PROCEEDINGS OF SCIENCE

INTEGRAL and XMM-Newton observations of the puzzling binary system LSI +61 303

Masha Chernyakova[*]
ISDC Versoix, Switzerland
Geneva Observatory, University of Geneva, Sauverny, Switzerland
E-mail: `masha.chernyakova@obs.unige.ch`

Andrii Neronov
ISDC Versoix, Switzerland
Geneva Observatory, University of Geneva, Sauverny, Switzerland
E-mail: `andrii.neronov@obs.unige.ch`

Roland Walter
ISDC Versoix, Switzerland
Geneva Observatory, University of Geneva, Sauverny, Switzerland
E-mail: `roland.walter@obs.unige.ch`

LSI +61° 303 is one of the few X-ray binaries with Be star companion from which both radio and high-energy gamma-ray emission have been observed. We present *XMM-Newton* and *INTEGRAL* observations which reveal variability of the X-ray spectral index of the system. The X-ray spectrum is hard (photon index $\Gamma \simeq 1.5$) during the orbital phases of both high and low X-ray flux. However, the spectrum softens at the moment of transition from high to low X-ray state. The spectrum of the system in the hard X-ray band does not reveal the presence of a cut-off (or, at least a spectral break) at 10-60 keV energies, expected if the compact object is an accreting neutron star. The observed spectrum and spectral variability can be explained if the compact object in the system is a rotation powered pulsar. In this case the recently found X-ray spectral variability of the system on the several kiloseconds time scale can be explained by the clumpy structure of the Be star disk.

VI Microquasar Workshop: Microquasars and Beyond
September 18-22, 2006
Como, Italy

---

[*] Speaker.

1. Introduction

The Be star binary LSI +61° 303 is known to be a source of variable optical, radio, X-ray, gamma-ray and very high-energy gamma-ray emission. The periodicity of $T = 26.4960$ days of radio emission was associated with the binary orbital period (Gregory et al., 2002). Optical data allow to constrain the orbital parameters of the system revealing the eccentricity of the orbit, $e \simeq 0.7$ (Casares et al., 2005). However, the measurements are not sufficient to determine the nature of the compact object (neutron star or black hole), because the inclination of the orbit is poorly constrained. Radio observations reveal the presence of 100 AU-scale jet in the system which places LSI +61° 303 among the Galactic micro-quasars (Massi et al., 1993, 2004). The system is also a Galactic "micro-blazar" due to its association with 100 MeV gamma-ray source 2CG 135+01 (Tavani et al., 1998) visible up to TeV energies (Albert et al., 2006). The spectral and timing properties of the system in different energy ranges is summarized in Figures 1 and 2.

Below we present a study of LSI +61° 303 in the 0.5-100 keV energy band with *XMM-Newton* and *INTEGRAL* and discuss the observed spectral variability on the different time scales.

2. Observations

XMM-Newton has observed LSI +61° 303 with the EPIC instruments five times during 2002, and once in 2005. Four 2002 observations have been done during the same orbital cycle, and the fifth one has been done seven months later. A simple power law with photoelectric absorption ($N_H = 0.49 \times 10^{22}$ cm^{-2}) describes the spectrum of LSI +61° 303 well, with no evidence for any line features. The details of data analysis are given in Chernyakova et al. (2006); Sidoli et al. (2006). The log of the *XMM-Newton* data along with the spectral characteristics is presented in Table 1.

For *INTEGRAL* analysis we have used all available public data spread over the period from the January 2003 (rev 25) until March 2005 (rev 288). Overall we have analyzed 600 science windows which resulted in an effective vignetting corrected exposure of 273 ksec. The averaged spectrum of the source in hard X-rays (20 - 100 keV) is described by a simple power law ($\Gamma = 1.6 \pm 0.2$, $F_{20-60} = 2.5 \pm 0.3 \times 10^{-11}$ergs s^{-1}cm^{-2}), see Chernyakova et al. (2006).

