Boletim da Sociedade Astronômica Brasileira, **35**, no. 1, 66-69

Observationl multi-technique studies of a new magnetic cataclysmic variable

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Abstract. In this work, I will present the results of the observational study of the candidate magnetic cataclysmic variable of the polar type CRTS J035758.7+102943 (CSS0357+10), with spectroscopy, photometry, and polarimetry data obtained from the SOAR, OPD observatories, and the TESS space telescope. The average spectrum is dominated by emission lines, mainly Balmer lines and HeII 4686 Å, with the latter almost as intense as H. The spectroscopic data revealed radial velocity curves typical of polars, showing variable line profiles with more than one component. The fit to H identified two components, one with a semi-amplitude of 720 km/s and the other with 270 km/s. One component has a maximum redshift near $\phi \approx 0.3$, while in the other, this point is at $\phi \approx 0.5$, evidence that each originates from distinct locations in the system. Polarimetric analysis showed that the system has a large fraction of circularly polarized light, reaching a maximum of $\approx 40\%$ in the V filter and $\approx 30\%$ in R and I, definitively classifying it as a polar. The light curve has a modulation with an amplitude of ≈ 0.75 mag, with its minimum coinciding with the maximum of the circular polarization curve, indicating that our line of sight is along the magnetic field, and its maximum with the minimum of circular polarization, when the magnetic field is parallel to the plane of the sky. In the search for periods, the Lomb-Scargle technique was applied to various combinations of data groups, resulting in a period of 0.0791810(8) days, reducing the uncertainty of the period published in the literature by 20%. In summary, it can be concluded that the CSS0357+10 system is indeed a polar-type magnetic cataclysmic variable with a period slightly below the period gap.

Resumo. Nesse trabalho apresentarei os resultados do estudo observacional da candidata a variável cataclísmica magnética do tipo polar CRTS J035758.7+102943 (CSS0357+10), com dados de espectroscopia, fotometria, e polarimetria, obtidos nos observatórios SOAR, OPD, e no telescópio espacial TESS. O espectro médio é dominado por linhas de emissão, principalmente linhas Balmer e HeII 4686 Å, com essa última quase tão intensa quanto H. Os dados espectroscópicos mostraram curvas de velocidade radial típicas de polares, revelando perfis de linhas variáveis com mais de um componente. O ajuste feito em H identificou duas componentes, uma com semi-amplitude de 720 km/s, e a outra com 270 km/s. Uma das componentes possui um redshift máximo próximo a $\phi \approx$0,3, enquanto na outra esse ponto se encontra a $\phi \approx$0,5, evidência de que cada uma delas tem origem em locais distintos do sistema. A análise polarimétrica mostrou que o sistema possui uma grande fração de luz circularmente polarizada, chegando a um máximo de $\approx$40% no filtro V, e $\approx$30% no R e I, classificando-a definitivamente como polar. A curva de luz possui uma modulação com amplitude de $\approx$0,75 mag, com seu mínimo coincidindo com máximo da curva de polarização circular, indicando que nossa linha de visada está ao longo do campo magnético, e seu máximo com o mínimo da polarização circular, momento em que o campo magnético está paralelo ao plano do céu. Na busca de períodos, foi usada a técnica Lomb-Scargle aplicada a várias combinações de grupos de dados, resultando em um período de 0,0791810(8) dias, reduzindo em 20% a incerteza do período publicado na literatura. Em suma, pode-se concluir que o sistema CSS0357+10, é de fato uma mVC do tipo polar com período ligeiramente abaixo do period gap.

Keywords. Cataclysmic Variables – Polarimetry – Spectroscopy

1. Introduction

Cataclysmic variables (CVs) are binary star systems composed of a white dwarf (primary) and a red dwarf (secondary). In a CV, the components are located at approximately a solar radius from each other, allowing the transfer of mass from the secondary to the primary through Roche lobe overflow. This matter flow does not directly impact the surface of the primary but follows a ballistic trajectory, forming a disk that is fed by the matter stream.

