

VERITAS observations of Gamma-ray binaries



HESS J0632+057 and LS I +61° 303: Long-term studies

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Gamma 2022, Barcelona





Gamma-ray binaries

Introduction: Why?

- A sub-class of high mass binary system:
 - Energy spectrum peaks at high energy (>100 MeV) and extends to very high energy (>100 GeV)
 - Compact object orbits a young and massive star (O or B type)

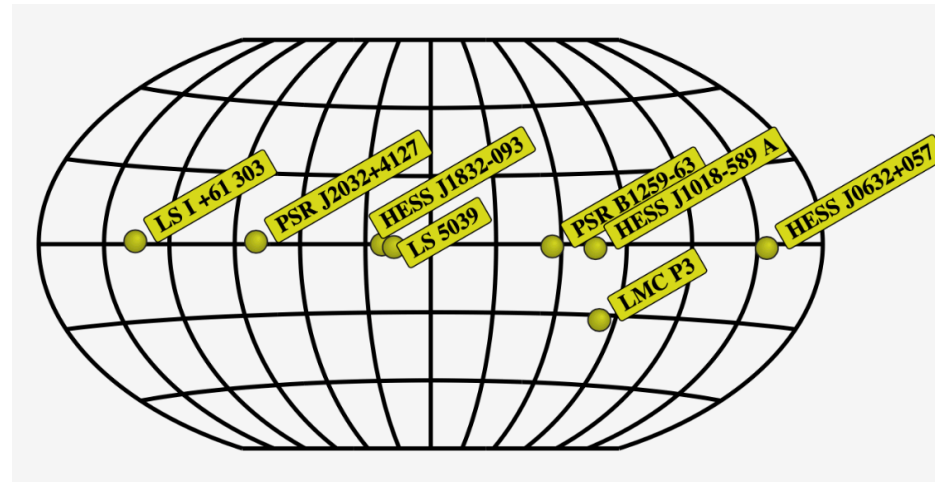
Variable Galactic TeV sources

Regularly repeating environment

What **modulates** the gamma-ray emission?

Particle acceleration
Where? Nature? Mechanism?

What **powers** the source?



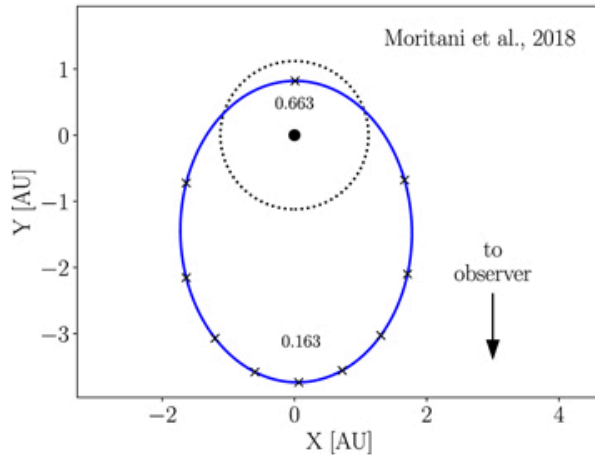
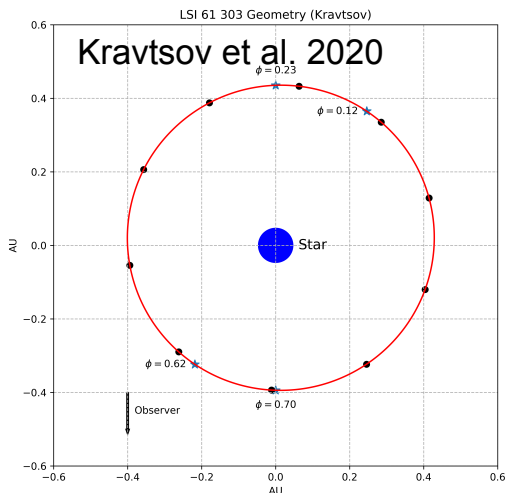
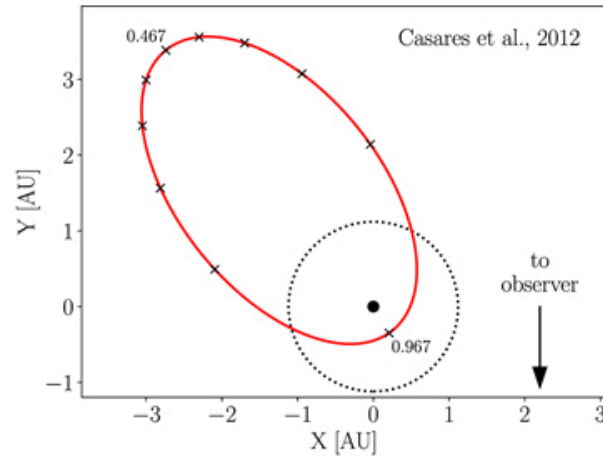
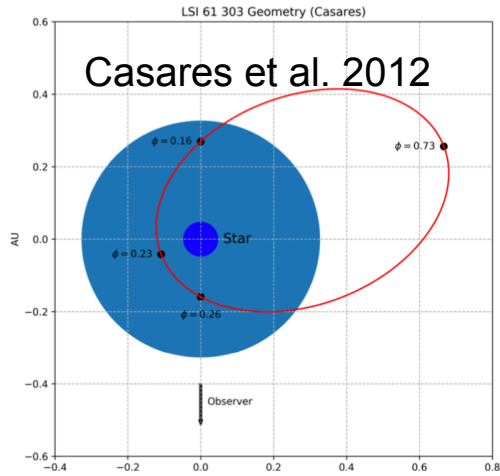
Gamma-ray binaries ([TeVCat](#))

