Very High-energy Gamma-ray Emission from LS I +61° 303 Binary

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LS I +61° 303

- LS I +61 303 is a Galactic HMXB consisting of a massive B0 Ve star and a compact object
- Located at a distance of 2.0 kpc
- Compact object can either be a neutron star (NS) or a stellar-mass black hole (BH)
- Companion star has a circumstellar disk
- Exhibits both persistent and orbitally modulated emission from radio to VHE gamma–ray
- Orbital period of 26.496 ± 0.0028 days
- A long-term (super-orbital) modulation has been found (1667 ± 8 days) in radio

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FAST Detected A Transient Periodic Signal In The Direction of LS I +61 303

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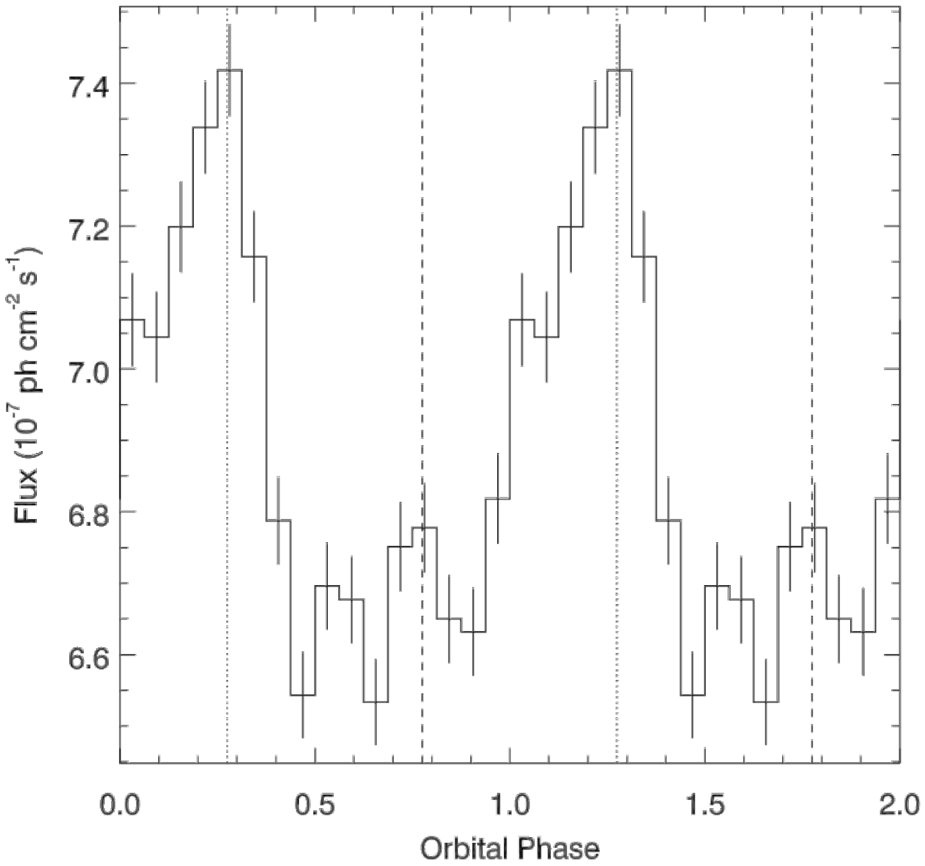
on 1 Jan 2021; 00:00 UT
Credential Certification: Shan-Shan Weng (wengss@ihep.ac.cn)

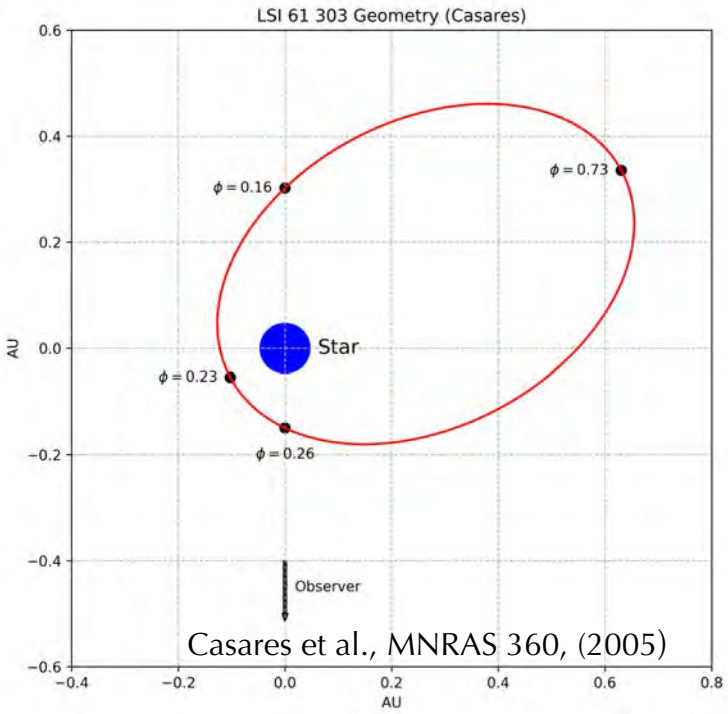
Multiwavelength Observation of LS I +61° 303

- Outbursts peak roughly at the orbital phase of ~ 0.5 – 0.8 for radio, TeV and X-ray
- Possible correlation between the X-ray light-curve and the TeV light-curve
- HE lightcurve is roughly anti-correlated with respect to the VHE, X-ray, and radio peaks
- Detected at VHE (TeV energies) with the MAGIC and with VERITAS
- A long-term superorbital modulation reported in all wavelength (1610 days by MAGIC).
- A second observed period of 26.93 days is a beat frequency between the orbital period (26.5 days) and the super-orbital period (1667 days).

