Lithium in very metal poor thick disk stars

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\section*{ABSTRACT}
A search for lithium is performed on seven metal poor dwarfs with metallicities ranging from $[\text{Fe/H}]=-1.5$ down to $[\text{Fe/H}]=-3.0$ but showing disk–like kinematics. These stars belong to the metal poor tail of the Galactic thick disk and they may be also the result of an accretion event (Beers and Sommer-Larsen 1995). The $\text{Li} \ 6707.8$ \AA{} line is present in all the seven dwarfs. The weighted average of the Li abundance for the stars is $A(\text{Li})=2.20 \pm 0.06$ and is consistent within the errors with the plateau Li abundance of $A(\text{Li})=2.24 \pm 0.012$ found in genuine halo stars in the same range of metallicities (Bonifacio & Molaro 1997). One of the stars, CS 22182-24, shows somewhat lower Li abundance ($A(\text{Li})=1.6\pm0.40$) and is a candidate to being a Li-poor star. Whether this group of stars belongs to the oldest stars in the disk or to the old population of an external galaxy accreted by the Milky Way, the present observations provide support to the universality of a pre-Galactic Li abundance as is observed in the Galactic halo stars.

\textbf{Key words:} Stars: abundances – Stars: Population II – Stars: fundamental parameters – Galaxy: halo – Galaxy: disk – Cosmology: observations

\section*{1 INTRODUCTION}
Spite & Spite (1982) discovered the presence of Li in the warm halo dwarfs at a constant value (the Spite plateau) and suggested that it is the primordial Li, i.e. Li synthesized in the Big Bang. The knowledge of primordial Li is of far reaching cosmological relevance since it is a function of $\eta \equiv n_\gamma / n_\nu$, the baryon to photon ratio, which is related to total baryonic density by $\Omega_B h^2 = 0.0066\eta_{10}$. The Spite & Spite findings have been confirmed by a number of investigations and Li is now measured in somewhat one hundred of halo dwarfs (see Ryan et al 1996 and references therein) including stars with metallicities down to $[\text{Fe/H}]=-4.0$ and few turn-off globular cluster stars (Molaro & Pasquini 1994; Deliyannis et al 1995; Pasquini & Molaro 1997). Only very few stars have been found with a Li abundance much less than the plateau value. The substantial flatness of the plateau and the remarkable absence of any scatter in the Li abundance have been recently confirmed by means of an accurate analysis of a subsample of stars with accurate effective temperatures (Bonifacio & Molaro 1997). These properties together with the detection of the more fragile isotope $^6\text{Li}$ in HD 84937 (Smith et al 1993 Hobbs & Thorburn 1997) are the main arguments to reject significant modification of the pristine Li abundance due to stellar and/or Galactic processes.

So far the Li measurements generically refer to halo stars regardless of their belonging to the inner or outer halo or other stellar associations. In fact several evidences suggest that the halo population is contaminated by accreted stars (Majewski 1992; Preston, Beers & Shectman 1994; Beers & Sommer-Larsen 1995; Carney et al. 1996 ). Beers and Sommer-Larsen (1995) have shown that the disk population rotating at roughly 200 km/s contains a metal poor tail extending down to $[\text{Fe/H}]=-3$ or lower. They also argued that a significant fraction of metal poor stars ($\approx 30\%$ of the stars with $[\text{Fe/H}]<-1.5$) belongs to the thick disk. Such a population with metallicities typical of halo stars is probably responsible for the lack of a clear correlation between the kinematical properties and stellar metallicities in the Galaxy.

The nature of these very metal poor stars with disk rotational properties is not well understood. They may be either the oldest stars of the disk or the result of the collision of a preexisting thin disk with a dwarf satellite galaxy. These stars allow to establish the chemical conditions at the onset of the stellar formation in the Galactic disk, in the former case, or in an old population of an accreted galaxy, in the latter case. Whichever the case they are a new important tool to verify the pregalactic abundance of lithium. Molaro (1997) already emphasized that the detection of Li in a star belonging to the Blue Metal Poor population, discovered by Preston, Beers & Shectman (1994), possibly resulting from a merger event, can be considered as an indirect \textit{extragalactic} Li detection.