Two mechanisms are responsible for draining angular momentum from the system, causing the components to approach each other and decreasing the orbital period as the cataclysmic variable (CV) evolves. This prevents the secondary from losing contact with its Roche lobe, ensuring that mass transfer does not cease. These mechanisms are: magnetic braking, which is dominant for systems with orbital periods greater than 3 hours and is a consequence of charged particles from the secondary's stellar wind that attach to its magnetic field, carrying angular momentum with them when expelled; and the second is gravitational radiation emission, dominant for periods less than 2 hours, increasing in intensity as the orbital period decreases. In systems with orbital periods between 2 and 3 hours, the secondary enters thermal equilibrium, adjusting its radius and losing contact with the Roche lobe, leading to a suspension of mass transfer and a significant decrease in the brightness of the CV. Consequently, few systems are known in this period range, which is referred to as the period gap.

A cataclysmic variable (CV) hosting a white dwarf with a very intense magnetic field can divert matter from its usual trajectory by capturing the flow along its field lines in a region called the threading region. This process forms an accretion column that collides with the surface of the primary near its magnetic pole. Due to its inhomogeneity, this region forms a soft X-ray emission region (denser region) and a hard X-ray emission region (less dense region), characterizing a magnetic cataclysmic variable of the polar type, referred to as a magnetic cataclysmic variable (mCV). Once captured by the field lines, the matter experiences the action of the Lorentz force, causing elec-

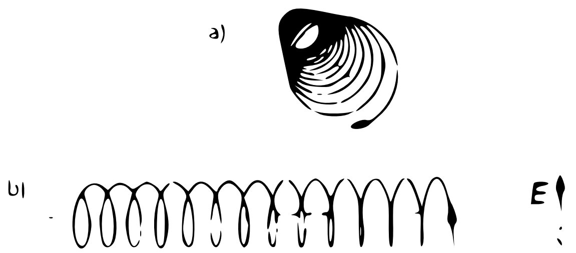

FIGURE 1. The trajectory of a charged particle in a magnetic field.

trons to spiral as they traverse it, resulting in a strong emission of circularly polarized light, a primary characteristic of a polar.

The type of polarized light observed strongly depends on the geometry of the system. When the accretion column is oriented with respect to the line of sight, which follows the field lines, we will see electrons describing a circular motion, consequently emitting circularly polarized light (Fig. 1 a). On the other hand, when the line of sight is perpendicular to the field lines, we will observe electrons oscillating perpendicular to it, emitting linearly polarized light (Fig. 1 b).

The diverse range of interactions present in these systems causes them to emit across a wide spectrum of the electromagnetic spectrum, ranging from radio waves to X-rays, making them an important subject of study for the understanding of these phenomena. This work aims to confirm the classification of the CSS0357+10 system as a polar, with the goal of increasing the number of known systems of this type to improve statistics and consequently enhance our understanding of them.

2. Observation and Data Reduction

The time series of spectra was observed on November 18 and 20, 2012, at the Southern Astrophysical Research Telescope (SOAR), which features a 4.1-meter diameter primary mirror and is located in the Chilean Andes, specifically on Cerro Pachón at an altitude of 2700 meters. Photometry and polarimetry data were collected on September 9 (V filter), September 10 and 12 (R filter) of 2019, and on September 2, 2021 (I filter), at the Pico dos Dias Observatory (OPD), situated in the city of Brasópolis, in southern Minas Gerais, at an altitude of 1864 meters above sea level. The Pico dos Dias Observatory is managed by the National Laboratory for Astrophysics (LNA), headquartered in Itajubá, and is equipped with various telescopes. The one used in this work was the Perkin-Elmer, with a 1.6-meter diameter mirror.

Data processing was carried out using standard routines in the IRAF data reduction software. The initial step involved subtracting bias to eliminate pre-existing counts in the CCD camera, followed by division by an average flat-field to correct for fluctuations in pixel gain, a common procedure for all the data.

The one-dimensional spectra were extracted from the two-dimensional image, where the horizontal axis represents the dispersion axis, and the vertical axis represents the spatial axis. The dispersion axis may deviate from a straight line by a few pixels; therefore, a smooth function that follows the trace of the axis, a process called tracing, is adjusted. In our case, a third-order Chebyshev function was employed for this purpose. Finally, wavelength and flux calibration were performed, with the former utilizing a comparison lamp whose emission line wavelengths are known, and the latter achieved using the standard star GD50 for comparison. All processes were conducted in IRAF.

In addition to the IRAF packages, the polarimetric data reduction also utilized the PCCDPACK package for polarimetric data reduction, with the addition of some codes developed by Dr. Claudia Vilega Rodrigues, all within the IRAF environment. The polarimeter consists of two main components: a retarder plate and a calcite block. The calcite block splits the light beam into two, so each star is represented by pairs in the image (Fig.), and the ratio between the difference and sum of the counts of the two beams is used to measure the polarization of the light source. During the OPD observations, images of polarized standard stars were taken to determine the initial position of the retarder plate, which in our case was 28 degrees. This allowed for the correct extraction of polarization values.

