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Research Note

Spectral variability of the massive X-ray binary LSI +65°010

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Abstract. We present optical spectroscopic observations of the massive X-ray binary LSI +65°010, the optical counterpart to the X-ray transient 2S0114+65. Our data show a dramatic variability in 1992 and only a mild variability during 1993–1995. An increase by a factor more than three in the equivalent width of the Hα emission line within four days is present in Nov. 1992. It is interesting to notice that changes have taken place only in the blue side on Nov. 4, 1992, when compared to similar spectrum taken one day before. We associate this phenomenon with the existence of an HII region around the neutron star. A double-peak profile is seen in the spectrum of Sept. 1994. If this double-peak profile is real, we suggest that such a profile may be explained by the emission line from an HII region around the neutron star, superposed on that from the stellar wind of the supergiant.

Key words: line: profiles – stars: individual: LSI +65°010 – stars: supergiants – X-rays: stars

1. Introduction

LSI +65°010, the optical counterpart to the hard X-ray transient 2S0114+65 (Dower et al. 1978), was identified by Margon & Bradt (1977) as an 11th magnitude B star, primarily due to its early spectral type and the presence of the emission. Margon (1980) classified the spectrum as B0.5 III, but Aab et al. (1984) suggested it may be slightly earlier with either a higher luminosity or the Balmer lines may be abnormally weak due to an anomalously low hydrogen abundance. The UV spectrum is consistent with a spectral type of B0.5III according to Bianchi (1981), but she noted that the 2200 Å ‘bump’ is shallower than expected from the reddening in the visual spectral region.

Although the spectral type of the primary is established at about B0.5, its luminosity classification is ambiguous with possibilities ranging between Ia and III. Previously, it was believed that the system was a Be/X-ray binary system consisting of a Be star and a neutron star. Both the intermittent flaring nature (Finley et al. 1992) and the optical transient events (van Kerkwijk & Waters, 1989; Minarini et al. 1994) supported this conclusion. However, in the pulse period vs. orbital period diagram, it falls into the region occupied by supergiants (Corbet, 1984). Crampton et al. (1985) also argued that the system was more consistent with the nature of a supergiant/X- ray binary than that of a Be/X-ray binary. Recently, the spectral classification made by Reig et al. (1996) confirmed that the system should be a supergiant/X-ray binary.

The X-ray flux from this source is found to be highly variable, varying from 3×10^{34} to 5×10^{36}ergs·s^{-1} between 2–10 keV energy range (Koeningsberger et al. 1983; Yamauchi et al. 1990), assuming the corrected distance of 7.0 kpc (Reig et al. 1996). The compact star is believed to be a neutron star judging from its hard X-ray spectrum index. A power spectral analysis showed significant power at a period of 14.9-min. (Koeningsberger et al. 1983), but this period has not been fully confirmed. The radial velocity measurements made by Crampton et al. (1985) showed an orbital period of 11.588$\pm$0.003 days and an eccentricity between 0 up to 0.16. The rotational velocity of the primary is between 45 km s^{-1} (Aab et al. 1984) and 100 km s^{-1} (Crampton et al. 1985; Reig et al. 1996). Spectroscopic observations exhibited a variability on a time scale of days (Margon, 1980; van Kerkwijk & Waters, 1989; Minarini et al. 1994), while the photometric measurements showed the V magnitude of the system remained nearly constant and failed to reveal fluctuations greater than 5 millimag (Bell, Hilditch & Pollacco, 1993; Taylor et al. 1995).

In this paper, we will present the results of the optical spectroscopy of this interesting object and show that its spectral features have short-term variability as well as long-term variability.

2. Observations and results

Since the autumn of 1992, we have chosen a set of Be stars, especially Be/X-ray binaries, that are observable from the Northern Hemisphere for spectroscopic and near infrared luminosity monitoring. LSI +65°010 was one of the program stars because it was regarded as a Be/X-ray binary (van den Heuvel & Rappaport, 1987). No infrared data were obtained due to its lower brightness. Spectral observations for LSI +65°010 previous to

