Gamma-Ray Astronomy on the Ground:

Results and Perspectives

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Physics in the VHE band

Cosmic ray origin and acceleration

- Supernova remnants ☑
- Starburst galaxies
- Unidentified galactic sources / Surveys ☑
- Clusters of galaxies

Astrophysics of compact objects

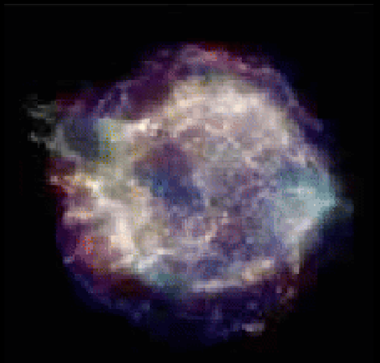
- AGNs ☑
- Micro-quasars and Stellar-mass black holes
- Pulsars ☑
- Gamma-ray bursts

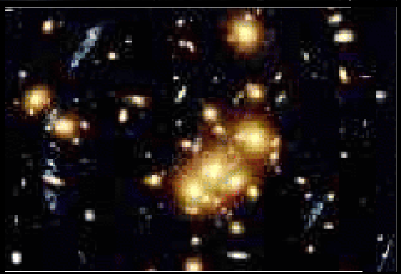
Cosmology

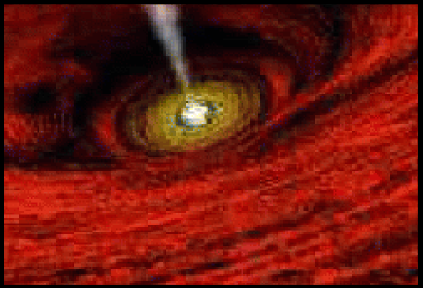
- Diffuse extragalactic radiation fields
  via cutoff in AGN spectra and AGN halos
- Clusters of galaxies

Astroparticle physics

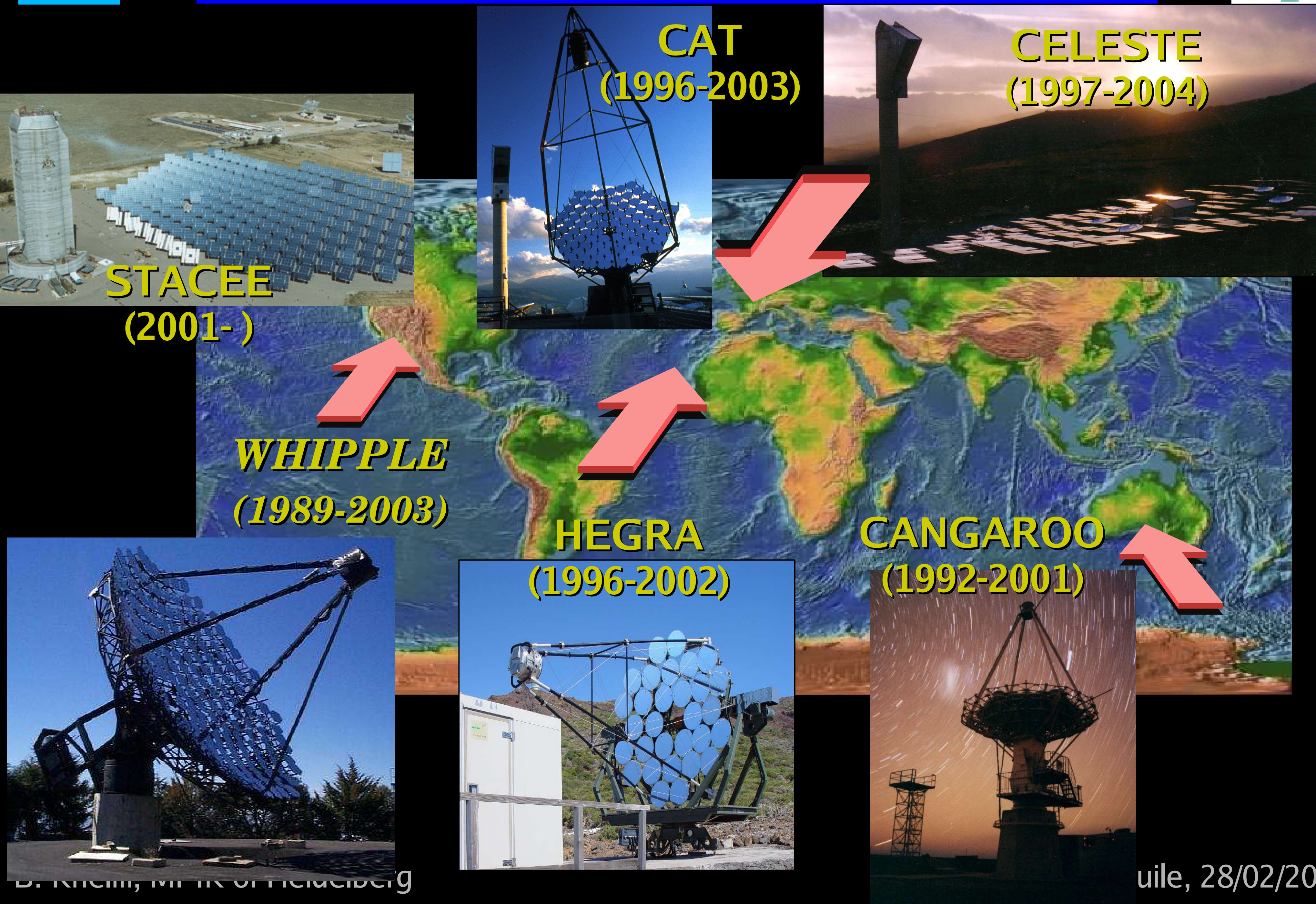
- Neutralino annihilation in DM halos ☑



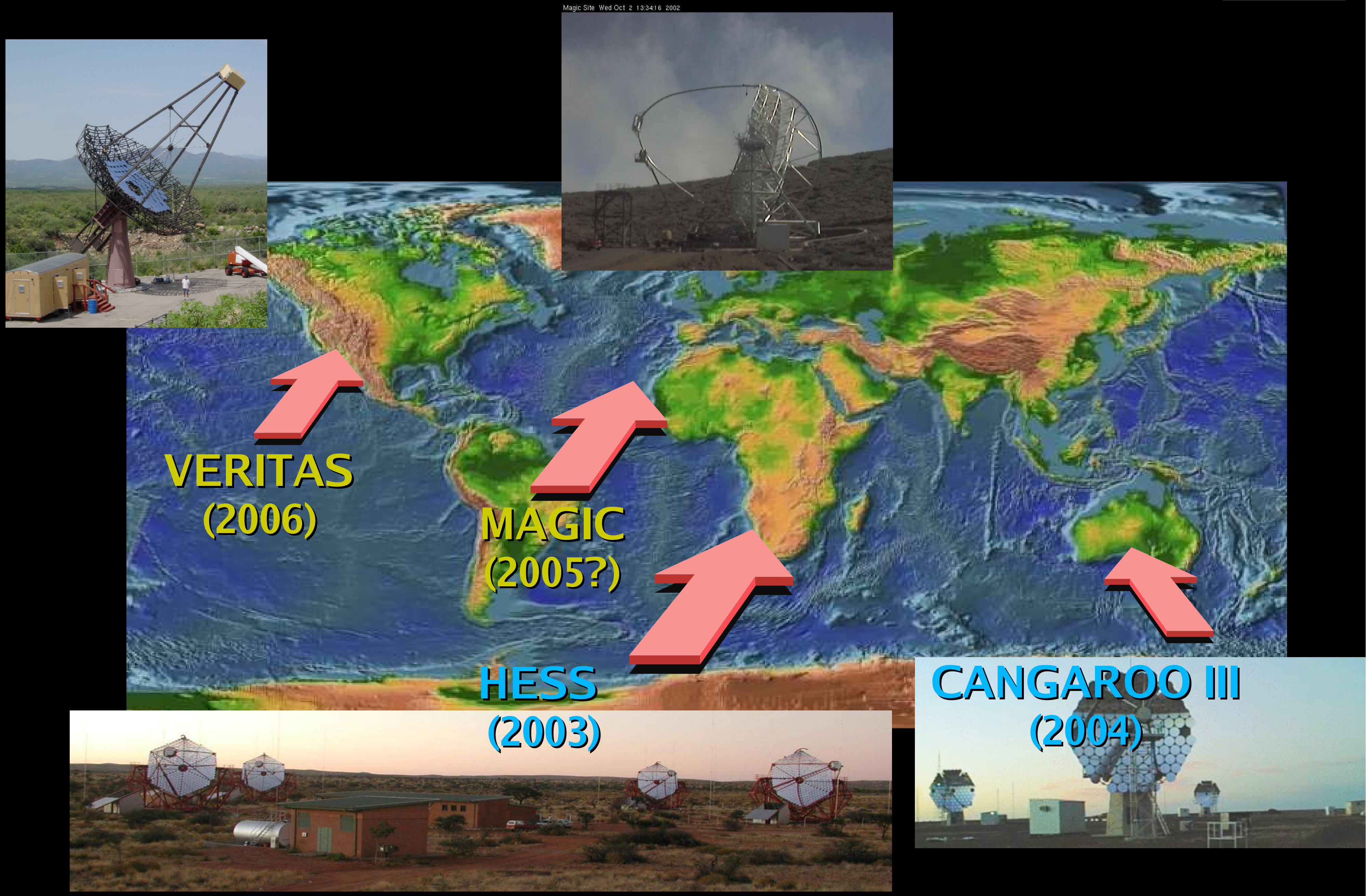




Atmospheric Cherenkov Technique: Last-Generation Detectors



Current and next Generation of ACTs



The H.E.S.S. experiment

Array

- Situated in Namibia, 1800 m asl
- 4 telescopes, separated by 120 m

Telescope

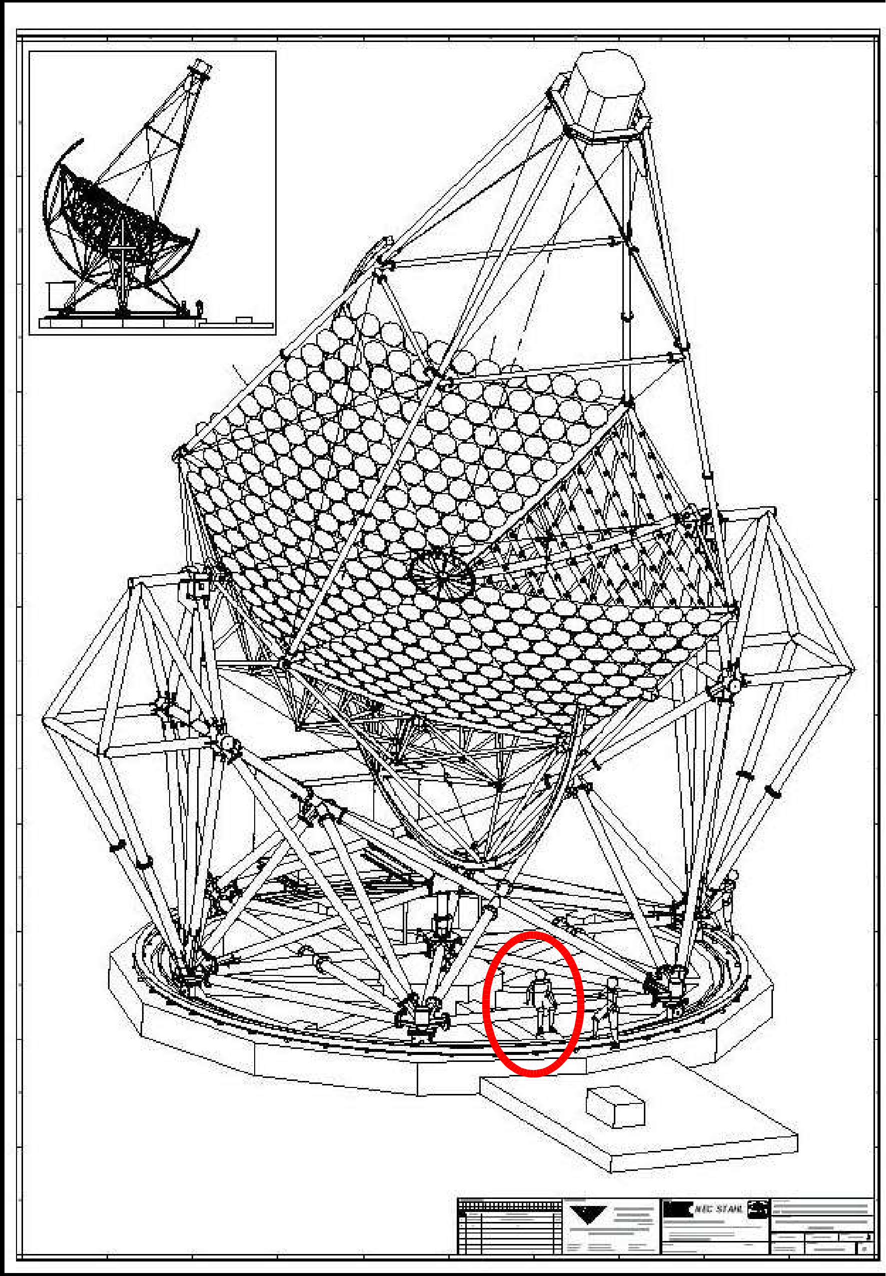
- Mirror area $\simeq$107 m^2
- Focal length: 15 m (f/d $\sim$ 1.2)

Camera

- 960 PMTs (0.16º)
- 5º field of view
- Readout integrated in camera body
- 16 ns integration, 1 GHz sampling

Central Trigger system

- Allows for telescope multiplicity requirement



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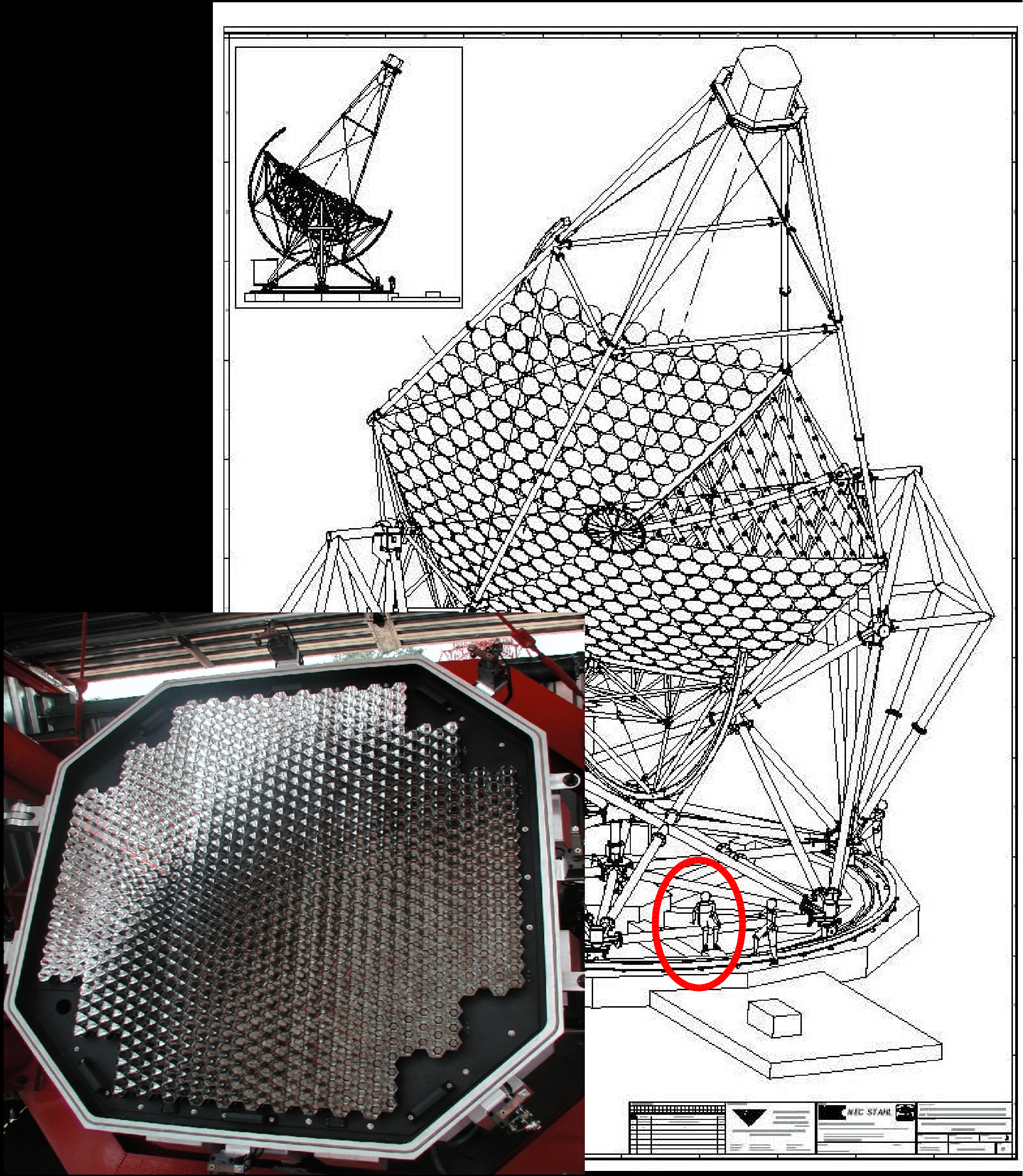

The H.E.S.S. experiment

Array

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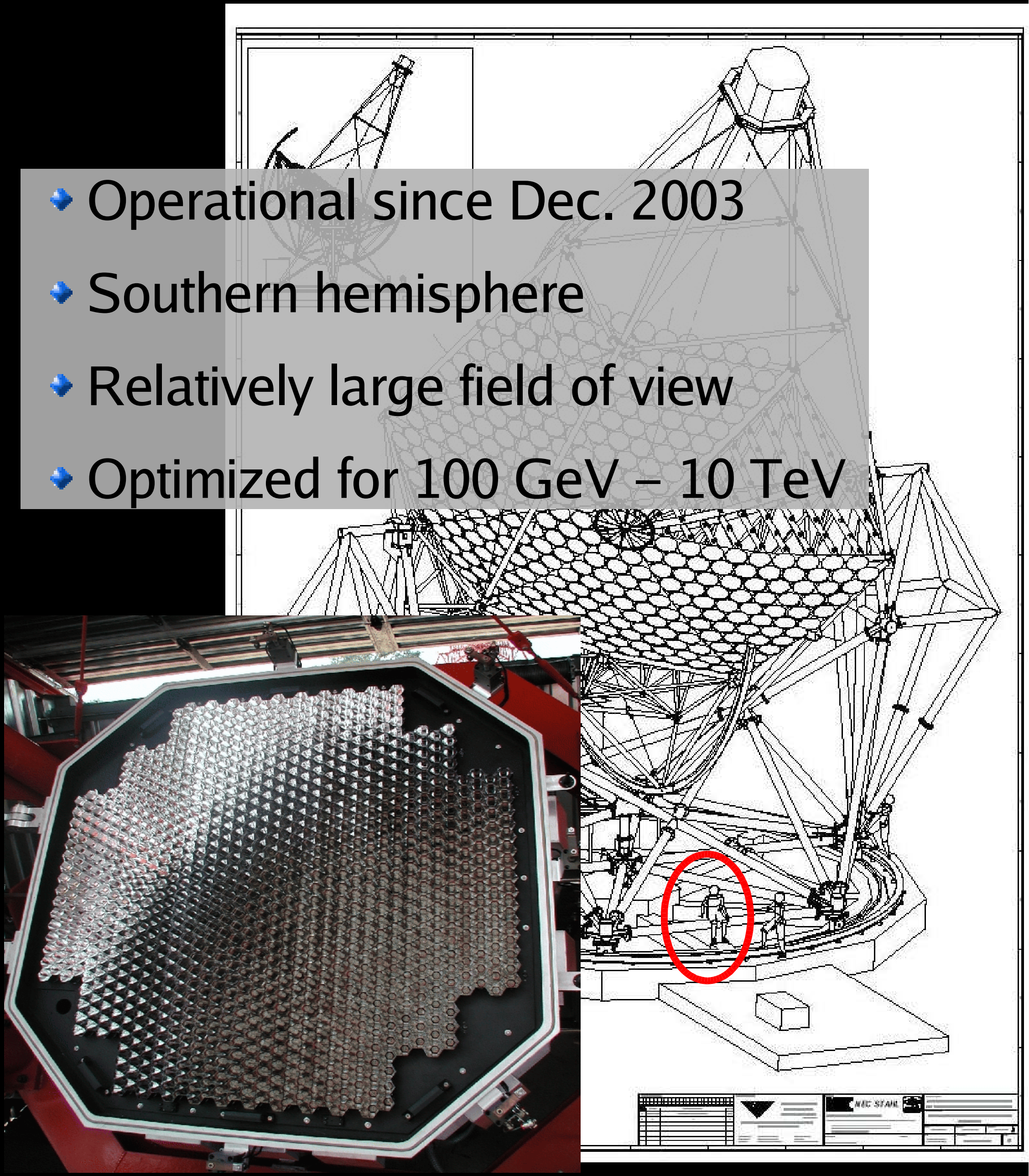
- 4 telescopes, separated by 120 m

- Operational since Dec. 2003
- Southern hemisphere
- Relatively large field of view
- Optimized for 100 GeV – 10 TeV



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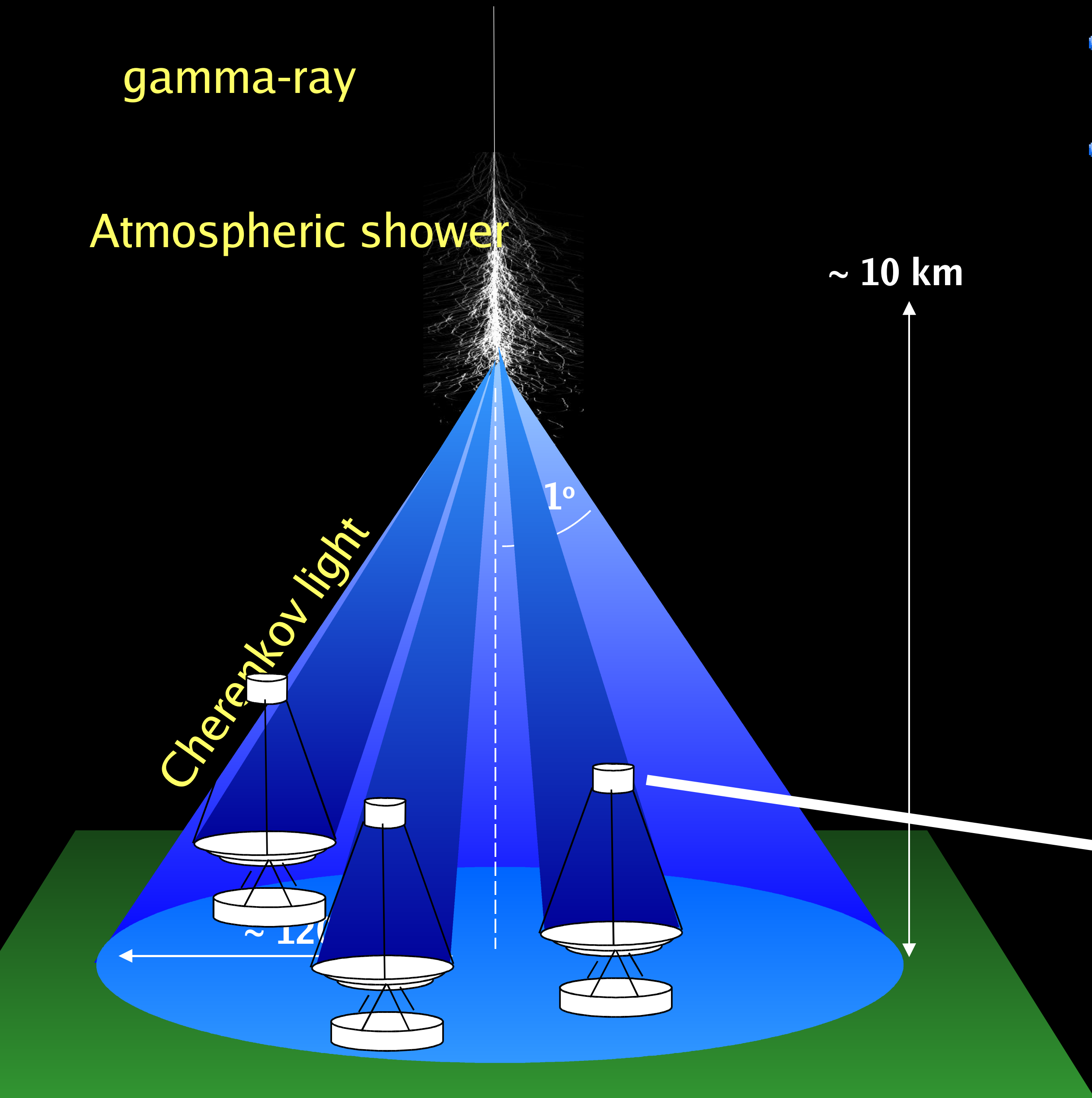
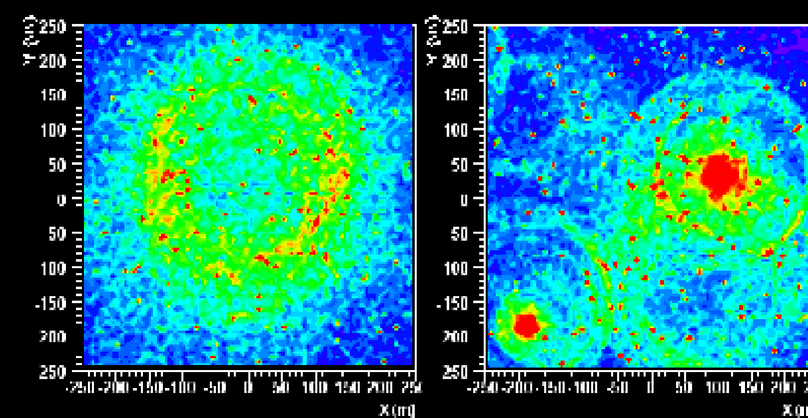
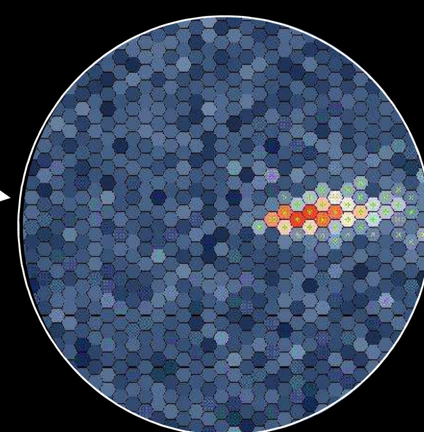
The Atmospheric Cherenkov Technique



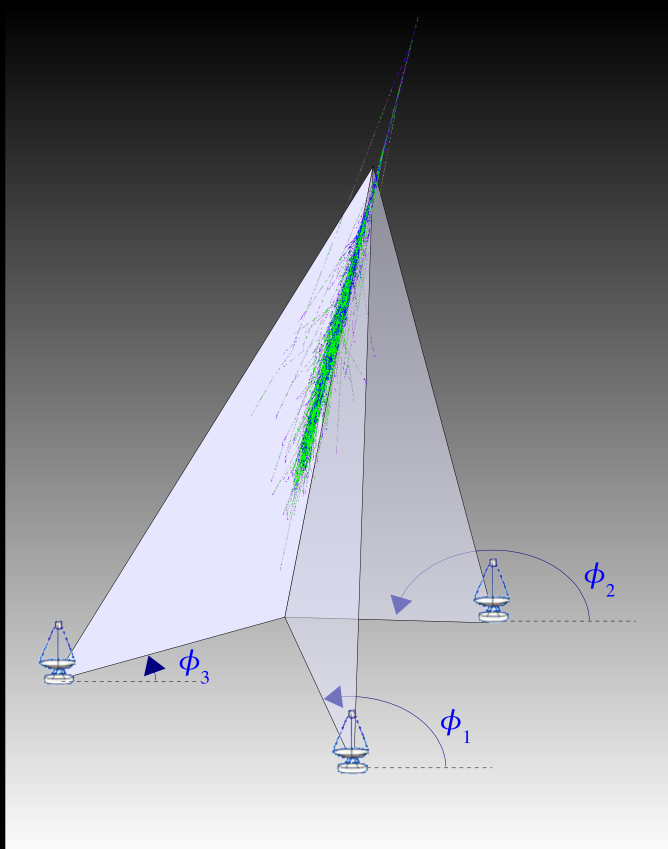
- Large collection area
- Discrimination between gamma-rays and hadrons:

