# The Cosmology of Interacting Vacuum Models

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**Abstract**

We report on linear interacting vacuum energy (IVE) models that transfer energy between vacuum energy and cold dark matter:$(i)Q_1 \propto HV$, and $(ii)Q_2 \propto H\rho_c$, with the aim of addressing the cosmological $H_0$ and $S_8$ tensions. We use Kosmulator, a modular, vectorized Python framework designed to accelerate statistical testing of cosmological models, to estimate cosmological parameters and assess the models' observational viability relative to the standard ΛCDM model. We constrain their dynamics through a joint analysis of late-time cosmological observations: cosmic chronometer (CC), Baryon Acoustic Oscillation (BAO), Pantheon+SHOES, and redshift-space distortion ($f\sigma_8$). For the joint analysis of CC+BAO+$f\sigma_8$, we find $H_0 = 69.437^{+2.310}_{-2.176}$ (km s$^{-1}$ Mpc$^{-1}$) and $S_8 = 0.757^{+0.0360}_{-0.0268}$, with coupling parameter $\iota = 0.052^{+0.336}_{-0.314}$, for the $Q_1 \propto HV$ model. For the $Q_2 \propto H\rho_c$ model, we find $H_0 = 69.268^{+1.726}_{-1.722}$ and $S_8 = 0.763^{+0.0101}_{-0.0093}$, with coupling parameter $\xi = 0.006^{+0.135}_{-0.128}$. The $H_0$ and $S_8$ values for both models are in slight agreement with the constrained standard ΛCDM values, $H_0 = 69.153^{+1.726}_{-1.703}$ and $S_8 = 0.765 \pm 0.0048$, which are consistent with values reported in the literature. We also use the Akaike Information Criterion ($AIC$) and Bayesian Information Criterion ($BIC$) to evaluate deviations from the ΛCDM framework. We obtain $\Delta AIC = 2.067$ for $Q_1 \propto HV$ and $\Delta AIC = 2.107$ for $Q_2 \propto H\rho_c$. These results indicate moderate support for the linear IVE models relative to ΛCDM, for which $\Delta AIC = 0$ implies the best model. For the corresponding $\Delta BIC$, we obtain $2 \leq \Delta BIC \leq 6$ for both models, indicating positive evidence against them compared with ΛCDM. Overall, the linear IVE models remain viable extensions of ΛCDM and offer a promising framework for addressing the $H_0$ and $S_8$ tensions.

**Keywords**: $H_0$ tension, $S_8$ tension, Vaccum energy, Cold dark matter