Identifying and Characterizing New Nearby White Dwarfs

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Abstract.

How confident are we that all of the nearest white dwarfs (WDs) have been identified? In an effort to answer this question, we have begun an initiative to identify and characterize new nearby WDs, particularly in the southern hemisphere. We estimate physical parameters for new WDs using medium resolution ($R \sim 1000$) optical spectroscopy, and distances using optical photometry combined with 2MASS near-infrared photometry. For objects within 25 pc (Catalogue of Nearby Stars, and NStars Database horizons), we determine a trigonometric parallax via CTIOPI (Cerro Tololo Inter-American Observatory Parallax Investigation). Of the 37 new WD systems discovered so far, fourteen are likely within 25 pc, a volume that contains 107 WDs with trigonometric parallaxes. Interesting objects include two that are likely double degenerates including one with a magnetic component, one that is a cool ($T_{\text{eff}} \sim 5000$ K) likely mixed atmosphere WD with deficient flux at near-infrared wavelengths, and two that are metal-rich. Observations are underway via the Hubble Space Telescope to resolve four potential double degenerates (the new magnetic WD and three other previously known WDs) for dynamical mass determinations. All ground-based observations are obtained as part of the SMARTS (Small and Moderate Aperture Research Telescope System) Consortium at CTIO.

1. Introduction

White dwarfs (WDs) are the end results for all stars less than $\sim 6 - 8 M_{\odot}$; therefore they are relatively numerous. WDs have been used as photometric and spectroscopic calibrators, as proxies for galactic population ages, and as constraints for stellar evolution theory. Intrinsic faintness makes WDs hard to study, yet a complete sample of the nearest WDs to the Sun (i.e. the brightest representatives of this class of stars) is essential to understand the precursor population.

Our goal is to identify previously unknown WDs in the solar neighborhood, to estimate distances, and to measure trigonometric parallaxes and confirm proximity. In addition, we estimate distances for previously known WDs without trigonometric parallaxes and obtain parallax determinations for objects presumed to be within 25 pc (Catalogue of Nearby Stars and NStars Database
horizons). All of the 37 newly identified WD systems reported here are brighter than \( V = 17.0 \) and most are in the southern hemisphere, a region sampled more poorly than in the northern hemisphere. Although this new sample is relatively small, we find several interesting objects, exemplifying the vast diversity seen in much larger WD samples, some of whose characteristics are not well understood within current theoretical framework.

2. Candidate Selection

Proper motion is the most definitive means to tease out WDs from the far more populous and distant main sequence stars that look identical photometrically. In collaboration with Nigel Hambly at the Royal Observatory at Edinburgh, Scotland, we have completed a survey of the southern sky for high proper motion objects using astrometric and photometric data from the SuperCOSMOS Sky Survey (SSS) (Hambly et al. 2004; Henry et al. 2004; Subasavage et al. 2005a,b). The SuperCOSMOS-RECONS (SCR) proper motion survey, in addition to discovering nearly 300 new high proper motion objects in the southern sky with \( 10.0 \lt R_{59F} \lt 16.5 \) and \( 0.4''/yr \lt \mu \leq 10.0''/yr \), has recovered thousands of known proper motion objects. Because of the quality of the photometric calibration of the SSS plates, the data for these known objects are superior to the magnitude data of the original discovery survey (i.e. Luyten 1980), enabling us to better identify WD candidates. We compliment the SSS photometry with near-infrared 2MASS \( JHK_s \) photometry. Utilizing both optical plate and near-infrared photometry and the SSS astrometry, we calculate the \( (R_{59F} - J) \) color and the reduced proper motion (RPM) as follows:

\[
H_{R_{59F}} = R_{59F} + 5 + 5 \log(\mu)
\]

RPM correlates proper motion (\( \mu \)) with proximity, an association that is certainly not always valid but is sufficient to delineate the luminosity classes. Figure 1 illustrates this technique. The filled circles are the SCR proper motion discoveries plotted to show the three distinct groupings. The asterisks are the 37 new WD discoveries presented in this work. The diagonal line separating the WDs from the subdwarfs was drawn arbitrarily to serve as an approximate division between the two luminosity classes. There are three objects well within the WD region that are not marked with asterisks because we have not yet obtained spectra, although they are most likely WDs. We have confirmed a fourth object just below the line at \( (R_{59F} - J) = 1.4 \) (not marked with an asterisk) to be a subdwarf contaminant.

3. Spectroscopy

After selection of WD candidates via the RPM diagram, spectra were obtained at the CTIO 1.5m telescope operated by the SMARTS (Small and Moderate Aperture Research Telescope System) Consortium. Observations were carried out during several observing runs between July 2003 and May 2006. The Ritchey-Chrétien Spectrograph and Loral 1200×800 CCD detector were used with grating #09, providing 8.6 Å resolution and wavelength coverage from 3500 Å to 6800 Å. Bias subtraction, dome / sky flat-fielding, and extraction of spectra were
performed using standard IRAF packages. Integration times were typically several minutes up to 30 minutes. Two spectra were taken in series for each object to allow cosmic ray rejection.

Spectra of the 37 new WD systems indicate that 30 are DA, four are DC, two are DZ, and one is DQ.

