FLAMES Spectroscopy of RGB stars in the Globular Cluster NGC 2808: Mass Loss and Na-O Abundances

A spectroscopic survey with FLAMES of 137 red giant stars in the globular cluster NGC 2808 has revealed the likely presence of mass loss in a large number of stars among the brightest sample. Chemical inhomogeneities all along the 3-mag monitored interval suggest primordial pollution from a previous generation of intermediate mass stars.

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The multi-object spectrograph FLAMES is one of the most recent and valuable additions to the instrument family of the ESO Very Large Telescopes. Its technical characteristics (see Pasquini et al. 2002 for details) make it the ideal instrument for medium-high resolution spectroscopic studies of large numbers of stars in relatively wide fields, reaching much fainter magnitude limits than previously possible with good accuracy. Galactic globular clusters (GC) are typical places where these conditions are met, and therefore are excellent targets for FLAMES.

The scope of this article is to highlight the results we obtained with the first FLAMES observations, taken during Science Verification (SV) in January-February 2003, on the GC NGC 2808. This is a very interesting and puzzling cluster (e.g. second-parameter bimodal horizontal branch [HB] morphology, possible connection with the recently discovered CMa dwarf galaxy), yet no detailed spectroscopic study of its RGB stars was available so far. The primary aim of these observations was to fill in this gap, with two scientific purposes in mind: i) investigate the mass loss phenomenon by detecting evidence of mass motions in the atmosphere of these stars; and ii) derive the abundance of some key elements (e.g. sodium and oxygen) to study the chemical (in)-homogeneity along the RGB.

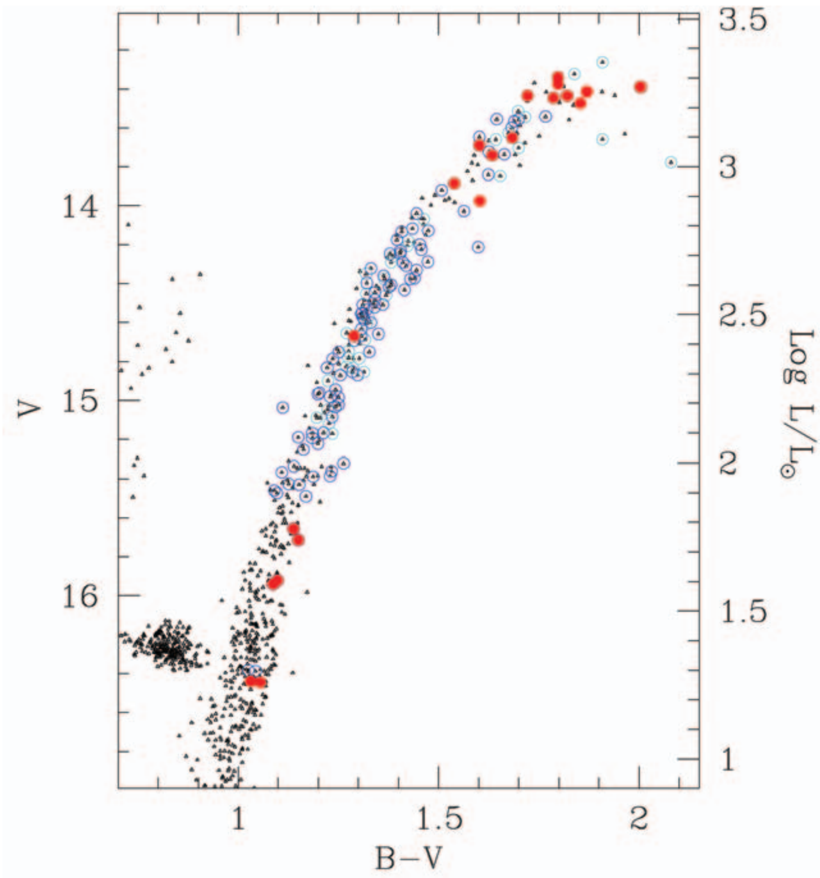

Figure 1: Colour-Magnitude diagram of NGC 2808 (Bedin et al. 2000) showing the 137 RGB stars observed with FLAMES. Filled red circles indicate the stars observed with UVES, circled blue dots indicate the stars observed with GIRAFFE/MEDUSA.

