

Long-term TeV Observations of the Gamma-ray Binary HESS J0632+057 with VERITAS

G.Maier¹ for the VERITAS collaboration²



¹Deutsches Elektronen-Synchrotron (DESY), email: gernot.maier@desy.de

²<http://veritas.sao.arizona.edu>

Introduction

The gamma-ray binary HESS J0632+057/VER J0633+057 has been observed at very-high energies for almost ten years by all major systems of imaging atmospheric Cherenkov telescopes. We present here new observations taken by the VERITAS observatory.

HESS J0632+057 in a nutshell:

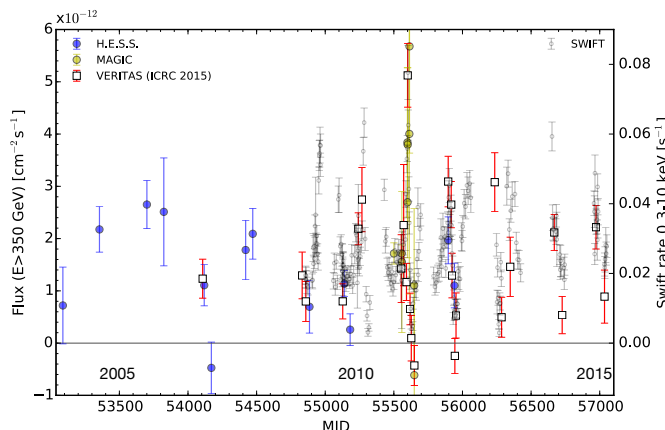
- binary system consisting of a massive star (B0 Vpe) and a compact object
- distance of 1.1-1.7 kpc
- orbital period 315 ± 5 days (from Swift XRT observations)
- eccentric orbit $e \sim 0.83$
- discovered in gamma rays by HESS in 2004/2005
- periodical flux modulations observed in X-rays (Swift) and gamma rays (VERITAS)
- not detected by Fermi LAT (it is the only gamma-ray binary which is not seen at MeV/GeV energies)

Long-term Swift and VERITAS Observations

HESS J0632+057 has been observed by VERITAS for a total of 200 hours between 2006 December and 2015 January at energies above ≈ 350 GeV.

At X-ray energies, Swift-XRT monitored HESS J0632+057 at 0.3-10 keV from 2009 January to 2015 January.

Fig 1: Long-term X-ray and gamma-ray light curve from 2004 to 2015



Phase-folded VERITAS gamma-ray observations

The variability pattern of the phase-folded gamma-ray light curve follows the X-ray light curve (see Fig 1). The first maximum at phases 0.2-0.4 is brighter than the emission at phases 0.6-0.75, but like the X-ray measurement exhibits flux variability at similar phases. The binary is clearly detected in phases 0.2-0.4, 0.6-0.75, and 0.75-0.2. No significant gamma-ray emission has been detected during the dip in X-ray fluxes around apastron.

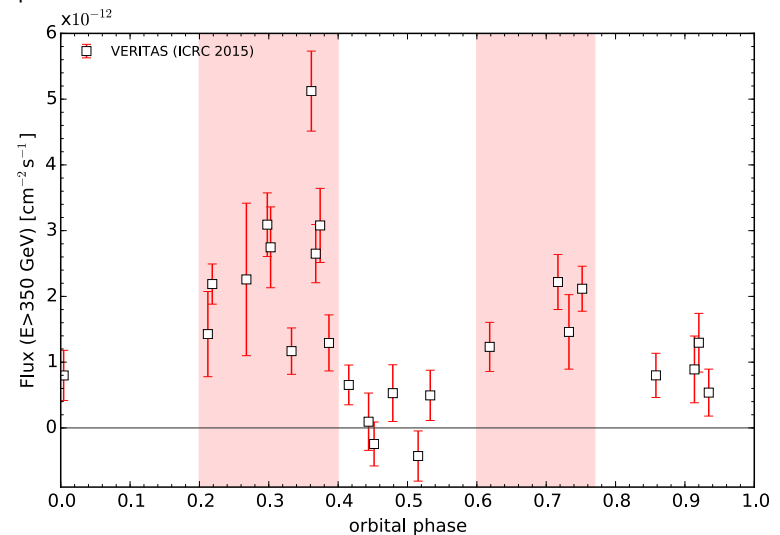


Fig 4: Phase-folded VERITAS gamma-ray light curve for energies > 350 GeV using an orbital period of 315 days. The shaded areas indicated the selection of phase ranges used for the spectral analysis

