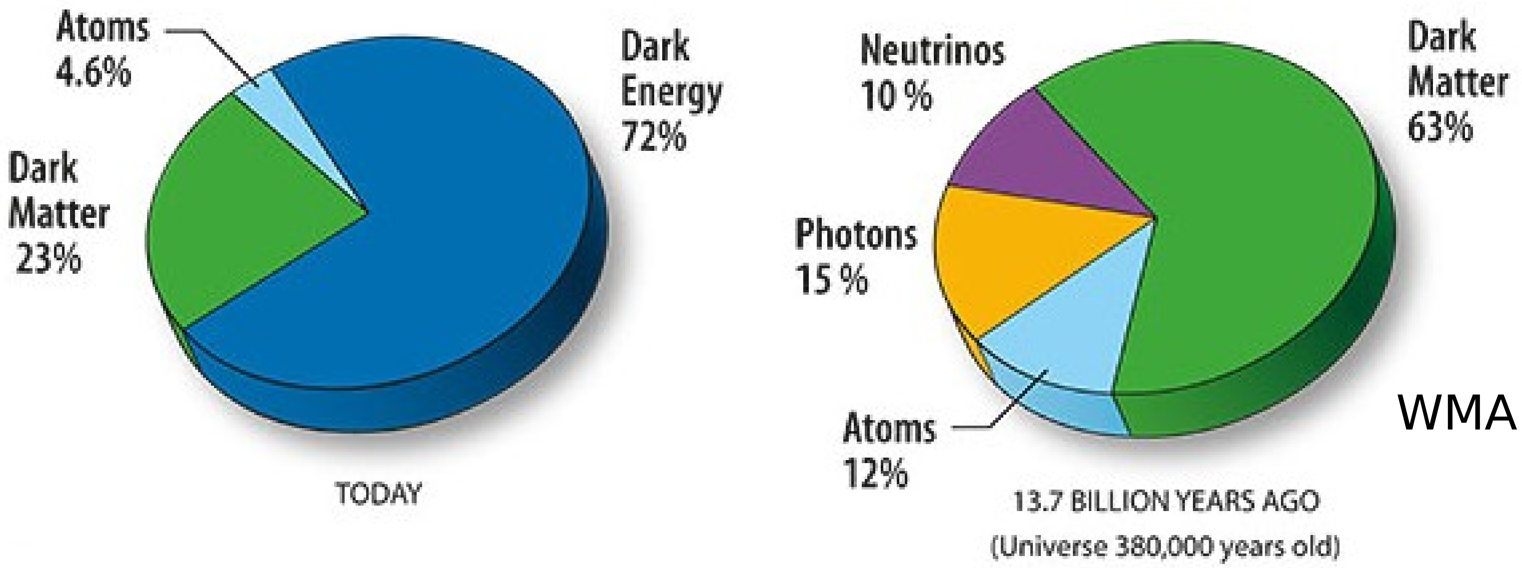
Neutrinos in Cosmology

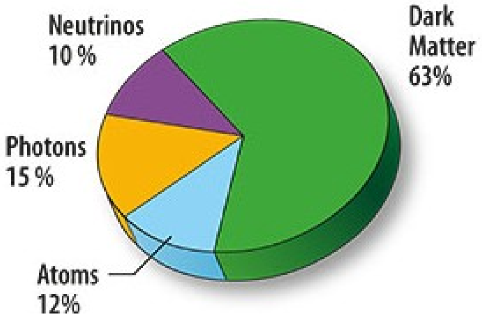


WMAP / NASA

Andreu Font-Ribera

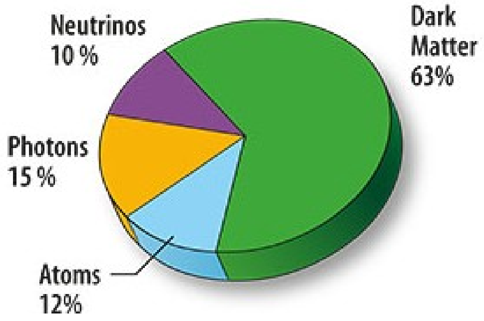
STFC Rutherford Fellow at University College London

Outline



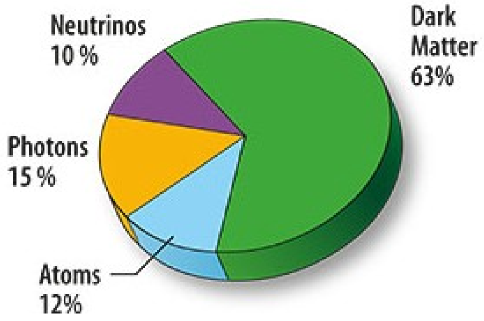
- Part I (this talk)
  - What neutrino properties can we measure?
  - Neutrinos and Big Bang Nucleosynthesis (BBN)
  - Neutrinos and the Cosmic Microwave Background (CMB)
- Part II (talk by Ofer Lahav)
  - Neutrinos and the Large Scale Structure (LSS)
  - Current constraints from cosmological surveys

What can we learn?



- There are three main neutrino properties we can learn:
  - Number of neutrino species (from BBN and from CMB)
  - Sum of neutrino masses (from CMB and LSS)
  - Lepton asymmetry (from BBN)

What can we learn?

