

# **H.E.S.S. Performance & Results**

**Wystan Benbow for the H.E.S.S. Collaboration  
MPI für Kernphysik, Heidelberg**

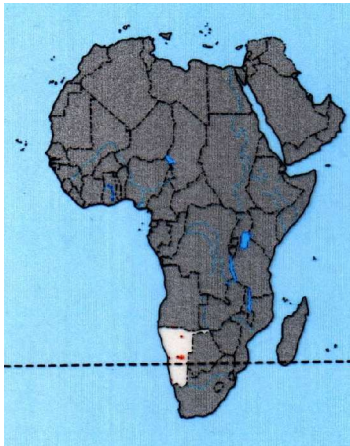




# The H.E.S.S. Phase-I Telescopes

## Location:

- Khomas Highland, Namibia
- Coordinates: 23°16' S, 16°30' E, 1800 m asl

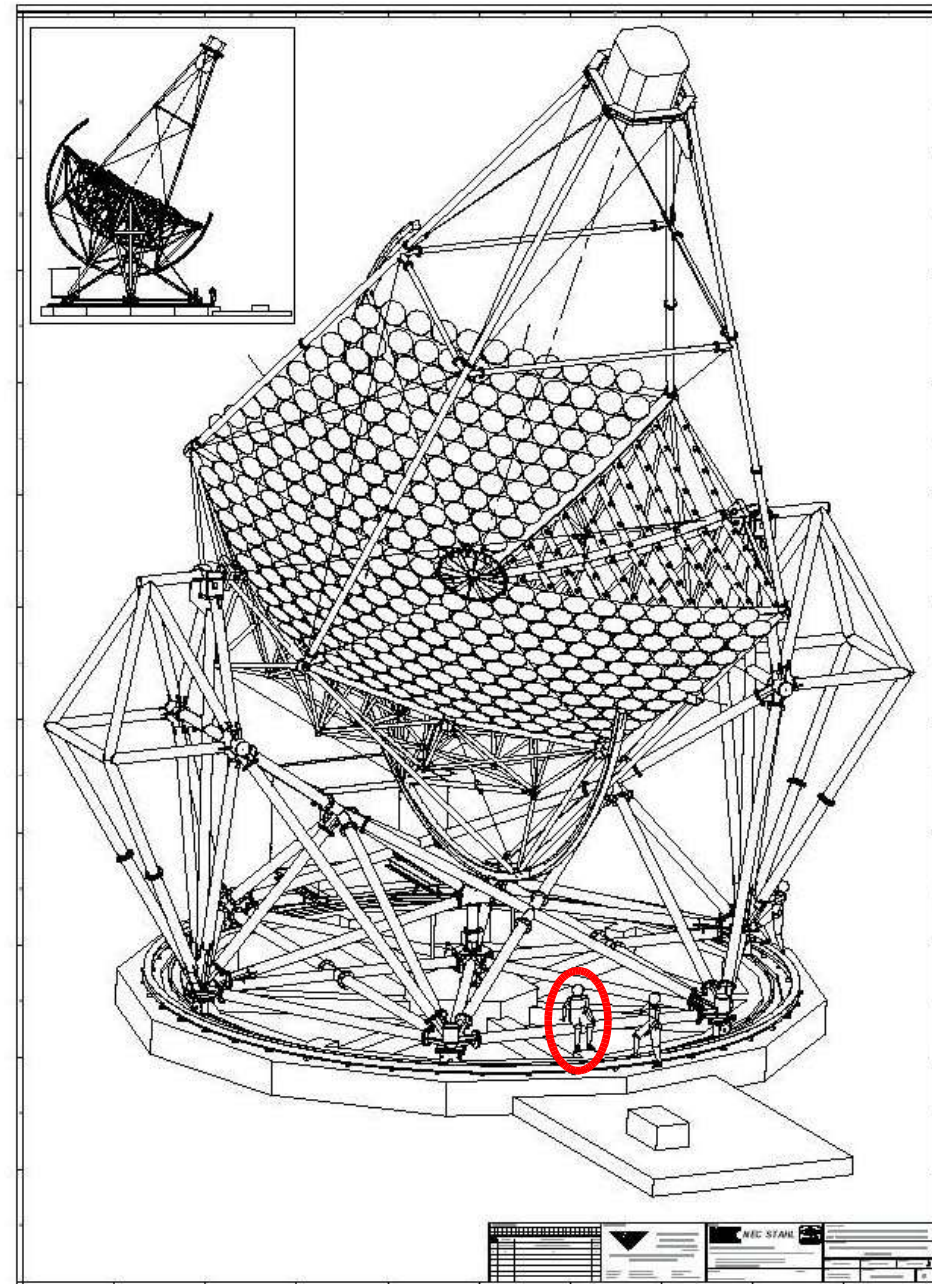


## Telescope:

- Altitude-azimuth mount, Davies-Cotton reflector
- Rigid steel structure
- Diameter: 12 m, Focal length: 15 m ( $f/d \sim 1.2$ )
- 4 telescopes separated by 120 m

## Mirror:

- Mirror area  $\sim 107 \text{ m}^2$
- 380 individual mirrors (60 cm diameter)
- Image of a star focused to 1/3 of camera pixel





# The H.E.S.S. Cameras

- 960 pixels of  $0.16^\circ$
- $5^\circ$  field of view (1.4 m)
- Readout integrated in camera body
- 16 ns integration, 1 GHz sampling



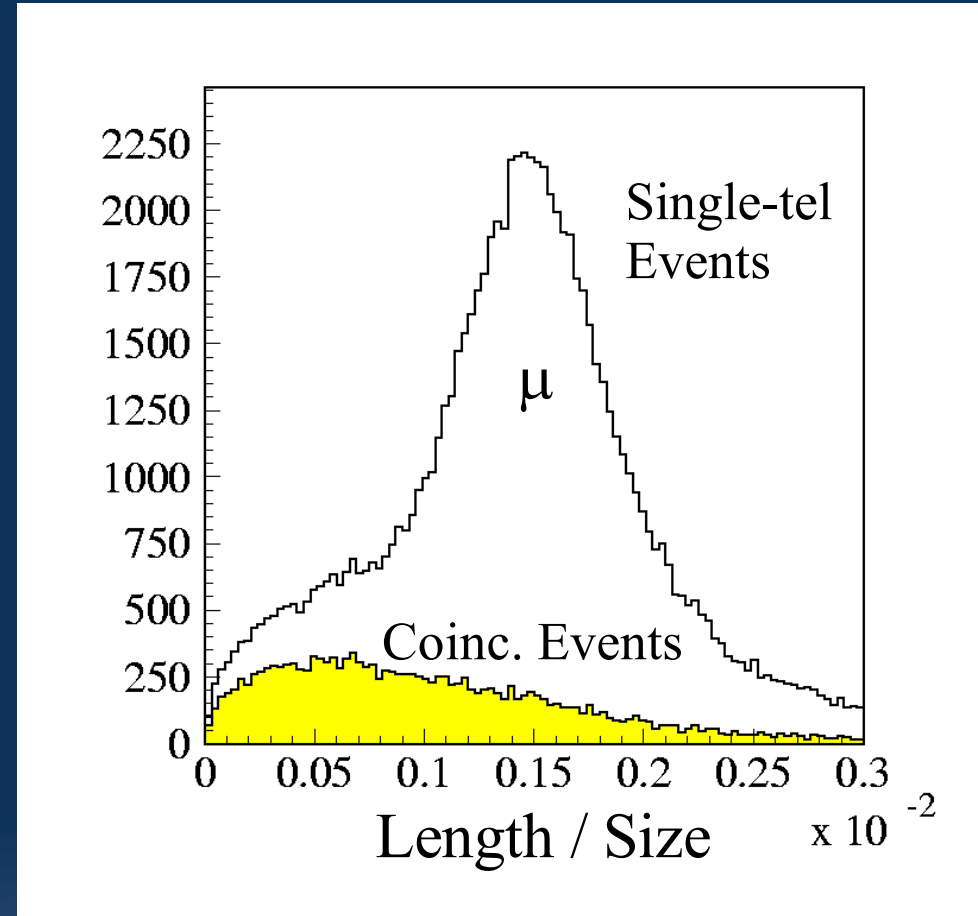
"Light in,  
light out"

# Central Trigger System

Requires a 2-telescope coincidence:

- Removes muons
- Lower energy threshold
- Stereoscopic techniques

Funk et al., 2004, *Astropart Phys*, 22, 385







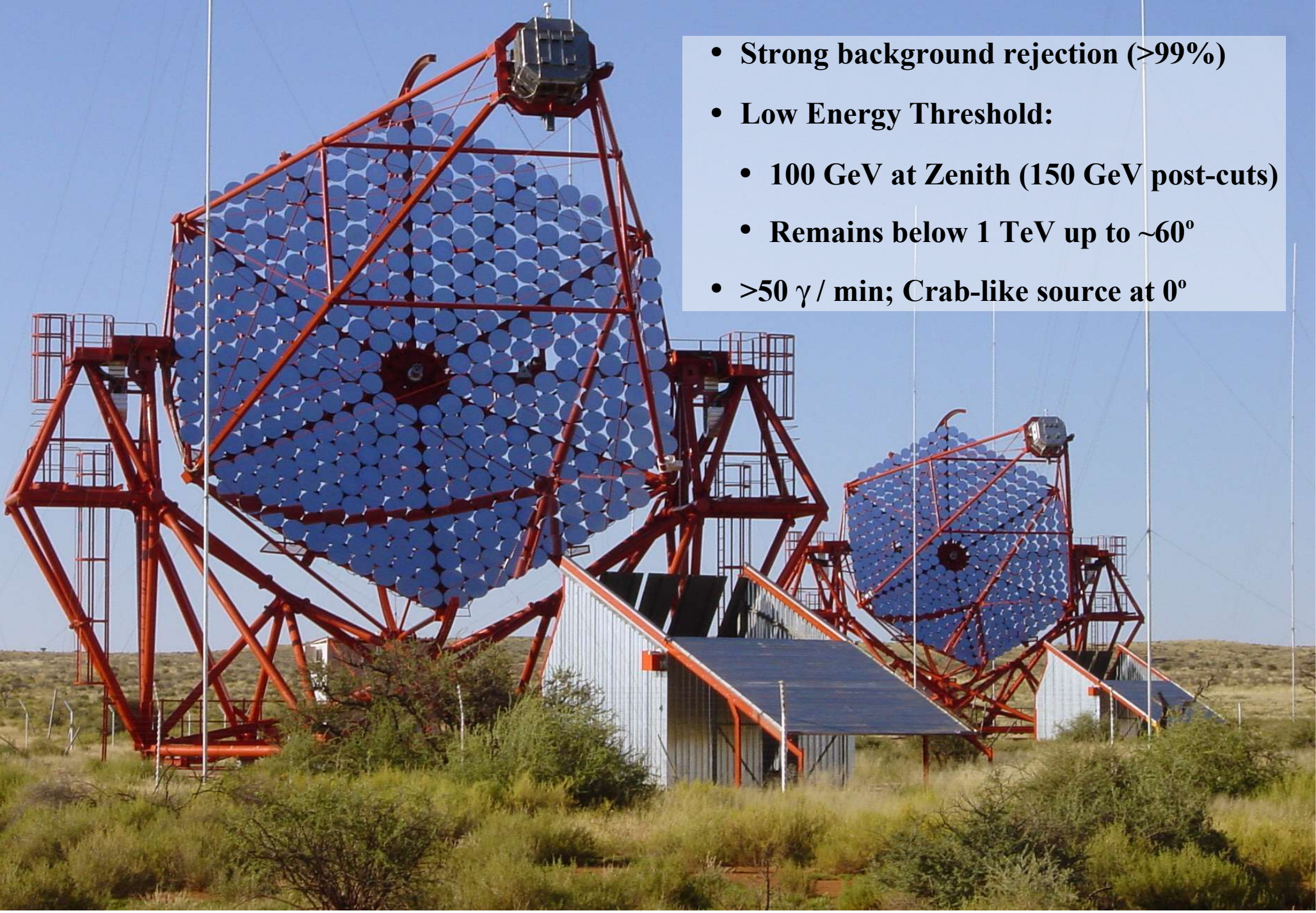
# H.E.S.S. Status

First light: June 2002; Fully operational: Dec. 2003  
Online analysis works well!



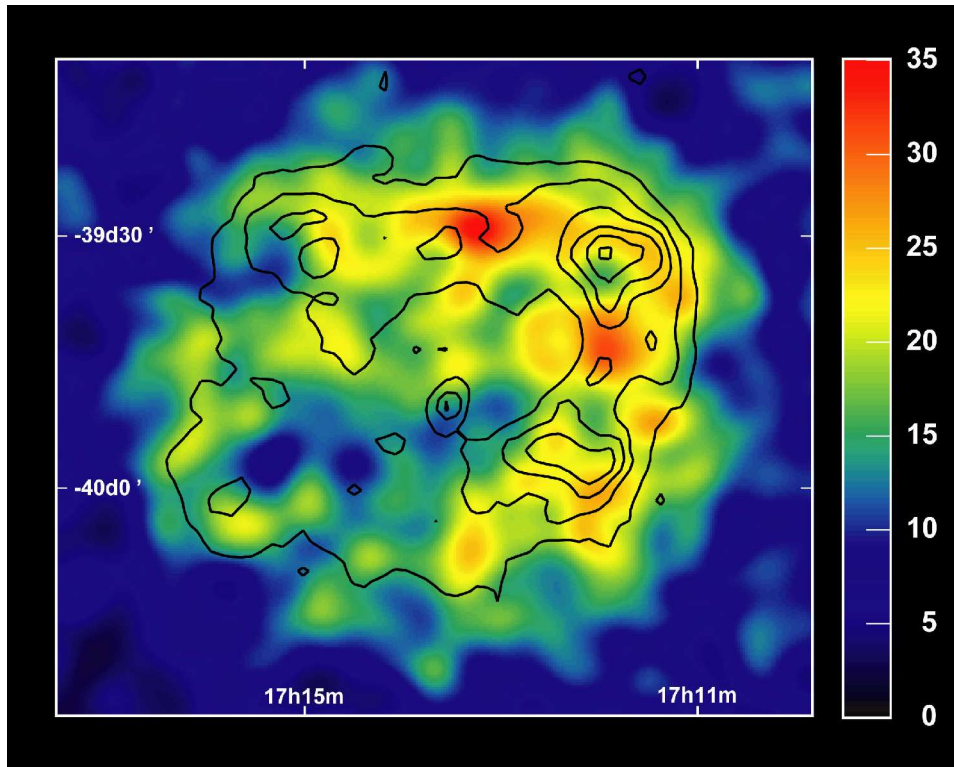
# H.E.S.S. Performance

- **Strong background rejection (>99%)**
- **Low Energy Threshold:**
  - **100 GeV at Zenith (150 GeV post-cuts)**
  - **Remains below 1 TeV up to  $\sim 60^\circ$**
- **$>50 \gamma / \text{min}$ ; Crab-like source at  $0^\circ$**





# H.E.S.S. Performance

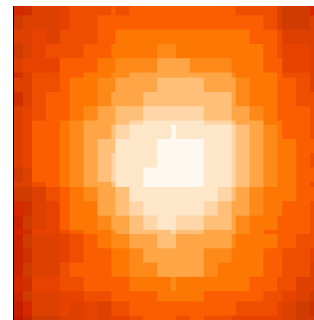


- **Small point spread function**
  - Width  $< 0.1^\circ$ ,
  - Comparable to ASCA
- **Large field of view ( $5^\circ$ )**
- **Pointing error  $< 20''$**
- **Great for surveys:**

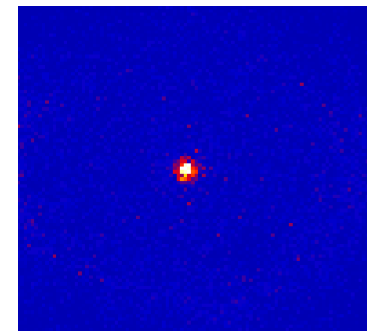
Aharonian et al., 2005, *Science*, **307**, 1938

**Resolve  $\gamma$ -ray morphology of  
extended objects (e.g. SNR)  
like RXJ 1713.7-3946**

Aharonian et al., 2004, *Nature*, **432**, 75



Crab with EGRET



Crab in TeV

# H.E.S.S. Spectral Performance

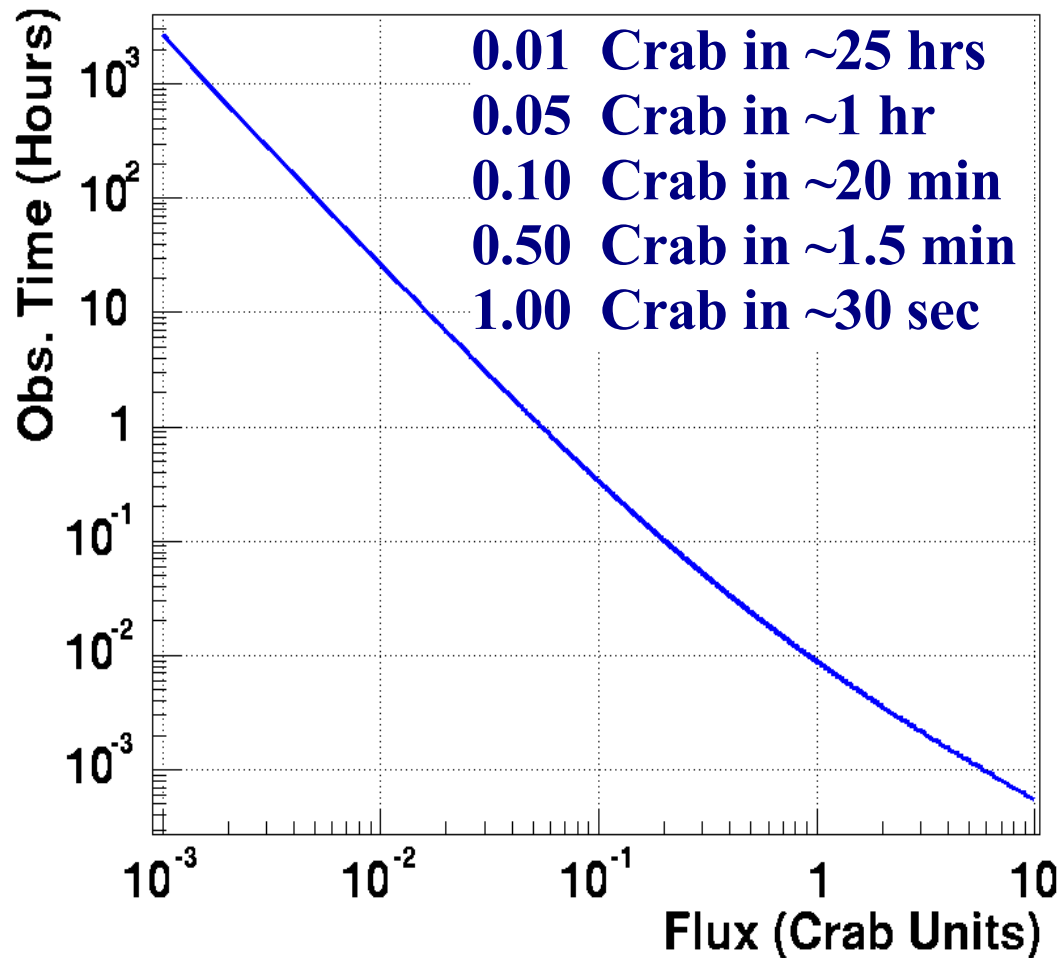


Energy Resolution  $\sim 15\%$ ; No bias above analysis threshold  
Systematic Errors: Photon index  $\sim 0.1$ ; Flux  $\sim 20\%$



