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High resolution spectroscopy of open clusters with SARG ⋆

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Abstract. We present high resolution spectroscopic observations of open clusters of different ages and metallicities obtained with SARG at TNG. We derived lithium abundances for solar–type stars in NGC 752 (∼2 Gyr) and NGC 188 (∼6–8 Gyr) and for early–K stars in Praesepe (∼600 Myr). We found that (i) Li depletion in solar–type stars might stop at an age of ∼2 Gyr; (ii) the spread in Li abundances observed in M 67 seems to be an exception rather than the rule in old clusters; (iii) Li evolution does not seem to be affected by small variations in metallicity.

Key words. stars – evolution – lithium

1. Introduction

Observations of lithium in stars are important for our understanding of Big Bang nucleosynthesis, Galactic chemical evolution, and stellar structure and evolution. Li is destroyed at a relatively low temperature ($T_{Li} \sim 2.5 \times 10^6$ K), thus it survives only in the outermost layers of a star and for this reason it is a good tracer of mixing mechanisms occurring in stellar interiors. Open clusters are coeval samples of stars with homogeneous chemical composition, thus they allow investigating Li evolution as a function of mass, age, metallicity and possibly other parameters.

The present scenario for Li evolution is very puzzling: focusing on solar–type stars, standard models (which include only convection as a mixing mechanism) predict that (i) little (if any) depletion occurs during the Main Sequence (MS), and (ii) Li destruction depends only on age, mass and chemical composition. In contrast with these predictions, the comparison of clusters with different ages clearly shows that stars do deplete Li while on MS; moreover, the solar–age solar–metallicity cluster M 67 is characterized by a large dispersion in Li abundances among solar–type stars with similar temperatures (Jones, Fisher and Soderblom 1999). This spread has not been observed so far in other old open clusters, while it is present among field stars (e.g. Pasquini, Liu and Pallavicini 1994). All these features suggest that Li depletion is affected

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⋆ based on observations collected at TNG
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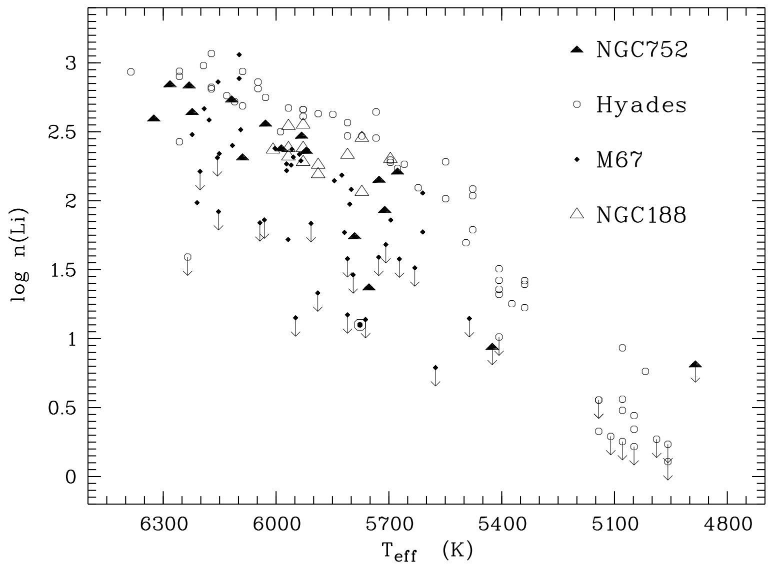

Fig. 1. log n(Li) vs. T_{eff}: comparison between the Hyades (Thorburn et al. 1993), NGC 752 (our sample+HP86), M 67 (Jones, Fisher and Soderblom 1999) and NGC 188 (Randich, Sestito and Pallavicini 2003); down–pointing arrows indicate upper limits in log n(Li). The Sun is also shown.

by additional parameters other than age, mass and metallicity; additional observations are required in order to unveil these parameters.

