# H.E.S.S.

# High Energy Stereoscopic System

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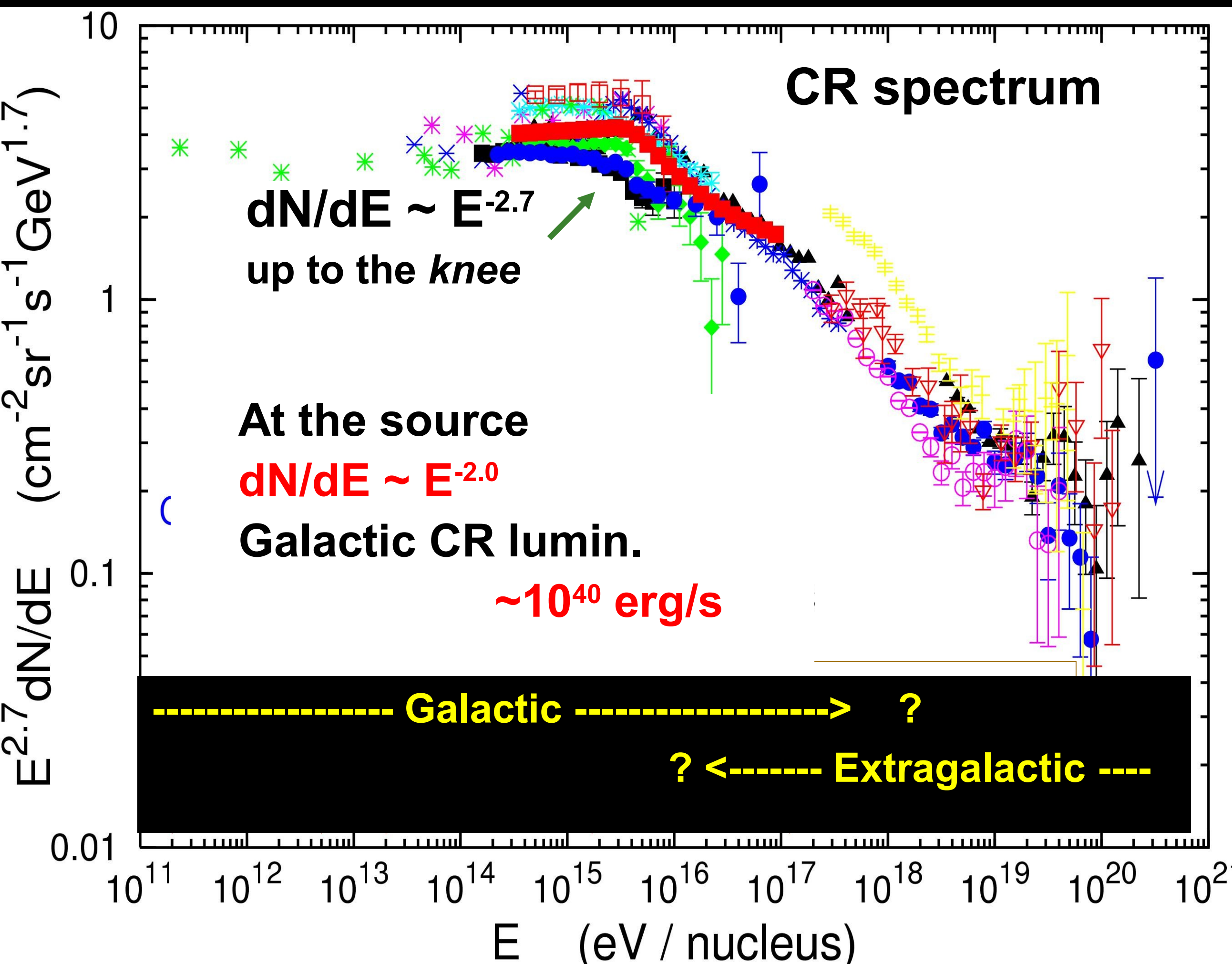
*(for the H.E.S.S. collab.)*

*3rd School of Cosmic-Rays, Arequipa, Peru (Aug/Sept 2008)*

# The Cosmic Ray Energy Spectrum

*Since discovery (1912, Victor Hess), CR origin still unknown!*

**CR Acceleration: How? Diffusive Shock Accel.**




Krymsky 1977, Axford 1977,

Blandford & Ostriker 1978,

Bell 1978

[following Fermi (1949, 1954)]

$dN/dE \sim E^{-2.0}$ at source

$E_{max} \sim 10^{14} – 10^{15}$ eV

see review Hillas 2005

<u>CR Origin: Where?</u>

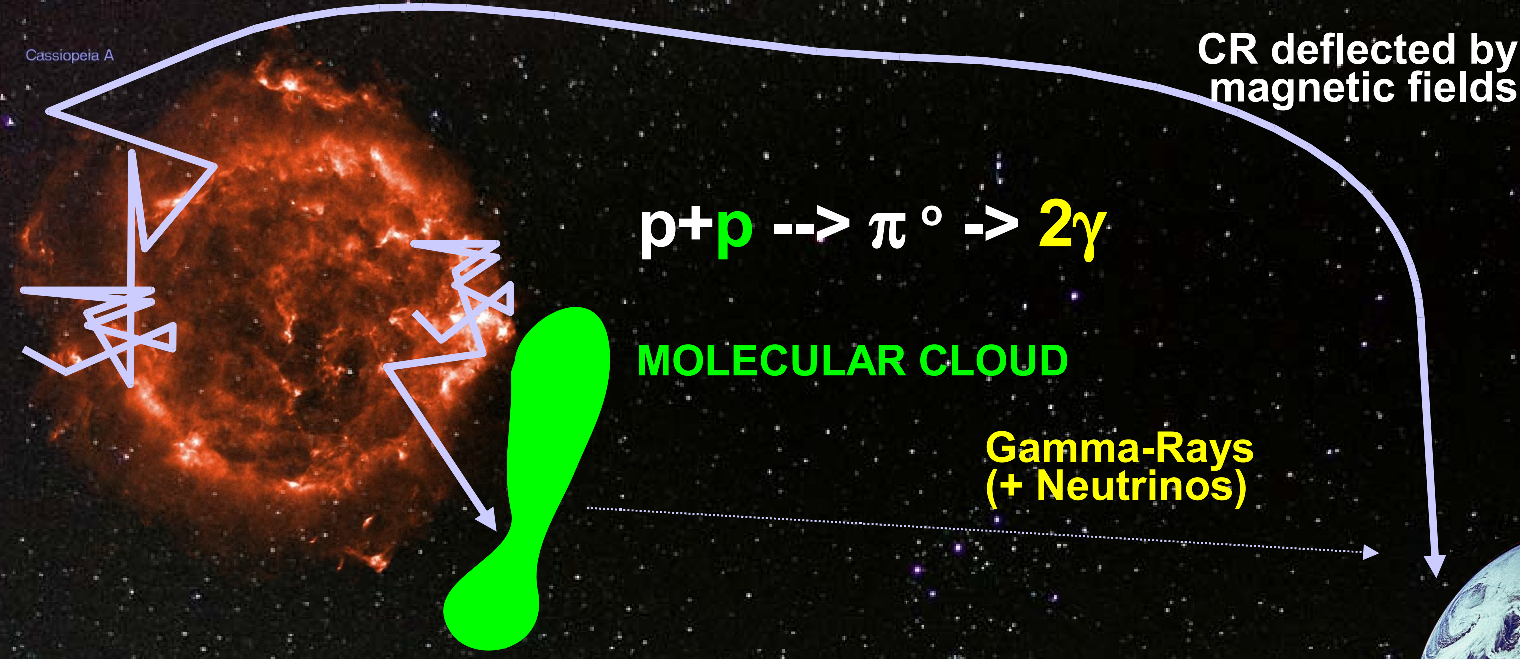
Shell-Type

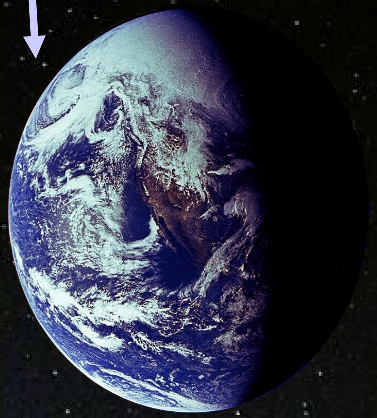
Supernova Remnants

Ginzburg & Syrovatskii (1964)

**$E_{SNR} \sim 10^{50}$ ergs**

# Gamma Rays from multi-TeV hadrons (Cosmic-Rays - CRs)



**Molecular Clouds act as targets for particle accelerators.**

**Key Signatures**

- **Broad-band flat spectra GeV to multi-TeV emission**

- **TeV gamma + Mol Cloud spatial correlation**
  ***--> TeV gamma and arc-min mm-wave observations***

***We also have!*** $p+p \to \pi^{\pm} \to \mu^{\pm} + \nu_{\mu} (\bar{\nu}_{\mu}) \to e^{\pm}$ **secondary radio to X-ray synchrotron**

# Gamma Rays from multi-TeV electrons


$\gamma$ – CMB, IR,
UV photon fields

**Accelerated TeV Electrons**

$e + \gamma\,(\text{soft}) \rightarrow e' + \gamma\,(\text{TeV})$ (inverse Compton scattering)

$e + B\,(\ \mu G) \rightarrow e' + \gamma\,(\text{keV})$ (X-ray synchrotron emission)

**Accelerated GeV Electrons**

$e + B\,(\ \mu G) \rightarrow e' + \gamma\,(\sim\text{eV})$ (Radio - optical synchrotron emission)

*see also sync. from 'secondary' electrons*

# Objectives (a growing list) of TeV Gamma-ray Astronomy

Oldest question in modern astrophysics!

## Origin of (Galactic) Cosmic Rays (CRs)

*Shell-SNRs, Molecular clouds, Diffuse radiation of the Galactic Disk..*

## *Particle acceleration/interaction & Photon production/transport.....*

*Pulsar Wind Nebulae (PWN), Compact Binaries.....*

## *Stellar Clusters & Stellar Wind Interactions*

*Shock accel in wind/wind/ISM interactions, Superbubbles*

## Galactic and Extragalactic Sources with relativistic flows

*Pulsars, Pulsar Winds, Microquasars, Small and Large Scale jets of AGN, GRBs*

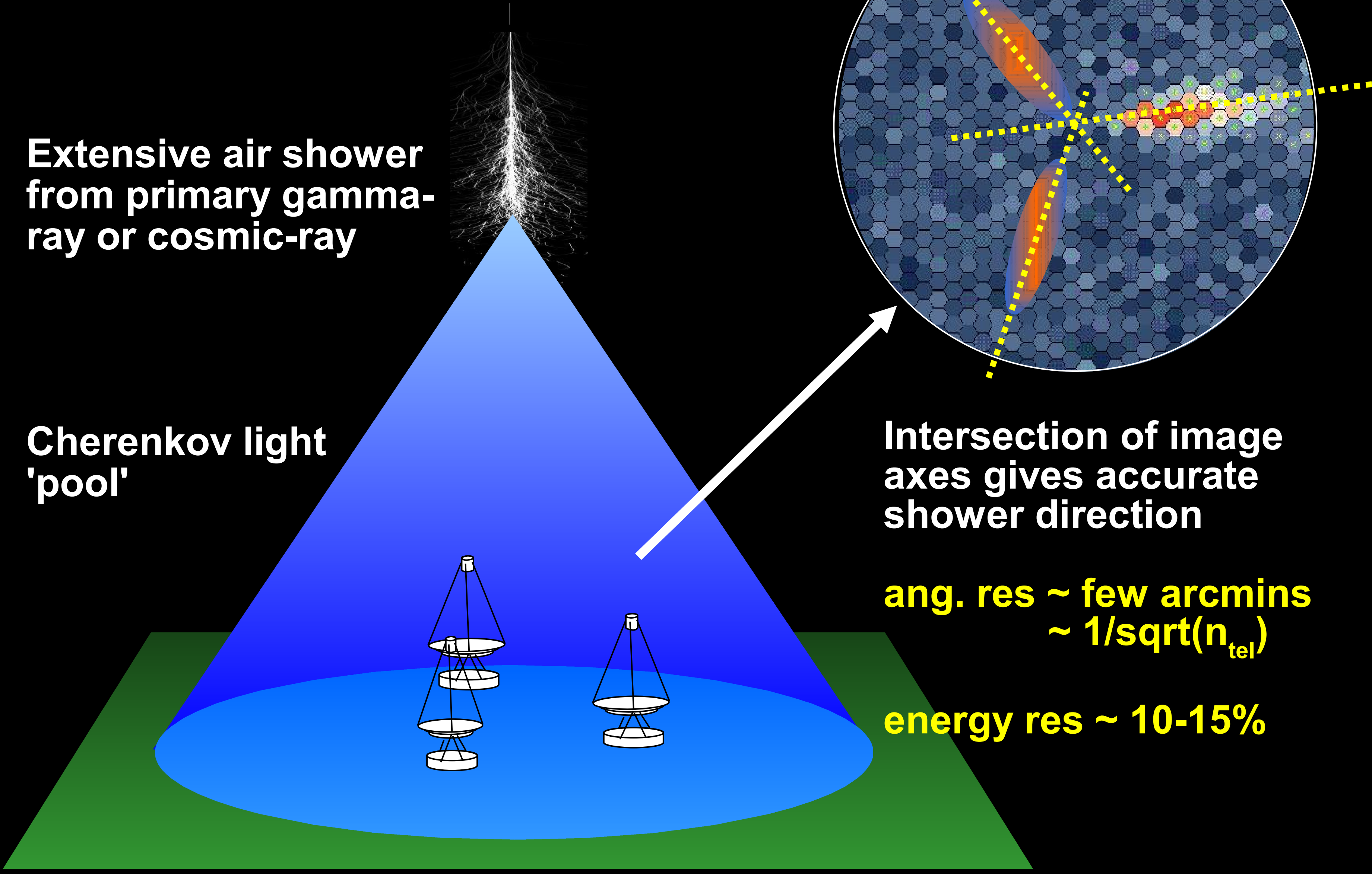
## Observational Gamma Ray Cosmology

*Diffuse Extragalactic Background radiation (constraints),*

## Others

*Large Scale Structure (Clusters of Galaxies), Dark Matter Halos, Pair Halos*

# Ground-Based Gamma-Ray Detection with Stereoscopic Cherenkov Imaging



# H.E.S.S. Array: 4 x Cherenkov Imaging Telescopes (22° S 1800m a.s.l. Namibia)


**4 x 12m diam dishes**

**focal-plane cameras**
**5 deg FoV**

H.E.S.S. >25 Institutions (Europe,Africa,Australia)

http://www.mpi-hd.mpg.de/hfm/HESS/HESS.htm

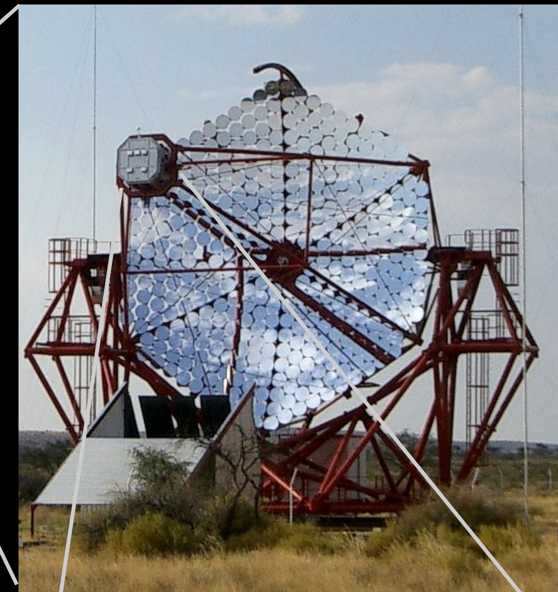
http://www.mpi-hd.mpg.de/hfm/HESS/public/som/current.htm

"Source of the Month"

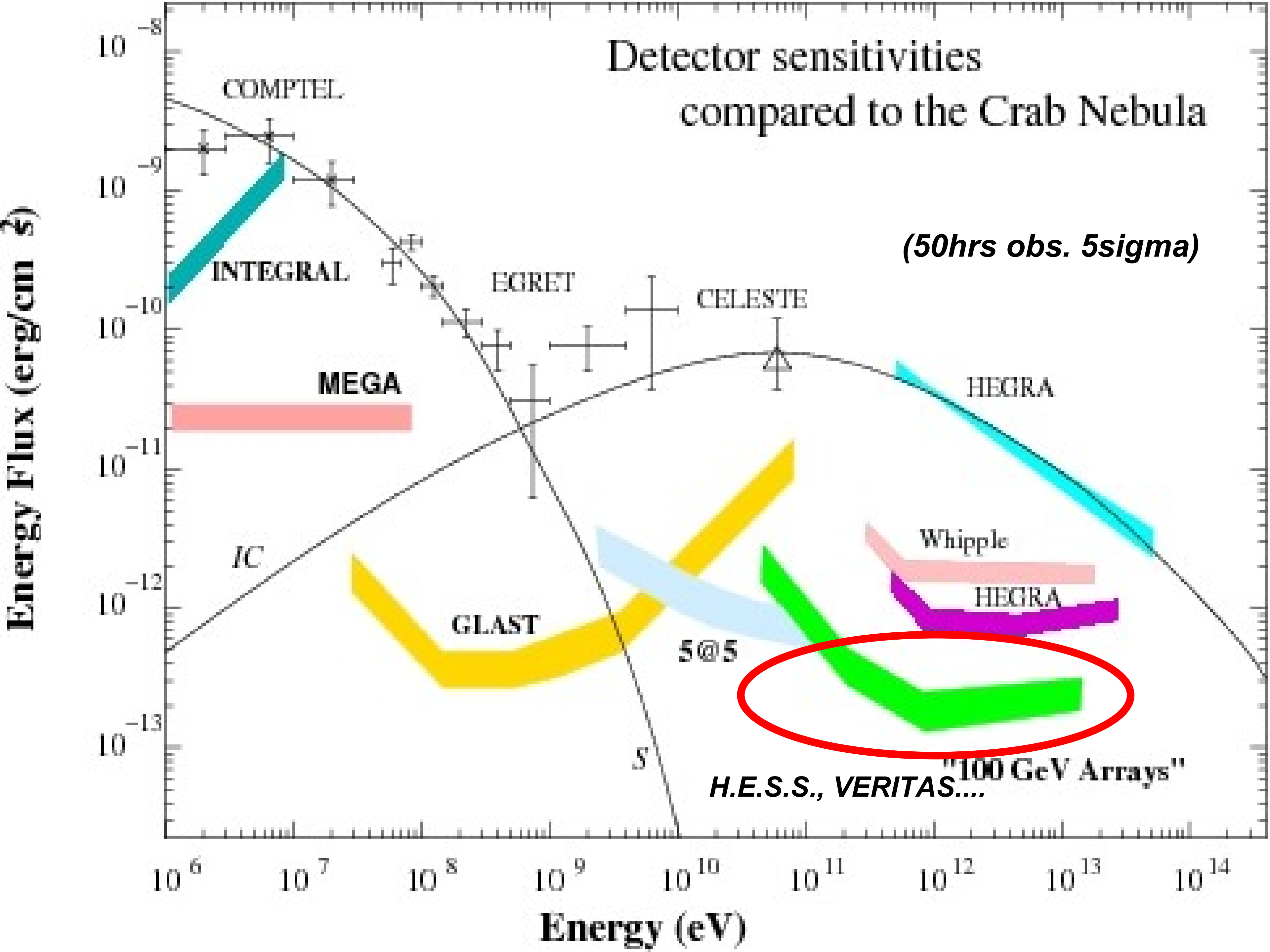
**ang. resolution**
**few arcmins**

# The H.E.S.S. Telescopes

12m

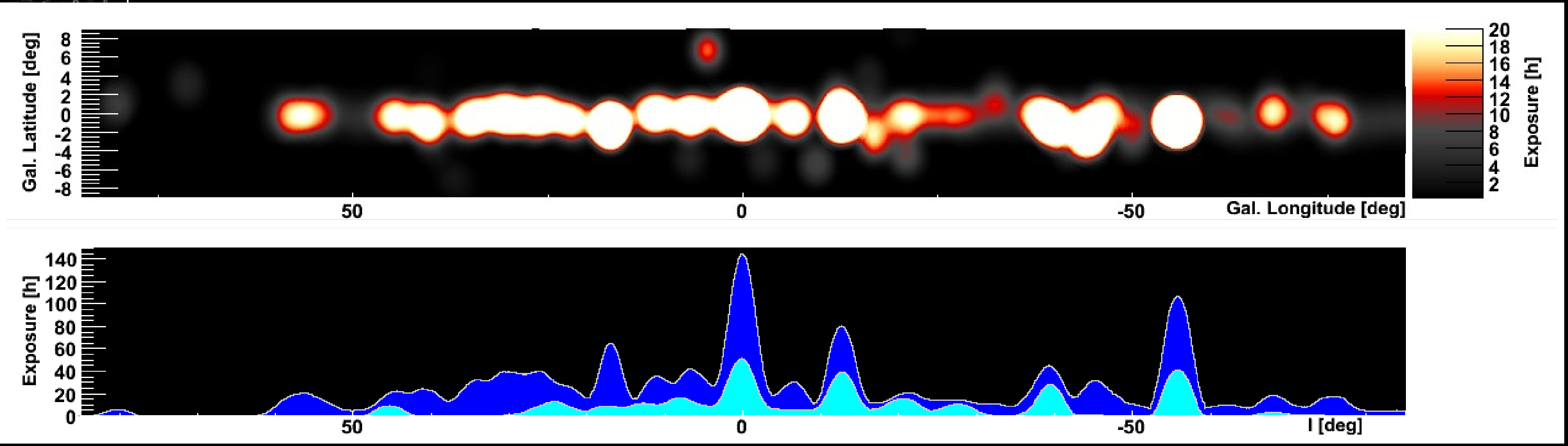


- **H**igh **E**nergy **S**tereoscopic **S**ystem
- 4 telescopes (in Namibia *23° S*)
  stereoscopic observation mode
- Each telescope: ~107m$^2$ mirror surface,
  380 facets
- Photomultiplier camera (ns response)
  960 PMTs, ***~5° field of view (FoV)***
- Sensitive energy range:
  0.1 TeV up to ~50 TeV
- ***Angular resolution: ~0.1° per event***
  ***arc-second src location***



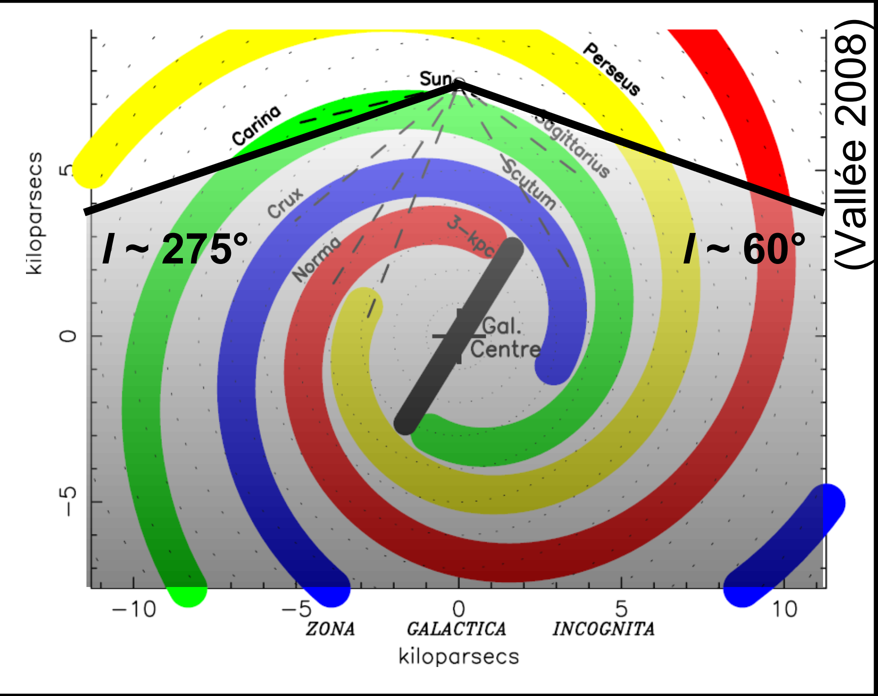
Detector sensitivities
compared to the Crab Nebula
(50hrs obs. 5sigma)
COMPTEL
INTEGRAL
EGRET
CELESTE
MEGA
HEGRA
IC
GLAST
5@5
Whipple
HEGRA
S
"100 GeV Arrays"
H.E.S.S., VERITAS....
Energy Flux (erg/cm$^2$ s)
Energy (eV)

