

# Gamma-ray binaries @ VHE: spectra and variability

Jim Hinton  University of  
**Leicester**

# 2 Current ACTs



VERITAS



HAGAR



Whipple 10m



MAGIC



TACTIC



HESS



CANGAROO-III



# 3 Current ACTs

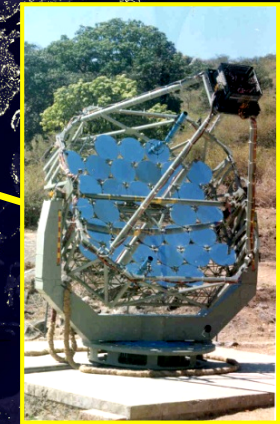
- **HAGAR**
  - ▶ Non-imaging array  $7 \times 7 \times 1$  m
  - ▶ Altitude 4300 m
  - ▶ Sensitivity  $\sim 35\%$  Crab
- **TACTIC**
  - ▶ 3.5 m imaging telescope
  - ▶ Altitude 1300m
  - ▶ Sensitivity  $\sim 70\%$  Crab
- **Whipple 10m**
  - ▶ Sensitivity  $\sim 15\%$  Crab
- **CANGAROO-III**
  - ▶ Operating with 2 telescopes
  - ▶ Sensitivity  $\sim 15\%$  Crab.



**HAGAR**



**Whipple 10m**



**TACTIC**

**CANGAROO-III**





# 4 Current ACTs



VERITAS



MAGIC



HESS

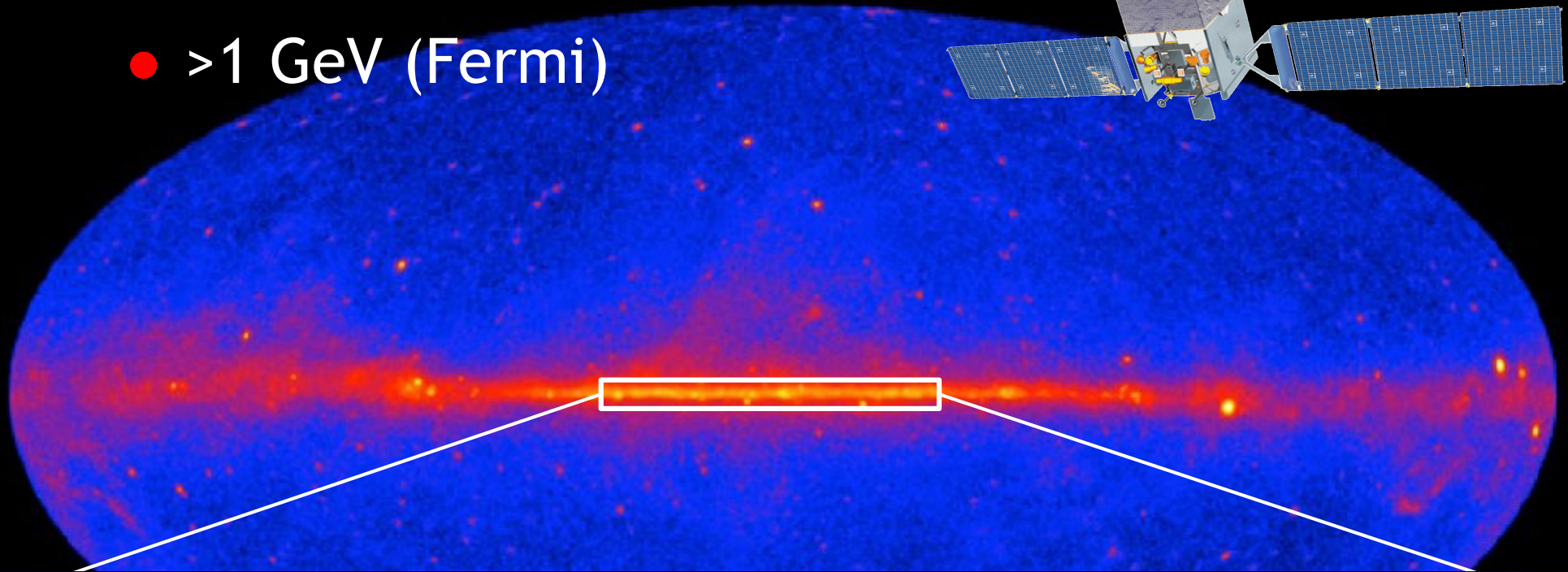
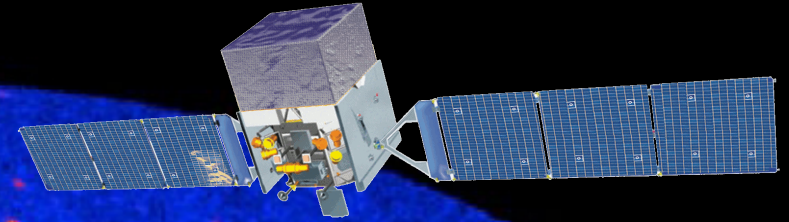
## The Big Three

- ▶ Sensitivity  $\sim 1\%$  Crab (50 h)
- ▶ Field of view  $\sim 4^\circ$
- ▶ Angular resolution  $\sim 0.1^\circ$
- ▶ Energy resolution  $\sim 15\%$
- ▶ Duty cycle  $\sim 10\%$
- ▶ Threshold 50-100 GeV
- ▶ Maximum 10-80 TeV



# 5 HE/VHE Sky

- $>1$  GeV (Fermi)

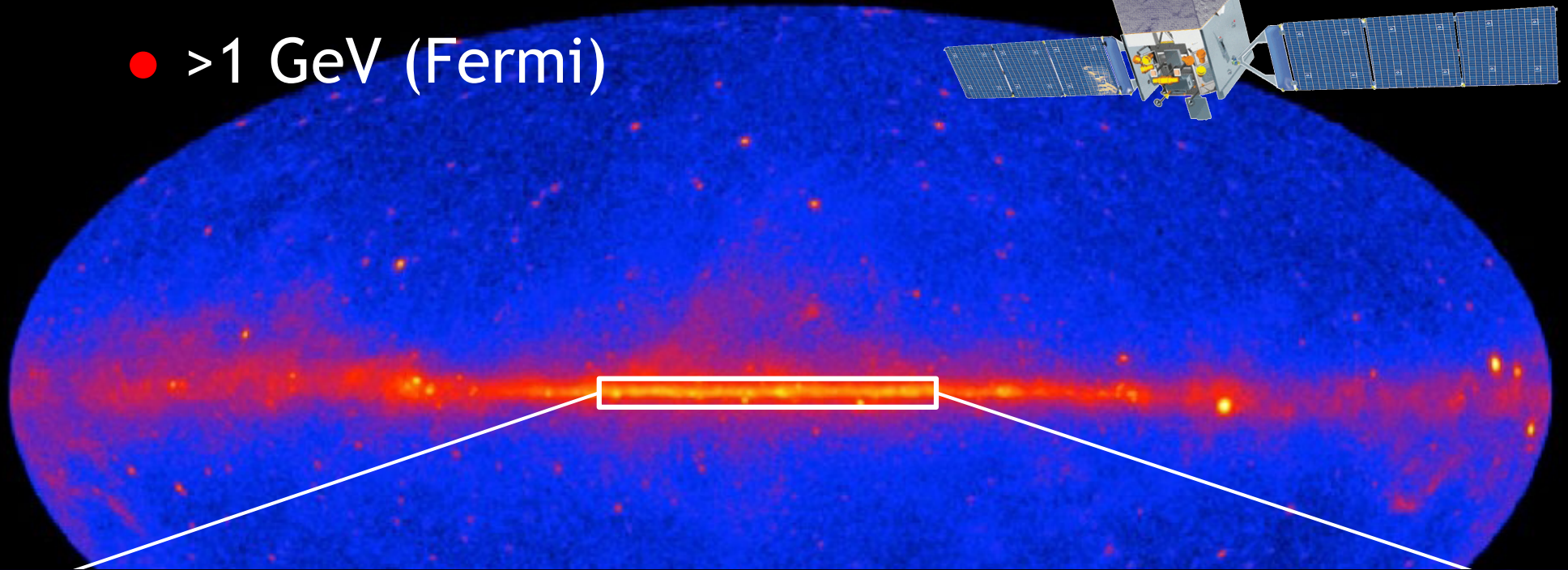
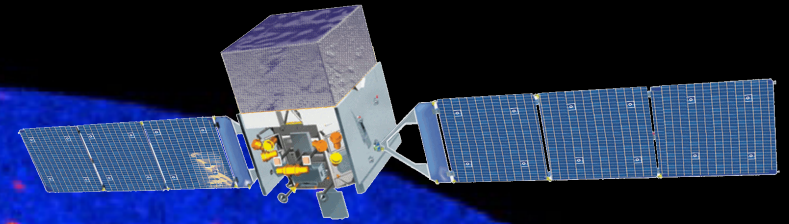


- $>5$  GeV (Fermi) cf  $>200$  GeV (HESS)



# 6 HE/VHE Sky

- $>1$  GeV (Fermi)