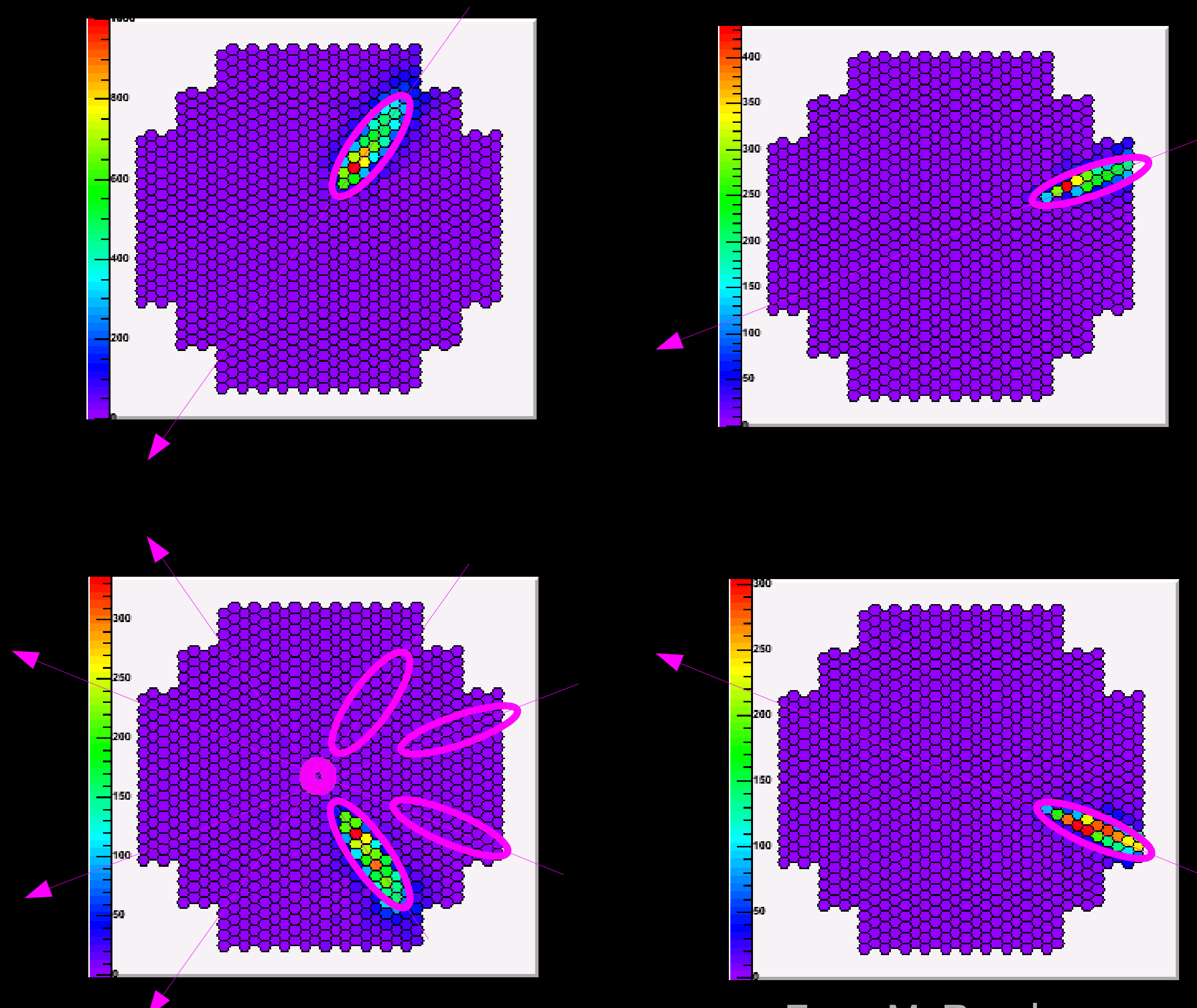


γ, 100 GeV   Proton, 500 GeV



Stereoscopic technique



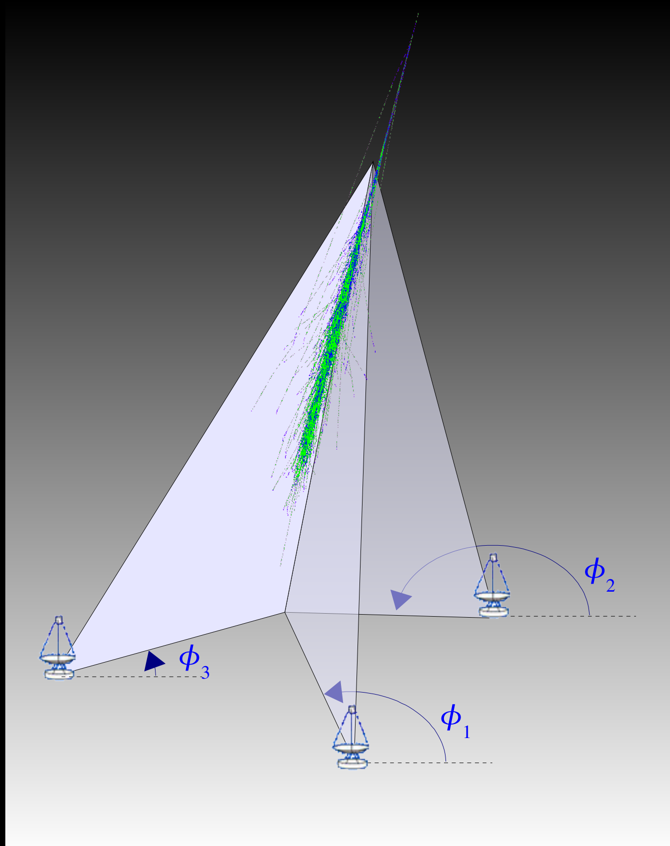


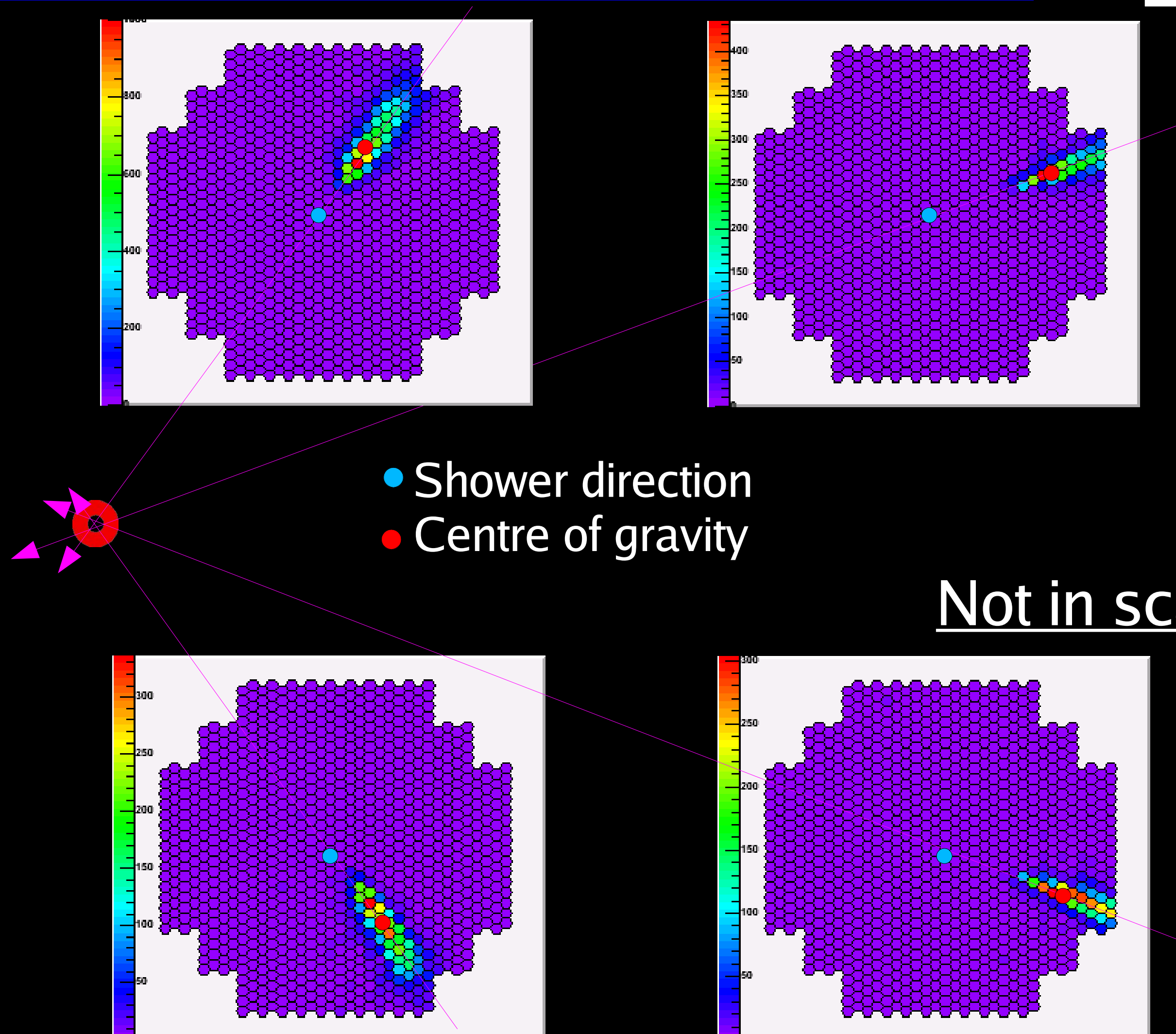
From M. Punch

Determination of arrival direction per photon:

0.14° in mono → **0.06°** en stereo

Stereoscopic technique - II





- Shower direction
- Centre of gravity

Not in scale

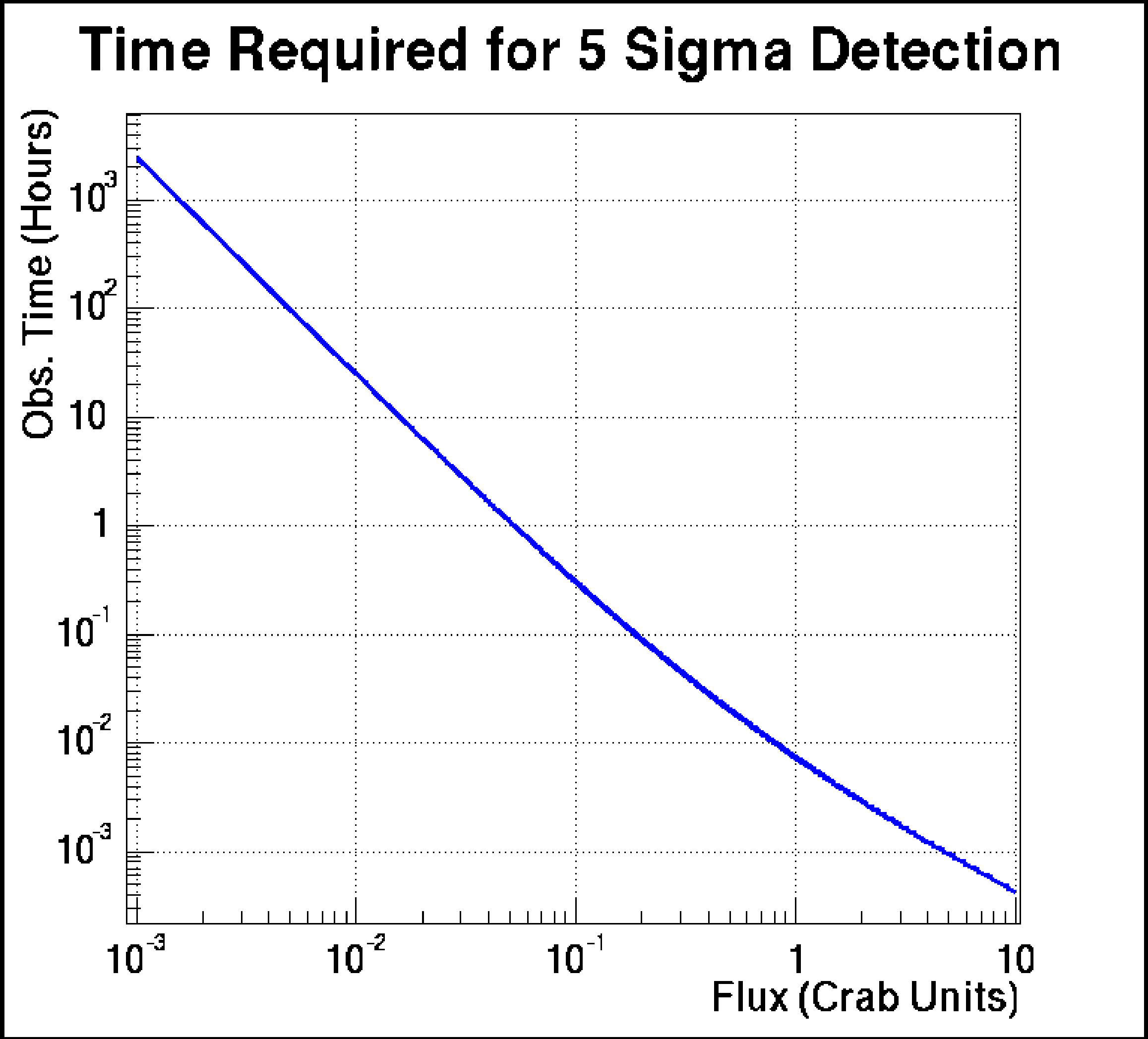
From M. Punch

Determination of shower impact: ±20m

⇒ No more degeneracy between intensity and shower impact

Energy resolution: **~15%**

H.E.S.S. Sensitivity



Use MC to predict time required to detect a source of a certain strength at zenith angle=20º:

0.01 Crab in ~25 hrs
0.05 Crab in ~1 hr
0.10 Crab in ~20 min
0.50 Crab in ~75 sec
1.00 Crab in ~30 sec

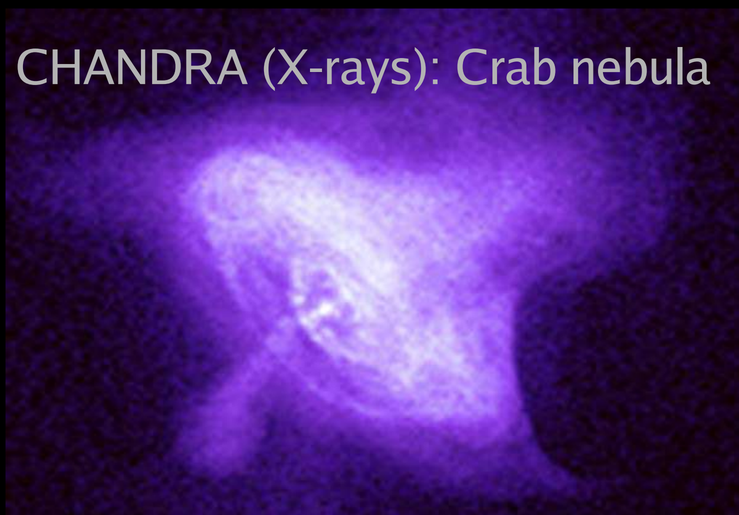
Progress in the detection of Crab

Whipple in 1989: 50 h
CAT in 1997 : 1h 20 min
H.E.S.S. in 2003: 30 sec

Pulsar Wind Nebulae

Millisecond pulsar

Acceleration of electrons: nebula

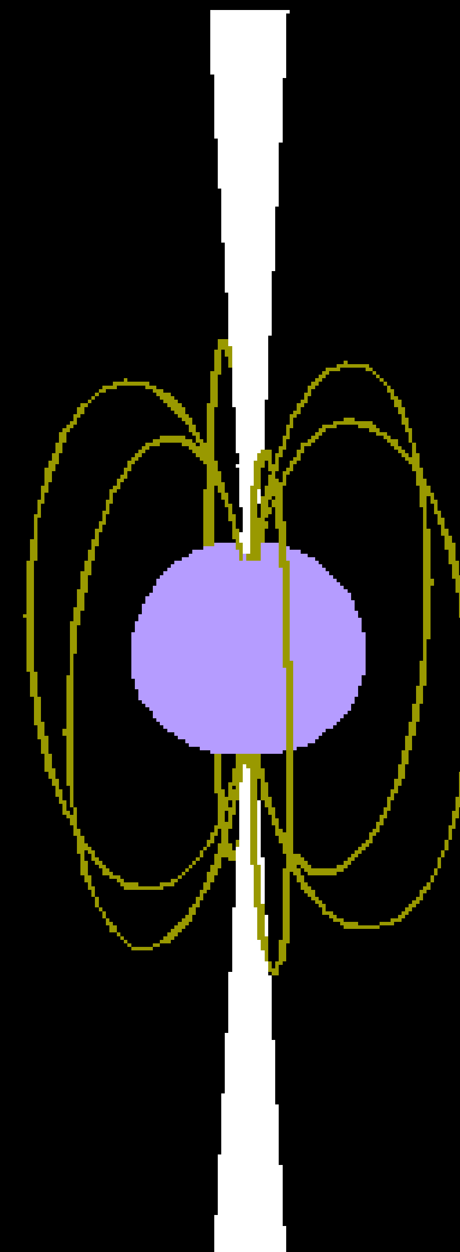


Previous detections in VHE:

- 1 confirmed (Crab), 2 detected by CANGAROO

Issue:

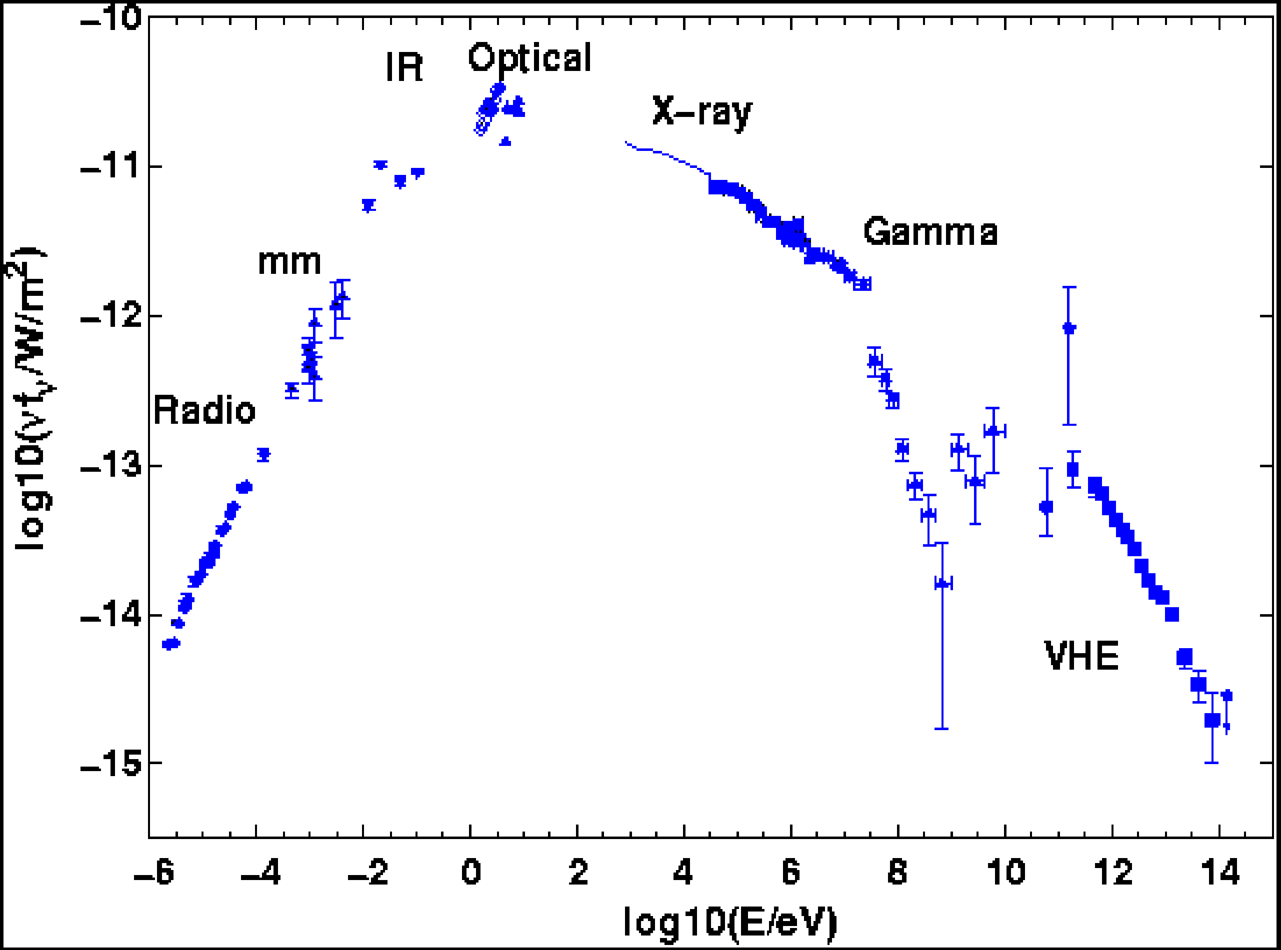
How are these particules accelerated? (E>100TeV)



Crab Nebula: a reference...

H.E.S.S. Observations

- 2003 data set (3 Tel), 2.8 hrs
- 30 $\sigma/\sqrt{h}$, 6.6±0.1 γ/min



Accelerated electrons

- Synchrotron radiation

$$dE/dt_{Sy} = k\gamma^2 U_{mag} \sim B^2$$

- Inv. Compton scattering

$$dE/dt_{IC} = k\gamma^2 U_{rad}$$

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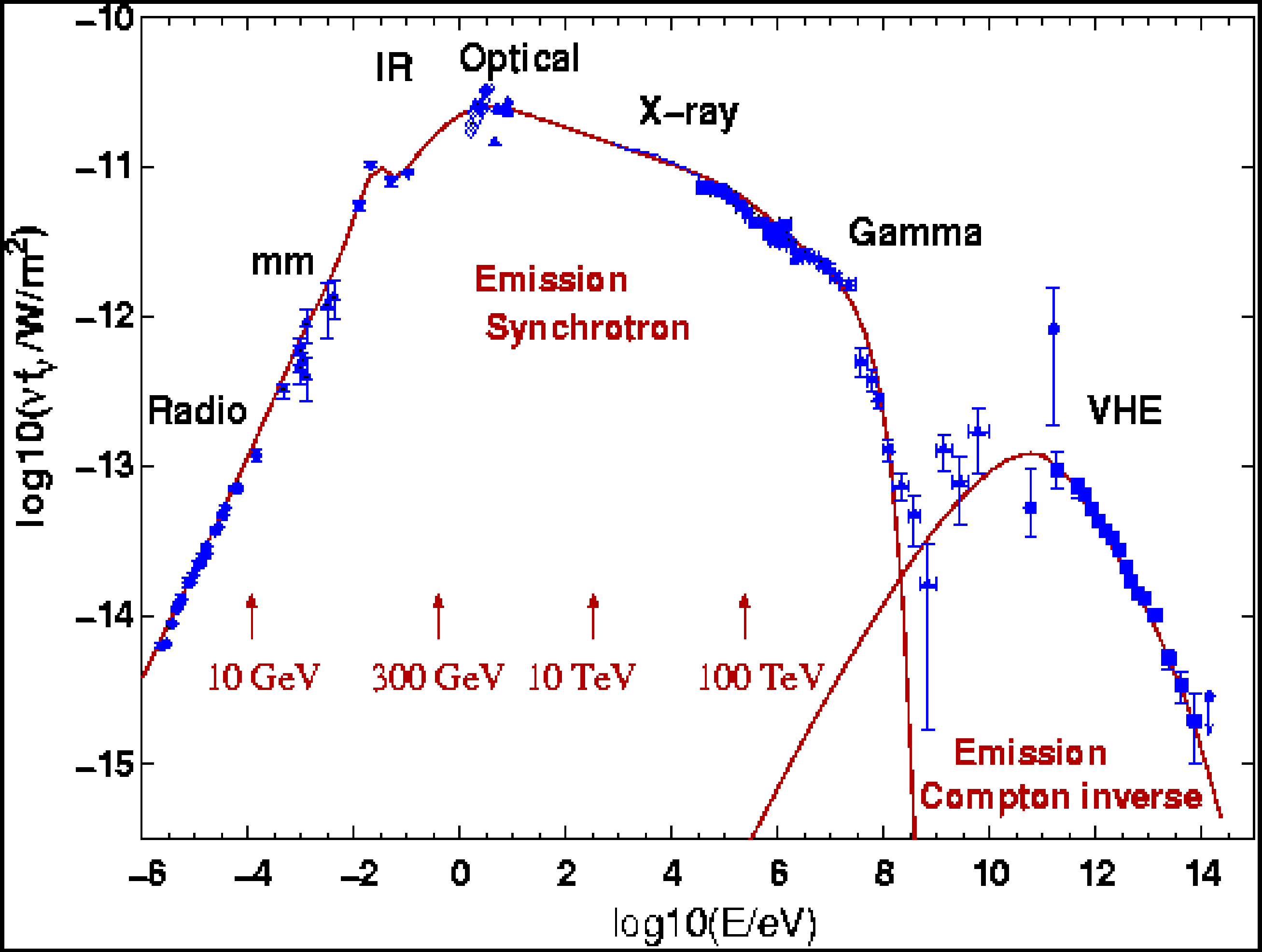
B ~160 μG

IC flux composed by:
~ 80% SSC
~ 20% on FIR, mm, CMB

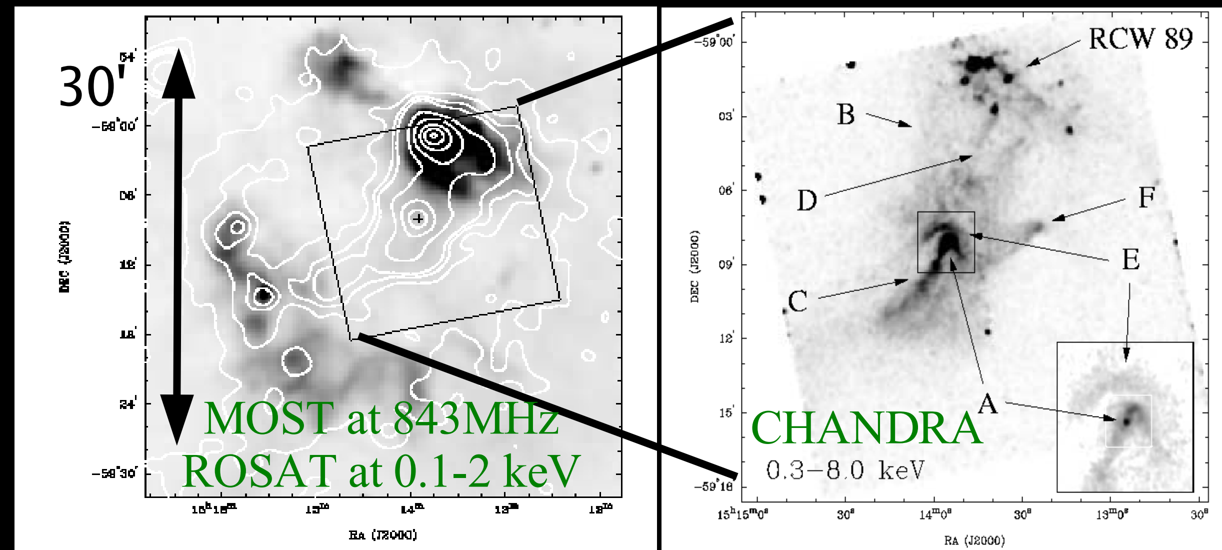


Horns et al., 2004

The PWN inside MSH 15-52

Clear PWN inside an SNR

- Age: 1.7–20 kyrs, Dist: 5.4 kpc
- «jets», no torus



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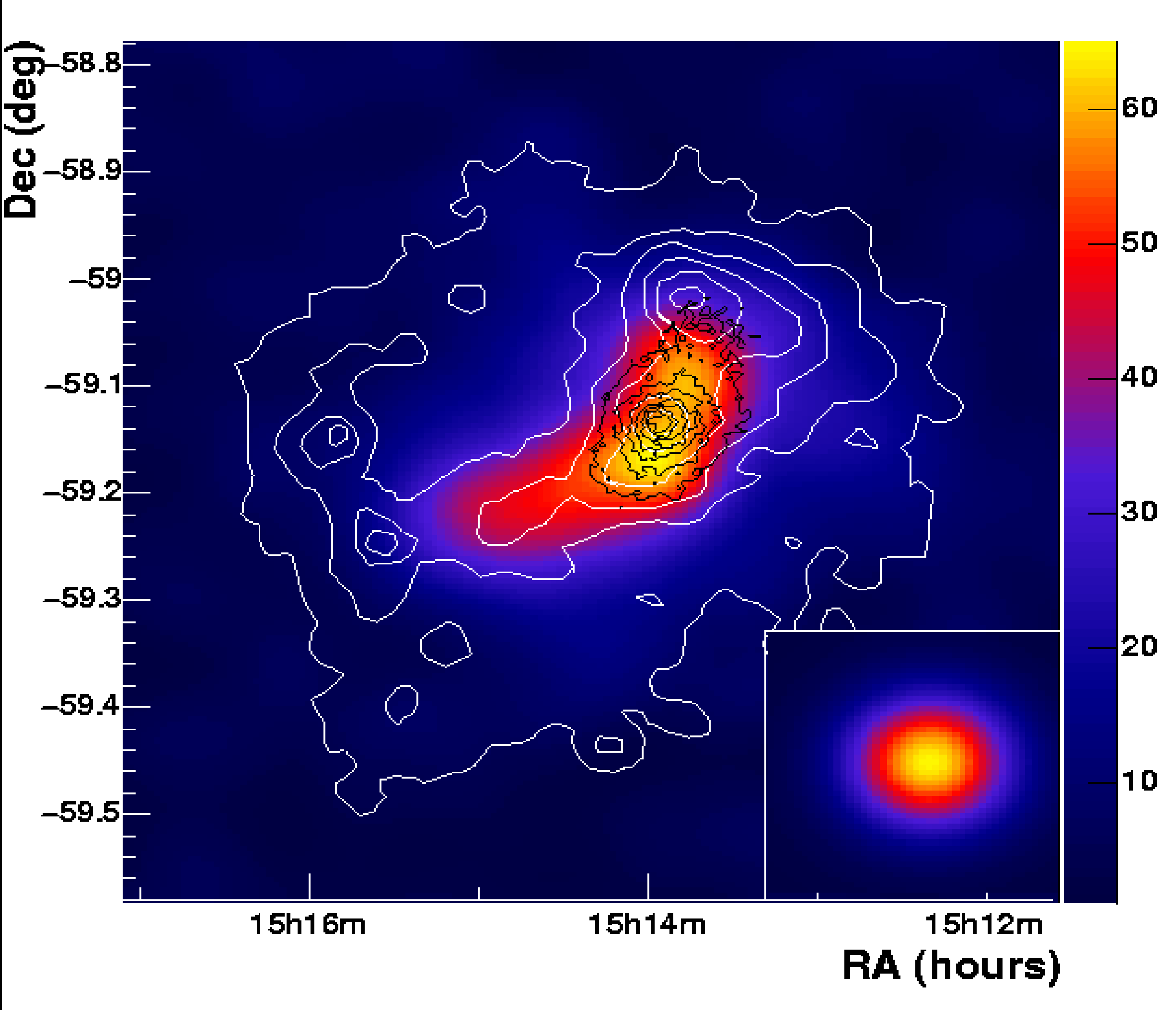
- 22 hrs, E_{th} ~ 280 GeV
- Excess of 27 σ
- Asymmetric excess
- Flux of 15% Crab, Γ = 2.3±0.03



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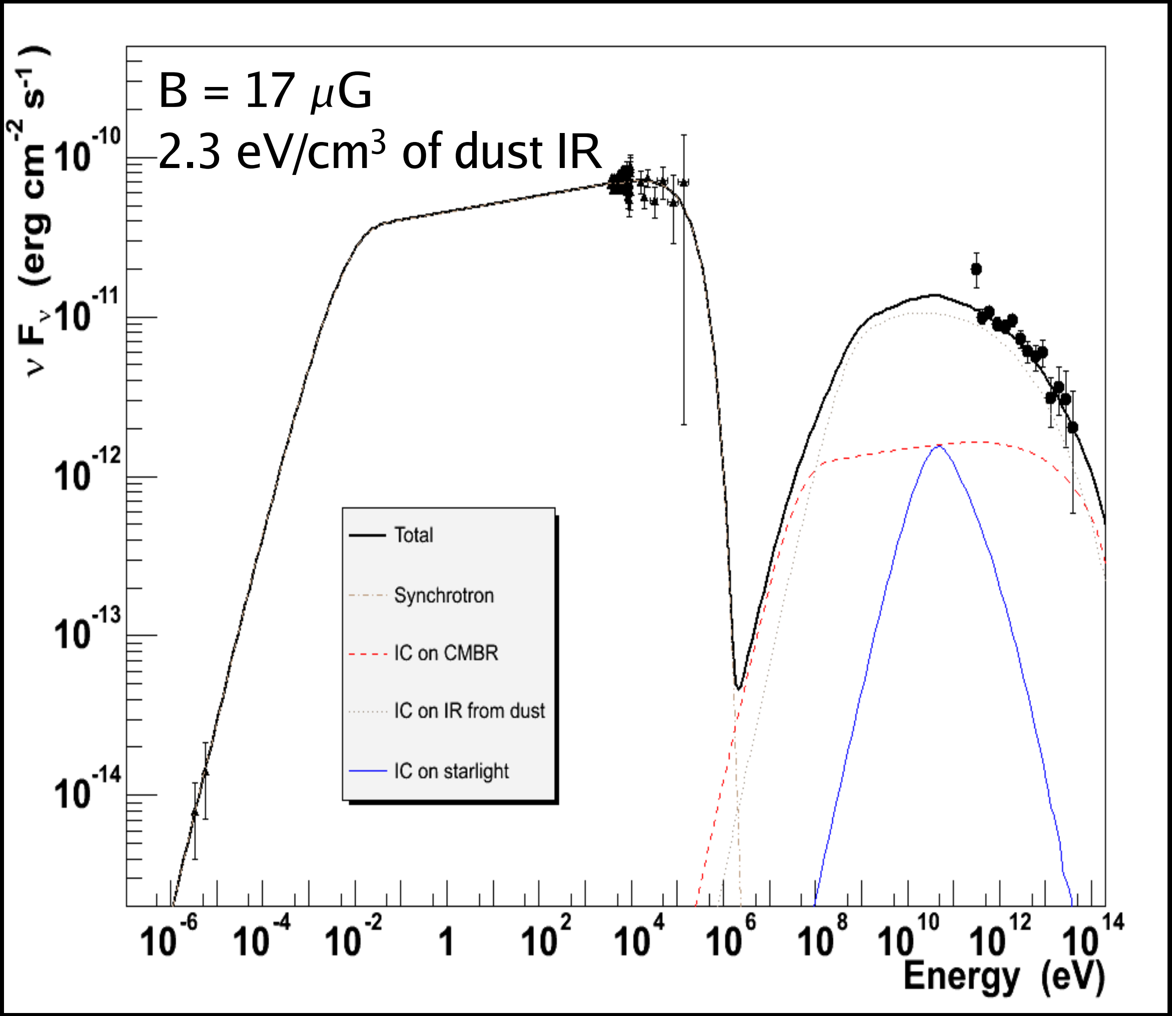
IC Interpretation

- Need an age >5 kyrs ....



