Highlights from HESS in TeV Gamma-Ray Astronomy

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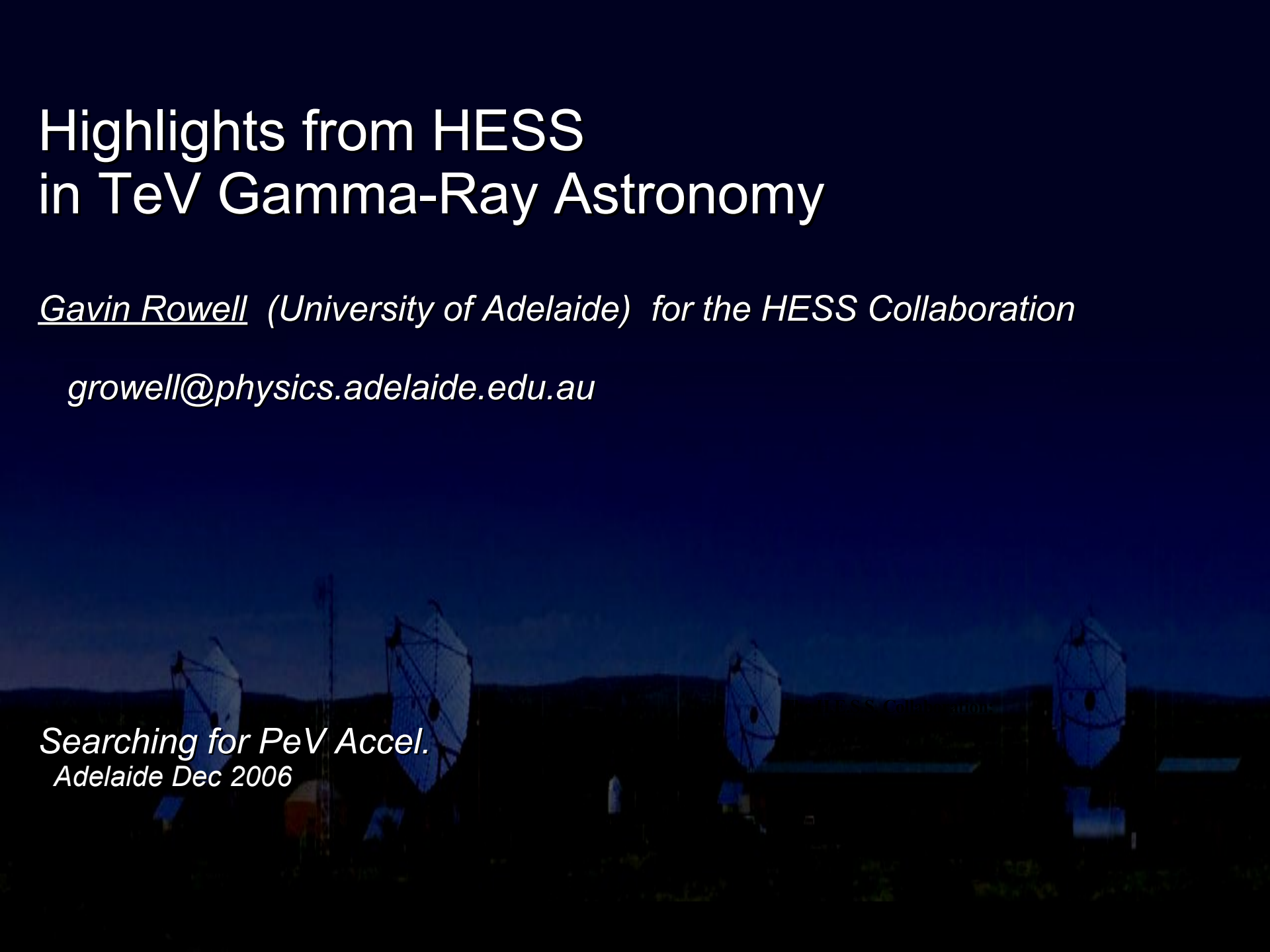
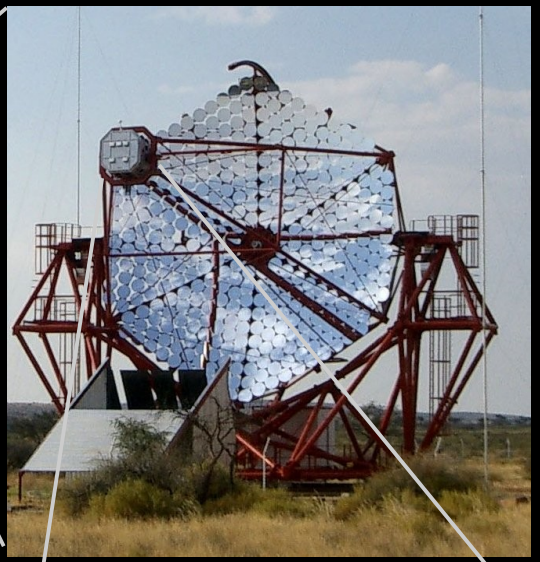


Searching for PeV Accel.
Adelaide Dec 2006

The H.E.S.S. Telescopes

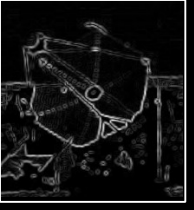


- **H**igh **E**nergy **S**tereoscopic **S**ystem
- Combines HEGRA & CAT experience
- 4 telescopes (in Namibia *23° S*)
  stereoscopic observation mode
- Each telescope: ~107m^2 mirror surface, 380 facets
- Photomultiplier camera (ns response)
  960 PMTs, ***~5° field of view (FoV)***
- Sensitive energy range:
  0.1 TeV up to several 10 TeV
- ***Angular resolution: ~0.1° per event***