# H.E.S.S. Sensitivity

Time Required for a  $5\sigma$  Detection at  $20^\circ$



For comparison: HEGRA needed ~100 hrs to detect  $5\sigma$  from a 5% Crab source



# Many Analysis Chains

## All agree well!

- **2 Independent simulations**

- **Camera calibration:**

  - *Astropart Phys*, 22, 109 (2004)

  - 2 independent methods

- **Geometrical reconstruction:**

  - 3 independent methods

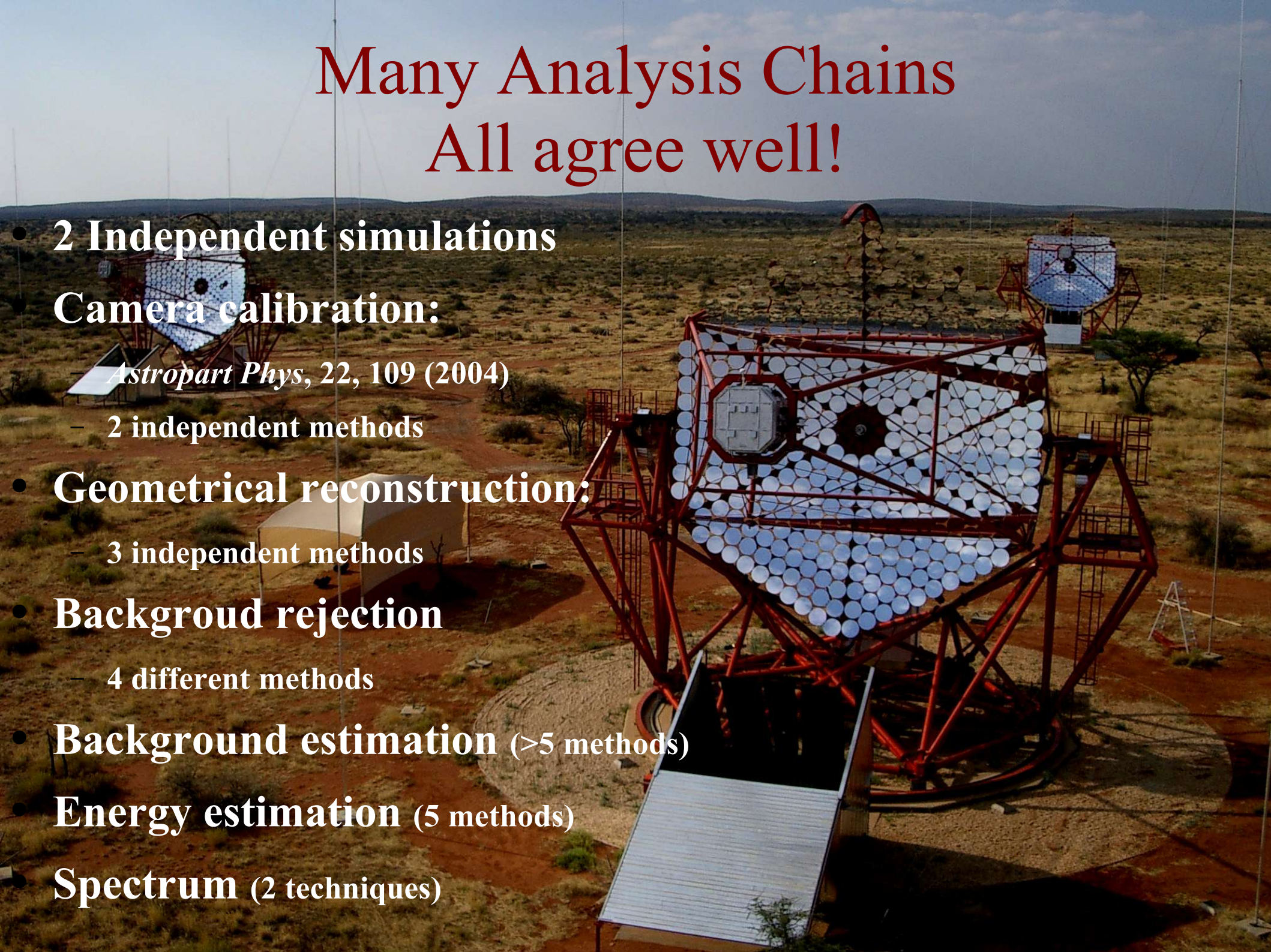
- **Background rejection**

  - 4 different methods

- **Background estimation (>5 methods)**

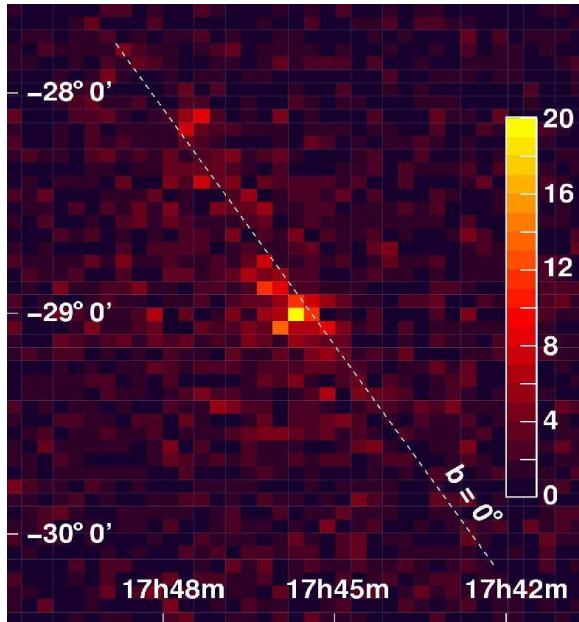
- **Energy estimation (5 methods)**

- **Spectrum (2 techniques)**



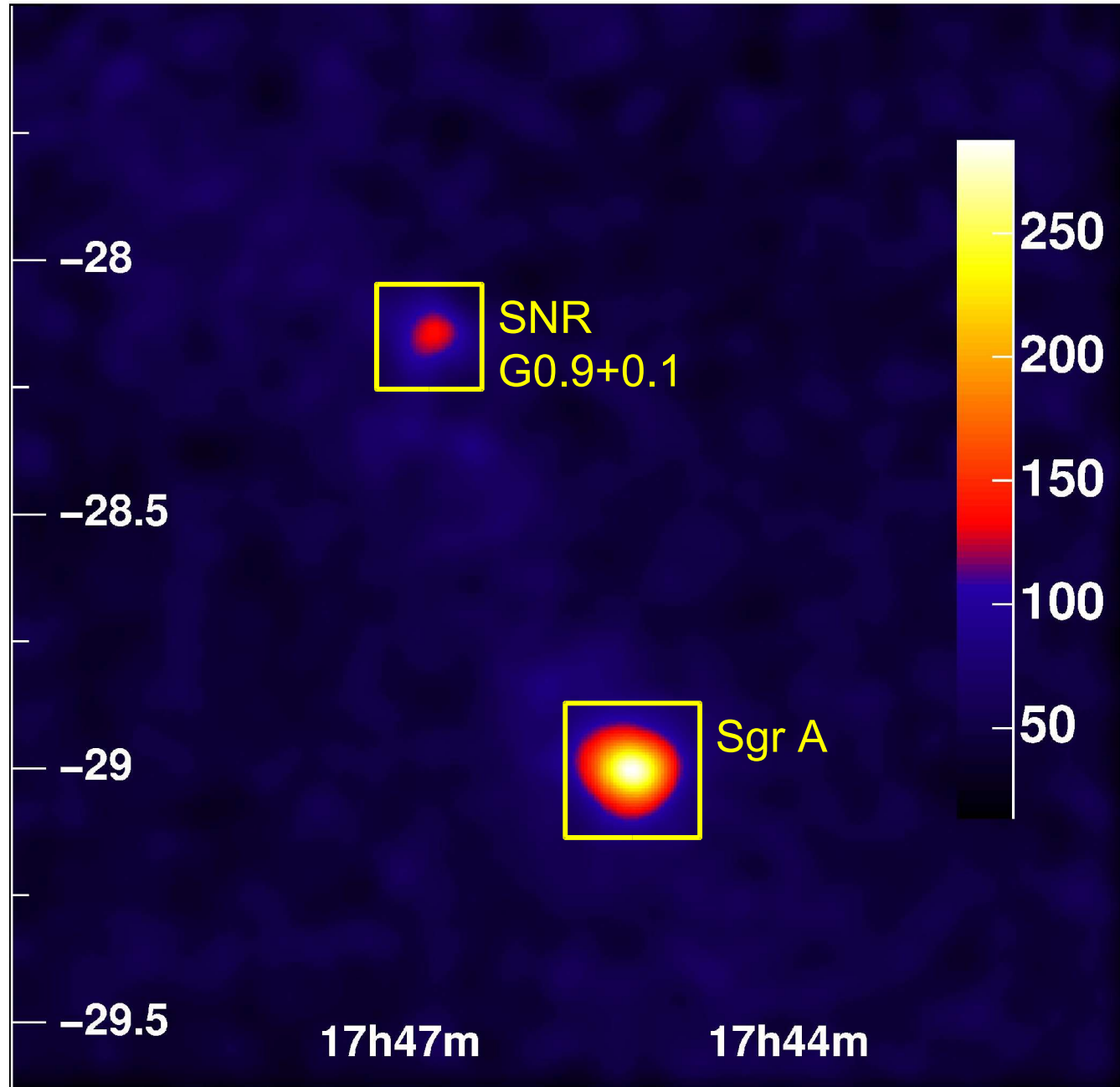


# H.E.S.S. Galactic Center in 2004



**2003:** 17 hrs of 2-tel data  
11  $\sigma$  signal near Sgr A\*  
A&A, 425, L13, 2004

**2004:** 50 hrs of 4-tel data  
>35  $\sigma$  signal

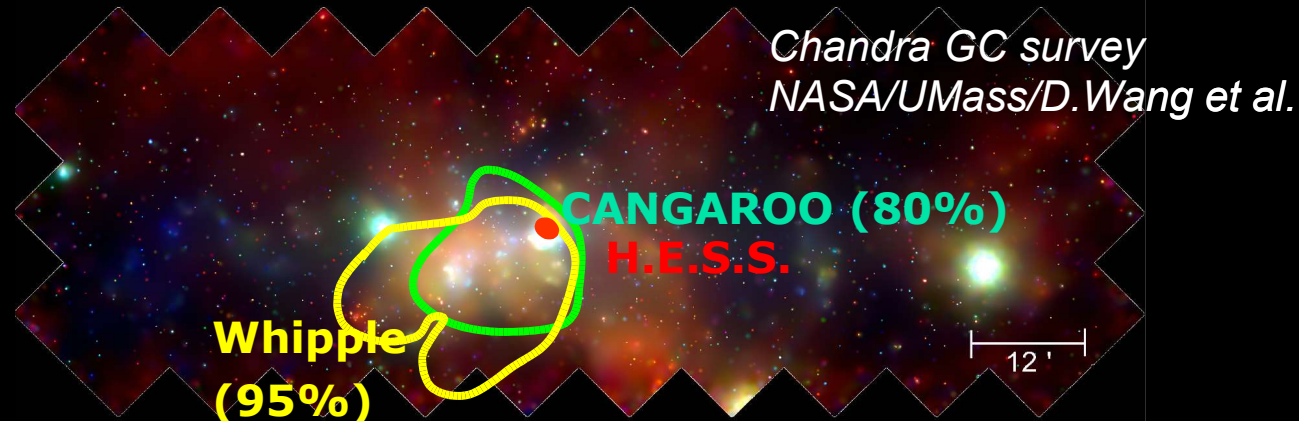




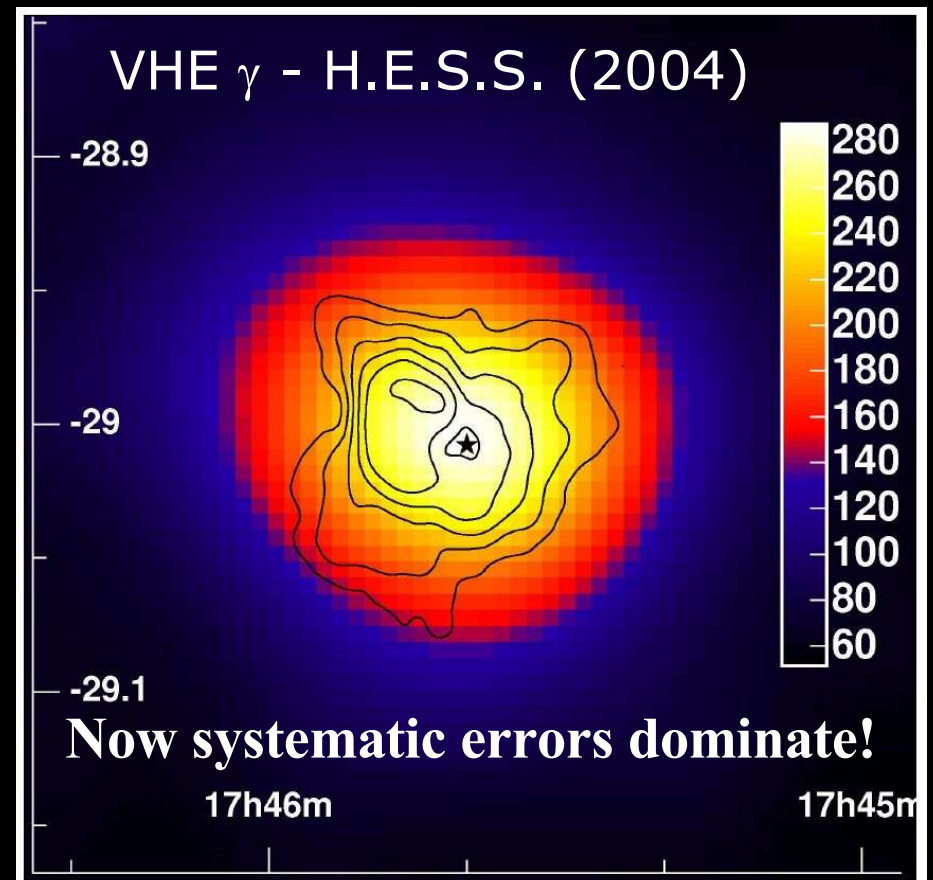
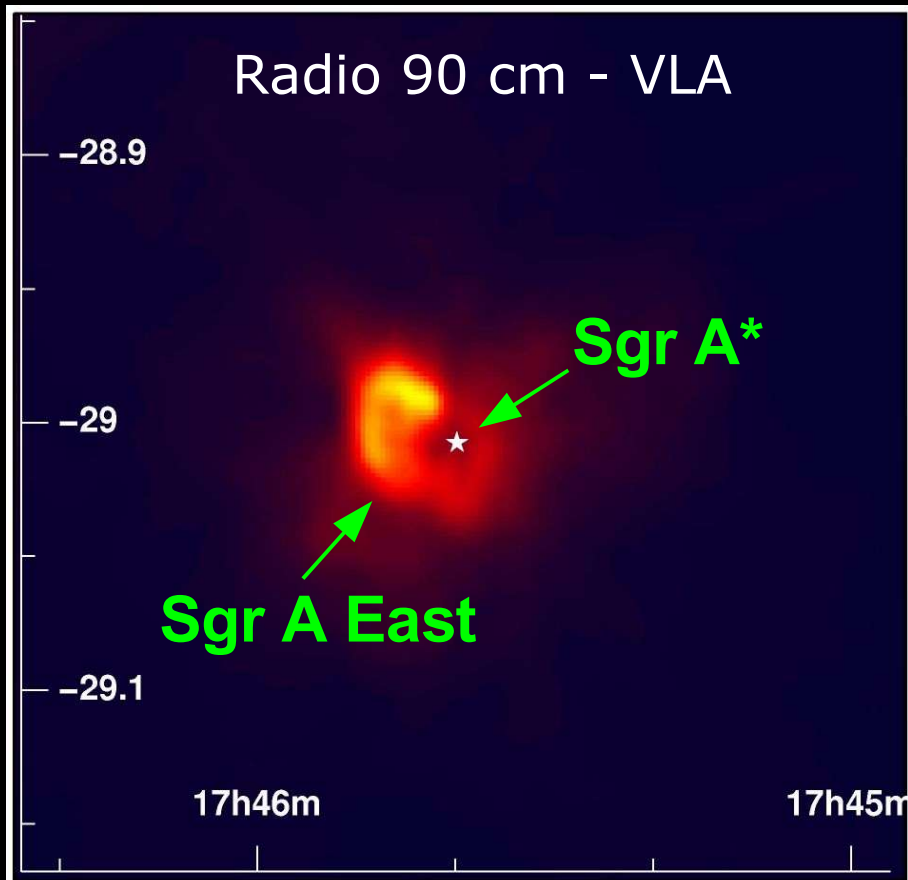
# HESS J1745-290

