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ASTRONOMY AND ASTROPHYSICS

# First UVES observations of beryllium in very metal-poor stars*

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**Abstract.** We report on a attempt to detect beryllium in two dwarf stars of the Galactic halo with metallicities below one thousandth solar. The data were obtained during the Commissioning of the Ultraviolet and Visible Echelle Spectrograph (UVES) mounted on the ESO VLT Kueyen telescope, and show the potential of UVES for studies in the UV-optical domain. We claim a beryllium detection in LP 815–43 ([Fe/H] $\sim -2.95$, [Be/H] = $-13.09$) at the 99.7% confidence level, while only an upper limit can be set for the second target CD$-24°$17504 ([Fe/H] $\sim -3.30$, [Be/H] $\leq -13.39$). These results suggest that the trend of beryllium with metallicity keeps decreasing as lower metallicities are probed, with no evidence for flattening. In CD$-24°$17504 we also analyzed the Li I line at 6708 Å, and derived a lithium abundance close to the Spite plateau.

**Key words:** stars: Population II – stars: abundances – stars: atmospheres – Galaxy: halo

## 1. Introduction

The rare light elements (Li, Be, and B) are probes of the early universe, Galactic evolution, and stellar structure. Beryllium has a special place in the general scheme of nucleosynthesis, being the lightest stable nuclide not synthesized in the Big Bang. Together with $^{6}$Li and $^{10}$B, it is considered a pure product of cosmic-ray (CR) spallation nucleosynthesis, being generated only by the bombardment of $^{13}$C and $^{16}$O by protons and $\alpha$-particles (Reeves et al. 1970; Meneguzzi et al. 1971). This unique origin has made it a particularly useful monitor of time-integrated factors of Galactic evolution such as the product of particle fluxes and abundance of targets, since its production during the Galactic epoch appears to be limited to the interstellar medium (ISM). Recent studies of Be in halo stars (e.g. Molaro et al. 1997, Boesgaard et al. 1999) have suggested that the nucleosynthesis processes responsible for its formation may be more complex than previously supposed; the linearity observed in the trend [Be/H] vs. [Fe/H][1] cannot be easily reproduced by spallation reactions between $\alpha$-particles and protons hitting CNO in the ISM. Hence, the study of the evolution of Be in the Galaxy is an important constraint of Galactic cosmic-ray (GCR) theory. The above–mentioned linearity, in fact, seems to support the idea that Type II supernovae (SN) accelerate freshly synthesized C and O and subsequently fragment into Be and B (Vangioni-Flam et al. 1998). New data, especially at low metallicities (below [Fe/H] = $-3.0$), are essential to distinguish between different hypotheses, like, for instance, the mass interval of the SN progenitor.

Although this linearity strongly suggests a Galactic origin for Be, some inhomogeneous Big Bang Nucleosynthesis models (IBBN) have shown to be able to produce beryllium abundances as high as log (Be/H) = $-13.00$ (Kajino & Boyd 1990; cf. Orito et al. 1997 for a more recent review), i.e. potentially observable in very metal-deficient stars. Such Big Bang component may appear as a constant Be-plateau, independent of metallicity, similar to what is found for lithium (cf. Spite & Spite 1982), but beryllium has been analyzed in one star only (BD $-13°$3442) at [Fe/H]$\sim -3.0$ (Boesgaard et al. 1999). Thus, this hypothesis has not been fully discarded yet.

Here, we report on our very recent attempt to measure beryllium in two of the most metal-poor stars ever observed in the spectral region near the atmospheric cut-off, where the Be lines fall (around 3130 Å). These two new measurements will be compared to the current observational picture and we will show that this type of observations and measurements are now well within reach of UVES at VLT.

## 2. Observations and data reduction

Despite of the fact that the first attempt of measuring beryllium in halo stars dates back to more than fifteen years ago (cf. Molaro & Beckman 1984), only in the past few years have technological improvements allowed us to obtain high resolution and high signal-to-noise (S/N) ratios to analyze the Be resonance doublet features in the near-UV.

The combination of atmospheric extinction, line crowding, and weakness of the Be II lines as lower metallicity stars are probed have made spectroscopic observations of beryllium very challenging when efficient near-UV detectors coupled to high-resolution spectrographs were not available. The first remarkable improvement in this respect (compared to the 4m class telescopes and instruments used at the beginning of the first ex-

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* Based on public data released from the UVES Commissioning at the VLT/Kueyen telescope, European Southern Observatory, Paranal, Chile

[1] $[A/H] = \log(A/H)_{*}/\log(A/H)_{\odot}$

**Table 1.** Log of the UVES observations.

| Star | V mag | Date | Setting | Slit Width arcsec | Exp. Time sec | S/N per pixel |
|---|---|---|---|---|---|---|
| LP 815-43 | 10.9 | Oct 16 | B346 | 0.8” | 1x5400 | 75 |
| | | Oct 8 | B346 | 1.1” | 2x2700 | 65[a] |
| | | | | | 10800 | 110[b] |
| CD−24°17504 | 12.2 | Oct 9 | B346 | 1.0” | 3x3000 | 80[b] |
| | | Oct 9 | R580 | 1.0” | 1x3000 | 200 |
| | | Oct 9 | R860 | 1.0” | 1x3000 | 170 |

[a] measured on each spectrum (always close to the Be II lines in the B346 setting)
[b] measured on the final summed spectrum (close to the Li I line in both R580 and R860 settings)

tensive analyses of beryllium in metal-poor stars) is represented by the 10m Keck I telescope equipped with HIRES (Vogt et al. 1994), that permitted the determination of the Be abundances to a much higher accuracy than ever done before. BD −13°3442, the most metal-poor star ([Fe/H] = −3.0) for which a Be detection has been claimed (Boesgaard et al. 1999) is a V=10.3 star, which required 11 hours of integration time with HIRES at Keck I in order to reach a S/N∼130 at 3130 Å.

