Mem. S.A.It. Vol. 91, 63

Memorie della

On the super lithium rich giant star phenomena

R. de la Reza

Observatorio Nacional - MCTI, General Jose Cristino 77, 20921-400 Rio de Janeiro, Brazil
e-mail: ramirodelareza@yahoo.com

Abstract. Since 1982 when the first K giant star rich in Li was discovered, the mechanism of enrichment of this element has continued to be a puzzle. Even if the presence of Li in giant stars is not supported by the standard theory of stellar evolution some thousands of Li rich giants have been detected recently. They represent however, only one percent of the normal K giants. We present here a new vision to tackle this mystery by adopting a non standard approach using on the one hand the new results of the aster-seismology and on the other hand, using the Li enrichment - stellar mass loss connection. Our results indicate that probably a rapid short lived instability related to the transfer of angular momentum inside the star is responsible for the ^{7}Li enrichment in the stellar surface. We show that this same mechanism, which is based on the internal nuclear burning of 3He, acts in the RGB–CLUMP stages of the giant star evolution.The lifetime of the fresh new ^{7}Li is short with episodes lasting less than 10^{5} yrs.

Key words. Stars: abundances – Stars: atmospheres–Stars: interiors – Stars: evolution

1. Introduction

The normal K-type giant stars, with low masses between 1.0M⊙ and 1.5M⊙, are in general Li poor objects in agreement with the standard theory of stellar evolution. Nevertheless, recent very large surveys involving some hundred of thousands of normal K giants have detected some thousands of Li rich and superrich K giant stars but always in the same proportion of one percent of Li rich objects. The physical reason for this Li enrichment remains a mistery until today. Since the discovery of the first Li K giant star, a large literature have existed trying to explain this puzzle. They consider two very different mechanisms, a stellar internal-one based on the known ^{7}Be decay and an external one involving the engulfing of planets enriching the star with the planetary isotopes;^{6}Li, ^{7}Li, ^{9}Be and ^{11}B. A hybrid type mechanism has been recently proposed without however an observational support where Li K giants are peculiar binary systems (Casey et al. 2019).

Here, we will consider only the internal mechanism specially motivated by our non detection of ^{11}B in some Li rich giant stars (Drake et al. 2019). In fact, the absence of ^{11}B is the most powerful test against the planetary engulfing mechanism. This is due to the fact that ^{11}B is the most resistant of the listed isotopes to burn in internal stellar layers. In short, the lithium phenomena is a rare one and already invokes an episodical nature with a short lifetime. Our approach to this problem is a non standard one and we use two main different aspects:

a) the use of the recent results on low mass giant stars in astero-seismology

b) the Lithium enrichment – stellar mass loss connection.

2. The upward mixing velocity problem

Without doubt one important key to decipher the Li enrichment mystery rests on the velocity of the upward transport of ^{7}Be to the stellar surface in order to be converted into fresh new ^{7}Li by means of ^{7}Be(e-,v)^{7}Li. In these giant stars this transport covers the distances between the upper layers of the H-burning zone and the external convecting zone. An important rapidity of this transport is necessary in order to avoid nuclear destructions of ^{7}Be and of the proper ^{7}Li. Of course, if we consider the very low upward nuclear combustion speed of 10^{-3} cm/s any fresh ^{7}Li will survive and additional high speed upward mixing is necessary.

Sackmann et al. (1999) explored numerically the nuclear conditions necessary to obtain very high fresh Li surface abundances. They used an artificial conveyor belt transporting material going up and down between these two zones using different mixing rates of stellar material and specific geometries. This mechanism is known as the Cool Bottom Process (CBP). Recently, Yan et al. (2018) have revive this mechanism to study their detected largest known rich Li K giant star with an extremely high Li abundance of A(Li) = 4.51.

Another approach to look for this non-convective mixing, this time using only physical (and not parametrical) arguments, was done by Eggleton et al. (2008) using a 3D model. Here, the conditions of the luminosity BUMP at the top of the H-burning zone are realised using the unique nuclear reaction ^{3}He(^{3}He, 2p) ^{4}He, capable of producing a molecular inversion. This mixing supposedly destroys a large part of the available ^{3}He However, the obtained upward speeds are of the order of 1 - 2 m/sec which continue to be much slower in order to produce a surface ^{7}Li enrichment. They can nevertheless, produce a reasonable enrichment of ^{13}C after a much larger period of time and reduce the ^{12}C/^{13}C ratio. For the moment, we can say that the completely different speeds, necessary to enrich ^{7}Li and ^{13}C respectively, can be one of the main reasons why these two elements are disconnected.

