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# Dark Matter search in dwarf irregular galaxies with *Fermi*-LAT

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In these proceedings we highlight the main results about dark matter (DM) search in dwarf irregular galaxies with the *Fermi* Large Area Telescope. We analyze 11 years of *Fermi*-LAT data corresponding to the sky regions of 7 dwarf irregular (dIrr) galaxies. DIrrs are DM dominated systems, recently proposed as interesting targets for the indirect search of DM with gamma-rays. We create a spatial template of the expected DM-induced gamma-ray signal with the CLUMPY code, to be used in the analysis of *Fermi*-LAT data. No significant emission is detected from any of the targets in our sample. Thus, we compute the upper limits on the DM annihilation cross-section versus mass parameter space. The strongest constraints are obtained for $b\bar{b}$ and are at the level of $\langle\sigma v\rangle \sim 7 \times 10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}$ at $m_\chi \sim 6$ GeV.

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## 1. Introduction

DM-dominated systems - e.g. galaxy clusters, dwarf spheroidal (dSph) galaxies as well as the Galactic center - are benchmark targets for indirect searches of DM (see e.g. [1, 2] and refs therein). Among other targets, Milky Way dSph galaxies are considered to be especially promising objects due to their relatively close position and their appearance as point-like or marginally extended sources in gamma-ray telescopes. Recently, dwarf irregular (dIrr) galaxies in the Local Volume have been claimed to be interesting targets for gamma-ray DM searches as well. In fact, unlike pressure-supported dSph galaxies, dIrrs are rotationally-supported galaxies, i.e. their DM profiles can be obtained from their rotation curves (RC) and, indeed, from these they appear to be DM-dominated systems at all radii [3–5] - just as dSphs. Nonetheless, dIrrs are isolated galaxies of the Local Volume with DM halo mass $M_{200} \approx 10^7 - 10^{10}\, M_\odot$. Here, we consider dIrrs at a distance less than $\sim 1$ Mpc. This kind of galaxies represents a clear example of the cuspy-core tension, originated by the different results in both observations and N-body simulations of the DM density distribution profiles. In this work, we faced the problem by considering two different DM profiles, based on both the fit to the rotation curve (in this case a Burkert cored profile [6]) and results from N-body cosmological simulations (i.e., NFW cuspy profile [7]). We also include halo substructure in our analysis, which is expected to boost the DM signal a factor of ten in halos such as those of dIrrs [8].

## 2. Dark matter modeling

First of all, we fit the observed RC data to a parametrized model described below and perform the global mass modelling. We get the best-fit maximum likelihood (ML) values of the MCMC analysis for the core-like Burkert profile. We follow the same procedure for the NFW profile, yet even in those cases where this profile shows reasonable fits to the RC data, the obtained best-fit values for the concentration parameter are unrealistically low for a ΛCDM Universe [9–11]. Consequently, either the DM in these galaxies is distributed somewhat differently from what is expected from the DM-only ΛCDM cosmological simulations, or the data contain unknown systematic uncertainties that should be taken into account, e.g. systematic uncertainties related to the inclination and/or distance errors in the RC reconstruction [12]. Thus – by looking out for an agreement with ΛCDM cosmology and the DM-only simulations – we still model each dIrr galaxy with an NFW profile but with one key assumption: $M_{200}$, the mass contained within the virial radius, $R_{200}$, and obtained by the fit of the RC for the Burkert profiles, is taken as a starting point to build also the NFW.

The DM modelling is used as the starting point to obtain the induced DM annihilation gamma-ray flux from these objects, in which we also include the effect of substructures of the main halo. The latter, in fact, enhance the expected DM flux. Such an enhancement is usually quantified in terms of the so-called substructure boost factor, $B$. This boost in the expected annihilation DM signal can range from $B = 0$, where the contribution of the substructure is absent, up to $\sim 2$ orders of magnitude, depending on the details of the subhalo population and of the host halo mass (e.g. [8, 13]). Given the impact that the substructure can have in the J-factors and its still uncertain nature (e.g., minimum mass to form clumps [14–16], tidal stripping, subhalo survival or precise shape of subhalo DM density profiles [17]), it becomes convenient to cover the range of different but possible scenarios. The computation of the J-factors and the two-dimensional templates - reproducing the spatial morphology of the expected DM annihilation signal - are performed using the `CLUMPY` code. We create maps for each dIrr galaxy and different models, taking into account the two different DM density distribution profiles in the main halo (Burkert or NFW) as well as different levels of substructures (see e.g. Fig 1). We use these maps as the inputs for our *Fermi* spatial and spectral analysis.

