Probing Self-Interacting neutrinos with large-scale structure observations

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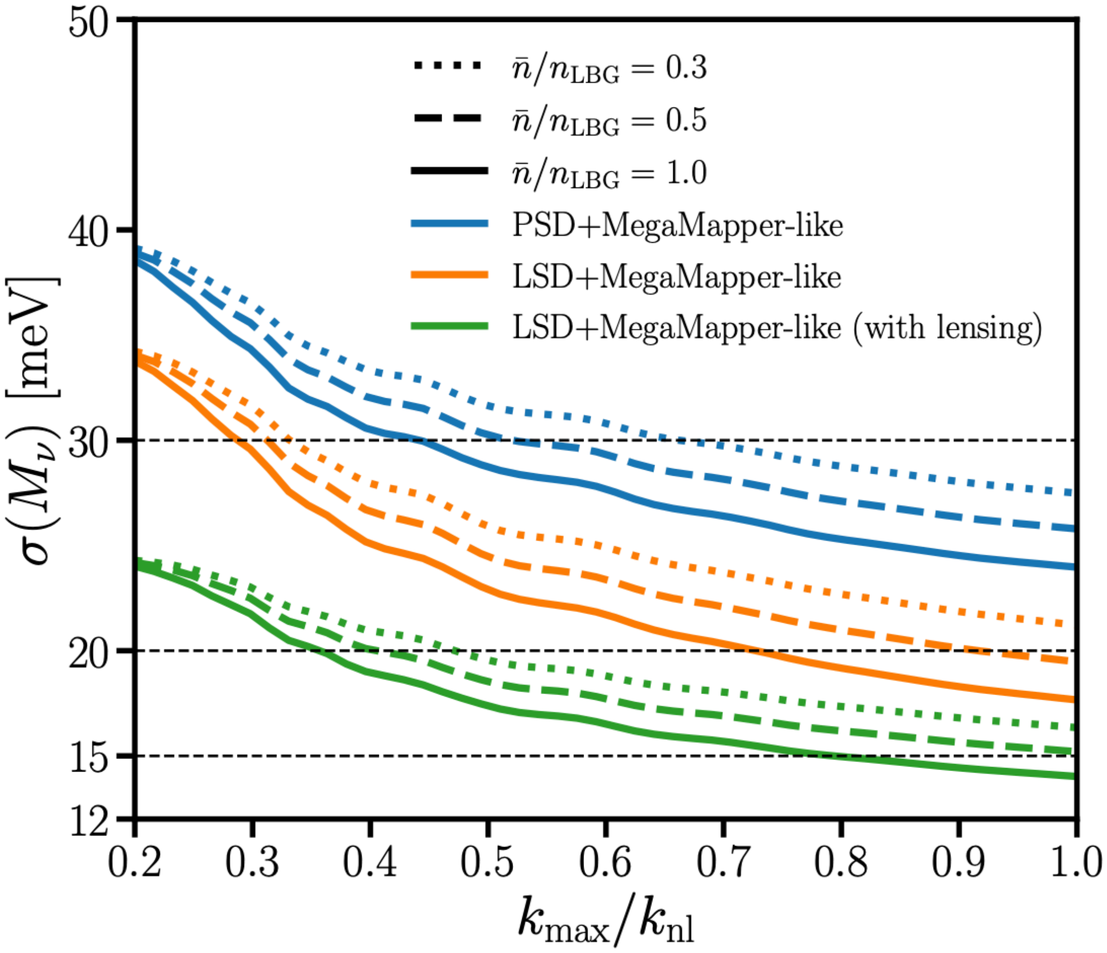
Neutrino cosmology

- Neutrinos represent 41% of the energy budget in the early Universe.
- Their gravitational interactions leave distinct imprints in various cosmological observables.
- Cosmological observations enable tight constraints on pivotal parameters describing neutrino properties, e.g., $\sum m_\nu$.
- Upcoming surveys will contribute to unveiling the nature of neutrinos!

N. Sailer et al., arXiv:2106.09713



A fundamental SM prediction

- According to the SM, neutrinos commence to free-streaming at $\sim$ 1 MeV (1s after BB).

$$\Gamma \sim G_F^2 T^5 \text{ and } H \sim T^2/m_{\rm Pl}$$

$$\left(\frac{\Gamma}{H}\right) \sim \left(\frac{T_{\rm FS}}{1\ \text{MeV}}\right)^3$$

- SM implies that before recombination, ν are the only source free-streaming radiation.
- As perturbations will be modified in function of the free-streaming nature of neutrinos, cosmological observables can be used to physics capable of modify the SM prediction!