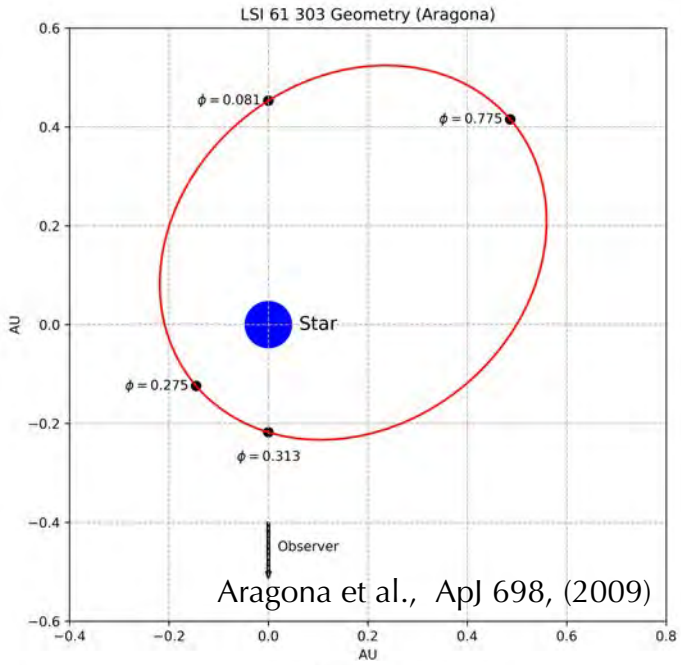


GeV lightcurve using 8 years of Fermi-LAT data from Xing et. al, ApJ 851, 2017. Two cycles are shown.

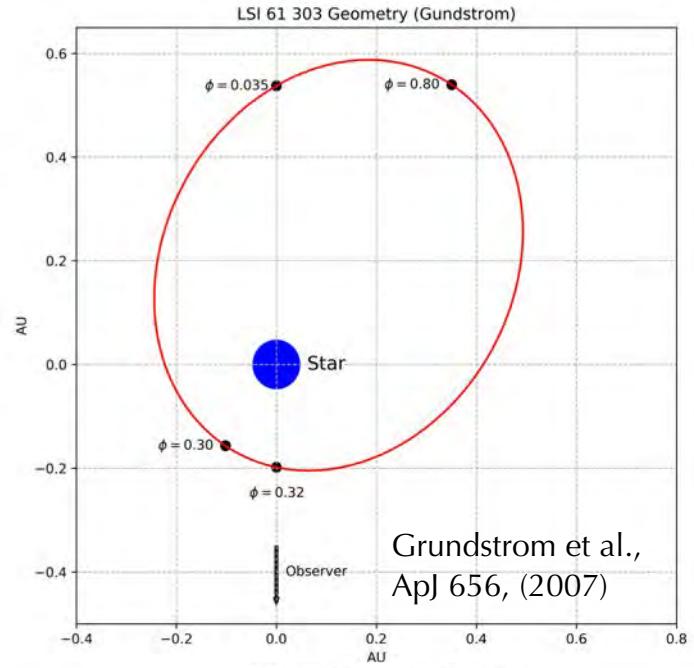
LSI +61° 303 Geometry



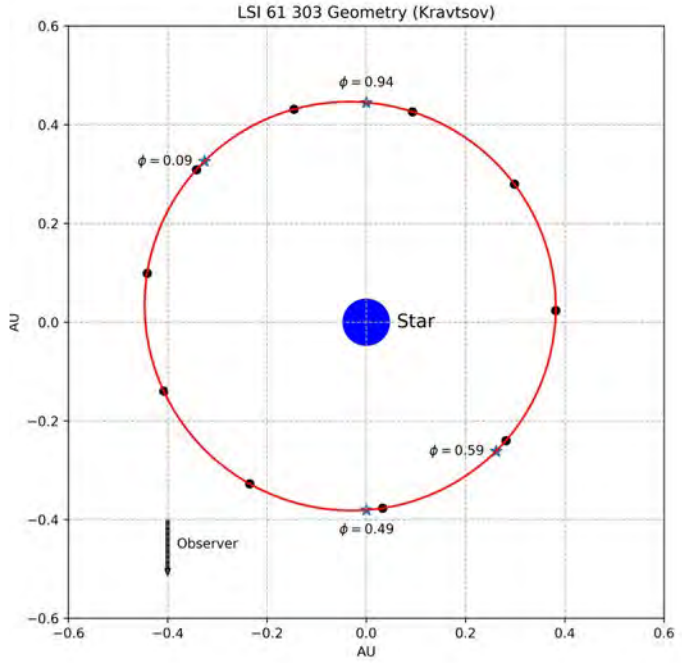
Casares et al., MNRAS 360, (2005)

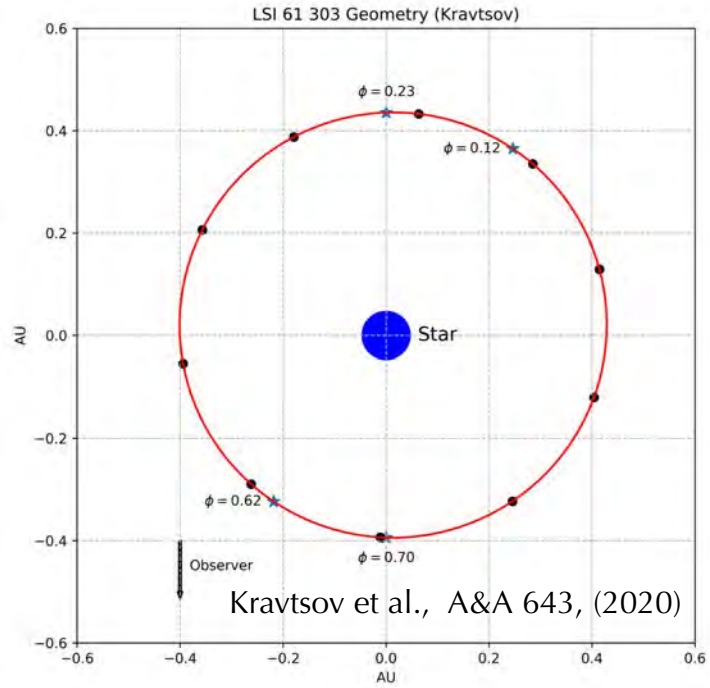


Aragona et al., ApJ 698, (2009)



Grundstrom et al., ApJ 656, (2007)





