White Dwarfs in the GALEX Survey

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ABSTRACT

We have cross-correlated the 2dF QSO Redshift Survey (2QZ) white dwarf catalog with the GALEX 2nd Data Release and the Sloan Digital Sky Survey (SDSS) data release 5 to obtain ultraviolet photometry (FUV, NUV) for approximately 700 objects and optical photometry (ugriz) for approximately 800 objects. We have compared the optical-ultraviolet colors to synthetic white dwarf colors to obtain temperature estimates for approximately 250 of these objects. These white dwarfs have effective temperatures ranging from 10 000 K (cooling age of about 1 Gyr) up to about 40 000 K (cooling age of about 3 Myrs), with a few that have even higher temperatures. We found that to distinguish white dwarfs from other stellar luminosity classes both optical and ultraviolet colors are necessary, in particular for the hotter objects where there is contamination from B and O main-sequence stars. Using this sample we build a luminosity function for the DA white dwarfs with $M_V < 12$ mag.

Key words: UV astronomy, white dwarfs

1. Introduction

The properties of white dwarf stars are relatively simple to measure. Ideally, a complete spectral energy distribution, from the optical to the ultraviolet, helps establish the white dwarf atmospheric properties, i.e., their effective temperature, surface gravity, and chemical composition, from which we may deduce their age and mass using theoretical mass-radius relations (e.g., [Wood, 1995]). These measurements lay the foundations for a study of the white dwarf cooling history (luminosity function).

The 2dF QSO Redshift Survey (2QZ) survey is a deep spectroscopic survey of blue Galactic and extra-Galactic sources which was conducted at the Anglo-Australian...
Telescope (AAT). Over 2000 white dwarfs were discovered during this survey (Croom et al., 2004). Vennes et al. (2002) obtained atmospheric parameters for many of these objects. Another survey is the Sloan Digital Sky Survey (SDSS), which aims to observe 1/4 of the sky in $ugriz$ photometric bands and obtain spectroscopy for many of these objects. A catalog of 9316 spectroscopically confirmed white dwarfs from the SDSS 4th data release was published by Eisenstein et al. (2006). The Galaxy Evolution Explorer (GALEX) is an orbiting observatory that aims to observe the sky in the ultraviolet. GALEX provides photometry in two bands, $FUV$ (1344-1786 Å) and $NUV$ (1771-2831 Å), and will conduct several surveys during its mission, including the All-Sky Imaging Survey (AIS) with a limiting magnitude of 21.5 mag and the Medium-Imaging Survey (MIS) with a limiting magnitude of 23 mag.

We cross-correlated the 2QZ DA white dwarf catalog with the SDSS 5th data release to obtain $ugriz$ photometry. Only the north Galactic cap (NGP) is covered by the SDSS and therefore we were only able to get $ugriz$ photometry for 795 objects. We also cross-correlated the 2QZ DA white dwarf catalog with the GALEX 2nd data release (GR2) to obtain ultraviolet photometry for approximately 810 objects, however some of these stars have only been detected in either the FUV or NUV band. Figure 1 shows the overlap between the 2QZ white dwarf catalog and GR2. Finally we cross-correlated our SDSS and GALEX samples to obtain 252 stars for which we have both optical $ugriz$ and ultraviolet photometry.

Figure 1: The overlap between 2QZ and GALEX (GR2) surveys.
Figure 2: (left) Optical and ultraviolet colors \((g - FUV \text{ vs. } FUV - NUV)\) of 2QZ white dwarfs compared to synthetic DA white dwarf colors. The full-lined grid includes the effect of Ly\(\alpha\) satellites, and the dotted-lined grid excludes them. (right) Optical \((u - g / g - r)\) colors of 2QZ white dwarfs compared to synthetic DA white dwarf colors. The effective temperature is indicated in units of 1000 K and the log \(g = 6.0, 7.0, 8.0,\) and 9.0 (from bottom to top). The main-sequence colors are also shown.

