From Lithium to Uranium: Elemental Tracers of Early Cosmic Evolution
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About two lithium problems

Francois Spite[1] **and Monique Spite**[1]

[1] GEPI, Observatoire de Paris-Meudon, F-92125 Meudon Cedex, France
Francois.Spite,Monique.Spite@obspm.fr

Abstract. Among the metal-poor dwarfs (Population II), a few are enriched in Nitrogen. Surprisingly, in spite of this peculiarity, their lithium abundance is similar to the Li abundance of the other dwarfs. Several scenarios of nitrogen enrichment are discussed, none is completely satisfactory, the most likely is a contamination by some very highly N-rich matter. But it could be speculated that these N-rich dwarfs may perhaps be stars escaped from N-rich globular clusters. An homogeneous analysis of this class of stars could be useful.

The rather low level of the lithium abundance in the old dwarfs, contrasting with the high level found in the Population I, requires a surprisingly large and rapid production of Li. Recent observations show in one Population I red giant, a very high lithium abundance. This observation, in agreement with some predictions of some theoretical models of giants and/or AGB stars is very encouraging.

Keywords. Nuclear reactions, nucleosynthesis, abundances, stars: atmospheres, stars: Population II, stars: AGB and post-AGB, globular clusters: general

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1. Introduction

After having been surprised by the discovery of lithium in Pop II dwarfs, and by the very small scatter of their Li abundances around a plateau, and by the similarity of abundance in Main Sequence stars, turn-off stars and early subgiants (but see Charbonnel & Primas 2005 and this symposium and also Bonifacio *et al.*, this symposium), we have been puzzled by the lithium abundance in N-rich dwarfs : it is surprisingly similar to the abundance of the other dwarfs of the plateau.

Also, the rather low value of Li abundance found in old Pop II stars requires a large and rapid increase of the Li abundance (an order of magnitude) from Pop II to Pop I, and this jump is difficult to explain.

Owing to considerable advances in the field, it seems interesting to rediscuss briefly these old problems, even if we are not yet able to solve them.

Classical notations will be used :

$[X/Y] = \log (X/Y)_* - (X/Y)_\odot$ for the logarithmic ratio of abundances (by number) of the elements X and Y compared to the solar ratio of these elements,

A(X) is $\log (N_X/N_H) + 12$

HBB is Hot Bottom Burning (and CBP Cool Bottom Processing) in the stellar convective envelope.

2. N-rich Population II dwarfs

The Pop II dwarfs with a metallicity lower than [Fe/H]= -1.5 (approximately), with a temperature hotter than Teff = 5700 K (approximately) show a constant lithium abundance (approximately), defining a plateau. These stars may be called warm metal poor stars (or warm Pop II stars), following a suggestion of Nissen *et al.* 2005.

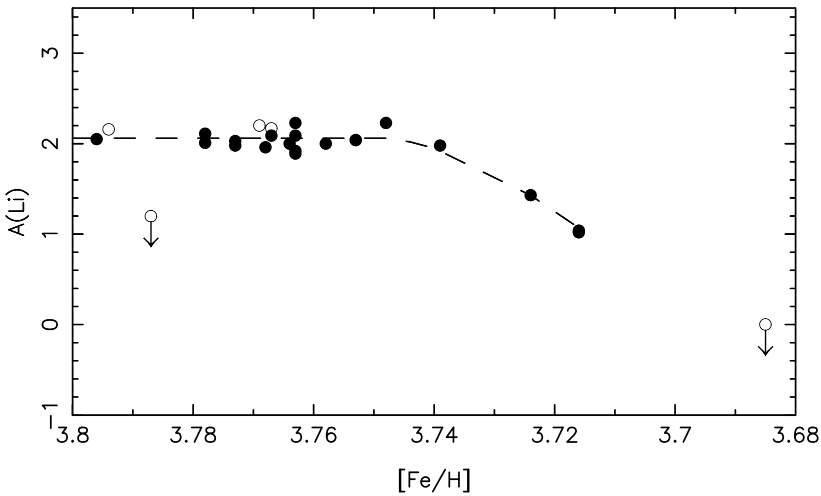

Figure 1. Lithium abundance of metal-poor dwarfs versus metallicity. The temperature is here in the scale adopted in 1985 (accordingly, the lithium abundance of the plateau is only slightly larger than 2.0). The N-rich stars are plotted as open circles. Except for two of them (one with a too low temperature and one with a too high metallicity) the N-rich stars have the same Li abundance as the other (normal) metal-poor dwarfs of the plateau

