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White Dwarfs population as seen by *Gaia*

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Abstract

The launch of *Gaia* satellite of ESA is approaching (scheduled in 2013) and the scientific community is preparing for the maximal scientific return. As white dwarfs are very faint (especially in the very cool regime, $T_{\rm eff} \leq 5,000$ K), they are very hard to detect and only the closest ones have been observed until now. *Gaia*, through its 5–6 years survey of the whole sky up to magnitude $20 - 25$ (depending on the colour of the source), will drastically increase the sample of known white dwarfs and provide a lot of new science in this field.
Using synthetic spectral energy distribution libraries and the most recent *Gaia* transmission curves, we derive colours of three different kinds of white dwarfs (pure hydrogen, pure helium and mixed composition with H/He $= 0.1$). With these colours we derive transformations to other common photometric systems (Johnson-Cousins, Sloan Digital Sky Survey and 2MASS). Different relationships have to be considered for different white dwarfs compositions. Pure-He white dwarfs show an unique behaviour valid at different temperatures, but pure-H white dwarfs need to be analysed in two different temperature regimes, as their behaviour changes around $T_{\rm eff} = 5,000$ K.
We also compare the estimations of number of white dwarfs as predicted by the *Gaia* Universe Model Snapshot and by a different model of white dwarfs population (Napiwotzky's simulations). Among all white dwarfs observed, the most interesting ones will be those in the very cool regime. According to our simulations, *Gaia* will be able to observe thousands of them for the first time.

1 Introduction

White dwarfs (WDs hereafter) are the final remnants of low- and intermediate-mass stars. About 95% of main-sequence stars will end their evolutionary pathways as WDs and, hence, the study of the WD population provides details about the late stages of the life of the vast majority of stars. Their evolution can be described as a simple cooling process, which is reasonably well understood [9, 26], with a duration of the order of the age of the Galaxy. So, WDs are very useful objects to understand the structure and evolution of the Galaxy, as they have imprinted memory of its history [12, 20].

Due to the fact that most WDs are intrinsically faint, it is difficult to detect them and a complete sample is currently only available at very close distances ([11] provide a complete sample up to 13 pc), although the number of known WDs has considerably increased thanks to several surveys[1]. However, the number of very cool WDs and members of the halo population is still very low. The *Gaia* mission will be extremely helpful to detect WDs close to the cut-off in luminosity[2] and even fainter.

Gaia is the successor of the ESA Hipparcos astrometric mission [3] and increases its capabilities drastically, both in precision and in number of observed sources. *Gaia* will determine positions, parallaxes and proper motions for a relevant fraction of the stars (10^9 stars, $\sim 1\%$ of the Galaxy) with unprecedented accuracy (see [28] for more details). Besides this, *Gaia* will acquire spectrophotometry and radial velocities.

[13] presented the broad *Gaia* passbands and colour-colour relationships for normal stars, allowing the prediction of *Gaia* magnitudes (G, $G_{\rm BP}$ and $G_{\rm BP}$)and uncertainties from Johnson-Cousins [2] and/or Sloan [10] colours. The aim of this paper is to provide a similar tool for characterizing *Gaia* observations of WDs. This work is aimed to be published soon [4].

2 Model atmospheres

To represent the SED of WDs, we use grids of pure hydrogen (pure-H), pure helium (pure-He) and also mixed composition (H/He = 0.1) models, with $7.0 < \log g < 9.0$. These modelled SED have been computed from recent photometric and spectroscopic analyses of WDs [15, 17, 27, 1].

The pure-H models are drawn from [27] and cover the range of $T_{\rm eff} = 1,500-140,000$ K. These models were recently improved in the cool temperature regime with updated collision-induced absorption (CIA hereafter) opacities. In the present paper we also account for the opacity due to the red wing of Lyman-α computed by [19]. Models with this opacity source have been successful in reproducing SEDs of many cool WDs [6, 15, 16, 18, 19]. These improved models are accessible from Pierre Bergeron's webpage[3].

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[1] Sloan Digital Sky Survey (SDSS) catalogue from [7] added 9316 WDs to the 2249 WDs included in [22]. The next data release is said to almost double that amount [14]

[2] Shortfall in the number of WDs below $\log(L/L_\odot) = -4.5$ due to the finite age of the Galaxy.