The high-resolution Ultraviolet and Visible Echelle Spectrograph, designed and built at the European Southern Observatory, and that has now been mounted at one of the two Nasmyth foci of the second VLT 8m telescope (Kueyen), represents the most recent instrumental achievement related to this specific field of research. The first Commissioning period of UVES took place between September 27 and October 17, 1999, and all the scientific data have now become publicly available to the ESO community. The near-UV spectral region was observed in two very metal-deficient objects, LP 815–43 and CD−24°17504 ([Fe/H] = −3.05 and −3.55 respectively, as found in the literature). The log of the observations and the spectra analyzed in this study are summarized in Table 1.

Standard tasks of the Echelle reduction package in IRAF were applied to both sets of spectra. The first step included order definition, subtraction of bias and background between the orders, and flat-fielding. Because of the extreme weakness of the Be lines, we further checked the spectral region of the Be II resonance doublet in the non-flatfielded spectra, which confirmed the same shape of the lines and eliminated the possibility that spurious effects might had been introduced during the flat-fielding process. Subsequently, the orders were extracted and wavelength calibrated. This calibration achieved an *rms* deviation for a 2-dimensional 3rd order fit between pixel and wavelength space of 0.0016 Å. The orders were then normalized to a continuum of 1, via a fitting procedure (continuum task) with a spline of the 5th order.

The resolution in the near-UV, as measured from the Full Width Half Maximum (FWHM) of the Th lines, is 48 000 and 40 000 (for the 2 sets of LP 815–43 spectra, which were taken with different slit widths), and 40 000 for the CD−24°17504 star.

All the spectra were then registered for radial velocity shifts and combined via a weighted sum (weighted by the inverse of the S/N squared of each spectrum). In the case of LP 815–43, because of the above–mentioned difference in spectral resolution (see Table 1), the highest resolution spectrum was degraded to the resolution of the second set of data by convolving it with a Gaussian function, before summing the spectra. Fig. 1 shows the beryllium spectral region in both stars and Fig. 2 shows the Li 6708 Å feature in CD−24°17504, at the end of the reduction procedure.

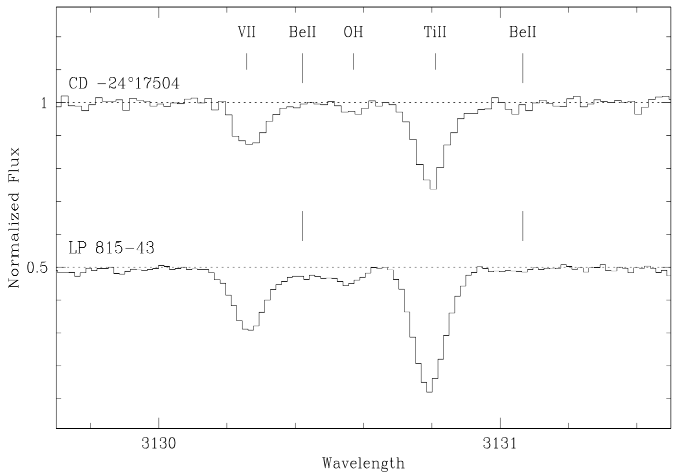


**Fig. 1.** Reduced and normalized observed spectra of the two program stars (LP 815–43 has been shifted by −0.5 in the y-coordinate)

## 3. Stellar parameters

Neither star has been widely studied in the literature. Ryan et al. (1991, 1999) performed an extensive chemical abundance analysis and derived the following stellar parameters: $T_{\rm eff}$ = 6340 ± 30 K (an average value of several colour-temperature calibrations), $\log g$ = 4.0 dex (based on the ionization balance of Fe I and Fe II lines), [Fe/H] = −3.05 dex (assuming $\log \epsilon({\rm Fe})_\odot$ = 7.50), $\xi$ = 2.0 $\rm km\,s^{-1}$ for LP 815–43, and $T_{\rm eff}$ = 6070 ± 20 K, $\log g$ = 4.0 dex (which in this case was *assumed*), [Fe/H] = −3.55 dex, $\xi$ = 1.5 $\rm km\,s^{-1}$ for CD−24°17504. From the fitting of the H$\alpha$ wings, Spite et al. (1996) determined $T_{\rm eff}$ = 6300 K for both objects.

In order to finalize our choice of stellar parameters, we decided to take advantage of the colour information available from

**Table 2.** Colour information and adopted stellar parameters.

| Star | (b-y) | $c_1$ | E(b-y) | $T_{\rm eff}$ K | $\log g$ cm s$^{-1}$ | [Fe/H] dex | $\xi$ km s$^{-1}$ |
|---|---|---|---|---|---|---|---|
| LP 815–43 | 0.304 | 0.382 | 0.033 | 6500 | 4.25 | $-2.95$ | 1.75 |
| CD$-24°$17504 | 0.322 | 0.283 | 0.015 | 6300 | 4.50 | $-3.30$ | 1.00 |

Ryan et al. (1999; cf. Table 2, this work). We used both Carney (1983) and King (1993) $T_{\rm eff}$ *vs.* (b-y) calibrations, and derived respectively $T_{\rm eff}$ = 6501.52 K and 6527.34 K in the case of LP 815–43 and $T_{\rm eff}$ = 6187.46 K and 6287.31 K for CD$-24°$17504. We note that both stars have recent (unpublished) JHK photometry, to which a direct application of the InfraRed Flux Method (IRFM) provides $T_{\rm eff}$ = 6557 K for LP 815–43 and $T_{\rm eff}$ = 6373 K for CD$-24°$17504 (Alonso, *private communication*).

