CMB S4

2024 Advances in Neutrino Physics Driven by Cosmological Data

CMB-S4 Summer Collaboration meeting

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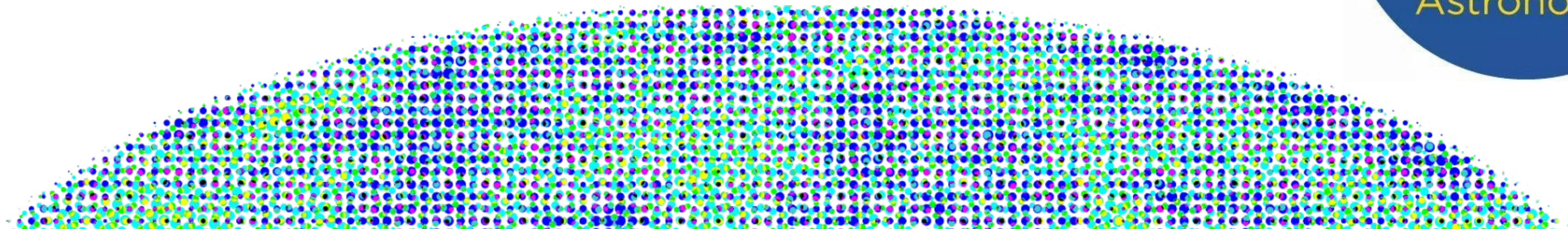


Cosmological observations and Neutrino physics

- CMB-S4 impact on our understanding of the Universe:
    - Inflation.
    - Neutrino physics

1.- Sum of the neutrino masses

2.- Effective number of light relativistic particles

3.- Beyond Standard Model Scenarios

What is the value of the neutrino mass?

IMAGE CREDIT: https://phys.org/news/2018-06-katrin-neutrino-mass.html

- KATRIN upper limit on effective electron anti-neutrino mass 0.8 eV

  (doi: 10.1038/s41567-021-01463-1)

- Cosmology can constrain neutrino mass > 20 times better today already!* arxiv 2404.03002

$$\Lambda\mathrm{CDM}+\sum m_\nu$$

$$\mathrm{DESI+CMB}$$

$$\sum m_\nu < 0.072\,\mathrm{eV} \quad [95\%\ \mathrm{CL}]$$

*model dependent

Sum of the neutrino masses and Cosmology

- DESI+CMB-S4 sensitivity 2-3 **σ** to the minimal neutrino mass (arxiv: 1610.02743) (58 meV from oscillation experiments, i.e.: Super-Kamiokande, SNO, KamLAND).

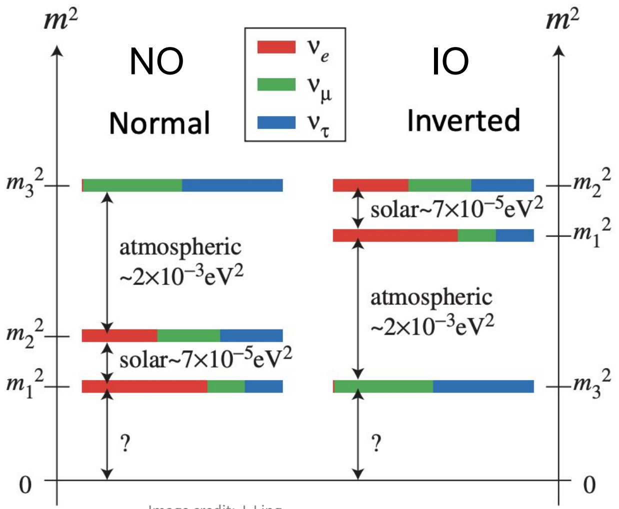


Image credit: J. Ling

- We found employing most robust data sets, statistical validations, theory accuracy :

