AN ASTROMETRIC COMPANION TO THE NEARBY METAL-POOR, LOW-MASS STAR LHS 1589.1,2

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ABSTRACT

We report the discovery of a companion to the high proper motion star LHS 1589, a nearby high-velocity, low-mass subdwarf. The companion (LHS 1589B) is located 0.220 ± 0.004″ to the southwest of the primary (LHS 1589A), and is 0.5 magnitude fainter than the primary in the Ks band. The pair was resolved with the IRCAL infrared camera at Lick Observatory, operating with the Laser Guide Star Adaptive Optics system. A low-resolution spectrum obtained at MDM observatory confirms that the system consists of a pair of low-mass subdwarfs, with a composite spectral type sdK7.5. A photometric distance estimate places the system at a distance d = 78 ± 18 parsecs from the Sun. We also measure a radial velocity \( v_{\text{rad}} = 75 \pm 25 \text{km s}^{-1} \), which, together with the proper motion and estimated distance, suggests that the star is roaming the inner Galactic halo on a highly eccentric orbit. With a projected orbital separation \( s = 17.2 \pm 4.8 \text{ AU} \), we estimate the orbital period of the system to be in the range 95 yr < \( P < 370 \) yr. This suggests that the dynamical mass of the system could be derived astrometrically, after monitoring the orbital motion over a decade or so. The LHS 1589AB system could thus provide a much needed constraint to the mass-luminosity relationship of metal-poor, low-mass stars.

Subject headings: astrometry — stars: double — stars: kinematics — Galaxy: kinematics and dynamics — solar neighborhood

1. INTRODUCTION

Astrometric binaries, defined as physical pairs whose projected orbital motions can be mapped out, are objects of high interest in astrophysics because the gravitational masses of the components can be directly calculated. Such systems are critical in constraining the mass-luminosity relationship (MLR), one of the most fundamental relationships in astrophysics.

The MLR allows one to convert the luminosity function (LF), an observable quantity, into the mass function or initial mass function (IMF) which is fundamental in understanding stellar populations (D’Antona 1998). The MLR is particularly critical to obtain reliable estimates of the stellar mass function and baryonic content of the Galaxy (Chabrier & Barbuy 1997; Phelps et al. 2000). The MLR further provides constraints to stellar evolutionary models (Baraffe et al. 1998). Differences have been observed in the luminosity functions of open and globular clusters which are best explained by a dependence of the MLR with metallicity (von Hippel et al. 1996). It is thus important to obtain calibrations of the MLR for stars over a wide range of metallicities.

There is extensive literature on the topic of low-mass astrometric doubles and the calibration of the MLR for relatively metal-rich (Population I), low-mass stars. Early calibrations, in the classic papers by Liebert & Probst (1987) and Henry & McCarthy (1993), relied on relatively few systems with well determined orbits and masses. Other known double stars have since had their orbits monitored with speckle interferometry (Mason et al. 1999; Witt et al. 2000), or with the Fine Guidance Sensor on HST (Franz et al. 1998; Henry et al. 1999; Torres et al. 1999; Benedict et al. 2000), yielding accurate masses for both components. New close doubles have also been resolved among nearby disk dwarfs with the NICMOS camera on HST (Pravdo et al. 2004), with adaptive optics (AO) observations from CFHT (Delfosse et al. 1999b) and from Palomar (Pravdo, Shaklan, & Lloyd 2005), and with Laser Guide Star Adaptive Optics (LGSAO) observations from Keck (Pravdo et al. 2006).

In contrast, there exists no calibration of the mass-luminosity relationship for metal-poor (Population II), low-mass stars. Perhaps the chief reason for this is that most metal-poor stars in the vicinity of the Sun are kinematically associated with the Galactic halo population, and are thus relatively scarce. Most studies estimate there is one halo star in the Solar Neighborhood for each 200-300 disk stars, which means that one expects to find only ~20 halo stars within 25 parsecs of the Sun. Numerous wide common proper motion doubles have however been identified as probable halo subdwarfs (Chanamé & Gould 2004), which suggests that the binary frequency among old metal-poor stars may be as high as that of the local disk population. Recently, a companion was resolved only 0.15″ from the nearby (~100pc) metal-poor sdG2 subdwarf Ross 530 (Law et al. 2006). If they could be found, subdwarf doubles with components of lower masses (sdK/sdM), and with separations short enough for the orbital motion to be astrometrically monitored, would be of great value to astronomy.