A detailed analysis of Li evolution in old (thus distant) open clusters requires a large aperture telescope (of the 4m class or larger), a high signal–to–noise ratio (S/N) and a high resolving power (the Li I line is often a very weak feature), and a sufficiently wide spectral range (to observe simultaneously a large number of Fe I lines to determine the clusters metallicity). SARG at the Telescopio Nazionale Galileo (TNG) thus appears a good instrument for this kind of investigation.

For these reasons, we have carried out observations of open clusters of different ages and metallicities using SARG, with the aim of filling the age–metallicity gaps in the present empirical scenario. Our surveys include: 1) Solar–type stars in NGC 752 [~2 Gyr, [Fe/H]=−0.15; Friel (1995)], with the goal of investigating the time scales of Li depletion between 1 Gyr and the solar age, as well as the issue of the spread in Li abundances; 2) Solar–type stars in NGC 188 [~6–8 Gyr, [Fe/H]= 0.01 ± 0.08; Randich, Sestito and Pallavicini (2003)], in order to study Li evolution beyond the solar age; 3) Early K–type stars in Praesepe [~600 Myr, [Fe/H]=+0.039; Friel and Boesgaard (1992)], which allow us to investigate Li depletion in lower–mass stars and its dependence on metallicity. We mention that we have also observed giant stars in the ~2 Gyr clusters NGC 2506 and NGC 7789, in order to study abundances of Li, C, N which are related to mixing processes occurring after the first dredge up: the results of this analysis will be reported elsewhere.

2. Li abundance analysis

The observations were carried out at TNG (La Palma, Spain) equipped with the high-resolution spectrograph SARG, in two different runs: August 2001 (NGC 188) and November 2002 (NGC 752, Praesepe). Details about SARG configuration, data reduction, and

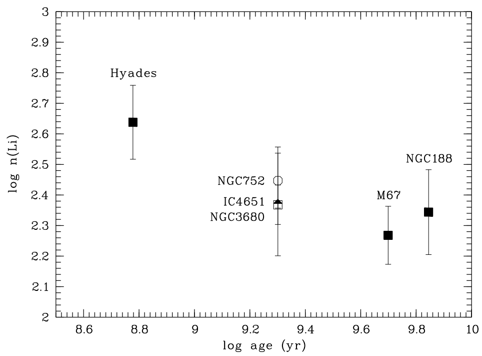

Fig. 2. Average log n(Li) vs. log age for stars in the T_{eff} range [5750–6050] K. Error bars indicate 1σ standard deviations.

abundance analysis can be found in Randich, Sestito and Pallavicini (2003).

In Fig. 1, NGC 752 and NGC 188 are compared to the Hyades and M 67. The Li distributions of solar–type stars in NGC 752 and NGC 188 are very similar, although the latter cluster is at least a factor 3 older than NGC 752; these clusters are both more depleted than the younger Hyades, but not as much as one would expect from the difference in age; moreover, the Li patterns of NGC 188 and NGC 752 lie on the upper envelope of M 67 (i.e. Li rich stars). These features suggest that the depletion might slow down before the solar age. No scatter is present in NGC 188, while in NGC 752 there are two stars with $T_{eff} \sim 5770$ K which may indicate the presence of a dispersion. These stars were observed by Hobbs and Pilachowski (1986) (hereafter HP86); we have found no evidence of a scatter in our sample (which includes 12 stars with $5677 \leq T_{eff} \leq 6282$ K); since the Li data retrieved from HP86 are limited by low S/N, further investigation of solar–type stars in NGC 752 is required in order to proof the presence (or lack) of a dispersion. If a more complete analysis would reveal that no scatter is present in NGC 752, M 67 would remain the only old open cluster in which a large Li dispersion among solar analogs is observed. For this reason M 67 might be a peculiar and/or a non homogeneous cluster (see the discussion in Randich, Sestito and Pallavicini 2003). This also raises the question whether a single cluster can be considered as representative of all clusters of the same age.

Finally, we briefly note that stars warmer than ~6200 K in NGC 752 have log n(Li) close to the meteoritic value [$\log n(Li)_0 \sim 3.1 - 3.3$] with the exception of the hottest object which may be experiencing the well known Li dip (see HP86); the coolest stars ($T_{eff} < 5500$ K) instead are clearly Li depleted.

