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Variations in the lithium abundances of turn off stars in the globular cluster 47 Tucanae⋆

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ABSTRACT

Aims. Our aim is to determine Li abundances in turn off stars of the globular cluster 47 Tuc and test theories about Li variations among turn off stars.

Methods. We make use of high resolution ($R \sim 43\,000$), high signal-to-noise ratio ($S/N = 50$–70) spectra of 4 turn off (TO) stars obtained with the UVES spectrograph at the 8.2 m VLT Kueyen telescope.

Results. The four stars observed span the range $1.6 \lesssim A(\mathrm{Li}) \lesssim 2.14$, providing a mean $A(\mathrm{Li}) = 1.84$ with a standard deviation of 0.25 dex. When coupled with data of other two TO stars of the cluster, available in the literature, the full range in Li abundances observed in this cluster is $1.6 \lesssim A(\mathrm{Li}) \lesssim 2.3$. The variation in A(Li) is at least 0.6 dex (0.7 dex considering also the data available in the literature) and the scatter is six times larger than what is expected from the observational error. We claim that these variations are real. A(Li) seems to be anti-correlated with A(Na) exactly as observed in NGC 6752. No systematic error in our analysis could produce such an anti-correlation.

Conclusions. Na production through p captures on ^{22}Ne at temperatures in excess of 3×10^7 K and the contemporary Li destruction could result in this anti-correlation. However, such nuclear processing cannot have taken place in the stars themselves, which do not reach such high temperatures, even at their centre. This points towards the processing in a previous generation of stars. The low N/O ratios in the observed stars and the apparent lack of correlation between N an Li abundances, place a strong constraint on the properties of this previous generation. Our results indicate a different behaviour among the globular clusters so far studied, as far as the abundance patterns are concerned.

Key words. diffusion – stars: abundances – stars: atmospheres – stars: Population II – Galaxy: globular clusters: 47 Tuc

1. Introduction

The Globular Cluster (GC) 47 Tuc is a good example of the metal-rich end population of these very old objects (age in the range 11 to 14 Gyr, Gratton et al. 2003). In view of its brightness it is one of the best studied GCs and with the advent of the UVES spectrograph at the ESO-VLT it has become possible to obtain abundances of individual stars on the main sequence, with an accuracy previously possible only for halo field stars which are several magnitudes brighter. It is one of the main targets of the ESO Large Programme 165.L-0263 (P.I. R.G. Gratton). The chemical composition of turn off (TO) and subgiant (SG) stars from our UVES data is given in another paper of this series (Carretta et al. 2004), which provided a metallicity [Fe/H] = –0.64 for the TO stars of this cluster.

It has been known for almost thirty years that 47 Tuc exhibits a bimodal distribution of CN band strengths, suggesting a bimodal distribution of N abundances, among giant stars (Norris & Freeman 1979) and also among TO stars (Briley et al. 1994). Thus abundance inhomogeneities among stars in this cluster are expected.

In this paper we examine the Li abundances in the TO stars. The only previous investigation of Li in this cluster was performed by Pasquini & Molaro (1997) who could detect the Li line in two TO stars, using spectra obtained with EMMI on the 3.5 m ESO NTT telescope. In the present investigation we shall make use of the equivalent widths measured by Pasquini & Molaro (1997).

Old metal-poor warm dwarfs in the Galactic Halo show a rather uniform lithium abundance, whichever their metallicity or effective temperature. This was discovered by Spite & Spite (1982) and is usually called the *Spite Plateau*. This behaviour of lithium is unique among chemical elements, all of which show a decreasing abundance with decreasing metallicity; lithium is the only element to display a plateau. The most obvious interpretation is still the one put forward by Spite & Spite (1982) that the lithium observed in the *Spite Plateau* is simply the "primordial" lithium, that is the lithium that has been produced during the big bang, together with the other light nuclei, D, ^{3}He and

⋆ Based on observations made with the ESO VLT-Kueyen telescope at the Paranal Observatory, Chile, in the course of the ESO-Large programme 165.L-0263.

^{4}He. The abundance of the nuclei produced in this way depends on the baryon to photon ratio ($\eta = n_b/n_\gamma$) which cannot be deduced from first principles, but has to be somehow measured. The WMAP satellite has provided this ratio with an accuracy of the order of 4% (Spergel et al. 2003, 2006), the precise value being $\eta = 6.11 \pm 0.22 \times 10^{-10}$. When inserted in standard big bang nucleosynthesis computations (SBBN) this value implies A(Li)[1] = 2.64. Current estimates of the level of the *Spite Plateau* range from 2.1 (Bonifacio et al. 2007) to 2.3 (Bonifacio et al. 2002; Meléndez & Ramírez 2004). There is thus tension between the observed lithium abundances in stars and the predictions of SBBN, when the baryonic density derived from WMAP is adopted. The most obvious ways to reconcile these results are either to look for new physics at the time of nucleosynthesis or to find mechanism(s) which have depleted uniformly Li from the primordial value to what is currently observed in Halo stars.

