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A consistency test of white dwarf and main sequence ages: NGC 6791

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Abstract. NGC 6791 is an open cluster that is so close to us that can be imaged down to very faint luminosities. The main sequence turn-off age (~ 8 Gyr) and the age derived from the cut-off of the white dwarf luminosity function (~ 6 Gyr) were found to be significantly different. Here we demonstrate that the origin of this age discrepancy lies in an incorrect evaluation of the white dwarf cooling ages, and we show that when the relevant physical separation processes are included in the calculation of white dwarf sequences both ages are coincident.

1. INTRODUCTION

NGC 6791 is a very well studied, metal-rich ($[\text{Fe}/\text{H}] \sim +0.4$), well populated ($\sim 3,000$ stars) and very old (~ 8 Gyr) open cluster that can be imaged down to very faint luminosities [1]. This has allowed us to detect the faintest white dwarfs in its degenerate sequence, thus providing us with a unique opportunity to check the accuracy and consistency of the evolutionary ages of main-sequence stars and white dwarfs. However, the main sequence turn-off age (~ 8 Gyr) and the age derived from the termination of the white dwarf cooling sequence (~ 6 Gyr) were significantly different. As white dwarfs cool, one of the ashes of helium burning, ^{22}Ne , sinks in the deep interior of these stars, due to its large neutron excess and to the strong gravity of white dwarf interiors [2, 3]. At even lower temperatures, white dwarfs crystallize and phase separation of the components of the core these stars (^{12}C and ^{16}O) occurs [4]. Both physical separation processes introduce significant delays in the cooling times. Here we show that the inclusion of these time delays solves the age discrepancy.

2. RESULTS AND CONCLUSION

The white dwarf luminosity function of NGC 6791 presents two prominent peaks — see Fig. 1. The first of these peaks is interpreted as the result of a population of unresolved binaries [5], while the second one and the subsequent drop-off in the luminosity function are a consequence of the finite age of the

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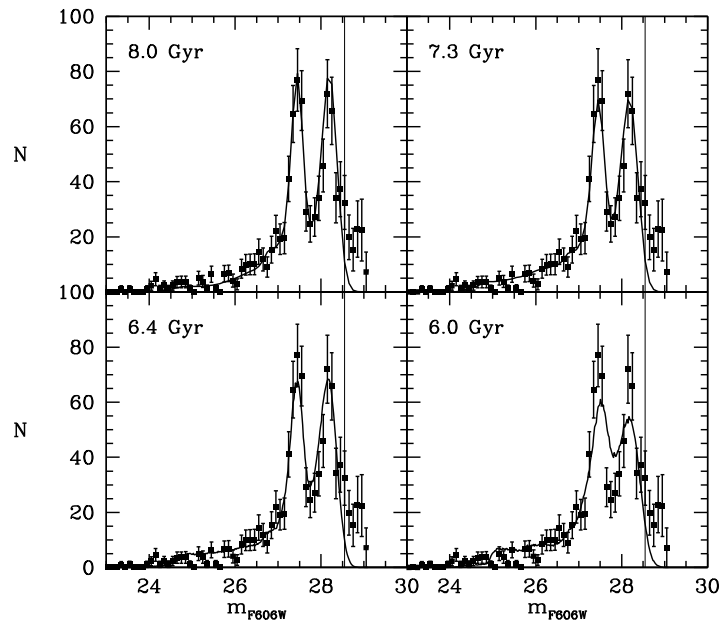


Figure 1. White dwarf luminosity function of NGC 6791. The observational luminosity function is shown as filled squares. The solid lines are the average of 10^4 Monte Carlo realizations corresponding to the age (8 Gyr), metallicity (0.04) and distance modulus (13.44) of NGC 6791 for different ages, as indicated in each panel. The thin vertical lines indicate the magnitude at which incompleteness becomes relevant.

cluster. The age derived using the drop-off of the luminosity function is in conflict with the age obtained using the main-sequence turn-off, for which we have a reliable determination, 8.0 ± 0.4 Gyr. Since the metallicity of this cluster is high physical separation processes are very relevant. Thus, we computed a set of white dwarf cooling sequences which include both effects [6]. We also simulated the white dwarf luminosity function of NGC 6791 using a Monte Carlo technique [7–9]. Figure 1 shows the observed and the theoretical luminosity functions. Note the existence of two peaks in the luminosity function which, as mentioned, are the direct consequence of the population of unresolved binaries and the finite age of the cluster. It is worth mentioning the very good agreement between the theoretical result and the observational data. Moreover, the main sequence turn-off and white dwarf ages are exactly the same, solving the age discrepancy of NGC 6791.

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