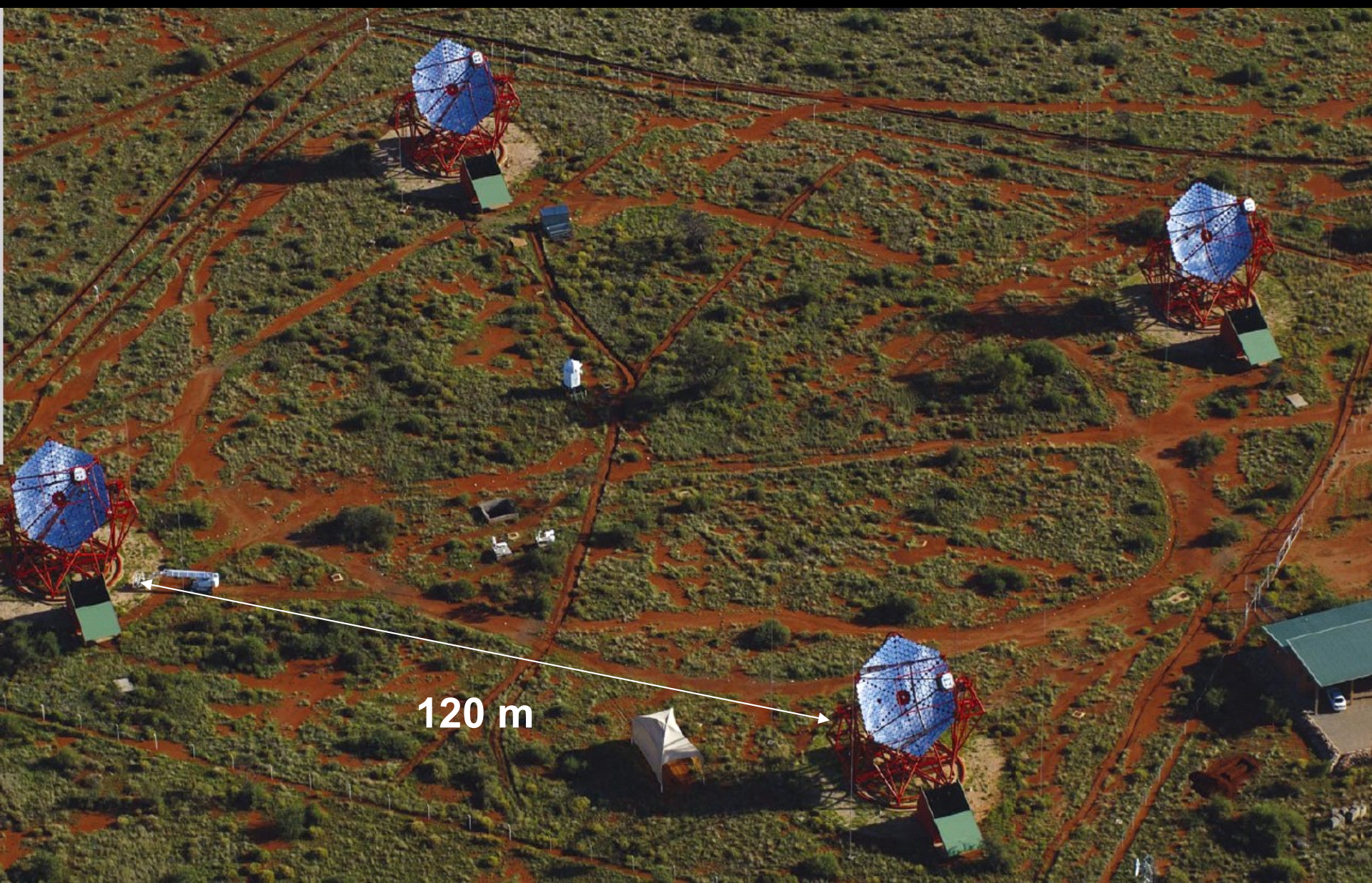
→ ***arc-second src location***

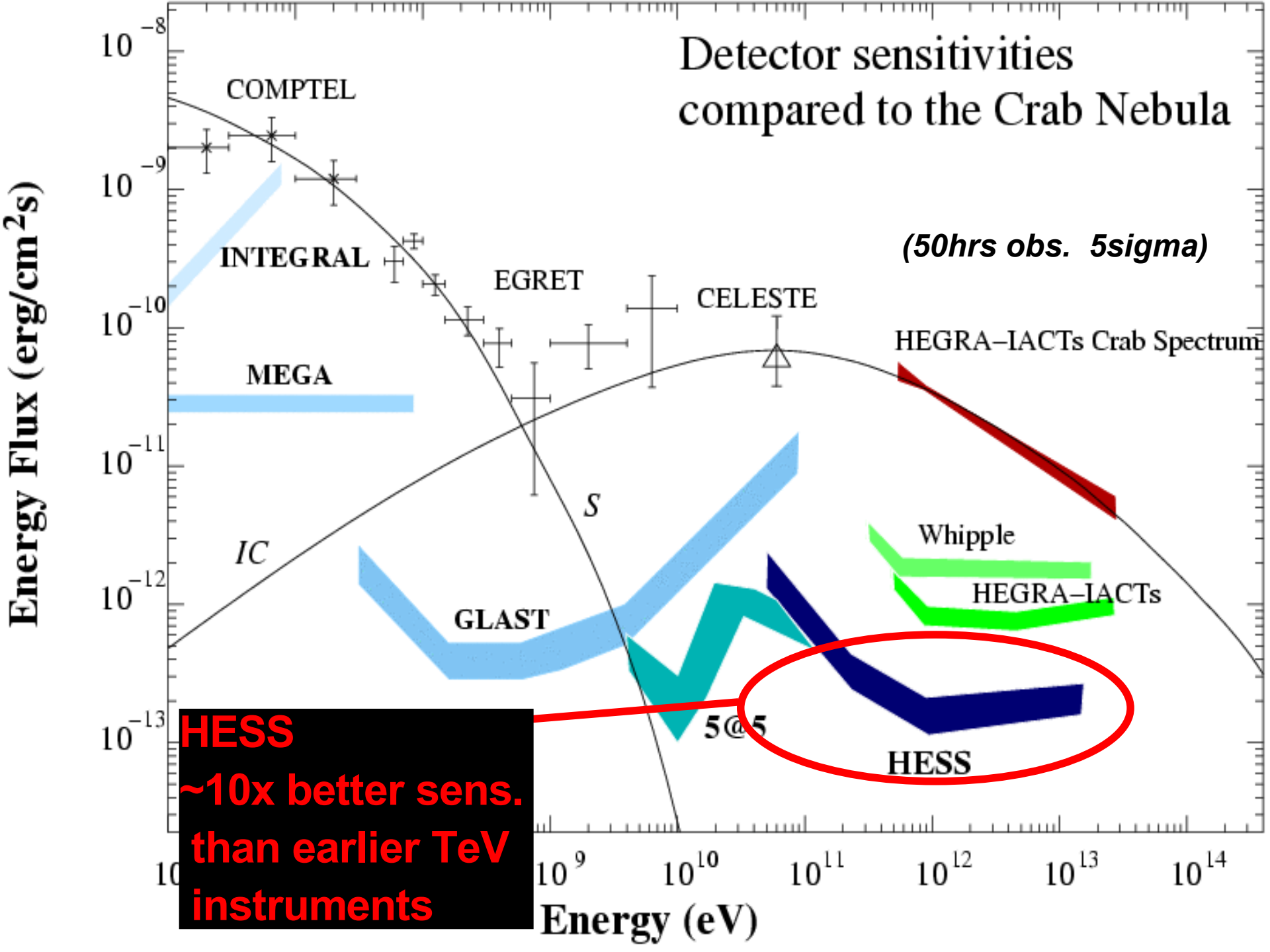
For details

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



HESS – From above



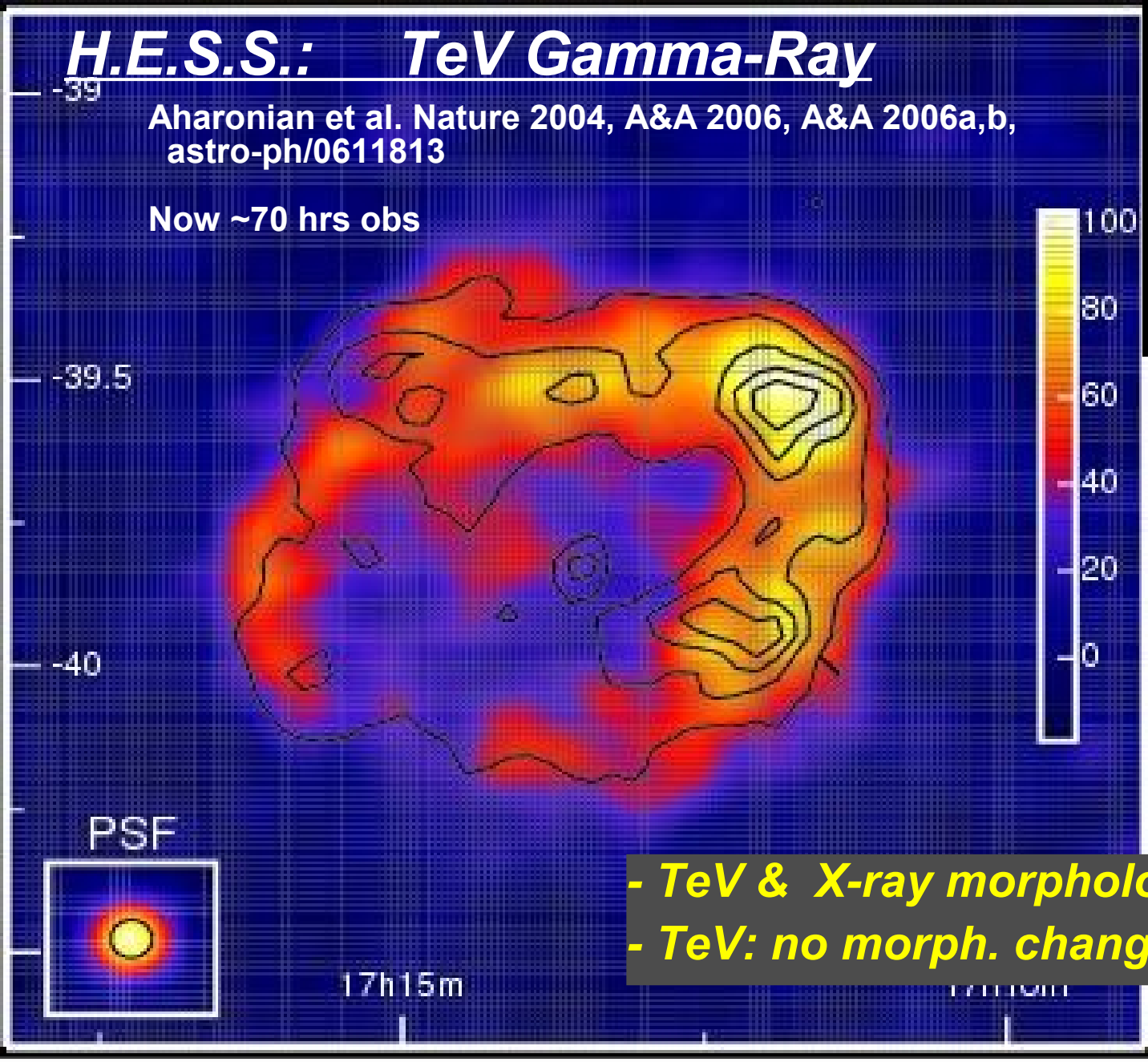

Detector sensitivities
compared to the Crab Nebula
(50hrs obs. 5sigma)
COMPTEL
INTEGRAL
EGRET
CELESTE
MEGA
HEGRA–IACTs Crab Spectrum
S
IC
Whipple
HEGRA–IACTs
GLAST
5@5
HESS
HESS
~10x better sens.
than earlier TeV
instruments
Energy Flux (erg/cm²s)
Energy (eV)

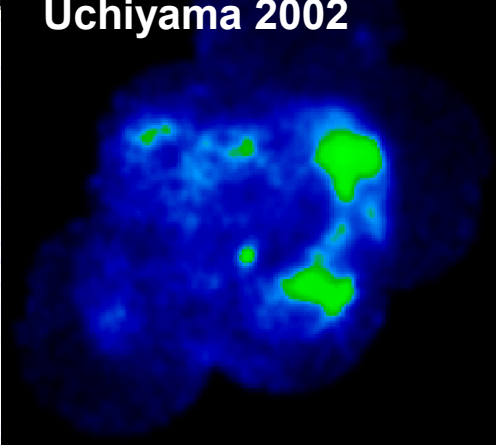
Galactic TeV Source Example Highlights

		Age	Dist kpc	Photon Index Γ
Shell/Comp. SNRs	RX J1713.7-3946	1-1.6ky	~1 (6)	2.2
	RX J0852.0-4622	0.5 – 1ky	0.5 – 2	2.1
	Sgr A* / Sgr A East	~few ky	~8	2.4
	W28	10 – 100ky	2 – 3	
	G0.9+0.1	~few ky	~8	2.4
	G12.8-0.0 (HESSJ1813-178)	0.3 – 2.5	~4	2.1
	G23.3-0.3 (HESSJ1834-087)		~5	2.5
Pulsar Wind Nebulae	Vela-Plerion	~10 ky	0.3	1.9 or 1.5 + cutoff
	MSH 15-52	2-20 ky	~5	2.3
	PSR B1259-63	8-33 ky	1.5	2.7
	HESS J1825-137	20 ky	4	2.4
	Kookaburra	2 & 13ky	5 & 6	2.2 & 2.3
Microquasars	LS 5039	<1.1 My	3	2.2
Unidentified	HESS J1303-631	?	?	2.2
* Galactic Survey	16 New Sources			< 2.3 >
Galactic Diffuse	Galactic Ridge		~8	2.3

* Several survey sources are possibly associted with pulsar-wind-nebulae and shell/composite SNR

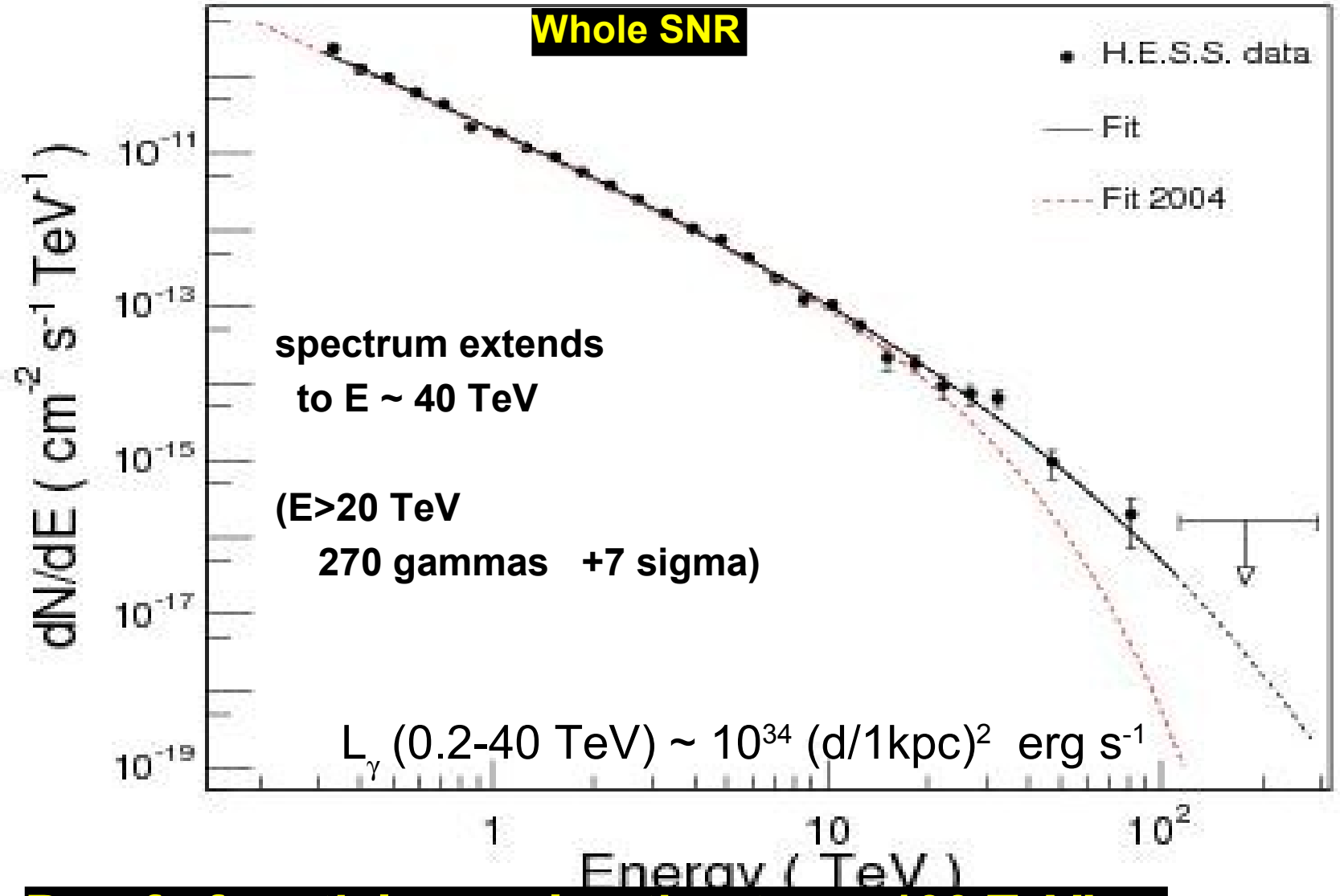
RX J1713.7-3946





- *TeV & X-ray morphology v. similar*
- *TeV: no morph. change with energy*

Energy Spectrum



Proof of particle acceleration to >= 100 TeV!

