ETH zürich

Reconstructing the neutrino mass as a function of redshift

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In collaboration with Lena Funcke, Matthias Löffler and Erminia Calabrese
Based on arXiv:2102.13618

Cosmology from Home Conference, July 2021

Neutrino mass bounds from cosmology

Impact of Σm_ν on the matter power spectrum:

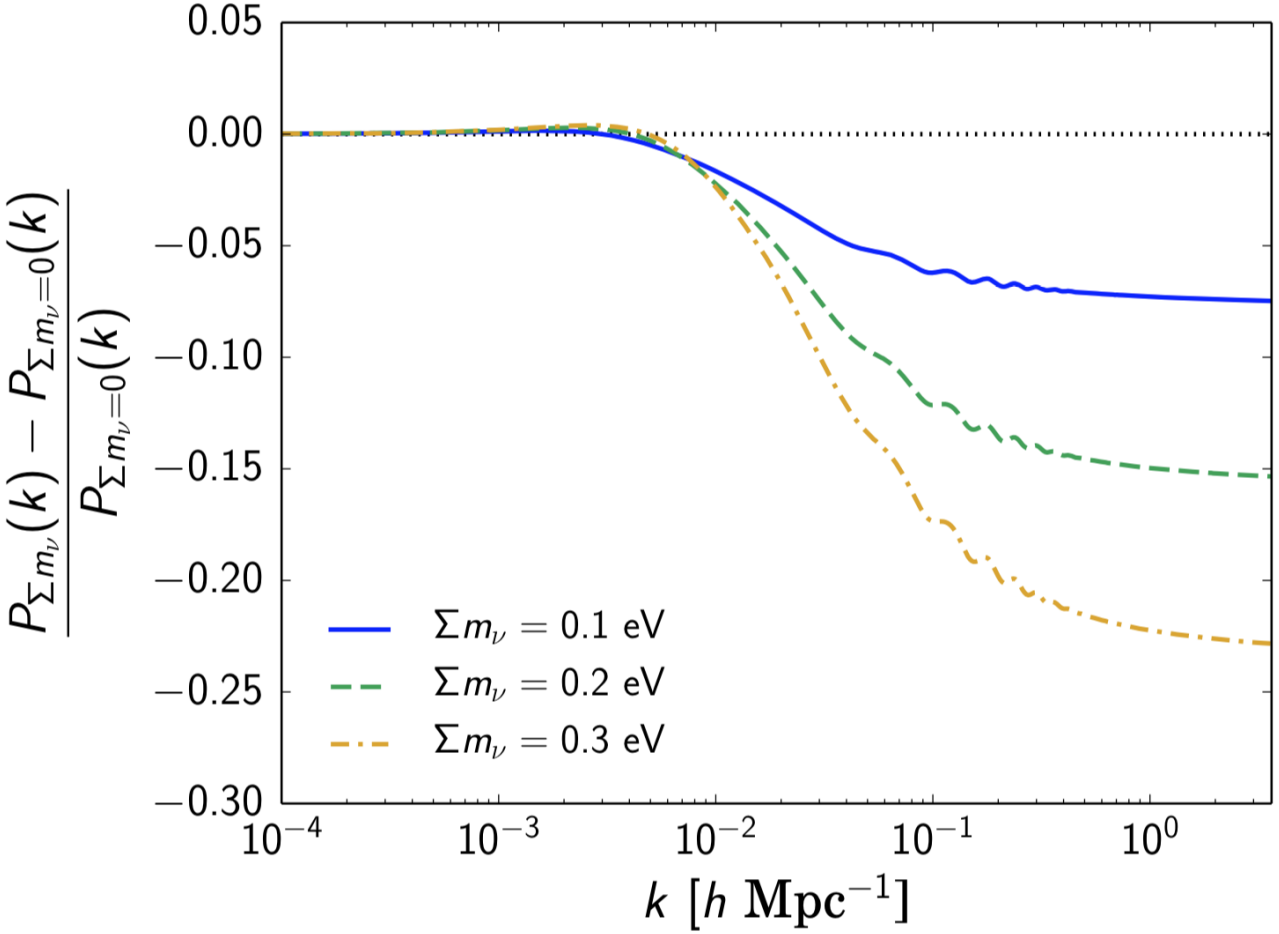

Image credit: Allison et al. (2015), arXiv:1509.07471

Good reviews on neutrino cosmology: Lesgourgues and Pastor (2006); Lesgourgues et al. (2013); Lattanzi and Gerbino (2017).

Neutrino mass bounds from cosmology

Less known: Impact of Σm_ν on the CMB

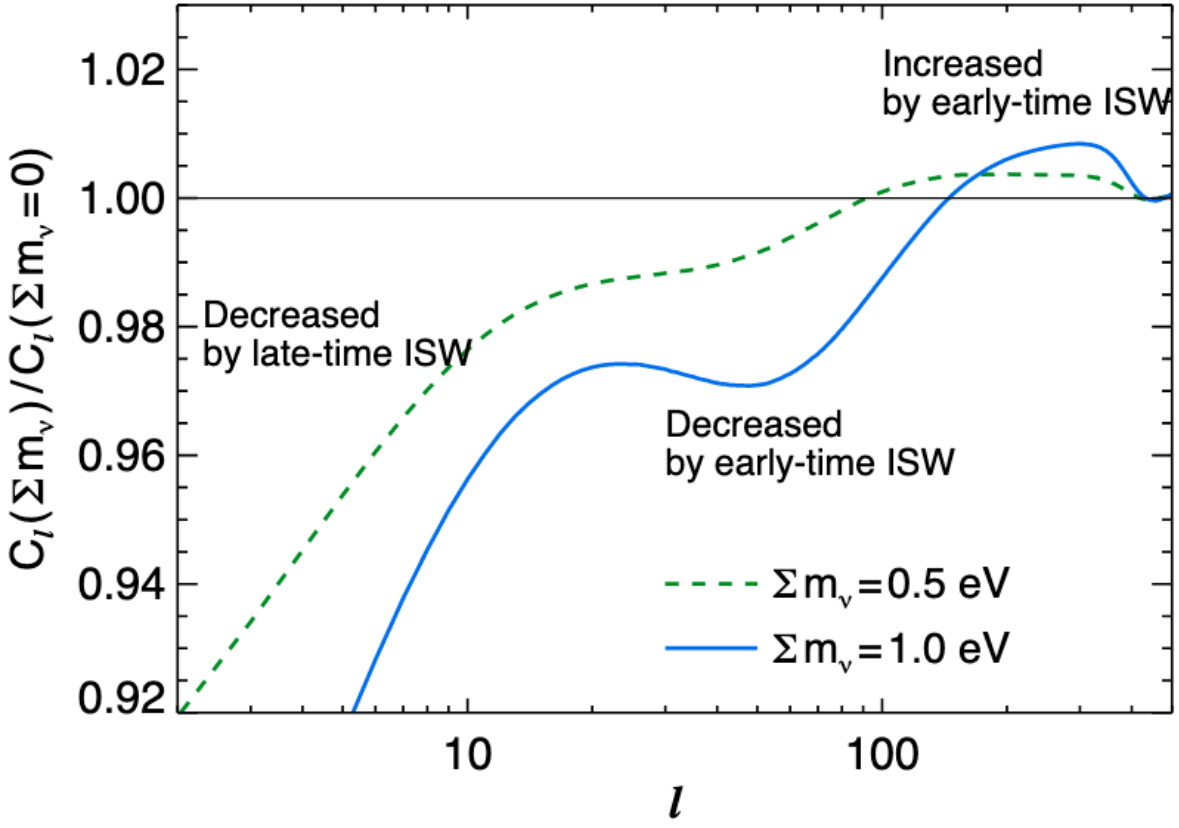

Image credit: Hou et al. (2014), arXiv:1212.6267

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Neutrino mass bounds from cosmology

