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Optical pulsations in the cataclysmic binary 3A 0729+103

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Summary. Fast photometric observations of the newly discovered cataclysmic variable 3A 0729+103 are reported. Regular optical pulsations, with an average semi-amplitude of ~0.15 mag in B-band and having a period in agreement with that reported by McHardy et al. (1982) are clearly detected in the light curve of the star. The optical pulse has a sinusoidal shape. Flares with a maximum amplitude of ~0.43 mag have also been observed. There is also suggestion of flickering on time scales of ≧10 s. It is suggested that 3A 0729+103 is similar in characteristics to H 2252−035 class of cataclysmic binaries containing rapidly rotating white dwarfs. Interpretation of the period of optical pulse as the beat period leads to prediction of X-ray pulse period to be about 847 s for prograde rotation and 991 s for retrograde rotation of the white dwarf compared to the reported ~900–1000 s period. Alternative interpretation of the observed optical pulse being due to directly beamed radiation from the vicinity of the pole of the white dwarf is also considered.

Key words: X-ray sources – cataclysmic variables – X-ray pulsars

1. Introduction

The X-ray source 3A 0729+103 was detected by the Ariel V satellite and first appeared in the 3A catalogue of high latitude ($|b|>10°$) X-ray sources (McHardy et al., 1981). It is a rather weak source with a flux equivalent to 0.74 ± 0.14 *UHURU* counts s^{-1}. Using a precise position obtained with the Imaging Proportional Counter (IPC) on the Einstein Observatory, McHardy et al. (1982) have identified it optically with a 14.5 mag variable star at R.A. (1950) = $07^h28^m44^s.4$, Dec. (1950) = $+10°02'46''$. Photometric and spectroscopic observations in the optical band, indicate that the star has all the characteristics of a cataclysmic variable (McHardy et al., 1982). This includes the occurrence of broad He and Balmer emission lines in spectra, occasional flaring and the presence of flickering. They also find the presence of coherent sinusoidal pulsations with a period of 913.48 s and an amplitude of 12% in white light. There is also a suggestion of possible orbital modulation in the light curve at a level of 8% with a period of 3.75 h. More recent observations seem to give an orbital period of 3.24 h (Ritter, 1983). The source also seems to pulsate in X-rays with period in the range 900–1000 s (McHardy et al., 1982), but the precise X-ray period is not yet reported. The presence of X-ray and optical pulsations suggest that this object is similar in nature to the remarkable cataclysmic binary H 2252−035 (Patterson and Price, 1981). This makes it an extremely interesting object for optical studies.

Following the announcement of this discovery by McHardy et al. (1982), we carried out optical photometry of the object to confirm the presence of pulsations and orbital modulations in its light curve. In this paper we report results of our optical observations.

2. Observations and results

The observations were carried out with the 1.2 m telescope at the Japal-Rangapur Observatory near Hyderabad, India. A single channel photometer with a thermoelectrically cooled RCA 8575 phototube and photon counting electronic system was used for this purpose. Observations were carried out only in the standard B-band on the night of February 17/18, 1983, beginning at time $T = 14^h43^m52^s$ UT. During our run, sky conditions were ideal for photometric observations. A diaphragm with 12″.5 aperture and integration time of 10 s were used throughout the observations. The star and the sky were monitored alternately to correct for the sky background and any variations in its surface brightness. A comparison star was also monitored periodically. Sky and dark counts were subtracted from the star counts observed in each 10 s time bin. The star counts were then corrected for extinction, the extinction coefficient being derived from the observations of the comparison star.

In Fig. 1a–c we show a plot of the counts, corrected for extinction, in 10 s bins as a function of time. Periodic variations, with well defined maxima and minima, are clearly discernible in the figures. However the amplitudes (maximum-minimum) of pulses, seem to vary from cycle to cycle, ranging from almost zero for the cycle at $T \sim 2000$ s to a value of ~0.7 mag for the cycle beginning at $T \sim 9000$ s. A few minima have larger than average depth as can be seen in Fig. 1a–c. Besides the regular pulsations, the presence of irregular variations and flaring is obvious in the light curve. Notice a prominent flare of 0.43 mag in Fig. 1a which commenced around $T \sim 2700$ s near the pulse maximum and lasted for about 300 s. A second similar flare was observed near the end of our observations as can be seen in Fig. 1c. Both the observed flares occurred near the maxima of pulses. It is interesting to note that the time seperation of ~3.25 h between the two flare events, coincides with one of the proposed orbital period of 3.24 h for this binary. Similar flare events of ~100 s duration and magnitude ~0.15 have been detected in H 2252−035 (Warner et al., 1981). Flickering, a common characteristics of AM Her and DQ Her