Puzzling results: self-interactions in the CMB

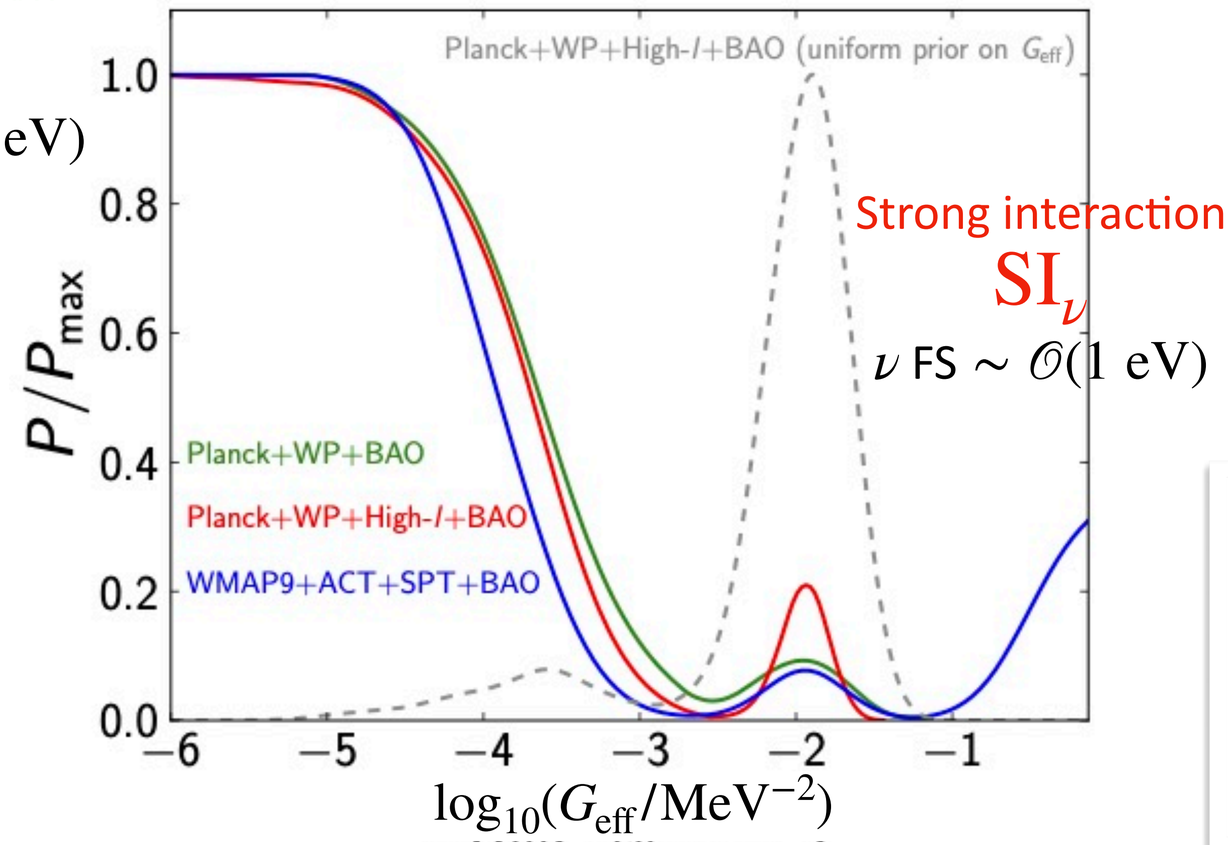
Some CMB data allow a cosmological scenario in which ν strongly interact, delaying their free-streaming until close to matter-radiation equality!