RX J0852.0-4622 'Vela Junior'

TeV discovery CANGAROO
Katagiri etal 2005

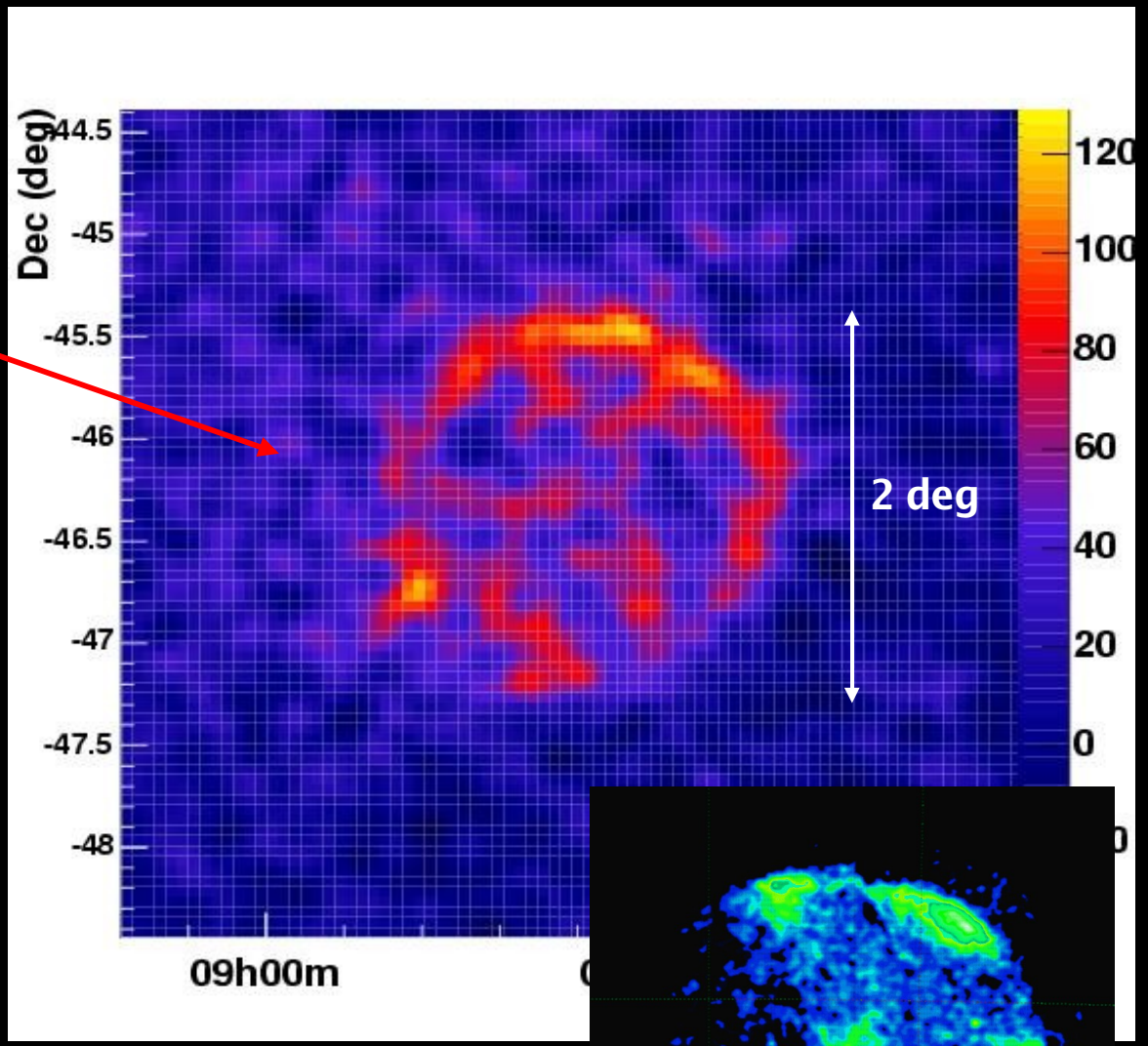
2004 & 2005 HESS Obs
Aharonian etal 2005, 2006 (in prep)

- 20 hr
- ~ 1 Crab flux in total
- 5200 events (19σ)

L_γ (1-10 TeV)
~ 10^{32} $(d/200pc)^2$ erg s^{-1}

Power Law spectrum

$\Gamma = 2.23$



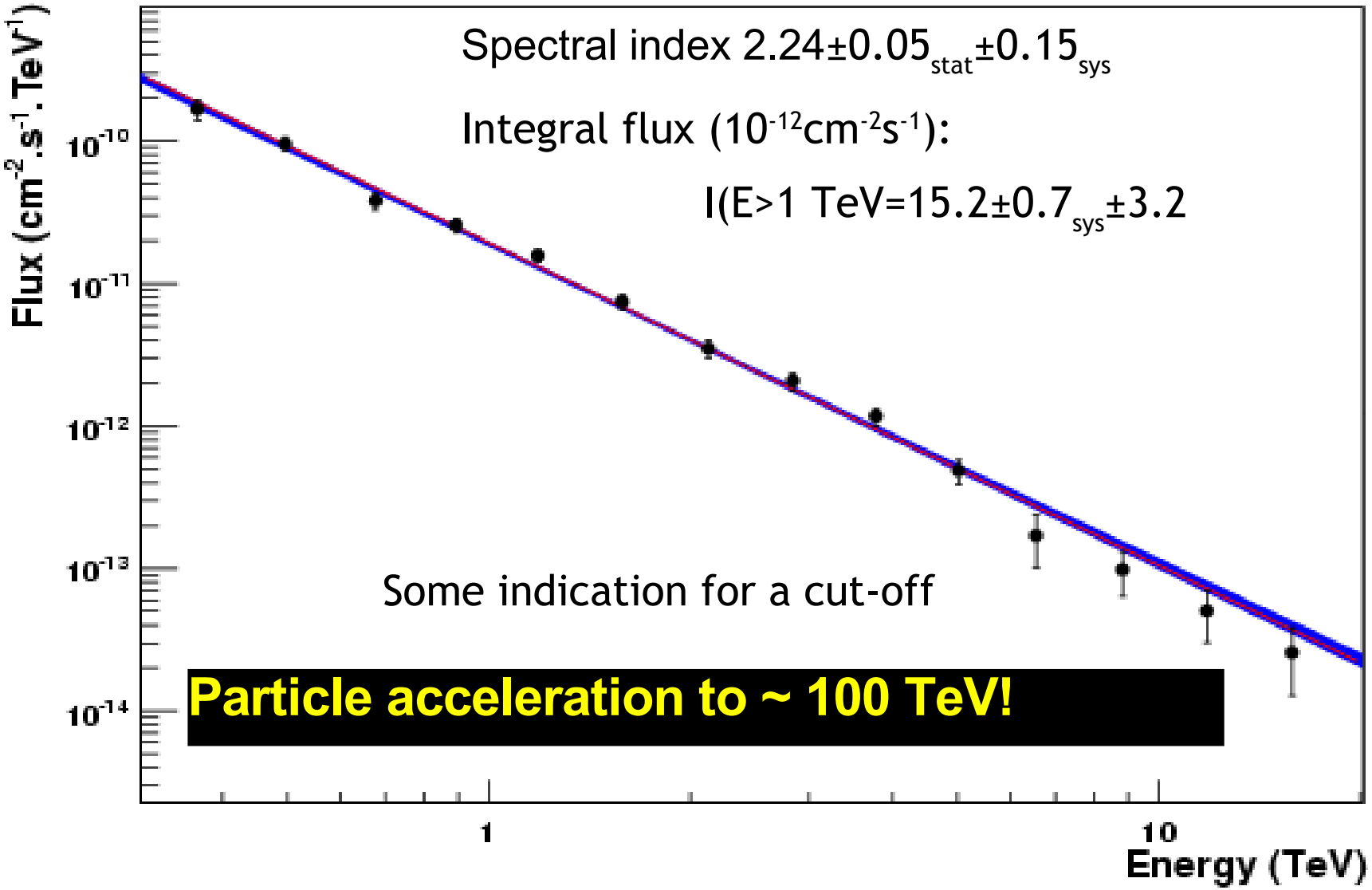
Energy spectrum: 0.3-20 TeV

Power law:

Spectral index $2.24 \pm 0.05_{stat} \pm 0.15_{sys}$

Integral flux (10^{-12}cm^{-2}s^{-1}):

$I(E>1\ \text{TeV} = 15.2 \pm 0.7_{sys} \pm 3.2$

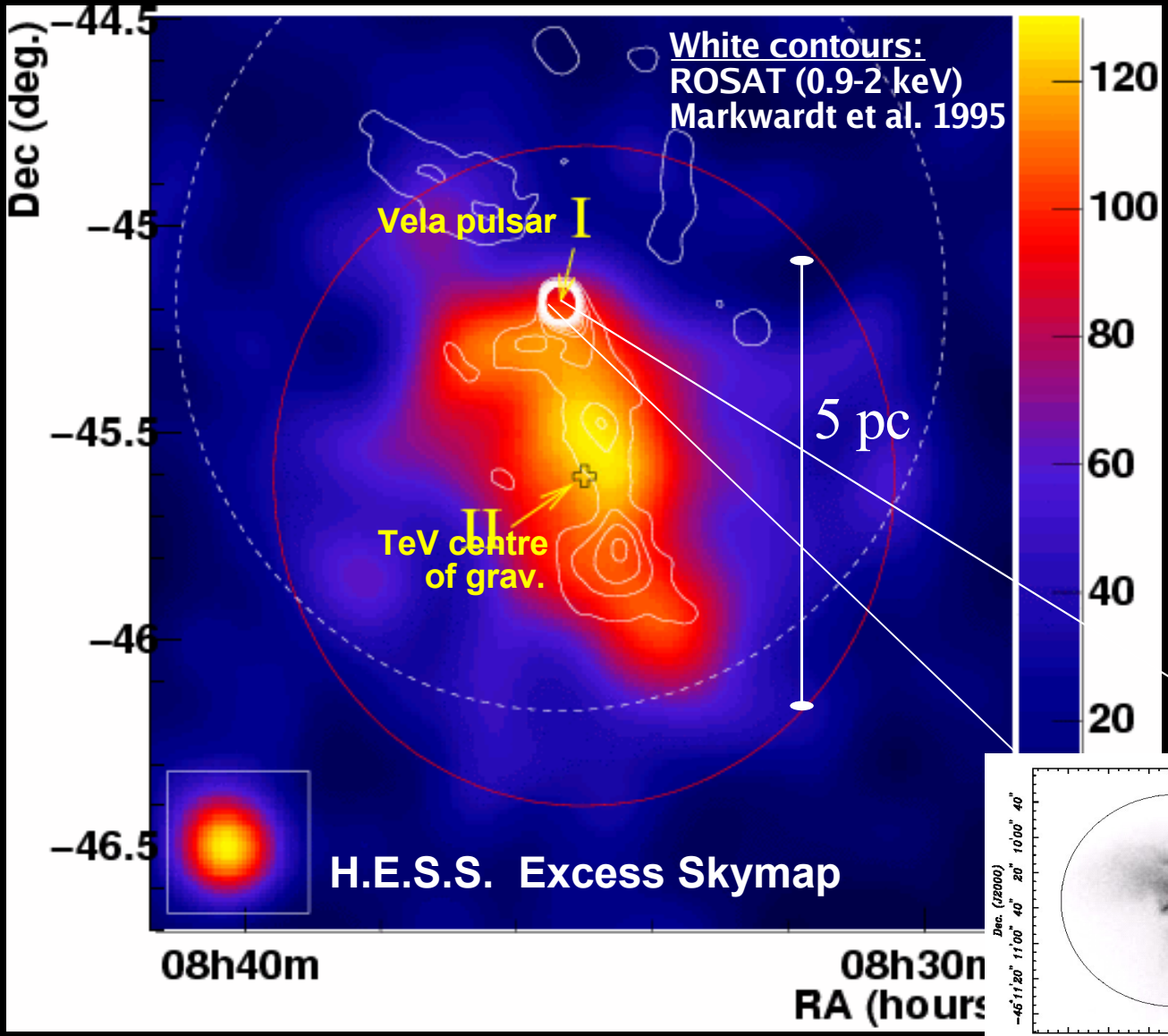


Some indication for a cut-off

Particle acceleration to ~ 100 TeV!

