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Adela Kawka
Murdoch University

Stphane Vennes
Australian National University

John R. Thorstensen
Dartmouth College

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OBSERVATIONS OF WHITE DWARFS IN THE SOLAR NEIGHBORHOOD

Adela Kawka
Division of Science and Engineering, Murdoch University, Murdoch, WA 6150, Australia

Stéphane Vennes[1]
Department of Mathematics, Mathematical Sciences Institute, Australian National University, Canberra, ACT 0200, Australia

and

John R. Thorstensen
Department of Physics and Astronomy, 6127 Wilder Laboratory, Dartmouth College, Hanover, NH 03755-3528
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ABSTRACT

High proper motion surveys are still adding much to our understanding of the local white dwarf population and, possibly, to the Galactic halo membership of some objects. As part of our study of white dwarfs in the solar neighborhood we have observed seven white dwarfs from the revised New Luyten Two Tenths (NLTT) catalog of Salim & Gould. We found four DA white dwarfs (NLTT 529, 49985, 53468, 55932), one DZ white dwarf (NLTT 40607) that shows a close resemblance to the unusual DZ white dwarf G165-7, and two DC white dwarfs (NLTT 19138, NLTT 52404). The white dwarf candidates were chosen using the $V-J$ reduced proper-motion diagram of Salim & Gould and an optical-infrared diagram ($V-J$ vs. $J-H$). We also observed five stars from the list of local white dwarfs by Holberg, Oswalt, & Sion that required confirmation of their spectral classification. We confirm that GD 1212 and WD 1717−345 are white dwarfs but that BPM 17113 (WD 0311−543), KUV 05097+1649, and BPM 19929 (WD 1013−559) are main-sequence F stars rather than white dwarfs. An analysis of a color-selected sample of white dwarf candidates extracted from the rNLTT catalog could contribute more than 200 new white dwarfs, most belonging to the thin disk, with a few ($N<15$) kinematically selected members of an older population (thick disk or halo).

Key words: Galaxy: disk — solar neighborhood — white dwarfs

1. INTRODUCTION

An updated membership of the white dwarf population is provided by the on-line version[2] of the Villanova catalog of spectroscopically identified white dwarfs (McCook & Sion 1999). The proper-motion catalogs of Luyten (Luyten 1970, 1977) contributed much to the local census, while deep colorimetric surveys such as the Sloan Digital Sky Survey (SDSS, Harris et al. 2003) and the 2dF Quasar Redshift Survey (Vennes et al. 2002) are uncovering hundreds of new faint white dwarfs. Key questions concerning the spectral evolution of white dwarfs, their spatial distribution and a possible correlation between scale height and mass distribution, and the possible membership of some objects in the Galactic halo population and their fractional contribution to the Galactic dark matter can be answered with large white dwarf samples currently being gathered.

High proper motion surveys are particularly interesting in helping complete the local census of white dwarfs and in identifying possible white dwarf halo candidates. Salim & Gould (2002) have used a $V-J$ reduced proper-motion (RPM) diagram ($V+5\log\mu$ vs. $V-J$) to identify 23 possible nearby white dwarfs among 35,725 stars from their revised New Luyten Two Tenths (NLTT) catalog (Salim & Gould 2003). In following up on these objects, Vennes & Kawka (2003) found five new white dwarfs among 16 candidates, with two of them having a distance that possibly place them within 20 pc of the Sun. Holberg, Oswalt, & Sion (2002) have compiled a list of 109 white dwarfs that lie within 20 pc of the Sun, and they found that the sample is complete to 13 pc and 65% complete to 20 pc. Therefore, ∼50 white dwarfs remain undiscovered within 20 pc of the Sun. In combining accurate photometric, as well as proper-motion, data over a large area of the sky, the SDSS is likely to contribute several new nearby white dwarfs. Harris et al. (2003) have compiled a catalog of 269 white dwarfs that were identified in the first release of the SDSS, only 44 of which were previously known. However, judging from the quoted spectral types and apparent magnitudes, this catalog does not appear to contain any new white dwarfs within 20 pc of the Sun.

Based on our previous analysis of the white dwarf candidates of Salim & Gould (2002), we suggest that the task of identifying white dwarfs among the 36,085 entries in the revised NLTT (rNLTT) requires a combination of proper-motion data, such as the $V+5\log\mu$ versus $V-J$ diagram proposed by Salim & Gould (2002), and colorimetric data, such as the $V-J$ versus $J-H$ diagram used by Vennes & Kawka (2003). The $V-J$ RPM diagram alone still shows substantial cross-contamination, especially among nearby candidates.

In this paper we describe how to fully exploit the rNLTT catalog in identifying new nearby white dwarfs, and we pursue our program of spectroscopic identification of such objects. We report our new spectroscopic observations in § 2.1 and the complementary optical and infrared photometric data in § 2.2, and we present our analysis in § 3. In § 4 we examine some implications of our findings, in particular for the atmospheric

[1] Current address: Department of Physics and Astronomy, 3400 North Charles Street, Johns Hopkins University, Baltimore, MD 21218.
[2] At http://www.astronomy.villanova.edu/WDCatalog/index.htm.

and kinematical properties of the sample of rNLTT white dwarf candidates. We summarize in § 5.

2. OBSERVATIONS

2.1. *Optical Spectroscopy*

The candidates NLTT 529, NLTT 19138, and NLTT 40607 were observed using the modular spectrograph attached to the Hiltner 2.4 m telescope at the Michigan-Dartmouth-MIT Observatory (MDM) on 2002 December 16, 2003 February 3, and June 22. We used the SITE 2048 × 2048 CCD and the 600 line mm^{-1} grating to obtain a spectral range of 4210–7560 Å with substantial vignetting toward the ends of this range. The 1″ slit gave ~3.2 Å spectral resolution (FWHM). The main observing program was focused on accurate radial velocities, and the procedures used gave stability better than 10 km s^{-1}. When observing at substantial air masses, we rotated the slit to the parallactic angle, avoiding atmospheric dispersion losses at short wavelengths. Flux standards were observed nearly every clear night, generally two per twilight, and a calibration for each observing run (typically of four to six nights) was derived from these. In addition, we observed bright B stars to derive approximate corrections for atmospheric absorption bands. Prior to flux calibration all the data were divided by a mean hot-star continuum in order to remove the gross sensitivity variation. The resulting flux calibration was easily fitted with a low-order polynomial. Some flux standard observations were discrepant, evidently because of variations in the fraction of the total light caught by the rather small slit; these were not used. Despite all these precautions, the continua often show a "wavy" distortion of unknown origin. Repeat observations of standards and hot stars show this to be present in the raw data and not an artifact of the calibration process. For this reason, the continua in our MDM data must be interpreted with some caution.

BPM 17113 (WD 0311−543), KUV 05097+1649, BPM 19929 (WD 1013−559), and GD 1212 (WD 2336−079) were observed using the Cassegrain spectrograph attached to the 74 inch (1.9 m) telescope at Mount Stromlo Observatory on 2002 October 19–21, 23, and December 11. We used the 300 line mm^{-1} grating blazed at 5000 Å and the 2k × 4k CCD camera binned 2 × 2. The spectra extend from 3850 to 7300 Å with a dispersion of 2.83 Å pixel^{-1}, and the spectral resolution is ≈8 Å. We obtained frequent FeAr and FeNe arc exposures. The spectra were calibrated with the flux standards EG 131 and EG 21.

NLTT 31748 and NLTT 8435 were observed using the Double Beam Spectrograph attached to the 2.3 m telescope at Siding Spring Observatory (SSO) on 2002 December 16. We used the 300 line mm^{-1} grating blazed at 4200 Å to obtain a spectral range of 3410–6140 Å and the 316 line mm^{-1} grating blazed at 7500 Å to obtain a spectral range of 5530–9120 Å with a dispersion of 2.18 and 2.08 Å pixel^{-1}, respectively. We used two SITE 1752 × 532 CCDs reduced to 1300 × 200 in the red and 1752 × 200 in the blue. We obtained frequent CuAr arc exposures of 20 and 1 s for spectra in the blue and red, respectively. The spectra were calibrated with the flux standard EG 21. The slit was aligned along the parallactic angle.

We observed NLTT 40607, WD 1717−345, and NLTT 49985, 52404, 53468, and 55932 on 2003 June 29 with the same setup as for NLTT 31748 and NLTT 8435, except that the spectral coverage in the blue is 3650–5940 Å, and in the red 5310–8900 Å. The spectra were calibrated with the flux standard EG 131. The data were reduced using the Image Reduction and Analysis Facility (IRAF)[3] routines.

2.2. *V Magnitudes and JHK Photometry*

We used V magnitudes from the revised NLTT catalog of Salim & Gould (2003), except for stars where more accurate photometry from another source was available.

The JHK photometry was obtained from the 2MASS database available at the Centre de Données Astronomique de Strasbourg. The data were converted from the 2MASS to the CIT system using color transformations provided by Cutri et al. (2000).[4]

3. LOCAL WHITE DWARF CANDIDATES

The list of objects that we have observed have been selected from Holberg et al. (2002) and Salim & Gould (2002, 2003). First, we will discuss the three new white dwarfs (NLTT 529, NLTT 19138, and NLTT 40607) and two previously observed white dwarfs (NLTT 8435 and NLTT 31748) from Salim & Gould (2002). Then we will discuss the four new white dwarfs that have been selected from Salim & Gould (2003) using a $V-J$ RPM and a optical-infrared diagram ($V-J$ vs. $J-H$). And, finally, we will discuss the candidates from Holberg et al. (2002), where we confirm that only two of the five candidates observed are white dwarfs. These stars are listed as white dwarfs, but no other form of assessments was offered; therefore their spectral classifications required confirmation. Table 1 lists the white dwarfs observed and includes basic data: the proper motion, the radial velocity from our spectroscopy, and the optical (V) and infrared (2MASS) photometry converted to CIT. Figure 1 shows the spectra of the DA white dwarfs, while Figure 2 shows the spectra of the non-DA white dwarfs.

The Balmer line profiles in the hydrogen-rich stars were analyzed using a χ^2 minimization technique and our grid of cool hydrogen atmospheres introduced in Vennes & Kawka (2003). The adopted errors are 1 σ and correspond to 66% confidence level. The models include convective energy transport as well as relevant broadening mechanisms for the hydrogen lines. The optical/infrared data for the DA and non-DA white dwarfs were analyzed using the calibrated colors of Bergeron, Wesemael, & Beauchamp (1995b) at log g = 8. We used the models of Wood (1995) to calculate the white dwarf masses. The distances are measured using the photometric parallax method, and the velocity components U, V, and W are computed using Johnson & Soderblom (1987). The results of the following analyses are recorded in Table 2.

3.1. *From the Candidate List of Salim & Gould (2002)*

The following stars belong to a list of 23 candidate white dwarfs tabulated by Salim & Gould (2002). Sixteen of these candidates have already been observed by Vennes & Kawka (2003), among them five white dwarf stars. Out of four additional candidates, we now report the discovery of three white dwarf stars.

NLLT 529 is also known as GD 5, and it is listed in Luyten's White Dwarf Catalogue (Luyten 1977) as LP 192-41. This catalog lists probable white dwarfs, which were selected using

[3] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

[4] Available on the World Wide Web at http://www.ipac.caltech.edu/2mass/releases/second/doc/explsup.html.

TABLE 1
CANDIDATE WHITE DWARFS

Name	μ,θ[a] (arcsec yr^{-1}, deg)	v_{rad} (km s^{-1})	V (mag)	$V-J$ (mag)	$J-H$ (mag)	$H-K$ (mag)
NLTT 529	0.237, 193.4	69	15.2 ± 0.2[a]	0.69	0.236	−0.094
NLTT 8435	0.622, 189.0	(0)	15.74 ± 0.07[b]	1.28	0.145	0.145
NLTT 19138	0.258, 166.5	(0)	15.1 ± 0.2[a]	0.76	0.232	0.002
NLTT 31748	0.349, 257.1	70	14.7 ± 0.2[a]	0.48	0.163	−0.025
NLTT 40607	0.248, 221.6	−38	15.07 ± 0.05[c]	0.94	0.246	−0.021
NLTT 49985	0.278, 130.0	51	15.60 ± 0.53[b]	0.65	0.197	0.087
NLTT 52404	0.234, 44.0	(0)	16.26 ± 0.17[b]	0.91	0.210	0.179
NLTT 53468	0.249, 72.0	49	15.30 ± 0.2[a]	−0.60	−0.083	0.372
NLTT 55932	0.339, 106.0	56	13.68 ± 0.06[b]	−0.59	0.010	−0.162
GD 1212	0.050, 140[d]	21	13.748 ± 0.144[e]	0.35	0.072	−0.074
SC 1717−345	...	42	16.28 ± 0.02[f]	0.50	1.566	0.700

[a] From Salim & Gould 2003.
[b] From SPM Catalog 2.0, Platais et al. 1998.
[c] From Eggen 1968.
[d] From Gliese & Jahreiss 1991.
[e] From Kharchenko 2001.
[f] From Reid et al. 1988.

optical colors and proper motion. Therefore, the white dwarf classification required a spectroscopic confirmation. The spectrum in Figure 1 shows this object to be a cool DA white dwarf. We fitted the Balmer line profiles with model spectra to obtain an effective temperature of $T_{\rm eff} = 7420 \pm 100$ K and surface gravity of log $g = 8.15 \pm 0.05$. The quoted errors are 1 σ statistical errors only. Figure 3 shows the Hα and Hβ line profiles fitted with model spectra.

NLTT 19138 is listed as a probable white dwarf in the Luyten White Dwarf Catalog (Luyten 1970), and in the Lowell Proper Motion Survey as G111-64 (Giclas, Burnham, & Thomas 1971), and required a spectroscopic confirmation of its classification. The absence of any absorption or emission features in the spectrum gives this object a DC classification. However, the spectrum shown in Figure 2 displays two broad absorption features at ~5000 and ~6500 Å, which are possibly the result of a fluxing problem with the spectrograph (§ 2.1), and therefore this object needs to be reobserved to confirm the broad absorption features. We measured a temperature of $T_{\rm eff} = 6200$ K based on a χ^2 minimization in the $V-J$ versus $J-H$ diagram for helium models (Bergeron et al. 1995b).

NLTT 40607 is also known as G137-24. Based on *UBV* photometry ($V = 15.07$, $B-V = +0.24$, $U-B = -0.63$), Eggen (1968) classified this star as a white dwarf, but a spectroscopic confirmation was required. Figure 4 shows details of a spectrum of NLTT 40607, which closely resembles the spectrum of the unusual DZ white dwarf G165-7 (Wehrse & Liebert 1980). The spectrum shows numerous heavy-element lines, and Table 3presents some of the identifications. The high heavy-element abundance of G165-7 was unique among DZ

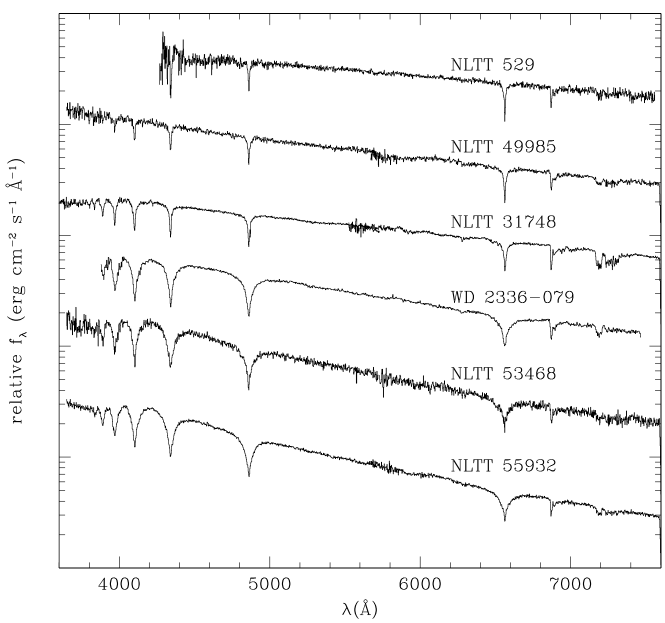

FIG. 1.—Spectra of the DA white dwarfs NLTT 529, NLTT 49985, NLTT 31748, WD 2336-079, NLTT 53468, and NLTT 55932 shown (*top to bottom*) in order of increasing temperature with NLTT 529 being the coolest. The spectra are shown offset for clarity.

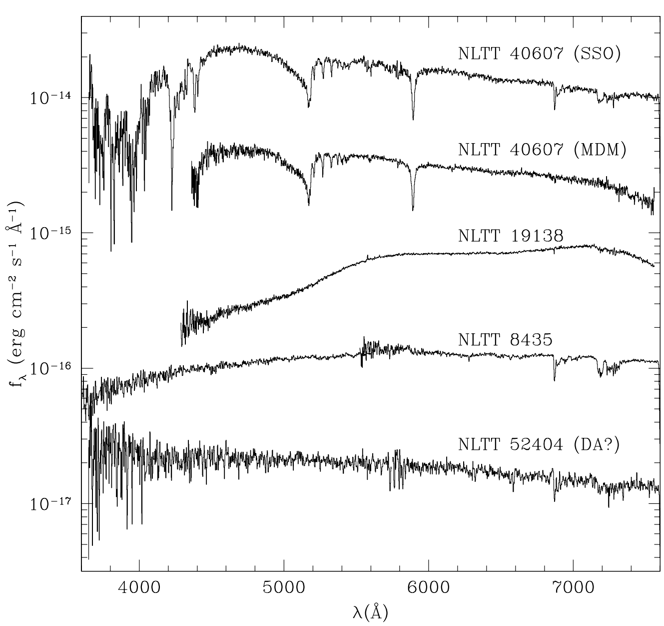

FIG. 2.—Spectra of the non-DA white dwarfs NLTT 40607, 19138, 8435, and 52404. The spectra are shown offset for clarity.

TABLE 2
White Dwarf Parameters and Kinematics

Name	White Dwarf	Spectral type	$T_{\rm eff}$ (K)	log g (cgs)	M ($M_\odot$)	M_V (mag)	d (pc)	U, V, W (km s^{-1})
NLTT 529	0008+423	DA (H)	7420 ± 100	8.15 ± 0.05	0.69 ± 0.03	13.5	22	−5, 61, −37
NLTT 8435	0233−242	DC	5300 ± 200	(8.0)	(0.58)	14.7	16	46, −22, 0
NLTT 19138	0810+489	DC	6200^{+1500}_{-900}	(8.0)	(0.58)	14.0	17	8, −15, 9
NLTT 31748	1242−105	DA (H)	8340 ± 40	8.13 ± 0.09	0.68 ± 0.06	13.0	22	2, −56, 56
NLTT 40607	1532+129	DZ (Mg, Fe, Na, Ca)	∼7500	(8.0)	(0.58)	13.2	24	−8, −30, −16
SC 1717−345	1717−345	DA+dMe (H)	12700 ± 200	7.75 ± 0.25	0.48 ± 0.13	11.2	147	. . .
NLTT 49985	2048−250	DA (H)	7600 ± 100	9.00 ± 0.03	1.24 ± 0.02	14.2	18	39, 6, −40
NLTT 52404	2152−280	DC (H?)	6500 ± 500	(8.0)	(0.58)	13.8	31	−14, 26, −4
NLTT 53468	2215−204	DA (H)	15800 ± 250	7.80 ± 0.08	0.51 ± 0.04	10.9	76	−45, 31, −74
NLTT 55932	2306−220	DA (H)	15120 ± 110	7.85 ± 0.05	0.53 ± 0.03	11.1	33	−10, −9, −65
GD 1212	2336−079	DA (H)	10960 ± 75	8.20 ± 0.10	0.73 ± 0.06	12.1	21	10, 9, −13