As far as the gravity is concerned, we initially assumed $\log g$ = 4.0, as suggested by Ryan and collaborators. From a quick inspection of the position of our targets in the evolutionary diagram $c_1$ *vs* (b-y) (which gives information on the evolutionary status of the object) compared to the Schuster & Nissen (1989) loci used as reference, we found that gravities lower than 4.0 could be excluded (the stars fall very close to the turn-off, if not still on the main sequence). A cross-check with the isochrones of Bergbusch & VandenBerg (1992) and VandenBerg & Bell (1985) provided consistent information: gravities slightly higher than 4.0 (4.35 and 4.45 respectively) were derived when an age of 14 Gyr (although no difference was detected between 12, 14, and 16 Gyr) and the most metal-poor isochrone (which corresponds to [Fe/H] = $-2.26$) are assumed. These gravity values correspond to $T_{\rm eff}$ = 6560 K (LP 815–43) and $T_{\rm eff}$ = 6300 K (CD$-24°$17504). Because beryllium is strongly dependent on the choice of gravity, we decided to further check $\log g$ via the ionization balance. For this purpose, several lines of both titanium and iron in two different ionization stages (neutral and ionized) were selected between 3100 and 3800 Å. Their oscillator strengths were taken from the latest works of Martin et al. (1988) and Fuhr et al. (1988), and in the case of neutral iron were further cross–checked with the compilation of Nave et al. (1994). The accuracy given in these compilations (from A to D, i.e. from 10 to 50%) drove the final selection of the subsample of lines that were then used to check the ionization balances (no "D" line was used, and only few "C"). The first run of WIDTH9 (Kurucz 1993) was performed assuming $T_{\rm eff}$ = 6500 K, $\log g$ = 4.0, [Fe/H] = $-3.0$ for LP 815–43, and $T_{\rm eff}$ = 6250 K, $\log g$ = 4.0, [Fe/H] = $-3.5$ for CD$-24°$17504 respectively. First, by requiring no dependence of the abundance on the equivalent width, the microturbulence was constrained to $1.75 \pm 0.2$ km s$^{-1}$ and $1.0 \pm 0.2$ km s$^{-1}$ for LP 815–43 and CD$-24°$17504 respectively. Then, the same code was run for different values of gravity ($\pm$ 0.25, $\pm$ 0.5) and temperature ($\pm$ 250 K). The ionization balance was checked by using (10Fe I, 8Fe II) and (5Ti I, 13Ti II) lines for LP 815–43, and (6Fe I, 7 Fe II) plus (2Ti I, 13Ti II) for CD$-24°$17504 (cf. Table 3, where LP and CD stands for LP 815–43 and CD$-24°$17504 respectively); slightly higher values (4.25 and 4.5) were found confirming what we had derived from the isochrones. These are in good agreement, within the errors, with the values determined by Thevenin & Idiart (1999), who studied non Local Thermodynamic Equilibrium (NLTE) corrections for iron abundances, and found $\log g$ = 4.39 for both stars.

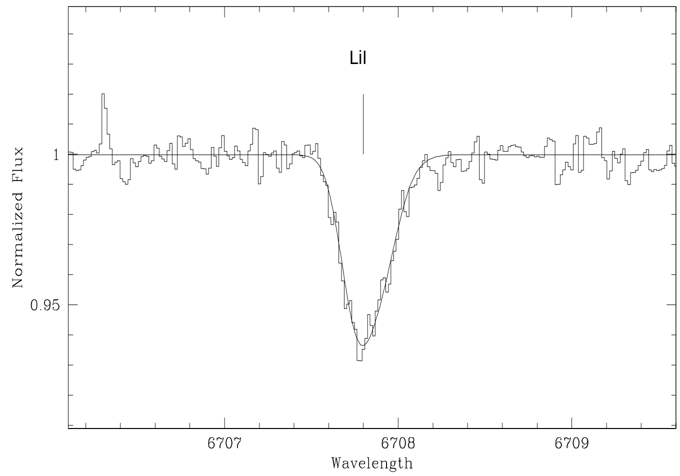


**Fig. 2.** The Li I $\lambda$6708 region in CD$-24°$17504 (histogram). The thin line represents a synthetic spectrum computed with an ATLAS9 no-overshooting $\alpha$ enhanced model ($T_{\rm eff}$ = 6373 K, $\log g$ = 4.5, [M/H] = $-3.5$).

Considering all the estimates of $T_{\rm eff}$ and $\log g$ thus obtained and their quite good agreement, we adopted $T_{\rm eff}$ = 6500 K, $\log g$ = 4.25, and $\xi$ = 1.75 km s$^{-1}$ in the case of LP 815–43, and $T_{\rm eff}$ = 6300 K, $\log g$ = 4.5, and $\xi$ = 1.0 km s$^{-1}$ for CD$-24°$17504 as our final stellar parameters.

