Neutrino Self-interaction as a solution(?) to the Hubble Tension

Anirban Das
SLAC National Accelerator Laboratory

Based on 2011.12315
with Subhajit Ghosh

Outline

- Cosmology of self-interacting neutrino
- Flavor-universal SInu & the Hubble tension
- Laboratory constraints on SInu
- Flavor-specific SInu

A phenomenological model

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

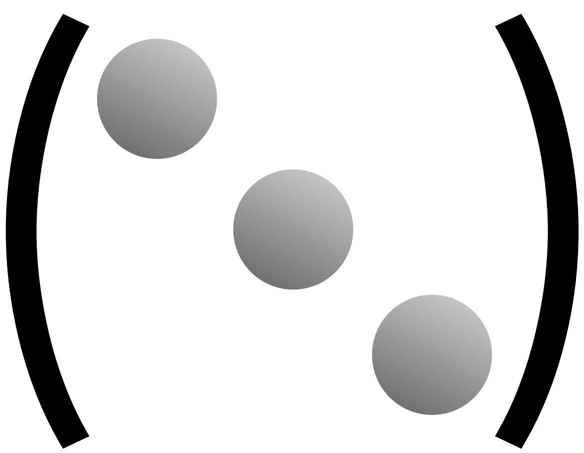
$$\mathcal{L} \supset G_{\text{eff}} \bar{\nu}\nu\bar{\nu}\nu, \quad G_{\text{eff}} = \frac{g^2}{M_\phi^2}$$

1306.1536

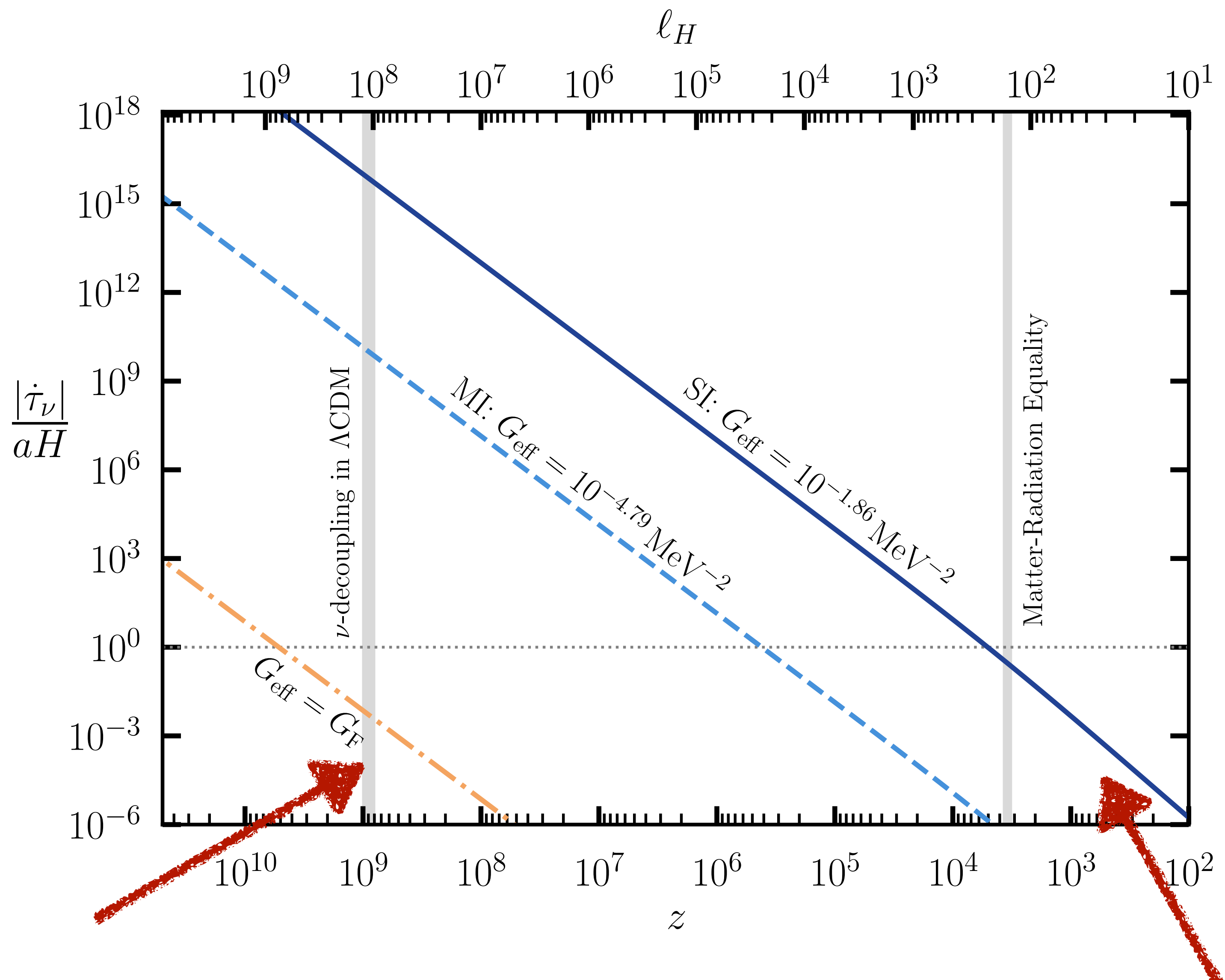
1704.06657

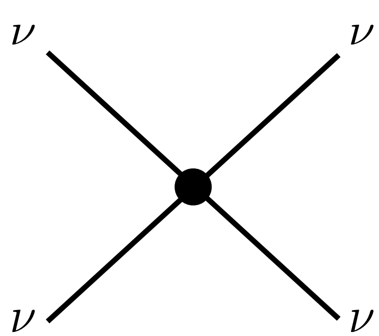
1902.00534

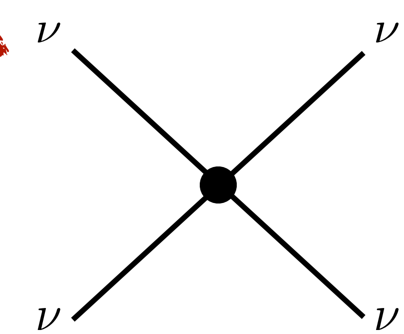
All neutrino flavors interact with the same strength



