Astrometric and photometric verification of faint blue white dwarfs in the Gaia catalogue of nearby stars

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ABSTRACT

The Gaia catalogue of nearby stars (GCNS) divided all objects with parallaxes $>10\text{ mas}$ into GCNS-selected and GCNS-rejected 100 pc samples. Below the white dwarf (WD) sequence in the complete GCNS color-magnitude diagram (CMD), at $G_{abs} > 14.7 + 4.7(G - RP)$, there appear 60 GCNS-selected faint blue white dwarfs (FBWDs). However this CMD region is also populated by 411 GCNS-rejected objects, mainly from crowded regions towards the Galactic centre and the Magellanic Clouds. The WD catalog of Gentile Fusillo et al. (2021) lists only 47 GCNS-selected but also 8 GCNS-rejected objects. I confirm 59 of the GCNS-selected but none of the GCNS-rejected objects as FBWDs from visual inspection and a proper motion check using additional optical sky surveys. Hence FBWDs form an additional branch in the CMD. Compared to the full GCNS-selected 100 pc sample, FBWDs have relatively high proper motions and tangential velocities. They represent interesting targets for studies of ultracool or infrared-faint, and possibly also ultramassive WDs.

Keywords: Parallaxes – Proper motions – white dwarfs – Hertzsprung-Russell and C-M diagrams – solar neighborhood

1. FAINT BLUE WHITE DWARFS IN THE GCNS COLOR-MAGNITUDE DIAGRAM

Gaia color-magnitude diagrams (CMDs) reveal small numbers of faint blue white dwarfs (FBWDs) with absolute Gaia magnitudes of $G_{abs} \gtrsim 15\text{ mag}$ and a wide range of blue Gaia colors. These FBWDs may constitute of "ultracool" (McCleery et al. 2020) or "infrared-faint" (Kilic et al. 2020), but possibly also "ultramassive" (Kilic et al. 2021) WDs. The Gaia catalogue of nearby stars (GCNS; Gaia Collaboration et al. 2021) is based on the Gaia Early Data Release 3 (EDR3; Gaia Collaboration et al.)
Based on many Gaia astrometric parameters and quality flags, about 500000 EDR3 objects with measured magnitudes $Gmag$ and colors $G - RP$ and parallaxes $Plx > 10$ mas were divided into a GCNS-selected 100 pc sample of $\approx$296000 stars (59%) and a GCNS-rejected sample of $\approx$204000 (41%) objects. Except for a few objects with extremely red $G - RP$ colors, all GCNS-selected stars are shown in Fig. 1(a). In this CMD the main sequence is well separated from the white dwarf (WD) sequence, which is mainly located within the marked color-magnitude box defined by Hollands et al. (2018) for all nearby WDs within 20 pc measured in the previous Gaia DR2. However, 60 FBWDs appear below this box, with absolute magnitudes

$$Gabs > 14.7 + 4.7(G - RP).$$

(1)

The GCNS-rejected sample is dominated by very faint objects towards the Galactic centre (GC) and the Magellanic clouds (MCs), where the Gaia photometry, in particular in the $RP$ and $BP$ bands, and astrometry is strongly affected by image crowding. Therefore, the tails of their $G - RP$ color distribution extend even outside the blue and red limits shown in Fig. 1(b). Interestingly, there is an overlap of the blue tail of GCNS-rejected objects (411 objects following Eq. 1) with the above mentioned CMD region of FBWDs that may throw discredit on the 60 GCNS-selected stars. On the other hand, only 55 WDs in the EDR3-based catalog of Gentile Fusillo et al. (2021) are found with Eq. 1, and 8 of them are members of the GCNS-rejected sample (Fig. 1(c)).

2. ASTROMETRIC VERIFICATION OF FBWD CANDIDATES BY PROPER MOTION CHECK

To investigate how much the apparent branch of FBWDs may be caused by Gaia measuring errors, I inspected their optical finder charts (including own measurements in corresponding FITS images) and catalogs from different sources. The idea was to not only estimate the influence of crowding or close companions but confirm EDR3 proper motions above a chosen limit of 15 mas/yr by combining the available Gaia DR1-DR3 (epochs 2015-2016) positions with additional positional data. The presence of a confirmed proper motion was considered as supporting the EDR3 parallax, and consequently the absolute magnitude of a FBWD candidate. However, I took also into account the occurrence of other EDR3 sources at small ($\lesssim 2$ arcsec) separations and EDR3 common proper motion (CPM) objects within 3 arcmin and their available parallaxes. External data were taken from the APM (Irwin et al. 1994) and SuperCOSMOS (SSS; Hambly et al. 2001) measurements of photographic Schmidt plates, the Sloan Digital Sky Survey (SDSS; Abazajian et al. 2009) and Pan-STARRS release 1 (PS1; Chambers & et al. 2017). A proper motion comparison was also made with the extended Gaia-PS1-SDSS catalog (GPS1+; Tian et al. 2020). In addition, I used the DESI Legacy Imaging Surveys (Dey et al. 2019, hereafter the Legacy Surveys),
but only in exceptional cases near-infrared data from the VISTA Hemisphere Survey (VHS; McMahon et al. 2013).

