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Elemental abundance analyses with Complejo Astronómico El Leoncito REOSC echelle spectrograms.
I. κ Cancri, HR 7245, and ξ Octantis

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Abstract. — Elemental abundances are derived for three sharp-lined stars κ Cnc, HR 7245, and ξ Oct using REOSC echelle spectrograms obtained at CASLEO. Comparisons are made with published equivalent widths. The derived abundances for κ Cnc and ξ Oct are slightly larger than those obtained with other high dispersion spectrographs. HR 7245 exhibits a pattern of abundance anomalies similar to other Mercury-Manganese stars. The spectra of the two HgMn stars in the $\lambda\lambda$4640−5100 region exhibit an interesting and useful variety of lines which can be used to supplement analyses of the photographic region.

Key words: stars: abundances — stars: chemically peculiar — stars: κ Cnc — HR 7245 — ξ Oct

1. Introduction

The Southern Hemisphere has many bright early type stars. Those towards the South Celestial Pole remain relatively unexplored compared with similar stars in the Northern Hemisphere. They include examples of both common and rare types. In selecting stars for space observations astronomers have often been biased in their choices as the well examined stars of a given type are often those accessible from observatories in the Northern Hemisphere. This paper, which we hope will be the first in a series, examines the sharp-lined Southern Hemispheric star ξ Octantis as well as κ Cancri and HR 7245 which are in the equatorial region.

κ Cnc (= HD 79316 = HR 3623) is a Mercury-Manganese (Hg-Mn) star analyzed most recently by Adelman (1987) using coadded Dominion Astrophysical Observatory (DAO) IIaO spectrograms. It is one of the hottest members of this class and a single-lined spectroscopic binary. Its apparent rotational velocity is 6 km s^{-1}. HR 7245 (= HD 178065) is a sharp-lined Mercury star which most recently analyzed by Zakharova (1994). Guthrie (1984, 1985) found that its elemental abundances are similar to those of other HgMn stars with similar temperatures. Its Y abundance is among the least overabundant for the class. It is a single-lined spectroscopic binary with a period of 6.87 days.

The sharp-lined B6 IV star ξ Oct (= HR 8663 = HD 215573) has elemental abundances which are typical for those of normal B main-sequence band stars (Adelman et al. 1993). On average the derived values are 0.28 dex less than solar. It is one of the very few known sharp-lined middle B stars. If its true rotational velocity is typical of similar stars, then we are looking almost directly at one of its rotational poles.

The spectra were obtained at the Complejo Astronómico El Leoncito (CASLEO) located at latitude −31° 47′ 57″, longitude 4 h 37 m 12 s West at an altitude of 2550 m. We used the 2.15-m telescope, a twin to the similarly sized telescope at Kitt Peak National Observatory (KPNO), and a REOSC echelle spectrograph, which is on loan from the Institute Astrophysique de Liège, Belgium and a Tek 1024 CCD. A grating with 1200 lines mm^{-1} was used as a cross disperser. The resolution is 0.10 Å pixel^{-1} and the spectral range is about 650 Å per CCD exposure. A Th-Ar lamp was used for the wavelength calibration.

As this paper contains the first analyses from this telescope-instrument combination, we decided to study three stars for which some equivalent widths have been

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Table 1. He/H values for ξ Oct and HR 7245

	ξ Oct				HR 7245	
	AAT		CASLEO		CASLEO	
λ(Å)	W_λ(mÅ)	He/H	W_λ(mÅ)	He/H	W_λ(mÅ)	He/H
3867	55	0.045:	70	0.060	...	...
4009	...	...	156	0.063	...	...
4026	704	0.082	618	0.063	163	0.015
4121	72	0.062	81	0.074	...	...
4143	...	...	310	0.108	86	0.040
4169	...	...	33	0.093	...	...
4388	294	0.074	288	0.071	...	...
4438	...	...	35	0.057	...	...
4472	...	...	671	0.117	155	0.020
4713	...	...	...	...	18	0.010
4921	...	...	...	...	56	0.020
Average		0.073		0.078		0.021

published. We will be working to understand any differences in the line profiles (and equivalent widths) such as those produced by the instrumental profiles including scattered light. CASLEO is a relatively high dry site which tends to minimize telluric lines. This is especially important in the red and infrared. For equatorial stars of interest, we can extend the analyses of stars from Northern Hemispheric observatories, for example, the DAO, whose coudé spectrograph is optimized for $\lambda\lambda 3800-5000$, into the yellow and red.

2. Reduction of spectrograms

The spectra reductions were made using IRAF 2.10[1]. With bias and flat fields we obtained a combined flat field which was used to divide the spectra to remove the pixel-to-pixel variations. The extraction was performed with APALL and the wavelength calibration with IDENTIFY and DISPCOR using the comparison spectra.

