The supergiant η Leo (A0 Ib)

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ABSTRACT

In this study we use preliminary atmospheric parameters of the A0 Ib supergiant η Leo (T_{eff}, log g and microturbulence velocity) to provide initial estimates of the elemental abundances from S II, Ti II, Cr II, Fe I and Fe II lines by using spectrograms with a two pixel resolution of 0.072 Å and high signal-to-noise ratio taken at Dominion Astrophysical Observatory.

1. INTRODUCTION

η Leo ($\alpha = 10^h\ 07^m\ 19.9523^s$, $\delta = +16^0\ 45'\ 45.592''$) is a Population I A0 Ib supergiant. CNO abundances analysis for η Leo were derived by Lambert, et al. (1988), Takeda and Takada-Hidai (1995,1998 and 2000), and Venn (1995b) in both LTE and non-LTE and by Pryzbilla et al. (2000, 2001) and Pryzbilla & Butler (2001) in LTE, non-LTE. Hill et al. (1986) claim it is a member of the Sco-Cen Association. It was classified as an visual binary, but not orbitting by Blazit et al. (1977) and occulting binary by Hill et al. (1986).

Venn (1995) derived T_{eff} = 9700 K, log g = 2 by using Hγ wing fitting and Mg I / Mg II non-LTE ionization equilibrium. Pryzbilla (2001) calculated its effective temperature and log g, respectively, as 9600 ± 150 K, 2.00 ± 0.15. Its mass, $9M_{\odot}$ and radius, $40R_{\odot}$ were determined by Wolf (1971).

2. SPECTRA and LINE MEASUREMENTS

This study uses spectrograms taken with the long camera of the Dominion Astrophysical Observatory's coude spectrograph and CCD dedectors. The two pixel resolution is 0.072 Angstroms. The signal-to-noise ratio of most spectrograms are at least 200. In this preliminary study spectrograms R122_99_15192 (λλ4488-4550), R122_99_15395 (λλ4434-4494), R122_99_1794 (λλ4212 -4274) and R122_99_14097 (λλ4884-5044) have been used. The spectra were rectified using the interactive computer graphics program REDUCE (Hill & Fisher 1986) for line measurements. First we determined v sin i = 8.5 ± 0.5 km s^{-1} by line fitting of clean weak lines with Gaussian profiles using VLINE (Hill & Fisher 1986). Then we used VLINE to measure all the lines. In these runs we used the parameter fixed mode for weak lines (EW < 20 mÅ) and Gaussian fits constrained by the spectrum for stronger lines (EW > 20 mÅ). We measured the radial velocity from the Doppler shift of unblended lines for each spectra. These were used to determine the rest wavelengths of all of the lines. Then we identified these lines by means of standard lists of atomic lines especially Moore (1945).

Table 1. Radial velocity corrections for measured spectra.

Spectra	Wavelength (Å)	RV (km s^{-1})
R122_99_15192	λλ 4488-4550	-37.13
R122_99_15395	λλ 4434-4494	-38.41
R122_99_1794	λλ 4212–4274	-17.56
R122_99_14097	λλ 4884-5044	+3.55

3. DERIVATION of MICROTURBULENT VELOCITY and ELEMENTAL ABUNDANCES

Firstly, we determined the microturbulent velocity of ξ = 2.4 km s^{-1} from Fe II lines by imposing two conditions: 1) The abundances are not dependent on the equivalent width and 2) The scatter of abundances be a minimum. The minimum value of slope for EWs to abundances is 2.1 km s^{-1} and the minimum scatter occurs at 2.6 km s^{-1}. So the mean value is ξ = 2.4 km s^{-1}. Then we have calculated the elemental abundances from lines of S II, Ti II, Cr II, Fe I and Fe II by using this microturbulent velocity. The elemental abundances of Eta Leo for these species are given in Table 2 calculated with a T_{eff} = 9400 K and log g = 2.30 preliminary model with zero microturbulent velocity. Changing to a model with 2 km s^{-1} microturbulence should change the derived values by only a few hundredths of a dex.

Table-2. Elemental Abundances of Eta Leo.

Species	Multiplet	λ(Å)	log gf	Source	W_λ (mÅ)	log N/N_T
S II	15	5014.040	+0.03	WS	11.5	-4.41
	43	4463.580	+0.02	WM	6.2	-4.26
	43	4483.343	-0.32	WM	3.7	-4.29
						log S II / N_T =-4.31±0.21
Ti II	19	4483.60	-0.70	MF	60.4	-7.92
	19	4450.49	-1.45	MF	19.2	-7.88
	31	4501.27	-0.75.	MF	60.3	-7.85
	115	4456.50	-1.41	KX	5.8	-7.22
	115	4488.32	-0.82	MF	22.6	-7.16
						log Ti II / N_T = -7.61±0.34
Cr II	31	4252.62	-2.02	KX	22.9	-6.46
	31	4261.92	-1.53	KX	67.3	-6.19
	31	4269.28	-2.17	KX	17.2	-6.46
						log Cr II/N_T =-6.37±0.13
Fe I	42	4250.790	-0.71	MF	8.8	-5.44
	42	4271.760	-0.16	MF	30.2	-5.11
	350	4466.550	-0.59	MF	5.6	-4.71
						log Fe I /N_T =-4.99±0.20
Fe II	187	4446.240	-2.58	KX	10.6	-4.60
	222	4449.660	-1.60	KX	10.1	-4.55
	J	4263.900	-1.64	KX	10.5	-4.40
	J	4451.540	-1.82	KX	41.2	-4.47
	J	4455.260	-1.99	KX	31.4	-4.44
	J	4984.480	+0.01	KX	20.9	-4.41
	J	4990.510	+0.98	KX	28.8	-4.35
	J	4499.710	-1.76	KX	12.3	-4.41
	D	4487.500	-2.12	KX	10.2	-4.14
						log Fe II /N_T =-4.42±0.12

