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Global One-armed Oscillations in the Be/X-ray Binary LS I +61° 235/RX J0146.9+6121

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Abstract. We present results of our long-term monitoring of LS I +61° 235 in the optical and infrared bands. This Be/X-ray binary exhibits V/R variability in the Hα line, which can be explained in the framework of the Global One-armed Oscillation model: a high density perturbation moves around inside the circumstellar disc of the Be star. The V>R and V<R peaks occur when the perturbation moves towards and away from the observer, respectively. In this work we show that the perturbation also affects the He I λ6678Å and Paschen lines. We also report on a correlation between the infrared emission and the V/R variability.

1. Introduction

LS I +61° 235 is the optical counterpart to the X-ray source RX J0146.9+6121. The X-ray emission is due to accretion of matter from a B1V-IIIe star onto a neutron star. The X-ray source was detected for the first time by White et al. (1987) when they used medium energy proportional counter array ME on board EXOSAT to observe the nearby source 4U 0142+61. They found that the high energy radiation was pulsed with a spin period of 1404 s. Since this instrument did not have imaging capabilities it was not possible to determine the origin of the 25-minute modulation. Motch et al. (1991) rediscovered the source from

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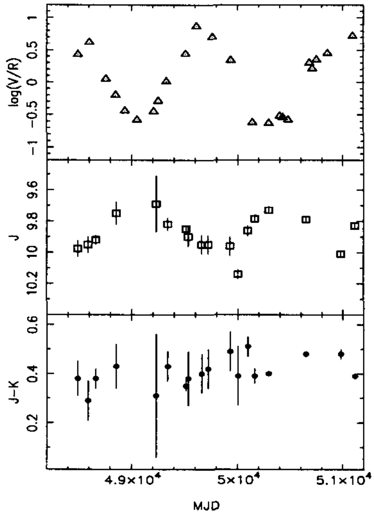

Figure 1. Correlated V/R and infrared variations

the ROSAT all-sky survey. They identified RX J0146.9+6121 with the V=11.2 Be-type star LS I +61° 235, hence defining the system as a Be/X-ray binary.

The first detailed study of the optical primary was undertaken by Coe et al. (1993), who noticed major changes in the profile of the Hα emission line as well as the presence of infrared excess. Reig et al. (1997) derived the astrophysical parameters of the system and reported on the long-term optical variability. They found V/R variations with a quasi period of $\sim$ 3 years and attributed them to the prograde precession of a one-armed mode in the Be star's disc. The system was classified as a B1Ve star at an estimated distance of 2.3$\pm$0.5 kpc.

2. Observations

Optical spectroscopic observations were made from the 2.6m telescope at the Crimean Astronomical Observatory (CAO) and from the Jacobus Kapteyn Telescope (JKT) and the William Herschel Telescope (WHT) located in the Observatorio del Roque de Los Muchachos in La Palma (Spain). Further service time observations were obtained using the Isaac Newton Telescope (INT).

The infrared observations were taken with the Continuous Variable Filter (CVF) infrared photometer, using the 1.5-m Carlos Sánchez telescope, located at the Teide Observatory, in Tenerife (Spain). A more detailed and technical description of the observations will be given in Reig et al. (1999, in preparation).

3. Results

Fig 1 shows the infrared light curve (J band) of LS I +61° 235 and its comparison with the V/R variations. Also, the $J - K$ index is shown in the lower panel. The data span over 7 years of observations, from 1991 October – 1998 October.

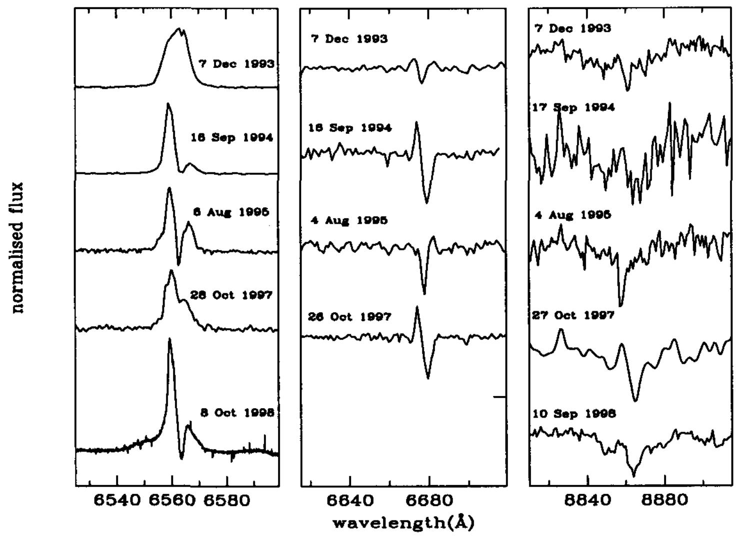

Figure 2. The changing profile also affects the Hα, He I λ6678Å and Paschen lines, implying that the oscillations are global.

When compared to the V/R variability the infrared data seem to mimic the V/R behaviour. The maximum brightness is found during the V $<$ R phases, following a V=R shell phase. However, the infrared colour $J - K$, i.e. the slope of the infrared continuum does not change.

In Fig 2 simultaneous optical and near-infrared spectroscopic observations are presented. The profile of the Hα, He I λ6678Å and Paschen lines is shown. Despite the different origin of these lines, this plot indicates they all show the same profile.

4. Discussion

The long-term V/R variations seen in LS I +61° 235 can be explained by the Global One-arm Oscillation model (Okazaki 1991; 1997, Savonije & Heemskerk 1993). This model suggests that the V/R periodicities are phenomena caused by a density perturbation which develops on one side of the disc. The precession of such density pattern causes a difference between the amount of emitting gas approaching the observer and that receding from the observer. The V/R variations are due to the gradual change of these amounts. The V>R phase occurs when the perturbation moves toward the observer, whereas the V<R phase takes place when the perturbation moves away from the observer. In between these two phases a certain amount of absorption should show up in the line profile, as it is indeed observed.

Okazaki (1991) developed the one-armed ($m = 1$) oscillation model and showed that it explains many observed features of the long-term V/R variations in Be stars. Hummel & Hanuschik (1997) solved the 3-D radiative transfer calculations for a quasi-Keplerian disc containing a one-armed global oscillation.

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They modelled the oscillation with a crude extrapolation of the linear solution to much larger amplitudes and found that it could reproduce both the shapes of emission lines and their temporal variability. Later Hummel, Hanuschik, & Vrancken (1998) argued that if very large circumstellar discs were assumed, the observed profiles could be reproduced without arbitrarily scaling the solution. This seems to be in conflict with the need for the modes to be confined to the inner part of the discs. Okazaki (1997) showed that confinement could be achieved due to the quadrupole gravitational potential of the central star (for late-B stars) or the radiation pressure from the central star (for early-B stars).

One prediction of the model is that no changes in the slope of the infrared continuum are expected. The reason is that the V/R variations are not the result of changes in the radial gradient of the circumstellar gas. The slope of the infrared continuum is a measure of the radial density distribution but since matter in the disc does not move radially no changes in the strength or shape of the infrared continuum are expected.

This is exactly the behaviour that we find in the case of LS I +61° 235. While the individual infrared photometric bands changed the infrared colours remained constant (Fig. 1).

The global character of the oscillation is demonstrated by the fact that the V/R variations are not only seen in the Balmer lines (Hα) but also in the Paschen series and He I λ6678Å (Fig 2). These lines are believed to form at different depths in the circumstellar envelope: outer parts for Hα, inner parts, very close to the star for He I and intermediate regions for the Paschen lines. Thus the perturbation extends over a very wide portion of the disc.

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