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Letter to the Editor

The lithium content of ω Centauri

New clues to the cosmological Li problem from old stars in external galaxies⋆,⋆⋆

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ABSTRACT

Context. A discrepancy has emerged between the cosmic lithium abundance inferred by the WMAP satellite measurement coupled with the prediction of the standard big-bang nucleosynthesis theory, and the constant Li abundance measured in metal-poor halo dwarf stars (the so-called *Spite plateau*). Several models are being proposed to explain this discrepancy, involving either new physics, in situ depletion, or the efficient depletion of Li in the pristine Galaxy by a generation of massive first stars. The realm of possibilities may be narrowed considerably by observing stellar populations in different galaxies, which have experienced different evolutionary histories.

Aims. The ω Centauri stellar system is commonly considered as the remnant of a dwarf galaxy accreted by the Milky Way. We investigate the lithium content of a conspicuous sample of unevolved stars in this object.

Methods. We obtained moderate resolution (R = 17 000) spectra for 91 main-sequence/early sub-giant branch (MS/SGB) ω Cen stars using the FLAMES-GIRAFFE/VLT spectrograph. Lithium abundances were derived by matching the equivalent width of the Li I resonance doublet at 6708 Å to the prediction of synthetic spectra computed with different Li abundances. Synthetic spectra were computed using the SYNTHE code along with ATLAS–9 model atmospheres. The stars effective temperatures are derived by fitting the wings of the H_α line with synthetic profiles.

Results. We obtain a mean content of $A(\mathrm{Li}) = 2.19 \pm 0.14$ dex for ω Centauri MS/SGB stars. This is comparable to what is observed in Galactic halo field stars of similar metallicities and temperatures.

Conclusions. The Spite plateau seems to be an ubiquitous feature of old, warm metal-poor stars. It exists also in external galaxies, if we accept the current view about the origin of ω Cen. This implies that the mechanism(s) that causes the "cosmological lithium problem" may be the same in the Milky Way and other galaxies.

Key words. nuclear reactions, nucleosynthesis, abundances – stars: abundances – stars: population II – cosmology: observations – globular clusters: individual: ω Cen – galaxies: abundances

1. Introduction

According to standard cosmology, light elements (^{2}H, ^{3}He, ^{4}He and ^{7}Li) were synthesized, starting from protons, during the initial hot and dense phase of the evolution of the Universe. The yields of this primordial nucleosynthesis depend on the baryon-to-photon ratio η, a cosmological parameter not constrained by first principles.

The remarkable constancy of the Li abundance, observed in warm, unevolved metal-poor stars of different effective temperature and metallicity – the so-called "Spite plateau" (Spite & Spite 1982a,b) has long been interpreted as a signature of big bang nucleosynthesis and a tool for measuring the baryonic density of the Universe (see Spite & Spite 2010; Steigman 2010).

However, the baryonic density η has been measured with unprecedented precision, from the fluctuations of the cosmic microwave background, by the WMAP satellite (Cyburt et al. 2008, hereafter C08). Coupled with the prediction of the standard big bang nucleosynthesis (SBBN) theory, this measurement implies a primordial Li abundance a factor of three to four higher than the Spite plateau. This discrepancy is often referred to as the "cosmological lithium problem".

Many solutions for this discrepancy have been proposed, including new physics at the time of the big bang (Jedamzik 2004, 2006; Jittoh et al. 2008; Hisano et al. 2009), astration in the pristine Galaxy (Piau et al. 2006, hereafter P06), and turbulent diffusion to deplete lithium in the stellar atmospheres (Richard et al. 2005).

A fresh look at the problem can be afforded by the study of lithium in metal-poor populations of external galaxies. Theories such as that of P06 can be immediately tested and also theories that invoke stellar phenomena can be constrained by the observation of systems that have experienced different star formation histories.

The ω Centauri stellar system is commonly considered as the remnant of a dwarf galaxy accreted by the Milky Way (e.g.,

⋆ Based on observations taken at ESO VLT Kueyen telescope (Cerro Paranal, Chile, program: 079.D-0021A).

