Investigating the circumstellar disc of PSR B1259-63/LS 2883 using optical SALT spectra

M. Kilian[1], B. van Soelen[1], L. Townsend[2]

[1]Department of Physics, University of the Free State, PO Box 339, Bloemfontein 9301, South Africa
[2]South African Astronomical Observatory, Observatory Road, Observatory, 7925 Cape Town, South Africa

Abstract

Gamma-ray binaries are a rare class of high-mass binary systems in which the non-thermal energy spectrum peaks in the gamma-ray regime. PSR B1259-63/LS 2883 is a gamma-ray binary with a 3.4 year orbital period and consists of a 48 ms pulsar and an O9.5Ve star. The emission from the system shows variability from one periastron to the next that is associated with changes in the size and/or structure of the circumstellar disc. In this work SALT optical spectra from 2018 to 2021 as well as around the 2024 periastron passage were used to investigate how the circumstellar disc changes over the orbital phase.

Introduction

PSR B1259-63/LS 2883 is a gamma-ray binary where the orbit of the pulsar around the optical companion is highly eccentric (e ~ 0.87), resulting in the pulsar moving through the inclined decretion disc of the Oe star around periastron (Shannon et al. 2014). This phenomenon is observed as an eclipse in the pulsed radio emission, as well as two peaks in the unpulsed radio and X-ray light curves, coinciding with the disc crossings (Johnston et al. 2005).

The interaction of relativistic electrons, originating from the pulsar wind, with the stellar wind and disc of LS 2883, produces a shock front that accelerates electrons from the pulsar. The observed multiwavelength emission can be explained as follows:

- The radio and X-ray emission is the result of synchroton emission.
- The GeV emission is assumed to be the result of inverse Compton and bremsstrahlung. The short scale variability can be explained by a clumpy disc (Chernyakova et al. 2021).
- The TeV emission is caused by inverse Compton scattering of the photons from the stellar companion interacting with the relativistic electrons of the pulsar wind.
- The IR and optical thermal emission can indicate the state of the disc, which in turn influences the rest of the emission.

Observations

Optical spectra were obtained with the Southern African Large Telescope (SALT) using both the Robert Stobie Spectrograph and the High Resolution Spectrograph across multiple nights between 2018 and 2021 as well as the 2024 periastron passage.

The Hα, Hβ, Hγ and He I emission lines were fitted with either a single or double peaked Voigt profile. The equivalent widths of the Hα and He I lines were calculated by using a numerical trapezium integration method.

Results and Discussion

The equivalent widths of both the Hα and He I emission lines have a notable increase during the first disc crossing and a much larger increase after periastron. For both lines the equivalent widths were higher in 2024 than in 2021. Additionally, the equivalent widths started to increase earlier in 2024 than in 2021, indicating that the disc changed in size or orientation.

Peak-to-peak radial velocity differences from the Hβ, Hγ and He I lines reaches a minimum value roughly when the Hα equivalent width is a maximum.

The change in radial velocity (ΔV) was used to constrain the size of the emitting region of the disc using equation 1.

