No apparent accretion mode changes detected in Cen X-3
(Research Note)

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ABSTRACT

Aims. The presence of two distinct spectral states has previously been reported for Cen X-3 on the basis of RXTE/ASM observations. Triggered by this result, we investigated the spectral properties of the source using the larger amount of X-ray data now available with the aim to clarify and interpret the reported behavior.

Methods. To check the reported results we used the same data set and followed the same analysis procedures as in the work reporting the two spectral states. Additionally, we repeated the analysis using the enlarged data sample including the newest RXTE/ASM observations as well as the data from the MAXI monitor and from the INTEGRAL/JEM-X and ISGRI instruments.

Results. We could not confirm the reported presence of the two spectral states in Cen X-3 either in the RXTE/ASM data or in the MAXI or INTEGRAL data. Our analysis showed that the flux variations in different energy bands are consistent with the spectral hardness being constant over the entire time covered by observations.

Key words. Editorials notices - pulsars: individual: Cen X-3 - Stars: neutron - X-rays: binaries

1. Introduction

Cen X-3 was first observed in 1967 (Chodil et al. 1967) and later identified as a pulsating high-mass X-ray binary system based on the Uhuru observations (Giacconi et al. 1971; Schreier et al. 1972). The pulsation period of the source was found to be \( \sim 4.8 \) s (Giacconi et al. 1971), the orbital period (determined from regular X-ray eclipses) is \( \sim 2.08 \) days (Schreier et al. 1972). Measuring the eclipse times, Avni & Bubcall (1974) derived a mass of 0.6–1.1 \( M_\odot \) for the compact object and of 16.5–18.5 \( M_\odot \) for the companion star, well in accordance with Hutchings et al. (1979) who determined the masses from the optical spectroscopic observations of the companion. The projected orbital radius was determined from the analysis of pulse arrival times to be \( \sim 39.75 \pm 0.04 \) light-seconds (Schreier et al. 1972). The system is located at a distance of about 8 kpc (Krzeminski 1974), with a lower limit of 6.2 kpc (Krzeminski 1974). Cen X-3 shows a non-periodic alternation of high and low states with a characteristic time of recurrence of 125–165 days, derived from analysis of Vela data (Priedhorsky & Terrell 1983). This long-term variability is sometimes attributed to a precessing accretion disk (Priedhorsky & Terrell 1983).

Our analysis was triggered by the work of Paul et al. (2005). Based on their analysis of RXTE/ASM data of Cen X-3, the authors reported the presence of two distinct spectral states/modes in the high state of the source distinguished by the hardness ratio. In the high state the peak flux is up to a factor of 40 larger than during the low state (Paul et al. 2005). It was found that when the source makes a transition from a low to a high state, it adopts one of these two spectral modes and during the entire high-intensity phase remains in that mode (Paul et al. 2005) showed that during all high states between December 2000 and April 2004 the source was in the hard spectral mode as indicated by large hardness ratio, while in all high states prior and subsequent to this period it was in the soft spectral mode. To exclude systematic effects the authors analyzed ASM data on three other sources: Her X-1, Vela X-1 and SMC X-1. But none of the sources showed the behavior similar to that reported for Cen X-3. Paul et al. (2005) interpreted their results as a manifestation of two accretion modes which are at work in Cen X-3 at different times.

We repeated the analysis of Paul et al. (2005) using the same data set and following the analysis procedures described in their paper. We then extended our analysis to the entire ASM data on the source available by now and included the data obtained with the MAXI, INTEGRAL/JEM-X and INTEGRAL/ISGRI instruments.

2. Observational data and analysis method

We used data from the All Sky Monitor (ASM) onboard the Rossi X-ray Timing Explorer (RXTE), from the Monitor of All Sky X-ray Image (MAXI) and from the JEM-X and ISGRI instruments of the INTEGRAL (INTErnational Gamma-Ray Astrophysics Laboratory) satellite.

