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Boosted Dark Matter Heating of Compact Stars Beyond Capture

Compact astrophysical objects, such as neutron stars and white dwarfs, can act as detectors of energetic particle fluxes originating from astrophysical accelerators. While most existing capture and heating calculations assume isotropic very low energetic incident fluxes from the halo dark matter, many realistic sources produce highly directional beams or jets, for which gravitational focusing, trajectory multiplicity, and local energy deposition must be treated consistently. In this work, we develop a general relativistic formalism to compute the local density, capture probability, and energy deposition of particles arriving as directed beams onto compact objects. The framework is based on the mapping of an asymptotic particle flux to local densities through geodesic congruences, allowing for gravitational focusing, multi–stream regions, and optical depth effects to be incorporated in a unified way. The formalism applies to arbitrary particle species and interaction models, and separates capture from through–going energy deposition in a frame–consistent manner. As an explicit application, we consider relativistic particle beams generated in astrophysical jets and evaluate their interaction with two compact objects samples: a white dwarf and a neutron star. In particular, we illustrate the framework using boosted dark matter produced in a list of 324 blazars as a representative case study, computing the resulting fluxes and the associated heating in the selected stars. Additional regimes such as the interaction roof and geometric limit are discussed, highlighting the conditions under which compact objects can efficiently convert incident beam energy into observable heating.

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