Mild interaction

MI_ν

ν FS $\gtrsim \mathcal{O}(100\ \mathrm{eV})$

F.-Y. Cyr-Racine, K. Sigurdson arXiv:1306.1536



Strong interaction

SI_ν

ν FS $\sim \mathcal{O}(1\ \mathrm{eV})$

SM Fermi constant

$G_{\rm eff} \sim \mathcal{O}(10^{-11})\ \mathrm{MeV}^{-2}$

$$\Gamma \propto G_{\rm eff}^2 T^5$$

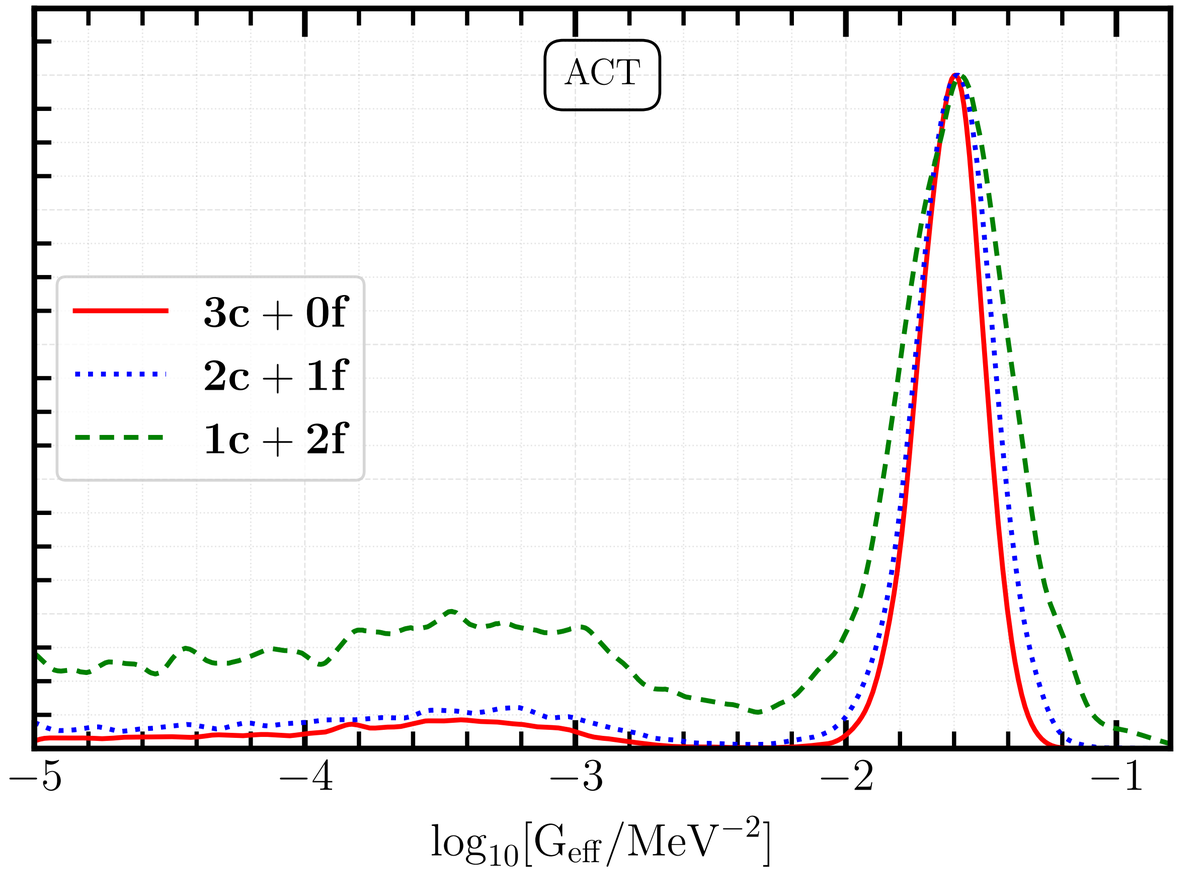
$$T_{\rm FS} \sim \left(\frac{G_F}{G_{\rm eff}}\right)^{2/3} \mathrm{MeV}$$

Archidiacono & Hannestad 2013,Lancaster et al. 2017,Oldengott et al.2017, Kreisch et al. 2017, Brinckmann et al. 2020, Das & Ghosh 2021 + others

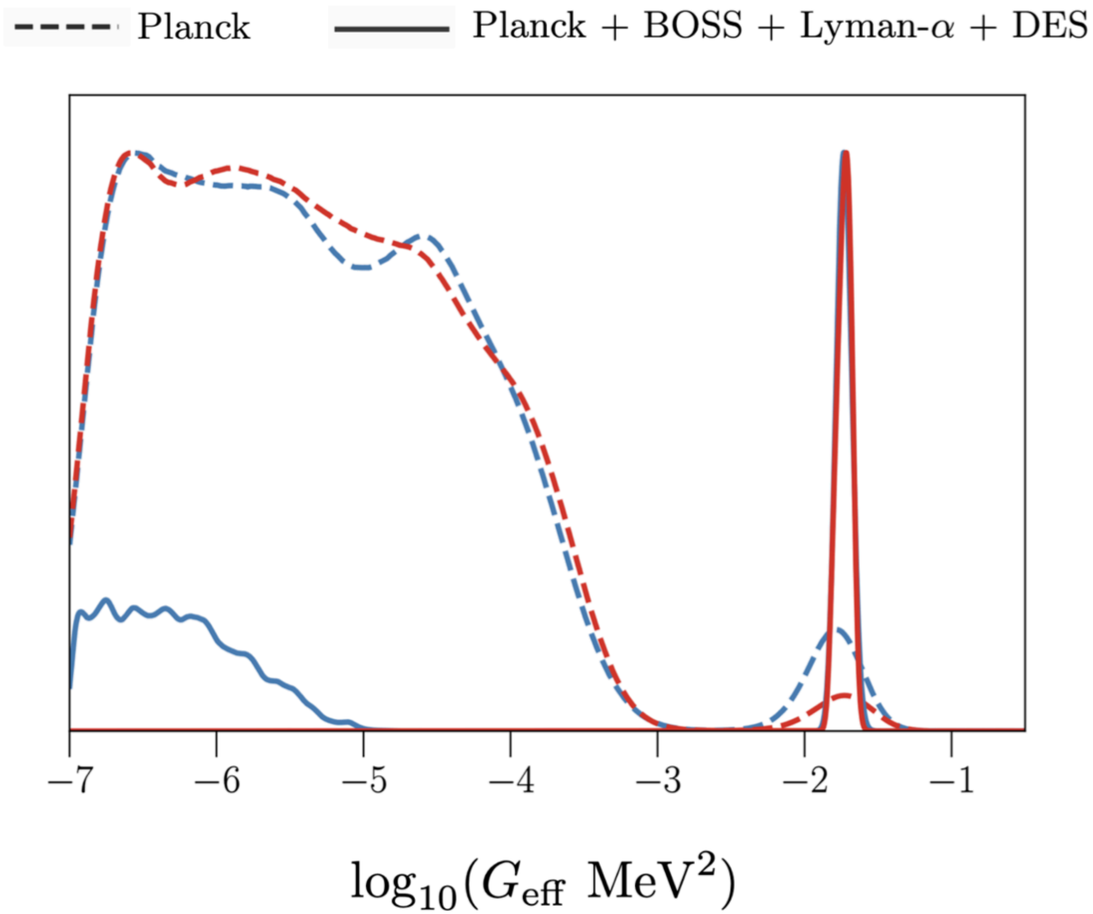
Puzzling results: self-interactions in the CMB

Some data display an outrageous preference for strongly self-interacting neutrinos!

