

Recent results in very high energy gamma ray astronomy

- Experimental status
- Galactic surveys
- Galactic Centre
- Dark matter searches
- AGN and bounds on quantum gravity scale

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Ground-based VHE gamma-ray instruments

VERITAS



MAGIC



MILAGRO



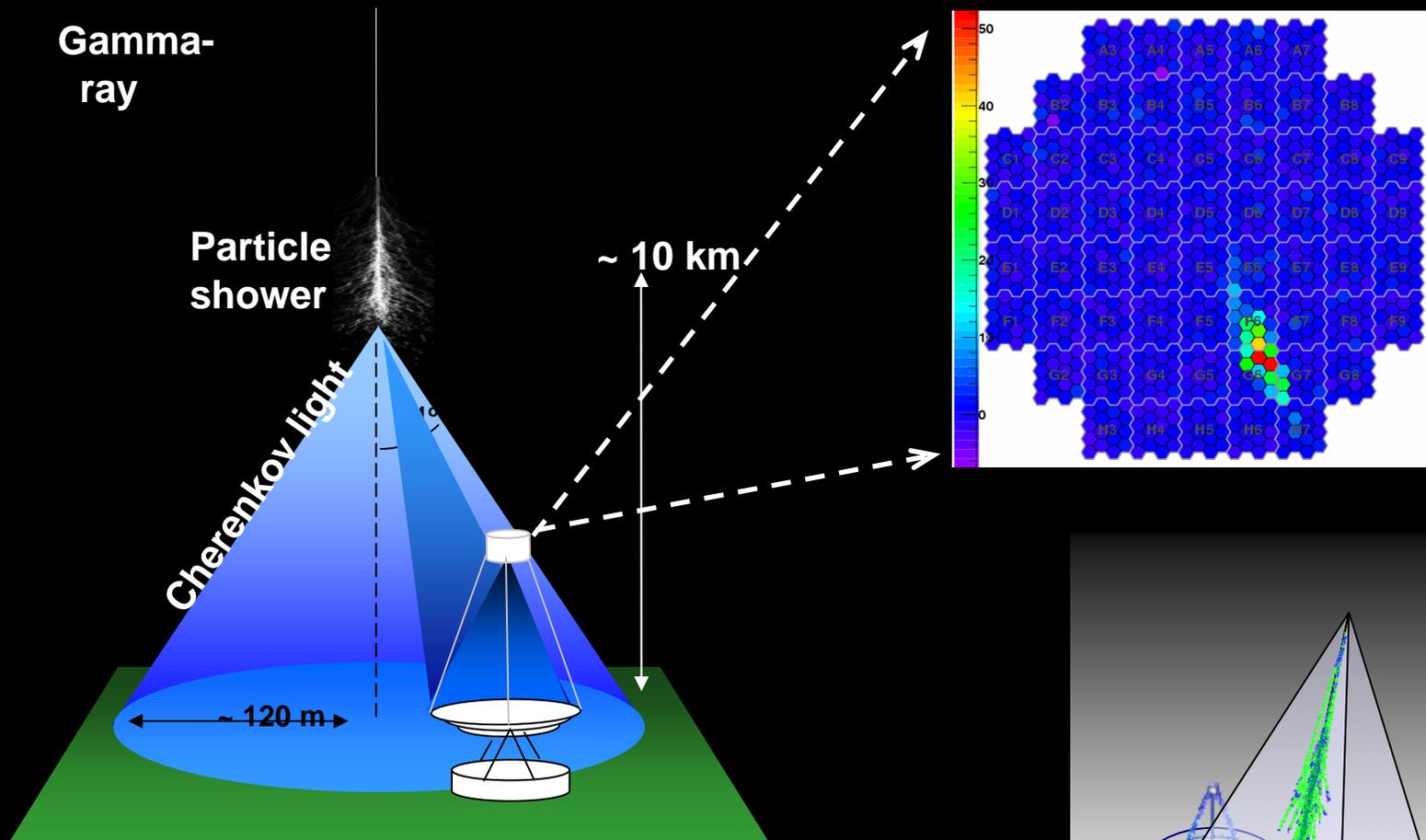
H.E.S.S.



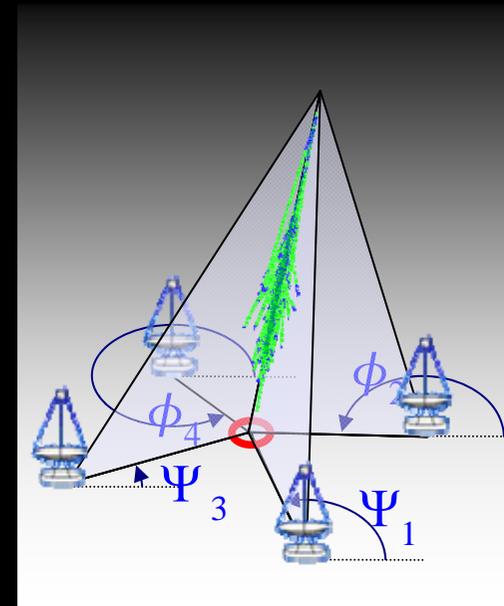
CANGAROO III



Imaging Atmospheric Cherenkov telescopes



- brief flash ~ 3 ns
- **stereoscopy**:
improved gamma ray reconstruction
muon background rejection



High Energy Stereoscopic System

located in Namibia, latitude= -23° , altitude=1800 m

4 telescopes, 107 m² each

cameras 960 PMT

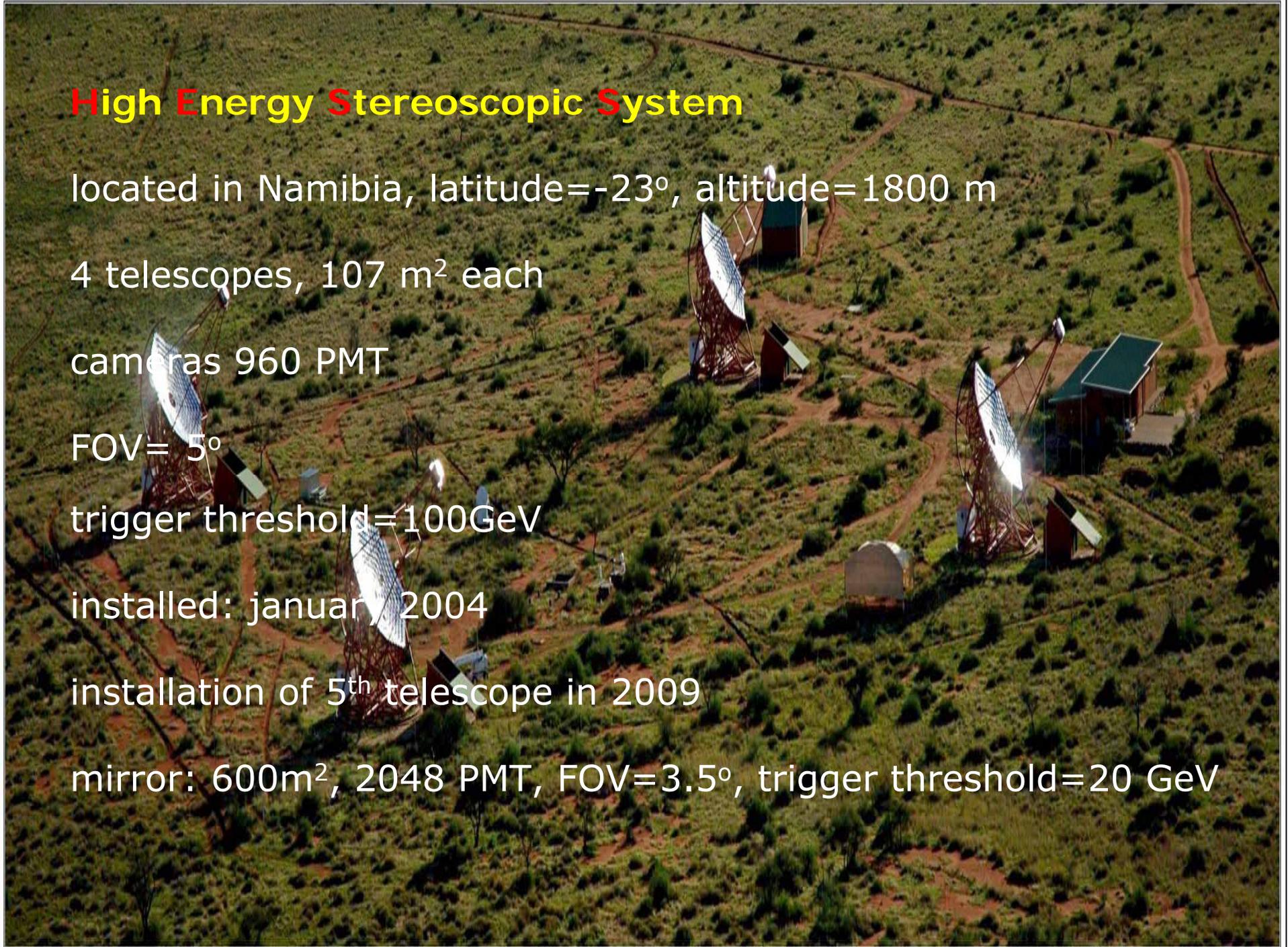
FOV= 5°

trigger threshold=100GeV

installed: january, 2004

installation of 5th telescope in 2009

mirror: 600m², 2048 PMT, FOV= 3.5° , trigger threshold=20 GeV



Major Atmospheric Gamma-ray Imaging Cherenkov

located in La Palma (Canaries Islands),
latitude=+29°, altitude=2225 m

mirror: 234 m²

camera 534 PMT

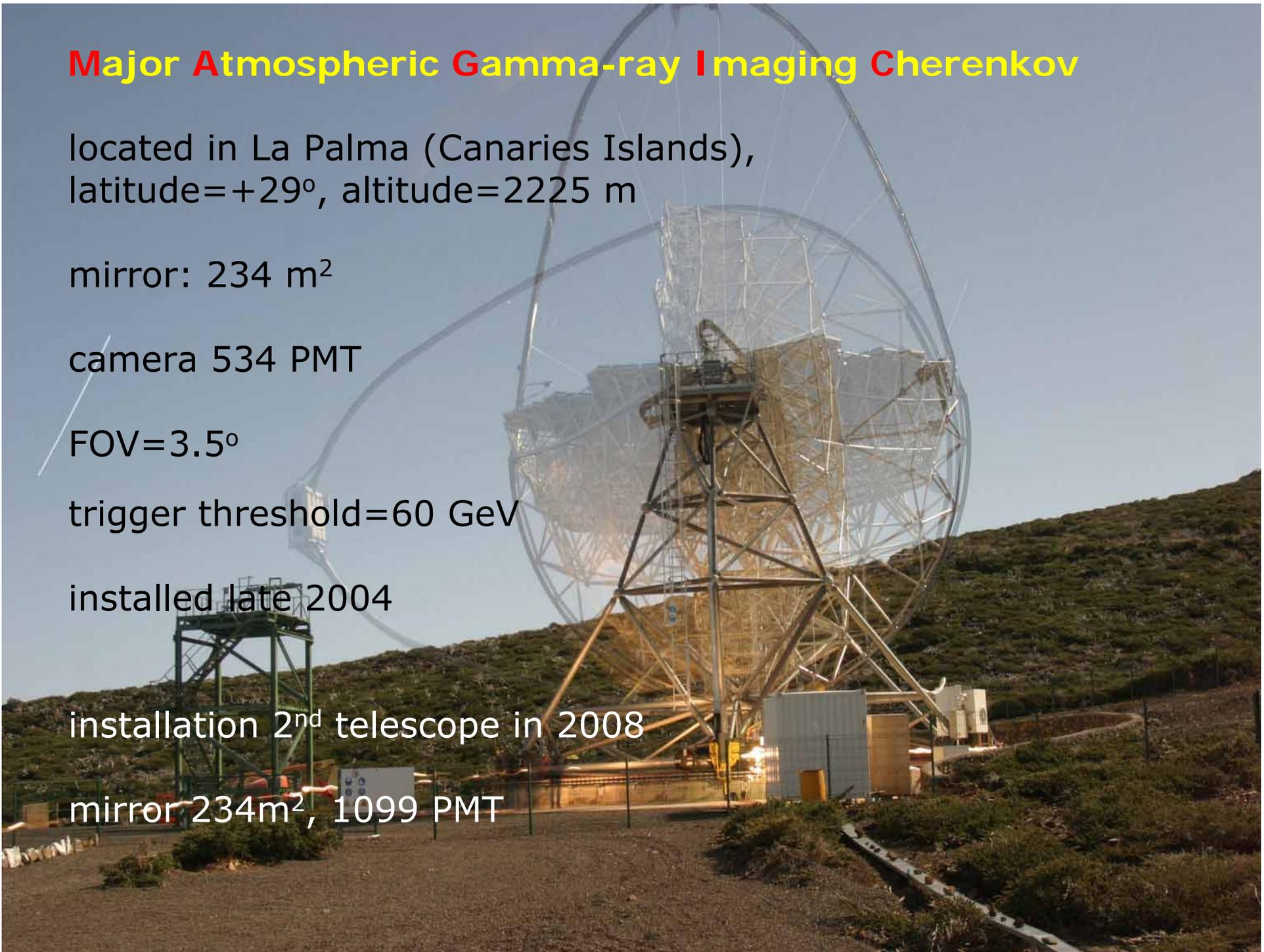
FOV=3.5°

trigger threshold=60 GeV

installed late 2004

installation 2nd telescope in 2008

mirror 234m², 1099 PMT



Very Energetic Radiation Imaging Telescope Array System

origin: Whipple collaboration (10 m, late 80s)

