OBSERVATIONS OF X-PER IN OPTICAL DOMAIN

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Abstract. We have monitored the X-ray source X-Per (4U 0352 + 30) on 31 August, 1979 through a *U* filter for about 1.5 hr using 102-cm telescope of Kavalur observatory. During this period intensity of X-Per fluctuated for some time, on time scales of few minutes but recovered in the end. It was again monitored from 27 December, 1979 to January 1980 through a standard *U*, *B*, *V* photometer attached to a 34-cm telescope. In this paper we present the data on the fast flickerings observed on 31 August, 1979 and on the long term monitoring from December 1979 to January 1980.

1. Introduction

Since the end of last century, X-Per has been known to have a peculiar optical spectrum and irregular variable luminosity. This source shot into prominence when it was discovered to be an X-ray source (Giacconi *et al.*, 1972). In optical region it has been classified as an irregular variable Be-star varying from 6.0 to 6.6 mag. The spectral type of the star is O9.5–B0pe and it exhibits UV excess (Brucato and Kristian, 1972; Brodskaya, 1968; Crampton and Hutchings, 1972; Wackerling, 1972; Cowley *et al.*, 1972; Glushneva *et al.*, 1974). This star is believed to rotate rapidly at the limit of stability (Moffet *et al.*, 1973). On the basis of spectroscopic observations the changes in the spectrum of the star have been interpreted as being due to radial velocity variations caused by orbital motion in the binary system with a period of approximately 580 days (Hutchings *et al.*, 1974, 1975). Also the emission and absorption line velocities are in antiphase, suggesting a dominant amount of emission from the companion. The estimated minimum mass function of the system is $18 M_\odot$ with indication that the mass of the companion must be at least $40 M_\odot$. Since it shows no appreciable optical emission, the latter is possibly a black hole candidate (Hutchings *et al.*, 1975). Assuming X-Per to be a member of the perseus 2 association, the estimated distance is 350 pc (Brucato and Kristian, 1972).

2. X-ray Characteristics

The nature of the X-Per has remained enigmatic at X-ray wavelengths in spite of a large number of observations. White *et al.* (1976) discovered that X-Per pulsates at X-ray wavelengths at the rate of about $13^{m}_{\cdot}9$ which has been confirmed by further observations (White *et al.*, 1976; Canizares *et al.*, 1977; Margon *et al.*, 1977). White *et al.* (1976) also reported that the X-ray intensity is modulated with a period of either 22 or 11 hr which

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has not been confirmed yet. The most detailed X-ray observation are reported by Becker *et al.* (1978) using their experiment onboard OSO-8 showing that the spectrum can be best fitted to thermal bremsstrahlung continuum. The X-ray emission is strikingly different from the other X-ray binary pulsars when we consider the spectral shape, iron line emission and the variation in the low energy cut-off (Becker *et al.*, 1978). X-Per does not show any line emission and its spectrum does not show any high energy cut-off whereas other binary pulsars do show. X-ray luminosity of X-Per is 5×10^{33} erg s^{-1} in 2–10 keV band.

3. Optical Characteristics

As pointed above, X-Per has been classified as an irregular variable spectral type O9.5–B0pe whose brightness varies between 6.0 and 6.6 mag. and exhibits variable ultraviolet excess (Brodskaya, 1968; Brucato and Kristian, 1972; Crampton and Hutchings, 1972; Wackerling, 1972; Cowley *et al.*, 1972; Glushneva *et al.*, 1974). It has been proposed that X-Per belongs to a binary system with an orbital period of about 580 days and whose secondary should also be a candidate for black hole (Hutchings *et al.*, 1974; 1975). The spectrum of X-Per is more peculiar than the typical Be-star spectrum (Ivanova, 1958; Boyarchuk and Pronic, 1965; Cowley *et al.*, 1972). For many years, at Michigan, Curtis and McLaughlin (1932, 1937) have followed the star as a V/R variable (see, Cowley *et al.*, 1972). In mid 1957 X-Per (Ivanova, 1958; Wackerling, 1972) showed abrupt changes in the Balmer and metallic-emission lines, in some underlying stellar absorption lines and in the ultraviolet energy distribution (they called it the 1957 outburst). Wackerling (1972) has described even earlier speculations on this type of sudden changes. McLaughlin suggested these sudden changes due to occasional interruption of a more or less steady infall of material through the rotating emission region by outbursts of material from the star. The outburst showed larges change in the energy in $\lambda\lambda$3650–3900 band.

