Optical spectroscopy of PSR B1259-63 around the 2014 periastron passage

B van Soelen[1], P Väisänen[2], I Sushch[3], L Klindt[1], PJ Meintjes[1], A. Odendaal[1] and R. Armstrong[4]

[1]Department of Physics, University of the Free State, Bloemfontein, 9301, South Africa
[2]South African Astronomical Observatory, PO Box 9, Observatory 7935, Cape Town, South Africa [3]Centre for Space Research, North-West University, Potchefstroom, 2520, South Africa
[4] SKA South Africa

E-mail: `vansoelenb@ufs.ac.za`

Abstract. PSR B1259-63 is a gamma-ray binary system which consists of a 48 ms pulsar in a 3.4 year orbit around a Be star. Of the five known gamma-ray binary systems, it is the only one where the nature of the compact object is conclusively known. This makes it an extremely important target for multi-wavelength observations. Near periastron, the interaction between the pulsar and stellar winds creates a shock front, producing non-thermal emission from radio to TeV energies. The 2010 periastron passage was the first that was observed with the *Fermi*-LAT telescope and, approximately 30 days after the 2010 periastron passage, an unexpected GeV flare was observed at a time when the other non-thermal emission was already decreasing. A repeat flare event (though on a lower scale) was observed after the 2014 periastron passage. We report on spectroscopic observations undertaken with the Southern African Large Telescope (SALT) from approximately 33 days before until 78 days after the 2014 periastron passage. These observations confirm the variability of the Hα and He-I lines during this period, as was previously reported. Combined with multi-wavelength results, this suggests that the circumstellar disc is disrupted during periastron. The reported multi-wavelength results are also briefly discussed.

1. Introduction

Gamma-ray binaries present a distinct class of binary systems that are characterized by a Spectral Energy Distribution (SED) that peaks in the gamma-ray regime (see [1] for a detailed review). All these systems consist of an early main-sequence star and a compact object, but it is only in PSR B1259-63/LS 2883 that the compact object is clearly detected as a pulsar. The 48 ms pulsar is in a $\sim$ 3.4 year orbit around a Be star [2] which has been classified as a late O-type (O 8-9V) type star [3].

Close to periastron the pulsar passes behind the Be star's circumstellar disc, as indicated by the eclipse of the pulsar [4]. A shock forms due to the interaction of the pulsar and stellar winds, resulting in particle acceleration and subsequent non-thermal emission from radio to TeV gamma rays. The flux of the non-thermal emission is, in general, highest around the period of periastron, with an indication of maxima around the time of the disc crossings (see [5] and references therein for discussion of the multi-wavelength observations around the 2010 periastron passage). However, the GeV gamma-ray emission (as observed with *Fermi*-LAT during 2010) showed only a slight detection around periastron, but showed a large flux increase around 30 days after periastron, at a period when the other multi-wavelength emission was already decreasing [6]. This emission peaked at an implied luminosity of ~ 100 per cent of the spin-down luminosity of the pulsar. A number of theoretical models have been investigated, but there is no clear consensus as to the cause of this emission [7, 8, 9, 10, 11, 12].

During 2014, PSR B1259-63/LS 2883 was monitored by a number of multi-wavelength observatories around the periastron passage that occurred on 2014 May 4. The GeV gamma-ray emission was re-detected at a similar orbital phase, though there was no detection at periastron and the detected flux was lower [13, 14].

Optical spectroscopic observations around the 2010 periastron passage showed a variation in the equivalent width (EW) of the Hα and He I λ6678 emission lines, as well as a change in the symmetry of the lines [5]. However, there were no observations around the period of the *Fermi* flare. In order to monitor the changes in the circumstellar disc around periastron we used the Robert Stobie Spectrograph (RSS) to undertake long-term monitoring of the binary system from 33 d before, until 78 d after, periastron ($t_p - 33$ d and $t_p + 78$ d, respectively, where t_p is the epoch of periastron).

2. Observations

Observations were undertaken with the RSS configured for a wavelength coverage of 6176.6 – 6983.0 Å with a resolution of $R = 11\,021$ at the central wavelength. The system was successfully observed 25 times, with each observation consisting of 3-4 exposures, with an integration time of between ~ 476 to 500 s. The exposures were averaged and reduced following the standard IRAF reduction processes.[1] Spectral shape correction was performed using observations of the spectroscopic standard LTT4364.

The EW width of the Hα emission line was measured by integrating over the line, following the standard IRAF procedures.[2] The He I λ6678 line lies in a larger, stellar absorption feature and since the emission line is always present a correction for this absorption feature would require the underlying intrinsic stellar absorption spectrum to be accurately modelled. Therefore, the EW of the double peak He I λ6678 line has been measured by fitting two Gaussian profiles (relative to the continuum level) and integrating over the area of the fitted lines.[3] While this ignores the underlying absorption feature, it allows for a better comparison to be made to the data presented in [5].

3. Results

The results for the Hα and He I λ6678 lines are discussed below.

3.1. Hα line

The Hα line is in emission throughout all observations. The average EW is -55.2 ± 0.8 Å before $t_p - 20$ d, which is consistent with previous measurements away from periastron [3, 16], and rises until the line strength peaks at -72.7 ± 0.7 Å around $t_p + 13$ d, before decreasing again to the pre-periastron value (figure 1).

