Indirect Dark Matter Searches with Cherenkov Telescopes

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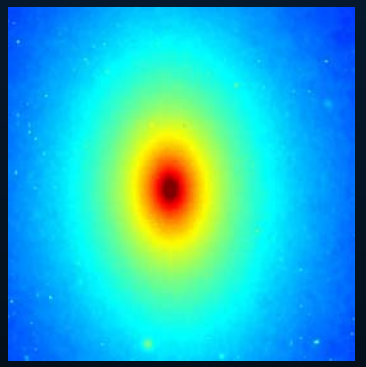
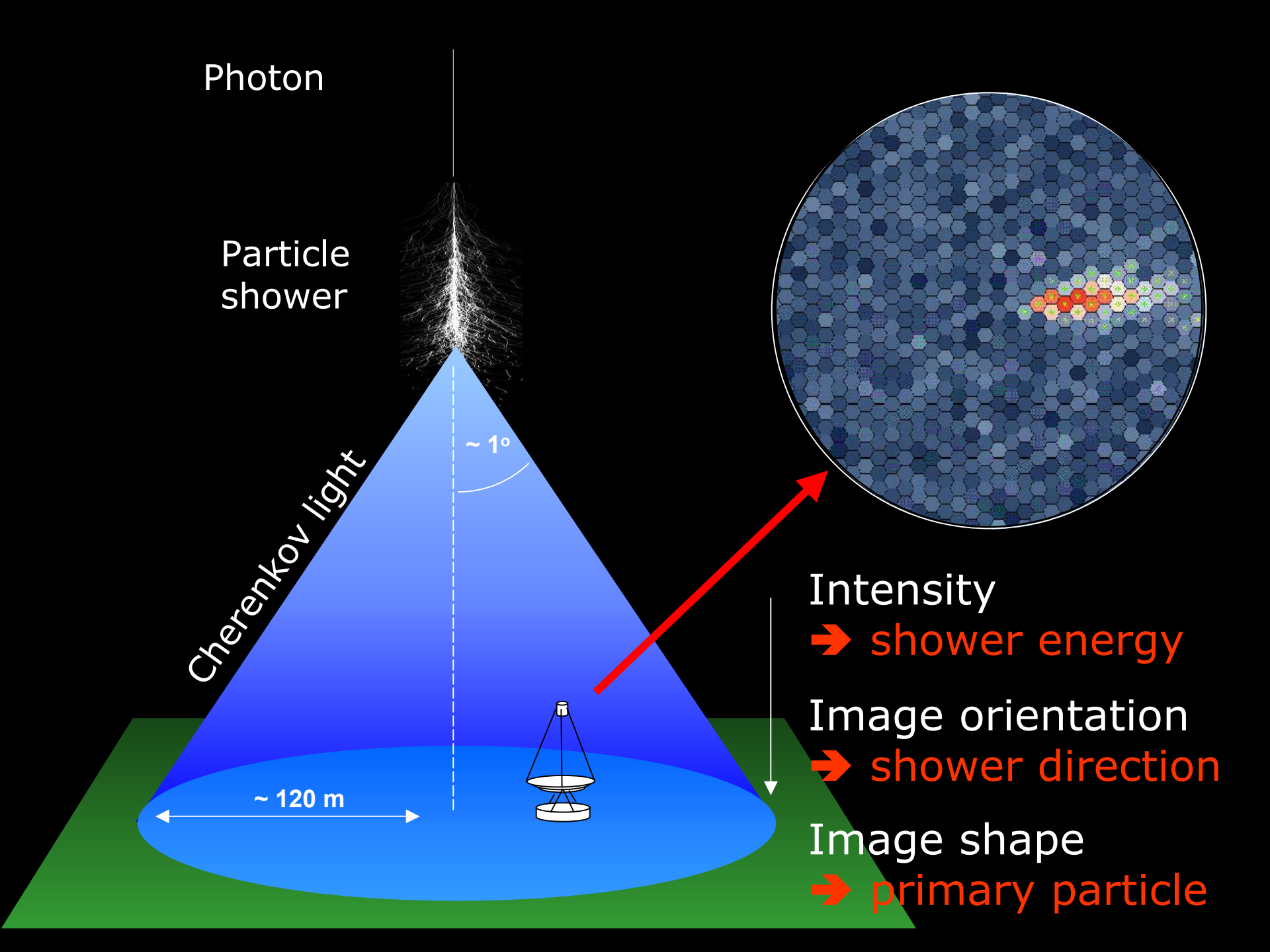


Imaging Atmospheric Cherenkov Telescopes


Photon
Particle shower
Cherenkov light
~ 1°
~ 120 m
Intensity
➔ shower energy
Image orientation
➔ shower direction
Image shape
➔ primary particle

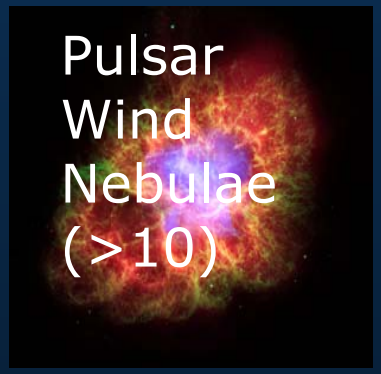
Experiments: Cherenkov Telescopes

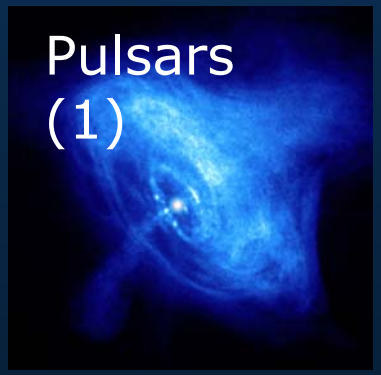
Cherenkov Telescopes

	Status	# Tel	Mirror (m^2)	F.o.V (^{o})	Energy threshold (GeV)
MAGIC	Data taking 08/2004	1	239	3.5	30-50
H.E.S.S.	Data taking 12/2003	4	108	5	100
CANGAROO III	Data taking 03/2004	4	57	4	~250
Veritas	Data taking 04/2007	4	100	4.5	100

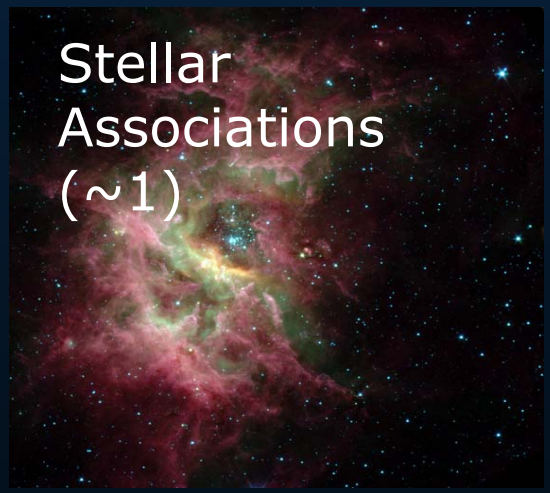
- Good angular resolution (0.05-0.1°)
- Low duty cycle (~15%)
- Detect Crab Nebula in ~30 seconds (H.E.S.S.)

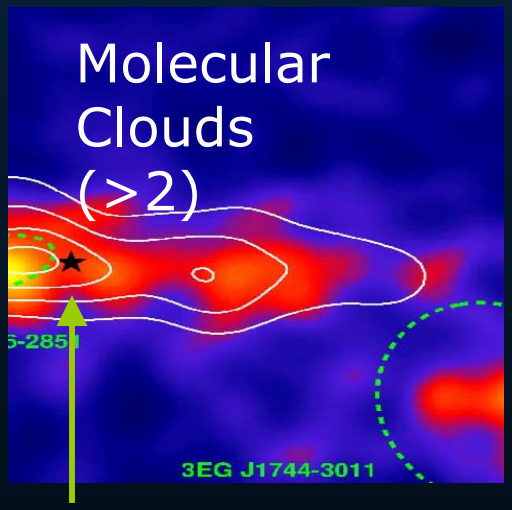
Galactic Targets





TeV
binaries
(~4)





Galactic Centre

Extragalactic Targets

Active Galactic Nuclei (>20)

Starbust Galaxies (2 (new!))

