Search for Dark Matter with the MAGIC Telescope

The Hunt for Dark Matter, FNAL, 2007

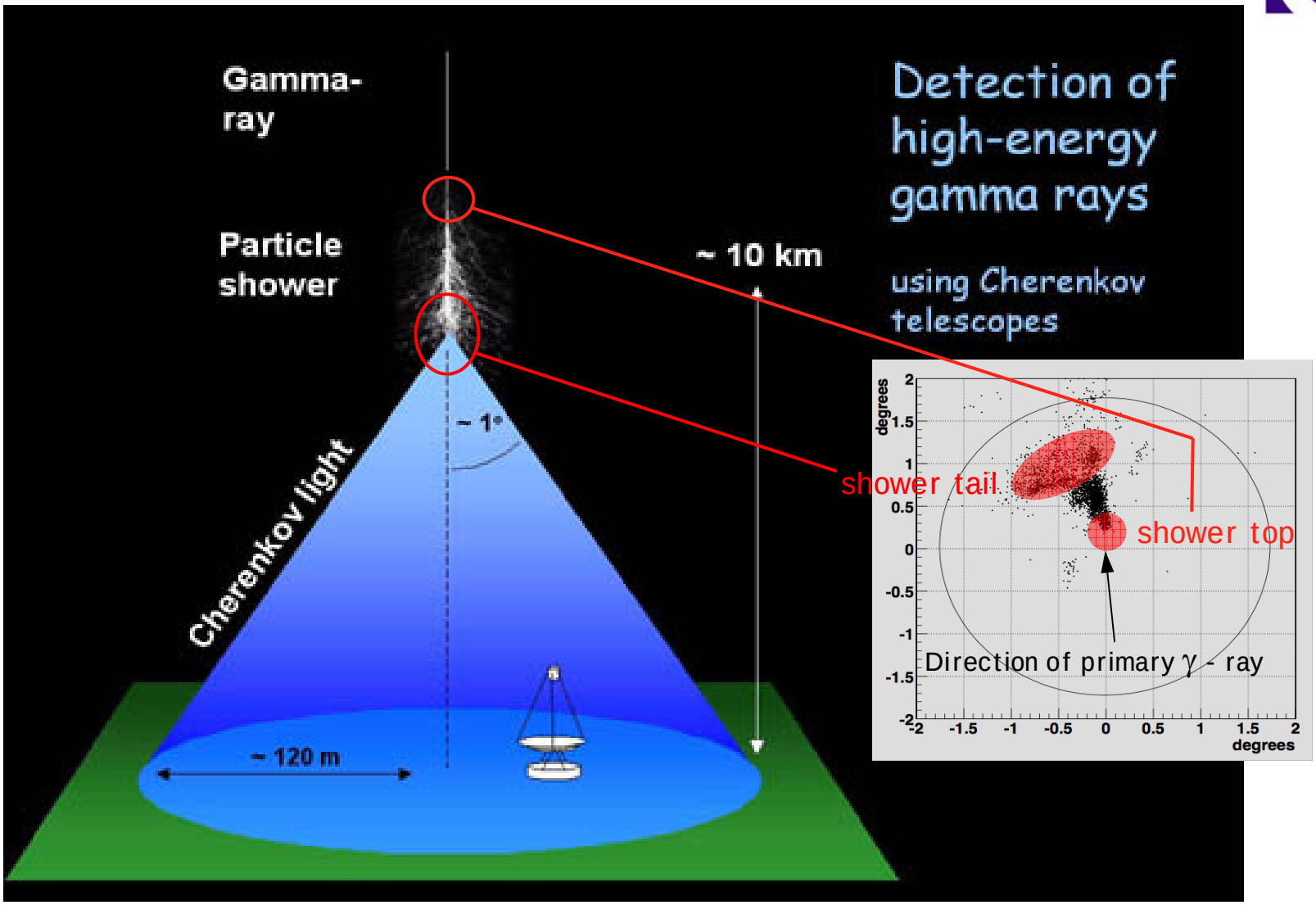
outline:

- the MAGIC telescope
- indirect search for particle dark matter
- conclusions / outlook

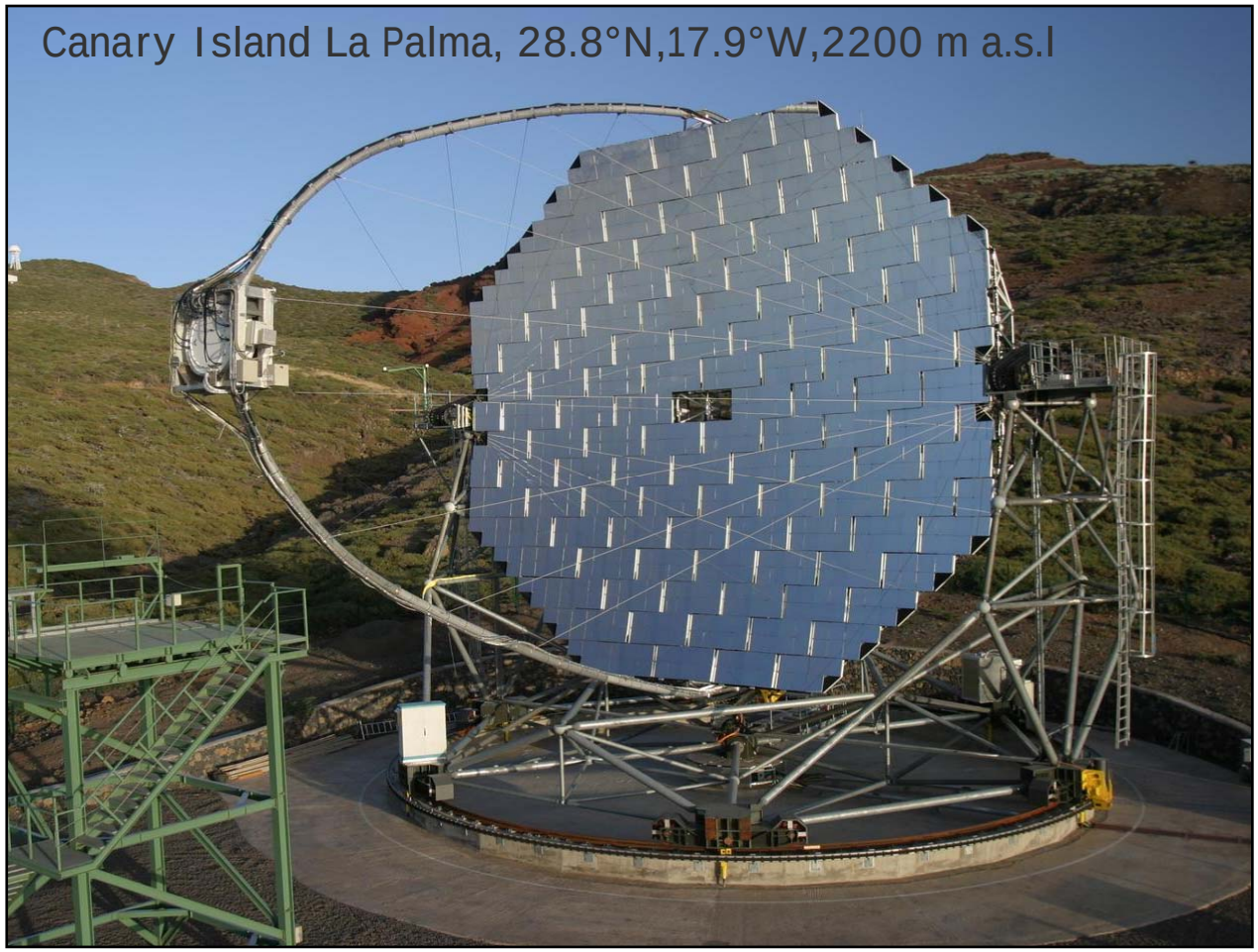
Hendrik Bartko, MPI Munich
for the MAGIC collaboration

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescope

The IACT principle

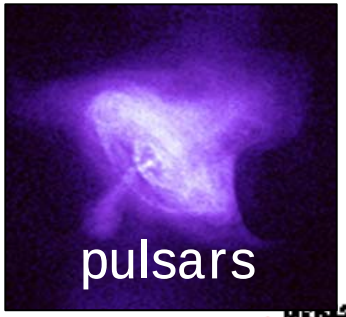


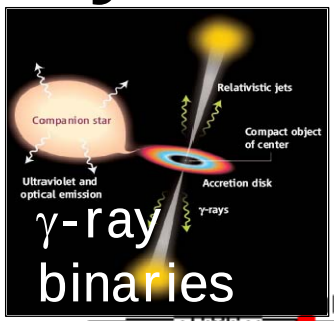
The MAGIC Telescope

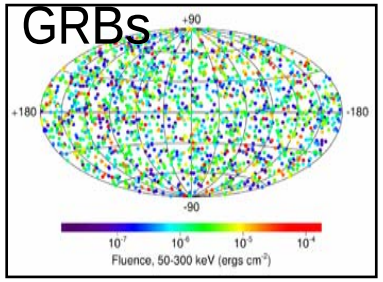


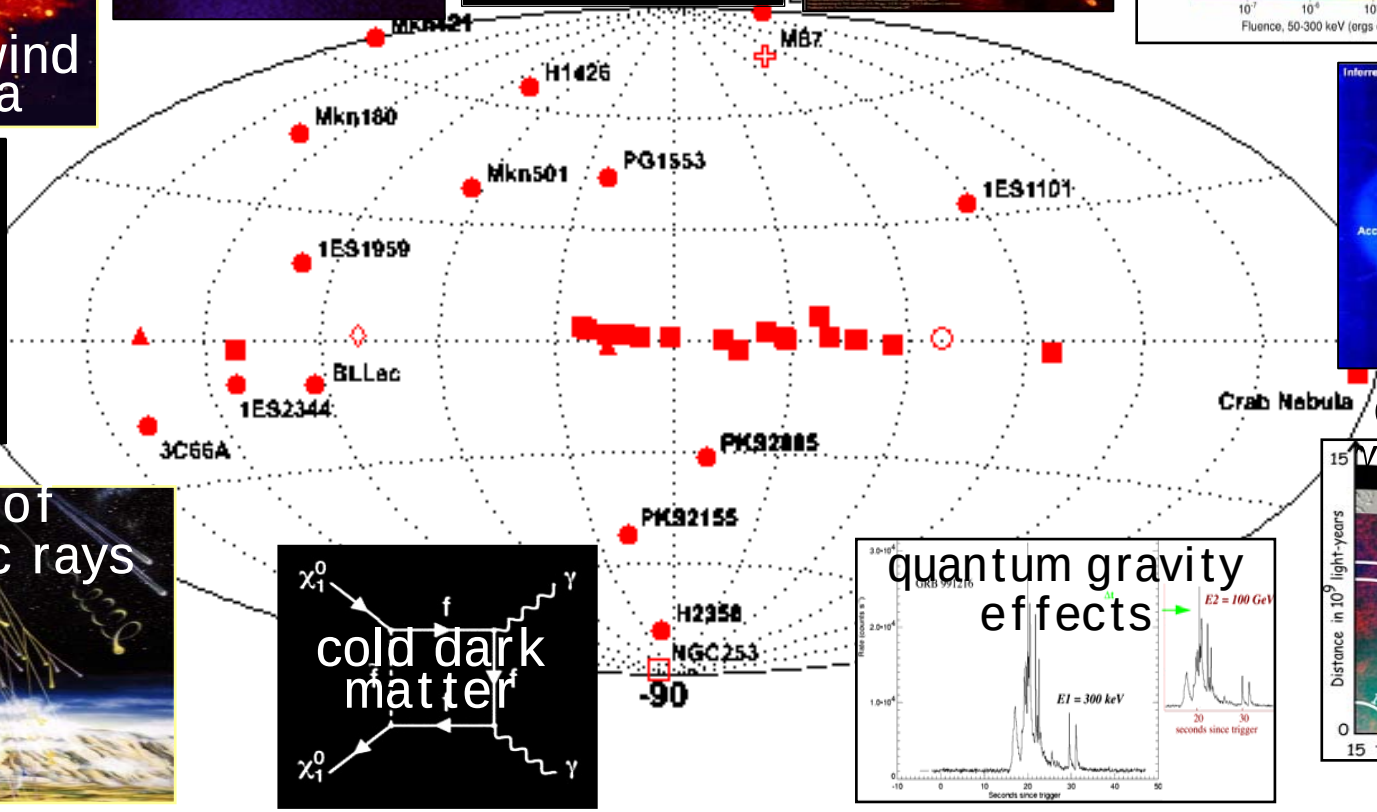
- field of view: 3.5°
- angular resolution: $\sigma \sim 0.1°$
- **energy region: 50 GeV – 10 TeV**
- energy resolution: 20-30%
- effective area: ~10^5 m^2
- flux sensitivity: 2% Crab Nebula flux (5σ in 50h @ 250 GeV)
- fast repositioning: <40s (average) for GRB observation

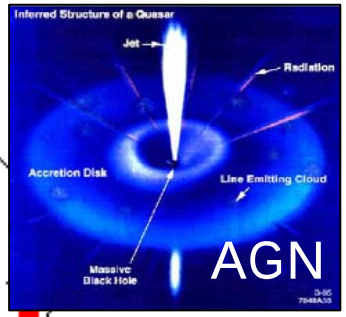
MAGIC Physics Objectives

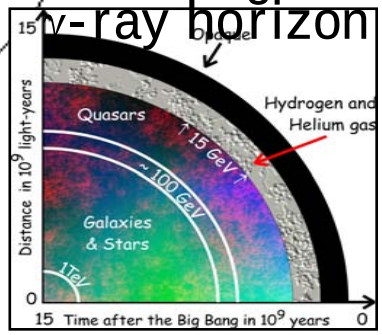


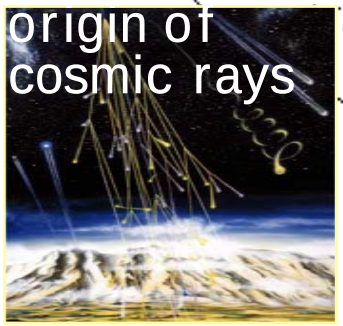








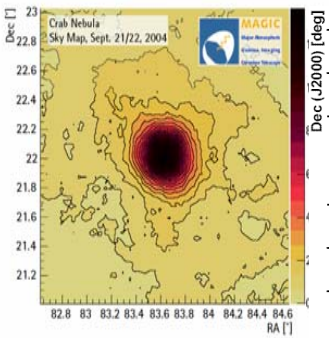




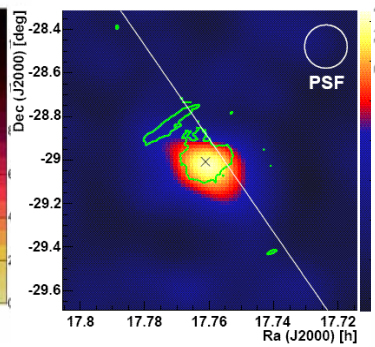
> 40 sources above 100 GeV, rapid growth in recent years

Published Sources (Cycle I)

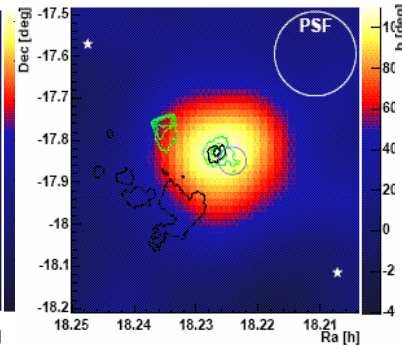
MAGIC catalog was authorized by IAU: “MAGIC JHHMM+DDMM”



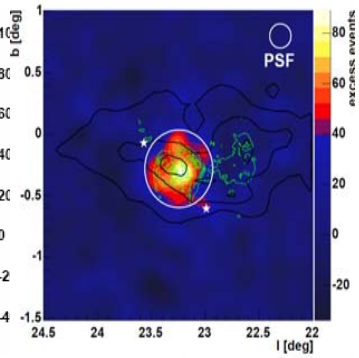
Crab Nebula



Galactic Center

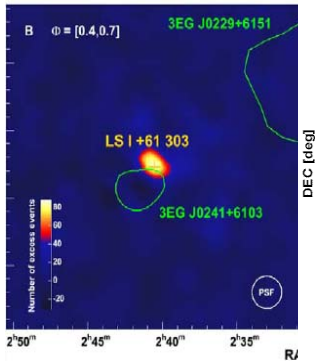


HESS J1813



HESS J1834

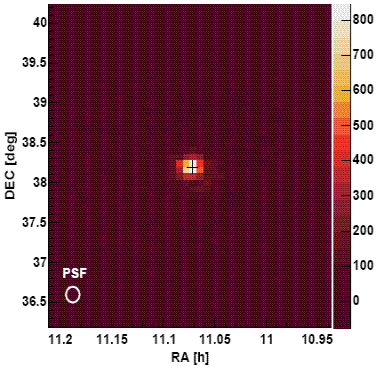
^{13}CO cloud



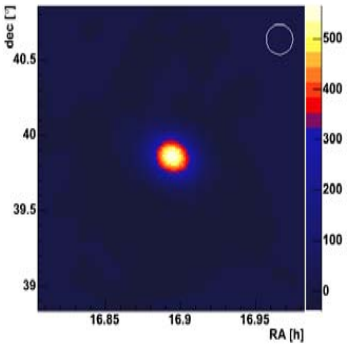
LSI+61 303

γ-ray binary

New source

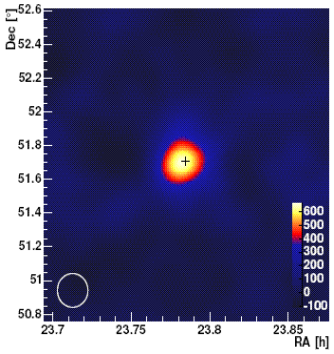


Mrk421 (0.030)

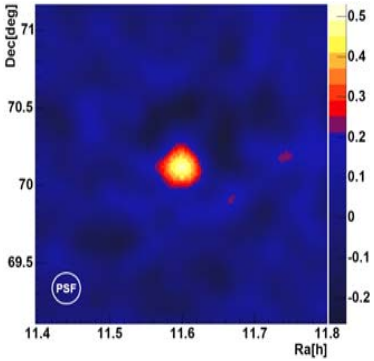


Mrk501 (0.034)

fast flares

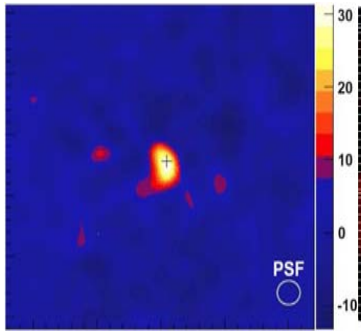


1ES2344 (0.044)



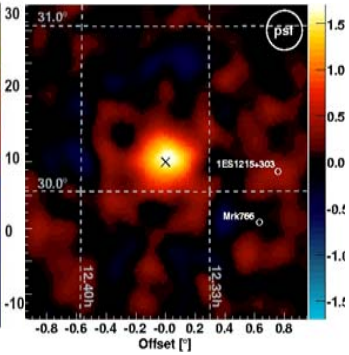
Mrk180 (0.045)

New source



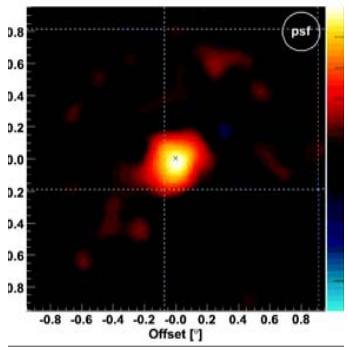
Bl Lac (0.069)

New source



1ES1218 (0.182)

New Source



PG 1553 (>0.25)

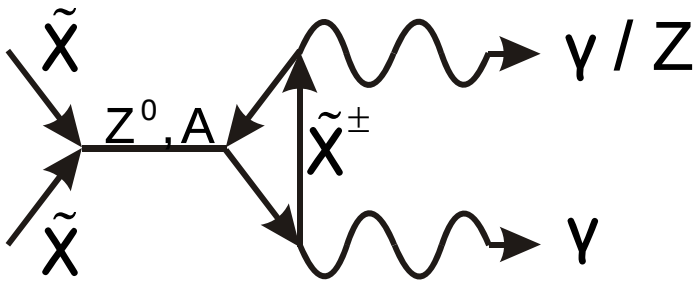
New source

Neutralino Annihilation

neutralino: Majorana Fermion (own anti-particle)

$\Rightarrow$ self-annihilation

annihilation into $\gamma\gamma$ / γZ



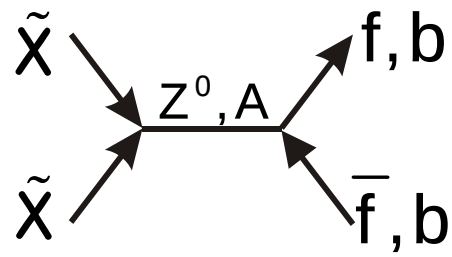
gamma line: loop suppressed

$$E_\gamma = m_\chi \qquad E_\gamma = m_\chi - \frac{m_Z^2}{m_\chi^2}$$

annihilation rate per unit volume:

$$\Gamma_{ann} = \frac{1}{2}\langle\sigma v\rangle_0 \frac{\rho_\chi^2}{m_\chi^2}$$

annihilation into fermions/bosons



continuum gammas from hadronisation ($\pi^0 \rightarrow \gamma\gamma$), hadronic tau decays, final state radiation

$$E_\gamma < m_\chi$$

Gamma Signal From Neutralino Annihilation

neutralino masses between 50 GeV and O(TeV)

⇒ expect continuum gamma signal above 30 GeV

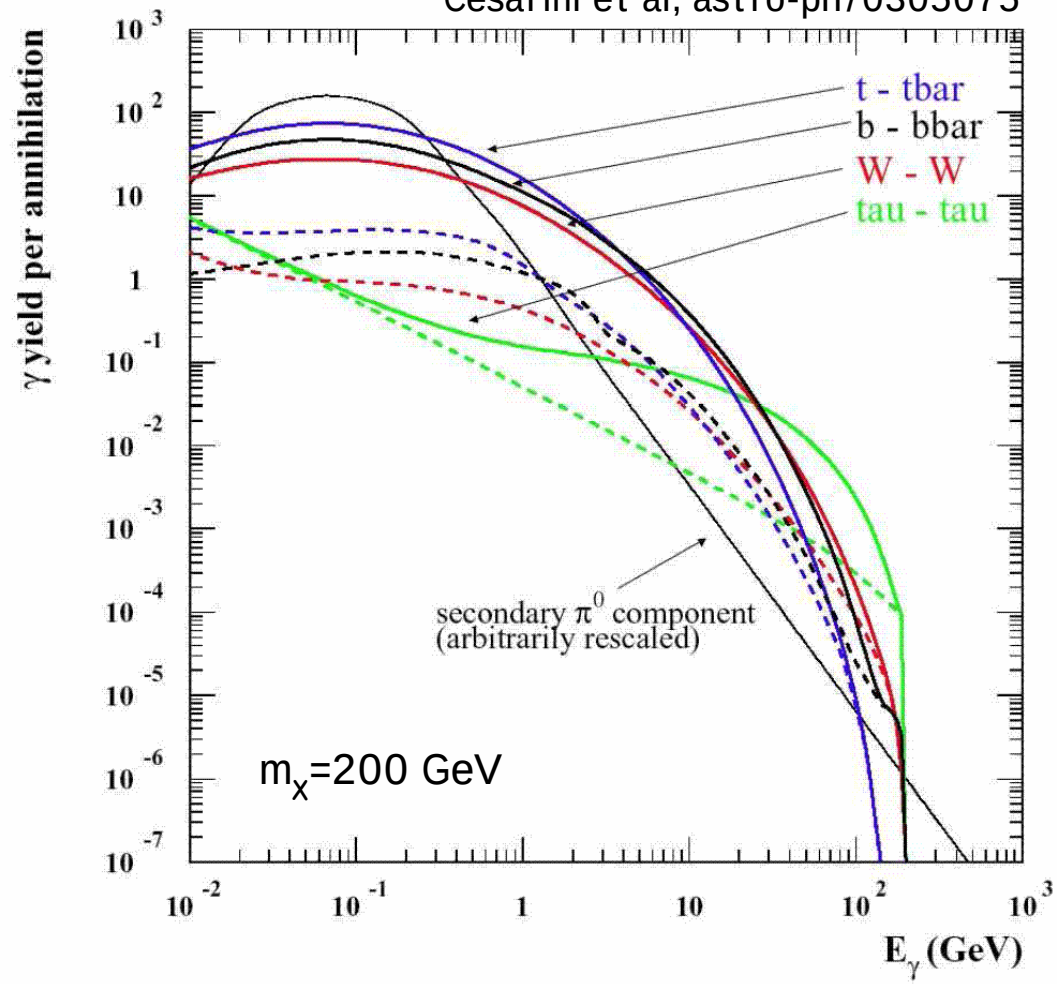
sharp cut-off at m_x

⇒ MAGIC energy range

total gamma yield depends on branching ratios and detector energy threshold

$$\Rightarrow N_\gamma(E_\gamma > E_{thresh.})$$

Cesarini et al, astro-ph/0305075



Gamma Flux from Neutralino Annihilation

$$\frac{dN_\gamma^{annihil}(\Omega,E,m_\chi)}{dt\ dA\ d\Omega\ dE} = \boxed{\frac{dN_\gamma(E,m_\chi)}{dE}\ \frac{\langle\sigma\cdot v\rangle}{8\pi\ m_\chi^{\ 2}}}\ \boxed{\int_{los}\rho_\chi^2(r(s,\Omega))\ ds}$$

particle physics

SUSY parameters
fragmentation function

$$\Omega_\chi \approx \frac{6\cdot 10^{-27}\,cm^3 s^{-1}}{\langle\sigma v\rangle_{fr}}$$

astrophysics

spatial dark matter distribution

$$\Omega_{CDM} \approx 0.23\ (WMAP)$$

gamma-ray flux ~ $\rho_\chi^{\ 2}$ $\Rightarrow$ search for CDM clumps
observe: galactic center (high diffuse gamma background),
dwarf spheroidal and nearby galaxies, globular clusters

Dark Matter Distribution

- numerical Λ_{CDM} simulations predict clumpy distribution of dark matter
- universal profile for dark matter halos:

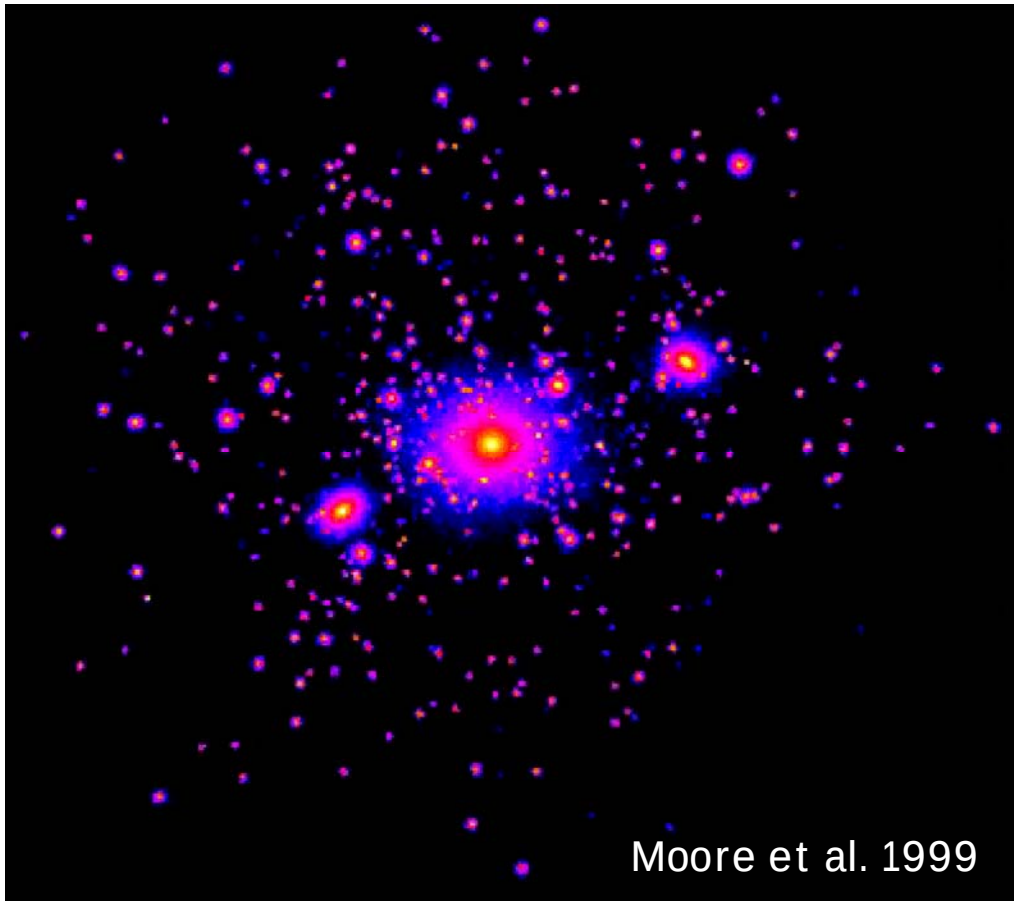
$$\rho_x \sim r^{-\alpha}, \quad 0 < \alpha \leq 1.5$$

still large uncertainties !

$\Rightarrow$ expect maximum gamma emission in center of dark matter halos

$\Rightarrow$ center of Milky Way nearest halo CDM clumps centers of external galaxies

dark matter distribution

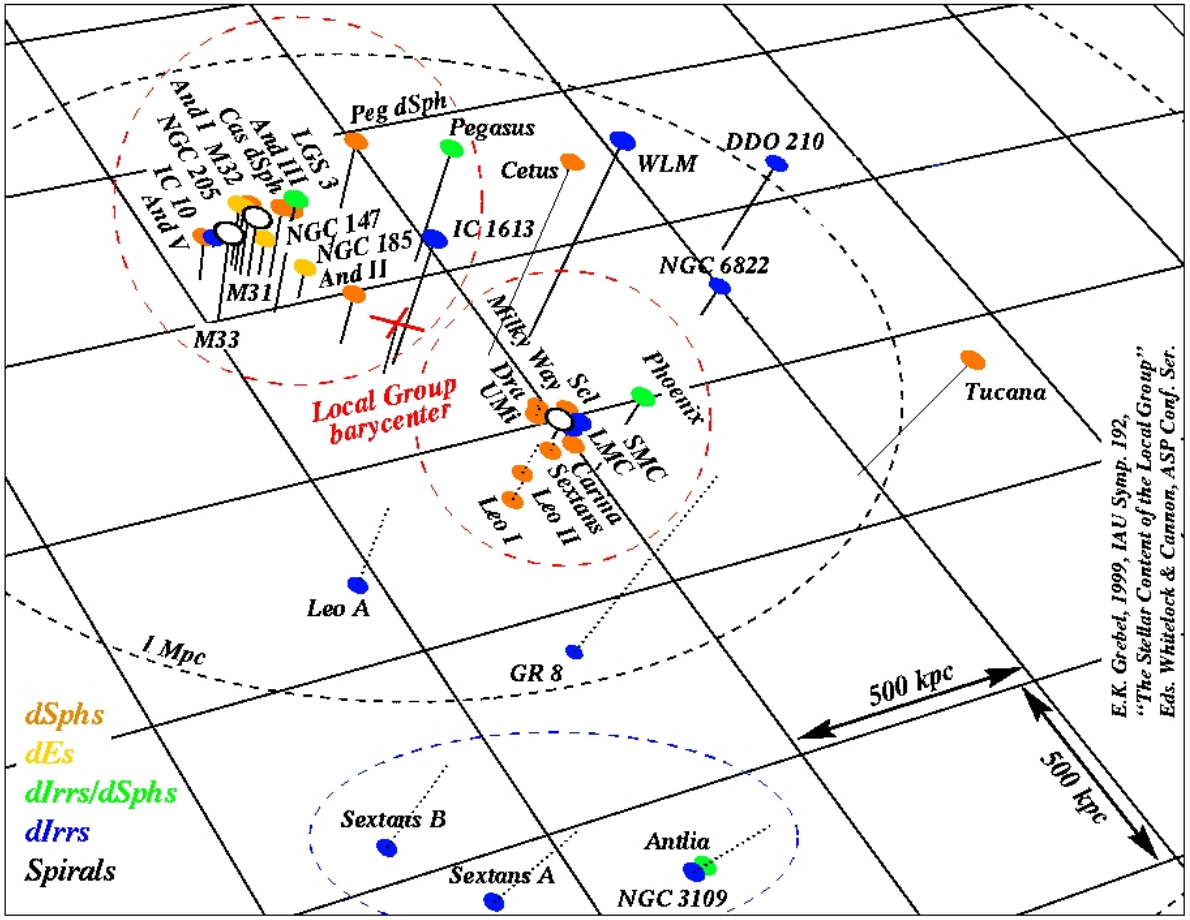


Target Candidates

- center of milky way
  ~8 kpc,
  ~$2*10^7$ M_{sun} in 300 pc
- Draco dwarf
  ~80 kpc, ~$8.6*10^7$ M_{sun}
- M31 (Andromeda)
  ~1 Mpc, ~ $3\text{-}4*10^{11}$ M_{sun}
- M87
  ~20 Mpc, ~10^{13} M_{sun}
- Dark Matter clumps / mini-spikes in the Galaxy halo

flux ~$1/R^2$

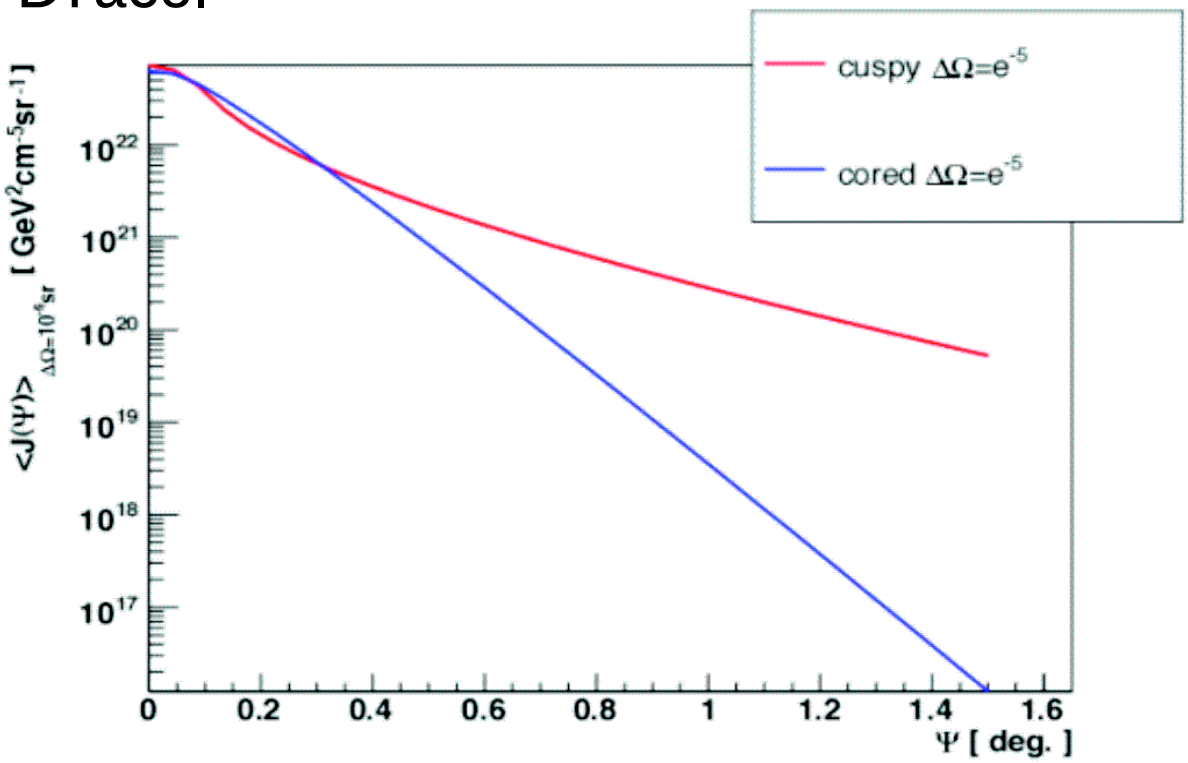
local group

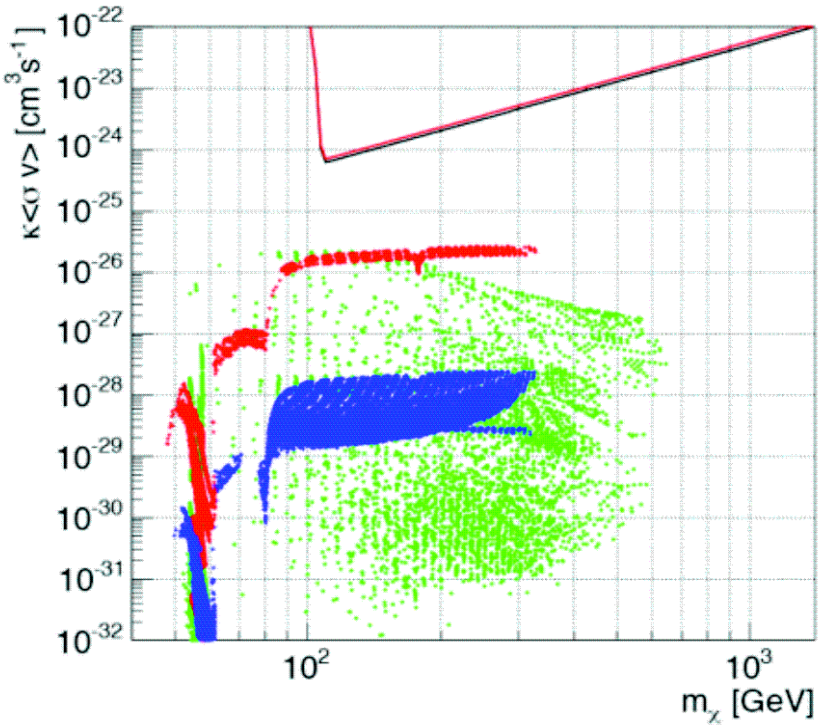


The Case of Draco

<J(ψ)> for core and cuspy DM profiles and an angular resolution of $\Delta\Omega=10^{-5}$sr for Draco.

MAGIC sensitivity for 50 hours of Observation. The difference between the two halo profiles is very small.





Unidentified EGRET – IMBH Association

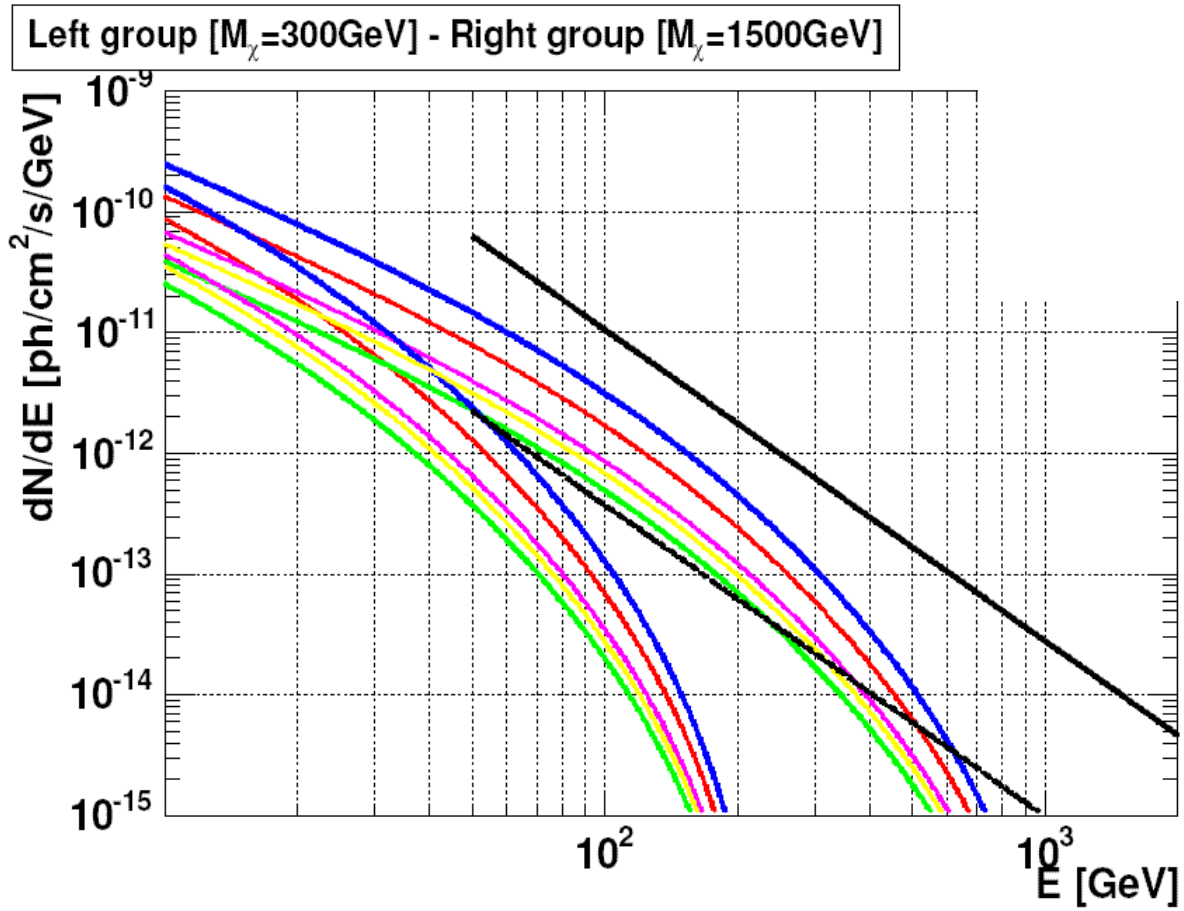
Bertone et al., 2005, Phys. Rev., D72, 103517.

SCENARIO: Intermediate Mass Black Holes (IMBHs) may be spherically distributed in the galactic halos.
No major merger -> baryonic accretion during their evolution.
->"mini-spike" of DM created onto the IMBH.
100-1000 IMBH (according to models of generation) must have the same γ-ray spectral index, and same cut-off at DM particle mass,
-> can be thus constituting a SMOKING GUN OBSERVATION.
Parameter dependence:

$$\frac{dN_\gamma^{annihil}(\Omega, E, m_x)}{dt\, dA\, d\Omega\, dE} \sim \frac{\langle \sigma \cdot v \rangle^{2/7}}{m_x^{9/7}}$$

Unidentified EGRET – IMBH Association

- Location of IMBH in galaxy halo unknown
- search for candidates among the high galactic latitude steady EGRET unidentified sources
- MAGIC selected a sample of such sources as possible observation targets.

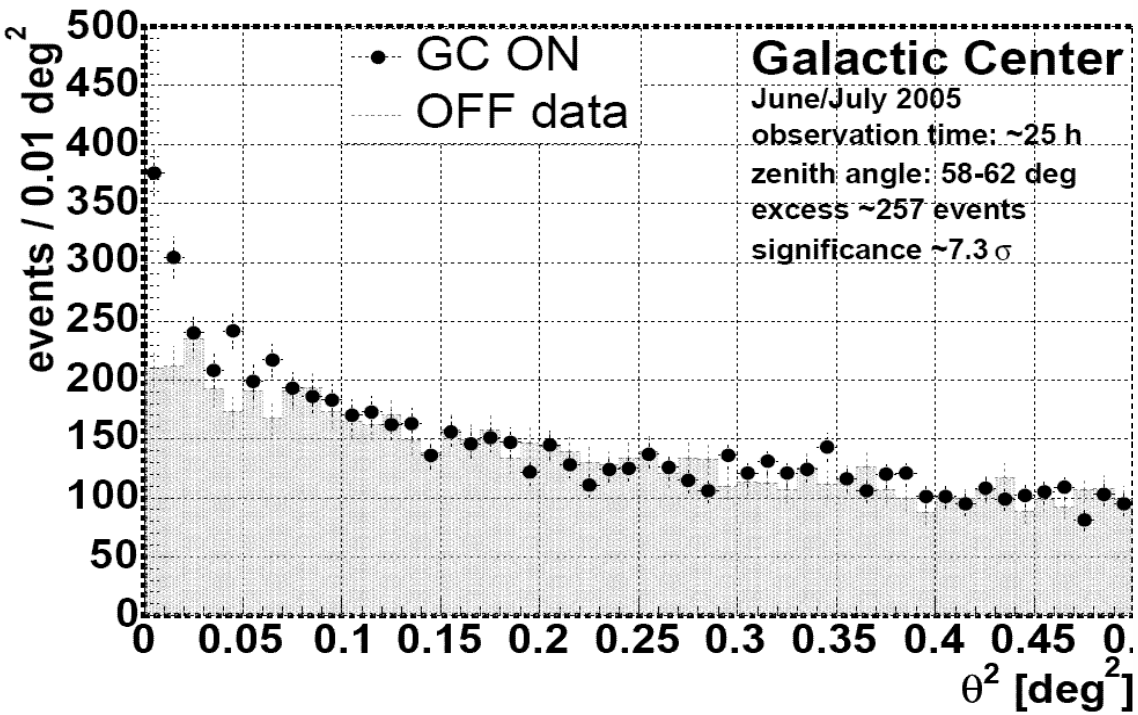


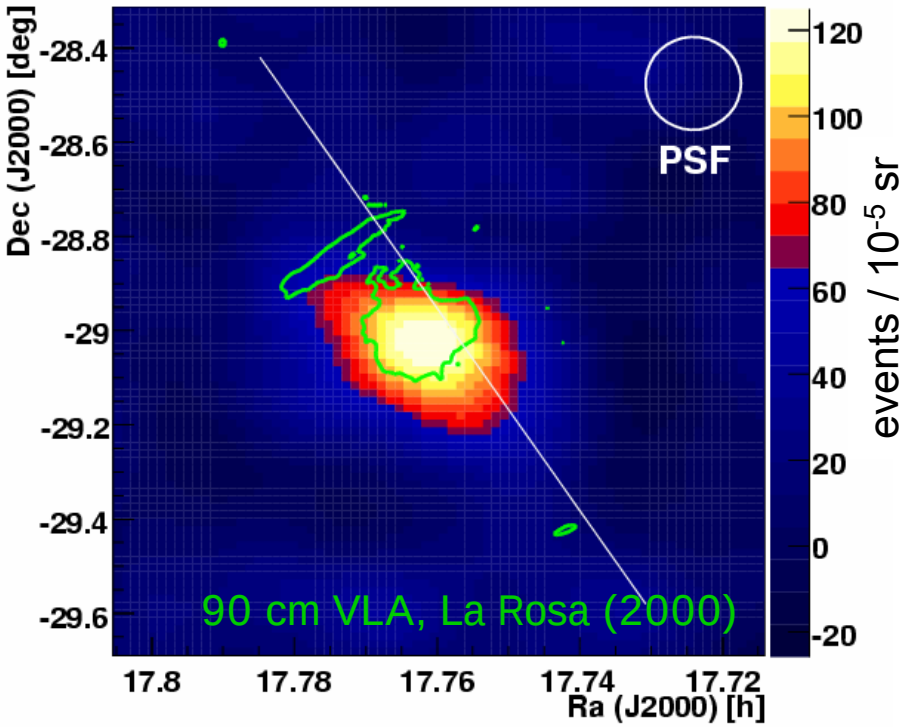
Differential energy spectra from different candidate unidentified EGRET sources extrapolated from EGRET fluxes with a typical IMBHs spectrum (Bertone et al. 2005) for two values of DM mass (m_χ=300 GeV and m_χ=1500 GeV). As reference the upper black line is the Crab Nebula differential energy spectrum, while the lower line is 1/20 of the Crab flux.

