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AN APRIL 1991 OUTBURST FROM 4U0115+63

OBSERVED BY BATSE*

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ABSTRACT

4U0115+63 is a recurrent transient X-ray pulsar in a moderately eccentric orbit with a Be star companion, V635 Cas. Many outbursts from this system have been reported over the past twenty years; yet despite the apparent relation between optical outbursts from the companion star and subsequent X-ray transient events, the physical mechanism for the mass transfer in the system remains unclear. In this paper, we present the preliminary results of analysis of observations made using BATSE during the 1991 April outburst from this system. This outburst does not fit the pattern of three year recurrence intervals previously suggested by Whitlock, Roussel–Dupré and Priedhorsky (1989). The orbital elements of the system have been updated and do not support the claim of Tamura et al., (1992) that apsidal motion was detected in this system based on the 1990 Ginga outburst.

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INTRODUCTION

X-ray pulsations with a period of 3.6 seconds were discovered by Cominsky et al., (1978) from 4U0115+63 using data from the SAS–3 satellite. Cominsky et al., also used data from SAS–3 to determine a precise position for the source from which a $\sim$ 15th magnitude Be star was identified as the optical candidate (Johns et al. 1978). Further observations using SAS–3 led to the determination of the 24.3 day orbital period (Rappaport et al. 1978). 4U0115+63 was the first hard transient source to be shown to be part of a binary system. Transient outbursts from 4U0115+63 are now known to have occurred in 1969 August, 1970 January and August (Vela satellites; Whitlock et al. 1989), 1971 January (UHURU; Forman, Jones, and Tananbaum 1976), 1974 August (Vela satellites; Whitlock et al. 1989), 1978 January (SAS–3; Cominsky et al. 1978), 1980 December (Ariel 6; Ricketts et al. 1981, optical; Kriss et al. 1983), 1987 February (Ginga; Tsunemi and Kitamoto 1987), 1990 February (optical; Mendelson and Mazeh 1989, Ginga; Makino et al. 1990, Tamura et al. 1992) and 1991 March/April (optical; Mendelson and Mazeh 1991; Ginga; Roussel–Dupré 1993, and BATSE; Fishman et al. 1993). These outbursts, which initially recurred with a quasi-period of 180 days during the early 1970s, seemed to have become separated by approximately 3 years (Whitlock et al. 1989). The recent small double-peaked outburst in 1991 March/April may have changed this pattern, as no large outburst was seen in 1993 January, despite multiwavelength monitoring (Roussel–Dupré 1993).

We present here the results of our preliminary analysis of the 1991 April outburst from 4U0115+63, which was observed by BATSE in the first data acquired after the high voltage turn-on of the instrument. The source was visible for another 14 days, which has allowed us to determine some of the orbital elements for the system.

OBSERVATIONS AND ANALYSIS

The 1991 April Outburst of 4U0115+63 occurred during the activation phase of the CGRO spacecraft. Pulsations due to the source were detected in the first minutes of data collected after the initial application of high voltage to the BATSE detector modules on April 16. The source remained detectable for the next two weeks.

The timing of the pulses from 4U0115+63 has been analyzed using the lowest channel (20–50 keV) of the 1.024 s DISCLA data. Rates from intervals during which the source was visible were combined over source exposed detectors using a projected area weighting and were fitted to obtain pulsed light curves. In the fitted model the background was represented with a quadratic spline with 300 s segments, and the pulses were represented by an arbitrary third order harmonic expansion in the trial phase model. Figure 1 shows the amplitude of 4U0115+63 throughout the outburst, as determined from the pulsed light curves. Note that the peak of the outburst was probably observed, and it appears to have occurred near orbital phase 0.5. This would make it a "weak outburst" according to Whitlock et al. (1989). At the peak of the outburst the pulsed flux was approximately 80 mCrab in the 20–50 keV band.

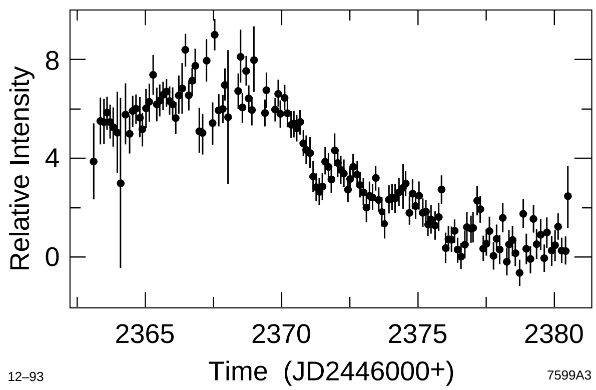

Fig. 1. Light curve of 1991 April outburst.

For each light curve, corrections to the trial phase model were determined by cross correlation of the light curve with a pulse template. The template was determined from the brightest portion of the outburst. The corrected pulse phases were then fitted with a model that included binary orbital corrections and a quadratic phase model. Our preliminary fitted parameters are given in Table I.