Metallicities, on the contrary, were taken from the work of Ryan et al. (1999), but corrected for the different temperature and gravity we adopted. The values thus found, [Fe/H] = $-2.90$ and $-3.32$ for LP 815–43 and CD$-24°$17504 respectively, are in very good agreement with the metallicity inferred from our spectrum synthesis analysis (see next section).

By evaluating the uncertainties in the different methods followed to determine the stellar parameters, we find that $\pm$100 K in $T_{\rm eff}$, $\pm$ 0.25 in $\log g$, $\pm$0.15 dex in metallicity, and $\pm$ 0.2km s$^{-1}$ in the microturbulent velocity are representative of the uncertainty associated to each single parameter.

## 4. Spectrum synthesis analysis

Our spectrum synthesis calculations were performed with the Kurucz' grid of model atmospheres and synthesis codes ATLAS

**Table 3.** Atomic data.

| Lambda Å | log*gf* | E.W.$_{LP}$ mÅ | E.W.$_{CD}$ mÅ |
|---|---|---|---|
| Ti I | | | |
| 3186.45 | −0.069 | 4.4 | ... |
| 3191.99 | 0.068 | 11.4 | ... |
| 3199.92 | 0.201 | 11.8 | ... |
| 3635.46 | 0.048 | 5.2 | 4.6 |
| 3653.49 | 0.220 | 9.9 | 5.9 |
| Ti II | | | |
| 3148.05 | −1.184 | 40.6 | 19.5 |
| 3152.26 | −1.075 | 42.7 | 29.1 |
| 3154.21 | −1.183 | 43.7 | 25.6 |
| 3155.68 | −1.053 | 40.5 | 19.7 |
| 3161.22 | −0.752 | 55.4 | 35.4 |
| 3161.78 | −0.559 | 62.2 | 43.9 |
| 3162.57 | −0.455 | 65.9 | 52.1 |
| 3217.06 | −0.581 | 71.4 | 55.3 |
| 3234.52 | 0.336 | 109.3 | 85.8 |
| 3236.58 | 0.145 | 90.8 | 73.0 |
| 3239.05 | −0.031 | 84.5 | 55.8 |
| 3241.99 | −0.136 | 84.7 | 66.0 |
| 3251.92 | −0.669 | 68.6 | 47.8 |
| Fe I | | | |
| 3175.45 | −0.620 | 11.7 | ... |
| 3193.23 | −2.220 | 33.9 | ... |
| 3199.53 | −0.510 | 12.0 | 10.5 |
| 3442.36 | −1.393 | 3.6 | ... |
| 3469.83 | −1.633 | 2.6: | ... |
| 3495.29 | −0.920 | 8.9 | ... |
| 3570.09 | 0.153 | 92.7 | 66.6 |
| 3608.86 | −0.100 | 70.0 | 60.0 |
| 3631.46 | −0.036 | 69.8 | 61.8 |
| 3758.23 | −0.027 | 83.9 | 70.0 |
| 3763.79 | −0.238 | 71.8 | 61.0 |
| Fe II | | | |
| 3183.11 | −2.100 | 33.4 | 17.1 |
| 3186.74 | −1.670 | 46.8 | 30.8 |
| 3192.91 | −1.950 | 49.2 | 20.9 |
| 3196.07 | −1.730 | 46.6 | ... |
| 3210.44 | −1.690 | 48.5 | 28.6 |
| 3213.31 | −1.270 | 62.5 | 44.7 |
| 3227.74 | −1.060 | 79.1 | 59.9 |
| 3277.35 | −2.300 | 49.8 | 32.8 |

and SYNTHE (Kurucz 1993, officially released on CD-ROMs). The model atmospheres were computed according to the above–mentioned adopted stellar parameters. Solar abundances were taken from the compilation of Anders & Grevesse (1989). We used the line list previously tested by Primas et al. (1997) and the abundance ratios determined by Ryan et al. (1991) in order to constrain the allowed variations of the elemental abundances that play a role in this part of the spectrum (e.g. titanium, vanadium and chromium).

Several syntheses were run until the best match between computed and observed spectra was achieved. Our best-fit syntheses were obtained with Kurucz' $\alpha$-enhanced

