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Hα line variations in the Be star binary LSI+61°303

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Abstract. The Be star LSI +61°303 shows an orbital variation in the ratio of the equivalent width of the blue wing to that of the red wing of the Hα line profile. This variation is shown to be due to the obscuration caused by the post shock gas of a shock produced by the supersonic orbital motion of the secondary through the gas disk of the Be star.

Key words: stars: binaries: general – stars: emission-line, Be – stars: individual: LSI+61°303

1. Introduction

LSI +61°303 is a Be star binary first discovered as a radio object (Gregory & Taylor 1978). The orbital period of the binary was determined to be 26.5 days (Taylor & Gregory 1982). A long term radio periodicity of $\sim$4 yr was also suggested by Gregory et al. (1989). X-ray emission was observed (Bignami et al. 1981) and the secondary object is considered to be a compact object (white dwarf, neutron star or black hole). The x-ray emission occurs at a phase 0.5 (Taylor et al. 1996), using the zero phase defined by Taylor & Gregory (1982). Hutchings & Crampton (1981), using radial velocity measurements of optical lines confirmed the above orbital period and suggest an orbit with an eccentricity e$\simeq$0.6. They also give the spectral type of the Be star as B0V. The observed x-ray emission is suggested to occur when the compact object passes through the gas envelope around the Be star at its periastron passage.

Hα line observations of the Be star binary were made (see Gregory et al. 1979; Paredes et al. 1994; Zamanov et al. 1996 and references therein). The Hα line profile has the characterestic double hump structure seen in several Be stars. The usual interpretation of this is that a gas disk exists around the Be star which is ionised by the Lyman continuuum radiation from the Be star; the observer lying approximately in the plane of the disk will receive radiation from both the approaching and receding parts of the rotating gas, giving rise to the double hump structure.

Recently Zamanov et al. (1999) used extensive Hα line observations of their own and others to find the orbital periodicity and a phase variation in the line profile. In particular they find that the ratio of the equivalent width of the blue hump E(b) to that of the red hump E(r), shows a value $\gtrsim$1 between phases $\sim$0.2 and $\sim$0.4 and a value $\lesssim$1 between phases $\sim$0.6 and $\sim$0.8. The ratio of the full width half maximum (FWHM) of the blue wing and the FWHM of the red wing also shows periodic variation.

Infrared and optical modulation at the orbital period was found by Paredes et al. (1994) and Marti & Paredes (1995). Apparao(1999) has explained the modulation as due to the contribution of the radiation from the host post-shock gas formed by a shock produced by the supersonic motion of the compact object through the Be star disk.

The E(b)/E(r) variations in single Be stars are suggested to be due to density variations induced by global one-armed oscillations of the Be star gas disk (Okazaki 1997 and references). However the periods of the oscillations are of the order of one year, which is larger than the observed period of the present variation. Morover it will be an unusual coincidence if the global oscillation period is the same as the orbital period, which is the period observed for the equivalent width variation. Apparao & Tarafdar (1986) suggested that the radiation from the accreting compact object produces additional Hα emission resulting in a E(b)/E(r) variation with the orbital period. The X-radiation observed from the compact object in the present case is too small to produce the required strength of Hα emission. Zamanov et al. (1996) suggested that the accretion on to the compact object will 'lead to an increase in the density in those parts of the outflowing disk where the secondary is, and will probably enhance the Hα emission in this region'. Negueruela et al. (1998) suggest that the variation in the equivalent width is due to global disruption of the Be star disk due to the compact object. The density change suggested however may not result in a change of the emission measure; for example if there is no change in the strength of the radiation that ionises the gas and it is ionization bound. It remains to be shown that the suggestions of Zamanov et al. (1996) and Negueruela et al.(1998) will result in a change of the emission measure from the region and thus result in the observed equivalent width variation.

