

# The difficulty of finding double-degenerate progenitors of type Ia supernovae

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## Abstract

The double-degenerate progenitors of type Ia supernovae (SNIa) are double white dwarf binaries with a total mass near the Chandrasekhar limit and with merger timescales smaller than the Hubble time. The fact that we have not yet observationally confirmed the existence of these objects arises the question of whether the double-degenerate channel is a viable path for producing SNIa. In this contribution we show that this lack of detections is due to observational effects and that the probability of finding double white dwarf SNIa progenitors in the Galaxy is  $(2.1 \pm 1.0) \times 10^{-5}$ .

## 1 Introduction

There is not yet a consensus on the leading paths to type Ia supernovae (SNIa; see Livio & Mazzali, 2018; Soker, 2018; Wang, 2018, for recent reviews). Among the proposed evolutionary channels, one of the most promising ones is the double-degenerate channel, where a close binary system composed of two white dwarfs merges due to angular momentum loss caused by the emission of gravitational waves and the resulting merger has a mass near the Chandrasekhar limit (Whelan & Iben, 1973; Iben & Tutukov, 1984; Liu et al., 2018). However, it has to be emphasised that not a single double-degenerate SNIa progenitor has been unambiguously identified among our currently available large samples of double white dwarfs. In this contribution we analyse whether this is due to observational biases. To that end we simulate the close double white dwarf population in the Galaxy and we analyse whether or not the SNIa progenitors in our simulations would be easily identified observationally with our current telescopes and instrumentation.

## 2 The synthetic double-degenerate population

We create synthetic models for the Galactic population of double white dwarfs by means of the binary population synthesis (BPS) method. We employ the code SeBa (Portegies Zwart & Verbunt, 1996; Toonen et al., 2012; Toonen & Nelemans, 2013) to simulate the formation and evolution of interacting binaries producing double white dwarfs. The main assumptions in our simulations are the following:

- The primary masses are drawn from the initial mass function of Kroupa et al. (1993) within the range  $0.1-100 M_{\odot}$ ;
- The masses of the companions follow a uniform mass ratio distribution between 0 and 1 (Raghavan et al., 2010; Cojocaru et al., 2017);
- The orbital separation  $a$  is drawn from a uniform distribution in  $\log(a)$  (Abt, 1983);
- The eccentricities ( $e$ ) follow a thermal distribution (Heggie, 1975):  $f(e) = 2e$  with  $0 < e < 1$ ;
- We adopt a constant binary fraction of 50% which is appropriate for A-, F-, and G-type stars (Raghavan et al., 2010; Moe & Di Stefano, 2017);
- The orbital inclinations  $i$  are obtained from a uniform distribution of  $\sin i$ .
- We employ two different models for the common envelope (CE) phase, the  $\alpha$ -formalism (Paczynski, 1976; Webbink, 1984; Livio & Soker, 1988) and the  $\gamma$ -formalism (Nelemans et al., 2000).

To study the visibility of the double white dwarfs in our Milky Way, we convolve the BPS data with the Galactic star formation history (SFH) and apply a white dwarf cooling. The SFH is based on the model by Boissier & Prantzos (1999), which adopts a total mass in stars of  $3.8 \times 10^{10} M_{\odot}$  and is a function of both time and position in the Milky Way. The *ugriz* magnitudes of the white dwarfs are estimated by their distances,

while taking into account extinction (Schlegel et al., 1998) and cooling through the evolutionary sequences of pure hydrogen atmosphere models (Tremblay et al., 2011, and references therein<sup>1</sup>). Knowing the magnitudes of each white dwarf component we can easily derive the magnitudes of the double white dwarf system by summing up the individual fluxes in each band. Here, we only consider systems where at least one component has a  $g$ -band magnitude below 23. We also note that we only simulate the hydrogen-rich double white dwarf population in the Galaxy. It is also important to mention that, once the double-degenerated binaries are formed, we take into account angular momentum losses by gravitational wave radiation, which reduce the orbital separation until present time. We consider a direct SNIa progenitor any synthetic double white dwarf that will merge within the Hubble time and with a total mass exceeding  $1.3 M_{\odot}$ .

The  $g$  magnitude, orbital period and distance distributions as well as the comparison between the component masses and effective temperatures of the two white dwarfs for the direct SNIa progenitors in our simulations are illustrated in Figure 1 and Figure 2, respectively.