In this paper we present lithium observations in seven main sequence stars spanning metallicities from -1.5 down to -3.0, but with kinematics belonging to the disk. The observations show that these stars have Li and that all, but one, share the same Li abundance with the genuine halo dwarfs.

\section*{2 STARS AND OBSERVATIONS}
The targets have been selected among the most metal poor stars of the Beers and Sommer-Larson (1995) sample. The
Fig. 1. The Li region for the thick disk stars ordered from the top by decreasing (B-V). On the vertical axis are plotted the residual intensities shifted by arbitrary amounts for display purposes. Each tick on the vertical axis corresponds to 0.1 in residual intensity.

Table 1. Journal of the observations

| Star      | α     | δ      | V     | date     | exp   | Instr |
|-----------|-------|--------|-------|----------|-------|-------|
| CS 29529-12 | 03 42 29.8 | -60 29.7 | 12.0 | 94 Oct 13 2400+1800 | E     |
| CS 29529-34 | 03 52 54.9 | -59 15.2 | 13.9 | 94 Oct 13 2×3600 | E     |
| CS 22182-24 | 04 18 03.9 | -31 29.0 | 12.9 | 94 Oct 13 3600 | E     |
| CS 22184-50 | 04 30 21.1 | -37 09.6 | 13.6 | 94 Oct 13 2×3600 | E     |
| CS 22959-7  | 18 36 02.1 | -67 18.3 | 14.4 | 96 Sept 25 2×3600 | C     |
| CS 22191-17 | 04 34 49.9 | -40 20.8 | 13.9 | 96 Sept 25 2X3600 | C     |
| CS 22894-19 | 23 36 45.2 | -60 12.9 | 13.9 | 96 Sept 25 3×3600 | C     |

objects are all turn-off stars with [Fe/H] ≤ -1.5, and have disk-like rotational properties. To reduce the probability of halo contamination the stars have been selected with a distance on the plane of |z| ≤ 1 Kpc, and in a position such that the line-of-sight component of disk rotation is at least 100 km/sec.

A first set of observations was obtained between October 11 and October 14, 1994 using the EMMI spectrograph at the Nasmyth focus of the 3.5 m NTT telescope. EMMI was used in echelle mode, with grism 3 as cross disperser, with a Tektronix 2040×2048 CCD detector and the F/5 Long Camera the scale in the Li region was of 0.067 Å/pixel. The slit aperture was set at 1.2 × 10 arc-seconds providing a resolving power of R = λ/δλ ≈ 31000. The slit height gives 35 pixels perpendicular to the dispersion direction allowing a satisfactory background-sky subtraction. The CCD was read in super-slow mode with a RON of ≈ 4e−/pixel. A second observing run was conducted on September 1996 using the CASPEC spectrograph at the Cassegrain focus of the 3.6 m ESO telescope. The echelle grating with 31.6 lines/mm and the long camera (f/3) were used. The detector was a Tektronix CCD 1024×1024 square pixels of 24 microns in size with a RON of 4e−/pixel. With the long camera the scale at the detector was of 0.077 Å/pixel. The slit was set at 12.2 × 10 arc-seconds providing a resolving power of R = λ/δλ ≈ 32000 as measured from the Th-Ar emission lines. The journal of the observations is summarized in Table 1.

The data were reduced using the MIDAS ECHELLE package. Special care was taken in the reduction in order to subtract the background contribution and to take into account the presence of high energy particles events. The uncertainty in the wavelength calibration is of ≈ 0.2 of the resolution element, or ≈ 2 km/sec. The heliocentric radial velocities, as measured from the NaI lines are reported in Table 3. The continuum was traced measuring the intensity of the spectra in several windows in selected regions surrounding the Li line. For multiple observations the spectra were coadded with the proper weight after reduction to a common heliocentric scale.

