Ages of white dwarf-red subdwarf systems[1]

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We provide the first age estimates for two recently discovered white dwarf-red subdwarf systems, LHS 193AB and LHS 300AB. These systems provide a new opportunity for linking the reliable age estimates for the white dwarfs to the (measurable) metallicities of the red subdwarfs. We have obtained precise photometry in the $V_J R_{KC} I_{KC}$JH bands and spectroscopy covering from 6,000°A to 9,000°A (our spectral coverage)for the two new systems, as well as for a comparison white dwarf-main sequence red dwarf system, GJ 283 AB. Using model grids, we estimate the cooling age as well as temperature, surface gravity, mass, progenitor mass and total lifetimes of the white dwarfs. The results indicate that the two new systems are probably ancient thick disk objects with ages of at least 6-9 gigayears (Gyr).

Key words: Aging estimates. Binaries. Subdwarfs. White dwarfs.

1 Introduction

White dwarfs (WDs) are the end products of the evolution of stars with masses of 1 $\mathrm{M}^{\odot}$ (solar masses) to 8 $\mathrm{M}^{\odot}$. If we consider any typical initial stellar mass function, it is instantly clear that this makes WDs the most common end state of stellar evolution. Because of their large numbers, ability to be modeled effectively, and age dispersion spanning our Galaxy's entire history, WDs provide important, interpretable clues about galactic timescales. This potential was recognized many years ago by Schmidt (1959) in a study of star formation rates. Many developments have occurred since then in both observational and theoretical studies of WDs. Observationally, with modern telescopes it has been possible to detect fainter objects, leading to more detailed information on the cool, old WDs (BERGERON et al., 2001), including those in globular clusters that are used to determine cluster ages (HANSEN et al., 2002; RICHER et al., 1997). Recent observations also suggest that an ancient WD population could exist in the galactic halo that may constitute an important part of the baryonic dark matter (OPPENHEIMER et al., 2001), although this is still rigorously debated (BERGERON et al., 2005; DAVIES; KING; RITTER, 2002; REID; SAHU; HAWLEY, 2001; REYLÉ; ROBIN; CRÉZÉ, 2001; SALIM et al., 2004; SILVESTRI; OSWALT; HAWLEY, 2002). Theoretically, models (BERGERON et al., 2001; FONTAINE; BRASSARD, BERGERON, 2001) continue to improve the understanding of WDs, in particular for the cool WDs that are members of the galactic thick disk or halo.

Subdwarfs are galactic fossils that provide answers to questions concerning the age of the Milky Way, its early composition, the rate of star formation at early epochs, and the Galaxy's overall construction by the cannibalism of nearby small galaxies. Subdwarfs of K and M types are presumably the most numerous stellar components of the early Galaxy, yet they are the types least studied because of their low luminosities. Subdwarfs are notoriously far more rare than disk stars, and therefore harder to identify and study. For example, of the 243 stellar systems now known within 10 parsec (pc) of the Sun, only two are confirmed subdwarf systems (with accurate parallax and spectra): μ Cas AB (GJ 53 AB, [Fe/H] = –0.71 (KARAALI et al., 2003) and CF UMa (GJ 451, [m/H] = –1.44 (CARNEY et al., 1994) Although they are difficult to find, a widely applied strategy used to identify subdwarfs, selecting stars with high proper motions, can yield a rich sample of subdwarf candidates that can be targeted for more detailed observations. Selection by proper motion is based on the reasoning that old stars tend to have large heliocentric velocities after billions of years of "heating" from many passages through the galactic disk. For example, Schmidt (1975), Gizis and Reid (1999) and Digby (2003) have used high proper motion criteria to select potential subdwarfs and to determine the subdwarf luminosity function. However, it has been found that only 19 (33%) of Schmidt (1957), subdwarf candidates are, in fact, spectroscopically confirmed subdwarfs (JAO, 2004), illustrating the significant contamination of proper motion samples by disk stars. Indeed, two observations are required to scrub samples of potential low mass subdwarfs of interlopers: 1) trigonometric parallax observations to confirm that candidates lie 1-3 magnitudes below the main sequence; 2) spectroscopic observations to confirm that candidates have low metallicity (strength of the CaH and TiO bands in particular for the cool subdwarfs). Some subdwarf candidates have been identified by one of these observations, but within 60 pc there are currently only 58 K and M type subdwarfs confirmed by both types of observations (JAO, 2004).

