Analyzing TeV Gamma-Ray Binary Candidates with the HAWC Observatory

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Astronomy/Astroparticle Physics - Professor Segev BenZvi
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HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

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Mapping the Northern Sky in High-Energy Gamma Rays

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

HAWC Observatory

HAWC operates day and night, providing a large field of view for the observation of the highest energy gamma rays.

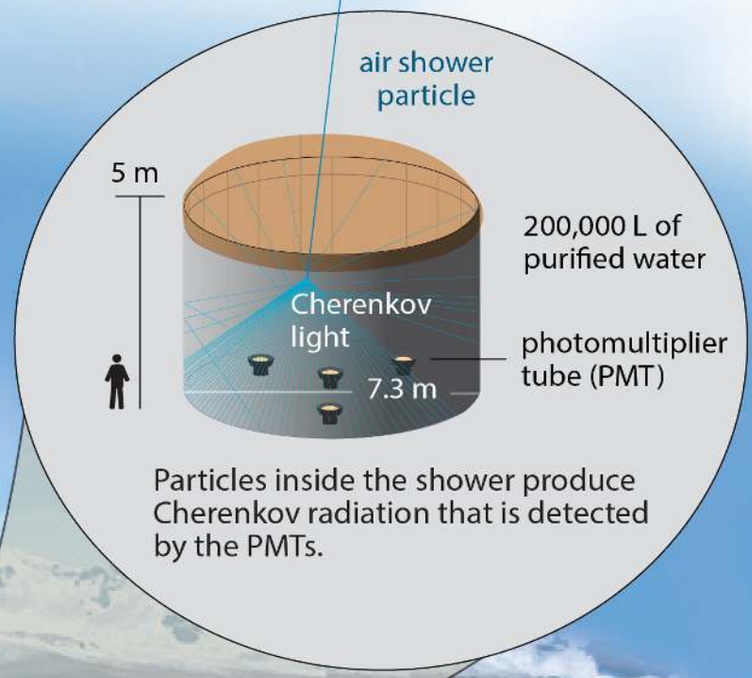
Pico de Orizaba
(5,626 m)

HAWC is located at 4,100 m above sea level, covering an area of 20,000 m^2.

150 m

Water Cherenkov tank

HAWC comprises an array of 300 tanks that record the particles created in gamma-ray and cosmic-ray showers.

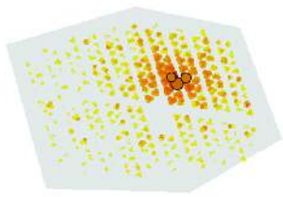


Particles inside the shower produce Cherenkov radiation that is detected by the PMTs.

Gamma rays vs cosmic rays

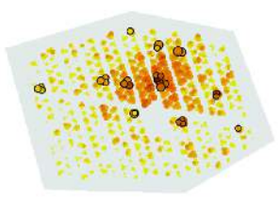
HAWC selects gamma rays from among a much more abundant background of cosmic rays.

gamma-ray shower



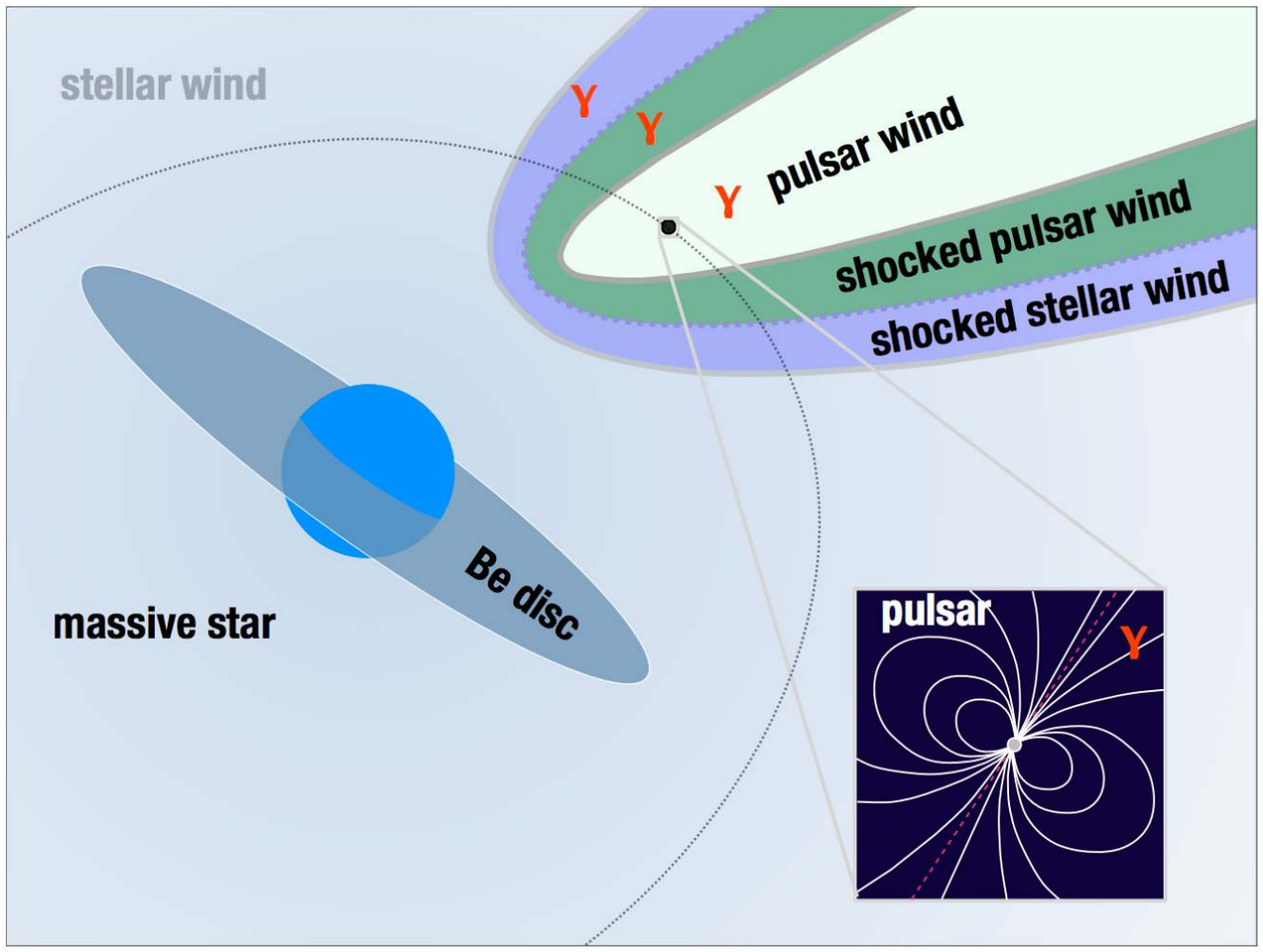
"hot" spots concentrate around the core

cosmic-ray shower



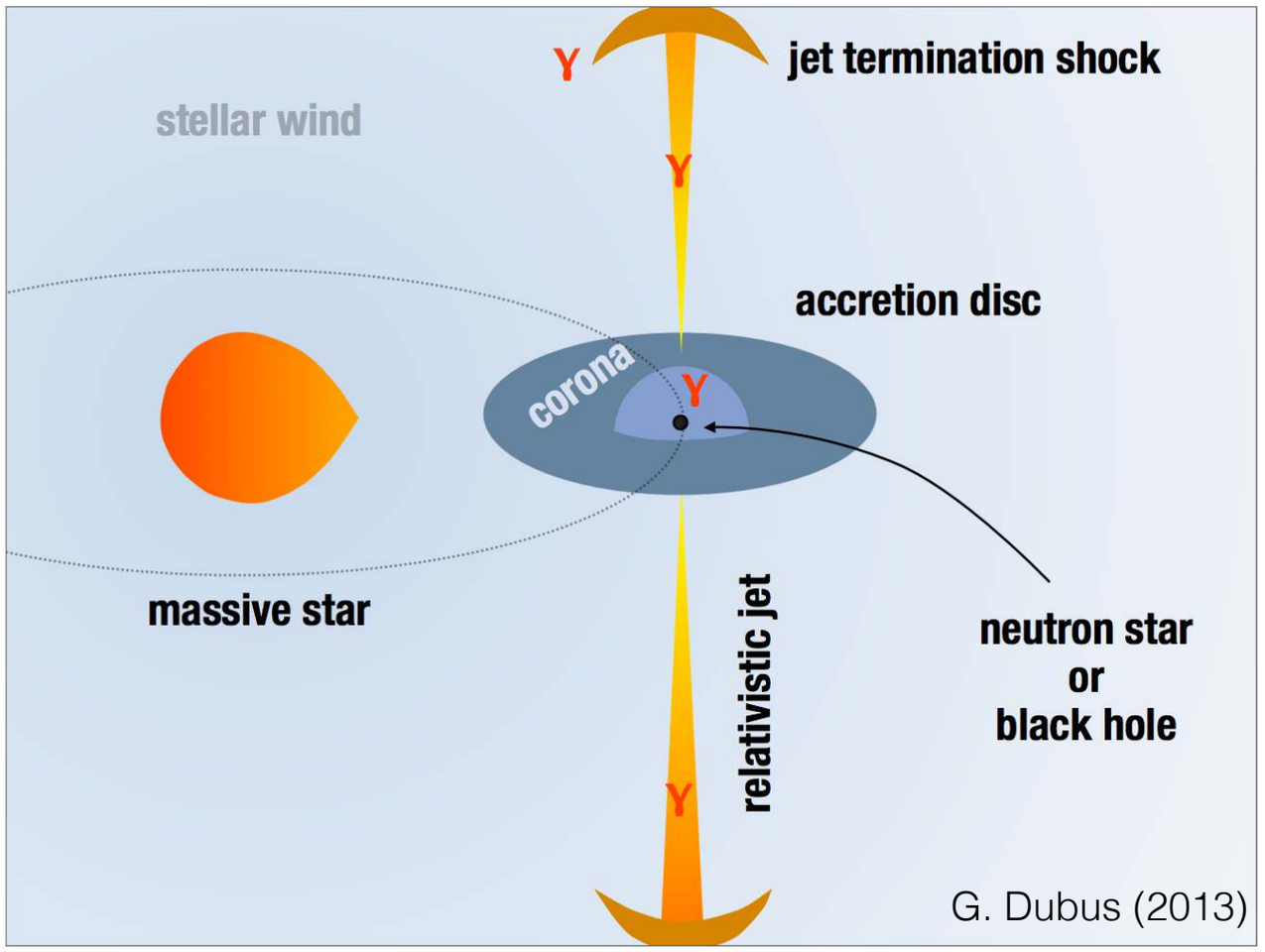
"hot" spots are more dispersed

Gamma-Ray Binaries



Binary Pulsar

- Pulsar wind interacting with stellar wind



Microquasar

- Energy released by accretion
- Relativistic jet acceleration
- Jet termination shock with ISM

Known TeV Binaries

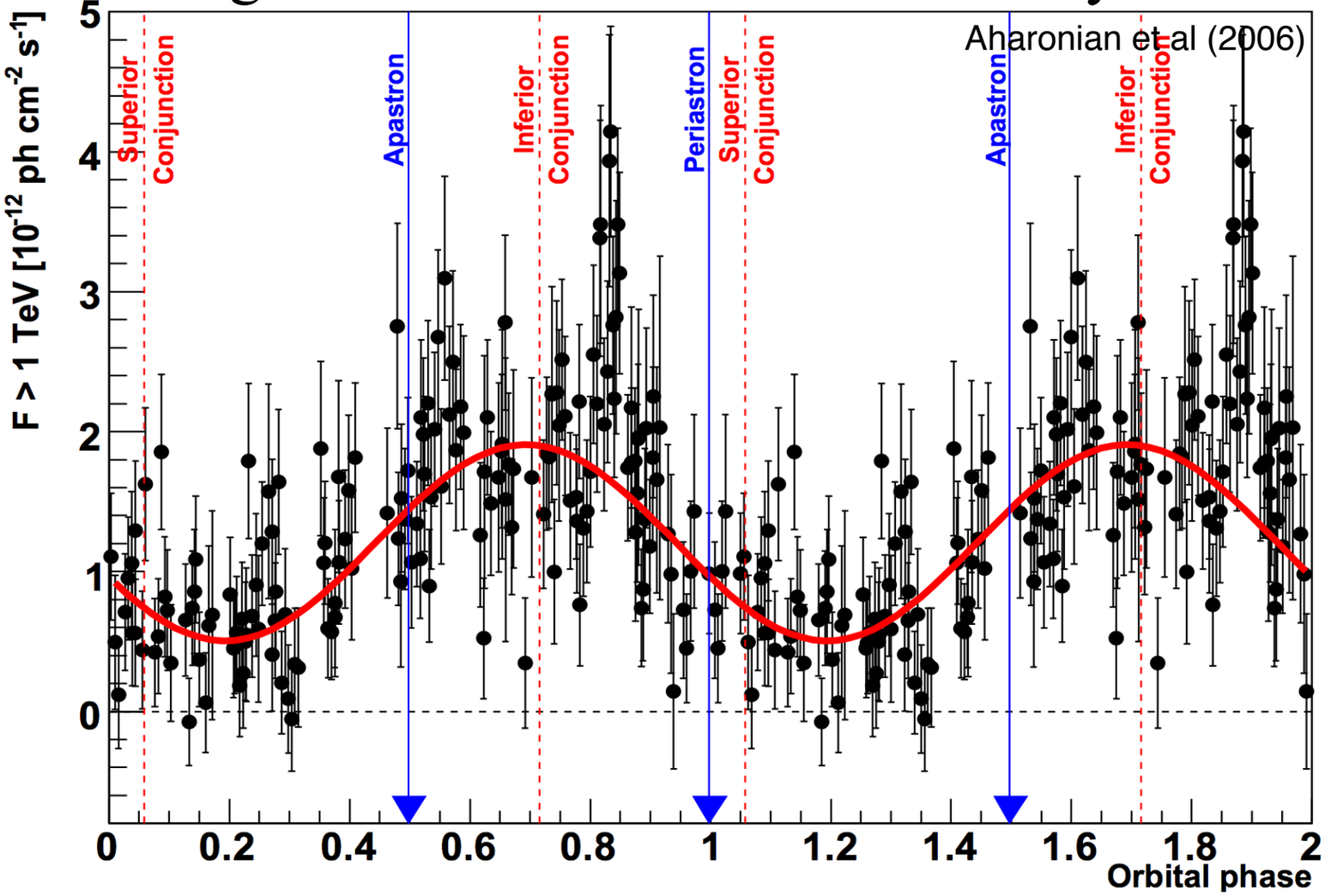
Visible from HAWC:

- HESS J0632+057
- LS I +61° 303
- LS 5039

Not Visible:

- PSR B1259-63
- 1FGL J1018.6-5856

Integral Flux of LS 5039 measured by HESS



Natural, regularly occurring (periodic) particle accelerators

Analysis with 3ML

- Multi-Mission Maximum Likelihood framework (3ML)
  - **Python**-based tool for multi-wavelength analysis
- Fit power law spectrum to data and calculate **likelihood** (L)
- Use min(-log(L)) as seed for Markov chain Monte Carlo
  - Get **full distribution of K**
- Calculate **integral flux** for each day
  - data from Nov 26, 2014 – Feb 12, 2016 (**444 days**)
- Cut out days where fractional transit < 0.75

