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Memorie della

Franca D'Antona and globular cluster science

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Abstract. Up today, Franca D'Antona has published 125 papers related to globular clusters (GCs), three quarters of them in the last decade. She used GCs as test-bed of stellar evolutionary models, most extensively in reference to the treatment of convection. In 1983 she pioneered the field of multiple stellar populations in GCs with a seminal paper on CNO self-pollution in GCs. In the last fifteen years she leaded the Monte Porzio group which developed the currently most popular theoretical scenario to interpret the multiple population phenomenon where the second generation(s) formed from cooling flow originated from mass lost by massive AGB stars. On the same area, she worked extensively on the connection between the multiple population scenario and the distribution of stars along the horizontal branch (HB), as well as on the study of peculiar objects in GCs. All this showed that Franca D'Antona has been among the most influential researchers on stellar evolution and GCs throughout the last forty years.

Key words. Galaxy: GCs – Stars: evolution – Stars: abundances

1. Introduction

Franca D'Antona is one of the most famous expert in stellar evolution and a major contributor to GC science in the last forty years. According to ADS (*http://adsabs.harvard.edu/abstract_service.html*), D'Antona first paper (devoted to GCs) appeared in 1971. Since then, she published 330 papers, 155 of them on refereed journals and 124 as first author. These papers received 7079 citations and 2470 normalized citations. Her h-factor is 44; the h-factor for reduced citations is 24. She is still a very active scientist (see Fig. 1) and the center of a wide network of collaborations (see Fig. 2).

D'Antona's career may be roughly divided into a few phases: (i) Youth (1971-75): working on GCs; (ii) Late 70s: becoming a white dwarf expert; (iii) in 1983 she published a seminal paper on pollution mechanisms in GCs (DAntona et al. 1983). (iv) Maturity (80s and early 90s): during this period she became a leader scientist in stellar evolution (very low mass stars, pre-MS stars, white dwarfs, problems related to the lithium abundances, evolution of stars in close binary systems). (v) During the late 90s, she worked with Vittorio Canuto and Italo Mazzitelli on a new model for convection, and with Luciano Burderi and others on the millisecond pulsars. (vi) In the new millennium, Franca interest came back to multiple populations in GCs, mainly in three areas: modelling of the massive AGB stars as potential polluters (mainly with Paolo Ventura), the explanation of extended HBs and multiple MSs by spreads in the helium abundances (mainly

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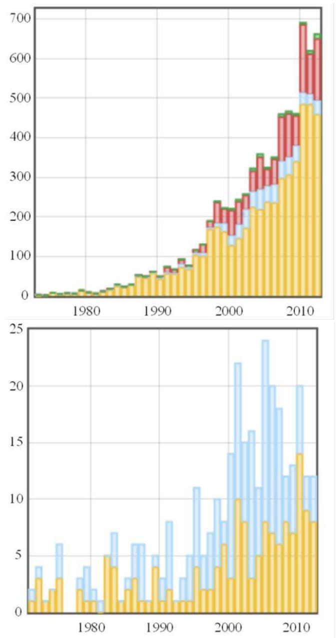

Fig. 1. Run of number (upper panel) and of citations (lower panel) of Franca D'Antona's papers with time, according to ADS.

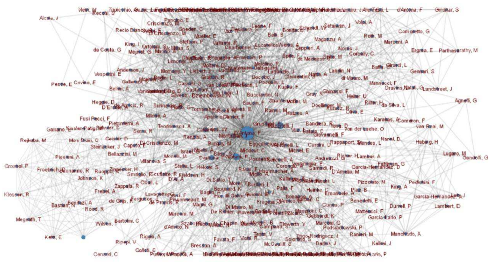

Fig. 2. Network of Franca D'Antona collaborations, according to ADS

with Vittoria Caloi), and the development of the cooling flow scenario for the formation of the second generation of stars in GCs (together with Annibale D'Ercole and Enrico Vesperini). In the mean time, Franca contributed to other areas too, including evolution of stars in binaries and asteroseismology. In the rest of this contribution I will outline some major contributions by Franca to our understanding of GCs.

1.1. D'Antona et al. (1983)

On my opinion, the first important contribution was D'Antona et al. (1983) paper, which came after a decade of studies of chemical inhomogeneities in GCs, with basic contributions by Australian, Canadian and US astronomers (see Kraft 1979). These studies, mainly limited to red giants due to observational constraints, revealed star-to-star variations in the abundances of mainly C and N, but possibly also of Na and O. There were essentially two alternative explanations: primordial variations and non-canonical deep mixing. The early observations by Hesser (1978) and Hesser and Bell (1980) of star-to-star variations in C and N in MS stars favoured primordial variations, but this appeared to require a very prolonged formation phase and too large a polluting mass (Cottrell & Da Costa 1981; Smith & Norris 1982). D'Antona et al. tried to explain the chemical anomalies observed in GCs by accretion of material ejected from massive AGB stars on already formed stars; since only the outer layers of the stars need to be polluted, this alleviated the mass problem. While this assumption is now abandoned, the suggestion of massive AGB stars as polluters was seminal. They supported such polluters because massive AGB stars experience hot bottom burning (that is, H-burning at high temperature) and have then the right nucleosynthesis, lose mass through slow winds and evolve when there is no strong UV emission within a GC. This was the first paper by Franca with more than 50 citations though it is published in the proceedings of a meeting that she could not attend due to her third maternity.

