CHEMICAL COMPOSITION OF HALO FIELD STARS AND THE CHEMICAL EVOLUTION OF THE HALO

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The abundance of the elements in the halo are mostly known from analysis of stellar atmospheres. Data from evolved stars and planetary nebulae have to be used with some caution. I will therefore rely primarily on unevolved cool dwarfs, using other information only as a complement.

I will designate these unevolved cool dwarfs indifferently by the words halo dwarfs or Population II dwarfs; such stars were formerly often called subdwarfs for historical reasons. Remaining in the field of vocabulary, I will call underdeficient an element which is deficient, but by a factor smaller than the general deficiency factor for the other elements. Finally, let us recall the classical notation:

$$[X] = \log X_{*} - \log X_{\odot}$$

GENERAL PICTURE OF HALO STARS

The halo dwarfs are generally metal-poor, the factor of deficiency relative to the Sun ranging between 1/1000 to 1/10 (this last limit is somewhat arbitrary; see however Carney, 1979).

As a very rough approximation, this deficiency factor is the same for all elements. This is why it is possible to calibrate the variation of blanketing (variation measured by photometry) with a scatter which is not too large. This method is a very powerful one, and has been used in several (UBV, uvby, RGU, Geneva, etc...) photometric systems. Metal deficiency appears to be correlated with the spatial velocity of the stars (or with its perpendicular component W, or with the eccentricity of the Galactic orbit of the star), but the correlation is not very tight.

DETAILED ANALYSIS

Detailed analysis is possible only using high dispersion spectrography. It is true that photometry through narrow band filters gives interesting

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information , but, up to now, completely undisputed calibrations have not yet been achieved.

I would like to repeat here the warnings of Prof. Pagel in his excellent review, "Abundances in unevolved cool stars" (Pagel, 1979), about claims in the literature on discovery of variations in relative abundances of elements, claims which are not always well founded, because the authors overlook or minimize a few causes of uncertainties. Pagel quotes, for instance, inadequate corrections for the effects of hyperfine structure and collision damping. Keeping this in mind, let us have a brief review of abundances in the halo.

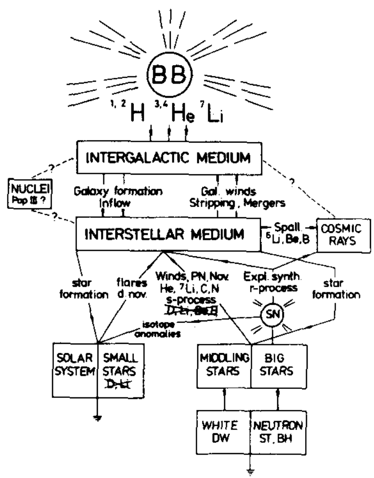

Figure 1. Nucleosynthesis of the elements from Pagel (1981).

A Special Case: Helium

No direct determination of helium abundance can be made from the analysis of the spectra of cool dwarfs of Population II. But the position of the Zero-Age Main Sequence for K dwarfs lies about 0.75 mag below the Main Sequence for disc stars in the Solar neighbourhood, which is quite consistent (Perrin *et al.*, 1979) with the halo dwarfs having the same helium abundance as the Sun. Data from planetary nebulae ascribed to the halo (Peimbert, 1978) point towards the same direction.

Light Elements: $^{2}H = D$, ^{3}H, Li, Be, B

Practically nothing is known about the abundance of these light elements in the halo. Only recently, (Cayrel, 1980) using the new Canada-France-Hawaii Telescope, lithium has been found in halo dwarfs (Spite and Spite, 1982) with a remarkably constant abundance, which probably reflects the ^{7}Li production by the Big Bang (this point is discussed in another discussion at this meeting).

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C, N, O Elements

These elements are very abundant relative to metals, and the determination of their abundances is therefore essential. Unfortunately, their abundances are difficult to determine, for several reasons.

Recently, B. Barbuy (1982) was able to confirm, by the analysis of a few extremely metal-poor halo dwarfs, that the carbon deficiency is roughly equal to the iron deficiency, [C/H] = [Fe/H] or [C/Fe] = 0, as was known from previous studies (Peterson and Sneden, 1978 and references therein). In contrast, she found that nitrogen is very underdeficient, and this new result suggests that, at least partly, nitrogen is a primary element. Oxygen was known to be slightly underdeficient (Sneden *et al.*, 1979). The work of B. Barbuy confirms this underdeficiency, and shows that it is even more conspicuous than previously admitted. Let us note that data from planetary nebulae go in the same way (Peimbert, 1978).