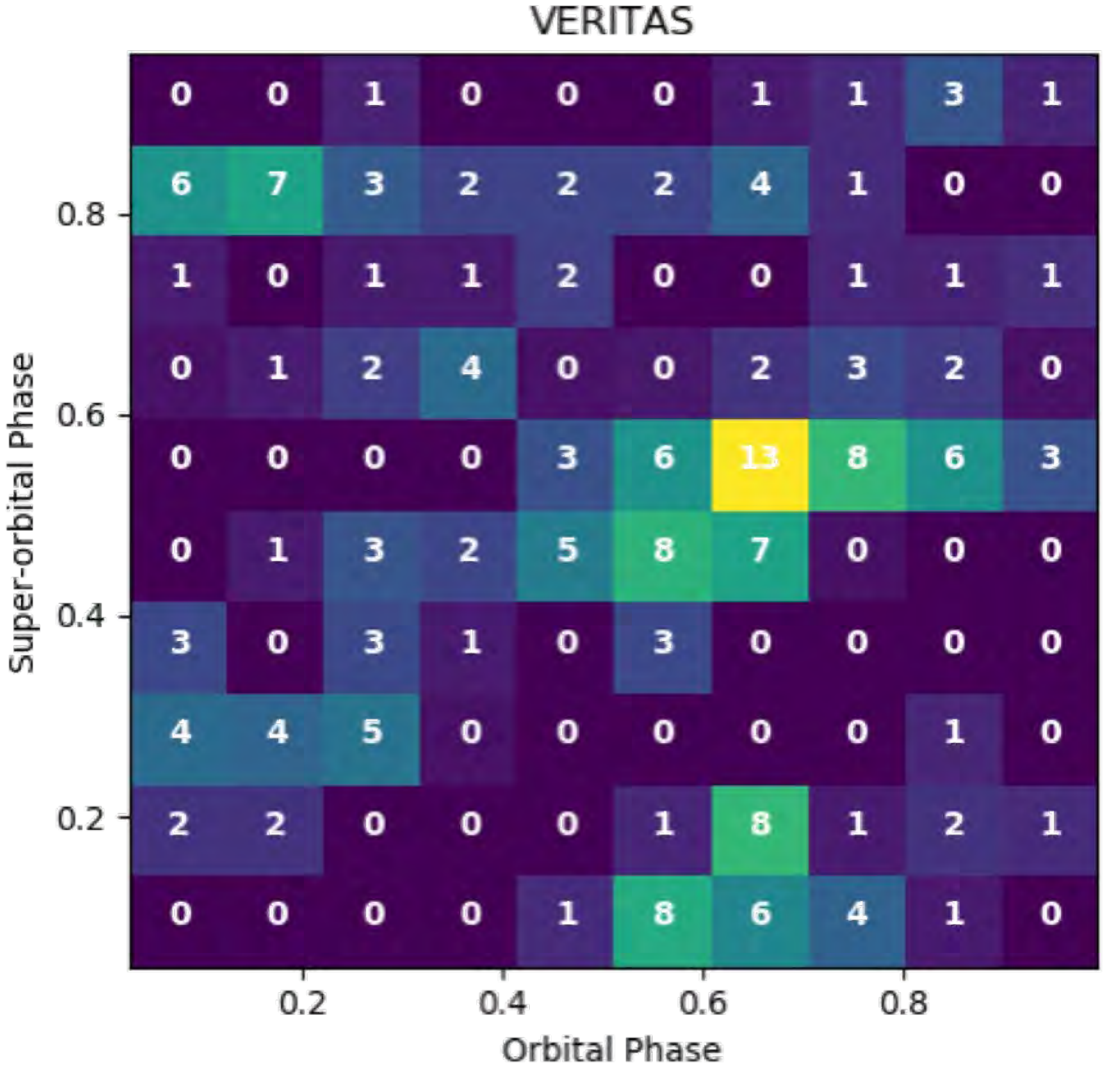
Kravtsov et al., A&A 643, (2020)

