1. Title

Constraining the formation of Li-rich Red Giants stars using abundances and radial velocities

2. Abstract

During the Red Giant Branch stage in the stellar evolution, Lithium is expected to be reduced in the interior of stars. However, there is a very small fraction of Lithium-rich stars with surface abundances A(Li)>1.5. In order to constrain how these objects are formed, very high-quality spectra are needed to obtain an accurate Lithium abundance. We propose to use the UVES spectrograph to obtain high-resolution spectra in 16 Red giants that do not have accurate measurements in Lithium from the GALAH survey, and that also are expected to have upper limit abundances of A(Li)∼1.5-2. Moreover, having new spectra will allow us to measure new radial velocities from these objects, which could be compared with other epochs to determine if some of these objects are a product of binary evolution.

3. Run Period Instrument Time Month Moon Seeing Sky Mode Type

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	111A	UVES	7.2h	any	n	1.0	THN	s	

4. N/A

5. Special Remarks

6. Principal Investigator Matias Castro-Tapia

7. Description of the proposed programme

A – Scientific Rationale:

Lithium-rich Red Giants: Lithium is the heaviest element which is expected to be formed after a few minutes of the Big Bang. One of the primordial values expected is about A(Li)∼2.7 from baryon densities estimated in modern experiments, such as the Planck Collaboration et al. (2016). On the other hand, in stellar interiors, due to nucleosynthesis and mixing processes, Lithium is expected to be depleted to very low values. During the Main Sequence, this element is destroyed quickly by proton capture in high temperatures zones, even if more Lithium is formed in the second proton-proton branch of the reaction chain via the Cameron-Fowler mechanism (Cameron & Fowler, 1971). Then, during the Red Giant Branch stage when a stellar envelope expands and the Hydrogen burning starts in a shell surrounding the core, the Lithium abundance on the surface decreases because of the quick growth of the convective zone (envelope), which allows the mixing of the products of the Main Sequence Hydrogen burning with the envelope. Although most Red Giants stars show values that are mainly described by this depletion in Lithium, there is a small percentage of denominated Li-rich giants that have abundances of A(Li)>1.5, being 1.5 a classical threshold for an upper limit of what is expected to see after the Li-depletion on the Red Giant Branch (e.g. Charbonnel et al., 2020; Martell et al., 2021).

Despite, in standard stellar evolution, convection is the only mechanism that describes the mixing in stellar interiors, some extra-mixing effects such as rotation and compositional instabilities have shown that red giants experiment even more depletion, this has been successfully applied to field stars and stellar clusters (e.g. Charbonnel & Lagarde, 2010; Magrini et al., 2021). Then, the formation of Li-rich giants remains without a clear explanation, even more, when some observations have reported the denominated Super Li-rich giants that have values of A(Li)>2.7. Some of the theories that have been proposed for the formation of Li-rich giants are the engulfment of a planet during the expansion of the host star when the RGB occurs (Aguilera-Gómez et al., 2016a,b) and the consequences of a binary system evolution where mass transfer could occur (Sackmann & Boothroyd, 1999) or the tidal effects can spin-up the rotation in the red giant allowing an even larger growth of the convective envelope and the internal fluid to rapidly transport the Lithium formed in the Hydrogen burning shell by the Cameron-Fowler mechanism throughout the stellar interior, i.e., the convective envelope and the Hydrogen burning zone are directly interacting and are almost overlapping (Casey et al., 2019).

Constraining the evolution of Li-Rich giants: Casey et al. (2019) have proposed a theoretical description of what should be expected for Li-rich giants based on the lifetime of the Lithium before being depleted by proton capture, the possible Lithium enhancement process, and the evolution stage of the star. They estimated that more than 80% of the Li-rich should be in binary systems where the tidal effects are producing anomalies in the lithium abundance. However, some studies have suggested that this should not be expected, Jorissen et al. (2020) followed up 11 Li-rich red giants by nine years and found that only 4 of them are likely in binary systems, and when comparing with a sample of about 200 giants the fraction of binaries seems to be the same for both samples. Moreover, Castro-Tapia et al. (in prep.) developed a method to identify variability in radial velocity using 3 epochs and made a cross-match to compare radial velocities of the Red Giants that are in GALAH DR3 survey (Martell et al., 2021), RAVE DR6, and Gaia DR3 simultaneously to classify which of them present high variability in radial velocities. Then, as GALAH DR3 has Lithium abundances reported, they were able to describe the relationship between the variability in radial velocities and the lithium abundances for about 1418 red giants, where 181 of them were Li-rich giants, and concluded that there is not a causal relation between a high variability in radial velocity and a high lithium abundance. However, binary evolution for the formation of Li-rich giants is not discarded and more work is required to properly constrain the evolution of this particular objects. As only a small fraction of red giants are Li-rich, the best way to develop a complete theory regarding their formation is studying them one by one.