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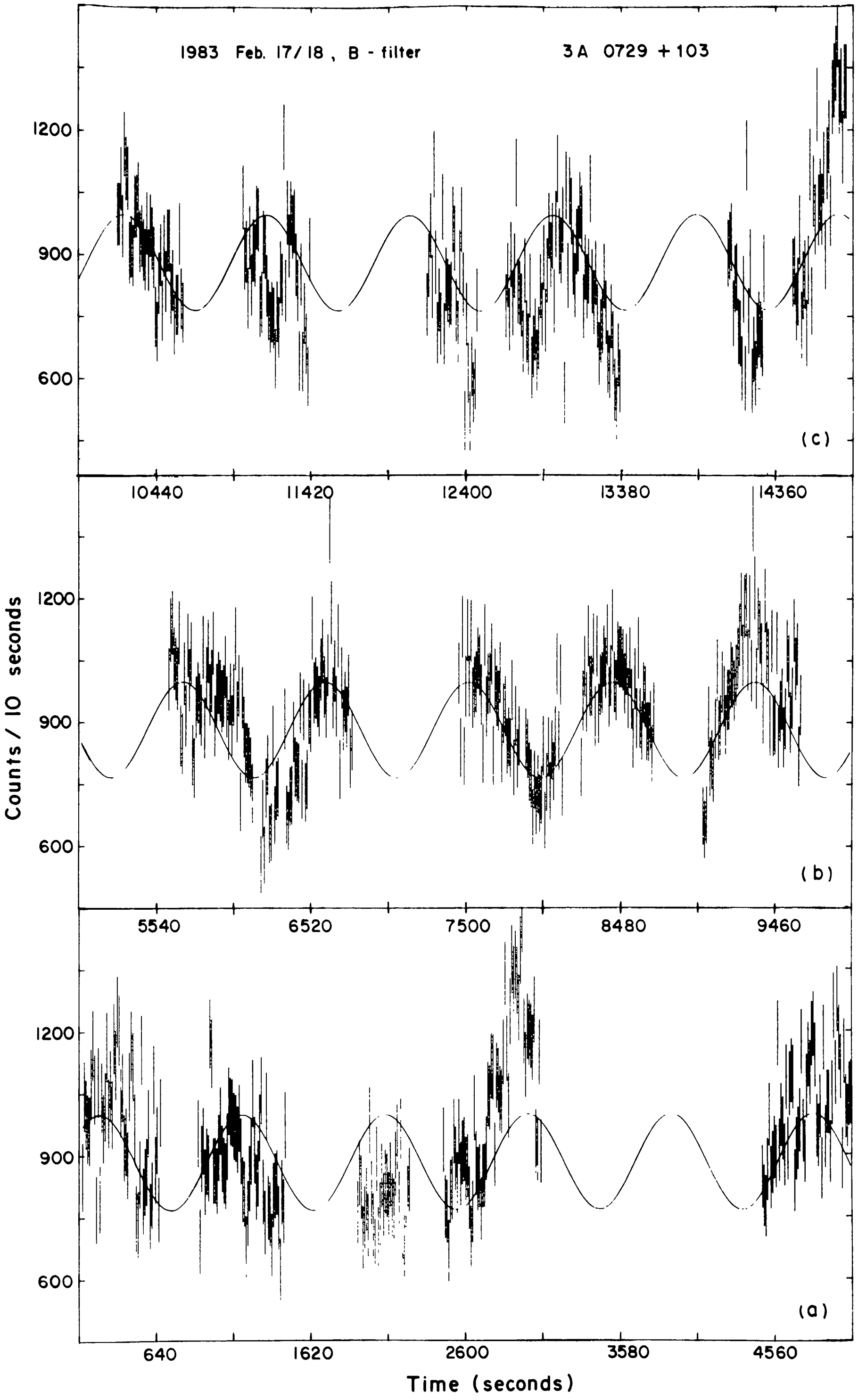

Fig. 1a–c. The light curve of 3A 0729+103 in the B-band observed on the night of February 17/18, 1983. Time $T=0$ corresponds to $14^h43^m52^s$ UT. Each point represents counts in 10 s time bin. Typical value of statistical error, shown for each data point in the figures, is about 10%

type binaries, also seems to be present on time scale of 10 s and more.

