Chin. J. Astron. Astrophys. Vol. 3 (2003), No. 5, 453–457
(*http://www.chjaa.org* or *http://chjaa.bao.ac.cn*)

Chinese Journal of
Astronomy and
Astrophysics

Lithium Abundance of Metal-poor Stars *

Hua-Wei Zhang[1,2,3] and Gang Zhao[1]

[1] National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012; zhw@bac.pku.edu.cn
[2] Department of Astronomy, School of Physics, Peking University, Beijing 100871
[3] Chinese Academy of Sciences-Peking University Joint Beijing Astrophysical Center, Beijing 100871

Received 2003 March 18; accepted 2003 June 23

Abstract High-resolution, high signal-to-noise ratio spectra have been obtained for 32 metal-poor stars. The equivalent widths of Li $\lambda 6708$ Å were measured and the lithium abundances were derived. The average lithium abundance of 21 stars on the lithium plateau is 2.33±0.02 dex. The Lithium plateau exhibits a marginal trend along metallicity, $dA(\mathrm{Li})/d[\mathrm{Fe/H}] = 0.12\pm0.06$, and no clear trend with the effective temperature. The trend indicates that the abundance of lithium plateau may not be primordial and that a part of the lithium was produced in Galactic Chemical Evolution (GCE).

Key words: stars: abundances – stars: Population II – Galaxy: evolution

1 INTRODUCTION

The knowledge of lithium in stars plays an important role in our understanding of Big Bang Nucleosynthesis (BBN), cosmic-ray physics, and stellar interiors.

Spite & Spite (1982) found that halo dwarfs with $T_{\mathrm{eff}} > 5700$ K have a nearly constant lithium abundance independent of the temperature of the star and of its metallicity (the so-called lithium plateau). This fact indicates that most of ^{7}Li in halo stars is primordial. Since this discovery by Spite & Spite (1982), this trace element has attracted much attention, and many papers have addressed the problems of Galactic evolution and stellar depletion of lithium. Below [Fe/H]=−1.4 one sees a lithium plateau with a very small dispersion of the lithium abundance and perhaps a marginal slope of $A(\mathrm{Li})$ vs [Fe/H] (Ryan et al. 1999), where $A(\mathrm{Li}) = \log_{10}(N(\mathrm{Li})/N(\mathrm{H}))+12.00$.

In order to verify and extend the previous results, we observed Li I $\lambda 6708$ line in 32 metal-poor stars and derived their lithium abundance.

2 OBSERVATIONS AND DATA REDUCTION

The observation was made using the Coudé Echelle Spectrograph mounted on the 2.16 m telescope of the National Astronomical Observatories in Xinglong, China. A 31.6 grooves/mm

---

* Supported by the National Natural Science Foundation of China.

echelle grating was used along with the prism as cross disperser, and a 0.5 mm slit leads to a resolving power of the order of 37 000. The spectra were imaged on to a 1024 × 1024 Tektronix CCD (Zhao & Li 2001). The spectra of 32 metal-poor stars were observed between 1997 and 1998 (see Zhang & Zhao 2003, in details). The signal-to-noise ratio of spectra at 6708 Å is about 100.

The spectra were reduced using the ESO MIDAS standard package. The wavelength scale was calibrated with a Th-Ar lamp. The pixel-to-pixel variation was corrected by dividing the external flat field taken on the same night. The continuum was determined by fitting a spline curve to a set of continuum windows estimated from the solar atlas. Dividing the spectrum by the fitting curve yielded the normalized spectrum. We present a portion of the normalized spectra around 6708 Å of BD−10° 4149 in Fig. 1 as a typical example.

The equivalent widths of the lithium lines were measured by three methods: direct integration, Gaussian fitting and Voigt function fitting, depending on which method gives the best fit of the line profile. Usually, weak lines are well fitted by Gaussian profile, while strong lines are well fitted by Voigt function. Direct integration is the best method for unblended lines. Considering the signal-to-noise ratio and the resolution of spectra, we estimate the error of the equivalent widths is about 3 mÅ.