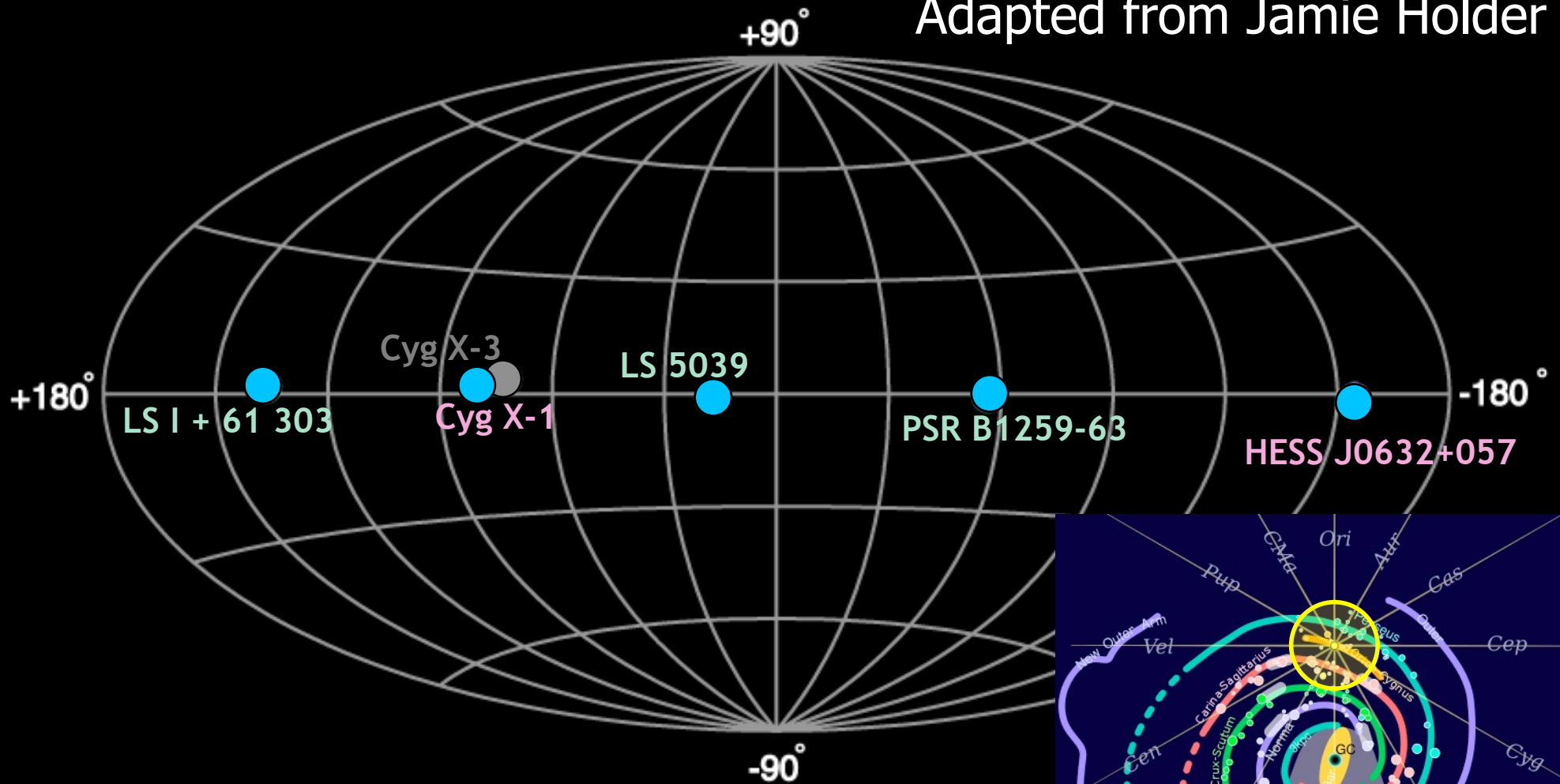
- $>5$  GeV (Fermi) cf  $>200$  GeV (HESS)



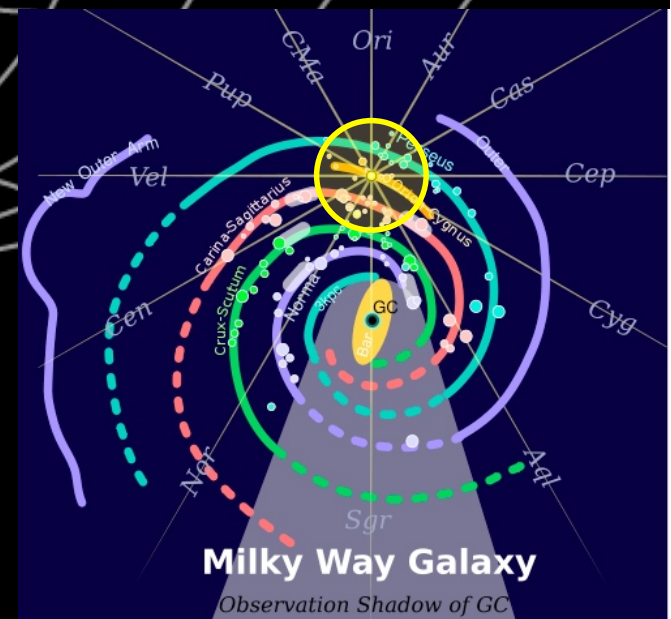


# 7 VHE Gamma-ray Binaries

Adapted from Jamie Holder

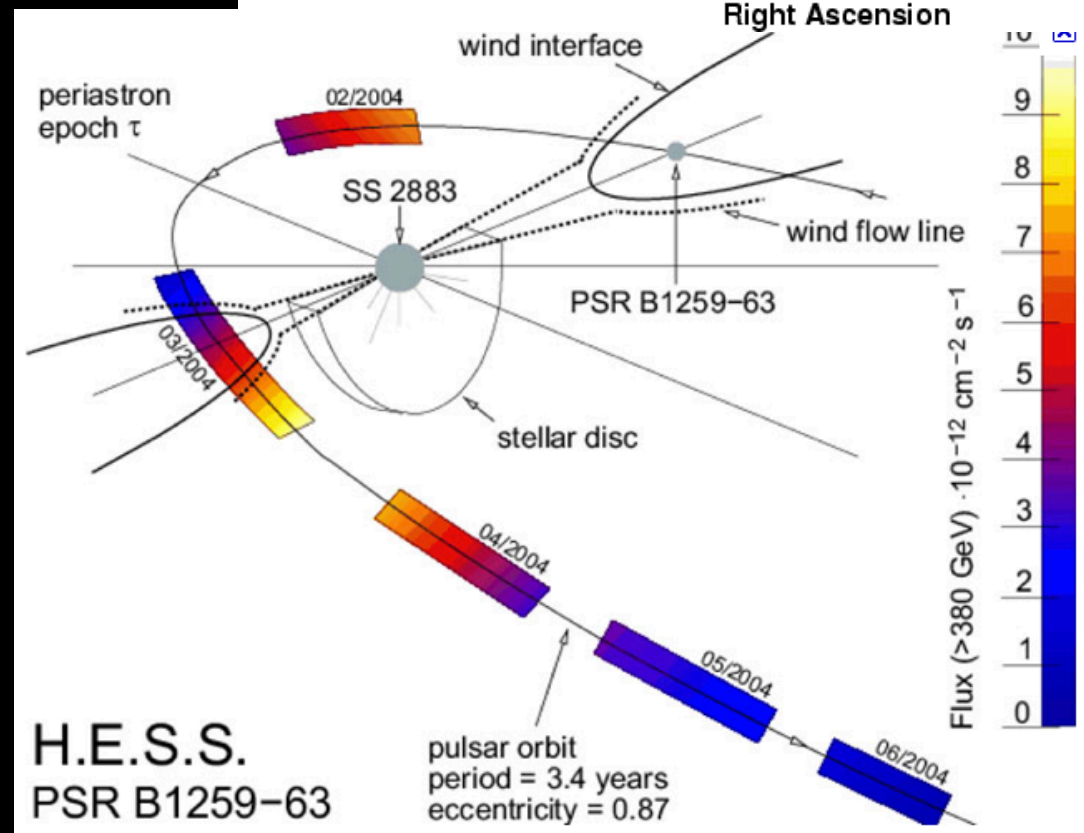
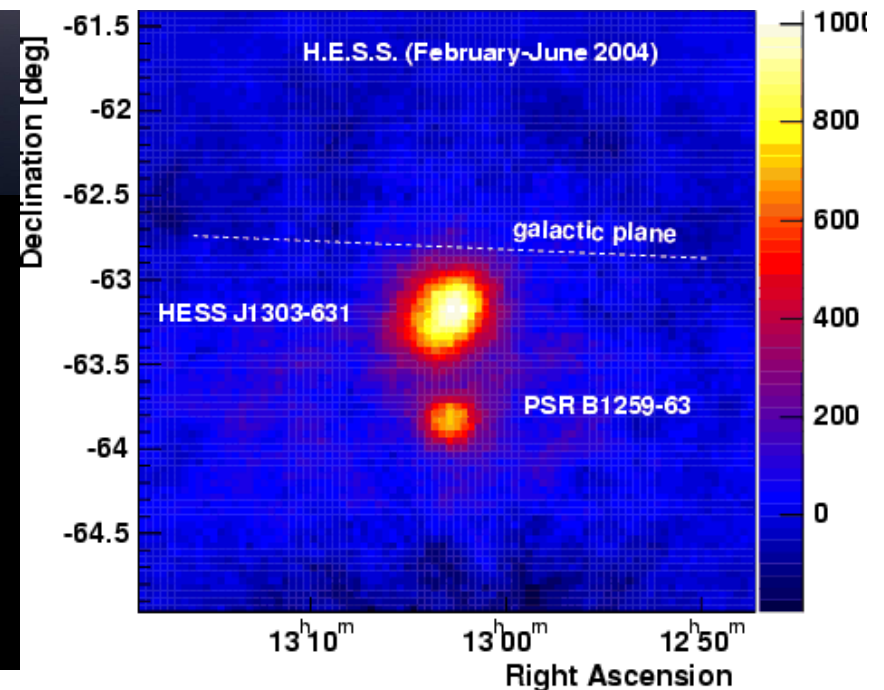


All "Local" - 1.5-3 kpc (no centre/anti-centre bias)  
→ 10× more equally luminous binaries in Galaxy



