SSSPM J1549−3544 IS NOT A WHITE DWARF

J. Farihi\textsuperscript{1,2}, P. R. Wood\textsuperscript{3}, & B. Stalder\textsuperscript{4}

ABSTRACT

Spectroscopy and photometry demonstrate that SSSPM J1549−3544 is not a cool white dwarf but a high velocity metal-poor halo star.

Subject headings: stars: kinematics — stars: fundamental parameters — stars: individual (SSSPM J1549−3544) — subdwarfs — white dwarfs

1. INTRODUCTION

Cool white dwarfs are typically identified through the combination of proper motion and apparent magnitude called reduced proper motion (Liebert et al. 1979; Gizis & Reid 1997; Salim & Gould 2002, 2003; Lépine & Shara 2005). At a given brightness and color, white dwarfs will have larger proper motions than main sequence stars owing to closer distances from the Earth implied by their small radii.

Metal-poor stars, or subdwarfs, also stand out well in reduced proper motion diagrams due to their lower luminosities (for the same color class) and typically higher velocities. Subluminous main sequence stars which distinguish themselves in reduced proper motion are kinematic members of the thick disk and halo (Mihalas & Binney 1981; Binney & Tremaine 1987; Binney & Merrifield 1998). Subdwarfs have long been a contaminant in surveys aiming to find cool white dwarfs because both stellar types are mixed in a reduced proper motion diagram at intermediate colors. Cool white dwarfs must be confirmed spectroscopically (Liebert et al. 1979; Gizis & Reid 1997; Salim & Gould 2002; Farihi 2004; Kilic et al. 2004).

Current complete and ongoing large-scale proper motion surveys are discovering numerous exotic objects including extreme subdwarfs, brown dwarfs, and cool white dwarfs.

\textsuperscript{1}Gemini Observatory, Northern Operations, 670 North A'ohoku Place, Hilo, HI 96720; jfarihi@gemini.edu

\textsuperscript{2}Department of Physics & Astronomy, University of California, Los Angeles, CA 90095

\textsuperscript{3}Research School of Astronomy & Astrophysics, Australian National University, Cotter Road, Weston Creek ACT 2611, Australia; wood@mso.anu.edu.au

\textsuperscript{4}Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822; bstalder@ifa.hawaii.edu
(see Oppenheimer et al. (2001); Scholz et al. (2004); Lépine & Shara (2005) and references therein). Most if not all of these searches are utilizing available large-scale optical photographic sky survey catalogs. This is potentially problematic for the identification of cool white dwarfs because optical photographic bandpasses do not yield broad color baselines, and photographic photometry has intrinsically large errors. These facts lead to a large overlap in the white dwarf and subdwarf sequences in reduced proper motion diagrams (Salim & Gould 2002). Yet even with spectroscopy, subdwarfs and other weak-lined objects can appear featureless in low resolution and/or low signal-to-noise (S/N) measurements – potentially mistaken as DC white dwarfs (McCook & Sion 1999; Farihi 2004). Identification of degenerates with $T_{\text{eff}} = 4000 - 5000$ K should include good S/N spectroscopy covering blue-green optical wavelengths (Farihi 2004; Kilic et al. 2004).

Contrary to the claim of Scholz et al. (2004), this paper presents evidence that the high proper motion star SSSPM J1549−3544 ($15^h\ 48^m\ 40.23^s, -35^\circ\ 44'\ 25.5''$, J2000) is neither the nearest cool white dwarf nor a degenerate star, but rather a very high velocity halo star passing through the solar neighborhood.

2. OBSERVATIONS & DATA

Optical $BVRI$ photometric data were obtained 14 February 2005 with the Orthogonal Parallel Transfer Imaging Camera (OPTIC; Tonry et al. 2002) on the University of Hawaii 2.2 meter telescope at Mauna Kea. Observing conditions were photometric with seeing $\sim 1.0''$ and some gusty winds 20 – 40 mph. Three identical exposures of SSSPM J1549−3544 were taken at each bandpass for a total integration time of 12 – 30 seconds, yielding S/N $> 10$ at all wavelengths in a 0.7'' aperture radius. A standard Landolt field (Landolt 1992) was observed similarly immediately following the science target.

The images were flat fielded, cleaned of bad pixels in the region of interest, and combined into a single frame at each wavelength for photometry. Calibration was performed with three stars and aperture photometry was executed using standard IRAF packages. Calibrator stars were measured in a 1.4'' aperture radius and the science target data were corrected to this standard aperture and adjusted for relative extinction. The results are listed in Table 1.

Optical 4200−10000 Å spectroscopic data were obtained 18 March 2005 with the Double Beam Spectrograph (DBS; Rodgers et al. 1988) on the Australian National University 2.3m Telescope at Siding Spring Observatory. Only the red arm of the spectrograph was operated, with no dichroic in the beam. The 158 l/mm grating used gave a spectral resolution of 10 Å (2.5 pixels) with the 2'' slit. The seeing was $\sim 2.3''$ and the sky was clear.
SSSPM J1549−3544 and the flux calibrator LTT 6248 were each observed for 600 seconds, yielding S/N > 20 over the majority of the science target wavelength shown in Figure 1. The spectral images were flat fielded, cleaned of bad pixels in the region of interest, and flux calibrated spectra were extracted using standard IRAF packages. The spectra were trimmed to show the region of interest, while no attempt was made to remove telluric features.

3. RESULTS

The combined optical and near-infrared colors of SSSPM J1549−3544 are consistent with a main sequence star of $T_{\text{eff}} \sim 4200$ K, late K spectral type (Bessell & Brett 1988). The near-infrared magnitudes are too bright for known cool and ultracool white dwarfs (Farihi 2005). For example, the reddest known degenerates have colors which peak near $I - K \lesssim 1.1$, after which they become bluer again as shown by observation and models (excepting pure helium models at $T_{\text{eff}} \lesssim 4250$ K; Bergeron et al. 1995, 2001), while SSSPM J1549−3544 has $I - K_s = 1.58$.

The spectrum in Figure 1 confirms the status of SSSPM J1549−3544 as a nondegenerate star, and the deep MgH feature near 5200 Å indicates it is metal-poor (Reid & Hawley 2000). Other unlabelled spectral features present include: weak Hα, several Fe and Ca lines, plus some weak CaH and TiO. These latter features are difficult to distinguish as they are located, for the most part, within and around the prominent telluric bands (Kirkpatrick et al. 1991) which are also seen in the calibrator star spectrum.

Following the methodology of Gizis (1997), a spectral type and subdwarf class of SSSPM J1549−3544 was estimated by measuring the TiO5, CaH1, CaH2, & CaH3 spectroscopic indices, which are listed in Table 2. Using equations 1−3 in Gizis (1997), a spectral type of K5 is found consistently across all three relations, and type sdK5 is found using equation 7 in the same work. However, given the fact that the spectral resolution achieved here is $\sim 3$ times lower than that of Gizis (1997), the spectroscopic measurements may be unreliable but are presented here as a rough guide. There are no distinctions between sdK and esdK stars before spectral type K7, and, combined with the uncertain spectroscopy, it is difficult to say whether or not SSSPM J1549−3544 is an extreme subdwarf without a direct metallicity measurement. The MgH band near 5200 Å is quite strong and an extreme subdwarf classification might be appropriate (Reid & Hawley 2000).

In order to assess the kinematics of SSSPM J1549−3544, a distance must be estimated. Conservatively assuming this star lies two magnitudes below the main sequence at spectral type K5, it would have $M_V \approx 9.5$ mag (Drilling & Landolt 2000; Reid & Hawley 2000).
This would place the star at $d = 114$ pc with a tangential speed of 430 km s$^{-1}$ based on the astrometric data in Scholz et al. (2004). Furthermore, fourteen spectral lines (many without high S/N) were used to measure the radial velocity, the crude result being $v_r = +210 \pm 70$ km s$^{-1}$, corrected for the motion of the Earth along the line of sight on the date of observation. Combining all this data, a Galactic $UVW$ space motion was calculated, corrected for the solar motion, $(U, V, W) = (-9, +12 + 7)$ km s$^{-1}$ (Mihalas & Binney 1981), relative to the local standard of rest ($U$ positive toward the Galactic anticenter, $V$ positive in the direction of Galactic rotation, $W$ positive toward the North Galactic Pole). The result is $(U, V, W) = (-46, -465, +42)$ km s$^{-1}$, making SSSPM J1549−3544 a halo star (Jahreiß & Wielen 1997; Beers et al. 2000). If we instead assume $v_r = 0$ due to the potential unreliability of the measured radial velocity, the result becomes $(U, V, W) = (143, -392, -10)$ km s$^{-1}$, which is still consistent with halo membership. Despite a fairly conservative assumption, the 114 pc distance estimate and space motions should be considered preliminary as subdwarfs can span a wide range of absolute magnitudes. If SSSPM J1549−3544 is closer to 150 pc, or around 1.5 magnitudes below the main sequence, it would have a total heliocentric velocity in the range 550 – 590 km s$^{-1}$. At one magnitude below the main sequence, or 180 pc, SSSPM J1549−3544 would have a total Galactocentric velocity of $\sim 470$ km s$^{-1}$ and would be among the fastest moving stars ever seen (Carney et al. 1988, 1996).

4. CONCLUSION

The star SSSPM J1549−3544 is shown to be a metal-poor sdK star rather than a cool white dwarf as previously claimed (Scholz et al. 2004). It is possible this star is an extreme K subdwarf, but in any case it is a very high velocity halo star passing through the solar neighborhood. With many new proper motion objects being discovered and studied, it is critical to correctly distinguish cool white dwarfs from subdwarf contaminants. There is great science potential in the oldest degenerates.

