Cosmological constraints on (massive) light relics: current status

2023 Summer Collaboration Meeting - 2 Aug 2023

Martina Gerbino - INFN Ferrara

Image credit: Sara Zollo

What next in neutrino cosmology

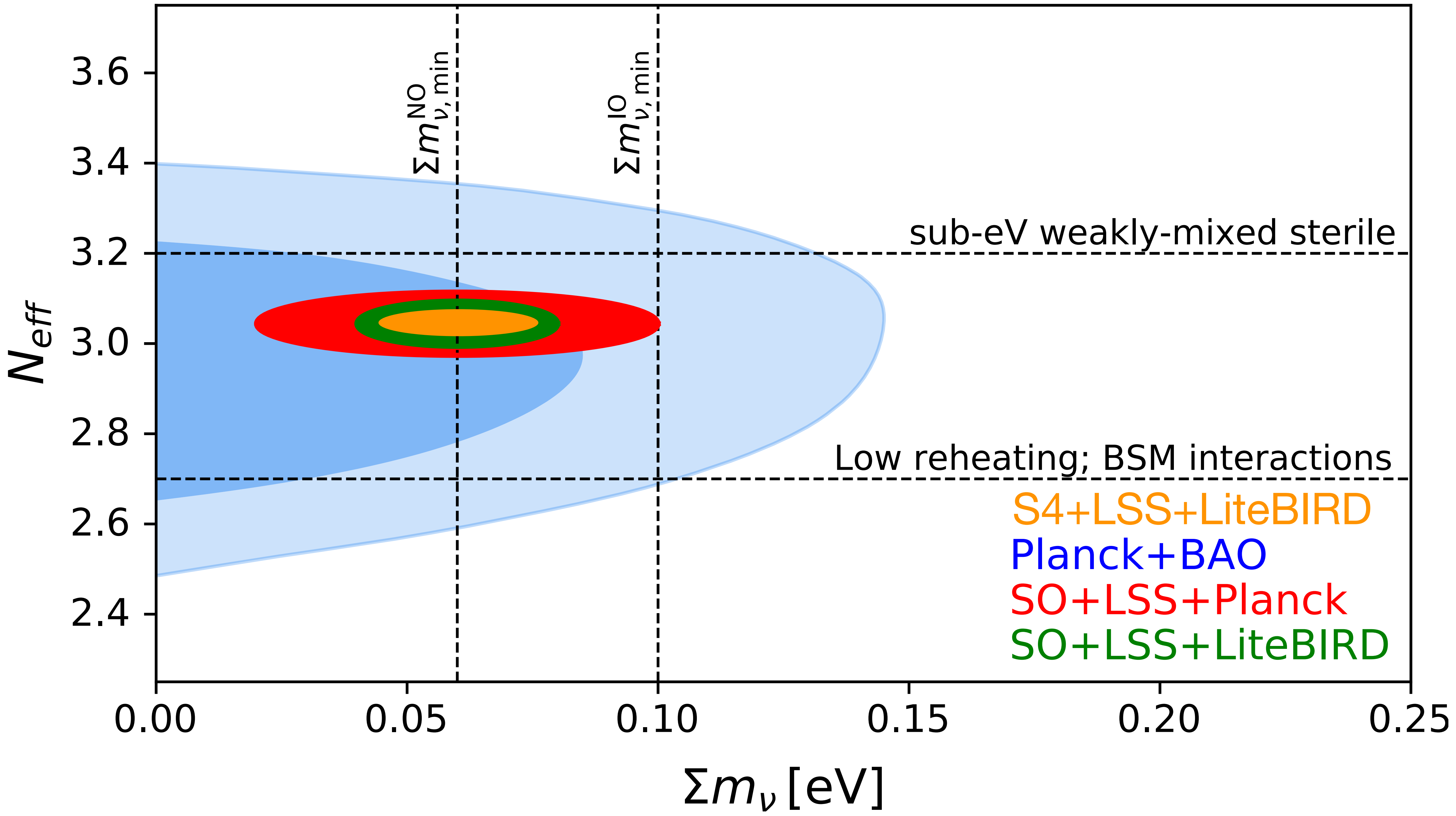
The new generation of cosmological surveys is approaching: Simons Observatory, Euclid, LiteBIRD, CMB-S4, DESI, Rubin, SPHEREx, SKA …
Does it mean that we are moving:

1) **Towards the first detection of the neutrino mass scale?**

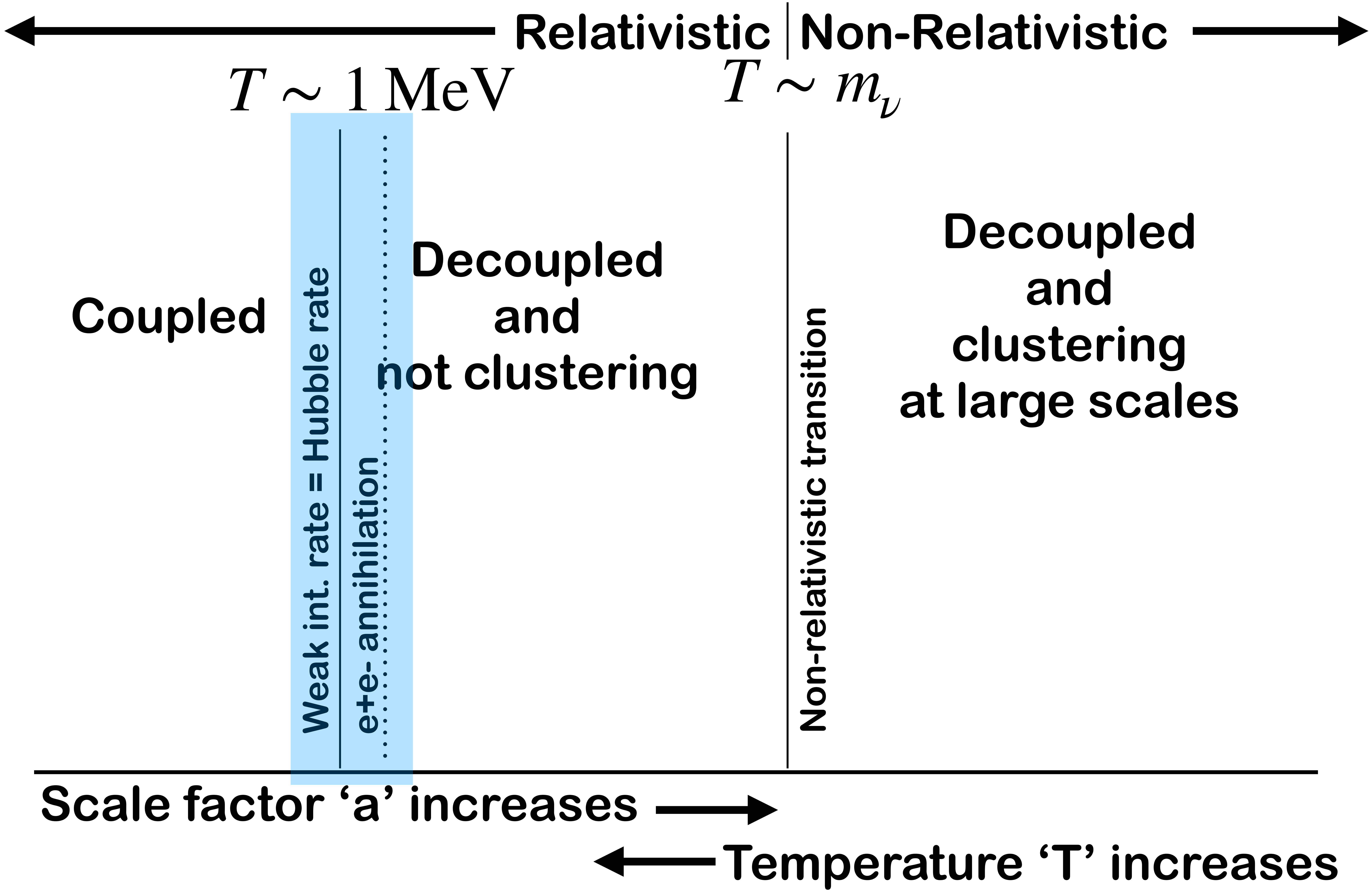
$$\sigma(\Sigma m_\nu) = 0.02\,\mathrm{eV}$$

2) **Towards the first probe of the physics of neutrino decoupling, and of BSM content at very early times?**

$$\sigma(N_{\rm eff}) = 0.03$$

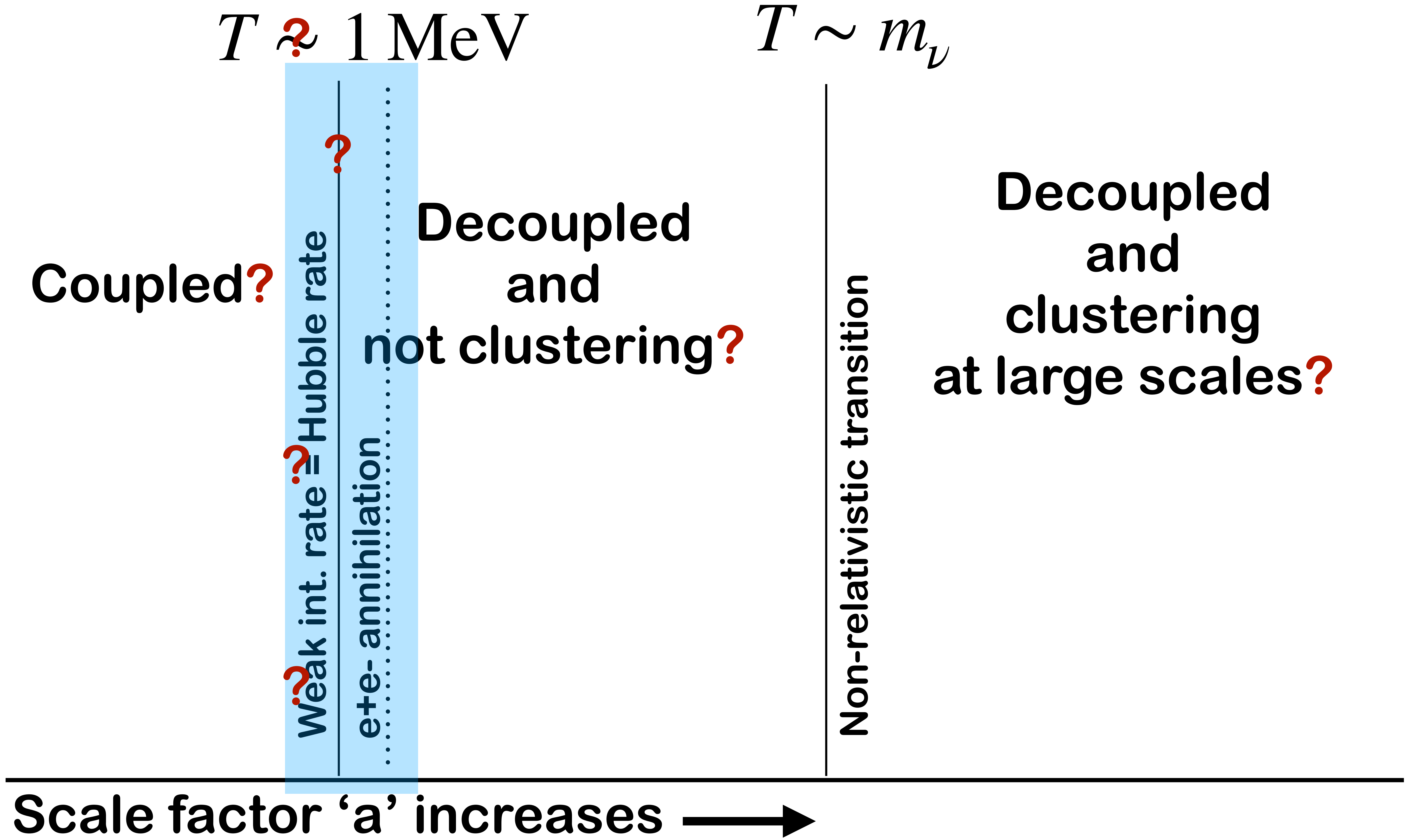


Neutrino cosmology



BSM neutrinos?

