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Lithium in the open cluster NGC 6475

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Abstract. We present the results of a lithium study of the 220 Myr old cluster NGC 6475. Our data are merged with those from previous Li surveys of this cluster in order to construct a more statistically significant sample. The Li vs. effective temperature distribution of the merged sample is compared with the one of the co-eval, but more metal poor cluster M 34 and with the ones of the younger Pleiades and older Hyades. The results are discussed in the framework of non-standard Li depletion on the main-sequence between the age of the Pleiades ($\sim$ 120 Myr) and that of the Hyades ($\sim$ 600 Myr).

1. Introduction

NGC 6475 is a well populated southern hemisphere cluster located at the distance of $\sim$ 250 pc. Its estimated age of $\sim$ 220 Myr is intermediate between the age of the Pleiades ($\sim$ 120 Myr) and that of older clusters such as the Hyades, Praesepe, and Coma Berenices (ages between 500 and 700 Myr). A metallicity [Fe/H]= +0.11 has been determined spectroscopically for this cluster (James & Jeffries 1997). Given its distance and relatively small reddening, which allow reaching down to late–K stars with 4 m class telescopes, it represents a key cluster for the study of the main sequence (MS) evolution of stellar properties (e.g., lithium, rotation, chromospheric and coronal activity) of solar–type and lower mass stars. We mention in passing that NGC 6475 is indeed the closest and most compact cluster at its (or similar) age.

Focusing on lithium, the study of a cluster intermediate in age between the Pleiades and the Hyades allows addressing the question of MS Li depletion and its timescales, for both solar and later type stars. It is now clear that non–standard Li destruction and/or preservation processes (i.e., including rotation, magnetic fields, mass loss) must be at work during MS (and PMS) evolution as suggested by several observational evidences (Pinsonneault 1997; Jeffries 1999a; Deliyannis 1999, 2000; Pasquini 2000, and references therein). We mention, among them: *i)* the finding that, at variance with standard model predictions,

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solar–type stars deplete Li while on the MS, as shown by the comparison between the Pleiades and the Hyades; *ii)* the existence of a star-to-star scatter in Li abundances among stars cooler than $\sim$ 5300 K as observed in the Pleiades and younger clusters such as α Persei and IC 2602 (see, e.g., Soderblom et al. 1993; Randich et al. 1997, 1998 and 2000; Jeffries 1999a). If Li depletion were driven only by convection, stars with the same age, mass, and chemical composition should have the same Li content. If the scatter reflects a real scatter in Li abundances and it is not caused by, e.g., the effect of chromospheric activity on the line formation process (e.g., Jeffries 1999b), its existence implies that additional mechanisms of Li destruction (or preservation) must be at work. In addition, standard models predict that Li depletion both on the MS and in the PMS should strongly depend on metallicity, a prediction that can be tested by observing clusters of similar age but different metallicities.

Li surveys of NGC 6475 were carried out by James & Jeffries (1997) and James et al. (1999). Both studies found that the Li vs. T_{eff} distribution of solar–type stars in NGC 6475 lie below that of similar stars in the Pleiades and above the Hyades; this in turn indicates that MS depletion does occur between 220 and 600 Myr. Not enough K-type stars were included in the two samples to allow firm conclusions about the existence of a star-to-star scatter.

Jones et al. (1997) carried out a Li study of M 34, a cluster that is about coeval to NGC 6475, but has a reported lower metallicity (either solar or slightly subsolar). They concluded that M 34 shows a Li depletion pattern which is intermediate between the Pleiades and the Hyades and that a dispersion in Li is present for stars cooler than 4700 K.

In this paper we present the results of additional Li observations of NGC 6475. Our data, merged with the ones of James & Jeffries (1997) and James et al. (1999) provides a larger (and thus more statistically significant) sample of stars to further address the issue of Li evolution between the Pleiades and the Hyades. In addition, our sample contains a few stars of later spectral–types than the previous surveys, allowing us to get some insight on MS Li depletion for very cool stars.

2. Sample, observations and data analysis

Our sample originally included 44 stars with $0.5 \leq (\mathrm{B-V})_0 \leq 1.44$: 10 of the stars were taken from the list of Koelbloed (1959) and are thus optically selected, while the remaining 34 are X–ray selected and come from Prosser et al. (1995).

Observations were carried out at ESO in April 1994, April 1995, and July 1996; the CASPEC spectrograph at the 3.6 m telescope was used. The resolving powers in the different runs ranged from $R \sim 20,000$ to $R \sim 41,000$. 60% of the stars were also observed with Coravel which allowed inferring radial velocities and checking for binarity. 13 stars eventually turned out to be cluster–non members, 28 were confirmed as members, whereas for the remaining 3 a more accurate radial velocity analysis is needed.

