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A leptonic one-zone model of the X-Ray/VHE correlated emission in LS I +61 303

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Abstract

The MAGIC collaboration has recently reported correlated X-ray and VHE gamma-ray emission from the gamma-ray binary LS I +61 303 during ∼60% of one orbit, thus suggesting that the emission in these two bands has its origin in a single particle population. Using a one zone population of relativistic leptonic particles with dominant adiabatic losses located at the position of the compact object we are able to reproduce the observed X-ray and VHE lightcurves. From the best fit result, we obtain the magnetic field, energy budget and acceleration efficiency of the accelerator, and discuss these in the context of the young non-acretting pulsar and acretting compact object scenarios. The results also confirm that the GeV emission detected by Fermi does not come from the same parent particle population as the X-ray and VHE emission.

1 Introduction

LS I +61 303 is one of the few X-ray binaries (along with PSR B1259-63, LS 5039 and Cygnus X-1) that have been detected in very high energy (VHE) gamma rays. It is a high-mass X-ray binary containing a compact object with a mass between 1 and 4 $M_\odot$ orbiting the main star every $\sim$ 26.5 d in an eccentric orbit [6]. Observations of persistent jet-like features in the radio domain prompted a classification of the source as a microquasar [12], but later observations along a whole orbital period revealed a rotating elongated feature that was interpreted as the interaction between a pulsar wind and the stellar wind [8]. In the X-ray domain LS I +61 303 shows an orbital periodicity [13] with quasi-periodic outbursts in the phase range 0.4–0.8 . The source shows short-term flux and spectral variability in timescales of kiloseconds [15, 14]. LS I +61 303 has been detected in the VHE domain by MAGIC [3] and VERITAS [2]. It shows a periodic behaviour [4] with maxima occurring around phase 0.6–0.7 and non-detectable flux around periastron ($\phi = 0.275$). Models of both accreting and non-accreting scenarios have attempted to explain the broadband spectrum and its orbital behaviour [9, 7].

The combined effect of short-term variability in the X-ray domain and night-to-night variability in the VHE domain has precluded a clear detection of X-ray/VHE emission correlation from archival observations. In 2007, a campaign of simultaneous observations with the MAGIC Cherenkov telescope and the XMM-*Newton* and *Swift* X-ray satellites revealed a correlation between the X-ray and VHE bands [5]. The suggestion that the emission in both energy bands comes from the same population of accelerated particles turns these observations in an ideal data set to test the properties of the accelerator in LS I +61 303. Here we present a leptonic one zone model to explain the exceptional data from these observations.

2 Model description and results

The discovery of correlation between the X-ray and VHE bands is important because it points towards the mechanism of emission modulation at both bands. The fast and simultaneous changes in flux in both bands indicate that the modulation mechanism has to directly affect the emission level of the IC and synchrotron processes for leptonic dominated emission. There are two mechanisms that may modulate IC emission independently of synchrotron emission: anisotropic IC scattering and photon-photon pair production [11, 10]. Synchrotron emission, on the other hand, would only be independently modulated through a modulation of the magnetic field. The only way to simultaneously modulate both the X-ray and VHE emission is to consider a modulation of the number of emitting particles through dominant adiabatic losses, which are a manifestation of the energy losses of electrons through (magneto)hydrodynamical processes in the accelerator region possibly related to the interaction of the pulsar wind or the black hole jet with the stellar wind of the massive companion. In the regime of dominant adiabatic losses the emitted X-ray flux is proportional to the number of emitting particles, so the orbital dependency of adiabatic losses can be inferred from the X-ray lightcurve. The hard X-ray spectrum with photon index $\Gamma \simeq 1.5$ also points towards dominant adiabatic losses, which imply an injection electron index of $\alpha_e \simeq 2$. [16] applied the same reasoning to understand the X-ray/VHE correlation found in LS 5039.

In this work we adopt a leptonic model for X-ray and VHE gamma-ray emission from LS I +61 303 in which emission comes from a single region with homogeneous physical properties located at the position of the compact object. We have calculated the broad band emission from this region along the orbit and obtained the fluxes and spectral indexes that would be observable in the X-ray (0.3–10 keV) and VHE gamma-rays ($E_\gamma > 400$ GeV).

The lack of detectable VHE emission during periastron [4] and the lack of pair production absorption due to angular effects indicates that the number of emitting particles is low even though significant X-ray emission (about half of the peak flux) is detected. This can be explained by considering that not all of the X-ray emission is correlated with the VHE band, but only an excess or flaring fraction over a pedestal flux. We have used the excess X-ray flux over a fixed pedestal to infer the phase dependency of adiabatic losses along a whole orbit.

In Fig. 1 we show the SED averaged over the phase ranges of the three observations

