PROCEEDINGS OF SCIENCE

Cataclysmic Variables in Narrow Band Wide Field Surveys

Alessandro Ederoclite[a,*] **and Antonio Ortega**[b]

[a] *Centro de Estudios de Física del Cosmos de Aragón, Plaza San Juan 1, Planta 2, Teruel, Spain*

[b] *Starion for European Space Agency (ESA), European Space Astronomy Centre (ESAC), Villanueva de la Cañada, Madrid, Spain*

E-mail: aedeorcl@cefca.es

The search for cataclysmic variables (CVs) has been historically characterised by serendipity. Even large photometric or spectroscopic surveys could not count on specific methods to reliably identify CVs from other astrophysical sources.

In this contribution, we explore three large photometric surveys carried out at the *Observatorio Astrofísico de Javalambre* (OAJ). The use of narrow-band filters and, in one case, the use of repeated observations, provide these projects with unprecedented potential for CV-related studies.

The Golden Age of Cataclysmic Variables and Related Objects - VI (GOLDEN2023)
4-9 September 2023
Palermo - (Mondello), Italy

[*] Speaker

1. Introduction

CVs have historically been identified through the serendipitous detection of their increase in brightness. Alternatively, their colours have been used to separate them from other astrophysical objects. For a review, see [1].

The work by [2] is remarkable because it provided a series of colours in the SDSS filter system which could be used to identify CVs. Yet, the detected candidates were highly affected by contamination by other sources like quasars and they had to be confirmed by visual examination of the spectra. Later, [3] showed that the use of the Hα filter, combined with blue optical filters, can be used to successfully identify CVs.

The launch of Gaia has been a major revolution for stellar astrophysics. In the event of the second data release [4], the database contained positions, proper motions, parallaxes and magnitudes (G, RP and BP) for 1.8 billion objects. [5] have shown that CVs can not only be identified on the Gaia colour magnitude diagram but their position can also give insights on the type of CV.

2. The Observatorio Astrofísico de Javalambre

The *Observatorio Astrofísico de Javalambre* (OAJ) is an observing facility dedicated to wide field photometric surveys. The OAJ is located in the *Pico del Buitre*, in the *Sierra de Javalambre*, in the province of Teruel, in mainland Spain. The OAJ is equipped with two telescopes, the Javalambre Survey Telescope (JST250) and the Javalambre Auxiliary Survey Telescope (JAST80).

The JST250 is a 2.5m telescope with a field of view of about 3 square degrees which can be imaged with JPCam, a panoramic camera built to carry on the Javalambre Physics of the accelerating universe Astrophysical Survey (J-PAS) [6], a photometric survey of about 8500 square degrees of the Northern extragalactic sky in 54 narrow band filters, 2 intermediate band filters and one broad band filter, iSDSS, which is also used as detection band. The observations of J-PAS have started in autumn 2023.

The JAST80 is an 80cm telescope with a 2 square degrees field of view which was originally built to provide a photometric calibration for JST250 but ended up hosting the first survey carried out at the OAJ, the Javalambre Photometry of the Local Universe Survey (J-PLUS). [7]. This survey is expected to cover the same region observed by J-PAS but in 12 filters only, the five filters of the SDSS system and seven narrow band filters located at specific stellar features.

Neither J-PAS nor J-PLUS have time-domain capabilities and both require photometric conditions. In order to maximise the efficiency of JAST80, the Javalambre Variability Survey (J-VAR) was conceived. This observes 11 times all the fields which have been already observed and calibrated by J-PLUS. Instead of using the 12 filters of J-PLUS, J-VAR only uses 7 filters.

3. CVs in J-PLUS

In December 2022, J-PLUS DR3 was made public. The database has 47 million objects covering about 3200 square degrees. There are 4.6 million objects with detection in all the J-PLUS bands. In order to be able to compare with the work by Scaringi [3] , we cross match with the WISE catalogue and then with the Gaia DR3, using the prescription of RUWE $<$ 1.4 and the error on the parallax to be less than 20%, which allow to consider the distance as the inverse of the Gaia parallax. We refer to this as the "Gold Sample" and it sums up 2.5 million sources. The photometric quality of this sample are shown in Figure 1.

