PERIODICAL VARIATIONS IN THE SPECTRUM OF X PERSEI. DISCOVERY OF A 22-HR PERIOD IN THE VARIATIONS OF THE RADIAL VELOCITIES OF Hα.

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The bright B0e star X Persei has been observed for over 50 years as an emission-line object and as a variable star. Throughout this time, the star displayed typical behavior for such an object. The discovery that it lies very close to the position of a weak X-ray source renewed interest in the star, which is now under close scrutiny. The probable association of X Persei with 3U 0352+30 has been subject to several discussions (Hutchings, Crampton and Redman, 1975; Margon, Bowyer, and Penegor, 1976; Hutchings and Walker 1976; Persi, Viotti and Ferrari-Toniolo 1977, 1978).

Hutchings et al. (1974) found evidence for a period of 581 days and an amplitude of 66 km/s in the radial velocities of broad Balmer absorption lines, which may indicate the presence of a massive companion. The mass function was found to be f(M) = 18.2 ± 3.5 M_O. Models based on these and on low-energy X-ray observations range from one involving a black hole (Hutchings et al. 1975) to another postulating an accreting white dwarf (Garavoglia and Treves 1976). Henrichs and van den Heuvel (1977) suggested a pulsating neutron star with a pulsation period of 13.9 minutes and an orbital period of 22.4 hours. The period of 581 days in then intepreted as due to apsidal motion.

Until now, observations could not definitely exclude any of the proposed models. No clear optical evidence existed for optical flux modulations with periods of 13.9 minutes and 22.4 hours (Hutchings 1977) corresponding to the variations in the X-ray range between 0.6 and 7.5 kev (White et al. 1976). Spectroscopic observations were therefore carried at the Crimean Observatory since 1974, covering about two long periods by about 100 spectrograms with dispersions 30 and 36 A/mm at Hα and in the region λλ 4950 - 3650 A.

Figure 1 shows that the broad Balmer absorptions vary in V_r in the long period found by Hutchings, with an amplitude of 50 km/s. The V emission component of Hα has an amplitude of 30 - 35 km/s. The He I lines have a smaller amplitude (22 km/s), large scatter, and a phase shift of about 0.25 P. A large scatter of radial velocities is observed

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at phases 0.45 - 0.70 P. There may be several contributing factors, hard to separate: (1) Rapid rotation of the star (V sin i = 270 km/s), (2) Gas motions, (3) Possible apsidal motion. The rotational velocity of the absorption component of the surrounding envelope was estimated at 62 km/s.

We searched for the 22.4 hr period in the radial velocities of the V and R emission edges of Hα. Three well-covered phase intervals were studied: (1) Phases 0.73 - 0.86, observed between November 1976 and January 1977; (2) 0.27 - 0.32 P, Sept.-Oct. 1977; (3) 0.41 - 0.49 P, Dec. 1977 - Jan. 1978. Fig. 2 shows these variations with phase of the 22.4 hr period (top curve). The zero point was taken to be the time of the minimum of the ratio of intensities (I_V/I_R) of the two components. The phase dependence of this intensity ratio is shown in the bottom curve. We find a good agreement for the three data groups: the radial velocities vary in a period of 22.4 hours with an amplitude of 15-17 km/s. We believe that Hutchings failed to detect this period because he studied too broad phase intervals.

We believe that our observations reveal an optical periodicity analogous to the known 22.4-hr X-ray modulation of 3U 0352+30. If the radius of the B0e star is 4.9 R_o and V sin i = 270 km/s, its period of rotation would be 22.5 hours. We think that the long period of 581 days is caused by the motion of the binary around a remote third body. Apsidal motion of a close eccentric orbit is not impossible either.