Spectral Fit Parameters

- Simple power law spectrum

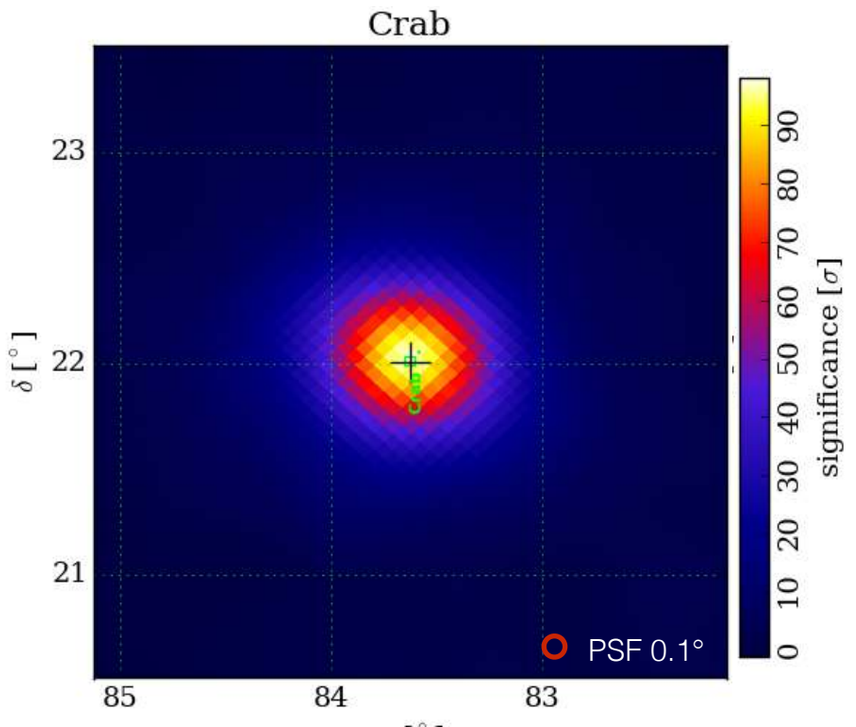
$$f(E) = K\left(\frac{E}{E_0}\right)^{-\Gamma} \tag{1}$$

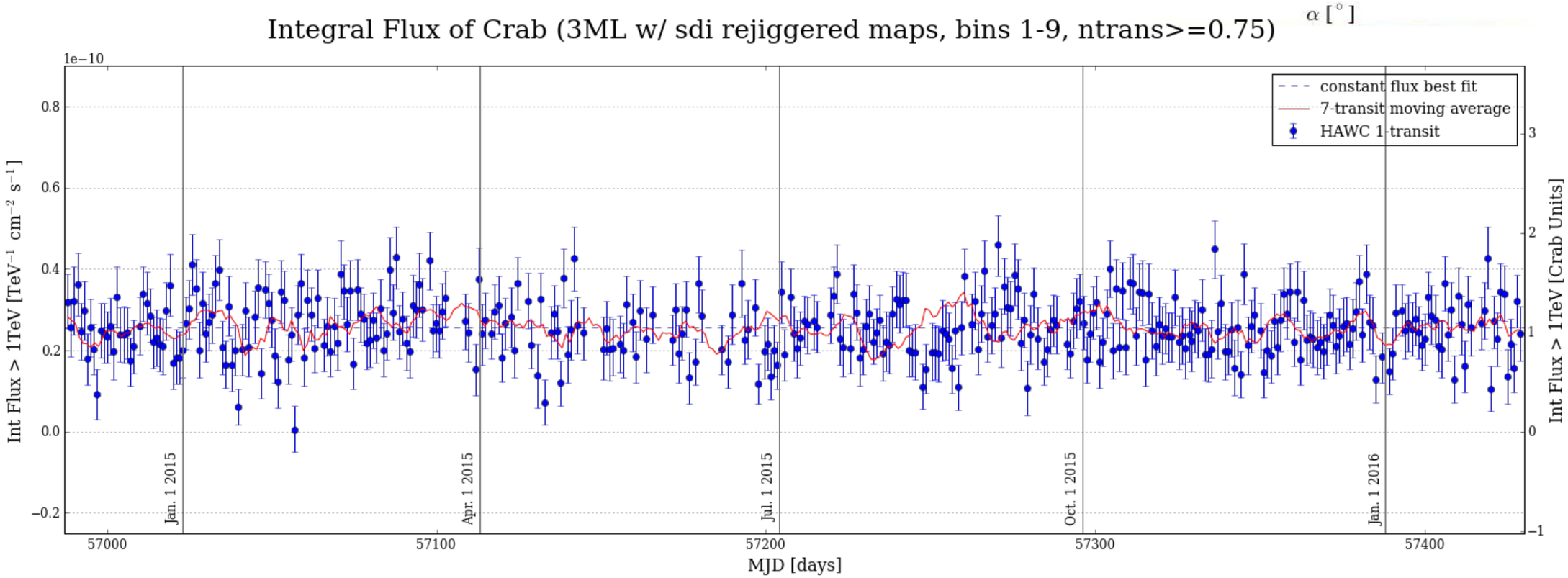
$$\mathrm{IntFlux} = \frac{E_0 \times K}{-\Gamma + 1} \tag{2}$$

- Pivot energy = 1 TeV
- **Fixed** spectral index: $\Gamma = 2.7$
- **Free** normalization K

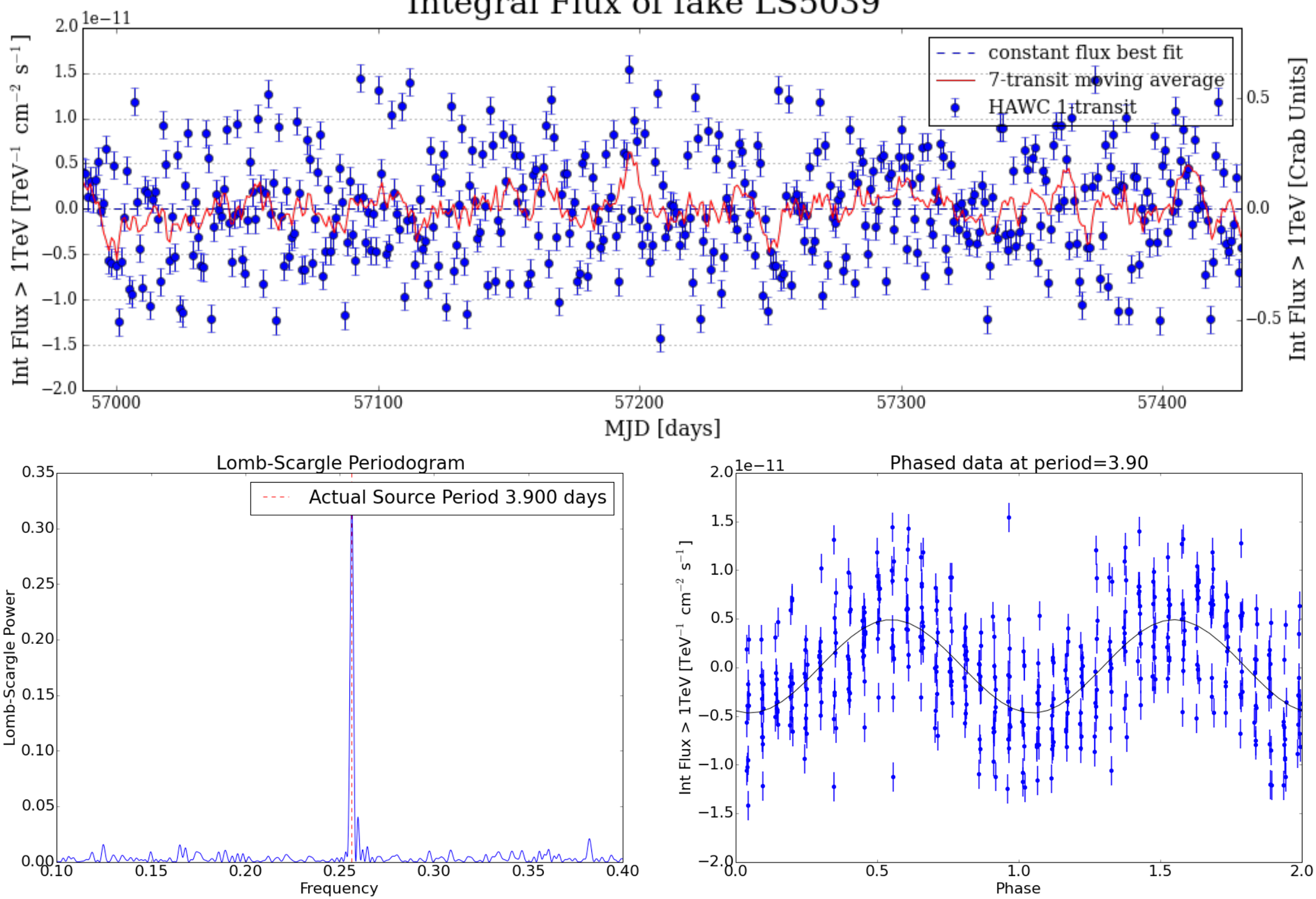
Crab Nebula

- RA: 83.63°, Dec: 22.01°
- Example of **constant flux**
- Mean IntFlux: 2.489×10^{-11} $TeV^{-1}cm^{-2}s^{-1}$



