

## ON THE REALITY OF THE HIGH LITHIUM ABUNDANCES IN CARBON STARS

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Because of recent advances in model atmospheres for cool stars, there may be some doubt as to the validity of previous estimates of the Li abundance in the super-Li stars. Through the behavior of the resonance lines of K I, we show that these analyses are correct, and that the super-Li stars represent a real abundance peculiarity of Li.

*Key words:* super-Li stars — Li abundances

The super-lithium stars, of which there are presently six known examples (Warner and Dean 1970; Catchpole and Feast 1971), display in their spectra enormously strong resonance lines of neutral lithium at 6707 Å. Several methods have been used by previous investigators to derive lithium abundances greater than that of the T Tauri stars, in which Li/H is approximately  $10^{-9}$ . These stars thus become important examples of stellar production of Li, presumably convected upwards from the envelope.

Since suitable model atmospheres for such cool stars are not available, the lithium abundance for T Sagittarii, a less extreme super-lithium star, has been derived by Boesgaard (1970) using a single layer approximation and comparing the resonance line of Li with several absorption lines of Ca I (including the resonance line at 6572 Å), to derive  $\text{Li}/\text{Ca} \approx 10^{-2}$  for this star. Spitzer (1949) has compared the behavior of the D lines of Na I and the Li I resonance line, assuming both to be on the damping part of the curve of growth, to obtain  $\text{Li}/\text{Na} = 5 \times 10^{-2}$  for WZ Cassiopeiae.

Recent advances in model atmospheres of cool stars have cast some doubt on each of the above procedures. Several investigators (Johnson 1973; Carbon 1973) have shown that the boundary temperatures of cool stars can be strongly depressed by CO and CN radiative cooling. Since we are considering strong resonance lines, they will be formed preferen-

tially in the outermost layers of the atmosphere. We will therefore be in the temperature region where Ca is largely neutral while Li may still be ionized due to the 0.721 eV difference in their ionization potentials. If the temperature is actually lower than expected, the Li becomes neutral and the Li resonance line becomes stronger. Since the temperature used by Boesgaard (1970) is that characteristic of a layer where the weaker Ca I lines are formed, this procedure becomes susceptible to errors, which may be large. For example, a change in temperature from 2500° K to 2200° K for an electron pressure typical of the outermost region of a giant star changes the ratio  $(\text{Li I}/\text{Li})/(\text{Ca I}/\text{Ca})$  by a factor of 20. If this were the case, the super Li stars would then have Li abundances close to those of the T Tauri stars.

Even though sodium and lithium have almost the same ionization potential (5.138 and 5.390 eV, respectively) under normal circumstances, the sodium lines, being so much stronger may be formed sufficiently far out in the atmosphere that, due to the drop in the boundary temperature, the Na is largely neutral while the Li may not be completely neutral. If we imagine that the super-Li stars are differentially C- or N-rich we may be able to produce enough additional line blanketing to force both the Li and Na resonance lines to be formed where both are largely neutral, thus producing stronger Li resonance lines. Although these conjectures may be slightly farfetched, the fact that the super-Li stars are among the coolest C and CS stars leads one to expect that effects such as were discussed above may be important.

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Since it would be extremely interesting from the point of view of nuclear astrophysics to decide whether or not we can force the Li abundance in the "super-Li" stars equal to or below that of the T Tauri stars, we have investigated the behavior of the resonance lines of K I at 7665 Å and 7699 Å in the super-Li stars. The first ionization potential of K is 1.051 eV less than that of Li, and the K I and Li resonance lines are of approximately the same strength. Therefore if the Li lines are enhanced because a drop in the boundary temperature is forcing more lithium into the lowest stage of ionization, we may expect strong lines of K I in the super-Li stars. Also, a comparison of Li and K neutral resonance line strengths using the approximation that both lines are on the damping part of the curve of growth may be more valid than a similar comparison of Li and Na neutral line strengths. Richer (1971) has noted that WZ Cas has extremely strong K I lines for its spectral class (which he gives as C5).

We have therefore taken spectra, with the Varo image tube at the 3-meter spectrograph and the coudé auxiliary telescope of Lick Observatory, of several super-Li and comparison stars. The stars, their spectral class, and K I line strength are listed in Table I. The K I line strengths are not very accurate due to problems of determining the continuum

position. Our measurements agree reasonably with those of Sanford (1950) for the two stars in common. We see that the super-Li stars do not have abnormally strong K I. The ratios  $(\text{Li}/\text{K})/(\text{Li}/\text{K})_{\text{normal}}$  listed in the last column of Table I, were derived using the approximation that both lines are on the damping part of the curve of growth, and comparing the line ratios in the super-Li stars with those in the control stars of the same spectral type.

The consistency of the enhancement of Li with that derived from the Na and Ca lines implies that there is no possible way of explaining the strong Li resonance line as a change in the atmospheric structure of temperature distribution. The super-lithium phenomenon is a real abundance peculiarity of lithium. An explanation, such as that proposed recently by Scalo and Ulrich (1973), for the super-lithium phenomenon is needed from nuclear astrophysics.

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TABLE I

	Type	K I LINE STRENGTHS		$(\text{Li}/\text{K})/(\text{Li}/\text{K})_{\text{normal}}$
		$W_{\lambda}(7699) \text{ \AA}$ K	$W_{\lambda}(6708) \text{ \AA}$ Li	
Super-Li Stars				
T Sgr	S5,8e	0.8A	1.5A*	100
WZ Cas	C5p	1A	10A†	75
WX Cyg	C9,1	3A	10A†	> 10
Comparison Stars				
R Cyg	S5,8e	2.5A	0.4A*	
VY UMa	C5 II	0.6A		
19 Psc	C5 II	0.5A	0.6A†	
U Hya	C5 II	0.5A	0.7A†	
R Hya	M6e	0.6A		

\*Boesgaard (1970).

†Torres-Peimbert and Wallerstein (1966).