⋆⋆ Tables 1 and 2 are only available in electronic form at http://www.aanda.org

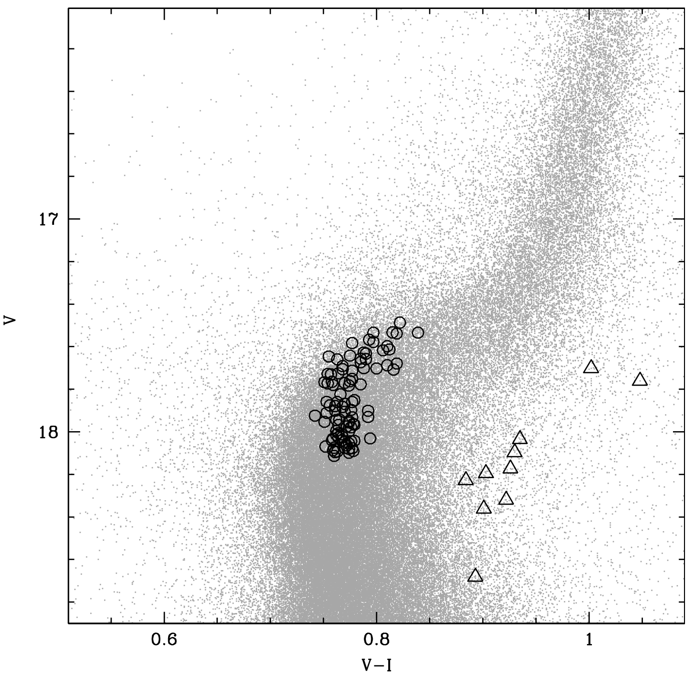

Fig. 1. Target stars are plotted on top of the ω Centauri V versus $V-I$ color–magnitude diagram. Open circles mark MS/SGB stars, open triangles SGB-a stars.

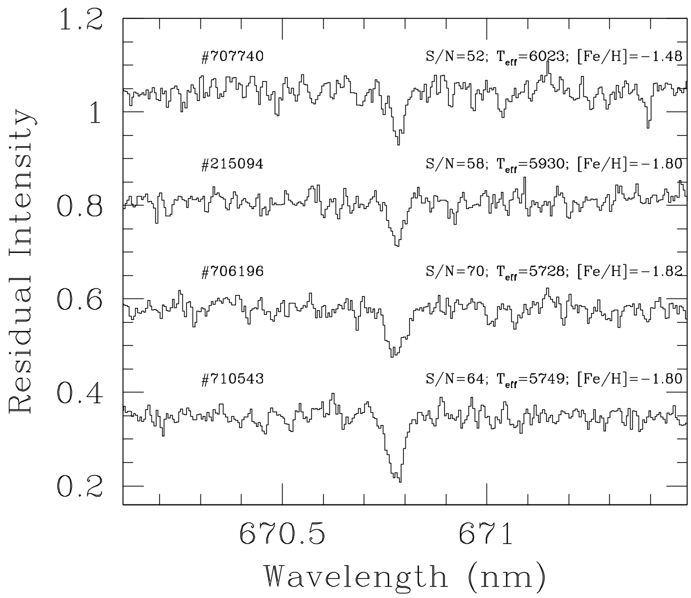

Fig. 2. Summed spectra for a subsample of stars with measured lithium abundances. The stellar $T_{\rm eff}$ and [Fe/H] in addition to the spectrum signal-to-noise ratio (S/N) are indicated.

Zinnecker et al. 1988; Freeman 1993; Carraro & Lia 2000). The complexity of its color–magnitude diagram (e.g. Lee et al. 1999; Pancino et al. 2000; Sollima et al. 2005a; Villanova et al. 2007) clearly testify the existence of multiple stellar populations, spanning a sizeable range in metallicities ($-0.6 <$ [Fe/H] < -2.1, Pancino et al. 2002; Sollima et al. 2005b; Villanova et al. 2007).

In this Letter, we present the first measurements of the lithium content in a conspicuous sample of main-sequence and early sub-giant branch (MS/SGB) stars in ω Cen.

2. Observations and data reduction

We selected targets at the turn-off and sub-giant branch level of ω Cen, mainly using the high precision FORS/VLT photometry of Sollima et al. (2005a, hereafter S05) and data from the spectroscopic survey of Villanova et al. (2007, hereafter V07). Ten targets were selected to trace the so-called SGB-a (S05). Target stars are shown in Fig. 1, superimposed on the wide field photometry of Bellini et al. (2009, hereafter B09). The MS targets selected from S05 cover a more central area. For these stars, we use in Fig. 1 the original S05 photometry corrected for the zero-point difference between B09 and S05 at the magnitude level of interest.