Mg, Si, Ca, Ti

The formation of these elements is ascribed to carbon-, oxygen- and silicon-burning. Since the pioneering work of Wallerstein (1962) it is claimed from time to time that some of these elements are underdeficient in halo stars, especially in mildly deficient stars. The deficiency factor is, however, small, near the limit of the accuracy of the determinations. Underdeficiency of Ca, for instance, does not grow more conspicuous when iron deficiency increases.

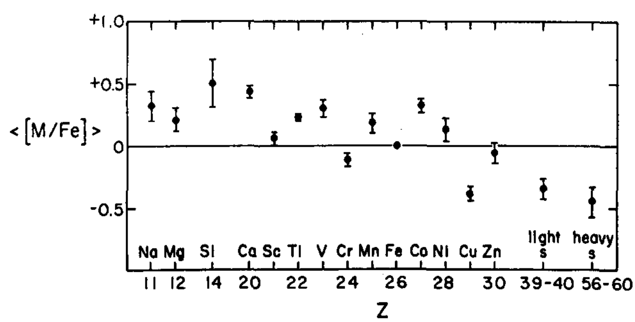

Figure 2. [M/Fe] ratio versus atomic number for halo stars from Luck and Bond (1981).

In this difficult situation, we may try to get some information from giant stars. Since, up to now, no theory of stellar evolution predicts any alteration of atmospheric abundances by the products of nucleosynthesis in their interior, the abundances of these metals in the atmospheres of Population II giants should give valuable information. The combined information of dwarfs and giants does not give a very clear picture, and my conclusion would tentatively be that the underdeficiency of these four elements, and especially Ca, is at the limit of significance; see the comparison between Peterson (1981) and Luck and Bond (1981).

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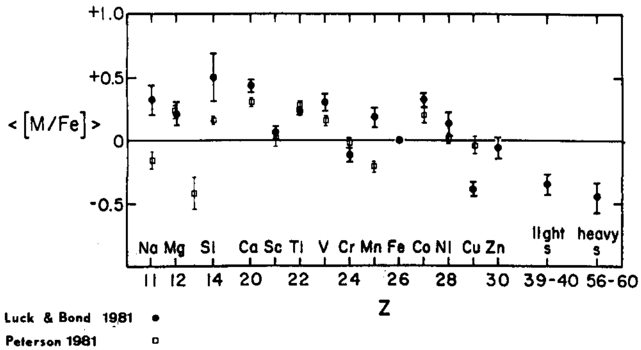

Figure 3. Comparison of the abundances of the different elements computed by Luck and Bond (1981) and Peterson (1981).

More interesting is the factor of 4 deficiency of ^{25}Mg and ^{26}Mg relative to ^{24}Mg in the cool halo dwarf Groombridge 1830 = HD 103095 (Tomkin and Lambert, 1980). Such a determination, based on the measurement of very tiny features, using spectra with very high signal-to-noise ratio, should be repeated on other halo dwarfs.

Odd Numbered Elements: Na, Al

Pure explosive nucleosynthesis (Truran and Arnett, 1971) predicts an overdeficiency of ^{27}Al and ^{23}Na relatively to "even-elements" for metal-poor stars. The observations of R. Peterson (1981) show indeed a number of halo dwarfs, all included among the hotter ones, having an over-deficiency of Al and Na, but often less than what is predicted by this theory and with a considerable scatter. Her most deficient dwarf, Giclas 64-12, for example, has a very moderate overdeficiency of Al, i.e. [Al/Fe] = -0.1. Generally, explosive nucleosynthesis should be preceded by hydrostatic burning (Woosley and Weaver, 1982) which reduces the odd-even effect. But it is puzzling to remark that in cool halo dwarfs and halo giants analysed by Spite and Spite (1980), using the spectrum synthesis technique, no significant overdeficiency of Al appears, in agreement with older determinations for two classical cool halo stars (e.g. HD 140283 and HD 122563). It would be safe, before ascribing such effects to nucleosynthesis alone, to consider other alternatives such as, for example, a possible diffusion in the atmospheres of the hottest dwarfs.

