Mem. S.A.It. Vol. 75, 282

Memorie della

Lithium abundances in Globular Clusters

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Abstract. Warm metal poor dwarfs display a constant Li abundance, regardelss of their effective temperature or metallicity: the so-called "Spite Plateau". If this constant value represents the primordial Li abundance, that is the lithium synthesized in the Big Bang, the Universal baryonic density may be derived comparing it to nucleosynthesis calculations. In the recent years there has been an active debate on whether these stars have indeed preserved their pristine Li or whether it has been depleted by some stellar phenomenon. Since the Globular Clusters are a homogeneous single-age population they are an ideal testing ground for any theory which predicts Li depletion. As part of the ESO Large Programme (165.L-0263, P.I. R. Gratton) we observed turn-off stars in the Globular Clusters NGC 6397([Fe/H]~ -2.0) and 47 Tuc ([Fe/H]~ -0.7) at high resolution and relatively high signal to noise ratios, with the UVES spectrograph on the ESO Kueyen-VLT 8.2m telescope. On behalf of the collaboration I report our results on the Li abundances and abundance dispersion, or lack thereof, in these clusters as well as a re-analysis of extant data of the metal-poor Globular Cluster M92.

Key words. Stars: abundances – Stars: atmospheres – Stars: Population II – Galaxy: globular clusters – Galaxy: abundances – Cosmology: observations

1. Introduction

Standard Big Bang cosmology predicts that protons and neutrons are assembled into nuclei of D, ^{4}He, ^{3}He and ^{7}Li during the first three minutes (Wagoner, Fowler, & Hoyle 1967). The abundances of these nuclei are a function of the baryon to photon ratio, which is simply related to the baryonic density of the Universe Ω_b. The concordance, within errors, of the measured primordial abundances for a unique value of Ω_b has been considered for the last twenty years one of the observational pillars which support Big Bang cosmology. The opportunity of measuring the primordial Li abundance arises from the observation that the Li abundance in warm halo dwarf stars is constant, regardless of the metallicity and the effective temperature (Spite & Spite 1982), the so-called "Spite plateau". In order to intepret this constant Li value as the primordial one two conditions must be fulfilled: a) the Li present in the stellar atmosphere must have been preserved throughout the stellar evolution ; b) the Li produced by Galactic sources must be neglegible compared to that produced in the Big bang.

Li is a relatively fragile element and can be destroyed by nuclear reactions at temperatures in excess of 2.5×10^6 K. Li destruction is believed to be responsible for the large scatter in Li abundances observed in solar-metallicity stars and for the low photospheric Li abun-

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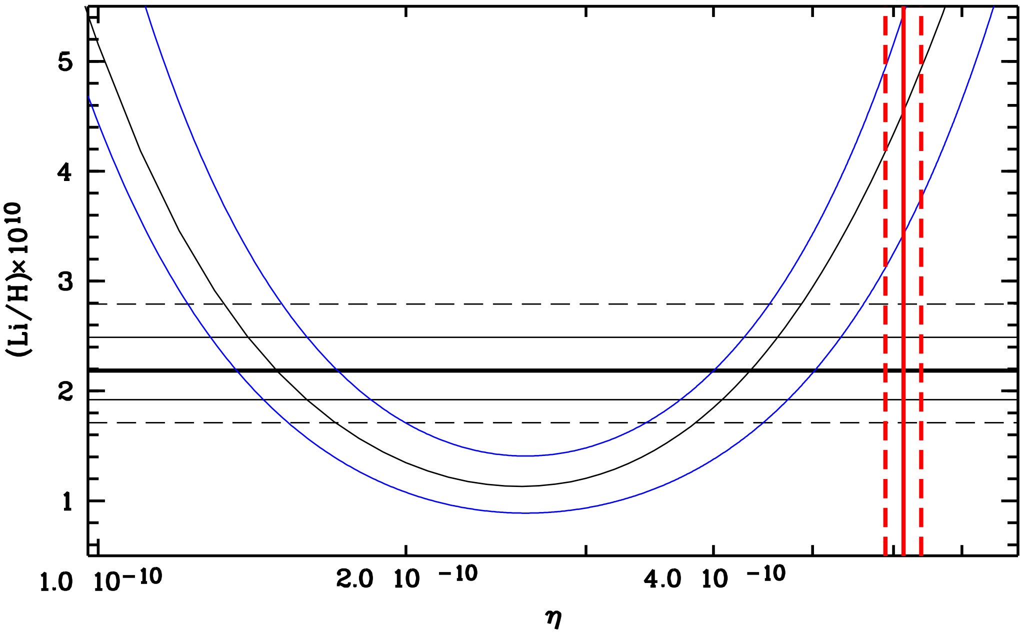