Gamma-ray binaries with known compact companion:

- PSR B1259-63
 - P_{orb} : ~ 1236 days, $e = 0.87$
 - ~ 43 ms radio pulsar orbiting a Be star
- PSR J2032+4127
 - P_{orb} : 45-50 years, $e = 0.94-0.99$
 - VERITAS: ~ 181 hr, MAGIC: ~ 88
([VERITAS Coll. & MAGIC Coll. 2018](#))
- LS I +61° 303
 - P_{orb} : ~ 27 days
 - existence of radio pulsation ([Shan-Shan Weng et al. 2022](#))

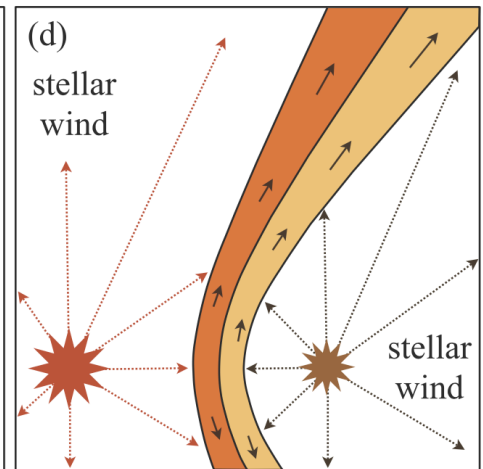
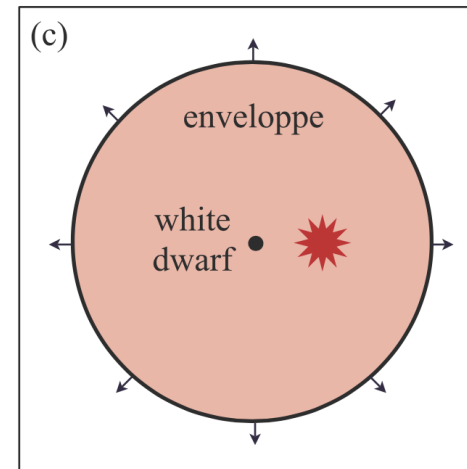
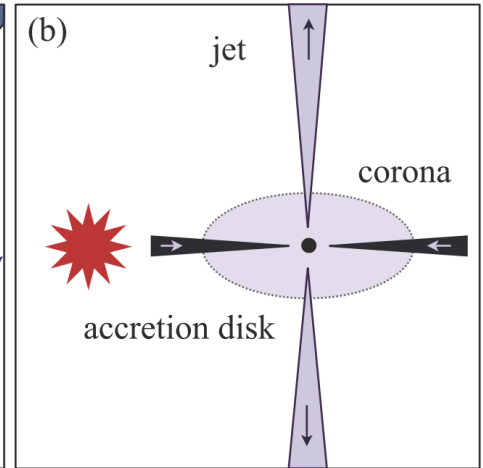
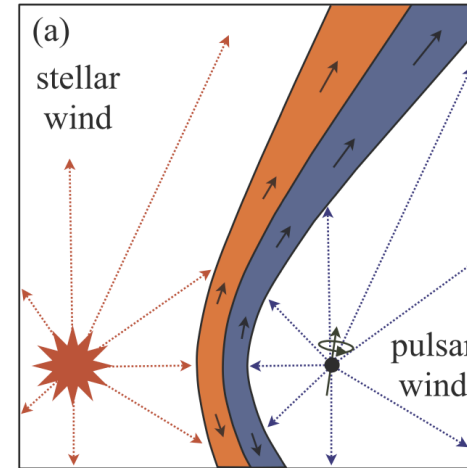
Gamma-ray binaries

Introduction: Orbits and Models



LS I +61° 303

HESS J0632+057



Dubus, G. (2015)

Long-term (large) dataset

Instruments: **VERITAS** and *Swift-XRT*



VERITAS:

Energy range: 100 GeV to >30 TeV

Energy resolution: 15-25%

Sensitivity: 1% Crab in ~25h

Angular resolution: $R_{68\%} < 0.1^\circ$ @ 1 TeV

Pointing accuracy: Error < 50 arcsec

Mirror diameter: ~12 m

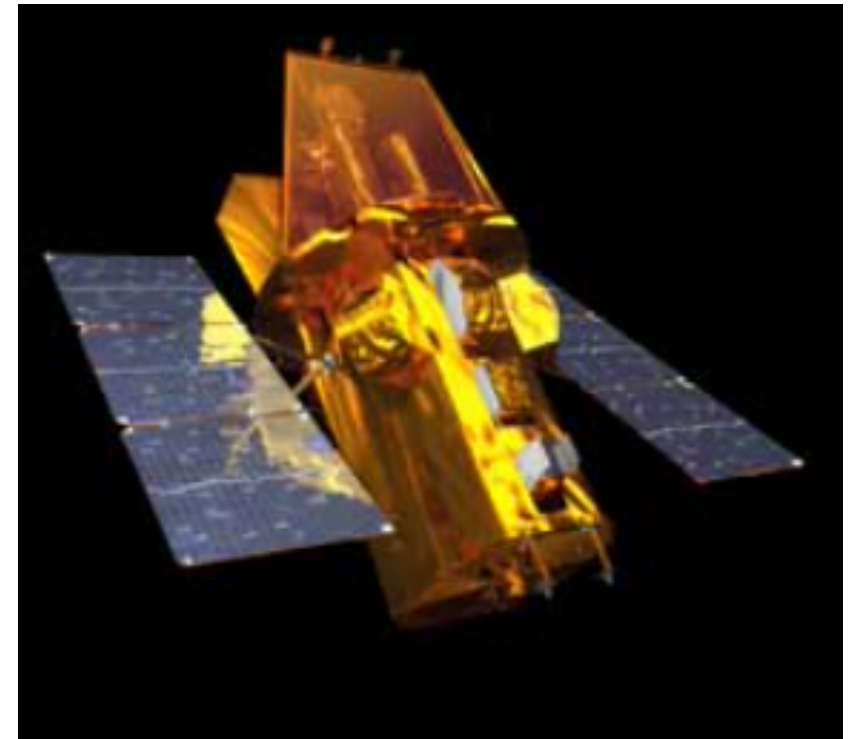
*Swift-XRT*1:

Energy range: 0.3-10 keV

Energy resolution: ~190 eV at 10 keV to
~50 eV at 0.1 keV

Sensitivity: 8×10^{-14} erg cm⁻² s⁻¹ in 10⁴ seconds

Angular resolution: 18 arcsec @ 1.5 keV



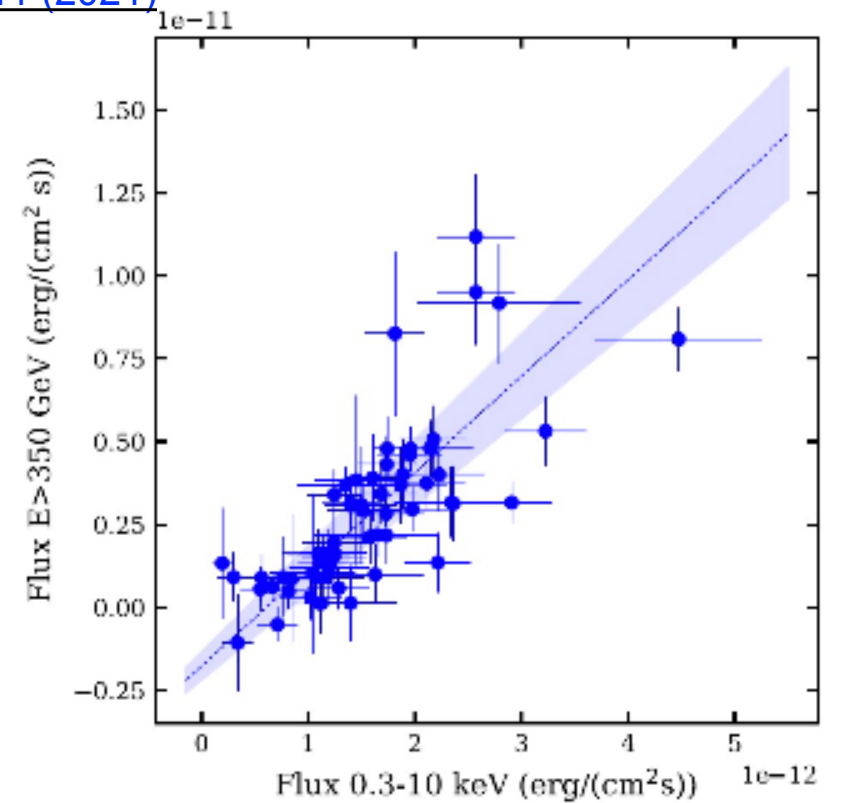
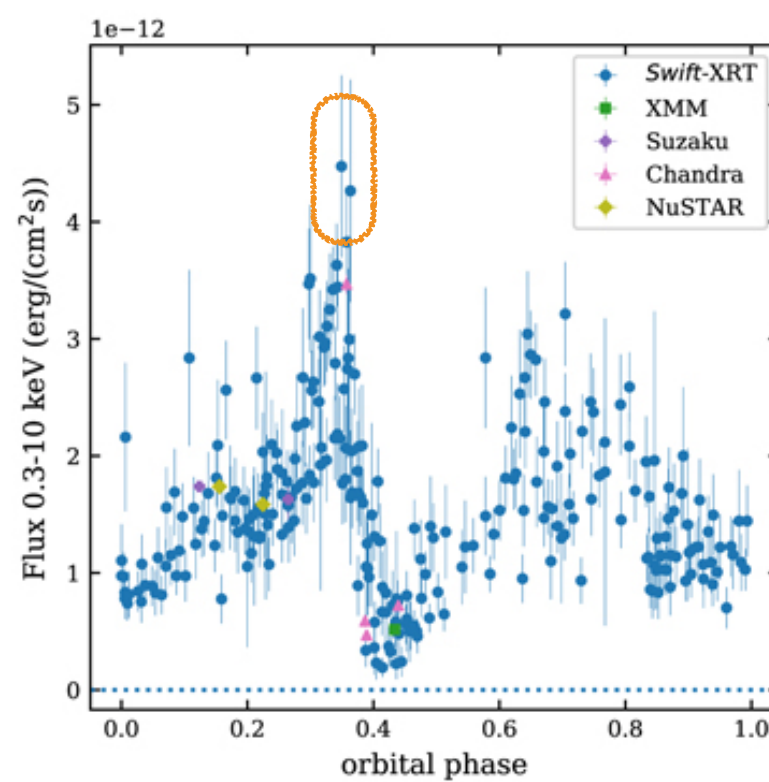
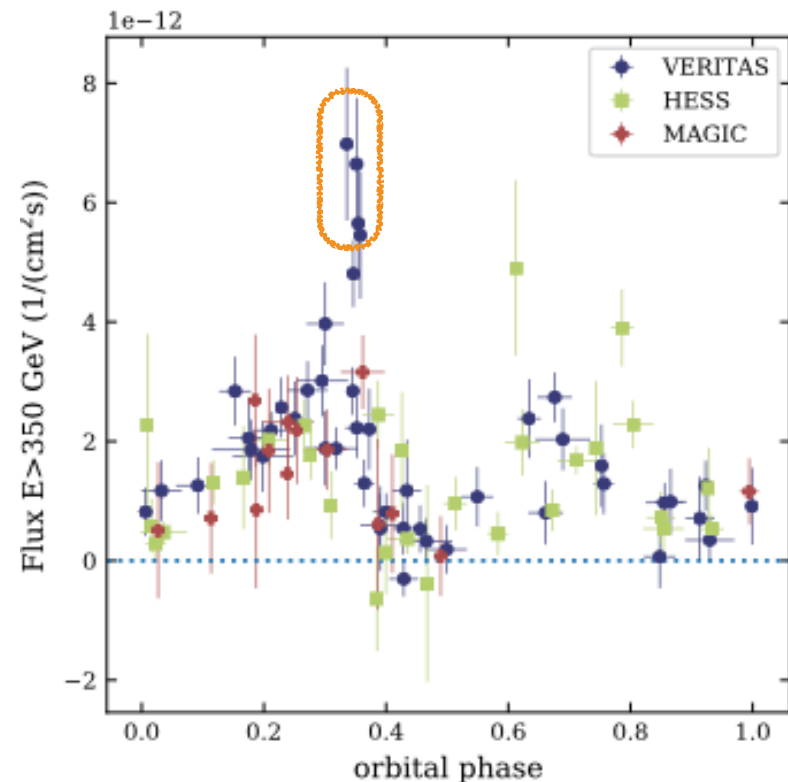
HESS J0632+057



