H.E.S.S. gamma-ray binaries

status and prospects

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(on behalf H.E.S.S. collaboration)

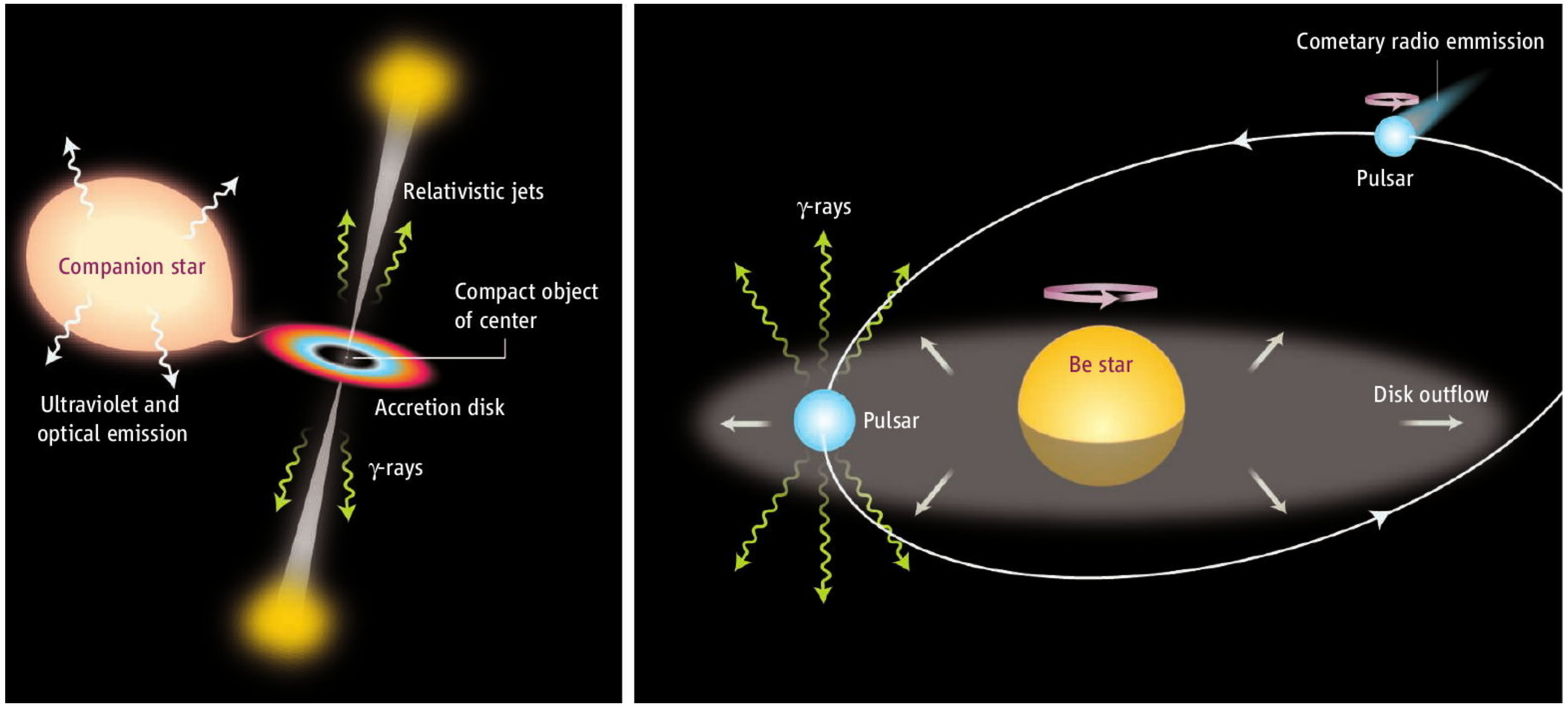
RICAP-14
Noto, Sicìlia

H.E.S.S. gamma-ray binaries

status and prospects

- Introduction
- status
  - PSR B1259-63
  - LS 5039, HESS J0632+057, 1FGL J1018.6-5856
  - Eta Carinae
  - transients (XRBs/μQs, novae)
- perspectives

Gamma-ray binaries



Mirabel (2006)

- Binary systems composed of Young massive star + compact object (BH, NS)
- Non-thermal emission from radio to VHE gamma-rays
- Highest energetic output in the MeV-TeV band
- Emission modulated with orbital period
- Extended non-thermal radio (and X-ray?) emission

Gamma-ray emitting binaries

- Young Pulsar Binaries
  The non-accreting pulsar wind against stellar wind interaction,
  leading to particle acceleration and emission (sync + IC)

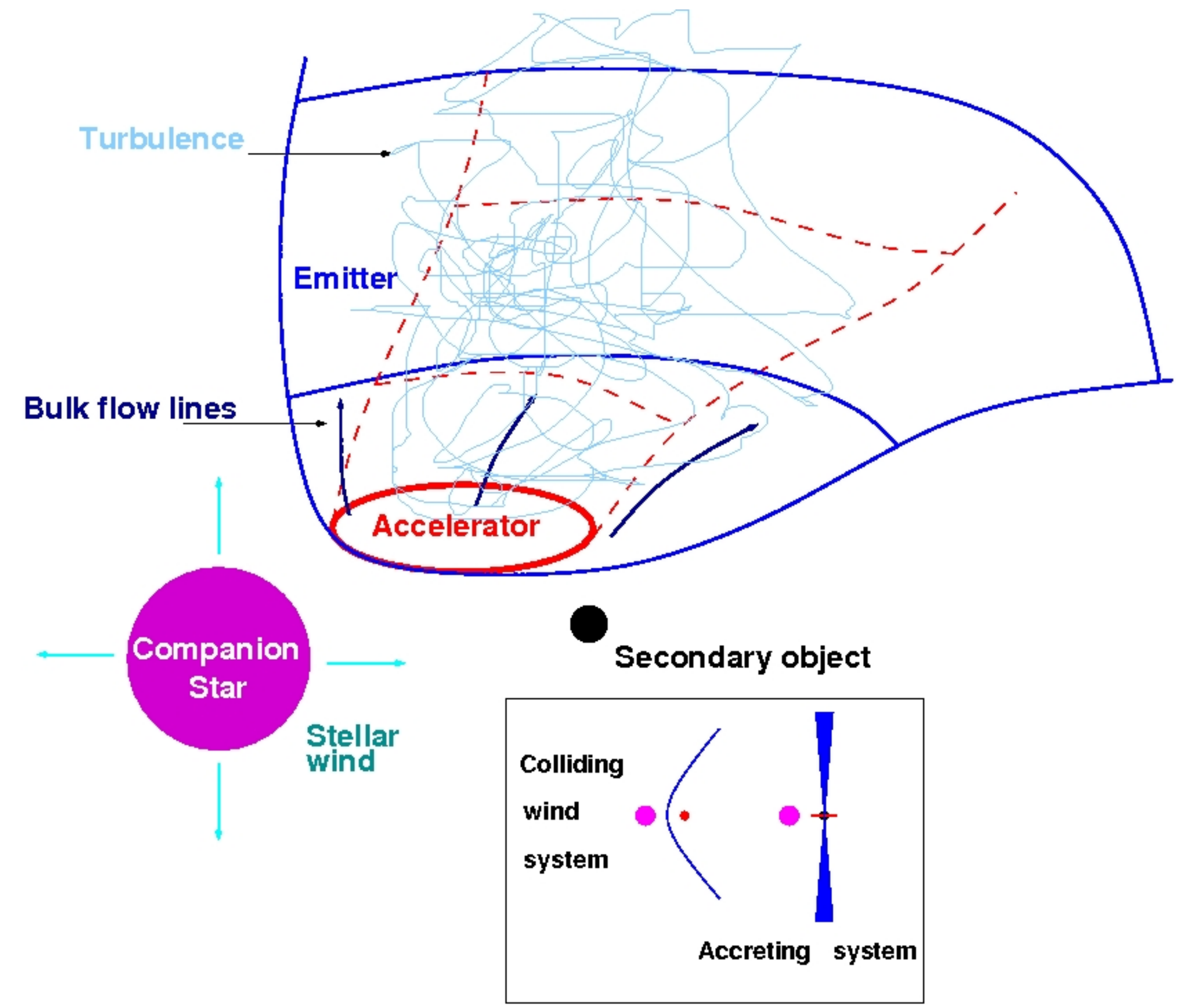
- Microquasars
  Accretion-powered jet accelerated particles (internal shocks, jet/medium interaction regions) and produce non-thermal emission (up to GeVs only?)

- Colliding Wind Binaries
  Powerful stellar winds collision yielding non-thermal activity.

- Symbiotic Novae
  The blast wave from a thermonuclear accretion burst (nova ejecta) interacts with the medium, triggering high-energy emission.

Gamma-ray emitting binaries

- Binary systems can produce powerful outflows.
- Energy source: accretion, BH/PSR rotation, stellar winds.
- Supersonic outflows impact on medium: kinetic/magnetic energy into heat, turbulence... → length-scales > $d_{\rm bin}$ ~ A.U.
- Strong shocks, turbulence and strong velocity gradients → particle acceleration.
- In compact binaries, ~10-100 GeV emission can provide information of non-thermal processes and the underlying flow dynamics.



Bosch-Ramon (2011)

Gamma-ray emitting binaries

	GeV	TeV	Class	Components
PSR B1259-63	yes	yes	PSR binary	Oe + PSR
LS 5039	yes	yes	?	O + C.O.
LS I +61 303	yes	yes	?	Be + C.O.
HESS J0632+057	no	yes	?	Be + C.O.
1FGL J1018.6–5856	yes	?	?	O + C.O.
Cygnus X-1	?	?	µQ	O + BH
Cygnus X-3	yes	no	µQ	WR + BH(?)
η-Carina	yes	no	CW binary	LBV + O(?)
V407 Cygni	yes	no	Symb. nova	Red Giant + WD
Nova Sco 2012	yes	no	Classical nova	Main Seq. + WD
Nova Mon 2012	yes	no	Classical nova	Main Seq. + WD

Gamma-ray emitting binaries with H.E.S.S.

	GeV	TeV	Class	Components
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η-Carina	yes	no	CW binary	LBV + O(?)
transients	yes	no	novae, µQs	---

pulsar

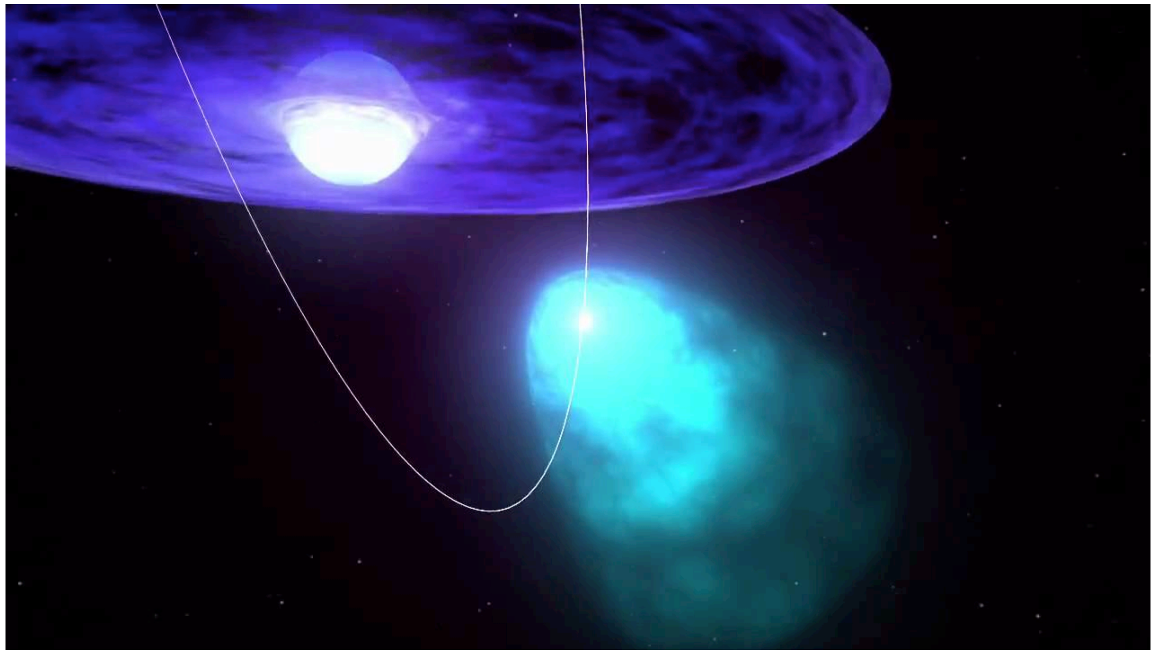
- P = 48 ms
- L_{sd}= 8 $\times 10^{35}$ erg/s
- age =3.3 $\times 10^{5}$ years

star

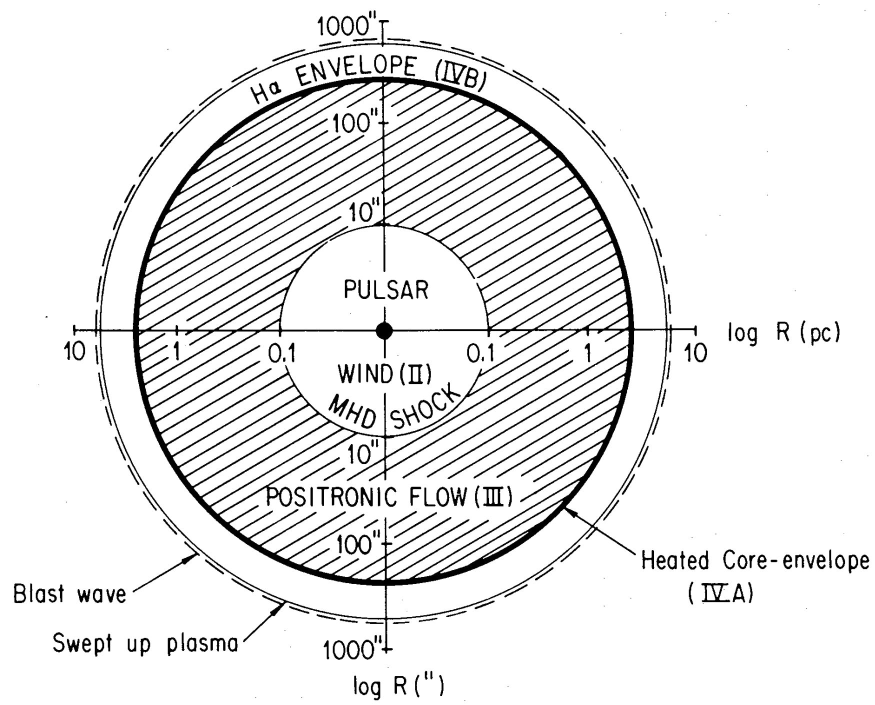
- O9.5 Ve star
- ∃ circumstellar disk
- L_{star}= 2.3 $\times$ 10^{38} erg/s
- T = 27500 – 30000 K
- M ≈ 31 Msun
- R = 8.1 –9.7 Rsun

binary system

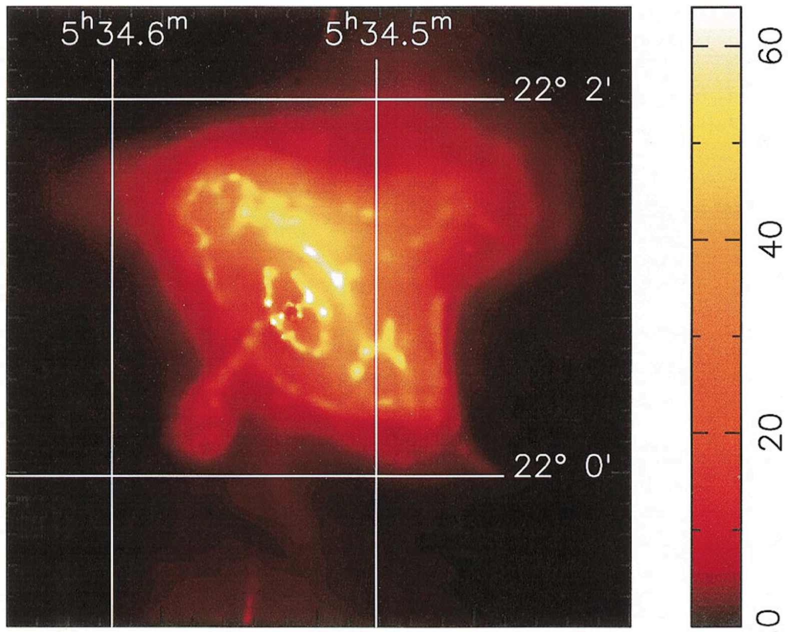
- D = 2.3 kpc
- Porb= 3.4 years
- Eccentricity = 0.87
- Orbital inclination i ~24^{o}



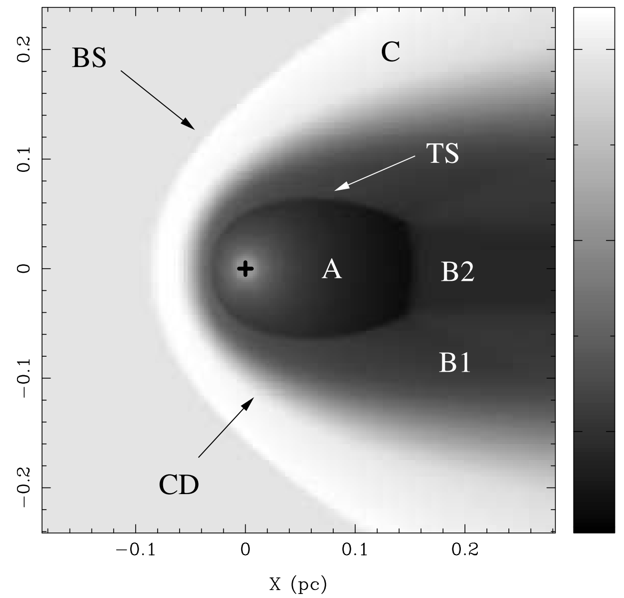
PSR B1259-63, credits: NASA archive



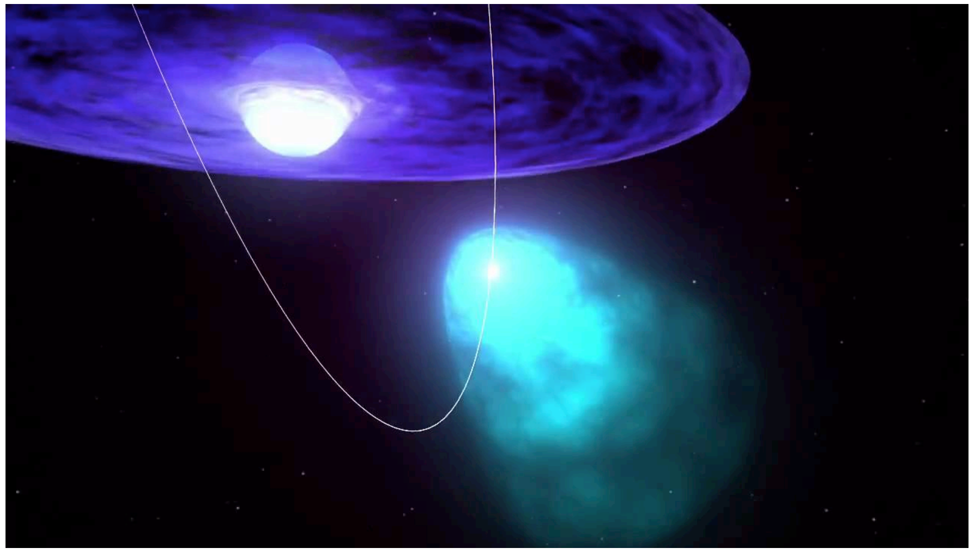
Crab Nebula, Kennel & Coroniti (1984)



Crab Nebula, Weisskopf et al. (2000)



J1747, “the Mouse”, Gaensler et al. (2004)