Table 1: Journal of *XMM-Newton* observations of LSI +61° 303

Data Set	Date	Orbital Phase	Exposure (ks)	F(2-10 keV) 10^{-11}erg s^{-1}	Γ	χ^2 (dof)
X1	2002-02-05	0.55	6.4	1.30±0.04	1.60±0.03	474(456)
X2	2002-02-10	0.76	6.4	1.24±0.04	1.54±0.03	440(446)
X3	2002-02-17	0.01	6.4	0.61±0.03	1.78±0.04	184(188)
X4	2002-02-21	0.18	7.5	0.44±0.03	1.52±0.06	137(150)
X5	2002-09-16	0.97	6.4	1.25±0.05	1.55±0.02	488(496)
X6a	2005-01-27	0.61	16.0	1.29±0.01	1.62±0.01	681(596)
X6b	2005-01-28	0.61	29.0	0.40±0.01	1.83±0.01	618(533)

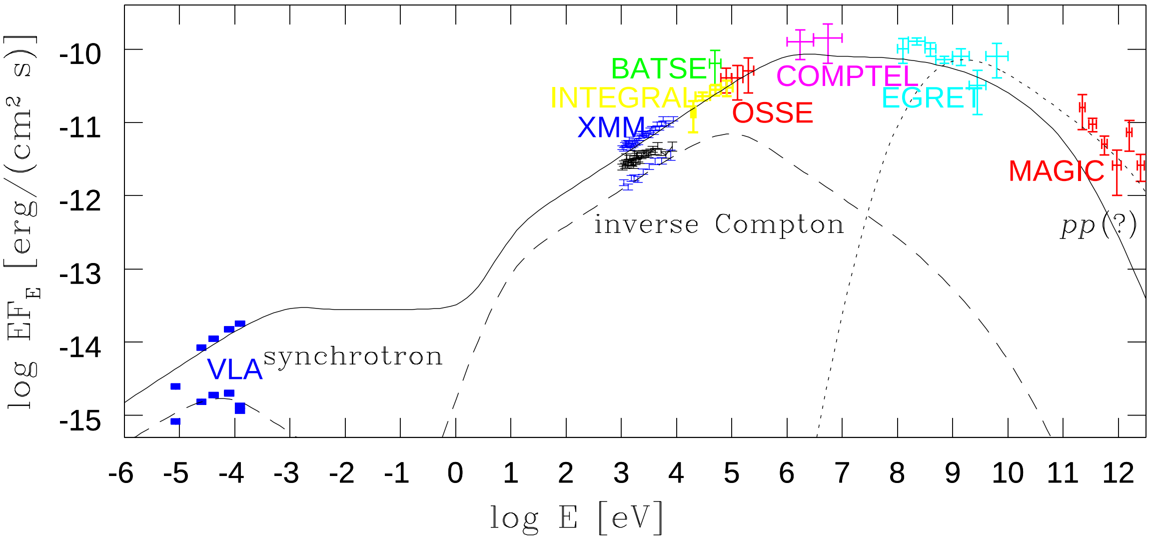

Figure 1: Broad band spectrum of LSI +61° 303. Radio data points are taken from Strickman et al. (1998). *CGRO* data points are from Tavani et al. (1998). MAGIC data points are from Albert et al. (2006). The solid (dashed) line shows the model fit within the synchrotron-inverse Compton model for the high (low) flux state of the source. The dotted line shows possible contribution from the proton proton interactions. The values of parameters of the model fits are cited in the text.

3. Broad band spectrum of the source.

Historically there are two broad classes of physical models of the source activity. The first one assumes that the activity is powered by accretion onto the compact object (either neutron star or a black hole) (Taylor & Gregory, 1984). Most of the Be star X-ray binaries contain an accreting neutron star as the compact object and most of them are transient sources. The spectra of these sources are characterized by the presence of an exponential cut-off in the hard X-ray band at energies 10-60 keV (Filippova et al., 2005). Our analysis of the *INTEGRAL* data shows that in the case of LSI +61° 303 no high-energy cut-off is found at the energies below 100 keV, the fact that does not fit well into the "conventional" accretion scenario.