Vela–PWN (G263.9-3.3) Aharonian et al 2006

Asymmetric pulsar wind nebula

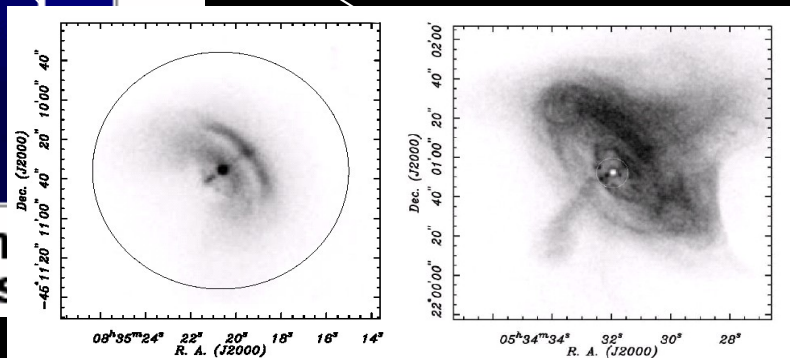


2004/2005 17 hrs obs

Extended TeV emission

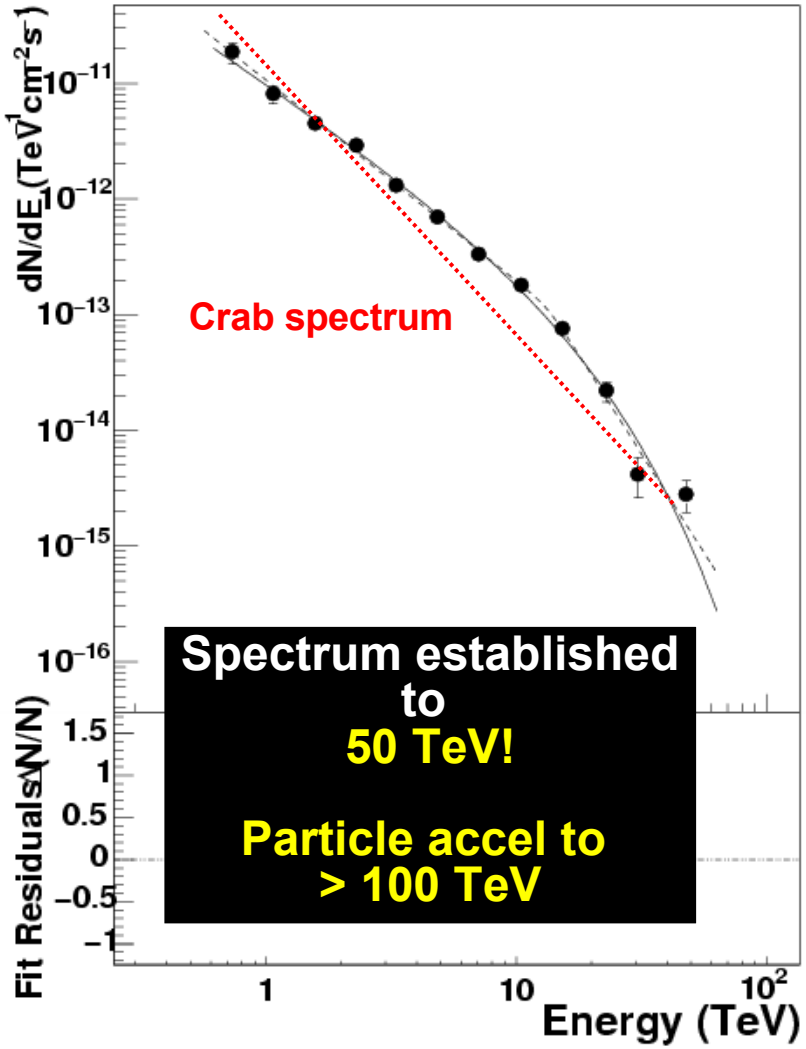
~ similar to X-ray morphology

Eff ~ 0.01%



TeV Energy spectrum: Vela Plerion

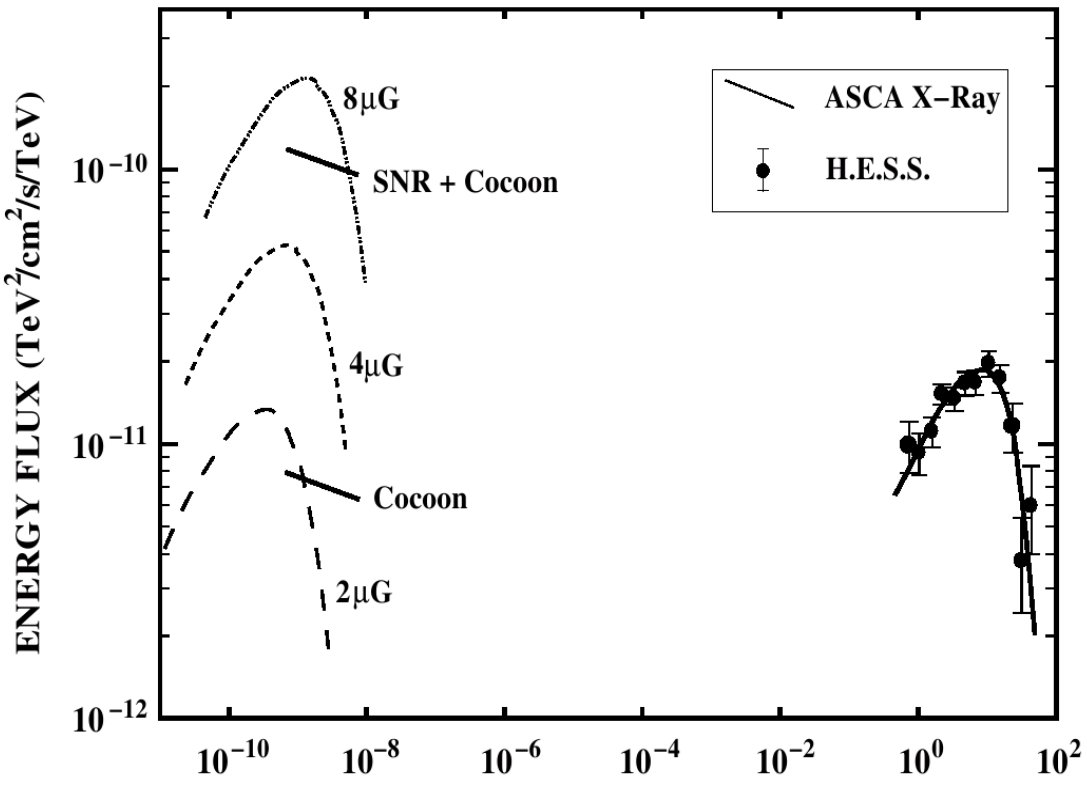
$dN/dE \sim E^{-1.45} \exp(-E/13.8)$



Spectrum established to 50 TeV!

Particle accel to > 100 TeV

VERY hard power law + exp cutoff



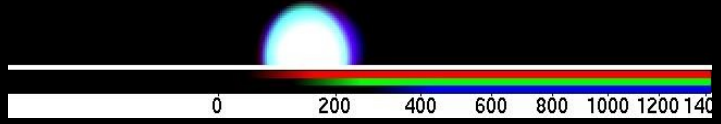
First observation of a νFν (energy-flux) peak in a gamma-ray source

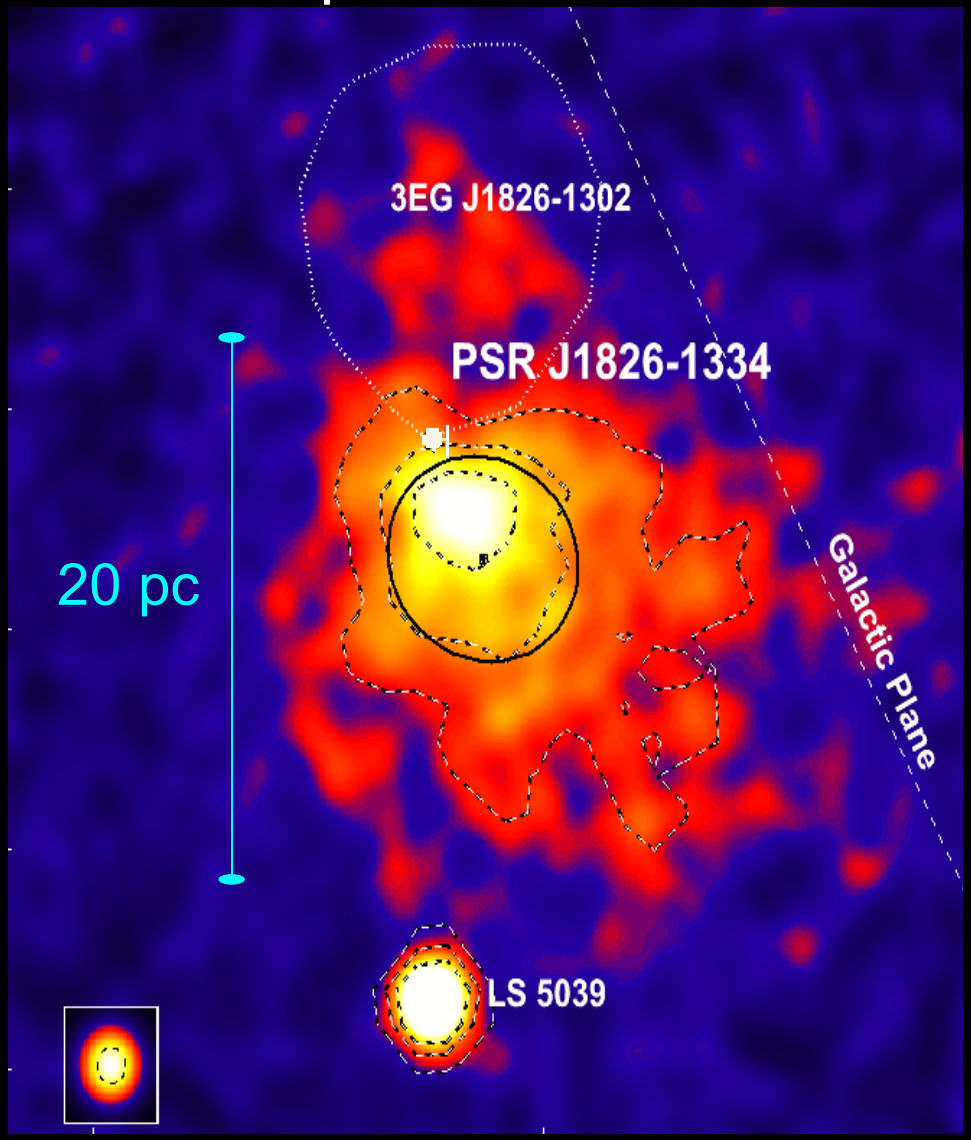
One zone IC model --> B-field few μG
(uncertainties in size of sync. X-ray nebula)

Hadronic origin considered (Horns et al 2006) B ~ 10μG

HESS J1825-137 – spatially-resolved spectral studies

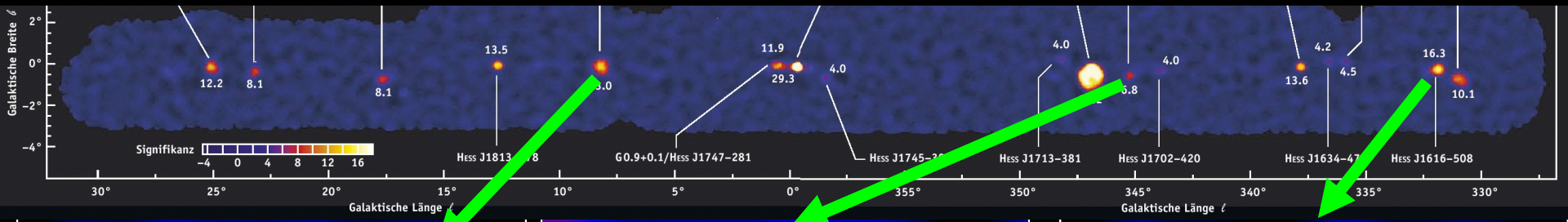
red – below 0.8 TeV
green – 0.8-2.5 TeV
blue – above 2.5 TeV

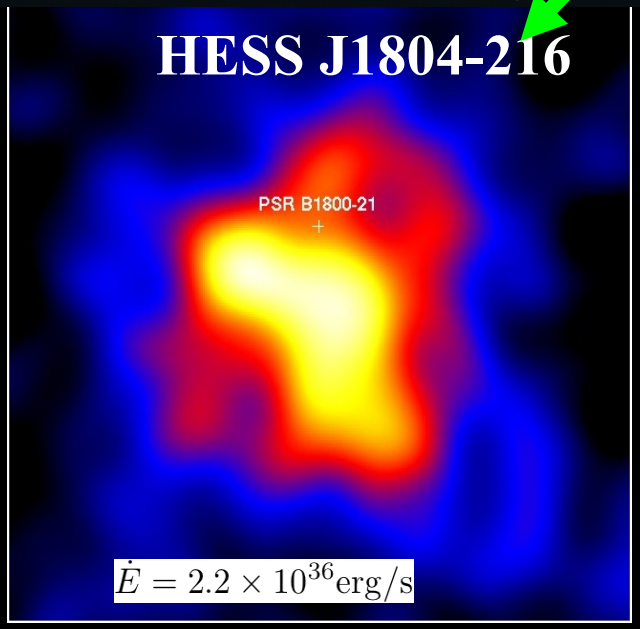


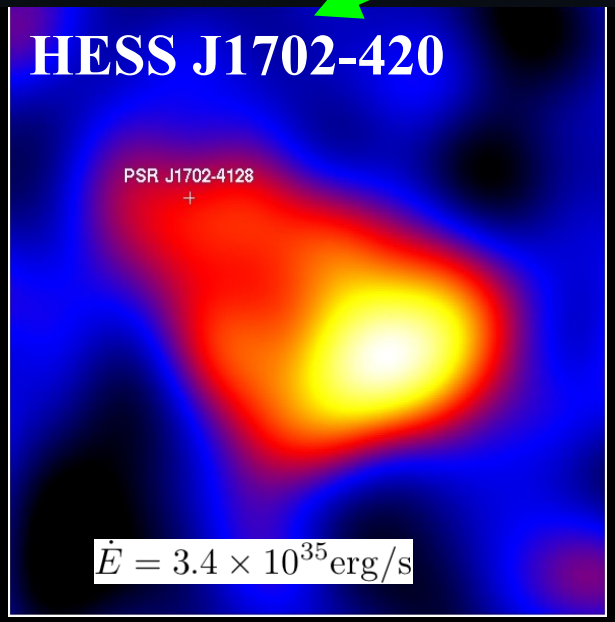


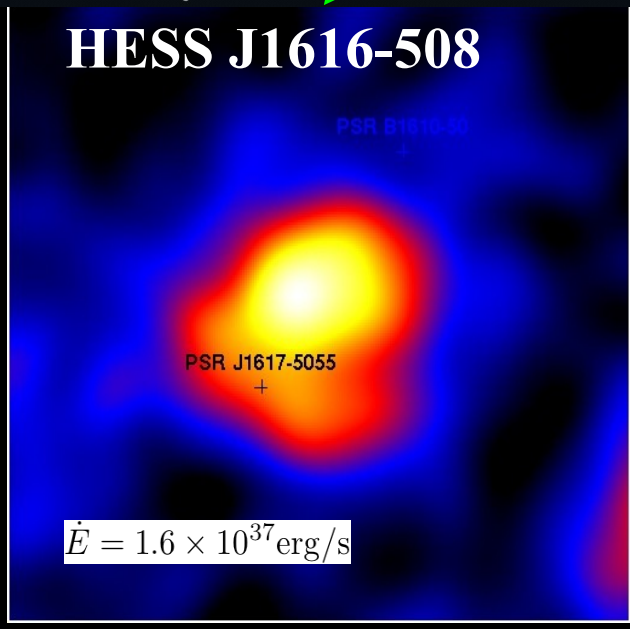
Softening of γ-ray spectrum with distance from the pulsar:
--> evidence in favor of inverse-Compton (electrons) origin of γ-rays!