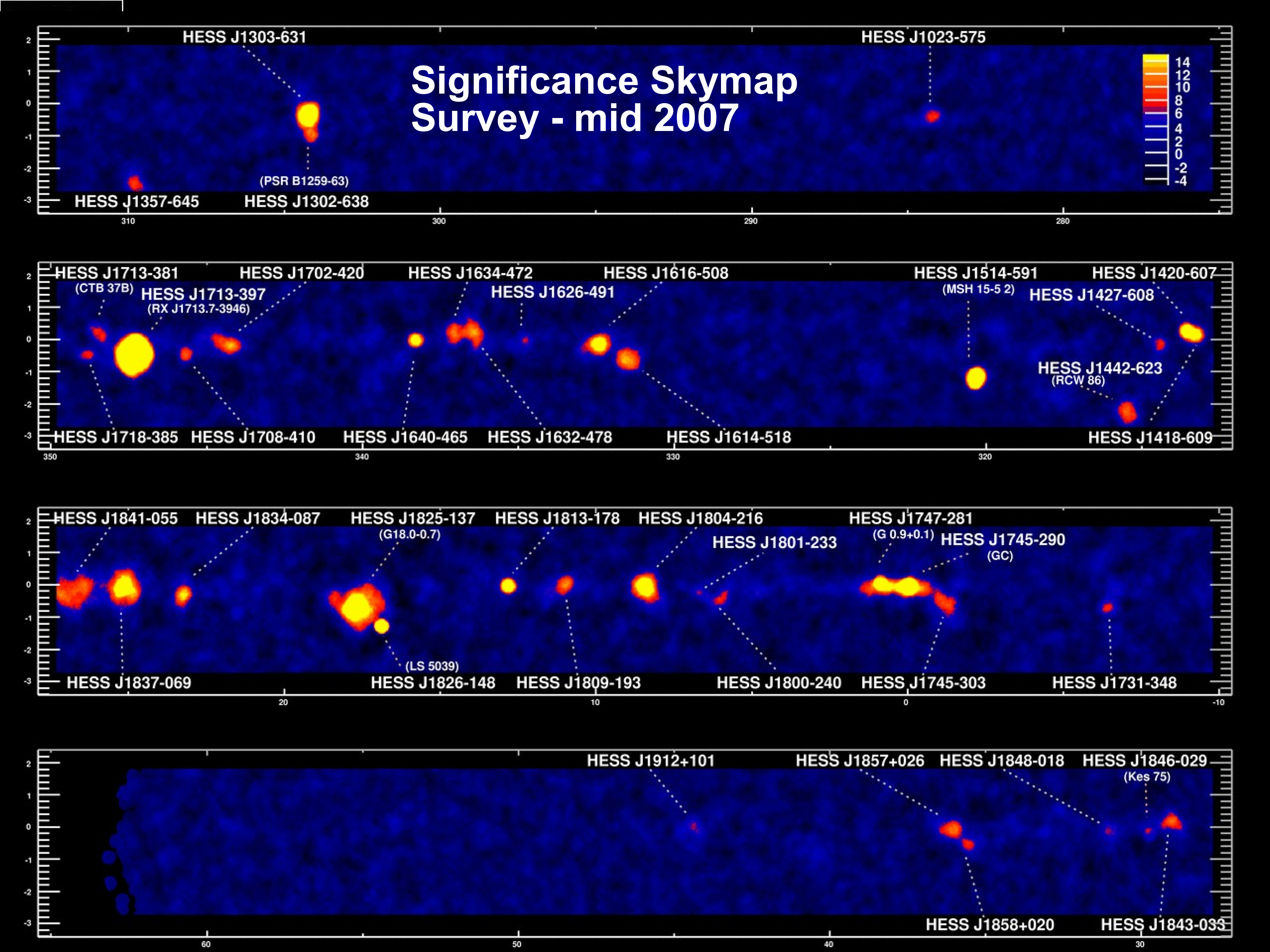
# Galactic Plane Scan – up to early 2008



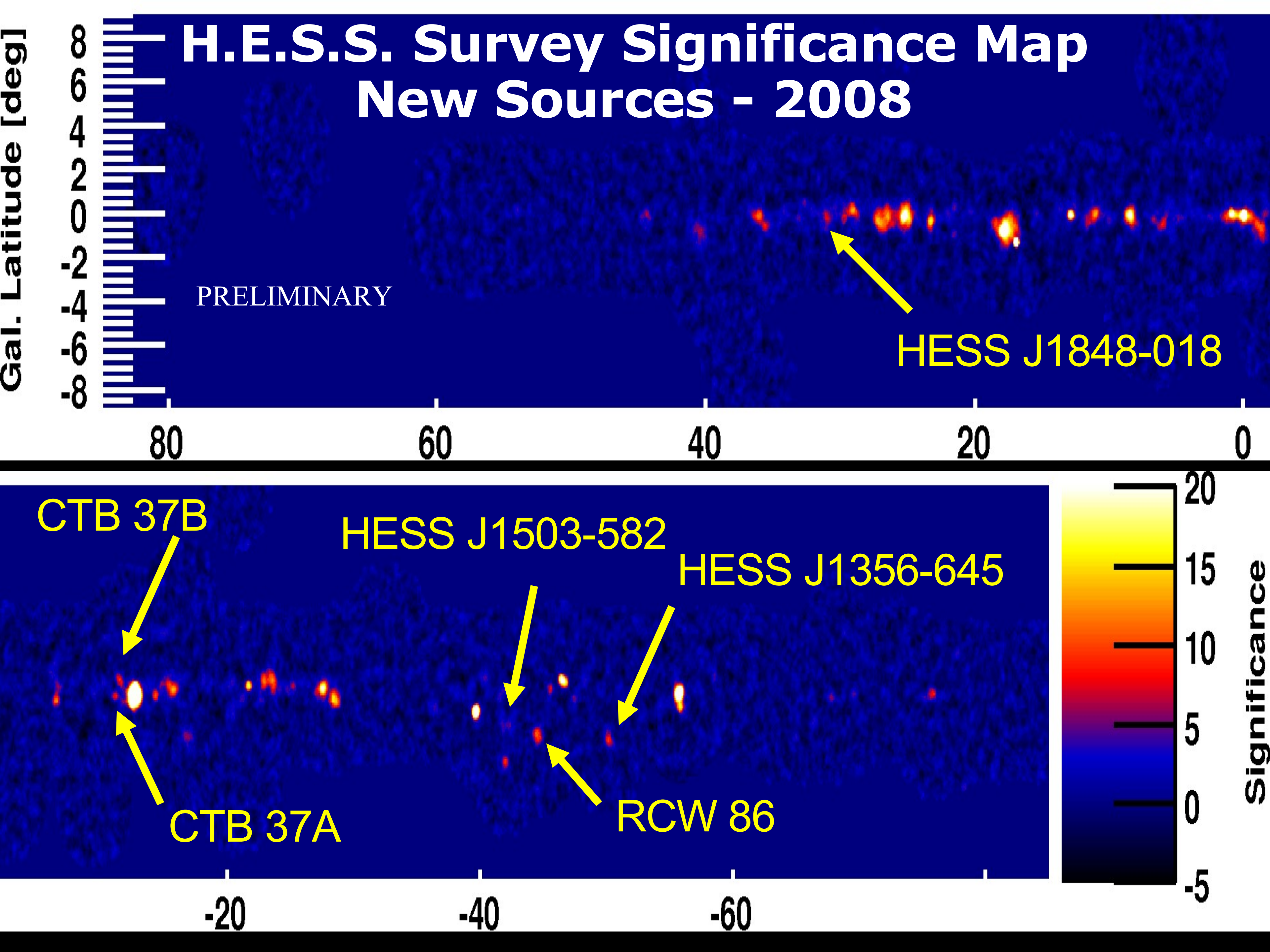

**Extended H.E.S.S. GPS**

- **-85° < *l* < 60°**
- -3° < *b* < 3°
- Scan mode: **400** h
- Detected **50+ Galactic sources** of VHE gamma-rays
- ICRC 2007, DPG 2008, Gamma08





Significance Skymap
Survey - mid 2007
14
12
10
8
6
4
2
0
-2
-4
HESS J1303-631
HESS J1023-575
(PSR B1259-63)
HESS J1357-645
HESS J1302-638
HESS J1713-381
(CTB 37B)
HESS J1713-397
(RX J1713.7-3946)
HESS J1702-420
HESS J1634-472
HESS J1626-491
HESS J1616-508
HESS J1514-591
(MSH 15-5 2)
HESS J1420-607
HESS J1427-608
HESS J1442-623
(RCW 86)
HESS J1718-385
HESS J1708-410
HESS J1640-465
HESS J1632-478
HESS J1614-518
HESS J1418-609
HESS J1841-055
HESS J1834-087
HESS J1825-137
(G18.0-0.7)
HESS J1813-178
HESS J1804-216
HESS J1801-233
HESS J1747-281
(G 0.9+0.1)
HESS J1745-290
(GC)
HESS J1837-069
(LS 5039)
HESS J1826-148
HESS J1809-193
HESS J1800-240
HESS J1745-303
HESS J1731-348
HESS J1912+101
HESS J1857+026
HESS J1848-018
HESS J1846-029
(Kes 75)
HESS J1858+020
HESS J1843-033


H.E.S.S. Survey Significance Map
New Sources - 2008
Gal. Latitude [deg]
8
6
4
2
0
-2
-4
-6
-8
PRELIMINARY
HESS J1848-018
80
60
40
20
0
CTB 37B
HESS J1503-582
HESS J1356-645
CTB 37A
RCW 86
-20
-40
-60
20
15
10
5
0
-5
Significance

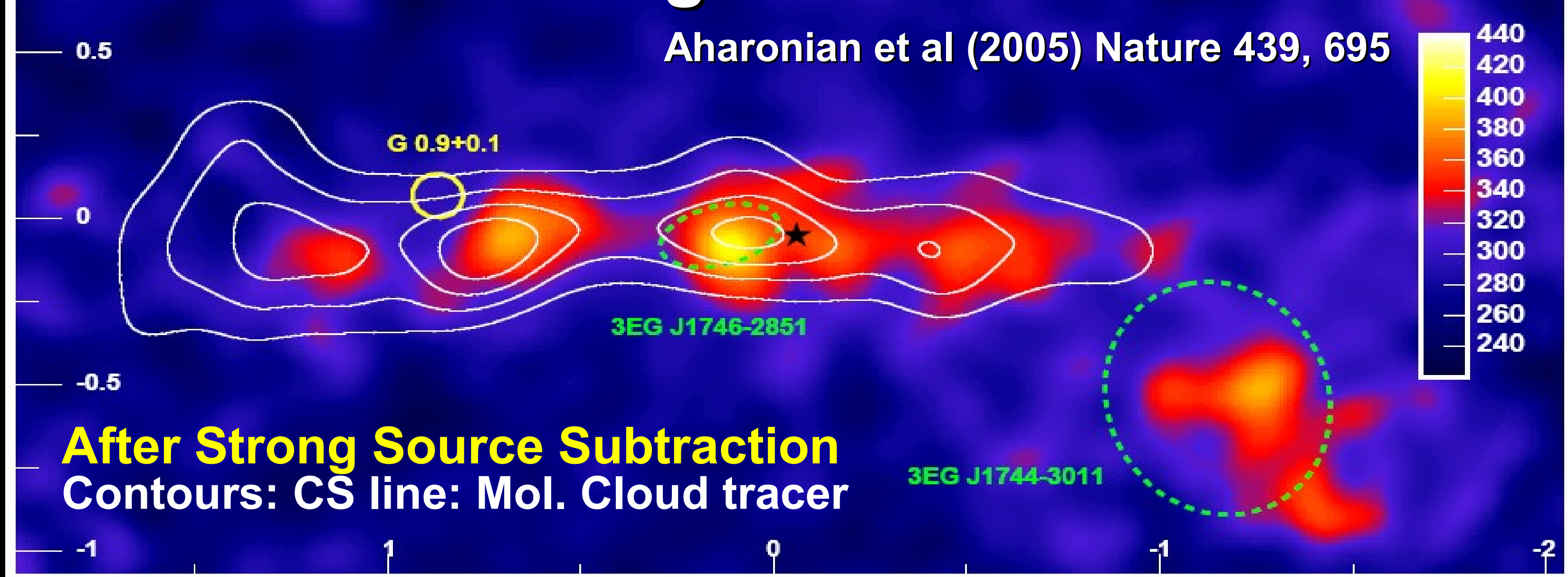
# TeV Source Types

| Class | 2003 | 2005 | 2007 | 2008 |
|---|---|---|---|---|
| PWN | 1 | 6 | 18 | 19 |
| SNR | 2 | 3 | 7 | 7 |
| Binaries + | | 2 | 4 | 4 |
| Diffuse | | 2 | 2 | 2 |
| AGN | 7 | 11 | 19 | 23 |
| Stellar Cluster * | | | 1 | 1 |
| UnID | 2 | 6 | 20 | 21 |
| TOTAL | 12 | 30 | 71 | 77 |

* Also includes massive high mass loss (egO,B, WR) stars

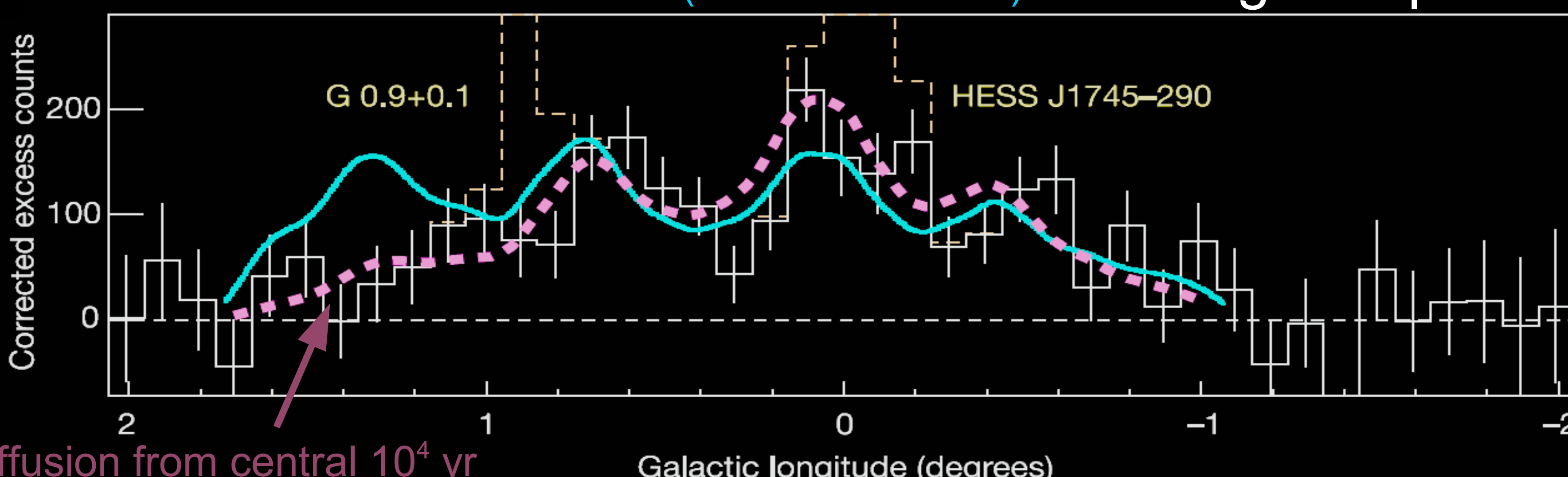
\+ Binaries – Includes wind/wind accretion, matter accretion and jet-powered

# Galactic Centre Region: Diffuse Emission




-- H.E.S.S. -- CS Data (Tsuboi etal 1999)

Longitude profile




Diffusion from central $10^4$ yr CR source

# CR accelerator + Molecular Cloud (passive target)

*further discussion see also Drury etal 1984, Naito et al 1984, Aharonian etal 1986*

## TeV Gamma Flux from pi-zero decay above energy E

$$F(\geq E) \sim 3\times10^{-13}\left(\frac{E}{\mathrm{TeV}}\right)^{-1.6} k(E)\,\frac{M_5}{d^2_{\mathrm{kpc}}}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$$

**Aharonian (1991) Ap & SS. 180, 305**

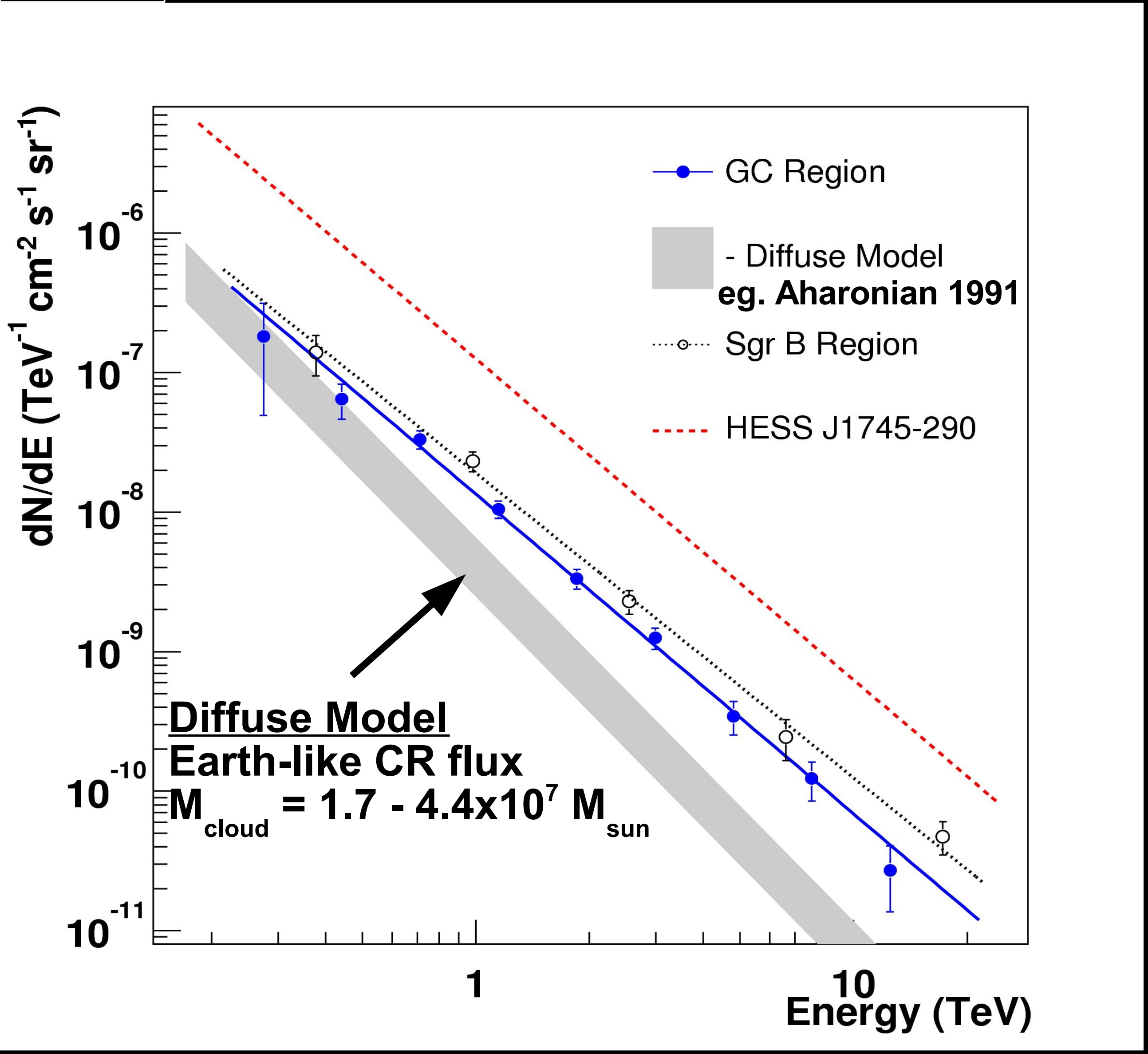
**$d_{kpc}$ – distance (kpc)**

**k(E) – E-dependent scaling factor: For 'Earth-like' CR spectrum k(E) = 1**

**$M_5$ – Mol. cloud mass (units: $10^5$ $M_{sun}$) from line tracers CO, CS etc......**

**If F & $M_5$ known --> can determine CR spectrum at source**

# Diffuse Emission from the GC Region




**<u>GC & Sgr-B</u>**
**Spectral index**
**$\Gamma = 2.29 \pm 0.07 \pm 0.20$**

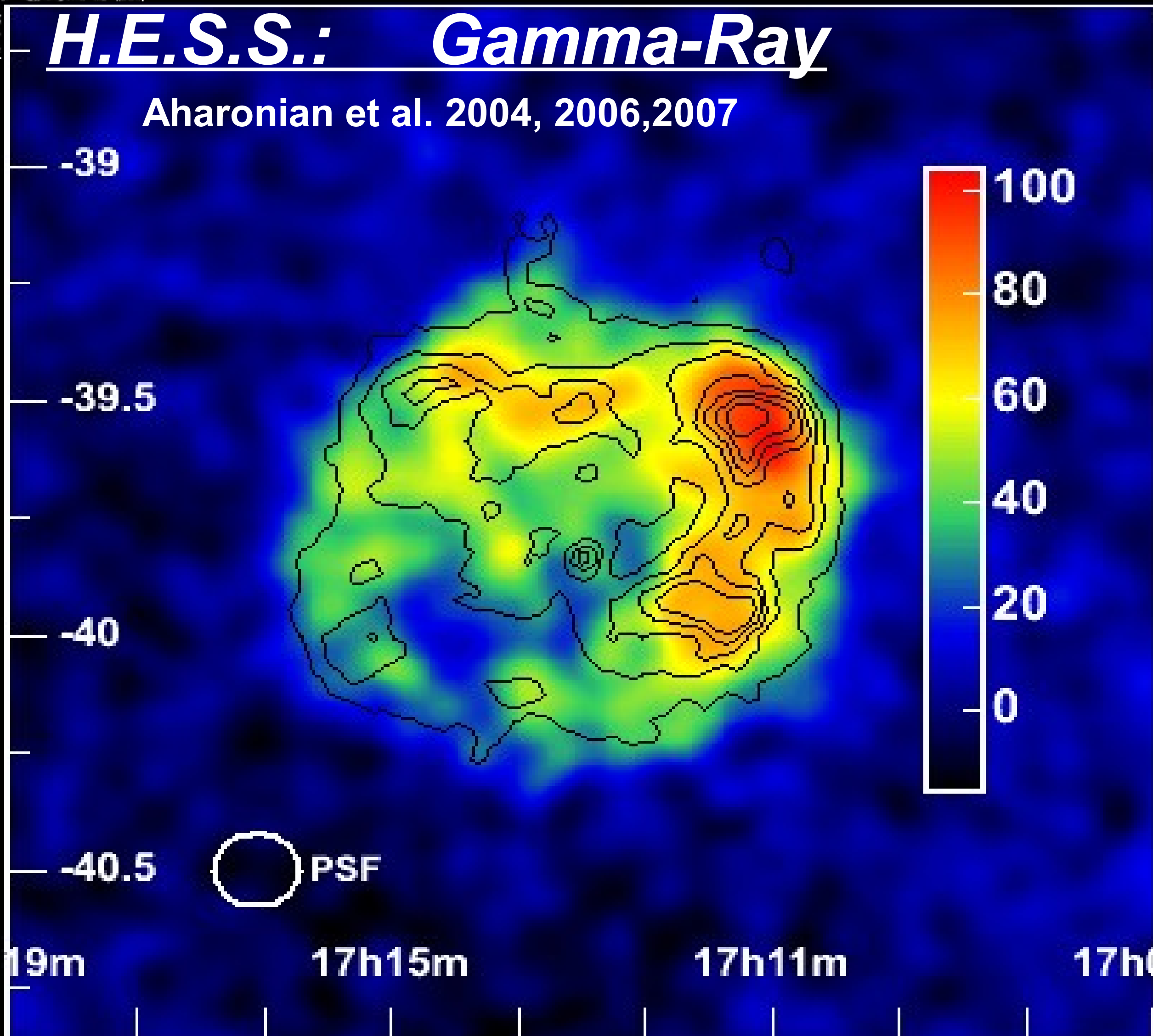
**Implies harder CR spectrum than in solar neighborhood**

**CR Enhancement factor k~ 3-9 (E>1 TeV)**

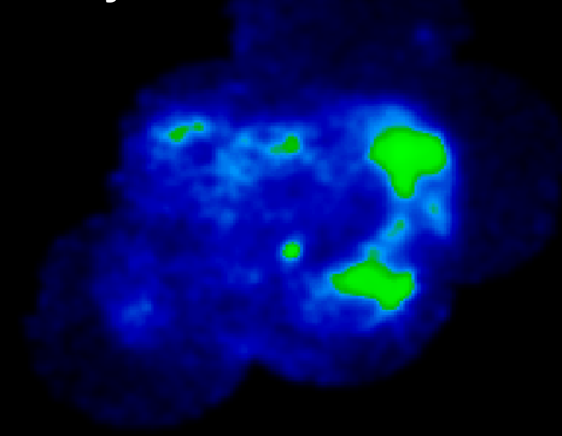
**--> Proximity of accelerator and Target (to avoid CR transport losses)**