located in Arizona, latitude = $+32^\circ$, altitude = 1275 m

4 telescopes, 106 m² each

cameras 499 PMT

FOV = 3.5°

trigger threshold = 100 GeV

installed in april 2007



MILAGRO

located in New-Mexico, altitude=2630 m

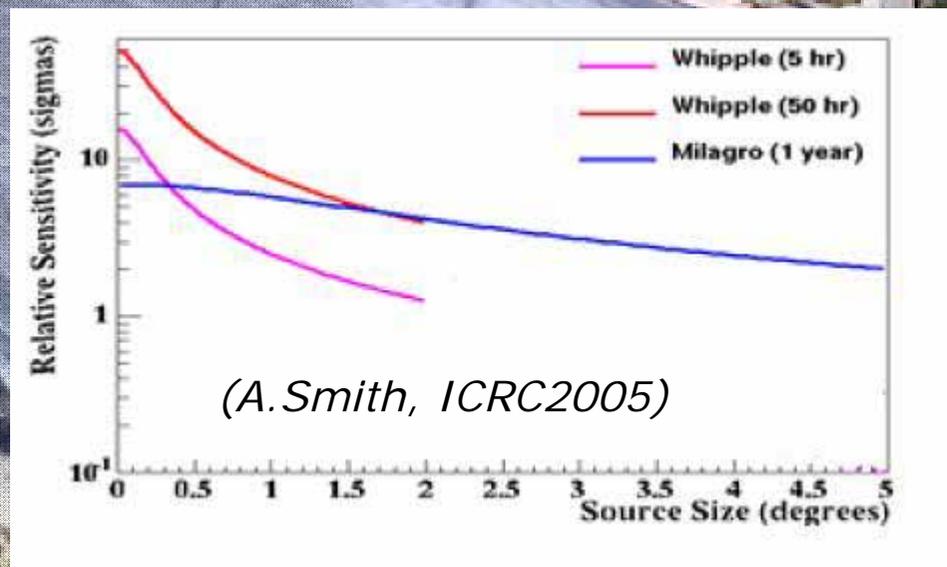
1 large water tank 80m \times 80m \times 8m
+ 175 small water tanks in 40000 m 2

450 + 723 PMTs (2 layers)

field of view: 2sr

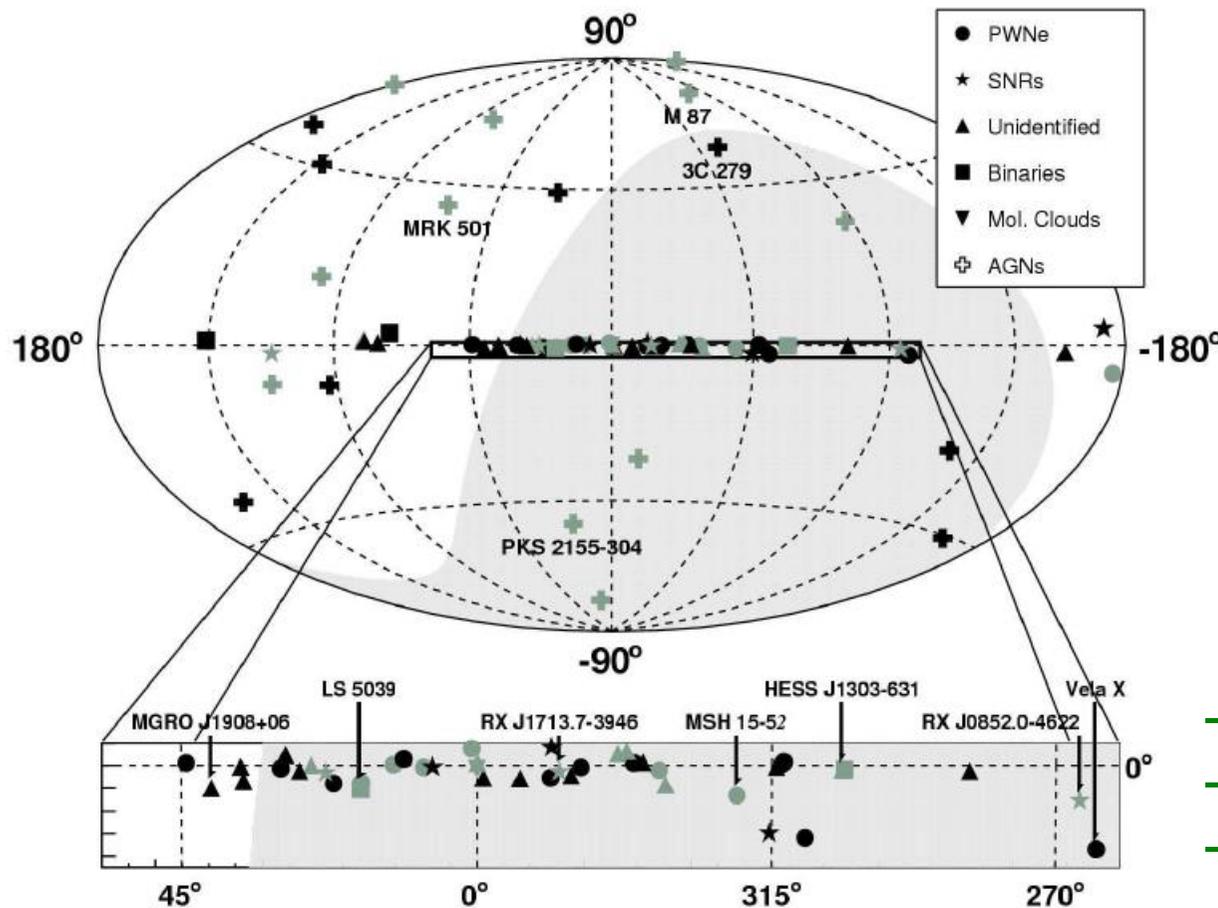
energy threshold \sim 1TeV

started January 2000

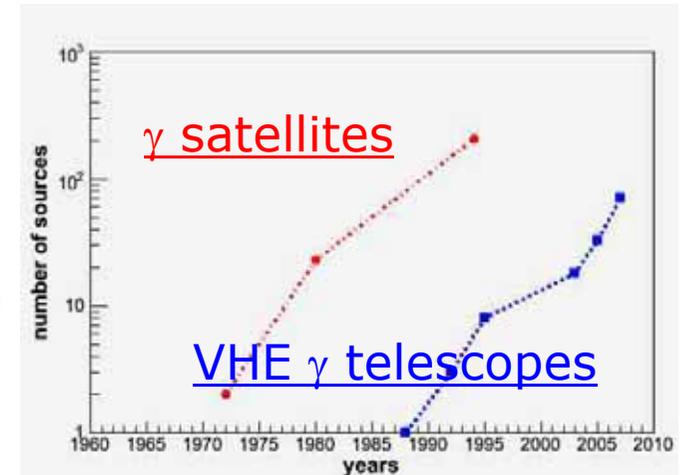


better sensitivity
to extended sources

A new field of astronomy

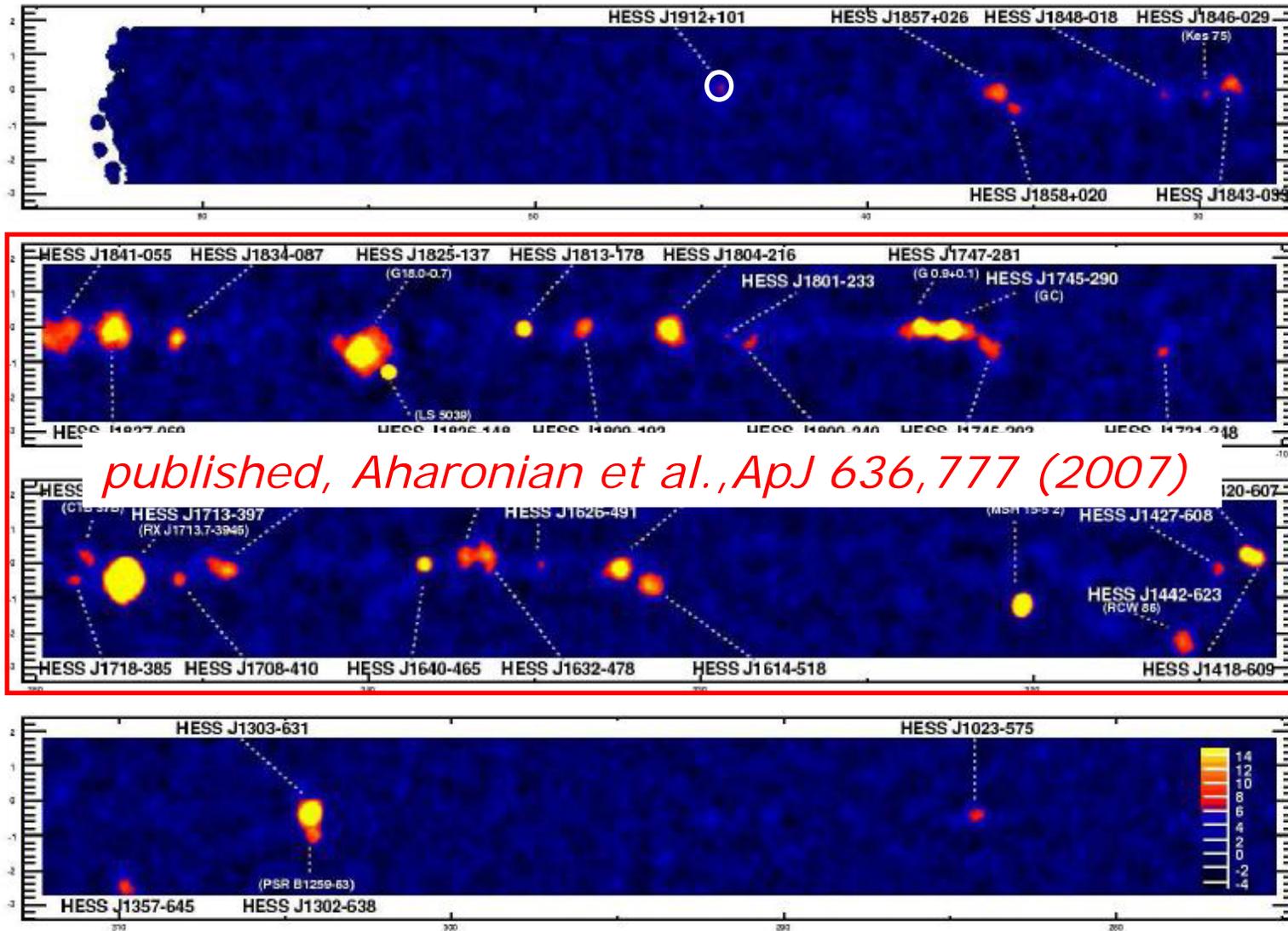


(J.Hinton, ICRC 2007)