white dwarfs (see, e.g., Sion, Kenyon, & Aannestad 1990 and Harris et al. 2003), and the discovery of another object with similar characteristics has implications for the two-phase accretion model of Dupuis, Fontaine, & Wesemael (1993): a similar abundance pattern would imply similar accretion rates. To determine the heavy-element abundance in NLTT 40607, we adopted the G165-7 model of Wehrse & Liebert (1980) at $T_{\rm eff}$ = 7500 K and log g = 8. Using the tabulated temperature, total gas pressure, and electron pressure, we rebuilt a new synthetic spectrum including the strongest lines of Na i (two lines), Mg i (four lines), Ca i (21 lines), Ca ii (two lines), Cr i (33 lines), and Fe i (996 lines). We varied the heavy-element abundance between a nominal 1/30 to a reduced 1/100 solar abundance (where the abundance relative to hydrogen is used relative to helium instead). Figure 4 reveals a good agreement between the data and a model for a 1/100 solar admixture. Wehrse & Liebert (1980) preferred a 1/30 solar admixture in the case of G165-7 but also concluded that the abundances are very uncertain (0.5 dex) and correlated with equally uncertain broadening parameters (van der Waals C_6). In practice, the two stars share similar stellar parameters. A much lower temperature of $T_{\rm eff} = 6000 \pm 400$ K is obtained using a χ^2 minimization in the $V-J$ versus $J-H$ diagram for helium models. Pure helium models do not describe well the observed spectroscopic properties of NLTT 40607, especially in the optical range, which shows heavy-element line blanketing, and the higher temperature estimate should be adopted.

Note that as in G165-7, NLTT 40607 shows an asymmetric Mg i λ5170 profile. This profile cannot be due to the presence of an MgH band, since there is no evidence of Hα or Hβ in the spectrum. Instead, Wehrse & Liebert (1980) suggest that this profile is characteristic of quasi-static van der Waals broadening, and we adopted their modeling technique in the present analysis.

We also obtained additional data for two white dwarfs observed by Vennes & Kawka (2003).

NLTT 8435 was observed by Vennes & Kawka (2003) and was classified as a DC white dwarf with a temperature of 5300 K based on a χ^2 minimization in the $V-J$ versus $J-H$ diagram for helium models. The spectrum which is shown in Figure 2 has a range from 3420 Å up to about 9100 Å. We have fitted the spectrum with a blackbody and found that a best fit occurs at $T_{\rm eff}$ = 4900 K.

NLTT 31748 was also observed by Vennes & Kawka (2003) and was classified as a DA white dwarf with a temperature of 8000 ± 500 K and surface gravity of log $g = 8.40 \pm 0.15$. These parameters were determined using *IUE* and optical spectra, but modeling of the FUV Lyα wing and satellite features is very uncertain. We have observed this star again in the optical at much higher signal-to-noise ratio and measured an effective temperature of 8340 ± 40 K and a surface gravity of log $g = 8.13 \pm 0.09$. Figure 3 shows Balmer line profiles compared with the best-fit model.

3.2. *From the Revised NLTT of Salim & Gould (2003)*

Based on our analysis of the original white dwarf selection of Salim & Gould (2002), we selected additional white dwarfs directly from the revised NLTT catalog of Salim & Gould (2003). First, we selected the candidates using the $V-J$ RPM diagram and by adopting the same demarcation line that Salim & Gould (2002) used to separate the white dwarfs from the subdwarfs.

Vennes & Kawka (2003) found that only one-third of the candidate white dwarfs listed by Salim & Gould (2002) were confirmed, because most of these were close to the demarcation line where substantial contamination by subdwarfs was noted especially among nearby candidates. Therefore, an additional criterion, defined in the $V-J$ versus $J-H$ diagram, is proposed. The white dwarf candidates are chosen if $V-J > 3.28(J-H) - 0.75$, with $V-J$ and $J-H$ in the 2MASS system, as this places the candidates in the white dwarf region of the diagram. The K band was not used in the selection because it is generally too uncertain. Using the $V-J$ RPM diagram alone, we selected 545 objects, further reduced to 417 candidate white dwarfs using the $V-J$ versus $J-H$ diagram. Note that this optical-infrared selection is likely to exclude accidentally composite WD+dM candidates.

NLTT 49985 is listed as a probable white dwarf in the Luyten White Dwarf Catalog (Luyten 1970), but the classification still requires a spectroscopic confirmation. The star was also recovered in the Yale/San Juan Southern Proper Motion (SPM) program and is listed in the SPM Catalog 2.0 of Platais et al. (1998). Figure 1 shows that this is a cool DA white dwarf. We fitted the Balmer line profiles with model spectra to obtain an effective temperature of $T_{\rm eff} = 7600 \pm 100$ K and log g = 9.00 ± 0.03 corresponding to a high mass of 1.24 $M_\odot$. Because they are intrinsically fainter and therefore more difficult to identify, ultramassive white dwarfs are still relatively rare in optical selections. This white dwarf has a mass comparable to several hot, hence young, ultramassive white dwarfs identified in extreme ultraviolet surveys (see Vennes 1999).

