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A spectroscopic study of RGB stars in the globular cluster NGC 2808 with FLAMES ⋆

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Abstract. We present the results of the first observations, taken with FLAMES during Science Verification, of red giant branch (RGB) stars in the globular cluster NGC 2808. A total of 137 stars was observed, of which 20 at high resolution (R=47,000) with UVES and the others at lower resolution (R=19,000-29,000) with GIRAFFE in MEDUSA mode, monitoring ∼ 3 mag down from the RGB tip. The MEDUSA spectra were centered on the Hα, Na I D and Ca II H & K lines.
Evidence of chromospheres and mass motions in the atmospheres was detected from Hα emission wings, and from asymmetry in the profiles and coreshifts of the Hα, Na I D and Ca II K lines, down to log $L/L_{\odot}$ ∼2.5, 2.9 and 2.8, respectively. These limits are significantly fainter, and the number of stars involved is much larger than in nearly all previous studies of any given cluster.
Na abundances have been derived for a subset of ∼100 stars, and O abundances for 20 of them. Our results show that large star-to-star variations exist in the abundances of these elements at all positions along the RGB, that are anticorrelated with each other. Some very O-poor stars have been detected. These variations in the abundance of proton capture elements down to ∼3 mag from the RGB tip with no clear dependence on luminosity indicate that they are most likely of primordial origin, i.e. due to pollution from a previous generation of intermediate mass AGB stars.

Key words. Stars: abundances – Stars: evolution – Stars: mass loss – Galaxy: globular clusters: general Galaxy: globular clusters: individual: NGC 2808

1. Introduction

Red giant branch (RGB) stars are the brightest objects in globular clusters (GC), hence they have been traditionally used for spectroscopic studies of the cluster chemical and dynamical characteristics. The multi-object spectrograph *FLAMES*, mounted on ESO VLT-UT2, is the ideal instrument for this type of studies thanks to the large field of view (25 arcmin), the high multiplex capability (130 fibres in mid-low resolution and 8 fibres in high resolution) and the capability of reaching very faint magnitudes, being mounted on an 8-m telescope (see Pasquini et al. 2002 for more details). A few hours of observing time during

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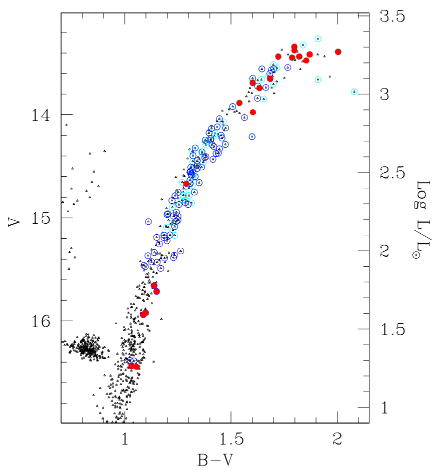

Fig. 1. Colour-Magnitude diagram of NGC 2808 (Bedin et al. 2000) showing the 137 RGB stars observed with FLAMES. Filled circles indicate the stars observed with UVES, open circles indicate the stars observed with GIRAFFE/MEDUSA.

Science Verification (Jan-Feb 2003) were dedicated to the observation of ~130 RGB stars in the GC NGC 2808 (cf. the corresponding Color-Magnitude diagram in Fig. 1).

In spite of it being a very interesting and puzzling cluster (e.g. second-parameter bimodal horizontal branch [HB] morphology, possible connection with the recently discovered CMa dwarf galaxy), no detailed spectroscopic study of its RGB stars was available so far.

The main aim of our observations was to fill in this gap, especially to investigate the mass loss phenomenon that must occur, to some extent, along the RGB evolutionary phase in order to account for the observed HB morphologies in GCs (Castellani & Renzini 1968; Iben & Rood 1970; Fusi Pecci & Renzini 1975). The results of this study, as well as a detailed discussion and references to previous studies, have been presented by Cacciari et al. (2003) and are here summarized in Sect. 2.

These same data were used to derive sodium abundances (for 81 of the stars observed with GIRAFFE), and sodium plus oxygen abundances (for the 20 stars observed with UVES). The results have been published by Carretta et al. (2003) and Carretta et al. (2004a), and are here summarized in Sect. 3.