In the second class of models, first proposed by Maraschi & Treves (1981), the activity of the source is explained by interactions of a young rotation powered pulsar with the wind from the companion Be star. Contrary to accreting compact object models, a featureless powerlaw keV – MeV spectrum is expected in the "rotation powered pulsar" scenario. In this scenario, radio, X-ray and gamma-ray emission come from the region where the pulsar wind interacts with the wind of Be star. An example of synchrotron – inverse Compton model fit of the broad band (radio to gamma-ray) spectrum of the source is shown in Fig. 1. The model parameters used for the fits of the broad band spectrum of the system in high (low) flux state in Fig. 1 are $B = 0.35$ G ($B = 0.25$ G), the electron spectrum described by a broken powerlaw with the spectral index $\Gamma_e = 2$ below the break energy $E_{br} = 2 \times 10^8$ eV ($E_{br} = 10^8$ eV) and $\Gamma_e = 3.5$ ($\Gamma_e = 4$) above the break energy. Such a break in the electron spectrum is natural if the relativistic electrons responsible for the X-ray emission are initially injected at high energies and subsequently cool down forming the characteristic E^{-2} cooling spectrum.

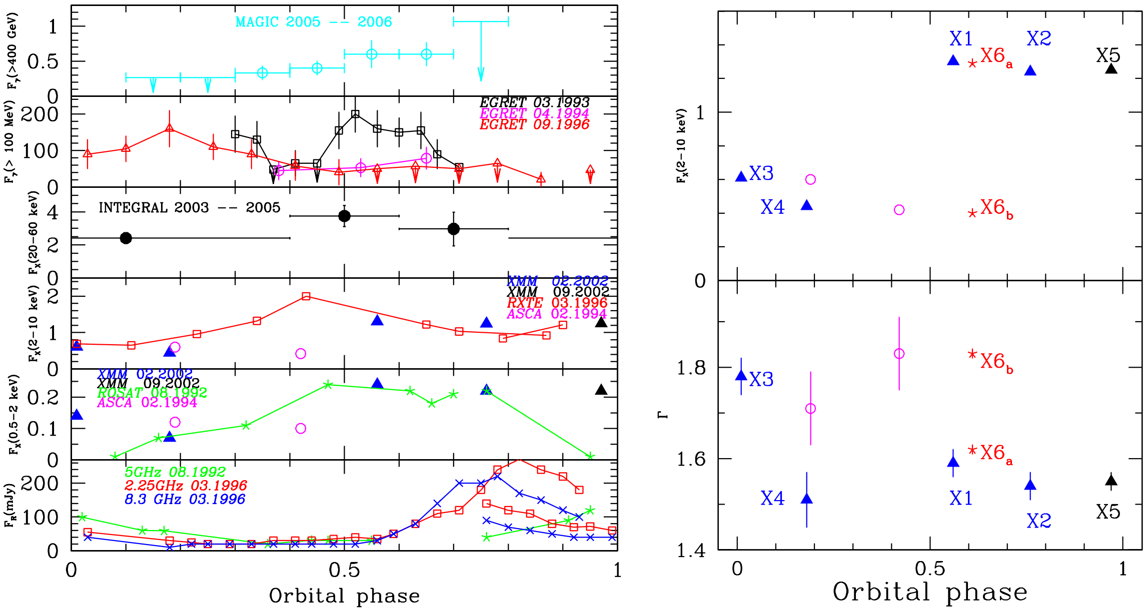

Figure 2: *Left panel:* Comparison between the TeV (top), GeV gamma-ray orbital lightcurves of LSI +61° 303 with the hard X-ray (20-60 keV), X-ray (2-10 keV), soft X-ray (0.5-2 keV) and radio (bottom) orbital lightcurves. The 0.5 - 2 keV and 2 - 10 keV X-ray flux is given in 10^{-11}ergs cm^{-2}s^{-1}. GeV γ-ray flux (>100MeV) is given in the units of 10^{-8}ph cm^{-2}s^{-1}. TeV flux (> 400 GeV) is in the units of 10^{-11} ph cm^{-2}s^{-1}). To guide the eye we have connected with lines data from the same orbital cycle. The time is assumed to increase from left to right, thus if the observation has started at the end of the orbital cycle it is shown with two lines of the same color, the line starting at larger orbital phase connects data points taken earlier. References for all data points are given in Chernyakova et al. (2006). *Right panel:* Spectral variability of the system in 2-10 keV energy range, as observed with *XMM-Newton* and *ASCA* (open circles).

