Flavor-specific Neutrino Self-interaction in Cosmology

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[Based on arXiv:2011.12315]

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Introduction

Neutrinos

The most illusive particle in the SM

Electroweak interaction

Secret Interaction ?

Self interaction, interaction with Dark sector etc.

- ✦ Anomalous signal in short- baseline experiments
- ✦ Supernova Neutrinos
- ✦ Cosmological signatures

Cosmological signatures of Neutrino self interaction

$$\mathscr{L}_{\text{int}} \supset \frac{1}{2} g_{ij} \bar{\nu}_i \nu_j \phi, \quad g_{ij} = g\delta_{ij}$$

← Flavor universal Self-interaction

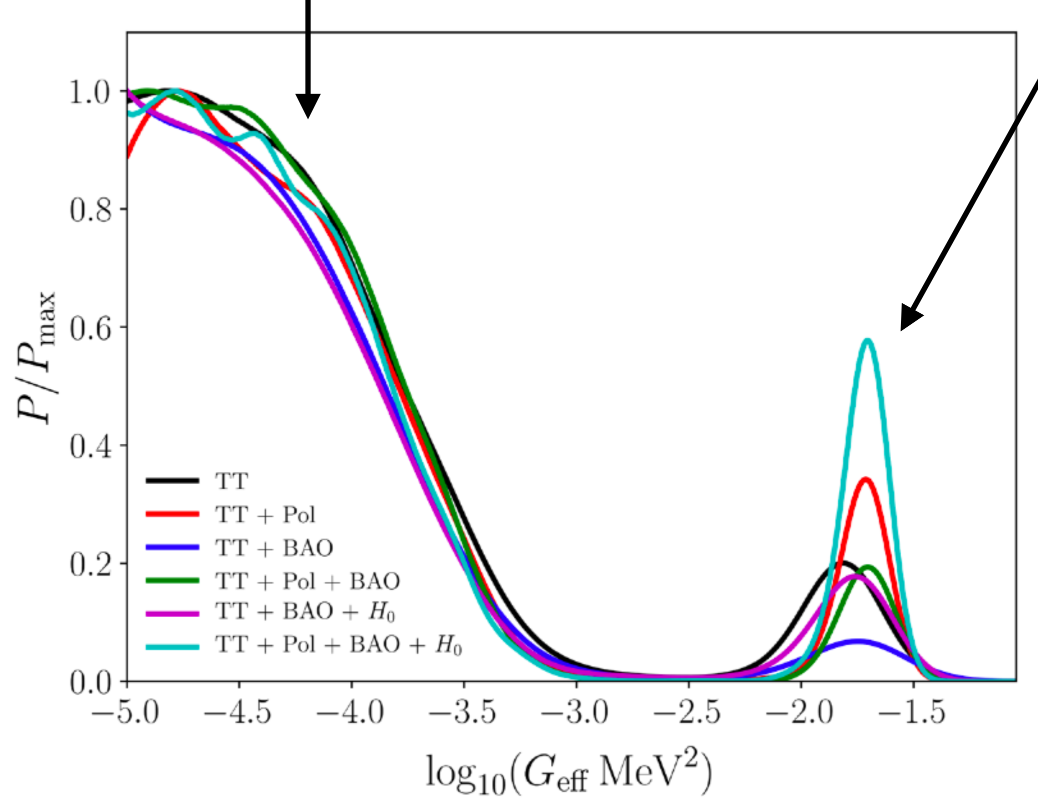
(Mediator can be vector)

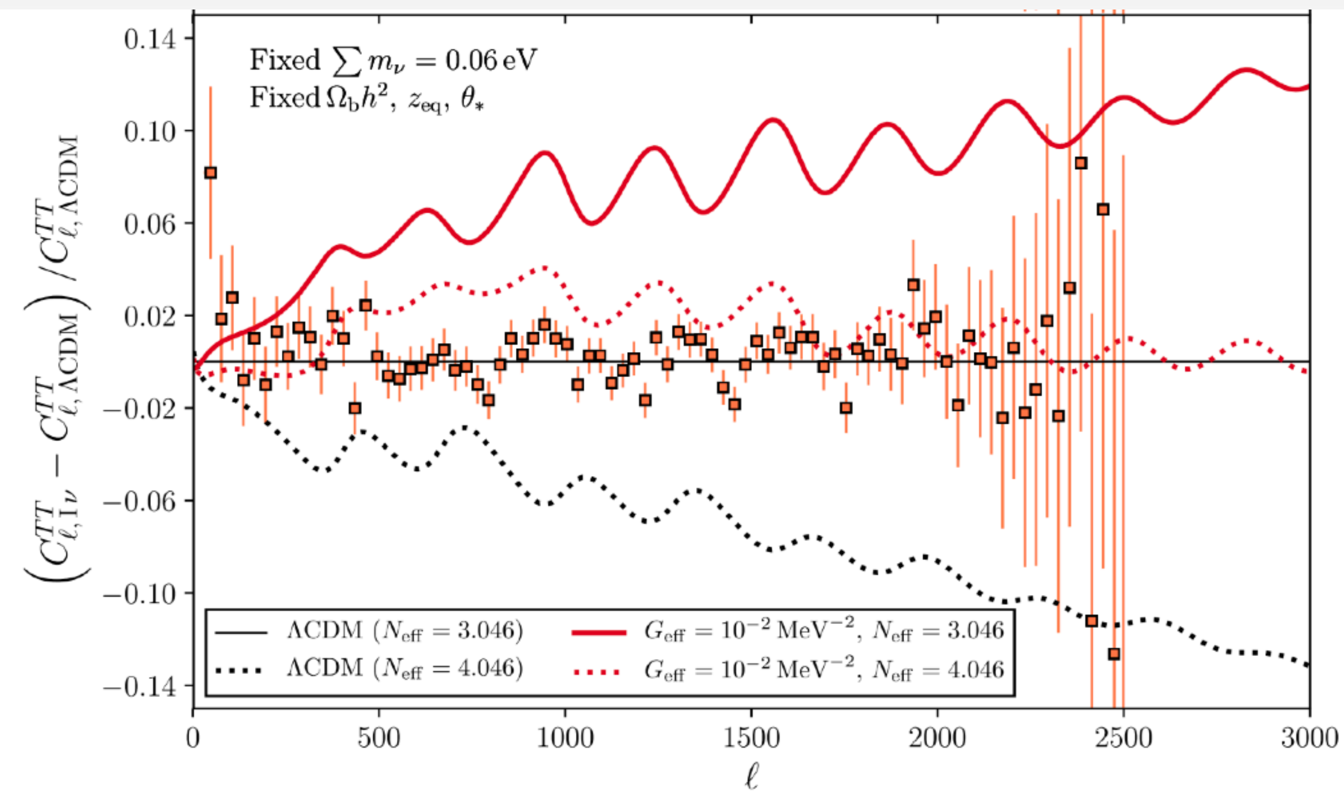
$$\mathscr{L}_{\text{eff}} = G_{\text{eff}}(\bar{\nu}\nu)(\bar{\nu}\nu), \quad G_{\text{eff}} = \frac{g^2}{m_\phi^2}$$

