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OUTBURST OF A BLACK HOLE X-RAY BINARY V4641 Sgr IN 2004 JULY

UEMURA, M.[1,2]; MENNICKENT, R.[1]; STUBBINGS, R.[3]; BOLT, G.[4]; MONARD, B.[5]; COOK, L. M.[6]; WILLIAMS, P.[7]; ISHIOKA, R.[8]; IMADA, A.[8]; KATO, T.[8]; NOGAMI, D.[9]; STARKEY, D.[10]; MAEHARA, H.[11]; NAKAJIMA, K.[12]; MÉSZÁROS, SZ.[13]; SZÉKELY, P.[13]; KISS, L. L.[14]; LINDSTROM, C.[14]; GRIFFIN, J.[14]

[1] Departamento de Física, Facultad de Ciencias Físicas y Matemáticas, Universidad de Concepción, Casilla 160-C, Concepción, Chile, e-mail: muemura@cepheid.cfm.udec.cl

[2] Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

[3] Tetoora Observatory, Tetoora Road, Victoria, Australia

[4] 295 Camberwarra Drive, Craigie 6025, Western Australia

[5] Bronberg Observatory, PO Box 11426, Tiegerpoort 0056, South Africa

[6] Center for Backyard Astrophysics (Concord), 1730 Helix Ct. Concord, California 94518, USA

[7] 3 McAuley Close, Heathcote, NSW, 2233, Australia

[8] Department of Astronomy, Kyoto University, Sakyou-ku, Kyoto 606-8502, Japan

[9] Hida Observatory, Kyoto University, Kamitakara, Gifu 506-1314, Japan

[10] AAVSO, 2507 County Road 60, Auburn, Indiana 46706, USA

[11] VSOLJ, Namiki 1-13-4, Kawaguchi, Saitama 332-0034, Japan

[12] Isato, Kumano, Mie, Japan

[13] Astron. Obs., University of Szeged, Hungary

[14] School of Physics, University of Sydney, Australia

V4641 Sgr is a close binary system containing a stellar-mass black hole and an intermediate mass secondary (Orosz et al. 2001). Its outburst behaviour is quite peculiar among other black hole X-ray binaries (Tanaka & Lewin 1995); it experienced a super-Eddington outburst in 1999 September, whose duration was only $\lesssim 1$ d in X-rays (Uemura et al. 2002; Revnivtsev et al. 2002). Radio observations spatially resolved relativistic jets associated with this outburst (Hjellming et al. 2000). The object again experienced an outburst in 2002 May, whose characteristics were, however, completely different from the last one. The X-ray flux during the 2002 outburst was 2 orders of magnitude smaller than that of the 1999 outburst. Optical light curves had many short flares having timescales of 10^{2-4} s (Uemura et al. 2004a). A similar outburst was again observed in 2003 August. Those two outbursts in 2002 and 2003 lasted for 7 d (Uemura et al. 2004b). Due to their short durations and rapid evolution of light curves, the detailed characteristics and time evolution of its short-term variability during outburst are still unclear.

Here, we report a new outburst of V4641 Sgr in 2004 July. Our photometric observations were performed with unfiltered CCD cameras attached to 30-cm class telescopes at Universidad de Concepción, Craigie, Bronberg Observatory, Concord, Kyoto University, Hida Observatory, Auburn, Saitama, and Mie. After correcting for the standard de-biasing

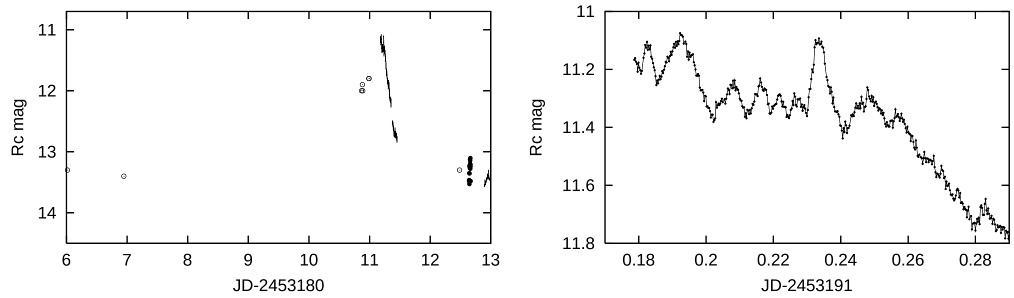

Figure 1. Optical light curves of the outburst of V4641 Sgr in 2004. The filled circles and solid lines are results from CCD photometric observations. The open circles are from visual observations.