The ASM instrument is an X-ray monitor covering the 1.5–12 keV energy range (Levine et al. 1996). It consists of three Scanning Shadow Cameras (SSCs) each with a position-sensitive proportional counter (Levine et al. 1996). The counts detected in three energy bands, 1.5–3, 3–5 and 5–12 keV, are accumulated in dwells of about 90 s. In our analysis we used the Dwell by Dwell data available from the ASM team on the web (http://xte.mit.edu/asmlc/). We checked that these data differ only in format from the data available at the NASA’s High Energy

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Fig. 1. The processed ASM lightcurve of Cen X-3 from MJD 50087 to 53501. The three energy bands A (1.5–3 keV), B (3–5 keV) and C (5–12 keV) are shown in different panels.

Astrophysics Science Archive Center (HEASARC) which were used by Paul et al. (2005).

MAXI is an X-ray monitor onboard of the International Space Station (ISS) (Matsuoka et al. 2009). It scans the sky each orbit of 92 minutes observing a particular source for about 40–150 seconds (Sugizaki et al. 2011), depending on the source position. MAXI has two cameras, the Gas Slit Camera (GSC) and the Solid-state Slit Camera (SSC). The main instrument, GSC, consists of proportional counters with slit and slat collimators (Matsuoka et al. 2009) with a total effective area of 5350 cm$^2$ (Matsuoka et al. 2009). Every orbit, about 85% of the sky is scanned in the 2–30 keV energy band (Sugizaki et al. 2011). MAXI lightcurves with a time resolution of one orbit are available on the web (http://maxi.riken.jp). The lightcurves are produced for three energy bands, 2–4 keV, 4–10 keV, and 10–20 keV.

The INTEGRAL satellite observes objects simultaneously in gamma rays, X-rays and visible light. JEM-X is one of its instruments and consists of two telescopes with coded aperture masks (Lund et al. 2003). JEM-X obtains X-ray spectra and imaging in the 3–35 keV energy band (Lund et al. 2003). IBIS is the gamma-ray imager of INTEGRAL and consists of two detector layers, ISGRI and PICsIT (Ubertini et al. 2003). ISGRI is the soft gamma ray imager (Lebrun et al. 2003). It consists of a CdTe detector camera with a sensitive area of 2621 cm$^2$ observing in the 15 keV–1 MeV energy band (Lebrun et al. 2003). INTEGRAL data can be downloaded from the web (http://www.isdc.unige.ch/heavens/webapp/integral/) for all instruments and for a number of predefined energy bands. For our analysis we selected following energy bands: JEM-X 3.0–5.5 keV, 5.5–10.2 keV, 10.2–18.9 keV, 18.9–34.9 keV, ISGRI 22.1–30.0 keV, 30.0–40.3 keV, 40.3–51.2 keV, 51.3–63.3 keV.

As mentioned above, our analysis follows the procedures described in Paul et al. (2005). First, we excluded data falling in the intervals of X-ray eclipses. We then averaged the data within each orbit of the system to avoid any spectral dependence on the orbital phase (Suchy et al. 2008), i.e. we produced light curves with one time bin per orbit. For consistency, we used the same orbital parameters as Paul et al. (2005): the orbital period $P_{orb} = 2.08702$ d, the mid-eclipse time $t_{mid} (TJD) = 10087.295$, and the eclipse duration in units of orbital phase $\Delta \phi = 0.306$ (including ingress and egress). First, we performed the analysis on the same ASM data set as used in Paul et al. (2005): from MJD 50087 to 53501. Then, to enlarge the data sample, we added ASM data on the source covering the time range from MJD 53501 to 55646 (i.e. all ASM observations available by the time of preparation of this work). For the MAXI analysis we used all the data available by now, from MJD 55097 to 55630. For the INTEGRAL analysis we used data from MJD 52650 to 54959 which is all available data in the archive.

