Using astronomical data to derive flux predictions for the annihilation of Dark Matter in the Local Group

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Abstract: The Dark Matter distribution inside the halos is a still unsolved cosmological issue. N-body simulations data, which are usually assumed to represent the Dark Matter shape inside the halos, suffer from the bug of fitting all types of Galaxy with a universal profile, without taking into account the peculiar properties of each Galaxy. In this work we extract informations on the Dark Matter distribution for the four closest and most Dark Matter dominated dwarf spheroidal galaxies of the Local Group, and we shape the density profile according to the available data. We then make a prediction for the γ-ray flux arising from the annihilation of Dark Matter in these structures, and study the experimental sensitivity of a GLAST-like satellite to these sources.

Introduction

The Dark Matter (DM) content of the Universe is still far from being understood. Uncertainties apply to the underlying particle physics as well as to the cosmological models that should fix the DM distribution. Indirect detection of DM annihilation signals has been widely studied [1].

Annihilation γ-rays from dwarf spheroidals would give a clean signal, because of the absence of high astrophysical uncertainties in modeling the expected background, and could hopefully be detected with upcoming experiments like GLAST. Many authors [2, 3, 4, 5, 6, 7] have studied the feasibility of such a detection. They have used a large variety of universal density profiles, reflecting the theoretical as well as the experimental uncertainties.

In this paper we use the more modern available astrophysical measurements for Draco, Ursa Minor, Carina and Sextans dwarf spheroidal galaxies, which are the closest dwarfs with the highest M/L ratio. We derive the density profile directly from the data and use an optimistic particle physics scenario to predict a γ-ray flux. We compare the results with a standard NFW profile. We then study the detection probability with a GLAST-like experiment.

Draco dwarf spheroidal

The mass density profile for the Draco dwarf spheroidal galaxy (DSG) has been taken from [8]. That analysis is based on the radial velocity measurements on a sample of 207 stars. The sample has been obtained through the merging of the datasets derived from [9] and [10]. The typical uncertainty in velocity measurements for each stellar radial velocity was less than 3 km/s. The data allow to derive the velocity dispersion radial profile at 7 different distances from the halo center. The profile is consistent to be constant with radius at a value of 10 km/s, showing a sharp drop only in the last measured point. If confirmed, the drop is indicative of a radial change in the isotropic orbital properties. The azimuthally averaged surface brightness profile is also derived by [9]. The authors of [8] use the Jeans equations in the hypothesis of isotropic orbital structure and radial and tangential anisotropy. Indeed, the knowledge of the surface brightness profile does not fix the total density distribution, though giving information about the spatial distribution of the kinematical tracers (stars) and about the velocity dispersion radial profile. There is a degeneracy between the anisotropy parameter describing the orbital structure and the mass. For instance, the presence of strong radial anisotropy in the center may mimic the presence of a mass concentration. The degeneracy may be broken by deriving the complete shape of the line-of-sight velocity distribution and not only the velocity dispersion. In the study of dwarf galaxies though, the limited number of stars for each radial bin allows only to derive the velocity dispersion. In the lack of data, the behaviour of the anisotropy is generally taken as a free parameter. In the case of Draco, the isotropic assumption applied to the data allow to derive the density distribution in the radial range between 150 and 500 pc. We impose an inner core to better follow the data shape, both for Draco and for the other dwarfs. We refer to the profiles directly derived by the data as to the DATA profiles.

An independent mass density profile for Draco has been obtained in [11]. The authors have used the data by [9, 14] to reconstruct a mass model for the galaxy. They assume that the galaxy is composed by a luminous component described by means of a King model, and a Dark Matter component described by a NFW model. In this way they derive the concentration parameter of the dark halo component directly from a fit to the data instead that from an *a priori* cosmological model. We will refer to this kind of profiles as to the DATA-NFW profiles.

In Fig.1 we plot the density profiles for Draco using the DATA and DATA-NFW (concentration parameter $c = 7.5$, scale radius $r_s = 3.56$ kpc) profiles. We plot the universal NFW profile ($c = 22.3$, $r_s = 0.26$ kpc) for comparison as well.

