Gravitational CMB lensing illuminates neutrino interactions

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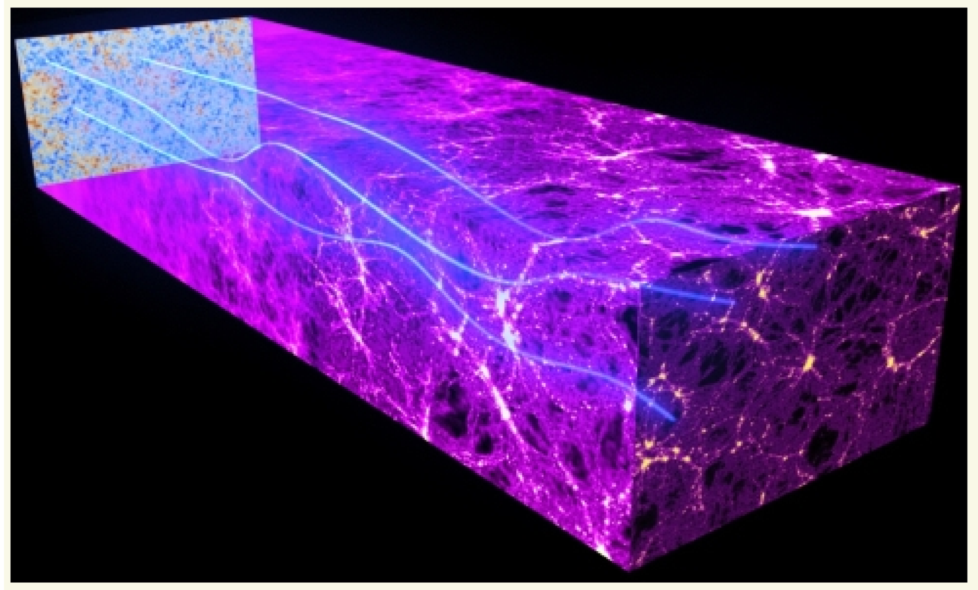
CMB lensing

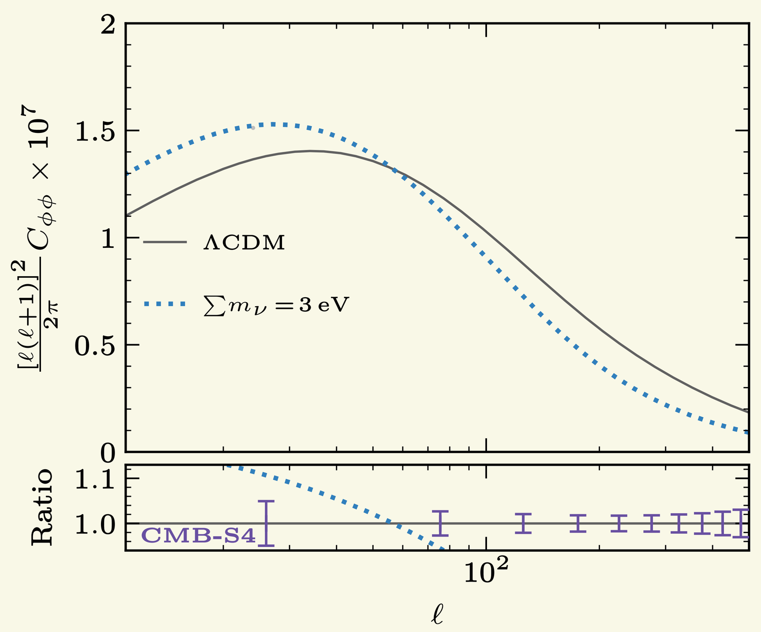


The CMB is lensed by the large-scale structure

Cosmological neutrinos shape the large-scale structure!

Effects of neutrino mass

Neutrinos have **many effects**.



Less lensing:

- Neutrinos move at c! (small scales)
- Neutrino mass increases ρ_ν, more early expansion!