Moderately interacting (MI)

Strongly interacting (SI)

Lancaster et. al. (1704.06657)





Kreisch et al (1902.00534)

Degeneracy of G_{eff} with N_{eff} (H_0)

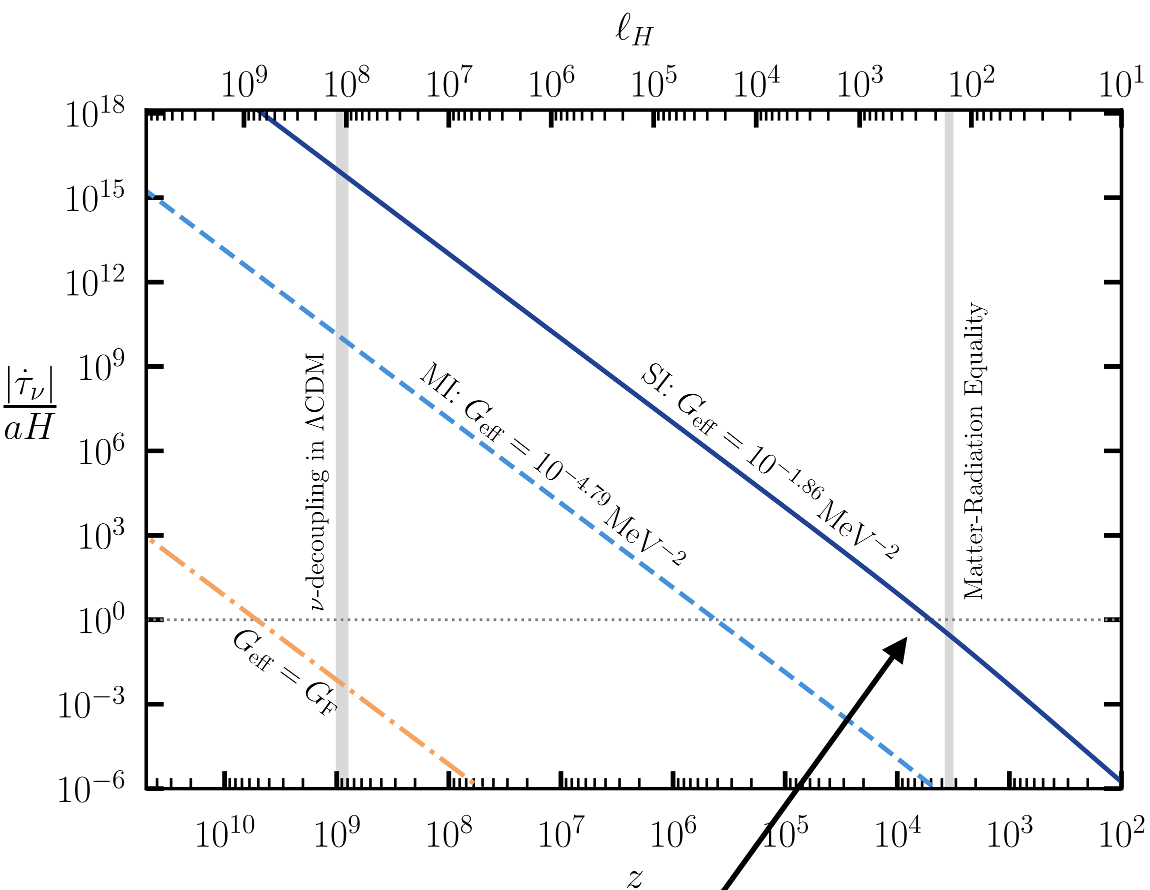
Proposed as a solution (?) of Hubble tension → *4.4σ discrency between CMB and local measurement of H_0*

(Doesn't work when CMB polarisation data is included)