We had two, three, and five exposures of approximately $\lambda\lambda 3830-4485$ for κ Cnc, HR 7245, and ξ Oct, respectively. Further for both κ Cnc and HR 7245, we had two and three exposures, respectively, covering approximately $\lambda\lambda 4500-5120$. For κ Cnc we also had two exposures covering $\lambda\lambda 4090-4800$. Within these spectral ranges not all of the spectra were equally useful. We obtained the spectra for ξ Oct in November 1994 and for κ Cnc and HR 7245 in April 1995. The signal-to-noise ratio (S/N) of these spectra is typically of at least order 300 in the centers of well exposed orders.

The REOSC spectrograms are better focused at the centers of the orders. There are also wavelength errors which we believe the IRAF reduction produces (as one of us SJA has had similar problems reducing KPNO coudé spectrograms). One can correct the wavelength scale of a particular order by using a second-order correction in the difference between the observed and laboratory wavelengths after sufficient lines have been identified. But then all radial velocity information is lost.

After the individual orders were extracted, they were normalized with REDUCE (Hill & Fisher 1986). The spectra of each star were coadded order by order to reduce the noise. One spectrum for each star was selected as a standard. Then its orders were cross-correlated with those of the other spectra using VCROSS before the orders were added using TSTACK. Finally the spectra were measured using VLINE. When broad lines such as those of He I occur near the peak of an order uncertainties in the placement of the continuum arise.

The stellar lines were identified with the general references A Multiplet Table of Astrophysical Interest (Moore 1945) and Wavelengths and Transition Probabilities for Atoms and Atomic Ions, Part 1 (Reader & Corliss 1980) as well as the more specialized references P II (Svendenius et al. 1983), P III (Magnusson & Zetterberg 1987), Mn II (Iglesias & Velasco 1964), Fe II (Johansson 1978), and Ga II (Isberg & Litzen 1985).

ξ Oct is a weak-lined star with relatively few lines per order at the observed spectral resolution. The unpublished line list of Adelman et al. (1993) based on Anglo-Australian Telescope (AAT) echelle spectrograph data was a useful guide in the regions of spectral overlap. We performed a least squares regression for 24 lines with equivalent widths less than 130 mÅ and found:

$$W_\lambda(\mathrm{CASLEO}) = -1.717 + 1.203 W_\lambda(\mathrm{AAT})$$

which reflects the lower resolution and S/N of the CASLEO data. The agreement of the two data sets is

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[1] IRAF is distributed by the National Optical Astronomical Observatories which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation.

Table 2. The analysis of the metal lines from CASLEO Spectra for ξ Oct

mult.	λ(Å)	log gf	Ref.	W_λ(mÅ)	log N/N_T
C II					(log C/N_T = -3.63 ± 0.32)
4	3918.98	-0.54	WS	26	-3.84
	3920.69	-0.24	WS	44	-3.79
6	4267.15	+0.97	WS	111	-3.26
Mg II					(log Mg/N_T = -4.71 ± 0.17)
4	4481.23	+0.97	WM	275	-4.46
9	4433.99	-0.90	WS	15	-4.78
10	4384.64	-0.78	WS	19	-4.81
	4390.58	-0.53	WS	27	-4.81
Si II					(log Si/N_T = -4.48 ± 0.10)
1	3853.66	-1.44	LA	68	-4.59
	3856.02	-0.49	LA	120	-4.43
	3862.05	-0.74	LA	112	-4.34
3	4128.07	+0.38	LA	105	-4.51
	4130.89	+0.53	LA	116	-4.51
S II					(log S/N_T = -4.89 ± 0.00)
49	4282.63	-0.01	WS	7	-4.88
	4294.43	+0.56	WS	16	-4.89
Ca II					(log Ca/N_T = -5.56)
1	3933.66	+0.14	WM	129	-5.56
Cr II					(log Cr/N_T = -6.39)
31	4242.38	-1.33	KX	6	-6.39
Fe II					(log Fe/N_T = -4.80 ± 0.20)
27	4233.16	-2.00	MF	46	-4.66
	4273.32	-3.34	MF	4	-4.91
	4303.17	-2.49	MF	14	-5.12
	4351.76	-2.10	MF	26	-5.12
	4416.82	-2.60	MF	24	-4.64
28	4178.86	-2.48	MF	26	-4.78
	4296.57	-3.01	MF	9	-4.86
173	3906.04	-1.83	MF	14	-4.56
J	4357.58	-2.10	KX	5	-4.59

Ref: KX = Kurucz (1995)
LA = Lanz & Artru (1985)
MF = Martin et al. (1988) and Fuhr et al. (1988)
WM = Wiese & Martin (1980)
WS = Wiese et al. (1966, 1969)

Table 3. Comparison of Abundances for ξ Oct

Species	AAT		CASLEO	
	log N/H	n	log N/H	n
He I	-1.14	3	-1.11	9
C II	-3.79	3	-3.59	3
O I	-3.24	1	...	...
O II	-3.42	5	...	...
Mg II	-4.68	2	-4.67	4
Si II	-4.73	5	-4.44	5
S II	-5.02	14	-4.85	2
Ca II	-6.08	1	-5.52	1
Ti II	-7.14	1	...	...
Cr II	-6.49	1	-6.35	1
Fe I	-4.27	3	...	...
Fe II	-4.72	20	-4.76	9
Ni II	-5.91	3	...	...

much better longward of 4150 Å than shortward of this value.