In order to test the theories which predict Li depletion, GCs are, in principle, an ideal target: the stars have the same age and chemical composition, at variance with what happens with field stars. Effects of Li depletion could be obscured by other concurrent metallicity or age effects. The Li abundance in GCs is therefore of great importance; we may try to detect some of the features which are predicted by models, such as a mild scatter in Li abundances, above what is expected from observational errors, or the existence of "outliers", i.e. heavily depleted stars.

Our observations of the GC NGC 6397 (Bonifacio et al. 2002) show that all the observed stars in this metal poor cluster share the same abundance and there are no "outliers". There is very little room for intrinsic scatter; this does not rule out any of the depletion models, but does place a very strong constraint to be fulfilled. Therefore the currently available observations seem to argue *against* any Li depletion in NGC 6397. Our result has recently been challenged by Korn et al. (2006) who claimed they found a difference in lithium content between the TO stars and subgiant stars at an effective temperature around 5800 K. According to their interpretation these observations are in agreement with the diffusive models of Richard et al. (2005). It should however be kept in mind that the result of Korn et al. (2006) depends on their adopted temperature scale and that an increase of only 100 K of the temperatures of the TO stars, as suggested by the cluster photometry, would erase this difference. Note that such an increase in the $T_{\rm eff}$ would at the same time erase the claimed "diffusion signatures" also in Fe, Ca and Ti. The question is therefore still not settled.

At variance, the GC NGC 6752, which is about a factor of 4 more metal-rich than NGC 6397, displays a strong variation (up to 0.4 dex) in Li abundances among TO stars (Pasquini et al. 2005). These variations, however, do not appear to be random, but are anti-correlated with the variations of sodium and nitrogen, and correlated with the variations of oxygen, in the same stars. Such variations cannot be produced by diffusion mechanisms, since the effect of diffusion would be similar for lithium and sodium. Neither can they arise from mixing occurring in the stars themselves, since the base of the convection zone in such stars attains a temperature of 1.5 MK, which is very far from the region of lithium burning (Piau 2005, private communication). Pasquini et al. (2005) suggest that the most likely source of such anomalies are intermediate mass asymptotic giant branch (IM-AGB) stars which have polluted either the material out of which the TO stars were formed, or their atmospheres. The nucleosynthetic signatures of IM-AGB stars are in qualitative agreement with the observed patterns, although quantitatively, none of the current models is capable of fully explaining the observations. We refer the reader to the papers of Fenner et al. (2004); Ventura & D'Antona (2005); D'Antona et al. (2006) and Ventura & D'Antona (2006) where some of the problems of IM-AGB models in reproducing the observed abundance variations in GCs are discussed, as well as possible solutions. From a different perspective Prantzos & Charbonnel (2006) examined the constraints on the cluster's Initial Mass Function in the case the polluters are IM-AGB stars or the winds of massive stars. Their main conclusion is that if IM-AGB stars were the main polluters the current mass of the clusters should be dominated by stellar remnants. Since this does not appear to be the case, they consider the winds of massive stars as a more attractive hypothesis. Following up on this idea, Decressin et al. (2007) investigated the possibility that winds of *rotating* massive stars are the polluters causing the observed abundance variations. We shall later discuss these results in the light of our findings.

In this paper we explore the Li content of 47 Tuc, at the metal-rich end of the metallicity range span by halo GCs. In spite of its relatively high metallicity 47 Tuc is very old (11.2 Gyr, Gratton et al. 2003) and the Galactic production should not have greatly enhanced its lithium content.

Table 1. Log of the observations.

Star #	α J2000	δ J2000	Date d/m/y	UT h:m:s	$t_{\rm exp}$ s	Seeing arcsec
952	00:21:39.14	–72:02:53.73	28/10/2001	00:37:18	6000	1.″6
952			28/10/2001	02:18:28	6000	1.″3
952			28/10/2001	06:14:43	2700	0.″8
975	00:20:52.72	–71:58:04.16	07/09/2000	06:28:57	5400	1.″7
975			07/09/2000	08:00:57	5400	1.″7
975			08/09/2000	05:42:13	3600	1.″5
975			08/09/2000	06:43:42	3600	2.″4
1012	00:21:26.27	–72:00:38.73	25/10/2001	03:31:42	6000	0.″6
1012			25/10/2001	05:12:35	6000	0.″8
1081	00:21:03.82	–72:06:57.74	29/08/2001	08:30:57	4500	0.″7
1081			30/08/2001	07:26:16	4500	0.″5
1081			30/08/2001	08:42:39	3600	0.″7

