Bioastronomy 2002: Life Among the Stars
IAU Symposium, Vol. 213, 2004
R.P.Norris and F.H.Stootman (eds.)

Refining the Search for ^{6}Li in Stars with Planets

A. M. Mandell, J. Ge

Department of Astronomy, Pennsylvania State University, State College, PA 16803

N. Murray

CITA, University of Toronto, Toronto, Ontario M5S 3H8

Abstract. The primary conflict between studies attempting to measure ^{6}Li in stars harboring planets, a potential indicator of planet formation, is the incompleteness and inaccuracy of current line lists for the lithium region. We are attempting to resolve these issues using very high-resolution (R $\sim$ 120,000) and very high quality (S/N between 250 and 1000) spectra of stars with a range of abundances.

1. Introduction

To explain the presence of massive extrasolar planets very close to their parent stars, current formation models often incorporate orbital migration and/or planetary scattering (see Trilling et al. 2002 for references). A possible consequence of these processes would be the ingestion of planets into the atmosphere of the star if migration is not halted. It is theorized that this deposition of planetary material could be detected as excesses of rare elements, most notably the ^{6}Li isotope. Theoretical calculations predict that ^{6}Li is completely destroyed in the pre-main sequence phase of stellar evolution, and anomalously high abundances of ^{6}Li in normal main-sequence stars could be an important diagnostic of planet formation processes. However, the spectral features for ^{6}Li are heavily blended with both ^{7}Li and other atomic and molecular lines; several groups (Israelian et al. 2001, Reddy et al. 2002) have reported conflicting results from recent studies of lithium-rich planet-bearing stars.

To resolve the issues behind unknown lines, we have taken observations of both lithium-rich stars (where additional lines would be hidden) and lithium-poor stars (where additional lines would be revealed). The stars span a range in lithium abundance and overall metallicity. We hope to use the stars with low Li abundances and high metallicities to accurately model the other blending lines; these results can then be compared to stars with strong lithium lines.

2. Observations

Observations were taken with the High Resolution Spectrograph at the Hobby-Eberly Telescope (Tull 1998) over a period of a year. The HRS is a fiber-coupled

https://doi.org/10.1017/S0074180900192964 Published online by Cambridge University Press

echelle spectrograph, using an R-4 echelle mosaic with cross-dispersing gratings. Due to lithium emission lines in the flatfield illumination lamp, it was necessary to use extremely high signal-to-noise observations of rapidly rotating B and A stars as flat fields. These calibration stars were observed as near in time to the program stars as possible. Reduction was performed using standard IRAF subroutines for one dimensional spectra. The S/N per pixel for each star is listed in Table 1.

Table 1. Atmospheric Parameters of Program Stars

Star	T_{eff}	Log g	ξ	[Fe/H]	S/N
HD 209458	6063	4.38	1.02	0.04	250
47 Ursa Majoris	5800	4.25	1.00	0.01	1000
Upsilon Andromeda	6140	4.12	1.35	0.12	700
Rho CrB	5750	4.11	1.20	-0.29	700[b]
51 Pegasi	5795	4.41	1.01	0.21	350[b]
HD 22484[a]	5950	4.00	1.35	-0.11	250
HD 12235[a]	5971	4.18	1.10	0.15	500[b]

[a] Stars without planets

[b] Observations have not been completed

3. Preliminary Calibrations

Stellar broadening parameters (Vsini, Vmac) were derived from χ^2 minimization to nearby Fe I lines at 6703.5 Å, 6705.1 Å, 6713.7 Å, and 6715 Å. We took the average of the three lines with the lowest χ^2 as our final value. The lithium lines are relatively insensitive to the specifics of the broadening parameters, and rerunning the lithium analysis for the various broadening results showed no visible differences.

Stellar radial velocity was evaluated using the nearby Fe I lines, and the effects of granulation noted by Allende Prieto et al. (2002) were accounted for. However, this calibration is under revision for most of our stars, and may account for some of the discrepancy seen in our current results.

4. Line List

Analysis of the solar lithium region for several decades, as well as recent analysis of lithium-poor stars with high-resolution instruments, has resulted in increasingly detailed line lists (Grevesse 1968; Brault & Muller 1975; Lambert et al. 1993; King et al. 1997). However, there are several factors that have impeded this progress. The obvious existence of an unknown line at 6708.025 Å has been commented on by many authors but never adequately resolved, and the ubiquitous presence of the CN red system remains a problem. Reddy et al. (2002) attempt to confront both issues, but their treatment is ad hoc and not necessarily complete. A full reanalysis of the CN lines in the lithium region is in