For HR 7245, a linear regression analysis with 39 equivalent widths from Guthrie (1984) who measured a 2.4 Å mm^{-1} DAO IIaO spectrogram yielded

$$W_\lambda(\mathrm{CASLEO}) = 5.212 + 0.617W_\lambda(\mathrm{DAO})$$

In addition we compared our values with 25 lines from Zakharova (1994) who used four 9 Å mm^{-1} spectrograms and found

$$W_\lambda(\mathrm{CASLEO}) = -6.934 + 0.775W_\lambda(\mathrm{Z})$$

But for κ Cnc, a comparison with 26 lines in the $\lambda\lambda$4500−4640 region with Adelman's (1987) study which used a coaddition of 10 2.4 Å mm^{-1} DAO IIaO spectrograms yielded

$$W_\lambda(\mathrm{CASLEO}) = -2.935 + 1.280W_\lambda(\mathrm{DAO})$$

which is a result similar to that found for ξ Oct. For κ Cnc we had a complete line identification list which we lacked for HR 7245 and could avoid blended lines. It is very difficult to reconcile these results which indicate the CASLEO equivalent widths are both too big and too small. We attempted to avoid blended lines in these comparisons.

3. Stellar parameters

We used Kurucz (1995)'s ATLAS9 model atmospheres which are the most appropriate for B and A type main sequence band stars. Programs SYNSPEC (Hubeny et al. 1994) and WIDTH9 (Kurucz, private communication) were employed, respectively, to determine the helium and metal abundances. The adopted metal-line damping constants were the default semi-classical approximations, except for iron-peak element lines, whose values were based on the data of Kurucz (1995); for C II, multiplet 6, Mg II multiplet 4, and Ca II multiplet 1, where the adopted values for the Stark broadening used the data of Sahal-Bréchot (1969); and for Si II multiplets 1 and 3, the damping constants were from Lanz et al. (1988). We used a 4% scattered light correction to account for light scattered along the direction of the dispersion, which is an appropriate value for clean optical systems.

To obtain initial estimates of the effective temperatures and surface gravities, we used homogeneous Stromgren $uvby\beta$ photometry (Hauck & Mermilliod 1990) and the formulation of Napiwotzki et al. (1993): T_{eff} = 13660 K, log g = 3.79 for κ Cnc, T_{eff} = 12360 K, log g = 3.45 for HR 7245, and T_{eff} = 14130 K, log g = 3.93 for ξ Oct. The photometry indicates that HR 7245 may be