Let us note, in order to clarify this confused situation, that it has been sometimes claimed that the observations of Tomkin and Lambert (1980) - quoted hereabove about Mg isotopes - confirm the odd-even effect; their analysis however shows that the Al/Fe ratio in Groombridge 1830 is not significantly different from the solar ratio; their analysis gives [Al/Fe] = -0.06±0.010.

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The Iron Group

In the iron group, there are practically no variations in the relative abundances, apart from a marginal effect in manganese. Here the results obtained from giants may be used with confidence. A catalogue of spectroscopic [Fe/H] determination has been published by Cayrel *et al.* (1980).

The "r"-process Elements

Only one of these elements is observable (europium) and hardly more than one of its absorption lines is measurable. Taking into account the hyperfine structure, Butcher (1972) for dwarfs and Spite and Spite (1978) for giants found Eu to be normal, relative to iron, in halo stars within a factor of 2 or 3. If any indication had to be extracted from the data,

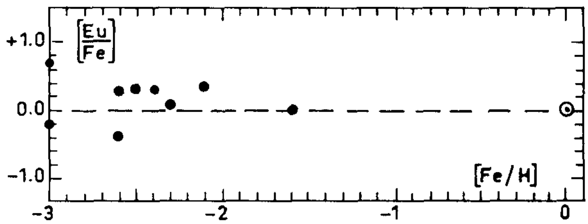

Figure 4. [Eu/Fe] vs. [Fe/H] from Spite and Spite (1978) updated.

it would be that, in general, Eu is slightly underdeficient. Luck and Bond find rather scattered values of [Eu/Fe]. Recently, Griffin *et al.* (1982) found a rather high value for the abundance of Eu for the very metal-poor giant HD 115444; but this abundance is found differentially, relative to the classical halo giant HD 122563 which happens to be abnormally Eu-deficient, so that the standard abundance of Eu would be slightly lower, still remaining higher than normal.

Here comes again, as a leitmotiv, the remark that the word "normal" relates to a very small sample of stars. Here again, more observations are urgently needed!

The "s"-process Elements

Barium has been studied in a number of metal-deficient stars by Peterson (1976) for dwarfs, Spite and Spite (1978) for dwarfs and giants, by Luck and Bond (1981) for giants. It happens that, in general, the behaviour of dwarfs and giants is the same. As an exception, Griffin *et al.* (1982) found a clear underdeficiency of Ba (relative to iron) in the giant star HD 115444. This unusual star has to be considered as a Population II barium star.

The slope of the [Ba/Fe] versus [Fe/H] line is larger in the analysis of Luck and Bond than in the Spites' analysis. The same is true for yttrium, and the reason should be ascribed to a few (very small)

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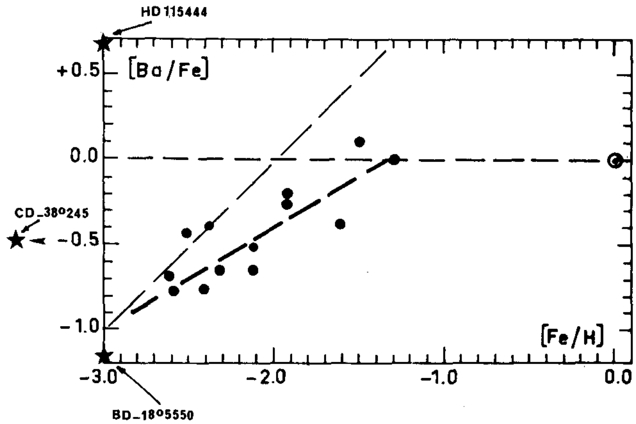

Figure 5. [Ba/Fe] vs. [Fe/H] from Spite and Spite (1978) updated.

