

# White dwarfs in the Gaia era

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**Abstract.** The vast majority of stars will become white dwarfs at the end of the stellar life cycle. These remnants are precise cosmic clocks owing to their well constrained cooling rates. *Gaia* Data Release 2 is expected to discover hundreds of thousands of white dwarfs, which can then be observed spectroscopically with *WEAVE* and *4MOST*. By employing spectroscopically derived atmospheric parameters combined with *Gaia* parallaxes, white dwarfs can constrain the stellar formation history in the early developing phases of the Milky Way, the initial mass function in the 1.5 to 8  $M_{\odot}$  range, and the stellar mass loss as well as the state of planetary systems during the post main-sequence evolution.

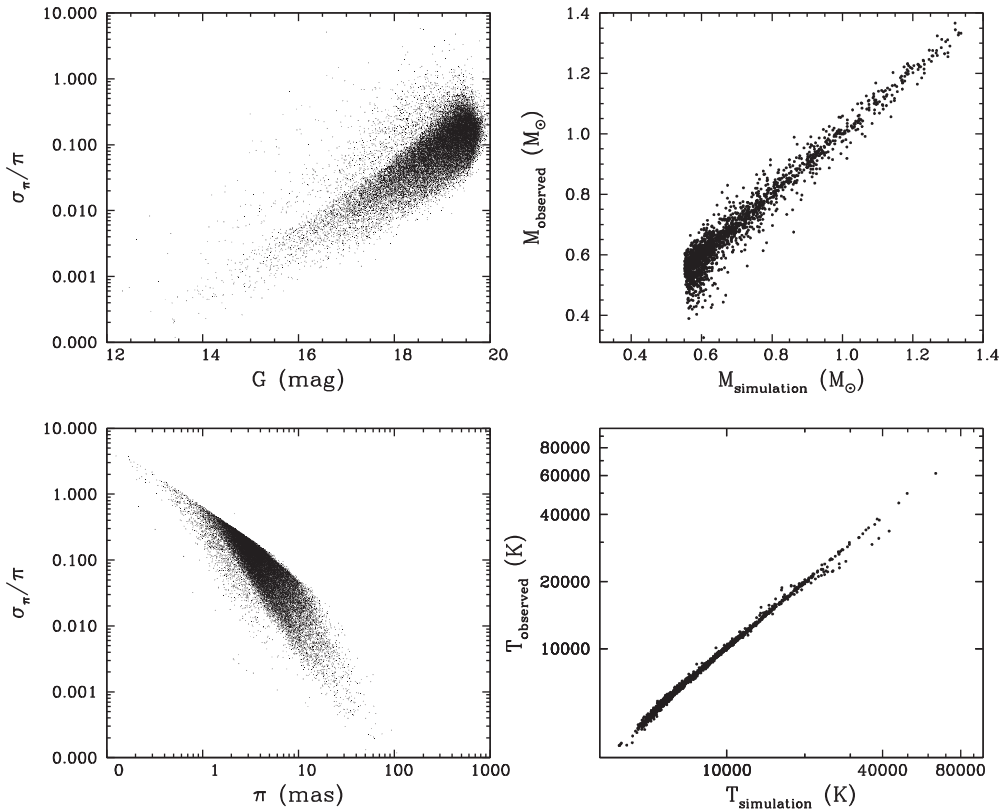
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## 1. Background

The European Space Agency (ESA) astrometric mission *Gaia* will determine positions, parallaxes, and proper motions for a full sky sample with  $V \lesssim 20$  mag, corresponding to  $\sim 1\%$  of the stars in the Galaxy (Gaia Collaboration *et al.* 2016a). In addition to astrometric measurements, the *Gaia* catalog will include  $G$  passband photometry, low-resolution spectrophotometry in the blue (BP, 330–680 nm) and red (RP, 640–1000 nm), and (for bright stars,  $G \lesssim 15$ ) higher-resolution spectroscopy in the region around 860 nm with the Radial Velocity Spectrometer (Jordi *et al.* 2010, Carrasco *et al.* 2014). The final data release is expected to include between 250,000 and 500,000 white dwarfs (Torres *et al.* 2005, Carrasco *et al.* 2014).

*Gaia* DR1 was limited to  $G$  passband photometry and the astrometric solution for stars in common with the *Hipparcos* and Tycho-2 catalogs (Gaia Collaboration *et al.* 2016b). However, not all *Hipparcos* and Tycho-2 stars are found in *Gaia* DR1 owing to source filtering. Tremblay *et al.* (2017) recovered only 6 directly observed white dwarfs but they have also selected 46 members of wide binaries for which the companion has a precise *Gaia* DR1 parallax. They compared observed and predicted spectroscopic distances and found that the mean agreement is better than 1% between *Gaia* parallaxes, published atmospheric parameters, and theoretical mass-radius relations (Fontaine *et al.* 2001). In this work, we examine the prospects of studying degenerate stars in *Gaia* DR2 planned for April 2018.