While the line remains single peak, it is asymmetric and is better fitted by multiple components. This is believed to be due to the blending of the underlying double (multiple) emission peaks arising from the circumstellar disc. ‘

[1] The data reduction was performed using the NOAO/CCDRED and NOAO/TWODSPEC packages.
[2] The analysis was performed using the tools available within the NOAO/ONEDSPEC package.
[3] The line profile fits were performed using the FITYK software package [15].

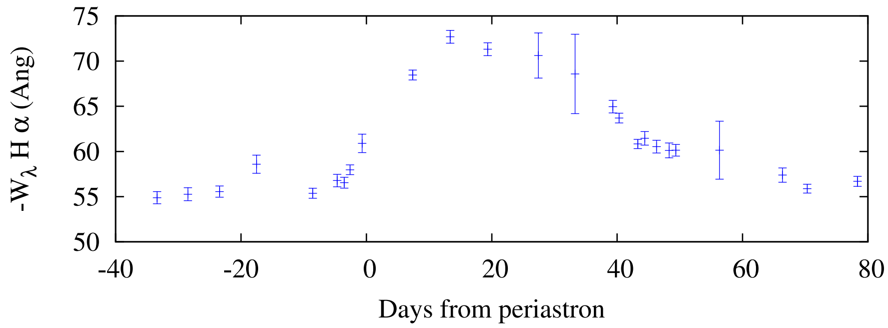

Figure 1. Variation in the Hα EW around periastron.

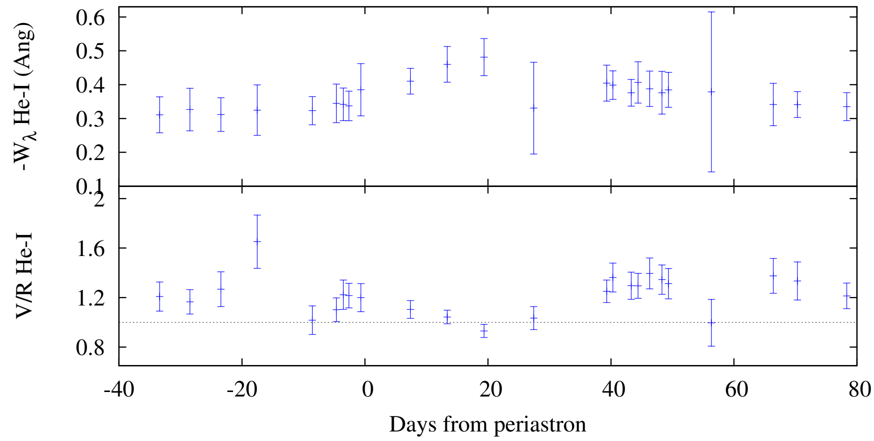

Figure 2. Variation in the He I λ6678 EW (top) and V/R (bottom) around periastron.

3.2. He I λ6678 line

The variation in the EW of the He I λ6678 line follows the same general trend as the Hα line, peaking at -0.48 ± 0.05 Å around t_p+19 d (figure 2-top). The line remained double peaked throughout all observations and exhibits a change in the relative height of the violet (V) and red (R) peaks, as shown in the V/R variation (figure 2 bottom).

While the variation in V/R is relatively smooth, there is a marked change at t_p-17.5 d where the violet line becomes stronger. This occurs around the period of the first disc crossing and corresponds to the marked increase in the EW of the Hα line. This may indicate a significant disruption of the circumstellar disc around this period or the introduction of instabilities. See for example the Smooth Particle Hydrodynamical (SPH) simulation undertaken by [17].

The change in the V/R around t_p+56 d is believed to be due to the lower signal to noise of the observation, as can be seen in the larger errors associated with the Hα and He I λ6678 EWs. The point is plotted for completeness.

4. Discussion

The variation in the Hα emission line around the 2014 periastron passage is consistent with what was previously observed around the 2010 periastron passage [5]. However, the absolute EW is lower around periastron in 2014 than it was in 2010/2011. After t_p+40 d, the EWs are comparable. We attribute this difference to the intrinsic variability of the circumstellar disc associated with Be stars.

The variation in the EW and V/R can be understood as the possible truncation of a circumstellar disc around periastron, as well as the indication of density structures in the disc around periastron. The EW of the Hα line was previous used by [5] to model the mass of the circumstellar disc in LS 2883 using the earlier model of [18]. The authors suggested a rapid decrease in the mass of the circumstellar disc after periastron that may be associated with the *Fermi*-LAT flare. A similar effect may be evident during the 2014 periastron passage [19].

Since the circumstellar disc can influence the shape of the shock front, detailed studies of the disc variability around the period of the *Fermi* flare may provide more clues to the underlying emission processes. Unfortunately, the observations reported here were hampered by weather and technical difficulties with RSS around $\sim t_p$+30 d, as indicated by the larger errors.

Unlike in the 2010 periastron, it has been suggested that there may be a correlation between the X-ray and GeV emission, with an increase in the X-ray emission detected with *Swift*-XRT around t_p+30 d [20] (see also [13] for corresponding modelling).

5. Conclusion

The optical observations with the RSS around the 2014 periastron passage present a similar trend as to previous observations. The newer observations provide a better resolution and show orbital variation in the emission line as well as shorter time scale changes, possibly associated with the pulsar disc crossing. A comparison to multi-wavelength observations may help develop a more detailed model for the interaction in this binary system.

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