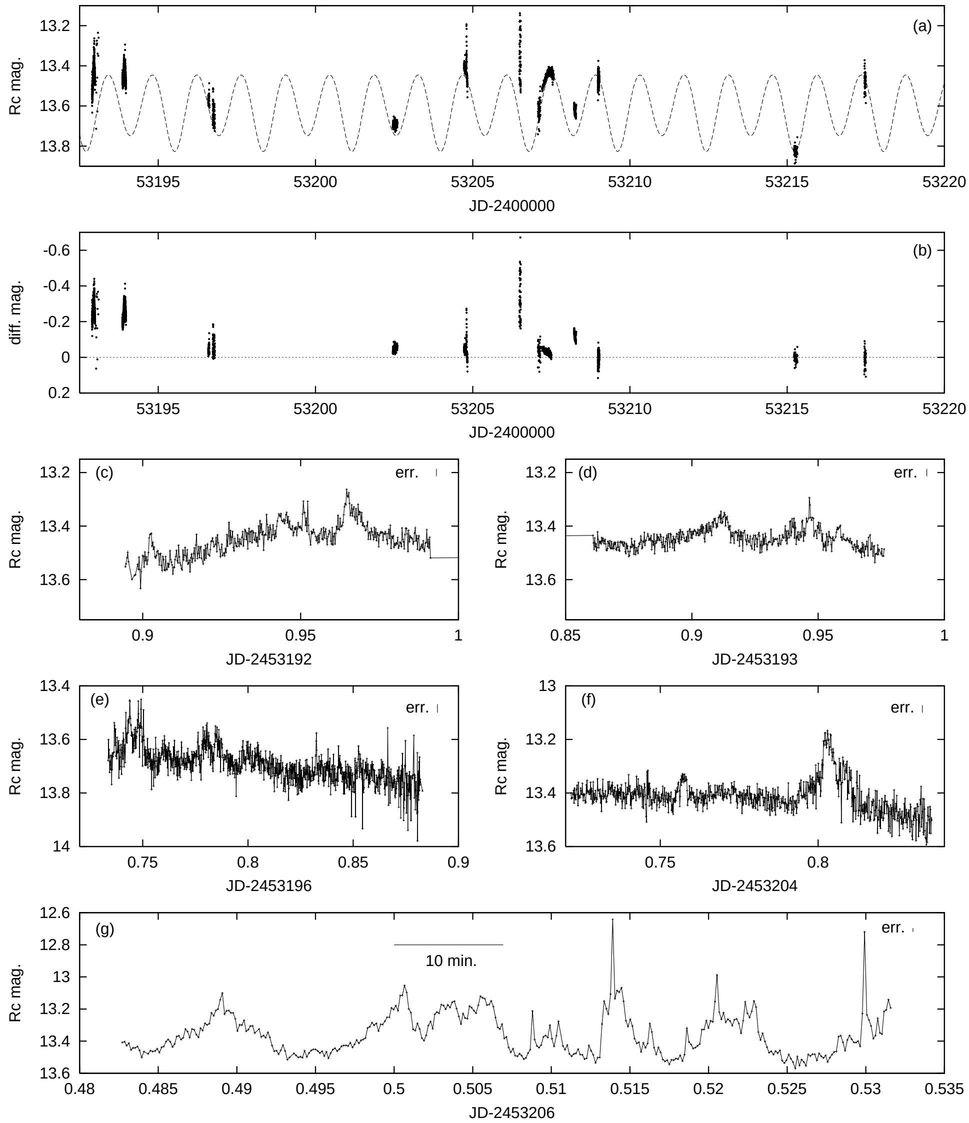

Figure 2. (a) Light curve of the post-outburst active phase in 2004. The dashed line indicates ellipsoidal modulations at quiescence. (b) Residual light curve from the ellipsoidal modulation. (c)–(g) Light curves for each night. Typical errors for the magnitude are indicated in each panel.

and flat fielding, we performed aperture photometry for obtained images. The differential magnitudes of the variable were measured against GSC 6848.3882 ($R_c = 13.19$[1]).

The outburst of V4641 Sgr in 2004 was discovered by a visual observation by one of our co-authors (RS) on 4.368 July (JD 2453190.868). It was then promptly confirmed by both visual and CCD observations. Light curves of the outburst are shown in Figure 1. As can be seen from the left panel of Figure 1, the object was at quiescence ($m_{\rm vis} = 13.4$) before 30 June (ex. 13.4 mag at JD2453185.002; 13.3 mag at JD2453186.016; 13.4 mag at JD2453186.947), about 4 day before the detection of the outburst. We succeeded in obtaining time-series data during the outburst. The resultant light curve is shown in the right panel of Figure 1. The light curve during the outburst was filled by short flares. These flares have durations of $\sim$ 10 min and amplitudes of 0.05–0.2 mag. Our observation detected an onset of a rapid fading at $\sim$ JD 2453191.26. We obtained simultaneous spectroscopic data with this photometric run, which is reported in Lindstrom et al. (2005, in prep.). The main outburst was terminated with this rapid fading (also see Revnivtsev et al. 2004). In conjunction with results from early visual observations (see the left panel of Figure 1), the duration of the main outburst was $<$ 4 d.

