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Probing Dark Matter with exoplanets

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One approach to understanding Dark Matter (DM) involves studying how it interacts with compact astrophysical objects. Through interactions with an object's constituents, DM in the region around an object can become gravitationally bound inside the object (capture) and, if DM undergoes annihilation processes, can leave an observable imprint on the object. Additionally, captured DM can escape the object through up-scattering with the object's nuclei distributions, a process known as evaporation. In Ilie et al. 2020, analytic expressions for the capture rate of DM are computed assuming the object's escape velocity () far surpasses the DM velocity dispersion ($\bar{v}$). In this work, we generalize those findings and find analytic expressions irrespective of any $\bar{v}-$ hierarchy. As in Ilie et al. 2020, we find analytic capture rates in four distinct regions of the DM mass () and scattering cross-section (σ) parameter space and further find that one of these regions is erased in the $\bar{v} >>$ limit. These results are important since computing capture rates numerically becomes very computationally expensive in the limit of high DM-baryon interaction.

Exoplanets are promising candidates for probing DM through these processes, particularly in the sub-GeV regime, as described in Leane and Smirnov 2021 who compute their sensitivity to DM at masses where evaporation is negligible. In this work, we improve on their results by including completely the effects of evaporation in addition to capture and annihilation. We compute our evaporation rate as per Garani and Palomares-Ruiz 2022, which includes the suppression from the so-called "ping-pong" effect whereby DM particles on outbound trajectories with speed $>$ down scatter and thus become effectively "re-captured." This effect adds a non-trivial dependence of the evaporation rate (E) on the scattering cross-section (σ), as opposed to the usual $E \sim \sigma$ when the ping-pong effect is excluded. With this non-trivial dependence, we find that, while sensitivity to DM is reduced when considering the effects of evaporation, these objects still serve as strong probes of DM below the mass where evaporation begins to dominate.

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