Search for Dark Matter annihilation signatures in the Segue 1 satellite galaxy with the MAGIC-I telescope

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

Simona Paiano(1), Saverio Lombardi(2), Michele Doro(3), Daniel Nieto(4) *for the MAGIC Collaboration**
Mattia Fornasa(5)

(1) University and INFN Padua, Astronomy Department Padua, Italy (2) University and INFN Padua, Italy (3) Universitat Autonoma de Barcelona, Spain (4) Universidad Complutense de Madrid, Spain (5) Instituto de Astrofisica de Andalucia, Granada, Spain
* for a complete list of MAGIC collaborators and extensive information on the telescopes: http://wwwmagic.mppmu.mpg.de/

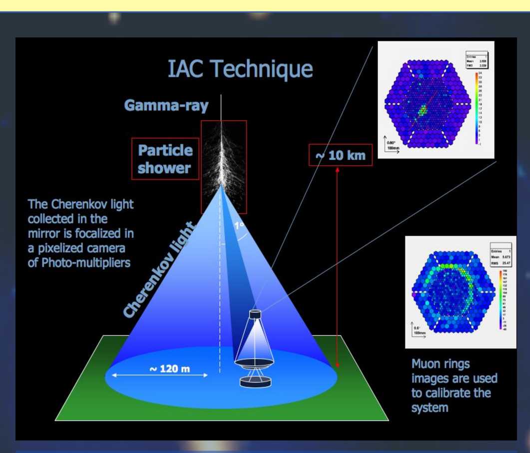
ABSTRACT - Despite the interest in Dark Matter (DM) searches is currently more focused on underground experiments, a signature of DM annihilation/decay in gamma-rays from the space would constitute a smoking gun for its identification. In this poster, we present the results of the survey of Segue 1 by the MAGIC-I telescope performed in 2008 and 2009. This source is considered by many as the most DM dominated Milky Way satellite galaxy known so far. The nearly 42 hours of data taken constitute the deepest observation ever made on a single dwarf galaxy by Cherenkov telescopes. No significant gamma-ray emission was found above an energy threshold of 100 GeV. Differential and integral upper limits on the gamma-ray flux were calculated assuming various power-law spectra for the possible emission spectrum and for different energy thresholds. We also show a novel analysis that fully takes into account the spectral features of the gamma-ray spectrum of specific DM models in a Supersymmetric scenario and the prospects of detection after the Fermi observation of similar objects at lower energies.

DM search with IACTs

The Imaging Atmospheric Cherenkov (IAC) Technique is based on the detection of Cherenkov photons produced by very fast charged particles created in the atmospheric showers initiated by cosmic rays and gamma-rays coming from the Universe.

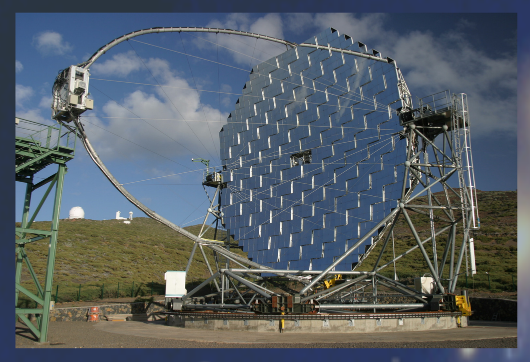
The indirect search for DM particles in the Universe through gamma-rays detection is nowadays obstructed by the large uncertainties in the flux prediction which depend on the knowledge of the astrophysical DM density profiles and of the particle physics beyond the Standard Model. These uncertainties put serious hindrances to the estimation of the detection capability (up to several orders of magnitude) [1].

The MAGIC-I telescope belongs to the second generation of IAC Telescopes (IACTs). Thanks to its low energy threshold (60 GeV at Zenith), high flux sensitivity (1.8% of the Crab Nebula flux in 50 hour above 100 GeV) and good angular and energy resolution [2], is best suited to search for DM candidates at the energy of the neutralino mass or of the Kaluza-Klein state.



