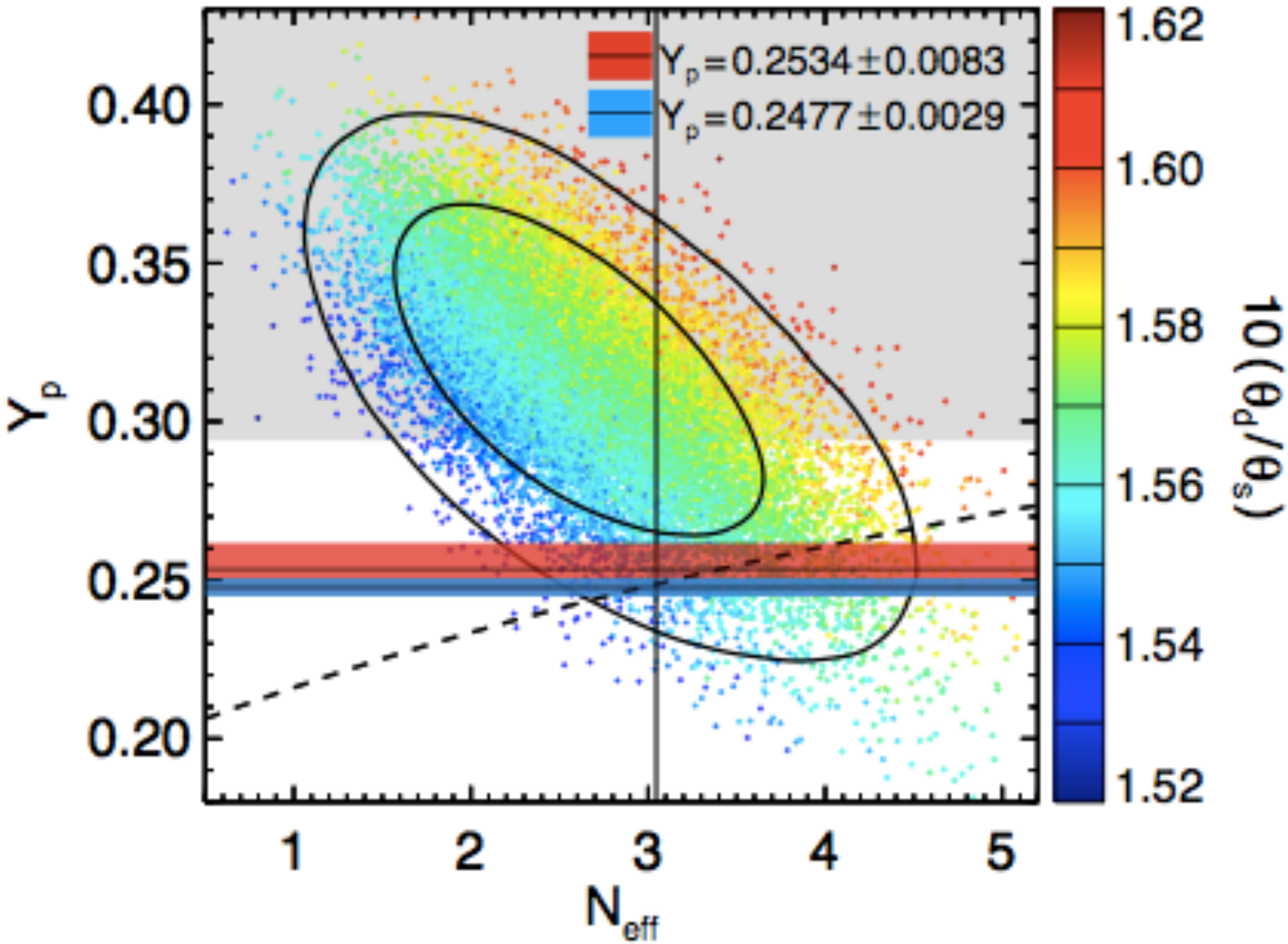


Hou et al. 2012; arXiv:1104.2333

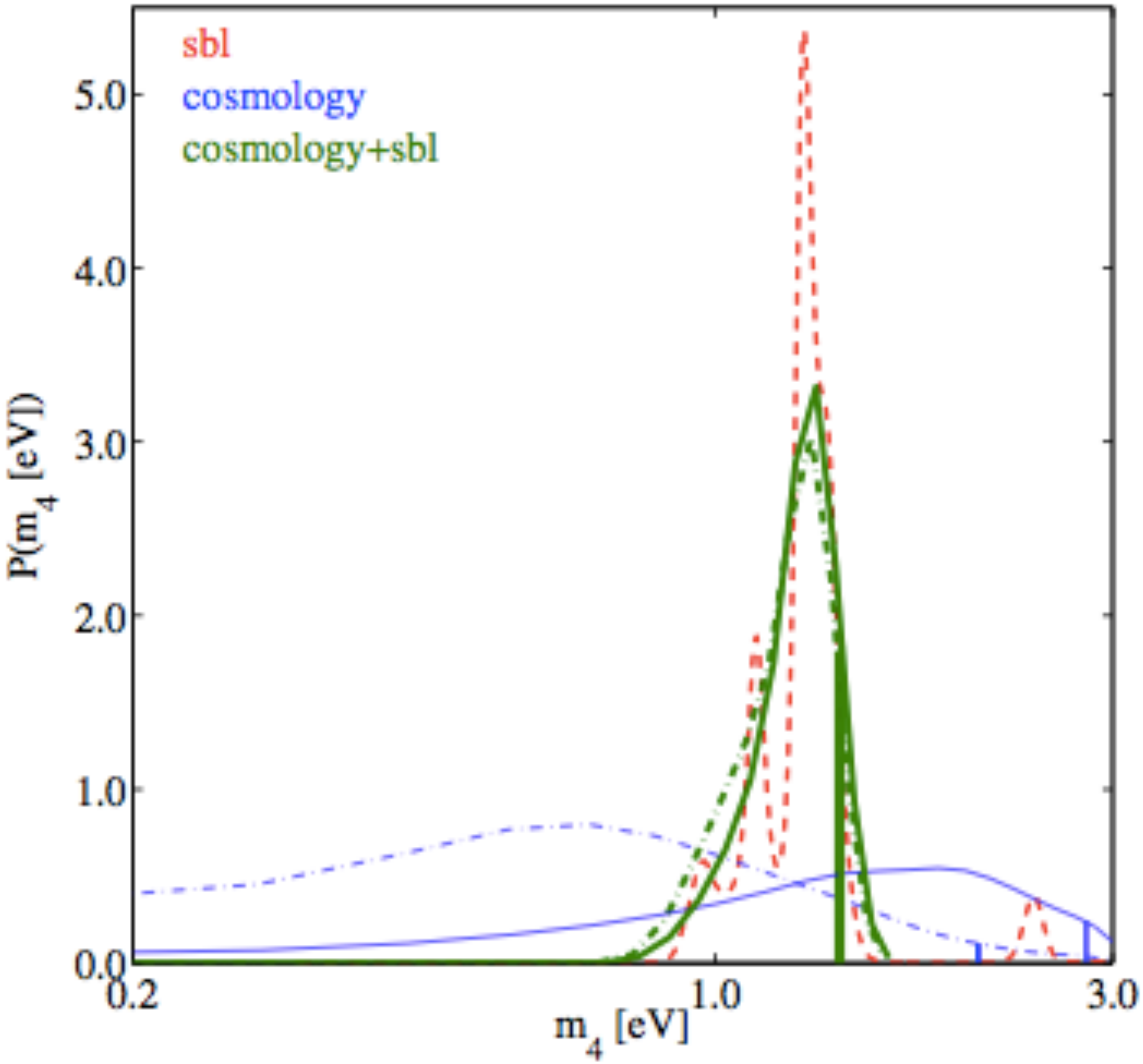