Observations were taken on three nights of 27–29 April 2007 using the FLAMES/VLT spectrograph at ESO Paranal. The fibers in Medusa mode fed the GIRAFFE spectrograph, configured in the HR15n setting, which covers both H_α and the Li I resonance doublet at 670.8 nm at a resolution of 17 000. The same plate configuration was observed for all three nights, with integration times between one hour and slightly over two hours. One additional plate configuration was observed, which has a partial overlap with the main plate configuration. We thus achieved a total integration time of between 17 and 19 h for most of our MS/SGB and SGB-a stars.

Frames were processed using version 2.13 of the FLAMES/GIRAFFE data reduction pipeline[1]. A total of 17 fibers were allocated for sky subtraction on each plate. The average of the sky fibers closer to each star was subtracted from the science spectra. The standard IRAF[2] task *fxcor* was employed to measure the star's radial velocities by cross-correlating the spectra with a synthetic one of similar atmospheric parameters. Correction to the heliocentric system were computed using the IRAF task *rvcorrect* and applied to the observed radial velocities. After being reduced to rest frames, multiple spectra of the same target were finally averaged. Typical errors of $\sim$1.2 km s^{-1} are derived from repeated measurements of the stellar radial velocity. We end-up with a total of 178 cluster members providing a mean cluster heliocentric velocity and dispersion of $v_\odot = 233.8$ km s^{-1} and $\sigma = 10.9$ km s^{-1}. These values are in good agreement with FLAMES-GIRAFFE/VLT measures presented by Pancino et al. (2007, hereafter P07, $v_\odot = 233.4$ km s^{-1}; $\sigma = 13.2$ km s^{-1}) for a sample of 649 ω Cen giants. Given the significant cluster rotation, a more detailed comparison should take into account the number of stars sampled in each cluster region.

In the following, we consider only stars with repeated observations. All of them (91 MS/SGB, 10 SGB-a) have radial velocities within 3σ of the cluster motion as derived above. After data reduction, we obtained averaged spectra for these stars with signal-to-noise ratios (S/N) in the range 30 to 90 with a mean around 60. Stars without repeated observations have a too low S/N, which make them unhelpful for the present analysis. Spectra for a subsample of stars with measured lithium abundance are presented in Fig. 2.

[1] http://girbldrs.sourceforge.net/

[2] IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

3. Abundance analysis

We derived stellar lithium abundances from the equivalent width (EW) of the Li I resonance doublet at ~6708 Å. The EWs were measured by fitting synthetic profiles, as done in Bonifacio et al. (2002). When we could not detect the Li line, we estimated an upper limit given by $2\sigma_{EW}$, where σ_{EW} was estimated using the Cayrel formula (Cayrel de Strobel & Spite 1988). Abundances were then derived by iteratively computing synthetic profiles until the EW of the Li doublet matched the measurements. For each star, synthetic spectra are calculated using the SYNTHE code along with an appropriate one-dimensional ATLAS-9 model atmosphere (Sbordone et al. 2004; Sbordone 2005; Kurucz 2005). The effective temperature of the stars was determined by fitting the wings of the H_α line. The theoretical profiles were computed with a modified version of the BALMER code[3], which uses the self-broadening theory of Barklem et al. (2000a,b) and the Stark broadening given by Stehle & King (1999). We assumed $\log g = 4.0$ and a metallicity of [Fe/H] = –1.5 for all stars, thus ignoring the dependence of the Balmer line profiles on both metallicity and surface gravity. A microturbulent velocity of 1 km s^{-1} was assumed. This, like the assumed surface gravity and metallicity, have effects of a few hundredths of dex on the derived Li abundance. This is totally negligible in the current context. Our S/N ratios are sufficiently high to ensure that the error in the Li abundances is totally dominated by the uncertainty in the effective temperatures. The latter is on the order of 150 K and is dominated by the uncertainty in the correction of the blaze function of GIRAFFE. Our estimated internal uncertainty in the Li abundance is 0.1 dex.

For none of the SGB-a stars did we detect the Li doublet. For these stars, we derived upper limits in the range $A(\mathrm{Li})$[4] <0.9–1.5 dex. Owing to their cool temperature ($T_{\mathrm{eff}} \leq 5650$ K), some level of lithium depletion is, however, actually expected for these stars. From a sample of 91 RGB/SGB stars, we could measure the Li abundance of 52, and for the remaining 39 we provide upper limits. The mean value was found to be $A(\mathrm{Li}) = 2.19$ with a dispersion of 0.14 dex. When we, instead, adopt effective temperatures based on the $V - I$ color (Alonso et al. 1996) the mean Li abundance and dispersion we obtain are identical to the above figures within the errors, i.e. $A(\mathrm{Li}) = 2.17 \pm 0.12$. We used a reddening of $E(B - V) = 0.11$ (Lub 2002).

