Planck constraints on secret neutrino interactions

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Work made in collaboration with M.Lattanzi and P.Natoli

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Summary

- Standard neutrino cosmology
- Non-standard interactions
  - Pseudoscalar interaction
  - Results
  - COrE forecast
- Conclusions

Standard neutrino cosmology

Neutrinos are neutral, weak-interacting particles

Decoupling:

At $\mathrm{T} \sim 1\mathrm{MeV}$ since $\Gamma_w = n_\nu < \sigma_w v >= H$

Their contribution is parametrized into the relativistic energy density:

$$\rho_r = \rho_\gamma + \rho_\nu = \left[1 + \frac{7}{8}\left(\frac{4}{11}\right)^{\frac{4}{3}} N_{eff}\right]\rho_\gamma$$

The standard value for $N_{eff} = 3.046$ [Mangano et al., 2005]

Planck bounds [Planck 2015 XVI] are:

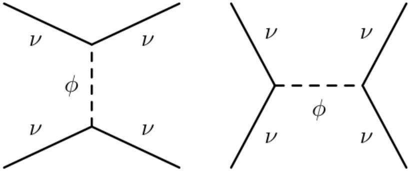
$$N_{eff} = 3.13 \pm 0.32\,(PlanckTT + lowP)$$
$$N_{eff} = 2.99 \pm 0.20\,(PlanckTT, TE, EE + lowP)$$

One extra relativistic degree of freedom is excluded at $3 - 5\sigma$

Non-standard interactions: Pseudoscalar

Two main classes:

- Pseudoscalar interaction
- Fermi like (4 points) interaction



Lagrangian

$$\mathcal{L} = h_{ij}\bar{\nu}_i\nu_j\phi + g_{ij}\bar{\nu}_i\gamma_5\nu_j\phi + h.c.$$

This induces a series of processes mediated by a massless scalar (h_{ij}) or pseudoscalar (g_{ij}) boson.

If νs are relativistic, the cross section has the form:

$$\sigma_{\nu\nu} \sim \frac{g_{ij}^4}{s} \simeq \frac{g_{ij}^4}{T^2}$$

and the scattering rate:

$$\Gamma_{\nu\nu} \sim < \sigma_{\nu\nu} v > n_\nu \simeq g_{ij}^4 T$$

We use an effective parametrization:

$$\Gamma_{eff} = g_{eff}^4 T \qquad (2)$$

Neutrinos recouple at "late" times

Cosmology : [FF, M. Lattanzi, P.Natoli, 2014]

$$g_{eff}^{(mass)} \leq 1.7 \cdot 10^{-7}\, 95\% c.l.$$

Cosmology : [Archidiacono, Hannestad, 2014]

$$g_{ij} \leq 1.2 \cdot 10^{-7}\, 95\% c.l.$$

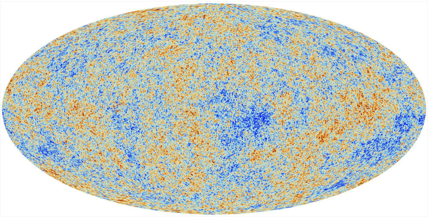
Supernovae: [M. Kachelriess et al., 2000]

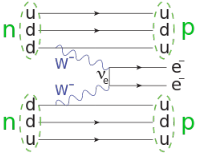
Excluded region (Majoron case):

