Age of a millisecond binary pulsar

SIR — The recently reported properties of the millisecond binary pulsar J1012+5307 and its white-dwarf companion[1] suggest that the ages of such systems can be substantially overestimated. Lorimer *et al.*[1] determined a characteristic age of the radio pulsar to be 7,000 million years (7 Gyr), whereas they estimated the companion to be at the most 0.3 Gyr old. The latter age was based on cooling timescales for white dwarfs, as calculated by Iben and Tutukov[2], and led to the suggestion that the pulsar did not start on the spin-up line, but near its current spin period of 5 milliseconds[3,4]. Our evolutionary calculations indicate, however, that the cooling timescales of very-low-mass white dwarfs (LMWDs) of mass $M_{wd} \leq 0.25\,M_\odot$ can be considerably underestimated by the traditional white-dwarf cooling curves, which were deduced for $M_{wd} > 0.3\,M_\odot$.

We calculated the formation and cooling of LMWDs in binary systems using a recent version of the evolution code developed by Eggleton[5]. The equation of state is extensively described by Pols *et al.*[6]. Our calculations indicate that the cooling timescale of a LMWD can be substantially larger than described in ref. 2 (see figure), because we saw no thermal flashes that resulted from thermally unstable shell-burning, as reported in other work[2,7,8]. This was the case even if the time step in our calculations was as small as 50–100 years.

Our results appear to confirm Webbink's[8] finding that white dwarfs with $M_{wd} < 0.20\,M_\odot$ do not show thermal flashes. The main effect of thermal flashes would be the reduced hydrogen content in the envelope. Because of the high luminosities reached, hydrogen is rapidly burned and may be lost via Roche lobe overflow. In Iben and Tutukov's model[2] (with $M_{wd} = 0.30\,M_\odot$), there is still an amount of hydrogen $M_H = 1.6 \times 10^{-3}\,M_\odot$ in the envelope when the white dwarf reaches its maximum effective temperature. This is comparable to our results. In Iben and Tutukov's model, two thermal flashes with consequential Roche lobe overflow later occur, reducing the amount of hydrogen to $M_H = 0.14 \times 10^{-3}\,M_\odot$. Because thermal flashes did not occur in our LMWD models, the amount of hydrogen in the envelope remained high and resulted in a much longer phase with significant hydrogen burning. This results in considerably longer cooling times of LMWDs that have hydrogen envelopes: the so-called DA white dwarfs.

The age τ_{wd} of the DA white-dwarf companion of PSR J1012+5307 is then defined as the time from the moment the mass-loss from the progenitor of the white dwarf stops until the effective temperature has decreased to the present value $T_{eff} = 8{,}481$ K. This last value, and the surface gravity $\log g = 6.5$, have been determined by fitting optical spectra — which indeed show strong Balmer lines of hydrogen — with theoretical models (M. H. van Kerkwijk, P. Bergeron and S. R. Kulkarni, manuscript in preparation). For a LMWD cooled down to $T_{eff} = 8{,}481$ K, our calculations show that τ_{wd} can be as high as approximately 8 Gyr (see figure), depending on the mass of the white dwarf (for a given composition). Assuming $\tau_{wd} = \tau_{pulsar} = 7$ Gyr, we find: M_{wd} approximately $0.185\,M_\odot$, $\log g$ approximately 6.7 and P_{orb} approximately 1 day. These are close to the measured values $\log g = 6.5$ and $P_{orb} = 0.6$ day. The final period in our calculations could be smaller if one assumes a little more efficient magnetic braking.

We thus conclude that all observational and theoretical evidence is consistent with an age of the white-dwarf companion of PSR J1012+5307 of the order of 7 Gyr, which agrees with the characteristic age of the pulsar.

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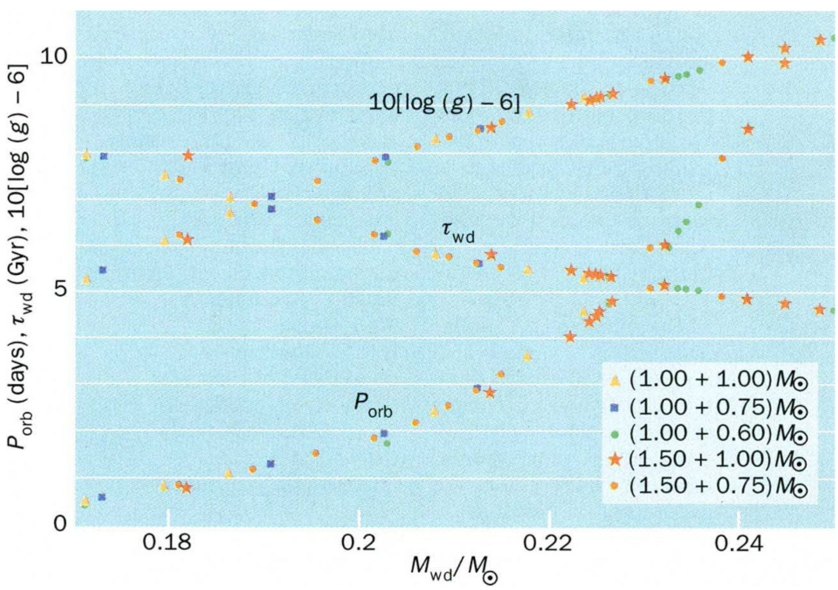

The orbital period P_{orb}, log g and the age τ_{wd} plotted as a function of mass M_{wd} for a white dwarf which has cooled down to $T_{eff} = 8{,}481$ K. We assume that the progenitor of the white dwarf is initially a zero-age main-sequence (ZAMS) star ($X = 0.70$, $Z = 0.02$) which fills its Roche lobe at a certain moment on or after the main sequence, losing mass to a compact object of unspecified origin. When almost the entire envelope is lost, the hydrogen envelope collapses and the contact star becomes a detached helium white dwarf. The mass of the white dwarf depends on the moment when the mass transfer in the system starts and is for short orbital periods in the range 0.17–0.25 $M_\odot$. The lower mass limit is determined by the bifurcation between converging and diverging systems[9]. Results are shown for binary stellar systems with different initial conditions. Each symbol denotes a specific set of initial masses, written in the key with the ZAMS star first and then the compact object in parentheses.

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