



IFAIR



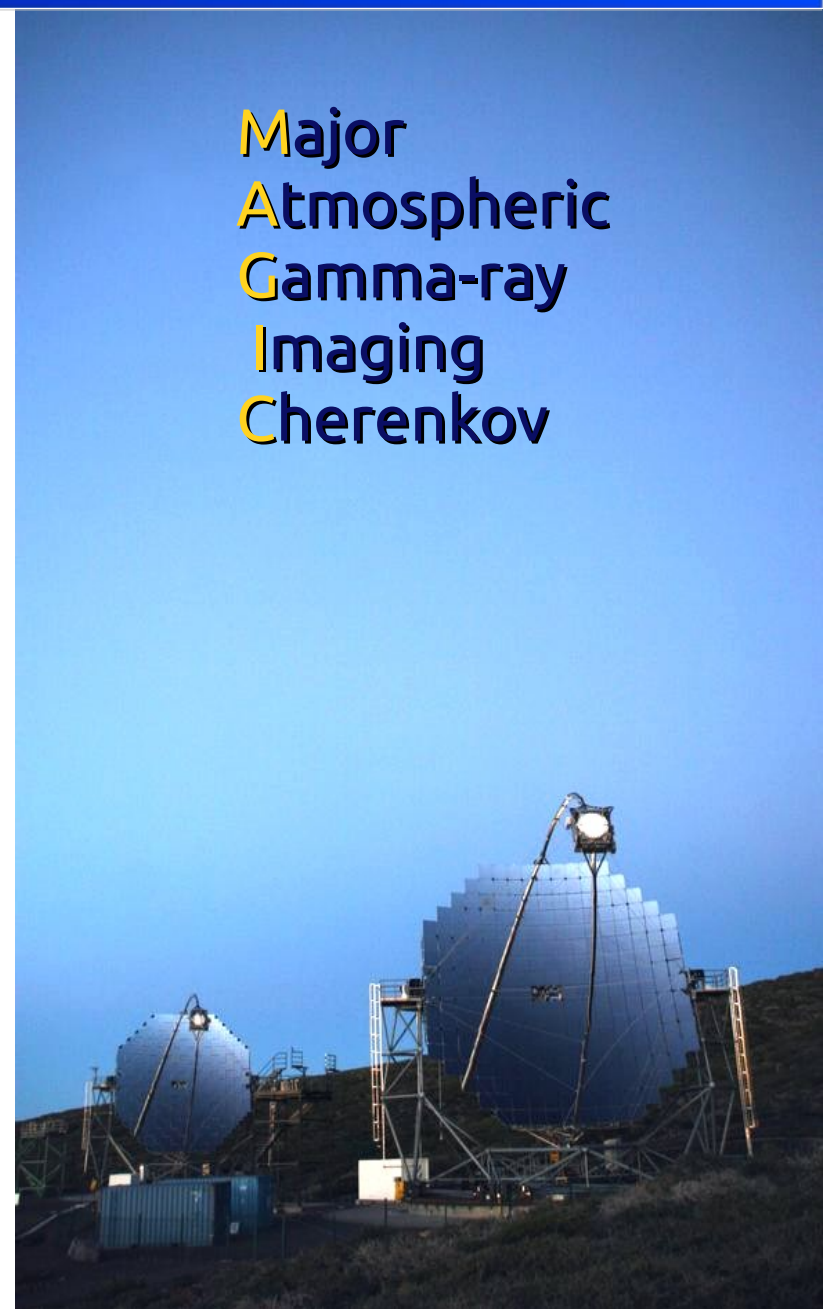
Indirect Dark Matter searches with the MAGIC Telescopes

Jelena Aleksić
(on behalf of the MAGIC Collaboration)

The MAGIC Telescopes

- Observatorio Roque de los Muchachos, La Palma, 2200 m altitude
- System of two, 17 m diameter IACTs
- Regular observations since 2004 (MAGIC 1) and 2009 (Stereo)
- Main characteristics:
 - Field of view: 3.5 deg
 - Energy threshold: ~ 50 GeV
 - Energy resolution: 15 - 25%
 - Angular resolution: 0.04° - 0.15°
 - Sensitivity: 0.8% Crab Nebula flux in 50h
 - Fast slewing: < 40 s to any position

Major
Atmospheric
Gamma-ray
Imaging
Cherenkov





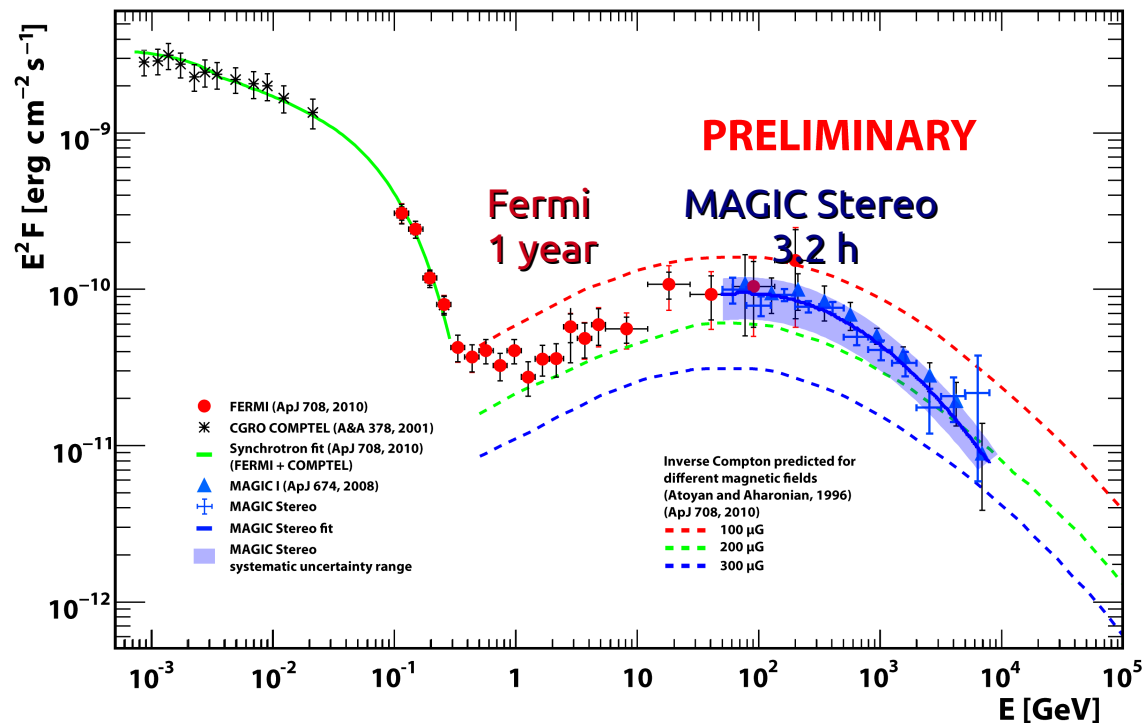
MAGIC

The MAGIC Telescopes

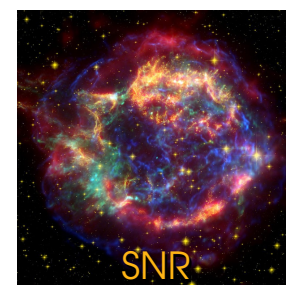
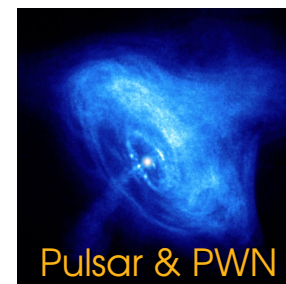
- Complementary with Fermi – the only IACT that overlaps with the satellite for $E < 150$ GeV

