

Stellar chronology with white dwarfs in wide binaries

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Abstract. White dwarfs are the evolutionary end product of stars with low and intermediate masses. The evolution of white dwarfs can be understood as a cooling process, which is relatively well known at the moment. For this reason, wide binaries containing white dwarfs are a powerful tool to constrain stellar ages. We have studied several wide binaries containing white dwarfs with two different purposes: when the age of the companion of the white dwarf can be determined with accuracy, we use the binary to improve the knowledge about the white dwarf member. On the contrary, if the companion is a low-mass star with no age indicator available, the white dwarf member itself is used to calibrate the age of the system. In this contribution we present some results using both methodologies to constrain the ages of wide binaries.

Keywords. stars: low-mass, stars: white dwarfs, stars: binaries: visual, stars: activity, stars: evolution

1. Introduction

It is sound to assume that the members of a common proper motion pair, or a wide binary, were born simultaneously and with the same chemical composition. Since the components are well separated (from 100 to 1000 AU), mass exchange between them is unlikely and it can be considered that they have evolved as isolated stars (Oswalt *et al.* 1988). Thus, these kind of systems can be used to perform tests on evolutionary models or even to infer the properties of a less known member from the study of the companion.

In our case, we have studied wide binaries containing white dwarfs. White dwarfs are the final remnants of low- and intermediate-mass stars. About 95% of main-sequence stars will end their evolutionary pathways as white dwarfs and, hence, the study of the white dwarf population provides details about the late stages of the life of the vast majority of stars. Since white dwarfs are long-lived objects, they also constitute useful objects to study the structure and evolution of our Galaxy (Liebert *et al.* 2005; Isern *et al.* 1998). The evolution of white dwarfs can be described as a cooling process, which is relatively well understood at the present moment (Salaris *et al.* 2000). The total age of a white dwarf can be expressed as the sum of its cooling time and the pre-white dwarf lifetime of its progenitor. So, if some external constraints are available, white dwarfs can be used as age calibrators, as it will be shown in the next sections.

White dwarfs in wide binaries have been studied for years. Wegner (1973) carried out a survey of Southern Hemisphere wide binaries containing degenerate members. Later, Oswalt (1981) performed a spectroscopic study of pairs containing white dwarfs, and continued with this work obtaining different catalogs (e.g. Oswalt *et al.* 1988), which

have been very useful for more recent works. In this contribution we study wide binaries containing white dwarfs with two main objectives. If the age of the companion of the white dwarf can be determined with relative accuracy, we use the binary system to better understand the white dwarf member, in our case, to improve the initial-final mass relationship of white dwarfs, specially at the low-mass domain. On the contrary, if the companion of the white dwarf is a low-mass star and no age indicators are available, the white dwarf member itself is used to constrain the age of the system.

2. Application I. The initial-final mass relationship of white dwarfs.

The initial-final mass relationship of white dwarfs connects the mass of a white dwarf with that of its progenitor in the main-sequence. This function is of fundamental importance for several aspects of modern astrophysics since it is required as an input for the study of the chemical evolution of galaxies, the determination of the ages of globular clusters and their distances, and also to understand the properties of the Galactic population of white dwarfs. Despite its importance, an accurate measurement of this relationship is still not available and, thus, more efforts are needed from both the theoretical and the observational perspectives to improve it (Weidemann 2001).

From an observational point of view, the final mass of a white dwarf can be determined from spectroscopic observations and the use of cooling sequences (Salaris *et al.* 2000). On the other hand, the initial mass can be derived by considering its progenitor lifetime and some stellar tracks (Domínguez *et al.* 1999). As previously pointed out, the total age of a white dwarf has two components, the cooling time (that can be easily obtained from cooling sequences) and the main-sequence lifetime of its progenitor, which depends on the metallicity. So, in order to obtain the progenitor lifetime, the knowledge of the total age of the white dwarf is necessary. For this reason, white dwarfs for which some external constraints are available are typically studied to be able to derive the initial and final masses. This is the case of white dwarfs belonging to open clusters, since the total ages and metallicities of the progenitors can be inferred from the cluster properties. However, until recently, open clusters data only covered the region of initial masses above $2.5 M_{\odot}$, since they are in general young and the resulting white dwarfs are massive.