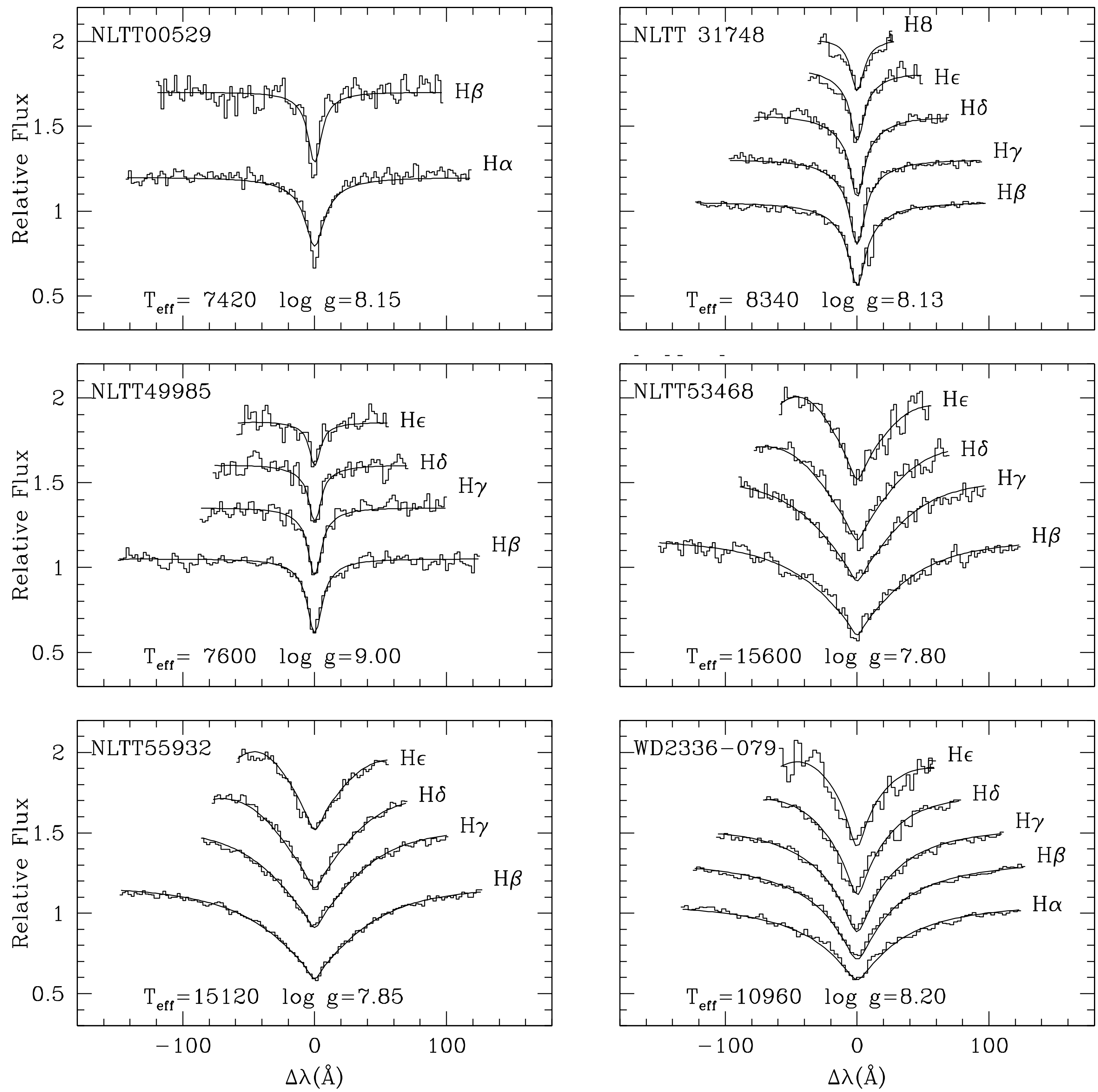

FIG. 3.—Balmer line profiles fitted with model spectra for the DA white dwarfs NLTT 529, 31748, 49985, 53468, 55932, and WD 2336−079

Many more cool ultramassive white dwarfs may populate the solar neighborhood.

NLTT 52404 is also listed in Luyten's White Dwarf Catalog and also requires a spectroscopic confirmation of its classification. Figure 2 shows that this is a cool DC white dwarf with a helium-rich atmosphere. Fitting a blackbody to the spectrum results in an approximate effective temperature of 6500 K, and at this temperature a hydrogen-rich atmosphere would exhibit the Balmer line series. A spectrum with a higher signal-to-noise ratio is required to set a firm upper limit to the hydrogen abundance. The temperature obtained from the $V-J$ versus $J-H$ diagram is 6000 ± 500 K, in agreement with the blackbody estimate.

NLTT 53468 is listed in Luyten's White Dwarf Catalogue and also in the PHL Catalog as PHL 218 (Haro & Luyten 1962) and requires spectroscopic confirmation of its classification. Figure 1 shows that this is a DA white dwarf. We fitted the Balmer line profiles with model spectra to obtain an effective temperature of $T_{\rm eff} = 15{,}800 \pm 250$ and $\log g = 7.80 \pm 0.08$ (Fig. 3).

NLTT 55932 is also known as LTT 9373 and G275-8. This star is also listed in the SPM Catalog 2.0. Figure 1 shows that this is a DA white dwarf. The Balmer line profiles are fitted with model spectra to obtain an effective temperature of $T_{\rm eff} = 15120 \pm 110$ and a surface gravity of $\log g = 7.85 \pm 0.05$ (Fig. 3).

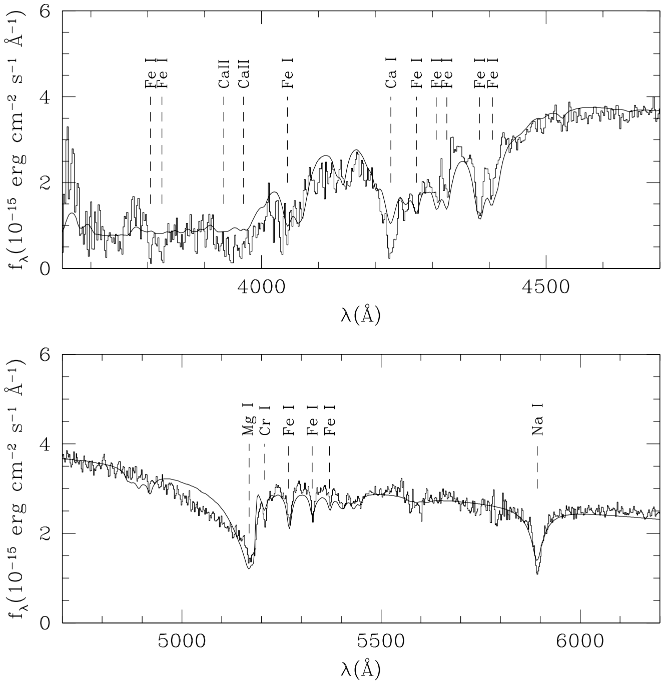

Fig. 4.—Spectrum (SSO) of the DZ white dwarf NLTT 40607 compared with a synthetic spectrum. Main spectral lines are marked.

3.3. *From the Local White Dwarf Sample of Holberg et al. (2002)*

The 109 white dwarfs listed by Holberg et al. (2002) were selected from the fourth edition of the Catalog of Spectroscopically Identified White Dwarfs (McCook & Sion 1999) with two stars selected from alternative sources. The classification of the white dwarfs are based on spectroscopy with varying quality. Bergeron, Ruiz, & Leggett (1997) have observed 37 of the listed white dwarfs with high signal-to-noise spectroscopy with a further 31 white dwarfs observed by Bergeron, Leggett, & Ruiz (2001). Another 17 white dwarfs were observed by Schmidt & Smith (1995) who also observed these objects using a spectropolarimeter. Kawka et al. (2004) observed seven more objects as part of their spectropolarimetric survey of southern white dwarfs. Finally, eight more were observed in other surveys such as that of Putney (1997), Bragaglia, Renzini, & Bergeron (1995), Silvestri et al. (2001), Zuckerman & Reid (1998), and Bergeron, Liebert, & Fulbright (1995a). The three stars, Procyon B, Sirius B, and WD 1917−077 have been part of numerous studies, and WD 1132−325 was found to be a companion to a K0 star (Henry et al. 2002).

Five stars remain in the list that required confirmation. We have observed these five objects and found only two of them to be white dwarfs.

