The Pulsar Period Manifestation in the X Persei Optical Emission

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Abstract. I report on the results of photoelectric UBV observations of the Be/X-ray star binary X Per (4U0352+30). The optical observations of X-ray binary show the periodic variability with an amplitude of $> 1\%$ and the 13.9 min period of the associated X-ray pulsar. So far the optical pulsations (13.9 min) with the same amplitude have been detected in the minimum of optical light ($V = 6.^m7$)(Latysheva & Lyuty 1987). It led us to conclude that the pulsar period manifestation of X Per in the optical emission did not connect with the Be star state. If the spectroscopic period of 580 days represents the orbital period of the X-ray source around the Be star then the binary separation is very large even at periastron. Consequently, it is highly improbable that we can observe the pulsar emission reflected from Be star or its disk. It is likely that the observed modulation in optics originates around the X-ray source itself. The reprocessing material might be the matter accreting onto the compact object.

Key words: Be/X-ray binary – neutron star – spin period – optical modulation

1. Introduction

X Persei is the prototype system of persistent Be/X-ray binaries. The primary is an O9.5IIIe star (Slettebak 1982; Fabregat et al. 1992), and pulsed X-ray emission is thought to arise from accretion onto a magnetized neutron star companion. A pulse period in X-rays of 835 s has been found by White et al.(1976). A possible (spectroscopic) 580 d orbital period (Hutchings et al. 1974; Penrod & Vogt 1985) has been suggested, although this is still unconfirmed. The wide binary orbits in Be/X-ray systems are such that accretion is thought to occur by stellar wind losses alone, as the Be primary does not fill its Roche lobe. Since the X-ray source in X Per is a pulsar with 13.9 min period, many searches have been made in order to detect corresponding optical modulation. Such modulation has been discovered from photoelectric observations (Latysheva & Lyuty 1987) and from high spectral resolution observations of the H_α profile (Mazeh et al. 1982). However, the question of connection between the optical pulsations and the X-ray activity and the Be star variability is still an open question. The purpose of our study is to search the pulsar period manifestation in the X Per optical emission and to investigate the possible connection between the shape of phase light curve corresponding to the X-ray pulsar period and its amplitude and other parameters of variability.

2. Observations

X Persei was put on the observing programme of the 60cm Cassegrain reflector of Crimean laboratory of Sternberg Astronomical Institute. Altogether 632 UBV observations were obtained during 5 nights between 1994 September 19 and October 20, using one-channel UBV photometer. The observations of X Per were made relative to a bright comparison star HR1197: $V = 6.^m25, B - V = 0.^m20, U - B = 0.^m14$. As patrol UBV measures as special ones during $2 - 3$ hours were carried in $1994 - 1995$ with time resolution 30 s (high-speed photometry). The pulses were accumulated during 10 s $(0.5 - 16) \times 10^6$ hence the statistical precision of single measure $\sqrt{N}/N$ was of the order 0.1% (N — the number of accumulated pulses). The phase light curves were folded with accepted pulsar period 13.9 min. For every night we choose compromise number of measures for averaging.

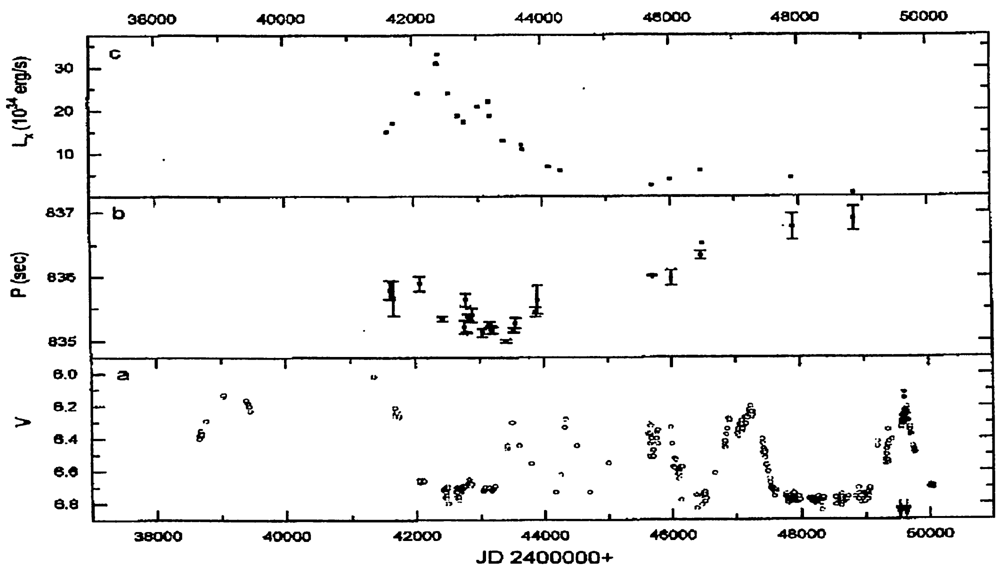

Figure 1. The long-term variability of X Per over the last 27 yr: a) the V band light curve; b) the pulsar period history; c) the X-ray light curve (2-10 keV)