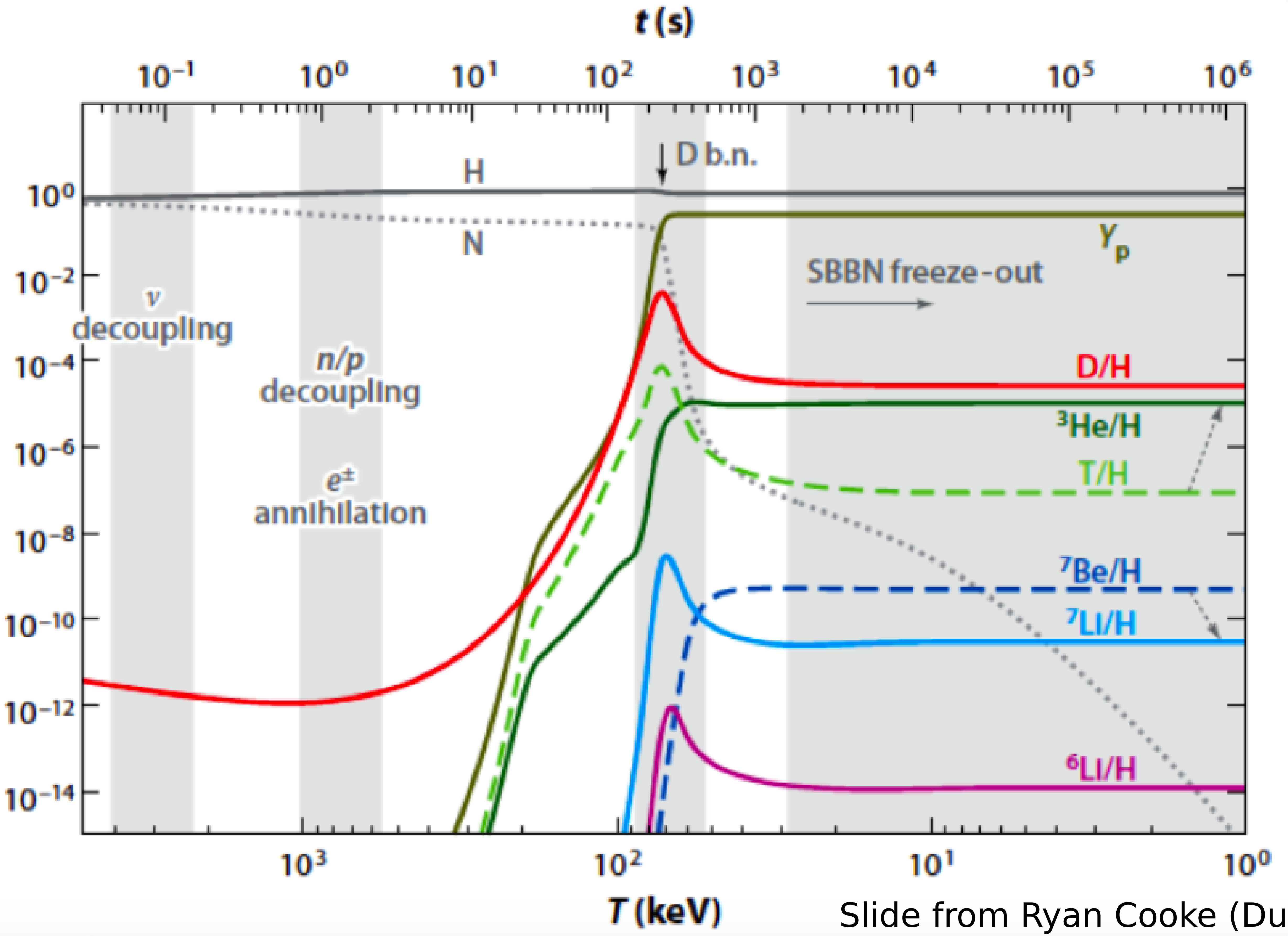


- There are three main neutrino properties we can learn:
  - Number of neutrino species (from BBN and from CMB)

    Ofer’s talk
  - ~~Sum of neutrino masses (from CMB and LSS)~~

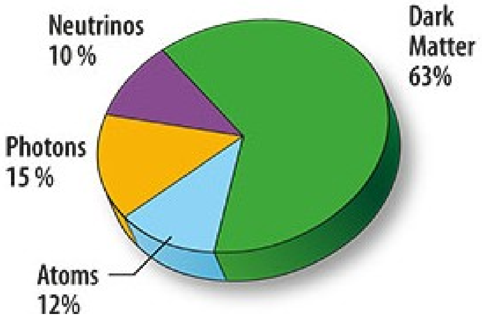
    Not today
  - ~~Lepton asymmetry (from BBN)~~

