Revista Mexicana de Astronomía y Astrofísica, **45**, 95–105 (2009)

CHEMICAL ABUNDANCES OF THE MAGNETIC CP STAR HD 168733

A. Collado,[1] and Z. López–García[1,2]

Received 2008 August 08; accepted 2009 February 16

RESUMEN

Se ha llevado a cabo un análisis detallado de las abundancias en la estrella CP magnética HD 168733 utilizando espectros de alta resolución obtenidos con el espectrógrafo echelle EBASIM del telescopio de 2.1 m de CASLEO en Argentina. Los espectros cubren la región 382–700 nm. La estrella no puede ser clasificada ni como una peculiar de HgMn ni como perteneciente al grupo CP2 de silicio. Comparada con el Sol, C, N son levementes sobreabundantes mientras que el Mg y S son deficientes, Si es normal y P y Cl son sobreabundantes. Los elementos del pico de hierro: Sc, Ti, Cr y Fe son sobreabundantes. Se han identificado también líneas de Ti III y Fe III. HD 168733 muestra una gran sobreabundancia de Ga, Sr, Y, Zr, Xe, Pt, Hg y algunas tierras raras.

ABSTRACT

A detailed abundance analysis has been carried out for the magnetic CP star HD 168733 using high-resolution spectra obtained with the EBASIM echelle spectrograph at the 2.1 m CASLEO telescope in Argentina. The spectral coverage is 382–700 nm. It is neither a silicon nor a mercury-manganese star. Compared to the Sun, C and N are slightly overabundant, while Mg and S are deficient, Si is normal and P and Cl are overabundant. The iron peak elements Sc, Ti, Cr and Fe are overabundant. Lines of Ti III and Fe III are also identified. HD 168733 shows a great overabundance of Ga, Sr, Y, Zr, Xe, Pt, Hg and of some rare earths.

Key Words: stars: abundances — stars: chemically peculiar — stars: individual (HD 168733)

© Copyright 2009: Instituto de Astronomía, Universidad Nacional Autónoma de México

1. INTRODUCTION

This research is part of the program undertaken at CASLEO for deriving elemental abundances among CP stars. For this paper we have selected HD 168733 (=HR 6870). It is neither a silicon star nor a mercury-manganese Star. Its unusual spectrum was first noted by Bidelman & Aller (1963). It has been classified as B7-8p by Osawa (1965). Jones & Wolff (1974) measured magnetic field variations from −260 to −1080 Gauss for which they gave a period of $14^{\rm d}.6$. They also measured low amplitude radial velocity variations and suggested that this star is a spectroscopic binary. Renson (1978) and Manfroid & Renson (1994) reported photometric variations of the order of 0.01 mag and a value of the rotational period of $6^{\rm d}.3540$ which seems inconsistent with the longitudinal magnetic field measurements of Jones & Wolff (1974). Mathys & Hubrig (1997) reported seven observations that sample the rotation cycle. From these observations they concluded that the longitudinal field was not detectably variable and that its mostly constant value was close to the average of their seven determinations, −636 G, consistent also with the average of Jones & Wolff (1974), −688 G. In a more recent paper Hubrig, North, & Schöeller (2007), reported a rms longitudinal magnetic field strengh of 815 G, a rotation period of $14^{\rm d}.78$, a projected rotation velocity $v \sin i = 12$ km s^{-1} and an obliquity angle β (orientation of the magnetic axis with respect to the rotation axis) of $18^\circ.17$.

Three coudé spectrograms taken at Lick Observatory of HD 168733 were investigated by Little & Aller (1970) and they found that the spectrum contained three ionization states of iron (Fe I, Fe II and Fe III), a complete absence of Mn lines, an enrichment of the lines of Cr II and Ti II lines, absence of lines of O but presence of C and N lines. After

[1]Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de San Juan, Argentina.

[2]Complejo Astronómico El Leoncito, CASLEO, CONICET, Argentina.