Laboratory constraint

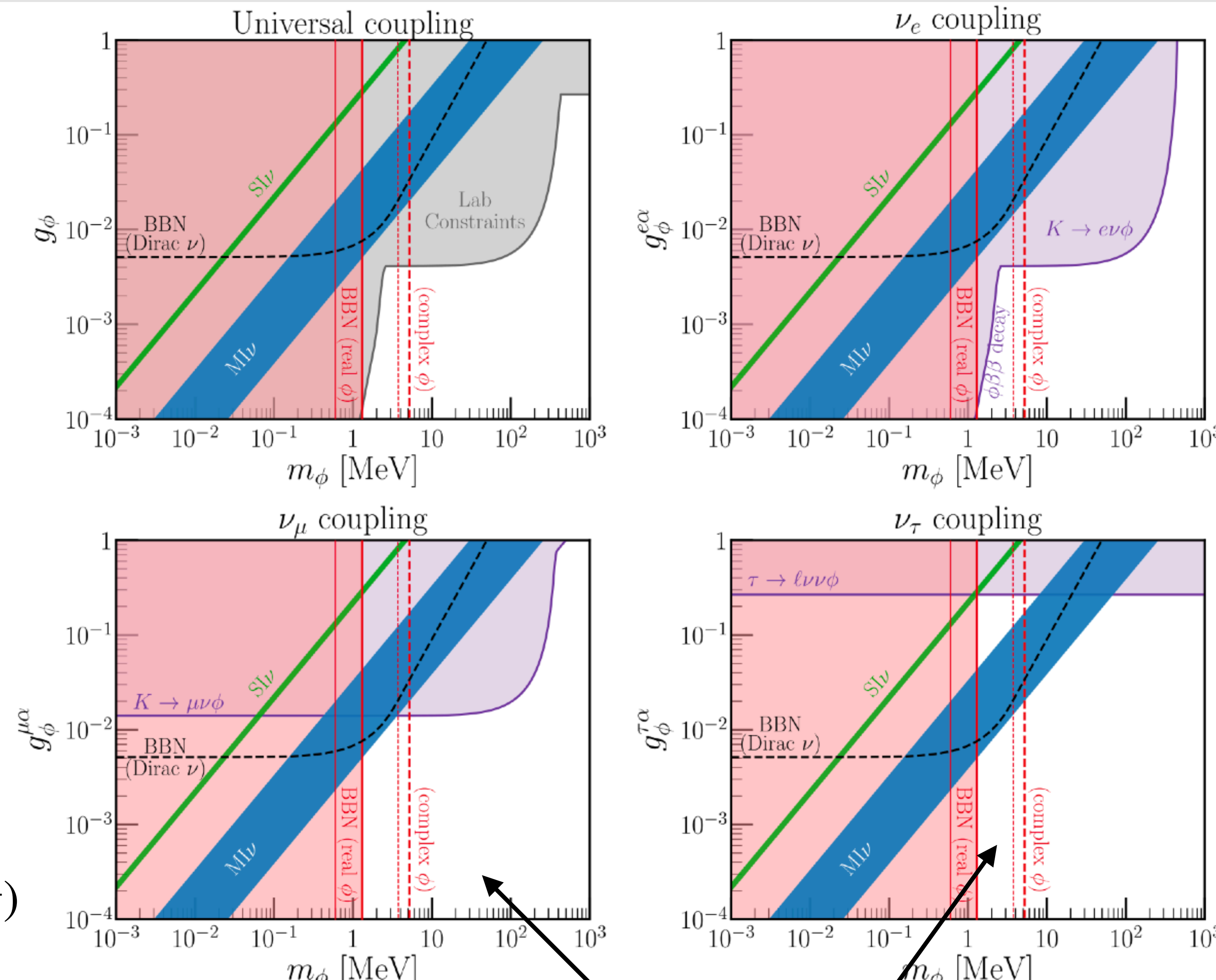
Universal coupling is strongly ruled out by laboratory constraints

$$\dot{\tau}_\nu = -a(G_{\rm eff})^2 T_\nu^5$$



SI mode decoupling happens roughly at matter-radiation equality

$(g_\phi \equiv g)$



Blinov et. al., 1905.02727

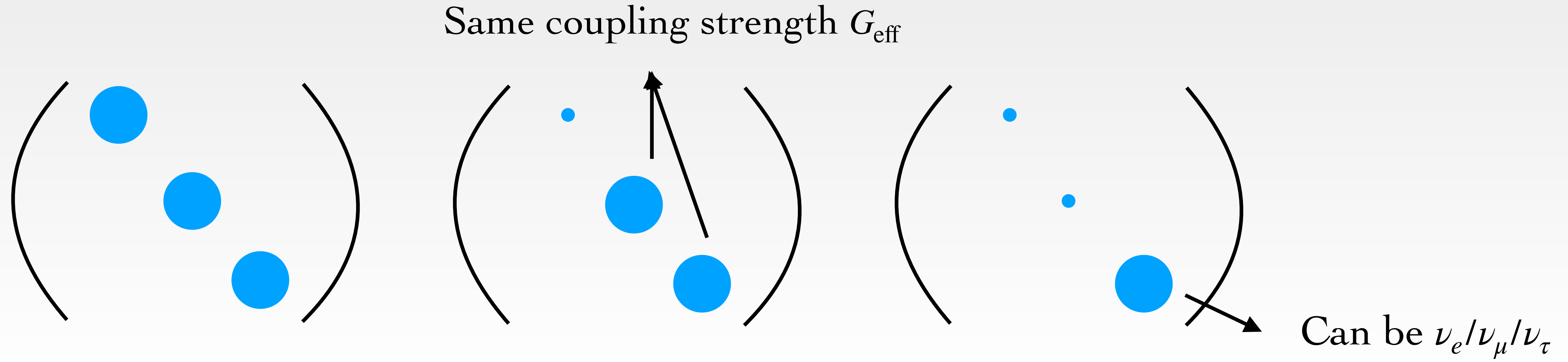
Constraints are comparatively weaker for coupling with ν_μ and ν_τ