Equivalent widths were measured from gaussian fit integration. The errors on equivalent widths have been quantified by taking σ_{EW} = K·(S/N)^{-1/2}, where K~1.503(F·d)^{-1/2}, where F is the spectral resolution and d the pixel size in Å (Cayrel 1988, Deliyannis et al 1993). With our setup values are of 189 and 168 mÅ for Emmi and Caspec spectra, respectively. The S/N ratio is measured in the continuum windows close to the Li line. Equivalent widths with errors are given in Table 3. The final spectra are presented in Figure 1 after rebinning to equal (0.05 Å) wavelength step.
Table 2. Basic data for the stars.

| Star            | [Fe/H] | (B-V) | E(B-V) | E(B-V)$_{NaI}$ | $T_{\text{eff}}$ |
|-----------------|--------|-------|--------|----------------|-----------------|
| CS 29529-12     | -1.54  | 0.40  | 0.00   | >0.06          | 6197            |
| CS 29529-34     | -2.48  | 0.44  | 0.00   | -5954          |                 |
| CS 22182-24     | -1.72  | 0.38  | 0.00   | >0.02          | 6259            |
| CS 22186-50     | -2.02  | 0.43  | 0.00   | -6014          |                 |
| CS 22191-17     | -2.13  | 0.39  | 0.00   | >0.01          | 6177            |
| CS 22959-7      | -1.69  | 0.37  | 0.05   | >0.06          | 6541            |
| CS 22894-19     | -3.03  | 0.44  | 0.02   | >0.05          | 6060            |

Table 3. Lithium abundances

| Star            | $V_{hel}$ | EW  | $A$(Li) | $A$(Li)$_c$ |
|-----------------|-----------|-----|---------|-------------|
| CS 29529-12     | 94        | 24±6| 2.21±0.17| 2.24        |
| CS 29529-34     | 55        | 32±7| 2.11±0.15| 2.18        |
| CS 22182-24     | 101       | 7±3 | 1.61±0.40| 1.63        |
| CS 22186-50     | 54        | 35±5| 2.20±0.12| 2.24        |
| CS 22191-17     | 48        | 23±4| 2.19±0.13| 2.21        |
| CS 22959-7      | 59        | 17±5| 2.21±0.19| 2.23        |
| CS 22894-19     | 35        | 25±3| 2.11±0.11| 2.17        |

3 Li ABUNDANCES

The stellar effective temperatures have been derived from the (B-V)$_0$ colour by using the calibration of Alonso et al. (1996b). The temperature scale is based on a set of $T_{\text{eff}}$'s obtained by Alonso et al. (1996a) with the Infrared Flux Method (IRFM) and is probably the most accurate temperature scale for metal poor stars. It is hotter by about 100 K than previously used temperature scales.

An independent evaluation of the foreground reddening by inspection of the NaI interstellar lines has been performed when the lines were not significantly affected by NaI sky emission. The foreground reddening derived by using the relations $\log N(\text{NaI})=1.04 \log N(\text{H}+[\text{II}])$ -9.09 (Ferlet et al 1985) and $N(\text{HI})/E(B-V) = 5.8 \times 10^{-21}$ (Bohlin et al. 1978) are given in Table 2. The values suggest that some of the stars might be in fact slightly more reddened than assumed and therefore slightly hotter than estimated here. A reddening of $E(B-V)=0.02$ corresponds to an increase of about 80 K in $T_{\text{eff}}$, i.e. about 0.08 dex in $A$(Li).

The programme stars are classified turn-off by Beers and Sommer-Larsen (1995) and we have adopted a gravity of $\log g=4.0$. Surface gravity is not at all critical in the lithium abundance determination, provided the star has not evolved away from the main sequence and is therefore Li diluted. Microturbulence was fixed to 1.5 Km/sec as this value is common for halo dwarfs. The precise value of microturbulence is also not critical for Li abundance determination.