2. Observations and data reduction

Our spectra were collected at ESO-Paranal with the UVES spectrograph (Dekker et al. 2000) at the Kueyen 8.2 m telescope in the course of three runs, covering two years. The log of the observations is given in Table 1, the DIMM seeing was noted. The data were reduced using the UVES context within MIDAS. Different spectra of the same star were co-added reaching S/N ratios in the range of 50 to 70 per pixel. The coadded spectra of the Li doublet for each star, together with the best fitting synthetic profile are shown in Fig. 1.

3. Lithium abundances

The equivalent widths of the Li doublet were measured by fitting synthetic spectra, as done by Bonifacio et al. (2002) and errors estimated through Monte Carlo simulations. The chemical composition and atmospheric parameters of these stars have been studied by Carretta et al. (2004). Both with respect to colours and Balmer line profiles the four stars studied here are twins and share the same effective temperature and surface gravity. We adopt here the parameters of Carretta et al. (2004), namely

[1] Throughout the paper we use the notation $A(\mathrm{X}) = \log[\mathrm{N(X)/N(H)}] + 12$.

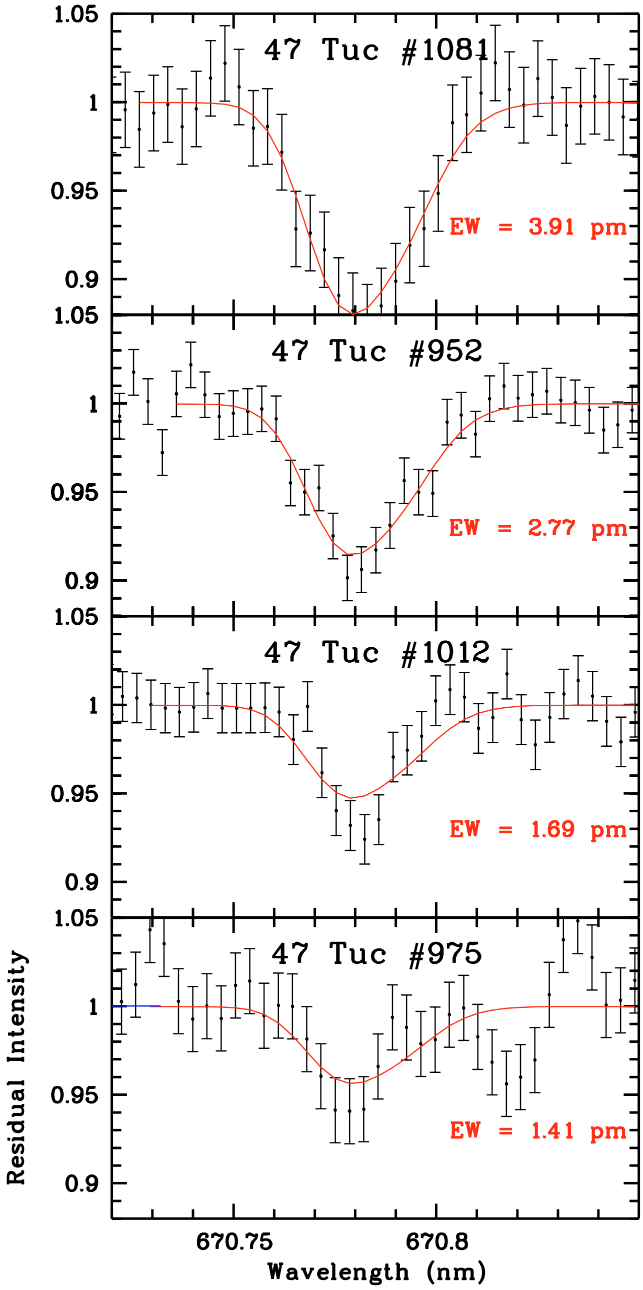

Fig. 1. Li doublet for the programme stars, the best fitting synthetic profile is shown as a thin line.

$T_{\rm eff} = 5832$ K, log g = 4.05 (cgs units) and a microturbulent velocity of 1.07 km s^{-1} for all the stars. The iron abundance measured for these stars by Carretta et al. (2004) is [Fe/H] = −0.64. We used the ATLAS code (Kurucz 1993; Kurucz 2005) to compute a model atmosphere, using the Opacity Distribution Function (ODF) of Castelli & Kurucz (2003) with [M/H] = −0.5, ξ = 1 km s^{-1} and α elements enhanced by 0.4 dex. The procedure for Li abundance determination was the same as in Bonifacio et al. (2002): we iteratively computed synthetic spectra using the SYNTHE code (Kurucz 1993; Kurucz 2005) until the equivalent width of the synthetic spectrum matched the measured equivalent width. The abundances are given together with the equivalent widths in Table 2.