Aharonian et al., 2005, for A&A

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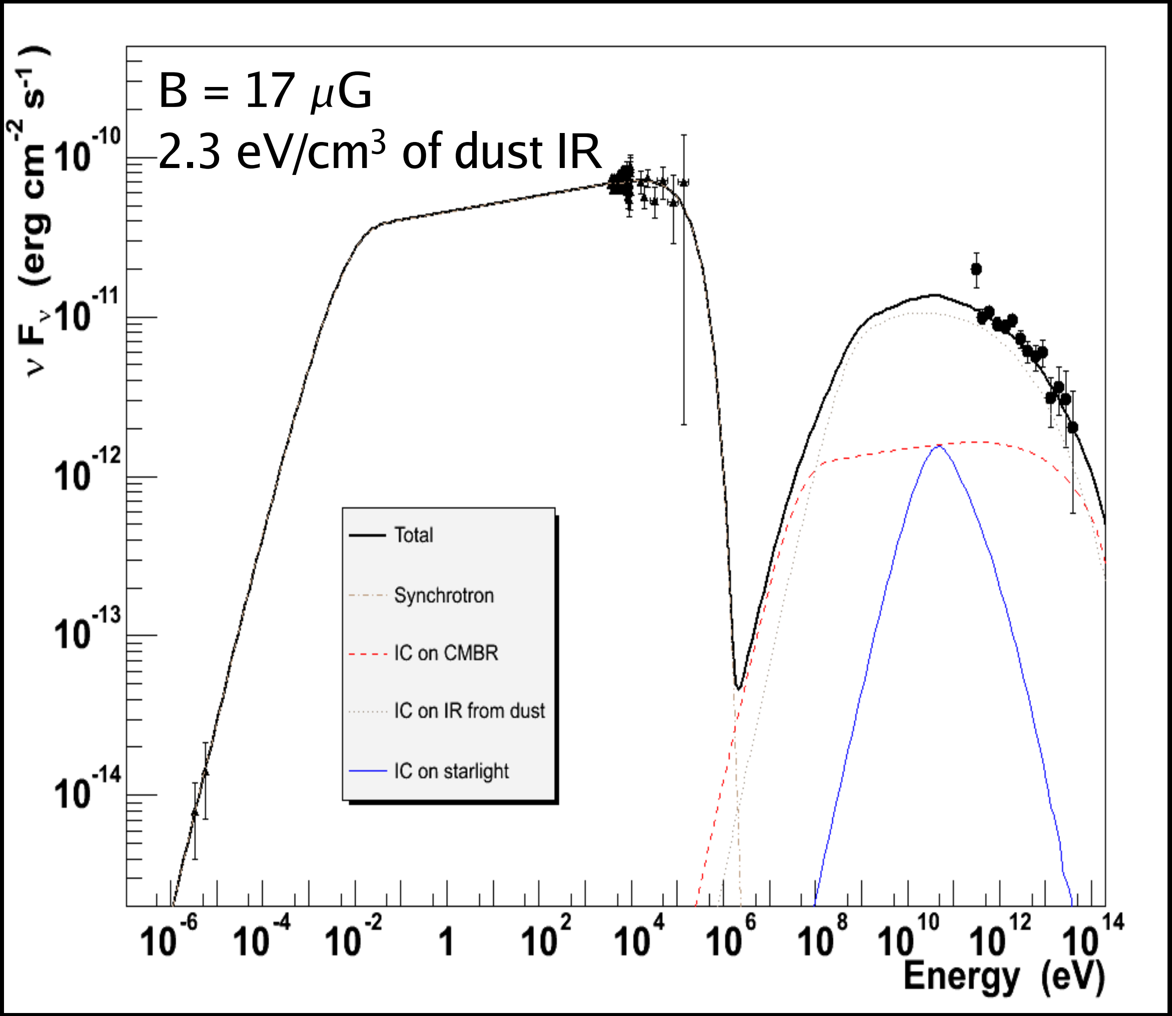
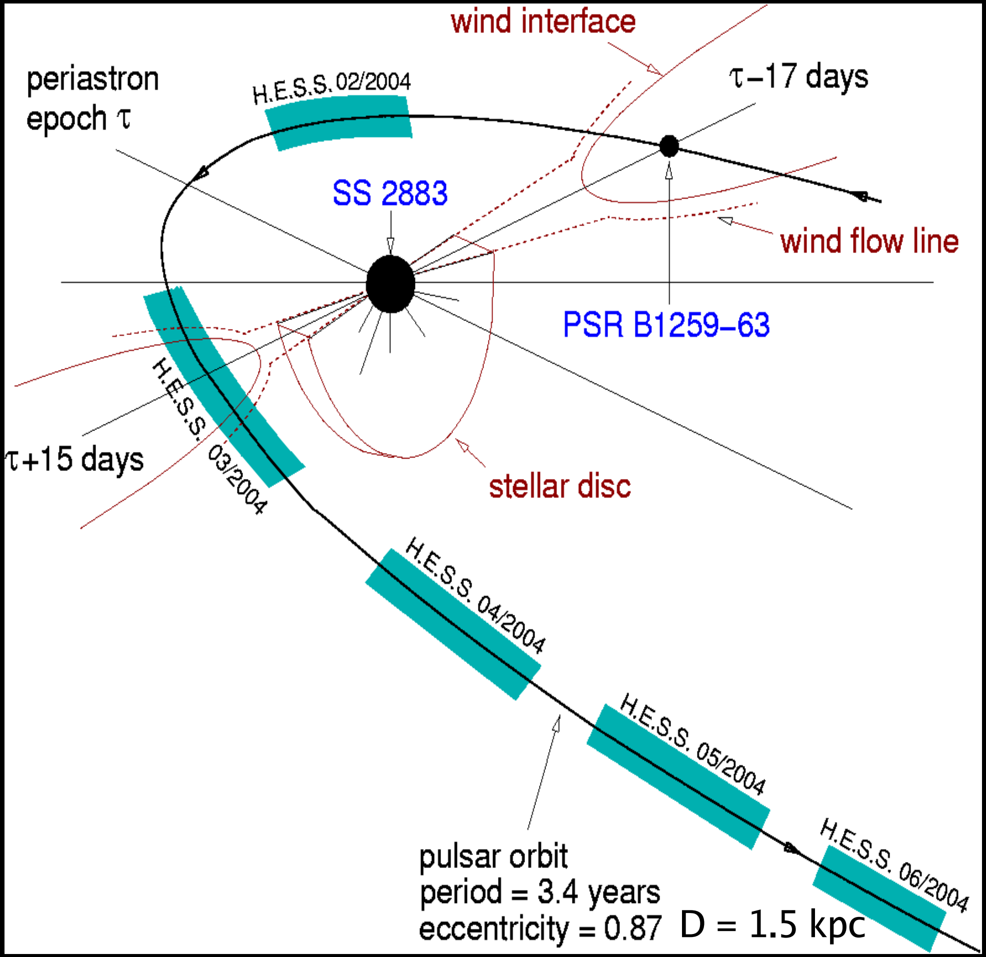


Aharonian et al., 2005, for A&A

⇒ First extended PWN detected in VHE

The binary PSR B1259 / SS2883



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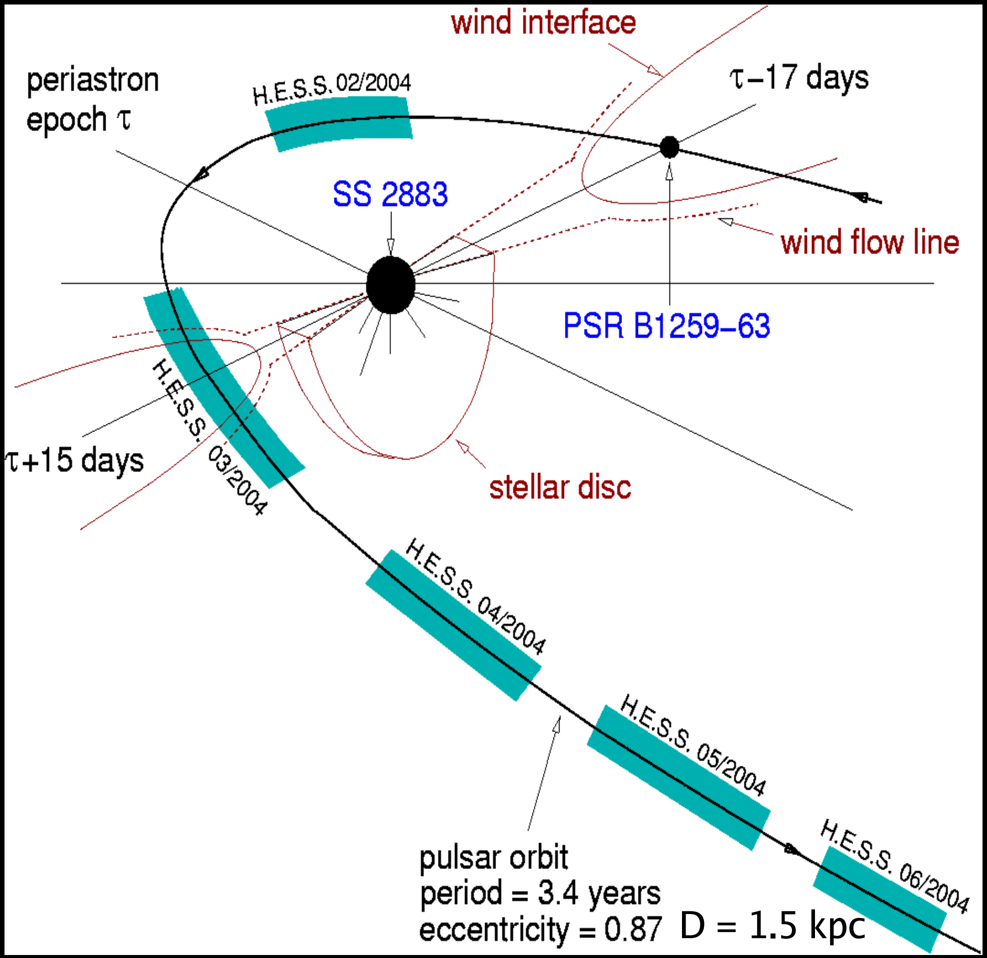

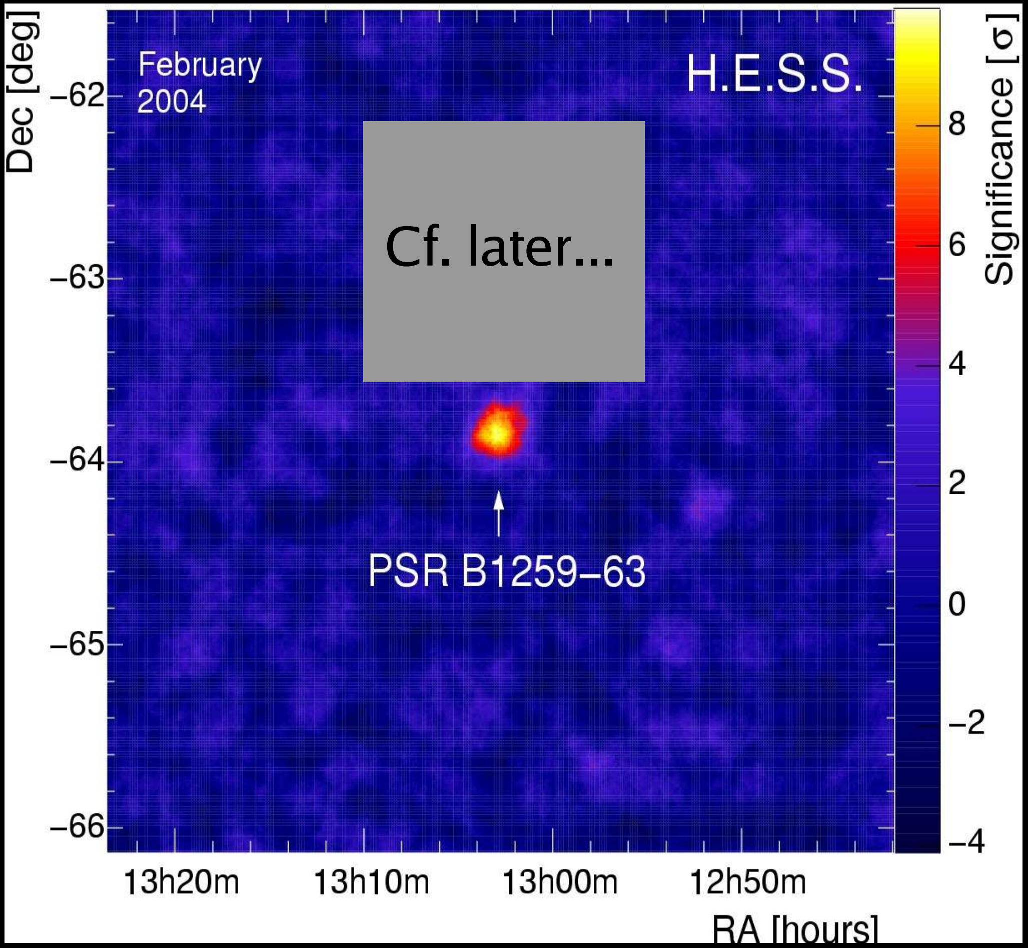

Data set: 50 hrs, > 13σ

Aharonian et al., 2005, for A&A

Spectrum: Flux of 4.5% Crab, Γ = 2.7±0.2

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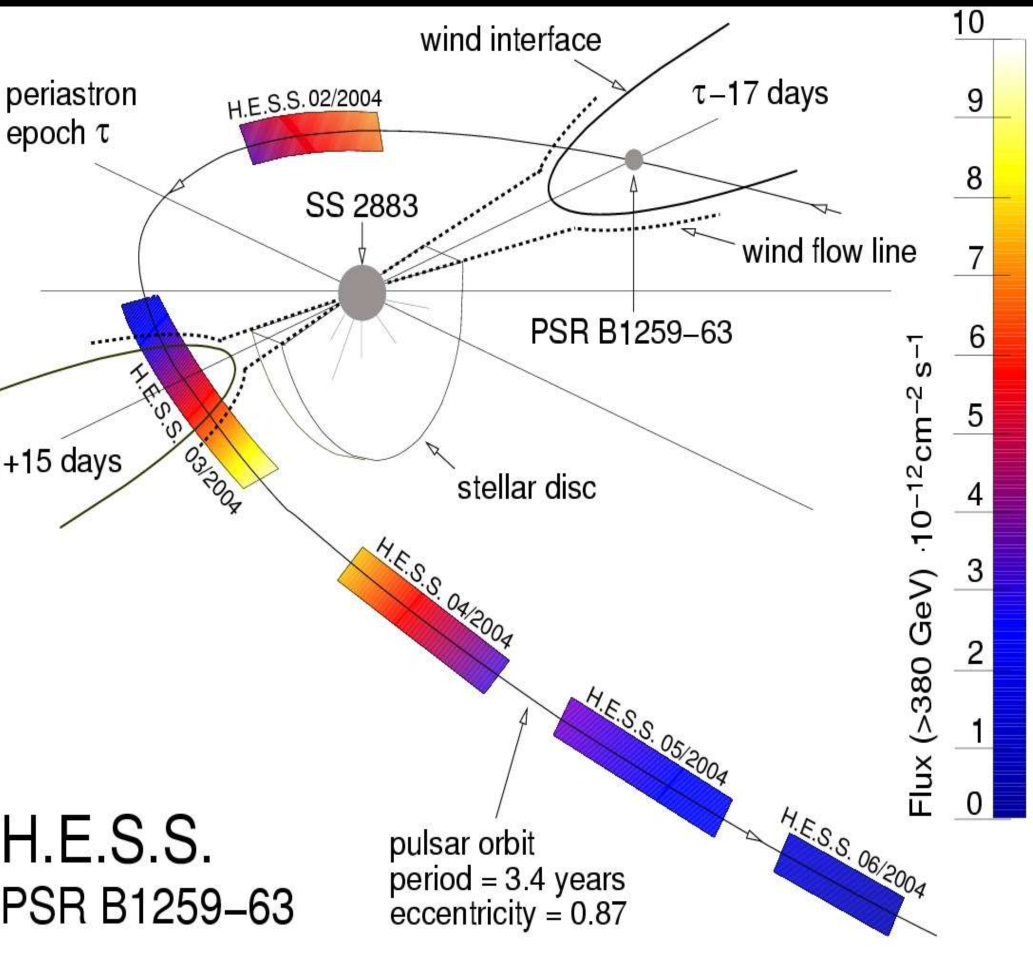

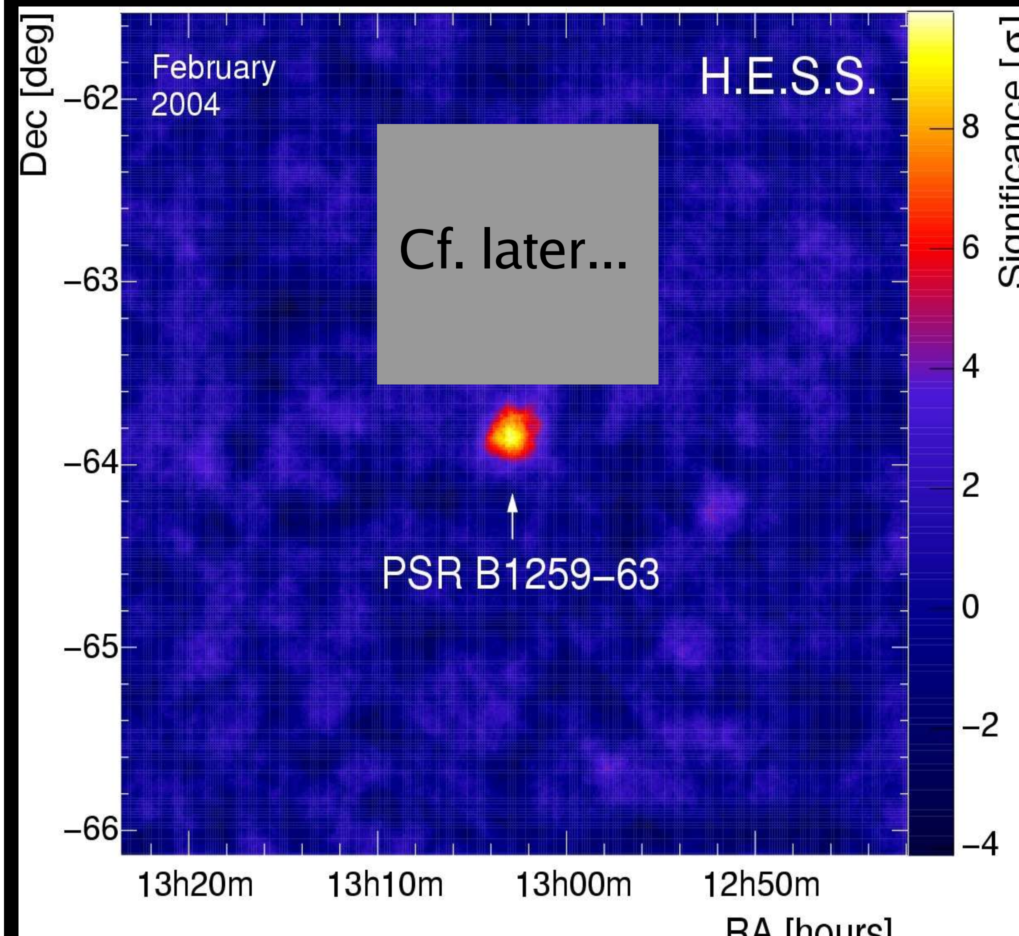

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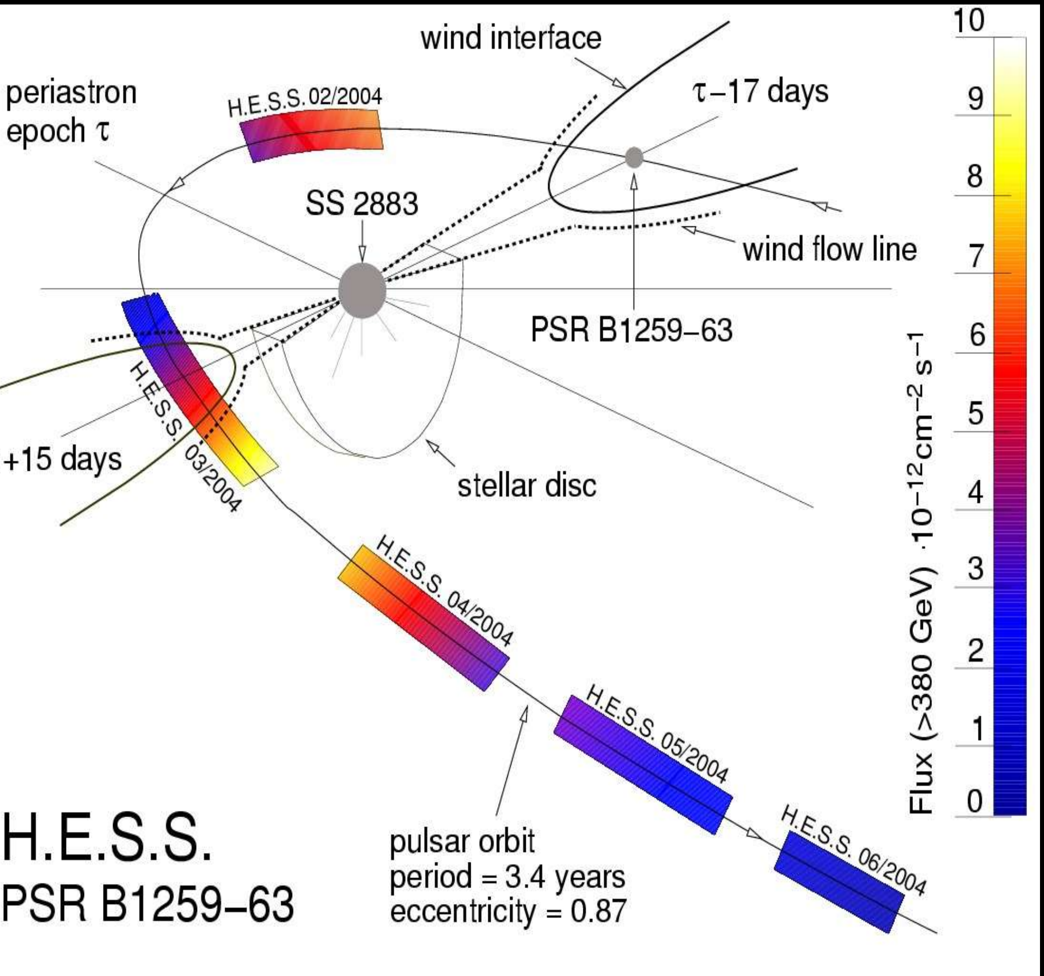
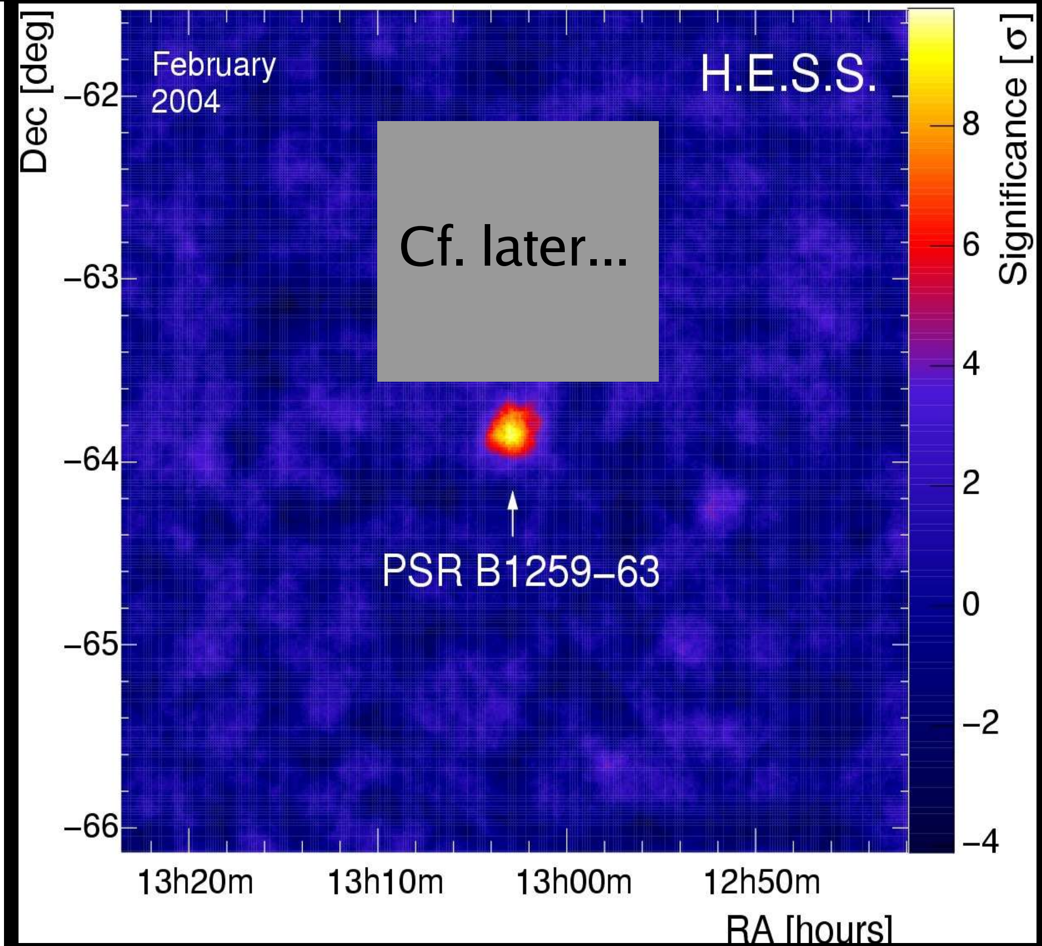




Data set: 50 hrs, > 13σ

Aharonian et al., 2005, for A&A

Spectrum: Flux of 4.5% Crab, Γ = 2.7±0.2

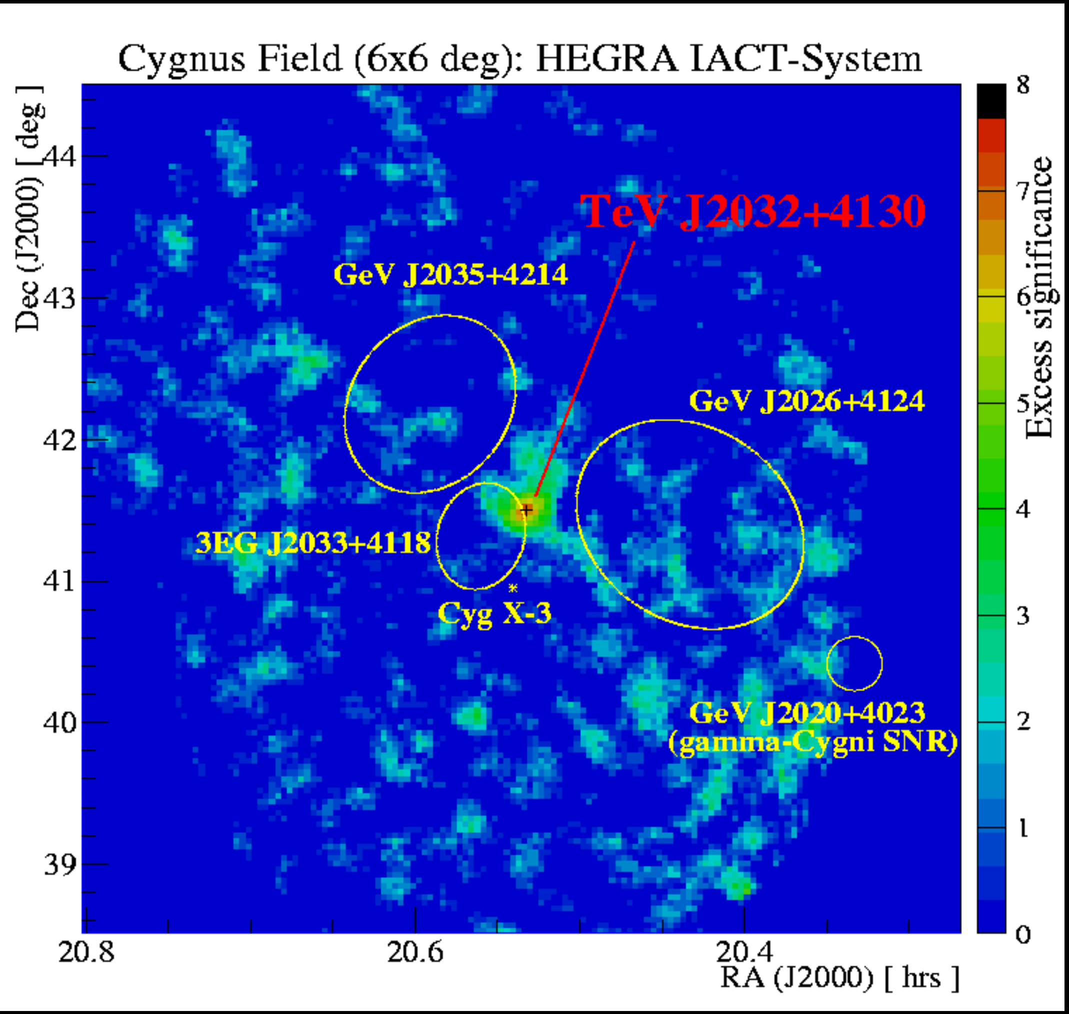
⇒ First variable galactic source in VHE

(Still) Unidentified VHE sources

Sources with no counterpart in radio, optics, X-ray, MeV, GeV, ...

New type of sources?

Known unidentified sources



Detection by HEGRA

Aharonian et al., 2001, 2004

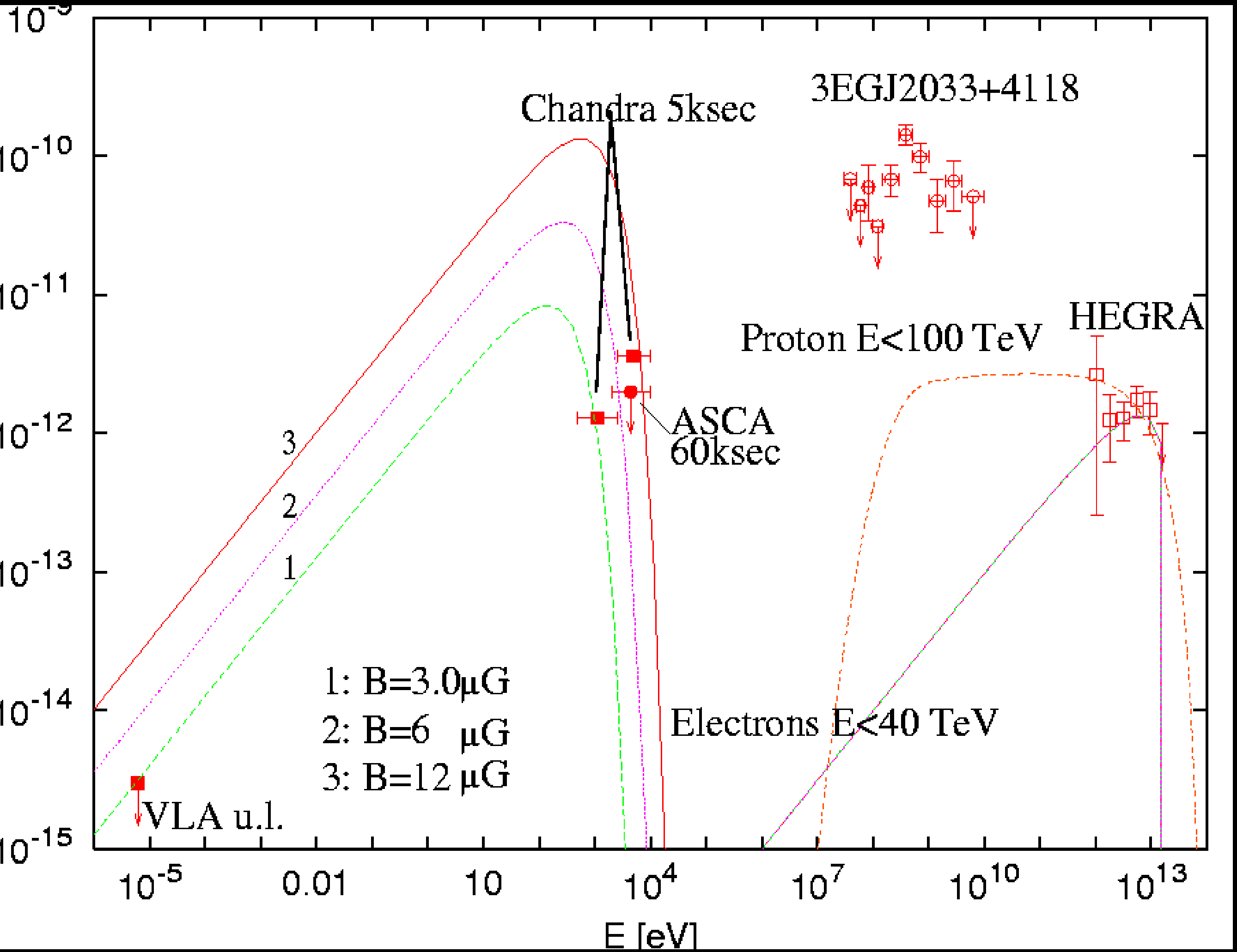
Spectrum

5% Crab, Γ = 1.9±0.1

Extended source

Radius = 6.2'±1.2'

Known unidentified sources



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5% Crab, Γ = 1.9±0.1

Extended source

Radius = 6.2'±1.2'

Type of accelerated particles?

