Sterile Neutrinos: Cosmology vs Short BaseLine experiments

Invisibles workshop, July 2014, Paris

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invisibles
neutrinos, dark matter & dark energy physics

MARIE CURIE ACTIONS
SEVENTH FRAMEWORK PROGRAMME

SOLIDUM PETIT IN PROFUNDIS · UNIVERSITAS ARHUSIENSIS

What can we really measure with cosmology?

If sub-eV!

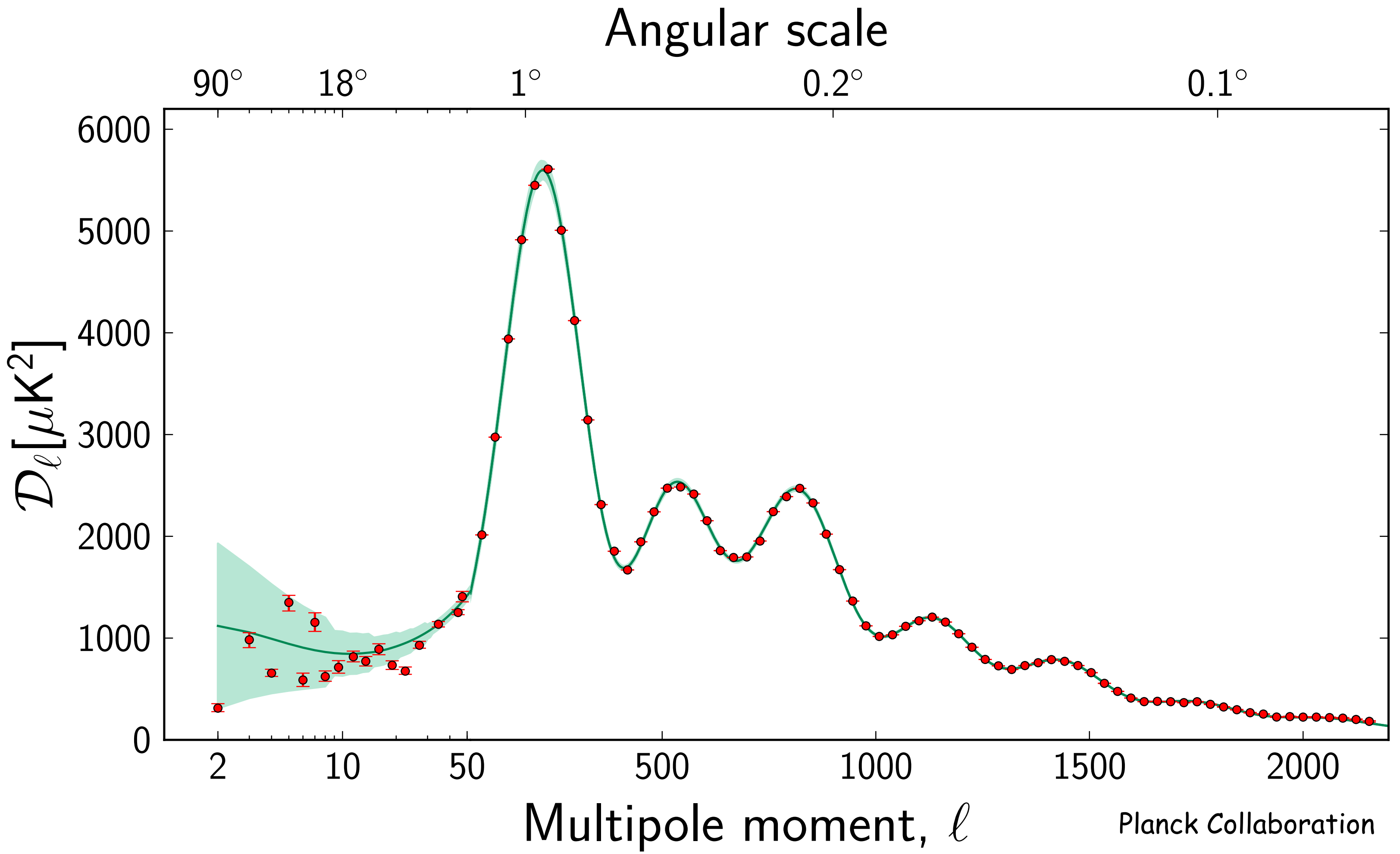
$$\Omega_\nu h^2 = \left(\sum_{i=1}^{3} m_{\nu_i} + m_{eff}^{sterile} \right) / 93.14 \ eV$$

$$m_{sterile}^{eff} = (T_s / T_\nu) m_{sterile}^{thermal} = (\Delta N_{eff})^{3/4} m_{sterile}^{thermal}$$

$$N_{eff} = 3.046 + \Delta N_{eff}$$

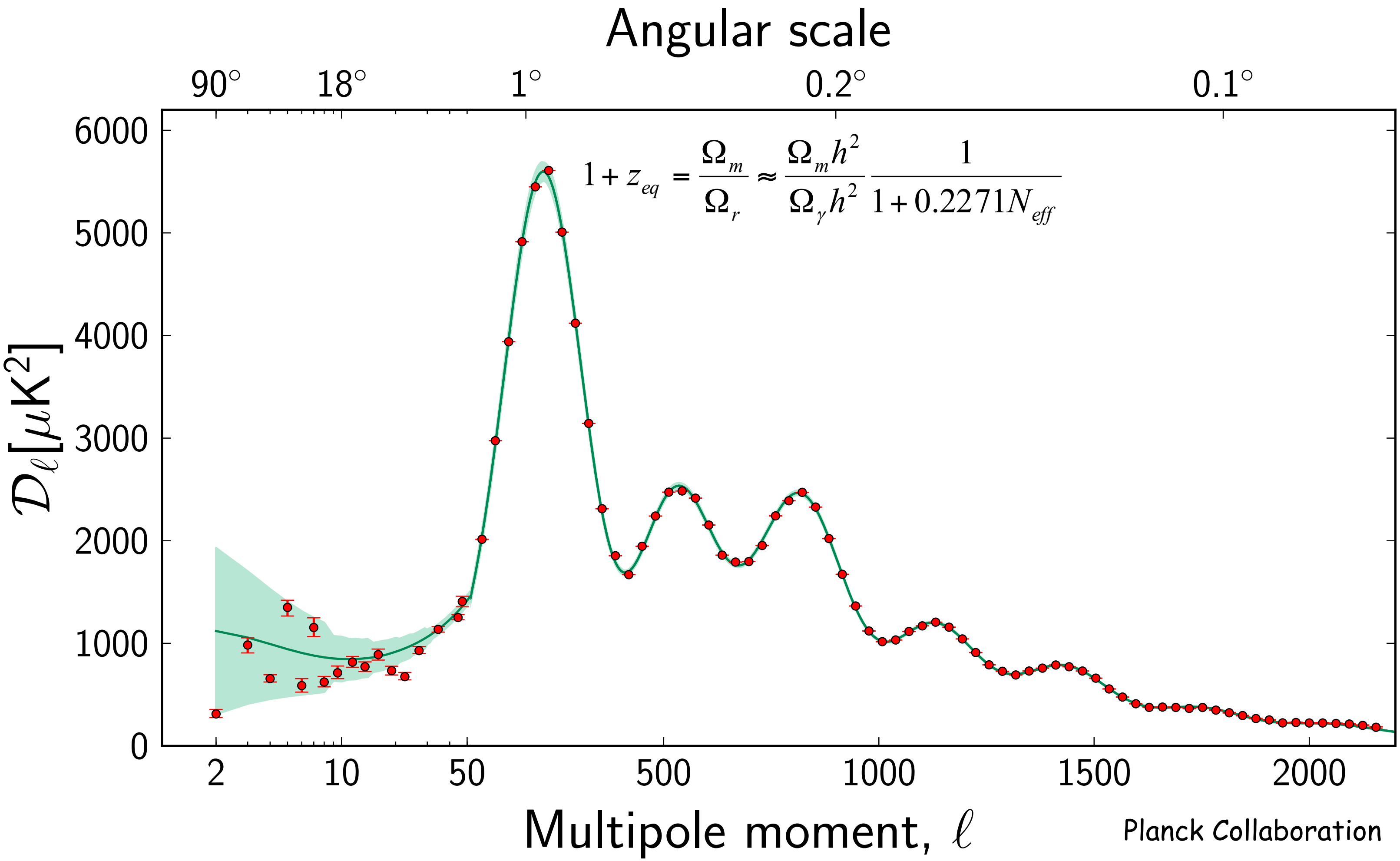
How can we measure N_{eff} with cosmological data?