Two papers (Laird 1985, Carbon Barbuy Kraft *et al.* 1987), have shown that, in a small proportion (about 1%), a few metal-poor dwarfs are enriched in nitrogen. In November 1985, we presented a brief discussion at the GA of the IAU (Spite & Spite 1987) of the observations of lithium made at the Canada-France-Hawaii Telescope of 5 N-rich Pop II dwarfs. Three of them had lithium abundances very similar to the abundance of stars on the plateau.

In the other two ones, the Li line was undetectable : the first one was too cool and its low Li abundance is in line with the similarly low Li abundance found in the normal (not N-rich) metal-poor dwarfs having the same temperature. The second one was not metal-poor enough, it was outside of the metallicity range of the stars on the plateau. In both stars, the opacity of the envelope was larger than for the stars of the plateau, the convection zone was deep enough for enabling the destruction of lithium in the deep layers, producing a severe depletion at the surface. The behavior of the convective zone of these two N-rich stars is indeed what is expected from the theory of stellar structure, indicating that the N-rich dwarfs discussed here are essentially normal, and therefore the abundances, derived in a classical way from the measurement of the spectral lines, are reliable.

Recently, two more N-rich warm Pop II stars have been found by Israelian *et al.* (2004) with again lithium abundances similar to the abundance of the plateau. Both are very metal-poor.

2.1. *N enhanced but Li unchanged*

What is the origin of these excesses of N ? A dredge up of N within the stars themselves ? Such a dredge up is not expected in dwarfs and would anyway bring, at the surface, processed (Li-poor) matter.

Mass transfer, from a (now extinct) more massive AGB companion, would be a solution (metal-poor AGB may produce winds with a high N abundance), but no radial velocity variation has been observed yet for these stars. Observation by speckle, by interferometry, or by Gaia in the future could bring a definite conclusion. In both cases the mass transfer could be a superficial pollution : a small amount of mass with a very high N/H ratio (keeping unaltered the inital ratio Li/H of the dwarf) or some material processed in the AGB, enriched in both N and in Li, the lithium having been produced in just the right amount (surprising).

A local pollution of the star forming cloud by one (or rather several) nearby AGB could be an alternative scenario, postulating a locally imperfect mixing of the interstellar matter before the formation of the stars. The whole mass of the star would then be enriched. Here also, it would be surprising to reach the right Li abundance.

A third scenario could be the pollution of the star (or of its forming cloud) by some very N-rich matter, from a massive metal-poor star. Meynet Maeder and Ekström (2004) have shown (see also Meynet, Maeder, this symposium) that in rotating massive metal-poor stars, a wind may indeed provide some matter with a very high N/H ratio. The initial Li/H ratio is then preserved.

3. A hint from two N-rich EMP stars ?

Two Extremely Metal-Poor stars (EMP) are N-rich, they are both slightly carbon-rich and could be called CEMP stars.

1) In the FIRST STARS programme (ESO : PI R. Cayrel) a VERY N-rich star was discovered (T. Sivarani, this symposium) : the ratio N/Fe is larger than solar by about 3 orders of magnitude. The lithium abundance in this star (BPS CS 29528-41) is A(Li) = 1.7 dex (P. Bonifacio this symposium) : it is significantly below the plateau.

2) In the Hamburg-ESO programme (PI : N. Christlieb) the EMP (CEMP) star HE 1327-2326 was found by Frebel, Aoki, Christlieb *et al.* (2005). It is extremely N-rich, possibly polluted (Cayrel 2005) by a wind from a rotating massive Pop III star (Meynet Maeder and Ekström 2004). An upper limit is found for lithium : the abundance is A(Li) $<$1.6 dex.

