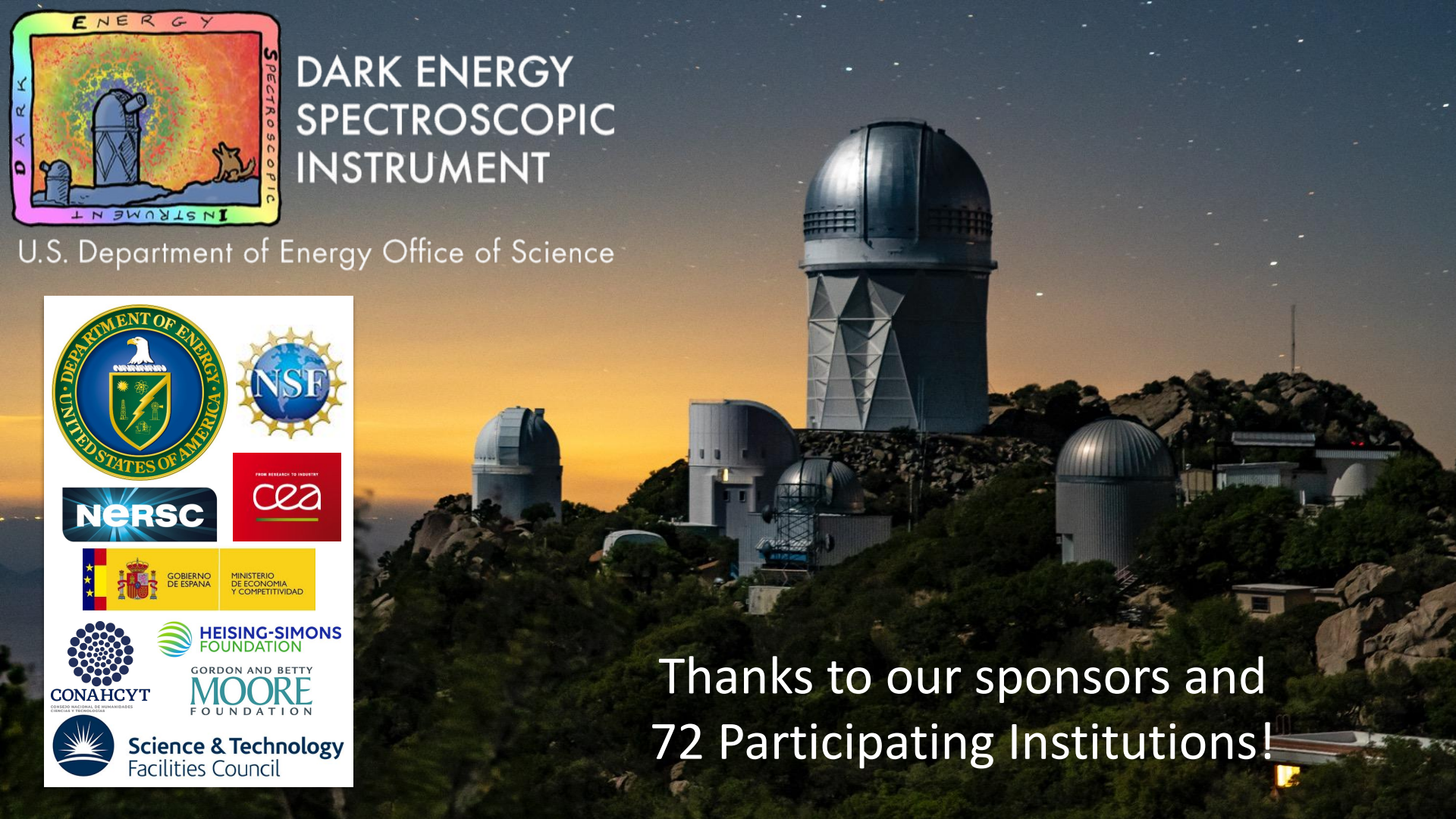
First neutrino results from the Dark Energy Spectroscopic Instrument (DESI)

On behalf of the DESI Collaboration

Willem Elbers
Institute for Computational Cosmology, Durham University
20 June 2024

Neutrino 2024


DARK ENERGY SPECTROSCOPIC INSTRUMENT
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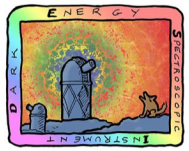

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Complementary measurements

Cosmology and experiments measure neutrino properties in complementary ways.

Number of neutrino species:

$$N_\nu = 2.9963 \pm 0.0074$$

$$N_{\rm eff} = 2.98 \pm 0.20 \quad (\rm CMB)$$

Sum of neutrino masses:

$$\sum m_\nu > \begin{cases} 0.058\,\rm eV & (\rm NO) \\ 0.10\,\rm eV & (\rm IO) \end{cases}$$

$$\sum m_\nu < 0.21\,\rm eV \quad (\rm CMB)$$

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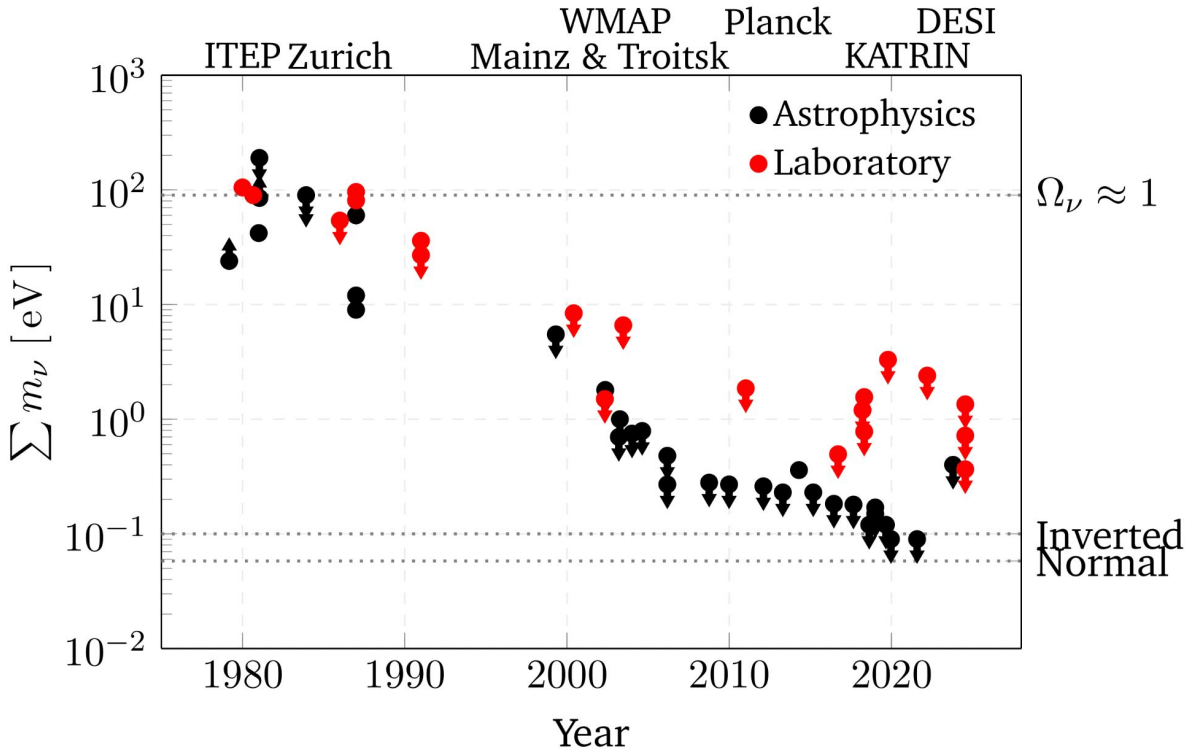
Progress on neutrino masses



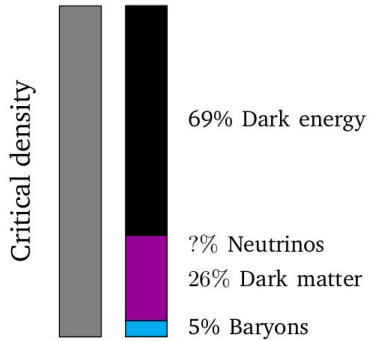
The distance-redshift relation

The distance-redshift relation depends on the energy density of various matter components, including massive neutrinos:

$$D_{\mathrm{M}}(z) = \frac{c}{H_0} \int_0^z \mathrm{d}z' \frac{H_0}{H(z')},$$

$$\frac{H(z)^2}{H_0^2} = \Omega_{\mathrm{r}}(1+z)^4 + \Omega_{\mathrm{m}}(1+z)^3 + \Omega_\Lambda + \Omega_\nu(z).$$

Radiation Matter Dark energy Neutrinos



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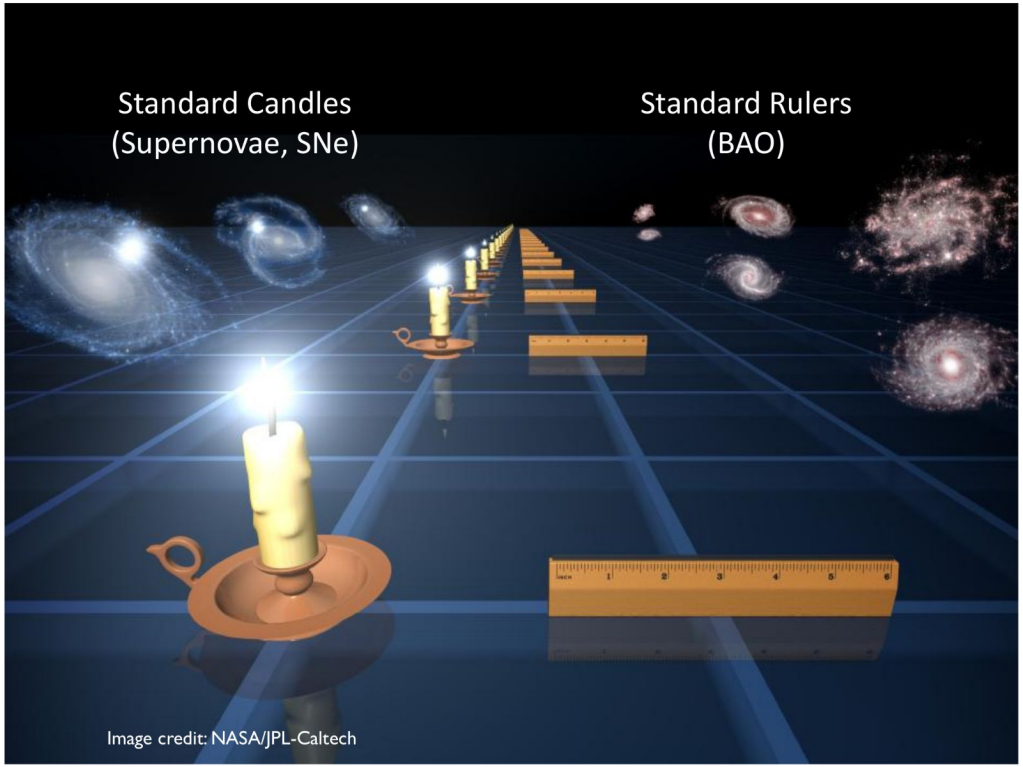
The distance-redshift relation