Cosmology of SInu







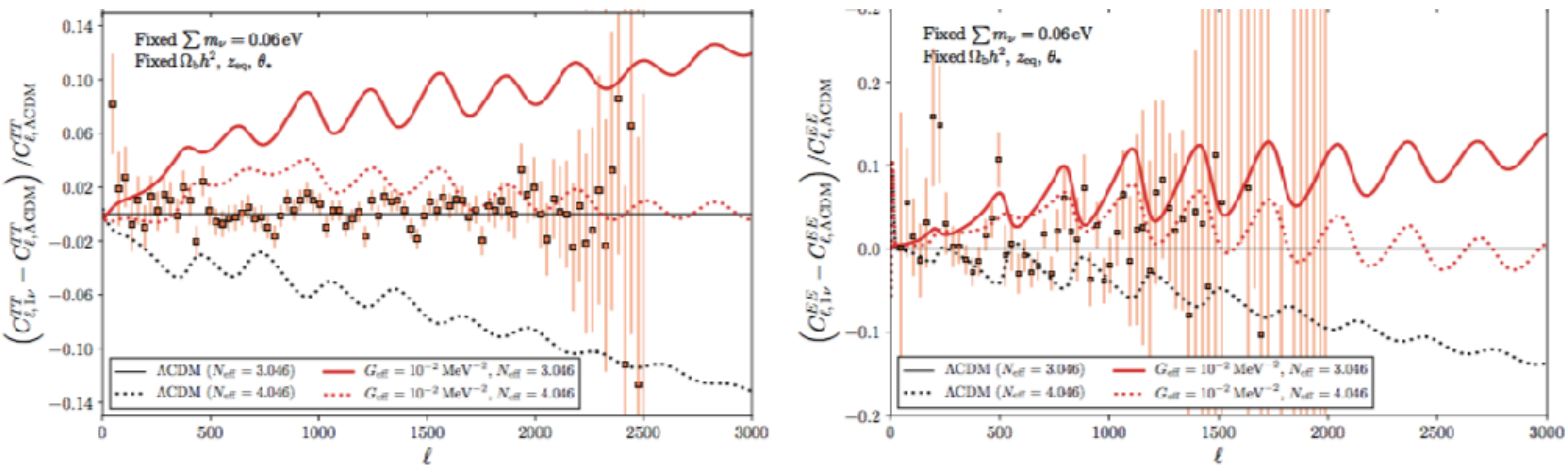
$\sigma \propto G_F^2$

$G_{\rm eff} \simeq 10^9 G_F$

$\sigma \propto \frac{g_\phi^4}{M_\phi^4} \equiv G_{\rm eff}^2$

CMB Power Spectra

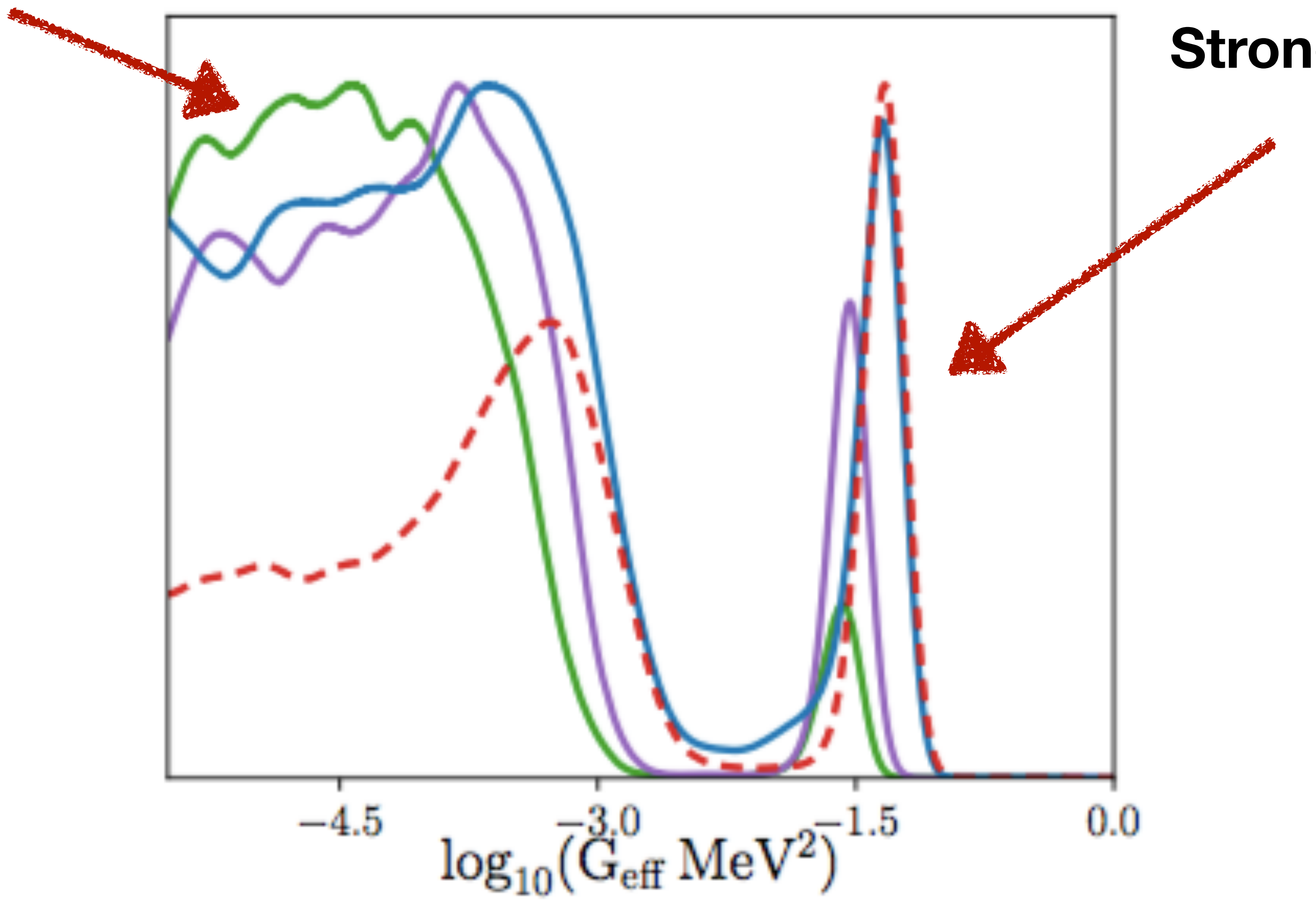
Gravitational potentials enhance photon perturbation $\Longrightarrow$ larger C_l