Crab Nebula Spectrum

MAGIC Stereo in combination with neighbouring wavelengths



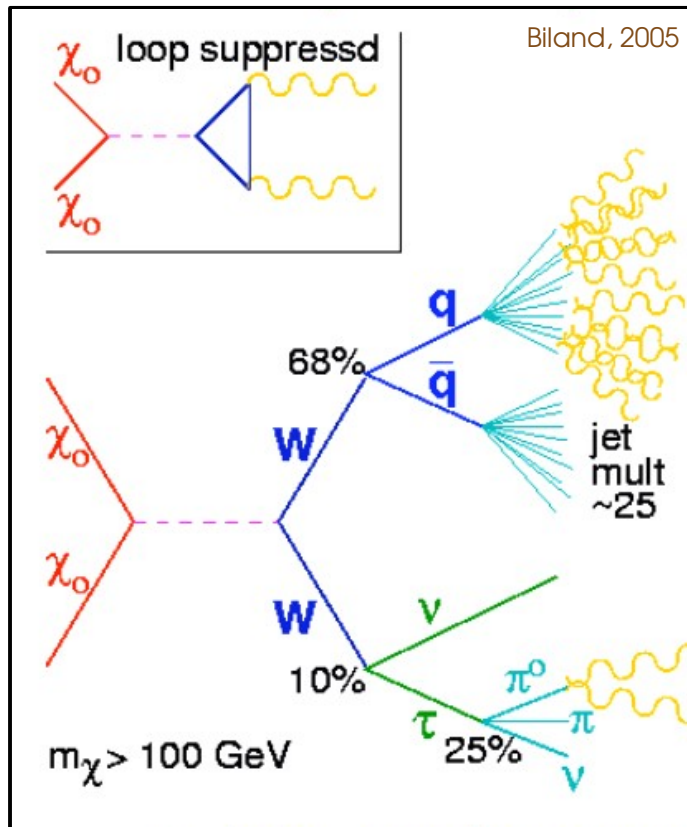
Physics with MAGIC →



Dark Matter and IACTs

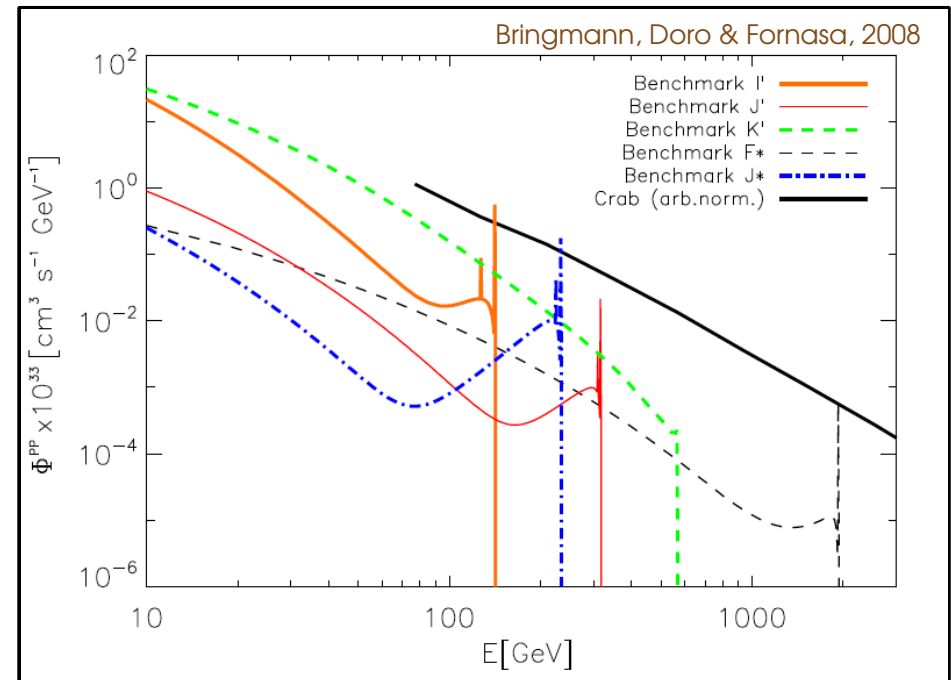
- For the IACTs, the best scenario (energy wise) is the supersymmetric Dark Matter annihilation

What should happen



(and other processes)

What should we expect



Monochromatic lines, IB, cut-off
Universal spectrum

Expected DM Flux

$$\Phi(E > E_0) = \Phi^{PP} \times J(\Delta\Omega)$$

Particle Physics factor

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

Astrophysics factor

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



Source dependent

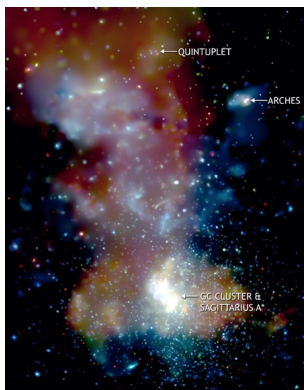
How do we choose what to observe?

Where to look?

- IACTs have limited FOV → all-sky search impossible

What do we look for in a candidate?

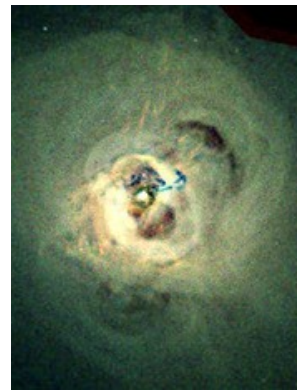
- high Dark Matter density
- small distance from us
- small apparent (angular) size
- as little as possible bkg from 'conventional' sources



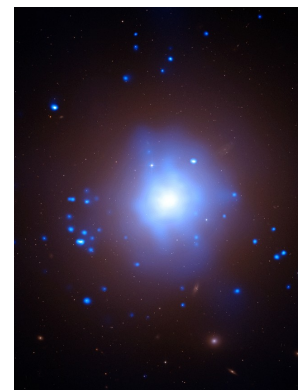
Galactic
Center



dSph
Galaxies



Galaxy
Clusters



Mini-halos
& IMBHs

MAGIC Results

Until September 2009 – only MAGIC 1!