Need for cosmological analysis of Flavor specific neutrino self interaction

Flavor specific neutrino self interaction in cosmology

CMB is insensitive to specific flavor (ν_e, ν_μ, ν_τ) of Neutrino
(Not sensitive to weak interaction)

<u>CMB is sensitive to flavor specific interaction 'collectively'</u>



$3c + 0f$
(Flavor universal)

$2c + 1f$

$1c + 2f$

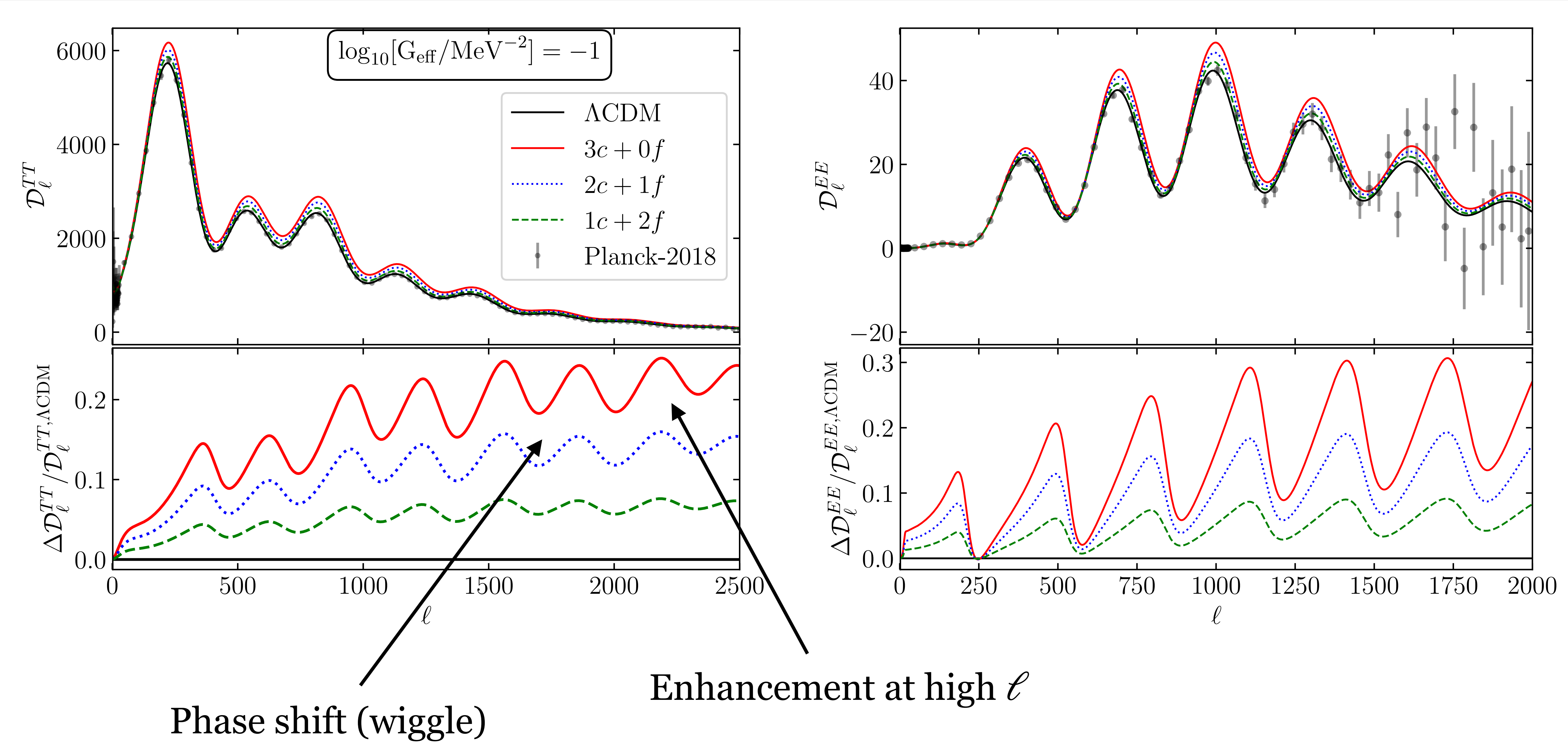
Common coupling strength $G_{\rm eff}$ for coupled flavors (CMB insensitive to specific flavor)

Assumptions

Massless neutrinos
3 flavor ($N_{\rm eff} = 3.046$)
Flavor diagonal interaction

c = coupled (interacting)
f = free-streaming (non-interacting)
$\bullet \equiv 0$