Gamma-ray bursts (0)

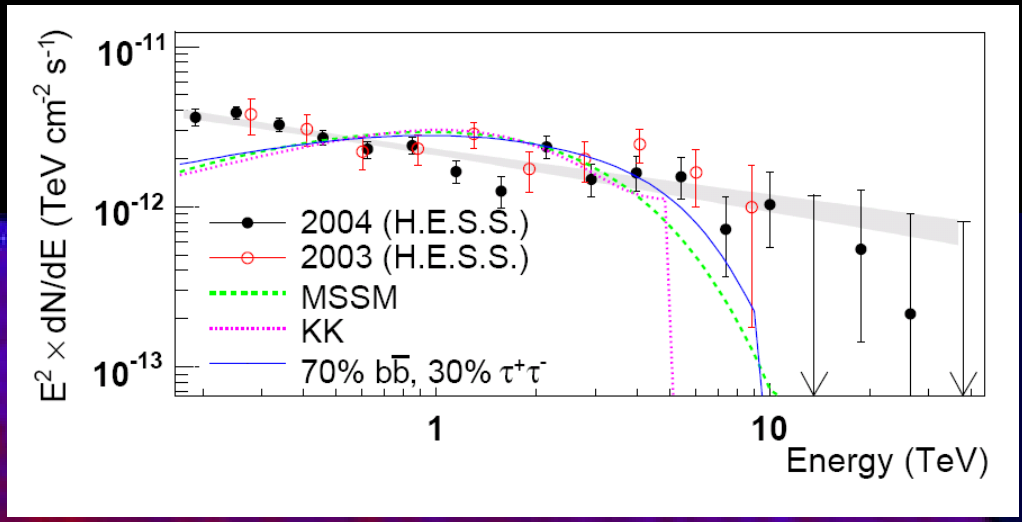
Virgo Galaxy Cluster (X-ray)

Galaxy Clusters (0)

Approaching source number 100 (2/3 galactic, 1/3 extra-galactic)

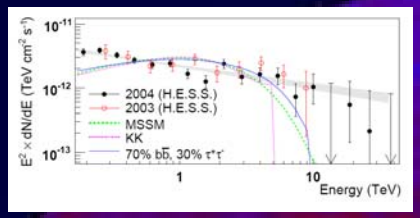
Indirect Dark Matter Searches

Galactic Centre



Galactic Centre

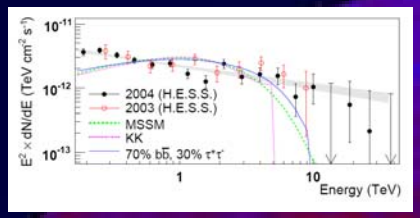
Unidentified sources from the H.E.S.S. scan



Galactic Centre

Unidentified sources from the H.E.S.S. scan

Neighbouring Galaxies, Globular Clusters



Galactic Centre

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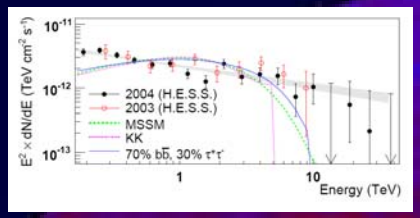
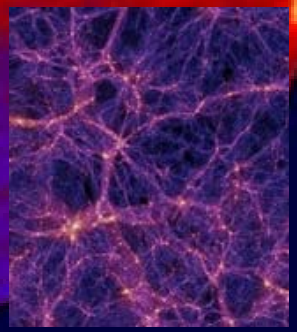
Neighbouring Galaxies, Globular Clusters



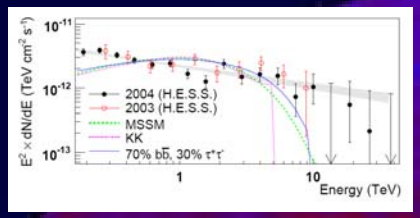


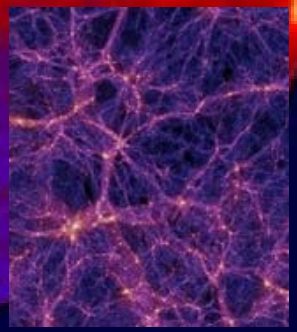
Anisotropies of Extragalactic γ-rays

Galactic Centre

Unidentified sources from the H.E.S.S. scan

Neighbouring Galaxies, Globular Clusters





This Talk!

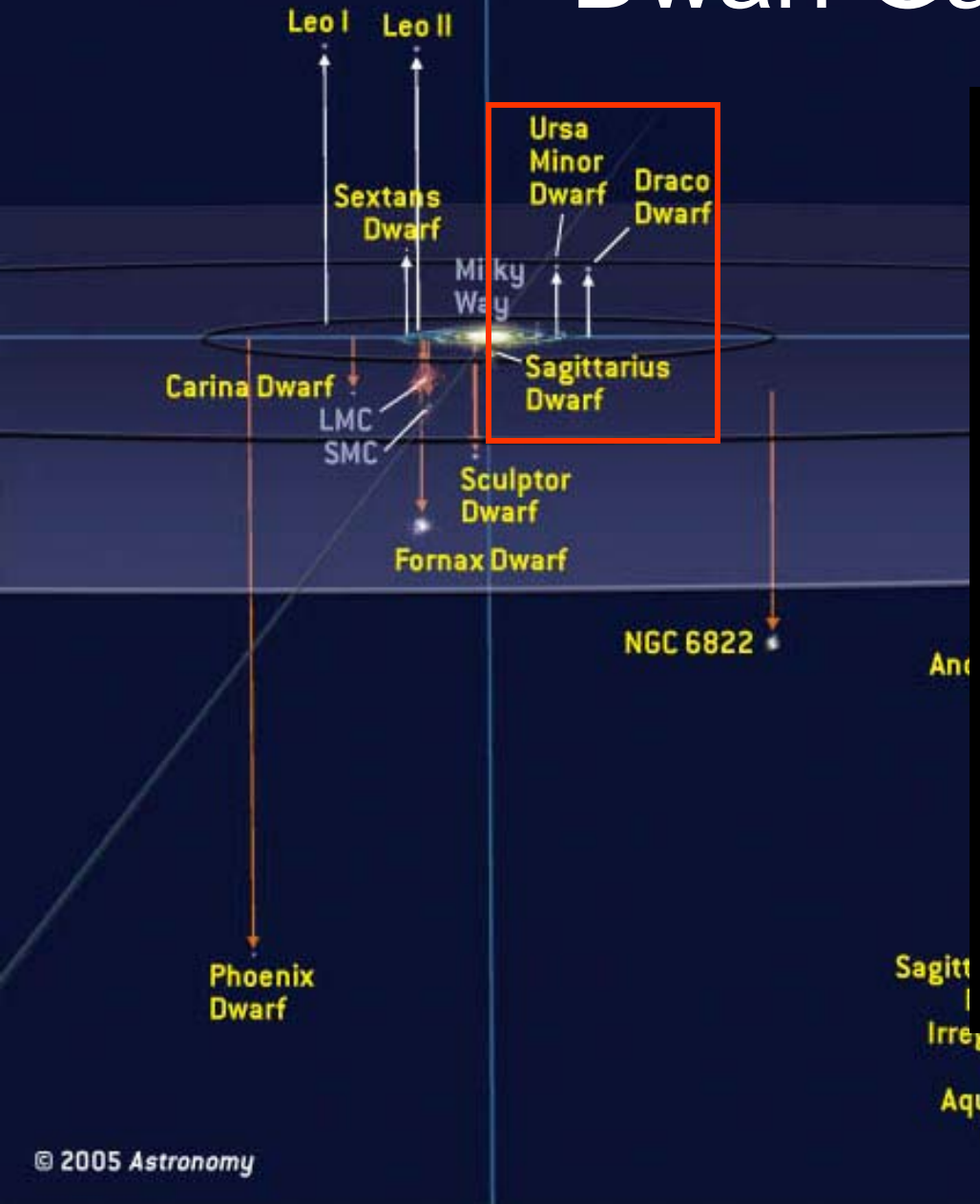
Dwarf Galaxies orbiting the MW

Milky Way Halo

Anisotropies of Extragalactic γ-rays

Dwarf Galaxies

Dwarf Galaxies



- DM dominated on all spatial scales (from measurements of surface birghtness and stellar velocity dispersion)
- Luminosity 10^2-10^8 L_{sun}
- M_{DM} = 10^5-10^8 M_{sun}
- Large observed mass-to-light ratios (M/L)
- Distance ~some 10 kpc
- Diameter ~1 kpc (extended for IACTs)
- Many new objects discovered by SDSS (in the northern hemisphere)

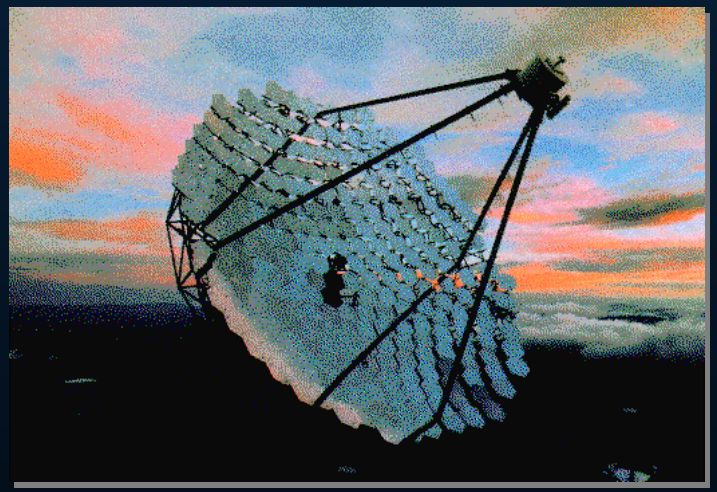
Ursa Minor and Draco (1/2)

Draco:

