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Calibrating brown dwarf ages using white dwarfs in wide binaries

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Abstract. Even though age is a critical parameter for all objects, it can also be one of the most difficult to measure, in particular for low-mass stars and brown dwarfs. Brown dwarf models suffer from degeneracy and are not useful to infer ages without well constrained atmospheric parameters (Pinfield et al. 2006). However, there is a way to overcome this problem by studying brown dwarfs for which some external constraints are available, for example brown dwarfs in wide binary systems. Wide binary members share proper motion and are supposed to have been born simultaneously and with the same chemical composition. Since they are well separated ($\gtrsim$ 1000 AU) we can assume that no interaction has occurred between them in the past and they have evolved as isolated objects. If the companion of the brown dwarfs is a white dwarf, we can use it to calibrate the age of the system. White dwarf evolution can be described as a cooling process which is relatively well understood (e.g. Salaris et al. 2000). Thus, they yield robust age constraints from the use of cooling sequences (Garcés et al. 2011). White dwarf cooling ages will uniformally give age lower limits (despite some uncertainty on progenitor life-time), and in some cases yield ages to better than 10% accuracy. Hence, wide binary systems containing a white dwarf can have system age constraints inferred from the white dwarf component. There are not many white dwarf-brown dwarf systems known so far, but with the combination of optical and IR surveys, SDSS+UKIDSS and Gaia + UKIDSS/VHS, new systems will be detected.

Key words. Stars: abundances – Stars: atmospheres – Stars: Population II – Galaxy: globular clusters – Galaxy: abundances – Cosmology: observations

1. Introduction

The age of a star is perhaps the most difficult stellar parameter to determine and nearly always depends on strong model assumptions (Mamajek et al. 2008). The most theoretical grounded method used to determine the ages of stars is stellar isochrones, but it can not be applied to the most common stars, the low-mass stars in the main sequence. In these cases proxy indicators of age are necessary (e.g. stellar activity, rotational period). If the age of a star can be obtained in an independent way several key areas in stellar astrophysics can be studied: the decrease of high-energy emissions of low-mass GKM stars with age (Silvestri et al. 2005; Zhao et al. 2011; Garcés et al. 2011), the evolution of planetary atmospheres (Lammer et al. 2003; Penz et al. 2008), the age-rotation relation (Chanamé & Ramirez 2012). There are actually activity-$P_{\rm rot}$ relations, but the link with age is problematic (Guinan et al. 1995; Mamajek et al. 2008).

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Table 1. List of white dwarf + brown dwarf wide binaries available in the literature

Object	Spec. type	Age (Gyr)	Separation (AU)	Reference
GD165	DA + L3	1.2-5.5	140	1, 2
PHL 5038	DA + L8	1.9-2.7	55	3
LSPM1459+0857	DAH + T4	>4.8	16500-26500	4
GJ3483	DQ + Y?	1.5-2.7	2500	5, 6

References: [1]Zuckerman & Becklin et al. (1992), [2]Kirkpatrick et al. (1999), [3]Steele et al. (2009), [4]Day-Jones et al. (2011), [5]Luhman et al. (2011), [6]Rodriguez et al. (2011).

A similar situation can be found with brown dwarfs. The determination of the age, mass and metallicity of brown dwarfs relies on model fitting, but the models depend strongly on $T_{\rm eff}$, $\log g$ and $[M/H]$. The mass-luminosity relation depends strongly on age, and in the absence of well constrained atmospheric properties there is no way to accurately determine mass and age (Pinfield et al. 2006). This is why benchmark objects are so necessary, i.e. brown dwarfs whose properties can be estimated independently. Benchmark brown dwarfs are useful to test prevailing models and theories (Burrows et al. 2004) and also understand how the spectral energy distribution of ultracool dwarfs is affected by dust and molecular opacities (Allard et al. 2011). Benchmark objects can be members of open clusters - identified by distances, proper motions and position in colour-magnitude diagram (Peña Ramírez et al. 2012; Lodieu et al. 2009), members of moving groups - kinematics are needed to confirm membership (Clarke et al. 2010; Galvez-Ortiz et al. 2010) and finally, members of wide binaries and multiple systems.

2. Wide binaries

It can be assumed that the members of a common proper motion pair (or wide binary) were born simultaneously and with the same chemical composition (Wegner 1973; Oswalt et al. 1988), hence, the ages and metallicities of both members of the pair should be the same. Also, the systems have relatively large orbital separations - 1000 AU (Oswalt et al. 1988; Silvestri et al. 2001, 2005) . Thus, one can safely assume that each component has evolved independently, unaffected by mass exchange or tidal coupling. We can consider that wide binaries are like an open cluster but with only two components.

