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^{6}Li/^{7}Li isotopic ratio in the most metal-poor binary CS22876−032

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We present high-resolution and high-quality UVES spectroscopic data of the most metal-poor binary CS 22876-032 ([Fe/H] ~ -3.7 dex) in the Li I λ 670.8 nm doublet spectral region to investigate the ^{6}Li/^{7}Li isotopic ratio. We add together all 28 spectra corrected for radial velocity and normalized. We create a grid of 3D-NLTE synthetic spectra, to take into account the line profile asymmetries induced by stellar convection, and perform Monte Carlo simulations to evaluate the error of the Li line profile fitting. Individual fits to the observed Li profile of the primary star show that the veiling factor does not affect the derivation of the ^{6}Li/^{7}Li isotopic ratio and only modifies the Li abundance, A(Li), by about 0.10 dex. The preliminary analysis of spectra at the velocity reference frame of the primary star of this binary system provides A(Li) $= 2.14 \pm 0.01$ dex and ^{6}Li/^{7}Li $= 0.05 \pm 0.04$ at 68% confidence level. This is therefore consistent with no detection of ^{6}Li and may provide an upper-limit to the isotopic ratio of ^{6}Li/^{7}Li < 0.09 ratio at this very low metallicity. In addition, we improve the determination of the Li abundance of A(Li) $= 1.60 \pm 0.05$ dex in the secondary star in this system, which is about 0.5 dex lower than the Li abundance of the primary star. These preliminary results does not solve nor aggravate the cosmological ^{7}Li problem but does not support either the need for non-standard ^{6}Li production in the early Universe.

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1. Introduction

The ^{6}Li isotope is believed to be a product of the interaction of Galactic cosmic rays (GCR) with the interstellar medium, where the ^{6}Li abundance increases with increasing metallicity similarly as has been found for B and Be [see e.g. 1]. Detecting ^{6}Li at low metallicities may suggest other production channels like e.g. non-standard physics in the Big Bang [2], or pre-galactic origin [3].

The presence of ^{6}Li in metal-poor halo stars is usually derived from a tiny asymmetry in the red wing of the ^{7}Li doublet line at λ 670.8 nm. The treatment of this line using 1D model atmospheres and LTE spectral synthesis produced presumably the detection of ^{6}Li in several stars at [Fe/H] < -2 [4]. However, convective flows in the atmospheres of metal-poor stars are probably the responsible of this asymmetry [5].The re-analysis of the Li feature, using 3D hydrodynamical models and a 3D-NLTE treatment, in some metal-poor stars was not able to confirm the detection of ^{6}Li [6,7].

The metal-poor spectroscopic binary CS 22876-032 offers a unique opportunity to test the cosmological Li problem and in particular, the ^{6}Li case, due to its very low metallicity at about [Fe/H] ~ -3.7, about one dex below other attempts. The Li abundances of both binary stellar components have been already reported, but only the primary star has a Li abundance at the level of the Spite plateau [8].

2. Observations and analysis

We carried out spectroscopic observations with UVES@UT2/VLT in Paranal (Chile) using the image slicer #3 on 2007 October 17, 18, 19 and 20. We obtained 28 useful observations with exposure times of 3600s at a resolving power of 110,000, covering the spectral region $\lambda\lambda$500–680 nm. The individual spectra are corrected for radial velocities using a cross-correlation of the observed Mg Ib triplet lines at $\lambda\lambda 516.7-518.3$ nm with a synthetic template. Thus, we normalize all the individual spectra to unity and following [9,10], we add them all together without rebinning in wavelength as shown in Fig. 1. The spectra is normalized so we decided to mask out all the points at flux higher than 1.03. The number of spectra and the relatively small binning in wavelength allow us to perform the fit of the ^{7}Li doublet line at λ670.8 nm including about 1600 flux points in the spectral range $\lambda\lambda 670.75-670.85$ nm. A combination of the flux points in wavelength bins of 0.001 nm increase significantly the S/N up to $\sim$ 820 and $\sim$ 580 at 517 and 670 nm, respectively. The spectral lines of each binary component appear weaker because of the veiling that produces the flux of the other component. We correct for the veiling at the Li I doublet spectral region with the factors of 1.36 and 3.74 for the primary and secondary respectively (see [8] for more details on the determination of veiling factors in this binary system).