What if they are not what we think?
(or: how sensitive are we to standard assumptions?)



Thanks to many collaborators!

Results shown in the next slides are in collaboration with several amazing people:

Junior: L. Caloni (UniFE), P. Carenza (Stockholm),
F. Forastieri (UniFE), G. Lucente (UniBA -> SLAC)

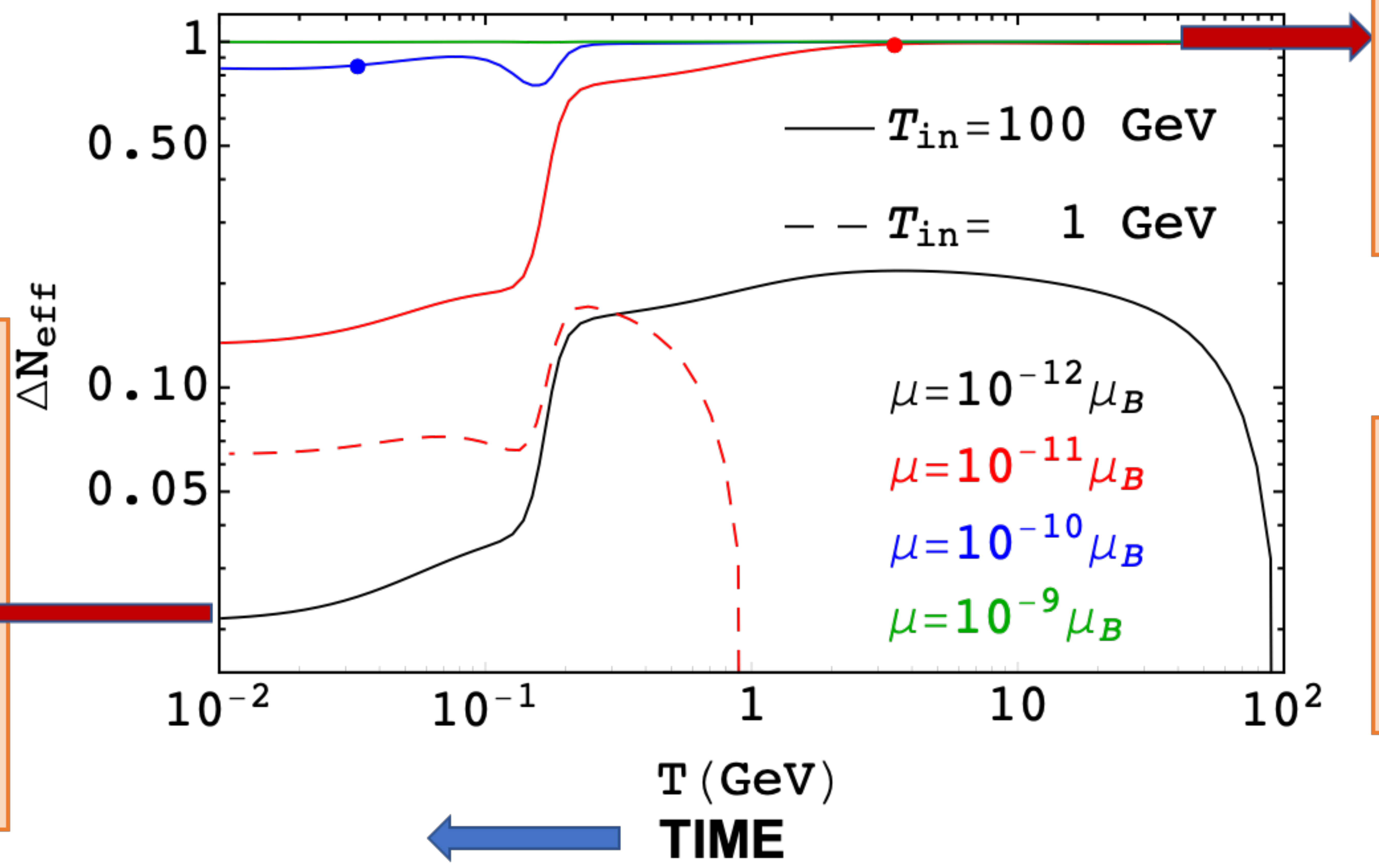
Staff: T. Brinckmann (UniFE), M. Lattanzi (INFN FE),
M. Giannotti (Miami), L. Visinelli (Shanghai)

and E. Grohs (Victoria and NC U) and all the co-authors of arXiv:2203.07377 (Snowmass contribution on Synergy between lab and cosmo probes)

Neutrino magnetic moment

If neutrinos have a magnetic moment, e.m. interactions in the plasma can flip the ν helicity

A population of right-handed neutrinos is created from a purely left-handed initial ensemble



"Large" magnetic moment: thermal equilibrium is established at early times.

"Small" magnetic moment: thermal equilibrium never established. Freeze-in production. Abundance depends on initial temperature.