To obtain pulse period, we attempted fitting a sine curve to the data points, using χ^2 minimization technique. The sine curve shown in Fig. 1 is the best fit to the observed maxima and minima and has a period 905 s. Irregular light variations and flaring superposed on the periodic pulsations result in a rather high χ^2/degree of freedom = 3.2. Due to the limited number of cycles (16) observed in our run, the error associated with the derived period is rather high. From the uncertainties associated with the location of the first and the last maxima, we estimate the error to be ± 9 s. The observed value of the period is therefore consistent with the value reported by McHardy et al. (1982). We also carried out an auto-correlation analysis for our data to confirm the periodic pulsations. The analysis clearly indicates persistence of pulsations in the entire stretch of the data. The best fit period derived from auto-correlation analysis is 909 s, in agreement with the value obtained from the sine curve fit.

To obtain the average pulse shape, the data grouped in 20 bins of 10 s, were folded with the best fit period (905) and suitably normalized to compensate for the data gaps. The resulting average pulse profile plot is shown in Fig. 2. The dotted line is a cosine curve fit to the pulse profile. This confirms the sine wave shape of the pulse used in fitting the light curve earlier. The mean semi-amplitude of the sinusoidal modulations as derived from this curve is 15.4±3.8%, in the B-band. This is slightly higher than the value of 12% observed in white light (McHardy et al., 1982).

We also searched the data for any possible 3.24 and 3.75 h orbital modulation. This was done by adding a sinusoidal variation term due to orbital modulation to the sine wave due to pulsations. This did not make any significant reduction in our best fit χ^2 value and thus we find no evidence for the presence of any orbital variations in the B-band light curve up to a limiting semi-amplitude of 5%.

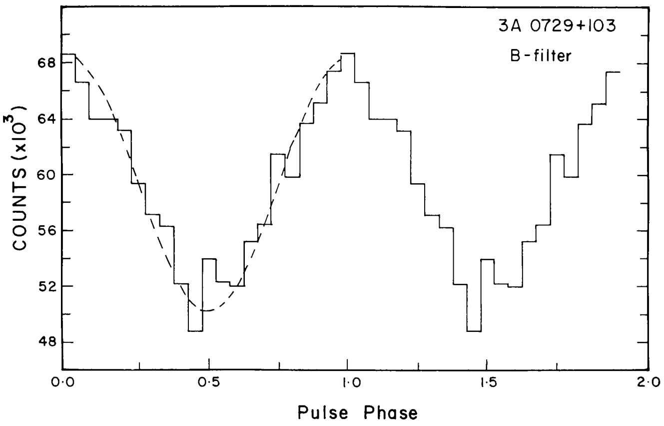

Fig. 2. Average shape of the optical pulse in B-band folded twice with the best fit 905 s period. Dotted line is a cosine curve fit to the observed pulse profile

3. Discussion

Our observations confirm the presence of optical pulsations in the optical counterpart of X-ray source 3A 0729+103. Presence of X-ray pulsations and the binary nature of the star is indicated by the work of McHardy et al. (1982). Using the X-ray flux value in 2–10 keV band from the 3A catalogue for $|b|>10°$ sources (McHardy et al., 1981) and taking $m_B \approx 14.5$ mag, we estimate the ratio of the X-ray to optical luminosity (L_x/L_{opt}) to be ~3. Patterson (1981) has shown that the ratio L_x/L_{opt} is a good indicator to distinguish between a neutron star and a white dwarf in an accreting close binary. This ratio is ~1 for the cataclysmic binaries, like the highly synchronous AM Her type systems and non-synchronous binaries like H 2252−035 and H 2215−086. The observed L_x/L_{opt} ratio for 3A 0729+103 is thus consistent with the X-ray source being a rotating white dwarf. All the observed optical and X-ray characteristics of this source strongly indicate that this object is similar in nature to the cataclysmic binary H 2252−035 which pulsates regularly in the X-ray and optical bands. There are only two other known objects of this type viz. 4U 1849−31≡V1223 Sgr (Steiner et al., 1981) and H 2215−086 (Shafter and Targan, 1982) both of which pulsate in the optical band with periods of 13.2 and 21 min, respectively. For a review of the properties of these systems refer to Warner (1982, 1983). The object 3A 0729+103 is now the fourth member of this new sub-class of cataclysmic binaries. In Table 1 we have summarised the characteristics of the four members of this class discovered so far. Their pulsation periods lie in the range 859 to 1254 s. This indicates that the rotation periods (P) of the white dwarfs in these binaries lie intermediate between those found in the Am Her type synchronous binaries (P ~ 80 to 222 min) and the much faster rotating DQ Her and AE Aqr ($P < 100$ s) type systems.