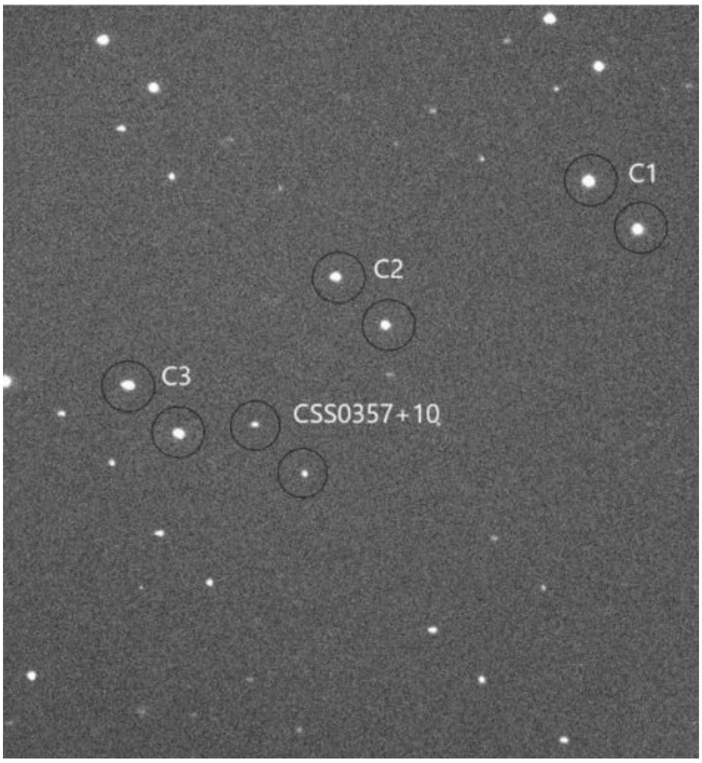

FIGURE 2. Field of CSS0357+10 indicating C1 and C2.

Photometry is a byproduct of polarization data. For the analysis of the photometric time series, we employed the technique of differential photometry. In this method, we identified a field star with constant brightness and minimal dispersion. We then subtracted its magnitude from the magnitude of our science target to detect variations in brightness. Figure 2 depicts the field of CSS0357+10, indicating the stars used for differential photometry, with C1 (USNO-A1.0b 0975-00880136) chosen for this purpose, and C2 and C3 used to ensure the stability of C1.

3. Results

For a search for periodicities, we employed the Lomb-Scargle method with our combined data along with photometry data obtained in 2009 generously provided by Schwope & Thinius (2012), referred to as S&T, and also data from the TESS space telescope, aiming to achieve broad temporal coverage and improved precision. This search applied to the OPD+S&T dataset resulted in a periodogram where the best peak is not very apparent. Therefore, we overlaid the periodogram of the TESS data to assist in this search. The result can be seen in Figure 3 , indicating the selection of the peak immediately near P=0.07981 as the most significant representative of the orbital period of the system. The maximum of this peak occurs at P=0.0791810±0.0000008 days, and we will consider this as the

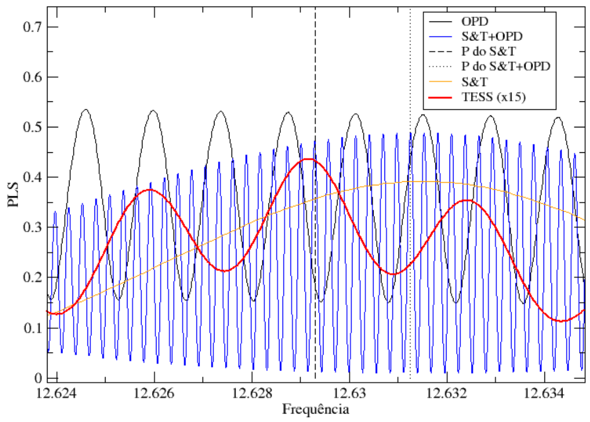

Figure 3. Lomb-Scargle periodogram of various datasets.