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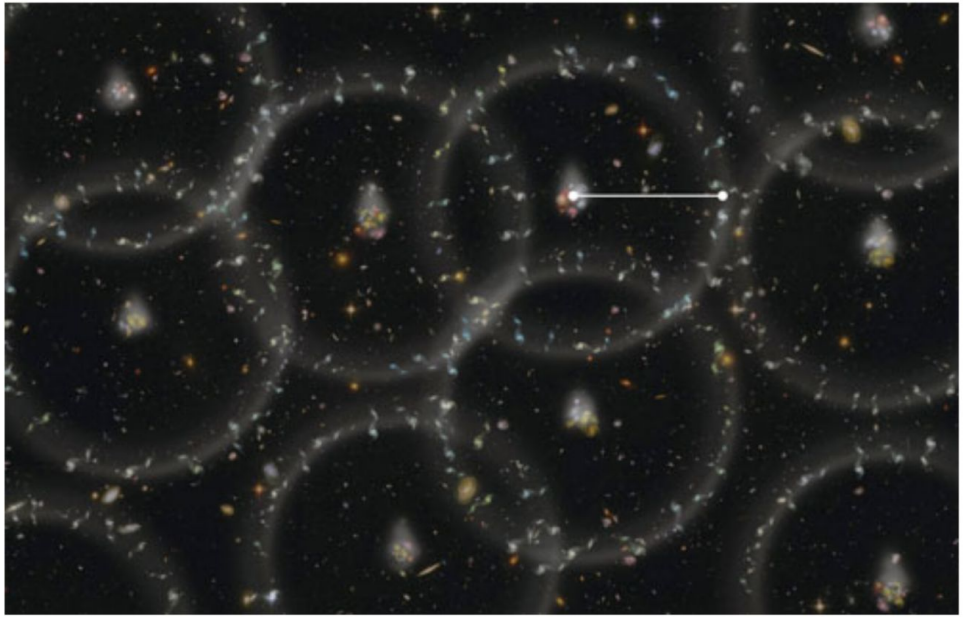
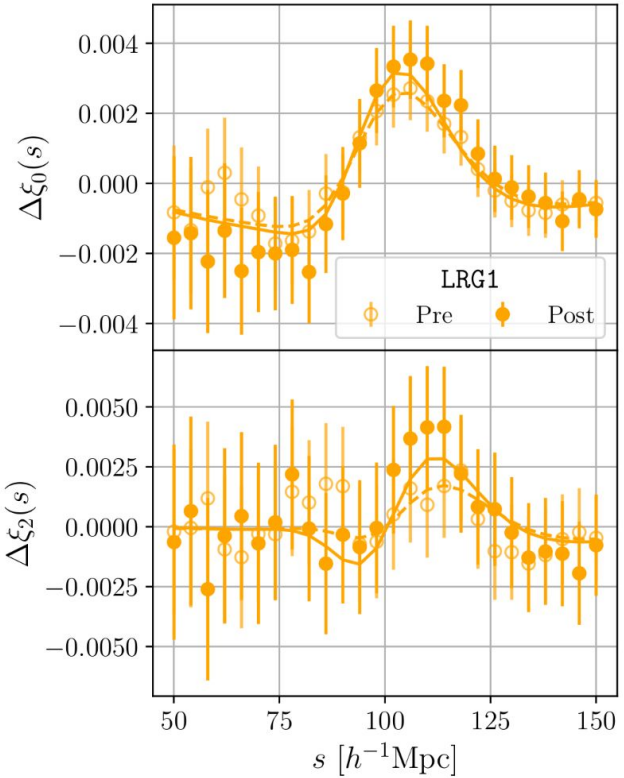
Baryon Acoustic Oscillations (BAO)





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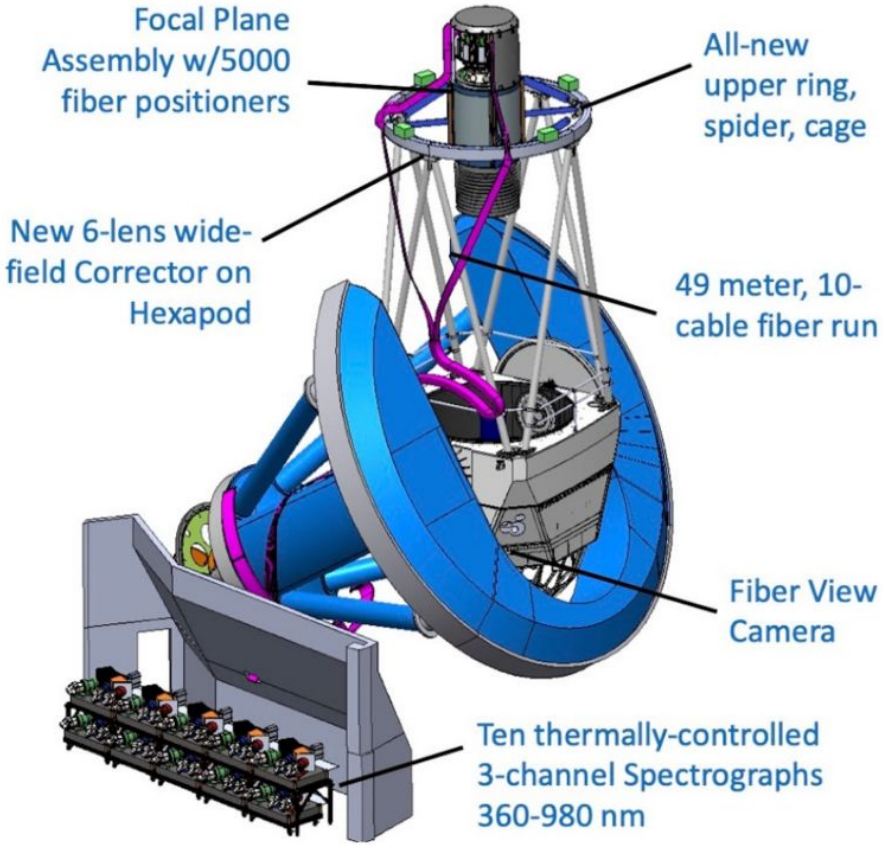
The Dark Energy Spectroscopic Instrument

DESI is a fiber-fed multi-object spectrograph, installed on the Mayall 4-meter telescope.

It uses 5000 robotic arms to position fibers on the focal plane.

The fibers are fed to ten 3-channel spectrographs.



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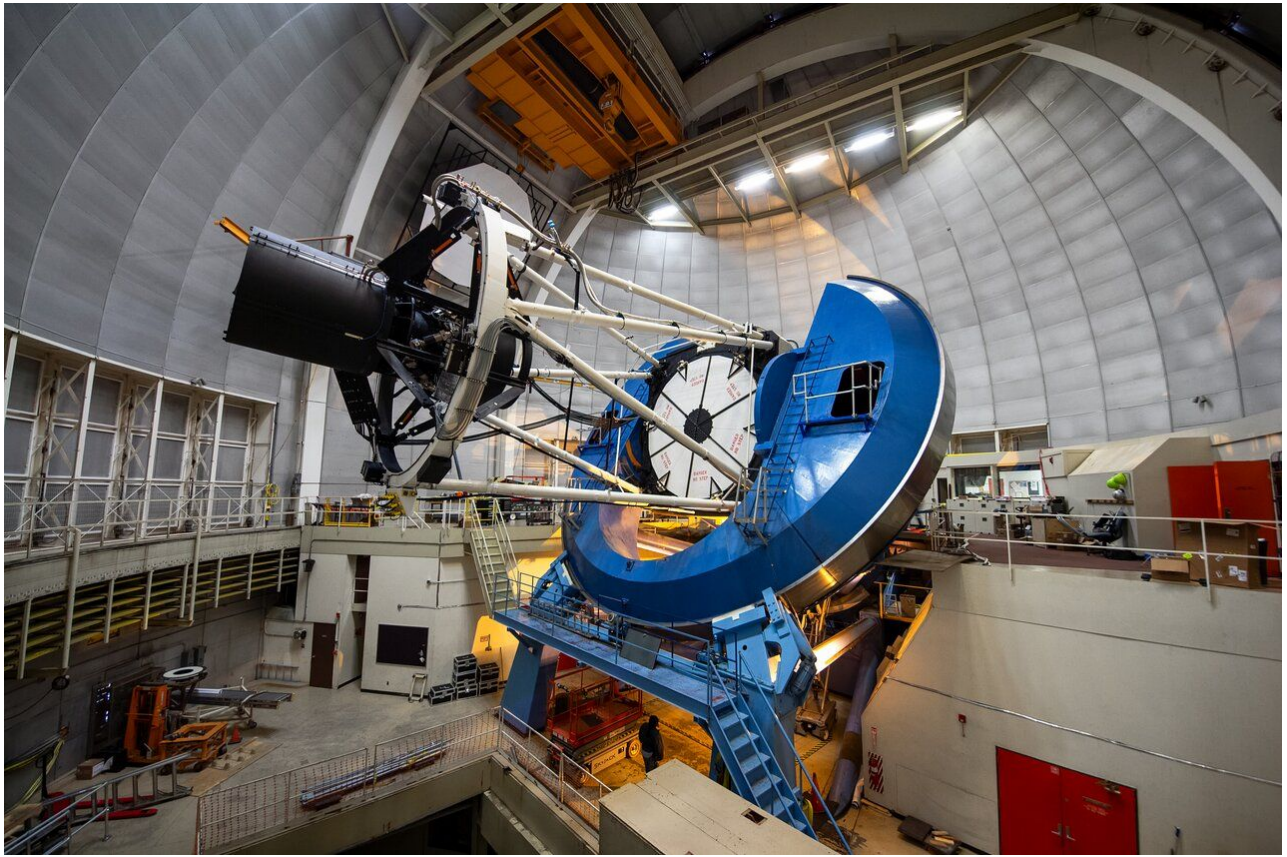
The Dark Energy Spectroscopic Instrument