- The system of Be star (MWC 148) and **unknown** compact object
- Located at 1.1-1.7 kpc distance
- Data:
 - TeV: H.E.S.S., MAGIC, VERITAS (450 hr of data over 15 yr)
 - X-ray: *Swift*-XRT, XMM, Suzaku, Chandra, NuSTAR
- **Modulation:**
 - VHE: 316.7 ± 4.4 days
 - X-ray: 317.3 ± 0.7 days

- Indication of orbit-to-orbit variability
- Confirms **VHE/X-ray correlation**: Indication of common population of particles
- Large uncertainty in **orbital parameters**

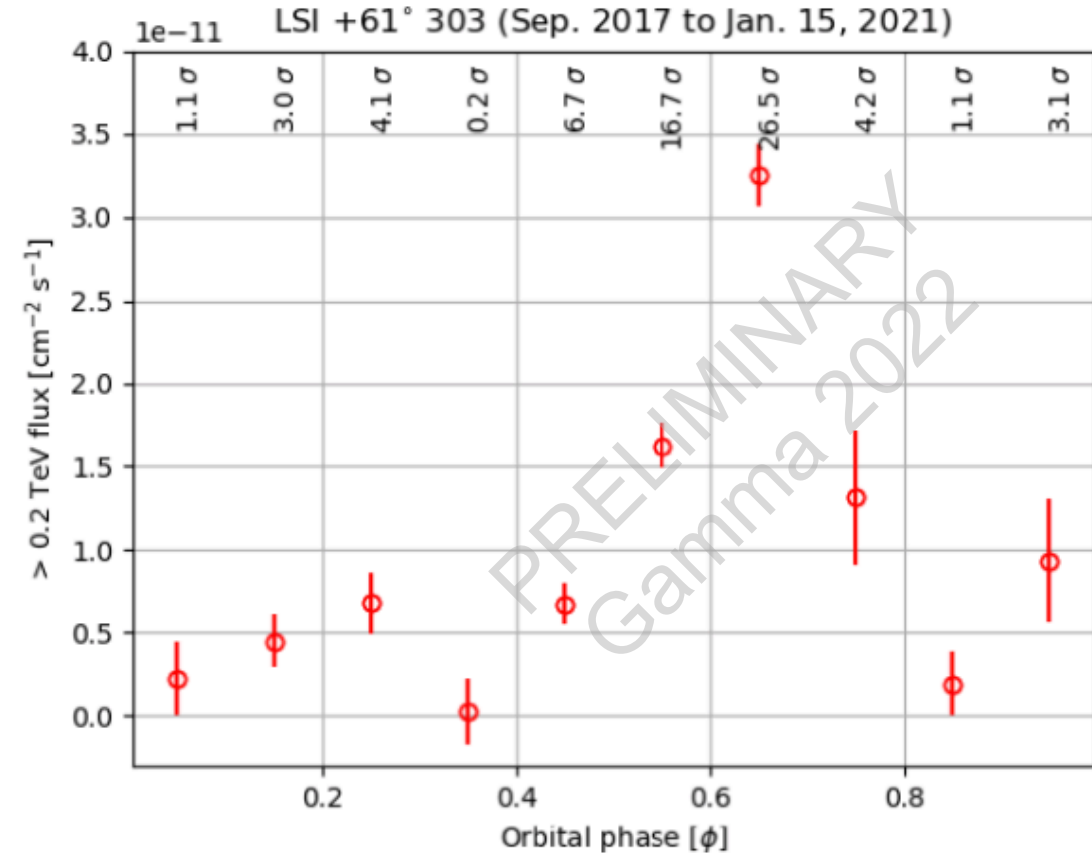
[VERITAS, MAGIC and HESS Collaboration ApJ 923, 241 \(2021\)](#)