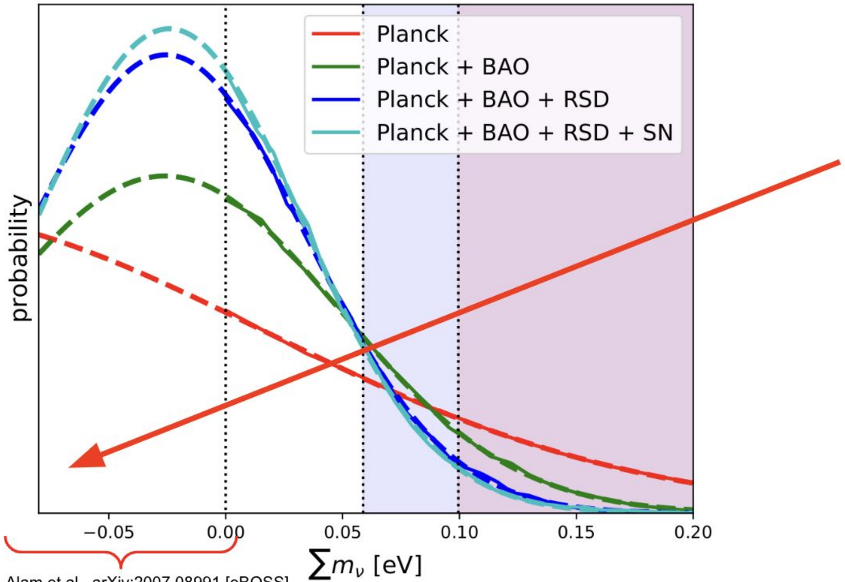
P18+DESI(BAO)	σ
Preference $\sum m_\nu = 0$ over NO	1.54
Preference NO over IO	1.86

H.Garcia Escudero and K. Abazajian 2024 (in prep)

- We are already approaching it today!

CMB-S4 expected to be sensitive to $\sum m_\nu$ in the minimal mass scenario.

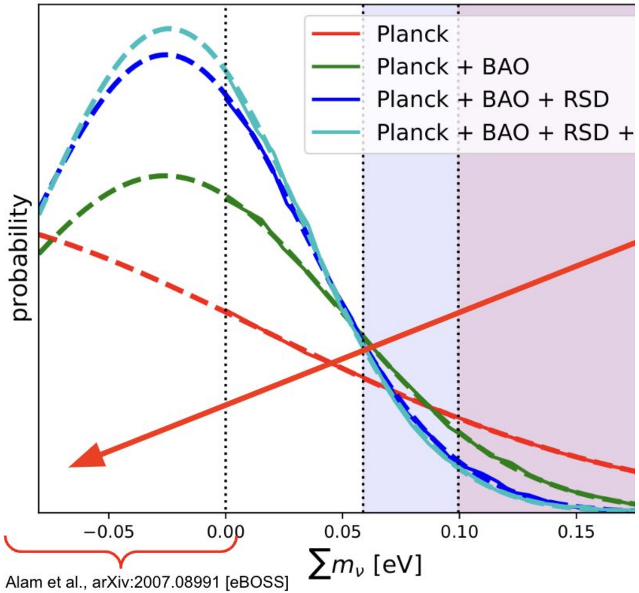
Negative neutrino mass anomaly



Alam et al., arXiv:2007.08991 [eBOSS]

Where is the stringency from Planck 2018 coming from?

Negative neutrino mass anomaly



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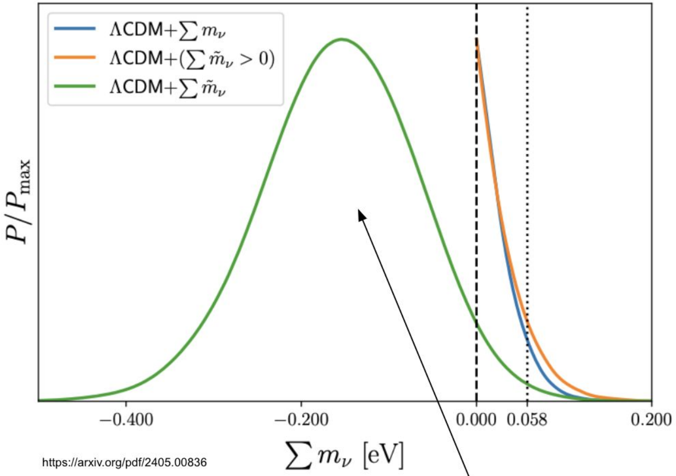
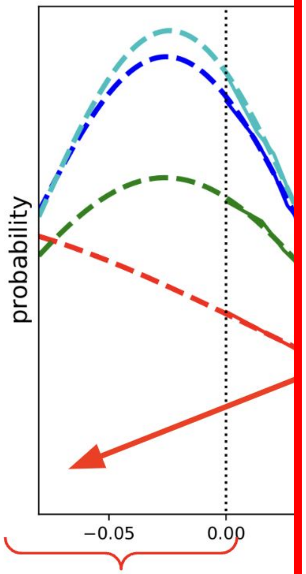


https://arxiv.org/pdf/2405.00836

$$\sum m_\nu = -160 \pm 90 \text{ meV} \ (68\%)$$

Posterior of $\sum m_\nu$ (eV) inferred from Planck + ACT Lensing + DESI

Negative neutrino mass anomaly



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- Possible origin of “negative” neutrino mass bounds:
  -CMB lensing arxiV: 2407.07878
  -CMB polarization determination of τ
  - z = 0.7 BAO systematics. arxiV: 2404.03002
- Unphysical negative masses weak tension at <~ 2σ but worth exploring.
- Future CMB-S4 data study this discrepancy.

