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TeV and X-ray Monitoring of LS I +61 303 With VERITAS, Swift, and RXTE

A. SMITH[1,2] FOR THE VERITAS COLLABORATION[3]
[1] *Smithsonian Astrophysical Observatory*
[2] *University of Leeds*
[3] *For a complete author list please see Maier et al., "VERITAS: Status and Latest Results", these conference preceedings.*
smith@egret.sao.arizona.edu

Abstract: Between September 2006 and February 2007, the galactic binary LS I +61 303 was monitored in the TeV band with VERITAS, a newly commissioned array of imaging Cherenkov telescopes. These observations confirm LS I +61 303 as a variable TeV gamma-ray source, with emission peaking between orbital phase 0.6 and 0.7. During this observational period, monitoring in the X-ray regime was also carried out using both the RXTE and Swift detectors, which offered complementary coverage of the source. Outbursts in the 0.2-10 keV band were observed by both satellites at close to the same orbital phase as the TeV peak during the 2 orbital cycles covered simultaneously in both bands. While this source has been extensively studied in the X-ray band in the past, this is the first observational campaign to utilize contemporaneous X-ray and TeV data on LS I +61 303.

Introduction

First associated with the COS-B source 2CG 135+01 [1] in 1978, LS I +61 303 has been a source of considerable interest for the last 3 decades due to its peculiar behavior in radio and X-rays. Located at $\sim$2 kpc distance [2], LS I +61 303 is a pairing of a Be star with a neutron star or a black hole which completes an orbital transit every 26.496 days [3]. Flaring behavior has been historically detected in radio[4], X-rays[5][6], and most recently TeV gamma rays[7]. X-ray campaigns show flaring activity occuring regularly, every orbital cycle around orbital phase 0.4$\rightarrow$0.7 [5][6][8][9]. The most interesting feature of the X-ray flares is that they consistently appear to precede the radio outbursts which occur several days later. LS I +61 303 has also been associated with the EGRET GeV source 3EG J0241[10] which showed evidence for outbursts both near perisastron passage ($\sim$0.23[3]) and later in the orbit near phase 0.5 [11].

Traditionally, there have been two classes of models surrounding variable high-energy emission from this source. The first [12][13] assumes that the broadband emission is generated by accretion around the neutron star as it encounters varying stellar wind densities in its orbit (microquasar models). Higher accretion rates cause a radio jet to form which can then upscatter stellar photons to TeV energies. Observations resolving compact one-sided radio emission from the system were taken as unambiguous evidence for the presence of a relativistic jet and thus proof of the microquasar model [13].

Alternatively, in the models of [14][15][16], the system is treated as a binary pulsar with particle acceleration taking place in the shock formed between the pulsar and stellar winds. These pulsar models interpret the resolved radio emission in [13] as coming from the cometary tail of the pulsar wind as it is blown about by the stellar wind. This assertion is lent further credence by the more in-depth radio imaging of this cometary tail detailed in [17]. Although the binary pulsar model for LS I +61 303 seems much more likely in light of these recent observations, there are still unresolved issues (see [18]) in both models which need further multiwavelength observations to investigate.