Less known: Impact of Σm_ν on the CMB

Table 26.2: Summary of $\sum m_\nu$ constraints.

	Model	95% CL (eV)	Ref.
CMB alone			
Pl18[TT+lowE]	ΛCDM+$\sum m_\nu$	< 0.54	[16]
Pl18[TT,TE,EE+lowE]	ΛCDM+$\sum m_\nu$	< 0.26	[16]
CMB + probes of background evolution			
Pl18[TT+lowE] + BAO	ΛCDM+$\sum m_\nu$	< 0.16	[16]
Pl18[TT,TE,EE+lowE] + BAO	ΛCDM+$\sum m_\nu$	< 0.13	[16]
Pl18[TT,TE,EE+lowE]+BAO	ΛCDM+$\sum m_\nu$+5 params.	< 0.515	[18]
CMB + LSS			
Pl18[TT+lowE+lensing]	ΛCDM+$\sum m_\nu$	< 0.44	[16]
Pl18[TT,TE,EE+lowE+lensing]	ΛCDM+$\sum m_\nu$	< 0.24	[16]
CMB + probes of background evolution + LSS			
Pl18[TT+lowE+lensing] + BAO	ΛCDM+$\sum m_\nu$	< 0.13	[16]
Pl18[TT,TE,EE+lowE+lensing] + BAO	ΛCDM+$\sum m_\nu$	< 0.12	[16]
Pl18[TT,TE,EE+lowE+lensing] + BAO+Pantheon	ΛCDM+$\sum m_\nu$	< 0.11	[16]

Image credit: Review of Particle Physics, 2021

Neutrino mass parameter space

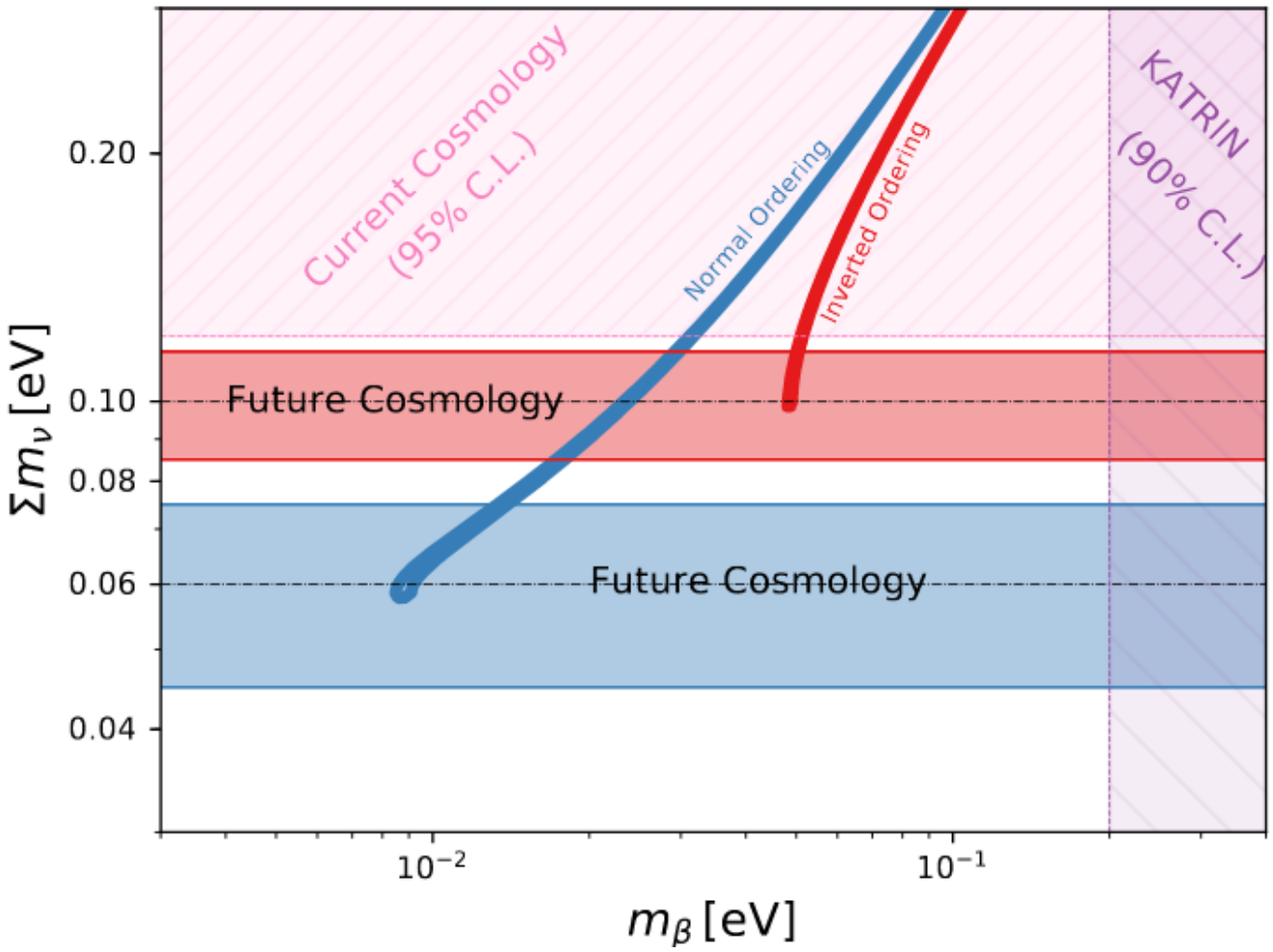

Image credit: Abazajian et al. (CMB Stage 4 Collaboration) (2019).

$\sum m_\nu$ for different cosmological models

$\sum m_\nu$ is constrained to be ...

