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Multi-wavelength observations of PSR B1259-63 during the 2014 periastron passage

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Abstract. The gamma-ray binary star system PSR B1259-63 is unique among the five known systems since it is the only one where a radio pulsar has been directly detected. Close to periastron the system produces non-thermal/unpulsed emission from radio to TeV gamma-ray energies. In 2010 *Fermi*/LAT detected a rapid increase and peak emission at $\sim$ 30 days after periastron, at a time when emission at other wavelengths was already decreasing. PSR B1259-63 will go through periastron again on 2014 May 4. We have proposed to use the Southern African Large Telescope and the KAT-7 radio telescope array in order to contribute to the multi-wavelength coverage of the system. An outline of this proposed multi-wavelength campaign is presented.

Key words. Gamma-ray binaries - individual: PSR B1259-63

1. Introduction

The gamma-ray binary star system PSR B1259-63 consists of a 48 ms pulsar in a 3.4 year orbit ($e \approx 0.8$) around a Be star (Johnston et al. 1992). LS 2883, the optical companion has been classified as a O9.5 Ve star, with a mass of $M_{\star} \approx 31 M_{\odot}$ (Negueruela et al. 2011). PSR B1259-63 is unique among the five known gamma-ray binaries because it is the only one where a radio pulsar has been directly detected in the system. This allows for a very well determined orbital period and epoch of periastron (Wang et al. 2004). Close to periastron, the pulsar appears to pass close to or behind the Be star's circumstellar disc and there is a eclipse of the pulsar radio signal. However, during this time there is a subsequent increase in non-thermal/unpulsed emission detected from radio to TeV gamma-ray energies.

The non-pulsed radio observations have been fairly consistent during all observed periastron passages, with the light curve showing a double peak structure around periastron (e.g. Johnston et al. 2005) with the peaks potentially corresponding to the period of the pulsar passing through the circumstellar disc. An extended radio structure has also been detected during periastron passage with the Long Baseline Array, while only a point source is detected far away from periastron (Moldón et al. 2011).

Similarly, X-ray observations have shown fairly consistent results over multiple periastron passages, exhibiting a potential double peaked light curve around periastron and indication of extended emission (Chernyakova et al. 2009; Pavlov et al. 2011).

The *Fermi*/LAT telescope has so far only observed the system during one periastron passage in 2010 (Abdo et al. 2011).[1] In contrast to the observations at other energies, the *Fermi*/LAT detected a rapid increase and peak emission at $\sim$ 30 days after periastron, at a time when emission at other wavelengths was already decreasing. Importantly, the one day maximum flux detected implied a luminosity of approximately 100 per cent of the pulsar spin–down luminosity.

Observations of the system with H.E.S.S. during three periastron passages have also been reported (Abramowski et al. 2013, and references therein), and the system has been detected at TeV energies. The spectrum is consistent with a power-law ($\Gamma \approx 2.8$) during all three observations. Observations were limited during 2010/2011 due to rain, however, observations were undertaken around the same period as the rapid increase detected by *Fermi*. In contrast to the GeV observations, the TeV observations were consistent with no change in the flux or spectral index.

The unexpected "flare" event detected by *Fermi* has led to a number of different models being put forward to attempt to explain the GeV emission. Before the 2010 periastron passage observations van Soelen et al. (2012) considered how the infrared photons could contribute to inverse Compton produced GeV emission if the same population of electrons produced GeV and TeV emission, though the prediction was orders of magnitudes below the subsequent detection. Khangulyan et al (2012) proposed that the emission was the result of inverse Compton scattering from the cold pulsar wind. Kong et al. (2012) proposed that it was Doppler boosted synchrotron emission originating in the outer shock front. Most recently Dubus & Cerutti (2013) have considered inverse Compton scattering of X-ray photons in the shock front to GeV gamma-rays. However, the exact cause behind the produced GeV emission remains unclear.