Phase-dependent spectral analysis

Orbital phase	all phases	0.2-0.4	0.4-0.6	0.6-0.75	0.75-0.2
Observation time (h)	201.6	74	46	29	52
Significance (σ)	20.5	19.2	2.5	9.7	7.1
Flux Normalization Φ_0 at 1 TeV	4.1 ± 0.2	7.18 ± 0.43	-	5.58 ± 0.74	3.23 ± 0.49
Photon index γ	2.69 ± 0.06	2.63 ± 0.07	-	2.48 ± 0.16	2.68 ± 0.2
χ^2/N	20.9/9	13.0/7	-	3.6/6	3.1/6

Table1: Analysis results for energies > 350 GeV for the phase-folded VERITAS measurements. The lower three lines of the table show the fit results assuming a power-law distribution $dN/dE = \Phi_0 \cdot E^{-\gamma}$ of the data, see Fig. 4. The flux normalisation constant Φ_0 is in units of $10^{-13} \text{ cm}^{-2} \text{ s}^{-1} \text{ TeV}^{-1}$.

Orbital period from Swift XRT data

The X-ray rate versus time shows non-sinusoidal variations, thus the autocorrelation function (Z-DCF) and phase dispersion minimisation method were applied. Results are consistent with an orbital period of 315 days.

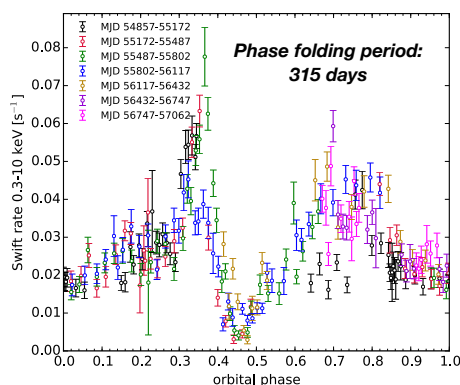


Fig 2: Phase folded Swift-XRT X-ray light curve. Different colours indicate different orbital periods

Correlation between X-ray and Gamma-ray emission

The correlation analysis (based on Z-DCFs) for contemporaneous observations (± 2.5 day intervals around the date of the gamma-ray observations) results in a significant correlation (Z-DCF/Z-DCF_{error} = 6.8) with a time lag consistent with zero.

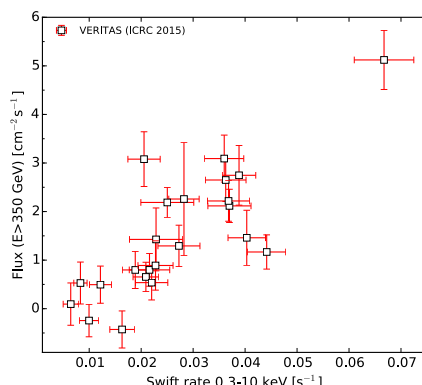


Fig 3: Gamma-ray fluxes vs. X-ray rates for contemporaneous observations

The differential energy spectra in gamma rays during the two maxima can be described by power-law distributions. The parameters of the spectral fits are consistent with each other, which points towards similar physical conditions at the gamma-ray emission sites during the high states before and after the apastron phase.

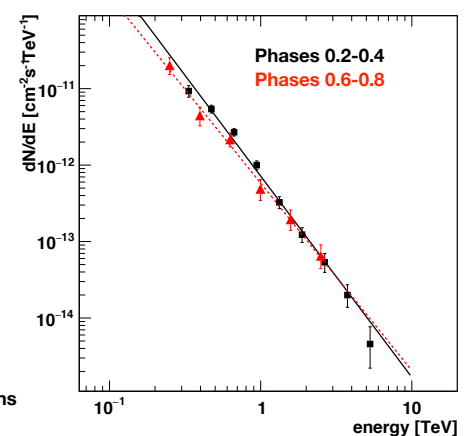


Fig 5: Differential energy spectra for gamma-ray photons for the orbital phase ranges 0.2-0.4 and 0.6-0.8.

Acknowledgments

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(See proceedings for a complete bibliography.)