# RX J1713.7-3946

(CANGAROO) Muraishi etal 1999, Enomoto et al 2002)




**ASCA: X-Ray**
**1 – 3 keV**
**Uchiyama 2002**

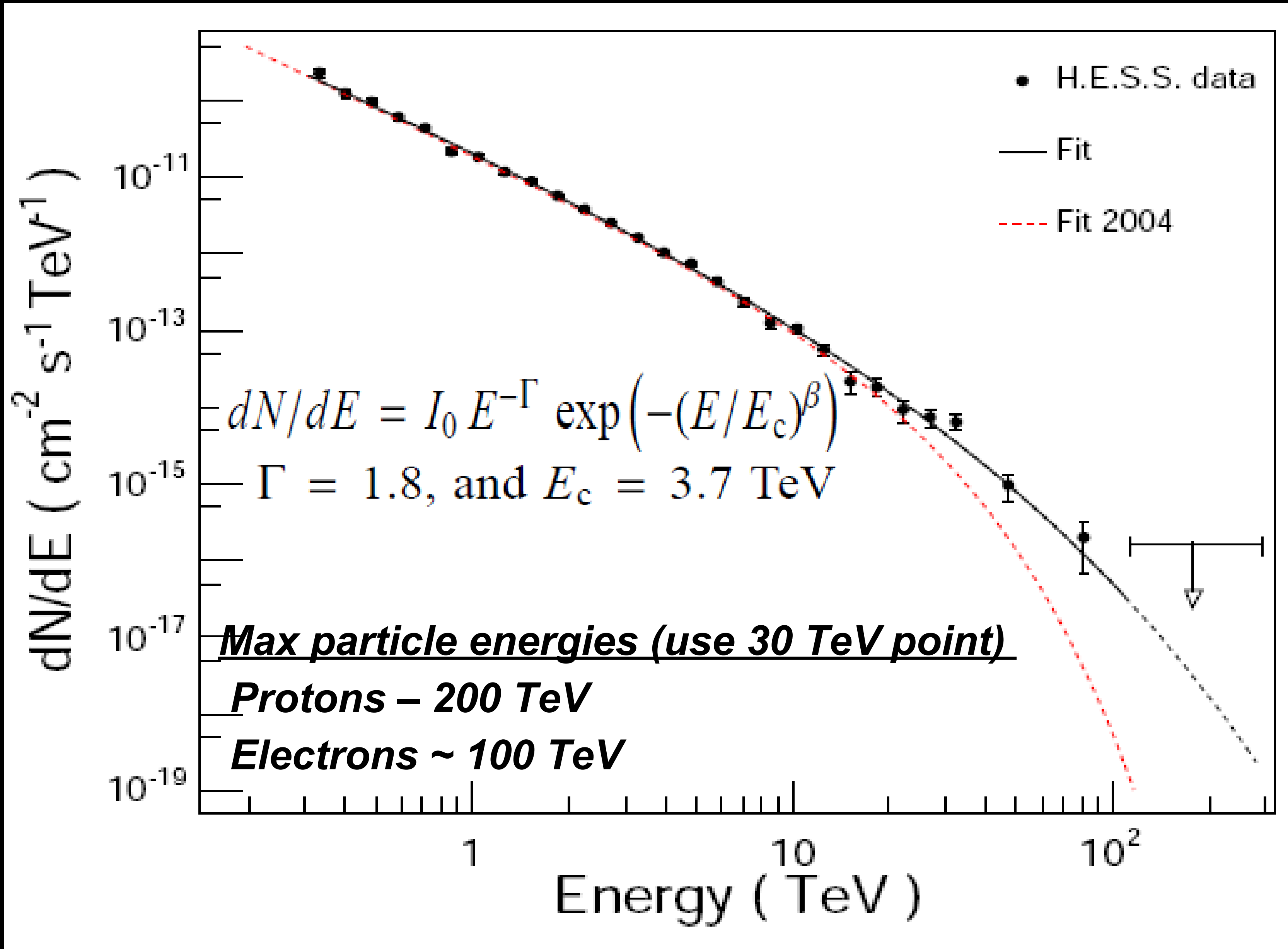


- *Gamma-ray & X-ray morphology are very similar.*

*TeV gamma-ray emission from electrons and/or hadrons??*

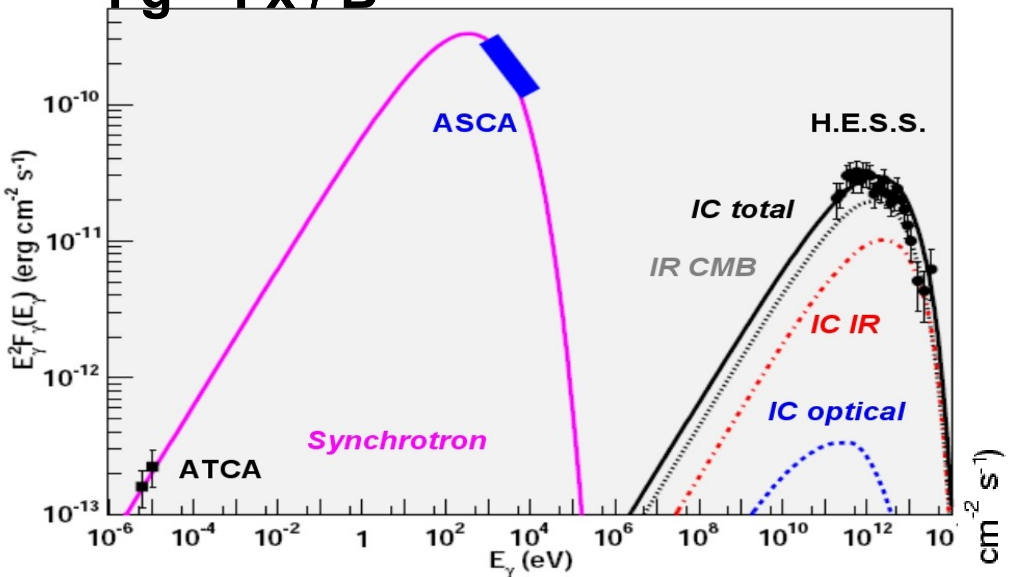
# H.E.S.S. RXJ1713 Spectrum extends to >40 TeV

**Aharonian etal 2007**



# RX J1713.7-3946 – Compare with Models

**Fg ~ Fx / B$^2$**



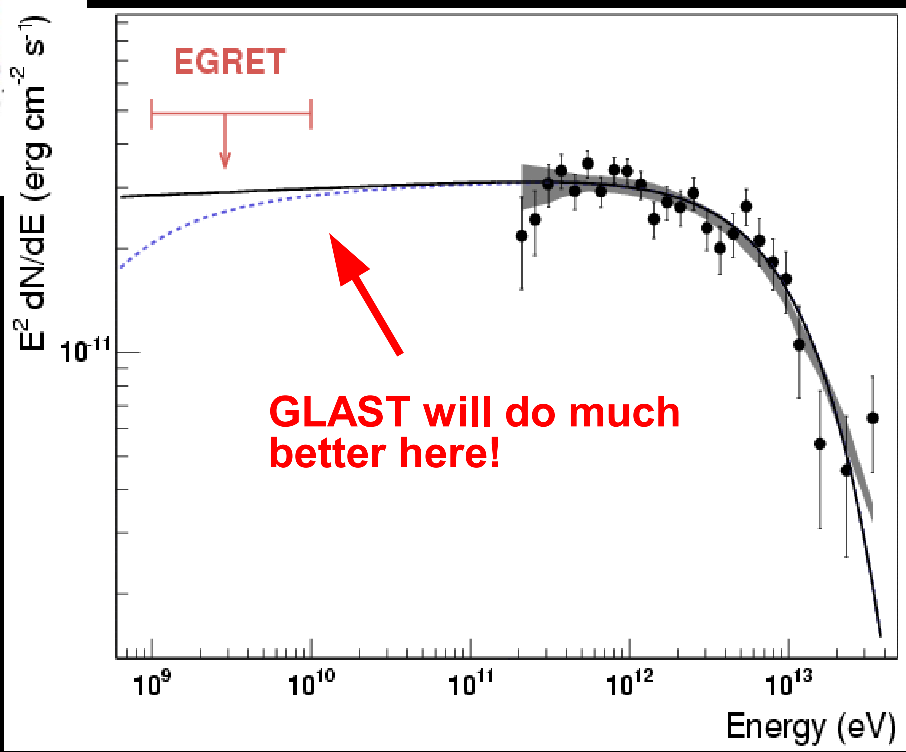

**LEPTONIC SCENARIO**

**Updated IR photon field**

**Porter etal 2007**

**B=12 $\mu$ G; d=1 kpc;**

**Electron spectrum**
**dN/dE ~ E$^{-2}$ exp(-E/25 TeV)**

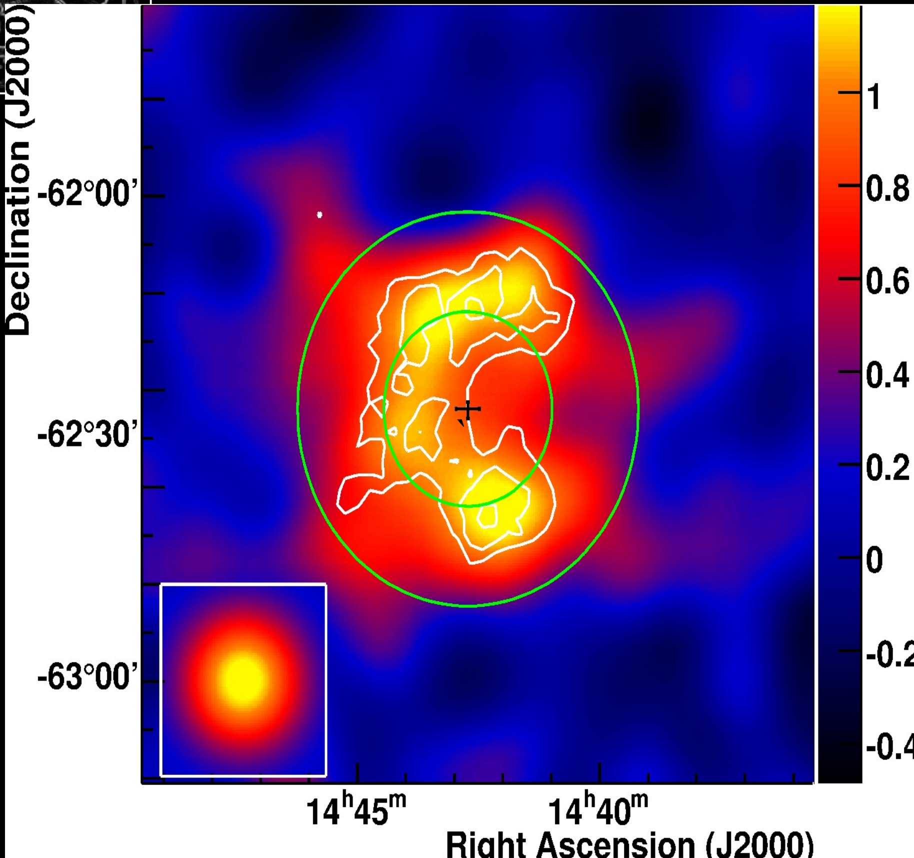



**HADRONIC SCENARIO**
**Aharonian etal 2006**

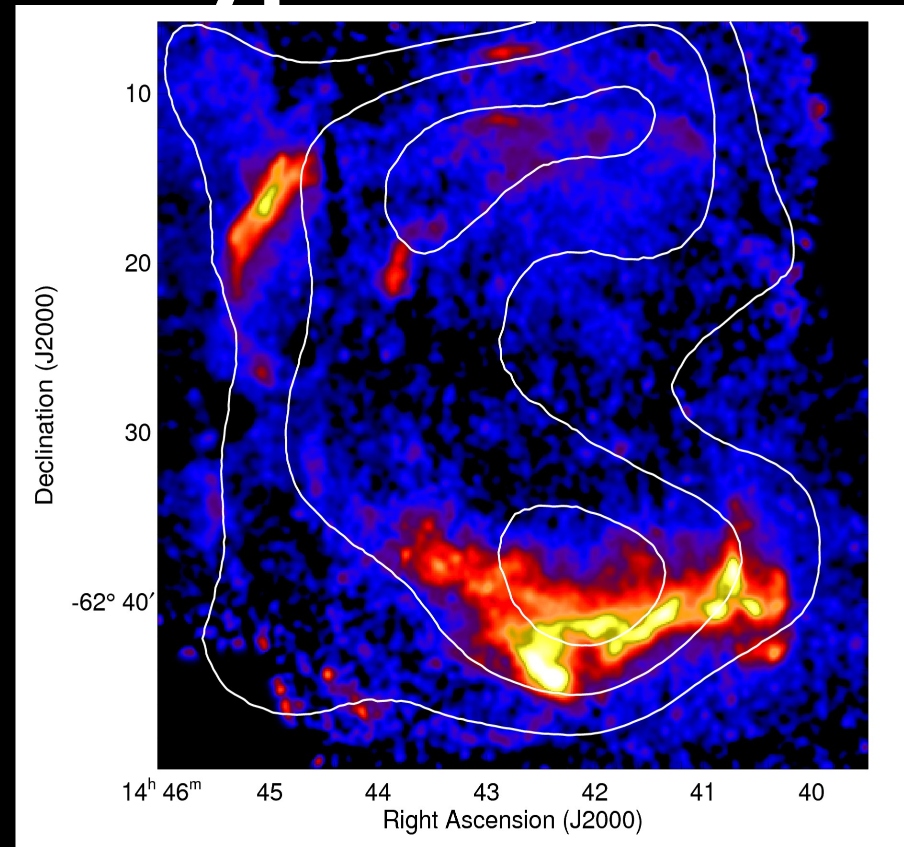
**proton spectrum**
**dN/dE ~ E$^{-2}$ exp(-E/E$_c$)**

**power in protons ~ 10$^{49}$ erg**
**Hadronic scenario:higher B-fields**
**> 100 $\mu$ G X-ray & TeV correlation**
**from similar acceleration sites.**

# RCW 86 – Shell Type SNR




H.E.S.S TeV




XMM X-ray

**Distance and age uncertainty:**

**d ~ 1 kpc; age ~1600 year; Type Ia (Bocchino, Vink) --> SN185**

**d~ 3 kpc; age~ 10000 yrs; Type II assoc with and OB cluster**

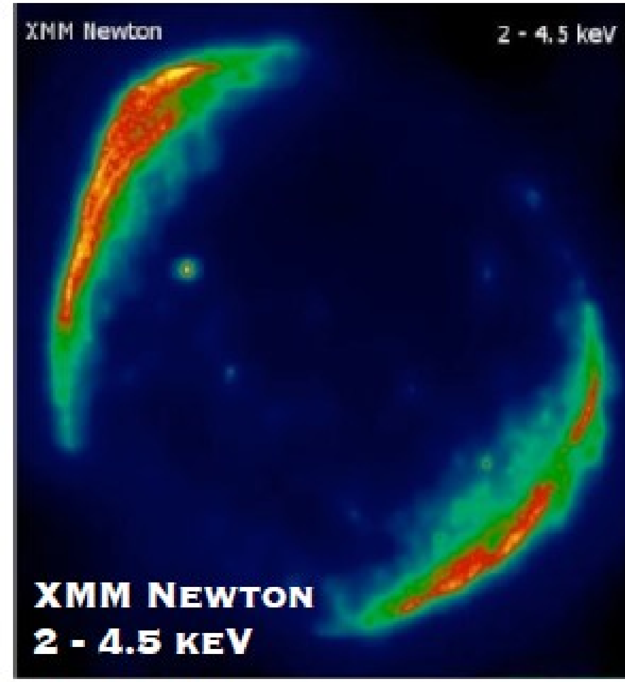
**Spectrum – power law with spectral index $\Gamma$ = 2.5**

# SN 1006: Historic SN

Type Ia
(White Dwarf)

Distance 2.2 kpc

Diameter
0.5 degrees

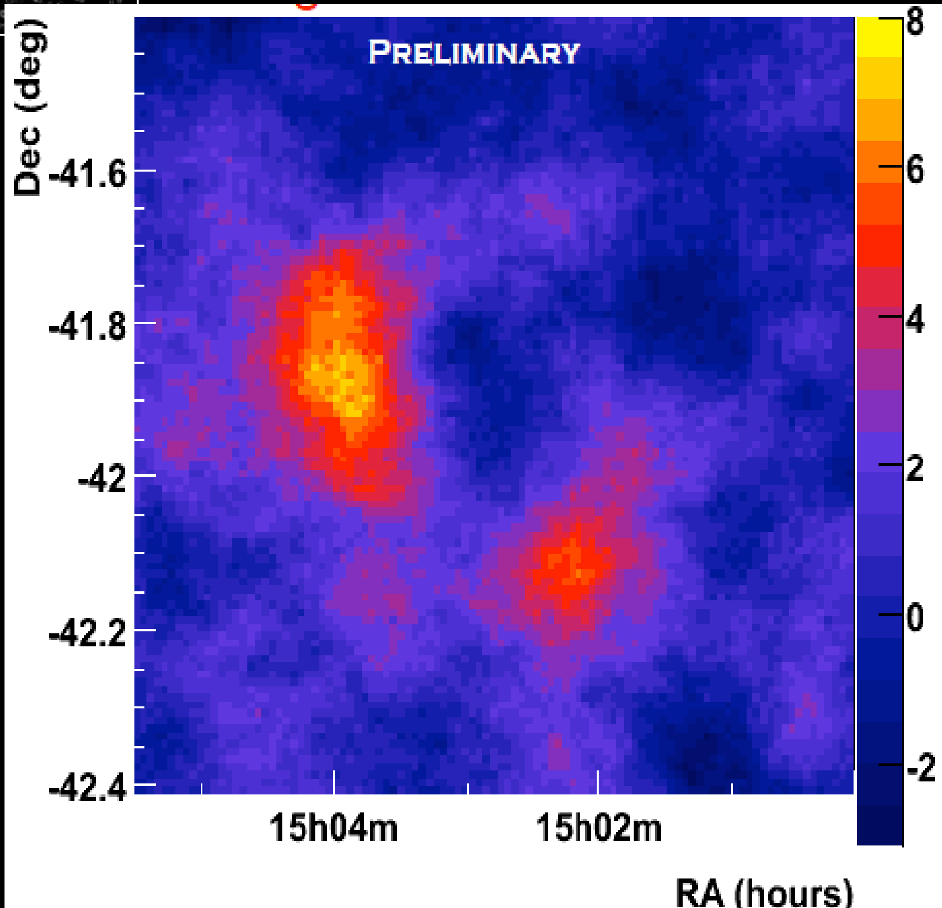



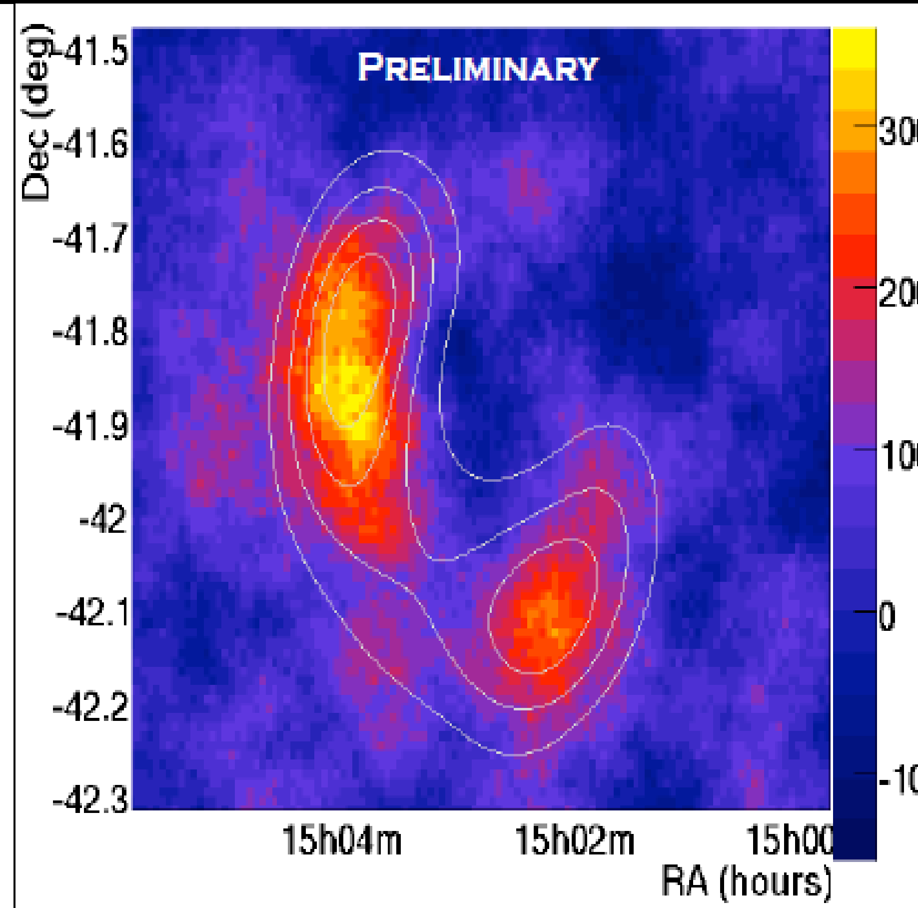

Was earlier detected by CANGAROO (Tanimori etal 1998) but HESS only revealed Upper Limits (Aharonian etal 2005) x10 lower.