PSR B1259-63 will go through periastron again on 2014 May 4. Below, we will briefly summaries the questions that still remain, the optical and radio proposal we have proposed for the Southern African Large Telescope (SALT) and the KAT-7 radio telescope array respectively, as well as initial, preliminary results.

2. Questions for the 2014 periastron passage

A number of questions still remain for PSR B1259-63, which include:

1. Will there be a repeat of the Fermi observations and if so, how do the different periastron passages compare?
2. Is there any indication of the flare at other wavelengths?
3. What is the affect on the circumstellar disc during periastron, including how does the shape of the circumstellar disc change around periastron and is there any indication of shock induced heating of the disc?
4. How will the TeV gamma-ray emission behave around periastron?

Since *Fermi* is an all sky telescope, observations will take place during periastron to attempt to answer question 1. Similarly PSR B1259-63 will be better located to undertake observations around periastron with the H.E.S.S. telescope during 2014 (question 4). In order to investigate questions 2 & 3 it is necessary to undertake multi-wavelength observa-

[1] This was true at the time of the presentation of this paper – subsequently Fermi has detected emission during the 2014 periastron passage.

tions of the system. In order to contribute from the South African observatories we have proposed to observe with SALT and KAT-7, with possible addition support from the SAAO 1.9-m telescope. PSR B1259-63 is an important source and observations by a number of different groups are planned for this period.

3. Observation proposals

3.1. SALT

SALT is a 10-m class telescope, located at the South African Astronomical Observatory (SAAO) near Sutherland, South Africa. Spectroscopic observations of PSR B1259-63 were proposed for the RSS spectrograph, a low to medium resolution spectrograph. Observations were proposed to be performed in long-slit mode with a 0.6” slit width within the wavelength range 6176.6–6983.0 Å, to achieve a predicted resolution of R=11021 at the central wavelength using the standard SALT tools.[2] The proposal was awarded $\sim$ 11 hours over semesters 2013-2 and 2014-1. The observations will focus on monitoring the variation in the Hα and He I (6678 Å) lines, as a change was reported around the 2010/2011 periastron passage by Chernyakova et al. (2014). Unfortunately there were no optical observations around the period of the *Fermi* flare event and so our proposal focusses on obtaining most observations around 30–40 days after periastron.

Preliminary analysis of the first observations show a strong, single peaked Hα emission line, and fainter, possibly double peak He I line. Fig. 1 shows the Hα line as measured on 2014 March 31. There is a clear asymmetry associated with the line.

3.2. KAT-7

KAT-7 is a seven dish telescope array in the Northern Cape, South Africa, built as the test instrument for the Karoo Array Telescope radio telescope. The system has, however, already been involved with science observations (see e.g. Armstrong et al. 2013).

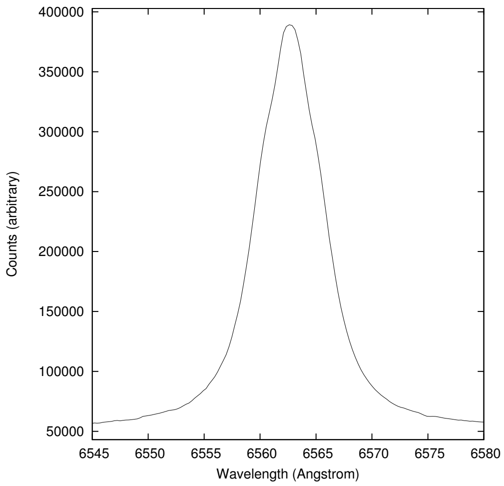

Fig. 1. Preliminary Hα spectral line obtained on 2014 March 31. The line shows a clear asymmetry, with the Violet component appearing slightly stronger than the Red component.

