Stellar archaeology with Gaia: the galactic white dwarf population

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Gaia WGB6

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Most ~F0-B2 stars ever formed are now faint white dwarfs.
Stellar archeology

- ~95% of all stars end as white dwarfs
- Teff, mass $\Rightarrow$ cooling age $\Rightarrow$ (stellar models) $\Rightarrow$ total age
- Key population to probe star formation history
White Dwarf Luminosity Function

- SDSS $V_{\text{tan}}>30$ ($\chi=0.73$, SH=250 pc)
- LHS
- PG (DA stars only)

Log ($N (\text{pc}^{-3} M_{\odot}^{-1})$) vs. $M_{\text{bol}}$

- Bright
- Hot
- Young
- Faint
- Cool
- Old
White Dwarf Luminosity Function

Cut-off at faintest, coolest, oldest white dwarfs

Cut-off in the white dwarf luminosity function due to the limited age of the Galaxy

Even the oldest white dwarfs (9-11 Gyrs) are still visible in the solar neighborhood

⇒ Measure the age of the Galaxy (e.g. Oswalt et al. 1996, Nature 382, 692)
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Luminosity functions from non-standard SFR as $f(M_{wd})$

**All white dwarfs**

1. Exponential SFR: $\Psi \approx \exp(-t/\tau)$ where $\tau = 25$ Gyr
2. Episodic SFR: 1 Gyr after the formation of the disk, lasting for 3 Gyr

**Massive WD = early-type progenitors**

Massive white dwarfs rapidly track changes in SFR
The local sample: 117 white dwarfs within 20pc

Tentative evidence of enhanced star formation over the past $\sim$5Gyr

The initial-mass final-mass relation

mostly based on WDs in open clusters & stellar models

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Gaia ⇒ IMFM relation from common proper motion pairs
(e.g. Catalan et al. 2008, A&A 477, 213; Girven et al. 2010, MNRAS 404, 159)

Stellar archaeology

- Gaia will identify ~400,000 white dwarfs
- *100% complete within ~50pc, 50% within ~300pc*

- Initial-final mass relation $\Rightarrow$ galactic life cycle of matter
- Luminosity function of thin/thick disc & halo
  $\Rightarrow$ star formation rate history
- Add main-sequence star counts $\Rightarrow$ initial mass function

**Need temperatures and masses for Gaia WDs**

Spectroscopic mass measurements

- Teff and log g from fitting spectral models to the Balmer lines
- Higher Balmer lines essential for accurate log g (Kepler et al. 2006, MNRAS 372, 1799)
- Evolution sequences provide the cooling age, mass, radius
- Gaia distances will improve accuracy
Only ~1000 white dwarfs with accurate masses!

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- Gaia BP/RP too low resolution for spectral modelling!

intermediate (R~5000) resolution spectroscopy covering 3800–6800Å
GAIA RVS data provide *no* radial velocities for WDs!

... necessary for full 3D velocity / galactic orbit reconstruction ....

intermediate resolution (R~5000) spectroscopy of the sharp Hα NLTE core

(Karl et al. 2005, A&A 434, 637)
Outliers (aka oddballs, freak stars...)

Short-lived phases in white dwarf evolution and the extremes of parameter space are rare!

- Hot carbon-rich white dwarfs: merger products, “failed SNIa”
  (Dufour et al. 2007, Nature 450, 522)

- Dynamically active planetary debris disks around white dwarfs
  (Gänsicke et al. 2006, Science 314, 1908)

- End states of close binary evolution
  (Littlefair et al. 2006, Science 314, 1578)

- Bare oxygen-neon cores, descending from near the core-collapse boundary
  (Gänsicke et al. 2010, Science 327, 188)

- Detection of water-bearing extra-solar asteroids
  (Farihi et al. 2013, Science 342, 218)
Gaia will identify a few 100000 white dwarfs

- Accurate mass-dependent luminosity function as tracer of galactic SFR
- Initial-to-final mass relation in HD
- Huge resource for stellar, binary & planetary evolution

**Gaia follow-up requirements:**

- Blue coverage down to $\approx 3800\text{Å}$ ⇒ accurate Teff, mass, age
- Resolution $\lambda/\Delta\lambda\approx5000$ ⇒ measure radial velocities from Hα
Gaia WD population G≤20 (GUMS-10)

~10-25 white dwarfs per deg²
Conclusions

Gaia will identify a few 100,000 white dwarfs
- Accurate mass-dependent luminosity function as tracer of galactic SFR
- Initial-to-final mass relation in HD
- Huge resource for stellar, binary & planetary evolution

Gaia follow-up requirements:
- Blue coverage down to ≈ 3800Å ⇒ accurate Teff, mass, age
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WEAVE / 4MOST / DESI:
- ≈10-25 white dwarfs per square degree
- 1-3% of the fibres will be sufficient to observe all Gaia white dwarfs
- White dwarfs are excellent flux / telluric calibrators
Higher Balmer lines are essential for $M_{\text{wd}}$ & $T_{\text{cool}}$

A wavelength cut-off at $\sim4000\text{Å}$ would result in $\sim30\%$ of all white dwarfs having mass / cooling age uncertainties $> 10\%$, adding substantial noise to the GAIA white dwarf LMF!
Higher Balmer lines are essential for $M_{\text{wd}}$ & $T_{\text{cool}}$

High & low mass WD @ $T=20000K$

1100 white dwarfs from SDSS