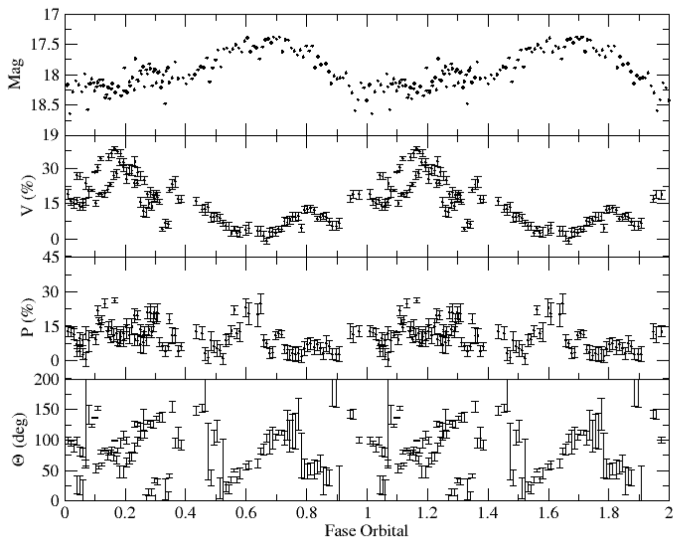

Figure 4. Light curve, fraction of polarized light, fraction of linearly polarized light, and polarization angle for the V filter.

orbital period of the system, without dismissing the possibility of neighboring peaks at P-=0.0791792 and P+=0.0791827 days.

The polarimetry and photometry data were phased with the period found above, revealing a significant portion of circularly polarized light, reaching approximately 40% in the V filter and 30% in R and I. A modulation on the orbital timescale is evident, with the maximum polarization coinciding with the minimum point of the light curve. The plots also depict a considerable level of linear polarization, along with a potential modulation in these data at the same orbital phase as the minimum circular polarization. The light curve exhibits an amplitude of variation of about 0.75 mag, with its maximum coinciding with the modulation of linear polarization. Figures 4, 5, and 6 displays the plots for the V, R, and I filters respectively.

The average spectrum of CSS0357+10 shown in Figure 7 is dominated by emission lines, notably the Balmer hydrogen emissions and HeII 4686 Å, with smaller emissions of He I. No noticeable absorption, which could be related to the secondary star, is observed, ruling out the possibility of an eclipsing system. Another noteworthy characteristic is the absence of cyclotron harmonics, indicating that our object may be in a high-brightness state. The lines exhibit variable profiles, potentially suggesting the existence of more than one component. The fit to $H\beta$ showed in figure 8 identified two components, one with a semi-amplitude of 720 km/s and the other with 270 km/s. One component exhibits a maximum redshift near phase 0.3, while in the other, this point occurs at phase 0.5, suggesting that each of them originates from distinct locations in the system.

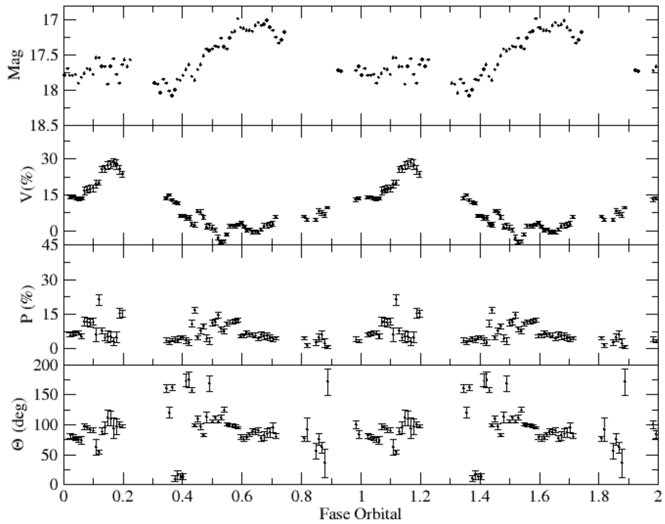

Figure 5. Light curve, fraction of polarized light, fraction of linearly polarized light, and polarization angle for the R filter.