B - Immediate Objective: Red giants from GALAH DR3 used by Castro-Tapia et al. (in prep.) were restricted to not have lithium abundances reported as upper limits to analyze the relation between Li abundance and radial velocity variation, this because, having accurate estimations on the parameters of these giants is crucial to understand how they were formed. The HERMES spectrograph used in the GALAH survey allows to have a spectral resolution of about $R = \lambda/\Delta\lambda \sim 28000$ with typical signal-to-noise values of S/N$\sim$ 50 (Buder et al., 2021), also the Lithium absorption line of 6708 Å is sensitive to different stellar parameters as high T_{eff} (Martell et al., 2021). Therefore, we propose to obtain the spectra of the Li-rich targets that were discarded by Castro-Tapia et al. (in prep.) with a higher signal-to-noise and resolution in order to have a more accurate estimation of their lithium abundances. UVES spectrograph in the VLT of ESO at Cerro Paranal, Atacama Desert, Chile; manages to operate for wavelengths from 3000 Å to 11000 Å through two arms, one for UV to Blue and the second for Visual to Red wavelengths with a maximum resolution of 80000 and 110000 respectively, then, we propose to use them to observe our targets with a resolution of $R \sim 60000$ and S/N$\sim$ 100.

These new observations will allow us to give more completeness to the mentioned study and to confirm if the targets are Li-rich giants or not. The left panel of Figure 1 shows the upper limit in A(Li) reported in GALAH vs T_{eff} for our targets, we must point out that all of them are in a very tight range of lithium abundance of about A(Li)$\sim$1.5-2, then, obtaining more accurate measurements on their abundances is needed to establish if they should be considered as Li-rich giants. The right panel of Figure 1 shows the T_{eff} distribution of all the giants in the GALAH-RAVE-Gaia cross-match made by Castro-Tapia et al. (in prep.), our proposed targets are in a range of high T_{eff}, which is at more than 1σ from the mean T_{eff} in this total sample. Then, a larger S/N than the typical GALAH value is needed to obtain a significant line of 6708 Å. Moreover, we included a scale of colors in the left panel of Figure 1, which indicates the type of variability on radial velocity obtained with the classification of Castro-Tapia et al. (in prep.), where 5a-5b indicates high variability in radial velocity, 3-4 are for medium variability, and 2-1 are for low variability. Having new spectra for these targets will allow us to obtain new radial velocities at recent epochs using the Doppler shift in the lines when compared to static templates of spectra using the cross-correlation between them. Therefore, we could confirm if these new radial velocities can confirm the degree of variability estimated in Castro-Tapia et al. (in prep.).

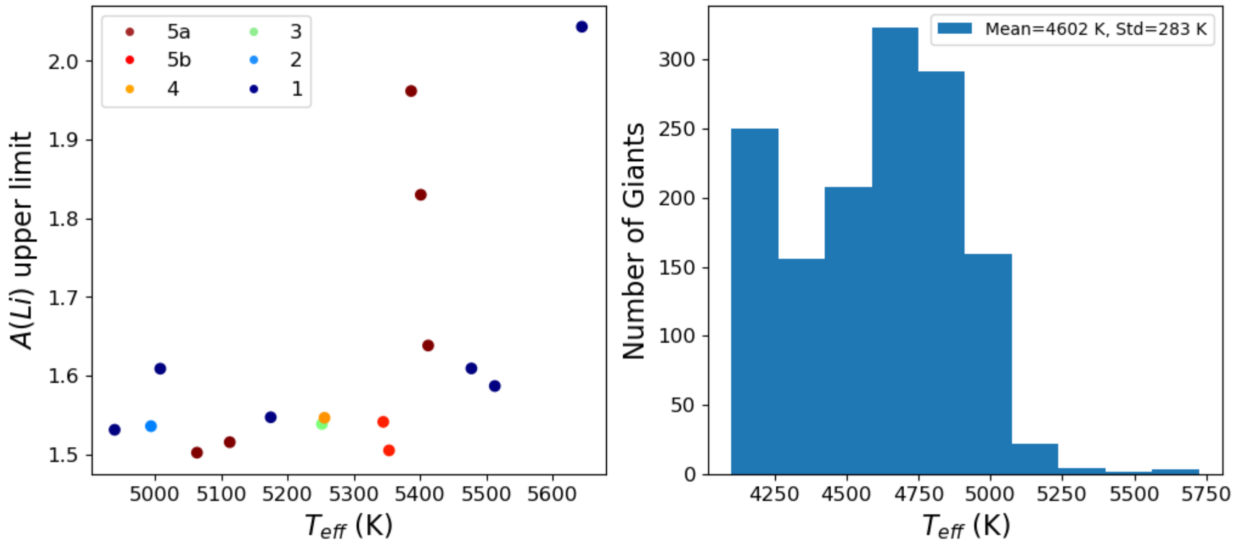

Figure 1: Left panel: A(Li) upper limit-T_{eff} distribution from GALAH survey for the proposed targets. The scale of colors indicates the grade of variability in radial velocity, being 1 for the lowest variability and 5 for the highest variability. Right panel: T_{eff} distribution of all giants from Castro-Tapia et al. (in prep.).

