LIGHT ELEMENTS ABUNDANCES: NEW INSIGHTS ON STELLAR MIXING AND GALACTIC PRODUCTION

F. PRIMAS
European Southern Observatory
Karl-Schwarzschild str. 2, D-85748 Garching b. München

1. Introduction

The remarkable finding that B follows Fe in almost direct proportion from the earliest times to the present, with little change of slope (if any) between halo and disk metallicities (cf Figure 1, open circles, Duncan et al. 1997), has stimulated the need for a revision of the classical cosmic-ray (CR) spallation scenario. A straightforward interpretation of Duncan et al. results is that the net rate of production of B (and Be too, since it shows a similar trend) does not depend on the CNO abundances in the ISM. It has been suggested that the CR spallation most important for light element production is not primarily protons and alpha particles colliding with CNO nuclei in the ISM (Reeves et al. 1970; Meneguzzi et al. 1971). Rather, it is C and O nuclei colliding with ambient protons and alpha particles, probably in regions of massive star formation (Cassé et al. 1995). This decouples light element production from the metallicity of the ISM and results in the approximately linear relationships observed, but some aspects are difficult to justify (see Prantzos, this volume).

Despite of the cosmological interest, lithium, beryllium, and boron are also sensitive probes of stellar interiors. They are destroyed in progressively deeper layers in the outer regions of stars by (p,α) reactions at about 2.5×10^6, 3.5×10^6, and 5.0×10^6 K respectively. Therefore, any detectable change in their abundances can be considered the observable consequence of internal processes. Only by gathering information on Li, Be, and B abundances in the same objects an overall understanding of light element production over Galactic history and stellar mixing can be successfully achieved. By combining a new set of B observations and the B data we had obtained in previous *Hubble Space Telescope* (HST) cycles, we are finally able to

K. Nomoto and J.W. Truran (eds.), Cosmic Chemical Evolution, 17–21.

gather a significant sample of stars for which Li, Be, and B abundances are known.

2. The Observed Sample

The boron 2500 Å spectral region has been observed with the Goddard High Resolution Spectrograph of the HST in a new set of stars with metallicities ranging between [Fe/H]=−2.0 and −1.0. With the choice of the G270M grating we obtain spectra of 26,000 resolution and typical S/N of 35 per pixel. We chose to target some Be-weak stars and few others characterized by very similar stellar parameters but with very different Li and/or Be abundances, with the aim of testing stellar mixing. The data has been reduced following the standard HST procedure using the IRAF **stsdas** package.

3. Abundance Analysis

The B abundances were determined via spectrum synthesis making use of the most recent Kurucz model atmospheres (Kurucz 1993a, 1993b). Slight adjustments to the line list tested by Duncan et al. (1997b) were introduced, in order to achieve a good overall match to the absorption features near the B I lines (cf Primas et al. 1997). The adopted solar B abundance is log n(B)=2.60 (Anders and Grevesse 1989).

A careful error analysis, combining uncertainties related to photon statistics in the points defining the line itself, continuum placement, and variations in the stellar parameters, was performed. In particular, the uncertainty in stellar metallicity is an indirect way of accounting for the likely existence of metal lines blending with the B feature. Since our spectra do not resolve the well-known blend between the Co I λ2496.716 feature and the B I λ 2496.772, then assuming a higher metallicity attributes more of the blend to the Co, decreasing the derived B abundance. We derived net errors ranging between 0.20 and 0.22 dex for each of our targets, and because of these negligible differences we decided to assign a conservative average error bar of 0.22 dex to each data point. A possible systematic error which has not been included yet could arise from NLTE effects. A more detailed description of our error analysis (including NLTE effects, which are under investigation) will be reported in Primas et al. (1997).

4. Discussion

Because of their low burning temperatures, circulation and destruction of the light elements can result in observable abundance changes, which in turn provide an invaluable probe of stellar structure and mixing. A large