VERITAS Observations of LS I +61 303

Energy range: 100 GeV to >30 TeV

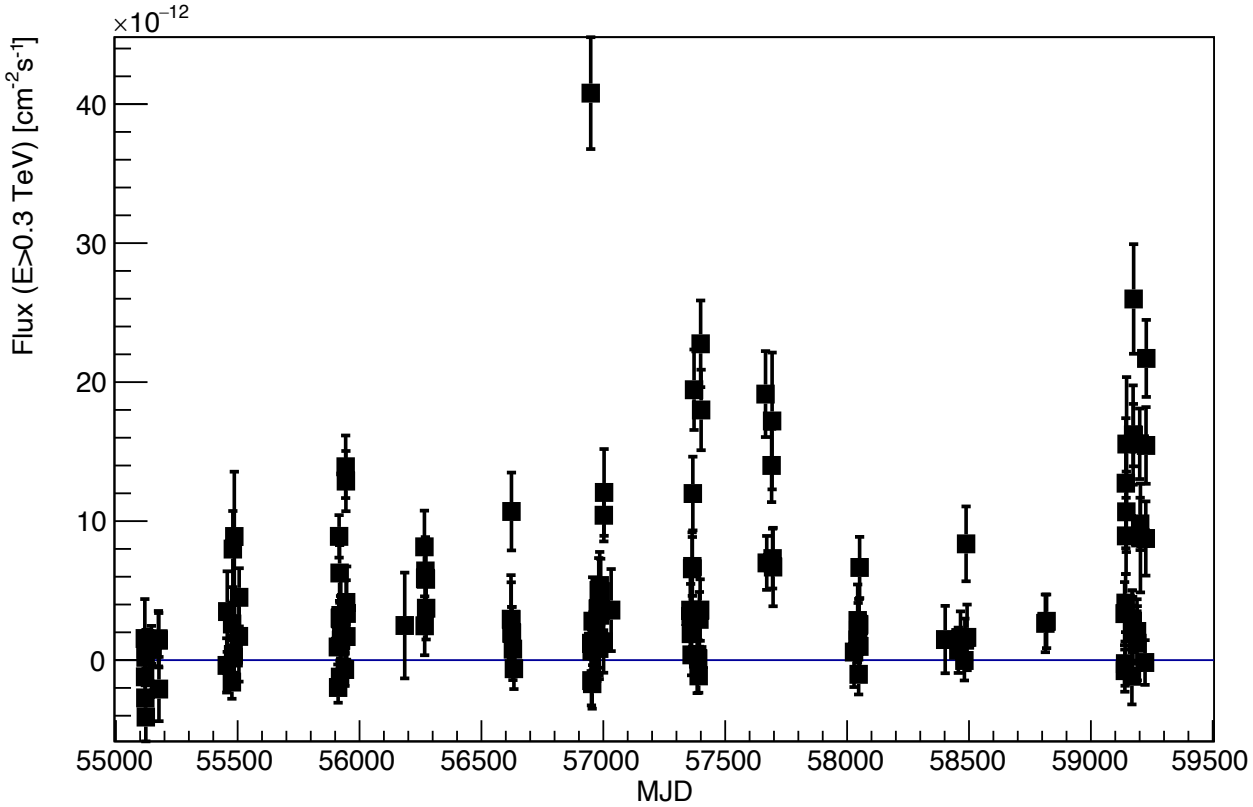
Energy resolution: 15-25%

Sensitivity: 1% Crab in ~25h

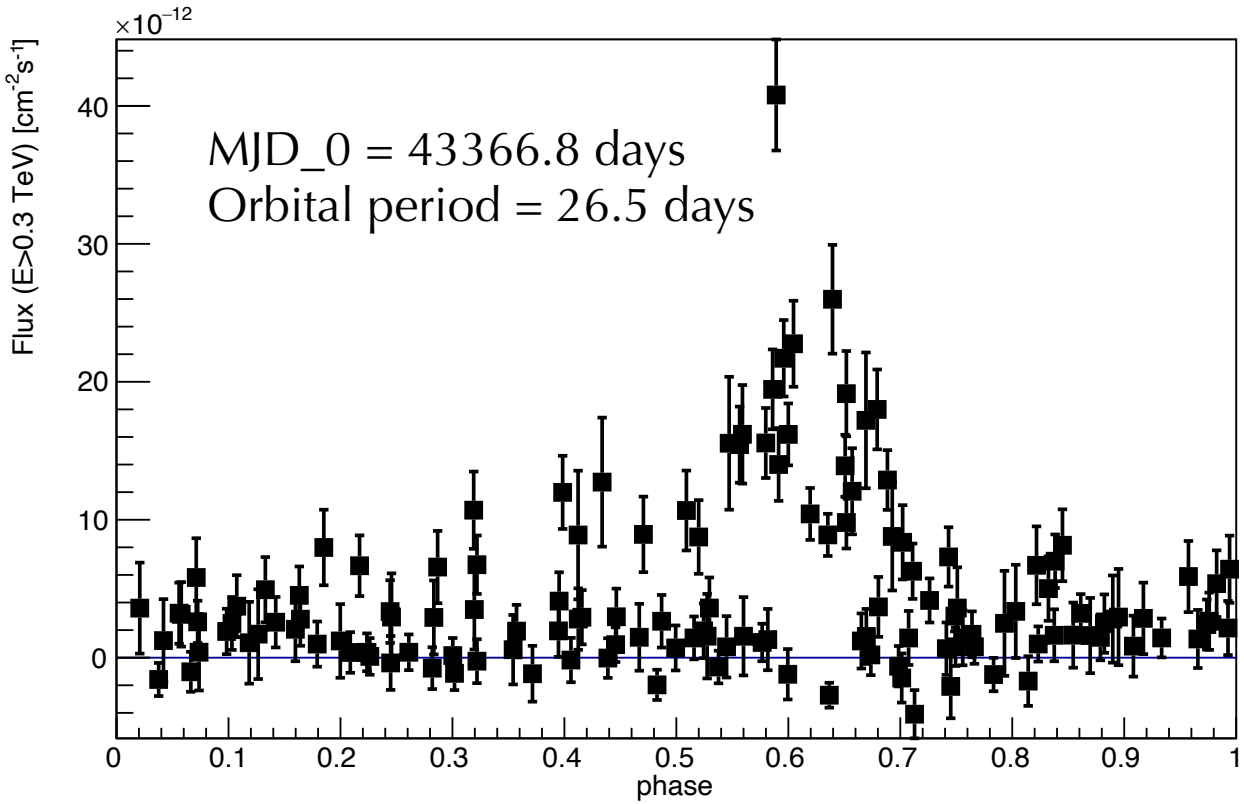


VERITAS observation of LS I +61° 303 since 2008. Each small square box represent hours of observation with yellow being the highest no. of observation hours.

Daily Lightcurve



VERITAS LS I +61° 303 daily light curve (> 300 GeV), Oct. 2009 – Jan. 2021



VERITAS orbital phased binned LS I +61° 303 light curve (> 300 GeV), Oct. 2009 – Jan. 2021

