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Search for cataclysmic variables in wide field surveys

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Abstract. Sky surveys covering thousands of square degrees are ideal for the search for rare objects. Cataclysmic variable stars (CVs) are interacting binaries in which a white dwarf is accreting mass from a less evolved companion. About one thousand of these objects are known and their search requires temporal and multi-wavelength information. The survey carried out by Gaia, providing both light curves and low-resolution spectra, is ideal for the study of CVs. In this proceeding, I present the steps towards the first catalogue of CVs based on Gaia DR3. I take advantage of the Gaia CV candidates in the colour-colour diagram.

Resumo. Levantamenos do céu cobrindo milhares de graus quadrados são ideais para a busca por objetos raros. Variáveis cataclísmicas (CVs) são binárias interativas nas quais uma anã branca está acumulando massa de uma companheira menos evoluída. Mil desses objetos são conhecidos e sua busca requer informações temporais e de vários comprimentos de onda. O levantamento realizado pela missão Gaia, fornecendo curvas de luz e espectros de baixa resolução, é ideal para o estudo de CVs. Nesta palestra, apresento os pasos para o primeiro catálogo de CVs com base no Gaia DR3. Aproveito da posição das candidatas CVs de Gaia no diagrama color magnitude.

Keywords. Surveys – novae, cataclysmic variables – Methods: data analysis

1. Introduction

Cataclysmic Variables (CVs) are close binary star systems where a white dwarf accretes matter from a companion star, typically a main sequence star. The mass transfer occurs when the companion star fills its Roche lobe, causing material to flow towards the white dwarf. Depending on mass transfer rate, magnetic field, and system inclination, CVs can have a wide variety of observational properties. CVs serve as crucial laboratories for understanding accretion physics, binary evolution, and stellar dynamics.

Identifying and cataloguing CVs helps to understand their population statistics, evolutionary paths, and the distribution of their physical parameters. Historically, CVs have been discovered through variability surveys and spectroscopic follow-ups. Key catalogues such as those compiled by Downes et al. (2001), Ritter & Kolb (2003), and Inight et al. (2023) have documented hundreds to thousands of CVs. However, these catalogues are limited by survey depth, completeness, and observational biases.

The Gaia mission (Gaia Collaboration et al. 2016) has revolutionised stellar astronomy by providing precise astrometry, photometry, and spectroscopy for over a billion stars. Recent work by Eyer et al. (2023) identified 7306 CV candidates within the Gaia data set. Gaia's ability to measure accurate parallaxes, proper motions, and photometric variability makes it an invaluable resource for identifying CVs. In addition, Gaia provides synthetic photometry derived from its spectra and light curves, facilitating the analysis of CV candidates.

Multi-band photometry has proven effective in distinguishing CVs from other variable objects. Studies such as Scaringi et al. (2013), Szkody et al. (2002), and Abril et al. (2020) have demonstrated the power of combining photometric data across different wavelengths to identify CVs. By merging existing CV catalogues and cross-matching them with surveys like Gaia and CatWISE, we can enhance the identification of bona fide CVs.

In addition to traditional CVs, there are borderline objects such as AM CVn stars (systems with very short orbital periods) and symbiotic stars (white dwarfs accreting from giant companions). These systems share some characteristics with CVs and enrich the diversity of accreting binaries. These objects are beyond the scope of this work.

In this paper, we present a methodology for identifying CVs using wide-field surveys, focussing on the Gaia data set. We outline the process of merging catalogues, cross-matching with Gaia and CatWISE, and constructing synthetic photometry for training machine learning models. We also discuss future prospects, including the use of narrow-band surveys such as J-PLUS and J-PAS to refine CV identification.

2. The Data

3. Input Catalogues

We utilized three existing CV catalogues as the foundation for our study:

- Downes et al. (2001) which contains 1314 CV objects identified through literature search.
- Ritter & Kolb (2003) which contains 1429 CVs, with detailed information on periods, magnitudes, and classifications; this work also took advantage of continuous literature search
- Inight et al. (2023) which provides 151 CVs, focused on follow-up of CVs discovered in the SDSS survey.

To create a workable list of CVs, we merged the three catalogues. This process involved, standardizing object names and coordinates, removing duplicates and resolving conflicting information, and retaining key parameters like periods, magnitudes, and classifications.

The merged catalogue was cross-matched with the Gaia DR3 catalogue (Gaia Collaboration et al. 2023) to obtain astrometric and photometric data. This was carried out with a 1 arcsecond radius. The sky distribution, colour-magnitude diagram and period distribution for the three input catalogues as well as for the merged catalogue are shown in Fig.1.

