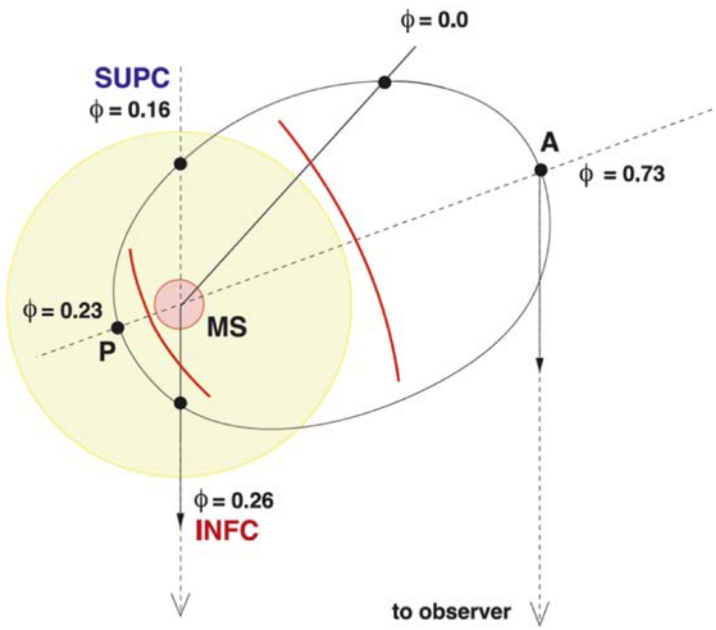
Characterizing the VHE emission of LS I +61 303 using VERITAS observations

D. Kieda[1] for the VERITAS Collaboration
[1]*University of Utah*

July 29, 2019

LSI +61 303 Binary System



Sierpowska-Bartosik et al. 2009 Ap J. 693, 1462S

High Mass X-ray Binary System

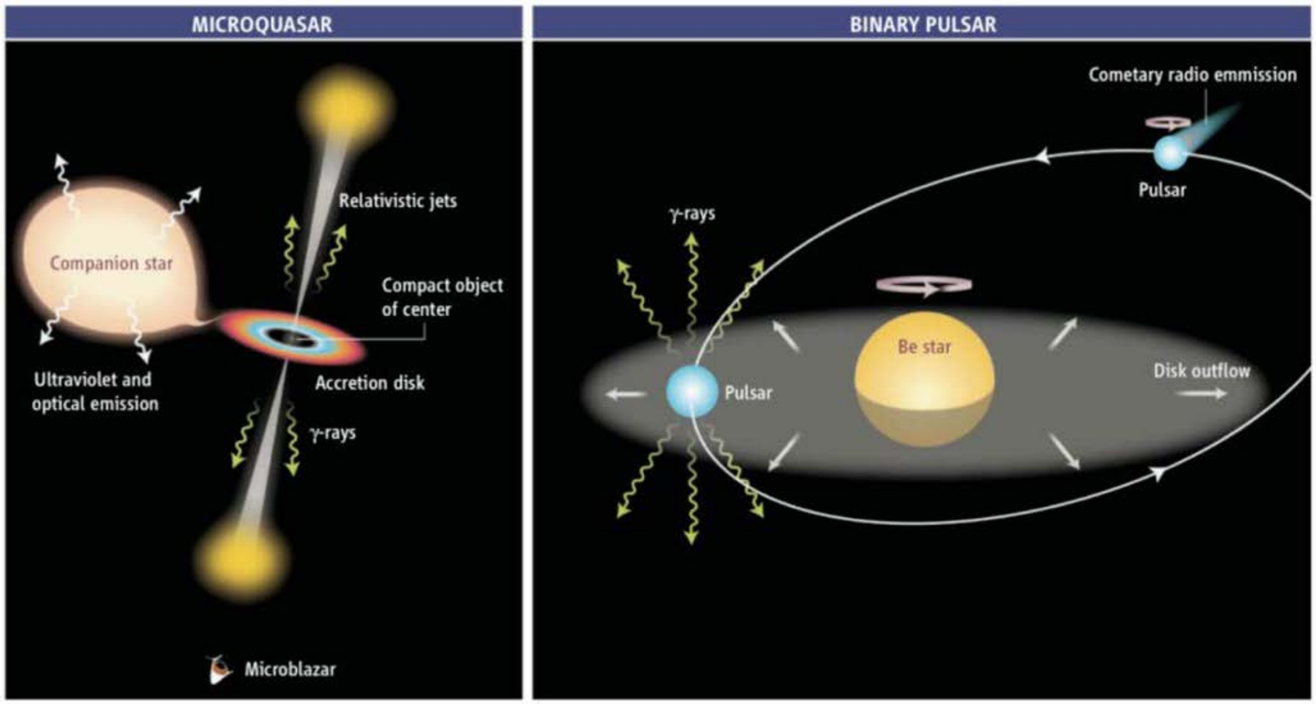
Compact object (2-3 $M_\odot$) in an eccentric (e=0.54) orbit around massive (10-15 $M_\odot$) Be star with strong wind/decretion disk.

24.496 day periodic modulation across entire electromagnetic spectrum

Superorbital modulation (1667 day) of radio, X-ray, GeV/TeV emission reported.