The object remained active and showed flares even after the main outburst (cf. Bikmaev et al. 2004). Light curves during this post-outburst active phase are shown in Figure 2. The dashed line in the panel (a) indicates ellipsoidal modulations at quiescence (Uemura et al. 2005, in prep.). The panel (b) shows residual magnitudes from the ellipsoidal modulations. As can be seen in these figures, the object was recorded 0.05–0.4 mag brighter than the quiescent level until it finally returned to the quiescence on JD 2453209. The post-outburst active phase, hence, continued for 17 d after the main outburst.

We detected several short flares during the post-outburst active phase. Light curves of these flares are also shown in Figure 2 [panel (b)–(g)]. Contrary to the repetitive flares during the outburst (see the right panel of Figure 1), these flares are rather sporadic. On the other hand, their timescales are analogous to those during the outburst.

Most active phase was observed on JD 2453206, $\sim$ 2 d before it returned to the quiescent level. The light curve on JD 2453206 is shown in the panel (g) of Figure 2. In this figure, we can see several steep brightenings superimposed on the 10-min flares. Similar phenomena were also observed during the 2002 and 2003 outbursts, and we call them optical flashes. In Uemura et al. (2004b), we set a phenomenological definition of optical flashes as brightenings by $\sim$ 0.5 mag within $\sim$ 50 s. The light curve in the panel (g) includes two optical flashes with this criterion at JD 2453206.514 and 2453206.530. Several rapid flares with smaller amplitudes ($\sim$ 0.2 mag) are also seen between JD 2453206.51–53.

The outburst in 2004 was also detected by X-ray observations. Swank (2004) reported a reappearance of the object in X-rays at 8.2 mCrab (2-10 keV) on JD 2453189.996. This observation indicates that the object had already been active 1 d before the optical detection of the outburst. Radio activities were also reported, though spatially resolved jets were not detected (Rupen et al. 2004a; Trushkin 2004; Senkbeil & Sault 2004). Rupen et al. (2004b) reported that the last clear detection was on JD 2453206.7 at 2.0 mJy (4.86 GHz). We detected the optical flashes at the same day of this radio detection (JD 2453206.5). The radio flux returned to a quite low level in their next radio observation on JD 2453209, which is consistent with the optical behaviour.

The outbursts in 2002, 2003, and 2004 have several common characteristics. First, the X-ray flux was relatively low compared with the optical flux. Second, the object showed short flares having a timescale of 10 min. Assuming a flat spectrum in the optical range, we can calculate a ratio of the X-ray flux to the optical one, $F_{\rm X}/F_{\rm opt} \gtrsim 0.4$ from

[1] ftp://ftp.nofs.navy.mil/pub/outgoing/aah/sequence/v4641sgr.dat

8.2 mCrab (2-10 keV; Swank 2004) and $R_c = 11.3$ (maximum) during the outburst in 2004. On the other hand, in the case that the optical–X-ray flux is dominated by the thermal emission from a standard accretion disk, F_X/F_{opt} should be $\sim 10^3$. Such a low X-ray flux indicates that the object was in the "low/hard state" of black hole X-ray binaries, during which a strong synchrotron emission is dominant in the radio–infrared range, or possibly even in the optical range (Fender 2001). The apparent radio–optical correlation around JD 2453209, which we mentioned above, supports that the optical activity originated from the synchrotron emission.

Another noteworthy characteristic is the post-outburst active phase, which was observed for the first time since 2002 (Uemura et al. 2004a). Optical flashes were observed during both post-outburst active phases in 2002 and 2004. It is interesting to note that, in both cases, the object soon returned to quiescence after those strongly active phases with optical flashes (Uemura et al. 2004a).

These common characteristics suggest that the 2004 outburst has the same nature as those in 2002 and 2003, and it is different from the super-Eddington outburst in 1999. On the other hand, the duration of the post-outburst active phase in 2004 was shorter (17 d) than that in 2002 ($\gtrsim 40$ d). As well as the post-outburst phase, the main outburst also had a shorter duration in 2004; the main outbursts in 2002 and 2003 lasted for 7 d, while that in 2004 for < 4 d (Uemura et al. 2004a, b). The total amount of energy release, hence, decreased from the outburst in 2002 to that in 2004. We need to keep monitoring this object to confirm whether this decreasing trend is only temporary or not.

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