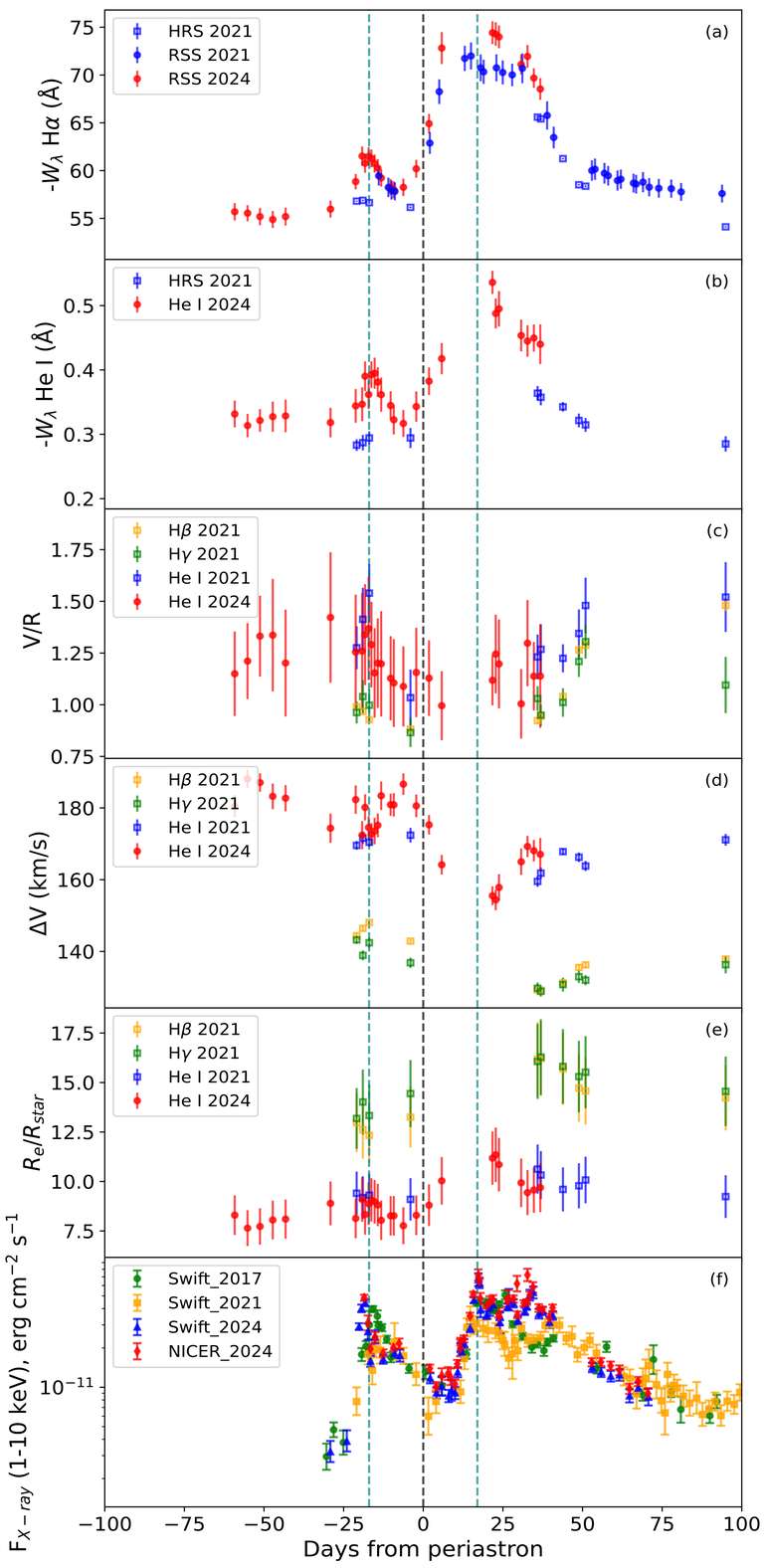


Figure 1 *Panels a and b:* The Hα and He I equivalent width. *Panel c:* The V/R ratios for various emission lines. *Panel d:* The change in radial velocity calculated for each peak of the emission lines. *Panel e:* The ratio between the emitting radius and the stellar radius of PSR B1259-63/LS 2883. *Panel f:* The X-ray light curve. Every panel is plotted against the days from periastron. The dashed lines indicate the time of periastron and the disc crossings.

$$\frac{R}{R_{star}} = \left(\frac{2\,vsini}{\Delta v}\right)^2, vsini = 260 \pm 15\,km/s \quad (1)$$

(Huang 1972, Negueruela et al. 2011)

It can be seen that the He I emission line is produced at a smaller disc radius than the Balmer lines (~ 7.6 < R/R_{star} < 11.3 for He I and, ~ 12 < R/R_{star} < 16 for Hα). This shows that the inner radius of the disc is hotter and denser than the outer radius. The emission radii increases with the disc crossings, which shows that the pulsar interaction is potentially heating up the disc at a further radius.

The X-ray light curve shows the two disc crossings. In 2024 the first peak arrived earlier than previous observations, and the second peak stayed elevated and variable up to 40 days after periastron. This is an indication of a bigger disc. The third X-ray peak is consistent with the pulsar dragging disc material with it and perturbing the disc.