Past Observations: The GC

J. Albert et al., 2006, ApJ, 638, L101.

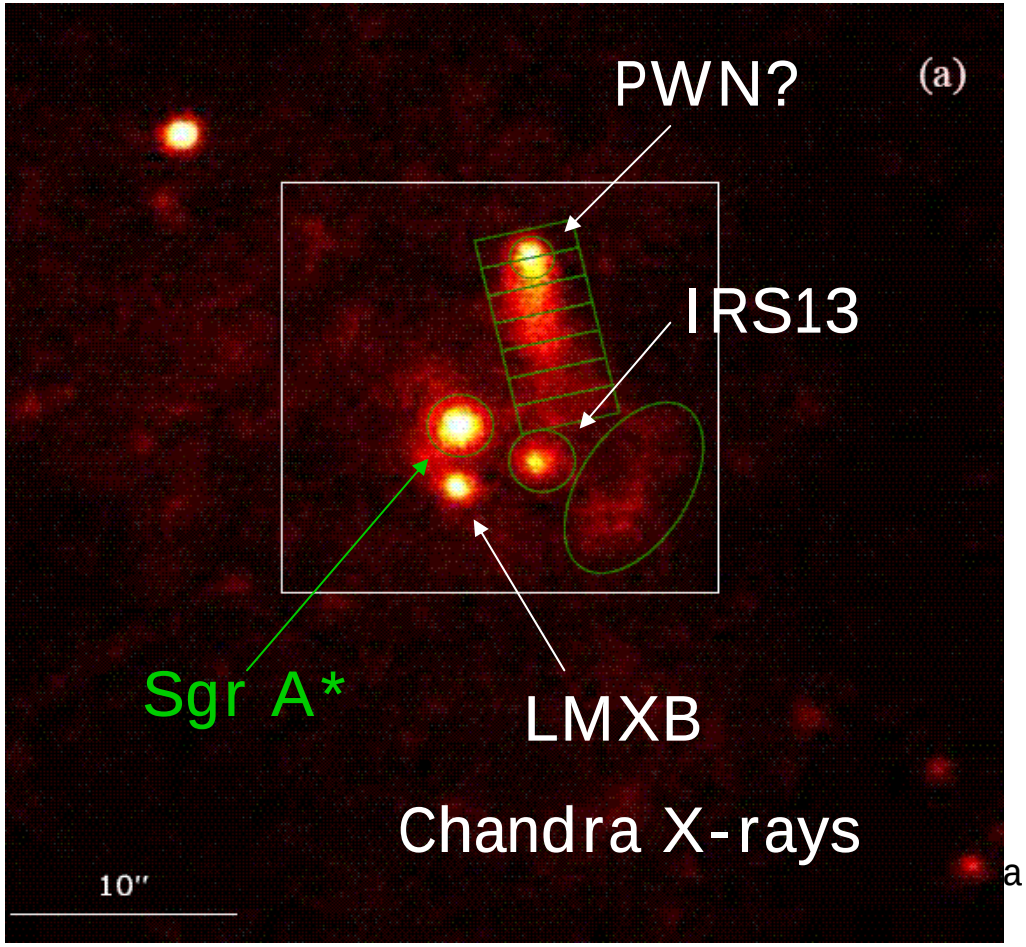
- large ZA>=58º -> large energy threshold (700 GeV)
- excess location: (Ra,Dec)=($17^h45'20''$, -29°2'), ±2' sys. error
- Galactic Center: within resolution compatible with point source

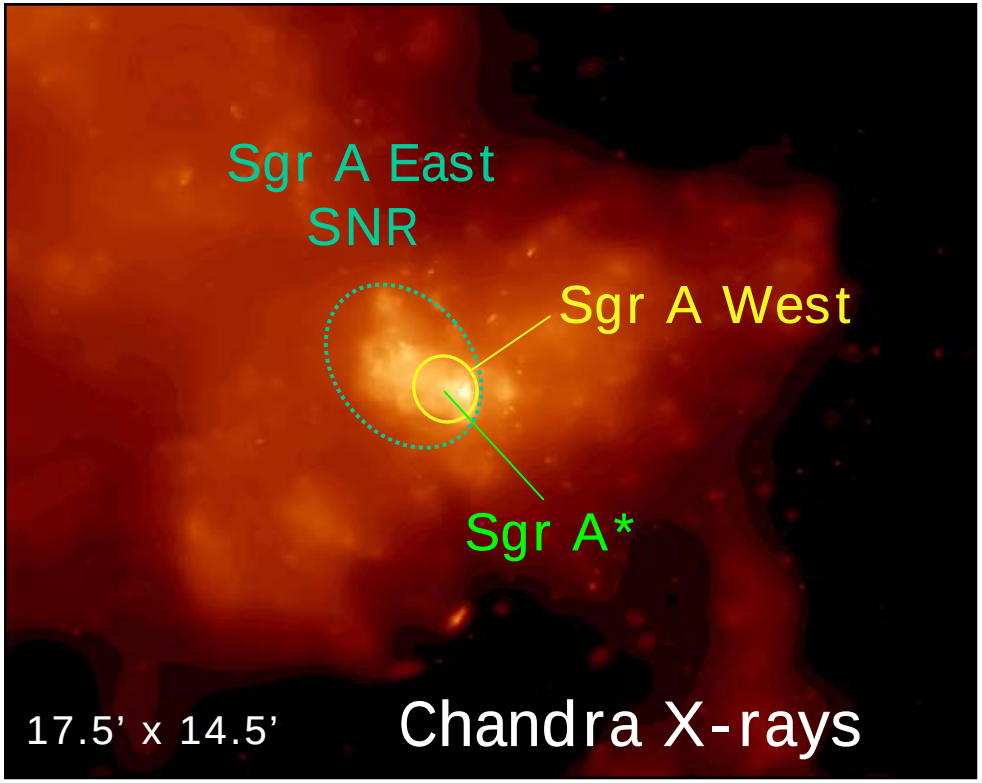




GC: Sky Map

TeV γ-ray emission spatially consistent with Sgr A*, Sgr A East and PWN G359.95-0.04, compatible with point source



