Contribution ID: **222** Type: **Poster**

Exploring Self-Interacting Dark Radiations in the Context of the Hubble Tension

Monday, 3 July 2023 15:30 (1 hour)

In this study, we investigate the scenario when dark radiations, i.e., sterile neutrinos, interact with a heavy scalar field (SIdr). We utilize cosmic microwave background (CMB) data from the Planck experiment to constrain the SIdr model and address the Hubble tension issue. We verify our results using Atacama Cosmology Telescope (ACT) and South Pole Telescope (SPT) data. Our theoretical analysis reveals that in the absence of explicitly incorporating additional neutrino species $N_{\rm eff} = 3.02 \pm 0.27$, a modified Hubble constant $H_0 = 69.3 \pm 2.0$ naturally emerges when all dark radiations are tightly coupled.
However, within a 3σ confidence level (corresponding to a 99.7\% probability), an upbound value of $H_0 < 72.9$ is predicted.

The predictions align well with all the datasets, leading to an increase in the Hubble constant to $H_0 = 70.1 \pm 1.3$ in the strong self-interacting region $\log_{10} G_{\rm eff} = -1.80^{0.13}_{-0.08}$. Moreover, $N_{\rm eff} = 3.23 \pm 0.25$ is consistent with the Planck results. The SIdr tends to favor the matter clustering as indicated by $S_8 = 0.832 \pm 0.011$, which is a combined effect of a decrease in Ω_m and an increase in H_0. Furthermore, the amplitude A_s and the spectrum index n_s are reduced to $\log(10^{10} A_s) = 2.978 \pm 0.016$ and $n_s = 0.9327 \pm 0.0064$ respectively, due to the effects implemented by self-interacting radiation. However, in the weak self-interacting region $\log_{10} G_{\rm eff} = -4.15^{0.55}_{-0.83}$, these parameters remain consistent with the Planck value.

Finally, we employ a Fisher forecast analysis to predict future constraints on the SIdr model. CMB-S4 experiment alone will improve the coupling strength $\log_{10} G_{\rm eff}$ upto 2.7 times. Additionally, both AliCPT and Planck experiments enhance coupling strength upto 3.5 times, considering $f_{\rm sky} = 0.4$ for AliCPT.

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Session Classification: Poster session & Coffee break