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High resolution spectroscopy of old late K dwarf stars around the lithium I 6707.8 Å line: is lithium there?*

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Abstract. We report recent high resolution, high signal to noise ratio spectroscopic observations of the region around the Li I 6707.8 Å line in two apparently old field late K-type main sequence stars. These stars exhibit a small equivalent width line at the same wavelength, within 10 mÅ, as the Li I line. Lithium is expected to be fully depleted in old low mass stars, and therefore its presence in Hyades age (or older), 0.6 $M_\odot$ stars is surprising. Given the richness and complexity of the spectra in these cool stars, the identification of the line with the Li I line is not obvious. We briefly discuss, using model atmospheres and synthetic spectra alternative explanations for this feature. Finally, we briefly look at the implications of the presence of lithium in low mass stars for current stellar interior models.

Key words: Stars: abundances

1. Introduction

The abundance of lithium has been studied in detail in several samples of Population I stars. In particular, solar type stars in open clusters of different ages (cf. Soderblom et al. 1993, hereafter SJB, and references therein) and pre-main sequence populations (cf. Basri et al. 1991) have been studied in detail, as well as samples of active binaries (Randich et al. 1993) and X-ray selected samples (Favata et al. 1993, Tagliaferri et al. 1994). Most of these studies have, however, concentrated on specially selected solar type stars down to early K or so; the recent volume-limited study of Pasquini et al. (1994) has for example focused on stars of spectral type F8-G5. Little attention has so far been given to normal later type stars. Their relative faintness makes them difficult to observe at high spectral resolution and, on theoretical grounds, one expects lithium to be burned down to low abundances early in their life, making them unattractive targets. According to the models of Pinsonneault et al. (1990, hereafter PKD), which consider the effects of stellar rotation and angular momentum loss, in a star of 0.6 $M_\odot$ (i.e. K7V) the photospheric lithium abundance should have decreased by about 3.2 orders of magnitude, down to about $N(\mathrm{Li}) = 0$ (in the usual scale where $N(\mathrm{H}) = 12$), by the time the star is 50 Myr old, and it should keep decreasing more or less exponentially with time. The equivalent width of the Li I 6707.8 Å line should therefore be reduced to 10 mÅ or less already at the age of 50 Myr, so that the largest majority of low mass disk population stars in the solar neighborhood should have no detectable lithium. However it should be noted that the applicability of theoretical models is not completely clear, as they are not able to fully describe the behavior of lithium in young open clusters (in particular they have difficulties in explaining the large spread of $N(\mathrm{Li})$ observed, as discussed by SJB, to which the reader is referred for details). So far, no samples of stars (except the Pleiades) with sufficiently low effective temperatures have been studied in detail to allow comparison of models and observations at this temperature at later ages.

2. Observations

We have recently conducted a volume limited survey of lithium in 136 dwarf G and K stars in the solar neighborhood, in order to study the behavior of lithium in an unbiased sample of "normal" stars (Favata et al. 1995). The survey has been conducted using the CAT 1.4 m telescope at the ESO La Silla observatory, with the associated CES (Coude Echelle Spectrograph). The observations were conducted on Nov. 1993 and Feb. 1994, using the short camera at a resolution of about 50,000. During the analysis of

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* Based on observations collected at the ESO La Silla observatory

these spectra we noted that a faint spectral feature at the expected position of the Li I 6707.8 Å line was present in some supposedly old stars of spectral type K5 and later. As discussed above, no lithium is expected in old low mass disk population stars, and to confirm the Li detection we have, during a run in Aug. 1994, re-observed some of them with the same CAT/CES combination, but using the Long Camera, yielding a resolution of about 100,000. The objects discussed here are three main sequence nearby K stars: GJ 879 (K5V), GJ 142 (K7V) and GJ 798.0 (K7V), all of which have been observed with signal-to-noise ratios of better than 150. The first one is a known active star, which is used as comparison here, while the other two were selected on the basis of their apparently showing the small lithium feature in the R = 50, 000 spectra.