More TeV Pulsar Wind Nebulae..









PSR B1800-21
D **= 3.9 kpc**
Required efficiency 2.4%

PSR J1702-4128
D = 4.8 kpc
Required efficiency 11%

PSR J1617-5055
D **= 6.8 kpc**
Required efficiency 1.3%

LS5039

HMXRB

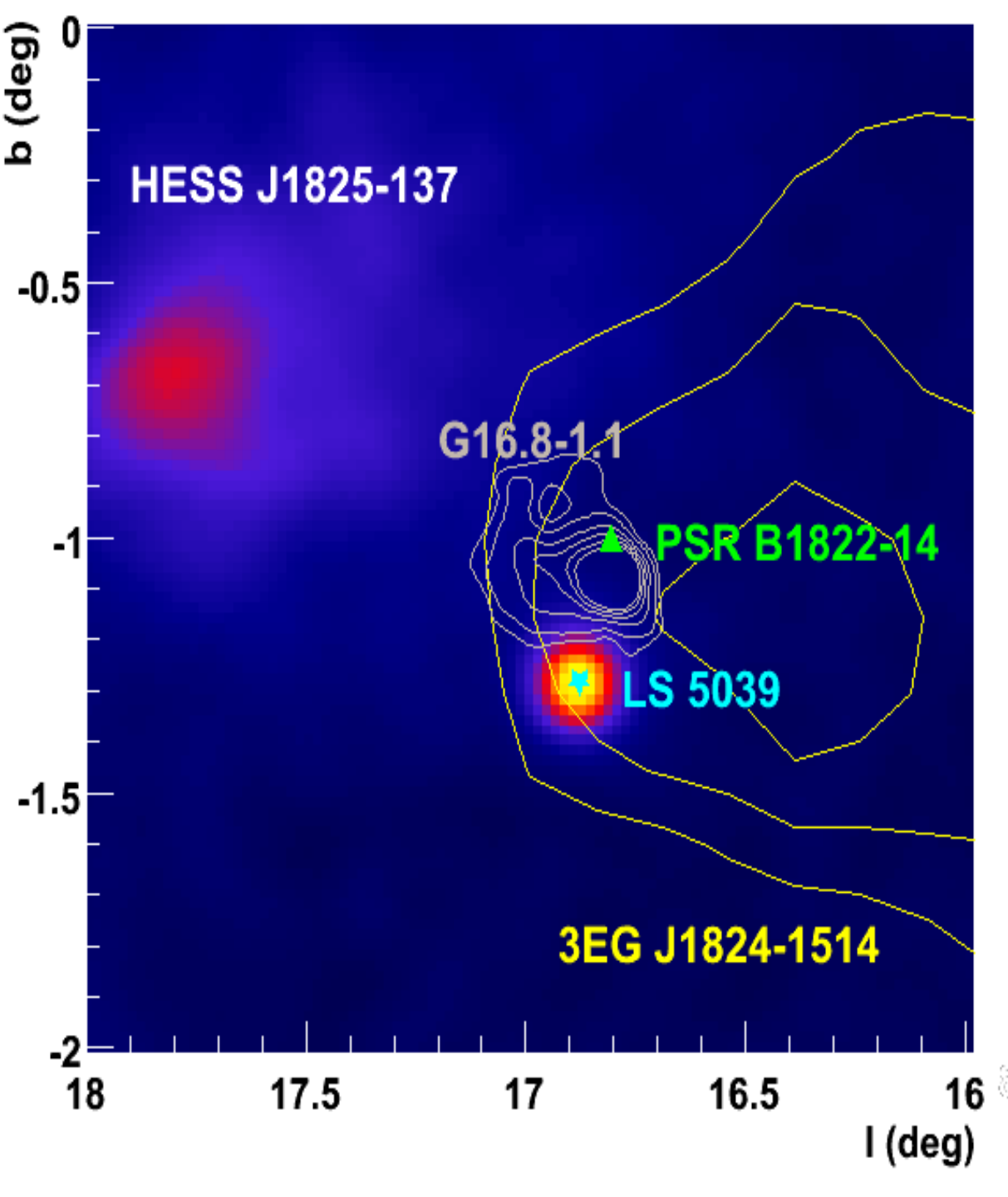
a microquasar

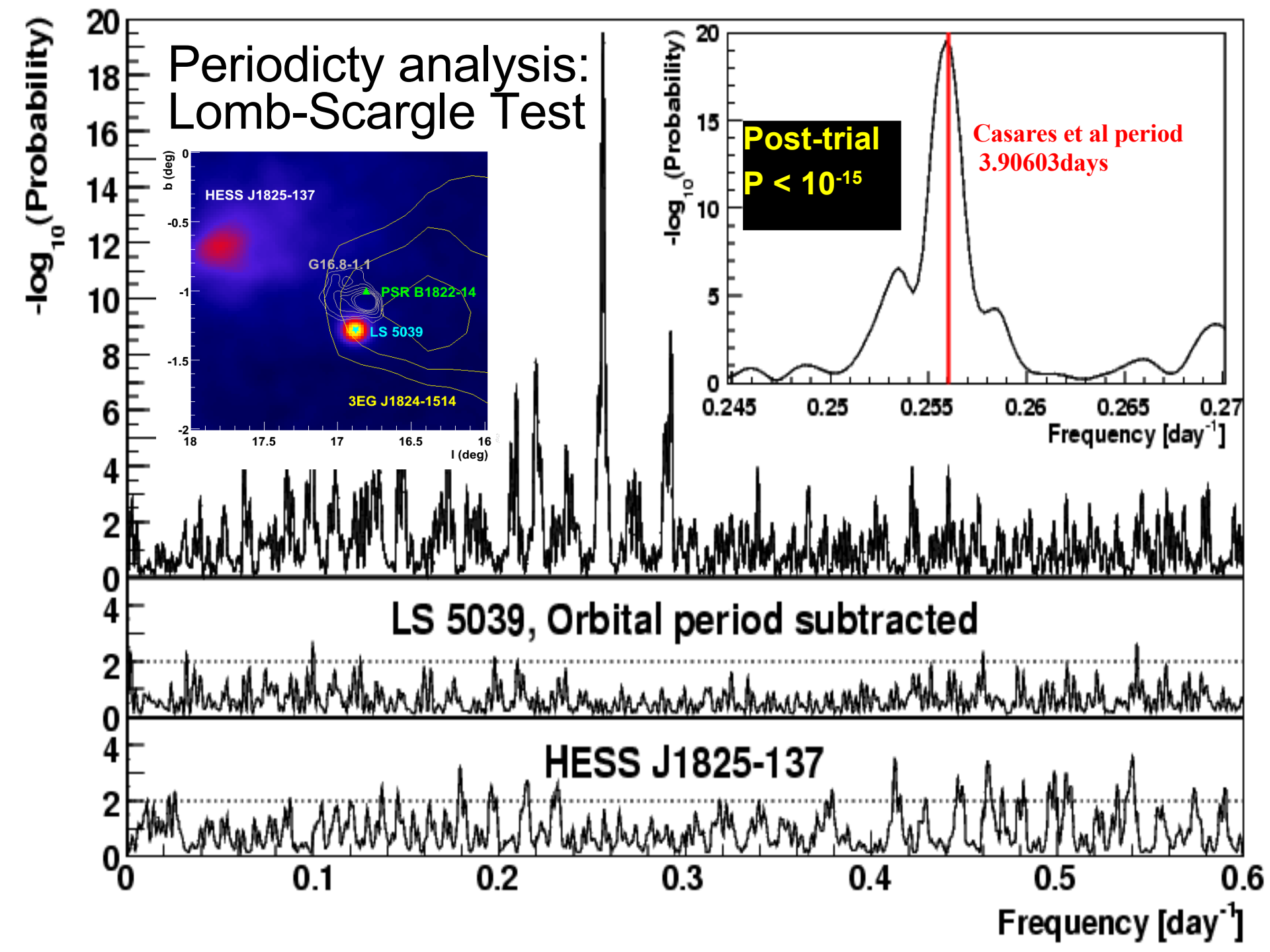
HESS 2004 to 2006

~60 hrs observation

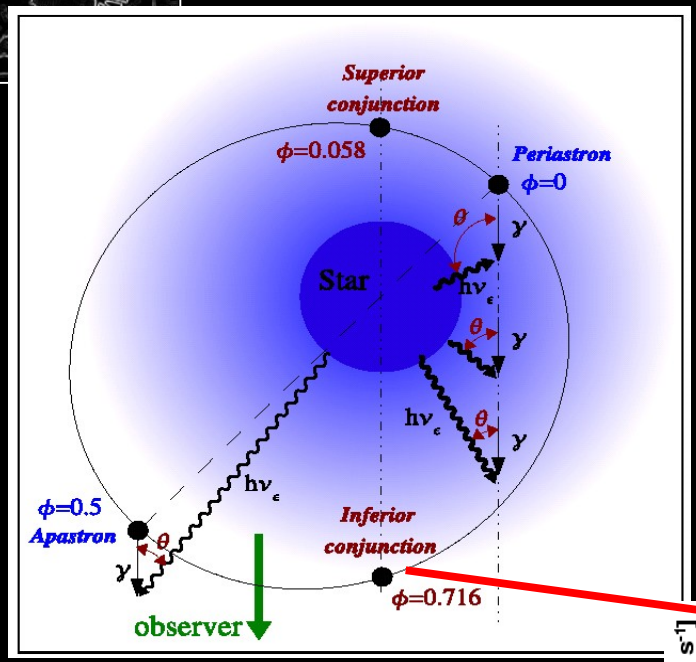
> 40σ detection

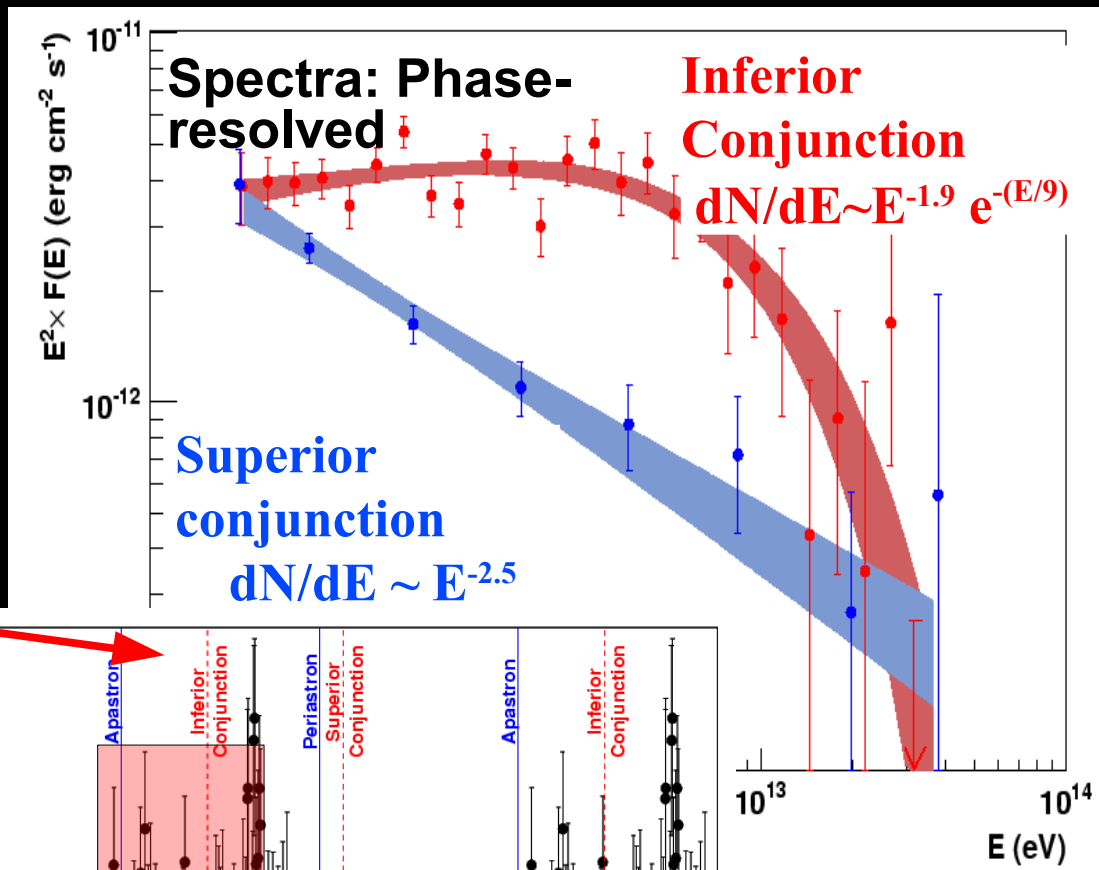
> 2000 gammas




Periodicty analysis:
Lomb-Scargle Test
-log10(Probability)
HESS J1825-137
G16.8-1.1
PSR B1822-14
LS 5039
3EG J1824-1514
b (deg)
l (deg)
Post-trial
P < 10-15
Casares et al period
3.90603days
Frequency [day-1]
LS 5039, Orbital period subtracted
HESS J1825-137

