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The supergiant η Leo (A0 Ib)

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Abstract. In this study we use preliminary atmospheric parameters for the A0 Ib supergiant η Leo ($T_{\text{eff}}, \log g$ and microturbulent 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 signal-to-noise ratio $\geqslant$ 200 taken at the Dominion Astrophysical Observatory.

Keywords. Stars: individual: (η Leo), stars: fundamental parameters, stars: abundances, stars: supergiants.

1. Introduction

η Leo ($\alpha(2000) = 10^h\ 07^m\ 19.9^s$, $\delta(2000) = +16^0$ 45’ 45.6”) is a Population I A0 Ib supergiant. CNO abundances for η Leo were derived by Lambert *et al.* (1988), Takeda and Takada-Hidai (1995, 1998, 2000), and Venn (1995b) in both LTE and non-LTE and by Pryzbilla *et al.* (2000, 2001) and Pryzbilla & Butler (2001) in LTE and non-LTE. Hill *et al.* (1986) claim it is a member of the Sco-Cen Association. It was classified as a visual nonorbiting binary by Blazit et al. (1977) and an occulting binary by Hill *et al.* y (1986).

Venn (1995) derived $T_{\text{eff}} = 9700\,\text{K}$, $\log g = 2$ by using $H\gamma$ wing fitting and Mg I/Mg II non-LTE ionization equilibrium. Pryzbilla (2001) calculated its effective temperature and $\log g$, respectively, as $9600 \pm 150\,\text{K}$, 2.00 ± 0.15. Its mass, $9\,M_\odot$ and radius, $40\,R_\odot$ 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 coudé spectrograph and CCD detectors. The two pixel resolution is 0.072 Å. The signal-to-noise ratio of most spectrograms are $\geqslant$ 200. In this preliminary study spectrograms R122_99_15192 ($\lambda\lambda$4488-4550), R122_99_15395 ($\lambda\lambda$4434-4494), R122_99_1794 ($\lambda\lambda$4212-4274) and R122_99_14097 ($\lambda\lambda$4884-5044) have been used. The spectra were rectified using the interactive computer graphics program REDUCE (Hill & Fisher 1986). Next we determined $v \sin i = 8.5 \pm 0.5\,\text{km}\,\text{s}^{-1}$ by line fitting several 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

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Table 1. Measured radial velocities.

Spectra	Wavelength (mÅ)	RV ($\mathrm{km\,s^{-1}}$)
R122_99_15192	4488-4550	-37.13
R122_99_15395	4434-4494	-38.41
R122_99_1794	4212-4274	-17.56
R122_99_14097	4884-5044	+3.55

Table 2. Elemental Abundances of η Leo.

Species	Multiplet	λ (Å)	$\log gf$	Source	W_λ(mÅ)	$\log(N/N_\mathrm{T})$
S II	15	5014.04	+0.03	WS	11.5	-4.41
	43	4463.58	+0.02	WM	6.2	-4.26
	43	4483.34	-0.32	WM	3.7	-4.29
				$\log \mathrm{S\,II}/N_\mathrm{T} = -4.31 \pm 0.21$		
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
				$\log \mathrm{Ti\,II}/N_\mathrm{T} = -7.61 \pm 0.34$		
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
				$\log \mathrm{Cr\,II}/N_\mathrm{T} = -6.37 \pm 0.13$		
Fe I	42	4250.79	-0.71	MF	8.8	-5.44
	42	4271.76	-0.16	MF	30.2	-5.11
	350	4466.55	-0.59	MF	5.6	-4.71
				$\log \mathrm{Fe\,I}/N_\mathrm{T} = -4.99 \pm 0.20$		
Fe II	187	4446.24	-2.58	KX	10.6	-4.60
	222	4449.66	-1.60	KX	10.1	-4.55
	J	4263.90	-1.64	KX	10.5	-4.40
	J	4451.54	-1.82	KX	41.2	-4.47
	J	4455.26	-1.99	KX	31.4	-4.44
	J	4984.48	+0.01	KX	20.9	-4.41
	J	4990.51	+0.98	KX	28.8	–4.35
	J	4499.71	-1.76	KX	12.3	-4.41
	D	4487.50	-2.12	KX	10.2	-4.14
				$\log \mathrm{Fe\,II}/N_\mathrm{T} = -4.42 \pm 0.12$		

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)

lines (equivalent width $W_\lambda < 20\,\mathrm{m\AA}$) and Gaussian fits constrained by the spectrum for stronger lines ($W_\lambda > 20\,\mathrm{m\AA}$). We measured the radial velocity from the Doppler shift of the 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 3. Calculated elemental abundances of η Leo relative to Sun (N/N_{H}).

Species	no 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

* $[X] = \log(N/N_{\mathrm{H}})_{\mathrm{star}} - \log(N/N_{\mathrm{H}})_{\odot}$
** Grevese et. al.(1996)

Table 4. Some equivalent widths.

Wavelength $\lambda(\AA)$	Wolf (1971)*	$W_{\lambda}(m\AA)$	This study*	$W_{\lambda}(m\AA)$
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

* $\log \varepsilon(X) = logN_{\mathrm{X}}/N_{\mathrm{H}} + 12.0$

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

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

3. Derivation of microturbulent velocity and elemental abundances

We determined the microturbulent velocity of $\xi_{\mathrm{T}} = 2.4$ km s^{-1} from Fe II lines by imposing two conditions: 1) the abundances are not dependent on the equivalent width W_{λ} and 2) the scatter of abundances is a minimum. The minimum value of slope for W_{λ} to the abundances is 2.1 km s^{-1} and the minimum scatter occurs at 2.6 km s^{-1}. So the mean value is $\xi_{\mathrm{T}} = 2.4\,\mathrm{km\,s^{-1}}$. Then we 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 η Leo for these species are given in Table 2 calculated with a $T_{\mathrm{eff}} = 9400$ 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.

The offset between the $\log N/N_{\mathrm{H}}$ and the $\log N/N_{\mathrm{T}}$ 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 I are overabundant by 0.12 and 0.46 dex, respectively. That the results for Fe I and Fe II are sufficiently different means that the model parameters need to be changed. Going to a higher temperature and/or to a lower $\log g$ will help.

Table 4 compares some equivalent widths of this study with those of Wolf (1971) who used $T_{\mathrm{eff}} = 10400$ 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 5 compares our results with those of Wolf (1971) and Venn (1995) for Ti II, Cr II, Fe I, and Fe II. Modifying our effective temperature and surface gravity should bring our results into closer agreement with Venn's (1995) values..

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. For this determination, many more lines need to be measured to obtain ionization equilibria and the profile of one or more Balmer lines will be used.

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