H.E.S.S. Observations of LS 5039 (2004 & 2005 Results Update)

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Yerevan Physics Inst.
Univ. Potchefstroom
Univ. of Namibia, Windhoek

LS5039: A Runaway M-Quasar

Ribo et al 2002 A&A 384, 954

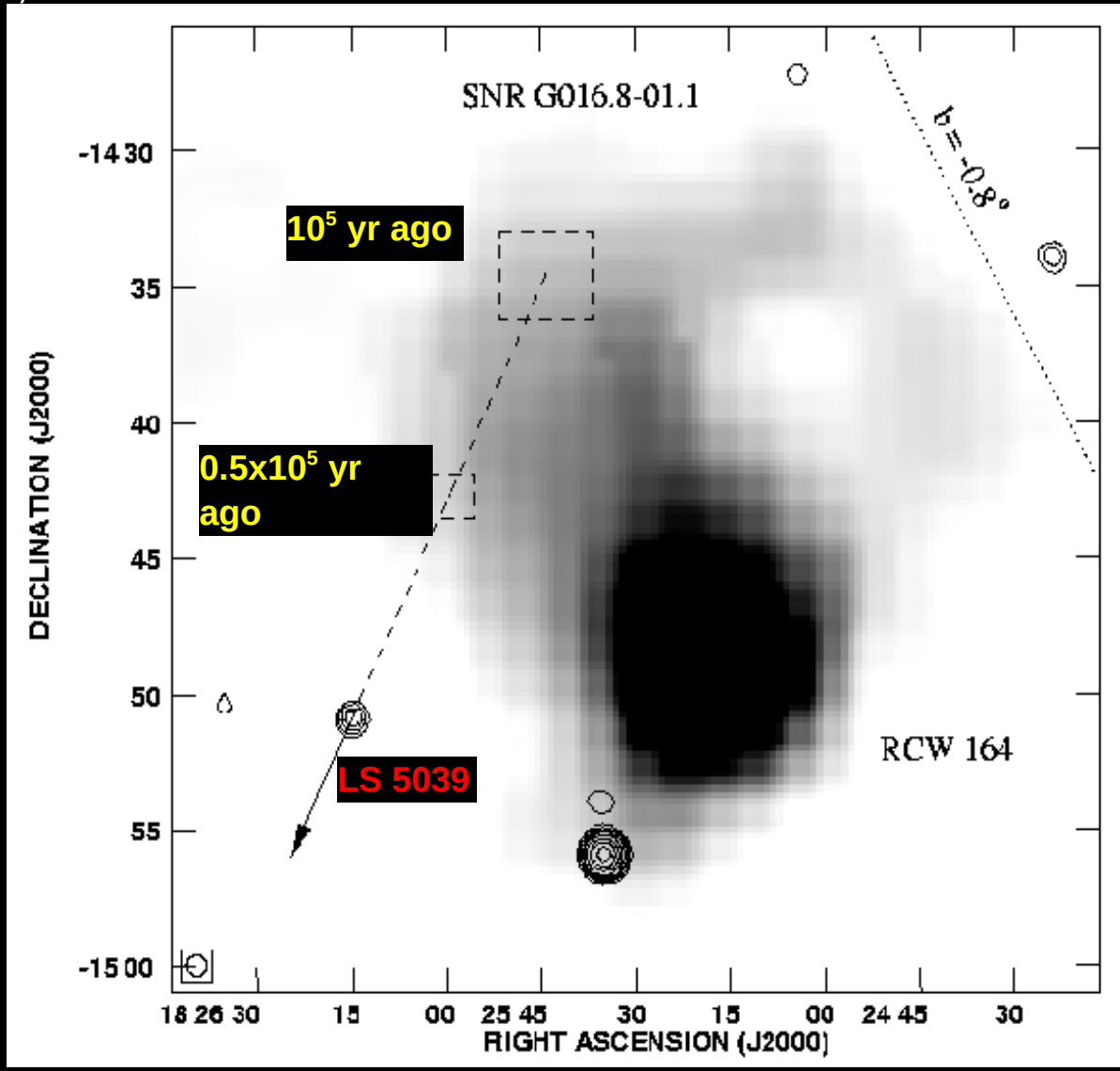
LS5039: v_{sys} ~ 150 kms^{-1}

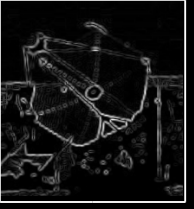
SNR G016.8-01.1
- dist > 2 kpc

(H166α line at 16.5 km s^{-1})

HI cavity (semi-open) at LS5039.
Blown out by O6.5Vf star?

LS 5039 could be a runaway m-quasar from SNR G016.8-01.1





Orbital Parameters

Recent ephemeris

Casares et al. 2005 MNRAS 364, 899

INT Optical Spectroscopy

Porb = 3.90603 ± 0.00017 days
eccen = 0.31 ± 0.04
incl = 25° ± 3°

O-star

M* = 25 M_{sun} (+3.4 -2.9)

R* = 9.3 R_{sun}

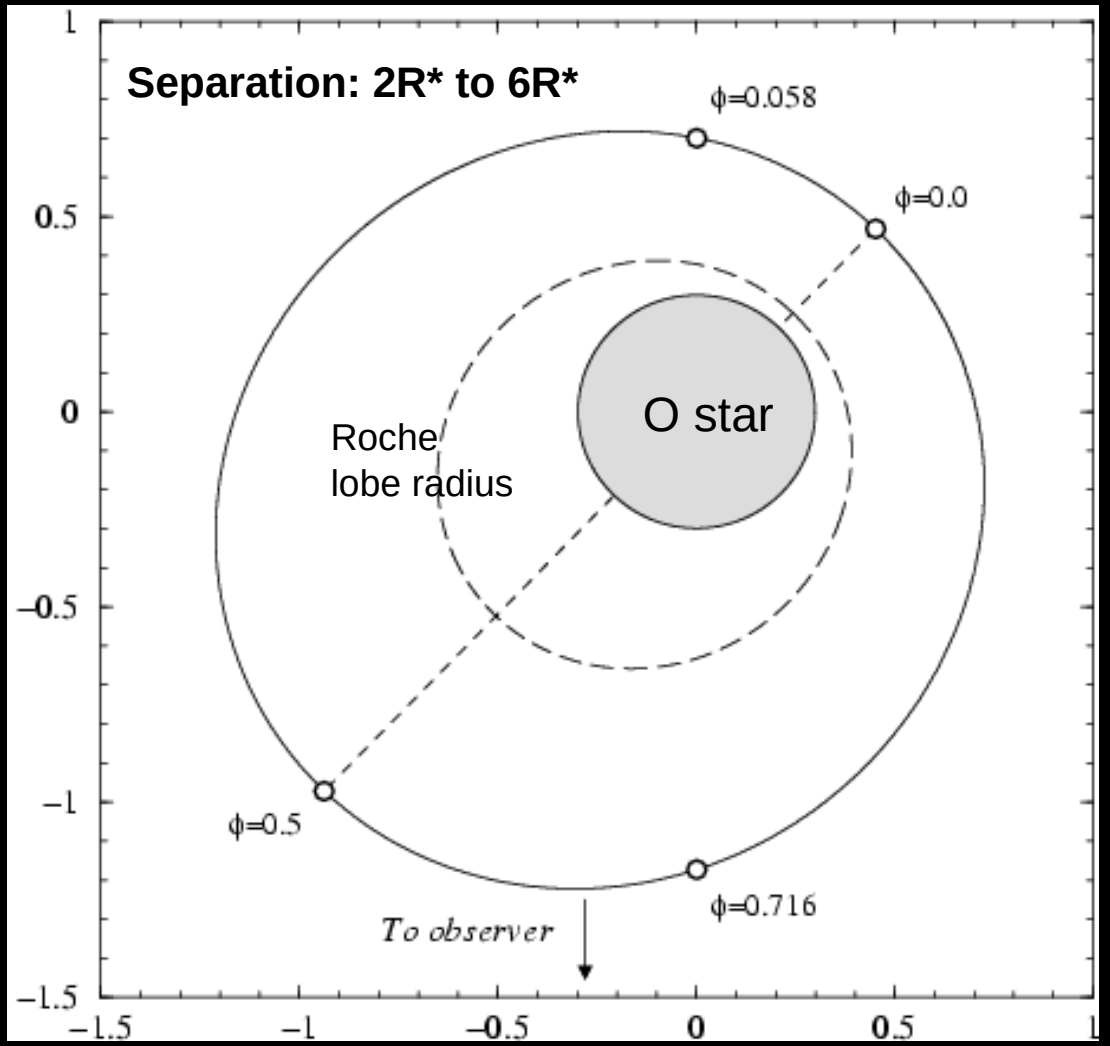
Compact object

M_x = 3.7 M_{sun} (+1.3 -1.0)

