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Improved Treatment of Dark Matter Capture in Compact Stars

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Compact stellar objects are promising cosmic laboratories to test fundamental interactions, in particular they could shed light on the nature of dark matter (DM). DM captured by the strong gravitational field of these stellar remnants transfers kinetic energy to the star during the collision. This together with further DM annihilation in the stellar interior can have various observational consequences such as the anomalous heating of old compact stars. A key ingredient to derive bounds on DM interactions in any scenario involving the accumulation of DM in a star is the proper calculation of the capture rate. We improve former calculations of the capture rate in both white dwarfs (WDs) and neutron stars (NSs), which rely on approximations or simplifying assumptions. We model the stellar interior and related microphysics by assuming an equation of state and solving the Tolman-Oppenheimer-Volkoff equations. Aside from the stellar structure, we account for gravitational focusing, a fully relativistic scattering treatment when relevant, the star opacity, multiple scattering effects, Pauli blocking when light DM scatters off degenerate targets, realistic form factors, and strong interactions in the case of baryonic NS target species. For WDs, we consider DM scattering off the non-degenerate ions and the degenerate electrons. Using an effective field theory approach, we show that if there is DM in the innermost region of the globular cluster Messier 4, which contains old WDs, these WDs can probe the elusive sub-GeV mass range for both DM-nucleon and DM-electron scattering. In NSs, DM can be captured via collisions with strongly degenerate nucleons, relativistic leptons, and hyperonic matter which may exist in the ultra-dense core of heavy NSs. We project the potential NS sensitivity to DM-lepton and DM-nucleon scattering which greatly exceeds that of direct detection experiments.

Author: Dr ROBLES, Sandra (King's College London)

Presenter: Dr ROBLES, Sandra (King's College London)

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