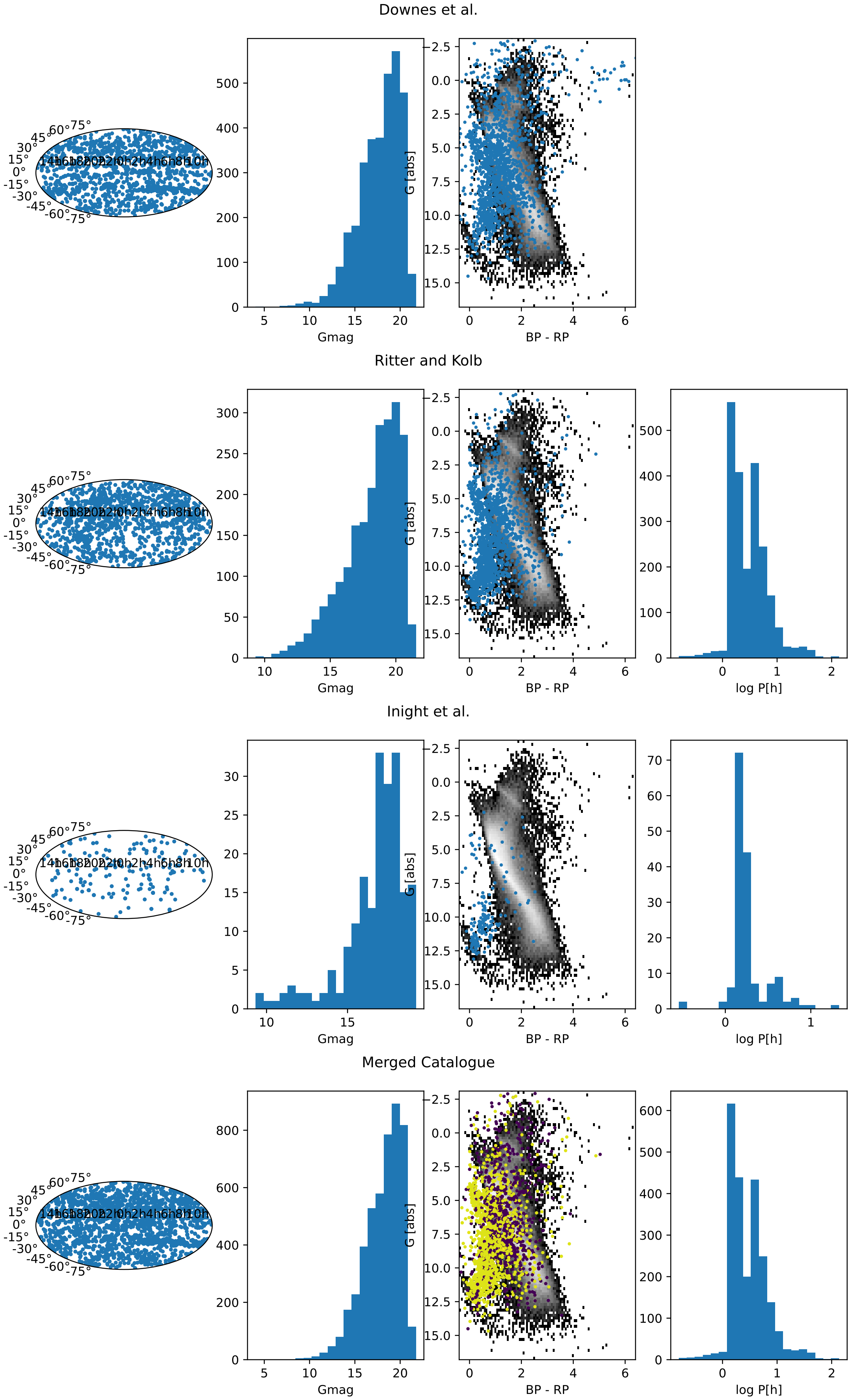

Figure 1. Each line shows the sky distribution, the colour-magnitude diagram and the period distribution for the catalogues discussed in the text. From top to bottom: Downes et al. (2001), Ritter & Kolb (2003), Inight et al. (2023), and the "merged catalogue". Note that the Downes et al. (2001) catalogue has no orbital period information.