Tension between BAO/H0



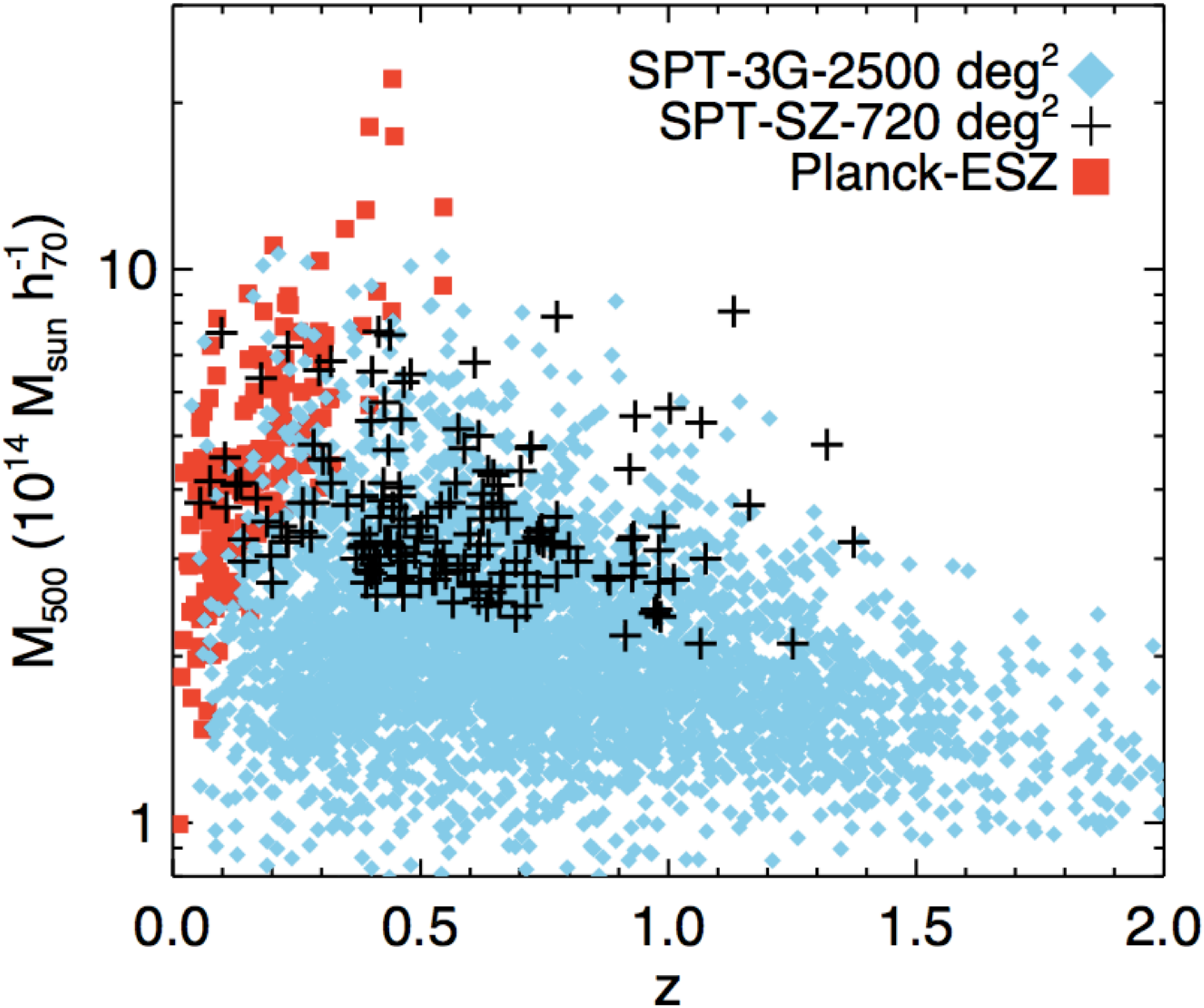
Hou et al. 2012; arXiv:1104.2333



