CONSTRAINTS ON THE SYSTEM PARAMETERS OF THE RAPID BURSTER

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ABSTRACT

We constrain the length of the orbital period $P_{\rm orb}$ of the remarkable low-mass X-ray binary, the Rapid Burster (MXB 1730–335), to lie between 3.5 and 5.5 hours, and the radius of the disk $R_{\rm disk} = 0.9\,R_{\rm lobe} = 3.7 \times 10^{10}$ cm – 5.0×10^{10} cm. All this emerged from the analysis of the parameters of a group of outbursts observed by $ASM/RXTE$, and making use of the model of King & Ritter (1998). This helps us in linking the properties of this object to the group of X-ray binaries. $P_{\rm orb}$ of the Rapid Burster thus lies above the period gap of LMXBs and its donor is an M4–K5 main-sequence star.

Key words: Stars: neutron; accretion, accretion discs; binaries: close; circumstellar matter; X-rays: binaries; Stars: individual: Rapid Burster.

1. INTRODUCTION

MXB 1730–335 (Rapid Burster, RB) is a remarkable system (Lewin et al., 1976) lying in the globular cluster Liller 1 at the distance of $d \approx 8$ kpc (Liller, 1977; Ortolani et al., 1996). RB displays two types of X-ray bursts during the outbursts: Type I – thermonuclear runaway of the accreted matter on the neutron star (NS), and Type II – spasmodic accretion (e.g. Lewin et al. (1995)). The outbursts of RB are similar to those in soft X-ray transients (SXTs) (see e.g. Chen et al. (1997) for a review on SXTs). The outbursts of SXTs are interpreted in terms of the thermal instability of the accretion disk (e.g. Dubus et al. (2001); King & Ritter (1998)). The orbital period $P_{\rm orb}$ of RB has been unknown since its discovery in 1976. Since $P_{\rm orb}$ of X-ray binaries lie in a very wide range (11 min – several days) (e.g. Ritter & Kolb (2003)), even an estimate of $P_{\rm orb}$ of RB makes sense.

2. DATA SOURCE AND ANALYSIS

Daily means of the $ASM/RXTE$ sum band 1.5–12 keV observations (Levine et al., 1996) (`http://xte.mit.edu`) were used. This analysis considers the outbursts of Group A with Phase 1 (intense persistent emission) (Fig. 1a) (see Guerriero et al. (1999) for details). The outbursts were matched to a representative outburst, taken as a template. The rising branch was used for folding the individual events. From the physical point of view, the rising branch represents the phase of the propagation of the heating front through the disk (Fig. 1abc), using the model of Dubus et al. (2001).

3. DISCUSSION

The initial part of the decaying branch of the outbursts of Group A is roughly exponential with the e-folding time $\tau = 8$ days while the final decay can be regarded as approximately linear (Fig. 1abc). The scatter of the decaying branches can be attributed to the rapid variability on the time scale of a few days rather than the systematic changes of the decay rate. Arrivals of the spiral arms into the inner disk region are a possible cause (see the models by Truss et al. (2002)). The physical interpretation of the exponential decay can be offered in terms of irradiation of the disk by X-rays strong enough to ionize all of the disk out to its outer edge according to the model by King & Ritter (1998).

Here we present an approach which enables us to constrain the length of $P_{\rm orb}$ of RB from the parameters of outbursts of Group A, using the model of King & Ritter (1998) and Shahbaz et al. (1998). Conversion of the X-ray flux of RB can be carried out in the following way: 3×10^{-12} erg/cm^2/s per 1 PCA ct/s (2–20 keV) (Guerriero et al., 1999). The intensity of RB at the peak of outburst (from the fitted profile in Fig. 1) is then $I_{\rm max} = 19$ ct/s = 0.253 Crab = 3290 PCA ct/s, which yields the peak flux $F = 9.9 \times 10^{-9}$ erg/cm^2/s. Correction for the extinction $N_{\rm H} = 1 \times 10^{22}$ cm^{-2}, using the spectra of the persistent emission by Masetti et al. (2000) and the cross sections by Morrison & McCammon (1983), increases the flux in the 0.7–12 keV passband by a factor of ~ 1.25 with respect to that observed in the 1.5–12 keV passband. The luminosity of RB at the outburst peak is thus $L_{\rm max} \approx 9.5 \times 10^{37}$ erg/s (0.7–12 keV).