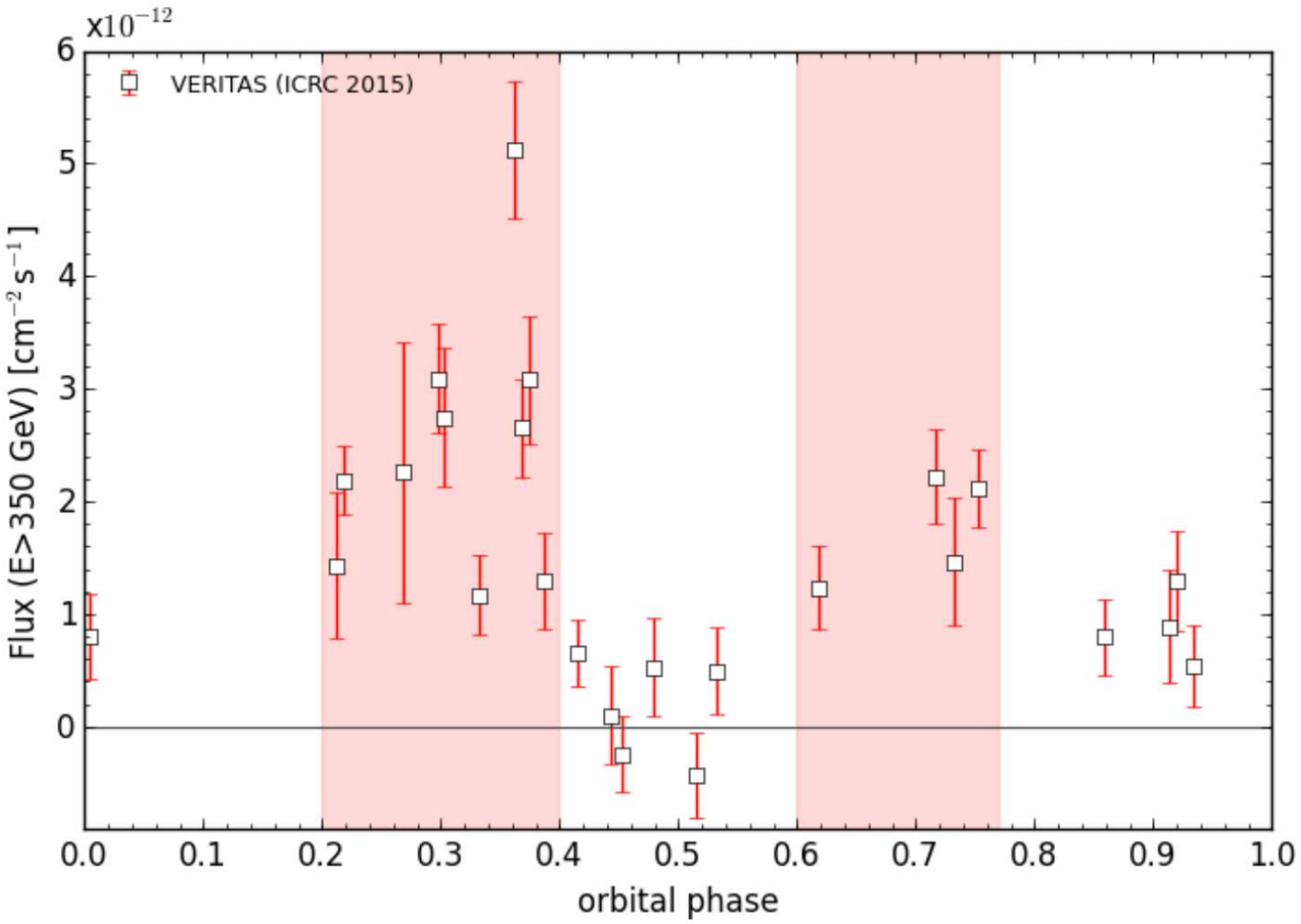


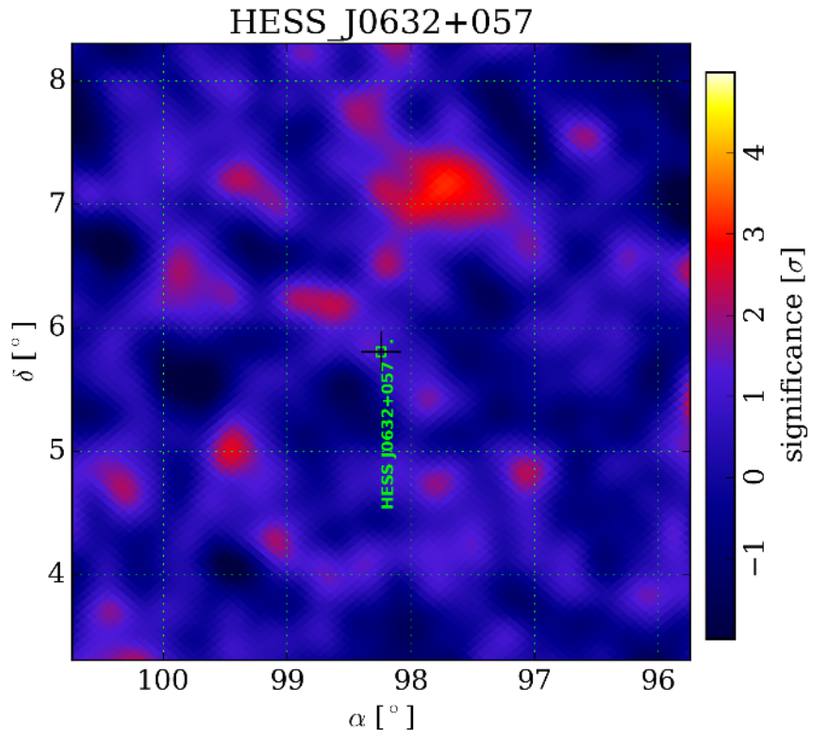
What To Look For



HESS J0632+057

- RA: 98.24°, Dec: 5.81°
- Period: 315 days
- Flux has **two maxima**

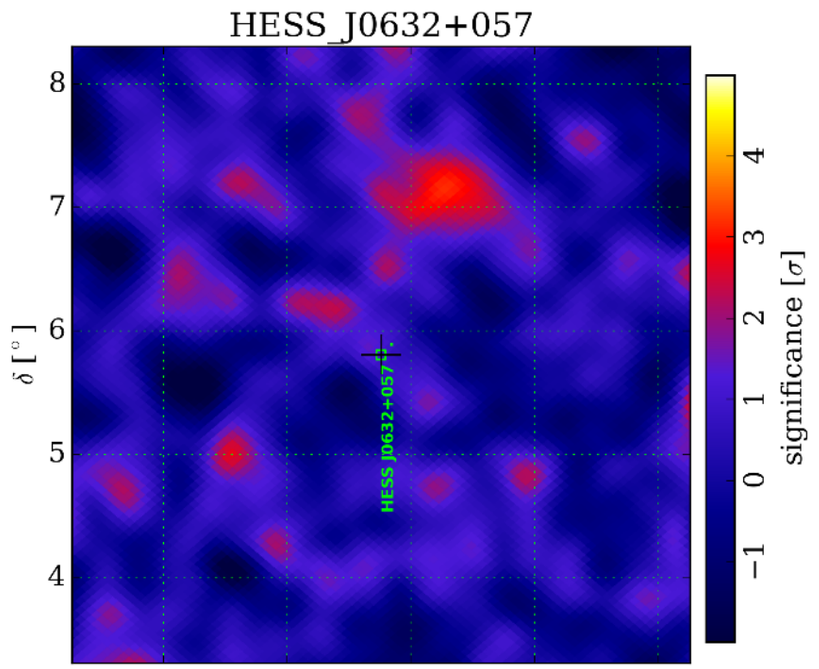


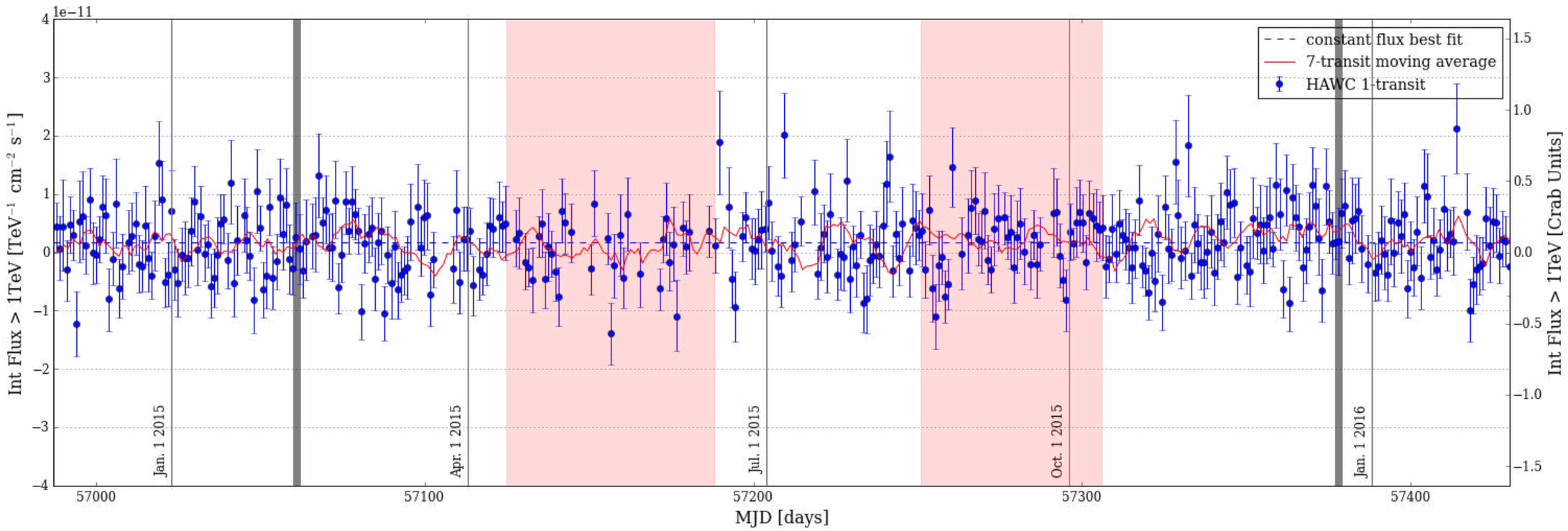


- Observations by VERITAS show periods of high flux (E>350 GeV)
- **0.2-0.4** and **0.6-0.78** phase

HESS J0632+057

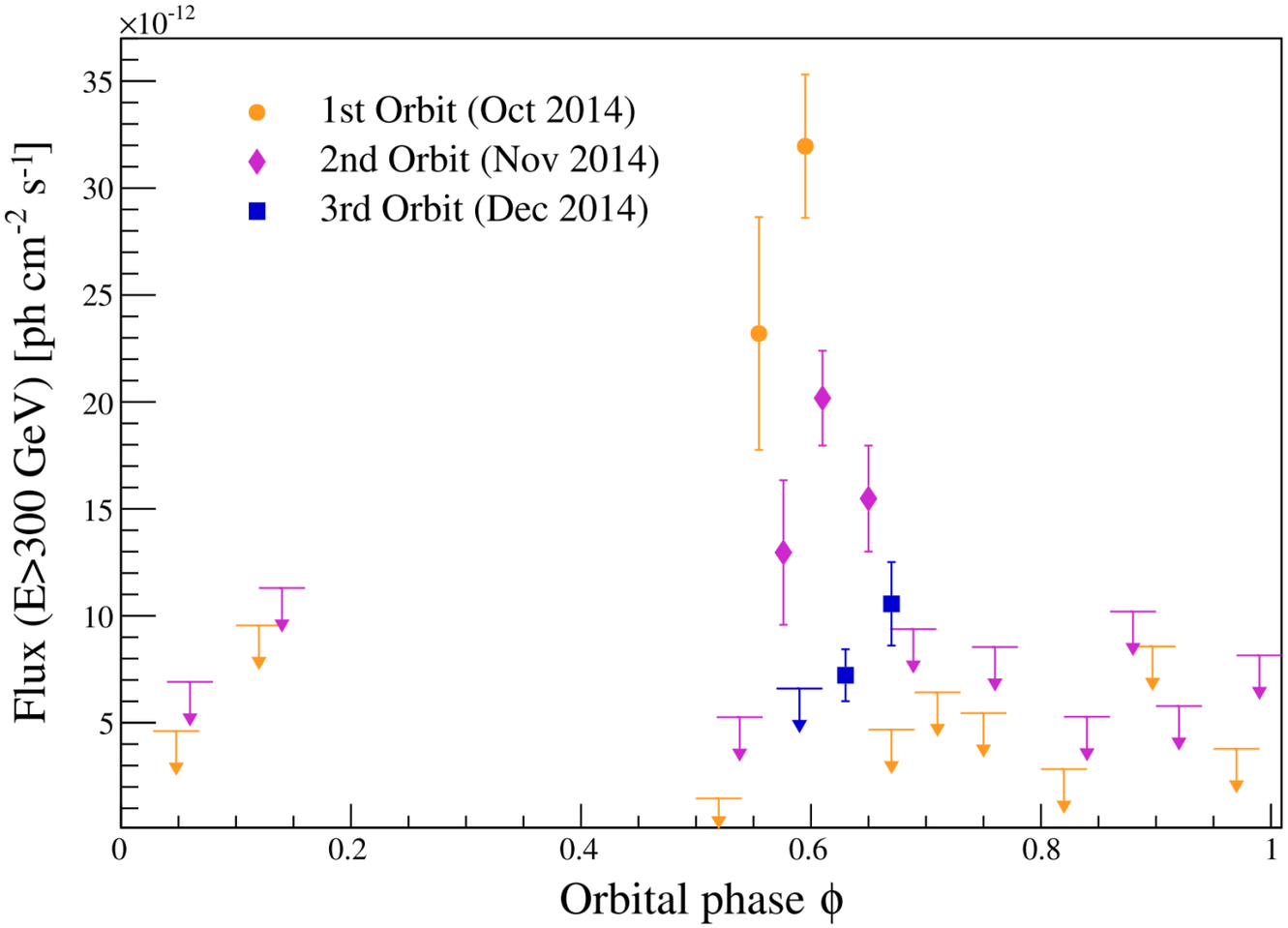
- RA: 98.24°, Dec: 5.81°
- Period: 315 days
- Mean IntFlux: 1.975×10^{-12} $TeV^{-1}cm^{-2}s^{-1}$
- High states **not observed**

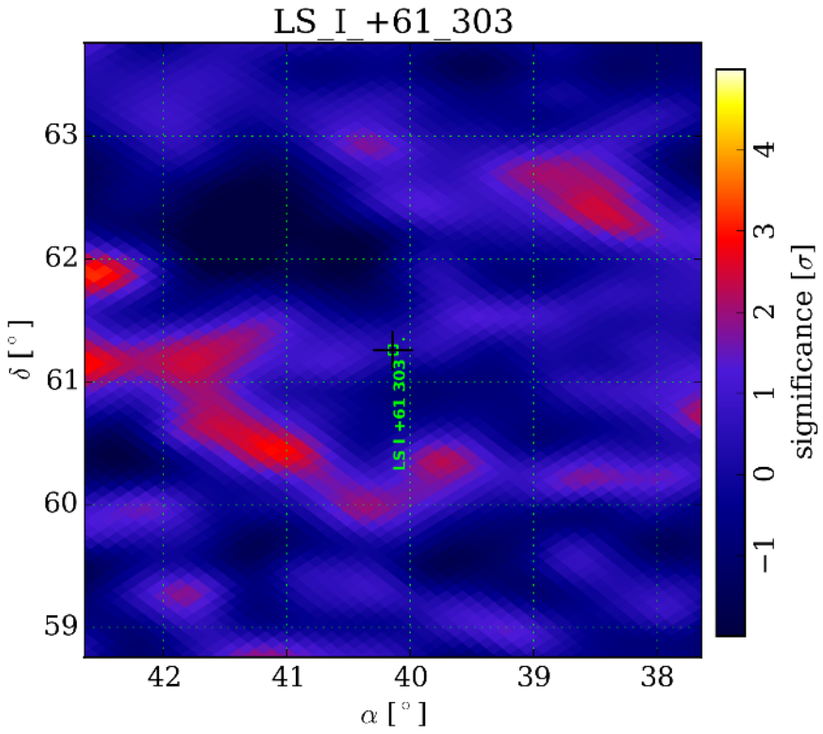




LS I +61° 303

- RA: 40.14°, Dec: 61.26°
- Period: 26.71 days
- **Intense flares** in flux

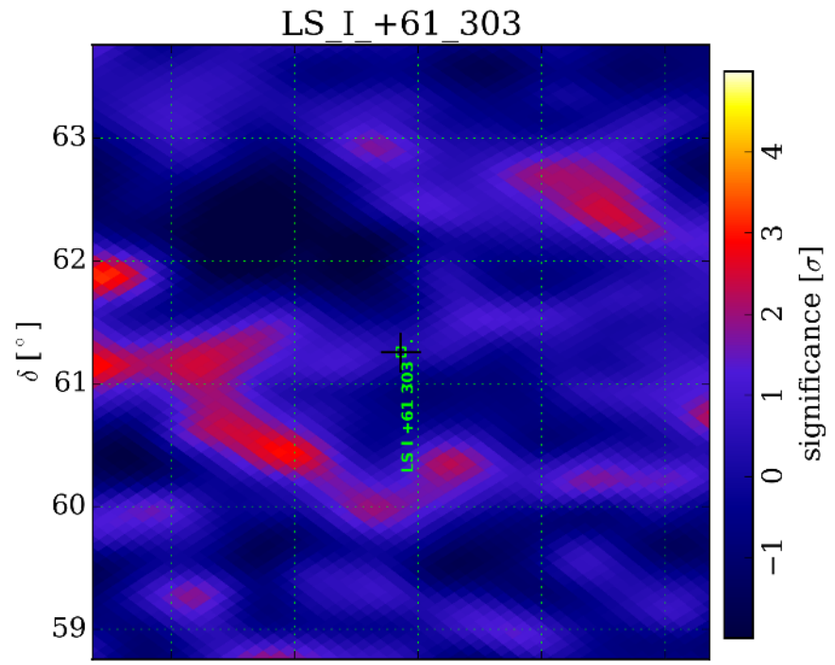


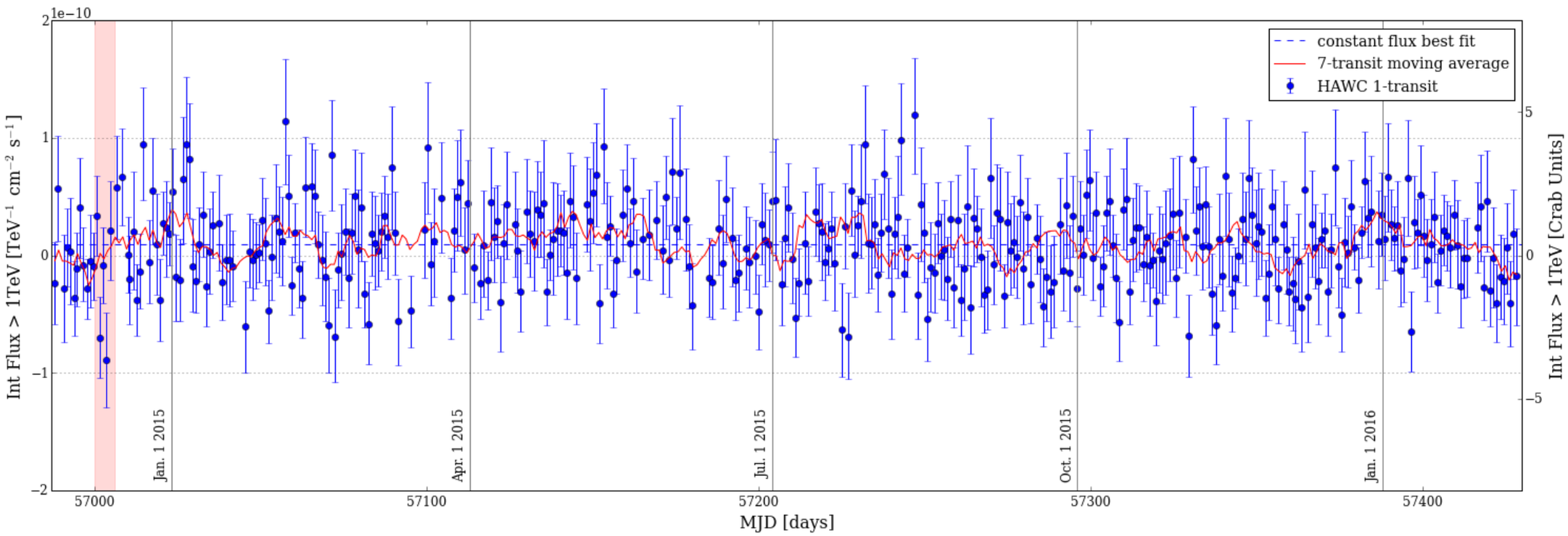


- Observations by VERITAS show **bright flares** (E>300 GeV)
- **0.5 - 0.6** phase
- Only TeV observations were during these flares

LS I +61° 303

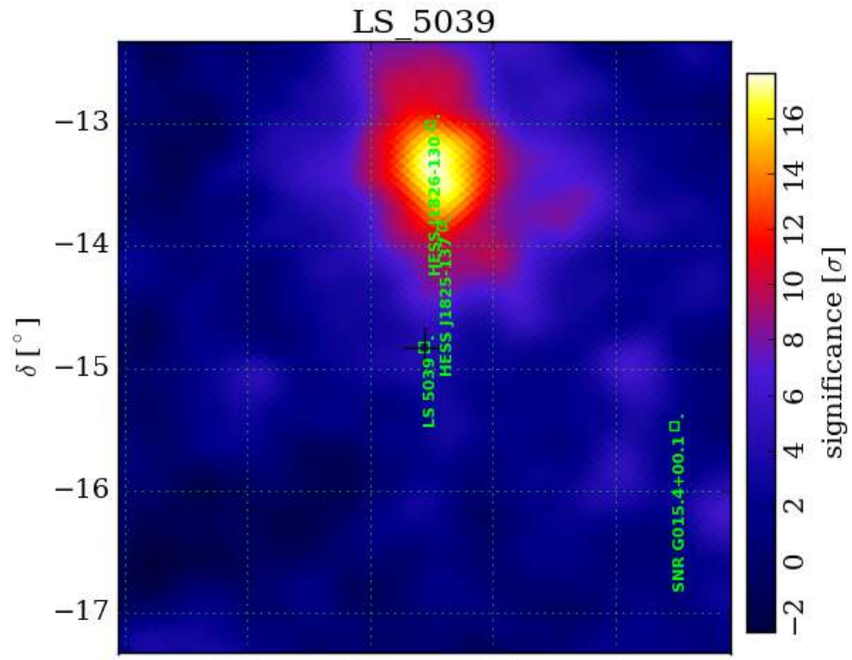
- RA: 40.14°, Dec: 61.26°
- Period: 26.71 days
- Mean IntFlux: 7.856×10^{-12} $TeV^{-1}cm^{-2}s^{-1}$
- December flare **not observed**

