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Spectroscopic characterization and search of Supersoft X-ray Sources

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Abstract. The small number of Close Binary Supersoft Sources identified in the Galaxy is associated with the difficulty of detecting their characteristic X-ray emission due to interstellar extinction. With the aim of searching for additional stars belonging to this rare class, this work sought to derive synthetic photometric indices for the emission lines characteristic of the optical spectra of CBSS, enabling the characterization of this feature and the search within large spectroscopic survey databases. The developed method has been applied, to date, to 390,152 spectra, among which one promising candidate has been identified.

Resumo. A pequena quantidade de *Close Binary Supersoft Sources* identificadas na Galáxia é associada à dificuldade de detecção de suas emissões típicas em raios-X, devido à extinção interestelar. Com o objetivo de buscar por mais estrelas desta classe rara, este trabalho visou derivar indíces fotométricos sintéticos para as linhas de emissão características dos espectros ópticos das CBSS, possibilitando a caracterização deste aspecto e a busca através de bases de dados de grandes surveys espectroscópicos. O método desenvolvido foi aplicado a 390.152 espectros, até o momento, dentre os quais foi identificada uma candidata promissora.

Keywords. binaries: close – white dwarfs – surveys

1. Introduction

The Supersoft X-ray Binaries class was first defined based on their intense emission in the soft X-ray and extreme UV ranges. A subset of these systems fits the Close Binary Supersoft Sources (CBSS) model, as described by Kahabka & van den Heuvel (1997). Their optical spectra exhibit remarkable similarities, most notably the presence of emission lines such as HeII (4684 Å), Hβ (4861 Å), OVI (3811–34 Å, 5290 Å, 5584 Å), and NV (4930–45 Å). The small number of such systems identified in the Galaxy, fewer than ten, according to Bhattacharya (2017), is generally attributed to interstellar extinction affecting their X-ray emission, which is typically used for detection.

The present work aims to characterize the optical spectra of these rare CBSS with respect to the aforementioned emission lines, and to employ this knowledge to develop a search method for similar spectra, with the goal of identifying new candidates within the Milky Way, among the data from the Sloan Digital Sky Survey (SDSS) and the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST).

2. Methodology

The emission-line intensities were evaluated based on equivalent widths, calculated from flux estimates in the line regions and their respective continua, using narrow-band synthetic photometry. The CBSS spectra used as reference for the analysis were collected from published studies. Initially, the intensity ratios of the highlighted spectral lines were examined by comparing CBSS with Wolf-Rayet (WR) stars and magnetic Cataclysmic Variables (mCVs), whose spectra display features similar to those of CBSS. The results were analyzed through spectral diagnostic diagrams. Subsequently, larger sets of spectra from the most recent Data Releases of LAMOST and SDSS were examined.

3. Results

A total of 390,152 spectra were analyzed, obtained both from survey-specific catalogs and from searches based on certain characteristics (such as the presence of emission lines, spectral types, etc.). The equivalent width results were filtered according to values consistent with those measured for CBSS. The spectra resulting from these filters were then visually and individually inspected for confirmation, since flux estimates derived from synthetic photometry are subject to errors due to the way the bands are adjusted to the features of each spectrum.

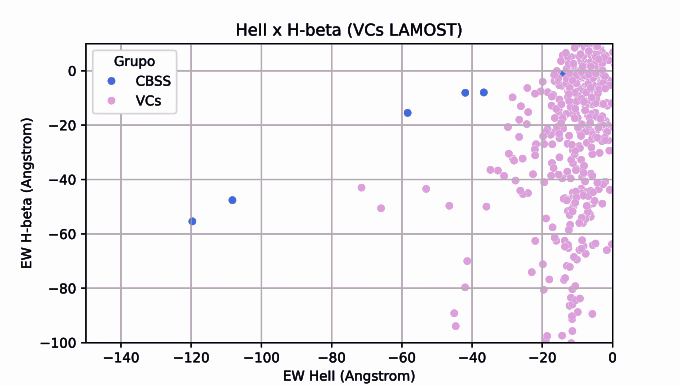

Figure 1. Spectral diagram for He II x Hβ, comparing the group of CVs from LAMOST and the known CBSS.

The results obtained for the catalog of Cataclysmic Variables (CVs) from LAMOST, regarding the relation between HeII and Hβ, are presented as an example in Figure 1. It is evident that there is little overlap between this set and the CBSS, except in the region of low line intensities, where the point corresponding to QR Andromedae (QR And) is located, the only CBSS used in this analysis with an equivalent width weaker than -30 Å. A careful inspection of the spectra in this region of the diagram led to the identification of the first candidate to CBSS in this work.