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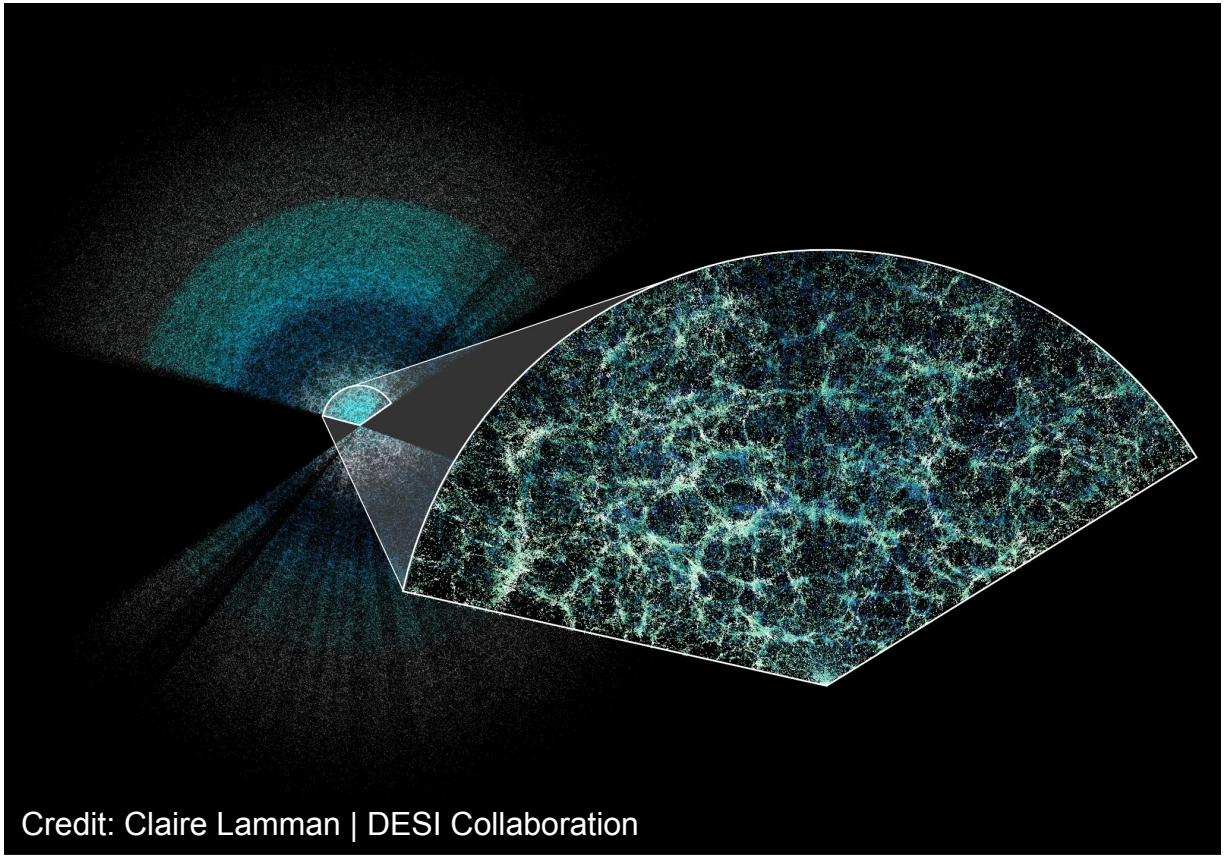
Creating a 3D map of the Universe



Credit: Claire Lamman | DESI Collaboration

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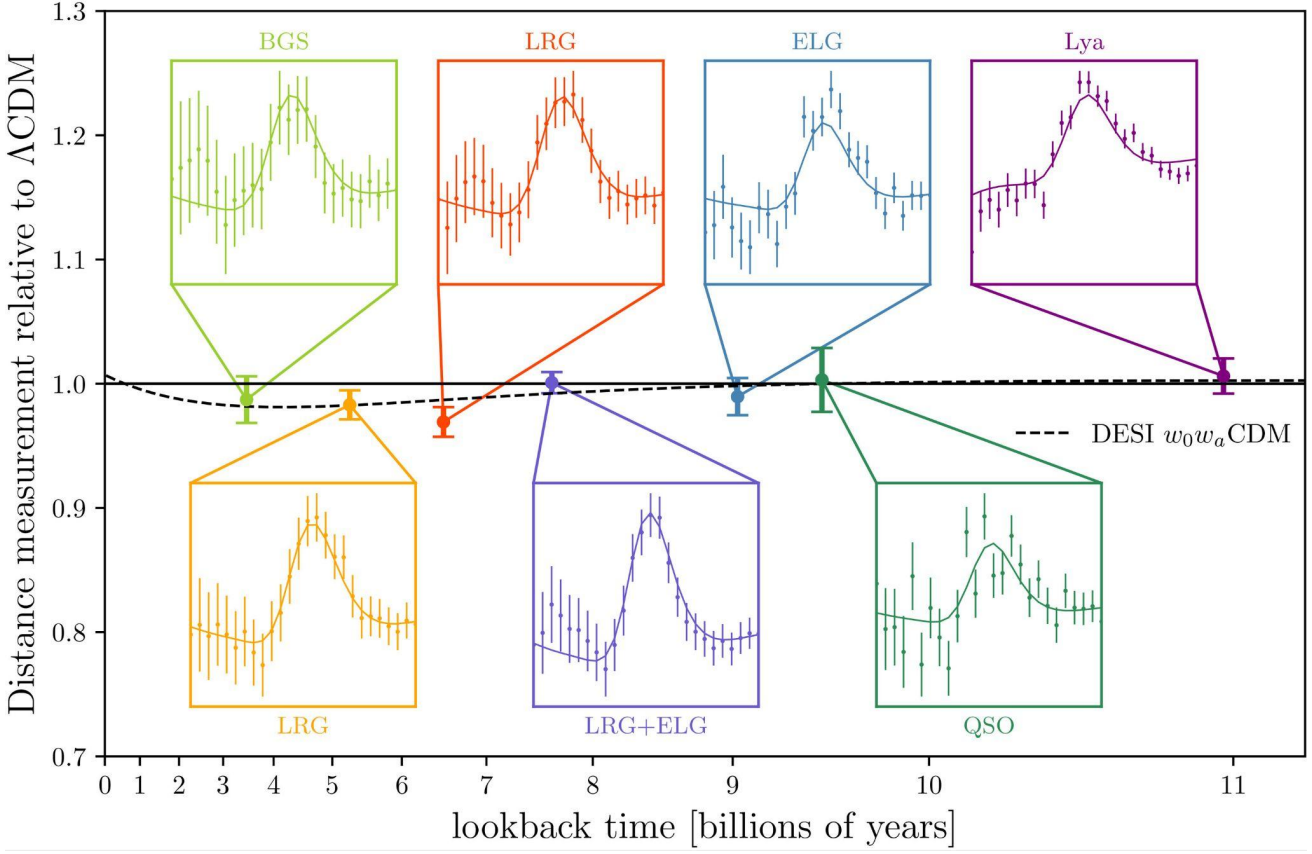
BAO measurements



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DESI BAO and Dark Energy

Dark energy has a negative pressure:

$$P = w\rho$$

Simplest case:

$$w = -1$$

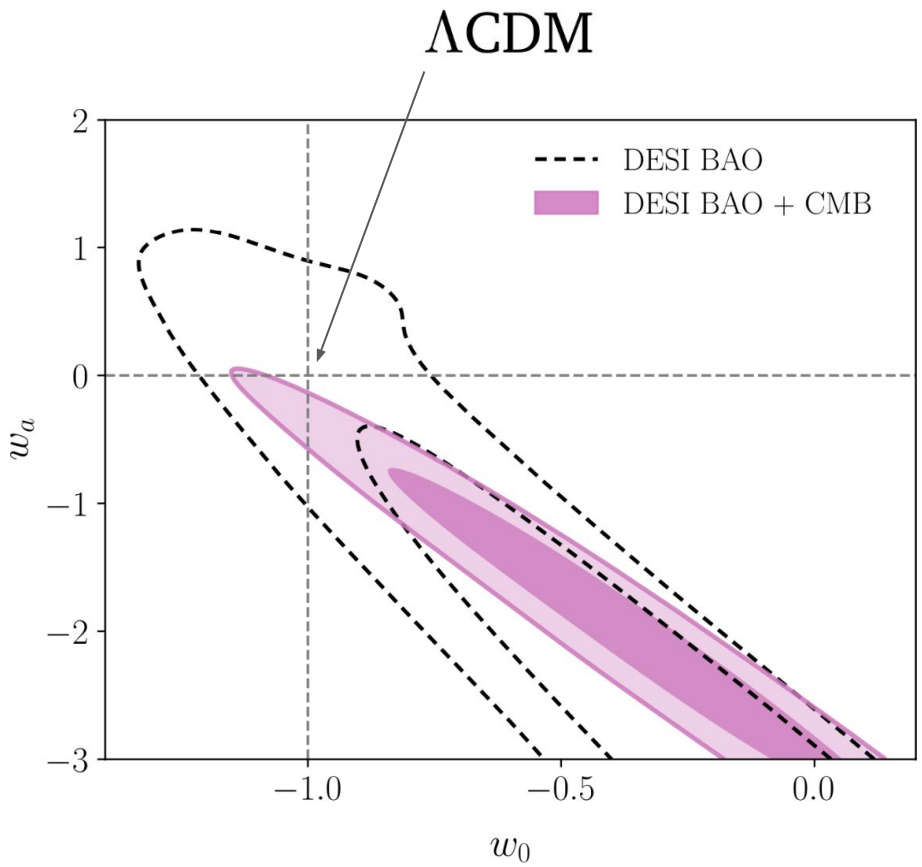
Introducing a time-varying equation of state:

$$w(a) = w_0 + w_a(1 - a)$$

Preference over ΛCDM:

