ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Nuclear and Particle Physics Proceedings 265–266 (2015) 52–55

www.elsevier.com/locate/nppp

Neutrino physics after *Planck*

G. Polenta

ASI Science Data Center, via del Politecnico, 00133 Roma, Italy

INAF - Osservatorio Astronomico di Roma, via di Frascati 33, 00040 Monte Porzio Catone, Italy

on behalf of the *Planck* Collaboration

Abstract

We present constraints on neutrino physics derived from the 2013 *Planck* data release, which involves data collected during the first 15.5 months of observations. After a brief description of the effect of neutrino masses and number of relativistic species on CMB anisotropies, we present results obtained from *Planck* data alone and in combination with other astrophysical probes. In particular, *Planck* set constraints on the sum of neutrino masses is $\sum m_\nu < 0.23$ eV, and on the number of relativistic species of $N_{\rm eff} = 3.30^{+0.54}_{-0.51}$ both at 95% C.L. Finally, we briefly discuss updated results from the *Planck* 2015 data release as well as future prospects for CMB experiments.

Keywords: Cosmology, Cosmic Microwave Background, Cosmological parameters, Neutrinos

1. Introduction

The *Planck* satellite[1] [1] is a third generation Cosmic Microwave Background (CMB) experiment. It was launched on 14 May 2009 and observed the sky continuously from 12 August 2009 to 23 October 2013. *Planck*'s scientific payload contains detectors sensitive to nine frequency bands between 25 and 1000 GHz with angular resolution between 33′ and 5′. The Low Frequency Instrument (LFI; [2]) covers bands centred at 30, 44, and 70 GHz using pseudo-correlation radiometers, while the High Frequency Instrument (HFI; [3]) is equipped with bolometers covering bands centred at 100, 143, 217, 353, 545, and 857 GHz. *Planck* imaged the whole sky with an unprecedented combination of sensitivity, angular resolution, and frequency coverage.

In January of 2011, the *Planck* Collaboration released a first set of scientific data, the Early Release Compact Source Catalogue (ERCSC; [4]) together with initial scientific results related to astrophysical foregrounds (A&A, Vol. 520, 2011). Since then, 34 Intermediate papers on foreground properties have been published. In March of 2013, the second release of scientific data took place, consisting mainly of temperature maps of the whole sky [5]; these products and associated scientific results are described in a special issue of A&A (Vol. 571, 2014). In February of 2015, the third data release has started and includes products and scientific results obtained using data collected throughout the entire mission in both temperature and polarisation [6].

In this paper we present how *Planck* 2013 data constrain neutrino physics, as extensively described in the *Planck* cosmological parameter paper [7], and we briefly discuss 2015 updates.

Email address: gianluca.polenta@asdc.asi.it (G. Polenta)

[1] *Planck* (http://www.esa.int/Planck) is a project of the European Space Agency (ESA) with instruments provided by two scientific consortia funded by ESA member states and led by Principal Investigators from France and Italy, telescope reflectors provided through a collaboration between ESA and a scientific consortium led and funded by Denmark, and additional contributions from NASA (USA).

http://dx.doi.org/10.1016/j.nuclphysbps.2015.06.014

2. CMB and neutrinos

In the standard scenario for the thermal history of the Universe, massless neutrinos are in thermal equilibrium with the primeval plasma through weak interactions until the temperature drops below $T_{dec} \approx 1$ Mev [8]. Thus, neutrinos are not reheated by $e^{\pm}$ annihilations favoured when the Universe becomes colder than the electron mass, and resulting in a background of cosmological neutrinos with a present temperature $T_\nu \approx 1.9\,\mathrm{K}$, corresponding to $\sim 0.2\,\mathrm{eV}$ at the last scattering surface. As a consequence, CMB primary anisotropies cannot probe neutrinos with masses below $\sum m_\nu \approx 1$ eV, since they are relativistic at CMB decoupling, and the effect on the background cosmology can be compensated by changes in the Hubble constant H_0. For larger values of the mass, changing $\sum m_\nu$ impacts on matter-radiation ratio and equality, leading to variations in the gravitational potential that are visible at angular scales around the first CMB acoustic peak (early Integrated Sachs-Wolfe effect; ISW). Moreover, neutrino masses also impact the early ISW at perturbation level through neutrino free streaming. It is important to note that increasing $\sum m_\nu$ suppresses clustering, thus reducing the lensing potential affecting CMB photons at small angular scales. Thanks to its angular resolution, *Planck* is sensitive to gravitational lensing, and can therefore overcome the limit of ≈ 1 eV on the sum of neutrino masses.