Almost not compatible with electrons

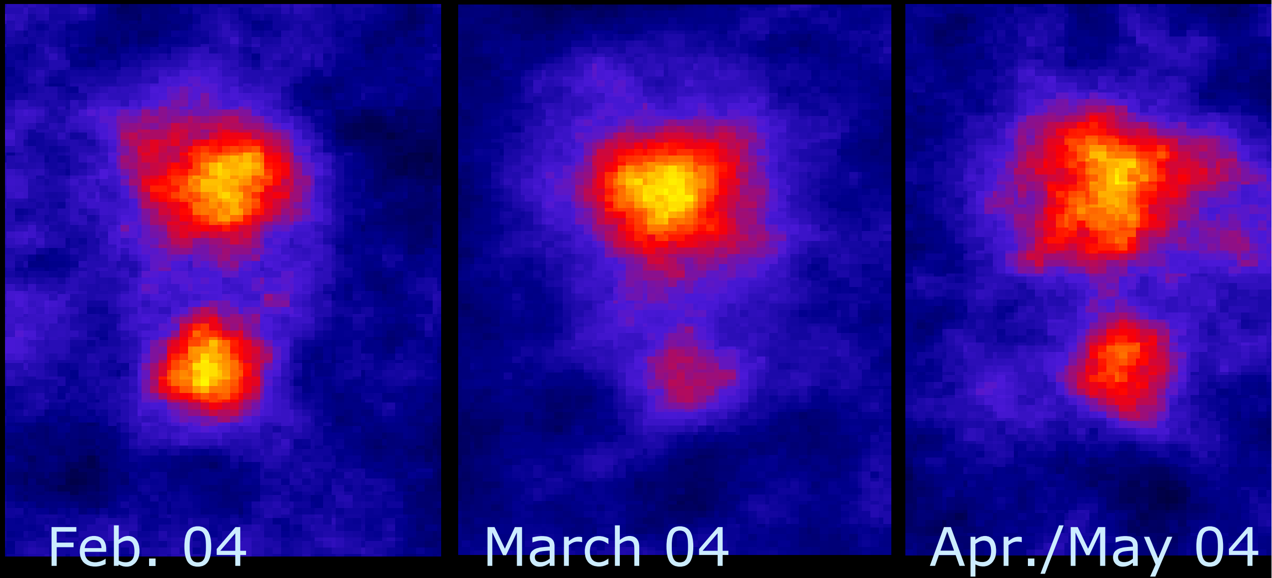
Near Cygnus OB2

HESS J1303-631

In the field of view of PSR B1259

21 σ in 48 hrs (2004)

Aharonian et al., 2005, for A&A



Morphology

Radius ~ 0.16°

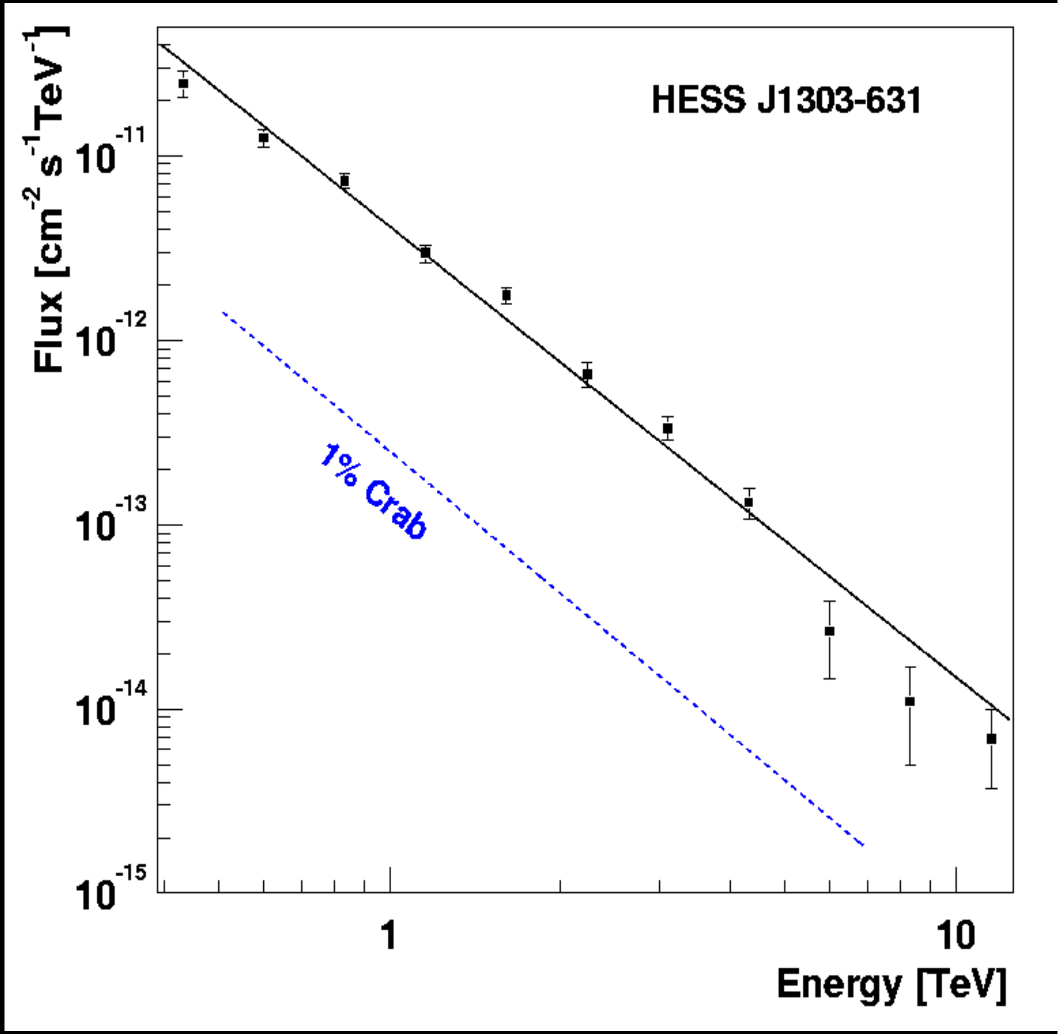
HESS J1303-631

In the field of view of PSR B1259

Morphology

Spectrum

- Steady flux
- Flux of 18% Crab, $\Gamma = 2.4 \pm 0.1$



HESS J1303-631

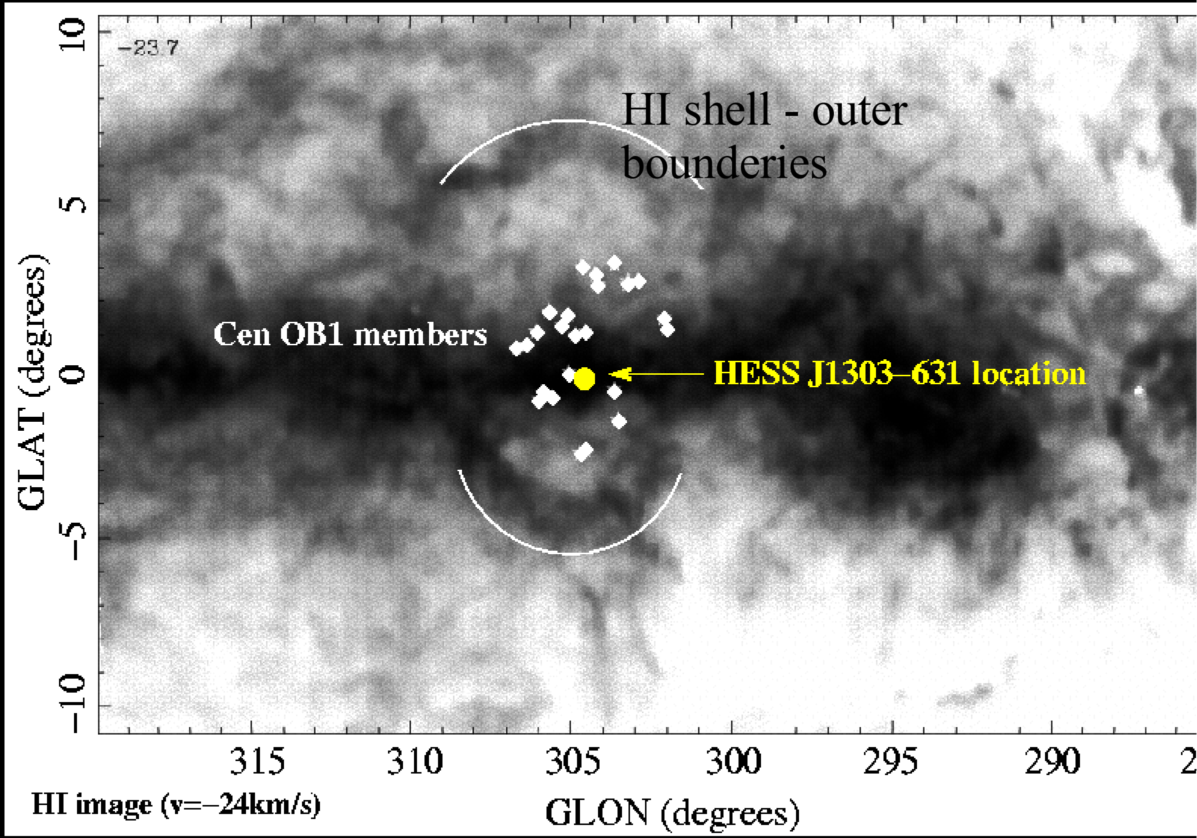
In the FoV of PSR B1259

Morphology

Spectrum

No counterpart at other wavelengths

But within a stellar association
and possibly a superbubble



Source of power for proton acceleration?

The supernova remnants

Expected to accelerate charged particules

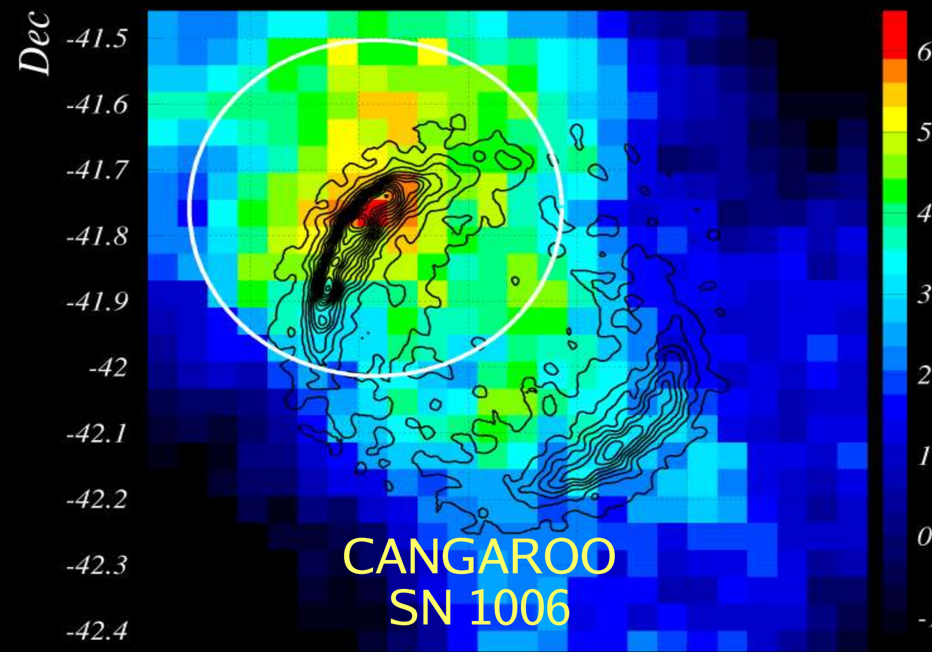
Source of galactic CRs??

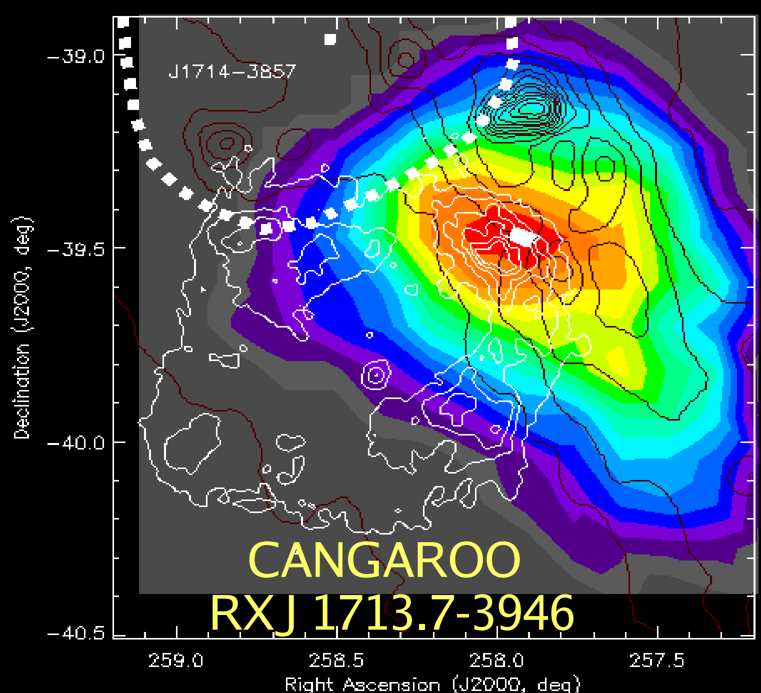
Established as VHE γ-ray sources

- CANGAROO: 4
- HEGRA: 1

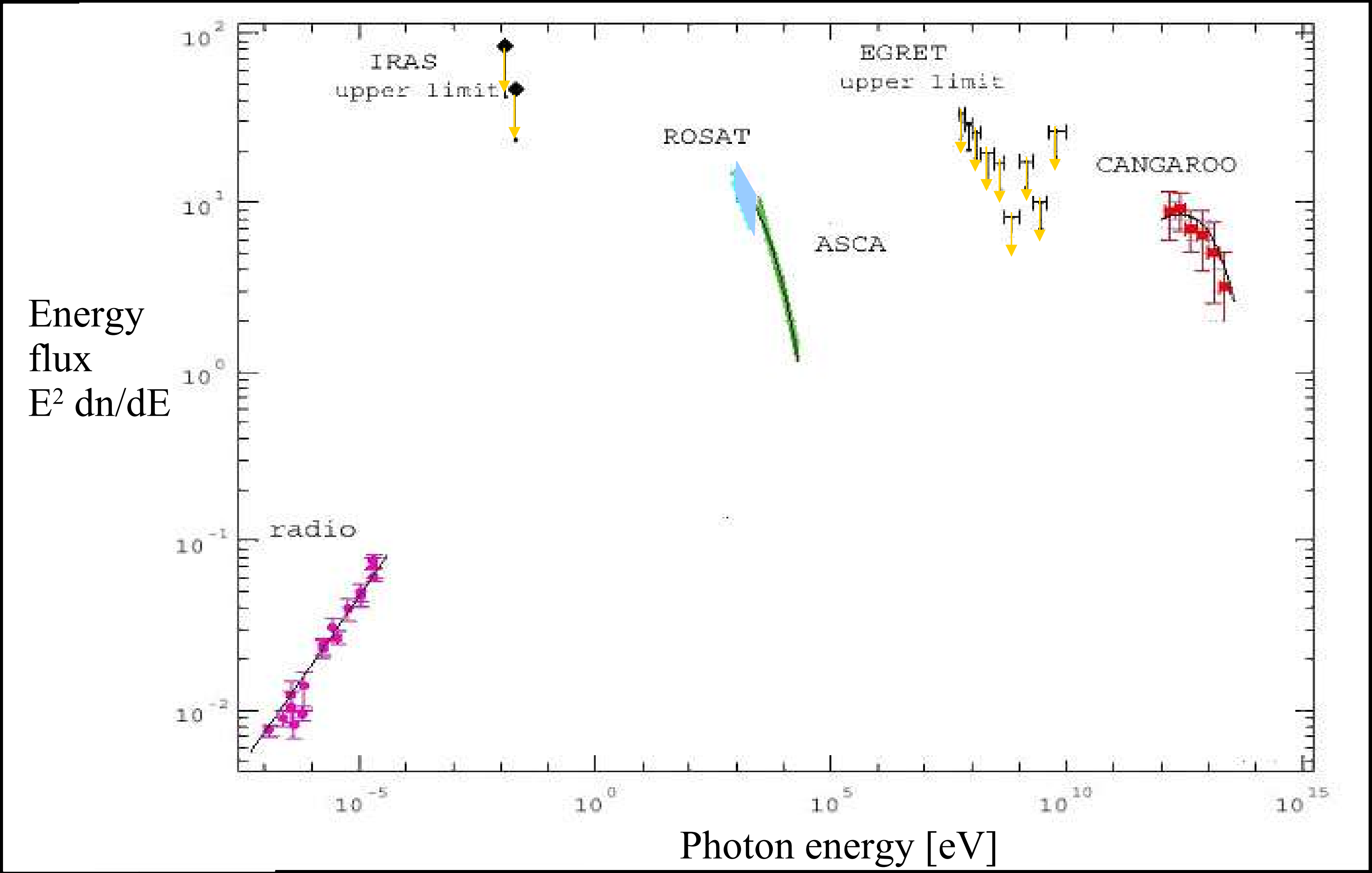
Big issue:

- Leptonic or hadronic scenario for γ-ray production





Example: RXJ 1713.7-3946



SNRs - Interpretation

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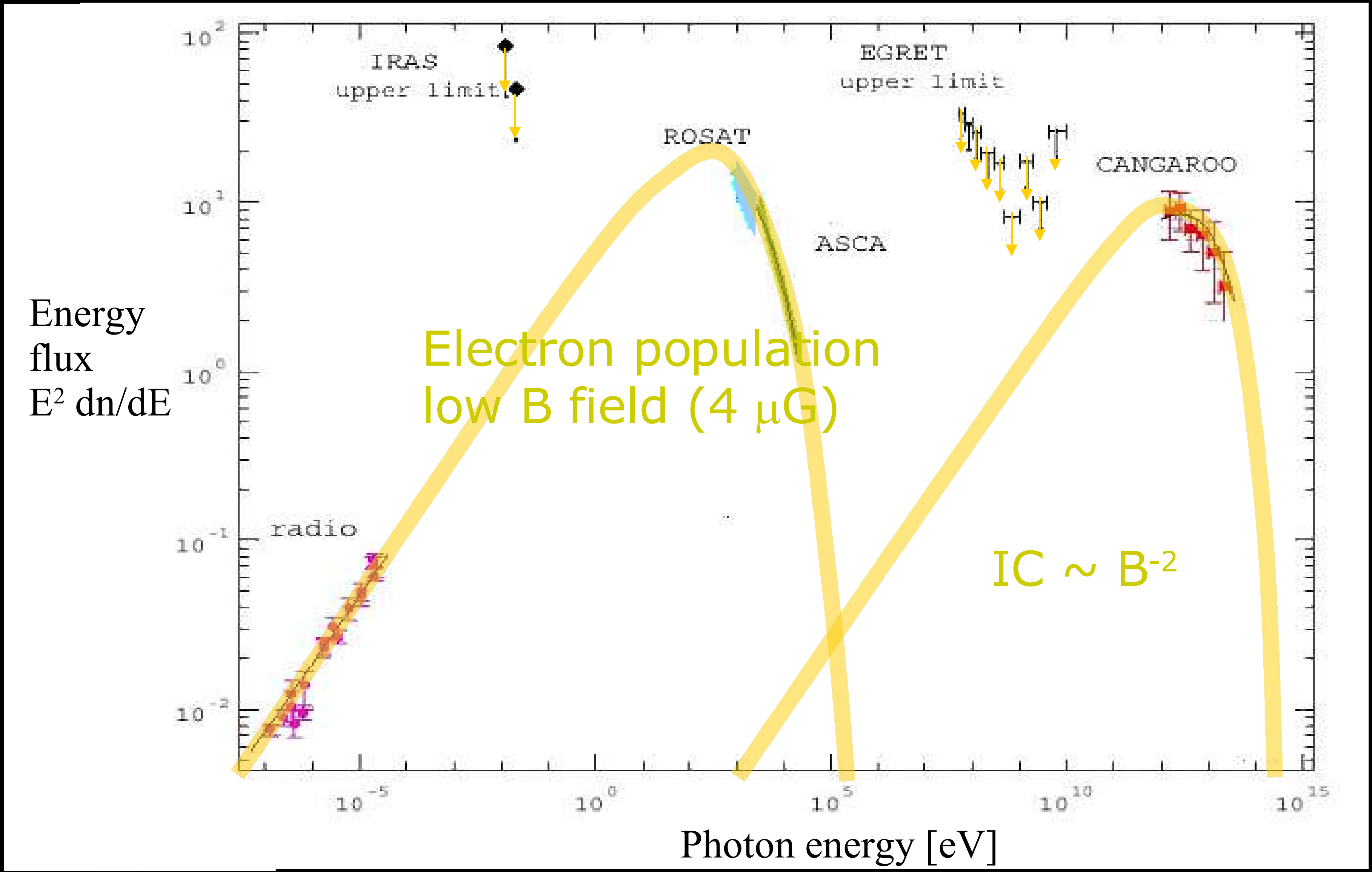

SNRs - Interpretation

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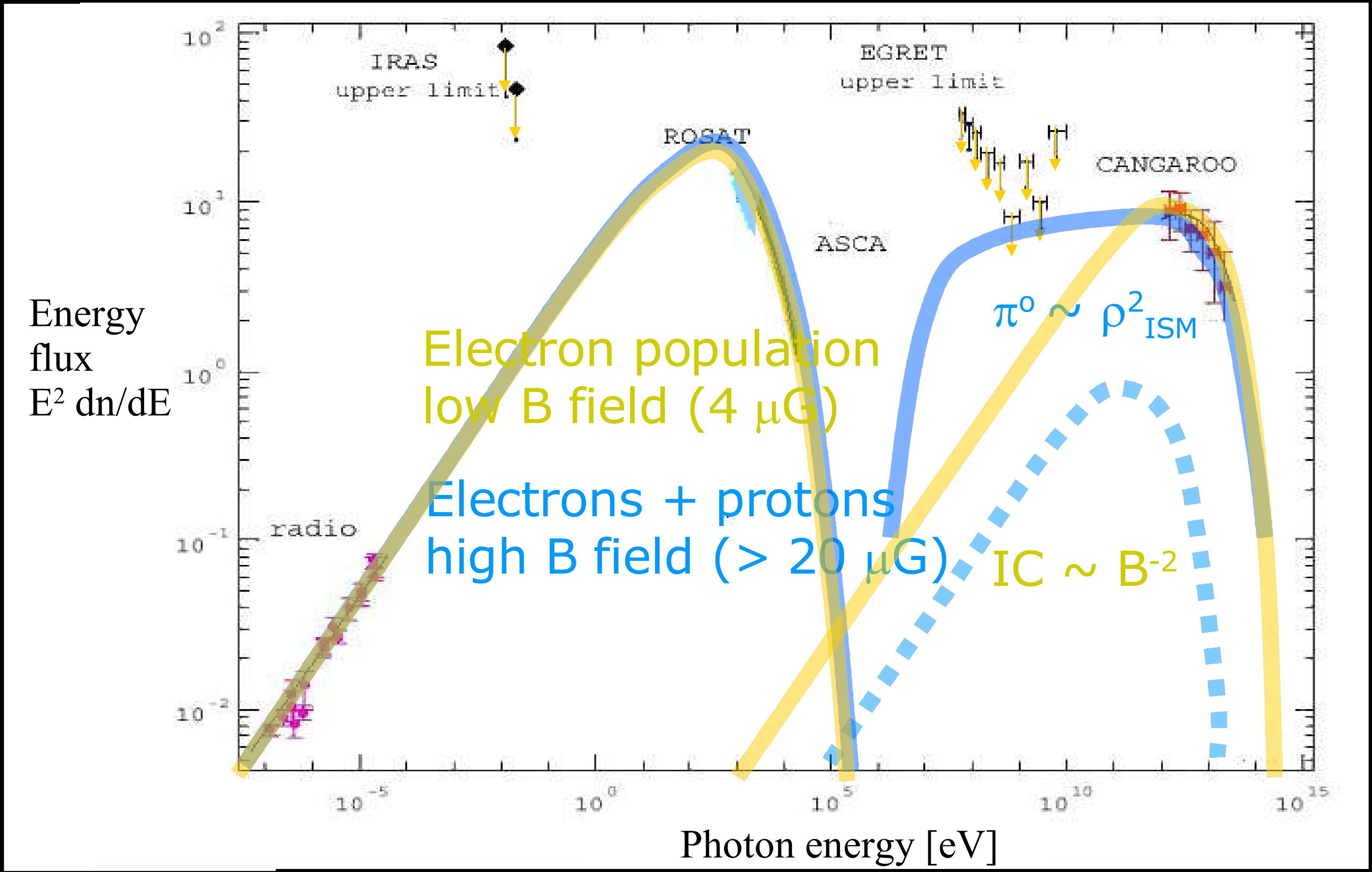


RXJ 1713.7-3946 viewed by H.E.S.S.

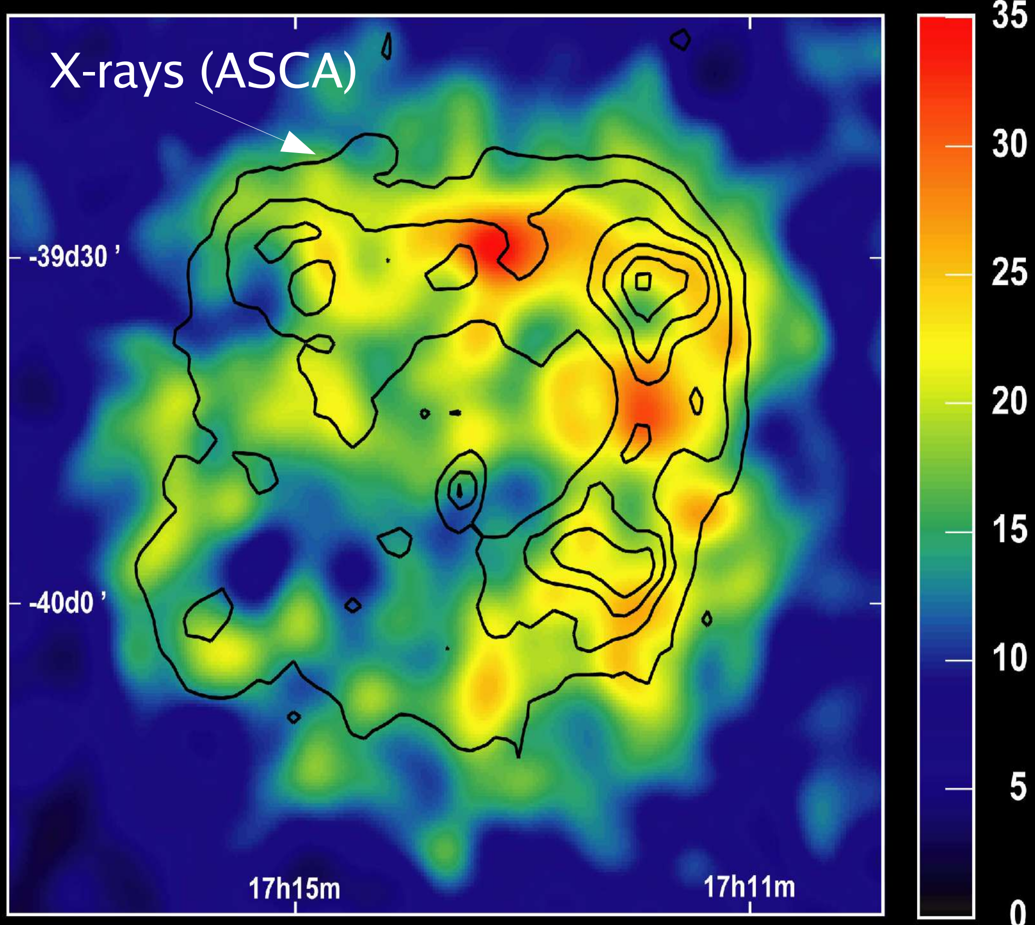
2003 data set

18.1 hrs, >15 σ

2004 data under analysis

Rim revealed in VHE γ-ray

(Nature, 2004, 432, 75)



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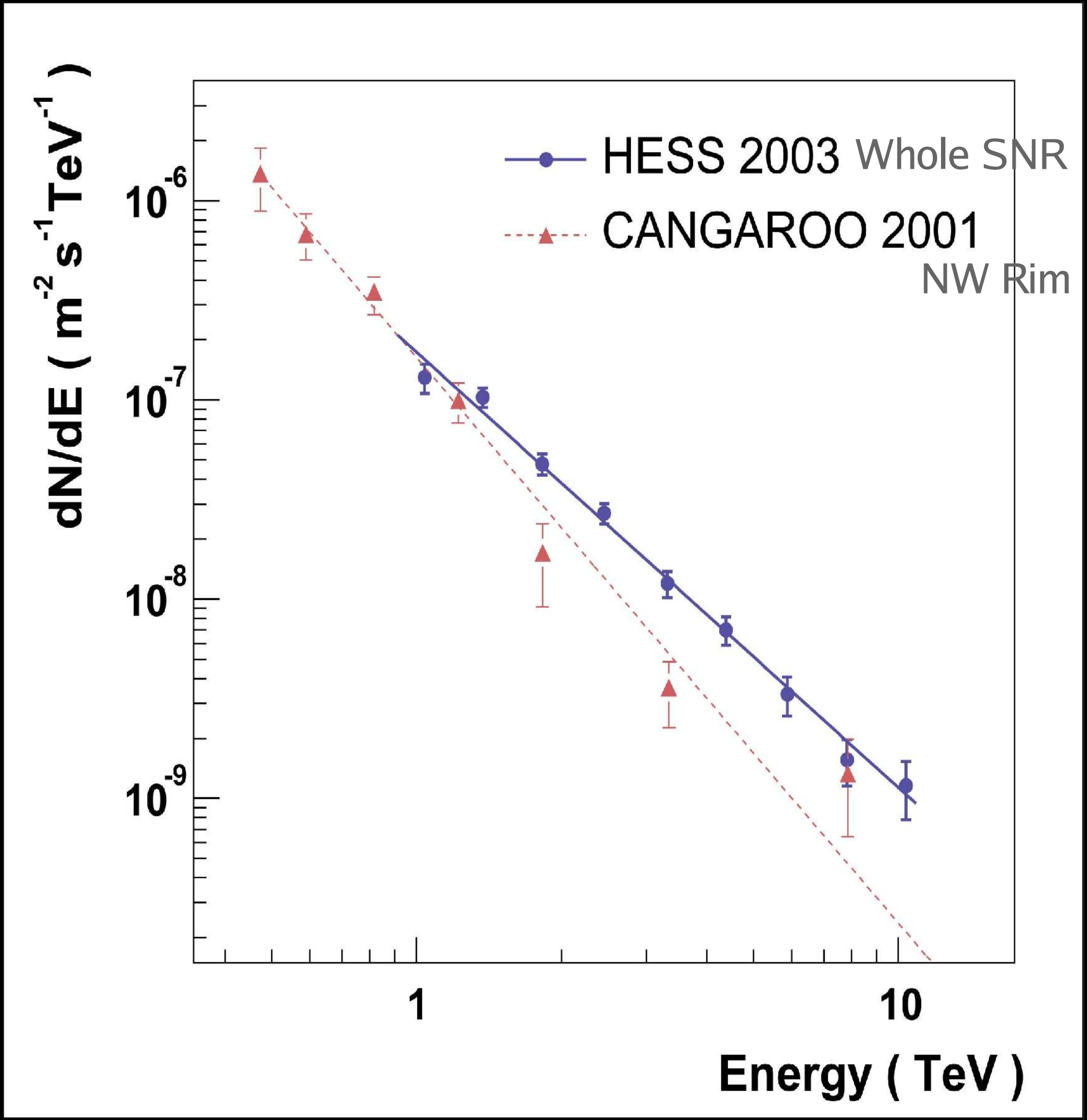
Spectrum