Kreisch et al 1902.00534

Cosmology of SInu

Moderately Interacting (MI)



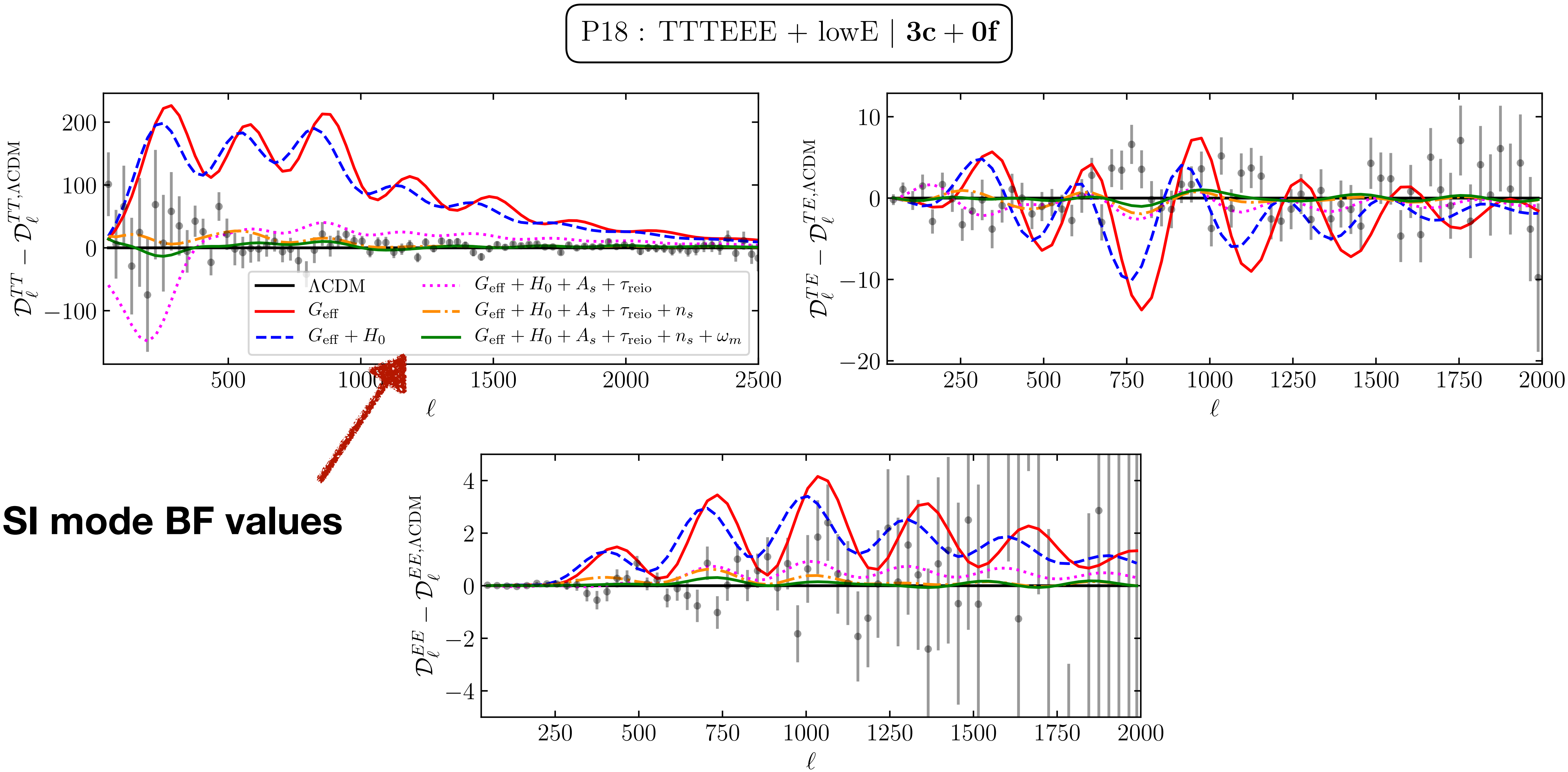
Strongly Interacting (SI)

