Binaries at VHEs with H.E.S.S.

VGGS (IV)

Rikkyo University (Tokyo), July 4-7 2017

Pol Bordas

H.E.S:S. Collaboration

	HE	VHE	Class	Components
PSR B1259-63	yes	yes	PSR binary	Oe + NS
LS 5039	yes	yes	?	O + ?
LS I +61 303	yes	yes	?	Be + ?
HESS J0632+057	no	yes	?	Be + ?
1FGL J1018.6–5856	yes	yes	?	O + ?
HESS J1832-093	no	yes	?	? + ?
LMC P3	yes	**yes**	?	O + ?
Cygnus X-1	?	?	μQ	O + BH
η-Car	yes	**yes**	CW binary	LBV + ?

Binaries at VHEs with H.E.S.S. II

outline

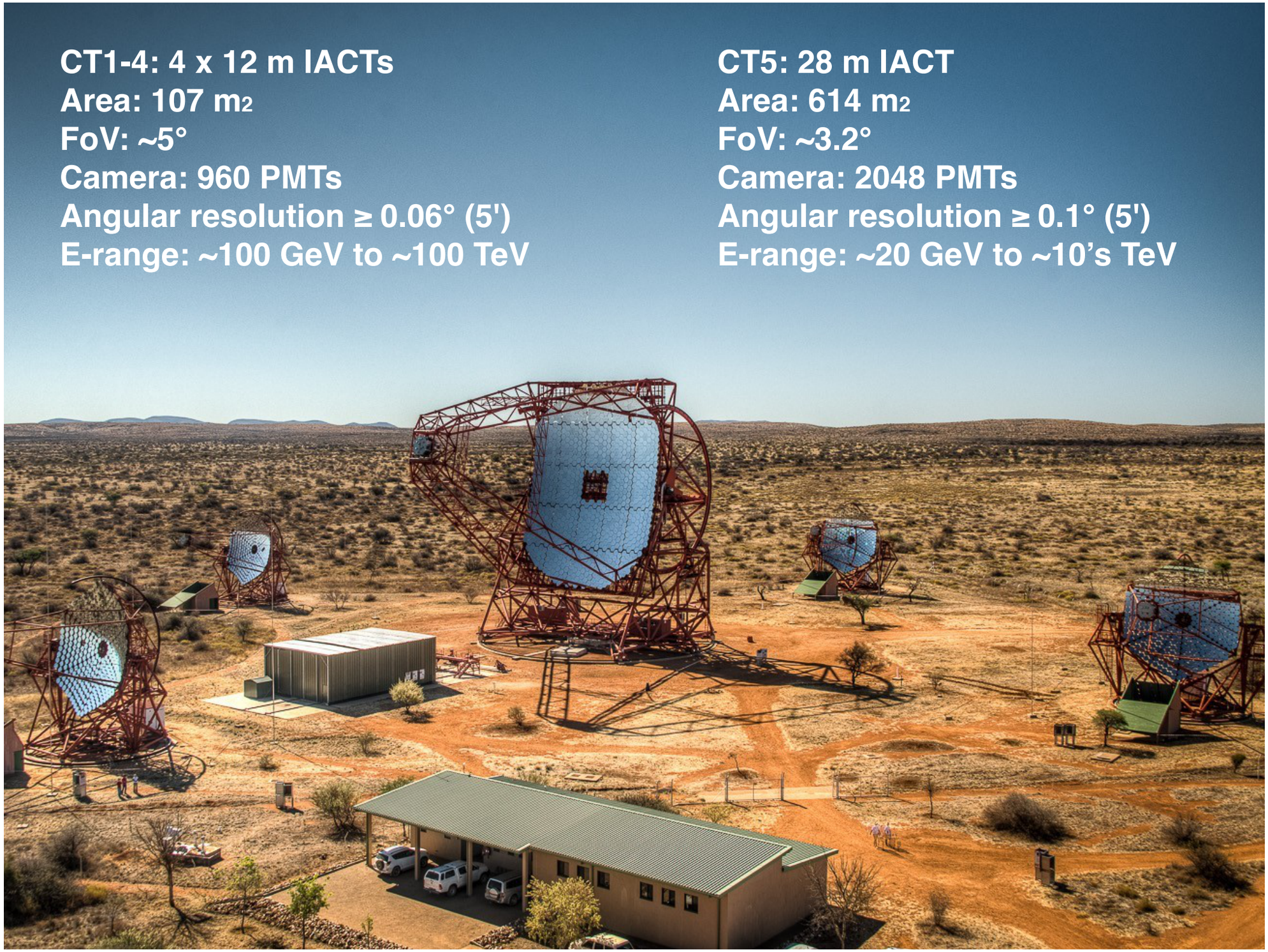
- the H.E.S.S. array
- LS5039, PSR B1259-63, LMC P3, (SS433), (Eta Carinae)
- 1FGL J1018. 6-5856, HESS J0632+057, HESS J1832-093
- summary

H.E.S.S.

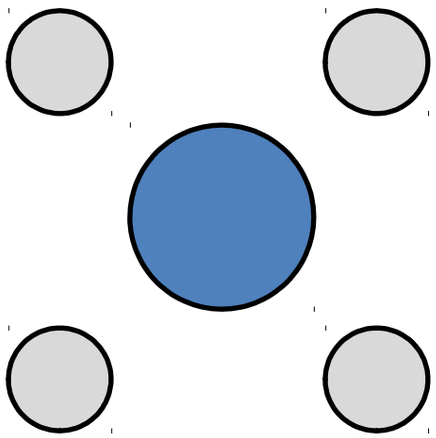
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

CT1-4: 4 x 12 m IACTs
Area: 107 m2
FoV: ~5°
Camera: 960 PMTs
Angular resolution ≥ 0.06° (5')
E-range: ~100 GeV to ~100 TeV

CT5: 28 m IACT
Area: 614 m2
FoV: ~3.2°
Camera: 2048 PMTs
Angular resolution ≥ 0.1° (5')
E-range: ~20 GeV to ~10's TeV

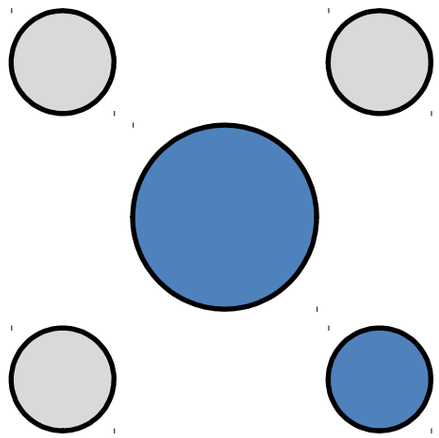


mono



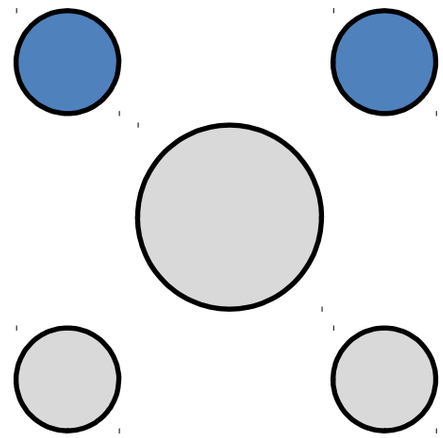
CT5 standalone
~65% of events

hybrid



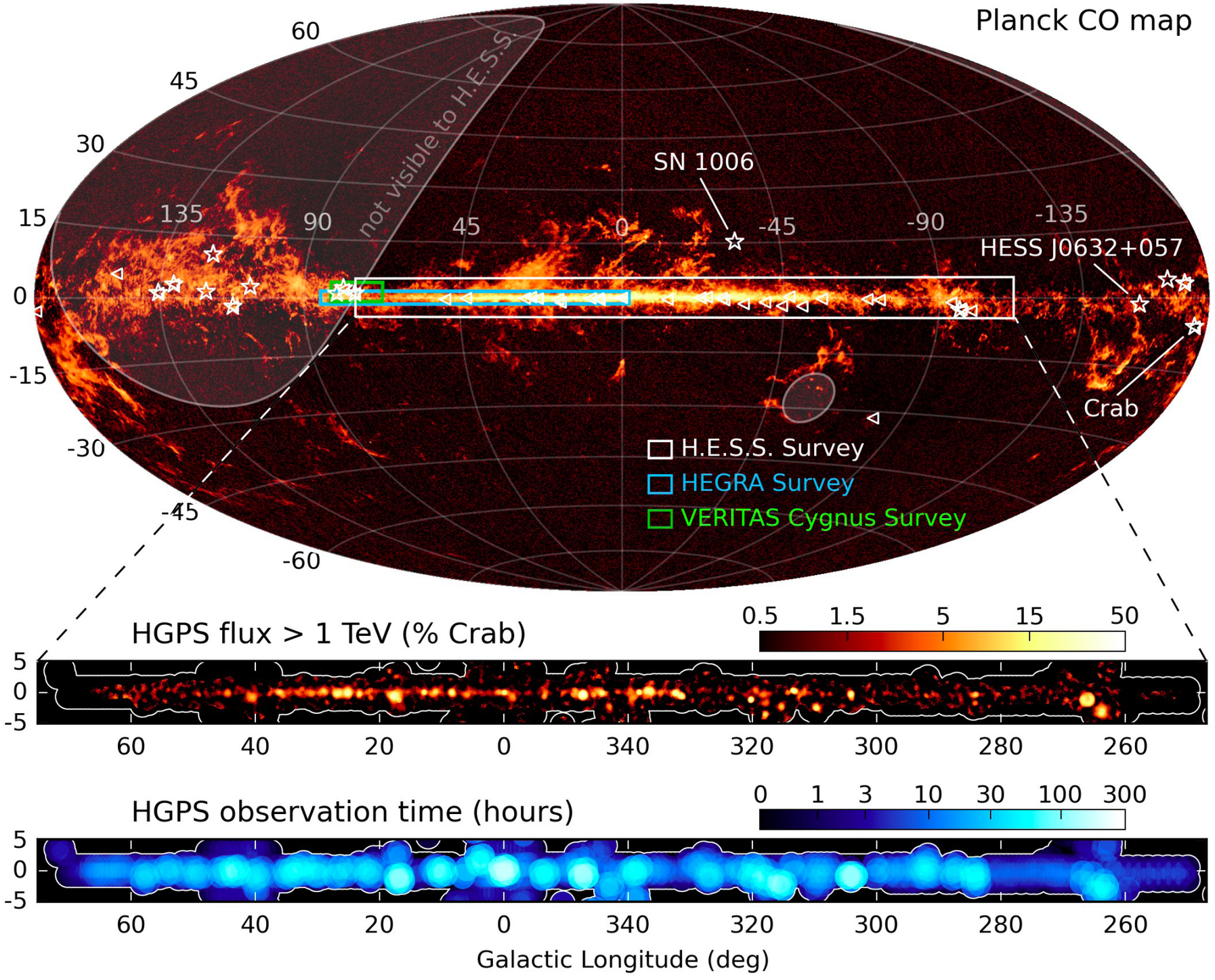
CT5 + ≥ 1 of CT1-4
~30% of events

stereo

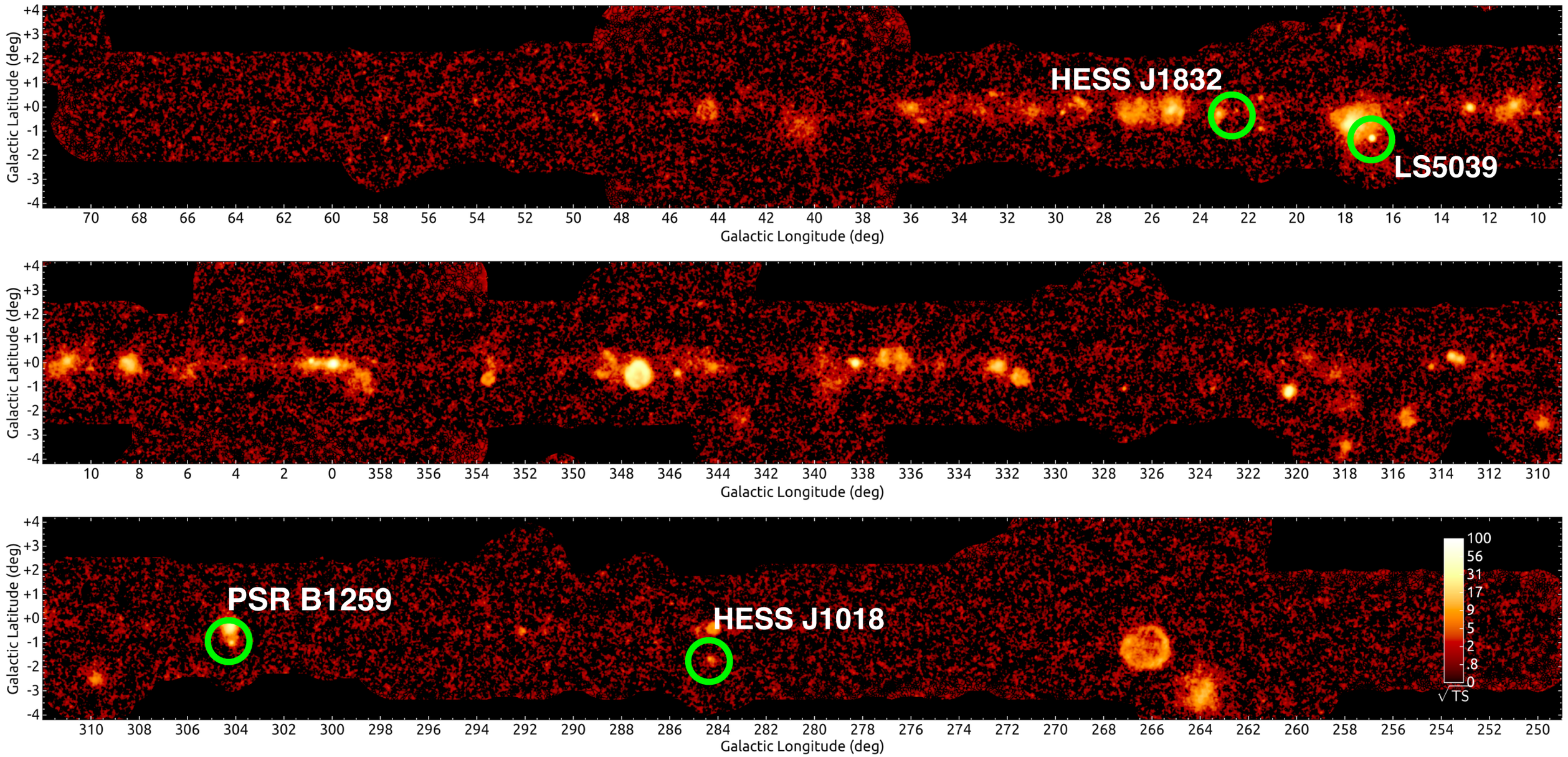


≥ 2 of CT1-4
~5% of events

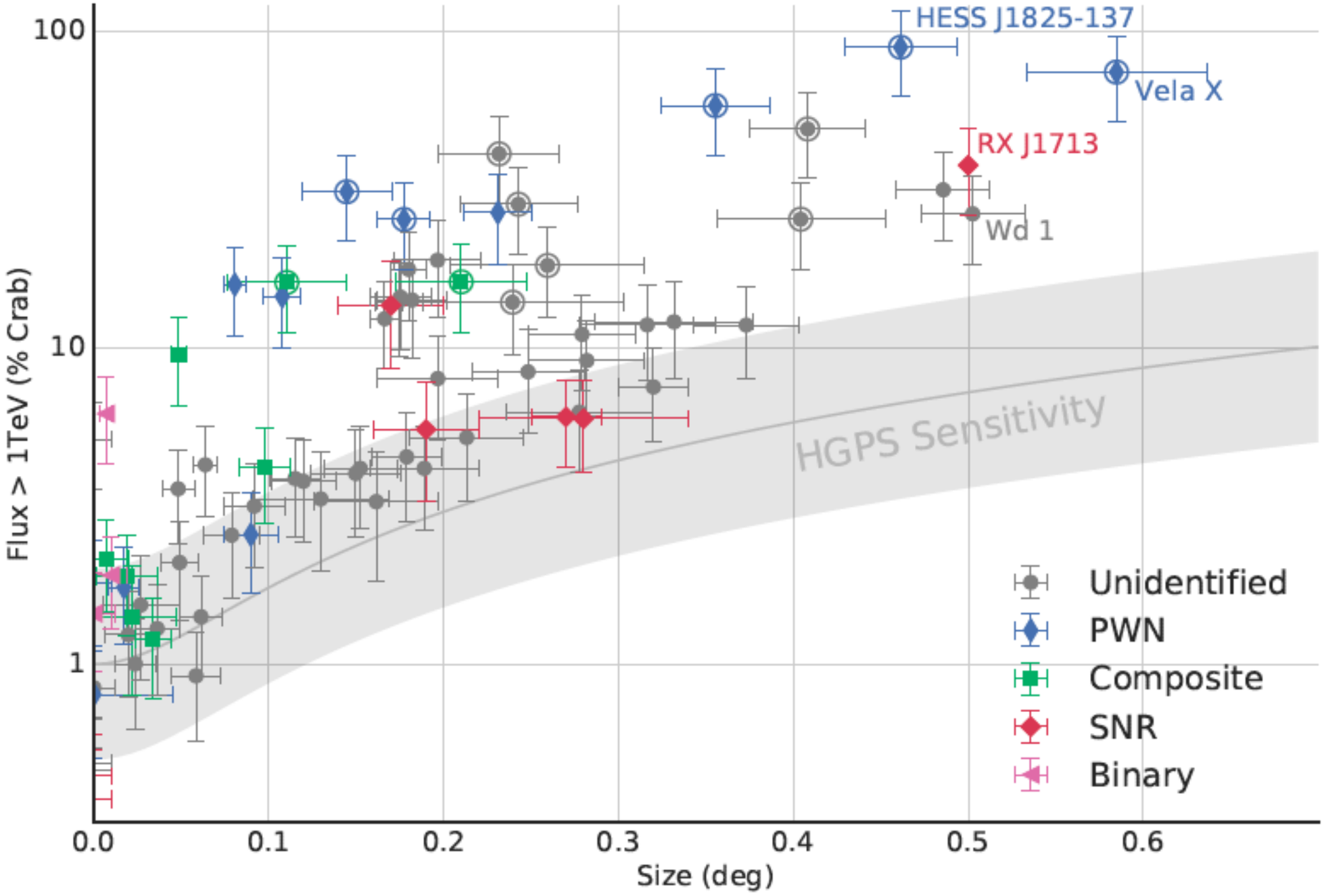
the H.E.S.S. HGPS



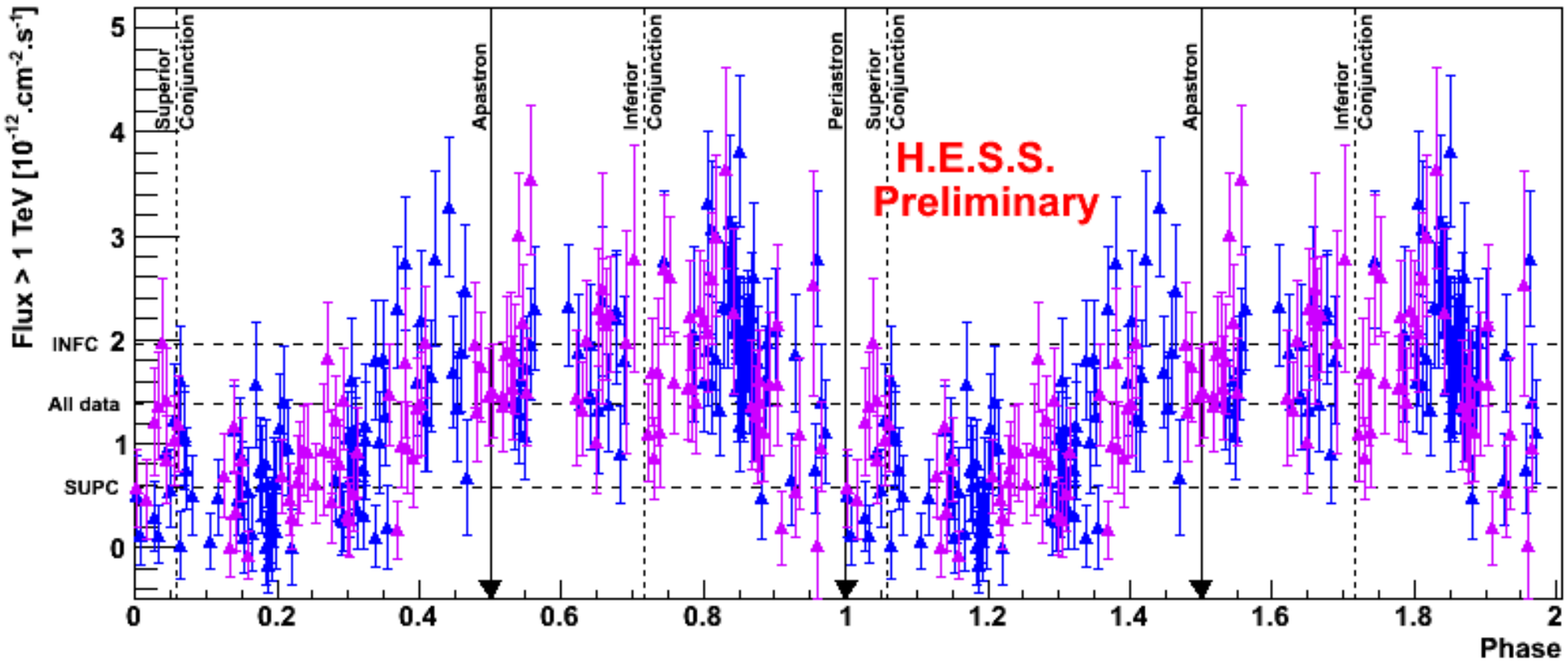
the H.E.S.S. HGPS



+ **HESS J0632** (not in HGPS), **Eta Car** (needs CT5), **LMC P3** (not in the Galaxy)