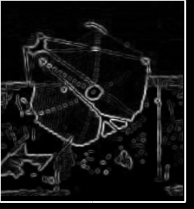
--> a possible black hole

cf. McSwain et al. 2004

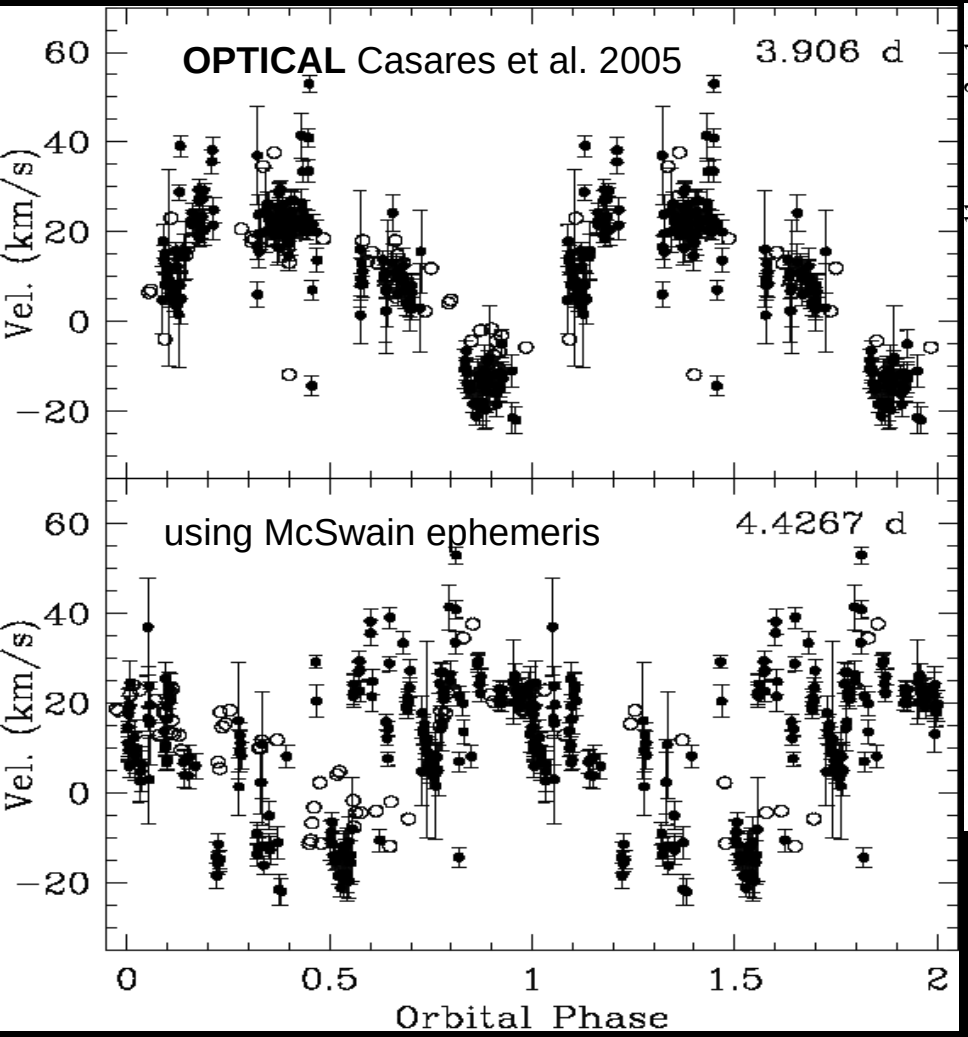
Porb = 4.4267±0.0005 days, eccen =0.48 ± 0.06, M_x = 1.4± 0.4 M_{sun}

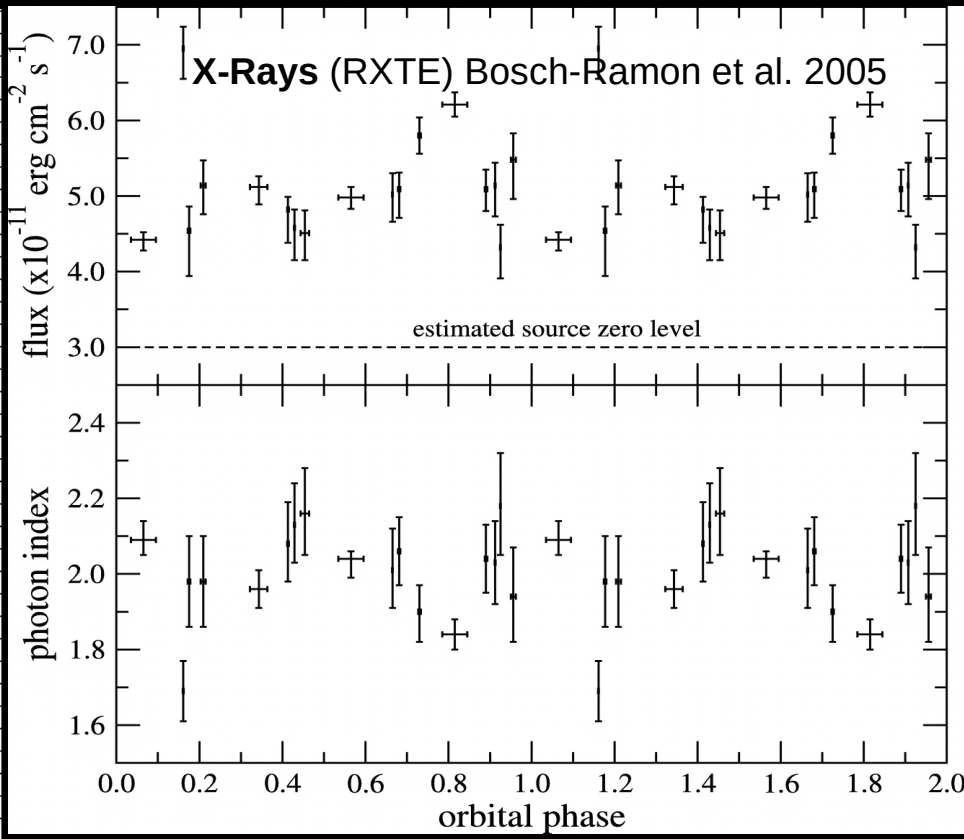


LS5039 System viewed from above (incl = 0°)
[scales are in semi-major axis units]
from Casares et al. 2005



Orbital Motion & Modulation (X-rays)





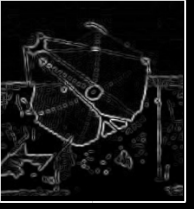
Clear evidence for orbital motion in line velocity.

X-ray peak near phase Φ~ 0.8, factor ~2 flux change over orbital phase.

X-ray eclipse not seen near Φ~ 0.0

see also Beppo-SAX results Rieg et al. 2003

--> system inclination < ~68°



High Energy Stereoscopic System

- Array of 4 Imaging Cherenkov Telescopes

  (square pattern 120m sides)

- Ground-based stereoscopic Cerenkov technique

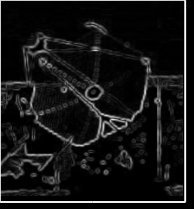
- In Namibia, 1800 m a.s.l.

  – Good infrastructure - dry, high and clear

--> 4-Tel System completed December 2003

--> Observations: roughly ½ Galactic, ½ Extragal

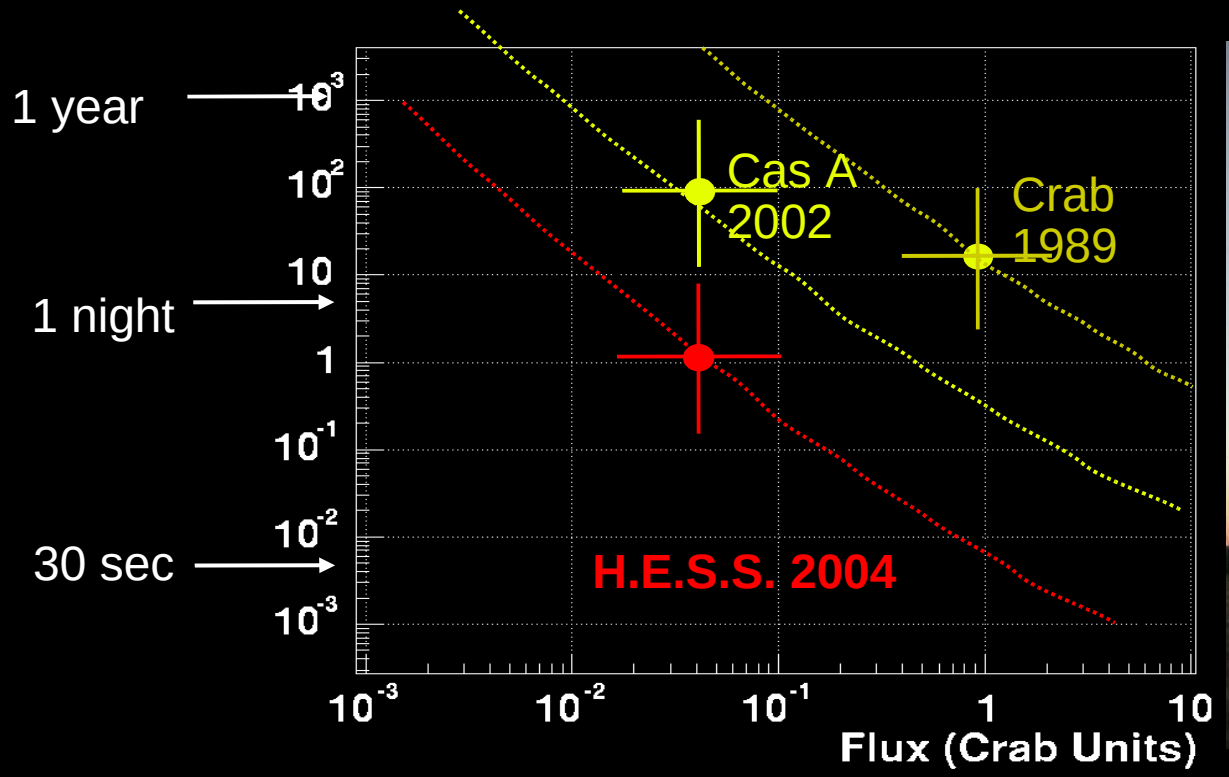
--> 2005: Much time for reobservation/confirmation of new sources!



