Feeding Compact Objects: Accretion on All Scales
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The transient neutron star X-ray binary KS 1741–293 in outburst and quiescence

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Abstract. KS 1741–293 is a transient neutron star low-mass X-ray binary that is located at an angular distance of $\simeq 20'$ from the Galactic center. We map out the historic activity of the source since its discovery in 1989, characterize its most recent X-ray outbursts observed with *Swift* (2007, 2008, 2010, and 2011), and discuss its quiescent X-ray properties using archival *Chandra* data. KS 1741–293 is frequently active, exhibiting outbursts that typically reach a 2–10 keV luminosity of $L_{\rm X} \simeq 10^{36}$ $(D/6.2$ kpc$)^2$ erg s^{-1} and last for several weeks–months. However, *Swift* also captured a very short and weak accretion outburst that had a duration of $\lesssim$4 days and did not reach above $L_{\rm X} \simeq 5 \times 10^{34}$ $(D/6.2$ kpc$)^2$ erg s^{-1}. The source is detected in quiescence with *Chandra* at a 2–10 keV luminosity of $L_{\rm X} \simeq 2.5 \times 10^{32}$ $(D/6.2$ kpc$)^2$ erg s^{-1}.

Keywords. Accretion, accretion disks, stars: neutron, X-rays: binaries, X-rays: individual (KS 1741–293)

1. Introduction

KS 1741–293 is a transient neutron star low-mass X-ray binary (LMXB) that was discovered in 1989 August by the TTM onboard the KVANT module of the Mir space station (in 't Zand *et al.* 1991). The detection of type-I X-ray bursts revealed its binary nature and testified to the presence of a neutron star. The source is located at an angular distance of $\simeq 20'$ from the Galactic center, at an estimated distance of $D \simeq 6.2$ kpc (as inferred from type-I X-ray burst analysis; Chelovekov & Grebenev 2011). Throughout this work we assume a distance of $D \simeq 6.2$ kpc when quoting X-ray luminosities.

2. The outburst history of KS 1741–293

We compiled a list of all (non-) detections of KS 1741–293 reported in literature, and combined these with the analysis of archival data (Sections 3 and 4) to map out its historic activity. Fluxes and upper limits were converted to the 2–10 keV energy band using PIMMS, assuming a power law spectrum with $N_{\rm H} = 21.5 \times 10^{22}$ cm^{-2} and $\Gamma = 2.1$. The long-term X-ray light curve as observed between 1989–2012 is shown in Figure 1.

After its discovery in 1989, the field around KS 1741–293 was observed with *ROSAT* in 1992, but the source was not detected (Figure 1; Sidoli *et al.* 2001). Renewed activity was seen in 1998 March and September by *BeppoSAX* and *ASCA*, which possibly covered the same outburst (in 't Zand *et al.* 1998; Sidoli *et al.* 1999; Sakano *et al.* 2002). *INTEGRAL* detected it in outburst in 2003, 2004 and 2005 (de Cesare *et al.* 2007; Kuulkers *et al.* 2007; Chelovekov & Grebenev 2011). Non-detections in between these epochs suggest

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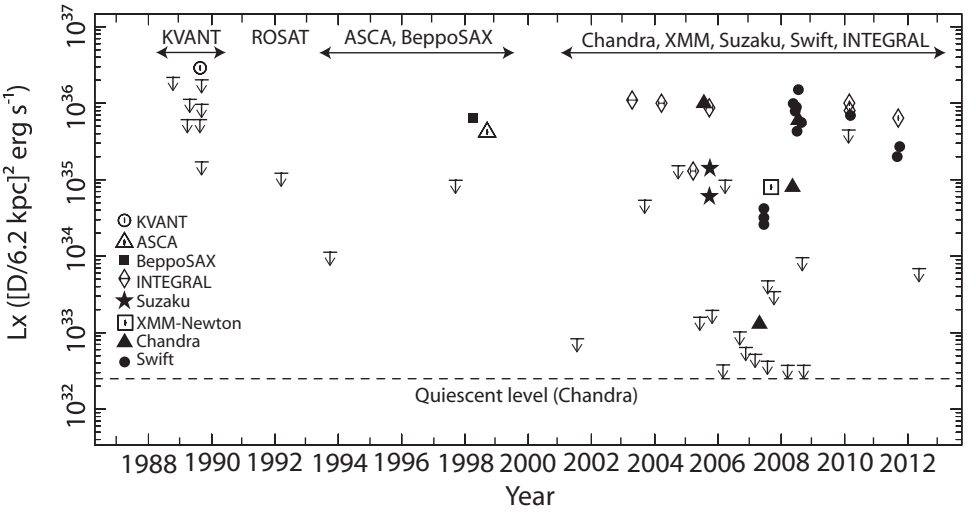

Figure 1. Long-term outburst history of KS 1741–293 (2–10 keV; see text for references).

that this were likely three separate outbursts (see Figure 1). The 2005 outburst was also observed by *Chandra* and *Suzaku* (Degenaar *et al.* 2008; Yuasa *et al.* 2008).