2. Mass motions in the atmospheres

Previous spectroscopic surveys of a few hundred RGB stars in various GCs did reveal Hα emission wings in a good fraction of stars brighter than log L/L$_\odot$ ~ 2.7, that could be interpreted as evidence of an extended atmosphere (Cacciari & Freeman 1983), but could also arise naturally in a static stellar chromosphere (Dupree et al. 1984). Profile asymmetry and coreshifts of chromospheric lines are indicators of mass motions, and in particular of the presence of a stellar wind and circumstellar material (Dupree 1986). Therefore, 117 stars were observed with GIRAFFE in MEDUSA mode along the entire magnitude range with 3 setups, namely HR02 (Ca II H&K, R=19600), HR12 (Na I D, R=18700) and HR14 (Hα, R=28800), and simultaneously 20 more stars were observed with UVES (R=47000, grating centred at 580nm). We note that this is the first time that such a large sample of RGB stars have been observed in any given GC and in all the major, deep optical lines (i.e., Hα, Na D and Ca II H & K) that are normally used to study the presence of chromospheres and/or mass motions in the atmospheres.

Details on the observations and data reduction, as well as on the determination of the stellar physical parameters, are given in Cacciari et al. (2003).

We show in Fig. 2 the Hα lines after subtraction of a template observed profile and of a theoretical profile, for the 13 stars observed with UVES and brighter than V=14.0 (log $L/L_\odot$=2.88). They all show clear evidence of emission wings. Considering also the GIRAFFE spectra, we found that ~95% of the stars brighter than this value do show Hα emission. This is a much larger fraction than detected by any previous analysis. The nature of this emission is not assessed definitely, as it may be present in either stationary or moving chromospheres. However, the blue-shifted absorption cores in 7 out of the 20 UVES stars

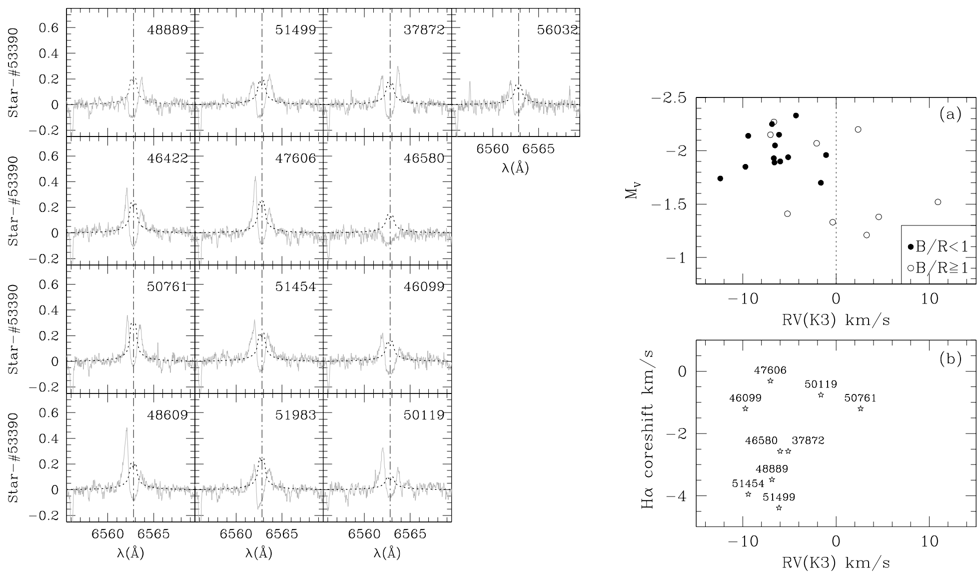

Fig. 2. Left panel: Hα lines after subtraction of a template observed profile, for the 13 stars observed with UVES and brighter than V=14.0 ($\log L/L_{\odot}$=2.88). The solid grey lines show the differences of the observed profiles, the dotted lines show the differences of the corresponding theoretical profiles. Right panel: a): K_3 velocity shifts as a function of luminosity. Stars with red asymmetry in the K_2 components (i.e. B/R<1) are shown as filled circles, stars with blue asymmetry (i.e. B/R>1) are indicated as open circles. b): Hα coreshift vs. K_3 velocity shifts for the 9 stars that have both sets of measures.

are indicative of outward motion in the layer of the atmosphere where the Hα line is formed. Similarly, we found negative coreshifts of the D_2 line in about 73% of the stars brighter than $\log L/L_{\odot}$ ~2.9. The Ca II K line was observed for 83 stars, 22 of which show the central emission K_2 and reversal K_3 features, with a detection threshold for these features at $\log L/L_{\odot}$ ~2.6. Asymmetry B/R (i.e. the intensity ratio of the K_{2b} and K_{2r} components) could be detected in about 75% of stars brighter than $\log L/L_{\odot}$ ~2.9, and is mostly red (B/R<1) indicating outward motion. Velocity shifts of the K_3 reversal relative to the photospheric LSR have been measured, and are mostly negative indicating that there is an outflow of material in the region of formation of the K_3 core reversal. The onset of negative K_3 coreshifts occurs at $\log L/L_{\odot}$ ~2.8, i.e. at a slightly lower luminosity level than the onset of red asymmetry, and it applies to nearly 90% of the stars brighter than this value.