Only 52000 objects of the Gold Sample have an entry in Simbad. Out of these, 76 are CVs (68 with measured orbital period). The positions of these objects are shown in Figure 2 which recreates the colour magnitude and colour colour plots previously used by [2] and [3]. It is clear that, although located in comparatively small regions of the diagrams, CVs are found in very contaminated regions. The right panel of the same figure shows the position of CVs in the Gaia colour-magnitude diagram, showing that they occupy a relatively less contaminated region. It is important to keep in mind that the use of the Gaia parallax as distance is not always possible and one should approach this database with a grain of salt, following the prescription provided by the Gaia team, in particular [8]. The spectral energy distributions of the 10 brightest CVs detected in J-PLUS are shown in Figure 3. This can be easily compared with SEDs from other types of objects and make the separation between CVs and other objects (e.g. hot stars or quasars) significantly more reliable than in previous surveys.

4. CVs in J-VAR

J-VAR has been observing for almost seven years and the first data release should be made public in the first half of 2024. The first data release of J-VAR contains slightly over one million objects and only 14 CVs. In the 100 square degrees observed for the first data release of J-VAR, there are 14 CVs. An example is shown in Figure 4. It is clear how the J0660 filter picks up the Hα in emission. In the lower plot, the SEDs are connected to show how the colours changed from night to night.

5. CVs in J-PAS

So far, the only region of sky observed with the 56 narrow band filters of J-PAS is the AEGIS region for the miniJPAS project [9]. This is a 1 square degree region, known for its value for extragalactic studies. [10] have explored the 2895 stars available in this field.

In order to prepare ourselves for the large amount of data that J-PAS will provide, we have studied the use of machine learning algorithms to identify CVs in this survey.

We have downloaded the Sloan spectra of objects in the catalogue by Ritter and Kolb [11]. This provided us with 318 objects. In order to compare with spectra of expected contaminants while at the same time having samples which were not too unbalanced, we downloaded 1000 spectra of quasars (with no previous selection on redshift), 1000 spectra of hot stars and the spectra from the catalogue of white dwarf and main sequence binaries by Rebassa Mansergas [12],[13]. The spectra have been convolved with the filter response curves. It is important to note that the bluest and the reddest J-PAS bands are not covered by the SDSS spectra and we ended up with 52 points in the SED instead of 56.

In order to visualise these high dimensional data, we used the "t-distributed stochastic neighbor embedding" (t-SNE). This is a dimensionality reduction algorithm which is largely used for visualisation. As it can be seen in the upper left panel of Figure5, CVs and non-CVs are difficult to