Li abundances are computed by using synthetic profiles computed by the SYNTHE code and atmospheric models with the ATLAS 9 code (Kurucz 1993). ODF's computed with $\alpha$ elements abundances enhanced by 0.4 dex, which better reproduce the chemical composition of Pop II stars, were used. Convection was treated with the mixing length theory, with a mixing length of 1.25 the pressure scale height. The overshooting option, which is implemented in the convection treatment in the ATLAS 9 code, does not seem to produce better agreement between computed and observed quantities in stars other than the sun (Castelli Gratton & Kurucz 1997) and it is not adopted here. To quantify the difference: if the Kurucz (1993) grid with over-shooting were used, the Li abundances would be increased by $\approx 0.05$ dex. The Li abundances are given in column 4 of Table 3. Corrections for NLTE according to Carlsson et al (1994) and expected depletions in the standard models following Deliyannis et al. (1990) are taken into account in the Li abundances reported in column 5 of Table 3.

4 DISCUSSION

The formation of our Galaxy is a process still to be understood in detail: metal-poor stars can be either the relic of a rapid collapse or the result of accretion of independent fragments (Carney et al. 1996). Analysis of rotational velocities and metallicities for metal poor stars does not show a tight correlation as it is expected from classical rapid collapse models. There is growing observational evidence that the old stars in the Galaxy comprise several populations. Nissen & Schuster (1997) found a group of halo stars ([Fe/H] $\approx -1.0$) with solar values for the [$\alpha$/Fe] ratios. This group of stars is characterized by large distances from the Galactic plane and Nissen & Schuster suggest they may be accreted from a dwarf galaxy with different chemical history. Beers and Sommer-Larsen (1995) from an analysis of $\approx 2000$ low metallicity ([Fe/H] $\leq -0.6$) Galactic stars found that the galactic disk contains a metal poor tail. As a part of a more general program of Li observations in the galactic populations we searched for Li in some of the stars showing disk-like rotational properties but still having metallicities [Fe/H] $\leq -1.5$, more typical of halo stars. In particular CS 22894-19 has the remarkably low metallicity of [Fe/H]=$-3.03$.

All these stars show a clear Li feature, with the exception of CS 22182-24 where the lithium line is detected at a poor statistical significance ($\approx 95\%$ C.L.) The Li abundances of the selected targets are shown in Fig 2 as a function of effective temperature. Also shown are the Li abundances for the 41 halo stars having [Fe/H] $<-1.5$ and $T_{\text{eff}} > 5700$ K from Bonifacio and Molaro (1997). The two sets of abundances can be directly compared to each other because they have been obtained by the same atmospheric codes and the stellar temperatures are based on the same IRFM temperature scale of Alonso et al. (1996a). As it is clear the Li abundances for the two different stellar populations largely overlap at all temperatures of the plateau, with the exception of CS 22182-24.

It is likely that CS 22182-24 is truly Li-poor, and is the analogue of the Li-poor stars found in the halo such as G122-69, G139-8, G186-26 (Thorburn 1994) and G66-30 (Spite et al. 1993). But other possibilities cannot be ruled out. The star can be more evolved of what assumed here or be a binary. If the companion is of similar temperature the correction for the veiling should double the EW, thus rising the Li abundance to the plateau level.

The weighted mean of the Li abundances for all the seven stars corrected for NLTE effects and for the standard depletion is $A$(Li)$=2.29\pm0.06$. The mean is only increased to 2.21 when CS 22182-24, is removed as outlier.

This value is slightly lower but fully consistent within less than 1 $\sigma$ with the plateau value of $A$(Li)$=2.24\pm0.012$.
obtained by Bonifacio & Molaro (1997) from the measurements of 41 plateau stars, thus providing evidence that the metal poor stars with disk-like kinematics share the same Li abundance of genuine halo stars. An even better consistency between the two values can be obtained when the stellar $T_{\text{eff}}$ are obtained from the dereddened colours assuming the colour excess derived from NaI interstellar lines, which result in somewhat larger Li abundances.

It is not clear whether these stars belong to the first stellar disk generations or whether they are accreted by the Galaxy. Thus they either probe the chemical conditions at the onset of the stellar formation in the Galactic disk or in an old population of an accreted dwarf galaxy. Whichever the case they allow to probe an environment which is different from the Galactic Halo. The fact that the two distinct metal-poor populations share the same Li abundance provides a new strong evidence that the pregalactic Li abundance was uniform and close to the value presently observed in the Galactic halo stars.

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