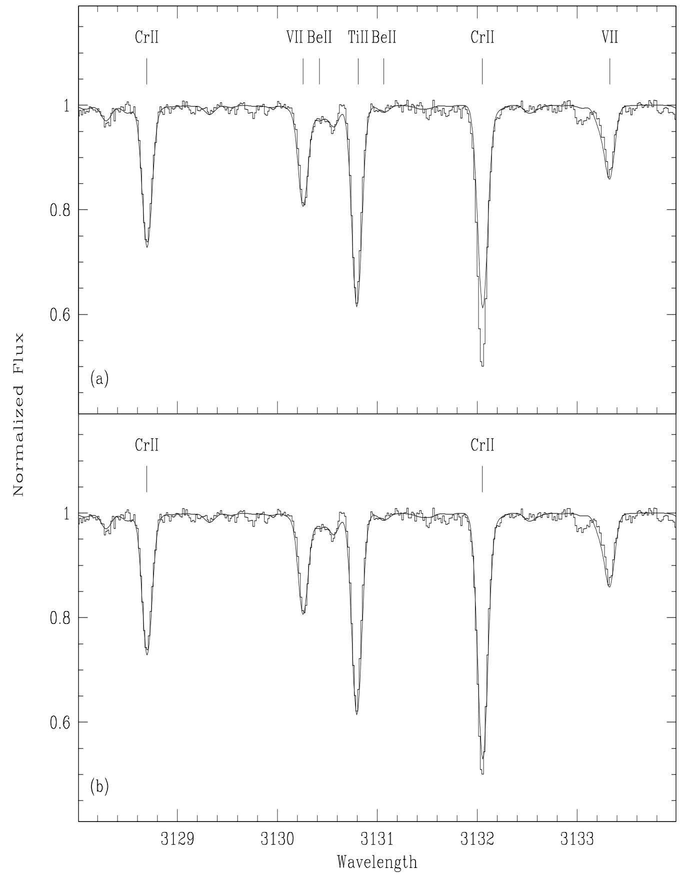


**Fig. 3a and b.** The region around the Be II resonance doublet in LP 815–43 is shown (histogram). Surrounding lines of major interest are marked for easy identification. The thin line represents our best-fit synthesis. Panel **b** shows a better agreement in the fit of the two Cr lines (see text for more explanations)

(i.e. [$\alpha$/Fe] = +0.4 dex) model atmospheres, that also include the approximate overshooting. This choice was driven by the need of comparing in a consistent way our results with data available from the literature (e.g. Boesgaard et al. 1999). The difference in the beryllium abundances derived by using models computed without the approximate overshooting was found to be negligible (on the order of 0.05 dex). Our best-fit syntheses are shown in Fig. 3 and Fig. 4, with all the relevant lines identified. They were obtained for $T_{\rm eff}$ = 6500 K, $\log g$ = 4.25, $\xi$ = 1.75 $\rm km\ s^{-1}$, and [Fe/H] = −2.95 for LP 815–43, and $T_{\rm eff}$ = 6300 K, $\log g$ = 4.5, $\xi$ = 1.0 $\rm km\ s^{-1}$, and [Fe/H] = −3.3 for CD−24°17504. Beryllium abundances equal to [Be/H] = −13.09 and −13.39 were adopted. Once the effect of using higher effective temperatures and gravities (compared to Ryan et al. 1991, 1999) on metallicity is considered, the metallicities we determine are in very good agreement with those of Ryan and collaborators.

The main source of uncertainty affecting Be measurements comes from the accuracy with which the surface gravity is known for the stars under investigation and from the uncertainty related to the placement of the continuum. The dependence of Be on gravity is of the order of ± 0.11–0.12 dex for a change in $\log g$ of ± 0.25. An uncertainty of the order of 1–2% in the de-

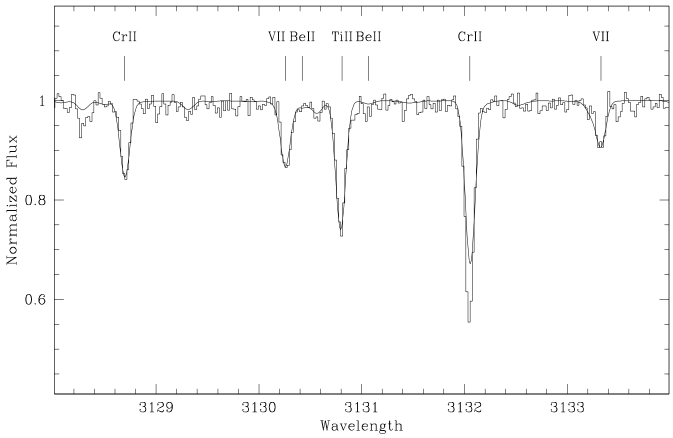


**Fig. 4.** Same as Fig. 3, but for CD−24°17504

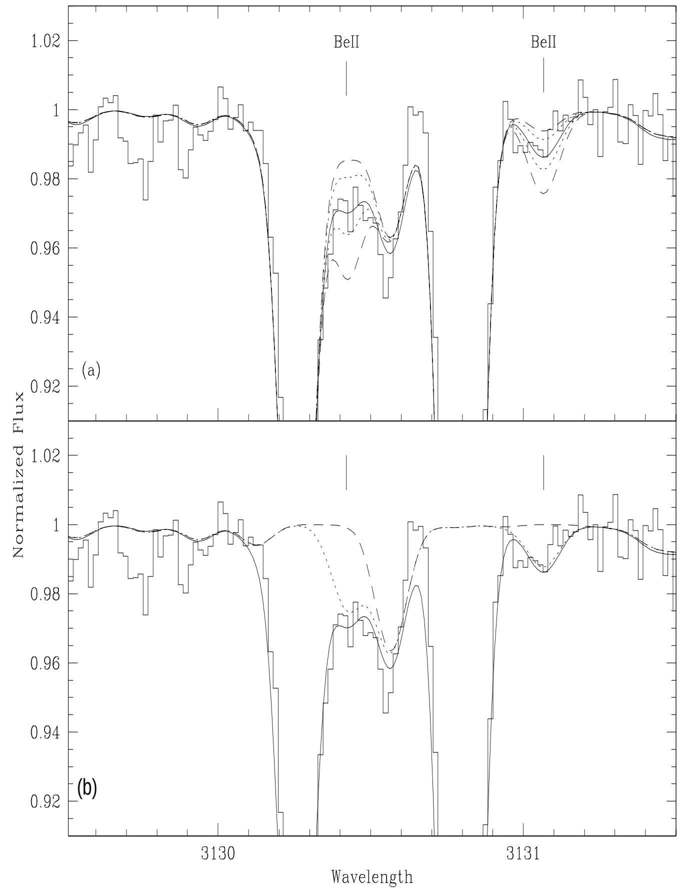


**Fig. 5a and b.** An enlarged view of the Be II resonance doublet in LP 815–43 (histogram), together with our best-fit synthesis (thin line). Overplotted are: **a** four syntheses computed with the beryllium abundance increased and reduced respectively by 0.15 dex (dotted lines) and 0.30 dex (dashed lines); **b** one synthesis computed with our best-fit Be abundance and without the most important blending lines (dotted line) and one synthesis computed with no Be and no blending lines (dashed line)

termination of the continuum translates into another $\pm$ 0.10 dex. Altogether, these sum up to $\pm$ 0.15 dex. However, inspection of Fig. 5a tells us that $\pm$ 0.15 dex may underestimate the total uncertainty to be associated with our measurements. Therefore, we decided to adopt $\pm$ 0.20 dex as our representative error bar.

Non-LTE effects on Be abundances have been discussed by Chmielewski et al. (1975), Kiselman & Carlsson (1996) and Garcìa Lòpez et al. (1995). Net NLTE corrections for halo dwarfs and other low mass stars are small, thus they were not included in the final estimate of the uncertainties.

The only disagreement which emerged from the spectrum synthesis, common to both stars, concerns the abundance of chromium: the two lines present in this small spectral region cannot be fitted simultaneously (see Fig. 3a and Fig. 4). The solution of such disparity is beyond the scope of this contribution, but probably suggests some uncertainty in the *gf*-values of these two lines. In the most recent works on transition probabilities, the log(*gf*) value of the line at 3128.7 Å is given an accuracy of "D" (50%), and the redder line does not even appear (cf. NIST, National Institute of Standards & Technology). As a test, we changed (lowered) the *gf*-value of the bluer line by different amounts (up to the allowed $\pm$50%) and increased the Cr abundance up to 0.3 dex trying to find an optimal match. We were only partially successful in this exercise, having found a very good fit but for LP 815–43 only (see Fig. 3b). Because of the lack of knowledge of the accuracy of the *gf*-value of the redder Cr II line (3132.06 Å), no conclusion can be drawn at this point.

## 5. The beryllium abundance and its implications

When the lines of interest are very weak, as in our case, the abundances inferred from the spectrum syntheses can be usually interpreted as just consistent with the observed data. In order to check the validity of our Be detection, we applied Cayrel's formula (Cayrel 1988), which estimates the minimum equivalent width detectable of a line, given the resolution, pixel size and signal-to-noise ratio of the observed data. In the case of our best spectrum (LP 815–43) and adopting a FWHM = 0.1078 mÅ and S/N = 110 (at 3130 Å), $EW_{min}(1\sigma)$ = 0.6 mÅ is found. Unfortunately, even for our best spectrum, it is very difficult to measure the equivalent width of the feature present at 3131.066 Å, that we think to be beryllium. Our attempt gives EW = 1.7 mÅ, thus implying that we may be very close to a $3\sigma$ detection. However, this procedure is not satisfactory.

Following the referee's suggestion, we also tried to subtract the Gaussian fit of the main features blending with the two Be II lines, and then to fit the presumed Be II lines. This should provide a further check on the wavelength of the Be II lines. The test was indeed successful, and proved that the remaining lines fall exactly at 3130.421 Å and at 3131.066 Å, i.e. at the expected positions. However, we were not completely satisfied with this procedure either because the subtraction of the contribution due to the blending lines is a very delicate task (especially in very metal-poor stars where the Be II doublet is very weak and the blending features are still quite strong).

A more compelling evidence that we have a detection in LP 815–43 may come from inspecting Fig. 5b. After having checked that the absorptions we attribute to beryllium in LP 815–43 fall at the expected wavelengths, we tried to obtain a better estimate of the importance of the blending features. For this purpose, we ran two more syntheses: both of them were computed taking out all the features blending with the two Be II lines, but one had our previously determined best-fit Be abundance (dotted line in the figure) and the other had no beryllium (dashed line), i.e. the beryllium abundance was lowered by a factor of 20. In our opinion, this test shows that the blending features do not affect our determination of Be in this star, and that the features we initially attributed to beryllium are indeed the beryllium doublet.

The observed spectrum of CD−24°17504 has a lower S/N∼80, that makes the measurement of the equivalent width even more difficult and highly uncertain. The Be abundance derived for this star from our spectrum synthesis ([Be/H] = −13.39) should be strictly considered an upper limit only. An observing strategy optimized for beryllium would likely have provided a detection.

Fig. 6 shows our two new Be results (filled circles) compared to the sample analyzed by Boesgaard et al. (1999, open circles – Be abundances determined on the King $T_{\rm eff}$ scale), which represents the highest quality Be spectra available at the moment (the abundances were derived from high resolution, high S/N Keck I HIRES spectra). Our two new data points (one detection, one upper limit) suggest that Be keeps decreasing as lower metallicities are probed, which is in support of a Galactic production of beryllium and argues against a primordial (Big Bang) component (although the latter cannot be excluded yet).