Timeline of Big Bang Nucleosynthesis



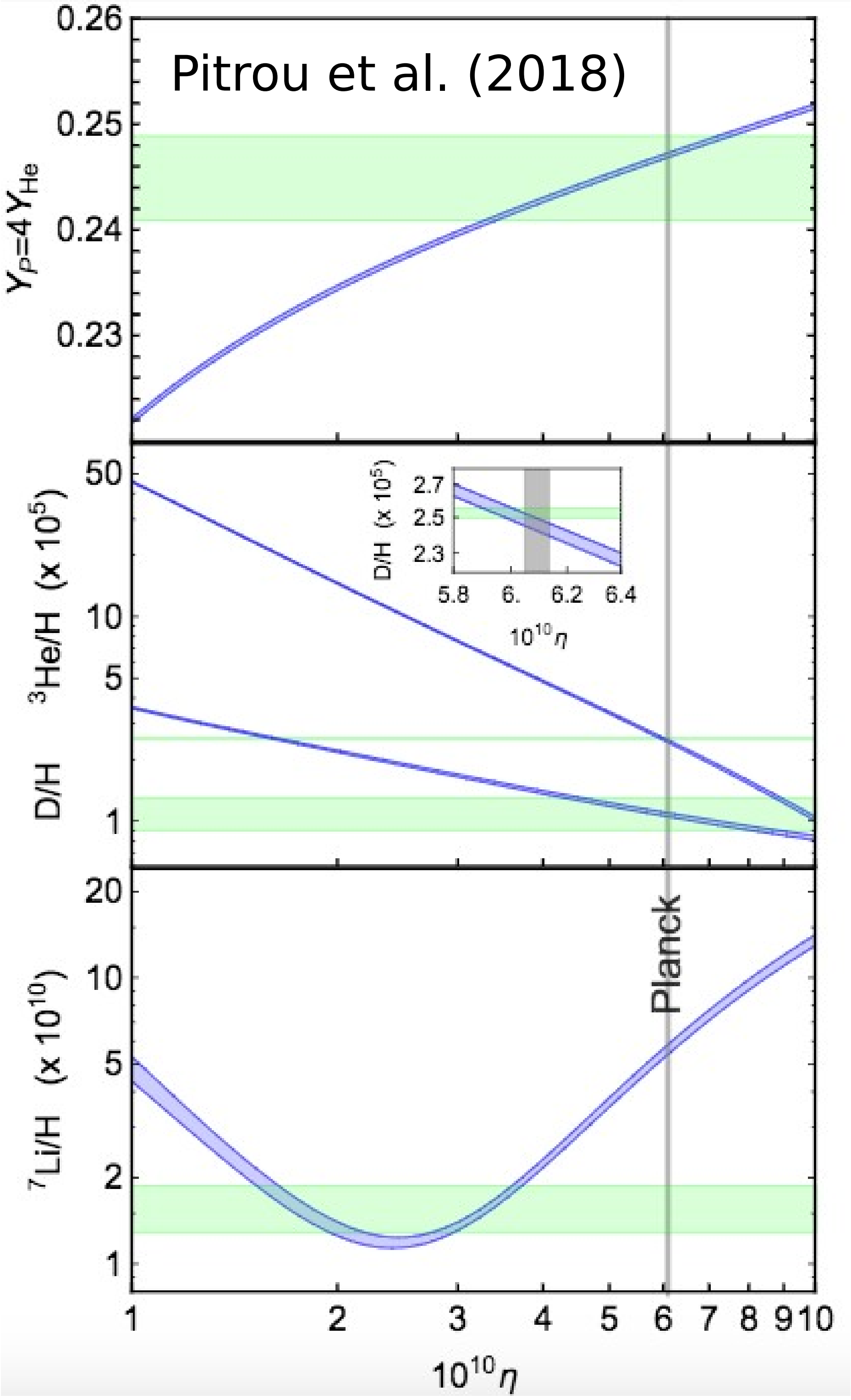
Slide from Ryan Cooke (Durham

Big Bang Nucleosynthesis (BBN)

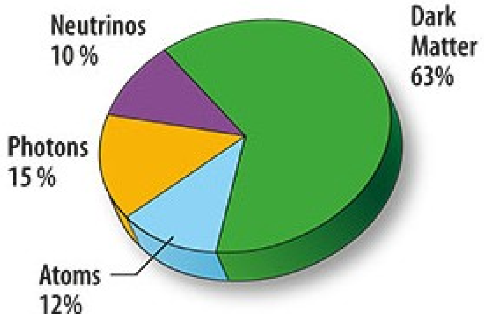


- Abundances depend on baryon density (baryon/photon ratio)
- Helium is also produced in stars
- Deuterium can only be destroyed, and it has a strong dependence on baryon density
- Lithium is difficult to measure, and currently in disagreement with others

$$\Omega_{\rm B} h^2 = \eta_{10}/273.9$$



Big Bang Nucleosynthesis (BBN)



At t=1s, we have 1 neutron for every 6 protons

During the next few minutes, some neutrons decay to protons

Final neutron/proton ratio depends on Universe expansion rate

$$H^2 = 8\pi G\rho/3$$

Prior to electron/positron annihilation $T_\gamma = T_e = T_\nu$

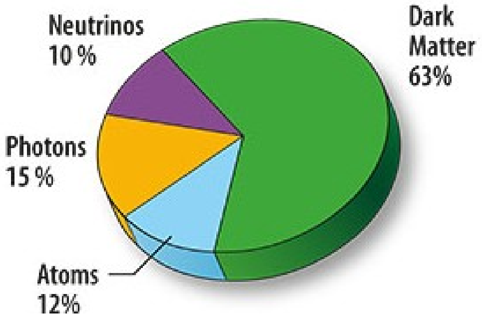
$$\frac{\rho_{\mathrm{R}}}{\rho_\gamma} = 1 + \frac{\rho_e}{\rho_\gamma} + \mathrm{N}_\nu\left(\frac{\rho_\nu}{\rho_\gamma}\right) = 1 + \frac{7}{8}\left[\left(\frac{4}{2}\right) + \left(\frac{3\times 2}{2}\right)\right] = \frac{43}{8}$$