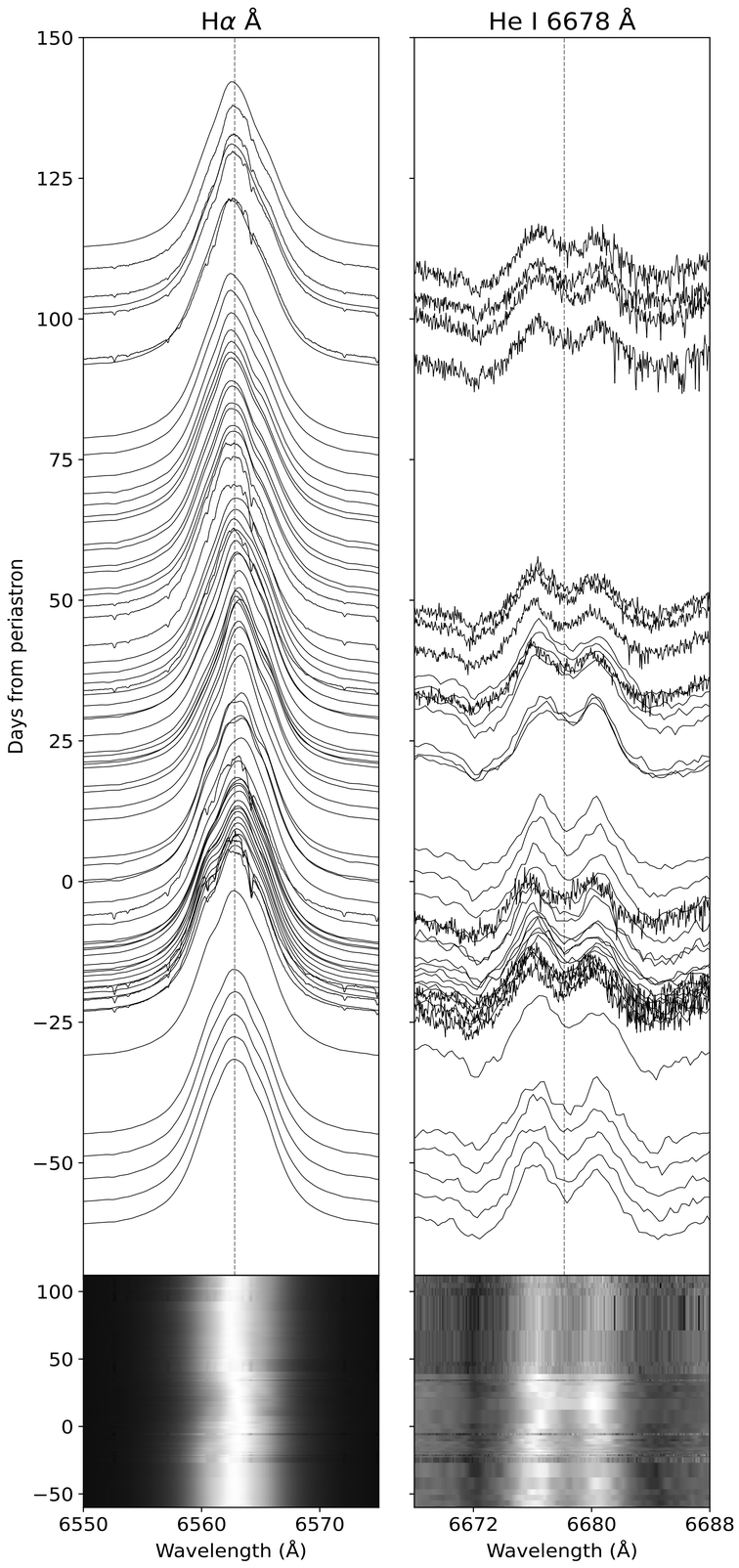


Figure 2 The emission line profiles for Hα (left) and He I (right) for each observation night sorted by the number of days from periastron. The He I emission feature from the disc is contained within a broader absorption feature from the star. The bottom panels show the same lines plotted in a heat map format where a lighter grey indicates a higher intensity at the corresponding wavelength. Note the asymmetry in in the emission lines near periastron and the disc crossings.

Conclusion

The Hα and He I equivalent widths increased from the 2021 to 2024 periastron passage. The Hα equivalent width peaked earlier in 2024 than in 2021, indicating a bigger circumstellar disc. Asymmetry in the emission lines shows variability around periastron, indicating a changing disc. The optical spectra were used to constrain the disc size, but the outer region of the disc is dominated by longer wavelengths. Future work will include modelling the disc with a curve of growth model and using NIR emission to better constrain the disc size and structure.

References

Chernyakova M., et al., 2020, MNRAS, 497, 648
Chernyakova, M., et al., 2021, Universe, 7(7), 242
Chernyakova M., et al., 2025, MNRAS, 536, 247
Huang S. S., 1972, ApJ, 171, 549
Johnston, S., et al., 2005, MNRAS, 358, 1069
Negueruela, I., et al. 2011, ApJL, 732, L11
Shannon R. M., et al., 2014, MNRAS, 437, 3255
van Soelen, B., et al. 2016, MNRAS, 455, 3674

This work is based on the research supported in part by the National Research Foundation of South Africa (Ref Number: AHPMDS260305400462)

www.ufs.ac.za
KilianM1@ufs.ac.za



High Energy Astrophysics in Southern Africa (HEASA 2026)

29 September – 2 October 2026

National Research Foundation | South African Astronomical Observatory

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA