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A New Measurement of the ^{6}Li/^{7}Li Ratio in HD 82943

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Abstract

We investigate the presence of possible blends in the spectral region of the Li resonance line at 6708 Å in solar-type metal-rich stars using high resolution and high S/N spectroscopic observations. Our analysis does not confirm the identification of a weak absorption feature at 6708.025 Å with the low excitation Ti I line proposed recently by Reddy et al. (2002). Our analysis suggests that the unidentified absorption is most probably produced by a high excitation Si I line proposed by Müller et al. (1975). New analysis of the ^{6}Li/^{7}Li isotopic ratio in HD 82943 was performed by taking the Si I line into account and using new VLT/UVES spectra of HD 82943 with a S/N ratio close to 1000. The presence of ^{6}Li in the star's atmosphere is confirmed while the updated value for the isotopic ratio is $f(^6\mathrm{Li}) = 0.05 \pm 0.02$.

1.1 Introduction

Recently we proposed a ^{6}Li test (Israelian et al. 2001) for testing the planet(s) ingestion scenario. The idea is based on looking for an element that should not appear in the atmosphere of a normal star, but would be present in a star that has swallowed a planet or a large number of planetesimals. A light isotope, ^{6}Li, is an excellent tracer of any planetary matter accretion. The detection of ^{6}Li in HD 82943 (Israelian et al. 2001) was considered as convincing observational evidence that stars may accrete planetary material, or even entire planets, during their main sequence lifetime. Other explanations (such as surface sports or stellar flares) of this phenomenon were ruled out (Israelian et al. 2001). It has been also suggested (Sandquist et al. 2002) that ^{6}Li can be used to distinguish between different giant planet formation theories.

Recently Reddy et al. (2002) updated the line list of Lambert, Smith & Heath (1993) and claimed that a previously noticed weak absorption in the solar spectrum at 6708.025 Å (Müller, Peytremann & De La Reza 1975) belongs to Ti I. With this assumption their analysis of the Li feature in HD 82943 did not confirm the presence of ^{6}Li.

With the goal of establishing the nature of the absorption at 6708.025 Å and better understanding the line list near Li, we have obtained high resolution, high S/N spectra for several metal-rich stars with no detectable Li line. Our targets cover a wide range of effective temperature, allowing a more reliable identification of the lines in the spectral window of the Li feature. We have obtained new very high quality spectra of HD 82943. In this article we present new analysis of the ^{6}Li/^{7}Li ratio in HD 82943 and critically discuss the line list of the

Table 1.1. *Abundance of Ti (column 4) as derived from the EWs of two Ti II lines (columns 2 and 3) measured in our spectra. The EW of the unidentified feature (column 5) at 6708.025 Å was computed assuming that it is due to the Ti line of Reddy et al. 2002) with abundances from column 4. Observed EWs of unidentified line are listed in column 5 with 3 σ errors estimated using a Cayrel formulae (Cayrel 1988). Values in parentheses in column 6 indicate that the line is not centered on 6708.025±0.01 Å. The last two columns provide the Si abundance in our stars from Bodaghee et al. (2003) and the EW of the unidentified feature assuming that it belongs to Si I with χ = 6 eV and* $\log gf = -2.97$. *It is not clear if the 6708.025 Å feature in HD 200790 is real.*

Target	Ti II 5418.77 Å	Ti II 5336.78 Å	[Ti/H]	EW_{pred}(Ti I) 6708.025 Å	EW_{obs} 6708.025 Å	[Si/H]	EW_{pred}(Si I) 6708.025 Å
HD 1461	61.0	84.1	0.18	1.1	1.6±0.8	0.20	1.2
HD 13445	38.2	61.2	–0.18	1.7	(1.5±1.0)	–0.14	0.4
HD 16141	61.3	86.6	0.09	0.8	0.9±0.5	0.10	1.0
HD 22049	39.7	62.8	–0.17	2.0	(2.0±0.5)	–0.10	0.5
HD 75732A	58.2	80.2	0.28	3.7	(3±1.0)	0.38	1.5
HD 82943	61.5	82.4	0.27	0.9	-	0.27	1.3
HD 130322	45.7	69.8	–0.06	1.4	$<$ 1.5	–0.04	0.7
HD 134987	62.6	85.2	0.3	1.4	$<$ 1.5	0.27	1.3
HD 137759	86.8	109.6	0.03	14.0	($<$ 1.5)	0.18	1.3
HD 145675	59.4	79.6	0.42	4.5	(5.5±1)	0.42	1.6
HD 177830	75.1	97.4	0.28	11.0	($<$ 2.0)	0.45	1.9
HD 192263	43.2	64.6	–0.01	4.0	($<$1.5)	0.02	0.5
HD 200790	63.5	89.7	0.02	0.3	$<$0.6$>$	0.04	0.7
HD 210277	58.3	81.3	0.2	1.8	1.5±1.0	0.23	1.3
HD 217107	59.5	83.6	0.29	1.8	1.5±0.5	0.37	1.7