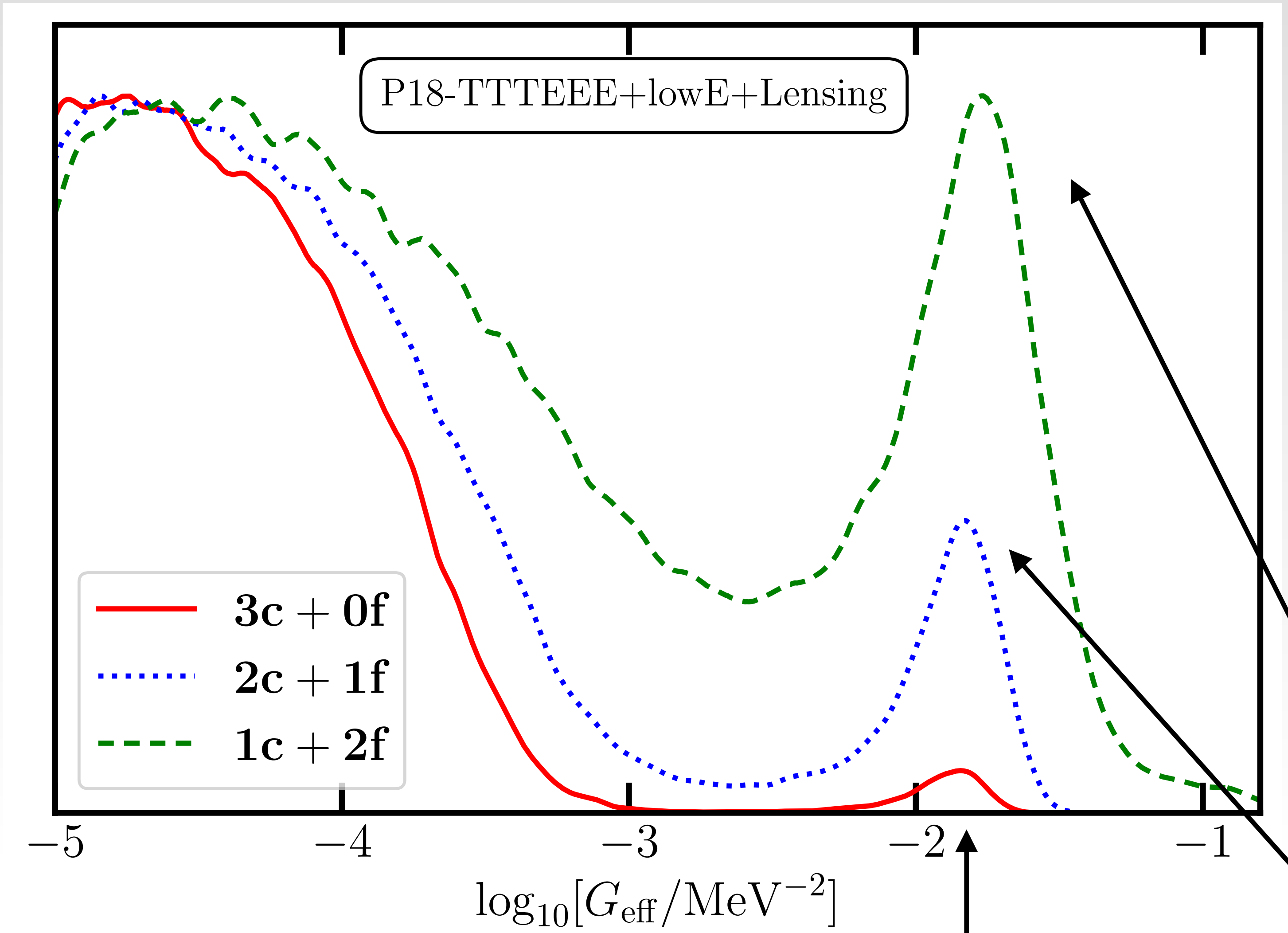
Effect on CMB spectrum



Changes are milder with less number of coupled neutrinos

$\Lambda CDM \equiv 0c + 3f$

Strong flavor specific interaction preferred by CMB



The position of the SI peak remains approximately the same

Significance of the SI mode increases dramatically in flavor specific scenario