We have recently undertaken a massive study of the local population of metal-poor, low-mass stars, following the identification of thousands of high-velocity subdwarfs in the new LSPM-north catalog of stars with proper motions \( \mu > 0.15 \) yr\(^{-1} \) (Lépine & Shara 2005) and in its upcoming southern-sky complement, the LSPM-south (Lépine et al. 2007, in preparation). In this Letter, we report the discovery of a close companion to the high proper motion star LHS 1589, which our spectroscopic observations confirm to be a metal-poor, cool...
FIG. 1.— Multi-epoch chart of the high proper motion star LHS 1589 generated from the Digitized Sky Surveys. The field is 4.25′ on the side. Left: first Palomar Sky Survey image (POSS-I) circa 1954.0. Right: Second Palomar Sky Survey image (POSS-II) circa 1988.9. The motion of LHS 1589 is quite apparent. The box shows the location of the field imaged with the Lick Adaptive Optics system on October 2006.

FIG. 2.— Adaptive optics image of LHS 1589, resolving this high proper motion star into two distinct sources. The secondary is found 0.220″ ± 0.004″ to the southwest of the primary. The image shown here represents only the central part of the full IRCAL field, as was constructed from a set of five dithered frames.

We have identified in the LSPM-north catalog (Lépine & Shara 2005) a list of probable low-mass subdwarfs with estimated distances $d < 100$ pc from the Sun, based on a relatively blue color, large reduced proper motion, and bright apparent magnitude. A first subset of 18 targets were observed on the nights of 2006 September 16-17, with the Shane 3.0-meter telescope at Lick Observatory on Mount Hamilton. Adaptive Optics (AO) observations were performed under operation of the Laser Guide Star (LGS) system. High angular resolution images were recorded with the IRCAL infrared camera, a 256×256 pixels Rockwell PICNIC HgCdTe array, with an effective field of view 19.4″ × 19.4″ in the focal plane (0.076 ″ pixel$^{-1}$). We operated the laser guide star system using the science target as a reference tip/tilt star. A total of 5 images were obtained in the K band with a dithering pattern. The images were reduced with IRAF, and combined with the drizzle algorithm, generating a composite image with twice the pixel resolution (0.038 ″ pixel$^{-1}$).

No companions were detected in 17 of the 18 targets. These stars yielded radially symmetric images, with the first Airy ring clearly visible. We conclude that these stars are either single star systems, or that they are multiples unresolved to within the diffraction limit of the telescope.

One of our targets however, the high proper motion star LHS 1589 (see Figure 1), was clearly resolved into a pair of close point sources. Five separate images were obtained with offsets ≈5″ forming a standard dithering pattern. All images showed the same pair of resolved point sources, with similar separation and orientation. A composite image was built using the drizzle algorithm in the IRAF STSDAS package, halving the effective pixel scale to 0.038″. Figure 2 shows the central 3.5″ × 3.5″ part of the composite image. Point spread function fitting of the two resolved sources yields an angular separation $\rho = 0.220″ ± 0.004″$, with a position angle on the sky from component A to B of $\phi = 207.1$ degrees.

We can rule out with near certainty the possibility that the two stars are a chance alignment. Each component is bright enough to be detected in any of the POSS-I or POSS-II image, yet on those plates the region of the sky imaged by IRCAL is clearly devoid of any optical source down to the magnitude limit of the photographic plates (see Fig.1). Likewise, an image from the 2MASS data archive shows a single, unresolved source near the location of LHS 1589, though the 2MASS data was acquired in 1999, at a time when LHS 1589 was > 5″ from its current location, and thus any background source located near the current location of LHS 1589 would have been clearly resolved in the 2MASS image. Hence, the two point sources are most likely co-moving stars. The only alternative would be for component B to be a strongly variable or transient source that just happened to erupt within a short angular distance of LHS 1589 at the time of the AO imaging, a very unlikely event.

