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Lithium in optically-selected G & K stars in NGC 6475 (220 Myr)

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Abstract. Photometric members of the open cluster NGC 6475 were observed using high resolution spectroscopy for analysis of lithium abundances in their atmospheres. We combine these new data with previously obtained lithium data, and present a comparison with one younger and one older open cluster of similar composition. The most interesting result from these data shows that metallicity is a relatively unimportant feature in describing the evolution of lithium abundance distributions from young ($\sim$ 100 Myr) metal-rich solar-type stars to older ones ($\sim$ 700 Myr). We also argue that there is tentative evidence for different lithium abundance distributions for NGC 6475 members depending on whether they are optically or X-ray selected.

1. Introduction

NGC 6475 is the closest (d = 220 pc) and most compact open cluster of those that occupy the astrophysically important position midway in age (t$\sim$ 220 Myr) between the nearby and well studied clusters of the Pleiades (t$\sim$ 80 – 100 Myr) and the Hyades (t$\sim$ 700 Myr). NGC 6475 is at an age that is diagnostically important for proposed mechanisms of angular momentum loss in low mass stars and the depletion of lithium in their convective atmospheres. The variation of rotation rate and lithium abundance with age and spectral type is of key importance in understanding the standard and non-standard physical processes occurring in stellar interiors. The measurement of Li abundances of low-mass stars in a sample of open clusters at a variety of ages permits the investigation of meridional circulation and diffusion (particle transport) in stellar interiors as a function of rotation (and its implicit dependence on age) and composition. Given that lithium burning is likely to be implicitly dependent on convection zone [CZ] depth, it is crucial to our understanding of lithium depletion that we isolate the effects of metallicity on CZ depth by observing stars of varying ages yet having the same composition.

Photometric members of the intermediate-age open cluster NGC 6475 were observed spectroscopically for analysis of lithium abundances in their atmospheres.

We combine these new data with previously obtained lithium data, and present a comparison with two other metal-rich open clusters.

2. Optically selected late-type members of NGC 6475

An optically-selected sample of stars in NGC 6475 was observed at the Anglo-Australian Observatory in July 1998, using UCLES, to measure their rotation rates, radial velocities and lithium 6708 Å equivalents widths. Three colour photometry has also been obtained for these stars using the 1.0m telescope at the South African Astronomical Observatory in June 1995 (James et al. 1999). The stars have BVI$_c$ photometry consistent with the CMD for the cluster (*cf.* Figure 1. in James & Jeffries 1997). Data reduction and measurement of radial velocities, rotational velocities and Li I 6708 Å equivalent widths are identical to those detailed in James & Jeffries (1997). Lithium abundances were derived in an identical manner to that in Jeffries (1999). Our cluster membership criteria centre on the star's proximity to the cluster ZAMS and the radial velocities (RVs) relative to the cluster mean of ~ -15 km s^{-1}. Celestial coordinates are taken from Digitized Sky Survey images. The relevant data are summarized in Table 1.

Table 1. Summary of data products for newly-observed NGC 6475 (M7) photometric members. Observations obtained during an AAT run, July 1998.