N_{eff} effects on CMB



Planck Collaboration

N_{eff} effects on CMB



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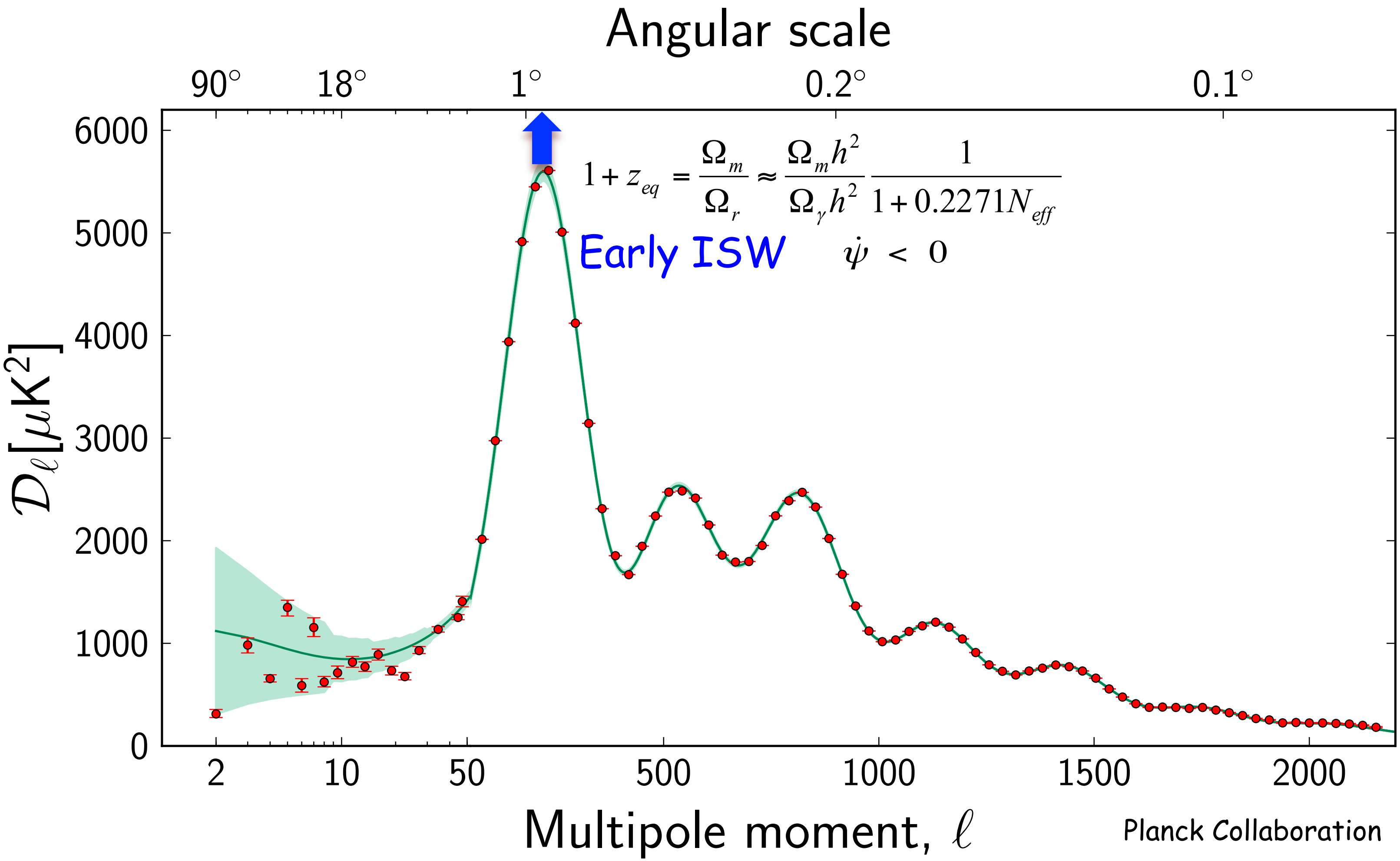

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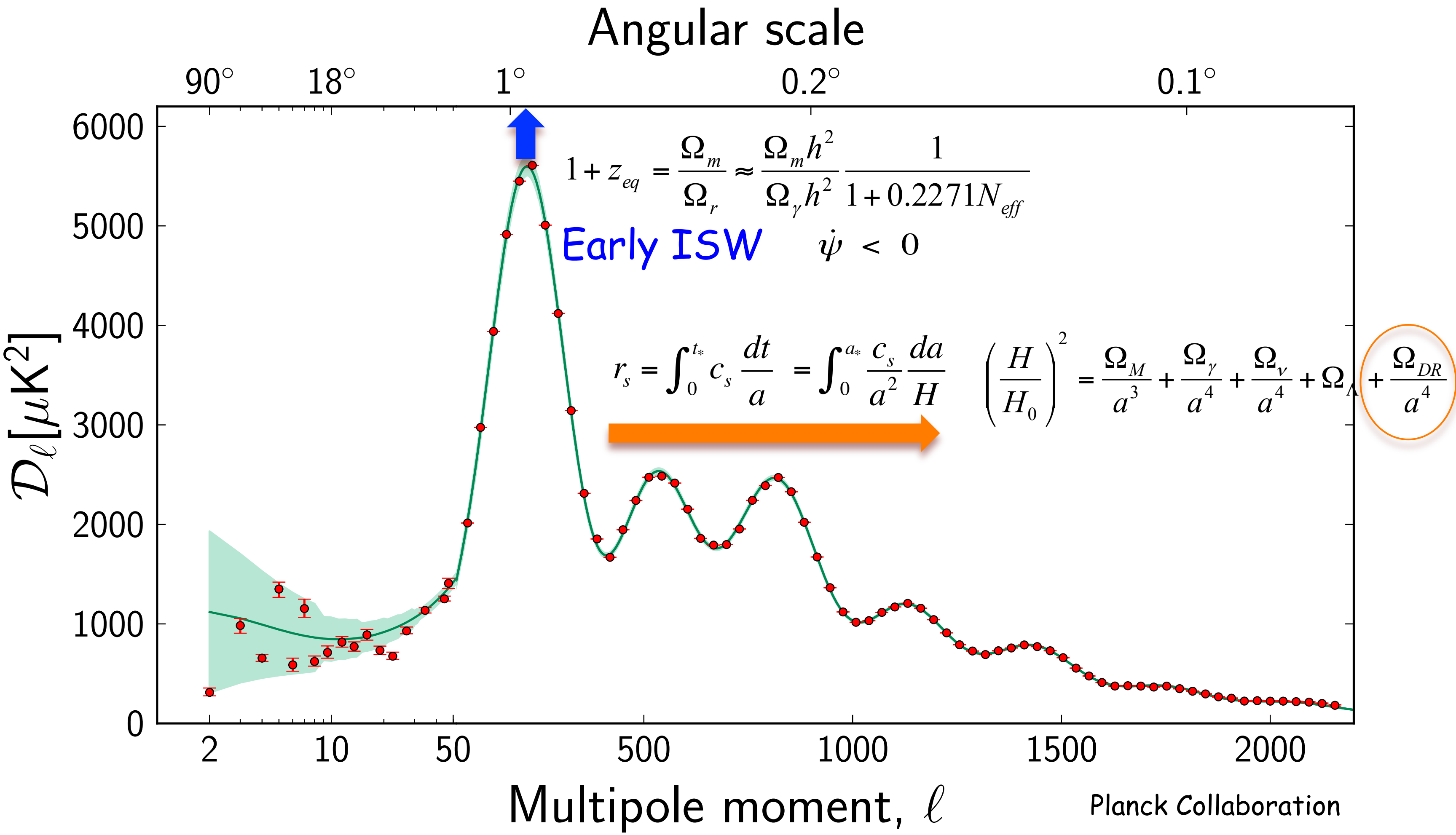

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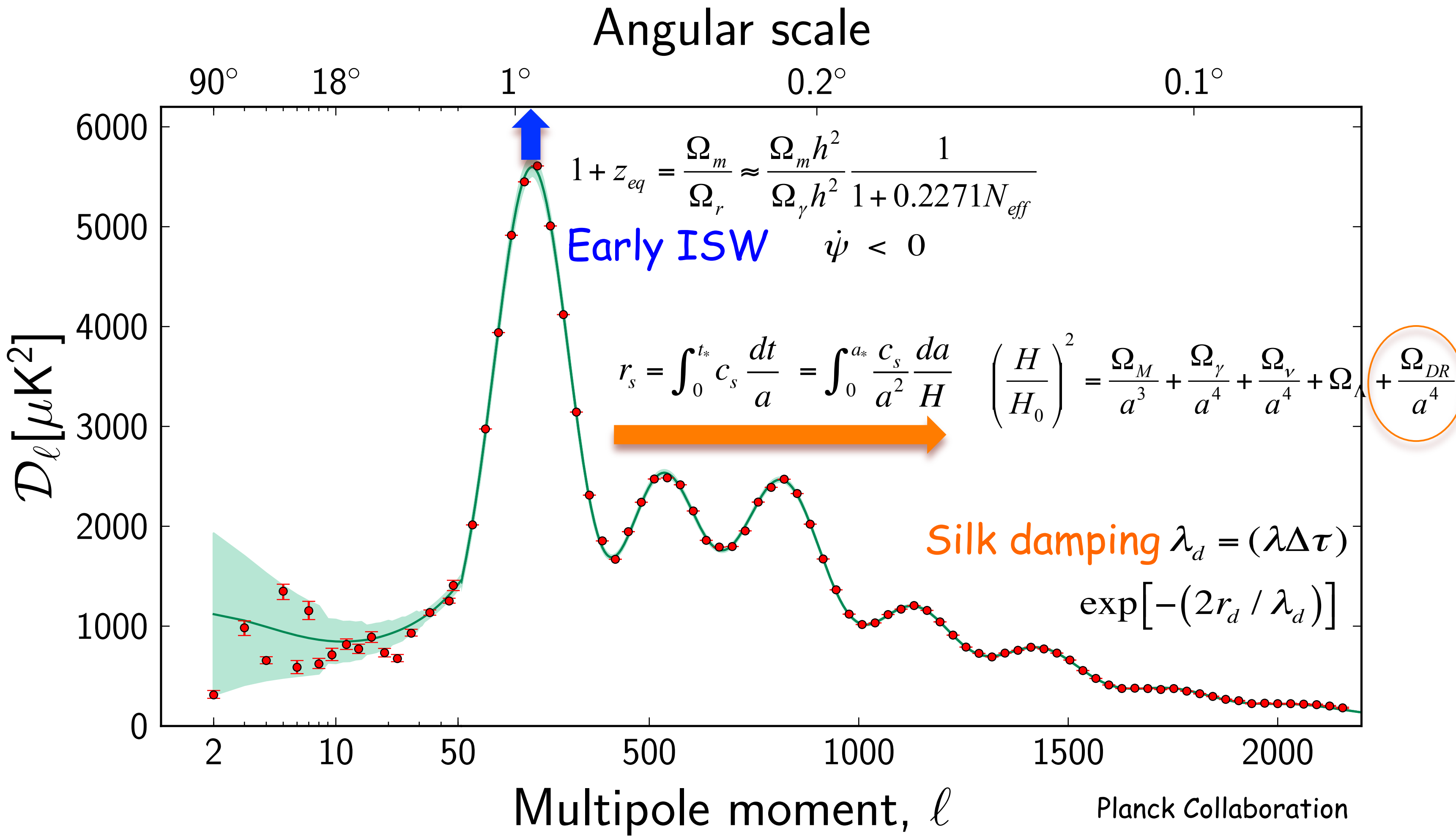

