

Cataclysmic variables in wide field surveys

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Abstract. Cataclysmic variables (CVs) are interacting binaries made of a white dwarf which is accreting material from a less-evolved secondary star which is filling its Roche lobe. The advent of wide field surveys has significantly improved our knowledge of this kind of systems. In particular, the second data release of Gaia has represented a complete revolution for stellar astrophysics and this continued with the third data release. In this presentation, I will address the role of wide field surveys in our understanding of CVs, I will show how the position in the Gaia colour-magnitude diagram is related with the CVs evolutionary stage and I also comment on the role of large surveys like J-PLUS and J-PAS on CV science.

Resumo. Variáveis cataclísmicas (CVs) são binárias interativas feitas de uma anã branca que está acumulando material de uma estrela secundária menos evoluída que está preenchendo seu lóbulo Roche. O advento de levantamentos de campo amplos melhorou significativamente nosso conhecimento desse tipo de sistema. Em particular, o segundo lançamento de dados do Gaia representou uma revolução completa para a astrofísica estelar e isso continuou com o terceiro lançamento de dados. Nesta apresentação, abordarei o papel dos levantamentos de campo amplo em nossa compreensão dos CVs, mostrarei como a posição no diagrama de cor-magnitude de Gaia está relacionada com o estágio evolutivo das CVs e também comentarei sobre o papel de levantamentos amplos como J-PLUS e J-PAS em CVs.

Keywords. novae, cataclysmic variables – Techniques: photometric – Surveys

1. Introduction

Cataclysmic variables are interacting binary stars made of a white dwarf and a less evolved companion, generally a main sequence star, which is filling its Roche lobe. The material flows through the inner Lagrangian point and forms an accretion disk. In case the white dwarf has a magnetic field, the disc is partly or completely destroyed. Depending on the mass accretion rate, the inclination of the system and the magnetic field of the white dwarf, cataclysmic variables can present a large variety of observational properties. CVs are ideal astrophysical laboratories. They are the result of the evolution of binary stars which have undergone a common envelope phase, they can be used to study accretion physics in a (mostly) Newtonian regime and they can be used to study thermonuclear reactions. Some CVs are even considered potential progenitors of type Ia supernovae. For a review, see Warner (1995). Historically, CVs have been discovered mainly via two methods: variability; the variation of brightness of CVs can be quite remarkable (hence, the name of “cataclysmic”); in case of high mass accretion, it is normal to observe a small amplitude brightness variation which is referred to as “flickering”. In the case of low mass accretion objects, it is quite common to see the disc going through phases of instability and passing through a high mass accretion phase; this phenomenon is called “outburst” (or “super-outburst”). When the material accreted on the surface of the white dwarf reaches pressure and temperature to ignite thermonuclear reactions, one can observe a nova explosion. colour: in general terms, the optical emission of CVs is dominated by the white dwarf in the blue, the main sequence star in the red and the accretion disk around the H α region. Depending on the mass accretion rate and the magnetic field of the white dwarf the accretion disk will be more or less relevant in the spectrum Being very rare, CVs are normally not the main goal of large astrophysical projects and they are usually found as a byproduct of surveys aimed at other sources. Especially in the last few years, the Sloan Digital Sky Survey has proved highly beneficial in discovering (intrinsically) faint

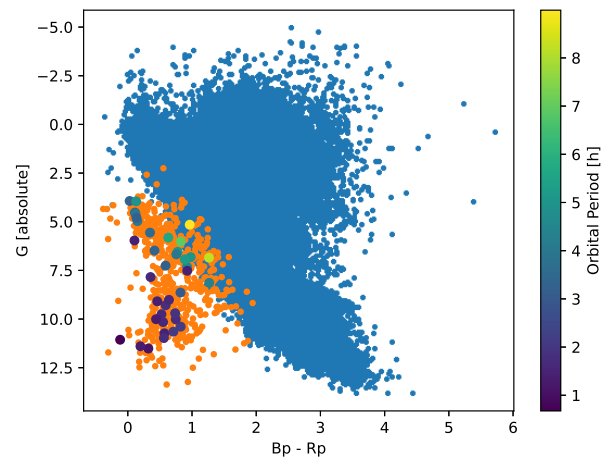


FIGURE 1. Colour magnitude diagram based on Gaia data. The blue points are one million randomly selected stars with magnitude error better than 20%. The orange points are the CVs available from the Gaia DR3 archive and the coloured points are CVs with periods from the Ritter & Kolb catalogue.