HESS J1825-137
Vela X
RX J1713
Wd 1
HGPS Sensitivity
Unidentified
PWN
Composite
SNR
Binary
Flux > 1TeV (% Crab)
100
10
1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Size (deg)

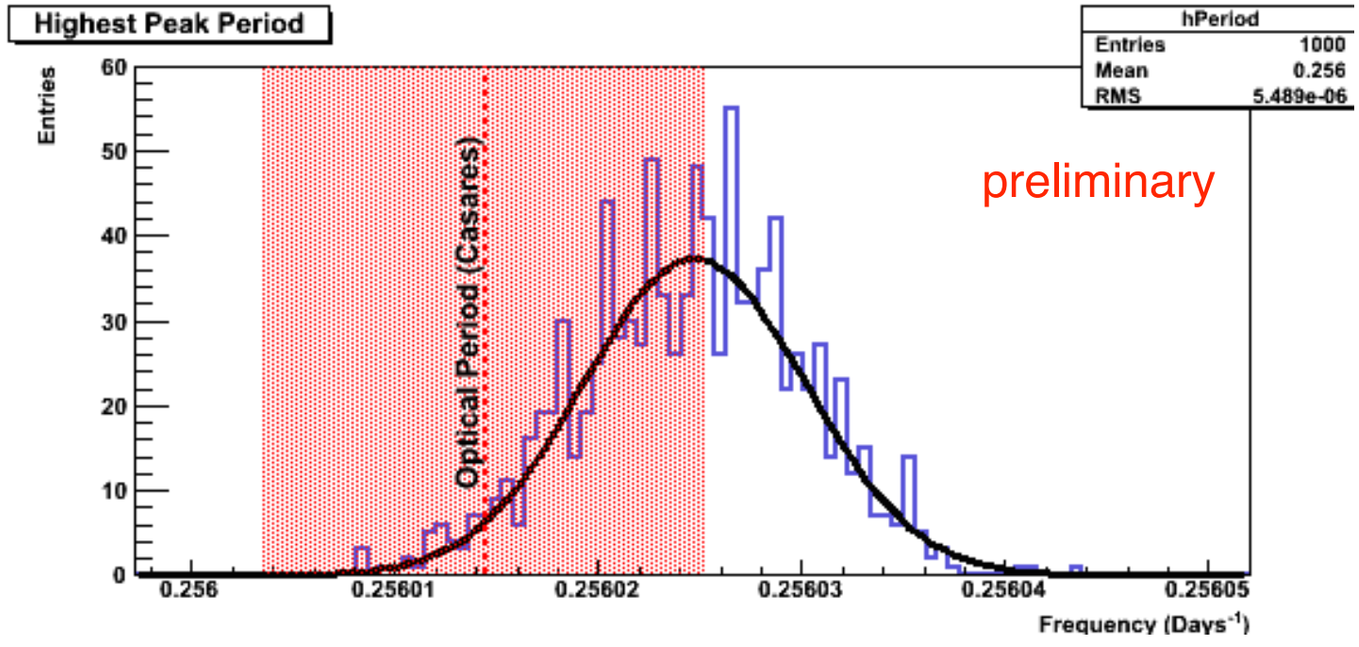
LS 5039 - the swiss clock



- First binary discovered @ TeVs
- compact object unknown nature + O6.5V companion star, P_{orb}= 3.9d
- long-term stability at VHEs: well behaved light-curve/spectra variability (the exception)

LS 5039 - the swiss clock

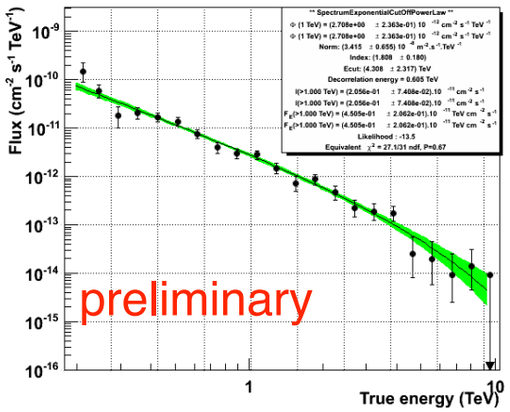
- updated stereo (CT1-4) data-set: 210h
- periodicity from VHEs: P_{VHE} = 3.905873 ± 0.000126 days (-> ± 11 sec. error)
- more precise than optical measures! $P_{optical}$ = 3.90603 days ± 15 s
- new phase-folding affects previous observations (> 10 years data set)



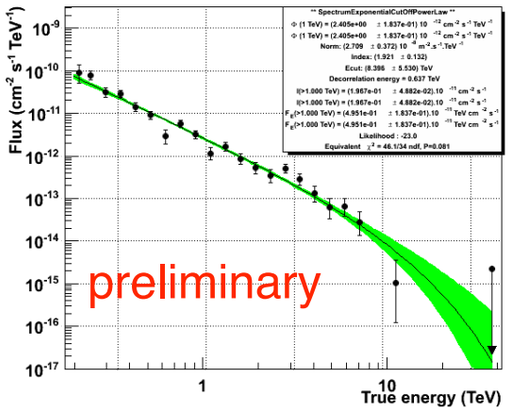
LS 5039 - the swiss clock

- excellent agreement with previous results back in 2006 (swiss-clock)
- significant detection (>5 σ) in every orbital phase (0.1-width)
- spectral features in some phase-bins (e.g. cutoffs)

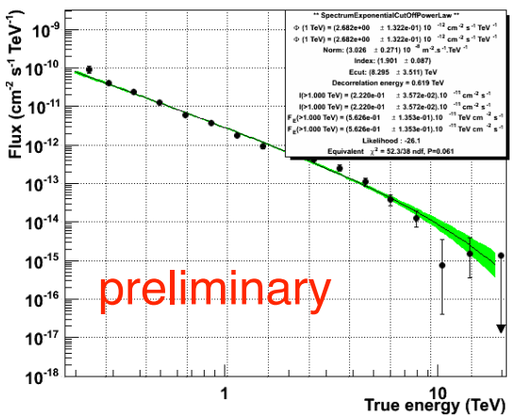
phase 0.6 - 0.7



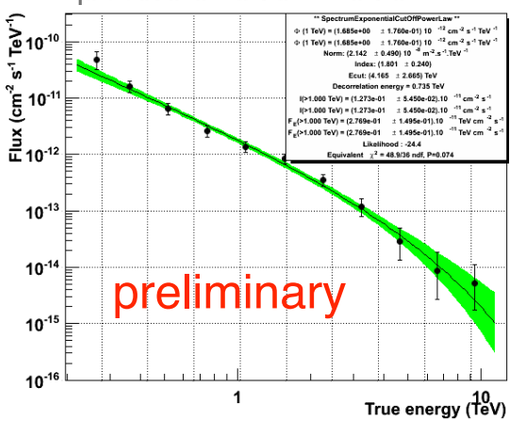
phase 0.7 - 0.8



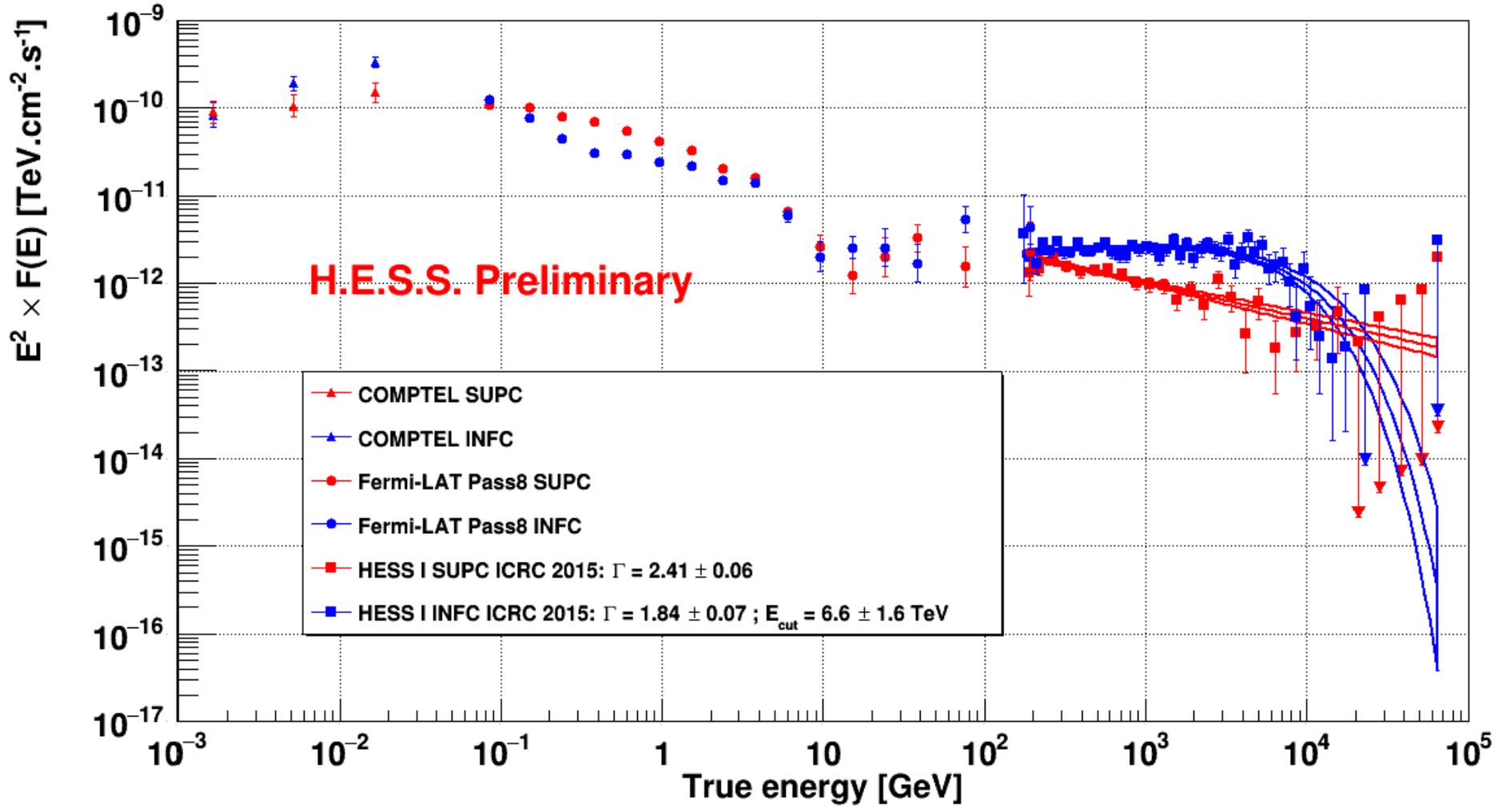
phase 0.8 - 0.9



phase 0.9 - 0.0



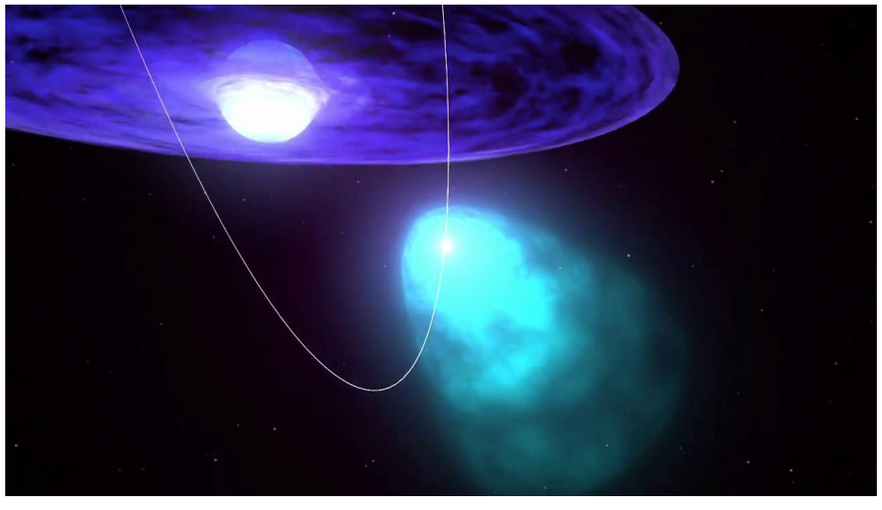
LS 5039 - the swiss clock



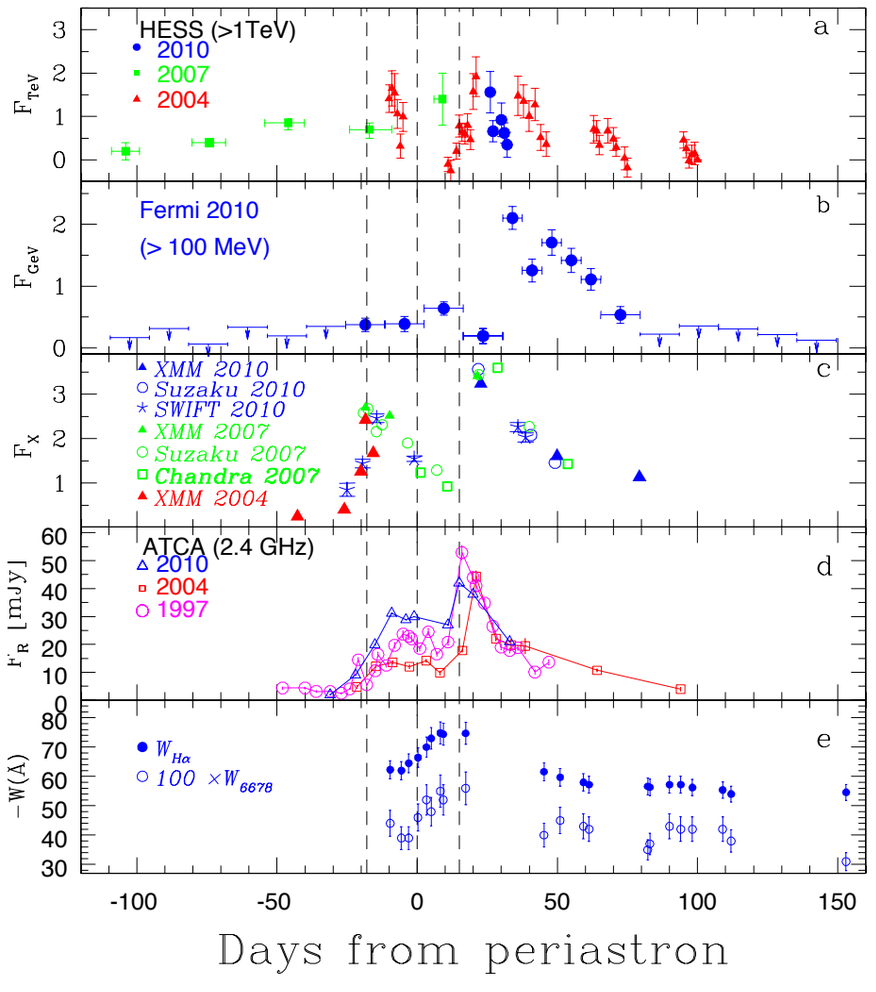
- gamma-ray spectrum of LS 5039 fully sampled (MeV-TeV) (COMPTEL, *Fermi*-LAT, H.E.S.S.)