$$3 \cdot 10^{-7} < g_{ij}^{(flavour)} < 2 \cdot 10^{-5}\ (inside\ medium)$$

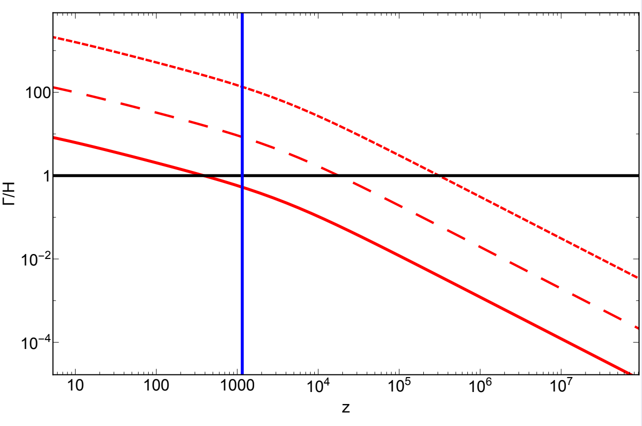
$0\nu 2\beta$ decay: A. Gando et al. 2012 [KamLAND-Zen Collaboration]

$$g^{(flavour)} < (0.8 - 1.6)\, 10^{-5}$$





Behaviour of the interaction rate



- $g_{eff} = 10^{-7}$
- $g_{eff} = 2 \cdot 10^{-7}$
- $g_{eff} = 4 \cdot 10^{-7}$
- Recombination

Parametrization

Relaxation time approximation :

$$\left.\frac{\partial f}{\partial \tau}\right|_{coll} = -\frac{f}{\tau_{coll}} \quad where \quad \tau_{coll} = \frac{1}{\Gamma}$$

Add interaction to fluid hierarchy

$$\dot{\delta} = -\frac{4}{3}\theta - \frac{2}{3}\dot{h},$$

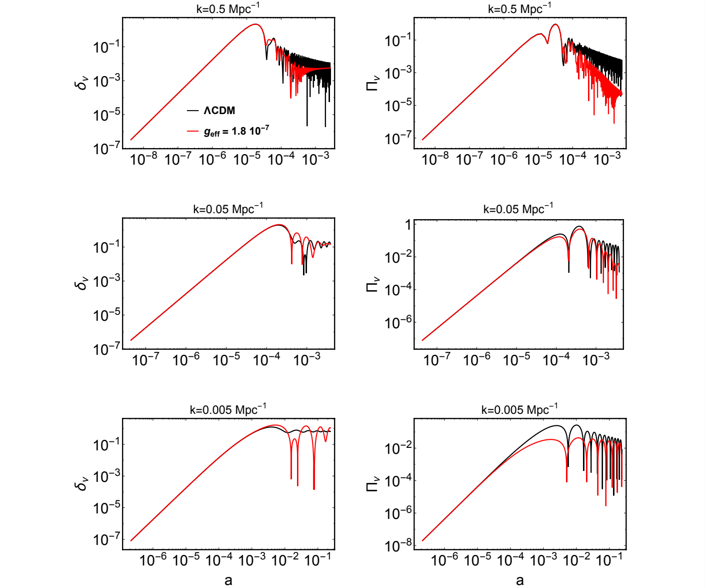
$$\dot{\theta} = k^2\left(\frac{1}{4}\delta - \Pi\right),$$

$$\dot{\Pi} = \frac{4}{15}\theta - \frac{3}{10}kF_3 + \frac{2}{15}\dot{h} + \frac{4}{5}\dot{\eta} - a\Gamma\Pi,$$

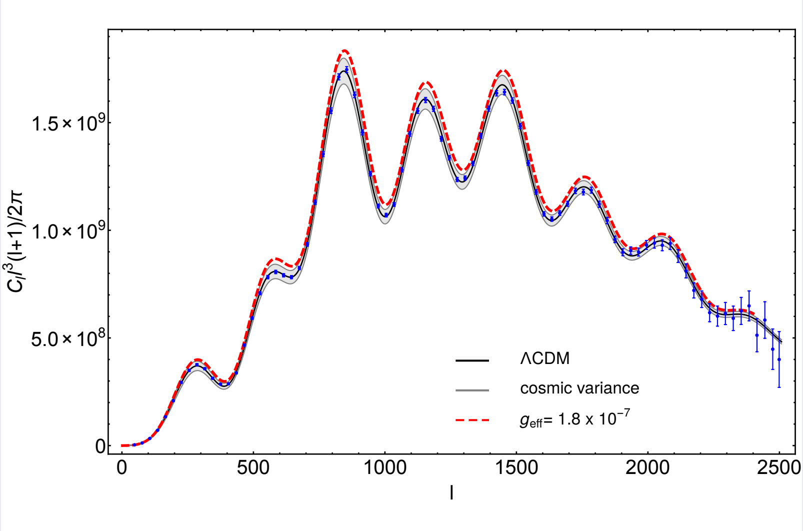
$$\dot{F}_\ell = \frac{k}{2\ell+1}\left[\ell F_{\ell-1} - (\ell+1)F_{\ell+1}\right] - a\Gamma F_\ell \quad (\ell \geq 3).$$