Table 4. The analysis of the metal lines from CASLEO Spectra for κ Cnc

mult.	λ(Å)	log gf	Ref.	W_λ(mÅ)	$\log N/N_T$
P II			(log P/N_T = -4.59 ± 0.19)		
13	4927.20	-0.68	WS	10	-4.49
	4943.50	+0.06	WS	29	-4.41
	4954.39	-0.54	WS	14	-4.43
	4969.70	-0.19	WS	23	-4.39
15	4658.31	-0.31	WS	11	-4.86
28	4679.03	-0.40	KX	9	-4.75
S	4935.63	-0.16	WS	12	-4.51
Cr II			(log Cr/N_T = -6.17 ± 0.11)		
30	4824.12	-1.22	MF	24	-6.02
	4848.24	-1.14	MF	21	-6.20
	4876.41	-1.46	MF	10	-6.31
190	4912.46	-0.95	KX	3	-6.12
Mn II			(log Mn/N_T = -4.43 ± 0.21)		
-	4717.26	-1.86	KX	18	-4.40
	4727.84	-2.02	KX	35	-4.44
	4730.40	-2.15	KX	34	-4.15
	4738.30	-2.24	KX	20	-4.49
	4749.11	-2.00	KX	14	-4.57
	4755.73	-1.24	KX	50	-4.51
	4764.73	-1.35	KX	33	-4.94
	4791.78	-1.72	KX	28	-4.37
	4806.82	-1.56	KX	44	-4.37
	4811.62	-2.34	KX	17	-4.46
	4830.06	-1.85	KX	24	-4.38
	4839.74	-1.86	KX	17	-4.61
	4842.32	-2.00	KX	22	-4.29
	4847.61	-1.81	KX	20	-4.88
	4851.54	-2.61	KX	13	-4.36
	4920.44	-2.09	KX	25	-4.43
	4921.23	-1.58	KX	33	-4.15
	5102.52	-1.93	KX	30	-4.17
	5107.09	-1.48	KX	19	-4.34
Fe II			(log Fe/N_T = -4.20 ± 0.20)		
36	4993.35	-3.65	MF	16	-4.13
37	4663.70	-4.28	KX	11	-3.68
42	4923.93	-1.32	MF	77	-4.36
	5018.45	-1.22	MF	93	-3.97
43	4656.87	-3.63	MF	8	-4.49
	4731.44	-3.36	MF	19	-4.26
-	4820.83	-0.69	KX	7	-4.19
	4826.68	-0.44	KX	5	-4.57
	4908.15	-0.30	KX	10	-4.33
	4913.29	+0.01	KX	12	-4.56
	4948.10	-0.32	KX	7	-4.52
	4948.79	-0.01	KX	15	-4.38
	4951.58	+0.18	KX	16	-4.54
	4977.03	+0.04	KX	18	-4.32
	4984.48	+0.01	KX	20	-4.22
	4990.51	+0.18	KX	24	-4.24
	5001.96	+0.90	KX	40	-4.44
	5004.20	+0.50	KX	29	-4.41
	5006.80	-0.43	KX	8	-4.33
	5007.74	-0.20	KX	15	-4.19
	5009.02	-0.42	KX	7	-4.37
	5021.59	-0.30	KX	11	-4.27
	5026.81	-0.22	KX	18	-4.04
	5030.63	+0.40	KX	22	-4.54
Fe II (cont.)					
-	5031.89	-0.78	KX	6	-4.09
	5032.71	+0.11	KX	26	-4.05
	5033.96	-0.73	KX	9	-3.97
	5035.71	+0.61	KX	31	-4.44
	5045.11	-0.13	KX	35	-3.54
	5047.64	-0.07	KX	20	-4.12
	5060.26	-0.52	KX	7	-4.28
	5061.72	+0.22	KX	20	-4.43
	5067.89	-0.20	KX	17	-4.09
	5070.90	+0.24	KX	27	-4.20
	5074.05	-1.97	KX	13	-4.08
	5075.76	+0.28	KX	24	-4.26
	5082.23	-0.10	KX	20	-4.04
	5086.31	-0.48	KX	14	-3.89
	5087.30	-0.50	KX	12	-4.01
	5093.58	+0.11	KX	27	-4.03
	5097.27	+0.31	KX	39	-3.82
	5106.11	-0.19	KX	28	-3.71

For gf value references: see Table 2

Table 5. Comparison DAO and CASLEO Abundances for κ Cnc ($\log N/H$)

Species	DAO	n	CASLEO	n
P II	-4.61±0.15	13	-4.56±0.19	7
Cr II	-6.37±0.16	22	-6.14±0.11	4
Mn II	-4.39±0.22	87	-4.40±0.21	19
Fe II	-4.47±0.25	101	-4.17±0.25	42

reddened. By comparing spectrophotometric fluxes (Adelman & Pyper 1979) and the Hγ profile (Adelman 1987) for κ Cnc with the predictions of a solar composition ATLAS9 model, we found $T_{\rm eff}$= 13000 K, $\log g = 3.65$ while for a [+0.2] dex model these values become $T_{\rm eff}$ = 12920 K, $\log g = 3.75$. For κ Cnc, Adelman (1987) used $T_{\rm eff}$ = 13125 K, $\log g = 3.45$ and found a mean metallicity close to solar. Thus we chose the solar composition model. For HR 7245, Guthrie (1984) adopted $T_{\rm eff}$ = 12300 K, $\log g = 3.8$ and Roby & Lambert (1990) $T_{\rm eff}$ = 12350 K, $\log g = 3.6$, in better temperature agreement than surface gravity agreement with our photometric values. For ξ Oct, Adelman et al. (1993) used $T_{\rm eff}$ = 13625 K, $\log g = 4.0$ while Hardorp et al. (1986) $T_{\rm eff}$ = 14000 K, $\log g = 4.0$. Such differences are within the uncertainties of ± 500 K in effective temperature and ± 0.2 dex in log surface gravity.

For ξ Oct we adopted a microturbulence of 0.0 km s^{-1} as we did not have a sufficient number of lines for a proper analysis and as recent analyses of other superficially normal middle B stars found this value (Adelman

Table 7. Comparison of Abundances for HR7245 (log N/H)