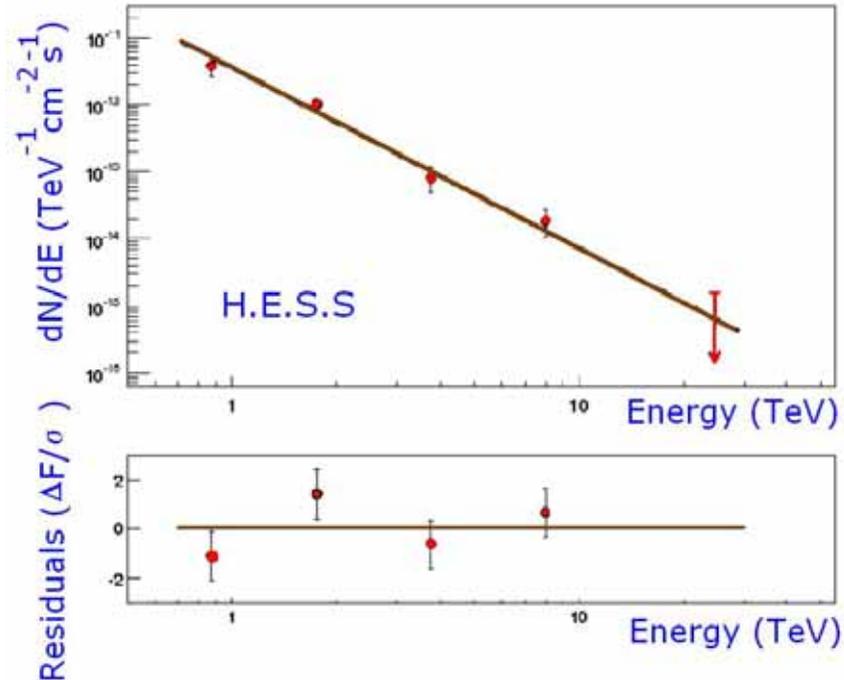
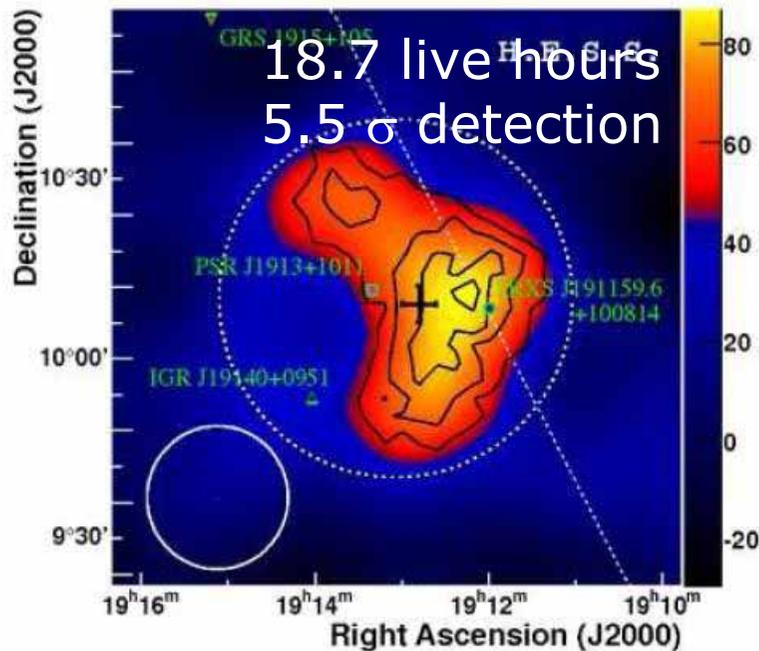
- 71 sources (mid 2007)
- mostly SNR, PWN, AGN
- survey capabilities

The H.E.S.S. survey of the Galactic plane



published, Aharonian et al., ApJ 636, 777 (2007)

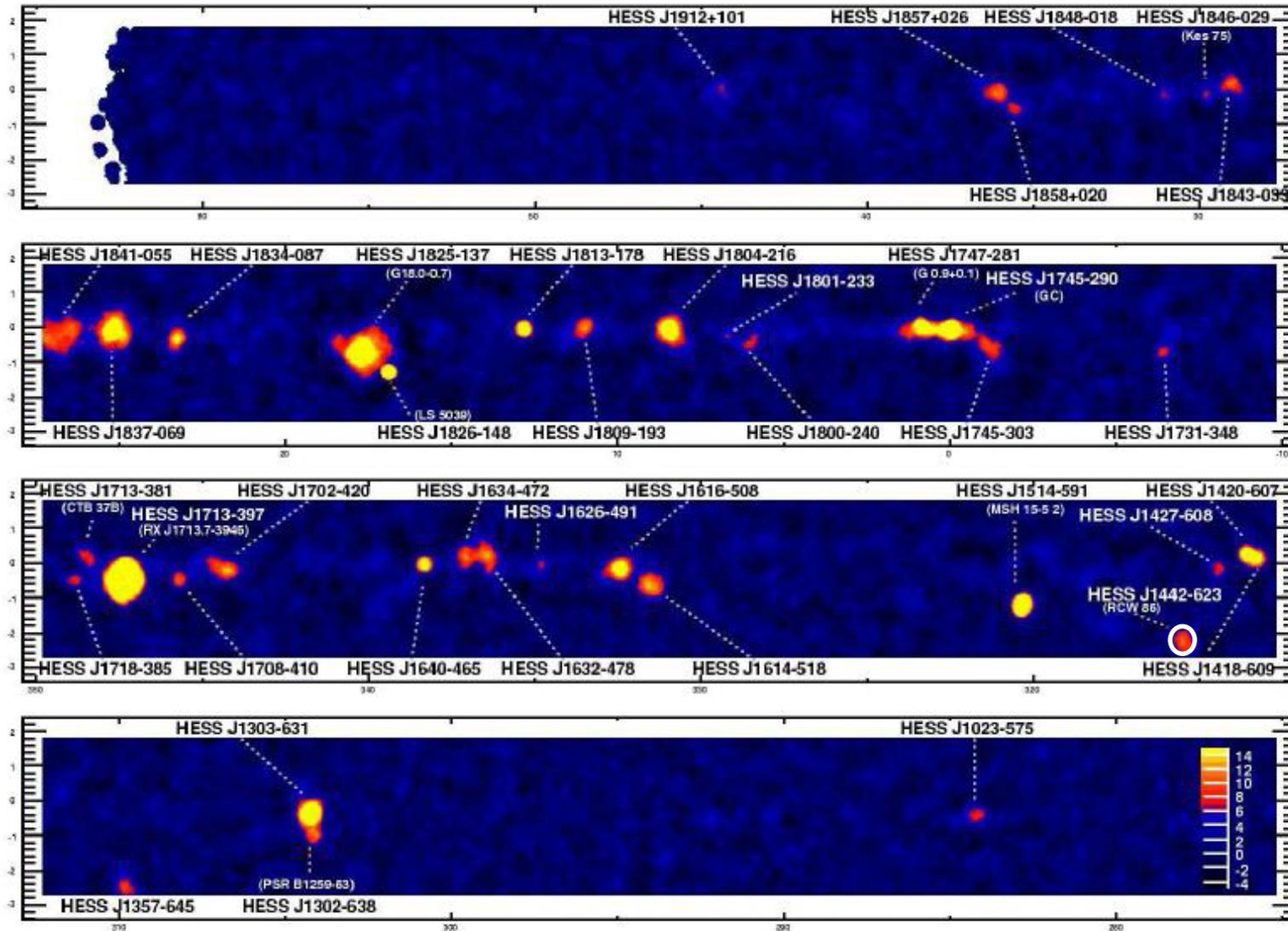
HESS J1912+101 (H.E.S.S)



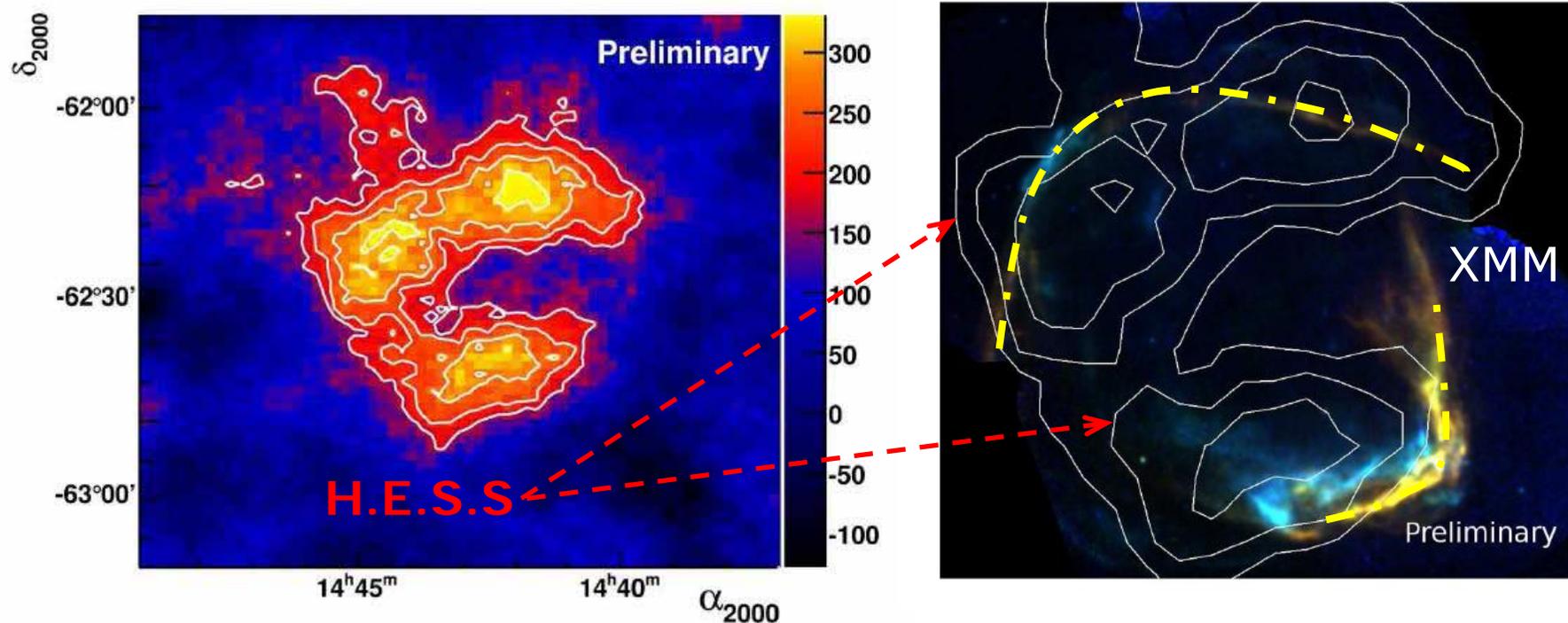
- possibly associated with high-spindown luminosity PSR J1913+011
- extended emission, $\sigma=0.26^\circ \pm 0.03^\circ$ (stat)
- flux $\sim 19\%$ of Crab nebula
- soft spectral index $\Gamma=2.7 \pm 0.2$ (stat) ± 0.3 (sys)

F.Aharonian et al, accepted in A & A (2008)

The H.E.S.S. survey of the Galactic plane



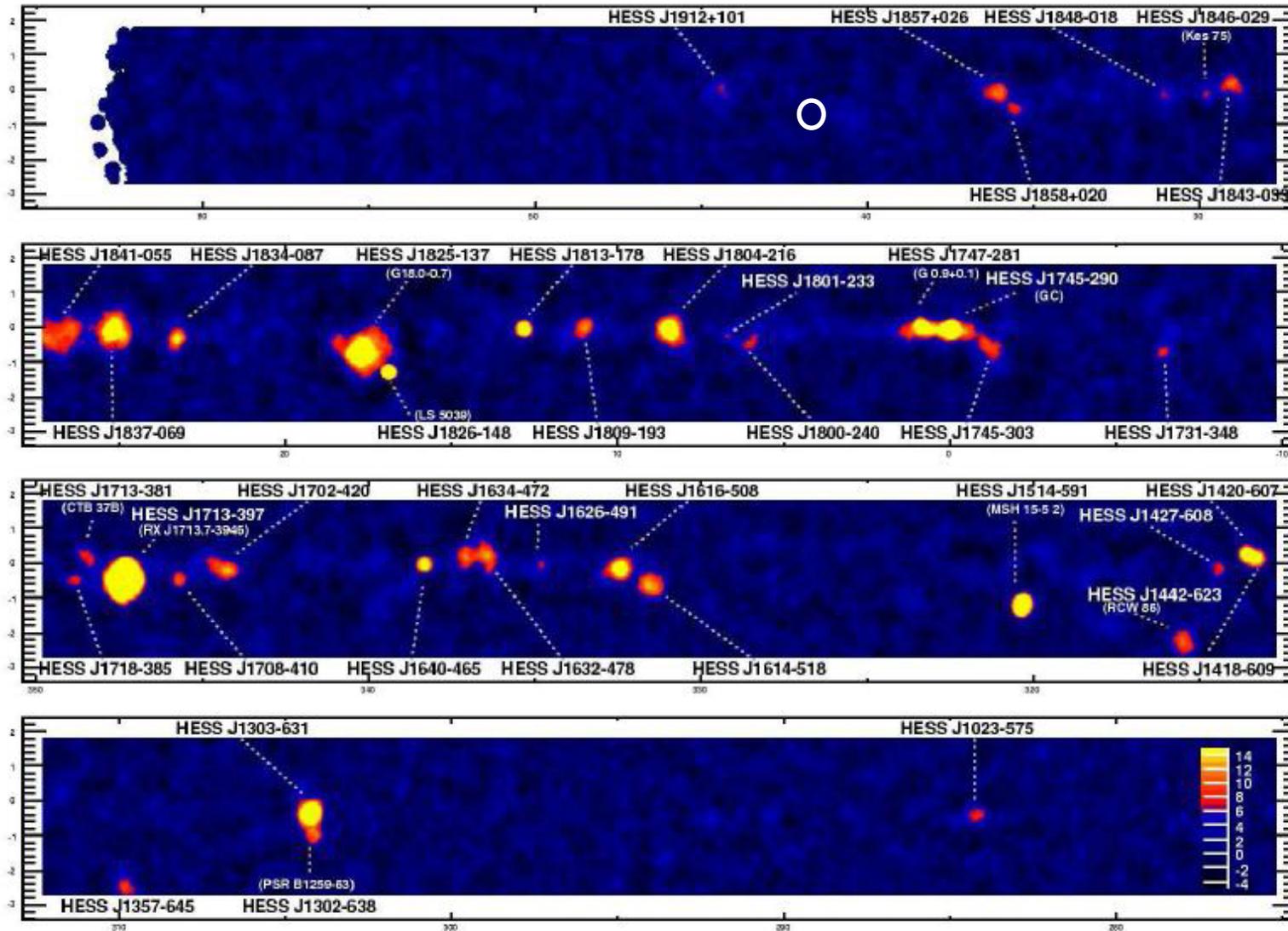
RCW86 (H.E.S.S.)



