

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

E. García-Berro^{1,2}, S. Torres^{1,2}, J. Isern^{3,2}, M. Salaris⁴, A.H. Córscico⁵
and L.G. Althaus⁵

¹*Departament de Física Aplicada, Universitat Politècnica de Catalunya, c/Estève Terrades, 5, 08860 Castelldefels, Spain*

²*Institute for Space Studies of Catalonia, c/Gran Capità 2–4, Edif. Nexus 104, 08034 Barcelona, Spain*

³*Institut de Ciències de l'Espai (CSIC), Facultat de Ciències, Campus UAB, Torre C5-parell, 08193 Bellaterra, Spain*

⁴*Astrophysics Research Institute, Liverpool John Moores University, 12 Quays House, Birkenhead, CH41 1LD, UK*

⁵*Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Paseo del Bosque s/n, (1900) La Plata, Argentina*

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

This is an Open Access article distributed under the terms of the Creative Commons Attribution License 2.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

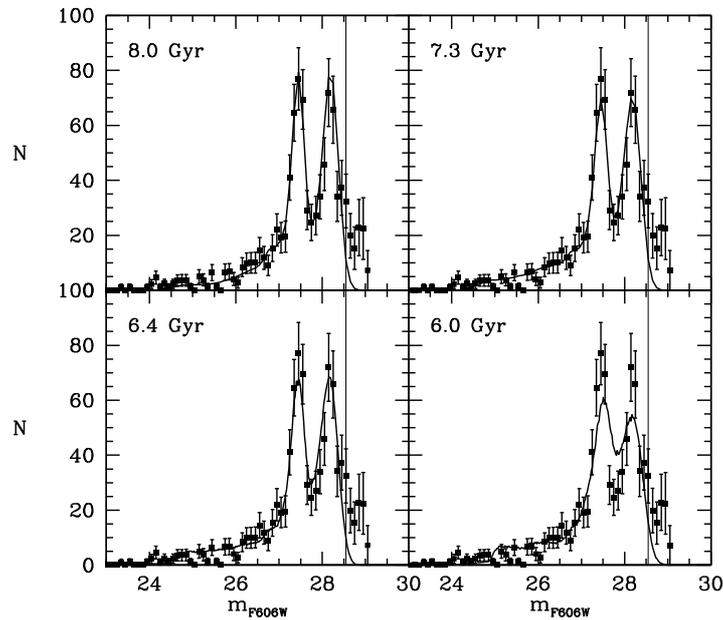


Figure 1. White dwarf luminosity function of NGC 6791. The observational luminosity function is shown as filled squares. The solid lines are the average of 10^4 Monte Carlo realizations corresponding to the age (8 Gyr), metallicity (0.04) and distance modulus (13.44) of NGC 6791 for different ages, as 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.

This work was partially supported by the AGAUR, by MCINN grants AYA2011–23102 and AYA08-1839/ESP, by the European Union FEDER funds, and by the ESF EUROGENESIS project (grant EUI2009-04167).

References

- [1] L.R. Bedin, I.R. King, J. Anderson, G. Piotto, M. Salaris, S. Cassisi, A. Serenelli, *ApJ* **678**, 1279 (2008)
- [2] E. Bravo, J. Isern, R. Canal, J. Labay, *A&A* **257**, 534 (1992)
- [3] E. García-Berro, S. Torres, L.G. Althaus, I. Renedo, P. Lorén-Aguilar, A.H. Córscico, R.D. Rohrmann, M. Salaris, J. Isern, *Nature* **465**, 194 (2010)

Ageing Low Mass Stars: From Red Giants to White Dwarfs

- [4] E. García-Berro, M. Hernanz, J. Isern, R. Mochkovitch, *Nature* **333**, 642 (1988)
- [5] L.R. Bedin, M. Salaris, G. Piotto, S. Cassisi, A.P. Milone, J. Anderson, I.R. King, *ApJL* **679**, L29 (2008)
- [6] E. García-Berro, L.G. Althaus, A.H. Córscico, J. Isern, *ApJ* **677**, 473 (2008)
- [7] E. García-Berro, S. Torres, J. Isern, A. Burkert, *MNRAS* **302**, 173 (1999)
- [8] S. Torres, E. García-Berro, A. Burkert, J. Isern, *MNRAS* **336**, 971 (2002)
- [9] E. García-Berro, S. Torres, J. Isern, A. Burkert, *A&A* **418**, 53 (2004)