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Spectral evolution and calcium white dwarfs in J-PLUS.

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Abstract

We complement the *Gaia*-based catalogue of white dwarfs with the optical photometry from the Javalambre Photometric Local Universe Survey (J-PLUS) DR2, covering 2 176 $\deg^2$ with 12 passbands ($ugriz$ + 7 medium bands). We define a common sample of 5 926 white dwarfs with $r < 19.5$ mag and derive their effective temperature ($T_{\rm eff}$), surface gravity, mass (M), and atmospheric composition (H- *versus* He-dominated). We also estimate the presence of polluting metals with the $J0395$ filter in J-PLUS, sensitive to the calcium H+K absorption. Using this information, we analyse the spectral evolution and the change in the fraction of metal-polluted white dwarfs with effective temperature. Finally, we expand our analysis to the eleven white dwarfs in the miniJPAS area, covered with the 56 medium-band passbands of 14 nm designed for the Javalambre Physics of the Accelerating Universe Astrophysical Survey (J-PAS).

1 Introduction

White dwarfs are the degenerate remnant of stars with masses lower than $8-10\ M_\odot$ and the endpoint of the stellar evolution for more than 97% of stars [16, 10]. This makes them an essential tool to disentangle the star formation history of the Milky Way, the late phases of stellar evolution and to understand the physics of condensed matter.

Decades of spectroscopic analysis revealed a diversity of white dwarf atmospheric compositions [30, 36], with sources presenting hydrogen lines (DA type), HeII lines (DO), HeI lines (DB), metal lines (DZ), and featureless spectra (DC) among others. White dwarfs can be selected from the general stellar population using their location in the Hertzsprung-Russell (H-R) diagram, typically ten magnitudes fainter than main sequence stars of the same effective temperature. Thanks to *Gaia* parallaxes and photometry, the efficient use of the H-R diagram to define the white dwarf population became feasible, with more than 350 000 candidates discovered so far [14]. It also permits the definition of high-confidence volume-limited white dwarf samples [15, 17, 18, 27, 12].

We complimented the most recent *Gaia*-based catalogue of white dwarfs [14] with the photometric information from the Javalambre Photometric Local Universe Survey (J-PLUS; [6]) second data release (DR2) to study the spectral evolution of white dwarfs and the presence of polluting metals. In addition, we explore the capabilities of the future Javalambre Physics of the Accelerating Universe Astrophysical Survey (J-PAS; [2]) with the miniJPAS [4] dataset.

2 J-PLUS and miniJPAS

Both J-PLUS and miniJPAS were carried out at the Observatorio Astrofísico de Javalambre (OAJ, [5]), located at the Pico del Buitre in the Sierra de Javalambre, Teruel (Spain). The data for J-PLUS were acquired using the 83 cm Javalambre Auxiliary Survey Telescope (JAST80) and T80Cam, a panoramic camera of 9.2k × 9.2k pixels that provides a 2 $\deg^2$ field of view (FoV) with a pixel scale of 0.55 arcsec pix^{-1} [25]. The data for miniJPAS were acquired with the 2.5m Javalambre Survey Telescope (JST250) and the JPAS-Pathfinder (JPF) camera, which was the first scientific instrument installed at the JST250 before the arrival of the JPCam [26]. The JPF is a single 9200×9200 CCD located at the centre of the JST250 FoV with a scale of 0.23 arcsec pixel^{-1}, providing an effective FoV of 0.27 $\deg^2$.

The J-PLUS photometric system is composed of five SDSS-like ($ugriz$) and seven medium band filters located in key stellar features, such as the 4 000 Å break ($J0378$, $J0395$, $J0410$, and $J0430$), the Mg b triplet ($J0515$), Hα at rest-frame ($J0660$), or the calcium triplet ($J0861$). The J-PAS filter system [24] comprises 54 filters with a full width at half maximum (FWHM) of 145 Å that are spaced every $\approx$ 100 Å from 3 800 Å to 9 100 Å. They are complemented with two broader filters at the blue and red end of the optical range, with an effective wavelength of 3 479 Å (u, FWHM = 509 Å) and 9 316 Å ($J1007$, FWHM = 635 Å), respectively.

The J-PLUS DR2 comprises 1 088 pointings (2 176 $\deg^2$) observed, reduced, and calibrated in all survey bands [21]. The limiting magnitudes (5σ, 3 arcsec aperture) of the DR2 are $\sim$ 22 mag in g and r passbands and $\sim$ 21 mag in the other ten bands. The median point spread function (PSF) FWHM in the DR2 r-band images is 1.1 arcsec. Objects near the borders of the images, close to bright stars, or affected by optical artefacts were masked from the initial 2 176 $\deg^2$, providing a high-quality area of 1 941 $\deg^2$. The DR2 is publicly available on the J-PLUS website.