Many astronomers have studied periodic and aperiodic emission of X-Per independently as well as simultaneously in optical and X-ray band. Ricker *et al.* (1972) and Frohlick and Neva (1974) have set an upper limit of 0.02 mag. to any periodic variations from 1 s to few minutes. Margon *et al.* (1976) failed to detect any co-variability while observing in optical and X-ray bands simultaneously. Robinson and Africano (1975) have analysed an 8 hr stretch of data in U-band and did not detect any period corresponding to X-ray period with in a limit of 4×10^{-4} mag. On the other hand, Liller (1975) did find a double sine-curve at 13.924 min folding period with an amplitude of 8.9×10^{-3} mag.

4. Present Observations

X-Per was observed on 31 August, 1979 using the 102-cm telescope of the Kavalur observatory in the U-band for about 1 hr. It was again monitored for a long time during the period December 1979 to January 1980 using the 34-cm telescope. The total

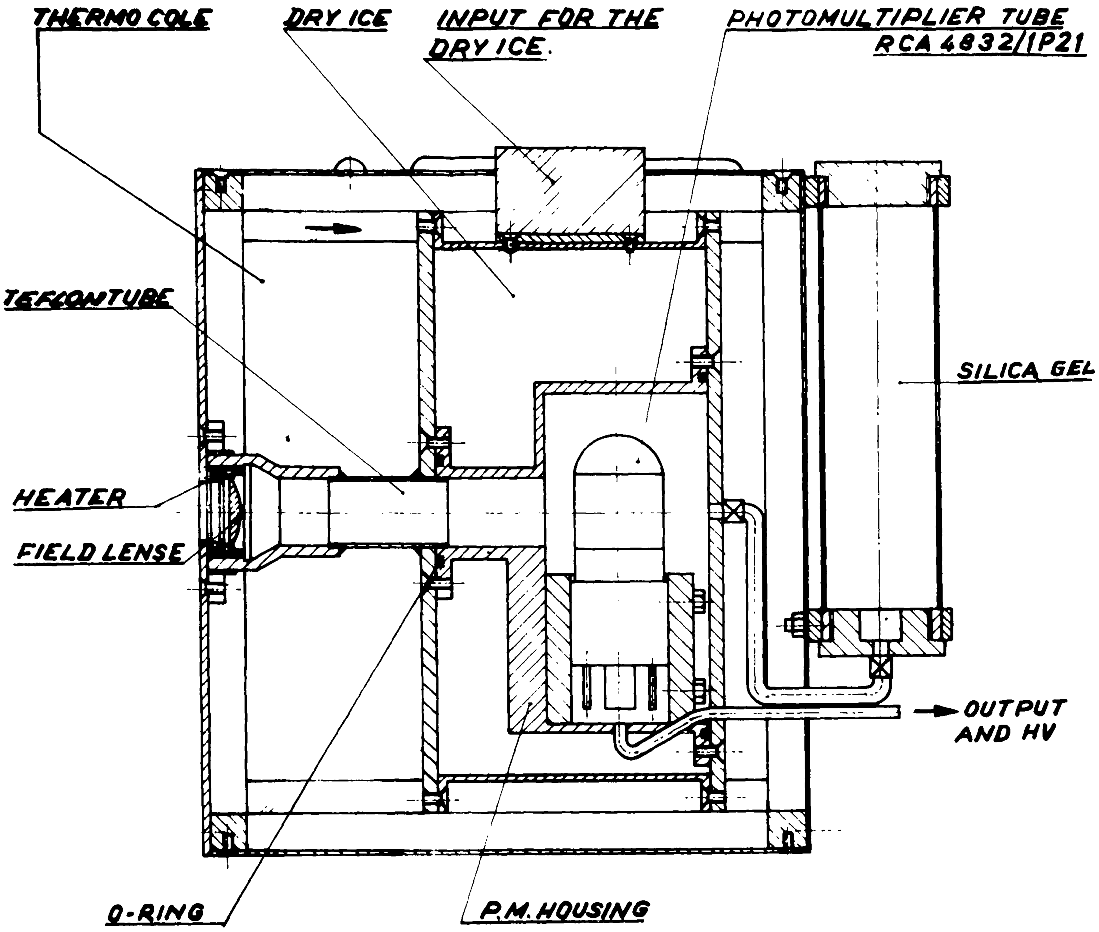

Fig. 1. Schematics of the single-channel photometer.

observation on the source was 23 hr during December/January period. The instrument used consisted of a single channel dry-ice cooled photometer (Sharma *et al.*, 1981) for 31 August, 1979 observations and an uncooled photometer for latter observations. The schematic of the photometer is shown in Figure 1. The photometer was coupled to the telescope through proper off-set devices which helped in putting the star in the centre of the diaphragm. The output of the photometer was fed to a pre-amplifier (response 100 MHz – pulse pair-resolution 4 ns). The discriminator output was fed to an ORTEC photon counting system controlled by a sampling control unit. The sampling/control unit also worked as a register/buffer between the printer and the photon counter to avoid the introduction of any dead time due to the finite printing time taken by the printer which is 50 ms. The data from sampling control unit was printed on paper using a high-speed printer (HP5050B). Data were collected with integration times ranging from 200 ms to 1 s.