A. Das and S. Ghosh, arXiv:2303.08843

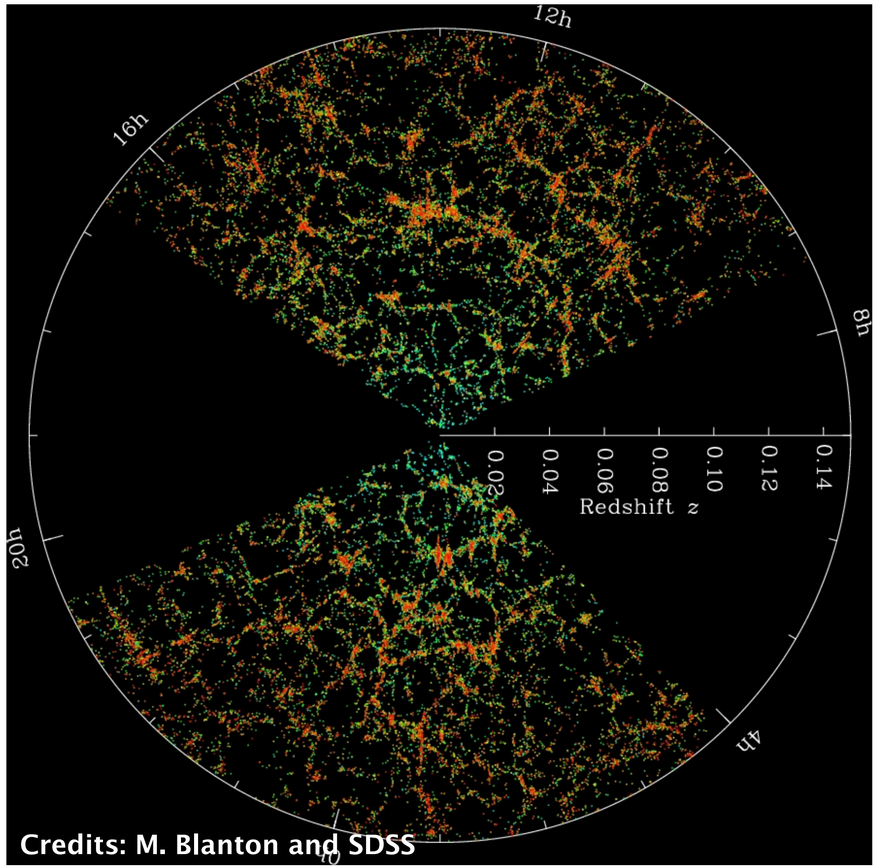


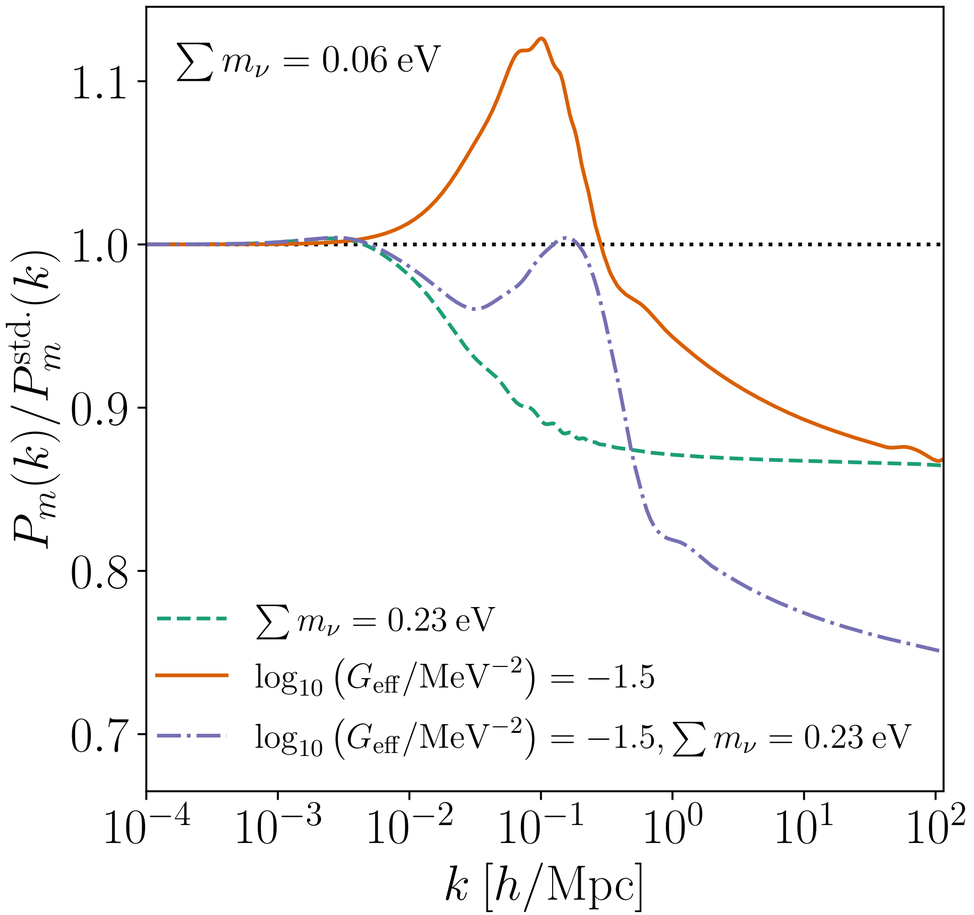
A. He, R. An et al., arXiv:2309.03956



Broadening the cosmological landscape

The evolution of perturbations as presented by the CMB data suggest that our Universe could feature novel interactions in the neutrino sector, yet…





