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Lithium in the Galaxy: current status and contribution from the low-mass giants?

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Abstract. We discuss the evolution of Li in the Galaxy based on a large sample of dwarfs and giants collected from the cross-match of the Gaia and GALAH surveys. Data spans a wide range in metallicity and cover various Galactic evolutionary phases. Metal-poor dwarfs with [Fe/H] < -0.8 dex are found to have constant mean A(Li) = 2.2 dex with standard deviation of 0.14 dex but with a very slightly increasing trend with increase in metallicity. However, in the sub-solar metallicity range (-0.8 < [Fe/H] < 0 dex), Li has increased significantly from the initial value of about 2.2 dex to the present value of about 3.3 dex. However, in super-solar metallicity stars, Li is found to be decreasing with increasing metallicity. We also discuss briefly about a rare class of so called Li-rich low-mass giants as one of the promising candidate for Li enrichment in the Galaxy.

Key words. Surveys – Stars: abundances – Galaxy: evolution – Galaxy: abundances – Stars: evolution – Nucleosynthesis

1. Introduction

Li is one of the three primordial elements produced in the Big Bang Nucleosynthesis (BBN), apart from H and He. Standard BBN Models, in combination with input parameter value of baryonic density measured from space missions such as Wilkinson Microwave Anisotropy Probe (WMAP), predict primordial Li abundance of A(Li) = 2.72 ± 0.06 dex (Cyburt et al. 2008), about 3 times higher than the widely suggested primordial Li abundance based on observations of metal-poor dwarfs which is also known as Spite-Plateu, A(Li) = 2.27 ± 0.03 (Lind et al. 2009). The reason for the discrepancy between the observed and predicted primordial Li is not very clear. On the other hand, Li abundance measured in young stars, interstellar medium, and meteorites is A(Li) = 3.32 dex which is about 10 times higher than the Li found in metal poor dwarfs, and about 3 times higher than the value predicted by BBN models. This clearly suggests Li enrichment in the Galaxy from its initial value (Guiglion et al. 2016). Studies suggest various sources of Li contribution to the Galaxy: cosmic ray spallation in ISM (Mitler 1972), novae explosions (Tajitsu et al. 2015) and nucleosynthesis in evolved stars. Here, we briefly discuss Li contribution by stars.

In general, stars are known to be sinks for Li as Li burns at relatively low temperatures of about $2.5 \times 10^6 K$, and is sensitive to enhanced mixing during first dredge-up which leads to rapid dilution of Li in stars' outer envelopes as

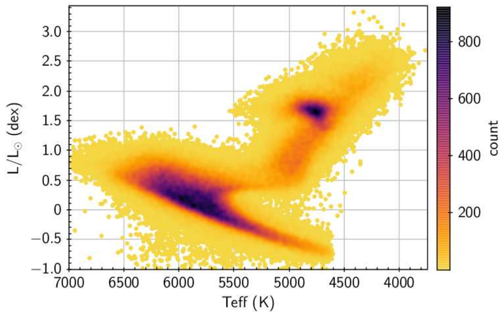

Fig. 1. Sample stars in the HR diagram.

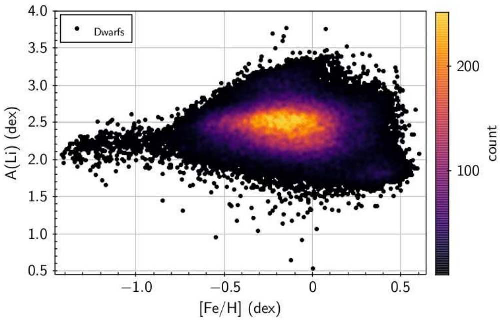

Fig. 2. Li versus [Fe/H] distribution for selected sample of low-mass dwarfs.

they evolve from the main sequence. However, in particular conditions, evolved stars such as red giant branch (RGB) stars are known to produce Li in their interiors via the Cameron-Fowler mechanism (Cameron & Fowler 1971). This has been observed in a small group of RGB stars which are known in the literature as Li-rich giants with A(Li) $\geq$ 1.5, an upper limit set by stellar models (Iben 1967). In sections 3.1 and 3.2 we discuss the evolution of Li in the Galaxy at different metallicity. In section 3.3 we discuss the contribution of low-mass evolved stars towards the Galactic Li enrichment.

2. Stellar sample

The stellar sample is collected from the cross-match of the second data release of Gaia astrometric and GALAH spectroscopic surveys (Gaia Collaboration et al. 2018; Buder et al. 2018). The sample is restricted to stars with $\sigma_{\mathrm{Teff}} \leq 150$ K and fractional error in parallax (π), $\sigma_\pi/\pi \leq 0.15$ along with best quality filter for the used stellar parameters from the GALAH survey i.e. $\mathrm{Flag}_{cannon} = 0$ for selected stars. Similar to Deepak & Reddy (2019), we restricted the sample to low-mass stars with $M \leq 2\mathrm{M}_\odot$. This entire sample of low-mass stars plotted in the luminosity versus temperature diagram (Figure 1) show a well defined main sequence (MS) and RGB. To study the evolution of Li in the Galaxy, we restrict our sample to MS dwarfs with Teff > 5500 K. Cooler dwarfs (with Teff < 5500 K) are rejected as their spectra is complex and derived abundances may be having large uncertainties. This resulted in a sample of about 60 000 stars. Further, to explore the probable contribution of low-mass stars to the Galactic Li enrichment, we use the sample of giants from Deepak & Reddy (2019).