During our southern parallax program CtioPI (Cerro Tololo Inter-American Observatory Parallax Investigation), we have observed two WDs in systems with red subdwarfs (LHS 193AB and LHS 300AB[2]) (JAO et al., 2005). These two systems contain the first WDs to have confirmed subdwarf companions, based on accurate parallax and spectroscopy, thereby giving us powerful insight into the nature of old WDs in low metallicity systems. Two other systems like these have been mentioned in the literature, GJ 781AB (GIZIS, 1998) and LHS 2139/2140 (GIZIS; REID, 1997), but both are speculative, being based on broad spectral features plus mass functions in unresolved binaries and noisy spectra of one component, respectively. A third system, reported in Silvestri, Oswalt and Hawley (2002), has been spectroscopically confirmed but no parallax is available. In this work we present a detailed analysis of the resolved systems with parallaxes, including photometric and spectroscopic observations, and estimates of the WDs' physical parameters. Finally, we discuss the results in the context of galactic stellar populations.

2 Observations

2.1 Photometry observations and reduction

Initial $V_J R_{KC} I_{KC}$ (hereafter, subscripts not shown) photometry observations for LHS 193AB and LHS 300AB were reported in Jao and collaborators (2005). Data were taken at the Ctio 0.9 m telescope, using a 1,024 x 1,024 Tek CCD with image scale 0."401 pixel – 1 during Ctiopi. An additional V RI observation set was recently acquired for LHS 300AB, and improved de-convolution techniques allow us to improve the photometry values for components in both systems. The aperture sizes applied to LHS 193B (aperture 4", separation 12. "6) and LHS 300B (aperture 2", separation 4."3) in Jao and collaborators (2005) were large enough to include contaminating flux from the primary stars' wings. A aperture 1" size has been used for the WD components in both systems, and the results are given Table 2. These improved results indicate that the two white dwarfs are not quite as red as reported in Jao and collaborators (2005), although they are still among the reddest WDs known (Figure 1). Infrared photometry of the LHS 193 and LHS 300 systems in the JH bands (standard CIT/Ctio filters) have been obtained using the Andicam detector at the Ctio 1.3 m telescope via SMARTS time. The IR Array for Andicam is a Rockwell 1,024 x 1,024 HgCdTe Hawaii Array with 18-micron pixels, providing an image scale of 0."137 pixel – 1 and a field of view of 2.'4 x 2.'4.

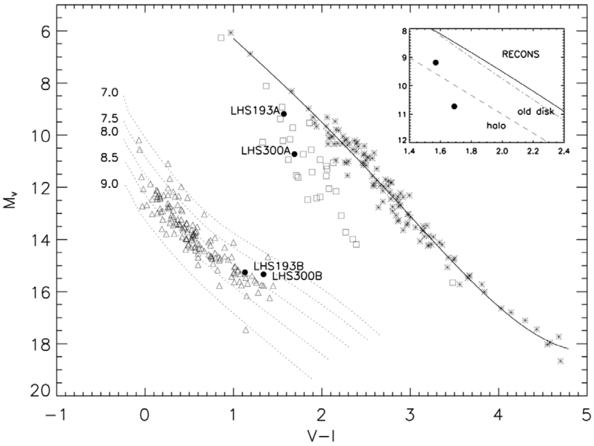

Figure 1: Components of the LHS 193 and LHS 300 systems are labeled with solid circles. The open squares represent subdwarfs with $\mu > 1^{N}.0\ \mathrm{yr}^{1}$ from Gizis (1997). Asterisks are recons stars (stars with 10 pc) used to outline the main sequence, and the solid line indicates the best fitted line for theses stars. Triangles are white dwarfs from Bergeron and collaborators (2001). The dotted line shows different helium-rich cooling curves with log(g) labeled. The inset is a zoom-in for both primaries. The solid line is the same as defined above. The dash-dot and dash lines are best fits for old disk and halo stars, respectively, from Leggett (1992).