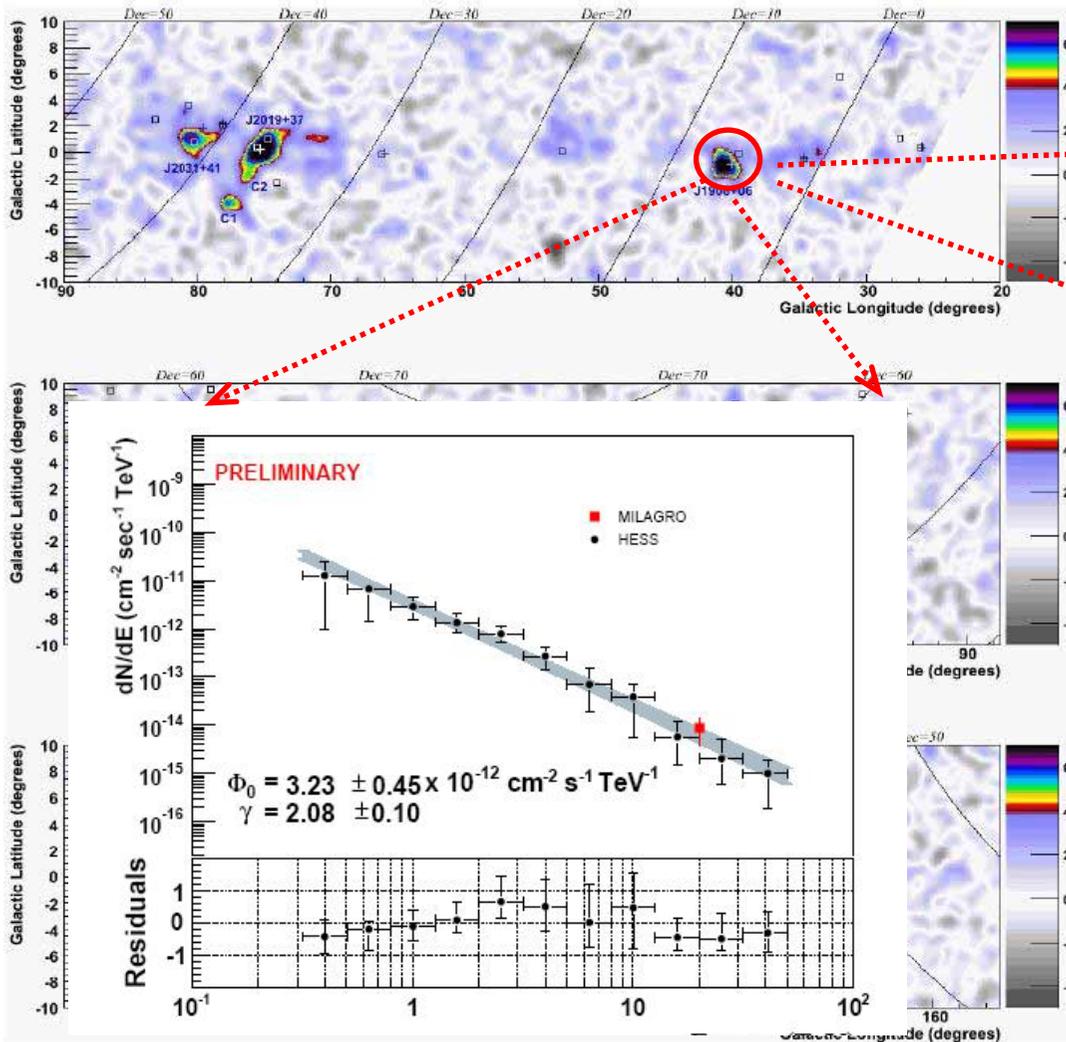
- SNR, possibly associated with SN185
- 30 hours of data, 9σ detection
- integrated flux (1-10 TeV) $\sim 8\%$ Crab flux
- morphology correlates well with X-rays (synchrotron)

M.Lemoine-Goumard et al (H.E.S.S. collaboration, ICRC 2007)

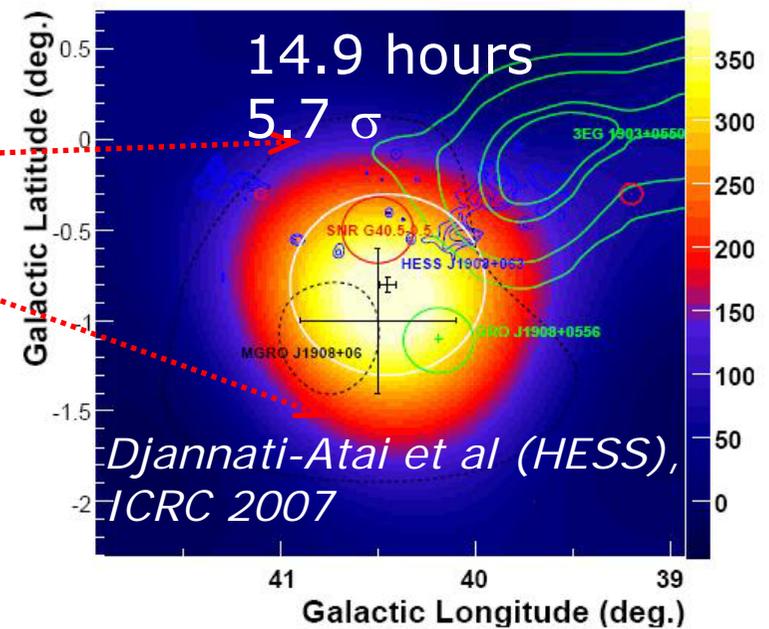
The H.E.S.S. survey of the Galactic plane



Milagro galactic plane survey

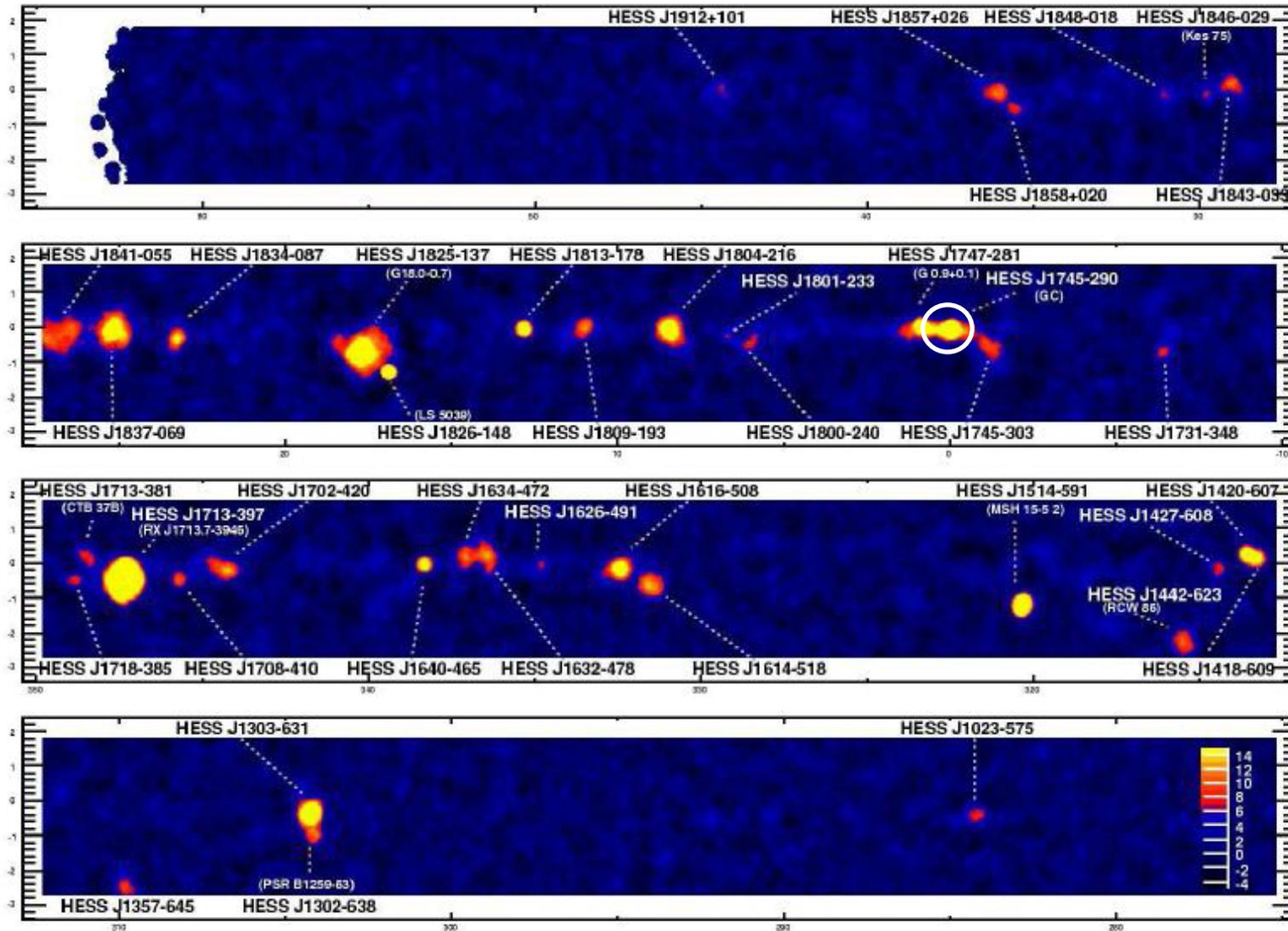


Abdo et al. (MILAGRO), ApJ 664L91 (2007)



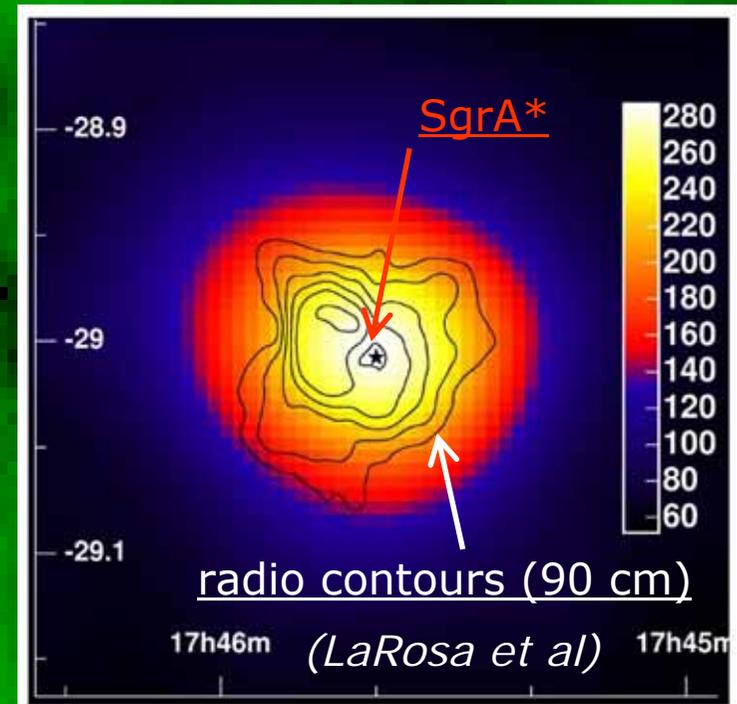
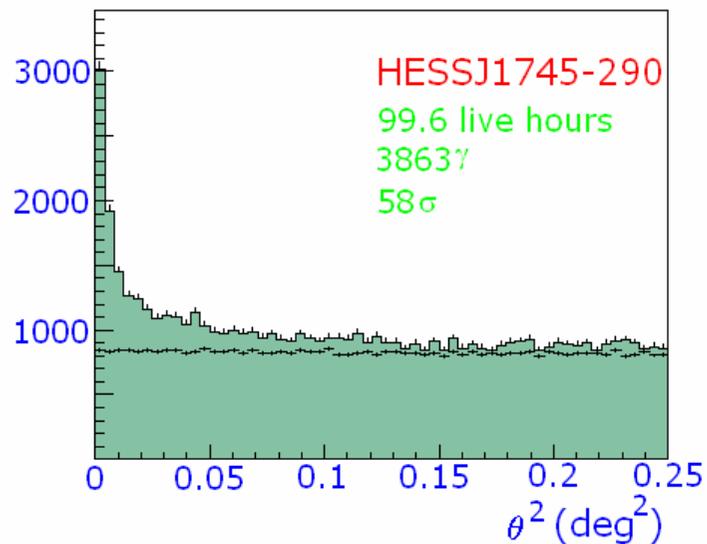
- 6.5 yr survey (2000-2007)
- 4 sources found at $> 4\sigma$
- typical energy ~ 20 TeV
- MGO J1908+06 confirmed by H.E.S.S.
- source extended, no obvious counterpart