One of the basic requirements of stellar evolution theory is that some amount of mass (~ 0.1-0.2 $M_\odot$) must be lost by GC stars during the RGB evolutionary phase, in order to explain the morphology of the subsequent HB evolutionary phase (cf. Renzini & Fusi Pecci 1988). However, very little observational evidence has been found so far either of the mass already lost, or of the mass loss phenomenon while it is happening. Several spectroscopic surveys have been carried out for this purpose during the past three decades, but no firm conclusion could be reached mainly because of lack of adequate data. The mass loss is likely a stochastic phenomenon, and accurate high resolution spectra of a large number of faint stars are needed in order to gather the statistical significance that is required for a correct understanding.

The indicators traditionally used to trace mass motions in the atmospheres (hence possibly mass loss) are the Ca II K, Na I D and Hα lines, through the analysis of profile asymmetries (e.g. Ha and Ca II K emission wings) and core (blue) shifts. Other, perhaps better, indicators exist in the UV and IR ranges (e.g. Mg II at 280nm, Lyα, He I at 1083nm, cf. Dupree 1986), but are inaccessible for such faint stars with available equipment. Therefore, we have observed these three visual lines in 137 RGB stars with GIRAFFE in MEDUSA mode (R=19,000–29,000), monitoring ~3 mag down from the RGB tip. Of these stars, 20 were observed in UVES mode to get the Na I D and Hα lines at higher resolution

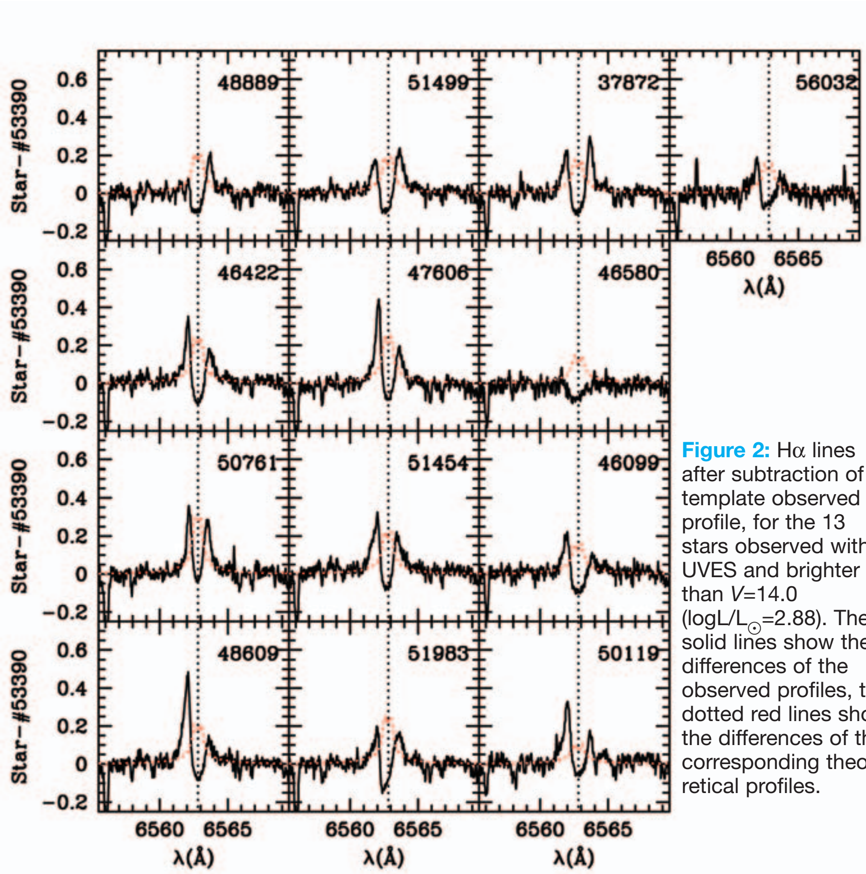

Figure 2: Hα lines after subtraction of a template observed profile, for the 13 stars observed with UVES and brighter than V=14.0 (logL/L$_\odot$=2.88). The solid lines show the differences of the observed profiles, the dotted red lines show the differences of the corresponding theoretical profiles.