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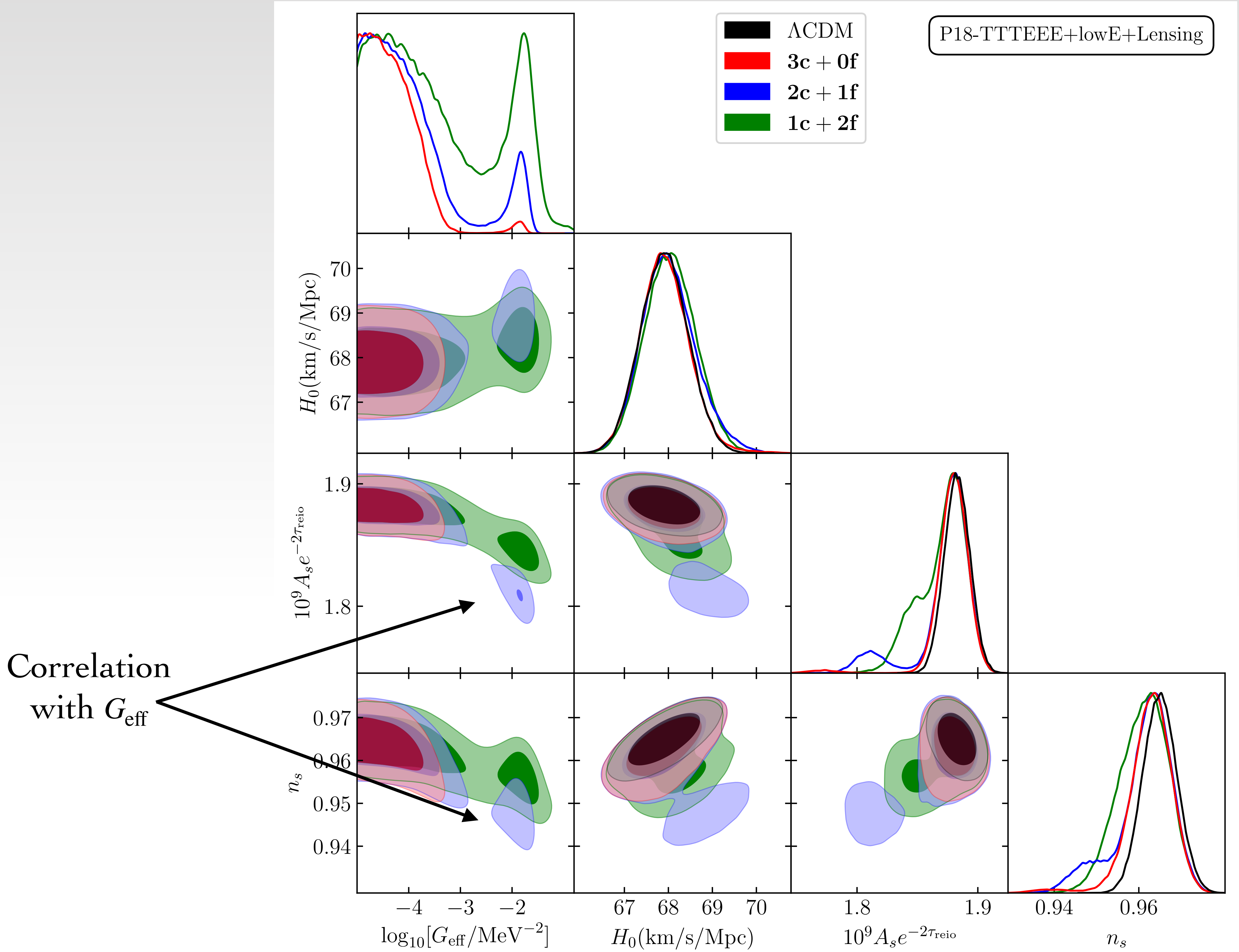
Strong flavor specific interaction preferred by CMB



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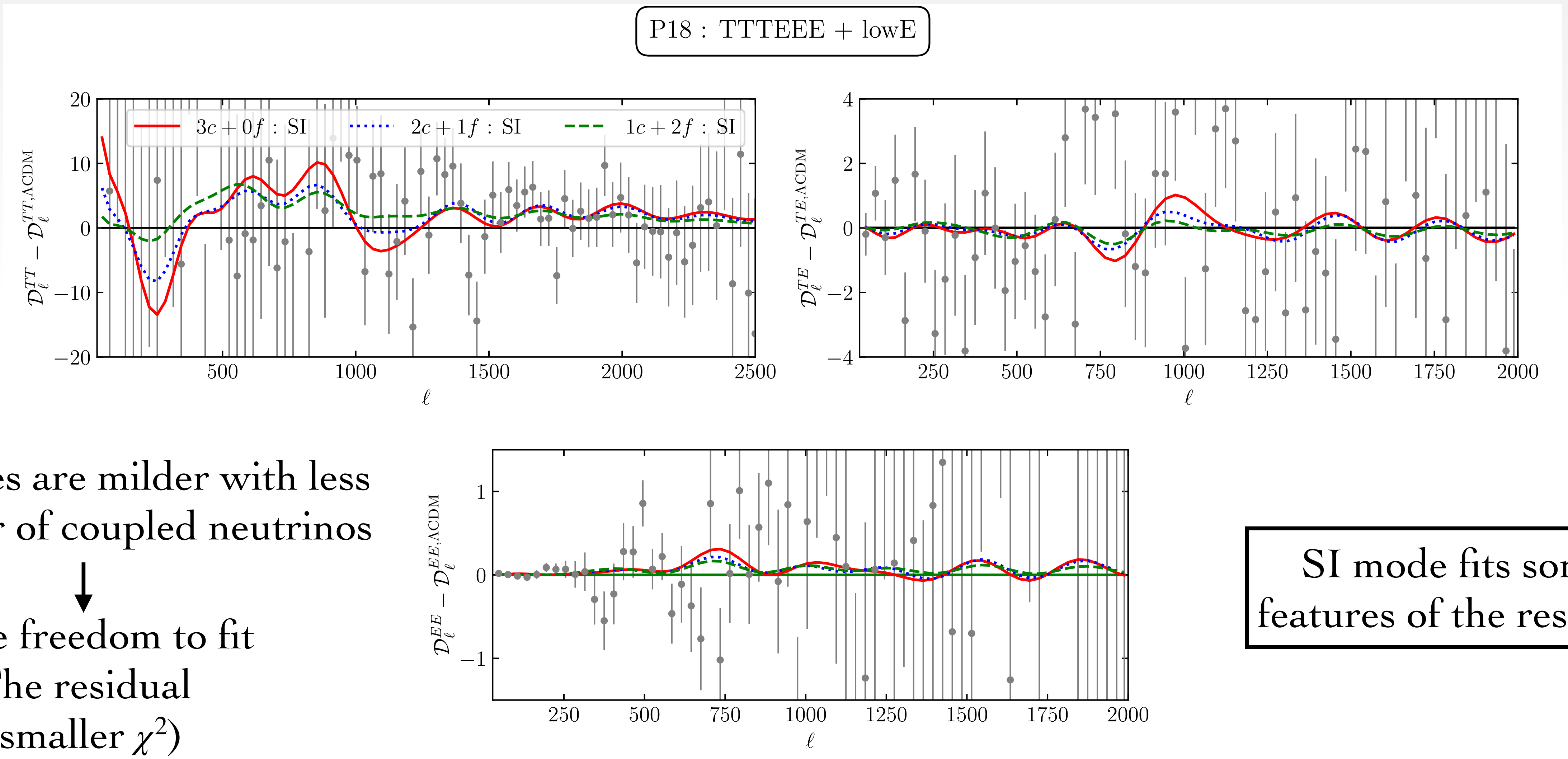
Origin of the SI mode and its enhancement in flavor specific scenario

