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CNPq, Lab Nacl Astrofis, BR-37500000 Itajuba, Brazil.
Univ Sao Paulo, Inst Astron & Geofis, BR-01065970 Sao Paulo, Brazil.
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Research Note

Detection of optical bursts from the transient X-ray source XTE J2123-058*

C.D. Gneiding[1], **J.E. Steiner**[1,2], **and D. Cieslinski**[3]

[1] Laboratório Nacional de Astrofísica/CNPq, CP 21, 37500–000 Itajubá, Brazil (clemens@lna.br)
[2] Instituto Astronômico e Geofísico, Universidade de São Paulo, CP 9638, 01065–970 São Paulo, Brazil (steiner@lna.br)
[3] Instituto Nacional de Pesquisas Espaciais, CP 515, 12201–970 São José dos Campos, Brazil (deo@das.inpe.br)

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Abstract. We report the detection of four large optical bursts from the transient X-ray burster XTE J2123-058. This is the third case of detection of optical bursts in an X-ray transient during the active phase; the bursts are recorded with high time resolution and signal-to-noise. The total duration of the bursts is about 80 seconds and the amplitudes vary from 0.7 to 1 magnitude.

Key words: X-rays: stars – X-rays: bursts – stars: individual: XTE J2123-058

1. Introduction

X-ray bursts sources were discovered in 1975 by Grindlay et al. (1976) and up to now, about 45 such sources have been identified (see Lewin et al. 1995 for a review). Type I burst sources, the most common ones, are believed to be the result of thermonuclear flashes on the surface of an accreting neutron star in a binary system, while type II bursts are only seen in one peculiar system, namely the "Rapid Burster" and may be due to unstable mass accretion.

Attempts to detect these objects in the optical band have been successful. The first simultaneous optical/x-ray burst was detected from the source 1735-444 (Grindlay et al. 1978). Optical bursts, in several cases correlated with their X-ray counterpart, have since been detected from 1837+049 (Hackwell et al. 1979) and 1636-536 (Pedersen et al. 1982a; Pedersen et al. 1982b). Optical detections without simultaneous X-ray observations have also been reported for the sources 1254-690 (Mason et al. 1980), Aql X-1≡V1333 Aql (van Paradijs et al. 1981; Robinson & Young 1997) and UY Vol (Schoembs & Zoeschinger 1990).

In the cases of simultaneous optical/X-ray detections, the optical burst is typically delayed by about 2-3 seconds relative to the X-ray event. This indicates that all optical emission from X-ray burst sources is the result of reprocessing of X-rays in material within a few light-seconds from the X-ray source, which is enhanced during the event.

In this paper we report about optical bursts observed in X-ray transient XTE J2123-058, which was detected by Levine et al. (1998). The optical counterpart was identified by Tomsick et al. (1998a) with a star of V=16.8 and B−V=−0.02 that showed weak HeII λ4686 in emission, typical of X-ray transients in outburst. The photometric orbital period was established as P=5.9567 hours (Tomsick et al. 1998b; Ilovaisky & Chevalier 1998). A second period of 7.2 days modulating the light curve was also suggested (Ilovaisky & Chevalier 1998). A spectroscopic period of 6.05±0.10 hours was established using the HeII λ4686 (Hynes et al. 1998), nearly identical to the photometric one and with a semi-amplitude of $\sim$180 km s^{-1}. Two weak X-ray bursts of type I have been reported by Takeshima & Strohmayer (1998) and five by Homan et al. (1999). Three optical bursts of amplitude 0.3 mag or larger (Tomsick et al. 1998b) have also been detected.

The source was discovered on 1998 June 27 and stayed at nearly constant optical brightness for one month. By early August 1998 the object started to decline at a rate of 0.1 mag/day (Zurita et al. 1998) reaching R=19.1 on August 16 and R=21.50 on August 26/27 (Zurita & Casares 1998).

Recently Homan et al. (1999) have shown that the X-ray source has twin kHz QPOs and classified the object as an Atoll type source. The distance to the system was estimated to be between 5 kpc and 15 kpc with a best value of 10 kpc. Tomsick et al. (1999) estimated a similar distance, between 4.5 kpc 15 kpc and also assume an average of 10 kpc. This would locate the star at a surprising distance of 6 kpc from the galactic plane, with a lower limit of 2.6 kpc.

