Projected rotational velocities of WD 1614+136 and WD 1353+409 – implications for the rate of galactic Type Ia supernovae.

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ABSTRACT

The white dwarf stars WD 1614+136 and WD 1353+409 are not sufficiently massive to have formed through single star evolution. However, observations to date have not yet found any evidence for binarity. It has therefore been suggested that these stars are the result of a merger. In this paper we place an upper limit of \( \approx 50 \text{ km s}^{-1} \) on the projected rotational velocities of both stars. This suggests that, if these stars are the results of a merger, efficient angular momentum loss with accompanying mass loss must have occurred. If the same process occurs following the merging of more massive white dwarf stars, the predicted rate of Type Ia supernovae due to merging white dwarfs may have been greatly over-estimated. Further observations to determine binarity in WD 1614+136 and WD 1353+409 are therefore encouraged.

Key words: white dwarfs – binaries: close – stars: rotation – supernovae: general – stars: individual: WD 1614+136 – stars: individual: WD 1353+409

1 INTRODUCTION

The finite age of the universe limits the time available for stars to evolve. The lowest mass stars have had insufficient time to evolve to the point where the remnant is seen as a white dwarf star. There is a monotonically increasing relationship between the initial mass of the star and the resulting white dwarf star and so this implies a minimum mass for white dwarf stars. The exact value is uncertain, but is around 0.55\( M_\odot \) (Bragaglia, Renzini & Bergeron, 1995). Nevertheless, white dwarf stars are found with masses well below this limit. These white dwarfs are the consequence of binary star evolution in which the evolution of a star through the red giant phase is interrupted by a common-envelope phase in which a companion star is engulfed by the expanding envelope and then rapidly spirals in towards the core, ejecting the envelope. This arrests the formation of the degenerate red giant core resulting in an anomalously low mass white dwarf star.

Dramatic evidence for this scenario was provided by Marsh, Dhillon & Duck (1996). They observed 7 DA white dwarfs selected for the low mass derived for them by Bergeron, Saffer & Liebert (1992) from their spectra. Marsh et al. were able to measure radial velocities with accuracies of a few km s\(^{-1}\) by using the narrow core of the \( \text{H}_\alpha \) absorption line. Periodic radial velocity variations showed at least 5 of the 7 stars to be binary stars. No evidence for binarity was found for WD 1614+136 or WD 1353+409.

It should be emphasized that the observations of Marsh et al. cannot rule out the possibility that these two white dwarf stars are binaries. Although a main-sequence companion more massive than 0.1\( M_\odot \) can be ruled out in both cases, the presence of another cool white dwarf, very low mass M dwarf or a brown dwarf, perhaps in a low inclination orbit, cannot be ruled out. With such strong evidence for the scenario outlined above it would seem to be inevitable that these white dwarfs were once members of binary systems. The nature of any companion, or its fate if it is no longer present, remain open questions.

The failure of Marsh et al. to detect binarity in WD 1614+136 and WD 1353+409 led Iben, Tutukov & Yungelson (1997) to suggest these stars are now single stars that are the result of a merger between a white dwarf and the companion responsible for the common-envelope phase. In this paper we show that the detection of a narrow core to the \( \text{H}_\alpha \) makes this suggestion very unlikely unless angular momentum loss from the merger product is extremely efficient.

2 THE ROTATIONAL VELOCITY OF THE WHITE DWARFS

A merger between a white dwarf and its companion will produce a star which will, initially at least, have a large angular momentum. If there is no mechanism to remove this angu-
lar momentum, the white dwarf observed now will be have a high equatorial rotational velocity, $V_{\text{rot}}$. This will usually, though not always, lead to a large projected rotational velocity, $V \sin i$. This was demonstrated in the case of a merger between two CO white dwarfs with masses of $0.9M_\odot$ and $0.6M_\odot$ by Segretain, Chabrier & Mochkovitch (1997) using a smoothed particle hydrodynamics simulation. They found that even if 90% of the angular momentum is lost, $V_{\text{rot}}$ will still be $\sim 1000\text{km s}^{-1}$.