Strongest TeV emission near apastron ϕ=0.73
Strongest GeV emission near periastron ϕ=0.23

Possible Models of LSI +61 303



Both the microquasar and the Binary pulsar scenarios have aspects that are supported by ongoing observations. Both are still considered to be viable models.

VERITAS Observations 2007-2016

Observing Season	Instrument Epoch	Quality Selected Livetime [mins]	Detection Significance (σ)
2007 / 2008	V4	1518	6.2
2008 / 2009	V4	2305	3.8
2009 / 2010	V5	1207	0.7
2010 / 2011	V5	933	4.6
2011 / 2012	V5	1551	14.0
2012 / 2013	V6	490	6.5
2013 / 2014	V6	522	5.6
2014 / 2015	V6	1746	21.4
2015 / 2016	V6	1137	16.0
2016 / 2017	V6	703	12.4
All	V4, V5, V6	12112	29.2

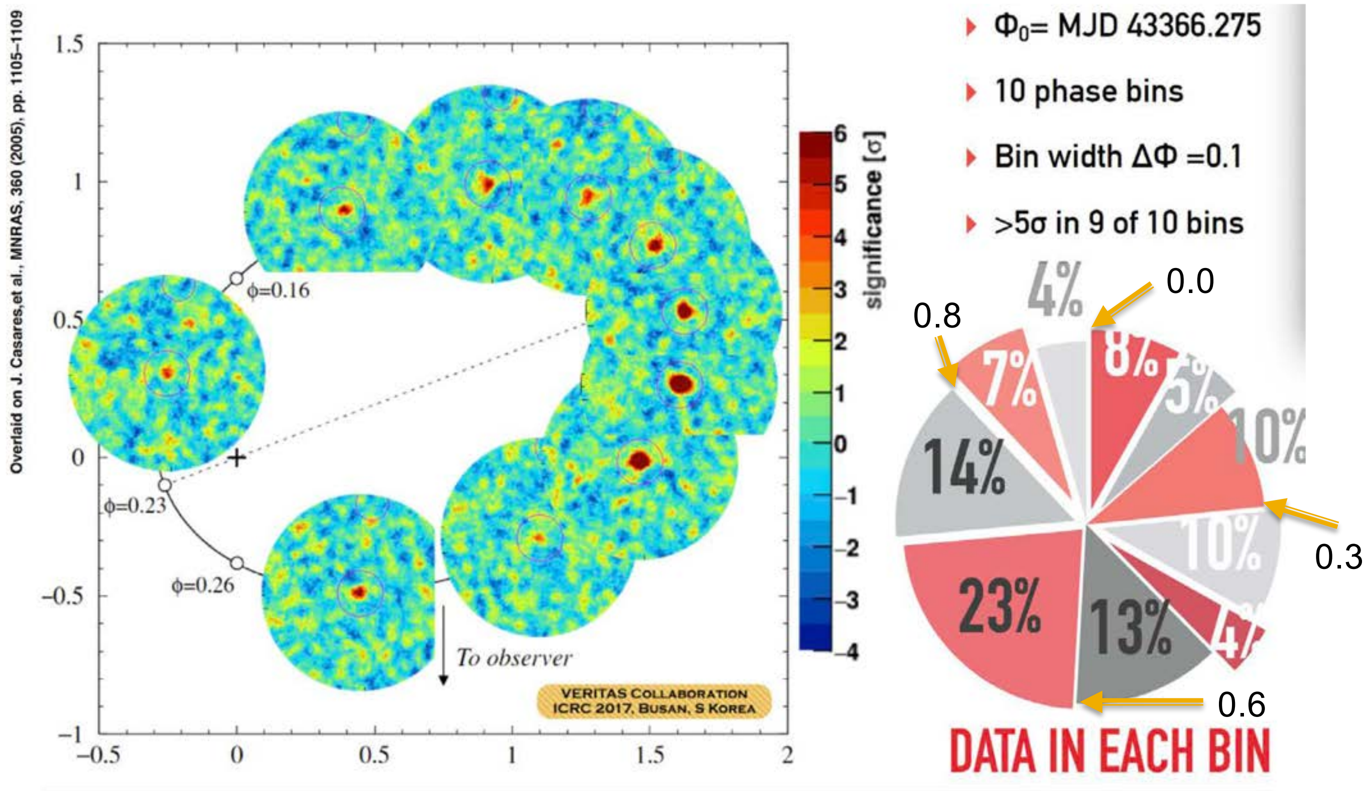
P. Kar, PhD Thesis University of Utah 2018

Extensive set
of LSI observations from
decade-long observing
campaign.