LS I +61° 303



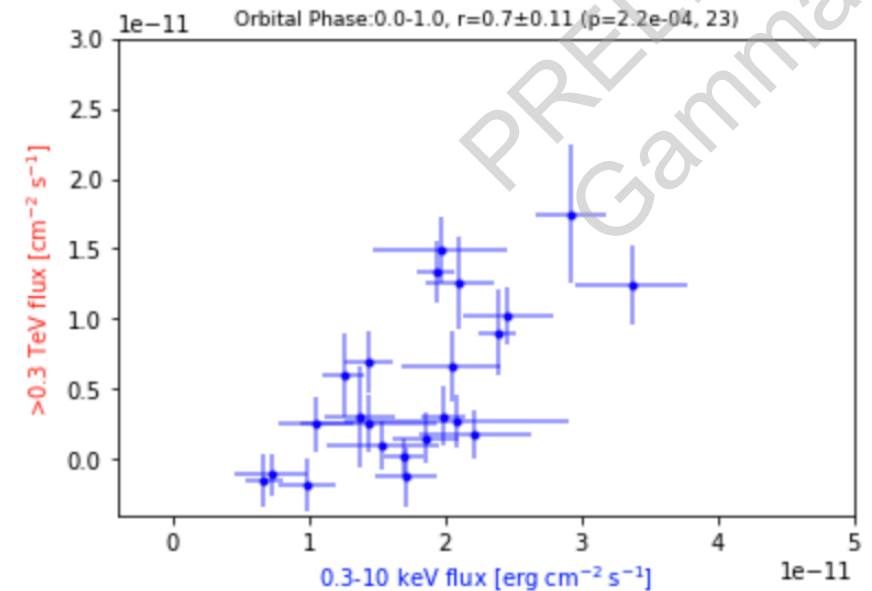
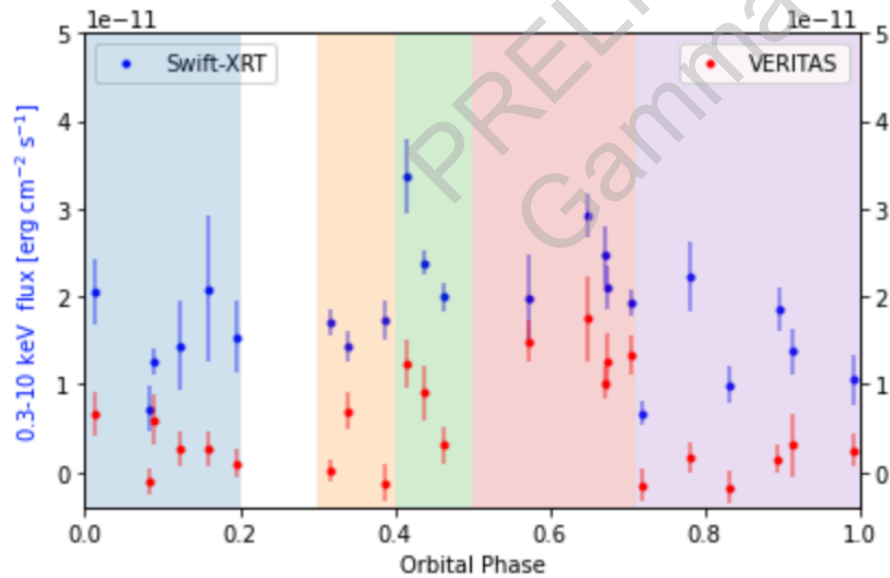
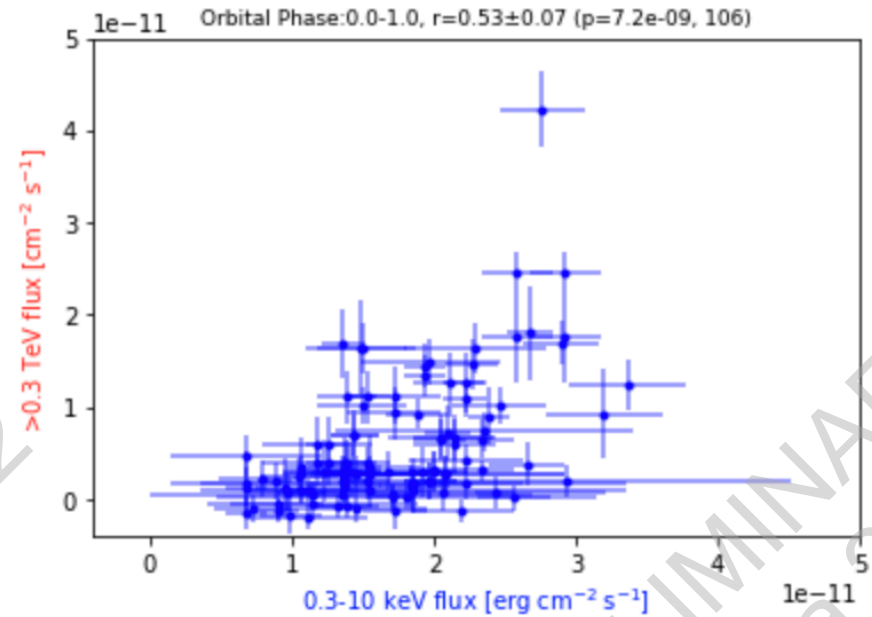
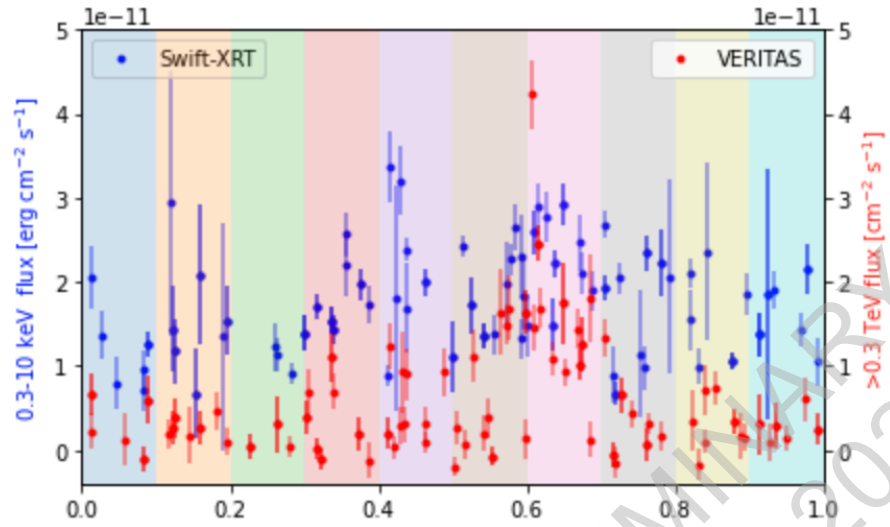
- Be star with **unknown** compact companion
- **Orbital period**: 26.5 days
- Super-orbital period: 4.6 years (radio, X-ray, GeV, TeV(?))
- Located at ~2 kpc distance
- Large uncertainty in **orbital parameters**
- Existence of transient **radio pulsation** with a period of ~269 ms ($>20\sigma$) by FAST [Shan-Shan Weng et al. 2022](#)



