Are the cross section upper limits from dSphs too tight?

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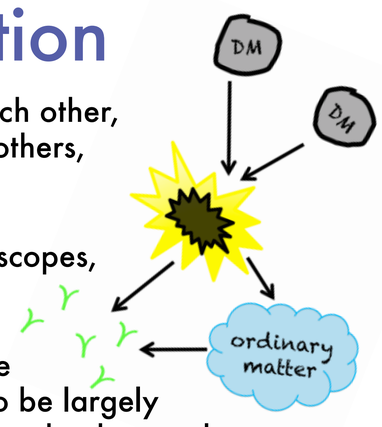
Introduction



When Dark Matter (DM) particles meet each other, they can annihilate. This results in, among others, gamma-rays.

These ϒ-rays can be detected by ϒ-ray telescopes, like the Fermi-LAT space telescope.

Dwarf spheroidal galaxies (dSphs), satellite galaxies of the Milky Way, are expected to be largely dominated by DM and have a very low ϒ-ray background.

A ϒ-ray excess in the direction of a dSph would be an indication for the detection of DM.

An important aspect in determining the expected annihilation flux is the DM density profile, i.e. how the DM is distributed through the dSph. The common assumption often adopted in the literature is that dSphs are characterised by a spherically symmetric, so-called Navarro-Frenk-White (NFW) profile [1]. This cusped profile, i.e. very steep at the center, originally predicted by N-body simulations of cold dark matter, might not be the best choice for all dSphs.

We investigate the impact of axisymmetric DM density profiles based on stellar kinematical data on the cross section upper limits of DM annihilation in dSphs.

The density profiles

The expected flux coming from DM annihilation is given by:

$$\phi_{\rm WIMP}(E,\Delta\Omega) = J(\Delta\Omega) \times \Phi^{\rm PP}(E) \quad (1)$$

Astrophysical factor (J-factor) — Particle physics factor

$$J(\Delta\Omega) = \int_{\Delta\Omega}\int_{\rm l.o.s} \rho^2(l)\,{\rm d}l\,{\rm d}\Omega \quad (2) \qquad \Phi^{\rm PP}(E) = \frac{1}{2}\frac{\langle\sigma v\rangle}{4\pi m^2_{\rm WIMP}}\sum_f \frac{dN_f}{dE}B_f \quad (3)$$

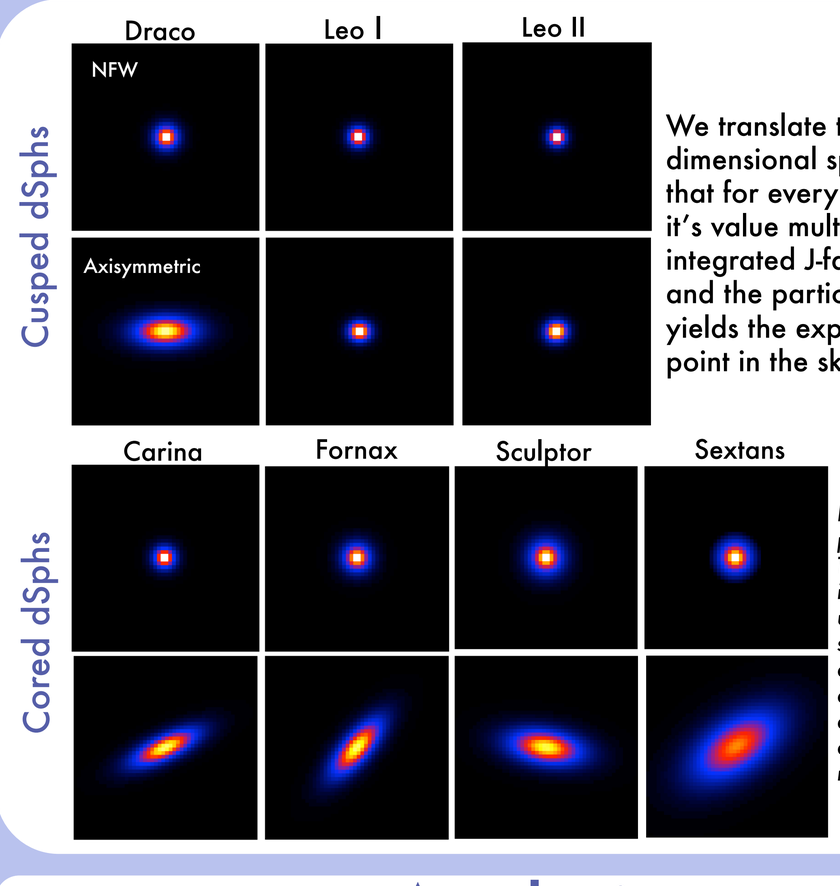
Describes the DM density distribution — Encloses the properties of the DM particle

In our analysis of the Fermi-LAT data, we compare an observationally-motivated axisymmetric DM density profile with the widely used spherically-symmetric NFW profile.

The NFW profile is given by: $\rho(r) = \begin{cases} \frac{\rho_s r_s^3}{r(r_s+r)^2} & \text{for } r < r_t \\ 0 & \text{for } r \geq r_t \end{cases}$

For the axisymmetric model, we use the non-spherical DM halo structure estimated by Ref. [2] to compute the J-factor maps. Because these models are determined for every Individual dSph separately based on their stellar kinematical data, they are better approximations for the DM halo than the more general NFW profile.

We analyze 7 dSphs: Draco, Carina, Fornax, Leo I, Leo II, Sculptor and Sextans. The profiles generated by Ref. [2] turn out to be cusped for Draco, Leo I and Leo II, while cored, i.e. more shallow at the center, for Carina, Fornax, Sculptor and Sextans.