TABLE 1

OBSERVING DETAILS

Date	Wavelength Range (nm)	Grating l mm^{-1}	Fiber	Number of Spectra
Oct. 2002	382–556	226	blue	2
	550–740	226	red	2
Jun. 2003	382–556	226	blue	3
	550–740	226	red	2
Jun. 2006	386–556	226	blue	1
	490–700	226	red	1

© Copyright 2009: Instituto de Astronomía, Universidad Nacional Autónoma de México

that, Little (1974) presented the results of a model atmosphere analysis, including only hydrogen lines blanketing, finding very large excesses of Cl, Sr and Ti, and an approximately normal Silicon abundance. Muthsam & Cowley (1984) using better model atmospheres –an extension of ATLAS5 Kurucz program (1970) including a modest metal lines blanketing– confirmed the general tendency of abundances shown in the paper of Little & Aller (1970).

The main goal of the present paper is to carry out a more detailed spectroscopic and abundance analysis using spectra of a high resolving power and signal to noise ratio in excess of 100, as well as ATLAS9 model atmospheres.

2. OBSERVATIONAL MATERIAL AND LINE IDENTIFICATIONS

Spectra of HD 168733 were obtained by Z. López García and S. Malaroda in 2002 and 2003 and by A. Collado and S. Malaroda in 2006 with the *Jorge Sahade* 2.15 m telescope at Complejo Astronómico El Leoncito (CASLEO) equipped with the fiber-feed bench echelle spectrograph EBASIM and a TEK 1024 × 1024 CCD for the first two observation runs, and a ROPER 1340 × 1310 CCD for the last one. The resolving power of the spectrograph is approximately 40000 at 500 nm. The S/N ratio of the spectra is around 200 at the order center. Table 1 lists the EBASIM spectra we have obtained.

The spectra were reduced using IRAF[3] standard procedures for echelle spectra and were normalized order by order with the *splot* task of the same package. The equivalent widths were measured by fitting Gaussian profiles through the stellar metal lines using the same task. The stellar lines were identified using A Multiplet Table of Astrophysical Interest (Moore 1945) and Wavelengths and Transition Probabilities for Atoms and Atomic Ions Part I (Reader & Corliss 1980), as well as more specialized references for P II (Svendenius, Magnusson, & Zetterberg 1983), S II (Petterson 1983), Ti II (Huldt et al. 1982), Mn II (Iglesias & Velasco 1964), Fe I (Nave et al. 1994), Fe II (Johansson 1978; Guthrie 1984; Adelman 1987), Ga II (Isberg & Litzén 1985), Y II (Nilsson, Johansson, & Kurucz 1991), Ce III (Bord, Cowley, & Norquist 1997), Pr III and Nd III (Dolk et al. 2002), Yb II and Yb III (Bord et al. 2003), Pt I and Pt II (Engleman 1989), Au II (Rosberg & Wyart 1997). The Kurucz[4], NIST[5] and DREAM[6] databases were also visited.

Lines of H I, He I, C II, N II, O I, Mg II, Al I, Si II, Si III, P II, S II, Cl II, Ca II, Sc II, Ti II, Ti III, Cr II, Fe I, Fe II, Fe III, Ga II, Sr II, Y II, Zr II, Xe II, Ba II, Ce II, Ce III, Pr III, Nd III, Pt II, Hg I and Hg II are definitely present in HD 168733, while Na I, Mg I, Ni II, Ce III and Pr III are doubtful. We compared the stellar and laboratory wavelengths after corrections were applied for the Earth's orbital velocity. We found 14.76 km s^{-1}, compared to 24.00 km s^{-1} from the material obtained on 2006, which would indicate that this star is a spectroscopic binary. No lines of the secondary were seen then, so we treated this star as single.

3. ATMOSPHERIC PARAMETERS

Little (1974) made the first estimation of the $T_{\rm eff}$ for HD 168733 and using a continuum scan determined a color temperature of 14500 K. Muthsam & Cowley (1984), with Kurucz models including the blanketing effect of a great number of metallic lines, obtained $T_{\rm eff}$ = 14250 K and log g = 4.0 from the $H\gamma$ profile. From a calibration of Geneva photometry Lanz (1987) obtained $T_{\rm eff}$ = 13500 K and log g

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

[4]http://kurucz.harvard.edu/linelists/gf100.