We have created a grid of 3D-NLTE synthetic spectra for different Li abundances and isotopic ratios for both components of this metal-poor binary (see [6,11] for further details on 3D model atmospheres and 3D-NLTE treatment). We perform a fitting procedure, including five free parameters: continuum location, f_c, rotational broadening, v_r, velocity shift, v_s, lithium abundance, A(Li), and isotopic ratio, ^{6}Li/^{7}Li. We verify that the fitting procedure provides the same result regarding the ^{6}Li/^{7}Li isotopic ratio for the unveiled and veiled spectrum of the primary star. Only the Li abundance change by 0.1 dex, obviously being lower for the veiled spectrum. We therefore decided

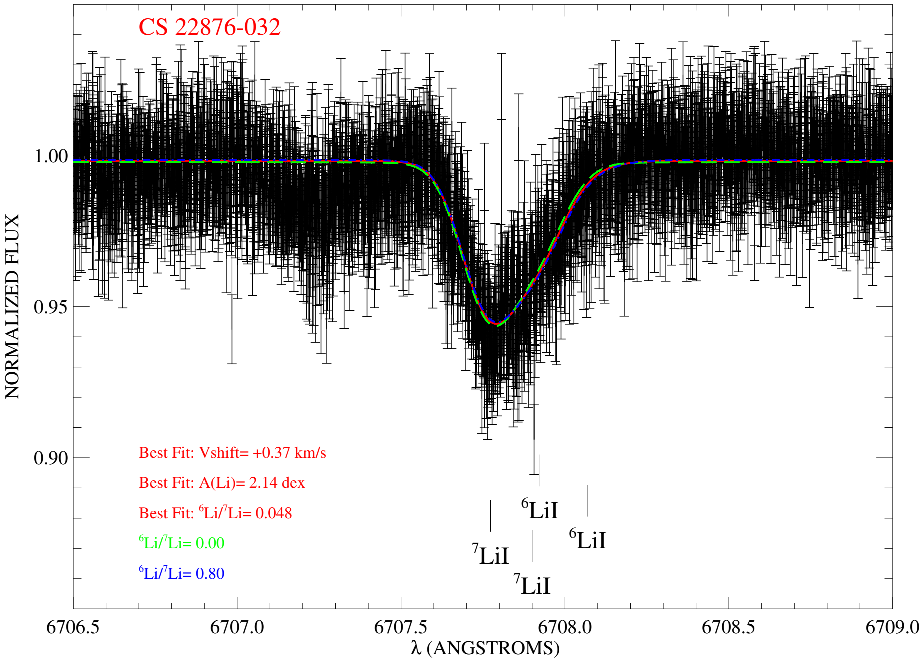

Figure 1: High resolution spectroscopic data of the most metal-poor binary CS 22876-032 acquired with UVES@UT2/VLT in the Li I λ 670.8 nm doublet spectral region in the velocity reference frame of the primary star. We show the 28 flux combined single 3600s exposures in the velocity reference frame of the primary star together with three synthetic spectra computed with ^{6}Li/^{7}Li isotopic ratio of 5% (solid red line), 0% (long-dashed green line), and 8% (short-dashed-dotted blue line). The observed Li profile has 1600 flux points to be fitted in the range $\lambda\lambda 670.75 - 670.85$ nm. The flux errors are adopted based on the S/N ~ 90 at continuum level of the spectrum.

to run the fitting procedure on the unveiled spectrum. In Fig. 1 we show the best fit of the Li line profile of the primary star, which gives ^{6}Li/^{7}Li ~ 0.052, A(Li) ~ 2.14 dex and a global velocity shift of the line profile of about +0.37 km/s. We adopt a flux error based on the signal-to-noise of the observed spectrum depicted in Fig. 1, which is S/N ~ 90 for the unveiled and unbinned spectrum. No rotational broadening appears to be needed when running the fitting procedure, providing values close to zero at ~ -0.23 km/s, so we decided to fix the rotational velocity equal to zero.