# 8 PSR B1259-63

- Radio Pulsar / Be Star (LS 2883) binary with 3.4 year period
  - ▶  $P \sim 48$  ms
  - ▶  $\dot{E} \sim 8 \times 10^{35}$  erg/s
- HESS detection of periastron passages in 2004 and 2007
- Next periastron - December
  - ▶ HESS will observe (but moon tricky)





# 9 Variability

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F. Aharonian et al.: HESS Observations of PSR B1259–63 2005–2007

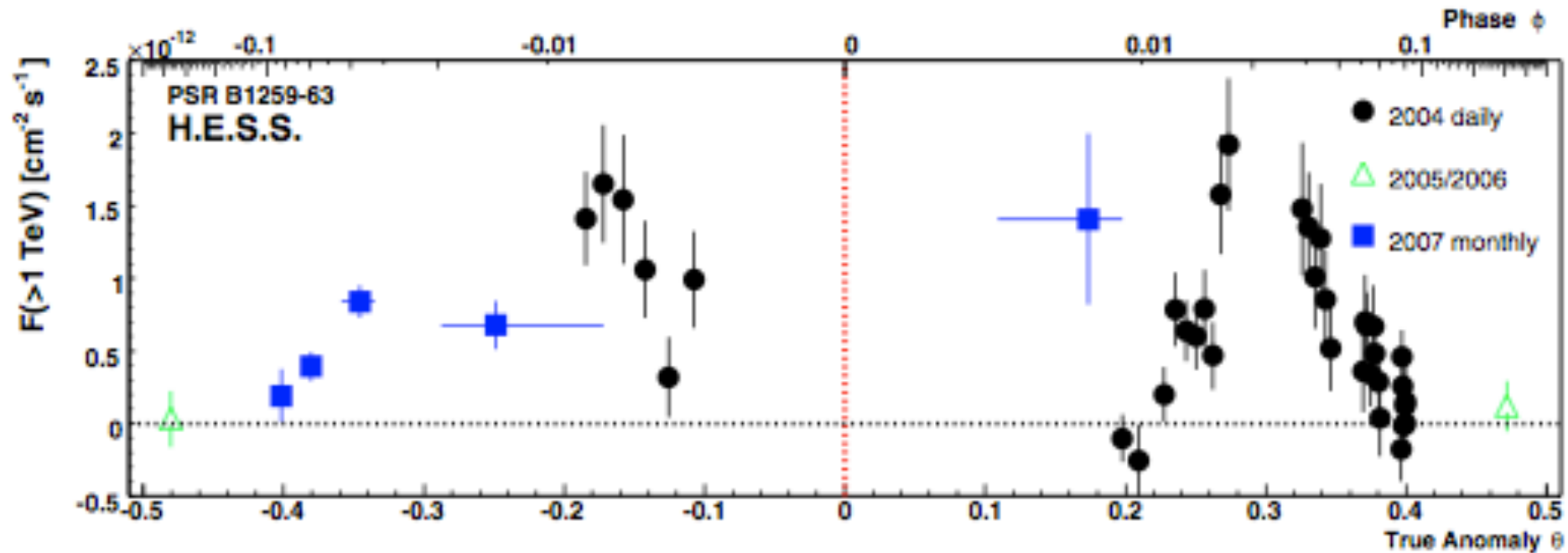


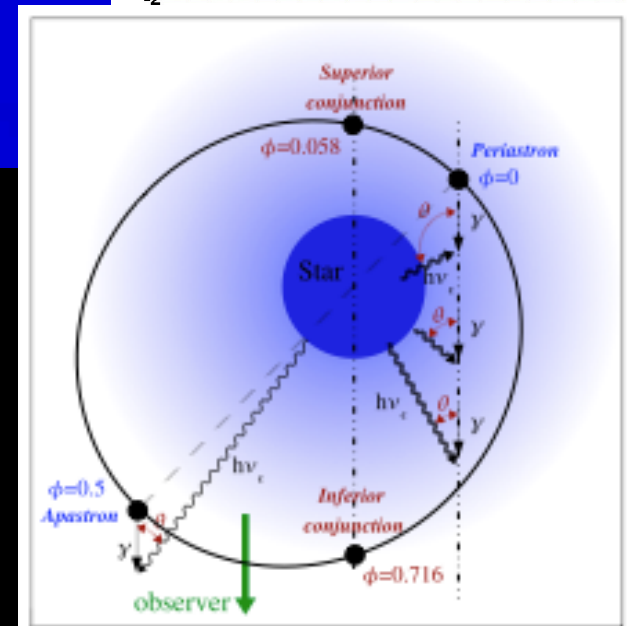
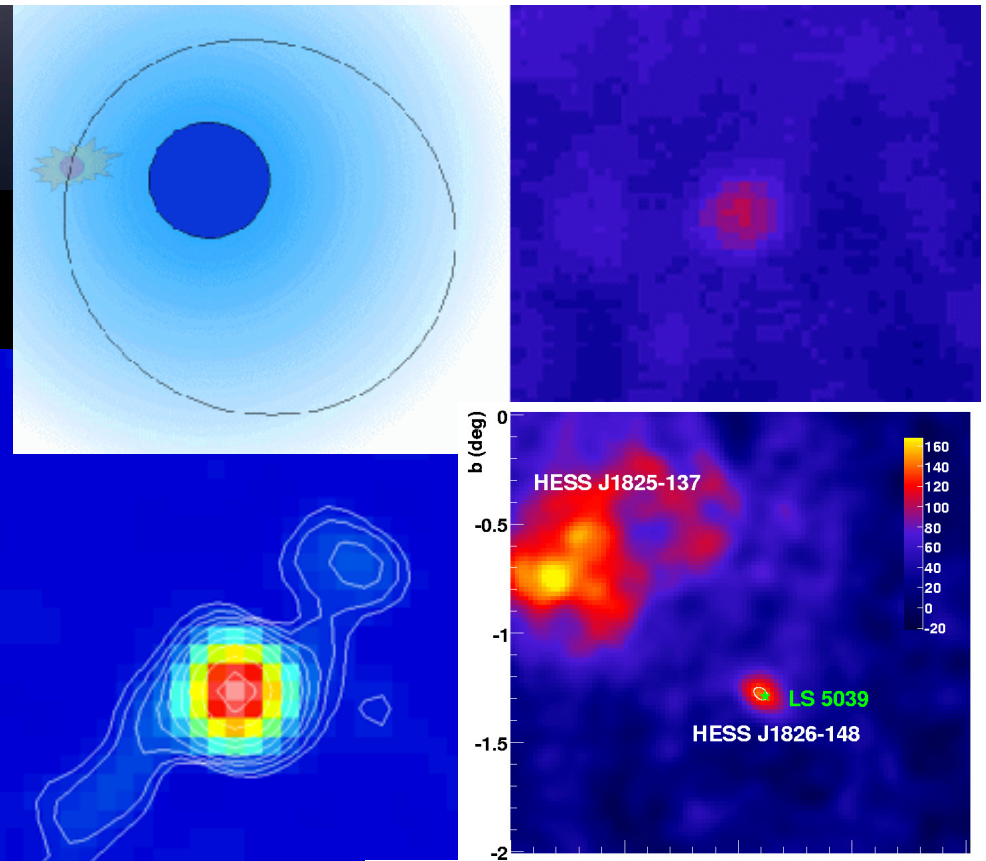
Fig. 5. VHE integrated flux from PSR B1259–63 above 1 TeV as a function of the true anomaly. The corresponding orbital phases (mean anomaly) are shown on the upper horizontal axis. The red vertical line indicates the periastron passage. Shown are data from the years 2004 to 2007: the black points are the daily fluxes as measured in 2004. Green empty triangles show the overall flux level as seen in 2005 and 2006. Blue filled squares represent the monthly fluxes taken from the campaign in 2007.

- No evidence for spectral variations (Gamma=2.8+/-0.1)