Σm_ν for different cosmological models

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$\Sigma m_\nu < 120$ meV ΛCDM (Planck 2018 CMB + BAO) [1]

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$\Sigma m_\nu < 290$ meV	ΛCDM with $w(a) = w_0 + w_a(1-a)$ (Planck 2018 CMB + BAO + SN)	[2]

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$\Sigma m_\nu < 4.8$ eV	**ΛCDM+$m_\nu(z)$ from supercooled phase transition in relic neutrino sector** (Planck 2015 CMB + BAO + SN)	[4]

[1] Aghanim et al. (Planck Collaboration) (2018). [2] Choudhury and Hannestad (2020).
[3] Chacko et al. (2019). [4] CSL et al. (2018).

Hints for high neutrino masses at low redshifts

KiDS-1000 Cosmology: constraints beyond flat ΛCDM

Tilman Tröster[1]*, Marika Asgari[1], Chris Blake[2], Matteo Cataneo[1], Catherine Heymans[1,3], Hendrik Hildebrandt[3], Benjamin Joachimi[4], Chieh-An Lin[1], Ariel G. Sánchez[5], Angus H. Wright[3], Maciej Bilicki[6], Benjamin Bose[7], Martin Crocce[8,9], Andrej Dvornik[3], Thomas Erben[10], Benjamin Giblin[1], Karl Glazebrook[2], Henk Hoekstra[11], Shahab Joudaki[12], Arun Kannawadi[13], Fabian Köhlinger[3], Konrad Kuijken[11], Chris Lidman[14,15], Lucas Lombriser[7], Alexander Mead[16], David Parkinson[17], HuanYuan Shan[18,19], Christian Wolf[14,15], and Qianli Xia[1]

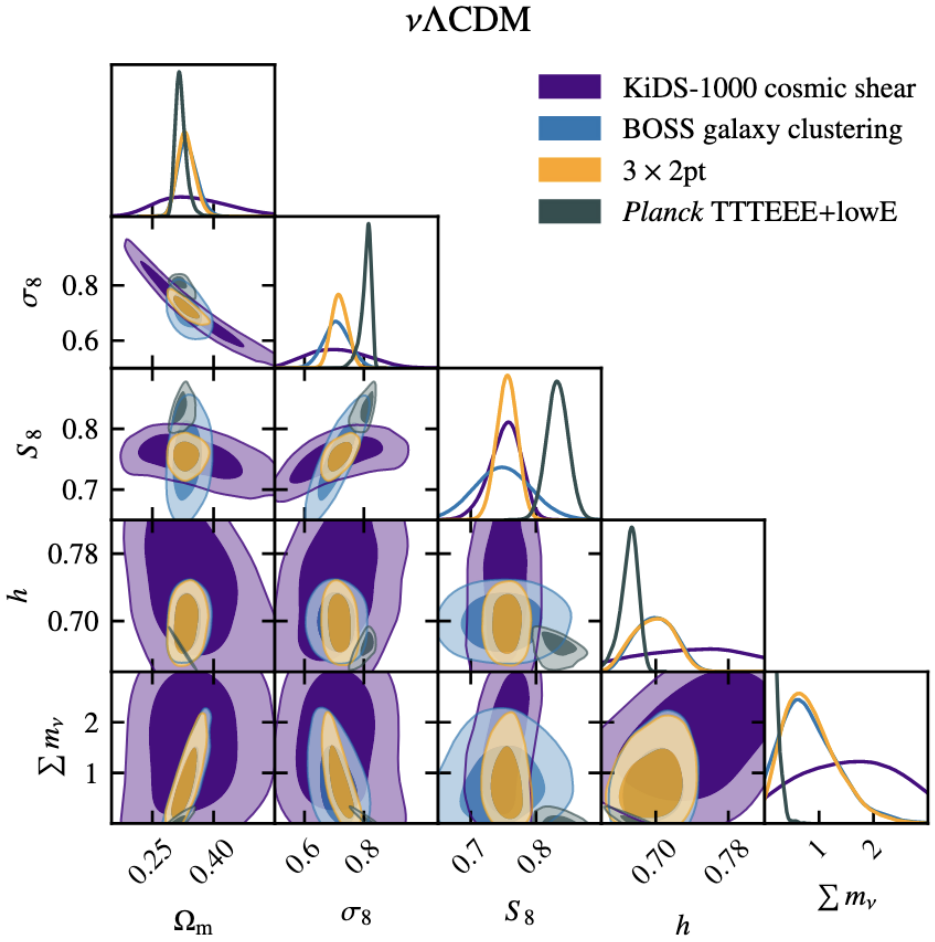


Image credit: Tröster et al. (2021), arXiv:2010.16416

Reconstructing cosmological parameters

Several examples in the literature: $H(z)$, $w_{\rm de}(z)$, primordial power spectrum...