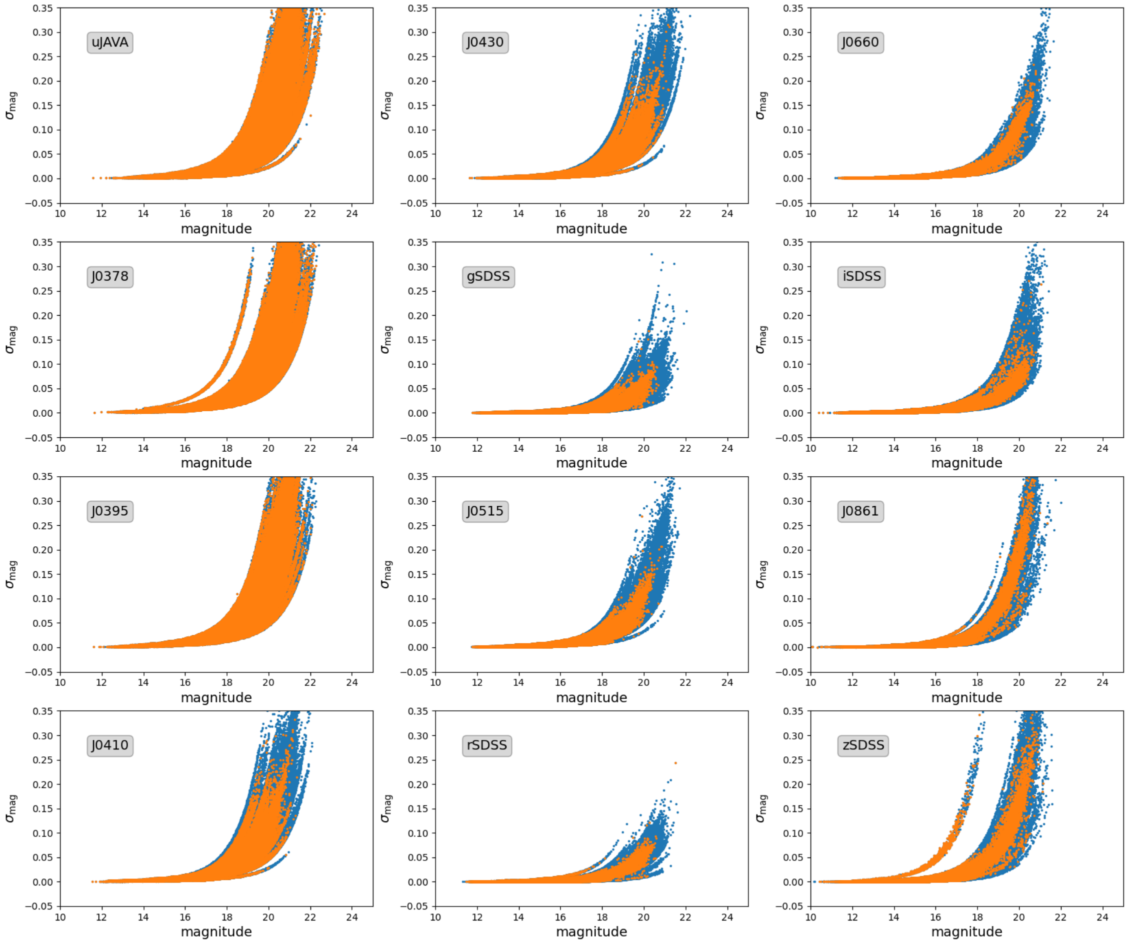

Figure 1: Photometric errors for each band of J-PLUS as function of the magnitude; in blue are the data from the 4.6 million objects and in gold are the points from the Gold Sample

separate. Although a decision tree using only two features (upper right panel) makes a reasonable job, it is clear that the use of 52 features (lower left panel) is significantly better. Although not easy to see by eye, the best performance was found for a multi-layer perceptron (a specific type of neural network) using all the 52 filters.

6. Conclusions

In this contribution, we have shown the work related with CVs in three surveys carried out at OAJ:

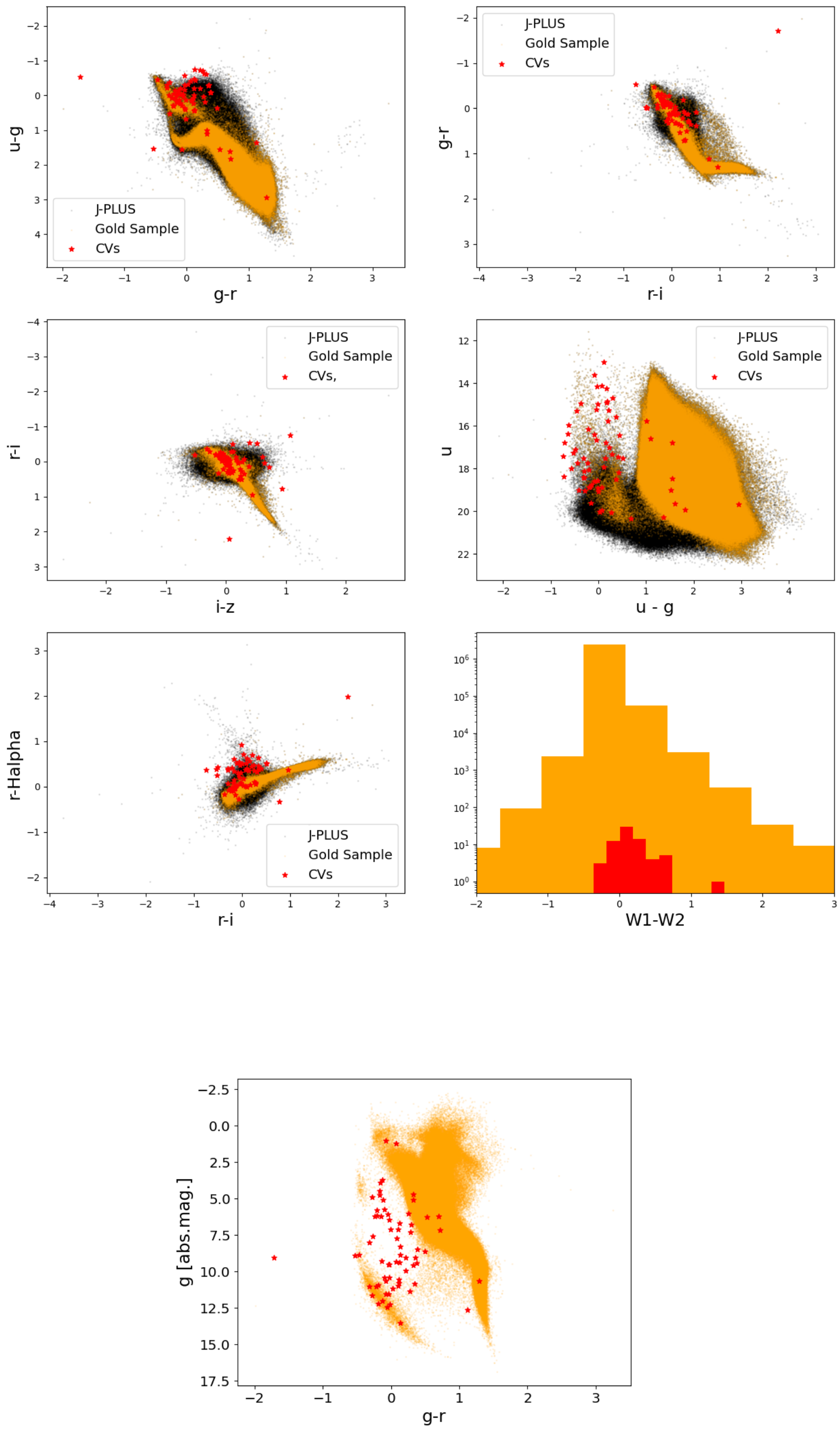

Figure 2: Colour magnitude diagrams and colour colour diagrams mimicking the works by [2] and [3]. The lower panel shows the location of CVs in the Gaia colour-magnitude diagram.