Now a few remarks on the gaseous envelope surrounding the primary component of X Persei. Great variations occurred in the emission spectrum of X Persei between 1962 and 1974. In 1974, the first three Balmer lines and the He I lines were much weaker than before. (Fig. 3). The activity continues to be weaker than 10 years ago: recently, emission was observed only at Hα , Hβ , and weakly at Hγ an He I 5876 A. We believe that this means weakening of matter ejection from the star, and decrease in the outflow velocity. Sometimes sharp components of He II 4686 A are observed in emission. Hα is the strongest emission line. Its variations have been observed as continuously as possible between November 1974 and March 1978. Marked changes in the intensity ratio V/R occur on a scale of 3-4 months. Between 11/5/76 - 12/30/76 we observed V/R < 1, then near Jan. 19, 1977 an inversion occurred. A new set of observations started in September 1977. Again, there was V/R < 1, then a reversal occurred, and from 11/30/77 to 3/15/78 there was V/R >1.

There is no definite explanation of the phenomenon of the V/R variations. Struve's model (1931) of a rotating gaseous ring was subsequently elaborated upon by Huang (1972, 1973, 1974). Kriz (1976) believes that an elliptical ring provides an adequate model. Huang (1977) invoked interaction between the existing ring and the newly ejected matter from the star. Boyarchuk (1957) showed that a stationary outflow cannot originate from the equatorial region of the Be star, and that active processes occur on the star's surface. Our observations

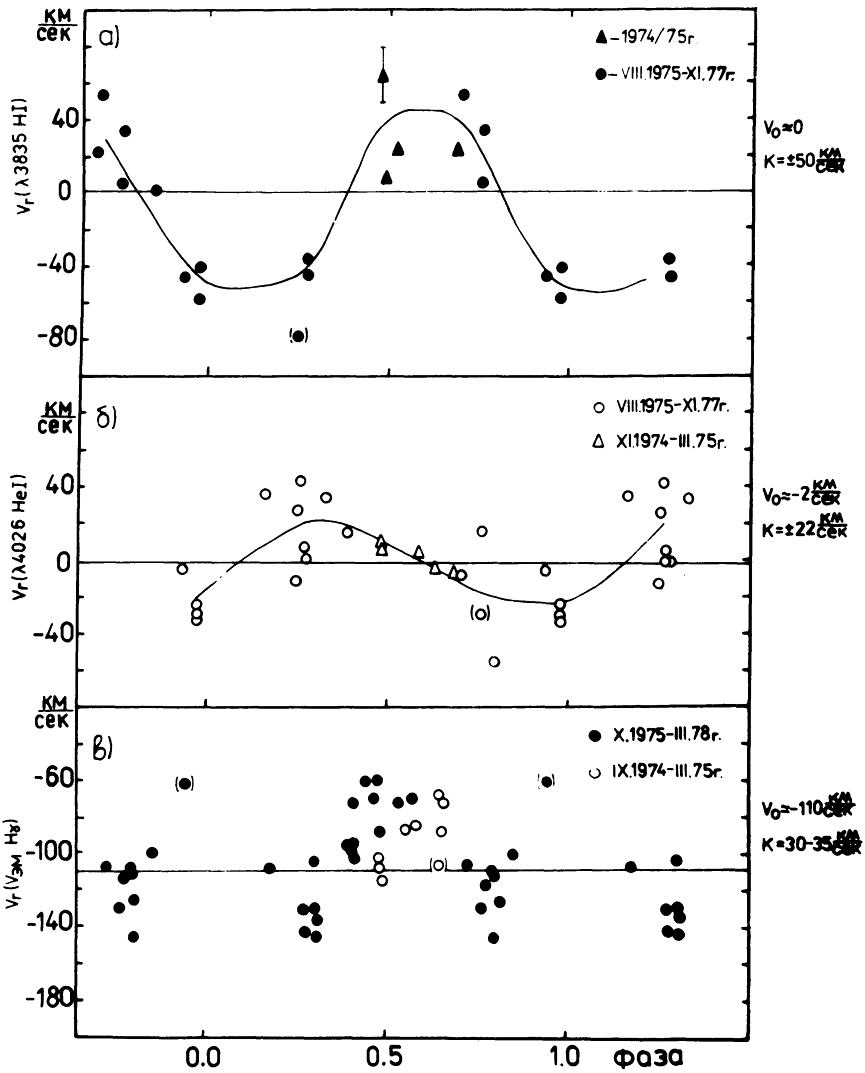

Figure 1. Radial velocity variations of X Persei in a period of 581 d.

confirm Boyarchuk's idea. Boyarchuk remarked that the variation in the ratio V/R might be a measure of the expansion of the Be star envelope: when V<R the envelope is extended, when V>R the envelope is shrunken. However, the envelope as a whole cannot pulsate.