MAGIC-I features:

High collection area:
$236 m^2$ surface, $10^5 m^2$ effective area
Low Energy Threshold (at zenith)
50 GeV (trigger), 60 GeV (analysis)
Energy Resolution
30% (100 GeV), 20% (1 TeV)
Angular Resolution
0.1° (Energy Threshold)
Flux sensitivity (E > 100 GeV)
1.8% Crab-flux/50h (~ 10^{-11} $ph \cdot cm^{-2} \cdot s^{-1}$)



Gamma-ray flux from DM annihilations

In the ΛCDM cosmological scenario about 80% of the matter of the Universe is believed to be constituted by cold, neutral, non-baryonic, weak-interacting stable particles (WIMPs) [3]. Among the huge plethora of WIMP candidates, the best motivated ones are related to the Supersymmetrical and Extra Dimensional extensions of the Standard Model of particle physics [4].

In the widely studied Minimal Supersymmetric extension of the Standard Model (MSSM) the lightest SUSY particle (LSP), the neutralino χ, is stable (due to the R-parity conservation) and represents an excellent cold DM candidate with a relic density compatible with the WMAP bounds.

Since the neutralinos are Majorana particles, pairs of χ can annihilate into Standard Model particles, e.g. quarks, leptons and W bosons. The hadronization of such particles results in a continuum emission of gamma-rays at energies $E_\gamma < M_\chi$. A direct annihilation in gammas ($\chi\chi \to \gamma\gamma$, $\chi\chi \to \gamma Z$) with a peculiar sharp line spectrum dependent on the neutralino mass is also possible even if loop-suppressed.

The expected gamma-ray flux due to DM annihilations in astrophysical objects can be factorized in two terms

$$\Phi(>E_0, \Delta\Omega) = \Phi_\epsilon^{PP}(>E_0)\, J\,(\Delta\Omega)$$

where Φ^{PP}_ϵ is the so-called particle physics factor

$$\Phi_\epsilon^{PP}(>E_0) = \frac{1}{4\pi}\frac{\langle\sigma_{\mathrm{ann}} v\rangle}{2m_\chi^2}\int_{E_0}^{m_\chi}\sum_{i=1}^{n} B^i \frac{dN_\gamma^i}{dE}\, dE$$

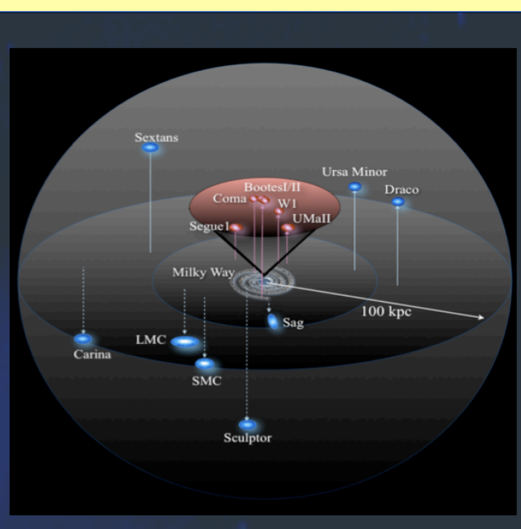
and $J(\Delta\Omega)$ is the astrophysical factor, given by the line-of-sight integral over the DM density squared within a solid angle $\Delta\Omega$

$$J(\Delta\Omega) = \int_{\Delta\Omega}\int_{los} \rho^2(r(s,\Omega))\, ds\, d\Omega$$

Among the interesting astrophysical targets to search for gamma-ray signals induced by DM, the most promising ones are the Galactic Center, the galaxy clusters and the dwarf Spheroidal (dSphs) galaxies satellite of the Milky Way. In particular, the dSphs are characterized by an high mass-to-light ratio and are free from potential gamma-ray astrophysical background [5,6].