Single telescope mode → **Sensitivity 2x worse** than in Stereo

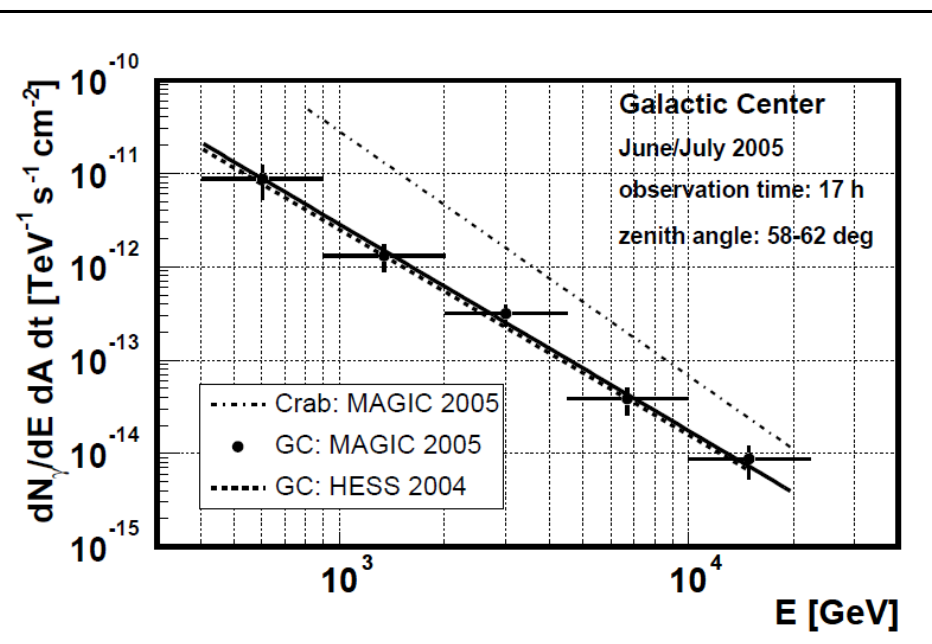
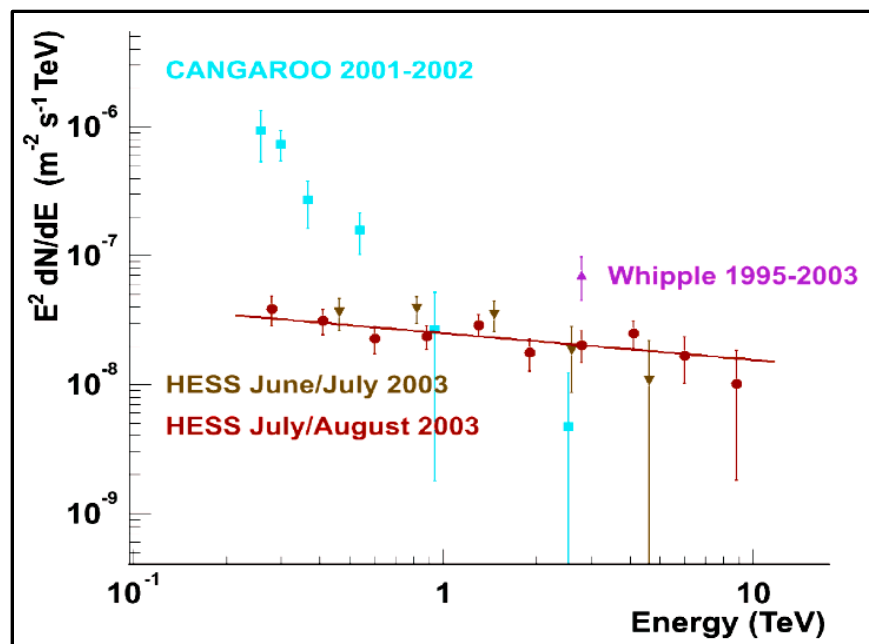
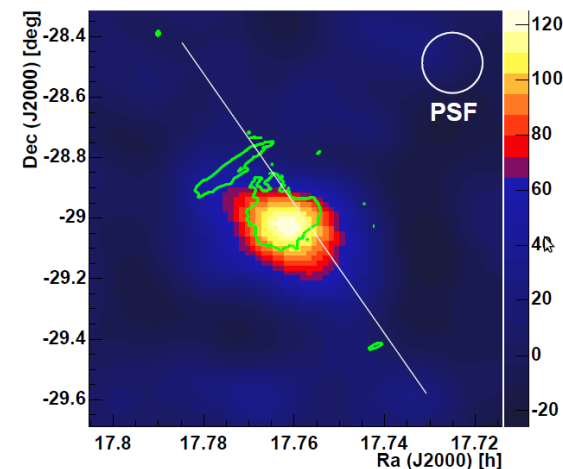


MAGIC

MAGIC Results: Galactic Center

ApJ Letters 638, L101 (2006)