Li region. Our observations do not confirm the Ti I line of Reddy et al. (2002) and support our previous claim for detection of ^{6}Li. Details of the computations presented in this article are given in Israelian et al. (2003).

1.2 Observations

We used the 8.2 m VLT Kueyen (ESO, La Silla), the UVES spectrograph and an EEV detector to obtain spectra of HD 82943 during the night of 2001 March 5. The 0.3 arcsec slit yielded a resolving power of $R \sim 105\,000$ as measured from the FWHM of Th–Ar lamp lines. Many high resolution (at least 50.000) and high S/N spectra of metal-rich solar type stars with no detectable Li were obtained with WHT/UES (La Palma), TNG/SARG (La Palma) and FEROS (ESO, Chile). The S/N of our spectra varies between 350 and 900.

1.3 Spectrum Synthesis and the Line List in the Li Region

Müller et al. (1975) were the first to notice the weak feature at 6708.025 Å in the solar spectrum and attributed it to the Si I line with $\log gf = -2.7$, χ = 6 eV. The line was also considered by Nissen et al. (1999) in their analysis of metal-poor disc stars. According to Nissen et al. (1999), the equivalent width (EW) of the 6708.025 Å absorption is 0.6 mÅ in the solar spectrum. Reddy et al.'s (2002) identification of this absorption with the Ti line ($\log gf = -2.252$, χ = 1.88) implies a slightly different value EW = 0.75 mÅ. We have

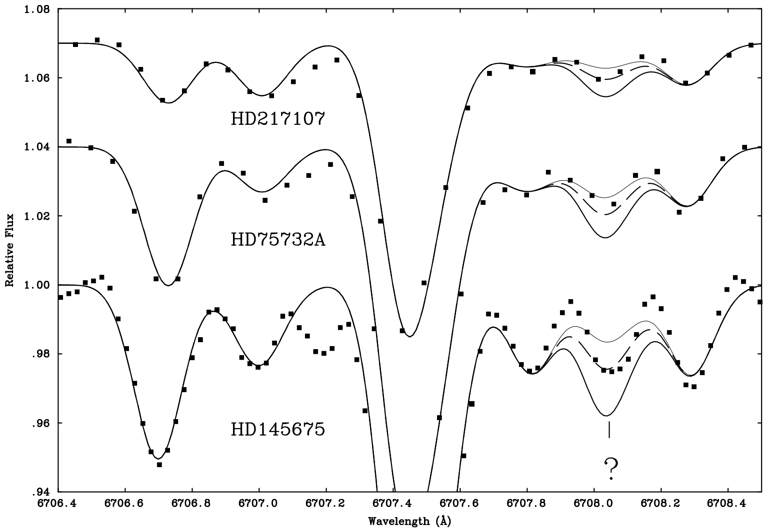

Fig. 1.1. Observed (filled small squares) and synthetic spectra of three metal-rich stars: HD 217107, HD 75732A and HD 145675. The Ti abundances were computed for [Ti/H] = 0 (thin continuous), 0.2 (dashed), 0.4 (thick continuous) in HD 217107, [Ti/H] = 0 (thin continuous), 0.15 (dashed), 0.3 (thick continuous) in HD 75732A and [Ti/H] = 0 (thin continuous), 0.2 (dashed), 0.4 (thick continuous) in HD 145675.