For star # 952, for which abundances are not given in Carretta et al. (2004), we measured the Na abundance from the 616.1 nm, 818.3 nm and 819.4 nm lines, and derived

Table 2. Equivalent widths and Li abundances for TO stars in 47 Tuc. Errors take into account only the uncertainty on equivalent widths, the effects of uncertainties in $T_{\rm eff}$ are neglected.

Star #	V	$B-V$	EW	$\sigma_{\rm MC}$	S/N	A(Li)	$\sigma_{\rm Li}$
	mag	mag	pm	pm			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
measures from our VLT-UVES data							
952	17.36	0.557	2.77	0.20	78	1.95	0.04
975	17.33	0.597	1.41	0.30	54	1.58	0.11
1012	17.36	0.581	1.69	0.21	71	1.68	0.07
1081	17.37	0.587	3.91	0.24	47	2.14	0.04
measures of Pasquini & Molaro (1997) from NTT-EMMI data							
BHB 7	17.38	0.57	5.30	0.80		2.30	0.08
BHB 5	17.35	0.59	5.60	1.10		2.33	0.12

log(Na/H) + 12 = A(Na) = 5.61, taking into account the NLTE corrections of Gratton et al. (1999).

The only two other TO stars of this cluster for which Li measures exist are the stars BHB 5 and BHB 7 (where BHB stands for Briley et al. 1994, who provide coordinates and finding charts for these stars) that have been observed by Pasquini & Molaro (1997) with EMMI on the ESO 3.5 m NTT telescope at a resolution $R \sim 18\,000$. These two stars have colours (see Table 2) which place them in the same position in the colour-magnitude diagram as the stars observed with UVES. We therefore decided to use the equivalent widths measured by Pasquini & Molaro (1997) and the same model atmosphere used for the stars observed with UVES to derive the abundances provided in Table 2.

4. Discussion

4.1. Are the Li variations real?

Although still very limited, the data suggest that there is a real scatter in the lithium abundances of this metal-rich cluster. The mean Li abundance is 1.84 with a standard deviation of 0.25 dex. We do not perform any correction for NLTE effects or standard depletion as done by Bonifacio et al. (2002) and Bonifacio (2002), since all the stars have the same $T_{\rm eff}$ and these would be the same for all the stars and would have no effect on the dispersion in Li abundances. A Monte Carlo simulation of 1000 ensembles of 4 "observations" with the errors reported in Table 2, as done by Bonifacio et al. (2002) and Bonifacio (2002), provides a mean dispersion of 0.063 dex with a standard deviation of 0.032 dex, we can claim that dispersion in excess of the expected measurement error is detected at the 6σ level. Since the errors in Table 2 arise only from errors in the equivalent widths one could argue that a real difference in the temperature of the stars could justify the scatter observed. A random scatter of 100 K in the effective temperatures would imply changes of the order of 0.08 dex in the derived Li abundances. If we increase all the errors in Li abundances by this amount and perform another Monte Carlo simulation, the mean dispersion is 0.141 dex with a standard deviation of 0.063 dex. At this point the detection of extra scatter is marginal at only 1.8σ, yet still present. In order for the observed dispersion to be entirely consistent with the observational errors, we would have to increase the scatter in $T_{\rm eff}$ up to 250 K. Given the similarity of the spectra of the different stars

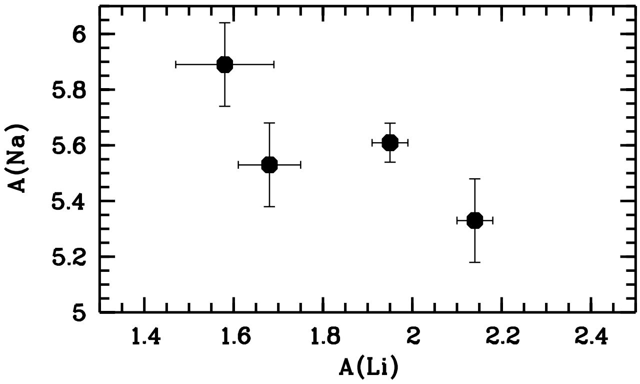

Fig. 2. Na abundances versus Li abundances for the four stars measured by us.

there is little support for the existence of such a spread in the effective temperatures of our stars. Furthermore, such a scatter in temperatures should also produce some scatter in derived iron abundances, which is not observed (Carretta et al. 2004). We believe it is simplest to accept that the stars observed by us do show real variations in the Li abundances. Clearly, the observation of a larger sample of stars is required to firmly establish the reality of Li variations. We have repeatedly tried in the last four years to obtain time at the VLT to observe further TO stars in this cluster, but have been unsuccessful.