Deep observations by HESS since 2003 – 103 hrs

Motivated by 'clean' ISM environment making it 'simpler' to model (eg. Berezhko etal). *SN1006 is ~15deg from the Galactic plane.*

# SN 1006: Discovery by HESS




**HESS TeV Image**
**+5.9sigma**

**Chandra X-ray contours (white) over TeV image**

**proton energetics ~ $10^{51}$ erg**

# W28: SNR & Molecular Cloud Interaction

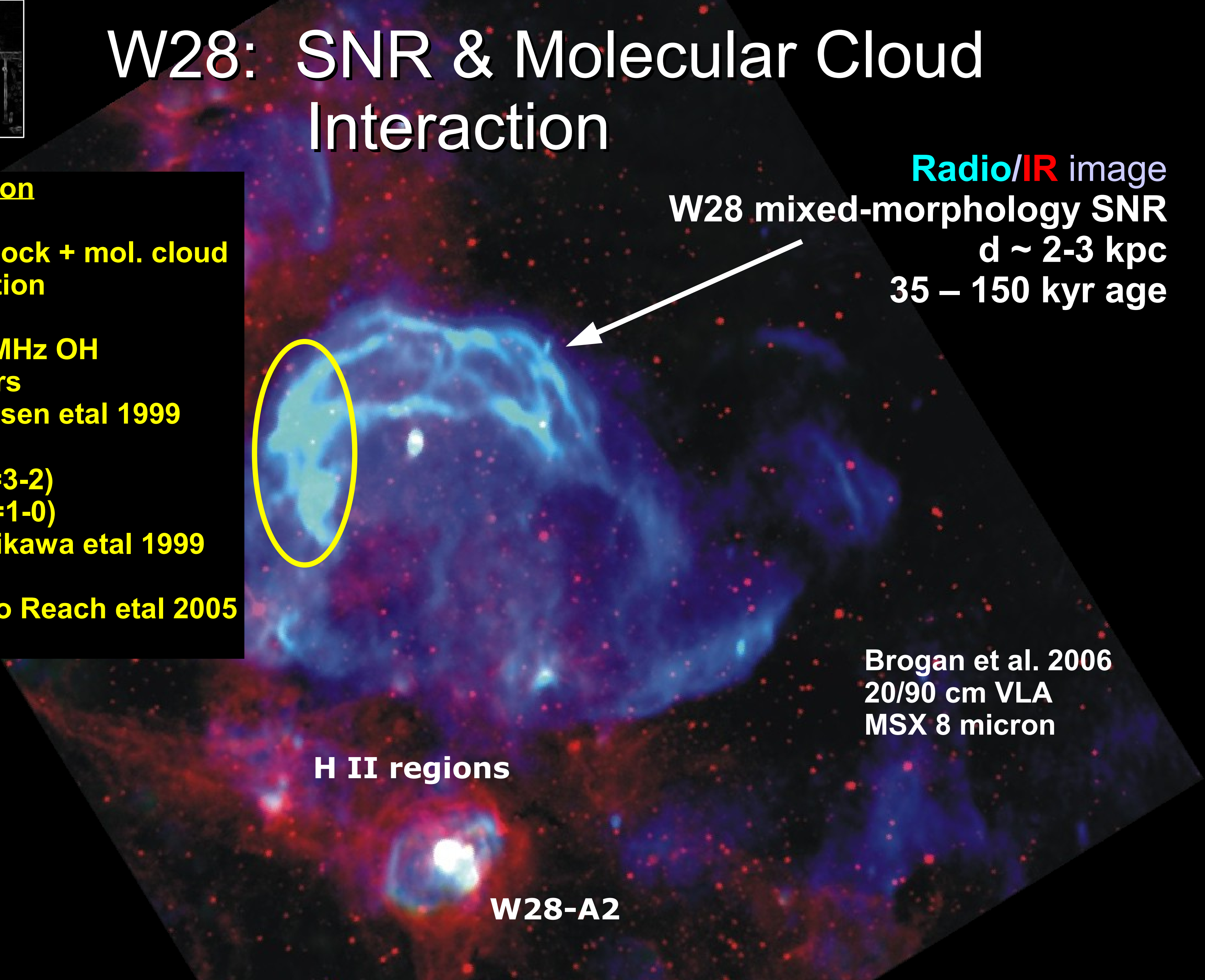
**NE region**

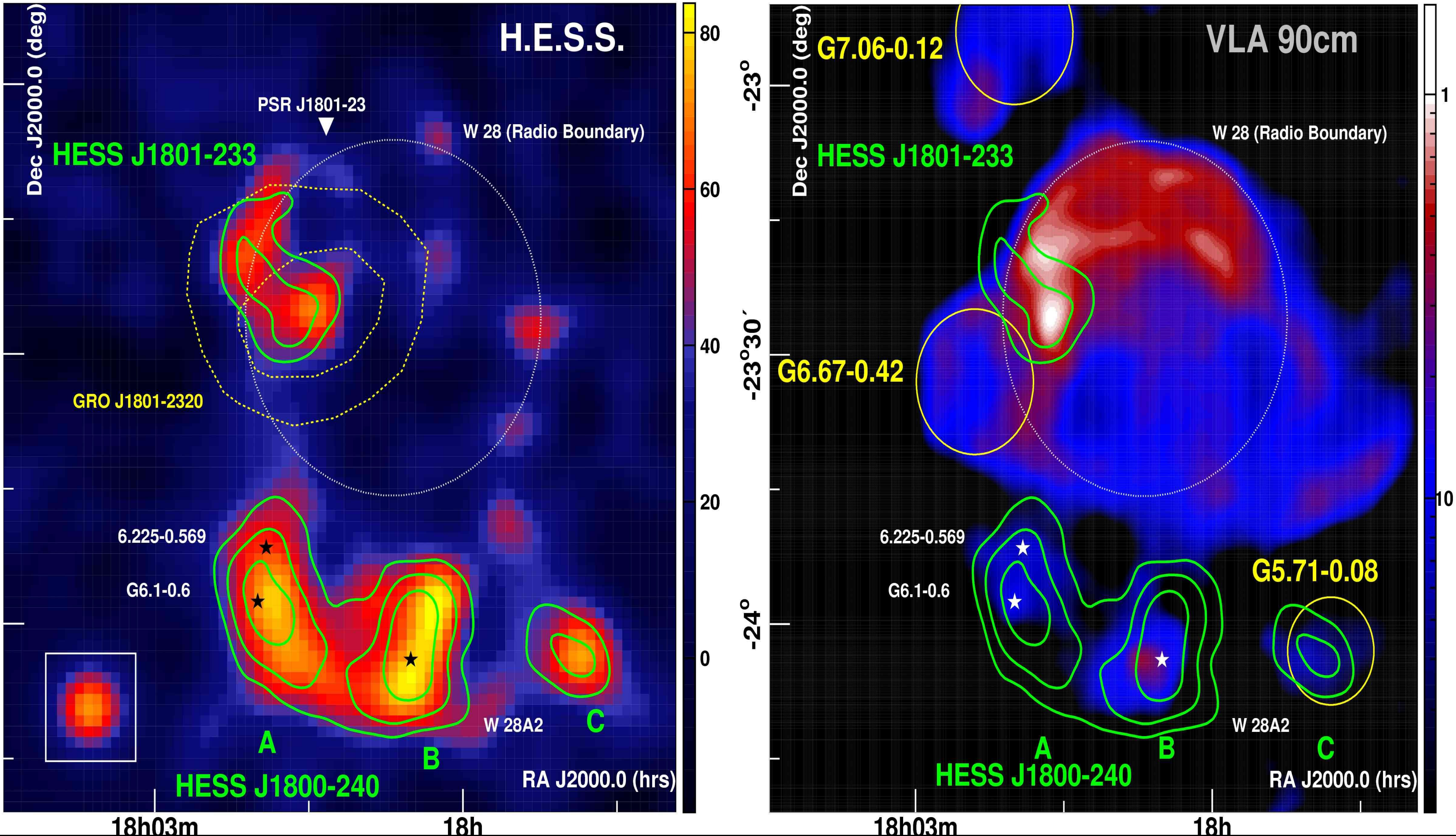
**SNR shock + mol. cloud interaction**

**- 1720 MHz OH Masers Claussen etal 1999**

**$^{12}$CO(J=3-2) (J=1-0) eg. Arikawa etal 1999**

**see also Reach etal 2005**



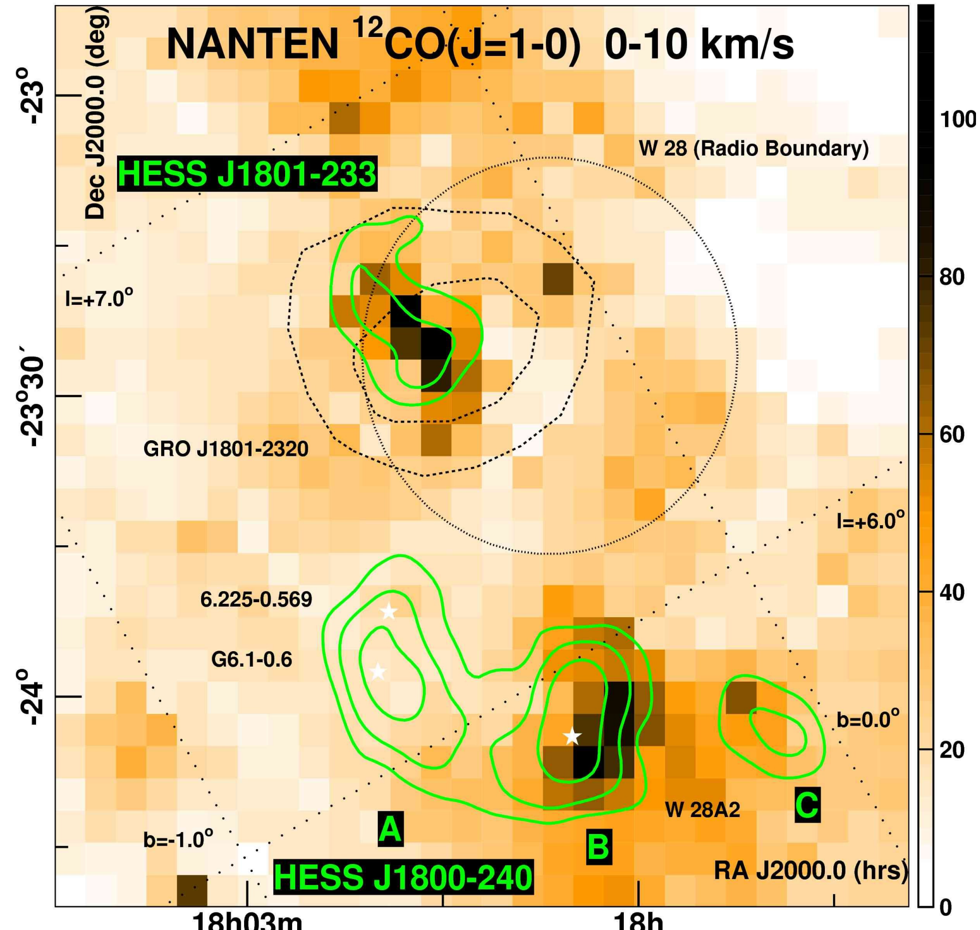


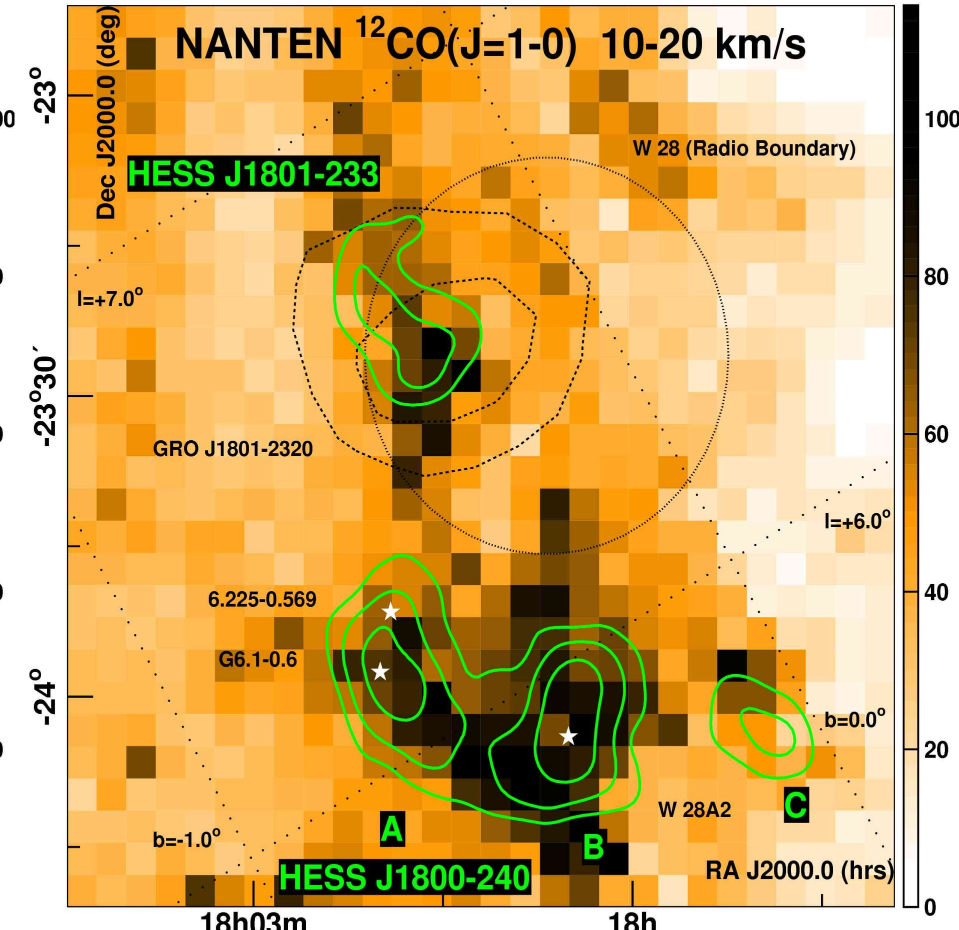

**H.E.S.S. 4,5,6 sigma contours**

**VLA - Brogan et al. 2006**

**TeV emission towards NE rim of W28 and 0.5 deg S**

**Aharonian etal 2008**




d ~ 0 to 2.5 kpc

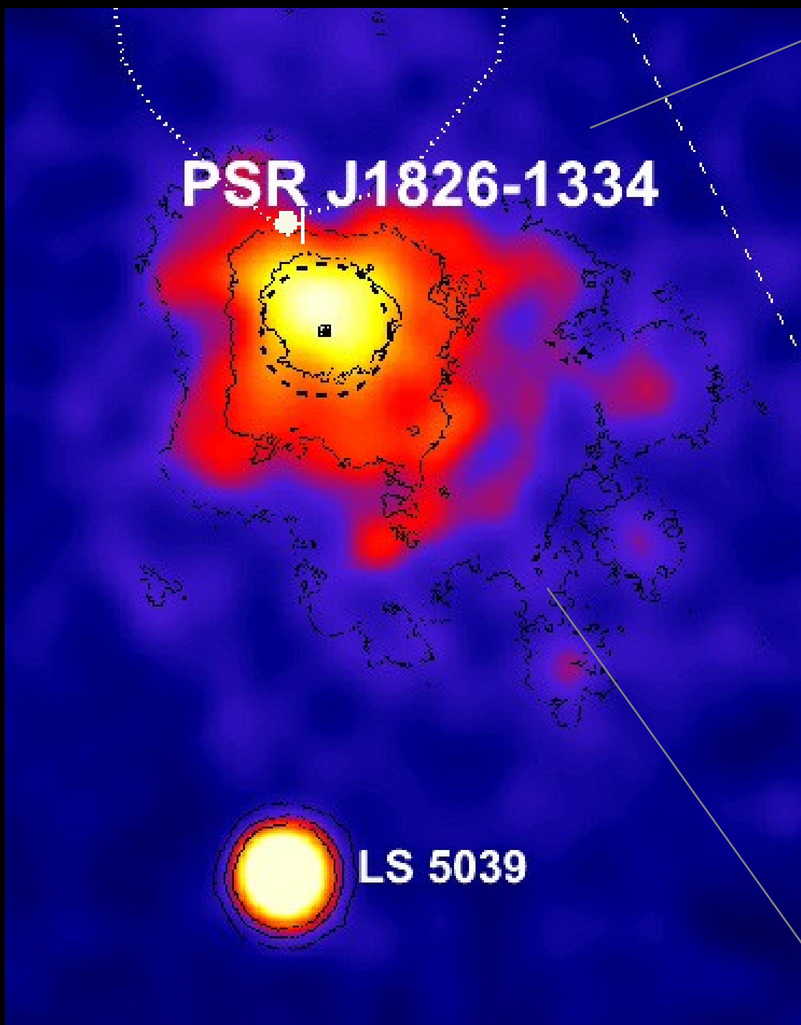
d~2.5 to 4 kpc

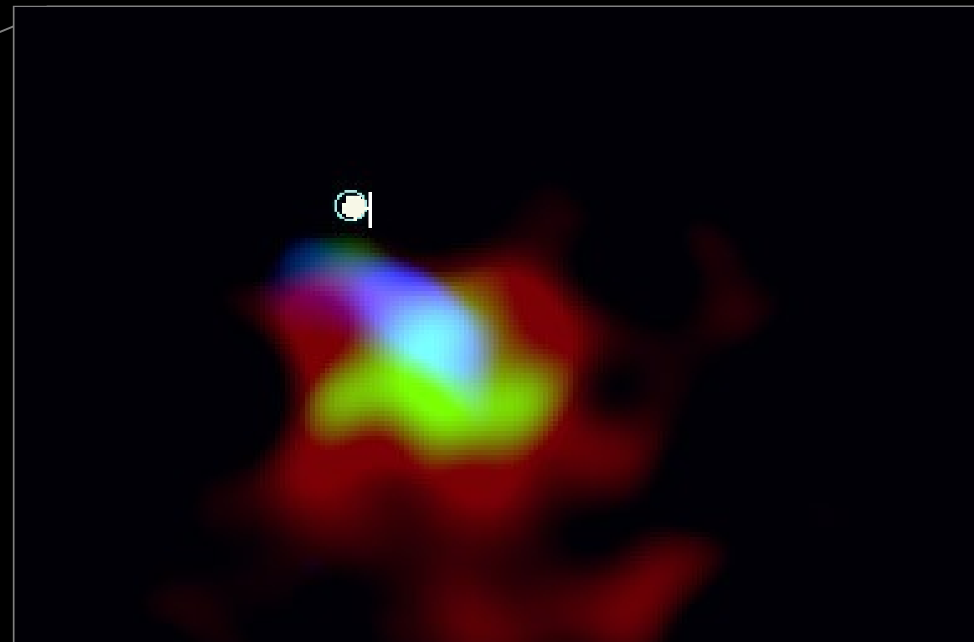
V. good TeV & CO spatial association *--> indication for hadronic origin*
However, several cloud velocity components present.
Are clouds connected or just projection effects?

Compare TeV flux with cloud masses: CR density ~10-35 x local value

# HESS J1825-137: An asymmetric pulsar wind nebula (PWN):

Aharonian etal 2006 A&A



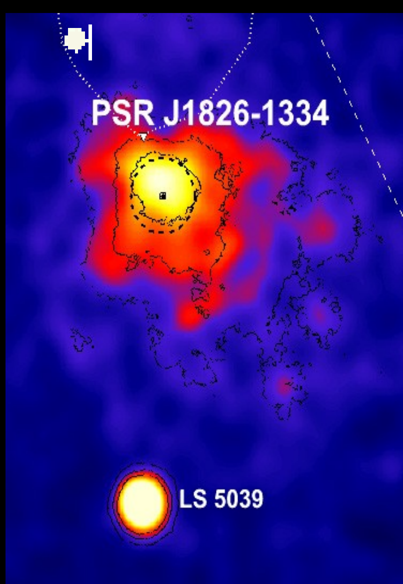
**> 2.5 TeV  1 – 2.5 TeV**
**< 1 TeV  - behavior consistent with leptonic origin due to synchrotron & IC losses**

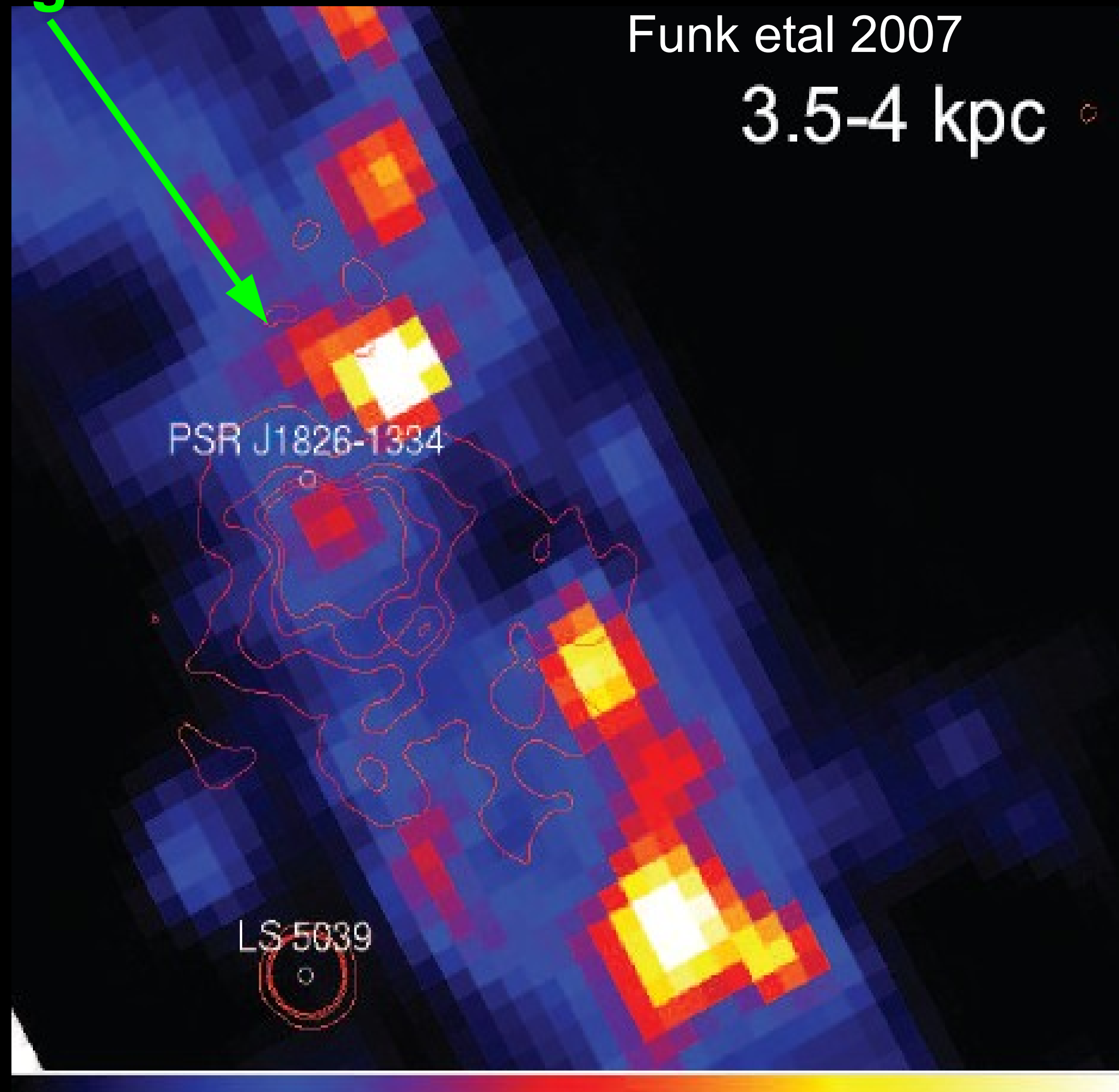
# HESS J1825-137 & NANTEN CO$^{12}$(J=1-0)

**Why asymmetric? Answer:**

**Dense mol. cloud at N edge.**

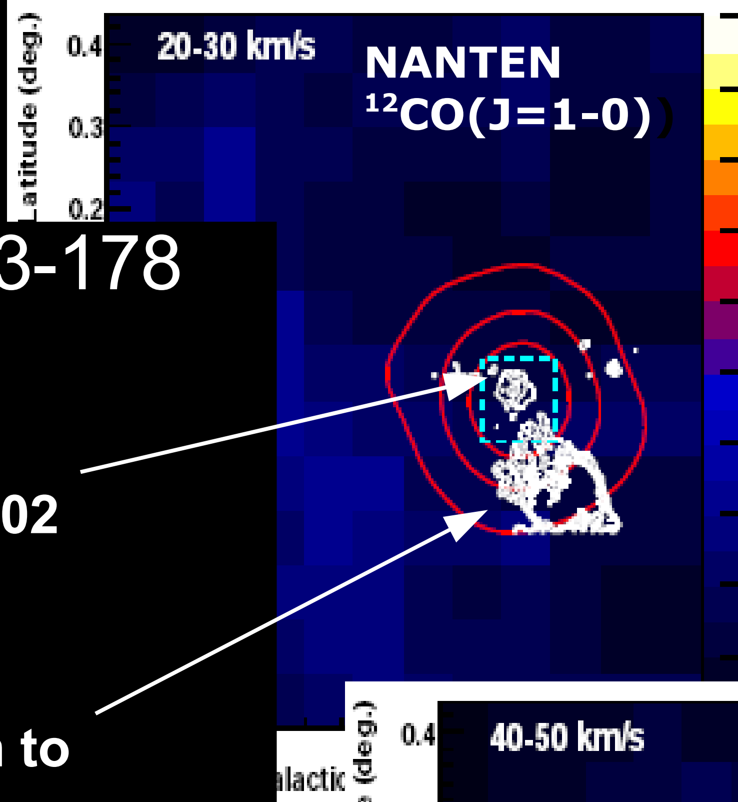
**PWN 'crushed' /distorted by SNR reverse shock after interaction with mol. cloud. see eg. Blondin etal 2001 Gaensler etal 2003 van derSwaluw etal 2004**