### 3 The double-degenerate synthetic spectra

In this section we describe our method for obtaining synthetic spectra of all double-degenerate SNIa progenitors arising from our simulations.

In a first step we obtain a synthetic spectrum for each white dwarf component by interpolating the corresponding effective temperature and surface gravity values on an updated grid of model atmosphere spectra of Koester (2010). Given that the orbital periods of the SNIa progenitors are very short (below  $\sim 1.5$  hours; see Figure 1), we apply a wavelength shift due to the corresponding radial velocity variation (shortened by the inclination factor). Moreover, we apply a wavelength shift equivalent to the gravitational redshift. We then obtain the double-degenerate (combined) spectrum by adding the fluxes of each white dwarf component, corrected both by the gravitational and maximum radial velocity shifts.

The double white dwarf synthetic spectra thus obtained represent ideal spectra in the sense that they are given at virtually infinity signal to noise ratio (SNR) as well as at a resolution which is typically larger than the ones provided by current spectrographs. Therefore, we require incorporating observational effects in the synthetic spectra, i.e. adding artificial noise and downgrading the spectral resolution. To that end we evaluate how the synthetic

spectra would look like if these objects were observed by the following telescopes/spectrographs: the 8.2m Very Large Telescope (VLT) equipped with the UVES spectrograph ( $R = 110,000$ ), the VLT equipped with X-Shooter ( $R = 7,450$ ), the 4.2m William Herschel Telescope (WHT) equipped with ISIS ( $R = 8,350$ ), the 6.5m Magellan Clay telescope equipped with the MIKE spectrograph ( $R = 22,000$ ) and the 10.4m Gran Telescopio Canarias (GTC) equipped with OSIRIS ( $R = 2500$ ). The choice of these telescopes/spectrographs was made with the aim of covering a wide range of telescope apertures (which translate into different SNR for the same spectrum assuming the same exposure time) as well as spectral resolutions.

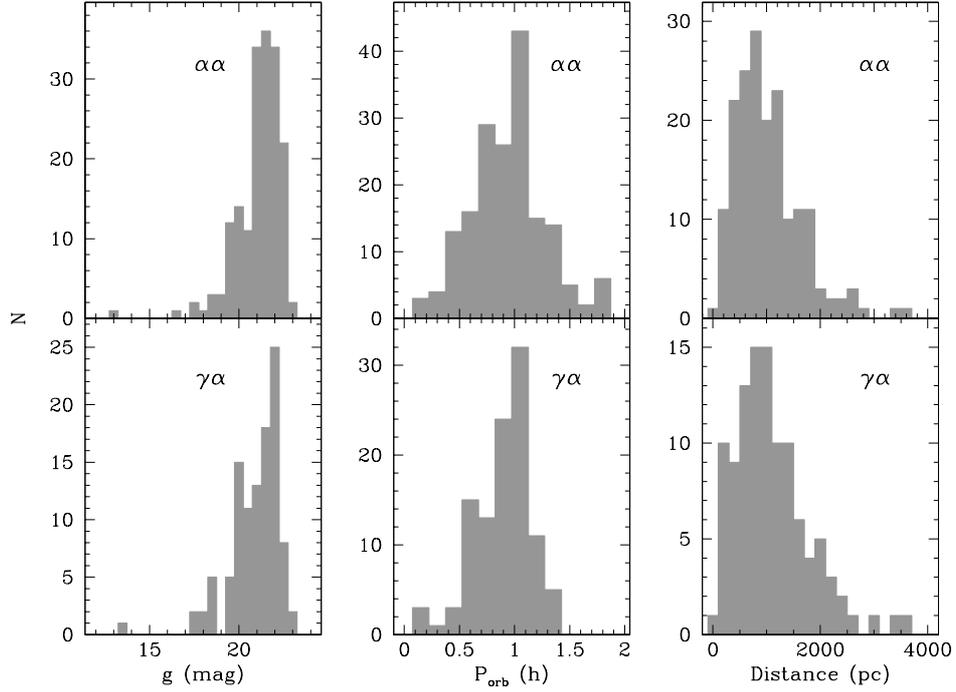
Fixing a 10 minute exposure time, we determined the expected SNR as a function of  $g$  magnitude for each of our selected telescopes/instruments. We did this by making use of the available exposure time calculators for each telescope/instrument pair. Before that, the spectra were downgraded to the required spectral resolving power.