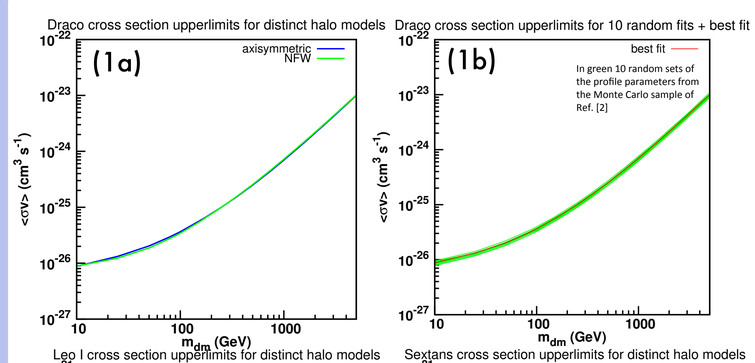
We translate the J-factor to two-dimensional spatial maps, such that for every pixel in the map, it's value multiplied by the total integrated J-factor of the dSph and the particle physics factor, yields the expected flux in that point in the sky.

DM density profiles projected onto the sky. The total flux of all images is normalised to unity, and the colour scale is the same in each pair of figures for every dSph. The maps are cropped to correspond to a 5° × 5° region in the sky.

Analysis

We perform a binned likelihood analysis of 86 months of *Fermi*-LAT PASS8 data in the direction of the selected dSphs with a region of interest of 10° x 10° around each dSph, using the Fermi Science Tools. For each dSph, we run the analysis for both the NFW profile as the axisymmetric one. We repeat the analysis for 18 different values of m_{dm} from 10 to 5000 GeV. We derive 95% confidence-level integrated flux upper limits between 100 MeV and 50 GeV and calculate limits on the DM annihilation cross section in the $b\bar{b}$-channel.

Results



For the cusped dSphs (fig. 1a,2,3) the difference between the upper limits is small. The NFW profile provides a good approximation of the actual halo of these dwarfs. In the cases of the cored dSphs (fig. 4-7) the difference is more significant. We find the largest difference of a factor of 2.5-7 in the case of Sextans, where we see that the DM halo in the axisymmetric case is the most extended compared with the corresponding NFW profile.

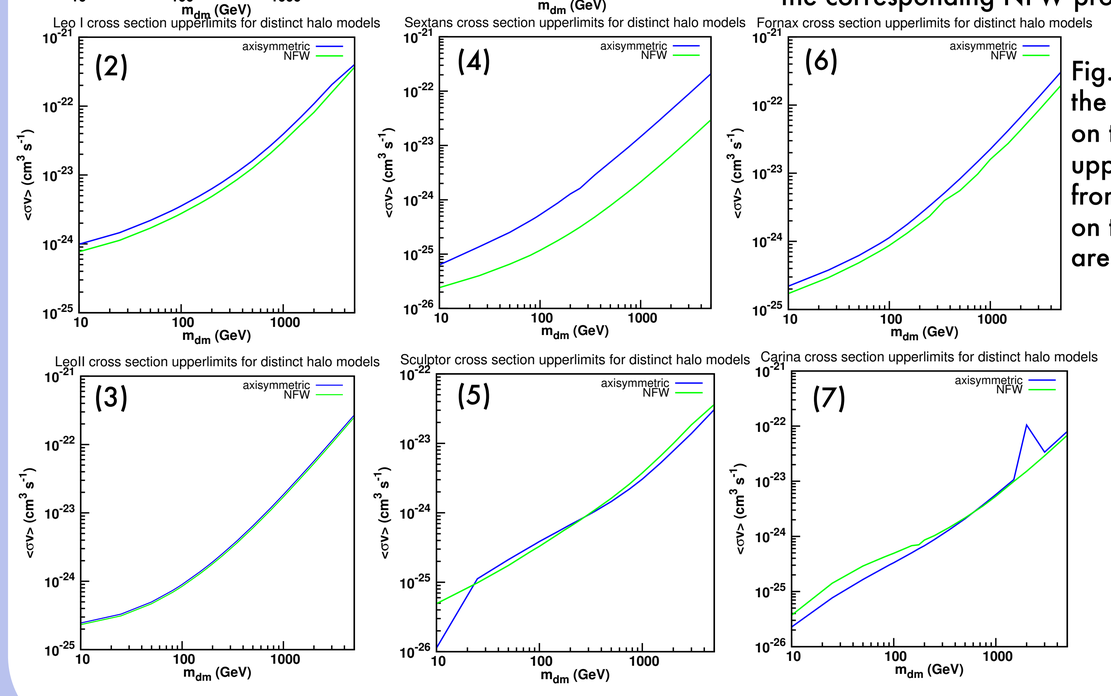


Fig. 1b shows that the uncertainties on the cross section upper limits coming from uncertainties on the halo model are at ~12% level.

Conclusion

DSphs are important targets for indirect DM detection. Recent observational data of stellar kinematics imply that the common choice of an NFW profile is not the best choice for dSphs, but are instead better described by an axisymmetric profile. Therefore, we investigated the impact of observationally motivated axisymmetric halo models on the DM annihilation cross section upper limits in seven classical dSphs. We find differences in the cross section upper limits between the two halo models for four of the investigated dSphs, those with a cored density profile. For these dSphs, an NFW profile is not a good approximation for the DM distribution and axisymmetric models are the preferred choice for obtaining annihilation cross section upper limits. The difference is most significant in the case of Sextans, in which the upper limits obtained with an axisymmetric profile are weaker by a factor of 2.5-7 compared to the upper limits obtained using an NFW profile. Therefore, upper limits in the literature obtained assuming a cusped spherical model such as NFW might have been overestimated. This demonstrates that it is important to properly determine DM density profiles from observational data.

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