The data collection scheme included monitoring of two comparison stars which were (i) HR 1197 ($V = 6.22$, $B - V = 0.22$, $U - B = 0.17$, and (ii) HR 1164 ($V = 6.25$, $B - V = 0.47$). All the stretches of X-Per runs were preceded and followed by one of

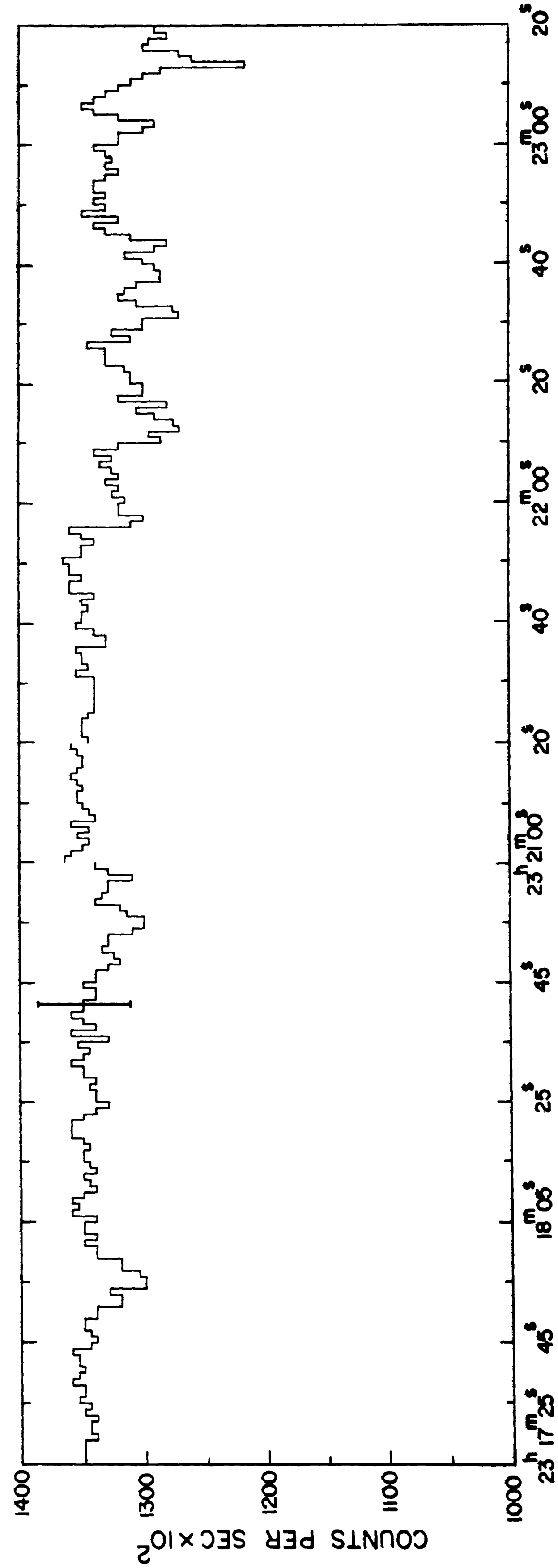

Fig. 2. Part of the data recorded from 102-cm telescope on 31 July, 1979.

the comparisons in the same band as X-Per. This was followed by sky-background observations.

Long stretches of data on both comparisons as well as X-Per were taken. These stretches were Fourier-analysed whenever possible to search for possible periodic components existing in the data.

5. Results

Part of the data obtained from 102-cm telescope is shown in Figures 2 and 3 where the data is plotted as counts per seconds vs time. The integration time was 1 s. It was