H.E.S.S. Performance

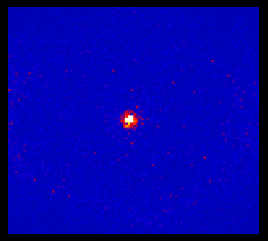
HEGRA (cf. Whipple, CAT)

- **5% of Crab flux in 100 hrs**
- **500 GeV Threshold**
- **Crab flux ~ 10 sigma/sqrt(hr)**



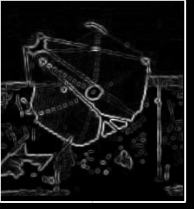
H.E.S.S. (cf. VERITAS…)

- **5% Crab flux in 1 hour**
- **0.5% Crab in 100 hours**
- **100 GeV Threshold**
- **Angular res better than 0.1° per event.**
- **Energy res <= 20%**
- **Similar to ASCA in ang & energy flux sensitivity!**



Ang. res: ~ few arc-minutes

Pt. src location: few arc-seconds (0.1 Crab flux ~ 25 hrs)



LS5039: H.E.S.S. 2004 Results

Aharonian et al. (2005) Science 309, 746

10.5 h obs. time

~250 gamma-rays

+8σ Excess

dN/dE ~ $E^{-\Gamma}$

Γ = 2.12 ± 0.15

Int. flux

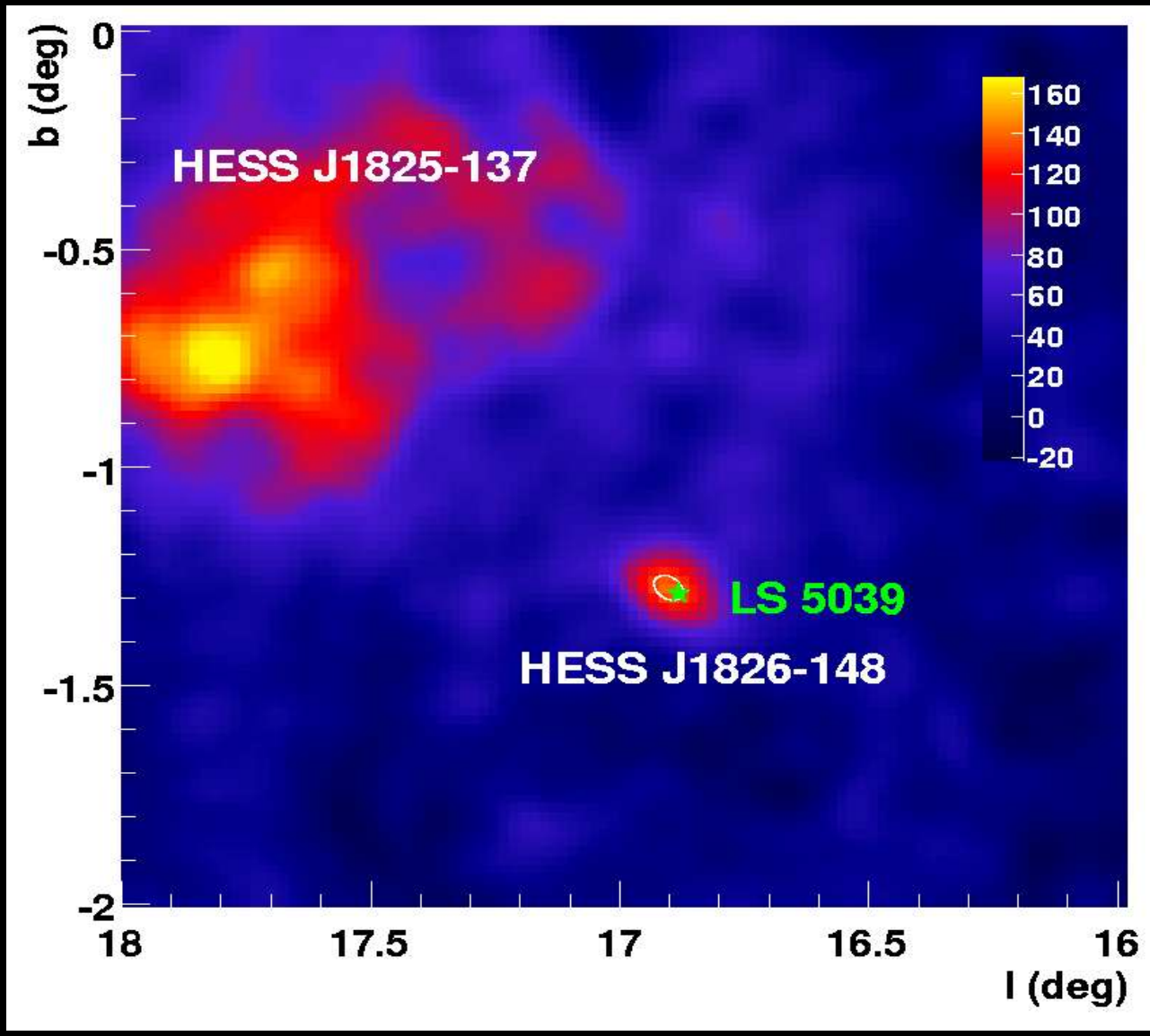
Φ (>0.25 TeV)

= 5.1(±0.8) x 10^{-12}

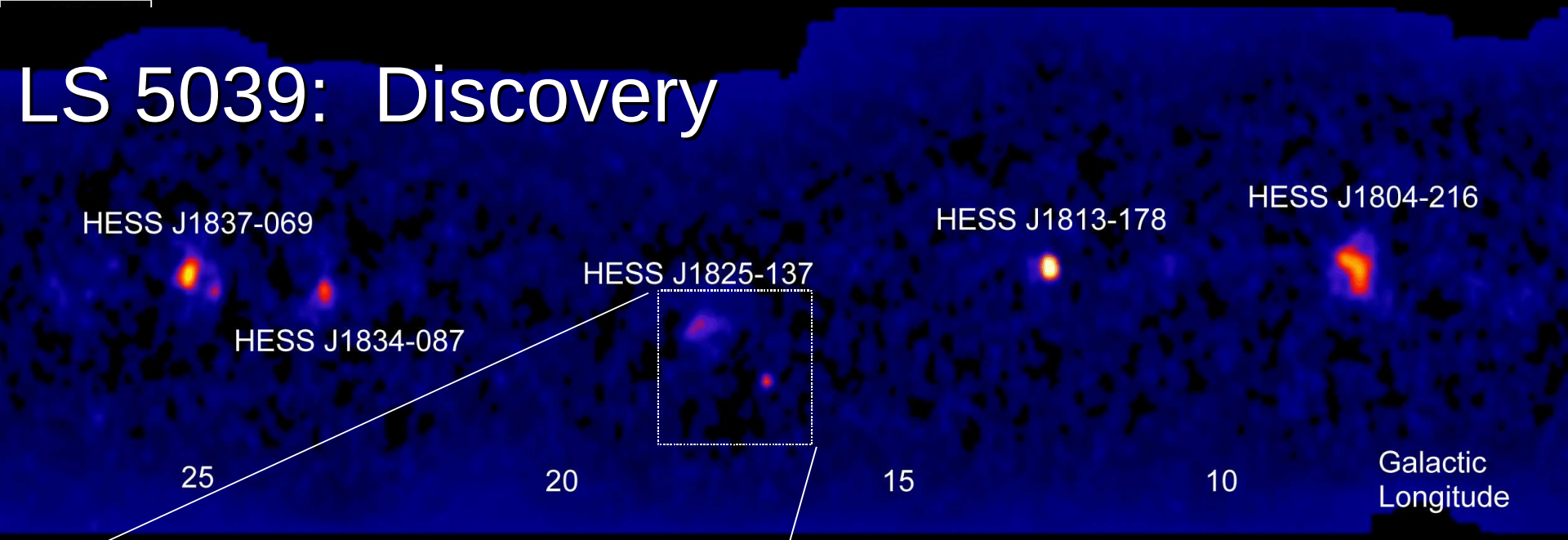
ph cm^{-2} s^{-1}

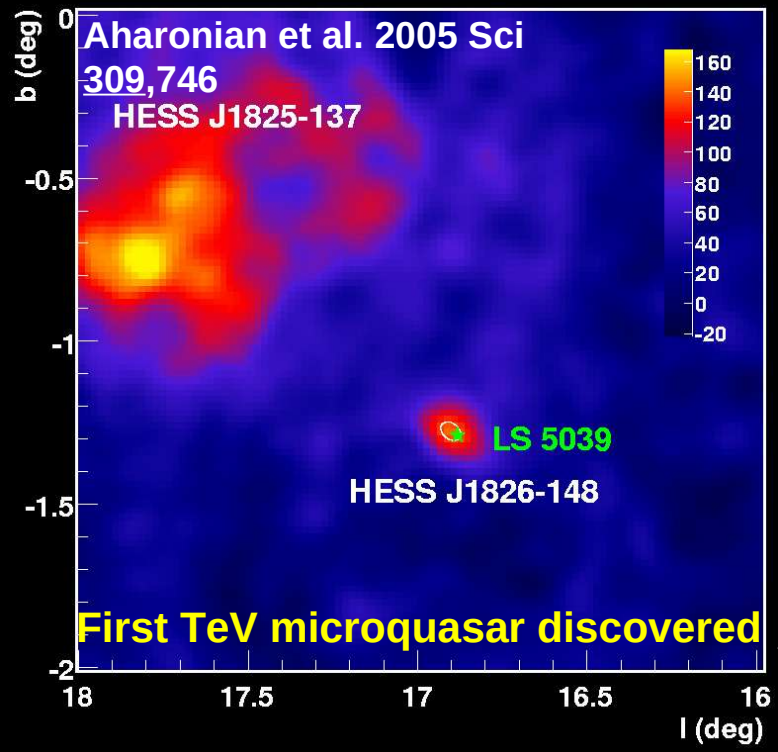
L_{TeV} ~ 4x10^{33} erg s^{-1}

(d=3 kpc)



