Lithium Abundance in NGC 3680

L. Pasquini\textsuperscript{1}, S. Randich\textsuperscript{1}, and R. Pallavicini\textsuperscript{2}

Abstract:
In the framework of a long-term program aimed at studying lithium abundance in solar stars belonging to intermediate and old clusters, we present the preliminary analysis of high resolution observations of 21 stars belonging to the intermediate age cluster NGC 3680. The targets range from the main sequence turnoff through the sub-giant branch.

The cluster shows a clear Li-dip, and no evidence for a spread is present among the observed main sequence stars.

Particularly relevant is the finding that out of the 6 giants (which have similar magnitudes and temperatures) three show a strong lithium line, while the other three are Li depleted.

1. Introduction

With the advent of efficient spectrographs coupled to 4m class telescopes, it is now possible to obtain high resolution, high signal to noise observations of solar-type stars in intermediate and old open clusters and globulars, to derive accurate Li abundances (Pasquini 1997).

It is clear (see e.g. the proceedings edited by D’Antona 1991) that the Li problem is complex: we do not yet fully understand how and when Li is produced as well as how and when it is depleted.

The answer to this puzzle would allow the understanding of several relevant questions, linked to primordial nucleosynthesis, chemical evolution of the Galaxy and mixing mechanism(s) in the stellar interiors.

It is also clear that in order to understand the Li problem a large observational effort is needed, in order to map properly the age, effective temperature, gravity and metallicity space. In this framework, observations of stars in clusters are a unique, powerful tool.

Until recently the study of Li in clusters was mainly limited to young open clusters like the Hyades (Soderblom et al. 1990), the Pleiades (Soderblom et al. 1993a), and Praesepe (Soderblom et al. 1993b).

This situation is now rapidly evolving: not only are more young open clusters being observed (see e.g., Randich et al. 1997; Jefferies et al. these proceedings), but also good quality data are available for the solar age, solar metallicity open cluster M 67 (Pasquini et al. 1997), as well as for three globulars: NGC

\textsuperscript{1}European Southern Observatory, Karl Schwarzschild Str. 2, D-87546, Garching, BRD
\textsuperscript{2}Osservatorio Astronomico di Palermo, Palazzo dei Normanni, I–90134, Palermo, Italy
Figure 1. Colour-magnitude diagram of the observed stars. Black triangles: \((B - V)\), Red triangles: \((b - y)\)

6397 (Pasquini & Molaro 1996), M 92 (Delyiannis et al. 1995) and 47 Tuc (Pasquini & Molaro 1997).

2. Observations

NGC 3680 is an intermediate age open cluster. Its age is estimated to be 1.6 Gyrs, and its metallicity is comparable to the Hyades. The reddening towards the cluster \((E(B - V) = 0.05)\) is quite low and well established (Nordström et al. 1996, 1997)

NGC 3680 is one of the best studied clusters: accurate photometry exists and membership has been established by means of proper motion and radial velocity studies. The cluster is not well populated, and only 37 stars are classified as bona fide members. Out of these, 17 are binaries.

In addition, 13 other stars are classified as possible (but not firm) cluster members (Nordström et al. 1996, 1997).

The observations were obtained at ESO la Silla, using the CASPEC spectrograph attached to the 3.6m Telescope and the EMMI spectrograph at the NTT telescope. The resolving power used was for both instruments \(\sim 30,000\) and the signal to noise ratio ranges from 150 for the brightest sources to 80 for the faintest ones.

Observations for a total of 23 stars, covering the whole cluster colour-magnitude diagram, were acquired in several observing runs, starting in 1995. Out of this sample, according to Nordstrom et al., 2 of the observed stars are
Figure 2. Li equivalent widths vs. stellar effective temperatures. Black squares are single members, Red squares cluster binaries, Triangles non members. Stars cooler than 5500K are giants

not cluster members, and 5 are members but binaries. Three are among the stars classified as “possible” members and 13 are firm single members.

In Figure 1 the colour-magnitude diagram (Black: $B - V$, Red: $b - y$) of the observed stars is shown.

3. Results

The data were reduced by using the MIDAS package (Banse et al. 1988), and Li equivalent widths were measured by simple integration. Note that at the resolution of our observations the Li complex is blended with the 6707.4 (Fe) line, and the equivalent widths values reported in the Figures contain the contribution from this blend.