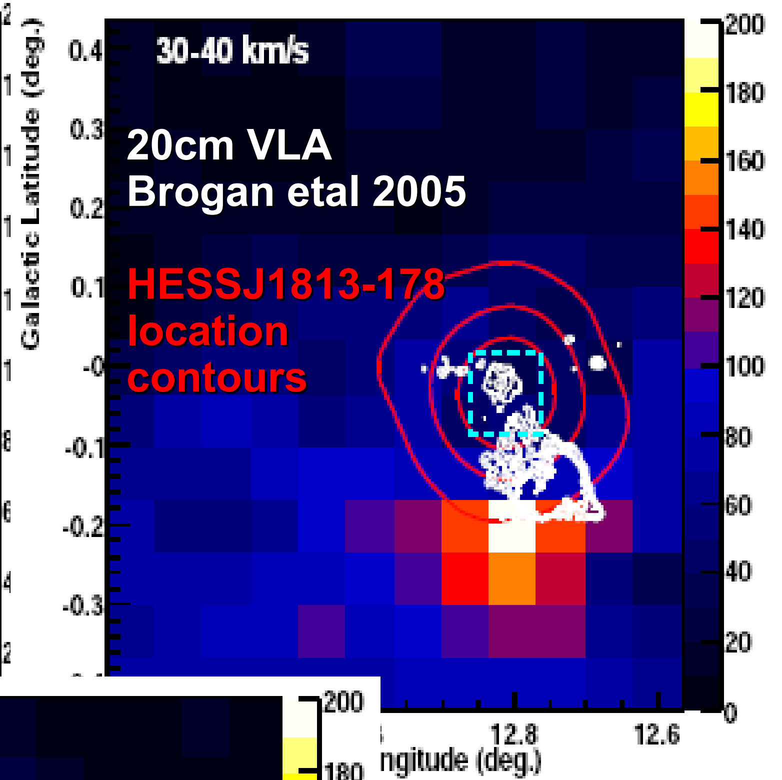


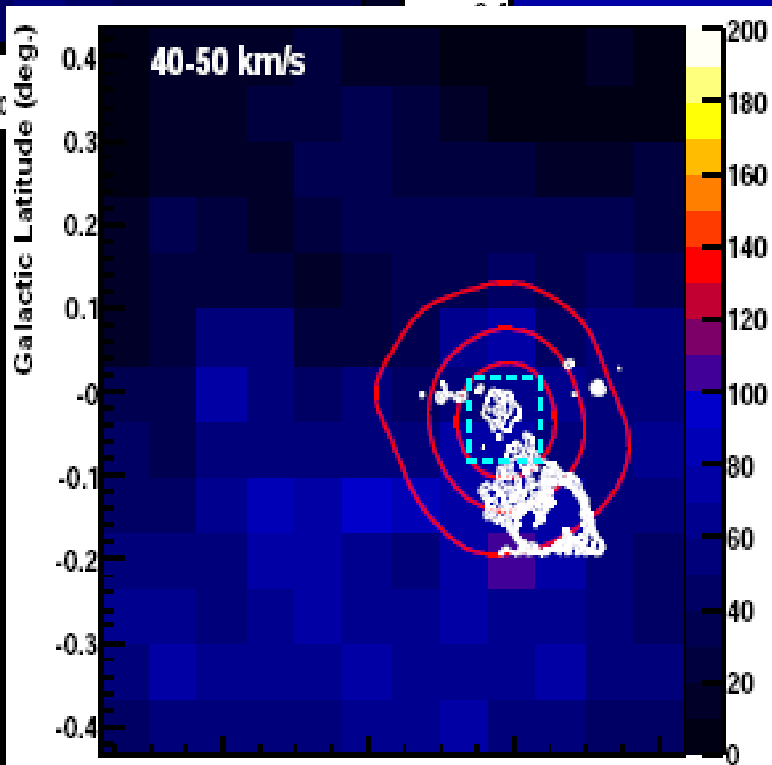



# HESS J1813-178

Funk etal 2007




**assoc. with**
**SNR G12.82-0.02**
**radio shell**
**X-ray core**

**W33 HII region to south**

**NANTEN CO**

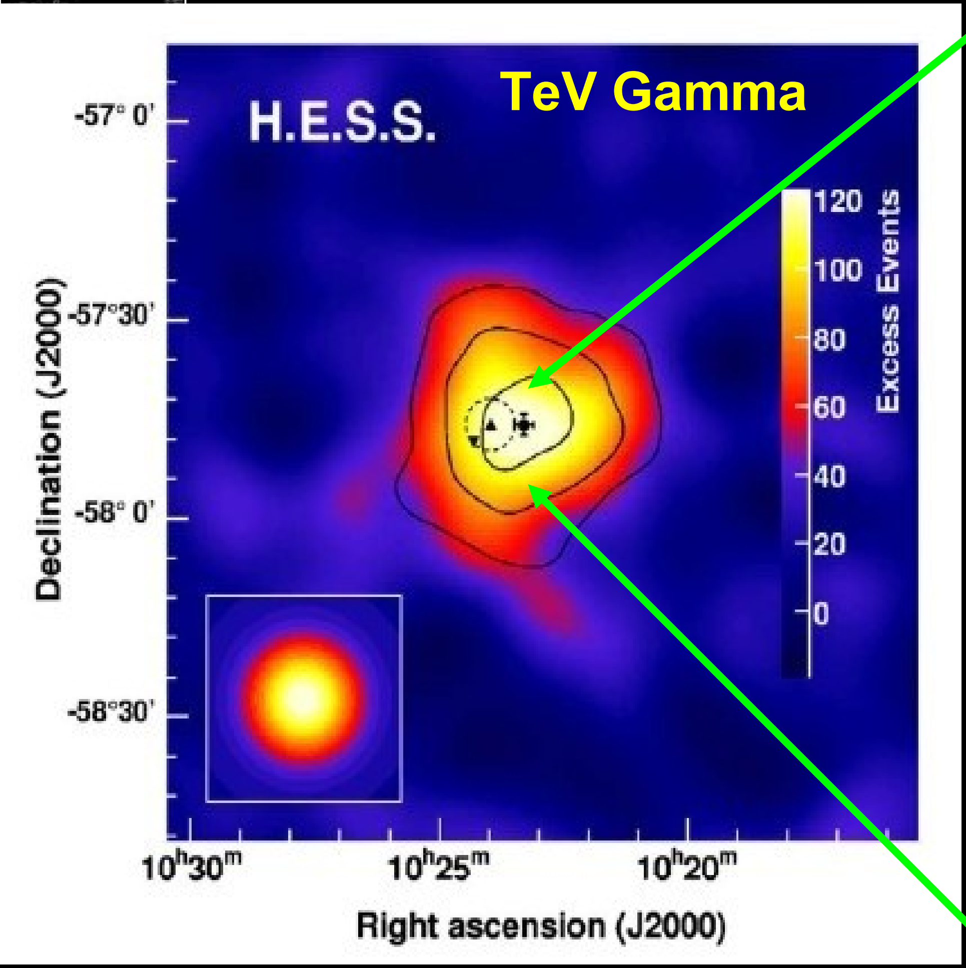
**$M_{cloud} \sim 2.5 \times 10^5$ $M_{sun}$**

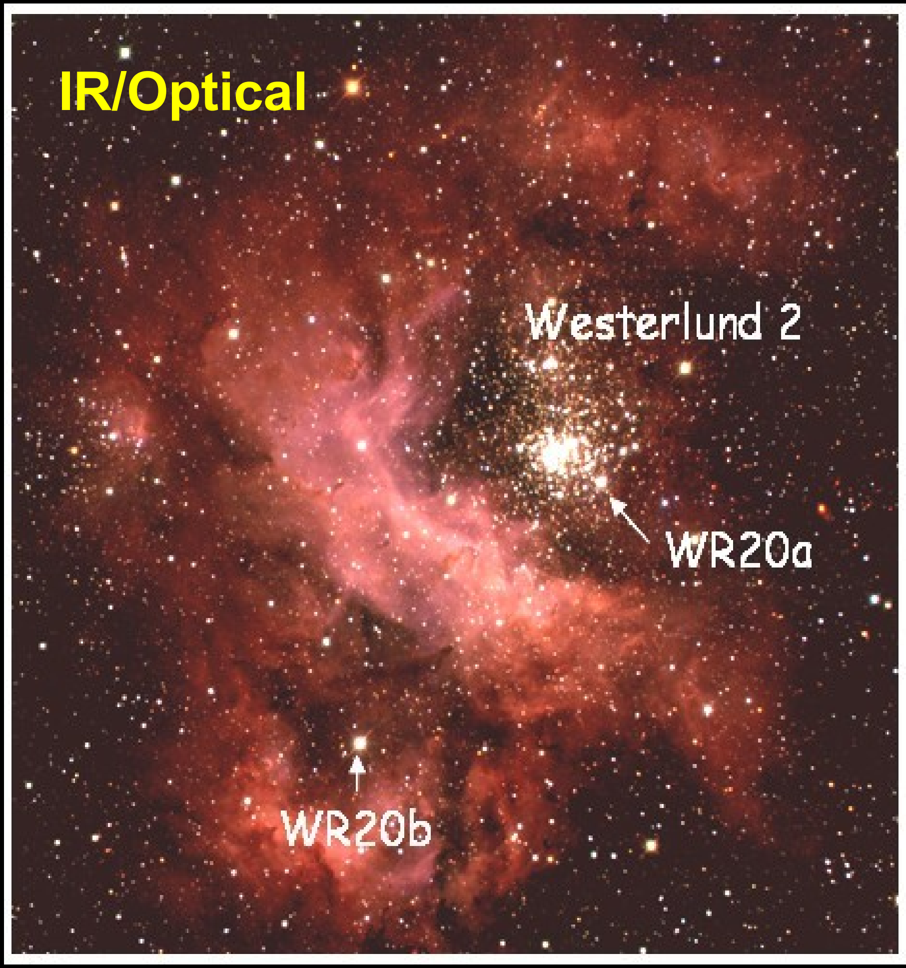
**$V_{lsr}$ =30-40 km/s**

**d ~ 4 kpc**

***Mol. Cloud has influenced G12.82-0.02 development***

# HESSJ1023-575 : A new type of (A&A 2007) CR accelerator? Young open cluster




**Westerlund2 – Young open cluster with two Wolf-Rayet stars (v.high stellar wind vel. & mass loss rate) WR20a is a binary**

***CR acceleration in colliding wind shocks? Similar to TeVJ2032+4130?***

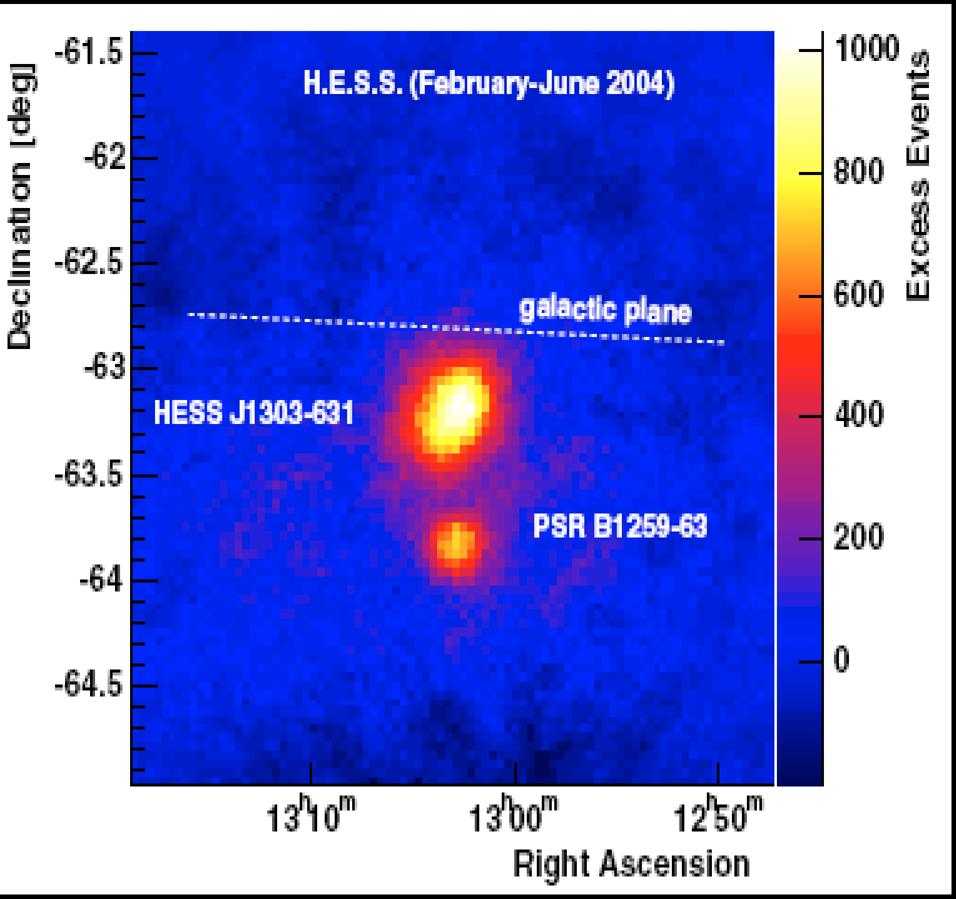
# Unidentified TeV Sources: No obvious counterparts

## A major subset of Galactic TeV sources

**The brightest H.E.S.S. examples...**

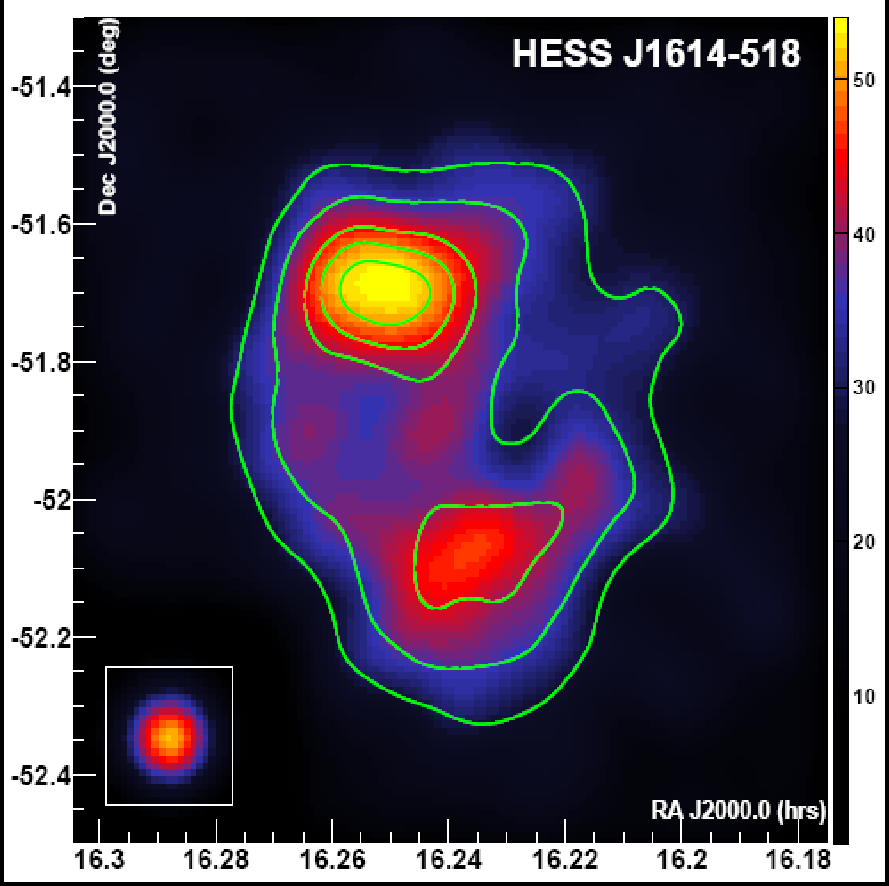
**HESS J1303-631**

Aharonian etal 2005

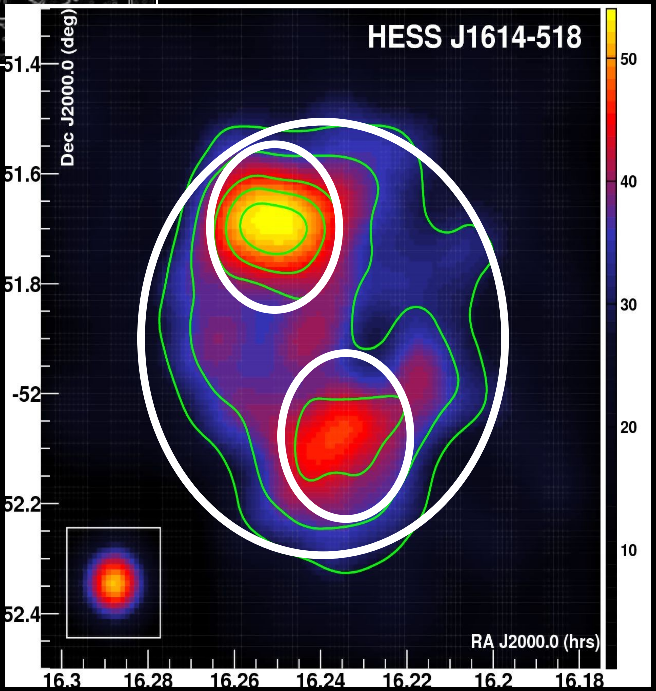



**HESS J1614-518**

Aharonian etal 2005,2006, Rowell etal 2008



# HESSJ1614-518: Spectra from Several Regions




**HESS J1614-518**
Entire source rad = 0.4deg

**HESS J1614-518N**
Northern hotspot rad=0.15deg

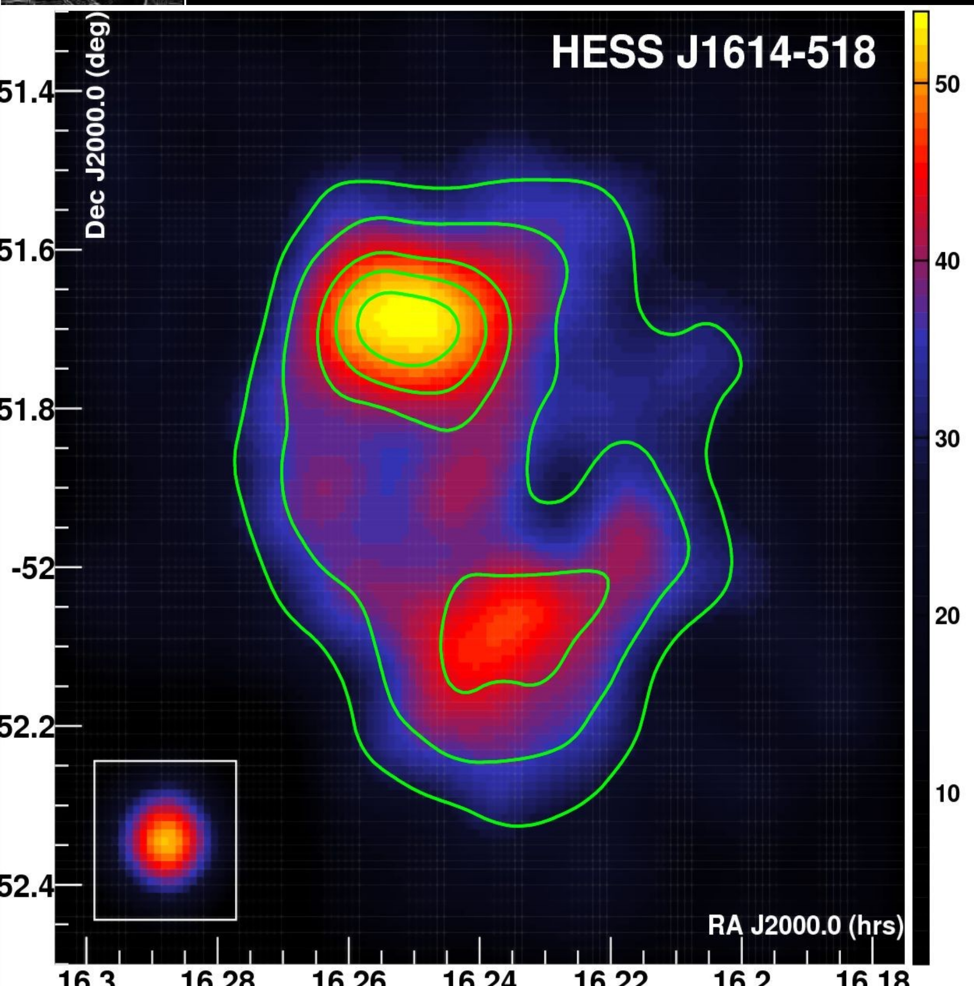
**HESS J1614-518S**
Southern hotspot rad=0.15deg

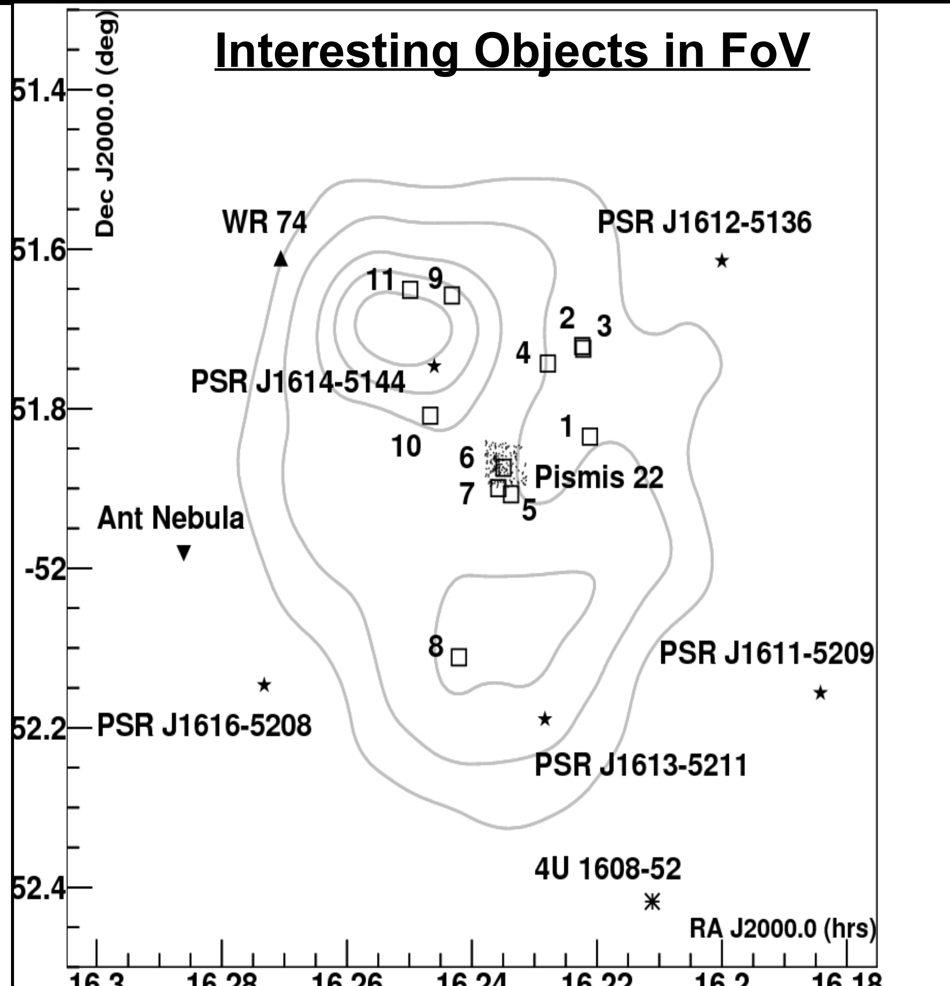
**HESS J1614-518P**
'Plateau' region
= Entire source minus hotspot regions of rad=0.17deg.

| Region | Position (J2000.0) R.A. [hr] | Dec [deg] | $\sigma_{\mathrm{region}}$ [deg] | [2] $S$ [$\sigma$] (evts) | Spectral analysis [3] $k$ | [3] $\Gamma$ |
|---|---|---|---|---|---|---|
| HESS J1614−158 | 16.235 | −51.90 | 0.40 | +19.1 (670) | $7.83 \pm 0.40 \pm 0.80$ | $2.26 \pm 0.05 \pm 0.06$ |
| HESS J1614−518N | 16.250 | −51.70 | 0.15 | +11.1 (150) | $1.71 \pm 0.16 \pm 0.04$ | $2.08 \pm 0.11 \pm 0.04$ |
| HESS J1614−518S | 16.232 | −52.07 | 0.15 | +8.7 (106) | $1.43 \pm 0.16 \pm 0.20$ | $2.07 \pm 0.12 \pm 0.08$ |
| HESS J1614−518P | 16.235 | −51.90 | [1] 0.40 | +12.5 (348) | $4.00 \pm 0.31 \pm 0.50$ | $2.18 \pm 0.08 \pm 0.09$ |

1. Plateau region excluding HESS J1614−518N and HESS J1614−518S each within a circular region of radii 0.17°
2. Statistical significance (using Li & Ma 1983) and excess events in brackets. The background is estimated from reflected and near-tracking regions.
3. Power law fit to photon spectrum: $dN/dE = k(E/1\ \mathrm{TeV})^{-\Gamma}$ ph cm$^{-2}$ s$^{-1}$ TeV$^{-1}$ with $k$ in units $\times 10^{-12}$ ph cm$^{-2}$ s$^{-1}$ TeV$^{-1}$ at 1 TeV (with statistical and systematic errors) Systematics errors in $k$ and $\Gamma$ are estimated from the range of values obtained from *hard* and *std* cuts.