DESI alone: 1.5σ

DESI + CMB: 2.6σ



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Simplest case:

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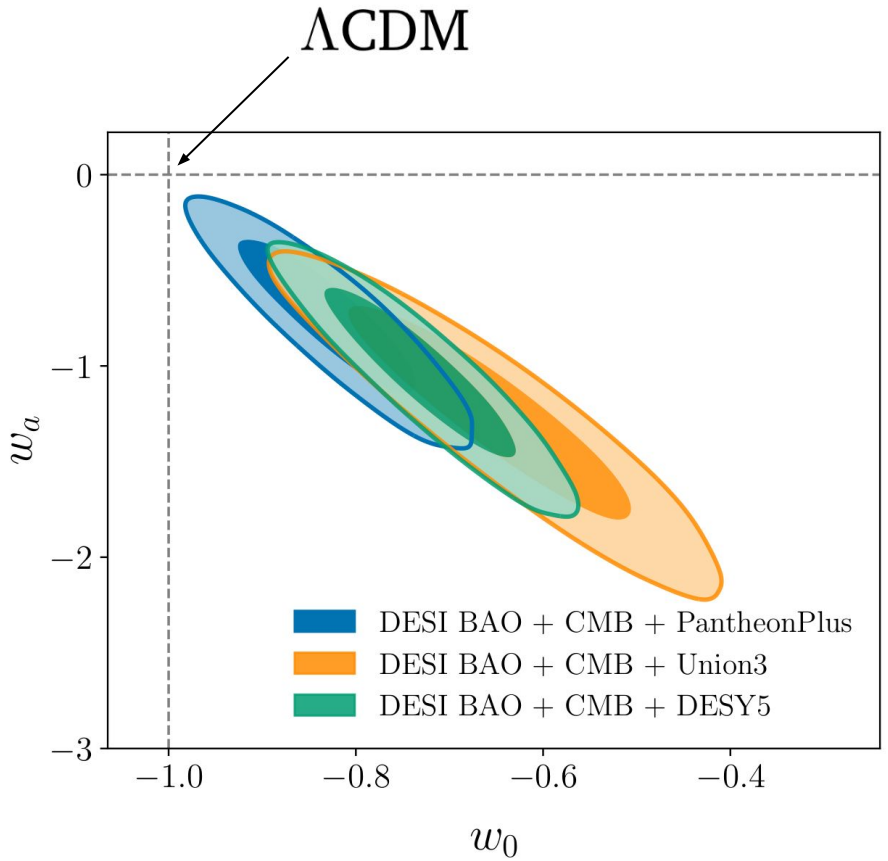
Introducing a time-varying equation of state:

$$w(a) = w_0 + w_a(1 - a)$$

Preference over ΛCDM:

DESI + CMB + PantheonPlus: 2.5σ
DESI + CMB + Union3: 3.5σ
DESI + CMB + DESY5: 3.9σ



First neutrino results from DESI

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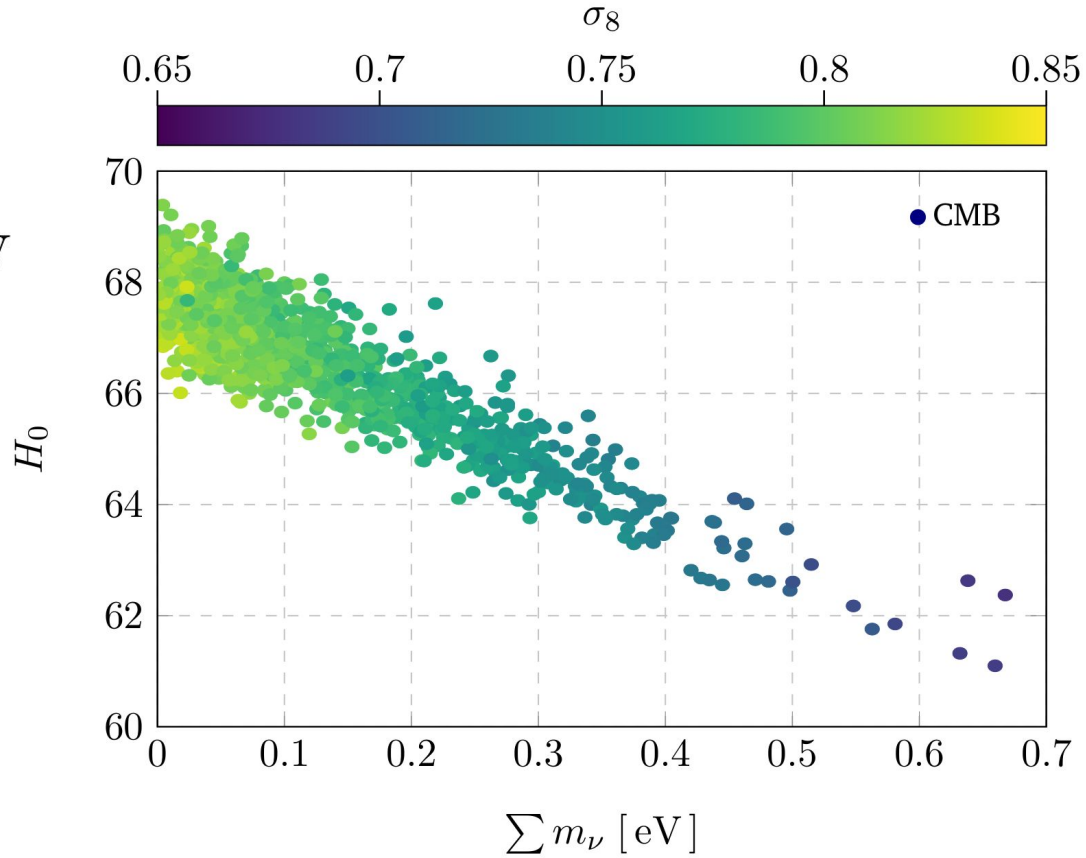
Constraints on the sum of neutrino masses

From CMB:

$$\sum m_\nu < 0.21\,\mathrm{eV}$$



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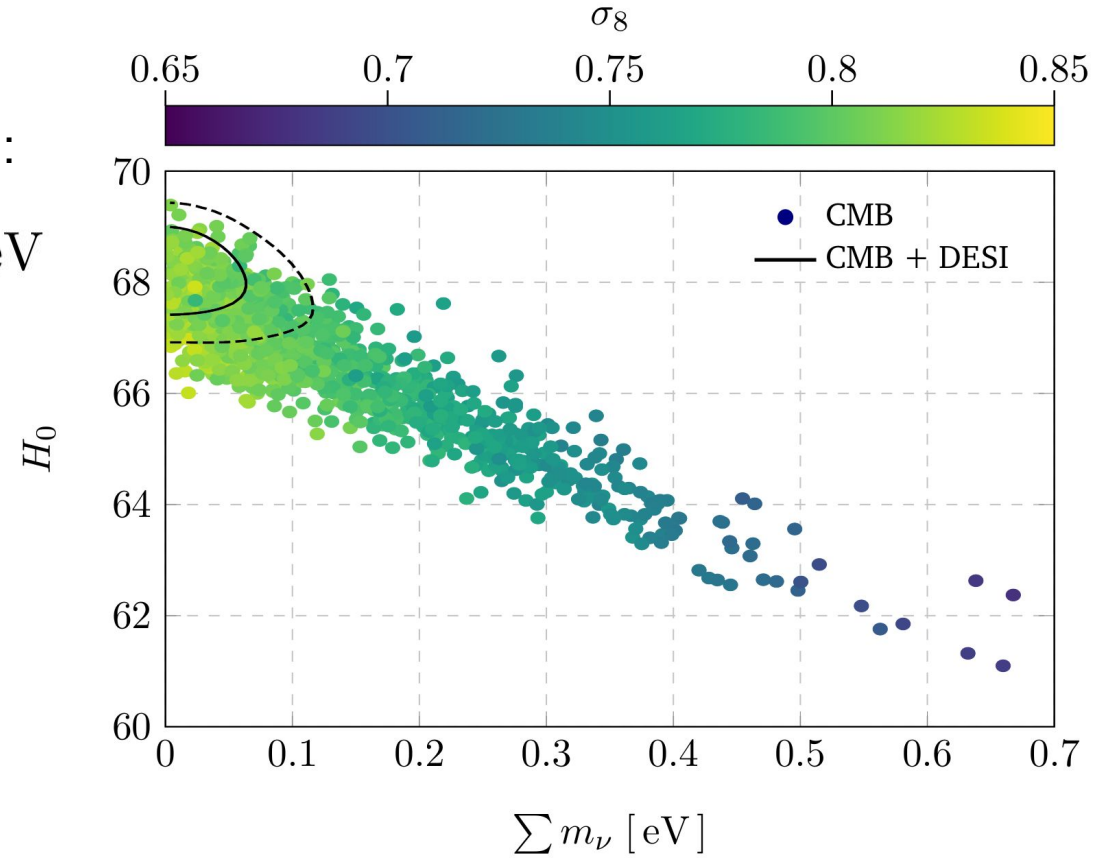
Constraints on the sum of neutrino masses