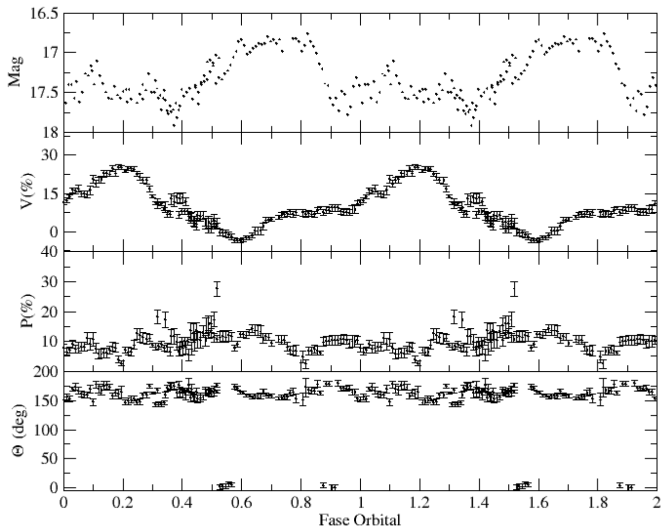

Figure 6. Light curve, fraction of polarized light, fraction of linearly polarized light, and polarization angle for the I filter.

4. Discussion

The search for periods in the photometry data, aided by TESS data, allowed us to refine the orbital period of CSS0357+10, reducing the error by 20% compared to the period reported in the literature.

Our average spectrum exhibits emission lines characteristic of high-ionization regions, such as the HeII 4686 Å emission line. The absence of any absorption related to the secondary star rules out the possibility of an eclipsing system, further confirmed

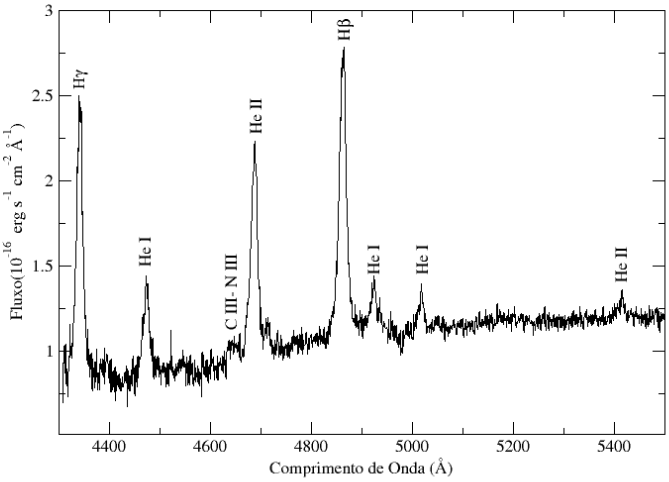

FIGURE 7. Mean Spectre.

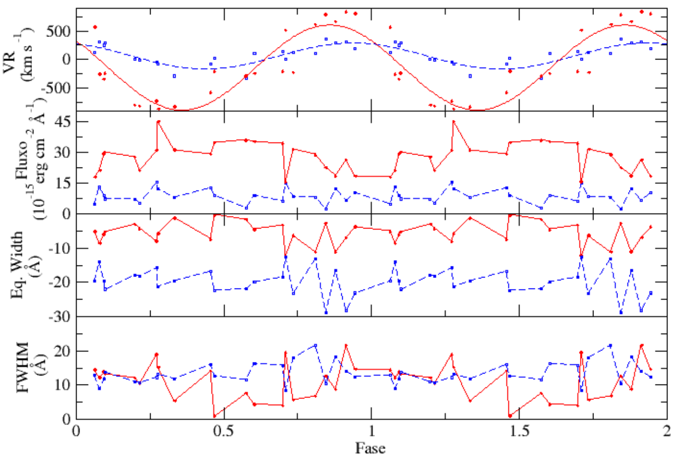

FIGURE 8. Radial Velocity curve.

by the lack of evidence for eclipses in the light curve. Gaussian fitting revealed two components in the *Hβ* emission line, likely originating from the shock region and the matter stream, respectively.

The circular polarization curves show high variation during the orbital period, possibly linked to changes in the position of the accretion column. The orbital phase where the light curve is at a minimum, coinciding with the maximum point of circular polarization, may indicate that we are looking along the field lines. Conversely, at the maximum point of the light curve, the field lines are possibly perpendicular to our line of sight (an effect caused by the anisotropy of cyclotron emission), a conclusion that may be supported by the oscillation in linear polarization.

5. Conclusion

In conclusion, we can affirm that CSS0357+10 is indeed a magnetic cataclysmic variable of the polar type with an orbital period of P=0.0791810. This conclusion is primarily supported by the high fraction of circularly polarized light but is further confirmed by other pieces of information, including the average spectrum, radial velocities, orbital period, etc. All these aspects are consistent with the characteristics expected for this type of celestial object.

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