- Flux of 66% Crab, Γ = 2.19±0.09
- CANGAROO: Γ = 2.84±0.15



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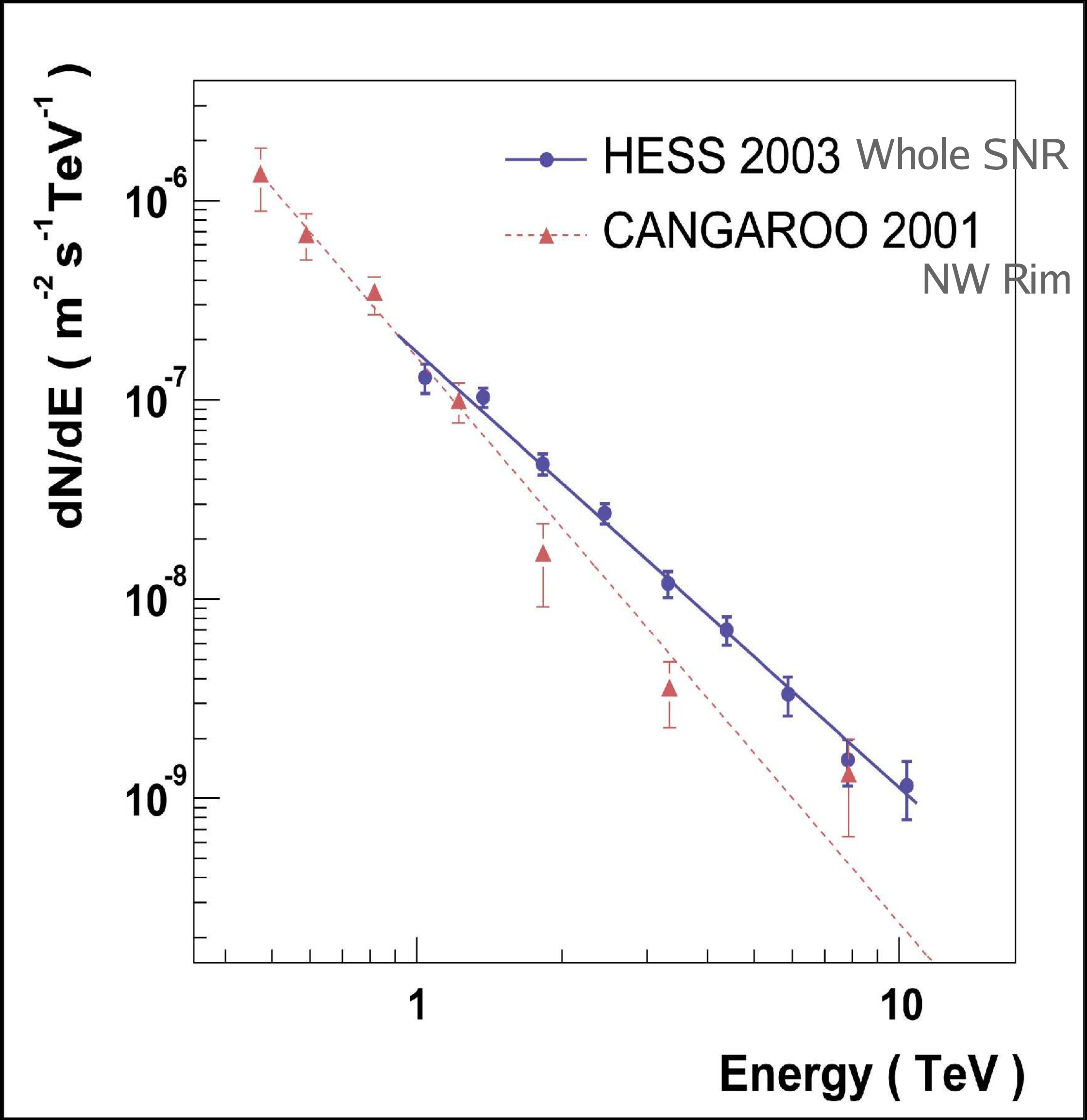


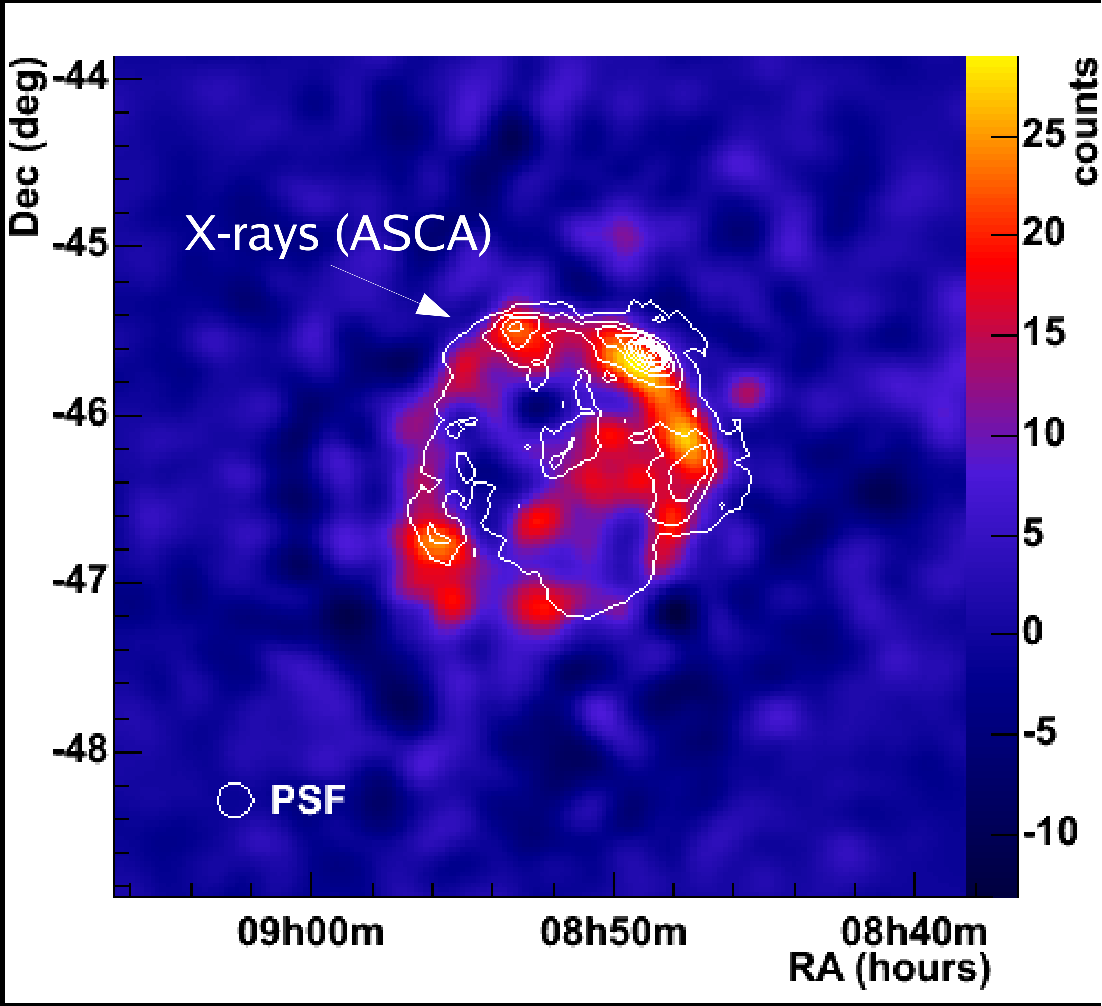
⇒ **First SNR rim resolved in VHE**

SNR RXJ 0852.0-4622 (Vela Jnr)

2004 data set

3.2 hrs, >12 σ

Rim revealed in VHE γ-ray



Aharonian et al., 2005, for A&A

SNR RXJ 0852.0-4622 (Vela Jnr)

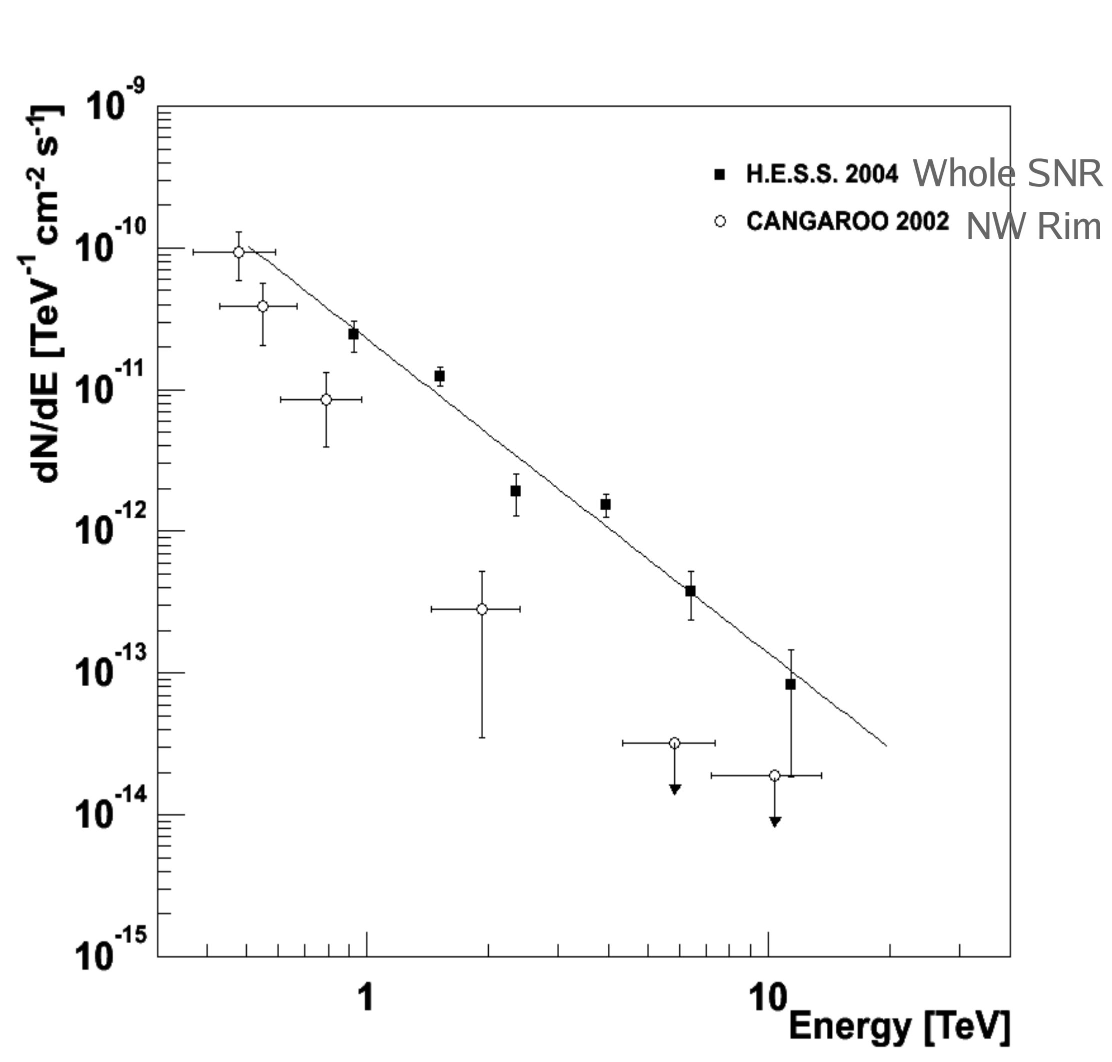
2004 data set

3.2 hrs, >12 σ

Rim revealed in VHE γ-ray

Spectrum

- Flux of 1 Crab, $\Gamma = 2.2 \pm 0.1$
- CANGAROO: $\Gamma = 4.3+1.7-4.4$



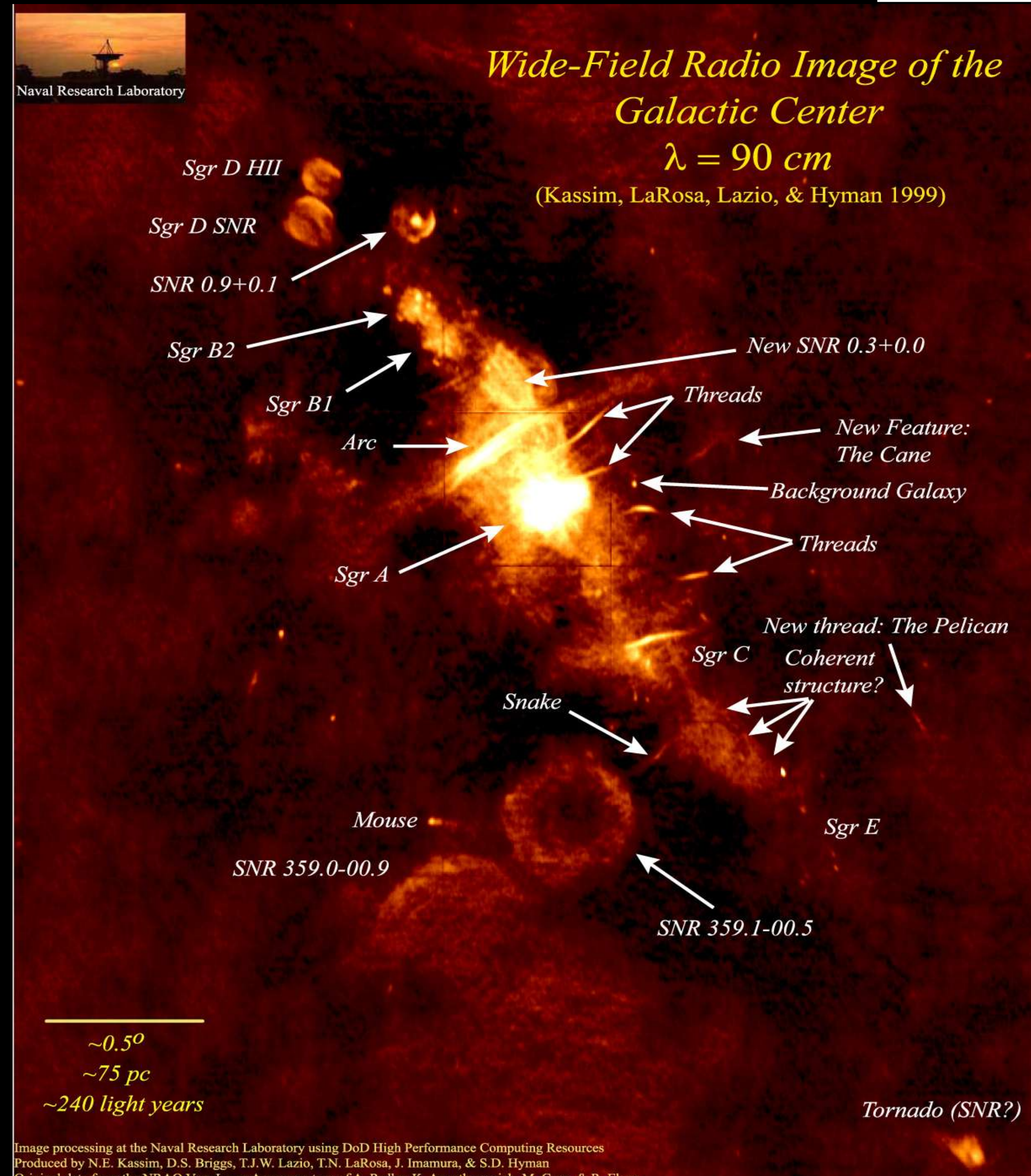
Aharonian et al., 2005, for A&A

The Galactic Centre

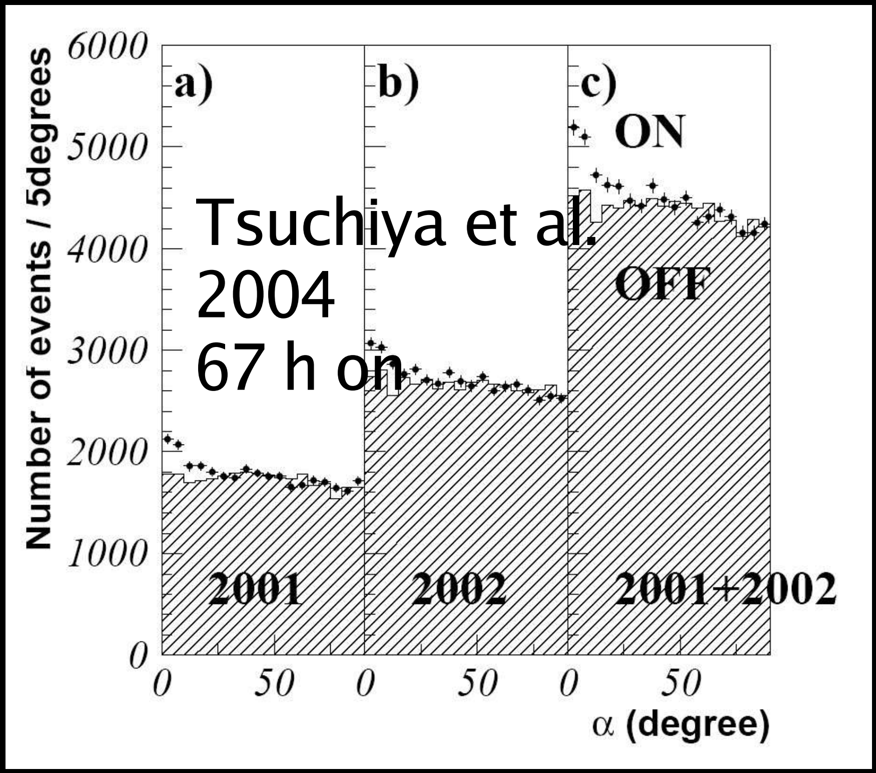
Source of gamma-rays?

- Shocks in Sgr A* from accretion flow or jet
- Acceleration in stellar winds from OB clusters
- Acceleration in supernova shocks (Sgr A East)
- Diffuse CR interacting with gas ($\rho \sim 10^3/cm^3$)
- Proton acceleration near event horizon and curvature radiation
- Neutralino / Wimp annihilation
- …

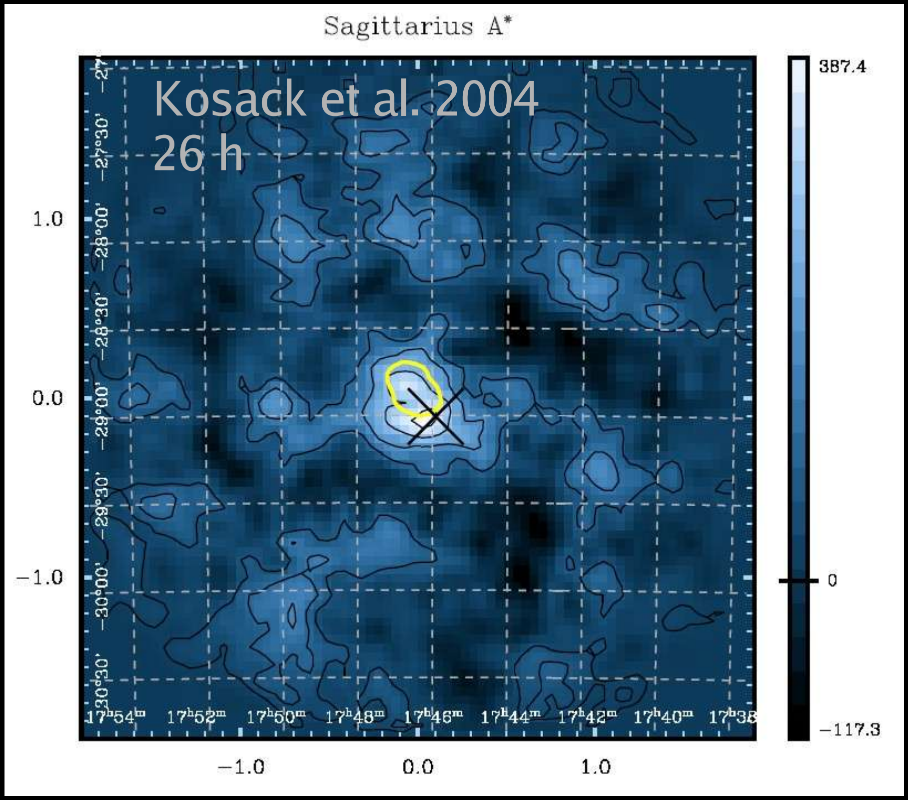
⇒ Spectrum, time variability, source size, location



Gamma-rays from the GC

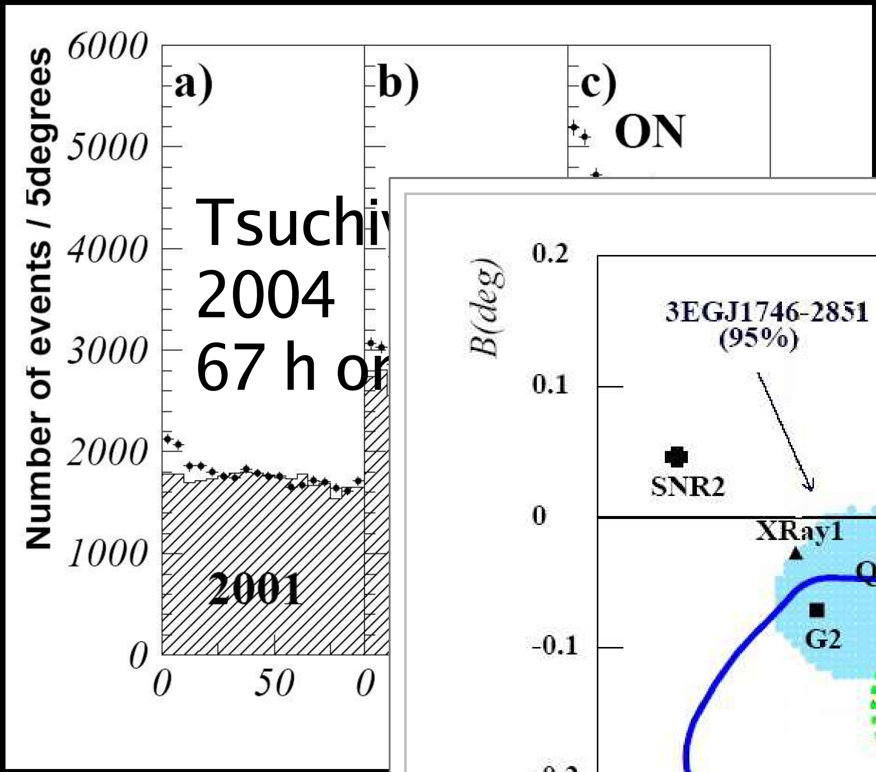


CANGAROO
2001/2002
> 10 σ

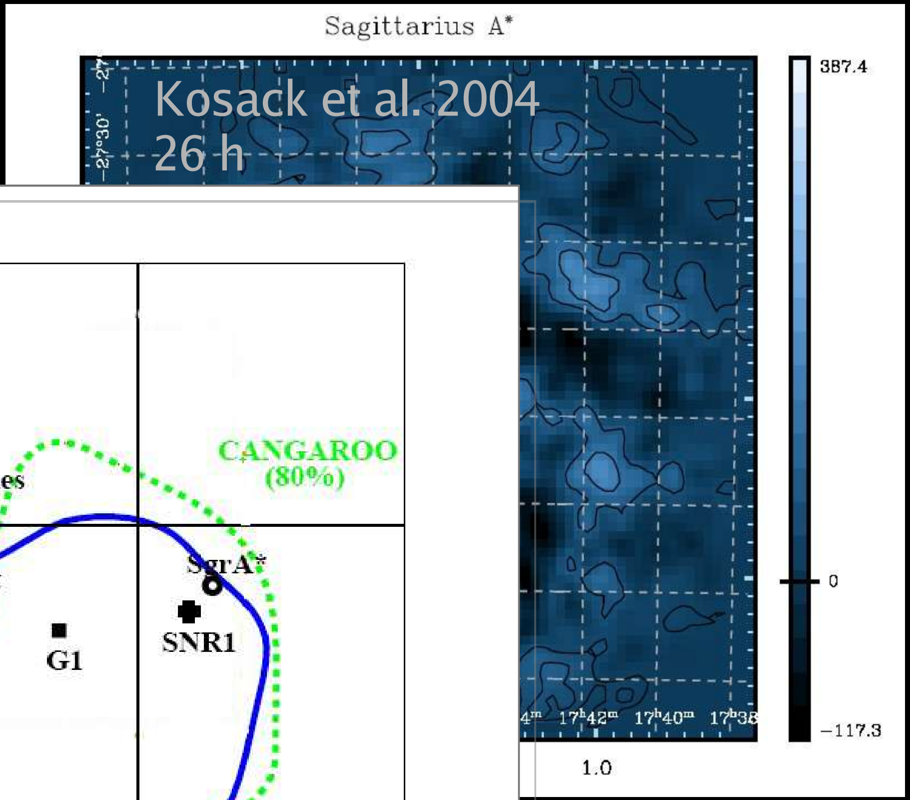


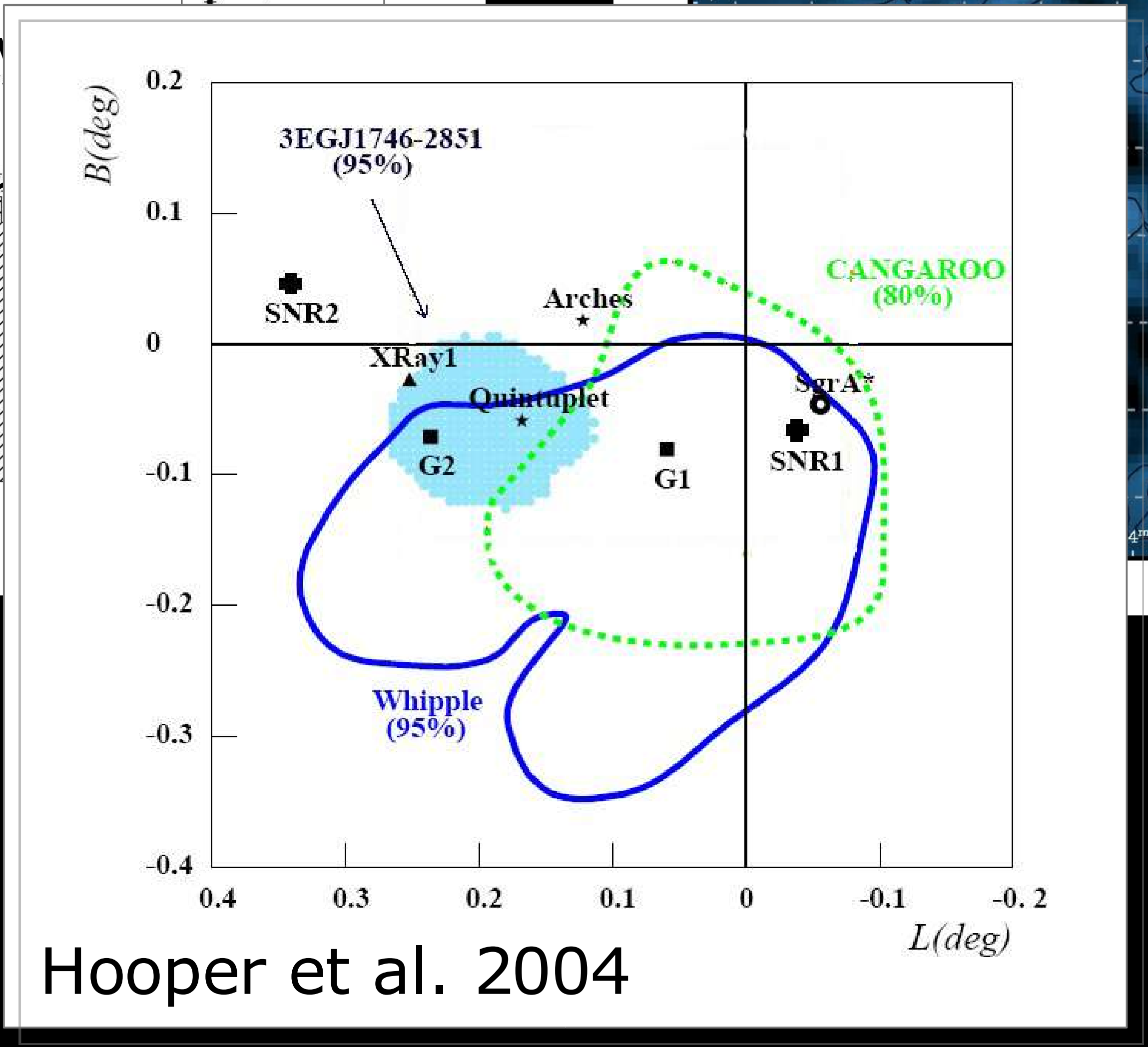
Whipple
1995 – 2003
3.7 σ

Gamma-rays from the GC



CANGAROO
2001/2002
> 10 σ





Hooper et al. 2004

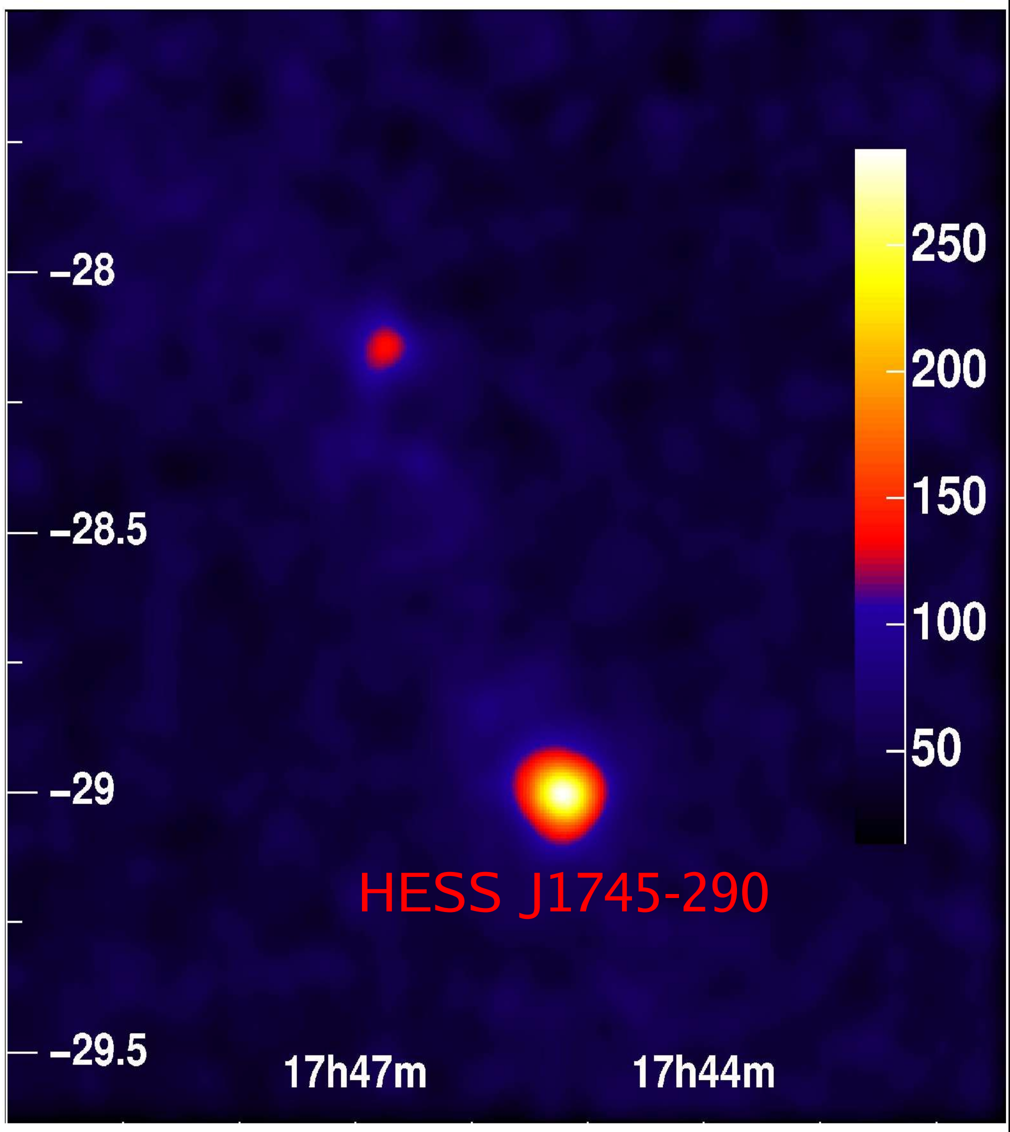
GC viewed by H.E.S.S.