From CMB + DESI:

$$\sum m_\nu < 0.072\,\mathrm{eV}$$



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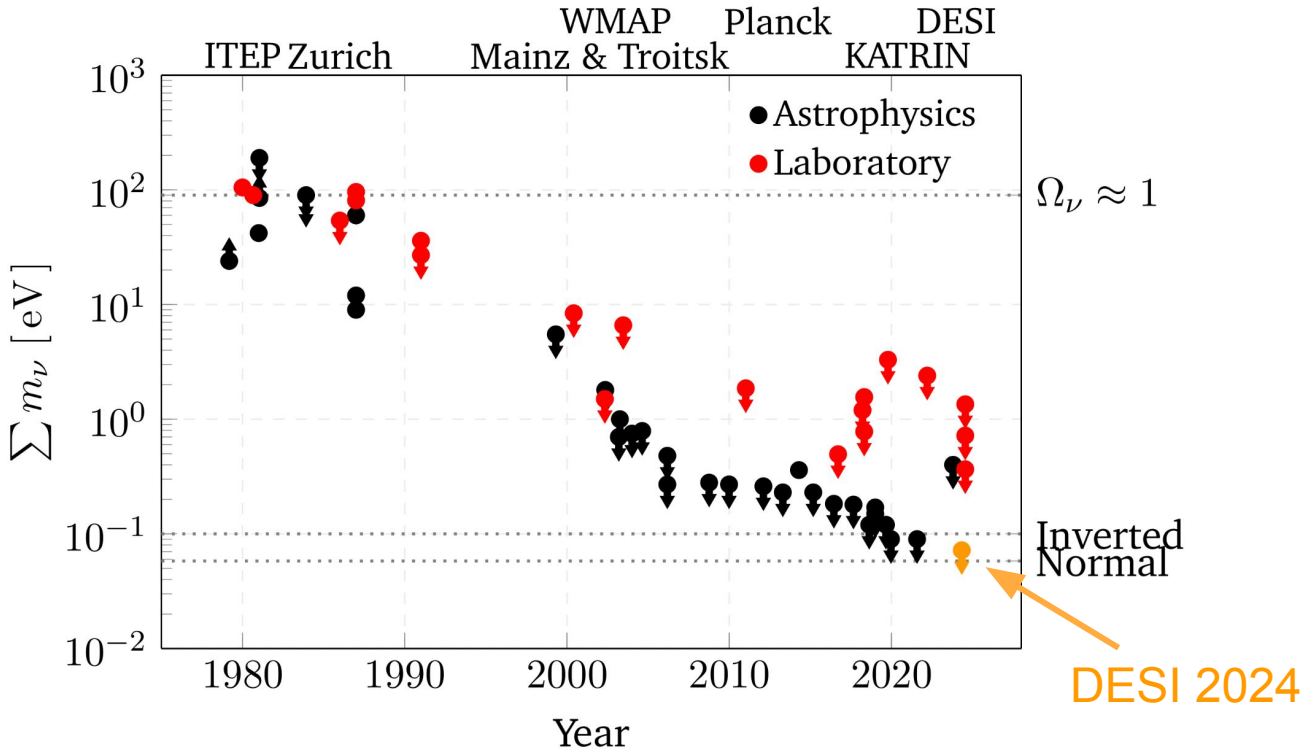
Progress on neutrino masses



Constraints on the sum of neutrino masses

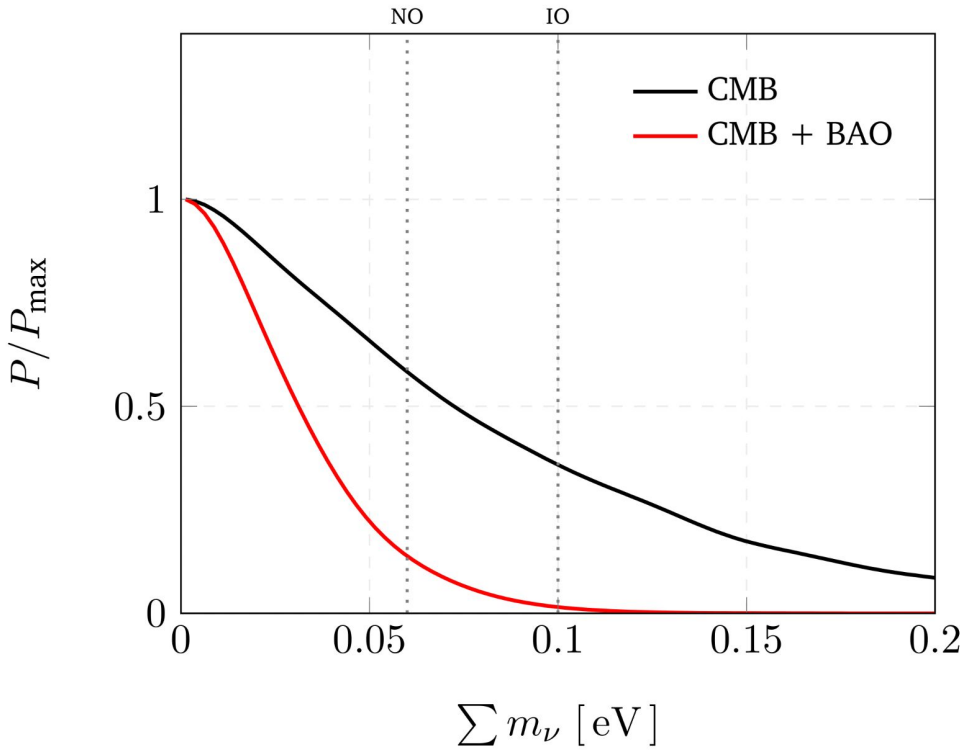
From CMB:

$$\sum m_\nu < 0.21\,\mathrm{eV}$$

From CMB + DESI BAO:

$$\sum m_\nu < 0.072\,\mathrm{eV}$$

(Both at 95%)



Constraints on the sum of neutrino masses

From CMB:

$$\sum m_\nu < 0.21\,\mathrm{eV}$$

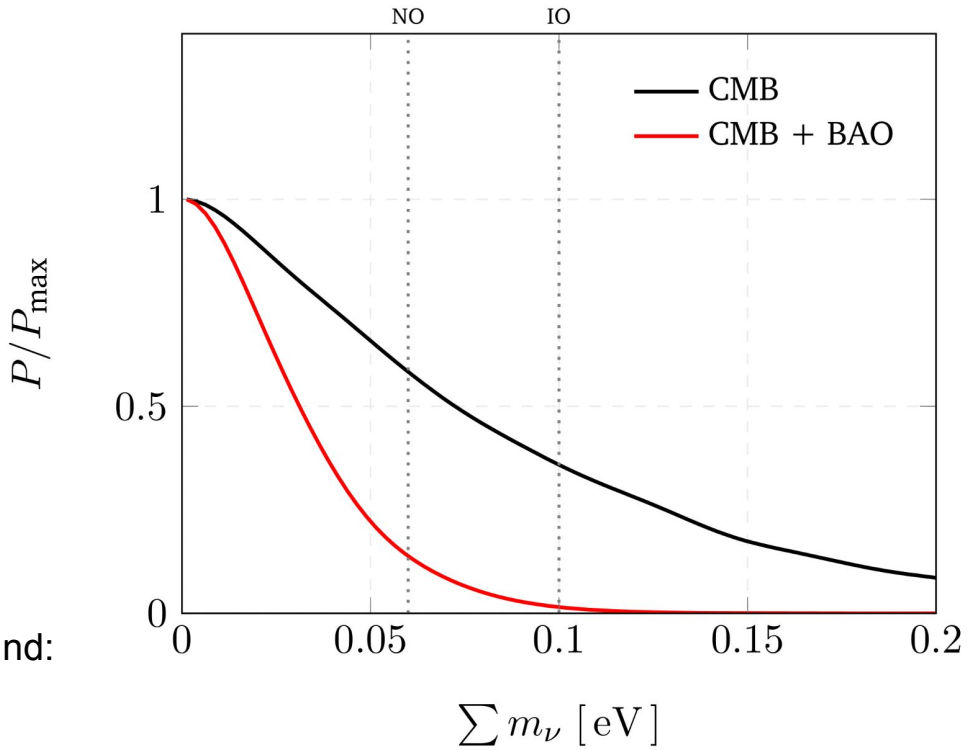
From CMB + DESI BAO:

$$\sum m_\nu < 0.072\,\mathrm{eV}$$

From CMB + DESI BAO + Other Background:

$$\sum m_\nu < 0.043\,\mathrm{eV}$$

See Wang et al. (arXiv:2405.03368)



Dependence on prior

Baseline constraint:

$$\sum m_\nu < 0.072\,\mathrm{eV}$$

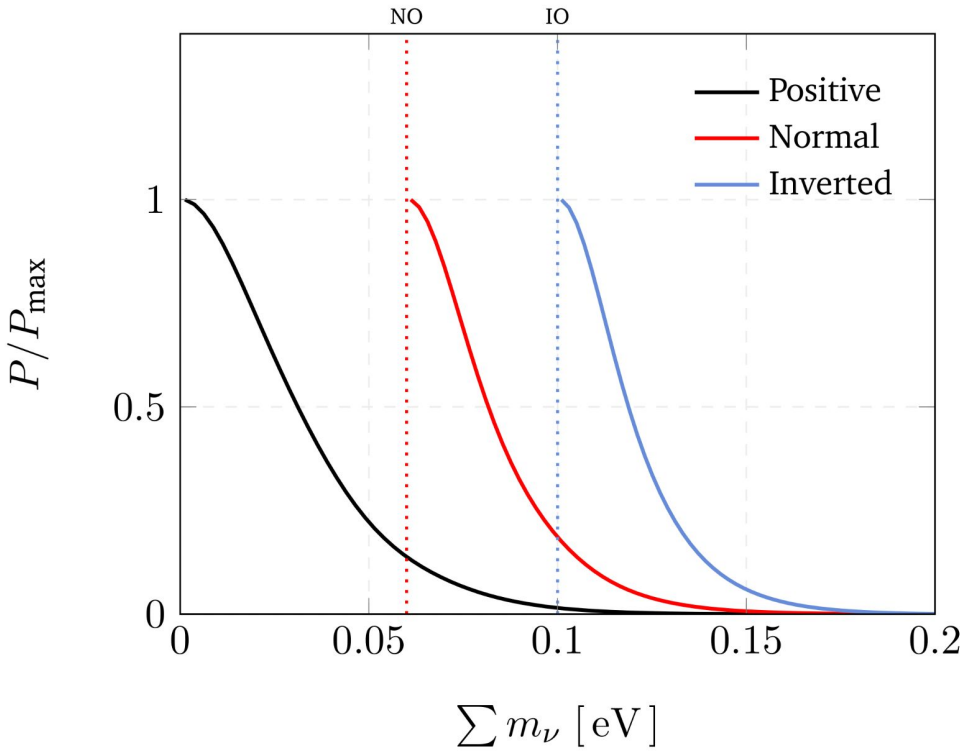
With oscillation priors:

Normal ordering:

$$\sum m_\nu < 0.113\,\mathrm{eV}$$

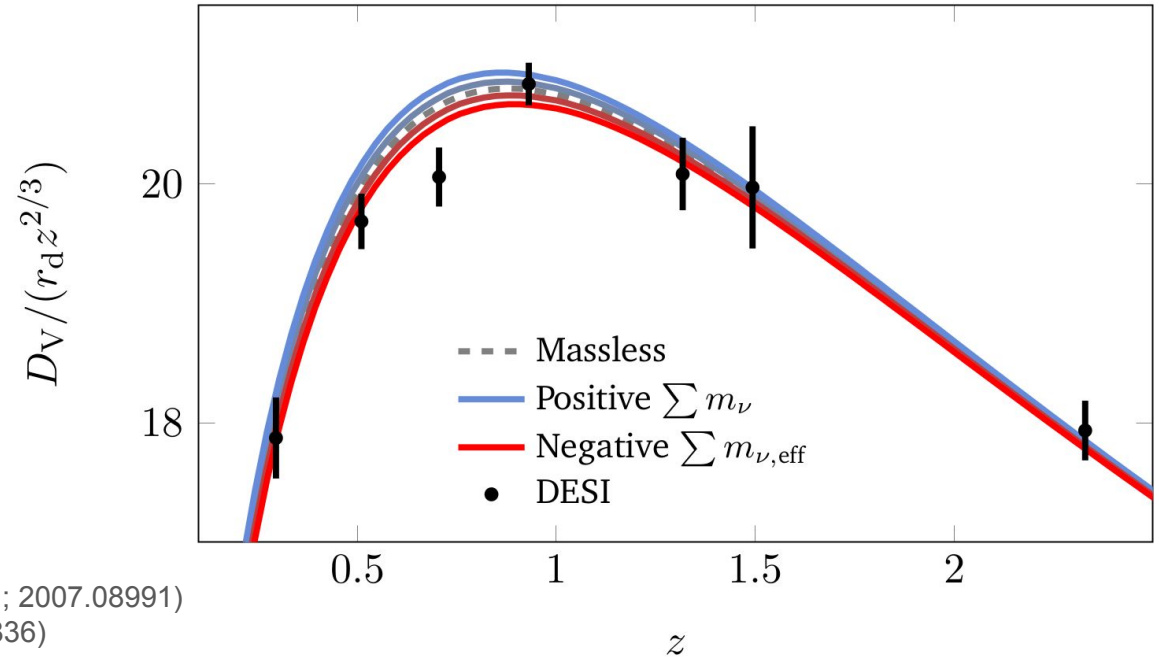
Inverted ordering:

$$\sum m_\nu < 0.145\,\mathrm{eV}$$



Relaxing the prior

Introduce an effective neutrino mass, $\sum m_{\nu,\mathrm{eff}}$, that coincides with the physical $\sum m_\nu$ for $\sum m_{\nu,\mathrm{eff}} \geq 0$ and extrapolate to negative values in data space.



See also:
eBOSS Collaboration (2021; 2007.08991)
Craig et al. (2024; 2405.00836)

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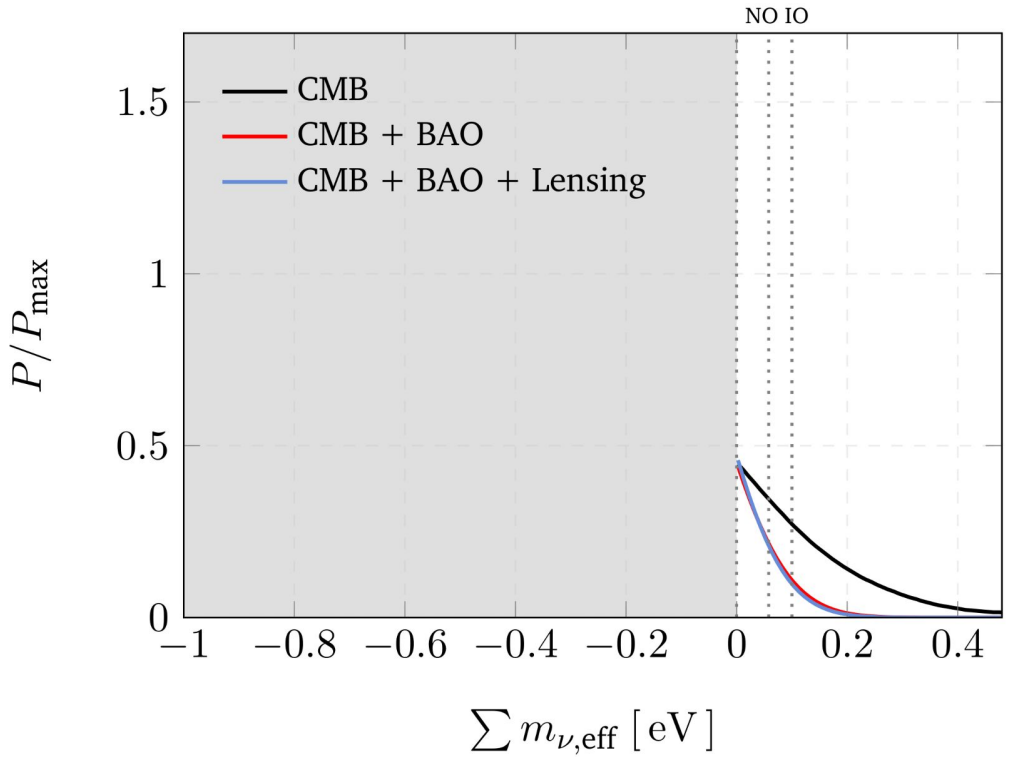
Constraints on the effective neutrino mass



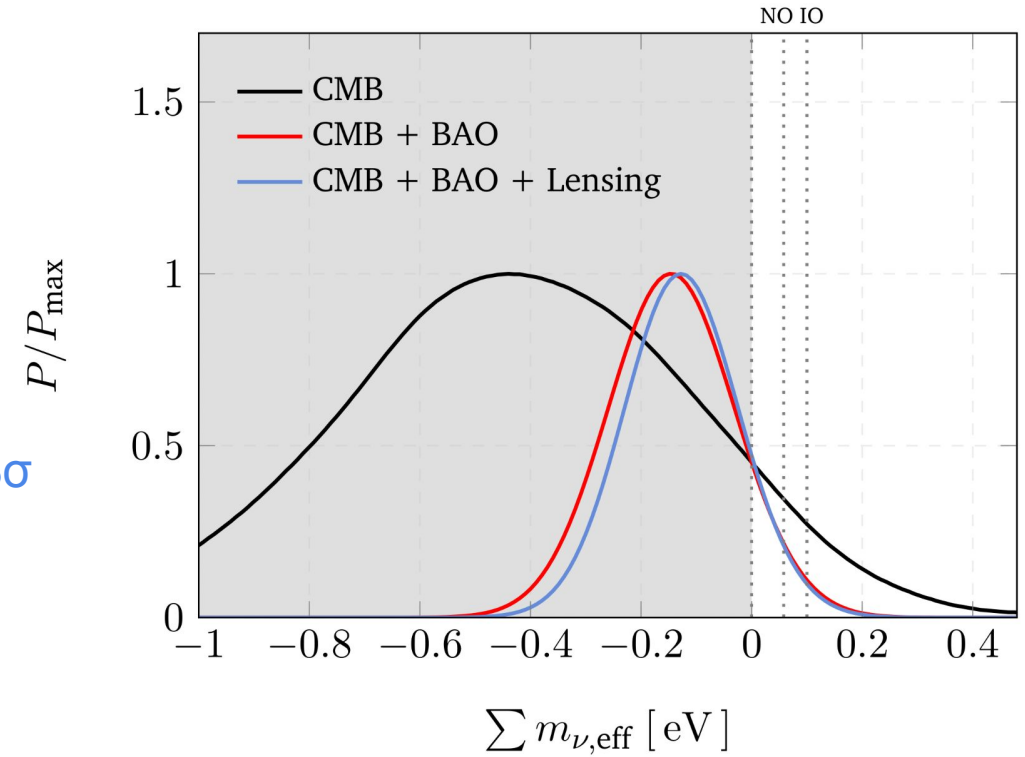
Constraints on the effective neutrino mass

Tension with oscillations:

CMB alone: 1.9σ

CMB + BAO: 2.6σ

CMB + BAO + Lensing: 2.8σ



Constraints on the effective neutrino mass

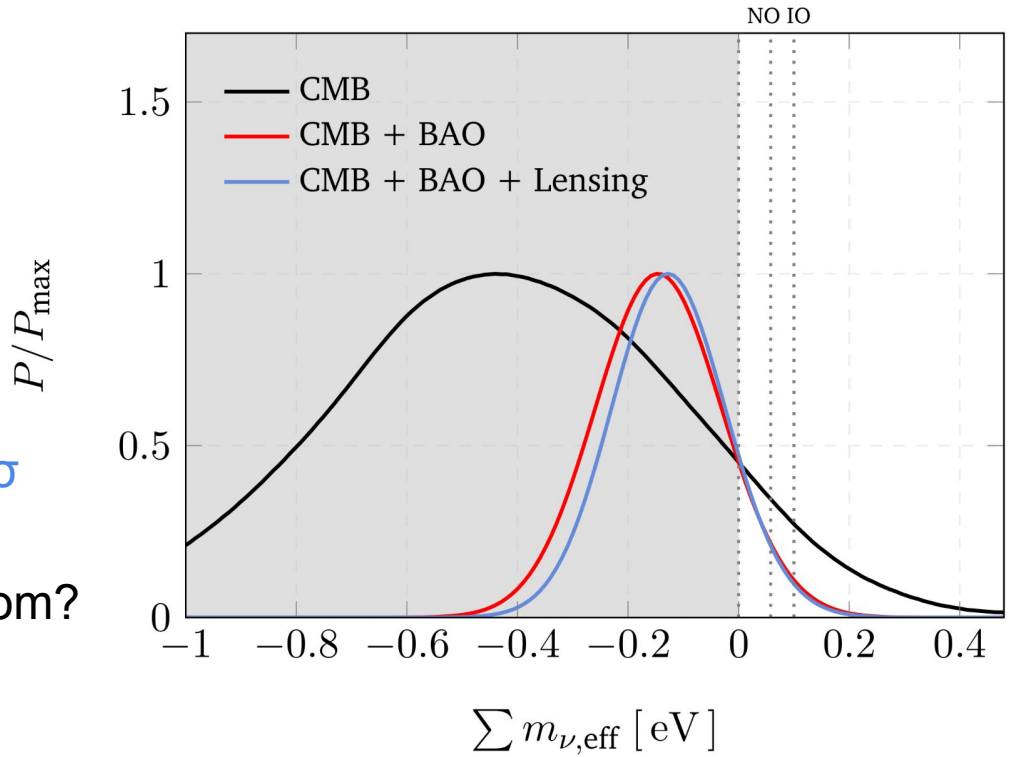
Tension with oscillations:

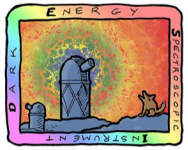
CMB alone: 1.9σ

CMB + BAO: 2.6σ

CMB + BAO + Lensing: 2.8σ

1) Where is this coming from?
2) What does it mean?