[5]http://physics.nist.gov/cgi-bin/AtData/lines.form.

[6]http://www.umh.ac.be/astro/dream.shtml.

TABLE 2

MICROTURBULENCE DETERMINATIONS

Element	Number of lines	ξ_1 1 (km s^{-1})	log N/NT	ξ_2 2 (km s^{-1})	log N/NT	gf values
Fe II	158	1.50	-3.57 ± 0.24	1.50	-3.57 ± 0.24	MF+KX+NIST
Fe II	160	1.6	-3.59 ± 0.24	1.6	-3.59 ± 0.24	MF+KX
	45	1.30	-3.63 ± 0.27	1.30	-3.63 ± 0.27	MF
	55	1.30	-3.66 ± 0.26	1.30	-3.66 ± 0.26	NIST
Ti II	67	0.40	-4.91 ± 0.26	0.40	-4.91 ± 0.26	
Cr II	44	0.00	-5.24 ± 0.30	0.00	-5.24 ± 0.30	

Adopted: 1.50 km s^{-1} gf values.

References: MF = Fuhr et al. 1988; KX = Kurucz & Bell 1995; NIST = Fuhr 2005.

© Copyright 2009: Instituto de Astronomía, Universidad Nacional Autónoma de México

= 3.3. Another estimation of the effective temperature was done by Glagolevskij (1994) who used the Shallis-Blackwell method (1979) starting with the total flux emitted by HD 168733; he found 13580 K.

For consistency with previous papers published by our group we used *uvbyβ* mean colors from Hauck & Mermilliod (1998) and the TEMPLOGG program (Rogers 1995) to obtain an initial estimate of the atmospheric parameters. The result was $T_{\rm eff}$ = 13812 K, log g = 3.583. As there are no spectrophotometric measures for this star, we used the correction given by Adelman & Rayle (2000) to estimate a spectrophotometric temperature using *uvbyβ* photometry and we found $T_{\rm eff}$ = 13270 K and log g = 3.60. To refine these values we generated a synthetic spectra of the $H\gamma$ region from ATLAS9 model atmospheres (Kurucz 1992, private comm.) with Program SYNTHE (Kurucz 1992, private comm.) for making an slightly correction to the gravity and we obtained log g = 3.70. With these parameters we have computed a model atmosphere using Kurucz's ATLAS9 code with [M/H] = +0.5. But this model did not satisfy the ionization balance condition of some elements present in two ionization states as Si, Ti and Fe. We then calculated abundances for models with log g = 3.5, 3.7 and 4.0 for $T_{\rm eff}$ ranging from 13000 K to 14000 K but now using [M/H] = +1.0, an abundance that agrees with the iron-peak elements overabundance previously observed in HD 168733. The model with $T_{\rm eff}$ = 14000 K, log g = 3.7 was finally chosen. With this model we have obtained both a good fit to the $H\gamma$ region and we have also resolved the ionization balance problem.

4. ABUNDANCE ANALYSES

The helium and metal abundances were determined using programs SYNTHE (Kurucz 1992, private comm.) and WIDTH9 (Kurucz 1992, private comm.), respectively. The Stark effect is an important source of line broadening. In the Kurucz line lists the damping constants are taken from the literature when available. The Griem (1974) tables are the source for the damping constants for a large number of light element lines, while for all the lines of the iron group elements the damping constants are taken from Kurucz & Bell (1995). For Si II lines there are some constants calculated for Lanz, Dimitrijević, & Artru (1988). Damping constants not available from the literature are computed inside the SYNTHE code with an approximate formula. To calculate microturbulent velocity we used the standard method. We calculated abundances for Fe II lines for a range of possible microturbulent velocities. To determine the final value we looked for the conditions where the abundances for Fe II were independent of the equivalent widths (ξ_1) and the rms scatter of the abundances becomes a minimum (ξ_2). Values for this species were derived using lines with *gf* values from Martin, Fuhr, & Wiese (1988) (MF values) and also with *gf* values with compatible sources, in this case Kurucz & Bell (1995) (KX values). Also, we substituted older values with the new NIST (Fuhr 2005) *gf* values. From the Fe II lines a mean microturbulence of 1.5 km s^{-1} is found for HD 168733 (Table 2). The Cr II lines yield 0.0 km s^{-1} while the Ti II lines suggest 0.40 km s^{-1}. The difference between the values estimated from different species can be attributed to the fact that the silicon stars have magnetic fields. Thus, the Zeeman broadening is different from line to line. For weak lines it is a pseudomicroturbulence that combines in quadrature with any real microturbulence. A mean value of 1.5 km s^{-1} was finally adopted. We should point out that the above difference between the Ti II, Cr II and Fe II results has been observed also in our previous analysis of other CP stars.

