Oxigen Abundances in Horizontal Branch Stars

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The history of galactic nucleosynthesis may be followed by looking at the element abundances in stars of different age. It is generally believed that, besides hydrogen, helium und traces of a few light elements, all the other elements have been essentially produced in the stellar interiors and then injected into the interstellar medium by supernova explosions and stellar winds, giving eventually origin to more and more metal rich new stellar generations. As the amount of a given element produced by a star is a function of its mass, a study of the chemical enrichment of our galaxy makes it possible to test the predictions of stellar nucleosynthesis and to cast some light on the behaviour of the star formation rate and the mass function in the past.

The oxigen abundance in stars of different iron content has already been measured in some main-sequence stars, subdwarfs, field and globular cluster red giants, but few observations of horizontal branch stars have been done for this purpose up to now, namely three field HB stars by Kodaira and Tanaka (1972) and one star belonging to the globular cluster M4 by Peterson (1985). The main result of all these studies is that [O/Fe] increases slowly with decreasing [Fe/H] reaching eventually a plateau about [O/Fe]$\sim$+0.6 (see Pilachowsky, Sneden and Wallerstein 1983 for a review). There are, however, some globular clusters of intermediate metallicity which do not show an oxigen enhancement, a feature that can be considered as a signature of non-homogeneity in the process of chemical enrichment of our galaxy. Quite recently, however, this result has been questioned by Butler et al. (1986) who found, from a sample of 20 field RR Lyrae stars that [O/Fe] increases with increasing [Fe/H].

The aim of this work was to look at the oxigen abundance in globular cluster HB stars, in order to check the results from their red giants, using the capability of the CASPEC spectrograph at the ESO 3.6-m telescope to reach 14-magnitude stars with a good resolving power (~0.2 Å) and adequate signal to noise ratio. Two globular clusters were selected, one oxigen-rich (NGC 6397) and the other oxigen-poor (NGC 6752), essentially on the basis of their HB stars' apparent magnitude. A number of field HB stars were also included in the programme in order to see whether they showed a similar bimodal distribution. The spectral feature looked for was the infrared triplet at 7772–7775 Å, which is practically the only measurable oxigen feature in metal poor A-type stars, with an expected total equivalent width of about 500 mÅ. This triplet, however, is formed in strong non-LTE conditions, so that its interpretation in terms of abundance is not straightforward.

Since the beginning of the observing run (June 11–14, 1985) it was clear that, due to the bad seeing and atmospheric transparency, the cluster HB stars could be observed with a reasonable S/N ratio only by reducing the resolving power. The CCD was therefore binned in both directions (along and across the dispersion) and the slit set up at 500 microns (3.5 arcseconds) giving, at 7775 Å, a net peak continuum level of about 300 counts/pixel with a two-hour exposure. In such a time, the number of cosmic rays collected by the CCD was, however, very high (about 1,000), the majority of them involving two or three pixels. Removing the resulting spikes from the images poses no problems if they occur between the spectral orders, but is quite questionable if they are on an absorption line of the stellar spectrum. This is a warning for first-time observers to limit the exposure time to less than one hour,

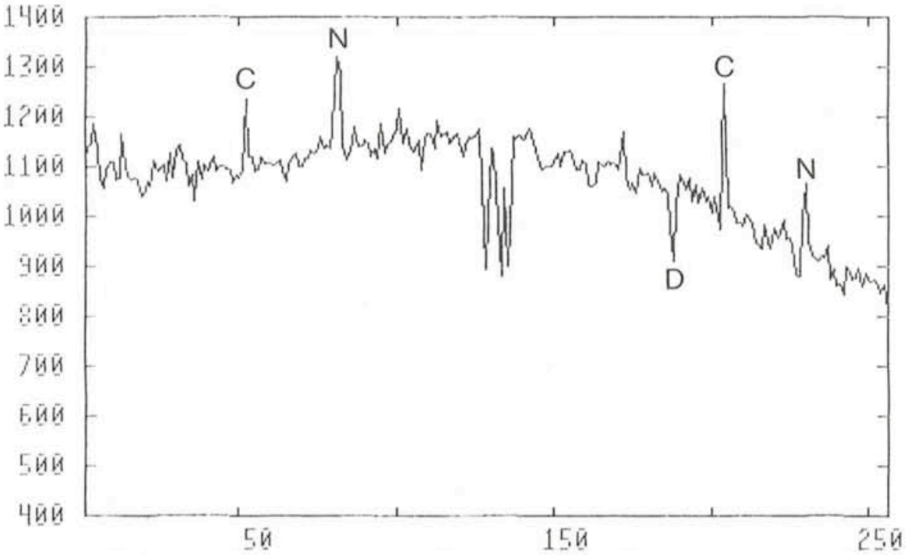

Figure 1: *Flat-fielded spectrum of HD 74721 showing the OI triplet: C are cosmic-rays spikes, N are night-sky lines, D is a CCD defect. Abscissa is in pixels, ordinate is in total net counts. A width of five pixels was used to extract the spectral order.*