The observation of Segue 1 dSph by MAGIC-I

The dwarf Spheroidal galaxy Segue 1 is a satellite of the Milky Way located at a distance of 28 kpc from the Galactic Center at (RA, Dec)=(10.12h, 16.08°). Despite the fact that its nature has been debated after discovery [7,8,9,10], it has now been interpreted as an ultrafaint Milky Way satellite galaxy in [11] through the identification of 66 member stars, therefore Segue 1 was highlighted as a good target for indirect DM detection [12,13].



The DM around Segue 1 dSph has been assumed to be distributed in a cusp halo modeled by the Einasto radial profile [14]

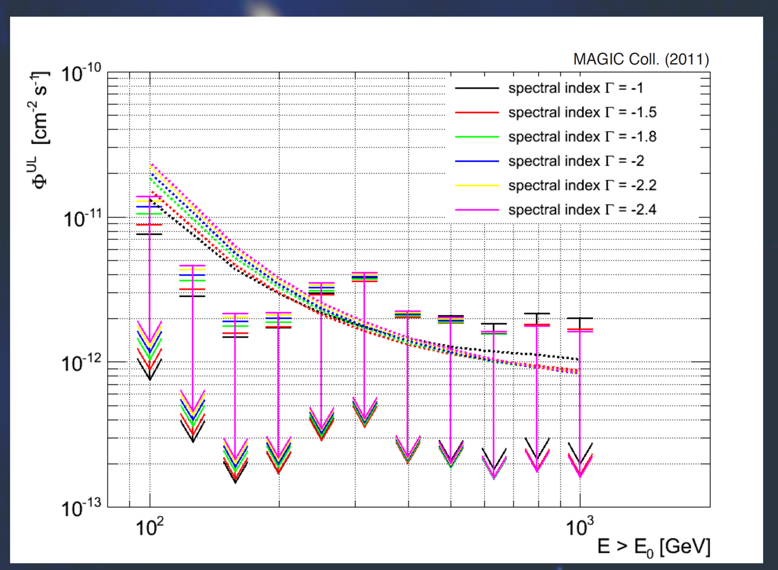
$$\rho_{\mathrm{EIN}}(r) = \rho_s e^{-2n\left[(r/r_s)^{1/n}-1\right]}$$

with $\rho_s = 1.1 \times 10^8\, M_\odot\, kpc^{-3}$, n = 3.3, and $r_s = 0.15$ kpc.

A search for a possible DM gamma-ray signal coming from Segue 1 was performed by the MAGIC-I telescope between November 2009 and March 2010, for a total of 29.4 hours of observation time (after data selection). The data analysis was performed using the standard MAGIC-I analysis and reconstruction software [15]. No significant gamma-ray emission was found above 100 GeV [16].
The integral flux upper limits (calculated from the Rolke method [17] at 95% confidence level, assuming 30% systematic uncertainty) were estimated for energies above a given energy threshold E_0 and for different power-law energy spectra with spectral index Γ

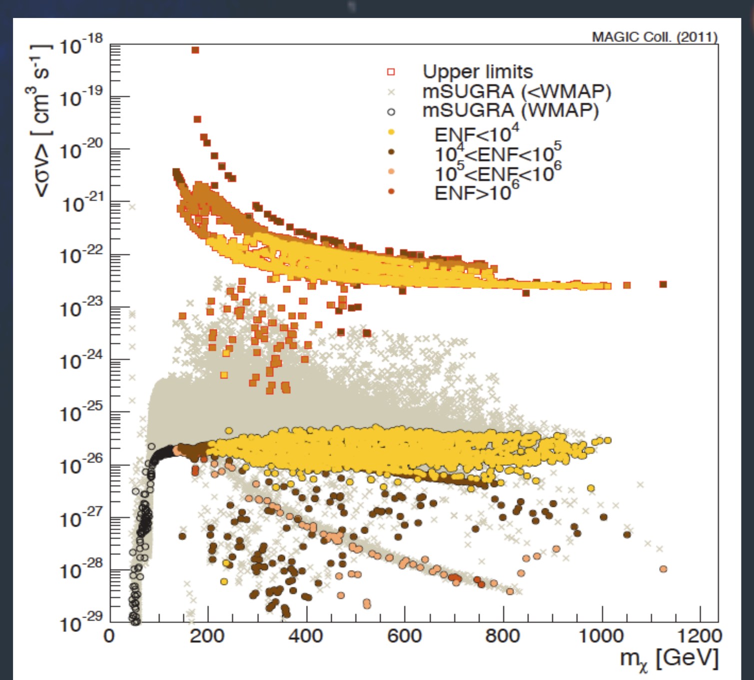
Integral flux upper limits from Segue 1. The arrows indicate the upper limits for different power law spectra and energy thresholds as in table. The dashed lines indicate the upper limits if zero significance Li&Ma is assumed.