More lensing:

- Neutrinos don'tmove at c! (large scales)
- Neutrino mass decreases H_0, less late expansion!

Overall, we expect a **suppression**. Exciting prospects!

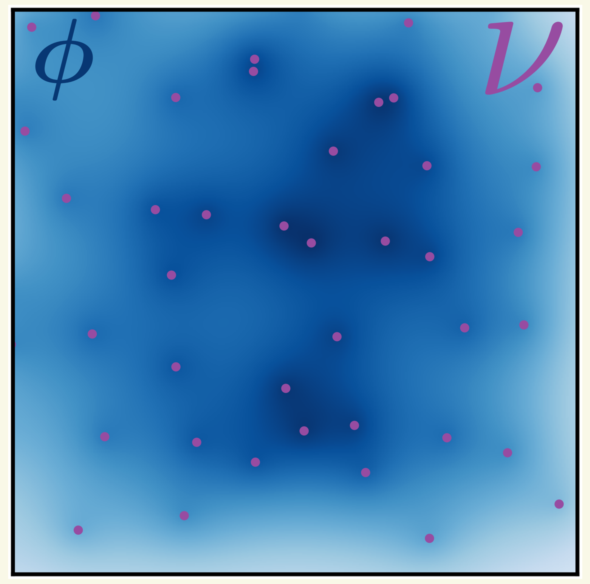
How robust is this?

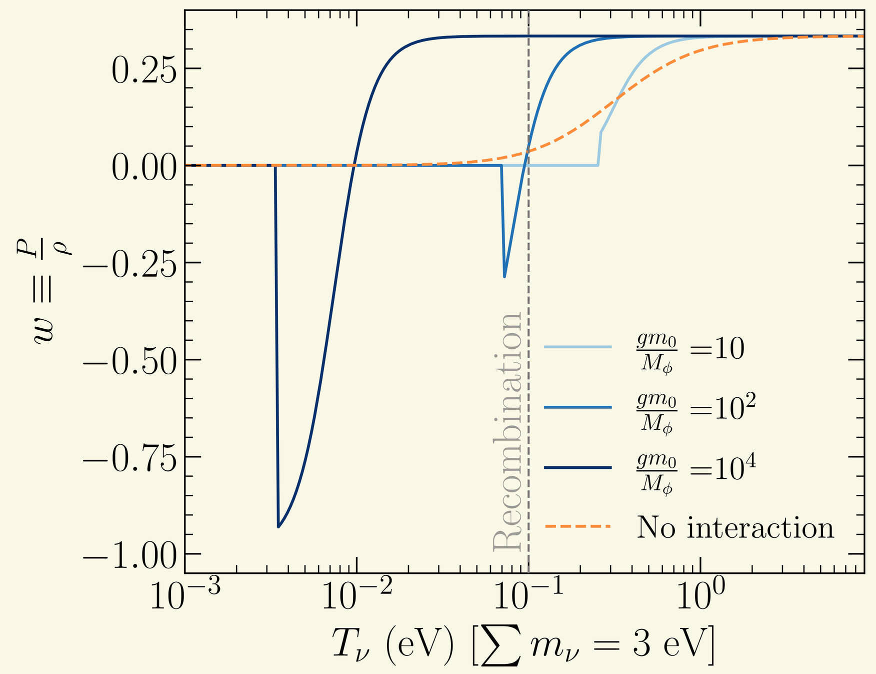
Cosmology is only sensitive to neutrinos through gravity.