The collisional term reduces the anisotropic stress Π ($l = 2$) and enhances the density perturbation δ ($l = 0$).

Impact on Cosmological perturbations



Impact on Angular Power Spectrum



Dataset

Planck 2015 data

- Third-generation CMB ESA satellite
- Low Frequency Instrument (LFI) observing at 30, 44, 70 GHz
- High Frequency Instrument (HFI) observing at 100, 143, 217, 353, 545 and 857 GHz
- Angular resolution form 30′ to 5′
- $\frac{\Delta T}{T} \sim 2 \cdot 10^{-6}$
- Latest public data release in Feb 2015, a full sky in temperature (PlanckTT) and polarization (PlanckTP)

+

SN

Supernova data from the SDSS-II/SNLS3 Joint Light-curve Analysis

H0

Hubble parameter constraint, $H_0 = 70.6 \pm 3.3$

BAO

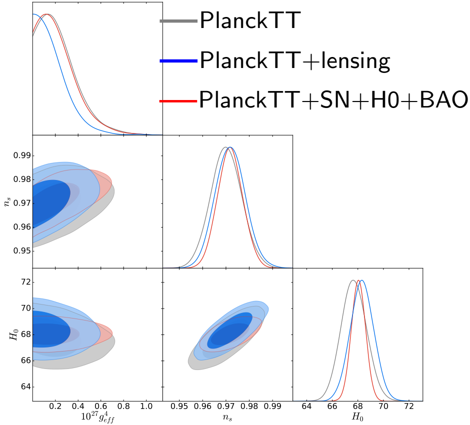
Baryon oscillation data from DR11 LOW, DR11C MASS, MGS and 6DF

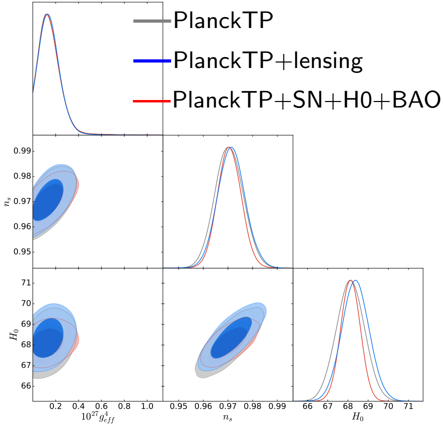
+

Lensing

Planck lensing power spectrum reconstruction

Results [ΛCDM + g_{eff}]





Constraints on g_{eff}:

$g_{eff} \leq 1.54 \cdot 10^{-7}$ (95%cl)

$g_{eff} \leq 1.47 \cdot 10^{-7}$ (95%cl)

$g_{eff} \leq 1.54 \cdot 10^{-7}$ (95%cl)

Constraints on g_{eff}:

$g_{eff} \leq 1.33 \cdot 10^{-7}$ (95%cl)

