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LETTER

Letter to the Editor

A first HIPPARCOS contribution to the light elements problem*

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Abstract. The interpretation of the observations of the light elements requires the knowledge of the evolutionary status of the observed stars. The HIPPARCOS accurate parallaxes solve several cases of ambiguous status. For example, it is shown that, since HD 84937 is a subgiant, its ^{6}Li abundance is compatible with the predictions of the standard models of Big Bang nucleosynthesis and of stellar evolution. Also the non-detection of ^{6}Li in Population II dwarfs is in agreement with these predictions. In order to reach more precise lithium abundances, more reliable temperature scales, and, more generally, better stellar models, are necessary.

Key words: stars: abundances – stars: atmospheres – astrometry

1. Introduction

The problem of the light elements, and especially lithium, has been often presented (e.g. Reeves 1994, Spite 1995, Balachandran 1995, Crane 1995, Spite 1996; see also Thorburn 1996 for a slightly different point of view) and in particular, it is clear that any transport of matter between the external layers (where the elements are preserved) and the hot internal layers (where the fragile elements are destroyed) will deplete the observed abundance of these elements. All stellar models include the transport by convection, which is deeper in cooler (less massive) dwarfs: in Pop II dwarfs cooler than $T_{\rm eff}$ = 5700 K, the ^{7}Li isotope is brought to deep enough layers to be destroyed (and *a fortiori* the more fragile ^{6}Li isotope). In hotter and more massive Pop II dwarfs (with shallower convective zones) the ^{7}Li may be preserved and in subgiants (which, at similar age, are even more massive) even the ^{6}Li could be partly preserved. The standard model includes only the convection, other models add one or several transport processes (diffusion, stellar wind, rotationally induced mixing, internal waves...), but a definitive solution has not yet been reached.

* Based on data from the ESA Hipparcos astrometry satellite

The HIPPARCOS parallaxes (Hipparcos Catalogue, ESA 1997) enable to locate the stars on the evolutionary tracks, enabling to evaluate the structure of the star, and the extent of preservation of the lithium isotopes according to various theories. The possible dilution of Be in a confirmed subgiant is discussed in Sect. 5.

2. Lithium in the star HD 84937

This star is a typical representative of the Population II: its metallicity is around [Fe/H] = -2.3 dex, well below the limit ([Fe/H] = -1.4 dex) of the EMD stars (defined by Rebolo et al. 1988). Below this metallicity limit, the lithium abundances of the "warm" stars ($T_{\rm eff} > 5700$ K) are remarkably constant, independant of the temperature (mass), metallicity (opacity), place of birth, suggesting that this constant value of the lithium abundance, (except a few, non-understood, Li-poor stars) is the essentially undepleted primordial abundance of lithium.

2.1. The uncertain status of the star HD 84937

The classical trigonometrical parallax has for a long time been recorded with a high value. In the 1991 version of the GCTP (van Altena et al. 1991) the parallax is 29.4 $\pm$ 6.4 mas (milli arc second); it implies that the star is a dwarf at contrast with some spectroscopic and photometric indications. A more recent value of the parallax (Dahn 1994) is ambiguous, locating the star (in the color-magnitude diagram) between the dwarf- and the subgiant-branch. Its color is $(B-V)_o$= 0.38, the reddening (Schuster & Nissen 1989) is small, corresponding to a total absorption of ΔV = 0.06 mag.

2.2. Importance of the evolutionary status

In this star, an additional information is available, since both lithium isotopes are observed (Smith et al. 1993, Hobbs & Thorburn 1996), the ^{6}Li amounting to about 6% of ^{7}Li. The ^{6}Li observed in the star is supposed (Lemoine et al. 1997) to have been produced by cosmic rays (it is not produced by the Big Bang nucleosynthesis). Therefore a similar (small) amount of ^{7}Li has