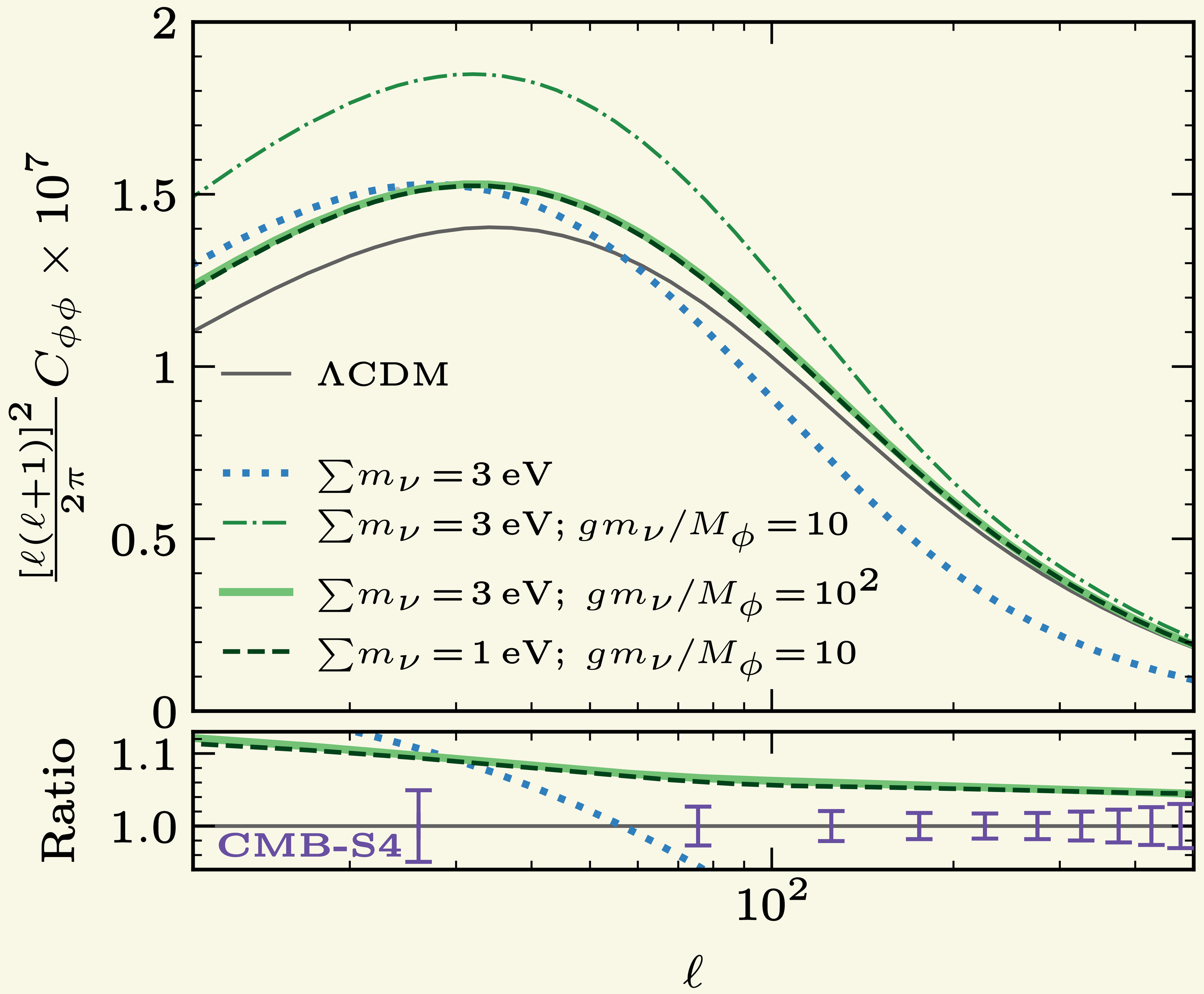
$$\dot{\rho}_\nu / \rho_\nu = -3H(1+w)$$

what if we change the equation of state w ...?

$$\mathcal{L} = -\frac{1}{2} M_\phi^2 \phi^2 - m_\nu \bar{\nu}\nu - g\phi\bar{\nu}\nu$$

