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White Dwarfs from the SDSS: 90 Prime – Goin' Deep in the White Dwarf Luminosity Function

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Abstract. A large sample of cool white dwarfs from the Sloan Digital Sky Survey has been used to construct a luminosity function (LF), with the selection based on the method of reduced proper motion. While the sample is 60 times larger than that from our Luyten Half Second proper motion survey, its sensitivity to the region past the peak of the LF is severely limited by the necessity to match positions with detections from Palomar plates. A new survey to realize the full limiting magnitudes of the SDSS is described.

1. Introduction

A new disk white dwarf luminosity function (WDLF) has been constructed from Luyten Half Second (LHS) white dwarfs with motions having a minimum value of $\mu > 0.6''$/yr (Dahn, Harris, Leggett, & Liebert 2007, in preparation). While about doubling the size of the 1988 sample, it still includes only 92 cool white dwarfs. To eliminate spurious matches, the selection required measurement of reasonable astrometric positions from at least four Palomar Observatory Sky Survey first (POSS1) and second generation (POSS2) plates. The limiting magnitudes and corresponding search volumes were accordingly modest.

This LHS WDLF and a detail of the cool end are shown in Figure 1. The sharp peak before the plunge is real, and is believed to be caused by the "convective coupling" with the degenerate core, and a corresponding rapid release of interior energy (Fontaine, Brassard, & Bergeron 2001). Despite the small total number of stars, note that the last three half magnitude bins have 16, 10, and 3 stars, respectively. The plunge is therefore not measured with great statistical significance, and it has long been known that a sample at least several times larger has been needed (Wood & Oswalt 1998).

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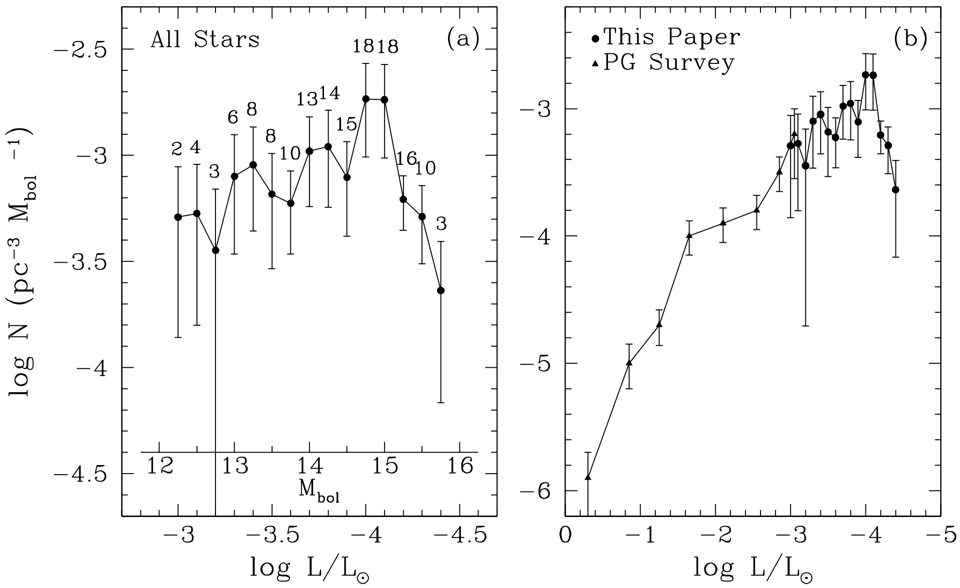

Figure 1. Luminosity Function from 92 White Dwarfs in the Luyten Half Second Survey with $\mu > 0.6''$/yr, in 1/4 bolometric magnitude bins (filled circles). Hot stars (smaller triangles) are taken from the old study of DA stars from the Palomar Green Survey (Fleming, Liebert, & Green 1986).

2. The Sloan Digital Sky Survey

The SDSS has resulted in a dramatic several-fold increase in the known number of white dwarfs with spectral classifications. Over 9,300 are included in the Eisenstein et al. (2006) catalog. The great majority of these, however, are hot DAs and DBs. This is because hot stars are targeted for followup SDSS spectra, but cool white dwarfs lie too near to the locus of cool main sequence stars and are not targeted.

A new, much larger WDLF sample has been constructed by selecting stars based on reduced proper motion (RPM) – $H_g = g + 5 \log \mu + 5$. This is a proxy for absolute magnitude if the population sampled is kinematically similar. Specifically, the distribution of tangential velocities needs to be similar, since $v_{\rm tan} = 4.738 \mu\, d$, where $v_{\rm tan}$ is in km/s and d is the distance in parsecs. Harris et al. (2006) published the WDLF and sample, based on reduced proper motion selection. To confirm where the boundaries between the bands of white dwarfs and main sequence subdwarfs lie, spectra obtained with the Hobby-Eberly and 6.5-m MMT were obtained for a subset published in Kilic et al. (2006).