Correlation study



Simultaneous data within 24 hr and 0.5 hr



Correlation study

TeV and X-ray

On timescale of 0.5 hr:

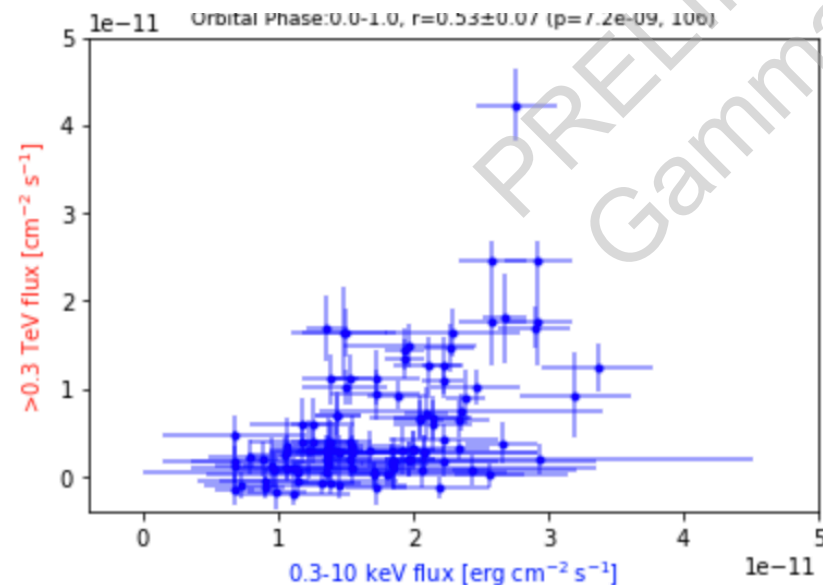
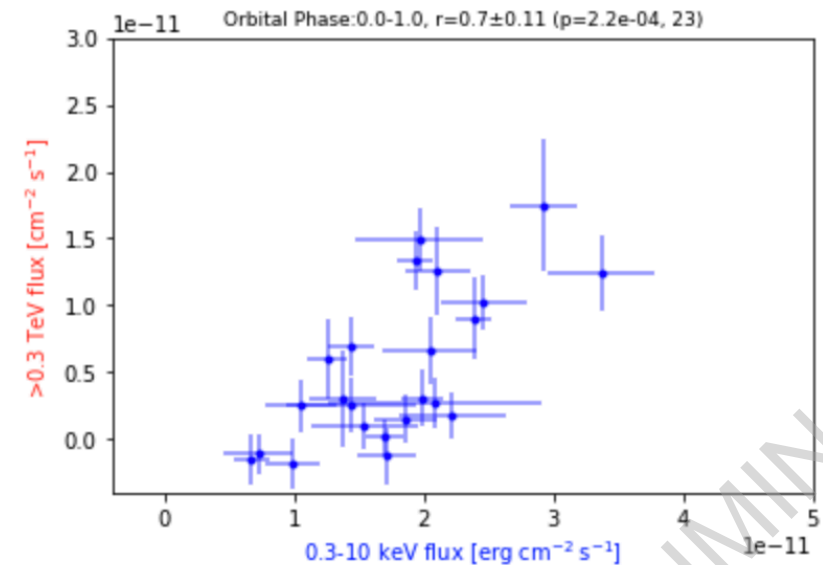
- Correlation coefficient = 0.69 ± 0.11
- Could be originating from same population of particles!

On timescale of 24 hr:

- Correlation coefficient = 0.53 ± 0.07
- Weaker
- Short correlation timescale?
- Intrinsic to the source or poor data sampling?
- Higher than linear order correlation?

Who I could be?

- **Pulsar** : X-ray to TeV emission powered by IC scattering off stellar UV photons (Zdziarski et al. (2008))
- **Magnetar** : rotationally powered region to a propeller regime (flip-flop behaviour) (Torres et al. (2012))
- ✗ **Microquasar** : Synchrotron dominates X-ray, while IC (SSC+EC) dominates above 1 MeV (Gupta & Böettcher (2006))





Summary

Results and outlook

Results:

- X-ray and TeV emissions appear to be correlated
 - **HESS J0632+057:**
 - X-ray and TeV variability: As short as hours
 - **LS I +61° 303:**
 - X-ray variability: timescale of ~ 1000 sec ([Smith, A et al. ApJ 693, 1621S \(2009\)](#))
 - TeV variability: Order of one day or less ([VERITAS Collaboration ApJ 817L, 7A \(2016\)](#))

Outlook:

- The Two-wind interactions ([Paredes-Fortuny et al. 2015](#)):
 - Relativistic pulsar wind and non-relativistic inhomogeneous wind of massive star
- Changing medium travelled by the compact object
 - Measurement of N_H along the orbit \longrightarrow Gradual build up and destruction of disk? 🤔

Thank you!

