Indirect Dark Matter Searches with MAGIC Telescopes

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In the last few years the indirect dark matter (DM) searches became a hot topic, with several experimental results showing hints of DM signal. The Major Atmospheric Gamma Imaging Cherenkov (MAGIC) telescopes are two 17 m diameter Cherenkov telescopes, located on the Canary island La Palma (Spain). MAGIC carries out a broad DM search program, including observations of dwarf galaxies, galaxy clusters and other DM dominated objects. In these proceedings recent MAGIC results from this field are presented, and discussed in a context of the present and future DM searches with Cherenkov telescopes.

1 MAGIC

MAGIC is a system of two, 17 m diameter Imaging Atmospheric Cherenkov Telescopes (IACTs), located at the Observatory Roque de los Muchachos, in the Canary island of La Palma (28.8 N, 17.8 W, 2200 m a.s.l.). IACTs are instruments optimised for ground-based detection of very high energy (VHE) gamma-rays, i.e. photons with energies between $\sim$50 GeV and 50 TeV. MAGIC-I has been in operation since 2004, and in 2009 it was joined by MAGIC-II. In 2012 a major camera and read-out system upgrade was completed, and currently, at low zenith angles, MAGIC achieves a sensitivity of (0.67+/-0.04)% of Crab Nebula flux, above 290 GeV (for 5σ significance detection in 50 hr) [1]. Due to its large mirror area MAGIC is also one of the best suited instruments to measure very high energy γ-rays below 100 GeV.

The MAGIC telescopes lead an extensive physics program covering γ-ray emission from many types of galactic and extragalactic sources. The collected data is analysed not only in terms of standard astrophysical topics such as the particle acceleration and emission mechanisms from cosmic sources, but also a wide range of fundamental physics studies is performed. These proceedings focus on the latest MAGIC results related to indirect dark matter searches.

2 Indirect dark matter searches

A major open question for modern physics is the nature of dark matter (DM): strong experimental evidence suggests the presence of this elusive component in the energy budget of the Universe (see e.g. [2]), without, however, being able to provide conclusive results about its nature. From the IACT point of view the most interesting are the theories offering DM particle candidates which could annihilate or decay into γ-ray photons, such as Weakly Interacting

Massive Particles (WIMPs) [3].

A γ-ray signal from DM origin would provide one of the clearest and most concluding evidences for DM. Spectral features such as annihilation lines [4] and internal bremssstralhung [5] as well as a characteristic cut-off at the DM particle mass would show up in a measured spectrum, shedding light over the nature of the DM constituent.

The expected DM annihilation flux is essentially proportional to the product of two parameters (see e.g., [6] for details). The first one, which we will label as Φ_{phys}, captures all the particle physics: DM particle mass, cross section, branching ratio, etc. The second one, J_{astro}, accounts for all the astrophysical considerations, such as the DM distribution and the distance to the source. Both of those factors are still poorly constrained and suffer from large uncertainties.

Astrophysical regions where high DM density is predicted are the best candidates to expect γ-ray emission from DM annihilation or decay. Here we describe in more detail MAGIC observations of the Perseus galaxy cluster, dwarf galaxies and Unassociated Fermi Objects.

2.1 Perseus galaxy cluster

Galaxy clusters are the biggest DM dominated objects in the local Universe, as much as 80% of their mass is believed to be constituted of DM. MAGIC observed the Perseus cluster in mono mode in November and December 2008 [7], collecting 24.4 h of high quality data. No significant VHE signal was detected and integral flux upper limit was derived for energies above 100 GeV and spectral index of -1.5: $F_{UL}(\geq 100\,\mathrm{GeV}) = 4.63 \times 10^{12}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$.

In order to estimate the expected DM annihilation flux we assumed an optimistic SUSY scenario [8], in which $\Phi_{phys} = 10^{32}\,\mathrm{GeV}^2\,\mathrm{cm}^3\,\mathrm{s}^{-1}$ above 100 GeV. The Navarro-Frenk-White [9] DM density profile was used to estimate the integrated astrophysical factor: $J_{astro} = 1.4 \times 10^{16}\,\mathrm{GeV}^2\,\mathrm{cm}^{-5}$. Finally we obtained a maximum DM annihilation flux of $1.4 \times 10^{16}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ for energies above 100 GeV.

It can be seen that we need a boost in flux of the order of 10^4 to reach the predicted DM annihilation flux values. This boost factor could come from different effects, such as the presence of substructures that may enhance the annihilation γ-ray flux notably and that were not taken into account in the above calculation.