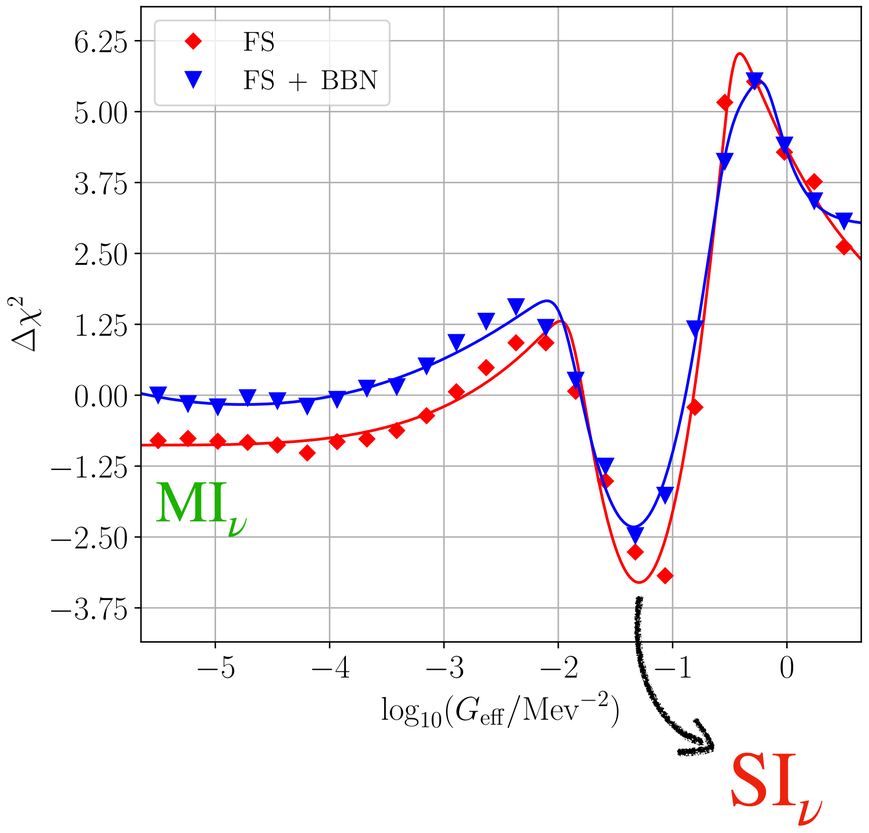
Matter clustering suppression at small scales

→ SI_ν

More puzzling results: self-interactions in the LSS

The galaxy power spectrum displays a mild preference for strongly self-interacting neutrinos!

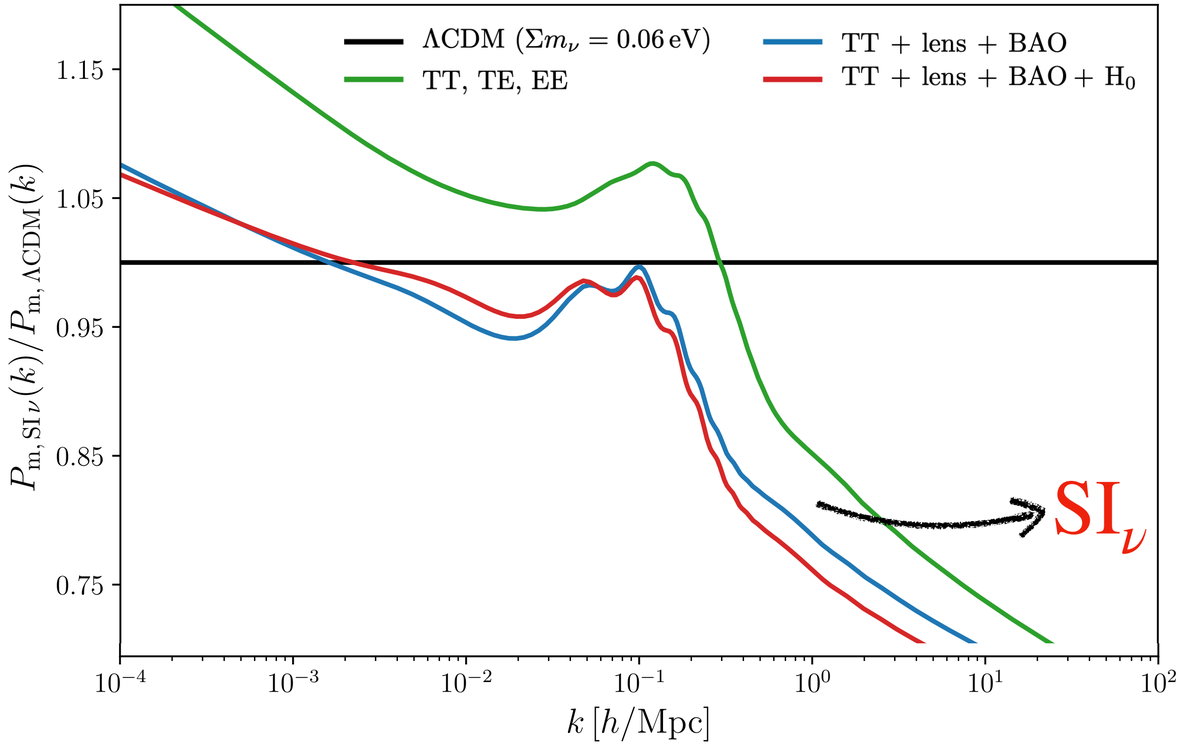
D.C, Cyr-Racine, Houghteling arXiv:2309.03941