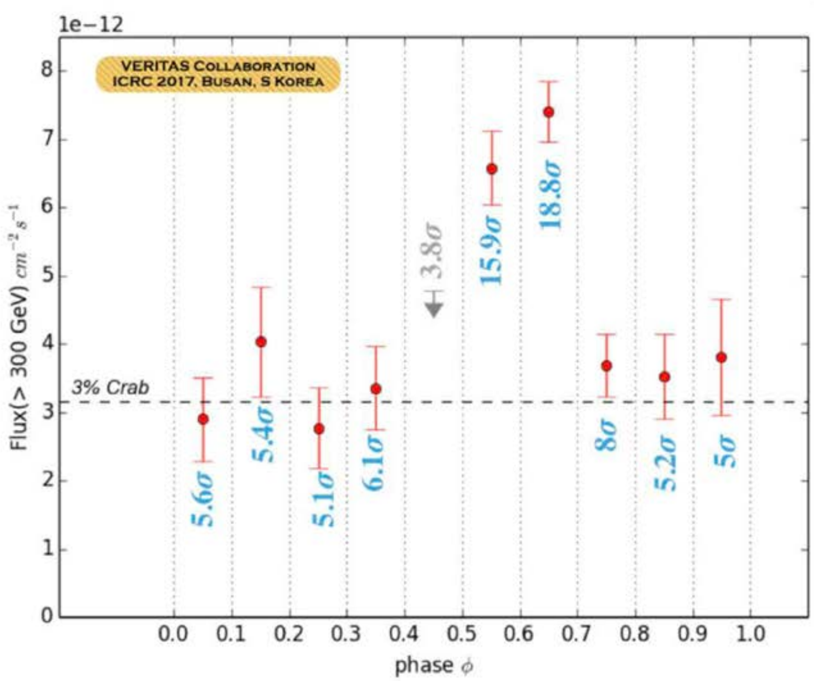
LSI +61 303
Is a KSP for VERITAS.

Observability of
apastron phase not
possible every year
due to observing
constraints
around full moon
(29.53 day period).

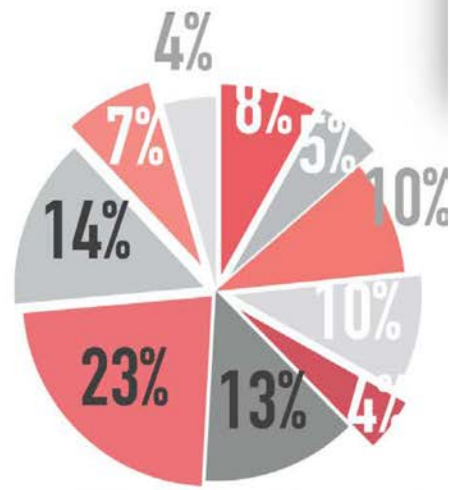
Orbital Phase Analysis 2007-2016



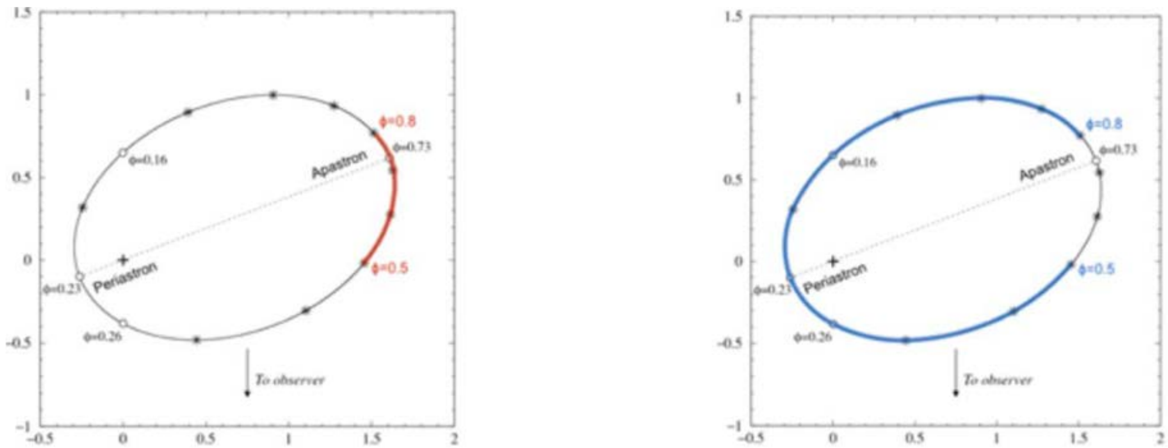
Orbital Phase Analysis 2007-2016



- ~3% Crab quiescent emission
- TeV outburst near apastron passage
- Limited exposure UL in 1 phase
- Highly variable VHE emission



Spectral Variability 2007-2016



	$0.5 \rightarrow 0.8$ Near Apastron	$0.8 \rightarrow 0.5$ Rest of Orbit
Exposure	6143 min	6048 min
σ	27.0	13.9
Flux	$(6.10 \pm 0.27) \times 10^{-12} \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$	$(3.27 \pm 0.25) \times 10^{-12} \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
Γ	-2.63 ± 0.06	-2.81 ± 0.16

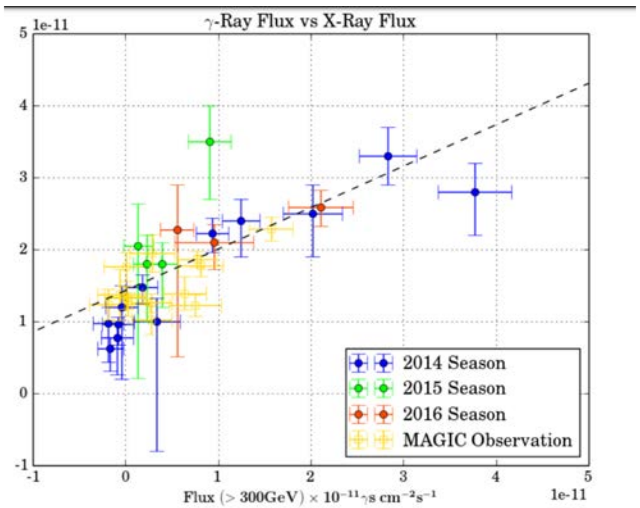
P. Kar, PhD Thesis University of Utah 2018