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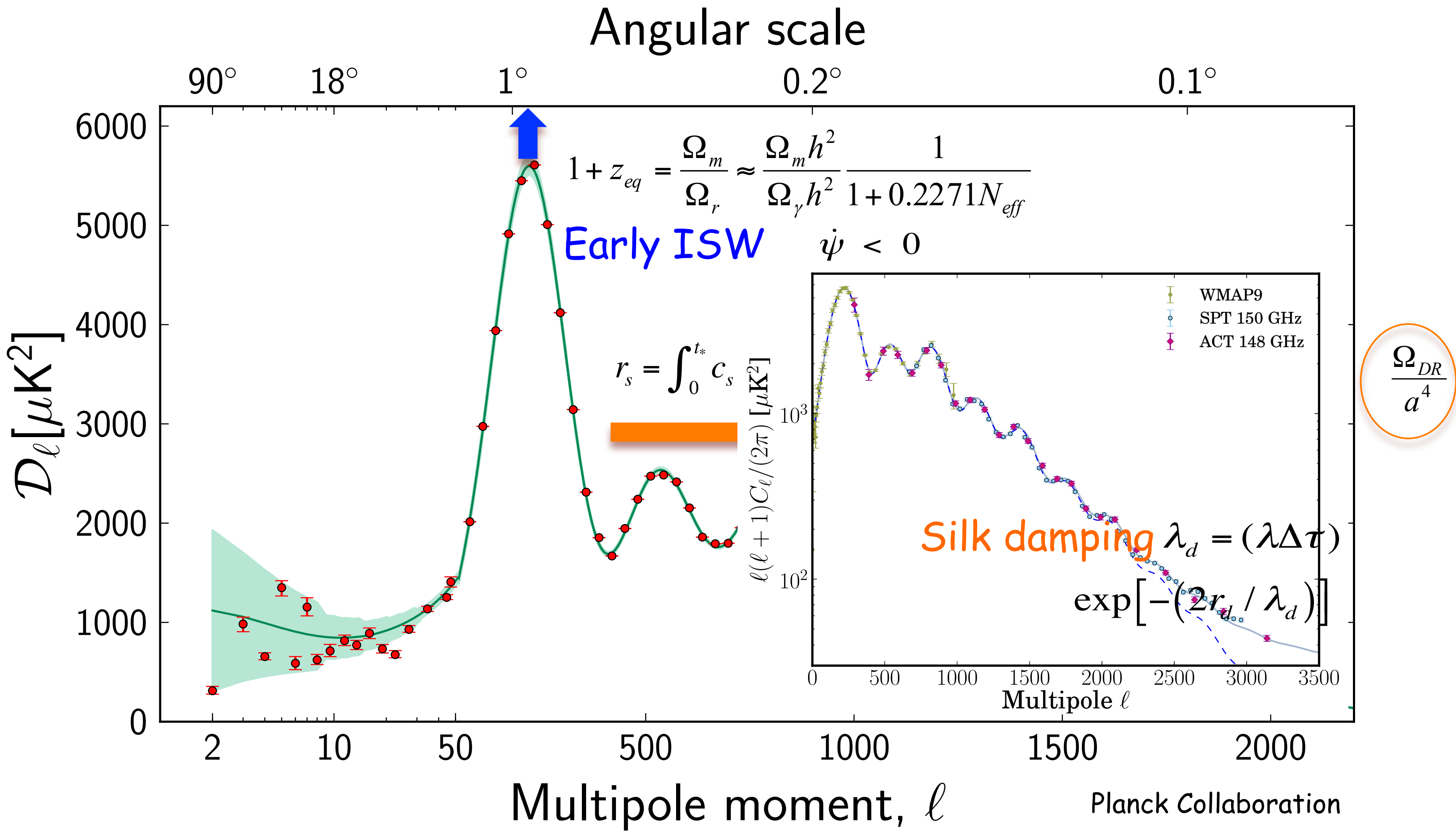


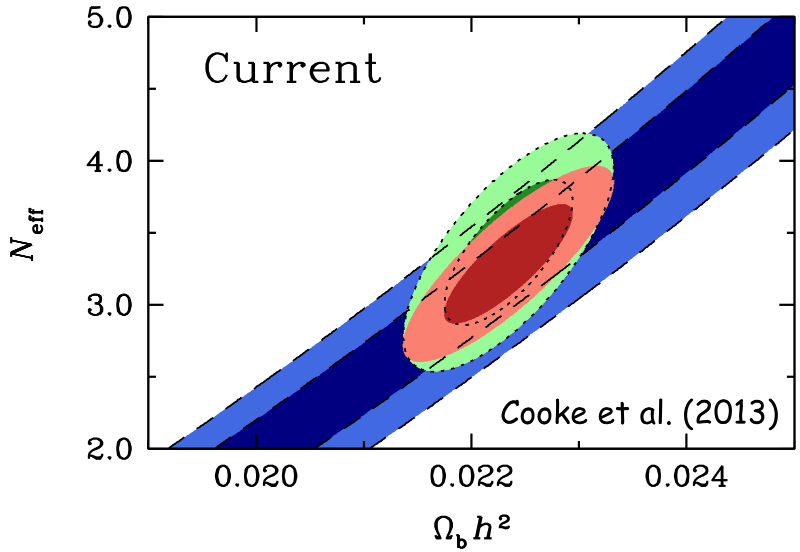
Planck Collaboration

N_{eff} effects on BBN

Friedmann equation: $$\left(\frac{H}{H_0}\right)^2 = \frac{\Omega_M}{a^3} + \frac{\Omega_\gamma}{a^4} + \frac{\Omega_\nu}{a^4} + \Omega_\Lambda + \frac{\Omega_{DR}}{a^4}$$

increase of the expansion rate. Earlier freeze-out!

Impact on primordial abundances



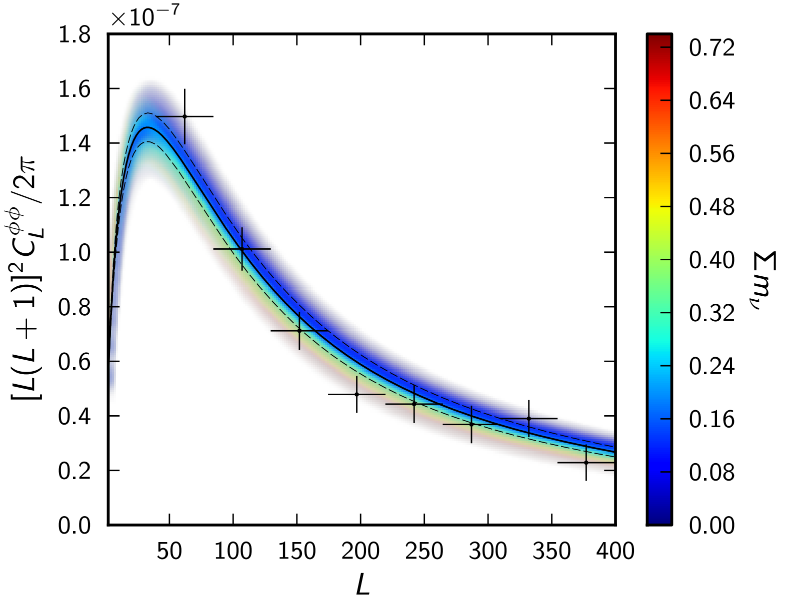
N_{eff} = 4.046 is excluded at 99.3% c.l. by BBN+CMB