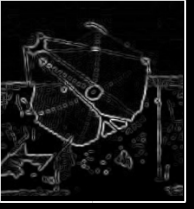
LS 5039: Discovery





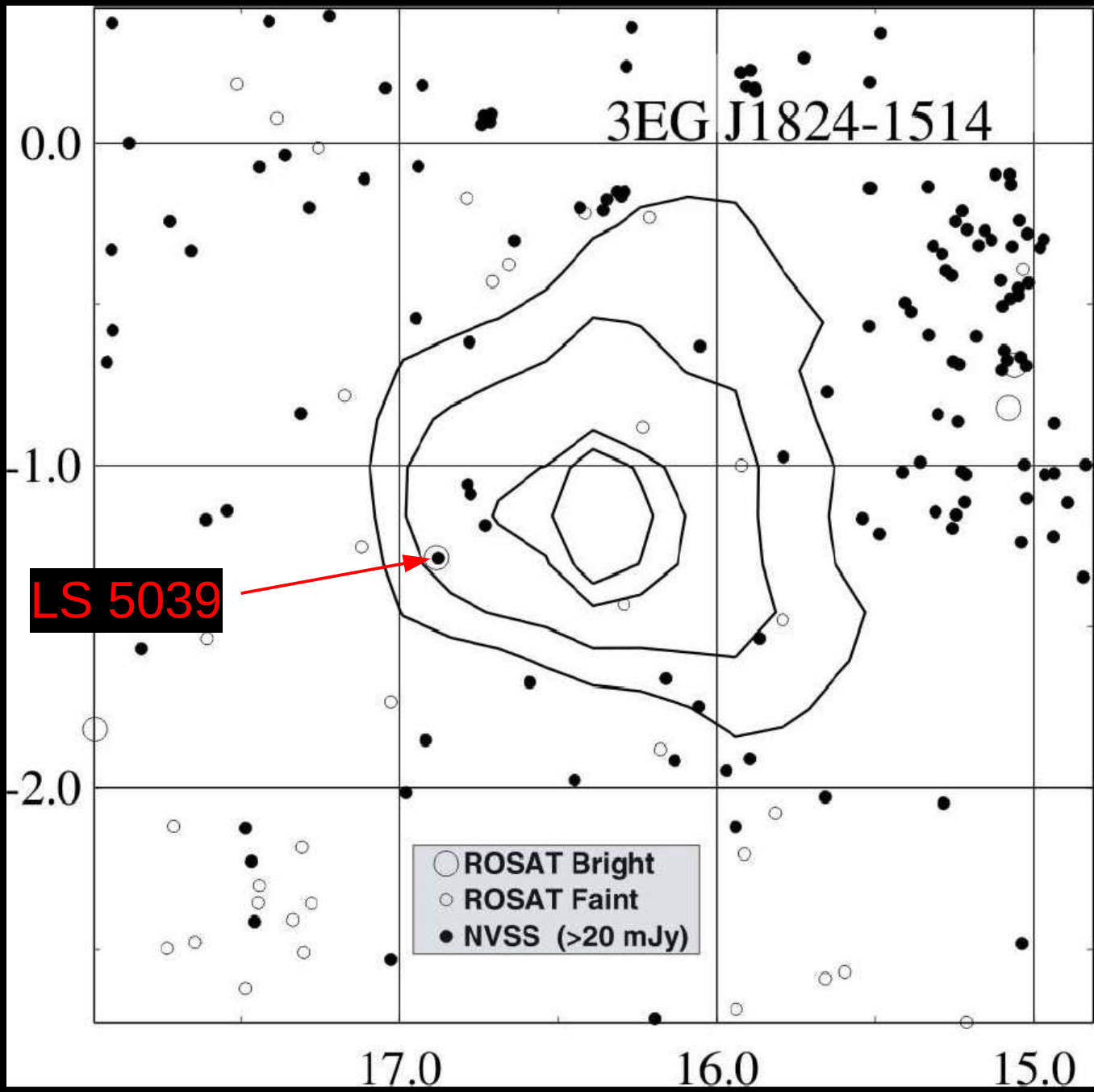
- Discovered in Galactic Scan data (serendipitously)

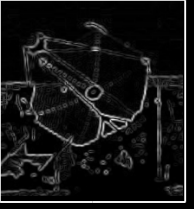
- In fact: The only pt src. discovered in Gal. Scan!



EGRET Source

Paredes et al 2000





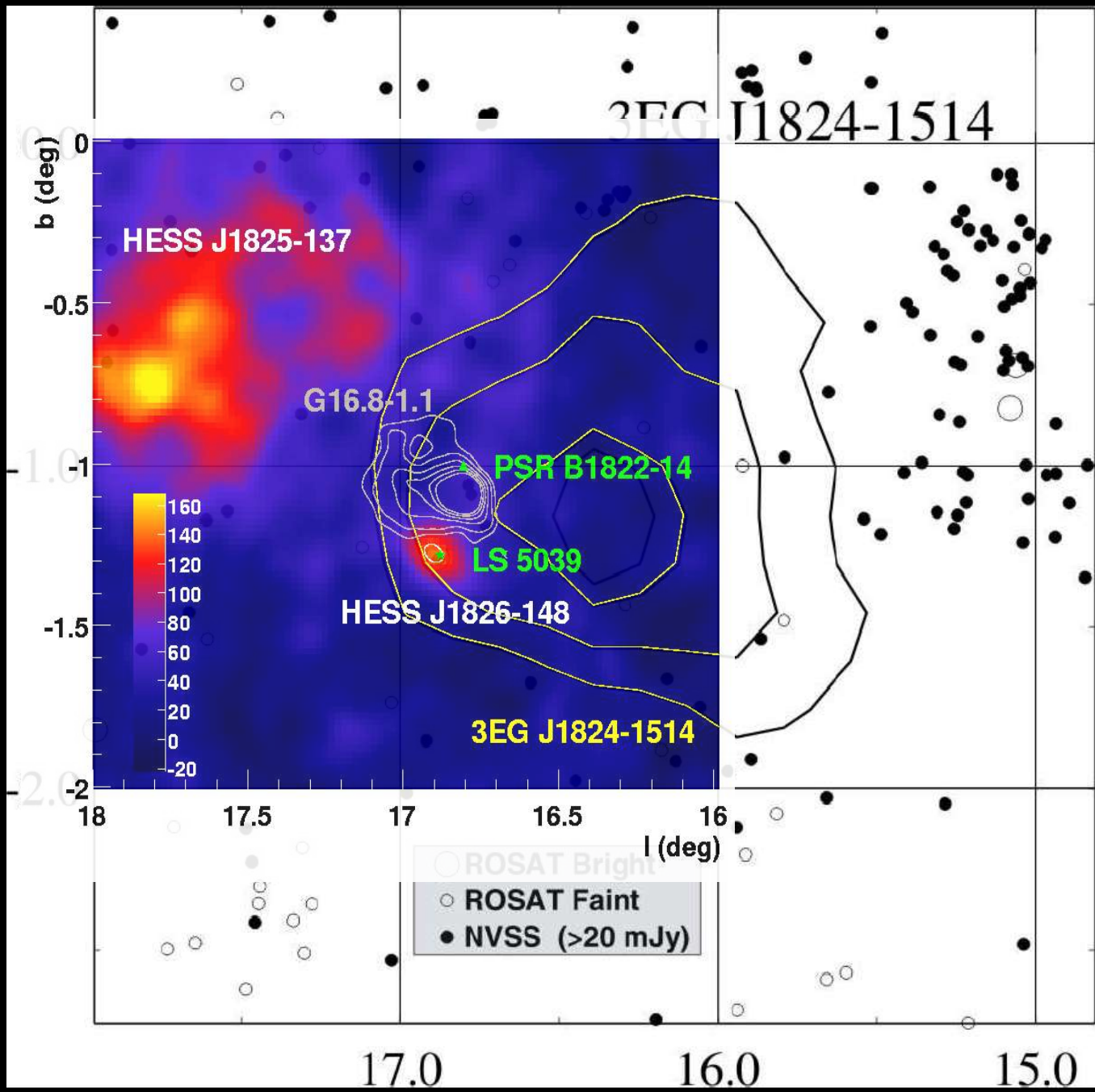
Other potential CR accelerators:
for HESS J1826-148

- SNR G16.8-1.1

possible birthplace of LS5039.