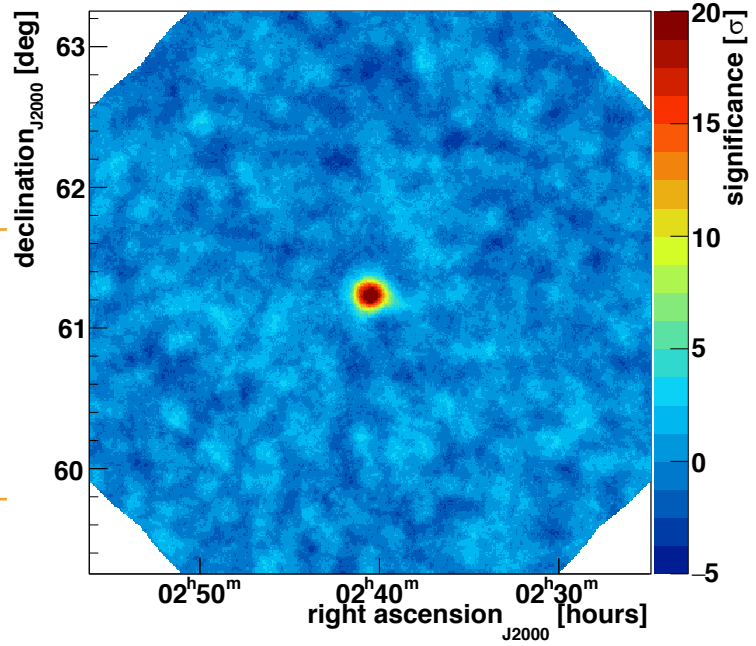
Significance in orbital phase bins

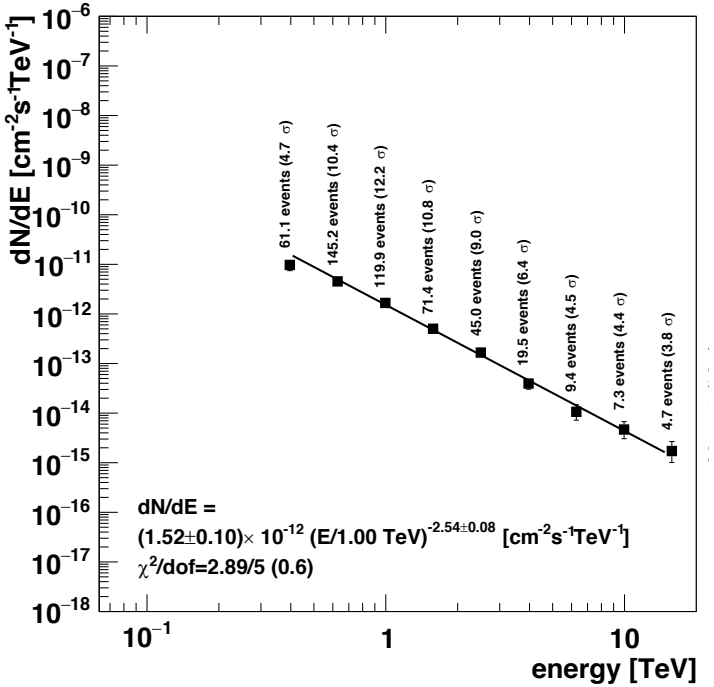
- Detected with 33σ above the energy threshold of ~ 260 GeV
- 10 orbital phase bins each 0.1 wide
- Not significantly detected in (0.1 - 0.2), (0.2 –0.3) and (0.9 – 1.0)
- Most significant in phase (0.6 - 0.7)

Phase	Live time (min)	Significance (σ)
0 – 0.1	761.87	5.0
0.1 – 0.2	**760.87**	**4.3**
0.2 – 0.3	**778.53**	**3.9**
0.3 – 0.4	760.63	5.9
0.4 – 0.5	759.08	7.1
0.5 – 0.6	1123.60	11.7
0.6 – 0.7	2090.47	31.7
0.7 – 0.8	1330.12	9.1
0.8 – 0.9	920.55	6.5
0.9 – 1.0	**555.83**	**4.2**
0.5 – 0.8	3286.27	20.4
0.8 – 0.5	5257.33	13.9
0.0 – 1.0	9801.52	33.0

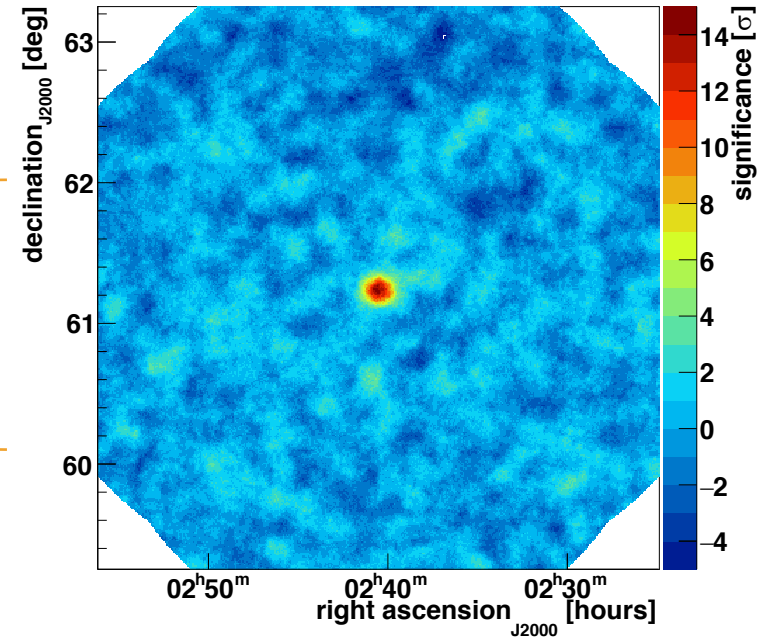
Orbital bins

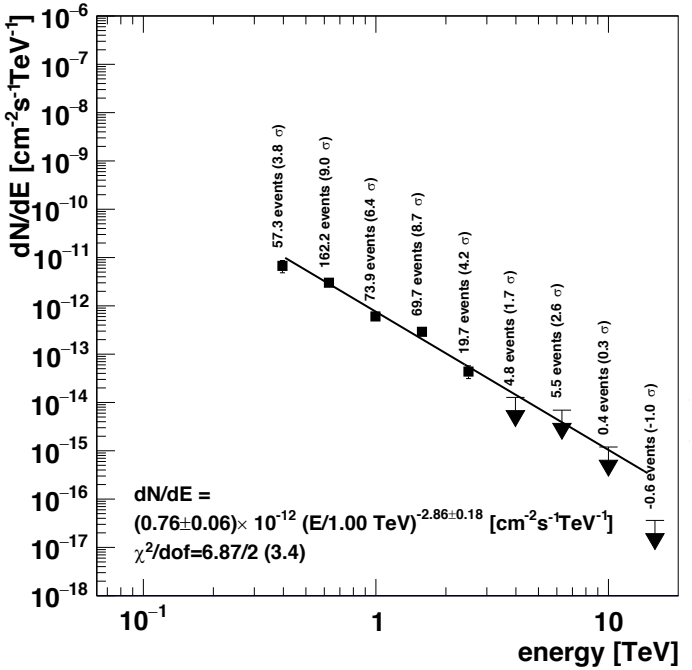
Skymap and Energy distribution for orbital phases (0.5 – 0.8)