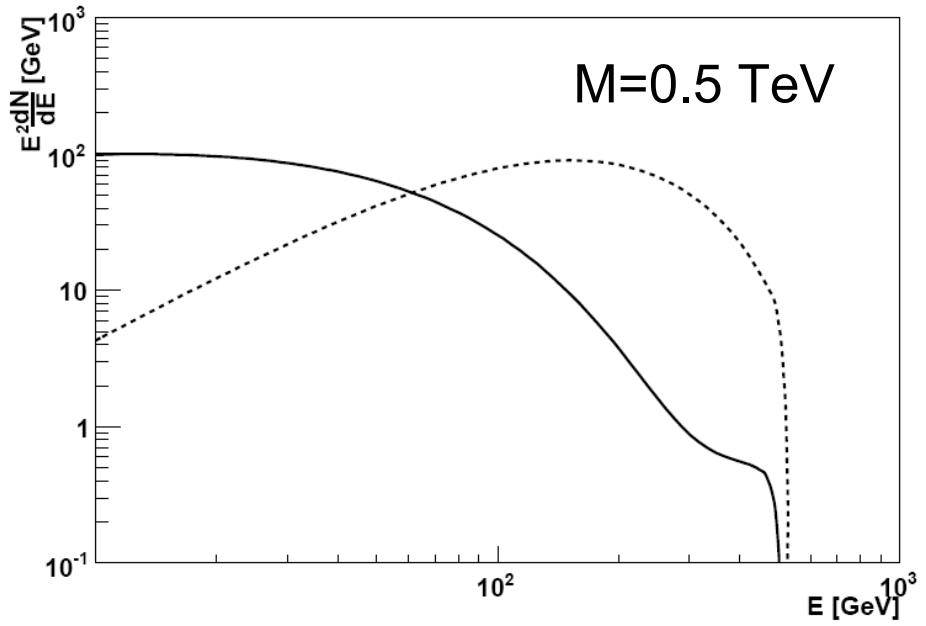
- 51‘ × 31‘
- D=80 kpc, d=2 kpc
- M/L > 200
- 3M stars, flat rotation curve
- Smooth symmetrical profile

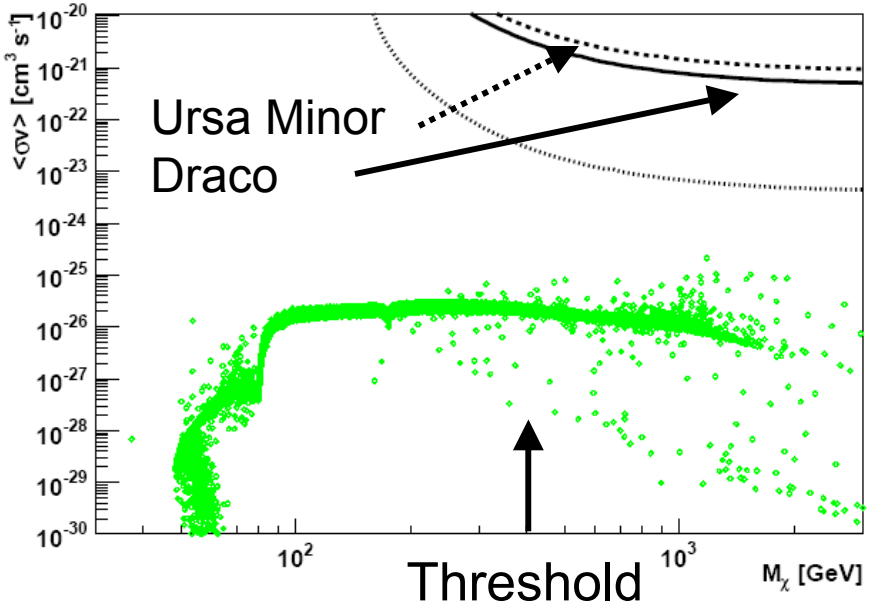
Ursa Minor:

- 30‘ × 19‘
- D=66 kpc, d=0.6 kpc
- Mainly older stars
- Structured core (tidal disruption?)



Ursa Minor and Draco (2/2)

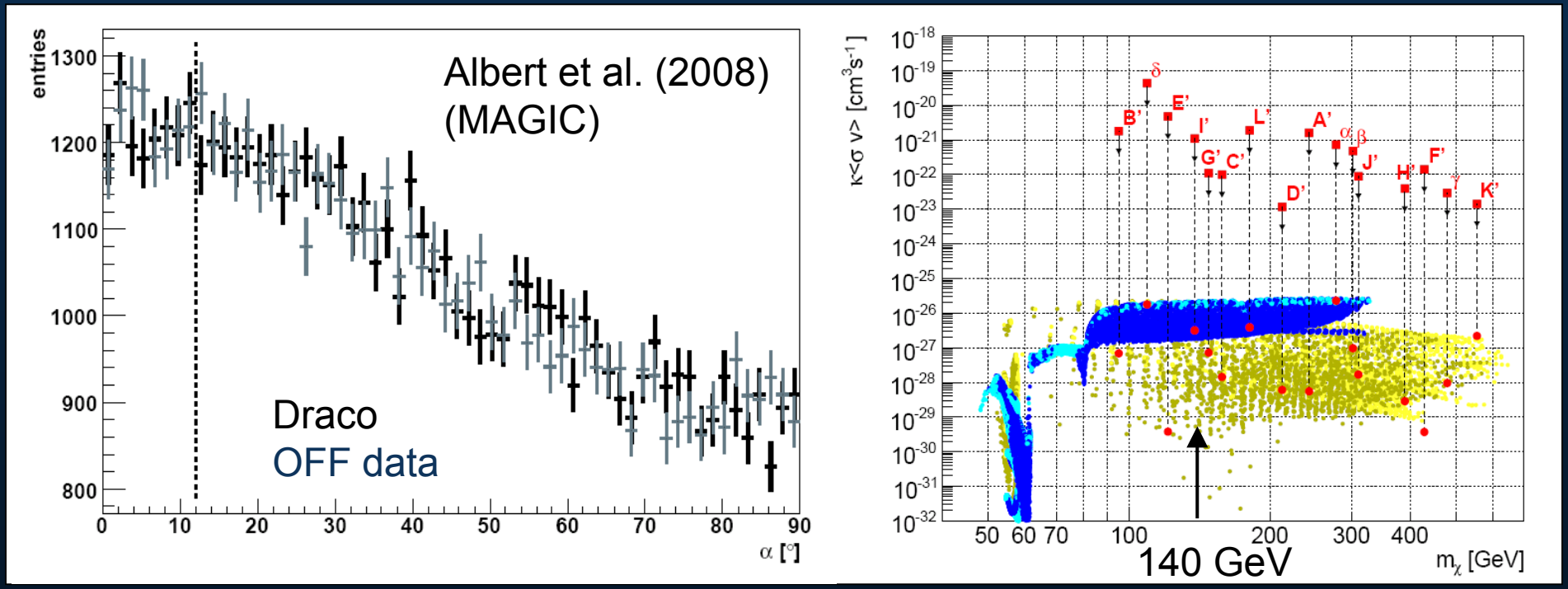




Wood et al. (2008) (Whipple/VERITAS)

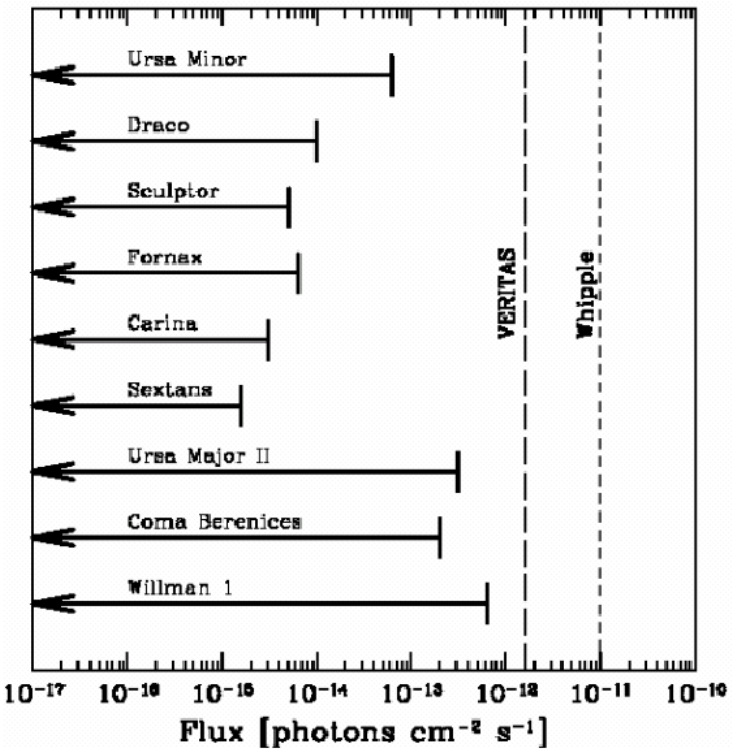
- 14.3 h (17.2 h) of data for Draco (Ursa Minor), Limits at the level of 6-9% Crab
- Used composite neutralino spectrum (10% $\tau\tau$, 90% bb)
- NFW DM profile, limits ~5 orders of magnitude above MSSM

Draco



- 7.8 h of data, limits at the level of 3% Crab (above 140 GeV)
- Cuspy and cored DM profiles (Sanchez-Conde et al. 2007)
- Flux upper limits are 3-9 orders of magnitude above mSUGRA benchmark models (Battaglia et al. 2004)

Willman 1



S. Koushiappas (2008)

- The most DM-dominated among all dwarf galaxies ?
- D = 38.7 kpc
- Half-light radius extremely small (21 ± 7) pc
- Also least massive (5 10^5 M_{sun})

BM	$\Phi^{model}(>100\ \mathrm{GeV})$	$\Phi^{u.l.}(>100\ \mathrm{GeV})$	$B^{u.l.}$
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}

