Planck 2014 constraints on neutrino perturbations

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Introduction

The standard cosmological model predicts the existence of a cosmic neutrino background of three families of relativistic and non-interacting particles contributing to the radiation energy density. In case of massless neutrinos, the background evolution follows a radiation-like behaviour ($w = 1/3$) and clustering properties are described by the classical hierarchy of distribution momenta $F_{\nu,\ell}$, with $F_{\nu,0} = \delta_\nu$, $F_{\nu,1} = q_\nu$, $F_{\nu,2} = \pi_\nu$ usually truncated at $\ell < 3$. In a wider scenario, the evolution of perturbations are generalised as follows [1]

$$\dot{\delta}_\nu = \frac{\dot{a}}{a}\left(1 - 3c^2_{\rm eff}\right)\left(\delta_\nu + 3\frac{\dot{a}}{a}\frac{q_\nu}{k}\right) - k\left(q_\nu + \frac{2}{3k}\dot{h}\right) \quad (1)$$

$$\dot{q}_\nu = k\,c^2_{\rm eff}\left(\delta_\nu + 3\frac{\dot{a}}{a}\frac{q_\nu}{k}\right) - \frac{\dot{a}}{a}q_\nu - \frac{2}{3}k\pi_\nu \quad (2)$$

$$\dot{\pi}_\nu = 3k\,c^2_{\rm vis}\left(\frac{2}{5}q_\nu + \frac{4}{15k}(\dot{h} + 6\dot{\eta})\right) - \frac{3}{5}kF_{\nu,3} \quad (3)$$

$$\frac{2\ell+1}{k}\dot{F}_{\nu,\ell} - \ell F_{\nu,\ell-1} = -(\ell+1)\,F_{\nu,\ell+1} \quad \ell \geq 3 \quad (4)$$

where $c^2_{\rm eff}$ is the sound speed in the neutrino rest frame, describing pressure fluctuations respect to density perturbations, and $c^2_{\rm vis}$ is the viscosity parameter accounting for anisotropic stress. According to the standard model, $c^2_{\rm eff} = c^2_{\rm vis} = 1/3$. Any deviation is a hint for non-standard physics in the neutrino sector. As an example, low-viscosity neutrinos involve models of interactions with light scalar particles (see [2] and references therein).
In this work, we investigate the constraints on the neutrino clustering parameters from the Planck full-mission temperature and polarisation data.

Methodology

We perform a Monte-Carlo Markov Chain analysis by varying the six main cosmological parameters $\Omega_b h^2$, $\Omega_c h^2$, θ, τ, n_S and $\ln[10^{10}A_S]$ together with the neutrino clustering parameters $c^2_{\rm eff}$ and $c^2_{\rm vis}$, assuming flat priors. We impose adiabatic initial conditions and fix the number of relativistic degrees of freedom at recombination at its standard value $N_{\rm eff} = 3.046$. For simplicity, we assume massless neutrinos. However, we checked that our results are marginally affected by considering a total neutrino mass of $\Sigma m_\nu = 0.06\,\mathrm{eV}$.
We test separetly Planck temperature data and the full Planck temperature and polarisation data. We also combine CMB data with baryon acoustic oscillations (6dFGS, SDSS-MGS, BOSS-LOWZ and CMASS-DR11 [3]).