3. Analyzing the light variability

3.1. Long-term variability

Studies of the long-term variability of X Per show that the star undergoes periods of slow brightening/fading, sometimes dropping to extreme low states. Figure 1a shows the V band light curve of X per over the last 27 yr (solid circles and arrows show our observations. It is seen that the star was in extremely low state ($V = 6.^m8$) during 1974 – 1977 and 1990 – 1993. It may well be that the extended low phase marks the beginning of a major change in the size and structure of the circumstellar disk, which resulted in deeper minima following that period. In both recent extended low states it is clear that the star becomes almost non-variable ($\Delta V \leq 0.^m1$ in 1974 – 1977, $\Delta V \leq 0.^m01$ in 1990 – 1993). If we associate these extended optical lows with disk-loss events, then it would appear that the optical variability is due to the presence of the circumstellar material. It thus appears that a high bright state of X Per is characterised by a red colour due to disk material presence, and the low states are accompanied by a blue colour, as we are seeing the unobscured O9.5 star beneath the shell. After low state during 1990 – 1993 X Per rapidly brightened and $(B - V)$ colour became redder and $(U - B)$ colour became bluer.

In 1994 September X Per was near its extremely high bright state (JD 2449615, $V = 6.^m21$). Under this state the most high fluctuations of light were observed during every night (up to $0.^m2$), but it should be noted that the amplitude of light fluctuations was less by a factor of 10 in 1994 October. In later 1995 the optical light of X Per became $0.^m5$ less, that is, the 1994 high state completed.

3.2. Comparison of optical behaviour with X-ray data

The X-ray pulsar period history of X Per is shown in Figure 1b. The X-ray satellites data, presented in Figure 1c, show that the spin-down episode seems to have continued up to date. The lack of correlation between the optical and X-ray light curves is may be related to the unknown orbit of the neutron star which may be highly eccentric and inclined to the equatorial plane. From all long-term data plotted in Figure 1a it may be suggested that in period 1970 – 1971 the circumstellar disk of X Per may have reached an unusually large size. The V magnitude of the star and disk has reached $6.^m0$, compared to usual maximum of around