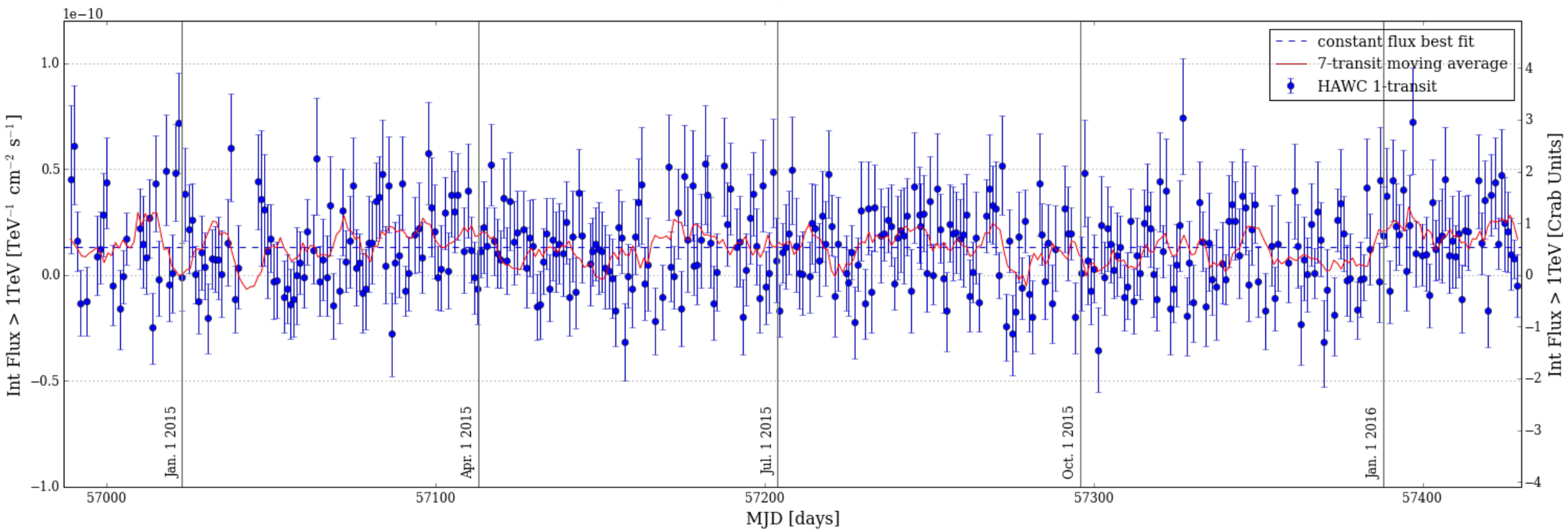




LS 5039

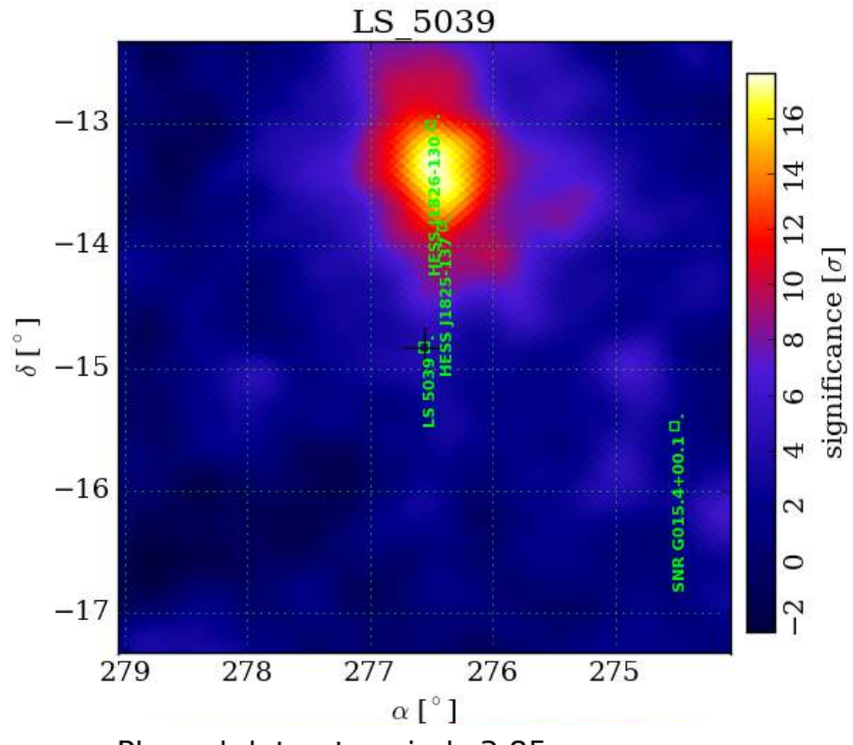
- RA: 276.56°, Dec: -14.83°
- Period: 3.907 days
- Near **2 bright TeV sources**
- Mean IntFlux: 1.391×10^{-11} $TeV^{-1}cm^{-2}s^{-1}$

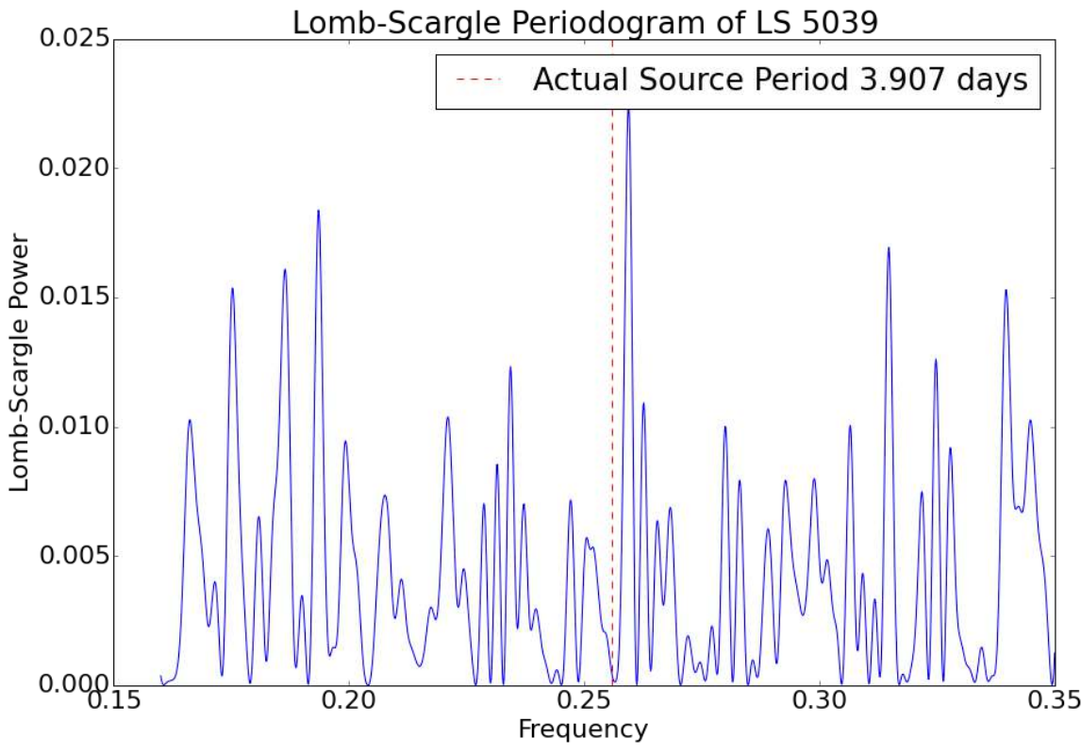


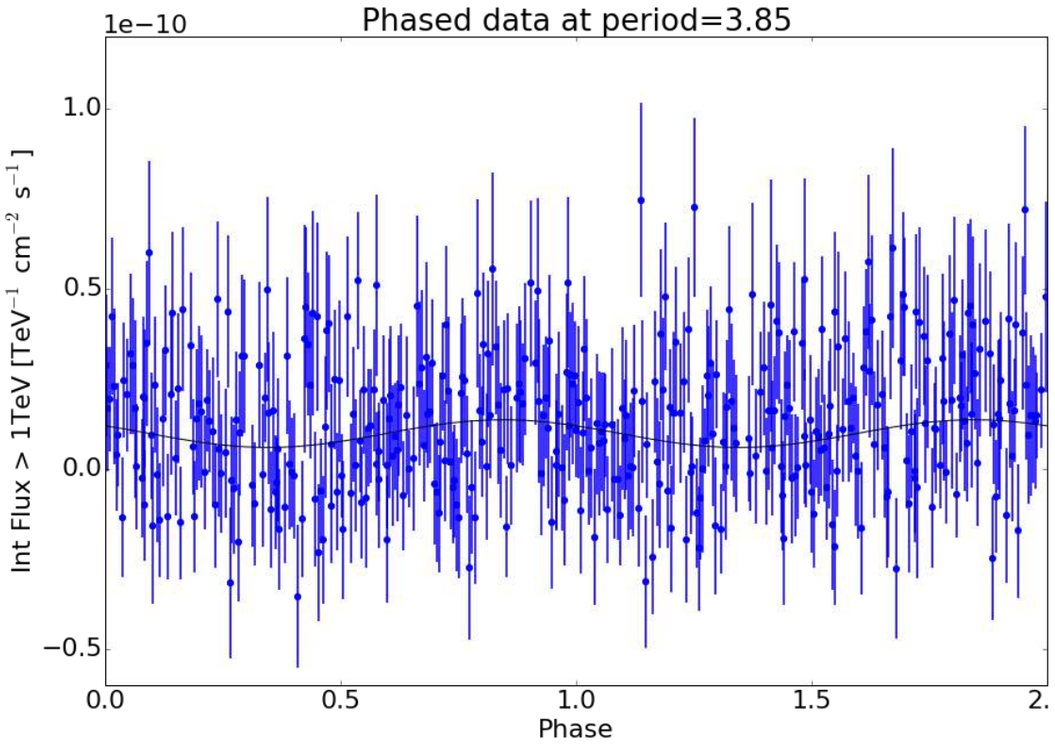


LS 5039

- Known period: 3.91 days
- Best fit period: 3.85 days
- **Probability peak is due to a background fluctuation is ~50%**







Future Work

- Better characterize background emission
- Fit nearby sources around LS 5039
- Extended source model
- Model diffuse emission from galactic plane

Acknowledgements

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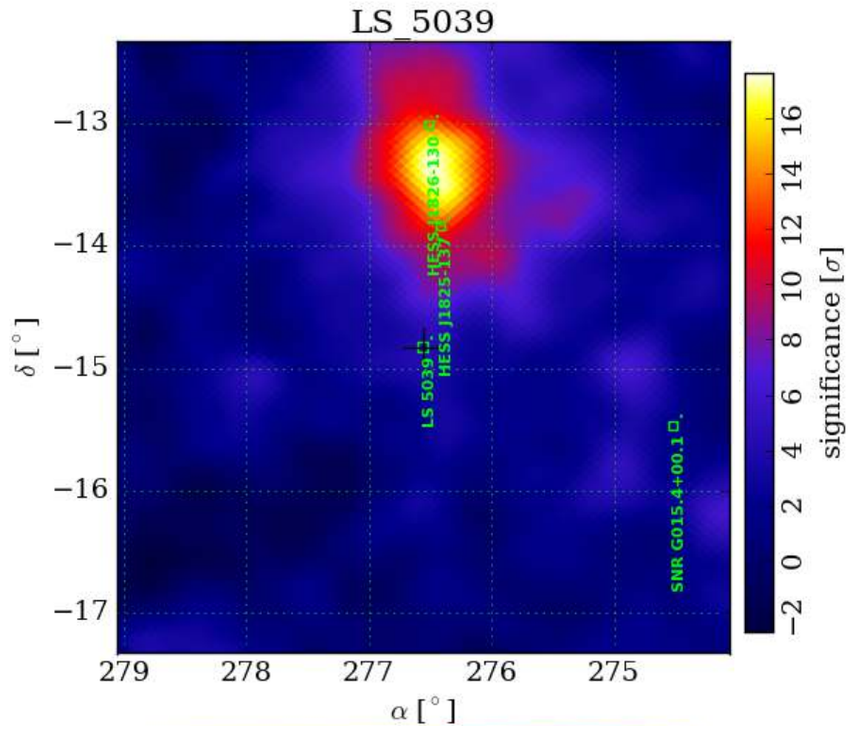
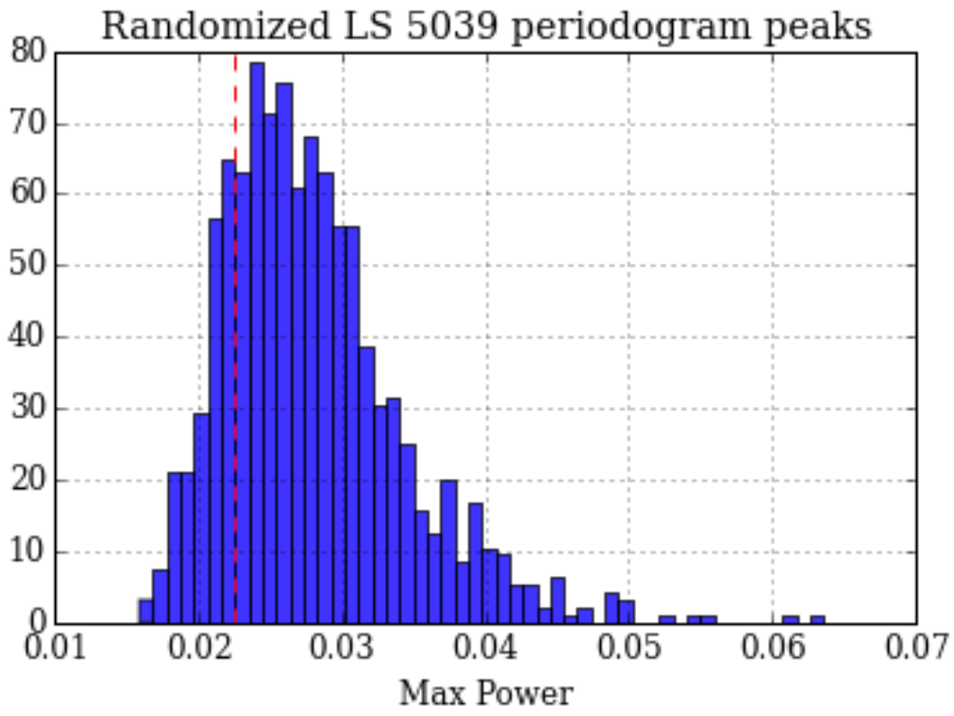
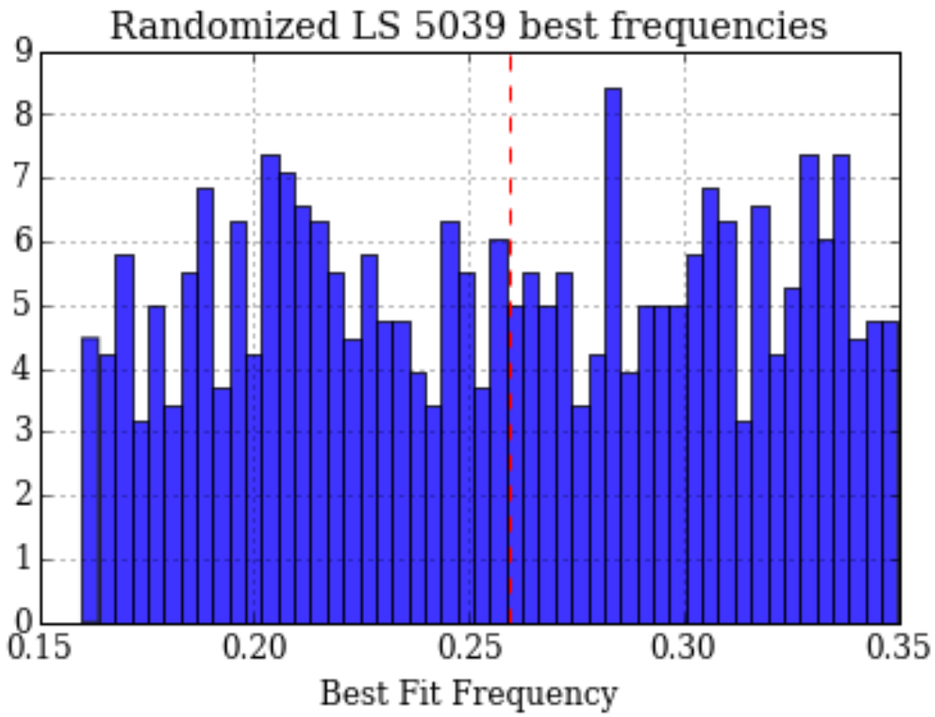
Extra