Ursa Minor dwarf spheroidal

The mass density profile for Ursa Minor has been taken from [8]. The analysis here is based on the radial velocity measurements on a sample of 162 stars. As in case of Draco afore mentioned, the sample has been obtained merging the datasets derived from [9] and [10]. The data allow to derive the velocity dispersion radial profile at 8 different distances from the center. The velocity dispersion radial profiles is consistent to be constant with radius at a value of 15 km/s, showing a sharp drop only in the last measured point. The azimuthally averaged surface brightness profile is also derived by [9]. The authors of [8] use the Jeans equations in the hypothesis of isotropic orbital structure and radial and tangential anisotropy. The data allow to derive the density distribution in the radial range between 100pc to 400pc.

As already described for Draco, the authors of [11] adopted a two component mass model to derive the DM halo parameters under the assumption of a NFW density distribution.

Carina dwarf spheroidal

Accurate radial velocity measurements of stars in Carina are reported by [12, 13, 14]. The authors of [14] have used these datasets to select a “conservative” sample of 260 plus additional 116 stars that probably belong to Carina too. The velocity dispersion radial profile has been measured out to 4.4 arcmin and is consistent to be constant with radius with a value of about 7 km/s. This dataset has been used by [11] to derive the parameters of the dark halo component adopting the NFW model.

[8] also derived the DM density radial profile of the Carina dwarf spheroidal. They did not made *a priori* assumptions on the profile and derived it from the velocity dispersion data and surface brightness radial profile solving the Jeans equations under the assumption of isotropic motions. The data allowed to derive the profile in the range between 60pc and 1000 pc. In the inner region the profile appear to be shallower than what predicted from the NFW model.

Sextans dwarf spheroidal

Accurate radial velocity measurements of stars in the Sextants DSG are reported in [15]. They have analysed a sample of 276 stars belonging to the dwarf galaxy. The velocity dispersion radial profile has been measured out to 30 arcmin and is consistent to be constant with radius with a value of about 7 km/s. These data have been used by [11] to derive the parameters of the dark halo component adopting the NFW model.

[8] also derived the DM density radial profile of the Sextans dwarf spheroidal. They did not made *a priori* assumptions on the profile and derived it from the velocity dispersion data and surface brightness radial profile solving the Jeans equations under the assumption of isotropic motions. They have derived the profile in the 200-600 pc radial range founding a constant density core.

Experimental detectability

The γ-ray annihilation flux $\Phi_\gamma = \Phi^{\rm PP} \times \Phi^{\rm cosmo}$ can be factorized into a term involving the particle physics and a second one where cosmology and experimental geometry play the main role:

$$\Phi^{\rm PP}(E_\gamma) = \frac{1}{4\pi}\frac{\sigma_{\rm ann}v}{2m_\chi^2} \times \sum_f B_f \int_E \frac{dN_\gamma^f}{dE_\gamma}dE\,; \tag{1}$$

$$\Phi^{\rm cosmo}(\psi,\Delta\Omega) = \int\int_{\Delta\Omega} d\phi d\theta \int_{\rm l.o.s} d\lambda \left[\frac{\rho_\chi^2(r)}{d^2}J(x,y,z|\lambda,\theta,\phi)\right]\,. \tag{2}$$

$\rho_\chi(r)$ is the DM density profile, ψ is the angle of view from the halo center, d the halo distance and r the radial coordinate inside the halo. We adopt $m_\chi = 40$ GeV, $\sigma_{\rm ann}v = 10^{-26}{\rm cm}^3{\rm s}^{-1}$, a 100% branching ratio in $b\bar{b}$ and $\Delta\Omega = 10^{-5}$ sr corresponds to the angular resolution of the instrument. In Fig.2 we plot the derived γ-ray flux expected from Draco as a function of ψ, for the three density profiles described in Sec.2.

We define the experimental sensitivity as the ratio $\sigma = \frac{n_\gamma}{\sqrt{n_{bck}}}$ of the number of annihilation photons to the astrophysical background fluctuation, as taken from [16, 17]. We compute the sensitivity in 1 year of effective data taking for a GLAST-like experiment. Results for the four dwarfs are shown in Fig. 3, for the DATA profile. We have checked that this profile gives the higher sensitivity curves. Nevertheless, we find that the sensitivity of each of the four galaxies is below the 1-σ level, which would unfortunately not let any conclusive statement about DM detection.