PSR B1259-63: a pulsar-powered gamma-ray binary

- pulsar (P 48ms, L_{sd}= 8 ×10^{35} erg/s) + O9.5Ve star (L_{star}= 2.3 × 10^{38} erg/s) + circ. disk
- binary system: D = 2.3 kpc, P_{orb}= 3.4 years, eccentricity = 0.87, orbital inclination i ~24º
- variable/periodic emission in radio, optical, X-rays, GeV and TeV γ-rays
- pulsations seen only in radio (and away from periastron)
- GeV flare in 2011; happening again in 2014

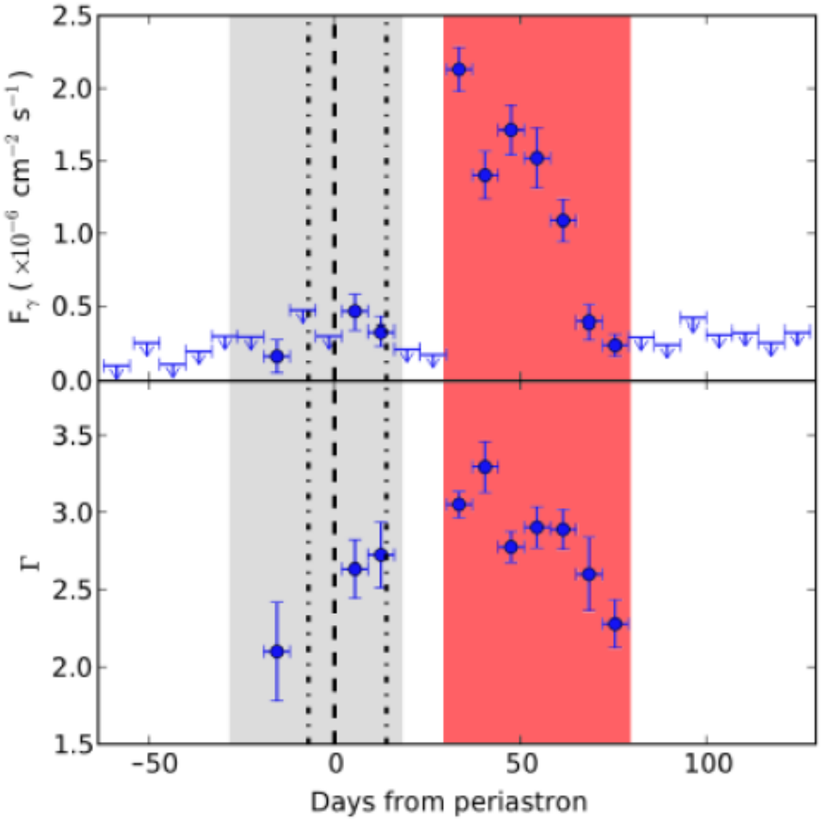


PSR B1259-63, credits: NASA archive

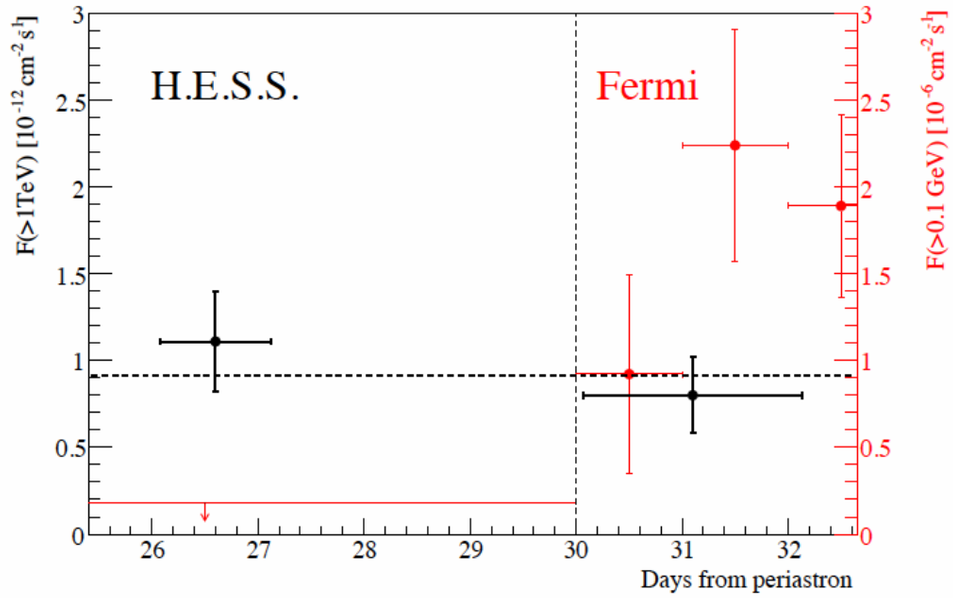


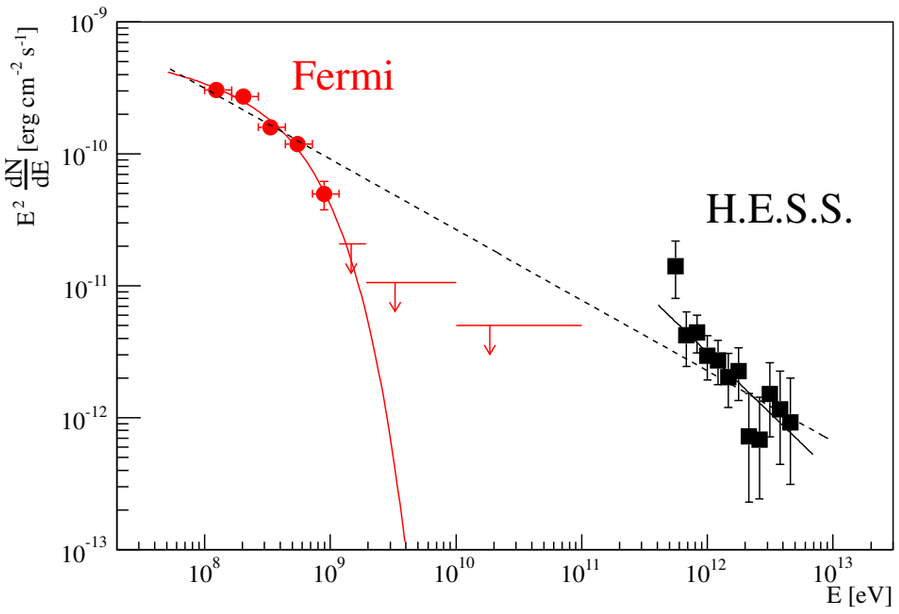
PSR B1259-63's powerful flares in HE gamma-rays

- firstly detected by LAT in 2011 passage
- only @ HE gamma-rays (no X-rays, VHEs?)
- isolated event (e.g. crab flares)?
- wait for 2014 periastron…



Abdo et al (2011)

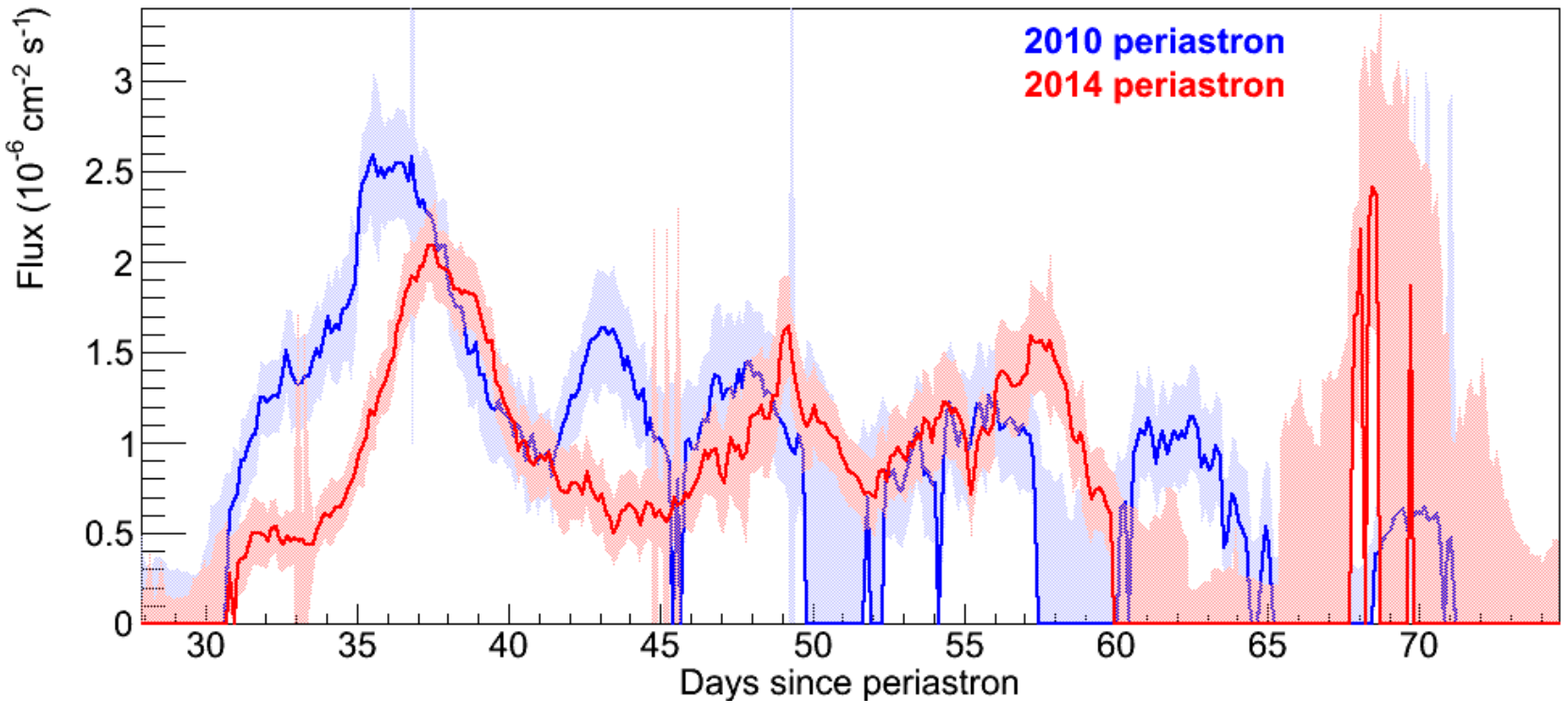




H.E.S.S. coll. 2013

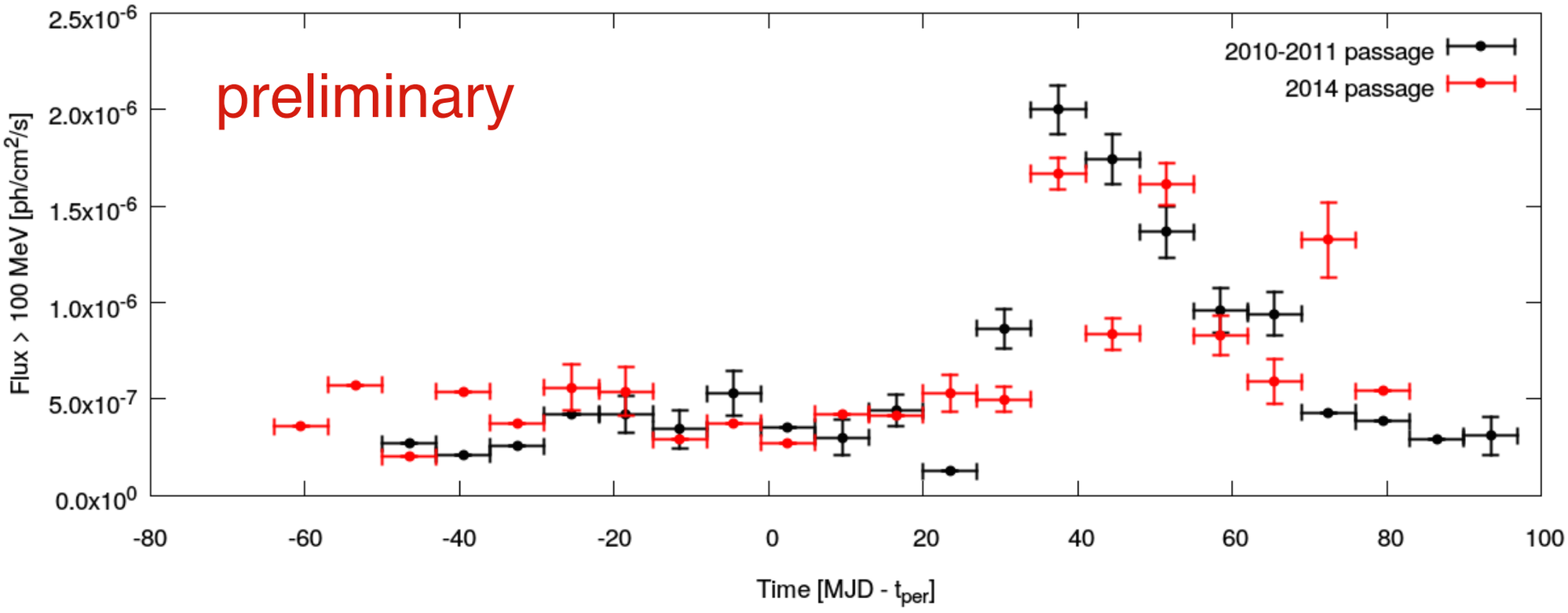
PSR B1259-63's powerful flares in HE gamma-rays

- firstly detected by LAT in 2011 passage
- apparently only @ HE gamma-rays (no radio?, no X-rays?, no VHEs?)
- happening again in 2014 periastron



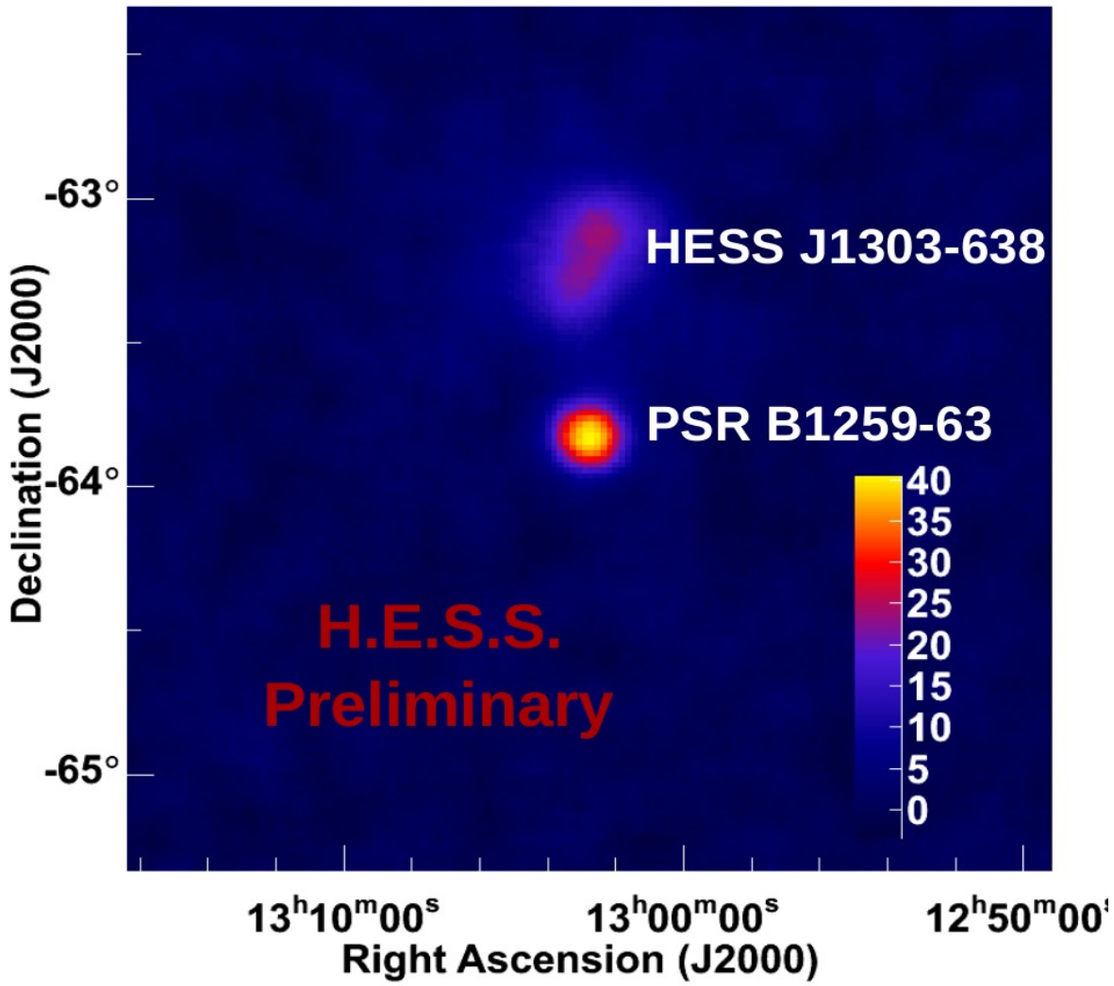
Caliandro et al (2015)

Fermi-LAT observations (2011, 2014) with pass8



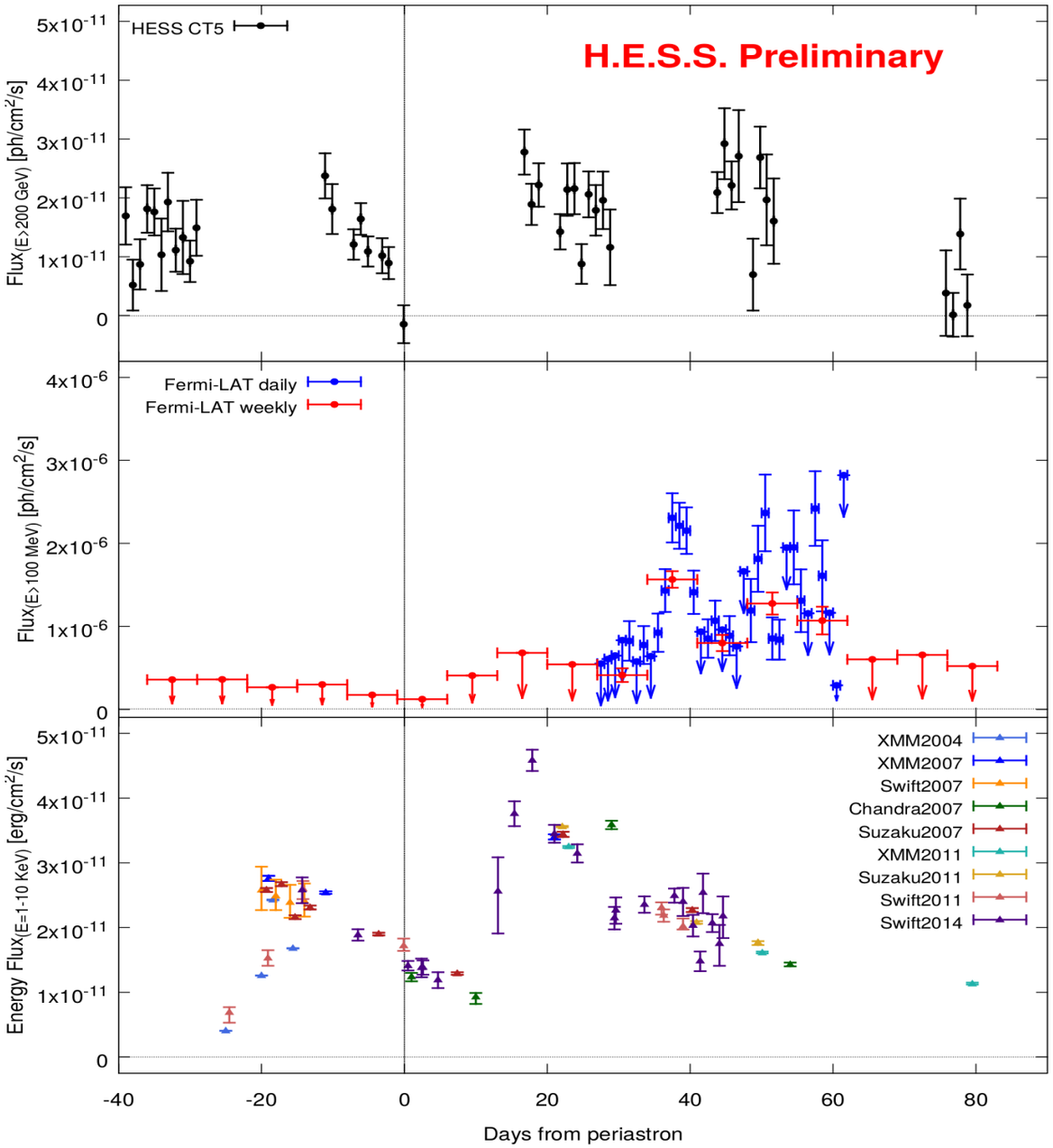
- Time interval in MJD: 55495 - 55645
- Radius ROI: 20 degrees
- Energy Range: 100 - 500000 MeV
- Analysis Method: Binned Likelihood
- Bin size: 0.2 degrees
- Filter gtmktime: (DATA_QUAL>0)&&(LAT_CONFIG==1)
- Maximum zenith: 90 degrees
- IRFs: P8R2_SOURCE_V6
- Model: 3FGL catalog + gll_iem_v06.fits + iso_P8R2_SOURCE_V6_v06.txt within 25 degrees