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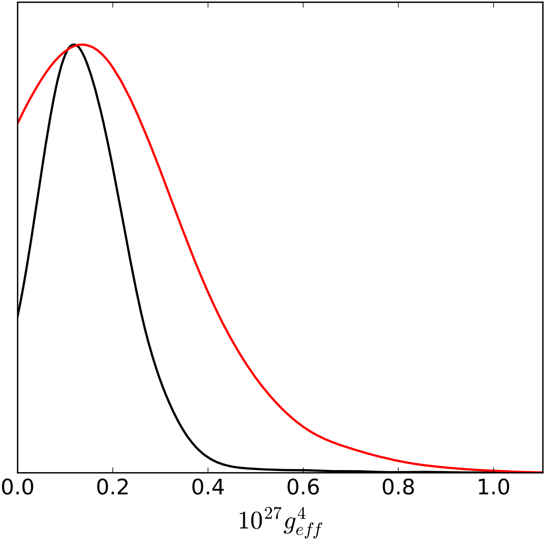
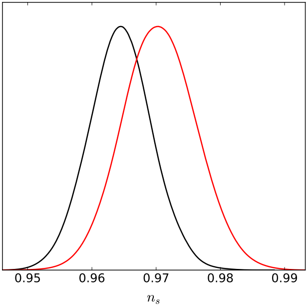
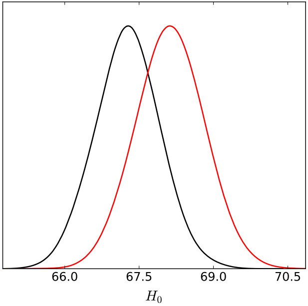
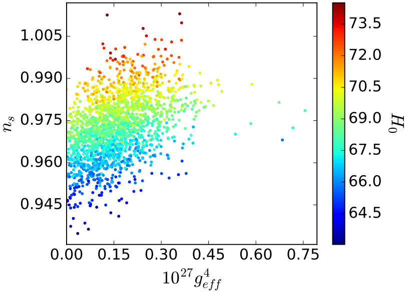
Results [ΛCDM + g_{eff}]



Results, [PlanckTP] focus on n_s and $H0$







— ΛCDM $+g_{eff}$ [PlanckTP]

— ΛCDM [PlanckTP]

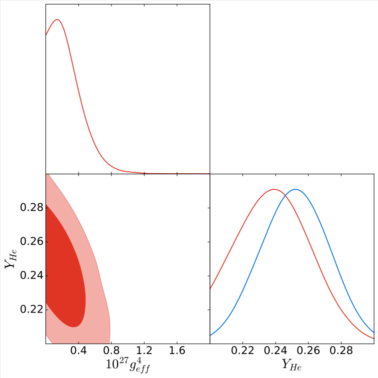
Constraints on n_s:

$n_s = 0.964 \pm 0.005$ [Planck 2015 XVI]

$n_s = 0.973 \pm 0.006$ [ΛCDM+g_{eff}, PlanckTP]

Results, $[\Lambda CDM + g_{eff} + Yhe]$

[PlanckTT]



ΛCDM $+g_{eff}$ + Yhe [PlanckTT]

ΛCDM $+Yhe$ [PlanckTT]

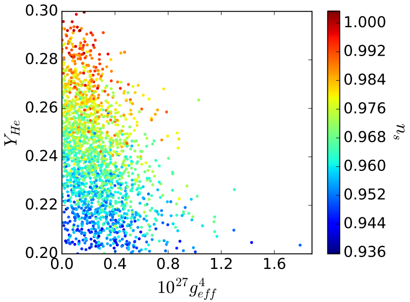
Constraints:

$Yhe = 0.252 \pm 0.023$ [Planck 2105 XVI]

$Yhe = 0.240 \pm 0.021$

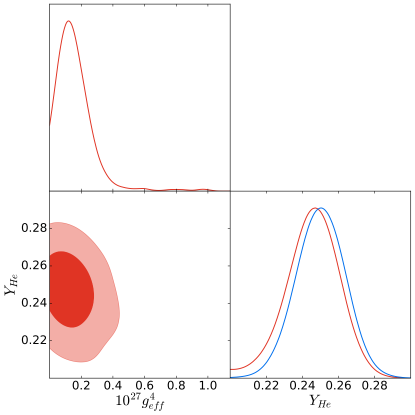
$g_{eff} \leq 1.6 \cdot 10^{-7}$ 95%*cl*.

