Lithium Abundances in the Young PMS Stars FN Tau and V927 Tau: an Interplay of Observations and Theory

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Abstract:

We present models of the Li\(^{	ext{I}}\) 670.8 nm resonance doublet and the subordinate Li\(^{	ext{II}}\) 812.6 nm doublet. These lines are important indicators of lithium abundance in pre-main sequence (PMS) stars. Model atmospheres from Alard & Hauschildt (1995) were used to synthesize the lines and to include LTE and NLTE effects. We used the models to determine lithium abundances in the PMS stars, FN Tau (M6.5 IV) and V927 Tau (M6 IV), for which we have Keck Observatory observations with the HIRES instrument. The observations have the extremely high resolution of 45000. The derived lithium abundances in the atmospheres of both stars are cosmic (log \(N(\text{Li}) \approx 3.2\)). Our procedure also permits the determination of each star’s rotational velocity, \(v \sin i\), and microturbulent velocity, \(V_t\). These parameters can be determined independently using each of the two Li doublets separately. Thus two measurements per star can be made.

For V927 Tau we find \(v \sin i = 22 \pm 2\) km/s and \(V_t \approx 3.0 \pm 1\) km/s for both lithium doublets.

Interestingly, using the same classical approach for the younger PMS star FN Tau, we obtained different \(v \sin i\) from the 670.8 and the 812.6 nm doublets: 13 \(\pm 2\) km/s and \(\leq 6\) km/s respectively for \(V_t = 3.0 \pm 1\) km/s.

This discrepancy may be explained by including two other effects in the models. These effects are veiling, which can affect the continuum by up to 10%, and/or the presence of chromospheric-like features.

1. Introduction

Recent theoretical investigations of K and M type pre-main sequence (PMS) stars (Magazzù et al. 1992; Martín et al. 1994; Zapatero Osorio et al. 1995; and García López et al. 1994) showed that lithium should be destroyed effectively during the first 20 to 30 Myr in the evolution of low-mass stars. The low-mass PMS stars should, however, maintain their initial lithium abundances during their first few Myrs (e.g., D’Antona & Mazzitelli 1994). This has been confirmed observationally through spectroscopic studies of various extremely young T Tauri stars. (see for example Basri et al. 1991 and various earlier references therein.)

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Here, we present synthetic spectra made to match regions of the spectra of the two young PMS stars V927 (M5.5 IV) and FN Tau (M5 IV). Both PMS stars lie above the main sequence, but their spectral energy distribution (SED) indices are different: III for V927 Tau and II for FN Tau (Kenyon & Hartman 1995). The spectrum of FN Tau is affected by veiling. Our purpose is to fit both lithium doublets with a single, consistent model for each of the stars. The model parameters are the lithium abundance, log N(Li), the rotational velocity, \( v \sin i \), and the microturbulent velocity, \( V_t \).

2. Procedure

The observational data were obtained with the Keck Telescope in conjunction with the HIRES instrument (Vogt 1992). The data reduction procedures are detailed in Oppenheimer et al. (1997). The data were obtained on the nights of 12, 13, and 14 of October 1994 in clear weather conditions. The spectra cover the range from 630.0 nm to 850.0 nm with small gaps between the spectral orders. The slit size was 0.861" resulting in a resolution of \( \lambda/\delta\lambda = 45,000 \). For the purposes of this paper only the regions around the Li lines at 670.8 nm and 812.6 nm were used.

Model spectra were synthesized with Kurucz’s (1993) molecular line lists and the VALD (Piskunov et al. 1995) atomic line lists assuming local thermodynamic equilibrium (LTE) and using WITA31 program (Pavlenco 1997). We use model atmospheres from the grid of Allard and Hauschildt (1995, hereafter AH95). These spectra were then convolved with the rotational line profile using Gray’s (1976) formulae.

The Kurucz (1993) line list gives the mean level of the molecular absorption around the Li lines. This permits us to reproduce the lithium line profiles along with the mean flux nearby (see Pavlenko 1997 for details). This is necessary for an accurate assessment of the observed spectra, which of course show heavily the effects of molecular absorption in these regions.

3. Results

3.1. V927 Tau

Lithium lines in the spectrum of V927 Tau are broadened by rotation. The comparison of observed and computed spectra for different \( v \sin i \) and log N(Li) models are shown in the Fig. 1. We found that the best fit for this star is \( v \sin i = 22 \) \( \text{km} \text{s}^{-1} \) for both lines.

We cannot reproduce yet the observed \( \text{V}i \) 811.6 nm line together with \( \text{Li}i \) subordinate doublet \( \lambda 812.6 \) nm profile. Interestingly, the rotational velocity of \( v \sin i = 22 \) \( \text{km} \text{s}^{-1} \) seems too high for the \( \text{V}i \) line.

Asymmetry of \( \text{Li}i \) 670.8 profile may be caused by the large-scale motions in the atmosphere of V927 due to the different contribution into the line flux of rising (hot) and moving down (cool) matter (Gray 1988).