In the generally accepted picture of these cataclysmic binaries, the X-ray and UV emission is produced from the magnetic pole and the accretion column of a rotating magnetic white dwarf, which accretes matter from a late type dwarf companion star (Chanmugam and Wagner, 1979; Patterson and Price, 1981). In this model, the X-ray pulsation period corresponds to the rotation period of the white dwarf. The optical pulse, explained as the reprocessed radiation from the surface of the secondary star, has a period which is the beat period between the X-ray pulsation period and the orbital period of the binary. In the case of H 2252−035, an additional optical component, pulsating with the same period as that of X-rays, has also been detected (Motch and Pakull, 1981). This component is most likely produced in a region close to the X-ray emitting region of the white dwarf.

If we assume the above scenario to be applicable to 3A 0729+103 then the optical period should be the beat period between the ~900–1000 s X-ray pulse period and the 3.24 h

Table 1. Summary of H 2252−0.35 type cataclysmic binaries

Object	m_v	Orbital period (h)	X-ray pulse period (s)	Whether optical pulse with X-ray period present	Reprocessed optical pulse: Period	Reprocessed optical pulse: Average semi amplitude (Δm) (mag)	$\frac{L_x}{L_{opt}}$	Ref.
3A 0729+103	14.5[a]	3.2366	900–1000	?	913.48	0.15	3	1, 2
4U 1849−31	13.2	3.3799	?	?	794.41	0.15	1	3, 2, 4
H 2215−086	13.5	4.0250	?	?	1254.44	0.20	2.4	5, 6
H 2252−035	13.3	3.5906	805.14	Yes	858.68	0.1	0.5	7–9

References: (1) McHardy et al. (1982); (2) Ritter (1983); (3) Steiner et al. (1981); (4) Bonnet-Bidaud et al. (1982); (5) Patterson and Steiner (1983); (6) Shafter and Targan (1982); Patterson and Price (1981); (8) Warner et al. (1981); (9) White and Marshall (1981)

[a] Blue magnitude

orbital period of the binary. Unfortunately the X-ray period is not yet reported to a sufficient precision to be able to verify the above hypothesis. Assuming 3.24 h value of the orbital period, we estimate that the X-ray pulsation period should be about 847 s under the assumption of a prograde rotation of the white dwarf. This is lower than the reported X-ray period of 900–1000 s. However, since this period is known only approximately, its value may still be compatible with the beat period hypothesis. Alternatively it is conceivable that the white dwarf may be in retrograde rotation. In that case the period of the X-ray pulse will be longer than that of the reprocessed optical pulse. Using 3.24 h orbital period, we estimate the X-ray pulse period to be 991 s in this case, which lies in the range of the reported X-ray period.

A second alternative explanation, though less likely, may be that the observed optical pulsations may not be due to reprocessed radiation but may be radiation beamed directly from the vicinity of the pole of the white dwarf as has been detected in H 2252−035 (Warner et al., 1981; Motch and Pakull, 1981). In this case the optical and the X-ray pulse periods will be the same, in agreement with the reported X-ray and optical pulse periods. However, an optical pulse due to the reprocessed radiation from the surface of the secondary star, should be observable as found in other similar objects. Using 913.48 s as the X-ray pulse period, we estimate period of this pulse to be about 991 s. We looked for the 991 s pulsed component in our data by adding an additional sinusoidal variation term of this period to the best fit 905 s sine wave term. The semi-amplitude of the 991 s sine wave was varied to minimize χ^2. From this we can only state that the semi-amplitude of the 991 s pulsations, if present, should be less than 4.8 %.

The major difficulty with this interpretation is that in all the other three similar binaries, the optical pulse due to the reprocessed radiation is dominant. In fact the pulse due to the directly beamed radiation has been detected clearly only in H 2252−035, in which the amplitude of the directly beamed optical pulse and that of the pulse due to reprocessed radiation are about equal in the U-band (Motch and Pakull). More detailed photometric observations in different bands are required to resolve this question. We plan to carry out further observations of this object in the coming months.

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