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Hα emission variability in the γ-ray binary LS I +61 303

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Abstract. LS I +61 303 is an exceptionally rare example of a Be/X-ray binary that also exhibits MeV–TeV emission, making it one of only a handful of "γ-ray binaries". Here we present Hα spectra that show strong variability during the 26.5 day orbital period and over decadal time scales. The Hα line profile exhibits a dramatic emission burst shortly before apastron, observed as a redshifted shoulder in the line profile, as the compact source moves almost directly away from the observer. Here we investigate several possible origins for this red shoulder, including an accretion disk, tidal mass transfer stream, turbulent gas in the wake of the neutron star, and a compact pulsar wind nebula in the system.

Keywords. accretion, accretion disks, stars: winds, outflows, stars: emission-line, Be, stars: individual (LS I +61 303)

1. Introduction

LS I +61 303 is a high mass X-ray binary (HMXB) that is also a confirmed source of very high energy γ-ray emission. The system consists of a B0 Ve optical star and an unknown compact companion in a highly eccentric, 26.5 day orbit (Aragona *et al.* 2009). We recently obtained an extensive collection of red optical spectra of LS I +61 303 to determine an updated orbital ephemeris for the spectroscopic binary. These observations also recorded the evolution of the Hα emission during a full orbital cycle (Fig. 1, left). We subtracted the mean emission line profile, shifted to the rest velocity of the optical star, to investigate the emission residuals carefully. A prominent emission feature stands out as a "red shoulder" in the Hα line profile near $\phi(\mathrm{TG}) \sim 0.6$ as the compact companion is receding from the observer. A more complete discussion of the short-term and long-term variability of the Hα emission, and its origin, is available in McSwain *et al.* (2010).

2. Discussion

To investigate the origin of the red shoulder, we measured the equivalent width of Hα, $W_{\mathrm{H}\alpha}$, by directly integrating over each line profile. $W_{\mathrm{H}\alpha}$ rises dramatically with the onset of the red shoulder. We also used Gaussian fits of the peak residual emission to measure its radial velocity, V_r, and full width half maximum, FWHM. The low FWHM of our difference spectra is generally consistent with a spiral density wave within the Be

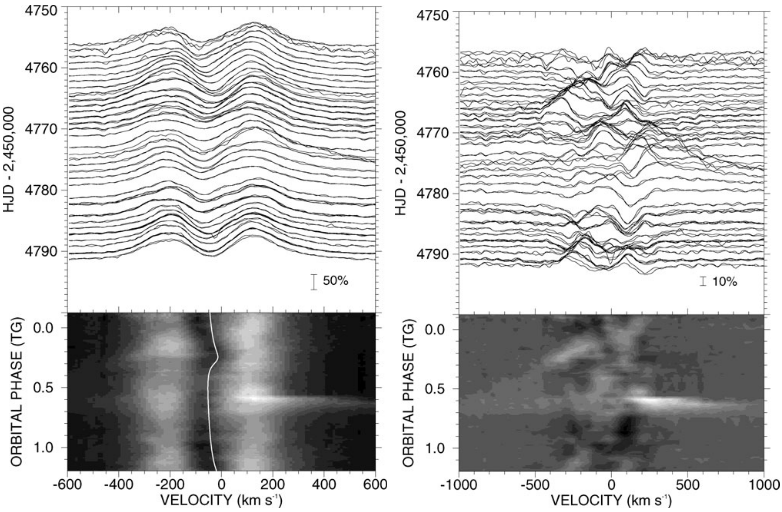

Figure 1. *Left:* The upper plot shows the Hα line profile of LS I +61 303 over our continuous 35 nights of observation, sorted by HJD, and the lower plot shows a gray-scale image of the same line. *Right:* Emission residuals, or difference spectra, in the same format.

circumstellar disk. The FWHM of the red shoulder is significantly higher, suggesting a more turbulent region of gas and an origin outside the circumstellar disk.

Paredes *et al.* (1994) first proposed that the increase in Hα emission in the red shoulder originates in an accretion disk. However, the observed V_r of the red shoulder does not correspond to the orbital motion of a compact companion. Therefore an accretion disk is an unlikely source of the red shoulder.

Neither can the red shoulder be due to turbulent gas trailing the neutron star. The orbital velocity of the neutron star is faster than the circumstellar disk only very close to periastron. If the Keplerian disk extended out to the neutron stars location, the disk would actually stream past the slow moving neutron star near apastron.

Grundstrom *et al.* (2007) propose the development of a tidal stream within the Be disk near periastron, extending beyond the truncation radius of the Be star disk and into the vicinity of the compact companion. The red shoulder could be formed as the induced tidal stream falls back onto the Be circumstellar disk. The resulting infall velocity of the tidal stream is somewhat comparable to the observed V_r of the red shoulder.

Alternatively, LS I +61 303 may contain a shrouded pulsar whose relativistic wind interacts with the optical stars wind to form a cone-shaped wind shock region (eg. Dubus 2006). The unusually broad FWHM of the red shoulder emission is consistent with a Balmer-dominated shock (BDS) sometimes observed in pulsar wind nebulae (Heng 2010). The temporary red shoulder may suggest that the BDS only forms when the high density tidal stream interacts with the neutron star.

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