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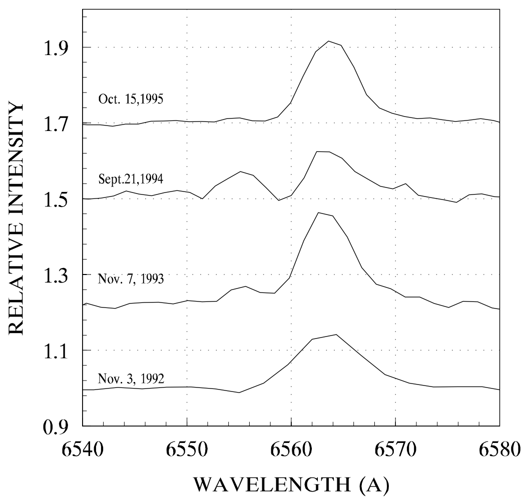

Fig. 1. Series of the selected Hα spectra of LSI +65°010 taken during 1992–1995. All spectra have had the continuum level normalized and are annually offset vertically to allow direct comparison. Note the double peak of the spectrum in 1994

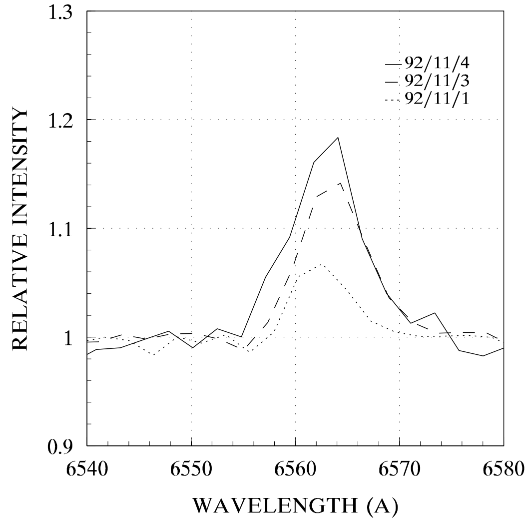

Fig. 2. Series of the Hα spectra of LSI +65°010 taken in Nov. 1992. All spectra have had the continuum level normalized. Note the dramatic variabilities in the spectra

our programme are limited. The optical spectroscopic observations were made at Xinglong station of Beijing Astronomical Observatory with a CCD grating spectrograph detector at the Cassegrain focus of the 216 cm telescope. The journal of the observations for LSI +65°010, together with the equivalent width (EW) of the Hα emission line, are shown in Table 1. He-Ar spectra were taken in order to obtain the pixel-wavelength relations. All spectroscopic data are reduced with IRAF software on our Sun-4 station except the spectra taken in 1992, reduced with FIGARO/DIPSO software on the Vax 11/780 computer of Purple Mountain Observatory.

The Hα spectra of LSI +65°010 obtained during the monitoring period 1992–1995 are shown in Fig. 1. All the lines have been normalized with respect to the intensity of neighboring continuum. An annually vertical shift between successive observations has been applied to avoid confusion. It is shown from Fig. 1 that the Hα is apparently always in emission. The profile of the Hα emission line is highly variable, although its intensity is not very strong. Nearly all the profiles show a single-peak structure with the peak located at the laboratory wavelength (λ6563) or slightly shifted.

The profile on Nov. 7, 1993 shows an absorption feature on the blue side and a marginal double peak seems to appear. Such a profile also existed in the spectrum in 1994 June obtained by Reig et al. (1996, Fig. 1). It is more apparent in the spectrum of September 21, 1994, although the signal to noise ratio is not high enough. The separation of the two peaks is nearly the same as that on Nov. 7, 1993. Its red peak is located at the laboratory wavelength while the blue peak is at -7.2 Å from the red one, corresponding to a Doppler velocity of some 329 km s^{-1}.

The most dramatic variations of the Hα emission line can be seen from the spectra obtained on Nov. 1, 3 and 4 of 1992 (Fig. 2). The profiles at the first two days are more or less symmetric, whereas the profile on Nov. 4 is asymmetric with a steep red wing. The dramatic increase of both the strength and the equivalent width of the Hα emission line is immediately apparent with the fact that, only three days later, the intensity has increased about three times, and the EW changed from -0.43 Å to -1.48 Å, more than a factor of three. Compared with the profile on Nov. 1, the blue side on Nov. 3 only increases a little while the red side looks greatly enhanced with the peak of the emission line shifting toward the red side as the intensity increases. The red side of the line does not further change on Nov. 4 while the blue side looks fairly enhanced.

3. Discussion

3.1. Spectral type

By comparing our spectrum taken at 100 Å/mm dispersion with the spectra of MK standards, the spectrum taken in 1997 showed that the spectral type of the primary is B1Iab, which is consistent with the conclusion drawn by Reig et al. (1996). The uncertainty of the classification is within about one subclass. We will consider the object as a supergiant in the following discussion.