or of $\sum m_\nu$
erred from
+ ACT
g + DESI

68%)

Effective Number of Neutrino Species, N_{eff}

- Total cosmological number density of neutrinos

$$n_\nu = N_{\rm eff} \left(\frac{3}{4}\right)\left(\frac{4}{11}\right) n_\gamma,$$

- $N_{eff} = 3$ ⇨ neutrinos instantaneously decoupled from the primordial plasma.

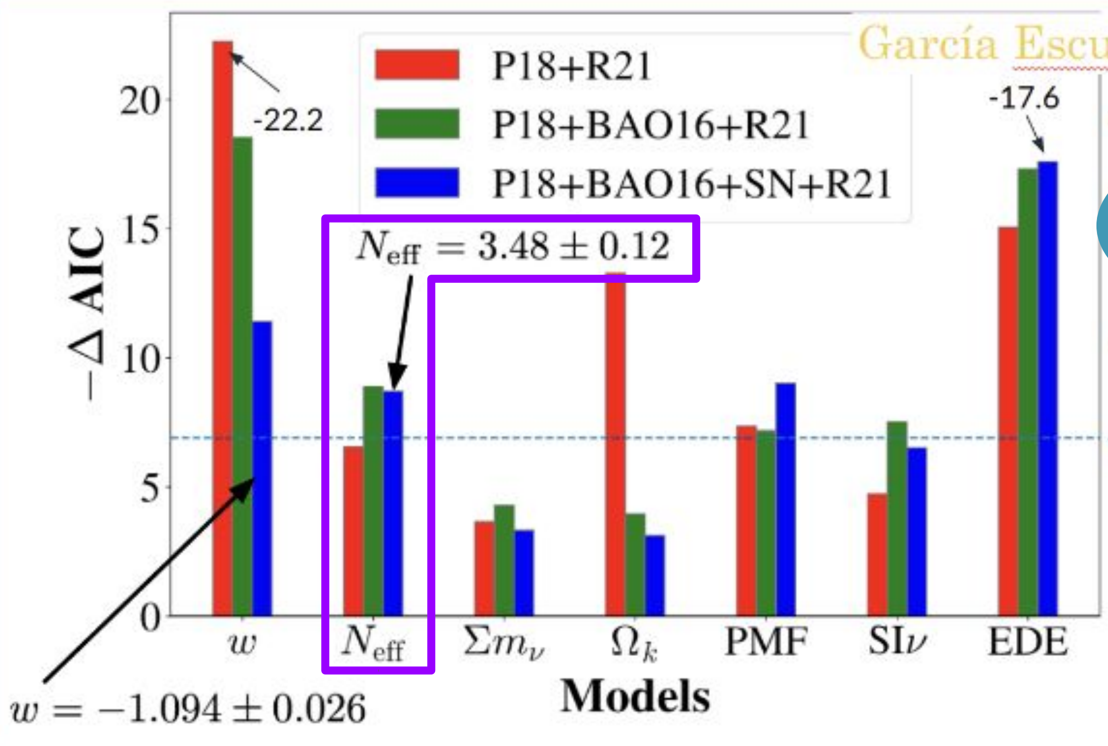
- Neutrino properties early universe → $N_{eff} = 3.044$ arxiv 2005.07047

  CMB-S4 observation with 2-3 **σ** sensitivity on N_{eff} can find:

N_{eff} consistent with 3.044 →

- Confirmation of standard cosmology arxiV 1807.06209
- Precise understanding thermal conditions universe.

N_{eff} significantly different from 3.044 = signature of new physics!



arxiv 2208.14435

- All n
  EDE, wCDM, PMF
  , and N_{eff}
- Only P18, wCDM

-6.91 (Strong threshold)

Explore alleviation cosmological tensions

N_{eff} is a preferred model comparable with other exiting candidates

Short baseline anomalies and Sterile neutrinos

- N_{eff} higher than 3.044 = new physics =?? hidden neutrino sector!

- Short baseline neutrino oscillations results (Super-Kamiokande, LSND, MiniBooNE) and Gallium anomaly (i,e.: SAGE, GALLEX, BEST), hint richer neutrino sector.