The spectral region covered by our observations is not rich in metallic lines. Nevertheless we used the available Fe I and Ca I lines to estimate the metallicity of the stars, assuming [Ca/Fe] = +0.4. For the stars in common, we find a rather good agreement with the results of V07, although we obtain slightly lower metallicities on the order of ~0.1 dex. In the online material we report, coordinates, effective temperatures, [Fe/H], $A(\mathrm{Li})$, and the equivalent width of the Li line for the target stars.

4. Discussion and conclusions

We have either measured or derived upper limits to the Li abundances of 91 MS/SGB stars in the ω Cen stellar system. We have also estimated upper limits for 10 stars belonging to the so-called SGB-a.

Our results for MS/SGB stars are summarized in Fig. 3. The ω Cen stars lie on the Spite plateau, well below the value implied by the WMAP measurement coupled with the SBBN theory.

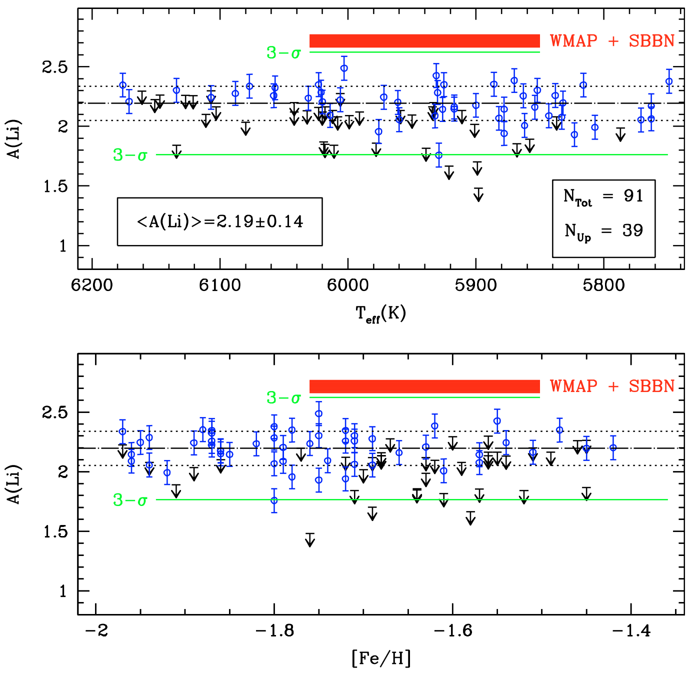

Fig. 3. Measured lithium abundances for targets on the main sequence/sub-giant branch as a function of the effective temperature (upper panel) and the star metallicity (*lower panel*). The mean Li abundance and dispersion derived for ω Cen, the number of stars analyzed (N_{Tot}), and the number of stars for which we derived upper limits (N_{Up}) are indicated in *the upper panel*. The mean Li abundance (dot-dashed line), the 1-σ (dotted lines), and 3-σ (continuous lines) levels from the mean and the primordial lithium level implied by WMAP measures plus SBBN theory (C8, shaded area) are also marked for reference.

Comparison with the Galactic field stars on the same effective temperature scale (Sbordone et al. 2010) shows that ω Cen stars occupy the same zone as the Galactic ones, in both the $A(\mathrm{Li})$–T_{eff} and the $A(\mathrm{Li})$–metallicity planes.

There are no obvious trends in Li abundance with temperature (upper panel) or metallicity (lower panel) and upper limits are not confined to any particular metallicity. The average lithium abundance of stars fainter than $V = 17.8$ (i.e., MS stars) is, however, slightly lower than that of brighter stars (i.e., early SGB stars) which are 0.06 dex richer: $A(\mathrm{Li})_{V<17.8} = 2.22 \pm 0.12$ (30 stars); $A(\mathrm{Li})_{V>17.8} = 2.16 \pm 0.17$ (22 stars). This is similar to what is observed in the globular cluster NGC 6397 and in the field (González Hernández et al. 2009; Charbonnel & Primas 2005) and may indicate a dependence of the Li content on the evolutionary state. The absence of stars with high Li abundances suggests that stars in our sample were not (significantly) polluted by lithium produced in asymptotic giant branch (AGB) stars by the Cameron & Fowler (1971) mechanism.

