Upgraded NTT
Provides Insights Into the Cosmic Big Bang

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The EMMI spectrograph with the upgraded NTT has been used to detect for the first time the Li I subordinate doublet at λλ 6104 Å (the doublet has three components: $2^2P_{1/2} - 3^2D_{3/2}$, $2^2P_{3/2} - 3^2D_{5/2}$, $2^2P_{3/2} - 3^2D_{3/2}$, at wavelengths 6103.538 Å, 6103.649 Å, 6103.664 Å respectively) in the prototype population II star HD 140283. The Li abundance from this line is consistent with that previously obtained from the widely used resonance line, thus giving confidence in the use of Li in the framework of standard nucleosynthesis (Bonifacio and Molaro, 1998).

On August 10 and 11, 1997, we were conducting an observing programme at La Silla, Chile, aimed at very precise measures of the Li I resonance line at λλ 6707 Å in a sample of halo dwarfs. On each night we observed HD 140283 for 40 and 20 minutes, respectively, as a calibration star since this is a very bright (V = 7.24) and metal poor ([Fe/H] ≈ –2.7) star. The telescope was the ESO NTT and the spectrograph was EMMI equipped with the R4 (i.e. tan θ = 4) echelle grating ESO #14 (D'Odorico and Fontana, 1994). The seeing in those nights was sub-arc-second and we used a projected slit width of 0.8″, obtaining a resolution of $\lambda/\Delta\lambda \approx 61000$, as measured from the Th-Ar lamp emission lines. As cross-disperser we employed grism # 6 which achieves a wide-order separation allowing to keep a slit height of 15″ projected on the sky. Such a high slit is essential for a good sky subtraction. After full reduction with the MIDAS echelle package the coadded spectrum had a signal-to-noise of ≈ 360.

On such high resolution, high S/N spectra we searched for the Li I $2^2P - 3^2D$, 6104 Å transition. This transition is the strongest subordinate line of Li I but is much fainter than the resonance line. So far this line has been detected only in young T Tauri stars (Hartigan et al., 1989) and Li-rich giants (Wallerstein and Sneden, 1982), were Li is about 1 dex more abundant than in Population II stars owing to the Galactic Li production. As can be seen in Figure 1, the Li I feature is clearly detected in the spectrum of HD 140283 at 6103.6 Å, redwards of the Ca I 6102.723 Å line, in the photospheric rest frame. The equivalent width is 1.8 ± 0.3 mÅ and the detection is at 6σ of confidence level.

This detection is clearly a credit to the high-resolution capabilities of the NTT, and its improved efficiency allowed us to perform the observations in a reasonable amount of time; however, what is its astrophysical significance? Lithium, together with D and ^{3,4}He, is one of the few elements produced by nuclear reactions in the first minutes after the big bang (Wagoner, Fowler and Hoyle, 1967). The observations of these elements and their extrapolation to the primordial values are about consistent with the predictions of the primordial nucleosynthesis providing, together with the relic radiation and the expansion of the Universe, a robust support to the standard big-bang theory (nothing to do with NTT here). Since the yields of light elements depend on the single parameter $\eta = n_b/n_\gamma$, the baryon to photon ratio, the determination of the primordial Li abundance, as well as the other primordial elements, allows us to fix the value of η, and therefore of Ω_b. The possibility to determine the primordial abundance of Li relies on the discovery made by Spite & Spite (1982) that metal-poor halo dwarfs showed the same Li abundance regardless their metallicity or effective temperature: the so-called *Spite plateau.* This was interpreted as evidence that the Li observed in these stars was of primordial origin. Recently, additional support to the primordial nature of Li in halo dwarfs has come from the observations of Li in metal-poor stars of the thick disk (Molaro, Bonifacio and Pasquini, 1997). This population is chemically and kinematically distinct from the halo, but has the same Li abundance as the halo. Minniti et al. (1997) claimed detection of Li, at the plateau level, in a metal-rich, but old star, belonging to the Galactic Bulge. Finally, Li at the plateau level has also been detected in a star which was possibly born in an external galaxy and then accreted by the Milky Way (Molaro, 1997).

So far the Li abundance has always been obtained only from the analysis of the Li I λλ 6707 Å resonance doublet. This is not a very comfortable situation. Quite seriously, our ability to determine the Li abundance using simple plane-parallel homogeneous atmospheres, has been challenged by Kurucz (1995). The analysis of several lines, which sample different depths in the stellar atmosphere is crucial to test the correctness of the modelling. The one-dimensional, homogenous, static models which are currently employed may arise concern because they ignore the fine structure and hydrodynamic phenomena such as granulation which are seen on the Sun. The detection of the Li I λλ 6104 Å transition in the spectrum of the metal-poor star HD140283 opens up for the first time the possibility of testing the applicability of our simple models to the determination of Li abundances. We have verified that both the subordinate