- More than 3 active neutrinos with one (or more) sterile flavors.

Preliminary results:

- We find >2σ preference eV sterile model compared to ΛCDM using Planck CMB +BAO (DESI).

H.Garcia Escudero and K. Abazajian 2024 (in prep)

Conclusions and upcoming future

- Cosmological observations are a **very powerful tool** for high precision determination neutrino cosmological parameters.

- Combined cosmological probes (CMB-S4 + BAO) **revolutionize understanding** of **neutrino physics**:

  1.- Test standard cosmological model predictions.
  2.- Shred light to existing cosmological anomalies.
  3.- Test new physics.

- Upcoming observational results next decade critical understanding Universe!

Thank you for attention!
Questions?

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Backup slides

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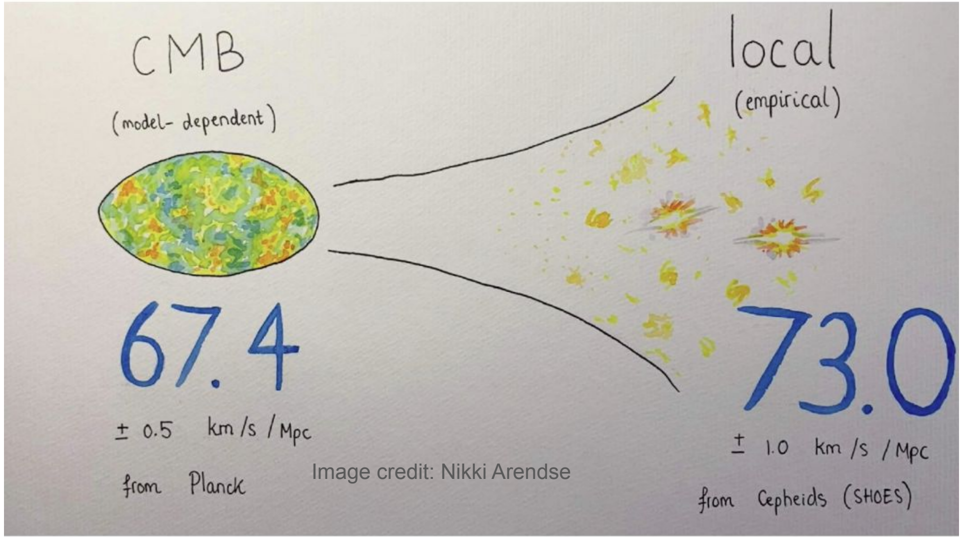
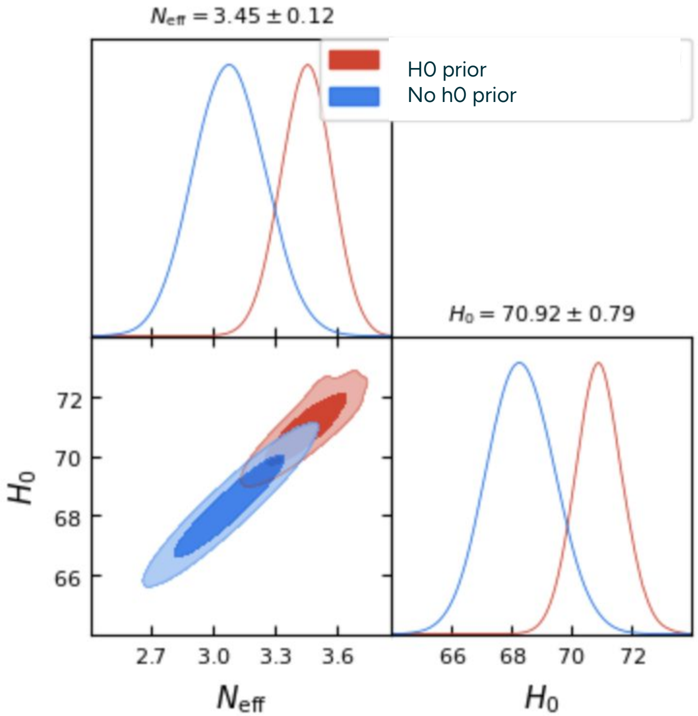
N_{eff} significantly different from 3.044 = signature of new physics!