We have a large number of upper limits, but only 3 stars are at 3σ from the mean lithium abundance and 10 at 2σ. If ω Cen has a He-rich population (Norris 2004; Piotto et al. 2005), we can expect this population to be essentially Li-free, since at the high temperatures necessary for He production, Li is completely destroyed. Higher S/N observations are required to robustly assess the number of Li-depleted stars, yet it is clear that if these stars belong, indeed, to a He-rich population, then a Li-normal, and by inference also He-normal, population of the same metallicity, also exists. The Spite plateau of ω Cen appears indeed to be uniformly populated at all metallicities sampled in the present analysis.

[3] The original version provided by R.L. Kurucz is available at http://kurucz.harvard.edu/

[4] $A(\mathrm{Li}) = \log \frac{n(Li)}{n(H)} + 12.00$.

Globular clusters are known to display light elements abundance variations down to the turn-off (Carretta et al. 2009). In NGC 6752, 47 Tuc and perhaps NGC 6397, the Na-O anticorrelation is accompanied in MS by a Na-Li anticorrelation (Pasquini et al. 2005; Bonifacio et al. 2007; Lind et al. 2009). Some of the stars for which the Li line was not detected may indeed be Na-rich. On the other hand, the spread observed in the measured Li abundances is compatible with the analysis uncertainties.

Based on the hypothesis that ω Cen is the remnant of an accreted dwarf galaxy, we can conclude that:

- the Spite plateau also exists in other galaxies;
- the mechanism(s) causing the "cosmological lithium problem" is(are) the same in the Milky Way and other galaxies.

The second conclusion is the simplest and most reasonable scenario we may envisage at the present stage but it clearly requires confirmation by Li measurements in additional external galaxies.

Solutions to the "cosmological lithium problem" that propose a special evolution for the Milky Way halo are disfavored by our results. To reconcile the primordial value with the current observed Spite plateau level, the astration model (P06) requires one third to one half of the Galactic halo ($\sim 10^9 M_\odot$) to have been processed through a generation of massive stars that effectively depleted lithium. However, ω Cen has a different type, mass, and has likely experienced a different evolution from the Milky Way. A fine tuning of the mass fraction processed through massive stars would be required for this different galaxy to end up with Li abundances similar to those of Milky Way stars.

In contrast, models based on cosmological simulations predict the formation of the Milky Way halo by the assembly of a large number of sub-units (see, e.g., Bullock & Johnston 2005). The similar Li content of old metal-poor stars in the halo and in ω Cen may, indeed, favor the hierarchical merging paradigm. What fraction of the stellar population in the Galaxy halo could have been built-up by this mechanism is still, however, a matter of debate. The chemical composition of the oldest, most metal-poor stars in the Milky Way dwarf satellites indeed provides conflicting evidence in this respect (Monaco et al. 2007; Aoki et al. 2009; Frebel et al. 2010).

It has been suggested that ω Cen may be the remnant of the nucleus of a, now destroyed, dwarf galaxy that had hosted a globular cluster (GC) at its center (Bellazzini et al. 2008; Carretta et al. 2010). ω Cen would then be a system similar to the GC M 54 plus the nucleus (SgrN) of the Sagittarius dwarf spheroidal galaxy (Sgr dSph) at whose center it lies. In this scenario, part of the ω Cen stellar population would belong to the former galaxy, and the remaining part to the GC residing at the nucleus center. While we cannot clearly identify with either origin, both type of stars would, in any case, be of extra-galactic origin. As for M 54 (Monaco et al. 2005; Bellazzini et al. 2008), the position of ω Cen at the bottom of a galaxy potential well, strongly implies that the GC originates within the galaxy.

Our observations also have an impact on theories invoking stellar atmospheric phenomena, such as diffusion (Richard et al. 2005). It has been shown that diffusion alone is unable to simultaneously reproduce the level of depletion observed in field stars for Li, Be and B (Boesgaard et al. 1998). The inclusion of internal gravity wave, on the other hand, has proven successful in reproducing both the solar rotation profile and the lithium abundance vs. age trend observed in open clusters (Charbonnel & Talon 2005). Unfortunately, similar models are still lacking for populations II stars. Diffusion associated with turbulent mixing has been proposed as a likely solution to the cosmological lithium problem (Korn et al. 2006). Recent observations, however, cast serious doubts on this hypothesis (González Hernández et al. 2009).