Since the Li abundance depends strongly on the stellar effective temperature, this parameter has to be determined with a high accuracy. We could not find a suitable, single temperature scale for dwarfs and evolved stars.

Effective temperatures for the main sequence stars were therefore obtained by using the $B - V$ calibration of Alonso et al. (1996), while for the evolved stars the effective temperature scale of Buser & Kurucz (1992) was adopted. The same scales were adopted by Pasquini & Molaro (1997) in their study of 47 Tuc.

The Li equivalent widths vs. $T_{\text{eff}}$ are given in Figure 2. Black squares indicate single cluster members. Red squares cluster binaries and triangles the two non members. All stars colder than 5500 K are giants.
In order to test the quality of our observations and the effects of non-membership and binarity, in Figure 3 the measured Ca I (6717Å) equivalent width is shown as a function of the \((B - V)\), (black) and \((b - y)\) (red) colours. The Ca I line is recorded in the same echelle order as the Li line, and it is a good tracer of stellar effective temperature.

The relationship of Figure 3 is tight, in particular when the \((b - y)\) colours are adopted. This confirms the high quality of the data and also the suggestion by Nordström et al. (1996, 1997) that existing Strömgren photometry for this cluster is more accurate than the published \((B - V)\).

In the following discussion, the main sequence stars will be treated separately from the giants.

### 3.1. Dwarfs

The Li equivalent width vs. \(T_{\text{eff}}\) diagram of Figure 2 looks quite scattered. This scatter is mostly due to the fact that in NGC 3680 the majority of the main sequence stars observed are around the turnoff, therefore the Li-\(T_{\text{eff}}\) diagram is degenerate for masses. Stars with different masses may have the same temperature, and in the presence of Li depletion, therefore, this plane may not be the most suitable to represent the Li evolution in the cluster.

This appears clear in Figure 4, where Li equivalent widths are shown vs. the apparent magnitude \(m_v\) or, in first approximation, vs. mass.

Figure 4 shows a regular and familiar behavior, similar to what is observed in the Hyades: the Li-dip is clearly present. On the cool side of the dip, moving
towards fainter stars, Li increases and it has an almost constant value among the three G stars.

For the dwarfs we can observe:

1. On the evolved side of the dip, some of the cluster members show the presence of Li. This would indicate that the cluster giants (more massive) likely evolved from Li-undepleted stars. Also, the behavior of the Li-dip in NGC 3680 could be somewhat different from what is observed in NGC 752, an intermediate age cluster to which NGC 3680 has been often compared. NGC 752 has similar age but lower metallicity than NGC 3680: in NGC 752 several turnoff stars completely out of the dip on the hot side are observed.

   A detailed comparison between the Li content of the two clusters could be used to infer cluster properties and to investigate the behavior of the Li-gap as a function of metallicity.

2. Opposite to what is observed in the older M 67 (Pasquini et al. 1997), our data do not support the presence of a real spread in the Li content among similar main sequence stars in NGC 3680. In Figure 4, the behavior is very regular, and the small differences in Li equivalent widths between similar stars can be well explained by photometric errors and/or the presence of companions. Only on the hot side of the gap one star seems to have a much higher Li content than the others. This star, although being fully compat-
Figure 5. Spectra of the Li region of two NGC 3680 giants, one Li poor (Black line) and one Li rich (Red line). Note as the only noticeable difference between the two spectra is around the Li line.

ible with membership, is flagged as “possible member” by Nordström et al. (1997).

3.2. Giants
In Figures 2 and 4 the results for the giants are also shown. It is clear that a large spread in Li equivalent widths is present among the evolved stars, even if in some case their magnitudes and effective temperatures are very similar.

Figure 5 contains the spectra of one Li-rich and one Li poor giant. The only significant difference between the two spectra is in the strength of the lithium line.

At which stage of the stellar evolution were these differences in Li abundance produced?

If the most massive stars at the turnoff are already out of the Li gap, as our observations could suggest, the difference in Li among the giants was produced in the post-main sequence phase. In this case, the difference in Li content could possibly discriminate between stars in the ascending RGB and stars belonging to the clump.

If, instead, the giants evolved from stars at the hot edge of the Li-gap, then the Li spread could reflect the small difference among their masses, indicating that the Li-rich are indeed the (originally) more massive stars.

A full analysis of the spectra will allow us to investigate if more spectroscopic differences are present among these stars.
References

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