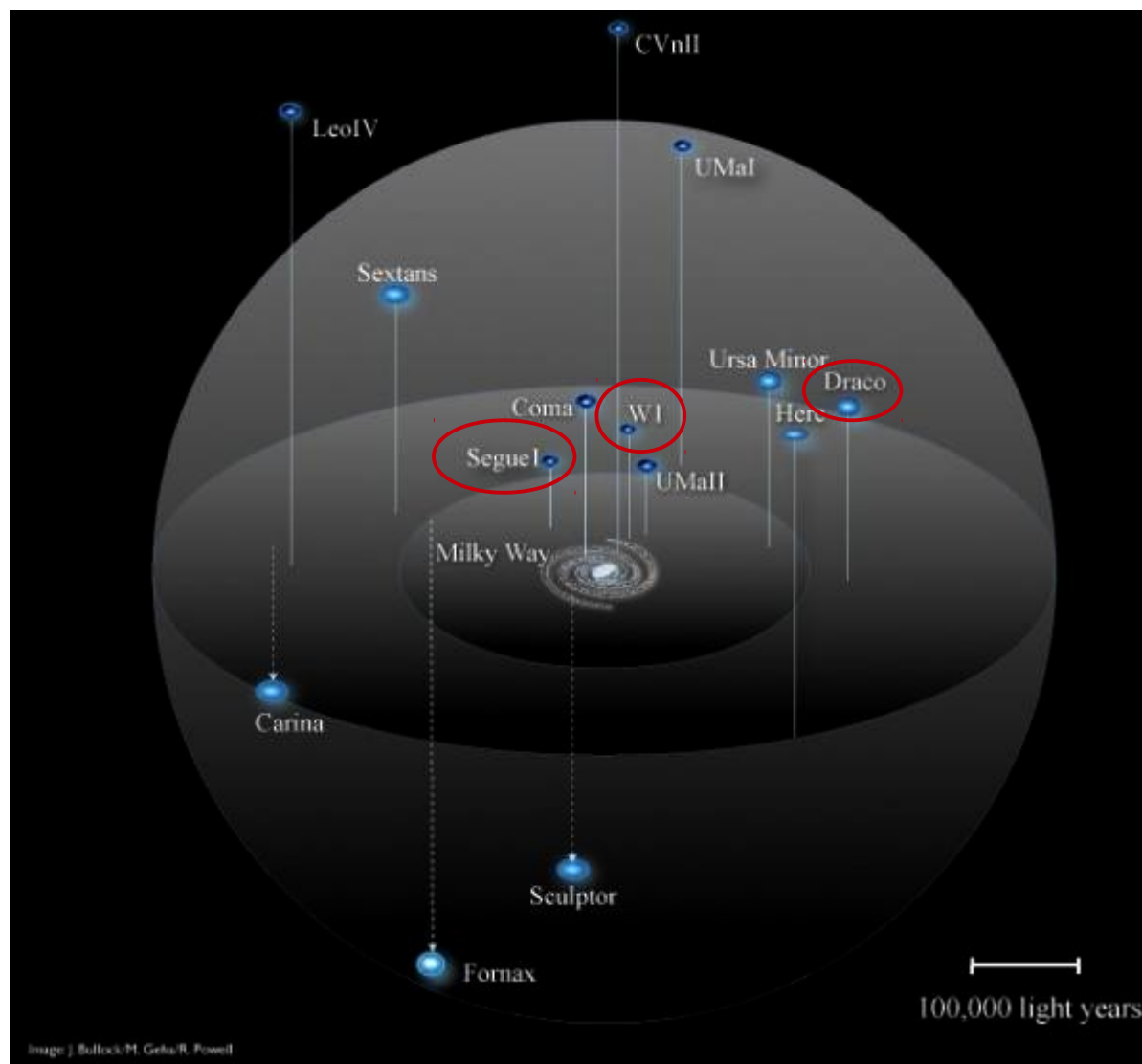
- 17 h of observations (2005)
- high zenith angles $\rightarrow$ only high energies for MAGIC
- too much background (Sgr A* + diff. gamma)
- results compatible with HESS





MAGIC

MAGIC Results: dSphs



Milky Way companions, highest known M/L , little astrophysical bkg

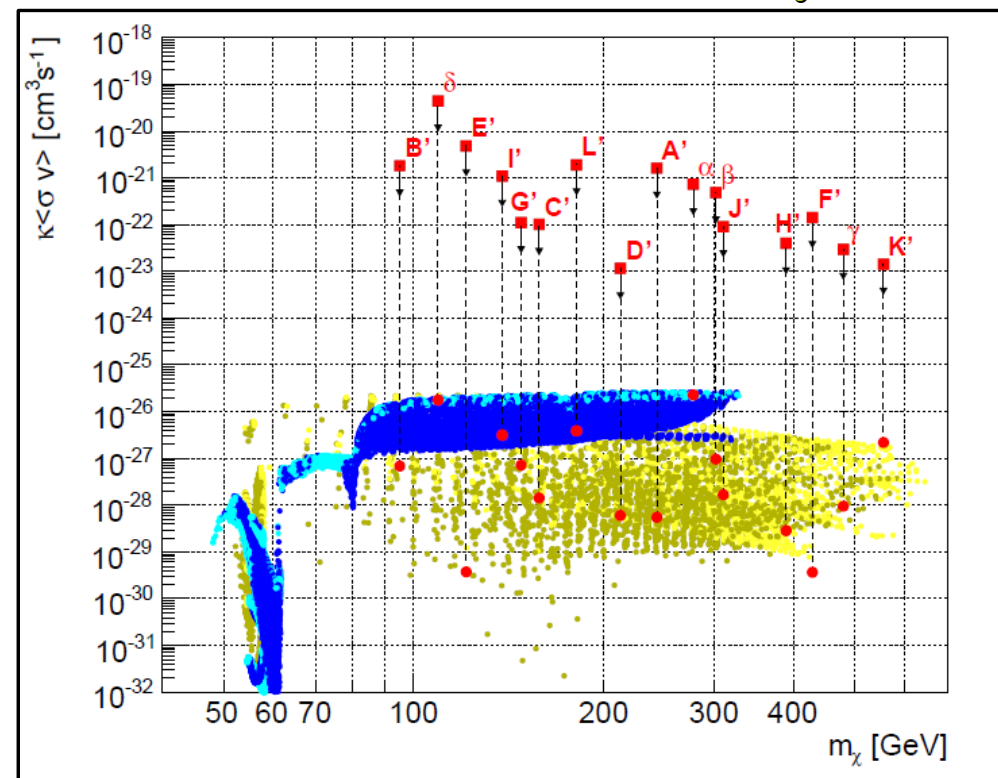
MAGIC Results: dSph Draco

ApJ 679, 428 (2008)

- 7.8 h of observations (2007)
- Medium zenith angles ($>29^\circ$)
- $E_{\text{peak}} = 140 \text{ GeV}$
- Upper limits for a set of mSUGRA benchmark points
- Halo model:
power law+ exp. cut-off
No IB (DarkSUSY 4.1)

$m_0 > 2 \text{ TeV}$

$m_0 \leq 2 \text{ TeV}$



U.L: $O(10^3)$ - $O(10^9)$ above models!