2003 Result:  
Point-like excess

Couldn't unambiguously  
identify with Sgr A\*

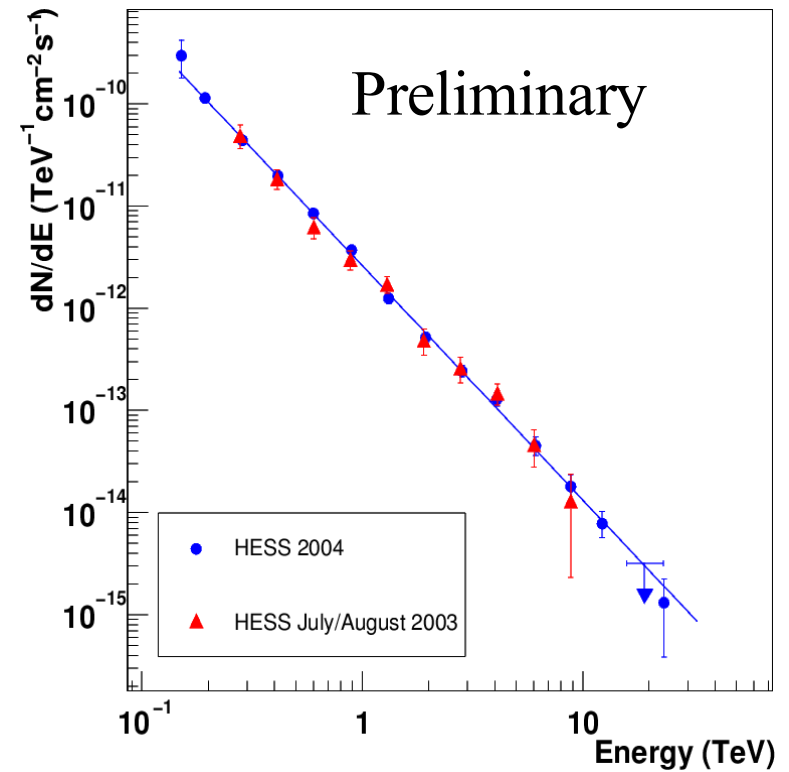
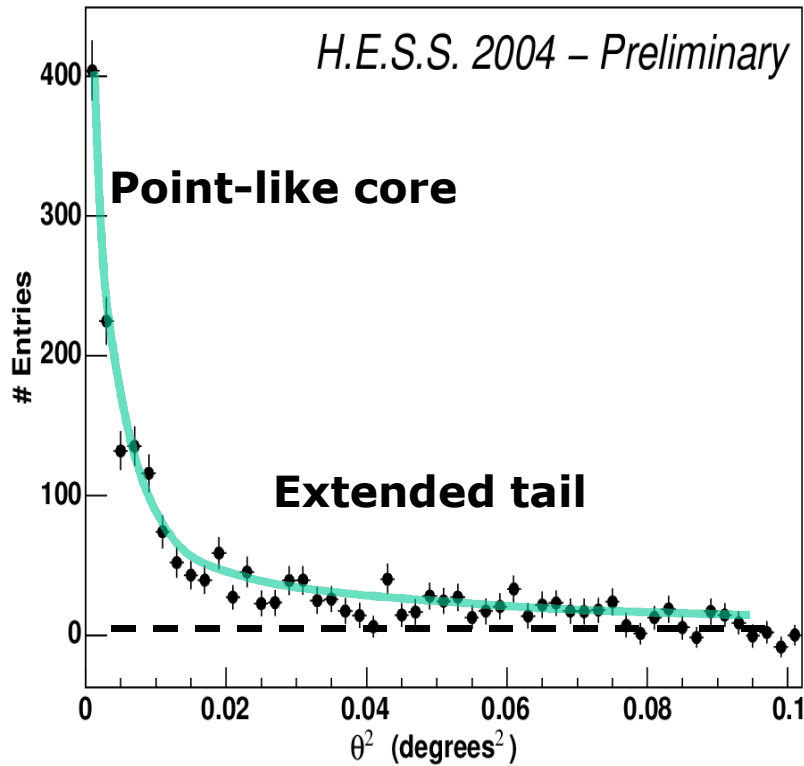


Contours from Hooper et al. 2004

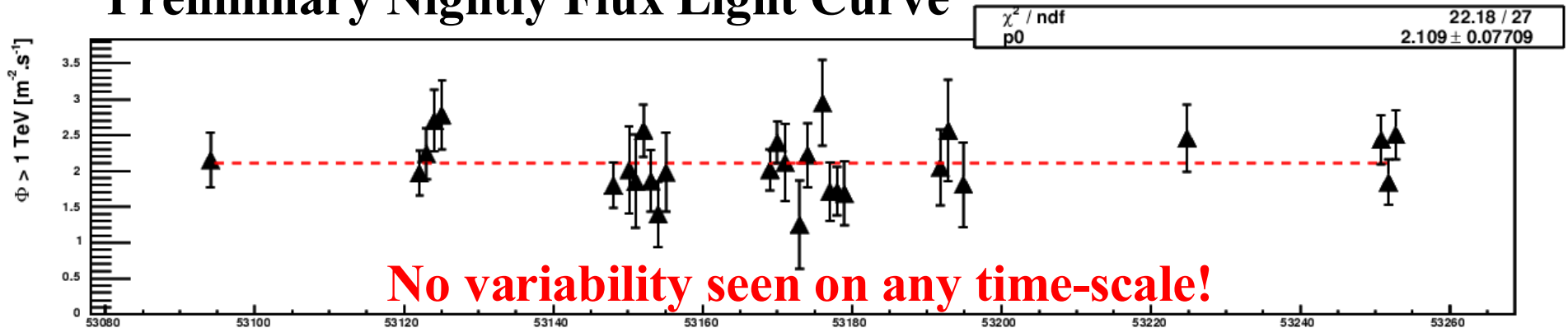




# HESS J1745-290 Update

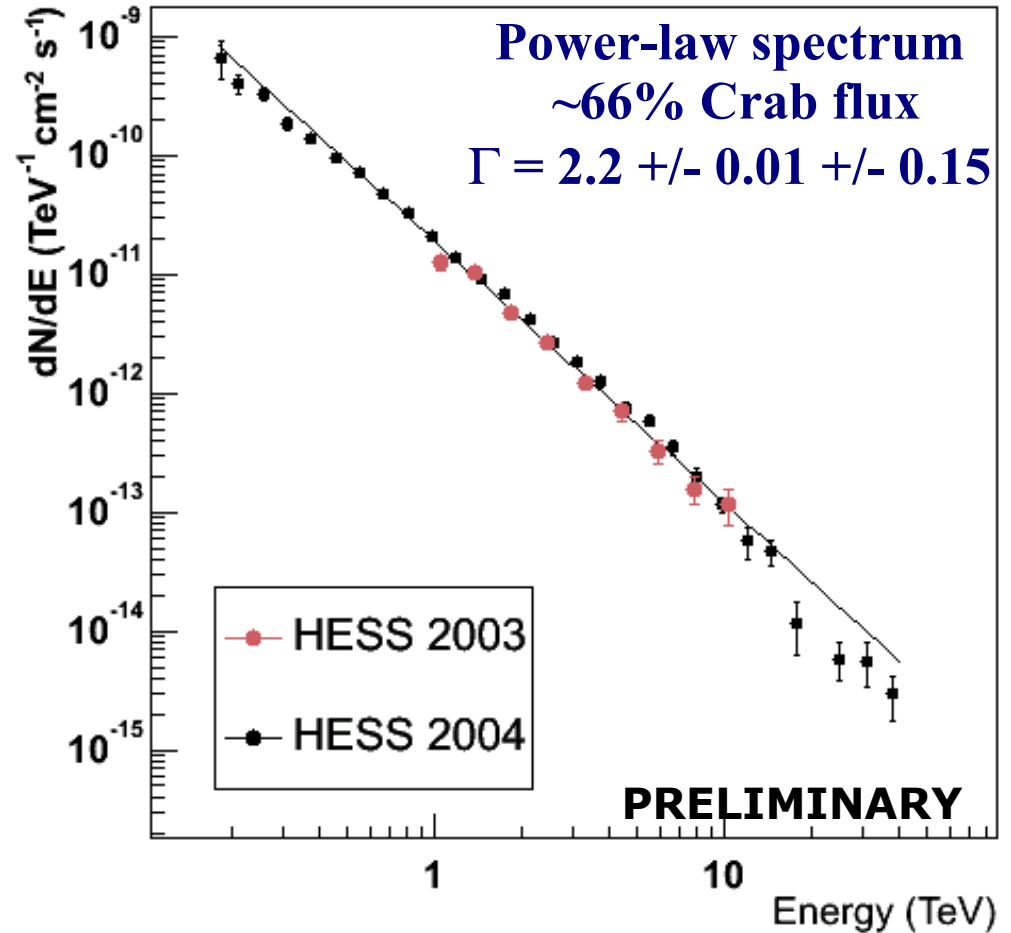
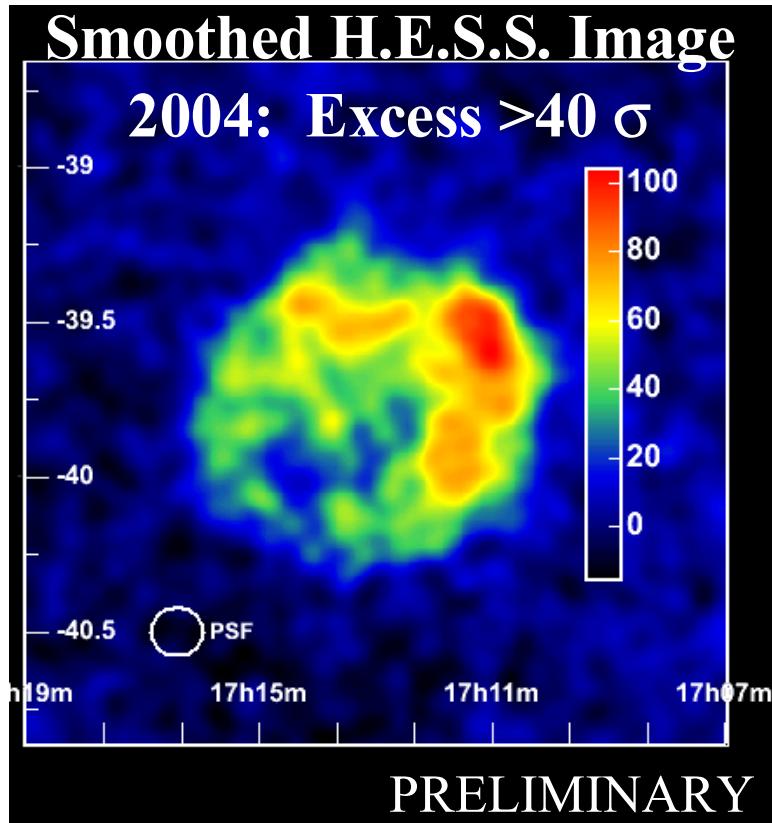


## Preliminary Nightly Flux Light Curve





# Observations of RXJ 1713.4-3946



Nature, 432, 75 (2004)

- 18 hr in 2003 with 2-tels ( $20 \sigma$ )
- Extension:  $\sim 1$  degree
- Confirms Cangaroo detection

**Excess  $>6$  sigma at  $E > 10$  TeV**

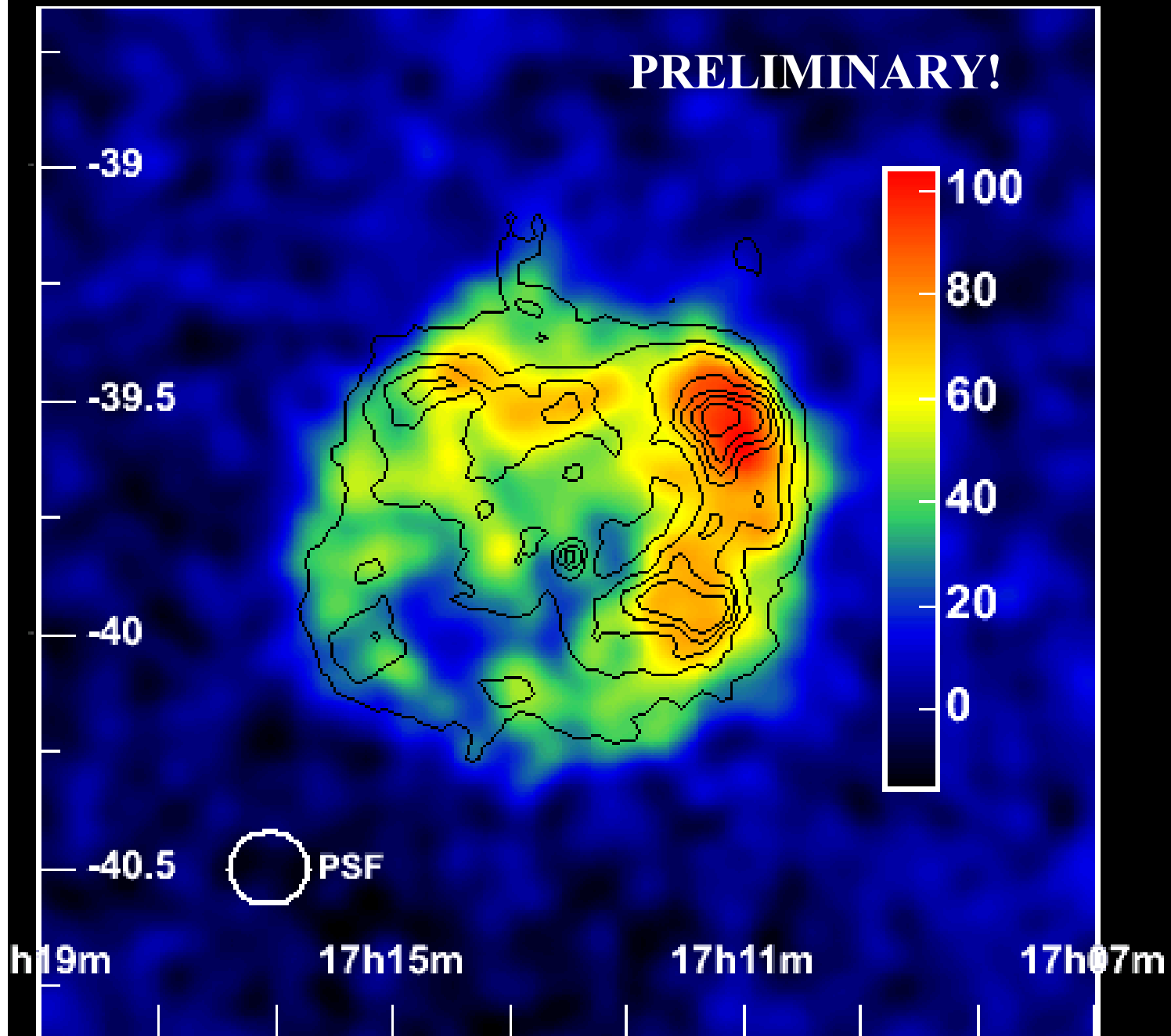
**2003: First-ever resolved image at VHE energies!**