Between 2006 and 2008, the source region was covered by monitoring campaigns of the Galactic center with *Chandra* and *XMM-Newton* (Wijnands *et al.* 2006; Degenaar *et al.* 2012), and *Swift* (Degenaar & Wijnands 2009, 2010). The source was found (weakly) active on three different epochs in 2007 (Section 3; Degenaar *et al.* 2012), and a new outburst was observed in 2008 (Degenaar & Wijnands 2008; Degenaar *et al.* 2012). *INTEGRAL* and *Swift* found the source active again in 2010 (Chenevez *et al.* 2010) and in 2011 (Barthelmy *et al.* 2011; Linares *et al.* 2011; Chenevez *et al.* 2011).

Only a few type-I X-ray bursts have been reported for KS 1741–293. KVANT detected two (in 't Zand *et al.* 1991), six have been seen with *INTEGRAL* (de Cesare *et al.* 2007; Chelovekov & Grebenev 2011), and recently one was picked up by *Swift* (Barthelmy *et al.* 2011; Linares *et al.* 2011). *RXTE* may have also detected one (Galloway *et al.* 2008).

3. Outbursts observed with *Swift* between 2007 and 2012

We obtained all *Swift*/XRT data covering KS 1741–293 from the public data archive. This encompasses 69 observations performed between 2007 May 5 and 2012 May 17. We extracted data products using the online XRT tools (Evans *et al.* 2009). Figure 2 displays the *Swift*/XRT light curve. It shows three major outbursts in 2008, 2010, and 2011, as well as a short and weak episode of activity in 2007. We extracted spectra for these four different outbursts and fitted these simultaneously in XSPEC to a simple absorbed power law model. The results of the spectral analysis are summarized in Table 1.

The region around KS 1741–293 was observed every few days by *Swift* between 2007 May 23 and August 9. The source is not detected during this epoch, except during three observations performed on June 13 and 14, when it displayed a 2–10 keV luminosity of $L_{\rm X} \simeq 3 \times 10^{34}$ erg s^{-1}. Non-detections in the preceding and subsequent observations (June 11 and 15) suggest that this episode of low-level activity had a duration of $\lesssim 4$ days.

KS 1741–293 was detected at similarly low intensities at another two epochs in 2007. *XMM-Newton* found the source active at $L_{\rm X} \simeq 8 \times 10^{34}$ erg s^{-1} on 2007 September 6. Non-detections with *Swift* on August 9 and September 27 constrain the duration of this

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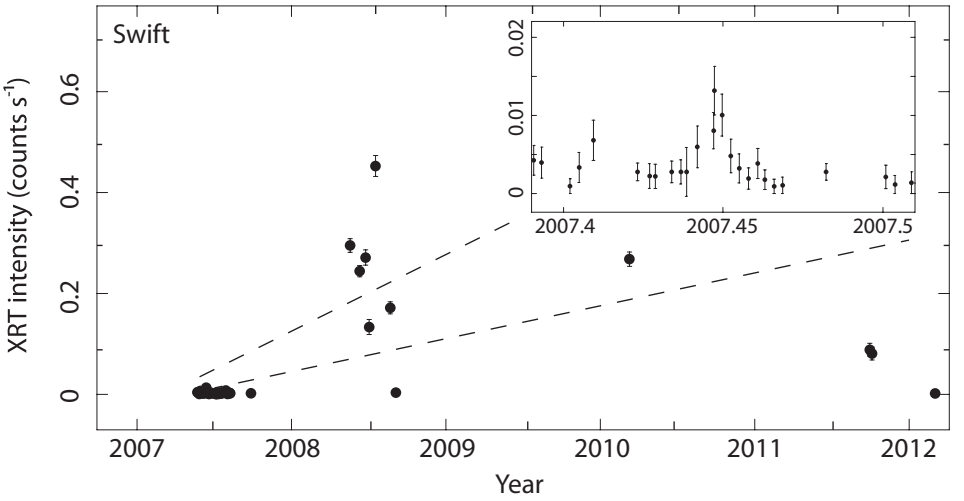

Figure 2. Long-term *Swift*/XRT light curve (binned per observation) showing three main outbursts of KS 1741–293 (2008, 2010, and 2011) and one episode of low-level activity (2007).

outburst to be $\lesssim$ 49 days. In an archival *Chandra* observation performed on 2007 April 25, KS 1741–293 is weakly detected at $L_{\rm X} \simeq 1.3 \times 10^{33}$ erg s^{-1} (Table 1). Non-detections with *Chandra* on 2007 February 19 ($L_{\rm X} \lesssim 5 \times 10^{32}$ erg s^{-1}) and *Swift* between 2007 May 23 and June 10 ($L_{\rm X} \lesssim 1 \times 10^{33}$ erg s^{-1}) suggest that the activity lasted for $\lesssim$3 months. KS 1741–293 was thus found active a factor $\simeq$10–100 above its quiescent level several times in 2007, but was not detected above $L_{\rm X} \simeq 10^{35}$ erg s^{-1}.