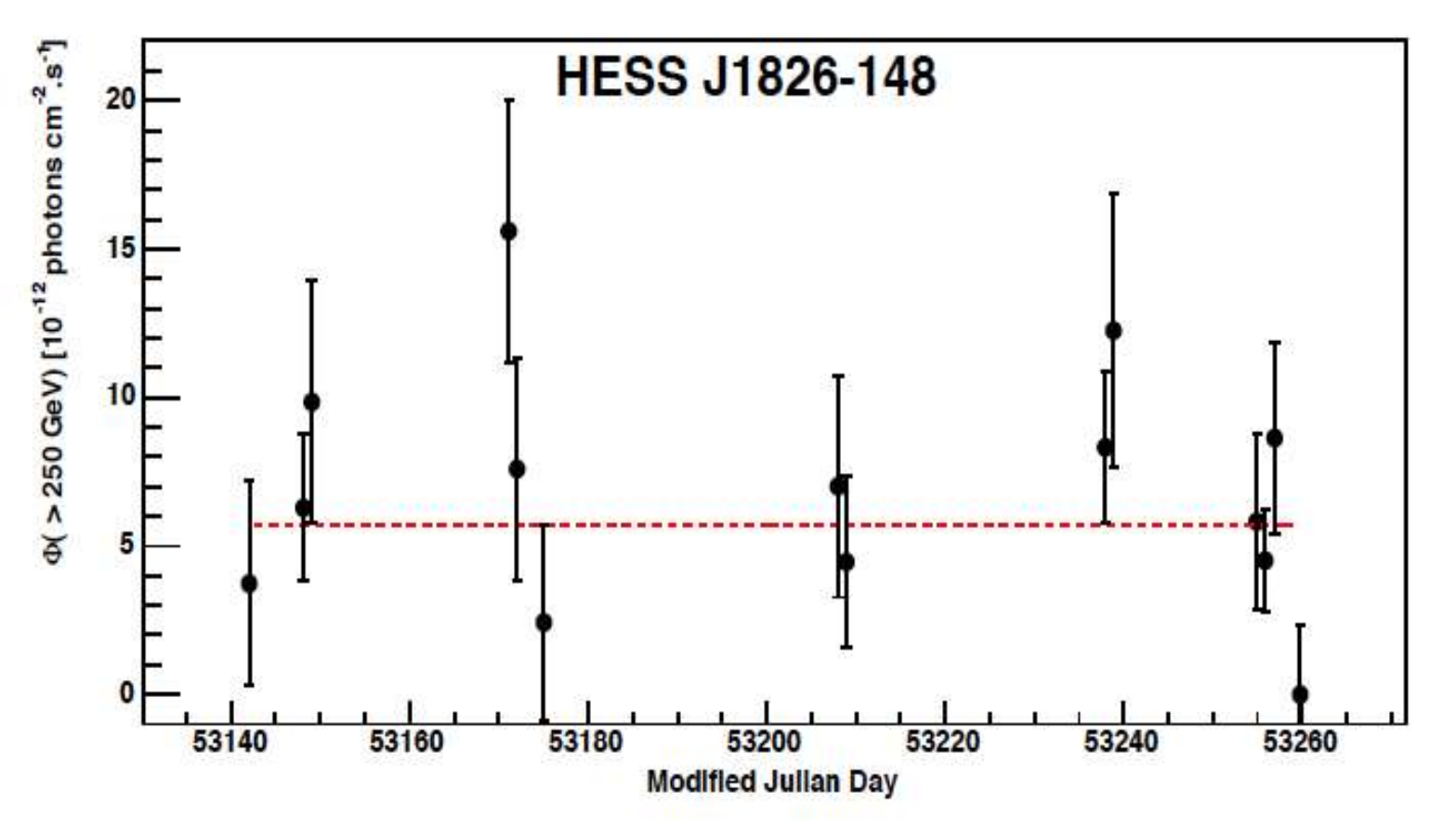
- PSR B1822-14

too far.



LS5039: 2004 Data

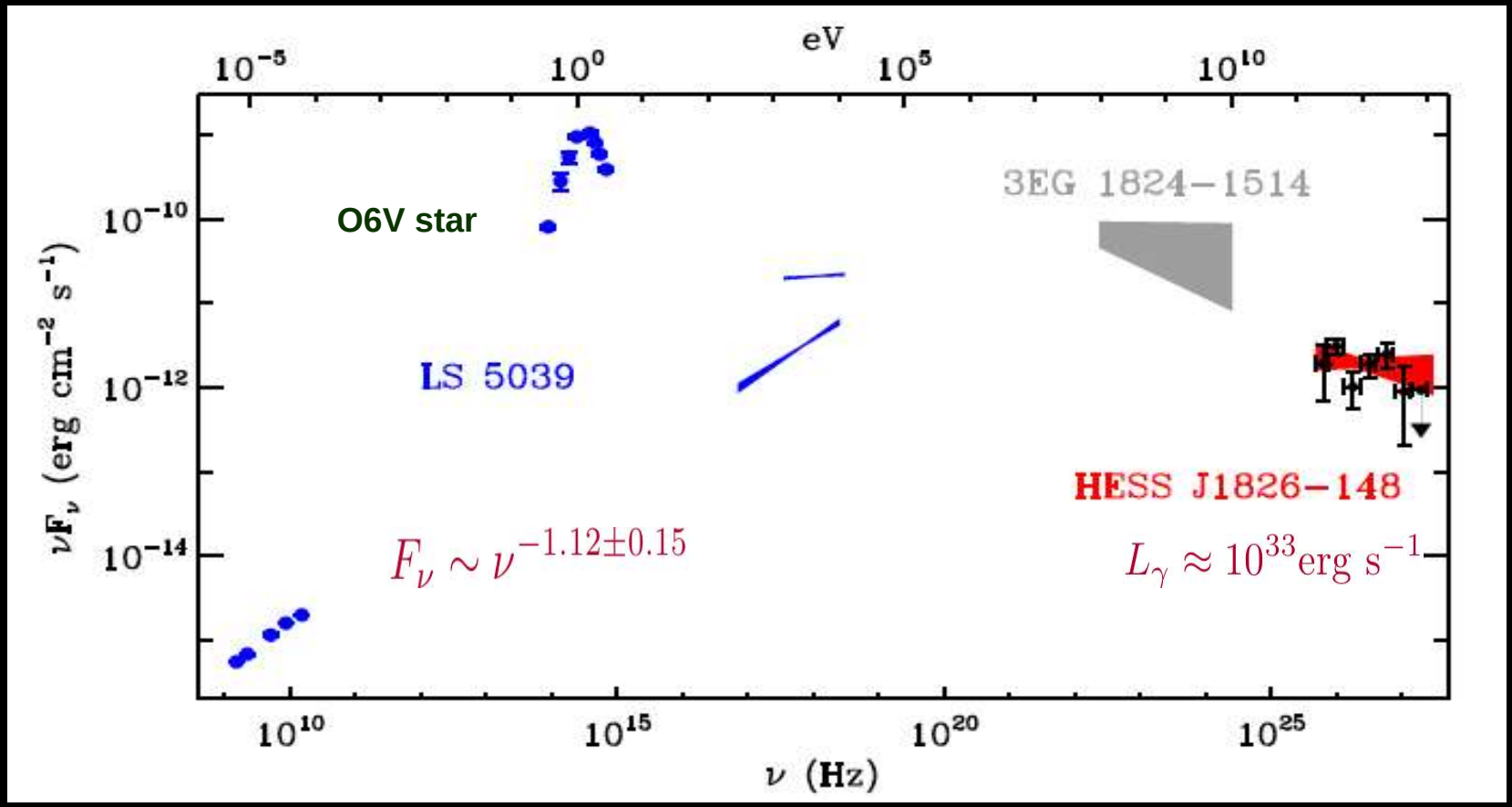
NightByNight Light Curve (E>250 GeV)

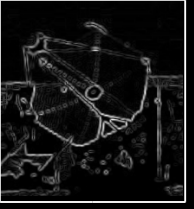


Insufficient statistics to establish variability

LS5039: 2004 Data

SED





H.E.S.S. Observations 2004 + 2005 prelim

2004 – Galactic Scan (May, Jun, Jul, Aug, Sept)

2005 – Dedicated + Scan + HESSJ1825 (Mar, Apr, May, Jun, Jul)

- Aug, Sept, Oct still to include!