3. Results

The reduced spectrum of GJ 879 is shown in Figure 1. It can be seen that the spectrum of GJ 879 (which has a color index $B-V \approx 1.1$) is a relatively clean one, with a clearly visible Li I line at 6707.8 Å with a measured equivalent width of about 35 mÅ. The line is well separated from the nearby Fe I line at 6707.4 Å, although it is visibly blended on the red side with a line most likely due to TiO. By using some strong lines of Fe I well visible in the spectrum to determine the red- or blue-shift of the spectra, and by fitting a gaussian to the center and blue wing of the Li I line (to minimize the effect of the blending on the red wing) we determined the observed rest wavelength of the Li I line in the spectrum of GJ 879. The inferred lithium abundance of GJ 879 is about 0.4, which is between the values observed for Pleiades (SJB) and Hyades (Thorburn et al. 1993) stars of the same effective temperature.

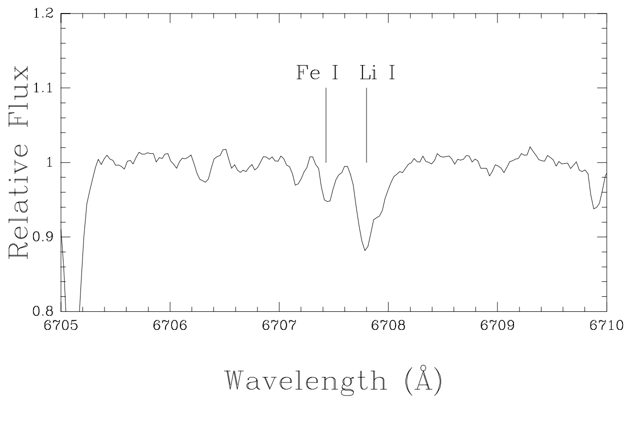

Fig. 1. The observed spectrum of GJ 879, shifted to the earth rest frame.

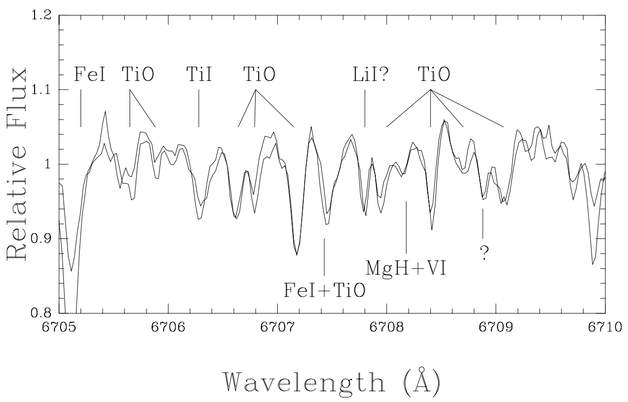

Fig. 2. The observed spectra of GJ 798 and GJ 142, both shifted to the earth rest frame and super-imposed. Also indicated are tentative line identification from the synthetic spectra described in the text.

The spectra of GJ 798 and GJ 142 (which are slightly colder than GJ 879, both having $B - V \approx 1.3$), shown super-imposed in Fig. 2, are visibly much richer in lines than the spectrum of GJ 879, with a ill determined continuum. A plethora of weak (equivalent widths 10 mÅ or less) lines are visible throughout the measured region. The Fe I 6707.4 Å line is still well resolved, although blended with a TiO feature, while several features absent in the spectrum of GJ 879 are visible red-ward (as well as blue-ward) of it. In particular, a narrow, apparently well resolved line is present at the expected position of the Li I 6707.8 Å line. We have determined the observed rest wavelength of the observed feature in both spectra, using the same procedure as for GJ 879, finding it to be within 10 mÅ of the wavelength of the Li I feature in the spectrum of GJ 879.

Before a claim that the detected features are indeed due to lithium can be made, it is necessary to exclude their being due to some other line or blend. To this end we have performed a spectral synthesis analysis of the spectra, using the latest Kurucz atmosphere models, thanks to the courtesy of R. Kurucz. By using a model atmosphere for $T = 4100$ K and $\log(g) = 4.5$ (corresponding to a K7 dwarf) we have computed spectra which include all the known atomic lines in the region from 6700 to 6711 Å, together with known lines with measured laboratory wavelength from the diatomic molecules MgH, SiH, CN, TiO. No sharp line at the position of the observed Li I feature was evident in the synthetic spectra. As a further test we have added to the line list a large number of TiO lines with *computed* wavelengths and gf values; given the very high line density, this depresses the continuum, but still fails to produce a visible feature in the synthetic spectrum at the Li I position. Finally, we have checked that a change in surface gravity of half a decade would not change the strength of weak lines to produce an observable feature at 6707.8 Å.