# Correlation of X-rays & VHE $\gamma$ -rays

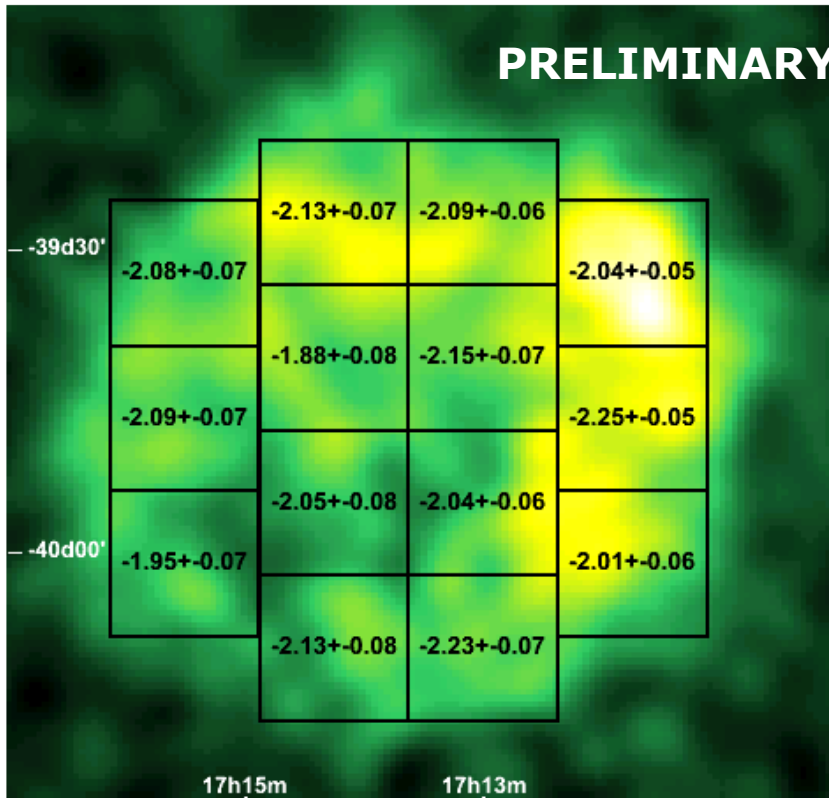
**Correlation  
coefficient = 0.7**

X-rays from ASCA

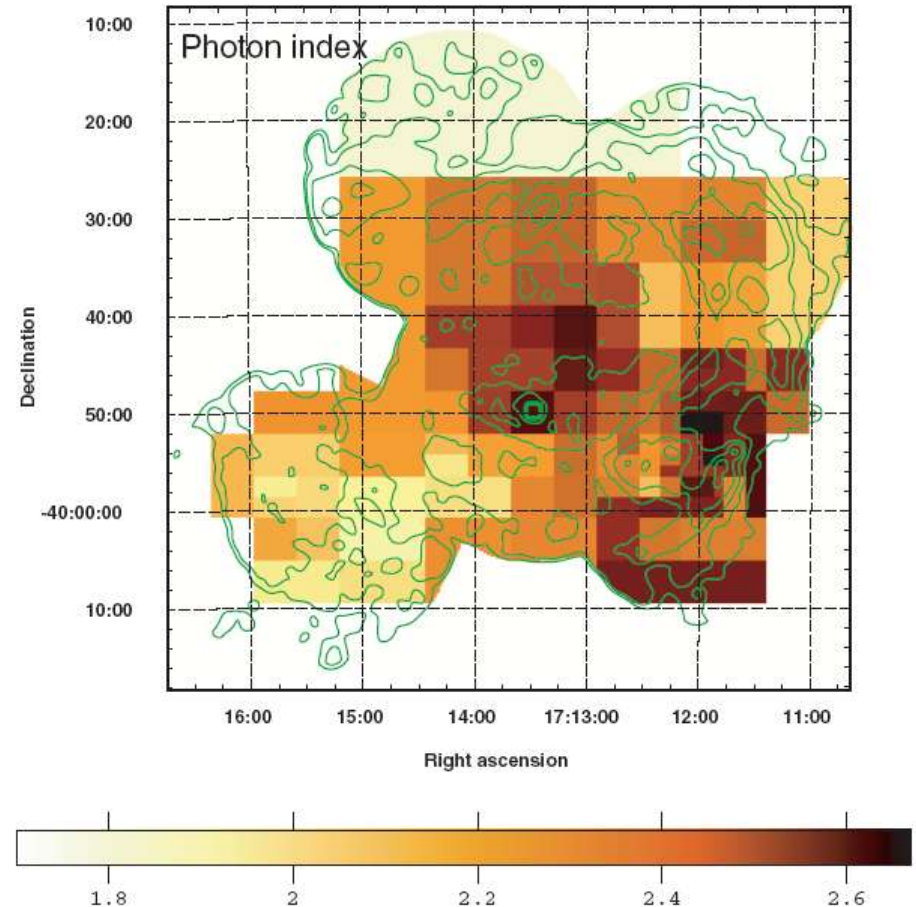




# RXJ 1713: Spectral Morphology



VHE photon index

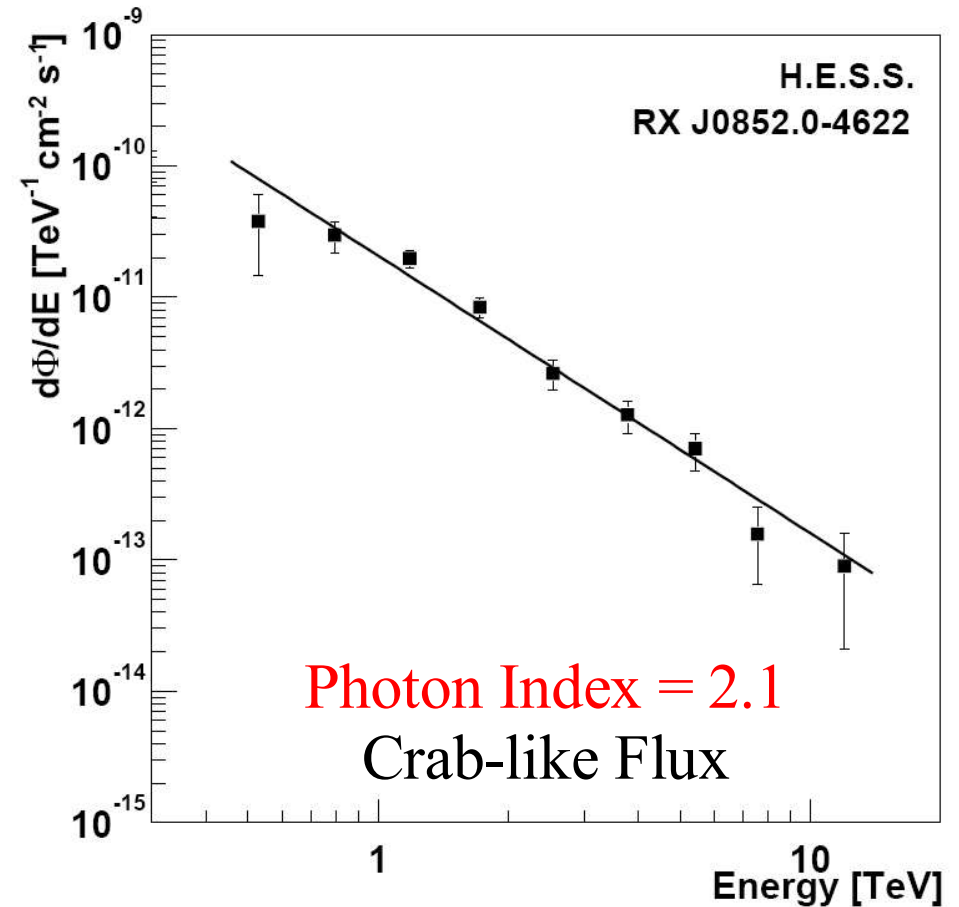
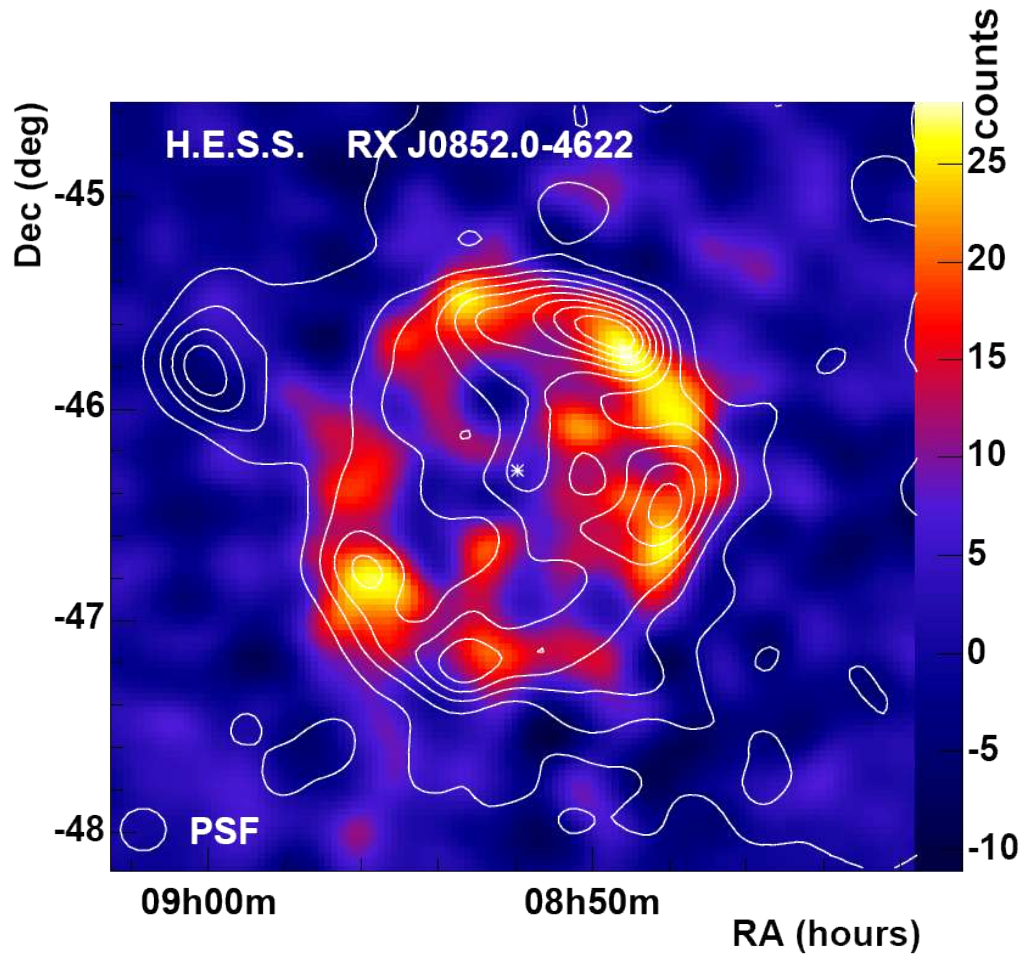


X-ray photon index (XMM)  
G. Cassam-Chenaï A&A 427, 199 (2004)

**Unlike X-rays, the VHE photon index doesn't change across remnant**



# RX J0852.0-4622 ("Vela Jr")

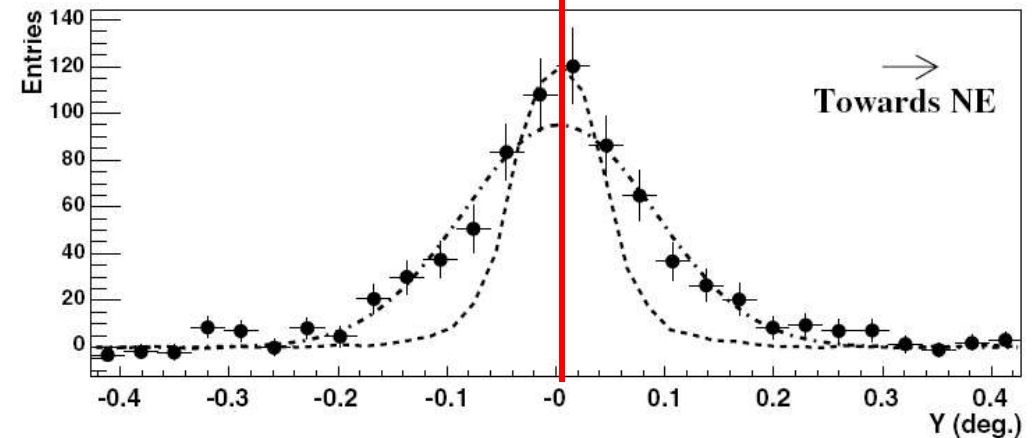
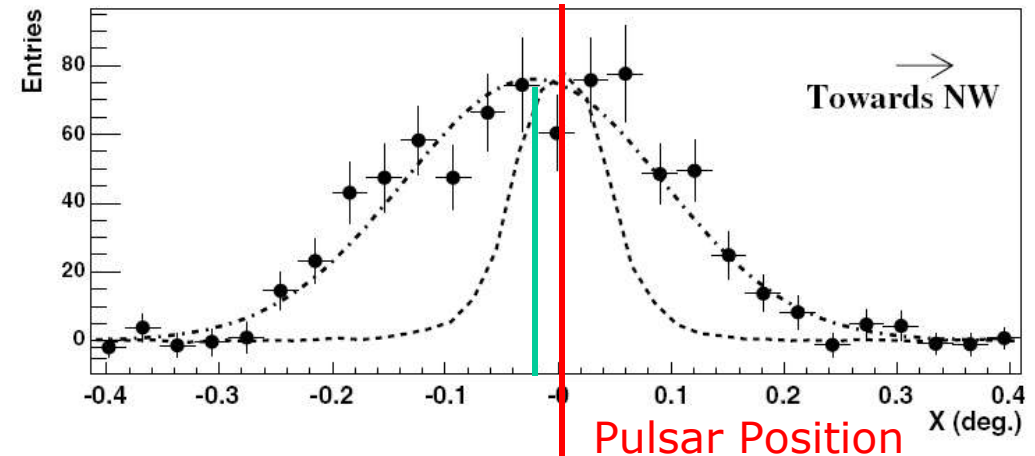
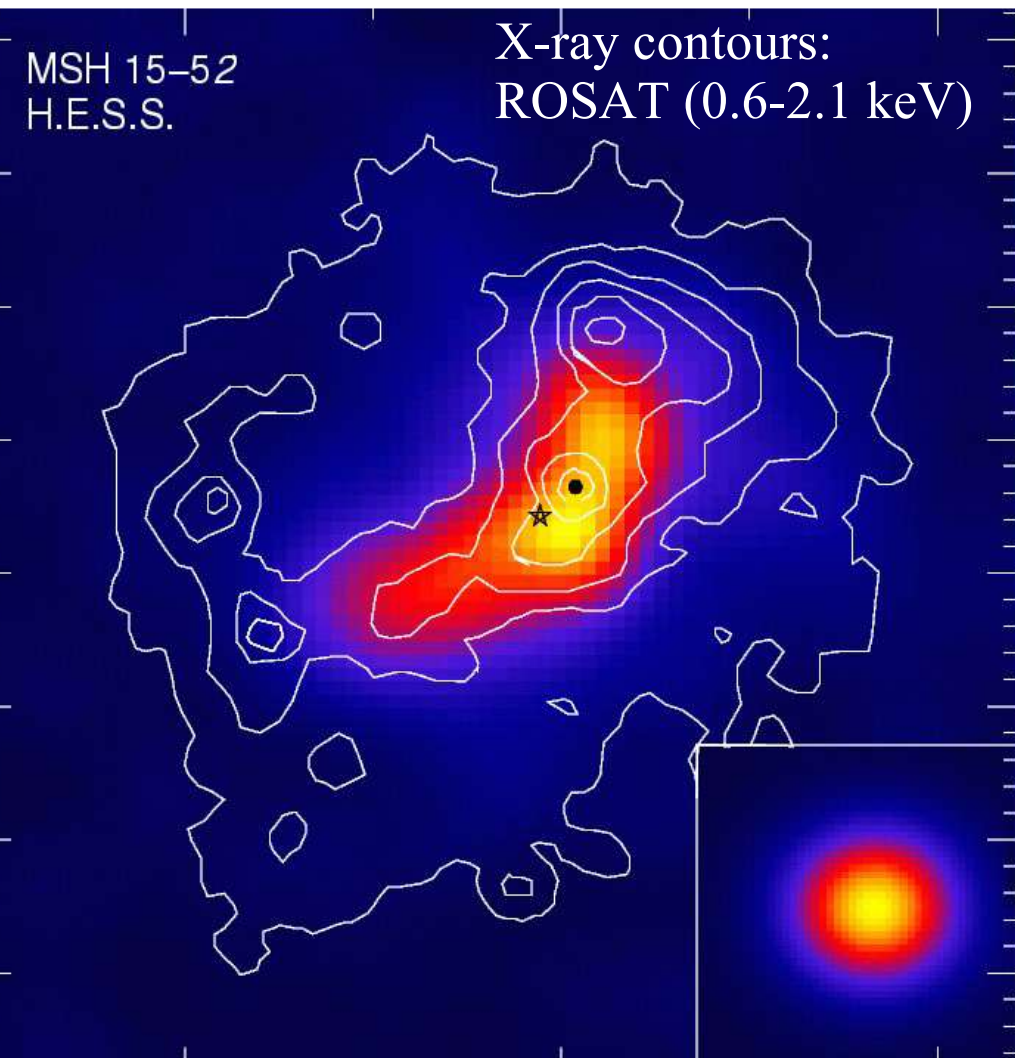


Observations: 3.2 hrs; **Excess: 700  $\gamma$ -rays ( $12 \sigma$ )**; Diameter:  $\sim 2^\circ$

Much more data in 2005!

Aharonian et al, 2005, A&A, 437, L7

# MSH 15-52: A pulsar wind nebula



**A  $25\sigma$  excess, Constant Flux ( $\sim 15\%$  Crab)  
COG shifted with respect to pulsar!**

**First VHE image of an extended (assymmetric) PWN!**

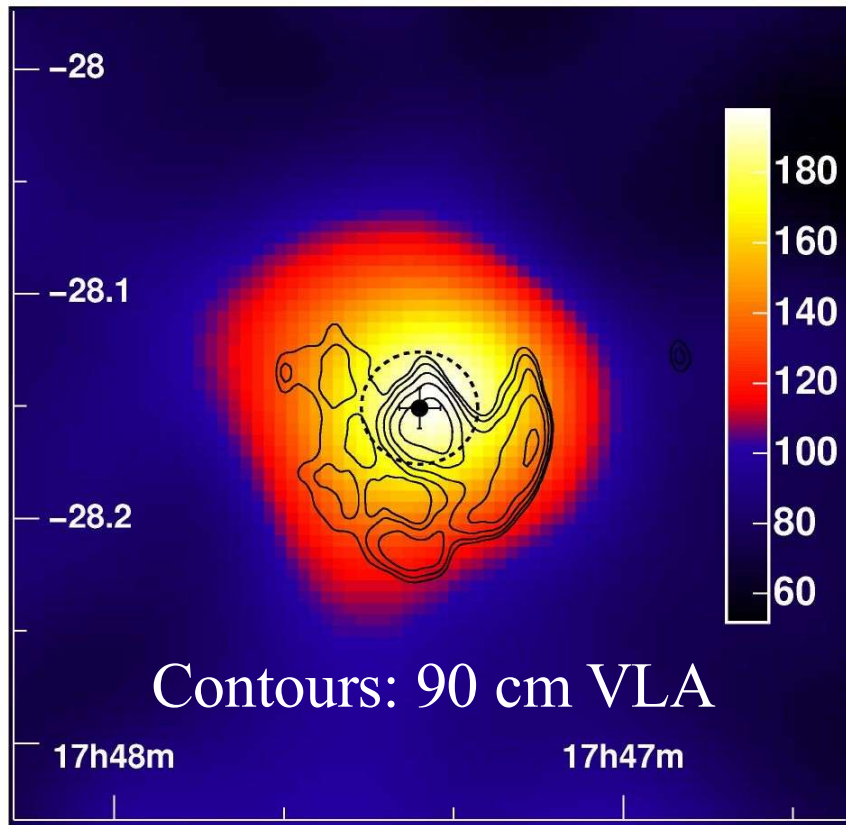
**Spectrum covers 2 orders of magnitude ( $\Gamma=2.3$ ); IC emission plausible**