WD 1717−345 was classified a DA by Reid et al. (1988). Based on their *UBV* photometry ($B-V = 0.91$, $U-B = -0.76$), they suggested that the white dwarf may have a cool companion. Figure 5 shows this object to be a DA white dwarf plus red dwarf binary. We have obtained a white dwarf spectrum by subtracting a series of M-type spectra from Pickles (1998) until the TiO bands were not observed in the resulting spectrum. This occurs with a M3.5 V spectrum contributing 90% of the flux at 7500 Å and 50% of the flux at 5500 Å. We then fitted the resulting white dwarf spectrum with model spectra to obtain an effective temperature of $T_{\rm eff} = 12{,}700 \pm 200$ K and a surface gravity of $\log g = 7.75 \pm 0.25$. The corresponding absolute V magnitudes are 11.3 for the white dwarf and 11.4 for the red dwarf, which suggest that the two stars form a physical pair at a distance of 110 pc.

The Hα emission was checked for any variations that may result from orbital motion, but no significant motion in the Hα emission was detected during a 3 hr coverage. However, further observations are required to see whether a period in the order of days exists.

WD 2336−079 was classified as a DA white dwarf by Berger & Fringant (1984) based on unpublished spectroscopy, and we confirm this classification. A summed spectrum was fitted with

TABLE 3

Line Identifications of NLTT 40607

λ (Å)	Element
3805.35	Fe I
3825.88	Fe I
3933.66	Ca II
3968.47	Ca II
4045.81	Fe I
4226.73	Ca I
4271.76	Fe I
4307.90	Fe I
4325.76	Fe I
4383.54	Fe I
4404.75	Fe I
5178.3	Mg I
5208.42	Cr I
5269.54	Fe I
5328.04	Fe I
5369.96	Fe I
5891.8	Na I

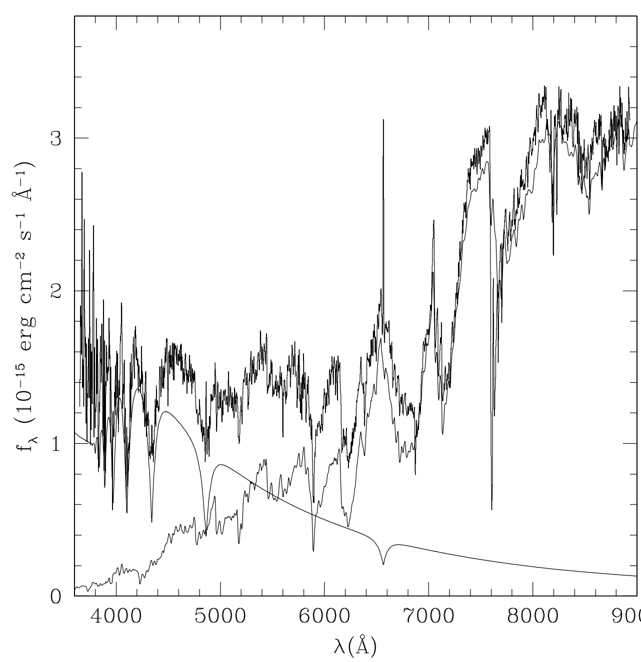

Fig. 5.—Observed spectrum of the DA plus dMe binary WD 1717−345, which has been decomposed into its two components using a white dwarf synthetic spectrum at $T_{\rm eff} = 12{,}700$ K and $\log g = 8.0$ and a M3.5 V template spectrum from Pickles (1998).

model spectra, resulting in an effective temperature of $T_{\rm eff} = 10{,}960 \pm 75$ K and surface gravity of $\log g = 8.20 \pm 0.10$ (Fig. 3).

The objects that were found not to be white dwarfs are listed in Table 4; the spectral types were determined by comparison with template spectra (Pickles 1998). The spectra are shown in Figure 6 where they are compared with a F5 V spectrum (Pickles 1998). To prevent possible confusion with other objects, we also provide recent coordinates measured in the second-epoch digitized sky survey.

BPM 17113 (WD 0311−543) was classified a DZ7 by Wegner (1975), who observed weak Ca II H and K lines, but Wickramasinghe & Bessell (1977) reclassified the object as "sdG." The spectrum in Figure 6 shows the presence of Ca II lines and narrow Balmer lines, which suggests that this star is a F-type star. *UBV* photometry ($B-V = 0.52$, $U-B = -0.42$) by Eggen (1969) places this star on the white dwarf sequence; however, Strömgren photometry ($b-y = 0.402$, $u-b = 1.524$) by Wegner (1979) places this star on the main sequence.

KUV 05097+1649 was classified a DA by Wegner & McMahan (1988), when they obtained follow-up spectroscopy for the Kiso Schmidt camera survey. Figure 6 shows the presence of Ca II lines and narrow Balmer lines, and therefore this object is a F-type star. *UBV* photometry ($B-V = 0.65$, $U-B = 0.20$) by Wegner, Africano, & Goodrich (1990) places the star on the main sequence.

BPM 19929 (WD 1013−559) was classified a DZ by Wegner (1973), who observed Ca II lines, but Wickramasinghe & Bessell (1977) reclassified the object as "sdGp." Figure 6 shows that WD 1013−559 has Ca II lines and weak Balmer lines, which suggests that this object is a F-type star. *UBV* photometry ($B-V = 0.68$, $U-B = -0.12$) by Eggen (1969) places this star on the white dwarf sequence; however, Strömgren photometry ($b-y = 0.445 \pm 0.023$, $u-b = 1.434 \pm 0.052$) by Wegner (1979) places this star on the main sequence.

4. DISCUSSION

Our results suggest that combining the $V-J$ RPM selection of Salim & Gould (2002) with a $V-J$ versus $J-H$ color selection results in new white dwarf identifications. We now examine the complete selection using these two criteria, in particular the color and kinematical properties.

4.1. *Optical-Infrared Sample*

The $V-J$ RPM preselection follows the criterion established by Salim & Gould (2002, 2003) and the subsequent optical-infrared selection is described in § 3.2. The total number of candidate white dwarfs extracted from the rNLTT in this manner reaches 417 objects. Among these objects, 217 are spectroscopically identified white dwarfs, including our own new identifications, and 200 are new candidates. None of the remaining 200 candidates have plausible counterparts among other classes of objects, with the exception of one listed sdB star, which may be a misclassified DA star. Many of the 200 objects are listed as suspected white dwarfs in the various Luyten's catalogs and are awaiting spectroscopic confirmation. Note that all four objects blindly selected in this manner are indeed white dwarfs (§ 3.2), and there is a high probability that the majority of the remaining 200 candidates in the rNLTT are also white dwarfs.

Figure 7 shows the optical-infrared locus of the RPM-selected objects. The objects above the dividing line are either nonwhite dwarfs or composite spectra possibly including a white dwarf component. Objects below the line are, within error bars (0.1–0.2 mag), following predicted white dwarf colors.