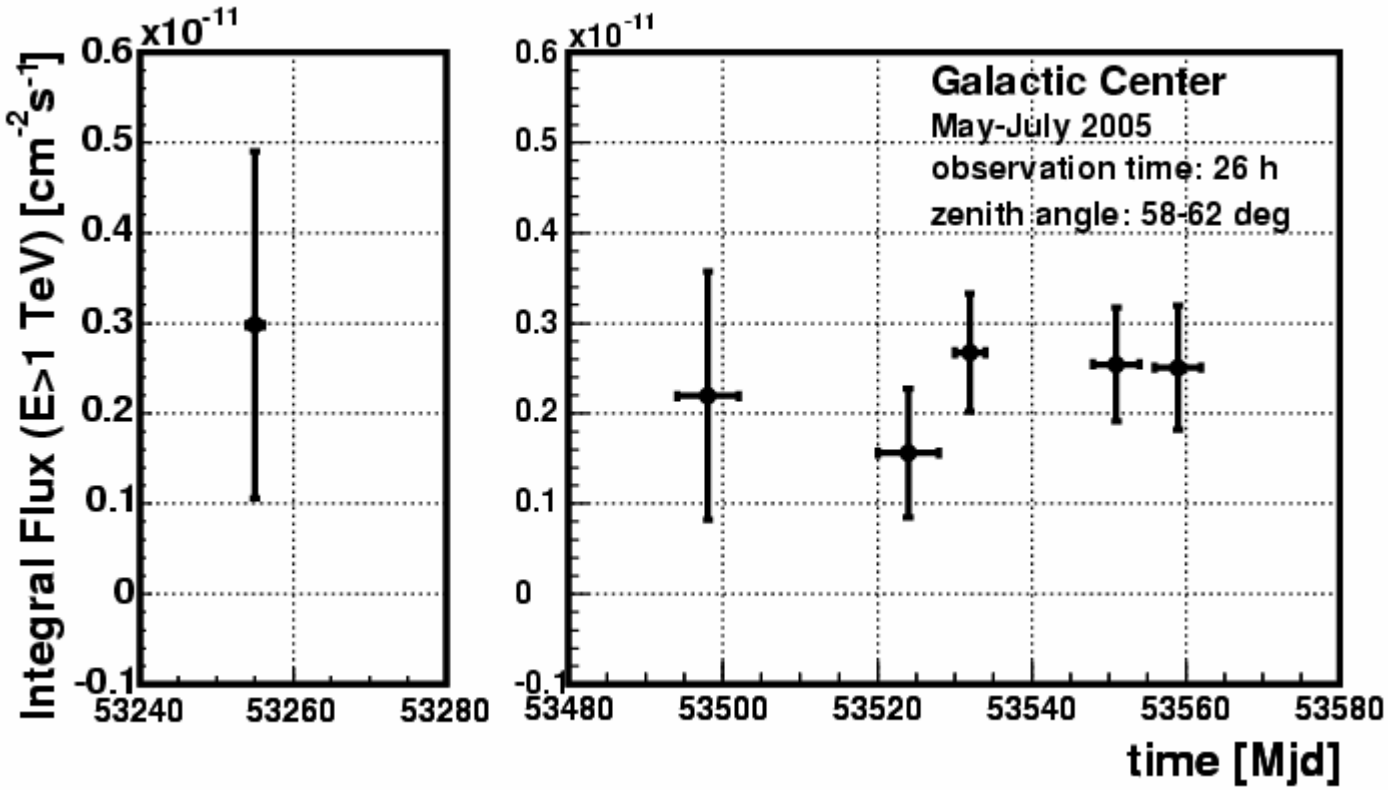


Light Curve

GC source: steady flux within errors

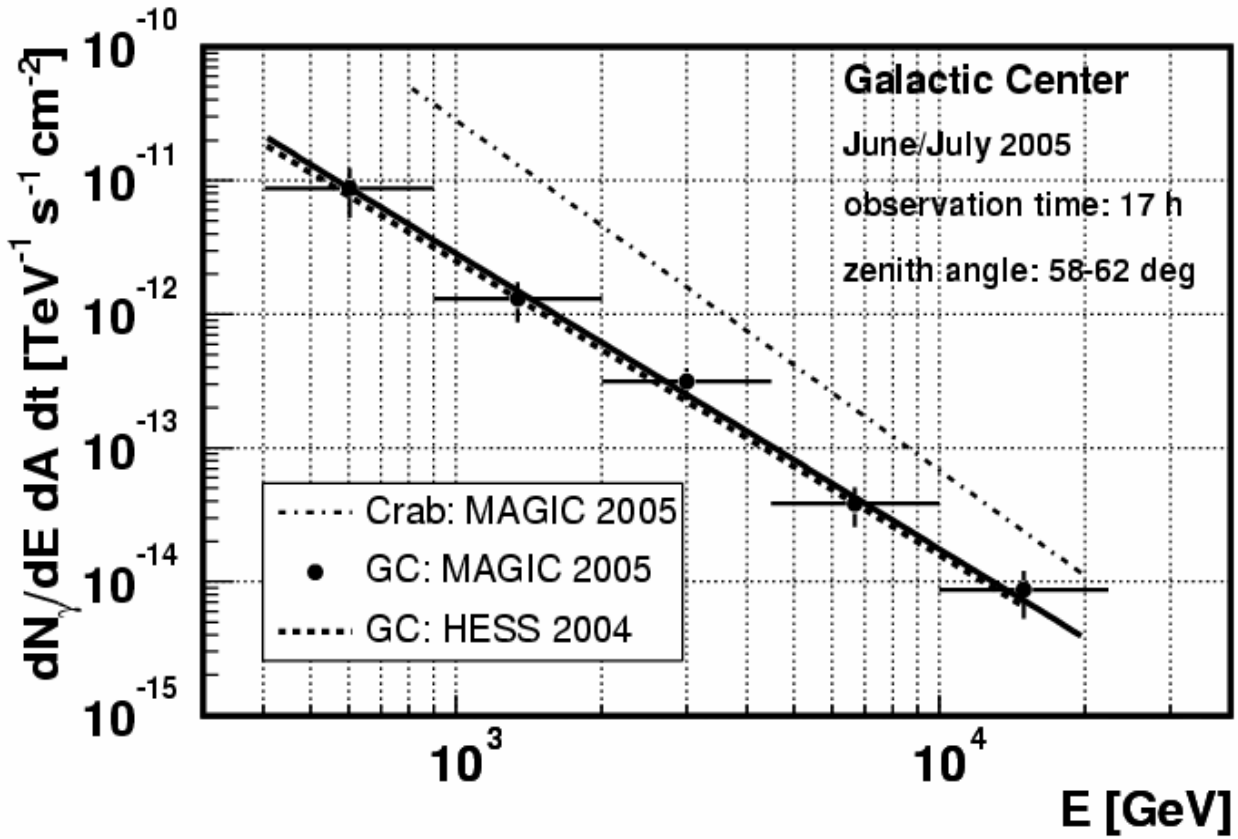
ON(2004): 2.5 h
Wobble : 6 h
ON/OFF : 17+12 h

Question:
Does a black hole scenario require gamma-variability?
On which time-scales?



GC Spectrum

- rather hard spectrum, Γ=-2.2±0.2
- flux: ~10% of Crab above 1 TeV
- corrected (unfolded) for detector energy resolution
- compatible with HESS measure-ments



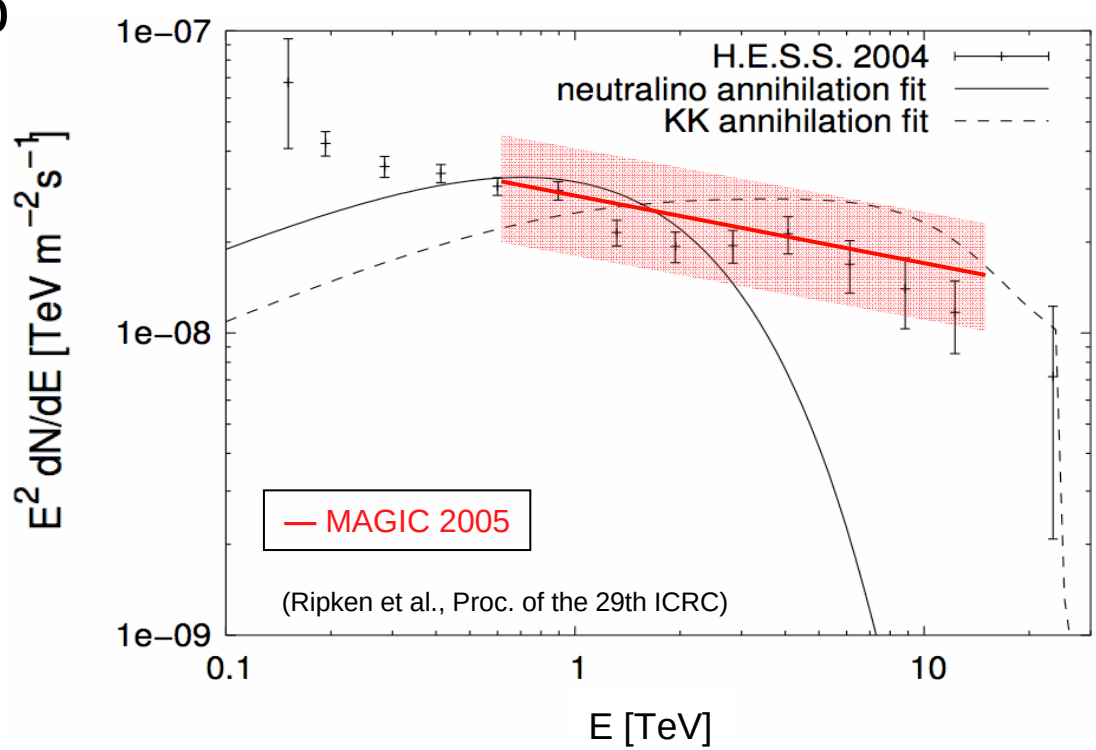
$$\frac{dN_\gamma}{dE_\gamma dAdt} = \frac{(2.9 \pm 0.6)\cdot 10^{-12}}{cm^2 \cdot s \cdot TeV}\left[\frac{E}{TeV}\right]^{-2.2\pm0.2}$$

(+systematic errors)

Dark Matter Annihilation?

$$\frac{dN_\gamma^{annihil}(\Omega,E,m_\chi)}{dt\,dA\,d\Omega\,dE} = \boxed{\frac{dN_\gamma(E,m_\chi)}{dE}\,\frac{\langle\sigma\cdot v\rangle}{8\pi\,m_\chi^{\,2}}}\;\boxed{\int_{los}\rho_\chi^2(r(s,\Omega))\,ds}$$

- SUSY DM annihilation leads to cutoff in γ-ray spectrum at m_χ
- data require high cutoff (> 10 TeV) implies $m_\chi \sim 12$ TeV
  $\Rightarrow$ rather unlikely scenario
- only part of observed γ-ray flux from SUSY DM annihilation?



Conclusions / Outlook

- neutralino good candidate for LSP and CDM
- neutralino annihilations yield gammas with E=O(100GeV)
  $\Rightarrow$ in principle observable with Cherenkov telescopes (e.g. MAGIC)
- flux proportional to CDM density squared $\Rightarrow$ look at CDM clumps
- small fluxes $\Rightarrow$ background dominated measurements

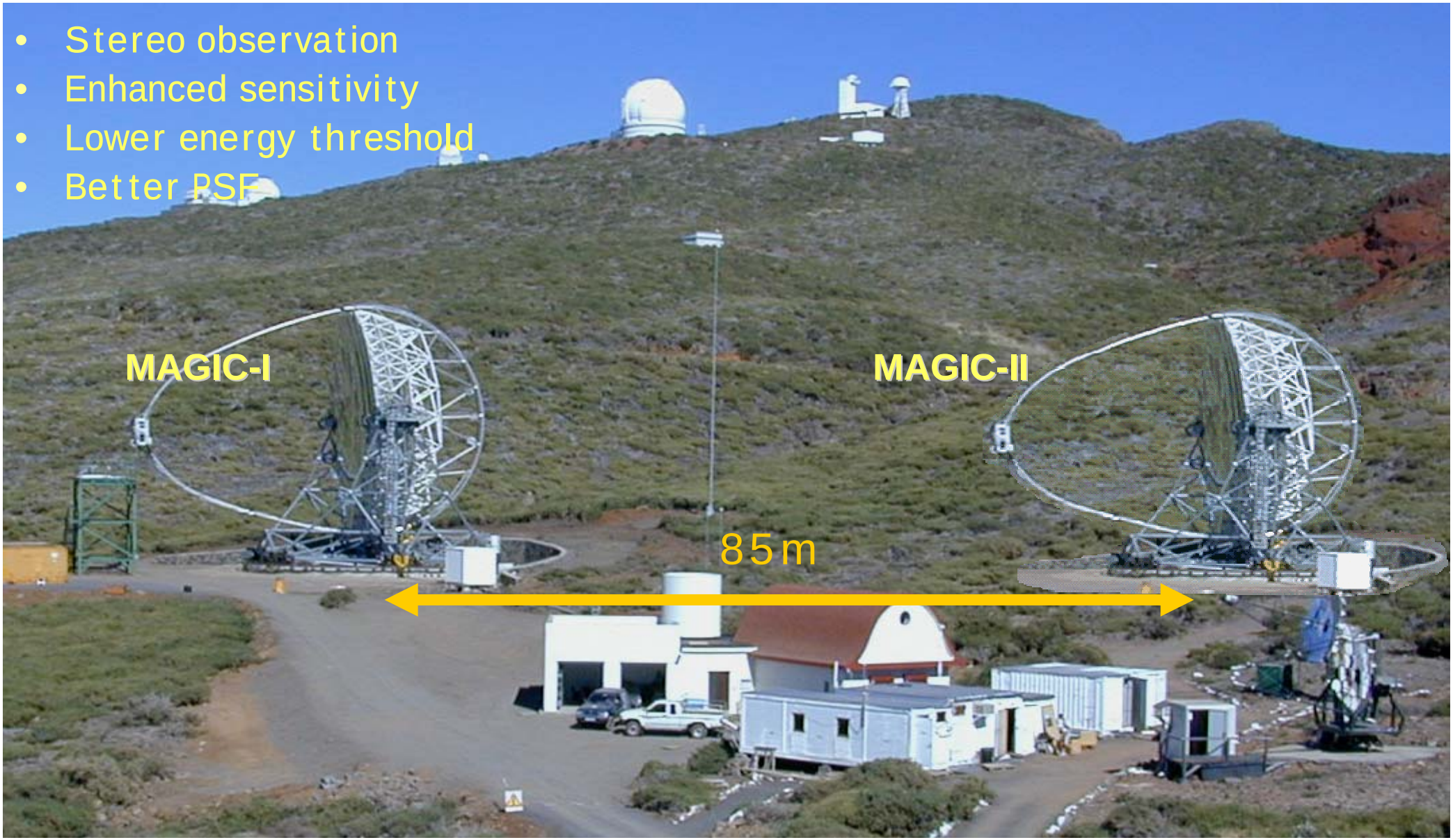
- need the highest sensitivity / lowest threshold
  best background rejection
- need to observe the best target