White dwarfs are the evolutionary end-product of stars with progenitor masses <8-12 $M_{\odot}$. Their evolution can be described as a cooling process, which is relatively well understood (Salaris et al. 2000). For this reason they can be used as stellar age calibrators. If a wide binary is composed by a brown dwarf and a white dwarf, the age of the system can be obtained by studying the white dwarf component. White dwarfs in wide binaries have been studied for years (Wegner 1973; Oswalt et al. 1988; Chanamé & Gould 2004), but the numbers were not very high. In the last few years there have been several studies of wide binaries containing white dwarfs and main sequence stars with the aim of improving the initial-final mass relationship of white dwarfs (Catalán et al. 2008a; Zhao et al. 2012), establishing a relationship between age and stellar activity for low-mass stars (Garcés et al. 2011; Zhao et al. 2011). Thanks to the Sloan Digital Sky Survey (SDSS), the number of spectroscopically confirmed white dwarfs has increased considerably (~20 000; Kleinman et al. 2013) and this has allowed new catalogues of wide binaries containing white dwarfs to be compiled (Andrews et al. 2012; Dhital et al. 2010).

The fraction of expected binaries with a white dwarf + brown dwarf is between 0.3-1.35 (Burleigh et al. 2011) or <0.55 (Farihi et al. 2005). There are several approaches to identify these kind of systems. The white dwarf

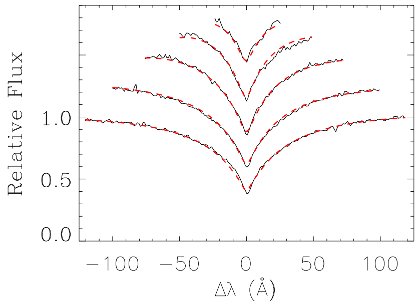

Fig. 1. Spectroscopic fit to white dwarf models to obtain atmospheric parameters, $T_{\rm eff}$ and $\log g$. Dashed lines correspond to the best fit.

member can be identified in optical surveys (e.g SuperCOSMOS, SDSS) while the brown dwarf can be detected in NIR surveys (e.g. 2MASS, UKIDSS). The radius search that should be imposed should be quite generous. When a star becomes a white dwarf, it undergoes mass loss, and during this process any wide companions will spiral out to greater separation (Burleigh et al. 2002), e.g. a system with a separation of 1000-5000 AU will end up having a separation of 4000-20000 AU. Both components should also have the same proper motion and the same distance (photometric or from parallax, the latter being the most accurate option). Up to now only 4 wide binary systems containing a white dwarf and a brown dwarf have been identified so far, but there were found by serendipity more than being the specific objective of a research project. This is why we can expect that there are many more of these systems waiting to be found. In Table 1 we list these 4 systems and the corresponding references. It is worth noting that all of them cover ages above 1 Gyr. Also, in the case of LSPM1459+0857, the separation between the components is much larger than in the other cases and also is the first one with a T dwarf as a companion. This is because the authors were looking for companions and used a generous radius, as recommended here.

3. Age determination method

To determine the age of a white dwarf we first need to obtain its atmospheric parameters ($T_{\rm eff}$ and $\log g$). For this purpose we need a high S/N (>50) low-resolution (e.g. R = 1000) spectrum of the white dwarf. $T_{\rm eff}$ and $\log g$ can be obtained by fitting the observed Balmer lines to white dwarf models (see Fig. 1). Once these two parameters are known the mass and cooling time of the white dwarf can be obtained from interpolating in cooling sequences (e.g. Salaris et al. 2000, see Fig. 2). The total age of the white dwarf can be expressed as the sum of its cooling time and the progenitor lifetime. If the white dwarf is relatively massive (> $0.8\,M\odot$) the progenitor lifetime should be negligible and we can consider that the cooling time is basically the age of the white dwarf. However, most of white dwarfs have masses around $0.6\,M_\odot$ and thus, the progenitor lifetime should be taken into account. To determine the progenitor lifetime we can consider an initialfinal mass relationship to obtain the progenitor mass (e.g. Catalán et al. 2008b) and stellar evolution models (e.g. Domínguez et al. 1999).