In Figure 2 a RPM diagram is shown, using the SDSS $g - i$ color. The dense contours to the right are a huge number of lower main sequence stars of the disk population. The main sequence stars of the local halo form a diagonal band off the lower left of the dense contours. Spectra confirming late-type subdwarf stars (sdK, sdM) are indicated with (red) squares. The white dwarfs form a broader diagonal band below and to the left of the subdwarfs. Those with spectral classifications – most hot ones from SDSS – are plotted as (blue) triangles. Black curves are the expected loci for white dwarfs with different mean $v_{\rm tan}$ values – the

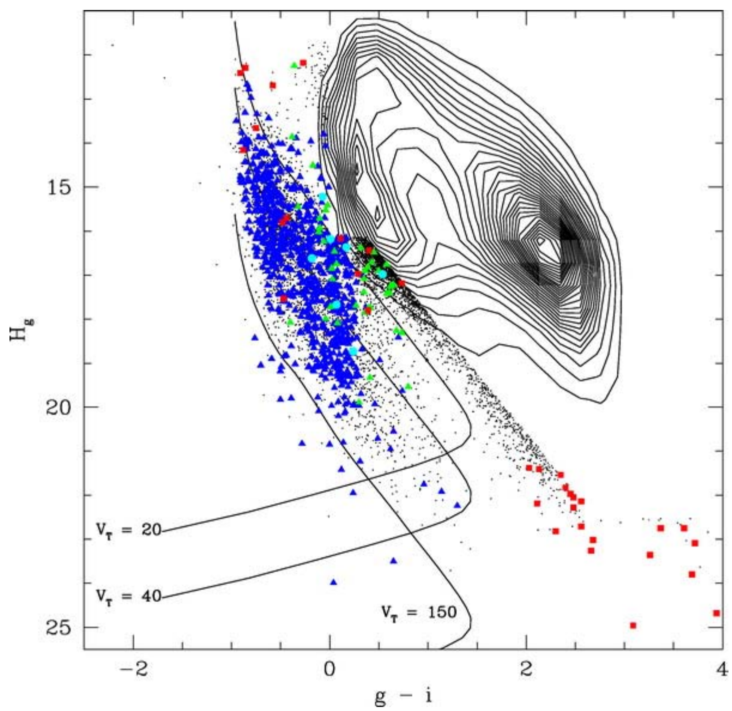

Figure 2. A reduced proper motion diagram, $H_g = g + 5 \log \mu + 5$ vs. $g - i$ from the SDSS sample. The triangles identify spectroscopically-confirmed white dwarfs. Squares are late subdwarfs, or Population II main sequence stars. The broad contours are discussed in the text. The curves track the expected positions of DA stars with the labeled tangential velocity ($V_{\rm T}$).

higher the velocity, the higher the RPM at a given color. The color predictions are from the models kindly provided by P. Bergeron, assuming pure hydrogen atmospheric composition. As a result of the onset of the collision-induced H_2 dipole absorption (CIA), the i band gets depressed for the coolest white dwarfs, and the curves are predicted to turn sharply blueward. Weaker CIA opacity effects have been measured in warmer white dwarfs in the near-infrared JHK bands (Bergeron, Ruiz, & Leggett 1997).

A few candidate cool CIA white dwarfs in the i band are identifiable near the bottom – middle of the figure. The limiting POSS magnitudes no doubt inhibit our ability to find many. Some were previously found in some SDSS-obtained spectra by Gates et al. (2004). When the signature is strong, the colors can be pulled away from the stellar locus, increasing the chance that the project would target them for spectra. The number of such objects, however, is small. By no means is the evidence from SDSS indicating that a large sample of such white dwarfs inhabit the Galactic halo, at least near the Sun.