LS 5039

- Shuffle x-axis data, recalculate periodogram
  - n = 1000
- Randomized datasets produce similar peaks ~50% of the time







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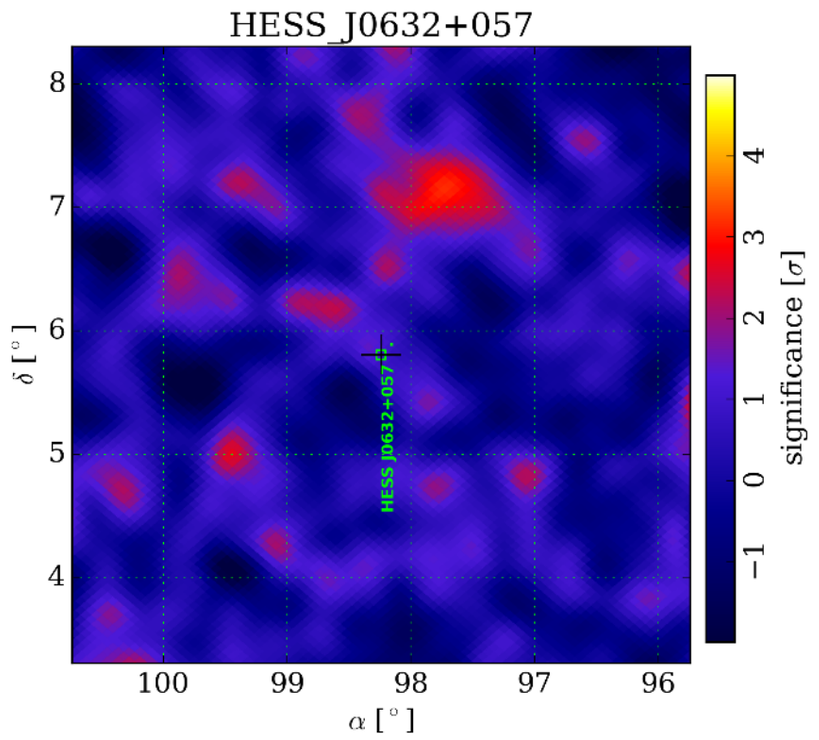

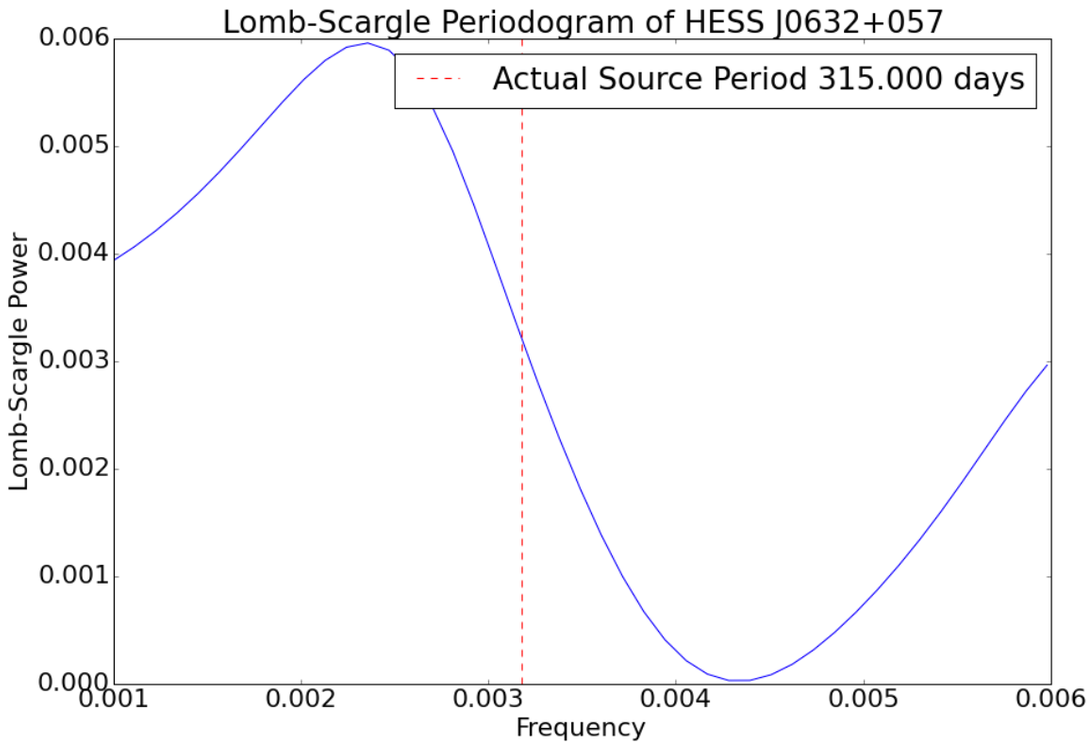

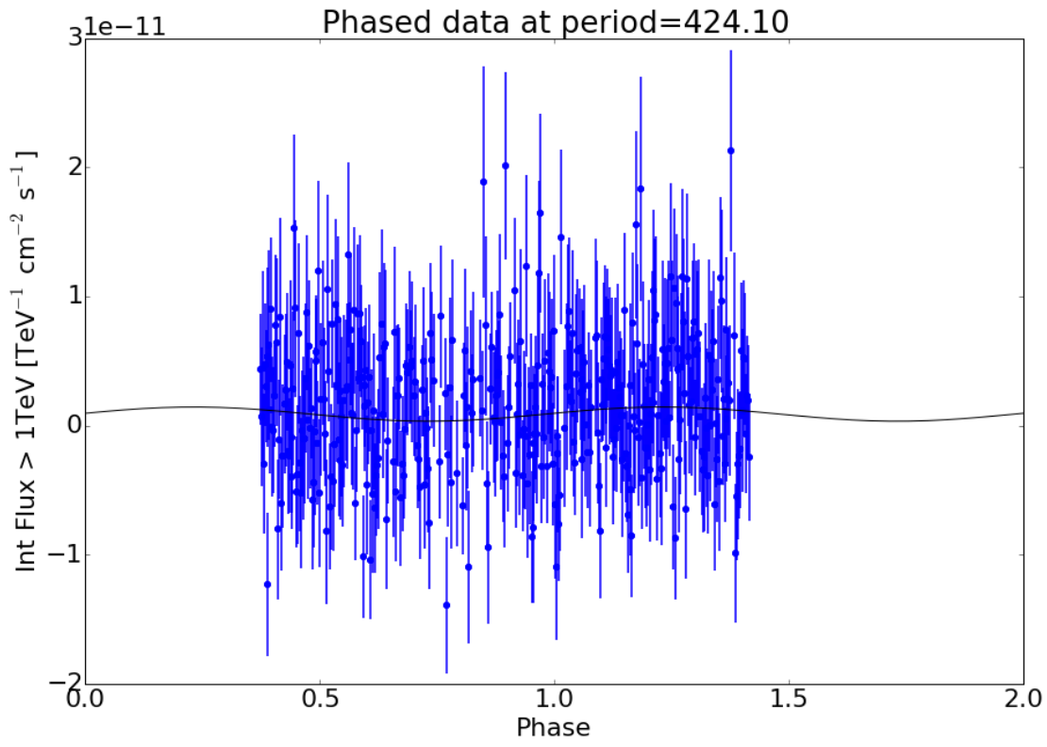

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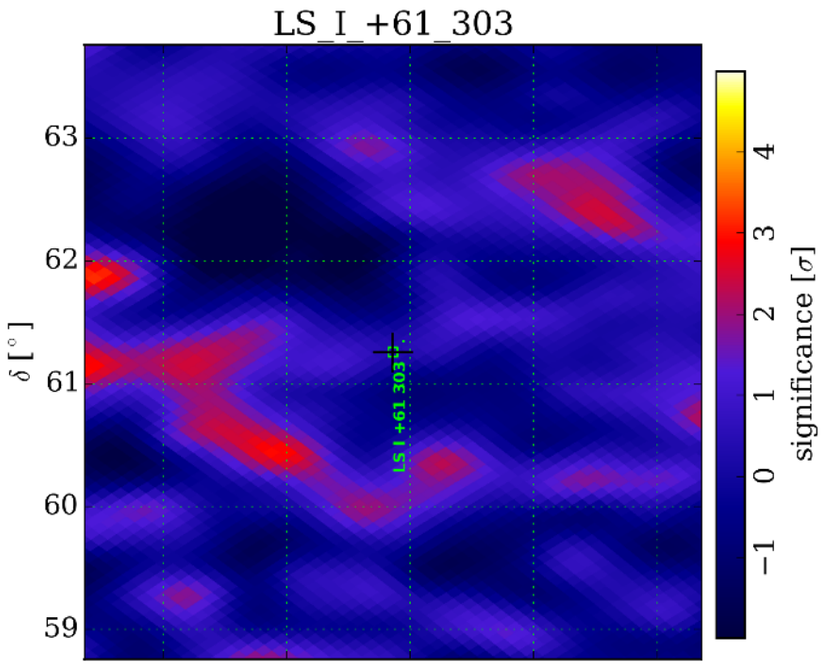
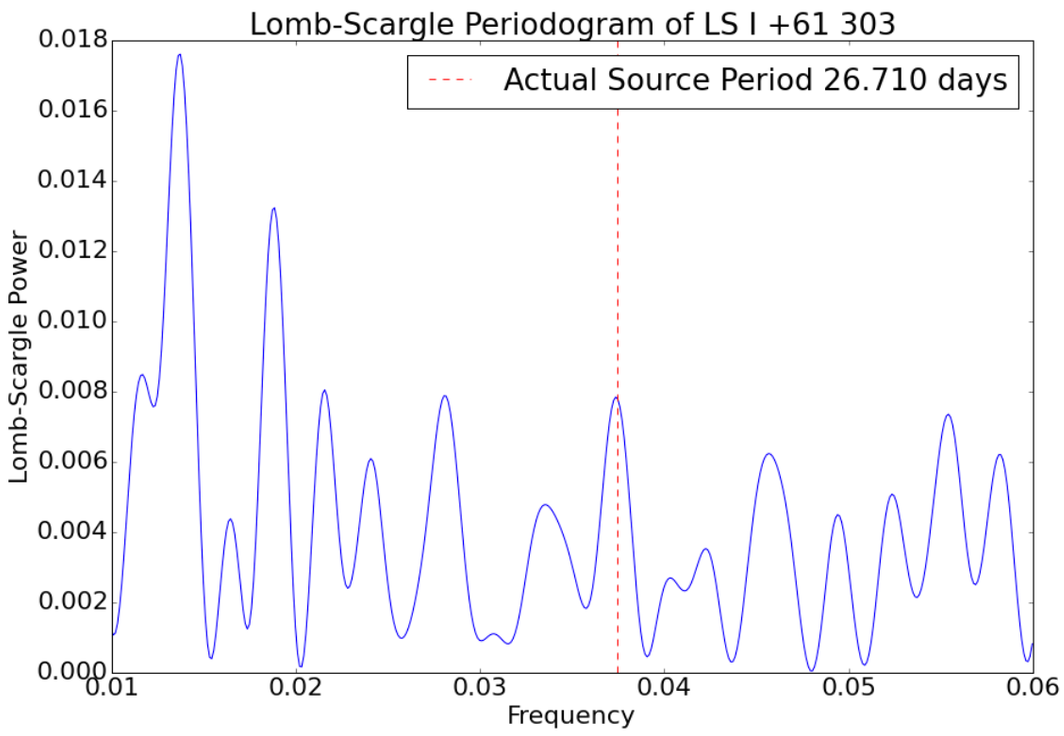
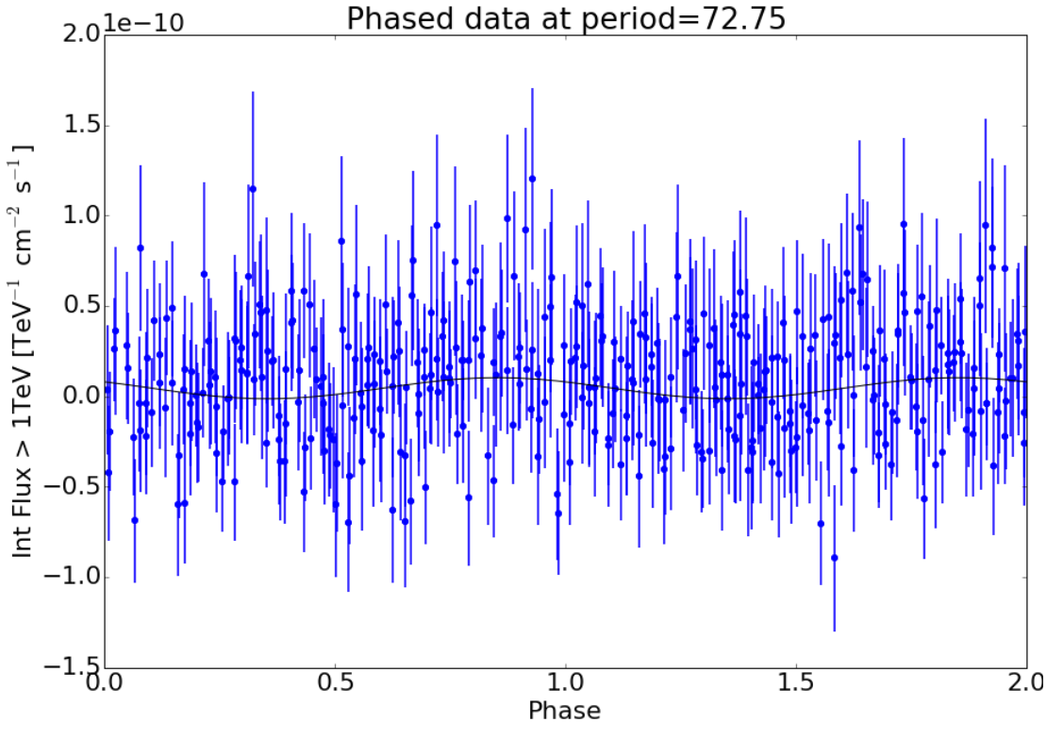
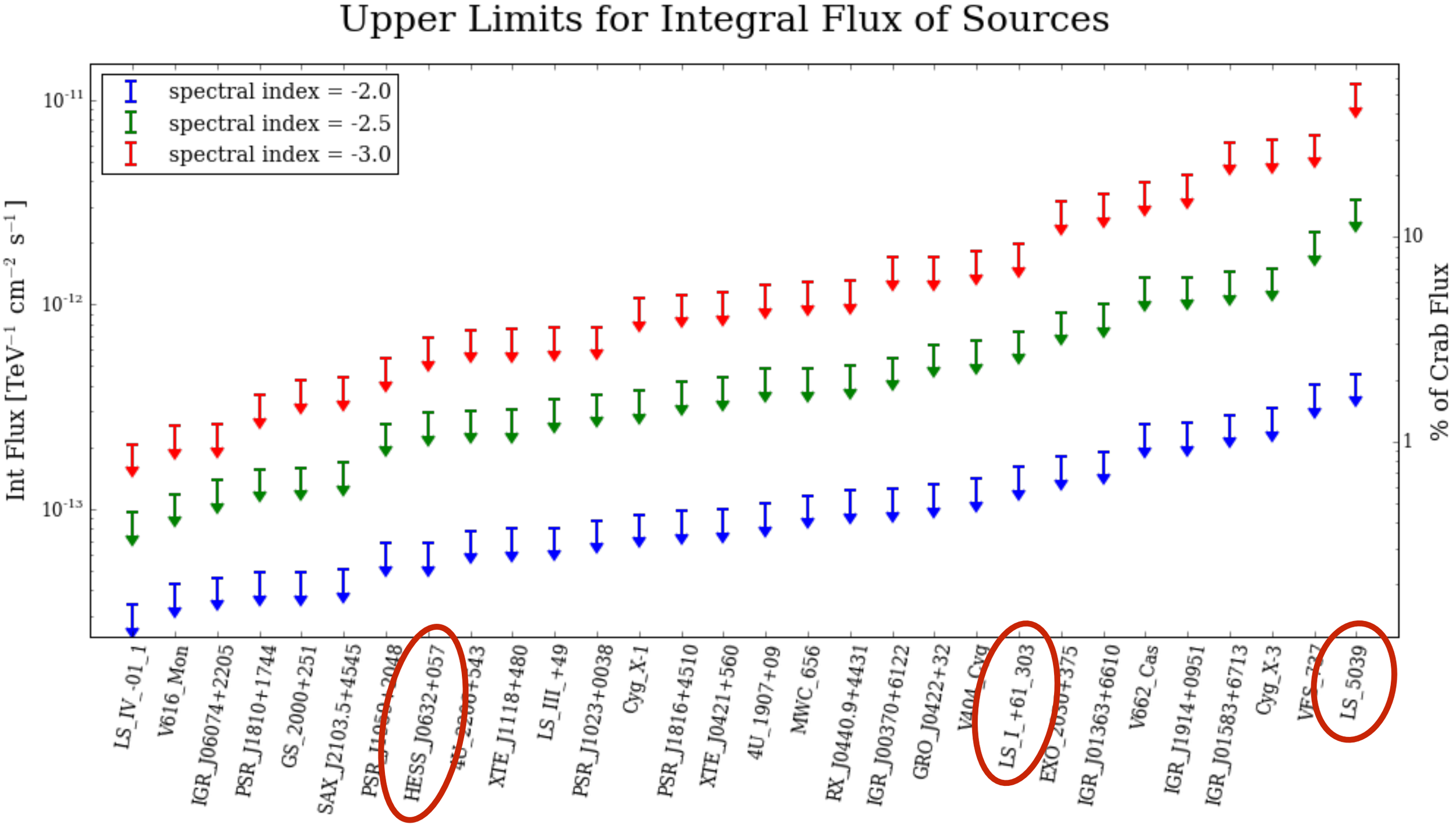