2003 data set

- 2 Tel., 17 hrs, $E_{th} \sim 160$ GeV
- 11 σ close to Sgr A*
- See A&A, 425, 13 (2004)

2004 data set

- 4 Tel., 50 hrs
- 35 σ



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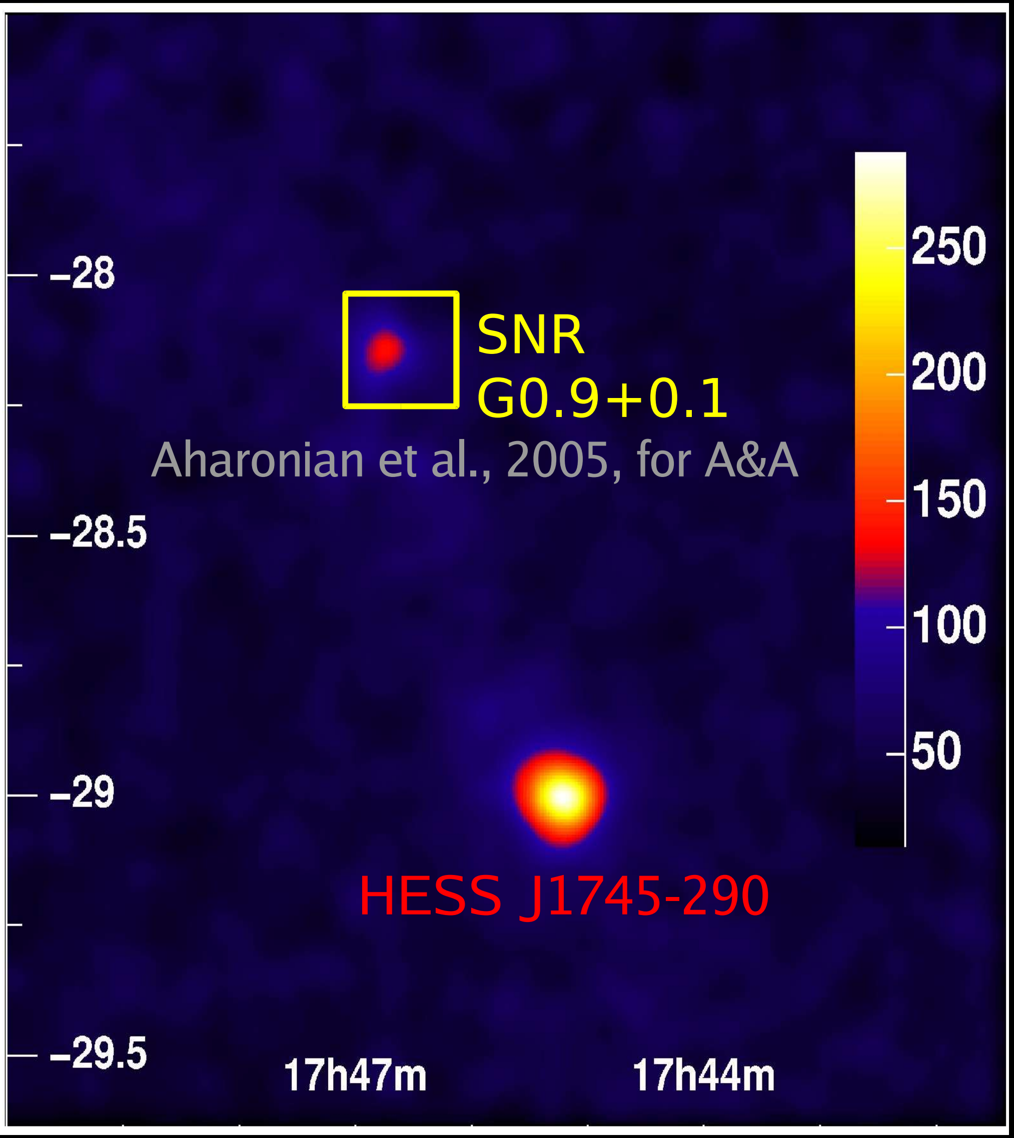
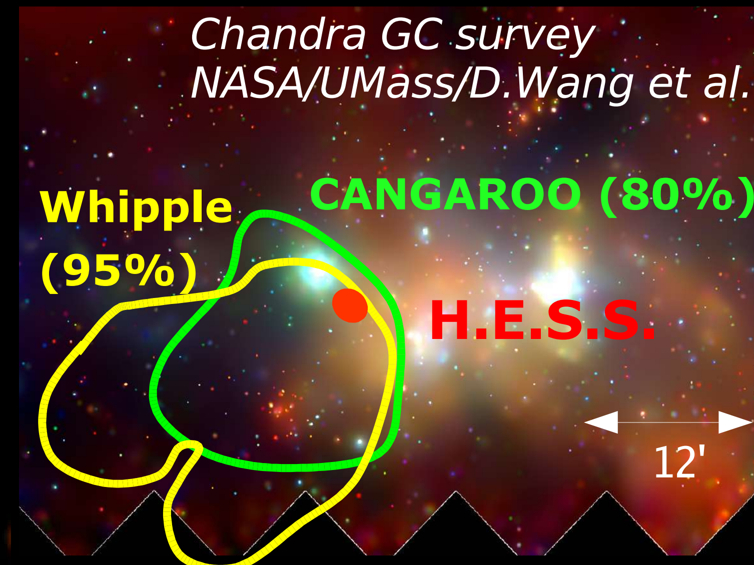


GC viewed by H.E.S.S.: morphology

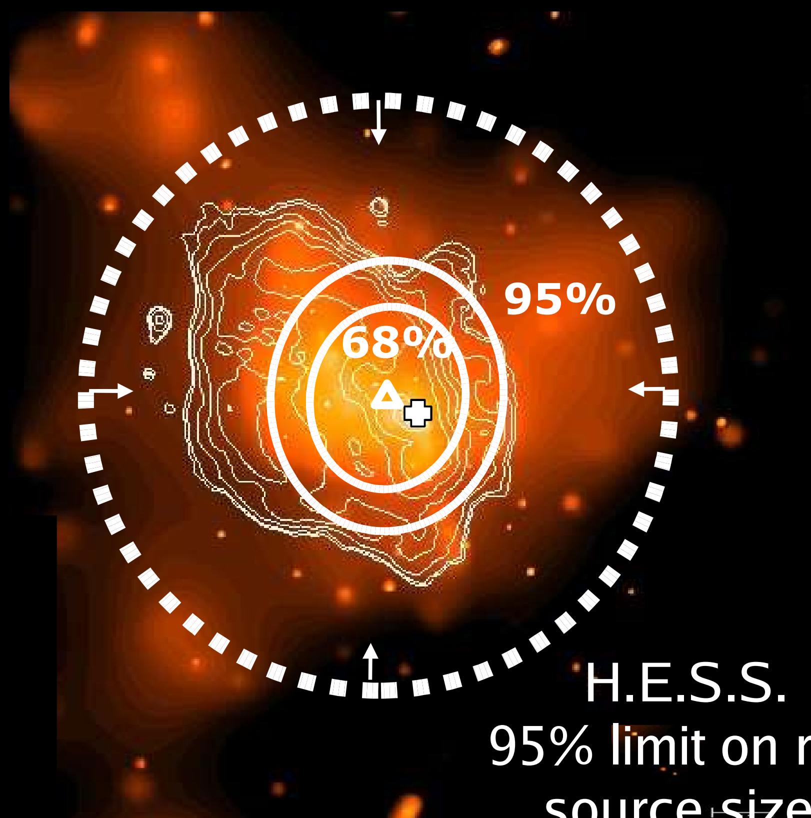
Point source emission

Position

- Compatible with Sgr A*
- But SNR Sgr A East not ruled out



Contours from Hooper et al. 2004



Sgr A East
Chandra & Radio
NASA/G.Garmire (PSU)
F.Baganoff (MIT)
Yusef-Zadeh (NWU)

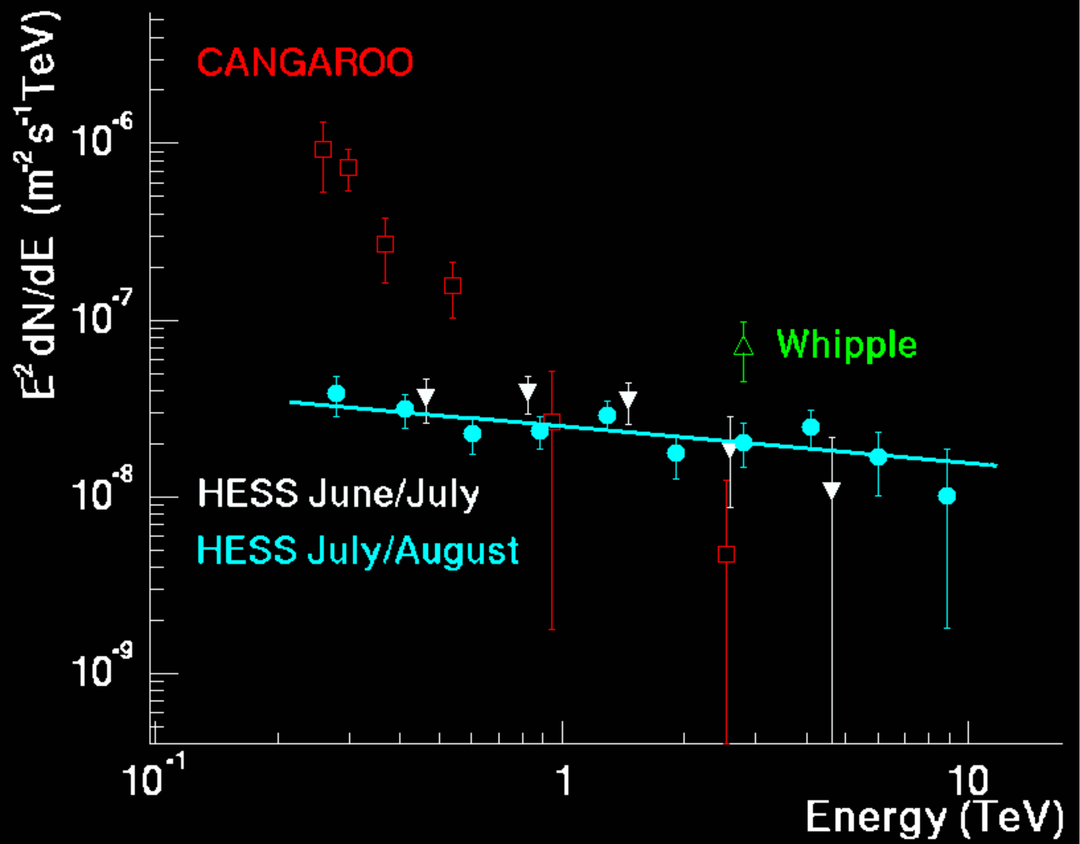
H.E.S.S.
95% limit on rms
source size:
3' or ~ 7 pc

GC viewed by H.E.S.S.: spectrum

Steady flux

Pure power-law

- Flux of 5% Crab
- $\Gamma = 2.2 \pm 0.1$



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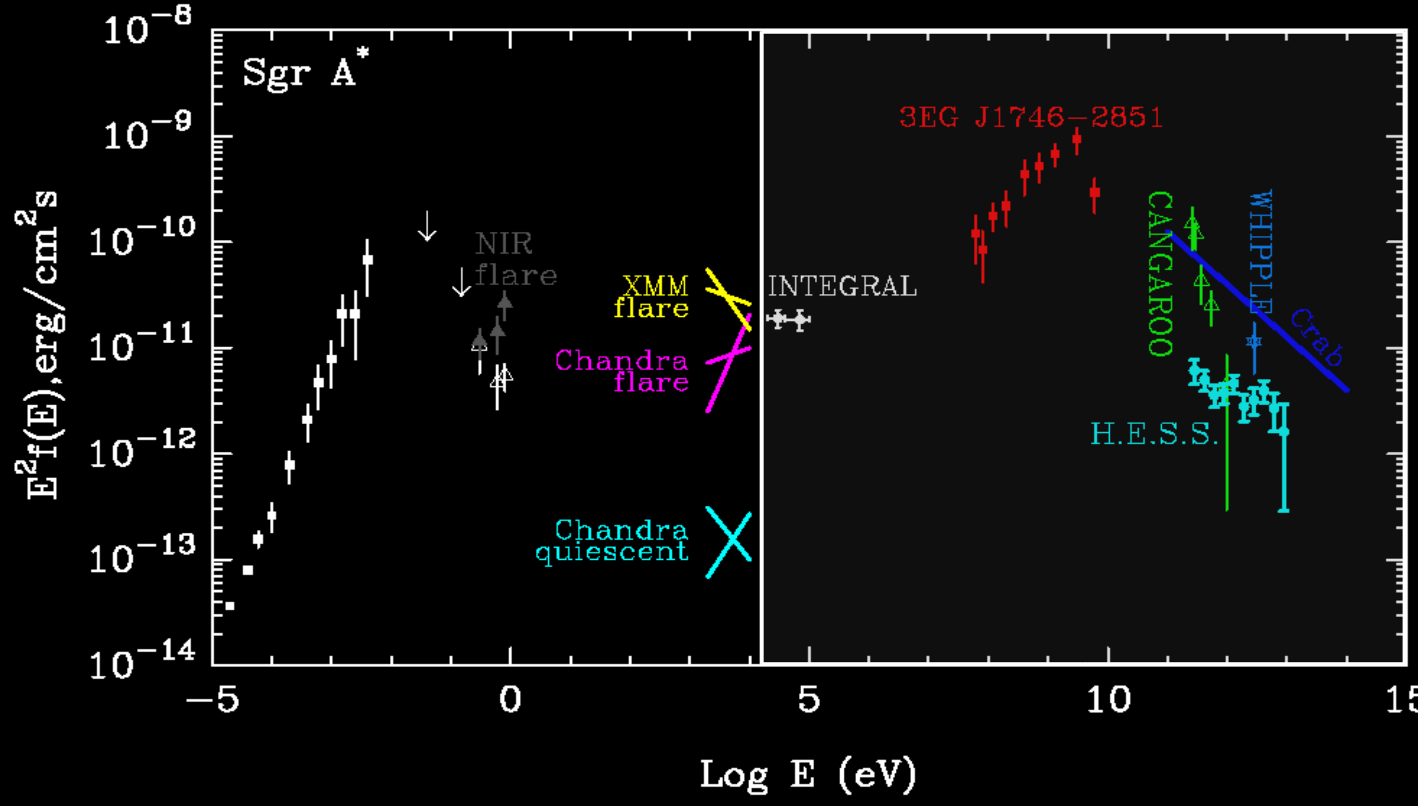

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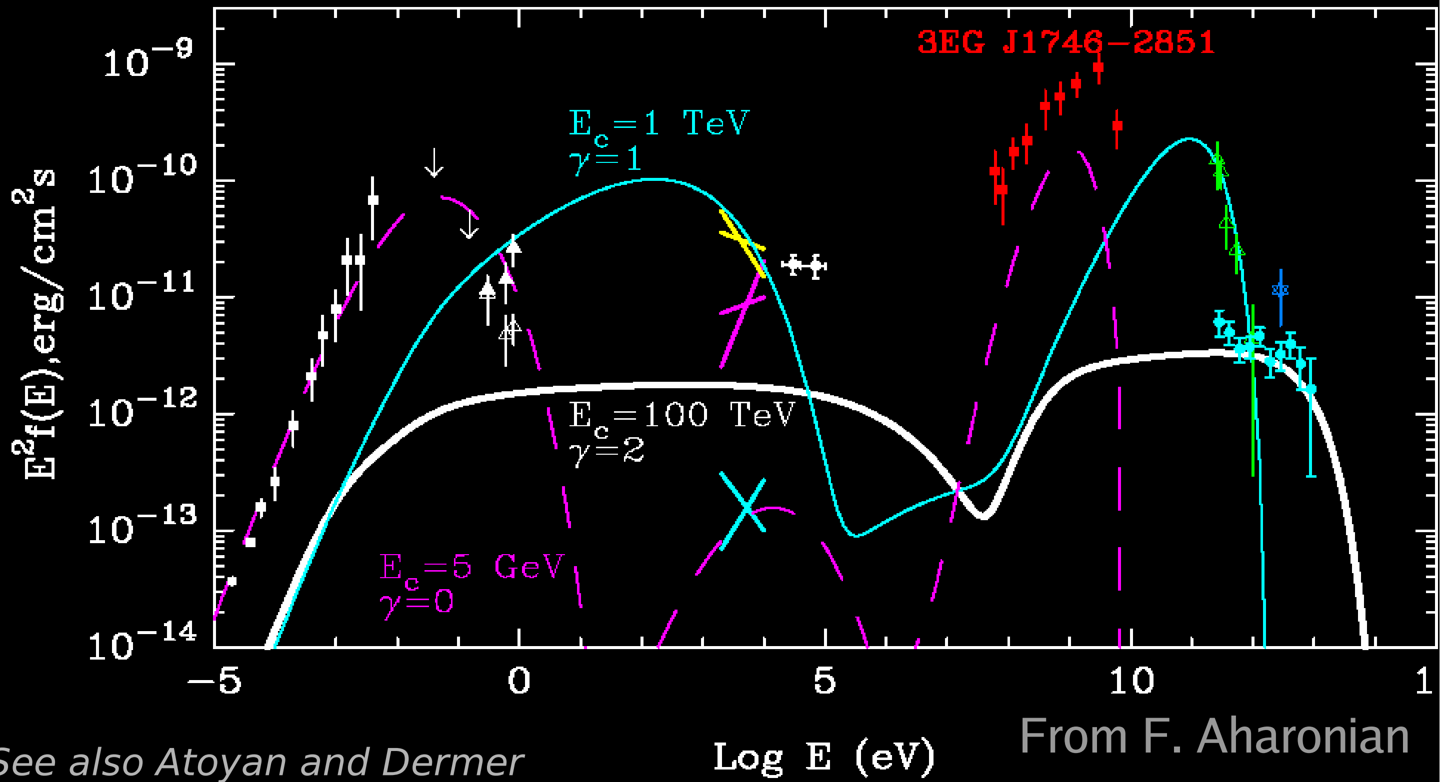


From F. Aharonian

See also Atoyan and Dermer astro-ph/0410243

Interpretation

- Data can be explained as radiation of accelerated protons…

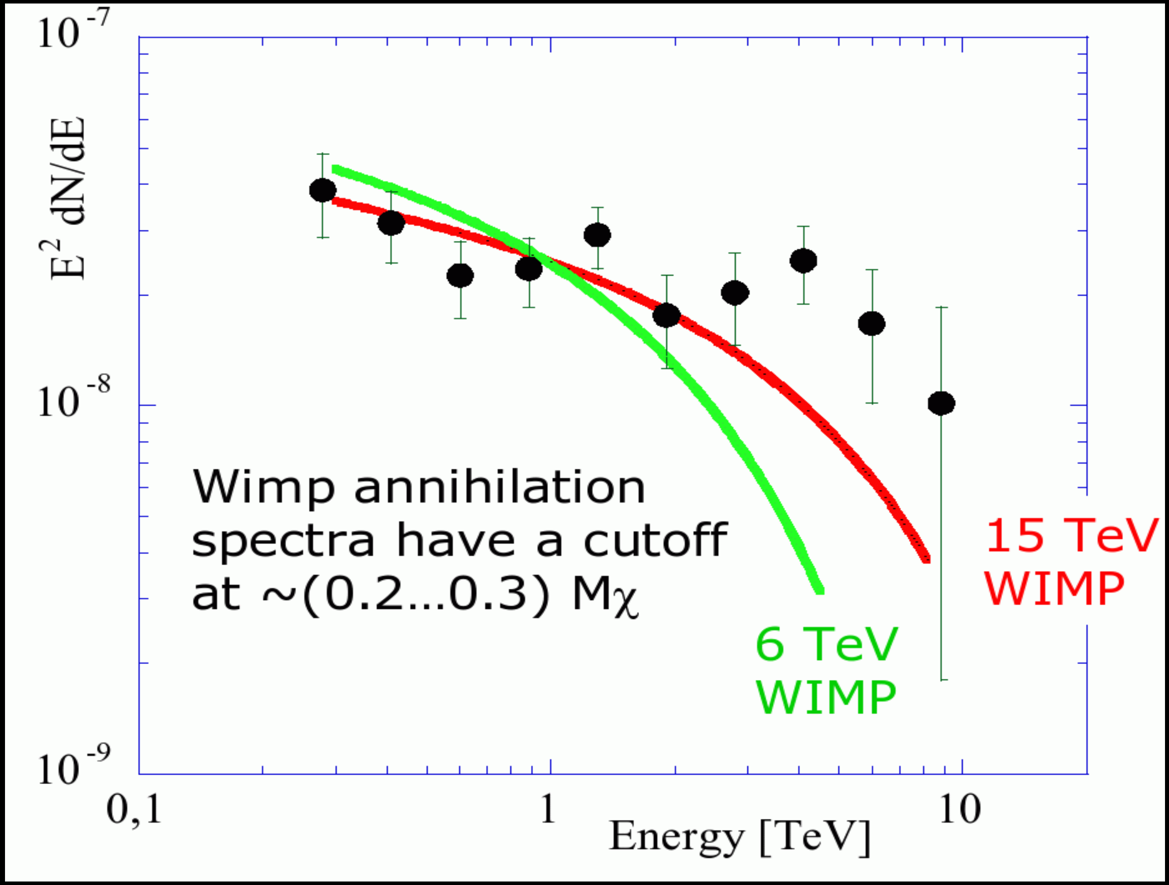
GC by H.E.S.S.: spectrum

Steady flux

Pure power-law

Interpretation

- Protons?
- WIMPs
  required E > 15 TeV



Horns, 2004, astro-ph/0408192

GC by H.E.S.S.: spectrum

Steady flux

Pure power-law

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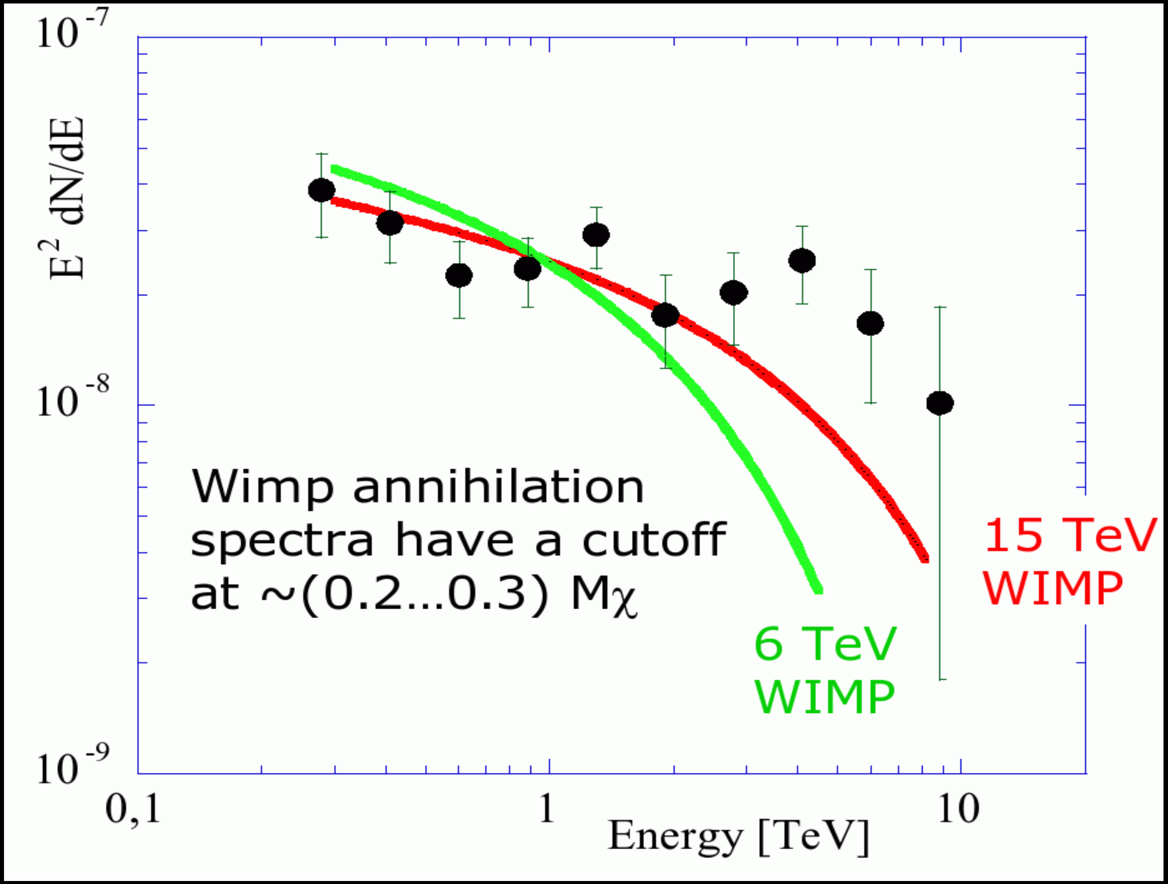
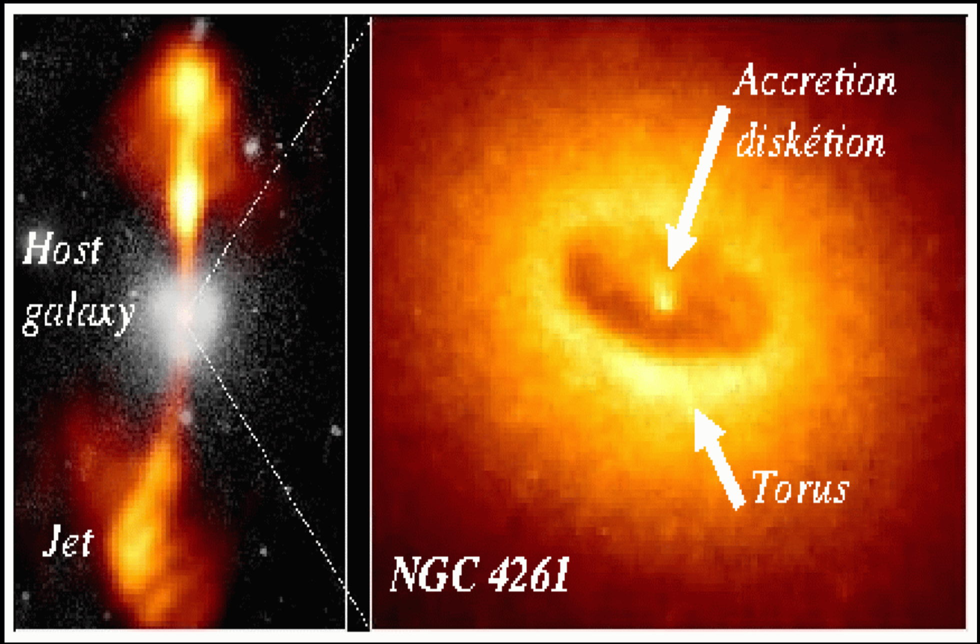


Horns, 2004, astro-ph/0408192

⇒ **Not favored by cosmological constraints**

Extragalactic sources



Active Galactic Nuclei

Blazar: jet toward the Earth

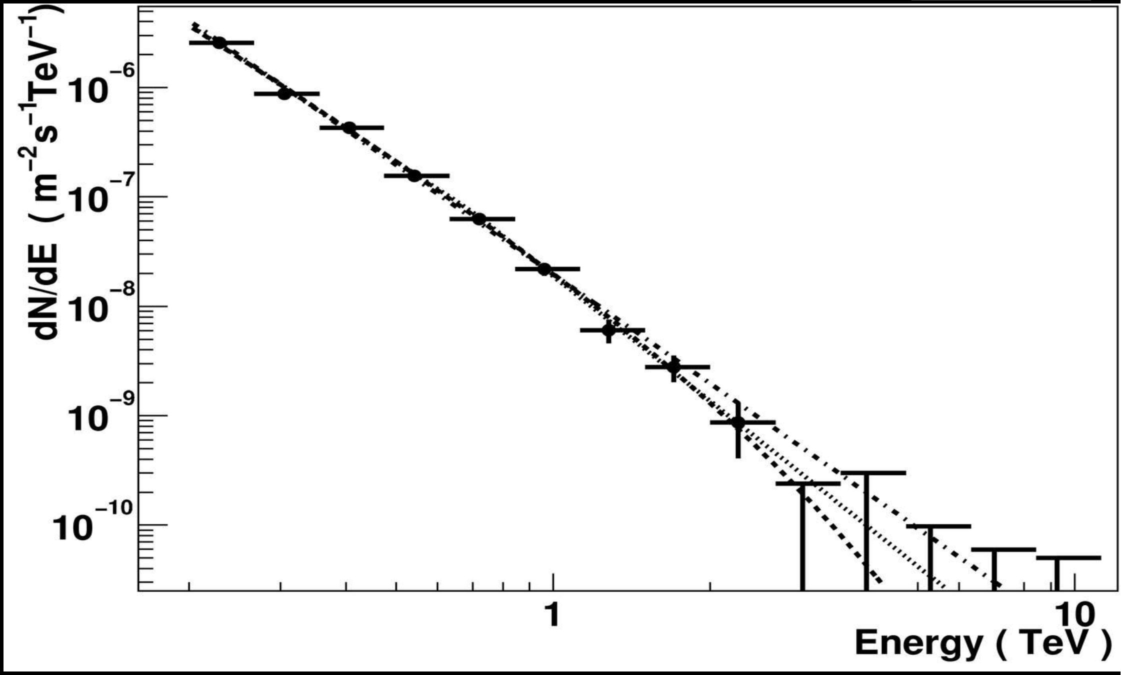
Acceleration of charged particles within jets

at least electrons....