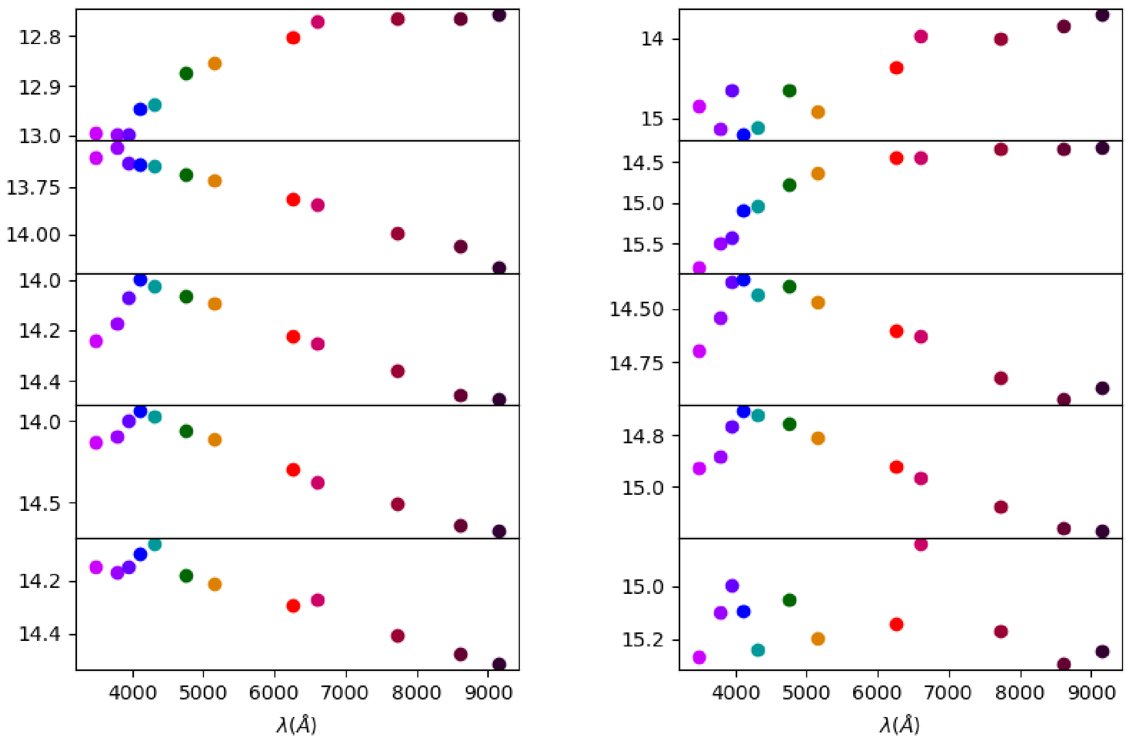

Figure 3: SEDs of the 10 brightest CVs in J-PLUS DR3.

- J-PLUS has already observed 3200 square degrees and contains 76 known CVs which can be used as "templates" to identify new ones. We have also shown the extraordinary quality of the J-PLUS SEDs.
- J-VAR is still in its infancy and it only contains 14 known objects. Yet, the combination of the narrow band filters and the time sampling opens a new discovery window in the OAJ portfolio.
- Finally, J-PAS has just started and the data are currently being assessed. In order to prepare, we have performed synthetic photometry on CVs and a sample of expected contaminants.

In the future, we expect that the use of narrow band photometry will be crucial in this field, especially in combination with time-resolved observations.

Acknowledgments

AE acknowledges the financial support from the Spanish Ministry of Science and Innovation and the European Union - NextGenerationEU through the Recovery and Resilience Facility project ICTS-MRR-2021-03-CEFCA . This work has been supported by the Spanish Ministry of Science and Innovation through project PID2021-124918NB-C42.