Another way to derive the initial and final masses of white dwarfs is to study white dwarfs belonging to wide binaries. Wide binaries can be relatively old, so, we expected to extend the observational data of the initial-final mass relationship to the low-mass domain. In this case, the total age and metallicity of the progenitor of the white dwarf can be inferred from the study of the companion star, taking into account that the stars were born at the same time and with the same chemical composition. We selected a sample list of wide binaries containing a DA white dwarf (i.e. with the only presence of hydrogen absorption lines) and a FGK star companion (see Catalán *et al.* 2008a, and references therein). The ages of the FGK companions were derived from isochrone fitting, if the star was relatively evolved, or using our preliminary X-ray luminosity-age calibration, which is well established for ages below 1 Gyr (see next section), if the star was close to the ZAMS. In Fig. 1 we group the data we obtained for 6 white dwarfs in wide binaries with our results from a recalculation of the final and initial masses of several open clusters' white dwarfs. The observational data contains now 62 white dwarfs. It is important to emphasize that all the values below $2.5 M_{\odot}$ correspond to our data obtained from wide binaries (WBs — Catalán *et al.* 2008a) and some recent data based on old open clusters (K08 — Kalirai *et al.* 2008). The coverage of the low-mass end of the initial-final mass relationship is specially important since it is the most populated bin according to the Salpeter's initial mass function and at the same time it guarantees,

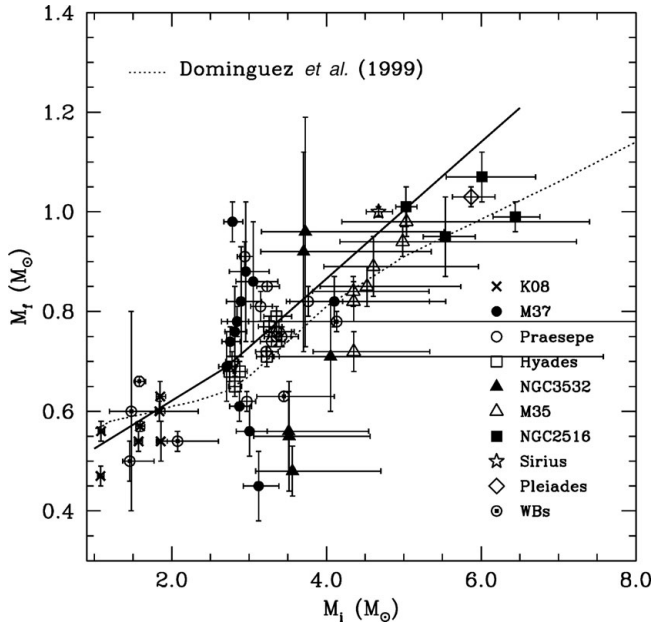


Figure 1. Final masses versus initial masses of the available data. The solid lines correspond to the analytical expressions derived from a weighted least squares linear fit of these data. The dotted line represents the theoretical relation for solar composition of Domínguez *et al.* (1999).

according to the theory of stellar evolution, the study of white dwarfs with masses near the most common value, $M \sim 0.57 M_{\odot}$, which is representative of the 90 per cent of the white dwarf population (Kepler *et al.* 2007). Thus, these new data increase considerably the statistical significance of the semi-empirical initial-final mass relationship.

2.1. An analytical relationship

Following some recent works on this subject (Ferrario *et al.* 2005, Williams 2007), we assume that the initial-final mass relationship can be described as a linear function. As can be seen in Fig. 1 the theoretical initial-final mass relationship of Domínguez *et al.* (1999) (dotted line) can be divided in two different linear functions, each one above and below $2.7 M_{\odot}$, with a shallower slope for small masses probably due to the smaller efficiency of mass loss. Taking this into account we have performed a weighted least-squares linear fit for each region, obtaining for $M_i < 2.7 M_{\odot}$:

$$M_f = 0.096M_i + 0.429 \quad \Delta M_f = 0.05 M_{\odot} \tag{2.1}$$

and for $M_i > 2.7 M_{\odot}$:

$$M_f = 0.137M_i + 0.318 \quad \Delta M_f = 0.12 M_{\odot} \tag{2.2}$$

These expressions have been overplotted in Fig. 1 as two solid lines. Taking into account the scatter of the data and the values of the reduced χ^2 of these fits (7.1 and 4.4, respectively) we have computed the dispersion of the derived final masses, obtaining $0.05 M_{\odot}$ and $0.12 M_{\odot}$, respectively. In past works, it was necessary to include in the fit a fictitious anchor point to represent the canonical white dwarf mass, $M_f \sim 0.57 M_{\odot}$ (Kepler *et al.* 2007), since no data were available at the low-mass domain. In our case,