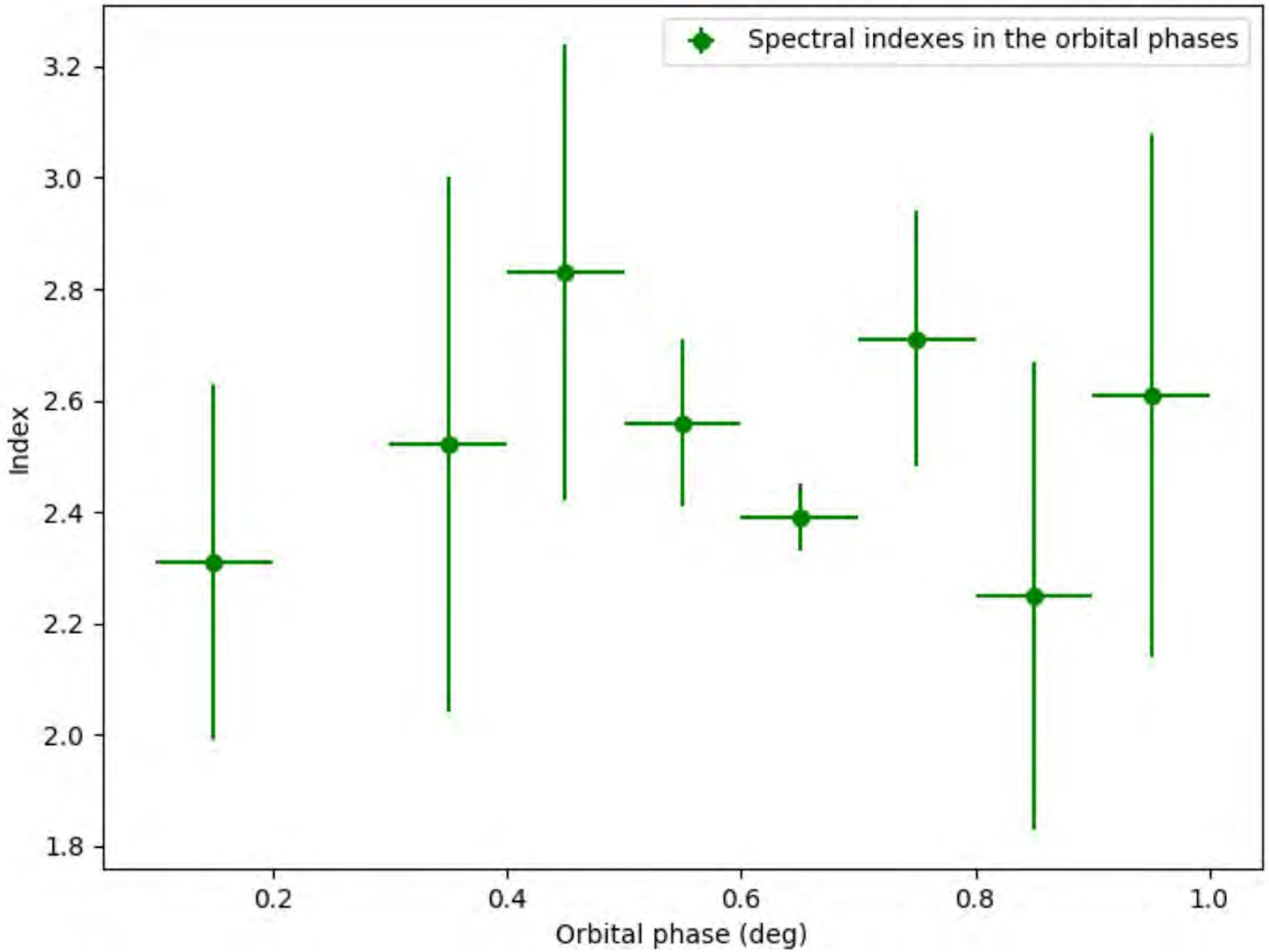
Skymap and Energy distribution for orbital phases (0.8 – 0.5)





Indexes in the Orbital bins

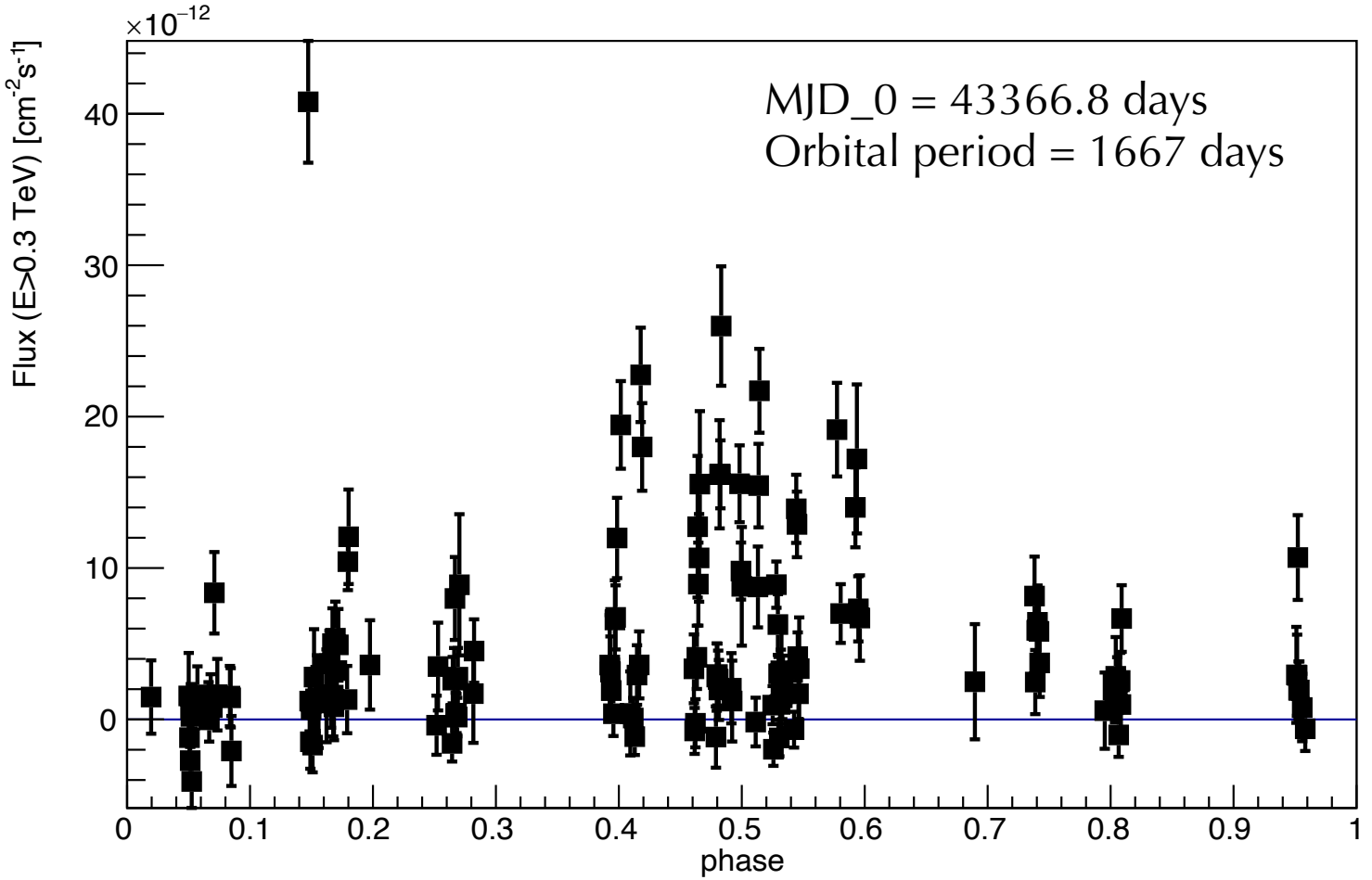
- X error is the bin width
- Very small variation of spectral indexes, not sensitive enough to detect the variation due to the large error bars