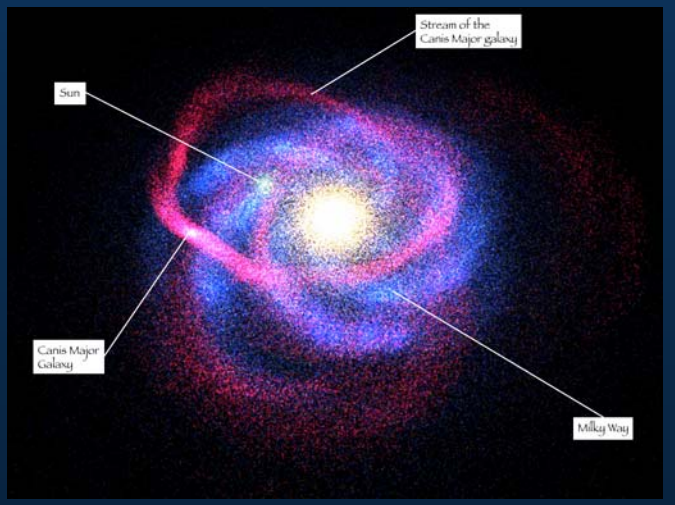
K‘:565 GeV, 2.6 10^{-26} cm^3 s^{-1}

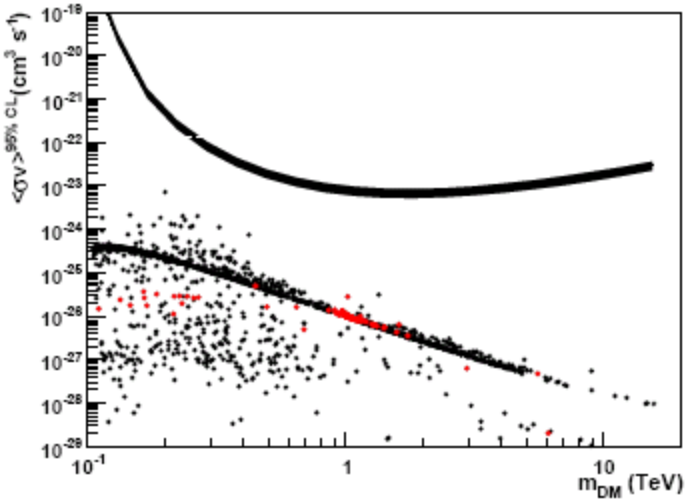
Albert et al. (2008) (MAGIC)

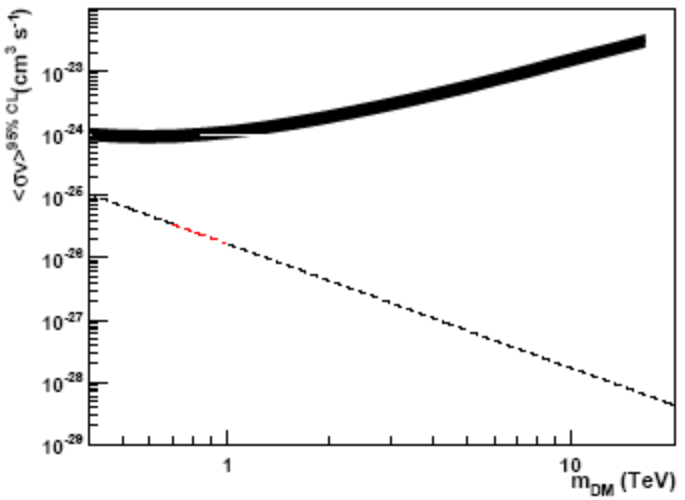
- 15.5 h of data, limits at the level of 1-1.5% Crab (above 100 GeV)
- NFW profile (Strigari et al. 2008)
- Flux upper limits are >3 orders of magnitude above mSUGRA benchmark models (Bringmann et al. 2008)

Canis Major

- A dwarf galaxy or warp/flare of galactic disc?
- Mass highly uncertain, lack of observational data, but close (8 kpc)





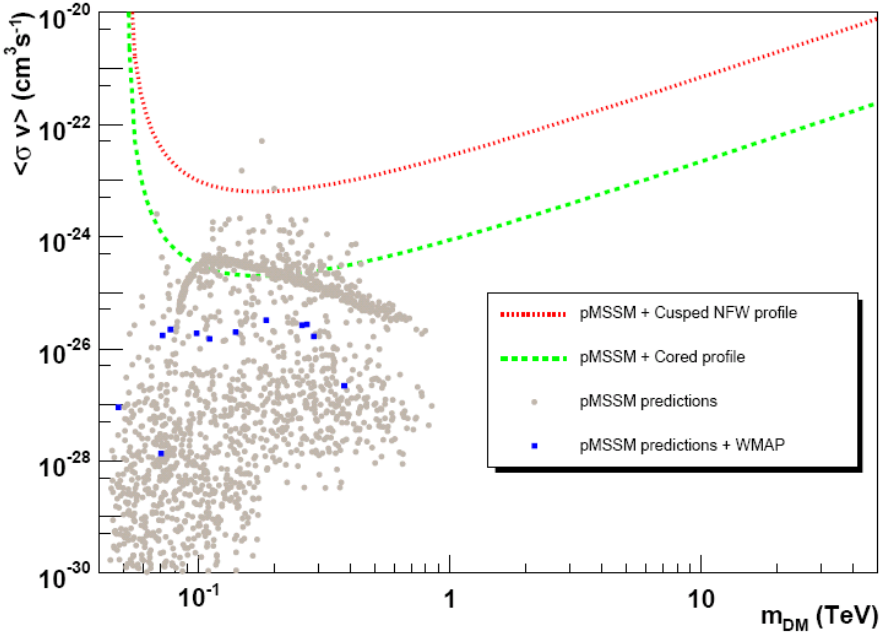


Aharonian et al. (2008) (H.E.S.S.)

- 9.6 h of data, NFW profile and mass assumption (3 10^8 M_{sun})
- Flux upper limits are 3 (1.5) orders of magnitude above MSSM (KK) models....

Sgr Dwarf Galaxy

- A well-measured dwarf galaxy
- D=24 kpc
- M/L ~ 25
- Compact core (3 pc FWHM) plus diffuse component with a size of 1.6 kpc



Aharonian et al. (2007) (H.E.S.S.)

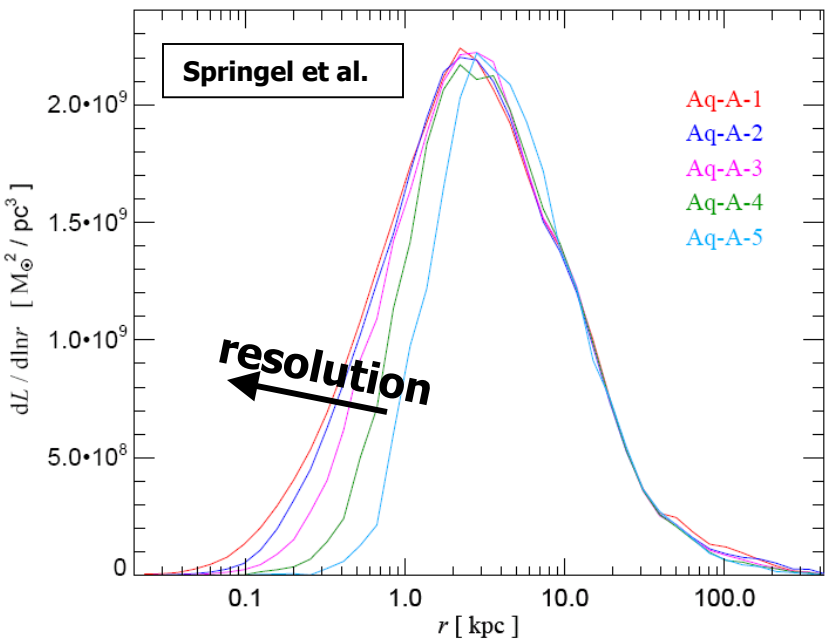
- 11 h of data, flux limit (>250 GeV) at the 2% Crab level
- Cusped NFW and cored profiles, assume that velocity dispersion is independent of position
- Still factor 10 uncertainty on DM profiles
- Flux upper limits are still a factor 10 above MSSM models...

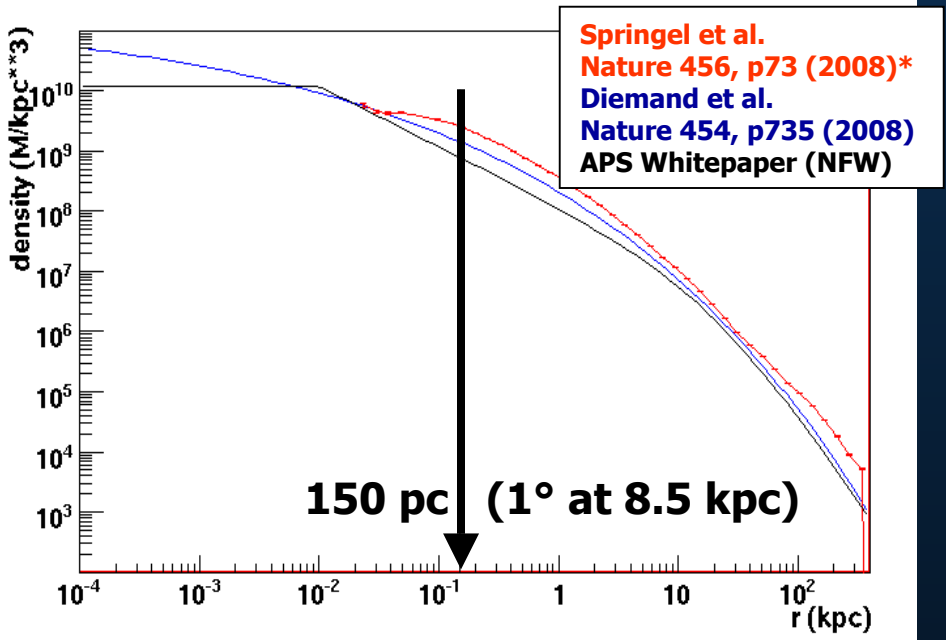
Dwarf Galaxies: Summary

- There is at least a factor of 10 between limits and predictions
- On order of magnitude uncertainties on DM profile even for well-measured dwarf galaxies
- Need a better understanding of DM profiles
- The northern arrays (VERITAS, MAGIC-II) will observe SDSS dwarfs, but at current sensitivities it will be difficult to obtain deep exposures for more than a few targets