CVs. This latter population helped in fixing a major discrepancy between theory and observation of CV population. For a review, see Gänsicke (2005) and Gänsicke et al. (2009).

2. Gaia DR3

The arrival of Gaia has had a great impact on CV science (as well as on most astrophysics). Abril et al. (2020) have shown that the position of CVs in the Gaia colour-magnitude diagram is related with the orbital period of the binary (see Figure 1) and, therefore (at least at first order), with the mass-accretion rate. Pala et al.

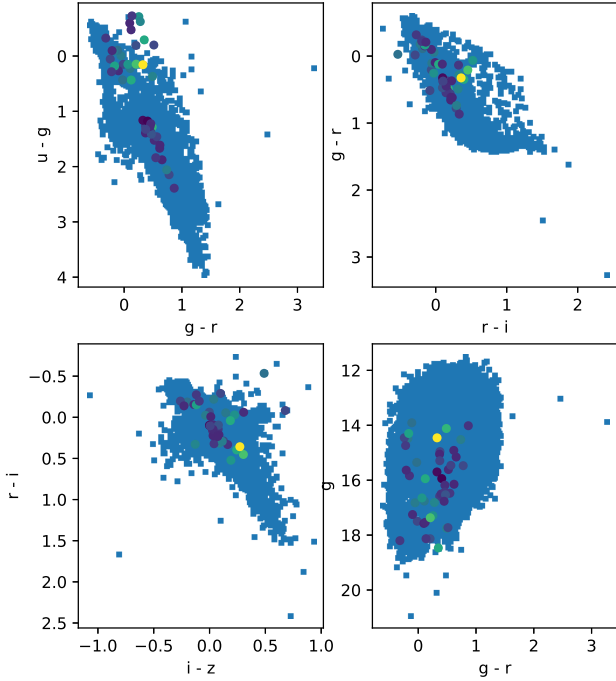


FIGURE 2. Colour-colour and colour-magnitude plots mimicking the ones from Szkody et al. (2002). Top right plot shows $u - g$ vs $g - r$, top left plot shows $g - r$ vs $r - i$, bottom left shows $r - i$ vs $i - z$ and bottom right shows g vs $g - r$. Blue points are stars from J-PLUS while coloured points are CVs with known periods, like in Fig.1. Note that the g magnitude in the bottom right plot is apparent magnitude and not absolute magnitude.

(2020) have also used Gaia DR2 data but in this case they built a volume limited sample of CVs.

There are 7306 objects marked as CVs in Gaia DR3. Of these only 2074 have parallax errors smaller than 20% which allow to determine the distance as the inverse of the parallax. These CVs have been cross matched with the catalogue by Ritter and Kolb (Ritter & Kolb 2003). Fig.1 shows a colour-magnitude diagram of Gaia data with CVs overplotted. Like in Abril et al. (2020), we find a relation between the position in the colour-magnitude diagram and the orbital period.

3. SDSS

The Sloan Digital Sky Survey (SDSS) has been a crucial change for astronomy both for the sudden availability of photometry and spectroscopy covering most of the Northern extragalactic sky both for the new need to work with massive amount of data.

Szkody et al. (2002) (and following papers of the same group) have contributed significantly to the CV field. In particular, they suggested that a series of colours would be useful to identify CVs: $u - g < 0.4$ mag, $g - r < 0.7$ mag, $r - i > 0.4$ mag, and $i - z > 0.4$ mag.

Although these colour cuts have been largely successful (see Gänsicke et al. 2009 for an example), the identification of new CVs still needs to be done via visual inspection of the optical spectrum. This issue can be noticed in Fig.2 where known CVs are plotted over other sources in J-PLUS.