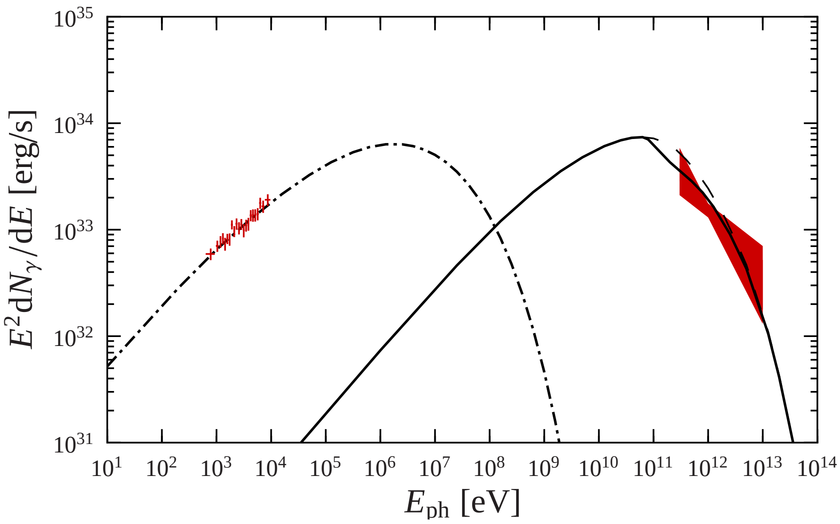

Figure 1: SED averaged over the observation periods during peak between phases 0.6 and 0.7, with synchrotron (dot-dashed) and IC (solid). The crosses show the XMM-*Newton* EPIC-pn spectrum averaged over three observations and deabsorbed taking $N_{\rm H} = 5 \times 10^{21}$ cm^{-2}. The MAGIC simultaneous spectrum is shown as a red bow-tie.

with phases between 0.6 and 0.7, along with the observed X-ray and VHE spectra. As can be seen in Fig. 2, we have been able to reproduce the X-ray and VHE lightcurves obtained during the 2007 multi-wavelength campaign. The adiabatic cooling times range from a few tens to a few hundred seconds and results in a quite efficient accelerator with $\eta \simeq 7 - 130$ and accelerator sizes of $R \simeq (1\text{–}16) \times 10^{12}$ cm. The X-ray/VHE flux ratio is best described by an ambient magnetic field of $B = 0.25$ G, and the fit is very sensitive to this parameter. The energy budget needed for these results is around $\sim 10^{35}$ erg/s, well within values attainable by both of the proposed scenarios for the source. A detailed account of this model and its results and implications will be shortly submitted for publication.

3 Discussion

While this work is not able to discern between the two proposed scenarios, the quality of the data and simple model place strong constraints on the accelerator physical properties that will have to be fulfilled by any detailed model of the source. However, it is clear that, at least during the phases around the X-ray and VHE peaks, adiabatic losses dominate over radiative losses. Phase-averaged emission in the GeV band is much lower and peaks at apastron instead of periastron when compared with the Fermi detection of the source [1]. Therefore, we conclude that GeV emission is not originated in the same particle population as X-ray and VHE.

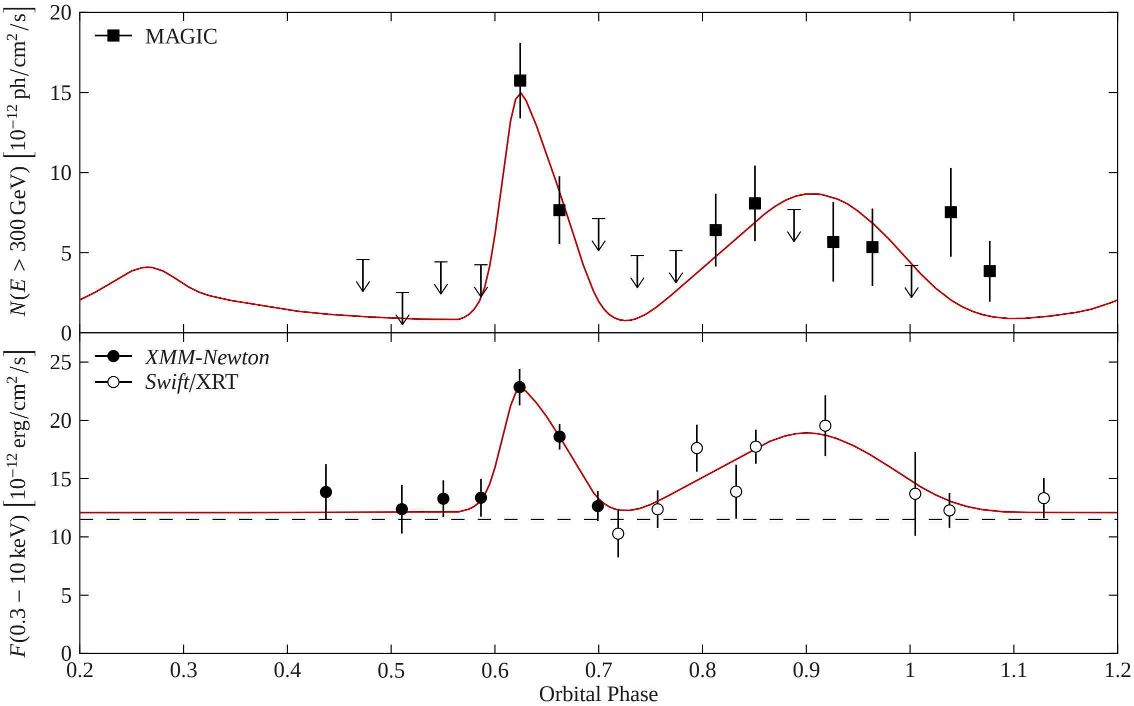

Figure 2: *Top:* Computed VHE lightcurve (red line) and observed VHE lightcurve by MAGIC. Observations with significance above 2σ are shown in filled squares while 95% CL upper limits are shown otherwise. *Bottom:* Computed X-ray lightcurve (red line) and X-ray lightcurve observed during the multiwavelength campaign with XMM-*Newton* (filled circles) and *Swift*/XRT (open circles). The pedestal flux is indicated by a horizontal dashed line. All error bars correspond to 1σ uncertainties.

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