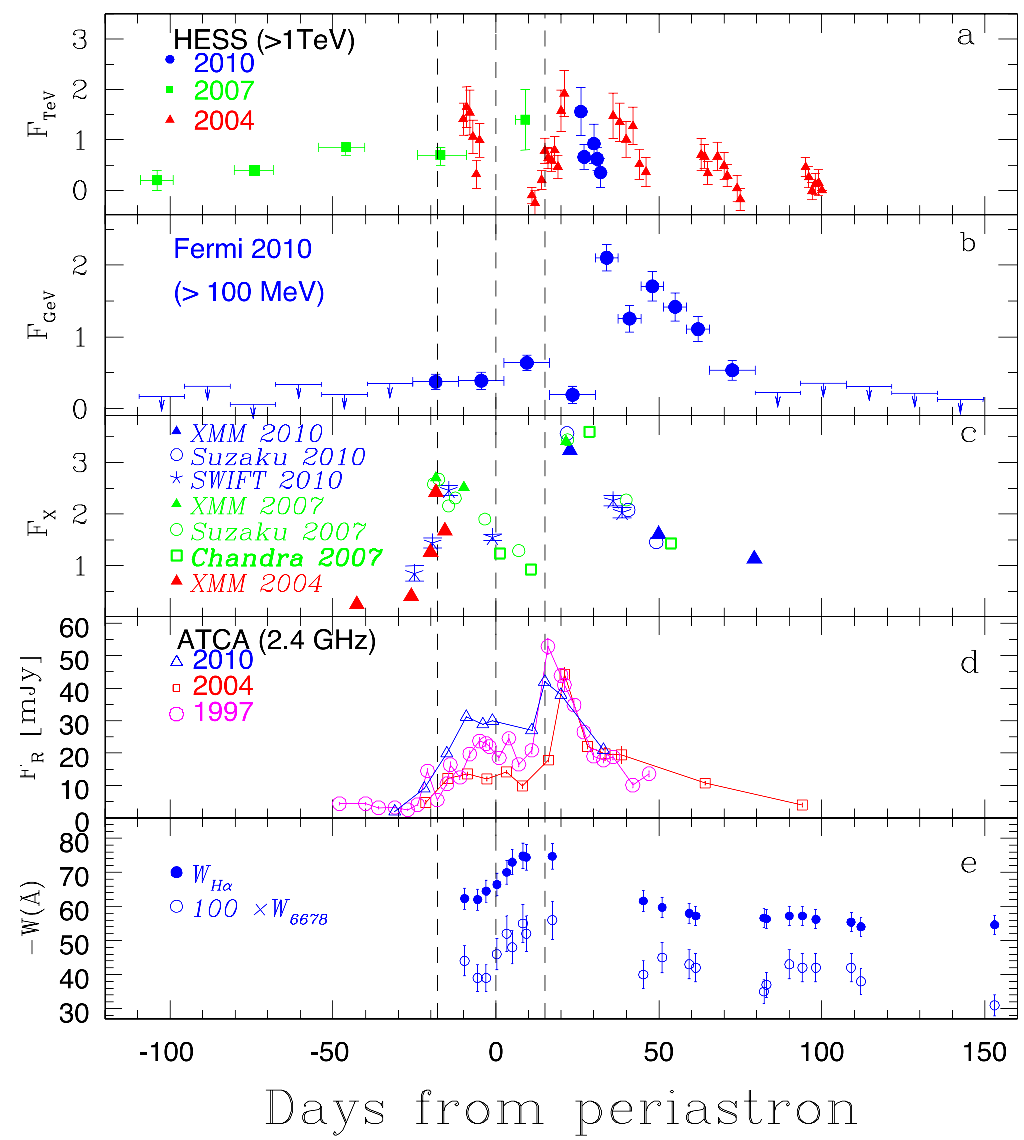


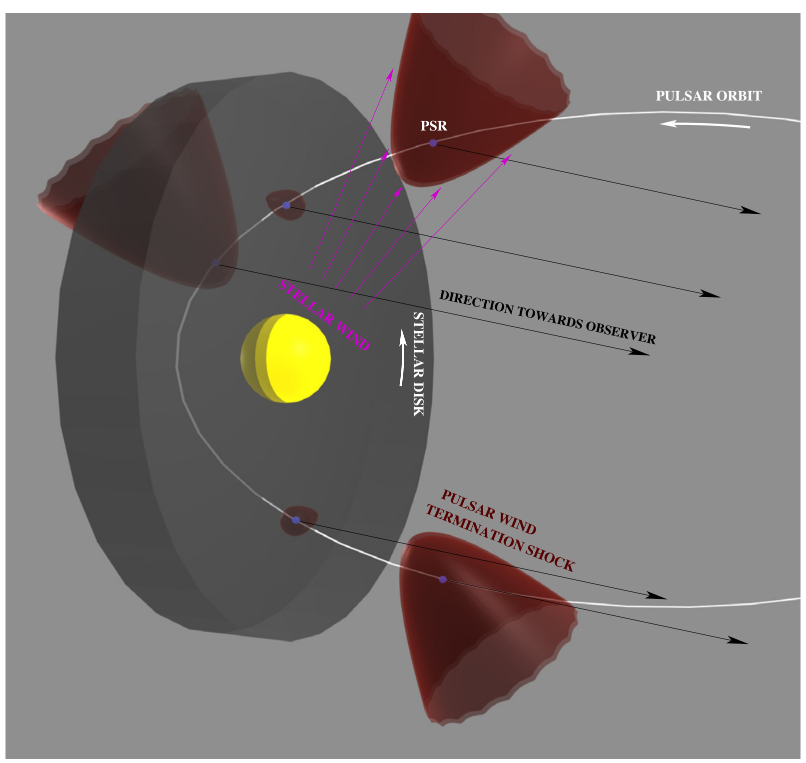
PSR B1259-63, *credits: NASA archive*

PSR B1259-63/LS 2883

- Variable emission in radio, optical, X-rays, GeV and TeV γ-rays
- Pulsations seen only in radio (away from periastron)
- Light-curves modulated with orbital period
- Double peak profile: radio, X-rays (and TeV?)
- GeV flare in 2010/2011 periastron

Chernyakova et al. (2013)



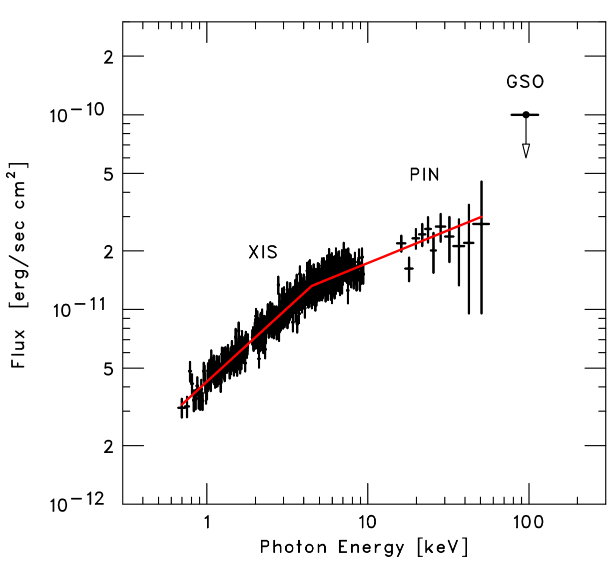


Khangulyan et al. (2012)

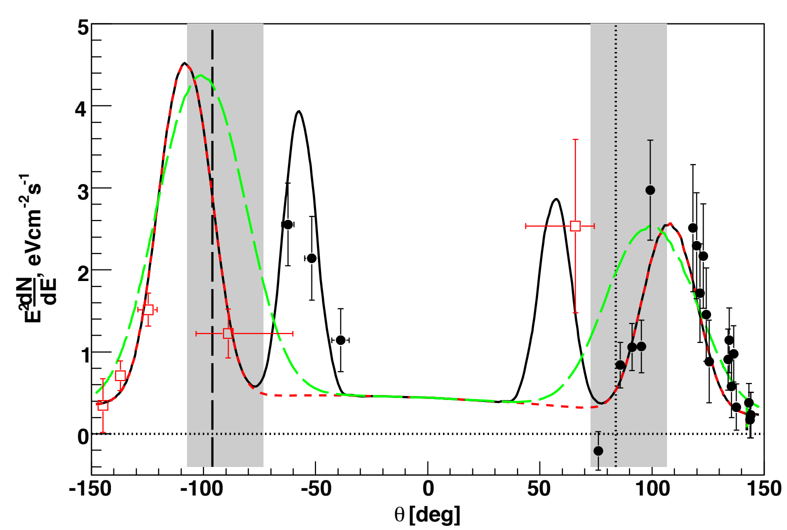
Johnston et al. 1992, Cominsky et al. 1994, Melatos, Johnston & Melrose 1995, Tavani & Arons 1997, Kaspi et al. 1995, Hirayama et al. 1999, Shaw et al. 2004, Aharonian et al. 2005, 2009, Khangulyan et al. 2007, 2011, Bogovalov et al. 2008, 2012, Chernyakova et al. 2006, 2009, 2013, Uchiyama 2009, Kerschhaggl 2011, Moldón et al. 2011, Abdo et al. 2011, Kong et al. 2011, 2012, Dubus & Cerutti 2013, HESS Coll 2013

PSR B1259-63/LS 2883

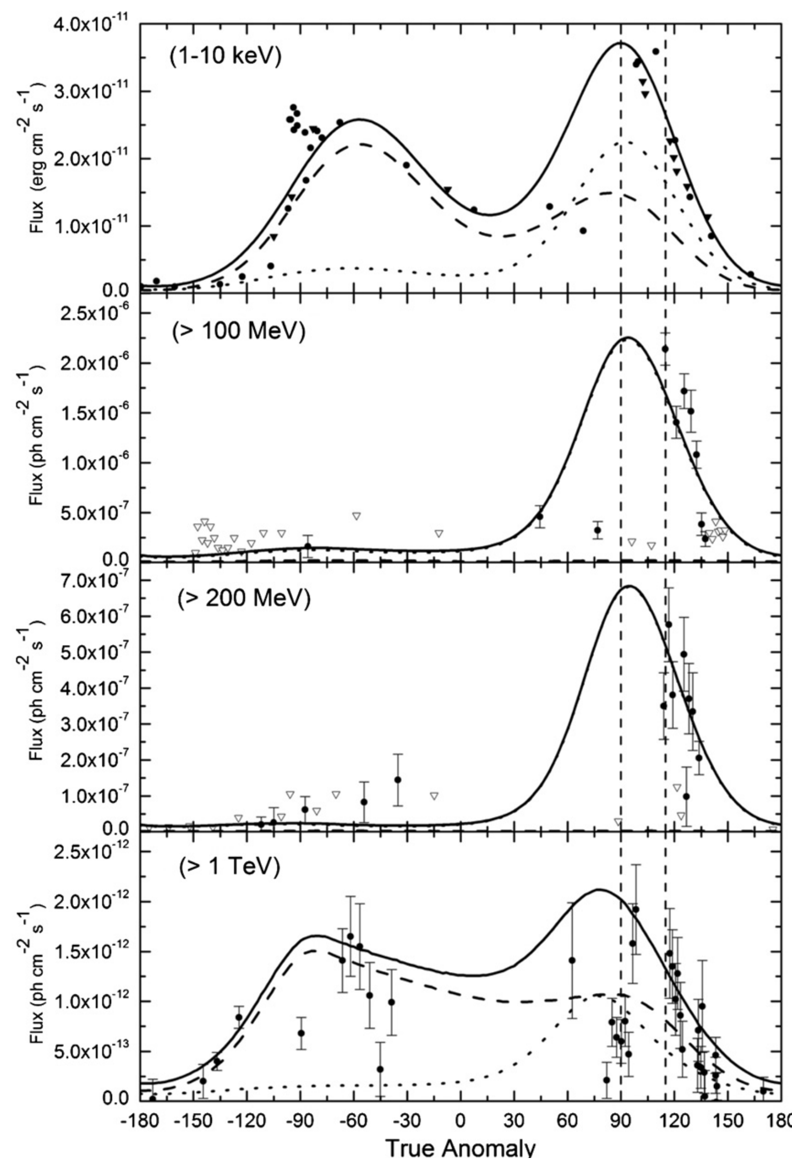
- **Low flux at periastron** (t_p = 0) not expected in early models (e.g. Kirk et al 1999):
  change of maximum energy, non-radiative losses? (e.g. Khangulyan 2007, Kerschhaggl 2011)
- **Spectral break at X-ray energies**, at ~ 4.5 keV (Uchiyama et al. 2009):
  transition from IC (KN) to synchrotron radiative losses
  low-energy cuoff in $N_e(E)$ ⇔ $\Gamma_{\text{unshocked wind}} \sim 4 \times 10^5$
- **Symmetry of the X-ray (TeV?) peaks** pre/post-periastron:
  non-isotropic pulsar energy flux (Bogavolov & Khangoulian 2002)
  non-radiative losses (e.g. Khangulyan 2007, Kerschhaggl 2011)
  Magnetization parameter distribution (Kong et al. 2011, 2012)



Uchiyama et al. (2009)



Kerschhaggl (2011)



Kong et al. (2012)

- **origin of the HE gamma-ray flares ?**

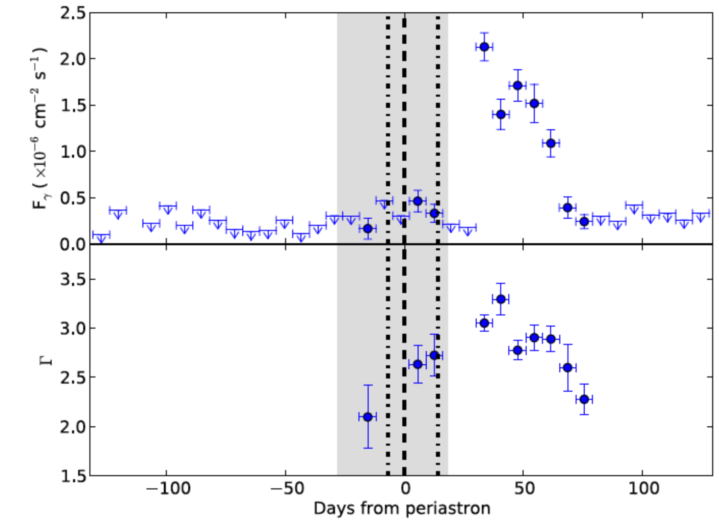
➤ Comptonisation of unshocked pulsar wind (Khangulyan et al. 2007, 2012).

➤ Circumstellar disk: feed with additional photon field (van Soelen et al. 2012)

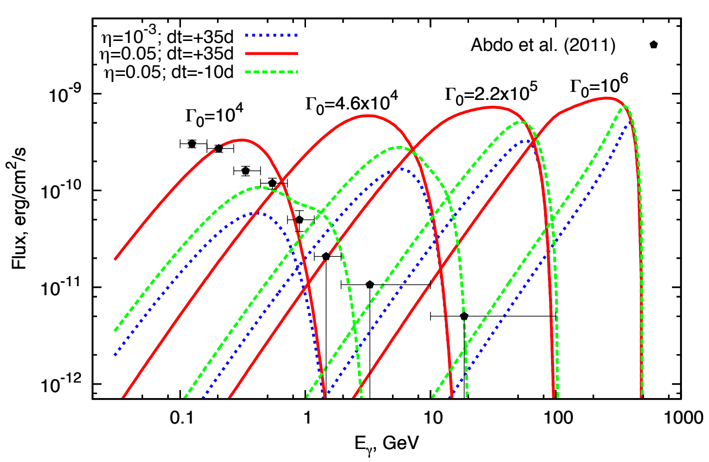
➤ Doopler boosted emission from shocked pulsar wind
(Bogovalov et al. 2012, Kong et al. 2012)

➤ Up-scattering of X-ray photons from the PWN (Dubus & Cerutti 2013)

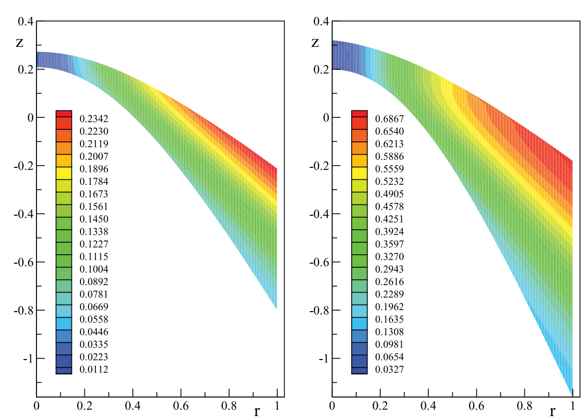
➤ VHE flux unrelated to HE flare (HESS Collaboration 2013)



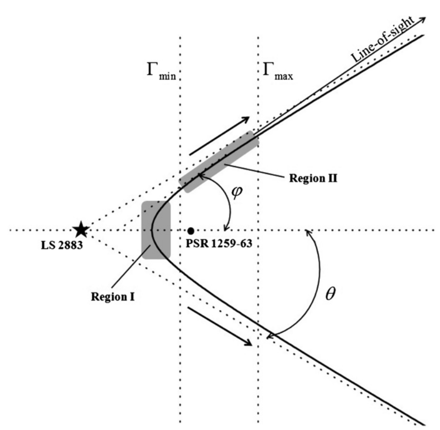
Abdo et al. (2012)



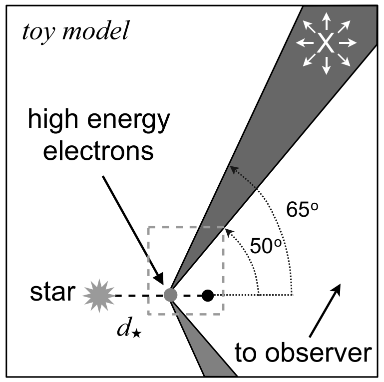
Khangulyan et al. (2012)



Bogovalov et al. (2012)