Species	Guthrie	n	Zakharova	n	This Paper	n	Sun
He I	...	...	-1.47	2	-1.68	5	-1.00
C II	...	...	-3.50	2	-3.95	2	-3.43
O I	...	...	...	...	-3.15	1	-3.14
Mg II	-5.1	2	...	...	-4.71	2	-4.42
Si II	...	...	-4.02	4	-4.31	3	-4.45
P II	-5.2	7	...	...	-5.51	3	-6.55
S II	...	...	...	...	-5.41	4	-4.67
Ca II	...	...	...	...	-4.80	1	-5.64
Sc II	-8.2	2	...	...	-8.69	1	-8.90
Ti II	-6.5	18	-6.15	10	-6.34	22	-7.01
V II	>-8.1	2	-6.46	3	...	...	-8.00
Cr II	-5.9	9	-5.80	5	-5.84	31	-6.26
Mn I	...	...	...	...	-4.30	1	-6.45
Mn II	-5.4	20	-4.62	36	-4.84	57	-6.45
Fe I	...	...	-4.48	1	-4.43	5	-4.52
Fe II	-4.6	9	-4.29	28	-4.54	78	-4.52
Fe III	...	...	-4.02	1	-4.85	1	-4.52
Ni II	>-6.5	3	...	...	-6.45	1	-5.75
Ga II	-5.6	3	-5.48	2	-5.93	2	-9.11
Sr II	...	...	-8.33	2	-8.73	2	-9.10
Y II	-8.6	2	-7.60	1	-8.12	1	-9.76
Zr II	>-8.8	1	-6.86	2	-7.71	4	-9.40
Xe II	...	...	-4.49	5	...	...	...
Ce II	...	...	...	...	-6.72	1	-10.45
Pt II	>-6.9	2	...	...	...	...	-10.20
Hg II	...	...	...	...	-6.52	1	...

1994a). For κ Cnc we used 0.0 km s^{-1} as found by Adelman (1987). When we tried find the microturbulence from the Fe II lines of HR 7245, they indicated a value of a few km s^{-1} which is contrary to Adelman's (1994b) result that most HgMn stars have little or no microturbulence. Our result reflects small errors in the gf-values and equivalent widths and that almost all the Fe II lines are on the linear part of the curve-of-growth. Thus we adopted a value of 0.0 km s^{-1} for this abundance analysis.

4. The elemental abundance analyses

For ξ Oct the derived He/H values (Table 1) are slightly smaller than 0.085 found by Adelman et al. (1993) using only λ4026 and λ4388. The CASLEO values show a greater scatter than those from the AAT. We did not analyze any He I lines for κ Cnc as we did not think that we could improve the value from DAO spectrograms. For HR 7245 we analyzed 5 lines and found He/H = 0.02, which is a value appropriate to a HgMn star.

We analyzed ξ Oct using both CASLEO and AAT data. Table 2 contains the metal line results from our spectra. For each line, it contains the multiplet number, the wavelength in Å, the equivalent width in mÅ, the gf value and its source, and the derived abundance (log N/N_T) where N_T is the total number of atoms per unit volume. Table 3 summarizes the abundance results. The CASLEO data contains a few lines which the AAT data lacks. The AAT results are given only in summary form as the details are in Adelman et al. (1993). In general ξ Oct now appears to be slightly more metal rich. The difference between the abundance of iron as derived from the Fe I and Fe II lines has been increased, but this may represent non-LTE effects. The differences are usually larger when only strong lines are involved in the analyses, e.g. Si II and Ca II. Those for species which have only weak lines are about 0.10 dex different.

For κ Cnc, we analyzed lines only in the $\lambda\lambda$4640−5110 region (Table 4) as these lines supplement those found using DAO spectrograms and as the DAO data is of higher spectroscopic quality in resolution if not in S/N. For comparison we reanalyzed the lines in Adelman (1987) for those atomic species in common (Table 5). The CASLEO values on average make κ Cnc about 0.14 ± 0.15 dex more metal rich, which is about that expected based on the difference in equivalent width scales. This suggests that this difference was reasonably determined well for this star although part of the discrepancies may be due to small gf value systematics.

Table 6 contains the analysis of the metal lines for HR 7245 while Table 7 compares our results with those of Guthrie (1984) and Zakharov (1994). Our values are often between those of these investigators which is somewhat surprising given the equivalent width comparisons. Compared to other HgMn stars of similar temperature (Adelman 1994b), its abundances fall mostly within the run of values. It apparently has the most nearly solar O abundance and its Ca abundance is the most above solar.

5. Final comments

Since we took our spectrograms, the CASLEO staff has made a substantial effort to improve the quality of the spectrograms taken with the REOSC echelle. This should alleviate some of the problems which we discussed. A further critical task is to better determine the relation of the CASLEO equivalent width scale to that of other major spectroscopic instruments.

Still we are working with an instrument which does not have the resolution of the most powerful coudé and echelle spectrographs in the blue. But in the yellow and the red, there are fewer lines and blending is less severe. The spectra of the HgMn stars in $\lambda\lambda4640-5100$ show many unidentified lines along with a nice selection of He I, Si II, P II, Ti II, Cr II, Mn II, and Fe II lines plus those of more exotic species such as Xe II. Kurucz (1995) has calculated the gf values of most of these lines. Part of the spectral region between $\lambda5100$ and $\lambda10000$ may prove even more interesting and provide abundances of elements such as C, N, and O, which often have not been obtained in the photographic region. Further cataloging the wavelengths and strengths of unidentified lines and then performing correlations with strengths of lines of known species may provide useful information to atomic spectroscopists who are extending analyses of astrophysically common and rare species.