In both cases, abundance is diluted by entropy production after decoupling

Carenza+(incl. MG), 2022; Slide: courtesy of M. Lattanzi

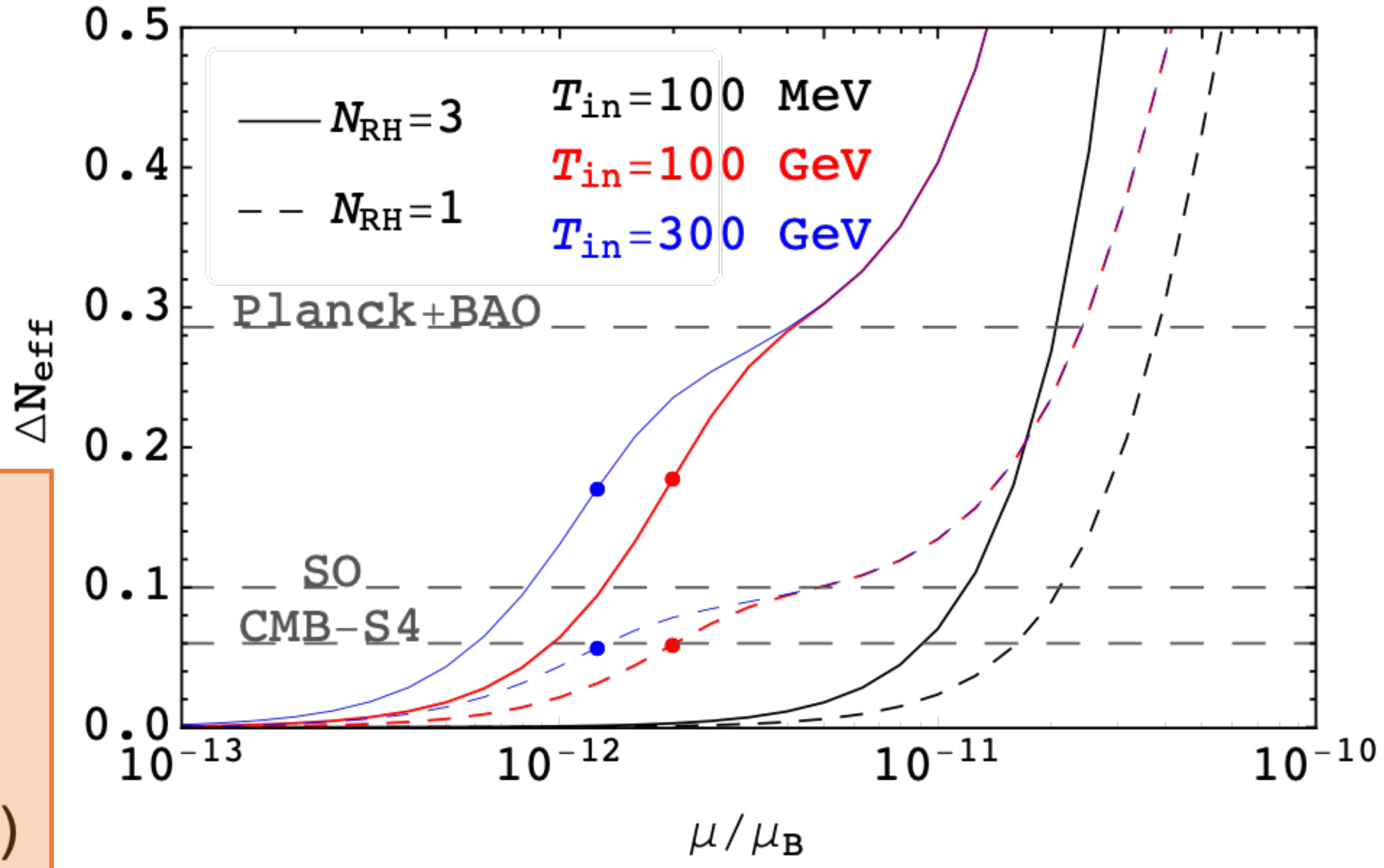
Neutrino magnetic moment

CMB experiments can provide competitive constraints on the neutrino magnetic moment

$\mu < 4.6 \times 10^{-12}\ \mu_b$ (Planck+BAO)
$\mu < 1.7 \times 10^{-12}\ \mu_b$ (Planck+BBN)
($T_{max} \geq 100$ GeV)

Carenza+ (incl ML, arXiv:2211.0432)

Compare with
- $\mu < 6 \times 10^{-11}\ \mu_b$ (cosmo, EERS87, assumes th. eq)
- $\mu < 2.7 \times 10^{-12}\ \mu_b$ (cosmo, Li&Xu arXiv:2211.04669) (assumes th. eq)
- $\mu < 6.4 \times 10^{-11}\ \mu_b$ (lab, XENONnT arXiv:2207:11330)
- $\mu < 1.2 \times 10^{-12}\ \mu_b$ (astro, Capozzi&Raffelt PRD2020)

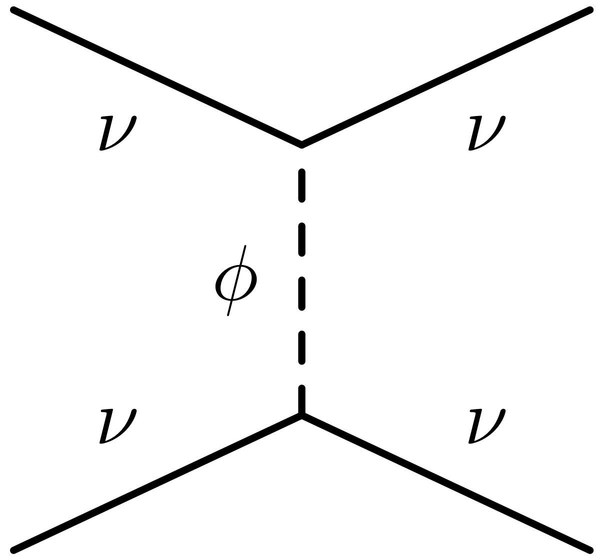


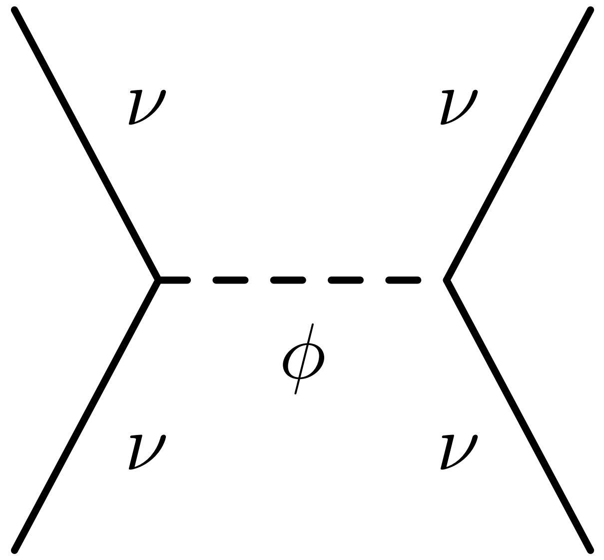
(95% CL bounds)