# HESS J1614-518 : Counterpart Search




Significance contours
+3,5,7,8,9 sigma

- Pulsars
- WR star
- Bipolar planetary neb. (Ant nebula)
- X-ray sources – open squares
- LMXRB 4U1608-52
- Open cluster Pismis 22 (C1609-517)
  *Stellar wind energetics sufficient*

# Open Cluster: Pismis 22 (C1609-517)

**Relatively young open cluster towards the centre of HESSJ1614.**

**age ~ 40 Myr**

**but sufficiently old to generate supernovae..**

**d ~ 1 kpc**

**Piatti etal 2000 A&A360, 529**

**Not well-studied and due to strong reddening E(B-V)~2.0, cluster size may be underestimated.**

**<u>2MASS image:</u>**
**Strong extinction to the north. See XMM results for this region.**

**No spectral measurements of individual stars at present but O and B type stars (or even WR) are likely present.**

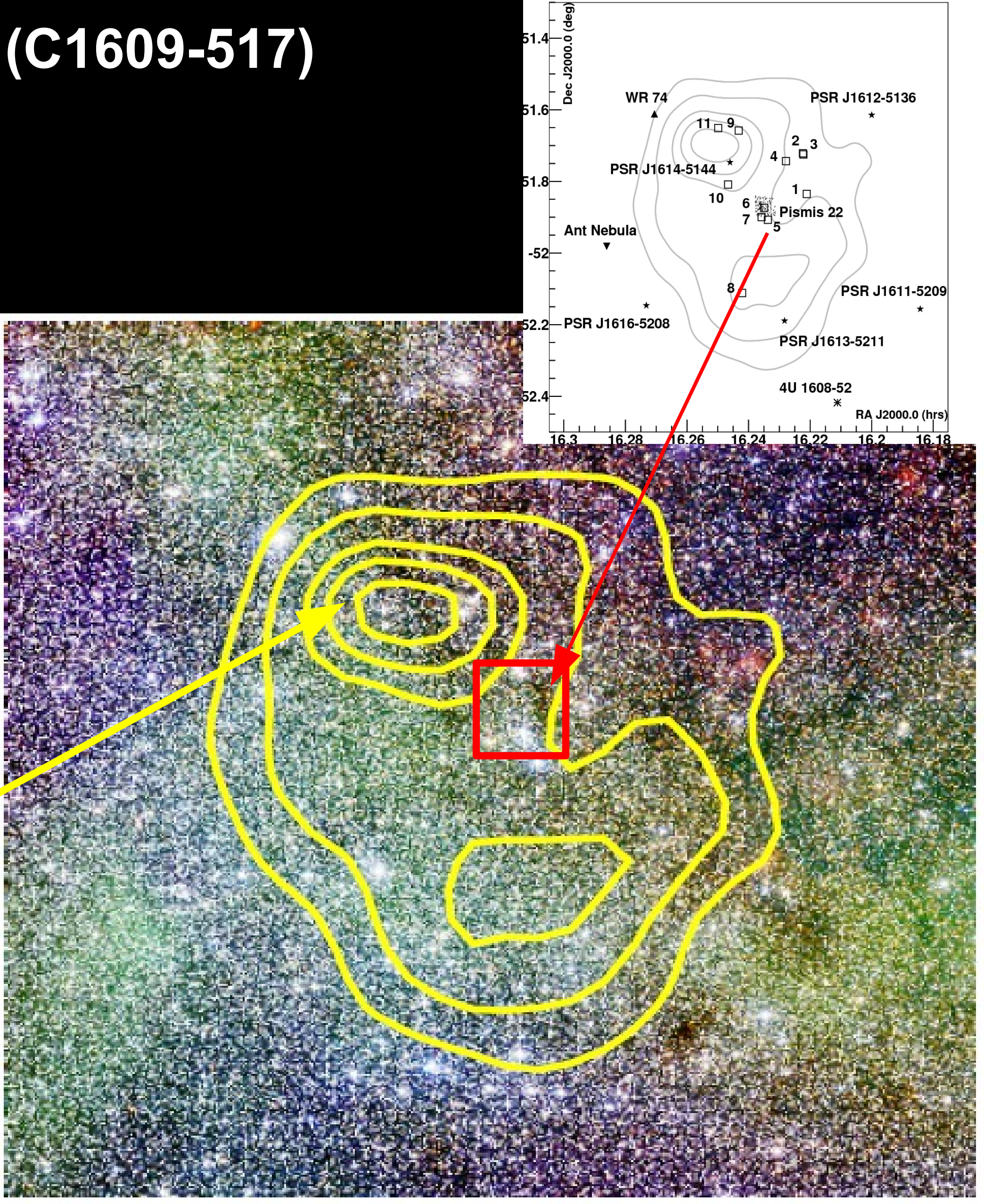


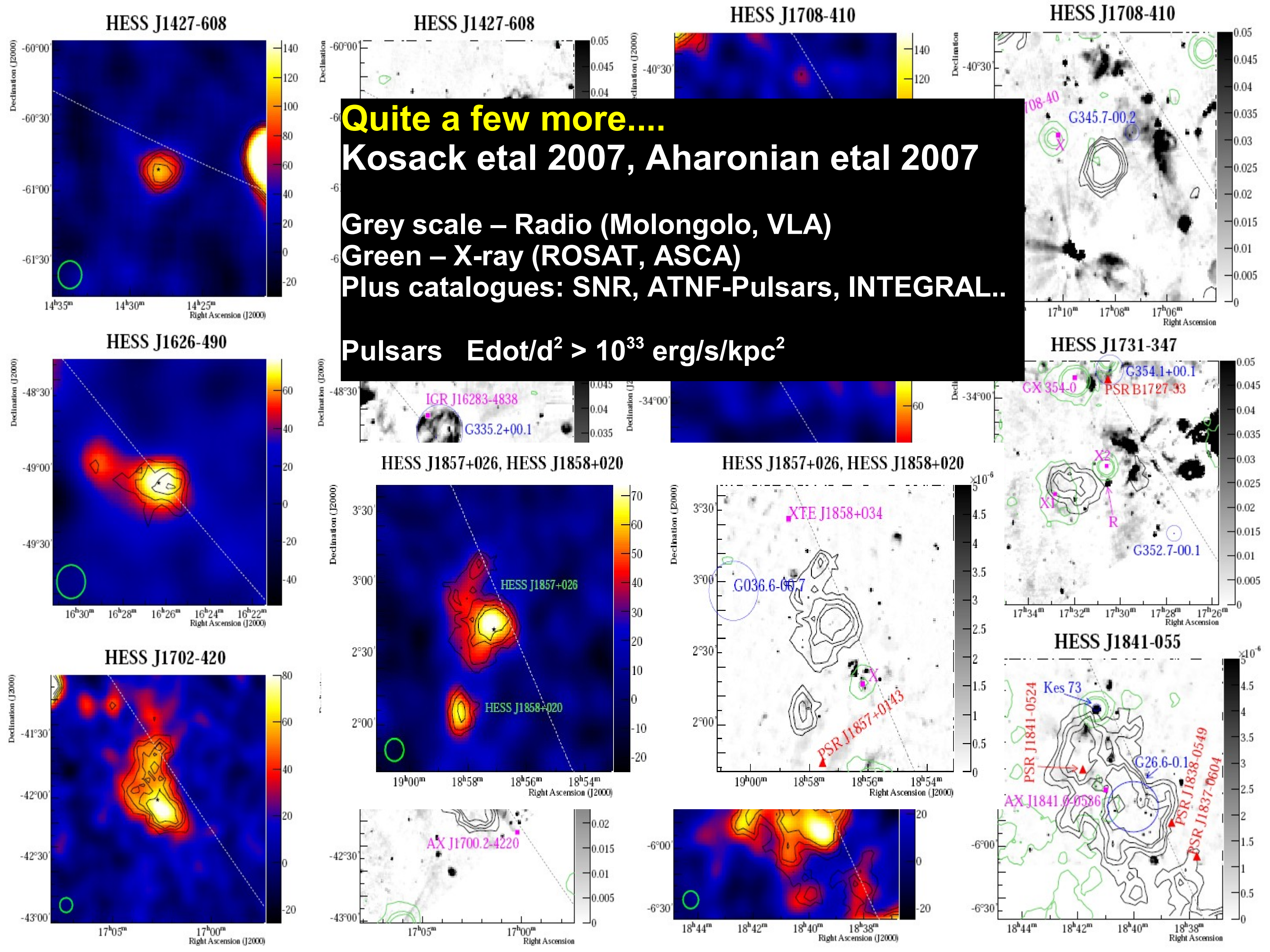

Fig. 6. Three colour 2MASS image of the HESS J1614−518 field (1.2°× 1.2°) – blue (J band 1.25$\mu$m) – green (H band 1.65$\mu$m) – red (K band 2.17$\mu$m). VHE significance contours (solid yellow lines - 3,5,7,8,9$\sigma$) of HESS J1614−518 are overlaid.

# Quite a few more....

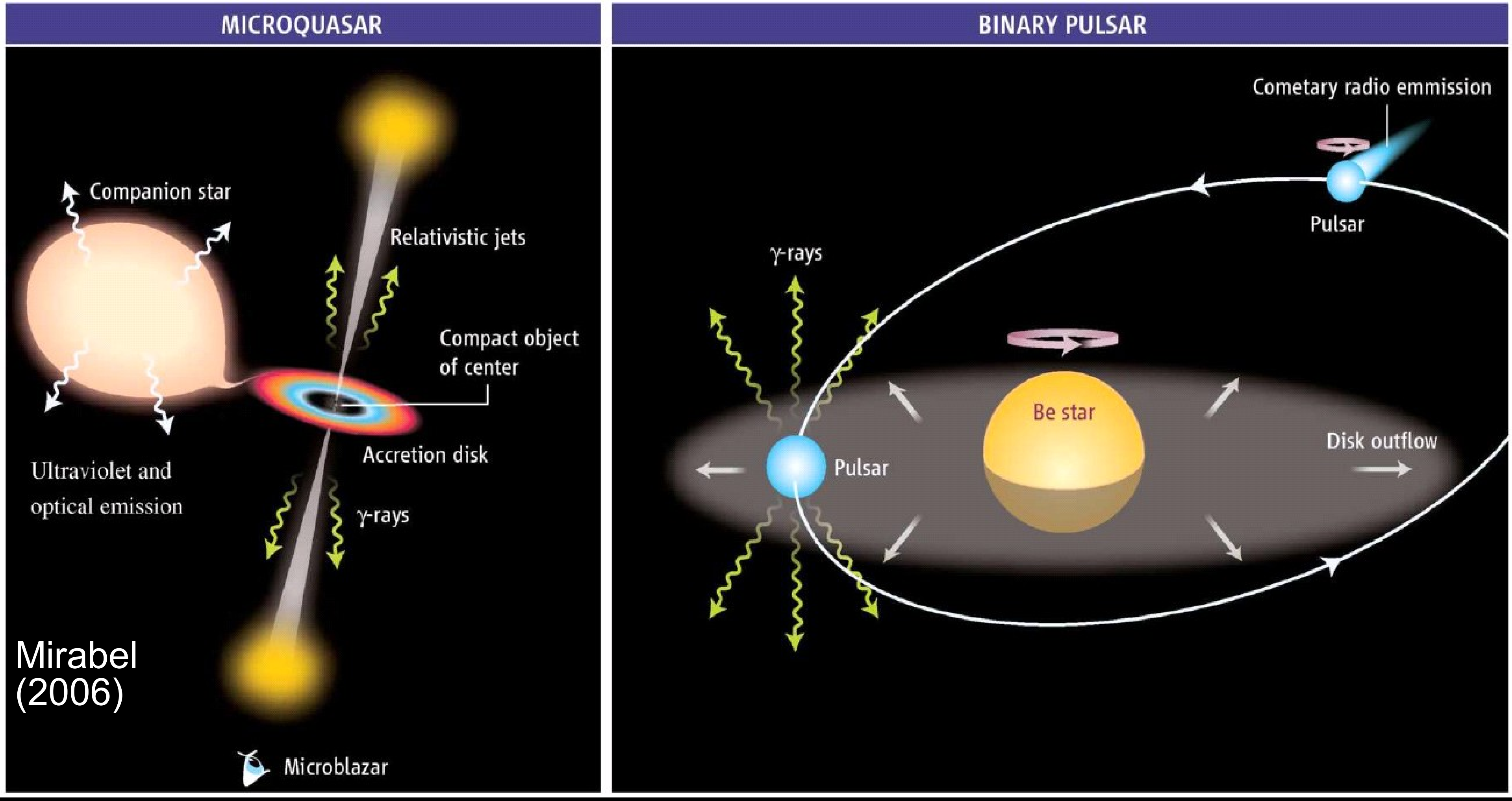
## Kosack etal 2007, Aharonian etal 2007

Grey scale – Radio (Molongolo, VLA)
Green – X-ray (ROSAT, ASCA)
Plus catalogues: SNR, ATNF-Pulsars, INTEGRAL..

Pulsars  Edot/d$^2$ > $10^{33}$ erg/s/kpc$^2$



# Gamma-rays from binary systems



# LS 5039 (see also LSI+61 303 by Albert etal 2006, Maier etal 2008)

**Science 2005, A&A 2006**

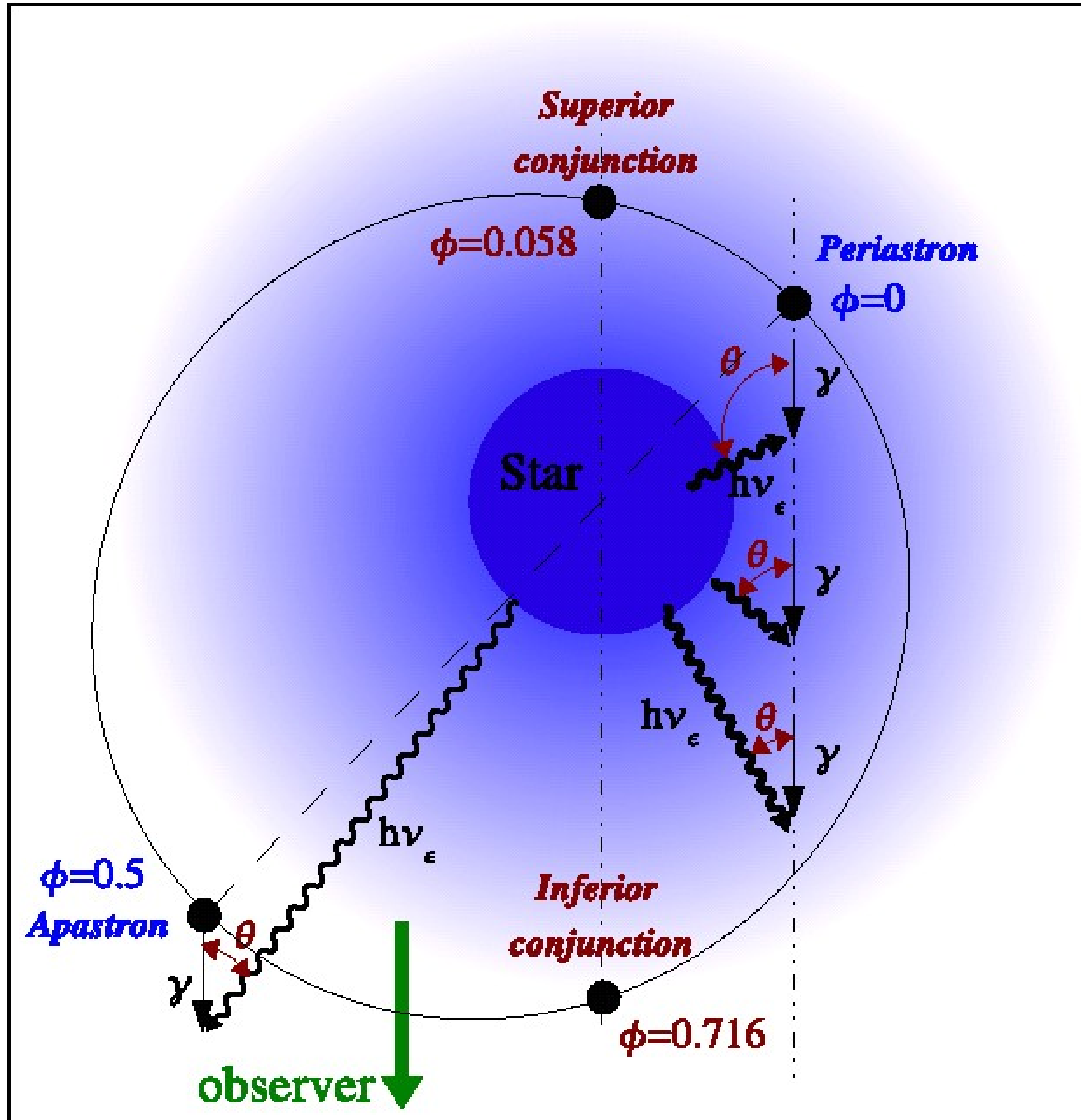
**Massive O6.5V star ~20 Msun**

**Compact Object 1.5 to 5 Msun**

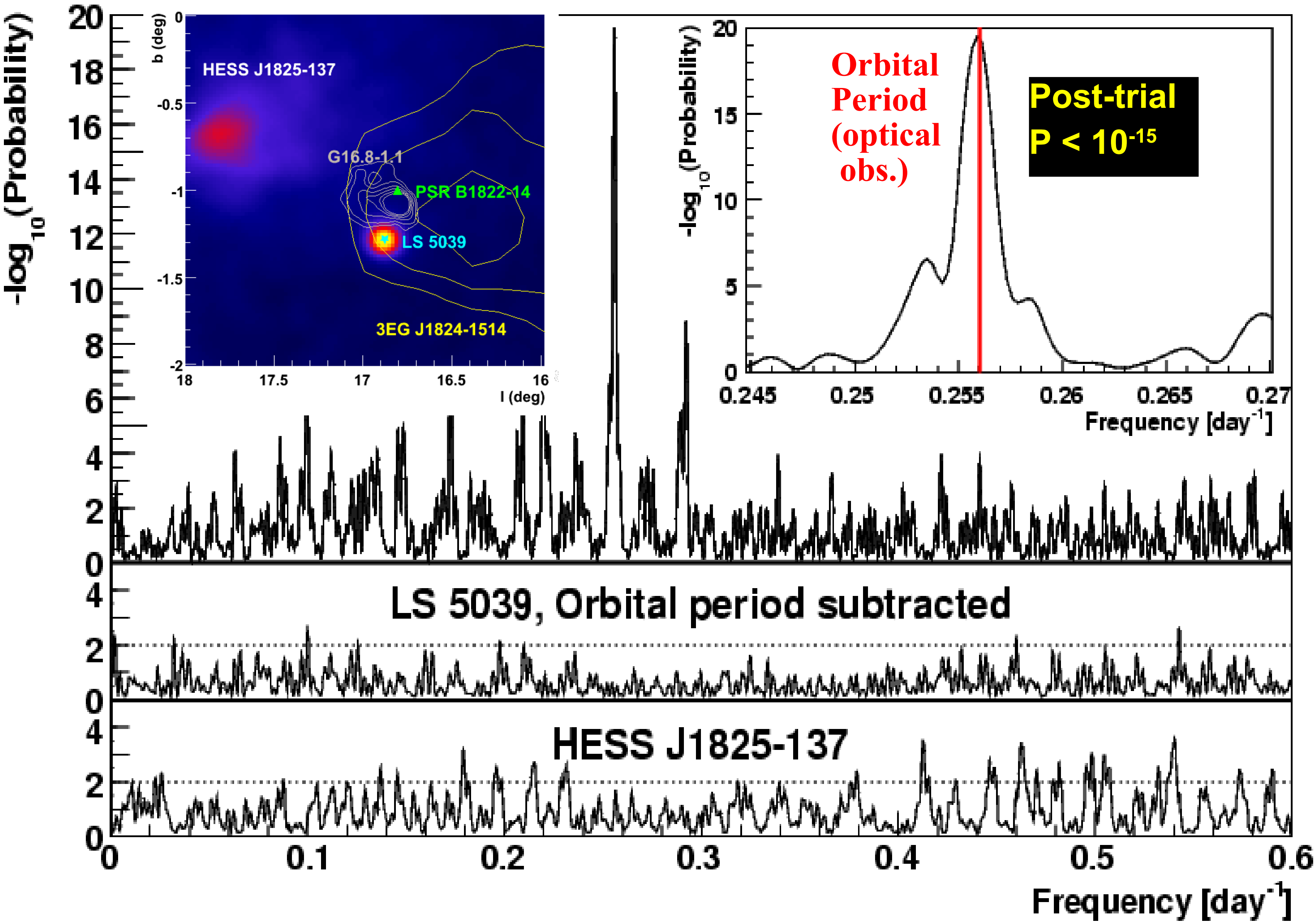
**(neutron star or black hole)**

**Orbital Period 3.90603 days Casares etal 2003**

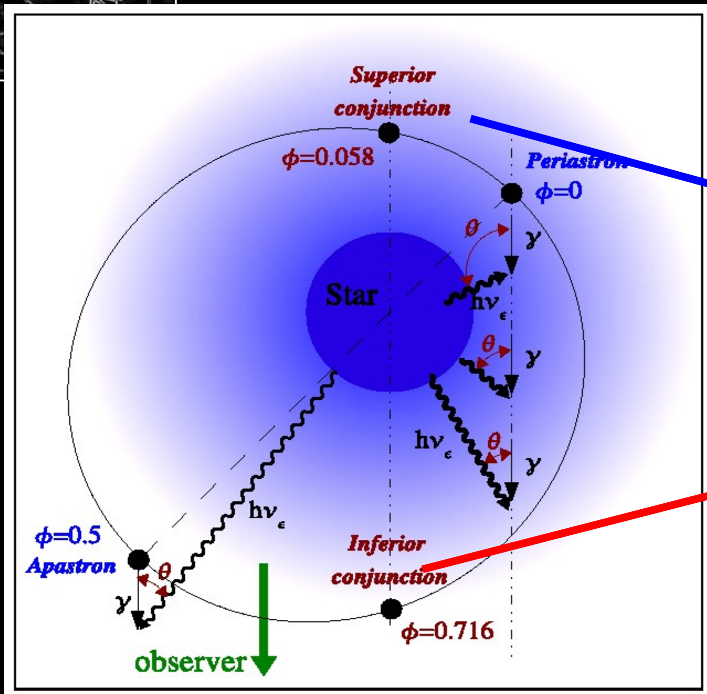
**Orbital Inclination 15 to 65deg (limits from lack of X-ray eclipse)**

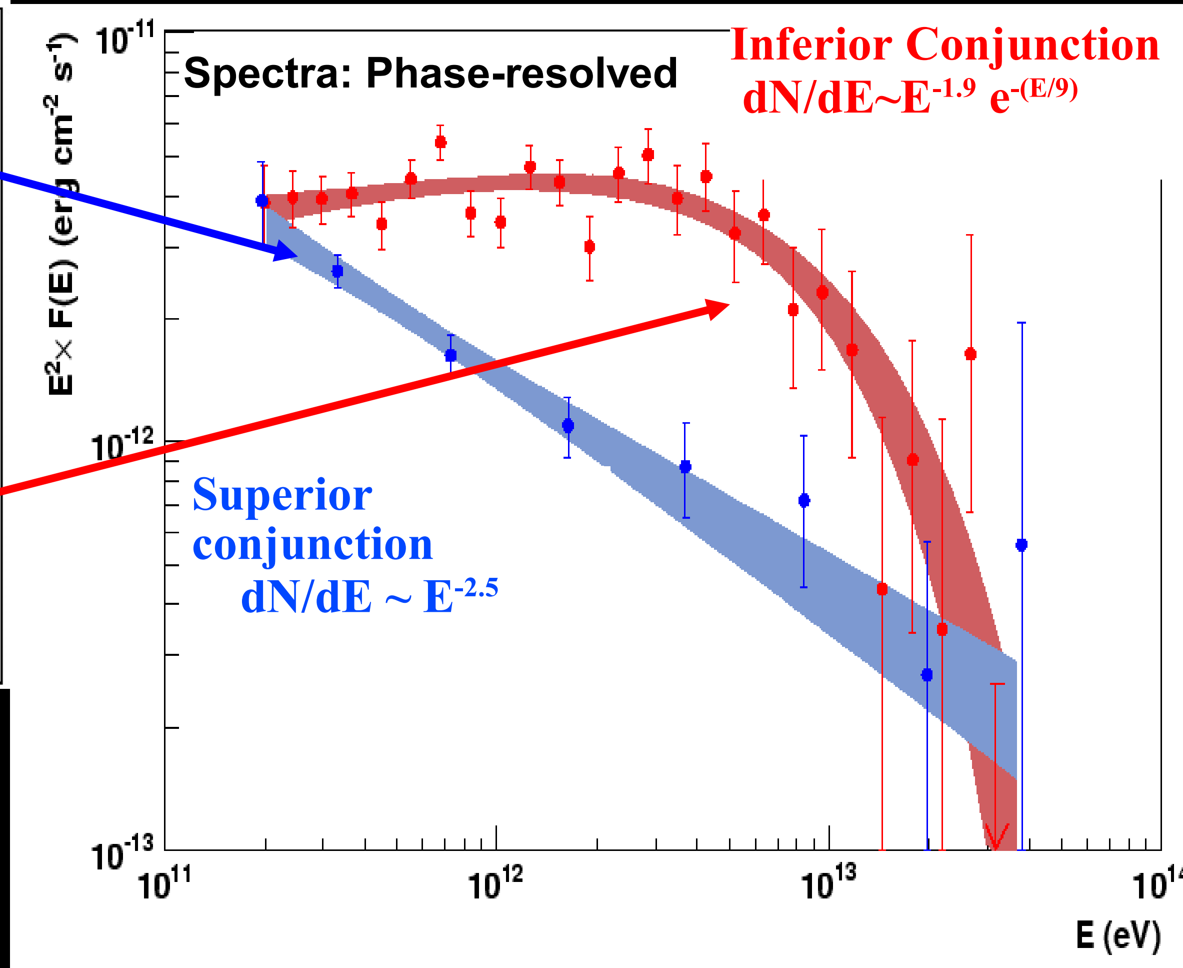


# Discovery of 3.9 day orbital period: Lomb-Scargle Test



# Phase-Resolved Energy Spectra




**Maximum coinciding with ~inferior conjunction**

**Minimum around superior conjunction (non-zero!)**

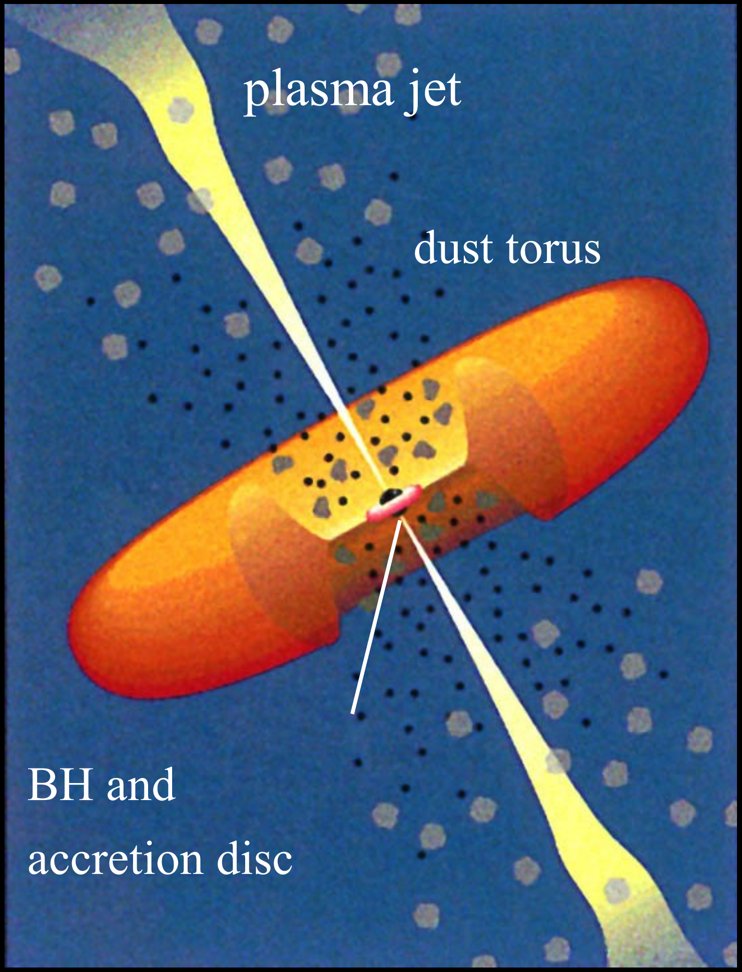
**--> Gamma absorption in UV field plays a role (pair prod X-section vs. angle)**