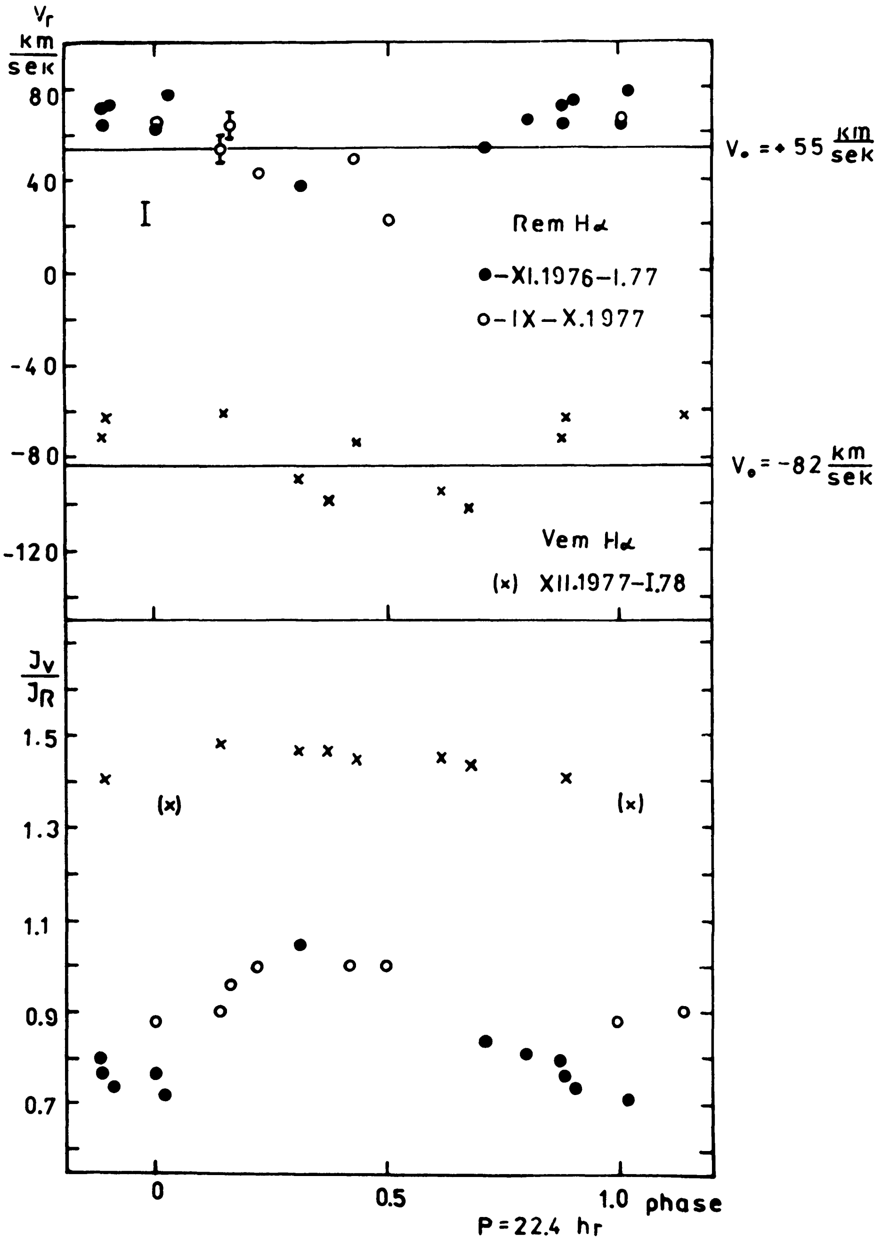

Figure 2.: The 22.4-hour periodicity in X Persei.