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Table 6. The analysis of the metal lines HR 7245

mult.	λ(Å)	log gf	Ref.	W_λ(mÅ)	log N/N_T
C II					(log C/N_T = -3.96 ± 0.30)
4	3918.98	-0.54	WS	13	-4.17
6	4267.25	+0.97	WS	44	-3.75
O I					(log O/N_T = -3.16)
5	4368.30	-1.77	WS	13	-3.16
Mg II					(log Mg/N_T = -4.72 ± 0.36)
4	4481.23	+0.97	WM	263	-4.47
9	4428.00	-1.20	WS	8	-4.98
Si II					log Si/N_T = -4.32 ± 0.14)
1	3856.02	-0.49	LA	126	-4.40
3	4128.07	+0.38	LA	128	-4.16
	4130.89	+0.53	LA	121	-4.39
P II					(log P/N_T = -5.52 ± 0.28)
13	4943.50	+0.06	WS	5	-5.51
15	4602.08	+0.74	WM	27	-5.18
-	4420.71	-0.34	WS	7	-5.86
S II					(log S/N_T = -5.42 ± 0.30)
7	5032.41	+0.18	WS	15	-4.98
44	4145.10	+0.44	WS	5	-5.49
	4153.10	+0.62	WS	6	-5.58
	4162.70	+0.78	WS	6	-5.64
Ca II					(log Ca/N_T = -4.81)
1	3933.66	+0.13	WM	312	-4.81
Sc II					(log Sc/N_T = -8.70)
7	4246.83	+0.32	MF	14	-8.70
Ti II					(log Ti/N_T = -6.35 ± 0.31)
19	4443.80	-0.70	MF	30	-6.74
	4450.49	-1.45	MF	10	-6.67
20	4287.89	-2.02	MF	11	-6.06
	4294.09	-1.11	MF	16	-6.76
34	3900.56	-0.45	MF	40	-6.67
	3913.46	-0.53	MF	46	-6.44
40	4290.22	-1.12	MF	16	-6.72
	4417.72	-1.43	MF	31	-5.95
41	4300.05	-0.77	MF	45	-6.21
	4301.93	-1.16	MF	11	-6.89
	4312.86	-1.16	MF	28	-6.30
	4314.98	-1.13	MF	27	-6.36
	4320.96	-1.87	MF	12	-6.11
50	4563.76	-0.96	MF	37	-6.24
82	4571.97	-0.53	MF	39	-6.43
92	4805.09	-1.10	MF	16	-6.28
104	4367.65	-1.27	MF	13	-5.98
	4386.86	-1.26	MF	8	-6.29
105	4163.64	-0.40	MF	33	-6.24
114	4911.18	-0.34	MF	14	-6.63
115	4456.63	-1.66	KX	5	-5.84
	4411.08	-1.06	MF	14	-5.93
Cr II					(log Cr/N_T = -5.85 ± 0.27)
18	4172.60	-2.36	KX	6	-6.24
19	4051.97	-2.19	KX	23	-5.66
20	3979.51	-0.73	KX	16	-6.11
26	4179.43	-1.77	KX	14	-6.04
30	4812.34	-1.80	MF	11	-6.14
	4824.12	-1.22	MF	47	-5.53
	4836.22	-2.25	MF	10	-5.72
	4848.24	-1.14	MF	32	-6.06
	4876.41	-1.46	MF	23	-6.01
Cr II (cont.)					
31	4261.92	-1.53	KX	35	-5.61
	4275.57	-1.71	KX	25	-5.71
	4252.62	-2.02	KX	19	-5.59
	4269.28	-2.17	KX	12	-5.70
39	4539.62	-2.53	MF	8	-5.44
	4565.78	-2.11	MF	10	-5.77
44	4555.02	-1.38	MF	33	-5.72
	4558.66	-0.66	MF	60	-5.55
	4588.22	-0.63	MF	58	-5.67
	4592.09	-1.22	MF	17	-6.34
	4616.64	-1.29	MF	25	-6.04
	4618.82	-1.11	MF	32	-6.00
	4634.10	-1.24	MF	30	-5.93
161	4195.41	-2.32	KX	6	-5.34
162	4145.77	-1.16	KX	19	-5.75
	4224.85	-1.73	KX	12	-5.46
165	4082.30	-1.23	KX	7	-6.23
177	4697.61	-1.88	MF	5	-5.62
190	4901.62	-0.83	KX	10	-5.88
193	4070.90	-0.75	KX	8	-6.12
194	4003.33	-0.60	KX	8	-6.28
-	4254.56	-1.75	KX	6	-5.52
Mn I					(log Mn/N_T = -4.31)
3	4030.76	-0.47	MF	23	-4.31
Mn II					(log Mn/N_T = -4.85 ± 0.32)
-	3844.17	-1.38	KX	35	-4.98
	3917.32	-1.15	KX	15	-5.21
	3941.22	-2.62	KX	14	-4.49
	3943.85	-2.46	KX	20	-4.45
	4000.04	-1.21	KX	16	-4.73
	4081.45	-2.24	KX	18	-4.39
	4083.66	-4.82	KX	5	-4.53
	4105.00	-1.35	KX	12	-5.52
	4110.62	-1.51	KX	38	-4.49
	4136.94	-1.29	KX	32	-4.87
	4140.44	-2.45	KX	8	-4.91
	4171.51	-2.11	KX	15	-4.58
	4184.47	-1.95	KX	12	-4.89
	4200.28	-1.74	KX	9	-5.25
	4205.39	-3.38	KX	26	-5.05
	4206.37	-1.57	KX	28	-5.08
	4237.87	-2.96	KX	5	-4.67
	4239.19	-2.25	KX	18	-4.72
	4240.39	-2.07	KX	15	-4.65
	4242.92	-2.99	KX	8	-4.47
	4244.24	-2.40	KX	17	-4.62
	4251.74	-1.06	KX	34	-5.04
	4252.96	-1.14	KX	55	-4.27
	4259.20	-1.59	KX	37	-4.78
	4260.46	-4.25	KX	12	-4.65
	4281.94	-2.55	KX	16	-4.51
	4282.47	-1.68	KX	16	-5.28
	4283.77	-2.20	KX	13	-4.96
	4288.07	-2.76	KX	6	-4.78
	4292.25	-2.23	KX	21	-4.65

