Perseus in Sicily: From Black Hole to Cluster Outskirts
Proceedings IAU Symposium No. 342, 2018
K. Asada, E. de Gouveia Dal Pino, M. Giroletti,
H. Nagai & R. Nemmen, eds.

doi:10.1017/S174392131800515X

Perseus – A Huge Reservoir of Dark Matter investigated with MAGIC

Michele Doro[1,2], Joaquim Palacio[3], Javier Rico[3] and Monica Vazquez Acosta[4]

[1]Department of Physics and Astronomy, University of Padova, I-35131 Padova, Italy
email: michele.doro@unipd.it

[2]Istituto Nazionale Fisica Nucleare sez. Padova, I-35131 Padova, Italy

[3]Institut de Fìsica dAltes Energies (IFAE), The Barcelona Institute of Science and Technology (BIST), E-08193 Bellaterra (Barcelona), Spain

[4]Inst. de Astrofisica de Canarias, E-38200 La Laguna, and Universidad de La Laguna, Dpto. Astrofisica, E-38206 La Laguna, Tenerife, Spain

Abstract. Galaxy clusters are excellent targets for high energy astrophysics with gamma rays. Not only they may host active galaxies, but they are often expected to provide signatures of accelerations of electrons and protons to PeV energies. Furthermore, according to ΛCDM scenario, they should be embedded in an extremely massive dark matter halo, the largest halo expected. In this report, we summarize the recently published MAGIC lower limits on the decaying dark matter lifetime using 202 h of selected high quality data taken on the Perseus galaxy cluster, in a 5-year long campaign.

Keywords. Keyword1, keyword2, keyword3, etc.

1. Dark Matter in galaxy cluster

In the current consensus theory called ΛCDM, the gravitational imbalance observed especially in the velocity distribution of stars in galaxies, is coped with the supposition that a new massive particle (or a set of them) populates the region around the galaxies in the form of halos. This new particle is generically known as dark matter (DM). There are no satisfactory Standard Model particles that can be valid candidate for DM. The main search is for weakly interacting massive particles (WIMPs), that are particle in the GeV-TeV mass range, with cross section of the order of the eletroweak one. There are plenty of theories producing valid DM candidates that need to be tested. Gamma rays provide a powerful probe, because, if the DM has some sort of interaction with the standard model (otherwise we would probably never see it), it would be through heavy elementary particles such as gauge bosons or quarks, that soon after production (via DM annihilation or decay) can give rise to an ample broad spectrum photon emission peaked in the MeV-GeV range (Bertone *et al.* (2004)). The highest fluxes for annihilating DM models are where DM is strongly concentrated, such as at the center of closeby satellite galaxies of the Milky Way or at its center. In the case of galaxy clusters, their large distance fosters a reduction of the annihilation signal, however, in case of decaying DM, the expected emission, connected to the total cluster mass, would still sufficiently high to allow for detection in some cases (Sanchez-Conde *et al.* (2011)).

Perseus is a galaxy clusters located at 77 Mpc from the Earth, with a total mass of the order of $10^{15}M_{\odot}$ mostly in the form of DM. It was subject of a multi-year campaign with the MAGIC telescopes started in 2012 and still ongoing, that so far has gathered more

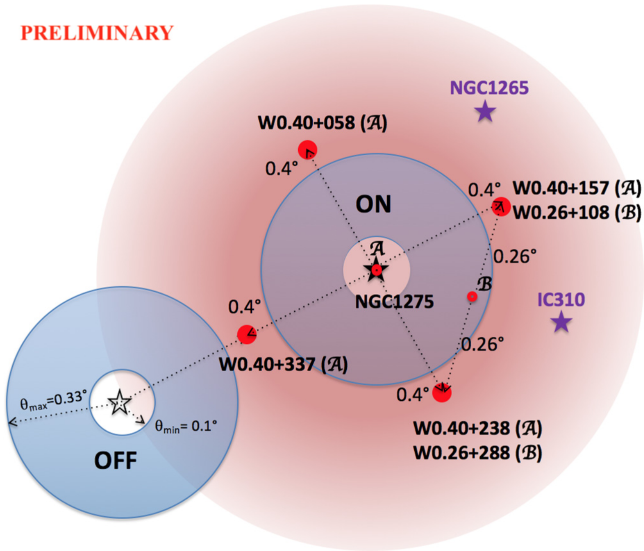

Figure 1. Sketch of the geometry of the region around Perseus observed by MAGIC. Stars marks the galaxies NGC 1275, IC 310 and NGC 1265. The circles mark the signal where the DM signal is searched and the background control region. From MAGIC Coll. (2018).

than 400 h through the years, as well as has allowed for a series of interesting discoveries: the extremely fast and strong activity of the two brightest radiogalaxies (see Fig. 1) hosted in the cluster: NGC 1275 and IC 310, which so far challenged any explanation. Furthermore, relevant limits on the magnetic field and cosmic ray to thermal pressure where obtained by searching for the cosmic ray induced emission toward the center, caused by re-acceleration of electrons or shocks. This communication summarizes the results obtained in search for decaying DM signals and recently published in MAGIC Coll. (2018).