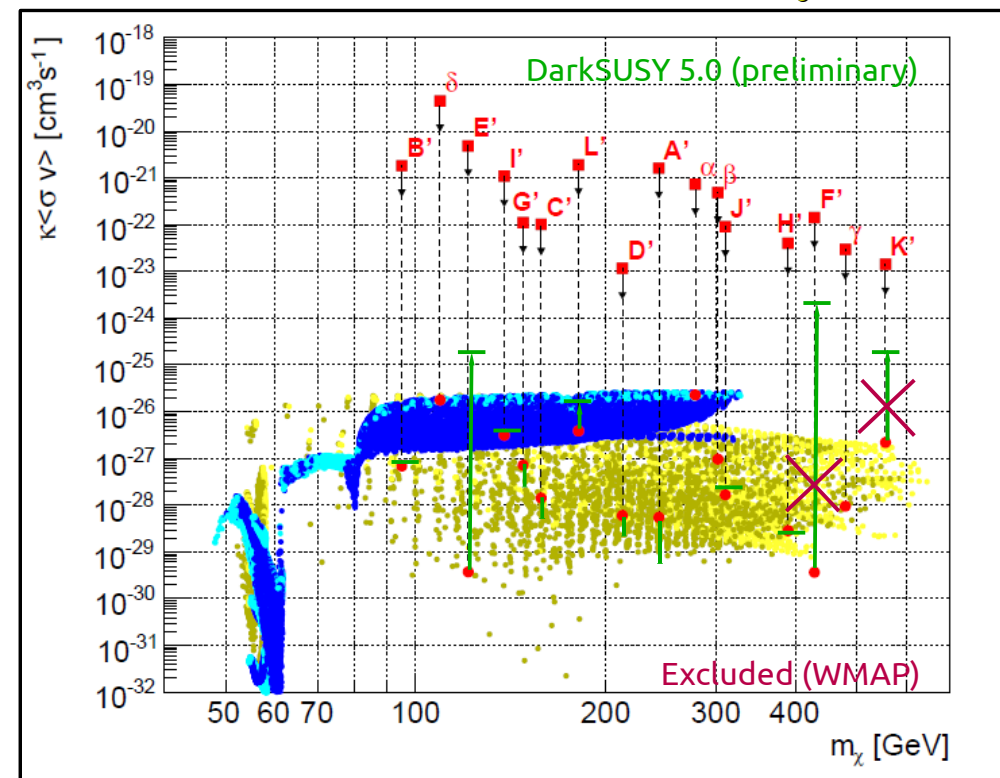
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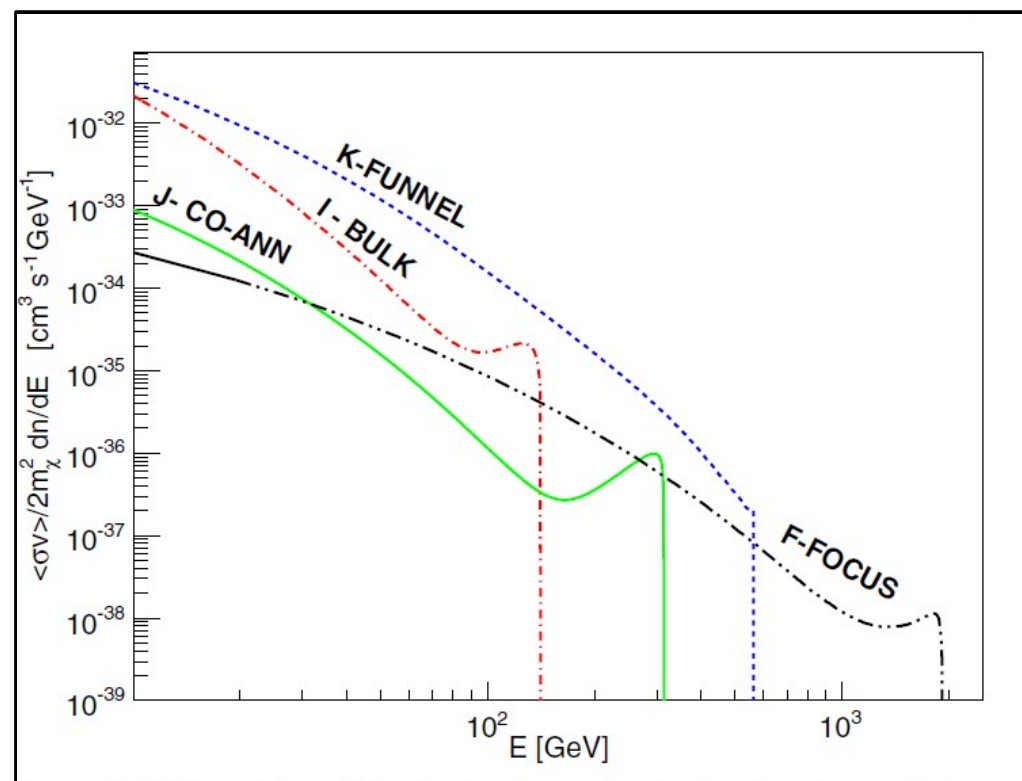


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MAGIC Results: dSph Willman 1

ApJ 697 (2009) 1299

- 15.5 h of observations (2008)
- Low zenith angles (22-30°)
- Upper limits for 4 mSUGRA benchmark points
- Halo model: NFW
- IB included (DarkSUSY 5.0)



U.L: $O(10^3)$ - $O(10^5)$

BM	$\Phi^{\text{model}}(> 100 \text{ GeV})$	$\Phi^{\text{ul}}(> 100 \text{ GeV})$	B^{ul}
I'	2.64×10^{-16}	9.87×10^{-12}	3.7×10^4
J'	4.29×10^{-17}	5.69×10^{-12}	1.3×10^5
K'	2.32×10^{-15}	6.83×10^{-12}	2.9×10^3
F^*	2.09×10^{-16}	7.13×10^{-12}	3.4×10^4

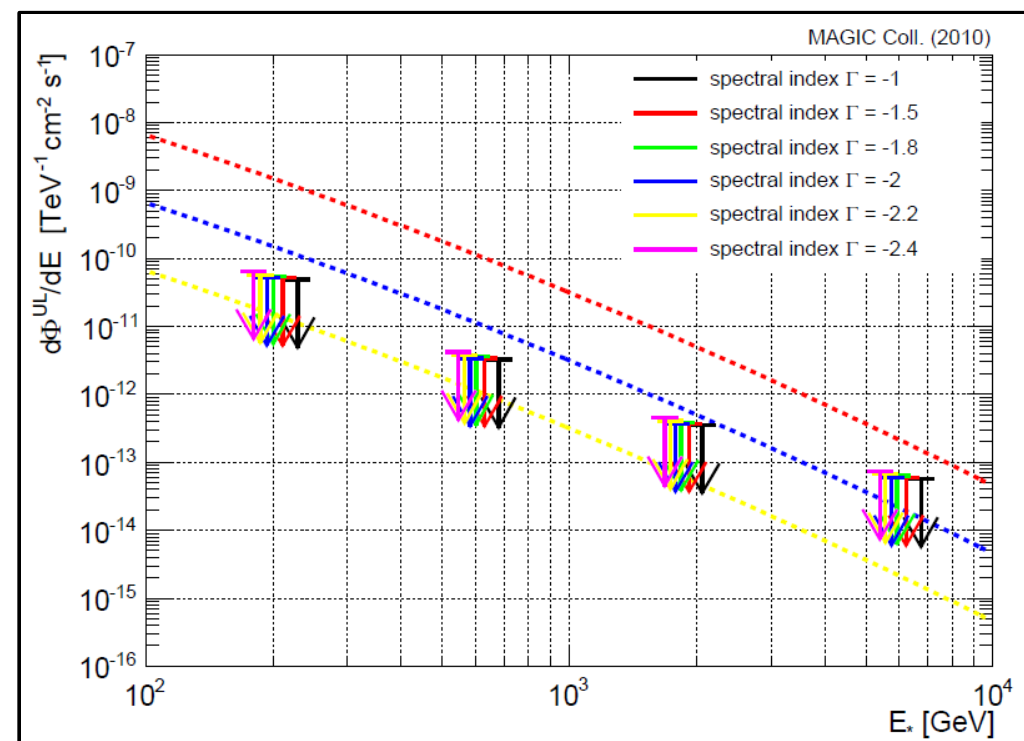


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MAGIC Results: dSph Segue 1

arXiv:1103.0477 (2011)