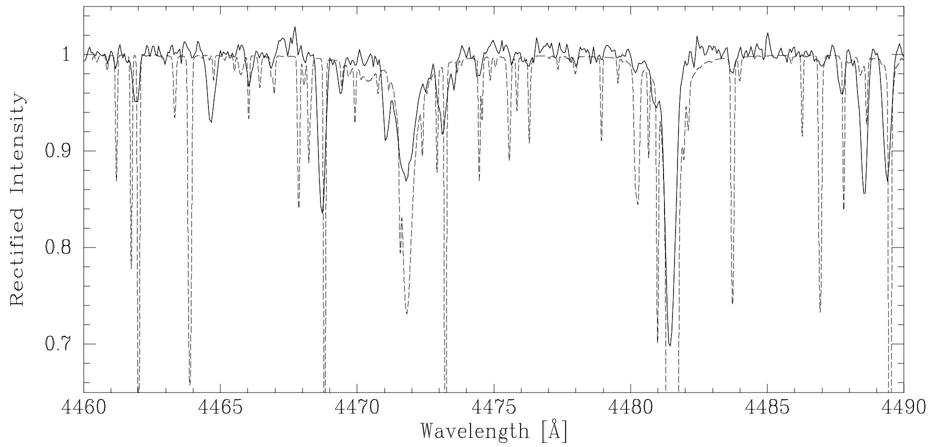

Fig. 1. The observed profile (full line) of He I λ 4471 is compared with synthetic profile (dotted line). Abundance = -2.5 dex.

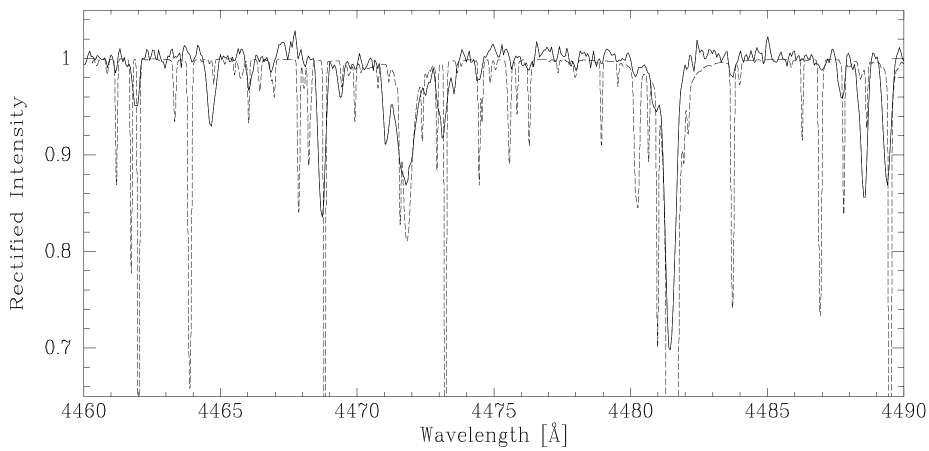

Fig. 2. The observed profile (full line) of He I λ 4471 is compared with synthetic profile (dotted line). Abundance = -3.0 dex.