Fig. 1. Comparison of the Li abundance measured in NGC 6397 (thick solid line) with the predictions of BBN nucleosynthesis. The middle curve is a Kawano-code computation performed using a UNIX version of the code (F. Villante private communication), the upper and lower curves correspond to 1σ errors as parametrized by Sarkar (1996). The horizontal thin solid lines correspond to the statistical error of 0.056 dex in the Li abundance, while the dashed horizontal lines correspond to the statistical error added linearly to a systematic error of 0.05 dex, due to the uncertainty on the temperature scale. The vertical solid lines corresponds to $\eta = 6.137 \times 10^{-10}$ as implied by the WMAP measurement of $\Omega_b h^2 = 0.0224$ (Spergel et al. 2003); the vertical dashed lines correspond to the 1σ error of 0.0009 on $\Omega_b h^2$, i.e. 0.246×10^{-10} on η.

dance in the Sun itself. The convective structure of a metal-poor G dwarf should be, however, different from that of the Sun, with a considerably thinner and more superficial convective zone, which should allow Li to survive in the star's atmosphere (Cayrel, Lebreton, & Morel 1999). However, models which are more sophisticated than "standard" models and include additional physical ingredients, such as rotational mixing (Pinsonneault et al. 2002), or diffusion (Salaris, & Weiss 2001), or diffusion and turbulence (Richard et al. 2002), or a combination of diffusion, rotation and composition gradient (Théado & Vauclair 2001), predict a mild Li depletion. A common feature of such models is the prediction of some star to star variation in Li abundances and, in some cases the existence of a small number, of the order of a few percent, of "outliers", i.e. stars which are consistently Li depleted. Globular Clusters (GCs) appear as the ideal testing ground for such models, since the observations are not complicated by the scatter in ages and metallicities which characterize samples of field stars.

In this paper I shall review recent results on the only three GCs for which Li abundances for the Turn Off (TO) stars have been reported: NGC 6397, M92 and 47 Tuc.

2. Li observations

2.1. NGC 6397

This is the GC with the brightest TO in the sky and, not surprisingly, was also the first for which Li abundances in TO stars were measured (Molaro & Pasquini 1994; Pasquini & Molaro 1996). The advent of UVES at the VLT allowed the measurement of Li in 12 TO stars

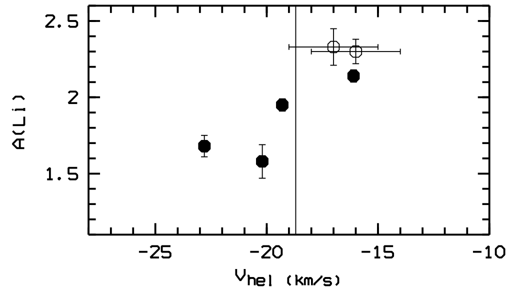

Fig. 2. Li abundances as a function of heliocentric radial velocities in the Globular Cluster 47 Tuc. The four stars observed in the course of ESO LP 165.L-0263, are shown as filled circles, while two stars observed by Pasquini & Molaro (1997) are shown as open symbols. The vertical line denotes the mean heliocentric radial velocity of the cluster.

with errors in the equivalent widths of the order of 0.2 pm (Thévenin et al. 2001; Bonifacio et al. 2002), i.e. comparable with what available for most field stars. The homogeneous analysis by Bonifacio et al. (2002) of all the high quality UVES data showed that there is no evidence for scatter in the Li abundances above what expected from the observational errors. The Li abundance in NGC 6397 is A(Li)= 2.34 ± 0.056 and is very close to what derived from field stars analyzed in a similar fashion, strongly suggesting that this is very close to the primordial Li abundance. A very tight limit on the maximum intrinsic scatter in Li abundances compatible with the data has been placed: 0.035 dex. This is a rather robust constraint which must be fulfilled by any theory which predicts Li depletion. Considering all the data in the literature a total of 15 TO stars have been observed in this cluster and none is Li-depleted. However outliers are expected to be of the order of a few percent, in order to test their existence I used FLAMES at the VLT in May 2003 to obtain medium quality high resolution spectra for over 120 stars in this cluster. The data is currently under analysis, however a quick look at the data has so far not revealed any outlier.

In Fig. 1 I compare this abundance with Big Bang nucleosynthesis (BBN) predictions computed with the Kawano code. Two possible values for η may be identified, however concordance with the fluctuations in the cosmic microwave background measured by WMAP (Spergel et al. 2003) requires that the low η root be rejected. The plot shows that A(Li)=2.34 is compatible with the WMAP measurement within 3σ. A large uncertainty is still linked to the theoretical BBN prediction, which is largely due to the uncertainty in the cross section for the $^4\mathrm{He}(^3\mathrm{He},\gamma)^7\mathrm{Be}$ reaction which is of the order of 18% and by itself results in an uncertainty of about 20% on the predicted Li abundance (Cuoco et al. 2003).