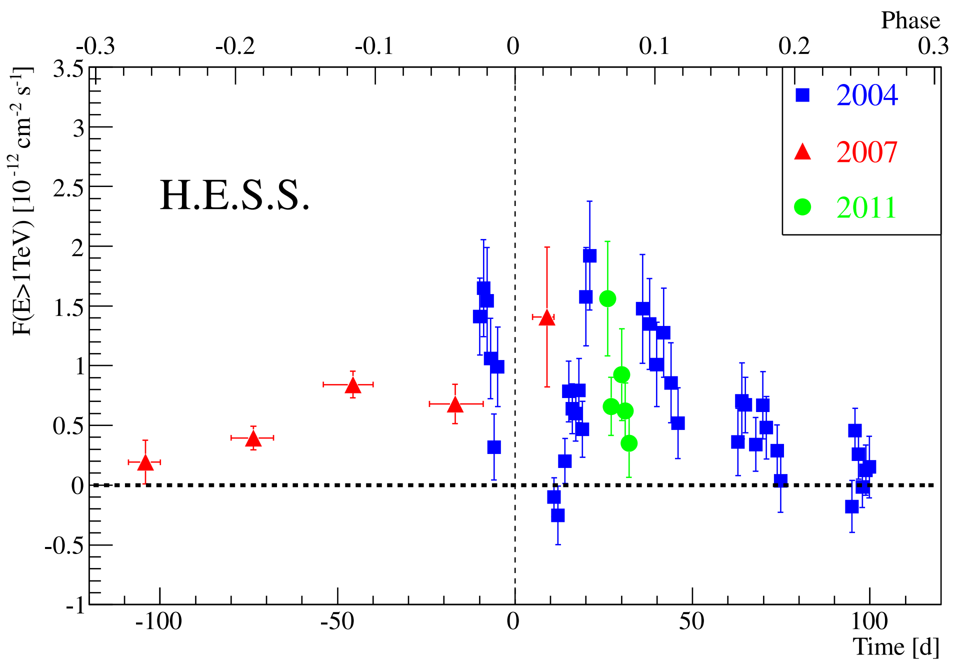


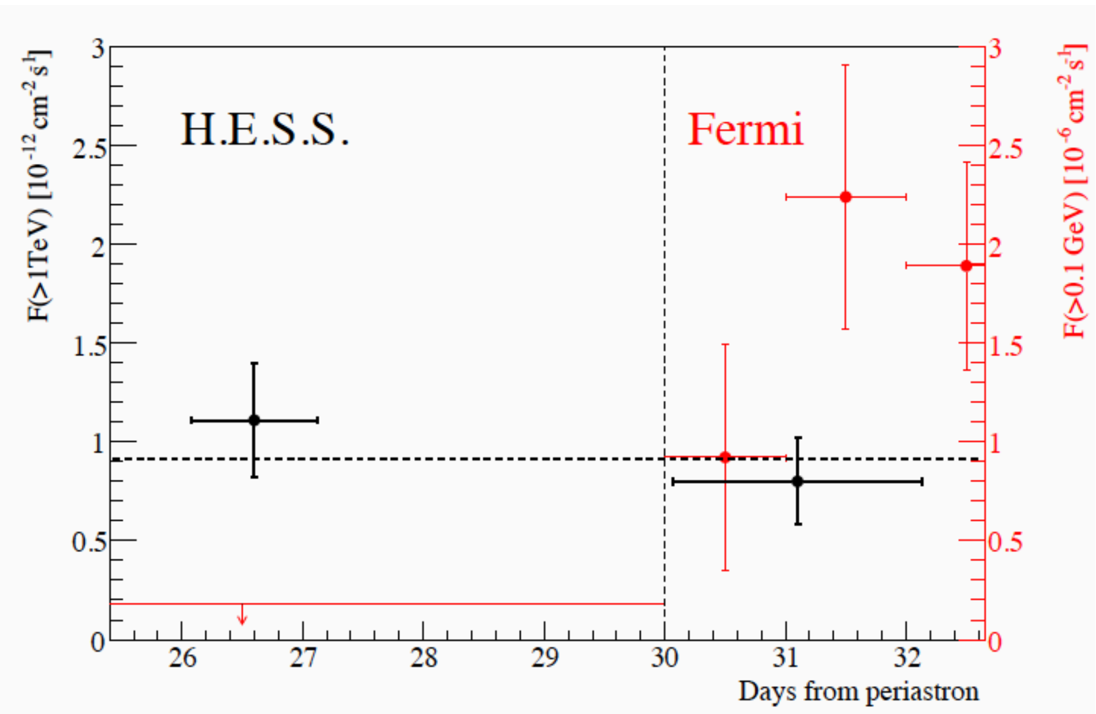
Kong et al. (2012)

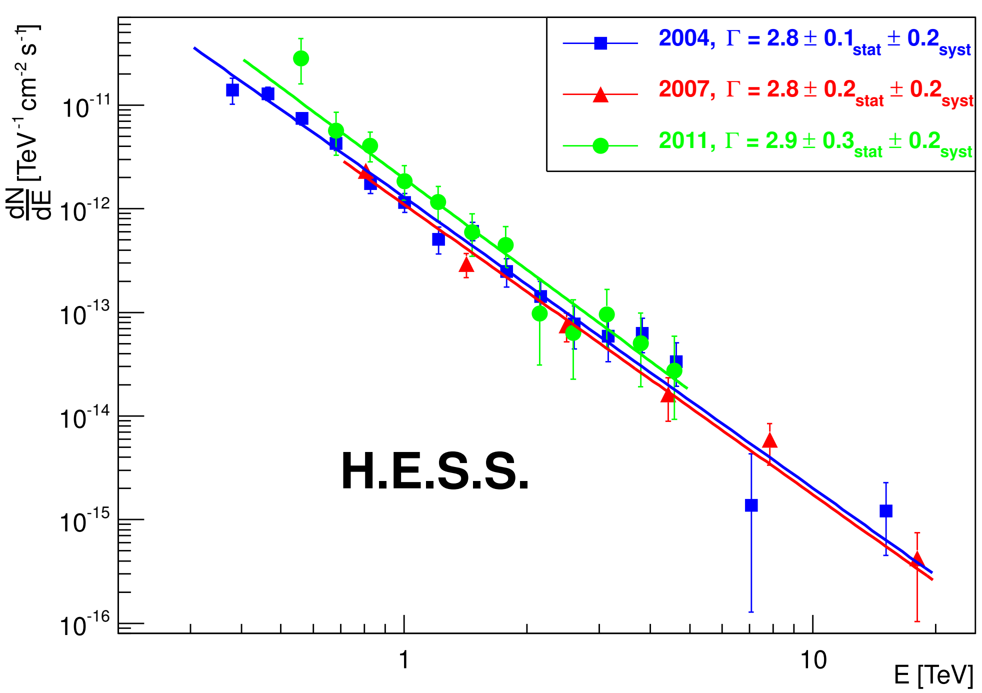


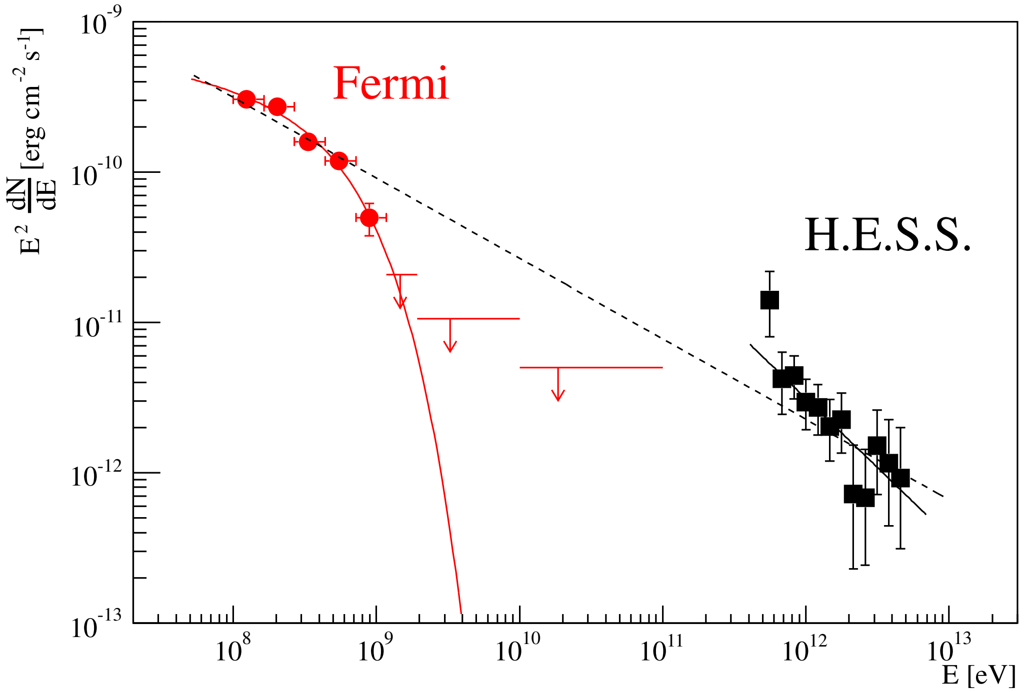
Dubus & Cerutti. (2013)

- **GeV flares: unrelated to TeV component?**





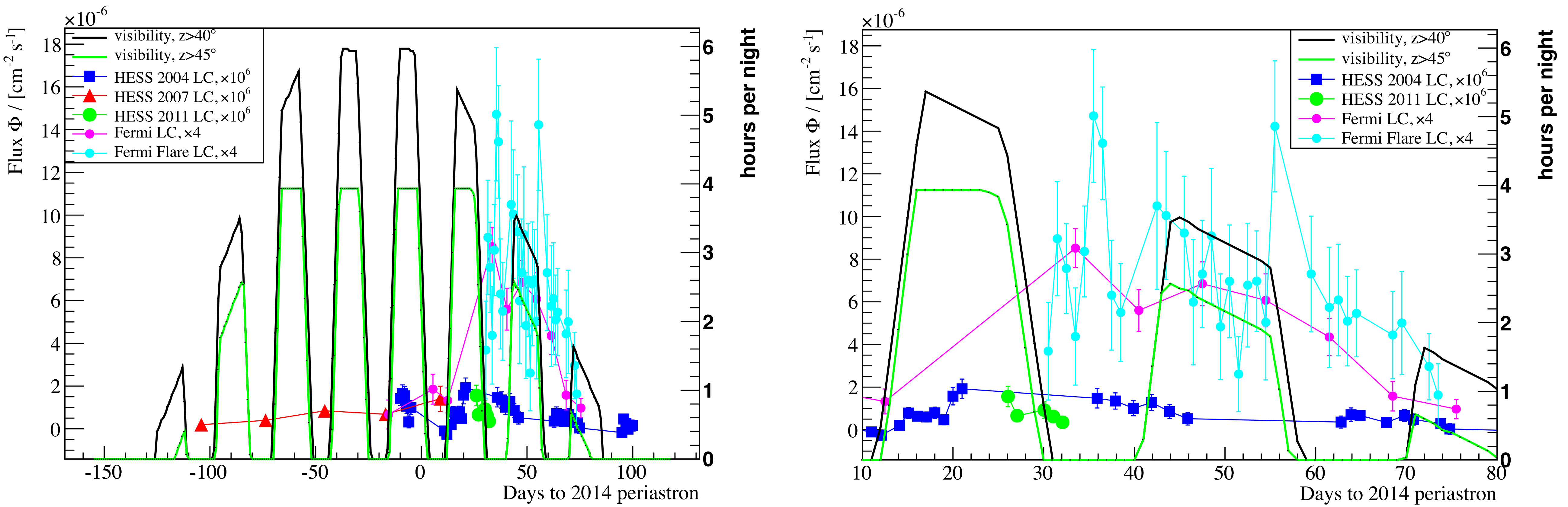




HESS Collaboration (2013)

PSR B1259-63/LS 2883 - 2014 periastron

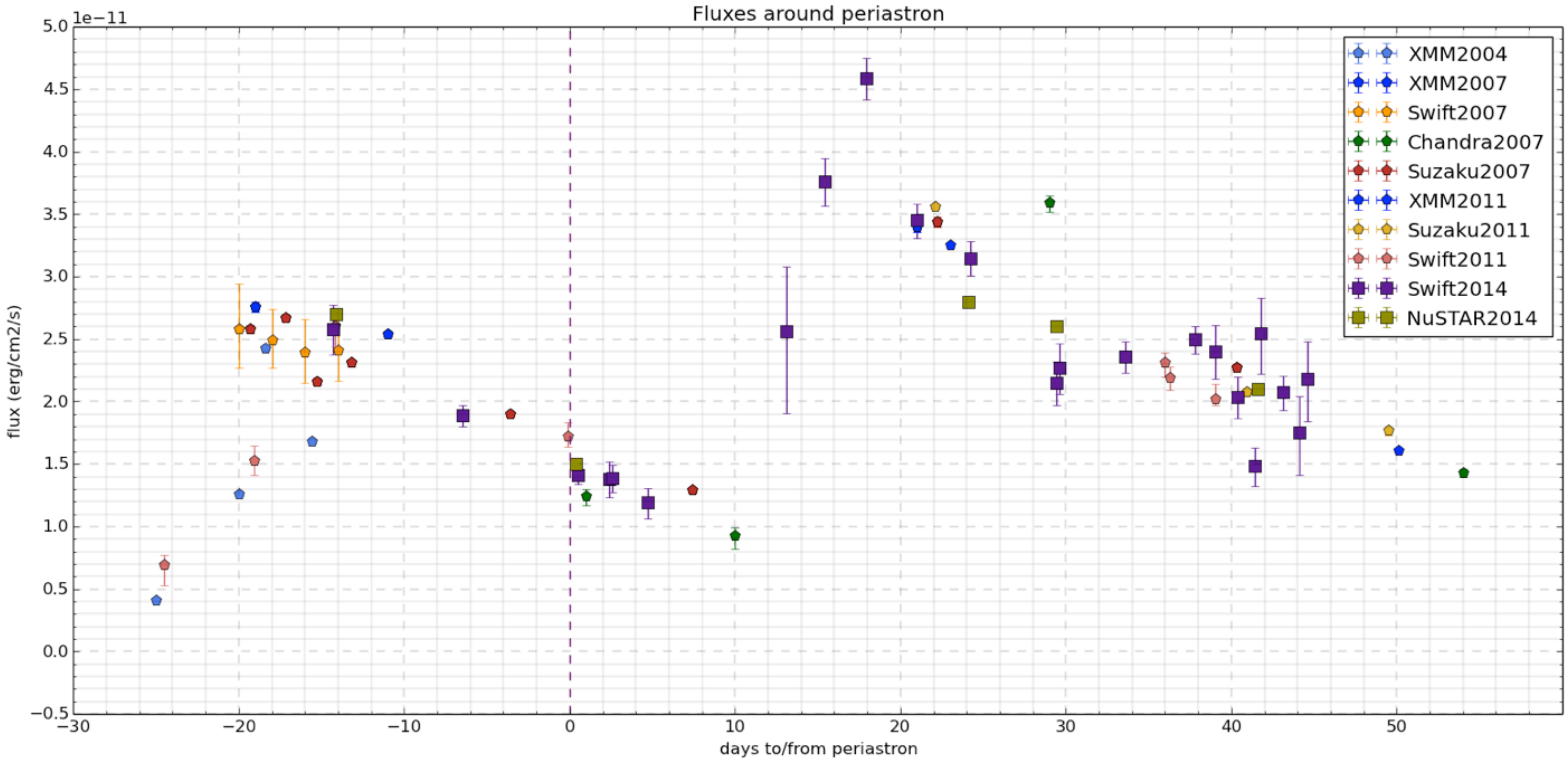
H.E.S.S. observation conditions in 2014 close to periastron



- ➤ H.E.S.S. has observed PSR B1259-63 in 2014 during the whole pre/post - periastron passage
- ➤ t_{per} oitself observed at TeVs for the first time
- ➤ H.E.S.S. data being processed (including first H.E.S.S.-II observations)
- ➤ Detailed MWL coverage: + *Fermi*, INTEGRAL, Suzaku, NuStar, SALT, ATCA...

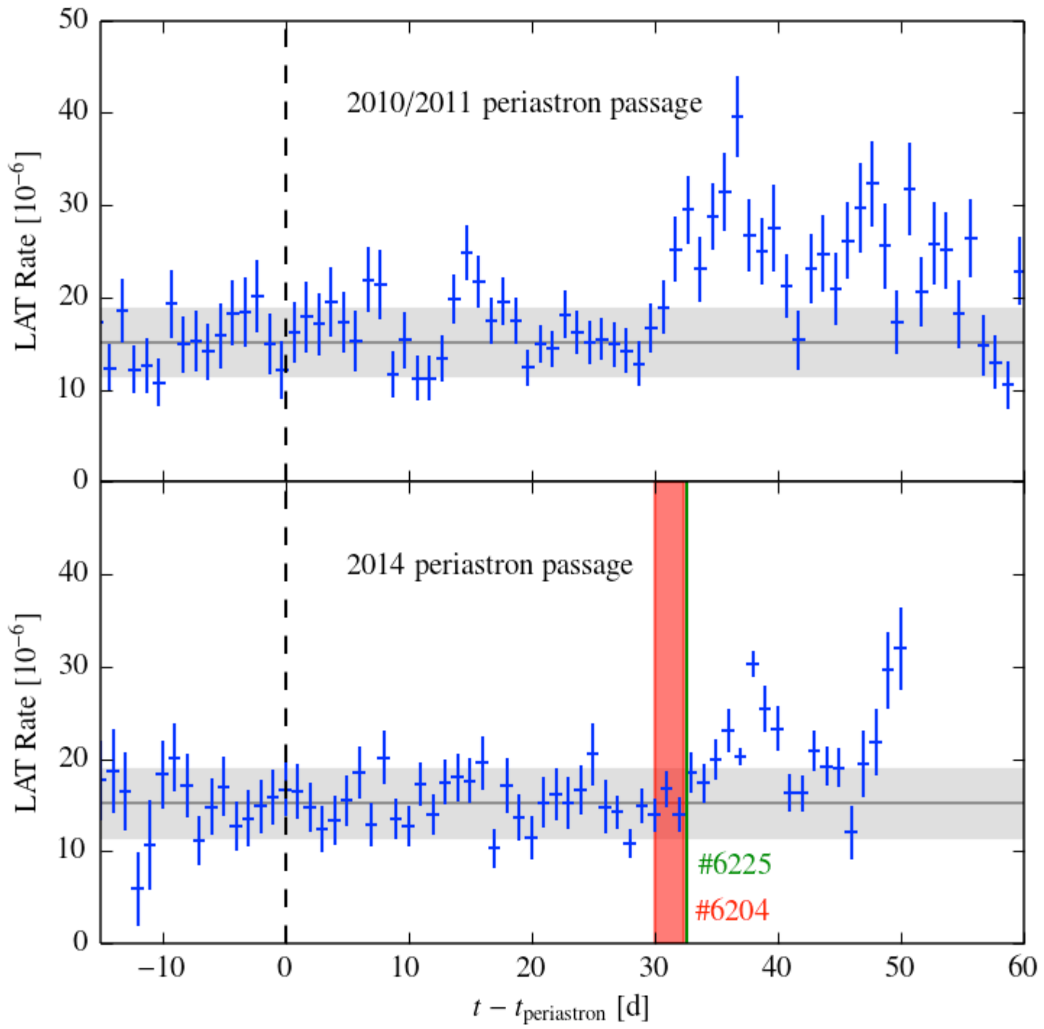
PSR B1259-63/LS 2883 - 2014 periastron

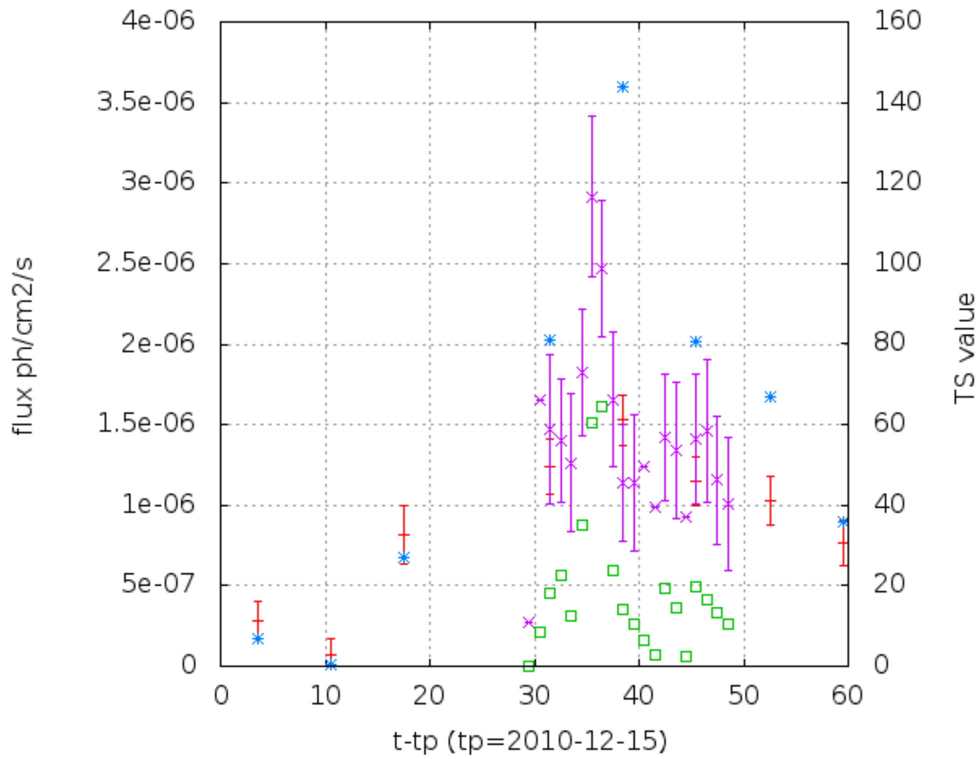
Swift-XRT (ToO) + NuSTAR (scheduled + ToO) observations