Prospects for Dark Matter Detection from the Milky Way Halo

Predictions (1/3)



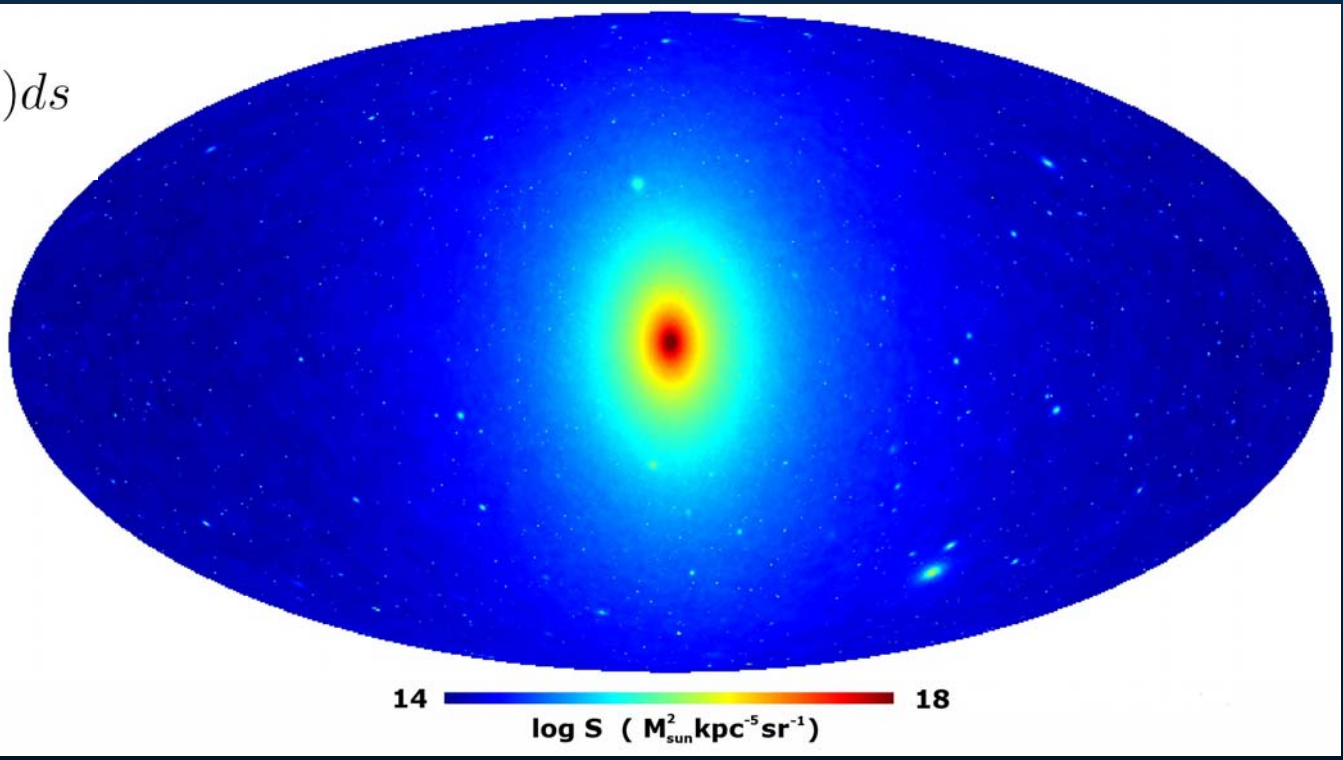


- The highest resolution N-body simulations (Springel et al.) used particle masses of 1700 M and attained converged length scales of ~120 pc
- All substructures taken into account, no additional boost factores expected (well, maybe from baryons)

***Only the density of the smooth halo component is shown.**

Predictions (2/3)

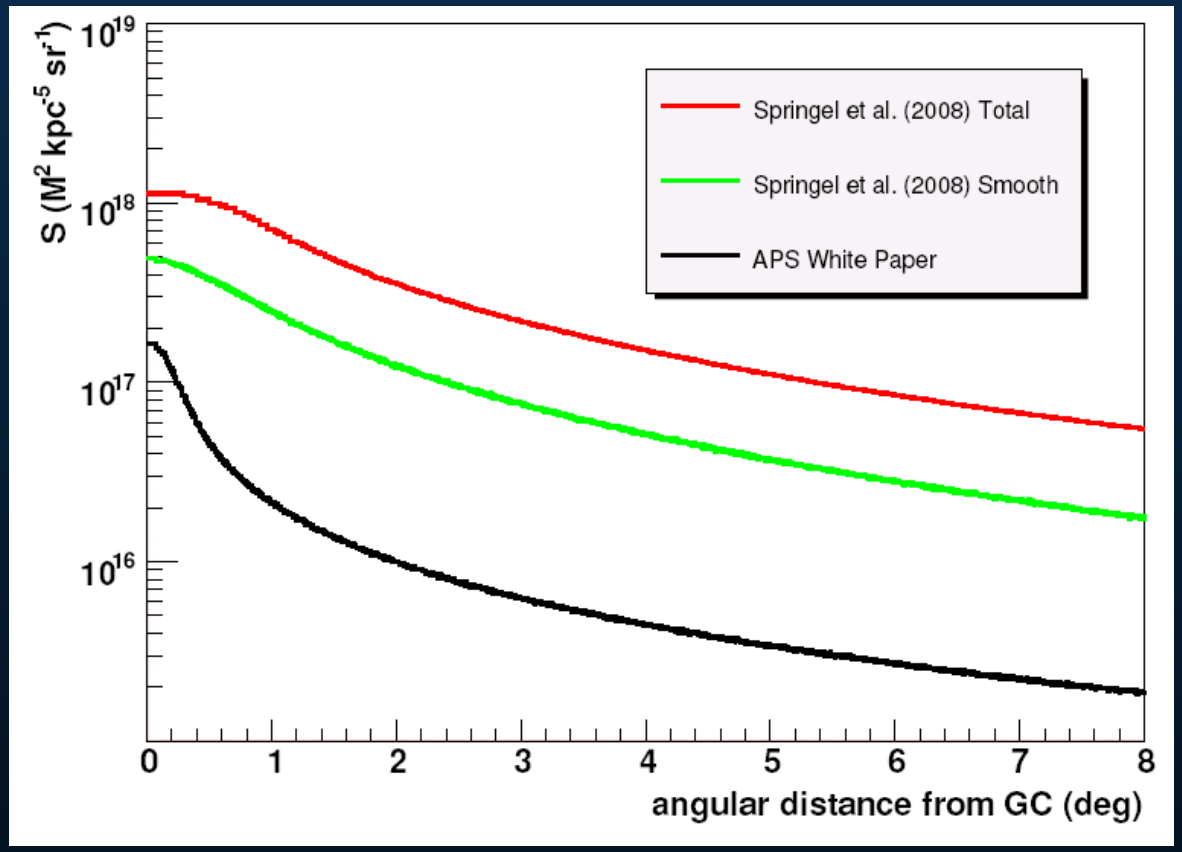
$$S = \frac{1}{4\pi} \int_{\mathrm{los}} \rho^2(r(s)) ds$$



Springel et al.

- Line-of-sight integrals averaged over various observer positions
- Smoothed with a PSF of 10‘ (H.E.S.S.: 6‘)

Predictions (3/3)

