SENSITIVITY OF COSMOLOGICAL DATA TO THE NEUTRINO MASS HIERARCHY

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based on Gerbino,Lattanzi,Mena,Freese,2017
What we know, from the outside

How do they behave?

Neutrinos oscillate, so they are massive

\[ 0.06 \text{ eV} < \sum m_\nu < 6 \text{ eV} \]
Massive neutrinos alter background and perturbation evolution

$\Sigma m_\nu = 0.06$ eV
$\Sigma m_\nu = 0.2$ eV
$\Sigma m_\nu = 0.4$ eV
$\Sigma m_\nu = 0.6$ eV
$\Sigma m_\nu = 0.8$ eV

Abazaijan+, 2015

WMAP9 data

Linear regime ends roughly here

3 active families, sub-eV masses
Relativistic at early times, non-relativistic today

(Almost) peculiar effects on cosmological observables

See M. Lattanzi & A. van Engelen’s talks

Martina Gerbino, TeVPA - Cosmology track, 9Aug2017
Joint constraints on Mnu – future

\[ \sum m_{\nu}, \text{(eV)} \]

\[ m_{\text{lightest}}, \text{(eV)} \]

- CMB-S4 + DESI BAO
- Inverted Hierarchy
- DUNE
- Normal Hierarchy

~3sigma detection

in the minimal mass scenario with S4 surveys
• Will we be able to discriminate the hierarchy?
• Can we provide a statistically robust answer?
The proposed method

Bayesian MCMC, Mnu + other cosmo params + h

Discrete Hyper-parameter h

h=NH

NORMAL HIERARCHY

\[ m_{\nu,1} = m_{\text{light}} \]

\[ m_{\nu,2} = \sqrt{m_1^2 + \Delta m_{12}^2} \]

\[ m_{\nu,3} = \sqrt{m_1^2 + \Delta m_{13}^2} \]

h=IH

INVERTED HIERARCHY

\[ m_{\nu,3} = m_{\text{light}} \]

\[ m_{\nu,1} = \sqrt{m_3^2 + \Delta m_{13}^2} \]

\[ m_{\nu,2} = \sqrt{m_1^2 + \Delta m_{12}^2} \]

Advantages:

- neutrinos modelled with exact mass spectrum
- information from oscillations taken into account
- quantifies sensitivity to the hierarchy
- takes into account uncertainties related to the hierarchy

Gerbino, Lattanzi, Mena, Freese 2017
Sensitivity to the hierarchy

\[ \mathcal{P}(h = NH) : \mathcal{P}(h = IH) \]

\[ \text{CURRENT LIMITS} \]

\[ M_\nu \text{ [eV]} \]

\[ \frac{P}{P_{\text{max}}} \]

\[ 0.06 \text{eV mass} \rightarrow 9:1 \]

\[ 0.1 \text{eV mass} \rightarrow 1:1 \]

\[ \text{FORECASTS} \]

\[ M_\nu \text{ [eV]} \]

\[ \frac{P}{P_{\text{max}}} \]

See also Hannestad & Schwetz 2016, Couchot et al 2017, Capozzi et al 2017
Sensitivity to the hierarchy

Fixed fiducial
As sigma increases, NH is as likely as IH

Fixed sigma
NH favoured for $M_{\nu} < 0.1\,\text{eV}$,
IH favoured for $M_{\nu} \sim 0.1\,\text{eV}$,
no preference for $M_{\nu} > 0.1\,\text{eV}$
CONCLUSIONS

• Tight bounds on neutrino mass from cosmology
• Inverted hierarchy in trouble: how much?
• By introducing an hyper-parameter we can: 1) easily account for exact neutrino mass spectra; 2) quantify sensitivity to the hierarchy; 3) take into account uncertainty due to imperfect knowledge of the hierarchy
• NH favoured 5:3 by current data
• NH favoured 10:1 by future measurements, if the mass is minimal
• Sensitivity driven by prior choice
BACK-UP
The standard method

\[ M_{\nu} \]

(+other cosmological parameters)

Degenerate spectrum:

\[ m_{\nu,i} = \frac{M_{\nu}}{3}, \ i = 1, 2, 3 \]

Different authors obtain upper bounds from current data approaching the “critical” value of 0.1 eV. These results suggest that IH starts to get under pressure from cosmology.

[...] Such a claim should be based on a proper statistical analysis. The question to be answered is, whether the hypothesis of IH can be rejected with some confidence against NH.

(Hannestad&Schwetz,2016)
Joint constraints on $M_{\nu}$ - present

$M_{\nu} \equiv \sum_i m_{\nu,i}$

Planck TT+lowP+BAO: $M_{\nu}<0.2\text{eV}$
Planck TT+lowP+Pk: $M_{\nu}<0.3\text{eV}$
Planck TT+lowP+BAO+Pk: $M_{\nu}<0.25\text{eV}$

Compilation of CMB and LSS data 95% CL

major improvement with a better measurement of the optical depth and/or use of CMB small scale polarisation: wait for Planck legacy release!

Take home message: tight, yet robust bounds
Sensitivity to the hierarchy

Physical effects due to different distribution of the sum of the masses for the 2 hierarchies

Total nu energy density

Matter power spectrum

Are current (and future) data sensitive to these effects? How much?
Sensitivity to the hierarchy

If $M_{\nu}=0.1\text{eV}$, $\sigma(m_{bb})\sim 10\text{meV}$ could guarantee $0n2b$ measurement.

$0n2b$ could in turn help unravel the hierarchy (wip, extending the results in Gerbino+2015 in the hierarchical bayesian context)