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Abstract. Dark matter direct detection experiments need to know the local phase space density of dark matter $f_{dm}(\mathbf{r}, \mathbf{v}, t)$ in order to derive dark matter particle properties. To date, calculations for $f_{dm}(\mathbf{r}, \mathbf{v}, t)$ have been based on simulations that model the dark matter alone. Here we include the influence of the baryonic matter. We find that a star/gas disc at high redshift ($z \sim 1$) causes merging satellites to be preferentially dragged towards the disc plane. This results in an accreted dark matter disc that contributes $\sim 0.25 - 1$ times the non-rotating halo density at the Solar position. We discuss the impact of the dark disc on dark matter direct detection experiments, and how we might be able to detect it in future Galactic surveys.

INTRODUCTION

The case for dark matter in the Universe is based on a wide range of observational data, from galaxy rotation curves and gravitational lensing, to the Cosmic Microwave Background Radiation [1, 2]. Of the many plausible dark matter candidates in extensions to the Standard Model, Weakly Interacting Massive Particles (WIMPs) stand out as well-motivated and detectable [1], giving rise to many experiments designed to detect WIMPs in the lab. Predicting the flux of dark matter particles through the Earth is key to the success of such experiments, both to motivate detector design, and for the interpretation of any future signal [1].

Previous work has modelled the phase space density distribution of dark matter at the Solar neighbourhood using cosmological simulations that model the dark matter alone (see e.g. [3, 4]). This results in the 'Standard Halo Model' (SHM) prediction that $f_{dm}(\mathbf{r}, \mathbf{v}, t)$ is well approximated by an isotropic Gaussian. In this proceedings, we discuss the first attempts to include stars and gas in these models. The Milky Way stellar disc presently dominates the mass interior to the Solar radius and likely did so also in the early Universe at redshift $z = 1$, when the mean merger rate in a ΛCDM cosmology peaks [5]. The star/gas disc is important because it biases the accretion of satellites, causing them to be dragged towards the disc plane where they are torn apart by tides. The material from these accreted satellites settles into a thick disc of stars and dark matter [6].

In this proceedings, we summarise the expected properties of this dark disc; the impact of the dark disc on $f_{dm}(\mathbf{r}, \mathbf{v}, t)$ and therefore on dark matter detection experiments; and we discuss prospects for detecting the dark disc in up-coming Galactic surveys.

QUANTIFYING THE DARK DISC

We use two different approaches. In the first approach, we use dark matter only simulations to estimate the expected merger history of a Milky Way mass galaxy, and then add a stellar disc to measure its effect. This work is presented in detail already in [5].

Figure 1(a) shows the accreted dark matter at the end of a simulation where we merged a Large Magellanic Cloud mass satellite (LMC) at $\theta = 10^\circ$ to the Milky Way stellar disc (the dotted contours show the underlying Milky Way stellar distribution). Notice that the accreted dark matter forms a thick disc that is aligned with the Milky Way stellar disc; this is what we call the *dark disc*. Figure 1(b) shows the dark matter disc to dark matter halo density ratio $\rho_{\mathrm{DDISC}}/\rho_{\mathrm{HALO}}$ as a function of height above the disc plane for similar merger simulations with increasing impact angle θ, as marked. Also shown is a higher mass merger – 'LLMC' – that was chosen to mimic the most massive mergers expected in our current cosmology. As the satellite impact angle θ is increased, the satellite contributes less material to a dark disc. For $\theta = 40^\circ$, the density at the Solar neighbourhood is nearly flat with z and less than a tenth of the underlying halo density; there is correspondingly less rotation in this simulation. Summing over the expected number and mass of mergers, we find that the dark disc contributes $\sim 0.25 - 1$ times the non-rotating halo density at the Solar position[1] [5], where the uncertainty reflects the unknown merger history of our Galaxy. It is important to stress that all satellites regardless of their initial inclination have some accreted material that is focused into the disc plane. As such, we expect that the accreted dark and stellar discs will comprise several accreted satellites; the most massive low-inclination mergers being the most important contributors.

Our first approach, above, allowed us to specify precisely the properties of the Milky Way disc at high redshift. In our second approach, we ran three fully self-consistent cosmological hydrodynamic simulations of Milky Way mass galaxies. All three were run with the GASOLINE code [10] using the "blastwave feedback" described in [11]. MW1 had no significant mergers after redshift $z = 2$; H204 and H258 both had massive late mergers at redshift $z < 1$ (see [9] for further details).

Figure 1(c) shows the distribution of rotational velocities v_ϕ at the Solar neighbourhood for stars (dashed) and dark matter (black) for the simulation H258. Notice that the dark matter is highly rotating. This same simulation run without any stars or gas gives the black dotted histogram that is the non-rotating 'Standard Halo Model' (SHM) prediction. In all three simulations, the local $f_{\mathrm{dm}}(\mathbf{r}, \mathbf{v}, t)$ is best fit by a *double Gaussian* that has a non-rotating component (the SHM), and a rotating component that we call the *dark disc* (DD). Averaging over the three simulations MW1, H204 and H258, we estimate that typical Milky Way mass galaxies in our cosmology will have a dark disc with density ratio $\rho_{\mathrm{DDISC}}/\rho_{\mathrm{HALO}} \sim 0.25 - 1.5$ consistent with the estimate from our first approach. The dark disc lags the rotation of the thin stellar disc by $v_{\mathrm{lag}} \sim 50 - 150\,\mathrm{km/s}$