3. The introduction of asteroseismology

Here, we propose a new potential source for the mixing mechanism based on the transport of angular momentum (AM) from the core of the star to its atmosphere (de la Reza et al. 2015). For this, we invoke the recent asteroseismic observations putting in evidence that the stellar core rotations of low-mass giants in the RGB and CLUMP phases are $\sim$ 100 times slower than those predicted by the standard evolution theory (see the review of Aerts et al. (2019). These slower stellar core rotations, which are however, 10 times larger than the stellar surface rotations, imply the existence of an efficient transfer of AM from the core to the surface. However the source of the operating AM transport is for the moment unidentified. Even if is not yet clear how this transfer is realised, we can at least consider that the total momentum J is conserved between the core and the surface. This momentum is finally lost at the stellar surface by means of an important mass loss.

4. The lithium enrichment-mass loss connection

In the nineties we discovered several Li K giants being associated to IRAS sources. We constructed a model connecting these IR sources as being circumstellar shells ejected by these stars when they were recently enriched by new ^{7}Li . This initial ejection lasts $\sim$ 1000 yrs. The emerging of the shells is measured in the NIR up to $\sim$ 25 μm (de la Reza et al. 1996, 1997)(see also Rebull et al. (2015) for a revision of these sources). Later, the ejected shells are far from the star and they are detected at 60 μm. These ejections made a loop in a color-color diagram. The loop is closed after $\sim$ 10^{5} yrs when the ejected shells finally disappear. We then consider that the enrichment episodes have lifetimes shorter than or equal to 10^{5} yrs. These stages are characterised by strong winds with mass losses of the order

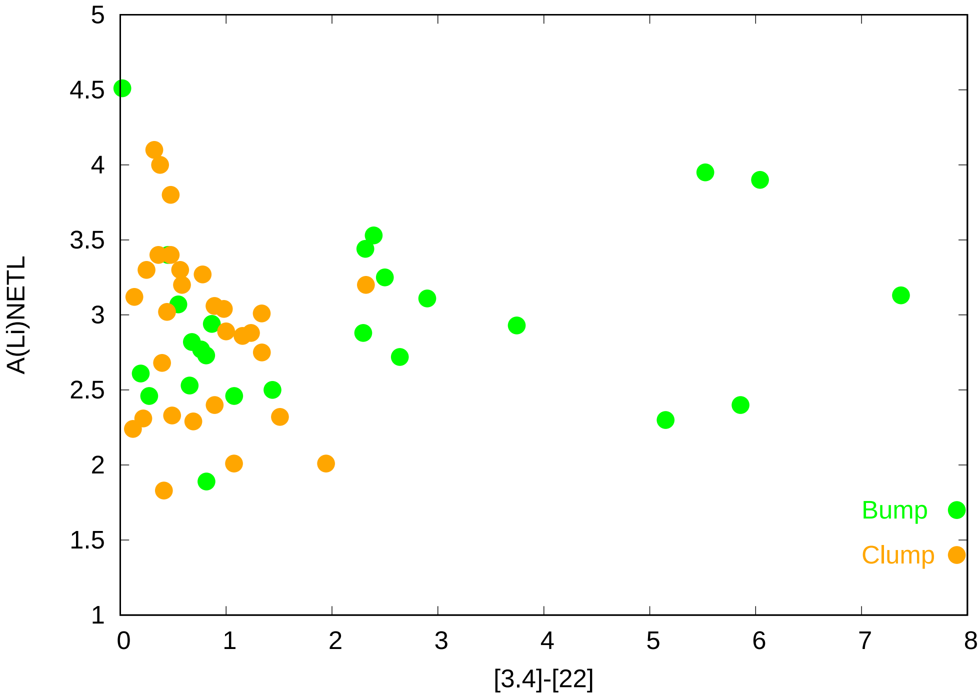

Fig. 1. Comparison of the NLTE Li abundances (vertical axis) with the NIR excesses measured by WISE of Li rich giant stars at the RGB BUMP and at the CLUMP (horizontal axis).