See talk by  
Matthias Kerschhaggl

# 10 LS 5039

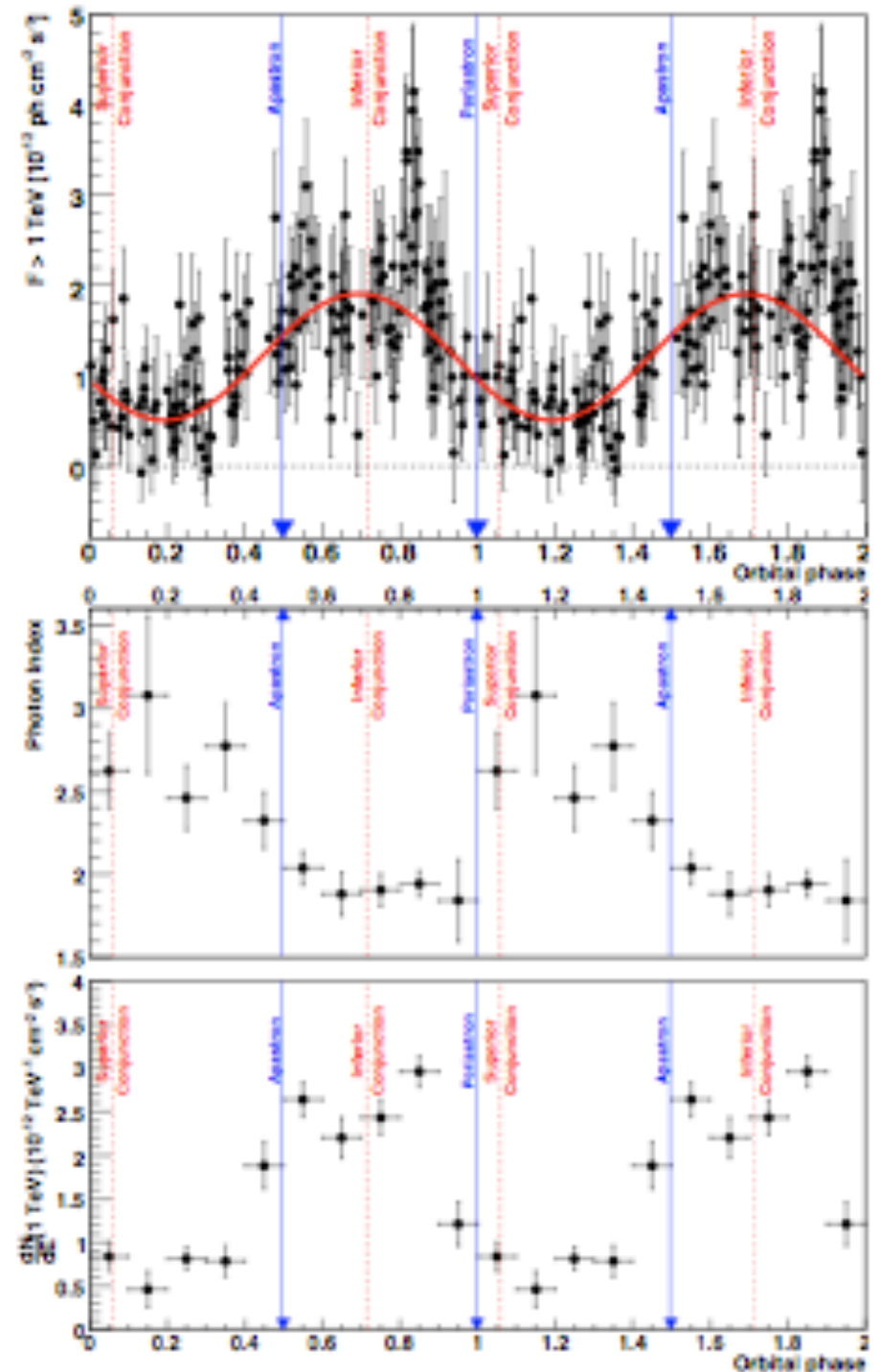
- 3.9 day period binary of O6.5V star with compact object
- Time variable radio morphology (jets?)
- VHE Discovery: HESS Galactic Plane Survey in 2004
  - ▶ (-15° Declination - VERITAS/MAGIC obs?)





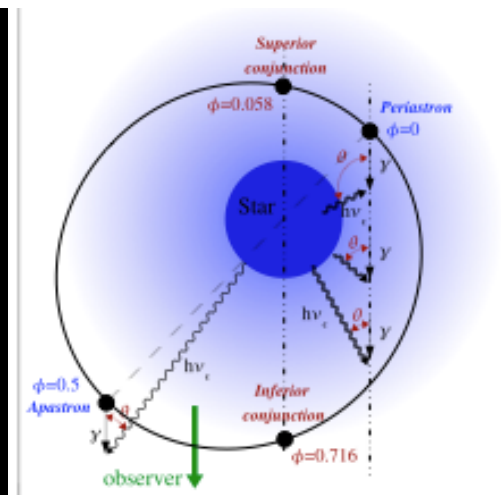
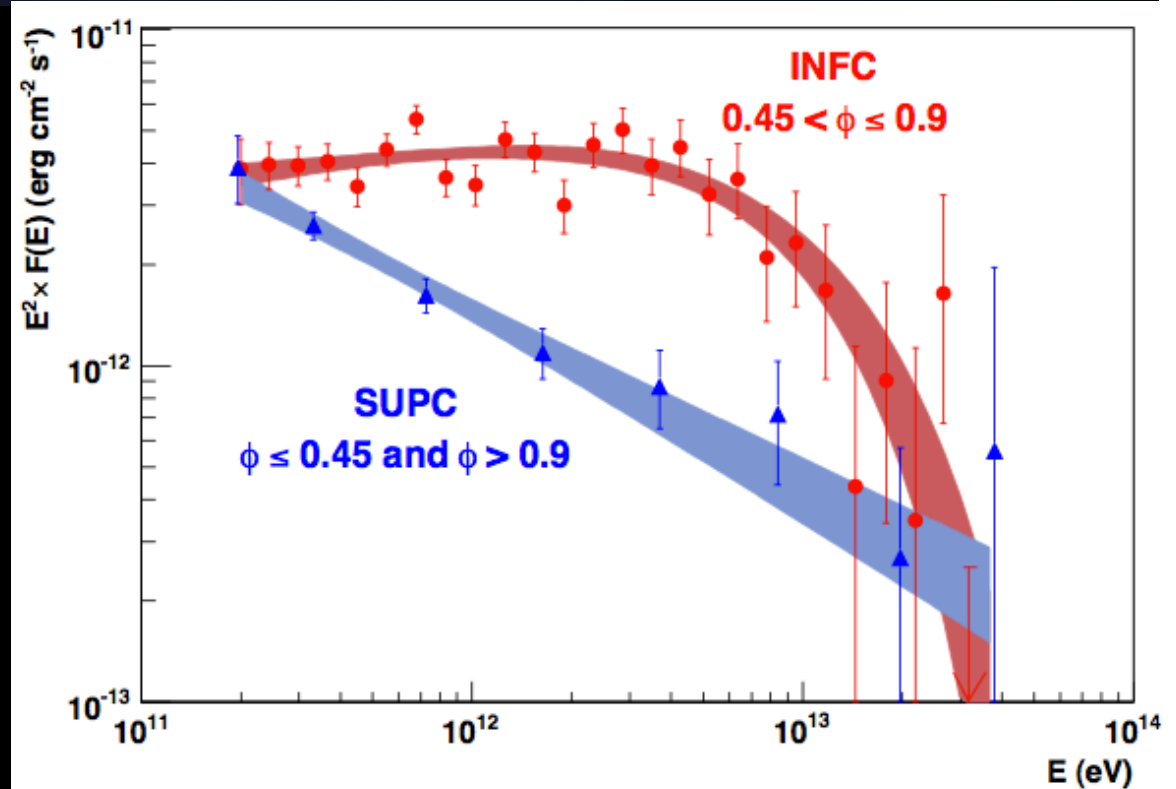
# 11 LS 5039

- Clear periodicity in VHE flux
- Maximum around the time of “inferior conjunction”
  - ▶ Compact object in front of massive star
- Almost sinusoidal
  - ▶ Feature at  $\Phi=0.9$ ?
- Spectrum
  - ▶ Hard when bright



# 12 LS 5039 Spectrum

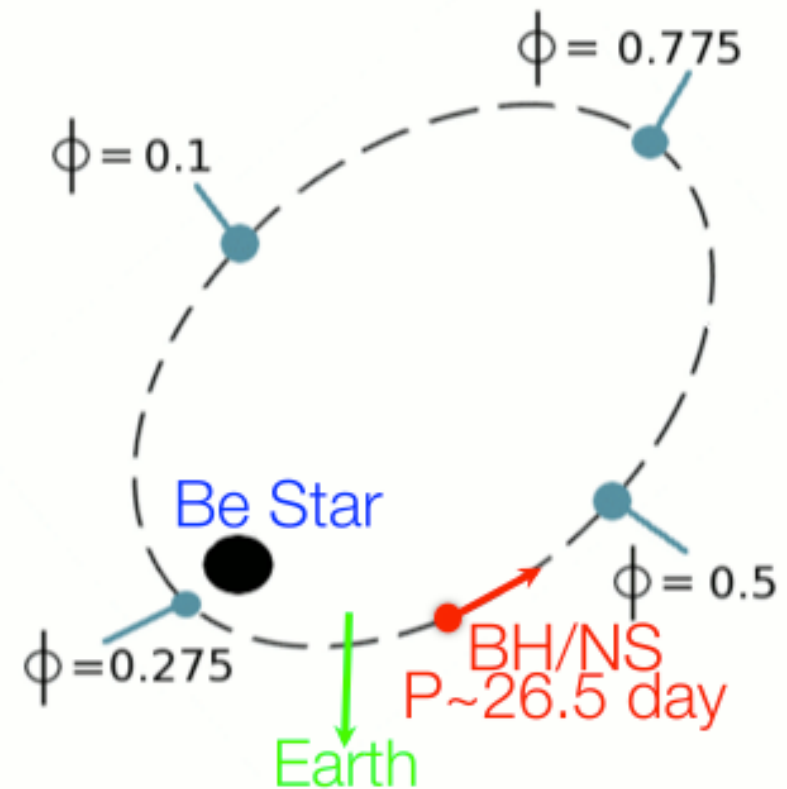
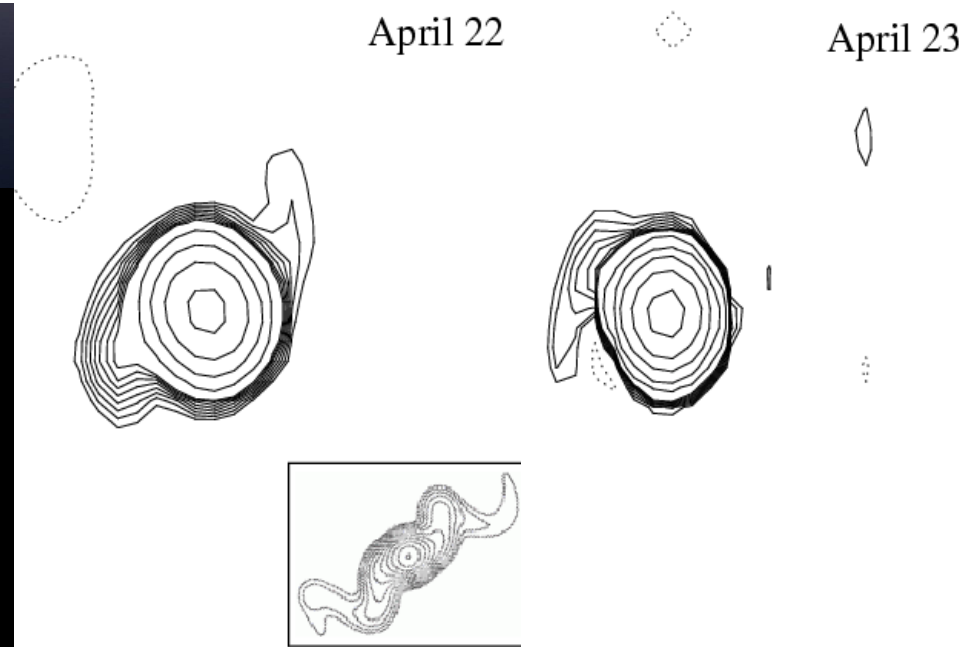
- Only evidence so far for orbital evolution of VHE spectrum
  - ▶ INFC:  $\Gamma=1.9$   
(9 TeV cut-off)
  - ▶ SUPC:  $\Gamma=2.5$
- Spectra in much smaller time bins would be nice...