Let us assume, for the sake of discussion, that the spread in Li abundances is entirely due to observational errors. In this case it is legitimate to average the values in Table 2 to obtain the Li content in 47 Tuc. The mean $A(\mathrm{Li}) = 1.84$ is 0.5 dex *lower* than the lithium content in NGC 6397. One is thus led to the inescapable conclusion that Li has been depleted in this cluster. Under these assumptions the depletion would have been fairly uniform.

We believe it is less contrived to assume that Li has been depleted in a non-uniform way and that this non-uniformity gives rise to the scatter in Li abundances. Finally one should not discard the information provided by the two stars observed by Pasquini & Molaro (1997), both of which show a higher A(Li) than any of the stars observed with UVES, and indeed to a level comparable to that observed in NGC 6397. This considerably strengthens the claim that there are indeed real variations in Li abundance among TO stars in 47 Tuc.

4.2. The Li-Na anti-correlation

The Li abundances in 47 Tuc appear to be anti-correlated with the Na abundances; in our view this is a fact which further supports the reality of the abundance variations. A plot of A(Li) versus A(Na) is shown in Fig. 2. Kendall's τ test provide a probability of 82% that this anti-correlation is real. It is a bit low to make a strong claim, but with only 4 points it is difficult to expect more definite results. If the spread in Li abundances were due to incorrect temperatures it could not possibly create such an anti-correlation, since any change in T_{eff} produces changes of *equal sign* and *comparable magnitude* on both Li and Na. There is no way to create the anti-correlation by an incorrect choice of atmospheric parameters.

If we accept the hypothesis that the "unpolluted" Na abundance of the cluster is provided by the stars with the highest Li abundance then it should be [Na/Fe] = –0.36, or perhaps even lower, if the stars BHB 5 and BHB 7 follow the trend traced by the other four stars. We examined again the EMMI spectra of the two stars observed by Pasquini & Molaro (1997) to see if it were possible to measure the Na abundance from those spectra. The only usable Na lines were those of the 615.4–616.0 nm doublet, which are weak in these warm TO stars. Given the low S/N of the spectra, the lines cannot be reliably used and only a very high (not significant) upper limit can be obtained.

4.3. The need for "pollution"

When considering field stars, the usual interpretation of relatively cool and metal-rich stars found below the *Spite plateau* is that Li is depleted in these stars due to a deeper convection zone and/or atomic diffusion (Michaud et al. 1984; Vauclair & Charbonnel 1995, 1998; Salaris & Weiss 2001; Richard et al. 2002a,b, 2005). In the case of 47 Tuc the observation of low Li abundances is accompanied by the finding of the Li-Na anti-correlation, which implies that some of the polluting material has been processed at temperatures in excess of 3×10^7 K so that Li has been destroyed and Na created by p captures on ^{22}Ne. These temperatures are high enough for extensive burning of oxygen through the CNO cycle, which can well explain the Na-O anti-correlation present in this cluster (Carretta et al. 2004). These temperatures are however too high to be found within TO cluster stars, which, even at the centre should not exceed a temperature of 2×10^7 K. Therefore the Na-O anti-correlation requires processing in a previous generation of stars and subsequent non-uniform pollution of the ISM. This view has to be consistent with the [N/O] ratio in the TO stars in this cluster, which has a mean value of –0.85 dex (Carretta et al. 2005), that is about 0.5 dex *lower* than what is observed in field stars of the same metallicity (Israelian et al. 2004). Also the ^{12}C/^{13}C ratio (>10, Carretta et al. 2005) argues against CNO cycling of material in the TO stars of 47 Tuc. This poses serious problems to explain the observed Li-Na anti-correlation. The polluting material probed by the abundances in the TO stars of 47 Tuc, must have experienced high temperatures in order to produce the Li-Na anti-correlation. However, we do not observe signature of extensive O burning, N production or ^{13}C production. A further complication in this picture is the possible *production* of Li, e.g. via Cameron-Fowler mechanism (Cameron & Fowler 1971) or otherwise. Any production of Li, however, would tend to erase the Li-Na anti-correlation, it is therefore likely that there is no, or very little, Li production.