A set of MMT spectra of confirmed cool white dwarfs from this RPM diagram, taken from Kilic et al. (2006), are shown in Figure 3. The vast majority of these stars do not show unusual spectra like the Gates et al. stars, or the strong-lined DZ and DQ white dwarfs illustrated in Harris et al. (2003). As can

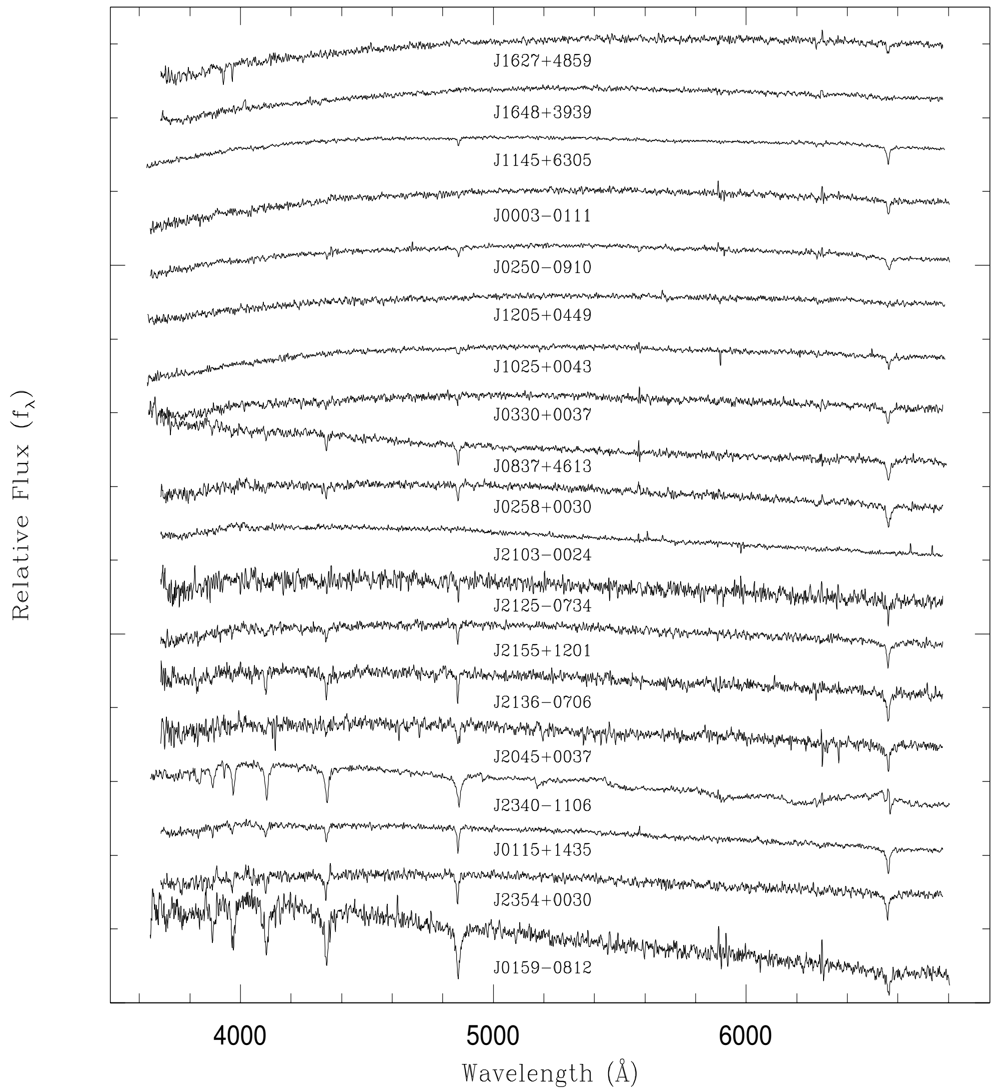

Figure 3. 6.5-m MMT spectra of some cool white dwarfs confirmed in the sample

be seen, most are simple DC or DA stars. One star does show weak DZ metal features. Their spread in $g - i$ and other SDSS colors is generally modest.

In Figure 4 the new WDLF constructed from this sample with 5,794 stars is shown. However, only two of these lie in the crucial last half-magnitude bin. Why is this? To measure a reduced proper motion, one needs to link the SDSS with other epochs to establish whether a consistent amplitude and position angle indicate a valid motion. We found that four matches were needed with this number of POSS plates. Thus, the selection of SDSS stars was also limited by the limits of the POSS. At the faintest absolute magnitudes, a sharp cut in the number of candidates thus occurred.