3. Results and discussion

3.1. Li versus [Fe/H]

The distribution of Li versus [Fe/H] for the selected sample of dwarfs shown in Figure 2 outlines various phases of Li evolution in the Galaxy. This plot can be divided into three main evolutionary phases.

i) **[Fe/H]** < **-0.8 dex**: Dwarfs with this metallicity have constant mean Li of A(Li)= 2.20 dex with standard deviation of 0.14 dex. This mean value is slightly less (by about 0.1 dex) than the observed primordial Li abundance in the old metal-poor halo stars. The main reason for this difference is that the latter value is defined by the upper envelope of the distribution instead of the mean value. Another important point suggested by this sample of metal-poor stars is a slightly increasing trend in Li with increasing metallicity. This slightly increasing trend is understood to be because of Li addition due to cosmic ray spallation over time (Ryan et al. 2000). However, a possible contamination from the disk where the initial Li is found to be higher can not be neglected.

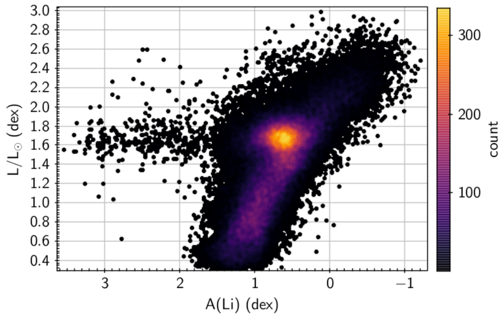

Fig. 3. Li as a function of luminosity for selected sample of low-mass giants.

ii) **-0.8 < [Fe/H] < 0 dex:** Li in dwarfs of this sub-solar disk metallicity range has increased significantly. The sharply increasing trend in the upper envelope of Li abundances with increasing metallicity suggest continuous enrichment of Li in the Galaxy over time.

iii) **[Fe/H] > 0 dex:** Dwarfs of super solar metallicity are showing a decreasing trend in Li. The reason for this lower Li is not known yet but two of the possible explanations are metallicity dependence of stellar evolution and the Galactic dynamic history. We comment more on this in the next section.

3.2. Lower Li at super-solar metallicity

It is thought that the lower Li in super-solar metallicity stars is related to the dynamical history of the Galaxy (Guiglion et al. 2019). These stars may have formed in the inner regions of the Galactic disk where [Fe/H] was higher but Li was still lower, and later migrated to their current position in solar neighbourhood. The majority of these stars are found to be older than 5 Gyr. To find evidences of the dynamical migration, we looked into kinematic properties (like, distribution in the Toomre diagram and orbital eccentricity) of these dwarfs relative to that of the dwarfs of solar metallicity, but found no significant difference. More studies are required to find an explanation for the lower Li in the super-solar metallicity dwarfs.

3.3. Contribution of low-mass giants to the Galactic Li-enrichment

The luminosity versus Li distribution (Figure 3) for the sample of giants collected by Deepak & Reddy (2019) shows the evolution of Li in giants. As star evolve from the main-sequence turn-off, Li depletes during the first dredge-up. However, as found in Deepak & Reddy (2019) and other previous studies, about one percent of giants are found to be Li-enriched. Most of these Li-enriched giants are found to be in red-clump or He-core-burning phase. These Li-enriched giants may contribute to the Galactic Li enrichment through mass loss during the asymptotic giant branch (AGB) phase. However, the newly enriched Li gets destroyed in about 2 Myr, which is much shorter than the time (∼100 Myr) a giant spends in the RC phase. Further studies are required to find the fraction of low-mass Li-enriched giants evolving to the AGB phase before the enriched Li in their atmosphere depletes. Some studies, for example Tomasko (1970); Cole & Deupree (1981) and references therein, suggest mass loss during the He-flash, in that case freshly created Li in the giants can be thrown out into the ISM and can contribute to the Galactic Li enrichment. However, more studies are needed to understand the mass loss process during the He-flash and quantify the amount of Li which can be added to the ISM through this process.

4. Conclusion

Based on the data from Gaia and GALAH surveys, we looked into the evolution of Li in the Galaxy over time. Metal-poor dwarfs with [Fe/H] < -0.8 dex have a mean A(Li) of 2.20 ± 0.14 dex, with a slightly increasing trend, which is understood to be because of Li addition due to the cosmic ray spallation over time. In the sub-solar metallicity range (-0.8 < [Fe/H] < 0 dex), Li has increased significantly from the initial value of about 2.2 dex to the present value of about 3.3 dex (Figure 2). Super-solar metallicity dwarfs, which are also found to be older than 5 Gyr, follows a decreasing trend in Li with increase in [Fe/H]. This decrease is thought to be because of metallicity dependent stellar evolution and the dynamical history of the Galaxy. However, we found no significant difference in kinematic properties of super-solar metallicity dwarfs compared to the dwarfs with solar metallicity. We further looked into the contribution of low-mass giants towards the Galactic Li enrichment. About one percent of low-mass giants in He-core-burning phase are found to be Li-enriched (see Deepak & Reddy 2019, and reference therin). These giants looks one of the promising source for the Galactic Li enrichment through mass loss either during He-flash or during fluctuations in AGB phase. However, further studies are needed to understand the mass loss process during the He-flash and find the fraction of low-mass Li-enriched giants evolving to the AGB phase before enriched Li in their atmosphere depletes.

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