We obtained a series of *Swift*/XRT ToO observations of KS 1741–293 between 2008 May 18 and September 4 to monitor the new outburst that was first detected by *Chandra* on May 10 (Degenaar *et al.* 2008; Degenaar & Wijnands 2008). The source remained active for $\simeq$3 months at an average 2–10 intensity of $L_{\rm X} \simeq 8 \times 10^{35}$ erg s^{-1} (Table 1) till August 21. It was no longer detected on September 4 with an upper limit of $L_{\rm X} \lesssim 9 \times 10^{33}$ erg s^{-1}. In 2010 and 2011, KS 1741–293 was again observed in outburst with *Swift* at an intensity of $L_{\rm X} \simeq (3-7) \times 10^{35}$ erg s^{-1} (Table 1, Figure 2).

4. KS 1741–293 in quiescence

To investigate the quiescent properties, we used archival *Chandra* observations performed in 2001, 2006 and 2007 (Obs IDs 2267, 7038, and 8459; from the campaign of Muno *et al.* 2009). The source is not detected in the individual images, but clearly visible when the observations are combined ($\simeq$51 ks). We created a combined spectrum using the CIAO tools, and fitted this simultaneously with the *Swift* outburst data (Table 1).

KS 1741–293 is detected in quiescence at a 2–10 keV luminosity of $L_{\rm X} \simeq 2.5 \times 10^{32}$ erg s^{-1}, which is typical for quiescent neutron star LMXBs. The very large extinction in the direction of the source ($N_{\rm H} \simeq 2 \times 10^{23}$ cm^{-2}) completely obscures the thermal emission that is often detected for quiescent neutron star LMXBs (typically $kT_{\rm bb} \simeq$0.1–0.3 keV). Therefore, we only detect the hard (non-thermal) power law tail.

5. Discussion

KS 1741–293 is a frequently active: between 1989 and 2012, the source exhibited at least 8 accretion outbursts that reached $L_{\rm X} \simeq 10^{36}$ erg s^{-1} (2–10 keV) and had a duration

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Table 1. Spectral properties of KS 1741–293 in outburst and quiescence.

Instr.	Date	State	Γ	$F_{\rm X}$ (erg cm^{-2} s^{-1})	$L_{\rm X}$ (erg s^{-1})
Chandra	2001/2006/2007	quiescence	$1.3^{+5.4}_{-1.3}$	$(5.5 \pm 5.0) \times 10^{-14}$	$(2.5 \pm 2.3) \times 10^{32}$
Chandra	2007 Apr 25	low activity	$0.2^{+1.6}_{-0.2}$	$(2.8 \pm 1.3) \times 10^{-13}$	$(1.3 \pm 0.6) \times 10^{33}$
Swift	2007 Jun 13–14	low activity	$0.8^{+2.4}_{-0.8}$	$(6.2 \pm 1.4) \times 10^{-12}$	$(2.9 \pm 0.6) \times 10^{34}$
Swift	2008 May 18–Aug 21	outburst	2.1 ± 0.4	$(1.7 \pm 0.4) \times 10^{-10}$	$(7.8 \pm 1.9) \times 10^{35}$
Swift	2010 Mar 10	outburst	2.2 ± 0.6	$(1.5 \pm 0.5) \times 10^{-10}$	$(6.9 \pm 2.3) \times 10^{35}$
Swift	2011 Sep 1–30	outburst	2.7 ± 1.6	$(6.0 \pm 2.4) \times 10^{-11}$	$(2.8 \pm 1.1) \times 10^{35}$

Note. Quoted errors refer to 90% confidence levels. A simultaneous fit to the spectral data resulted in $N_{\rm H} = (21.5 \pm 2.8) \times 10^{22}$ cm^{-2} and $\chi^2_\nu = 1.1$ for 142 dof. $F_{\rm X}$ represents the unabsorbed 2–10 keV flux and $L_{\rm X}$ the corresponding luminosity assuming $D = 6.2$ kpc.

of several weeks–months. This suggests a recurrence time of $\simeq$2 yr and a duty cycle of $\simeq$12.5%. In addition to these main outbursts, we found indications of low-level accretion activity a factor of $\simeq$10–100 above the quiescent level of $L_{\rm X} \simeq 2.5 \times 10^{32}$ erg s^{-1}. Such peculiar behavior has now been observed for a number of transient neutron star LMXBs, such as XMM J174457–2850.3, GRO J1744–28, GRS 1741–2853, and XTE J1701–462 (Degenaar & Wijnands 2009, 2010; Degenaar *et al.* 2012; Fridriksson *et al.* 2011).

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