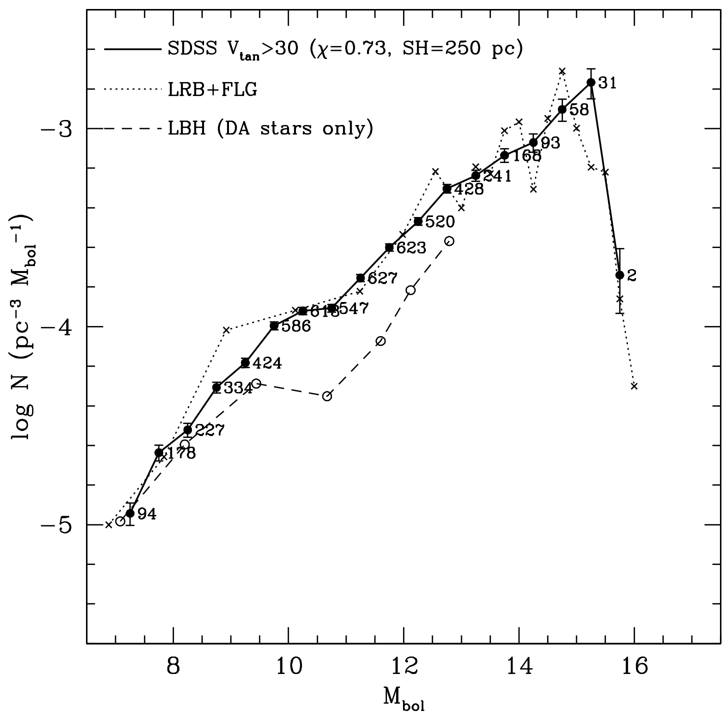

Figure 4. The luminosity function (LF) from the SDSS sample, in 1/2 magnitude bins, with the number of stars per bin labeled. Also shown are the new LF for hot DA white dwarfs from Liebert, Bergeron, & Holberg (2005), and the old LF of Leggett, Ruiz, & Bergeron (1998) from the 1988 LHS sample, again connected to the Fleming, Liebert, & Green (1986) sample of hot stars.

3. 90 Prime

In order to realize the limiting magnitudes of SDSS which extends about two magnitudes fainter than the POSS, it is obviously necessary to obtain at least one second epoch reaching similar magnitudes. For this purpose we have begun a large survey using a new prime focus imager on the Steward Observatory Bok 2.3-m (or 90-inch) reflector, described in Williams et al. (2004). The principal investigator is Ed Olszewski. The imager has an array of four thinned Lockheed 4096×4096 pixel CCDs. The f/2.98 system provides a plate scale of 0.45"/pixel and a total field-of-view of $1.16^o \times 1.16^o$.

We have estimated that several thousand square degrees of SDSS fields need to be repeated if we are to increase adequately the numbers of white dwarfs beyond the WDLF peak. This entails a huge observing project, estimated to be as many as 100 successful nights, assuming about 50 fields per night. An SDSS r band filter is available with the instrument, and only this band is being used. Early measurements indicate that valid proper motion stars may be found with only two epochs separated by several years in time. Both point spread functions are obtained with CCDs, so that more accurate astrometry is obtainable than with plates.

Eventually, additional epochs will be obtained by other projects. The most immediate is from the Pan-Starrs project (Hodapp et al. 2004). Using just the one telescope prototype to what is intended to be a 4-telescope system, an all-sky survey will be undertaken of the 3π steradians of sky accessible from Maui, Hawaii. Five bands will be covered, including an "r" band. Multiple measurements of the same sky fields are planned, resulting in the opportunity for multiple epochs for astrometry. Similar (deeper) multi-epoch imaging of astrometric quality may eventually be obtained when the Large Synoptic Survey Telescope (Tyson 2005) is built. However, the site selected for LSST is in Chile, affording less overlap with SDSS survey fields.

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References

Bergeron, P., Ruiz, M. T., & Leggett, S. K. 1997, ApJS, 108, 339

Eisenstein, D. J., et al. 2006, ApJS, 167, 40

Fleming, T. A., Liebert, J., & Green, R. F. 1986, ApJ, 308, 176

Fontaine, G., Brassard, P., & Bergeron, P. 2001, PASP, 113, 409

Gates, E., et al. 2004, ApJ, 612, 129

Harris, H. C., Liebert, J., Kleinman, S. J., et al. 2003, AJ, 126, 1023

Harris, H. C., Munn, J. C., Kilic, M., et al. 2006, AJ, 131, 571

Hodapp, K. W., Kaiser, N., et al. 2004, Astron. Nach., 325, 636

Kilic, M., Munn. J., Harris, H. C., Liebert, J., von Hippel, T., Williams, K. A., Metcalfe, T. S., Winget, D. E., & Levine, S. E. 2006, AJ, 131, 582

Leggett, S. K., Ruiz, M. T., & Bergeron, P. 1998, ApJ, 497, 294

Tyson, A., 2005, in ASP Conf. Ser. 339, Observing Dark Energy, eds. S. C. Wolff & T. R. Lauer, (San Francisco: ASP), 95

Williams, G. G., Olszewski, E., Lesser, M. P., & Burge, J. H. 2004, SPIE, 5492, 787

Wood, M. A., & Oswalt, T. D. 1998, ApJ, 497, 870