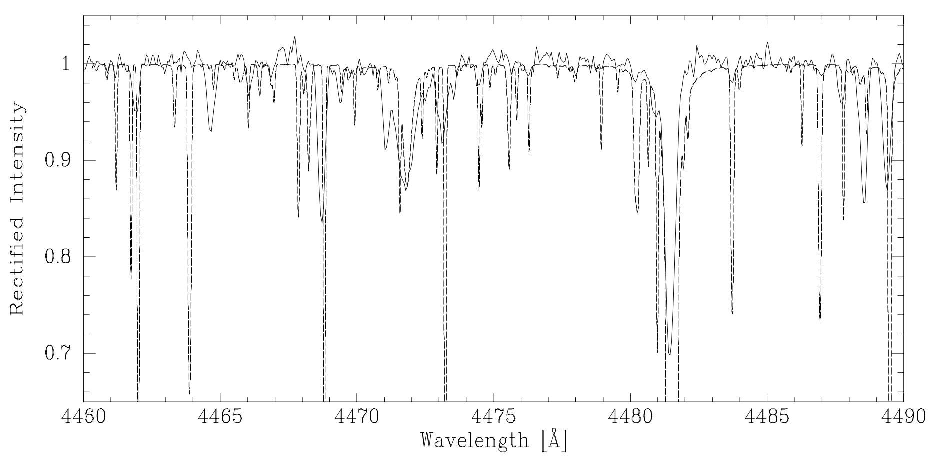

Fig. 3. The observed profile (full line) of He I λ 4471 is compared with synthetic profile (dotted line). Abundance = -3.4 dex.

© Copyright 2009: Instituto de Astronomía, Universidad Nacional Autónoma de México