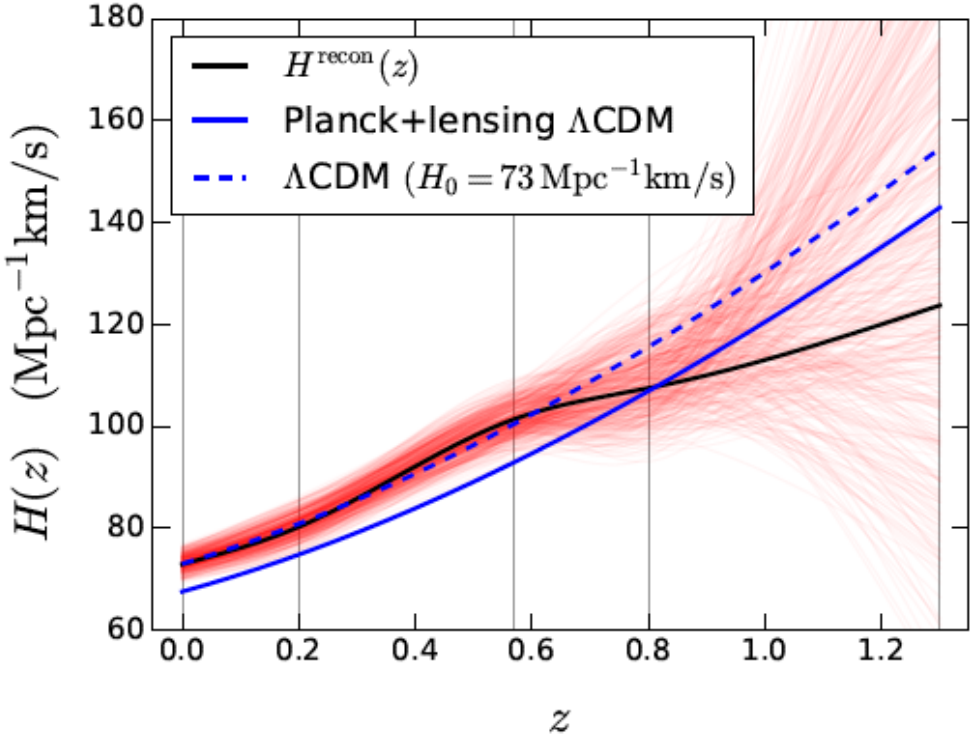
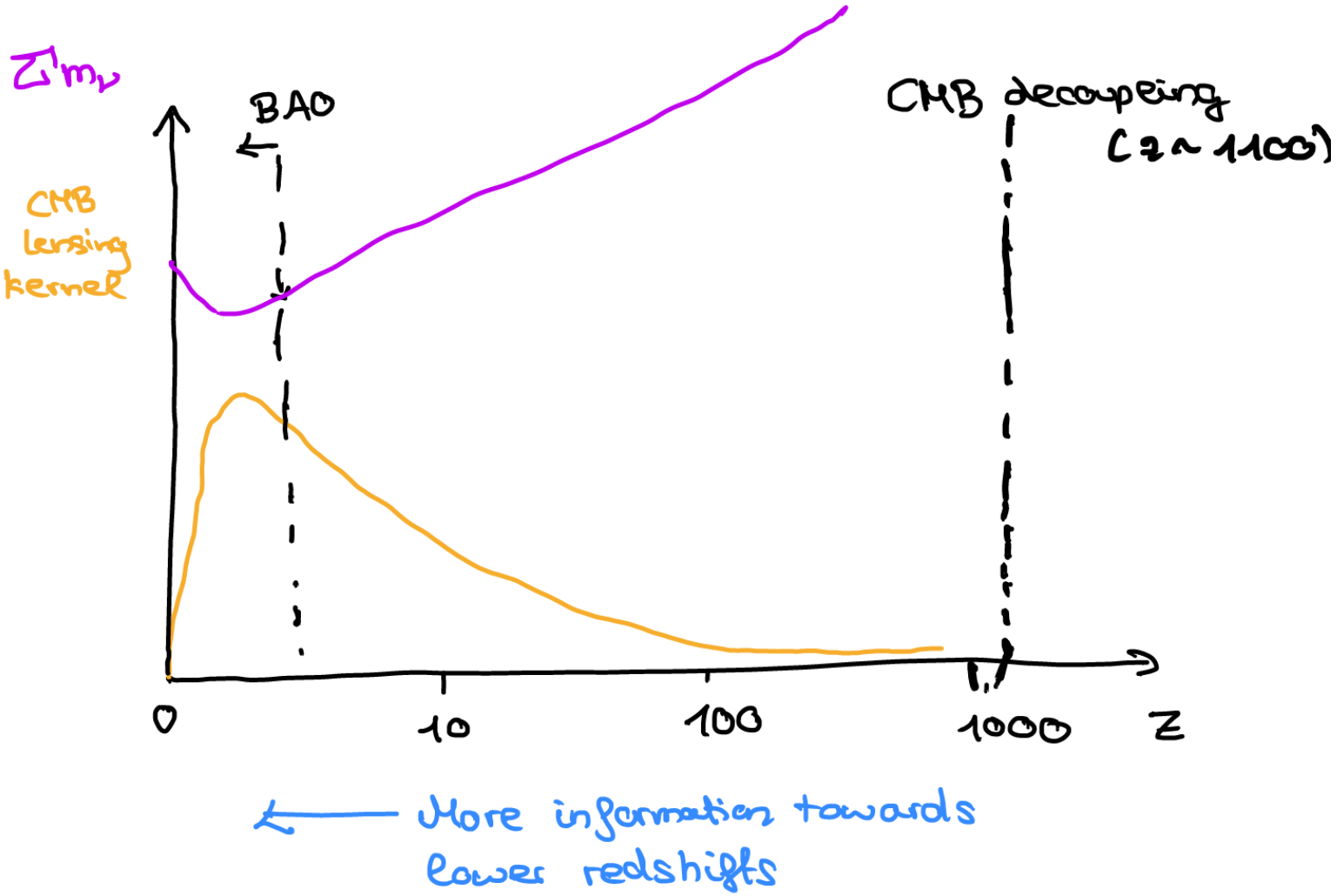


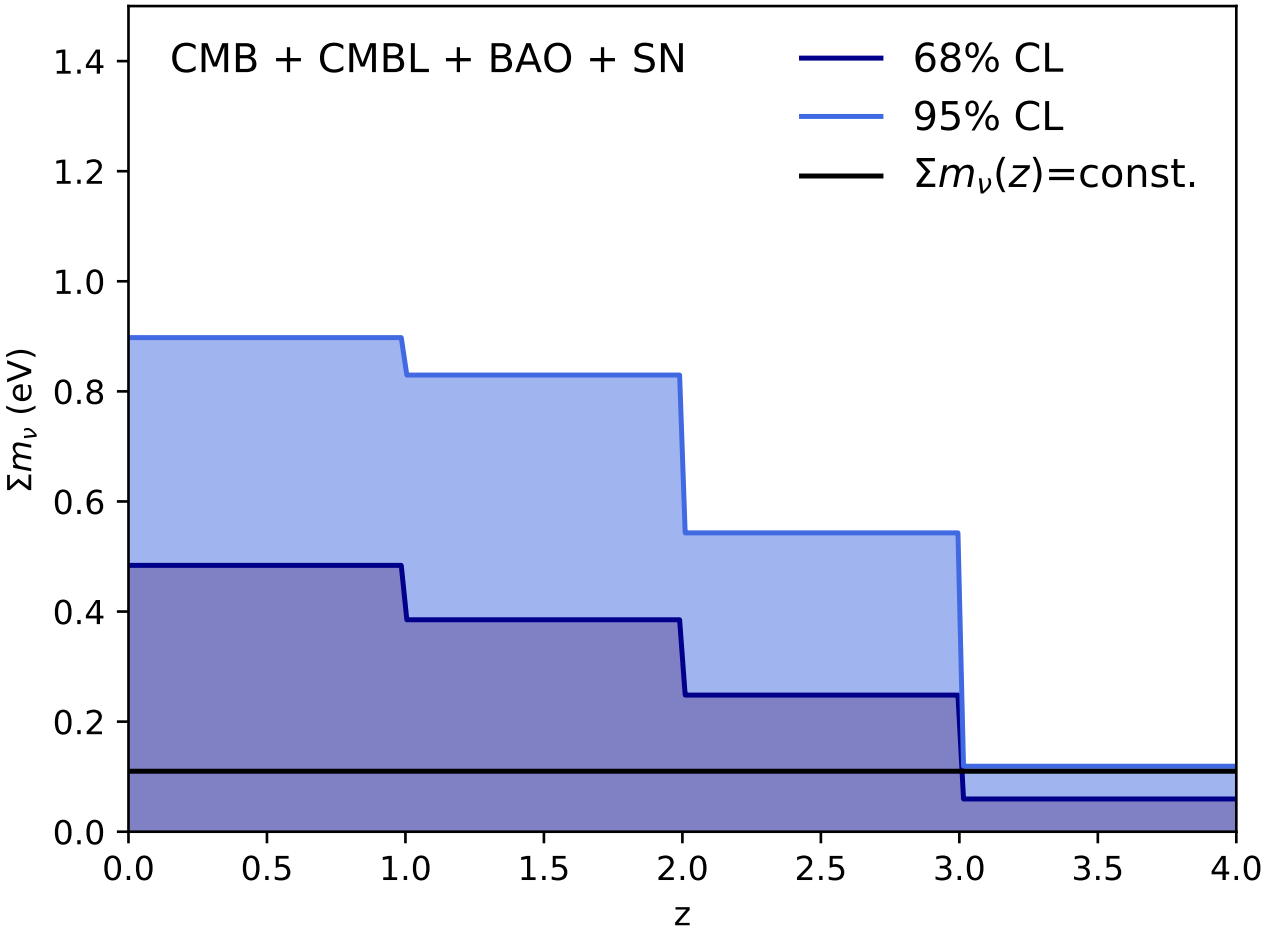
Image credit: Bernal et al. (2016), arXiv:1607.05617

Reconstructing $\sum m_\nu(z)$

What should we expect if we reconstruct $\sum m_\nu(z)$?