Hou et al. 2012; arXiv:1104.2333

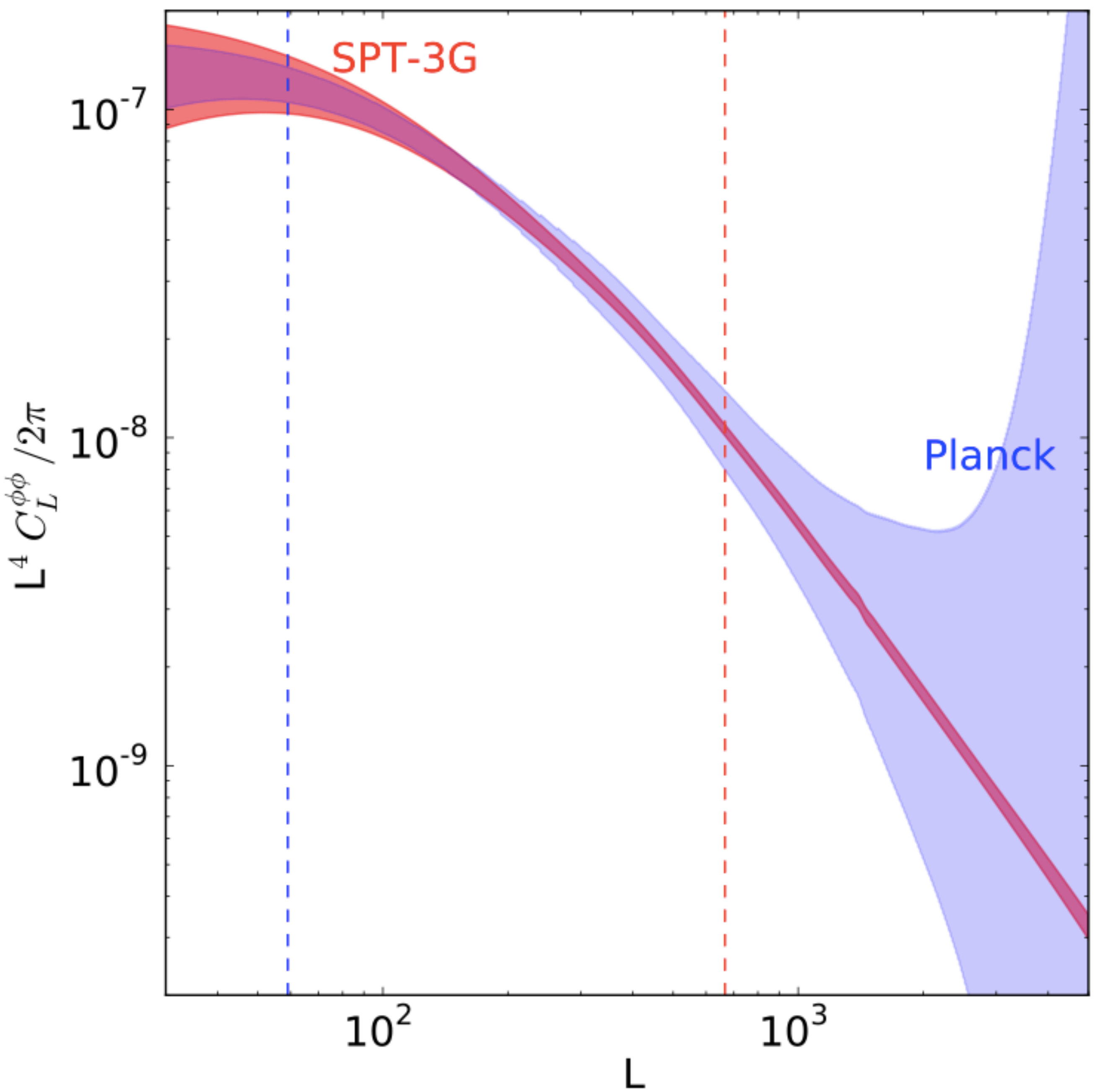


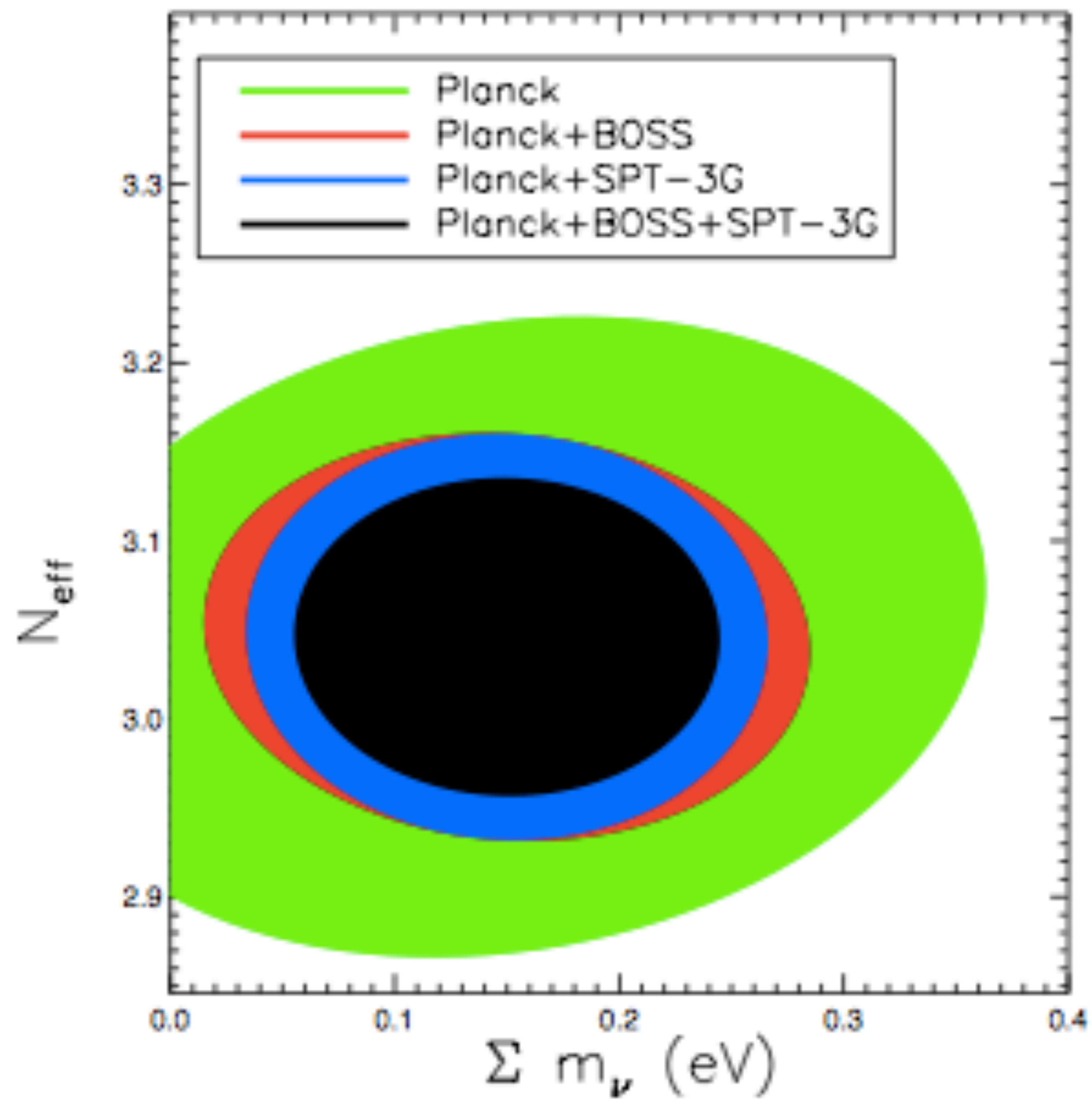
Archidiacono et. al: **ArXiv:1302.6720**



SPT3G proposal

Effect of lensing on neutrino observables





Current constraints on lensing: Amplitude to within ~20%

SPT3G proposal: constraints on three 50meV neutrinos