In conclusion, this survey of RGB stars in NGC 2808 searching for mass motion diagnostics has been able to reach fainter luminosity thresholds and monitor in much more detail along the RGB than any previous study in a given GC. This is due to the FLAMES ability of reaching faint magnitudes with good S/N and good spectral resolution for a large number of stars simultaneously. Although some of our diagnostics (e.g. Hα emission) may not provide an unambiguous interpretation, others give clear indications of the presence of both chromospheres and mass outflows.
These results are important for a better understanding of the subsequent stellar evolutionary phases, in particular of the HB morphologies.

From the same set of data it was possible to derive Na abundances for the 81 RGB stars

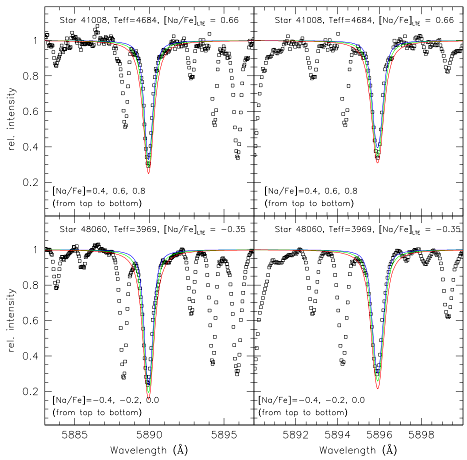

Fig. 3. Spectrum synthesis of the Na D1 and D2 lines in two RGB stars. Open squares are the observed spectrum, while lines represent the synthetic spectra computed for appropriate values of temperature and 3 different sodium abundances: [Na/Fe]=0.4, 0.6 and 0.8 dex from top to bottom, respectively. All abundances are given in the LTE assumption.

observed with GIRAFFE, and Na and O abundances for the 20 stars observed with UVES. The results have been presented and discussed in detail by Carretta et al. (2003) and Carretta et al. (2004a), respectively.

3. Na and O abundances

The astrophysical scenario that considered GCs as the best approximation of Simple Stellar Populations, i.e. groups of coeval stars with the same chemical abundance, has been questioned in the recent years. Apart from the peculiar case of ω Cen, stars in any given GC share the same metallicity only as far as heavy elements (those belonging to the Fe group) are concerned. Early studies (see e.g. the comprehensive review by Kraft 1994), based on indexes from photometry or low dispersion spectroscopy, showed that the lighter element (*in primis* Carbon and Nitrogen) abundances were markedly different along the RGB in several GCs. Moreover, striking variations in the CH band strenghts, anticorrelated with CN (and NH, when available) strenghts, were observed in several nearby clusters even down to main sequence and turn-off stars (see e.g. Cannon et al. 1998 and references therein). More recently, it was found that: i) Na and O abundances are anti-correlated among the first ascent RGB stars in almost all the GCs surveyed, for at least 1 magnitude below the RGB tip (Ivans et al. 2001); and ii) these anomalies are found only in cluster stars, whereas the abundance pattern of field stars is well explained by the classical scenario of a first dredge-up and a second mixing episode taking place above the magnitude level of the RGB-bump (Gratton et al. 2000). These facts indicate that both the CN-cycle and the ON-cycle (of the complete CNO H-burning cycle) are at work in GC stars. In particular, the proton-capture fusion mechanism, taking place in the same (inner) regions where high temperatures are reached and O is transformed in N, is able to produce Na from ^{22}Ne, as indicated by the Na-O anticorrelation. However, the Na-O anticorrelation was recently found for the first time also among unevolved turn-off stars in NGC 6397 and NGC 6752 (Gratton et al. 2001) and in 47 Tuc (Carretta et al. 2004b), where both Na-rich/O-poor and Na-poor/O-rich stars are present. Since these stars do not have the requirements (central high temperatures and an extended envelope able to bring the products of proton fusion to the photosphere) that produce the observed abundance pattern as a consequence of internal mixing during their evolution, this pattern must be due to pre-existing abundance variations. Among the possible sources of primordial contamination, a previous generation of intermediate-mass AGB stars has been proposed, that might have polluted with Na-rich, O-poor ejecta the surface layers of the subsequent generation of stars we now observe (Ventura et al. 2002).