First attempt: Binned reconstruction

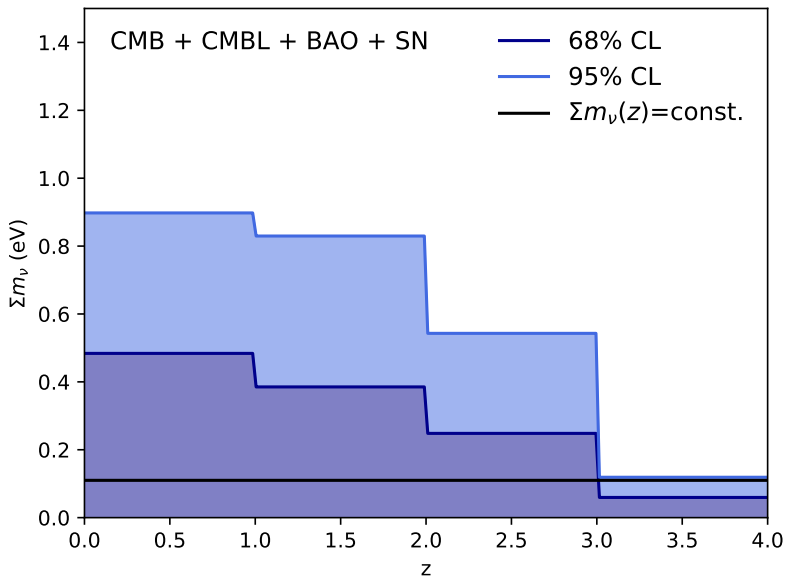


CSL et al. (2021), arXiv:2102.13618

Improving the reconstruction method

Questions

- Why is the constraint in the last redshift bin so tight?
- At which redshift does the sensitivity of $\sum m_\nu(z)$ decrease?
- Can we use our results to constrain extended neutrino models?



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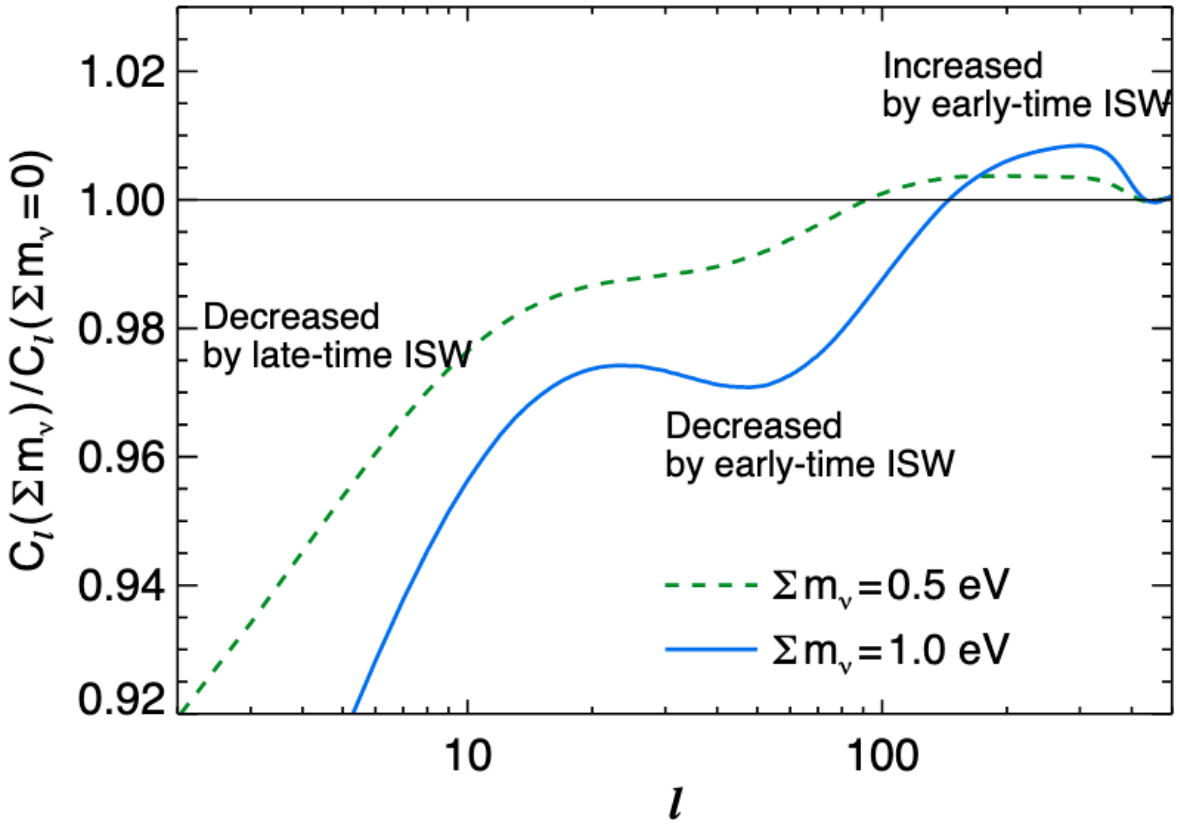
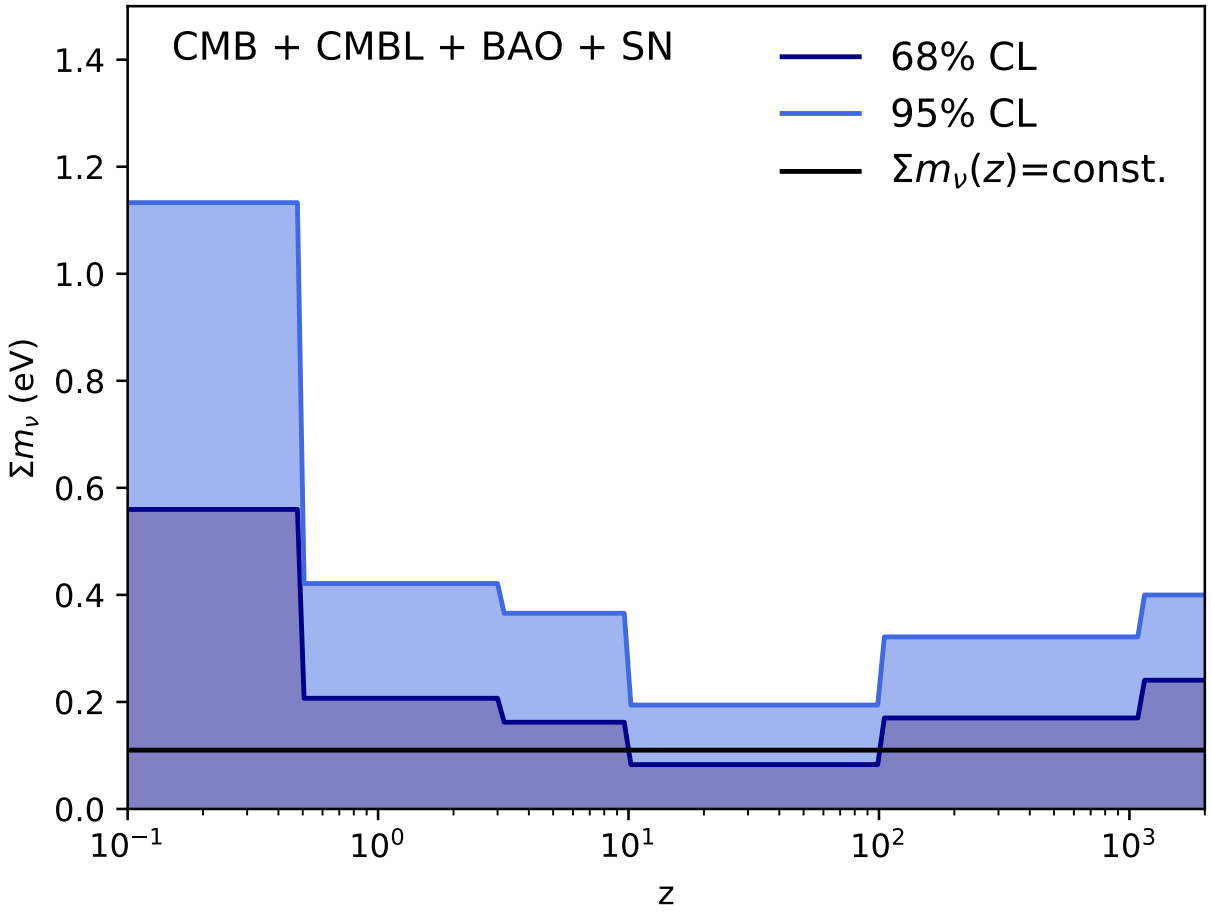