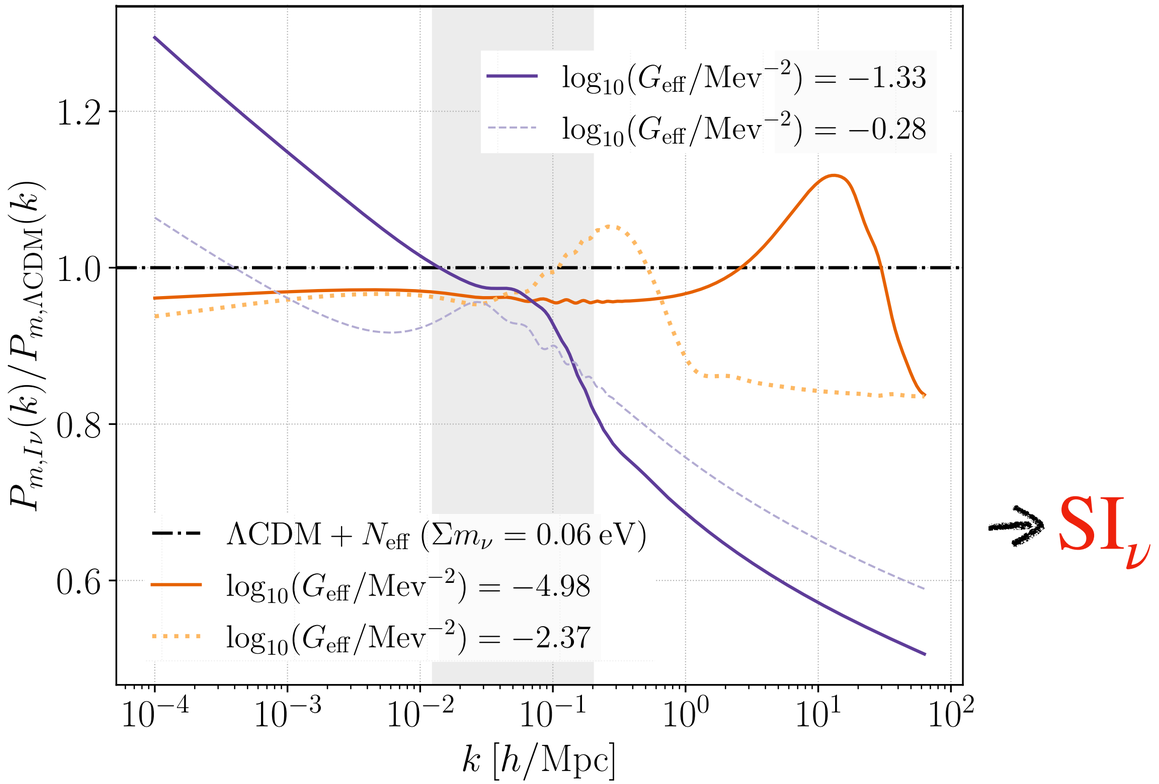
Apparent agreement between CMB and LSS

Owing to correlations with the primordial power spectrum parameters, self-interacting neutrinos predict an important clustering suppression at sub-galactic scales!