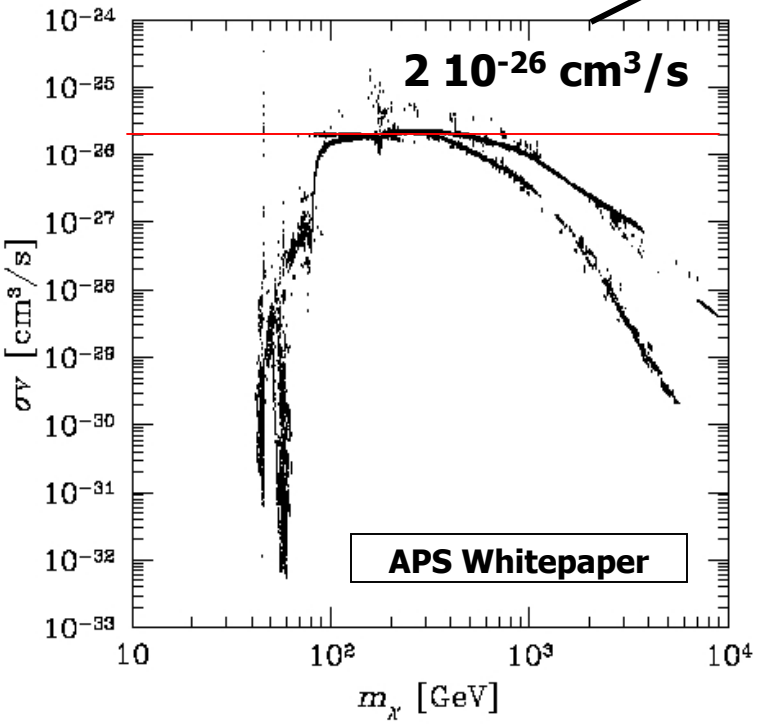


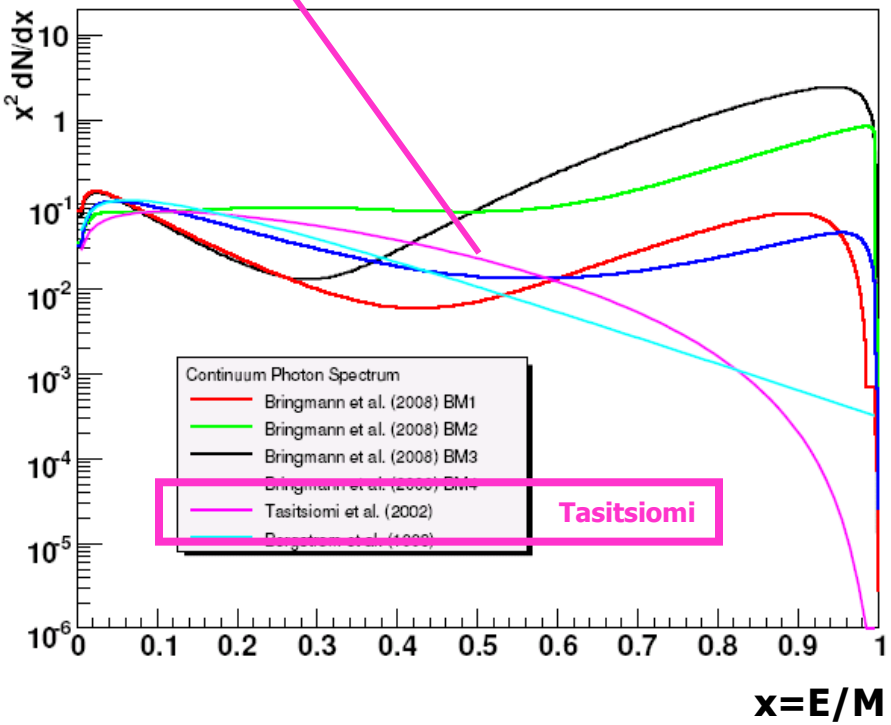
- Less steep towards GC than NFW
- Overall flux level ~30 higher
- Boost factor due to substructure is ~3 (near GC)

Concise Assumptions...

$$\frac{d\Phi}{dE} = \langle \sigma v \rangle \cdot \frac{1}{M^2} \frac{dN_\gamma}{dE} \cdot S$$

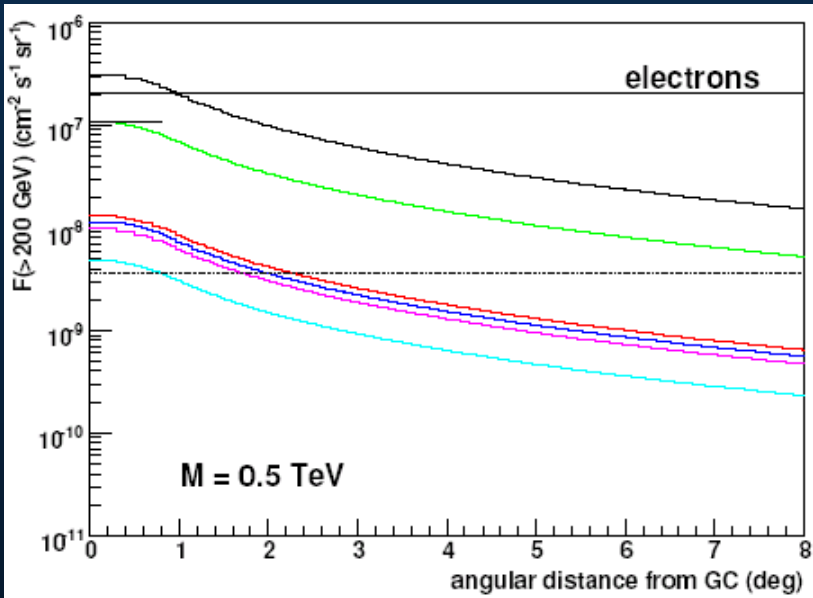
Springel et al.

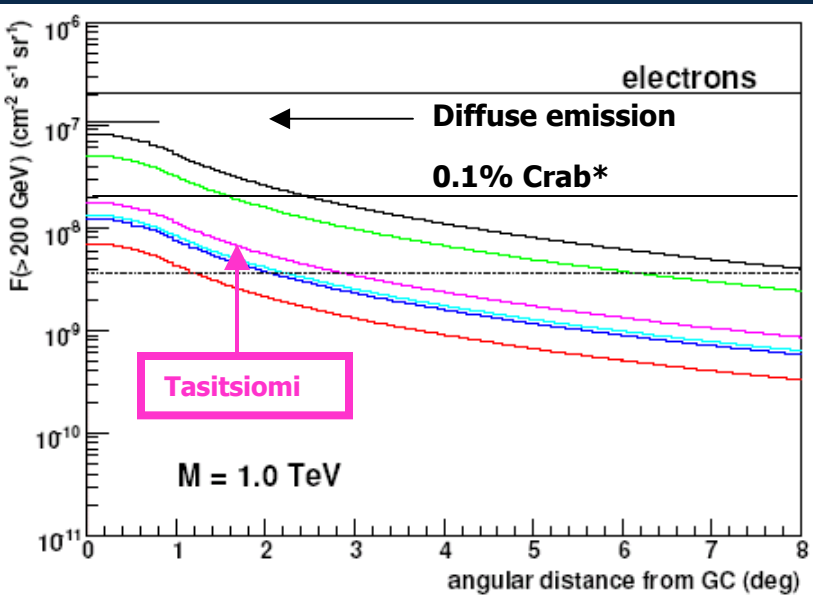




- WIMP mass M = 0.5 – 1 TeV

...Diffuse Fluxes



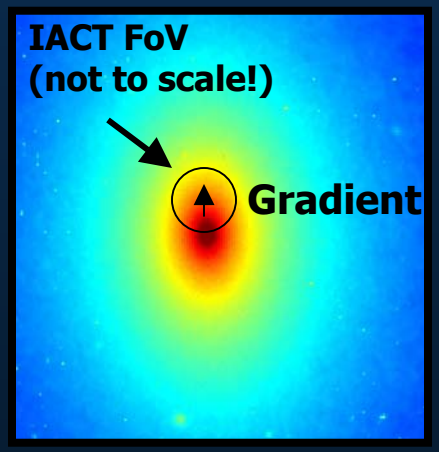


- At 1° from the Galactic Centre, the predicted DM photon flux is a factor ~10 (~20) below the diffuse emission from the Galactic Plane (the electron flux)
- Flux falls by one order of magnitude when going from 1° to 8°

*** Solid angle of $\Delta\Omega=2\pi(1-\cos(0.1°))$**

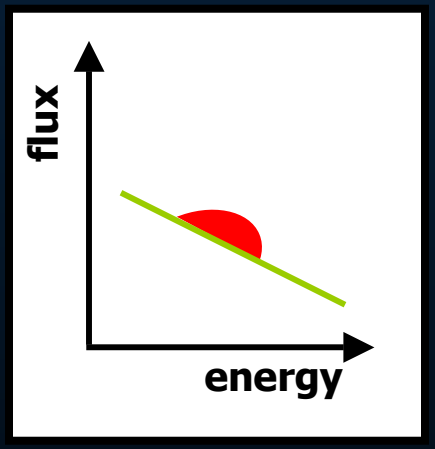
IF, IF, IF

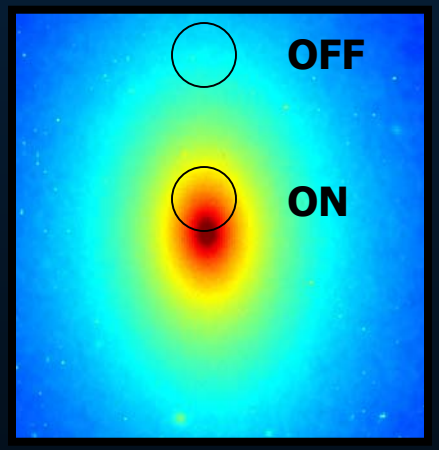
- IF the N-body simulations are correct...
- IF their mapping on the Mily Way is correct
- IF nature is kind to us (annihilation cross-section, WIMP mass)...
- The flux is likely still too low to see a gradient within one field of view