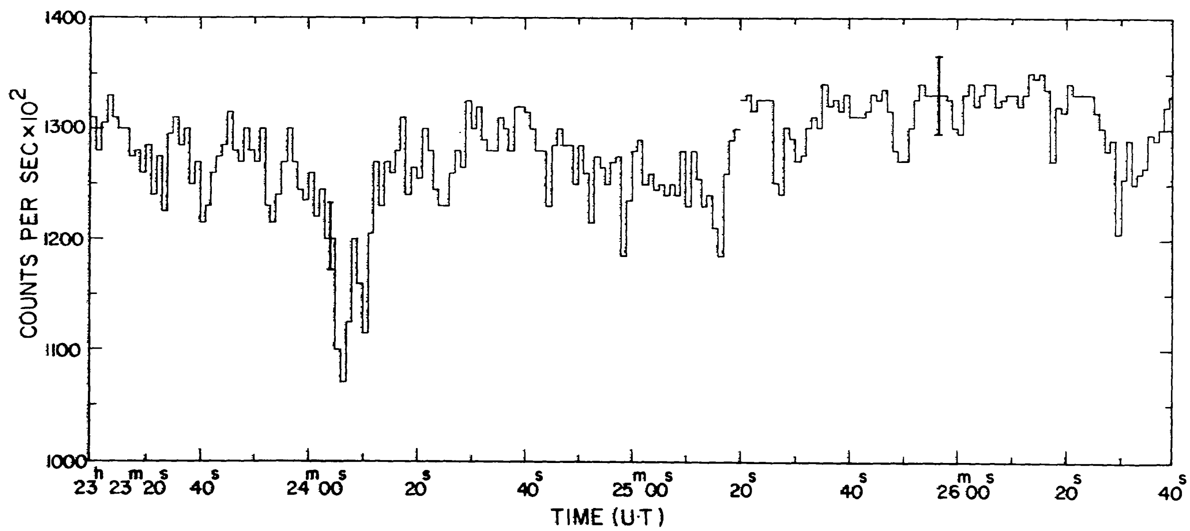

Fig. 3a. Data recorded on 31 July, 1979, showing the dips.

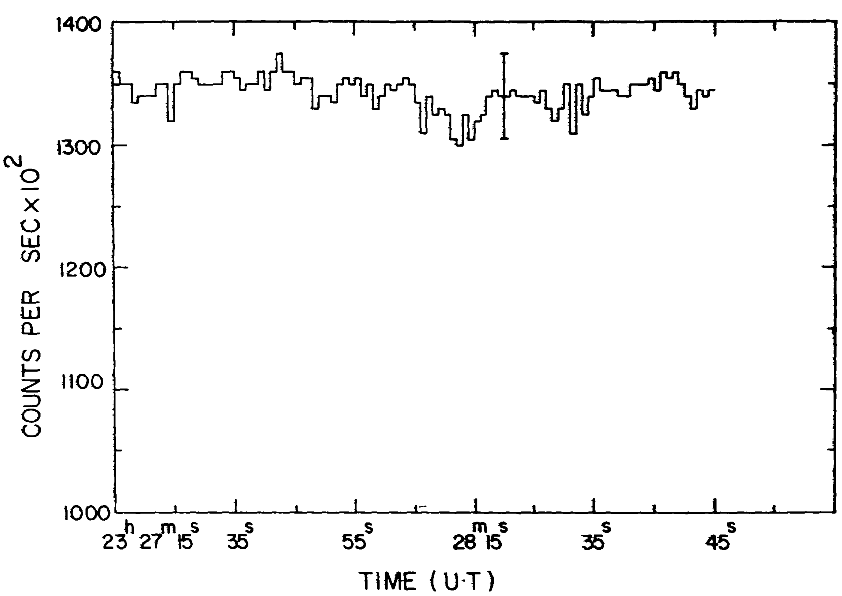

Fig. 3b. Data recorded on 31 July, 1979, showing the recovery from the fluctuating behaviour.

observed that the source showed a steady emission for a considerable time from $22^h12^m55^s$ to $23^h22^m22^s$ but from 23^h23^m to $23^h26^m40^s$ (Figure 3a) the intensity was highly fluctuating. The source emission again became steady after $23^h27^m15^s$ till the observation lasted (Figure 3b). The largest fluctuation in intensity was observed at $23^h24^m7^s$ (Figure 3a) when the count rate decreased abruptly from about 1.250×10^5 per sec (average) to about 1.070×10^5 (averge) per sec corresponding to a decrease of about 51σ in the intensity. This 'dip' in intensity lasted only for about 6 s. The dip itself showed a double peak like structure. During the observation of this phenomena a check on the sky conditions showed visibility to be very good (2 arc sec) and no detectable traces of any cirus clouds. We believe the phenomena to be due to the star itself. The diaphragm used was 10 arc sec excluding the possibility of contribution from ADS 2859B, a 12th mag. star, which is 20 arc sec away.