Among the seven sources that have optical bursts detected (see Table 1), only UY Vol, Aql X-1 and XTE J2123-058 are X-ray transient sources, all the other showing persistent X-ray emission.

As the object has high galactic latitude of 36°.2, which is unusual for X-ray transients, it is ideal for optical studies as its

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Send offprint requests to: C.D. Gneiding (clemens@lna.br)

* Based on observations made at Laboratório Nacional de Astrofísica/CNPq, Brazil

Table 1. Binary X-ray sources with detected optical bursts

X-ray Source	Type(*)	Optical ID	V	B−V	P_{orb} (hrs)
0748-676	TBDE	UY Vol	16.8–>23	0.14	3.82
1254-690	BD	GR Mus	19.1	0.3	3.93
1636-536	BA	V801 Ara	17.5	0.7	3.80
1735-444	BA	V926 Sco	17.5	0.2	4.65
1837+049	B	MM Ser	19.2	–	–
1908+005	TB	V1333 Aql	14.8–19.4	0.6	19.0
2123-058	TBA	–	16.8–∼21	−0.02	5.95

(*) *Notes:* B = X-ray Burster; D = Dipping LMXB; T = Transient X-ray source; A = Atoll source; E = Eclipsing system

Table 2. Burst properties of XTE J2123-058

Burst #	HJD – 2450000	T_w (hrs)	Δm (mag)	ΔT_r (s)	ΔT_d (s)	ΔT_t (s)	ϕ orb
1	1022.86633	>3.6	1.05	7	14	57	0.34
2	1023.63560	>1.3	0.68	14	14	70	0.44
3	1023.73452	2.3	0.95	13	13	76	0.84
4	1023.81093	1.8	0.71	9	14	51	0.15

Notes: T_w = waiting time; ΔT_r = rise time; ΔT_d = e-folding decay time; ΔT_t = total duration

interstellar extinction is quite low. For this reason we decided to search for optical bursts in this object.

2. Observations

The observations were made with the 1.6-m telescope at the Pico dos Dias Observatory, operated by the Laboratório Nacional de Astrofísica - CNPq/LNA. We used a direct imaging CCD camera (Wright Instruments, thermoelectrically cooled) fitted with a EEV CCD02-06-1-206 sensor (385H × 578V pixels, back illuminated, with a shielded store region) operated in the frame transfer mode. The timing for the instrument is provided by a global position system (GPS) receiver. The observations were taken in the fast photometer mode with an integration time of 1 second and dead time of only 2 ms between integrations. In order to maximize the detection of photons and improve the signal to noise ratio, we observed in integral light. The object was observed on July 27 and 28, 1998. On the second night, thin cirrus were present on occasions.

The data were reduced using standard IRAF[1] routines. The images have been debiased and corrected for flat-fielding. Photometry for the variable star and for three field stars (used as comparisons) was then done with the APPHOT package. The task of extraction of the fluxes and transformation to instrumental magnitudes was facilitated by using scripts written and kindly provided by F.J. Jablonski.