In Fig. 3 we show [Na/Fe] as a function of [N/Fe] for both the dwarf and subgiant stars observed in 47 Tuc. There is a hint of a correlation, albeit with a very large scatter. We inspected all the spectra of the subgiant stars observed in this cluster with UVES, but could not convincingly detect the Li doublet in any of them. Considering the quality of the spectra we set an upper limit on the equivalent width of the Li doublet in these stars of 1 pm, this implies an upper limit $A(\mathrm{Li}) < 0.34$. In Fig. 4 we show the Li abundances, or upper limits, as a function of [N/Fe], contrary to what is observed in the cluster NGC 6752 (Pasquini et al. 2005), Li and N appear to be totally uncorrelated. We stress that some caution must be exerted in interpreting this data since too few stars have been observed. It should be noted that according to the measures of Briley et al. (1994), BHB 5 is CN-weak CH-strong, while BHB 7 is CN-strong CH-weak (see Fig. 7 of Briley et al. 1994). If we interpret the CN band strength in terms of N abundance, this would be further evidence of what is hinted at by Fig. 4: that Li abundance does not seem to be correlated to N abundance. It would clearly be of great interest to re-observe stars BHB 5 and BHB 7 with an 8 m class telescope

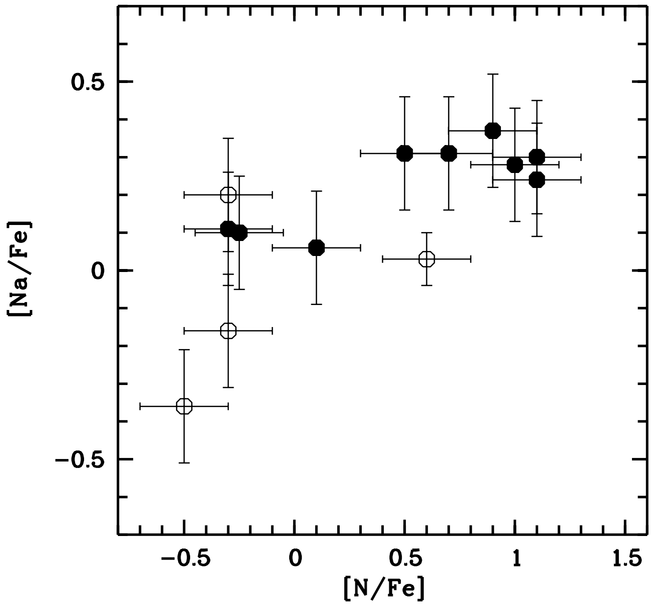

Fig. 3. Na abundances versus N abundances for the four dwarf stars (opens symbols) and for the subgiant stars (Carretta et al. 2004, 2005).

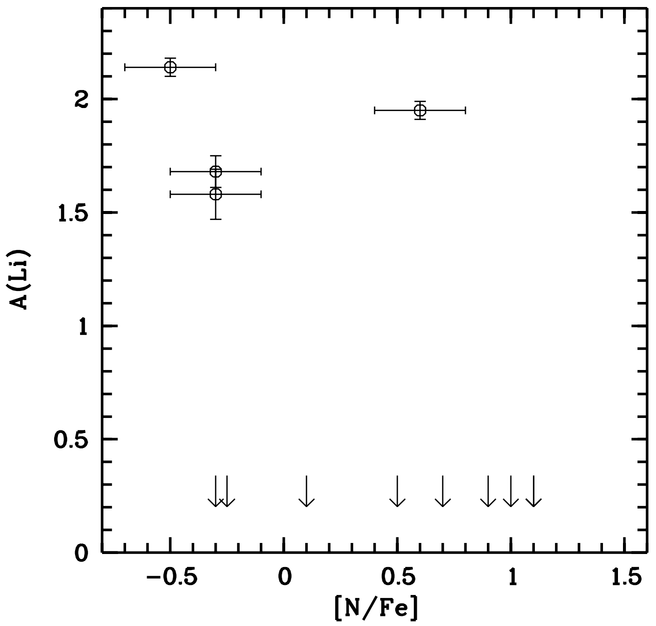

Fig. 4. Li abundances versus N abundances for the four dwarf stars and for the subgiant stars (Carretta et al. 2004, 2005). Only upper limits are available for the subgiant stars.