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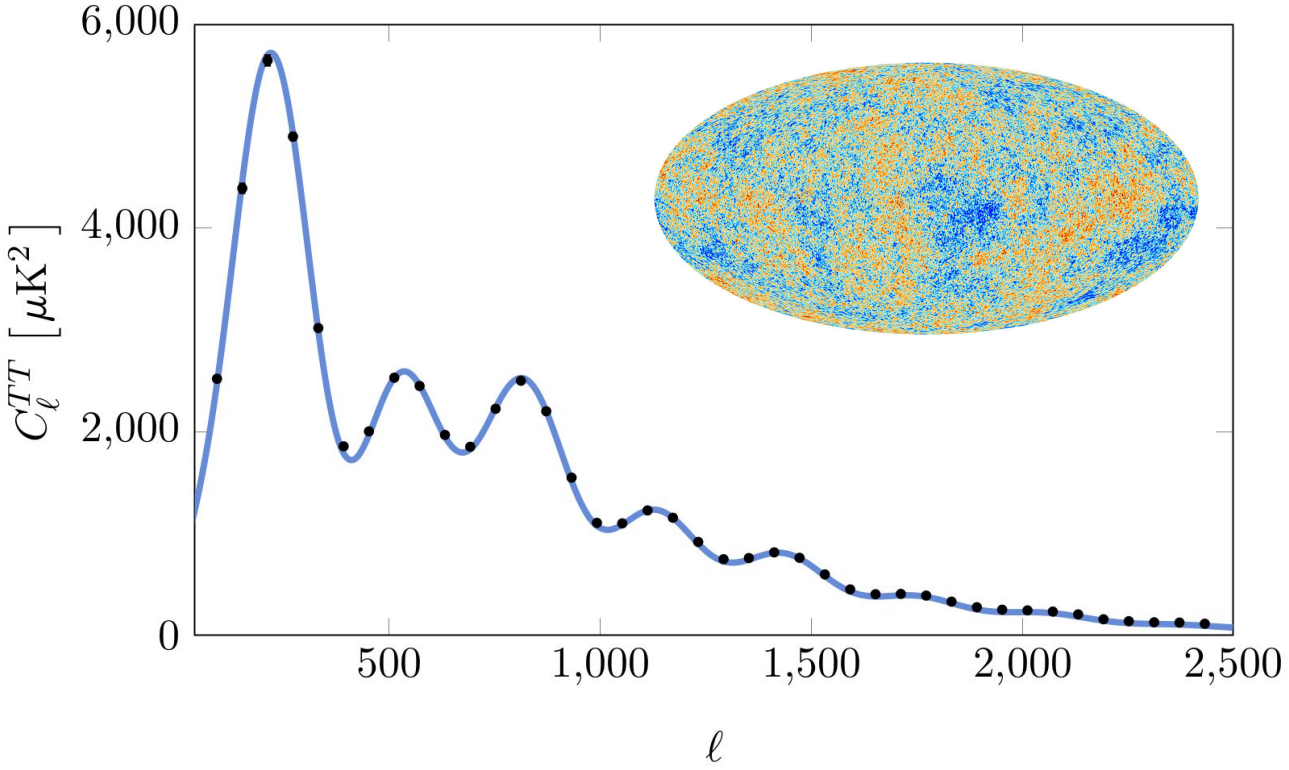
CMB temperature power spectrum



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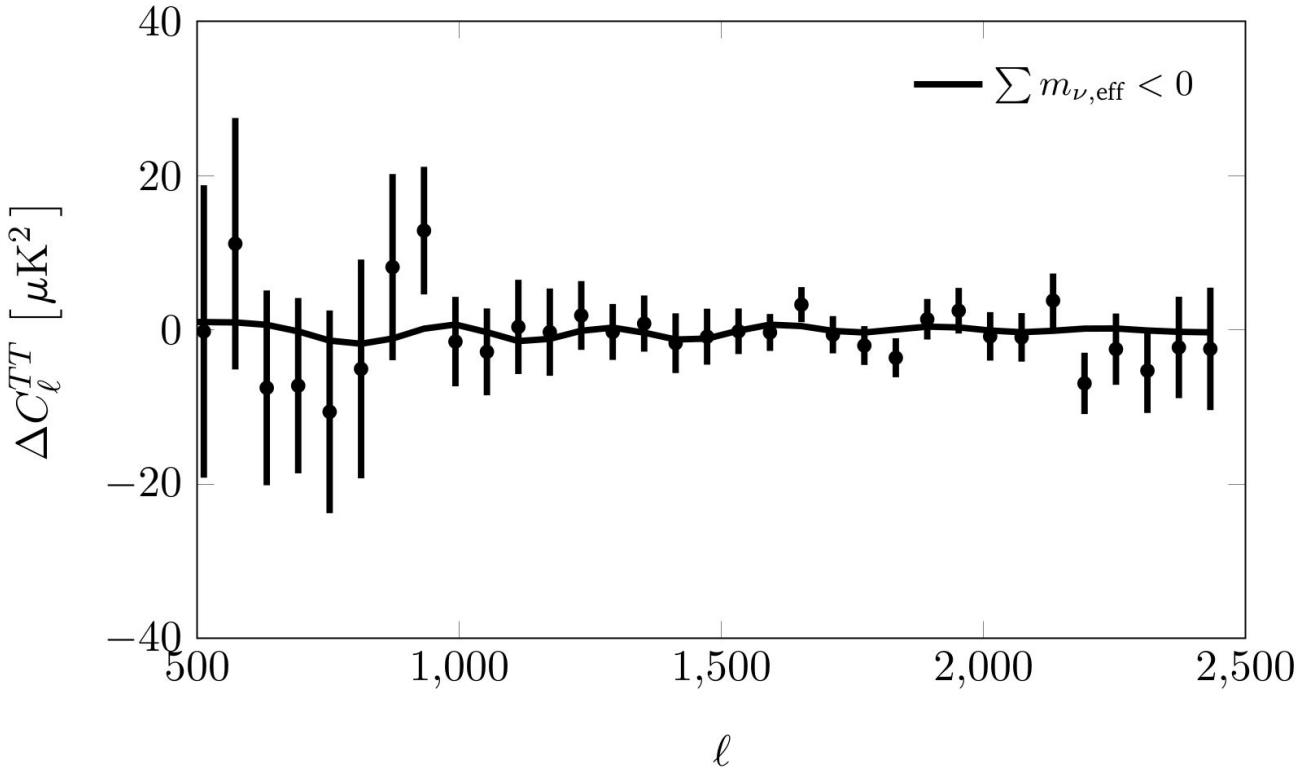
CMB temperature power spectrum



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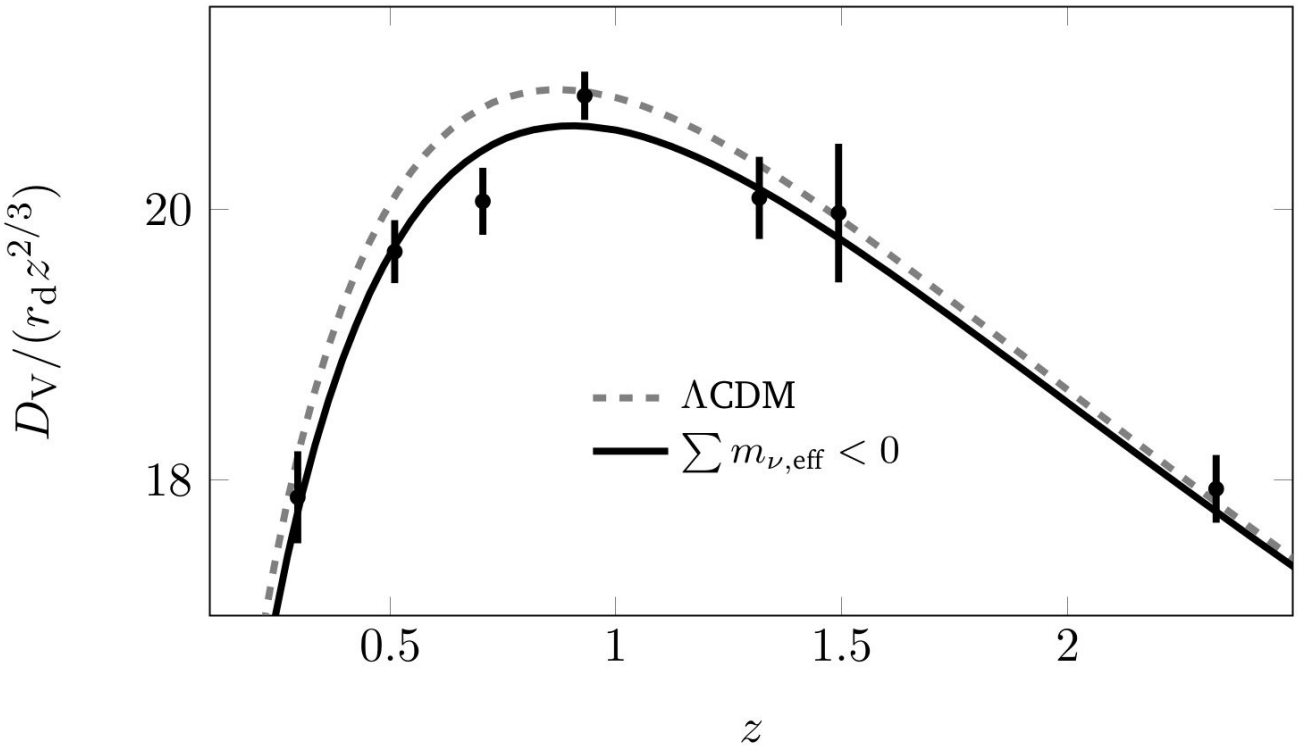
Isotropic BAO measurements