A proposal has been submitted to undertake a 80-day campaign to observe PSR B1259-63 at 1.822 GHz (for a 8-hour observations) every fifth day (for a total of 16 epochs). Not only does this provide an opportunity to undertake science observations but will also allow the results of KAT-7 to be compared to other radio observations of PSR B1259-63 during this same period. The preliminary image from the 22 April observations is shown in Figure 2.

4. Discussion

The spectroscopic observations undertaken with SALT will be used to probe the variation in the circumstellar disc around the periastron passage. The relevant strength of the lines gives an indication of the amount of material located within the circumstellar disc, while variation of the double peak structure of the He I line (V/R variation) will probe asymmetries in the circumstellar disc structure.

The structure of the circumstellar disc can have important consequences for the GeV gamma-ray production (as well as other multi-

[2] The SALT proposal tools are available from http://salt4scientist.salt.ac.za/.

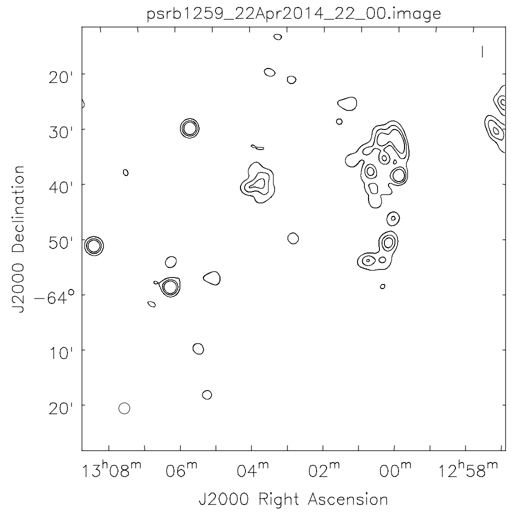

Fig. 2. Preliminary image from KAT-7 observations on the 22 April (22:00 SAST) using 7 antennas for 3 hours and 6 antennas for another 8 hours. The contours are at 0.2, 0.4, 0.6, & 0.8 times 162 mJy. The source flux is fit with a gaussian of 40.14 mJy/beam, and the image rms noise is $\sim$ 3 mJy.

wavelength results). For example, an increase (or decrease) in the brightness of the circumstellar disc will provide additional (less) seed photons for inverse Compton scattering and may subsequently increase (decrease) the resulting gamma-ray emission. An increase in brightness may result from, for example, shock induced heating of the disc or increased decretion from the Be star, while a decrease in brightness could result from disruptions and a breaking up of the disc or a confinement of the disc during periastron (see e.g. Takata et al. 2012, for numerical modelling results). Further, the structure of the circumstellar disc may also influence the structure of the shock around the pulsar, which could influence the multi-wavelength emission.

5. Conclusion

PSR B1259-63 is a very important source as it is the only one of the gamma-ray binaries where the nature of the compact object is known. The period around periastron provides an important opportunity to investigate the interaction of pulsar with the Be star, allowing us to investigate the high energy physics that occurs during this period. PSR B1259-63 will be going through periastron on the 4th of May 2014 and will be the focus of multi-wavelength observations by a number of different groups focusing on multi-wavelength observations from radio up to gamma-ray energies.

Here we have presented a short overview of the system as well as optical and radio observations we have proposed for SALT and KAT-7 respectively. This periastron passage will provide a very important opportunity to follow the system at multiple wavelengths and attempt to better understand the physics that is at work within the system.

Addendum

In the time between the presentation of this paper and its subsequently submission, observations of PSR B1259-63 have been reported around periastron with *Fermi*/LAT, *Swift*/XRT and AGILE (Tam & Kong 2013; Malyshev et al. 2014; Tam et al. 2014; Wood et al. 2014; Pittori et al. 2014; Bordas et al. 2014). We have also observed PSR B1259-63 26 times with SALT between 2014 March 31 and 2014 July 21 (34 d before to 78 d after periastron). The KAT-7 telescope also obtained observations during eight epochs between 2014 April 22 and 2014 June 21 (12 d before to 48 d after periastron).

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