PSR B1259-63 in 2014



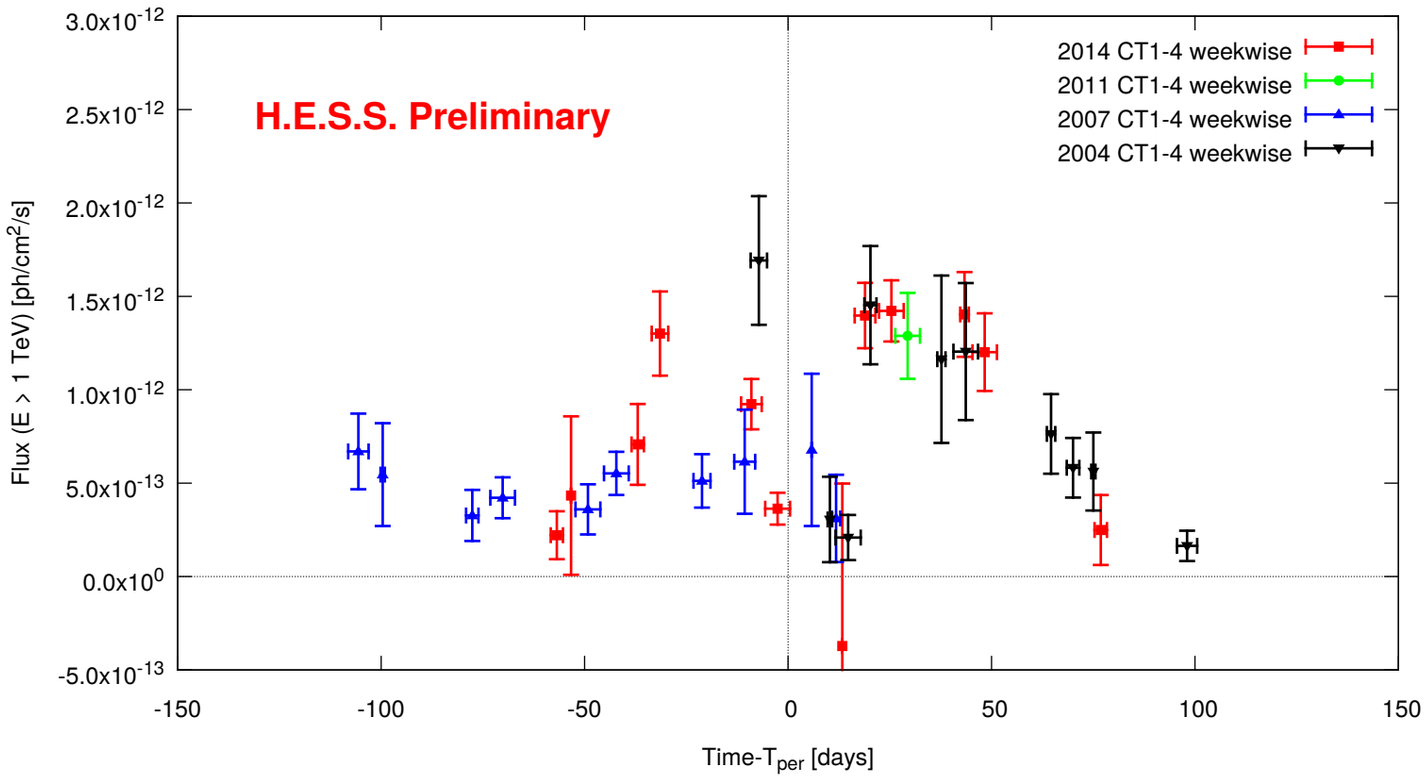
- long-term H.E.S.S. monitoring campaign to cover 2014 periastron
- coordination with MWL observatories for simultaneous observations
- more than 57 hours of live-time analysed with STEREO and MONO analysis chains
- source detected at 40σ level, HESS J1303-638 also detected

PSR B1259-63 in 2014



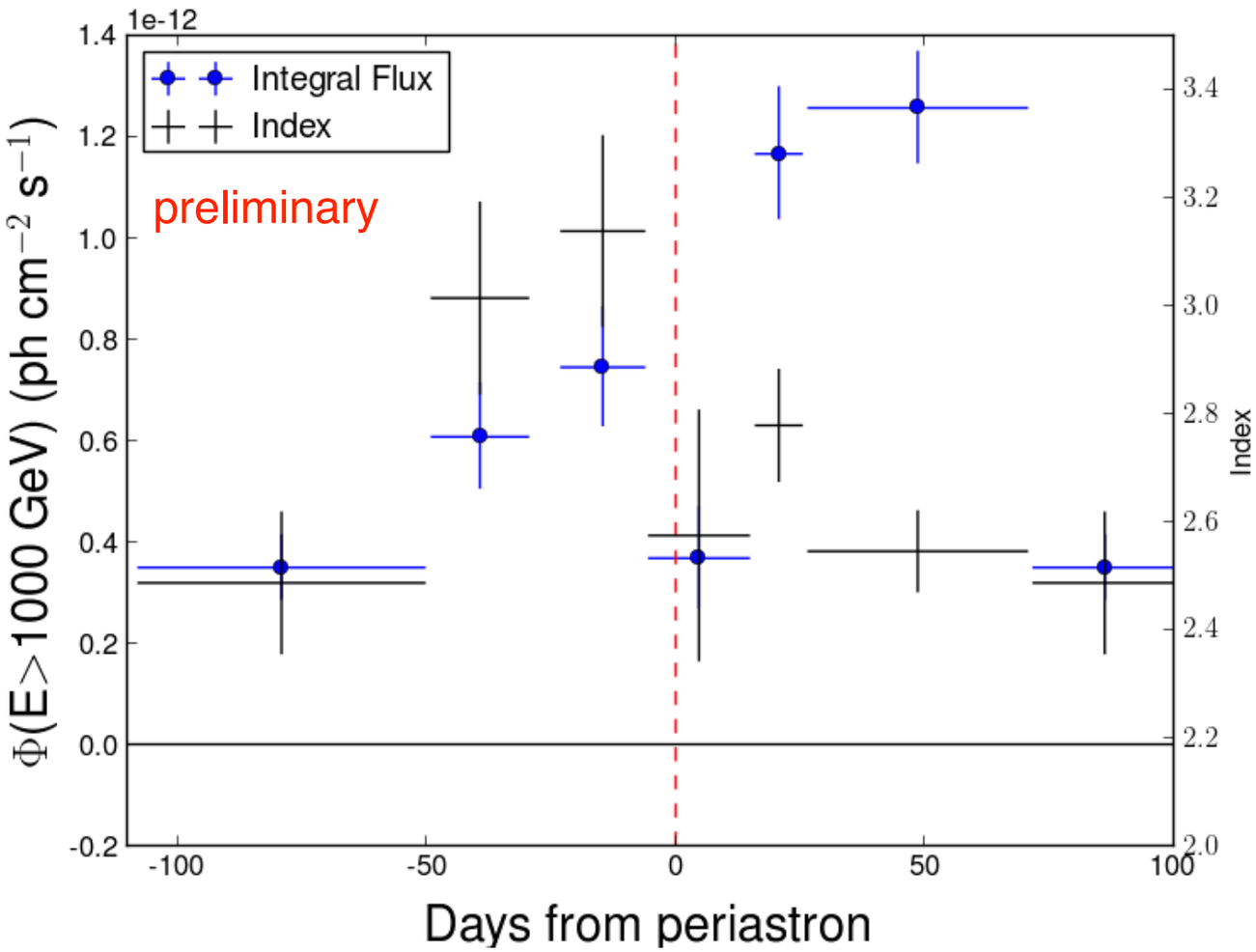
- Comparison of results from H.E.S.S., *Fermi*-LAT and Swift-XRT simultaneous observations
- X-rays: highest-ever flux recorded in 2014 (2nd disk crossing). Hints of variability during GeV flare?
- Fermi-LAT: reappearance of the gamma-ray flare (slight differences), marked variability
- H.E.S.S. (stereo & mono): high emission state at VHEs during the "GeV flare"

PSR B1259-63 in 2004-2007-2011-2014



- reanalysis of all periastron passages with same and updated software
- double-peak pattern, local minimum at exact t_{per}
- source still active at VHEs at 40-50 days after periastron (“GeV flare”)
- enhanced emission appearing ~35 days before periastron (?)

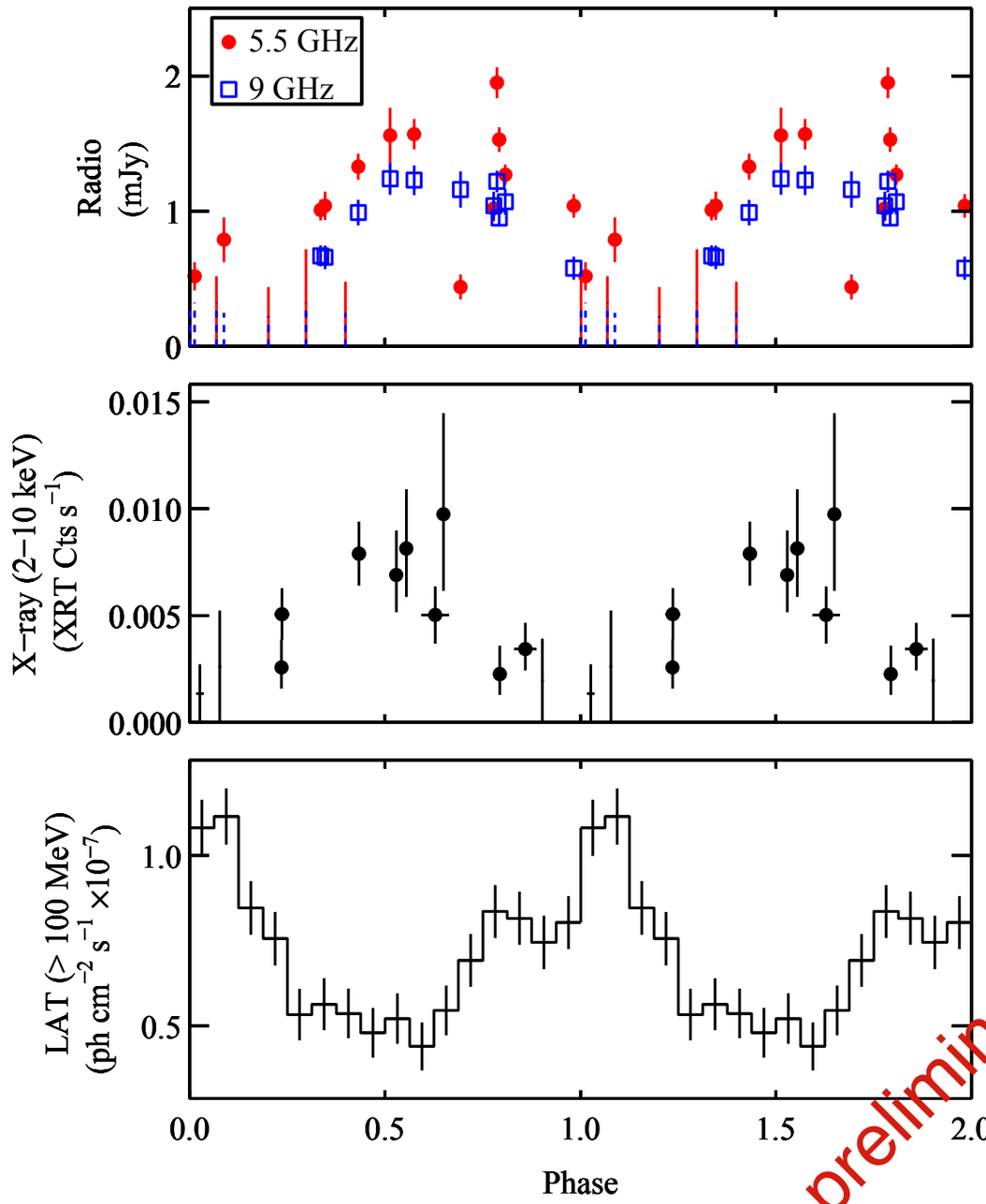
PSR B1259-63 in 2004-2007-2011-2014 (stacked analysis)



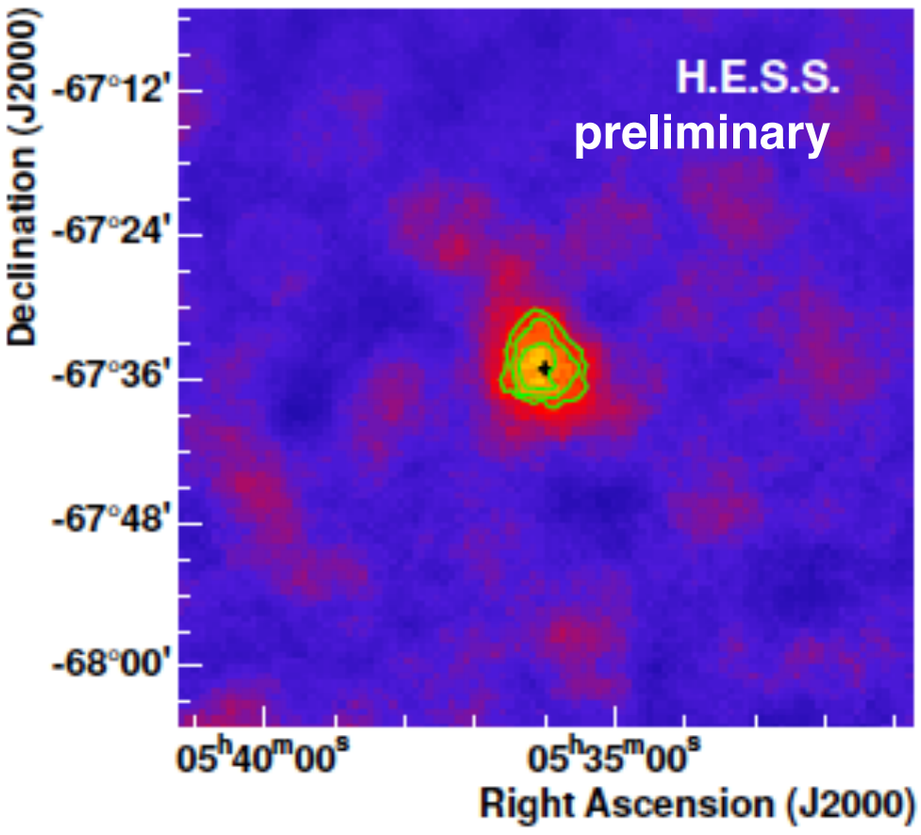
- phase-folded 2004-to-2014 stacked analysis (assume same mechanisms)
- pre-defined intervals: baseline, pre & disk-crossings, t_{per}, GeV flare,
- spectral evolution: softer (harder) in pre (post) periastron?

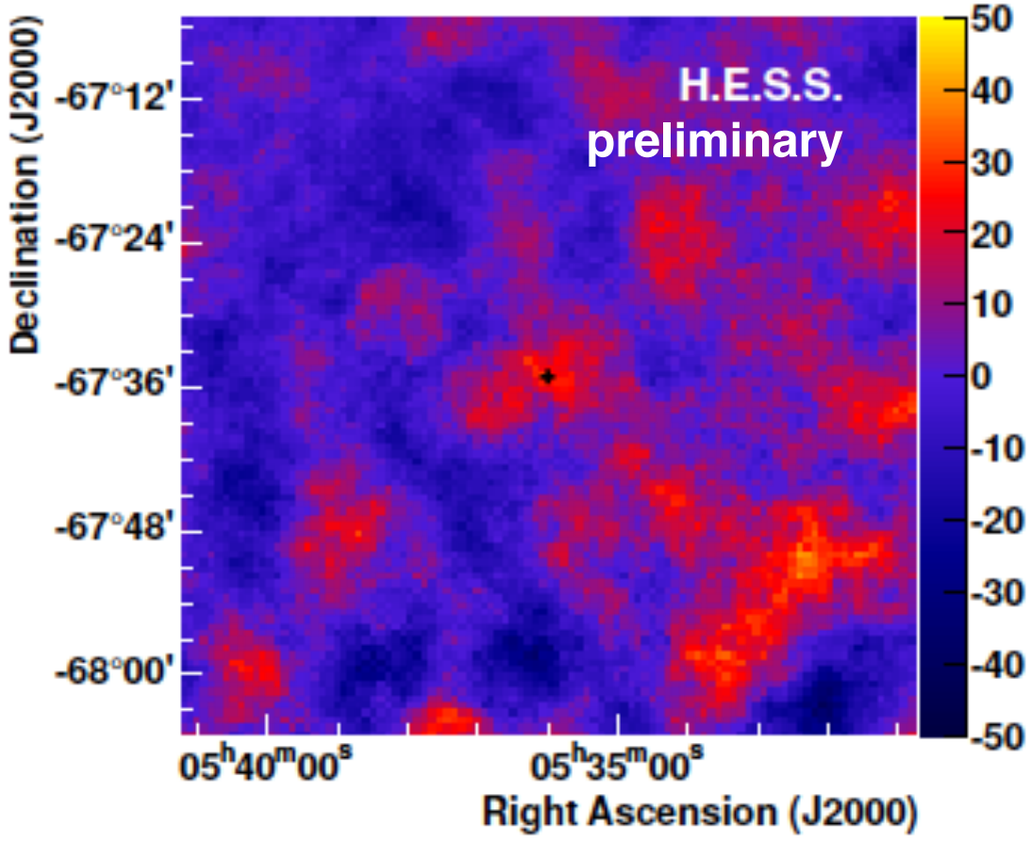
LMC P3: a new HE gamma-ray binary

- blind-search discovery with *Fermi*-LAT (Corbet et al. 2016)
- orbital period:~10.3 days
- anti-correlated X-rays and radio
- companion star: O5 III (Seward et al. 2012)
- no orbital parameters: inclination distance, periastron phase ?



LMC P3 at TeV gamma rays

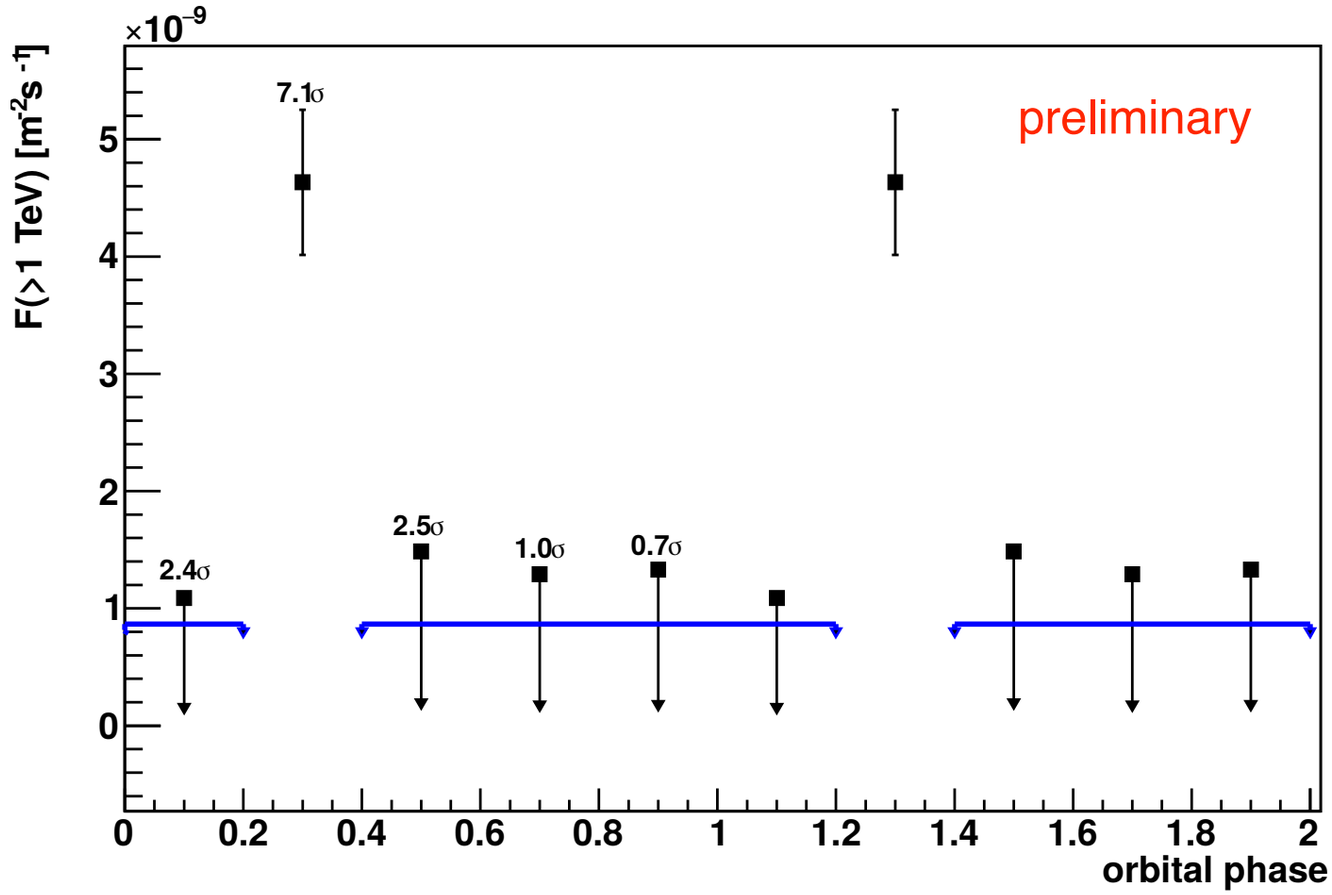




- 100h corrected live-time, 65 excess events → 5.5 σ detection
- integral flux > 1 TeV = 2e-13 ph/cm^2/s, d = 50 kpc => brightest binary so far
- emission variable and modulated with the LAT period

LMC P3 at TeV gamma rays

- no periodicity from TeV alone (Lomb-Scargle, z-CDF)
- phase-folded TeV light-curve (phase = 0 at *Fermi* maximum)
- emission only in phases 0.2 - 0.4: → 6.8 σ (6.6 σ after 5 trials)
- TeV maximum = GeV minimun, so at first glance TeV in-phase with X-rays & radio

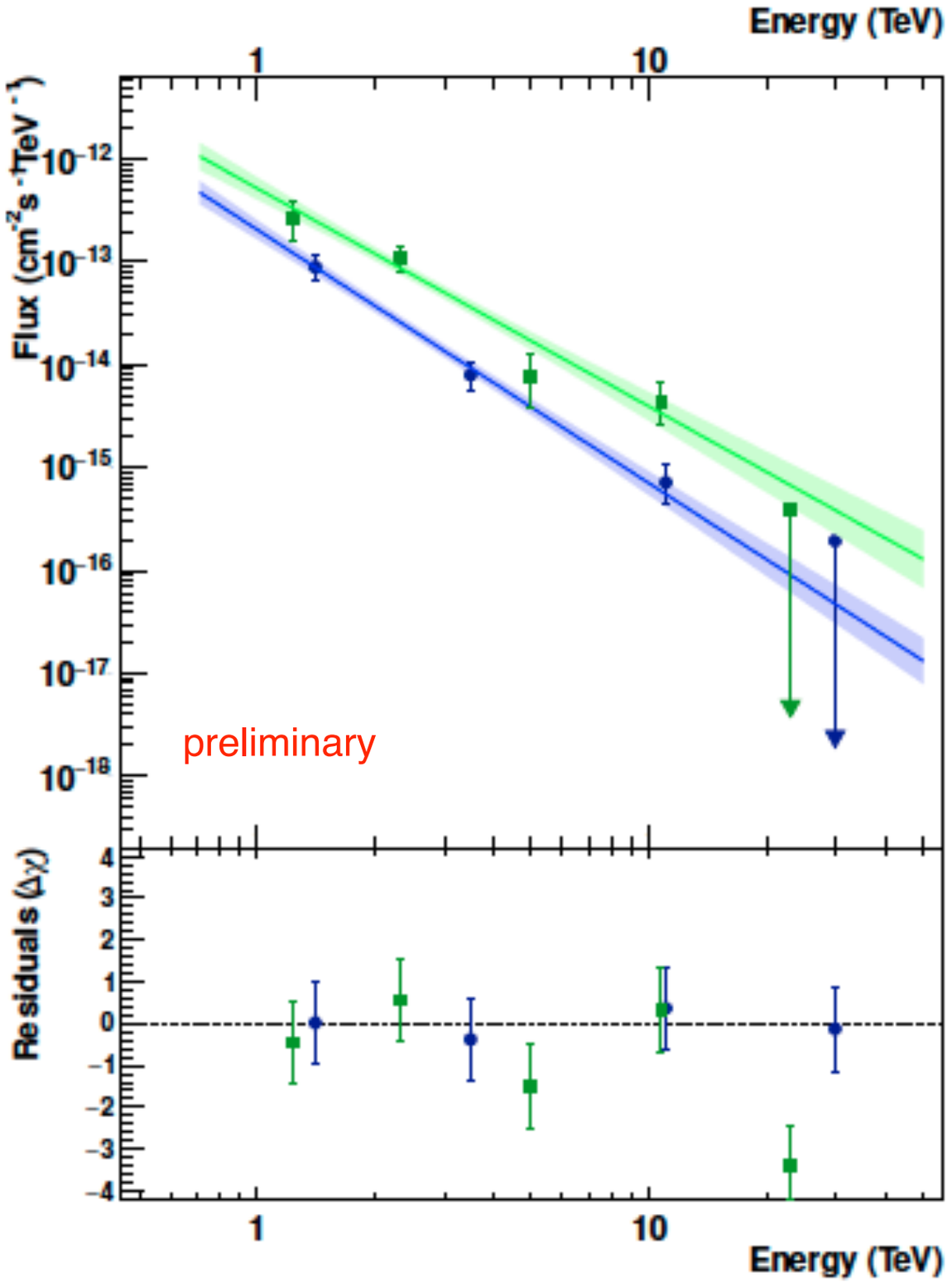


LMC P3 at TeV gamma rays

- **whole orbit**:
  index = 2.5 +/- 0.2
  highest E-bin: 7-23 TeV

- **phase 0.2 - 0.4**:
  index = 2.4 +/- 0.2
  highest E-bin: 8-17 TeV

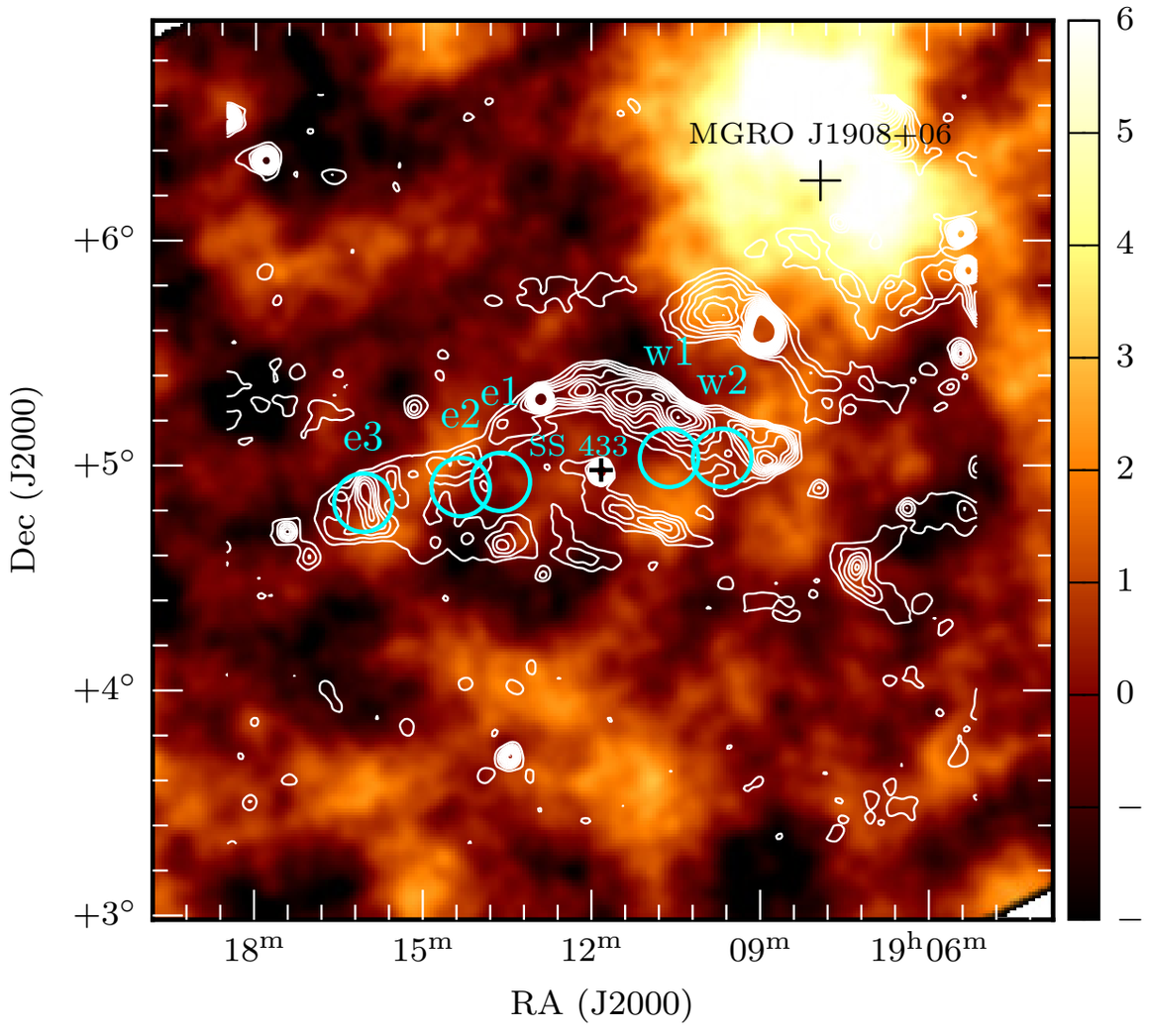
- no significant cut-off



SS433

- scheduled observations during expected enhanced gamma-ray activity (low-absorption phases)
- MAGIC + H.E.S.S. campaign to maximize yearly coverage
- SS433/W50 interaction regions also observed (no detection)
- merging stats between two different IACTs for the first time

=> see next talk by Daniela



MAGIC & HESS Collaborations (2017)

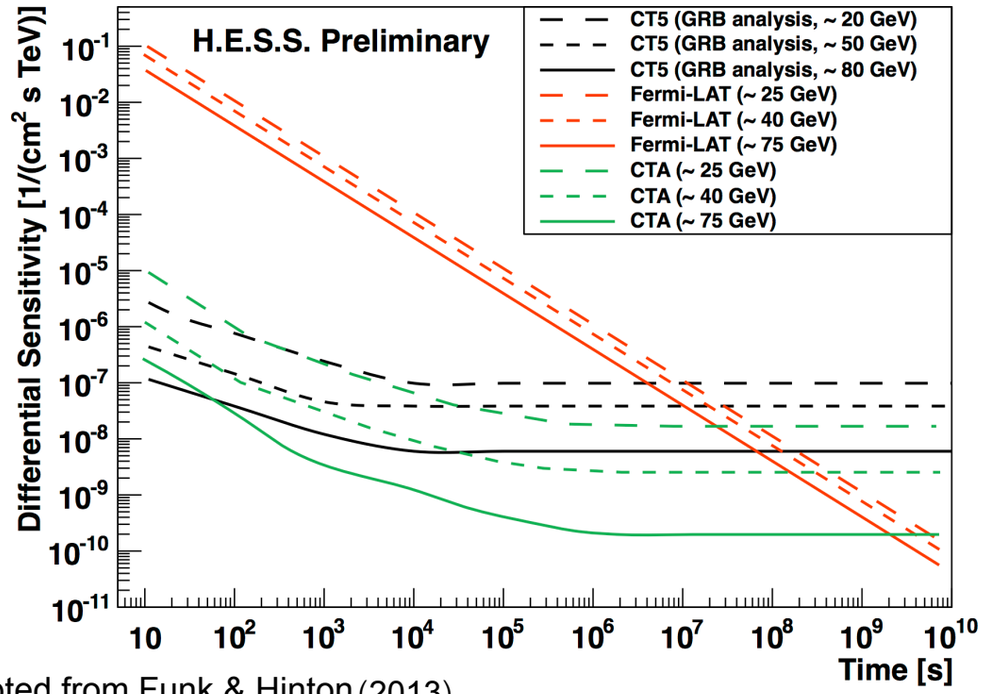
summary

- **>10 yrs observations of gamma-ray binaries with IACTs**
  - unprecedented high-quality observations became available
    LS5039: period determination with accuracy ~optical
    PSR B1259: short-term variability in gamma-rays, only possible with IACTs
  - population slowly increasing: blind-searches, CT5, 100's hours observations…
    LMC P3: new system in the LMC

- **observations keep feeding theory**
  - variable and repetitive conditions for particle acceleration and radiation processes
  - sill, source-by-source differences seem to be "the rule"
- - powering source unclear: accretion *vs* rotation
  - highly-efficient, un-predicted gamma-ray flares, GeV-TeV anti/correlation: several emitters?
  - main emission mechanisms unclear: double-peak profiles at periastron/apastron
  - variability at all-scales: short-term to super-orbital modulation

- **H.E.S.S. II & CTA**

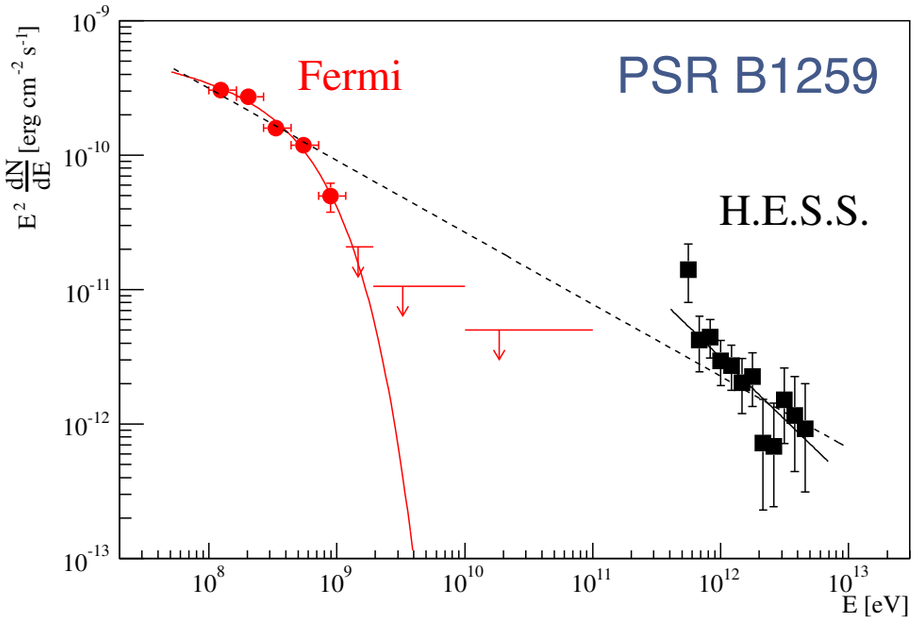
  - CT5 & CTA's LSTs: transient machines (new binary classes?)
  - blind-searches: focus on unidentified point-like sources in GPS, search for variability both in VHE data and through MWL coordination, re-examine (phase-fold) VHE data

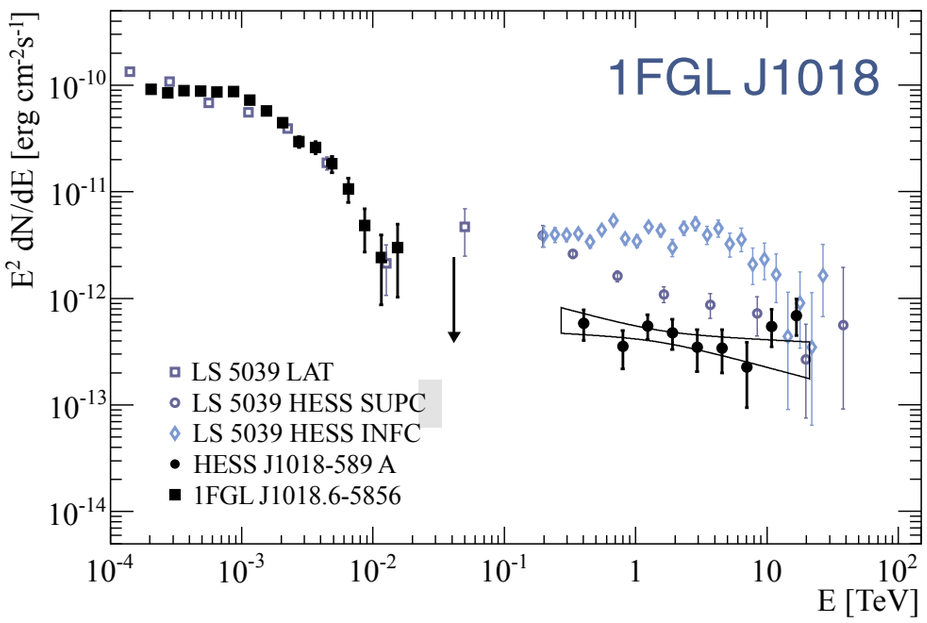


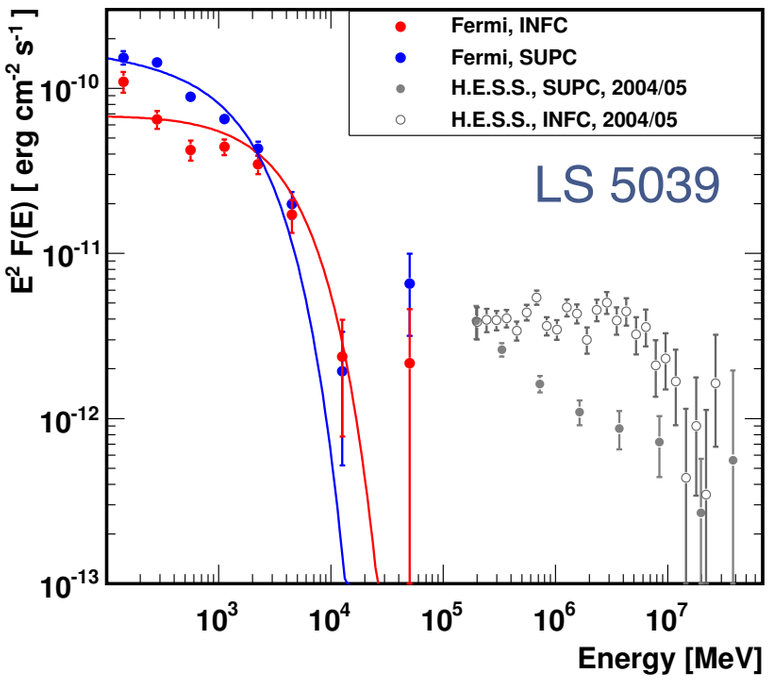
adapted from Funk & Hinton (2013)

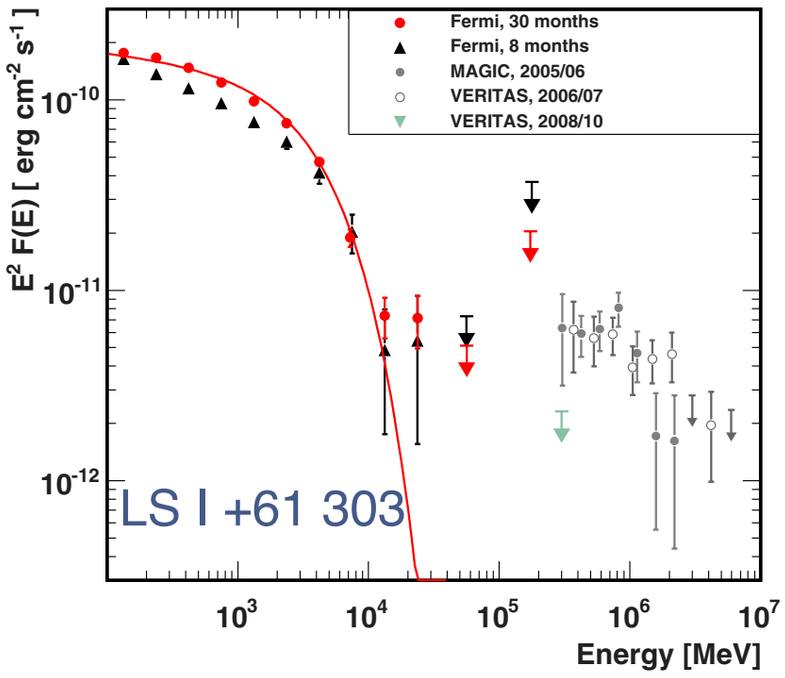
backup

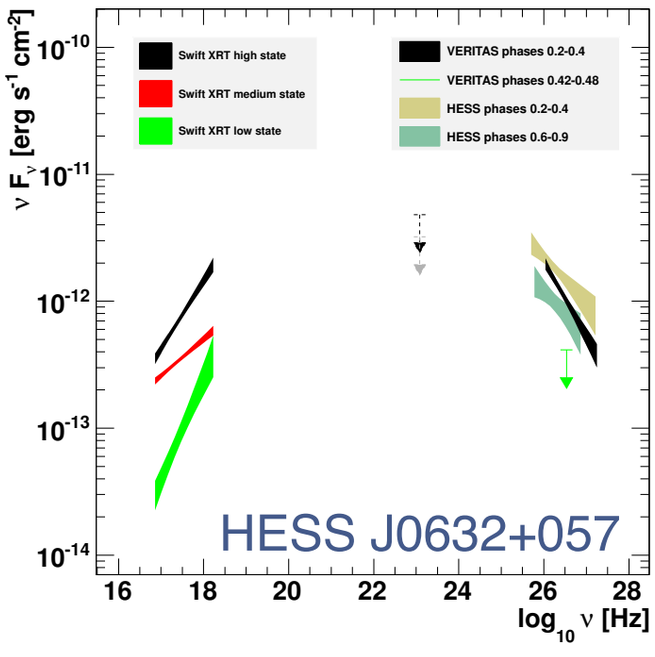
1 - The GeV-TeV (non) connection: different accelerators/emitters?





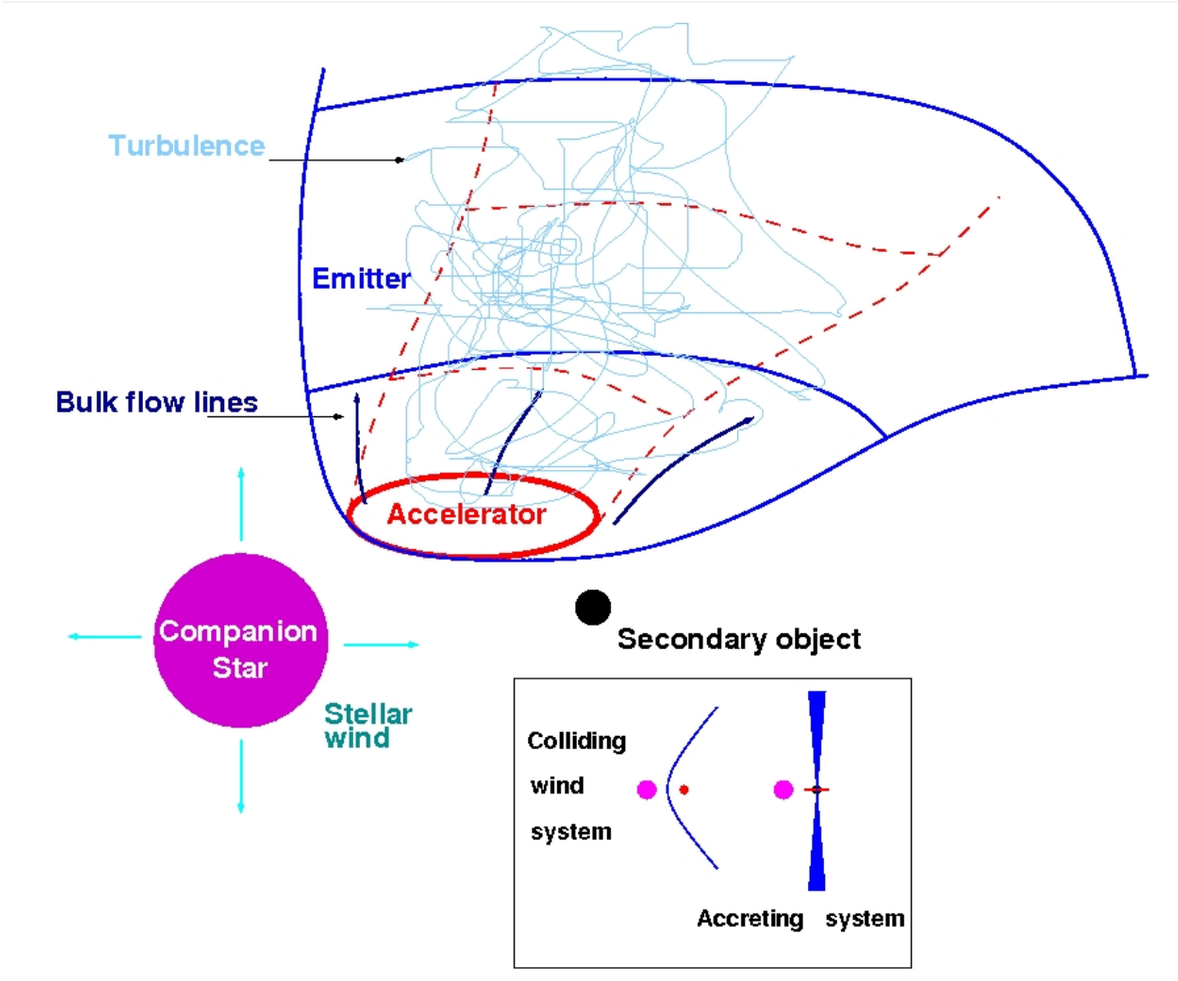






Gamma-ray *emitting* binaries

- Binary systems can produce powerful relativistic outflows
- Energy source: accretion, BH/PSR rotation, stellar-winds
- Supersonic outflows impact on medium: kinetic/magnetic energy into heat, turbulence, work, non-thermal particles
- Strong shocks, turbulence and strong vel. gradients lead to particle acceleration
- Radiation reprocessing affecting the emitter structure at diff. wavelengths
- In compact binaries, high-energy emission can provide information of non-thermal processes and the underlying flow dynamics

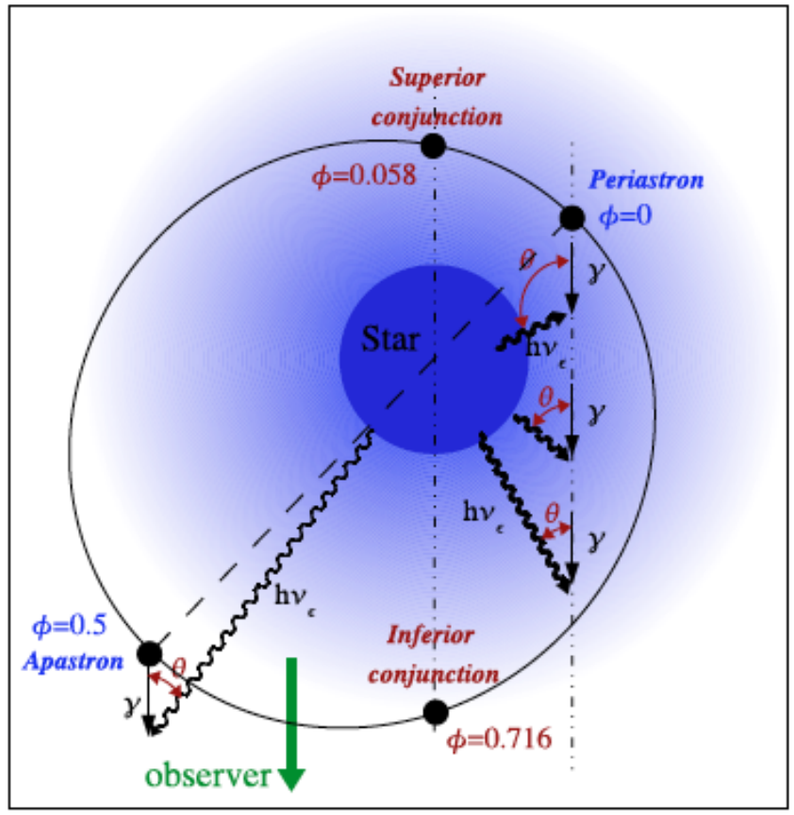


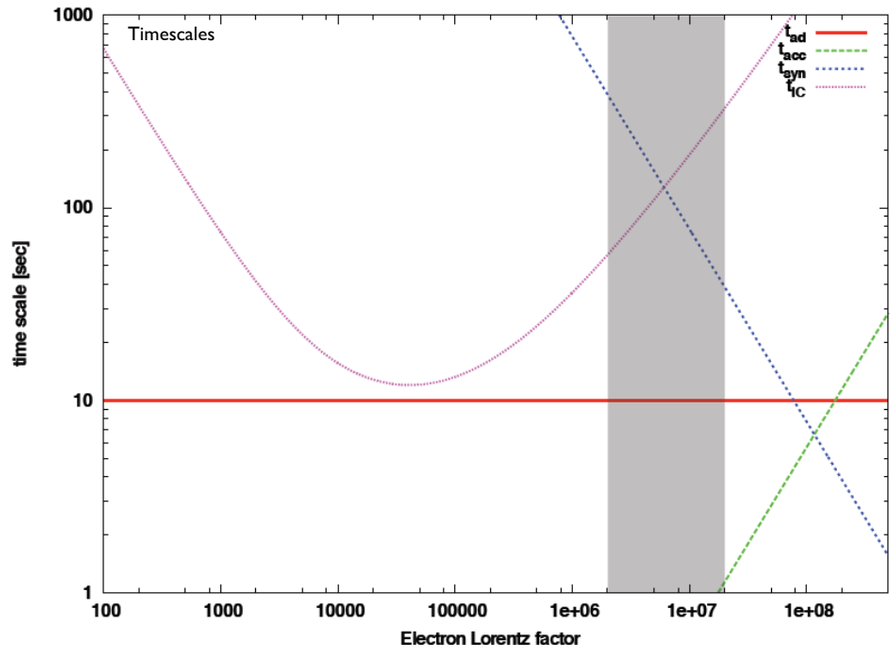
Bosch-Ramon (2011)

- Periodically modulated TeV emission
  - produced **inside** or **very close** to system
  - due to **γγ-absorption** and **anisotropic IC**
- VHE spectrum extends beyond 10 TeV
  - stellar radiation peaks ~10 eV (T~4 x10^4 K)
  - IC scattering (KN!) needs **>10 TeV electrons**
- highly-efficient acceleration required
  - **$t_{acc} := \eta\, r_g / c$, $\eta \in [10, 10^3]$**
  - where/how are particles accelerated?

- Fermi 1st order $\Delta E/E \propto (u_{ups}-u_{down})/c$, **$N_\gamma \propto \gamma^{-s}$, $s \gtrsim 2$**
- *stochastic*: $\Delta E/E \propto [(u_{ups}-u_{down})/c]^2$, **$N_\gamma \propto \gamma^{-s}$, $s \lesssim 2$**
- *shear*: $\Delta E/E \propto [(\langle u \rangle)/c]^2$, **$N_\gamma \propto \gamma^{-(1+\alpha)}$**, $\tau \propto p^{\alpha}$, $\alpha > 0$

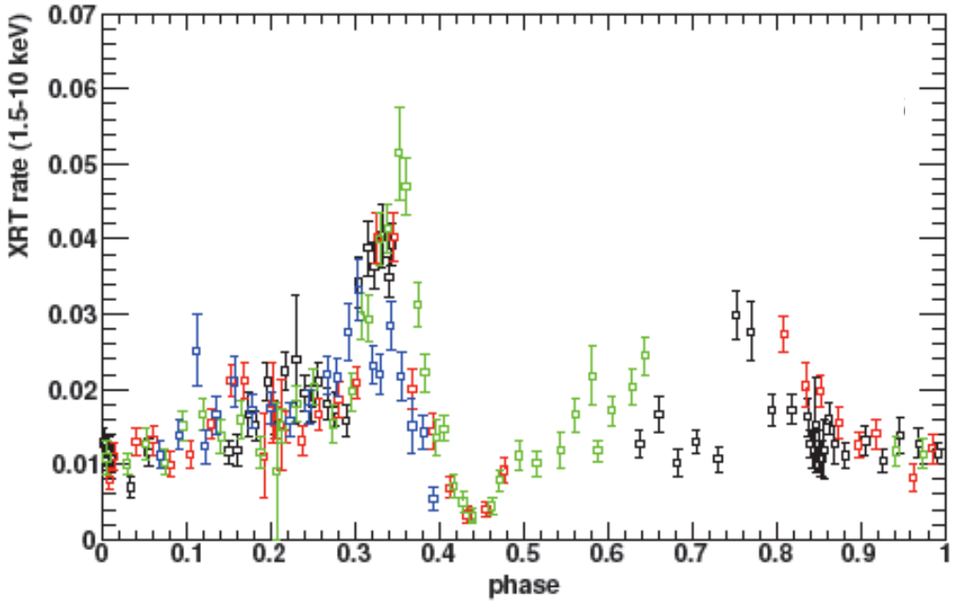
Drury (1983), Jokipii (1987). Blandford & Eichler (1987)
Kirk & Duffy (1999), Rieger & Bosch-Ramon (2007) …



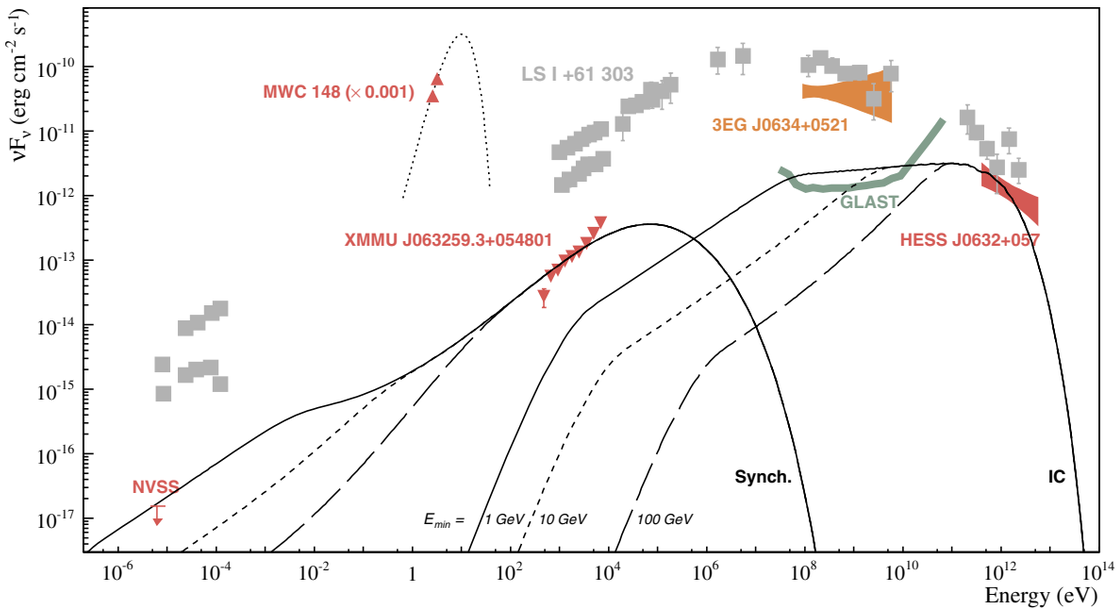


HESS J0632+057: double peaks in an eccentric-orbit system

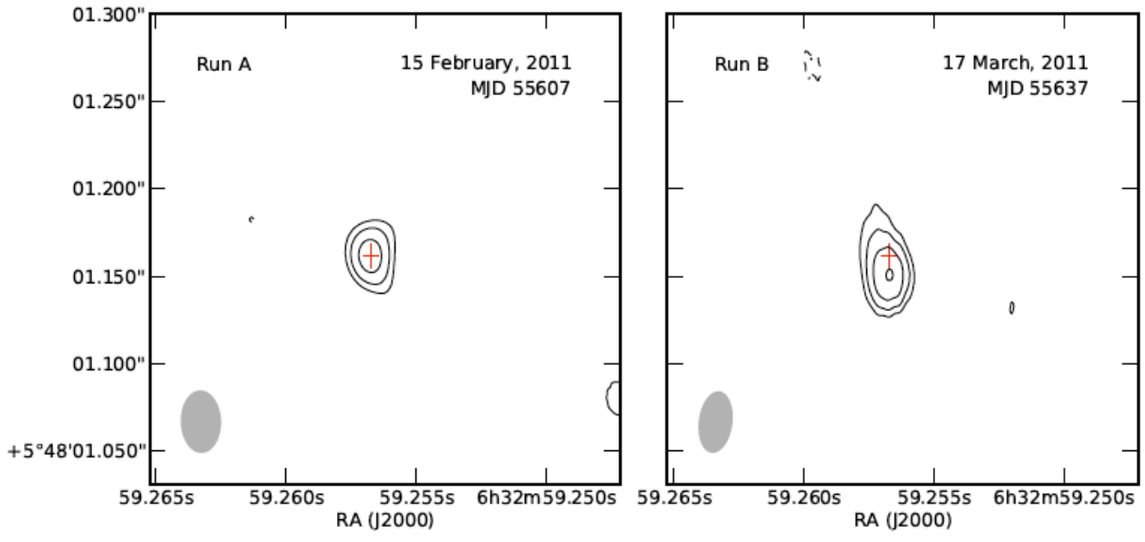
- binary nature from optical data (Casares+ 2012)
- **MWC 148**: High-Mass, B0pe star, d = 1.1 - 1.7 kpc
- X-rays: 321±5d periodic modulation (Bongiorno+2011)
- no pulsations found (Chandra, GBT) (Rea & Torres 2011)
- point-like → extended radio source
  (+30d after X-ray burst) (Moldón+ 2011)



Bongiorno et al (2011)



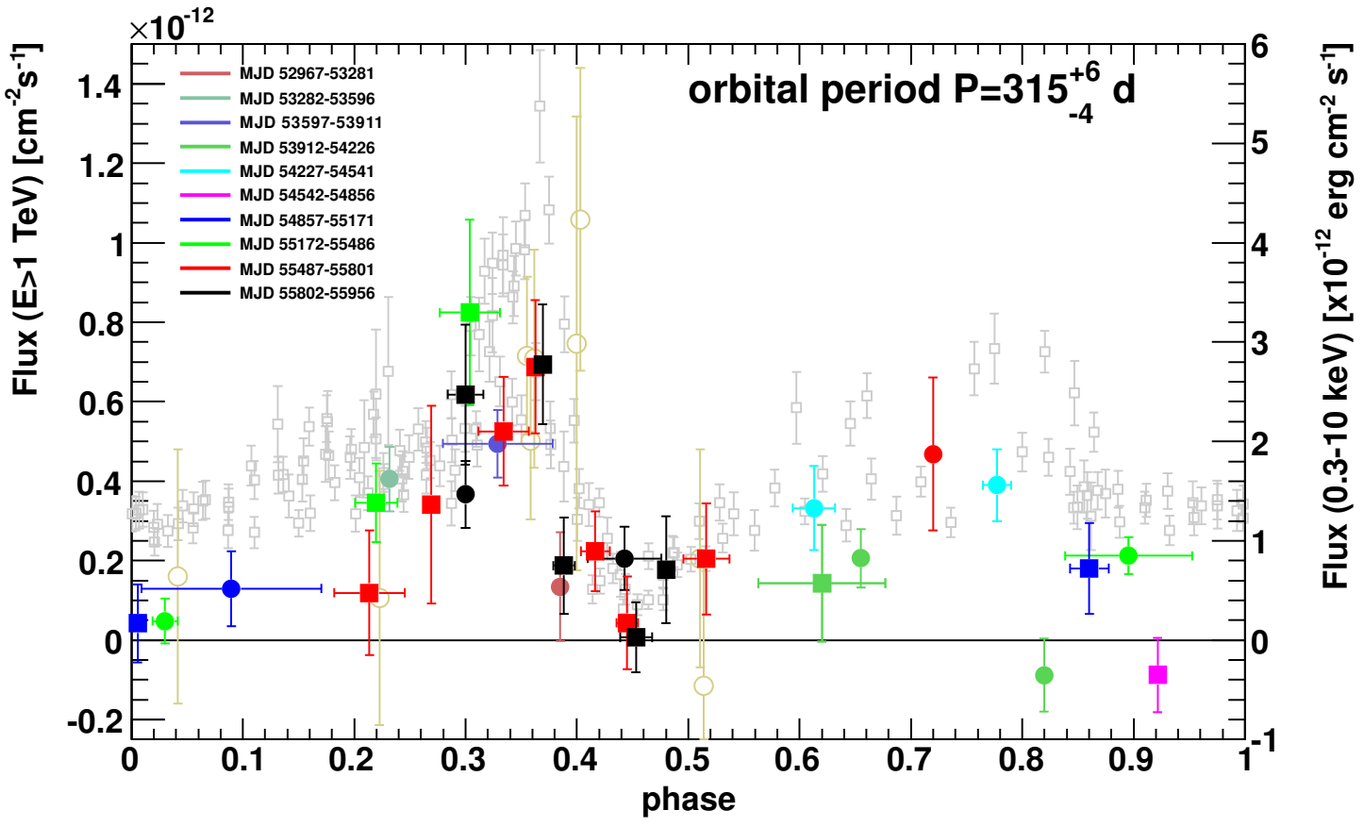
Hinton et al (2009)

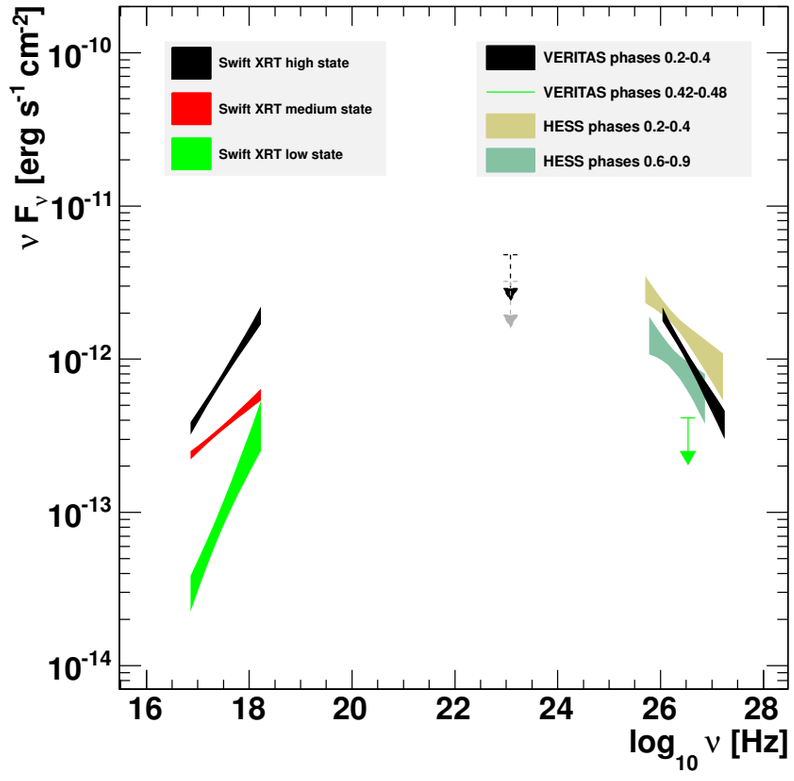


Moldón et al. (2011)

Long-term TeV and X-Ray Observations of the Gamma-Ray Binary HESS J0632+057

Aliu+ (VERITAS coll.), Abramowski+ (H.E.S.S. coll) 2014, ApJ, 780, 168A



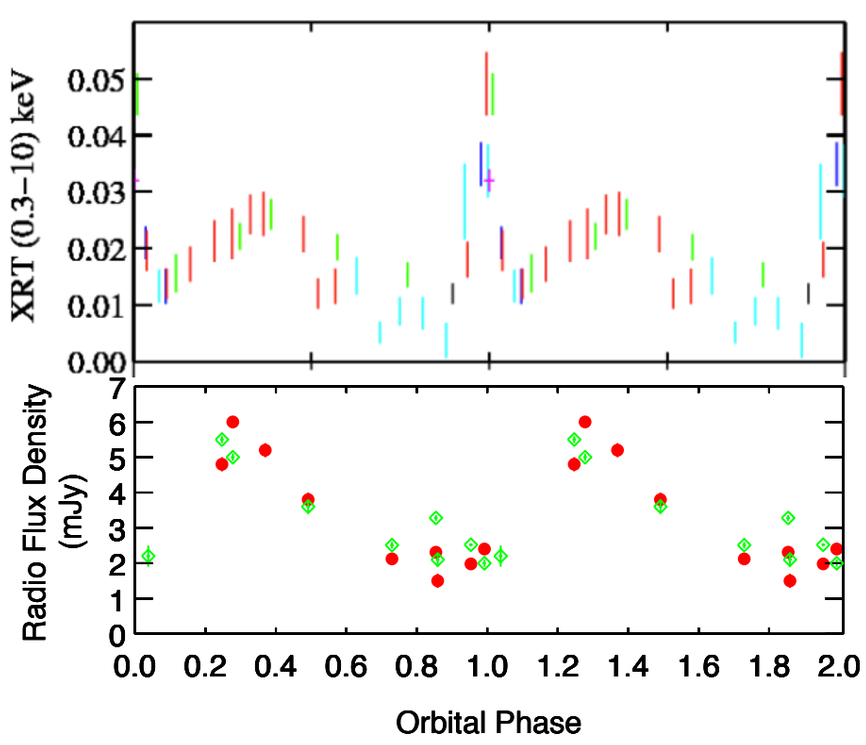


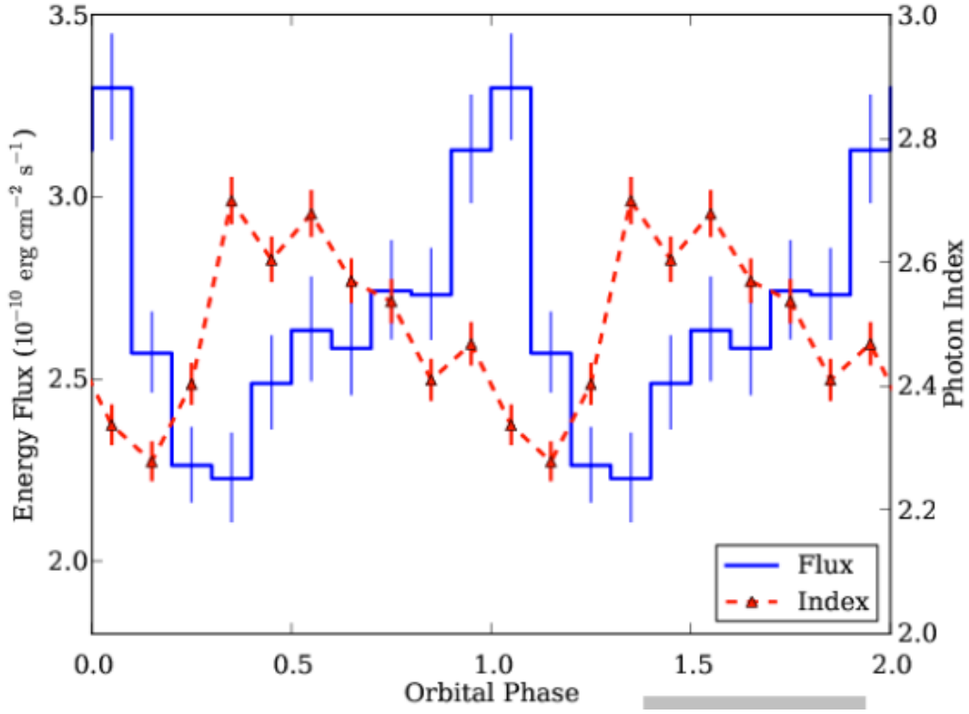
- correlated X-ray/TeV emission driven by sharp rise-and-fall at phases ~0.3
- TeV emission reported for the first time at phases ~ [0.6 - 0.9]. Secondary peak?
- only gamma-ray binary not detected at GeV energies (Caliandro+ 2013)

1FGL J1018.6-5856: a confirmed new gamma-ray binary

"Periodic Emission from the Gamma-Ray Binary 1FGL J1018.6-5856"

Fermi-LAT coll. 2012, Science, 335, 189F



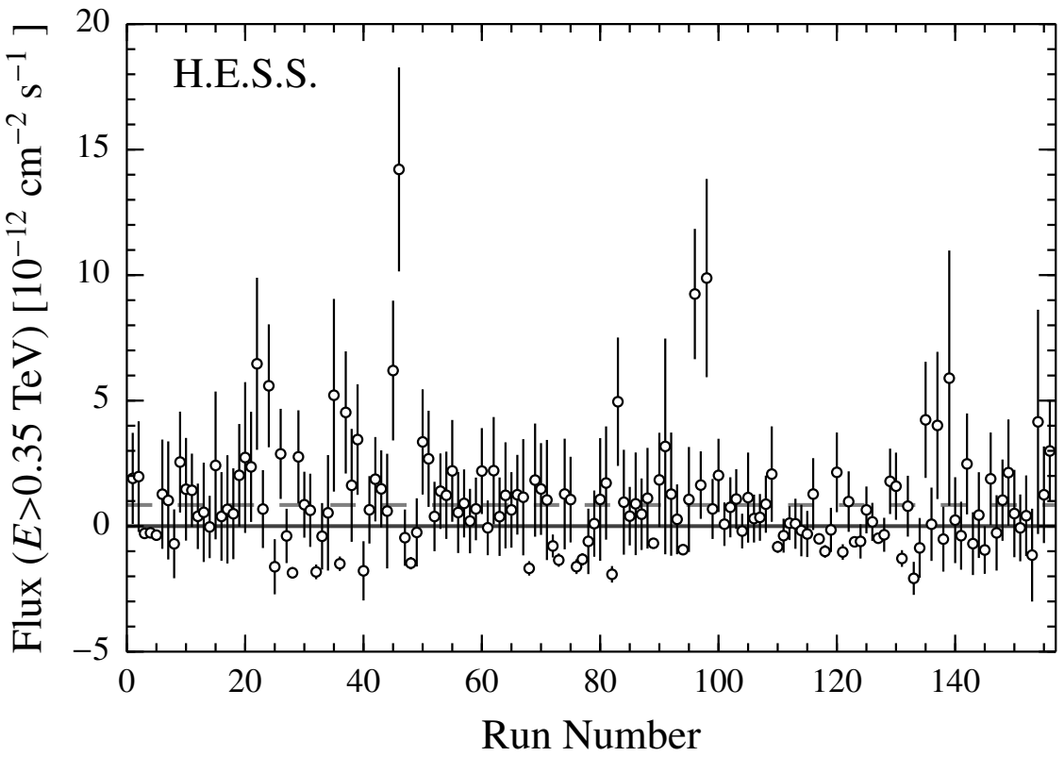


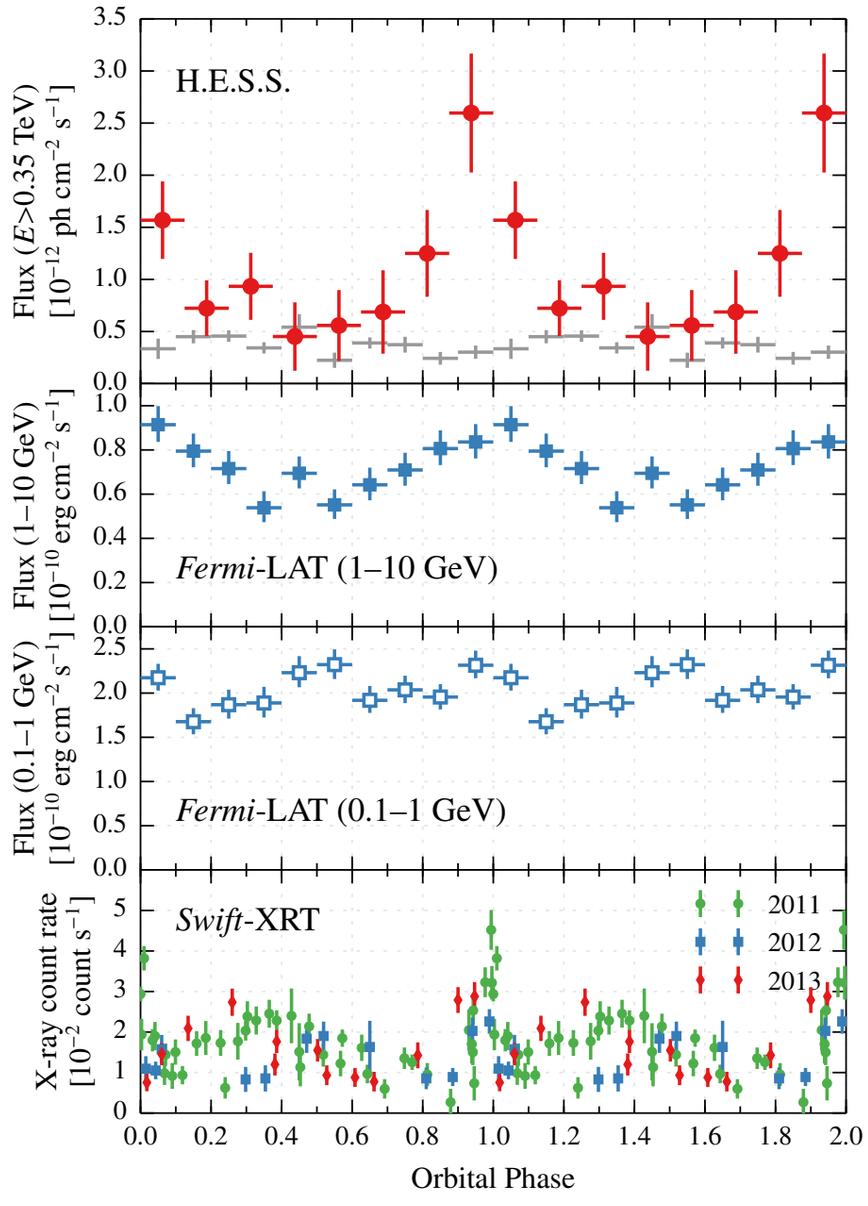
- "genuine" γ-ray binary, *Fermi*-LAT discovery through periodicity (16.6d) *(Fermi-LAT coll. 2012)*
- periodic emission observed also in X-rays (+ radio variability, but no peak at phase ~ 0.0)
- similar to LS 5039 (e.g.companion O6Vf)… but correlated hardness-intensity at GeV

"Discovery of variable VHE gamma-ray emission from the binary system 1FGL J1018.6-5856"

H.E.S.S. coll. 2015, A&A, 577, 131

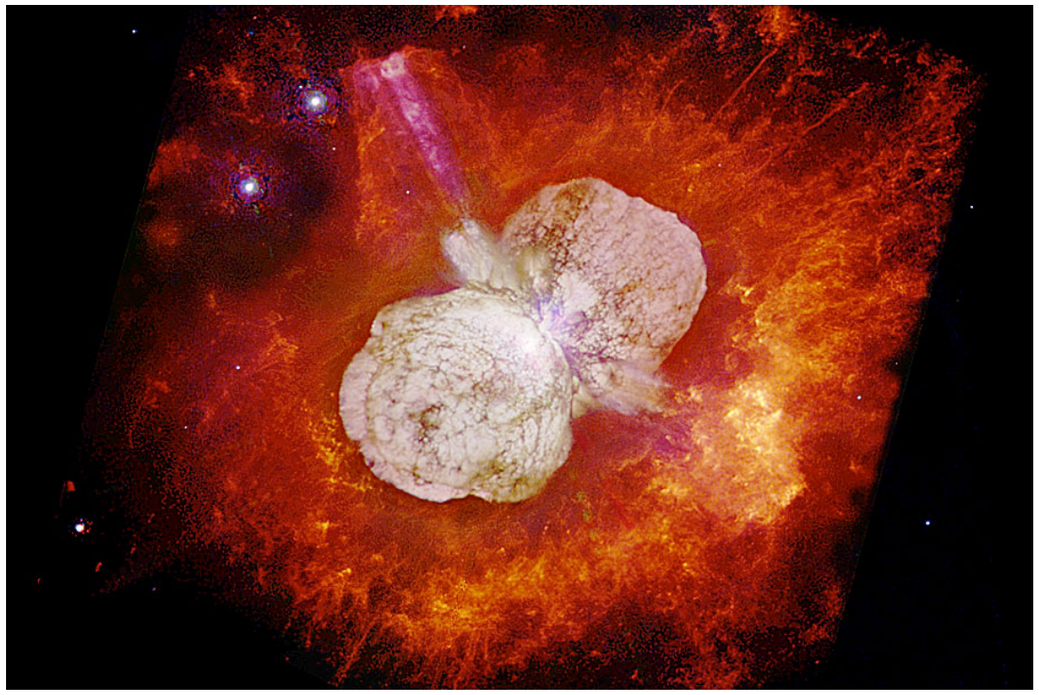
- Variability: LTR with cte. flux as null hypothesis:
  $\chi^2/\nu = 238.3/155$ => **4.3 σ**
- Periodicity: P = 16.58d, $MJD_0 = 55403.3$
  $\chi^2/\nu = 22.7/7$=> **3.1 σ**





Eta Carinae: a colliding-winds binary @ gamma-rays

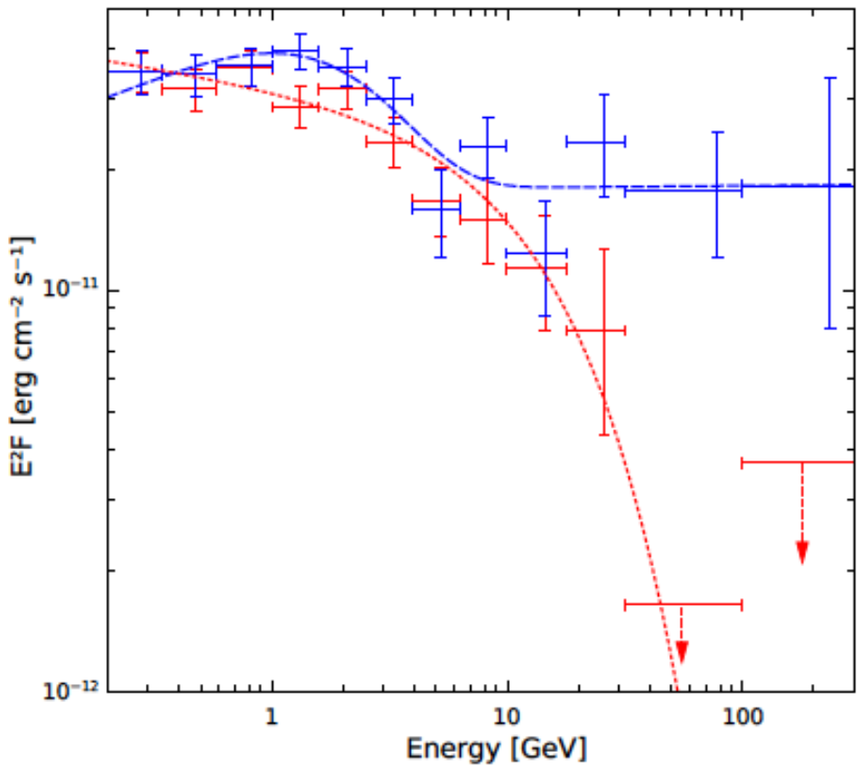
- Highest star mass-loss rate system in the Galaxy
- **primary star**: Luminous Blue Variable
  - M ~120 M_{sun}, R ~100 R_{sun}
  - dM/dt ~10^{-3} M_{sun} yr^{-1}, v_{wind} ~ 500 km/s
- **secondary star**: O or Wolf-Rayet
  - M ~ 30 Msun, R ~30 R_{sun}
  - dM/dt ~10^{-5} M_{sun} yr-1, v_{wind} ~ 3000 km/s
- **system parameters**
  - d = 2.3 kpc,
  - period = 5.5 years
  - eccentricity ~0.9
  - separation @ periastron ~1.7 A.U.