Extra neutrinos will change the expansion rate at early times

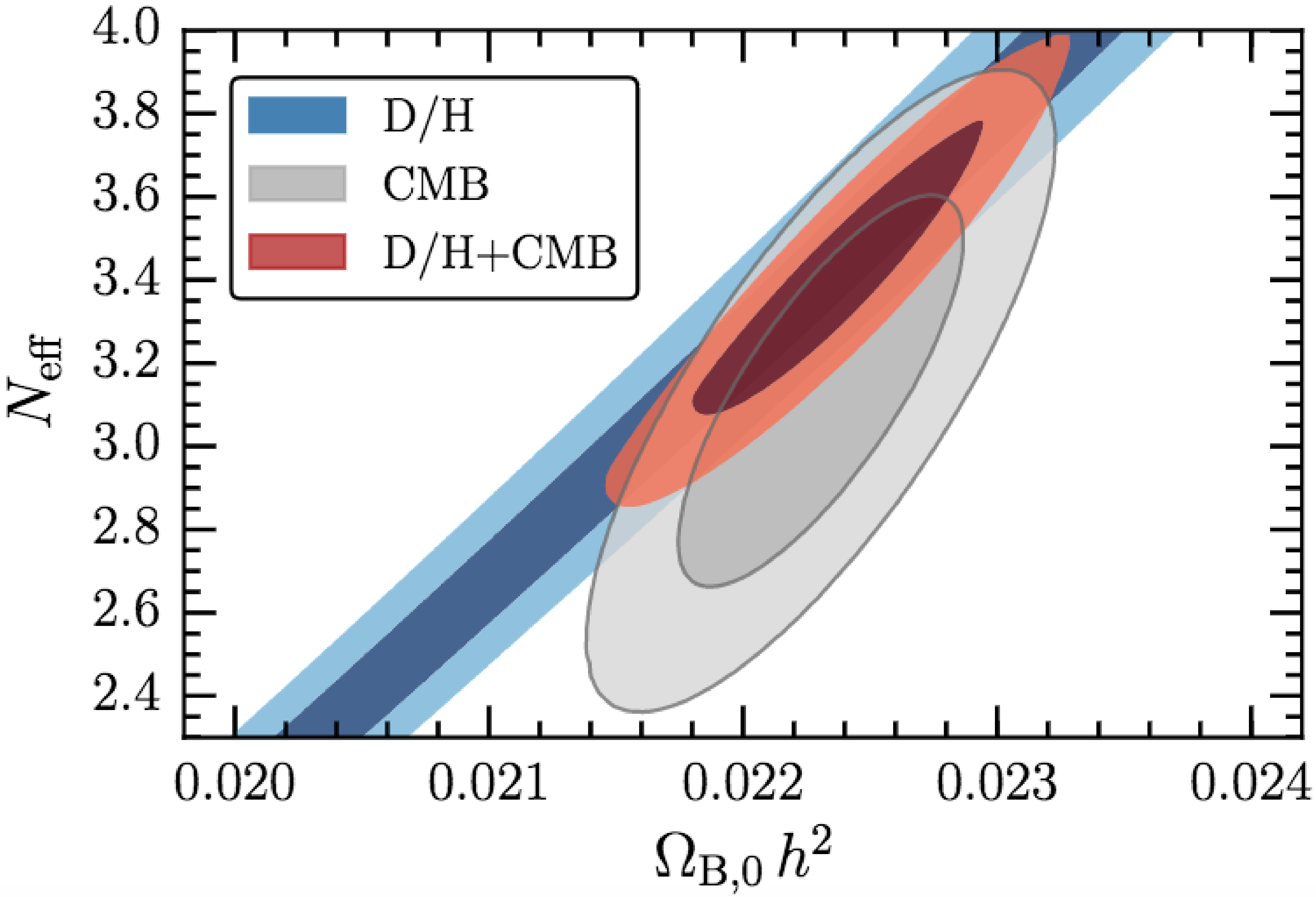
$$\frac{H'}{H} = \left(\frac{\rho'_{\mathrm{R}}}{\rho_{\mathrm{R}}}\right)^{1/2} = \left(1 + \frac{7\Delta\mathrm{N}_\nu}{43}\right)^{1/2}$$