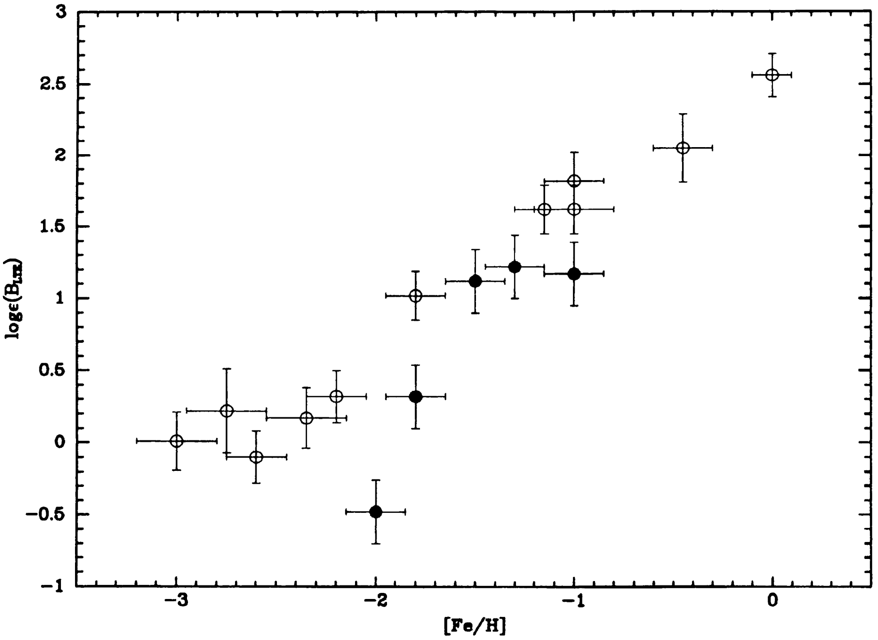

Figure 1. log $\epsilon(\mathrm{B}_{LTE})$ vs. [Fe/H], combining the stars analyzed by Duncan et al. (1997a) and this work (filled circles)

amount of information can be obtained by studying the LiBeB pattern in single targets and/or by comparing spectra of stars with very similar stellar parameters, i.e. stars which have supposedly shared a common evolutionary history.

Although the most striking feature emerging from Figure 1 is the existence of real differences in the B content among stars at almost the same metallicity, for most of our stars, when analyzed singularly, the combined LiBeB information can be accounted for within known stellar structure scenarios. The only exception is HD 160617, a metal-poor ([Fe/H]≈ −1.80) subgiant star, with an effective temperature of about 6000 K. Its Li abundance is very close to the Spite plateau value (logN(Li)=2.2, where logN(Li)=log(N(Li)/N(H)) + 12), but it has a lower Be abundance with respect to stars with similar stellar parameters. Its subgiant status cannot account for any B depletion primarily because a 6000 K star is not expected to have experienced any dilution yet (Deliyannis et al. 1997). Even adopting the much lower effective temperature determined by Fuhrmann et al. (1994) for this star, i.e. T_{eff}=5664 K, does not justify the depletion we observe (≈ a factor of 3). No standard nor non-standard stellar structure scenario account for a pattern in which Li is "unchanged" from what is currently considered its primordial value (the Spite plateau), while B (and Be) shows depletion. No firm conclusion can be drawn until different possible solutions will be further tested in the near future. The theoretical predictions of Be and B dilution factors might be incorrect: they have not been extensively tested, therefore light element abundances will need to be analyzed in a larger sample of subgiant stars, in order to better constrain the final numbers. HD 160617 might have formed with unusually low B (and possibly Be), which could explain its normal Li: we should be able to test such a picture by determining Be and B abundances in many more stars with similar stellar parameters, in order to get a sample statistically more significant. If we make the hypothesis that the primordial Li abundance was originally much higher, i.e. that the value logN(Li)=2.2 could reflect a depletion of a factor as large as ≈1.1 dex, it is then likely that the resulting LiBeB pattern might well resemble a standard light element depletion pattern.