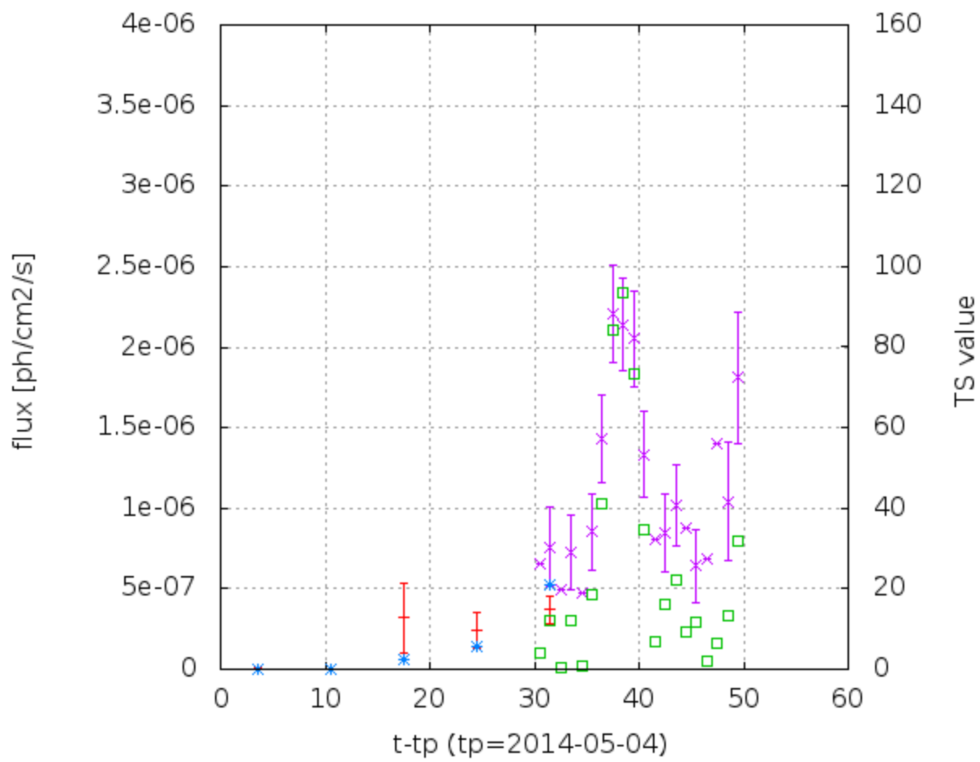


PSR B1259-63/LS 2883 - 2014 periastron

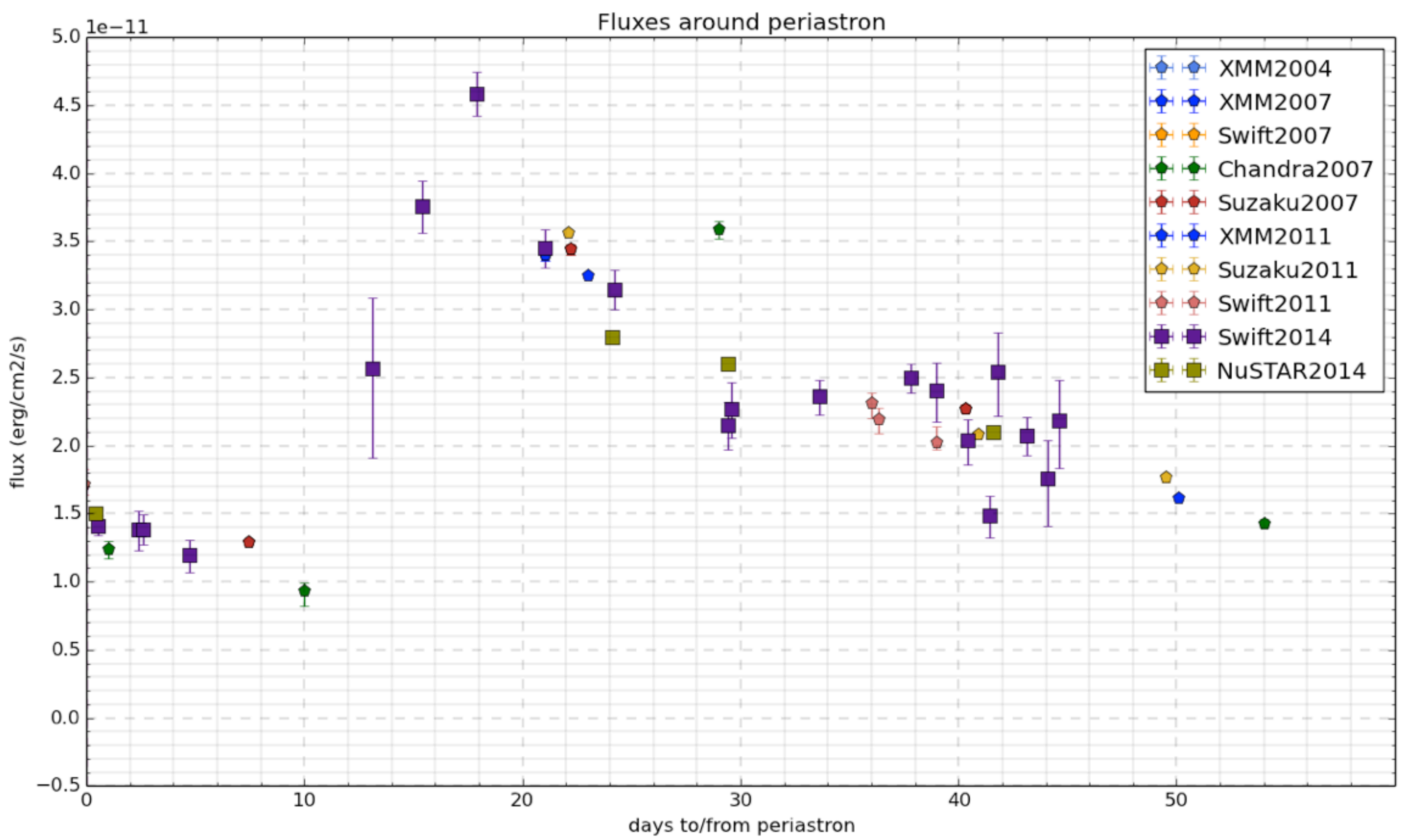
Fermi-LAT observations - 2014 flare event

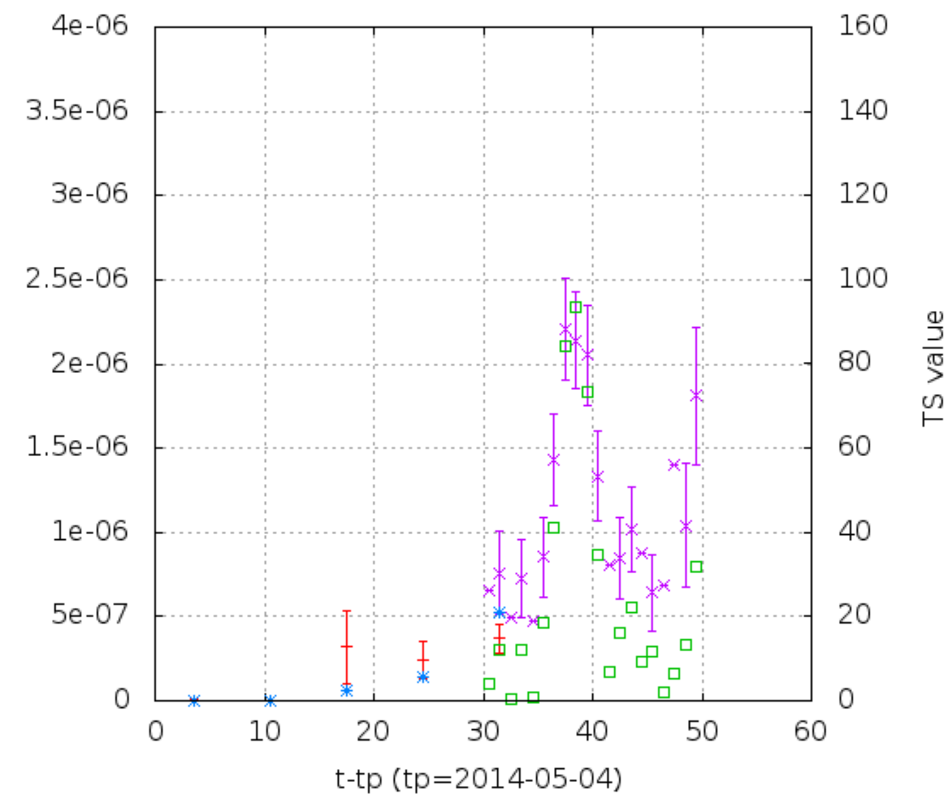






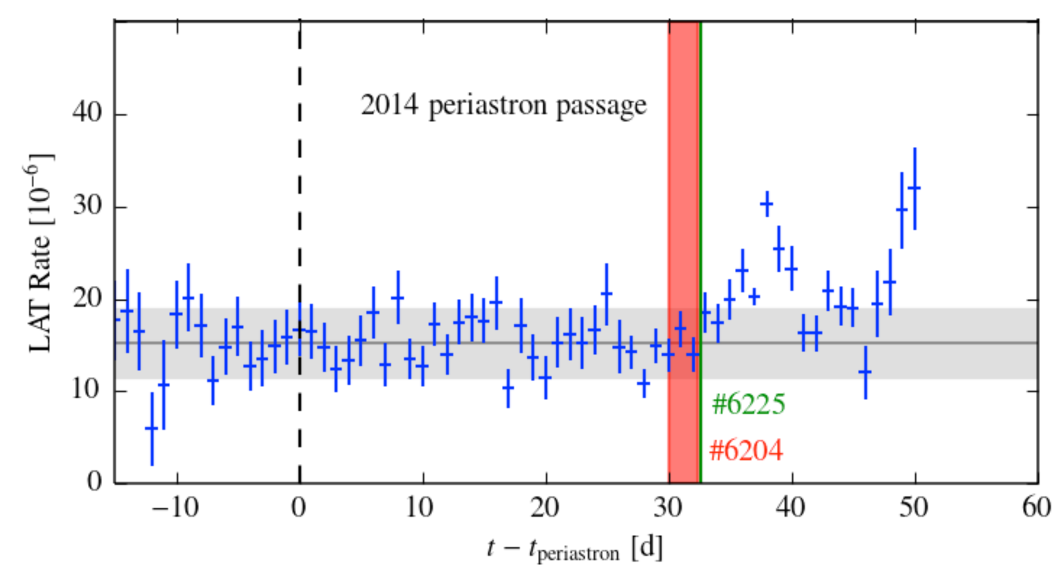
PSR B1259-63/LS 2883 - 2014 periastron



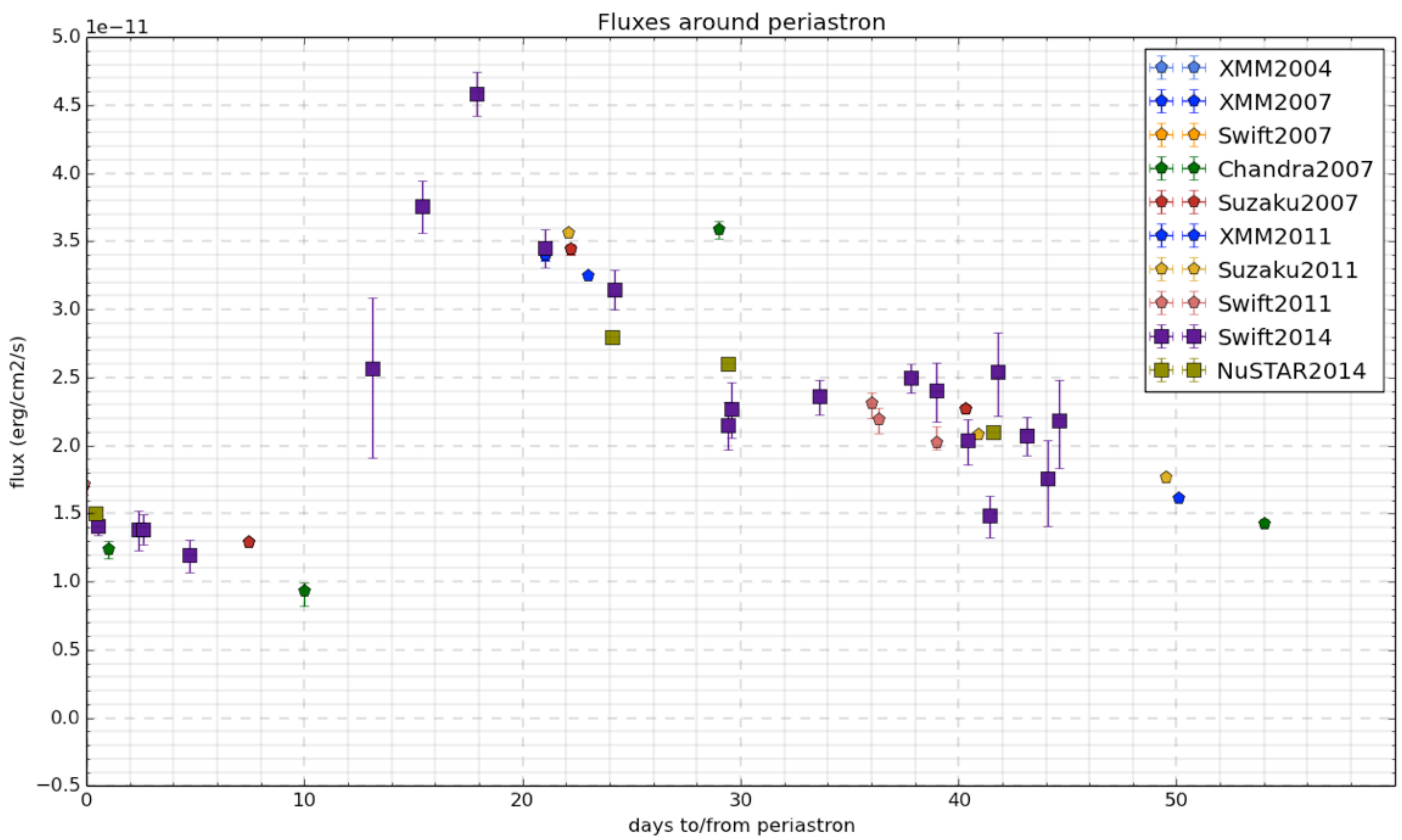


Short-term X-ray/gamma-ray variability from PSR B1259-63

ATel #6248; ***P. Bordas (Max-Planck-Institut fur Kernphysik), V. Zabalza (Department of Physics and Astronomy, University of Leicester), C. Romoli (Dublin Institute for Advanced Studies), D. Khangulyan (Institute of Space and Astronautical Science/JAXA) and G. Puehlhofer (Institut fur Astronomie und Astrophysik, Universitat Tuebingen)***
*on **19 Jun 2014; 14:06 UT***



PSR B1259-63/LS 2883 - 2014 periastron



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- *X-ray/gamma-ray un/correlated variability?*

⇒ IC by unshocked wind not responsible for X-rays...

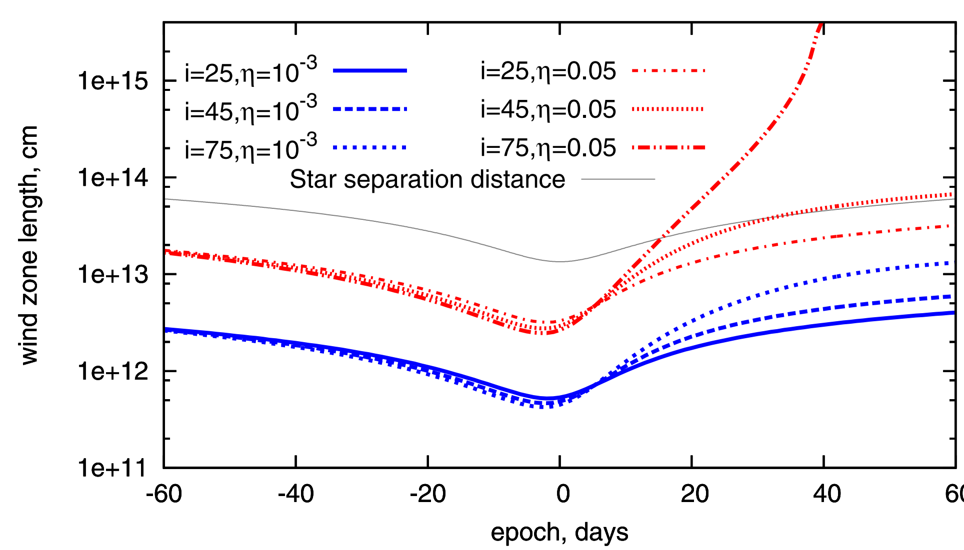
⇒ If flare from Doppler boosting:

- should have a brighter X-ray counterpart
- should have a TeV counterpart

⇒ different mechanisms for both emissions

⇒ η-transition when "leaving" circ. disk

- provide larger PWZ for IC
- hydrodynamical instabilities affecting shocked wind
- explain delay (~5d) 2014 flare?