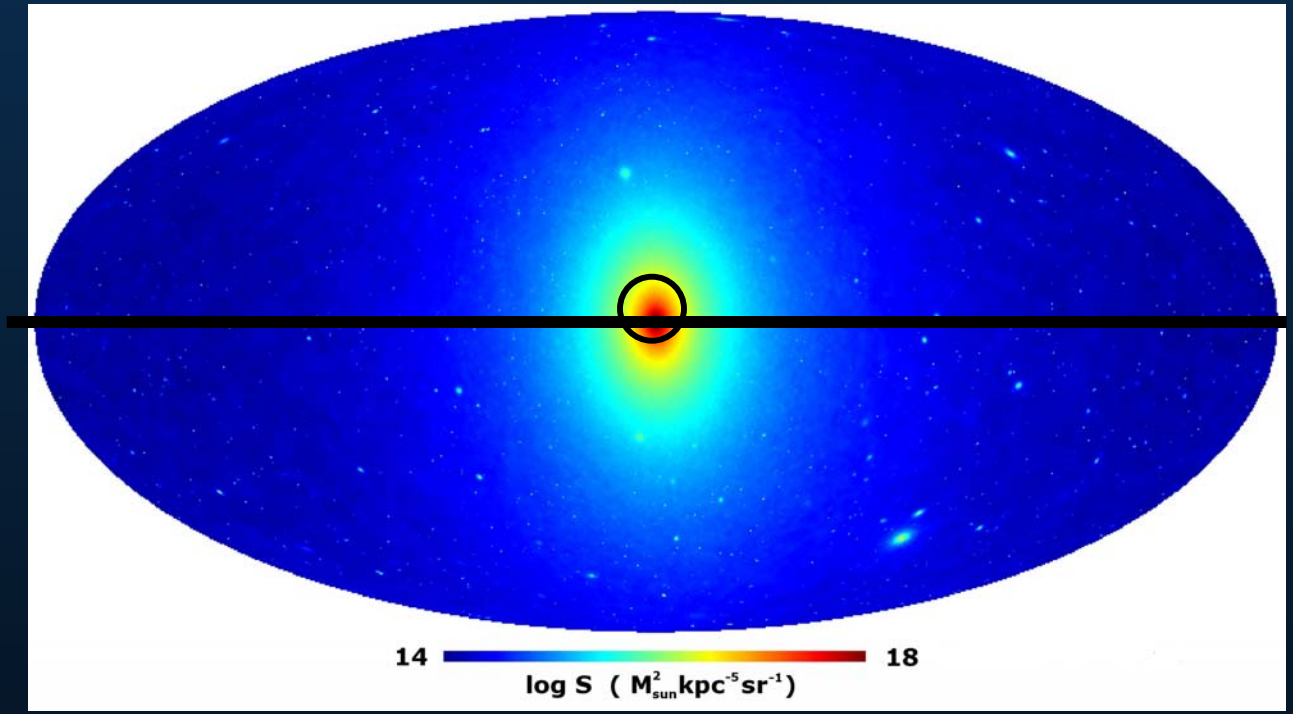
Alternatively:

- Sum flux over entire FoV
- Use FoVs far away from the GC for normalization
- Exploit spectral features on top of an astrophysical (power-law?) background



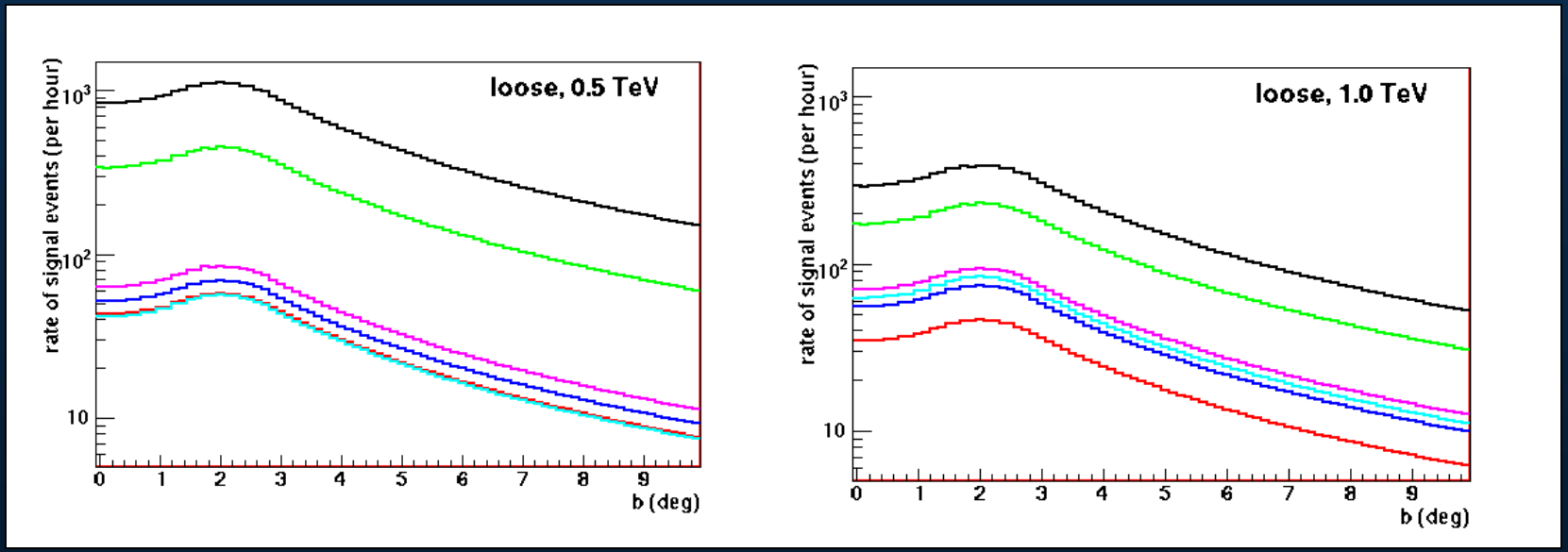


Sensitivity (1/3)



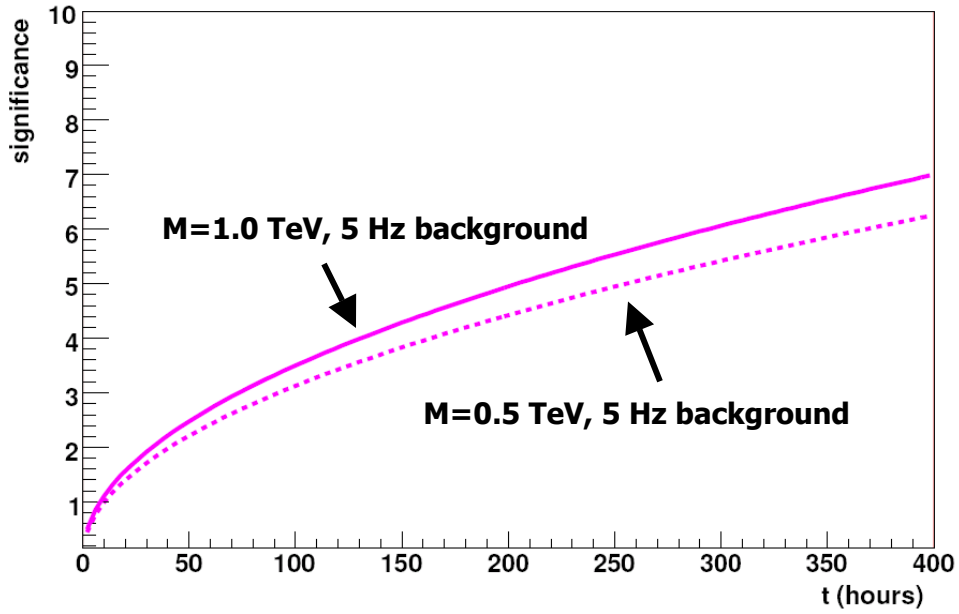
- Ignore areas of diffuse emission: -0.8° < l < +0.8°
- Assumed observations at l=0°, varied b
- Applied Hillas analysis and H.E.S.S. Phase 1 effective areas to calculate detected photon rate

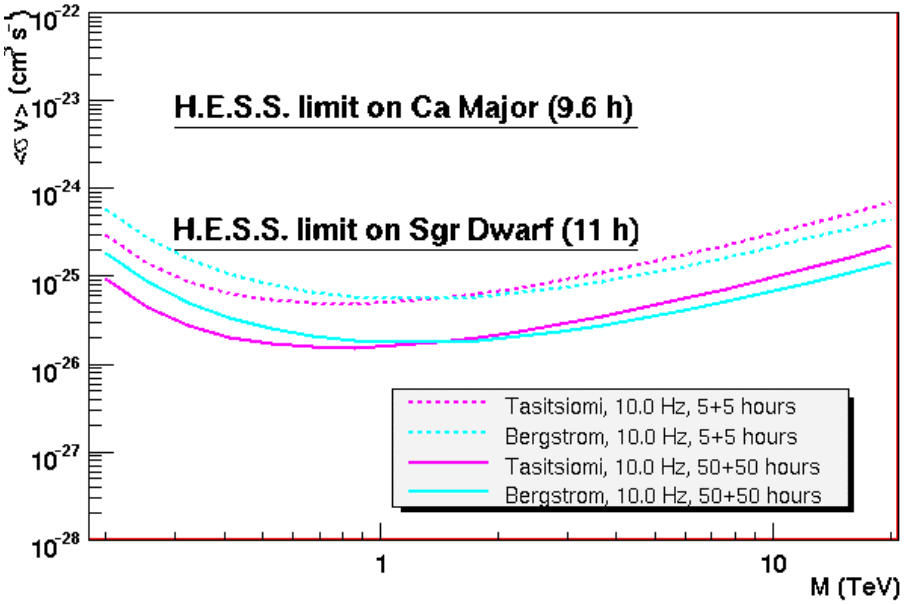
Sensitivity (2/3)



