Study of the Spectral and Temporal Characteristics of X-ray Emission of the Gamma-ray Binary LS 5039 with Suzaku

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Abstract

We report on the results from *Suzaku* and previous X-ray observations on the galactic binary LS5039, a TeV γ-ray emitting binary. The *Suzaku* observation which covered continuously more than one orbital period revealed strong X-ay flux modulation at the orbital period for the first time, with its close resemblance to the TeV γ-ray light curve. The X-ray data up to 70keV measured with *Suzaku* are described by a hard power-law spectrum with a phase-dependent photon index which varies within Γ=1.45–1.6. We also found that the modulation curves are surprisingly stable in 1999–2007. The long-term behavior of the non-thermal X-ray light curves over eight years favors that a scenario in which the radiation is related to an ultrarelativistic pulsar wind would be able to account for the stable clock-like X-ray/TeV γ-ray behaviors.

Key words: Binaries: close — X-ray binaries — stars: individual (LS 5039)

1. Introduction

X-ray binaries are the brightest galactic X-ray sources, consisting of a collapsed object (a white dwarf, neutron star, or black hole) and an ordinary star. Recent discoveries of periodic very high energy (VHE) radiation from a few X-ray binaries have opened a new research avenue, i.e. gamma-ray binaries. However, no previous X-ray observations were successful in determining the nature of X-ray emission from such systems. Here we report X-ray observations of LS 5039, a high mass X-ray binary that shows a 3.9-day orbital modulation in the VHE domain. Our X-ray light curves continuously obtained for more than one orbital period, have revealed periodically changing (in terms of both flux and spectral shape) non-thermal emission from the binary system.

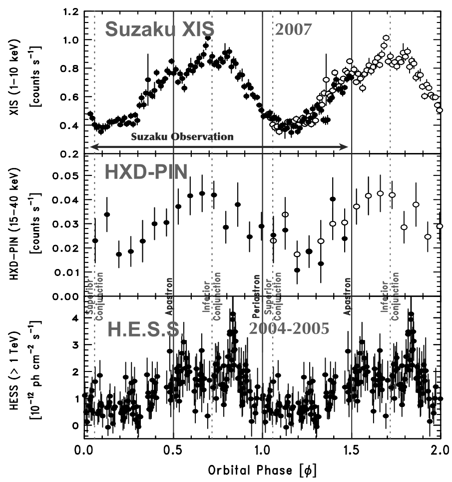

Fig. 1. Orbital light curves observed for LS 5039.

2. Temporal Property

Figure 1 shows the light curves obtained by *Suzaku*. The orbital phase is calculated with the period of 3.90603 days, and $\phi = 0$ with reference epoch T_0 (HJD − 2400000.5 = 51942.59) taken from Casares et al (2005). The amplitude of the modulation is roughly the same between the XIS and HXD-PIN, indicating small changes of spectral shape depending on the orbital phase. Structures of the X-ray and hard X-ray light curves are similar to that discovered in the phase diagram of integral fluxes at energies > 1 TeV obtained on a run-by-run basis from H.E.S.S. data (2004 – 2005; Aharonian et al. 2006).