4. Photometry

Using a subsample of WDs from the Bergeron et al. (2001) sample of WDs with $BVRIJHK$ photometry and trigonometric parallaxes, we created a suite of color relations linked to $M_V$. These relations can be used to estimate distances of WDs for which no trigonometric parallax is available. We obtained multi-epoch $V_JR_{KC}I_{KC}$ photometry at the CTIO 0.9m telescope and extracted 2MASS $JHK_s$ for the 37 new WD systems and other known WD systems for which no trigonometric parallax exists. The photometry allowed us to (1) estimate a distance using the suite of relations, and (2) reproduce the spectral energy distribution (SED) and obtain an effective temperature (assuming either H or He atmosphere, which can be constrained by the spectrum). Table I displays the number of new and known WDs presumed to be within 25 pc. The trigonometric parallax is needed to constrain log $g$ and other parameters.
dependent on log $g$ (i.e. mass, age, and luminosity). Because these objects do not yet have trigonometric parallaxes, a log $g$ of 8 is assumed – an entirely valid assumption when compared to a large WD sample for which log $g$ is constrained via trigonometric parallax (i.e. [Bergeron et al. 2001]). However, other dependent parameters may not be well constrained and are disregarded in this analysis.

| Table 1. Photometric Distance Estimates for New and Known WDs Without Trigonometric Parallaxes |
|-----------------------------------------------|
| Sample | $D \leq 10$ pc | $10$ pc $< D \leq 25$ pc | $D > 25$ pc |
| New | 0 | 14 | 23 |
| Known | 2 | 15 | 0 |
| Total | 2 | 29 | 23 |

5. Astrometry

In order to be certain that a WD is indeed nearby, a trigonometric parallax is needed. For objects estimated to be within 25 pc, we determine a trigonometric parallax via the 0.9m Cerro Tololo Inter-American Observatory Parallax Investigation (CTIOPI) program [Jao et al. 2005]. To date, there are 107 WDs with trigonometric parallaxes within 25 pc. One of our goals is to increase this sample by 25% or 27 new systems. Currently there are 44 WD systems on the parallax program and of those, 23 have preliminary parallaxes placing them within 25 pc. We are confident that our goal will be realized.

6. Interesting Objects

Once all of the previously mentioned data are collected, we are able to characterize these objects precisely. In some cases, interesting attributes present themselves when all the data are available. Here we highlight a few of the interesting new objects.

6.1. WD 0622-329

This WD has both H and He lines in its spectrum. When we attempt to fit the spectrum, we get a $T_{\text{eff}} \sim 43,000$ K and the fit is moderately good except that it predicts He II absorption at 4686 Å, which is certainly not seen in the spectrum. If we use the photometry and perform a SED fit, we obtain $T_{\text{eff}} \sim 10,500$ K. We then tried to reproduce the spectrum assuming the WD is an unresolved double degenerate with one component’s atmosphere being H and the other being He. The fit (dashed line) is shown in Figure 2 and a convolution of the two temperatures is consistent with the SED fit.

6.2. WD 2138-332

One of only two DZ WDs from the new sample, this object exhibits strong absorption due to Ca and Mg. Theoretical models have only recently provided
accurate treatment for these objects such that spectral features are reproduced reliably. Figure 2b exemplifies this point. The solid line represents the observational data while the dashed line represents the model. This object is well characterized as a DZ at $T_{\text{eff}} = 7188$ K and a $\log \frac{N(\text{Ca})}{N(\text{He})} = -8.64$.

### 6.3. WD 2008-600

This object exhibits no features in its spectrum. Using the photometry for the SED fit, one obtains vastly different $T_{\text{eff}}$ depending on whether this object is assumed to have a pure H ($T_{\text{eff}} = 2977$ K) or pure He ($T_{\text{eff}} = 6494$ K) atmosphere. Neither fit is satisfactory (see Figure 3a), but when one uses the preliminary trigonometric parallax to constrain the model, one obtains a mixed H / He atmosphere with $T_{\text{eff}} = 5078$ K and $\log \frac{N(\text{He})}{N(\text{H})} = 2.6$. This object is similar to the cool WD, LHS 3250, except that this object is nearly two magnitudes brighter and roughly half the distance ($17.1 \pm 0.4$ pc) from the Sun than LHS 3250.
6.4. WD 0121-429

This object is a moderately cool DA WD that exhibits Zeeman splitting in the Hα and Hβ absorption lines. Furthermore, the absorption lines appear quenched (i.e. not as strong as the model would predict). Again using the preliminary trigonometric distance (18.2 ± 0.8 pc) to constrain the model, this object is either a single 0.3M⊙ or a pair of unresolved degenerates each at 0.6M⊙. The double degenerate scenario is the more likely simply because we do not expect to find many low mass WDs due to galactic age constraints. This would also help explain the quenched absorption lines. If one assumes a double degenerate with one component being a DAH and the other being a DC, both contributing equally to the total luminosity, one can reproduce the spectrum fairly well using $T_{\text{eff}}$ from the SED fit as an input. Figure 3 displays the best fit and the resultant magnetic parameter values. The viewing angle, $i = 65^\circ$, and the dipole offset, $a_z = 0.06$ R$_{\text{star}}$ are not well constrained, but what is important is the fit of the central Hα line, which assumes a 50% dilution factor. For a complete description of fitting WDs with strong magnetic fields, see Bergeron et al. (1992). We have targeted this object to be observed using the Fine Guidance Sensors (FGS) on the Hubble Space Telescope (HST) in hopes of resolving this binary and obtaining fractional masses, which, if successful, would be the first dynamical mass measured for a magnetic WD.

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