Nine of the stars were in common with the sample of James & Jeffries (1997); for most of them we find a very good agreement between their and our Li equivalent widths. In the following we will use our own measurements.

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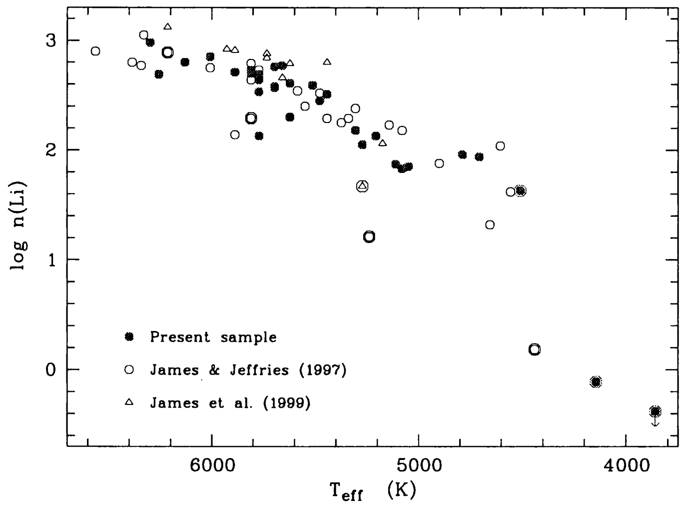

Figure 1. log n(Li) vs. T_{eff} for our sample stars (filled circles), James & Jeffries (1997) sample (open circles) and James et al. (1999) sample (open triangles). Circled symbols denote stars to be confirmed as members.

Li abundances were derived in the same fashion as in Randich et al. (1997) for their IC 2602 sample. Namely, effective temperatures were estimated from dereddened B−V colors using the calibration of Soderblom et al. (1993). LTE Li abundances were derived from the measured equivalent widths using Soderblom et al. COGs; abundances of stars warmer than 4500 K were then corrected for NLTE using the prescription by Carlsson et al. (1994). Both James & Jeffries (1997) and James et al. (1999) data were re-analyzed in the same way for consistency.

3. Results

In Figure 1 we compare the log n(Li) vs. T_{eff} distribution of our sample stars with those of James & Jeffries (1997) and James et al. (1999): the three distributions appear to be very similar (although the James et al. sample may lie slightly above the other two samples – see discussion in James et al.); in particular no systematic difference (due, e.g., to the use of different instruments or spectral resolutions) is present among the various samples. The three samples therefore can be safely merged into a single larger sample.

In Figures 2 and 3 the merged sample is compared to M 34 (Fig. 2) and to the Pleiades and Hyades (Fig. 3). Several conclusions can be drawn from these two figures. **1.** No significant difference appears to exist between the mean log n(Li) vs. T_{eff} patterns of NGC 6475 and M 34, confirming the finding of Jeffries & James (1999) that metallicity (or at least the Fe abundance) does not affect Li depletion significantly. Note that, although based on very few

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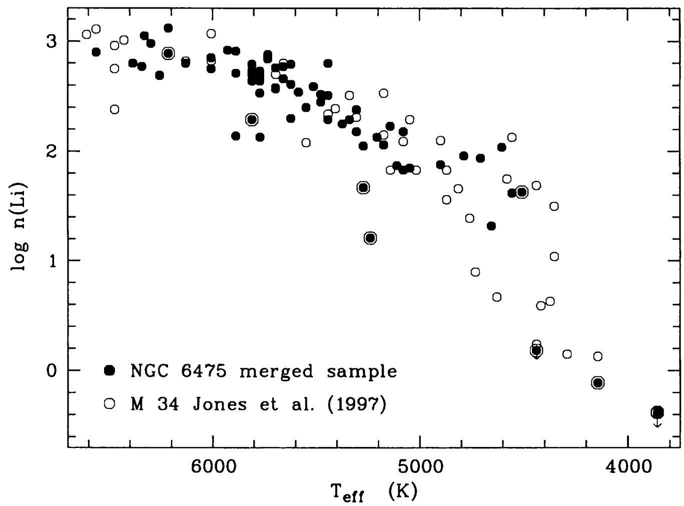

Figure 2. log n(Li) vs. $T_{\rm eff}$ for the merged NGC 6475 sample (filled circles) and the M 34 stars (from Jones et al 1997 – open symbols).

stars to be confirmed as members, this conclusion seems to hold also for stars considerably less massive than the Sun, for which convection should be the major Li destruction mechanism. For these stars the metallicity (which affects the depth of the convection zone) is expected by standard models to have a significant effect on Li depletion;