# 13 LS I +61 303

- B0Ve + compact object
  - ▶ Changing radio morph.
- Eccentric orbit ( $e=0.54$ ) and period 26.5 days
  - ▶ Very close to Lunar period, tricky for IACTs
- TeV Detections: MAGIC and VERITAS
  - ▶ Pointed observations

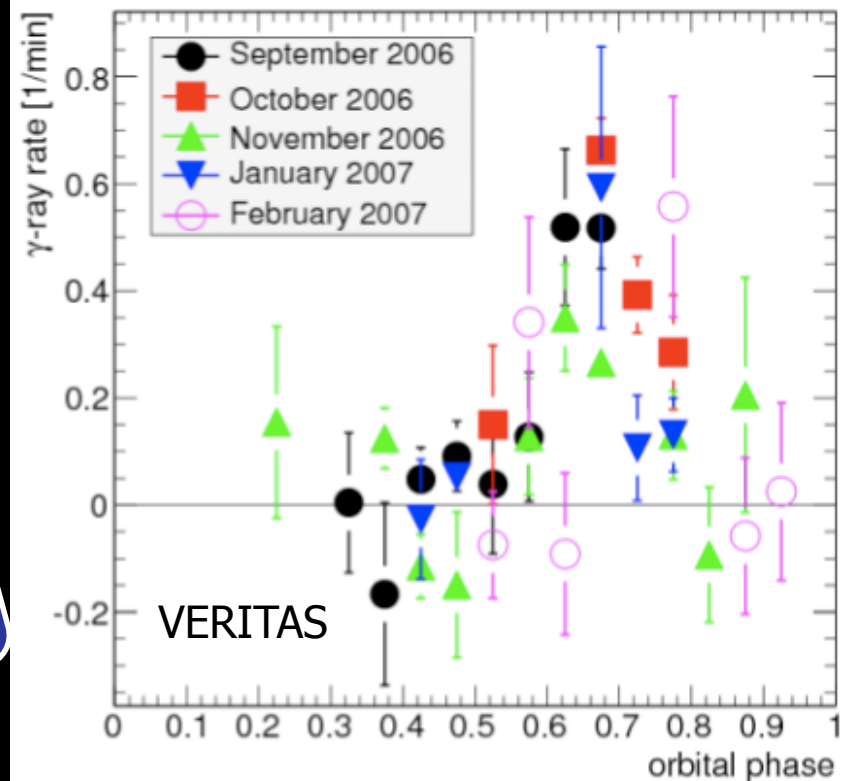
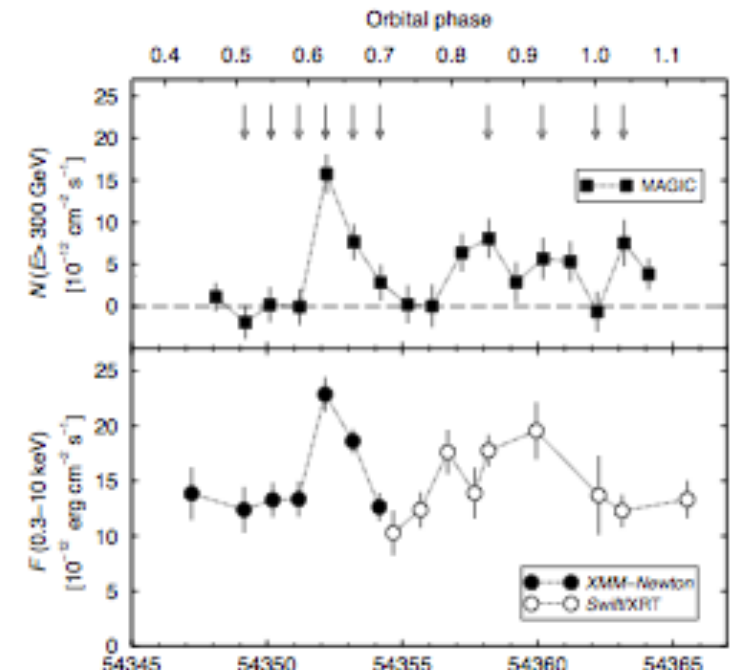


# 14 LS I +61 303

- VHE Lightcurve
  - ▶ Varies from orbit to orbit?
  - ▶ Peak just before apastron?
- MAGIC collab. 2009
  - ▶ X-ray/TeV correlation in Sept. 2007 campaign
- VERITAS
  - ▶ Many orbits
  - ▶ Broadly reproducible

See talk by  
Tobias Jogler

See talk by  
Gernot Maier





# 15 LS I +61 303

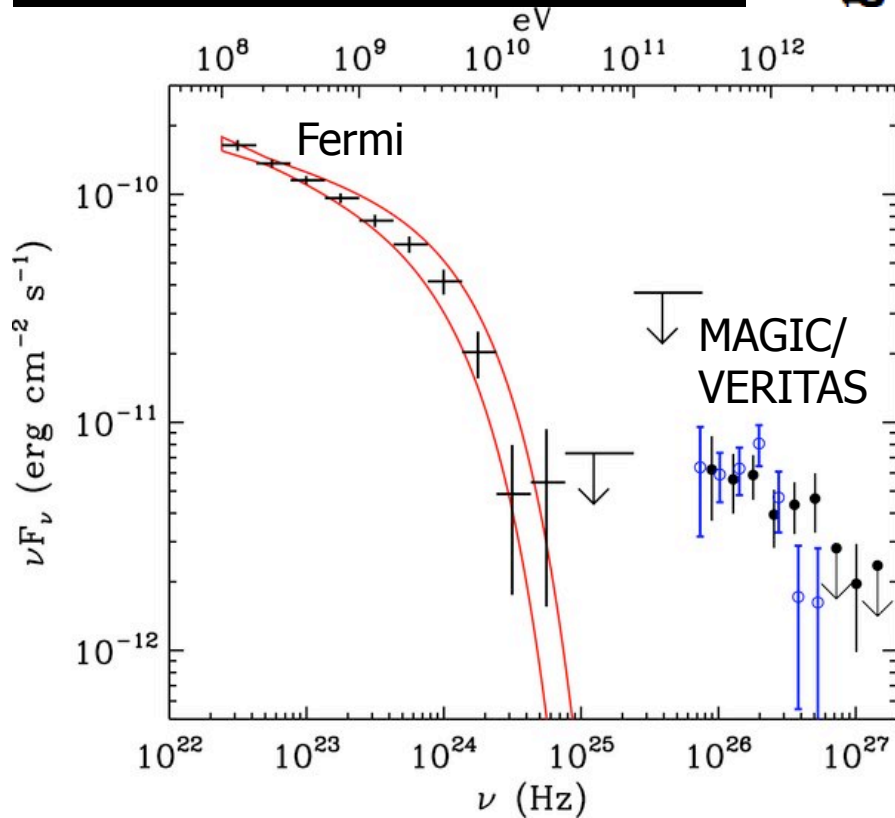
- TeV emission disappeared at Fermi launch???

## VERITAS Observations of LS I +61°303 in the Fermi Era

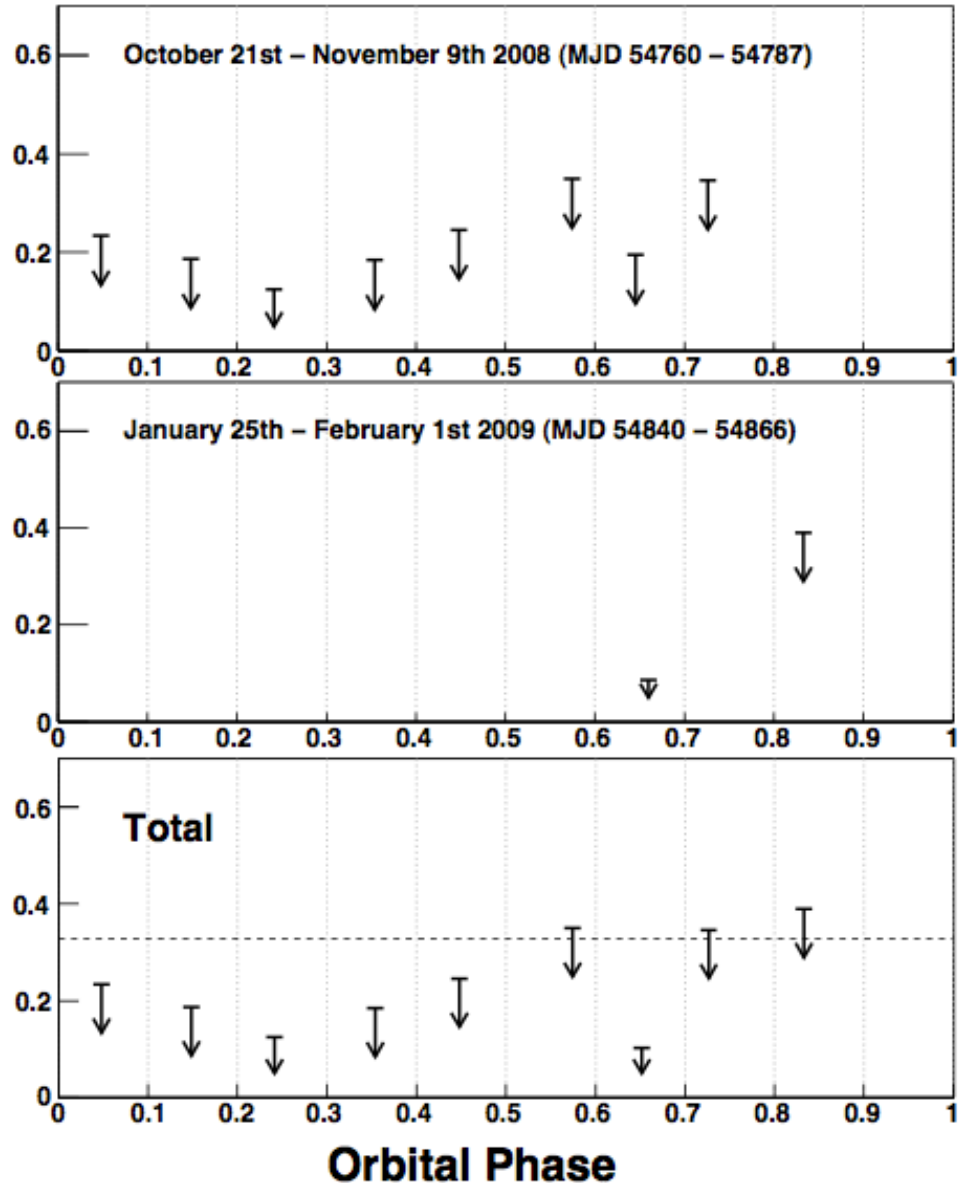
Jamie Holder\* for the VERITAS Collaboration†