These phenomena are time dependent. Since the age spread of the Galactic halo is very small, however, models cannot be constrained by the observations of halo dwarfs at the Spite plateau. The true age spread in ω Cen and within each of its subpopulations remains a matter of lively debate. Several studies (Hughes et al. 2004; Sollima et al. 2005b; Stanford et al. 2006) concluded that ω Cen enriched itself on a timescale <2–5 Gyr, with each subpopulation being essentially coeval within the uncertainties implied in the analysis (~1.5 Gyr, see, e.g., Sollima et al. 2005b). On the other hand, Johnson et al. (2009) presented evidence of different degrees of s-process enrichment among stars in the metal-poor population, which is the one sampled in the present analysis. This implies a time span of 0.1–3 Gyr (Schaller et al. 1992) for 1.5–3.0 $M_\odot$ AGB stars to pollute part of the metal-poor group, depending on the true mean mass of the AGB population. Further evidence comes from the relative ages derived from color–magnitude diagrams, combined with spectroscopic metallicities (V07), which infer an age range of ~6 Gyr over the whole ω Cen metallicity range. For the 35 stars in common with the present study, the age spread is 5.6 Gyr, of which 31 have an age spread of ~2.5 Gyr.

Coupled with our results, we can conclude that theories invoking time-dependent phenomena should prescribe a constancy of the lithium abundance (at the level of the observed dispersion, i.e. 0.14 dex) over a timescale comparable to the above ranges.

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Table 1. Basic data for MS/SGB stars studied in this paper.