Kreisch et al 1902.00534

Questions:

- **Origin of the SI mode?**
- **Why is there a valley in between?**

Cosmology of SInu: G_{eff} degeneracy w/ other params



SI mode BF values

SI mode coupling affects *l* > 200

SInu & Hubble

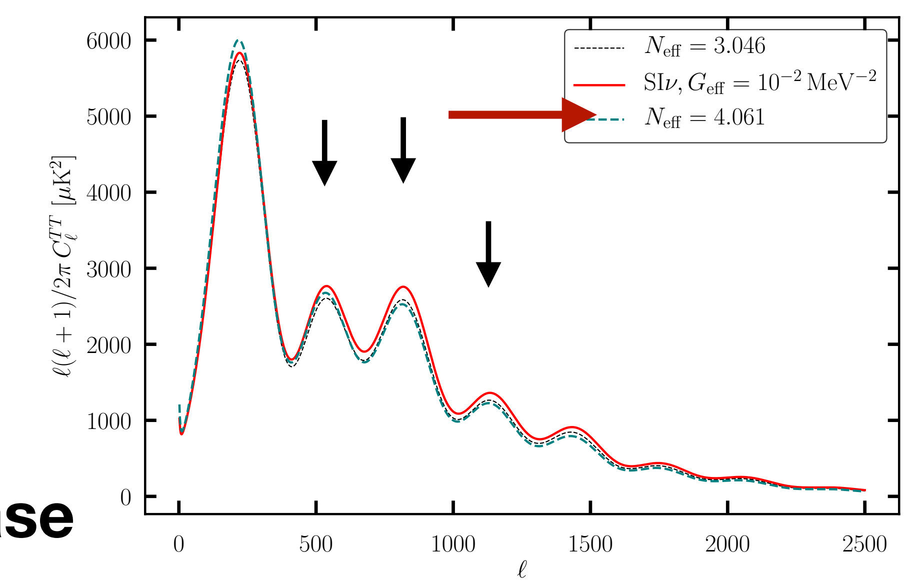
$$\phi_\nu \simeq 0.19\pi R_\nu$$

Phase shift

Free-streaming neutrino

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

SInu phase shift increases ℓ



To keep the spectrum fixed, $\theta_* = \frac{r_s^*}{D_A^*}$ **needs to increase**

Larger H_0 **decreases** D_A^* **& increases** θ_*

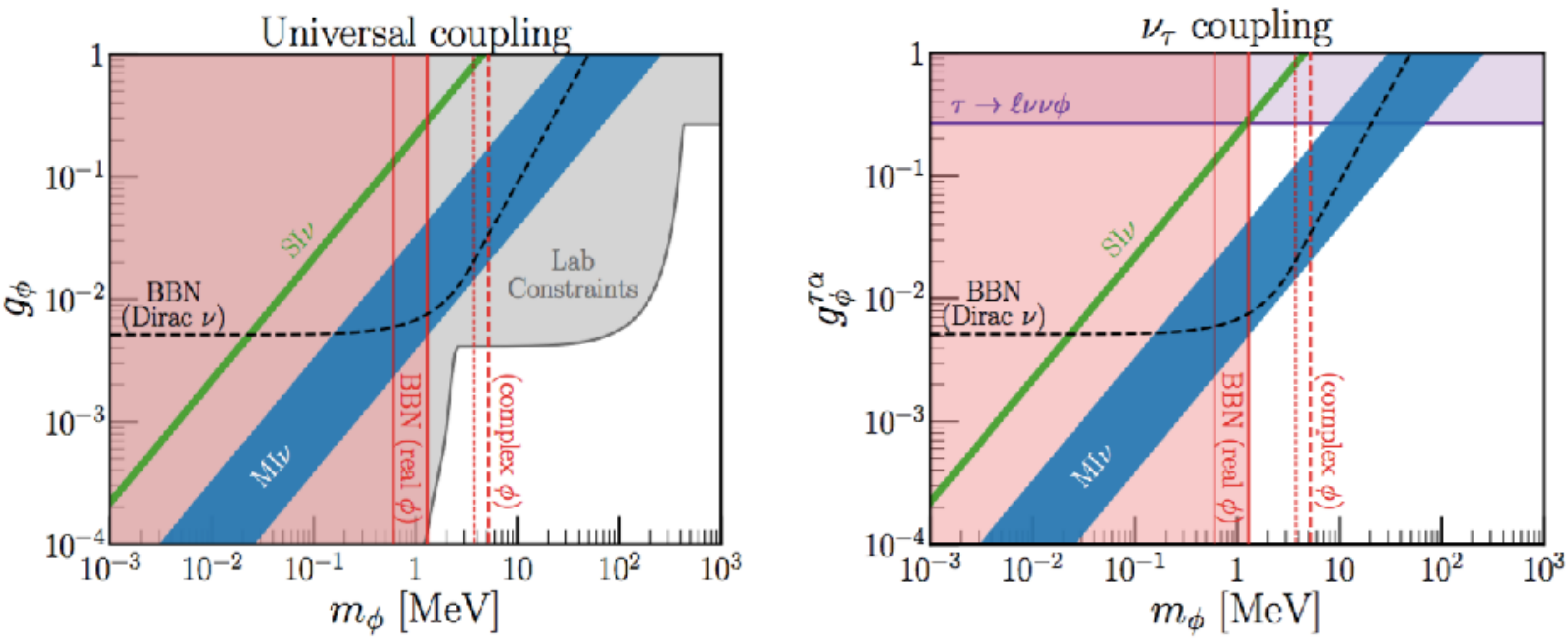
$$D_A^* = \int_0^{z^*} \frac{1}{H(z)} dz, \qquad r_s^* = \int_{z^*}^{\infty} \frac{c_s(z)}{H(z)} dz$$