Carenza+(incl. MG), 2022;
Slide: courtesy of M. Lattanzi

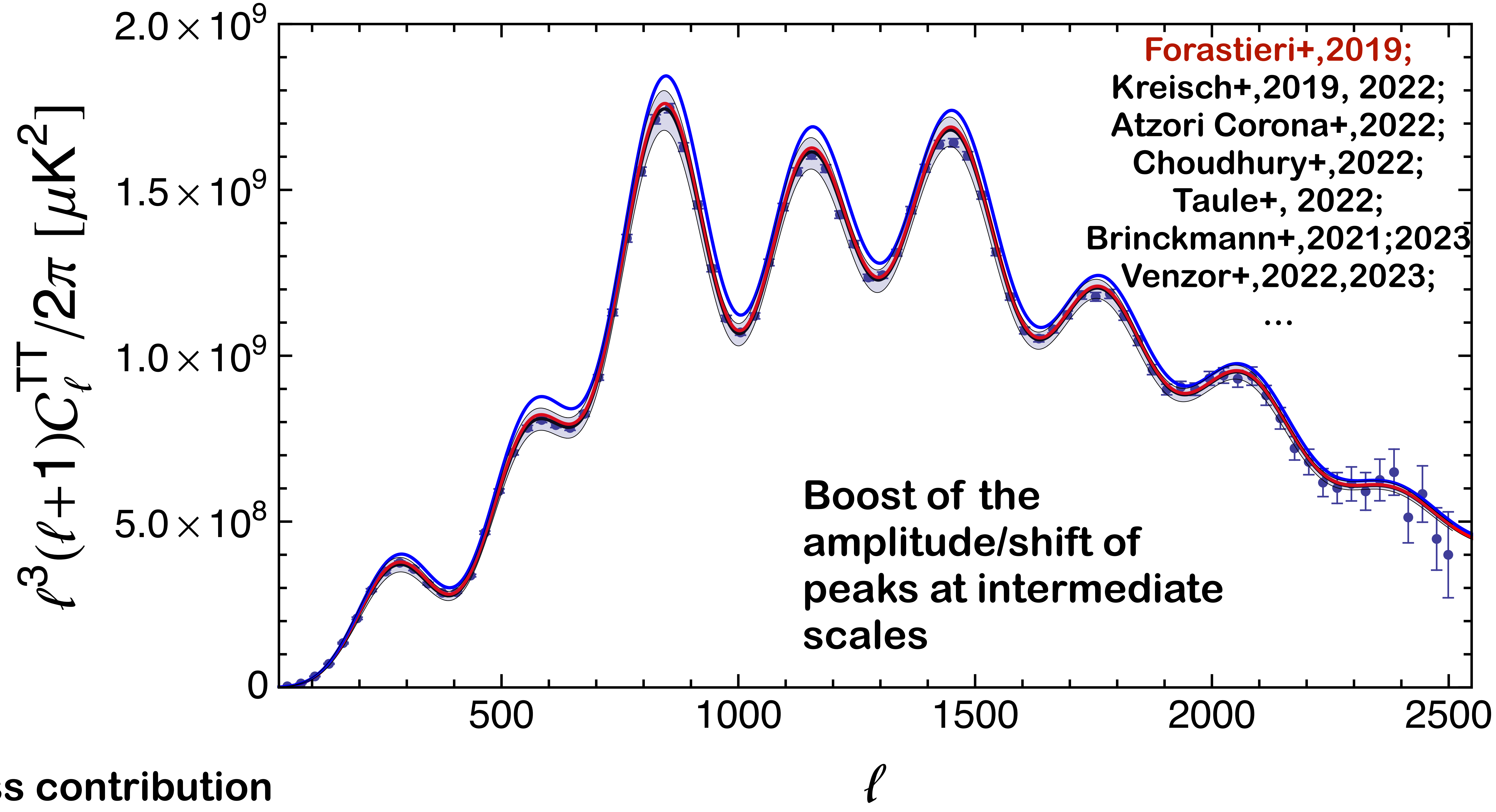
Neutrino non-standard interactions

$$\mathcal{L} \supset h_{ij}\bar{\nu}_i^c \nu_j \phi + g_{ij}\bar{\nu}_i^c \gamma_5 \nu_j \phi + h.c.$$





Collisional processes suppress stress and affect the perturbation evolution.
Neutrino free-streaming altered non-trivially.