Orbital Phase-Resolved Analysis

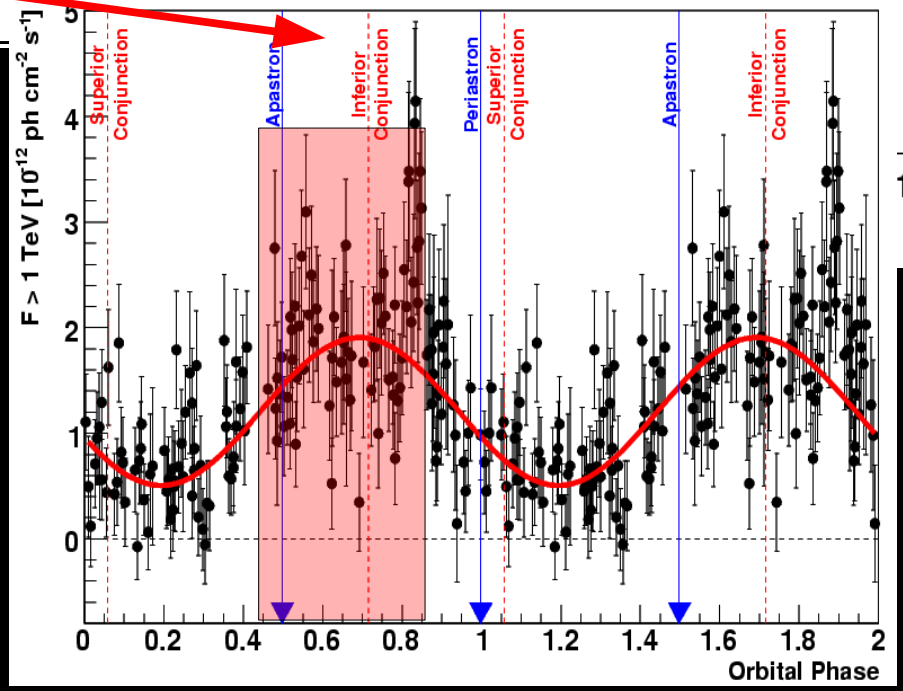




Maximum coinciding with ~inferior conjunction

Minimum around superior conjunction (non-zero!)

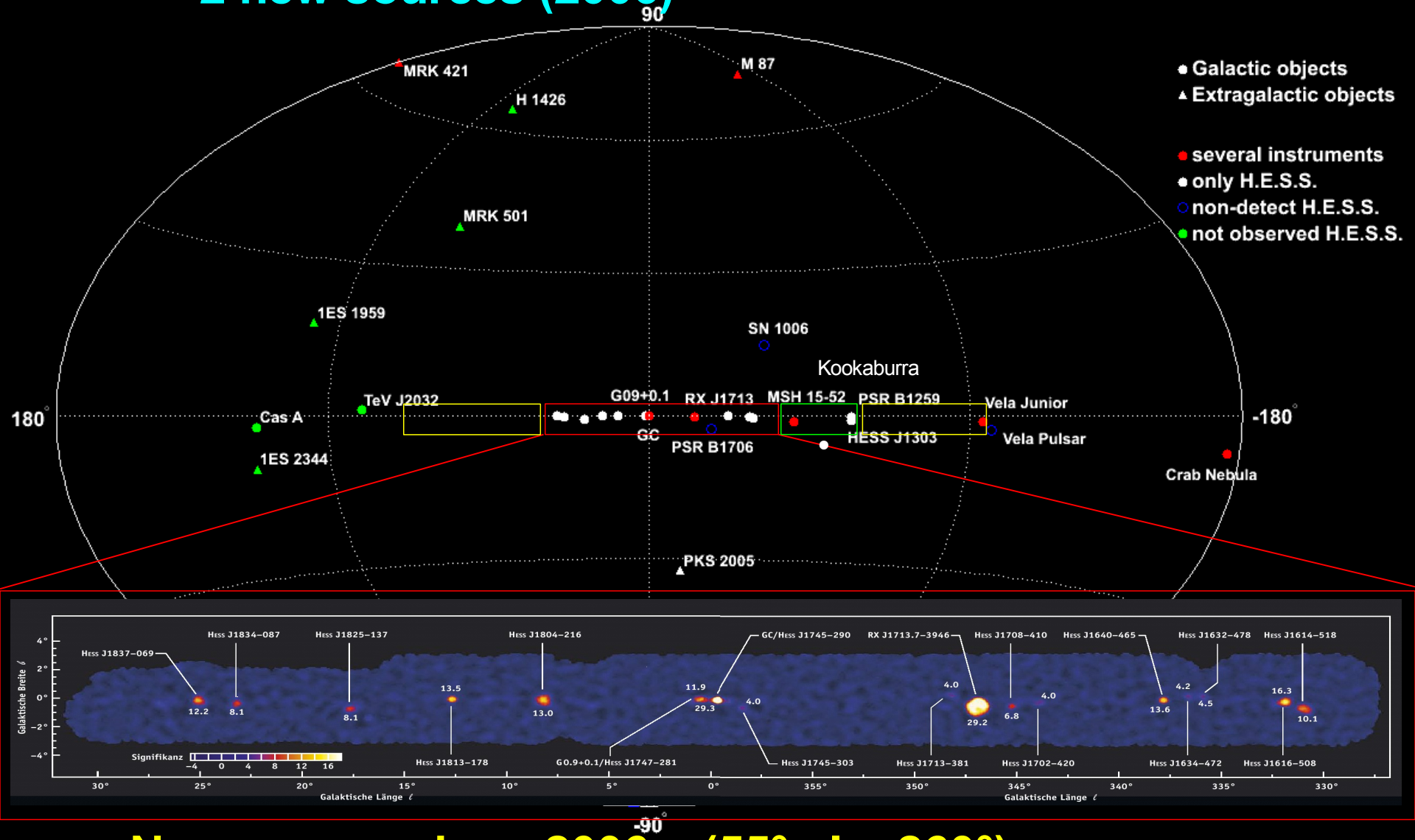
Sufficient statistics for phase-resolved spectroscopy



H.E.S.S. surveys of the central Galactic Plane

14 new sources (2004) **2 new sources (2005)**

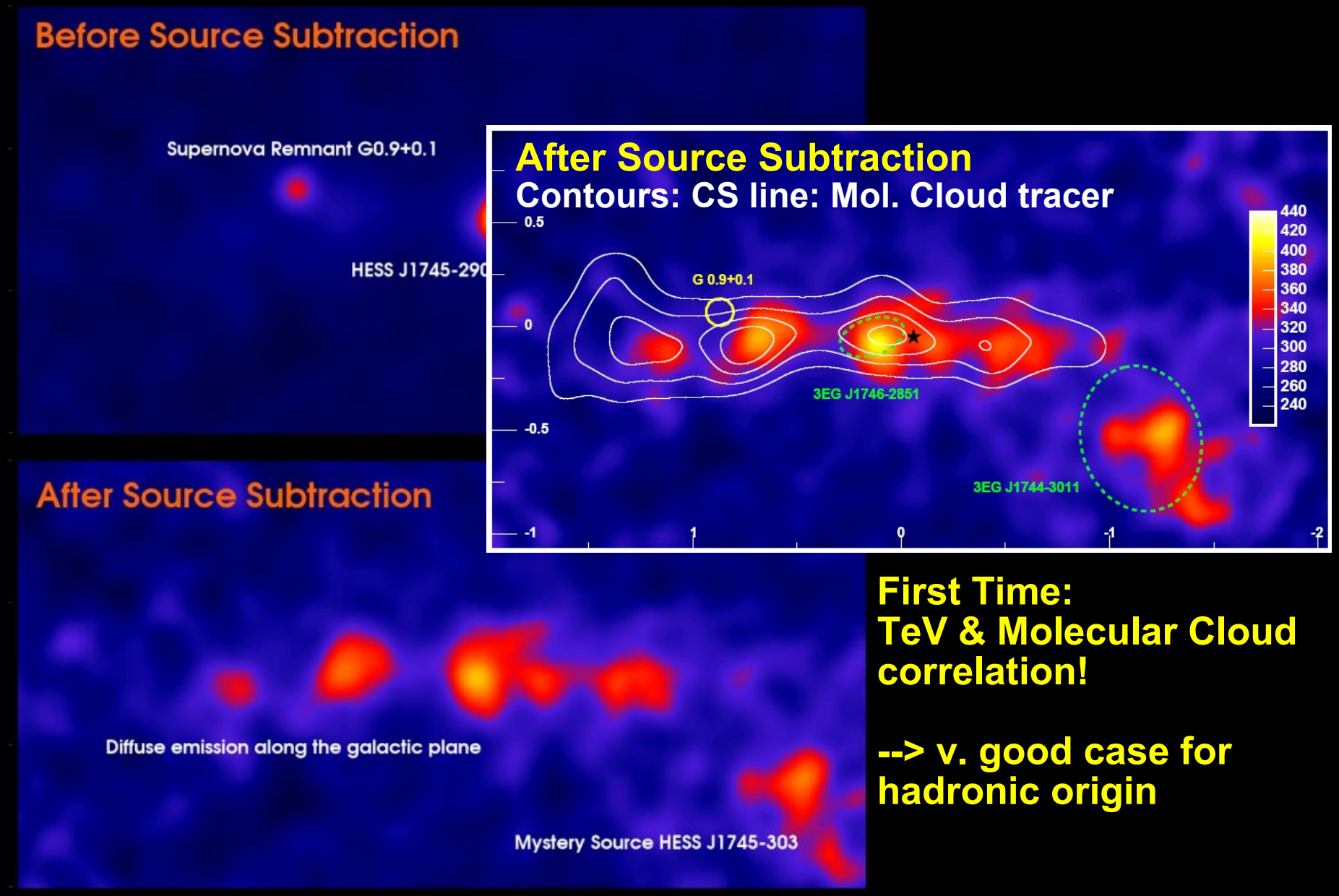
2 new sources (2006)



New scan regions 2006 (55°< l < 260°)

Galactic Centre Region: Diffuse Emission

Aharonian et al (2005) Nature 439, 695



First Time:
TeV & Molecular Cloud correlation!