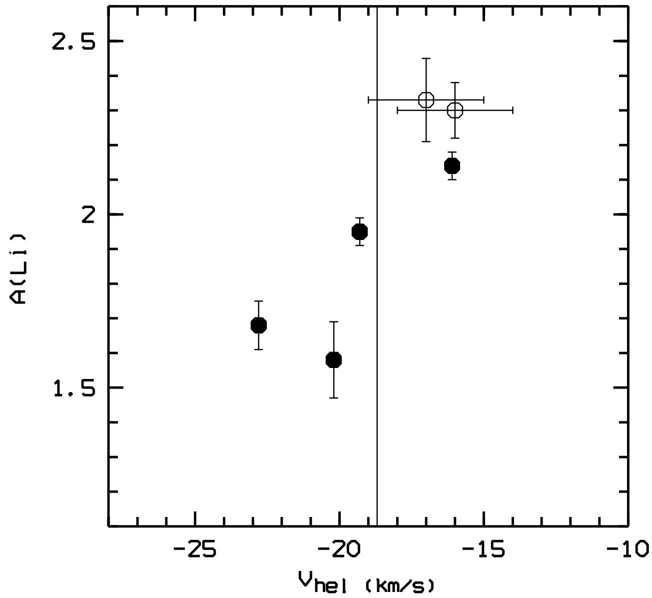

Fig. 5. Li abundances as a function of heliocentric radial velocities. The four stars observed by us are shown as filled circles, while the two stars observed by Pasquini & Molaro (1997) are shown as open circles.

in order to perform a complete chemical analysis and improve their Li abundances.

4.4. Neutron capture elements: absence of an AGB signature

It is interesting to look also at the abundances of the *n*-capture elements in these stars, which have been measured by James et al. (2004). In this respect the cluster seems extremely homogeneous and the abundances are consistent with those observed in field stars of the same metallicity, with the exception of Sr, for which both the [Sr/Fe] and the [Sr/Ba] ratios are slightly *higher* than in field stars of the same metallicity. This situation makes it unlikely that these stars have been formed out of, or polluted by, material heavily enriched by *s*-process elements, as may be expected in the ejecta of AGB stars which have undergone thermal pulses.

It should be here noted that a recent investigation of the chemical composition of AGB stars in this cluster (Wylie et al. 2006) has claimed a true scatter in the ratios of *n*-capture elements. Since the stars currently observed on the AGB in 47 Tuc are of too low mass to have undergone the third dredge-up one should conclude that this inhomogeneity is intrinsic and not due to self-pollution. To further support this point of view Wylie et al. (2006) point out the large scatter in sodium abundances in their stars ($+0.3 \lesssim$ [Na/Fe] $\lesssim +1.0$) and claim that this, and the variations in *n*-capture elements could be explained by the presence of at least two separate stellar populations. This suggestion is intriguing, but the results of Wylie et al. (2006) for *n*-capture elements are at odds with those of James et al. (2004) for the stars examined in the present paper and with those of Alves-Brito et al. (2005) for a sample of 5 giants stars in this cluster. Further investigation would be desirable to rule out the possibility of systematic differences among the different analysis. Note that the Na enhancements observed by Wylie et al. (2006) are all larger than what observed in our TO stars.

4.5. Do all GCs evolve in a similar way?

It appears clear that GCs exhibit a considerable diversity in their abundance inhomogeneities. NGC 6397 displays no Li–Na anticorreation and a marked enhancement of N. NGC 6752 displays a well defined Li–Na anti-correlation, accompanied by a rather large enhancement of nitrogen, compared to field stars, and a [N/O] ratio which ranges between 0.6 and 1.8, over two orders of magnitude larger than what is observed in field stars of the same metallicity. 47 Tuc displays a Li–Na anti-correlation, however N does not appear to be enhanced and subsolar values of [N/O] are found. Recently Bekki et al. (2007) have proposed a scenario by which GCs are formed at high redshift in dwarf galaxies, embedded in dark matter subhalos and the polluters are mainly the field IM-AGB stars of the host galaxy, which is subsequently tidally disrupted. Such a scenario has several appealing aspects, among which, in our view, the most interesting is that it may accomodate quite naturally differences in self-enrichment histories of GCs, which may be traced to the different properties (masses, dynamics, age...) of the, now disrupted, host galaxies and dark matter subhalos. Currently such models are unable to explain the Na-O anti-correlations, and, by inference, they should likewise be unable to explain the Li-Na anti-correlation. However, more generally, the abundance pattern in the GC hosting dwarf galaxies may result from complex histories, which may allow to explain the variety of abundance patterns observed in GCs. The scenario of Bekki et al. (2007) is supported by the dynamical simulations of Gnedin & Prieto (2006), which suggest that GCs may form in giant molecular clouds within high redshift galaxies. By computing the orbits of such clusters in a Milky Way-sized galaxy Gnedin & Prieto (2006) conclude that all clusters found at distances larger than 10 kpc from the Galactic center were indeed formed in satellite galaxies, which have now been tidally disrupted.