\*Department of Physics and Astronomy and the Bartol Research Institute, University of Delaware, USA.

†see R.A. Ong et al. (these proceedings) or <http://veritas.sao.arizona.edu/conferences/authors?icrc2009>



[cm<sup>-2</sup>s<sup>-1</sup>]



Orbital Phase

# Stop Press!

From Jamie Holder

## VERITAS Detects VHE Gamma-Ray Emission from LS I +61 303 Near Periastron

ATel #2948; [Rene A. Ong \(UCLA\), for the VERITAS Collaboration](#)  
on 17 Oct 2010; 0:04 UT

*Distributed as an Instant Email Notice (Request for Observations)*  
*Password Certification: Rene Ong (rene@astro.ucla.edu)*

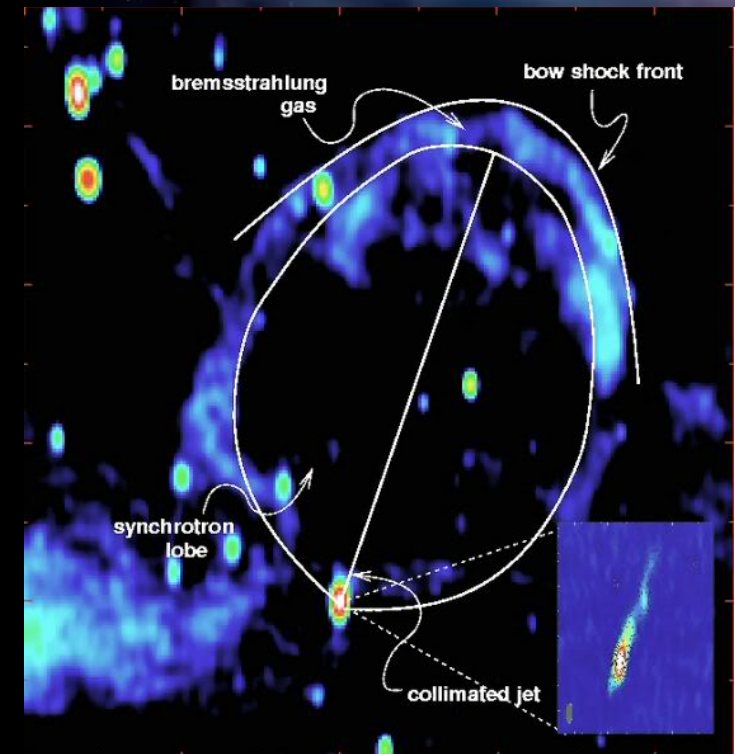
**Subjects: Gamma Ray, TeV, VHE, Request for Observations, Binaries**

LS I +61 303 is a HMXB system composed of a Be star and a compact object of unknown nature (Casares et al. 2005, MNRAS, 360, 1105). Its elliptical orbit has a period of 26.5 days, with periastron occurring at phase 0.225 and apastron at phase 0.775. LS I +61 303 has previously been detected as a VHE ( $E > 100$  GeV) gamma-ray source, with significant emission only observed near apastron passage, around phases 0.5-0.8 (Albert et al. 2006, Science, 312, 1771; Acciari et al. 2008, ApJ, 679, 1427). No VHE emission at any phase has been reported since summer 2008. Observations with the VERITAS gamma-ray observatory between Oct 7 and Oct 12 2010, corresponding to the orbital phase range of 0.05 to 0.23, reveal evidence for VHE gamma-ray emission with a statistical significance of greater than 5 standard deviations. The total exposure was 7.7 hours, and the measured flux is approximately 5% of the Crab Nebula flux above 300 GeV. VERITAS will continue to monitor this source and hard X-ray observations with Swift have also been scheduled. Since the detection of VHE emission from LS I +61 303 during these orbital phases is not expected, we encourage observations at all wavelengths.



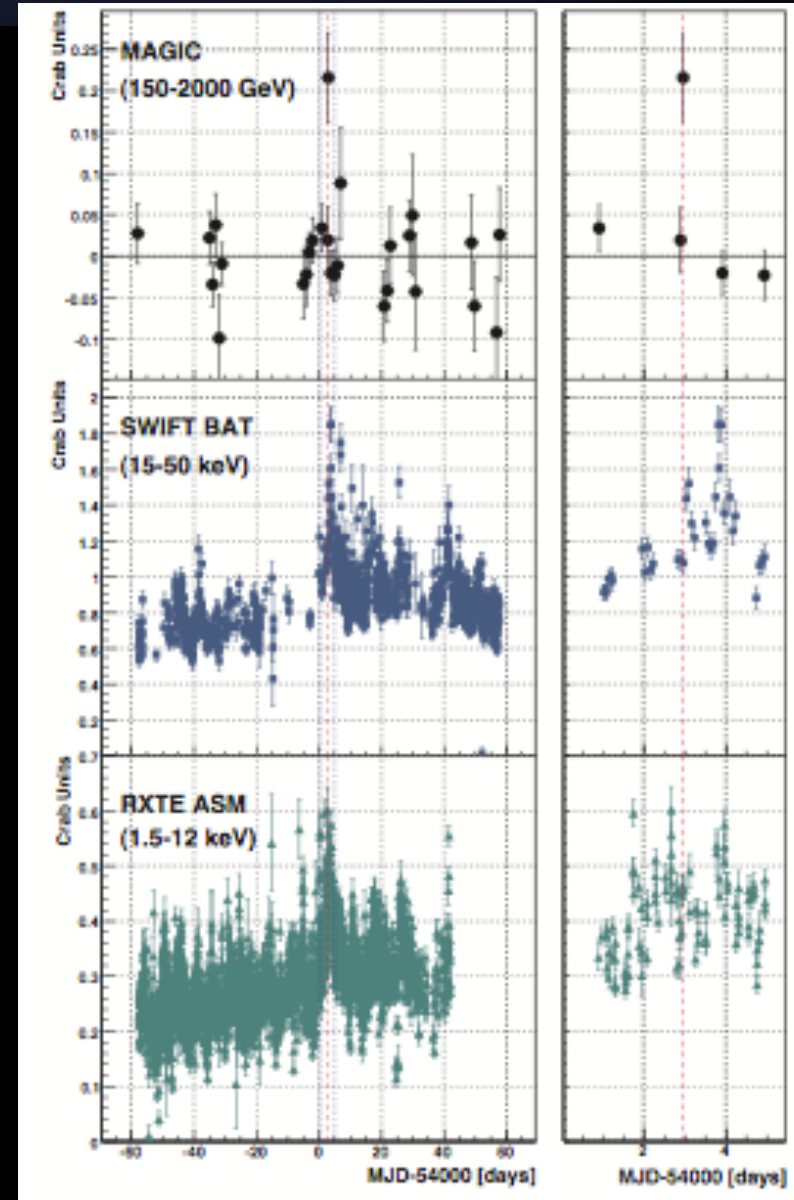
# 17 Cygnus X-1

- Unambiguous Black hole binary  $\sim M_{\text{BH}} > 13M_{\odot}$ 
  - ▶ Companion is O9.7 super-giant
  - ▶ 5.6 day period
- Jets
  - ▶ Single-sided small-scale radio jet (milli-arcsecond/100 AU)
  - ▶ Large-scale bow shock - 5pc/8'
- VHE?
  - ▶ MAGIC detection of a single flare in 2006