- get DM density profiles from observations / theory modeling
- astrophysical VHE gamma-ray sources are backgrounds

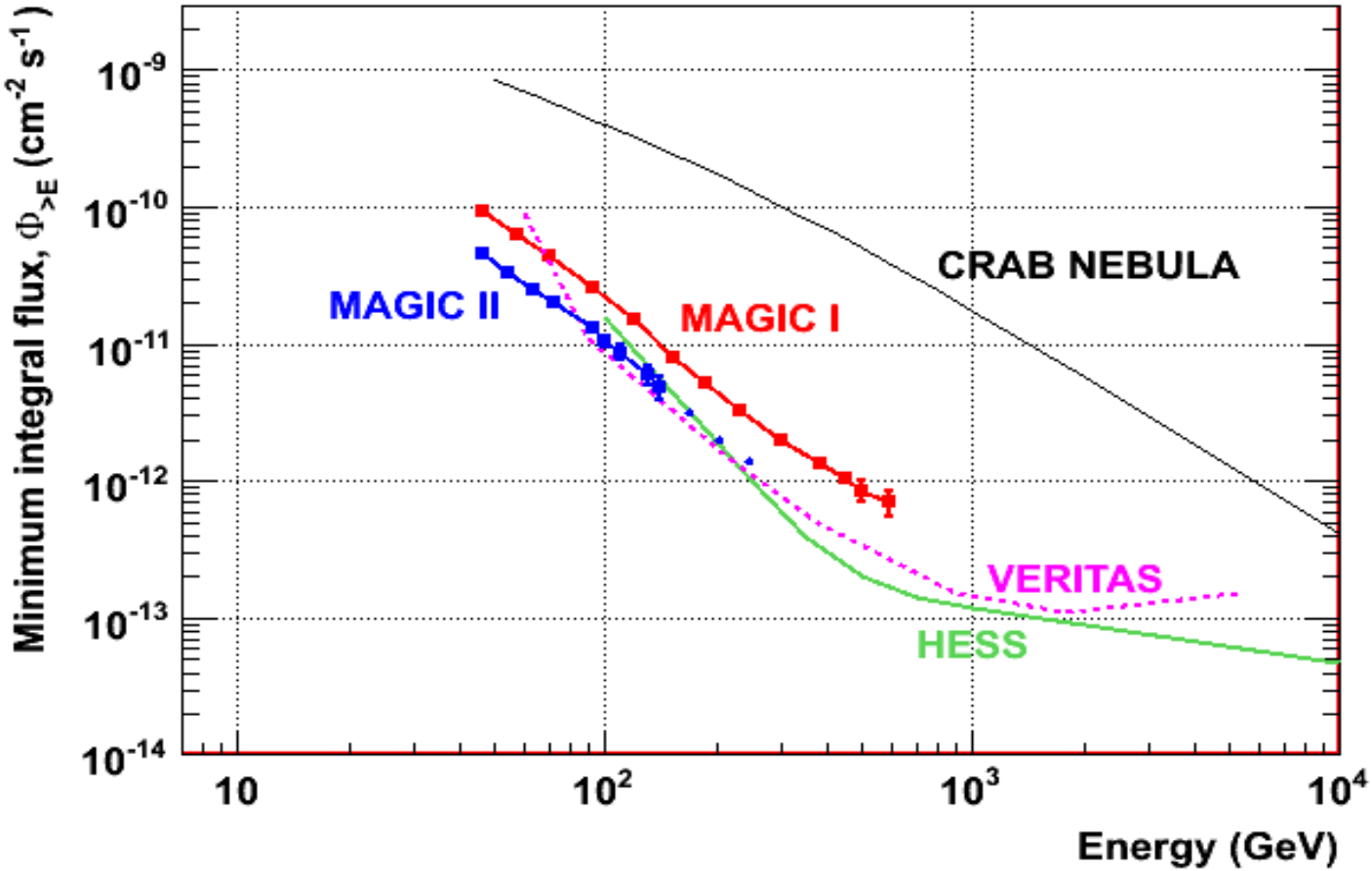
$\Rightarrow$ derive limits for neutralinos as dark matter particles

Outlook: MAGIC II (2007)

- Stereo observation
- Enhanced sensitivity
- Lower energy threshold
- Better PSF



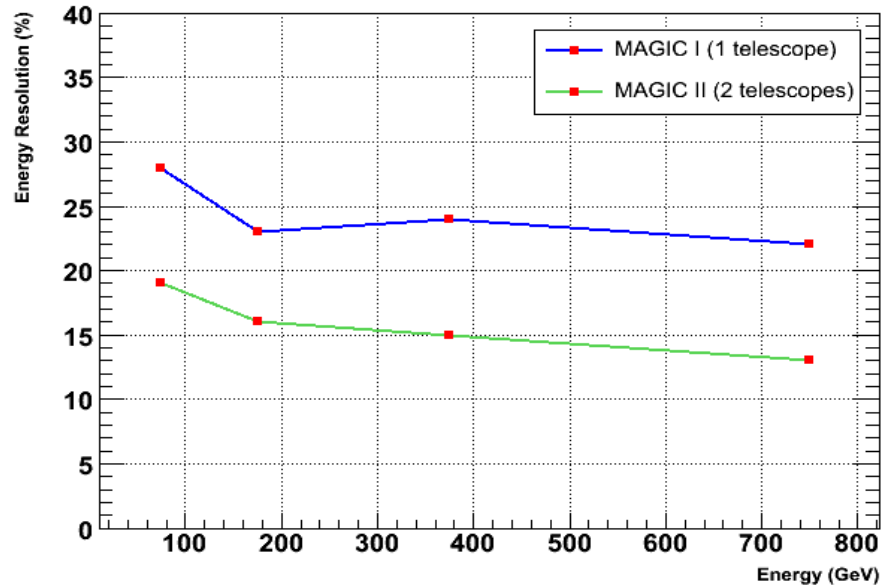
Sensitivity Estimate (MC)

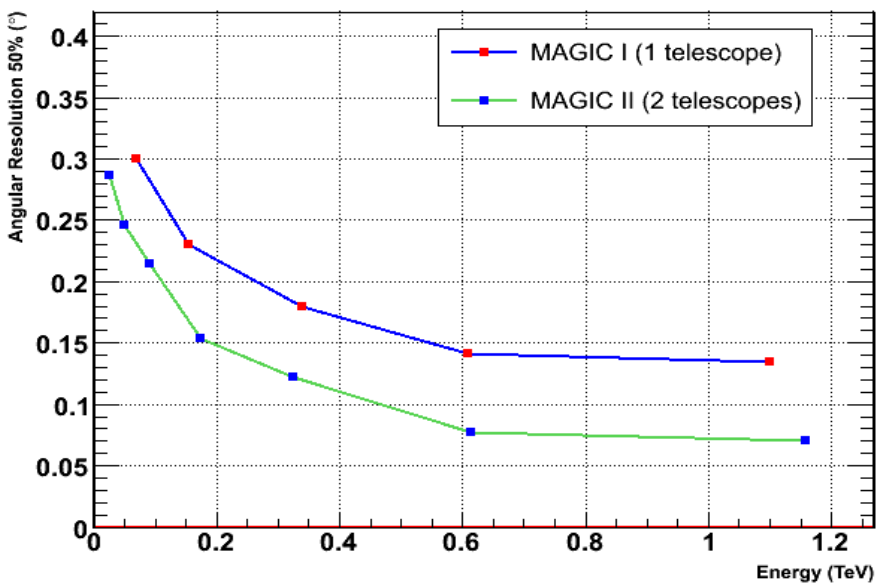


- Factor 2 improvement in integral sensitivity, 1% Crab @ 200GeV

Angular and Energy Resolution

- Improved impact parameter allows an improved energy resolution
- ~40% improvement in energy resolution





- Image axis intersection is more precise
- ~30% improvement in angular resolution