See also Berryman+(incl.MG) 2023, Snowmass contribution

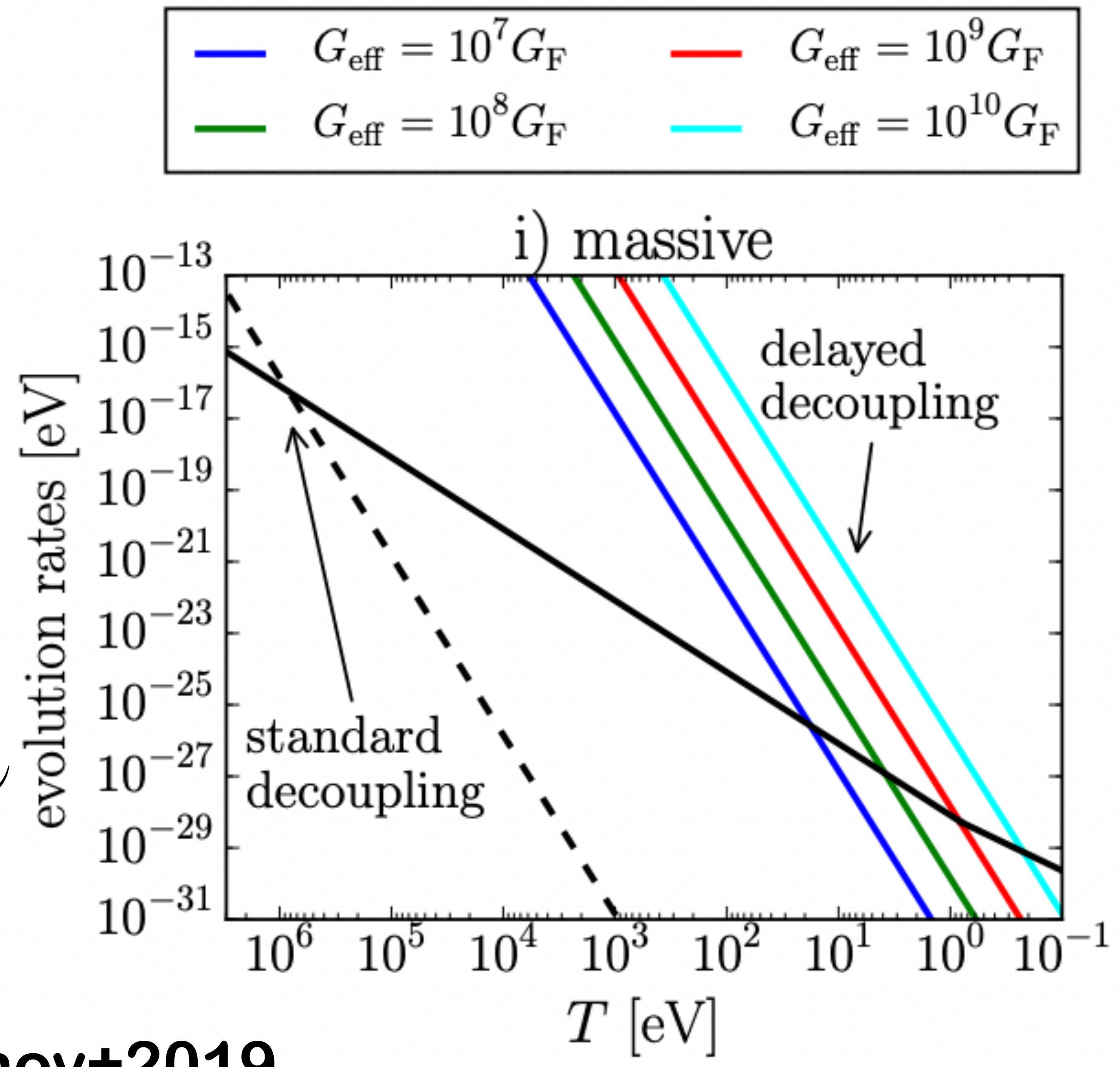
Neutrino non-standard interactions

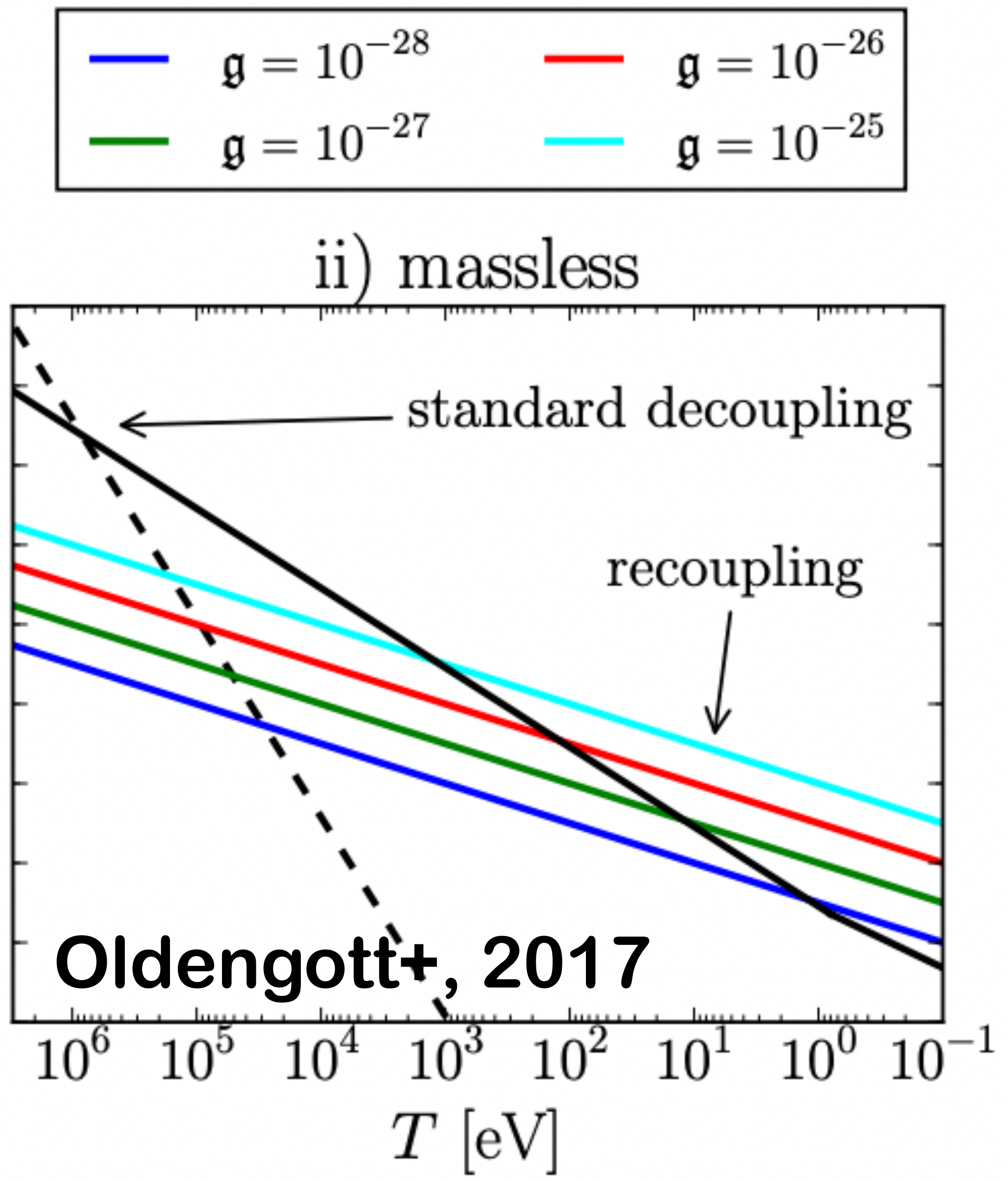
$$\Gamma_{\rm NSI} = G_{\rm eff}^2 T^5$$

$$\log_{10}(G_{\rm eff}\,{\rm MeV}^2) \lesssim -3 \quad {\rm MI}\nu$$

$$\log_{10}(G_{\rm eff}\,{\rm MeV}^2) = -1.61^{+0.11}_{-0.077} \quad {\rm SI}\nu$$