The absolute magnitudes for all 417 objects are estimated using absolute magnitude M_V versus $V-J$ relations for H- and He-rich atmospheres (Bergeron et al. 1995b) and the observed $V-J$. Many objects are found beyond the maximum $V-J$ for H-rich stars and are assumed to be He-rich. The resulting $M_V^* = f(V-J)$ is compared with M_V obtained from a detailed analysis of 81 objects by Bergeron et al. (1997) and Bergeron, Leggett, & Ruiz (2001). The two measurements are tightly correlated but with a systematic deviation corresponding to a linear correction $M_V = 1.25M_V^* - 3$. Therefore, all measurements are corrected using the previous relation, and the distances are then estimated using the photometric parallax method.

4.2. *Kinematics*

We now examine the kinematical properties of the sample of 417 color-selected white dwarfs. The velocity components *U*, *V*, and *W* were computed using Johnson & Soderblom (1987) and assuming $v_{\rm rad} = 0$. This assumption may reduce the number of objects identified as thick disk candidates, as opposed to thin disk, by almost a quarter (Pauli et al. 2003). The velocity components should be redetermined after radial velocities become available to confirm the kinematical classifications. All three distributions, *U*, *V*, and *W*, are well fitted with Gaussian functions, where (σ_U, σ_V, σ_W) = (41, 23, 22) and ($\langle U\rangle$, $\langle V\rangle$, $\langle W\rangle$) = (1, −21, −2), in agreement with Anselowitz et al. (1999), although our *V* distribution appears somewhat narrower. Our distributions along all three components are narrower than measured by Sion et al. (1988). The average velocity component $\langle V\rangle = -21$ is markedly more negative than the velocity component of normal stars in the thin disk (Binney & Merrifield 1998, $\langle V\rangle = -6$ km s^{-1}), which suggested the label "old thin disk" (Sion et al. 1988). The integrated area of the Gaussian fit to the *U* distribution corresponds to 416 objects out of 417, with WD 2316−065

TABLE 4

NONWHITE DWARF STARS

Name	Spectral Type	μ,θ (arcsec yr^{-1}, deg)	*V* (mag)	R.A. (J2000.0)	Decl. (J2000.0)	Epoch
BPM 17113 (WD 0311−543)........	F5 V	0.081, 163	14.75[a]	03 12 46.66	−54 06 29.7	1994.929
KUV 05097+1649	F2 V	. . .	14.35[b]	05 12 33.52	+16 52 09.1	1993.856
BPM19929 (WD1013−559)	F3 V	0.136, 298	15.10[a]	10 14 58.60	−56 11 12.8	1996.153

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.
[a] From Eggen 1969.
[b] From Wegner et al. 1990.

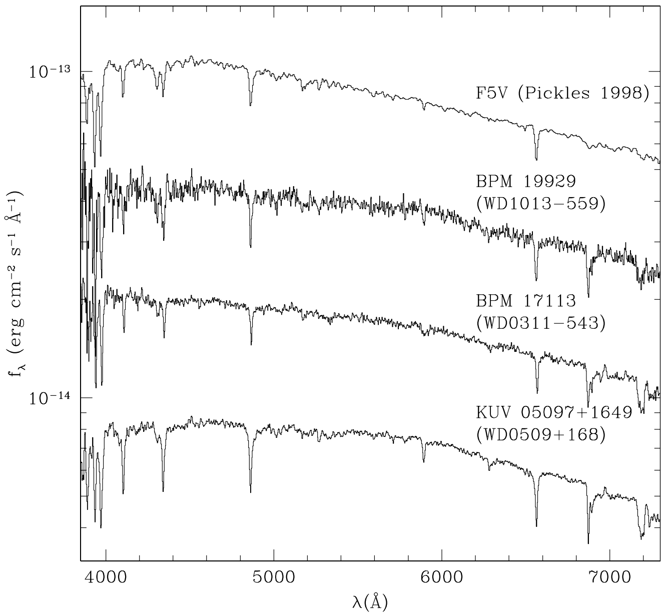

FIG. 6.—Spectra of BPM 19929 (WD 1013−559), BPM 17113 (WD 0311−543), and KUV 05097+1649 compared with a F5 V template from Pickles (1998).

(LHS 542) the only peculiar object in the U distribution. The integrated area of the Gaussian fit to the V distribution corresponds to only 395 objects. The V distribution shows an extended tail of ~22 high-velocity objects near $V = -70$, -120 km s^{-1}. Finally, the Gaussian fit to the W distribution corresponds to 408 objects. Therefore, at least 395 objects, out of 417, appear to belong to the same population, which we identify with the thin disk.

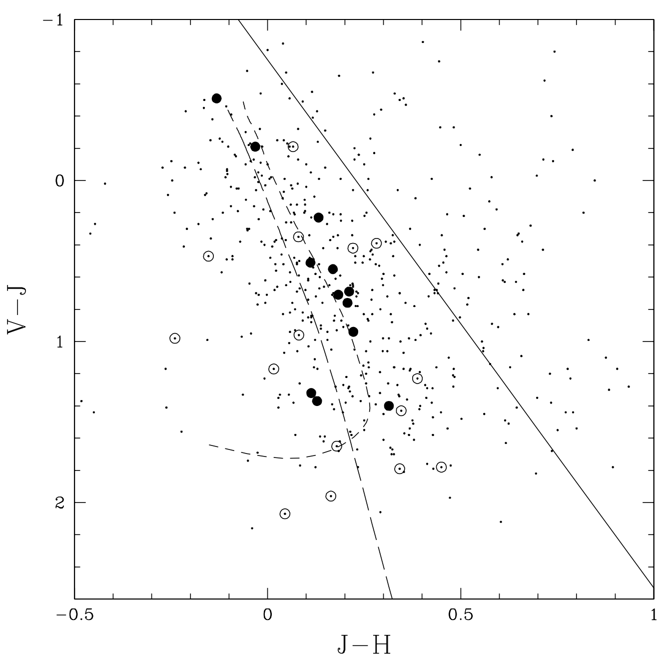

FIG. 7.—Optical-infrared photometry of all the white dwarf candidates selected using the RPM diagram. The white dwarf candidates are all below the solid line and they are compared with the hydrogen (*short-dashed line*) and helium (*long-dashed line*) sequences with log $g = 8$. The large filled circles correspond to the sample of newly identified rNLTT white dwarfs (Vennes & Kawka 2003 and this work), and the open circles correspond to the white dwarfs with large velocity (Table 5).

Figure 8 shows the measurements in the U versus V plane. The measurements are compared with velocity ellipses, and, as noted above, most objects belong to the thin disk. Where should we expect to find thick disk and halo stars? Chiba & Beers (2000) determined $(\sigma_U, \sigma_V, \sigma_W) = (141, 106, 94)$ and $\langle V \rangle = -187$ for halo stars, based on the kinematics of metal-poor stars, and also determined $(\sigma_U, \sigma_V, \sigma_W) = (46, 50, 35)$ and $\langle V \rangle = -20$ for thick disk stars.