Established as VHE γ-ray sources

- Southern hemisphere: 1
- Northern hemisphere: 5

PKS 2155-304



Blazar at z=0.117

- 2003 data set, >55 hrs
- > 45σ

Aharonian et al., 2005, A&A, 430, 865

- Multiwavelength campaign (radio, optics, X-rays)

Aharonian et al., 2005, for A&A

Spectrum

- Steep spectrum: Γ = 3.32±0.06
- Only flux variability
- No correlation with X-rays
  (historically lowest flux in X-rays)

PKS 2155-304

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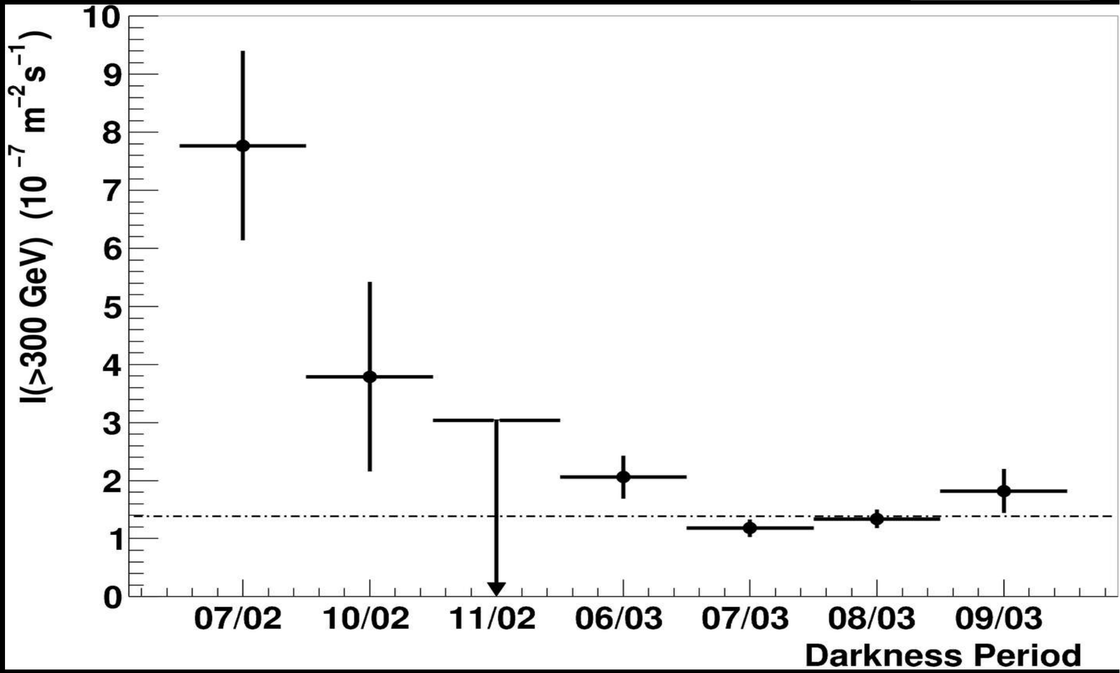

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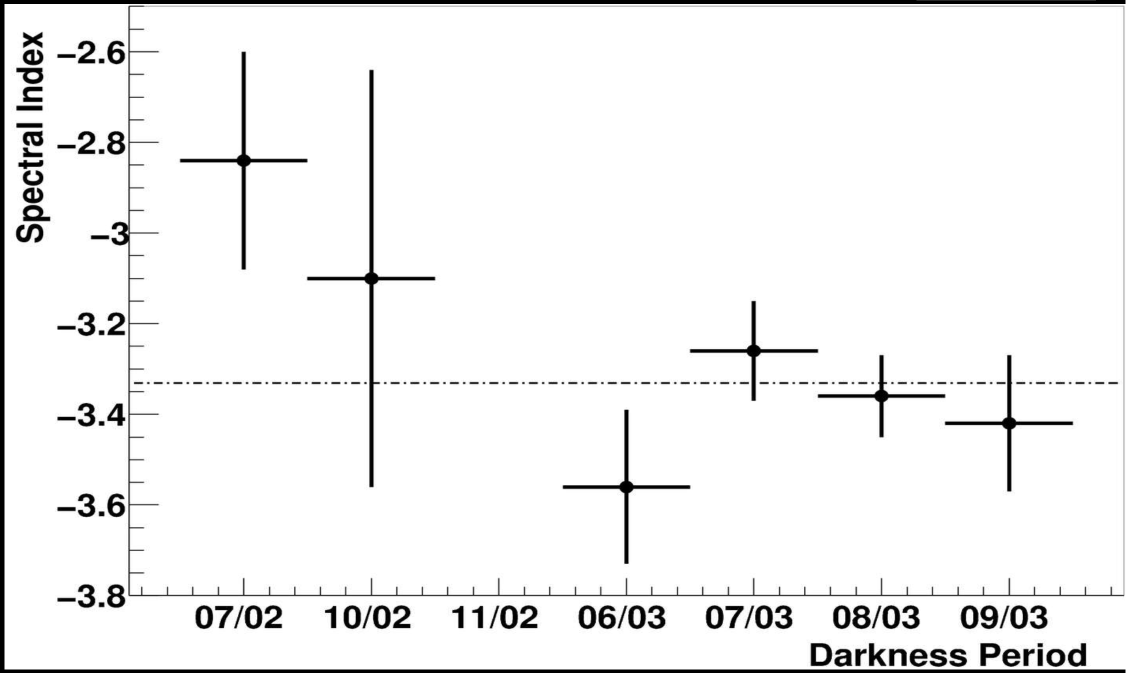

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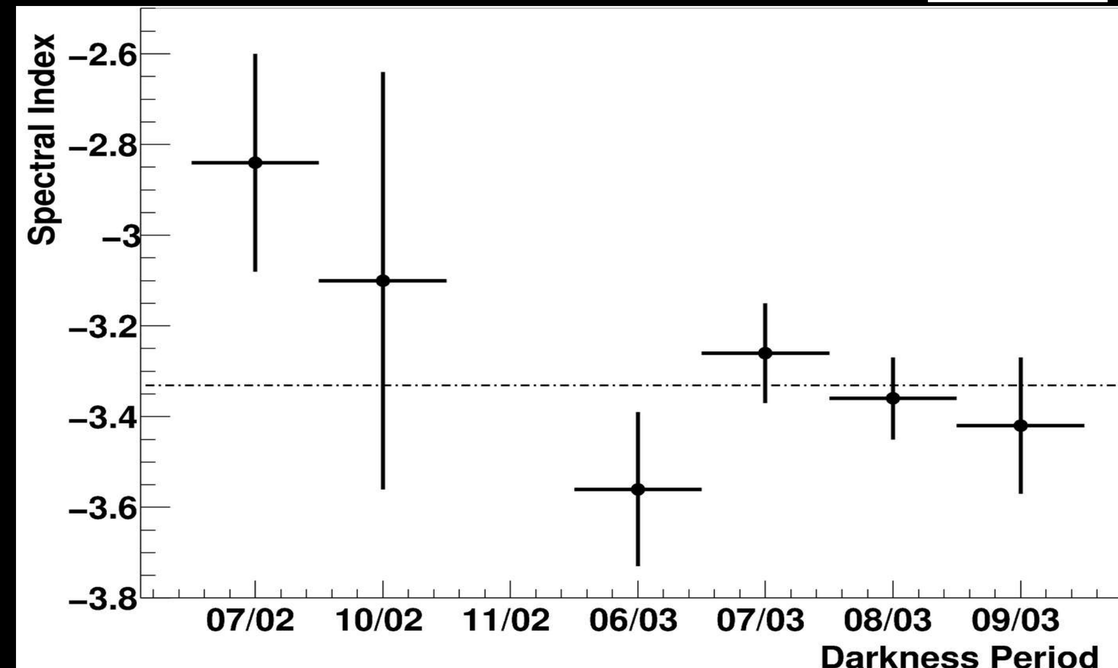

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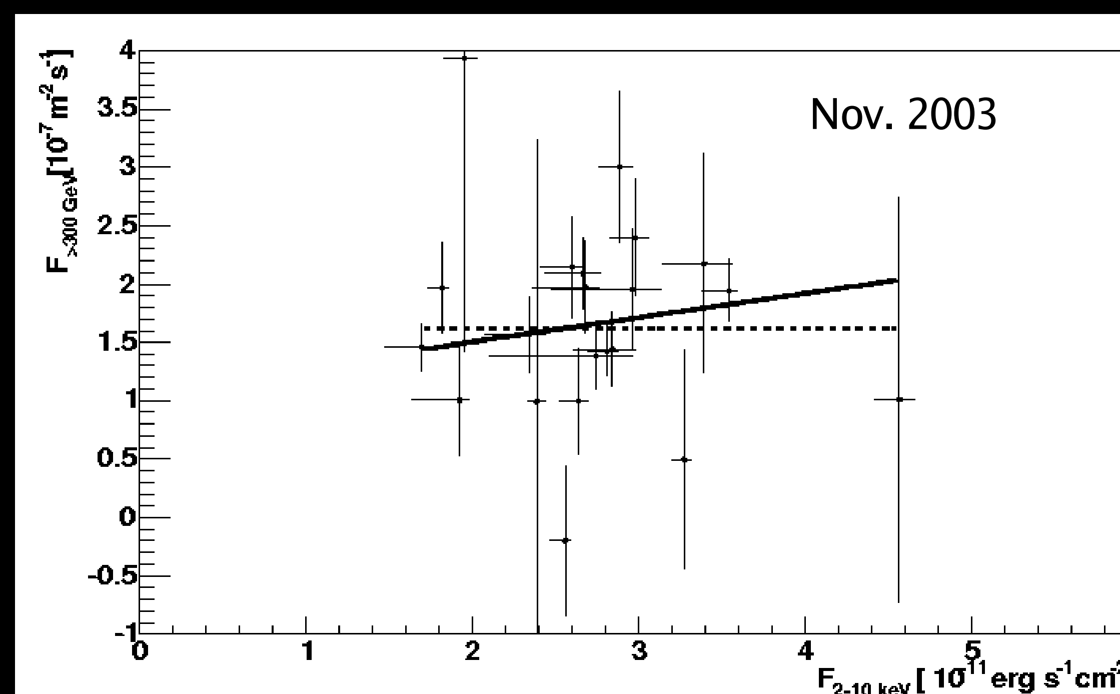
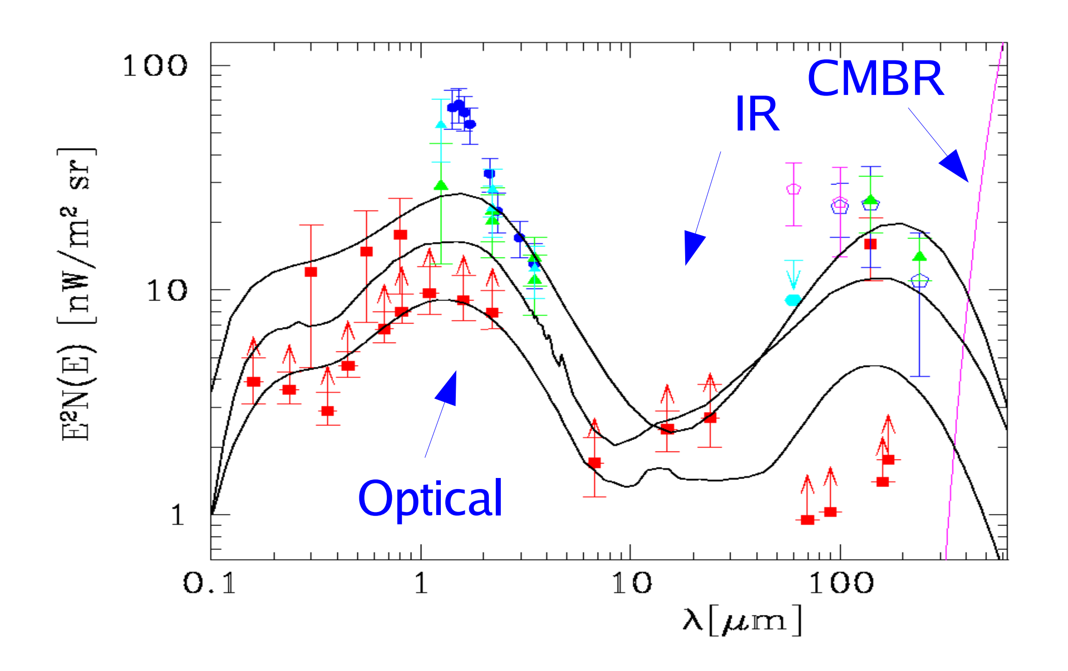


B. Khélifi, MPIK of Heidelberg

PKS 2155-304 - II

Difficult interpretation

- Absorption of γ-rays on the Extragalactic Background Light by γ-γ collision
- And EBL spectrum poorly known



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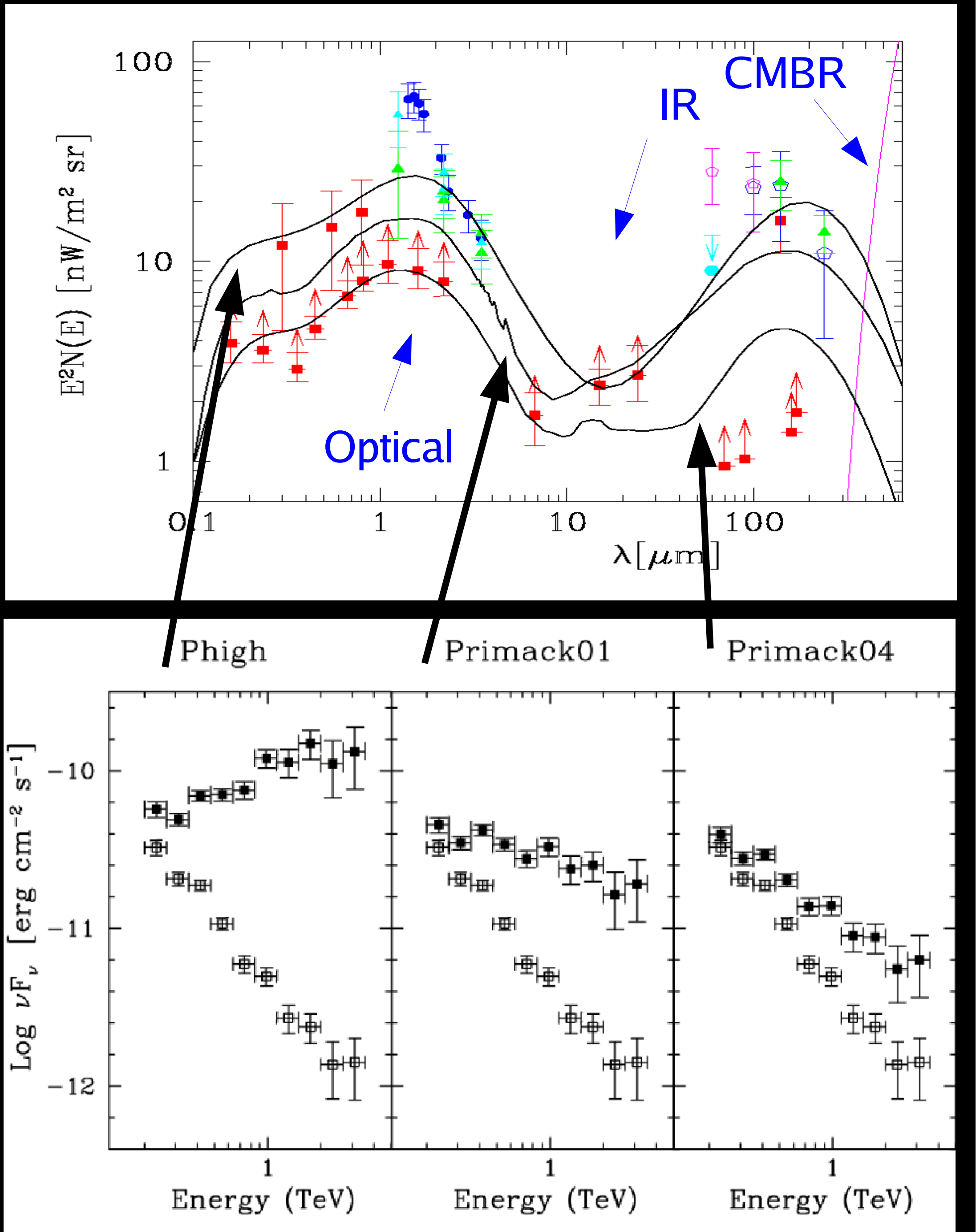

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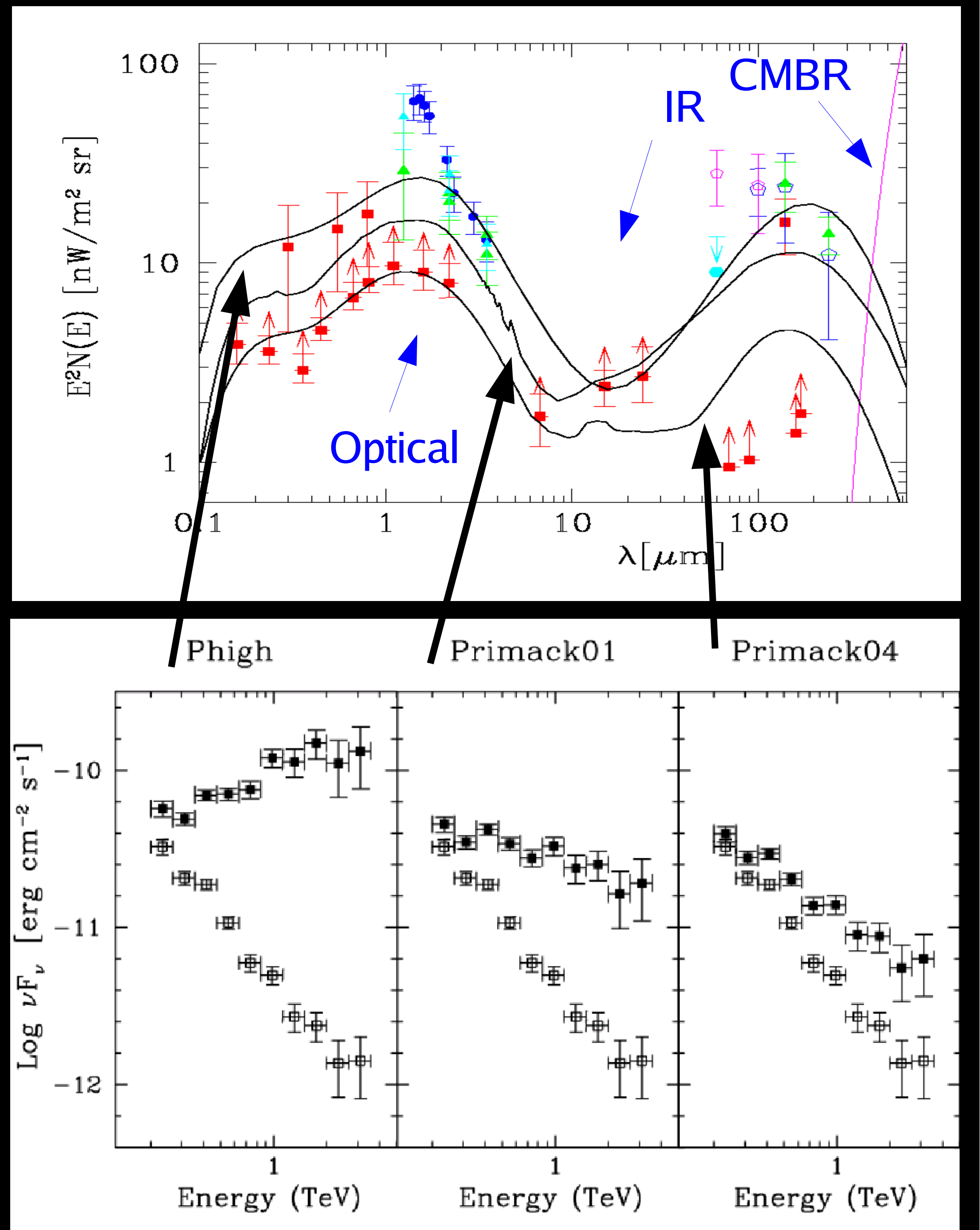

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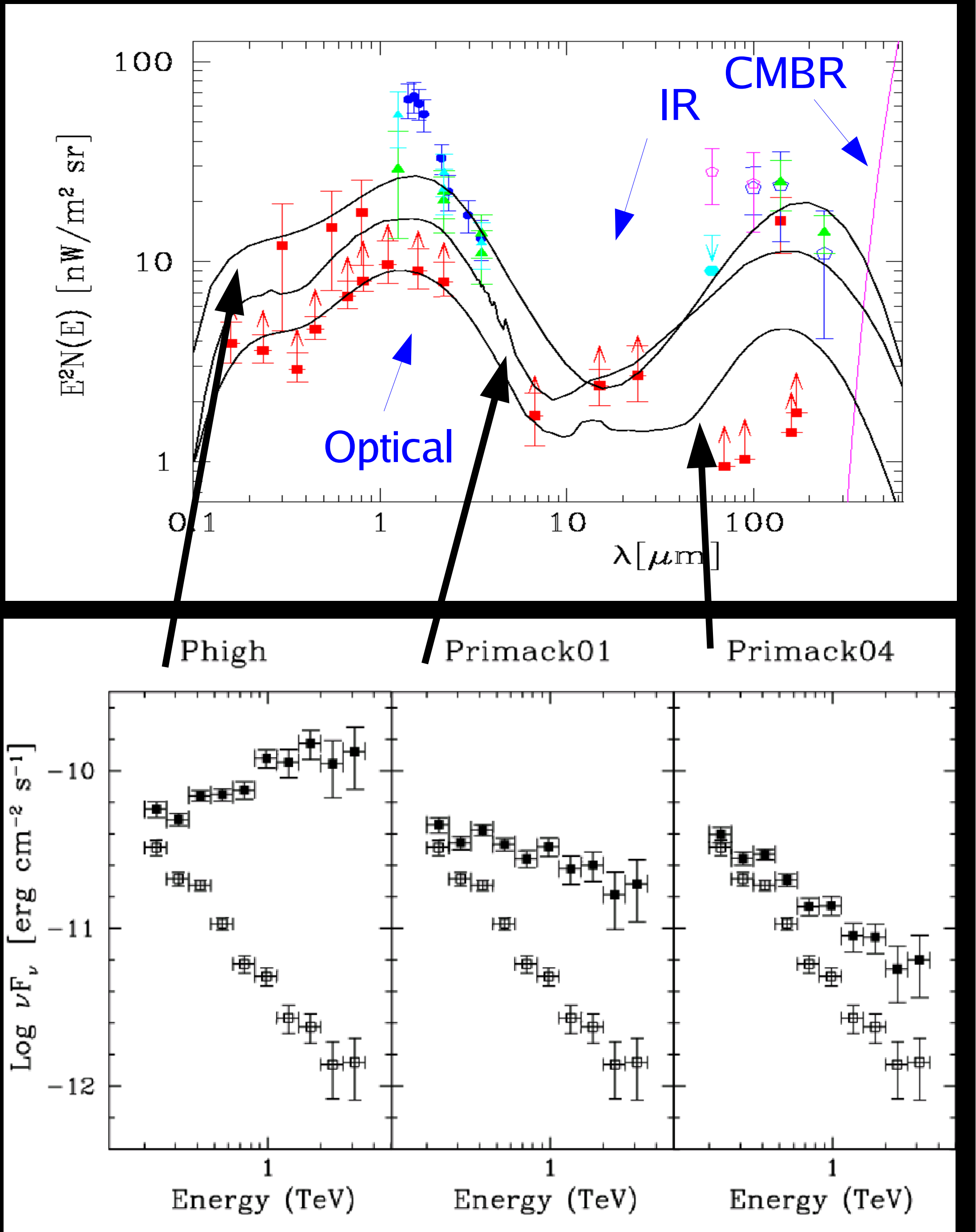


Leptonic or hadronic scenario?

- Flux variability
  - correlation between X-rays and VHE disfavors hadronic scenario
  - no correlation: ??

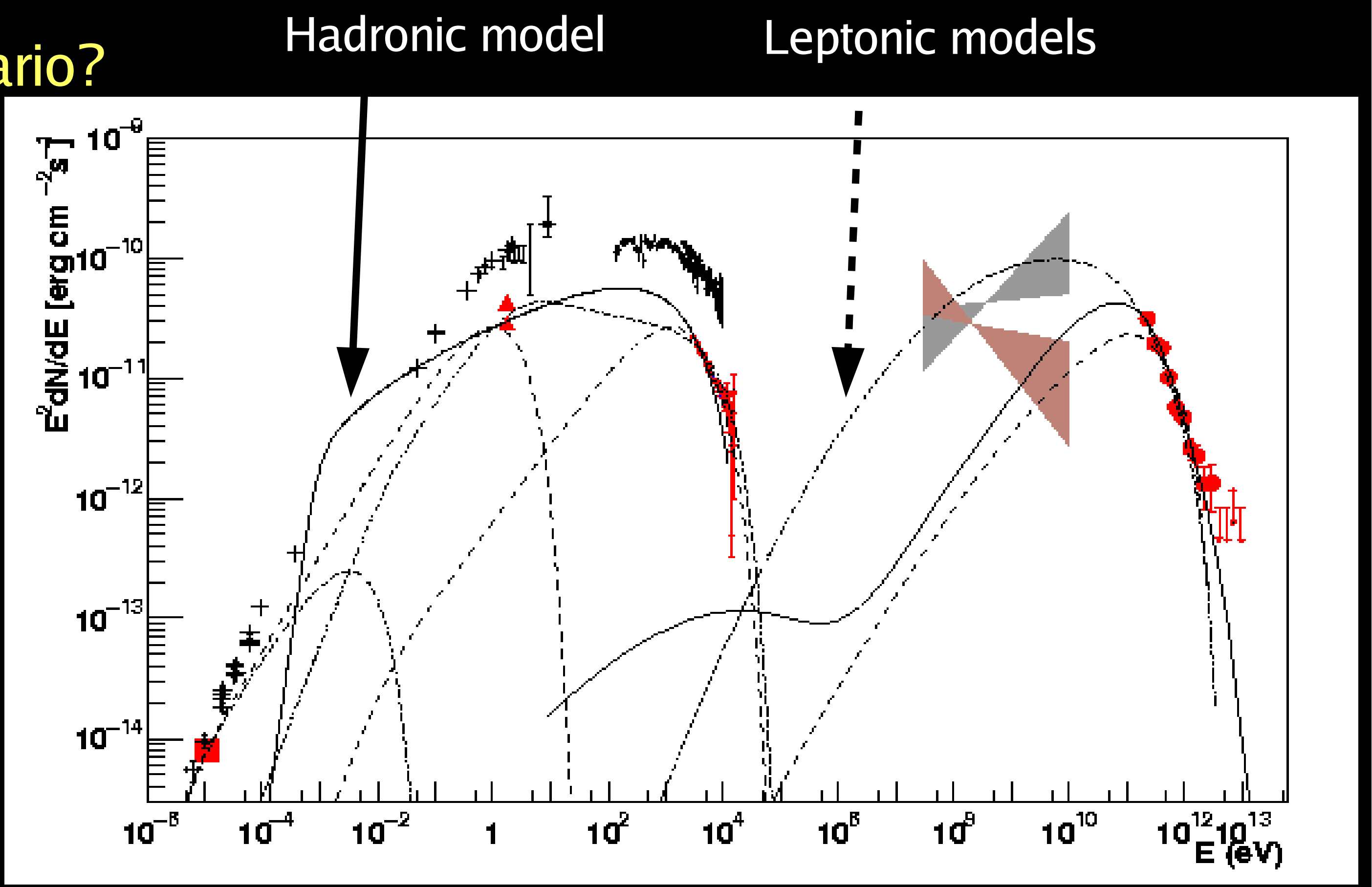
PKS 2155-304 - II

Difficult interpretation

⇒ **Big incertainties on the intrinsic spectrum**

Leptonic or hadronic scenario?

- Flux variability
- Broadband spectrum



In red, contemporaneous data
Other colors, archival data

PKS 2155-304 - II

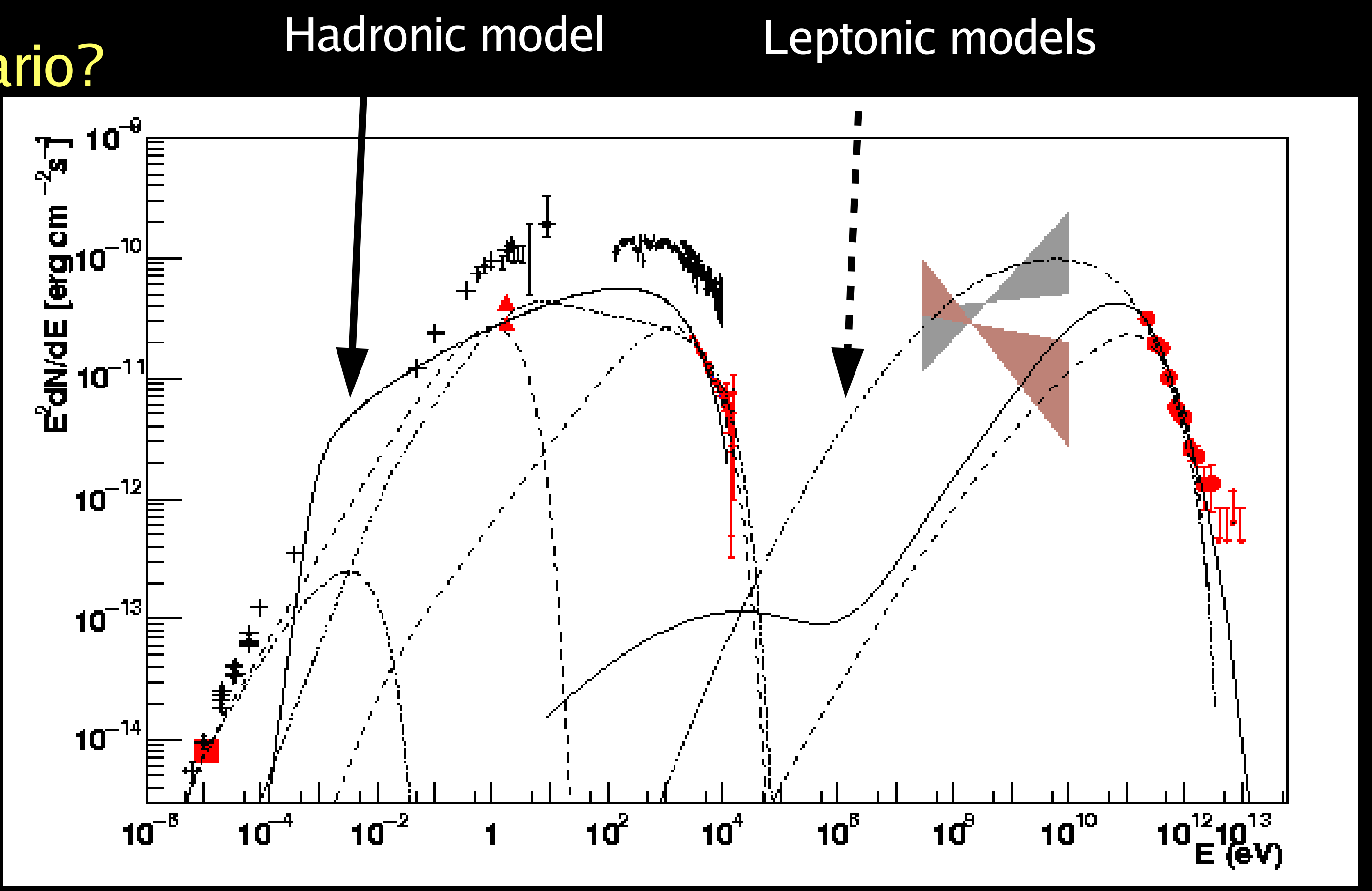
Difficult interpretation

⇒ **Big incertainties on the intrinsic spectrum**

Leptonic or hadronic scenario?

- Flux variability
- Broadband spectrum

⇒ **Need more data**



In red, contemporaneous data
Other colors, archival data

Conclusions

H.E.S.S. is fully operational since 2004

- Performance is as expected
- Most sensitive detector above 100 GeV

In two years, numbers of sources almost doubled

SNR: 3 +2-1
PWN: 3 +3-2
UnId: 1 +1
GC: +1
AGN: 5 +2

And exciting new results are in press...

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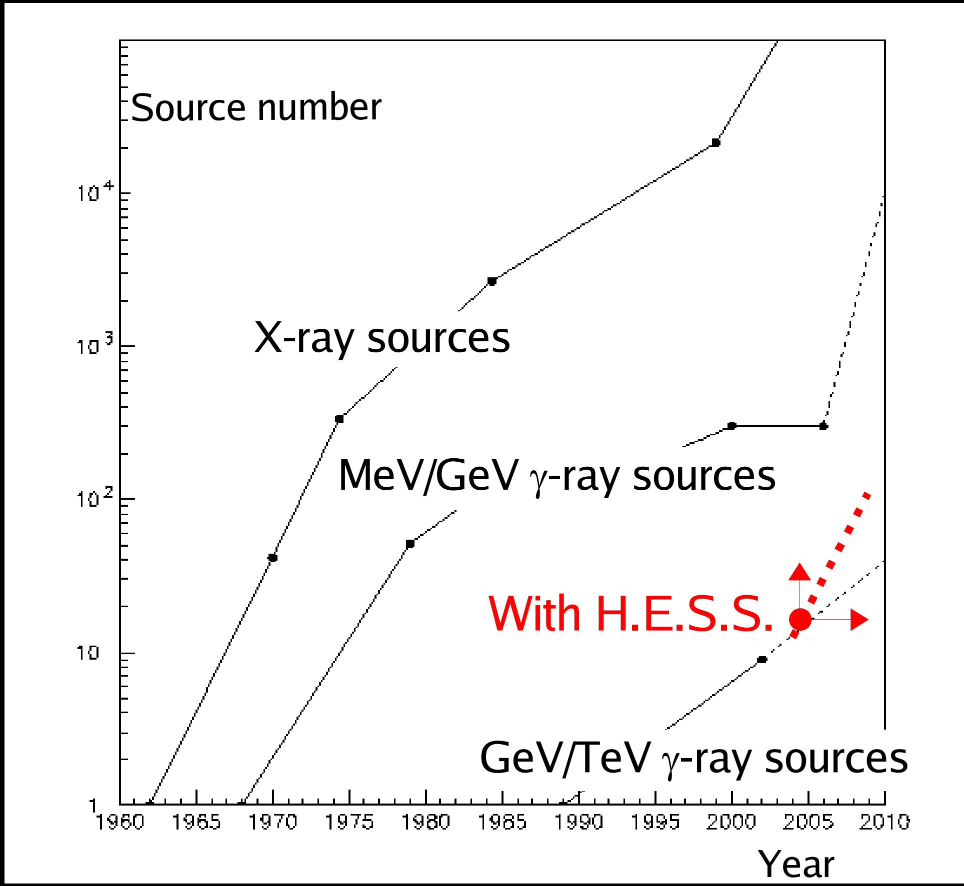

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And new exciting results are in press...

Conclusions - II

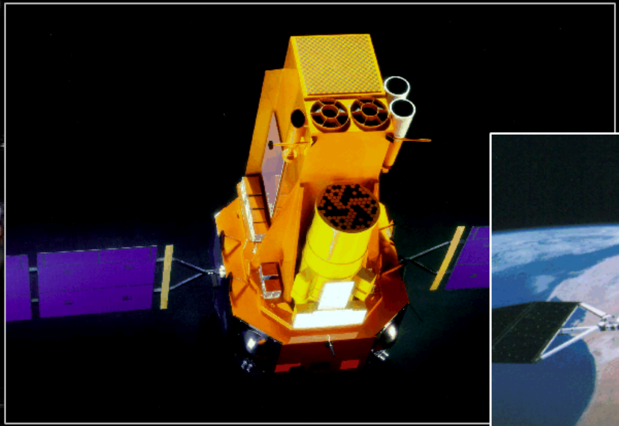
Stereoscopic Atmospheric Cherenkov Technique (H.E.S.S.)