The H.E.S.S. survey of the Galactic plane



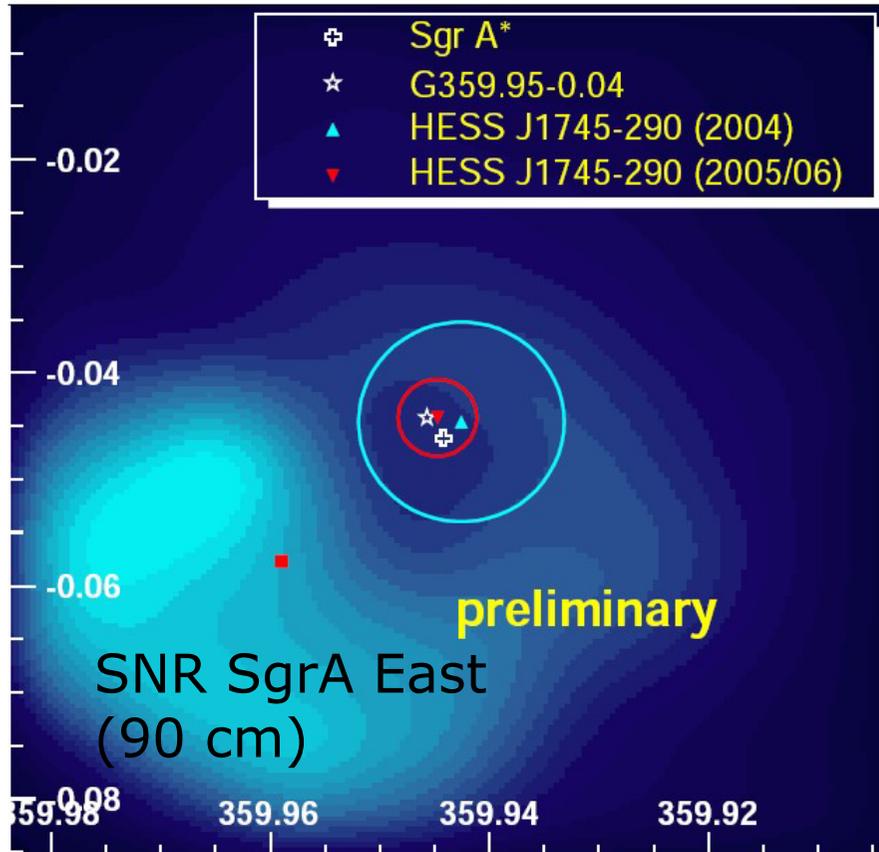
Galactic Center (H.E.S.S.)

diffuse emission



- ~ 100 hours of data taking (2003 \rightarrow 2005)
- excess $\sim 60 \sigma$
- compatible with **point-like source**

Interpretations of the HESSJ 1745-290 signal



– vicinity of the Sgr A* black hole
 ⇒ correlation with X-ray/radio signal

– interaction of protons or electrons in the ISM in central stellar cluster

– emission from PWN G359.94-0.04

– ~~emission from SNR SgrA East?~~

– annihilations of WIMPs near GC

– new preliminary result:

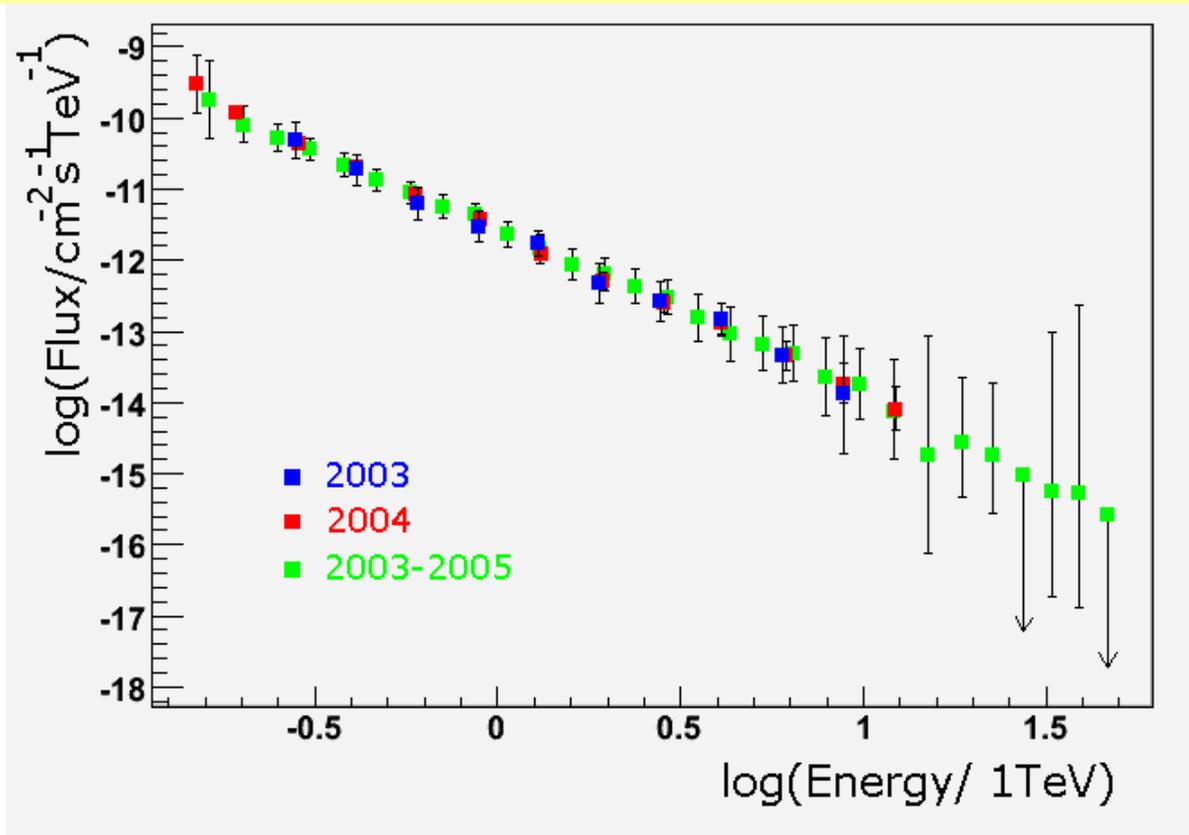
$l = 359^{\circ}56'41.1'' \pm 6.4'' \pm 6''$

$b = -0^{\circ}2'39.2'' \pm 5.9'' \pm 6''$

– position of TeV signal incompatible with radio maximum SgrA East (7σ)

(C. VanEldik et al. (H.E.S.S.), ICRC 2007)

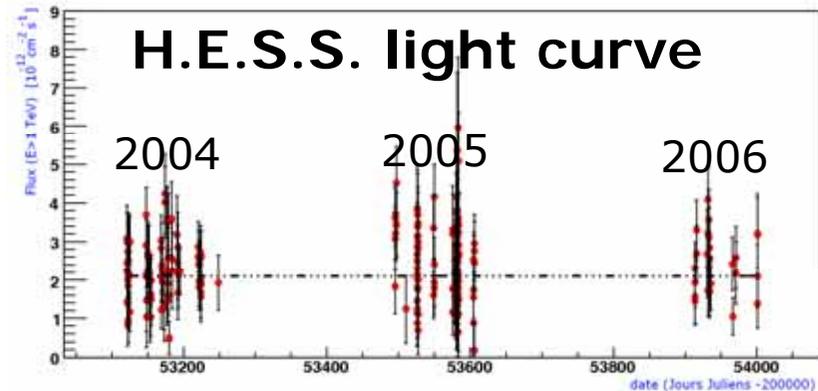
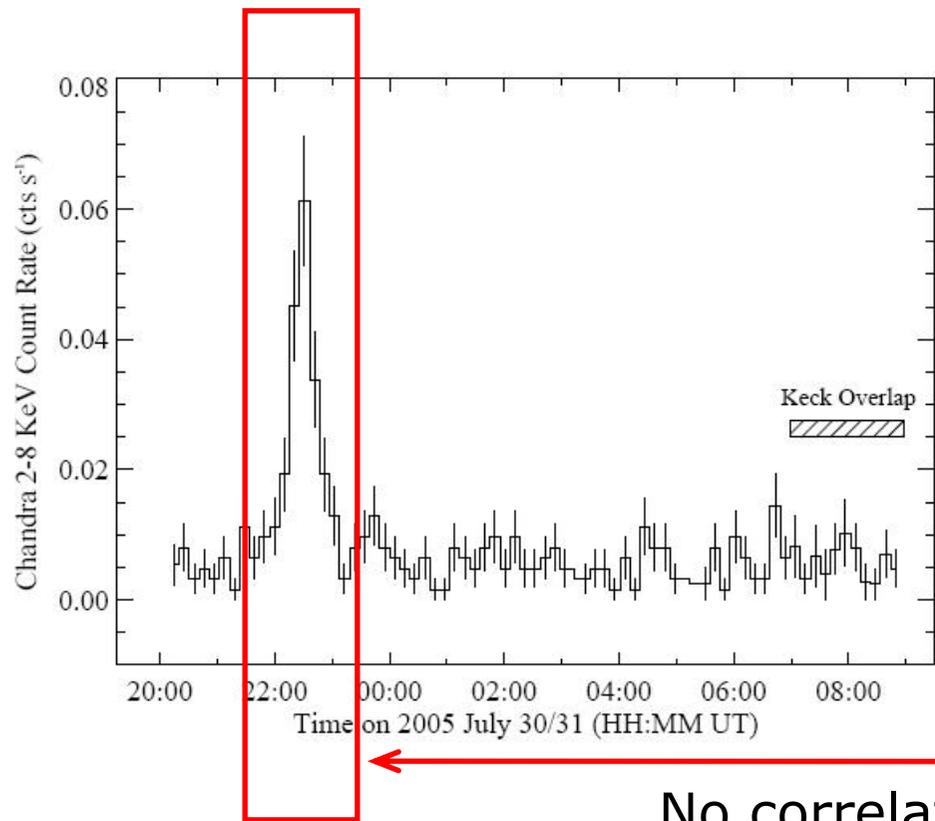
HESS J1745-290: energy spectrum



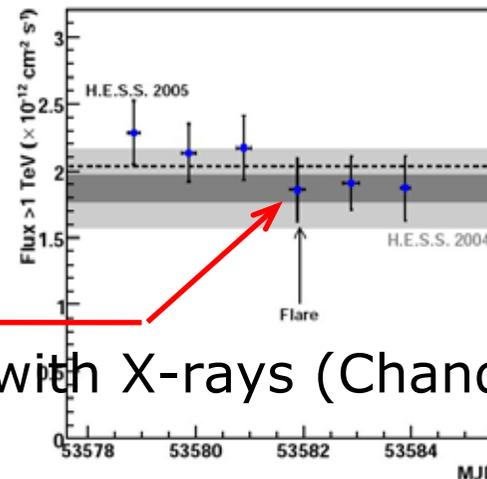
- compatible with a power-law, cut-off energy > 6 TeV (95%CL)
- spectral index: $\Gamma = 2.29 \pm 0.05$
- integrated flux (>1 TeV) $\Phi = 1.87 \pm 0.1 \cdot 10^{-12} \text{ cm}^{-2} \text{ s}^{-1}$
- no apparent spectral variability (2003 \rightarrow 2005)

Non-variability of the H.E.S.S. J1745-290 signal

30th July 2005



No periodicities/flares
(a few minutes → 1 year)



No correlation with X-rays (Chandra)