Year	hrs	<zen>	runs
2004	10.2	33.6	24
2005	46.2	19.1	108
Total	56.4	21.8	132

Analysis

- Hillas-based cuts (mean-scaled-width & length) (Aharonian et al. 2004)
  HARD cuts 200 pe image cut

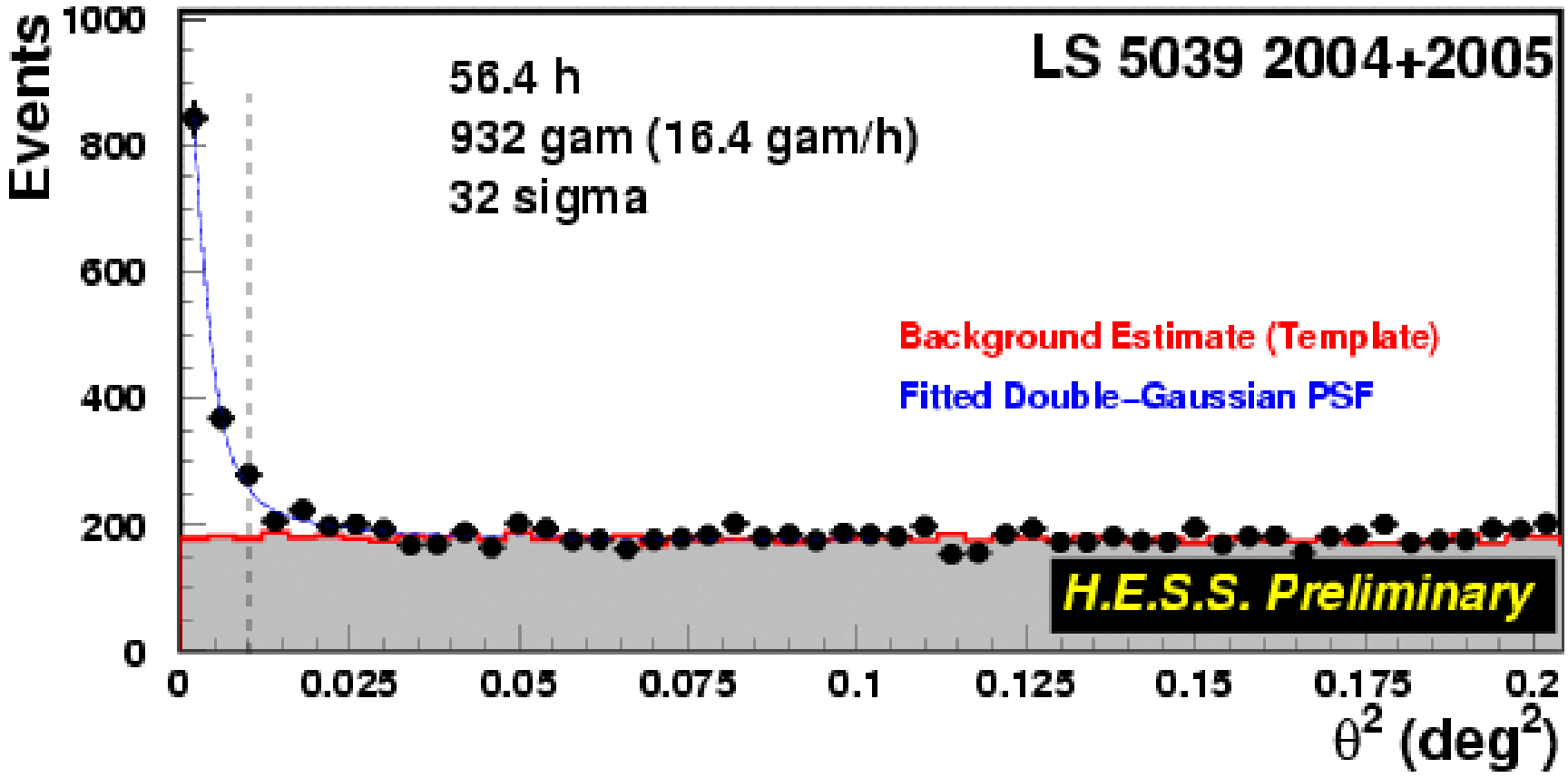
(preliminary results presented here)

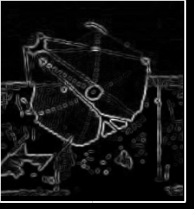
- Model + Hillas-based Analysis combination (deNaurois et al. 2003, 2005)
  1. MC-Model of EAS showers --> Max Likelihood
  2. Hillas-based cuts

Results: Hard Cuts Analysis (Hillas-based)

Compare two Background Estimates $\Theta < 0.1°$

ON	1366				
Template	2707	31.9σ	α=0.160	932.1 evts	16.5 gam/hr
Mirror	5061	32.8σ	α=0.080	921.3	16.4





Location and Size

- 2D hist. of ON evts (uncorrelated)
- 50x50 bins 0.5° x0.5°
- Fit 2D Double Gaussian + pedestal
- incl. PSF

Fitted Location J2000.0

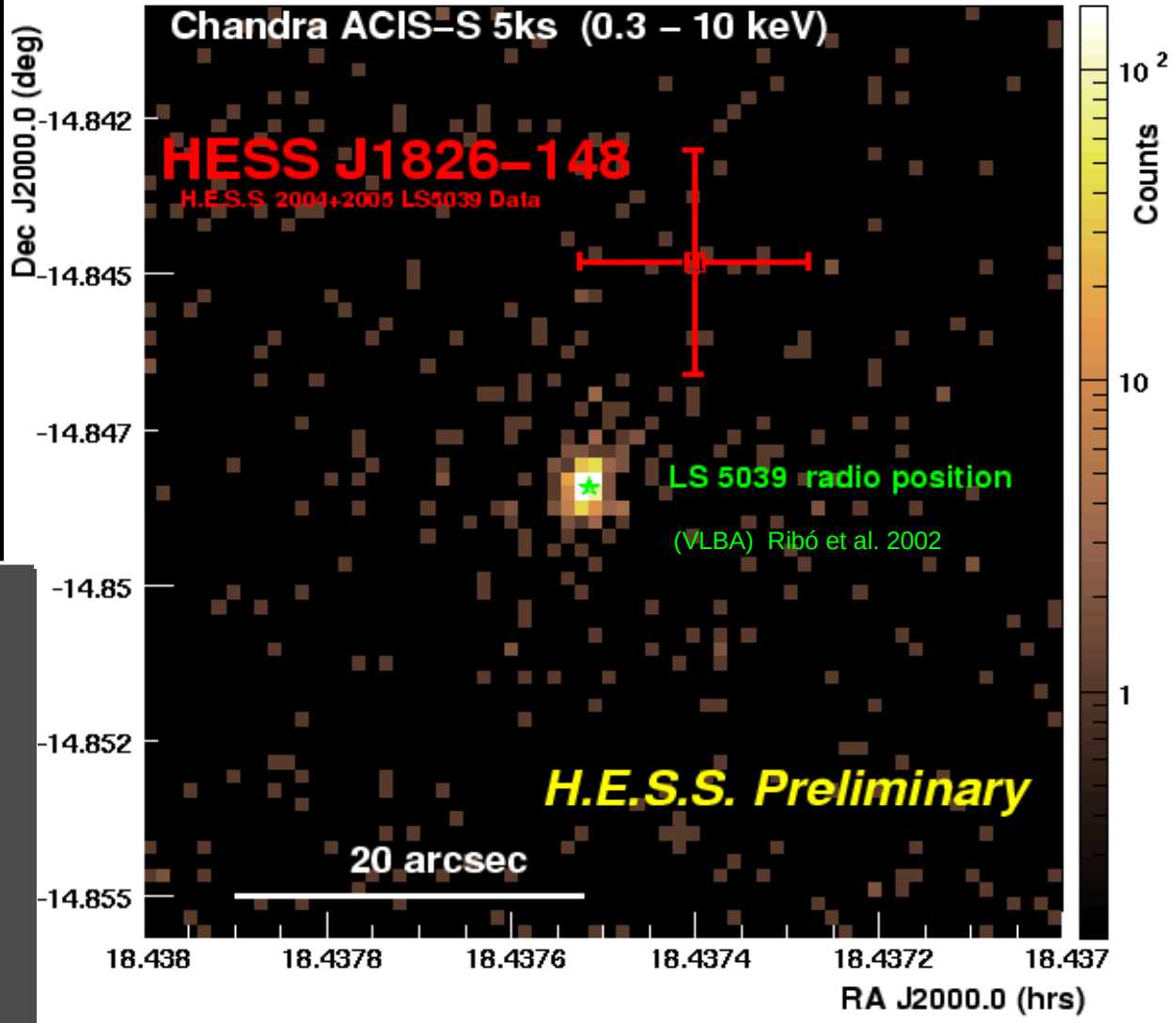
```
RA  (hrs)     18.4374 (+-6.7")
Dec (deg)    -14.8448 (+-6.5")

       18h 26m 14.6s (+-6.7")
      -14d 50m 41.3s (+-6.5")
```