**Aharonian et al., 2005, A&A, 435, L17**

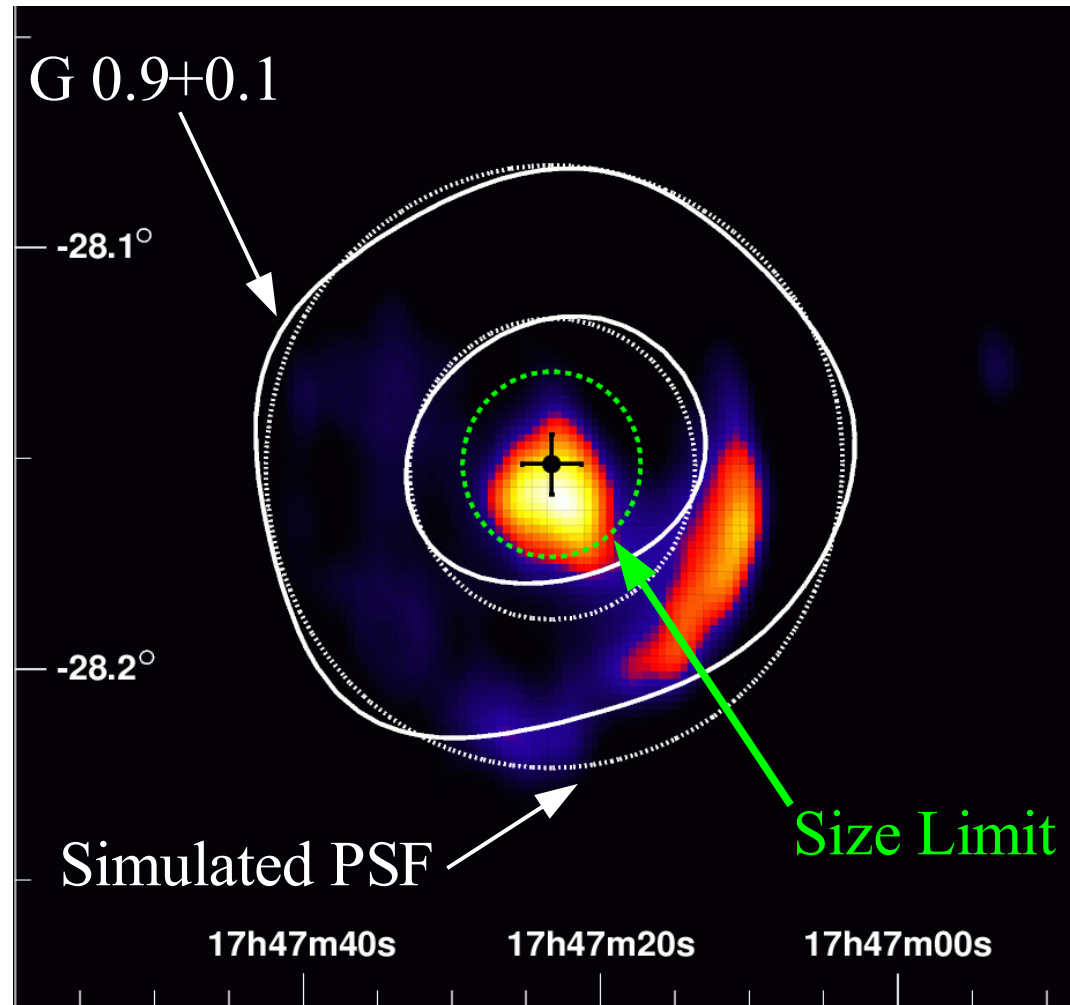


# G 0.9+0.1: The Pulsar Wind Nebula

## H.E.S.S. Smoothed Excess Map



**Excess:  $13\sigma$  in 2004;  $4\sigma$  in 2003**



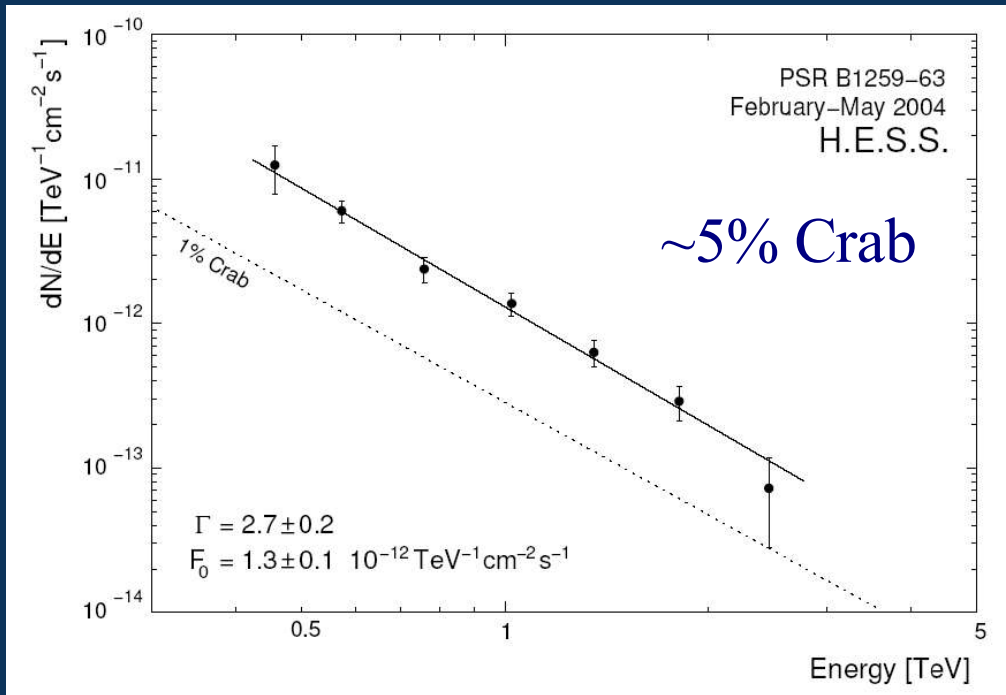
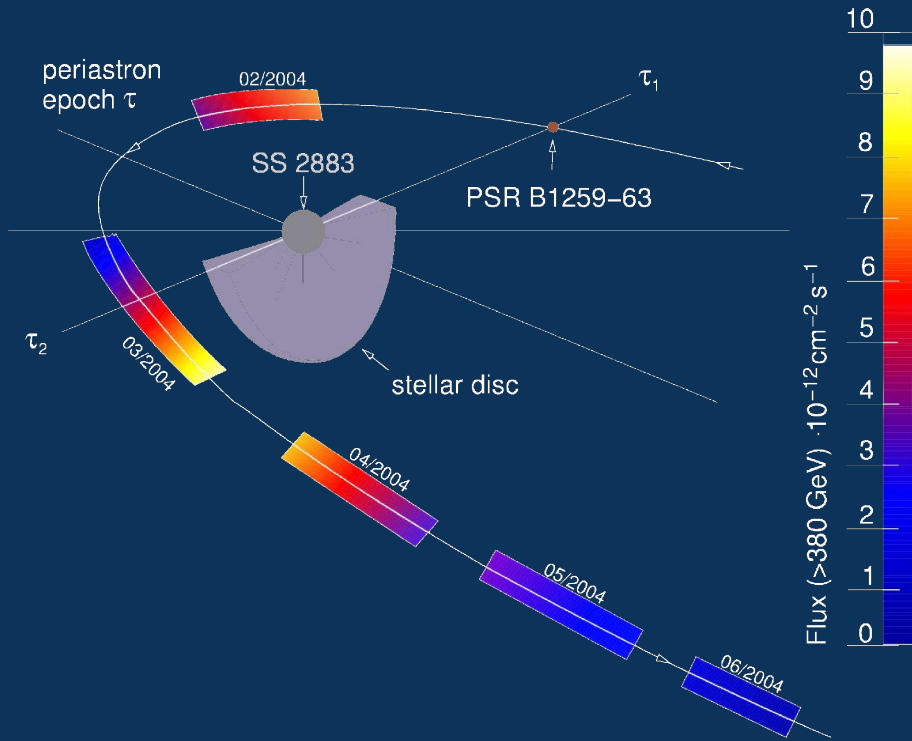
**Point-like excess: From core, not SNR shell; 2% Crab Flux;  $\Gamma=2.4$**

X-rays: Core bright & shell weak; A population of synchrotron  $e^-$  in Nebula

**Origin of  $\gamma$ -rays from Inverse Compton scattering on seed photons likely!**

Aharonian et al, 2005, 432, L25

# Observations of PSR B1259-63

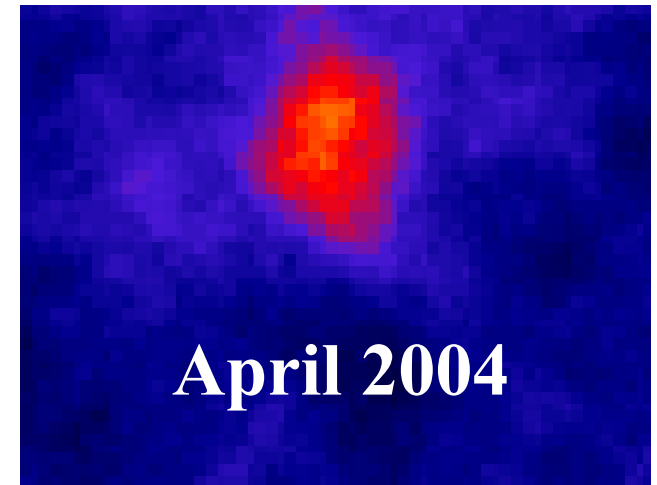
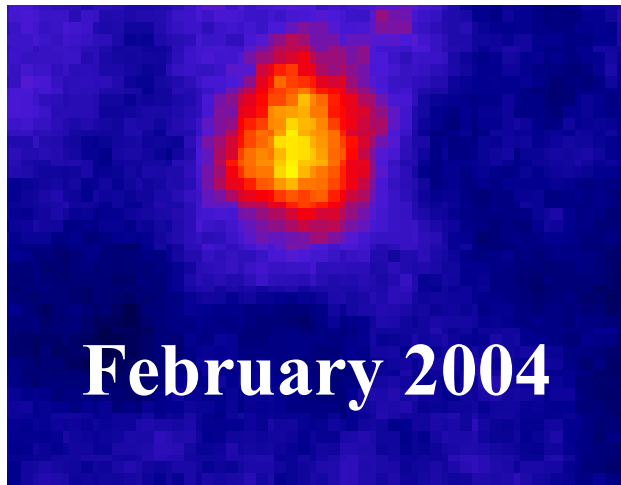
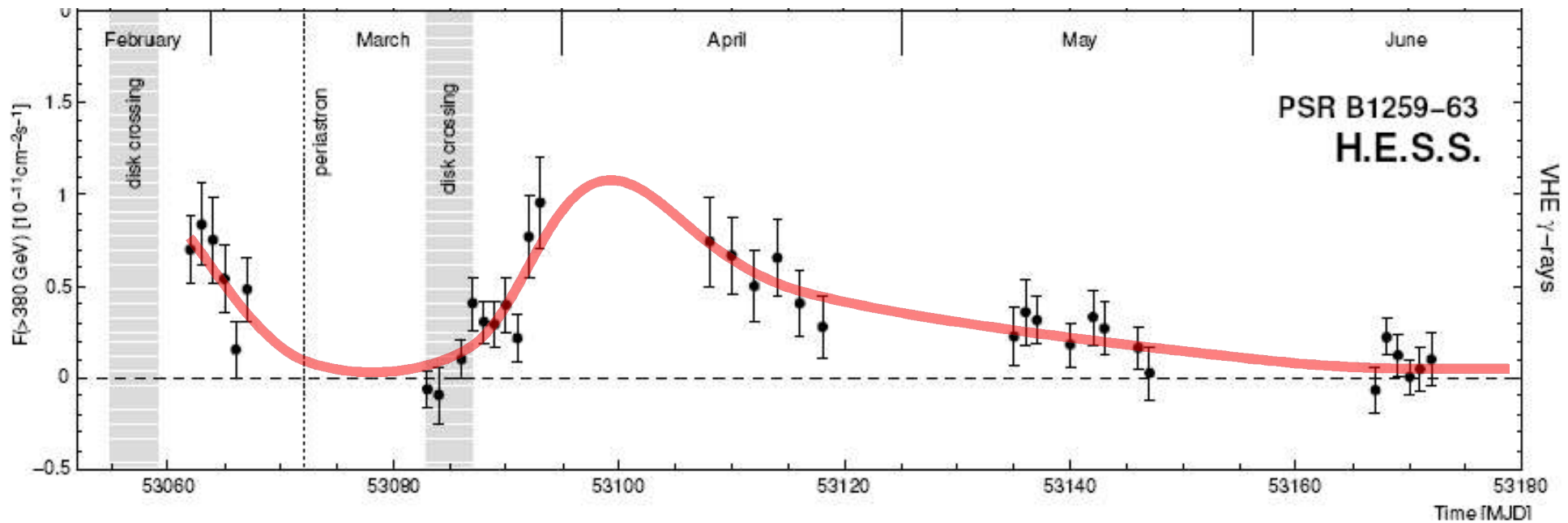


H.E.S.S. 2004 Data:  $\sim 50$  hrs ( $43^\circ$ )  
Point-like excess:  $\sim 1000$   $\gamma$ -rays,  $13.8 \sigma$   
Aharonian et al., A&A, in press (2005); astro-ph/0506280



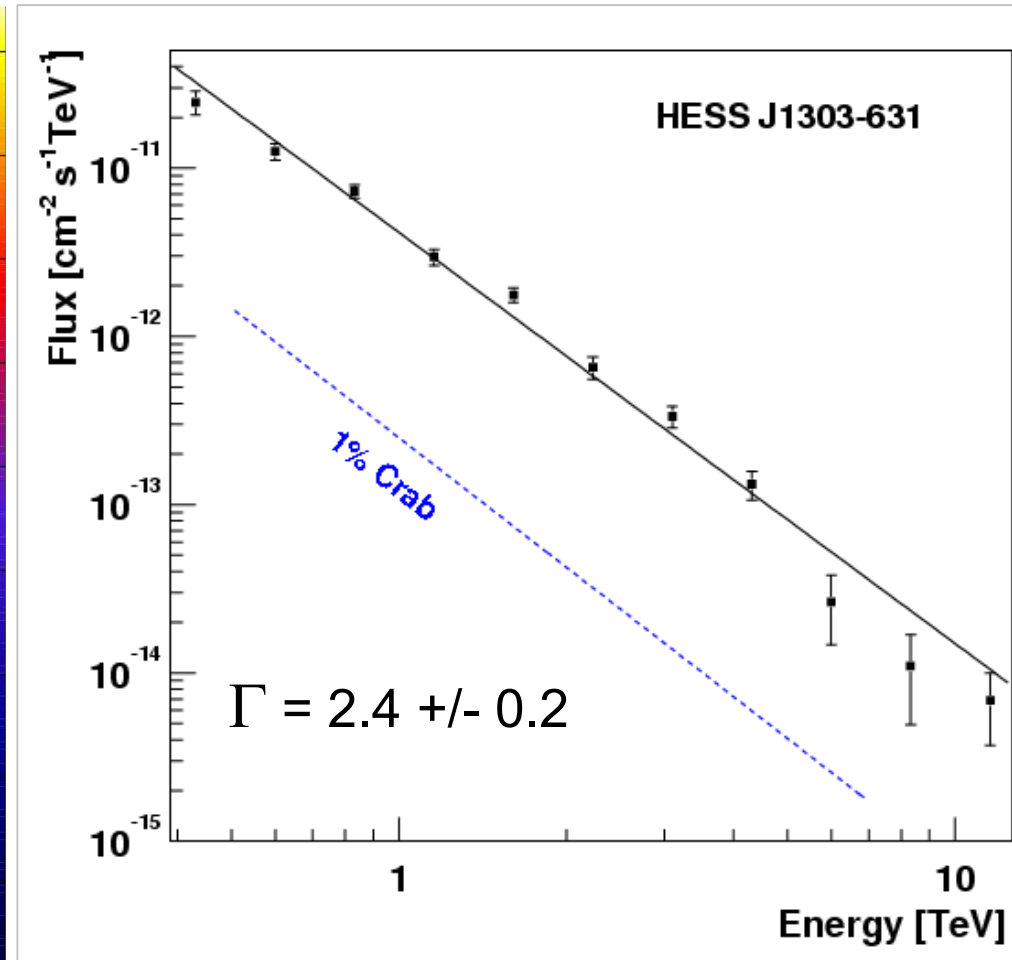
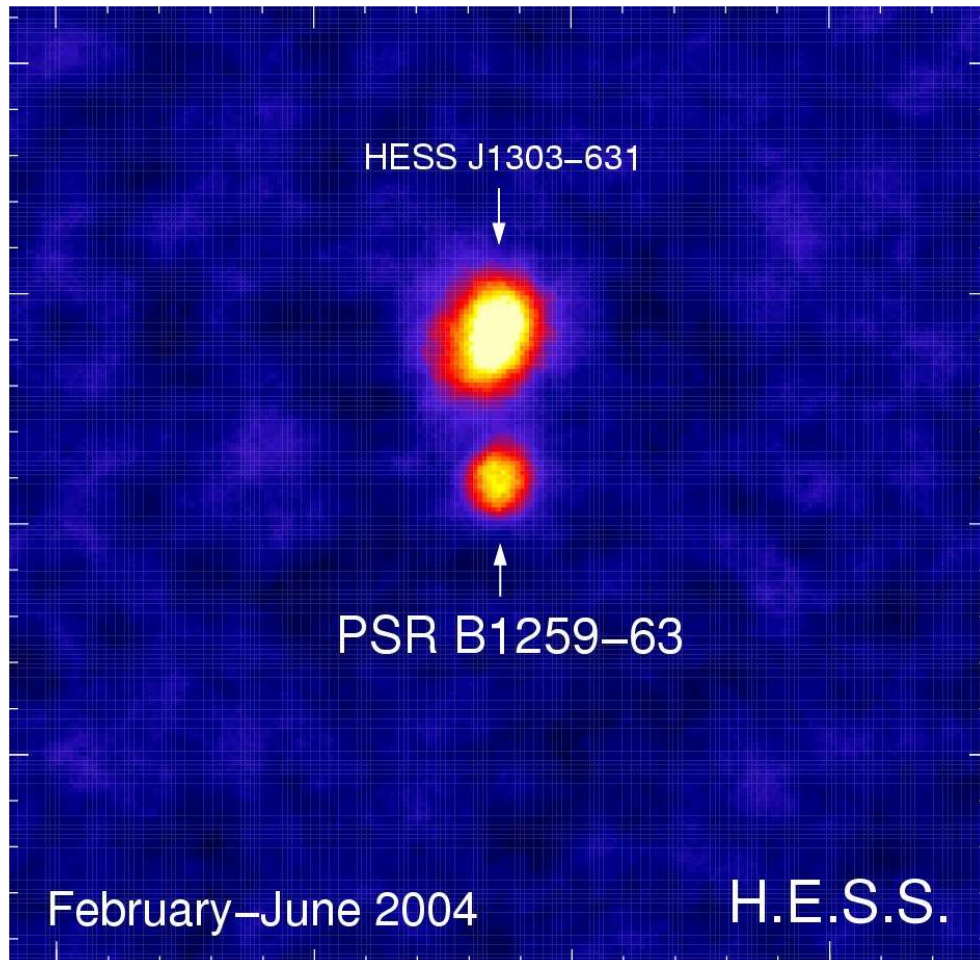


# VHE Variability of PSR B1259-63



First variable galactic source at VHE energies!  
Observed spectrum does not vary vs time!

# A Serendipitous Discovery



21  $\sigma$  Excess, Extended ( $0.16^\circ \pm 0.02^\circ$ )

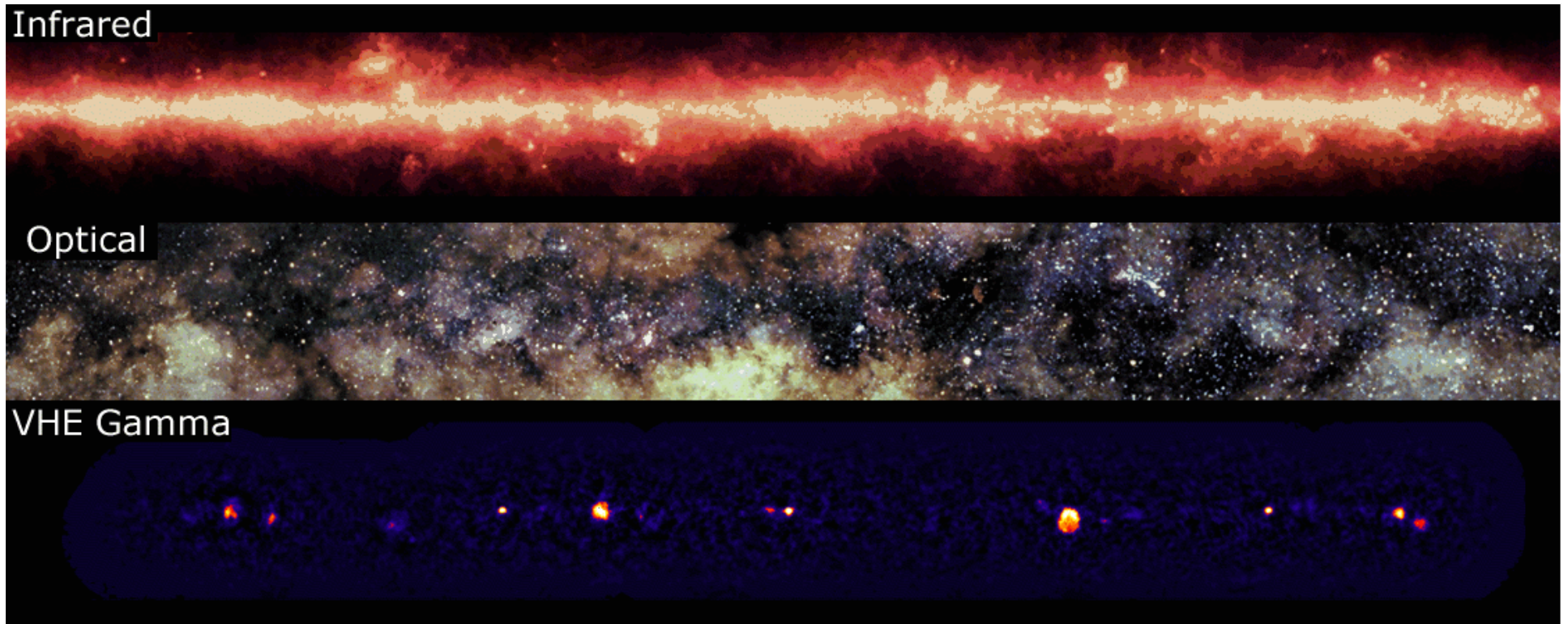
Constant emission at level of  $\sim 17\%$  Crab flux

No known counterparts in X-ray or radio!