2. MAGIC data reconstruction

The search for decaying DM is performed by selecting a signal region centered around NGC 1275 (see Fig. 1) which encompass a significant fraction of the DM halo (red shadowed area). A central circle of 0.1 deg is excluded due to the presence of the bright NGC 1275. A symmetric background control region is selected at a 0.8 deg from NGC 1275, a value that is related to the specific pointing conditions of MAGIC. Signal leakage into the background region was computed. Periods in which NGC 1275 and IC 310 were active were excluded to control the systematics. A specific Monte Carlo re-weighting was used in order to provide accurate estimation of the instrument response functions (IRFs), especially the effective area and in the energy resolution (Palacio (2018)). The reason is that the response of the instrument is not completely flat over the field of view, mostly due to the parabolic shape of the primary mirror which introduce spherical aberrations which in turns make the performance worsening for region far from the optical axis of the telescope. Furthermore, the center of the DM halo is never observed in the center of the camera, but always at a rotating offset, as shown in Fig 1 (four symmetric red circles). Therefore, Monte Carlo are re-weighted in order to match the exposure of the telescope. Furthermore, the target was observed using 6 different instrument hardware setups, each with its own IRFs. At the end, more than 24 different samples were combined to provide the global analysis.

https://doi.org/10.1017/S174392131800515X Published online by Cambridge University Press

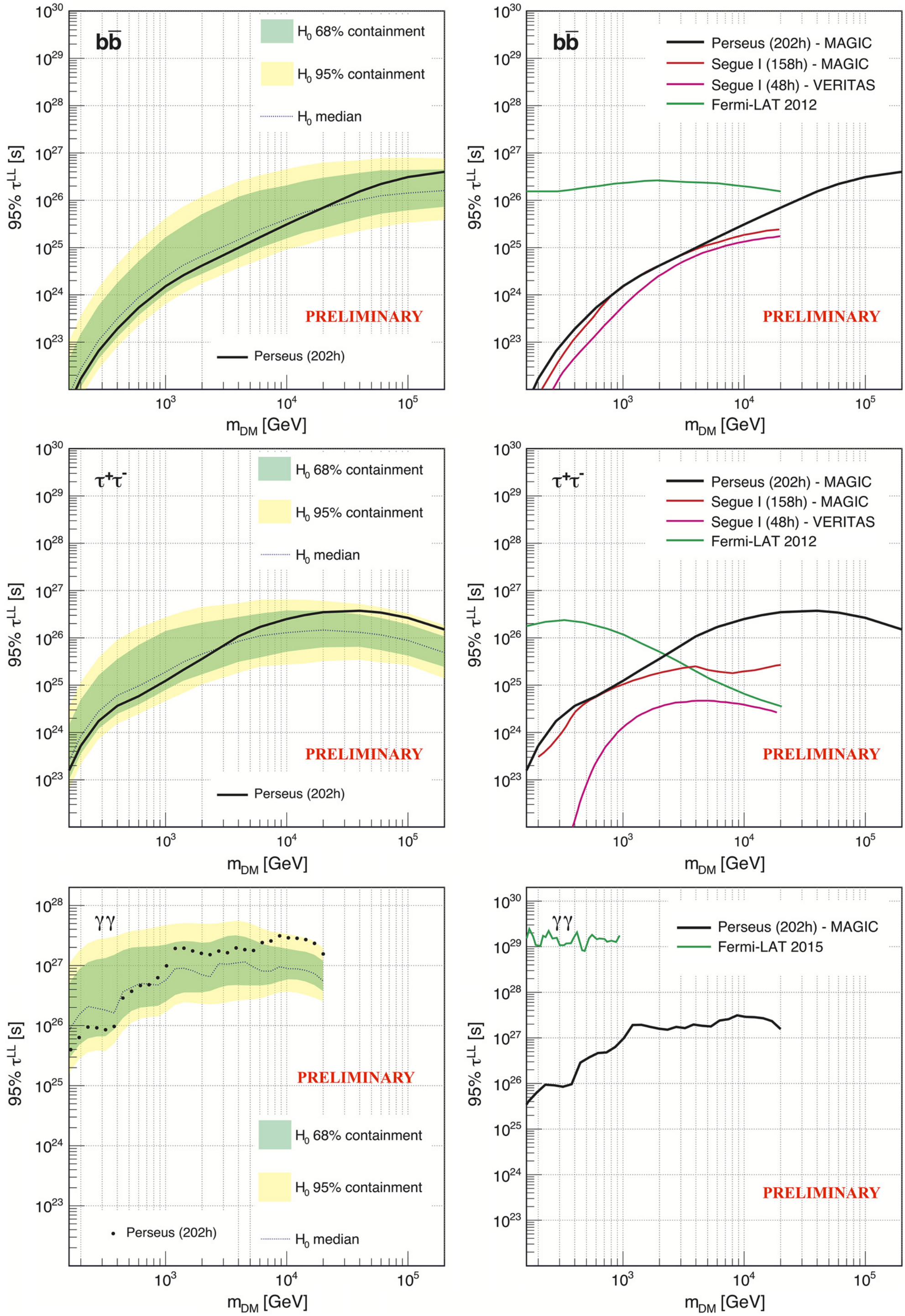

Figure 2. Lower limits on the decay lifetime of a dark matter particle as obtained with 202 hours of selected data in the direction of the Perseus Galaxy Cluster. Continuous decay spectra as pure decay into $b\bar{b}$ and $\tau^+\tau^-$ are searched (topmost plots). The lowest plots indicates limits for a $\gamma\gamma$ decay. The left column plots show the actual limits compared with the distribution of limits for the null hypothesis (median, one and two sigma bands). The right column plot show the limits compared with published results. From MAGIC Coll. (2018).