- 30 h of observations (2008/09)
- Low zenith angles (12.7-33.9°)
- Integral Upper limits:
 - > 100 GeV: $<10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$
 - > 200 GeV: $<2 \times 10^{-12} \text{ cm}^{-2} \text{ s}^{-1}$



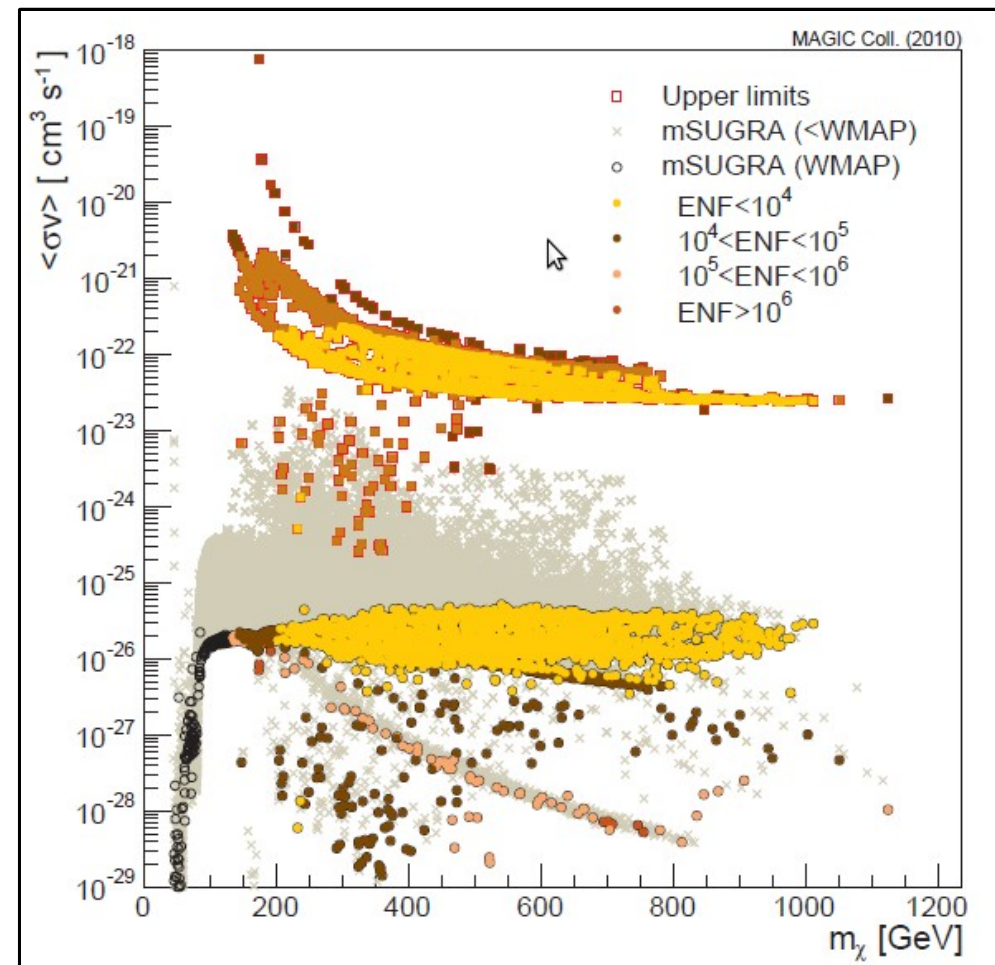
MAGIC Results: dSph Segue 1

arXiv:1103.0477 (2011)

- Halo profile: Einasto
- more than 5×10^6 models scanned over mSUGRA

Parameter	Range	Steps
m_0	50 ; 5000 GeV	40
$m_{1/2}$	0 ; 5000 GeV	40
$\tan \beta$	2 ; 62	40
A_0	-7000 ; 7000	40
$\text{sign}(\mu)$	+ ; -	2
Total number of models scanned		5.12×10^6
& passing SM bounds		2.42×10^6
& with $\Omega_{\text{DM}} h^2 - \Omega_{\text{DM}}^{\text{WMAP}} h^2 < 3\sigma_{\text{WMAP}}$		42427
& with $ \Omega_{\text{DM}} h^2 - \Omega_{\text{DM}}^{\text{WMAP}} h^2 < 3\sigma_{\text{WMAP}}$		4180

- Each square (limit) corresponds to the model (circle)



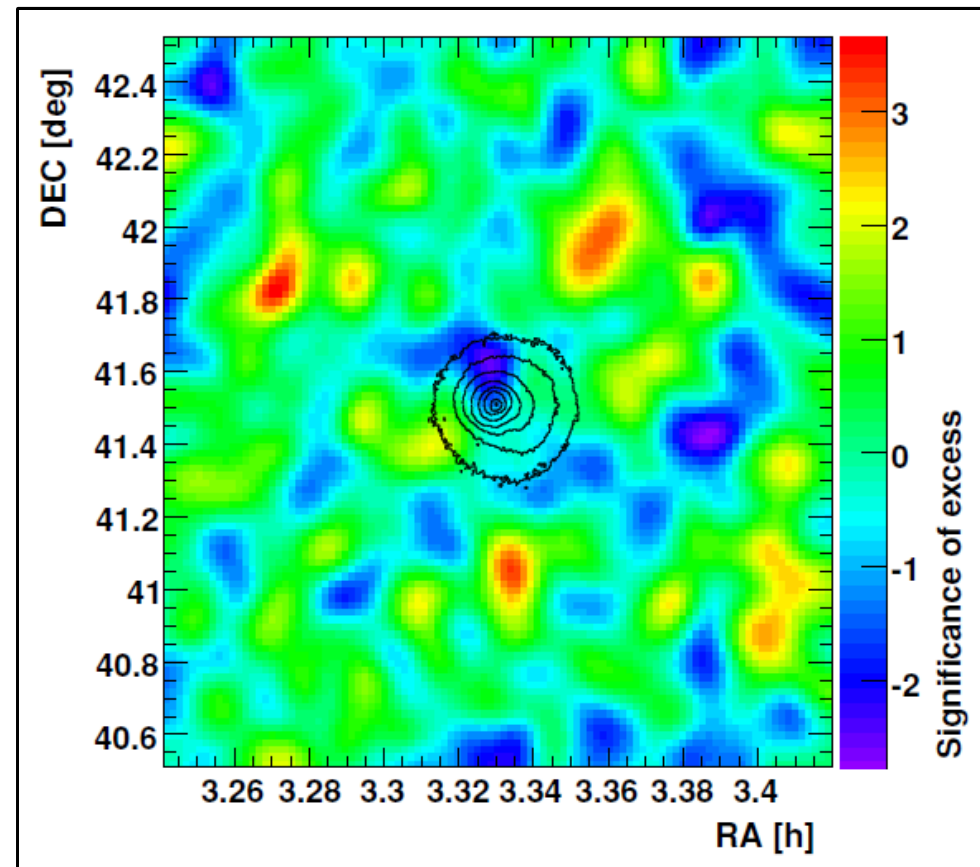
- For $\Omega_{\text{DM}} = \text{WMAP} \pm 3\sigma$, the boost factor is $> 600 \rightarrow$ still far from constraining mSUGRA