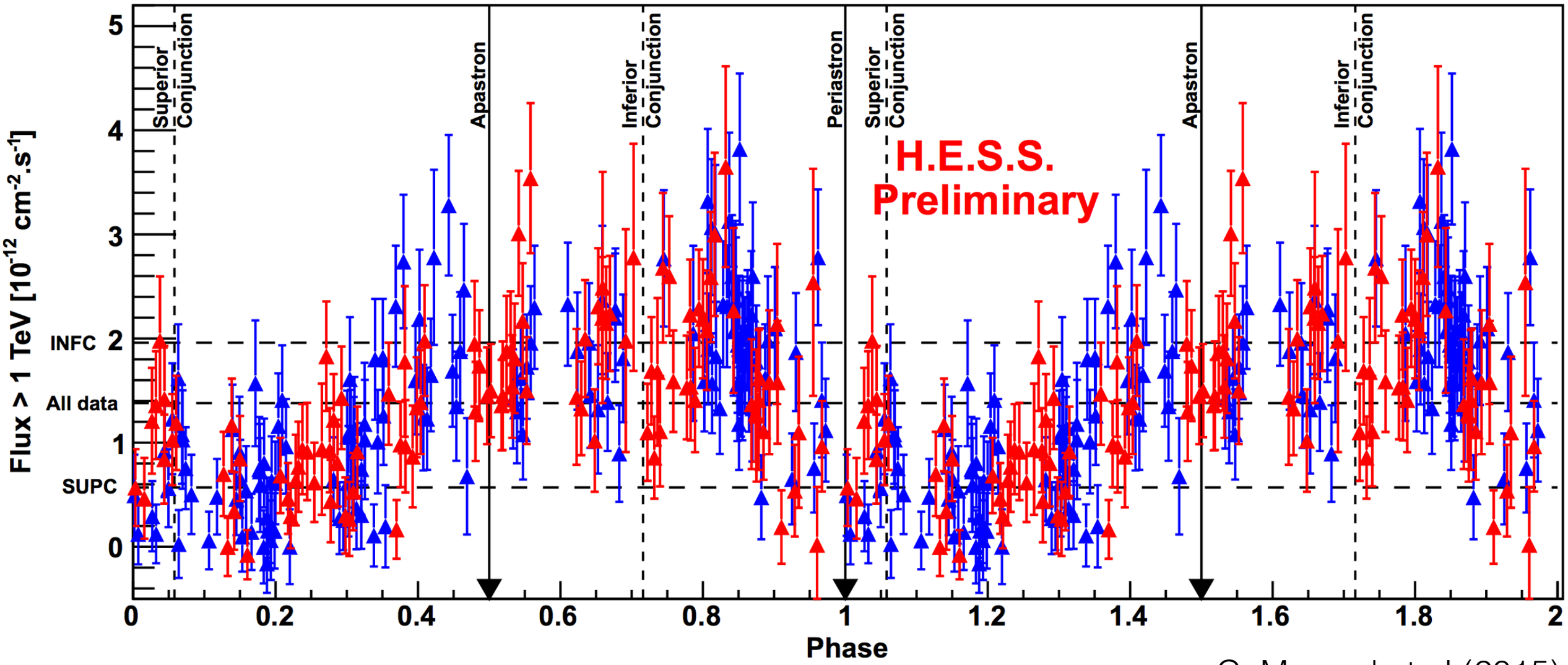


Binary Candidates



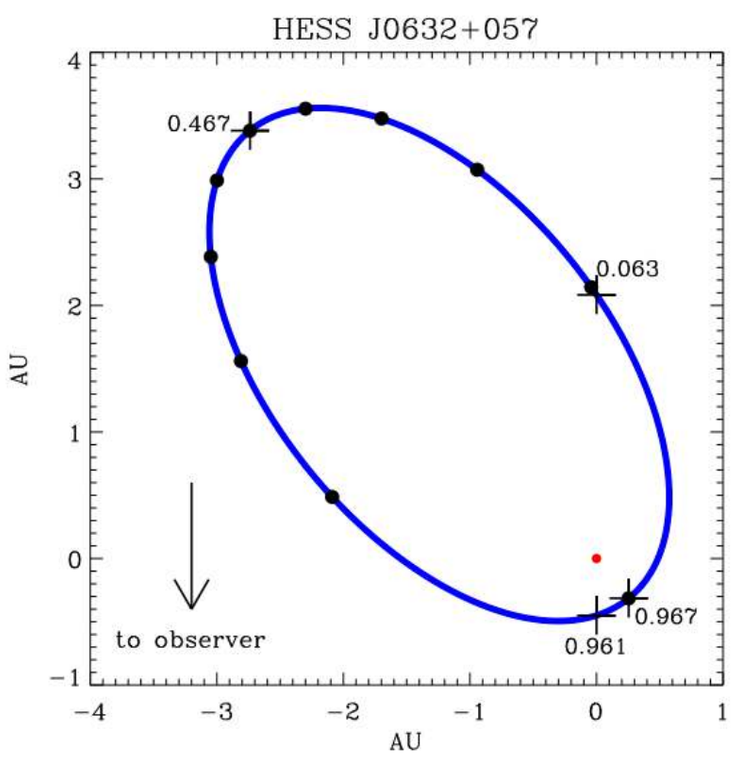
Latest LS 5039 Observation by HESS

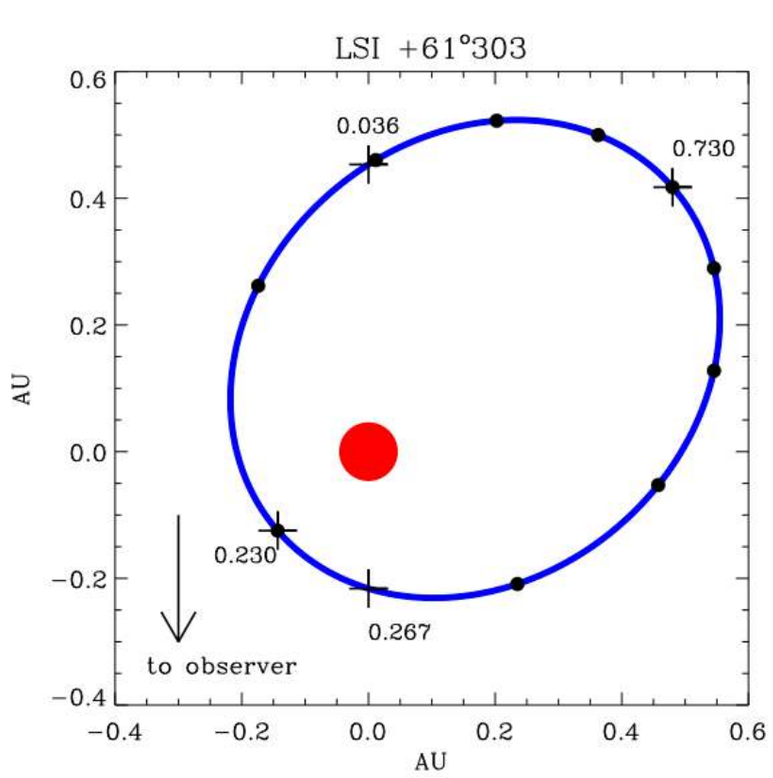
Integral Flux of LS 5039 measured by HESS

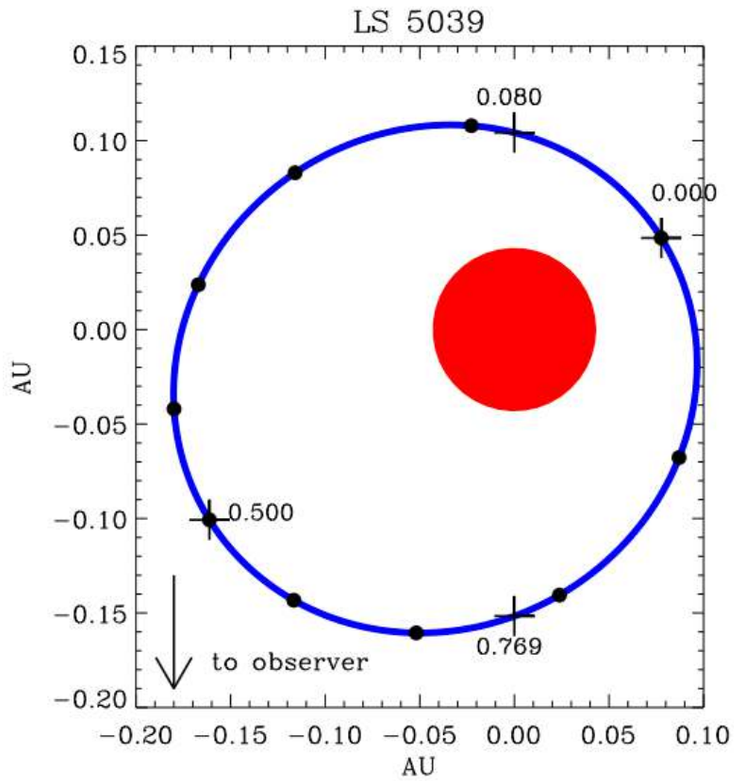


C. Maraud et al (2015)

Orbital Configurations







	HESS J0632+057◇		LS I +61°303•		LS 5039†
P_{orb} (days)	315(5)	P_{orb} (days)	26.496(3)	P_{orb} (days)	3.90603(8)
e	0.83(8)	e	0.54(3)	e	0.35(3)
ω (°)	129(17)	ω (°)	41(6)	ω (°)	212(5)
i (°)	47–80	i (°)	10–60	i (°)	13–64
d (kpc)	1.6(2)	d (kpc)	2.0(2)	d (kpc)	2.9(8)
spectral type	B0Vpe	spectral type	B0Ve	spectral type	O6.5V((f))
$M_\star$ ($M_\odot$)	16	$M_\star$ ($M_\odot$)	12	$M_\star$ ($M_\odot$)	23
$R_\star$ ($R_\odot$)	8	$R_\star$ ($R_\odot$)	10	$R_\star$ ($R_\odot$)	9.3
$T_\star$ (K)	30000	$T_\star$ (K)	22500	$T_\star$ (K)	39000

◇ Aragona et al. (2010); Casares et al. (2012); Bordas & Maier (2012)

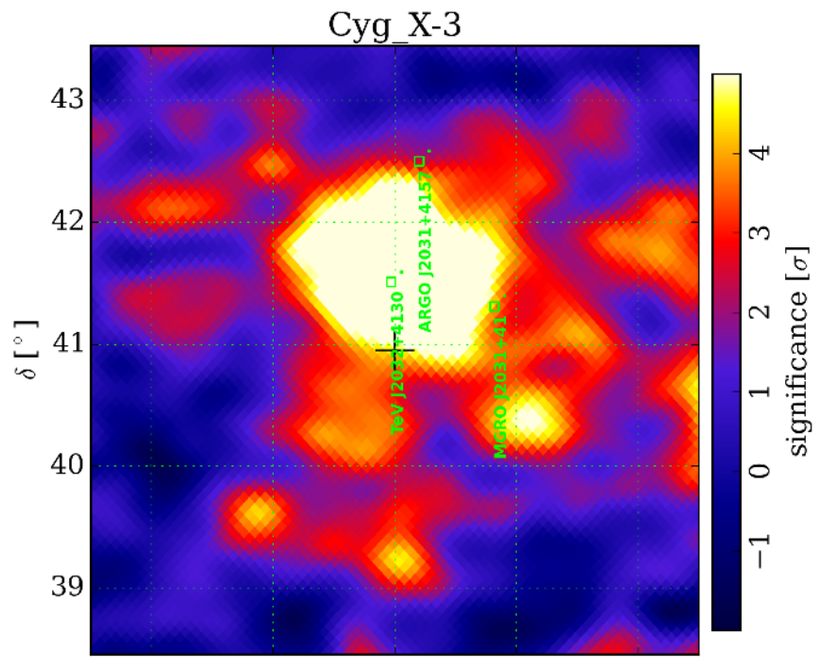
• Howarth (1983); Frail & Hjellming (1991); Martí & Paredes (1995); Gregory (2002); Aragona et al. (2009)

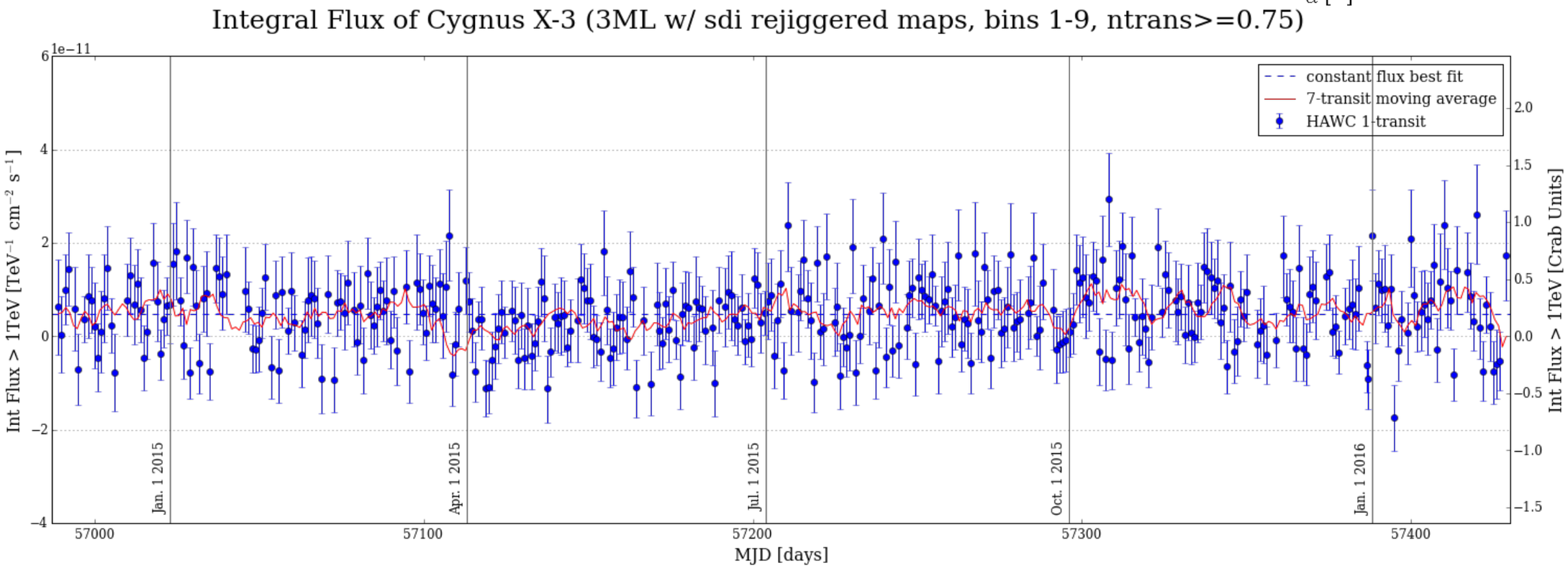
† McSwain et al. (2004); Casares et al. (2005, 2011)