Spectral Variability 2007-2016

Phase bin (ϕ)	Significance (σ)	Flux [$\times 10^{-12}$ cm^{-2} s^{-1}]	% of Crab	Spectral Index	Exposure [min]
$0.5 \to 0.8$	27.0	6.10 ± 0.27	5.8	-2.63 ± 0.06	6143
$0.8 \to 0.5$	13.9	3.27 ± 0.25	3.1	-2.81 ± 0.16	6048
Just Before $0.8 \to 0.2$	10.9	3.57 ± 0.35	3.4	-2.86 ± 0.21	3120
Just After $0.2 \to 0.5$	8.8	2.96 ± 0.37	2.8	-2.62 ± 0.22	2928

- Strong evidence of flux variation near apastron
- Some hints of spectral hardening near apastron

TeV/X-ray Correlation



19 obs Swift VERITAS ⟶ $r = 0.756^{+0.09}_{-0.13}$

VERITAS + MAGIC ⟶ $r = 0.773^{+0.07}_{-0.09}$

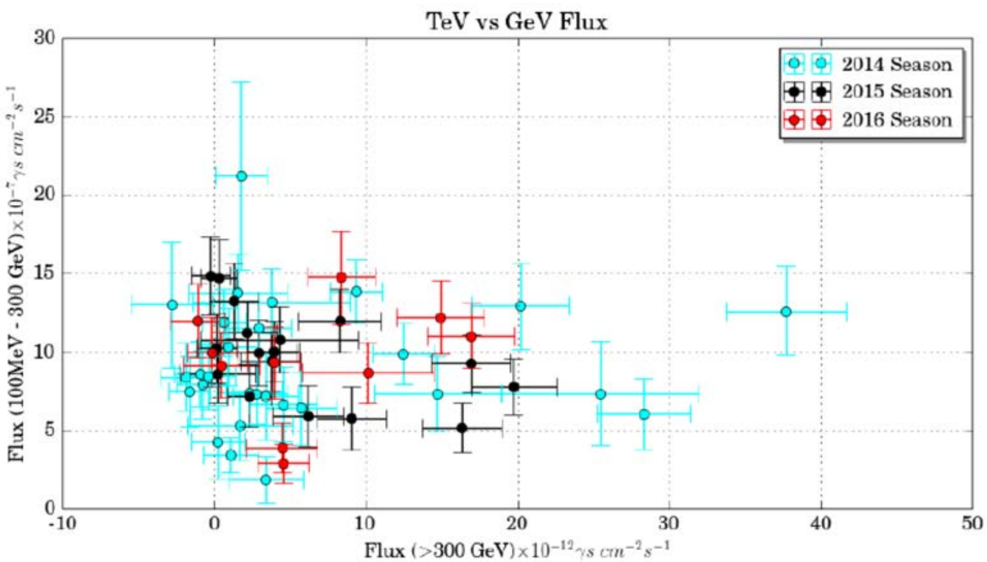
$$\frac{F(0.3-10keV)}{10^{-12}\, erg\; cm^{-2}\, s^{-1}} = 12.36 + 0.5602 \times \left[\frac{N(E>300GeV)}{10^{-12}\, \gamma s\; cm^{-2}\, s^{-1}}\right]$$

Significant correlation in individual LSI flares
between
VERITAS/Magic observed TeV flux
and
Swift observed X-ray flux

Note that the strongest correlations
occur in 2014-2015 observing season

P. Kar, PhD Thesis University of Utah 2018

TeV/GeV non-correlation



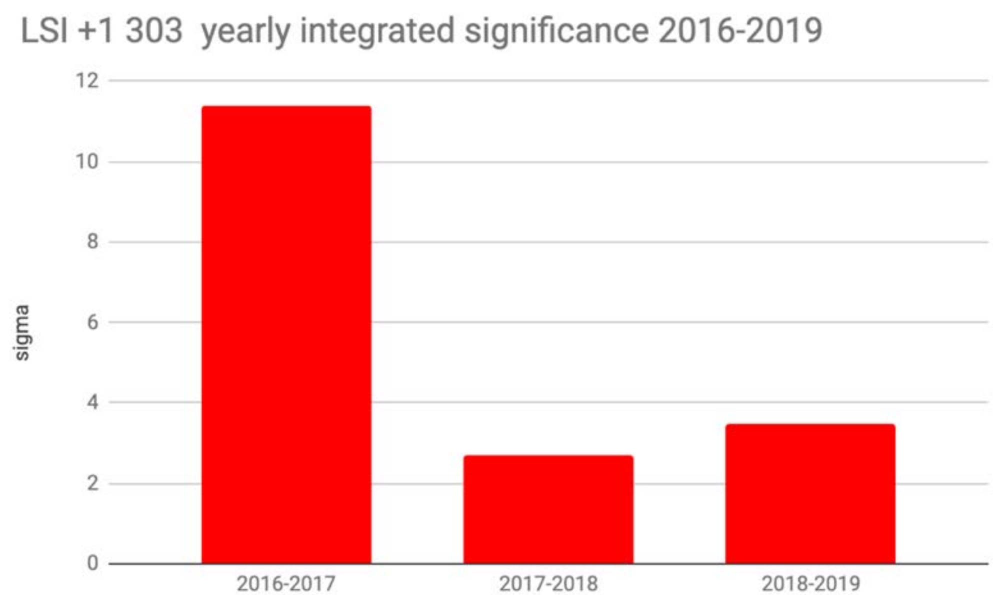
Possible need for
Two separate
Emission processes
In LSI?