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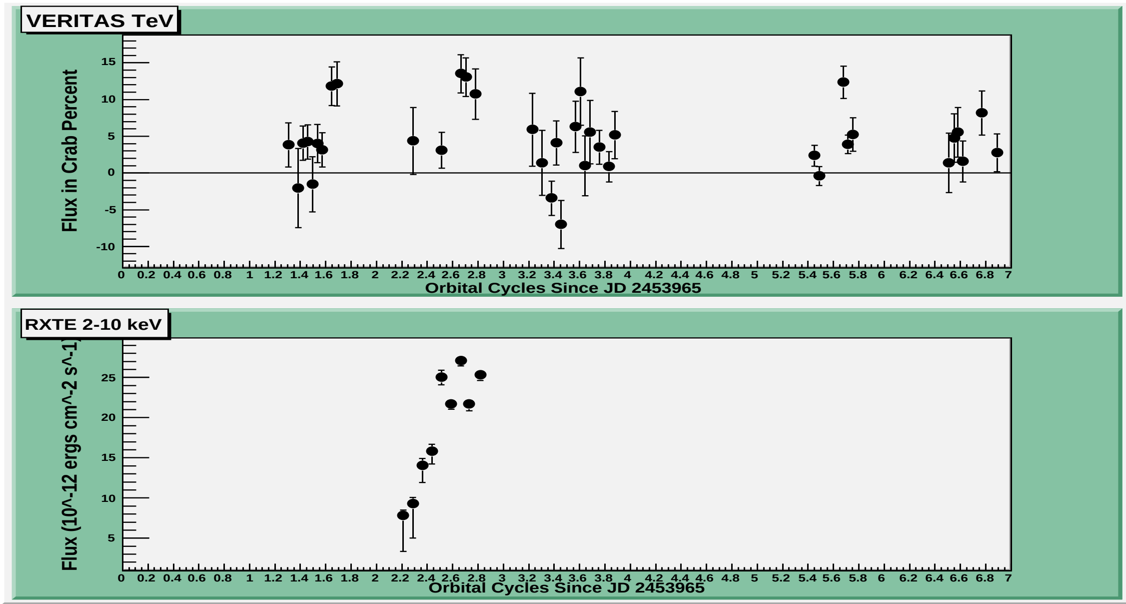

Figure 1: VERITAS and RXTE monitoring of LS I +61 303 over seven orbital periods. The Swift data will be presented at the ICRC 07. Peaks can be seen in both data sets at around ϕ=n+0.7 (n=0$\rightarrow$6). The RXTE data also shows emission peaking near the same phase.

Observations

VERITAS TeV Observations

Sensitive in the energy range 100 GeV to 30 TeV, VERITAS is a newly-commissioned array of four 12m imaging Cherenkov telescopes which has begun its full observational program as of January 2007 (see G. Maier in these proceedings). During the Fall of 2006, the initial 2-telescope stereo array was in operation, with a third telescope being added for observations from January onward. TeV rates quoted henceforth are in terms of Crab Nebual fluxes taken from contemporaneous observations (see O.Celik in these proceedings).

From September 2006 until February 2007, LS I +61 303 was observed for a total of 43.3 hours covering orbital phases 0.2$\rightarrow$0.9. These observations covered 5 orbital cycles with reliable detections resulting in every orbital period with the exception of the February dark run (see G. Maier in these conference proceedings). However, the data taken in February was a shorter exposure and is consistent with the behavior seen in the other months. During the "OFF" phases, i.e., 0.2$\rightarrow$0.5 and 0.8$\rightarrow$0.9, the source is quiescent in the TeV range, with no reliable detection resulting. During the "ON" phase, 0.5$\rightarrow$0.8, VHE gamma rays are significantly detected every orbital cycle with emission ranging between 4% and 13% of the Crab nebula flux. VERITAS observations showed the TeV flux peak centered at around 0.65$\rightarrow$0.74, which is later in phase than the TeV maximum observed by MAGIC [7] at 0.5$\rightarrow$0.6.

RXTE Observations

Monitoring in the 2-10 keV band was carried out by RXTE [19] for nine 1 ks observations from 2006/10/15 to 2006/10/31. Spectral fitting was carried out with XSPEC 5.12.3.1 assuming an absorbed power law model. Fluxes shown in figures 1 and 2 come from integrating this model over the 2-10 keV range and are scaled to emission seen by RXTE from the Crab Nebula [20]. The light curve produced from this fitting shows a clear flare evolving from around orbital phase 0.45, peaking at around 0.7 and persisting until the end