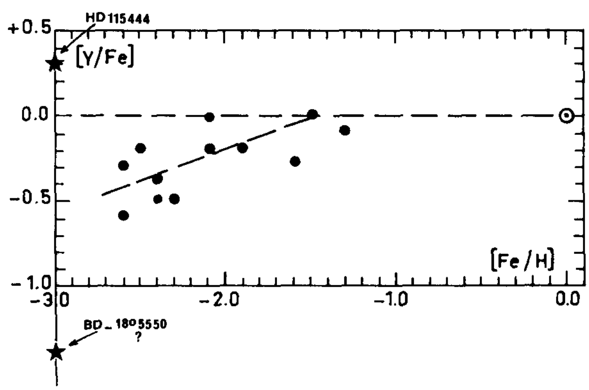

Figure 6. [Y/Fe] vs. [Fe/H] from Spite and Spite (1978) updated.

systematic errors, such as errors in temperature determination. Although the behaviour of "s"-elements abundance can be easily understood in a general way, the slope value (Tinsley, 1980) and the stabilization of [Ba/Fe] at about [Fe/H] = -1.5 is not easy to understand; Twarog (1981) has discussed this problem.

My conclusion is that the relative abundances of elements are bringing us so much useful information that the corresponding studies have to be continued. But the astronomers should be aware of the importance of several causes of systematic errors, and should try to conduct their program in a way which avoids these errors as much as possible.

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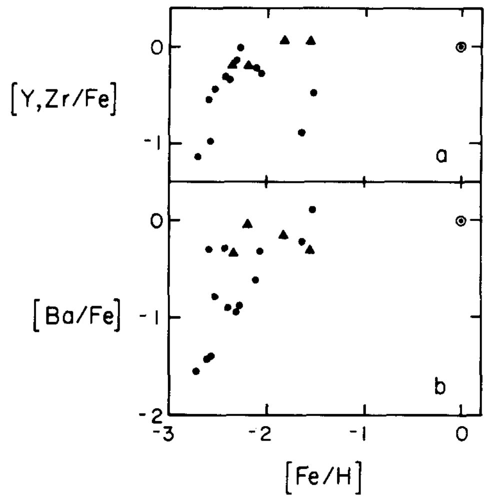

Figure 7. [Ba/Fe], [Y/Fe], [Zr/Fe] from Luck and Bond (1981).

CHEMICAL EVOLUTION OF THE HALO

Complete studies and models of the chemical evolution of the Galaxy have been made by several authors (Audouze and Tinsley, 1976; Pagel, 1979b; Pagel, 1981; Tinsley, 1980). I will here only stress a few important points or update them:

1) A few stars with an extreme metal deficiency have been found these last years, but their number is very small and no star with no metals at all has ever been found. This could suggest that some degree of prompt initial enrichment may have preceded the formation of any low-mass star in the halo; or that some metal synthesis was made by pre-galactic stars; or that Population III stars were only very massive stars; or that the detection of stars devoid of any metals is difficult, since they can be easily misidentified with reddened stars of A0 spectral type.

2) The nitrogen underdeficiency in very metal-poor stars, found in a few halo dwarfs by B. Barbuy, shows that nitrogen is, at least partly, a primary element. This, in turn suggests that there was a first generation of stars including a large proportion of very massive stars. This could possibly lead simultaneously to an early production of oxygen, explaining the confirmed underdeficiency of this element in very metal-poor stars. However, another possibility is suggested by Pagel; I quote him here: "it is possible too that nitrogen is built by a secondary process in which the shortage of seed nuclei in low abundance stars is

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more or less compensated by an increase in the vigor of mixing processes (this could also have some relevance to s-process abundances)."

3) The abundances of "r" elements show that the Galaxy was enriched in Eu as fast (and even slightly faster at first) as in iron. This is not in contradiction with the idea that iron and "r" elements are produced both by intermediate-mass stars.

This talk owes much to Pagel (1979, 1979b), to Audouze and Tinsley (1976), Tinsley (1980) and Trimble (1975, 1982). My conclusion would be that, as I repeated all along, although many results have been obtained during these last years, the situation is not entirely clear. Efforts have to be made towards the elimination of systematic errors on one hand, and towards more efficient and more numerous observations on the other hand. I hope that the Committees, which allocate telescope time, will take this conclusion into consideration (let us note that it is in agreement with one of the conclusions often stressed by B. Tinsley).

By author's error, the discussion and the reference to the work of E.M. Leep and George Wallerstein was skipped. The reader is kindly requested to refer to:

Abundances in 11 field stars with large metal deficiencies, Monthly Notices Roy.Astron.Soc. 196, 543 (1981).

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