computed Ti abundance in the sample of metal-rich stars using two lines of the ionized Ti from Santos et al. (2000). The EWs of these lines and derived abundances are listed in Table 2. Using the abundances from the Ti II lines, we have estimated the EW of the feature at 6708.025 Å, assuming that it belongs to the line proposed by Reddy et al. (2002). Predicted and observed EWs of the Ti line are listed in Table 1. We see an obvious disagreement at low $T_{\rm eff}$: the predicted line is much stronger than the observed one. In Figs. 1.1 and 1.2 we show spectrum synthesis for three metal-rich stars with different parameters. These plots clearly demonstrate that the feature at 6708.025 Å disappears at low temperatures while a different line at 6708.094 Å (not clearly observed in the solar spectrum) becomes stronger. We have attempted a new identification of the 6708.025 Å feature knowing that the strength of the line does not increase towards cooler temperatures. Our analysis shows that it is more likely that the spectral feature at 6708.025 Å belongs to a high excitation transition of some neutral atom. The small spectral window near 6708 Å contains many high excitation Si lines; therefore, the identification proposed by Müller et al. (1975) seem to be the best choice.

1.4 The ^{6}Li/^{7}Li Ratio in HD 82943

Reanalysis of the ^{6}Li/^{7}Li ratio has been carried out using the same tools as in Israelian et al. (2001) and the line list of Reddy et al. (2002). The only change we have made in this list is a replacement of the Ti I line at 6708.025 Å by the high excitation Si I line with $\log gf = -2.97$ and χ_l = 6 eV. Furthermore, an accurate abundance of Si in HD 82943 needs

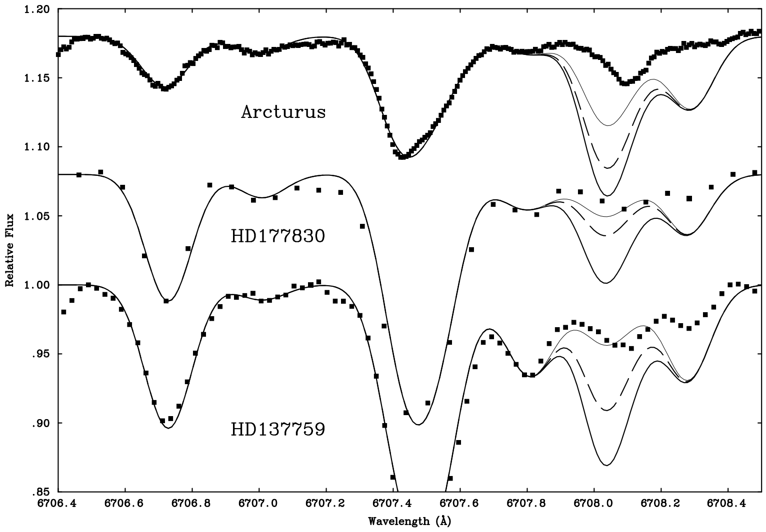

Fig. 1.2. Observed (filled small squares) and synthetic spectra of the Arcturus, HD 177830 and HD 137759. The Ti abundances were computed for [Ti/H] = –0.2 (thin continuous), –0.3 (dashed), –0.5 (thick continuous) in Arcturus, [Ti/H] = –0.2 (thin continuous), 0.0 (dashed), 0.3 (thick continuous) in HD 177830 and [Ti/H] = –0.4 (thin continuous), 0.0 (dashed), 0.4 (thick continuous) in HD 137759.

to be calculated. For this purpose we have used eleven Si lines (Israelian et al. 2003) and computed their EWs using very high S/N spectra obtained with VLT/UVES and WHT/UES. We found [Si/H] = 0.27 ± 0.02. In obtaining the broadening parameters we used the same Fe I lines as in our first paper (Israelian et al. 2002). From the χ^2 analysis of two Fe lines we obtained a mean $v \sin i = 1.6 \pm 0.05\,\mathrm{km\,s^{-1}}$ and $V_{\mathrm{mac}} = 4 \pm 0.3\,\mathrm{km\,s^{-1}}$, in good agreement with our previous results and also with those of Reddy et al. (2002).