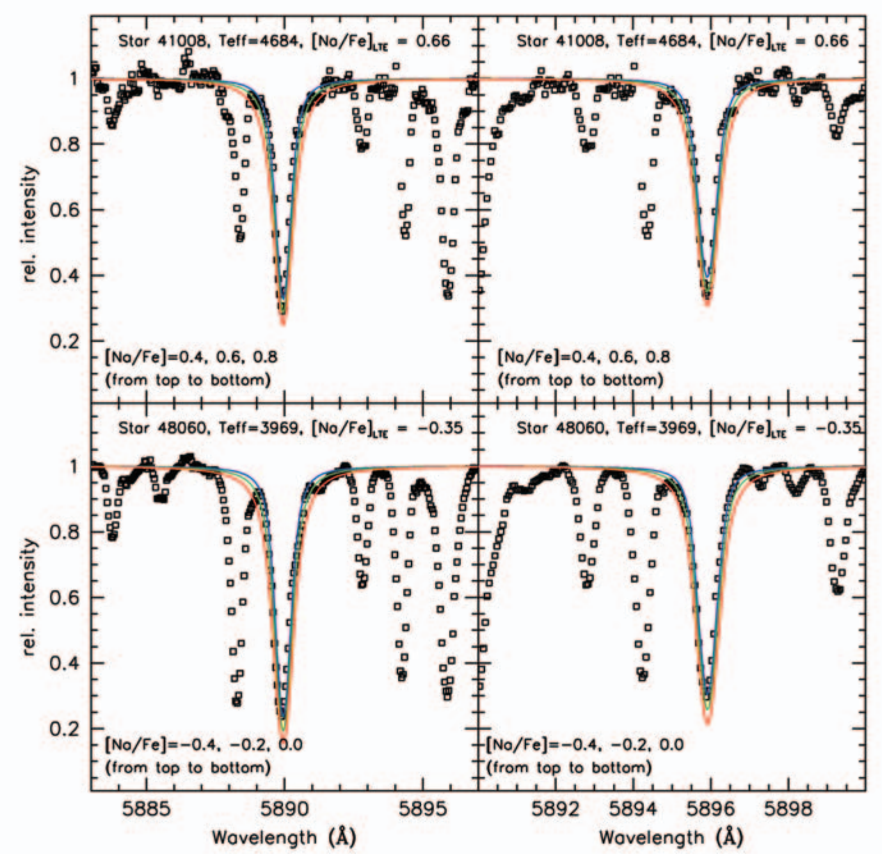

Figure 3: Spectrum synthesis of the Na D_1 and D_2 lines in two RGB stars. Open squares are the observed spectrum, while lines represent the synthetic spectra computed for appropriate values of temperature and 3 different sodium abundances: [Na/Fe]=0.4 (blue), 0.6 (green) and 0.8 (red) dex. All abundances are given in the LTE assumption.

(R=47,000). The location in the Colour-Magnitude diagram of these 137 RGB stars in shown in Figure 1. 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.

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 (logL/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 wings. 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, blue-shifted Hα absorption cores were detected in 7 out of the 20 UVES stars, and these are indicative of outward motion in the layer of the atmosphere where the Hα line is formed. Similarly, we found negative coreshifts of the Na I D_2 line in about 73% of the stars brighter than logL/L$_\odot$~2.9. The Ca II K line was observed in 83 stars, 22 of which show the central emission K_2 and reversal absorption K_3 features, with a detection threshold for these features at logL/L$_\odot$~2.6. Asymmetry B/R (i.e. the intensity ratio of the blue [K_{2b}] and red [K_{2r}] emission components) could be detected in about 75% of stars brighter than logL/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 lines 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 logL/L$_\odot$~2.8, i.e. at a slightly lower luminosity level than the onset of red asymmetry, and applies to nearly 90% of the stars brighter than this value. This set of observational evidence confirms that mass loss may indeed be present along the RGB, especially in the brightest ~0.8 mag interval from the RGB tip, and in a larger number of stars than previously estimated within any given GC.

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, 2004), and are briefly summarized here.

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 recent years. Apart from the blatant, peculiar case of ω Cen, stars in any given GC share the same metallicity only as far as heavy elements