Fitted Intrinsic Size

```
0.00 +- 0.01 deg
```

Compare to Chandra X-ray Image



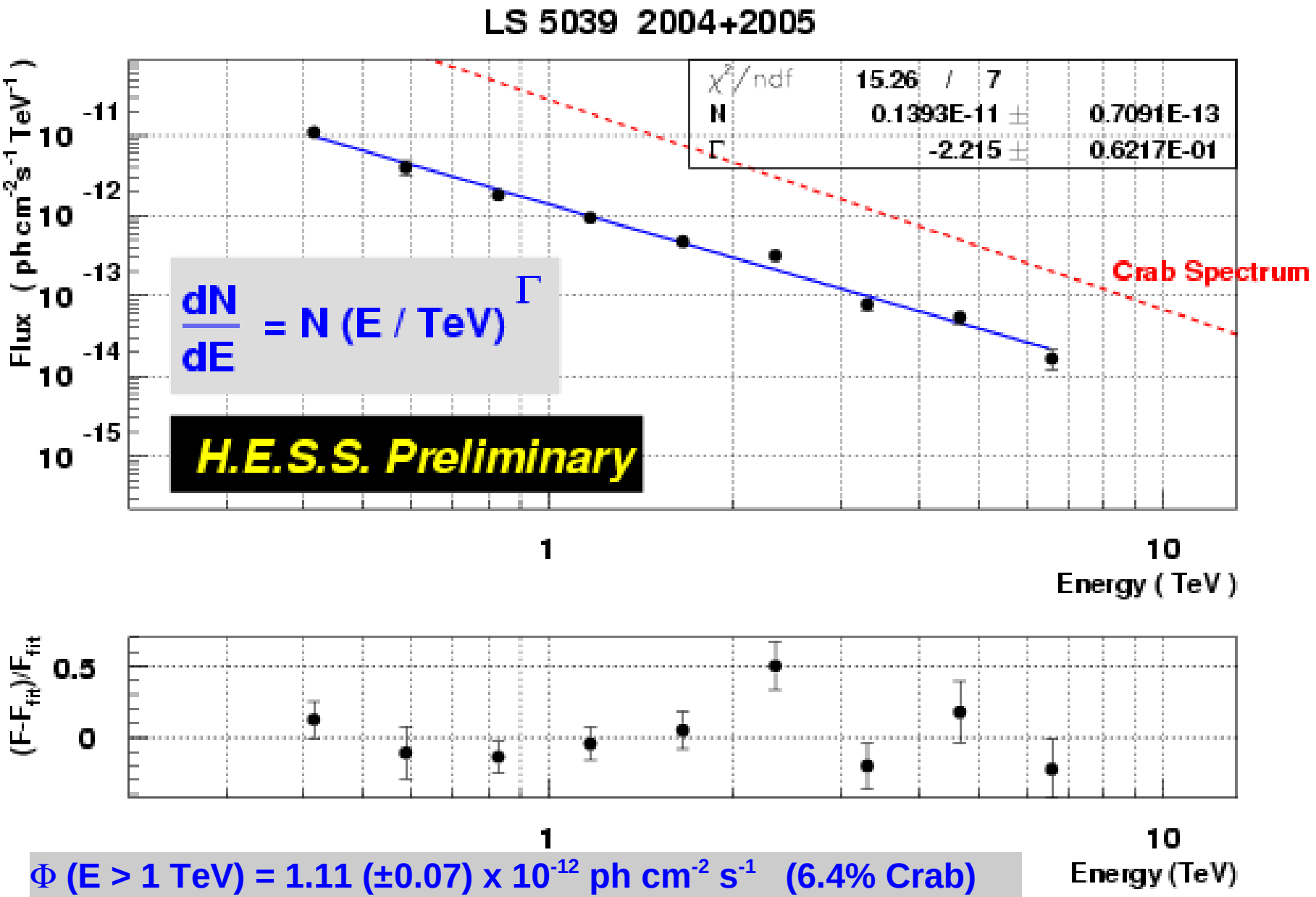
--> ~7 arcsec stat. error

--> point source

systematic error 20 arcsec

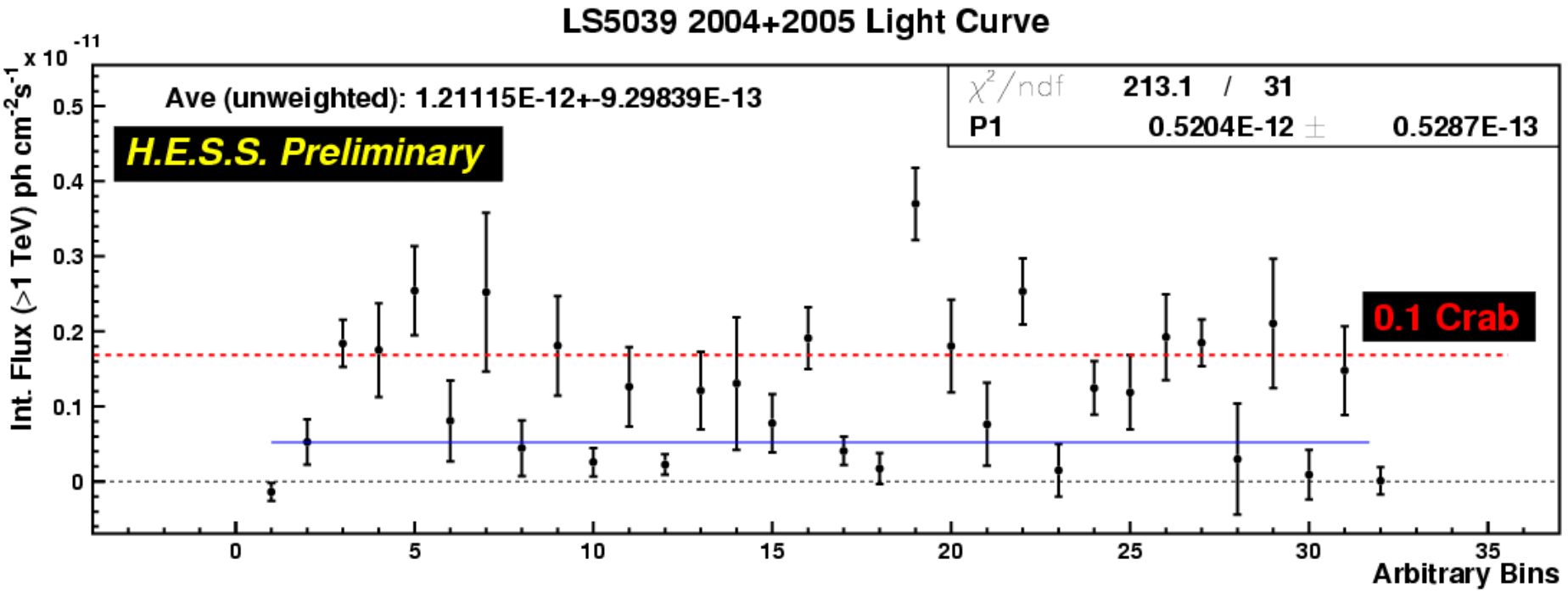
--> TeV/Radio/X-ray location all consistent

Energy Spectrum (2004+2005) E>0.35 TeV



Φ (E > 1 TeV) = 1.11 (±0.07) x 10^{-12} ph cm^{-2} s^{-1} (6.4% Crab)
[consistent with 2004 results]

Light Curve: Night-By-Night Flux (E>1 TeV)

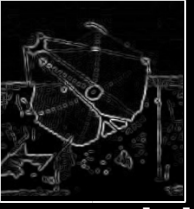


Prob(χ^2)= 4.6x10^{-29}

Studies on the (expected steady) CR flux suggest ~10 to 15% inter-night systematic:

Conservatively, include 30% random systematic (added in quadrature) χ^2 = 88.1/31 --> Prob(χ^2)= 2.2x10^{-7}

--> Clear indication of variable flux



TeV Gammas: How?

Particles (e and/or p) accelerated in jet (or further out):

<u>Leptonic:</u> Inverse-Compton scattering of UV phot. from O-star
(Bosch-Ramon etal. 2004)

<u>Hadronic:</u> interaction of protons with stellar wind (π^o decay) (Aharonian et al 2005)

If TeV gamma-rays are produced within the binary system

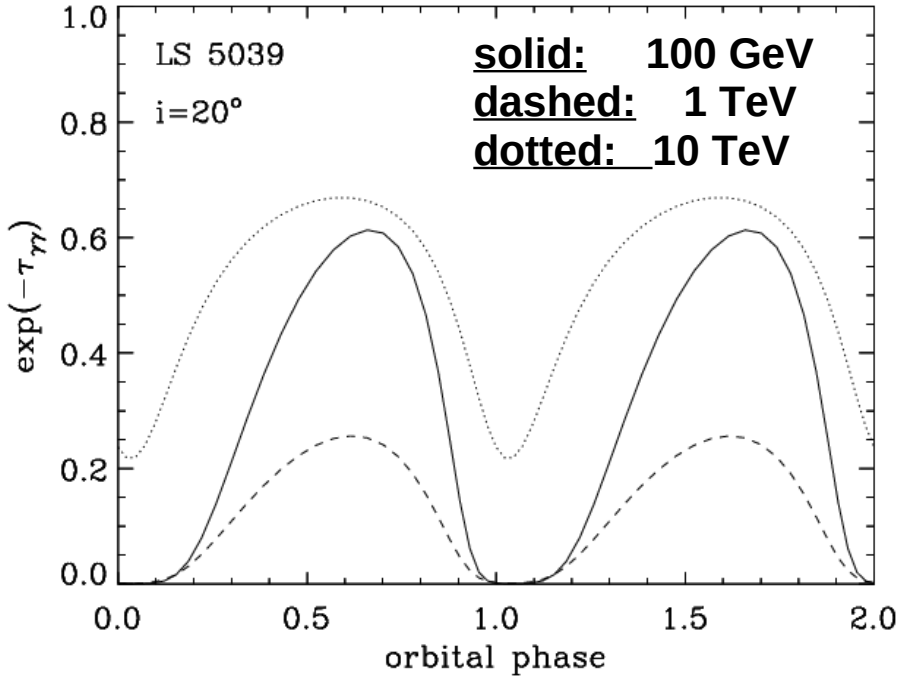
(R <10^{12}cm)

--> severe absorption (factor 10-100) of >100 GeV gammas (γ + UV -> e^+e^-)

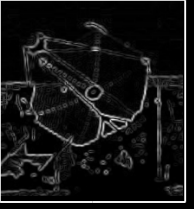
$\tau_{\gamma\gamma} = \sigma_{\gamma\gamma}$ **n r ~ 20** **(n~10^{14} ph cm^{-3} r=10^{12} cm)**

--> Depends on inclination angle *i*
larger i --> stronger modulation

Dubus 2005 astro-ph/0509633



(see also Böttcher etal. 2005)



A Hadronic/Neutrino Source?