Laboratory Constraints

Example: nu self-interaction could come from a scalar (1905.02727)

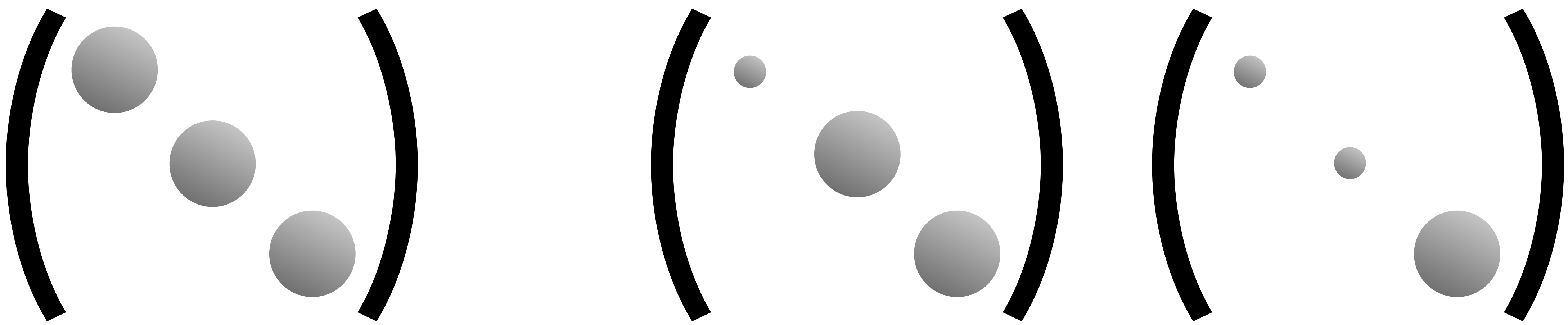
$$\mathcal{L} \supset -\frac{1}{2} m_\phi^2 \phi^2 + \frac{1}{2}(g_\phi^{\alpha\beta} \nu_\alpha \nu_\beta \phi + \text{h.c.})$$

$$G_{\text{eff}} \equiv \frac{g_\phi^2}{m_\phi^2} = (10\ \text{MeV})^{-2} \left(\frac{g_\phi}{10^{-1}}\right)^2 \left(\frac{\text{MeV}}{m_\phi}\right)^2$$