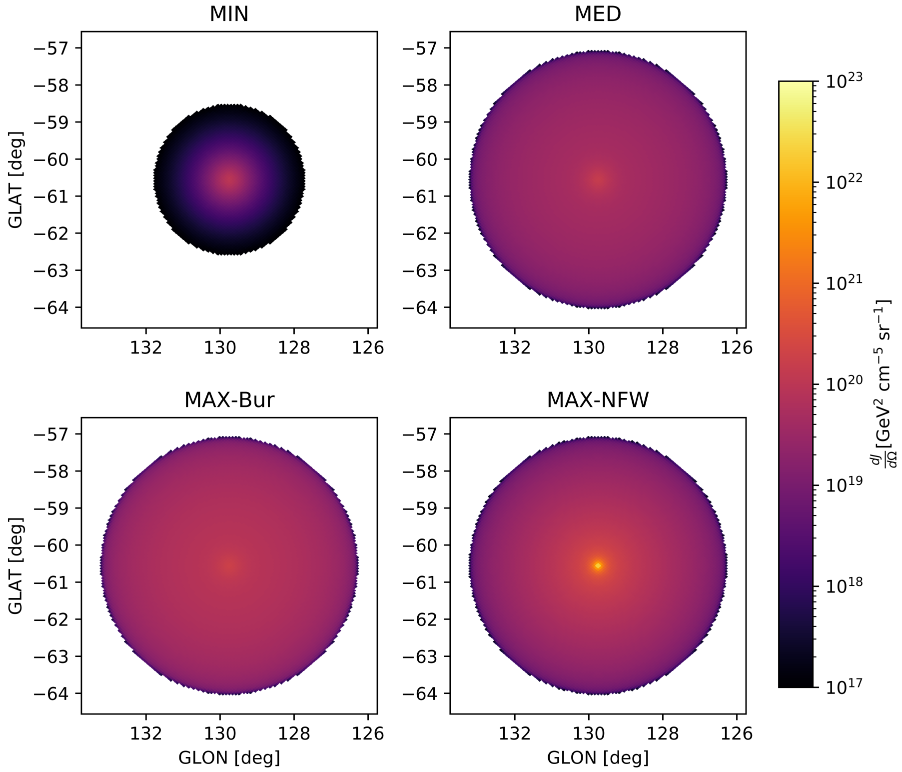


**Figure 1:** Two-dimensional spatial templates of the expected spatial morphology of the DM annihilation fluxes from the IC1613 dIrr, as obtained with `CLUMPY` for four DM substructure models, i.e Burkert without any substructures (MIN), Burkert with some substructures (MED), and both Burkert and NFW with the maximum contribution from substructes (MAX-Burk/NFW). The z-axis represents the values of the differential J-factor. We chose the colour scale in such a way that we still could appreciate details in the MED and MAX models. However, for the MIN case, this colour scale implies that the outer regions of the object are not visible.

## 3. *Fermi*-LAT data analysis

Once the DM modeling of the dIrrs in our sample is complete, we can perform a search for gamma-ray signals in *Fermi*-LAT data. To do so, we use `Fermipy`, a Python package that automates the ScienceTools[1] analysis. `Fermipy v0.19.0` and ScienceTools `v1.3.7` are used.

The first step is the photon event selection. We will use 11 years of LAT data, from 2008 August 4 to 2019 August 8. The class event is Pass 8 SOURCEVETO [18], with the corresponding

[1]`https://Fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/`

P8R3_SOURCEVETO_V2 instrumental response function. We choose an energy range from 500 MeV to 1 TeV, with a zenith cut of $\theta_z > 105°$. The data is binned using 8 energy bins per decade in energy and 0.08° pixel size, defining a region of interest (ROI) of $12° \times 12°$, centered at the position of each dIrr. The Galactic diffuse emission is modeled with the latest LAT template, gll_iem_v07, while the isotropic contribution is modeled with the corresponding template, iso_P8R3_SOURCEVETO_V2.txt. We have performed a search for gamma-ray signals in *Fermi*-LAT data in each of the targets' ROI. After our analysis, no significant emission is detected, with the highest TS values $TS \sim 9 - 11$ (see e.g. Fig. 2). These TS values are not considered to be significant, mainly because they are pre-trials and thus are expected to decrease significantly in a more complete statistical analysis. Also, the presence of little excesses at a few GeV is common in this type of analysis due to our imperfect knowledge of the Galactic foregrounds, which may contribute at this TS level.