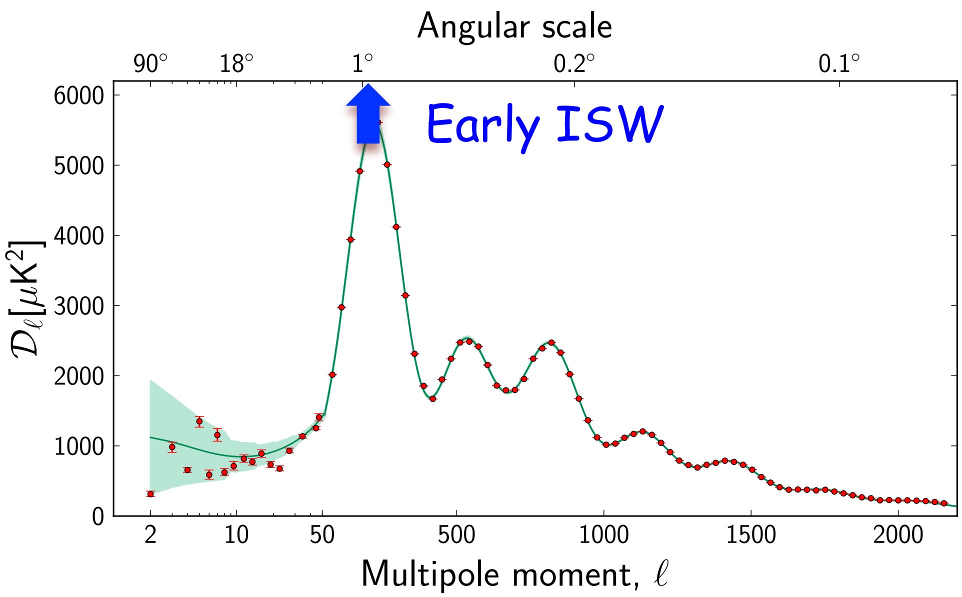
… N_{eff} is not constant!

$$N_{eff}^{BBN} \neq N_{eff}^{CMB}$$

How can we measure the neutrino mass with cosmological data?

Neutrino mass effects on CMB

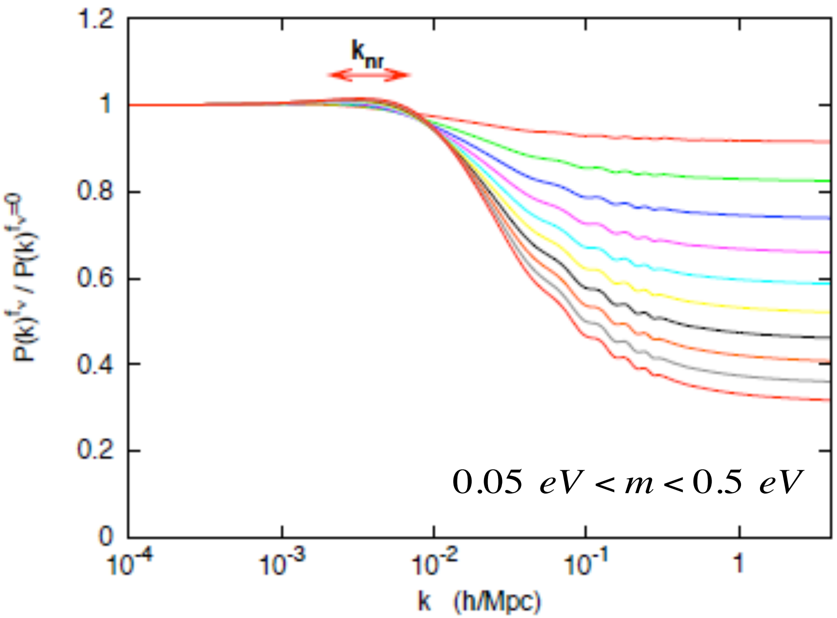


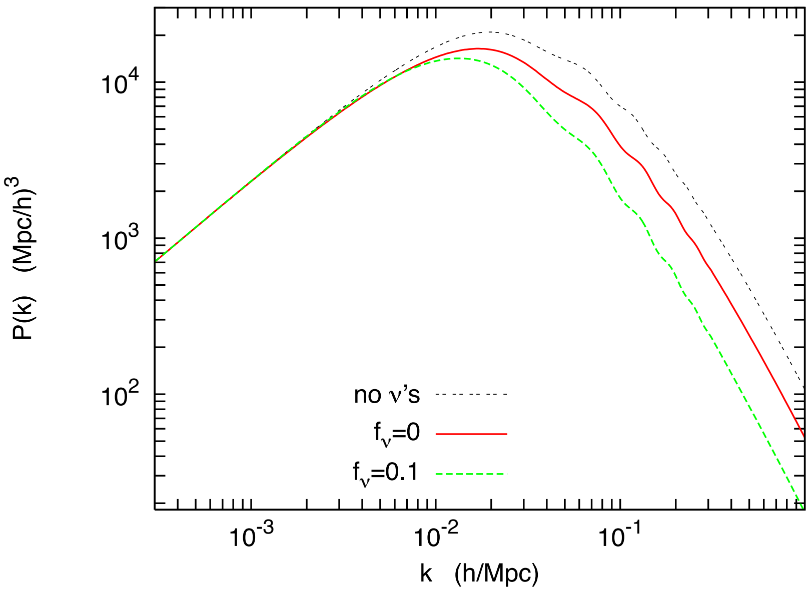


Free-streaming:
Suppression of lensing potential

Neutrino mass effects on MPK

Free-streaming:
Effects on matter power spectrum:
Suppression on scales smaller than the scale of the horizon at the non-relativistic transition.



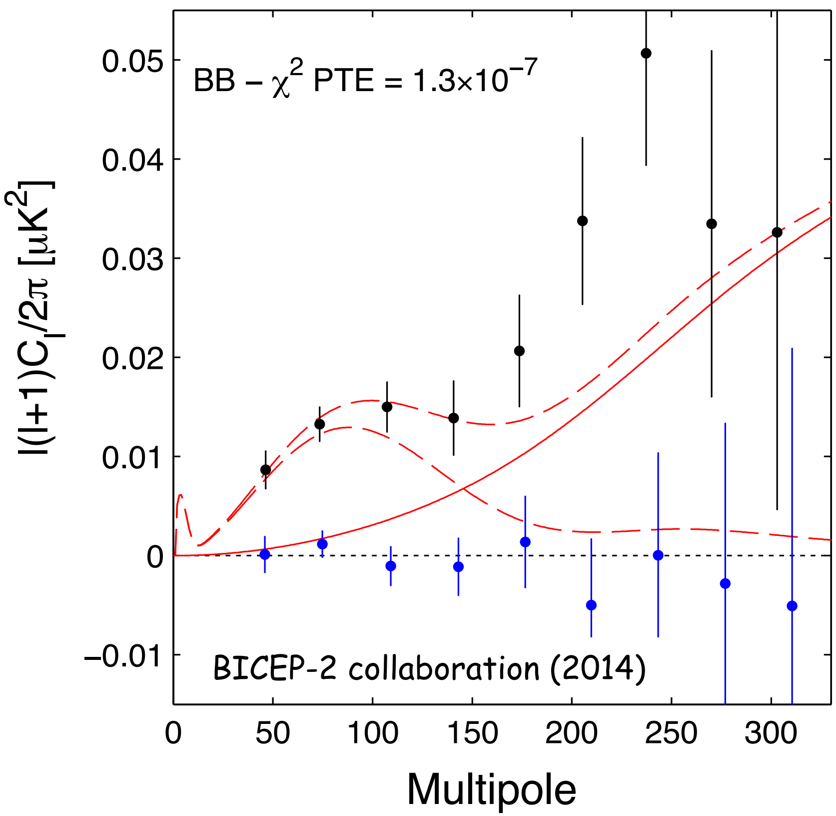


Lesgourgues & Pastor (2012)

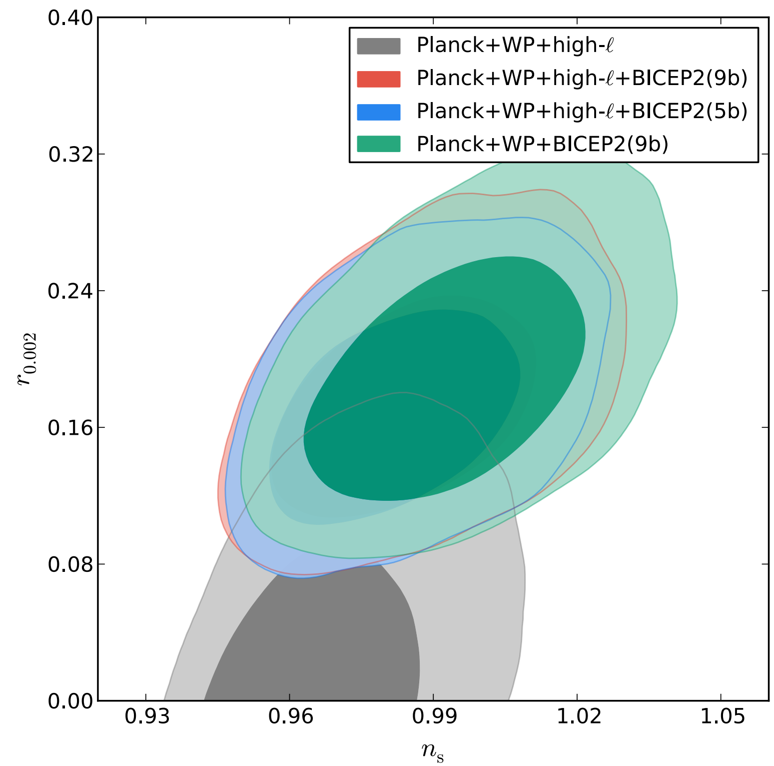
Cosmological constraints on neutrino number and mass after BICEP-2