In Fig. 1 we also display two additional fits, at ^{6}Li/^{7}Li ~ 0.00 and ~ 0.08, with the velocity shift and rotational broadening fixed to +0.37 km/s and 0 km/s, just to see the sensitivity of the 3D-NLTE Li profile to small variations of the isotopic ratio. Given the number of fitting flux points of about 1600 flux points in the spectral range $\lambda\lambda 670.75 - 670.85$ nm, we think that statistically speaking we may be able to distinguish between those slightly different isotopic ratio.

We thus run Monte Carlo simulations to evaluate the errors of the five fitting parameters by leaving them all free. The Monte Carlo is done by injecting Poisson noise, according to the adopted flux errors used in the fitting, into the best fitting synthetic spectrum and performing the fit with the same code used for the observed spectrum, for over 10,000 samples. The distribution of the 10,000 Monte Carlo events of each parameter has roughly gaussian shape, thus a gaussian fit to these distributions provide as most-likely values: ^{6}Li/^{7}Li $= 0.048 \pm 0.039$, A(Li) $= 2.14 \pm 0.01$ dex,

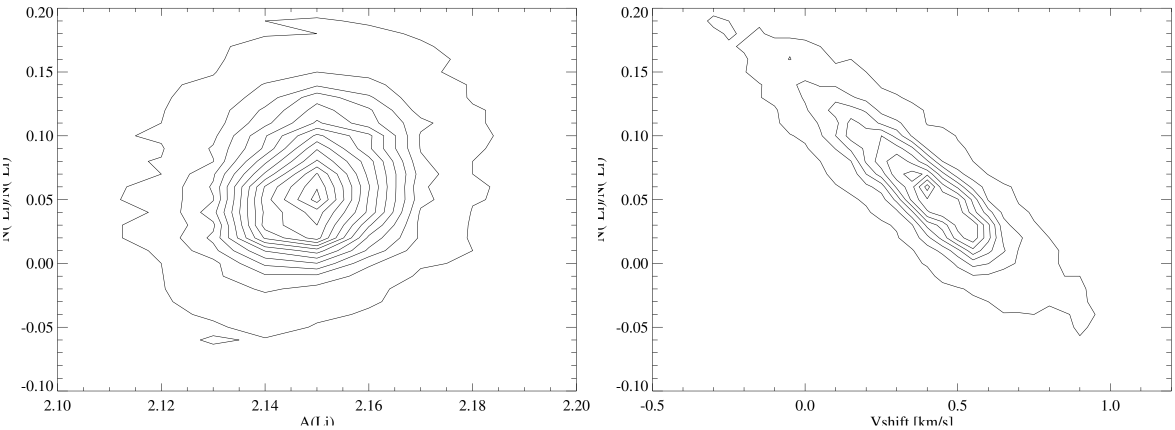

Figure 2: Contour lines of Monte Carlo fitting events of the Li I λ670.8 nm of the primary star depicted in Fig. 1. The outer contours includes 99% of events. *Left panel*: ^{6}Li/^{7}Li isotopic ratio versus Li abundance. *Right panel*: ^{6}Li/^{7}Li isotopic ratio versus line shift.

$f_c = 0.998 \pm 0.001$, $v_r = -0.23 \pm 1.30$ km/s, $v_s = +0.356 \pm 0.177$ km/s, where the errors are given at 68% confidence level. In Fig. 2 we depict the contours of these the ^{6}Li/^{7}Li isotopic ratio with respect to the Li abundance and the global velocity shift of the Li line. In the left panel we do not see any correlation of the ^{6}Li/^{7}Li isotopic ratio with the Li abundance. In the right panel, however a strong correlation appears, as expected, between the ^{6}Li/^{7}Li isotopic ratio and the velocity shift, although the peak of the distribution is located at the values ^{6}Li/^{7}Li ~ 0.06 and $v_s \sim +0.40$ km/s.