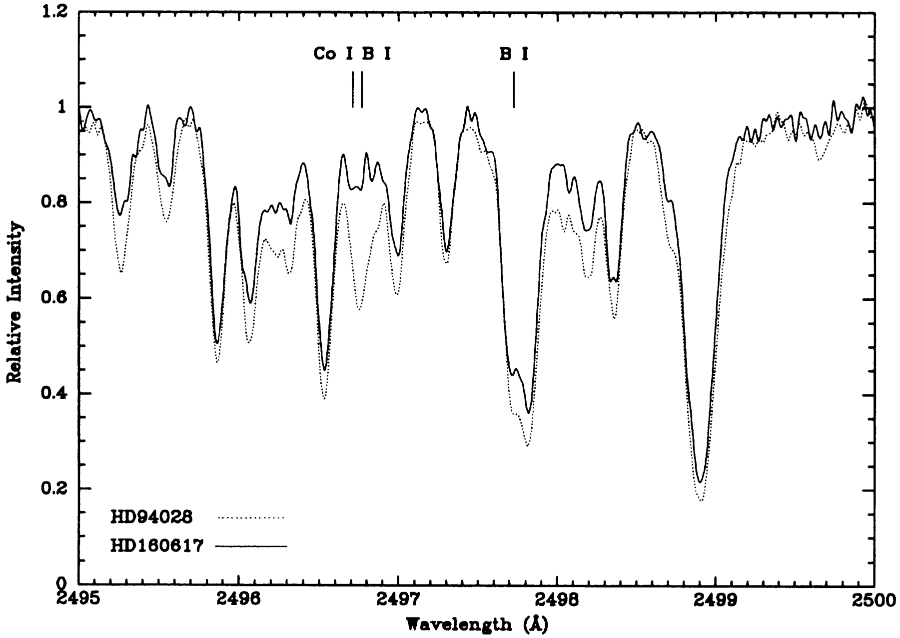

Figure 2. HD 160617 overplotted to HD 94028, a star with similar stellar parameters, although slightly more metal-rich

But a further piece of information can be obtained by inspecting Figure 2. When HD 160617 is compared to HD 94028, a star with similar stellar parameters, same Li abundance, but "normal" (i.e. *undepleted*) Be and B, it is clear that whatever causes the B (and Be) abundances to be different, does not grossly affect the Li content, as would be anticipated for light element depletion. A tentative conclusion could then be that the abundance contrasts observed in these two stars indicate inhomogeneity in their initial B (and Be) content rather than different light element depletion factors.

5. Conclusions

A new set of B observations has been analyzed with the aim of testing and better understanding depletion and/or mixing mechanisms in stellar interiors. We find real differences in the B content of stars characterized by very similar stellar parameters (T_{eff}, log g, [Fe/H]) that challenge the current predictions of different stellar depletion and mixing calculations. One case has been presented in more detail, and possible different interpretations of the results suggested. More data will need to be collected, in order to follow the steps we have pointed out. Only with a larger sample of data points available, it will be possible to address the new questions arisen from our analysis, e.g. if spatial variation of light element production in the Galaxy can or cannot be a valuable explanation for the observed dispersion.

References

Anders, E. and Grevesse, N.: 'Abundances of the Elements – Meteoritic and Solar', *Geochim. Cosmochim. Acta* **53**, pp. 197–214

Cassé, M., Lehoucq, R. and Vangioni-Flam, E.: 1995, 'Production and Evolution of Light Elements in Active Star-Forming Regions', *Nature* **373**, pp. 318–319

Deliyannis, C.P., Boesgaard, A.M., King, J.R. and Duncan, D.K.: 1997, 'New Observations of Beryllium in the Galactic Halo', *ApJ (submitted)*

Duncan, D.K., Primas, F., Rebull, L.M., Boesgaard, A.M., Deliyannis, C.P., Hobbs, L.M., King, J.R. and Ryan, S.G.: 1997a, 'The Evolution of Galactic Boron and the Production Site of the Light Elements', *ApJ* **488**, pp. 338–349

Duncan, D.K., Peterson, R.C., Thorburn, J.A. and Pinsoneault, M.H.: 1997b, 'Boron Abundances and Internal Mixing in Stars I: The Hyades Giants', *ApJ (submitted)*

Fuhrmann, K., Axer, M. and Gehren, T.: 1994, 'Balmer Lines in Cool Dwarf Stars II. Effective Temperatures and Calibration of Colour Indices', *A&A* **285**, pp. 585–594

Kurucz, R.L.: 1993a, 'ATLAS9 Stellar Atmospheres Programs and 2 km/s Grid', *Smithsonian Astroph. Obs.* **CD-ROM no. 13**

Kurucz, R.L.: 1993b, 'SYNTHE Spectrum Synthesis Programs and Line Data', *Smithsonian Astroph. Obs.* **CD-ROM no. 18**

Meneguzzi, M., Audouze, J. and Reeves, H.: 1971, 'The Production of the Elements Li, Be, B by Galactic Cosmic Rays in Space and its Relation with Stellar Observations', *A&A* **15**, pp. 337–359

Primas, F., Duncan, D.K. and Thorburn, J.A.: 1997, 'A New Set of B Observations: Implications for Stellar Mixing and Cosmology', *in preparation*

Reeves, H., Fowler, W.A. and Hoyle, F.: 1970, '', *Nature* **226**, pp. 727–729