--> v. good case for hadronic origin

HESS J1303-631: Unidentified TeV

Aharonian et al A&A 2005

- **First time: Two TeV sources in same FoV**

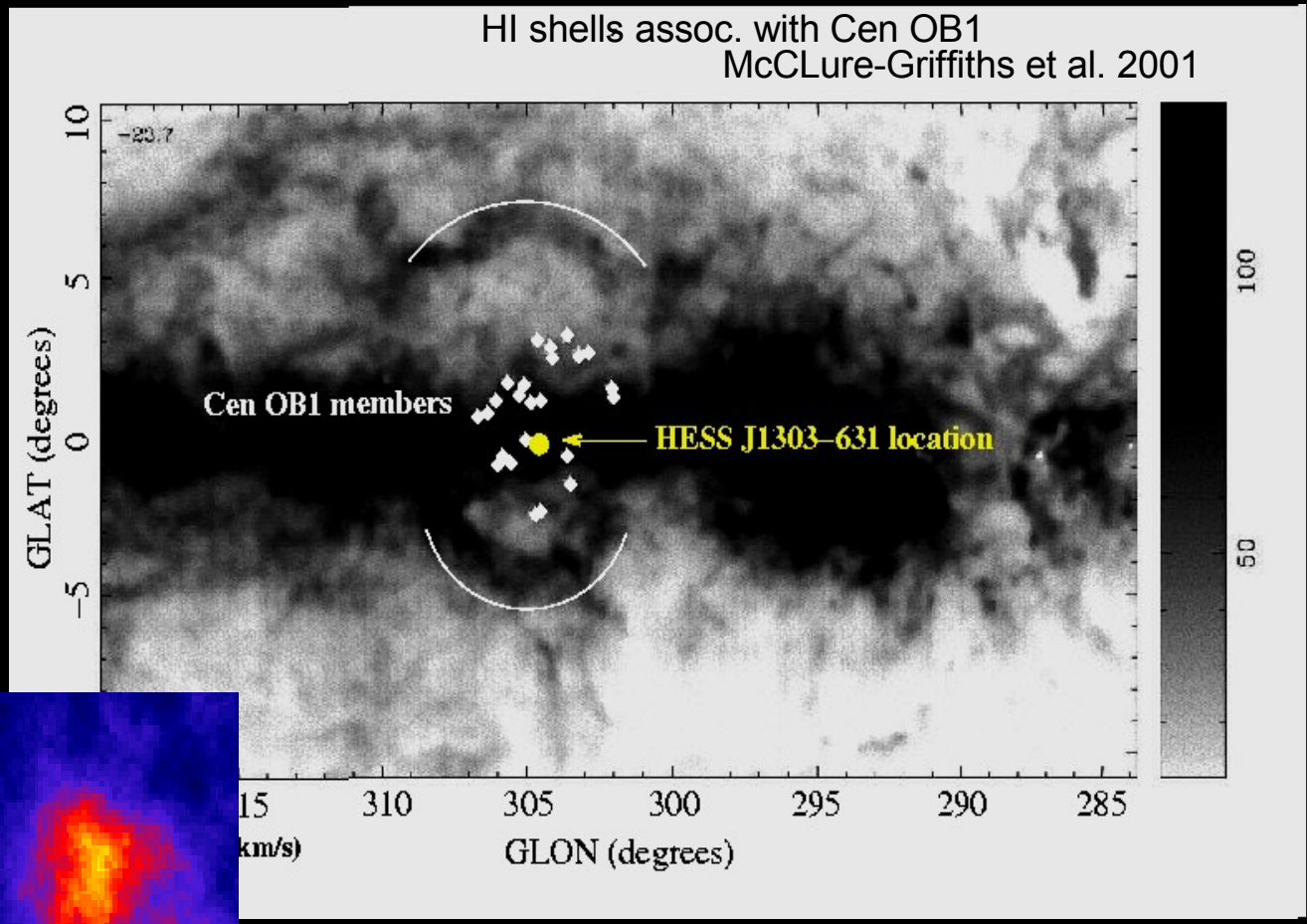
- **dN/dE ~ $E^{-2.2}$**
  17% Crab

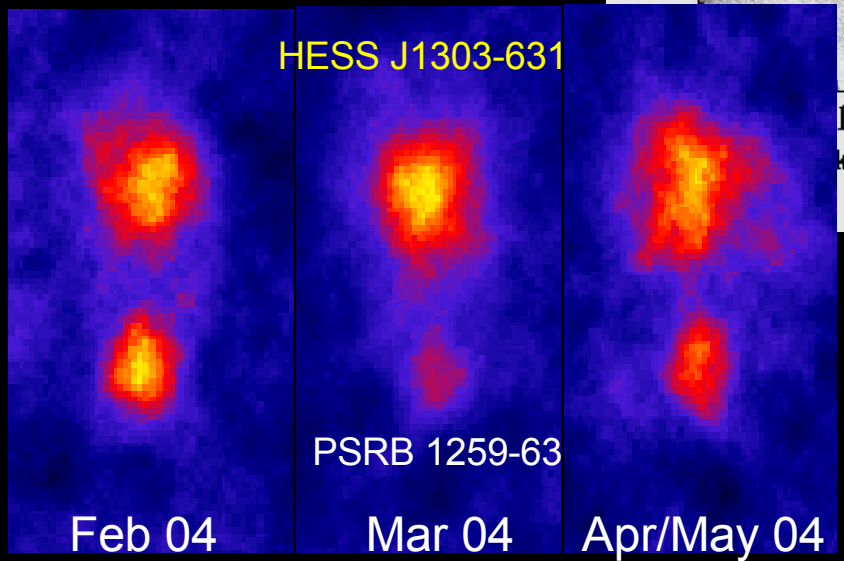
- **Extended:**
  radius ~ 10 arcmin

- **Located in OB assoc Cen OB1**

HI shells assoc. with Cen OB1

McCLure-Griffiths et al. 2001





- **Similar to TeVJ2032+4130 & Cyg-OB2 ?**

- **some pulsars nearby...**

Extragalactic TeV γ-ray sources

	Name	redshift	reference
●	M 87	0.004	Aharonian et al, A&A, 403, L1 (2003)
	Markarian 421	0.030	Punch et al., Nature, 358, 477 (1992)
	Markarian 501	0.034	Quinn et al., ApJ, 456, L83 (1996)
	1ES 2344+514	0.044	Catanese et al., ApJ, 501, 616 (1998)
	Markarian 180	0.045	Albert et al., ApJL, submitted (2006)
	1ES 1959+650	0.047	Nishiyama et al., 29th ICRC, 3, 370 (1999)
	PKS 2005-489	0.071	Aharonian et al, A&A, 436, L17 (2005)
●	PKS 2155-304	0.116	Chadwick et al., ApJ, 513, 161 (1999)
	H 1426+428	0.129	Aharonian et al., ApJ, 571, 753 (2002)
●	H 2356-309	0.165	Aharonian et al, Nature, 440, 1018 (2006)
	1ES 1218+304	0.182	Albert et al., ApJ, 642, L119 (2006)
●	1ES 1101-232	0.186	Aharonian et al, Nature, 440, 1018 (2006)
	PG 1553+113	>0.25?	Aharonian et al, A&A, 448, L19 (2006)

discovered by H.E.S.S. ●

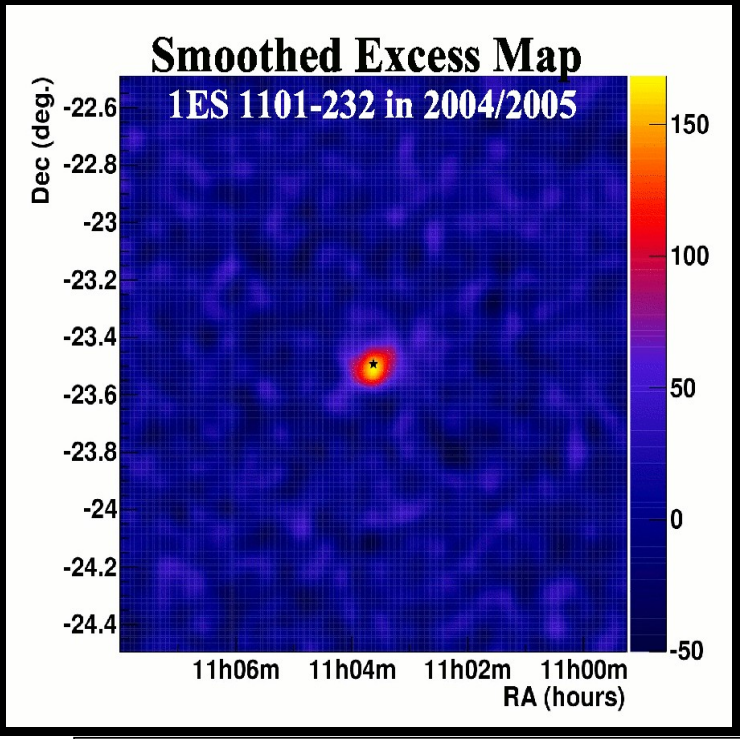
seen by H.E.S.S.

Provides constraints on the extragalactic background light (EBL)

Except for M87, all extragalactic TeV γ-ray sources are blazars

1ES 1101-232 (z=0.186) & H2356-309 (z=0.165): Two New Distant Blazars

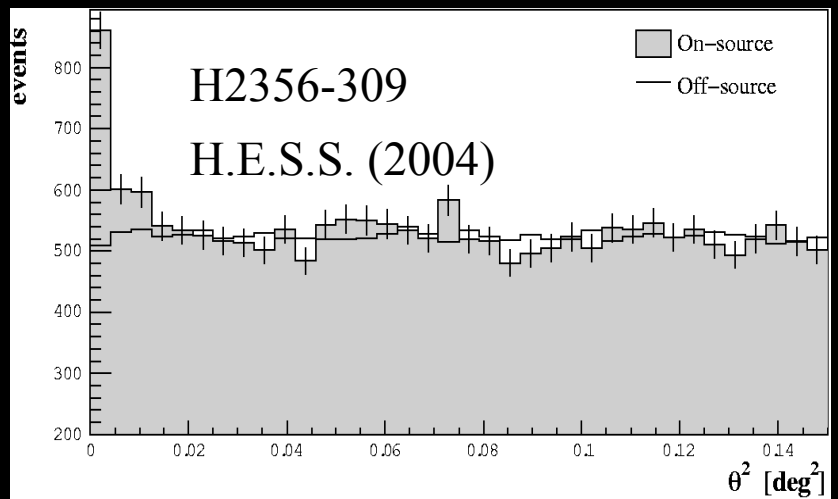
Discovered by H.E.S.S. in 2004
~40h of observations, (>10σ)



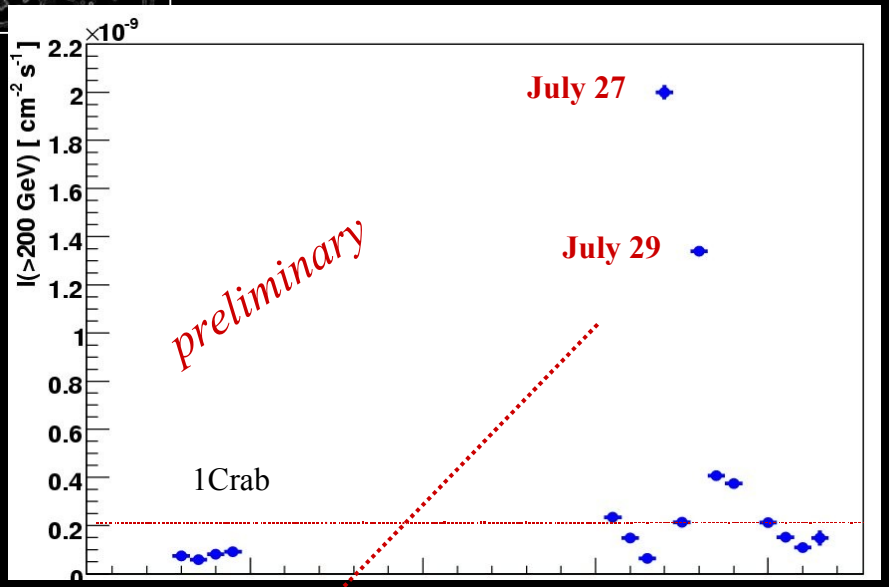
Enery spectra both are steep power laws

1ES1101: $\Gamma = 2.88 \pm 0.17$
H2356-309: $\Gamma = 3.06 \pm 0.2$

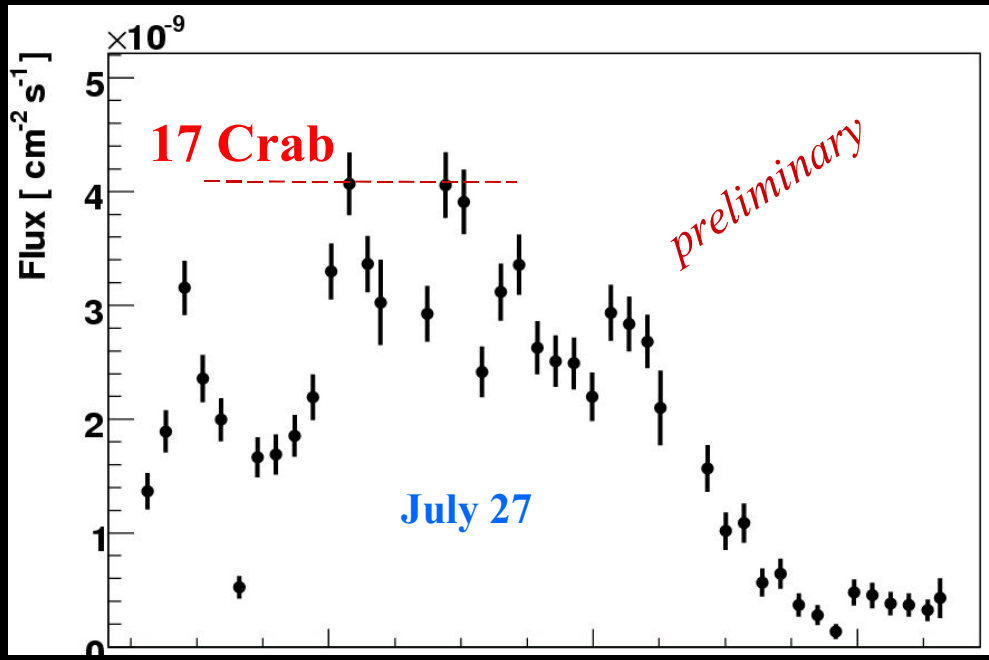
Expect γ absorption from EBL
→ strong implications on EBL