The data collected using 34-cm telescope is shown in Figures 4a, b, c, and d where differential magnitudes averaged over 5 s intervals, obtained with respect to the two comparisons are plotted with time for all the days the X-Per was monitored. Star ADS 2859B was always inside the diaphragm. In this paper, observations derived using comparison 2 (top curve) will only be discussed because the variational behaviour computed using each comparison is similar. The examination of all the figures show that the star did not vary by greater than 0.05 mag. on a long-term basis. However, short-term variations are clearly visible. Figure 4a shows that the U-band intensity flickered considerably on time scales of few minutes. Variations as large as $\Delta m = 0.2$ can be noticed in the U-band intensity. Data recorded after 28 December, 1979 was mostly in B-band. Short runs in other bands were also recorded to estimate the magnitude. The observations of 28 December, 1979 showed the star to be very quiet except a short rise between 18:20 and 28:30 UT. On 29 December, 1979 the behaviour of the source was quite erratic. It showed a slow decrease in Δm after 18:50 UT and a slow recovery by about 19:00 UT. There was a sudden drop in Δm from 0.4 to 0.3 around 19:20 to 19:30 UT after which the observations were stopped that night but a recovery trend is noticeable towards the end of the observations. On the night of 30 December, 1979 the star showed a very stable behaviour. In the beginning of the night of 14 January, 1980 a very high value of Δm (= 0.48) is recorded which is the highest in the total period for which X-Per was monitored. The intensity dropped back to normal about an hour later. The average magnitudes calculated for all the dates and corrected for extinction is listed in Table I. The magnitude of the star varied from $B = 6.70 \pm 0.05$ to $B = 6.78 \pm 0.05$.

6. Discussion

For a long time, Be-star X-Per has been known to be a slow variable (Mook *et al.*, 1974; Gottlieb *et al.*, 1975; and others printed in references). On the whole, X-Per shows: (i) long-term variation on the time scales of months and years; (ii) short-term variation on the timescale of hours and less and the 834 s X-ray period; and (iii) the dips, lasting from few seconds to few minutes.

Most detailed long-term observations have been described by Mook *et al.* (1974) and

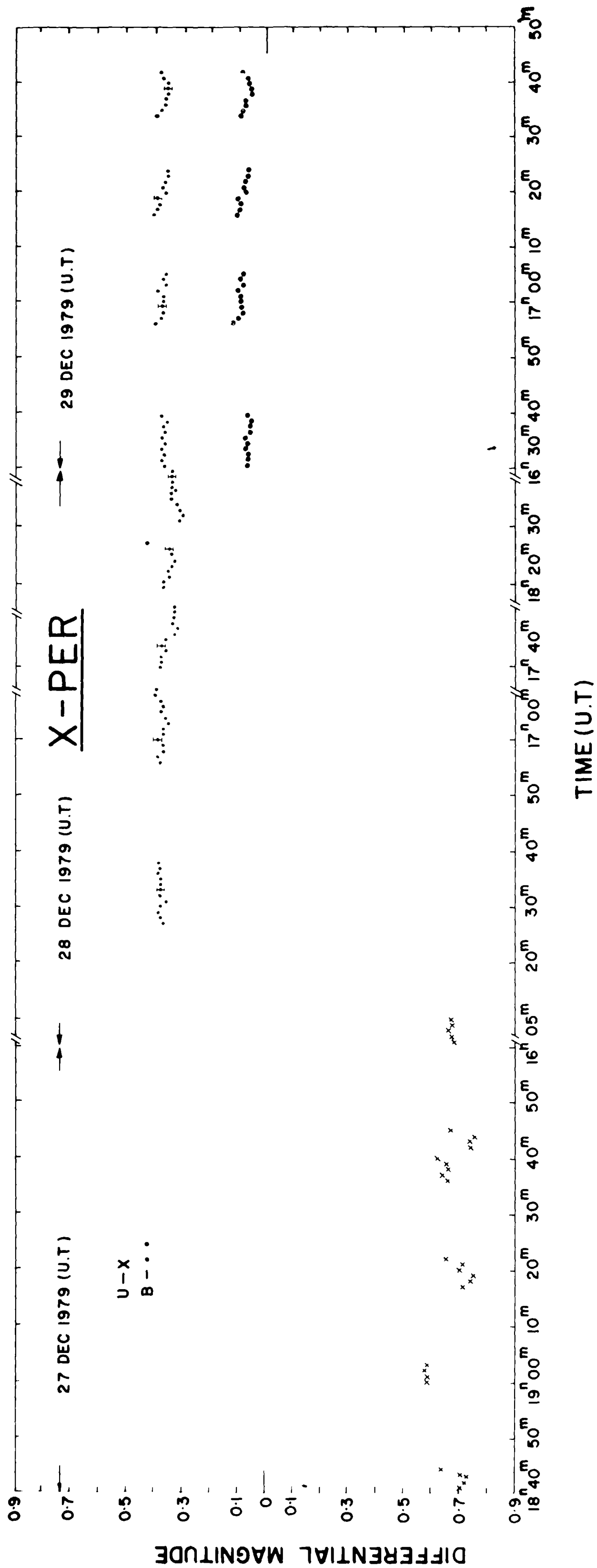

Fig. 4a. Variation of X-Per observed on 27, 28, and 29 December, 1979. The plot is made with differential magnitude vs UT. The data points are averages at the interval of 5 s.