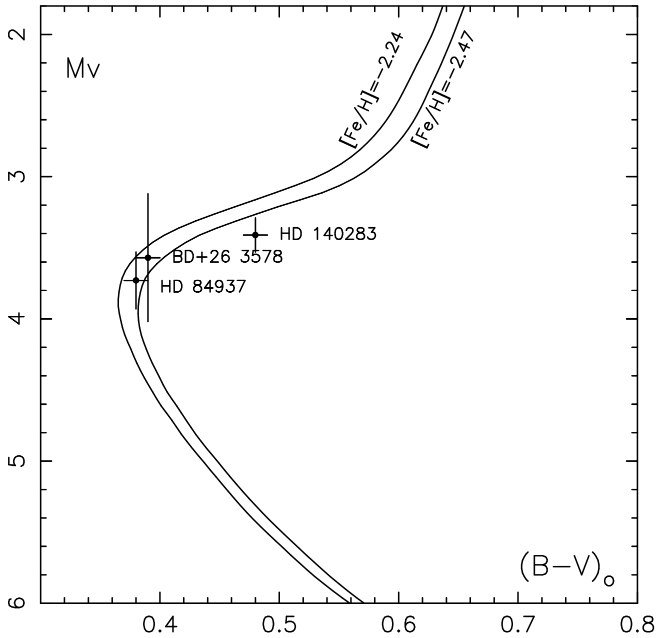

Fig. 1. Position, according to HIPPARCOS' parallaxes, of the very metal-poor stars of our sample, relatively to two extreme isochrones of Bergbusch & VandenBerg (1992), computed for an age of 14 Gyears and for the metallicities -2.26 dex and -2.03 dex, corresponding to [Fe/H] = -2.47 and -2.24 dex respectively, according to Sandquist et al. (1996). A shift of 0.03 mag in B-V has been applied, also following Sandquist et al. These three stars are obviously subgiants, a fact explaining the detection of ^{6}Li in the hotter ones, and the absence of dilution of Be in the cooler one (Sect. 5).

also been formed by the cosmic rays, since they produce both Li isotopes in approximately equal amounts.

The ^{6}Li isotope is more fragile than ^{7}Li, and is destroyed at lower temperatures. The interpretation of the observed ^{6}Li is quite different whether the star is a dwarf or a giant. Owing to the convection:

– if the star is a dwarf, the detection of ^{6}Li is not understood; this isotope is more fragile than ^{7}Li, and is expected to be entirely depleted in most Pop. II dwarfs, surviving only in the warmest (more massive) ones. According to the standard models of Chaboyer (1994) and/or Deliyannis and Malaney (1995), a dwarf of this color (and effective temperature) is not massive enough, so that its ^{6}Li should be depleted below detection level.

– if the star is a subgiant, it is more massive than a dwarf, and should retain virtually all its ^{7}Li and some ^{6}Li. The Chaboyer's standard model predicts for a subgiant of this color, a dilution of ^{6}Li by a modest factor (2.8). Alternatively, the observed ^{6}Li could have been produced recently in stellar flares (Deliyannis and Malaney 1995) but this explanation is controversial (Lemoine et al. 1997).

Chaboyer (1994) and Deliyannis & Malaney (1995) predicted that, as a subgiant, the star should have a parallax of about 11 mas (milli arc second): the HIPPARCOS parallax is 12.44 ± 1.06 mas, indicating that the star is indeed a subgiant (cf. Crifo et al. 1997). Its absolute magnitude is Mv = 3.73 ± 0.2 mag. For a mainly qualitative illustration, the approximate position of the star is shown (Fig. 1) in a drawing of two isochrones of Bergbusch & VandenBerg (1992), computed for 14 Gyears and shown to provide a good fit to M 5 (Sandquist et al. 1996). The metallicities of the isochrones are about 0.2dex larger than the iron abundances, owing to the excess of the α-elements in the metal-poor stars (Sandquist et al. 1996). A shift of 0.03 mag has also been made, following these authors, in order to account for a better calibration of the $B-V$ color into $T_{\rm eff}$.

2.3. An evaluation of the primordial abundance?

If we accept now the predictions of both standard models (a negligible production of ^{6}Li in the Big Bang, and the preservation of ^{7}Li in the subgiant HD 84937), it is possible to derive the primordial ^{7}Li abundance from the observation of this well analysed star, subtracting the Cosmic Rays contribution, amounting to 0.07dex as indicated by the remnant of the initial ^{6}Li. The Li abundance, in the usual notations:

$A(\mathrm{Li})_p = \log\epsilon(\mathrm{Li}) = \log(N_{\mathrm{Li}}/N_{\mathrm{H}})_p + 12.00$ is therefore

$= 2.12\mathrm{dex} \pm 0.05\mathrm{dex} - 0.07\mathrm{dex} \pm 0.03\mathrm{dex} \pm 0.14\mathrm{dex}$ (systematic)

$= 2.05\mathrm{dex} \pm 0.08\mathrm{dex} \pm 0.14\mathrm{dex}$ (systematic) following Smith et al. (1993), but a higher value is found (2.22dex) if the IRFM temperature scale (Alonso et al. 1996 and references therein) is adopted.