Khangulyan et al. (2012)

Gamma-ray emitting binaries with HESS

	GeV	TeV	Class	Components
PSR B1259-63	yes	yes	PSR binary	Oe + PSR
LS 5039	yes	yes	?	O + C.O.
HESS J0632+057	no	yes	?	Be + C.O.
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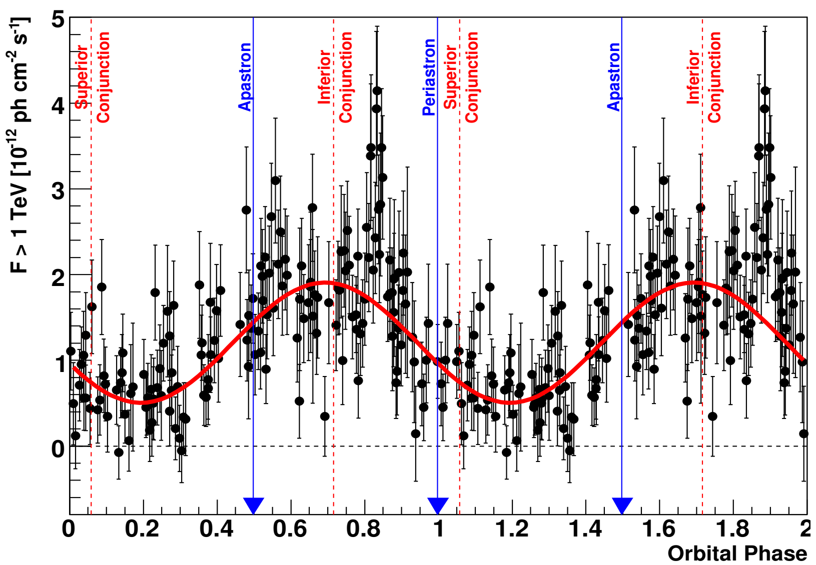
η-Carina	yes	no	CW binary	LBV + O(?)
transients	yes	no/?	novae, µQ	---

Gamma-ray emitting binaries with HESS

LS 5039

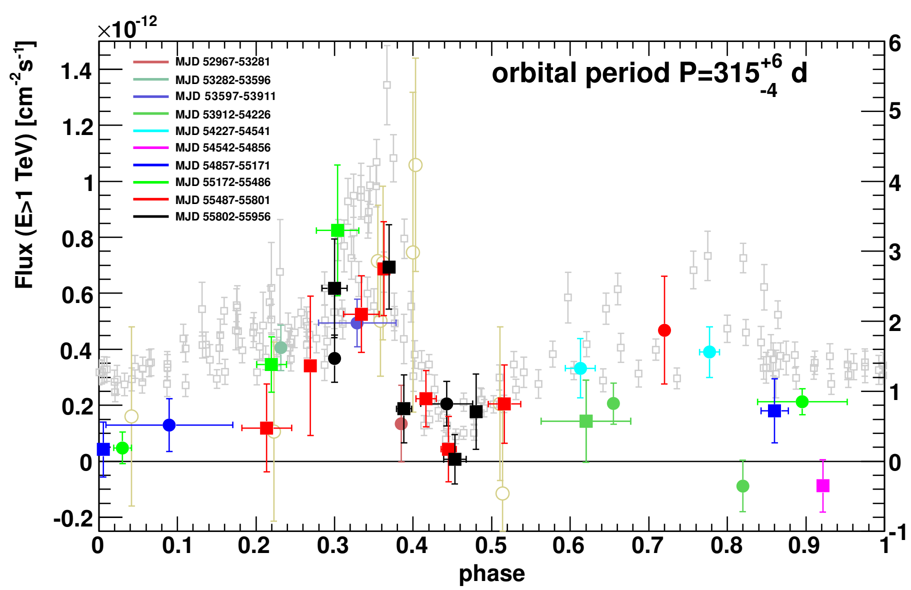
- P_{orb}= 3.9d,
- comp. star = O6.5V,
- C.O.= 1.7 - 5.0 M_{sun}



Aharonian et al. (2005)

HESS J0632+057

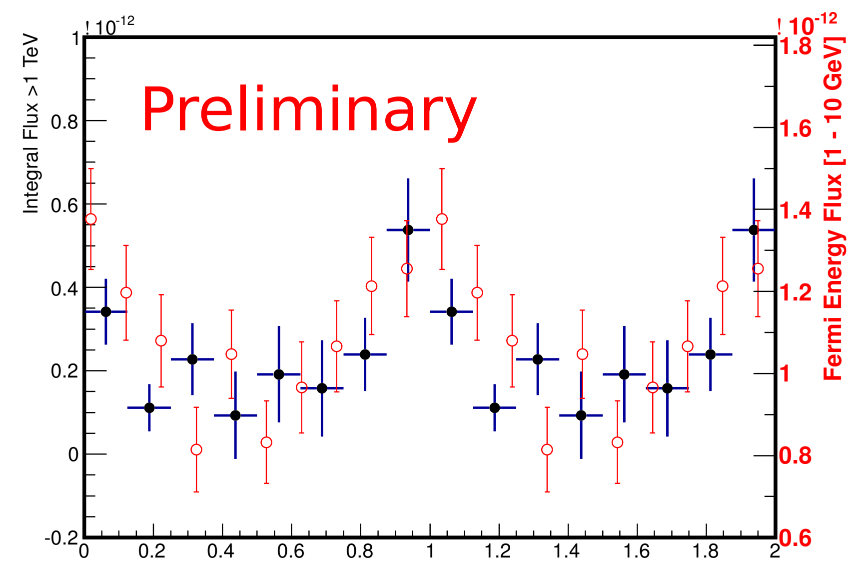
- P_{orb}= 315d,
- comp. star = B0pe
- C.O.= 1.3 - 7.1 M_{sun}



HESS & VERITAS Collaborations (2013)

1FGL J1018.6-5859

- P_{orb}= 16.6d,
- comp. star = O6.5V,
- C.O.= ?

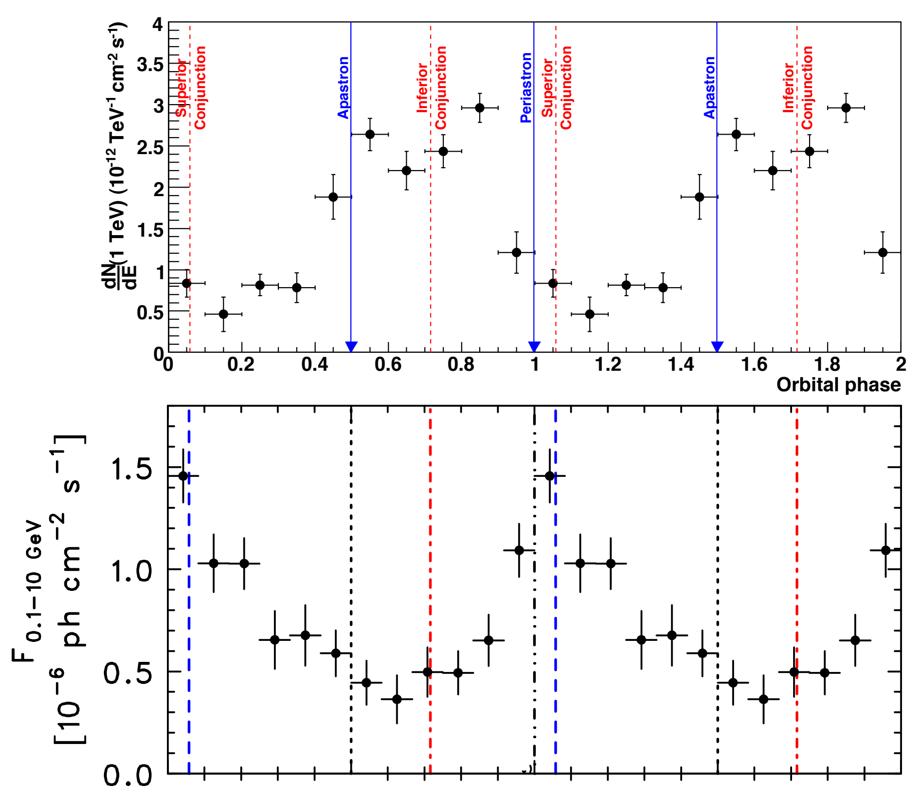


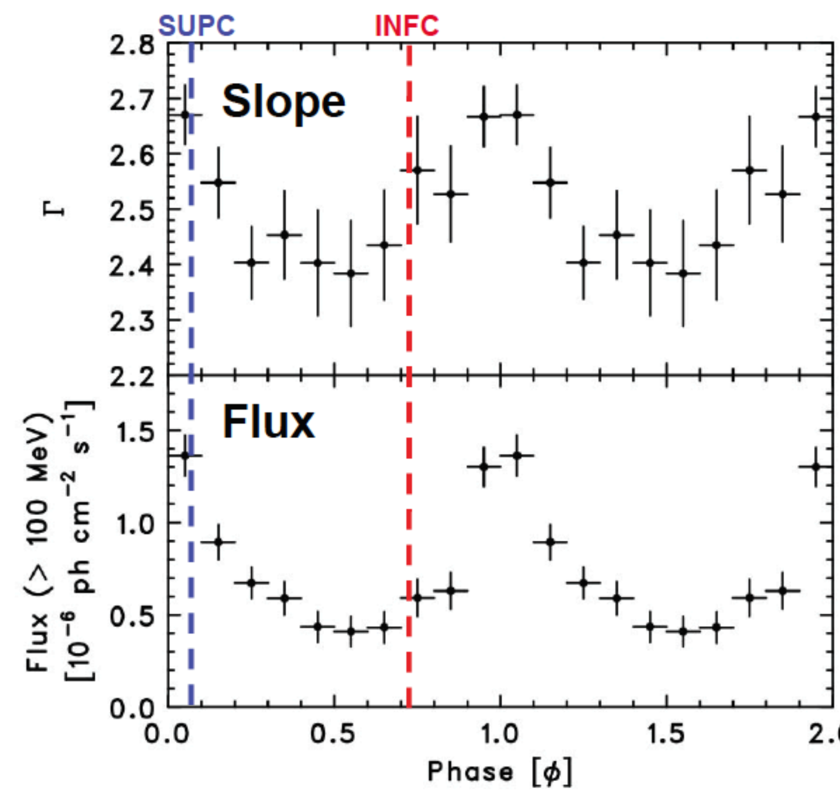
ICRC 2013, HESS Collaboration

LS 5039 *vs* 1FGL J1018.6-5859

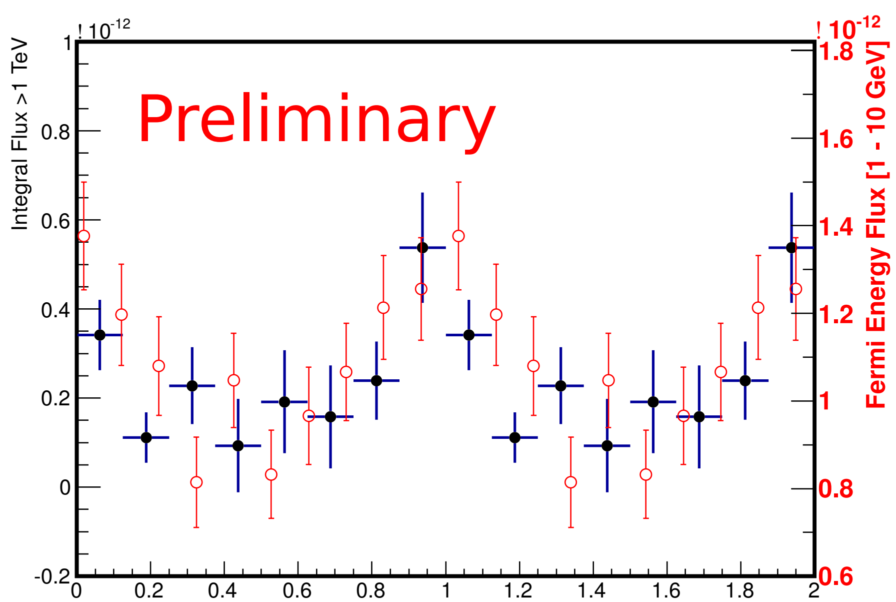
similar companion star, orbital periods...
but opposite phase-folded GeV-TeV lightcurve and flux-vs-hardness behaviour

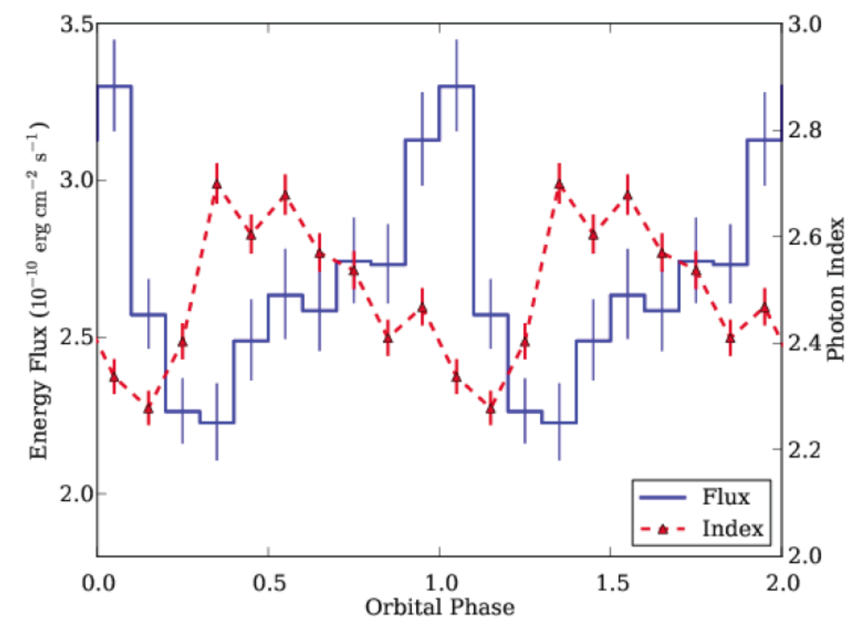
LS 5039



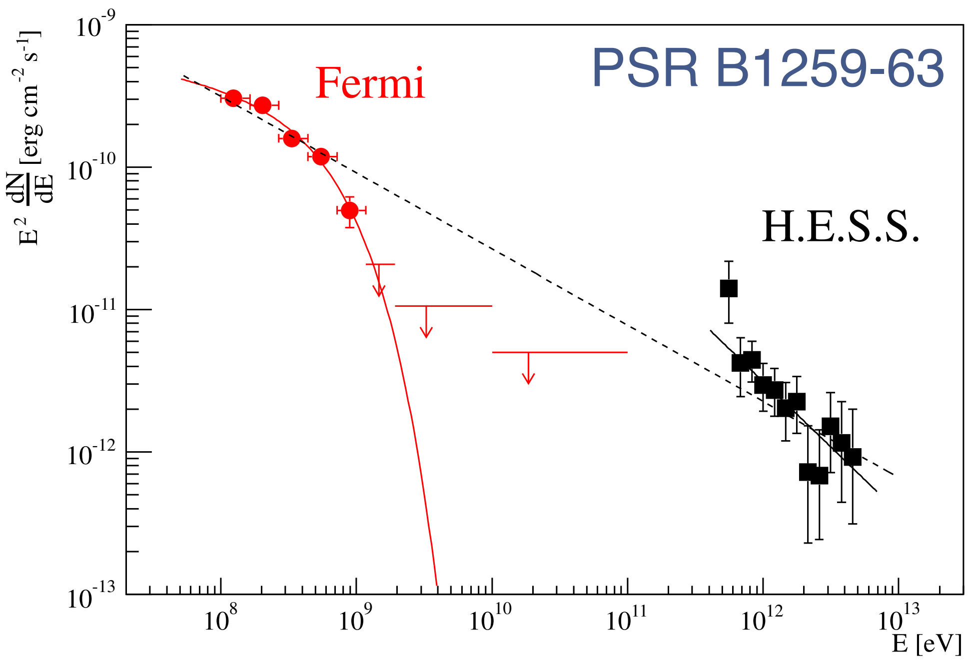


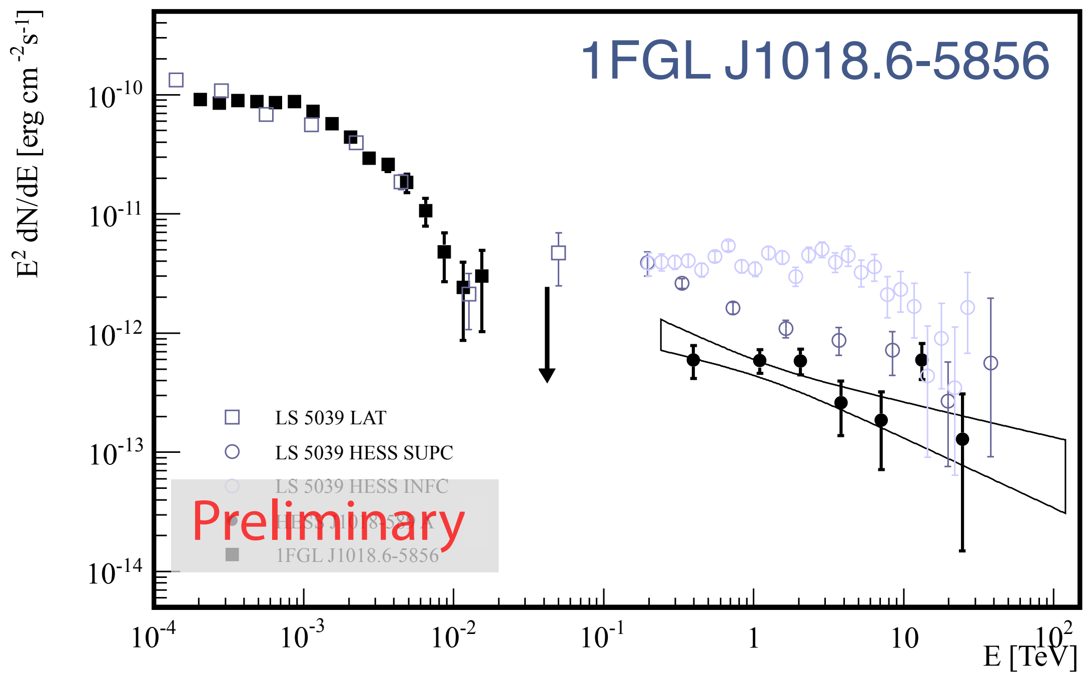
1FGL J1018

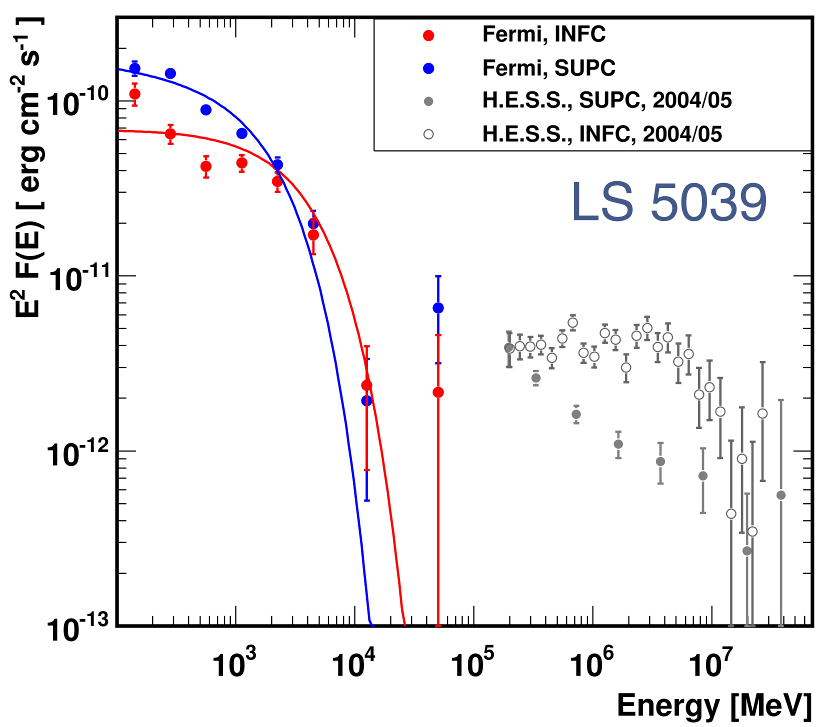


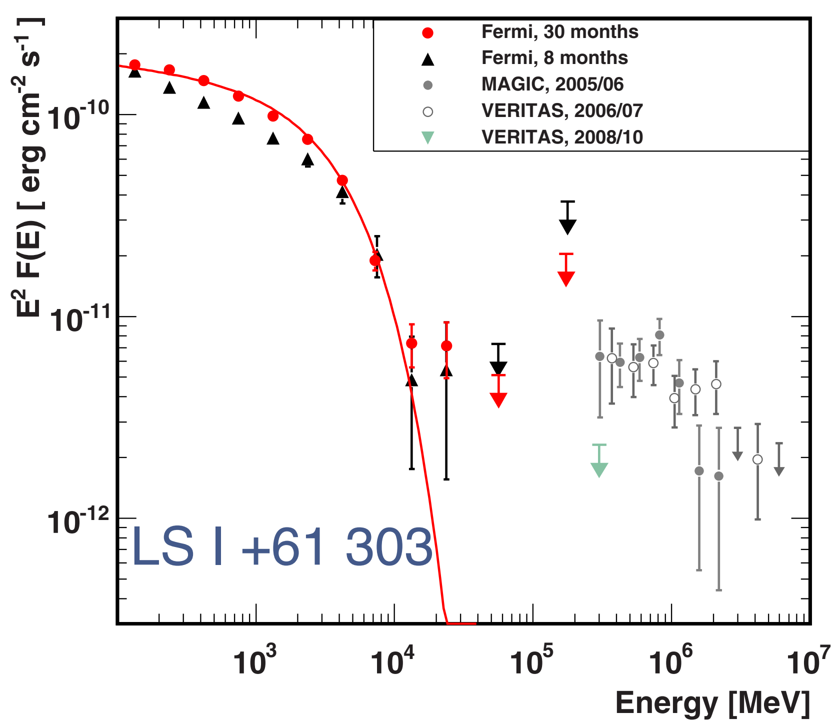


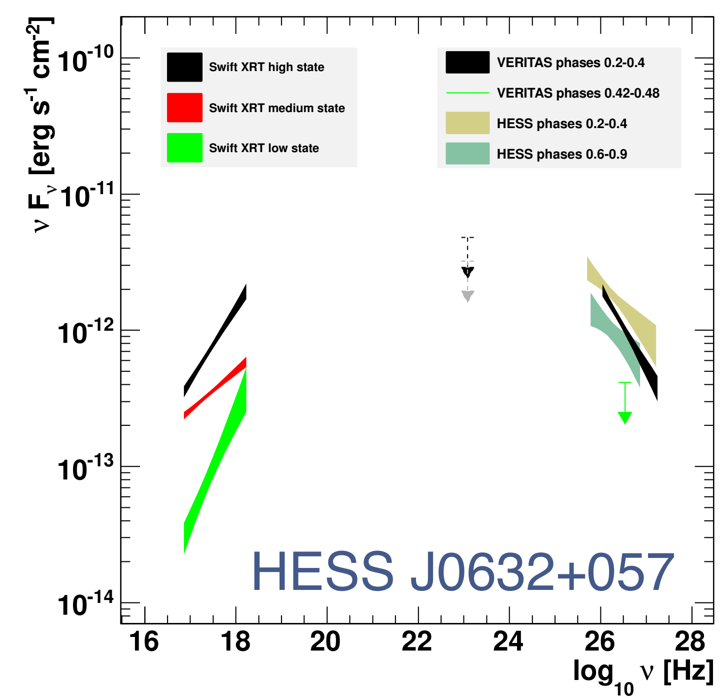
GeV - TeV connection in gamma-ray binaries











