The white dwarf mass-radius relation with Gaia, Hubble and FUSE

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Why are white dwarfs interesting?

Cosmochronology: Using the temperature of a white dwarf to find its age, and the ages of associated stars.

Potential to study the elemental composition of exoplanet systems.

Natural laboratory for physics in a high gravity environment

The initial-final mass relation and chemical evolution of the galaxy.

Mass of star

Mass of white dwarf

Material returned to ISM
White Dwarf Cosmochronology: Using the temperature of a white dwarf to find its age, and the ages of associated stars.

The white dwarf mass-radius relation

Refinements to the white dwarf mass-radius relation

Solid line = thick hydrogen layer, dashed line = thin hydrogen layer

How to measure the mass of a white dwarf

The spectroscopic method

Strong gravitational field causes broadening of the hydrogen lines. The value of log g is found by fitting a spectral model to the data.

Figure from Bergeron et al 1992 ApJ, 394, 228
Why is the distance measurement so important?

Gaia parallax - distance

\[ R = \sqrt{\left( \frac{D^2 \times \text{norm}}{1\times10^{-20}} \right)} \div R_{\text{sol}} \]

From spectral model fitting:
Normalisation
Log g

\[ M = \frac{\dot{g}R^2}{G} \]
How good are the pre-Gaia distance measurements?

Parallaxes, comparison between Hipparcos and Gaia for the same stars
The advantages of Sirius-like binaries

How can Sirius-like binaries help?

- The initial Gaia data release (DR1) only contains parallaxes for a few WD’s.

- For Sirius-like binaries we can take the distance of the main sequence companion star to be the same as the distance for the WD. Many more of these MS stars are included in DR1.


WD in a multiple system resolved with HST
The benefits of Lyman lines

UV excess caused by the white dwarf.

Emission from the F6V main sequence stars.

At the wavelength range of the Lyman lines there is minimal contamination from the main sequence companion.

Balmer lines can only be used if the WD can be resolved and an uncontaminated spectrum obtained.

Example of Lyman and Balmer spectra for HZ43

FUSE Lyman line spectrum

HST Balmer line spectrum
The Mass-Radius relation using Hipparcos parallaxes

M-R relation from HST and FUSE spectroscopic method with Gaia distances.
The Mass-Radius relation using Gaia parallaxes

M-R relation from HST and FUSE spectroscopic method with Gaia distances.
How accurately can we expect to measure distances in the future?

For this sample, the average parallax error in DR1 is 0.39 mili arc sec. The final data release is expected to have parallax error of ~6.7 micro arc sec.
Conclusions and future plans

- The distances from Gaia have removed much of the scatter in the observed mass-radius data and show that the overall form of the MRR is correct.
- The improved accuracy of the white dwarf distances in later data releases will allow us to begin to truly test the theoretical mass-radius relation at an accuracy level where temperature and H layer thickness in the models can be distinguished.
- The limiting factors contributing to uncertainty in the M-R measurements are the reliability of the spectral fitting and log g determination.
- A comparison of results from Lyman and Balmer lines shows that there may be an unexplained systematic offset.
- It will be important to quantify the remaining sources of error and develop the gravitational redshift method to the required level of accuracy to take full advantage of the Gaia data.