SI mode interaction strength keep neutrino coupled till matter-radiation equality

Affects all the CMB peaks ($\ell \gtrsim 100$)

ΛCDM parameter ($A_s, n_s \ldots$) can compensate the changes

In flavor specific cases SI mode value of G_{eff} does not change



Changes are milder with less number of coupled neutrinos

↓

More freedom to fit
The residual
(smaller χ^2)

SI mode fits some features of the residual

*MI mode residual is virtually equivalent to ΛCDM

*Planck 2018 data with error bar are shown

Effect on H_0 : Phase shift

Neutrino self interaction can enhance H_0 even when $N_{\rm eff}$ is kept fixed

Photon transfer function — $\cos(kr_s^* + \phi_\nu)$

Phase shift due to
free-streaming neutrinos

$$\ell \approx kD_A^* = (m\pi - \phi_\nu)\frac{D_A^*}{r_s^*}$$

$$\phi_\nu \simeq 0.19\pi R_\nu$$

$$R_\nu = \frac{\rho_\nu}{\rho_\gamma + \rho_\nu}$$

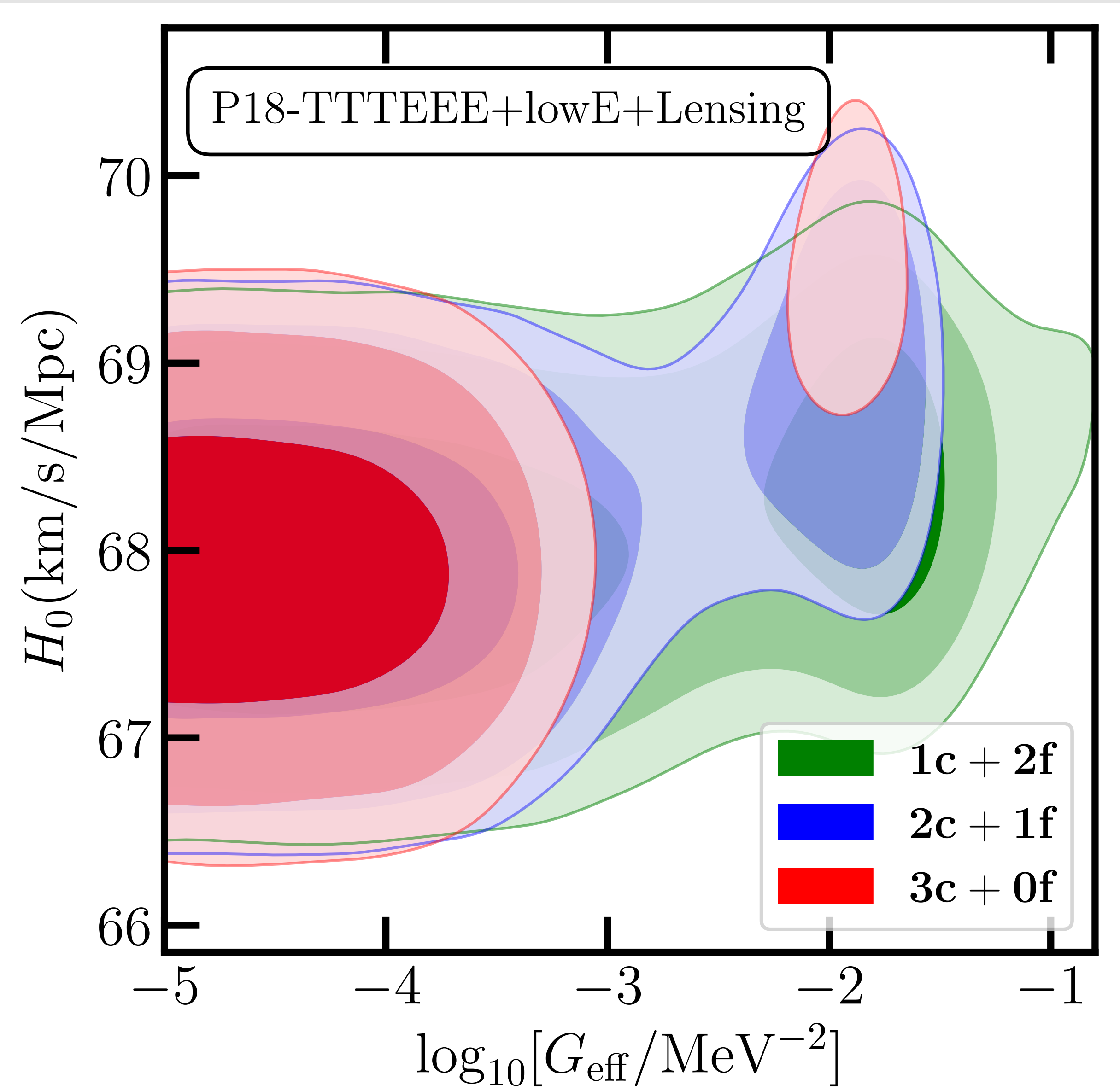
$$D_A^* = \int_0^{z^*} \frac{1}{H(z)} dz$$

$$r_s^* = \int_{z^*}^{\infty} \frac{c_s(z)}{H(z)} dz$$

$$R_\nu = R_\nu^{\Lambda\rm CDM} \times \begin{cases} 0, & \text{for } 3c + 0f \\ \frac{1}{3}, & \text{for } 2c + 1f \\ \frac{2}{3}, & \text{for } 1c + 2f \end{cases}$$