4. Spectral variability of the source.

The graphical representation of the evolution of the spectral parameters along the orbit is given on the right panel of Figure 2. In the *XMM-Newton* energy band the powerlaw photon index is $\Gamma \simeq 1.5$ in all 2002 observations except for the observation X3, where we find significantly softer spectrum with $\Gamma = 1.78 \pm 0.04$. This indicates that the X-ray spectrum softens during the transition from higher to lower flux state. The softening of the spectrum can be explained assuming that the injection of electrons at high energies drops and higher energy electrons (emitting in the hard X-ray band) cool faster than the low energy ones (emitting in the soft X-ray band).

Injection from high energies can be explained if the electrons responsible for the X-ray emission originate from the cold pulsar wind with bulk Lorentz factor $\geq (several) \times 10^2$. In this case all electrons have initial energies larger than 100 MeV and the electron spectrum below 100 MeV formed in the process of inverse Compton cooling has the spectral index $\Gamma_e \simeq 2$. However, an immediate difficulty with such simple injection model is that the injection rate is not expected to vary with time, contrary to what is observed.

The variable injection rate could be provided if relativistic protons are either present in the pulsar wind or accelerated in the shock at the contact surface of pulsar and stellar wind. Such relativistic protons could interact with the low energy protons from the disk and produce injection of electrons at energies above $\sim$ 100 MeV via production and subsequent decays of charged pions. In this case variable injection rate of high-energy electrons is explained by the variations in the density of the stellar wind protons along the pulsar orbit.

The 2005 *XMM-Newton* observations reveal X-ray spectral variability of the system on the several kiloseconds time scale (Sidoli et al., 2006). This time scale coincides with the Compton cooling time $t_{ic} = 5(10^{38}/L_*)(R/10^{12})^2(E_{IC}/1KeV)^{0.5}ks$, and in the frame of the proton-proton interaction model can be explained by the presence of the clumps in the wind of the Be star. Indeed, if the pulsar wind meets a dense clump on its way it will lead to the higher injection rate of the relativistic particles, which will decrease after the passage through the clump, leading to the total intensity decrease and softening of the spectrum in agreement with the observations. The size of the clump can be estimated as $R_{clump} \sim v_p \Delta t \sim 10^{11}$cm (here v_p is the pulsar relative velocity, and Δt is the variability time).

A straightforward consequence of high-energy proton interactions in the Be star disk is the appearance of additional component in the high-energy γ-ray spectrum, resulting from the two photon decays of neutral pions. The spectrum of the pion decay gamma-rays in the GeV-TeV energy band has the same spectral index as the spectrum of the high-energy protons. In Fig. 1 we show possible contribution to the γ-ray spectrum of the source which can be produced in result of proton-proton interactions.

References

Albert J., et al., 2006, Science, 312, 1771

Casares J., Ribas I., Paredes J.M. et al., 2005, MNRAS, 360, 1105

Chernyakova M., Neronov A., Walter R., 2006, MNRAS, in press [astro-ph/0606070].

Filippova, E. V., Tsygankov, S. S., Lutovinov, A. A., Sunyaev, R. A., 2005, Astr. Lett., 31, 729.

Gregory P.C. 2002, ApJ, 575, 427

Massi M., Paredes J.M., Estalella R., Felli M., 1993, A&A, 269, 249

Massi M., Ribo M., Paredes J.M. et al., 2004, A&A, 414, L1.

Maraschi L., Treves A., 1981, MNRAS, 194, 1P

Sidoli L., Pellizzoni A., Vercellone S. et al., A&A, in press [astro-ph/0606307]

Strickman M. S., Tavani M., Coe M. J. et al., 1998, Ap.J. 497, 419.

Tavani M., Kniffen D., Mattox J.R. et al., 1998, ApJ, 497, L89

Taylor A.R., Gregory P.C., 1984, ApJ, 283, 273

PoS(MQW6)049