**--> other physics issues also: anisotripic inverse Compton**

**--> Max electron energies (B field changes)**

# Active galactic nuclei (AGN) and blazars

- **AGN:** Luminous central region of a galaxy (found in ~1% of all galaxies)
- **AGN model:**
  - Central supermassive black hole
  - Matter accretion (thermal emission from radio to X-rays)
  - Relativistic plasma jet
- Observed AGN features depend on viewing angle (unification)
- **Blazar:** viewing angle ~ jet axis
  - Relativistic beaming
    **Doppler-boosting** $E_{obs} \sim \delta\ E_{src}$
  - **Pointlike TeV emission ( *pair halos)**
  - **Extreme variability**



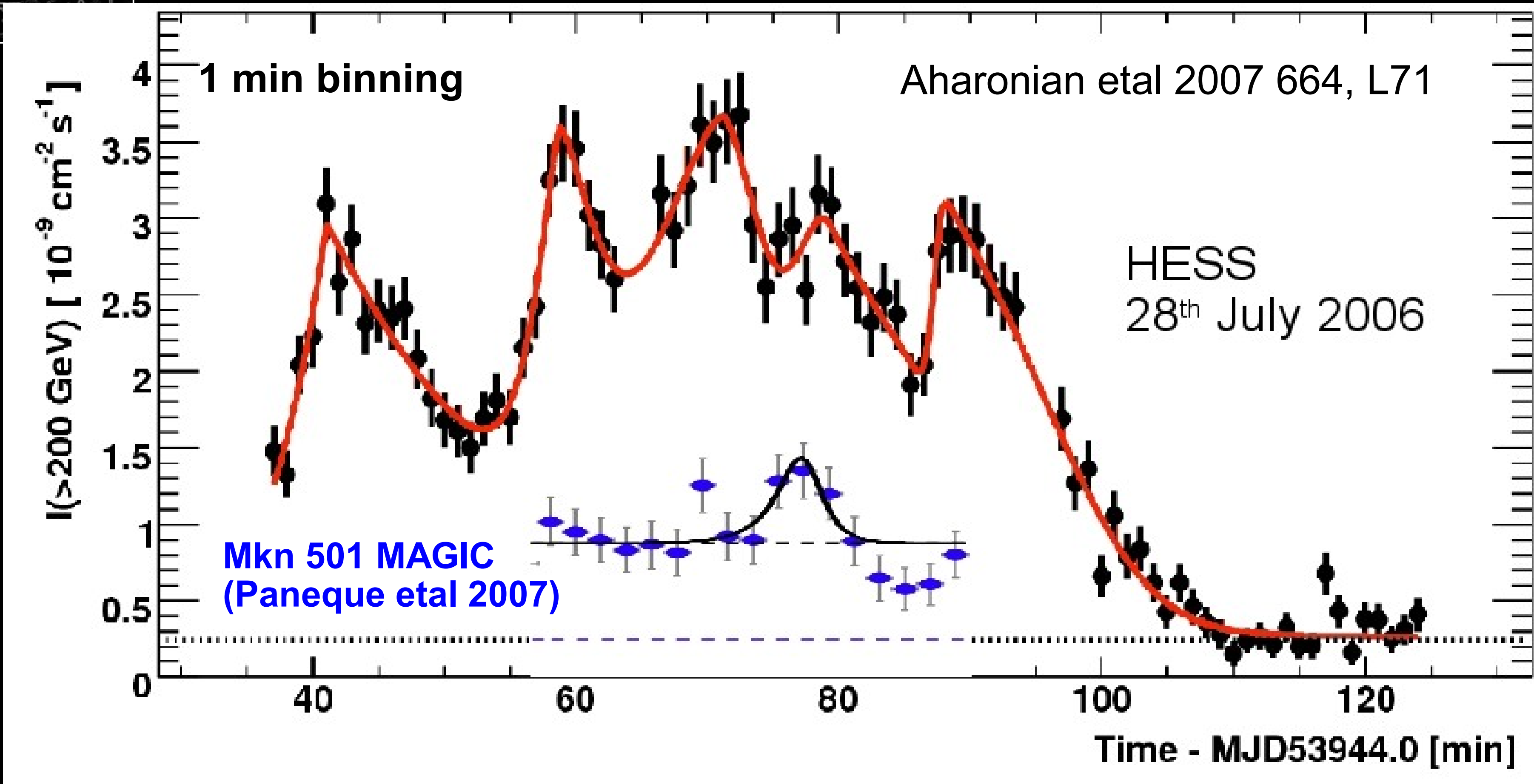
# TeV AGN Sources: Mid-2007

| Name | Type | Redshift | Signif. ***: >10 | Discovered |
|---|---|---|---|---|
| M 87 | FR I | 0.004 | *** | HEGRA |
| Mrk 421 | BL Lac | 0.031 | *** | Whipple |
| Mrk 501 | BL Lac | 0.034 | *** | Whipple |
| 1ES 2344+514 | BL Lac | 0.044 | *** | Whipple |
| Mrk 180 | BL Lac | 0.046 | 5.5 | MAGIC |
| 1ES 1959+650 | BL Lac | 0.047 | *** | TA |
| BL Lac | BL Lac | 0.069 | 5.1 | MAGIC |
| PKS 0548-322 | BL Lac | 0.069 | 5.8 | HESS |
| PKS 2005-489 | BL Lac | 0.071 | *** | HESS |
| PKS 2155-304 | BL Lac | 0.116 | *** | Durham |
| H 1426+428 | BL Lac | 0.129 | 7.5 / 5 | Whipple |
| 1ES 0229+200 | BL Lac | 0.14 | 6.6 | HESS |
| H 2356-309 | BL Lac | 0.165 | *** | HESS |
| 1ES 1218+304 | BL Lac | 0.182 | 9 / 6.4 | MAGIC |
| 1ES 1101-232 | BL Lac | 0.186 | *** | HESS |
| 1ES 0347-121 | BL Lac | 0.188 | *** | HESS |
| 1ES 1011+496 | BL Lac | 0.212 | *** | MAGIC |
| PG 1553+113 | BL Lac | ? | *** | HESS/MAGIC |
| 3C 279 | FSRQ | 0.536 | ~8 (trials?) | MAGIC |

## Mid-2008

| | | | | | |
|---|---|---|---|---|---|
| S5 0716+714 | z=0.31 | +7sig | BL-Lac (LBL) | MAGIC | ATEL #1500 |
| W Comae | z= 0.102 | +6sig | BL-Lac (IBL) | VERITAS | ATEL #1422 |
| 1ES 0806+524 | z=0.138 | +7sig | BL-Lac (HBL) | VERITAS | ATEL #1415 |
| RGB J0152+017 | z=0.080 | +7sig | BL-Lac (HBL) | HESS | A&A 2008 |

# PKS2155-304 (z=0.116) : Huge Flare




Peak flux ~15Crab; $L\gamma \sim 10^{12}$ Crab

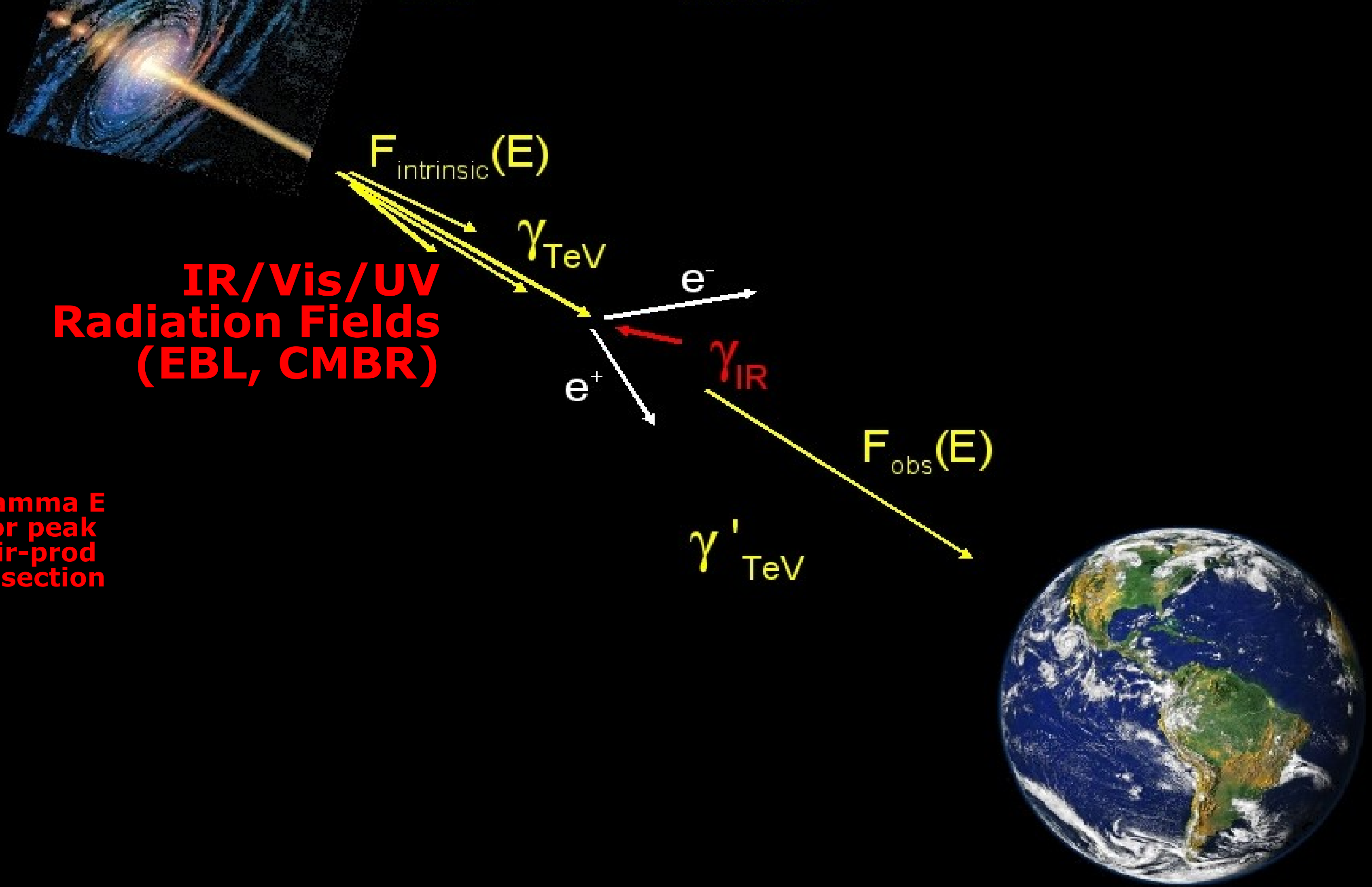
Minimum variability timescale $\Delta t \sim 173$s

Causality: constrain source size $R_{src} < c\,\Delta t\ \ \delta / (1+z)$

For Black Hole $\delta \sim 60$ to 100!

# Gamma absorption on soft photon fields

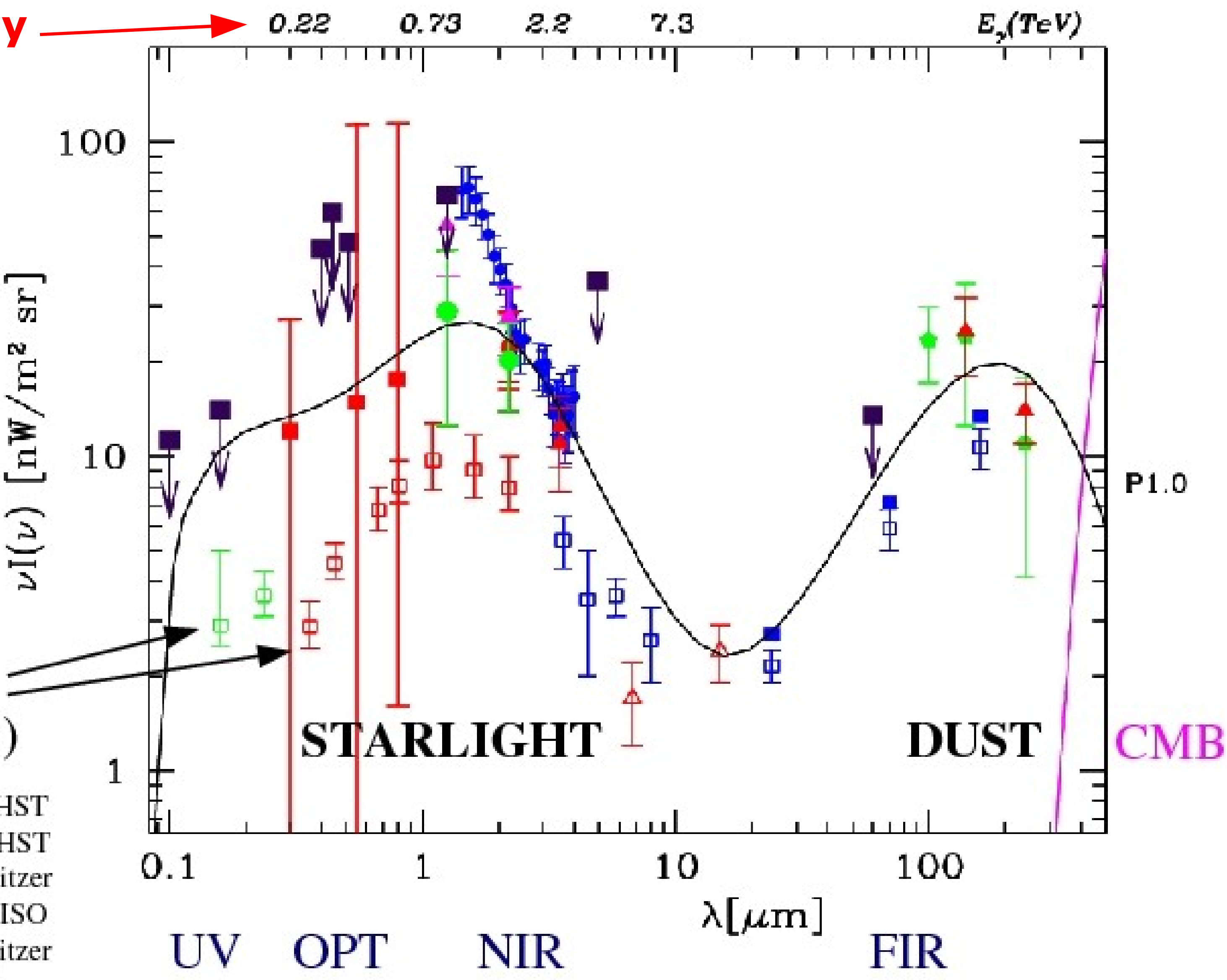
$$F_{obs}(E) = F_{intrinsic}(E) \cdot e^{-\tau(E,z)}$$




Gamma E
for peak
pair-prod
X-section

# Extragalactic Background Light: the SED

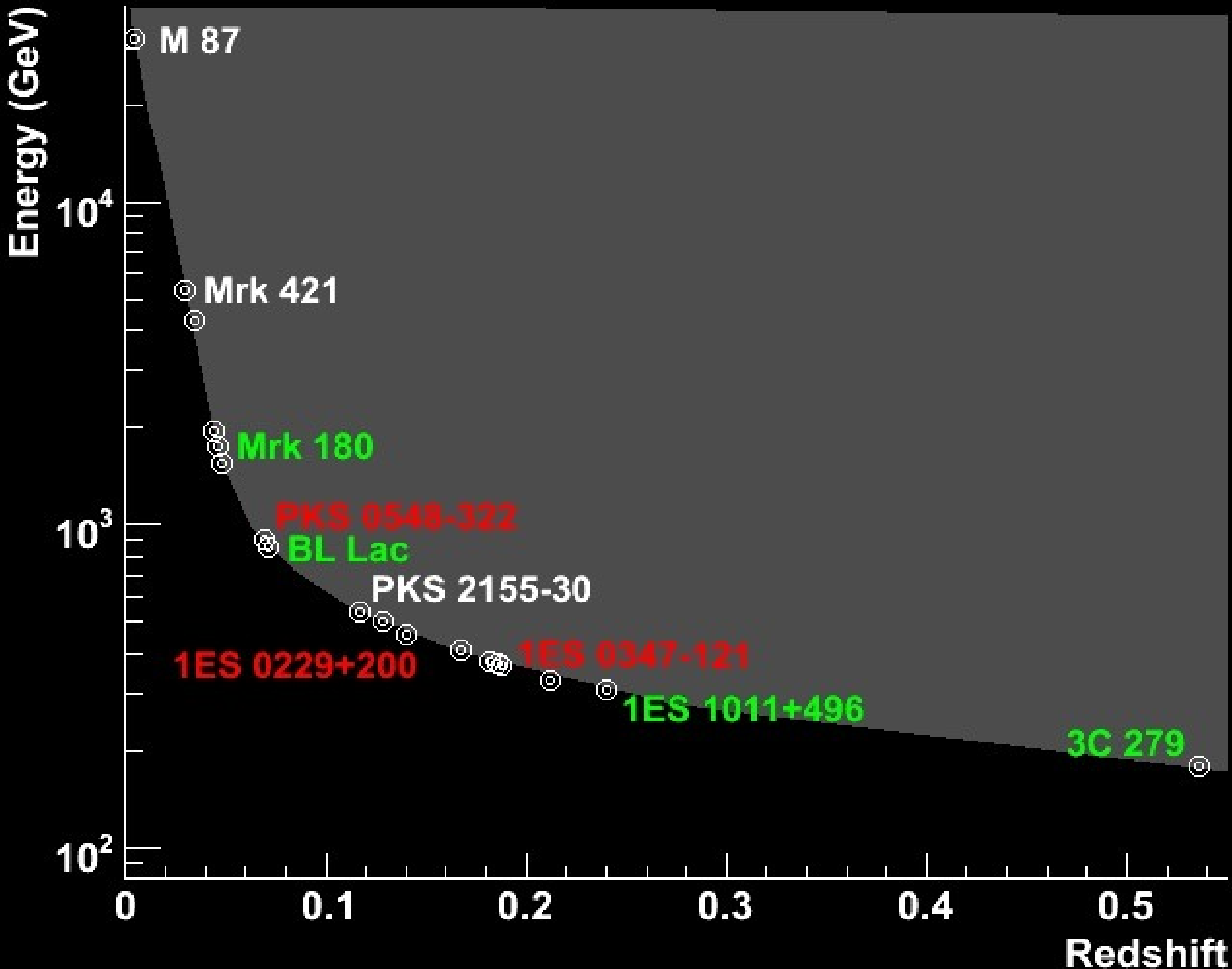
Gamma Energy for peak pair production X-section




Lower limits (source counts)

| | |
|---|---|
| Gardner et al. 2001 | HST |
| Madau & Pozzetti 2000 | HST |
| Fazio et al. 2004 | Spitzer |
| Elbaz et al. 2002 | ISO |
| Dole et al. 2006 | Spitzer |