ID	RA	Dec.	*EW*	ϵ (*EW*)	A(Li)	S/N	$T_{\rm eff}$(K)	[Fe/H]	ϵ ([Fe/H])
200876	13:26:36.82	–47:35:55.49	43.3	2.7	2.17	84	5763	–1.86	0.20
202055	13:26:50.23	–47:35:35.57	32.3	3.1	2.15	72	5917	–1.85	0.04
212980	13:26:45.74	–47:32:58.26	–	–	<1.86	67	5978	–1.64	0.17
213239	13:26:37.69	–47:32:55.16	54.2	6.8	2.42	33	5931	–1.55	0.40
215094	13:26:25.00	–47:32:29.91	41.4	3.9	2.28	58	5930	–1.80	0.24
215324	13:26:31.64	–47:32:26.92	–	–	<1.85	59	6018	–1.64	0.22
215862	13:26:44.65	–47:32:19.14	–	–	<1.48	69	5898	–1.76	0.11
216091	13:26:39.09	–47:32:16.33	–	–	<2.04	57	6080	–1.89	0.40
216284	13:26:58.90	–47:32:13.07	–	–	<2.13	55	5959	–1.56	0.13
216434	13:26:46.08	–47:32:11.40	–	–	<1.84	52	6134	–1.52	0.12
216941	13:26:40.28	–47:32:04.95	–	–	<2.29	67	6161	–1.60	0.22
217251	13:26:30.08	–47:32:00.75	28.0	3.8	2.09	59	5932	–1.79	0.18
217350	13:26:56.03	–47:31:58.72	–	–	<1.87	54	6019	–1.45	0.18
217836	13:26:54.36	–47:31:51.95	–	–	<1.85	54	5868	–1.57	0.15
218599	13:26:28.06	–47:31:42.16	–	–	<2.20	63	5933	–1.77	0.08
218941	13:26:39.40	–47:31:37.41	–	–	<2.26	54	6147	–1.45	0.22
219646	13:26:23.86	–47:31:28.38	37.6	5.0	2.34	45	6077	–1.97	0.39
219921	13:26:48.18	–47:31:24.39	13.9	3.5	1.76	64	5929	–1.80	0.38
220173	13:26:31.33	–47:31:21.29	32.2	4.5	2.30	49	6134	–1.71	0.27
220472	13:26:39.15	–47:31:17.16	26.4	4.2	2.01	53	5862	–1.61	0.13
220539	13:26:51.79	–47:31:16.01	31.9	3.6	2.08	63	5833	–1.57	0.11
220543	13:26:25.51	–47:31:16.60	–	–	<1.99	54	5787	–1.63	0.11
221047	13:27:01.15	–47:31:09.23	–	–	<2.23	64	6151	–1.97	0.19
221944	13:26:27.77	–47:30:57.94	31.1	5.0	2.20	45	6020	–1.79	0.05
224278	13:26:46.11	–47:30:25.83	–	–	<2.16	68	6018	–1.49	0.02
225188	13:26:30.13	–47:30:13.63	24.9	3.1	2.09	71	6014	–1.74	0.19
226046	13:27:05.23	–47:30:01.08	–	–	<2.09	65	5999	–	–
228016	13:26:25.53	–47:29:34.41	27.9	5.0	1.99	45	5807	–1.92	0.21
228199	13:26:26.89	–47:29:31.87	29.0	3.6	2.07	62	5882	–1.80	0.32
232117	13:26:24.07	–47:28:37.49	–	–	<2.02	52	5901	–1.70	0.17
232161	13:27:01.29	–47:28:35.98	–	–	<1.70	87	5899	–1.69	0.02
233415	13:27:08.78	–47:28:17.85	–	–	<2.10	72	5950	–1.62	0.34
234553	13:26:24.61	–47:28:03.58	–	–	<2.12	56	6020	–1.63	0.18
234927	13:26:26.85	–47:27:58.39	–	–	<2.08	68	5837	–1.94	0.28
238398	13:27:03.93	–47:27:09.94	–	–	<2.28	58	6006	–1.67	0.16
238851	13:26:58.42	–47:27:04.45	–	–	<2.12	63	6042	–1.72	0.02
240490	13:26:23.83	–47:26:42.34	–	–	<2.20	50	6042	–1.51	0.26
240604	13:26:25.92	–47:26:40.71	–	–	<2.13	53	5911	–1.68	0.19
241341	13:26:46.69	–47:26:29.98	–	–	<1.89	79	5858	–1.91	0.37
241861	13:26:22.08	–47:26:23.51	–	–	<2.10	59	6111	–1.86	0.00
242697	13:26:56.94	–47:26:11.44	33.8	3.8	2.20	59	5961	–1.42	0.23
242803	13:26:23.68	–47:26:10.98	25.2	4.2	2.21	54	6171	–1.63	0.28
244548	13:26:41.42	–47:25:47.46	22.3	3.6	1.94	62	5878	–1.72	0.24
245711	13:26:22.65	–47:25:31.92	–	–	<2.30	50	6107	–1.56	0.23
246815	13:27:08.72	–47:25:15.22	–	–	<2.08	47	6008	–1.59	0.16
246822	13:26:43.28	–47:25:16.07	–	–	<1.84	51	6011	–1.71	0.21
246899	13:26:57.38	–47:25:14.46	–	–	<2.26	59	6127	–1.46	0.28
246949	13:26:59.34	–47:25:13.73	33.3	4.4	2.35	51	6176	–1.72	0.21
247449	13:26:36.70	–47:25:07.74	–	–	<2.13	61	6012	–1.68	0.17
248411	13:26:51.38	–47:24:54.65	–	–	<1.82	58	5939	–1.61	0.14
248991	13:26:54.85	–47:24:46.72	–	–	<2.13	40	6032	–1.54	0.24
249154	13:26:56.74	–47:24:44.10	–	–	<2.16	58	6023	–1.68	0.28
249555	13:26:24.96	–47:24:39.03	31.6	4.9	2.14	46	5926	–1.57	0.13
249952	13:26:28.89	–47:24:33.44	–	–	<2.26	48	6121	–	–
250239	13:26:49.98	–47:24:28.90	45.2	3.5	2.26	65	5838	–1.71	0.17
250295	13:26:47.08	–47:24:28.29	23.9	3.3	1.93	68	5823	–1.75	0.14
250960	13:26:41.05	–47:24:19.16	–	–	<2.16	67	5934	–1.55	0.21
300010	13:25:42.83	–47:36:09.89	47.9	3.5	2.35	64	5925	–1.78	0.22
300098	13:25:52.22	–47:36:06.94	48.1	4.1	2.30	55	5852	–1.75	0.22
300147	13:25:47.93	–47:36:05.63	33.2	2.7	2.22	83	6006	–1.87	0.37
311493	13:25:45.82	–47:31:39.66	29.9	4.1	2.24	54	6107	–1.89	0.38
608199	13:26:39.18	–47:41:25.72	–	–	<2.12	45	5991	–1.69	0.15
608330	13:26:41.25	–47:41:21.00	40.7	4.4	2.20	51	5832	–1.45	0.16
608523	13:26:38.02	–47:41:13.32	36.7	3.3	2.29	68	6021	–1.94	0.20

Table 1. continued.