Cosmology after BICEP2

$$\Omega_s h^2 = \frac{(\Delta N_{eff})^{3/4} m_s}{94 eV}$$



MA, Fornengo, Gariazzo, Giunti, Hannestad, Lavader (2014)



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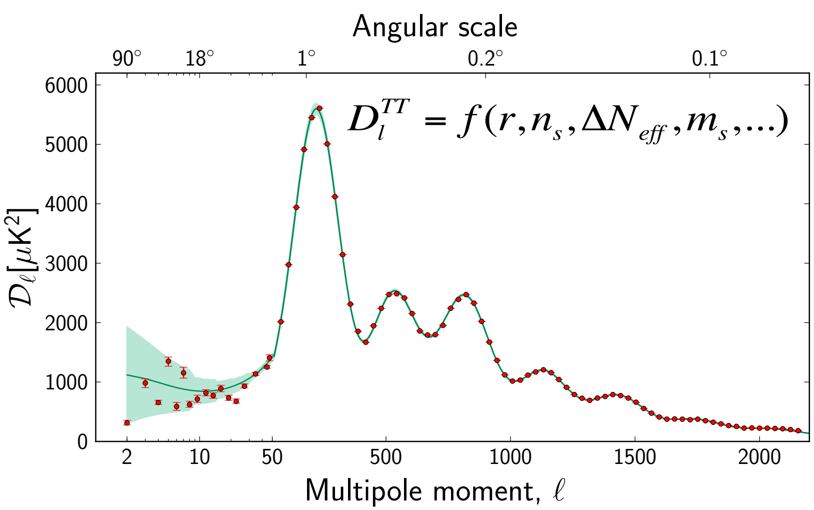
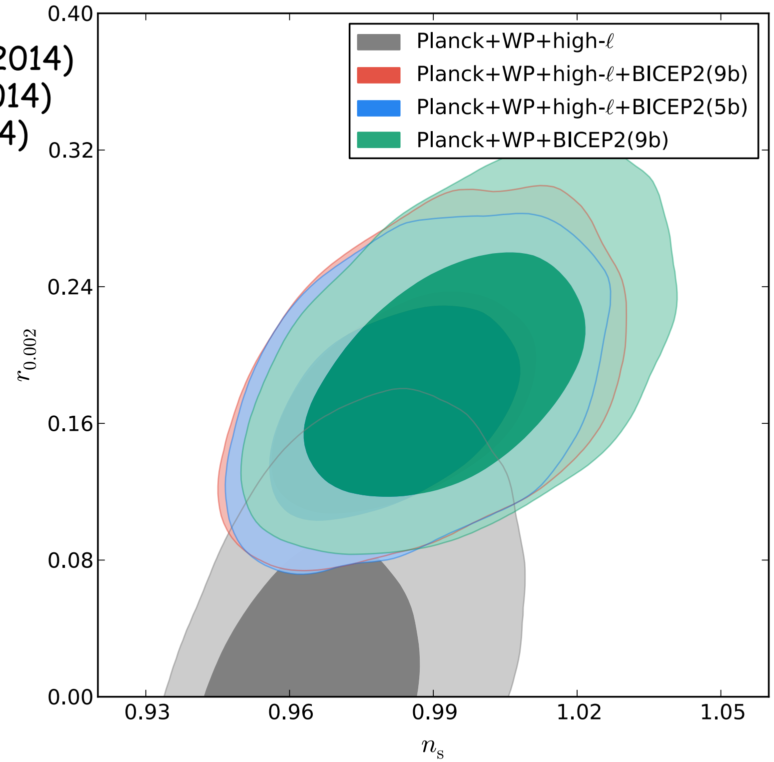


Giusarma et al. (2014)
Dvorkin et al. (2014)
Zhang et al. (2014)

Neutrinos?

MA, Fornengo, Gariazzo, Giunti, Hannestad, Lavader (2014)



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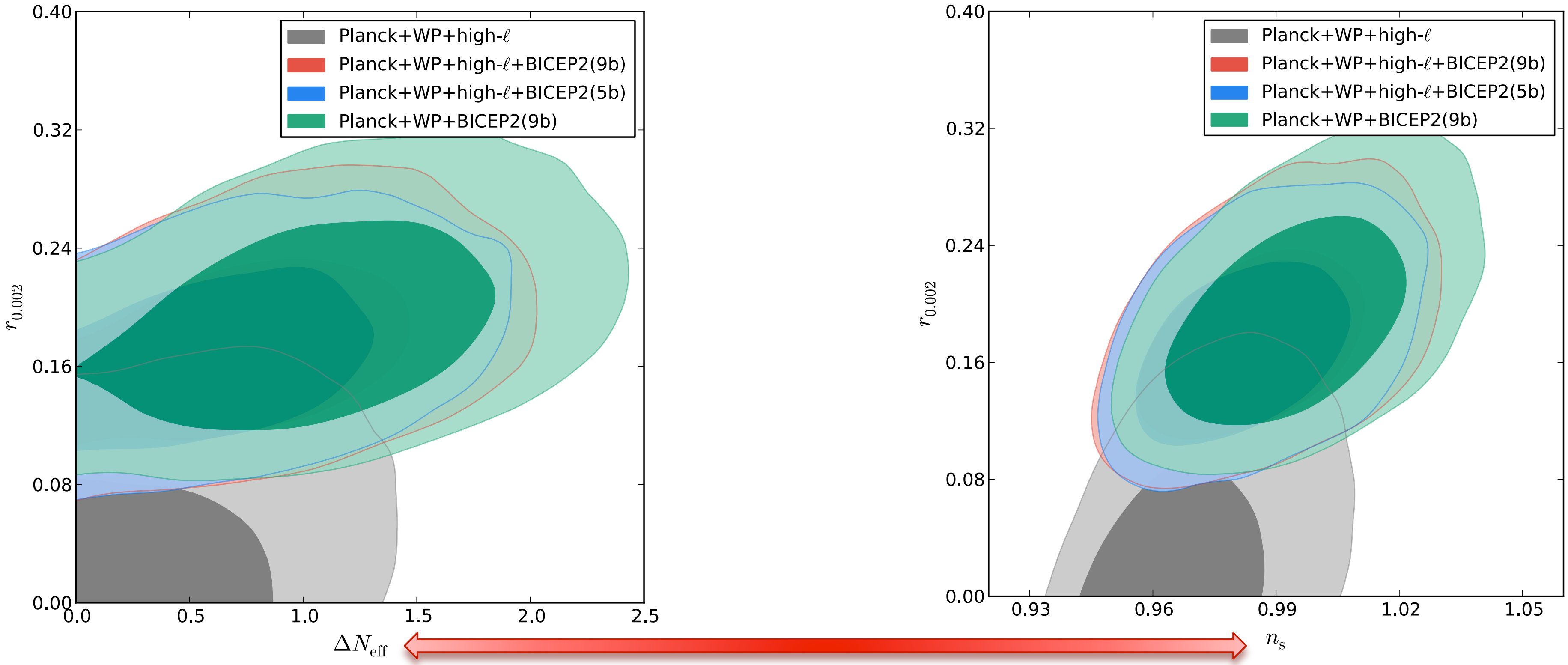