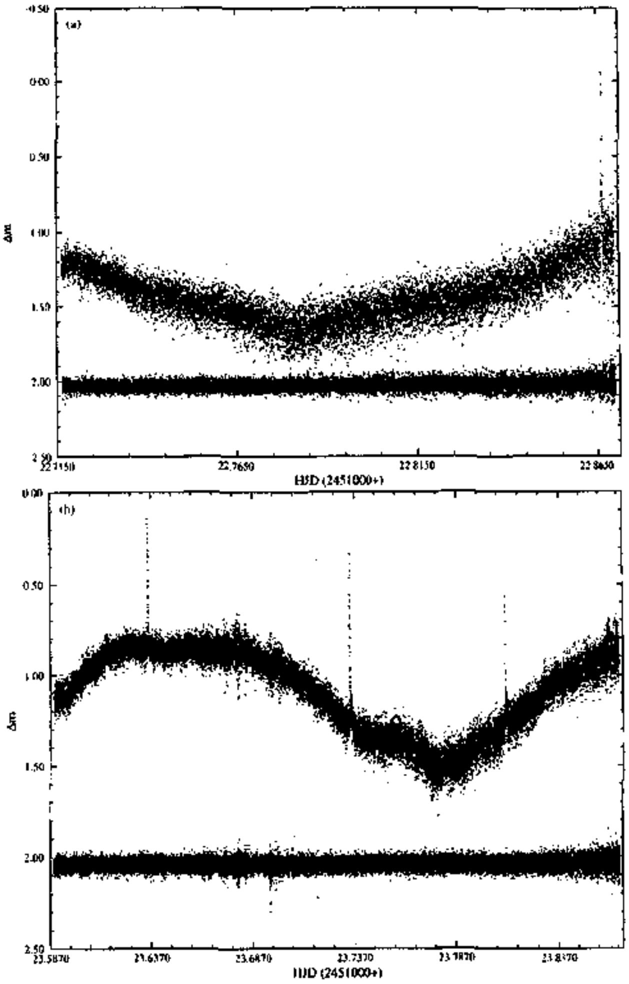

Fig. 1a and b. The optical light curves of the transient XTE J2123-058 on July 27, 1998 **a** and on July 28, 1998 **b**. The upper curve in these frames is the difference between the variable and a comparison star. The lower curve is the difference between two comparison stars (this curve was shifted by +2.5 magnitudes for better visualization).

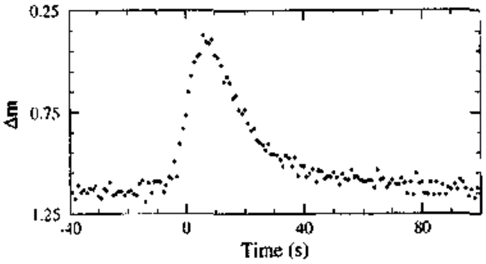

Fig. 2. The average burst profile from the three bursts recorded on July 28, 1998.

3. The optical light curves

The optical light curves obtained on the nights of July 27 and 28, 1998, both show clearly orbital modulation, similar to that described by Casares et al. (1998), Ilovaisky & Chevalier (1998) and Tomsick et al. (1998b). It has an amplitude of $\Delta m \simeq 0.65$

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[1] IRAF is distributed by National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

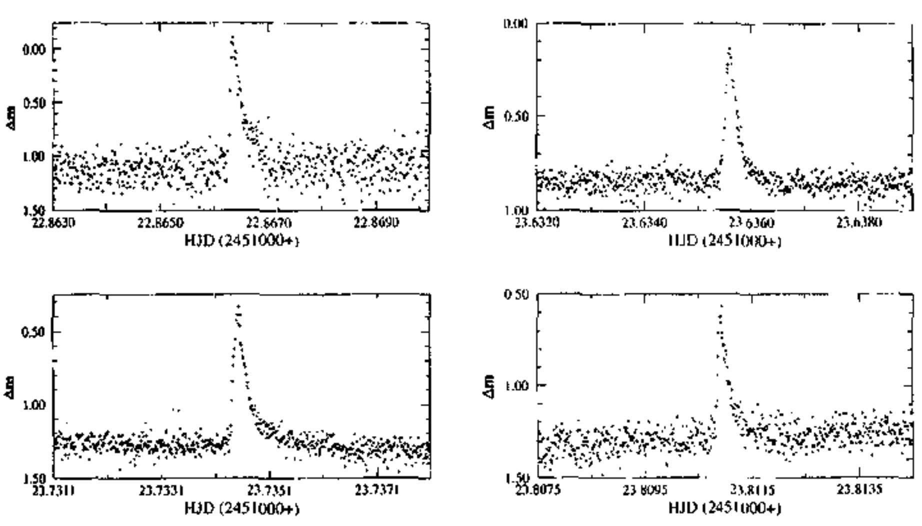

Fig. 3. The four optical bursts recorded for XTE J2123-058.

magnitude as can be seen in Fig. 1. The minima are consistent with the ephemeris

$$T_{min}(HJD) = 2451022.782(\pm5) + 0.24820(\pm6)\,E,$$

To derive the orbital period, we have used the ephemeris provided by Ilovaisky & Chevalier (1998) and Tomsick et al. (1998b) in addition to our timings and it is identical to that given by these authors.