1.2. Multiple populations in GCs

For almost two decades after 1983, D'Antona worked on other important topics in stellar evolution; GCs appeared only in a few of her papers. After publications of the Hipparcos parallaxes, she contributed to the debate on GC ages considering models computed with the Canuto-Mazzitelli treatment of convection (D'Antona et al 1997), and began a long collaboration with Vittoria Caloi on the interpretation of the horizontal branch (Caloi et al. 1997). GCs were also used as test bed for stellar evolutionary models in Silvestri et al. (1998).

However, a new important season of D'Antona's work on GCs began with the turn of the millennium and the ESO Large Program 165-L0263 that re-launched the multiple population scenario for GCs, which had remained not very popular since the seminal works of the late '70s and early '80s. This work intended to extend to unevolved stars the extensive studies of the Na-O anti-correlation made by the Lick-Texas group (see Sneden et al. 1991 and Kraft 1994) in order to discriminate between primordial variations and non-canonical mixing. With the evidence for star-to-star variations of O, Na, Mg, and Al abundances among MS and subgiants (Gratton et al. 2001), which complemented the variations of C and N earlier found by Hesser and Bell (1980) and Briley et al. (1994), the need for self-pollution in GCs became inescapable. A year later, Cohen et al. (2002) showed that the accretion mechanism cannot work: multiple generation of stars were needed. A new vision of GCs was raising: a further very strong impetus came shortly after from the acknowledgement that MSs in ω Cen and moreover NGC 2808 split in a number of sequences (Bedin et al. 2004; D'Antona et al. 2005; Piotto et al. 2007), and that this splitting could only be explained by large variations in He abundances (Norris 2004; Piotto et al. 2005).

The work by D'Antona and co-workers on multiple population in GCs is monumental and cannot be easily summarized in a short contribution. Summarizing, she gave three fundamental contributions.

First, together with Paolo Ventura she developed the first convincing models for potential polluters in GCs considering the evolution of massive AGB stars (that is, stars with masses between 4 and 8 $M_{\odot}$) undergoing hot bottom burning. This work followed the plot outlined D'Antona et al. (1983) but with much modern physics and details. Since the very first paper in 2001 (Ventura et al. 2001), they have published fifteen refereed papers refining these models. They showed that if convection is vigorous (as predicted by the Canuto-Mazzitelli treatment), mass loss is rapid, and with some fine tuning of the nuclear cross sections (however, well within the large existing uncertainties), the whole observed pattern of C-N, O-Na, and Mg-Al anti-correlations can be produced by having in GCs stars with primordial composition as well as others formed from the ejecta of the massive AGB stars. Their grid of models was recently extended to super-AGB stars (Ventura & D'Antona 2011). While the required H-burning at high temperature can also occur in other stars (e.g. fast rotating massive stars), massive AGB stars are still the preferred polluters for most investigators, and this mainly thanks to the work by Franca and Paolo.

Second, together with Vittoria Caloi, Franca worked on the connections between horizontal branch morphology and the multiple population phenomenon. Vittoria and Franca (D'Antona et al. 2002) noticed that the ejecta of massive AGB stars should be rich in He produced during the MS phase and brought to the surface by the second dredge up before the stars begin their AGB evolution. Second generation stars forming from this material should then be He-rich, and then have a faster MS evolution. As a consequence, red giants and HB stars of this population should be less massive. Second generation HB stars should then be bluer. The idea that stars in the bluer portion of the HB might be He-rich was not new: it was already advanced in the '70s by Rood (1973) and Norris et al. (1981). However, the much more prominent data set now available and the existence of a quite well established theoretical framework allowed Franca and Vittoria to make detailed predictions about the consequences on such predictions on the MSs. For instance, they concluded (D'Antona & Caloi 2004) that the MS of NGC 2808 had to be broad, and likely split in several sequences. They found support to this prediction from HST photometry by Michele Bellazzini and co-workers (D'Antona et al. 2005): a spectacular confirmation of this explorative work came soon later by the beautiful colour-magnitude diagram obtained by Piotto et al. (2007). Franca, Vittoria and others have then modelled many other cases, publishing eleven refereed papers on the subject. Thanks to the work of Vittoria and Franca, it is now clear that the presence of the multiple populations is one of the basic ingredients required to explain the HBs of GCs, along with metallicity and age variations (see the talk by Dotter at this meeting). The third basic contribution by Franca has been to set up for the first time a team able to provide a comprehensive picture for the multiple populations in GCs. This required not only star modelling - which is important in order to predict chemistry and establish the timescale of the phenomenon -, but also hydrodynamical and N-body simulations, to study the fate of the gas expelled from stars and the long term evolution of the cluster. A wide range of expertise is needed: this was provided by Annibale D'Ercole and Enrico Vesperini, Stephen McMillan and Simone Recchi. This was perhaps the very first time experts in such different areas worked together on modelling the very early phases of evolution of GCs. This allowed very important innovations: for the first time it became clear that in the absence of relevant heating mechanisms, the material lost at low velocity from AGB stars should originate a cooling flow, implying that second generation stars should form in a very compact region at the very center of the cluster. Long term dynamical evolution of second generation stars should then be very different from that of first generation ones, at least before a few relaxation times (see D'Ercole et al. 2008). The rate at which first and second generation stars are lost from GCs in the early phases is then dramatically different, allowing present day GCs to be formed mainly by second generation stars (Carretta et al. 2009) even though at origin they were much less than first generation ones. Once combined with the observation that the multiple population phenomenon is ubiquitous (Carretta et al. 2009), this sets a completely new vision of early GC evolution and of their impact on the formation of the galactic halo (see e.g. Carretta et al. 2010 and Vesperini et al. 2010).

From this brief summary, it is clear that the contribution of Franca D'Antona to our understanding of GCs has been fundamental. We thank her a lot for such a wonderful work.

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