G. Dubus (2013)

Cygnus X-3

- RA: 299.59°, Dec: 35.20°
- Period: 0.2 days
- Mean IntFlux: 5.022×10^{-12} TeV^{-1}cm^{-2}s^{-1}





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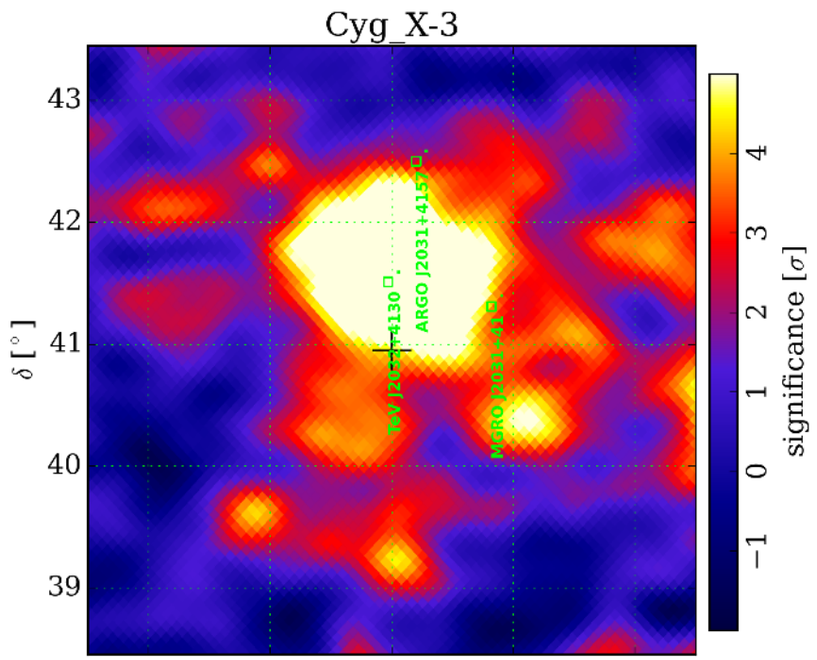
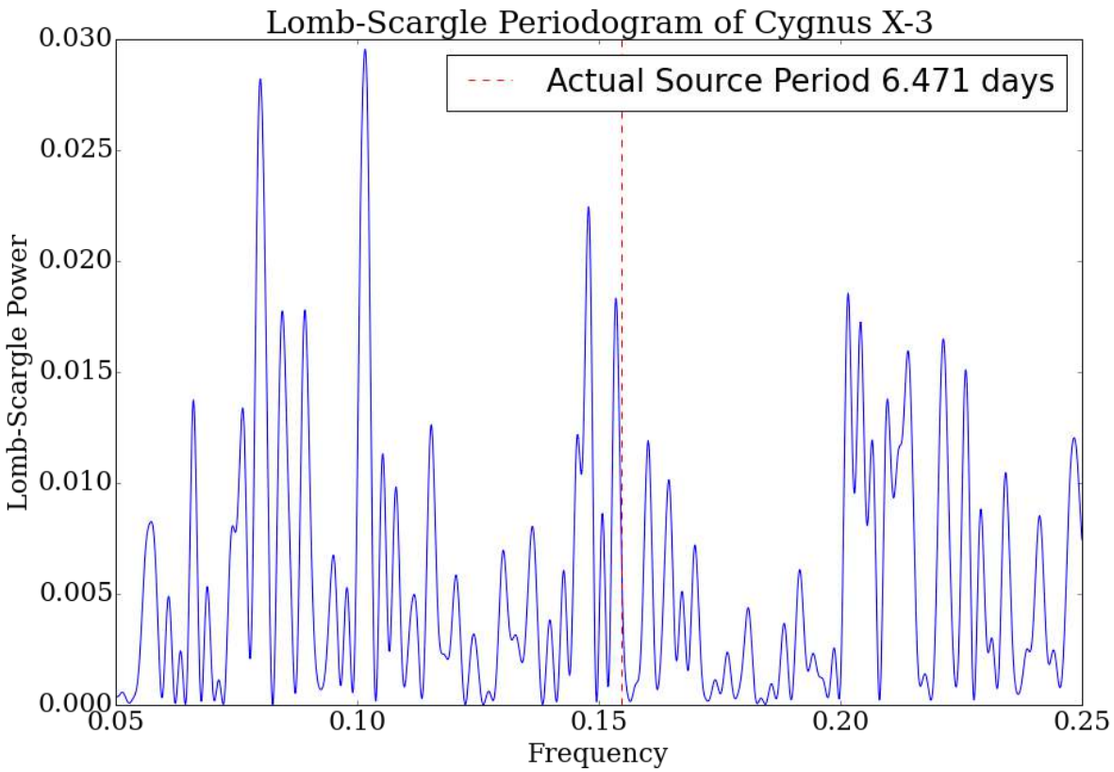
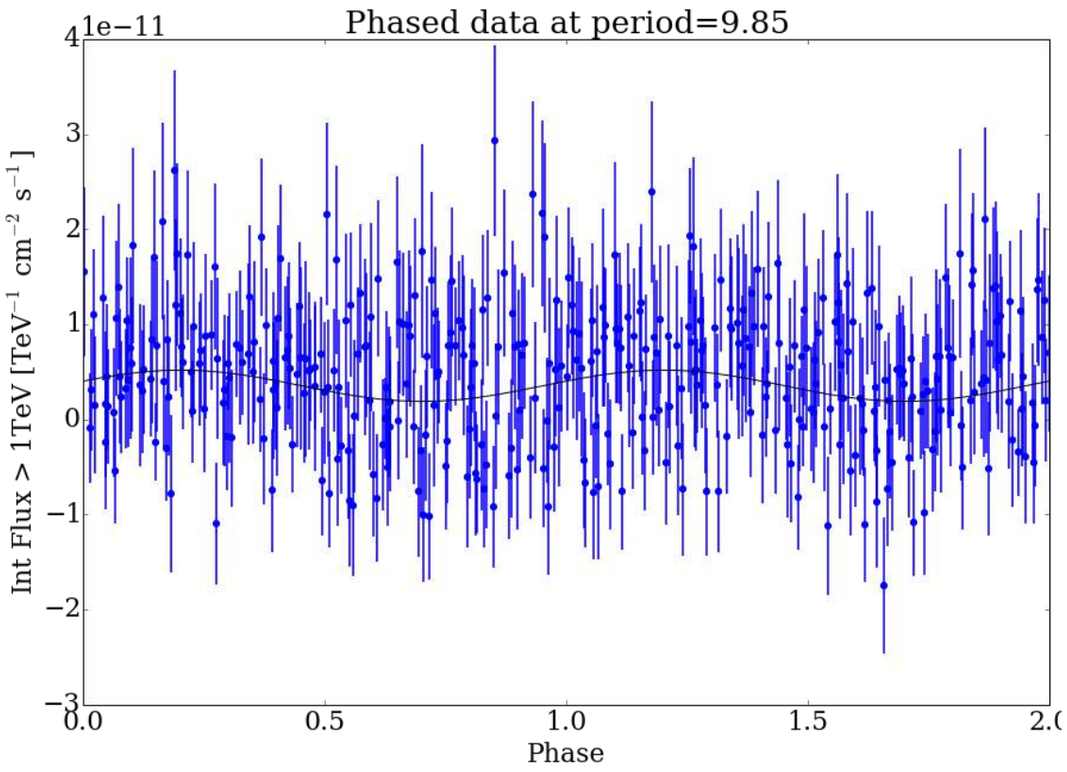
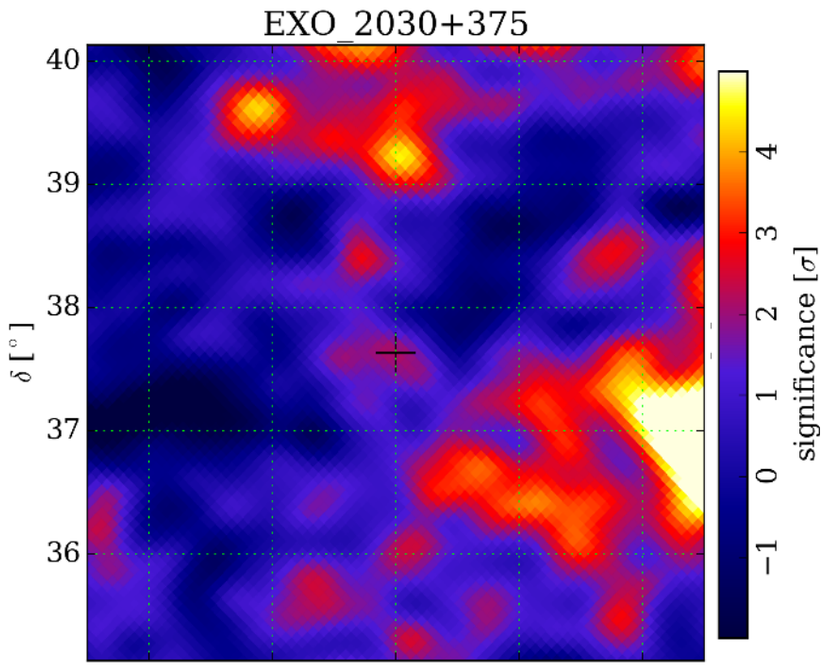


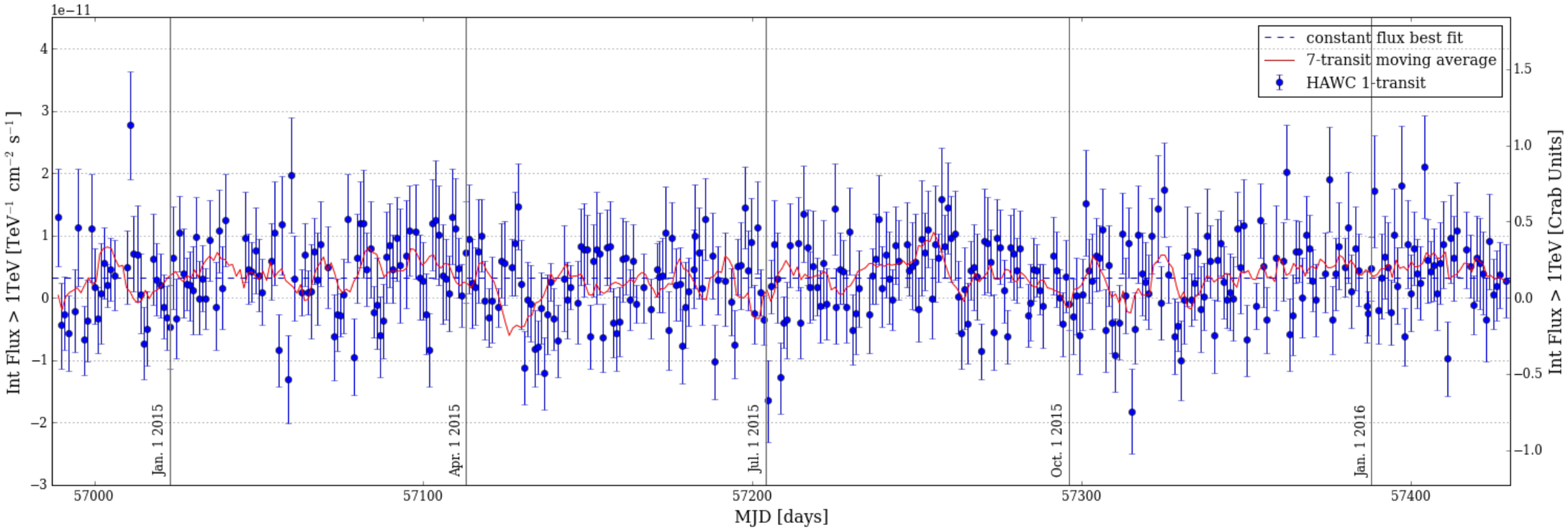




EXO 2030+375

- RA: 308.0°, Dec: 37.6°
- Period: 46.021 days
- Mean IntFlux: 3.919×10^{-12} $TeV^{-1}cm^{-2}s^{-1}$