Table I. Orbital elements from the 1991 April outburst observed by BATSE

Orbital Element	Symbol	Value
Pulsar Frequency	$1/P$	0.2766621695 s^{-1}
Period Derivative	$\dot{P}$	$-1.05 \times 10^{-12} \pm 2.2 \times 10^{-12}$
Epoch of Periastron	τ	JD 2448355.706 $\pm$ .004
Longitude of Periastron	ω	47.66 ± 0.03
Orbital Period	P_{orb}	24.309 d[a]
Amplitude of SemiMajor Axis	$a_x \sin i$	140.13 lt s[a]
Eccentricity	ϵ	0.3402[a]

[a] Element assumed constant and taken from Rappaport et al., (1978)

APSIDAL MOTION

The eccentricity of the 4U0115+63 orbit provides an excellent opportunity to measure the advance of the longitude of periastron with time, $\dot{\omega}$. The apsidal motion constant, k, is related to $\dot{\omega}$ through a standard series of equations which depend on the mass, radius and rotation rate of the companion star, the mass of the neutron star, and the orbital elements (Kelley et al. 1981). Since the neutron star is essentially a point mass, determination of k provides a one parameter description of the internal mass structure of the B star (Schwarzschild 1958, Rappaport, Joss, and Stothers 1980). Based on Ginga observations of an X-ray outburst from 4U0115+63 in 1990, Tamura et al. (1992) found that the longitude of periastron, $\omega = 48.02 \pm 0.11$. This was significantly different than the value of 47.66 ± 0.17 found by Rappaport et al. (1978), and led Tamura et al. to claim the first detection of apsidal motion in an X-ray binary system, with $\dot{\omega} = 0.030 \pm 0.016° y^{-1}$. However, our BATSE observations of the 1991 outburst do not support this claim. We find that $\omega = 47.66 \pm 0.03$, consistent with

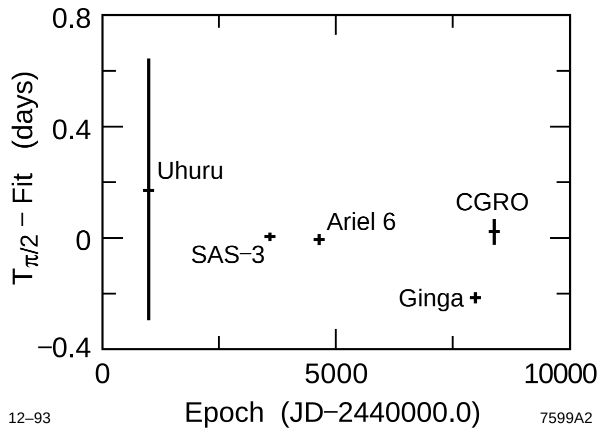

Fig. 2. This figure shows the difference between the binary epoch derived from pulse measurements and a fit to a constant orbital period for outbursts observed by various satellites. The best fit orbital period (excluding the Ginga data) yields for the time of passage of mean longitude: $T_{\frac{\pi}{2}} = \mathrm{JD}2444662.367 \pm .012 + \mathrm{n} \times (24.316479 \pm .000023)$

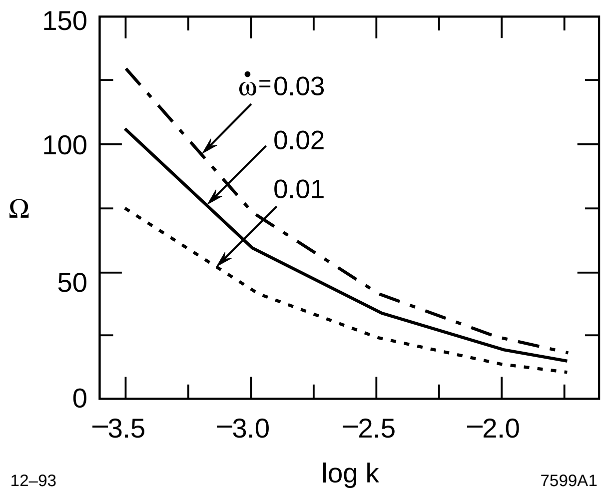

Fig. 3. The relationship between $\log k$ and the ratio of the Be star's angular velocity to the orbital frequency, Ω, for given values of the change of the longitude of periastron, $\dot{\omega}$. For this figure we have assumed that the mass and radius of V635 are those of a typical B3 main sequence star.

the value reported by Rappaport et al. (1978). This leads to a 2σ upper limit on $\dot{\omega}$ of 0.02. Furthermore, our solution for the time of mean longitude, $T_{\frac{\pi}{2}}$, is consistent with previous data points from Uhuru (Kelley et al., 1981), SAS–3 (Rappaport et al., 1978), and Ariel 6 (Ricketts et al., 1981), but not with the Ginga value (Tamura et al. 1992). This is shown in Figure 2.

If we assume that V635 Cas is a B3 main sequence star with effective temperature equal to 20,000 K (Hutchings and Crampton 1981), its implied mass and radius are 11 $M_{\odot}$ and 5.2 $R_{\odot}$, respectively. This allows us to determine the relationship between the companion's angular velocity in units of the orbital frequency, Ω, and the log of the apsidal motion constant as a function of the measured $\dot{\omega}$, as shown in Figure 3. For a Be star, typical values of $\Omega = 10$ would give the upper limit $\log k < -2$ (for example, see Stothers 1974). Optical observations to better determine the mass, radius and rotation rate of V635 Cas would be very useful in helping to further interpret the apsidal motion information.

CONCLUSIONS

We have used BATSE data to determine orbital elements for the 1991 April outburst from 4U0115+63. This outburst does not fit the pattern of the three year cycle proposed by Whitlock et al. (1989). The elements that we derive are inconsistent with those found by Tamura et al. (1992) in which apsidal motion was detected. We see no evidence yet for apsidal motion from this system.

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