TeV/X-Ray & GeV

TeV (VERITAS) vs GeV(Fermi-LAT) Fluxes

Pearson Correlation coefficient r = -0.0255 $^{+0.13}_{-0.14}$ +/- 0.7131 for the datasets.

2016-2019 Observations

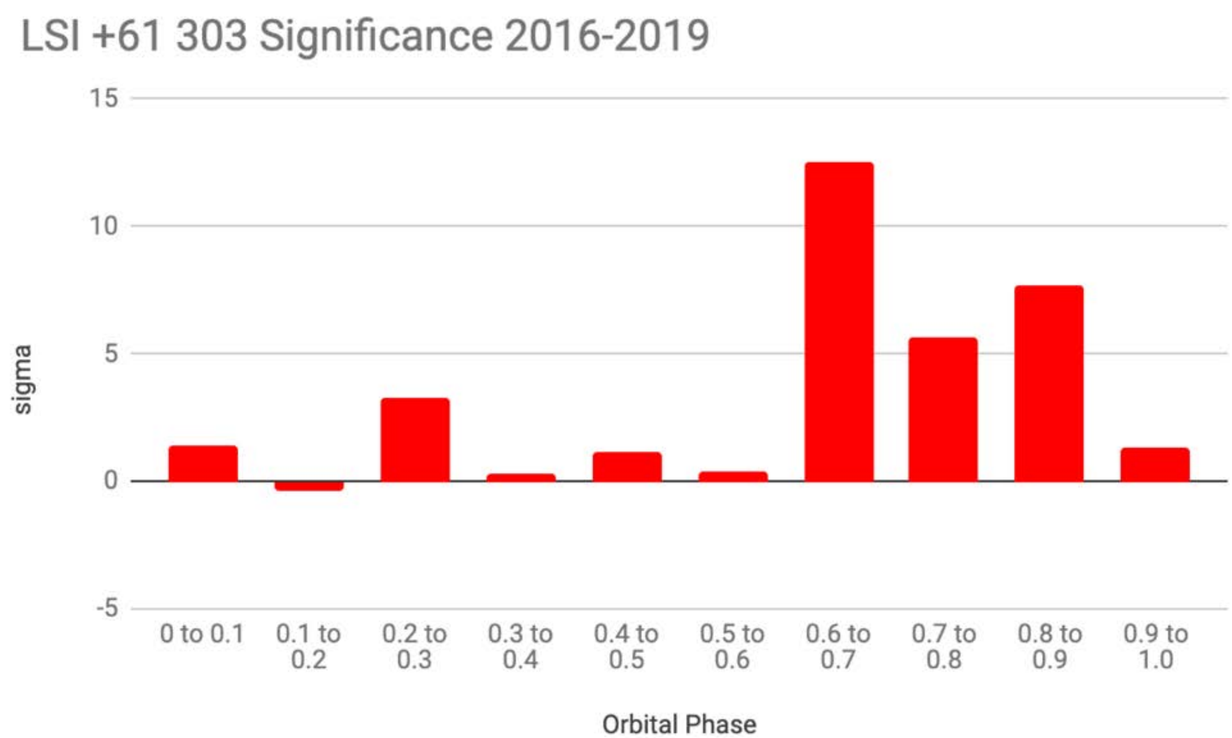


Strong Detection in 2016-2017

2017-2018 & 2018-2019
- Reduced exposure
- marginal significance

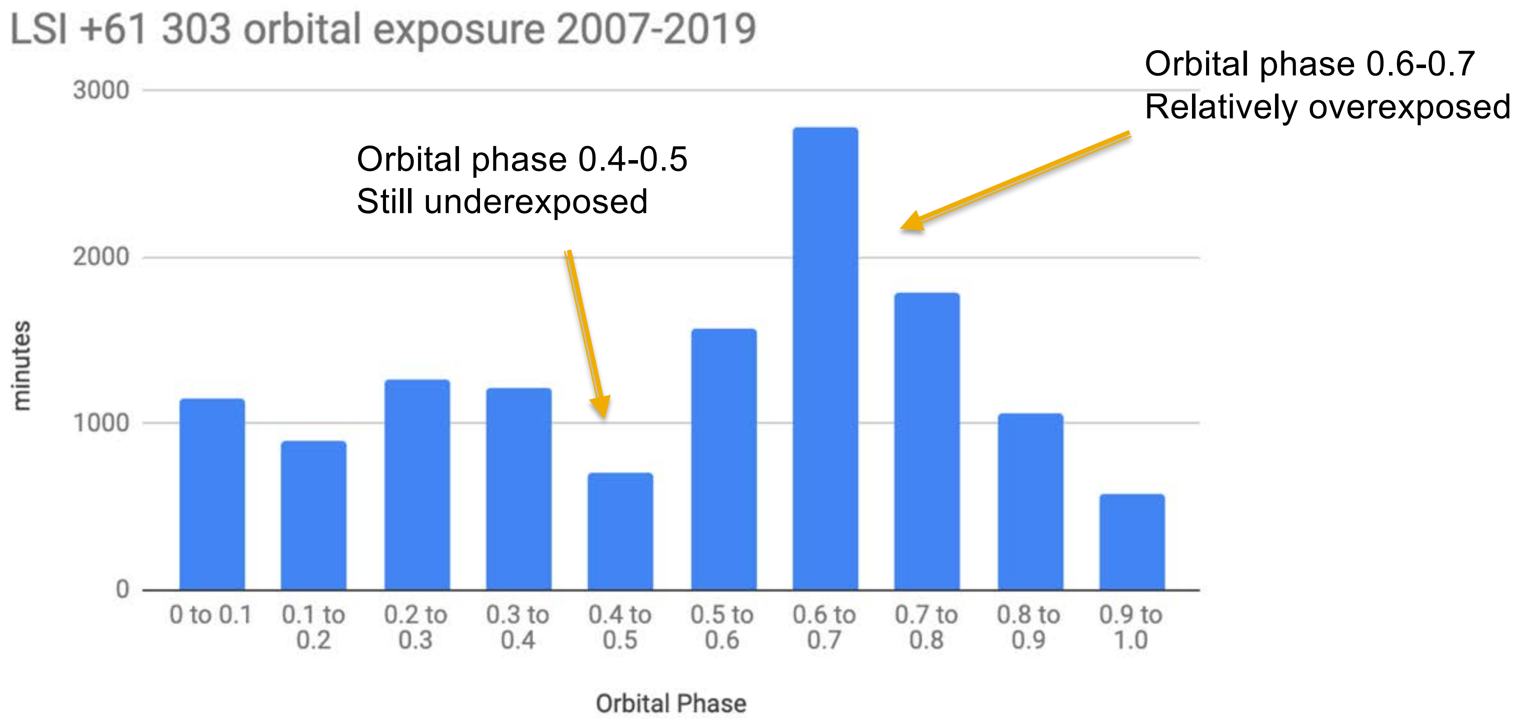
Observing Season	MJD Observation Date Range	Total Significance σ	Normalized. Significance $\sigma/\sqrt{hours}$
2016-2017	57662-57696	11.37	3.32
2017-2018	58028-58051	2.72	0.77
2018-2019	58402-58492	3.48	1.18

