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Analytic nuclear cascades: a unified framework for UHECR sources and propagation

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The interactions of ultra-high energy cosmic ray nuclei (UHECR) in astrophysical scenarios can be of stochastic or deterministic nature. Simulation frameworks often employ Monte Carlo techniques or numerically solve systems of ordinary differential equations (ODEs) to describe such interactions and the resulting nuclear cascades. Monte Carlo approaches are best suited to asses the impact of the probabilistic quantities but may be limited by computation time, while ODEs can be faster at the cost of neglecting the stochastic effects. The limitations of each of these approaches are known and somehow complementary, yet, a framework where the speed of computation is not sacrificed while including the stochastic effects would have much scientific potential by overcoming the current limitations.
This is the goal of the probabilistic description presented in this work, which is based on the theory of matrix exponential distributions. This approach provides analytical expressions for the probability distributions of the nuclear cascades resulting from interactions of UHECR nuclei in both sources and during propagation. The description allows for a larger number of nuclear species due to being easily computable, and integrates nuclear decays without the need of ad-hoc limitations on nuclear species on the basis of the decay time. The inclusion of more complex effects such as time variable photon fields, magnetic diffusion and escape in this framework are also discussed, emphasizing that no additional simplifying assumptions are required to achieve a time efficient and precise computation. The method is implemented in a python package called CRISP, to be presented in this talk.

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