Target	RA (J2000)	Dec (J2000)	V	B-V	RV km s^{-1}	v sin$i$ km s^{-1}	Li I EW mÅ	N(Li)
JJ 100	17 51 22.3	-35 05 58	12.06	0.66	$+78.6 \pm 0.2$	≤ 5	39 ± 20	2.31
JJ 101	17 51 45.9	-34 48 17	13.49	0.83	-25.5 ± 0.2	≤ 5	≤ 8	≤ 1.18
JJ 102	17 52 47.1	-34 46 07	13.61	0.95	-32.4 ± 0.2	≤ 5	159 ± 9	2.42
JJ 103	17 52 49.8	-34 57 56	12.55	0.72	-13.7 ± 0.3	8.5 ± 0.9	123 ± 15	2.74
JJ 104	17 52 50.2	-34 37 19	12.18	0.78	-15.6 ± 0.3	9.6 ± 0.8	192 ± 13	2.92
JJ 105	17 52 55.7	-34 38 43	12.92	0.83	-10.6 ± 0.2	5.1 ± 0.9	34 ± 15	1.84
JJ 106	17 53 43.2	-35 27 57	12.20	0.70	-15.2 ± 0.3	9.8 ± 1.1	148 ± 11	2.94
JJ 107	17 53 47.0	-34 31 00	14.15	0.96	-83.5 ± 0.8	17.0 ± 2.4	63 ± 28	1.85
JJ 108	17 53 47.1	-34 20 22	13.54	0.92	-30.5 ± 0.8	10.0 ± 1.5	105 ± 18	2.21
"	"	"	"	"	$+3.9 \pm 0.8$	"	"	"
JJ 109	17 53 52.8	-34 30 31	12.07	0.73	-13.5 ± 0.4	9.1 ± 1.0	156 ± 35	2.87
JJ 110	17 54 15.0	-35 25 04	12.96	0.86	-14.1 ± 0.2	6.6 ± 0.8	90 ± 13	2.25
JJ 111	17 54 43.3	-34 58 37	11.59	0.58	-13.4 ± 0.6	17.4 ± 1.8	132 ± 13	3.15
JJ 112	17 55 47.0	-34 42 24	13.30	0.97	-69.7 ± 0.5	17.9 ± 1.5	216 ± 17	2.62
JJ 113	17 55 49.0	-34 42 30	11.80	0.65	-13.1 ± 0.6	17.6 ± 1.3	133 ± 17	2.98
JJ 114	17 56 08.9	-34 32 40	12.93	0.90	-37.7 ± 0.2	≤ 5	41 ± 11	1.77
JJ 115	17 56 16.6	-34 31 17	11.70	0.66	-14.0 ± 0.3	11.0 ± 1.1	137 ± 13	2.97
JJ 116	17 56 19.6	-34 32 01	12.29	0.70	-13.9 ± 0.3	6.7 ± 0.9	158 ± 12	2.95

Lithium data for optically-selected single late-type probable members of NGC 6475 are plotted, in Figure 1, together with previously published data for X-ray selected members of NGC 6475 (James & Jeffries 1997). A comparison is made to the young Blanco 1 cluster and the Hyades cluster because all their members are metal-rich compared to the solar value (James & Jeffries 1997, Jeffries & James 1999), and of a similar composition to that of NGC 6475 (James & Jeffries 1997). This should allow us to understand any lithium abundance distribution