Steigman 2012

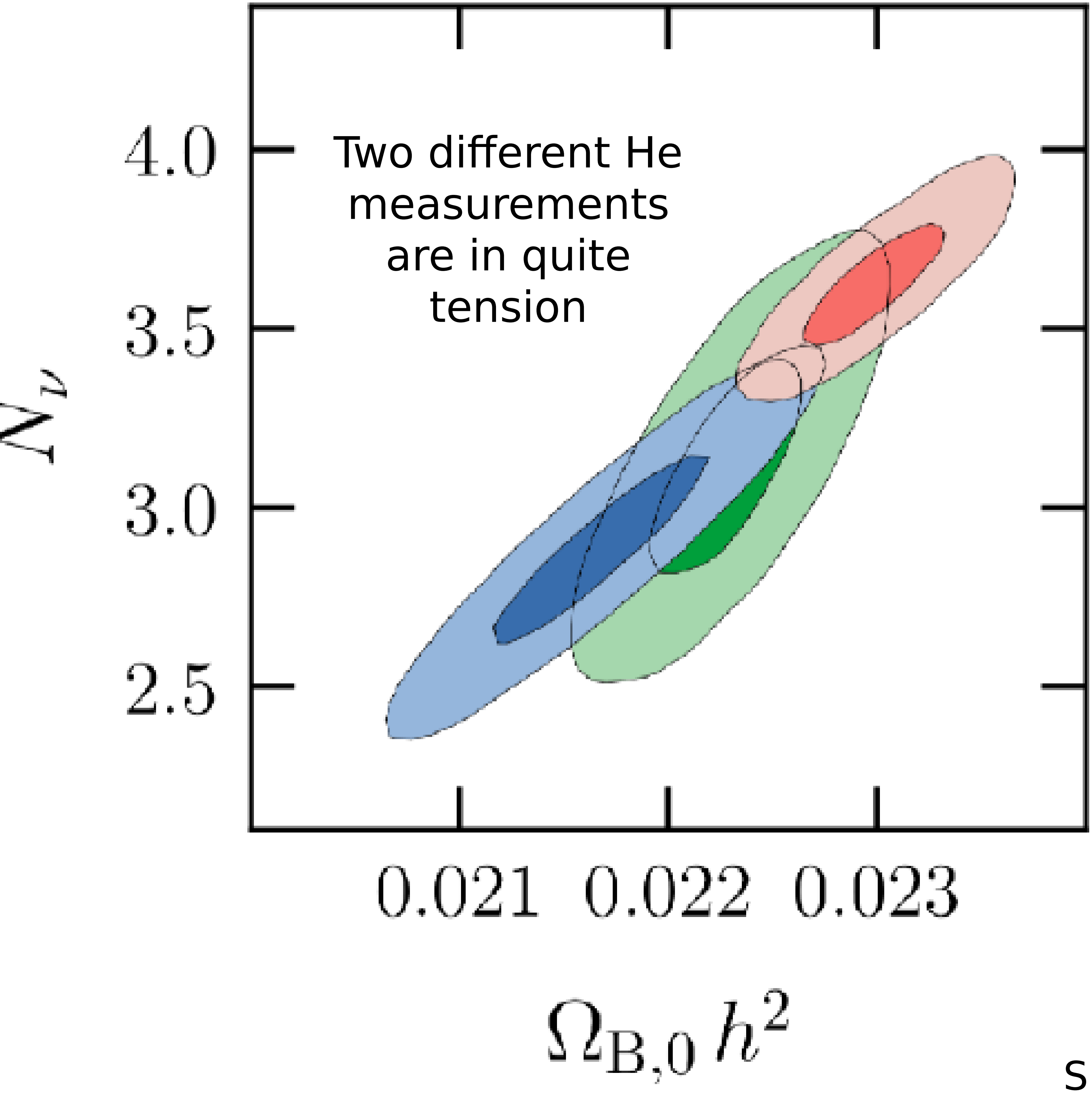
Big Bang Nucleosynthesis (BBN)



Current BBN / CMB constraints (Cooke et al. 2018)



New physics or inconsistencies?



Two different He measurements are in quite tension

N_{eff} = 3.63 ± 0.17 (1σ)

Izotov et al. (2014), MNRAS, 445, 778

N_{eff} = 2.89 ± 0.28 (1σ)

Aver et al. (2015), JCAP, 07, 011

N_{eff} = 3.12 ± 0.31 (1σ)

Planck collaboration (2015)

D/H from Cooke et al. (2018)

BBN code:
Pitrou et al. (2018), arXiv:1801.08023

Slide from Ryan Cooke (Durham

Neutron lifetime

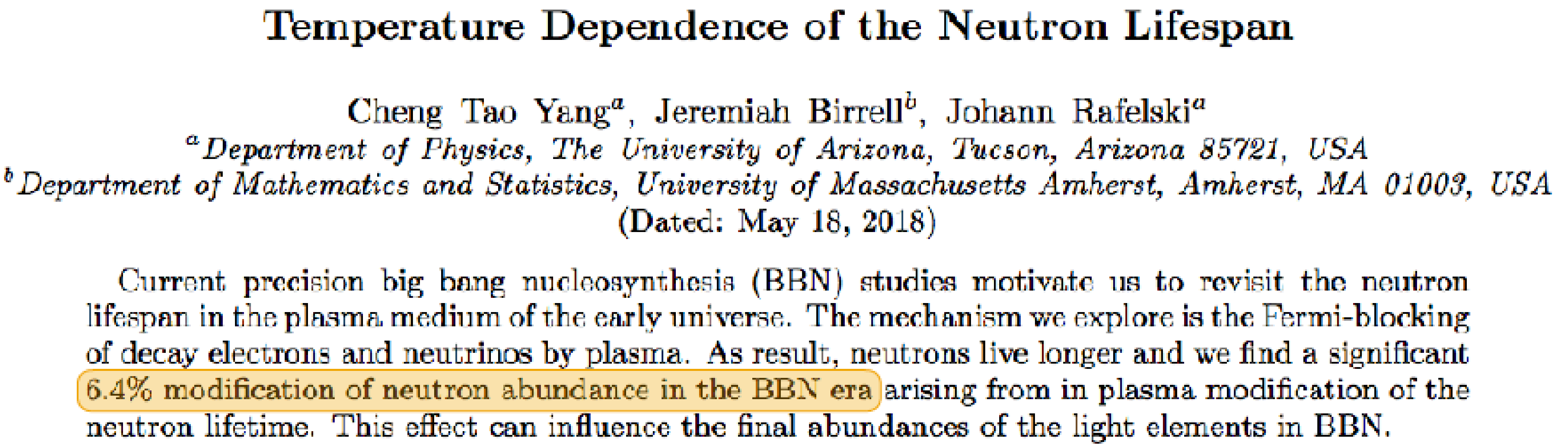
$$\boxed{\tau_n = 880.2 \pm 1.0}$$

PDG (2016), Chin. Phys. C, 40, 100001

$$\boxed{\tau_n = 877.7 \pm 0.7}$$

Pattie et al. (2018), Science, 360, 627

"This state of affairs is a particularly unhappy one, because the value is so important. We again call upon the experimenters to clear this up." (PDG)