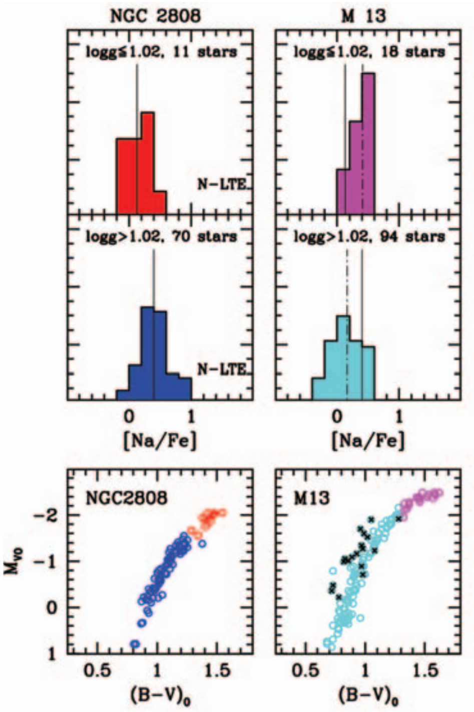

Figure 4: [Na/Fe] abundance histograms for the NGC2808 RGB stars, shown separately for the brightest stars (log g ≤1.02) and the fainter ones (log$g$>1.02). Similar data for M13 (Kraft et al. 1997) are shown for comparison.

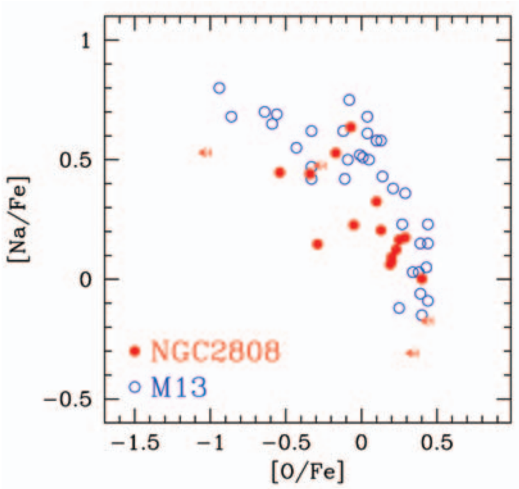

Figure 5: [Na/Fe] vs [O/Fe] for the RGB stars in NGC2808 (red dots) compared to M13 (blue dots).

(i.e. those belonging to the Fe group) are concerned. On the contrary, lighter elements (*in primis* carbon and nitrogen) show significant abundance variations along the RGB, and even among unevolved main sequence and turn-off stars. Sodium and oxygen abundances are anti-correlated among the first ascent RGB stars in almost all the GCs surveyed, for at least one magnitude below the RGB tip. This Na-O anticorrelation has been detected also among turn-off stars in three GCs so far, i.e. NGC 6397, NGC 6752 and 47 Tuc, where both Na-rich/O-poor and Na-poor/O-rich stars are present. 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. We refer the reader to Gratton et al. (2004) for a recent and comprehensive review of this intricate subject.

The presence of these abundance variations and anticorrelation in RGB stars indicates 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. The products of these nucleo-synthesis mechanisms are then brought to the surface by the convective motions in the red giant extended atmospheres. However, the presence of these abundance variations in unevolved stars cannot be explained this way. These stars do not have the physical characteristics needed to produce the observed abundance pattern, namely central high temperatures (to produce these elements in the observed proportions) and extended convective envelopes (to bring them to the surface by internal mixing). Therefore, this pattern must be due to preexisting 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 material from which the subsequent generation of stars was formed. Most likely, the overall chemical pattern observed in GC stars requires a contribution of both primordial contamination and evolutionary mixing. The debate seems presently focussed on how to disentangle primordial variations and subsequent evolutionary effects, and to properly ascertain their relative proportions in 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 has led to very interesting results in NGC 2808. We show in Fig. 3 an example of Na I 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. The histograms of the abundances, plotted separately for the 11 brightest stars (log$g$≤1.02) and the 70 fainter ones (log g > 1.02), reveal a similar spread in the distributions, and slightly lower average values 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. So it seems 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, 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 likely of primordial origin. In Fig. 5 we show the anticorrelated [Na/Fe] and [O/Fe] abundances for the 20 stars analysed in NGC 2808 (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.

To conclude, we note that this is the first time that such a large sample of RGB stars have been observed in any given GC with high resolution spectroscopy. This survey has allowed us to assess that mass loss may indeed be present along the RGB, and to trace the occurrence and onset of this phenomenon down to fainter luminosity thresholds than previously estimated. These results are important for a better understanding of the subsequent stellar evolutionary phases, in particular of the peculiar HB morphology of NGC 2808. The chemical inhomogeneities detected in these stars seem to be mostly due to a previous generation of intermediate mass stars, as has been found also in other clusters. This has important consequences for a better understanding and modelling of GC formation processes.

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