The correlation of Be abundances with metallicity in the early Galaxy (Boesgaard et al. 1999) and the finding of a B/Be ratio equal to that predicted by spallation (between 10 and 20, e.g. Duncan et al. 1997; Garcìa Lòpez et al. 1998) have been usually considered a clear evidence for a Galactic (as opposed to primordial) production mechanism. Unfortunately, no B measurement is available for either of our two stars. This, together with the lack of Be determinations in stars below a metallicity of 1/1000 solar has so far prevented us from testing the efficiency of cosmic-ray spallation versus any possible primordial Be synthesis, as predicted by some Big Bang nucleosynthesis models that take into account inhomogeneities during the first few minutes after the Big Bang. The detection of a plateau in the relationship between [Be/H] and [O/H] (or [Be/H] vs [Fe/H], although less stringent) has usually been considered a possible evidence for such primordial abundance of Be, although the level of such plateau has remained quite uncertain (recent calculations, e.g. Orito et al. (1997), predict $\log$ N(Be/H) + 12 = −3.0, thus below the abundances we have been able to detect so far).

However, should a plateau be detected, the interpretation may not be straightforward. Some of the theoretical scenarios recently proposed predict a Be plateau below [Fe/H] = −3.0 that is not correlated with a primordial production of beryllium. Yoshii et al. (1995) suggest that the finding of a Be plateau at low metallicities may derive from accretion phenomena of interstellar matter. These authors analyze how the accretion of metal-enriched interstellar gas onto metal-poor halo stars, while crossing the Galactic plane, may have affected the observed surface abundances of the light elements, beryllium and boron.

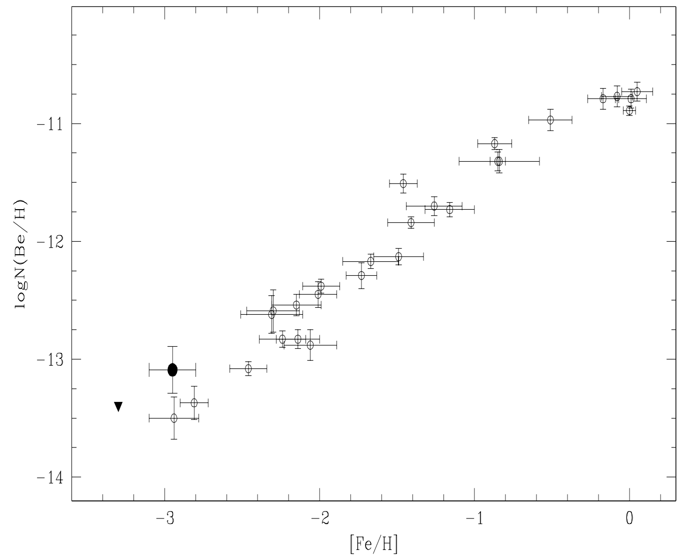


**Fig. 6.** logN(Be/H) vs. [Fe/H] for the highest quality data points currently available. Open circles represent the work from Boesgaard et al. (1999) whereas the filled symbols represent this work (the circle is LP 815–43 and the upside-down triangle is the upper limit for CD−24°17504)

According to their scenario, a key parameter that may distinguish between a primordial production of beryllium and the accretion scenario is the B/Be ratio (independent of the accretion rate, but strongly dependent on the baryon density in low- and high-density regions). Determinations of both Be and B in the same stars and in the region of the plateau become then a high priority in order to fully test the accretion scenario. But a similar plateau may also be related to the progenitor mass of the exploding supernova. Vangioni-Flam et al. (1998) proposed two possible different scenarios responsible for Be production. If shock acceleration in the gaseous phase of superbubbles produced by collective SN II explosions is the main mechanism, then only the most massive stars (with initial mass $M \geq 60 M_{\odot}$) can play a role because of their much shorter lifetimes. Whereas, a much larger mass range ($M \geq 8 M_{\odot}$) is involved if Be production is due to acceleration of the debris of grains formed in the ejecta of (in this case) SN II. Determining the [Be/Fe] ratio in very metal-poor objects is then the key not only to fully test the hypothesis of a possible Big Bang Be production, but also to disentangle between the two other possibilities: in the first case [Be/Fe] is predicted to be enhanced at very early times, in the second case is constant. Of course, in order to do that, several new accurate measurements are needed.

## 6. The lithium abundance of CD−24°17504: an important data point

As summarized in Table 1, CD−24°17504 was observed in different instrumental settings, thus a larger spectral coverage is available, including the region around the Li I line at 6708 Å, which appears on both UVES Red settings (Red 580 nm and Red 860 nm). The coadded spectrum of the Li I region has a total S/N ratio of $\sim 270$. Due to its low metallicity the star plays a crucial role in connection to the possible presence of a dependence of the Li abundance on metallicity in the Spite plateau.

In the combined spectrum, shown in Fig. 2, the EW of the Li line is found to be EW = $20.57 \pm 0.58$ mÅ, where the error bar was estimated with the Cayrel formula (Cayrel 1988). This value is consistent with the mean value obtained by measurements on the individual spectra ($20.44 \pm 0.56$). Previous measurements in the literature show a wide scatter between $15.1 \pm 2.3$ mÅ (Ryan et al. 1999) and $25.1 \pm 4.1$ mÅ (Spite & Spite 1993). The average of all the available measurements is in good agreement with our measurement. However, if we compare our result to the recent study of lithium by Ryan et al. (1999), who adopt the value of $18.1 \pm 1.3$, which is the mean of three measurements, we measure an EW which is larger by 2.5 mÅ, though consistent at 1.7 $\sigma$. We computed the Li abundances as described in Bonifacio & Molaro (1997), from ATLAS9 no–overshooting, $\alpha$ enhanced models and obtained A(Li) = $2.13 \pm 0.08$ for $T_{\rm eff}$ = 6300 K, and A(Li) = $2.19 \pm 0.08$ for $T_{\rm eff}$ = $6373 \pm 102$ K. By correcting the latter value (in order to be consistent with the temperature scale used by Bonifacio & Molaro 1997) for the NLTE effects, according to Carlsson et al. (1994) we obtain A(Li) = 2.20, which is in agreement, within errors, with the plateau level of $2.238 \pm 0.012$ derived by Bonifacio & Molaro (1997) using the same technique and IRFM temperatures. Thus our measure does not support the decrease of Li abundance for lower metallicities as claimed by Ryan et al. (1999). Although a full discussion of the slope on the Spite plateau is beyond the scope of the present paper, we note the upwards revision of the EW which implies a Li abundance 0.06 dex higher than the value derived by Ryan et al. (1999). This slight increase would then bring the data point up again, closer to the average Spite-plateau Li value, weakening their claim for the existence of a slope. By performing ordinary least squares and BCES[2] fits to the Ryan et al. data, increasing their Li abundance for CD$-24°$17504 by 0.06 dex, we find that the slope decreases by $\sim$ 19%. Therefore the main effect remains the true effective temperature of this star and in general which is the "best" temperature scale for metal–poor stars.