2. A few stars in NGC 6475 appear as depleted as (or more depleted than) the older Hyades. Whereas some of them are not confirmed as members, others seem to be *bona fide* cluster members (but one is probably a photometric binary from its position on the color-magnitude diagram). These stars more depleted than the Hyades should be further monitored; if additional observations confirm their cluster membership and the measured Li EWs, they will represent a very puzzling problem; **3.** The larger sample confirms that MS Li depletion occurs for stars cooler than ~ 6200 K both between 120 and 220 Myr and between 220 and 600 Myr. Li destruction, however, appears to be slower between the Pleiades and NGC 6475 than between the latter one and the Hyades. If we consider, for example, the mean Li abundance of stars with $5500 \leq T_{\rm eff} \leq 5600$ K, we have a factor of ~ 2 in Li depletion between the Pleiades and NGC 6475 (i.e., in a factor ~ 1.9 in time) and of ~ 5.4 between NGC 6475 and the Hyades (i.e., in a factor ~ 2.7 in time). This is surprising and suggests that the MS Li depletion mechanism (which cannot be convection for solar–type stars that have not deep enough convective zones) becomes faster after 200–300 Myr; **4.** MS Li depletion between 220 and 600 Myr is more efficient for cooler/lower mass stars, probably witnessing the increasing contribution of convection to Li depletion. On the other hand, below 5400 K the NGC 6475 distribution lies on the lower envelope of the Pleiades distribution and, more specifically, several Pleiades stars exist that show the same amount of depletion as NGC 6475 stars; **5.** If we exclude the outliers discussed in point 2. above, no significant star-to-star scatter is present

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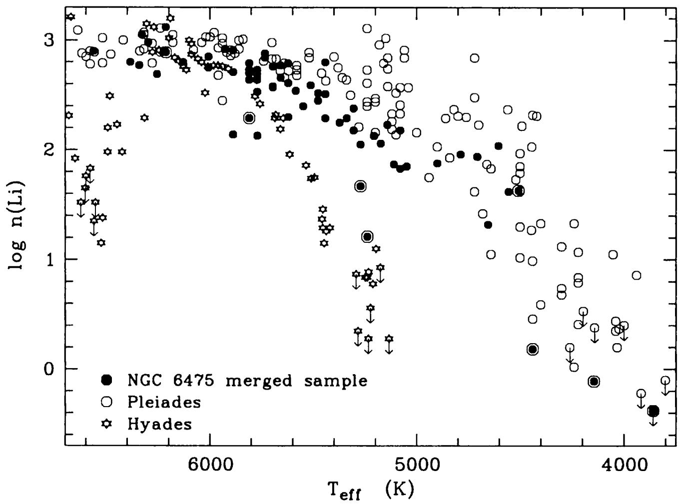

Figure 3. The NGC 6475 merged sample (filled circles) is compared with the Pleiades (open circles: data from Soderblom et al. 1993 and Jones et al. 1996) and the Hyades (star symbols – from Balachandran 1995).

down to ~ 4800 K. Among cooler stars, there might be a slight indication of the presence of a scatter, but this is evidenced only by two stars at present. Our sample contains too few cool stars to put sensible constraints on the existence of a scatter. Should further Li observations of NGC 6475 demonstrate that no spread is present for NGC 6475, while it does exist for M 34, this would suggest that, whereas metallicity does not affect the main Li depletion mechanism (i.e., the one determining the mean depletion pattern), it may indeed affect the mechanism causing the dispersion in Li.

4. Conclusions

The observations of the intermediate age cluster NGC 6475 confirm that MS Li depletion does occur for solar-type and lower-mass stars, both between the age of the Pleiades and that of NGC 6475 (and M 34) and between the latter age and that of the Hyades. The lack of any significant difference between the log n(Li) vs. T_{eff} distributions of NGC 6475 and M 34 indicates that metallicity does not play a significant role in Li depletion, if the reported metallicities for these two clusters are indeed correct (no spectroscopic determination of the metallicity of M 34 does yet exist, while the metallicity of NGC 6475 has been determined so far only by James & Jeffries 1997). Whereas a star-to-star scatter in Li abundances is clearly present for M 34, there is no significant scatter in NGC 6475 down to ~ 4800 K. Additional data on cooler stars are required to ascertain whether a scatter is present at lower temperatures. Finally, a few stars exist in NGC 6475 which are as depleted as, or more depleted than, stars in the older Hyades; conversely, stars exist in the younger Pleiades which are as depleted as the coolest stars in NGC 6475 and M 34.

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