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Cosmological Simulations with Self-Interacting Dark Matter

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We use cosmological simulations to study the effects of self-interacting dark matter (SIDM) on the density profiles, substructure counts and shapes of dark-matter haloes from the scales of spiral galaxies to galaxy clusters, focusing explicitly on models with cross-sections over dark-matter particle mass $\sigma/m = 1$ and 0.1 cm2 g-1. Our simulations rely on a new SIDM N-body algorithm that is derived self-consistently from the Boltzmann equation and that reproduces analytic expectations in controlled numerical experiments. We find that well-resolved SIDM haloes have constant-density cores, with significantly lower central densities than their cold dark matter (CDM) counterparts. In contrast, the subhalo content of SIDM haloes is only modestly reduced compared to CDM, with the suppression greatest for large hosts and small halo-centric distances. Moreover, the large-scale clustering and halo circular velocity functions in SIDM are effectively identical to CDM, meaning that all of the large-scale successes of CDM are equally well matched by SIDM. Our results show that halo core densities in $\sigma/m = 1$ cm2 g-1 models are too low to match observations of galaxy clusters, low surface brightness spirals (LSBs) and dwarf spheroidal galaxies. However, SIDM with σ/m ⊠ 0.1-0.5 cm2 g-1 appears capable of reproducing reported core sizes and central densities of dwarfs, LSBs and galaxy clusters without the need for velocity dependence. Higher resolution simulations over a wider range of masses will be required to confirm this expectation. We discuss constraints arising from the Bullet cluster observations, measurements of dark-matter density on small scales and subhalo survival requirements, and show that SIDM models with σ/m ⊠ 0.1-0.5 cm2 g-1 ⊠ 0.2 barn GeV-1 are consistent with all observational constraints.

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