TABLE 3

CHEMICAL ABUNDANCES

Element	Multiplet	λ (nm)	log gf	Ref.	E.W.	$\log N/N_{\rm tot}$
		$\log N/N_T = -3.52 \pm 0.19$				
C II	4	392.0681	−0.232	WF	6.82	−3.731
C II	4	391.8968	−0.533	WF	5.46	−3.690
C II	6	426.7158	0.740	WF	12.00	−3.346
C II	15	566.2460	−0.249	WF	1.05	−3.217
C II	16	513.3281	−0.178	WF	1.06	−3.513
C II	16	514.5165	0.189	WF	1.56	−3.635
		$\log N/N_T = -3.93 \pm 0.24$				
N II	3	566.6629	−0.045	WF	1.30	−3.816
N II	5	460.1478	−0.430	WF	1.25	−3.905
N II	5	461.3868	−0.660	WF	0.95	−3.845
N II	5	462.1393	−0.514	WF	2.13	−3.433
N II	5	463.0539	0.094	WF	2.25	−3.987
N II	5	464.3086	−0.360	WF	1.47	−3.839
N II	12	399.4997	0.208	WF	2.40	−4.305
N II	15	444.7030	0.228	WF	0.90	−4.237
N II	19	500.5150	0.594	WF	1.35	−3.962
		$\log N/N_T = -2.89 \pm 0.10$				
O I	3	394.7295	−2.096	WF	1.11	−2.836
O I	11	543.6862	−1.398	WF	0.91	−2.896
O I	12	532.9110	−1.695	WF	0.62	−2.787
O I	12	532.9681	−1.473	WF	0.54	−3.072
O I	12	533.0735	−0.984	WF	2.39	−2.851
		$\log N/N_T = -4.47 \pm 0.00$[a]				
Na I	6	568.8250	−0.452	NI	1.00	−4.467
		$\log N/N_T = -2.88 \pm 0.00$[a]				
Mg I	2	518.3604	−0.158	NI	3.12	−2.881
		$\log N/N_T = -5.03 \pm 0.37$				
Mg II	4	448.1230	0.970	NI	15.00	−4.685
Mg II	9	442.7994	−1.208	NI	0.46	−4.972
Mg II	10	438.4637	−0.776	NI	0.27	−5.652
Mg II	9	443.3988	−0.907	NI	1.23	−4.802
		$\log N/N_T = -5.05 \pm 0.19$				
Al I	1	396.1520	−0.640	WF	0.59	−4.861
Al I	1	394.4010	−0.640	WF	0.26	−5.236
		$\log N/N_T = -4.48 \pm 0.27$				
Si II	1	385.6017	−0.557	BB	10.61	−4.888
Si II	1	386.2595	−0.817	BB	8.88	−4.960
Si II	1	385.3664	−1.517	BB	6.52	−4.705
Si II	3	413.0893	0.530	LA	12.23	−4.732
Si II	3	412.8067	0.380	LA	10.70	−4.783
Si II	3.01	407.5452	−1.403	SG	2.23	−4.496
Si II	4	595.7559	−0.349	NI	6.92	−4.327
Si II	4	597.8930	−0.061	NI	7.32	−4.537
Si II	5	505.5984	0.441	NI	15.43	−4.090
Si II	5	504.1024	0.174	NI	10.81	−4.356
Si II	7.03	546.6432	−0.190	NI	3.54	−4.460
Si II	7.05	462.1722	−0.390	NI	2.36	−4.365
Si II	7.05	462.1418	−0.540	NI	2.13	−4.374
Si II	7.33	566.9563	0.266	LA	2.87	−4.129
Si II	7.33	568.8817	−0.106	LA	1.55	−4.143
		$\log N/N_T = -4.65 \pm 0.20$				
Si III	2	455.2622	0.292	NI	2.76	−4.567
Si III	2	456.7840	0.068	NI	1.48	−4.922
Si III	2	457.4757	−0.409	NI	1.46	−4.453
		$\log N/N_T = -6.15 \pm 0.26$				
P II	5	602.4178	0.137	NI	2.24	−5.794
P II	6	542.5880	0.180	NI	0.83	−6.421
P II	-	442.0712	−0.330	NI	0.41	−6.2
		$\log N/N_T = -5.29 \pm 0.39$				
S II	1	502.7203	−0.710	NI	0.29	−5.790
S II	6	542.8660	−0.130	NI	0.61	−5.766
S II	6	543.2820	0.260	NI	4.50	−4.728
S II	6	545.3830	0.480	NI	3.08	−5.304
S II	6	547.3614	−0.180	NI	2.13	−4.973
S II	6	550.9560	−0.140	NI	0.44	−5.890
S II	6	556.4958	−0.320	NI	2.25	−4.741
S II	7	499.1974	−0.650	NI	0.87	−5.129
S II	9	471.6271	−0.410	NI	1.53	−5.102
S II	9	481.5550	0.090	NI	1.32	−5.651
S II	11	532.0720	0.490	NI	0.77	−5.746
S II	11	552.6243	−0.530	NI	0.44	−5.466
S II	11	560.6150	0.310	NI	4.10	−4.781
S II	11	561.6640	−0.640	NI	1.30	−4.779
S II	14	563.9977	0.280	NI	2.31	−5.152
S II	14	564.7020	0.040	NI	1.24	−5.354
S II	14	581.9250	−0.760	NI	0.74	−4.786
S II	15	491.7210	−0.320	NI	0.73	−5.426
S II	15	501.4042	0.100	NI	1.10	−5.583
S II	44	414.2259	0.240	NI	0.44	−5.744
		$\log N/N_T = -5.13 \pm 0.27$				
Cl II	1	479.4540	0.455	WS	2.33	−5.669
Cl II	1	481.0060	0.292	WS	2.54	−5.429
Cl II	1	481.9470	0.019	NI	2.35	−5.220
Cl II	2	542.3257	−0.260	NI	1.95	−4.820
Cl II	3	522.1360	−0.030	WS	1.92	−5.009
Cl II	16	507.8267	0.320	WS	1.02	−5.199
Cl II	16	509.9303	−0.120	WS	0.92	−4.819
Cl II	17	489.6783	0.460	WS	1.34	−5.213
Cl II	17	490.4776	0.310	WS	1.12	−5.181
Cl II	17	491.7730	0.130	NI	0.80	−5.202
Cl II	29	413.2492	0.310	NI	2.51	−4.720
		$\log N/N_T = -7.74 \pm 0.46$				
Sc II	7	424.6822	0.320	MF	0.72	−8.255
Sc II	15	431.4083	−0.100	MF	2.19	−7.137
Sc II	15	432.5000	−0.440	MF	0.28	−7.813
		$\log N/N_T = -4.97 \pm 0.25$				
Ti II	17	479.8521	−2.680	PT	0.26	−5.303
Ti II	17	476.2776	−2.710	FW	1.48	−4.445
Ti II	19	418.4303	−1.858	KX	2.80	−4.927
Ti II	19	439.5033	−0.540	PT	7.04	−5.351
Ti II	19	444.3794	−0.720	PT	5.73	−5.458
Ti II	19	445.0482	−1.520	PT	4.88	−4.831
Ti II	19	432.0960	−1.870	MF	3.41	−4.747
Ti II	20	428.7872	−1.790	PT	3.19	−4.909
Ti II	20	434.4288	−2.090	FW	0.97	−5.277
Ti II	21	416.1540	−2.090	PT	1.16	−5.185
Ti II	21	419.0233	−2.398	CW	0.60	−5.196
Ti II	31	450.1273	−0.770	PT	6.40	−5.251
Ti II	34	391.3468	−0.420	PT	6.93	−5.457
Ti II	34	388.2291	−1.910	PT	3.38	−4.723
Ti II	38	463.6320	−2.855	K88	0.54	−4.759
Ti II	39	458.3409	−2.720	FW	0.44	−4.988
Ti II	40	444.1734	−2.330	PT	1.96	−4.630

