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Long-term Spectroscopic and Near-Infrared Monitoring of Be/X-ray Binaries

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Abstract A long-term monitoring of 13 Be/X-ray binaries and 34 Be stars have been carried out with the 1.26 m reflector and the 2.16 m telescope at Xinglong Station. The observations cover the period of about 13 years in the optical spectroscopy and about 5 years in the near-infrared photometry. We present the monitoring results of two sources, X Persei and LSI +65°010, in the program. We detect changes of Hα EWs and JHK magnitudes in X Persei which reflect the formation of the extensive and dense envelope. The JHK magnitudes increase and decay rapidly while the variation of the Hα is wild. The behavior is suggestive of the envelope with different optical depth. The red-shift component in LSI +65°010 have been found in the monitoring program. The component may be brought from the neutron star with the movement in the line of sight.

Key words: stars: binaries: general — X-ray: binaries — infrared: stars — stars: emission line, Be

1 INTRODUCTION

More than 100 Be/X-ray binaries have been discovered (see Liu, van Paradijs & van den Heuvel 2000). Be/X-ray binaries constitute the major subclass of massive X-ray binaries, in which X-ray emission is due to the accretion of matter from Be stars by compact companions. The compact objects, mostly magnetized neutron stars (or black holes), orbit the massive Be stars in relatively eccentric orbit. The neutron stars in Be/X-ray binaries, as a tool, can explore the physical properties of the outer region of Be disc and may provide an extra means to understand the Be phenomenon. It has been shown that detailed information may be derived, such as the structure of the circumstellar disc of Be stars, if good optical and infrared data are available (Waters 1986).

In order to investigate the origin and physical properties of the circumstellar disc of Be stars, we since 1992 have conducted a long-term program, which is similar to that of Coe et al. (1993), to monitor a group of Be stars, 13 Be/X-ray binaries and 34 classical Be stars, in both the optical and near infrared bands. The optical and infrared observations of the Be star, when coupled with simultaneous X-ray observations, can help us understand the properties of Be stars and Be/X-ray binaries.

2 OBSERVATIONS

The near infrared photometry was carried at Xinglong Station of NAO by using the 1.26 m reflector with a liquid nitrogen cooled InSb photometer covering the JHK bands. Typical errors are $\pm$ 0.05 for J, H bands, and $\pm$ 0.07 for K band. Unfortunately the near-infrared observations were interrupted since 1996 due to unsatisfactory condition of the telescope. The intermediate-resolution optical spectroscopic observations were mainly made at Xinglong Station with a CCD grating spectrograph at the Cassegrain focus of the 2.16 m telescope. Sometimes low-resolution spectra are also employed.

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3 COMPLETE DISC-LOSS EVENTS AND SUBSEQUENT GAIN

Some Be stars sometimes lose their disc. It is used to determine the intrinsic characteristics of the underlying B stars. The following emission phase is valuable for understanding the origin of the Be phenomenon. The disc loss and subsequent renewal events can provide a great deal of information about the conditions required to form and disperse the circumstellar disc. X Persei is this kind of source in our program.

X Persei, the optical counterpart to the X-ray source 4U0352+30 (Braes & Miley 1972), is a sixth magnitude B0 III-Ve star (Lyubimkov et al. 1997) with a neutron star companion. The pulse period is 835 s and the orbital period of the system is 250.3 days (Delgado-Marti et al. 2001). X Persei sometimes showed extreme, extended low states (Mook et al. 1974; Roche et al. 1993). This behavior indicated the loss of the circumstellar disk around the Be star as is also known from single Be star. It has been used for determining the physical parameters of the primary star by Fabregat et al. (1992).

The equivalent widths of the Hα emission line and the near-infrared photometry of the Be star X Persei are shown in Figure 1. The maximum Hα EWs and JHK magnitudes between 1994 and 1995 are larger than but still comparable to the 1986-1989 maxima, which reflects that a more extensive and dense envelope has formed. We notice that the near infrared magnitude decayed earlier than the Hα emission did when the envelope began to dissipate. This is very obvious in the data between 1989 December and 1995 October, where the Hα emission is still very strong , whereas the near infrared excess is rather small or nearly disappeared (see Phase I in Fig. 1). However, when the envelope began to form, the near infrared magnitude increased later than the Hα emission did, as seen at the early stage of the new emission phase. The JHK magnitudes increased rapidly and so did the subsequent decay, while the variation of the Hα emission was mild. This phenomenon may be interpreted by the model of the envelope with different optical depth (Liu & Hang 2001). Since the maximum emission level of Hα in 1995 October, two decaying phases (Phase II & Phase IV) are clear seen in Figure 1. This optical fading phenomenon does not result from the complete dispersal of the circumstellar disc. It has been reported by Clark et al. (2001). Since 2002 October, the