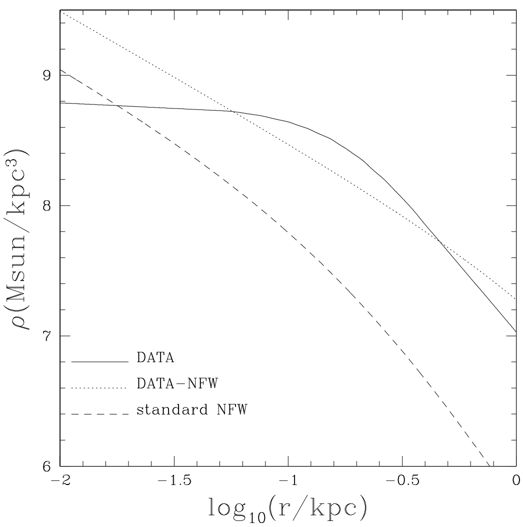

Figure 1: Density profiles for Draco: DATA profile taken from [8]; DATA-NFW profile [11] where constraints on the NFW parameters are set using available data, resulting in $c = 7.5$, $r_s = 3.56$ kpc; universal NFW profile with $c = 22.3$ and $r_s = 0.26$ kpc.

We refer to [18] for a complete explanation of symbols in this section.

Conclusions

We have estimated the experimental sensitivity of a GLAST-like experiment for four of the closest and most DM dominated dwarf spheroidal galaxies in the Local Group. We have chosen an optimistic value for the unknown particle physics contribution, and we have derived the DM density profile from available data rather than using universal models.

We found that the use of such data-derived profiles does indeed predict a bigger γ-ray flux compared with standard universal profiles. Yet, this flux is just too small to be detected with the most modern experimental apparata such as GLAST, unless an unpredictable boost in the particle physics model

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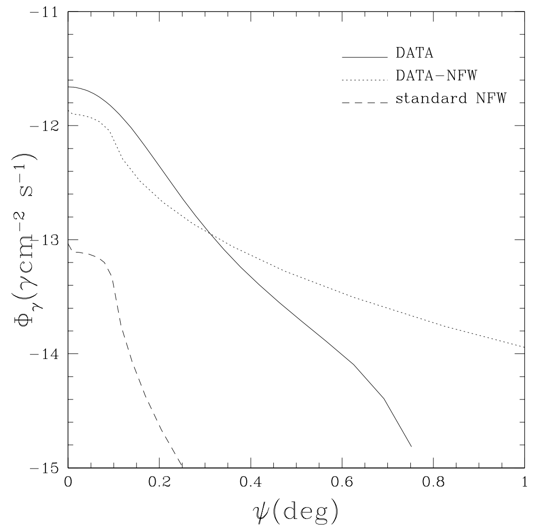

Figure 2: Annihilation γ-ray flux from DRACO using the different density profiles of Fig. 1

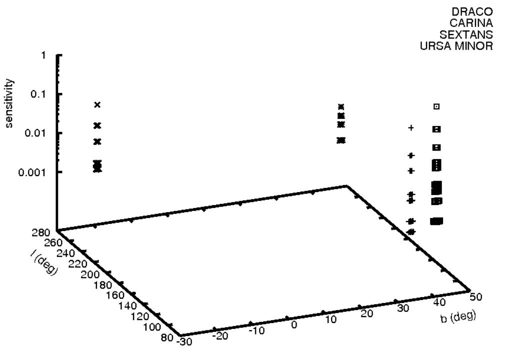

Figure 3: Sensitivity to the expected annihilation γ-ray flux for the four galaxies analysed in this work, computed for a GLAST-like experiment. The DATA profiles have been used. Galaxies are located at their position in the sky, labeled by their galactic latitude (b) and longitude (l)

or a mayor effect due to the existence of subhalos inside the dwarfs would increase the expected signal. A multifrequency analysis would probably better allow a possible DM detection in the dwarf galaxies rather than the γ-ray observations alone.

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