Image credit: Hou et al. (2014), arXiv:1212.6267

At which redshift does the sensitivity of $\sum m_\nu(z)$ decrease?

First step: Wider redshift bins

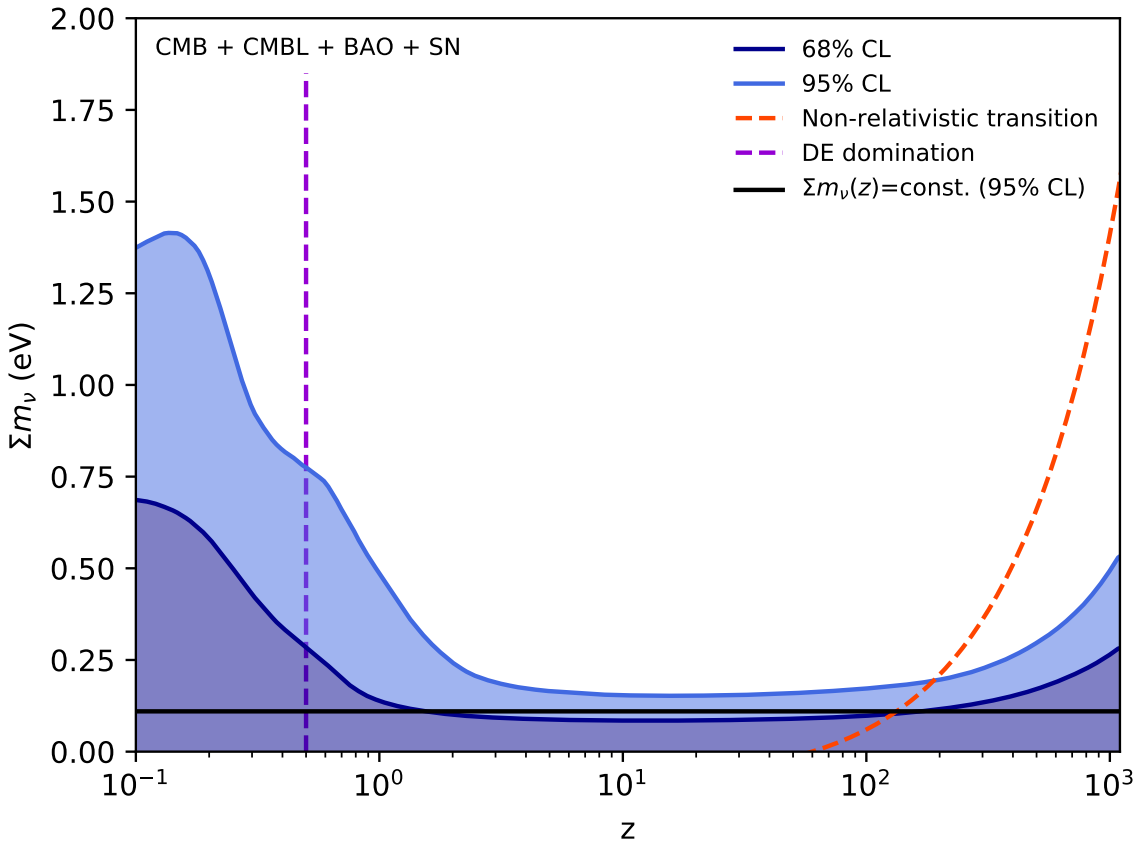


CSL et al. (2021), arXiv:2102.13618

At which redshift does the sensitivity of $\sum m_\nu(z)$ decrease?