8. Justification of requested observing time and observing conditions

Lunar Phase Justification: We do not require any specific lunar phase.

Time Justification: This proposal is focused on obtaining spectra for Li-rich giants candidates that have poor quality on previous lithium abundances measurements, and whose upper limits are very near the minimum value for being considered as Li-rich. In order to obtain a significant line of lithium we request an S/N larger than the typical values of the GALAH survey, we proposed a S/N$\sim$ 100. Furthermore, to obtain accurate estimations on the lithium abundances we also proposed a higher resolution than what is expected in GALAH, the value we consider as optimal is R$\sim$ 60000 because it allows obtaining small errors in measurements of Li equivalent width of about 3 mÅ. We suggest obtaining spectra using the UVES spectrograph in the VLT. Although we are able to obtain a maximum resolution of $\sim$ 110000 with the Red Arm of UVES, the resolution for this instrument just could be increased by choosing a very narrow slit, which also implies a very long time of observation per target.

To achieve the resolution required we need a slit width of 0.7". We used UVES Exposure Time Calculator version P109 to estimate the time required per target for having the required S/N. The parameters used for computing the times were seeing of 1.0 arcsec, a fraction of lunar illumination (FLI) of 0.5, an airmass of 2, CCD binning 1x1, and standard template Dic2, Red arm, CD4, which has a range of wavelengths of 6000-8000Å. The total time required without overheads is 4.5 hrs. Considering 10 minutes extra per target due to overhead time, i.e., including telescope pointing, target acquisition, instrument setup, and read-out time, the total time required is 7.2 hrs. For the faintest source of magnitude V=13.3 the time estimated is 41 minutes, and for the brightest of magnitude V=10.5, the time is 13 minutes.

8a Telescope Justification: UVES is the only facility in the ESO that can provide us with the required signal-to-noise and resolution for the Lithium line of 6708 Å with a required time per target of less than 1 hr in the range of magnitudes $\sim$10-13.

8b. Observing Mode Justification (visitor or service): Service mode is efficient enough for our proposed targets because we require a standard setting and the observations are straightforward.

8c. Calibration Request: Standard Calibration.

9.Report on the use of ESO facilities during the last 2 years: None.

9a. ESO Archive - Are the data requested by this proposal in the ESO Archive (`http://archive.eso.org`)? If so, explain the need for new data. No spectra are found for our target stars in the ESO Archive covering the wavelength range of the Li line.

9b. GTO/Public Survey Duplications: None.

10. Applicant's publications related to the subject of this application during the last 2 years: None.

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT (hrs.)	Mag.	Diam.	Add. info	Ref. star
A	GaiaDR3 6359046634778502144	21 57 24.41	-72 50 12.6	0.47	12.6			
A	GaiaDR3 6312749837968219648	15 02 40.31	-11 53 55.0	0.68	13.3			
A	GaiaDR3 6295488093823705344	13 51 36.34	-16 44 26.2	0.50	12.7			
A	GaiaDR3 6434864146268003584	18 55 18.44	-66 14 30.3	0.68	13.3			
A	GaiaDR3 2893870280245214720	06 30 16.84	-31 36 59.9	0.45	12.3			
A	GaiaDR3 5796440725425239936	14 18 36.20	-74 12 03.7	0.33	11.7			
A	GaiaDR3 5232130435604381696	10 32 04.21	-70 19 05.2	0.30	11.5			
A	GaiaDR3 5229770505692349568	10 40 50.17	-71 34 48.9	0.30	11.6			
A	GaiaDR3 4666202003955809024	03 58 14.64	-70 09 05.7	0.35	12.1			
A	GaiaDR3 5721409605262828160	08 17 53.55	-16 03 38.1	0.22	10.5			
A	GaiaDR3 5415415381818758784	10 07 16.19	-42 58 28.1	0.28	11.3			
A	GaiaDR3 6252325115615921024	15 21 12.48	-21 57 41.6	0.67	13.0			
A	GaiaDR3 6590338663847178880	21 27 25.50	-35 17 28.1	0.67	13.1			
A	GaiaDR3 5232090818824653952	10 34 08.24	-70 14 41.6	0.27	11.2			
A	GaiaDR3 5118164303027601024	02 10 29.36	-25 41 50.7	0.58	12.7			
A	GaiaDR3 5791299305976294912	13 55 21.58	-73 56 23.6	0.42	12.0			

12. Scheduling requirements: None.

13. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
111	UVES	A	Dic-2	Standard setting: 437+760, slit width 0.7 arcsec, CCD binning 1x1

References

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