MAGIC Results: Perseus

- Galaxy Clusters: huge amount of DM (80%), distant ($O(100 \text{ Mpc})$), background

ApJ 710 (2010) 634

- 24.8 h of observations (2008)
- Possible emissions from:
individual galaxies
cosmic rays
Dark Matter (?)
- Integral U.L:
> 100 GeV: $(4.6-7.5) \times 10^{-12} \text{ cm}^{-2} \text{ s}^{-1}$
- $O(10^4)$ above expected DM emission
- Upper limits for the central radio galaxy NGC 1275





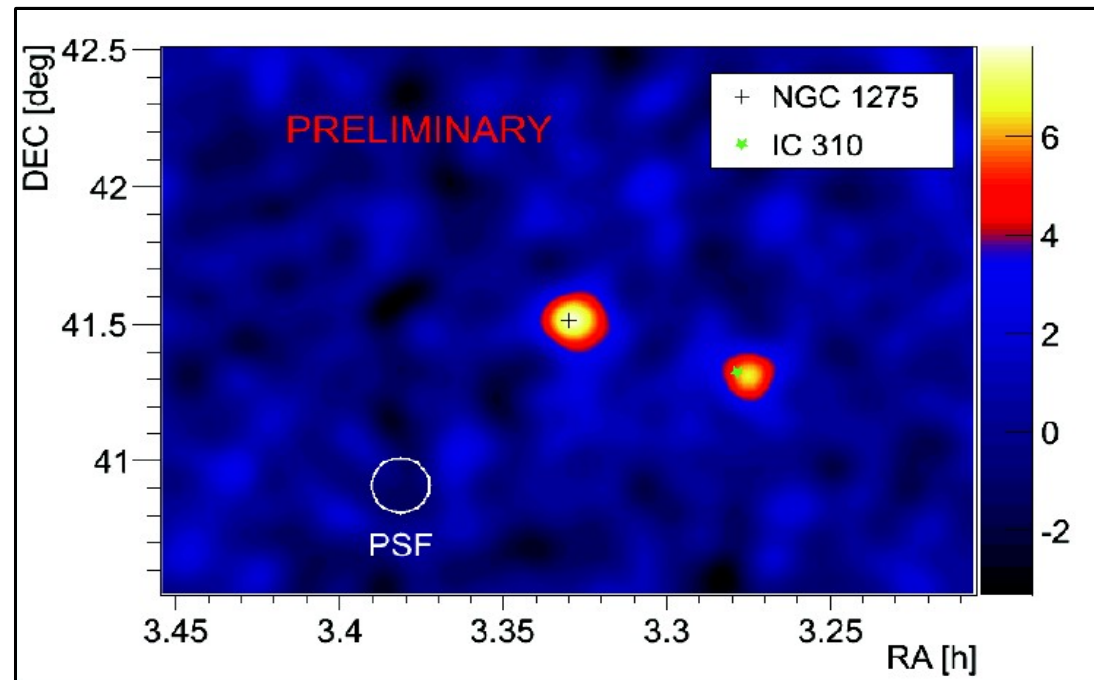
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MAGIC Results: Perseus (STEREO)

ApJ Lett. 723 (2010) L207

STEREO: 2x improved sensitivity, lower E_{th} and better angular and energy resolution

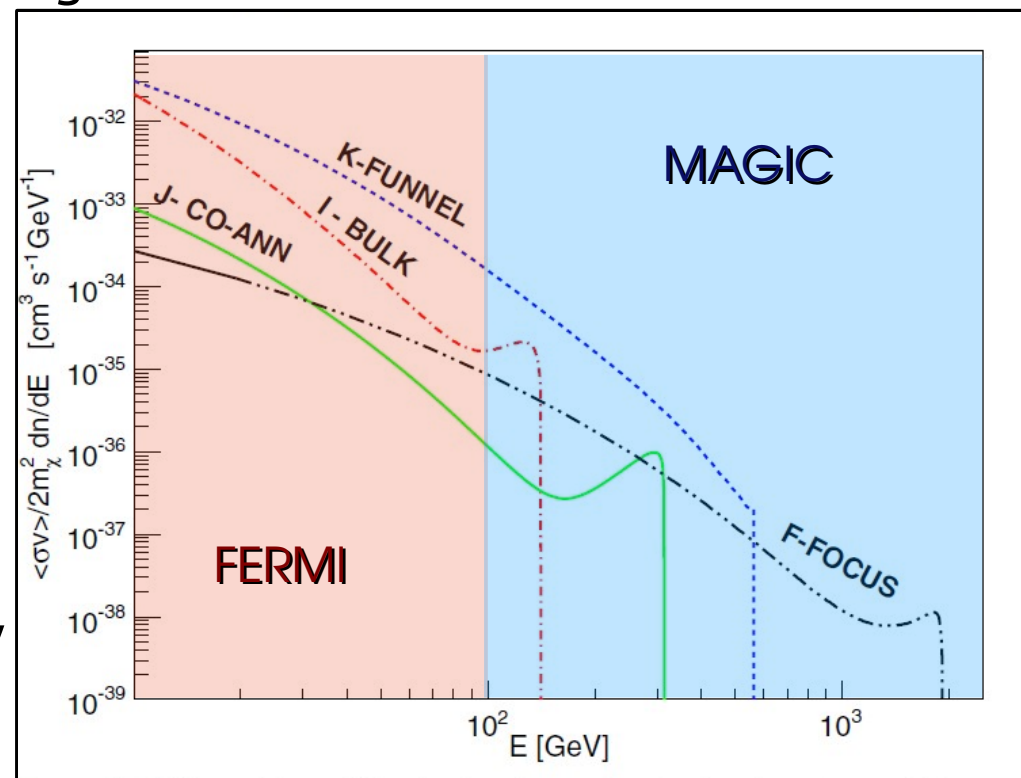
- 20.6 h of stereo observations (2009/2010):
Discovery of VHE emission from head-tail radio galaxy IC 310
- Stereo observations (2010/11):
Detection of NGC 1275