$n_s = 0.968 \pm 0.011$



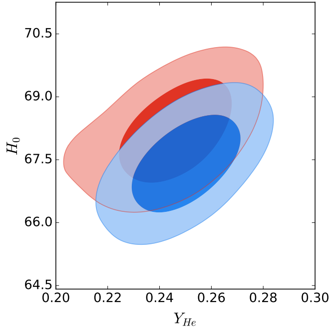
Results, [ΛCDM $+ g_{eff} +$ *Yhe*]

[PlanckTP]



Constraints:

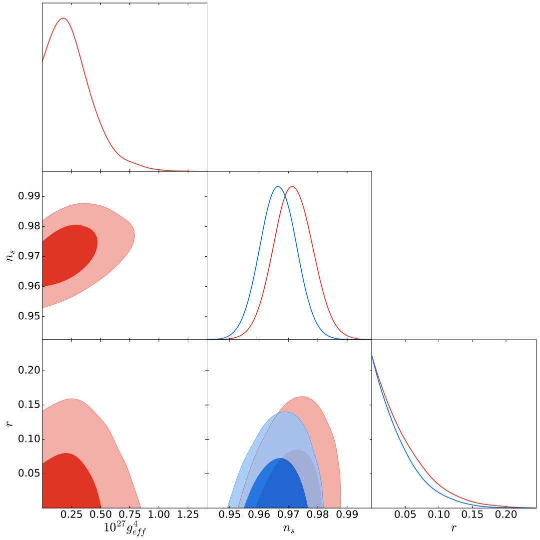
$Yhe = 0.246 \pm 0.015$
$g_{eff} \leq 1.37 \cdot 10^{-7}$ 95 % *c.l.*
$n_s = 0.971 \pm 0.009$

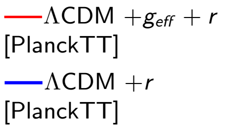


— ΛCDM $+ g_{eff} +$ *Yhe* [PlanckTP]
— ΛCDM $+$ *Yhe* [PlanckTP]

Results, $[\Lambda\text{CDM} + g_{eff} + r]$

[PlanckTT]



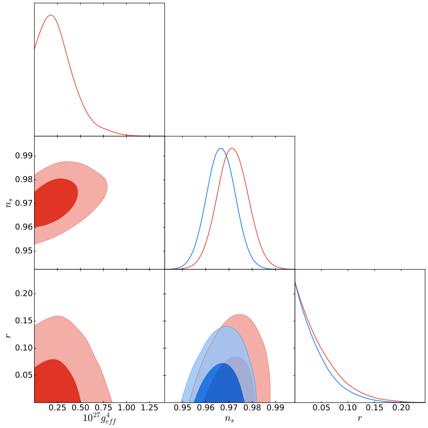


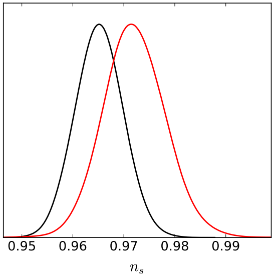
Constraints:

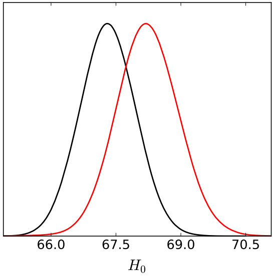
$r_{0.002} = 0.1$ 95% *c.l.*
$r_{0.002} = 0.13$ 95% *c.l.*
$g_{eff} \leq 1.58 \cdot 10^{-7}$ 95 % *c.l.*
$n_s = 0.972 \pm 0.007$

Results, $[\Lambda CDM + g_{eff} + r]$

[PlanckTP]