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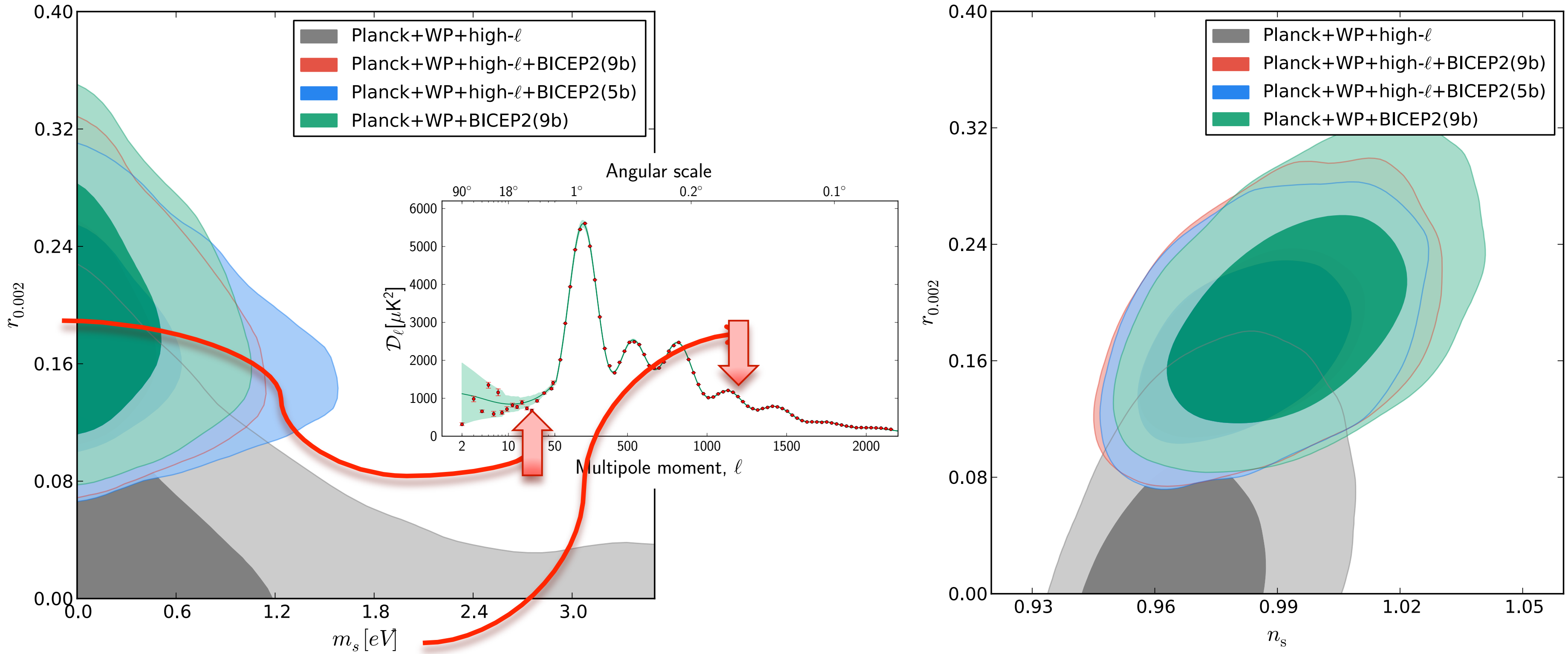
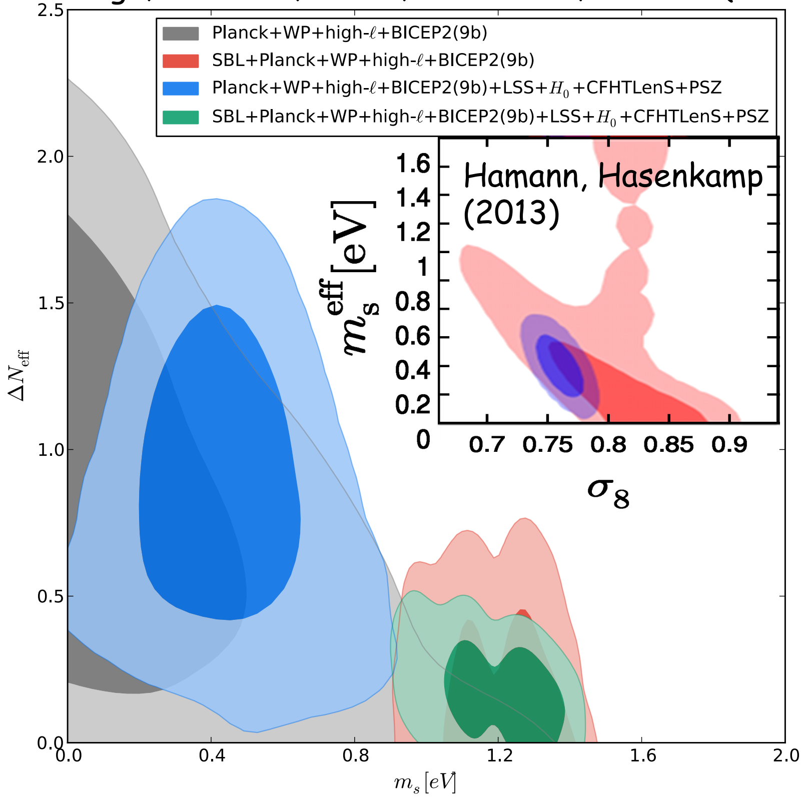


Cosmology after BICEP2

	CMB	CMB+all
ΔN_{eff}	$0.82_{-0.57}^{+0.40}$	$0.89_{-0.37}^{+0.34}$
m_s (eV)	<0.85 (95%cl)	$0.44_{-0.16}^{+0.11}$

MA, Fornengo, Gariazzo, Giunti, Hannestad, Lavader (2014)



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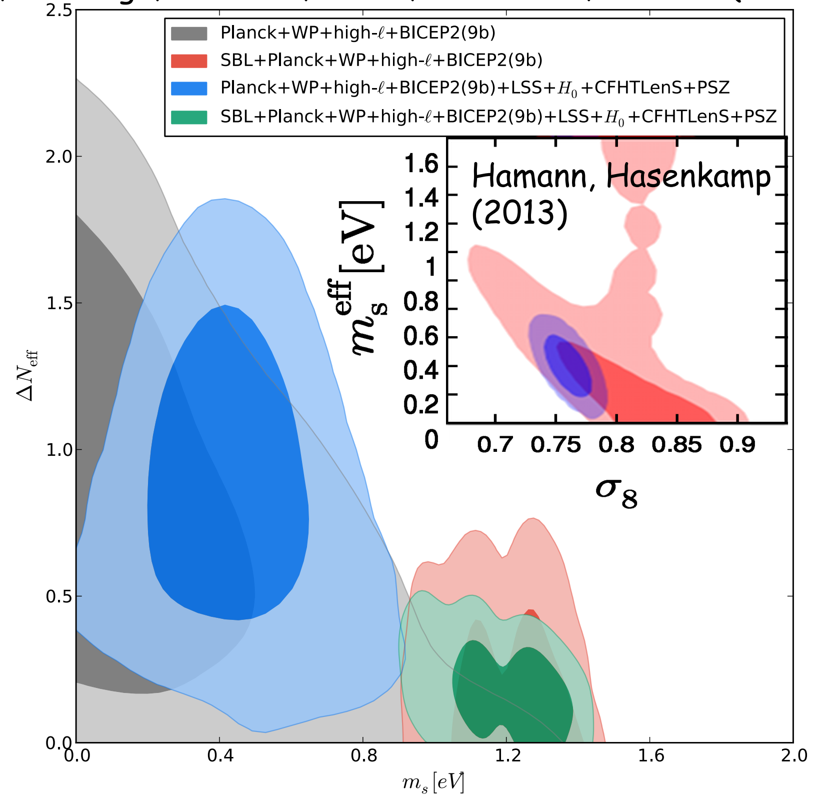

Combining Cosmology and SBL…

Cosmology after BICEP2

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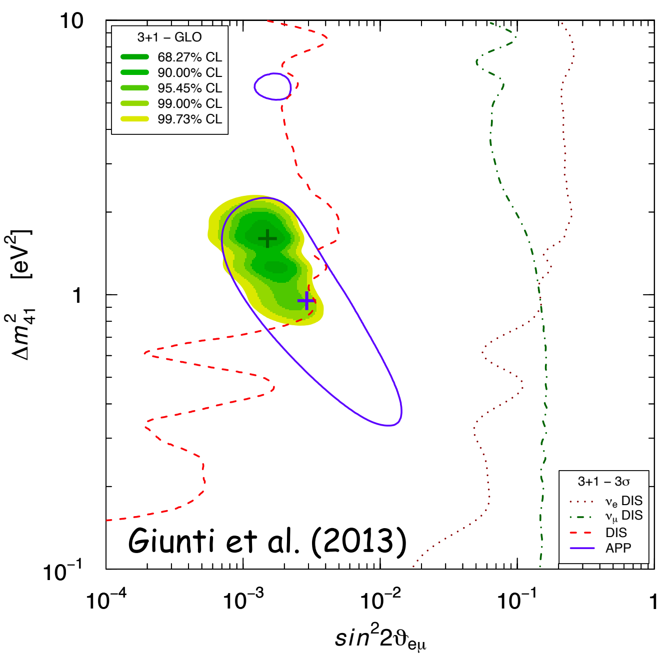
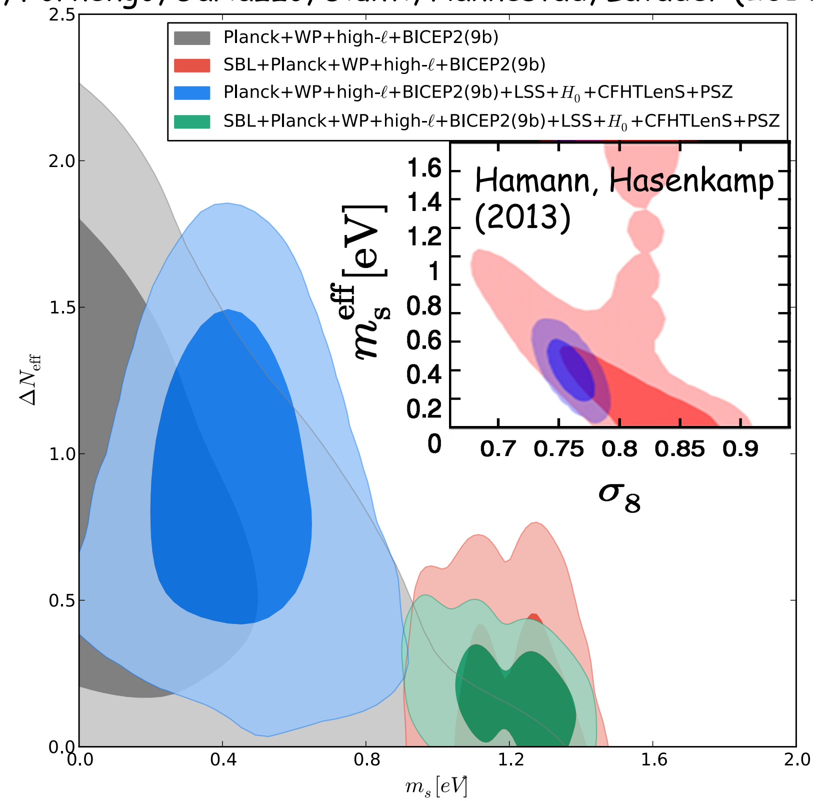