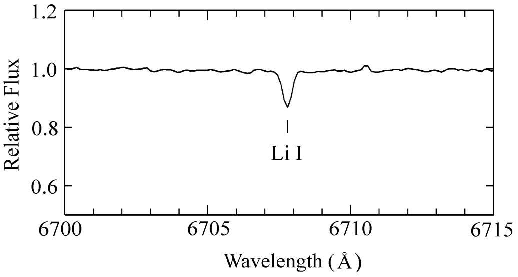

Fig. 1 A portion of the spectrum around 6708 Å of BD-10° 4149.

3 MODEL CALCULATION AND ABUNDANCE ANALYSIS

The abundance analysis was based on the LTE plane-parallel model atmospheres given by Kurucz (1993). Effective temperature is determined from the $(B-V)$, $(V-K)$, and $(b-y)$ color indexes by using the calibration of Alonso et al. (1996). Thanks to the Hipparcos survey (ESA 1997), the gravity is determined via Hipparcos parallaxes according to the method given by Nissen et al. (1997). [Fe/H] is taken from Zhang & Zhao (2003). Microturbulence velocity is adopted with an average value of 1.5 km s^{-1}. The uncertainties of the atmospheric parameters are $\sigma(T_{\mathrm{eff}}) = 100\,\mathrm{K}$, $\sigma(\log g) = 0.2$ dex, $\sigma([\mathrm{Fe/H}]) = 0.1$ dex, and $\sigma(\xi_{\mathrm{t}}) = 0.5\,\mathrm{km\ s}^{-1}$.

The analysis program, ABONTEST8, was used to calculate equivalent widths of the Li I line as a function of the Li abundance and oscillator strengths of the Li doublet components taken from Wiese et al. (1966). In the calculation, the contribution of the ^{6}Li isotope is assumed to be negligible. Li abundance is then determined by requiring that the theoretical equivalent width should match the observed one. The stellar parameters, equivalent widths and lithium abundances are given in Table 1.

Table 1 Atmospheric Parameters and Lithium Abundances

Name	T_{eff} (K)	$\log g$ (dex)	[Fe/H] (dex)	EW (mÅ)	A(Li) (dex)
BD−09 122	6022	4.12	–1.08	39.4	2.46
BD+71 31	6113	4.05	–1.96	29.0	2.33
BD+47 435	6028	4.61	–1.86	37.4	2.20
BD−10 388	6170	3.65	–1.83	28.0	2.36
BD+25 495	5912	4.36	–2.03	38.0	2.27
BD+66 268	5210	4.44	–2.05	8.8	0.78
BD+34 796	4741	4.68	–1.75	4.0	0.09
BD+58 876	5757	4.57	–1.67	42.0	2.29
BD+24 1676	6199	4.34	–2.52	35.0	2.33
BD+31 1684	5394	4.51	–1.60	18.5	1.52
BD+80 245	5446	3.31	–1.66	16.9	1.54
BD+54 1216	5942	4.24	–1.57	30.0	2.18
BD−15 2546	6126	4.01	–1.85	33.6	2.39
BD+14 2151	6261	4.07	–1.92	32.0	2.39
BD+44 1910	6067	3.96	–2.14	29.7	2.13
BD+21 2247	5917	4.21	–1.37	49.6	2.37
G146−76	5202	2.85	–1.61	19.4	1.26
BD+36 2165	6127	4.22	–1.39	39.7	2.48
BD+49 2098	4855	2.80	–0.90	10.0	0.59
BD−04 3208	6152	3.91	–2.34	30.0	2.21
BD+02 2538	6047	4.32	–1.75	36.5	2.41
BD+34 2476	6242	3.98	–2.06	30.0	2.44
BD+33 2560	5132	3.21	–1.27	14.1	1.12
BD−10 4149	5698	3.65	–2.36	61.5	2.32
BD+42 2667	5957	4.12	–1.43	50.0	2.44
BD+23 3130	5228	2.94	–2.40	26.3	1.47
BD+20 3603	6183	4.49	–1.96	33.2	2.31
BD+26 3578	6213	3.90	–2.12	22.0	2.26
BD+10 4091	5473	4.47	–1.40	25.8	1.75
BD+42 3607	5710	4.31	–1.99	60.0	2.45
BD+00 4470	5102	4.72	–1.72	6.5	0.73
BD−09 6150	5475	3.95	–0.16	19.6	1.55