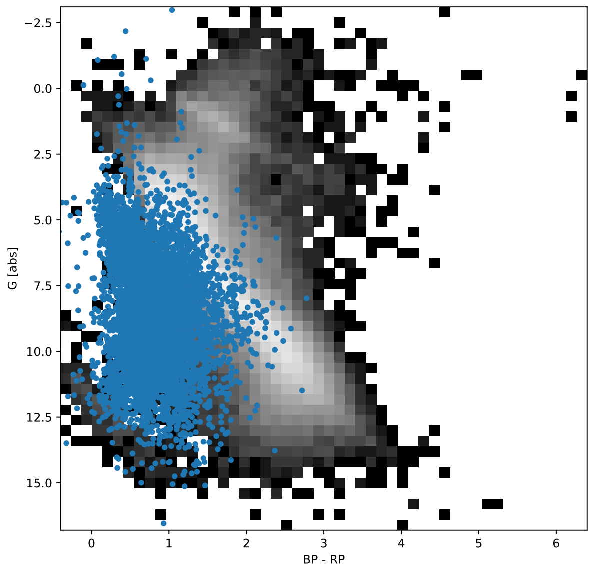

Figure 2. In blue, the position of the Gaia CVs in the colour magnitude diagram. In the background, a random selection of stars is shown for reference.

3.1. The Gaia CVs

Eyer et al. (2023) reported 7306 CVs based on their Gaia light curves (hereafter, "Gaia CVs"). 789 of these objects are found in the merged catalogue obtained in the previous section and 699 have periods. 2378 Gaia CVs are listed in Simbad. About half of these objects (1076) are classified as CVs, clearly showing the limitation of the current "merged catalogue" and 492 are marked as "candidate CVs". Interestingly, 4 Gaia CVs are classified as galaxies in Simbad. The position of the Gaia CVs in the Gaia colour magnitude diagram is shown in Fig.2. As expected (see Abril et al. 2020), the CVs are mostly found between the main sequence and the WD sequence.

It is worth remembering that Gaia provides low resolution spectra which can be used to obtained synthetic photometry of any given object. As commented, light curves are also available. There are 6,372,667 objects for which both low resolution spectroscopy and light curve is available.

4. Perspectives

We further cross-matched the Gaia CV candidates with the CatWISE catalog, which provides mid-infrared photometry from the WISE mission. This step helps in identifying objects with excess infrared emission, indicative of dusty environments or cool companions. Scaringi et al. (2013) shows that including the $W1 - W2$ colour is one of the most important steps in disentangling Galactic from extragalactic emission-line objects.

Our analysis aimed to identify bona fide Cataclysmic Variables (CVs) by combining synthetic photometry from Gaia with cross-matched catalogue data. The present CVs can be placed in diagnostic diagrams as previously done by Szkody et al. (2002); Scaringi et al. (2013); Abril et al. (2020). Fig.3 shows that this work agrees with previous works. In particular, the u vs $u - g$ relation (first plot in the second row) is particularly powerful. Yet, it is important to remember that it is the wavelength range where Gaia is less sensitive.

In the future, we plan to apply clustering algorithms to the synthetic photometry data to group objects with similar photometric properties.

The narrow-band filters of J-PLUS (Cenarro et al. 2019) and J-PAS (Benitez et al. 2014) surveys offer new opportunities to refine CV identification. Combining J-PLUS/J-PAS data with Gaia photometry will improve the accuracy of clustering algorithms and enable the discovery of new CVs.

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This work has made use of data from the European Space Agency (ESA) mission *Gaia* (`https://www.cosmos.esa.int/gaia`), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, `https://www.cosmos.esa.int/web/gaia/dpac/consortium`). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement.

This work made use of Astropy:[1] a community-developed core Python package and an ecosystem of tools and resources for astronomy (Astropy Collaboration et al. 2013, 2018, 2022).

This work made use of the Matplotlib module (Hunter 2007)

This research has made use of the SIMBAD database, CDS, Strasbourg Astronomical Observatory, France

References

Abril J., Schmidtobreick L., Ederoclite A., López-Sanjuan C., 2020, MNRAS, 492, L40. doi:10.1093/mnrasl/slz181

Astropy Collaboration, Price-Whelan A. M., Lim P. L., Earl N., Starkman N., Bradley L., Shupe D. L., et al., 2022, ApJ, 935, 167. doi:10.3847/1538-4357/ac7c74

Astropy Collaboration, Price-Whelan A. M., Sipőcz B. M., Günther H. M., Lim P. L., Crawford S. M., Conseil S., et al., 2018, AJ, 156, 123. doi:10.3847/1538-3881/aabc4f

Astropy Collaboration, Robitaille T. P., Tollerud E. J., Greenfield P., Droettboom M., Bray E., Aldcroft T., et al., 2013, A&A, 558, A33. doi:10.1051/0004-6361/201322068

Benitez N., Dupke R., Moles M., Sodre L., Cenarro J., Marin-Franch A., Taylor K., et al., 2014, arXiv, arXiv:1403.5237. doi:10.48550/arXiv.1403.5237