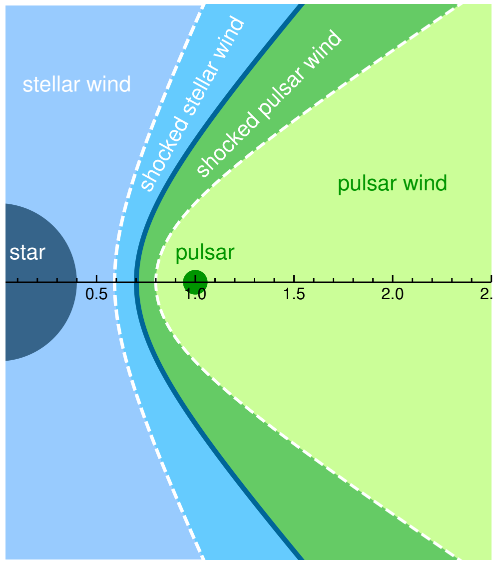
GeV - TeV connection in gamma-ray binaries

➤ **The GeV and TeV components are difficult to reconcile with a single IC emitter**

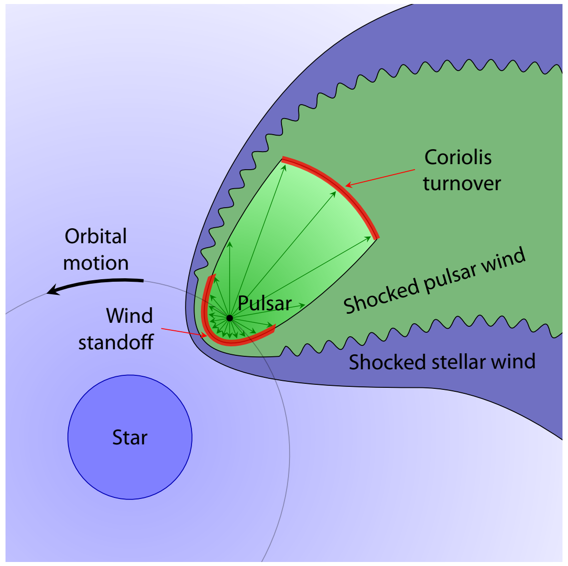
GeV emitter requires:
- High efficiency in converting pulsar wind power into non-thermal luminosity.
- Injection high energy cutoff at $E_e \sim 10$ GeV → low acceleration efficiency
- A location close to the compact object → good variability behaviour for IC

TeV emitter requires:
- High energy cutoff at $E_e \sim 10$ TeV → high acceleration efficiency
- $\gamma\gamma$ absorption precludes a deep TeV emitter

➤ **different GeV/TeV components?**
- magnetospheric + pulsar wind (e.g. Torres 2011)
- striped pulsar wind (e.g. Petri & Dubus 2010)
- unshocked wind (PSR B1259-63 flare; Khangulyan et al. 2012)
- high-Γ shocked wind (Bogavolov et al. 2012, Kong et al. 2012)
- shock apex + Coriolis turnover (Bosch-Ramon & Barkov 2011)



Szostek & Dubus (2011)



Bosch-Ramon & Barkov (2011), Zabalza et al. (2013)

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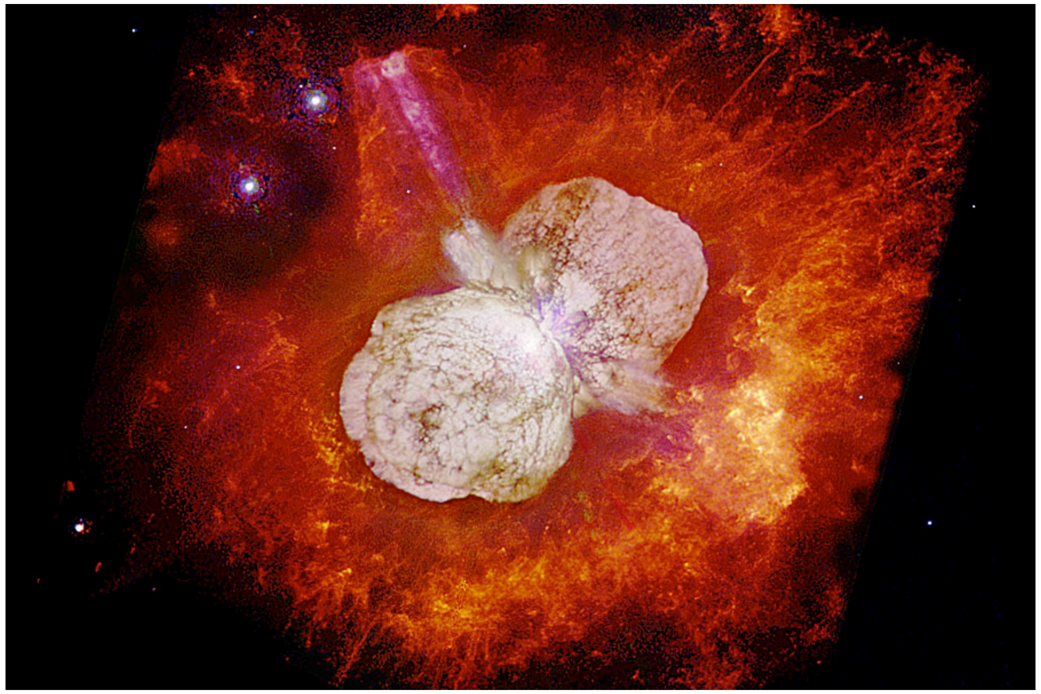
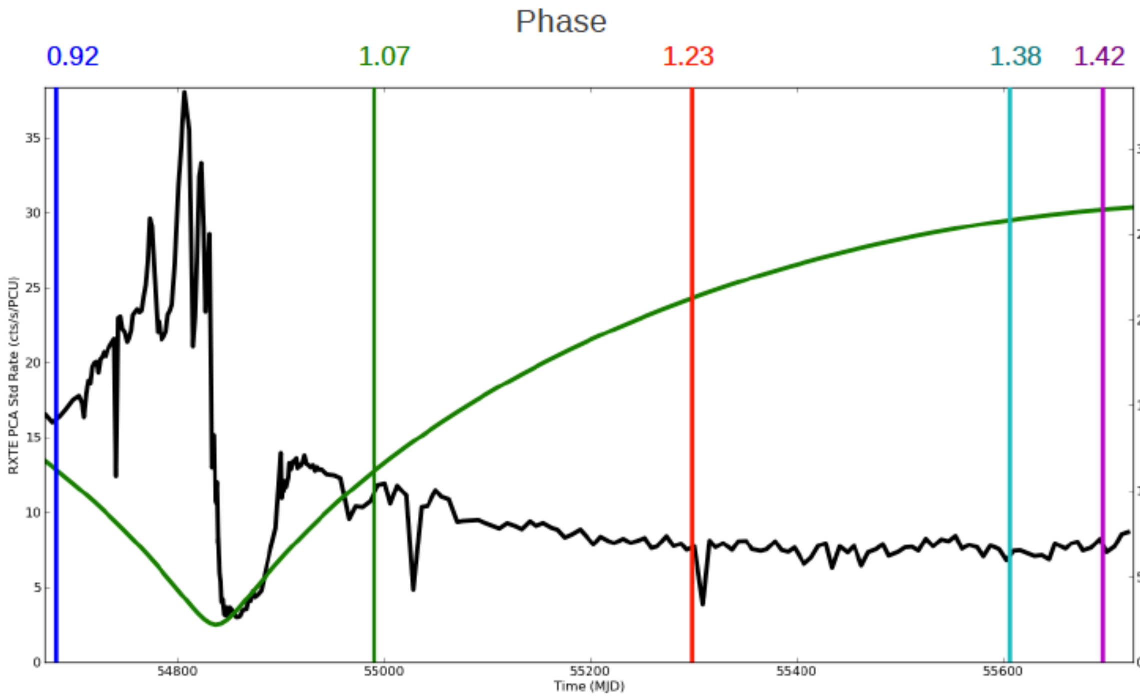
η-Carina	yes	no	CW binary	LBV + O(?)
transients	yes	no/?	novae, μQ	---

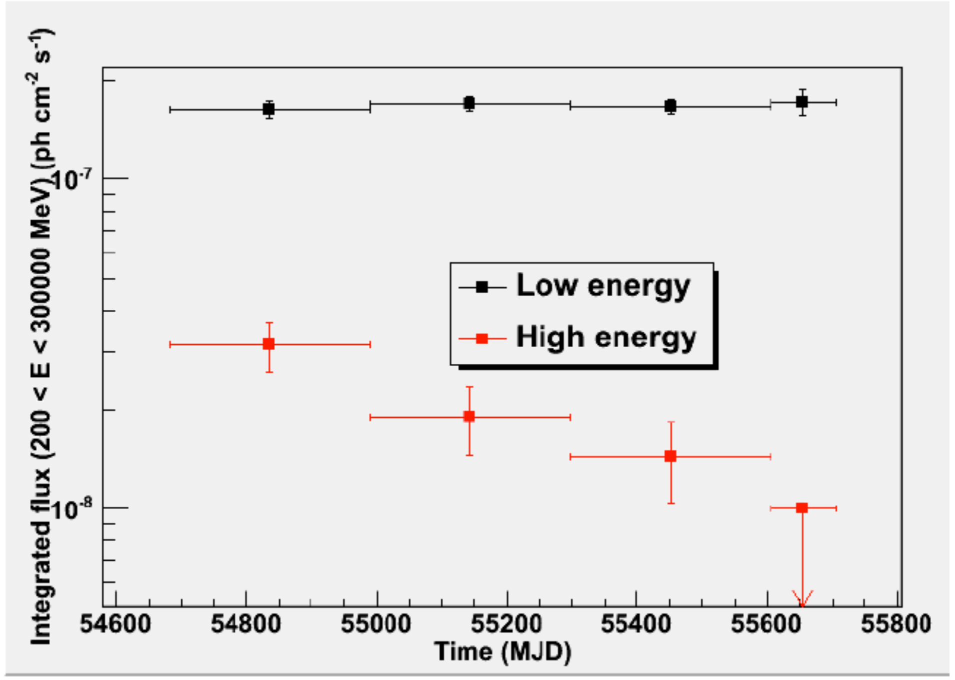
Eta Carinae

- distance: 2.3 kpc
- eccentricity: ~0.9
- period: 5.54 years
- primary star = LBV, M = 80 - 120 M_{sun}, $dM/dt \sim 10^{-4}$ - 10^{-3} M_{sun} yr^{-1}
- secondary star = O/WR, M = 30 M_{sun}, $dM/dt \sim 10^{-5}$ M_{sun} yr^{-1}



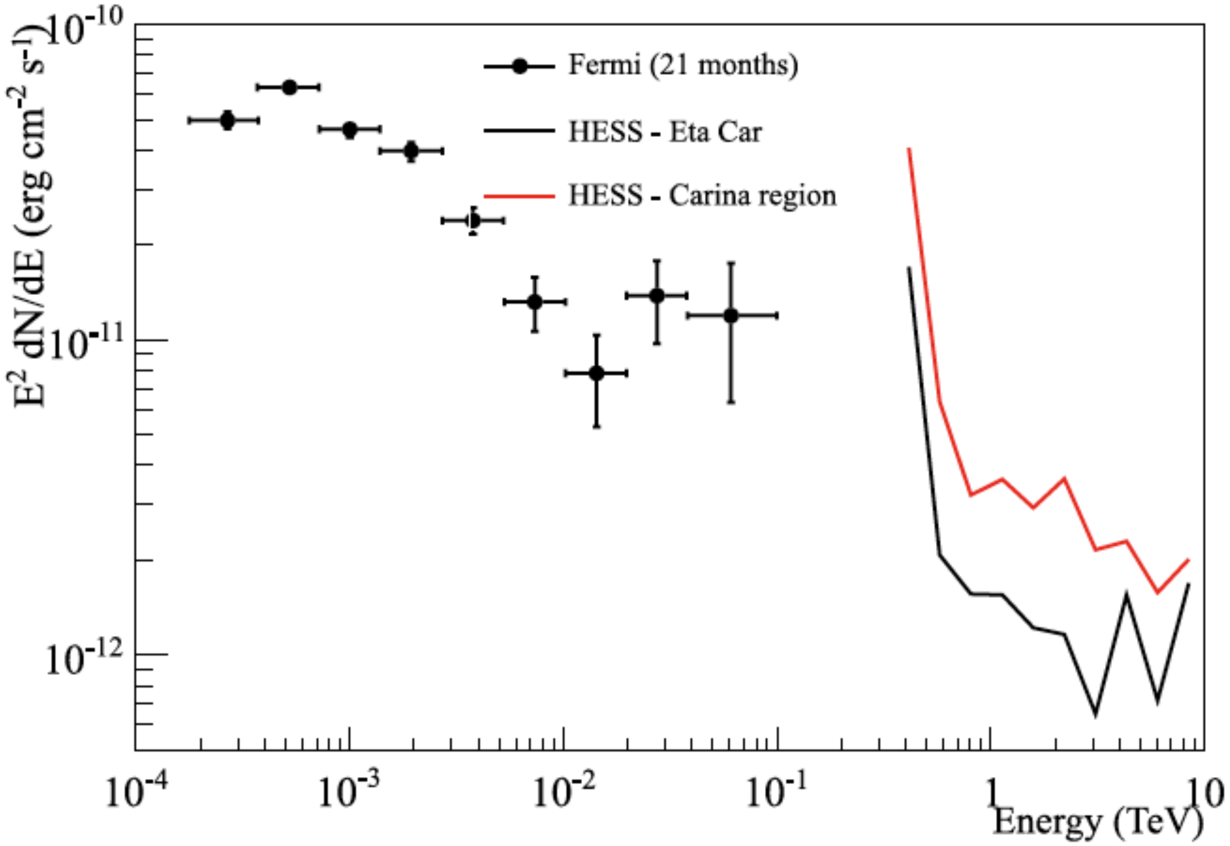
credits: N. Smith & J. A. Morse





Farnier et al. (2011)

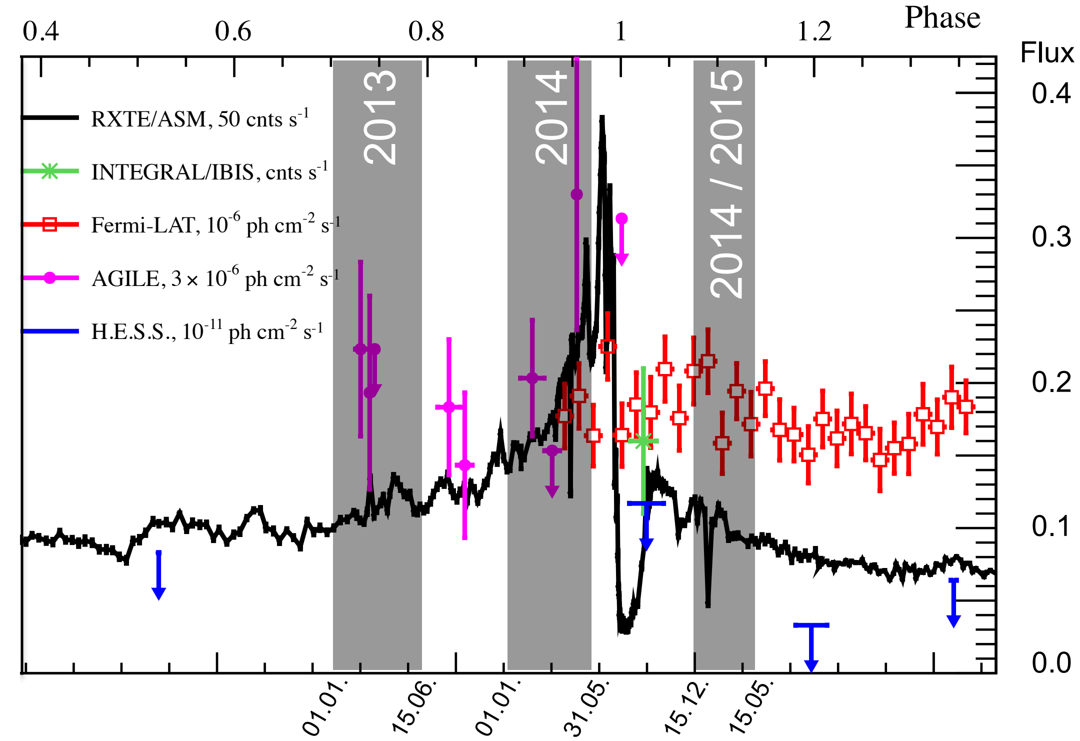
H.E.S.S. upper limits

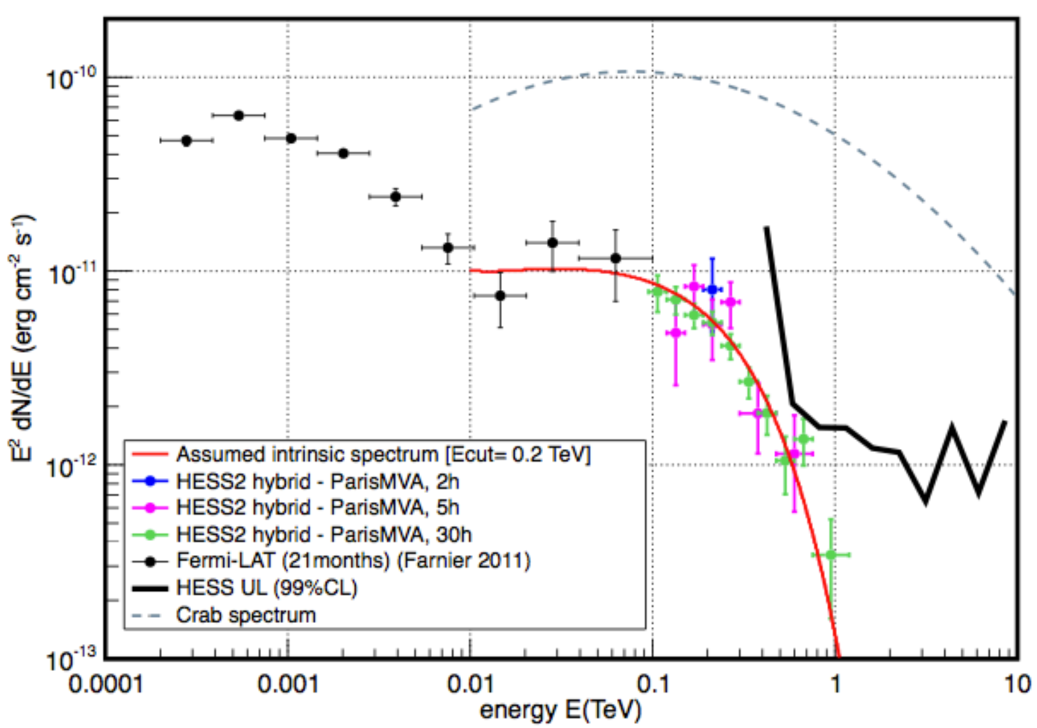


- **No positive signal found yet** (@ E_{th} > 470 GeV)
  - Eta Carinae ≤ 7.7×10^{-13} ph cm^{-2} s^{-1}
  - Carina Nebula ≤ 4.2×10^{-12} ph cm^{-2} s^{-1}