# 18 Cygnus X-1

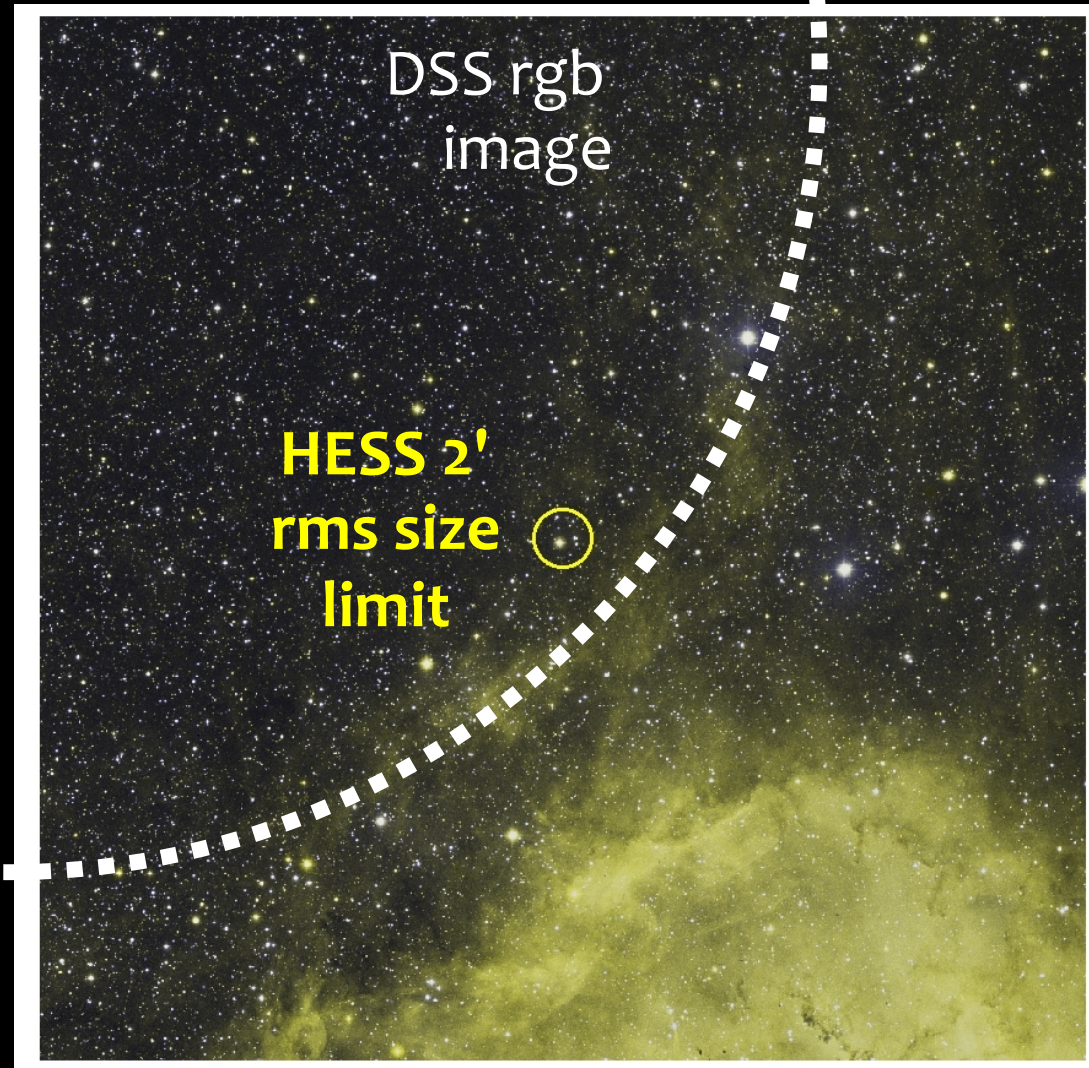
- MAGIC detection of a single flare in 2006
  - ▶ 40 hour observation
  - ▶  $4.9\sigma$  in one 79 minute bin - about  $4.1\sigma$  post-trials
  - ▶ Coincident with a high state in X-ray
- More recent MAGIC and/or VERITAS obs?

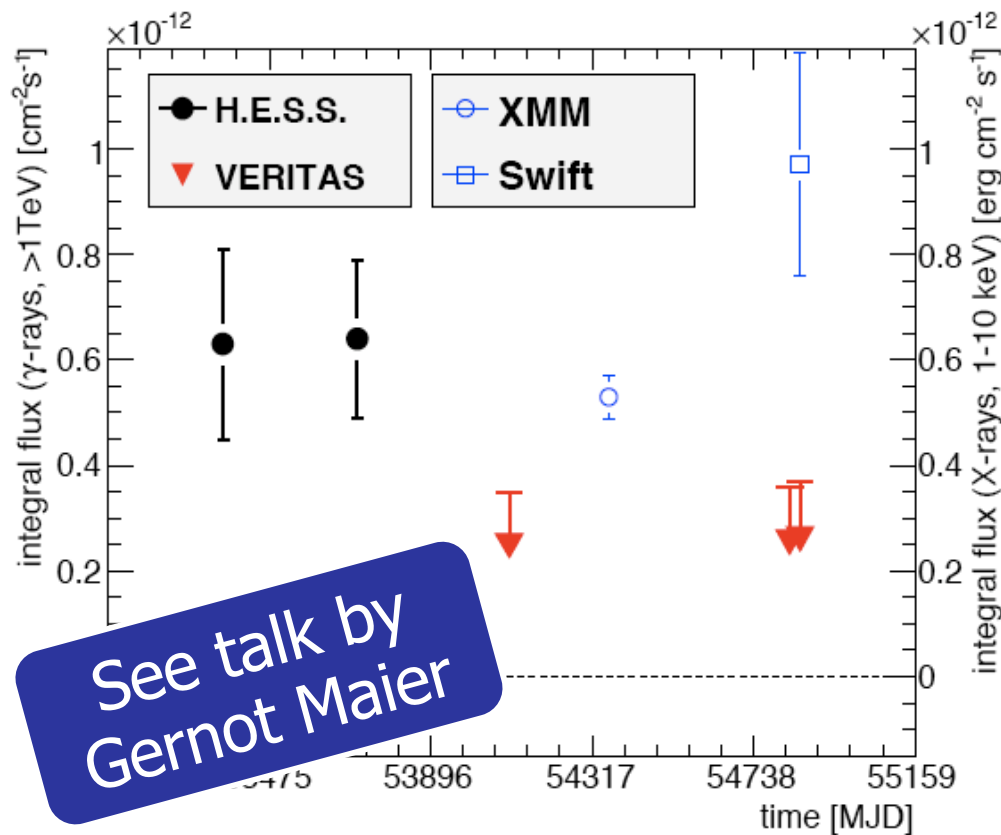




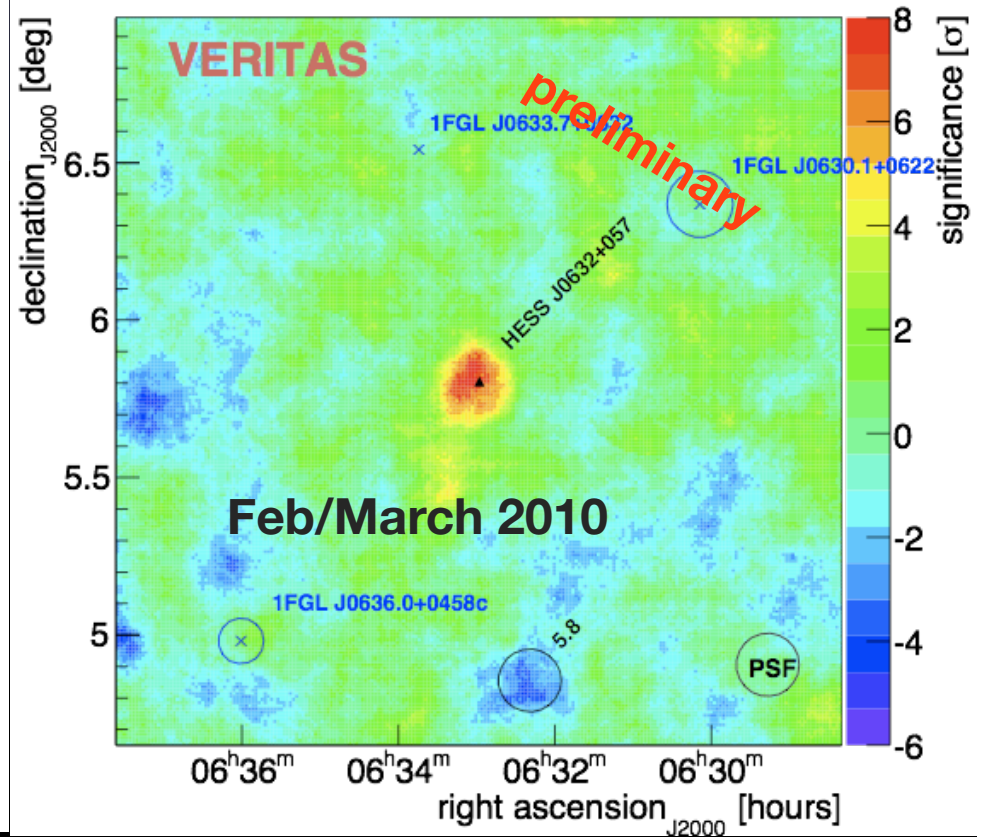
# 19 HESS J0632+057

- HESS obs.  
Targeting the  
Monoceros Loop  
SNR / Rosette  
Nebula
- Binary Candidate
  - ▶ Point-like source
  - ▶ Coincidence with  
Be(0pe) star
  - ▶ Radio and X-ray  
point source  
close to star