Results

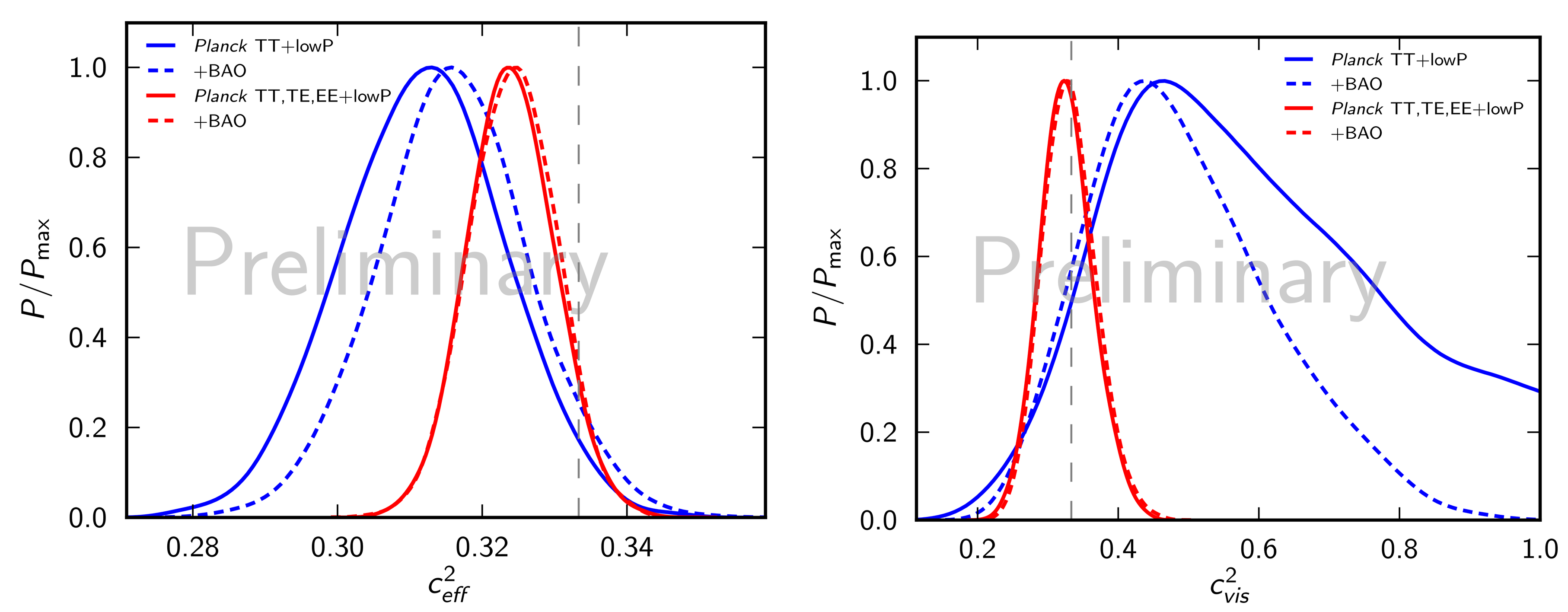

Figure: One dimensional marginalised posterior probability of the neutrino perturbation parameters $c^2_{\rm eff}$ and $c^2_{\rm vis}$ from the listed combinations of datasets. The vertical dashed line indicates the standard expected value.

Parameter	TT+lowP	TT+lowP+BAO	TT,TE,EE+lowP	TT,TE,EE+lowP+BAO
$c^2_{\rm vis}$	$0.47^{+0.26}_{-0.12}$	$0.44^{+0.15}_{-0.10}$	0.327 ± 0.037	0.331 ± 0.037
$c^2_{\rm eff}$	0.312 ± 0.011	0.316 ± 0.010	0.3240 ± 0.0060	0.3242 ± 0.0059

Table: Constraints at 68% CL for the neutrino perturbation parameters from the indicated datasets.

Constraints on $c^2_{\rm eff}$ are fully compatible with $1/3$, showing no hints for deviations from the standard model. A vanishing value of $c^2_{\rm vis}$, that could imply an interaction between neutrinos and other species, is also excluded at more than 95% c.l. from temperature data and even more (at about 9 standard deviations) when polarization data is included, representing the first CMB-only-driven evidence for neutrino anisotropies. These results are also consistent with the forecasts discussed in [2]. The temperature value is off by little more than one standard deviation from the expected value of $1/3$. This is most probably due, as showed in [4] and next panel, to degeneracies with other parameters as the scalar spectral index that skews the posterior towards larger values. When polarization data is included indeed this small tension disappears and the constraints are fully compatible with the standard value. Since TE power spectrum is able to constrain cosmological parameters better than TT, as shown in [5], this reflects on $c^2_{\rm vis}$ constraints.
Overall, we find a good consistency with the standard expected values $c^2_{\rm vis} = 1/3$ and $c^2_{\rm eff} = 1/3$. The addition of BAO slighlty tightens the constraints.

Discussion

In the following, we discuss the impact of the neutrino perturbation parameters on the CMB power spectra.