2016-2019 Observations

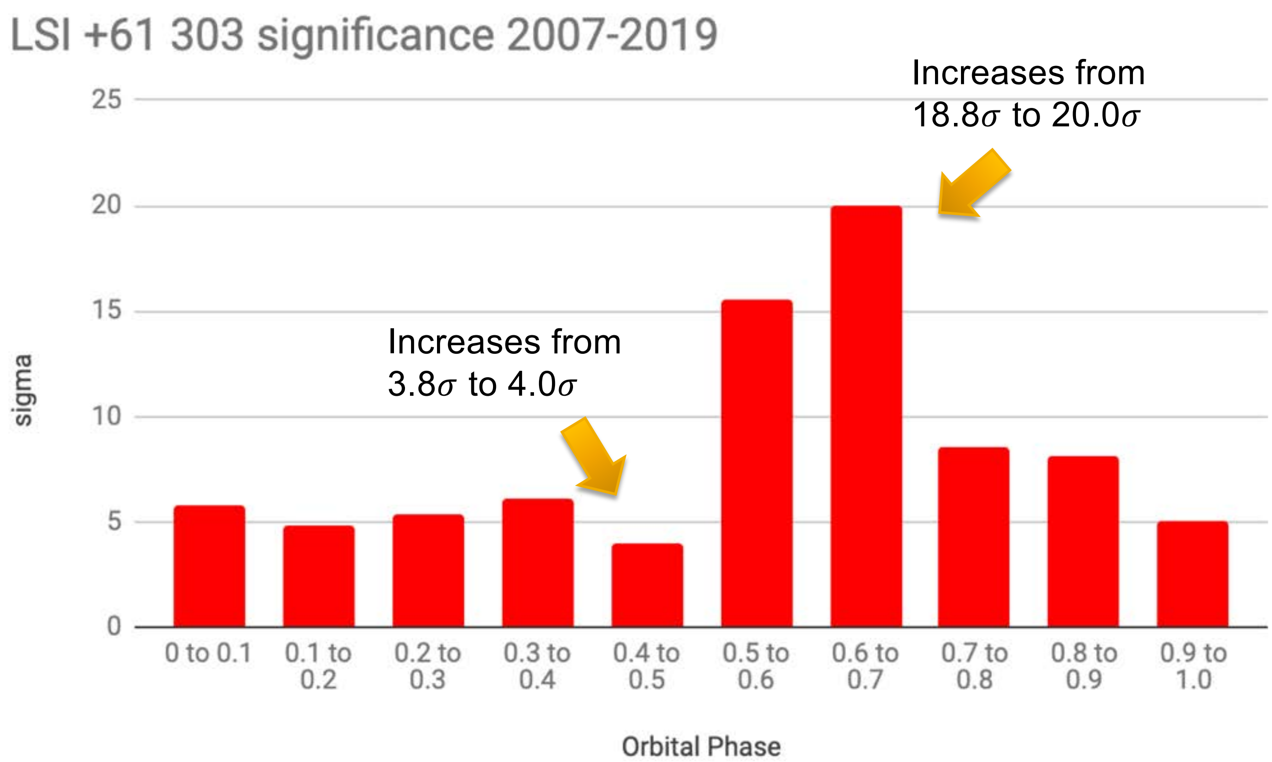


Characteristic TeV emission near Apastron continues

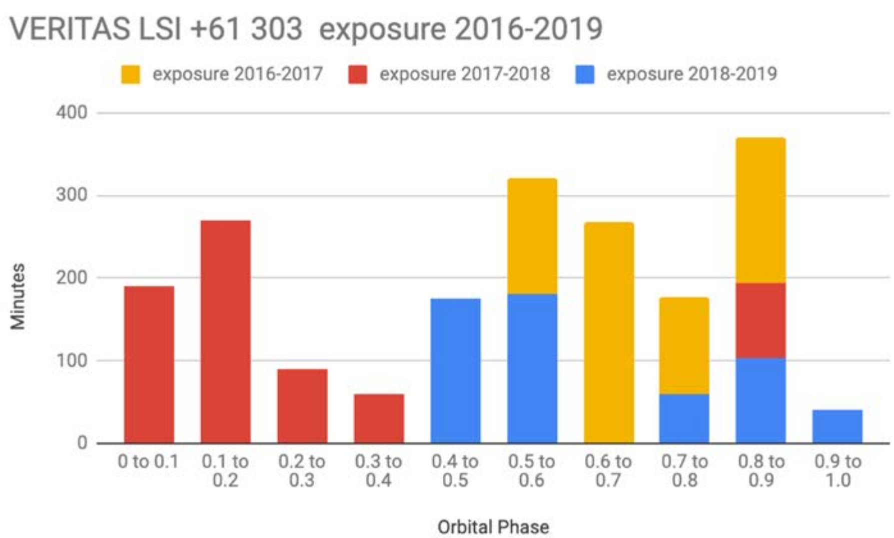
12 Years of integrated LSI +61 303 observations

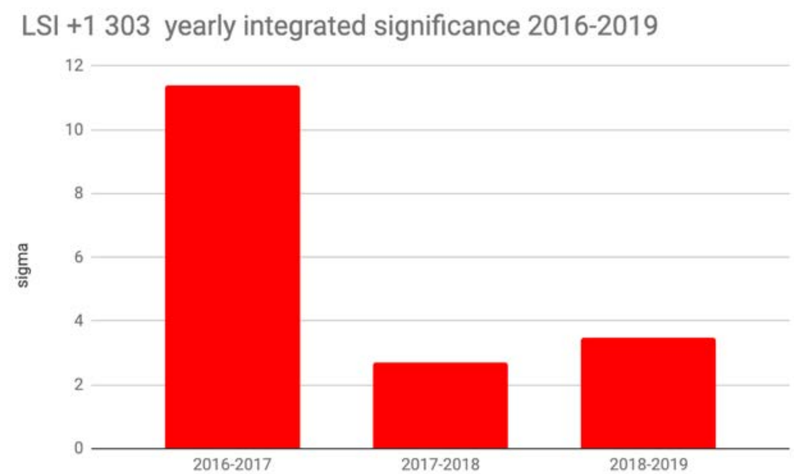