In Figure 3 we show the synthetic spectra zoomed to the  $H\alpha$  region for the five telescope/instrument pairs considered of four direct SNIa progenitors.  $H\alpha$  is a widely common spectral feature used to both identify double-lined binaries and to measure the orbital periods and component masses (Koester et al., 2001; Maxted et al., 2002; Rebassa-Mansergas et al., 2017). Inspection of Figure 3 reveals a wide variety of different possibilities for the clear (visual) identification of the double-lined profiles. For instance, these can be easily identified in the spectra illustrated in the top left panels in all cases except for the GTC/OSIRIS configuration, where the low resolution is not enough to clearly resolve the two absorption lines despite the high SNR achieved. Conversely, only when considering the GTC/OSIRIS pair we can clearly identify the profiles when inspecting the spectra illustrated in the top-right panels. In the bottom-left panels, the spectra resulting from the Magellan/MIKE, VLT/XShooter and GTC/OSIRIS configurations reveal the two absorption profiles for this particular white dwarf binary, whilst no double absorption profiles can be detected in any of the spectra displayed in the bottom-right panels. This implies we would not be able to measure the white dwarf masses for this system and, consequently, we would not detect it as a SNIa progenitor.

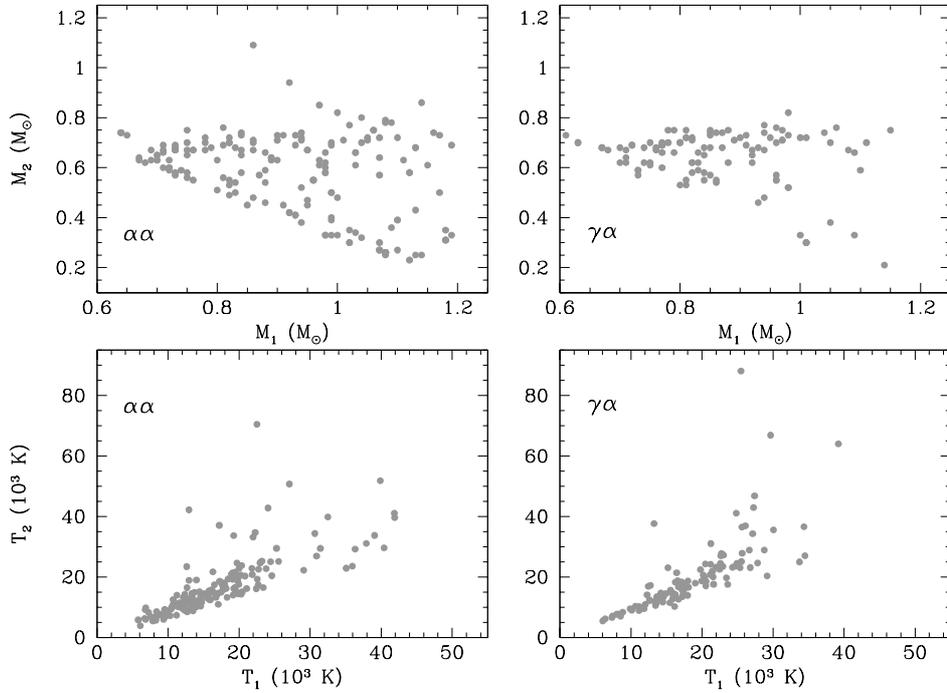
## 4 Results

In order to evaluate the impact of the observational effects described in the previous section in the detection of double-lined profile white dwarf binaries we provide in Table 1 the number of white dwarf binaries