Superorbital Phase

- MJD_0 = 43366.8 days
- Superorbital period = 1667 days

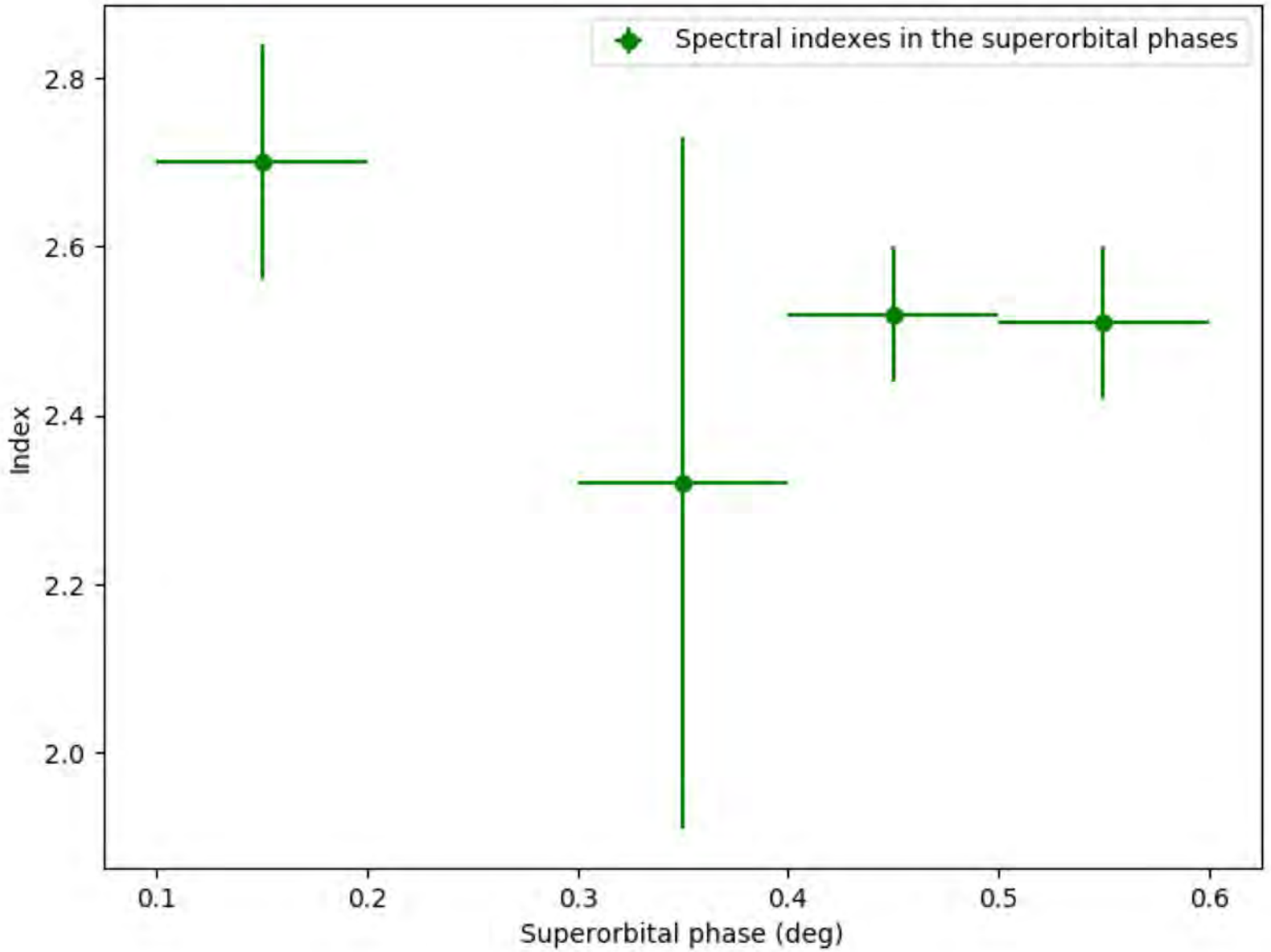
Superorbital Phase	Live time (min)	Significance (σ)
0 - 0.1	1316.18	1.4
0.1 – 0.2	1240.15	13.1
0.2 – 0.3	1004.62	4.3
0.3 – 0.4	494.73	6.7
0.4 – 0.5	1934.35	23.3
0.5 – 0.6	2406.18	23
0.6 – 0.7	20.03	0.7
0.7 – 0.8	364.03	6
0.8 – 0.9	650.35	3.6
0.9 - 1	370.88	4.4



VERITAS superorbital phased binned LS I +61° 303 daily light curve (> 300 GeV), Oct. 2009 – Jan. 2021

Indexes in the Superorbital bins

- X error is the bin width
- Not enough significant bins to detect the spectral variation