The EDR3 total proper motions $PM$ and numbers of visibility periods $N_{per}$ (an important astrometric quality parameter, in particular in crowded regions) of 411 GCNS-rejected objects are both systematically smaller than those of 60 GCNS-selected stars (Fig. 1(d)). Compared to the full sample of $\approx 302000$ GCNS-selected stars with $Plx > 10$ mas, where 27% have $PM$ around the peak of the distribution at $50 \pm 20$ mas/yr, only 15% of the 60 stars fall in this interval. Consequently, their tangential velocities are relatively high (median $\approx 50$ km/s, maximum $\approx 160$ km/s).

I confirmed the relatively high proper motions of all 60 GCNS-selected stars, including the brightest (B = Gaia EDR3 4049566372499936640) and faintest (F = Gaia EDR3 1674805012263764352) of them (Figs. 1(c,d)). With $Gabs \approx 17.3$ mag, the latter is nearly as faint as, but much bluer than, the unusual cool WD candidate Gaia EDR3 6584418167391671808 (Apps et al. 2021). Only one of the 60 blue stars (H = Gaia EDR3 1643819327188791040) was previously classified as high-mass WD by Cheng et al. (2019). It has another WD (Gaia EDR3 1643819331484091136) as CPM companion (separation 8.9 arcsec) with similar parallax. The 60 objects are uniformly distributed over the sky, but one (W = Gaia EDR3 411033184616593280) appears in PS1 and Legacy Surveys as a blue foreground object in the GC. It has a redder CPM companion separated by 4 arcsec with a slightly smaller but more precise parallax. Using the latter, the absolute magnitude changes as indicated by an arrow in Fig. 1(c). Of 13 GCNS-selected stars missing in Gentile Fusillo et al. (2021) I confirmed 12 as FBWDs. As seen in Fig. 1(d), half of them have $N_{per} < 12$ (one overlaps here with the unconfirmed object R, see below).

All eight WDs of Gentile Fusillo et al. (2021) in the GCNS-rejected sample have very small $PM$ and $N_{per}$ (Fig. 1(d)) including five objects in the GC and MCs regions and a quasar candidate (Q = Gaia EDR3 6696431605961218176) from Bailer-Jones et al. (2019). Only one (C = Gaia EDR3 5155424067737827968) has a relatively high $PM \approx 25$ mas/yr that I confirmed using SDSS, PS1, and Legacy Surveys data. However, it has a large parallax error of about 3 mas and a CPM companion (separation 46 arcsec) with a much smaller parallax and ten times smaller error indicating a distance of 700 pc. When checking the proper motions of about 70 more GCNS-rejected objects with $PM > 15$ mas/yr, 85% of which were in the crowded GC and MCs regions, I did not find further FBWD candidates.

3. CROWDING AND CLOSE COMPANIONS AFFECTING GAIA COLOR MEASUREMENTS

The error bars shown in Fig. 1(c) are dominated by $RP$ magnitude errors and relative parallax uncertainties. For GCNS-rejected objects (green) they are larger than for GCNS-selected stars (black). Most (53 of 60) GCNS-selected stars were also measured in PS1 or Legacy Surveys (22 in both). All but one of these appear blue
on the corresponding finder charts. Surprisingly, the exception is the object at the blue end of the shown CMD \((R = \text{Gaia EDR3 } 6309477283343732096)\), which in fact appears red in PS1 and VHS and is probably not a WD. It has a close (separation 3 arcsec) brighter CPM companion \((\Delta G \approx 5.8 \text{ mag but } \Delta J \approx 3.0 \text{ mag !})\) with a similar parallax that obviously affected the \(RP\) photometry.

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Figure 1. Color-magnitude diagram of full GCNS-selected (a) and GCNS-rejected (b) 100 pc samples. The zoom in (c) shows only the region of FBWDs (Eq. 1). The green and black error bars represent mean uncertainties of GCNS-rejected (green pluses) and GCNS-selected (black crosses) subsamples, respectively. Their total proper motions ($PM$) and numbers of visibility periods ($N_{per}$) are displayed in the inserted panel (d). Objects labelled in (c) and (d) are discussed in the text.