Backup

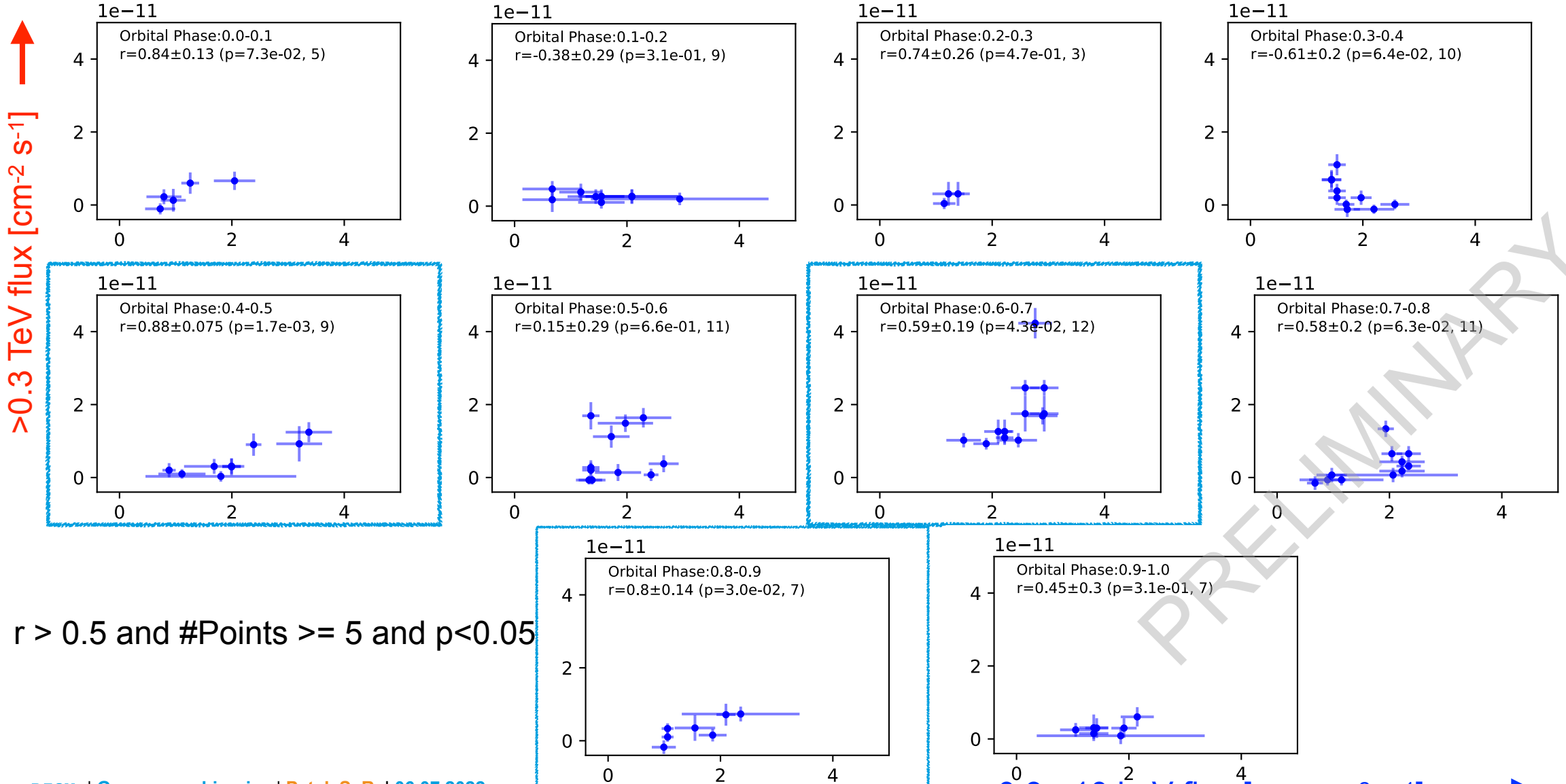


Correlation: Orbital phase-wise

TeV and X-ray (simultaneous within 24 hr)



>0.3 TeV flux [cm⁻² s⁻¹]