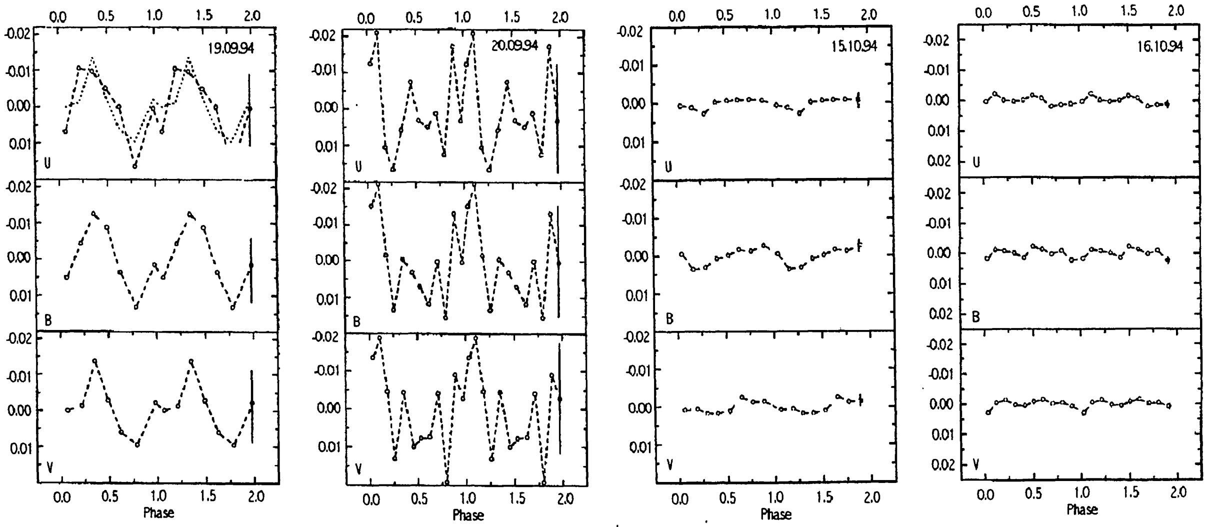

Figure 2. The optical light curves folded with period 13.9 min

6.^{m}25, suggesting much more disk material is present. If the disk becomes hyper-extended, and contains substantially more material than usual, than as it dissipated we would expect to see a rise in the accretion rate onto the neutron star. This may explain a connection between the optical and X-ray luminosities and the pulsar period — as the optical luminosity fades from a maximum in 1971 – 1972 (hyper-extended disk dissipates) the X-ray luminosity steadily increases (increased accretion rate onto the neutron star due to the presence of the dissipating disk material) and the increased accretion rate spins-up the pulsar. As the additional material from the dissipating disk has been accreted, the X-ray luminosity of the system fades and the pulsar reverses to its usual state of spin-down.

Based on the *Ariel V* and *Copernicus* observations in the 1974 – 1977, we might expect a steadily decreasing X-ray flux from X Per at present. However, based on the recent observations of *Ginga* in Jan. 1990 (Robba et al. 1996) and *BBXRT* in Nov. 1990 (Schlegel et al. 1993), the source does not appear to have attained the unusually high X-ray luminosity seen in 1972 – 1975. We may suggest that during the last phase change the disk loss occured at another orbital phase and dissipating circumstellar material has not reached the compact component due to its large distance from the neutron star.

3.3. The pulsar period manifestation

In our study it is not proposed to determine the pulsar period value in the optical range, as more long observations are requared during every night. The basic purpose of this study is to fold the measurements with period 13.9 min, and to clear up the question about its manifestation in optical emission and about the shape and the amplitude of the mean light curve, and to elucidate whether the dependence of the mean light curve is on the colour and the mean luminosity of the star, etc.

In Figure 2 we have plotted the light curves, folded into period of 13.9 min. The vertical line shows a root-mean square error of the mean measurement. For one night 19.09.1994 (JD 2449614) we can say with reasonable confidence that the manifestation of a neutron star period was observed. Although the error of the mean measurement is only less by half than amplitude, it is seen that the luminosity varies with phase and the mean amplitude is 0.^{m}02 and is much the same in all bands. In the next night the random fluctuations with phase have much more amplitude, although it is possible that the optical modulation (with 13.9 min period) is present with lower amplitude.

One of the central task of the rapid *UBV* photometry perfomance was to find the possible dependence of the light amplitude and the light curve shape upon wavelength. It is seen in Figure 2 (the first plot) that the curve shape varies substantially in going from *V* band to *U* band: in the former case a maximum is more narrow, it is very apparent in superposition of the light curves (see top of Figure 2 (the first plot), the V band light curve are shown by the dashed line).

After the month the optical pulsar period amplitude decreased by 10. And although in October 15 the optical modulation appears only slightly, in October 16 the pulsar period manifestation are entirely absent although there is some evidence for its presence in V band. In October 20 no evidence is for optical modulation with 13.9 min period.

Since the mean luminosity has not varied from September 19 to October 20 but the optical modulation amplitude decreased more than by 10, it may be stated that the pulsar period manifestation in the X Per optical emission does not depend on Be star disk state. The observational results of Latysheva & Lyuty (1987) give one more reason for its statement: in the lower state ($V = 6.^m7$) the optical 13.9 min modulation was detected with an amplitude similar to that observed in September 19 ($V = 6.^m2$). If the spectroscopic period of 580 days represents the orbital period of the X-ray source around the Be star then the binary separation is very large even at periastron. Consequently, it is highly improbable that we can observe the pulsar emission reflected from Be star or its disk. The fact that the X-ray luminosity is very small compared to the optical intensity may be an additional proof for this. It is likely that the observed optical modulation originates around the X-ray source itself. The reprocessing material might be the matter accreting onto the compact object.

4. Conclusions

The results obtained in our study provide answers some questions formulated in the introduction. In one night (September 19, 1994) the optical pulsations with the pulsar period 13.9 min and the amplitude > 1% were observed. In September 20, these pulsations possibly present with a lower amplitude and after the month the modulation totally disappeared. The mean light of X Per was constant within the range $V = 6.21 - 6.25$. Taking into account that in the minimum of light ($V = 6.^m7$) the pulsations were observed with the same amplitude (Latysheva & Lyuty 1987), one may conclude that the 13.9 min optical modulation appearence does not depend on the Be star state. It seems likely that the presence of the 13.9 min optical modulation does not depend on the value of the amplitude of rapid fluctuations.

In order to answer question about the nature of the 13.9 min optical pulsations of X Per the data obtained are unsufficient, the continious observations of rapid variability are requared during a long time (at least during one year).

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