Source: The author.

The observations were carried out with the intent of doing differential photometry using reference stars with well determined 2Mass magnitudes. To optimize image quality we have used a dithering pattern with offsets of 15”. Because of the limited field of view, there were only 1 and 3 suitable reference stars for LHS 193B and LHS 300B, respectively, but all four reference stars have 2Mass JHKs magnitude errors of less than 0.04. The 2Mass photometry has been converted to the CIT system by using the second generation relations from Carpenter (2003).

The images were corrected for bias and flat-fielded using standard IRAF procedures. The reduced science frames were used to obtain aperture photometry in Interactive Data Language (IDL). After subtraction, the aperture photometry of the faint secondary components and reference stars was completed using a series of apertures with radii of 3 to 9 pixels in steps of 0.5 pixels. The final adopted magnitude was the average of all these values with the uncertainty given by the standard deviation of the mean (0.08 mag for J and 0.1 mag for H).

3 Spectra of the red subdwarfs and white dwarfs

A sample of cool subdwarfs was previously studied by Gizis (1997), who showed that the subdwarf absorption bands of CaHn (n = 1-3) and TiO are the best features to separate subdwarfs from main sequence stars between 6,000° and 9,000°A (our spectral coverage). Here we have applied the same spectroscopic index method for both primary stars, LHS 193A and LHS 300A. Results are presented in Figure 2. The spectroscopic indices show that both stars fall in the early M type subdwarf region.

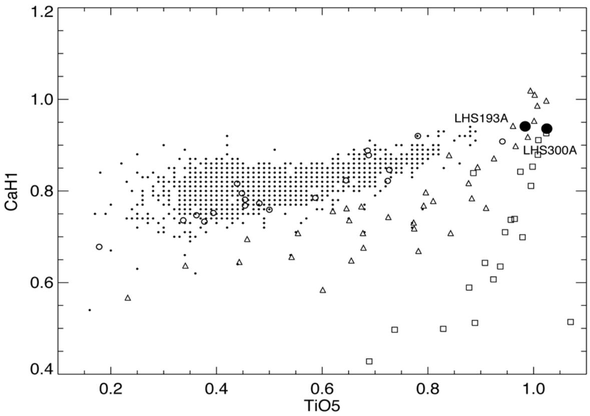

Figure 2: Stars classified as main sequence stars from Gizis (1997) appear as open circles, subdwarfs as open triangles and extreme-subdwarfs as open boxes. Small dots represent main sequence stars from Hawley, Gizis and Reid (1996) using the same indices. Two filled circles represent our two science stars, LHS 193°A and LHS 300°A. The CaH1 band if from 6380°A to 6390°A and TiO5 band is from 7126°A to 7135°A.

Source: The author.

4 Ages of the white dwarf components

One of the most interesting aspects of WDs in general is that they provide a means of determining the age of the system to which they belong, because the physics of WD cooling is relatively well-understood and unhindered by assumptions about nuclear reaction rates, among others. In this section we show an estimate of the total ages of the LHS 193 and LHS 300 systems by summing each WD’s cooling age and its main sequence lifetime. The set of models described in Bergeron and collaborators (1995) is used here to determine the cooling ages, as well as other stellar parameters. The choice of this model is due to the fact that it provides complete grids for various photometric filters and physical quantities of the WDs, making it possible to use interpolation procedures to get physical parameters from observed photometrical data. From these results, we have used the initial to final mass relations of Wood (1992) and Iben

Junior and Laughlin (1989) to estimate the progenitor masses and consequent main sequence lifetimes. A modern revision of such relations is presented by Weidemann (2000) where a new form for the mass function is suggested. However, this revised relation is not significantly different from the one in Iben Junior and Laughlin (1989), which we have adopted here to maintain consistency with the discussion of Wood (1992).

