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Lithium-rich giants in the Sagittarius dSph tidal streams

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Abstract.
The nature and origin of Lithium rich giant stars is still matter of debate. In the contest of our spectroscopic survey of giants in the tidal streams of the Sagittarius dwarf spheroidal (dSph) galaxy, we present the serendipitous discovery of 2 super Li-rich stars (A(Li)>3.5-4.0). Besides D461 in Draco, these are the only Li-rich stars known in a Local Group dSph galaxy. The high Li abundance and the low mass of these stars support their origin as due to fresh Li production in the stars associated with some kind of extra-mixing process.

Key words. Stars: abundances – Stars: atmospheres – Galaxies: individual: Sagittarius dSph

1. Introduction

Since the serendipitous discovery by McKellar (1940) that the giant star WZ Cas was anomalously rich in Lithium (see also McKellar 1941), the nature and origin of such Li-rich stars has been object of considerable interest. These stars are very rare, which can immediately be connected to the fact that the Li-rich status is experienced during a short-lived phase. Up to 1991 only 8 such stars were known (see Faraggiana et al. 1991, for a brief account of the literature prior to this date). Currently this number has risen to over 50, thanks to dedicated surveys (Smith et al. 1995). A few Li-rich giants are known in globular and open clusters (Kraft & Shetrone 2000; Hill & Pasquini 1999) and one such star has also been found in the Local Group dwarf spheroidal Draco (Domínguez et al. 2004).

As a star evolves off the Main Sequence up the Red Giant Branch (RGB), the convective envelope brings to the surface material which experienced temperatures in excess of 2×10^6K and was, therefore, depleted in Lithium. This mixing of unprocessed material with Li-depleted material is referred to as dilution. The dilution factor has been estimated to be 1.8 dex for a 3 $M_\odot$ star and 1.5 dex for a 1 $M_\odot$ star (Iben 1967a,b). Thus, assuming a star begins its life with A(Li)[1]=3.0, any giant with A(Li)> 1.5 should be considered as “Li rich”,

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[1] A(Li)=log(Li/H)+12

i.e. with a Li content above what expected by standard models. Typically 1-2% of giant stars is Li-rich (Charbonnel & Balachandran 2000) and just a handful of stars have Li abundances exceeding the meteoritic value.

The proposed explanations for the Li-rich phenomenon fall into three categories:

1. preservation: mixing is inhibited or less efficient and the dilution is lower than expected from standard models predictions;
2. planet or brown dwarf engulfment: the star has swallowed one or more planets or brown dwarfs, which are rich in Li, since none or little has been destroyed during their formation;
3. Li formation: fresh Li is produced through the Cameron-Fowler mechanism (Cameron & Fowler 1971).

A less efficient dilution process should preserve ^{9}Be and the ^{12}C/^{13}C ratio as well. On the contrary, ^{9}Be is strongly depleted in the sample observed by Castilho et al. (1999) and Melo et al. (2005). Li-rich giants also present low ^{12}C/^{13}C ratios (see Balachandran 2005, and references therein). Therefore, mixing seems at play in these stars.

On the other hand, an engulfment episode should enrich the star also in ^{9}Be, ^{6}Li and ^{11}B. We already noticed the low ^{9}Be abundances observed in Li-rich giants. Apparently, Li-rich giants are also devoided of ^{6}Li (see Balachandran 2005; Drake et al. 2002, and references therein).

Furthermore, the first two scenarios can hardly account for the existence of giants with Li abundances exceeding the meteoritic value (Siess & Livio 1999; Balachandran 2005). Therefore, Li production appears as the most likely cause for the observed Li abundances, although probably not all of the Li-rich stars share a common origin (Drake et al. 2002).

In the contest of our high resolution spectroscopic survey of stars in the tidal streams of the Sagittarius dwarf spheroidal galaxy (Sgr dSph), we present here the serendipitous discovery of two Li-rich giants.

2. Li-rich stars in the Sgr Streams

The Sagittarius dwarf spheroidal galaxy (Ibata, Gilmore, & Irwin 1994) is currently disrupting into the Milky Way. It presents a very significant core remnant (30° tidal radius), and its giant tidal streams indicate that the disruption process is still ongoing. Recently, Majewski et al. (2003, hereafter M03) traced the Sgr tidal streams all over the sky using 2MASS data. Using different high resolution facilities, we observed a sample of 2MASS selected giants belonging to the Sgr streams (Monaco et al. 2007, hereafter M07).