1983Ap&SS..95...65S

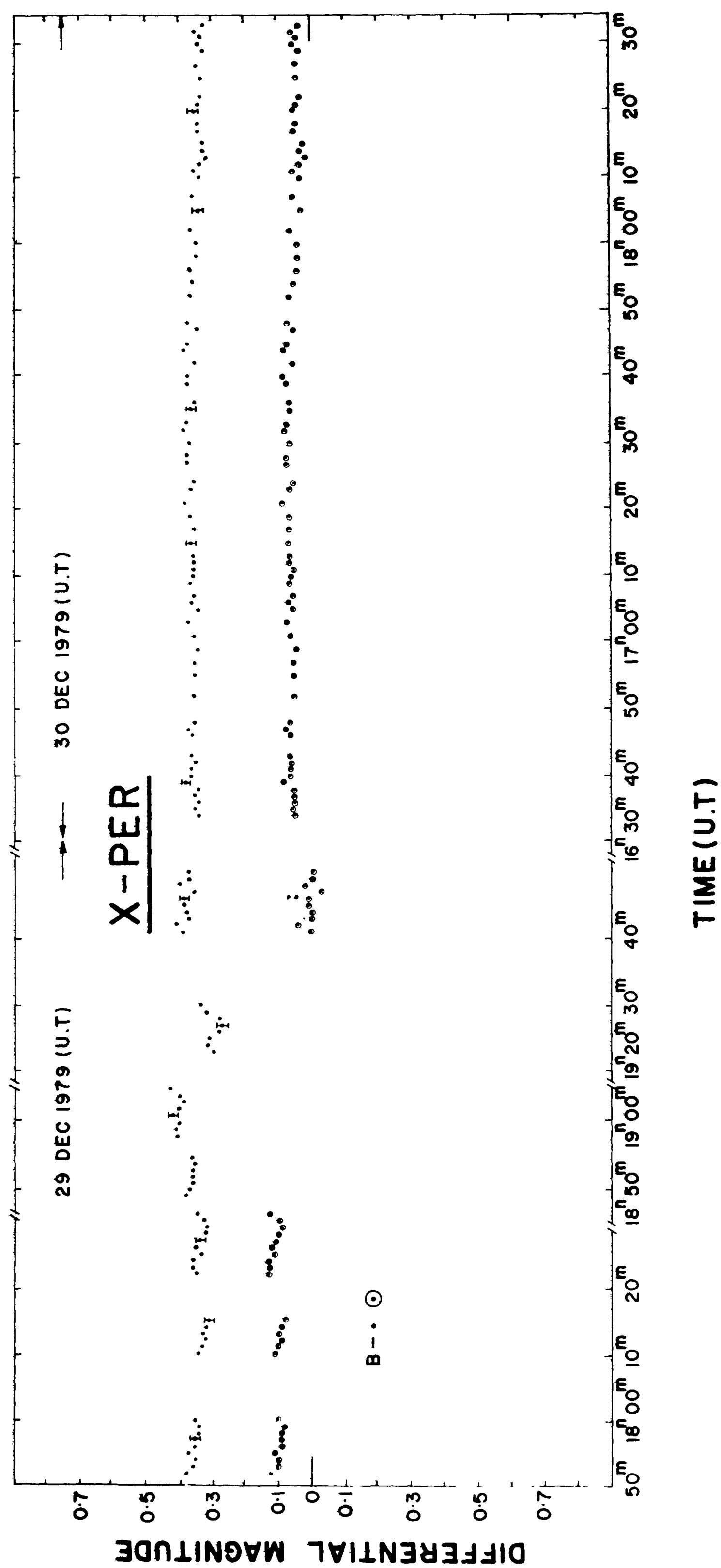

Fig. 4b. Same as Figure 4a but data recorded on 29 and 30 December, 1979.