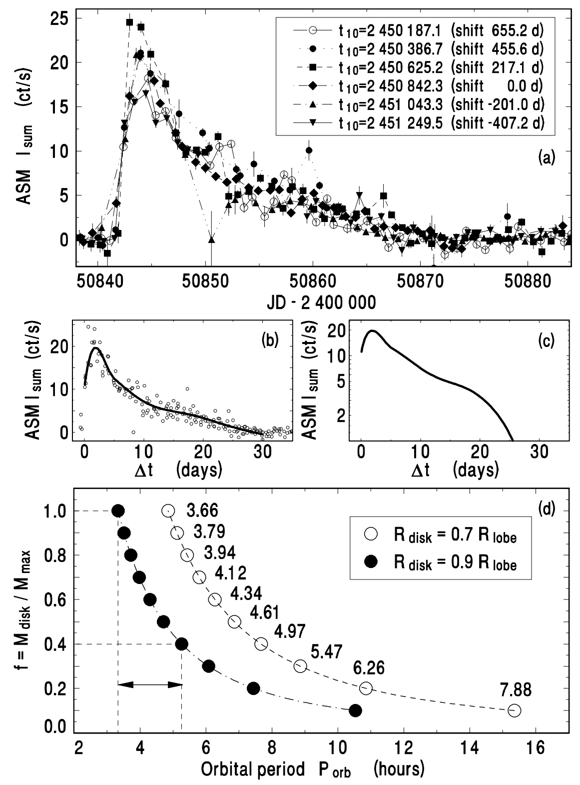

Figure 1. (a) Superposition of 6 outbursts of Group A, shifted along the time axis to match the rising branch of the template at $I_{\rm sum} = 10$ ct/s (the moment t_{10} in JD is listed). (b) Merged $ASM/RXTE$ light curves from Fig. 1a. Δt gives the time interval with respect to crossing $I_{\rm sum} = 10$ ct/s on the rising branch. The folded light curves were smoothed by the code HEC13 (author Dr. P. Harmanec, method of Vondrák (1969, 1977)). (c) The fit displayed in the logarithmic scale of the ordinate. (d) $P_{\rm orb}$ of RB versus the factor f. The numbers at the points denote $R_{\rm disk}$ in units of 10^{10} cm. The most likely range of $P_{\rm orb}$ of RB is marked by the horizontal arrow.

The disk mass at the outburst peak is $M_{\rm h(0)} = (L_{\max}\ \tau)/(\eta\ c^2) \approx 4.9 \times 10^{23}$ grams. $\eta = 0.15$ (King & Ritter, 1998) and c is the speed of light. The radius of the disk at the outburst peak is $R_{\rm h(0)} = [(3\ M_{\rm h(0)})/(3\ 10^{-8}\ f)]^{1/3}$ cm. f is the ratio of the mass of the hot disk at $L_{\max}$ with respect to its maximum possible mass. The $P_{\rm orb} - R_{\rm disk}$ relation for various values of f is shown in Fig. 1d. $P_{\rm orb}$ can be determined if we assume a reasonable value of $R_{\rm F} = R_{\rm h(0)}/R_{\rm lobe}$, giving $R_{\rm h(0)}$ as a fraction of the radius of the lobe of the NS, $R_{\rm lobe}$. Here we use $R_{\rm F} = 0.9$ and 0.7.

$$P_{\rm orb} = \left(\frac{R_{\rm lobe}}{1.63 \times 10^{10}}\right)^{3/2} \left(\frac{M_\odot}{M_{\rm NS}}\right)^{1/2} \quad [\rm hr] \qquad (1)$$

$P_{\rm orb}$ is longer than ~ 3.5 hours (Fig. 1d). We argue that the plausible values of f lie in the range 0.4–1.0 (since the largest part of the decaying branch is exponential), which enables us to constrain $P_{\rm orb}$ even better. The resulting constraints on the system parameters are in Table 1.

Table 1. Constraints on the system parameters of the Rapid Burster.

Mass of the neutron star: $M_{\rm NS} = 1.4\ M_\odot$ (def.)
Disk radius in outburst: $R_{\rm disk} = 0.9\ R_{\rm lobe} =$ 3.7×10^{10} cm – 5.0×10^{10} cm
Orbital period: $P_{\rm orb} = 3.5 - 5.5$ hours
Spectral type of the donor *: M4V–K5V
Radius of the donor *: $0.3 - 0.6\ R_\odot$
Mass of the donor *: $0.3 - 0.6\ M_\odot$
* Using the relations of Smith & Dhillon (1998).

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