The orbital modulation of XTE J2123-058 is similar to that of the X-ray binary UY Vol (Schoembs & Zoeschinger 1990).

Four large optical bursts were observed. On the first night only one burst was observed in 3.7 hours of observations while on the second night 3 bursts were detected in 6.5 hours of observations, shown in Fig. 1. The events can be described by a fast rise (ΔT_r=7–14 s), and an e-folding decay time ($\Delta T_d \simeq 14$ s) that seems to be constant. The total duration of the bursts varied from 51 seconds to 76 seconds. The amplitude of the bursts were quite large, varying from 0.68 to 1.05 magnitudes. The parameters of each burst are listed in Table 2. Fig. 3 displays each of the four bursts. At the time of the optical observations, no X-ray data are available.

In order to improve the signal-to-noise, we averaged the three bursts observed on the second night. To do this we defined a "fiducial time", for each burst, as the time at which the burst raises half of its maximum intensity. After coinciding the "fiducial time" of each burst, we averaged the intensity; this is shown in Fig. 2. An interesting feature that appears in this figure is that the burst starts at about 7-8 seconds before the fiducial time and lasts for about 80 seconds after that.

Power spectra were calculated for one hour intervals immediately before and after the bursts. Before calculating the power spectrum, a third order polynomial was subtracted from the light curve segments in order to remove long term trends. There is no evidence for periodic or quasiperiodic oscillations. In particular, an upper limit of 0.005 magnitude for any periodic oscillation can be set.

4. Discussion

The orbital period of XTE J2123-058 is somewhat longer than the average orbital period of X-ray bursters. There seems to be a trend in the sense that among the X-ray bursters, the transients have longer orbital periods than persistent sources. According to the compilation by van Paradijs & McClintock (1995), among the transients, only one period is shorter than 5.8 hours while 5 are longer. Among the persistent sources, on the contrary, 9 have orbital periods shorter than 5.8 hours while only 3 are longer. This, in fact, is the case for LMXBs (King et al. 1996) and bursters are a subclass of LMXBs.

The star was at an average magnitude of $V \simeq 17.0$ (Tomsick et al. 1998b, 1999). For a typical burst amplitude of $\Delta m=1$ magnitude, the peak optical flux is estimated to have been $f \sim 5 \times 10^{-12}$ erg/cm^2 s^{-1} and at a distance of 10 kpc (Homan et al. 1999), the peak luminosity was $L_{peak} \sim 5 \times 10^{34}$ erg s^{-1}. The total optical energy released in the burst was typically $E_{burst} \sim 10^{36}$ erg.

There is a trend for bursts with larger amplitude to have a longer waiting time since the previous burst. This is consistent with what was observed for 4U 1636-53 (Pedersen et al. 1982b) with a much better statistics. Schoembs & Zoeschinger (1990) have shown that the rise time of optical bursts is related to the orbital phase. The difference in the rise time for distinct orbital phases due to light travel time is only ≤ 2 seconds. The four bursts in Table 2 have a difference of 7 seconds in rise time, much longer than expected from simple light travel time arguments.

The distance to the system has been estimated to be 10 kpc (Homan et al. 1999, Tomsick et al. 1999). This places the object at 6 kpc from the galactic plane, right in the halo. Such a displacement from the galactic plane is quite unusual for a LMXB. The origin of such a system is not clear. Homan et al. (1999) have proposed two alternatives. A high speed system as a consequence of a supernova kick, or ejection from a globular cluster. We would like to suggest a third hypothesis: capture from the Magellanic Clouds. The Clouds have orbital periods of about 2 Gyrs around or through the Galaxy. In the event of a close approximation a binary system may have been captured. In such a case, the location in the halo is quite natural. A similar argument can be made in relation to the dwarf galaxy in Sagittarius (Ibata et al. 1994). An unusual halo object could be a left-over from the capture process of a dwarf galaxy. At the present time, all three suggestions are quite speculative.

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