These two stars are different from the N-rich stars discussed here and a discussion of their low Li is outside the scope of this short paper. At least they show that the Li abundance in metal-poor N-rich stars is not in EVERY possible circumstance, riveted at the level of the plateau.

3.1. *Hints from abundances of the other elements*

The abundances of some elements in some of the N-rich Pop II stars are published in the literature. The odd element Al has been analysed by François (1986) and found slightly enhanced. Two stars have been analysed in some detail (LTE) by Beveridge & Sneden (1994) and (NLTE) by Mashonkina, Gehren, Travaglio *et al.* (2003) and one star (NLTE) by Gehren, Liang, Shi, *et al.* (2005). A few abundances are provided by Fulbright (2000). There is a slight enhancement of Mg and Al, a clear enhancement of Na for one (see HD 74000 in Fig. 6 of Gehren *et al.* 2005), of Zr for the other, of Ba for both, and low Eu for both. Mashonkina et al. (2003) note that the abundance patterns of the two stars they have analysed, are dominated by the s-process.

These anomalies suggest qualitatively an enrichment by an AGB which could explain simultaneously the enhancement of N, of Na or Al and possibly of some s-process elements. But in AGB producing large quantities of such elements, Li is easily destroyed. The destruction may be compensated by some production of Li (by HBB or CBP) : why would this production bring the Li abundance just at the level of the plateau ?

Massive stars may also produce large quantities of Al, Mg and Na (Maeder & Meynet, this symposium), and winds with a high N/H ratio, keeping unchanged the initial Li/H.

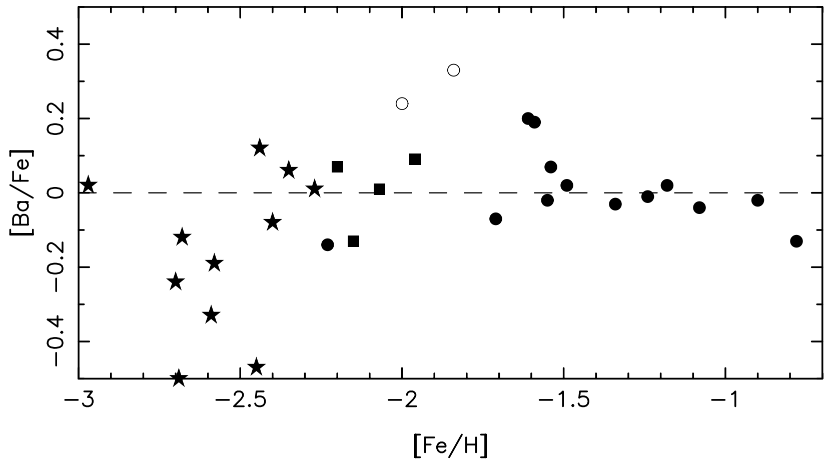

Figure 2. The two analysed N-rich dwarfs (open circles) are enriched in Ba (and other s-process elements) as compared to "normal" stars (solid circles and squares : Mashonkina *et al.* 2000, 2001, 2003 and solid stars : Cohen *et al.* 2004). The higher Ba abundance of the two dwarfs may perhaps suggest an enrichment by an AGB.

3.2. *Similarity with some globular clusters ?*

If the chemical anomalies in these N-rich stars are confirmed, they would then be rather similar to the stars of NGC 6397 (and similar globulars). The stars in NGC 6397 are N-rich, and those who are unevolved have lithium abundances at the level of the plateau.

Our N-rich warm field stars have large galactic velocities U V W, sometimes large eccentricities, similar to the kinematic parameters of the globulars : it could even be speculated that they have escaped from globular clusters. Their abundance anomalies could perhaps be explained by the processes (not yet well known) existing in some globulars.

Since the anomalies in globulars are still debated, and if the similarity of the field N-rich stars with globular stars is confirmed, the analysis of the (brighter) field stars could perhaps, reciprocally, help to solve the problem of the globulars.

