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Connecting UHECR theory to data: the benefits of Bayesian hierarchical models

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The study of UHECR is challenged by both the rarity of events and the difficulty in modelling their production, propagation and detection. The physics behind these processes is complicated, requiring high-dimensional models which are impossible to fit to data using traditional methods. Whilst non-trivial, it is indeed possible to directly fit realistic, physical models to the UHECR data. The combination of Bayesian hierarchical modelling with the advanced computational methods available allows us to fit complex models with a large number of parameters whilst naturally connecting to the underlying physics. The main benefits are that all aspects of the data (energy, composition and arrival direction) can be used simultaneously and that uncertainties are modelled consistently, resulting in an approach that can constrain UHECR models in a way that is both physically and statistically principled. A framework for such an analysis is presented, along with results from the fit of a phenomenological model to data from the Pierre Auger Observatory. The potential to extend this method to more realistic physical models and multi-messenger observations is also discussed.

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