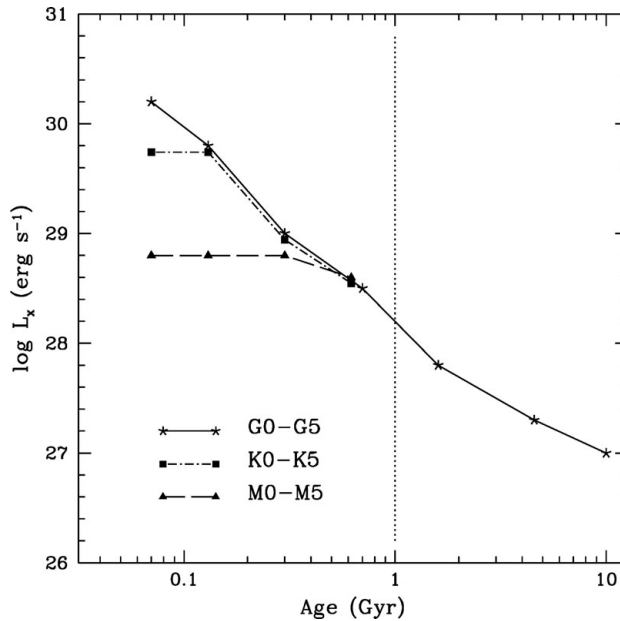


Figure 2. Calibration between the X-ray luminosity and age for stars belonging to the Sun in Time program (G type) covering up to 10 Gyr (solid line). The dashed-dotted and dashed lines correspond to our preliminary extension of this calibration to other spectral types (K and M, respectively) with data up to 1 Gyr.

this is not necessary since we are including new data that cover this typical mass value of white dwarfs.

It is worth mentioning that as an indirect test we have computed the theoretical white dwarf mass distribution considering different initial-final mass relationships, and the best fit to the recent observational data based on the SDSS (Degennaro *et al.* 2008) is obtained when our two analytical expressions are used (see Catalán *et al.* 2008b).

3. Application II. The determination of ages of low-mass stars.

When a wide binary is composed of a white dwarf and a low-mass star for which no age indicator is available, the white dwarf component can be used as the age calibrator (Silvestri *et al.* 2005). The determination of the ages of low-mass stars has many applications in Astrophysics such as, for instance, the calibration of the decrease of high-energy emissions. Magnetic activity in the Sun, and low-mass stars in general, manifests itself in the form of high-energy and particle emissions. Besides an associated strong level of variability over various timescales (rotational modulation, flares, cycles), the overall activity decreases very rapidly with time. This is related to the rotational spin down and the subsequent loss of efficiency of energy generation mechanisms.

The case of the Sun has been studied specifically within the Sun in Time program, using stars with the same spectral type but different ages, in order to estimate its past history and future evolution (Ribas *et al.* 2005). In Fig. 2 we show our calibration of the X-ray luminosity and age for G stars (solid line), covering up to 10 Gyr. We also show our preliminary results from the extension of this study to K and M stars (dashed-dotted and dashed lines, respectively). For this purpose we used stars with well known ages, for instance, stars belonging to open clusters or moving groups (NGC2547, IC2391, IC2602,

α Per, Pleiades, UMa moving group, Hyades). As can be seen in Fig. 2, high-energy emissions decrease monotonically with age. The flat part of these diagrams (i.e., constant $\log L_x$) corresponds to the saturation phase, which is longer in lower-mass stars. It can be noticed as well that no accurate data above 1 Gyr is available for K and M spectral types. By studying wide binaries containing white dwarfs we will be able to extend these calibrations to older ages, and at the same time estimate the decrease of the rotational speed of stars with age. At the present moment, there are some relations between the rotational period and the activity of stars, but the link with age is still problematic although some improvements have been achieved recently (Mamajek & Hillenbrand 2008, Messina *et al.* 2001). A major application of this method will be to obtain Age-Rotation-Activity relations for different spectral types (GKM) and perform a cross-check with ages derived from the gyrochronology method (Barnes *et al.* 2007).