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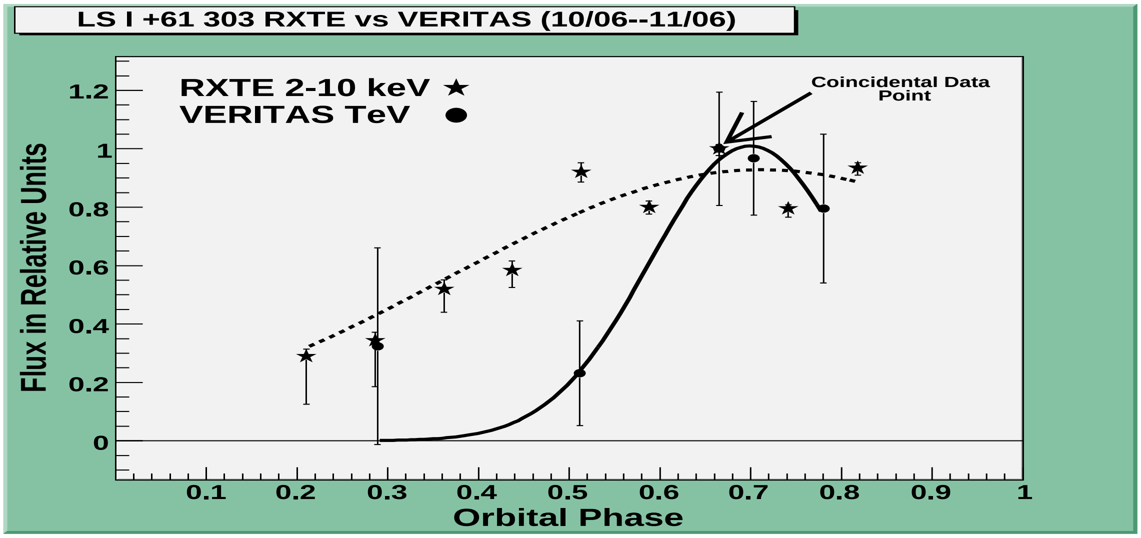

Figure 2: Comparisons between contemporaneous TeV and X-ray data taken with VERITAS and RXTE, both fit with Gaussian curves. The flux values for each light curve have been scaled with respect to their own maximum flux for easy comparison. Note the coincidental data point in both bands at orbital phase 0.66, this night of observations will be used for spectral comparison to be presented at the 2007 ICRC.

of the data set at 0.8. This flare was particularly strong, with emission peaking at 27.09×10^{-12}ergs $s^{-1}cm^{-2}$ which is larger than, but consistent with, past RXTE observations of this source[5]. The spectra fit to each data point show no strong evidence for spectral variation, however, the relatively short exposure time and reduced instrument operation (i.e. only one PCU on for some nights) must be taken into account. A more detailed description of these observations will be provided in an upcoming publication.

Swift Observations

From September 2006 to October 2006, and again in November-January 2006, the XRT experiment aboard the Swift satellite [21] was used to monitor LS I +61 303 in the 0.2-10 keV band. Reduction and analysis procedure can be found in Holder, Falcone and Morris (this conference). This data set overlapped only once with VERITAS TeV data but fortunately it covered a region where VERITAS saw a clear detection of the source. This data will be presented at the 2007 ICRC in Merida.

Results

TeV Variability

It can be seen from figures 1 and 2 that the phase of the peak emission in the VERITAS data is always near the phase region 0.65→0.7. The VERITAS data has a maximum flux between 0.65 and 0.75, which if compared to the location of the reported MAGIC TeV maximum of 0.5 to 0.6, appears to be slightly offset in phase. However, a full statistical analysis of the lightcurves has yet to be carried out. Also, both the MAGIC and VERITAS lightcurves do not evenly sample the entire orbital phase. More long-term, evenly sampled observations are needed to investigate the nature of the TeV variability from the LS I +61 303.

Correlation Between Data Sets

Shown in figures 1 and 2 are the comparisons between the light curves derived from the RXTE data taken contemporaneously with VERITAS. While the X-ray curve is temporally broader in development, there is evidence for correlation between the

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different bands. Further analysis of the data as well as further long-term simultaneous observations are necessary to investigate this correlation further.

Discussion

With the preliminary analysis presented here we are unable to make any firm statements constraining either the microquasar or the binary pulsar models. It is noted that the X-ray and TeV emission appear to be correlated in time. Further analysis will be performed to study the nature of a possible correlation between the collected data from RXTE, Swift, and VERITAS. This will be presented at the 2007 ICRC meeting in Merida, MX.

Acknowledgments

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