MA, Fornengo, Gariazzo, Giunti, Hannestad, Lavader (2014)



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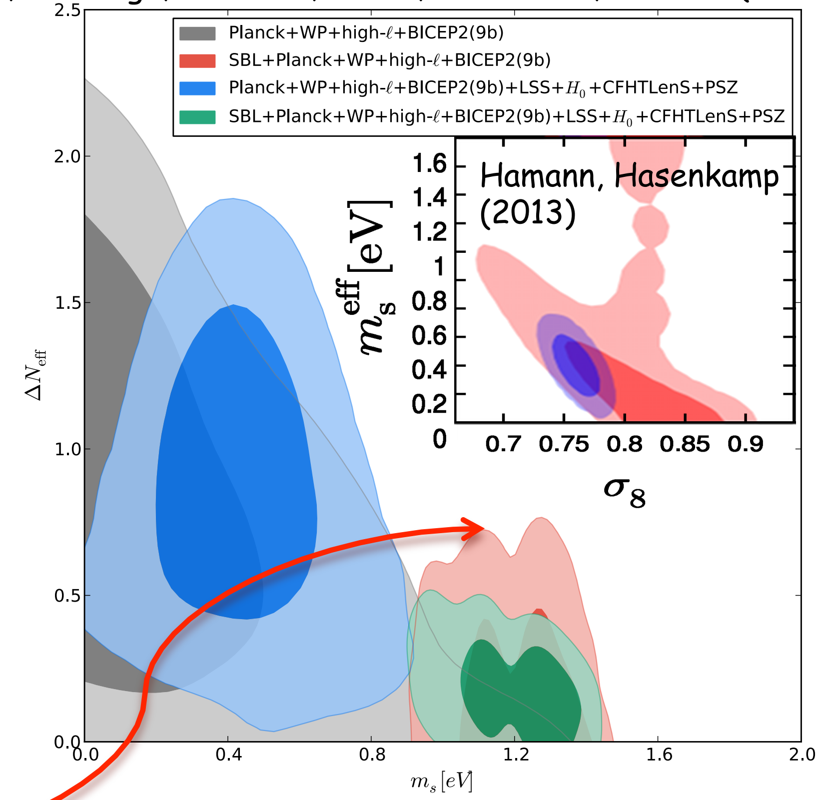
m_s (eV)	<0.85 (95%cl)	$0.44_{-0.16}^{+0.11}$

	CMB +SBL	CMB+all +SBL
ΔN_{eff}	<0.63 (95%cl)	<0.42 (95%cl)
m_s (eV)	$1.21_{-0.13}^{+0.14}$	$1.19_{-0.12}^{+0.15}$

MA, Fornengo, Gariazzo, Giunti, Hannestad, Lavader (2014)



$$\Omega_s h^2 = \frac{(\Delta N_{eff})^{3/4} m_s}{94eV}$$

1eV sterile neutrino is ruled out by cosmology, unless…

Solutions?

Solutions:

How can cosmology face SBL? Partial thermalization:

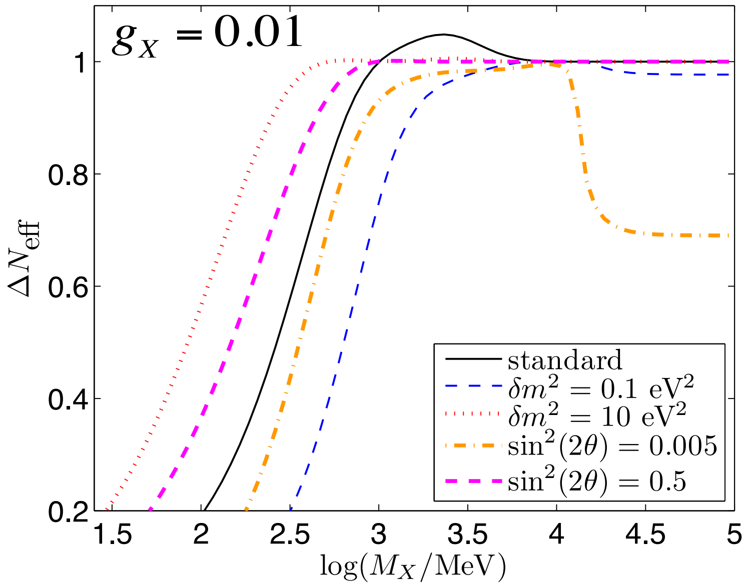
- Non-standard interactions MA, Hannestad, Hansen, Tram (2014); Hannestad, Hansen, Tram (2013); Dasgupta, Kopp (2013)
- Lepton asymmetry Mirizzi, Saviano, Miele, Serpico (2012); Hannestad, Tamborra, Tram (2012)
- Low reheating temperature Rehagen, Gelimini (2014)
- Non-standard expansion rate at MeV scale

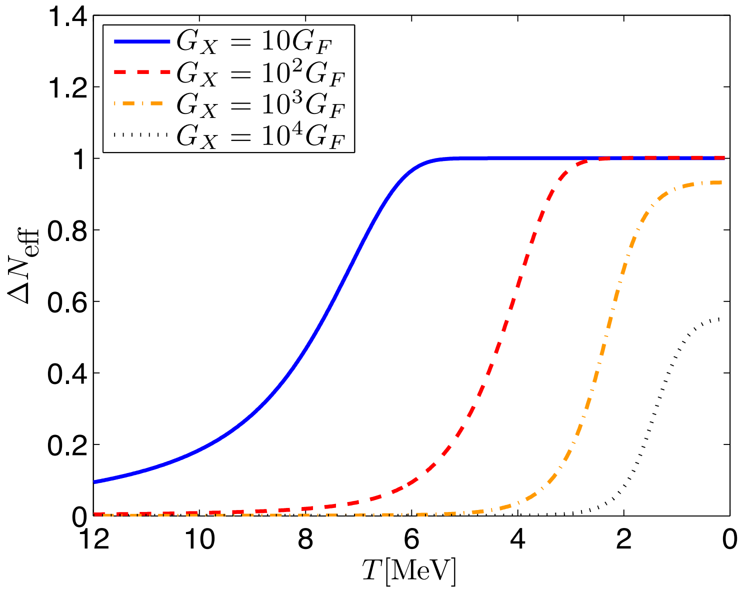
Non-standard interactions

$$G_X = \frac{g_X^2}{M_X^2}$$

$$M_X > 100 \ \ MeV$$

Hannestad, Hansen, Tram (2013)





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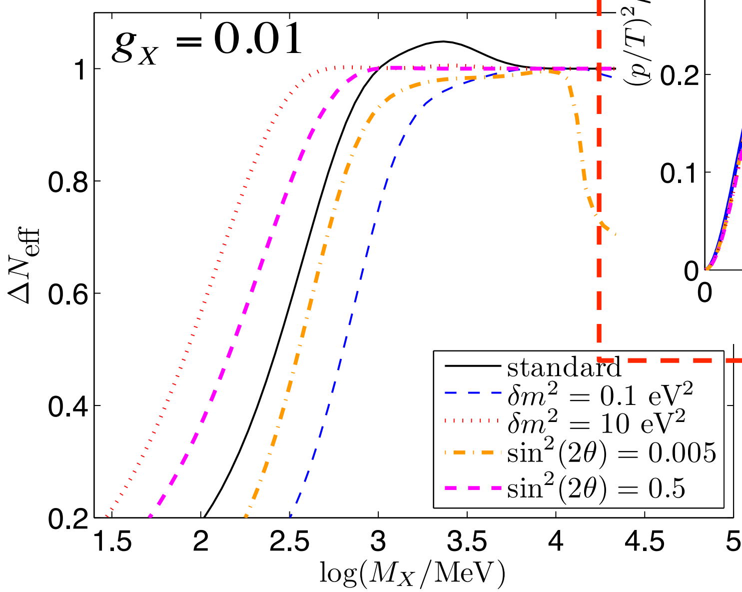
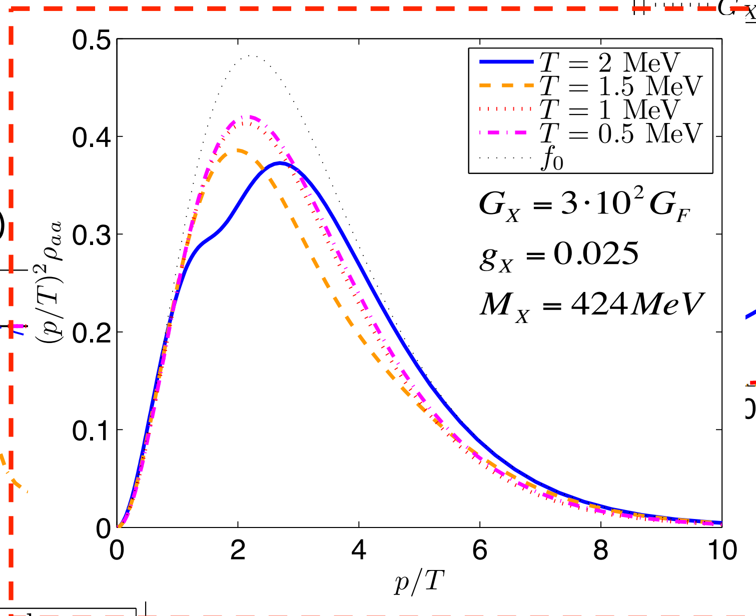
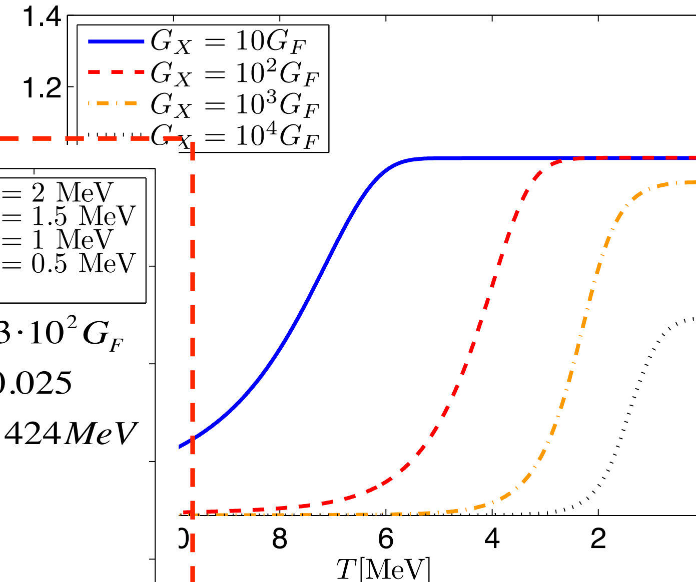