(Aharonian et al. astro-ph/0508658)

If TeV gamma-rays are produced within the binary system ($R < 10^{12}$cm)

--> severe absorption (factor 10-100) of >100 GeV gammas (γ + UV -> e^+e^-)

Electrons

severe radiative (synchrotron and Compton) losses B ~ O(1 Gauss)

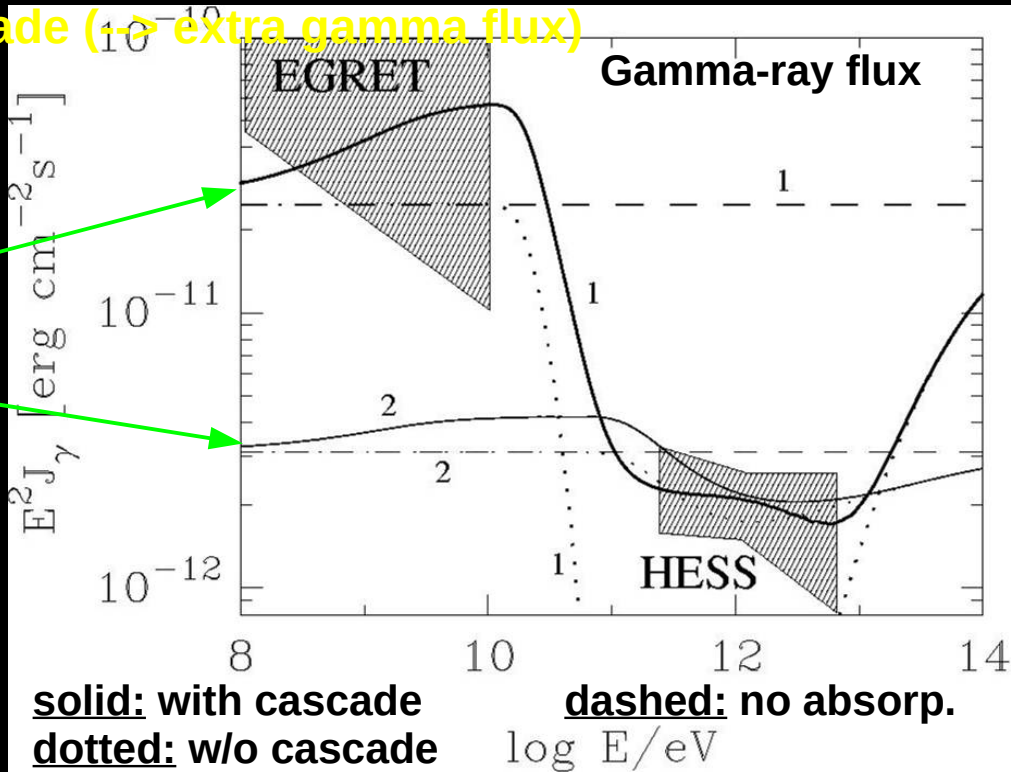
---> difficult to accelerate electrons to multi-TeV energies within binary sys.

Conclusions **TeV gamma-rays of hadronic origin with high luminosity, and consequently TeV neutrino fluxes (!) Pair prod gives rise also to pair-gamma cascade (--> extra gamma flux)**

Orbital modulation ---> suggests hadronic origin...?

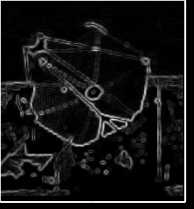
TeV gamma/neutrino production sites:

1. Base of the jet/accretion disk
2. wind/atmosphere of the star



solid: with cascade **dashed:** no absorp.

dotted: w/o cascade



ROSTE IIIc Observations

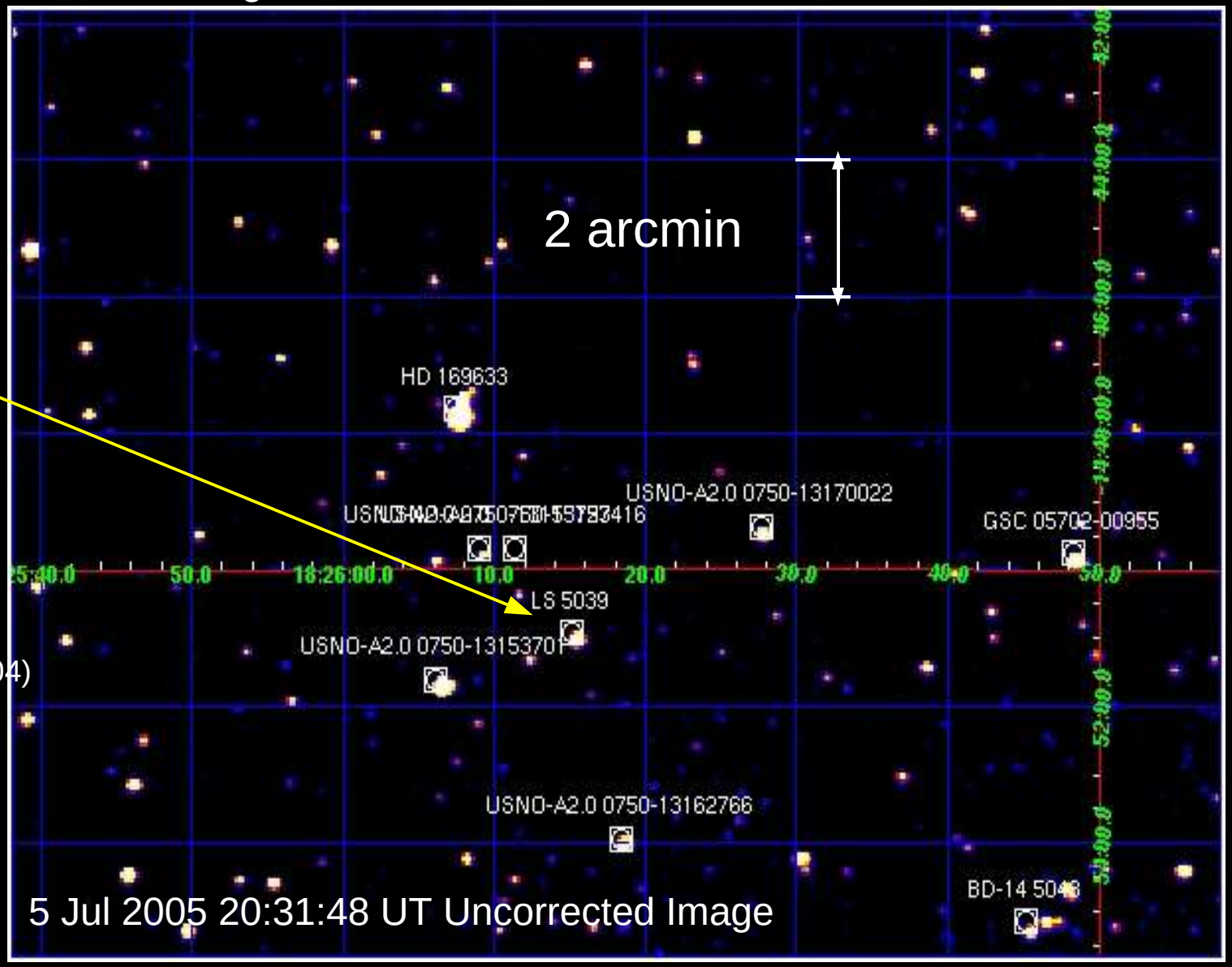
- Optical photometry via CCD : 5sec frames overlapping HESS LS5039
- cross check with neighbour stars

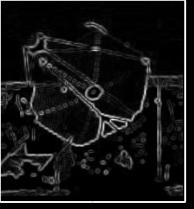
Companion star

B_v ~ 11.2

O-type

see Combi et al. (2004) for prev. optical studies...





Conclusions – 2004 & 2005 (Prelim)

- LS5039 is established as a variable, pointlike TeV source.
  Detection > 30 sigma, > 900 gamma-ray events.

- Location consistent with radio VLBA position
  within systematic error 20 arcsec.

- Hard photon spectrum: power law $\Gamma \sim 2.2$ (0.35 to 7 TeV)

Work in progress

- Additional data from Aug, Sept & Oct 2005 still to include

- Investigating orbital modulation (flux) (using Casares et al. 2005 ephemeris)

- Investigating spectrum vs. orbital phase

- *Chandra* X-ray obs (5ks 13 April 2005)
  overlaps 2 HESS runs (~1 h)