The spectra of WD 1614+136 and WD 1353+409 are shown in Fig. 1. These parameters for these stars derived by Bergeron et al. and orbital periods if applicable are shown in Table 1. Aside from binarity, these stars are all quite similar.

The narrow core of the Hα line is apparent in the spectra of all these white dwarfs. Also shown in Fig. 1 is a model spectrum for Hα from Heber, Napiwotzki & Ried (1997). This was calculated using a self-consistent NLTE model atmosphere for the parameters $T_{\text{eff}}=22000\text{K}$ and $\log g=8.0$. The spectrum for $T_{\text{eff}}=25000\text{K}$ has a similar shape and the value of $\log g$ has only a minor effect on the shape of the core. The spectrum has been convolved with a Gaussian profile with full width at half maximum of $0.7\text{Å}$ to account for instrumental broadening after the addition of two broad Gaussian profiles to extrapolate the spectrum into the wings of the line. The first point to note is the good match between this model spectrum and the observed spectra for all four stars. In contrast, convolving the model spectrum with a rotational broadening profile for $V \sin i$ of only $50\text{km s}^{-1}$ results in a very poor match to the observed spectra. Therefore we adopt an upper limit to $V \sin i$ for all four stars of $50\text{km s}^{-1}$.

It is, of course, possible that WD 1614+136 and WD 1353+409 are rapidly rotating stars which are seen almost pole–on. To obtain some impression of the probability of this scenario we assumed both stars have the same value of $V_{\text{rot}}$ and then calculated the probability of observing $V \sin i \leq 50\text{km s}^{-1}$. For a supposed value of $V_{\text{rot}}=1000\text{km s}^{-1}$ the probability is $1.6 \times 10^{-6}$. The probability rises to 1/1000 for a $V_{\text{rot}}=200\text{km s}^{-1}$.

### Table 1. Parameters for the white dwarfs discussed in this paper.

| Name         | $T_{\text{eff}}/\text{K}$ | $\log g$ | Period/d |
|--------------|----------------------------|---------|----------|
| WD 1614+136  | 22400                      | 7.34    | –        |
| WD 1353+409  | 23600                      | 7.54    | –        |
| WD 1241−010  | 24000                      | 7.22    | 3.35     |
| WD 1713+332  | 22000                      | 7.40    | 1.13     |

loss can reduce the mass of the resulting white dwarf below the Chandrasekhar mass preventing white dwarf mergers from becoming Type Ia supernovae. However, ignition in white dwarf mergers is an extremely complex phenomenon for which theoretical models have yet to come to a definite conclusion. WD 1614+136 and WD 1353+403 may therefore be key objects for the study of the white dwarf merging and its implication for the galactic rate of Type Ia supernovae. If the rate of galactic Type Ia supernovae due to merging white dwarfs is found to be lower than the observed rate, some other source of Type Ia supernovae will need to be found (e.g. supersoft X-ray sources, Branch et al. 1995).

Further radial velocity measurements may yet show WD 1614+136 and WD 1353+403 to be binaries, as may further spectroscopic and photometric measurements covering a wide wavelength range, particularly the infrared. Such observations are to be encouraged given the implications of non-binarity discussed here.

### 4 CONCLUSION

If WD 1614+136 and WD 1353+409 are now genuinely single stars, their low projected rotational velocity implies efficient angular momentum loss following the merging of these stars with the companion star responsible for the common envelope phase. If the accompanying mass loss occurs following the merging of more massive white dwarfs, their role as the progenitors of Type Ia supernovae is put into doubt.

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Projected rotational velocities of WD 1614+136 and WD 1353+409

Figure 1. Spectra of WD 1614+136, WD 1353+409 and the known low-mass binary white dwarfs WD 1241-010 and WD 1713+332 (solid lines, histogram style). Also shown are the model spectra of Heber et al. (1997) without any rotational broadening (smooth, dashed lines) and with an additional 50 km s$^{-1}$ rotational broadening (smooth, solid lines).