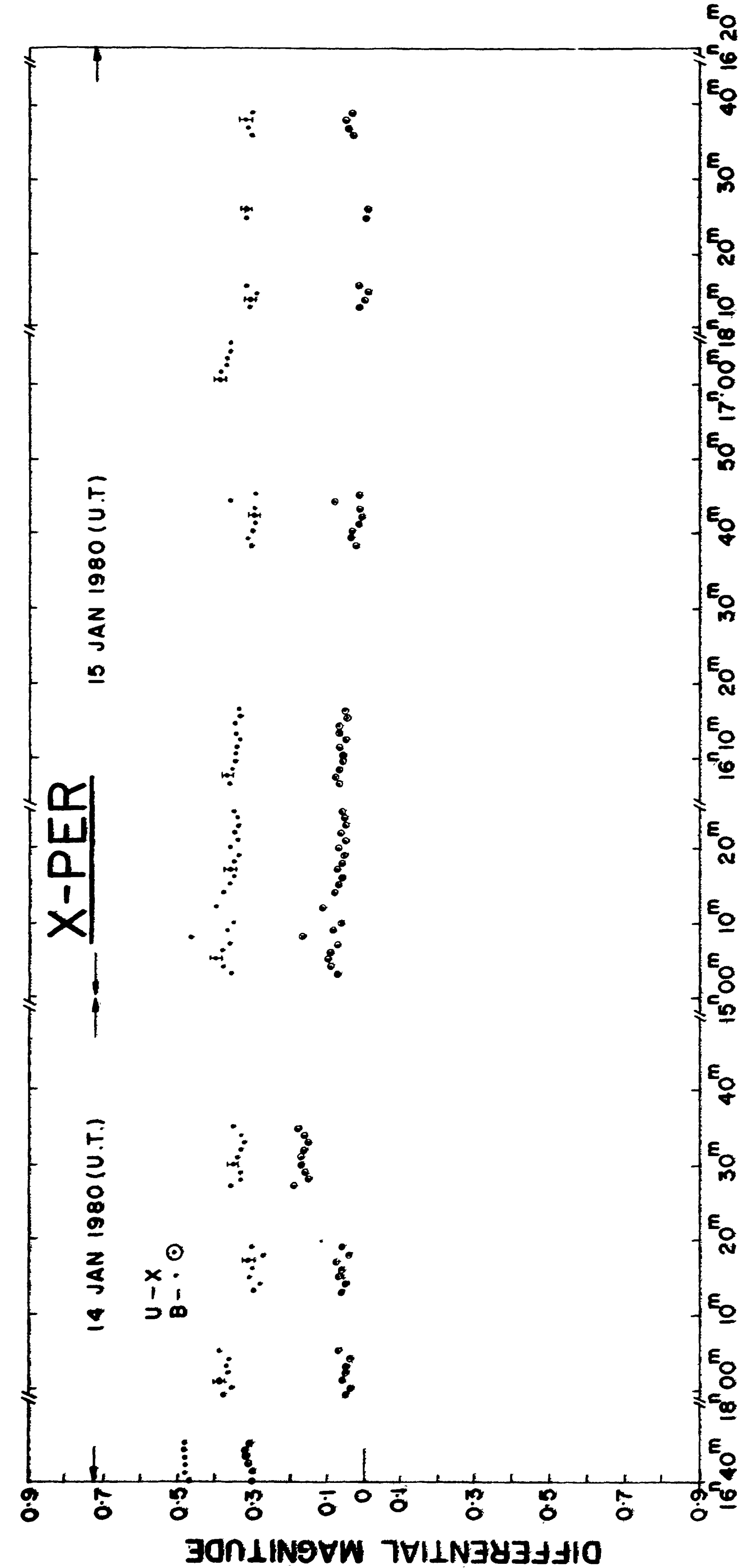

Fig. 4c. Same as Figure 4a but data recorded on 14 and 15 January, 1980.