## 7. Concluding remarks

We have presented the analysis of two new high resolution and high S/N near-UV spectra, obtained during the Commissioning of UVES, with the main purpose of measuring Be. We have detected Be in LP 815–43 ([Be/H] = $-$13.09, 99.7% confidence level), whereas an upper limit was found in the case of CD$-24°$17504 ([Be/H] $\leq -$ 13.39). We have also measured lithium in CD$-24°$17504, and found to be A(Li) = 2.20, in good agreement with the Spite-plateau level.

These new observations clearly show the potential of the new ESO VLT high resolution echelle spectrograph UVES, especially in the near-UV spectral range. Its (now measured) efficiency at 3130 Å (where the Be II doublet falls) is a factor of 3 to 4 higher than the combination of Keck I and HIRES. New accurate measurements in a large sample of targets are foreseen in the near future and will have an important impact on our knowledge of Galactic cosmic-ray spallation.

[2] Bivariate Correlated Errors and Intrinsic scatter (Akritas & Bershady 1996).

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## References

Akritas M.G., Bershady M.A., 1996, ApJ 470, 706
Anders E., Grevesse N., 1989, Geophys. and Cosmochim. Acta 53, 197
Bergbusch P.A., VandenBerg D.A., 1992, ApJS 81, 163
Boesgaard A.M., Deliyannis C.P., King J.R., et al., 1999, AJ 117, 1549
Bonifacio P., Molaro P., 1997, MNRAS 285, 847
Carlsson M., Rutten R.J., Bruls J.H.M.J., Shchukina N.G., 1994, A&A 288, 860
Carney B., 1983, ApJ 88, 623
Cayrel R., 1988, In: Cayrel de Strobel G., Spite M. (eds.) The Impact of Very High S/N Spectroscopy on Stellar Physics. Kluwer, Dordrecht, p. 345
Chmielewski Y., Brault J.W., Mueller E.A., 1975, A&A 42, 37
Duncan D.K., Primas F., Rebull M.L., et al., 1997, ApJ 488, 338
Fuhr J.R., Martin G.A., Wiese W.L., 1988, Journal of Physical and Chemical Reference Data Vol. 17, Suppl. 4
Garcìa Lòpez R.J., Rebolo R., Perez de Taoro M.R., 1995, A&A 302, 184
Garcìa Lòpez R.J., Lambert D.L., Edvardsson B., 1998, ApJ 500, 241
Kajino T., Boyd R.N., 1990, ApJ 359, 267
King J.R., 1993, AJ 106, 1206
Kiselman D., Carlsson M., 1996, A&A 311, 680
Kurucz R.L., 1993, CD-ROM # 1, 13, 18
Martin G.A., Fuhr J.R., Wiese W.L., 1988, Journal of Physical and Chemical Reference Data Vol. 17, Suppl. 3
Meneguzzi, M., Audouze J., Reeves H., 1971, A&A 15, 337
Molaro P., Beckman J.E., 1984, A&A 139, 394
Molaro P., Bonifacio P., Castelli F., Pasquini L., 1997, A&A 319, 593
Nave G., Johansson S., Learner R.C.M., Thorne A.P., Brault J.W., 1994, ApJS 94, 221
Orito M., Kajino T., Boyd R.N., Mathews G.J., 1997, ApJ 488, 515
Primas F., Duncan D.K., Pinsonneault M.H., Deliyannis C.P., Thorburn J.A., 1997, ApJ 480, 784
Reeves H., Fowler W.A., Hoyle F., 1970, Nat 226, 727
Ryan S.G., Norris J.E., Bessell M.S., 1991, AJ 102, 303
Ryan S.G., Norris J.E., Beers T.C., 1999, ApJ 523, 654
Schuster W., Nissen P.E., 1989, A&A 221, 65
Spite M., Spite F., 1982, Nat 297, 483
Spite F., Spite M., 1993, A&A 279, L9
Spite M., Francois P., Nissen P.E., Spite F., 1996, A&A 307, 172
Thevenin F., Idiart T.P., 1999, ApJ 521, 753
VandenBerg D.A., Bell R.A., 1985, ApJS 58, 561
Vangioni-Flam E., Ramaty R., Olive K.A., Cassé M., 1998, A&A 337, 714
Vogt S.S., Allen S.L., Bigelow B.C., et al., 1994, SPIE 2198, 362
Yoshii Y., Mathews G.J., Kajino T., 1995, ApJ 447, 184