- Energy resolution ⇒ Fine determination of spectra
- Sensitivity ⇒ Better statistics (source number, source localisation, ...)
- Angular resolution ⇒ morphology studies (SNRs)

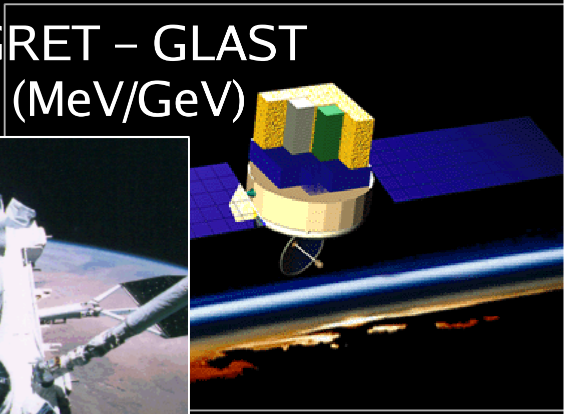
Better astrophysical interpretations with data from all wavelengths

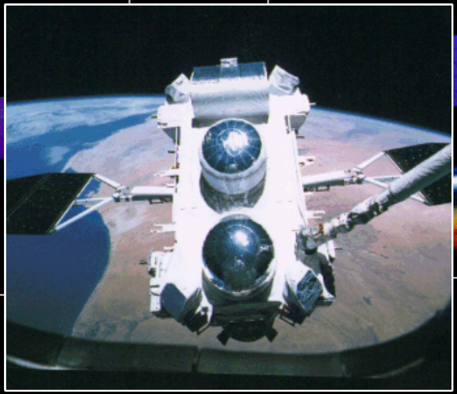
X-ray satellites

INTEGRAL (E<MeV)



EGRET – GLAST (MeV/GeV)

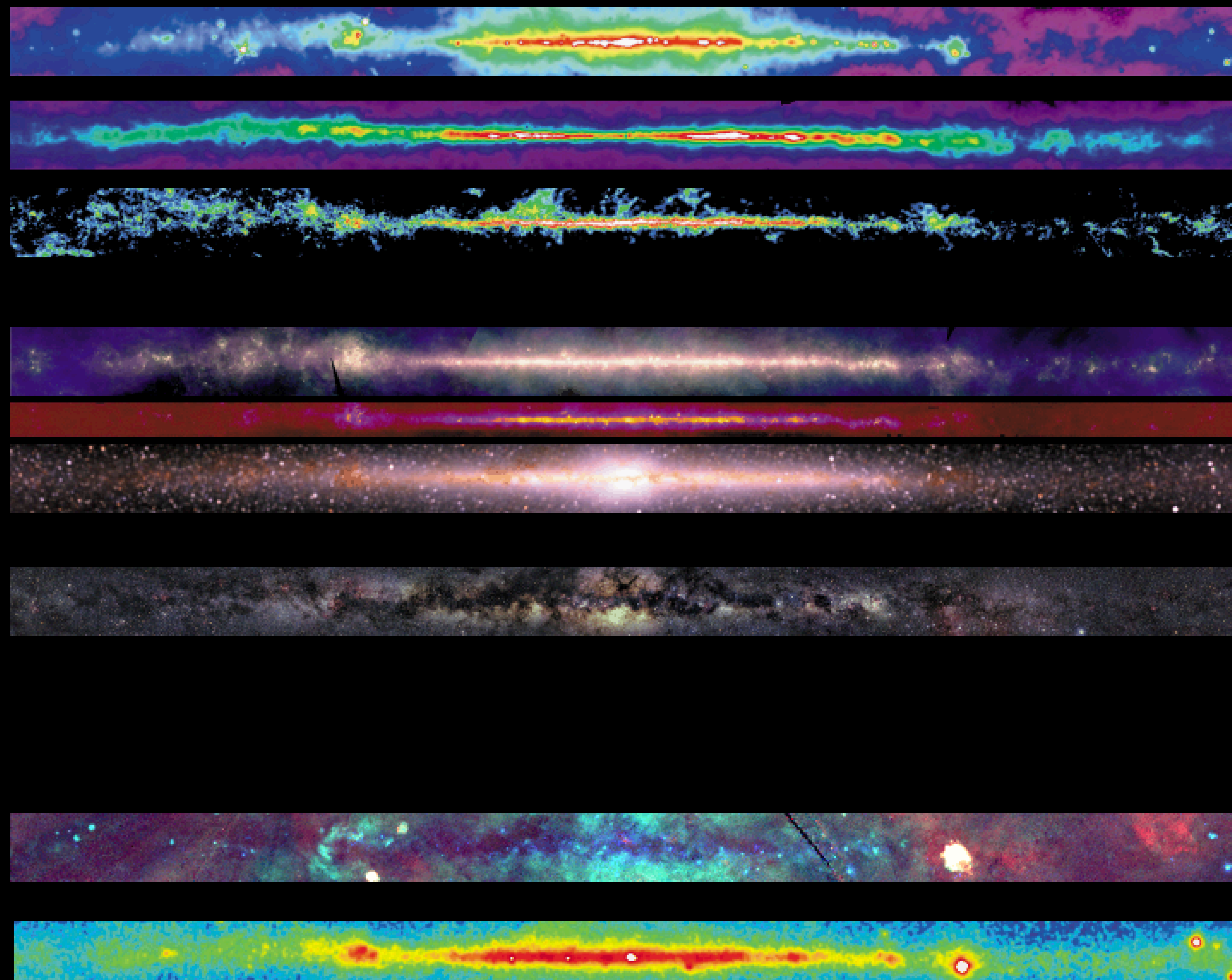




Detectors with E_{th} ~ 20-50 GeV scheduled

MAGIC, VERITAS, H.E.S.S. II, ...

The Milky Way



Radio
- 0.4GHz
- 1.4 GHz
- 115 GHz

Microwave

Infrared
- 12 – 100 μm
- 7 – 11 μm
- 1 – 3 μm

Optical 0.4 – 0.6 μm

UV

X-ray 0.2 – 1.5 keV

γ-ray
- 0.3 – 10 GeV
- 0.1 – 10 TeV: Very soon from H.E.S.S. (to appear in *Science*)

Air shower detectors

Survey capability

- Wide-angle instruments surveying ~ 2-3π
- But high energy threshold (>0.5 TeV)
- But poor sensitivity (~yrs) compared to ACTs (~min.)

Milagro
USA

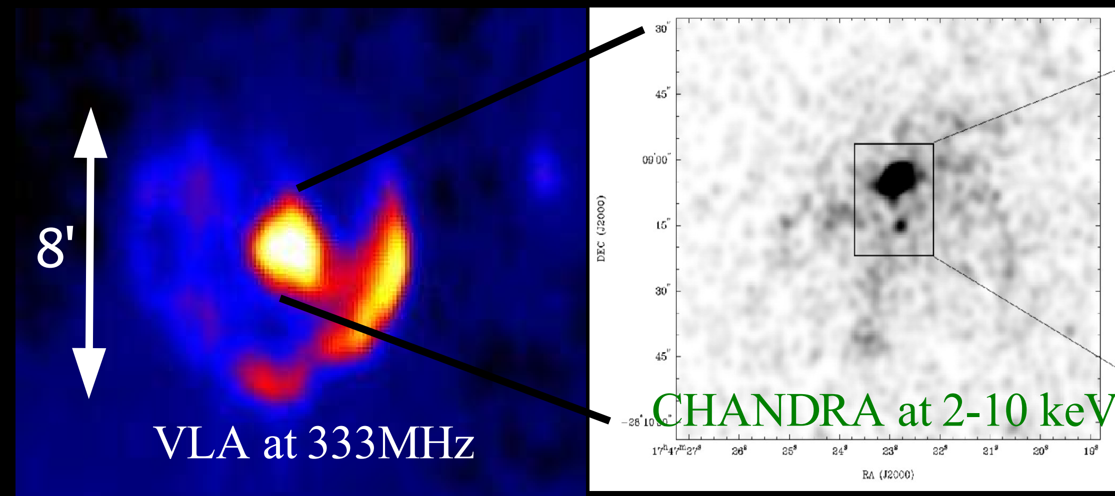
Tibet array

ARGO YBJ
Tibet

The PWN inside G 0.9+0.1

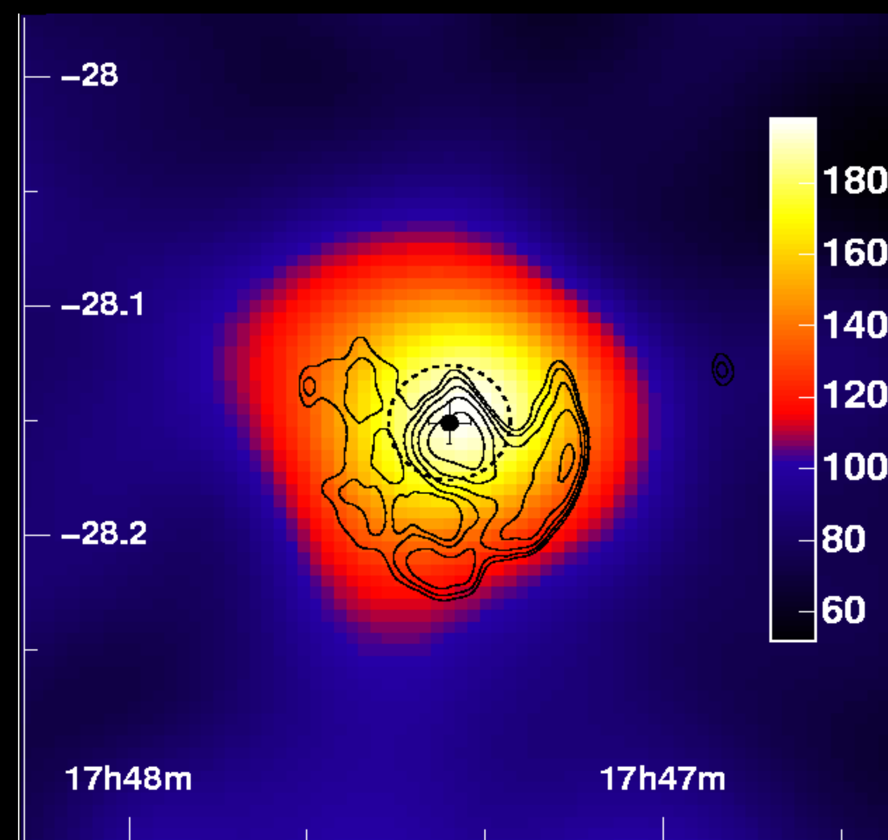
Evidence for a PWN, but no pulsar detected

Near the Gal. Center (~8.5 kpc)



H.E.S.S. observations

- 50 hrs, E_{th} ~ 170 GeV
- Excess of 13 σ
- Point source
- Flux of 2% Crab, Γ = 2.4±0.1



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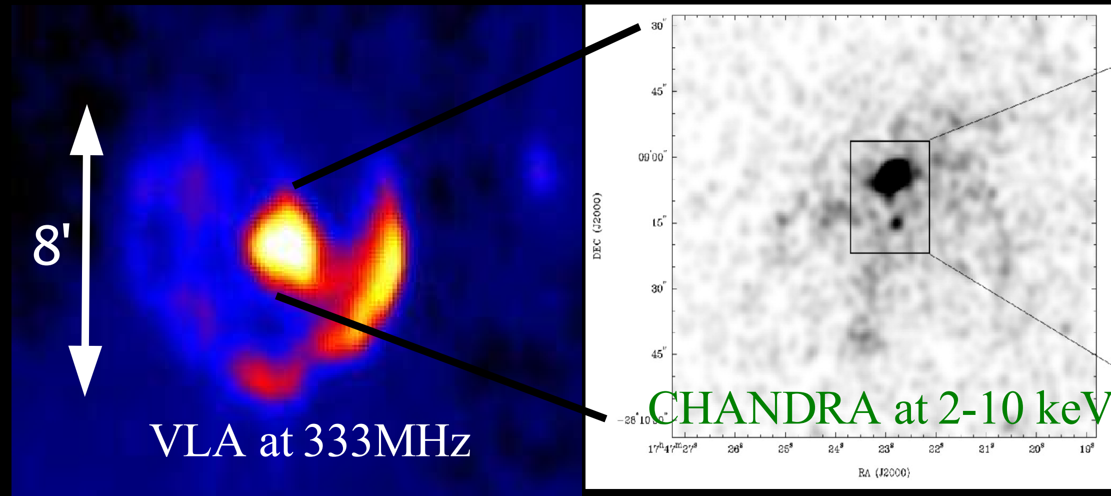

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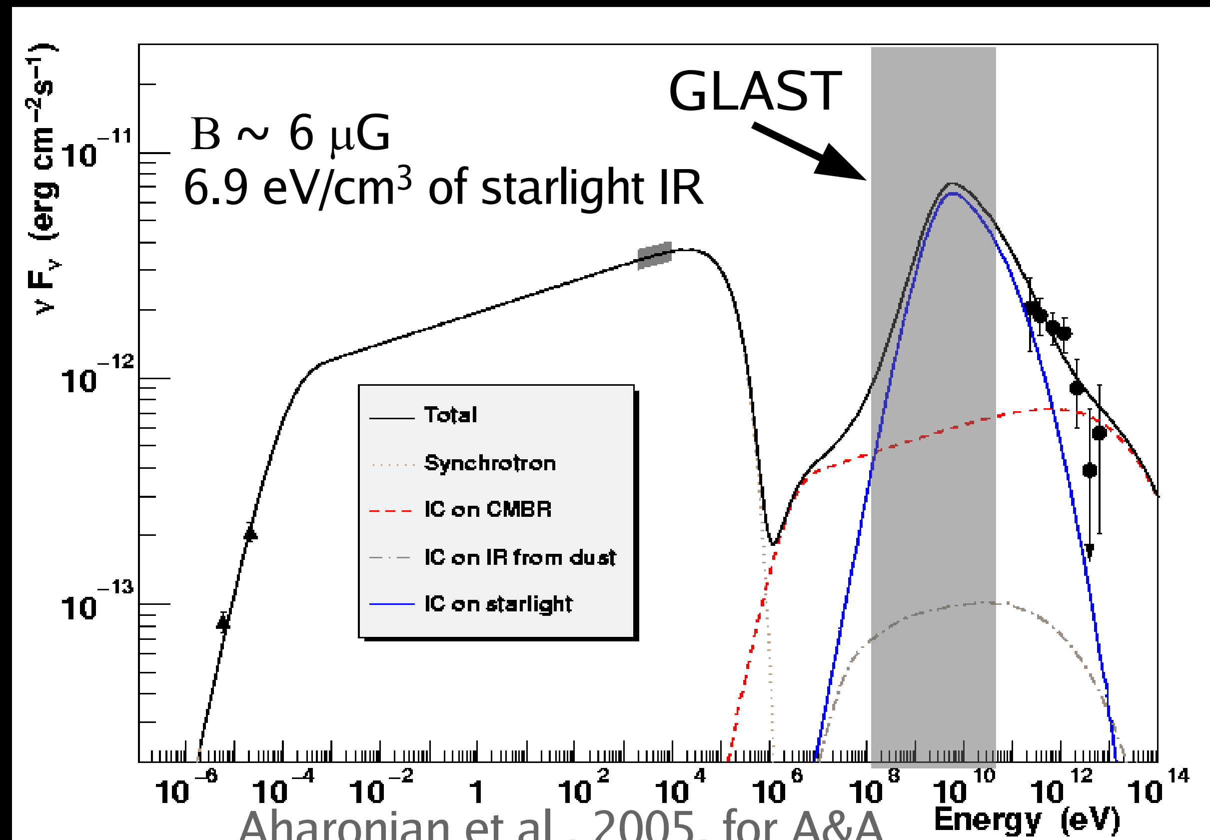
IC Interpretation

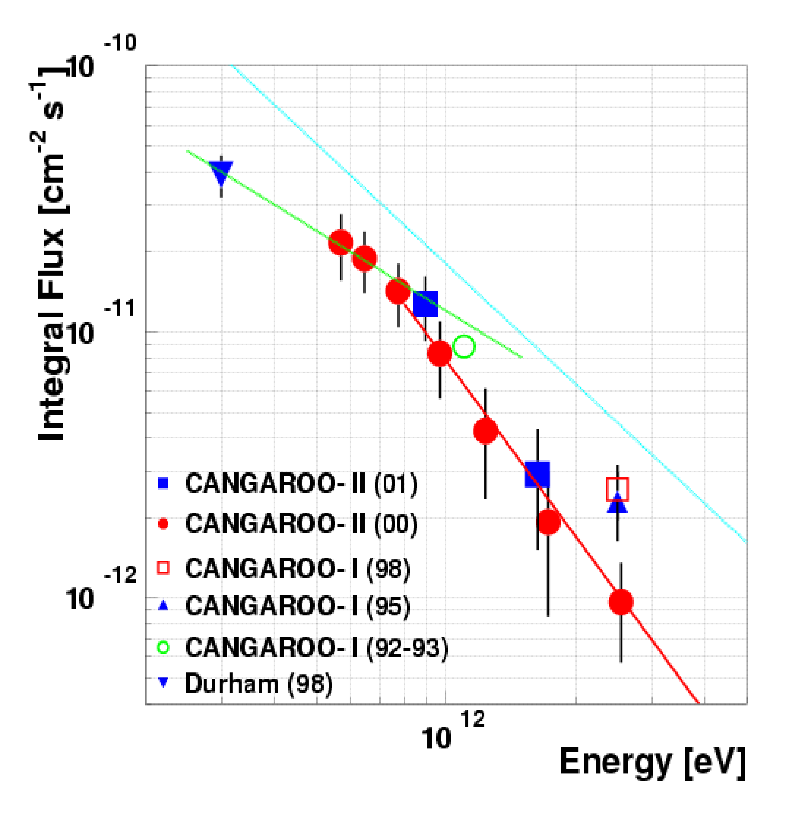
- Need starlight as seed photons

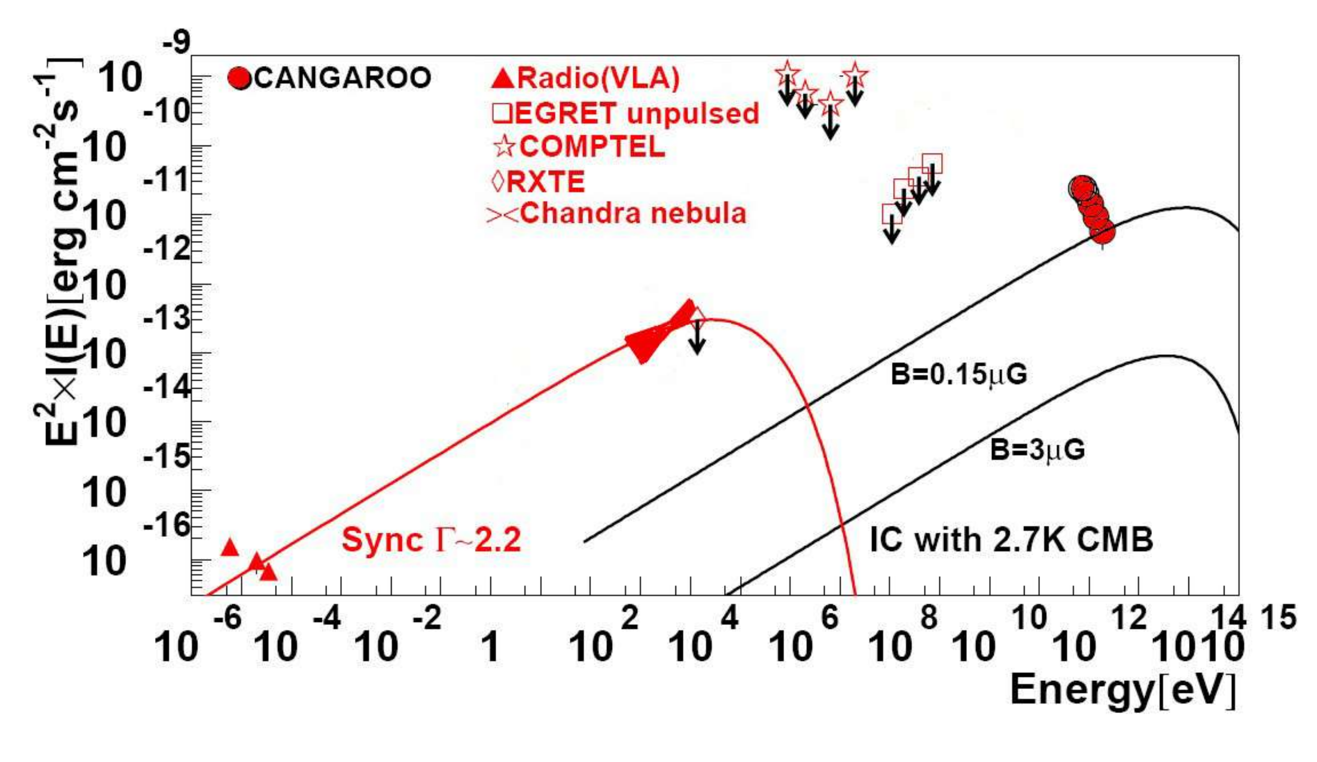
⇒ **Need more data at lower and higher energies**



Aharonian et al., 2005, for A&A

The PWN around PSR B1706-44





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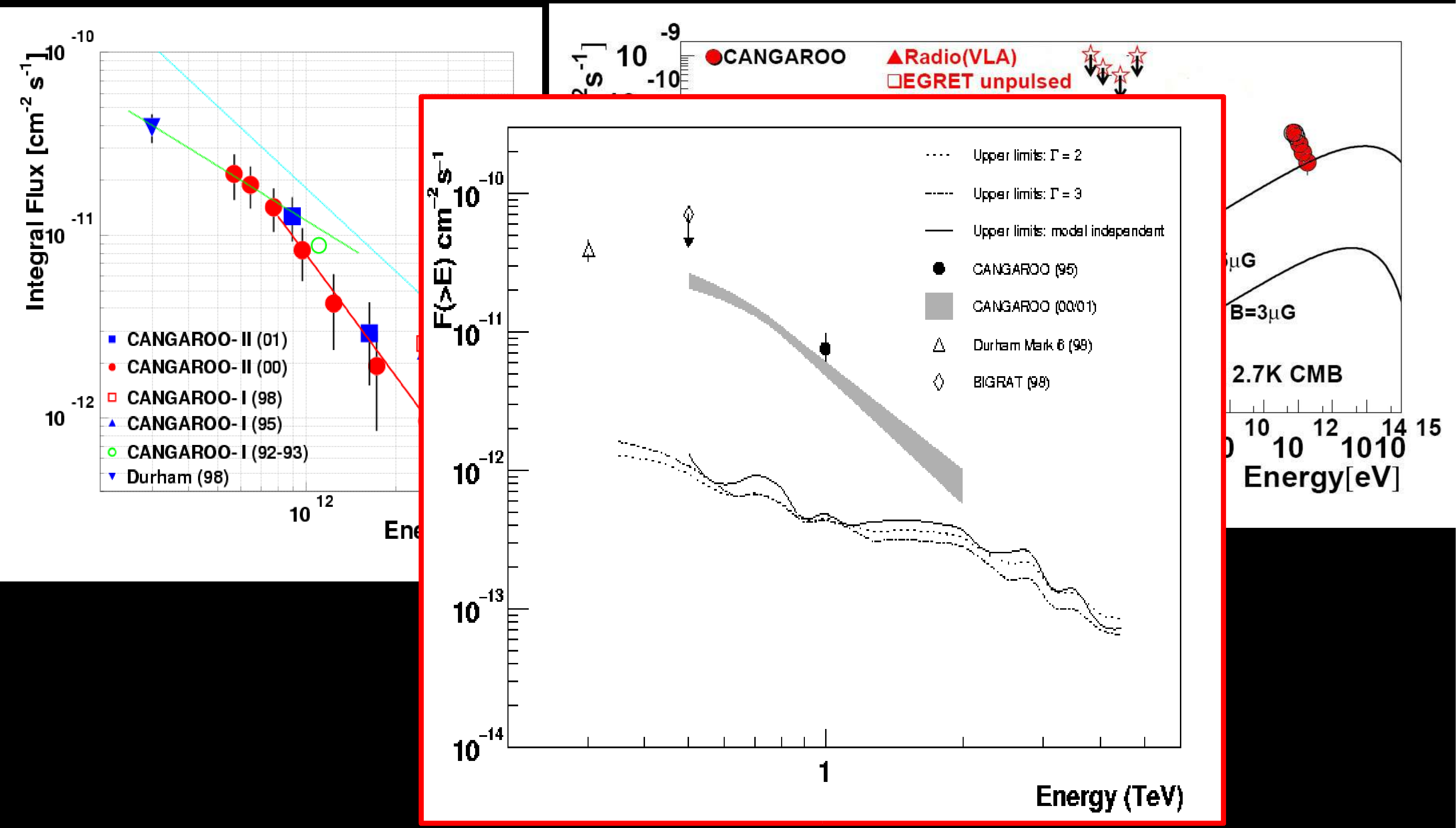
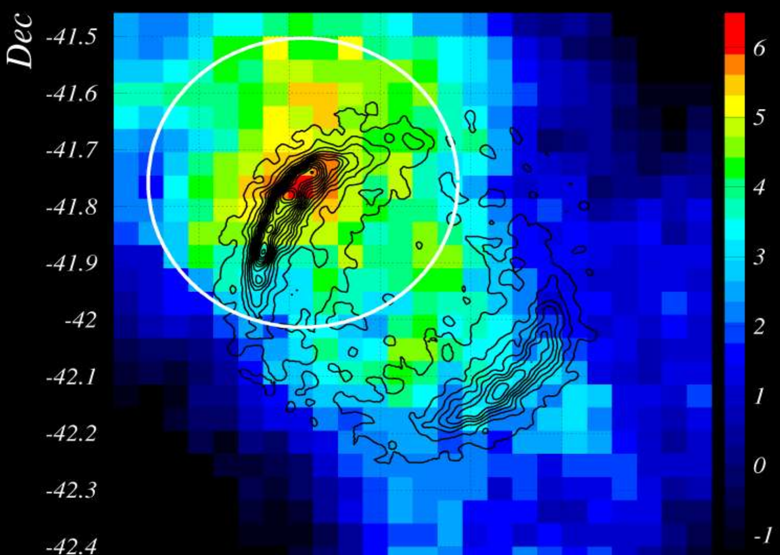
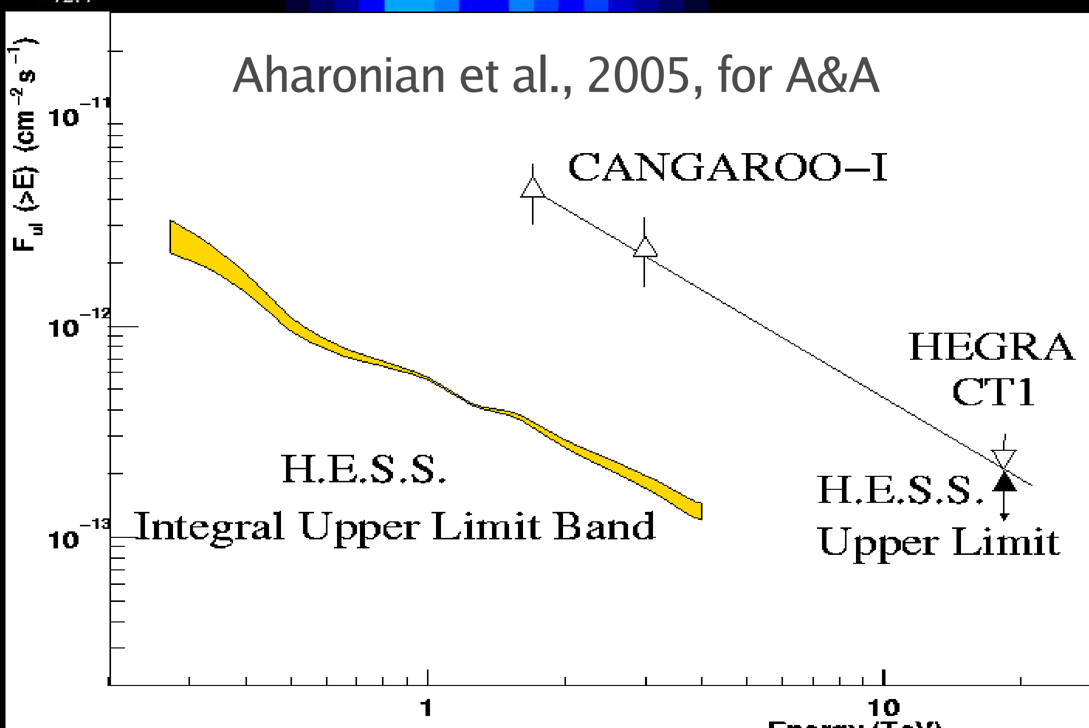


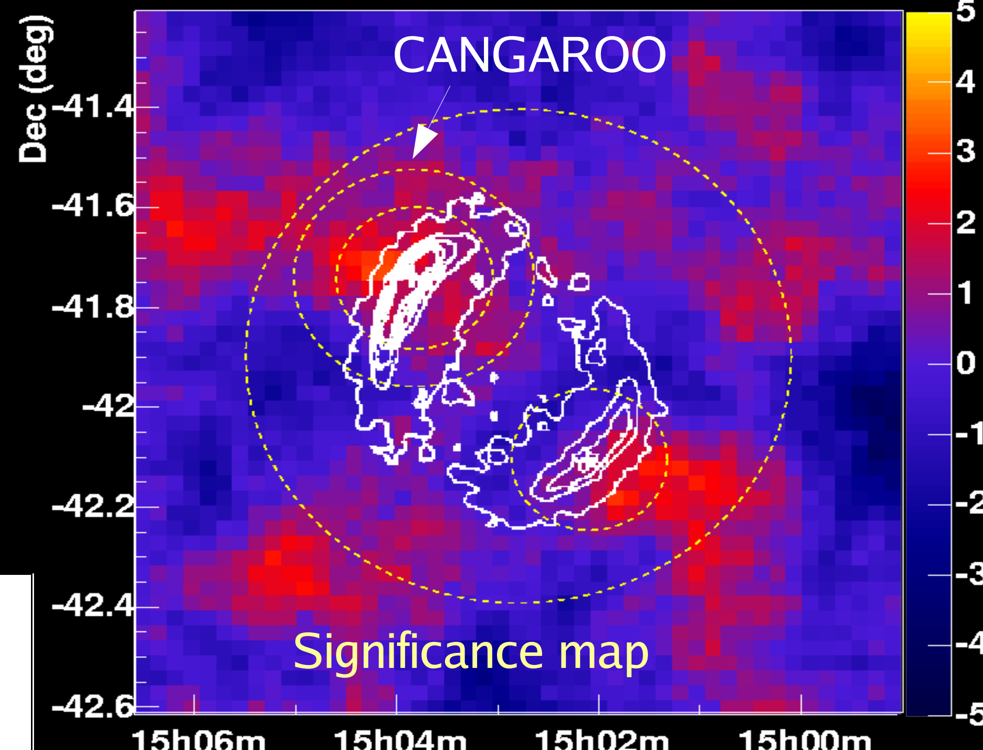
SN 1006: a problem?

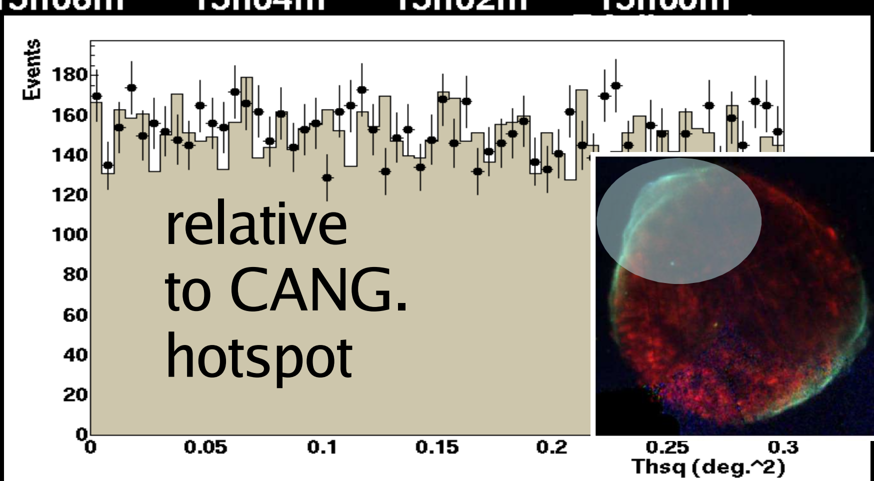
CANGAROO 2001





H.E.S.S. 2003-04 (18.2h)





La Thuile, 28/02/2005