12 Years of integrated LSI +61 303 observations



2016-2019 Observations





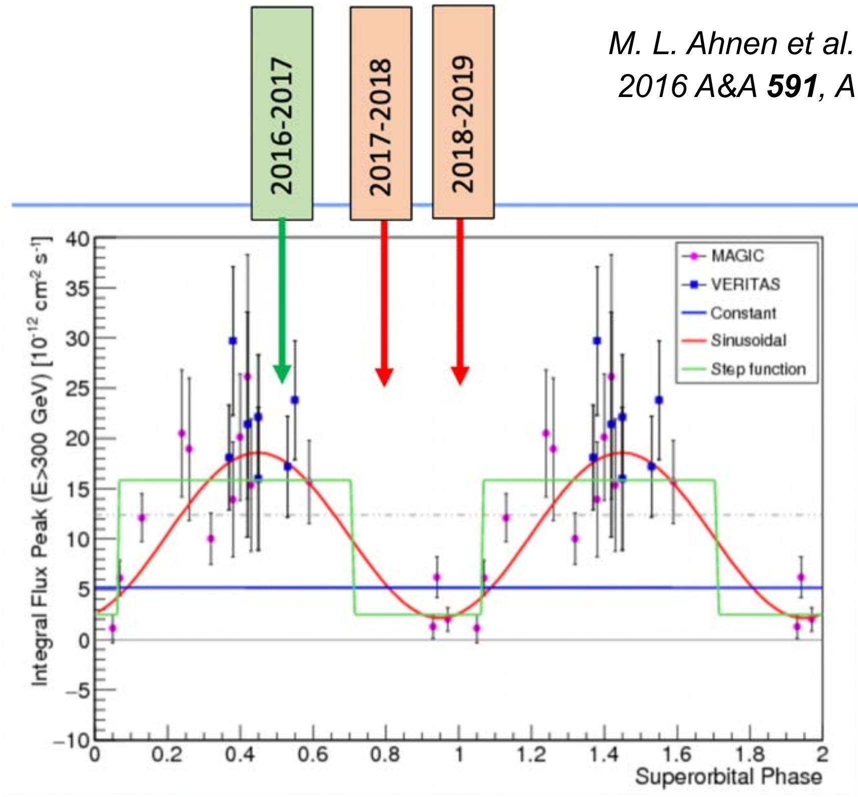
Dominant periastron exposure (2017-2018): expect low flux
Dominant apastron exposure (2016-2017), (2018-2019) expect high flux

2018-2019: low flux state?