Temperature Dependence of the Neutron Lifespan

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[a] *Department of Physics, The University of Arizona, Tucson, Arizona 85721, USA*
[b] *Department of Mathematics and Statistics, University of Massachusetts Amherst, Amherst, MA 01003, USA*

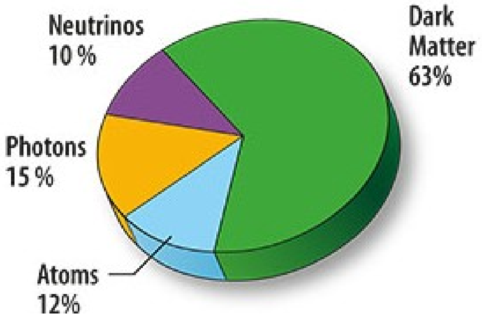
(Dated: May 18, 2018)

Current precision big bang nucleosynthesis (BBN) studies motivate us to revisit the neutron lifespan in the plasma medium of the early universe. The mechanism we explore is the Fermi-blocking of decay electrons and neutrinos by plasma. As result, neutrons live longer and we find a significant 6.4% modification of neutron abundance in the BBN era arising from in plasma modification of the neutron lifetime. This effect can influence the final abundances of the light elements in BBN.

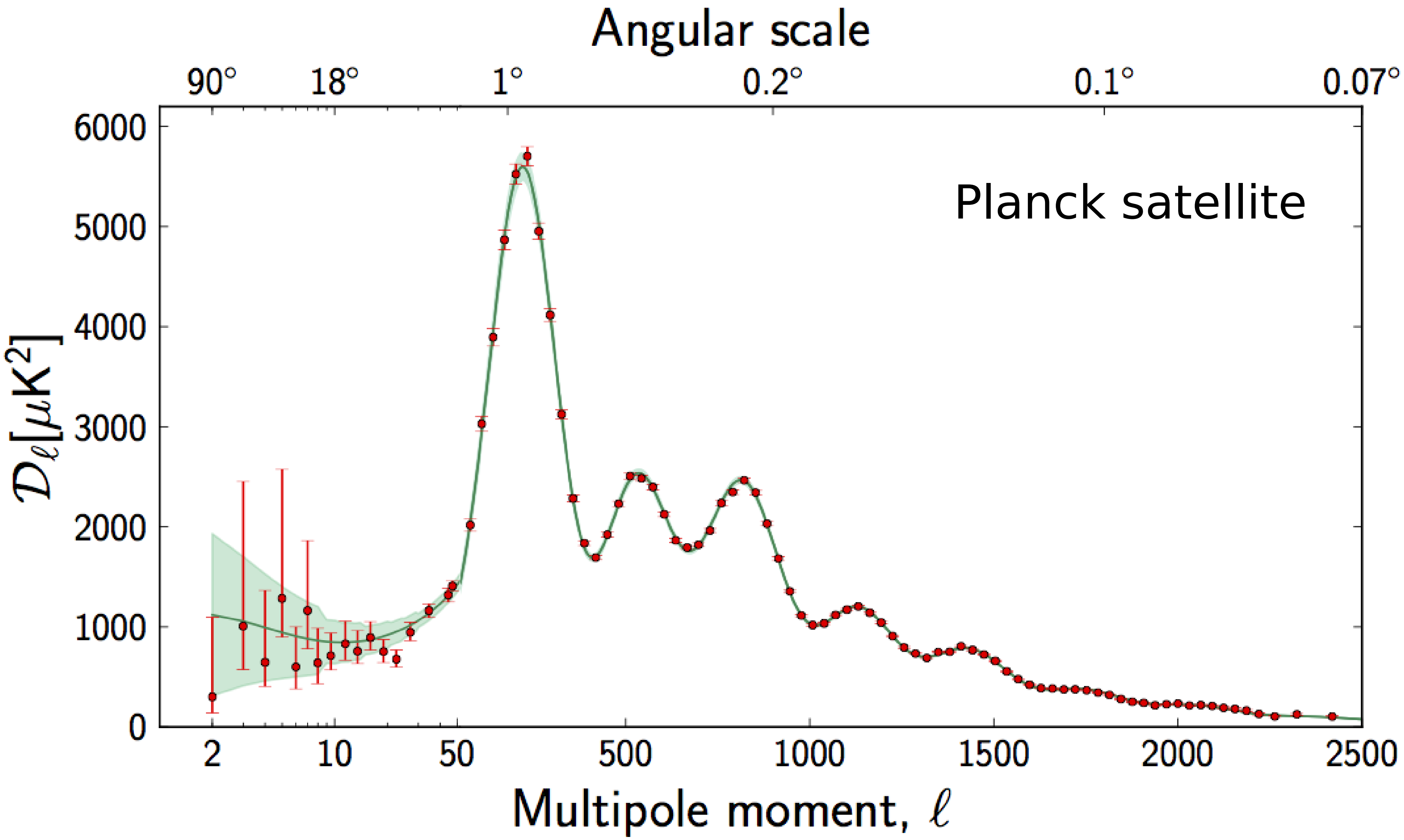
arXiv:1805.06543

Slide from Ryan Cooke (Durham

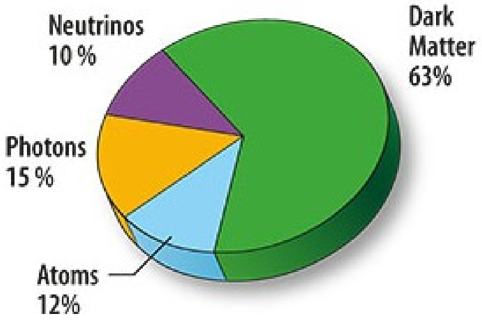
Cosmic Microwave Background (CMB)