[3] http://www.astro.umontreal.ca/~bergeron/CoolingModels/

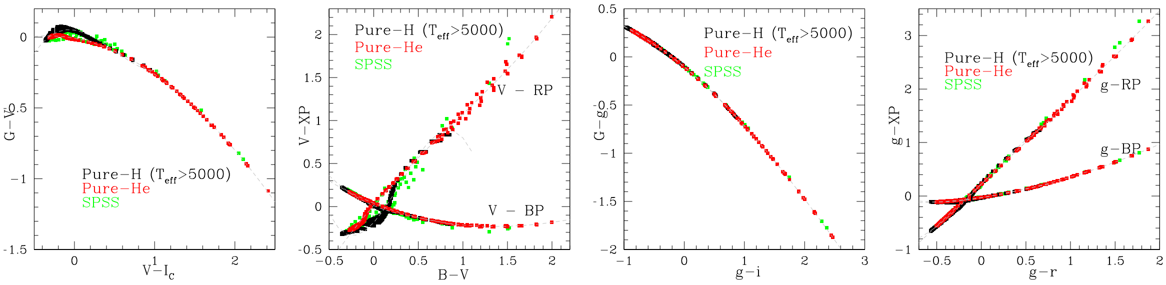

Figure 1: Examples of colour-colour diagrams obtained using *Gaia*, Johnson-Cousins and Sloan passbands for the 'normal' regime of pure-H ($T_{\rm eff} > 5,000$ K; black dots) and for pure-He (red dots) WDs. Green dots are true WDs selected from [24].

We additionally use pure-He models drawn from [1], which cover a range of $T_{\rm eff} = 3,500 - 40,000$ K.

The mixed model atmospheres used here cover a range of $T_{\rm eff} = 2,500 - 6,000$ K, and are taken from [17]. In the following sections, we use an abundance ratio of H/He = 0.1 as a typical example for the composition of known mixed WDs [8, 15, 17, 21].

3 *Gaia* photometric transformations

For each available WD SED in the libraries described in §2, we derived their *Gaia* photometry. From these simulated data we derived transformations between *Gaia* and other commonly used photometric systems (Johnson-Cousins, Sloan and 2MASS) following the same strategy that [13]. These transformations, together with the individual values for each WD in form of on-line tables can be found in [4].

Figure 1 shows several colour-colour diagrams relating *Gaia*, Johnson-Cousins [2] and Sloan passbands [10]. The relationship among colours is tight for each composition, i.e., independent of the gravities. However, the B and to a lesser degree the V passband induce a distinction among the pure-H and the pure-He WDs at $T_{\rm eff} \sim 13,000$ K, where the Balmer lines and the Balmer jump are the strongest in pure-H WDs.

Because of the very tight relationship among colours, polynomial expressions have been fitted in order to allow prediction of *Gaia* magnitudes for every known WD in the validity range of the expressions. These dispersions are smaller than 0.02 mag for the Sloan passbands, while for the Johnson-Cousins passbands can they reach 0.06 mag in some case, mainly for pure-H and when blue B or $G_{\rm BP}$ passbands are involved.

In the cool regime, $T_{\rm eff} < 5,000$, and for pure-H composition the colours depend a lot on the surface gravity of the WDs (specially when blue passbands, B and $G_{\rm BP}$, are involved), yielding a spread in some of the colour-colour diagrams (see Fig. 2). Therefore, no attempt has been made to include these cool pure-H WDs into the computation of the polynomial transformations.

The relationships derived when using 2MASS [5] colours (Fig. 3) are not so tight because

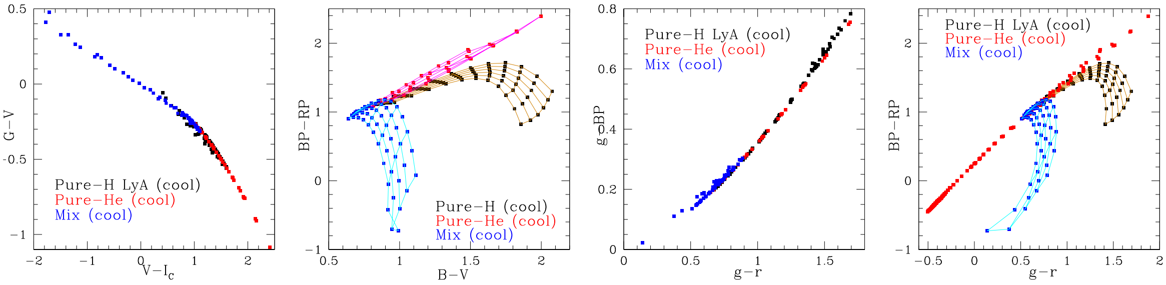

Figure 2: Examples of colour-colour diagrams obtained using *Gaia* and Johnson-Cousins and Sloan passbands in the cool regime ($T_{\rm eff} < 5,000$ K).