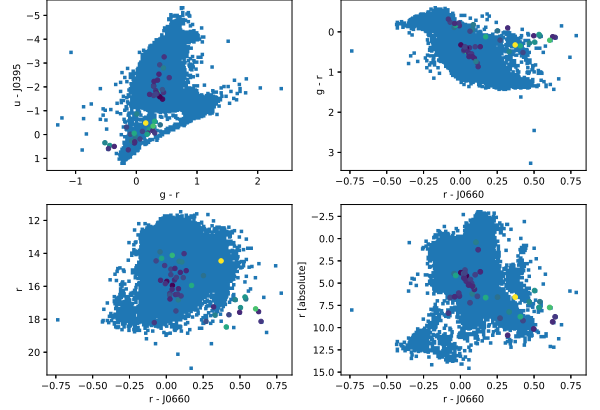


FIGURE 3. Four colour-colour and colour-diagrams showcasing the potential of the narrow bands of J-PLUS. The top left plot shows $u - J0395$ (basically Ca H+K) vs $g - r$, the top right plot shows $g - r$ vs $r - J0660$ (basically H α), the bottom left plot shows r vs $r - J0660$ and the bottom right is the same as the bottom left but r now is absolute (for these objects with parallax measured with an error better than 20% in Gaia DR3).

4. J-PLUS

The Javalambre Photometric Local Universe Survey (J-PLUS, Cenarro et al. 2019) is the main project of T80Cam at JAST80. It is surveying the Northern sky with 12 optical filters: 5 broad bands ($ugriz$) and 7 medium bands (J0378, J0395, J0410, J0430, J0515, J0660, J0861) located on key spectral features of MW stars and nearby galaxies. The J-PLUS DR3 (3.000 deg²) has been made public in December 2022. About 300 objects classified by Gaia DR3 as CVs fall in the footprint of J-PLUS DR3.

The narrow band filters of J-PLUS open an intriguing research space for CV identification. As CVs can be red and/or blue and can have H α emission, the J-PLUS filter system seems ideal for their identification. Yet, Fig.3 shows how even with this filter system alone, the amount of contaminants is non negligible, although smaller than in the case of using SDSS filters alone. It is worth noting the potential given by adding the Gaia parallax, which provides physical insights otherwise inaccessible.

5. J-PAS

The Javalambre Physics of the Accelerating Universe Astrophysical Survey (J-PAS, Benitez et al. 2014) is the main project of JPCam at JST250. It will cover thousands of square degrees with 54 narrow band filters (145Å) at a depth of 22.5 mag (3" aperture, 5 sigma) and a surface brightness limit of 26 mag/arcsec² (3 sigma, over 100 arcsec²) per filter. This will provide a low-resolution ($R \sim 50$) photo-spectrum for each observed pixel, leading to superb photometric redshifts (photo-zs) with 0.3% accuracy (Hernán-Caballero et al. 2021) for several million galaxies. We have already made public the miniJPAS survey (Bonoli et al. 2021). This J-PAS precursor comprises about 4.000 MW stars, 12.000 galaxies and 150 QSOs with $r < 22.5$ mag over 1 deg². An extra 0.25 deg² located at the JWST North Ecliptic Pole Time-domain Field, called J-NEP, is available for this CP and will be public in the future.

Only one known CV is in the area covered by miniJPAS or J-NEP. With this lack of data, we turned to synthetic photometry of known sources in order to test the ability of J-PAS to identify