Fig. 2 shows the average Li abundance as a function of age for solar–type stars in the clusters of Fig. 1 and in the 2 Gyr old clusters NGC 3680, with [Fe/H] = −0.17 (Pasquini, Randich and Pallavicini 2001) and IC 4651, with [Fe/H] = +0.16 (Bragaglia et al. 2001); data for these two clusters were retrieved from Randich, Pasquini and Pallavicini (2000). Note that for M 67 only stars in the upper envelope have been considered ($\log n(Li) \geq 2$). The most important feature is the presence of a "plateau" in log n(Li) vs. age for ages ≥ 2 Gyr. This could be explained with three different scenarios: (i) as mentioned above, Li depletion stops in all clusters at 2 Gyr; (ii) different clusters have different depletion time scales, due to different initial conditions and/or different heavy metal abundances; (iii) different clusters have different initial Li abundances. The first hypothesis is the simplest one, although no theoretical model so far developed predicts such a behaviour. Hypothesis (ii) is unlikely, since metallicity does not seem to affect the time scales of Li evolution, as suggested by the comparison of NGC 752 and NGC 3680 with the more metal–rich IC 4651 (see Fig. 2); moreover, only the solar metallicity cluster M 67 shows a Li spread, although NGC 188 has a similar [Fe/H]. However, we stress that, besides iron, also α element abundances could affect Li depletion. Finally, we have no independent evidence supporting the third scenario (see Randich, Sestito and Pallavicini 2003) for a more detailed discussion).

In Fig. 3 the log n(Li) vs. T_{eff} distribution of Praesepe is compared to that of the Hyades ([Fe/H]= +0.13): it is evident that a complete Li destruction occurs at similar temperatures for the two clusters, in spite of the different

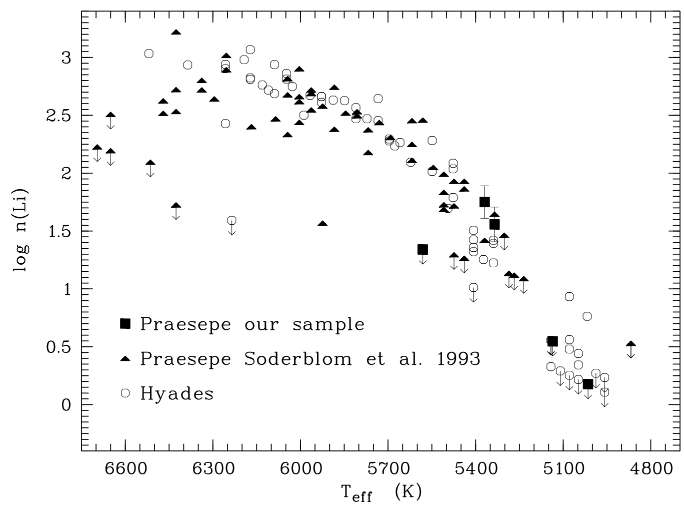

Fig. 3. log n(Li) vs. T_{eff}: Praesepe (our sample+Soderblom et al. 1993) is compared to the Hyades (Thorburn et al. 1993).

metallicities. This suggests that there is no Li–metallicity dependence for these stars.

3. Conclusions

We have presented high resolution spectroscopic observations obtained with SARG for clusters of different ages and [Fe/H]. Our Li analysis has evidenced these relevant features: 1) Li depletion on the MS slows down in solar-type stars and may eventually stop at an age of ~2 Gyr; 2) M 67 is so far the only old open cluster in which the presence of a large Li dispersion among solar–type stars has been firmly established; 3) Small variations of metallicity (~0.2 dex) do not seem to affect Li evolution of early K stars at the age of the Hyades, and of solar–type stars beyond ~ 2 Gyr.

Our analysis suggests that new observations of solar analogs and cooler stars in NGC 752 are required, in order to further address the issue of the scatter in clusters older than the Hyades. In addition, the analysis of Li abundance and metallicity needs to be complemented with investigations of other element abundances: namely, O, N, and other α elements which affect the depth of the convective zone and hence mixing processes in stellar interiors.

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