PKS 2155-304: Huge flares in July/August 2006



night by night lightcurve July-August 2006



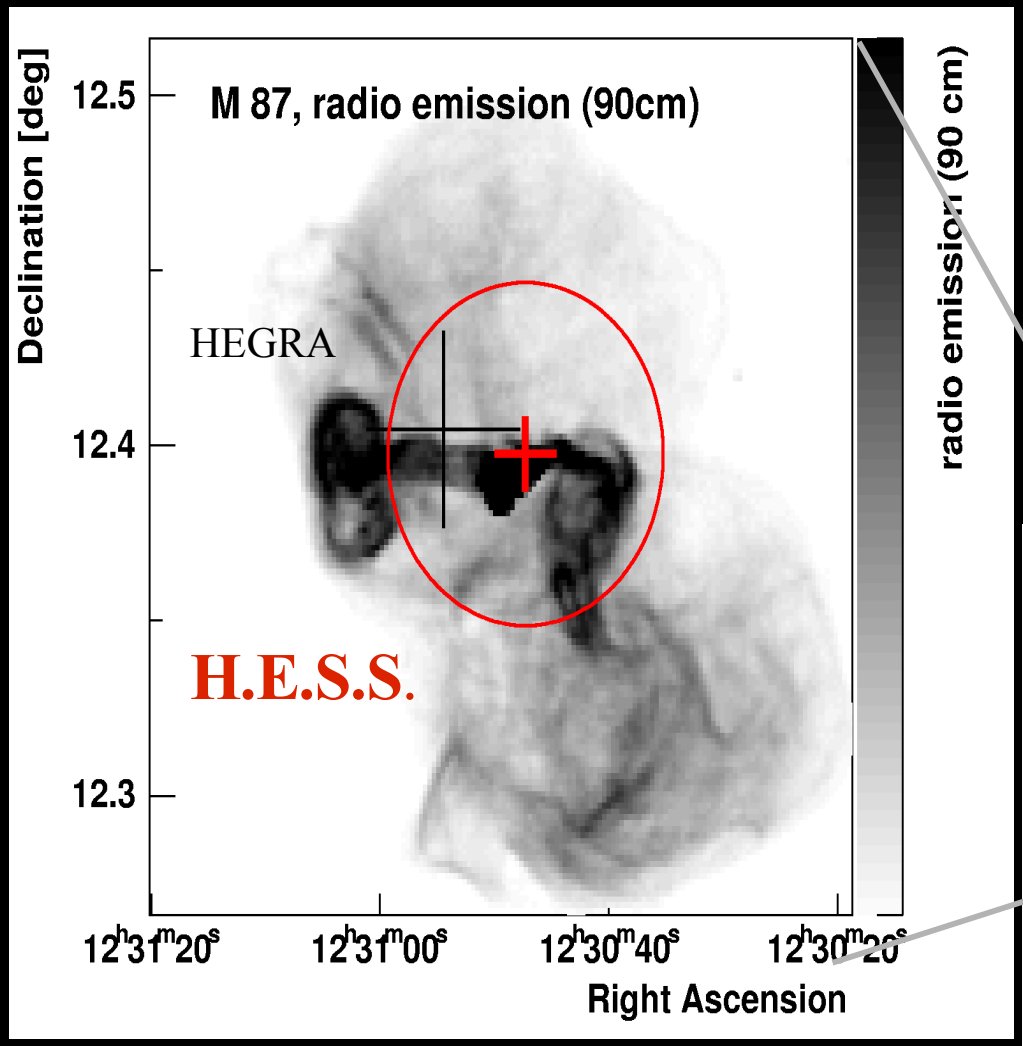
X-ray (RXTE, Swift, Chandra) observations available:
Chandra – simultaneous coverage for 6 continuous hours !
strong variability - a factor of 2
timescales – 10 minutes or so)

Strong evidence for **variability on a few minute timescales !**
on average 70 γ/min rate ➔ spectrometry on minute timescales

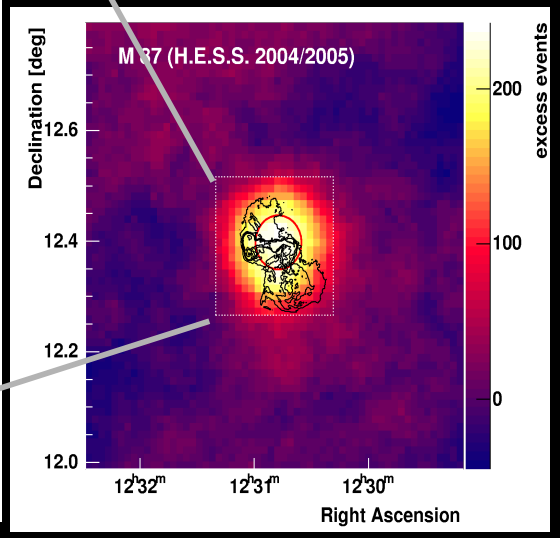
finally ! we do have simultaneously obtained keV/TeV data for proper modelling of blazar jets

M87: TeV γ-ray source – HEGRA & H.E.S.S.

Dist: ~16 Mpc (z=0.00436)

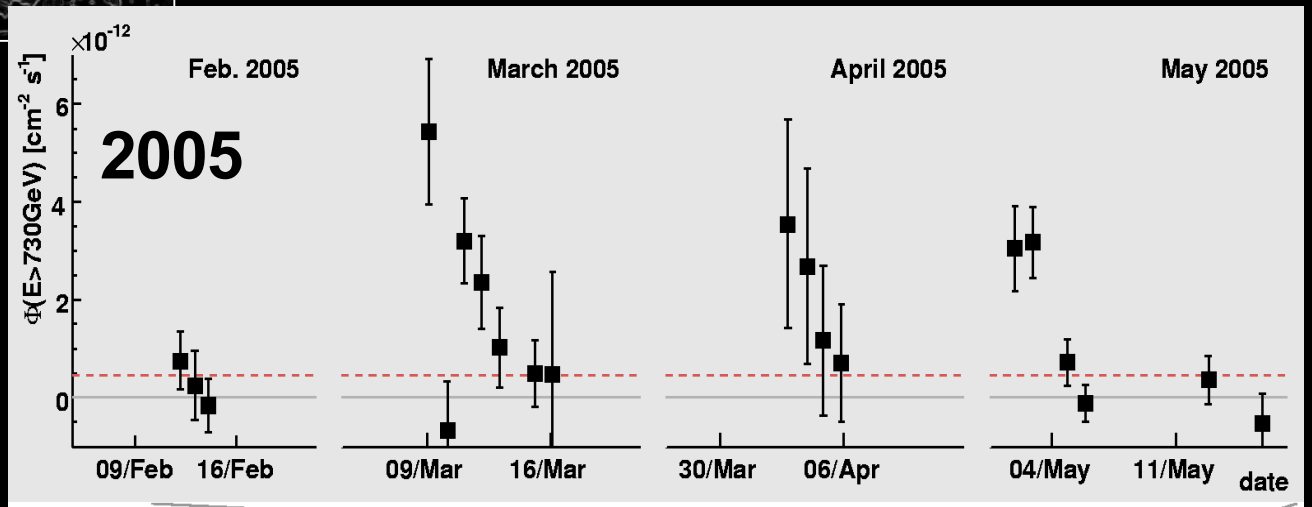


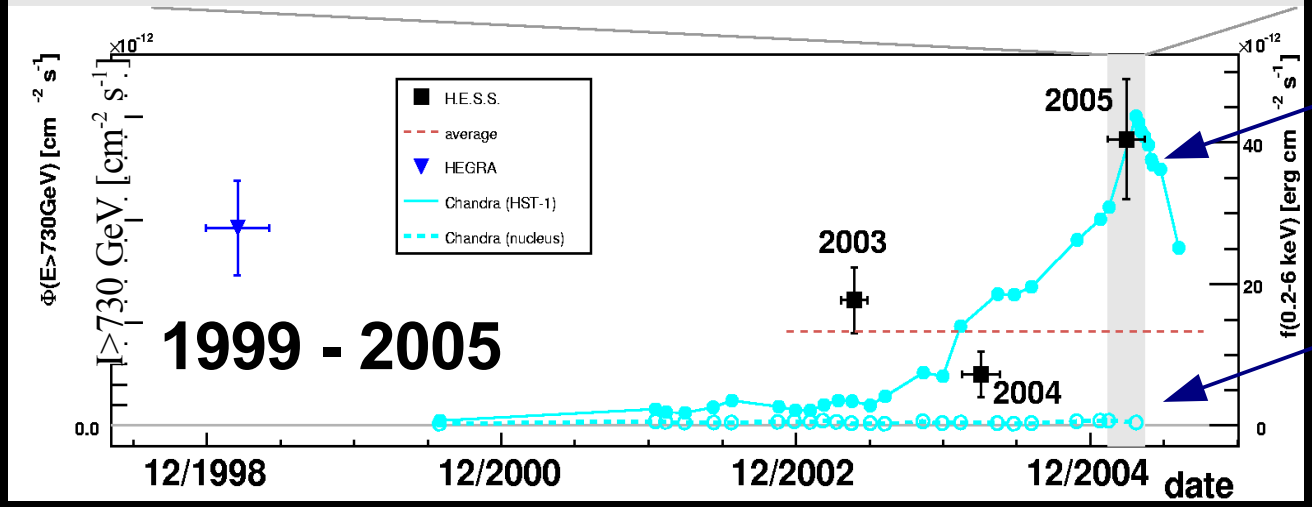
- H.E.S.S: 2003 to 2005
  - → 2003 (19 h) 2005 (52h)
- Point-source, position compatible with M87 nucleus
- UL size 3 arcmin [14 kpc]
- **Spectrum to >10 TeV**

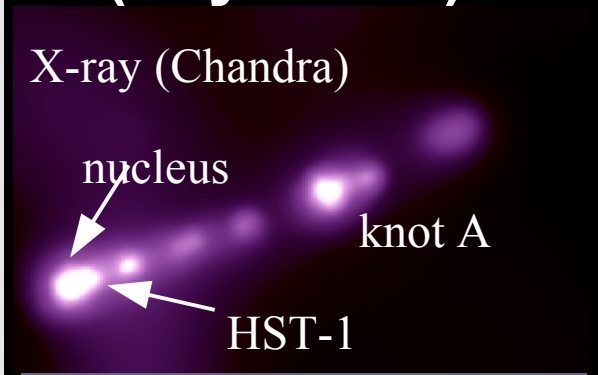


First extragalactic non-blazar TeV γ-ray source

M87: TeV light curve and fast variability (day-scale)







X-ray emission:

- **knot HST-1**
  [Harris et al. (2005), ApJ, 640, 211]
- **nucleus**
  Courtesy to D.Harris (priv. communication)

Variability: Constrain size of emission region: $R \sim 5 \times 10^{15}\ \delta$ cm

No X-ray/TeV correlation: Require further MWL observations

H.E.S.S. Phase II

30 metre diameter Cherenkov telescope

--> push energy threshold down to < 50 GeV

now *under construction*

- AGN, GRBs, microquasars & XRBs

Summary

- A growing TeV Gamma Ray catalogue due to HESS et al.
  - now *TeV astronomy* *(mainstream discipline)*
  - can study Astrophysical sources in detail

- Detailed TeV gamma-ray studies of Shell-SNR and a growing number of pulsar-wind-nebulae (PWN)
  (emission up to 50 TeV in some cases)
  --> particle acceleration above 100 TeV!!

- Shell SNRs: Shells are resolved
  few x 10^{49} erg necessary in protons

- Pulsar Wind Nebulae: Spectral evolution in HESSJ1825-137
  Asymmetric morphology is often seen.

- Compact Binaries: TeV Orbital modulation – probe of gamma production & absorption

- Extragalatic jet sources: Sites of multi TeV particle production: fast variable down to minute timescales