We continue observations of Perseus in stereo mode. In the years 2009-2015 MAGIC collected ~ 300 h of data from this target. The preliminary results of the analysis, focusing on the decaying DM models, were presented during the 34th ICRC [10].

2.2 Dwarf galaxies

The dwarf spheroidal galaxies (dSphs) represent the best known targets for indirect DM searches thanks mainly to their very large mass-to-light ratios and low baryonic content. So far, around thirty dSphs have been identified in the MW. MAGIC observed three of them in mono mode: Draco [11], Willman [12] and Segue 1 [13].

Here, we will focus on the most recent Segue 1 observations, performed in stereo mode between January 2011 and February 2013 for a total time of 158 h [14], which makes these observations the longest exposure of any dwarf satellite galaxy by any IACT so far. Segue 1 data were analysed using the full likelihood approach [15], which takes into account the complete spectral information of the recorded events and the potential signal. The sensitivity improvement of about a factor of 2 was achieved with respect to the conventional method [16], commonly used in IACT data analyses.

No significant gamma-ray excess above the background was found. Consequently, we derived 95% confidence level upper limits on the velocity-averaged annihilation cross section ($\langle \sigma \nu \rangle$), and lower limits on the dark matter particle lifetime, assuming several different annihilation and decay channels. These are the strongest bounds from observations of dSphs by any IACT so far. Additionally, for leptonic annihilation channels we achieved the strongest limits above a few hundreds GeV from any dShp observation till now, including the Fermi-LAT observations of 15 dSphs [17]. For the quark-antiquark channel and higher DM particle masses, the most constraining bounds are derived from the HESS observations of the Galactic Center halo [18, 19].

2.3 Unassociated Fermi Objects as dark matter clump candidates

DM subhalos with masses lower than the dSphs could be too small to have attracted enough baryonic matter to start star-formation and would therefore be invisible to past and present astronomical observations. Since γ-ray emission from DM annihilation is expected to be constant, these clumps would most probably only show up in all-sky monitoring programs at very high energies. This can be best provided by the Fermi satellite telescope[1] as Unassociated Fermi Objects (UFOs) not detected at any other wavelengths. Very likely, the distinct spectral cut-off at the DM particle mass is located at too high an energy (see, e.g. the neutralino mass lower limits in [20]) to be measurable by Fermi within reasonable time and can only be limited by IACTs observations.

We selected the most promising DM subhalo candidates out of the 1FGL [21] and 2FGL [22] catalogs, basing on their spectral characteristics, time variability and potential associations. In order to assess their detection prospects for IACTs for each source we estimated the time needed for detection by MAGIC by extrapolating the spectrum measured by Fermi-LAT. We also counted the number of photons $\geq$10 GeV seen by Fermi coming from their vicinity, to confirm that this extrapolation is sound. Finally, four most optimal candidates were observed in stereo mode and 50 h of good quality data were collected. More details on the selection procedure and the observations can be found in [23, 24].

The analysis did not reveal any significant VHE signal and upper limits for source emission were calculated with a confidence level of 95%, using the conventional method [16]. Assuming $z = 0$ we can exclude the direct extrapolation of Fermi-LAT spectrum for two of the candidates. We cannot neither rule out nor confirm the possibility that the emission in the Fermi-LAT energy range is due to DM, but the recently collected multiwavelength data seem to support the hypothesis that those sources belong rather to the standard AGN class of emitters.

3 Summary and outlook

The modern IACTs lead a wide range of astroparticle physics studies and MAGIC is one of the leading experiments in this field, especially designed to achieve the lowest energy threshold and high sensitivity below 100 GeV. MAGIC continues its wide DM search program with stereo observations of the most promising targets. We plan to operate the telescopes during the next few years, depending on the progress of the Cerenkov Telescope Array (CTA)[2] construction.

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[1] http://fermi.gsfc.nasa.gov/

[2] https://www.cta-observatory.org/

CTA will be an open observatory, consisting of more than 100 IACTs located on two sites: one in Chile (CTA South) and one on the Canary island of La Palma (CTA North). In comparison to the present generation of instruments, CTA will have a factor of ten better sensitivity, larger field of view and considerably improved energy and angular resolution. Recent studies show that CTA will be capable of probing the ($\langle \sigma \nu \rangle$) parameter space below the natural cross-section for DM particle masses above a few hundreds of GeV [25].

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