J.Hinton, M.Vivier et al, (HESS) ICRC 2007, M.Vivier et al. (HESS) ICRC 2007

Indirect dark matter search strategy

Annihilation flux into γ rays observed in solid angle $\Delta\Omega$:

$$\frac{d\phi_\gamma}{dE} \propto \left[\frac{dN_\gamma}{dE} \left(\frac{\langle\sigma v\rangle}{3 \cdot 10^{-26} \text{ cm}^3/\text{s}} \right) \left(\frac{1 \text{ TeV}}{M_\chi} \right)^2 \right] \left[\bar{J}(\Delta\Omega) \Delta\Omega \right] \quad \Delta\Omega_{\text{HESS}} = 2 \cdot 10^{-5} \text{ sr}$$

particle model

dark halo model

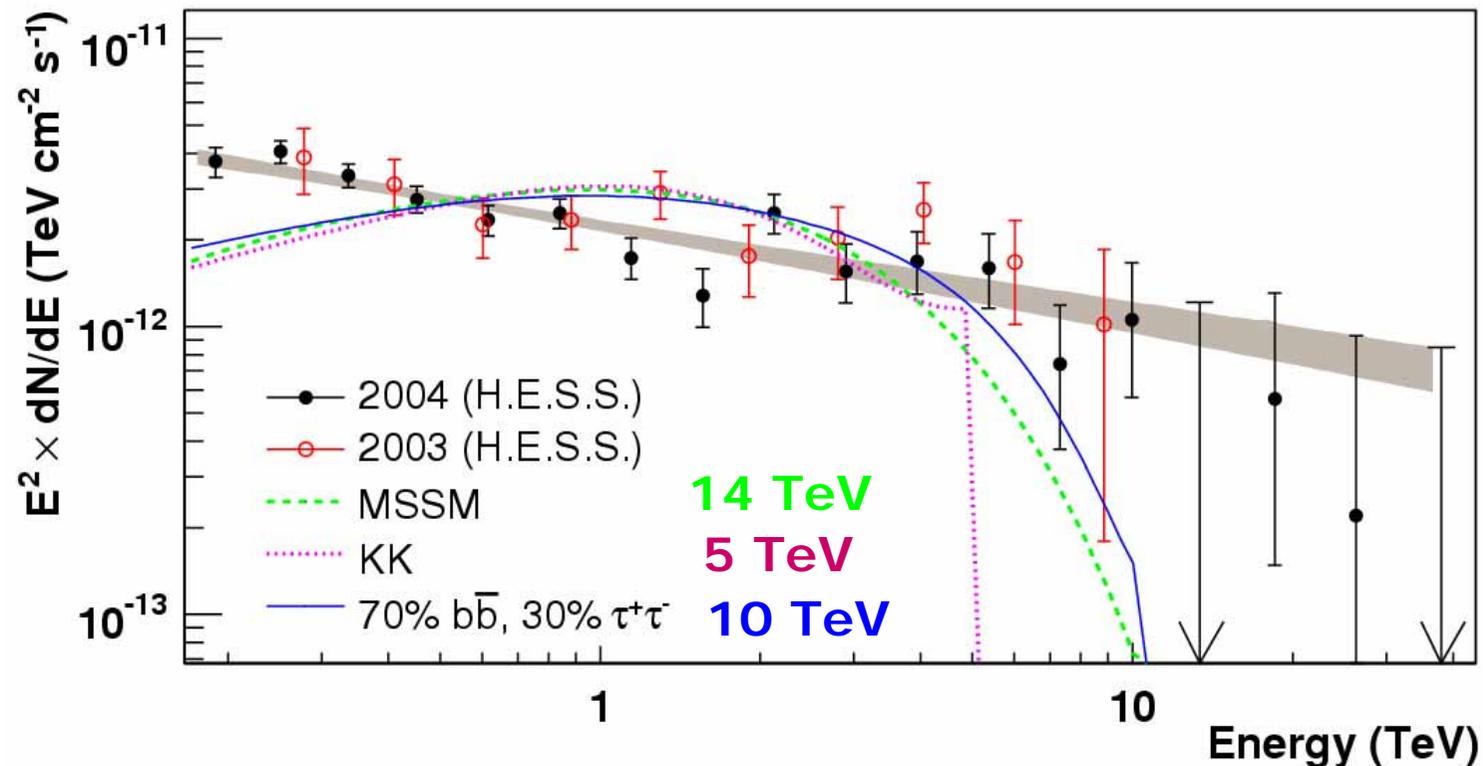
- dN_γ/dE given by selected particle models:
 - U Extra Dimensions (*Servant, Tait 2003*) boson B
 - neutralinos (MSSM)

- Astrophysical factor:
observe dense targets.

$$\bar{J} \propto \int_{l.o.s} \rho_{DM}^2 dl$$

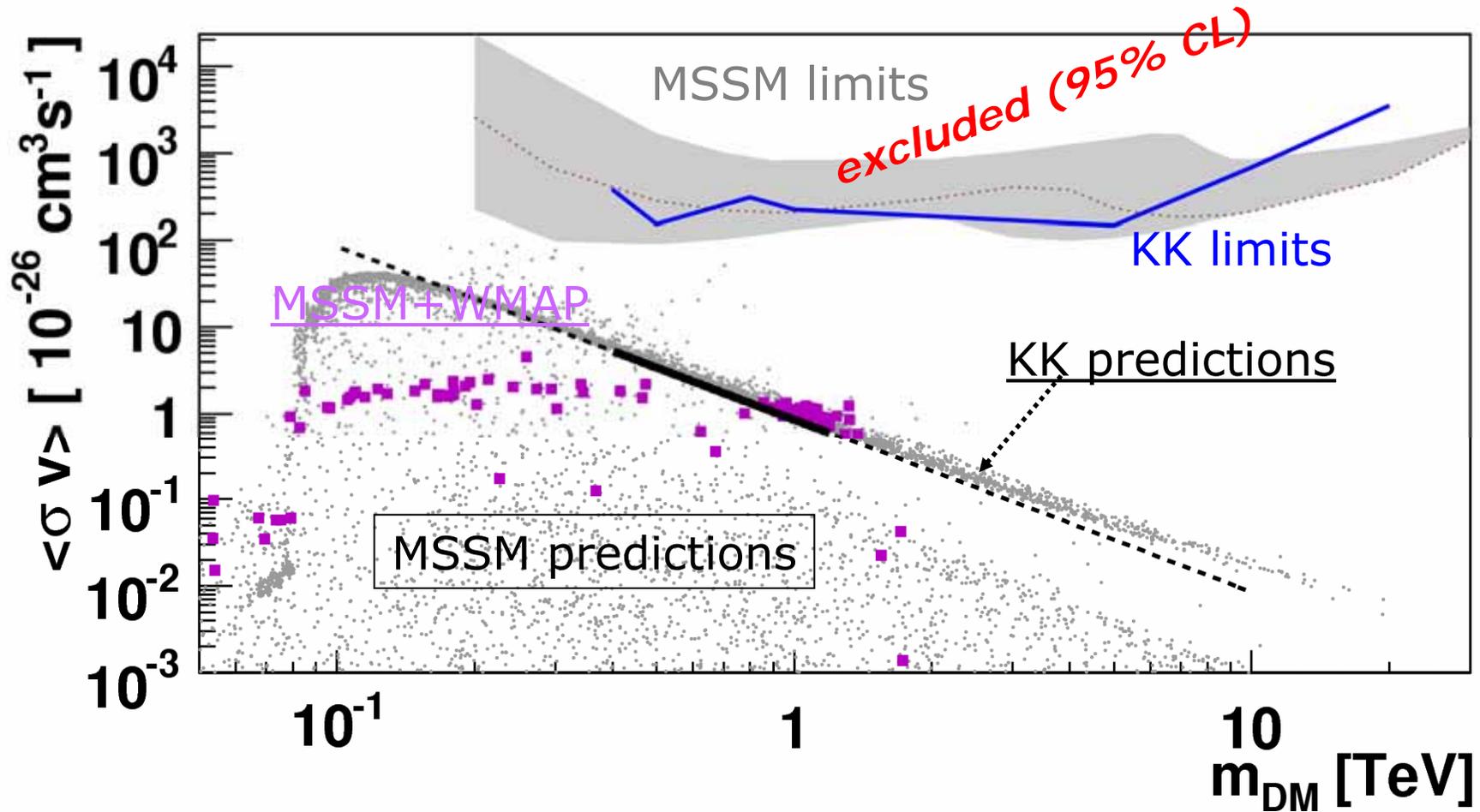
Galactic Center
nearby galaxies
nearby galaxy clusters

Galactic Center: spectral constraints



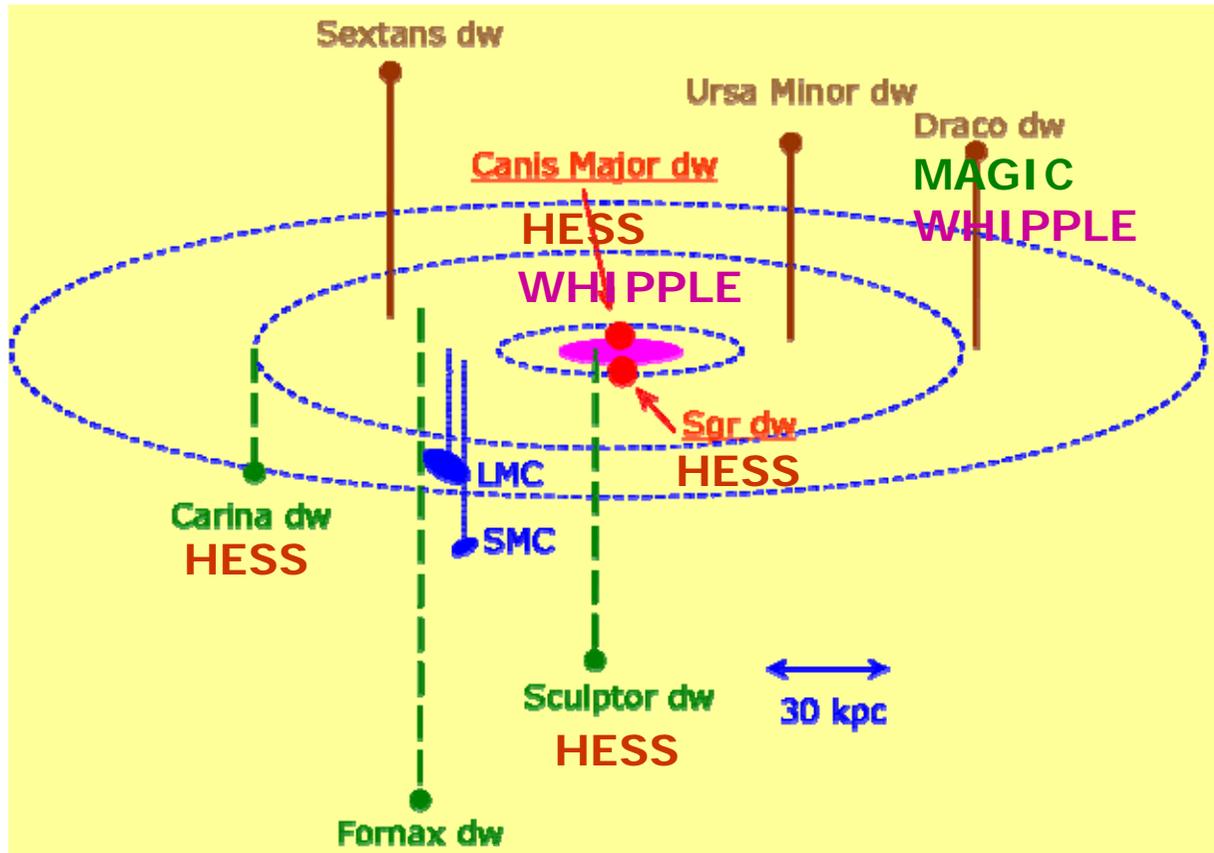
- KK, $b\bar{b}$ and $\tau^+\tau^-$ spectra with PYTHIA 3.625
- poor fit at the low energy end
incompatible with a DM only source
- *F.Aharonian et al., Phys.Rev. Letters, 97, 221102 (2006)*

GC: exclusion plot



(p)MSSM predictions: *DarkSusy 4.1*

Selecting DM annihilation targets



For a given particle model:

$$\bar{J} \propto \frac{M(r < r_{\text{PSF}})^2}{d_{\text{target}}^5}$$

dwarf galaxies:

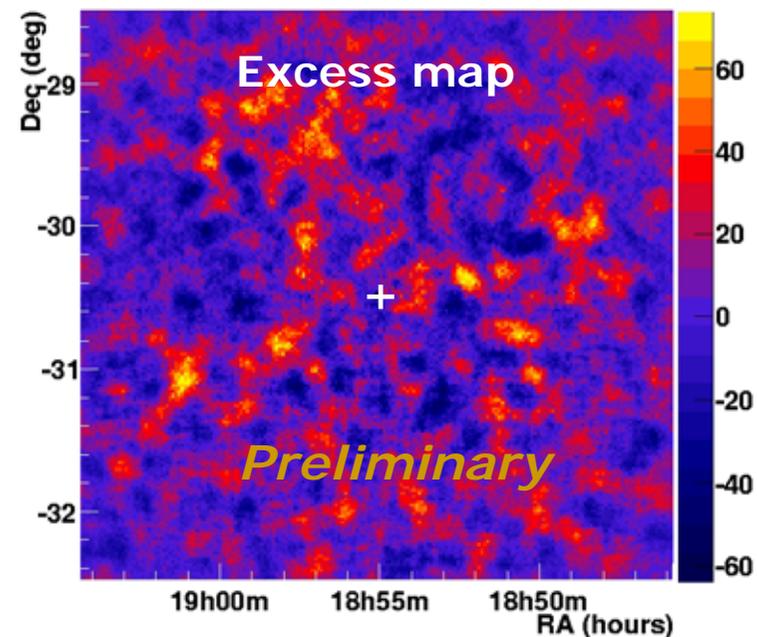
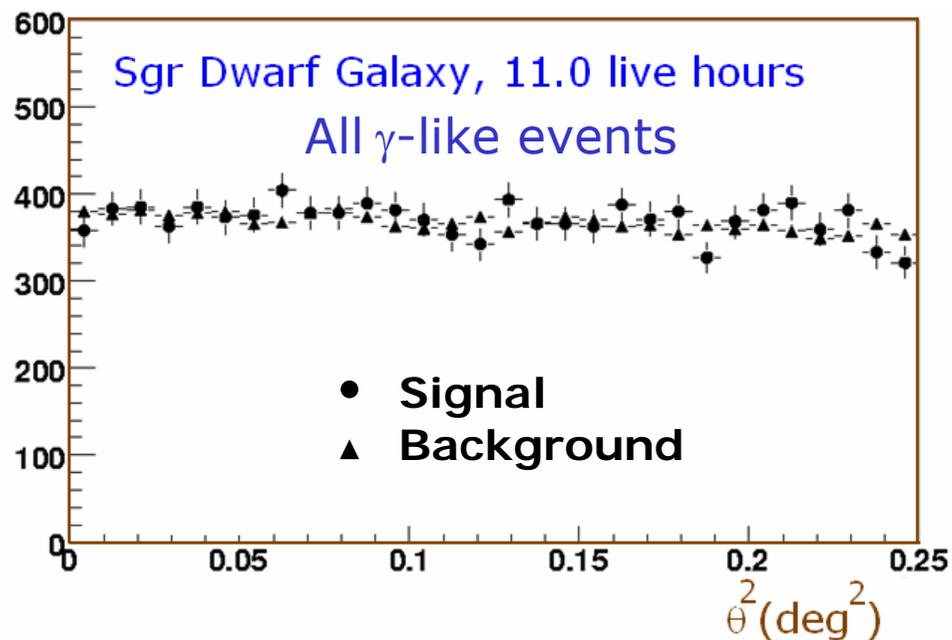
- Sgr dwarf (25 kpc)
 $\Phi(\text{Sgr})/\Phi(\text{GC}) \sim 0.3$
 tidal effects?
- Draco (80 kpc)
 $\Phi(\text{Draco})/\Phi(\text{GC}) \sim 0.1$

other targets: galaxies:
 clusters:

LMC: $\Phi(\text{LMC})/\Phi(\text{GC}) \sim 4 \cdot 10^{-8}$
 Virgo: $\Phi(\text{Virgo})/\Phi(\text{GC}) \sim 3 \cdot 10^{-3}$

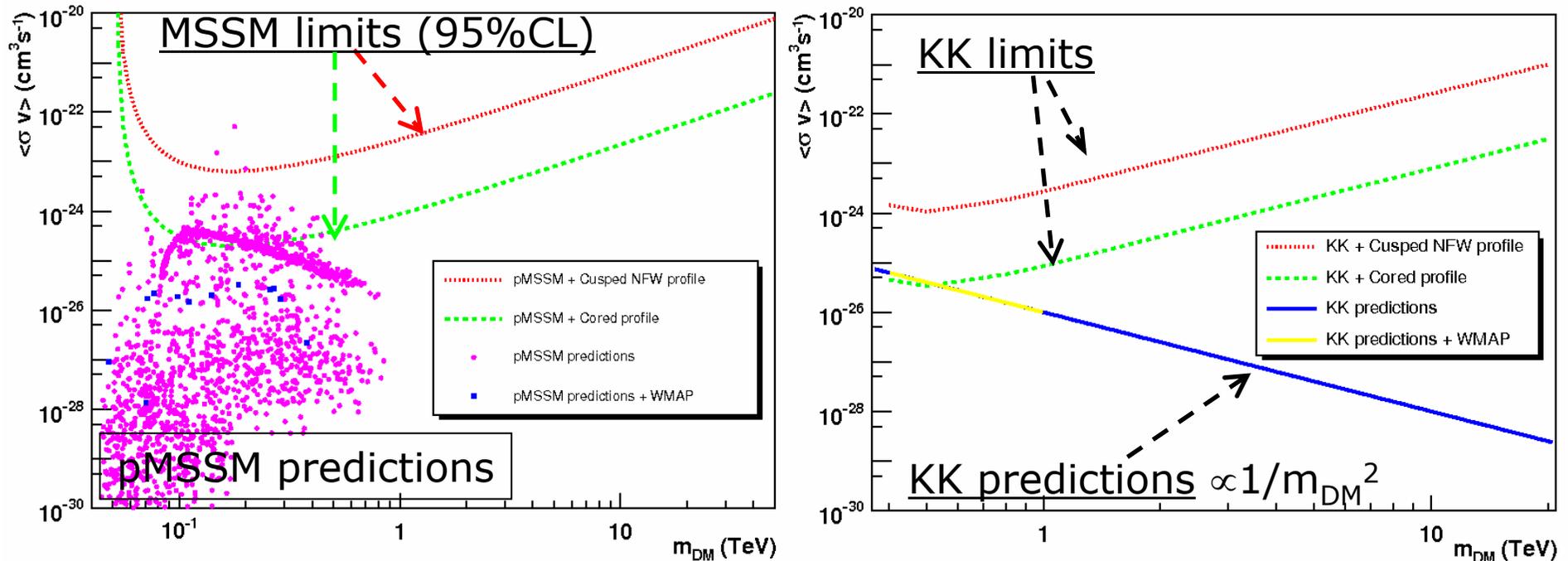
Sgr dwarf galaxy: HESS data

- 11 live hours in 2006
- average zenith angle = 19°
- pointing position: M54
- no significant γ excess



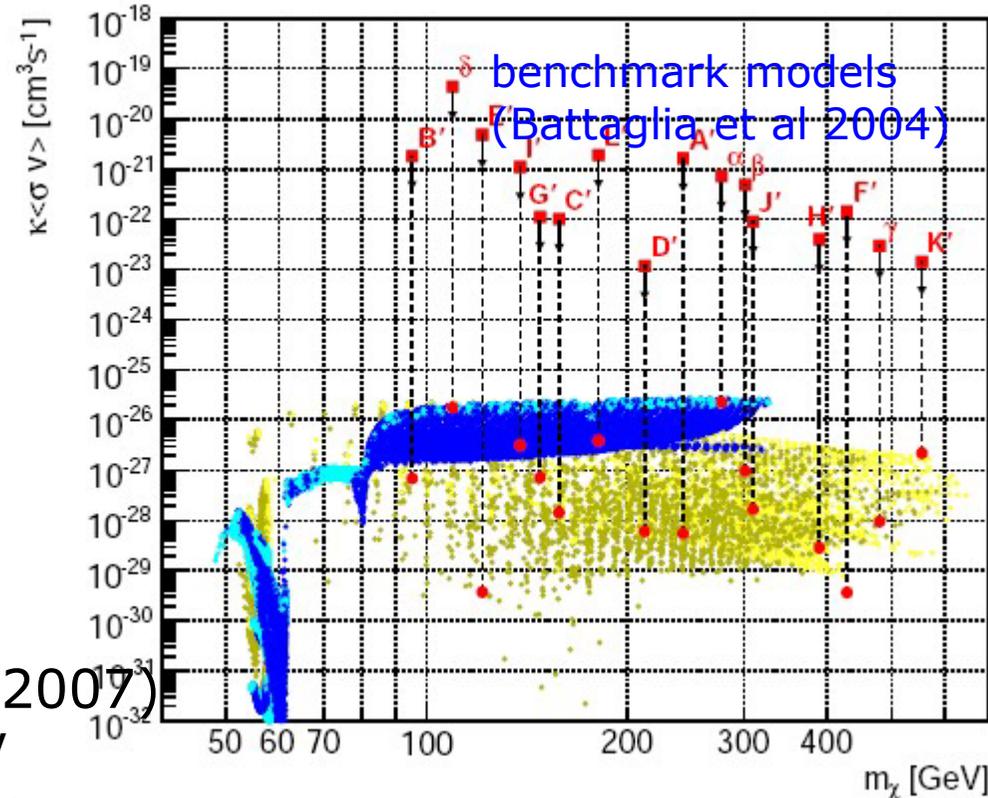
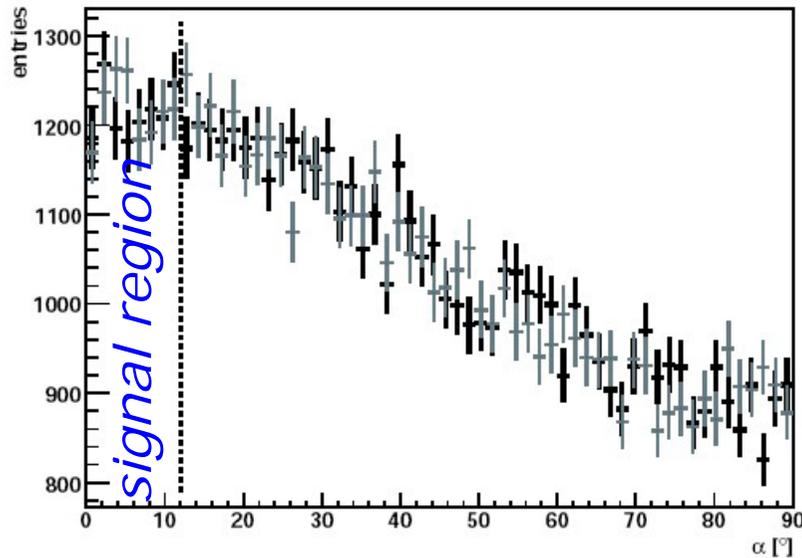
- cuts (point-like)
 $\theta^2 < 0.02$
 $E_\gamma \geq 250$ GeV
- Upper limit on γ excess:
 $N_\gamma < 56$ (95 % C.L.)

Sgr Dwarf: exclusion plots (HESS)



- MSSM models with Higgsino-like neutralino excluded with core model
- mass of KK B^1 boson constrained > 500 GeV (core model)
- *F.Aharonian et al, Astropart.Physics 29,55(2008)*

MAGIC constraints on Draco



- 7.8 hours observation time (2007)
- analysis threshold: 140 GeV
- no excess events with $\alpha < 12^\circ$
- $\Phi_{\text{Draco}} < 1.1 \cdot 10^{-11} \text{ } \gamma/\text{cm}^2/\text{s}$ (2σ)
- constraints $\sim 10^4$ above predictions

Albert et al, accepted in ApJ (2007)

Whipple constraints on Draco/UMi/M15

M. Wood et al (Whipple) arXiv0801.1708 (2008)

– Observations:

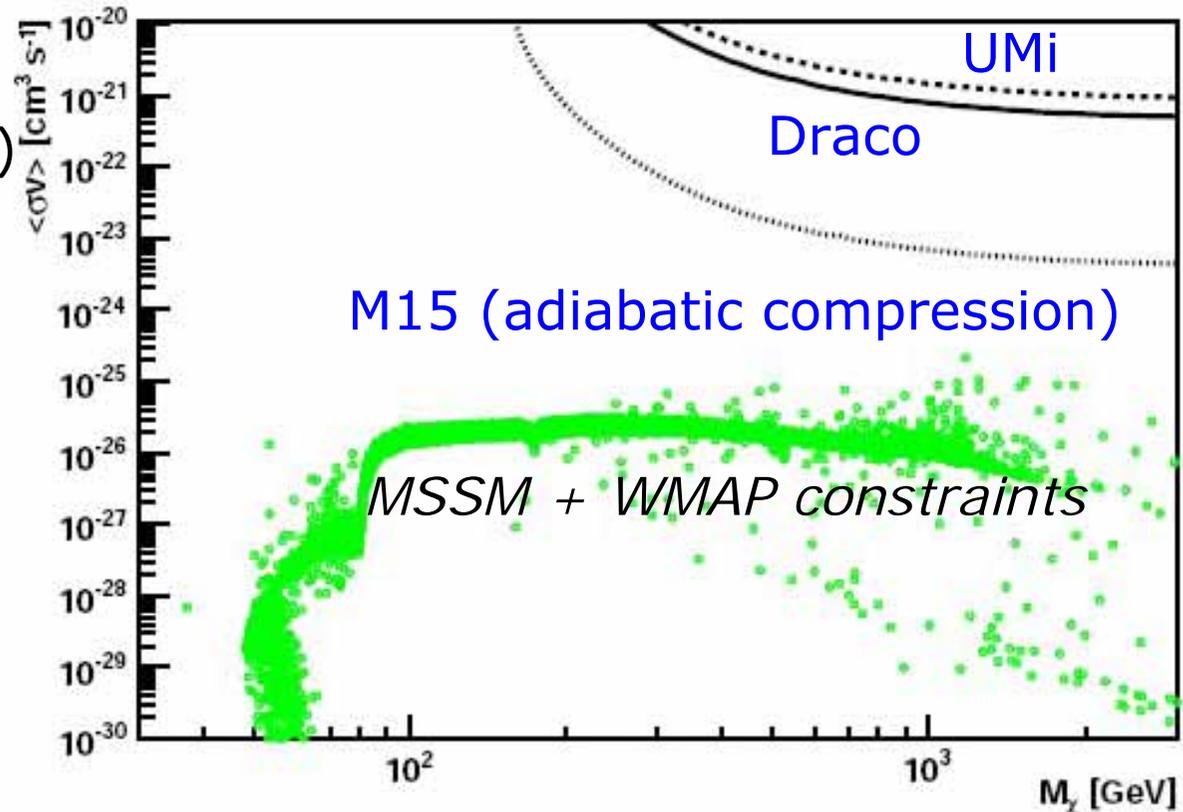
Draco: 14.3 hours (2003)