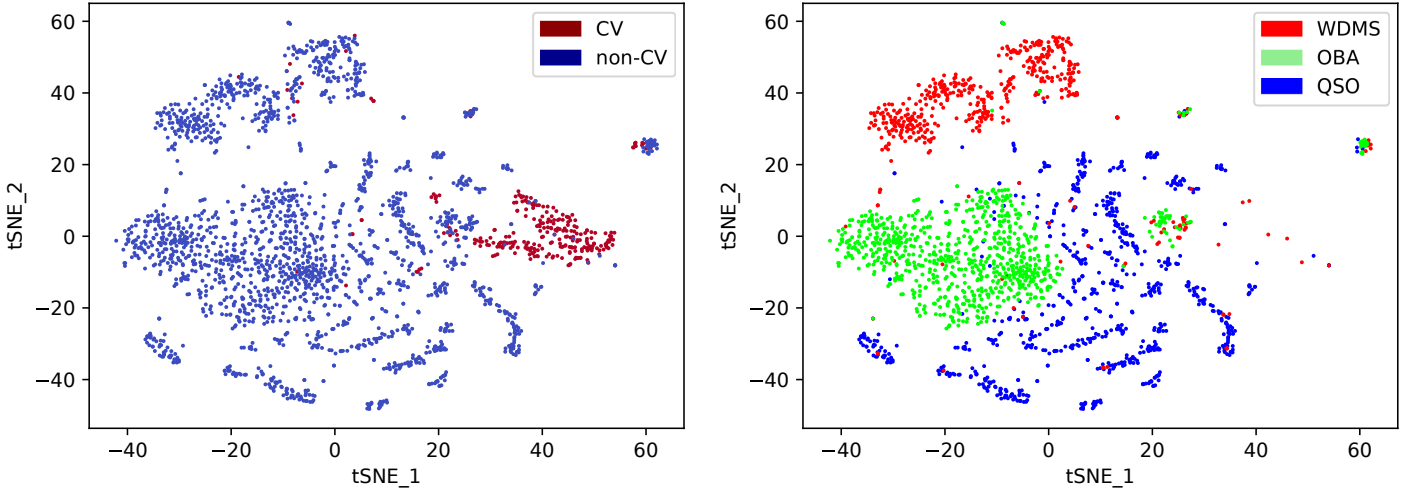


FIGURE 4. Dimensional reduction of JPAS synthetic photometry. On the right, one can see how CVs separate comparatively well from the rest of the contaminants. On the right, one can see how the contaminants fall into specific regions.

CVs. We downloaded spectra of CVs, quasars (at any available redshift) and a sample of potential stellar contaminant (single white dwarfs, hot stars, binary systems made of a white dwarf and a main sequence star). This spectra in this sample were convolved with the J-PAS filters. A visual analysis of all the possible colour-colour plots would have been a prohibitive task. A dimensional reduction carried out with the tSNE algorithm is shown in Fig.4. This gave us confidence and therefore several machine learning algorithms were run to test the possibility to identify CVs. As a result, a relatively simple neural network provided a purity and completeness both higher than 80%.

6. Conclusion

As it can be naively assumed, a larger amount of filters improves our ability to separate CVs from their contaminants. The broad band filters of SDSS have provided a great service to CV science but the parallaxes from Gaia (first through DR2 and now through DR3) are the real game changer. So far, J-PLUS has shown some limitations in its ability to identify CVs, yet the combination of the Gaia parallaxes and the J-PLUS 12 filters photometry is showing some potential. Our simulation show that J-PAS will be able to identify CVs without the need of external data sets, hence pushing the limit which, currently, is dictated by the quality of the Gaia parallaxes.

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Appendix A: ADQL Queries

Although the cross matches between tables were made with TOPCAT, the queries to the databases of Gaia and J-PLUS were performed via the Table Access Protocol offered by both projects. The ADQL query which was used to prepare the back-ground points of Figure 2 is:

```
select top 1000000 bp_rp , phot_g_mean_mag
- 5.0 * LOG10(distance_gspphot) + 5.0 AS
phot_g_mean_mag_absolute from gaiadr3.gaia_source
where phot_g_mean_flux_over_error > 10 AND ruwe <
```

```
1.4 AND parallax_over_error > 10.0 AND random_index
BETWEEN 0 AND 10000000
```

The Gaia CVs were selected through the following query:

```
select vari.* , gdr3.*
from gaiadr3.vari_classifier_result vari
join gaiadr3.gaia_source gdr3 on gdr3.source_id =
vari.source_id
where best_class_name = 'CV'
```

Finally, the query to the J-PLUS archive is:

```
select cb.tile_id,cb.number,cb.alpha_j2000,cb.delta_j2000,
dp.MAG_APER_COR_3_0,dp.MAG_ERR_APER_COR_3_0,
gaia.parallax, gaia.parallax_error from
MagABDualPointSources dp join MagABDualObj
cb on cb.tile_id = dp.tile_id and cb.number
= dp.number join xmatch_gaia_dr3 gaia on
gaia.tile_id = dp.tile_id and gaia.number =
dp.number where array_max_float(cb.mag_err_auto)
< 0.1 and gaia.parallax_over_error >
5 and (array_max_int(cb.flags) < 3 OR
cb.flags[jplus::rSDSS] BETWEEN 2048 AND 2051)
AND array_min_float(cb.NORM_WMAP_VAL) > 0.8 AND
array_max_int(cb.MASK_FLAGS) < 1
```

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