Note, the effect could not be explained by the molecular absorption because \( \lambda 670.8 \) \( \text{Li}i \) line core is formed above the region of the molecular line forming region.
Figure 1. Observed V927 Tau and computed spectra for several lithium abundances in the 670.8 a) and 812.6 nm b) regions are shown by solid and dashed lines, respectively. Model atmosphere 3100/4.5/0, $v\sin i = 22$ km s$^{-1}$
High lithium abundance provides strong constraints on the age of V927 (≈ 2–4 Myr).

### 3.2. FN Tau

FN Tau presents a more complicated case for analysis. Strictly speaking, for FN Tau we cannot arrive at a unique solution.

The profile (except for the core) of the resonance doublet λ 670.8 nm can be well-fitted by the synthetic spectrum of the 3100/4.5/0.0 AH95 model atmosphere, with \( v \sin i = 13 \text{ km s}^{-1} \), and \( \log N(\text{Li}) = 3.3 \) (Fig. 2). However, for that rotational velocity we cannot fit the 812.6 nm doublet with the same lithium abundance. Instead the 812.6 nm doublet is best fit with \( \log N(\text{Li}) = 4.0 \).

Alternatively, we may fit the subordinate doublet for \( \log N(\text{Li}) = 3.3, V_t = 2.0 \text{ km s}^{-1} \) and \( v \sin i = 0 \text{ km s}^{-1} \), but these parameters are not acceptable for the 670.8 nm doublet. These results are shown in Figure 2.

NLTE abundance corrections for the 3100/4.5/0 are +0.1 dex for 670.8 nm doublet and –0.2 dex for 812.6 nm doublet. So the discrepancies between our results cannot be explained by NLTE effects.

It is important to note that we see in the profile of 670.8 doublet an emission core (Fig. 2). The 812.6 nm feature, in contrast, does not show core-reversal.

To fit the whole profile of the resonance doublet of 670.8 nm as well as 812.6 line we supposed that the FN Tau has a strong “chromospheric-like” feature (CLF) to provide the emission core of the 670.8 doublet (see Pavlenko 1995, Pavlenko et al. 1995 and Houdebine & Doyle 1995).

We built up the CLF with \( T_{\text{min}} = 0.7 T_{\text{eff}} = 2100 \text{ K}, G_r = \partial T / \partial \log m = -300 \) over the photosphere of 3100/4.5/0 (Fig. 3).

Using the model atmosphere with CLF we may fit observed spectra for \( v \sin i = 6 \text{ km s}^{-1}, V_t = 3.0 \text{ km s}^{-1} (V_t < V_s, \text{ see Fig. 3}) \) and \( \log N(\text{Li}) = 3.3 \) for both lithium lines (Fig. 4). Furthermore, using the same model we may fit the observed core of the 670.8 nm lithium resonance doublet. Note, only the resonance doublet is affected by the CLF, which agrees with the observations in that the 812.6 nm line does not show evidence of an emission core. This makes physical sense because subordinate lithium doublets, like the 812.6 nm line are formed in deeper layers of the atmosphere (Fig. 3).

### 4. Discussion

We used “non-dusty” model atmospheres computed by Allard & Hauschildt (1995) in the frame of the classical approach. As was shown by Tsuji et al. (1996) and Jones & Tsuji (1997) dust plays a major role in the opacities of stellar atmospheres with \( T_{\text{eff}} < 2700 \text{ K} \). Furthermore, TiO depletion processes should be taken into account as another kind of “dusty” effect (Pavlenko 1998).

Our fits of V927 Tau and FN Tau are of different quality. In the case of V927 Tau, the value of \( v \sin i \) is large and well-defined for both lithium lines. In the case of FN Tau \( v \sin i \) is lower so that a solution is less certain. Moreover, the veiling effects are much more pronounced in FN Tau, and with the first step in model fitting we were unable to achieve a single consistent model for both lines. The lithium resonance doublet λ 670.8 nm has a core-reversal feature. Only by adding the CLF effects were we able to reconcile the models with the...
Figure 2. Observed FN Tau and computed spectra for several lithium abundances in the 670.8 nm region are shown by solid and dashed lines, respectively. Model atmosphere 3100/4.5/0, V\textit{sin}\textit{i} = 13 km/s

observations. However, to decide whether this CLF effect or another effect, such as duplicity, is responsible for FN Tau’s spectrum, a more extended study has to be carried out. NLTE may be important also. A study of the K\textsc{i} 769.9 nm line might provide the answer to this question. That line shows strong dependence on the temperature. We are in the process of examining the K\textsc{i} line.

For the slow-rotating stars the W-like shape of strong lines may be caused by the duplicity effect. Indeed both stars are members of multiple systems. Still we see the normal shape of Li\textsc{i} 812.6 and V\textsc{i} 811.6 subordinate lines. For the
time being we conclude the hypotheses of duplicity effects in the creating of the W-like profile seems not too probable.

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Figure 4. Observed FN Tau and computed spectra for several lithium abundances in the 670.8 nm region are shown by solid and dashed lines, respectively. Model atmosphere 3100/4.5/0 with CLF, $v \sin i = 6$ km s$^{-1}$
References

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