https://doi.org/10.1017/S174392131800515X Published online by Cambridge University Press

The expected photon flux from decaying DM from Perseus can be written as:

$$\frac{\mathrm{d}^2\Phi}{\mathrm{d}E\,\mathrm{d}\Omega} = \frac{1}{4\pi}\,\frac{1}{\tau_{\mathrm{DM}}\,m_{\mathrm{DM}}}\,\frac{\mathrm{d}N_\gamma}{\mathrm{d}E}\cdot\int_{\mathrm{l.o.s.}}\mathrm{d}l\,\rho(l,\Omega). \tag{2.1}$$

where m_{DM} is the DM mass, τ_{DM} the DM particle lifetime, $\mathrm{d}N_\gamma/\mathrm{d}E$ is the average decay spectrum per reaction, and the last factor is often called the differential J-factor $\mathrm{d}J_{\mathrm{dec}}/\mathrm{d}\Omega$ and is obtained integrating the DM density ρ over the line-of-sight (l.o.s.) for the decay reaction. The total J-factor enclosed in a given sky region can be obtained integrating over a solid angle $\Delta\Omega$, and the total flux integrating also over energy.

The parameter of interest is the decay lifetime τ_{DM}, therefore a specific likelihood was built in order to infer on this value and consider all other parameters, including the DM mass, photon spectra, instrument effective area and energy resolution as nuisance parameters. The null hypothesis was tested with mock Monte Carlo simulation of backgrounds. The likelihood reads as:

$$\begin{aligned}&\mathcal{L}\left(1/\tau_{\mathrm{DM}};\boldsymbol{\nu}\,|\,\boldsymbol{\mathcal{D}}\right)\\ =\;&\prod_{i=1}^{N_{\mathrm{samples}}}\mathcal{K}(\kappa_i|\kappa_{\mathrm{obs},i},\sigma_{\kappa,i})\\ &\times\prod_{j=1}^{N_{\mathrm{bins}}}\left[\frac{\left(g_{ij}(\tau_{\mathrm{DM}})+b_{ij}+f_{ij}\right)^{N_{\mathrm{ON},ij}}}{N_{\mathrm{ON},ij}!}e^{-\left(g_{ij}(\tau_{\mathrm{DM}})+b_{ij}+f_{ij}\right)}\right.\\ &\left.\times\frac{\left(\kappa_i b_{ij}+g_{ij}^{\mathrm{OFF}}(\tau_{\mathrm{DM}})\right)^{N_{\mathrm{OFF},ij}}}{N_{\mathrm{OFF},ij}!}e^{-\left(\kappa_i b_{ij}+g_{ij}^{\mathrm{OFF}}(\tau_{\mathrm{DM}})\right)}\right],\end{aligned} \tag{2.2}$$

where $\boldsymbol{\nu}$ collectively refers to the nuisance parameters and $\boldsymbol{\mathcal{D}}$ to the data.

3. MAGIC results and discussion

The main results of the study are shown in Fig. 2 for two pure decay channels: into $b\bar{b}$ and into $\tau^+\tau^-$, which roughly brackets the minimum and maximum number of photons expected from decay. Constrain for line-like emission is also shown. Fig. 2 reports both the distribution of upper limits for the Monte Carlo generated background null hypothesis, as well as the comparison of MAGIC limits with other relevant limits in the same energy range. The limits are of the order of 10^{26} s, the most constraining so far achieved for DM particle masses of the order of few hundreds GeV and above. It is unlikely that observation on different DM targets can provide stronger limits in the close future, considering the large observation time needed. In the future, the Cherenkov Telescope Array will instead be significantly more sensitive to decay DM signals (CTA Consortium (2017)).

References

G. Bertone, D. Hooper and J. Silk, Phys. Rept. **405**, 279 (2005)

M. A. Sanchez-Conde, M. Cannoni, F. Zandanel, M. E. Gomez and F. Prada, JCAP **1112** (2011) 011

J. Palacio, Phd Thesis. Institut de Fisica d'Altes Energies, Universitat Autonoma de Barcelona (2018).

MAGIC Collaboration (Acciari *et al.*), arXiv:1806.11063 [astro-ph.HE]. CTA Consortium (2017)

CTA Consortium, B. S. Acharya *et al.*, arXiv:1709.07997 [astro-ph.IM].

https://doi.org/10.1017/S174392131800515X Published online by Cambridge University Press