Table 6. continued

mult.	λ(Å)	log gf	Ref.	W_λ(mÅ)	log N/N_T
Mn II (cont.)					
-	4310.70	-0.16	KX	5	-5.06
	4326.63	-1.25	KX	62	-4.32
	4328.80	-3.63	KX	30	-4.70
	4343.98	-1.09	KX	53	-4.77
	4348.39	-1.50	KX	21	-5.35
	4363.25	-1.91	KX	13	-5.17
	4365.22	-1.35	KX	10	-5.38
	4377.74	-2.14	KX	10	-5.12
	4379.61	-1.85	KX	10	-5.44
	4478.64	-0.95	KX	19	-5.38
	4689.56	-2.54	KX	9	-4.49
	4717.26	-1.86	KX	7	-5.10
	4727.84	-2.02	KX	15	-5.05
	4730.40	-2.15	KX	23	-4.66
	4742.95	-2.98	KX	7	-4.49
	4738.30	-2.24	KX	32	-4.29
	4755.73	-1.24	KX	45	-4.87
	4764.73	-1.35	KX	45	-4.76
	4791.78	-1.72	KX	20	-4.80
	4806.82	-1.56	KX	26	-5.13
	4811.62	-2.34	KX	6	-5.22
	4830.06	-1.85	KX	12	-4.96
	4839.74	-1.86	KX	15	-4.81
	4842.32	-2.00	KX	10	-4.94
	4847.61	-1.81	KX	10	-5.48
	4920.44	-2.09	KX	23	-4.66
	4921.23	-1.58	KX	18	-4.76
Fe I			(log Fe/N_T = -4.44 ± 0.13)		
41	4383.54	+0.20	MF	11	-4.56
42	4271.76	-0.16	MF	10	-4.23
43	4045.82	+0.28	MF	13	-4.54
	4063.59	+0.07	MF	11	-4.40
	4071.74	-0.02	MF	7	-4.47
Fe II			(log Fe/N_T = -4.59 ± 0.19)		
3	3938.29	-3.89	MF	18	-4.53
	3945.21	-4.19	MF	5	-4.87
22	4124.79	-4.20	MF	5	-4.52
25	4670.17	-3.97	KX	5	-4.68
26	4580.06	-3.65	KX	10	-4.65
27	4128.74	-3.77	MF	17	-4.26
	4273.32	-3.34	MF	19	-4.55
	4385.38	-2.57	MF	31	-4.91
	4416.82	-2.60	MF	28	-4.96
28	4258.16	-3.40	MF	20	-4.45
	4296.57	-3.01	MF	12	-5.16
	4369.40	-3.67	MF	7	-4.72
29	4002.08	-3.37	KX	8	-4.98
32	4314.29	-3.49	KX	24	-4.24
	4384.33	-3.50	MF	14	-4.59
36	4993.35	-3.65	MF	10	-4.55
37	4472.92	-3.43	MF	11	-4.72
	4515.34	-2.48	MF	49	-4.40
	4520.22	-2.60	MF	45	-4.42
	4555.89	-2.29	MF	53	-4.46
	4582.84	-3.10	MF	17	-4.80
	4629.34	-2.37	MF	58	-4.23
	4663.70	-4.28	KX	4	-4.32
38	4541.52	-3.05	MF	28	-4.47
	4576.33	-3.04	MF	21	-4.72