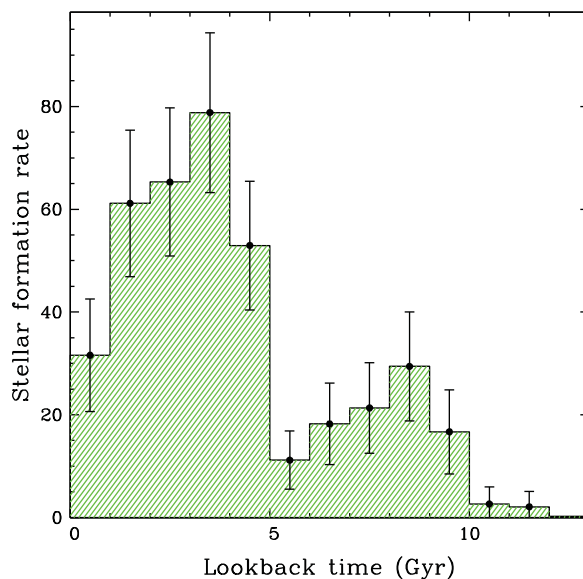
**Figure 1.** (Left:) *Gaia* DR2 parallax errors as a function of  $G$ -band magnitude (top left) and parallax (bottom left) for our simulated Galactic white dwarf population. (Right:) Photometric fit for all white dwarfs within 100 pc in our *Gaia* DR2 mock catalog. We rely on *Gaia* data alone and our simulation does not include binary evolution. *Gaia* colours are predicted assuming a ratio of 1/4 between He- and H-atmospheres.

## 2. White dwarfs in *Gaia* Data Release 2

*Gaia* DR2 is expected to have the astrometric solutions and integrated  $G$ ,  $G_{\text{BP}}$  and  $G_{\text{RP}}$  photometric fluxes for all sources with acceptable formal standard errors. It will have significantly higher individual precision due to a longer measurement time (22 months instead of 11 months, which is already 36% of the total mission time). Systematic errors are also expected to decrease significantly resulting from a more sophisticated calibration, including a better definition of the line spread function, the application of a chromaticity correction, a more accurate calibration of the basic angle variation, and a calibration and correction of micro clanks.

We have simulated the *Gaia* DR2 white dwarf population using assumptions similar to those presented in Tremblay *et al.* (2016) for the magnitude-limited SDSS sample. The main difference is that *Gaia* is all-sky and it is currently expected that remnants of all colours will be released in DR2 given the discussion above. Our simulation is similar to those presented in Torres *et al.* (2005) and Carrasco *et al.* (2014), except that we use the most recent predicted DR2 errors on parallaxes and colours drawn from `PyGaia`†. The total number of white dwarfs in *Gaia* DR2 is expected to be between 250,000 and 500,000 depending on the Galactic model. In particular, by extrapolating the current

† <https://github.com/agabrown/PyGaia>



**Figure 2.** Derived total stellar formation rate (relative number) as a function of lookback time for the Galactic disk at 8 kpc from Galactic centre (see Tremblay *et al.* 2014). The source of the data is the volume complete 20 pc white dwarf sample (Giammichele *et al.* 2012) and the initial-to-final mass relation of Kalirai *et al.* (2008, 2009) to convert white dwarf parameters to initial stellar parameters. We accounted for biases due to the missing main-sequence stars and the velocity dispersion as a function of total stellar age in the direction perpendicular to the plane of the disk. The error bars take into account number statistics uncertainties and are derived from the uncorrected number of white dwarfs. We do not account for radial mixing and as such this represents the formation of stars that are at present day at 8 kpc Galactic radius.

remnant space density in the complete 13 pc sample (Holberg *et al.* 2016), we obtain  $\sim 2200$  white dwarfs within 50 pc, the maximum distance for which we can hope for a volume complete DR2 sample (Carrasco *et al.* 2014).

Fig. 1 (left panel) illustrates the *Gaia* DR2 parallax precision as a function of *G*-band magnitude and parallax for our mock white dwarf catalog. It is noted in particular that all white dwarfs within 100 pc will have a distance precision better than  $\sim 4\%$ . We performed *Gaia* data only photometric fits of all simulated remnants within 100 pc. *Gaia* colours were predicted assuming a ratio of 1/4 between He- and H-atmospheres. Fig. 1 (right panel) demonstrates that it is possible to extract white dwarf parameters within a few percent from *Gaia* data alone within 100 pc. It is observed that *Gaia* integrated photometric fluxes are not very sensitive to the atmospheric composition since the bandpasses are broad, yet the photometric precision is large enough for accurate  $T_{\text{eff}}$  determinations. We note that our mock catalog does not include binary evolution, and as such the actual *Gaia* catalog is expected to have a significant number of outliers when using single white dwarf models.

### 3. Future outlook

Starting with DR2 it will be feasible to compare predicted spectroscopic distances (Holberg *et al.* 2008) for large samples of pure-hydrogen (DA) and pure-helium atmosphere remnants (DB) with *Gaia* parallaxes. This will effectively test white dwarf atmosphere and structure models at the 1% level over a wide range of cooling ages and masses. It will also be possible to derive precise mass distributions for other white dwarf subtypes,

such as cool metal rich objects (DZ, DQ) and magnetic remnants, providing crucial information on the internal structure and progenitors of these spectral types. Furthermore, *Gaia* DR2 will be invaluable in characterising the binary white dwarf population (Toonen *et al.* 2017) and identifying a halo white dwarf sample from proper motions and calculate its luminosity function (Cojocaru *et al.* 2015). Most of these applications can only be performed for a small part of the *Gaia* DR2 sample with currently available independent spectroscopic observations. *WEAVE* (Dalton *et al.* 2016) and *4MOST* (de Jong *et al.* 2014) spectroscopic follow-up surveys will thus have a major impact in enlarging the science output from *Gaia* white dwarfs.

*Gaia* DR2 will make it possible to update the local stellar formation history shown in Fig. 2 as derived from white dwarfs within 20 pc (Tremblay *et al.* 2014). The *Gaia* sample within 100 pc will be 10 times larger, significantly reducing the error bars from number statistics. Once again, *WEAVE* and *4MOST* spectroscopic follow-ups will be essential to improve the precision of the conversion of white dwarf parameters to initial stellar parameters from the initial-to-final mass relation (Cummings *et al.* 2016). *Gaia* will evidently allow for a strong synergy between white dwarf research and Galactic archeology.

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