Contribution ID: **166** Type: **Poster**

Halo-to-Halo Similarity in IllustrisTNG Dark Matter Velocity Distributions

Experiments that aim to directly detect dark matter have placed increasingly constraining bounds on the cross section for interaction between dark matter and standard model particles. This requires an understanding of the phase-space distribution function (DF) of dark matter in the detector volume, which is a longstanding source of astrophysical uncertainty. We study the dark matter DF in 98 Milky Way analogues from the IllustrisTNG simulation and produce dark matter–nucleon interaction cross section constraints for the XENON1T experiment. Nominally, the dark matter DF at the observed solar position in these simulations yields constraints that vary from halo to halo by a factor of two near threshold (for dark matter masses around 10 GeV). Moreover, these simulated galaxies do not generically reproduce observations of the Milky Way itself, such as the circular velocity of the sun. To correct for this effect, we apply a one-parameter rescaling to the DF which recovers the observed solar velocity and find that the factor of two uncertainty due to cosmic variance is reduced by an order of magnitude. This suggests that the halo-to-halo variance is not as significant a source of uncertainty as previously assumed and motivates renewed attention to other systematics.

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