Table 6. continued

mult.	λ(Å)	log gf	Ref.	W_λ(mÅ)	log N/N_T
Fe II (cont.)					
38	4583.83	-2.02	MF	51	-4.83
	4620.51	-3.28	MF	10	-4.92
42	4923.93	-1.32	MF	89	-4.16
43	4731.44	-3.36	MF	23	-4.30
126	4032.95	-2.83	KX	15	-4.35
127	4024.55	-2.48	MF	35	-4.05
128	3845.18	-2.26	KX	20	-4.75
168	4953.98	-2.76	KX	12	-4.02
172	4044.01	-2.36	KX	6	-4.77
173	3935.94	-1.86	MF	26	-4.46
173	3906.04	-1.83	MF	22	-4.61
186	4625.91	-2.22	KX	6	-4.76
	4635.33	-1.65	MF	23	-4.53
190	3938.97	-1.85	MF	15	-4.69
212	4057.46	-1.54	KX	11	-4.54
-	4357.58	-2.10	KX	10	-4.58
	4451.54	-1.82	KX	13	-4.67
	4596.02	-1.82	KX	15	-4.55
	4455.26	-1.99	KX	8	-4.69
	4480.69	-2.34	KX	11	-4.19
	4579.52	-2.36	KX	8	-4.35
	4820.83	-0.69	KX	7	-4.22
	4826.68	-0.44	KX	4	-4.76
	4908.15	-0.30	KX	7	-4.58
	4913.29	+0.01	KX	16	-4.43
	4948.10	-0.32	KX	7	-4.56
	4948.79	-0.01	KX	9	-4.71
	4951.58	+0.18	KX	15	-4.64
	4977.03	+0.04	KX	8	-4.80
	4984.48	+0.01	KX	11	-4.62
	4990.51	+0.18	KX	8	-4.99
	4999.18	-0.48	KX	6	-4.49
	5001.96	+0.90	KX	46	-4.27
	5004.20	+0.50	KX	30	-4.40
	5006.80	-0.43	KX	8	-4.34
	5019.46	-2.70	KX	14	-3.99
	5030.63	+0.40	KX	17	-4.75
	5035.71	+0.61	KX	13	-5.14
	5045.11	-0.13	KX	13	-4.39
	5047.64	-0.07	KX	10	-4.62
	5060.26	-0.52	KX	6	-4.36
	5061.72	+0.22	KX	19	-4.48
	5067.89	-0.20	KX	12	-4.35
	5070.90	+0.24	KX	18	-4.56
	5074.05	-1.97	KX	7	-4.53
	5075.76	+0.28	KX	13	-4.76
	5082.23	-0.10	KX	8	-4.66
	5086.31	-0.48	KX	7	-4.33
	5089.21	-0.04	KX	10	-4.61
	5094.91	-0.56	KX	9	-4.13
	5093.58	+0.11	KX	23	-4.19
	5097.27	+0.31	KX	18	-4.60
Fe III				(log Fe/N_T = -4.86)	
4	4419.59	-2.22	KX	5	-4.86
Ni II				(log Ni/N_T = -6.46)	
11	4067.05	-1.83	KX	12	-6.46
Ga II			(log Ni/N_T = -5.94 ± 0.13)		
-	4251.15	+0.46	JS	14	-5.85
	4255.72	+0.68	JS	14	-6.03

Table 6. continued

mult.	λ(Å)	log gf	Ref.	W_λ(mÅ)	log N/N_T
Sr II					(log Sr/N_T = -8.74 ± 0.39)
1	4077.71	+0.15	WM	9	-9.02
	4215.52	-0.17	WM	14	-8.47
Y II					(log Y/N_T = -8.13)
22	4883.68	+0.07	HL	7	-8.13
Zr II					(log Zr/N_T = -7.72 ± 0.27)
17	3915.94	-0.77	BG	7	-7.52
19	4156.24	-0.71	GB	5	-7.74
41	4149.22	-0.03	GB	8	-8.09
42	4161.20	-0.58	GB	9	-7.52
Ce II					(log Ce/N_T = -6.73)
2	4460.21	+0.17	KX	16	-6.73
Hg II					(log Hg/N_T = -6.53)
-	3983.96	-1.73	DW	57	-6.53

gf values References:
BG = Biemont et al. (1981)
DW = Dworetsky (1980)
GB = Grevesse et al. (1981)
HL = Hannaford et al. (1982)
JS = Jugaku et al. (1961)
KX = Kurucz (1995)
LA = Lanz & Artru (1985)
MF = Martin et al. (1988) and Fuhr et al. (1988)
WM = Wiese & Martin (1980)
WS = Wiese et al. (1966, 1969)