A FIRST HIPPARCOS CONTRIBUTION TO THE LITHIUM PROBLEM

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ABSTRACT

A small but significant amount of the ^{6}Li isotope has been detected in the old metal-poor star HD 84937. Following the standard model of stellar evolution, the presence of this fragile element in the star is not expected if the star is a dwarf. The classical parallax indicates that the star is a dwarf, challenging either the standard stellar model or the standard primordial nucleosynthesis model. The Hipparcos parallax solves the problem, indicating that the star is a subgiant, the existence of ^{6}Li is then in agreement with the standard model of stellar evolution.

Key words: Population II, lithium abundance; primordial nucleosynthesis.

1. INTRODUCTION

The problem of the light elements, and especially lithium, has been often presented (e.g. Reeves 1994, Spite 1995, Balachandran 1995, Spite 1996, Spite et al. 1996, see also Thornburn 1996 for a slightly different point of view. The lithium observed in the atmosphere of the old metal-poor stars, has been formed only by the Big Bang nucleosynthesis and (marginally) by the so-called 'cosmic rays'. But lithium is a fragile element, destroyed in the hot internal layers of the stars. Any transport of matter between the external layers (where lithium is preserved) and the hot internal layers (where the fragile lithium nuclei are destroyed) would dilute the observed abundance of lithium.

Therefore, the observed lithium abundance could be only a fraction of the initial abundance in the stellar material: but which fraction? The importance of such a transport of matter in stars is not definitively estimated.

We can try to answer this question by using some additional information, observing and comparing both Li isotopes in a star of known evolutionary status.

The ^{6}Li isotope, is much more fragile than the ^{7}Li isotope, and the standard model (i.e. the simplest model of stellar structure) predicts that only in the warmer (more massive) metal-poor stars, some ^{6}Li could be preserved.

2. A CRUCIAL STAR: HD 84937

A small amount of ^{6}Li, is observed in the old metal-poor star HD 84937. This star is a typical Population II star: its metallicity (Table 1) is well below the limit [M/H] = –1.4dex of the 'extreme metal deficient' stars (Rebolo & Molaro 1988). Let us note that in all this paper we use the classical notation $[X] = \log X_* - \log X_\odot$.

Below this metallicity limit, the lithium abundance of the warm stars (Teff > 5600K) are remarkably constant, closely gathered around a value which could be near the primordial abundance of lithium, if lithium is not destroyed in these stars.

Table 1. Main parameters of HD 84937.

V	8.32	
B-V	0.40	Turon et al. 1992
E(B-V)	0.02	Schuster & Nissen 1989
$(B\text{-}V)_o$	0.38	
$T_{\rm eff}$	$\approx$ 6100K	
$[M/H]$	≈ -2.2 dex	
A(Li)	2.12 dex	Smith et al. 1993

The standard model does not predict that a dwarf with a temperature of 6100K can preserve ^{6}Li. However, if the star is a subgiant, it would be a little more massive and thus some ^{6}Li could be preserved.

The ratio ^{6}Li/^{7}Li in HD84937 ranges between 0.05 and 0.1dex (Pilachowski et al. 1989, Smith et al. 1993, Hobbs & Thornburn 1994).

Between 1935 and 1991 the parallax of HD84937 has been found between 25.0 and 29.4 mas (Figure 1). The modern parallaxes (Table 2) are significantly different.

The different locations of HD 84937 in the diagram: absolute magnitude (Mv) versus $(B\text{-}V)_o$, are shown in Figure 2. The absolute magnitudes are derived from the classical Yale catalogue of parallaxes (Van Altena, GCTP 1991), from the parallax of Dahn (1994) and from Hipparcos data (ESA, 1997). The absorption corresponding to the reddening has been taken into account in the computation of this absolute magnitude. Two evolutionary tracks of the grid of Van-

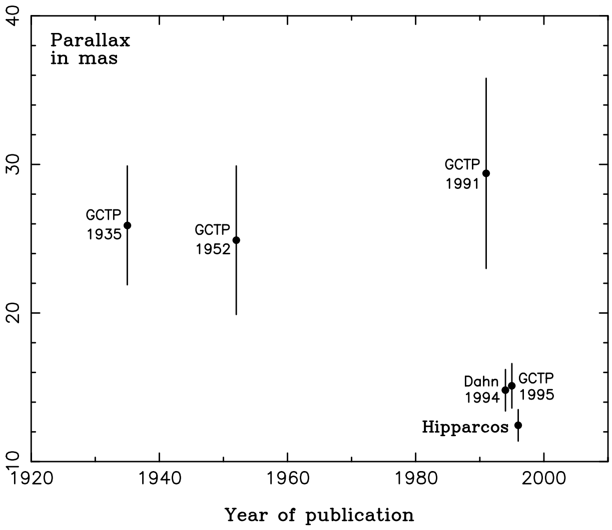

Figure 1. Evolution of the published trigonometric parallax of HD 84937 with time.