2. ADAPTIVE OPTICS OBSERVATIONS

In §2, we describe our Adaptive Optics observations, performed at Lick Observatory with the Laser Guide Star system. Our spectroscopic observations are detailed in §3. We discuss in §4 the prospects for using this system to constrain the mass-luminosity relationship in the metal-poor, low-mass star regime.
Figure 3.— Composite spectrum of the halo subdwarf binary LHS 1589AB. The strong CaH molecular band near 7000Å flanked by a relatively weak TiO bands indicates that the star is a metal-poor, low-mass subdwarf. Based on the strength of the CaH band, the spectral subtype of the composite spectrum is sdK7.5. Two other stars from our MDM spectroscopic survey are shown for comparison: the K7.5 dwarf LSPM J2328+3219, and the esdK7.5 extreme subdwarf LSPM J1320+1129.

Component B currently lies to the South-West of the brighter component A. Based on our aperture photometry, the secondary is 0.52 magnitudes fainter that the primary in the K_s band. Infra-red 2MASS photometry of the unresolved source yields K_s=11.33 mag, from which we derive magnitudes for the individual sources of K_s=11.85 mag for component A, and K_s=12.36 mag for component B.

3. SPECTROSCOPIC OBSERVATIONS

A red optical spectrum of the unresolved binary system was collected at the MDM observatory with the 1.3m McGraw-Hill telescope on the night of 14 October 2006. We used the Mark III spectograph with the 300 lines/mm grating blazed at 8000Å. The spectrum was recorded with a LORAL 2048 x 2048 CCD camera (“Wilbur”), yielding a spectral resolution of 3.11Å per pixel. Reduction was done with IRAF, including standard flat-fielding, sky-subtraction, extraction, calibration, and telluric correction. Wavelength calibration was determined from a NeArXe arc spectrum collected right after the exposure on the star, yielding an estimated calibration accuracy of ±0.35Å. Flux calibration was determined based on observations of the spectrophotometric standard star Hiltner 600.

The reduced, composite spectrum is displayed in Figure 3. The relatively weak TiO/CaH band ratio is consistent a cool subdwarf of sdK/sdM subclass. We measured the three spectroscopic indices CaH2, CaH3, and TiO5, which measure the depth of the CaH and TiO molecular bandheads near 7040Å (Reid, Hawley, & Gizis 1995), finding CaH2=0.781, CaH3=0.890, TiO5=0.906. These values, following the revised classification system of Lépine, Rich, & Shara (2007), yield a spectral type sdK7.5. The TiO/CaH bandstrength ratio (main metallicity diagnostic in cool stars) is actually quite weak in LHS 1589AB, and the star falls just short of being classified an extreme subdwarf (esdK7.5).

A direct comparison with spectra from other cool dwarfs and subdwarfs confirms this impression. Figure 3 shows MDM spectra of the high proper motion stars LSPM J2328+3219 and LSPM J1320+1129, respectively classified as K7.5 and esdK7.5, respectively. Each is typical of stars of its own metallicity subclass, and both have CaH bandstrengths similar to those observed in LHS 1589AB. The TiO bands in LHS 1589 are clearly intermediate between the two comparison objects, but are closer to those of the esdK7.5 star, which again indicates that LHS 1589AB consist in two subdwarfs (sd) close to the extreme subdwarf (esd) metallicity class.

A radial velocity was calculated from the shift of individual lines in the K II doublet and Ca II triplet, whose centroids were calculated in IRAF with the SPECRED package. After correction for the Earth’s orbital motion, we determined a heliocentric radial velocity $v_r = +75 \pm 25$ km/s.

4. DISCUSSION

The star LHS 1589 was first discovered as a high proper motion star in the Lowell Proper motion survey (Giglas, Burnham, & Thomas 1961), and was initially known as G 79-69. The star was later included in the Luyten Half Second catalog (Luyten 1979) under the catalog number 1589. Olin J. Eggen also included the object is his catalog of stars with proper motions $\mu > 0.7''/yr^{-1}$ under the designation PM 03436+1134. Eggen also recognized it to be a metal-poor subdwarf based on its relatively blue $R-I$ color (Eggen 1983).