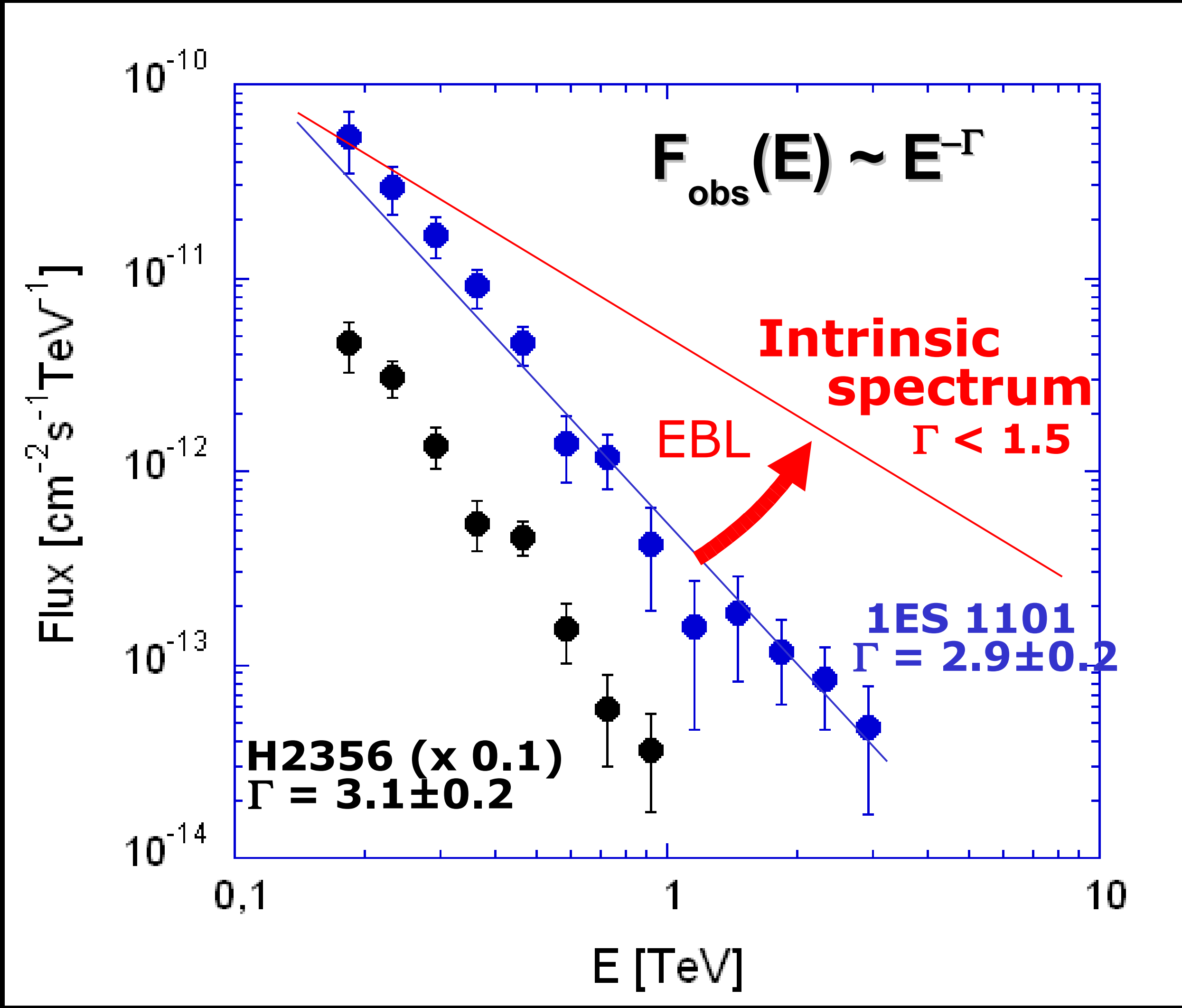
# Gamma horizon $\tau$ (E,z) = 1




from Blanch, Martinez etal 2005

# TeV Spectra & ExtragalacticBackgroundLight

We can de-absorb the observed TeV spectra to estimate the intrinsic spectra



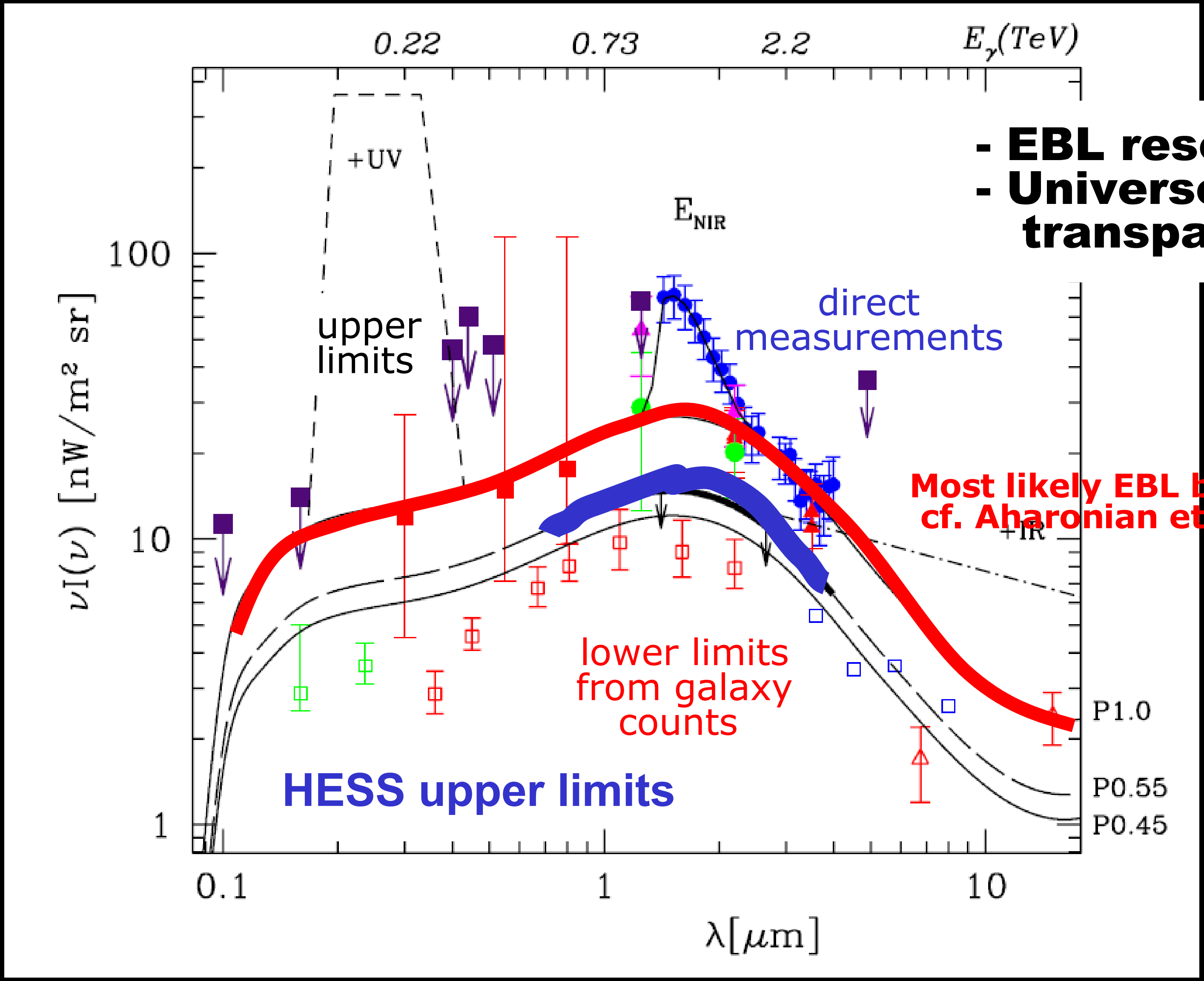

But intrinsic specrum should not be too hard!

$\Gamma < 1.5$

**Due to Inverse-Compton limit Thompson regime**

# Spectra & ExtragalacticBackgroundLight

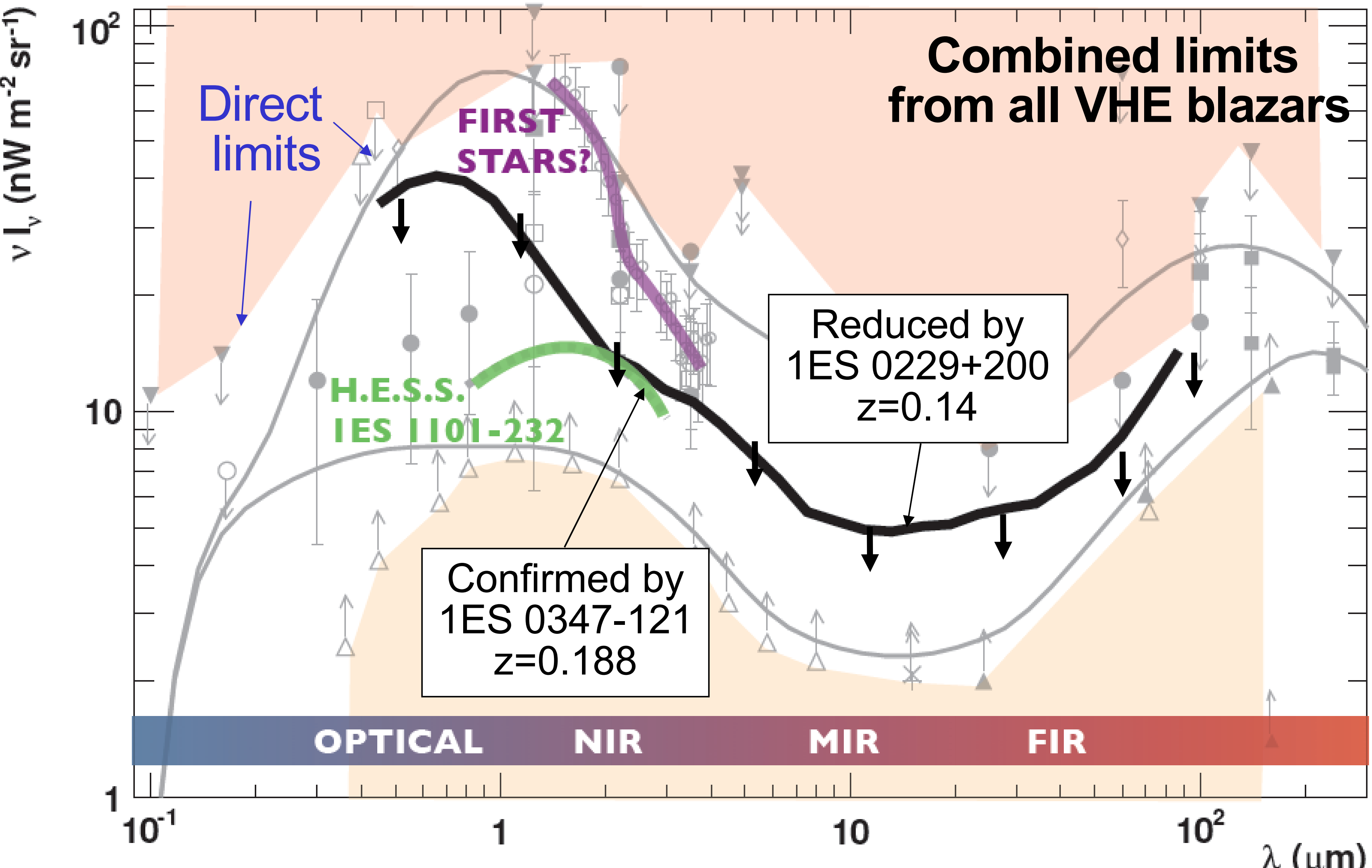
**See Aharonian et al. (2005) Nature 440, 1018**



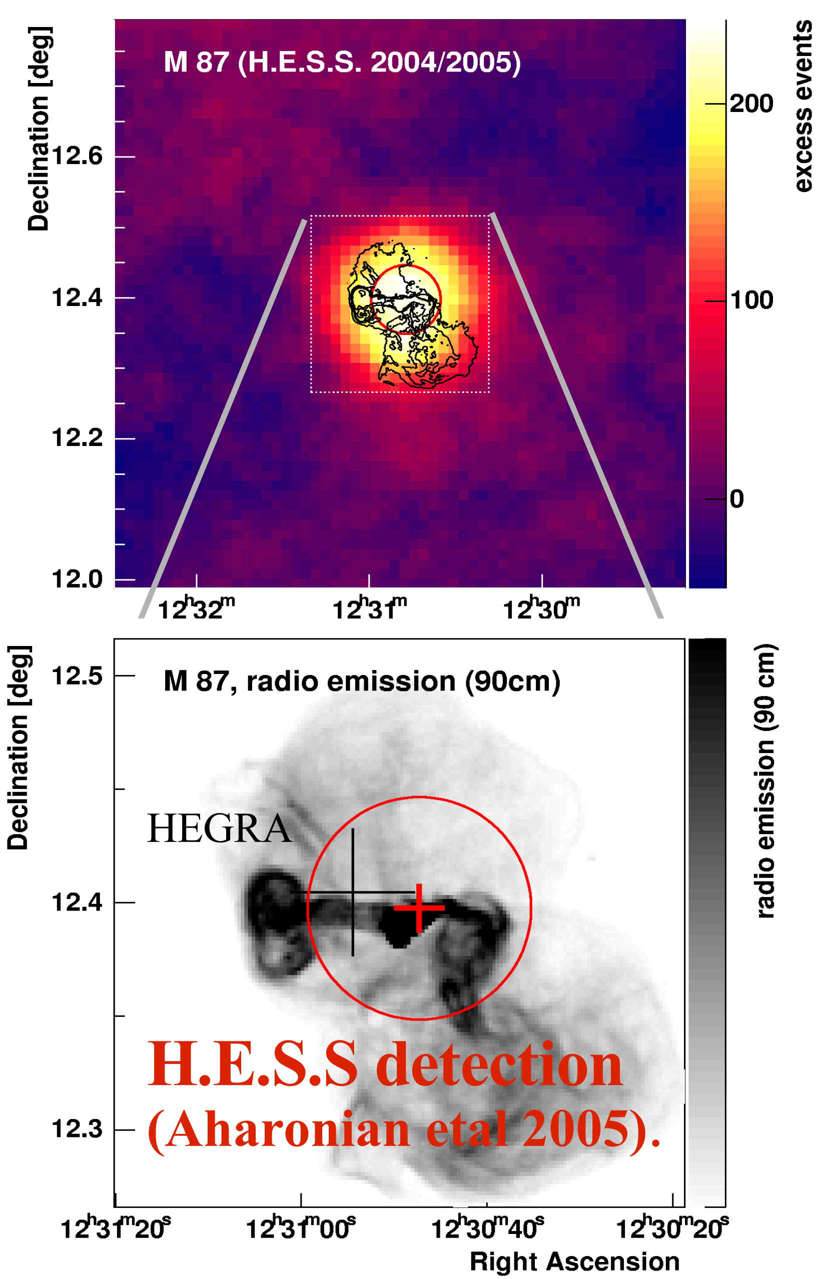

- **EBL resolved**
- **Universe more transparent**

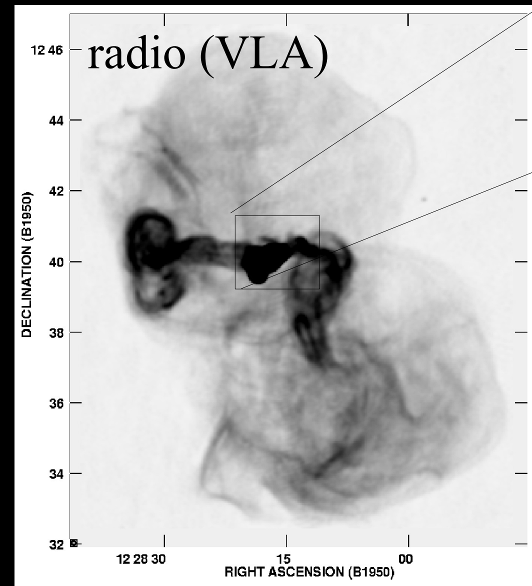
# Updated EBL Limits from new TeV Spectra

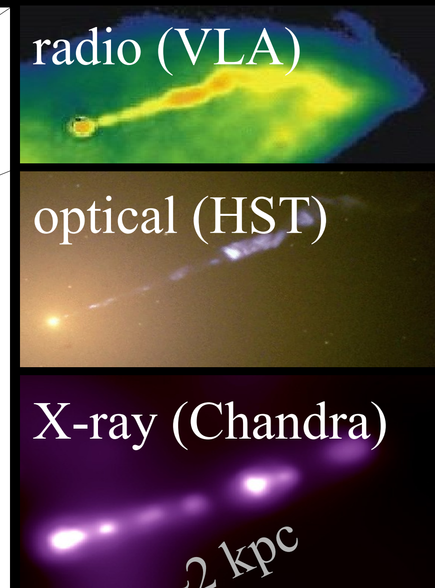
Raue etal, Mazin etal, Puehlhofer etal 2007



# The Giant Radiogalaxy M87




**Distance:~16 Mpc** (z=0.00436)

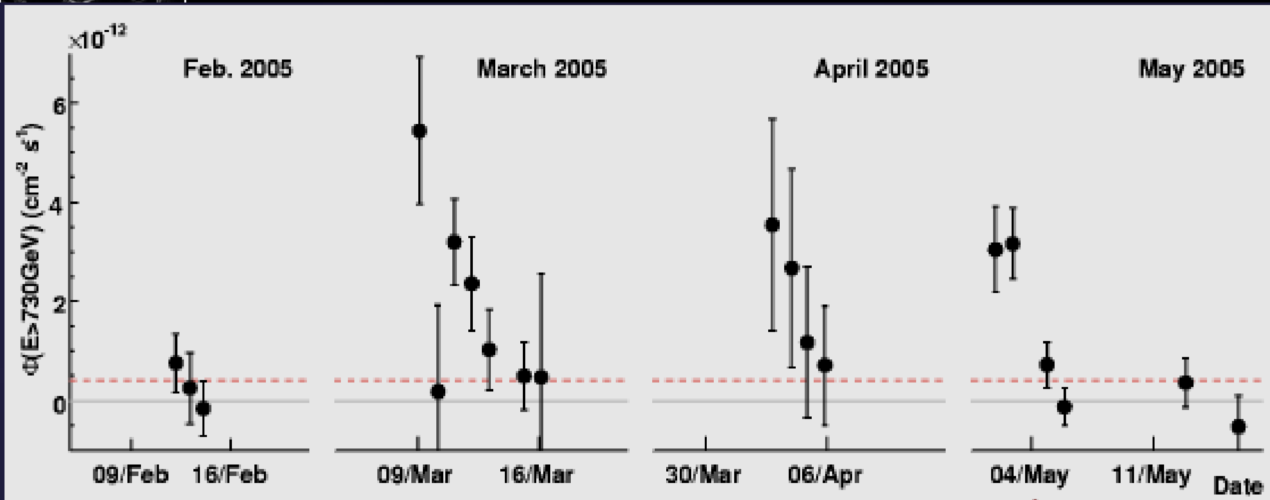
**Central BH:** $M_{BH} \sim 3 \cdot 10^9\ M_{\odot}$

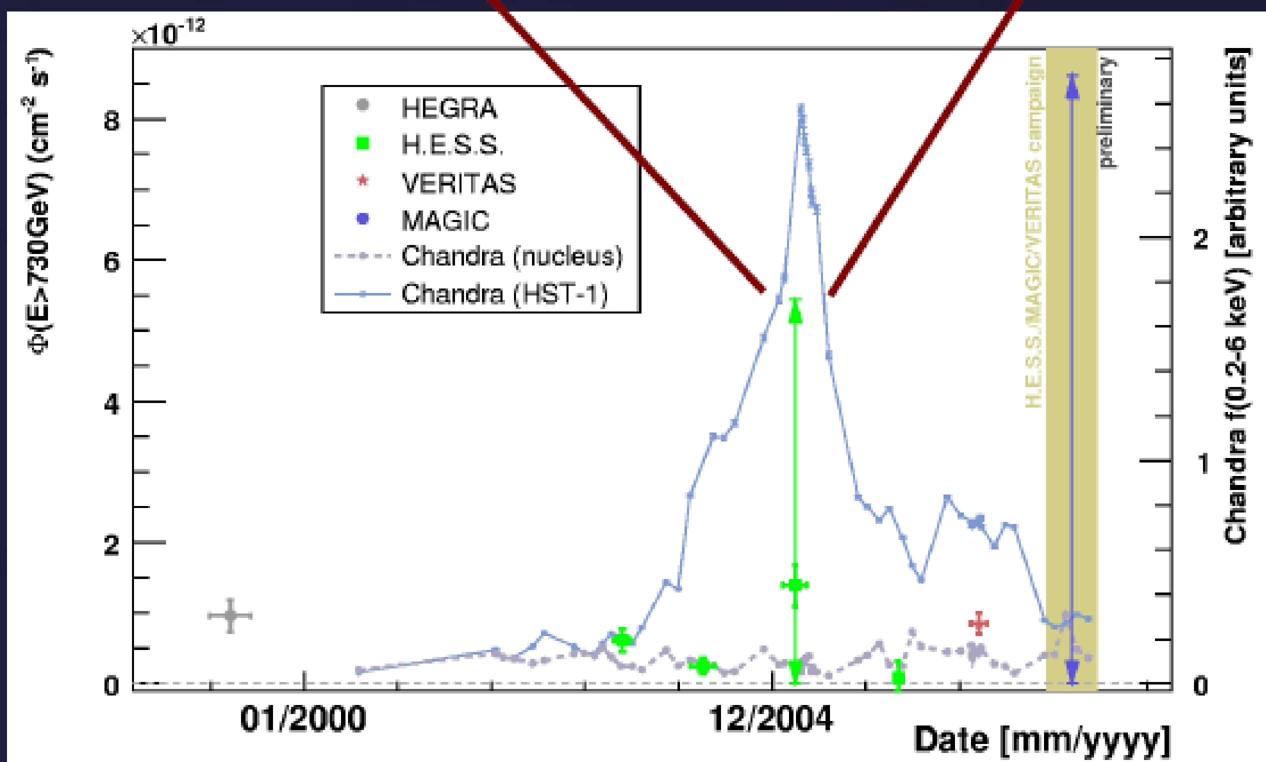
**Jet angle: ~30° ⇒ not a blazar!**

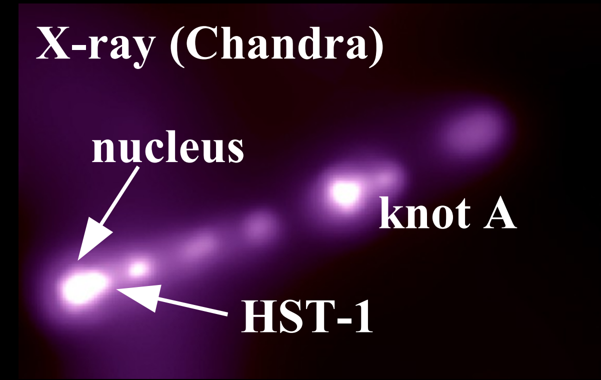
**Predictions of TeV emission and $10^{20}$ eV particles (UHECR)**

**First TeV detection (>4σ) by HEGRA in 1998/99** (Aharonian etal 2003

# M87: A variable Source




**<u>HESS 2-day variability</u>**

**constrain source size to $< 5\,\delta\,R_s$**

**(Aharonian etal 2005)**

**<u>TeV location:</u>**

**HST-1 X-ray knot or Central Black Hole?**

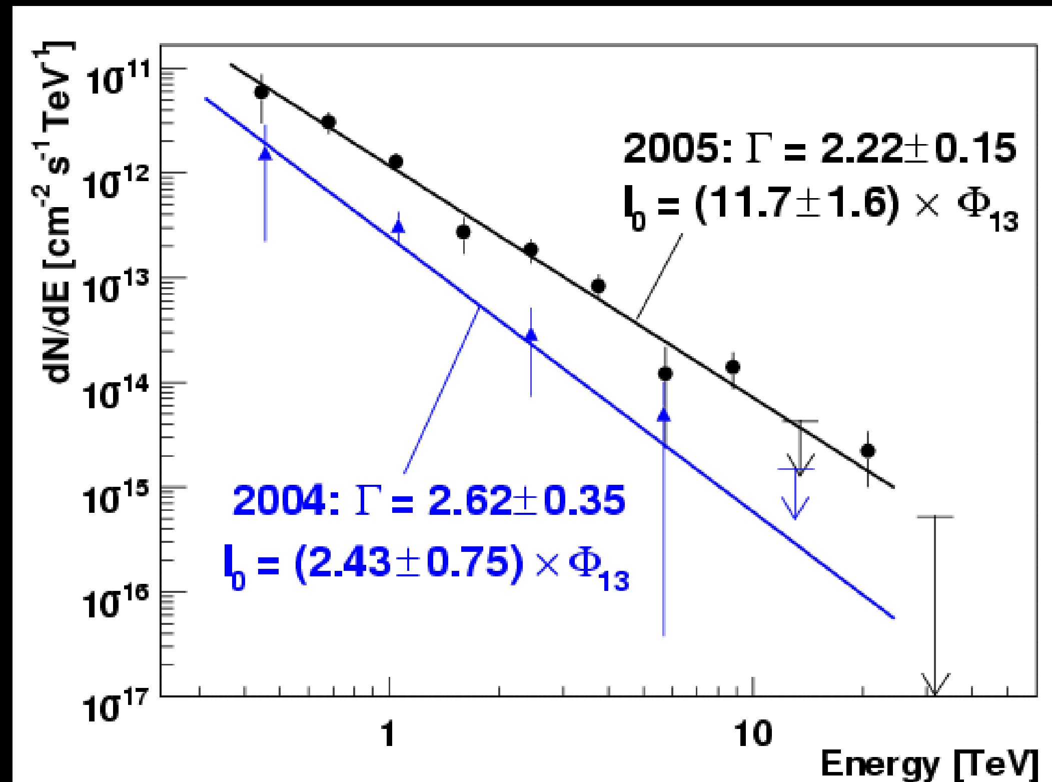
**<u>HESS/MAGIC/VERITAS Campaign 2008</u>**

**(Beilicke etal 2008)**

# M87: energy spectra

- Separate energy spectra
  2004 (~5σ)
  2005 (~10 σ)
- Spectra well described by pure power-laws:

M87 energy spectrum




$\Phi_{13} = 10^{-13}$ cm$^{-2}$ s$^{-1}$ TeV$^{-1}$

Comparison of 2004 vs. 2005:
Photon indices $\Gamma$ compatible, but different flux levels

# H.E.S.S. II

H.E.S.S. II 30 metre diameter Cherenkov telescope under construction

--> push energy threshold to < 50 GeV
reaching to GLAST's upper energy limit (few x 10's GeV)

HESS II
Foundation completed

Dish construction
underway
(status early 2008)

# Summary

- A growing TeV Gamma Ray catalogue due to HESS

- Shell SNRs: Shell in TeV gammas: Hadronic &/or leptonic accelerators. $\sim 10^{49}$ erg necessary in protons.

  Some cases for TeV/Molecular-Cloud overlap
  --> strong hint for hadronic origin

- In many TeV Galactic Sources emission up to >30 TeV
  --> particle acceleration above 100 TeV.

- Pulsar Wind Nebulae: Spectral evolution; Asymmetric morphology. Electronic origin.

- Open Clusters & Massive Stars: New CR accelerators?

- Compact Binaries: orbital modulation

- Unidentified TeV Sources – a growing mystery

- Extragalatic sources: Sites of multi TeV particle production: probe background radiation, fast variability to minute timescales

- HESS II is coming < 100 GeV studies: AGN, XRB, GRBs....

*- Additional Topics (not dicussed): Pulsar power population studies; Galaxy clusters; Dark matter searches*