3. Discussion and Conclusions

The preliminary analysis of the spectrum of the most metal-poor binary CS 22876-032 using 3D-NLTE synthetic spectra of the Li I λ670.8 nm doublet does not provide a strong detection of the ^{6}Li isotope. The results of the primary star can be interpreted as an upper-limit of the Li isotopic ratio of the ^{6}Li/^{7}Li < 0.09. However, the result is also consistent with no detection of ^{6}Li. This together with the upper-limits and/or non-detections of ^{6}Li in other single metal-poor stars when performing a 3D-NLTE analysis point to the confirmation that the so-called *second cosmological Li problem* may be solved (see [6,7]).

The quality of the spectrum of the secondary star is not sufficient to search for ^{6}Li isotope, but it provides an improved determination of the ^{7}Li abundance of A(Li) $= 1.60 \pm 0.05$ dex (see Fig. 3) which is a downward revision of the previous determination of the Li abundance in this star [8]. The difference in Li abundance between the primary and the secondary star is about 0.5 dex, and possibly enhanced the already known *meltdown* of the Spite plateau, and thus the *cosmological Li problem* that still awaits an explanation (see [12,13] and references therein).

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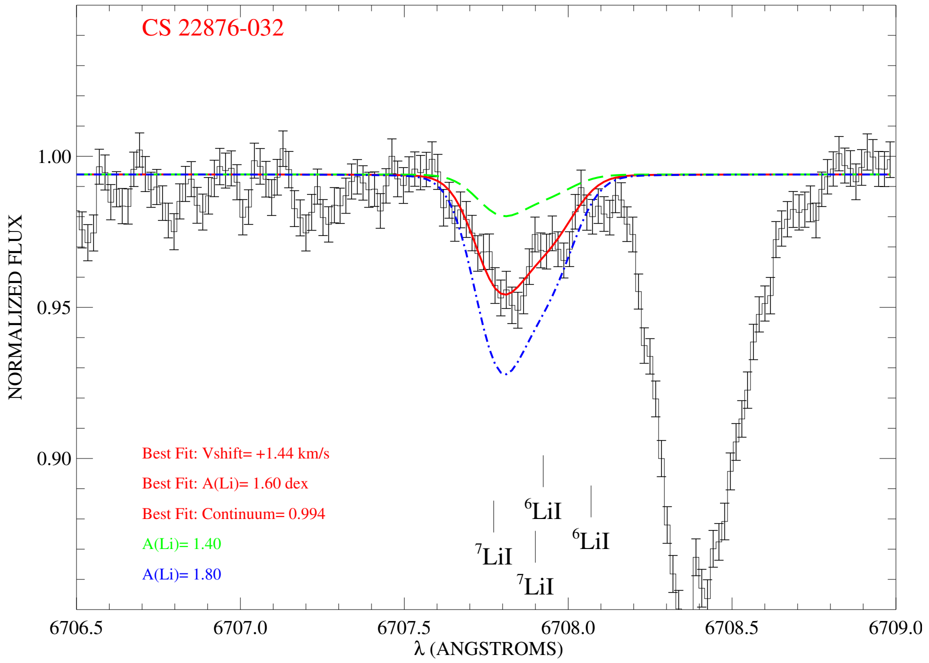

Figure 3: High resolution spectroscopic data of the most metal-poor binary CS 22876-032 acquired with UVES@UT2/VLT in the Li I λ 670.8 nm doublet spectral region in the velocity reference frame of the secondary star. Now we show the flux 28 spectra combined and rebinned in wavelength steps of 0.001 nm. The flux errors are adopted based on the S/N $\sim$ 90 at continuum level of the spectrum. The spectrum shifted to the velocity reference frame of the secondary star is depicted together with three synthetic spectra computed with a Li abundance of A(Li) $=$ 1.60 dex (solid red line), 1.40 dex (long-dashed green line), and 1.80 dex (short-dashed-dotted blue line). The observed Li profile has 63 flux points to be fitted in the range $\lambda\lambda 670.70 - 670.81$ nm.

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