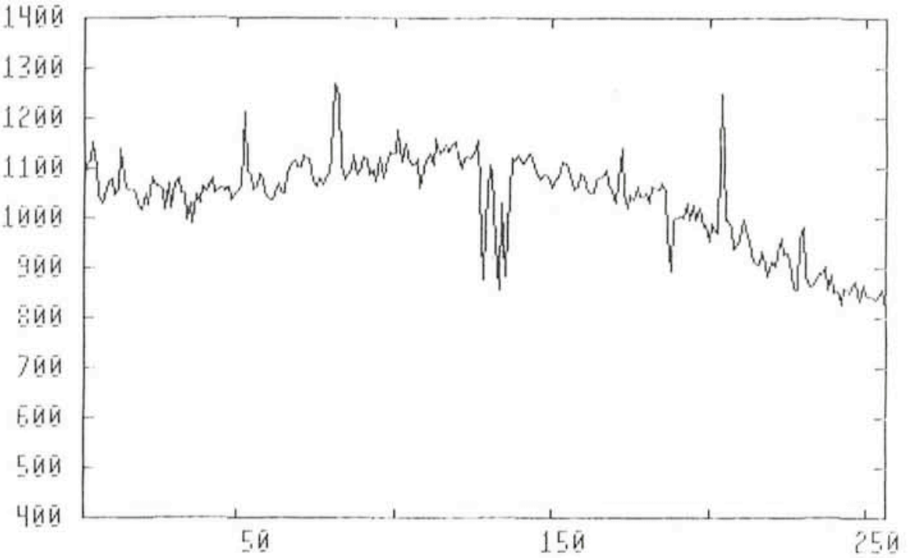

Figure 2: *Same as Figure 1 but with the flat-field correction applied after the spectral order extraction as explained in the text. A width of 11 pixels was used to extract the flat-field spectral order and of 5 pixels for the star.*

taking, if necessary, several spectra of the same star. In addition, one should not forget that cosmic rays are detected by the CCD also when the shutter is closed, so that it is not possible to interrupt an exposure for, say, one hour (due to the clouds, for instance) and then continue: the CCD will be filled by cosmic rays spikes!

For sake of homogeneity with the spectra of the cluster stars, the field HB stars, which were intended as comparison stars, were taken with the same instrumental configuration, so they are actually not the best that can be obtained with the CASPEC. Eventually, they came out to be the only useful observations of this unlucky run. Indeed, bad weather conditions and a number of technical troubles prevented us from securing blue spectra for any programme star and allowed only two stars of NGC 6397 to be observed in the infrared. Unfortunately, these last spectra showed an atmospheric emission line at 7774 Å which largely overfilled the stellar OI absorption triplet, located at the same wavelength due to the low radial velocity of the cluster. One would expect night-sky subtraction to be possible for CASPEC spectra, as the slit used was higher than the stellar image diameter. As a matter of fact, due to the CCD binning and the bad seeing, only one pixel at each side of the stellar spectrum was left to estimate the night sky luminosity, not enough to safely evaluate the emission line strength and recover the stellar absorption line.

Two main problems were found during the data reduction, which was performed at the Rome Astronomical Institute with home-made software. The first was that the stellar spectrum does not always fall completely on the same pixels as the flat-field spectrum. This is due to the fact that, during the observations, it is difficult to know if the star is on the slit centre as the slit is not actually visible on the guide monitor. One way to overcome this point would be to take the stellar spectrum through one of the small apertures of the spectrograph decker (beside the slit, obviously) reserving the full slit width to the flat-field spectrum. Unfortunately, this procedure was developed only towards the end of the observing run. A posteriori, two ways are left to retrieve the data: one is to use another flat-field exposure which better matches the stellar spectrum position; the other is to extract both the stellar and the flat-field spectrum of a given order from the raw data and then divide the stellar spectrum by the flat-field one. Although this procedure is in principle not correct, I found that it gave nearly the same result as the normal flat-fielding procedure: differences may be judged from a comparison of Figure 1 and Figure 2.

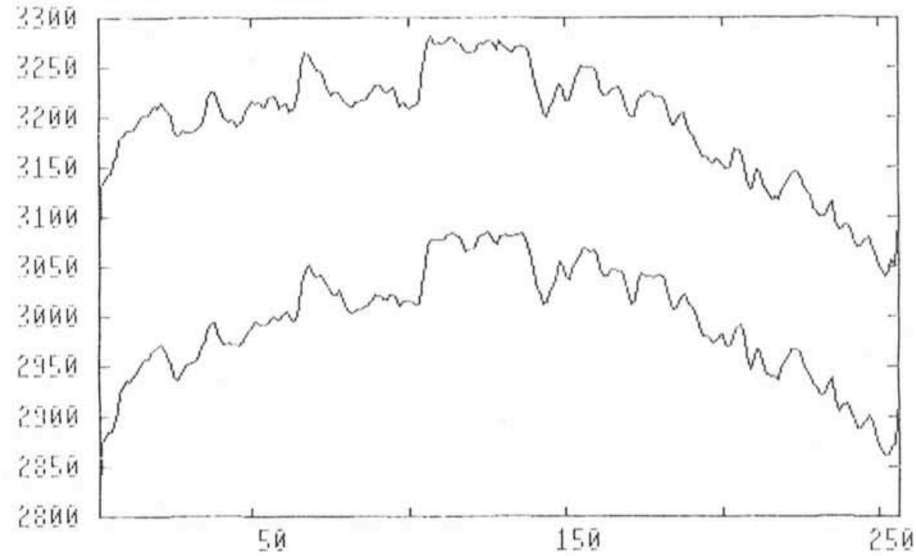

Figure 3: *Flat-field spectra of the order containing the OI triplet taken in different nights. Abscissa is in pixels, ordinate is in net counts/pixel. The spectra have been vertically shifted for a better comparison.*

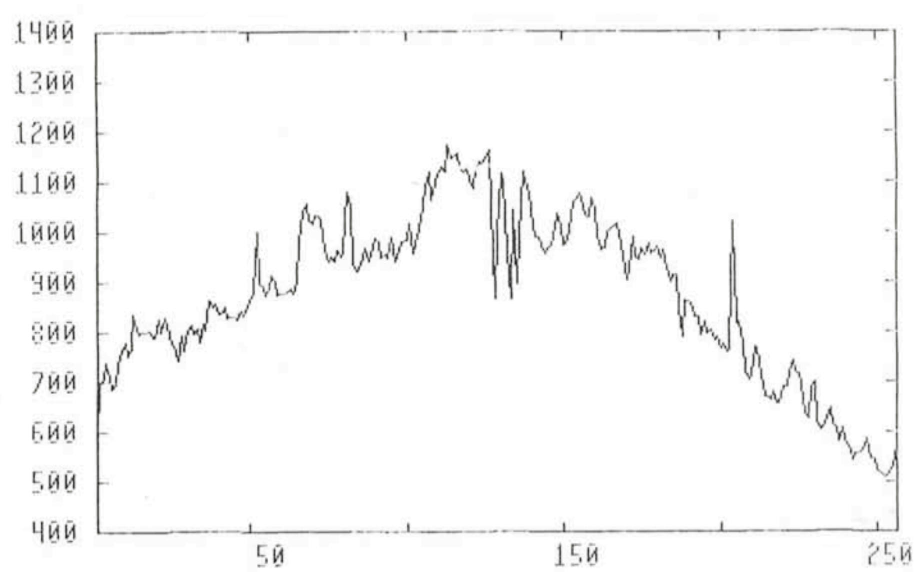

Figure 4: *Spectrum of HD 74721 without flat-field correction: the effect of the interference fringes is quite evident. Scales as in Figure 1. The spectrum of Figure 2 is obtained dividing this spectrum by the (normalized) flat-field spectrum of Figure 3.*

The second problem was a small non-linearity in the response of the CCD, which can hardly be corrected *a posteriori.* During the observing run, 3 consecutive flat-field spectra were taken with exposure times of 1, 2 and 3 seconds, to roughly test the CCD linearity. Then a given order was extracted from each exposure and the resulting spectra compared with each other: no differences were found in the interference patterns and the count levels were proportional to the exposure times within the limit of the clock accuracy. However, when flat-field exposures taken in different nights were compared, small variations in the fringes amplitude and in the overall shape of the flat-field spectrum were found (see Fig. 3). A further signature of a small non-linearity are the long-term wavy pattern of the flat-fielded stellar continuum and the incomplete correction, at a 4% level, of the interference fringes: the importance of this effect may be estimated by comparing the raw spectrum of Figure 4 with the corrected spectrum of Figure 1.