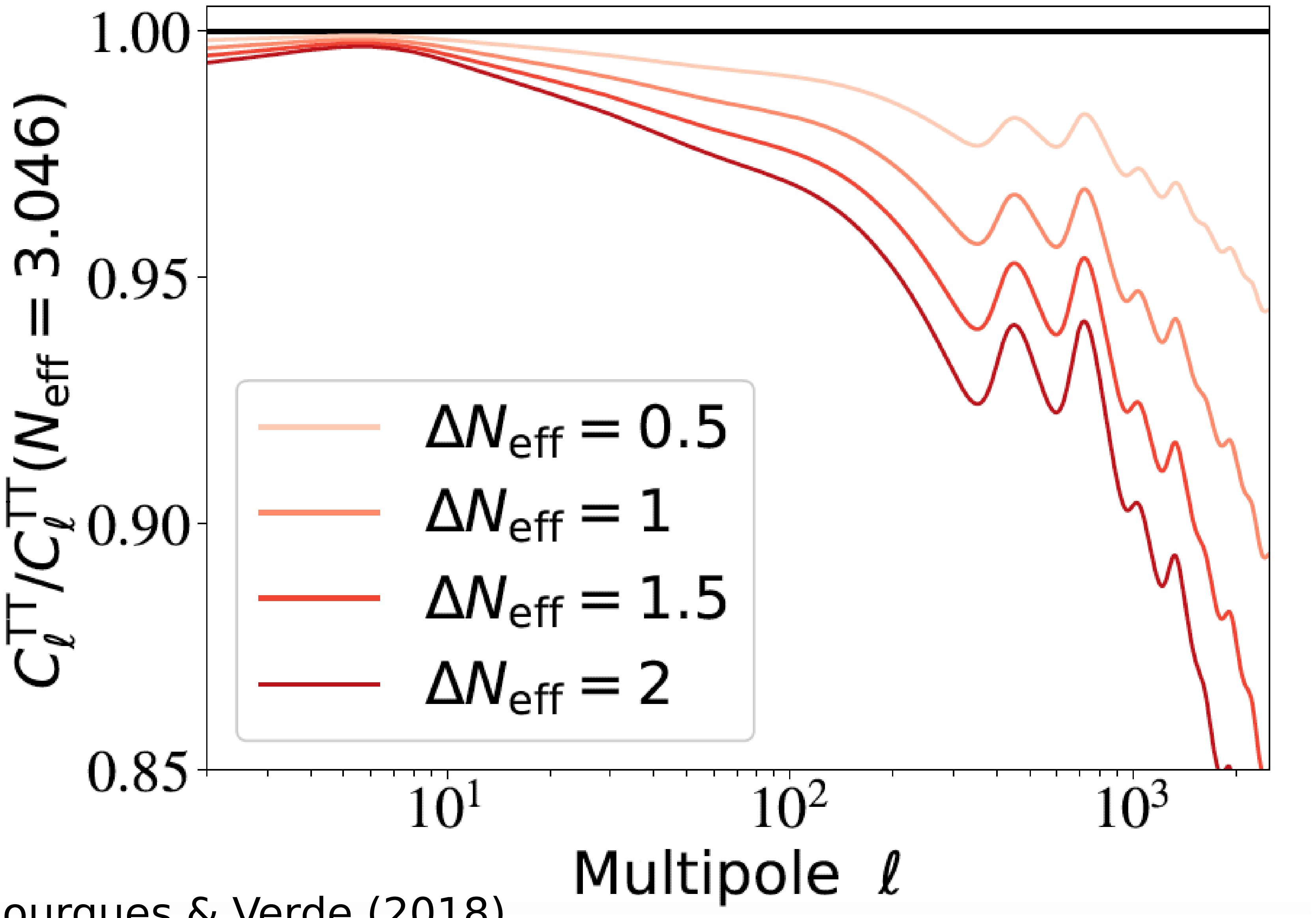
Angular power spectrum of CMB temperature fluctuations



Cosmic Microwave Background (CMB)



Effect of extra neutrinos on the CMB temperature fluctuations



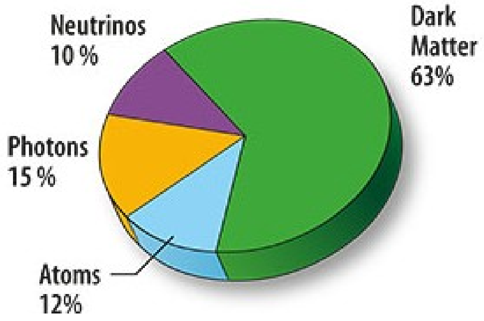
Lesgourgues & Verde (2018)

Main effect is to change the diffusion scale
(Silk damping)

Baryon Acoustic Oscillations (BAO) are also affected

There are degeneracies with other cosmological parameters

Cosmic Microwave Background (CMB)