We find 344 objects residing inside the 2 σ thin disk ellipse described by the relations

$$\left(\frac{U}{2\sigma_U}\right)^2 + \left(\frac{V}{2\sigma_V}\right)^2 < 1$$

or

$$\left(\frac{U}{\sigma_U}\right)^2 + \left(\frac{V}{\sigma_V}\right)^2 < 4,$$

where U and V have been centered on their mean values. Both distributions in U/σ_U and V/σ_V are normal. The combined distribution is a bivariate normal density distribution. The probability of finding thin disk objects within the 2 σ ellipse is given by integrating the probability density function inside the ellipse:

$$P\left[(U/\sigma_U)^2 + (V/\sigma_V)^2 < 4\right] = \frac{1}{2\pi}\int_{-2}^{2} e^{-u^2/2} \int_{-\sqrt{4-u^2}}^{\sqrt{4-u^2}} e^{-v^2/2}\, dv\, du,$$

or

$$P(2\ \sigma) = 0.8646,$$

where $u = U/\sigma_U$ and $v = V/\sigma_V$. Assuming that 395 objects are genuine thin disk members, we predict that 342 of them

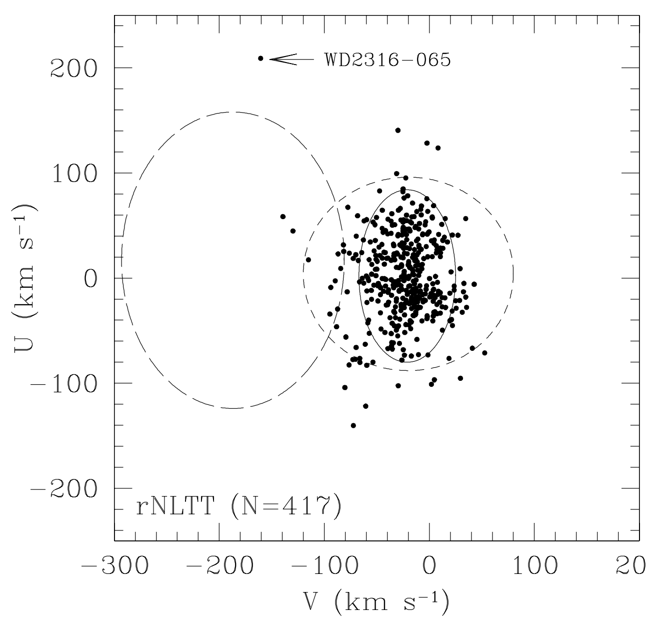

FIG. 8.—U vs. V diagram showing 417 color-selected rNLTT white dwarfs. The 2 σ velocity ellipse of the identified thin-disk population is shown (*full line*) along with the 2 σ ellipse of the thick disk (*short dashed line*), and the 1 σ ellipse of the halo (*long dashed line*) populations. The halo candidate LHS 542 (WD 2316−065) is marked.

TABLE 5
High-Velocity NLTT Objects (UV > 100 km s^{-1})

NLTT	WD	V	M_V[a]	UV
17486	...	15.87	13.22	101.0
54047	...	17.82	14.65	104.7
8733	...	16.73	13.22	104.9
43149	1633+571	15.27	14.21 (14.19)	102.5
26933	1115−029	15.11	12.02 (12.44)	107.5
14558	...	17.69	14.65	113.0
6996	...	18.24	15.18	113.7
31347	...	17.53	14.21	115.2
32057	1247+550	17.74	15.50 (15.78)	119.7
32727	1300+263	18.68	15.87 (16.04)	124.5
431	0007+308	16.80	13.22 (12.89)	131.1
53283	2211+372	16.70	13.22 (14.3)	132.6
30094	1212−023	17.85	14.21 (14.1)	140.7
24793	1033+714	16.99	15.50 (15.4)	145.2
56473	2316−065	18.08	15.50 (15.69)	243.9[b]

[a] In parentheses, M_V from Bergeron et al. 1997 and 2001.
[b] With $v_T > 250$, Liebert et al. 1989.

should reside within the 2 σ ellipse, in agreement with the data (344). It would therefore appear that only 22 objects from the sample belong to either the thick disk or the halo. The white dwarf WD 2316−065 is already recognized as a halo candidate (Liebert, Dahn, & Monet 1989). Two objects in Figure 8 reside within the 1 σ halo region at the exclusion of all other regions and are also excellent halo candidates (NLTT 8733 and NLTT 32057=WD 1247+550). Overall, ≈5% of the sample may belong to the thick disk, and ≈1% to the halo.

Table 5 presents a sample of 15 high-velocity stars selected by placing a velocity cutoff at $UV = [U^2 + (V + 35)^2]^{1/2} > 100\ ^{-1.}$ Nine are previously known white dwarfs, including the halo candidate WD 2316−065, and six are new. Figure 7 shows that our high-velocity stars do agglomerate toward low luminosities (V–$J \sim 2$) and are characteristically old stars. But do these objects have the correct kinematics and not simply large tangential velocities, i.e., is $V \sim -200$? Three of our objects seem to conform to this requirement.

Recently, Pauli et al. (2003) proposed that a very high fraction of 4% of white dwarfs belong to the halo, based on kinematics and Galactic orbit calculations. Most objects from their selection are young. The luminosity function for halo white dwarfs (Liebert et al. 1989; Hansen 2001) is likely to peak at very low luminosity, and the fraction of luminous halo candidates in the sample of Pauli et al. (2003) might imply, when extrapolated to lower luminosity, that all cool white dwarfs are halo members. Another explanation is that the peculiar velocity of some white dwarfs may be the result of past binary interaction (Hansen 2003).

5. SUMMARY

We have identified seven new white dwarfs from the rNLTT survey of Salim & Gould (2003), including three objects proposed by Vennes & Kawka (2003) based on their optical-infrared colors. Parallax measurements of the new nearby objects should be obtained.

We also found that three objects still listed in nearby samples of white dwarfs (Holberg et al. 2002) are definitely not white dwarfs (BPM 17113, KUV 05097+1649, and BPM 19929) and that SC 1717−345 is a distant binary system, taking away four objects from the sample with $d < 20$ pc. Three of these were also comprised in the sample with $d < 13$ pc. Because we added four objects in the $d < 20$ pc sample, this census remains unaltered. However, the three objects removed from the $d < 13$ pc sample reduce the estimate of Holberg et al. (2002) of the local white dwarf space density by 6%. Note that recent discoveries may replenish that sample (e.g., Jao et al. 2003).

We also show that the RPM of Salim & Gould (2003), combined with detailed 2MASS information, is an effective means to identify new white dwarfs. We propose to follow-up spectroscopically 200 candidate white dwarfs, including a number of high-velocity objects. Radial velocity measurements for the sample of 417 color-selected white dwarfs should also be obtained to improve the kinematics.

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