ACT+Planck
LCDM+NSI+Neff+mnu
Kreisch+, 2022; however, see Blinov+2019

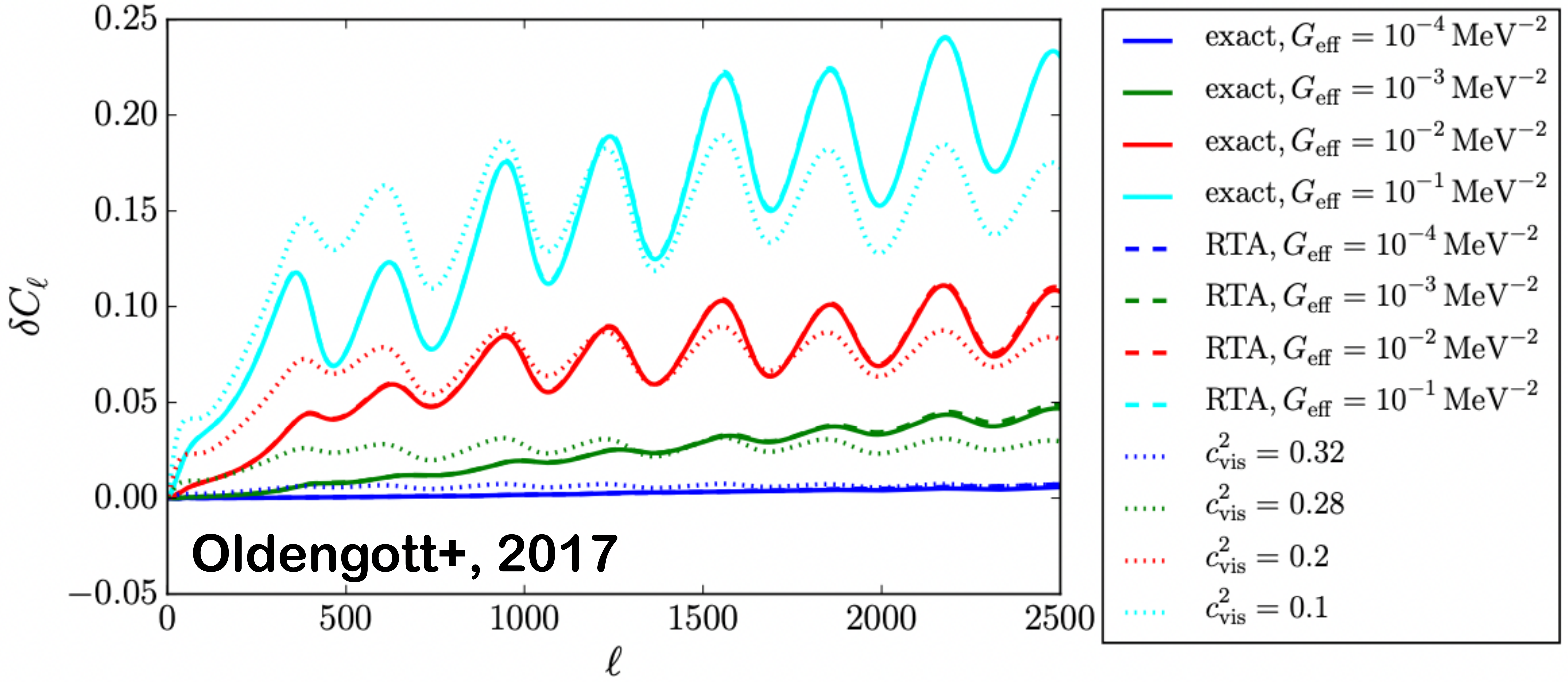




$$\Gamma_{\rm NSI} \propto g_{\rm eff}^4 T$$

$$g_{\rm eff}^4 < 1.64 \times 10^{-27}$$

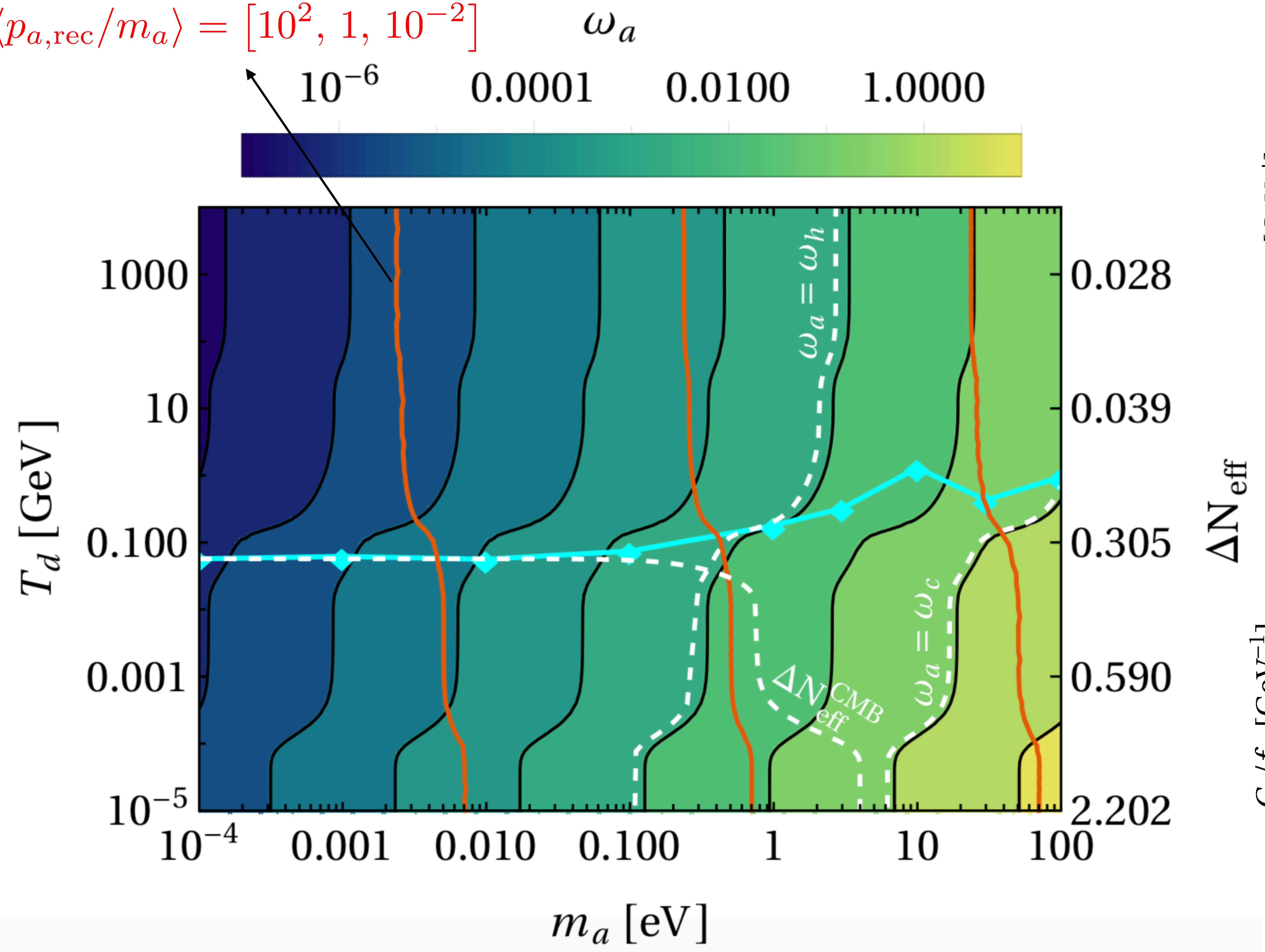
Planck
LCDM+NSI
Forastieri+, 2019

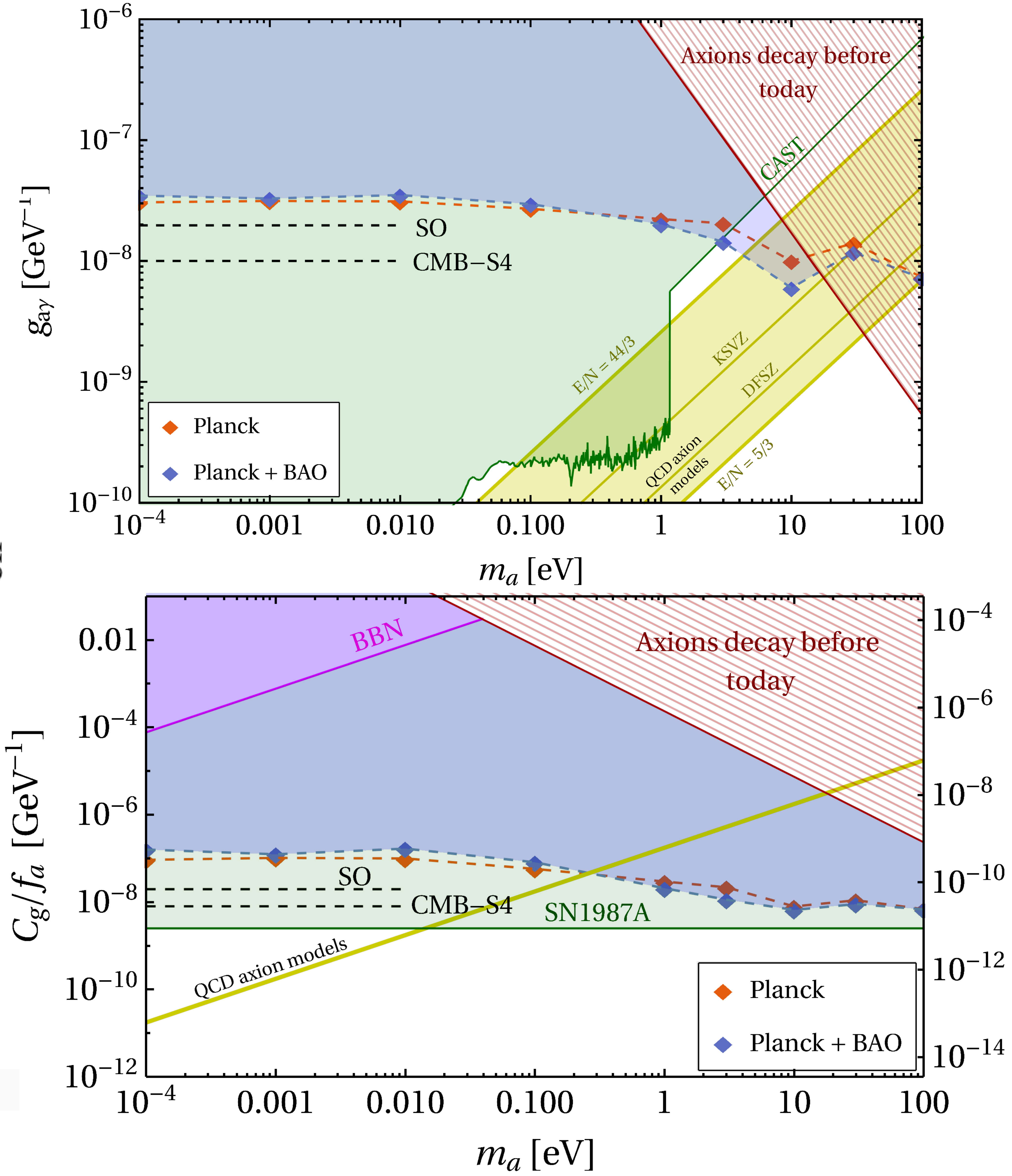


Detailed comparison is more complicated
due to physics scenario
and evolution equations

Axion-like Particles (ALPs)

$\langle p_{a,\mathrm{rec}}/m_a \rangle = [10^2,\, 1,\, 10^{-2}]$





Caloni, MG,+, 2022

Conclusions?

Massive light relics: very similar phenomenology (contribution to energy density). How to disentangle?

Enhanced sensitivity of future surveys demands enhanced accuracy: is it possible and feasible to achieve?

Entering the synergy epoch: CMB alone can do a lot for BSM particle physics; can do much more when combined with LSS; can do even more when cosmology meets astro&lab searches