UMi: 17.2 hours (2003)

Globular cluster M15:
1.2 hours (!!) (2002)

– analysis threshold:
400 GeV

– no excess events in
sources:



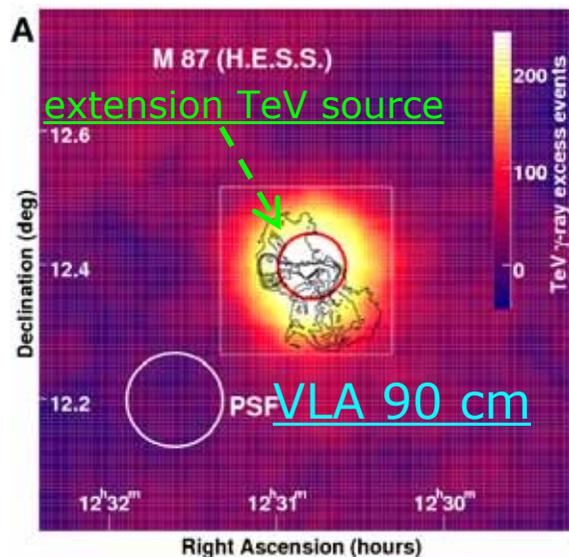
Flux(Draco) $< 6.2 \cdot 10^{-2}$ C.U (95% C.L)

Flux(UMi) $< 8.9 \cdot 10^{-2}$ C.U (95% C.L)

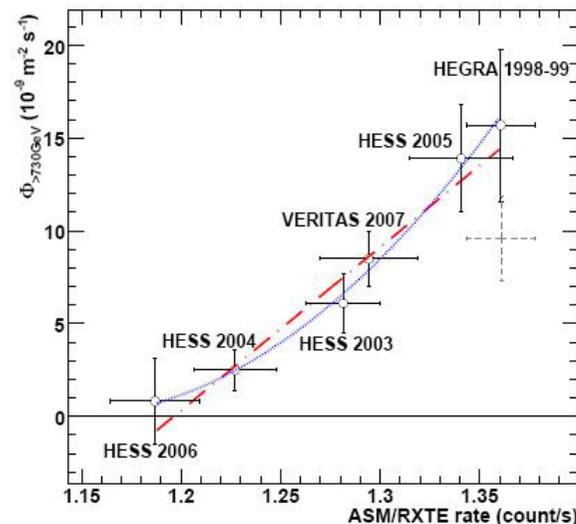
Flux(M15) $< .38$ C.U (95% C.L)

Active Galactic Nuclei

- ~ 20 AGN detected in the TeV regime
- most of them are blazars (jet with angle $< 10^\circ$ w.r.t. the line of sight)
- only known exception: **M87** (center of Virgo cluster)



- first detected by HEGRA (2003)
- TeV emission **variable** (scale days \rightarrow years)



bulk of emission
not dark matter
annihilation

HESS: *F.Aharonian et al., Science 314, 1424 (2006)*

VERITAS: *V.Aciari et al, arXiv:0802.1951 (2008)*

Bounds on the quantum gravity scale

- At the quantum gravity scale, photons and neutrinos expected to experience a non-trivial refractive index in vacuum.

- Parametrization:

$$v = 1 - \xi \left(\frac{E}{M_1} \right) \quad \left(v = 1 - \xi \left(\frac{E}{M_2} \right)^2 \right)$$

with $M_{1,2} \sim M_{\text{Planck}}$

- One expects a time difference for photons of different energies emitted at the same time.

- Sensitivity to M_1 (M_2):
$$M_1 \approx \frac{L \Delta E}{c \Delta t_{\text{burst}}} \approx 10^{15} \text{ GeV} \left(\frac{L}{500 \text{ Mpc}} \right) \left(\frac{\Delta E}{1 \text{ GeV}} \right) \left(\frac{60 \text{ s}}{\Delta t_{\text{burst}}} \right)$$

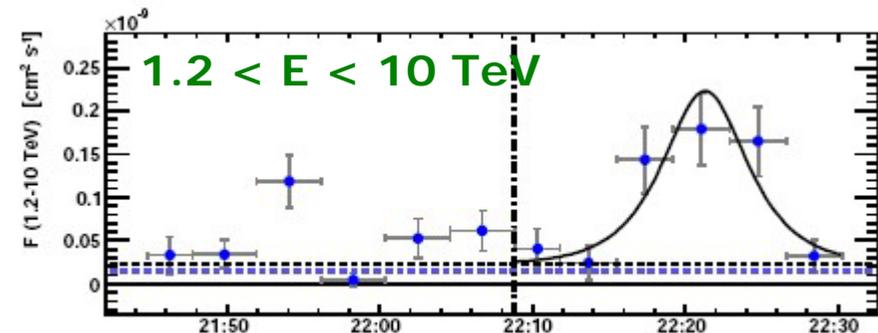
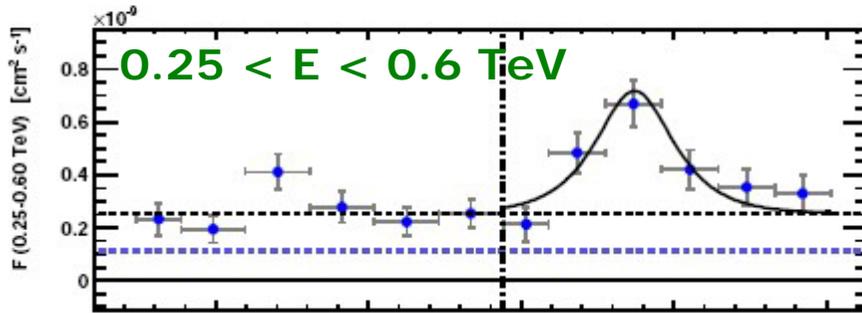
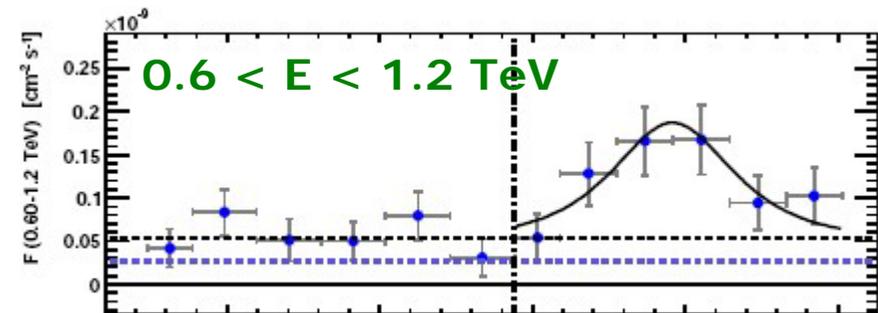
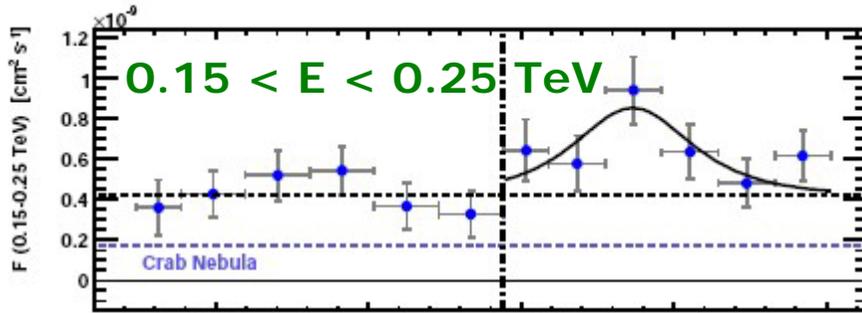
- Pulsar observed at GeV energies, $L \sim 1 \text{ kpc}$, $\Delta t \sim 1 \text{ ms}$

$$M_1 \sim 10^{14} \text{ GeV}$$

- AGN with Cerenkov telescopes, $z \sim 0.1$, $\Delta t \sim 1 \text{ mn}$, $E \sim 1 \text{ TeV}$,

$$M_1 \sim 10^{18} \text{ GeV}$$

Mkn501 (MAGIC)

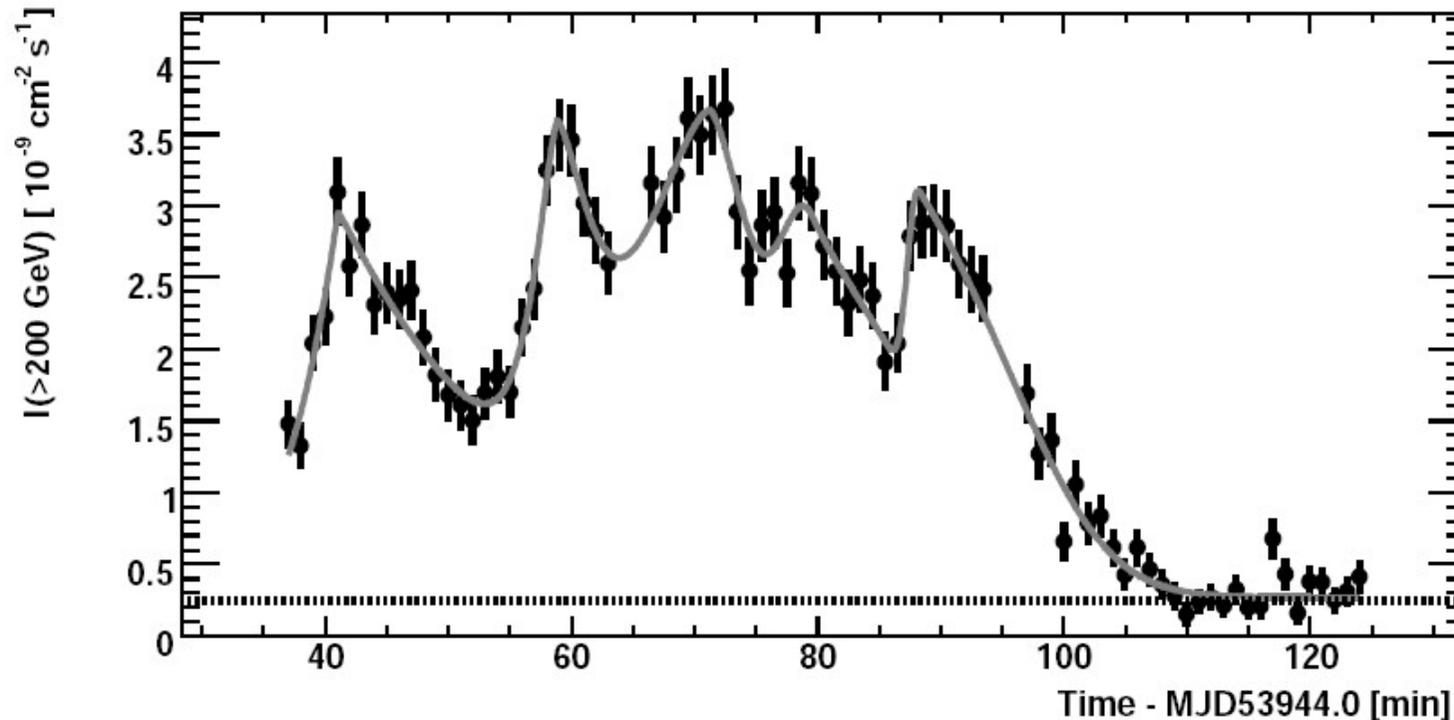


- blazar at $z=0.034$ ($L \sim 170$ Mpc)
- large flare (~ 3.5 Crab units) on 9/07/2005
- flux-doubling time ~ 2 minutes
- time of maximum energy dependent: $t_{\max}(>1.2 \text{ TeV}) - t_{\max}(<0.6 \text{ TeV}) = 4 \pm 1$ minute
- limits on quantum gravity scale: $M_1 > 0.26 \cdot 10^{18} \text{ GeV}$ (95%CL)
 $M_2 > 0.39 \cdot 10^{11} \text{ GeV}$ (95% C.L.)

*Albert et al (MAGIC)
ApJ, 669, 862 (2007)*

Albert et al (MAGIC) + J. Ellis et al. (arXiv:0708.2889, 2007)

PKS2155-304 (H.E.S.S)



- blazar at $z=0.116$ ($L=580\text{Mpc}$)
- > 5 outbursts (up to 15 Crab Units) observed on 28/07/2006
- flux-doubling time = $330 \pm 40 \text{ s}$
- shortest rise time = $173 \pm 28 \text{ s} \sim (R_{\text{Schwarzschild}}/c)/100$
 \Rightarrow large boost factor

F.Aharonian et al. (HESS), ApJ 664,L71 (2007)

summary and perspectives

- Surveying capabilities (HESS) ⇒ new sources found on a regular basis
- Galactic Center: signal from Sgr East excluded (HESS)
- Indirect dark matter search:
new results from HESS (Sgr dwarf), MAGIC (Draco), Whipple
still lacking 2-3 orders of magnitude
- interesting bounds on quantum gravity scale (MAGIC)
- new instruments coming very soon:
 - ground-based: MAGIC-II (2008)
HESS-II (2009)
 - satellite: GLAST (2008)