Some data used in this paper are part of the Two Micron All Sky Survey, a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center / California Institute of Technology, funded by the National Aeronautics and Space Administration (NASA) and the National Science Foundation. J. Farihi acknowledges support by grants from NASA. PRW acknowledges the support provided by a grant from the Australian Research Council.
REFERENCES

Beers, T., Chiba, M., Yoshii, Y., Platais, I., Hanson, R., Fuchs, B., & Rossi, S. 2000, AJ, 119, 2866

Bergeron, P., Leggett, S., & Ruiz, M. 2001, ApJS, 133, 413

Bergeron, P., Wesemael, F., & Beauchamp, A. 1995, PASP, 107, 1047

Bessell, M. S., & Brett, J. M. 1988, PASP, 100, 1134

Binney, J., & Merrifield, M. 1998, in Galactic Astronomy, (New Jersey: Princeton)

Binney, J., & Tremaine, S. 1987, in Galactic Dynamics, (New Jersey: Princeton)

Carney, B. W., Laird, J. B., Latham, D. W. 1988, AJ, 96, 560

Carney, B. W., Laird, J. B., Latham, D. W., & Aguilar, L. A. 1996, AJ, 112, 668

Cutri, R., et al. 2003, 2MASS All Sky Catalog of Point Sources (IPAC/CIT)

Farihi, J. 2004b, Ph.D. Thesis, UCLA¹

Farihi, J. 2005, AJ, 129, 2382

Gizis, J. E. 1997, AJ, 113, 806

Gizis, J. E., & Reid, I. N. 1997, PASP, 109, 849

Jahreiß, H., & Wielen, R. 1997, Hipparcos '97, ed. B. Battrick (Noordwijk: ESA SP-402), 675

Drilling, J. S., & Landolt, A. U. 2000, in Allen’s Astrophysical Quantities, 4th edition, ed. A. N. Cox (New York: Springer-Verlag), 388

Kirkpatrick, J., Henry, T., & McCarthy, D. 1991, ApJS, 77, 417

Landolt, A. U. 1992, AJ, 104, 340

Lépine, S. & Shara, M. M. 2005, AJ, 1483

Liebert, J., Dahn, C. C., Gresham, M., Strittmatter, P. A. 1979, ApJ, 233, 226

¹Available at http://www.whitedwarf.org
Kilic, M., Winget, D. E., von Hippel, T., & Claver, C. F. 2004, AJ, 128, 1825

McCook, G., & Sion, E. 1999, ApJS, 121, 1

Mihalas, D., & Binney, J. 1981, in Galactic Astronomy, (San Francisco: W. H. Freeman & Co.)

Oppenheimer, B. R. Hambly, N. C., Digby, A. P., Hodgkin, S. T., & Saumon, D. 2001, Science, 292, 698

Reid, I., & Hawley, S. 2000, in New Light on Dark Stars, (New York: Springer)

Rodgers, A. W., Conroy, P., & Bloxham, G. 1988, PASP, 100, 626

Salim, S., & Gould, A. 2002, ApJ, 575, 83

Salim, S., & Gould, A. 2003, ApJ, 582, 1011

Scholz, R., Lehmann, I., Matute, I., & Zinnecker, H. 2004, A&A, 425, 519

Tonry, J. L., Luppino, G. A., Kaiser, N., Burke, B. E., & Jacoby, G. H. 2002, SPIE, 4836, 206

This preprint was prepared with the AAS LaTeX macros v5.2.
Fig. 1.— Optical spectrum of SSSPM J1549–3544 taken with the Double Beam Spectrograph on the 2.3 meter telescope at Siding Springs Observatory. The data are flux calibrated and normalized near 5500 Å. The most prominent stellar absorption features are labelled along with telluric O$_2$ and H$_2$O bands. The spectral type should be considered preliminary (§3).
Table 1. Optical & Near Infrared Photometric Data

| Band | $\lambda_0$ (\(\mu\)m) | SSSPM J1549–3544 (mag) |
|------|-----------------|-----------------|
| $B$  | 0.44            | 16.13           |
| $V$  | 0.55            | 14.78           |
| $R$  | 0.64            | 14.00           |
| $I$  | 0.80            | 13.20           |
| $J$  | 1.25            | 12.34           |
| $H$  | 1.63            | 11.77           |
| $K_s$| 2.16            | 11.62           |

Note. — The uncertainties are all $\leq 5\%$. $JHK_s$ data are taken from 2MASS (Cutri et al. 2003).
Table 2. Spectroscopic Measurements

| Band   | Strength |
|--------|----------|
| TiO5   | 0.986    |
| CaH1   | 0.983    |
| CaH2   | 1.034    |
| CaH3   | 0.997    |

Note. — Spectroscopic Band Measurements of SSSPM J1549−3544, using the method of Gizis (1997). A spectral type of sdK5 is found on the basis of these data.