Some models, which include more transport processes than the standard model, predict a significant ^{7}Li depletion, in spite of the ^{6}Li partial preservation, leading to higher values for the ^{7}Li primordial abundance.

3. A recent detection of ^{6}Li: BD +26 3578

Smith (1996) has announced the preliminary detection of the ^{6}Li isotope in another very metal-poor star: BD +26 3578 whereas Hobbs & Thorburn (1994), found only an upper limit to the ^{6}Li/^{7}Li ratio. The metallicity is around [Fe/H] = -2.4 dex. The color is $B-V$ = 0.40 with a small reddening. The star is very similar to HD 84937 and has also a very similar temperature according to Alonso et al. (1996). HIPPARCOS' parallax indicates that the star is a subgiant (Mv = 3.57 ± 0.52 mag), located near the turn-off. Since the star is very similar to HD 84937, this ^{6}Li detection, if confirmed, is welcome because of the difficulties encountered in these delicate measurements.

4. A solved problem: HD 201891

In a first paper, Hobbs and Thorburn (1994) detected ^{6}Li in this star, surprisingly, since from classical parallaxes and from spectroscopy (Edvardsson et al. 1993), the star should be a dwarf: the preservation of ^{6}Li is not expected in a dwarf with such a moderate temperature (mass) and with such a moderate metal deficiency, both factors indicating a rather deep convective zone. It has been conjectured that the star might possibly be a subgiant, alleviating the difficulty.

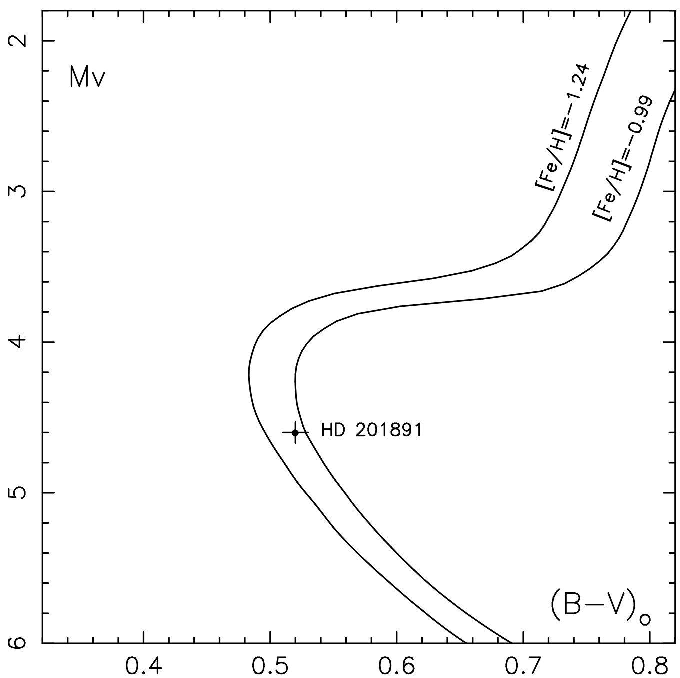

Fig. 2. Same as Fig. 1, for HD 201891. The metallicities of the isochrones are -1.03, and -0.78, corresponding approximatively to [Fe/H] values of -1.24, and -0.99 repectively.The star is on the dwarf-branch, near the turn-off.

On the other hand the matter progressively enriched in iron during the chemical evolution of the Galaxy, is also progressively enriched in the products of the cosmic rays (Duncan et al. 1997), and especially in ^{6}Li (Lemoine et al. 1997).

The new HIPPARCOS parallax is 28.26 $\pm$ 1.01 mas, indicating an absolute magnitude Mv = 4.60 $\pm$ 0.08 mag, confirming the dwarf status of the star, even if it is not far from the turn-off (Fig. 2). A recent work of Hobbs and Thorburn (1997) concludes that only an upper limit of ^{6}Li is found, so that the new ^{6}Li evaluation and the new parallax are both compatible with the predictions of the standard stellar model. The star has a moderate metal deficiency: [Fe/H] is -1.06 dex according to Edvardsson et al. (1993) and -0.98 dex (Axer & Fuhrmann 1994). Carney et al. (1996) consider the star as a member of the Galactic disk.

The HIPPARCOS parallax therefore indicates that, since the star is a dwarf, the deep convection zone, owing to the rather low mass and rather high metallicity (and opacity), prevails on its high initial ^{6}Li content.