It should be stressed that the computed line position and strengths for TiO are often affected by significant errors (Kurucz, private communication), so that it cannot completely be ruled out that the observed feature at the Li I position is actually due to some yet unmeasured TiO line (or one whose computed position is significantly in error). This could be tested in the future observing a larger sample of stars with a range of TiO abundances, to look for a correlation (or lack thereof) between the 6707.8 Å feature and the rest of the TiO lines. Also, we cannot rule out its being due to some molecule not included in the line lists we have used.

We have indicated in Figure 2 proposed identifications for each spectral feature between 6705 and 6709 Å based on comparison of the line position between the synthetic spectra discussed above and our observations. As it can be seen, most of the features present in the spectrum are identified (mostly with TiO lines) with the exception of the feature at 6708.8 Å marked with a "?". All of the TiO lines shown have measured (rather than computed) positions.

We have compared our results with the work which has been done by Denn et al. (1991) and by Lambert et al. (1993) on spectral synthesis of the Li I line in carbon stars and in barium stars respectively. Lambert et al. (1993) have studied, through spectral synthesis, the lithium abundance in barium giants. The stars they studied have similar effective temperatures to the stars shown here, although the surface gravity is much lower. They show that in their stars the lithium feature is blended with a CN line, whose wavelength they list as 6707.816 Å, i.e. about 56 mÅ away from the two lines composing the ^{7}Li doublet. If the observed lithium feature were to be due to the CN line, we should expect a measurable wavelength shift between the spectrum of GJ 879 and the spectra of GJ 798 and GJ 142, which we do not find. Lambert et al. (1993) also show that a tight correlation exists between the abundance of Ce in the stars and the strength of the feature at the lithium wavelength, and therefore claim that the lithium feature they see in their spectra is due to a line of an unidentified element (or possibly Ce itself), whose abundance should be correlated with Ce through s processing enhancement, at a wavelength 15 mÅ blueward of the lithium doublet. It is hard to see how this could justify the feature at the lithium wavelength in normal, not chemically peculiar K dwarfs, although the possibility cannot be discarded *a priori*.

Denn et al. (1991) present spectral syntheses of a few cool C stars (mostly below 3,000 K). These stars have much more complex spectra than than our K stars (their spectra are also taken at $\mathrm{R} = 100,000$), however their careful analysis could provide some clues to the nature of the spectral feature at the position of lithium in K dwarfs. The spectrum of Y Tau shown by Denn et al. (1991), with a temperature of 2,600 K, is very rich in CN, and C_2 lines, with the lithium line blended on both sides. Even in this case, however, at $\mathrm{R} = 100,000$ the nearby blending lines are visibly shifted, by 25 mÅ or so in wavelength, from the position of the lithium line, a shift which again we do not measure in our spectra.

Finally, neither GJ 798 nor GJ 142 are known to be binary from the literature, barring possible misidentification of the line due to the presence of an SB2 companion. GJ 142 has been searched for radial velocity variations by Young et al. (1987) who find a constant radial velocity; for GJ 798 we found no specific velocity variation searches in the literature, but the published values of its radial velocity are in agreement with each other.

4. Discussion

The age of GJ 879 can be inferred to be, from its high activity level and its kinematics (see Favata et al. 1995), intermediate between the age of the Pleiades and the age of the Hyades. Therefore, its lithium abundance intermediate between the abundance of comparable mass stars in the two clusters is in line with observational expectations.