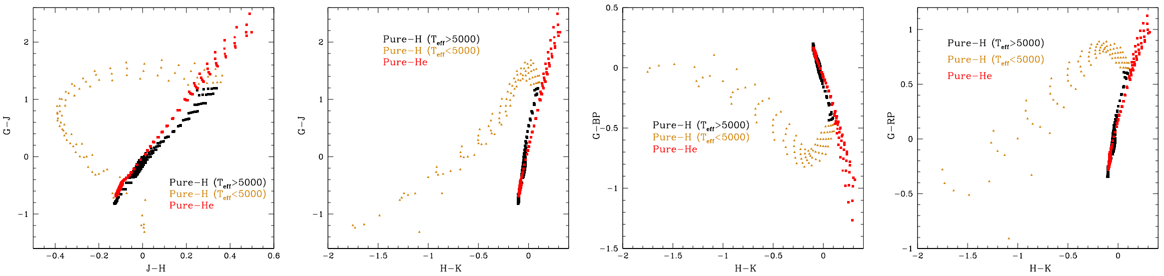

Figure 3: Several colour-colour diagrams obtained using *Gaia* and 2MASS passbands for all $T_{\rm eff}$.

Gaia and 2MASS passbands are sampling different wavelength ranges of the SED and IR 2MASS regime is more sensitive to the composition of WDs than *Gaia* optical range. This fact makes the dispersion values to be larger (increasing up to 0.1 mag in the worst cases) than in the case of Johnson-Cousins or Sloan.

We recommend the user to skip the polynomial expressions when the dispersion of the fitting is too large (cold regime and 2MASS) and to use instead the individual values for the desired temperature and surface gravity listed as on-line tables in [4].

4 WDs in the Galaxy

The current known population of WDs presently amounts $\sim 13,000$ objects (White Dwarf Catalog[4],[22]). This census will be tremendously increased with the *Gaia* all-sky deep survey [29], and more significantly for the halo population and the cool regime. In Table 1 we present estimations of the number of WDs that will be observed according to two different simulations: one based on [23] (and adapted to the *Gaia* limiting magnitude, $G_{\rm lim} = 20$) and the other one extracted from the recent publication of the *Gaia* Universe Model Snapshot (GUMS, [25]).

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[4] http://www.astronomy.villanova.edu/WDCatalog/index.html

Table 1: Total number of WDs with $G \leq 20$ expected in *Gaia* for different $T_{\rm eff}$ ranges.

$T_{\rm eff}$	$N_{\rm Thin}$	$N_{\rm Thick}$	$N_{\rm Halo}$
Based on [23]			
All range, single	196,765	48,673	9,705
< 5,000 K, single	925	1,883	347
GUMS, [25]			
All range, single	198,107	3,557	63
All range, Comp A	64,905	2,340	47
All range, Comp B	296,976	1,153	4
< 5,000 K, single	8,845	142	63
< 5,000 K, Comp A	862	95	47
< 5,000 K, Comp B	244	12	4

Table 2: Number of WDs with parallaxes better than a certain percentage from [25].

	All WDs		Single WDs	
σ_π / π	N	% of observed	N	% of observed
≤1%	20,000	3.5%	10,000	5%
≤5%	150,000	25%	75,000	40%
≤10%	300,000	50%	135,000	70%
≤20%	450,000	80%	190,000	95%

The differences between GUMS and [23] simulations are reasonably in agreement taking into account that both approaches have not used the same calibrations, densities, LFs, . . . , especially for thick and halo populations. Small number statistics of thick and mainly halo known WDs are still a limiting factor to constrain the properties of these populations. Then, a comparison of the true *Gaia* data with these kind of simulations will also help to improve the knowledge about the Milky Way formation.

Table 2 provides estimations of the number of WDs with better parallax precision than a certain threshold. Parallax errors were computed using *Gaia* performances prescriptions[5].

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[5] http://www.rssd.esa.int/index.php?project=GAIA&page=Science_ Performance

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