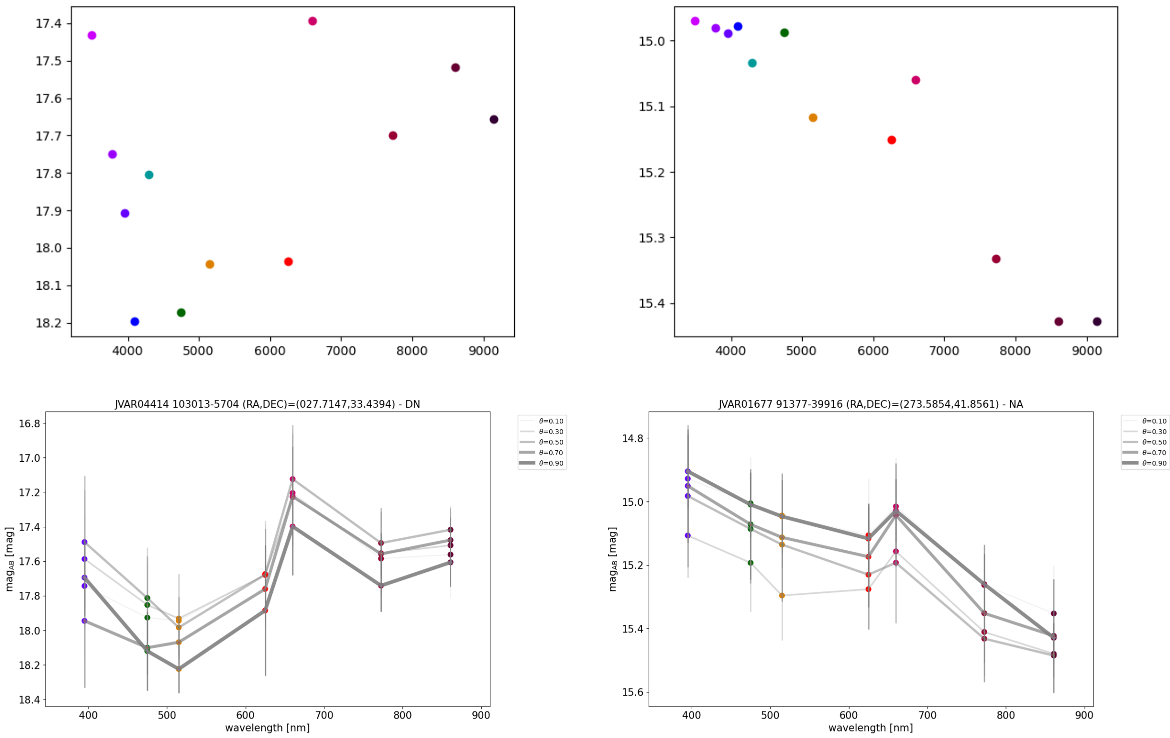

Figure 4: Two of the 14 CVs detected in J-VAR; in the upper row are the SEDs observed by J-PLUS; in the lowest row are the SEDs observed by J-VAR grouped per night.

References

[1] B.T. Gänsicke, *Observational population studies of cataclysmic variables - The golden era of surveys*, in *The Astrophysics of Cataclysmic Variables and Related Objects*, J.M. Hameury and J.P. Lasota, eds., vol. 330 of *Astronomical Society of the Pacific Conference Series*, p. 3, Aug., 2005, DOI [astro-ph/0410412].

[2] P. Szkody, S.F. Anderson, M. Agüeros, R. Covarrubias, M. Bentz, S. Hawley et al., *Cataclysmic Variables from The Sloan Digital Sky Survey. I. The First Results*, *AJ* **123** (2002) 430 [astro-ph/0110291].

[3] S. Scaringi, P.J. Groot, K. Verbeek, S. Greiss, C. Knigge and E. Körding, *Spectroscopic identifications of blue-Hα-excess sources in the Kepler field of view*, *MNRAS* **428** (2013) 2207 [1210.3038].

[4] Gaia Collaboration, A.G.A. Brown, A. Vallenari, T. Prusti, J.H.J. de Bruijne, C. Babusiaux et al., *Gaia Data Release 2. Summary of the contents and survey properties*, *A&A* **616** (2018) A1 [1804.09365].

[5] A.J. Cenarro, M. Moles, D. Cristóbal-Hornillos, A. Marín-Franch, A. Ederoclite, J. Varela