The most likely explanation of the overall chemical pattern observed in GC stars is that a contribution of both aspects (primordial contamination and evolutionary mixing) is required. The debate seems presently shifted to how to disentangle the primordial variations and overimposed evolutionary effects, and to properly ascertain their relative proportions in

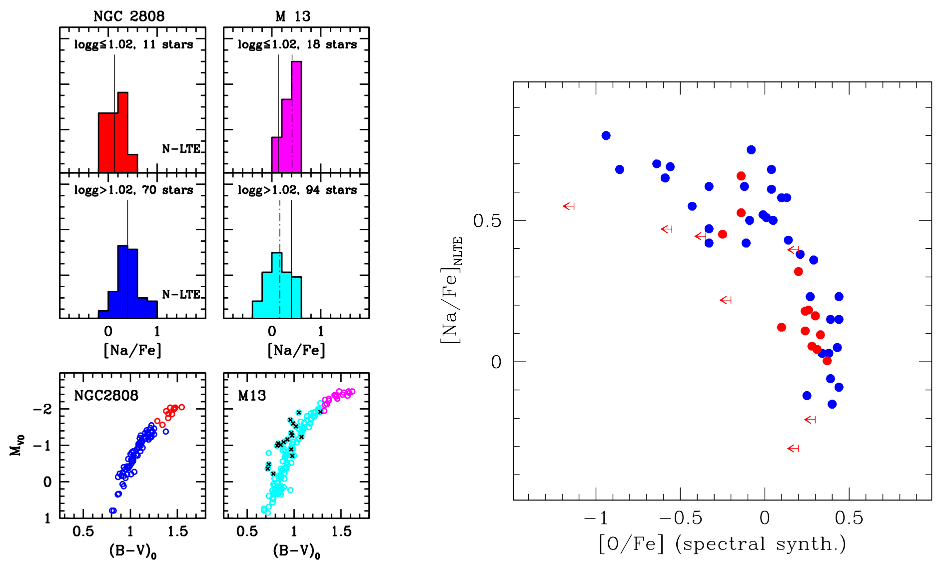

Fig. 4. Left panel: [Na/Fe] abundance histograms for the NGC2808 RGB stars, shown separately for the brightest stars (log $g \leq 1.02$) and the fainter ones (log $g > 1.02$). Similar data for M13 (Kraft et al. 1997) are shown for comparison. Right panel: [Na/Fe] vs [O/Fe] for the RGB stars in NGC2808 (red dots) compared to M13 (blue dots).

a given cluster and in clusters of different physical properties (HB morphology, density, age, metallicity, etc.). This, of course, requires the accurate knowledge of chemical abundances for a large number of GCs and for many stars within each cluster. For this reason the use of FLAMES is especially important, and had led to very interesting results in NGC 2808.
We show in Fig. 3 an example of Na D lines that were analysed with spectral synthesis techniques to derive the Na abundances. Similarly, O abundances were derived.

The [Na/Fe] abundances thus derived are shown in Fig. 4 (left panel). The histograms of the abundances, plotted separately for the 11 brightest stars (log $g \leq 1.02$) and the 70 fainter ones (log $g > 1.02$), reveal a similar spread in the distributions and slightly lower values, on average, for the brighter group. The spread in the distribution is therefore independent of luminosity and most likely of primordial origin, whereas the average abundance value, that depends on luminosity, is likely due to internal mixing phenomena. It seems therefore that the [Na/Fe] abundance variations found in NGC 2808 are mostly primordial, with some noise added by evolutionary effects. We show for comparison the results obtained in M13 by Kraft et al. (1997), where the situation is similar except that the brighter stars have *higher* values of [Na/Fe] than the fainter stars. Incidentally, a comparison with other clusters, i.e. M5, M15 and M92, not shown here, where the average [Na/Fe] abundance values do not vary significantly with luminosity, indicates that in these latter clusters the [Na/Fe] abundance variations detected along the RGB are entirely of primordial origin.
In Fig. 4 (right panel) we show the anticorrelated [Na/Fe] and [O/Fe] abundances for the 20 stars analysed in NGC2808 (red dots), and for comparison the analogous data for M13 (blue dots). In both clusters the anticorrelation is clear and well defined, and very O-poor stars are present.
These results are important for a better modelling of GC formation.

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