In this note we show that the cooling post-shock gas obscures the emission from the Be star disk at certain phases, which leads to the observed variations in the ratio E(b)/E(r) as a function of phase. In Sect. 2 we give the structure of the post-shock gas and also calculate the Lyman continuum form the post-shock gas. In Sect. 3 we calculate the emission of ultraviolet and Hα radiation

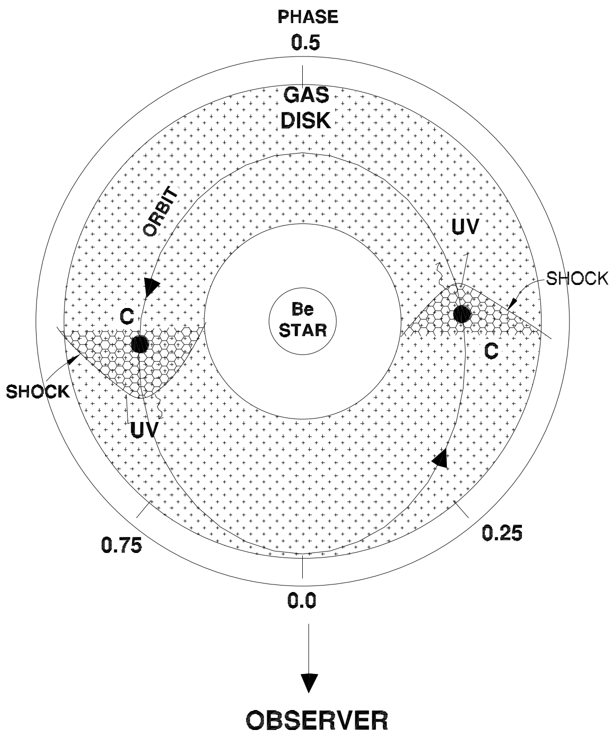

Fig. 1. A schematic of the Be star binary (not to scale) with the gas disk associated with the Be star. C is the compact object (dark spot). The shock front due to the supersonic motion of the compact object is also shown. The ionised region of the disk due to the Be star is shown by pluses. The ionised post shock gas is shown honey-combed.

from the post shock gas. In Sect. 4 we discuss the effects of both these aspects on the equivalent width ratio mentioned above. In Sect. 5 we consider the Hα variation with the ∼4 yr period.

2. Structure of the post-shock gas

The velocity of the compact object, using the mass of the Be star (B0V) and the orbital period is $v_r=2.2\times10^7$ cm s^{-1}. This velocity is supersonic for the gas in the disk around the Be star and a shock is formed ahead of the compact object.The radius of the shock is $r_s\simeq5\times10^{12}$ cm.

In order to calculate the shock structure, we need to know the disk structure. Several models of Be star disk structure have been proposed (Poeckert & Marlborough 1978; Apparao 1984; Waters et al. 1987; Paredes et al. 1994). Here we will use for simplicity of calculation a disk of uniform density; calculations with variation of density in the disk will necessitate solving of complicated equations (see Hollenbach & Mckee 1979), which is beyond the scope of the present note.

Apparao(1999) has obtained the temperature and density profiles of the post shock gas, using the work of Hollenbach & Mckee (1979). The post shock temperature was found to be $T_s\simeq6.7\times10^5$K. The post shock density structure is given by $n(x)=n_0[16T_s/3T(x)]$, where n_0 is the pre-shock density and T(x) is the temperature at a distance x from the shock front. The temperature structure is given by: $T^{3/2}(x)=T_s^{3/2}$-ax, where a is a constant. This equation is valid till the gas temperature reaches a value $\simeq10^4$K at a distance x_0. Beyond this (Shull & Mckee 1979) the temperature falls and while the density keeps increasing, the ionised fraction decreases. The partial ionisation is maintained by the strong ultraviolet flux from the hot post-shock gas. The determination of the ionisation fraction as a function of x beyond x_0 requires fresh calculations and solving the full panoply of equations involved, which is beyond the scope of this work. Instead we will use the slope of the fall of ionised gas density in this region as obtained by Shull & Mckee (1979), since the various values involved scale as density, and obtain the structure in the present case. Using the profile of the ionised gas in this region, the ionised gas density in this region can be expressed as,

$$logn = logN_0 - A[(x/x_0) - 1] \quad (1)$$

where N_0 is the density at x_0. Using the values from Fig. 3 of Shull & Mckee (1979), A=0.271. The expression for the density profile of the ionised gas beyond x_0 becomes,

$$logn = 14.13 - 0.271[(x/x_0) - 1] \quad (2)$$

The temperature in this region is $\sim10^3$K.

3. Emission from the post-shock gas

The post shock gas emits ultraviolet radiation. The monochromatic luminosity in a given wave band due to the post-shock gas is given by (Apparao 1999):

$$L_\nu = 5.4\times10^{-39}2\pi AZ^2 g\int_0^{x_0} n_e(x)n_i(x)T^{-0.5} \times e^{-h\nu/kT}e^{-\tau}dx \quad (3)$$

in erg $s^{-1}Hz^{-1}$. The energy in the Lyman continuum of this radiation can be calculated using (3) and the density and temperature profiles given above (also see Apparao 1999).Using $n_0=5\times10^{11}$ cm^{-3}, we find $E_{Ly}\sim4\times10^{36}$ erg s^{-1}.This is approximately the same as the Lyman continuum from the Be star.