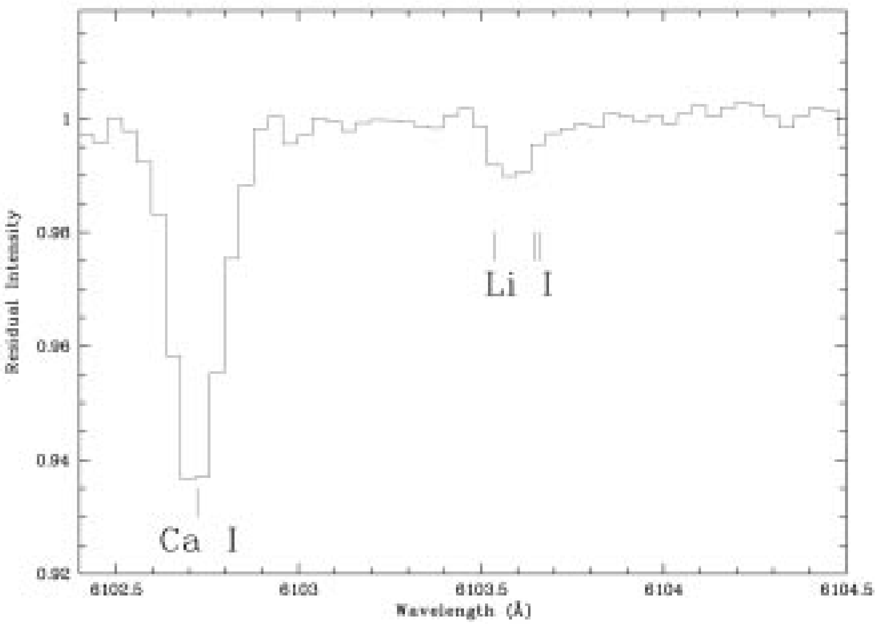

Figure 1: The observed Li I 2^2P – 3^2D transition.

and the resonance line are consistent with the computations made using a one-dimensional, homogeneous model atmosphere, thus increasing our confidence that this model represents a satisfactory average of the complex fine structure expected in metal-poor stars (Bonifacio and Molaro, 1998). The VLT and the high-resolution capabilities of the UVES spectrograph will allow to measure the Li 6104 Å Li I subordinate doublet in other much fainter population II stars, thus permitting to verify the consistency between the resonance and subordinate Li I lines on a statistically significant sample, thus achieving a more accurate measurement of the primordial Li abundance and ultimately of Ω_b.

In addition to the problems with the Li abundance determination, one must be careful about two other possible effects which are important in this context: Li production by galactic sources and Li depletion in the stars. Consider Li production first: we know that the meteoritic value is $(Li/H) = (2.04 \pm 0.19) \times 10^{-9}$, i.e. over one order of magnitude larger than that observed in the Pop II stars. Several mechanisms may contribute to raise the Li abundance from the Pop II value to the meteoritic value like spallation by cosmic rays in the ISM, production in AGB stars (Cameron-Fowler mechanism) or neutrino-induced nucleosynthesis in supernova explosions. There are several uncertainties in the various contributions, but it seems that there are no problems for a Galactic Li production of the order of 90% of the Li presently observed (Matteucci D'Antona and Timmes, 1995). Consider Li depletion next: Li is a very fragile element and can be destroyed if convection takes it down to temperatures of about 2.6×10^6 K where the Li(p,α)He reaction is effective. This is what probably happened in the sun where the Li abundance in the solar photosphere is two orders of magnitude less than the meteoritic value, and in solar metallicity field stars which show a scatter in the Li abundance of three orders of magnitude. For Pop II stars the situation is remarkably different. The Spite plateau shows no evidence for scatter in Li abundance (Bonifacio and Molaro, 1997). The surface convection zone of a metal-poor star is much shallower and more superficial than that of a solar-metallicity star of the same effective temperature probably preventing Li destruction. Standard models predict no Li depletion for metal-poor stars. Depletion is predicted by non-standard models which take into account rotational mixing or diffusion (Pinsonneault, Deliyannis and Demarque, 1992, Vauclair and Charbonnel, 1995). However, these models predict a downturn of the hot side of the Li plateau and considerable dispersion, which are not seen in the observations. This suggests that diffusion or rotational mixing do not affect significantly the Li observed at the stellar surface of metal-poor dwarfs.

Overall, the case for a primordial lithium at the value observed in the Population II stars, with no production by galactic sources or destruction inside the stars, is rather robust. The primordial yields for Li are not a monotonic function of η, due to the different contribution of the Li forming reactions at different η regimes. They show a minimum, i.e. the *Li valley.* This implies that in general a value for Li will provide two solutions for η. Only knowledge of the primordial abundance of the other light elements allows to rule out one of the two roots. The more recent value is $(Li/H) = 1.73 \pm 0.05_{stat} \pm 0.2_{syst} \times 10^{-10}$ (Bonifacio and Molaro, 1997), which gives two different values for η: $\eta = 1.7 \times 10^{-10}$, which is in agreement with the high deuterium *(D/H* $= 2.0 \times 10^{-4}$ Webb et al., 1997) and the low primordial helium ($Y = 0.228$ Pagel et al., 1992) and $\eta = 4.0 \times 10^{-10}$ which is in much closer agreement with the low deuterium (*D/H* $= 3.4 \times 10^{-5}$ Burles and Tytler, 1998) and relatively high primordial helium ($Y = 0.243$ Izotov et al., 1997). Thus a perfect concordance on the η value derived from the observations of the primordial elements has still to be found.

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Ground-Based Detection of the Isolated Neutron Star RXJ185635-3754 at V = 25.7 Mag with the Upgraded NTT

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We report the first ground-based detection of the isolated, non-pulsating neutron star RXJ185635-3754 at V = 25.7 mag, obtained with the upgraded NTT in August 1997. This object has been detected first as ROSAT source and was subsequently identified as neutron star with the HST. It is located foreground to a dark cloud, i.e. at a distance of less than 130 pc. With future VLT observations, we may be able to measure its parallax.

The unidentified ROSAT X-ray source RXJ185635-3754 has been claimed to be an isolated (i.e. not in a binary system) old neutron star (NS), because (1) it shows constant X-ray emission both on short time-scales (no pulses) as well as on long time-scales, having been detected by the Einstein Observatory Slew Survey, the ROSAT All-Sky