Flavor-specific SInu

Flavor Space



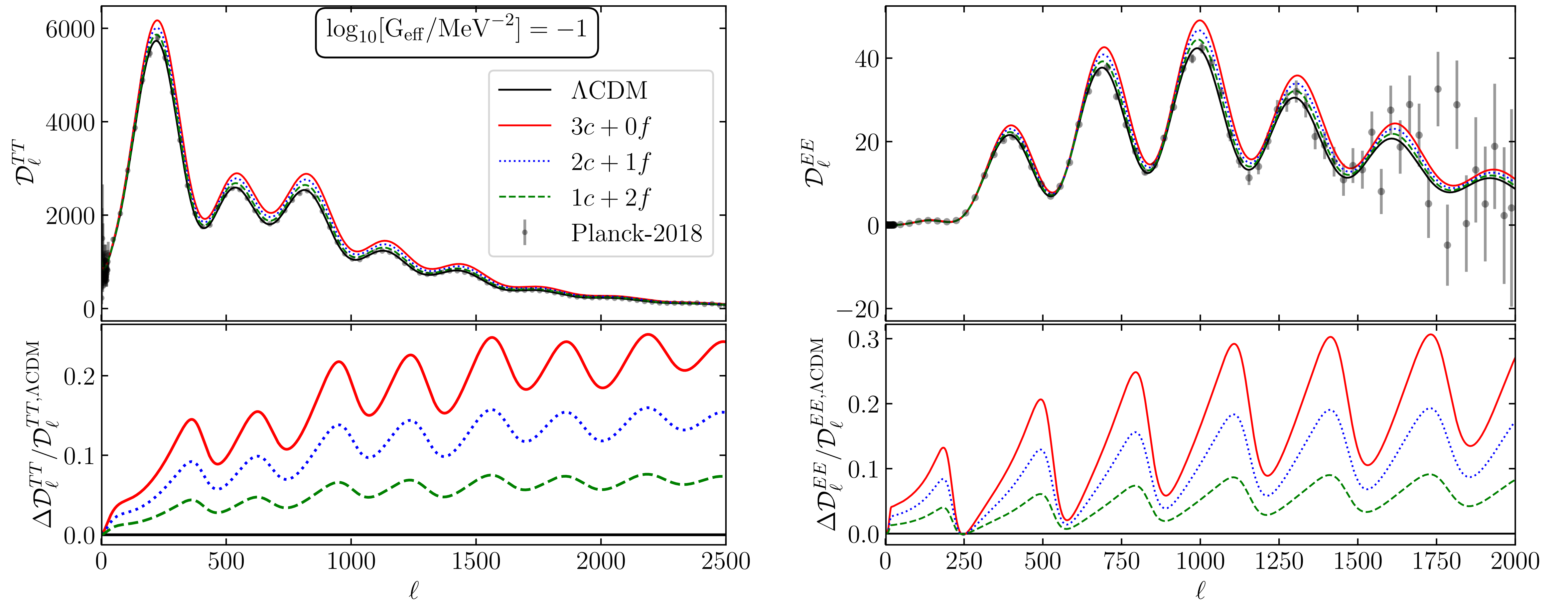
3c+0f

2c+1f

1c+2f

$$\mathcal{L} \supset G_{\rm eff}^{(ijkl)} \bar{\nu}_i \nu_j \bar{\nu}_k \nu_l, \qquad G_{\rm eff}^{(ijkl)} = \frac{g_{ij} g_{kl}}{M_\phi^2}$$