E_0 [GeV]	N_{ON}/N_{OFF}	N_{exc}^{UL}	$\sigma_{Li,Ma}$ 95% C.L.	$\Phi^{UL}/\times 10^{-12}$ [$cm^{-2}s^{-1}$] $\Gamma=-1.0$	$\Gamma=-1.5$	$\Gamma=-1.8$	$\Gamma=-2.0$	$\Gamma=-2.2$	$\Gamma=-2.4$
100	52978/53301	453	-0.99	7.5	8.8	10.5	11.6	12.7	13.7
126	18835/19233	174	-2.04	2.8	3.2	3.6	4.0	4.3	4.6
158	6122/6374	93	-2.25	1.5	1.6	1.8	1.9	2.0	2.1
200	3012/3088	110	-0.97	1.7	1.7	1.9	2.0	2.1	2.2
251	1687/1654	194	0.57	3.0	2.9	3.1	3.2	3.4	3.5
316	1107/1030	250	1.67	3.8	3.6	3.7	3.9	2.9	4.1
398	792/761	147	0.79	2.2	2.0	2.1	2.1	2.2	2.2
501	613/580	140	0.96	2.1	1.9	1.9	1.9	2.0	2.0
631	536/509	124	0.84	1.8	1.6	1.6	1.6	1.6	1.6
794	486/445	146	1.34	2.1	1.8	1.8	1.8	1.8	1.8
1000	411/373	135	1.36	2.0	1.7	1.6	1.6	1.6	1.6



In the framework of a 5-dimensional subspace of Minimal Supersymmetric Standard Model, so-called mSUGRA [18,19], a scan was performed over the parameter space. Subsequently, for each simulated DM model, the upper limits on the averaged cross section $<\sigma v>$ were derived separately for each point in the scan in order to completely account for the dependence on the specific spectra

Annihilation cross section upper limits from Segue 1 data computed for individual points in the scan. Grey crosses indicate the annihilation cross section value for those points in the scan which pass the Standard Model constraints and with relic density lower than WMAP bound. The full circles only consider models within 3σ from WMAP. For each of these full circles the upper limit on the cross section can be computed from the Segue 1 data (after an energy threshold optimization) and it is indicated here by a square. Circles and squares are color coded in terms of the enhancement factor (ENF), i.e. the minimum boost required to meet the detection.



CONCLUSIONS

Within the mSUGRA scenario, a minimum boost on the flux is found of the order of 10^3 (for models compatible with WMAP) while "typical" values are at 10^{4-5}. The robustness of our results depends mainly on the assumptions on the astrophysical factor, due to its uncertainty of two orders of magnitude (at 2σ) [20]. Comparing MAGIC-I results on Segue 1 with those of Fermi/LAT [21], the different energy range covered by the two experiments implies that the latter is more constraining for low mass DM candidates, while MAGIC (or Cherenkov telescopes in general) can produce better upper limits only for DM heavier than few hundreds of GeV. Nevertheless, IACTs could represent essential instruments to characterize peculiar spectral features belonging to DM annihilations, as the expected intrinsic cut-off.

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