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The Universality of Dark Matter Density Profiles for Milky Way Analog Galaxies

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For nearly five decades, the interplay between dark matter (DM) halos and baryonic (or luminous) matter has shaped our understanding of galaxy formation and evolution. Recent observational data (e.g., the latest DESI results) suggests that the standard Λ-CDM model, although remarkably successful, may need to be revisited to fully explain the Universe. This tension motivates a more detailed track of DM on galactic scales, where its gravitational imprint is more directly observable. To address the DM density in galaxies, we combine cosmological simulations with multi-wavelength observations to constrain DM profiles. The structure, extension, and mass of the Milky Way (MW) still hold observational challenges due to the fact of globally analyzing the system in which we are located. The study of MW analogs helps us with this challenge. We are interested in studying the galaxy-halo connection on a more local scale, from the center of disk galaxies up to the outskirts of those systems. In this work we present a comprehensive study of DM distribution in MW-like galaxies: we analyze a large sample of $>$100 galaxies from the state-of-the-art Illustris TNG-50 cosmological simulation, combined with 21 cm line observations of nearby MW analogs. Using both spatial and spectral high-resolution data from VLA and GMRT radio telescope arrays, we employ the 3D-Barolo algorithm to derive precise kinematic maps and rotation curves. We use Spitzer mid-IR imaging at 3.6/4.5 \textmu m, the best single-band tracer of stellar mass, to perform a careful analysis of the baryonic component–strongly dominated by the emission from low-mass stars. We decompose the rotation curves into their different mass components (stars, gas, and DM), enabling the construction of a DM radial profile for each galaxy. By using a Markov Chain Monte Carlo-based routine, we account for the DM contribution for the observed rotation curves. This allows us to test the universality of DM halo shapes and its possible deviations when taking baryonic physics into account. One of our goals is to constrain the DM density in the solar neighborhood of the MW, based on drawing analogies with the DM distribution in our MW analog sample. In general, current values in the literature rely on the study of stellar orbits in the solar neighborhood or under assumptions about the shape of the DM halo in the MW (e.g., NFW or Einasto profiles). Instead, we calculate the DM density at the corresponding location of the solar neighborhood in each of the analog galaxies. For this purpose, the galactocentric distance from the Sun of $\sim 8\ kpc$ can be translated into $1.6 \times R_{eff}$, where R_{eff} is the radius that encompasses half of the light ($R_{eff} = 5\ kpc$, for a MW reference). Our analysis yields an average local DM density of $\rho_{DM}\ \sim 0.01\ M_{\odot}\ pc^{-3}$ for the sample of simulated galaxies–consistent with the rotation curve results based on HI observations. This provides a critical link to direct DM detection experiments on Earth, as the local DM density is a key parameter for estimating expected interaction rates with DM particles. Such a result contributes to sharpening both the empirical basis for DM searches and our understanding of its role in astrophysical and cosmological scenarios.

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