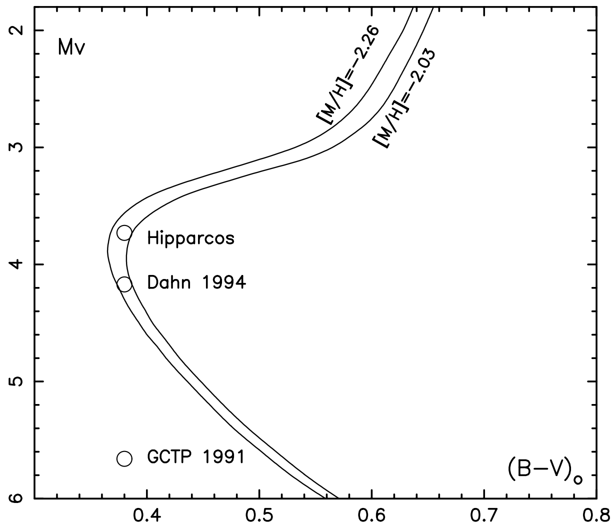

Figure 2. Location of the star HD 84937 in the diagram: Mv versus (B-V) compared to the isochrones of VandenBerg computed for 14 Gigayears and two values of the metallicity [M/H]=-2.03 et -2.26 encompassing the metallicity of the star. The absolute magnitude deduced from the Hipparcos parallax shows that the star has evolved toward the subgiant branch.

denBerg (1992) are drawn for two metallicities encompassing the metallicity of the star.

In contrast with the classical parallax (indicating that the star is a dwarf), the modern parallaxes (especially those from Hipparcos) show that the star is a subgiant. Technically a small adjustment of the theoretical tracks has been made: a small shift in B-V, adopting the value found by Sandquist et al. (1996). Similarly in Figure 22 of Sandquist et al. (1996) the Hipparcos parallax pushes the star in the CMD from an ambiguous position to a position on the subgiant branch.

Table 2. Evolutionary status of HD 84937.

source of π	π mas	$\sigma\pi$ mas	M_v	σM_v	Evol. status
GCTP 91	29.4	6.4	5.66	0.47	dwarf
Dahn 94	14.8	1.4	4.17	0.21	subgiant ?
GCTP 95	15.1	1.5	4.21	0.22	subgiant ?
Hipparcos	12.44	1.06	3.73	0.18	subgiant

3. CONSEQUENCES

The standard model implies that, since the very fragile ^{6}Li is (partially) preserved, the less fragile ^{7}Li isotope is a fortiori essentially preserved: the abundance of ^{7}Li measured in the star is therefore the initial abundance or close to it.

If (encouraged by the agreement of predictions and observations), we assume that the standard model is correct, it is possible to derive the Big Bang lithium abundance, by correcting for the contribution of the 'cosmic rays', as indicated by the presence of some ^{6}Li.

The numerical value of the ^{7}Li primordial abundance depends on the refinements of the stellar temperature calibrations. It is between 2.07 and 2.22 dex and random errors of about 0.1dex have to be added to this uncertainty.

Other models predict the preservation of some ^{6}Li even with a significant ^{7}Li depletion: e.g. the rotationnally induced Li depletion model (Pinsonneault et al. 1992), or the model combining diffusion and stellar wind (Vauclair & Charbonnel 1995). Such models indicate a depletion of ^{7}Li by factors ranging from about 2 to 10, and therefore predict a ^{7}Li primordial abundance higher than the value indicated hereabove.

Of course, the primordial lithium abundance should be derived from more than just a single star. Let us note however that the lithium abundance of HD 84937 is in agreement with the lithium abundace of the warm population II stars (on the plateau) and that the spread around this plateau is very small (Spite et al. 1996).

4. CONCLUSION

The Hipparcos parallax brings, for a crucial star (HD 84937), some support for the standard model of stellar structure (which remains to be understood). This model provides in turn an estimation of the initial ratio ^{6}Li/^{7}Li in the star (which is in agreement with the standard model of Big Bang nucleosynthesis) and an estimation of the primordial abundance of ^{7}Li.

Other models (e.g. rotationnally induced mixing, or diffusion and wind) predict that, in spite of the preservation of some ^{6}Li, the ^{7}Li is significantly depleted in the star, so that the primordial ^{7}Li abundance would be higher than the value (hereabove) predicted by the standard model.

These values of the primordial lithium abundance have to be compared to the controversial primordial abundances of the other elements produced in the Big Bang: ^{4}He, ^{3}He, and D.

On the observational side, the accuracy of the lithium abundance is limited by difficulties in finding correct temperatures for the stellar atmosphere models. On the theoretical side, the evaluation of the primordial lithium abundance is hampered by the difficult problem of transport of matter in stars. Improvements in stellar atmospheres (convection) and in stellar structure are needed for bringing significant progresses about the primordial lithium abundance.

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