H.E.S.S. Collaboration (2012)

H.E.S.S.-II observations in 2014



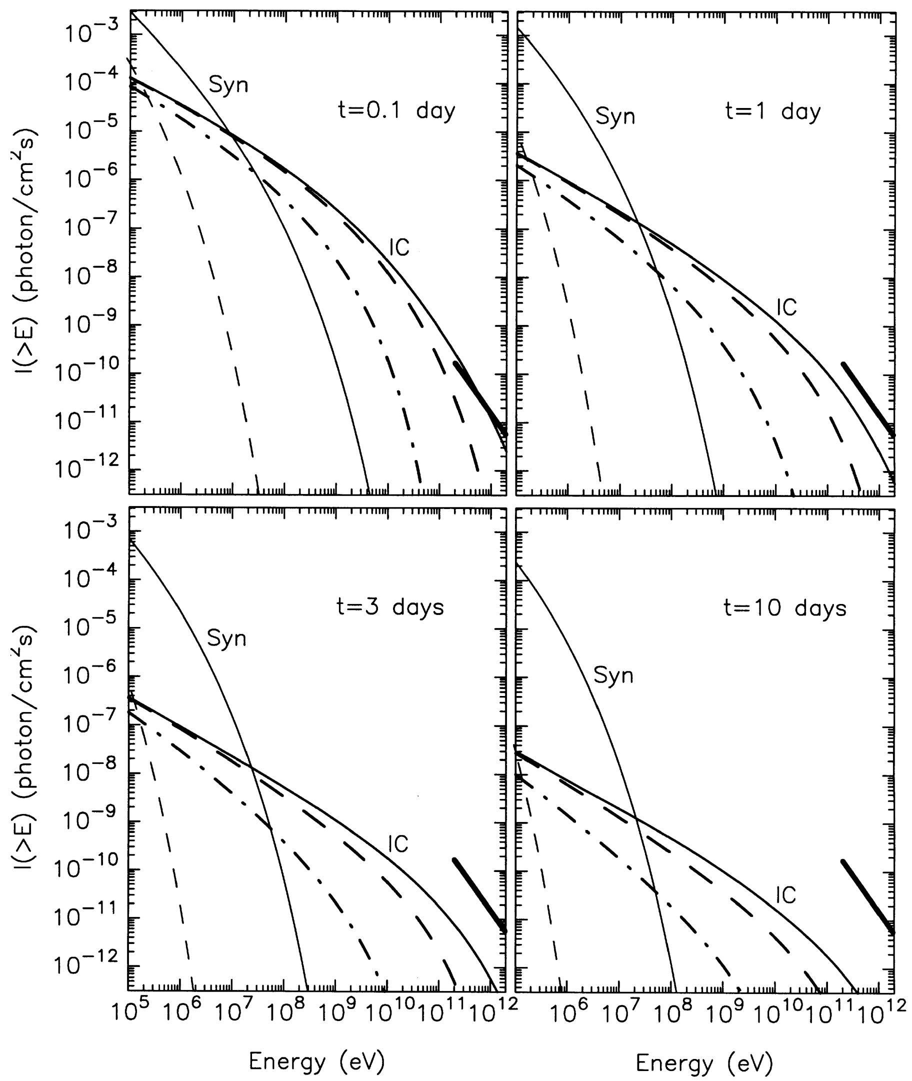


Gamma-ray emitting binaries with HESS

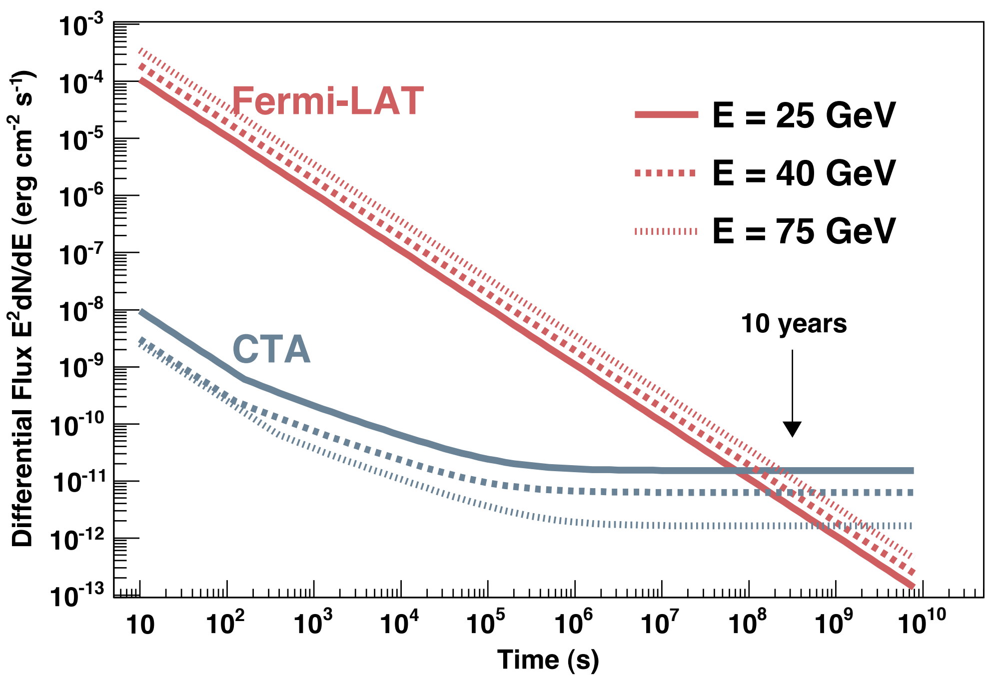
	GeV	TeV	Class	Components
PSR B1259-63	yes	yes	PSR binary	Oe + PSR
LS 5039	yes	yes	?	O + C.O.
HESS J0632+057	no	yes	?	Be + C.O.
1FGL J1018.6–5856	yes	?	?	O + C.O.
η-Carina	yes	no	CW binary	LBV + O(?)
transients	yes	no/?	novae, μQ	---

transients: µQs

- **GRS 1915+105, Cyg X-3, Cyg X-1, SS433, Cir X-1, V464 Sgr, 1E 1740 ...**:
  - ➤ Steady HE/VHE γ-ray emission still lacking (Acero+ 2009), (Aleksic+ 2010), (Saito+ 2009)...
  - ➤ HE outbursts in Cyg X-3 (Tavani et al. 2009; Abdo et al. 2010) and Cyg X-1 (Sabatini et al. 2010)
  - ➤ At VHE, only a hint during outburst of Cyg X-1 (Albert et al. 2007) - needs confirmation



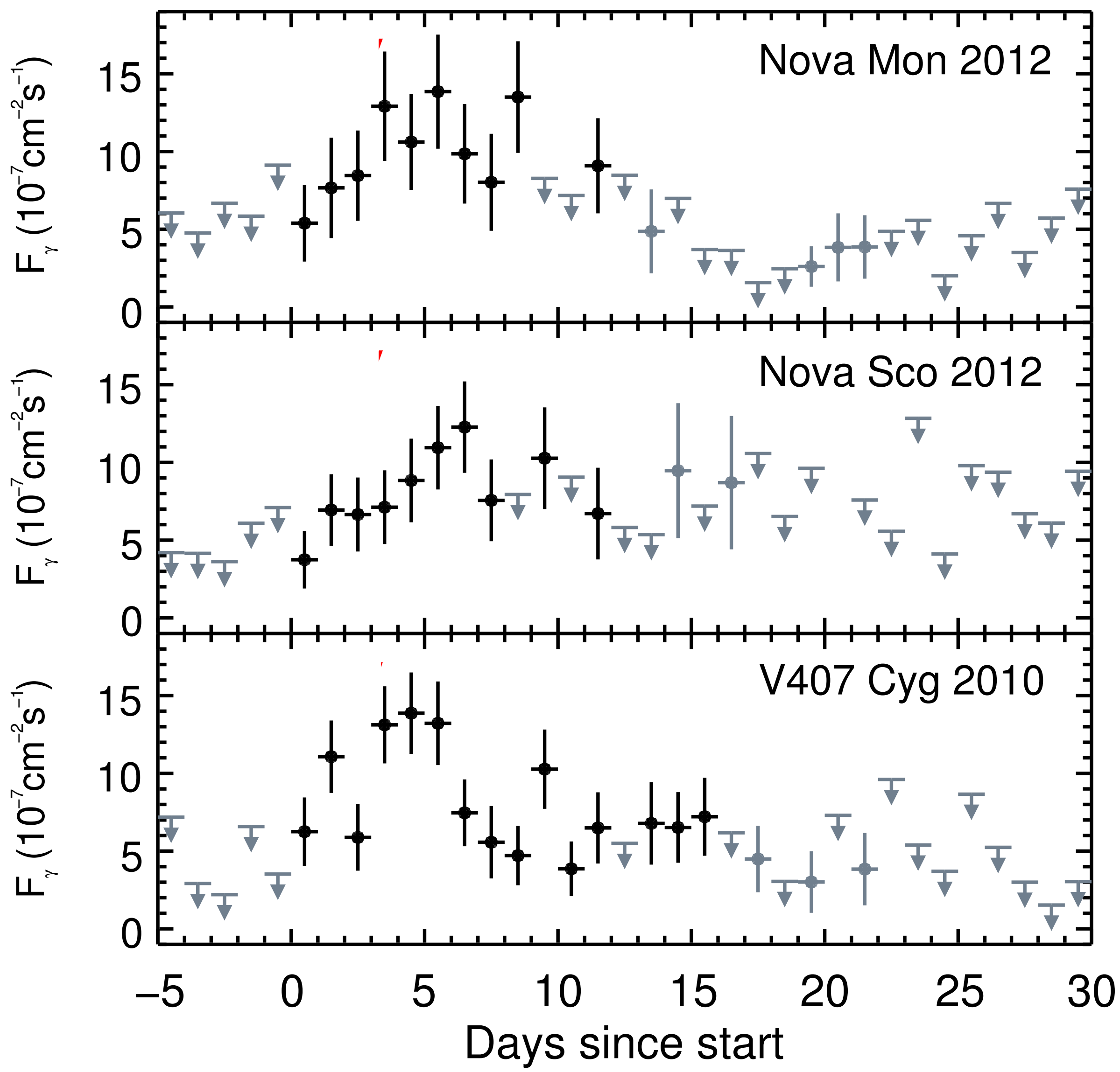
Atoyan & Aharonian (1999)



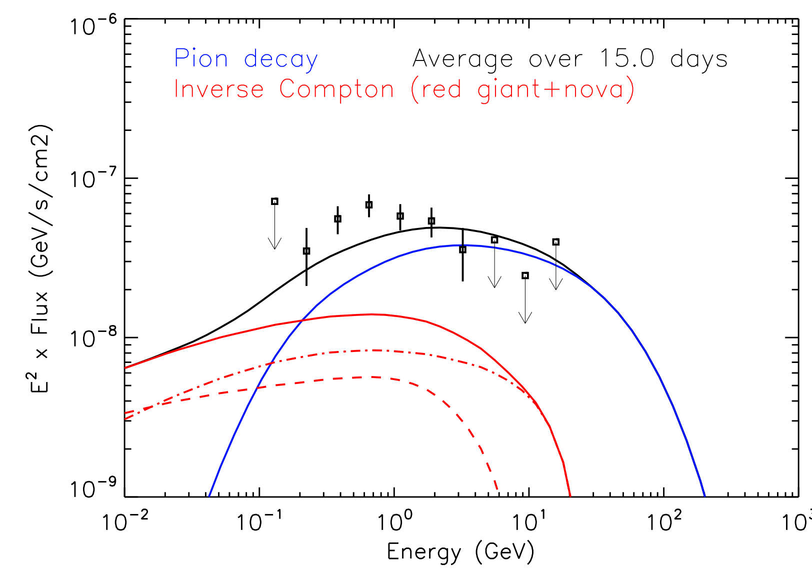
Funk & Hinton (2012)

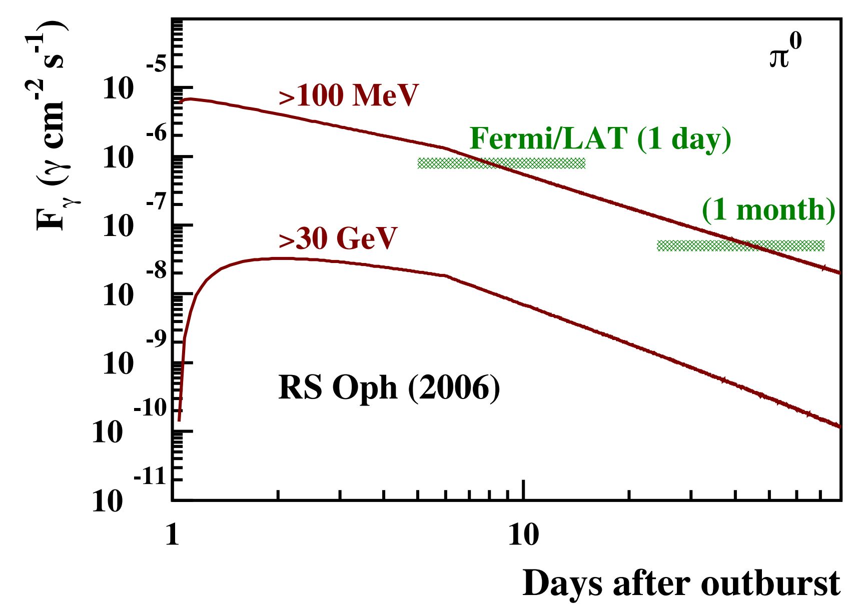
transients: novae

- *Fermi*-LAT new gamma-ray source class: Symbiotic novae... and Classical novae



Cheung (2012)



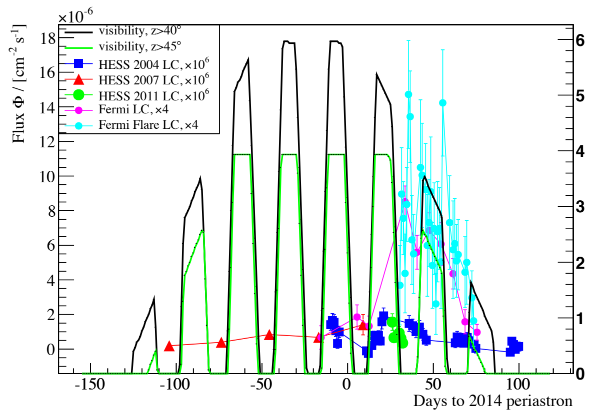


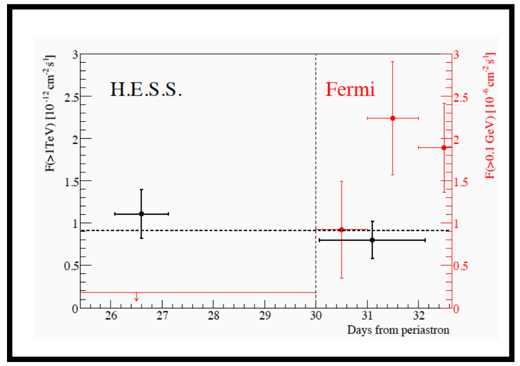
Martin & Dubus (2013), Hernanz & Tatischef (2011)

Summary

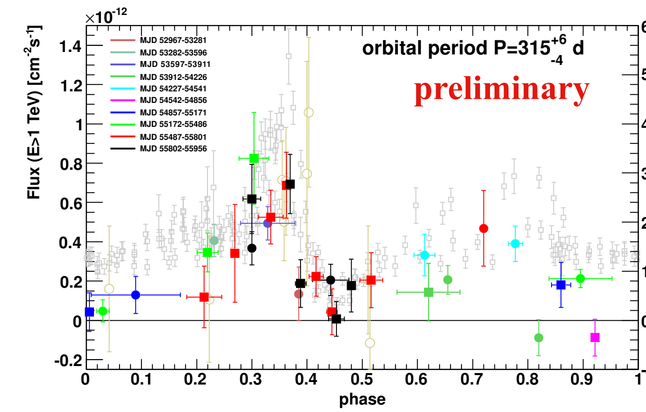
- Gamma-ray binaries offer unique conditions to test particle acceleration and emission processes in geometrically variable (and predictable) conditions
- Five systems detected so far at VHEs (four with H.E.S.S), new systems, transients, µQs, expected
- The GeV-TeV phenomenology is however extremely rich
    - ➤ PSR B1259-63: only known pulsar-binary - but still far from understood (flares, double-peak...)
    - ➤ LS 5039, 1FGL J1018: O-star, similar P~days... but strong differences (hardness ratio, phase-folded l.c)
    - ➤ HESSJ0632, LS I +61 303: Be-stars, GeV long-term variability/ non-detection, double-peak in l.c.
- H.E.S.S.-II already here: lower threshold (enter Fermi range), higher statistics (short-term variab.)
    - ➤ PSR B1259-63 and Eta Carina: periastron passages in 2014