The understanding of the past and current evolution of stars is also essential for characterizing the atmospheres of their planets (if any) since the particle emissions may have a relevant influence on them (e.g. Scalo *et al.* 2007). Moreover, having a method to derive the ages of low-mass stars above 1 Gyr will have many applications in dynamic and kinematic studies of our Galaxy (Famaey *et al.* 2005).

3.1. Method

We have selected a sample of 27 wide binaries containing a DA white dwarf and a GKM star (2 G, 6 K and 19 M) from the recent revision of the NLTT Catalogue (Chanamé & Gould 2004). Since a spectroscopic analysis of these white dwarfs to obtain their atmospheric parameters at the present moment is still not possible, we have used the available photometry to obtain an effective temperature to be able to derive a rough estimation of the ages. We have used the photometric effective temperature and assumed the canonical value for the surface gravity of white dwarfs, $\log g = 8.0$, in order to obtain the masses and cooling times considering the cooling sequences of Salaris *et al.* (2000). Then, we have considered the analytical expressions given in the previous section (Catalán *et al.* 2008b) to obtain their initial masses. Finally, using the stellar tracks of Domínguez *et al.* (1999) we have derived the progenitor lifetimes. Adding these to the cooling times, we have obtained preliminary values for the total ages of the white dwarfs, i.e. the ages of the low-mass companions. The values obtained are generally larger than 1 Gyr, so, with this method we will be able to derive the ages of old low-mass stars for which no age indicator is currently available.

At the present moment, we have been granted time at several observatories to obtain spectroscopic observations for the white dwarf members. Once these data are available, a more precise value for the effective temperature and surface gravity will be obtained from performing a fit of the Balmer lines to synthetic spectra. Then, an accurate value for the masses of the white dwarfs will be derived straightforwardly using cooling sequences. It should be taken into account that when white dwarfs are very cool ($T_{\text{eff}} < 12000$ K) the spectroscopic masses are not completely reliable, since their atmospheres could be well enriched in helium, while retaining its DA appearance, and this would mimic a larger surface gravity (Bergeron *et al.* 1992). In those cases we will use other methods, like, for instance, the derivation of the gravitational redshift of the white dwarf using the radial velocity of the GKM companion.

Considering the dependency of this method on the cooling sequences, stellar models and the initial-final mass relationship assumed, an accuracy of 20-40% is expected to be achieved in the ages derived. Thus, although in some cases the uncertainty in the age can be large, with this method we will be placing age constraints to stars that did not have any age indicator up to now.

The next step in this work will be the characterization of the low-mass companions. A photometric and spectroscopic analysis of these stars will be performed to determine their effective temperatures and metallicities. Moreover, the activity of these stars will be studied as well using X-ray data (e.g. ROSAT), if available, or some flux-flux relationships, for instance, those of Montes *et al.* (1996). This will allow us to obtain the necessary data to accurately define the activity-age relations.

4. Conclusions

In this contribution we have explored two different methods to constrain the ages of wide binaries composed of a white dwarf and a low-mass star. When the age of the companion of the white dwarf can be determined with accuracy we have used the wide binary to improve the initial-final mass relationship of white dwarfs. This study has allowed us to cover the low-mass domain of this relationship, which was poorly studied until now. This has a great importance since the low-mass domain is the most populated bin of masses according to the Salpeter's initial mass function. On the other hand, when no age indicators are available for the companion, we have used the white dwarf member itself to constrain the age of the system. Our preliminary study of 27 wide binaries from the NLTT Catalogue has shown that wide binaries are a powerful tool to derive the ages of low-mass stars. This method has many applications in stellar and planetary physics such as the calibration of Age-Rotation-Activity relations for different spectral types (GKM), the understanding of the evolution of the high-energy emissions of exoplanet host stars and dynamic and kinematic Galactic studies, among others.

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Discussion

R. JEFFRIES: You have made an implicit assumption that the components are non-interacting. But components with separations up to ~ 100 AU may have interacted in the past: the slow wind of the AGB progenitor of the WD can be accreted by the low-mass companion, resulting in spin up and higher x-ray activity (Jeffries and Stevens 1996, MNRAS, 279, 180).

S. CATALAN: The typical separations of this type of systems is 100 AU or usually more (up to 1,000 AU), so I don't think that is probable that they have been interacting in the past.

L. HILLENBRAND: Just a question of clarification: the sample is nearby enough for spatially-resolved data on the two components, correct? What is the distance range of your pairs?

S. CATALAN: A few tens of parsecs, out to 100 pc.



Silvia Catalán