Aharonian et al., A&A, in press (2005); astro-ph/0505219



# H.E.S.S. Galactic Plane Scan

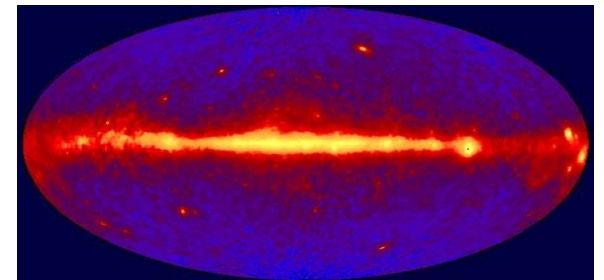


Region:  $-30^\circ < l < 30^\circ$ ;  $-3^\circ < b < 3^\circ$

Data: 230 hrs in 2004;

Flux Sensitivity:  $\sim 3\%$  Crab

Dominated by sources, unlike EGRET



# H.E.S.S. Galactic Plane Scan

Science, 307, 1938 (2005)

## Post-trials sources (original):

- 8 sources with  $>6$  sigma
- Possible associations:
  - 4 SNR (1 EGRET)
  - 3 PWN (1 EGRET)
  - 1 None

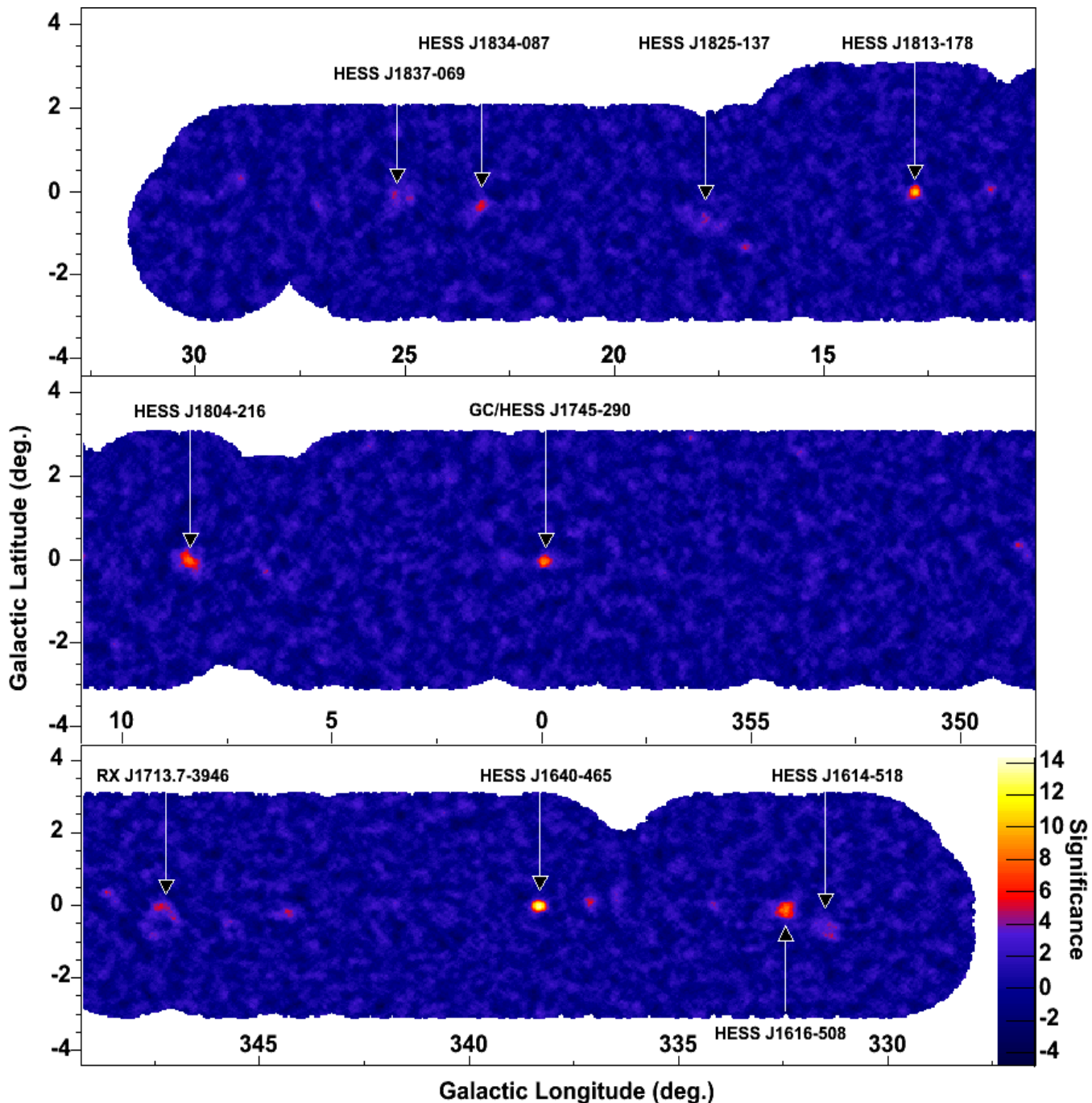
## All extended beyond P.S.F.

- Diameter:  $2'$  to  $12'$

## Spectra:

- 3 to 18% Crab flux
- Hard photon indices

All  $\sim$ centered on the plane





# Detection of an X-ray Binary

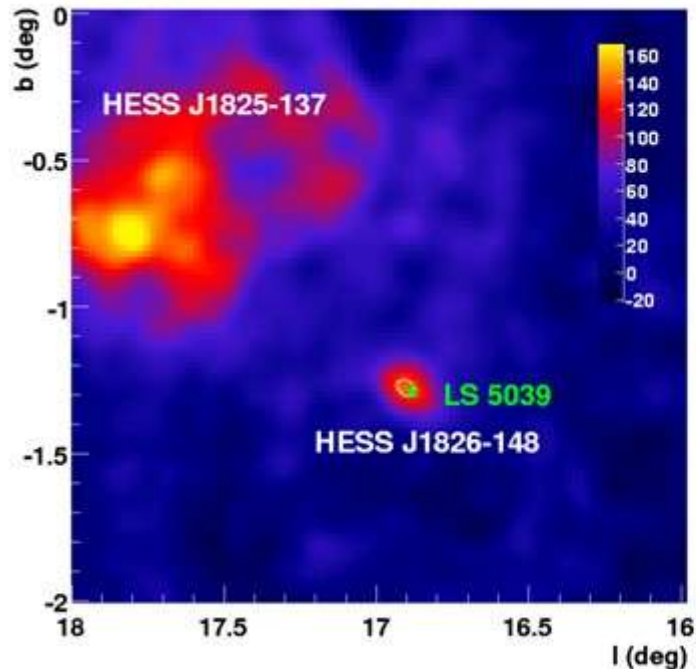


Image: ESA & Hubble European Space Agency Information Centre

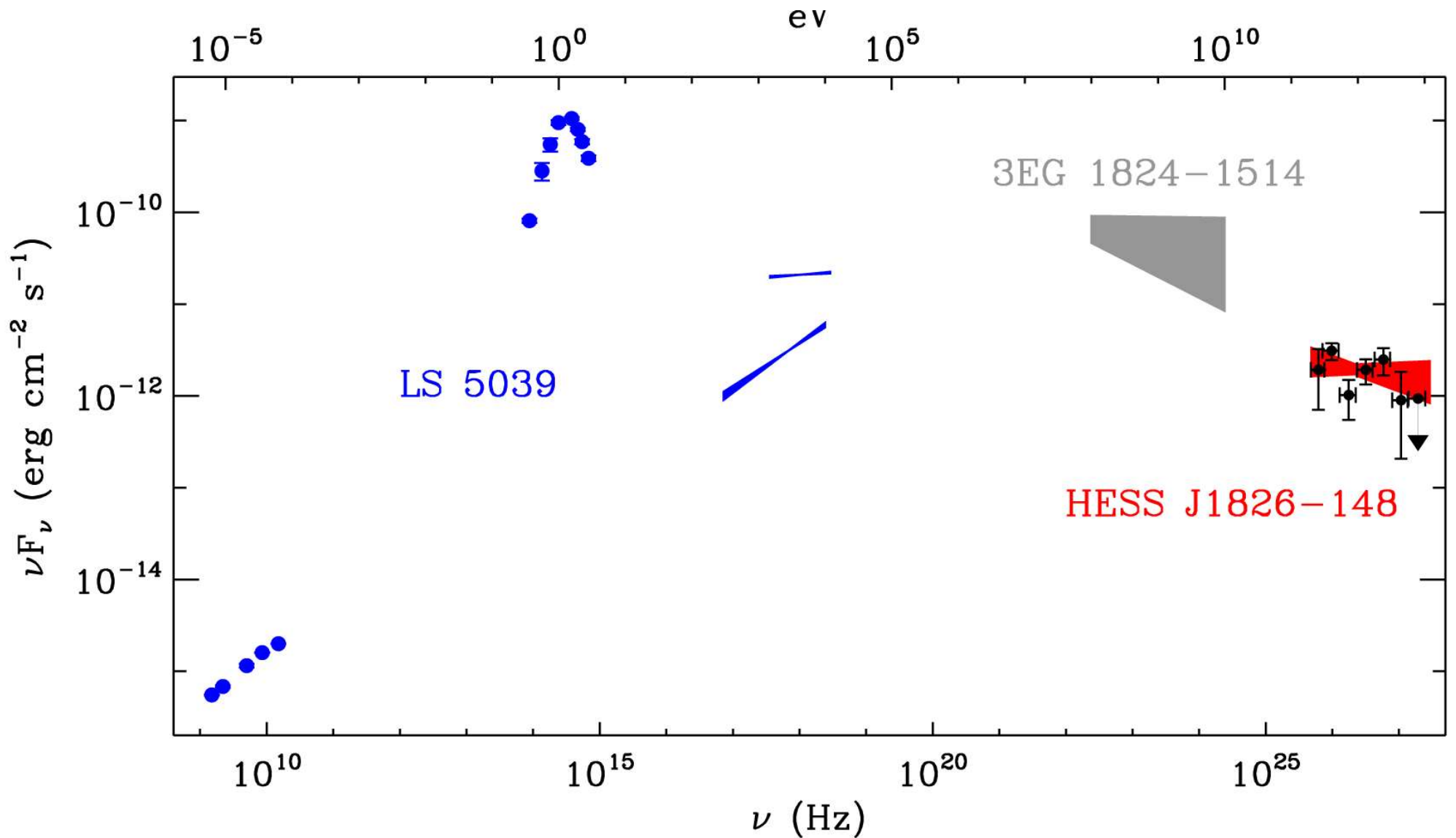
**10.5 hours during the H.E.S.S. Galactic Plane scan in 2004**

**Excess:  $7 \sigma$ , point-like (size limit  $< 50''$ )**

**Appeared On-line July 7, 2005 in Science**

**Science Express: DOI: 10.1126/science.1113764**

# LS 5039 SED

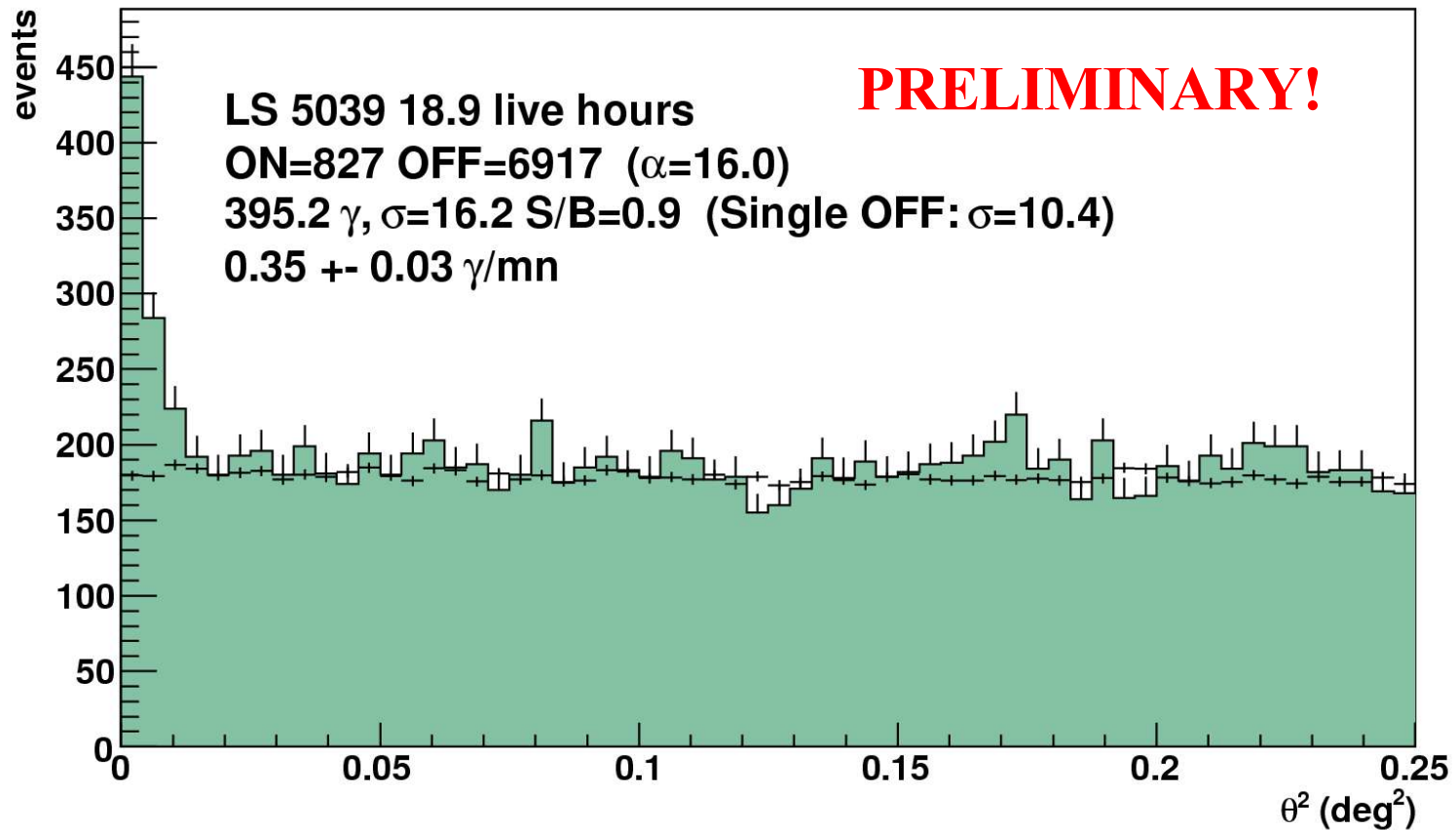


**Photon index:  $2.15 \pm 0.15 \pm 0.1$ ; Flux  $\sim 3\%$  Crab**  
**Flux is constant versus time (within statistics)**



# LS 5039 Update

LS 5039 / 2004-2005



**There is even more data (>50 hrs, but still in Africa)!**

# Important H.E.S.S. Upper Limits

Object	Type	Detection	H.E.S.S. Limit
SN 1006	SNR	CANGAROO, HEGRA-CT1	<b>A&amp;A, 437, 135, 2005</b>
PSR B1706-44	Pulsar	CANGAROO, Mark 6	<b>A&amp;A, 432, L9, 2005</b>
NGC 253	Starburst Galaxy	CANGAROO	<b>A&amp;A, submitted</b>

**The H.E.S.S. upper limits are more than an order of magnitude below the claimed fluxes!**





# H.E.S.S. Detection of PKS 2155-304

VHE (>160 GeV) emission is clearly detected (>4500  $\gamma$ -rays;  $\sim 45 \sigma$ )

- 63 hrs (live time) of observations
  - During detector construction
- Confirms previous detection
- 2<sup>nd</sup> furthest VHE AGN ( $z=0.116$ )

VHE flux is clearly variable

- Monthly time-scales
- Nights within months
- Runs (30 min) within nights
- Possibly even sub-hourly