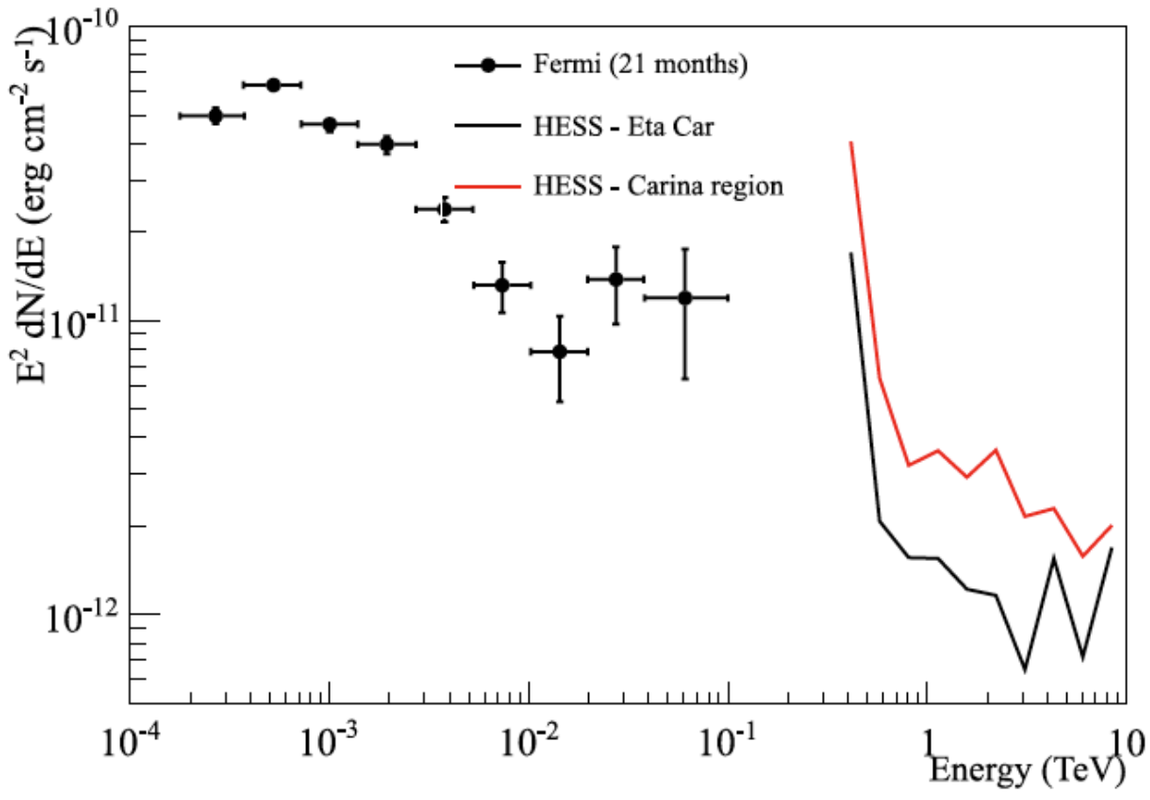
credits: N. Smith & J. A. Morse

Eta Carinae: a colliding-winds binary @ gamma-rays

- Fermi-LAT observations: different low/high-energy components?
- VHEs: H.E.S.S. upper limits so far (high NSB => E_{th} + 470 GeVs)

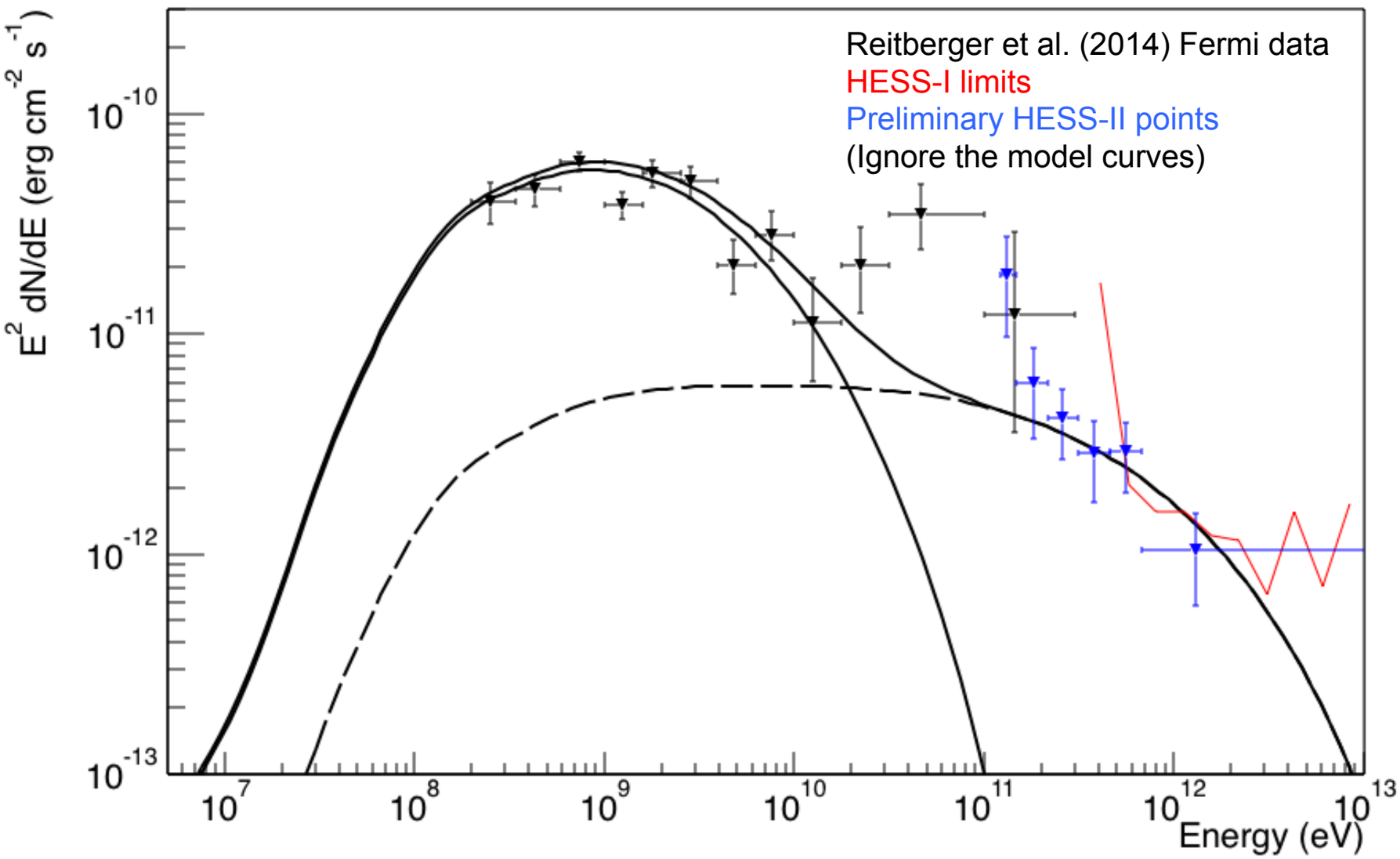


Reitberger et al. 2015



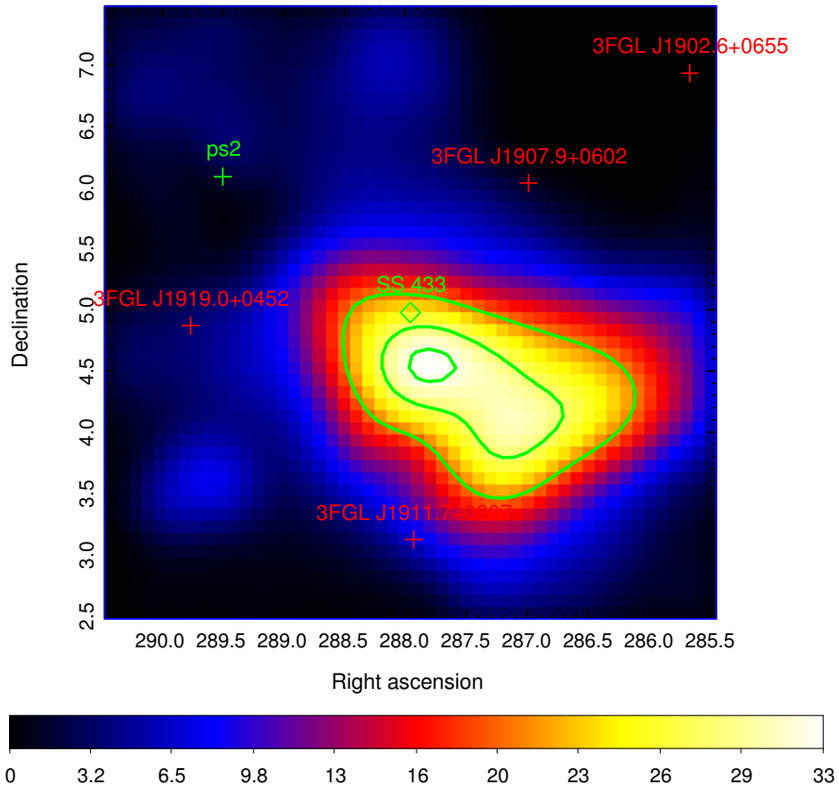
H.E.S.S. collaboration (2012)

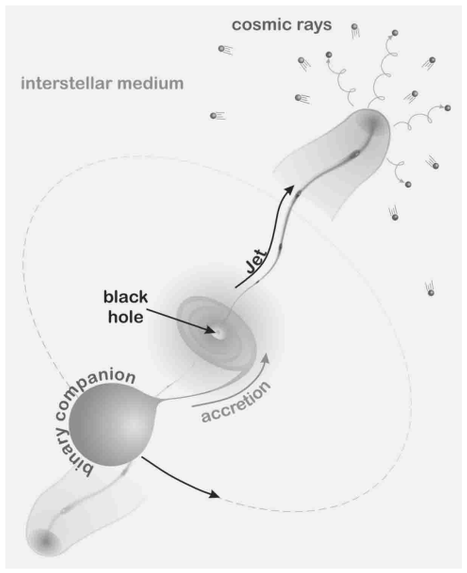
Eta Carinae: HESS-II observations in 2014-2015



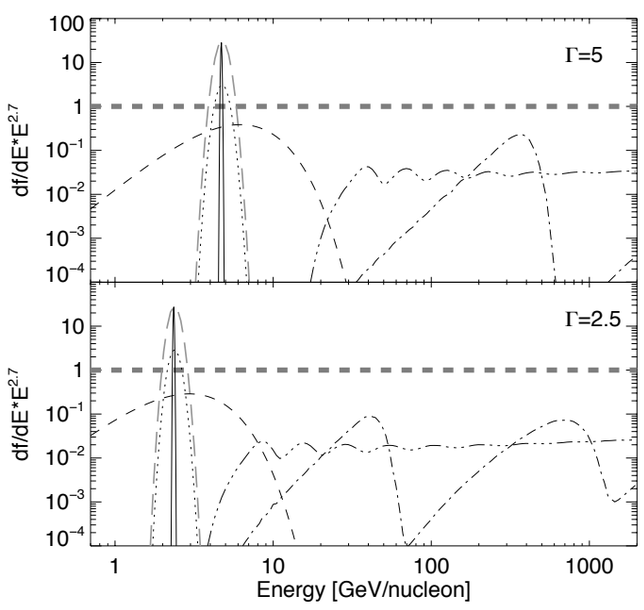
“Detection of persistent gamma-ray emission towards SS433/W50“

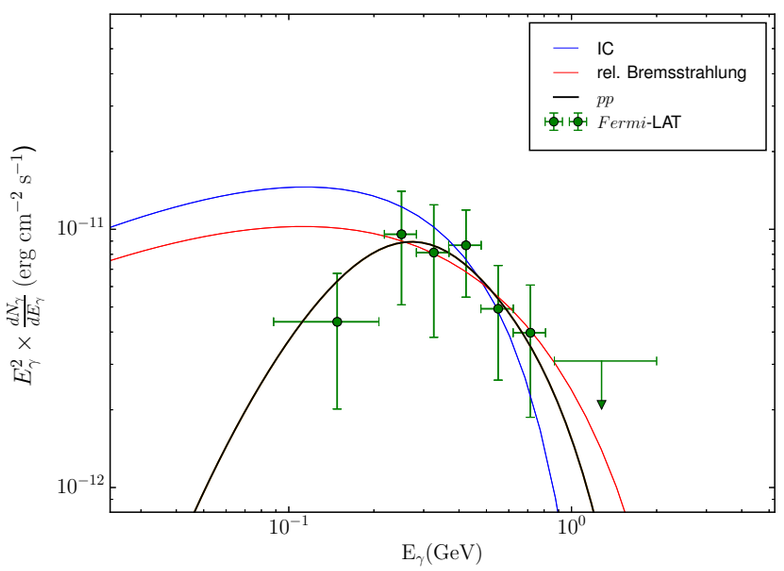
- 5-years LAT data, 3FGL, TS = 57
- 3-sigma position contours enclosing SS433/W50
- spectrum: sharp peak at ~250 MeV, up to ~800 MeV only
- no significant variability (phase-folded orbital/precession)
- pp-interactions favoured, IC/rel.-Bremss not discarded
- jet/medium interaction regions as possible scenario





Heinz & Sunyaev (2002)





Bordas+ (arXiv1411.7413B)

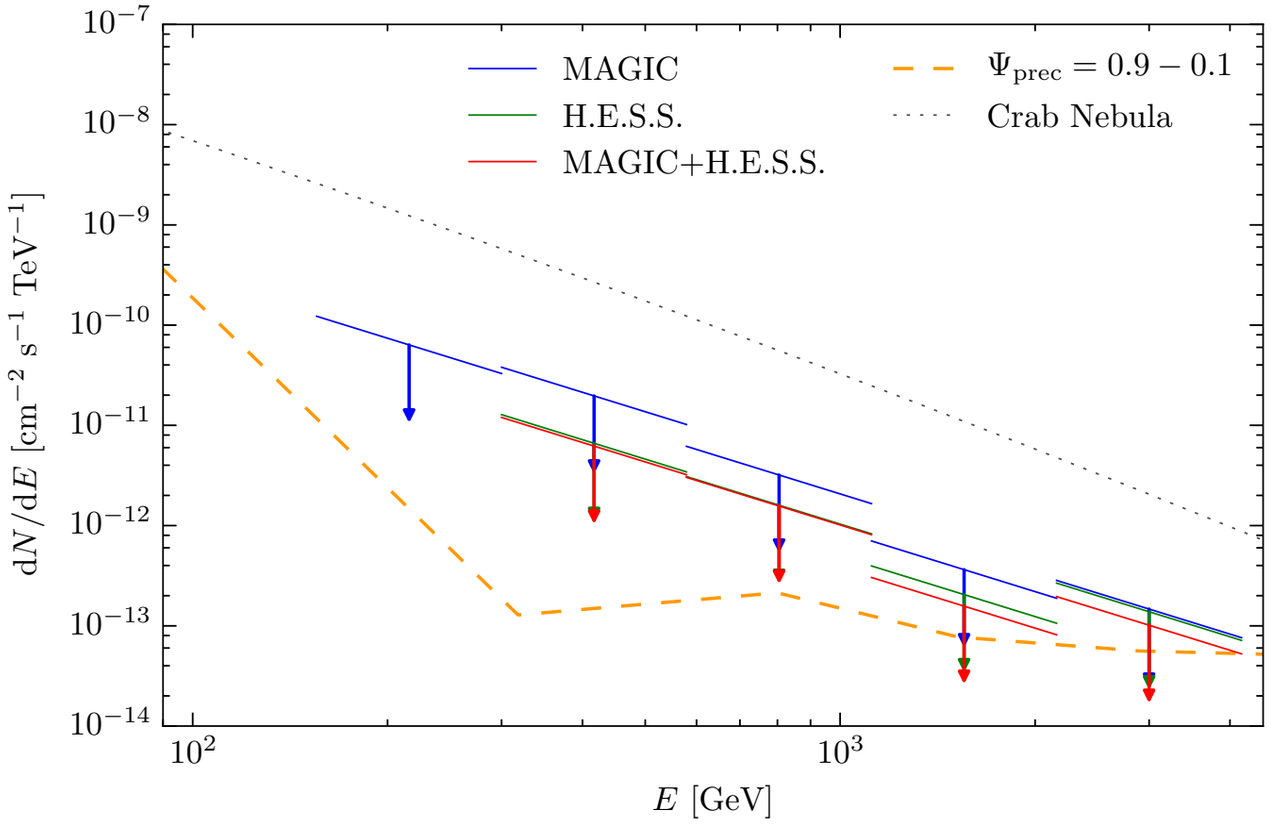
HESS/MAGIC joint campaign on SS433/W50

Why? MAGIC/H.E.S.S. upper limits paper: long-term coverage of low-absorption phases

- H.E.S.S.: 2006, 2007, (3runs)-2009, 2011; low-absorption phases ~8h
- MAGIC: 2008, 2010, all low-absorption phases

Region	IACT	t_{eff} [h]	E_{th} [GeV]	Integral flux UL [cm^{-2} s^{-1}]
SS433	HEGRA	96.3	800	8.9×10^{-13}
	H.E.S.S	8.7	300	2.3×10^{-12}
	H.E.S.S	8.7	800	3.9×10^{-13}
	MAGIC	7.8	300	1.8×10^{-12}
	MAGIC	7.8	800	4.3×10^{-13}
e1	HEGRA	72.0	800	6.2×10^{-13}
	H.E.S.S	36.5	300	6.8×10^{-13}
	H.E.S.S	36.5	800	1.4×10^{-13}
	MAGIC	7.8	300	1.6×10^{-11}
	MAGIC	7.8	800	1.9×10^{-12}
e2	HEGRA	73.1	800	9.2×10^{-13}
	H.E.S.S	34.8	300	6.0×10^{-13}
	H.E.S.S	34.8	800	1.3×10^{-13}
	MAGIC	7.8	300	1.7×10^{-11}
	MAGIC	7.8	800	2.0×10^{-12}
e3	HEGRA	68.8	800	9.0×10^{-13}
	H.E.S.S	18.9	300	1.1×10^{-12}
	H.E.S.S	18.9	800	9.3×10^{-13}
	MAGIC	7.8	300	8.7×10^{-12}
	MAGIC	7.8	800	6.1×10^{-13}
w1	HEGRA	104.9	800	6.7×10^{-13}
	H.E.S.S	62.5	300	2.2×10^{-13}
	H.E.S.S	62.5	800	4.0×10^{-14}
	MAGIC	7.8	300	1.3×10^{-11}
	MAGIC	7.8	800	2.2×10^{-12}
w2	HEGRA	100.7	800	9.0×10^{-13}
	H.E.S.S	60.8	300	3.2×10^{-13}
	H.E.S.S	60.8	800	7.6×10^{-14}
	MAGIC	7.8	300	1.4×10^{-11}
	MAGIC	7.8	800	2.6×10^{-12}

E low	E high	<E>	HESS	MAGIC
155.4	300.0	215.9	–	1.02e-12
348.0	579.2	416.8	9.88e-12	1.02e-12
579.2	1118.3	804.8	1.08e-12	7.53e-12
1118.3	2159.1	1553.8	2.20e-13	1.05e-13
2159.1	4168.5	3000.0	8.68e-14	1.95e-13



“Gamma-ray emission from transitional pulsars”

“caught in the act” (by *Fermi*-LAT): PSR J1023, XSS J12270, IGR J18245

- state transition from pulsar-winds to accretion-dominated states: ejector ↔ accretor (e.g. D.Torres+)
- eccentric orbits provide up to O(10^3) changes in dM/dt (e.g., LS I +61 303, HESS J0632, A. Ozazaki+)