Superorbital Phases 2016-2019

*M. L. Ahnen et al. 2016 A&A **591**, A76*

Observing Season	MJD Observation Date Range	Total Significance σ	Normalized. Significance $\sigma/\sqrt{hours}$	Orbital Phase Range	Superorbital Phase
2016-2017	57662-57696	11.37	3.32	0.5-0.8	0.5
2017-2018	58028-58051	2.72	0.77	0.8-1.4	0.8
2018-2019	58402-58492	3.48	1.18	0.4-0.9	0.0



<u>Orbital period 26.496 days</u>
Gamma-ray flux depends upon
Orbital phase (apastron ~ 0.7).

<u>Superorbital period 1667 days</u>
Gamma-ray Flux may also depend upon
superorbital phase (peak ~0.5).

LSI +61 303
Superorbital phases (2007-2017)

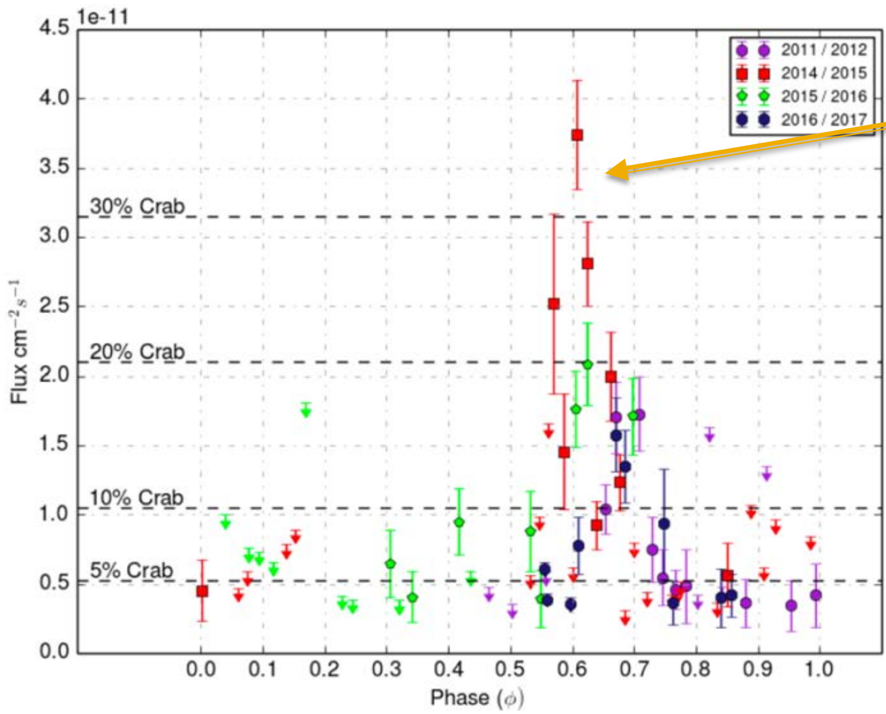
Observing Season	Instrument Epoch	Quality Selected Livetime [mins]	Detection Significance (σ)	Superorbital phase
2007 / 2008	V4	1518	6.2	0.6
2008 / 2009	V4	2305	3.8	0.8
2009 / 2010	V5	1207	0.7	0.0
2010 / 2011	V5	933	4.6	0.2
2011 / 2012	V5	1551	14.0	0.5
2012 / 2013	V6	490	6.5	0.7
2013 / 2014	V6	522	5.6	0.95
2014 / 2015	V6	1746	21.4	0.15
2015 / 2016	V6	1137	16.0	0.4
2016 / 2017	V6	703	12.4	0.5
All	V4, V5, V6	12112	29.2	

!!!

Generally Good agreement

2014-2015 flares completely break the superorbital paradigm

LSI +61 303 Flares



P. Kar, PhD Thesis University of Utah 2018

2014-2015 Flares

Brightest of four flares observed during 12 years

Occur with $\Delta\phi$~-0.1 before before apastron

2014-2015 flare provides the strong TeV/X-ray correlation

Summary

- 12-years of VERITAS Observations of LSI +61 303
- Continuing strong TeV emission near apastron
- Evidence for low level emission (3% crab) along entire orbit
- Modest evidence of spectral hardening near apastron
- Continuing hints of superorbital modulation across entire dataset…but dataset contains a glaring exception

- 2014-2015 flaring
  - Provides Strongest evidence for TeV/X-ray correlation
  - Occurs during superorbital minimum: three possibilities
    1. No simple superorbital hypothesis
    2. Huge flare to be large after superorbital suppression
    3. Flare mechanism independent from canonical apastron emission