It is critical that the distance to the pair be properly measured so that its orbital can be estimated. This in turn will determine the potential for the system to have its orbital motion mapped out astrometrically. We have compiled parallaxes of spectroscopically confirmed, nearby subdwarfs to estimate a photometric distance to the LHS 1589AB system. Figure 4 shows the $M_K$, $V$ vs $K_s$ color-magnitude diagram for a large sample of nearby stars with parallax measurements (Monet et al. 1992; van Altena et al. 1995). Optical V magnitudes are from the original parallax tables, while infra-red $K_s$ magnitudes are from the 2MASS All-Sky Point Source catalog (Cutri et al. 2003). Spectroscopically confirmed subdwarfs (sdK,sdM) and extreme subdwarfs (esdK, esdM) are plotted with distinct symbols in Fig. 4 (filled triangles and open circles, respectively). These include subdwarfs classified by Gizis (1997) and Reid & Gizis (2005), as well as subdwarfs confirmed in our own spectroscopic survey (Lépine et al. 2007, in preparation).

As can be seen in Fig.4, the color-magnitude relationship has a strong dependence on metallicity for stars with $3 < V-K_s < 5$, with more metal-poor stars being less luminous at a given color. Our parallax data suggests that $\Delta M_K \sim 1.7\Delta (V-K_s)$ for sdK/sdM subdwarfs. Given that $(K_s-K)$ es = 0.51, we estimate $V-K_s \sim 3.6$ for LHS 1589A, and $V-K_s \sim 3.9$ for LHS 1589B. In Fig.4, we display our best guess of the absolute magnitude range of LHS 1589A assuming $V-K_s=3.6$, and assuming the star to be in the lower range of the sdK/sdM distribution, close to the esdK/esdM objects. From an absolute magnitude $M_K = 7.4 \pm 0.5$ for LHS 1589A, we estimate a distance $d = 78 \pm 18$ pc. The small parallax of $2.1 \pm 1.9$ milliarcsecond reported in Harrington & Dahn (1980) for LHS 1589 is inconsistent with our photometric distance estimate,
Fig. 4.—Color-magnitude diagram of nearby stars with measured trigonometric parallaxes from various sources. Spectroscopically confirmed subdwarfs (sdM) are shown as filled triangles; spectroscopically confirmed extreme subdwarfs (esdM) are shown as open circles. Component A in LHS 1589 has an estimated color V-K = 3.6 (vertical line). Based on our spectroscopy (Fig. 3), we assume that LHS 1589 is a subdwarf close to the group of extreme subdwarfs, and we estimate an absolute magnitude M_K = 7.4 ± 0.5 (horizontal lines), which suggests a distance d = 78 ± 18 pc.

and should be considered doubtful, especially given the now established binarity nature of LHS 1589.

At a distance of 78 pc, and assuming V_rad = +75 km s^{-1}, the system would have components of motion (U, V, W) = (-158, -250, +106) km s^{-1} with respect to the local standard of rest. An integration in the Galactic potential yields a very eccentric orbit sharply inclined to the Galactic plane, consistent with a membership with the inner Galactic Halo.

The projected orbital separation between the components is estimated at s = 17.2 ± 4.8 AU. Assuming that the MLR for dwarfs and subdwarfs is roughly similar, and based on the MLR calibration of Delfosse et al. (2000), we would expect the total mass of the system to be in the range 0.35 M_{⊙} < M_{tot} < 0.55 M_{⊙}, given the possible range of M_K for LHS 1589A a LHS 1589B (see above). Based on the range of possible values for the total mass and orbital separation, we estimate the orbital period to be 95 yr < P < 370 yr. A fraction of the orbit could thus be mapped within a decade, from which the total dynamical mass of the system could be constrained with much greater accuracy (Schaefer et al. 2006).

We conclude that the low-mass subdwarf double LHS 1589AB should be considered a high priority target for high angular resolution, astrometric monitoring. The system is a good candidate for a direct measurement of dynamical masses, and may prove critical for calibrating the mass-magnitude relationship in metal-poor stars. At the very least, an accurate parallax for the system should be obtained, in order to estimate how much of an investment in time would be required to map out the orbital motion. Systems with much shorter orbital separations would clearly be more useful, however. At the least, our demonstration that astrometric doubles do exist, and can be detected among nearby low-mass subdwarfs, provides renewed impetus in the search for additional systems. We are currently expanding our LGS-AO survey with the aim of surveying all known low-mass subdwarfs within 100 parsecs of the Sun.

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