At this point it is perhaps worth to mention the significative difference in HB morphology between NGC 6752 and 47 Tuc, the former being characterized by an extended blue tail. Of course this difference could be simply due to the different metallicity of the two clusters, however the long blue tail in the HB of NGC 6752 could also be linked to stars polluted by He-enriched matter, according to the scenario suggested by D'Antona & Caloi (2004).

4.6. Are massive stars the polluters?

The lack of nitrogen enhancement seems difficult to reproduce using AGB stars as polluters. A distinct possibility is that the polluters are instead massive stars, an alternative which is favoured by Prantzos & Charbonnel (2006). These authors suggest that it is the wind of massive stars which is retained in the cluster, while the SN ejecta are lost, due to their higher speed of ejection. Meynet et al. (2006) present the results for models of 60 $M_\odot$ star of very low metallicity ($Z/Z_\odot = 10^{-8}$ and $Z/Z_\odot = 10^{-5}$), both with and without rotation. According to these computations the *wind* of such a star, can provide at the same time large $^{12}C/^{13}C$ ratios, and very small N/O ratios, as observed in this cluster, only if the star has a low enough rotational velocity, so that rotational mixing is unimportant. If, instead, also the SN ejecta are mixed to the wind, due to the large production of O, the N/O ratio is considerably lowered, whatever the rotational velocity. It seems however likely that the fast SN ejecta are lost to the cluster and do not contribute to its chemical evolution, at variance to what we expect from the relatively slow-moving winds. The investigation of Meynet et al. (2006) has been extended by Decressin et al. (2007), who computed also models for 20, 40, 60 and 120 $M_\odot$, for a metallicity of $Z = 0.0005$, which corresponds, roughly, to [Fe/H] = –1.5, adequate, e.g. for NGC 6752. These rotating models seem to produce winds with a composition apt to reproduce the C, N, O and Na variations in NGC 6752. We cannot apply directly these models to 47 Tuc, which is considerably more metal-rich. We note, however, that the winds of mass 60 and 120 $M_\odot$, according to Decressin et al. (2007), display low N/O ratios only up to the end of central H-burning. After this phase, N/O is always greater than the solar ratio, which is ~0.1, while the observed N/O ratio in 47 Tuc is lower than solar. The 20 $M_\odot$ model never provides wind with $N/O > 1$ and the 40 $M_\odot$ does so only after the appearance of the He-burning products at the surface. Decressin et al. (2007) do not provide the fraction of ^{13}C in the wind, so that we cannot tell if at any of these phases a low N/O is accompanied by high $^{12}C/^{13}C$. Even if it were so, one would have to admit that the pollution was made only during such phases (or by stars of such masses, e.g. masses of 20 $M_\odot$ or lower). Decressin et al. (2007) assume that the massive stars winds are essentially Li free and invoke a dilution of the wind with about 30% of pristine gas, in order to reproduce the lowest Li abundance observed in NGC 6752, assuming the pristine lithium was what derived from the SBBN predictions, and the baryon to photon ratio provided by WMAP. In the case of 47 Tuc, since some of the observed values of Li are even lower than in NGC 6752, these should have been formed almost exclusively out of the winds, with an addition of at most 9% of pristine material. It is certainly true that at the temperature necessary for sodium production the lithium should be completely destroyed, therefore to be consistent with the observed Li abundances, the processed material must anyway be diluted with material in which Li has been preserved. Such a pollution may provide the observed Li-Na anti-correlation, however the abundances of N and ^{13}C should follow this pattern.

4.7. A kinematical signature of pollution?

An interesting feature emerges if we plot Li abundances as a function of radial velocities (see Fig. 5): there is a mild hint (probability of correlation between radial velocity and Li abundance ~91%) that the most Li-rich stars have a radial velocity different from the less Li-rich. This may point towards a kinematic distinction between the more polluted and the less polluted stars. However, given the limited size of the sample, it is premature to claim this is a real feature; nevertheless it surely prompts for the observation of a larger sample of stars.

5. Conclusions

The new high quality spectra of the Li doublet in TO stars of 47 Tuc strongly suggest that Li has been depleted in a non-homogeneous way in this cluster. The existence of an anti-correlation between A(Li) and A(Na) effectively rules out the possibility that the spread in A(Li) arises from incorrectly chosen atmospheric parameters.

The newly established Li-Na anti-correlation, and the Na-O anti-correlation argue in favour of the nuclear processing which has taken place in a previous generation of stars. The low nitrogen abundance in these stars places however a strong constraint on the properties of this previous generation of stars. It appears unavoidable to conclude that the self-enrichment history of 47 Tuc has been distinctly different from that of the more metal-poor cluster NGC 6752.

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