The emission of Hα line from the post shock gas can also be calculated, using the above profiles and using the emission coefficient (Osterbrock 1974) $4\pi j_{H\alpha}n_e n_i=2.4\times10^{-25}$, in erg $cm^{-3}s^{-1}$. We find $E(H\alpha)=6\times10^{32}$ erg s^{-1} which is smaller than the observed Hα emisson, which is 1.3×10^{34} erg s^{-1} obtained using the equivalent width of ∼17 Å The Hα emission calculated using the Lyman continuum of a B0V Be star exceeds this value; however self-absorption reduces it to the observed value (see Apparao & Tarafdar 1987; Apparao & Tarafdar 1997).

4. Hα equivalent width ratio variation

Zamanov et al. (1999) have plotted the ratio of the equivalent width of the blue wing of the Hα line profile to that of the red wing as a function of orbital phase. They find a ratio $\gtrsim$1 between phases ∼0.2 and ∼0.4 and $\lesssim$1 between phases ∼0.6 and ∼0.8. We suggest that it is due to the obscuration of part of Hα line emission from the Be star gas disk (due to the Be star Lyman continuum), by the shock produced by the compact object.

We had suggested (Apparao 1999) that the orbital phase 0.0 used by Taylor & Gregory (1982) corresponds to the configuration in which the compact object is in front of the Be star along the line of sight. The phase 0.25 will then correspond to the ascending node of the compact object and the phase 0.5 will correspond to the periastron of the orbit (Fig. 1).

The optical depth for free-free absorption by the ionised post shock gas is

$$\tau(x) = \int_0^x \kappa_{ff}(y)dy \quad (4)$$

where κ_{ff} is the free-free absorption coefficient given by Allen (1976),

$$\kappa_{ff} = 1.37\times10^{-23} Z^2 g \lambda^3 n_e(x) n_i(x) T^{-1/2}(x) \quad (5)$$

The integral (4) can be evaluated, for λ=6562 Å, for the region 0 to x_0 and x_0 to infinity using the density and temperature profiles given above. We find them to be τ=0.5 and 25.7 respectively. Thus optical radiation seen through the post-shock gas can effectively be absorbed.

We can now synthesise a picture to explain the variation of the equivalent width ratio of the blue and red humps. As shown earlier the Hα line emission can effectively be absorbed by the ionised portion of the post-shock gas (IPPSG). Thus between phases of ∼0.2 and ∼0.4 (the ascending node side of compact object) a portion of the Be star ionised disk Hα emission (the red hump) is absorbed by the IPPSG, leading to a higher value of the ratio E(b)/E(r) as is observed. The IPPSG absorption of the Hα emission from the Be star disk also produces a decrease in the ratio E(b)/E(r) on the descending node side of the compact object, that is between phases ∼0.6 and ∼0.8. However the UV emission from the shock can ionise the portion of the disk not ionised by the Lyman continuum of the Be star, thus somewhat compensating for the absorption by the IPPSG(It is difficult to calculate this compensation because of the asymmetric nature of the geometry involved in order to estimate the effect). Thus it is possible for the absorption and emission effects of the shock to produce the observed Hα equivalent width ratio variation.

5. The ∼4 yr variation of Hα line emission

Zamanov et al. (1996) found that the equivalent width of Hα line emission varies with the ∼4 yr quasi-period which was also found in radio emission from the object (Taylor & Gregory 1982). This quasi-period is attributed to the formation and dissipation of the Be star gas disk (Apparao 1999; Zamanov et al. 1999). The peak of the Hα emission however occurs later in the ∼4 yr period phase when compared to the peak of radio emission. This can be understood as due to the variation of the density of the gas disk. The gas density when formed is very dense and the radio emission which is likely proportional to the density (Apparao 1999b) is at its maximum. At this time however the disk is optically thick to Hα emsision (Apparao & Tarafdar 1987). The gas disk expands and the density reduces till the disk becomes optically thin to Hα line and the peak emission is seen by the observer at this time.Thus there is a delay between the maximum radio emission and maximum Hα emission as observed.

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