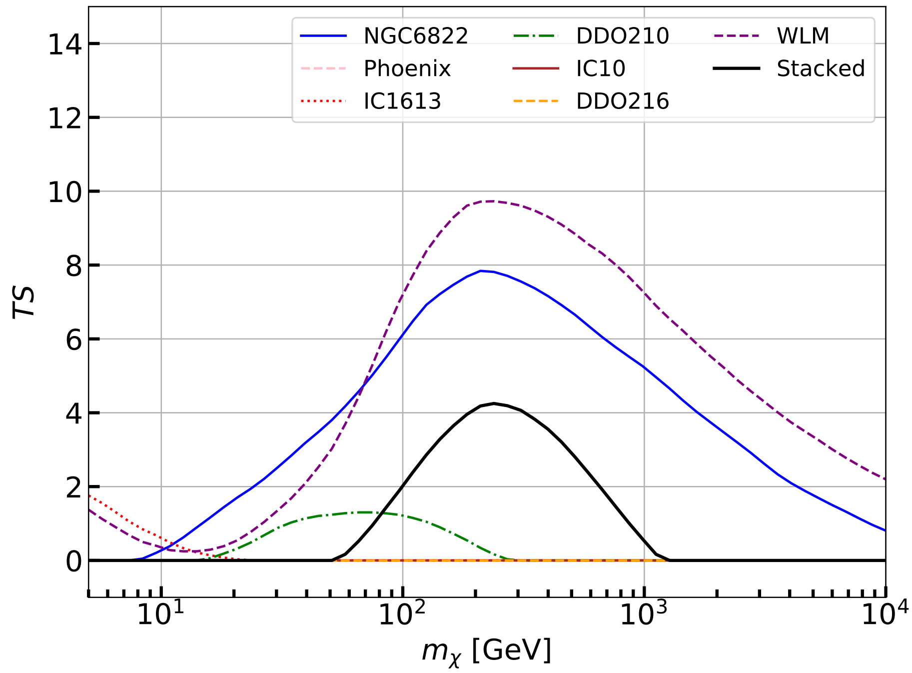


**Figure 2:** Likelihood profiles as a function of the WIMP mass, for each of the dIrrs and the combined targets, assuming the MED model and the $b\bar{b}$ annihilation channels. The $\langle\sigma v\rangle$ is left free for each mass bin.

## 4. Dark matter constraints

Since no gamma-ray emission is conclusively observed from any of the targets, we use our flux upper limits to set constraints on the WIMP mass vs. annihilation cross section parameter space.

In Figure 3 we show the main results of this work: the combined DM limits obtained from the spatial data analysis for the Burkert profile with a medium level of substructures (MED model) and the $b\bar{b}$ annihilation channel (blue line). The strongest constraints are obtained for the $b\bar{b}$ annihilation channel and are at the level of $< \sigma v > \sim 7 \times 10^{-26}$ cm$^3$s$^{-1}$ at $m_\chi \sim 6$ GeV. IC10 dominates these combined limits. In fact, in the single-target analysis, the most stringent constraints are obtained for

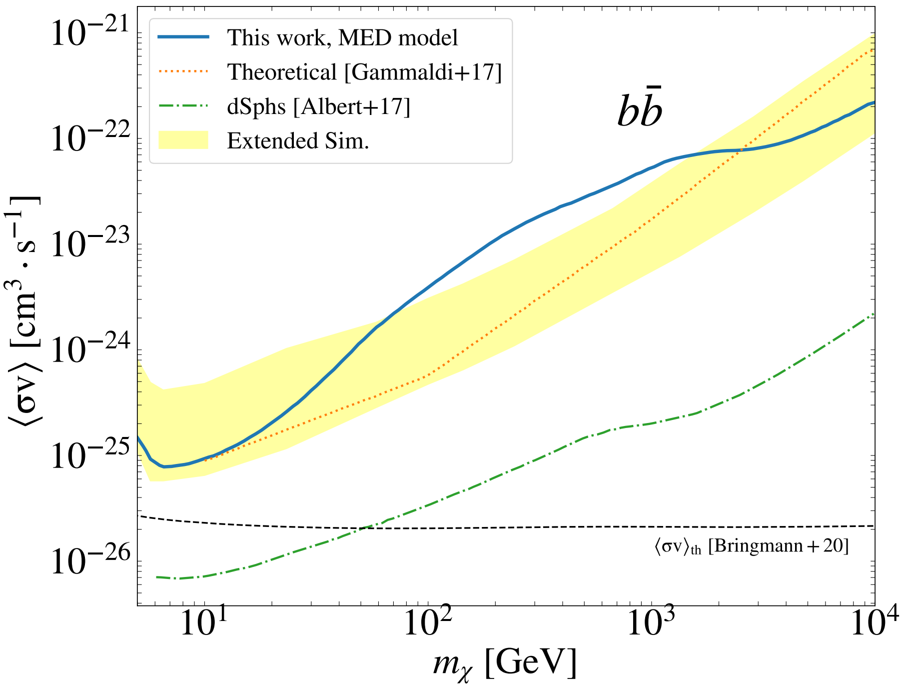


**Figure 3:** Comparison between different limits for the $b\bar{b}$ annihilation channel. We include the ones derived in this work, assuming the spatial template (solid blue), the theoretical predictions from [19] (dashed orange), the null extended simulations 95% containment band, and the LAT dSphs [20] in dot-dashed green.

IC10, independently of the adopted DM profile. Though these limits are a factor of ~ 3 higher than the thermal relic cross section at low WIMP masses, they are independent from and complementary to those obtained by means of other targets. For comparison, in Figure 3 we also show the constraints obtained by the *Fermi*-LAT collaboration from the combined analysis of tens of dSph galaxies [20]. Interestingly, our combined DM limits are in remarkable agreement with the constraints obtained in the previous theoretical work [19] (Fig. 3 yellow-dotted line), where the Universal Rotation Curve was assumed as the basis for the DM modelling and the targets were considered to be point-like just as a first approximation. We note that the limits obtained with the spatial analysis are slightly different from the yellow band shown in the same plot, which represents the 95% C.L. containment band after having performed 100 control simulations assuming no DM content in the targets, yet modeled with their corresponding spatial templates (null simulations). The observed mismatch can be easily attributed to the small local TS excesses found for some objects in our sample at the relevant energies. More details about this analysis can be found in [21]

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