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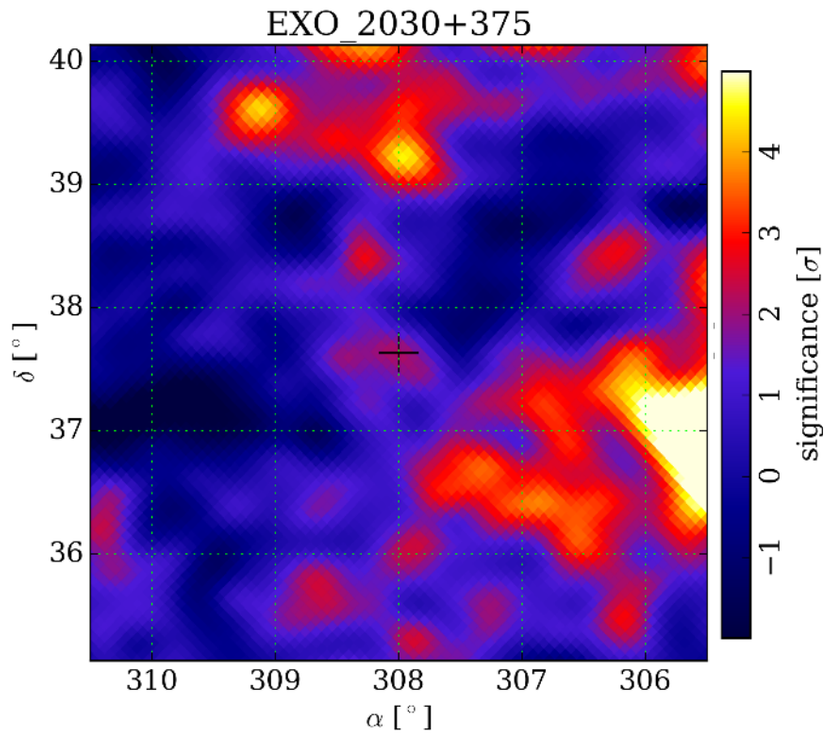
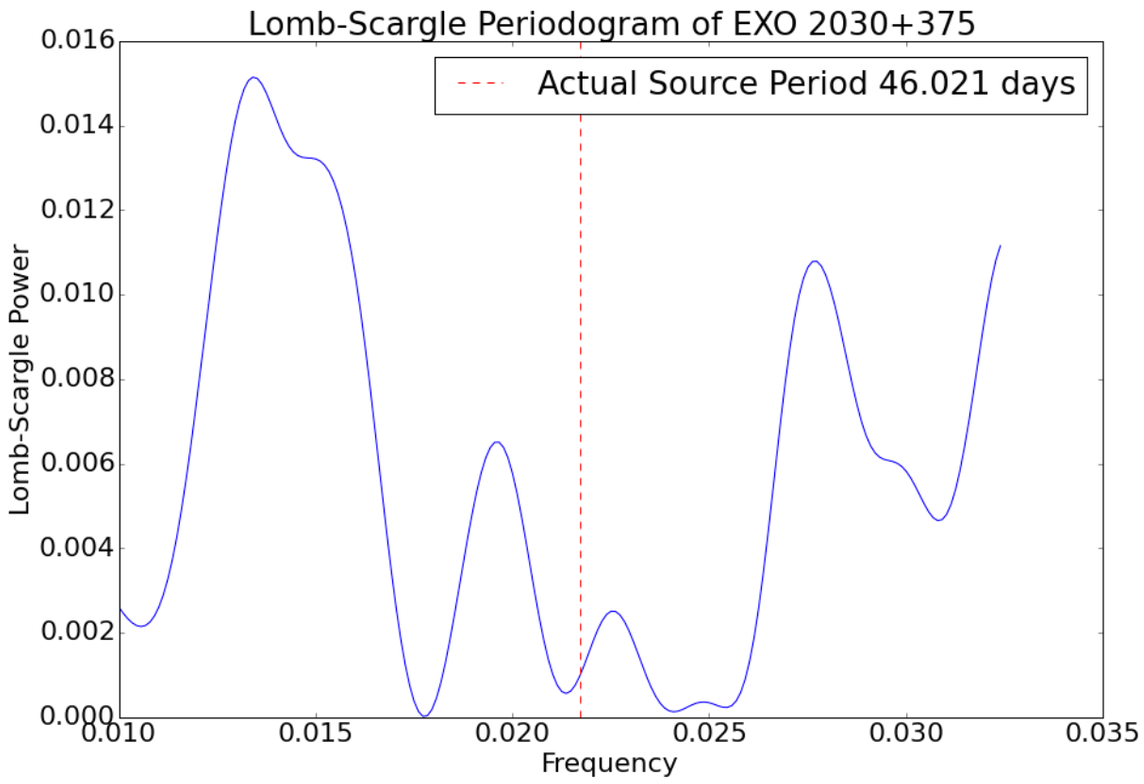
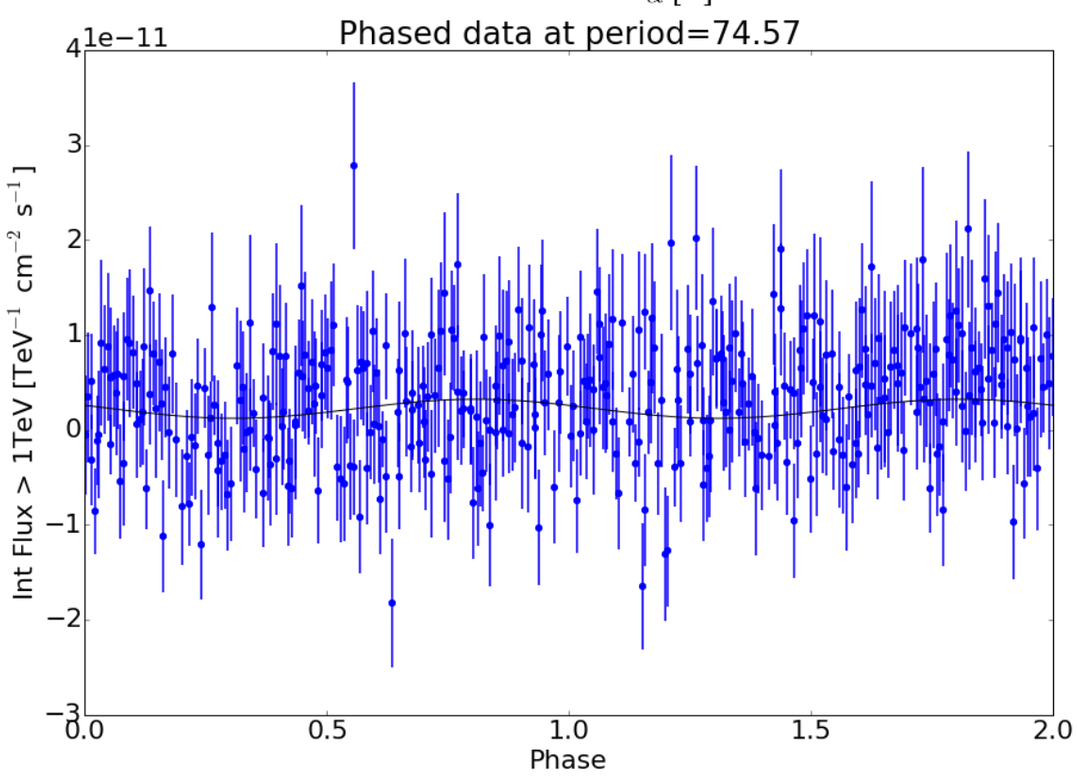
- Period: 46.021 days
- Mean IntFlux: 3.919×10^{-12} TeV^{-1}cm^{-2}s^{-1}

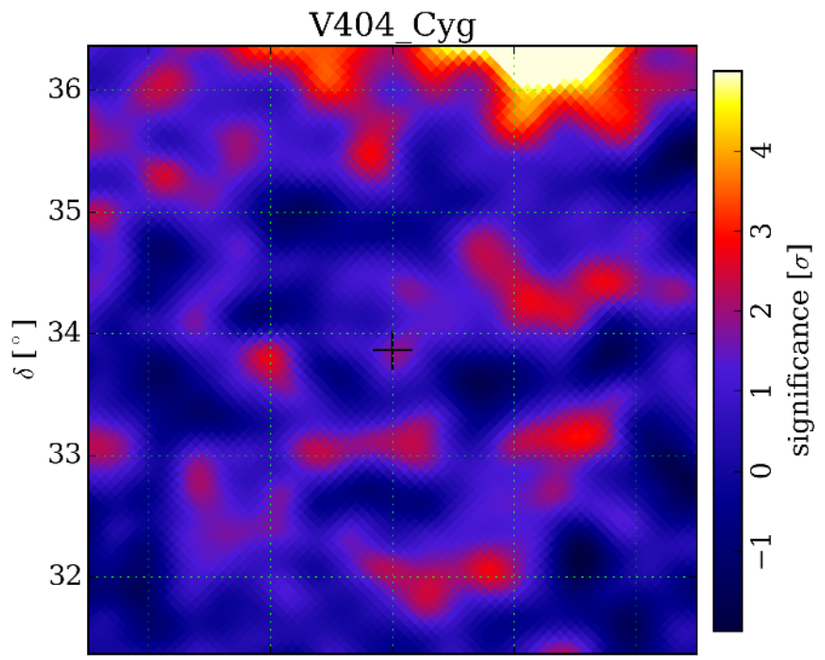


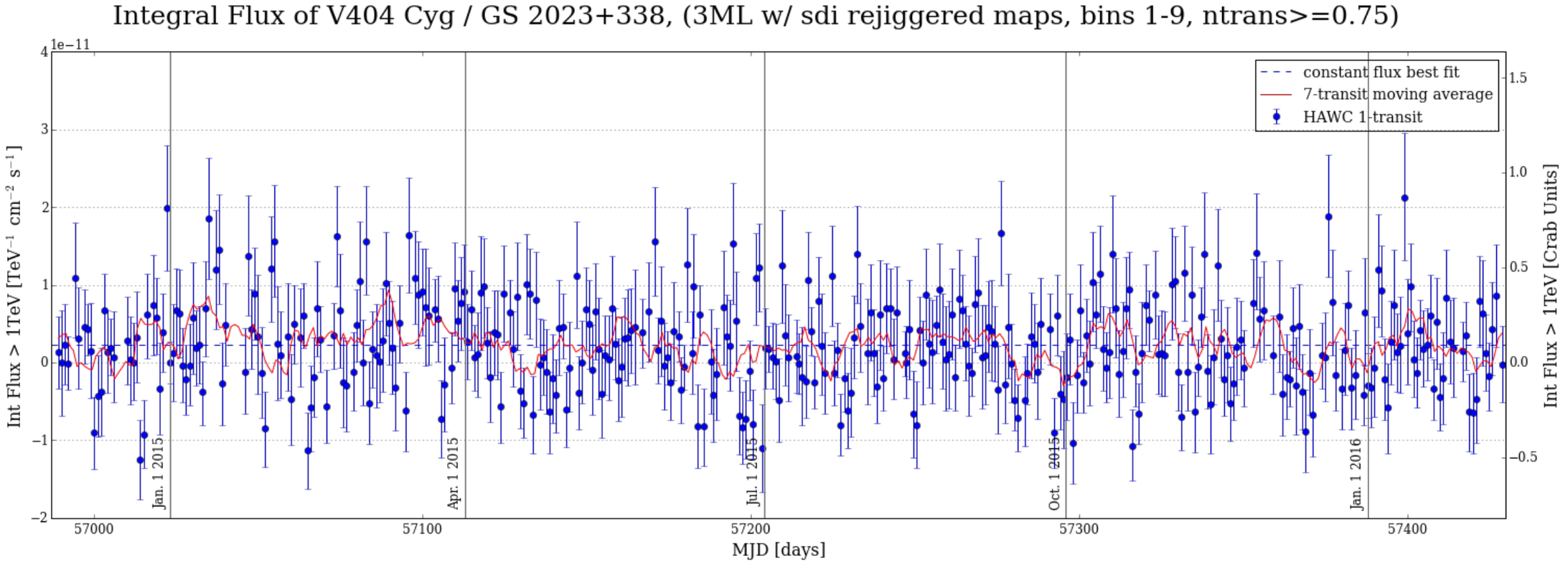


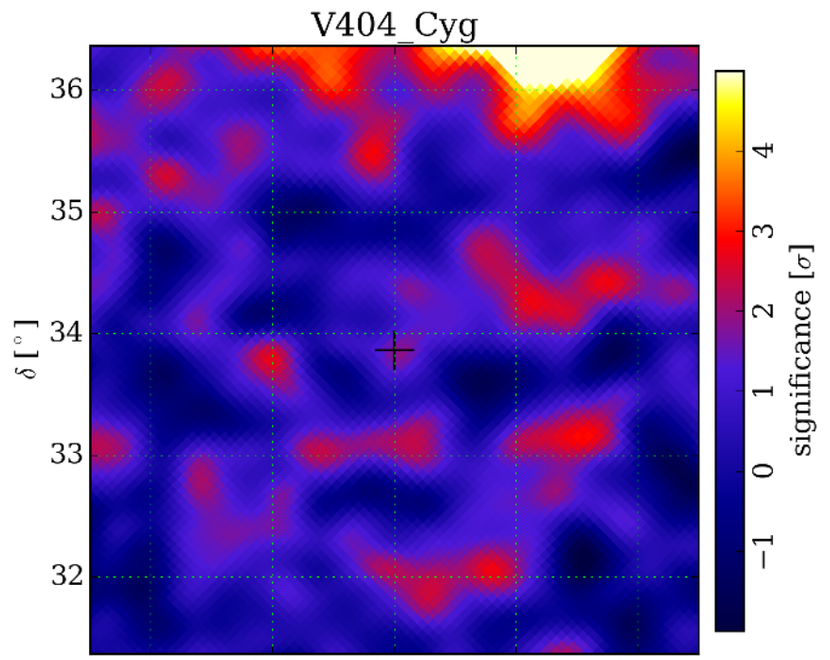
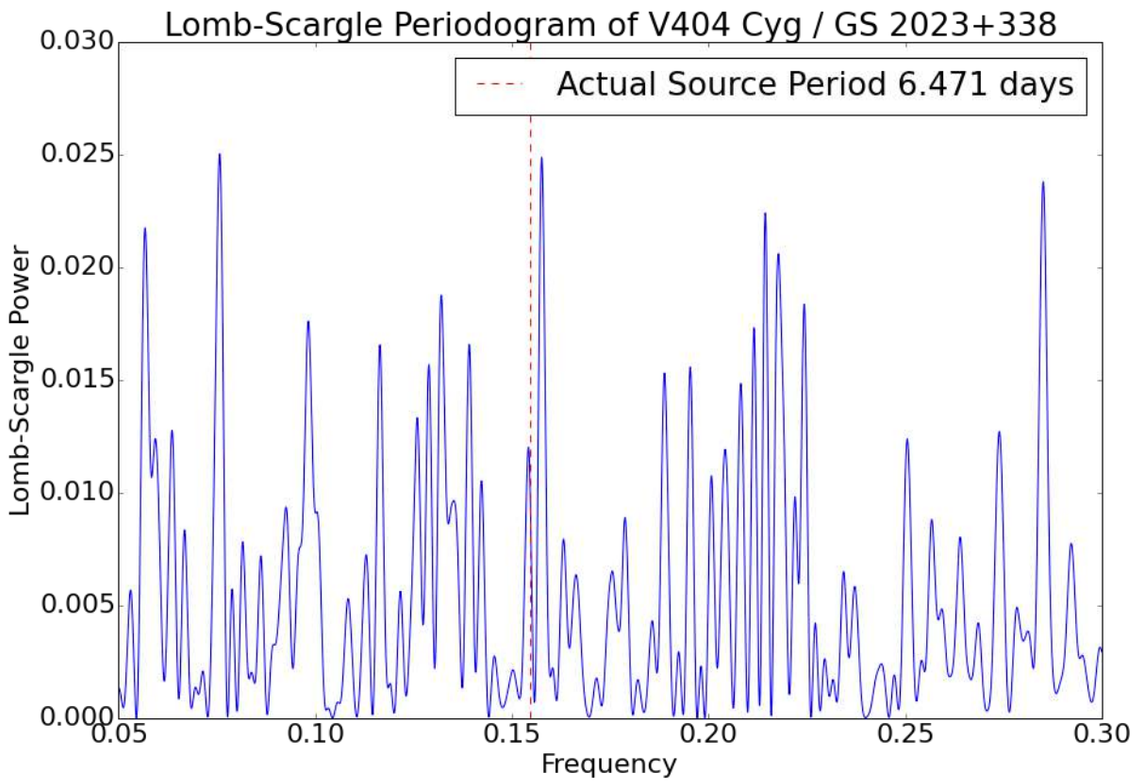
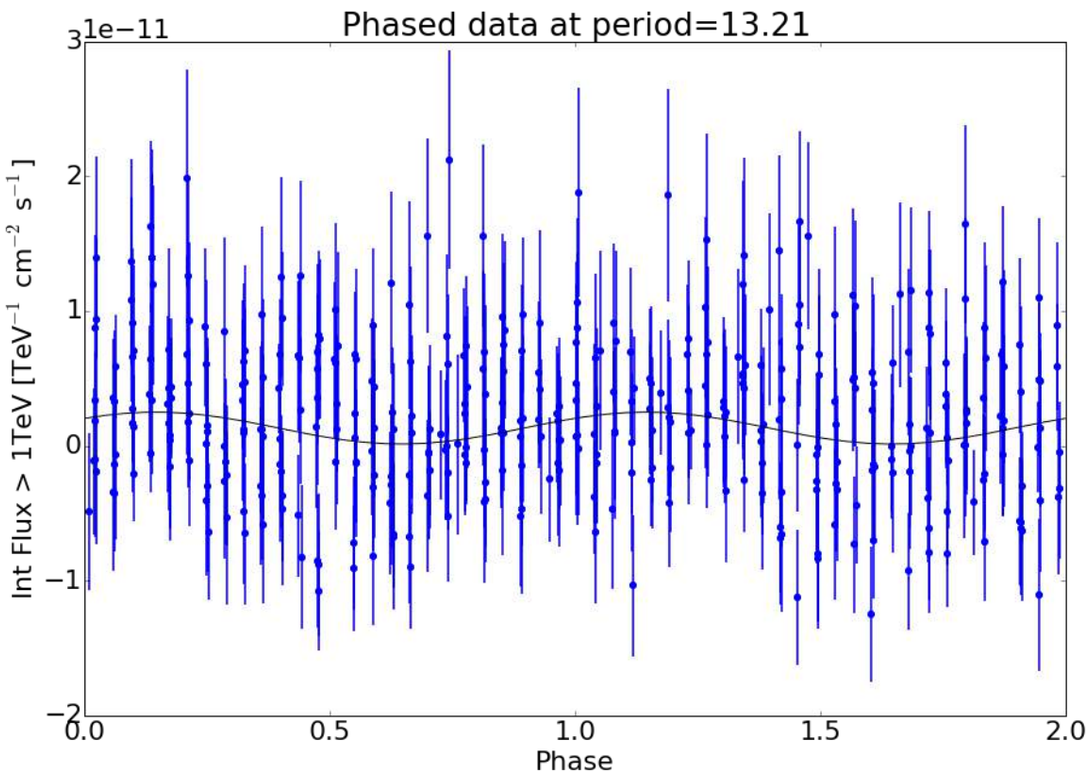


V404 Cygnus

- RA: 306.0°, Dec: 33.9°
- Period: 6.471 days
- Mean IntFlux: 7.589×10^{-12} TeV^{-1}cm^{-2}s^{-1}





V404 Cygnus

- RA: 306.0°, Dec: 33.9°
- Period: 6.471 days
- Mean IntFlux: 7.589×10^{-12} TeV^{-1}cm^{-2}s^{-1}