2. Determining the parameters

We obtained effective temperatures for the 2QZ DA white dwarfs by comparing the ultraviolet/optical colors \((g - FUV / FUV - NUV)\) and optical colors \((u - g / g - r)\) to synthetic DA colors. Figure 2 shows the ultraviolet and optical colors of the 2QZ white dwarfs compared to synthetic DA and main-sequence colors. The optical and ultraviolet photometry of the 2QZ white dwarfs were corrected for interstellar extinction using the dust maps of Schlegel et al. (1998) and the extinction law of Cardelli et al. (1989), where we have assumed \(R_V = 3.1\). Note that \(R_V\) can vary anywhere between \(\sim 2.5\) to \(\sim 5.5\) which can change the extinction in the ultraviolet by a very significant amount (Cardelli et al., 1989). In addition, the true extinction toward a star is possibly only a fraction of the total extinction in the line of sight. The synthetic DA colors were calculated using a grid of pure hydrogen LTE models (Kawka & Vennes, 2006). The grid of models extend from \(T_{\text{eff}} = 7000\) to 84000 K at log \(g = 6.0\) to 9.5. The spectra include the effect of Ly\(\alpha\) satellites (Allard & Koester, 1992), however we also calculated spectra which exclude the effect. Figure 2 (left) shows the effect of Ly\(\alpha\) satellites on UV colors, which is most prominent in the cooler white dwarfs \((T_{\text{eff}} \lesssim 12000\) K). The color diagrams also show the main-sequence, which was calculated using Kurucz synthetic spectra (Kurucz, 1993). Figure 2 (right) shows
some stars that have colors corresponding to the main-sequence rather than the DA white dwarf sequence, therefore some contamination by main-sequence stars is still present in the 2QZ DA catalog. We found that the combination of both diagrams helps distinguish between white dwarfs and main-sequence stars.

Figure 3 shows a comparison between the temperatures obtained using the $g - F_{\text{UV}}/F_{\text{NUV}}$ colors and the $u - g/g - r$ colors. A relatively good agreement between the temperatures is observed with a few points which appear to give very low optical temperatures compared to their UV temperatures. A check of the 2QZ spectra for these objects reveal them to be DA white dwarfs with cool companions and therefore the UV temperatures should be adopted as the white dwarf temperatures. Figure 3 also shows a comparison of the UV temperatures determined with grids which include or exclude the effect of Ly$\alpha$ satellites. Temperatures determined using models which exclude the effect of Ly$\alpha$ satellites are significantly lower than those which do not for $T_{\text{eff}} \lesssim 12000$ K.

3. Luminosity Function

We constructed the DA luminosity function using the 2QZ/SDSS5/GR2 and the 2QZ/SDSS5 samples by using the accessible-volume method (see 

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Figure 4: The DA luminosity function measured using the 2QZ/SDSS/GR2 survey compared to the luminosity function measured using AAT-UVX and Palomar-Green (PG) survey. The theoretical luminosity function assuming a DA white dwarf birthrate of $0.5 \times 10^{-12}$ pc$^{-3}$ yr$^{-1}$.

references therein) and assuming a scale-height of 250 pc. Using the temperatures obtained from the $g-FUV/FUV-NUV$ and $u-g/r$ diagrams, we calculated the absolute magnitudes ($M_V$), assuming $\log g = 8.0$ and using the mass-radius relations of Benvenuto & Althaus (1999). Figure 4 shows the 2QZ/SDSS5 and 2QZ/SDSS5/GR2 luminosity functions compared to the luminosity functions determined in the PG Survey (Fleming et al., 1986), the AAT-UVX survey (Boyle, 1989) and a theoretical luminosity function based in the cooling sequence of Wood (1995) and a constant DA birthrate of $0.5 \times 10^{-12}$ pc$^{-3}$ yr$^{-1}$. Both the 2QZ/SDSS5/GR2 and 2QZ/SDSS5 luminosity functions are incomplete at the cool end ($M_V \geq 12.0$ mag). The two main reasons for this is that fewer objects were selected due to the limiting colors at the cool end and the cooler objects are very faint in the ultraviolet and hence would not be detected by the GALEX survey. Also there appears to be an excess of stars in the $M_V = 11.5$ bin, in particular in the 2QZ/SDSS5/GR2 sample. Interstellar reddening could be a contributing toward this excess since our extinction correction did not consider the distance toward the star, and therefore cooler objects which would be closer would be over corrected resulting in higher temperatures.
4. Summary and Future Work

We have presented our initial analysis of DA white dwarfs from the 2QZ survey using SDSS5 and GR2 photometry. Using these photometric data, we obtained temperature and absolute magnitudes from which we built a luminosity function. We will extend this analysis to the He-rich sequence of white dwarfs (DO/DB). We will investigate the effect of interstellar extinction on the temperature distribution and hence the luminosity function in more detail. Also, we will examine the effect of heavy elements on the UV/optical temperature scales. Many hot white dwarfs show heavy element lines, and the abundance of these elements can vary many orders of magnitude.

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