Denominated ZTF04, the candidate's spectrum closely resembles that of QR And, with which it is compared on Figure 2. The presence and intensity of O VI and N V emission lines, in addition to the intensity relation of He II against Hβ, are all the spectral characteristics expected for a CBSS, according with the

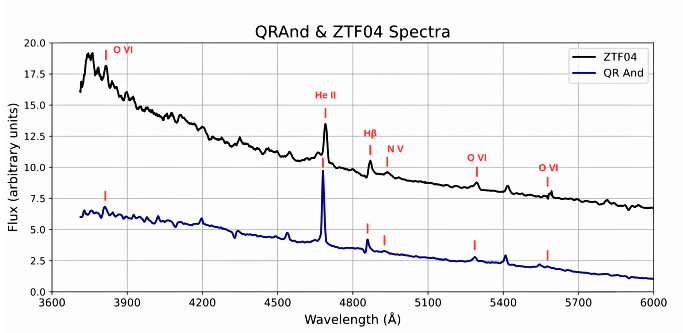

Figure 2. Spectrum of ZTF04, shown in comparison against the one of QR And, with the relevant spectral lines demarked in red.

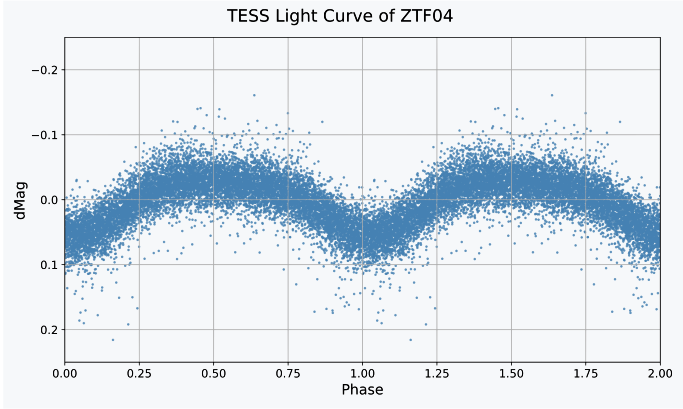

Figure 3. Light curve of ZTF04 obtained from TESS data, phase folded considering the period of 5.42 hours.

studies developed on the initial part of this work. This object was already identified as a CV for its spectrum, by Sun *et al.* (2021), although it is very unusual to find a relation of He II / Hβ > 2 in such a system, which is the case for this spectrum. Furthermore, Chen *et al*. (2020) identified ZTF04 as a contact eclipsing binary (a W UMa type), because of its light curve obtained from the Zwicky Transient Facility (ZTF), with an orbital period of 10.85 hours.

We were able to retrieve a light curve for ZTF04 from TESS data, which is much better sampled than that from ZTF, and derived a most probable period of variation of 5.42 hours based on Fourier transform periodogram analysis, agreeing with the range of orbital periods derived for the CBSS. The referred light curve, phase folded for the found period, is displayed as Figure 3, on which it is possible to verify that the variation presented by the system could agree well with orbital illumination on a non-contact binary.

The candidate has an apparent magnitude of $\sim$ 16 *mag* on the visible part of the spectrum, and a Gaia DR3 distance determined as $5.8^{+1.9}_{-1.1}$ kpc. Given its position, with only 7 degrees of inclination from the galactic plane, it is possible to infer that ZTF04 is an intrinsically bright source, a property uncommon for W UMa stars. Furthermore, the associated interstellar extinction, with reddening determined by a blue excess of $E(B-V) \sim 0.7$, could explain the lack of an identification of this object on X-ray bands.

4. Conclusions

Based on the comparisons between the results for CBSS and those obtained for WRs and mCVs, it was determined that the intensity ratios of HeII relative to OVI and Hβ can effectively discriminate CBSS spectra from others. Accordingly, we used the equivalent widths of these lines, together with the presence of NV 4930–45 Å, as selection criteria for searching candidate systems of the class of interest. This selection and filtering method was applied to 390,152 spectra from LAMOST and SDSS. A large fraction of the spectra resulting from these filters were readily recognized as evidently distinct from the targeted CBSS, the associated line measurements were incorrectly estimated due to the photometric bands employed, which were specifically adjusted to provide accurate measurements for spectra like those of CBSS.

A significant candidate was identified, exhibiting a spectrum extremely similar in both continuum and emission lines to that of QR And, and possessing all other characteristics that define CBSS, except for an X-ray detection. This lack of detection may be attributed to interstellar extinction, given its location in the galactic plane and its distance. Additional spectra are considered potential candidates but require further detailed investigation in the literature.

For the next steps of this work, we aim to search for new candidates to the CBSS class through the Dark Energy Spectroscopic Instrument (DESI) DR1 stellar data, processing approximately 4 million spectra. Another clear objective is to collect more observational data from ZTF04, in order to better establish this object as a new galactic CBSS. For this, we will try to obtain a X-ray detection of this source, in addition to a spectrum of higher resolution, and perform a study of its Spectral Energy Distribution (SED), for comparison with models and SEDs from well established components of this class.

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