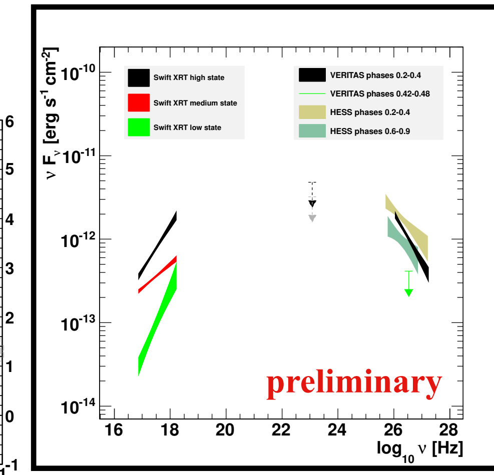
PSR B1259-63



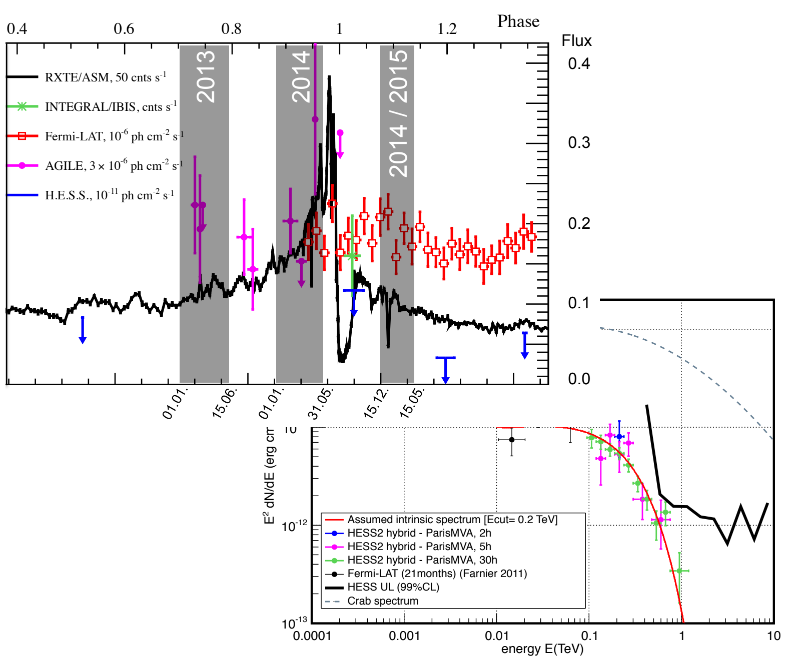


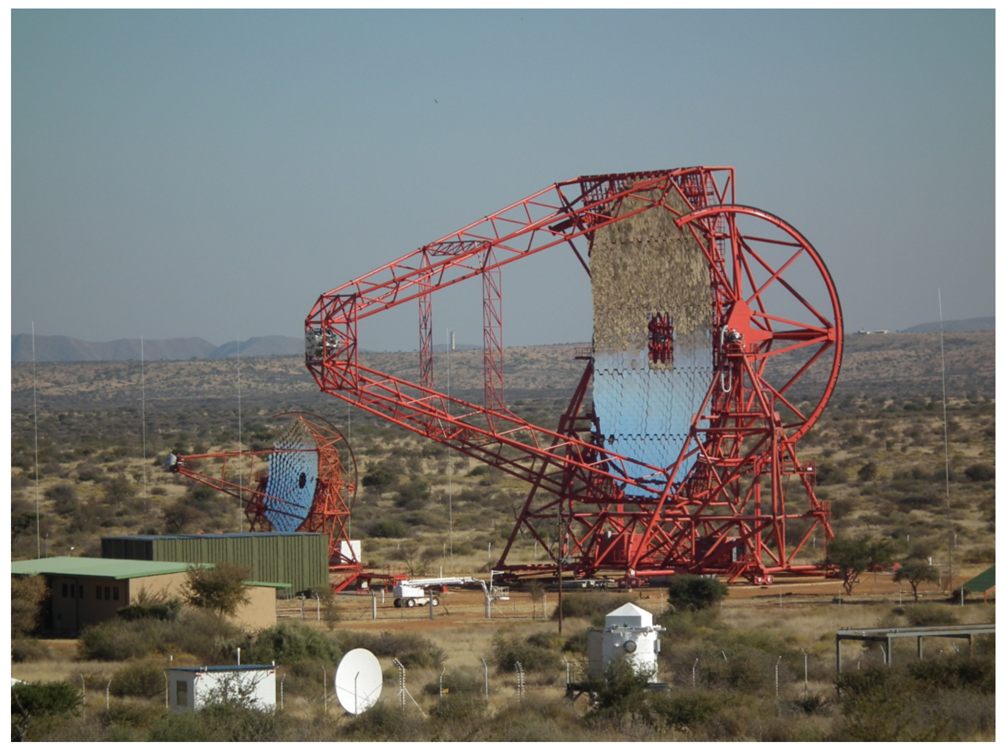
HESS J0632+057



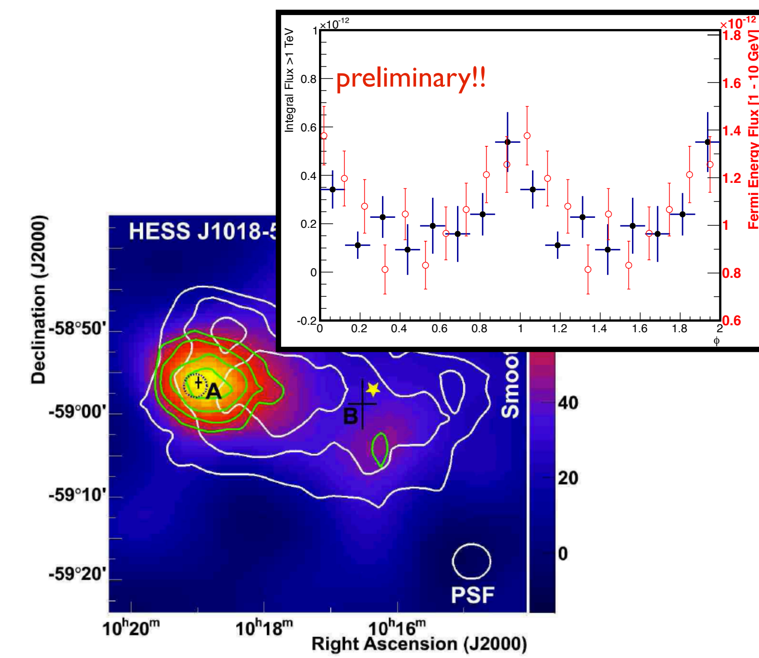


Eta Carinae

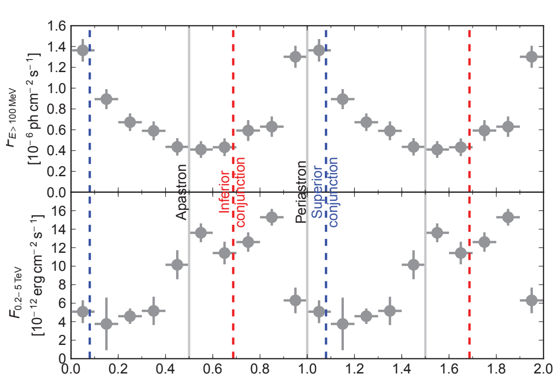


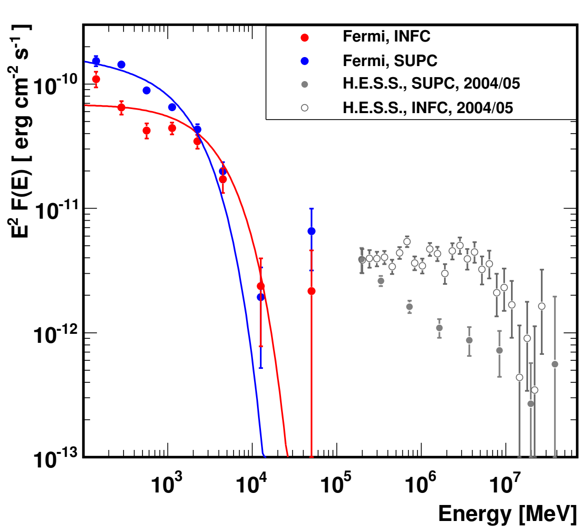


1FGL J1018.6-5856

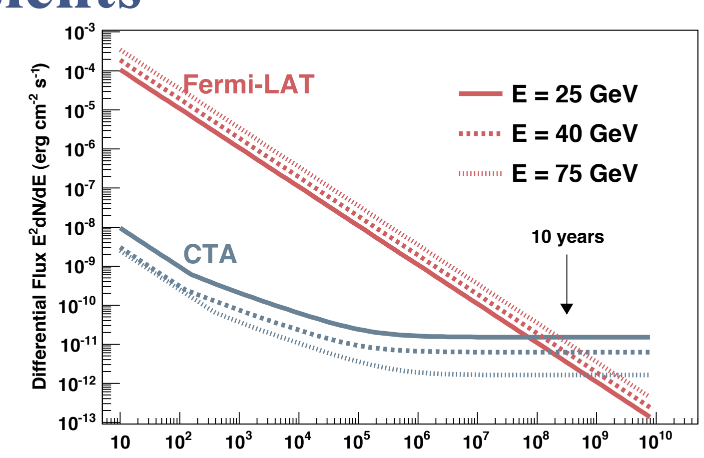


LS 5039



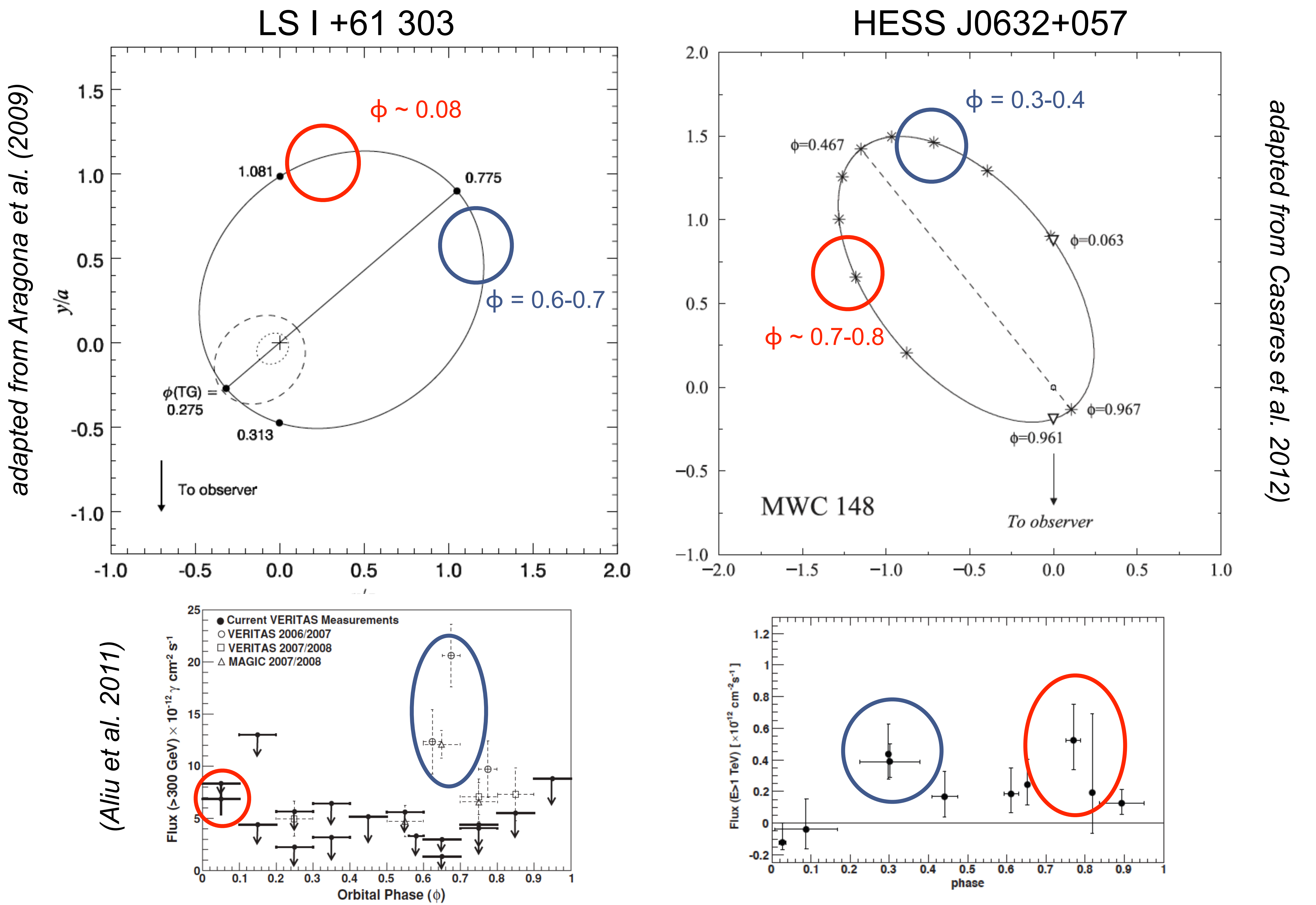


transients

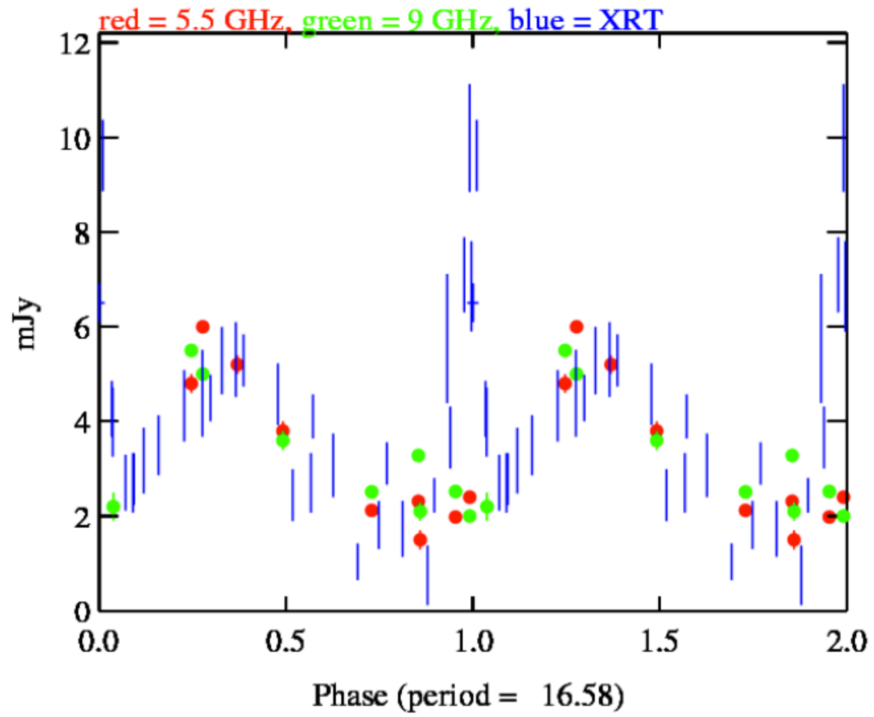


BACKUP

HESSJ0632+057

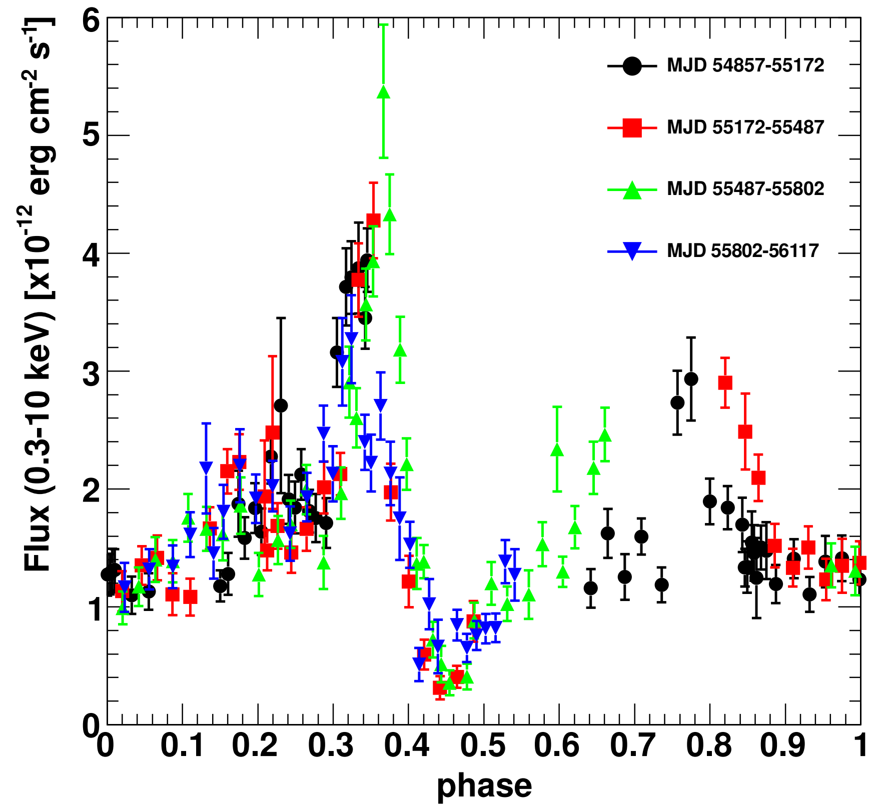


1FGL J1018.6-5856



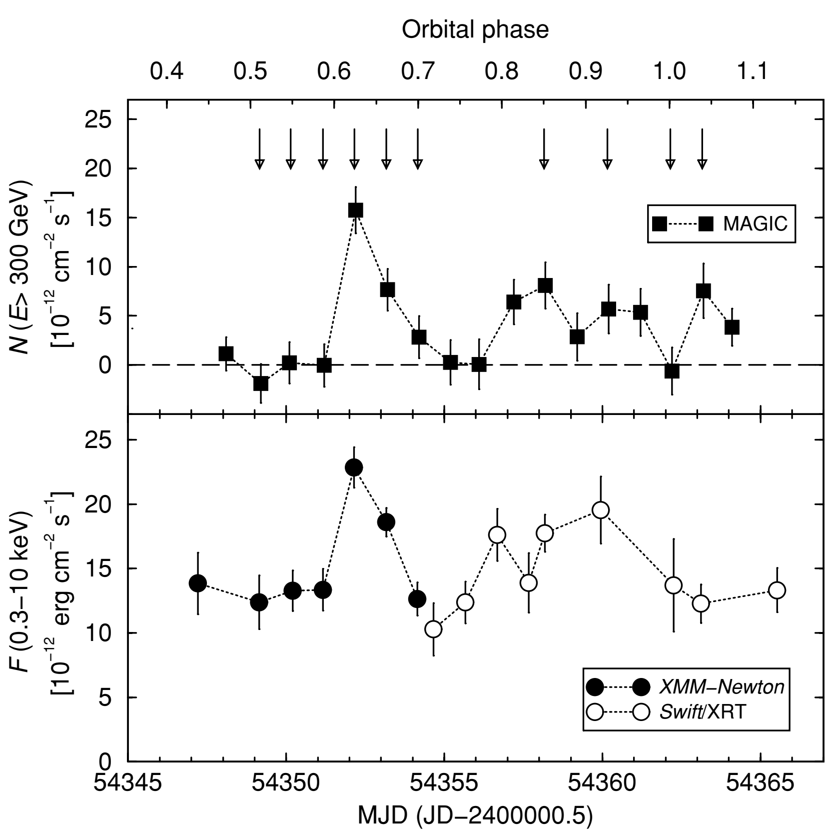
Fermi-LAT Collaboration (2012)

HESS J0632+057



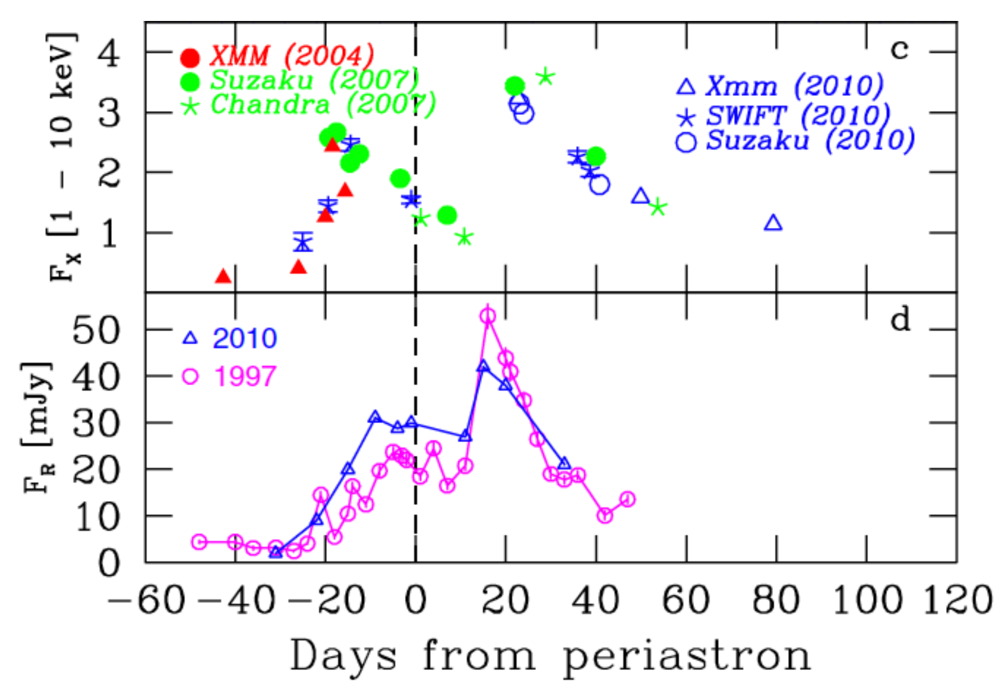
HESS Collaboration (2013), in prep.

LS I +61 303



Anderhub et al. (2009)

PSR B1259-63



Fermi-LAT Collaboration (2011)