The uncertainty in the Li abundances, resulting from errors of the equivalent widths, is around 0.08 dex. Changes of the Li abundance due to errors in the atmospheric parameters are 0.07 dex for $\Delta(T_{\mathrm{eff}}) = 100\,\mathrm{K}$, less than 0.01 dex for $\Delta(\log g) = 0.2$ dex, $\Delta([\mathrm{Fe/H}]) = 0.1$ dex, and $\Delta\ (\xi_{\mathrm{t}}) = 0.5\,\mathrm{km\ s^{-1}}$. The total uncertainty in the Li abundances is 0.11 dex. The NLTE corrections of Li I 6708 Å are negligible (Carlsson et al. 1994).

4 DISCUSSION

Figure 2a, b shows the lithium abundances vs. [Fe/H] and T_{eff} for all the 32 stars in the present study. One can see that 21 stars with effective temperature higher than 5600 K and [Fe/H] lower than -1.0 are located in the lithium plateau, the average lithium abundance is 2.33 ± 0.02 dex ($\sigma = 0.10$ dex, 21 stars). Considering that the error of our results is 0.11 dex, we cannot say whether the spread of the lithium abundances is real or not. More accurate results of Ryan et al. (1999) also indicated that the intrinsic spread is effectively zero. The essentially zero intrinsic spread leads to the conclusion that either these stars have all changed their surface lithium abundance very uniformly, or they exhibit close to the primordial abundance that has been sought for because of its cosmological significance.

Figure 2a shows that the lithium plateau obviously varies with metallicity, a usual least-squares fit gives

$$A(\mathrm{Li}) = (2.558 \pm 0.11) + (0.12 \pm 0.06)[\mathrm{Fe/H}]\,.$$

The slope is $\mathrm{d}A(\mathrm{Li})/\mathrm{d}[\mathrm{Fe/H}] = 0.120 \pm 0.060$, consistent with previous results of Thorburn (1994) (0.13), of Ryan et al. (1996) (0.111±0.018), and of Ryan et al. (1999) (0.118±0.023). Bonifacio & Molaro (1997) have even argued that this slope does not exist at all, but Ryan et al. (1999) showed that this claim is likely to have been influenced by their adopting incorrect [Fe/H] values for a number of stars in their sample.