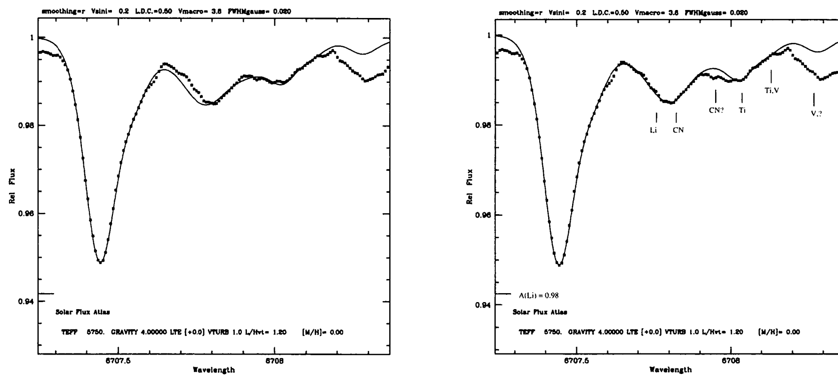

Figure 1. Comparison between lithium abundance of earlier work (graph on left) and a decreased lithium abundance and increased CN line (graph on right), which gives a better fit to the lithium line but requires additional lines at longer wavelengths.

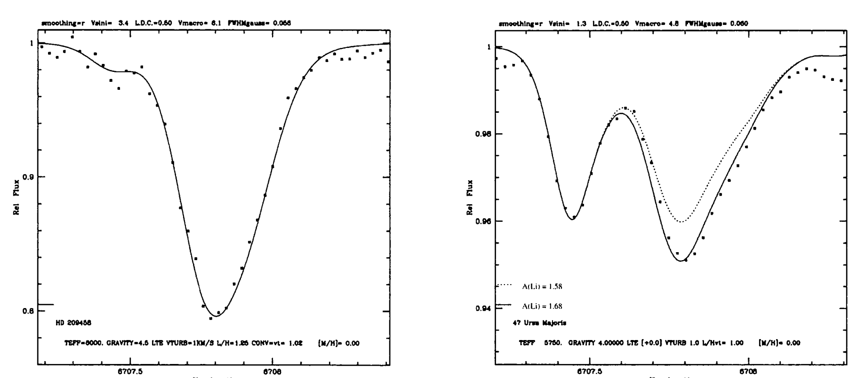

Figure 2. Observed and synthetic spectrum for HD209458, a lithium-rich star, compared with 47 Ursa Majoris, a lithium-poor star. The importance of additional lines in stars with a low lithium abundance is evident.

https://doi.org/10.1017/S0074180900192964 Published online by Cambridge University Press

progress, and a fit to the Kurucz Solar Flux spectrum (Hinkle 2000) suggests that adjustments to the gf values and wavelengths of the existing CN lines are necessary.

Our current fit to the solar spectrum is presented in Figure 1; the strength of the CN line at 6707.82 Åhas been increased in the second plot for a better fit. However, with this value the presence of additional lines is necessary at 6707.92 Å (most likely CN, as suggested by Brault & Muller). When the lithium line is over-abundant compared to the other weak lines in the region, the additional blended lines do not affect the deepest part of the feature but may affect the wings. This is evidenced by fits to HD 209458 (a lithium-rich star) compared to 47 UMa (a lithium-poor star) in Figure 2.

The fit to 47 UMa actually raises the question of whether the CN line at 6707.82 should be increased, or whether another line should be added instead. The fit does not work with a larger amount of lithium (similar to the fit to the Sun by Reddy et al. (2002)), but CN does not account for the line depth when lithium is decreased. The addition of another line should be investigated as a distinct possibility. If this proves to be correct, the analysis of both lithium isotopes would be radically altered in lithium-poor stars.

5. Conclusion

Currently the debate on ^{6}Li in planet-bearing stars is still open. Most likely the question will not be settled until the lithium region can be accurately modelled with a complete line list, and this is accomplished most effectively by observing lithium-poor stars at very high quality. We hope to resolve these issues, and in doing so confirm either the existence or absence of ^{6}Li in stars with planets.

References

Allende Prieto, C., Lambert, D. L., Tull, R. G., & MacQueen, P. J. 2002, ApJ, 566, L93

Brault, J. W. & Muller, E. A. 1975, Solar Phys., 41, 43

Grevesse, N. 1968, Solar Phys., 5, 159

Hinkle, K., Wallace, L., Valenti, J., & Harmer, D. 2000, Visible and Near Infrared Atlas of the Arcturus Spectrum 3727 - 9300 Å(San Francisco: ASP)

Israelian, G., Santos, N. C., Mayor, M., & Rebolo, R. 2001, Nature, 411, 163

King, J. R., Deliyannis, C. P., Hiltgen, D. D., Stephens, A., Cunha, K., Boesgaard, A. M. 1997, AJ, 113, 187

Lambert, D. L., Smith, V. V., & Heath, J. 1993, PASP, 105, 568

Reddy, B. E., Lambert, D. L., Laws, C., Gonzalez, G., Covey, K. 2002, in press, astro-ph/0205268

Trilling, D. E., Lunine, J. I., & Benz, W. 2002, in press, astro-ph/0208184

Tull, R. G. 1998, Proc. SPIE, 3355, 387