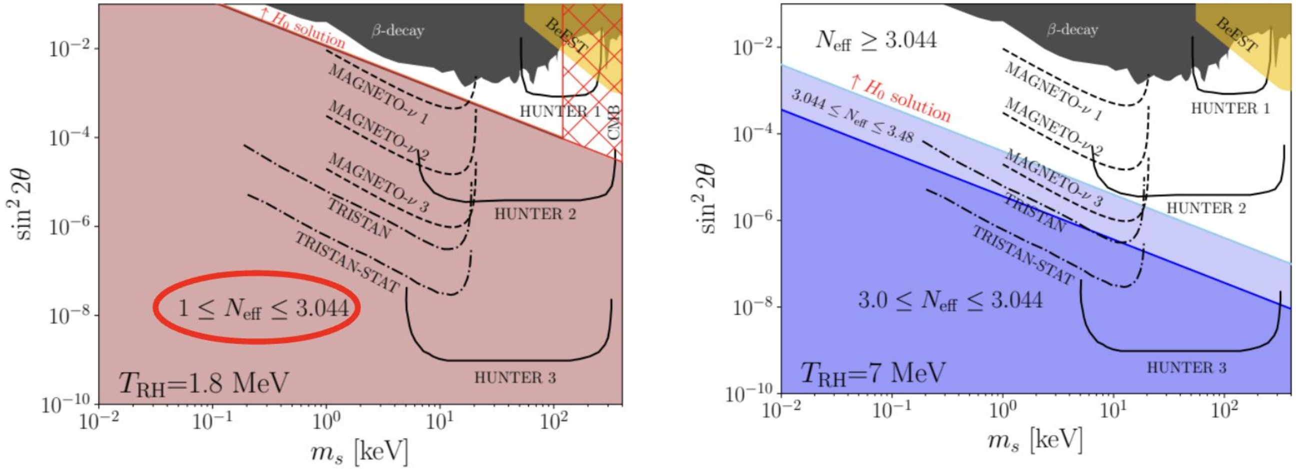


- Explore alleviation cosmological tensions

arxiv: 2107.10291

Negative neutrino mass anomaly

LRT Universes might also be driving a < neutrino masses



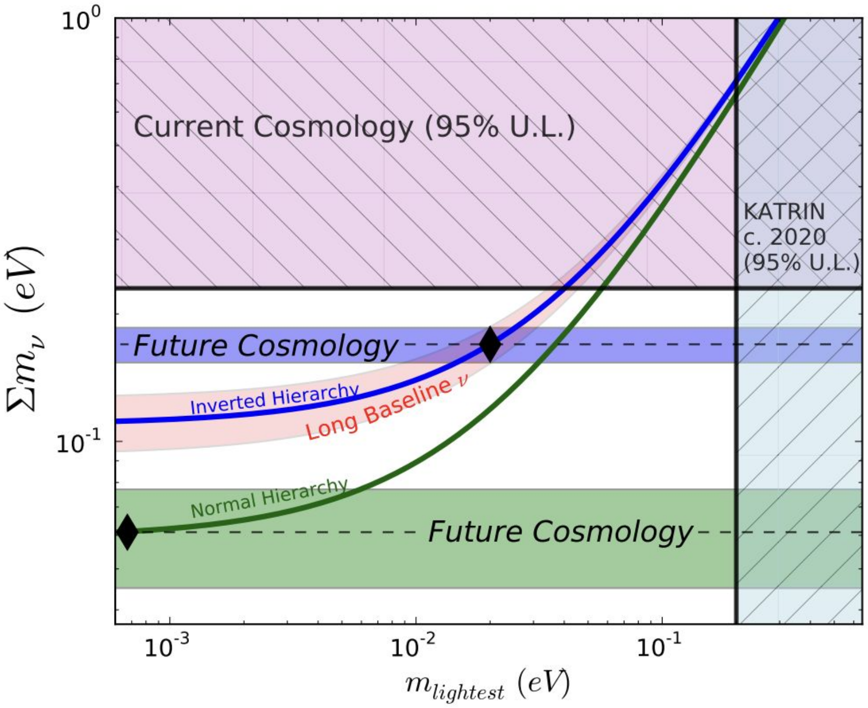
-LRT universes + new neutrino physics ➡ broad new observationally-consistent & novel cosmologies!

-DR can be a combination of thermal + non thermal radiation ➡ novel CMB signature!

-↑ N_{eff} ➡ alleviation of the H_0 tension!

https://arxiv.org/pdf/2309.11492.pdf

Conclusions and upcoming future



Combined probes CMB-S4 experiment + BAO precision neutrino cosmological parameters (within LCDM):

$$\sigma\left(\sum m_\nu\right) = 16 \text{ meV},$$
$$\sigma\left(N_{\text{eff}}\right) = 0.020,$$

arxiv 1309.5383