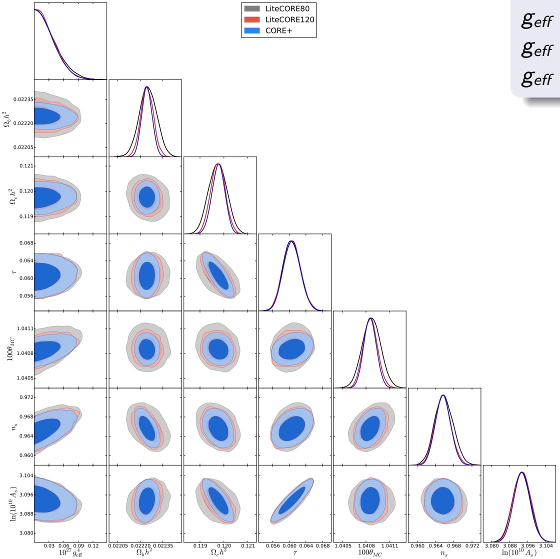




Constraints:

$r_{0.002} = 0.12$ 95% *c.l.*
$g_{eff} \leq 1.4 \cdot 10^{-7}$ 95 % *c.l.*
$n_s = 0.972 \pm 0.007$

$[\Lambda\text{CDM} + g_{eff}]$, COrE



Constraints:

$g_{eff} \leq 9.4 \cdot 10^{-8}$ 95%*cl*. [*LiteCOrE* 80]
$g_{eff} \leq 9.2 \cdot 10^{-8}$ 95%*cl*. [*LiteCOrE* 120]
$g_{eff} \leq 9.2 \cdot 10^{-8}$ 95%*cl*. [*COrE*+]

Channel [GHz]	FWMH [arcmin]	ΔT [μK arcmin]	ΔP [μK arcmin]
LiteCORE-80, $l_{\rm max} = 2400$, $f_{\rm sky} = 0.7$			
80	20.2	8.8	12.5
90	17.8	7.1	10.0
100	15.8	8.5	12.0
120	13.2	6.7	9.5
140	11.2	5.3	7.5
166	8.5	5.0	7.0
195	8.1	3.6	5.0
LiteCORE-120, $l_{\rm max} = 3000$, $f_{\rm sky} = 0.7$			
80	13.5	8.8	12.5
90	11.9	7.1	10.0
100	10.5	8.5	12.0
120	8.8	6.7	9.5
140	7.4	5.3	7.5
166	6.3	5.0	7.0
195	5.4	3.6	5.0
CORE+, $l_{\rm max} = 3000$, $f_{\rm sky} = 0.7$			
100	8.4	6.0	8.5
115	7.3	5.0	7.0
130	6.5	4.2	5.9
145	5.8	3.6	5.0
160	5.3	3.8	5.4
175	4.8	3.8	5.3
195	4.3	3.8	5.3
220	3.8	5.8	8.1

Conclusions

- All models studied are consistent with no interaction (free-streaming neutrinos)
- The goodness of fit for all considered models is comparable with the ΛCDM ones
- The effective strength of non-standard interactions is constrained at 95% c.l. $g_{eff} \leq 1.5 \cdot 10^{-7}$ for [PlanckTT]
- Polarization data seem to prefer a non zero value for g_{eff} peaked at $g_{eff} = 1.2 \cdot 10^{-7}$

  Considering a specific model in which the pseudoscalar boson is a Nambu-Goldstone boson, the Majoron, the constraint becomes:

$$g \leq 4.74 \cdot 10^{-7}\, 95\%\, c.l.\, [PlanckTT]$$

$$g = 3.8 \cdot 10^{-7}\, best\ fit\, [PlanckTP]$$

- Using polarization data, all models seems to prefer higher values of n_s and $H0$.
- Future generation experiments like COrE will improve the constraints on g_{eff} going below 10^{-7}