of 10^{-7} to 10^{-8} M⊙/yr. Their NIR spectra are characterise by a strong continuum emission. It is interesting to note that these strong wind types provoke the formation of complex carbonic organic and inorganic particles which are identified by emissions peak lines superposed to the mentioned emission continuum. The carbon material necessary to form these particles is obtained by partial destruction (by means of dragging by these strong winds) of the debris disks of these stars which remained when these same stars were dwarf A-type stars in the MS phase (de la Reza et al. 2015). Examples of organic are Aromatic and Aliphatic complex material. Examples of inorganic are Forsterite, Enstatite, Silica etc. Keeping in mind this wind model, we observed near 500 Li rich K giants by means of the WISE observatory in all wavelengths between 3.4 and 22 μm. In this way, we characterise the emerging shells after their sudden fresh ^{7}Li enrichment in the RGB and CLUMP phases. We found that nearly 10 per cent of these 500 Li rich K giants have excesses in the NIR measured by WISE. In Fig. 1 the measured NIR excesses representing the ejected shells are presented. It is shown that these shells ejections are much more energetic in the RGB BUMP stage than in the CLUMP stage. We speculate here that a strong and rapid instability related to the AM transport could be the origin of an important burning of ^{3}He, forming ^{7}Be and ^{7}Li. At the same time this sudden mixing episode could also transport the formed ^{7}Be and ^{7}Li to the stellar surface. Recent studies are beginning to explore different types of internal magnetic instabilities as the Tayler instability as the most promising for the AM transport (Fuller et al. 2019; Aerts et al. 2019).

The following three reactions would be acting mainly in the H-burning zone: ^{3}He(^{3}He,2p) ^{4}He; ^{3}He(^{4}He, γ)^{7}Be; ^{7}Be(e-,v) ^{7}Li. We can then have the following situation: The first two reactions are in some way in competition, but it is expected that ^{7} Li will be finally formed. In any case, this instability is supposed to furnish the energy for the upward final fast transport of ^{7}Be and ^{7}Li to the stellar surface. The same mechanism is expected to act at the CLUMP. However, this one is less energetic because the reservoir of ^{3}He will be lower at this stage. We can conclude that our positive detections of NIR excesses at these two stages indicate that Li enrichments occur in these two phases. Also probably in both cases, impulsed by the same general mechanism provoked by the transfer of AM as mentioned before.

5. Some conclusions

Li K giants are $\sim$ 1 percent of normal K giants. We consider here that the Li phenomena have a short duration with episodes lasting shorter than or equal to 10^5 yrs. We propose that a short lived instability produced during the AM transport inside the star, could be related to the ^{7}Li enrichment mechanism in both, BUMP and CLUMP stellar stages. We speculate that this fast formed instability could be related to an important burning of ^{3}He material in the H-burning zone. This sudden mixing episode could transport ^{7}Be to be transformed into ^{7}Li in the stellar surface. If the surface ^{7}Li enrichment is related to stellar mass losses, our observations of emerging shells in the NIR show that the effect is more energetic at the initial RGB BUMP stage. Here, very strong mass losses appear capable of partially destroying the reminiscent debris disks, furnishing carbon material to originate the observed organic and inorganic particles. Also, our observations of the NIR excesses at both BUMP and CLUMP stages indicate the action of similar processes. However, they show that at the CLUMP they are less energetic. This, because at this stage less ^{3}He,is available. The Li rich puzzle has not yet been solved because this sporadic and fast instability has to be found. But in any case, we believe that this could be a new avenue that deserves further investigation.

Acknowledgements. I am grateful to Carolina Chavero for her assistance to prepare the manuscript.

References

Aerts, C., Mathis, S., & Jermyn, A. 2019, ARA&A, 57, 35
Casey, A.R., Ho, A.Y.Q., Ness, M., et al. 2019, ApJ, 880, 125
de la Reza, R., Drake, N.A., da Silva, L. 1996, ApJ, 456, 115
de la Reza, R., et al. 1997, ApJ, 482, 77
de la Reza, R., et al. 2015, ApJ, 806, 86
Drake, N., et al. 2019, arXiv: 1911.12856
Eggleton, P.P., Dearborn, D.S.P. & Lattanzio, J.C 2008, ApJ, 677, 581
Fuller, J., Piro, A.L., & Jermyn, A.S. 2019, MNRAS, 485, 3661
Rebull, L.M., Carlberg, J.K., Gibbs, J.C., et al. 2015, AJ, 150, 123
Sackmann, J.J. & Boothroyd, A.I. 1999, ApJ, 510, 217
Yan, H.L., Shi, J.R., Zhou, Y.T., et al. 2018, Nature Astronomy, 2, 790