MAGIC DM Search: UFOs

- Predicted existence of DM clumps within our Galaxy
 - IMBHs (?) could have accreted large amounts of DM
 - Might be very close, and very bright, but only through DM emission (Fermi, Agile could see them?)
 - Unidentified Fermi Objects (UFOs) – recently detected by Fermi, without known counterpart in other wavelengths
 - Possible DM candidates:
 - + hard spectrum
 - + stable
 - + outside Galactic plane
- Smoking gun: several UFOs with same spectrum!
- MAGIC might be more suitable to detect cut-off for $m_\chi < 100$ GeV
 - Observations ongoing



Conclusions and Prospects

- MAGIC is observing promising DM targets since 2005.
- No detection yet, but chances increased with Stereo system:
 - + sensitivity less than 1% Crab Nebula → go lower in flux
 - + lower energy threshold → go lower in m_χ
 - + angular resolution 20% better → study extended sources
 - + energy resolution < 20% → look for spectral features
- Active group for Dark Matter searches
- Ongoing efforts on dSphs, Galaxy Clusters and UFOs
- For objects with 'known' DM distribution, MAGIC still can not constrain mSUGRA models
- Testing other DM theories? :)



MAGIC



MAGIC

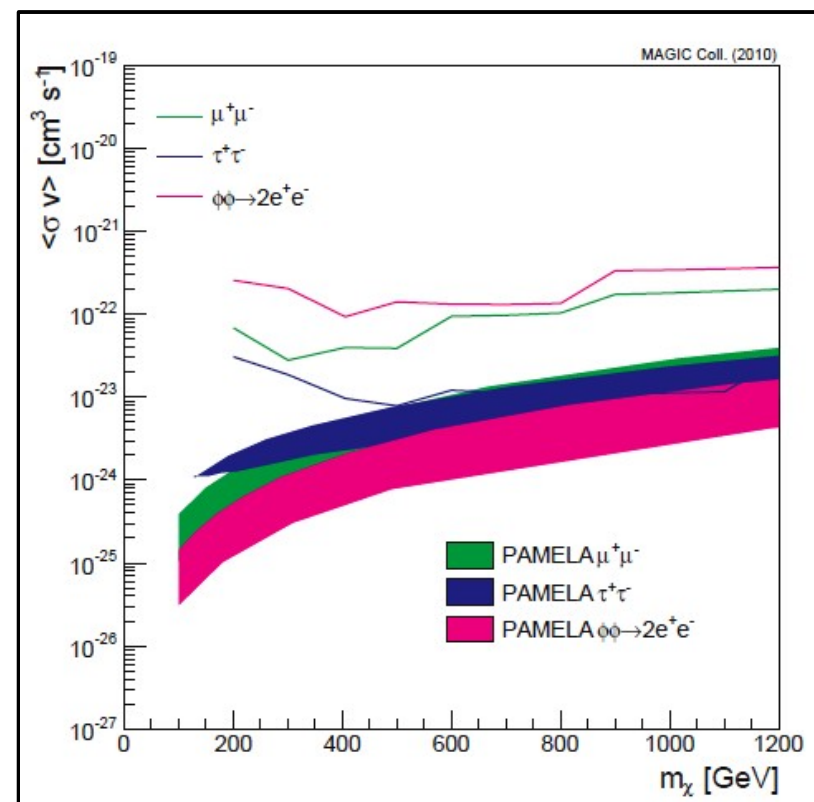
MAGIC Results: dSph Segue 1

arXiv:1103.0477 (2011)

- Compared models fitting PAMELA e^+/e^+e^- ratio (adapted from:
Essig et al., PRD 82,
Meade et al., Nucl. Phys. B 831)

- MAGIC limits start to probe the relevant region for

$$\chi\chi \rightarrow \tau^+\tau^-$$

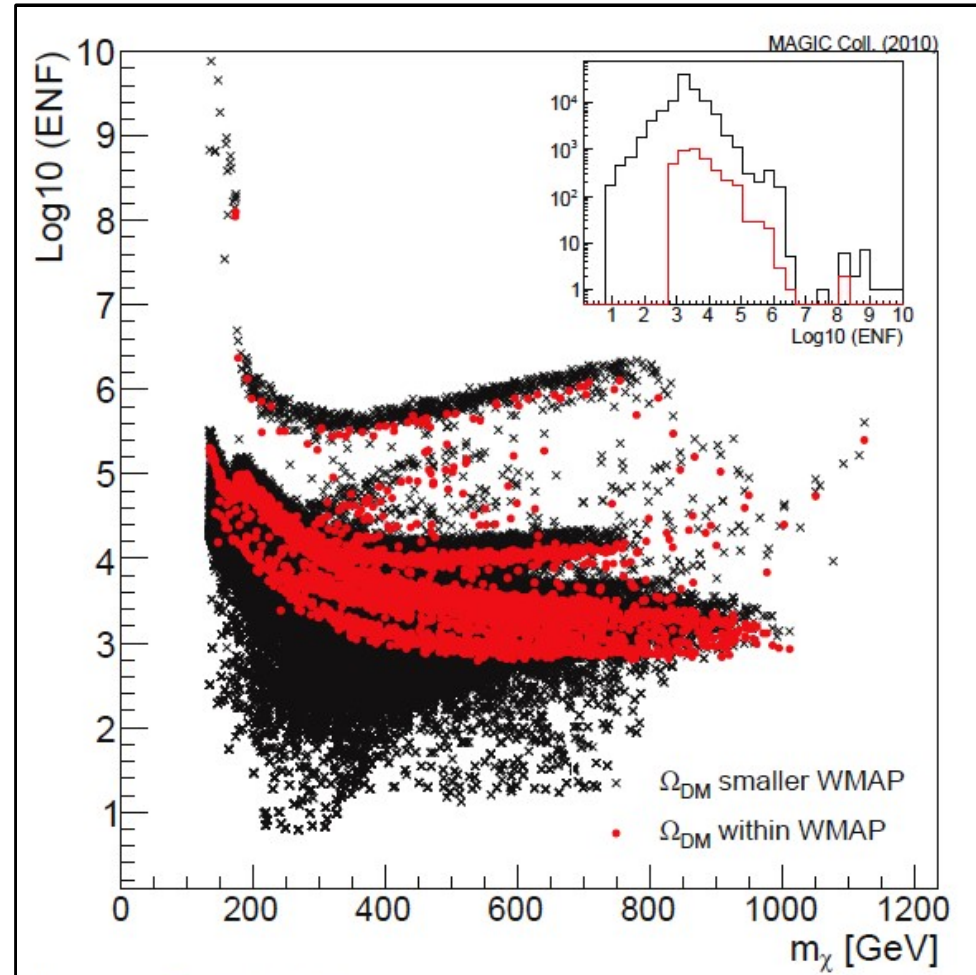




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MAGIC Results: dSph Segue 1

arXiv:1103.0477 (2011)



Enhancement factors as a function of the DM mass for models in the scan providing a relic density compatible with WMAP value (red crosses) or below (black crosses). The panel in the upper right part indicates the distribution of the ENFs for these two sets of models with the same color coding.