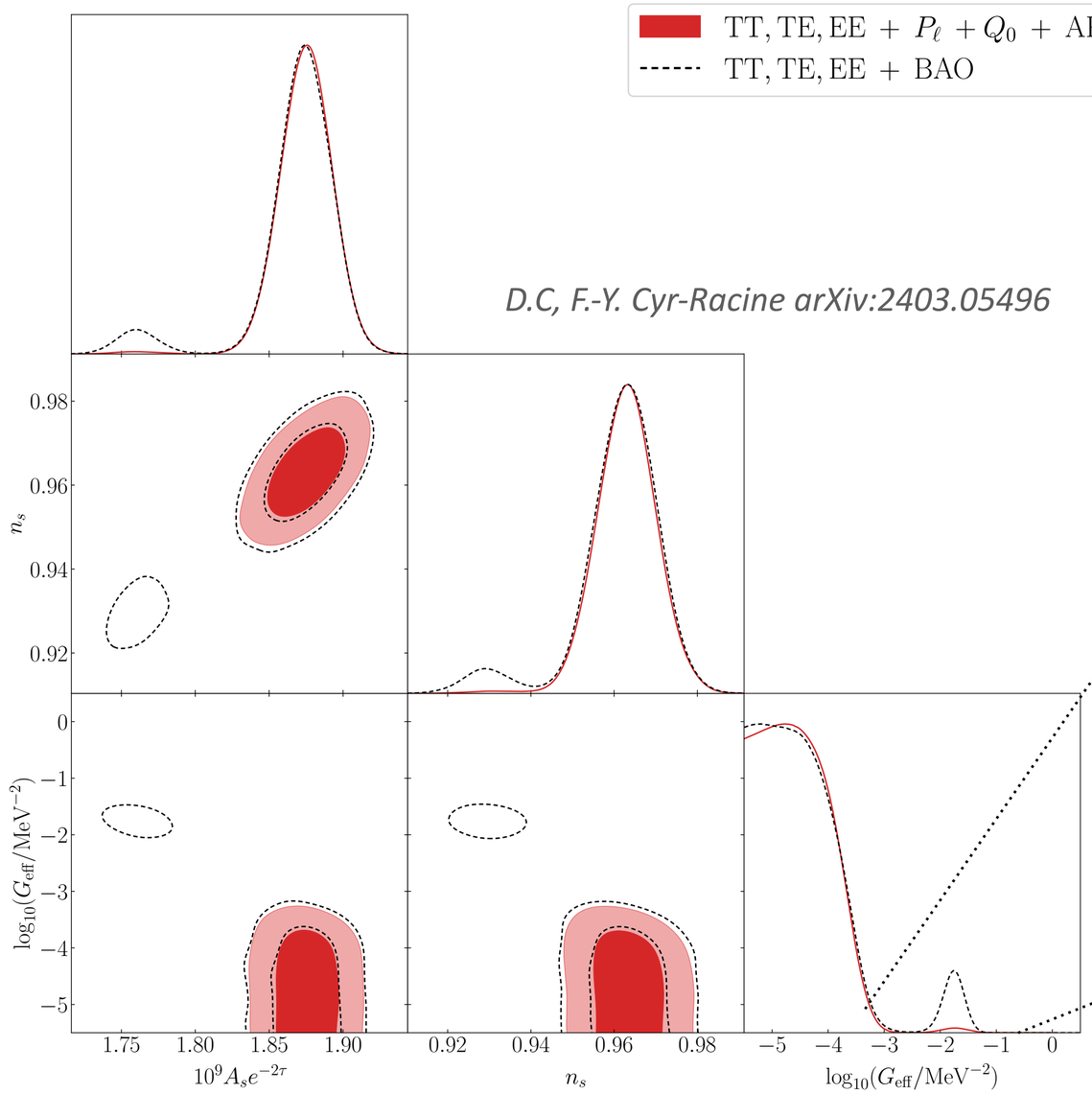
CMB + BAO



Galaxy power spectrum

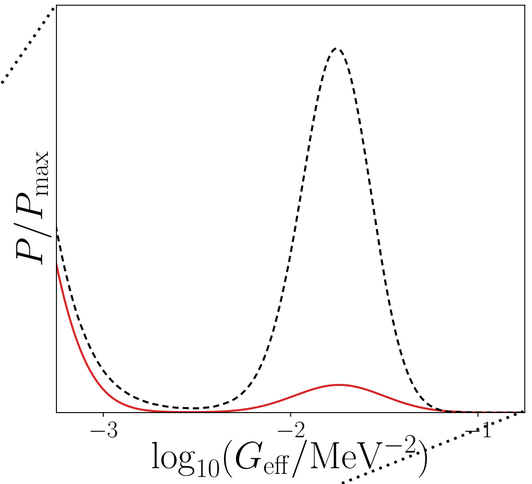


Challenges to the simple self-interacting ν cosmology



D.C, F.-Y. Cyr-Racine arXiv:2403.05496

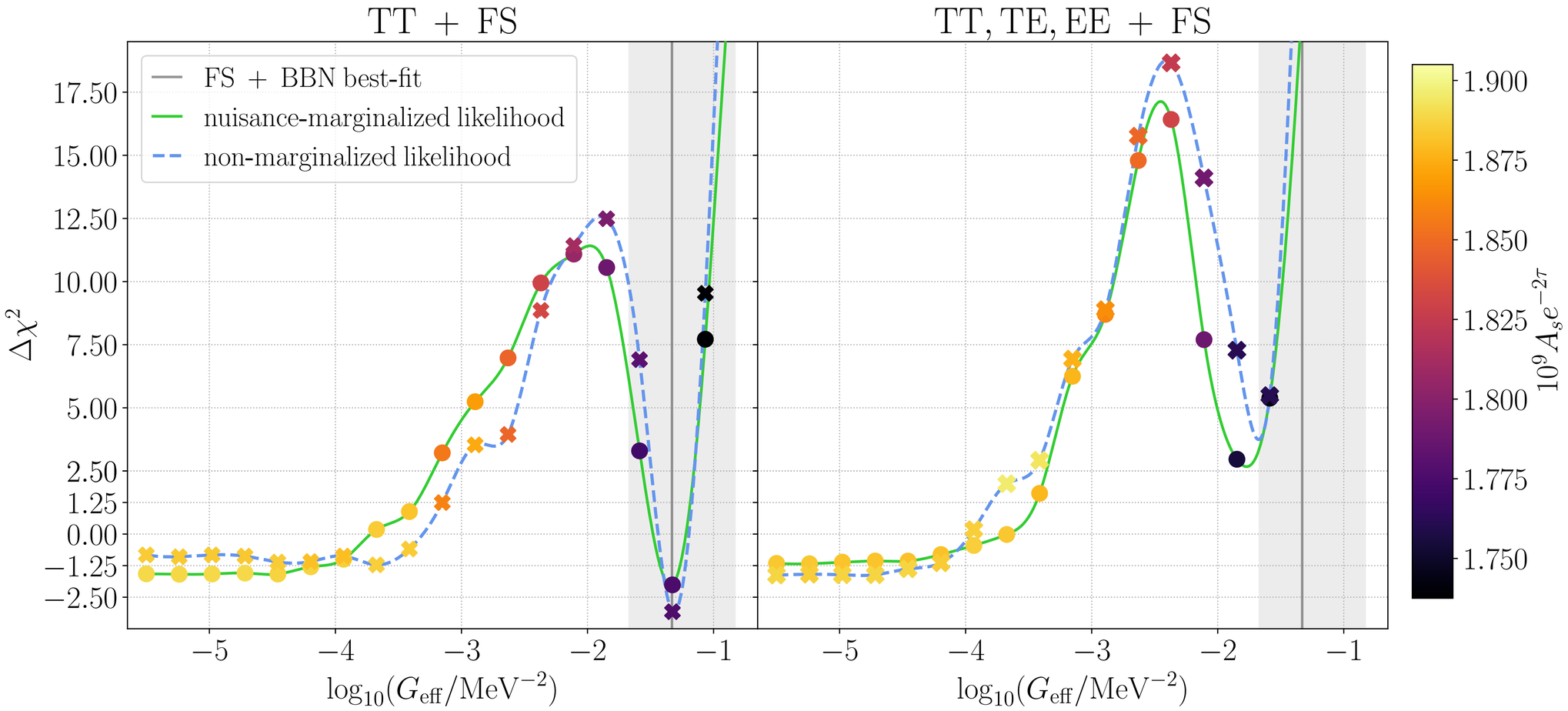
Data	ΛCDM	ΛCDM + $N_{\rm eff}$ + $\sum m_\nu$	MI$_\nu$
$\Delta\chi^2_{\rm total}$	2.46	3.84	3.65
$\Delta{\rm AIC}_{i0}$	8.46	5.84	3.65
B_{i0}	0.0007 ± 0.0005	0.023 ± 0.015	0.0066 ± 0.0045



Our analysis disfavor the simplest representation of the $\rm SI_\nu$ mode

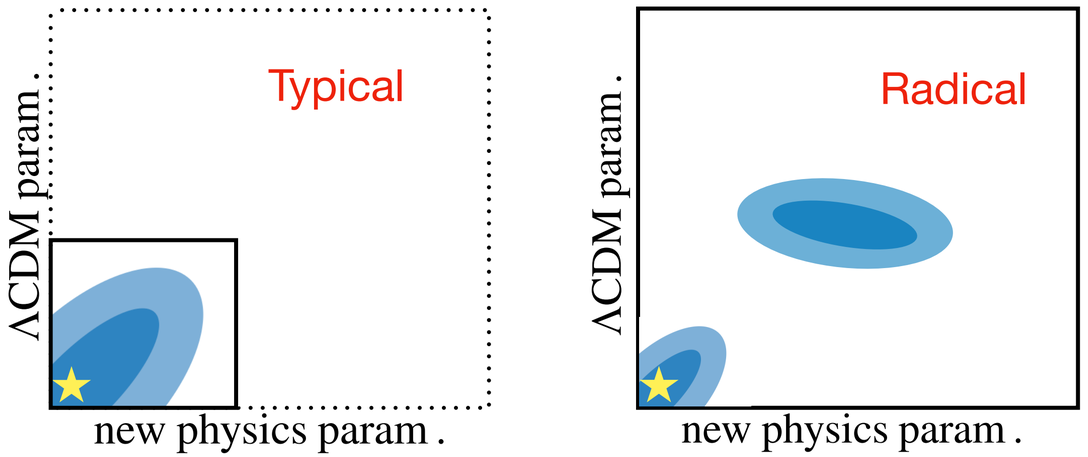
Simultaneous analysis of LSS and CMB

The difficulty of simultaneously fitting the CMB and galaxy power spectra employing the simplest neutrino self-interaction scenario relates to the S8 tension!



Takeaways

- Galaxy power spectrum also allows the SI_ν mode (it is not an incidental feature in the CMB).
- It is difficult to simultaneously fit the galaxy and CMB data (related to the S8 tension).
- The SI_ν mode could hint at a yet-to-be-discovered feature in the Early Universe.
- Our results motivates the exploration of more complex models.



It is crucial to bear in mind that radically different scenarios could provide a good fit to the cosmological observables!