The more recent computations of Cuoco et al. (2003) with their new BBN code arrive at a similar conclusion: the Li abundance in NGC 6397, if taken as primordial, is consistent with BBN at less than 3σ. I thus believe it premature to claim that concordance with WMAP requires a Li depletion in metal-poor dwarfs.

2.2. M 92

For this metal-poor GC ([Fe/H]=-2.52 King et al. 1998, [Fe/H]=-2.26 Sneden et al. 1991) a spread in Li abundances of the order of 0.5 dex was claimed by Boesgaard et al. (1998). A reanalysis of the equivalent widths of Boesgaard et al. (1998)by Bonifacio (2002) with a careful assessment of the errors and the use of Monte Carlo simulations concluded that there is no strong evidence for an intrinsic dispersion of Li abundances in this cluster. However, since the TO of this cluster is about 2 magnitudes fainter than that of NGC 6397, the quality of the data is considerably lower. Although an intrinsic dispersion as large as 0.5 dex can be safely ruled out, a dispersion of 0.18 dex could exist and be undetected. Clearly higher quality data are needed to resolve the issue. It is interesting to note that by using the equivalent widths of Boesgaard et al. (1998), and the same temperature scale used for NGC 6397, Bonifacio (2002) derived for M 92 A(Li)= 2.36 ± 0.19 in remarkably good agreement with that found in NGC 6397.

2.3. 47 Tuc

This is among the most metal-rich GCs ([Fe/H]=-0.67, Carretta et al. in preparation).

Pasquini & Molaro (1997) observed for Li three TO stars of this cluster with the 3.5m ESO-NTT, in two the Li doublet was detected, but not in the third one. Although the detected Li was close to the value of the "Spite plateau" of field stars, the lack of detection of Li in the third star suggested that some dispersion in Li abundances is present in this cluster. Another four TO stars have been observed with UVES-VLT in the course of the ESO LP 165.L-0263 led by R. Gratton. Li was detected in all of them. However, the measured A(Li) spans a range of almost 0.6 dex. A proper Monte Carlo analysis of the data is underway. However, the conclusion that there is real dispersion in Li content among TO stars in 47 Tuc seems difficult to escape. In Fig. 2 I show the Li abundnaces for all the 6 TO stars of 47 Tuc for which Li has been detected versus the radial velocity.

3. Conclusions

The study of Li in GCs has just started and I expect more exciting results in the next few years from multi-fibre facilities such as FLAMES and high efficiency spectrographs such as ESI and X-shooter. With the present data at hand it seems that Li in metal-poor GCs tracks the "Spite plateau" while Li dispersion is present at higher metallicity. This suggests that the mechanism(s) producing such dispersion are not efficient at low metallicities.

Acknowledgements. I am grateful to R. Gratton and to all the researchers of the Large Programme led by him, for the excellent work done and for allowing me to present some results in advance of publication. It is a pleasure to acknowledge the many helpful discussions on the topic of Li abundances with M. Spite, F. Spite, P. Molaro and R. Cayrel.

References

Boesgaard, A. M., et al. 1998, ApJ, 493, 206
Bonifacio, P. 2002, A&A, 395, 515
Bonifacio, P. et al. 2002, A&A, 390, 91
Cayrel, R., Lebreton, Y., & Morel, P. 1999, Ap&SS, 265, 87
Cuoco, A. et al. 2003, ArXiv Astrophysics e-prints, 7213
King, J. R. et al. 1998, AJ, 115, 666
Molaro, P. & Pasquini, L. 1994, A&A, 281, L77
Pasquini, L. & Molaro, P. 1996, A&A, 307, 761
Pasquini, L. & Molaro, P. 1997, A&A, 322, 109
Pinsonneault, M. H. et al. 2002, ApJ, 574, 398
Richard, O. et al. 2002, ApJ, 568, 979
Salaris, M., & Weiss, A. 2001, A&A, 376, 955
Sarkar, S. 1996, Reports of Progress in Physics, 59, 1493
Sneden, C. et al. 1991, AJ, 102, 2001
Spergel, D. N. et al. 2003, ArXiv Astrophysics e-prints, 2209, ApJ, in press
Spite, M. & Spite, F. 1982, Nature, 297, 483
Théado, S., & Vauclair, S. 2001 A&A, 375, 70
Thévenin, F., et al. 2001, A&A, 373, 905
Wagoner, R. V., Fowler, W. A., & Hoyle, F. 1967, ApJ, 148, 3