The presence of an apparent Li I feature in GJ 798 and GJ 142 is on the other hand hard to justify on the basis of their age, given that both stars should be of Hyades age or older. GJ 142 is considered a member of the Hyades supercluster by Eggen (1993), while GJ 798 is considered a member of the ζ Her old-disk stellar group by Eggen (1971). In both cases the age and group membership have been estimated considering both kinematics and activity. In the case of GJ 142 literature data on chromospheric activity (as discussed by Eggen 1993 for the Hα equivalent width, which is comparable to the equivalent width in stars of the same color in the HR 1614 super-cluster, which is estimated to be $5 \cdot 10^9$ years old) are indicative of an age slightly older than the Hyades. The observed 6707.8 Å spectral feature has in both stars an equivalent width slightly in excess of 10 mÅ. If due to lithium, this implies a photospheric abundance of $N(\mathrm{Li}) \approx -0.5$, i.e. low but still well above the value of -1 or less that can be extrapolated for Hyades-age stars of this mass from the observations of Thorburn et al. (1993). Their observed lithium abundance is therefore higher than what would be expected on the basis of straight extrapolation of the observed lithium-age relationship in open clusters. As discussed below, it is also higher than what would be expected on the basis of current stellar interior models.

The precise nature of the mechanism governing photospheric lithium depletion in low mass stars is still subject to debate, although there is general agreement that lithium burning at the basis of the convective envelope is the main driver of depletion (see SJB for a detailed discussion). Therefore, the precise amount of depletion will depend on a complex combination of factors such as the depth of the convection zone, the convective turnover time and the (eventual) meridional circulation. While classic, spherically symmetric models cannot even account for the observed lithium abundance in the Sun, models which include rotationally induced mixing (PKD) are much more successful in reproducing the observed behavior of lithium in open clusters than "standard" models. PKD models predict that at 500 Myrs rotating stars of 0.6 $M_\odot$ should have depleted their surface lithium by more than 4 orders of magnitude, i.e. down to $N(\mathrm{Li}) < -1$, and should continue to lose lithium exponentially with age. The amount of depletion is nearly independent on the history of surface angular momentum loss for "smooth" evolutionary histories (PKD), making detailed assumption on the rotational history unnecessary.

Therefore, the detection of lithium in old, low mass stars, once confirmed, appears to be hard to explain using current rotating models. The amount of depletion predicted by PKD models depends fairly strongly on both the initial angular momentum and on the details of the coupling between the convective envelope and the internal layers. In particular, higher initial angular momentum should lead to higher surface lithium abundance. To justify the lithium abundance of GJ 142 and GJ 798 on the basis of high initial angular momentum would however require an initial angular momentum well above the maximum possible angular momentum for such low mass stars. The rotational coupling between surface and interior in low mass stars is strongly dependent on the (poorly determined) critical Reynolds number (PKD). One possible explanation for the lithium abundance observed in GJ 142 and GJ 798 would therefore be a very low interior-envelope angular momentum coupling in lower mass stars (implying the presence of a fast rotating core), leading to much reduced mixing and therefore lower depletion. The corresponding higher Reynolds number would have little influence on higher mass models, although it should influence the rotation period of old low mass stars (on which very little observational material is available).

The inhibition of rotationally induced mixing, as it should presumably happen in tidally locked binaries, could cause a large amount of lithium to be preserved. This effect which has been observed, for example, in the Hyades binaries and in a short period binary in the old cluster M 67 (Deliyannis et al. 1994), does not however seem relevant in the present context given that both GJ 142 and GJ 798 appear to be single.

Should the observed feature prove not to be lithium, its presence might prove to constitute an effective limit to the detectability of lithium in low mass stars. Contamination from this feature could for example be (partially) responsible for the possible spread in the equivalent width of the Li I feature in the coolest Hyades members studied by Thorburn et al. (1993), although the two coolest stars in their sample are apparently tidally locked binaries, in which surface lithium abundance might actually be enhanced by tidal locking, as discussed in their paper.

5. Summary

We have shown that some high resolution (R = 100,000) spectra of apparently old late-type main sequence stars present a feature indistinguishable in wavelength from the Li I 6707.8 Åline. Given that lithium should be burned, according to current models, on short time scales in these low mass stars, no surface lithium would be expected in them. Should the feature prove to be lithium, this would have significant implications on stellar interior models. We feel that through understanding of the complex spectra of these late type stars will require some extensive modeling work, which we hope to stimulate with the present paper.

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