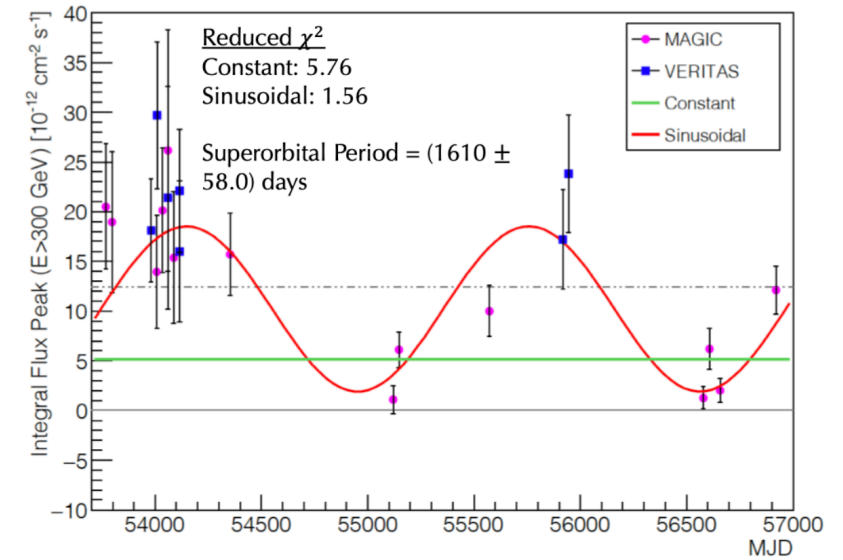
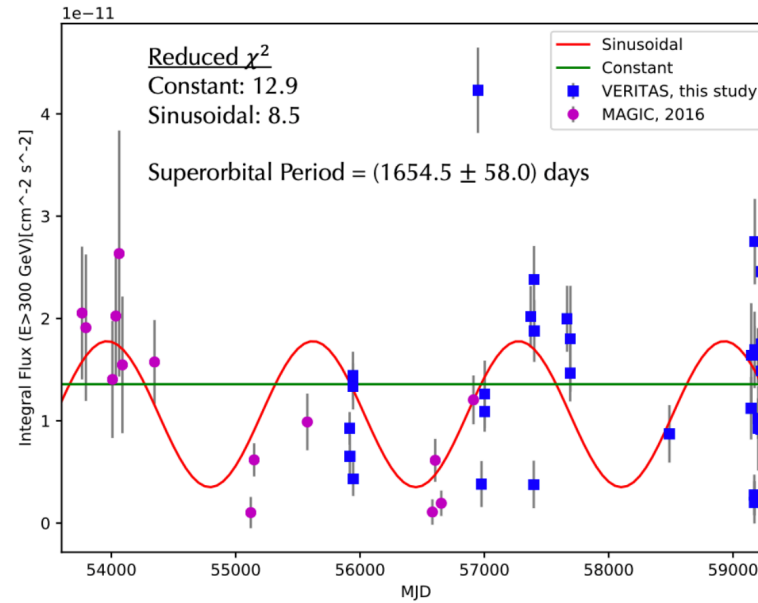
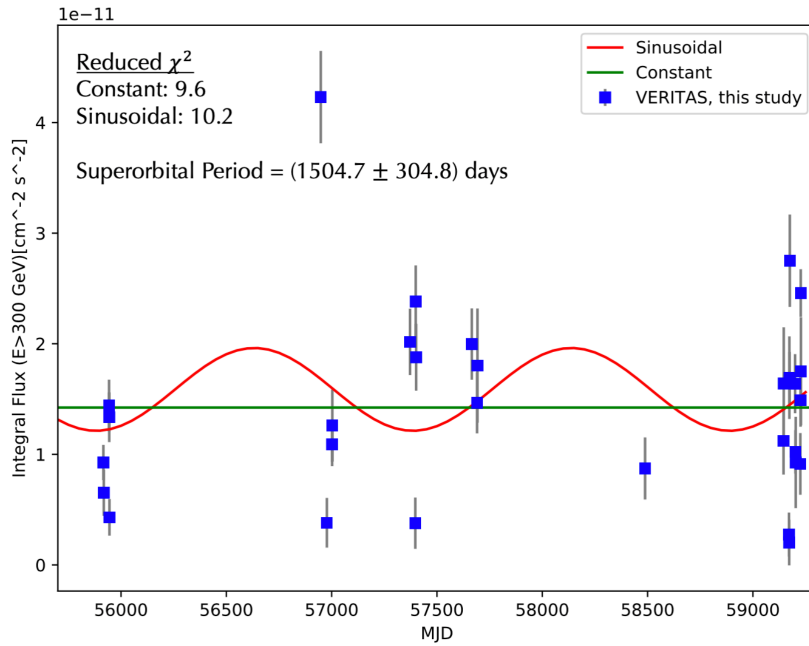
$r > 0.5$ and #Points ≥ 5 and $p < 0.05$

Back up

Super-orbital period (TeV)



Orbital period: 0.5-0.75



M. L. Ahnen et al.: Multi-year study of LS I +61° 303

Gamma-ray binaries

General Properties



	PSR	LS	LS I	HESS	1 FGL	HESS	LMC P3 (* *)
	B1259-63 (·)	5039 (†)	61° 303 (·)	J0632+057 (·)	J1018.6-5856 (‡)	J1832-093	
P_{orb} (days)	1236.724526(6)	3.90603(8)	26.496(3)	315(5)	16.544(8)	-	10.301(2)
e	0.86987970(6)	0.24(8)	0.54(3)	0.83(8)	0.31(16)	-	0.40(7)
ω (°)	138.665013(11) (#)	212(5)	41(6)	129(17)	89(30)	-	11(12)
i (°)	153.3 ^{+3.2} _{-3.0}	13-64	10-60	47-80	-	-	-
d (kpc) ⁽¹⁾	2.39 ± 0.18	2.07 ± 0.22	2.63 ± 0.26	2.76 ± 0.34	6.52 ± 1.08	-	50.0 ± 1
Spectral type	O9.5Ve	O6.5V(f)	B0Ve	B0Vpe	O6V(f)	-	O5 III(f)
$M.$ (M_{\odot})	14.2-29.8	23	12	16	31	-	-
$R.$ (R_{\odot})	9.2	9.3	10	8	10.1	-	-
$T.$ (K)	33 500	39 000	22 500	30 000	38 900	-	40 000
$d_{\text{periastron}}$ (AU)	0.94	0.09	0.19	0.40	(0.41)	-	-
d_{apastron} (AU)	13.4	0.19	0.64	4.35	(0.41)	-	-
$\phi_{\text{periastron}}$	0	0	0.23	0.967	-	-	0.13
$\phi_{\text{sup. conj.}}$	0.995	0.080	0.036	0.063	-	-	0.98
$\phi_{\text{inf. conj.}}$	0.048	0.769	0.267	0.961	-	-	0.24
IRF:	South_z40	South_z20 North_z40	North_z20	South_z40 North_z20	South_z40	South_z20 North_z40	South_z40