In particular, 46 stars belonging to the Sgr southern stream were observed with the UVES spectrograph mounted at the VLT (Paranal, Chile). Details of the observations are reported in M07. In Fig. 1 we present for these stars the measured radial velocity (in the galactic standard of rest, v_{gsr}) as a function of the Sgr longitude scale ($\Lambda_{\odot}$) along the orbital plane (see M03 for definitions and details). As can be seen, the Sgr southern stream is a very coherent and dynamically cold structure (σ=8.3±0.9kms^{-1}, see also Majewski et al. 2004). Therefore, we are quite confident that the observed stars were once part of the Sgr galaxy.

The five stars marked with solid symbols[2] in Fig. 1 present a clearly detectable Lithium resonance line (see Fig. 2). Stars #1016 and #1076, in particular, present a very strong absorption line. These two stars also show a strong Li-subordinate line at 6103.6Å (Fig. 3), while this line is completely absent in the remaining three stars.

3. Chemical abundances

We performed a preliminary chemical abundance analysis for stars #1016 and #1076. The adopted atmospheric parameters are reported in Table 1. Effective temperatures were derived from the 2MASS dereddened (J-K) infrared color, adopting the Alonso et al. (1999) calibrating relations. Putative distance for the program stars were derived assuming that Sgr stream stars follow the same

[2] Identification numbers refer to Table 1 in M07.

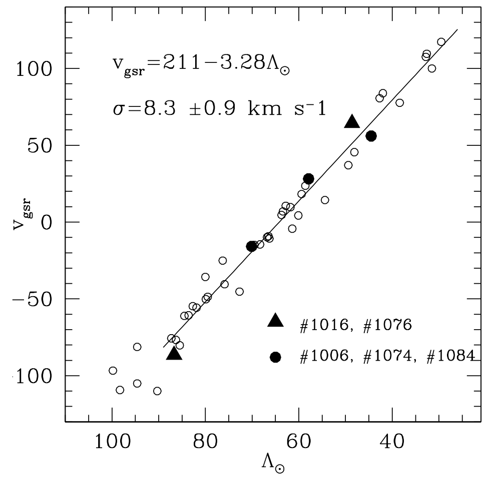

Fig. 1. Measured radial velocities as a function of the longitude of the Sgr orbital plane for the Sgr stream stars observed with UVES. Filled symbols mark stars presenting a clear Li resonance line.

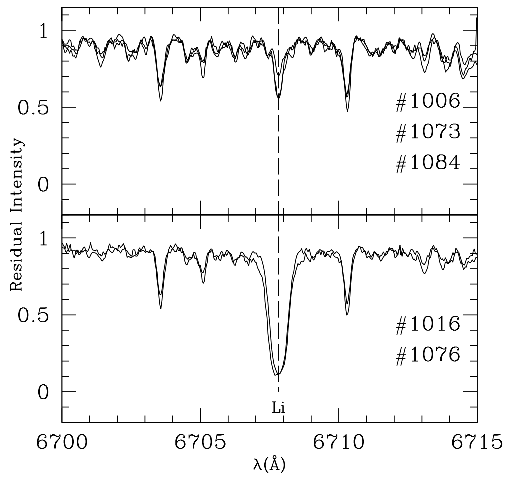

Fig. 2. Sample of the UVES spectra of the 5 stream stars presenting a clear Li resonance line.

color-magnitude relation as stars in the core of Sgr (see M07). After correcting for their distance and reddening, gravity was derived by comparison with theoretical isochrones (see M07 and Fig.4). ATLAS model atmospheres were calculated using the atmospheric parameters reported in Table 1 and the Opacity

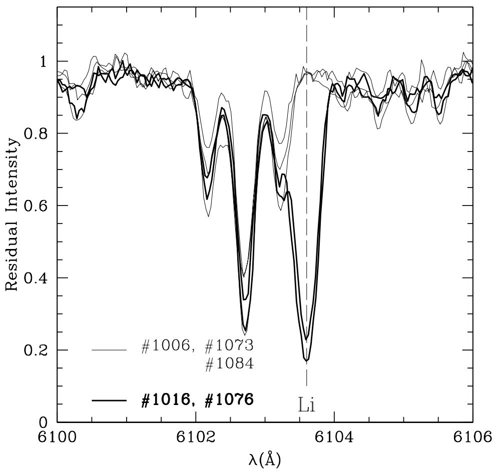

Fig. 3. Same as Fig. 2 but in the spectral region around the 6103.6Å Li subordinate line. Only #1016 and #1076 present a strong Li line.

Table 1. Atmospheric parameters adopted for stars #1016 and #1076

Star #	T_{eff}	log g	ξ
1016	3800	0.8	1.9
1076	3750	0.7	2.0

Distribution Functions of Castelli & Kurucz (2003) under the Local Thermodynamic Equilibrium (LTE) approximation. We measured equivalent widths (EWs) on the spectra for a selected sample of Fe I lines using the standard IRAF task *splot*. Iron abundances were derived from the measured EWs using the calculated model atmospheres within the WIDTH code. The GNU-Linux ported version (Sbordone, Bonifacio, Castelli, & Kurucz 2004) of both the WIDTH and ATLAS codes (Kurucz 1993) were employed. Microturbulent velocities (ξ) for each star were determined minimizing the dependence of the iron abundance from the EW.