5. Beryllium dilution in HD 140283

The classical Pop. II star HD 140283 has an intermediate temperature ($B - V$ = 0.48) and a very low metallicity ([Fe/H] = –2.5 dex). The classical parallax has for a long time indicated that the star should be a dwarf (van Altena et al.1991), but some spectroscopic and photometric measurements suggest a subgiant status, as does Dahn's (1994) parallax of 14.5 $\pm$ 1.5 mas. If such a moderately cool star is a dwarf, its Be is preserved in its external layers. But if the star is a subgiant, and if its temperature is lower than a critical temperature Tc, its Be is diluted, owing to the greater depth of the convective zone, which reaches the layers where Be has been destroyed. Such a dilution would imply that the initial Be abundance of the star was higher than it is observed now, high enough to suggest a Be plateau, *i. e.* a significant production of Be by the Big Bang, in contradiction with the standard Big Bang nucleosynthesis (Chaboyer, 1994).

The HIPPARCOS' parallax shows that the star is definitely a subgiant (Fig. 1). According to Schuster & Nissen (1989), the reddening is small: $E(B-V)$ = 0.03 as well as the absorption (ΔV = 0.09), and the star's absolute magnitude is therefore Mv = 3.37 $\pm$ 0.13 mag.

The temperature determinations in the literature extend from 5814 K (Fuhrmann et al. 1994) to 5540 K (Nissen et al. 1994), a range including the critical temperature T_c , which is, following the standard model, approximately 5550 K according to Deliyannis and 5750 K according to Chaboyer, corresponding to the beginning of the dilution of Be in a subgiant. The observations show (Duncan et al. 1997) that the star has a normal Be abundance suggesting no dilution. Better models should define which is the value of T_c (and in which temperature scale). It has however to be noted that, within the current uncertainties, the Be abundance is again compatible with the predictions of the standard models.

As expected for its low temperature, ^{6}Li is diluted, and is not detected in the star. Even, depending of the chosen T_{eff} scale, a very small ^{7}Li dilution is not excluded, explaining the slightly low Li abundance of the star, compared to the warmer Pop II subgiants.

6. Conclusion

1 – The accuracy of the HIPPARCOS parallaxes enables us to discriminate between conflicting evidences about the status of several stars.
2 – Chaboyer noted that if both the standard evolutionary stellar model AND the Big Bang nucleosynthesis model are acceptable, the ^{6}Li abundance observed in the Pop II star HD 84937 implies that the star is a subgiant : it is. If the standard model is adopted, the ^{7}Li abundance of HD 84937 is then essentially undepleted. It is therefore enough to subtract the (small) amount of ^{7}Li produced by the cosmic rays in order to recover the primordial abundance. The value obtained in this way is plagued by the uncertainties of the stellar temperature determination. Models including transport processes other than convection would predict a larger value of primordial abundance.

3 – The ^{6}Li isotope has been detected in the metal-poor star BD +26 3578; the HIPPARCOS parallax shows that the star is a subgiant, very similar to HD 84937, supporting therefore the ^{6}Li detection in both stars.

4 –The HIPPARCOS parallax of HD 201891 indicates that the star is a dwarf. The recent work of Hobbs & Thorburn (1997) indicates that only an upper limit of ^{6}Li is found in this star, and both this new result and the new parallax are now in agreement with the predictions of the standard model.

5 –The HIPPARCOS' parallax show that the star HD 140283 is undoubtedly a subgiant. The abundance of Be is normal (Duncan et al. 1997), so that the lack of dilution indicated by the subgiant status and by a rather high (but unfortunately uncertain) effective temperature, is compatible with both the standard stellar model and the standard model of Big Bang nucleosythesis.

6– The detection of ^{6}Li in two hot subgiants, the non-detection of ^{6}Li in cooler subgiants and in dwarfs, the detection of Be in the subgiant HD 140283 with a rather correct temperature, are in agreement with the predictions of the standard models. These facts, although not a proof, may be considered as an argument in favor of these models, even if we do not understand how transport processes (such as diffusion, wind, rotation, internal gravity waves etc.) fail to leave an undisputable signature. More precise conclusions need a clarification of the determinations of the effective temperatures of the observed stars, *i. e.* better model atmospheres (cf. Spite et al. 1996).

Finally, when a distortion is observed in the Li line, it is usually interpreted as a significant abundance of the ^{6}Li isotope, but it is not impossible that it could be due to an abnormal velocity field in the stellar atmosphere, affecting especially the Li line: obviously some more work is needed in the field.

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