Tension with BBN

Future perspectives?

Euclid

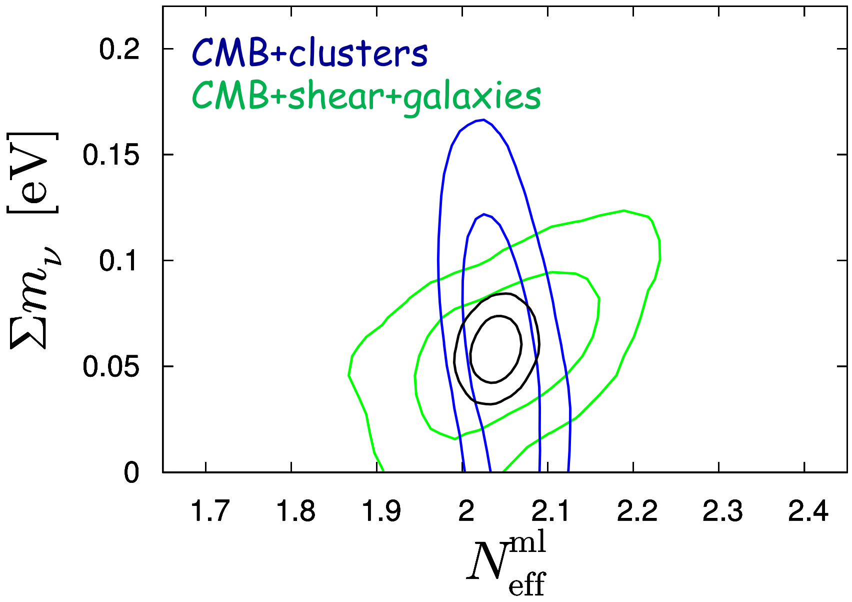
Euclid produces a legacy dataset with images and photometry of more than a billion galaxies and several million spectra, out to high redshifts z > 2.

$$N_{eff}^{fid} = 2.046 \qquad \sigma(N_{eff}) = 0.019$$

$$\Sigma m_\nu = 0.06\ eV \qquad \sigma(\Sigma m_\nu) = 0.0098\ eV$$

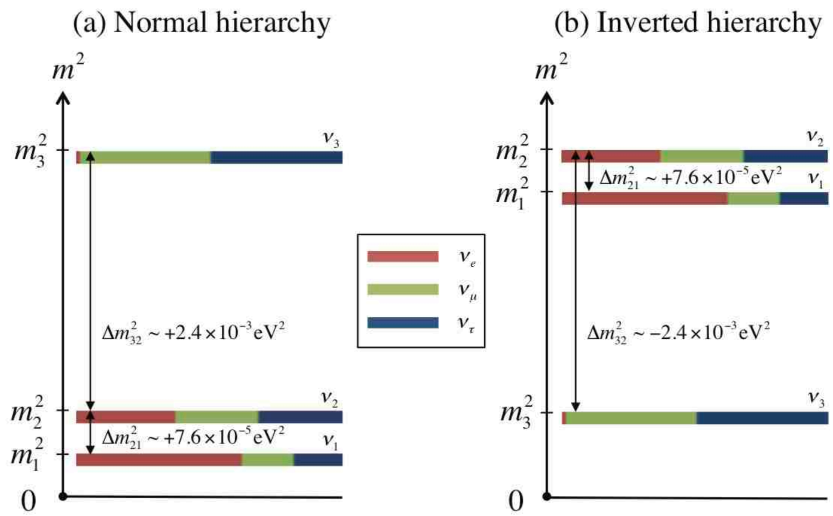
More than 5σ detection of neutrino mass

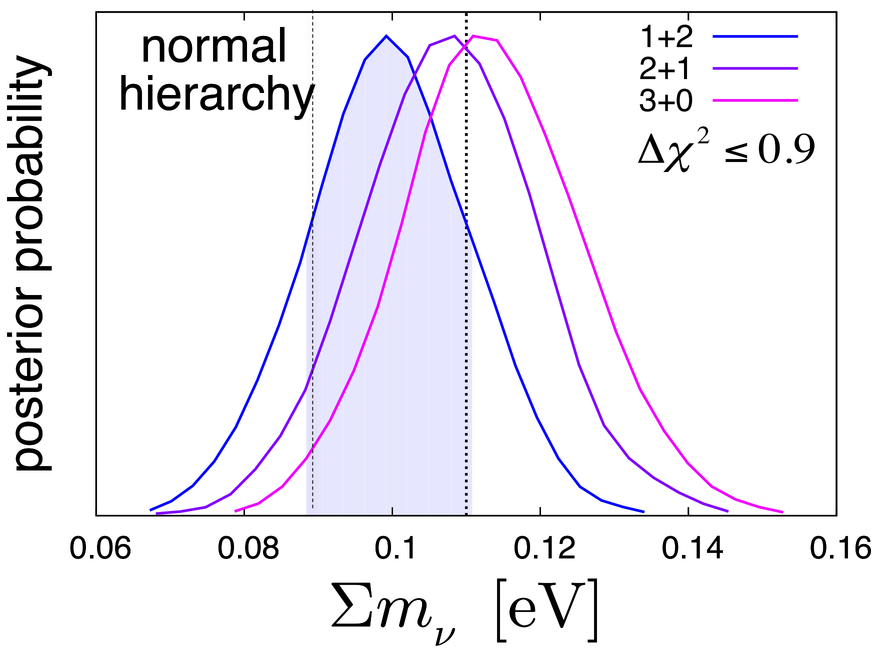
Basse, Bjaelde, Hamann, Hannestad, Wong (2013)

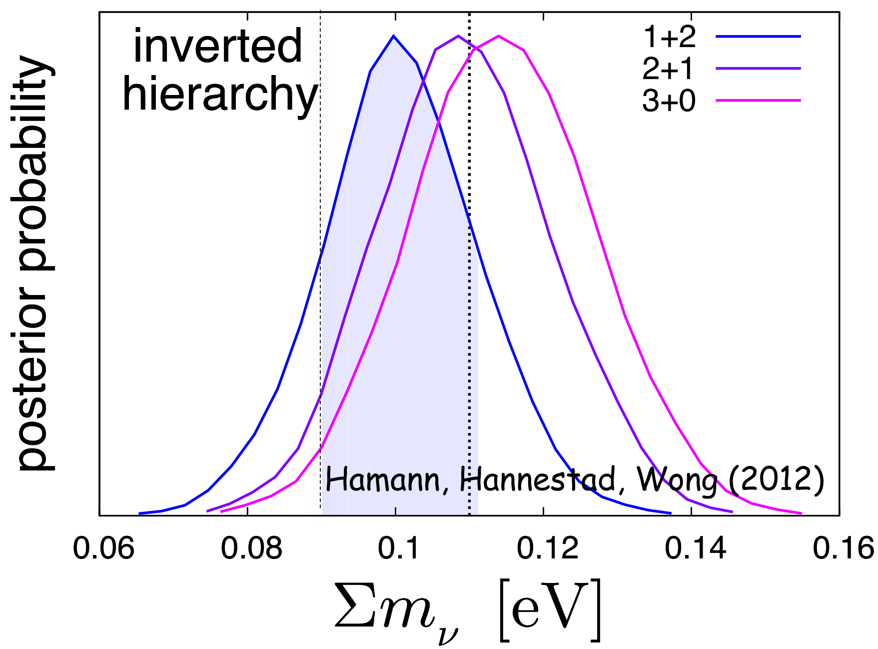


Euclid

$$\Sigma m_\nu = 0.11\ eV$$







Conclusions

- ✓ Despite the progress of precision cosmology, N_{eff} is still an open question.
- ✓ The tension between cosmology and Short BaseLine exacerbates the debate: light sterile neutrinos are too massive for cosmology
- ✓ Solutions → tension with BBN
- ✓ Euclid: final answer on the mass sum, but not on the single mass eigenstate