The number of relativistic species $N_{\rm eff}$ reflects the energy density of neutrinos: $\rho_\nu = N_{\rm eff}\,(7/8)\,(4/11)^{4/3}\,\rho_\gamma$. This parameter actually accounts for the energy density of all relativistic components but photons, i.e. it includes also possible forms of dark radiation. In the standard model with 3 families of neutrinos, detailed calculations provide $N_{\rm eff} = 3.046$ [9]. Increasing $N_{\rm eff}$ increases the expansion rate before recombination, leading to an increase of the diffusion angular scale θ_d that reduces the power in the damping tale of the CMB power spectrum.

3. Results from the *Planck* 2013 data release

3.1. Constraints on $\sum m_\nu$

When constraining the sum of neutrino masses we assume 3 degenerate massive neutrinos. This approximation is accurate enough given the *Planck* sensitivity. As discussed in [10, 7], we combine: *Planck* temperature power spectrum (labelled *Planck*; [10]); *Planck* lensing likelihood derived from lensing 4-point correlation function [11]; WMAP low-ℓ polarisation (labelled WP; [12]); data coming from high-resolution CMB experiments (labelled HighL), namely the Atacama Cosmology Telescope [13] and the South Pole Telescope [14], whose primary role is to improve modelling of unresolved foreground components. Results are shown in Fig. 1. Corresponding 95% upper limits are

$$\sum m_\nu < 0.66\,\mathrm{eV} \quad \textit{Planck}\text{+WP+HighL},$$
$$\sum m_\nu < 0.85\,\mathrm{eV} \quad \textit{Planck}\text{+lensing+WP+HighL},$$

thus confirming that *Planck* entered a new regime thanks to its sensitivity to gravitational lensing. It is interesting to note that adding the *Planck* lensing likelihood weakens the upper limit. In fact, *Planck* tem-

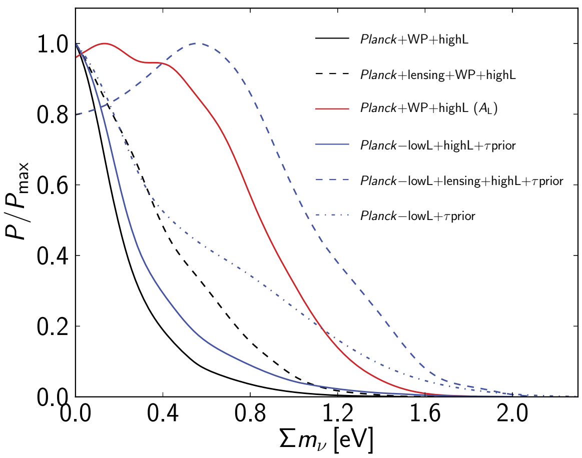

Figure 1: Marginalised posterior distributions of $\sum m_\nu$ for different data combinations (from [7]).

perature power spectrum favours a slightly higher lensing amplitude to add more lensing smoothing than predicted in ΛCDM. Neutrino mass acts in the opposite way, i.e. increasing $\sum m_\nu$ reduces the predicted smoothing even further. On the other hand, lensing likelihood directly probes the lensing power with a mild preference for a lensing amplitude slightly below (but consistent with) ΛCDM predictions. Therefore combining *Planck* temperature power spectrum with lensing likelihood pulls the sum of neutrino masses towards higher values. This is even more evident when we remove low-ℓ data and add a prior for the optical depth τ (labelled -lowL+τprior), which results in a best-fit value away from zero.

Baryon acoustic oscillations (BAO) in the matter power spectrum have proven to be very useful in constraining neutrino masses, because these are basically geometric measurements that are sensitive to the evolution of the angular-diameter distance and the Hubble