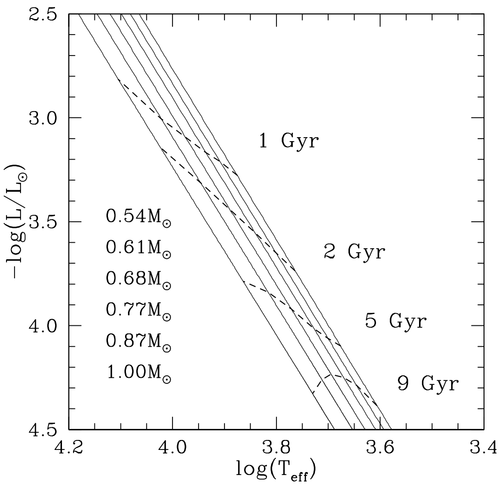

Fig. 2. Cooling tracks for white dwarfs of different masses (data from Salaris et al. 2000). Dashed lines correspond to isochrones.

Although all white dwarfs can be used as age calibrators, the ones that fulfill the following characteristics are the best suited for this purpose:

- Spectral type DA: i.e. white dwarfs with hydrogen absorption lines. The models for DA white dwarfs are well studied and the atmospheric parameters can be determined with accuracy by spectroscopic fitting.
- Massive: they have a short progenitor lifetime and the age method determination is then independent on the initial-final relationship used, which is the step that introduces more error in the age obtained (see Fig. 3).
- Relatively hot, with $T_{\rm eff} > 12000$ K: in this regime the $\log g$ obtained from spectroscopic fit is accurate. Below this temperature convection processes take place and Helium can be brought to the outer envelope of the white dwarf, while retaining its DA spectral type. For cool white dwarfs it is better to use only photometry to obtain the $T_{\rm eff}$ and assume $\log g = 8.0$ (unless distance is known).

Considering the dependency of the age determination method on cooling models, the initial-final mass relation adopted (intrinsic dispersion) and the stellar tracks used, the ages are derived with an error as good as $\sim 5-10\%$ if a good WD age calibrator is used or $\sim 20-30\%$ in the worst case scenario. This is sufficient in our context since the ages of brown dwarfs are not possible to determine directly due to the degeneracy in the models.

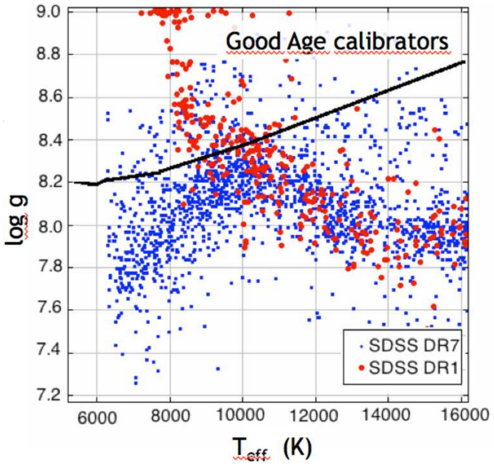

Fig. 3. $\log g$ vs $T_{\rm eff}$ for spectroscopically confirmed WDs from SDSS DR1 (circles) and DR7 (small squares). White dwarfs with progenitor lifetimes less than 10% of the total age are located above the black line.

4. Future and conclusions

It is crucial to know the ages of ultra-cool dwarfs in order to fully characterize them, but due to the degeneracy in the brown dwarf models, it is very difficult to calculate their ages and it is necessary the use of benchmark objects. Ultra cool dwarfs in wide binaries with white dwarfs provide excellent constraints on current models and theories since their age can be independently inferred.

The evolution of white dwarfs can be expressed as a cooling process, which is well understood (Salaris et al. 2000). Thus, white dwarfs are good age calibrators, specially if the white dwarf is of type DA, it is massive and has a $T_{\rm eff} > 12000$ K. If a brown dwarf is in a wide binary with a white dwarf as a companion, we can determine the age of the brown dwarf by studying the white dwarf component. In fact, wide binaries with white dwarfs allow to infer the total age of brown dwarfs with ages accurate to 5-10% to 20-30% depending on the white dwarf.

With the combination of optical and NIR surveys like: SDSS+UKIDSS and Gaia + UKIDSS/VHS surveys (up to 4 mag deeper than 2MASS) + WISE, new systems will be detected (Pinfield et al. 2006). According to the simulations by Napiwotzki (2009), about 200 000 white dwarfs down to the Gaia limit $G = 20$ will be detected by Gaia (Carrasco et al. 2013, submitted). Considering the current fraction of white dwarf + brown dwarf binaries of 0.3-1.3% (Burleigh et al. 2011), between 600-1600 of these white dwarfs will have a brown dwarf as a companion. In order to detect the brown dwarf the Gaia data should be complemented by NIR data to study the brown dwarf member: e.g. UKIDSS, VHS, VIKING.

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