KX: Kurucz (1995) and Kurucz & Bell (1995)
MF: Fuhr, Martin & Wiese (1988) and Fuhr & Wiese (1988)
WM:Wiese & Martin (1980)
WS: Smith & Glennon (1966) and Wiese, Smith & Miles (1969)

The offset between the log N/N(H) and the log N/N_T values is about 0.04 dex. An analysis of the He I lines is needed to find the exact value. Table 3 gives the results of the preliminary studies of η Leo and their means. Ti II and Fe I are 0.59 and 0.46 dex deficient relative to Sun, respectively, Cr II has a solar abundance and Fe II and S II are overabundant by 0.12 and 0.46 dex respectively. That the results for Fe I and Fe II are so different means that the model parameters need to be slightly changed. Going to a higher temperature and lower log g will help.

Table 3. Calculated elemental abundances of Eta Leo relative to Sun (N/N_H)

Species	# of species	Eta Leo	Sun**	[X]*
S II	3	-4.27±0.21	-4.67	+0.40
Ti II	5	-7.57±0.34	-6.98	-0.59
Cr II	3	-6.33±0.13	-6.33	0 00
Fe I	3	-4.96±0.21	-4.50	-0.46
Fe II	9	-4.38±0.21	-4.50	+0.12

*$[X] = \log (N/N_H)_{star} - \log (N/N_H)_{Sun}$
**Grevesse et al. (1996)

Table 4 compares some equivalent widths of this study with those of Wolf (1971) who used T_{eff} = 10400 K and log g = 2.05. His equivalent widths are systematically larger. The dispersion of much of his material is similar to ours, but the signal-to-noise ratios of his photographic spectrograms are much less than ours.

Table 4. Some equivalent widths

Wavelength (Å)	Wolf (1971)*	W_λ (mÅ)	This study*	W_λ (mÅ)
Ti II (4450.5)	4.85	38.9	4.12	19.2
Cr II (4252.6)	5.22	32.4	5.54	22.9
Cr II (4269.3)	5.83	38.9	5.81	17.2
Fe I (4271.8)	7.68	50.1	6.89	30.2

*$\log \varepsilon (X) = \log N_X / N_H + 12.0$

Table 5 compares our results with same species Ti II (5), Cr II (3), Fe I (1), Fe II (22). In these parantheses, we give that the number of lines studied. Modifying our effective temperature and surface gravity should bring our results into closer agreement with hers.

Table 5. Comparison of the results with Wolf and Venn's.

Species	Wolf(1971)	Venn(1995a)	This study
S II	-	-	7.73 ± 0.21
Ti II	4.78	4.77 ± 0.14	4.43 ± 0.34
Cr II	6.35	5.80 ± 0.28	5.67 ± 0.13
Fe I	7.79	7.38 ± 0.12	7 04 ± 0.21
Fe II	7.75	7.52 ± 0.18	7.62 ± 0.21

4. SUMMARY

Ti II and Fe II are deficient relative to solar abundances. Cr II has the same abundance. Fe II and S II are overabundant. Fe I and Fe II are sufficiently different that our effective temperature and surface gravity need to be adjusted. A higher temperature and/or a lower log g is needed to get accurate abundances. For this determination, many more lines need to be measured to obtain ionization equilibrium and the profile of one or more Balmer lines will be used.

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6. REFERENCES

Blazit, A., Bonneau, D., Koechlin, L., Labeyrie, A., 1977, ApJ, 214, L79
Grevesse, N., Noels A., Sauval, A. J., 1996, Astronomical Society of the Pacific Conference Series, Volume 99, 117
Fuhr J.R., Martin G.A., Wiese W.L., 1988, J. Phys. Chem. Ref. Data 17, Suppl. 4
Hill, G., & Fisher, W. A., 1986, Publ. Dom. Astrophys. Obs., 16, 13
Hill, G.M., Walker G.A.H., Yang S., 1986 PASP, 98, 1186
Kurucz R.L., 1995, In: Adelman S.J., Wiese W.L. (eds.) Astrophysical Applications of Powerful New Databases. ASP Conference Series, p. 205.
Lambert D.L., Hinkle K.H., Luck R.E., 1988, ApJ, 333, 917
Martin G.A., Fuhr J.R., Wiese W.L., 1988, J. Phys. Chem. Ref. Data 17, Suppl. 3
Moore C.E., 1945, A Multiplet Table Astrophysical Interest. Princeton University Observatory
Takeda Y., Takada-Hidai M. 1995, PASJ. 47, 169
Takeda Y., Takada-Hidai M. 1998, PASJ. 50, 629
Takeda Y., Takada-Hidai M. 1995, PASJ. 52, 113
Przybilla N., Butler K., Becker S.R., Kudritzki R.P., Venn K.A, 2000, A&A 359, 1085
Przybilla N., Butler K., Kudritzki R. P., 2001, A&A, 379, 936
Przybilla N., Butler K., 2001, A&A, 379, 955
Venn, K.M. 1995a, ApJS, 99, 659
Venn, K.M. 1995b, ApJ, 449, 839.
Wiese W.L., Smith M. W. and Glennon, B. M. 1966, NSRDS-NBS 4 US, Goverment Printing Office, Washington DC.
Wiese W.L., Smith M.W., Miles B.M., 1969, NSRDS-NBS 22, US Government Printing Office, Washington DC
Wiese W.L. and Martin G.A., 1980. NSRDS-NBS 68 Part 2, US Government Printing Office, Washington DC
Wolf, B., 1971, A&A 10, 383