The miniJPAS observations comprise four JPF pointings in the Extended Groth Strip area along a strip aligned at 45 deg with respect to North at (RA, Dec) = (215, +53) deg, amounting to a total area of ~ 1 deg^2 [4]. The depth achieved is fainter than 22 mag for filters bluewards of 7 500 Å and ~ 22 mag for longer wavelengths. The images and catalogues are publicly available on the J-PAS website.

3 Results

We define a common sample of 5 926 white dwarfs with $r < 19.5$ mag and derive their effective temperature ($T_{\rm eff}$), surface gravity, parallax, mass (M), and atmospheric composition (H- *versus* He-dominated) by comparison with theoretical models for pure-H atmospheres ([32, 33]; H-dominated) and mixed atmospheres with H/He $= 10^{-5}$ ([7, 8]; He-dominated). The mass-radius relation in [11] for thick (H-atmospheres) and thin (He-atmospheres) hydrogen layers was assumed in the modelling. The obtained likelihood is weighted with the prior information from the parallax observed in *Gaia* DR3. Moreover, a self-consistent prior in the fraction of white dwarfs with He-dominated atmospheres ($f_{\rm He}$) was derived with a hierarchical Bayesian model. The technical details of the procedure are presented in [22]. The derived atmospherical parameters are publicly available in the J-PLUS database[1] and ViZieR.

As a second layer in the analysis, the equivalent width in the filter $J0395$ was used as a proxy for the presence of polluting metals in the white dwarfs' atmosphere via the CaII H+K absorption. The equivalent width was estimated by comparing the expected flux in the $J0395$ filter from the fitting to the other eleven J-PLUS passbands with the observed flux.

We find that

- The fraction of white dwarfs with He-dominated atmospheres ($f_{\rm He}$) has a minimum of $8 \pm 2\%$ at $T_{\rm eff} > 20\,000$ K. Then, $f_{\rm He}$ increases by $21 \pm 3\%$ between $T_{\rm eff} \sim 20\,000$ K and $T_{\rm eff} \sim 5\,000$ K [22]. This is in good agreement with previous results [31, 13, 28, 3, 1, 27, 9].

- The mass distribution at $d < 100$ pc for H-dominated white dwarfs agrees with previous work, presenting a dominant $M = 0.59\,M_\odot$ peak and an excess at $M \sim 0.8\,M_\odot$. This high-mass excess has been reported in several studies [19, 20, 29, 34, 17, 18, 35]. Interestingly, the high-mass excess is absent in the He-dominated distribution, which presents a single peak [22].

- The fraction of white dwarfs with calcium H+K absorption increases from nearly zero at $T_{\rm eff} \sim 14\,000$ K to 15% at $T_{\rm eff} \sim 6\,000$ K. This trend reflects the dependence of the calcium absorption intensity on both the temperature and the Ca/He abundance.

- We defined a sample of 39 white dwarfs with a high probability ($> 99\%$) of having polluting metals. Of them, 20 sources are already classified as DZs in the literature, and we confirmed 6 more as DZs with new OSIRIS/GTC spectroscopy.

[1] Table jplus.WhiteDwarf

The medium bands from J-PLUS complement the *Gaia* data to derive atmospheric compositions and spot the presence of polluting metals. This analysis will be improved thanks to J-PAS, which with 56 medium bands of 14 nm spaced by 10 nm to cover the optical range will provide low-resolution ($R \sim 50$) data down to $r = 21.5$ mag.

We used the miniJPAS data as a pathfinder, and analysed the eleven confirmed white dwarfs in the field [23]. We find that the effective temperature determination has a typical relative error of 2%, whereas the estimation of a precise surface gravity demands parallax information from *Gaia*. Regarding the atmospheric composition, the J-PAS filter system is able to correctly classify H- and He-dominated atmosphere white dwarfs, at least in the temperature range covered by the miniJPAS white dwarf sample, $7\,000 < T_{\rm eff} < 22\,000$ K. We also show that the presence of polluting metals can be revealed by the calcium, as traced by the $J0390$ and $J0400$ passbands. Furthermore, the miniJPAS low-resolution information is able to disentangle between white dwarfs with $T_{\rm eff} > 7\,000$ K and extragalactic QSOs with similar broad-band colours.

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