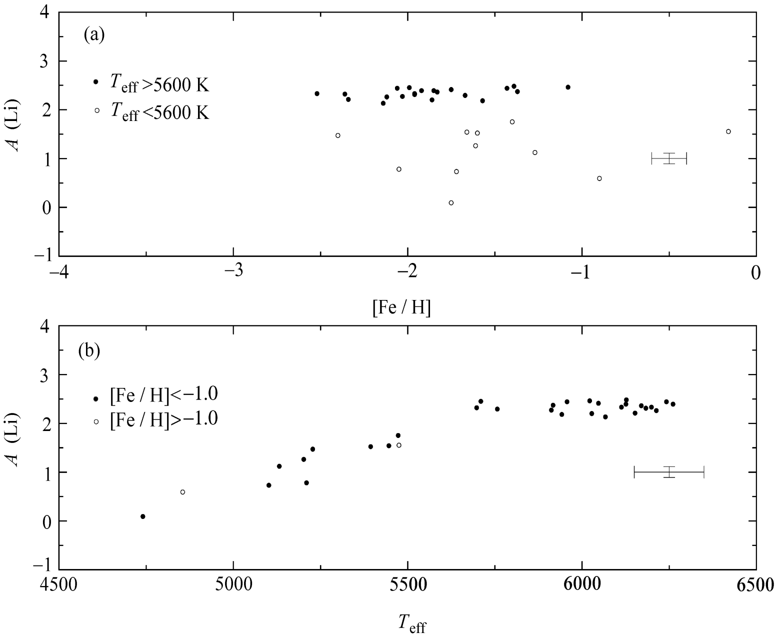

Fig. 2 A(Li) ver. [Fe/H] and T_{eff}.

The slope indicates that the abundance of lithium plateau is not primordial, that a part of the lithium was produced in Galactic Chemical Evolution (GCE). The observed lithium trend with metallicity can be used to constrain Galactic production mechanisms. Post-BBN sources of lithium in the halo stars are the Galactic cosmic-ray (GCR) nucleosynthesis of ^{6}Li and ^{7}Li and the supernova ν-process that produces ^{7}Li and ^{11}B.

The primordial lithium abundance, $A(\mathrm{Li})_{\mathrm{p}}$, can be estimated from extrapolation of the metallicity trend to [Fe/H]=−4 where most of the known metal-poor stars are found and where the metallicity distribution of the halo stars shows signs of truncation (Ryan et al. 1999). The value obtained is $A(\mathrm{Li})_{\mathrm{p}}\approx 2.08$ dex.

Figure 2b shows that the lithium plateau does not vary with effective temperature, when the accuracy of our results is noted. Some previous works (Ryan et al. 1996) claimed that a slope of lithium abundance versus effective temperature may exist, but it may depend crucially on the adopted temperature scale. The lithium abundance of 11 stars with $T_{\rm eff} < 5600\,{\rm K}$ decreases with decreasing effective temperature, the usual least squares fit gives a slope of 0.198 ± 0.03 dex per 100 K, which is the result of depletion due to stellar convection.

Considering the trend of lithium abundance with metallicity, more accurate observation and analysis for larger samples of very metal-poor stars ([Fe/H]<-3.0) are needed to obtain the primordial value of ^{7}Li. After a correction for effects such as GCE production and depletion, primordial lithium abundance can be used to set limits on cosmological parameters, such as η (the baryon-to-photo ratio) and $\Omega_{\rm B}$ (the universal baryon density).

Acknowledgements This work was supported by the National Natural Science Foundation of China under Grant No. 10173014, and NKBRSF No. G1999075406.

References

Alonso A., Arribas S., Martinez-Roger C., 1996, A&A, 313, 873
Bonifacio P., Molaro P., 1997, MNRAS, 285, 847
Carlsson M., Rutten R. J., Bruls, J. H. M. J. et al., 1994, A&A, 288, 860
ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200
Kurucz R., 1993, Atlas Stellar Atmosphere Program and 2 km/s Grid CDROM vol 13, Smithsonian Astrophysical Observatory, Cambridge
Nissen P. E., Hog E., Schuster W. J., 1997, ESA SP-402, Hipparcos Venice'97, Barrrick B. ed., p.225
Ryan S. G., Beers T. C., Deliyannis C. P. et al., 1996, ApJ, 458, 543
Ryan S. G., Norris J. E., Beers T. C., 1999, ApJ, 523, 654
Spite F., Spite M., 1982, A&A, 115, 357
Thorburn J. A., 1994, ApJ, 421, 318
Wiese W. L., Smith M. W., Glennon B. M., 1966, Atomic Transition Probabilities (NSRDS-NBS4), Vol. 1
Zhang H. W., Zhao G., 2003, submitted to A&A
Zhao G., Li H. B., 2001, Chin. J. Astron. Astrophys., 1, 555