4.1 White dwarf physical parameters and cooling ages

Photometry alone is not enough to decide between DA or non-DA model atmospheres and spectroscopy should always be available to pinpoint the type of WD being studied. This is very important, especially for age determinations, because cooling times are strongly dependent on the type of model considered. In the case of LHS 193B and LHS 300B, both spectra show no evidence of hydrogen lines (as discussed in section 3), indicating very low abundance of the element in the atmosphere, thus both were studied with He models.

We have estimated the physical characteristics and ages of the WD components using the V RIJH photometry for LHS 193B and LHS 300B. We interpolated values in the (V-R, M_V), (V-I, M_V), (V-J, M_V), (V-H, M_V) planes for each object to find their surface gravities, effective temperatures, masses, and cooling ages. The independent determinations from these color combinations are then averaged to obtain a final value for each parameter. Results are given in Table 3.

To determine the reliability of our method we have compared our results with those of a "control" WD, GJ 283A with type DQ, which is the primary star of a binary system with an M6.0V main sequence red dwarf companion.

Using our method and the observed values from Bergeron and collaborators (2001) for GJ 283A, we have found differences of 1% in surface gravity, 4% in temperature, 14% in mass and 10% in cooling age. These differences are likely due to the nature of the interpolation process and on model grid resolution. Derived cooling ages and other physical parameters for all three white dwarfs are listed in Table 3.

4.2 White dwarf progenitor masses and main sequence lifetimes

$$MWD = A \text{ x } e \ (B \text{ x } (M/M^{\odot})) \qquad (1)$$

$$tMS = 10 \text{ x } (M/M^{\odot}) - 2.5 \text{ Gyr} \qquad (2)$$

Where M_{WD} is the mass of the white dwarf, A and B are constants (see description below), M is the mass of the progenitor (both masses in solar units), and t_{MS} is the main sequence lifetime in Gyr. The constants in Equation 1 need to be defined so that a value of M can be determined.

In this work we have adopted three different prescriptions for these constants, two from Wood (1992) and one from Iben Junior and Laughlin (1989). The two prescriptions from Wood (1992) are the ones referred to in that work as Model D (A = 0.40 and B = 0.125) and Model E (A = 0.35 and B = 0.140). Model D in particular is what the author defines as the "Best Guess Model". The third prescription uses the initial-final mass relation defined by Iben Junior and Laughlin (1989). Here, we refer to these different prescriptions as Wood D, Wood E and Iben Junior (1989), respectively. Results for all three methods are given in Table 3.

6 Discussion

The HR diagram and spectroscopic analysis both indicate that the red components in the WD-subdwarf systems are true subdwarfs. From our astrometry results of the subdwarf components (JAO et al., 2005), we also know that the tangential velocities are indicative of an old population – 147 km/sec for LHS 193A and 183 km/sec for LHS 300AB. Comparing our results to the kinematic study of low mass stars of Leggett (1992) (shown in the inset of Figure 1), both primaries appear to have halo-like kinematics. The WD total ages of 6-9 Gyr derived here indicate that the systems are not members of the young disk or extremely old halo, but they are probably members of the old disk (or young halo) population.

7 Final considerations

We find that the systems studied are likely members of the thick disk population of the Galaxy, which is supported by the systems' large tangential velocities. Even when errors are considered, the systems are not likely to be members of the halo because the total ages are below the canonical age of 12 to 14 Gyr usually adopted for halo type objects (GILMORE; WYSE; KUIJKEN, 1989). Nonetheless, we find the compelling result that there exist ancient stars in the solar neighborhood of low metallicity that are fossils of the early star formation epochs of our Galaxy.

Notes

1 N. Ed.: A versão original deste texto foi publicada em The Astrophysical Journal (MONTEIRO, 2006).

2 Both systems have L447-10 and L395-13 identifiers, respectively, in the New Luyten Two-Tenth (NLTT) catalogue. However, in order to keep consistent with the IDs we used in Jao and collaborators (2003; 2005), the LHS IDs will be used throughout this manuscript.

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