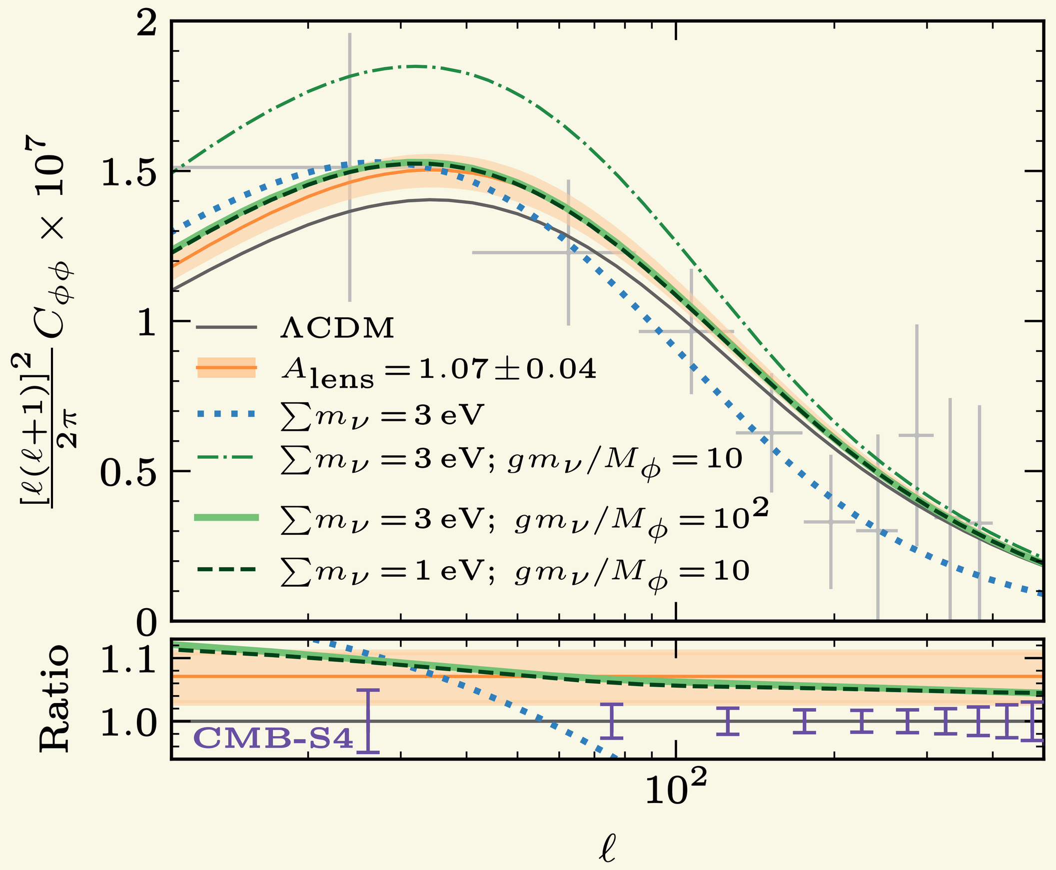






The effects now go in other directions.
We can now **increase** lensing!

There is an anomaly ...



What is the effect on the anomaly?

$$\Delta\chi^2_{\rm eff} = \chi^2_{\rm eff}(A_{\rm lens}=1) - \chi^2_{\rm eff}(A_{\rm lens}\neq 1)$$

	TTTEEE+lowl	TTTEEE+lowl+lensing	TTTEEE+lowl+lensing+BAO
ΛCDM	$p = 0.2\%$	$p = 6\%$	$p = 4\%$
Self-interactions	$p = 3\%$	$p = 38\%$	$p = 10\%$

Looking to the future

- CMB lensing is a **very sensitive** probe of neutrinos. We have been promised very good precision, a great window into neutrino masses!
- But cosmology is only **indirectly** sensitive to neutrinos.
- Neutrino self-interactions can alter dramatically the shape. They even alleviate an anomaly!
- Stay tuned!
- Other probes?
  - Supernovae?
  - Solar neutrinos?
  - Astrophysical neutrinos?