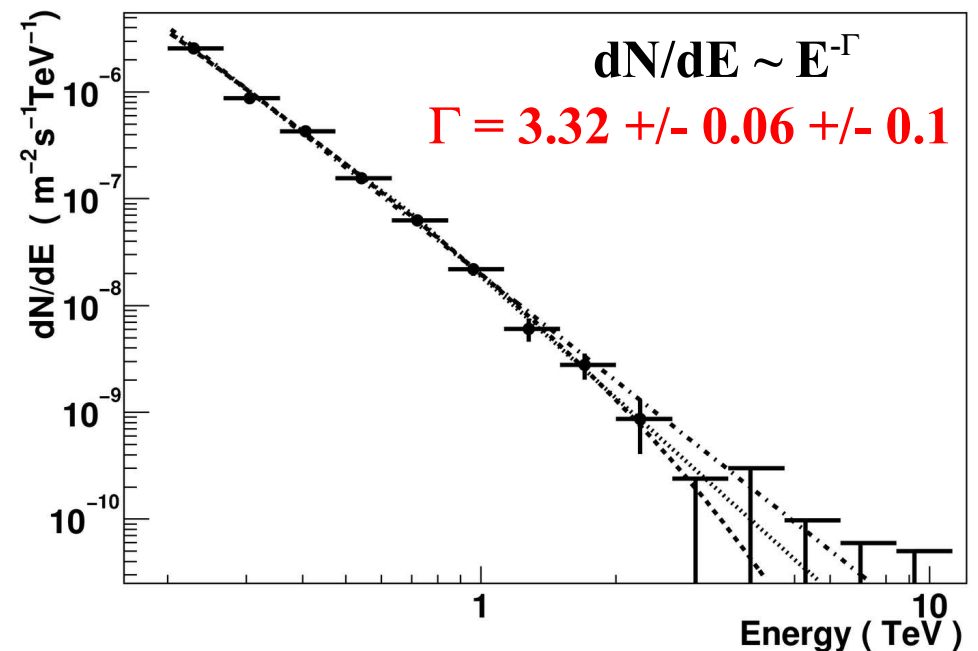
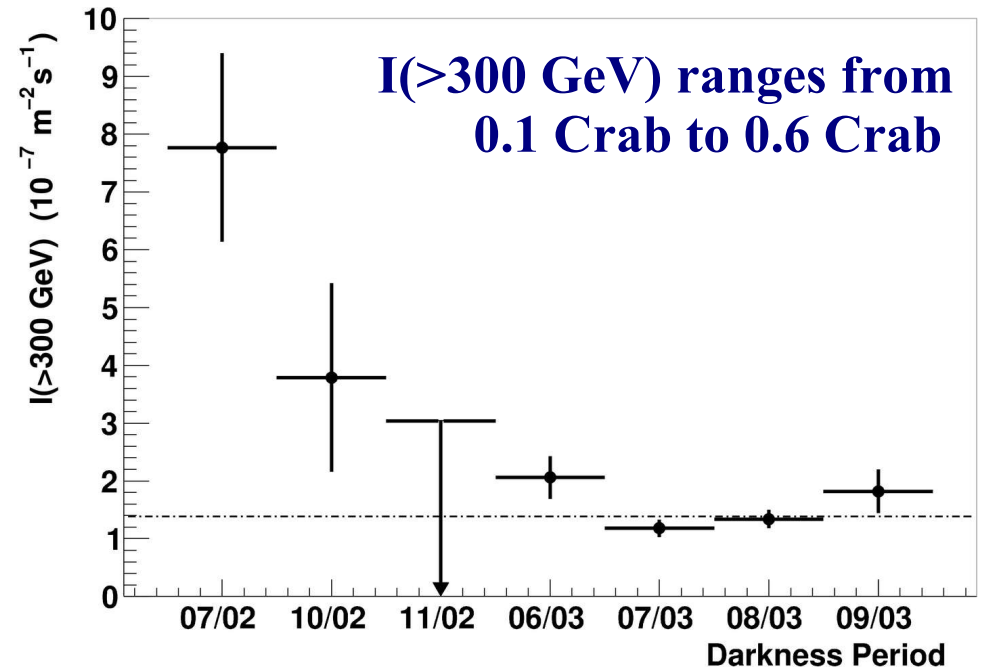
No spectral variability

- No hardening with increased flux

Curved spectra  $\Rightarrow$  improved  $\chi^2$

- Improvement is marginal ( $\sim 2 \sigma$ )

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



# PKS 2155-304: A MWL Campaign

## Simultaneous observations in October & November 2003

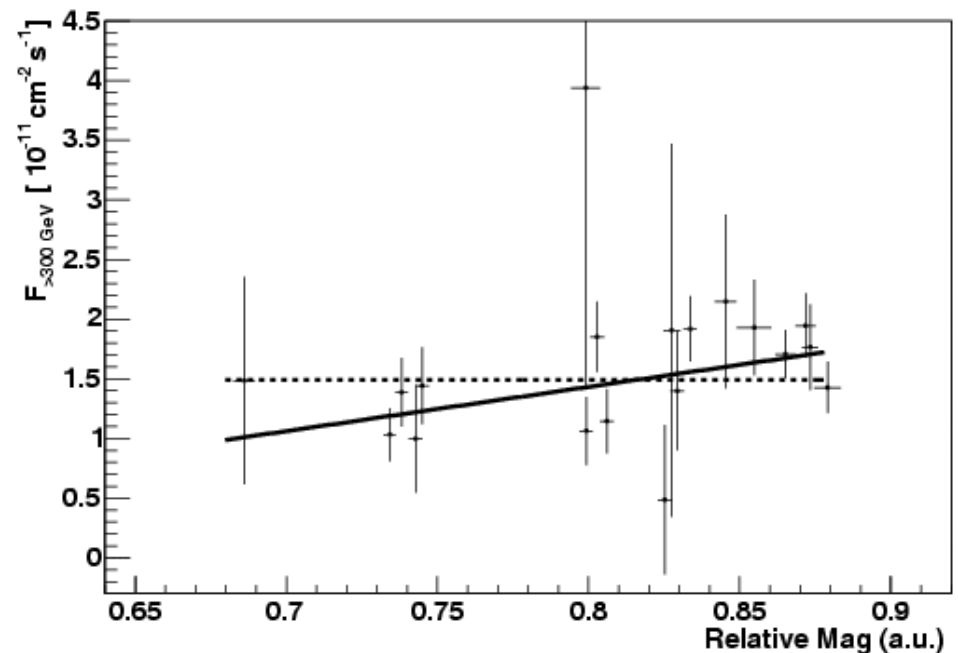
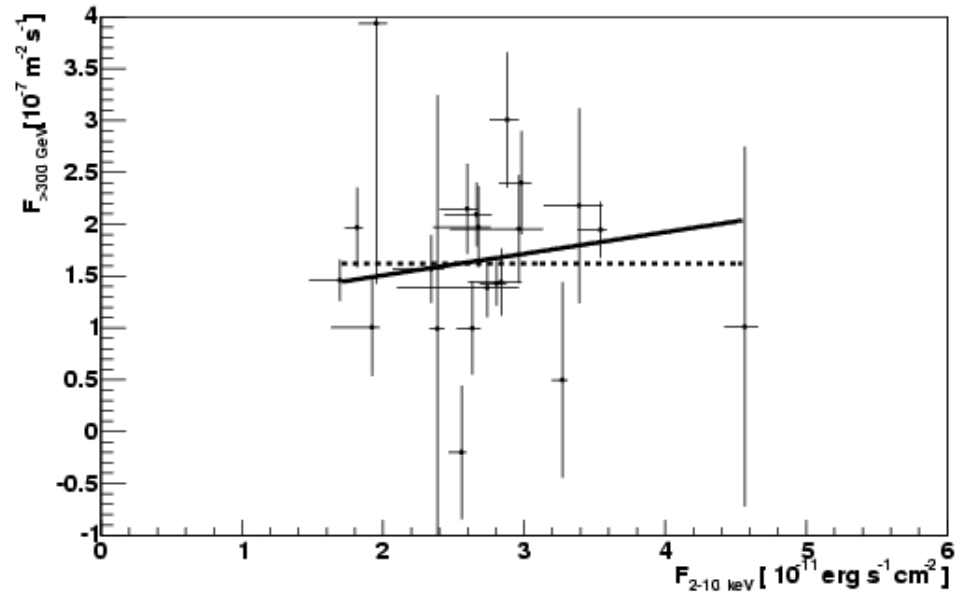
- VHE: H.E.S.S. (2-tels.)
- X-ray: RXTE
- Optical: ROTSE
- Radio: NRT

## Clear detection by H.E.S.S.

- ~1800  $\gamma$ -rays,  $\sim 34 \sigma$  in 32.4 hrs
  - VHE flux & spectrum ~same as in detection paper
  - Detected every night
  - [A&A, in press, astro-ph/0506593](#)
- **Clear flux variability**
    - VHE, X-ray, optical

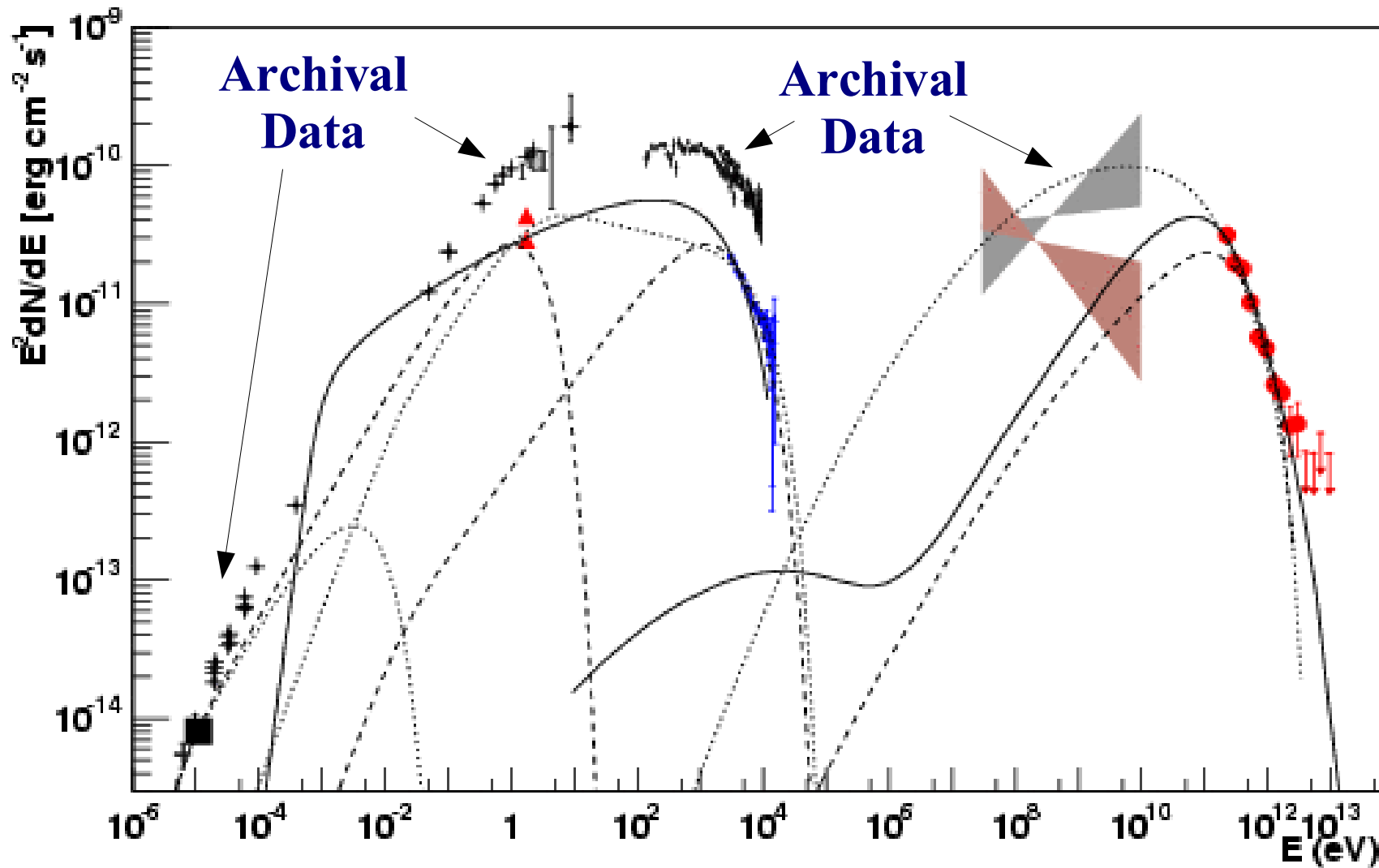
## No evidence for correlated flux variability

Smaller data set ( $\sim 11$  hrs)





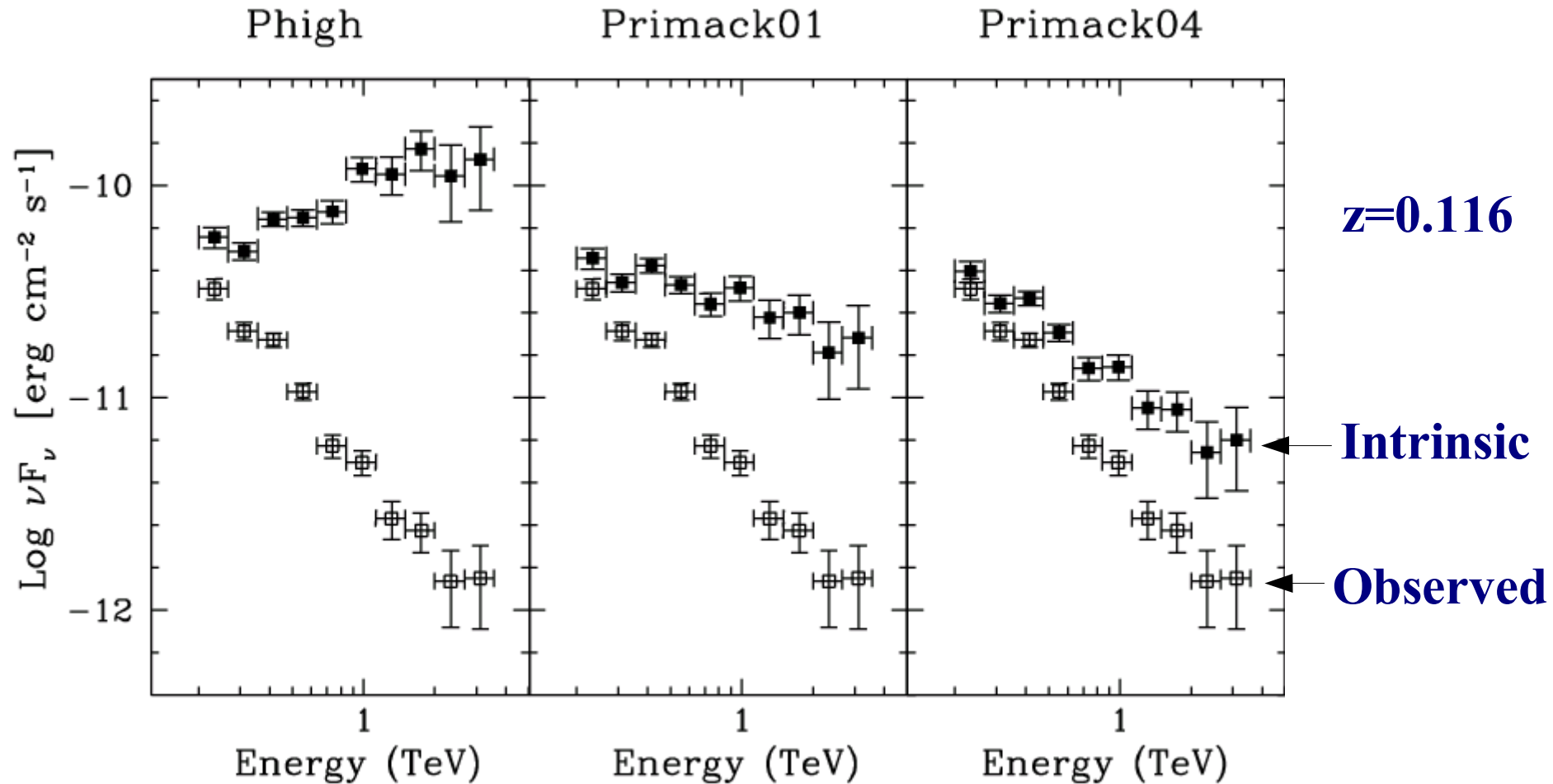
# SED Modelling



**Leptonic (dashed & dotted lines) & Hadronic (solid line) models**

**PKS 2155-304 in a "low" state**

# EBL Modelling with PKS 2155-304

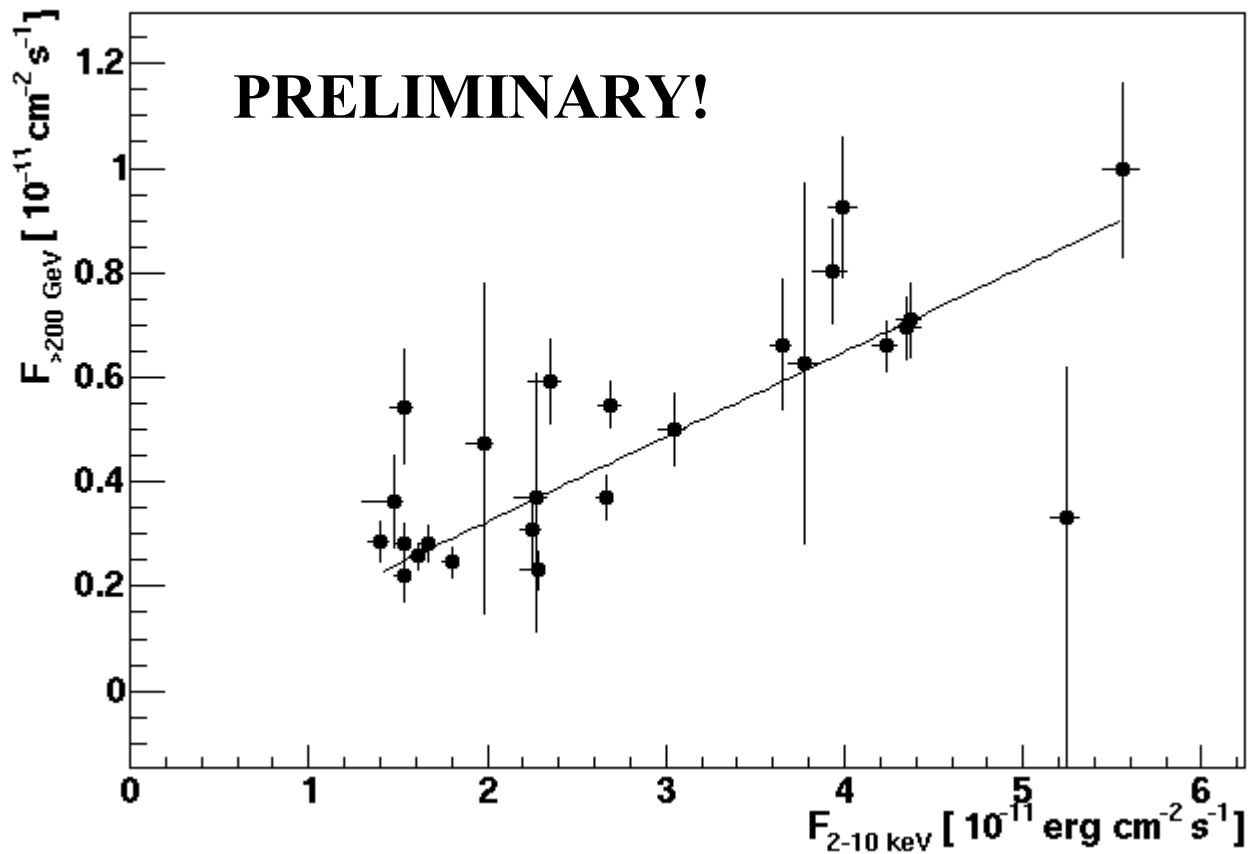


**3 different EBL models show different intrinsic spectrum**

Need sample of AGN at different redshifts to determine which is "correct"