Oxygen and Carbon abundances were obtained performing spectral synthesis of the 6300Å line and around the G-band spectral region (4300-4340Å), respectively.

Synthetic spectra were calculated adopting the ATLAS models described above and using the SINTHE code (Kurucz 1993; Sbordone, Bonifacio, Castelli, & Kurucz 2004). The final abundances were derived taking into account the coupling between C and O abundances (see Gratton & Sneden 1990).

Finally, Li abundances were derived by spectral synthesis of the resonance and subordinate lines, considering also the calculated values for the C and O abundances.

Table 2 reports the measured Fe, C, O and Li abundances.

4. Discussion

The abundances reported in Table 2 confirm that both #1016 and #1076 are Li-rich stars. Actually, the Li abundances derived from both the resonance and the subordinate lines are higher than the meteoritic value. Besides these two stars, only one Li-rich star is known in a Local Group dSph galaxy: the Carbon star D461 in Draco (C/O=3-5, Domínguez et al. 2004). On the other hand, #1016 and #1076 are O-rich stars, given the low measured C/O ratio (0.15-0.29). We also note that the measured [Fe/H] abundances are perfectly in line with the mean stream abundance measured by M07.

As already noted in §1, preservation of primordial Li or planet/brown dwarf engulfment can hardly account for the existence of super Li-rich giants (Balachandran 2005). Therefore, the super meteoritic Li abundance measured in #1016 and #1076 points toward a production of fresh Li in these stars.

We point out that the abundances reported in Table 2 were calculated under the LTE approximation. However, non-LTE approaches usually results in even higher Li abundances (de La Reza & da Silva 1995; Abia et al. 1999).

Li-production can happen through the Cameron and Fowler mechanism (Cameron & Fowler 1971). According to this model, ^{3}He in the convective envelope is converted to ^{7}Be. Then, ^{7}Be must be circulated to the star surface where it decays into ^{7}Li.

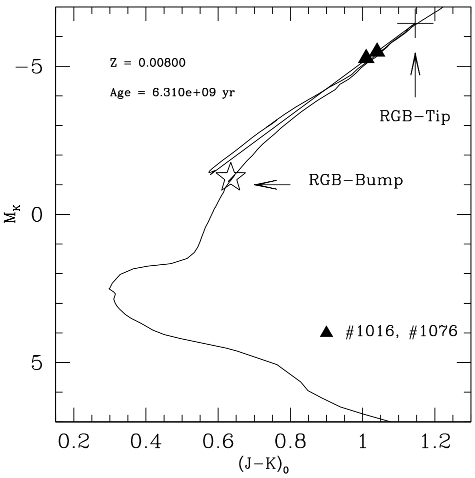

Fig. 4. The positions of stars #1016 and #1076 are marked in the infrared absolute color-magnitude diagram (triangles). Distance and reddening were adopted from Majewski et al. (2004). A isochrone matching the position of the two stars is plotted. The RGB-tip and RGB-bump positions along the isochrone are also labeled.

As can be seen from Fig. 4, #1016, #1076 are low mass star (M=1-1.5$M_{\odot}$) on the Red/Asymptotic Giant Branch close to the RGB tip. The adopted isochrone (Girardi et al. 2002) has age and metallicity compatible with current estimates of these parameters for the main Sgr stellar population (see Monaco et al. 2005; Bellazzini et al. 2006).

In such low mass stars, temperatures high enough for ^{3}He burning are reached in the vicinity of the hydrogen burning shell. Therefore, an extra-mixing process is required to circulate material from the convective envelope in and out of this region.

In summary, the high Li-abundance measured in our stars and their low masses suggest the production of fresh Li should have been coupled with some kind of rather extreme extra-mixing process in #1016 and #1076 (see also Sackmann & Boothroyd 1999; Uttenthaler et al. 2007).

Table 2. Chemical abundances measured in #1016 and #1076

Star #	[Fe/H]	$A(Li)_{@6707.8Å}$	$A(Li)_{@6103.3Å}$	C/O	[C/O]	[C/Fe]	[O/Fe]
1016	-0.78 ± 0.23	4.29 ± 0.01	4.20 ± 0.03	+0.29	−0.22	+0.09	+0.31
1076	-0.74 ± 0.27	3.58 ± 0.02	3.50 ± 0.03	+0.15	−0.50	−0.37	+0.13

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