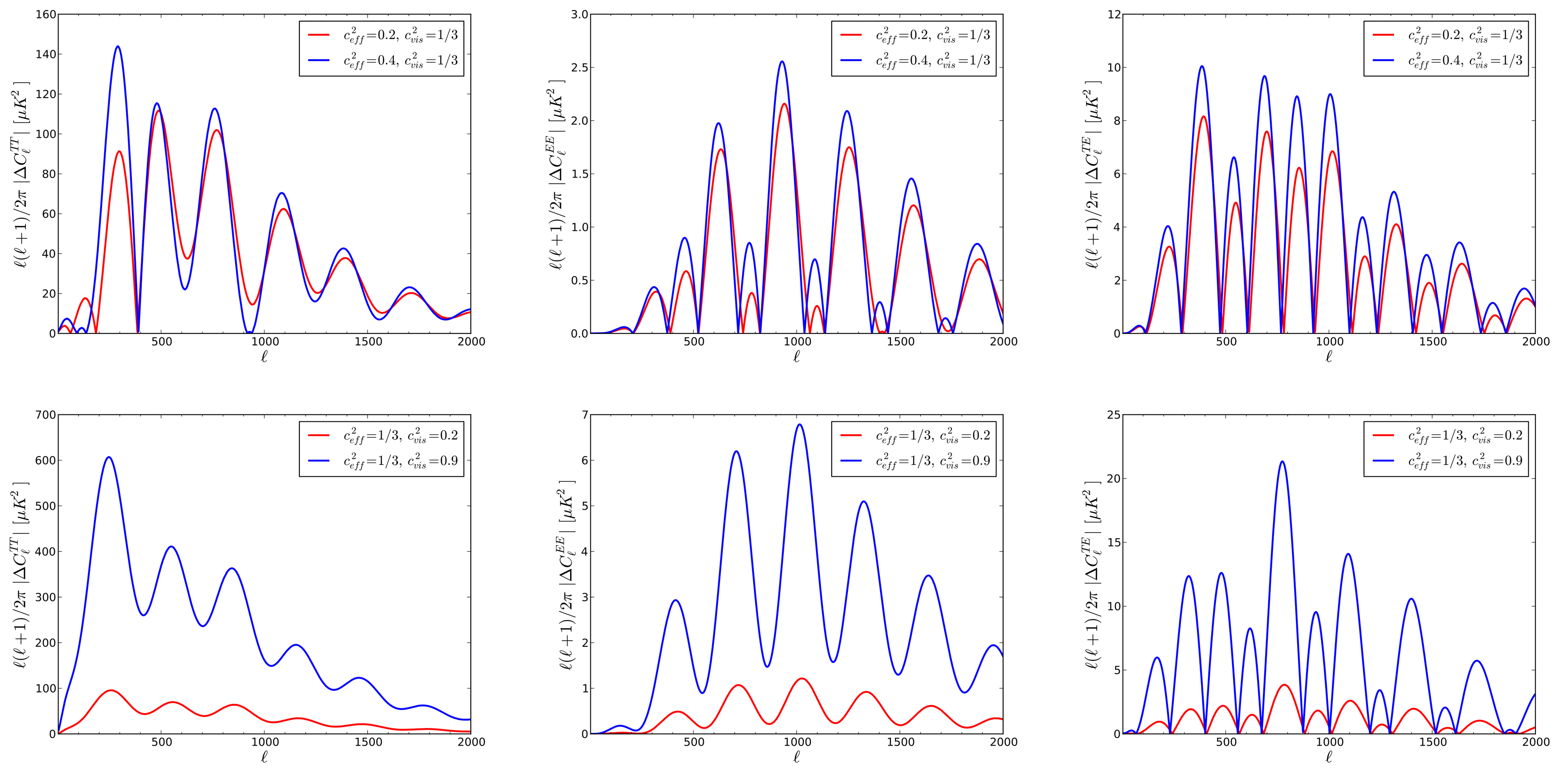

Figure: Absolute difference between standard model ($c^2_{\rm eff} = c^2_{\rm vis} = 1/3$) and model with variable neutrino perturbation parameters (free $c^2_{\rm eff}$ in the top panels, free $c^2_{\rm vis}$ in the bottom).

As far as the TT spectrum is concerned, the main effect of $c^2_{\rm vis}$ is essentialy a rescaling of the overall amplitude, since changing this parameter alters how neutrino perturbations are damped ($c^2_{\rm vis} = 0$ yealds undamped oscillations). As a result, its effect is easily mimicked by acting on other parameters, such as $\Omega_b h^2$ or $\ln[10^{10}A_S]$ and the constraints on $c^2_{\rm vis}$ from TT-only dataset are broad. On the other hand, varying $c^2_{\rm eff}$ alters the neutrino sound scale, shifting the acoustic peaks. This peculiar effect results in tighter bounds on $c^2_{\rm eff}$. As reported in [5], adding polarisation help constraining cosmological parameters, the main reason being the sharpness of the acoustic peaks with respect to temperature. As a result, bounds on $c^2_{\rm eff}$ and $c^2_{\rm vis}$ are considerably tightened, due to two effects. Firstly, tighter constraints on the six main cosmological parameters reflect on $c^2_{\rm eff}$ and $c^2_{\rm vis}$ because of degeneracies. Secondly, the shift induced by variation of $c^2_{\rm eff}$ and $c^2_{\rm vis}$ is more evident.
The plot below summarizes the impact of polarisation and the main degeneracies between cosmological parameters and neutrino parameters.