ID	RA	Dec.	EW	ϵ (EW)	A(Li)	S/N	$T_{\rm eff}$(K)	[Fe/H]	ϵ ([Fe/H])
610001	13:26:39.48	–47:40:20.13	32.9	3.5	2.28	65	6088	–1.69	0.26
610873	13:26:46.88	–47:39:51.34	36.4	3.8	2.24	59	5972	–1.54	0.15
611625	13:26:33.36	–47:39:29.26	54.7	3.3	2.38	68	5870	–1.62	0.17
612223	13:26:52.72	–47:39:11.66	33.5	4.5	2.16	49	5917	–1.51	0.31
612310	13:26:39.46	–47:39:09.45	50.5	3.2	2.35	71	5886	–1.88	0.10
612354	13:26:24.63	–47:39:08.21	34.7	4.2	2.06	53	5763	–1.71	0.28
613844	13:26:32.11	–47:38:29.44	55.1	3.5	2.35	65	5816	–1.87	0.24
614247	13:26:23.67	–47:38:19.62	35.3	3.6	2.18	62	5900	–1.86	0.30
614387	13:26:27.86	–47:38:16.08	19.8	3.7	1.96	61	5976	–1.78	0.16
614413	13:26:50.27	–47:38:15.14	32.8	3.2	2.24	69	6031	–1.76	0.21
614706	13:26:22.07	–47:38:08.14	36.7	4.1	2.16	54	5854	–1.66	0.20
615000	13:26:35.56	–47:38:01.05	32.9	4.1	2.26	55	6058	–1.72	0.37
615659	13:26:25.62	–47:37:46.49	–	–	<1.67	56	5921	–1.58	0.23
615841	13:26:31.83	–47:37:42.53	–	–	<2.16	63	6103	–1.56	0.20
617253	13:26:53.48	–47:37:12.63	52.2	3.7	2.25	61	5725	–1.95	0.27
617587	13:26:40.17	–47:37:06.10	37.7	3.3	2.32	68	6057	–1.87	0.21
619767	13:26:38.98	–47:36:24.68	43.6	3.5	2.25	63	5863	–1.87	0.13
706196	13:26:18.98	–47:41:06.91	50.9	3.2	2.23	70	5728	–1.82	0.24
707431	13:26:10.29	–47:39:57.26	36.5	3.6	2.06	62	5722	–1.69	0.13
707740	13:26:17.15	–47:39:41.58	41.3	4.3	2.35	52	6023	–1.48	0.12
709357	13:26:13.14	–47:38:31.22	33.6	3.6	2.05	63	5771	–	–
709669	13:26:01.52	–47:38:18.12	32.2	3.7	2.09	61	5843	–1.96	0.15
710011	13:26:11.96	–47:38:05.21	55.1	3.3	2.49	68	6003	–1.75	0.38
710543	13:25:58.10	–47:37:44.77	64.1	3.5	2.38	64	5749	–1.80	0.10
711304	13:26:19.02	–47:37:16.13	25.1	3.1	2.06	72	5960	–1.94	0.19
711572	13:25:55.45	–47:37:07.35	43.4	3.2	2.15	71	5732	–1.86	0.18
711606	13:26:03.26	–47:37:06.37	34.1	2.8	2.14	80	5878	–1.96	0.16

Notes. For each star, we report ID, coordinates, the Li line EWs and errors, and the lithium abundances. The spectra signal-to-noise, H_α-based effective temperatures, and the estimated [Fe/H] and its errors are also reported. For three stars, no [Fe/H] was estimated. These stars were not plotted in the bottom panel of Fig. 3.

Table 2. Basic data for SGB-a stars studied in this paper.

ID	RA	Dec.	A(Li)	S/N	$T_{\rm eff}$(K)
120117	13:27:15.18	–47:29:52.13	<1.50	38	5654
213295	13:26:42.67	–47:32:54.29	<1.42	32	5490
213952	13:26:23.23	–47:32:45.23	<1.23	45	5479
215700	13:26:30.16	–47:32:21.81	<1.33	44	5542
216031	13:26:27.23	–47:32:17.22	<1.00	33	5081
223861	13:26:22.04	–47:30:31.76	<1.36	51	5330
224921	13:27:08.47	–47:30:15.98	<1.39	37	5528
243327	13:26:32.84	–47:26:03.91	<0.92	46	5148
247798	13:26:31.46	–47:25:03.30	<1.30	44	5503
248814	13:27:05.20	–47:24:48.71	<1.28	43	5465

Notes. For each star, we report ID, coordinates, and the derived upper limits to the lithium abundances. The spectra signal-to-noise and the H_α-based effective temperatures are also reported. A metallicity of [Fe/H] = –1.5 was assumed.