3.2. The double-peak of the Hα emission line

According to the orbital and stellar parameters obtained by Crampton et al. (1985) and Reig et al. (1996), the orbital velocity of the neutron star at periastron is about 320 km s^{-1}, nearly the same with the Doppler velocity of the violet peak. If the violet peak of the Hα emission line in LSI +65°010 is not a spurious one, we suggest that the red peak is the usual one, that is, from the shell around the supergiant, while the violet one is from an HII region formed in the gas shell by X-rays emitted by the accreting neutron star (cf. Kallman & McCray, 1982). An X-ray luminosity of some 5×10^{36} ergs $\cdot s^{-1}$ is needed to produce the same intensity of the violet peak on Sept. 17, 1994 (Apparao, 1991; Liu, Hang, & Xia, 1998), which is consistent with the maximum X-ray luminosity in LSI +65°010.

Table 1. Journal of the spectroscopic observations of LSI +65°010.

JD +2448900	Date	Spectral Range (Å)	Dispersion (Å/mm)	Resolution (Å/pixel)	Hα EW (-Å)
28.2141	01-11-92	5500-6800	101	2.26	0.43±0.08
30.1295	03-11-92	5500-6800	101	2.26	1.06±0.09
31.1755	04-11-92	5500-6800	101	2.26	1.48±0.10
396.1509	04-11-93	4300-6800	50	1.39	2.07±0.11
399.0855	07-11-93	4300-6800	50	1.39	1.64±0.10
718.2415	21-09-94	4300-6800	50	1.22	1.22±0.10
1106.1722	15-10-95	4300-6800	50	1.22	1.58±0.09
1108.1831	17-10-95	4300-6800	50	1.22	1.60±0.09

3.3. The short term spectral variability

The short term variability from LSI +65°010 over a few nights in 1992 may well be real since they were all taken with the same instrument set-up. A variability on a shorter variable scale might be present, and further observations on much more short-time scale are needed. It is also interesting to note that the enhancement of the Hα spectral intensity first appears almost at the red side and then only at the blue side on the spectra obtained in Nov. of 1992. The behavior of the Hα emission line seems to point out that the radial velocity of the Hα line emission source altered its direction between Nov. 3 and Nov. 4. We associate the phenomenon with the orbital motion of an HII region caused by X-ray emission around the neutron star in the massive X-ray binary. Otherwise it may be due to a blob of gas moving away from, and then returning to, the supergiant. Polcaro et al. (1993) reported that the blue side of the Hγ line does not change while the red side looks greatly enhanced in the other massive X-ray binary He 3-640/A1118-61, and they associated it with a major X-ray outburst of the binary two weeks before.

Presence of dramatic optical transient enhancement was also found in a massive X-ray binary A0538-66 with a similar orbital period of 16.6 days (Charles, Booth, Densham et al. 1983). Many other emission line stars have been found to be variable, but on a longer time scale of months or years. Although very rapid variability on Hα line has been found in some massive X-ray binaries such as BD+37°1160 (Rossi, Norci & Polcaro, 1991), He 3-640/A1118-61 (Villada, Giovannelli, & Polcaro, 1992) and γ Cas (Slettebak & Snow, 1978), the variability is much milder than that from the present observations.

4. Conclusions

We present spectrum variability of the massive X-ray binary LSI +65°010 from 1992 to 1995. The Hα emission line is weak. Apart from the spectrum of September 21, 1994, all the Hα emission lines show a single peak with a low equivalent width, which is consistent with previous results. A series of spectra taken in 1992 show a sudden increase of a factor more than three in the EW of the Hα line only within four days. The intensity and profile variability on the spectra is unusual. We attribute these phenomena to an HII region around the neutron star in the massive X-ray binary and to its orbital motion together with the neutron star. The spectra taken in 1993-1995 show only mild variability, such as changes in the line profiles of the Hα line on a time scale of days. We also want to remark that our spectra show some interesting differences with respect to the published ones. The splitting of the Hα line which was never reported before now seems to be present in a few spectra, especially in the spectrum of 1994. The double-peak could not be explained by the rotating circumstellar shell, due to both its low rotational velocity of the star and only the shorter line peak shifted. We suggest that the double-peak profile on September 21, 1994 may be explained by the superposition of two emission lines, one from the shell of the primary star, another from an HII region around the neutron star. Generally, the two components merge together, and are difficult to distinguish from one another.

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