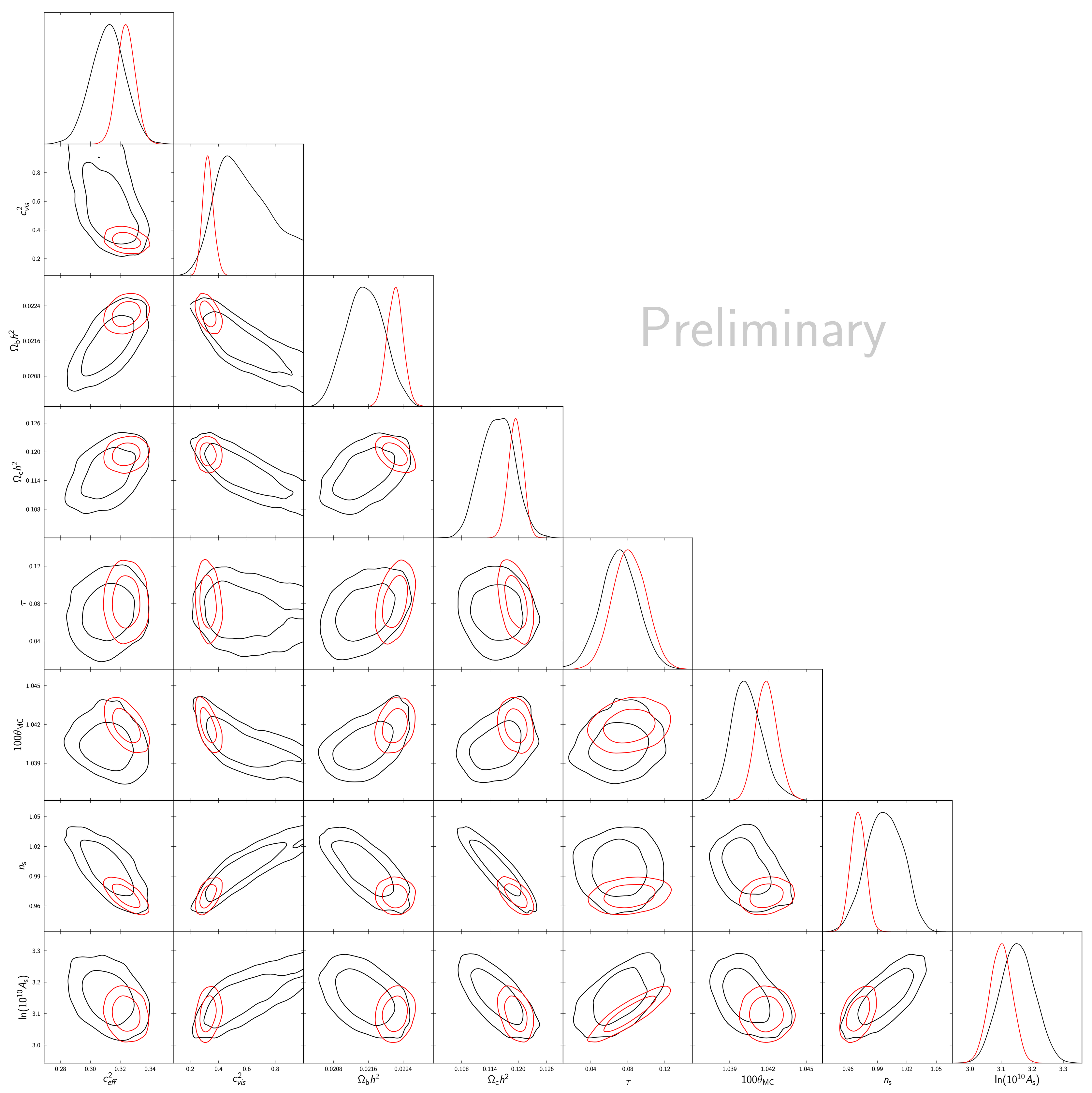

Figure: Triangle plot showing degeneracies between cosmological parameters and the neutrino perturbation parameters for the *Planck TT* (black contours) and *Planck TT,TE,EE* datasets (red contours).

Conclusions

We presented in this poster the work done within the *Planck* Collaboration for the 2014 data release. We showed here the constraints on the neutrino perturbation parameters $c^2_{\rm eff}$ and $c^2_{\rm vis}$ from the Planck 2014 data release in combination with other comsological datasets. The addition of CMB polarisation data results in the first CMB-only-driven evidence for non-zero neutrino viscosity.

References

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