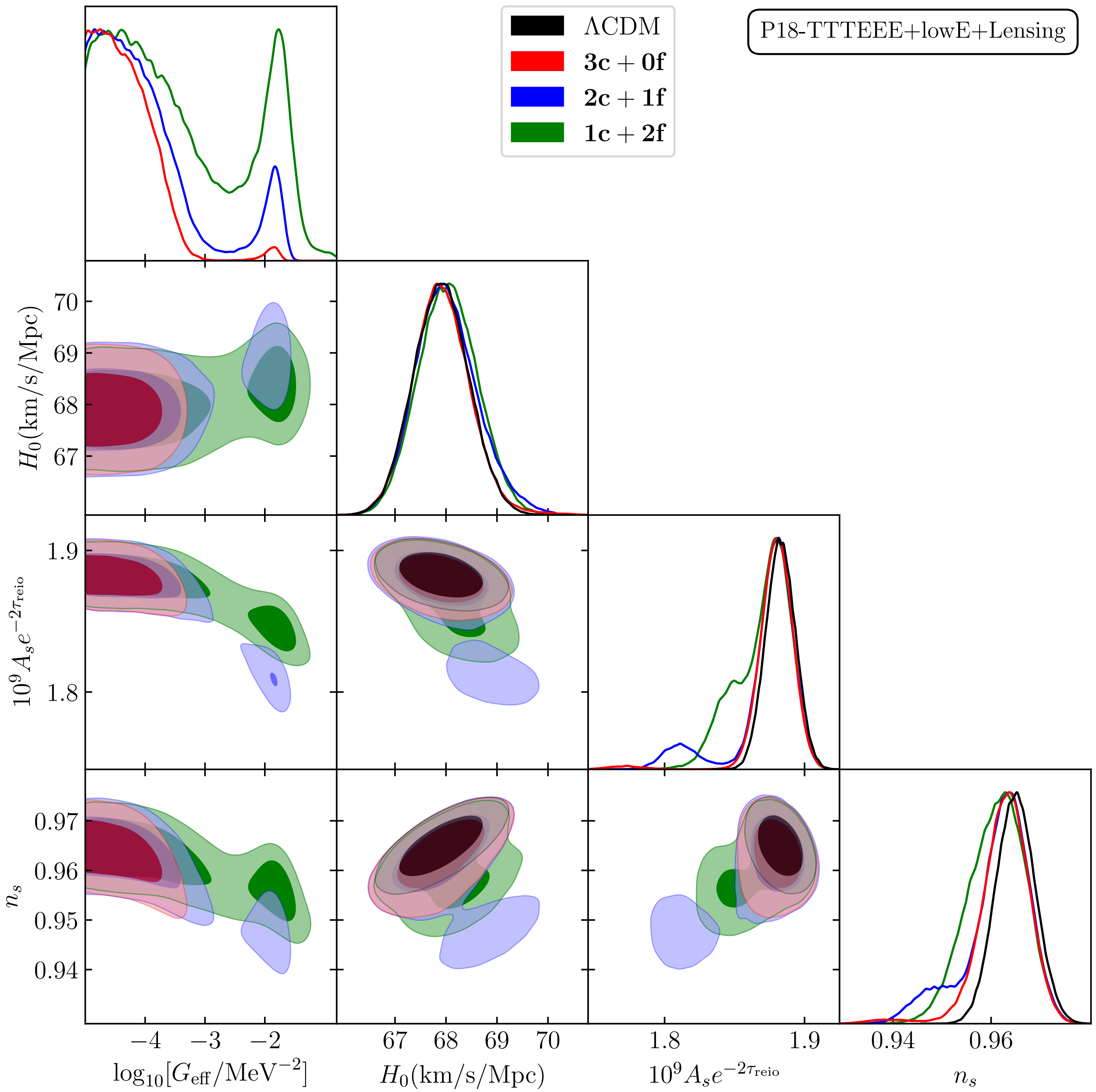
Flavor-specific SInu



2011.12315

Less number of interacting neutrinos reduces the change in the CMB power spectra

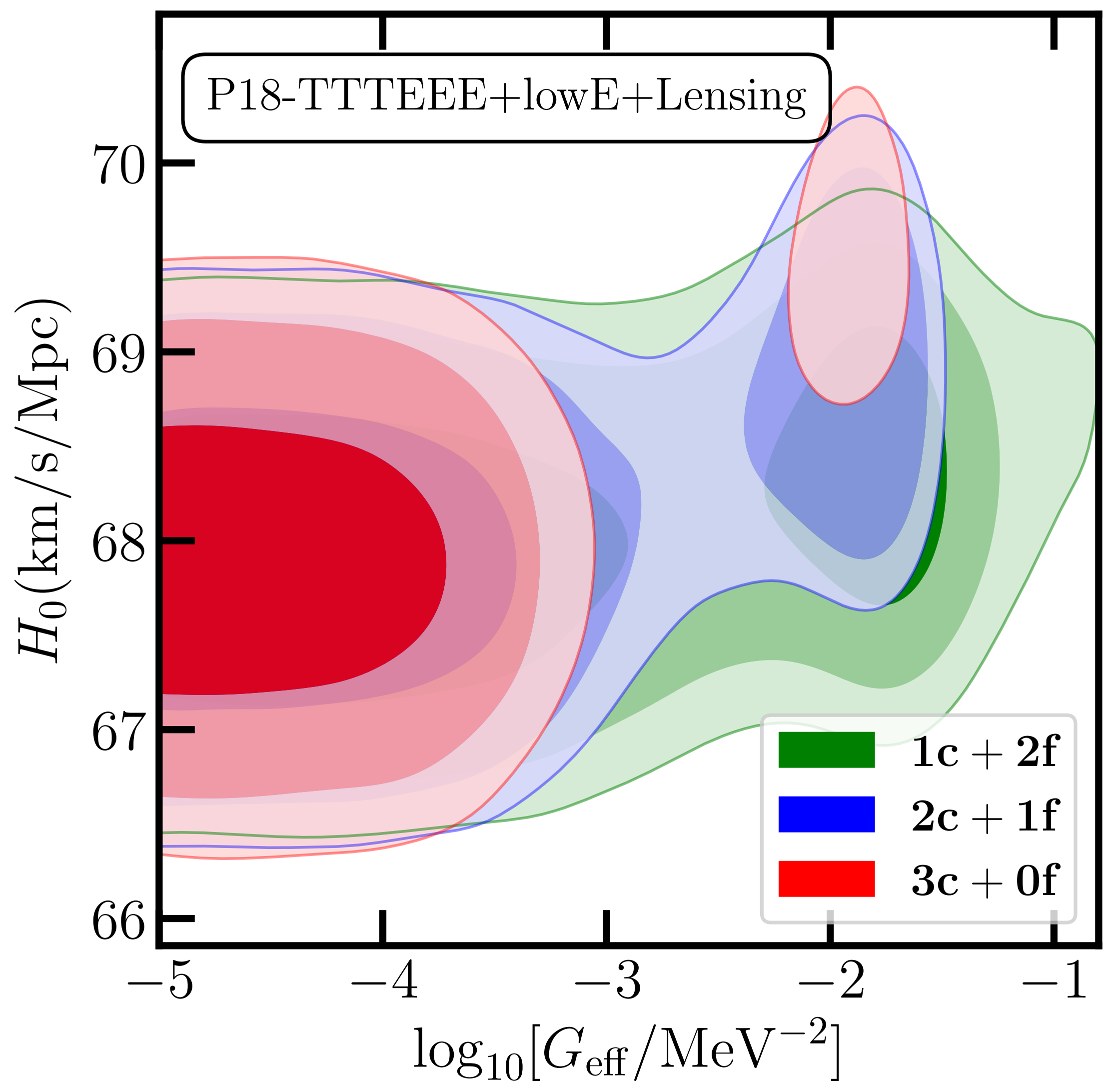
Flavor-specific SInu



2011.12315

Flavor-specific SInu: effect on H_0

Geff has positive correlation with H_0



H_0 = 69.5±0.6 km/s/Mpc for TTTEEE+lowE+lens (2011.12315)

H_0 = 69.6±2.5 (TRGB, 2002.01550)

H_0 = 73.2±1.3 (Riess et al, 2012.08534)

Conclusions & Future Outlook

- **Neutrino self-interaction is phenomenologically motivated**
- **Flavor-universal large Geff (~10^{-2} MeV^{-2}) is incompatible with BBN & laboratory data. However, flavor-specific interaction may still be allowed.**
- **Changes in CMB spectrum is less with less #interacting nu, hence, more room to exploit the deg. with A_s, n_s, τ_{reio}, H_0 $\Longrightarrow$ enhances the SI mode**
- **The SI mode bestfit coupling in the flavor-specific case remains almost the same**
- **More work needed with massive neutrinos and off-diagonal couplings**

Parameter values

Table 4: Parameter values and 68% confidence limits in **2c + 1f**.

Parameters	TT+lowE		TTTEEE+lowE	
	SI	MI	SI	MI
$\Omega_b h^2$	0.022 ± 0.00027	0.022 ± 0.00021	0.022 ± 0.00016	0.022 ± 0.00015
$\Omega_c h^2$	0.1211 ± 0.0023	0.1203 ± 0.002	0.1205 ± 0.0014	0.1201 ± 0.0013
$100\theta_s$	1.0452 ± 0.00059	1.0419 ± 0.0005	1.045 ± 0.00076	1.0419 ± 0.00031
$\ln(10^{10} A_s)$	2.99 ± 0.0179	3.036 ± 0.01714	3 ± 0.0167	3.042 ± 0.0161
n_s	0.9407 ± 0.0079	0.9596 ± 0.0068	0.9473 ± 0.0046	0.9628 ± 0.005
$\tau_{\rm reio}$	0.0501 ± 0.008	0.0516 ± 0.0079	0.0538 ± 0.0077	0.0538 ± 0.0077
$\log_{10}(G_{\rm eff}/{\rm MeV}^{-2})$	-1.69 ± 0.2	-4.03 ± 0.6	-1.93 ± 0.24	-4.24 ± 0.5
$H_0(\,{\rm km\,s^{-1}Mpc^{-1}})$	68.34 ± 1.00	67.57 ± 0.92	68.81 ± 0.63	67.83 ± 0.6
σ_8	0.823 ± 0.01	0.824 ± 0.009	0.829 ± 0.0079	0.824 ± 0.0075

Table 5: Parameter values and 68% confidence limits in **1c + 2f**.