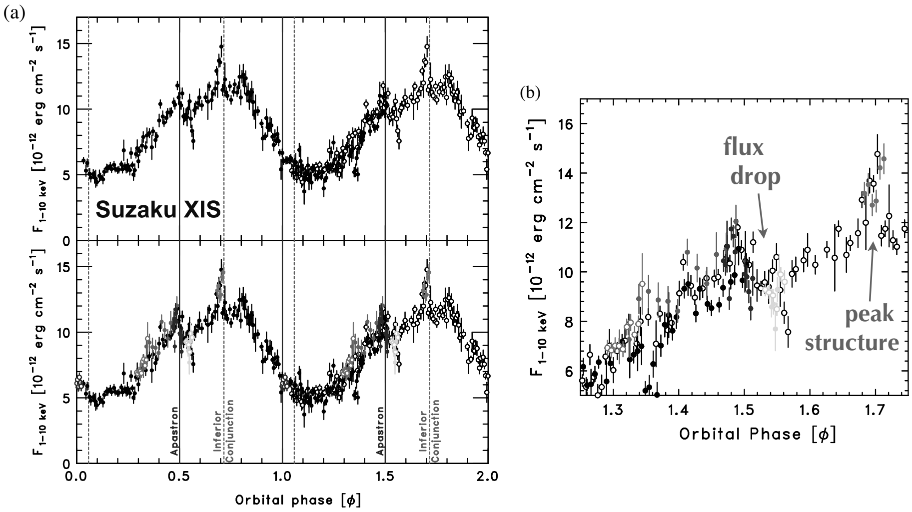

Fig. 2. (a) Orbital light curves of the unabsorbed flux. Top: Suzaku XIS data with a time bin of 2 ks. Bottom: comparison with the past observations. Each color corresponds to XMM-Newton (blue, cyan, green), ASCA (red) and Chandra (magenta). (b) Close up in $1.2 < \phi < 1.8$ (see Kishishita et al. 2009 for more detailed description).

3. Spectral Variation

We study time-resolved (phase-resolved) X-ray spectra. The data are divided into data segments with respect to the assigned phase, and model fitting is performed for XIS spectra for each segment with $\Delta\phi = 0.1$. A single power-law function with photoelectric absorption provides a good fit for all the segments. The spectral shape varied such that the spectrum is steep ($\Gamma \simeq 1.61$) around the superior conjunction ($\phi = 0.06$) and becomes hard ($\Gamma = 1.45$) around apastron (see Takahashi et al. 2009 for more detailed analysis results). The modulation behavior of Γ is somewhat different from that observed using H.E.S.S. in the VHE range. The amplitude of the variation is ± 0.1, which is much smaller than the change of ± 0.6 in the VHE region (Aharonian et al. 2006).

4. Long-term Stability of X-ray Modulation

To investigate the long-term behavior of the X-ray modulation, we compared the light curve by *Suzaku* and those obtained in the past observations (Bosch-Ramon et al. 2005, 2007; Motch et al. 1997; Martocchia et al. 2005). Figure 2 shows the flux light curves in the energy range of 1 – 10 keV. The phase-folded X-ray light curves from the *ASCA*, *XMM-Newton*, and *Chandra* observations are in remarkable agreement with those from *Suzaku*. More surprisingly, short-time variability seen in the *Suzaku* 2007 data can be recognized in the previous 1999 – 2005 data. For instance, a small peak around $\phi = 0.70$ is evident both in the *Suzaku* and *Chandra* data although the two observations are performed almost three years apart. The flux increase around $\phi = 0.48$ with a subsequent drop around $\phi = 0.51$ are consistent between the *Suzaku* and *XMM-Newton* data within statistical errors. The *ASCA* data, which were obtained 8 years before the *Suzaku* observation, also reproduce the *Suzaku* light curve not only for the overall flux increase but also for the small peaks around $\phi = 0.40$ and $\phi = 0.48$.

5. Discussion

A plausible mechanism of non-thermal X-ray production is synchrotron radiation by very energetic electrons, which are accelerated in a relativistic outflow from the compact object. The clock-like synchrotron X-ray emission is most likely related to the orbital modulation of the emission volume (about the size of the Sun) via adiabatic losses. As discussed in Takahashi et al. (2009), extremely fast acceleration of electrons, i.e. acceleration to 20 TeV in a second, is necessary to account for the X-ray and VHE data simultaneously. This suggests that this binary system is the fastest known accelerator in the Universe. We suggest that magneto-hydrodynamical collisions between the relativistic outflow from a compact object and the stellar wind from the O star play an important role to generate the clock-like non-thermal X-ray emission over eight years through continuous production of high-energy particles near the binary system.

References

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