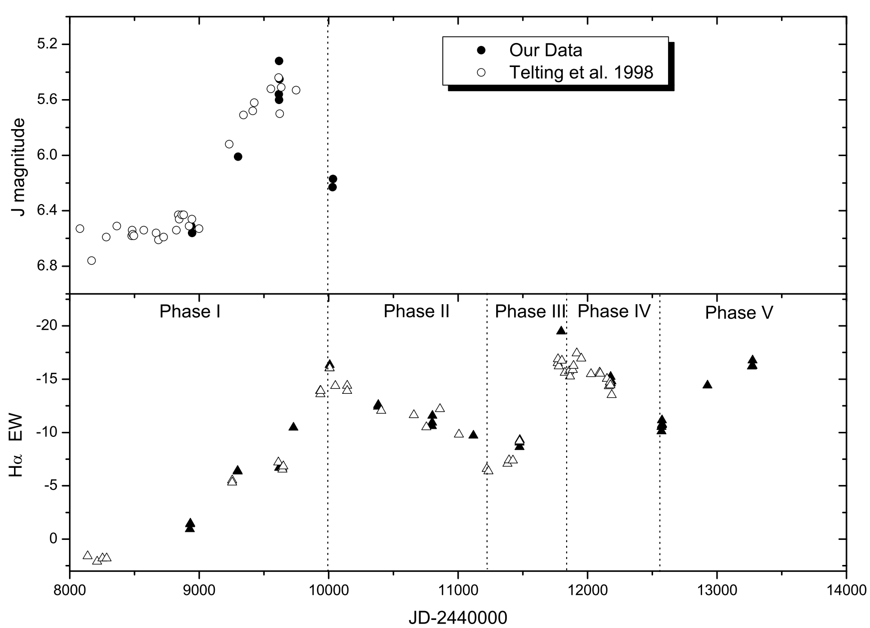

Fig. 1 The J magnitudes (upper panel) and the equivalent widths of the Hα emission line (lower panel) of X Persei covering the period 1987 December - 2004 October. Open circles in upper panel are cited from Telting et al. (1998) and open triangles in lower panel from Roche et al. (1993) and Clark et al.(2001), and the filled symbols are from our program.

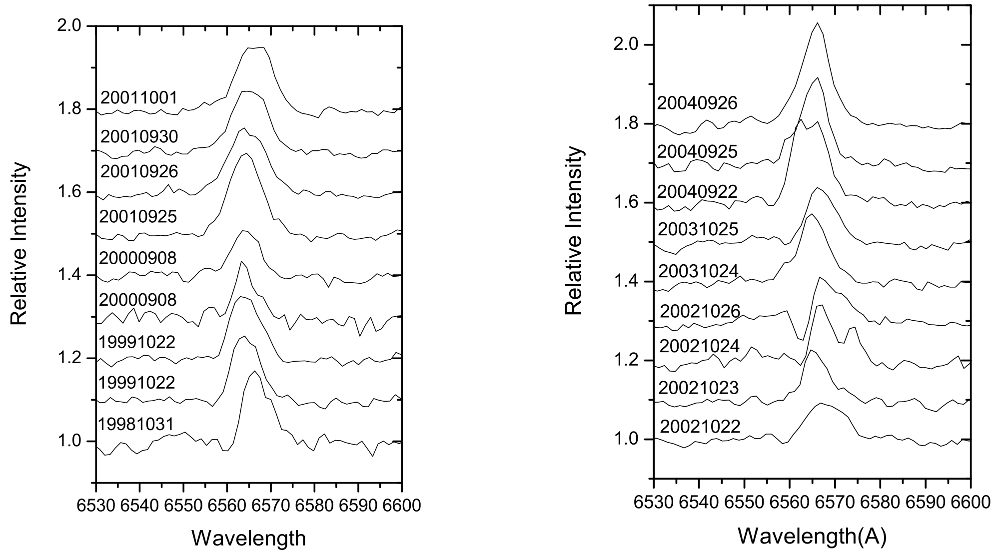

Fig. 2 Series of the selected Hα spectra of LSI +65°010 taken during our program from 1998 to 2004.

emission of Hα is again in its increasing phase seen in Figure 1, which indicates that a more extensive or denser circumstellar disk is forming.

4 CLUES TO OPTICAL EMISSION RELATED TO THE NEUTRON STAR

The neutron star in Be/X-ray binaries can explore the physical properties of the Be envelope. It also introduces turbulence that may result in the disruption of Be envelope (Reig et al. 1997), and instability that may relate to the material ejection from the massive star. The physical conditions in the envelope can be determined from observations of the Be star in the optical and infrared. In addition to the optical and infrared emission from the envelope of the primary, the reprocessing of X-ray irradiation can also produce these emissions. The clue of the optical and the infrared emission associated with the neutron stars can be extracted from optical and infrared observations. Two examples of this group of sources are LSI +61°303 and LSI +65°010. About LSI +61°303, the detailed observational results have been discussed by Liu et al. (2000) and Liu & Yan (2005).

LSI +65°010, an 11th magnitude B star, is the optical counterpart to the hard X-ray transient 2S 0114+65, which has an orbital period of 11.59-day. The spectral classification confirms that the system is a supergiant/X-ray binary with a spectral type B1Ia (Reig et al. 1996) or B1Iab (Liu & Hang 1999) of the primary. Liu & Hang (1999) reported the observational results before 1995. They found an additional peak can occasionally be discerned in the blue wing of some spectra (eg. 1993 Nov., 1994 Sep. in Fig. 1 of their paper). The additional peak may be explained by the emission from H II region around the neutron star, since the velocity deduced from the Doppler shift is consistent with the orbital velocity at periastron and the X-ray emission required for the Hα emission is comparable to its maximum X-ray luminosity. Figure 2 shows the selected Hα spectra obtained during our long-term monitoring program from 1998 to 2004. The same blue-shifted emission component also can be seen in the 2000 spectra. With a different phenomenon, we find an another emission component in the red wing of Hα lines and the blue-shifted component that we reported in 1999 is replaced with an absorption component, which forms a P-Cyg profile. Especially for the spectrum on 2002 Oct. 26, it has an obvious P-Cyg phenomenon. The red-shifted Hα emission component may also originate from the neutron star which just approached the line of sight. The P-Cyg feature is indicative of energetic mass outflows which may correspond to the strong wind from the supergiant star in the system of 2S 0114+65. Thus our observations again provide evidence for optical emission related to the neutron star.

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