The free parameters in a standard χ^2 analysis of the ^{6}Li/^{7}Li ratio in HD 82943 were the total abundance of Li, the wavelength shift, the ^{6}Li fraction and the position of the continuum. The abundance of the Si line was also considered as a free parameter in the range [Si/H] = 0.27 ± 0.1 but after a few iterations it was fixed to [Si/H] = 0.27. The minimum χ^2 was derived by optimizing all free parameters for each value. Our analysis using Reddy et al.'s (2002) line list and the Si line yields $f(^6\mathrm{Li})=0.05 \pm 0.02$ (Figs. 1.3 and 1.4). The final value of $f(^6\mathrm{Li})$ is not sensitive to the Si abundance. If we repeat the analysis fixing the continuum but changing the abundance of Si, we will find that the best fit to the observed profile is achieved for [Si/H] = 0.27. The same analysis for $f(^6\mathrm{Li}) = 0$ yields [Si/H] = 0.51 which is ruled out by our data. However, even if we assume that it is possible, the quality of the fit when $f(^6\mathrm{Li}) = 0.05$ and [Si/H] = 0.27 is about 4 times better (i.e. χ^2 is smaller) compared with the case when $f(^6\mathrm{Li}) = 0.0$ and [Si/H] = 0.51.

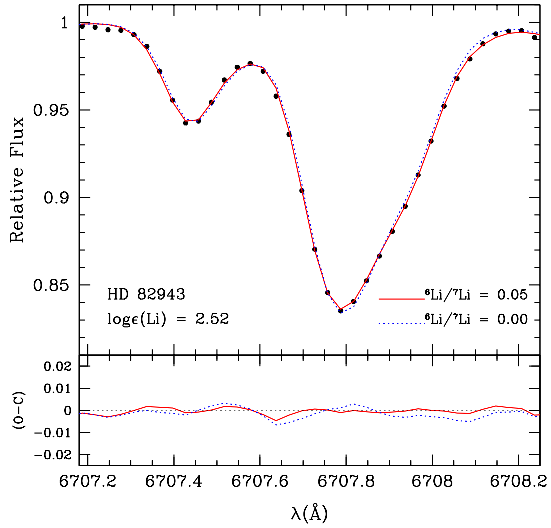

Fig. 1.3. Comparison of the observed (filled large dots) and synthetic spectra of HD 82943 corresponding to ^{6}Li/^{7}Li = 0.05 (continuous) and ^{6}Li/^{7}Li = 0 (dotted) isotopic ratios. They correspond to the best fits with $f(^6\mathrm{Li}) = 0$ and a wavelength offset of $-0.65\,\mathrm{km\,s^{-1}}$ (small dots) and to the f(^{6}Li) = 0.05 with a wavelength offset of $-0.44\,\mathrm{km\,s^{-1}}$ (continuous line). Fits to the blue wing of the Li profile can be improved if we adopt the wavelengths of CN lines from Brault & Müller (1975). The CN lines observed in the arc spectrum by these authors appear at 6707.55 Å while Reddy et al. (2002) and Lambert et al. (1993) list them between 6707.464 and 6707.529 Å. The residuals (O-C) of the observations after subtraction of the synthetic spectra are shown.

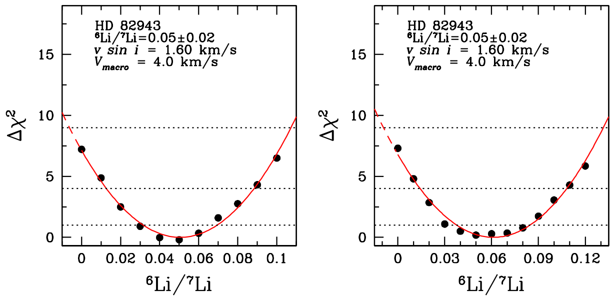

Fig. 1.4. Results from the χ^2 analysis for the ^{6}Li/^{7}Li ratio. $\Delta\chi^2$=1,4,and 9 correspond to 1,2 and 3σ confidence limit is (dotted lines). Continuum adjustments were allowed within 0.2 % (left panel) and 0.5% (right panel).

1.5 Conclusions

Our results clearly rule out the Ti I line at 6708.025 Å suggested by Reddy et al. (2002). We propose that this feature can be attributed to the Si I line of Müller et al. (1975).

The analysis of the new VLT/UVES spectra (S/N=1000), taking into consideration the Si I line at 6708.025 Å, yields an isotopic ratio ^{6}Li/^{7}Li = 0.05±0.02 in HD 82943. This ratio implies a contribution to the total absorption in the Li region of 1.3 mÅ and 2.7 mÅ due to Si I and ^{6}Li, respectively.

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