Parameters	TT+lowE		TTTEEE+lowE	
	SI	MI	SI	MI
$\Omega_b h^2$	0.022 ± 0.00023	0.022 ± 0.00021	0.022 ± 0.00015	0.022 ± 0.00015
$\Omega_c h^2$	0.1207 ± 0.0021	0.1203 ± 0.002	0.1203 ± 0.0014	0.1201 ± 0.0013
$100\theta_s$	1.0434 ± 0.00062	1.0419 ± 0.0004	1.043 ± 0.00058	1.0419 ± 0.0003
$\ln(10^{10} A_s)$	3.01 ± 0.0179	3.037 ± 0.01664	3.024 ± 0.0166	3.042 ± 0.016
n_s	0.9513 ± 0.0069	0.9609 ± 0.0059	0.9553 ± 0.0049	0.963 ± 0.005
$\tau_{\rm reio}$	0.051 ± 0.008	0.0519 ± 0.008	0.0539 ± 0.0076	0.0539 ± 0.0077
$\log_{10}(G_{\rm eff}/{\rm MeV}^{-2})$	-1.75 ± 0.4	-3.94 ± 0.6	-1.9 ± 0.37	-4.06 ± 0.6
$H_0(\,{\rm km\,s^{-1}Mpc^{-1}})$	67.9 ± 1.00	67.56 ± 0.93	68.3 ± 0.62	67.83 ± 0.61
σ_8	0.821 ± 0.01	0.823 ± 0.009	0.825 ± 0.0083	0.824 ± 0.0075

2011.12315

Parameter values

Table 11: Parameter values and 68% confidence limits in **2c + 1f**.

Parameters	TTTEEE+lowE+lens		TTTEEE+lowE+lens+BAO+H_0	
	SI	MI	SI	MI
$\Omega_b h^2$	0.022 ± 0.0001	0.022 ± 0.00014	0.022 ± 0.0001	0.022 ± 0.00013
$\Omega_c h^2$	0.1202 ± 0.0013	0.1199 ± 0.0012	0.12 ± 0.001	0.1188 ± 0.0009
$100\theta_s$	1.045 ± 0.0008	1.0419 ± 0.0003	1.045 ± 0.00068	1.042 ± 0.00029
$\ln(10^{10} A_s)$	3 ± 0.0158	3.041 ± 0.014	3 ± 0.0151	3.044 ± 0.0145
n_s	0.9476 ± 0.0043	0.9629 ± 0.0048	0.9483 ± 0.004	0.966 ± 0.0046
τ_{reio}	0.0541 ± 0.0074	0.0536 ± 0.0072	0.0544 ± 0.007	0.0565 ± 0.0071
$\log_{10}(G_{\text{eff}}/\text{MeV}^{-2})$	-1.96 ± 0.26	-4.22 ± 0.51	-1.91 ± 0.22	-4.22 ± 0.52
$H_0(\text{km s}^{-1}\text{Mpc}^{-1})$	68.87 ± 0.58	67.9 ± 0.53	69.08 ± 0.42	68.47 ± 0.4
σ_8	0.829 ± 0.007	0.823 ± 0.006	0.827 ± 0.0065	0.821 ± 0.0059

Table 12: Parameter values and 68% confidence limits in **1c + 2f**.

Parameters	TTTEEE+lowE+lens		TTTEEE+lowE+lens+BAO+H_0	
	SI	MI	SI	MI
$\Omega_b h^2$	0.022 ± 0.0001	0.022 ± 0.00014	0.022 ± 0.0001	0.022 ± 0.00013
$\Omega_c h^2$	0.1201 ± 0.0012	0.1199 ± 0.0012	0.12 ± 0.0009	0.1188 ± 0.0009
$100\theta_s$	1.043 ± 0.0006	1.0419 ± 0.0003	1.043 ± 0.00056	1.042 ± 0.00029
$\ln(10^{10} A_s)$	3.023 ± 0.0153	3.041 ± 0.015	3 ± 0.0151	3.045 ± 0.0142
n_s	0.9555 ± 0.0046	0.9633 ± 0.0045	0.9572 ± 0.004	0.966 ± 0.0042
τ_{reio}	0.0536 ± 0.0073	0.0536 ± 0.0074	0.0554 ± 0.007	0.0566 ± 0.0071
$\log_{10}(G_{\text{eff}}/\text{MeV}^{-2})$	-1.91 ± 0.37	-4.04 ± 0.61	-1.86 ± 0.36	-4.03 ± 0.61
$H_0(\text{km s}^{-1}\text{Mpc}^{-1})$	68.35 ± 0.56	67.9 ± 0.54	68.75 ± 0.41	68.48 ± 0.41
σ_8	0.824 ± 0.007	0.823 ± 0.006	0.822 ± 0.0071	0.821 ± 0.006

2011.12315