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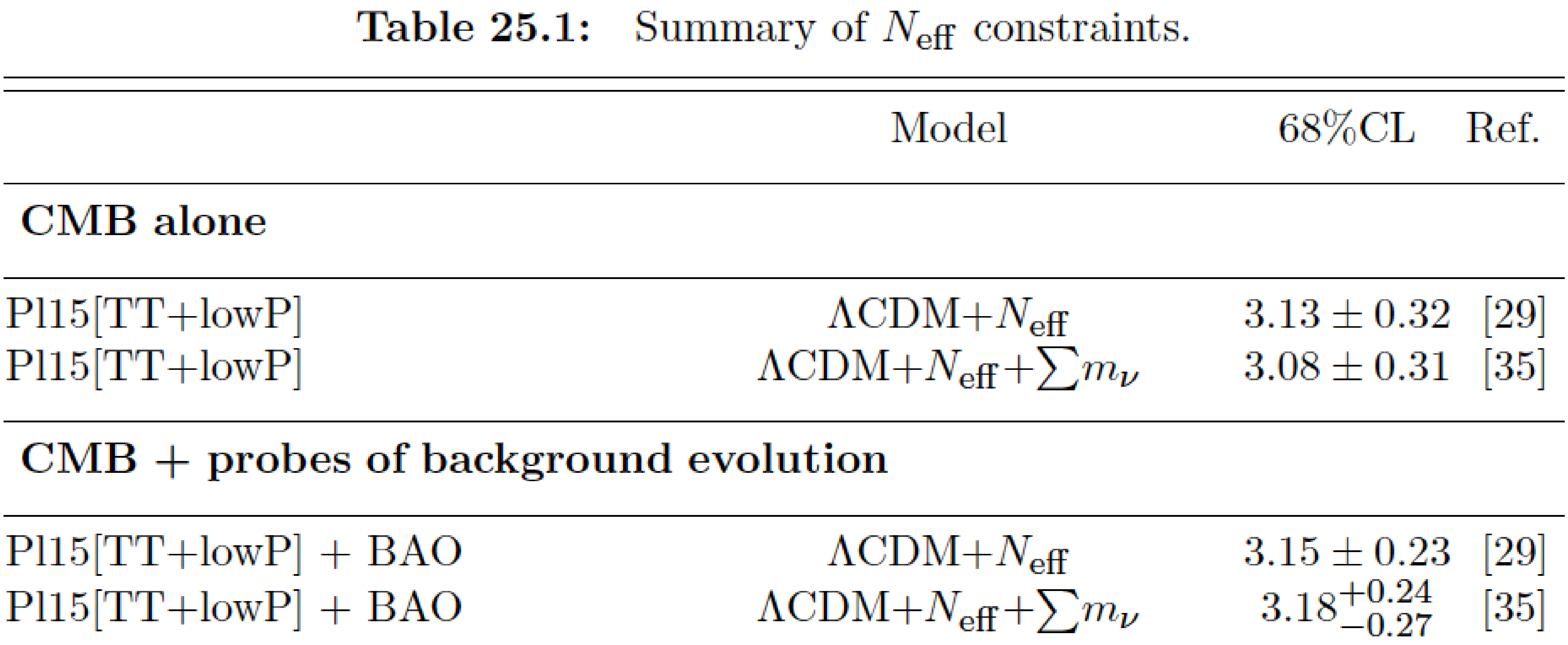
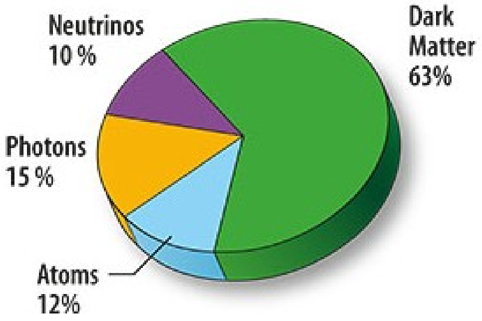


Table 25.1: Summary of $N_{\rm eff}$ constraints.

	Model	68%CL	Ref.
CMB alone			
Pl15[TT+lowP]	ΛCDM+$N_{\rm eff}$	3.13 ± 0.32	[29]
Pl15[TT+lowP]	ΛCDM+$N_{\rm eff}$+$\sum m_\nu$	3.08 ± 0.31	[35]
CMB + probes of background evolution			
Pl15[TT+lowP] + BAO	ΛCDM+$N_{\rm eff}$	3.15 ± 0.23	[29]
Pl15[TT+lowP] + BAO	ΛCDM+$N_{\rm eff}$+$\sum m_\nu$	$3.18^{+0.24}_{-0.27}$	[35]

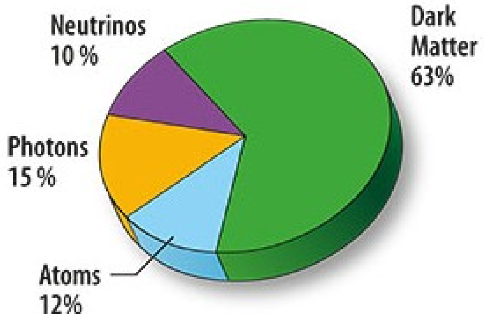
eutrinos quite disfavoured, error bars will get considerably smaller in the next few ye



Summary

- BBN and CMB put limits on number of extra neutrinos
- Nuclear rates are now one of the dominant uncertainties
- Future CMB-S4 will have x10 precision

Further references



- Neutrinos in Cosmology (Lesgourgues & Verde, Chapter 25 of the 2018 PDG review)
- Neutrinos and Big Bang Nucleosynthesis (Steigman 2012)
- Neutrino Physics from the Cosmic Microwave Background and Large Scale Structure (Abazajian, Carlstrom, Lee et al. Snowmass 2014)
- DESI and other dark energy experiments in the era of neutrino mass measurements (Font-Ribera et al. 2014)