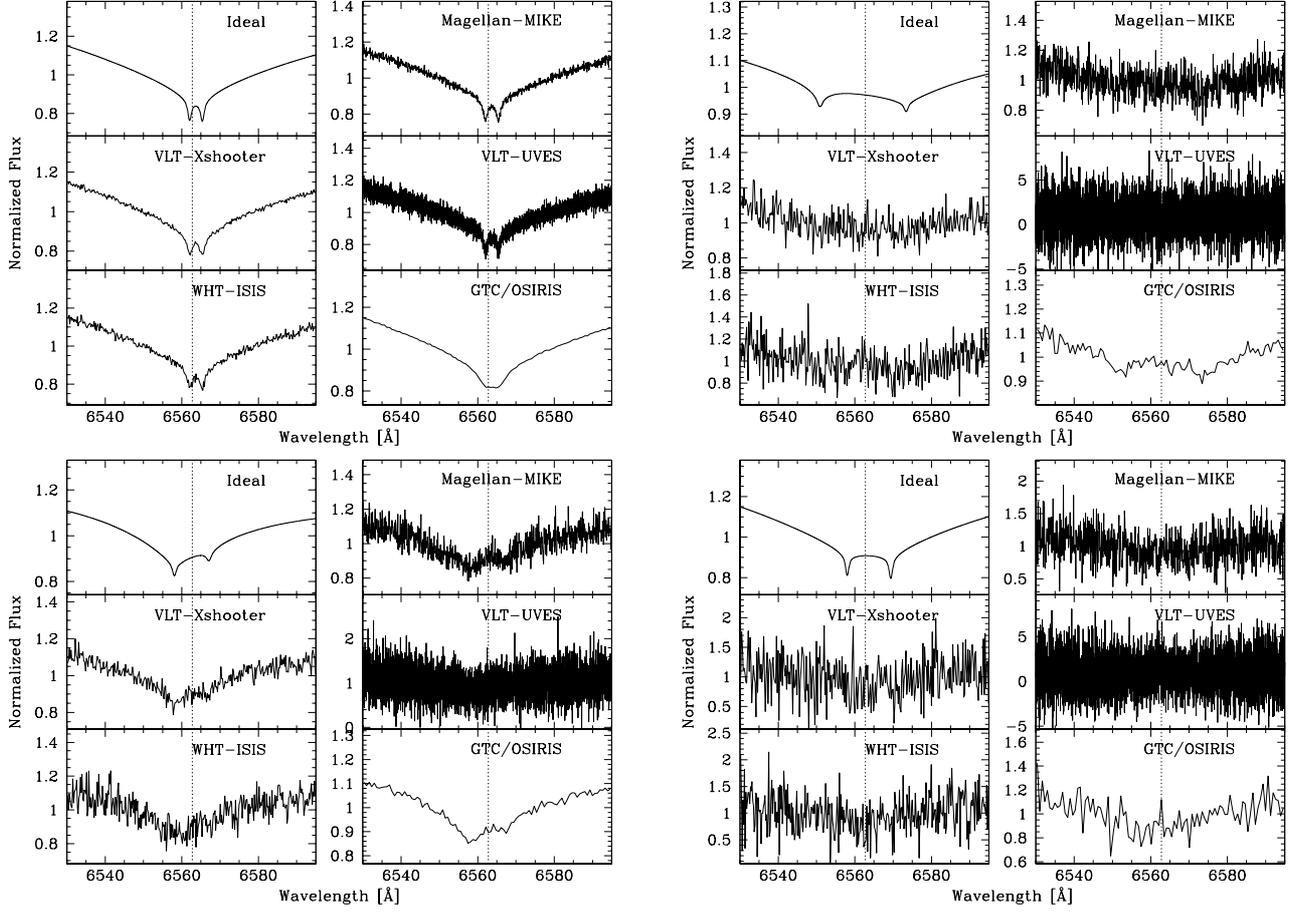
<sup>1</sup>See also <http://www.astro.umontreal.ca/bergeron/CoolingModels>.



**Figure 1:** The distribution of  $g$  magnitudes, orbital periods and distances for the direct SNIa progenitors arising from our simulations when a cut off at  $g = 23$  mag is adopted for the white dwarf components. The upper panels illustrate systems that evolved through  $\alpha\alpha$  CEs, the bottom panels systems that evolved through  $\gamma\alpha$  CE.



**Figure 2:** Comparison between the component masses and effective temperatures of the two white dwarfs in those binaries that are direct SNIa progenitors when a cut off at  $g = 23$  mag is adopted for the white dwarf components. The left panels illustrate systems that evolved through  $\alpha\alpha$  CEs, the right panels systems that evolved through  $\gamma\alpha$  CE.