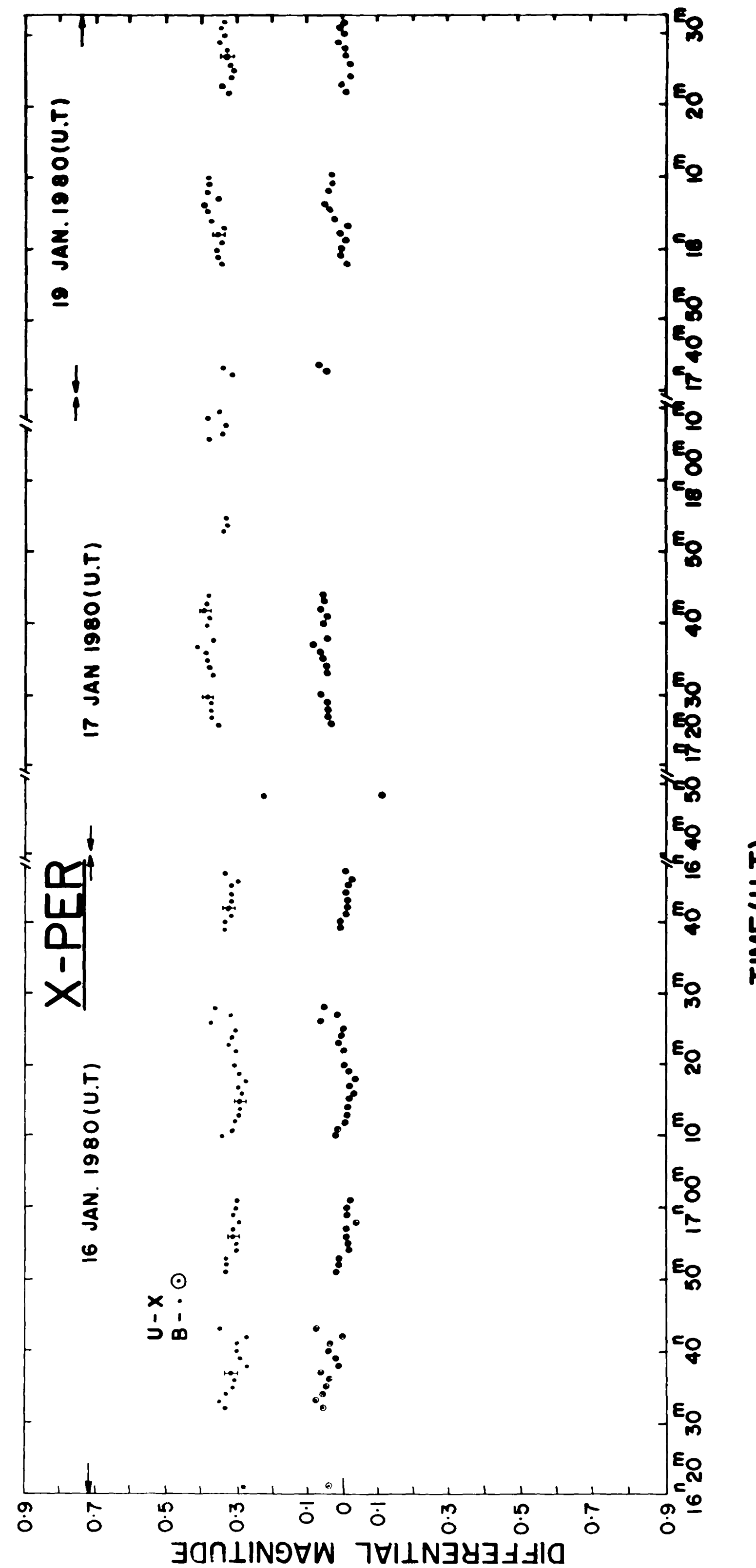

Fig. 4d. Same as Figure 4a, but data recorded on 16, 17, and 19 January, 1980.

TABLE I

Estimated magnitude of X-Per

Date of observation	Magnitude* (± 0.05)
27 Dec., 1979	$U = 5.97$
28 Dec., 1979	$B = 6.78$
29 Dec., 1979	$B = 6.78$
30 Dec., 1979	$B = 6.73$
14 Jan., 1980	$B = 6.72$
15 Jan., 1980	$B = 6.73$
16 Jan., 1980	$B = 6.78$
17 Jan., 1980	$B = 6.71$
19 Jan., 1980	$B = 6.70$

* Average over the night.

also later by Dorrent *et al.* (1979). Recent photometric studies coupled with old data (Mook *et al.*, 1974; Ferrari-Toniolo *et al.*, 1977, 1978; de Loore, 1979; Margon *et al.*, 1976a, b; Dorrent *et al.*, 1979), show that X-Per has undergone three-light increases, since 1964 showing an increase of ~ 0.6 mag. at the interval of six years. The last maxima ($V = 6.33$) occured during early 1978. From April 1974 to March 1977 the star remained nearly constant at $V = 6.70$. This is the faintest that the star has been since 1904 when intensity fell to a magnitude of 6.90.

In the short-term variations regime no periodic variations corresponding to X-ray period of 834 s has been reported so far. Short-term variations observed by us have been described earlier. Similar variations have also been reported by Ferrari-Toniolo *et al.* (1977) who found variations of ~ 0.02 mag. occuring in several tens of minutes. Short-period variations have also been reported by Persey *et al.* (1981) for several other Be-stars. Thus this seems to be a general property of all Be-stars for which no satisfactory explanation exist. The 'dips' in intensity have been reported by several observers (Campisi *et al.*, 1976; Canizares *et al.*, 1977; and the present observation). The biggest dip reported by Campisi *et al.* (1976), lasted for about 10 min and intensity decreased by 30%. Canizares *et al.* (1977) observed a series of complex dips followed by a long interval of steady count rate. The deepest dip observed by them showed a decrease in intensity by about 35% and lasted for about 4–5 min. However, their observations were in $\lambda\lambda 4486$ Å $\pm$ 12 Å band and, hence, dips cannot be compared with those of others. We recorded (see Figure 3) three dips, deepest corresponding to about 15% reduction in intensity and lasted for about 10–15 s. These are very important observations in the light of discovery of several antiflares in some type of stars (Mahmoud and Soliman, 1981; Paugach, 1975). The origin of dips can be best understood if some more observations are made in *U*-band and sufficient data is available. This is very important in the light of further observations by Campisi *et al.* (1976).

All Be-stars are identified by Hβ as emission line in their spectra. They can be rapidly rotating single stars, interacting binaries, supergiants, early type nebular variables, and

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