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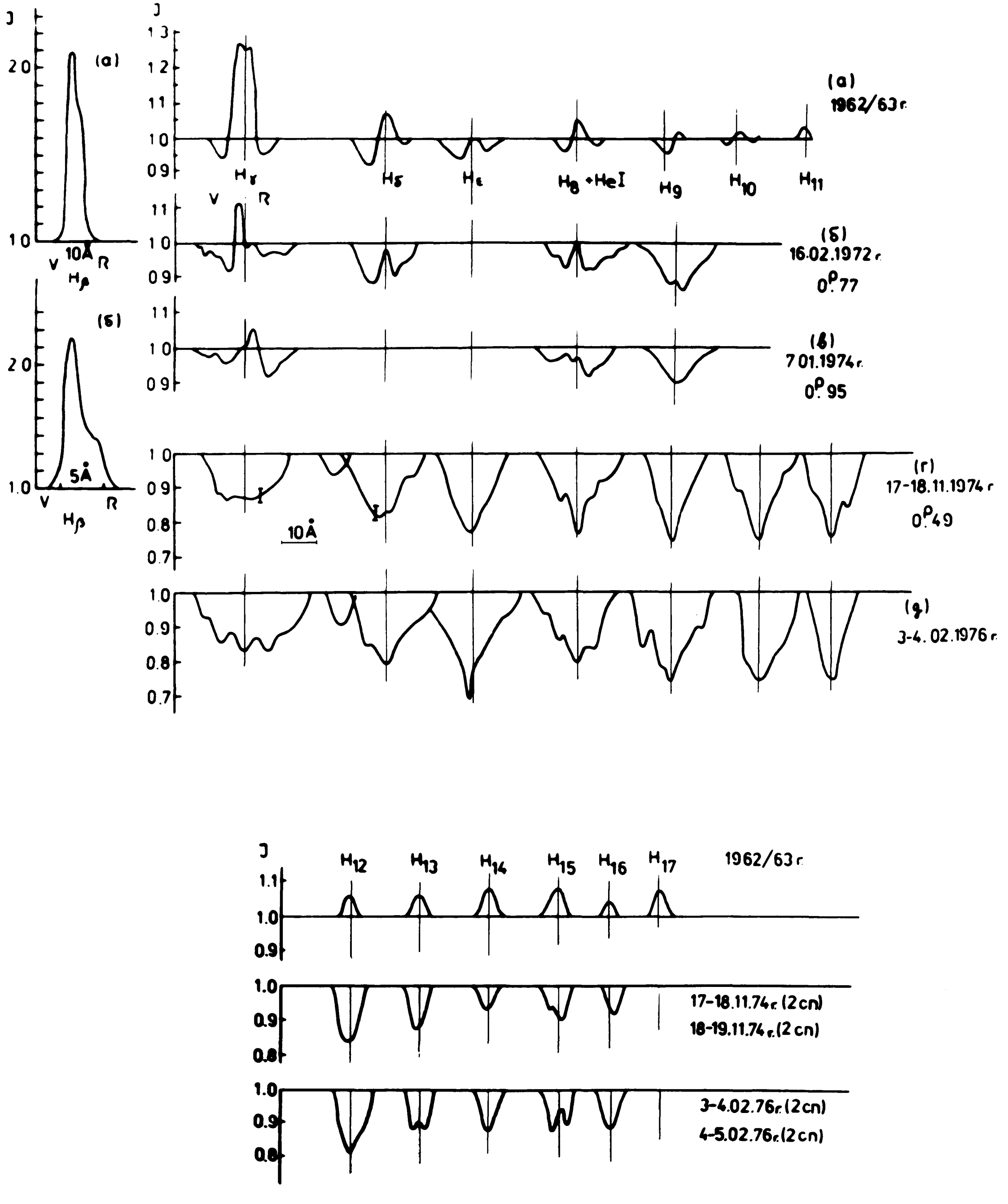

Figure 3. Profiles of the Balmer lines in X Persei.