The wavelength range of the spectra obtained was from about 6870 to 7900 Å. Few absorption lines, besides the atmospheric HO and O bands, are present in metal-poor A-type stars in this spectral region. Besides the strong OI triplet, some CI, NI, FeII and MgII lines were expected but none of them was unambiguously detected. Preliminary equivalent widths, obtained simply summing up the depth of each pixel

TABLE 1

Star	W(A)	[O/H]	[Fe/H]			[Ca/H]
HD 2857	0.41	−0.4	−1.3	−1.9		
HD 74721	0.61	+0.1			−1.2	0.0
HD 86986	0.57	0.0		−1.1	−1.6	−2.0
HD 117880	0.58	0.0				−1.0
HD 130095	0.32	−0.7	−0.6			−0.6
HD 139961	0.53	−0.1				−1.6
HD 213468	0.43	−0.3				<−1.1

Values of [Fe/H] are (from left to right) from Kodaira and Davis Philip (1981), Danfort and Lea (1981), Klochkova and Panchuk (1985). [Ca/H] values are from Rodgers (1972).

normalized to the continuum level, are shown in the second column of Table 1 for all the programme field HB stars. Their accuracy should be of the order of 15 %, the main source of error being the continuum position. A comparison with previous observations may be done only for HD 86986, whose O I triplet equivalent width was found 0.65+0.13 Å by Kodaira and Tanaka from an image-tube spectrum. Given the observational errors, the agreement may be considered good.

As it was told above, the formation of this O I absorption triplet happens in strong non-LTE conditions, which have been extensively studied by Baschek, Scholz and Sedlmayr (1977). From their computations it is clear that temperature and gravity differences have only a small effect on the total equivalent width of the triplet for HB A-type stars, while major effects are expected from microturbulence and metal content variations. Several determinations of Te and log(g) are available for the present stars (see Huenemoerder, de Boer and Code 1984 for the most recent results) all in fair agreement among them. On the contrary, microturbulence has been measured for only 4 stars, and there is no agreement between different authors. However, the spread of this parameter is not large when stars observed with the same instrument are compared, and the resulting maximum spread in the triplet equivalent widths should be less than 20 %. If one assumes, as a first approximation, that microturbulence is nearly the same for all the programme stars, then the ranking in oxigen equivalent width may be considered as a ranking in abundance too.

From the paper of Baschek et al. one may roughly derive that $\Delta \log [O/H] \simeq 2.8\, \Delta \log (W_\lambda)$ for $[O/H] \simeq -1$ and a microturbulence of 5 km/s. This allows a preliminary conversion from equivalent widths to relative abundances to be made, which is shown in column 3 of Table 1, where HD 86986 is taken as reference star. The definition of the trend of [O/H] vs [Fe/H] is not possible by now, because a homogeneous set of [Fe/H] determinations is not available and the published values, also collected in Table 1, are clearly inadequate. A first result that can be remarked, however, is that the oxigen abundances found span a range of about a factor 6 within this star sample, with the most oxigen-poor star being relatively iron rich. It may also be noted that the [Ca/H] ranking found by Rodgers (1972) from the H and K line intensities in low dispersion spectra does not agree with the present (preliminary) [O/H] ranking. A homogeneous set of spectroscopic (blue) observations of these stars is clearly needed to derive their microturbulence and [Fe/H] values and then the trend of [O/Fe].

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The Optical Counterpart of OH/IR 17.7−2.0

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Type-II OH sources are characterized by maser emission at 1,612 MHz (18 cm), with a double-peaked velocity pattern. The emission is supposed to arise in an expanding circumstellar shell, the blue-shifted peak being produced in its front side, and the red-shifted peak in its back side. In such a model, the velocity separation is equal to twice the expansion velocity of the circumstellar envelope. Very often, these sources are associated with long-period variables of spectral type later than M5, such as Miras or supergiants whose spectral energy distributions peak at ~ 2 μm. Systematic radio surveys have led to the discovery of numerous type-II OH masers not associated to previously known stellar objects. Research of counterparts at infrared wavelengths have led to the discovery of objects extremely red to the point that they could not be identified optically. For that reason, these new objects have been designated "unidentified OH/IR sources". As they show similarities, in the OH and IR properties, with Miras or supergiants, they have been considered to be cool stars in the late stages of evolution on the Ascending Giant Branch (AGB), or core-helium burning supergiants (de Jong, 1983). These stars are in a phase of enhanced mass loss and, consequently, produce an envelope so dense that they are completely hidden to observers at short wavelengths; this phase is assumed to precede the planetary nebula stage. Usually, the energy distribution is dominated by reradiation from circumstellar dust grains and, except for a feature at 10 μm, it is similar to that of a blackbody at a temperature lower than ~ 1,000 K. The 10 μm feature is generally attributed to silicate grains and characterizes oxygen-rich circumstellar matter. The prototype of this class of objects is OH/IR 26.5+0.6: its spectrum, comparable to the one of a blackbody at ~ 400 K, peaks around 10 μm and it is not detected at $\lambda < 2$ μm. It is variable in the IR and OH emissions, with a very long period (P ~ 1,630 days). From the OH spectrum, the expansion velocity is ~ 14 km s^{-1}. Using the Very Large Array (VLA), Herman et al. (1985) resolved the OH-shell structure and showed it to be