Anomalies of O, N, Na, Al in globular clusters have been often attributed to a contamination by AGB stars (explaining also small overabundances of s-elements if any), but the AGB models do not yet predict yields in perfect agreement with observations : the interpretation should not be discarded however, since these models suffer from several uncertainties and the agreement could turn out to be better in the future. The Li abundance, at the level of the plateau, remains puzzling.

A very deep mixing (enhanced by rotation ?) in evolved giants of a previous generation has been considered (e. g. Denissenkov & VandenBerg 2004 and Denissenkov & Weiss 2004) : these previous stars would have provided some of the critical elements O, N, Na and Al differently from the AGB (but seemingly no s-elements). They cannot by themselves explain all the anomalies.

Some astronomers are unsatisfied either with AGB, or evolved giants, or a mixture of both, and, noting a correlation between light elements and heavy ('s') elements, propose tentatively a new (unknown) process in a new class of stars (Yong, Grundahl, Nissen *et al.* 2005) producing simultaneously both light and heavy (neutron-capture) elements.

As noted above, the intensive production of N by massive rotating stars (Meynet, Maeder & Ekström 2004) could explain both the observed abundances of N and Li : their wind, with high N/H ratio, could keep the Li/H ratio at its initial level. They would

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moreover be able to bring adequate amounts of O, N, Na, Al. But it is not yet known if the resulting abundances would display the so-called correlations and anticorrelations found in most globular clusters.

3.3. *Conclusion for N-rich warm Pop II stars*

They appear to have normal internal structures, the external enrichment (of simultaneously N, Na or Al, s-process elements) could (once confirmed) be explained (qualitatively) by a pollution by the products of previous AGB stars, probably not by a mass transfer from a companion (but a check is necessary), possibly by the local contamination by an AGB of the gas of the forming cloud. Since Li is easily destroyed in AGB, but also produced, it turns out that the production should restore the lithium abundance at the level of the plateau : a surprising coincidence.

A rather likely hypothesis would be the pollution of the star (or of its forming cloud) by a wind with a very high N/H ratio, leaving virtually unaltered the Li/H ratio. A rotating massive star (Meynet, Maeder & Ekström 2004 and this symosium) could produce the high N/H wind, explaining the Li abundance, and produce Na and Al, explaining their enhancement. If confirmed the enhancement of the s-elements could have been produced by an independent previous contamination of the gas forming cloud.

The difficulties in explaining the abundance pattern of the N-rich Pop II stars are rather similar to the difficulties encountered in trying to explain the abundance anomalies observed in at least some globular clusters. If these N-rich stars are escaped from globulars, their peculiarities would have the same origin as the peculiarities of the globular clusters.

A more complete and homogeneous analysis of the abundances of the N-rich field stars would be useful.

4. Rapid rise of Lithium in Pop I

The interpretation of the relatively low abundance of Li in Pop II stars by the primordial abundance has a consequence : a large production of lithium in the Galaxy, raising rapidly the Li abundance by an order of magnitude. The sources of this production are not well known :

– the ν-process does not explain such a jump, and lithium has not yet been observed in novae

– among the red giants some Li-rich giants are observed but in small proportion and they are generally not very Li-rich.

Some models predict a high lithium abundance in Pop I AGB or red giants. Recently, a red giant with A(Li) = 4.2 has been observed (Reddy & Lambert 2005).

Obviously, this single observation does not by itself solve the problem, but the production, of such a high abundance of Li, even in a phase of brief duration, is encouraging, since the number of red giants in the Galaxy is so enormous.

5. Conclusion

The behavior of lithium is nowadays better understood (but not completely), owing to considerable progresses in observation and theory. It was not without hard work from many people.

Reading the comments of Padmanabhan (2005) about the black holes controversy, it happens that lithium was never a topic as hot as the black holes, but sometimes perhaps some kind of misunderstandings arouse, for example between observers and theoreticians : in the astronomical community however, it may be noted that, happily, friendship finally overcomes any (temporary) divergence of opinion.

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