Superorbital phases in the Orbital bins

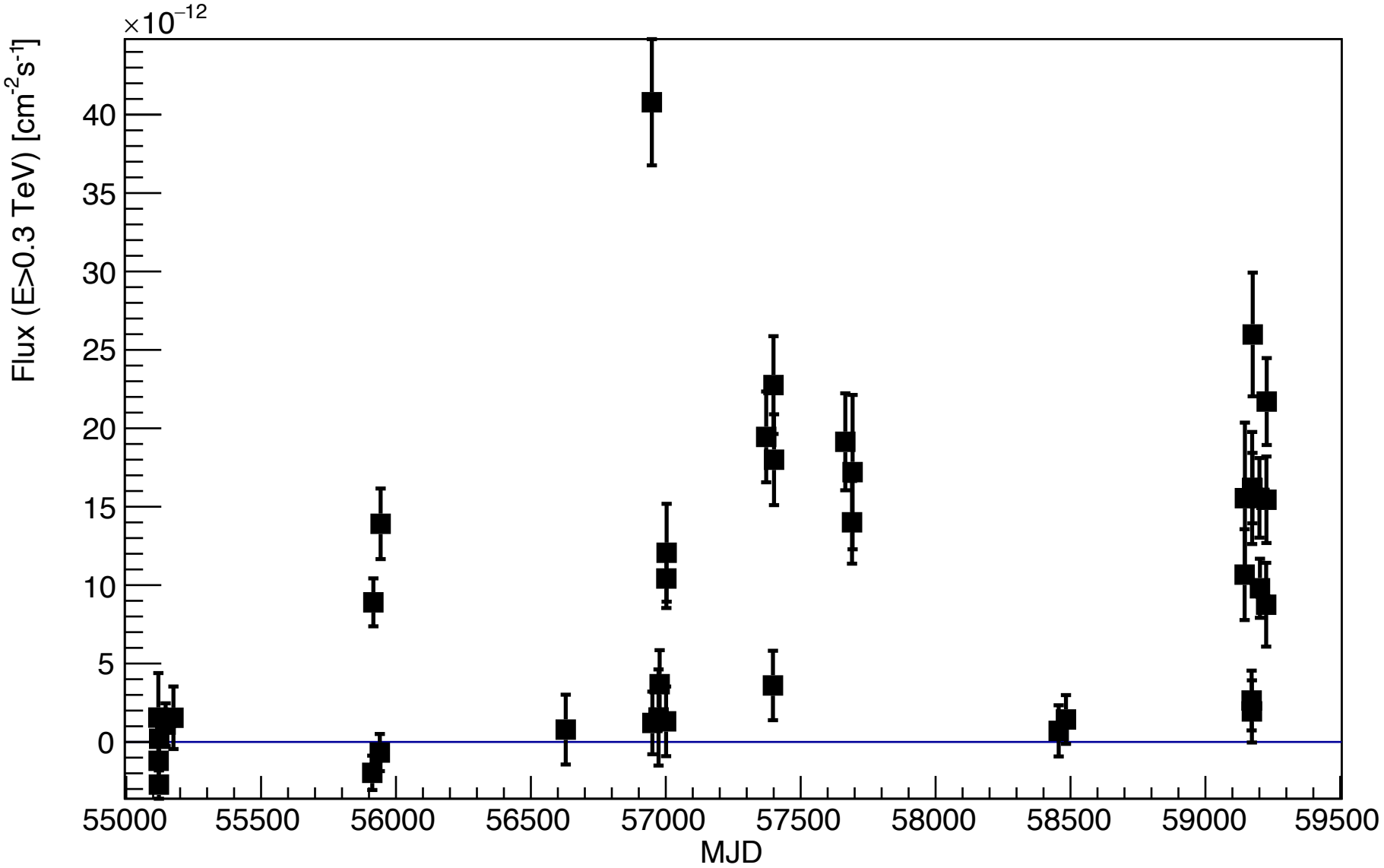
Orbital Phase	Superorbital Phase									
	(0 – 0.1)	(0.1 –0.2)	(0.2 – 0.3)	(0.3 – 0.4)	(0.4 – 0.5)	(0.5 – 0.6)	(0.6 – 0.7)	(0.7 – 0.8)	(0.8 – 0.9)	(0.9 – 0.1)
(0 – 0.3)	0	237.58	769.32	270.15	270.15	0	0	163.73	520.28	520.28
(0.3 – 0.5)	120.07	0	180.27	224.58	599.37	145.18	0	30.02	0	220.23
(0.5 – 0.7)	701.62	511.60	0	0	1064.83	895.97	0	0	0	40.05
(0.7 – 0.1)	494.50	490.97	55.03	0	0	1365.03	20.03	170.28	130.07	80.58

Live time (min) in 2D bins

Orbital Phase	Superorbital Phase									
	(0 – 0.1)	(0.1 –0.2)	(0.2 – 0.3)	(0.3 – 0.4)	(0.4 – 0.5)	(0.5 – 0.6)	(0.6 – 0.7)	(0.7 – 0.8)	(0.8 – 0.9)	(0.9 – 0.1)
(0 – 0.3)		3.6	3.4	1.7	1.8			4	3.3	3.3
(0.3 – 0.5)	0.2		2.3	**7.6**	3.9	1.2		0.2		**5.0**
(0.5 – 0.7)	-0.7	**15.1**			**26.1**	**21.5**				0.3
(0.7 – 0.1)	3.1	1.9	1.3			**11.8**	0.7	4.5	1.3	-0.6

Significance (σ) in 2D bins

Light Curve of orbital phase (0.5 – 0.7)°



VERITAS LS I +61° 303 daily light curve (> 300 GeV), Oct. 2009 – Jan. 2021

Orbital phases in superorbital phase bin (0.1 to 0.3)° and (0.4 – 0.6)°

- Explored orbital phases in superorbital phase bins (0.1 – 0.3) and (0.4 – 0.6)
- No significant variation of the spectral indexes in the significant bins

Orbital Phases	Live time (min)	Significance (σ)	Live time (min)	Significance (σ)
(0 to 0.1)	378.08	3.2	30.02	1.0
(0.1 to 0.2)	280.53	3.4	60.03	0.9
(0.2 to 0.3)	348.28	1.8	180.10	1.3
(0.3 to 0.4)	160.22	1.6	260.17	-1.0
(0.4 to 0.5)	20.05	2.2	484.38	**5.6**
(0.5 to 0.6)	30.02	0.5	732.87	**13.6**
(0.6 to 0.7)	481.58	**15.3**	1227.93	**31.7**
(0.7 to 0.8)	210.43	0.6	653.25	**10.9**
(0.8 to 0.9)	150.30	1.4	491.42	**5.5**
(0.9 to 1)	185.27	1.8	220.37	2.5
	Superorbital phase (0.1 – 0.3)		Superorbital phase (0.4 – 0.6)	

Summary

- Significant TeV detection of LS I +61° 303 in both flaring and quiescent orbital bins
- TeV Orbital phase bin light curve peaked at 0.65
- Little sensitivity to test TeV spectral variation in either the orbital and superorbital bins
- Study of superorbital/long-term TeV variability in orbital phase bin (0.5 – 0.7) is underway
- Modelling of LS I +61° 303 using the full dataset is also underway