Second step: Reconstruction with linear splines and variable knots

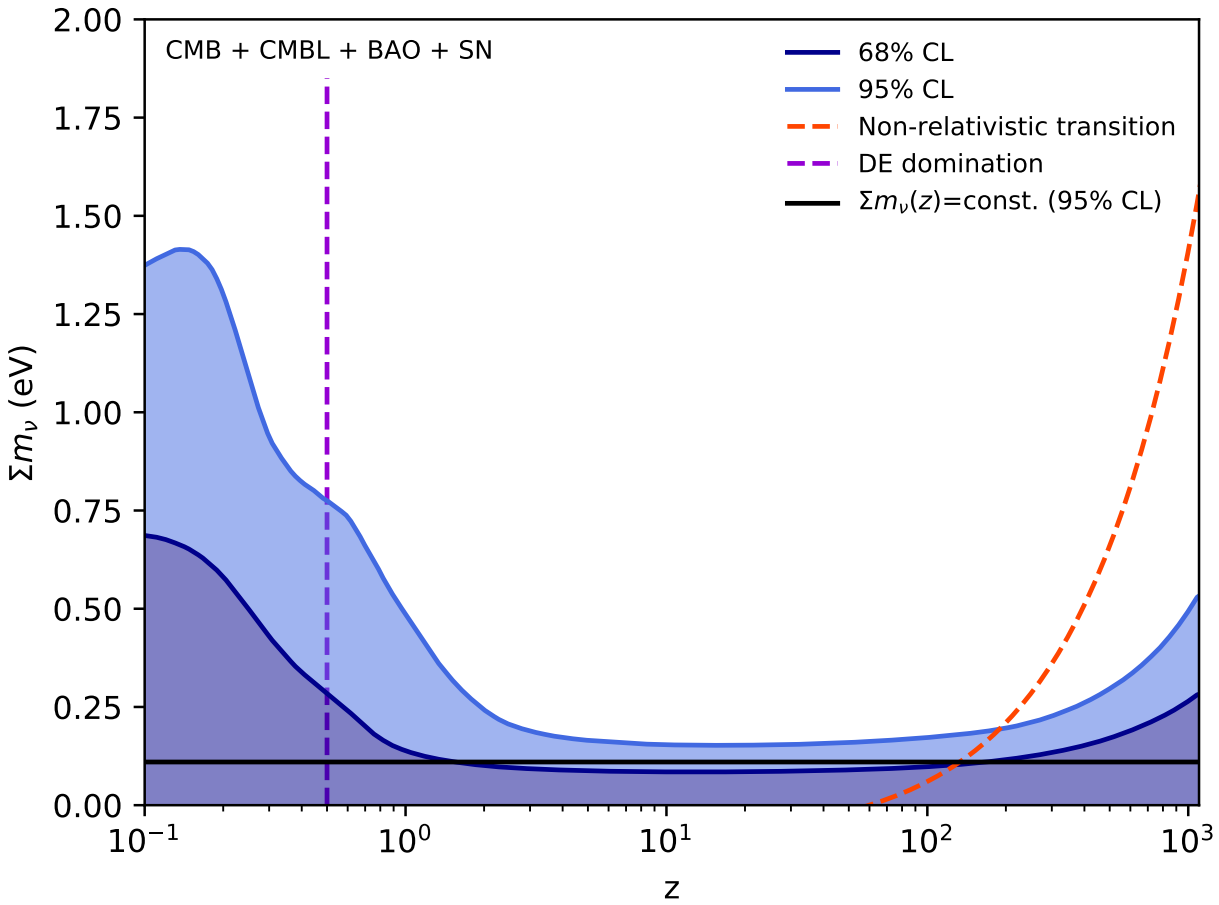
$\longrightarrow$ Two new parameters: The knots (change points) z_1 and z_2



CSL et al. (2021), arXiv:2102.13618

Can we constrain extended neutrino models?

Reconstruction results can be converted into limit for neutrino decay models: $\sum m_\nu < 0.21$ eV