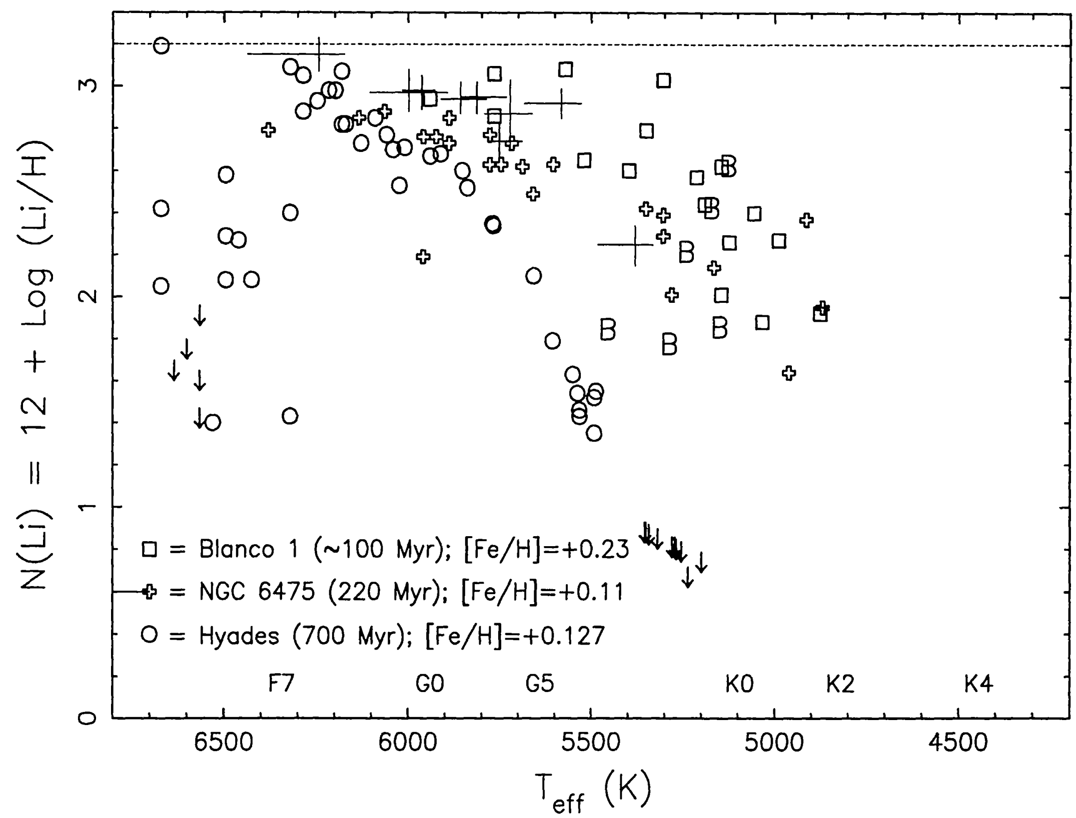

Figure 1. Lithium abundances for optically-selected probable single members of NGC 6475 are plotted against effective temperature (error bar points - some binary data are also plotted, indicated by **B**). Also plotted are data points for X-ray selected NGC 6475 members and similar mass stars in the Hyades and Blanco 1 clusters (James & Jeffries 1997, Jeffries & James 1999). Spectroscopic metallicity determinations for each cluster are shown (from Jeffries & James 1999). The cosmic lithium abundance, represented by a dashed line, is assumed to be 3.2 - on a scale where hydrogen is 12.

patterns solely in terms of age-related processes (under the somewhat shaky assertion that initial conditions were identical in all three clusters).

Several important points are evident from the figure. First, pre-main sequence lithium depletion **cannot** account for the differences between the lithium abundance distributions of solar-type stars in the younger systems and the older Hyades. The Li distributions are consistent with quite substantial lithium depletion occurring on the main sequence in solar-type stars from a couple of hundred million years up to about 700 Myr or so. These observations are **inconsistent** with the predictions of the standard models. It is now clear that non-standard processes other than those linked to metallicity must be responsible for the lithium depletion occurring in these low-mass stars.

Second, among the late-F to mid-G NGC 6475 stars, there appears to be a difference in the general trend of lithium abundances versus effective temperature for the optically and X-ray selected stars. The optically selected stars appear to have more lithium than similar mass X-ray selected stars in the cluster (the

error bars are of similar magnitude for the X-ray selected NGC 6475 data points). Given that these stars were observed with identical instruments, analyzed using identical techniques and curves of growth etc, we conclude that this effect is real. Its cause may be linked to the formation conditions in the lower atmospheres of these stars, or something less obvious such as higher spot fractions on X-ray selected stars. Suppose that the X-ray selected stars have more active dynamos and magnetic heating in their outer atmospheres. A natural consequence of the rotation-activity paradigm would be that these stars are rotating more rapidly or maybe have more differential rotation. It is generally believed that more rapidly rotating late-type stars will be more spotted as a consequence of their rotation (see Hussain 1999 for instance). Therefore more rapid stars may be extremely *spotted* ($\geq$ 10%) and as such may have enough lower temperature regions that the derived lithium abundances are generally lower for a given **real** atmospheric lithium abundance. This hypothesis is based on rather a small sample but it will be interesting to see if this effect is real. If and when the XMM and/or Chandra X-ray telescopes detect some of the more distant young clusters in X-rays, it is likely that such a hypothesis could be investigated if used in concert with optical data from the new generation of 8 and 10-metre class telescopes.
Third, the data presented in Figure 1 clearly indicates that lithium depletion must be **mass-dependent** in these stars. For instance, the late-F to mid-G stars in Blanco 1 and NGC 6475 only need to deplete lithium by a factor of about 2-4 to reproduce the lithium abundance distribution pattern in the Hyades cluster by the Hyades age. However, for the late-G and early-K stars in the two younger systems, depletion factors between about 10 and 100 must be achieved if the current Blanco 1 and NGC 6475 lithium distributions are to look anything like the Hyades lithium distribution in this mass range at the Hyades age (essentially all upper limits after 700 Myr main sequence evolution). This factor difference is somewhat startling and is likely to be linked to the differences in convection zone depth between the two sets of mass range.

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