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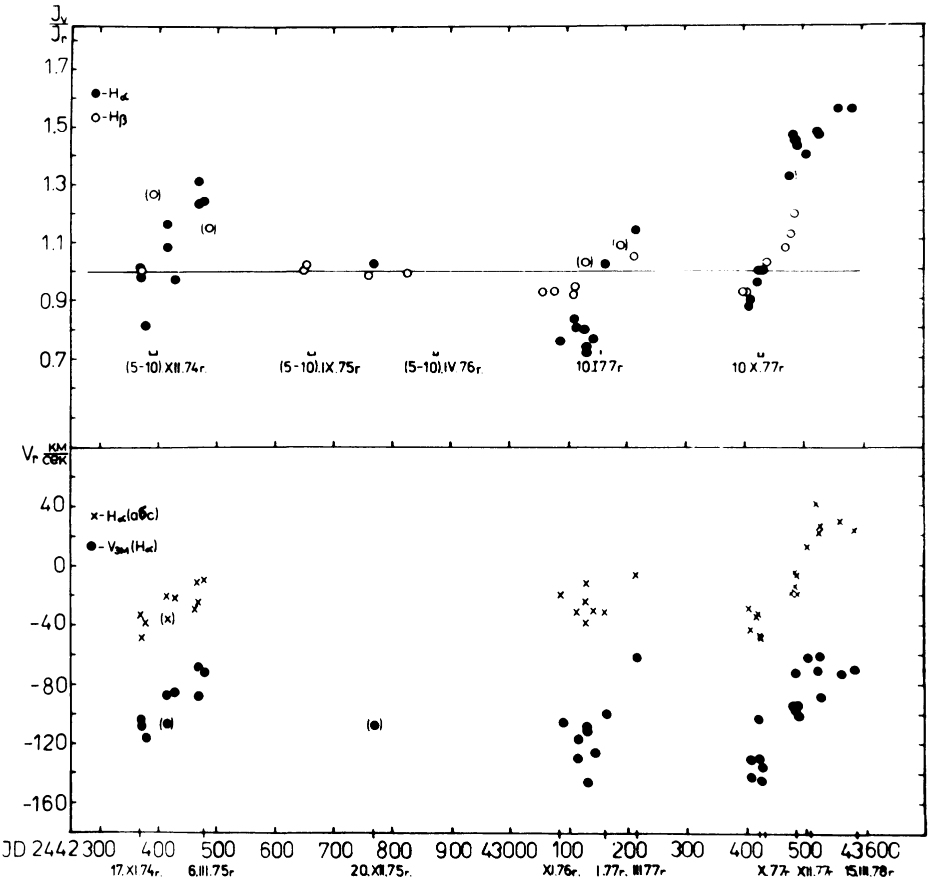

Fig. 4. V/R variations and radial velocity changes in X Persei.

Figure 4 shows the variation of V/R with time between November 1974 and March 1978 (top), and the corresponding variations of the radial velocities of the V emission edge and of the absorption core of Hα (bottom). Three V/R reversals were observed. Interval between them may be about 9 months, i.e. one half of the 581-day period. The phenomena seem to be correlated. Unfortunately, the descending branch of the V/R variation curve cannot be observed from the Crimea. The equality V=R lasts only 5-10 days, while the growt of the V/R ratio takes 4-5 months. The reversal of this trend indicates the start of expansion. We have not been able to determine the phase of this reversal. The amplitude of the V/R variations seems to differ from cycle to cycle. This behavior of V/R may be due to irregular ejections and interactions in the close eccentric orbit of the neutron star, and the wide orbit about the remote companion. Highly ionized material ejected from the B0e star probably recedes to some definite distance, depending on the power of ejection and the velocity of the flow. The ejected material is not dissipated and may be returned to the star's surface, as suggested by Boyarchuk. Interaction of the ejecta with the existing envelope/ring may lead to the observed contractions (V>R) and expansions (V<R) of the envelope.

Persi et al. (1977, 1978) found, from optical and infrared observations, a correlation between the star's brightness and the extent of the circumstellar envelope. They also explain the brightness variations as due to contraction and expansion of the envelope. Our observations overlapped with those by Persi. During the faint stage of X Persei (1974-76), the ratio V/R is >1, which corresponds to contraction, while at the phase of higher brightness (September 1977) the reversed ratio indicated expansion.

We urge further observations, in particular between March and September, in order to determine the phase of the V/R reversal.

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