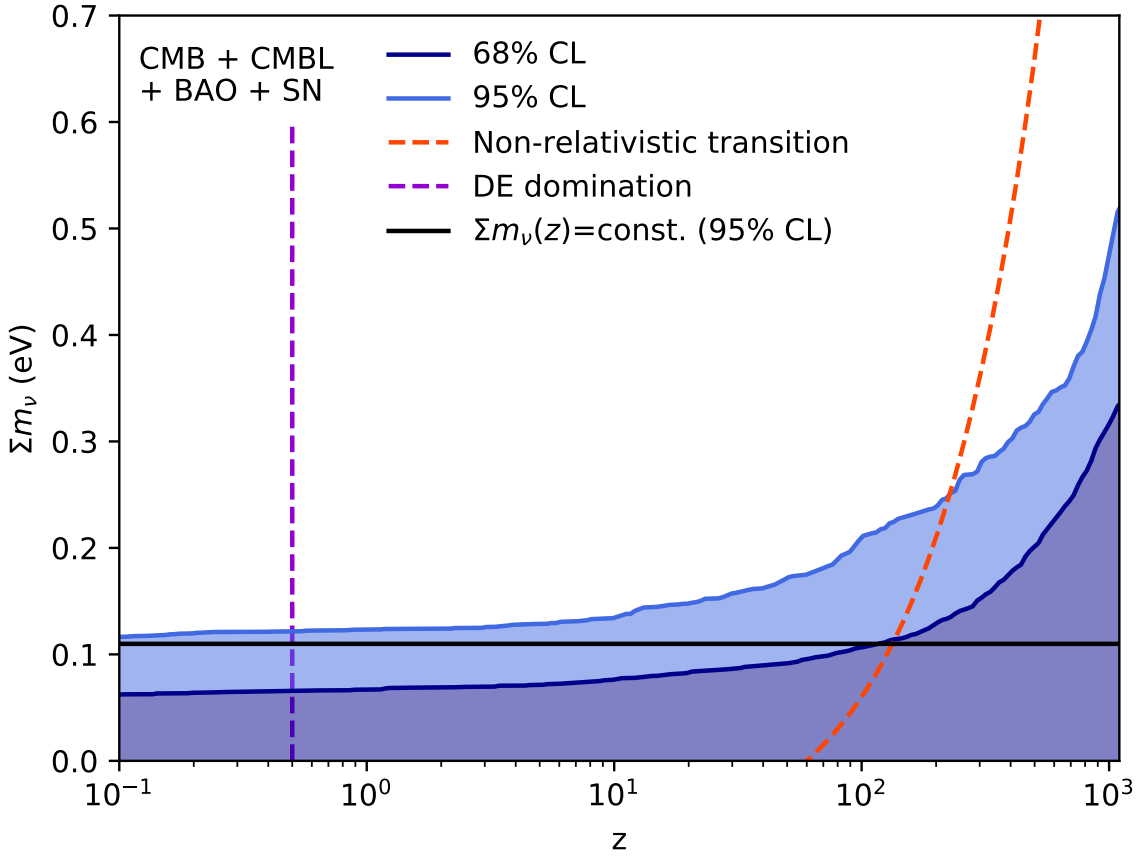


CSL et al. (2021), arXiv:2102.13618

Consistency test 1: Neutrino decay prior

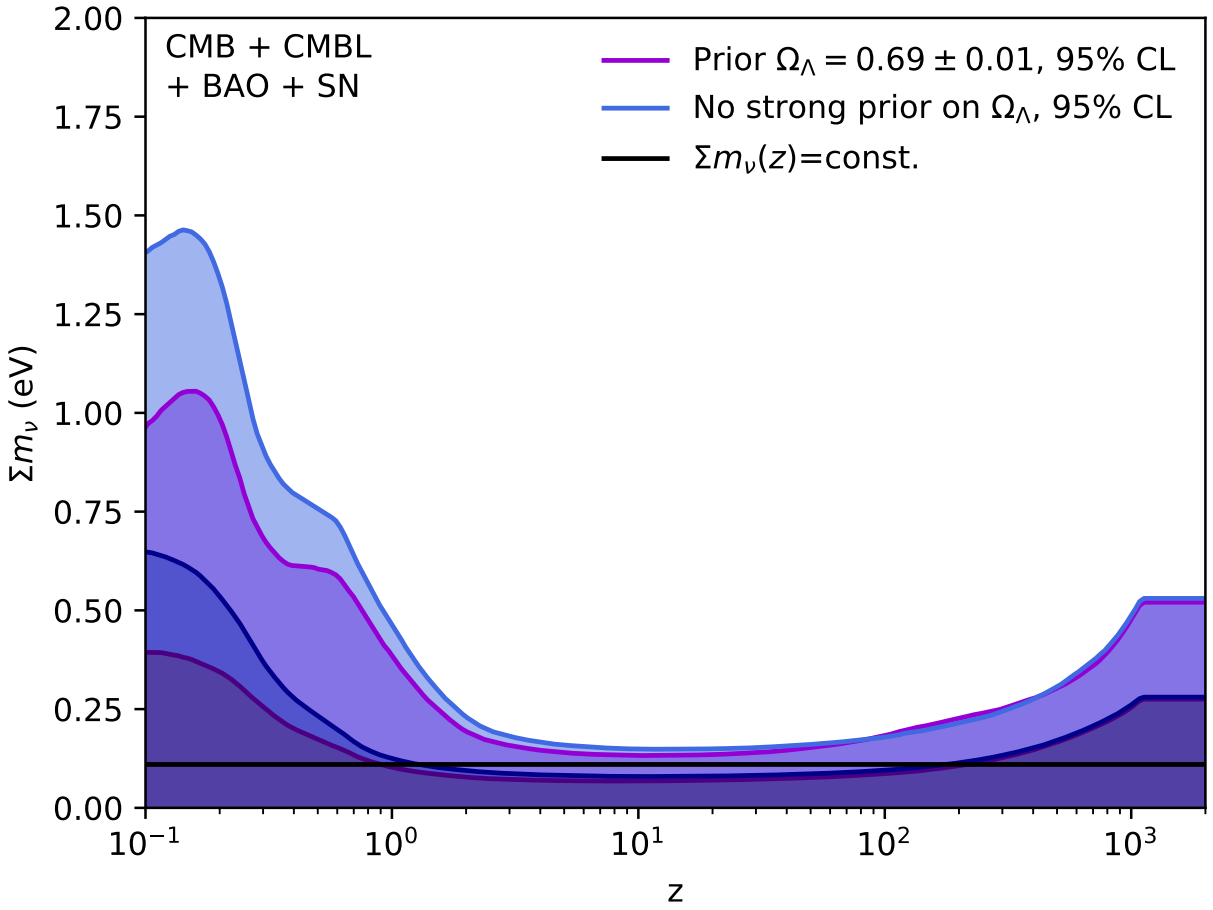
Prior requirement with $\sum m_{\nu,z_i} \leq \sum m_{\nu,z_j}$ for $z_i \leq z_j$

$\longrightarrow$ Limit for neutrino decay models: $\sum m_\nu < 0.25$ eV



CSL et al. (2021), arXiv:2102.13618

Consistency test 2: Dark energy and neutrino masses



CSL et al. (2021), arXiv:2102.13618

Reconstructing the neutrino mass as a function of redshift

Summary

- Current cosmological data constrain $\sum m_\nu$ tightly at high redshifts
- Higher neutrino masses are still allowed at low redshifts ($z \leq 3$)

$$\sum m_\nu(z=0) < 1.46 \quad \text{eV}$$

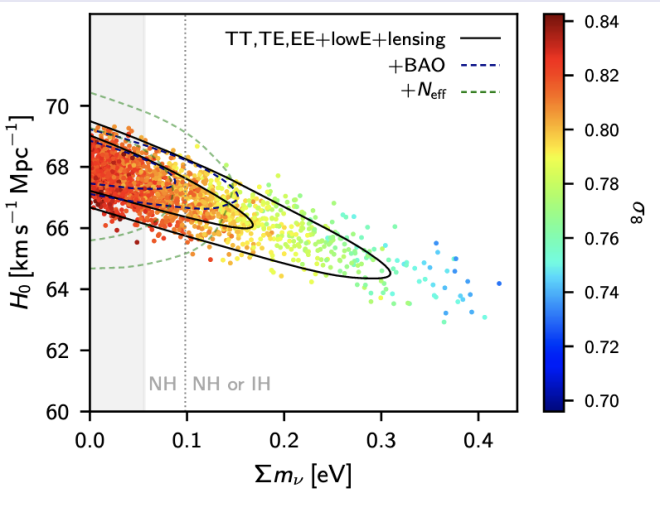
$$\sum m_\nu(z=1100) < 0.53 \quad \text{eV}$$

- Neutrino decay models can no longer explain a potential detection of absolute neutrino masses by KATRIN

Thank you for your attention!

Open questions

- Why are high neutrino masses allowed at low redshifts?
- Why is the neutrino mass limit measured by *Planck* so low?
- Which models could explain discrepancies between cosmological and terrestrial neutrino mass measurements?



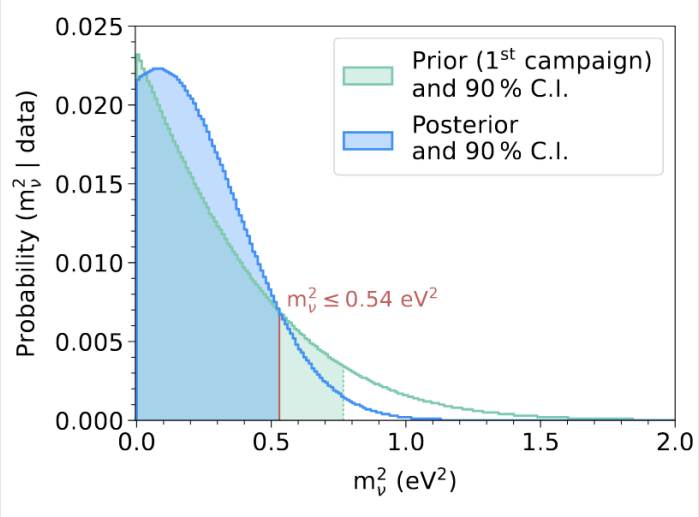


Image credit: Aghanim et al. (Planck Collaboration) (2018); M. Aker et al. (KATRIN Collaboration) (2021).