# A New MWL Campaign on PKS 2155-304



**Extensive campaign in Aug/Sept 2004**

**~100  $\sigma$  detection in >50 hrs**

**Clear correlation (factor = 0.74) between X-ray & VHE!**

# H.E.S.S. Observations of Mkn 421

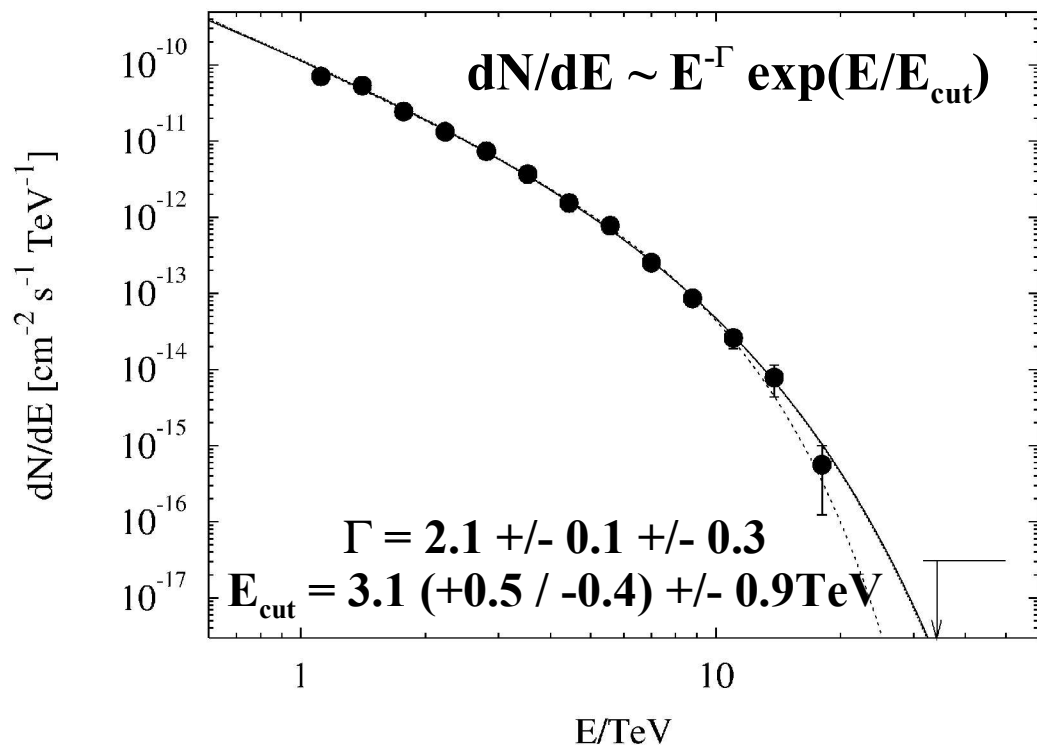
9 nights in April & May 2004; Zenith angle range 60-65°;  $E_{th} \sim 1.5$  TeV

7000 photons in  $\sim 15$  hrs; 8  $\gamma$ /min;  $>100 \sigma$

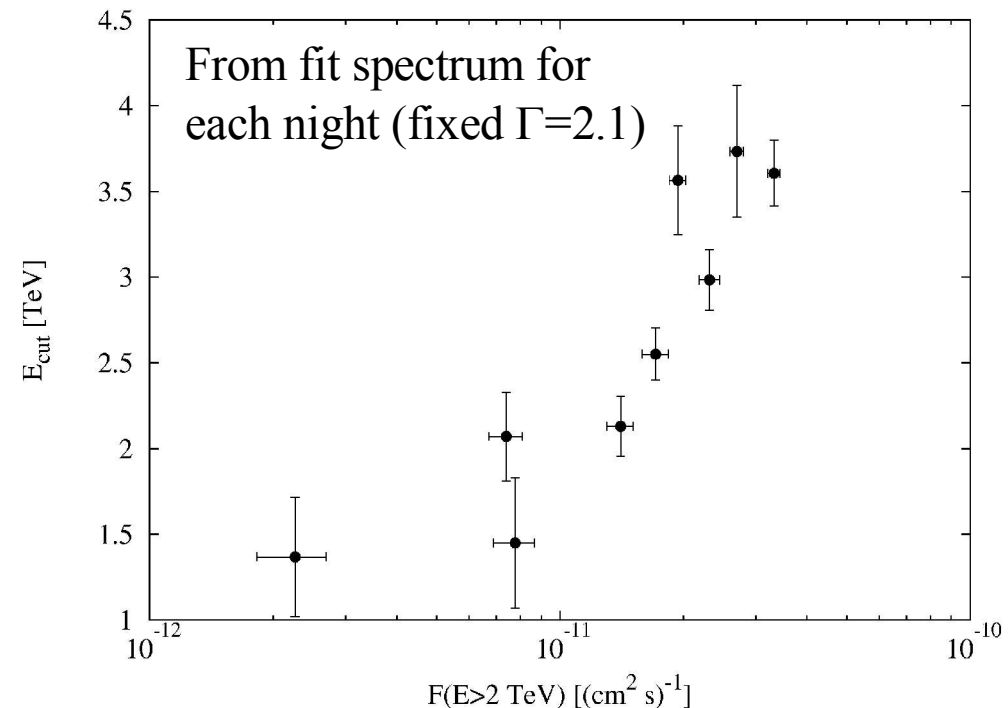
**Flux ( $>2$  TeV) varies by factor of 4.3; Average value  $\sim 3$  Crab**

**Doubling time-scale less than 1 hour**

**Spectrum clearly curved!**



**Clear evidence for spectral hardening with increased flux!**



**Aharonian et al., 2005, A&A, 437, 95**



# H.E.S.S. Detection of PKS 2005-489

## A bright, well-studied, "nearby" HBL

- $z = 0.071$
- Predicted VHE  $\gamma$ -ray source (many papers)

## No previous VHE detection

- Cangoon (1993-94, 1997, 1999, 2000)
- Durham Mark 6 Telescope (1996-2000)

## H.E.S.S. (6.3 $\sigma$ detection)

**2003:** 27.3 hrs live time; < 4 tels.

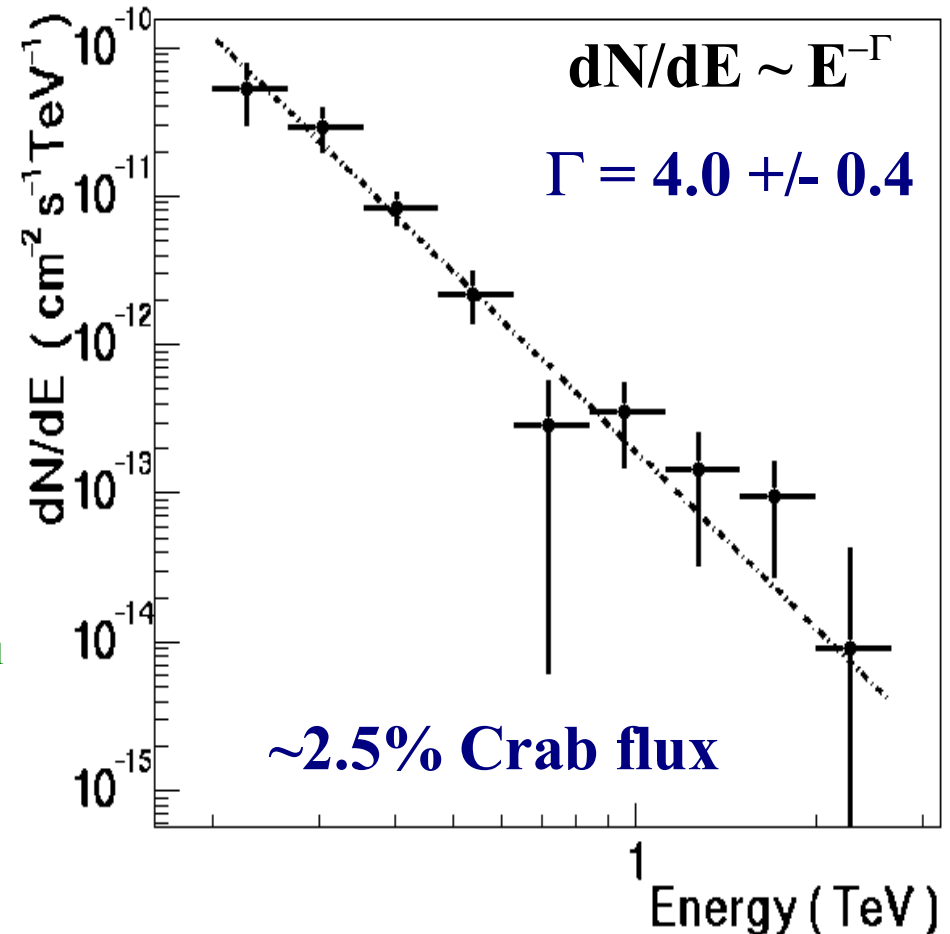
- No Significant excess, 1.4  $\sigma$
- **99% limit:  $I(>200 \text{ GeV}) < 5.2 \text{ e-12 cm}^{-2} \text{ s}^{-1}$**

**2004:** 24.3 hrs live time; Full array

- Excess: 288  $\gamma$ -rays, 6.7  $\sigma$
- **$I(>200 \text{ GeV}) = (6.9 \pm 1.0) \text{ e-12 cm}^{-2} \text{ s}^{-1}$**

## No evidence for flux variability

- Months within years
- Nights within months
- Runs (30 min) within nights



**Lowest flux & steepest spectrum ever detected from a VHE AGN!**

**We also have "simultaneous" MWL data**

**1<sup>st</sup> AGN "discovered" by H.E.S.S.**

**Only the 2<sup>nd</sup> known VHE AGN in the Southern Hemisphere**

**Aharonian et al, 2005, A&A 436, L17**

# M 87: A non-blazar VHE AGN

## Fanaroff-Riley Type-I Galaxy:

- A mis-aligned BL Lac?
- Jet angle:  $20^\circ$  to  $40^\circ$
- Distance:  $\sim 16$  Mpc

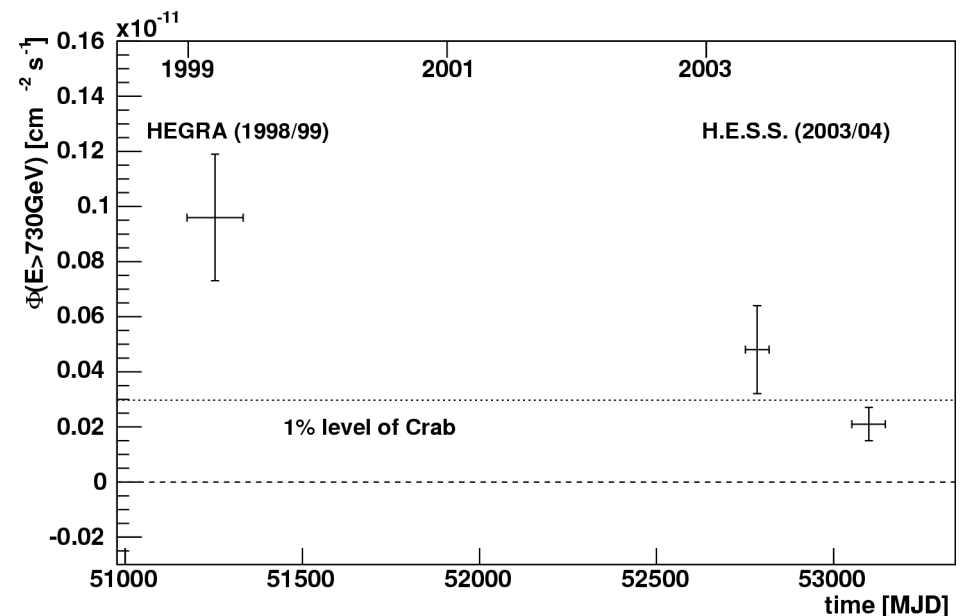
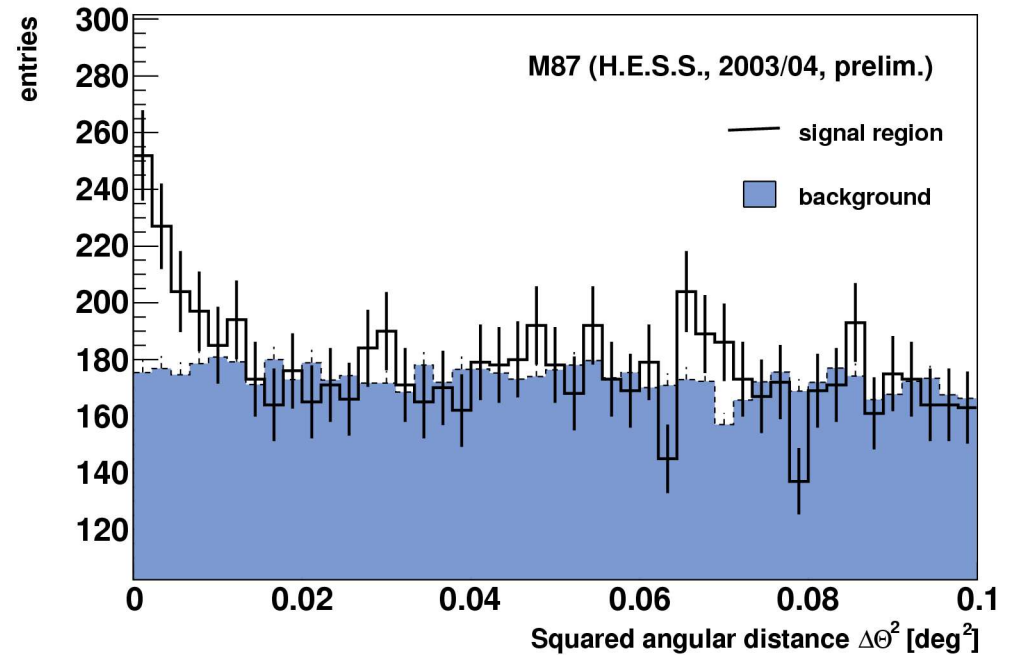
## HEGRA:

- Detected in 1998-99
- $4.7 \sigma$  in 77 hrs

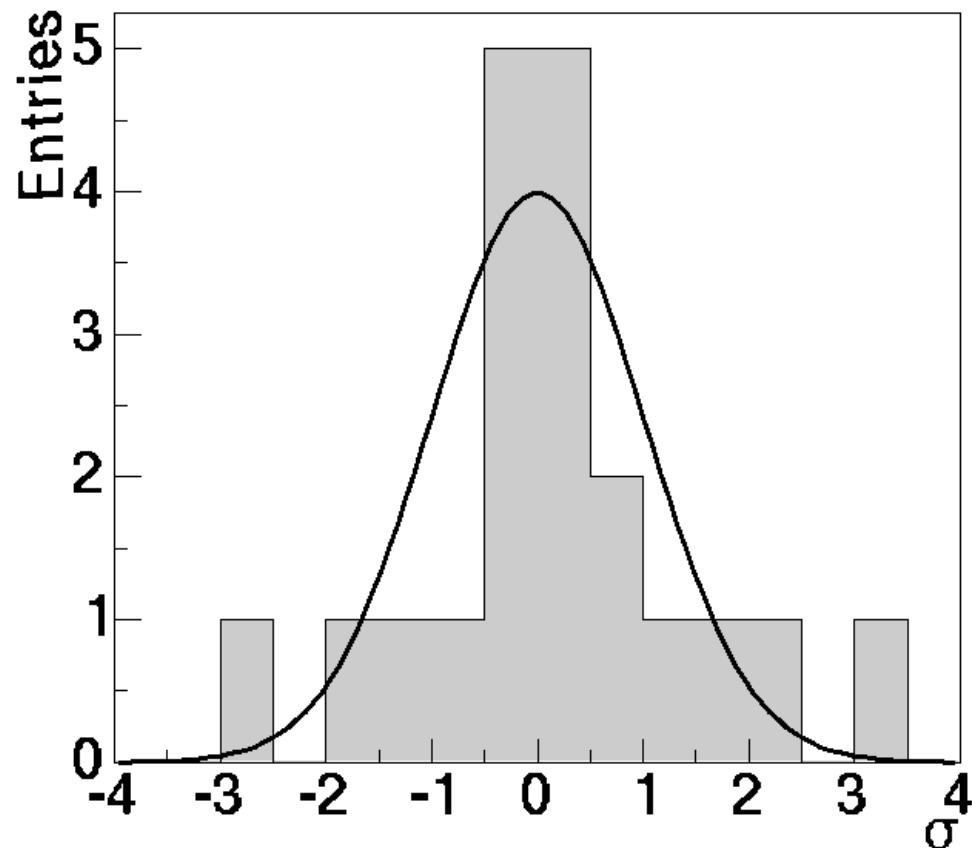
**Whipple:** Upper limits in 2000-03

## H.E.S.S.:

- 13 hr in 2003, 32 hr in 2004
- $5.8 \sigma$  (211  $\gamma$ -rays in 2003-04)
- Point-like excess
- Consistent with central source & HEGRA position
- $>6 \sigma$  in 2005 (Preliminary)



# AGN Upper Limits



## 20 other AGN observed

- 13 BL Lacs
- 4 Radio-loud objects
  - 3C 120, 3C 273, Pictor A, Cen A
- 3 Seyferts
  - NGC 1068, NGC 3783, NGC 7469

## No significant signal

- Mkn 501 ( $3.1 \sigma$ ,  $\sim 15\%$  Crab flux)

**Exposure:** 1 to 8 hrs each (avg 3.2 h)

**99.9% Upper limits:** 0.4 to 5.1% Crab

A&A, in press: [astro-ph/0507207](https://arxiv.org/abs/astro-ph/0507207)

**Don't get depressed! New & exciting results soon to appear!**



# A New AGE for VHE Astronomy!

**H.E.S.S. has reported >20  
VHE sources**

- **Only ~10 (mostly AGN)  
before H.E.S.S.**

**Many new & different classes**

- **Gal. Center, SNR, PWN,  
Unknown Objects, Binary  
Systems, Microquasars, AGN**



**Not ONLY new sources!**

**Detailed studies of morphology,  
spectra & variability possible**

**Many other objects observed &  
more sources still to come!**

- **Analysis ongoing (2005 ICRC)**

**Much exciting physics in the queue**