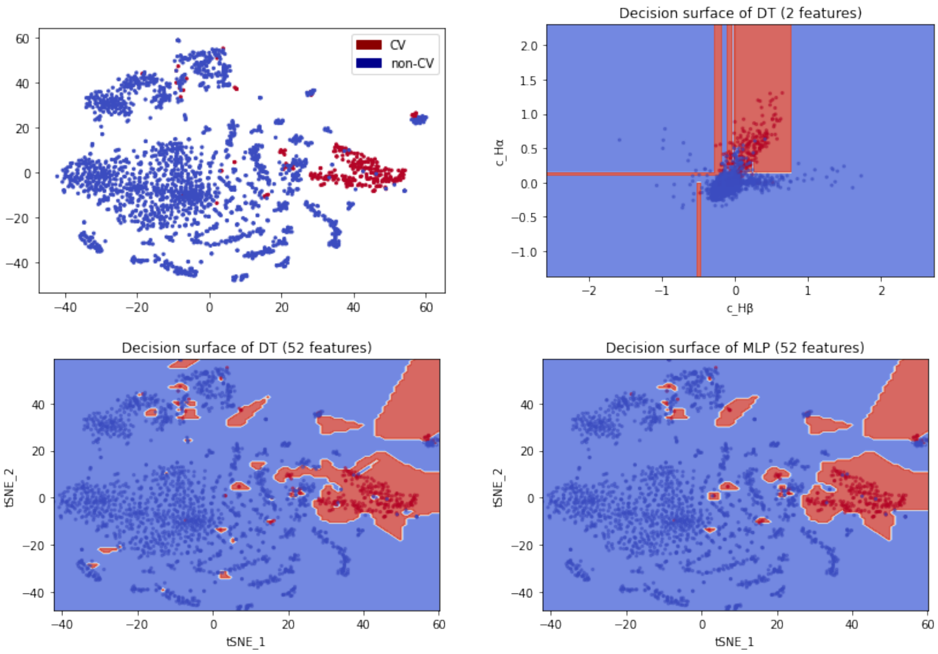

Figure 5: *Upper left*: t-SNE visualisation of the location of the CVs and the non CVs using all 52 filters; *Upper right*: visualisation of the use of a decision tree using only two features; *Lower left*: t-SNE visualisation of the classification obtained using a decision tree on the 52 filters available; *Lower right*: t-SNE visualisation of the classification that was achieved with a multi-layer perceptron applied to all the features available.

et al., *J-PLUS: The Javalambre Photometric Local Universe Survey*, *A&A* **622** (2019) A176 [1804.02667].

[6] N. Benitez, R. Dupke, M. Moles, L. Sodre, J. Cenarro, A. Marin-Franch et al., *J-PAS: The Javalambre-Physics of the Accelerated Universe Astrophysical Survey*, *arXiv e-prints* (2014) arXiv:1403.5237 [1403.5237].

[7] A.J. Cenarro, M. Moles, D. Cristóbal-Hornillos, A. Marín-Franch, A. Ederoclite, J. Varela et al., *J-PLUS: The Javalambre Photometric Local Universe Survey*, *A&A* **622** (2019) A176 [1804.02667].

[8] X. Luri, A.G.A. Brown, L.M. Sarro, F. Arenou, C.A.L. Bailer-Jones, A. Castro-Ginard et al., *Gaia Data Release 2. Using Gaia parallaxes*, *A&A* **616** (2018) A9 [1804.09376].

[9] S. Bonoli, A. Marín-Franch, J. Varela, H. Vázquez Ramió, L.R. Abramo, A.J. Cenarro et al., *The miniJPAS survey: A preview of the Universe in 56 colors*, *A&A* **653** (2021) A31 [2007.01910].

[10] H.B. Yuan, L. Yang, P. Cruz, F. Jiménez-Esteban, S. Daflon, V.M. Placco et al., *The miniJPAS survey: stellar atmospheric parameters from 56 optical filters*, *MNRAS* **518** (2023) 2018 [2210.17133].

[11] H. Ritter and U. Kolb, *Catalogue of cataclysmic binaries, low-mass X-ray binaries and related objects (Seventh edition)*, *A&A* **404** (2003) 301 [astro-ph/0301444].

[12] A. Rebassa-Mansergas, C. Agurto-Gangas, M.R. Schreiber, B.T. Gänsicke and D. Koester, *White dwarf main-sequence binaries from SDSS DR 8: unveiling the cool white dwarf population*, *MNRAS* **433** (2013) 3398 [1306.0952].

[13] A. Rebassa-Mansergas, J.J. Ren, S.G. Parsons, B.T. Gänsicke, M.R. Schreiber, E. García-Berro et al., *The SDSS spectroscopic catalogue of white dwarf-main-sequence binaries: new identifications from DR 9-12*, *MNRAS* **458** (2016) 3808 [1603.01017].