Change in ϕ_ν is compensated (mostly) by change D_A^* — through change in Ω_Λ and H_0

Effect on H_0 : Phase shift



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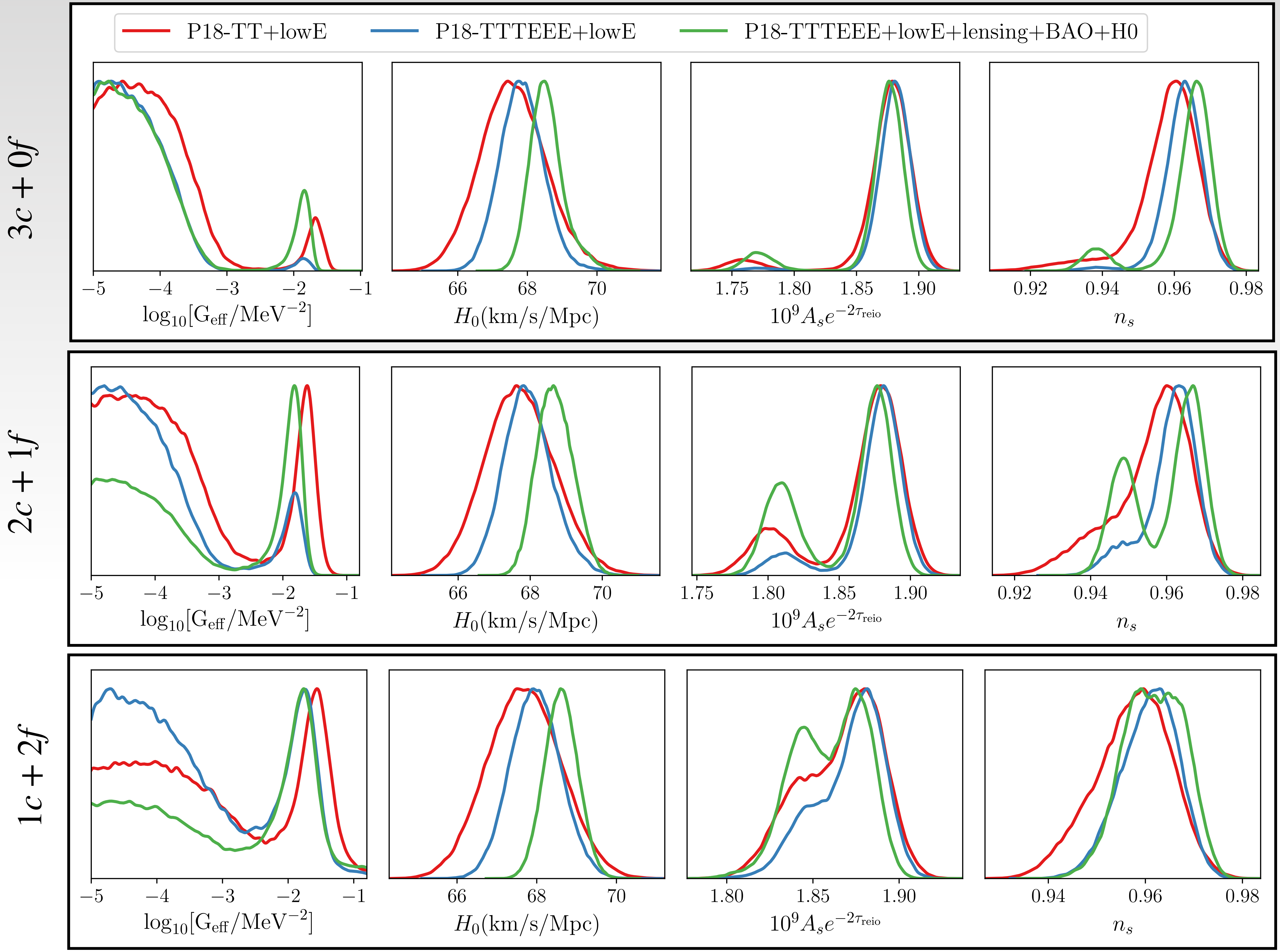
*Even when $N_{\rm eff}$ is varied in $1c + 2f$ scenario H_0 does not increase substantially

Constraints with other dataset



Anirban Das, SG : 2011.12315

Conclusion

- Flavor specific neutrino self interaction is phenomenologically motivated

  → takes into account laboratory constraints
- The significance of the SI mode is increased dramatically

  → similar in χ^2 to ΛCDM fit
- The position of the SI mode peak in Flavor specific interaction remains almost the same in Flavor universal case
- However, does not predict a larger H_0 than flavor universal case

Flavor specific neutrino self interaction can provide similar (in some case better) fit to the CMB (& LSS) data

Cosmology favors Flavor specific neutrino self interaction