Cenarro A. J., Moles M., Cristóbal-Hornillos D., Marín-Franch A., Ederoclite A., Varela J., López-Sanjuan C., et al., 2019, A&A, 622, A176. doi:10.1051/0004-6361/201833036

Downes R. A., Webbink R. F., Shara M. M., Ritter H., Kolb U., Duerbeck H. W., 2001, PASP, 113, 764. doi:10.1086/320802

Eyer L., Audard M., Holl B., Rimoldini L., Carnerero M. I., Clementini G., De Ridder J., et al., 2023, A&A, 674, A13. doi:10.1051/0004-6361/202244242

Gaia Collaboration, Prusti T., de Bruijne J. H. J., Brown A. G. A., Vallenari A., Babusiaux C., Bailer-Jones C. A. L., et al., 2016, A&A, 595, A1. doi:10.1051/0004-6361/201629272

Gaia Collaboration, Vallenari A., Brown A. G. A., Prusti T., de Bruijne J. H. J., Arenou F., Babusiaux C., et al., 2023, A&A, 674, A1. doi:10.1051/0004-6361/202243940

Hunter, J. D., 2007, Computing in Science & Engineering, 9, 3, 90, doi:10.1109/MCSE.2007.55

Inight K., Gänsicke B. T., Breedt E., Israel H. T., Littlefair S. P., Manser C. J., Marsh T. R., et al., 2023, MNRAS, 524, 4867. doi:10.1093/mnras/stad2018

Ritter H., Kolb U., 2003, A&A, 404, 301. doi:10.1051/0004-6361:20030330

Scaringi S., Groot P. J., Verbeek K., Greiss S., Knigge C., Körding E., 2013, MNRAS, 428, 2207. doi:10.1093/mnras/sts189

Szkody P., Anderson S. F., Agüeros M., Covarrubias R., Bentz M., Hawley S., Margon B., et al., 2002, AJ, 123, 430. doi:10.1086/324734

[1] http://www.astropy.org

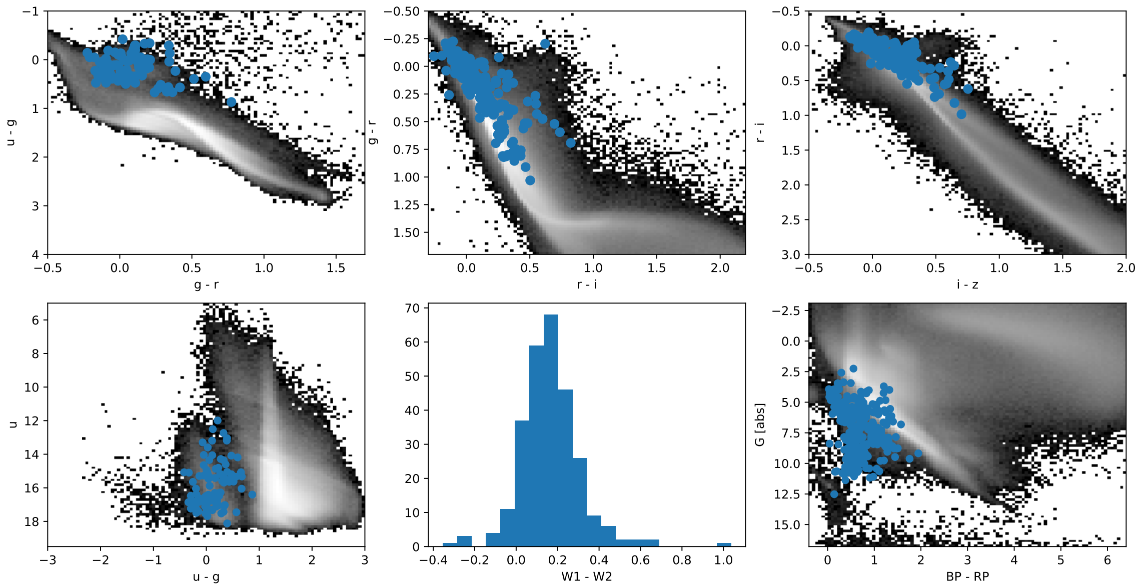

Figure 3. Diagnostic diagrams for comparison with other works. The first row shows colour-colour diagrams which are used also in Szkody et al. (2002). The first plot of the second row, shows u vs $u - g$, inspired by Scaringi et al. (2013), similarly to the second plot which shows the histogram of the $W1 - W2$ WISE colour. The last plot is the Gaia colour-magnitude diagram also used by Abril et al. (2020).