- ~100 events per hour
- Flux above 200 GeV is ~8% Crab
- Backgrounds:
  - Hadrons + Electrons: ~15 Hz (Hillas Analysis on data)
- A better analysis should reduce the background rate by a factor 2-3
  - Electrons: ~1.5 Hz (from the MC)

Sensitivity (3/3)

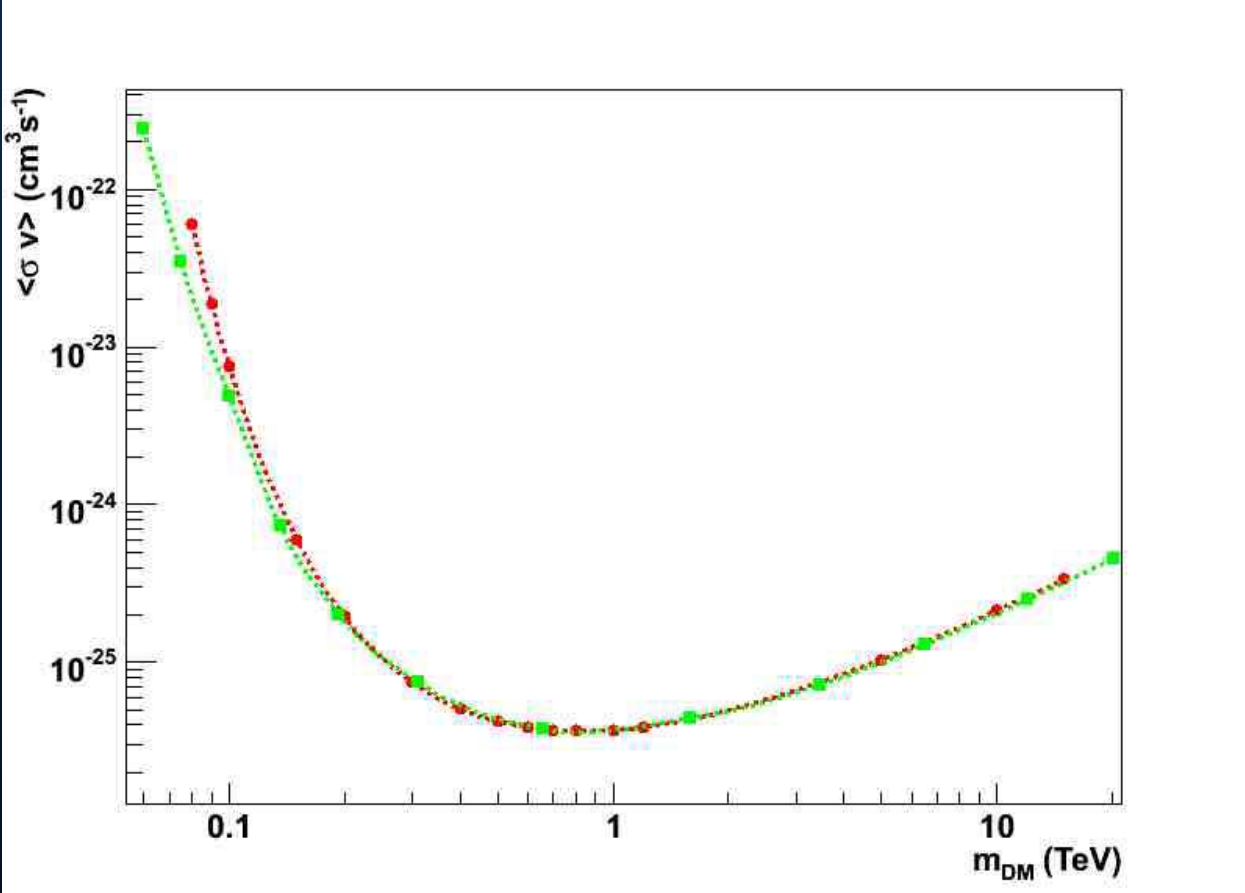




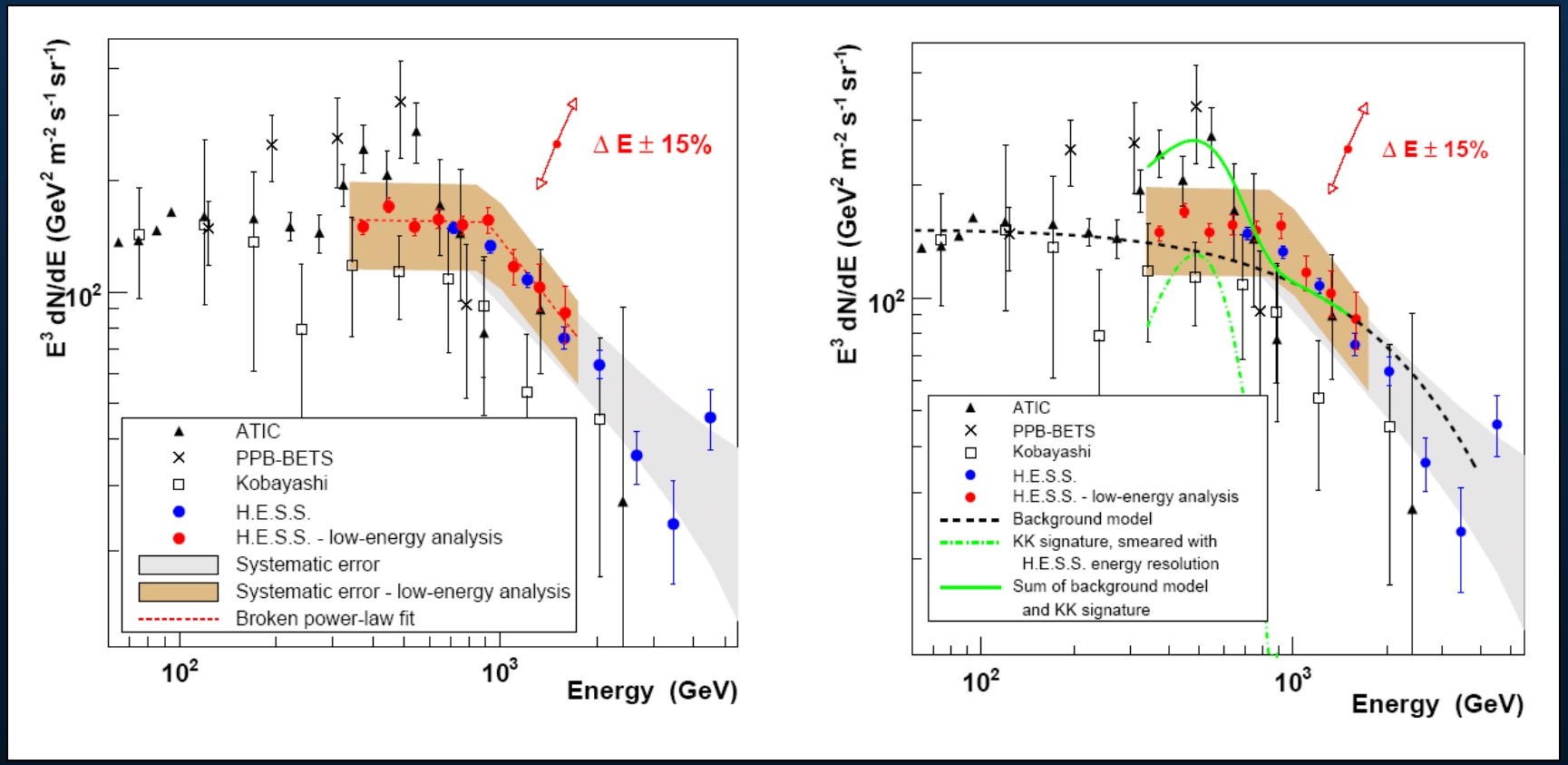
- 80 hours to get to the 3σ level ... With perfect background substractions
- After 5h ON + 5h OFF, the limit is comparable or better than limits obtained from the dwarf galaxies (assuming the astrophysical factor from the Aquarius simulations)
- Southern IACTs have sensitivity for DM photons from the halo at a boost factor of ~1 – if systematics can be brought under control

Summary

- Current IACTs are running for source #100
- Dust has settled over early DM claims (Galactic Centre, unidentified sources)
- Deep exposures (~100h) on dwarf galaxies (and in particular on northern SDSS sources) might exclude models with $<\sigma v> \sim 10^{-26}$ $cm^3 s^{-1}$ if DM distribution can be inferred with certainty.
- Prospects for DM Detection from the Galactic Halo are good (also for Fermi/GLAST)
- Low-threshold essential for next-generation instruments (Cherenkov Telescope Array, AGIS)


$\langle\sigma v\rangle$ (cm^{3}s^{-1})
10^{-22}
10^{-23}
10^{-24}
10^{-25}
0.1
1
10
m_{DM} (TeV)

Electrons


E^3 dN/dE (GeV^2 m^{-2} s^{-1} sr^{-1})
10^2
10^2
10^3
Energy (GeV)
Δ E ± 15%
ATIC
PPB-BETS
Kobayashi
H.E.S.S.
H.E.S.S. - low-energy analysis
Systematic error
Systematic error - low-energy analysis
Broken power-law fit
E^3 dN/dE (GeV^2 m^{-2} s^{-1} sr^{-1})
10^2
10^2
10^3
Energy (GeV)
Δ E ± 15%
ATIC
PPB-BETS
Kobayashi
H.E.S.S.
H.E.S.S. - low-energy analysis
Background model
KK signature, smeared with
H.E.S.S. energy resolution
Sum of background model
and KK signature