See talk by Gernot Maier

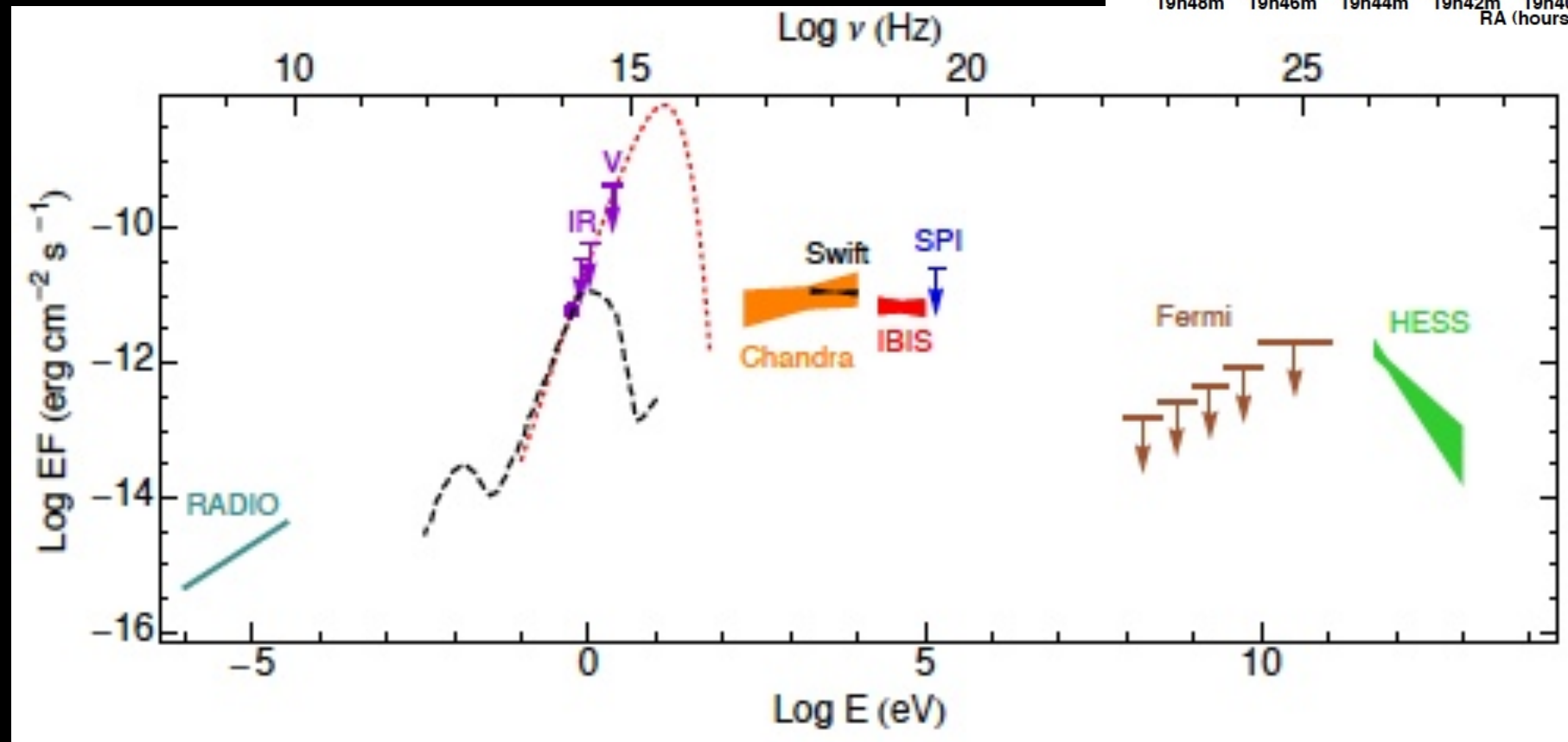
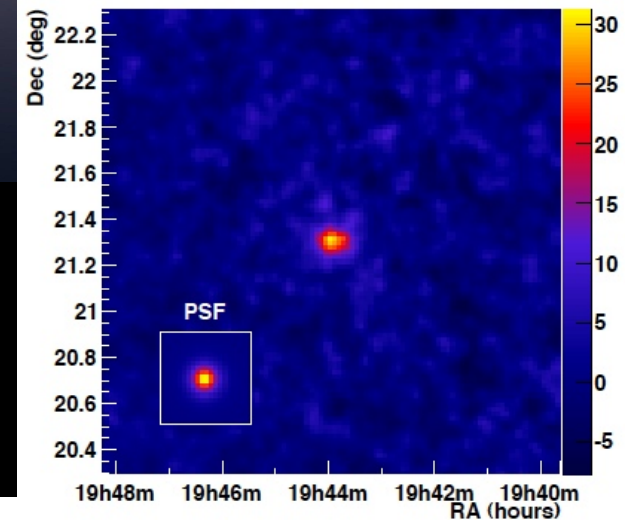


- Not detected in initial VERITAS observations
  - ▶ Implies ~year timescale variability
  - ▶ No evidence for spectral variability -  $\Gamma \sim 2.7$
- HESS/VERITAS campaign early 2010 - joint publication in preparation

See talk by Jo Skilton

# 21 HESS J1943+213

Point-like source – galactic latitude  $-1.3^\circ$   
No variability, No stellar companion  
*See HESS source of the month webpage*



*An extreme BL Lac shining through the galactic plane?*



## 22 Flux Limits

- Several observations of colliding-wind binaries with IACTs - no detections yet
  - ▶ WR 146, WR 147, ...
  - ▶ (HESS collab. will report soon on obs. of Eta Car)
- SS 443 (everyone,  $< \sim 1\%$  Crab)
- GRS 1915+105 (HESS 2009,  $< 0.5\%$  Crab +MAGIC)
- Cygnus X-3 (MAGIC 2010,  $< 1.3\%$  Crab)
- Recent VERITAS limit on 1A0535+262
  - ▶ HMXB, Be-star and X-ray pulsar ( $P_s = 104$  s,  $P_o = 110$  day) ( $\sim 1\%$  Crab limit during flare)

See talk by  
Gernot Maier

# 23 Object Summary

	PSR B1259-63	LS 5039	LS I +61303	Cyg X-1	HESS J0632+057
D (kpc)	1.5	2.5	2.0	2.2	1.5
Detected	H, (F?)	H, F	M,V,F	(M)	H,V
Flux Var	✓	✓	✓	✓	✓
Spec. Var.	no	yes	no	no	no
Periodic?	yes	yes	yes	no	no
Identical?	maybe	maybe	no	no	unlikely
Gamma	$2.8 \pm 0.1$	1.9 - 2.5	$2.6 \pm 0.2$	$3.6 \pm 0.4$	$2.7 \pm 0.2$
Flux (%Crab)	0-10	5-15	0-15	0-10	0-3
Shortest dt	1 week	1 day	1 day	1 hour	1 year?

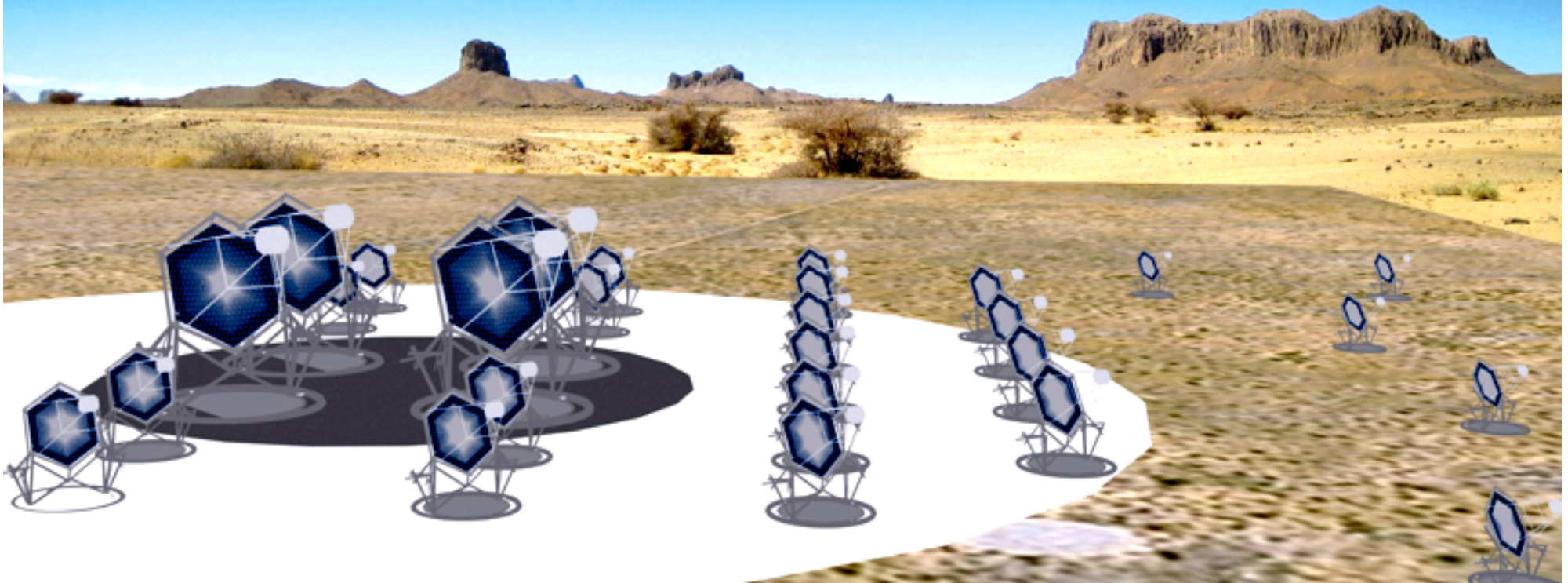
The likely TeV binaries

*See e.g. Juan Cortina arXiv:1007.2557 for more info.*

# The Cherenkov Telescope Array

- Have to wait a few (~5) years but will be a very powerful probe of galactic variable objects
  - ▶ Shorter timescales
  - ▶ Wider energy range / better measured spectra
  - ▶ More objects
  - ▶ New object classes?

(Specifications meeting this week at project office!)





- Three well-established TeV binaries
  - ▶ PSR B1259-63+, LS 5039, LS I +61303
- Candidates
  - ▶ Cyg X-1 (needs reobs.)
  - ▶ HESS J0632+057 (needs period.) (and HESS J1943+213)
- Local objects only so far (implications for luminosity function?)
- Similar VHE properties for most objects
  - ▶ Photon Index  $\sim 2.6$  - not much spectral variability
  - ▶ Peak emission away from periastron
  - ▶ Also similar SEDs - see later