**Figure 3:** A zoom-in to the  $H\alpha$  region of the synthetic spectra of four direct SNIa progenitors as they would have been observed by the five different telescope/spectrograph configurations considered in this work. For comparison, we also show the “ideal” spectra, i.e. spectra not affect by any observational bias, of the four binaries. The temperatures and masses of the white dwarf components are  $M_1 = 0.83 M_\odot$ ,  $M_2 = 0.68 M_\odot$ ,  $T_1 = 15778$  K,  $T_2 = 15472$  K (top left panels);  $M_1 = 1.13 M_\odot$ ,  $M_2 = 0.68 M_\odot$ ,  $T_1 = 35076$  K,  $T_2 = 22896$  K (top right panels);  $M_1 = 1.10 M_\odot$ ,  $M_2 = 0.39 M_\odot$ ,  $T_1 = 19234$  K,  $T_2 = 33677$  K (bottom left panels) and  $M_1 = 0.81 M_\odot$ ,  $M_2 = 0.76 M_\odot$ ,  $T_1 = 15107$  K,  $T_2 = 14533$  K (bottom right panels)

**Table 1:** Number of systems that would be identified as SNIa progenitors. We provide the numbers for each combination of telescope/spectrograph and CE envelope formalism adopted.

CE formalism	GTC/OSIRIS	Mag./MIKE	VLT/UVES	WHT/ISIS	VLT/X-Shooter
$\alpha\alpha$	3	5	1	1	2
$\gamma\alpha$	0	3	0	1	1

that would be able to be identified as SNIa progenitors (based on the clear identification of the two profiles in the  $H\alpha$  region) taking into account both the CE formalism adopted and the different telescope/spectrograph configurations. Table 1 reveals that the number of identified progenitors does not depend much on the CE formalism and that the number of identified progenitors varies considerably depending on the telescope/spectrograph configuration, as expected from Figure 3. If we consider the Magellan/MIKE pair and the  $\alpha\alpha$  synthetic population, which results in the maximum number of SNIa progenitors identified, then the fraction of SNIa progenitors that are expected to be identified is 3%. Taking into account that the complete  $\alpha\alpha$  white dwarf binary synthetic population contains  $\sim 370,000$  objects, of which  $\sim 237,000$  are unresolved, then the estimated probability for finding SNIa progenitors is  $(2.1 \pm 1.0) \times 10^{-5}$ . The uncertainties in the probabilities are obtained assuming Poisson errors in the values provided in Table 1. We obtain similar values when considering the  $\gamma\alpha$  synthetic population.

Judging from Table 1, the most efficient telescope aperture/resolution combination seems to be the one provided by the Magellan/MIKE pair, followed by the VLT/X-Shooter. In both cases, the apertures are large enough for achieving higher SNR spectra and the resolving powers are high enough for sampling the double-lined profiles. This is also true for the WHT/ISIS configuration, which results in a similar resolving power as the one by the VLT/X-Shooter, but for a lower number of systems due to the smaller telescope aperture. The GTC/OSIRIS pair achieves the highest SNR, however the spectral resolution is rather low in this case, thus making it difficult to sample the two absorption profiles and hence reducing considerably the number of identified progenitors. The VLT/UVES pair is the less efficient configuration for identifying SNIa progenitors. This is due to the extremely high resolving power achieved, which limits considerably the SNR of the obtained spectra.

## 5 Conclusions

With the aim of evaluating the observability of double-degenerate SNIa progenitors we simulated the double white dwarf binary population in the Galaxy and obtained synthetic optical spectra for each progenitor. To that end we considered a set of ground-based telescopes of different diameter sizes and equipped with spectrographs covering a wide range of spectral resolutions.

We analysed the detectability of clear  $H\alpha$  double-lined profiles in the synthetic spectra and considered a positive detection as a sufficient condition for deriving accurate orbital periods and component masses

of the two white dwarfs. In these cases we assumed the systems would be identified as SNIa progenitors. Due to the intrinsic faintness of the double-degenerate SNIa population, our simulations indicate that only a handful of objects are expected to be found with clear double-lined profiles in their spectra, which resulted in a probability of finding double white dwarf SNIa progenitors of  $(2.1 \pm 1.0) \times 10^{-5}$ . We found the best combination of telescope/spectrograph for finding SNIa progenitors is the Magellan Clay/MIKE, followed by the VLT/X-Shooter.

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