3. Results

3.1. RXTE/ASM results

The resulting ASM lightcurve of Cen X-3 in the time range MJD 50087–53501 in three energy bands with removed eclipse intervals with each bin corresponding to one orbit of the system is shown in Figure 1. In the 5–12 keV light curve, one can already see substantial differences with respect to the results of Paul et al. (2005) (see Fig. 1 in their paper). The reported spectral hardening accompanied with an increase of the flux between MJD 51800 and 53100 in the highest energy band could not be confirmed in our analysis. The reported two spectral states should emerge as two branches of data points in a plot of the countrates in the 3–5 keV band versus the 5–12 keV band, as shown in Figure 3 of Paul et al. (2005). In the corresponding plot resulted from our (re)-analysis of the data (Fig. 2), we could not find any hint of different branches.

The inclusion of the new ASM data that became available since the work of Paul et al. (2005) (MJD 53501 to 55646) also did not reveal any separation of the data points in two spectral
states. The two modes do not appear either in the new data alone or in the entire set of ASM data. Figure 3 shows the ASM fluxes in the 3–5 keV band versus fluxes in the 5–12 keV band. The data from the new observations (after MJD 53501) are plotted with a different marker. We could not detect any change with respect to the older ASM observations.

3.2. MAXI results

The long-term Cen X-3 lightcurve in all three energy bands of MAXI is shown in Figure 4. As for the ASM data we plotted the fluxes in different energy bands versus each other. Also with the MAXI data we could not confirm the presence of the two states reported for Cen X-3. The two spectral modes are expected to appear best in a plot of the 2–4 keV versus 4–10 keV fluxes as those energy bands are closest to the bands “B” and “C” of ASM where the most clear separation in two spectral states is seen in Paul et al. (2005). However, we could not find any indication of the two branches (see Fig. 5).

3.3. INTEGRAL results

Following the procedure of Paul et al. (2005) we made countrate versus countrate plots for the selected JEM-X and ISGRI energy bands. As it follows from the results of Paul et al. (2005), the separation of the two spectral states should appear best in a 3.0–5.5 keV versus 5.5–10.2 keV countrate plot of JEM-X. As for the MAXI data we could not find the presence of two spectral states (see Fig. 6). Extending the energy bands up to higher energies, e.g. using ISGRI data, did not reveal any spectral separation of the source as well.
4. Conclusions

Triggered by the finding of Paul et al. (2005), we performed a study of Cen X-3 using the data taken with two all sky monitors, RXTE/ASM and the MAXI as well as data taken from the JEM-X and ISGRI instruments of INTEGRAL. Using the same data and analysis procedures as Paul et al. (2005), we could not find any spectral transitions either in the lightcurve or by plotting fluxes in different energy bands versus each other. The result does not change with addition of newest RXTE/ASM, MAXI or INTEGRAL data or by extending the analysis up to higher energy bands. Although Paul et al. (2005) ruled out possible instrumental effects on the basis of their analysis of the ASM data of some other sources for the same time interval as for Cen X-3, we suggest that systematic and/or analysis effects are responsible for the previously reported appearance of the two spectral states. To clarify this issue we have contacted the ASM instrument team inquiring whether any substantial recalibration of ASM data took place after the work of Paul et al. (2005). According to them, major calibration changes occurred around MJD 51956 when telemetry modes switched from ASM “Position Histogram” to ASM Event mode. ASM camera SSC 1 was mainly influenced by this change and a discontinuity around that time might have led to a change in the observed fluxes as reported in Paul et al. (2005). However, the spectral discontinuity was seen in each ASM camera separately for Cen X-3, but not seen at all for a set of other pulsars. Additionally, the data software ran through major updates in April 2005 and 2007. This could have also led to the reported behavior if the data for Her X-1, Vela X-1, and SMC X-1 used by Paul et al. (2005) to check for possible instrumental effects were downloaded after the software update. The instrument team also generally claimed that although it is now difficult to check if the recalibration or data analysis software updates could lead to the reported effect, the regular improvement of the ASM calibration over time suggests that any later analysis is generally more reliable as the earlier one.

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