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[1] Recently, [7] have argued that the Milky Way must be very quiescent. If this is the case, then its dark disc will lie at the lower end of this range, with slower associated rotation and higher vertical dispersion.
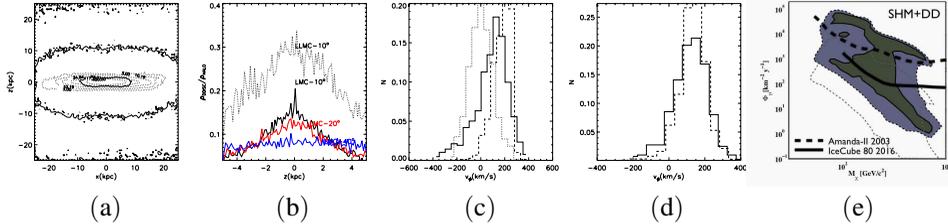
(a)	(b)	(c)	(d)	(e)

FIGURE 1. From left to right: **(a):** Accreted dark matter (solid contours) at the end of a simulation where we merged an LMC mass satellite at $\theta = 10^o$ to the Milky Way stellar disc (the dotted contours show the underlying Milky Way stellar distribution). **(b):** The dark matter disc to dark matter halo density ratio ρ_{DDISC}/ρ_{HALO} as a function of height above the disc plane (at the Solar neighbourhood; $8 < R < 9$ kpc), for selected merger simulations. **(c):** The distribution of rotational velocities v_ϕ at the Solar neighbourhood of stars (dashed) and dark matter (solid) in the cosmological hydrodynamic simulation H258. The dotted histogram shows the dark matter distribution from the same simulation run without any stars or gas. **(d):** The v_ϕ distribution at the Solar neighbourhood of stars (dashed) and dark matter (solid) that were accreted from the four most massive disrupted satellites in H258. **(e):** Total muon flux due to neutrinos originating in the Sun Φ_μ for muon energy $E_\mu > 1$ GeV, as a function of WIMP mass M_χ. We show results for the standard halo model (SHM; light grey shaded region) and the SHM plus fiducial dark disc model (DD; dark grey shaded region). Overlaid are experimental constraints on the muon flux from AMANDA-II and (predicted) IceCube 80 (see [8] for details). The closed contours show 95% (dashed) and 68% (solid) of the probability density of CMSSM models consistent with both astrophysical and collider constraints, assuming flat priors (all figures adapted from [5, 9, 8]).

and has an approximately isotropic velocity dispersion in the range $\sigma = 50 - 90$ km/s. (This depends on how the double Gaussian is decomposed into SHM and DD components. Assigning the material accreted from the four most massive mergers to the dark disc gives a radial dispersion in the range $\sigma_R \sim 100 - 150$ km/s, which is higher than the σ_ϕ and σ_z components [9]). Simulations that have more late mergers have a dark disc that is more massive, more rapidly rotating and of lower dispersion. Other groups are now confirming these findings [12].

DARK DISC IMPLICATIONS

We investigated the implications of the dark disc for dark matter direct and indirect detection in [13, 8]. Using a *fiducial* dark disc that is in the median of the above derived ranges, we showed that the dark disc boosts the direct detection signal at low recoil energy by a factor ~ 3 in the $5 - 20$ keV range, shifts the phase of the annual modulation signal allowing the WIMP mass to be determined, and significantly boosts WIMP capture in the Sun and Earth by factors of ~ 10 and ~ 1000, respectively. This latter point is perhaps the most exciting as it makes neutrino telescopes a competitive WIMP probe. Figure 1(e) shows the total muon flux due to neutrinos originating in the Sun Φ_μ for muon energy $E_\mu > 1$ GeV, as a function of WIMP mass M_χ. We show results for the standard halo model (SHM; light grey shaded region), and the SHM plus fiducial dark disc (DD; dark grey shaded region). The closed contours show 95% (dashed) and 68% (solid) of the probability density of constrained minimal standard supersymmetric

(CMSSM) models consistent with both astrophysical and collider constraints, assuming flat priors (see [8] for further details). Notice that – once we account for the dark disc – current constraints from AMANDA-II already appear to rule out many CMSSM models. However, this is for our fiducial dark disc model that might not be correct for the Milky Way. To make further progress, we must determine whether or not the Milky Way has a significant dark disc, and measure its properties. We discuss prospects for this next.

DETECTING THE DARK DISC

The dark disc does not have a strong dynamical influence on the Milky Way. It contributes just a fraction of the expected local dark matter density which is already difficult to detect using the kinematics of Solar neighbourhood stars (see e.g. [14]). However, as discussed above, the dark disc does have potentially important consequences for dark matter detection experiments. For this reason, it is important to determine whether the Milky Way has a significant dark disc and measure its properties. Figure 1(d) shows the v_ϕ distribution of stars and dark matter at the Solar neighbourhood that were accreted from the four most massive disrupted satellites in simulation H258. Notice that the accreted stars and dark matter share very similar kinematics. This is true also for the other velocity components v_R and v_z. We see similar results in all of our simulations. Thus, if we can find these accreted stars, then we have found the smoking gun for the dark disc. Furthermore, the kinematics of these stars give us strong constraints on the kinematics of the dark disc. Hunting for these disc-like accreted stars in the Solar neighbourhood is the subject of ongoing investigations.

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