Dark energy and neutrino masses

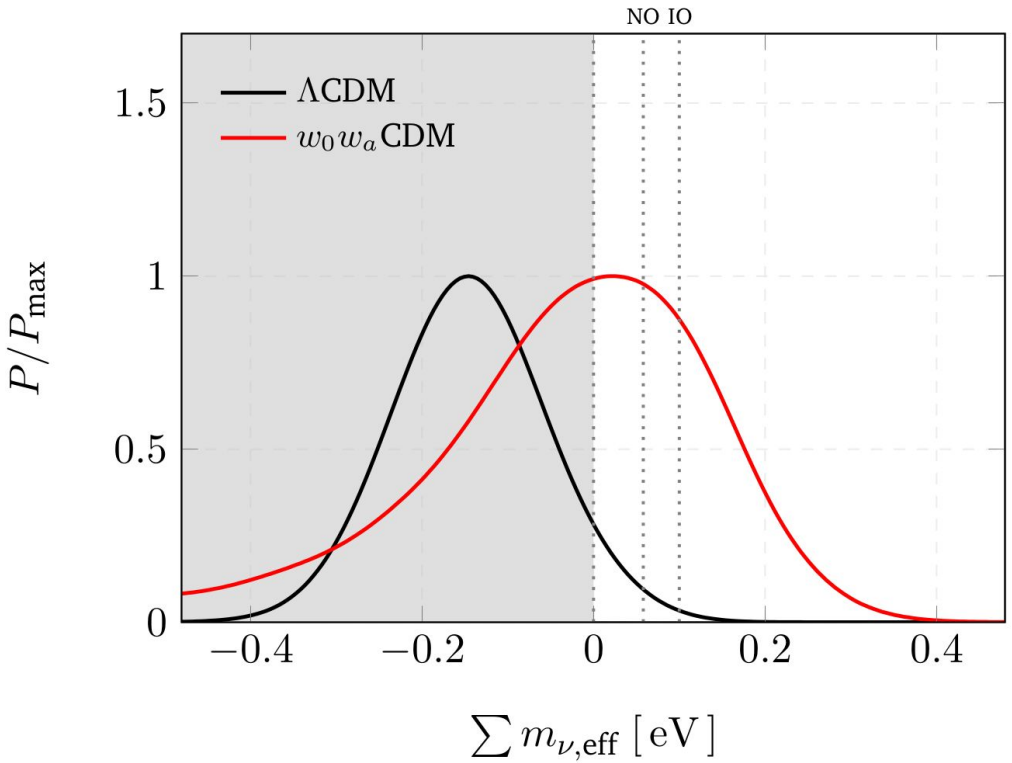
Constraints on the effective neutrino mass

Tension with oscillations reduced to <1σ

Returning to the physical sum of neutrino masses

$w_0 w_a$CDM bound:

$$\sum m_\nu < 0.195\,\mathrm{eV}$$



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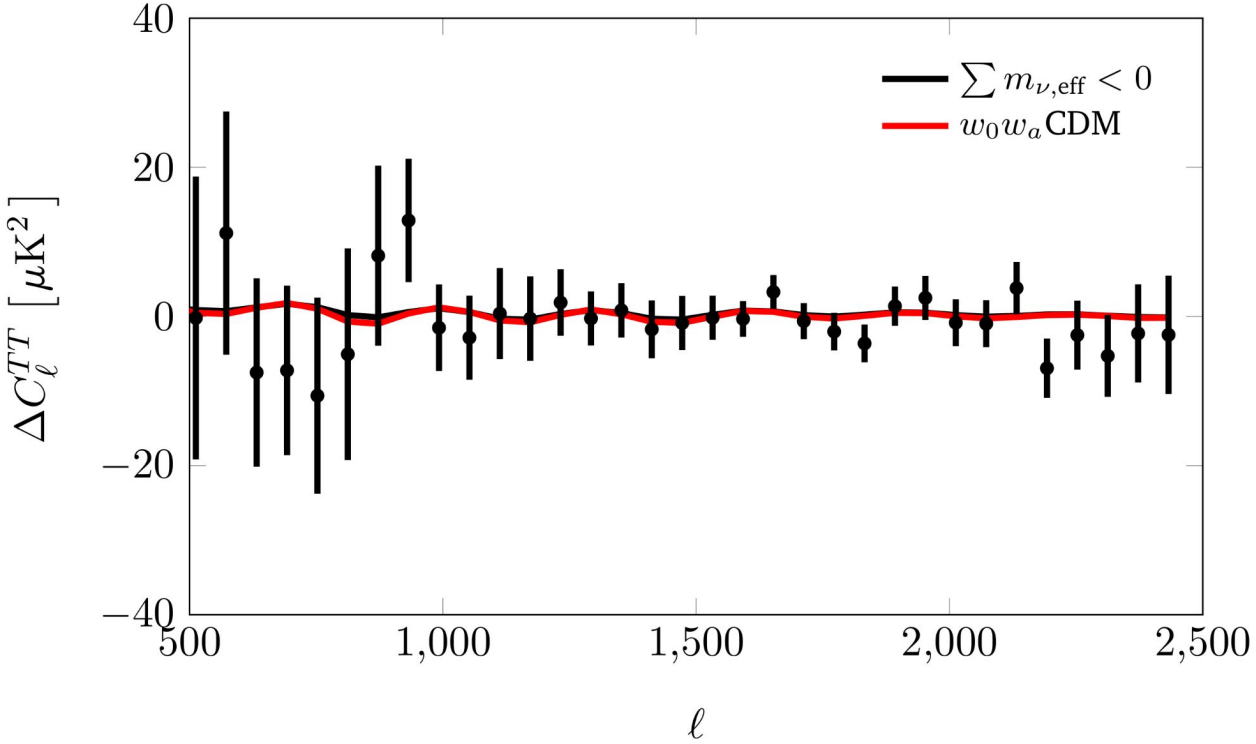
CMB temperature power spectrum



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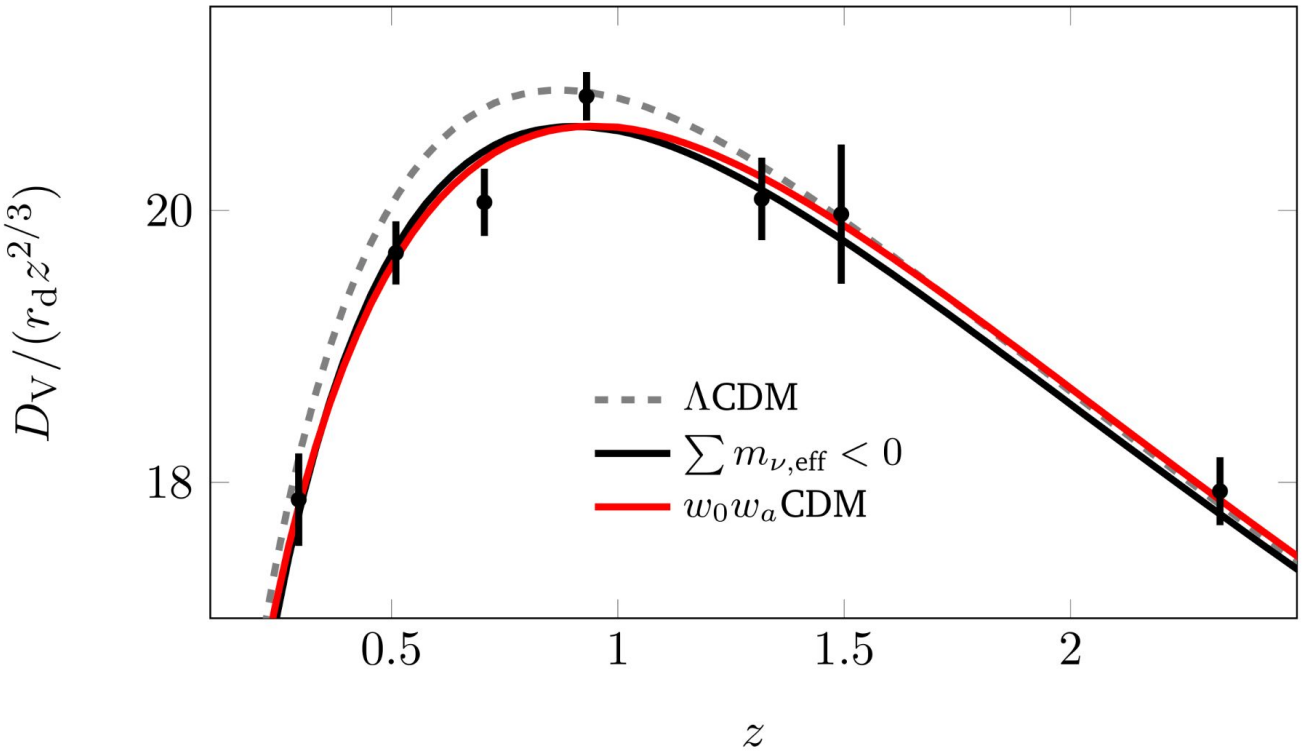
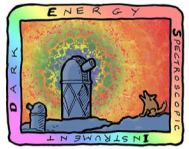
Isotropic BAO measurements





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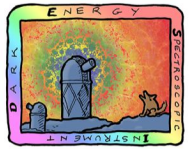
Beyond DESI Year 1 BAO

- Full-shape analysis of P(k) from the Year 1 sample.
- Data collection for Year 3 completed. Look out for the new BAO results.
- Beyond 2-point statistics will provide additional constraining power.



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Summary

- Constraint from CMB + DESI BAO for ΛCDM:

$$\sum m_\nu < 0.072\,\mathrm{eV}$$

- Relaxing the prior and introducing an effective neutrino mass, we find a ~3σ tension with neutrino oscillations.

- This tension is significantly reduced in the time-evolving ($w_0 w_a$) dark energy model, for which

$$\sum m_\nu < 0.195\,\mathrm{eV}$$