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The spectrum of the axion dark sector, cosmological observable and black hole superradiance constraints.

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Axions or axion-like particles are ubiquitous in many theoretical extensions of the Standard Model of particle physics, in particular the ''string axiverse" scenario [1-3]. If the phenomenologically defining parameters, the axion mass, m_a, and (effective) decay constant, f_a, fall in specific ranges, then axions contribute to the cosmological dark matter and dark energy densities of the universe [4]. In the framework of string/M theory a systematic construction of the axion decay constant and mass spectrum in explicit realisations of the string axiverse is a daunting task to undertake, often requiring the extensive details of instanton corrections to the superpotential and a detailed knowledge of the full scalar potential for the supersymmetric theory when considering realistic axion/moduli population numbers.

We present the background cosmological (quasi-)observables for a series of random matrix (RMT) models inspired by several axion field alignment mechanisms [5,6], with the associated parameter spectra for a large number of axion fields, $n_{\rm ax} \sim \mathcal{O}(10-100)$, where the masses and decay constants are drawn from statistical distributions [7]. Using the RMT formalism we also consider the spectra of more physically motivated models, specifically a class of G_2 compactified M-theory models [3,8,9] where all the moduli are stabilised in a non-supersymmetric minima. This process effectively reduces the number of parameters from $2n_{\rm ax}$ to a limited number of ''hyperparameters" allowing us to use Bayesian methods to constrain the hyperparameters of the distributions in the context of the cosmological (quasi)-observables.

These methods are also used to constrain the axion parameter space via the black hole superradiance process [10,11]. The presence of multiple fields can enhance the exclusion bounds on both solar and supermassive black holes in the so called Regge spin plane as apposed to considering just a single field. We present an analysis of the statistical likelihoods for each of these models with recorded black hole data in order to provide a picture of the significance of the axion parameter space its phenomenology in effective theories.

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