© Copyright 2009: Instituto de Astronomía, Universidad Nacional Autónoma de México

TABLE 3 (CONTINUED)

Element	Multiplet	λ (nm)	log gf	Ref.	E.W.	log $N/N_{\rm tot}$
Ti II	40	447.0857	−2.280	MF	1.74	−4.753
Ti II	40	441.7719	−1.190	PT	4.77	−5.148
Ti II	40	446.4450	−1.810	PT	3.87	−4.713
Ti II	41	429.0219	−0.850	PT	7.46	−4.910
Ti II	41	430.0049	−0.770	MF	7.48	−4.981
Ti II	41	431.2864	−1.160	FW	6.83	−4.738
Ti II	41	431.4975	−1.130	FW	5.23	−5.117
Ti II	41	433.0695	−2.040	FW	1.94	−4.926
Ti II	41	430.1914	−1.150	PT	4.64	−5.216
Ti II	41	430.7863	−1.290	MF	4.80	−5.043
Ti II	48	476.4526	−2.770	K88	0.33	−5.039
Ti II	51	439.9772	−1.190	PT	4.34	−5.206
Ti II	51	439.4051	−1.780	PT	3.16	−4.868
Ti II	51	441.8330	−1.970	PT	2.03	−4.847
Ti II	60	454.4028	−2.580	PT	1.25	−4.595
Ti II	61	439.1031	−2.280	PT	2.30	−4.566
Ti II	61	441.1925	−2.520	PT	0.70	−4.946
Ti II	69	533.6780	−1.590	PT	3.12	−4.904
Ti II	69	538.1020	−1.920	PT	2.39	−4.752
Ti II	69	541.8751	−2.000	PT	2.10	−4.742
Ti II	70	518.8680	−1.050	PT	5.39	−4.976
Ti II	70	522.6533	−1.260	PT	4.94	−4.864
Ti II	71	501.3677	−2.190	PT	2.24	−4.522
Ti II	82	457.1968	−0.320	PT	7.41	−5.282
Ti II	82	452.9474	−1.640	PT	2.89	−4.920
Ti II	86	512.9152	−1.390	FW	3.09	−4.982
Ti II	87	402.8343	−0.960	PT	4.63	−5.093
Ti II	87	405.3834	−1.130	PT	4.46	−4.958
Ti II	92	480.5085	−1.100	MF	4.55	−4.897
Ti II	92	477.9985	−1.370	FW	3.87	−4.774
Ti II	93	442.1938	−1.660	PT	1.81	−4.976
Ti II	93	437.4815	−1.610	PT	2.59	−4.814
Ti II	94	435.0834	−1.400	FW	1.74	−5.258
Ti II	94	431.6799	−1.420	FW	2.28	−5.088
Ti II	94	433.0245	−1.401	K88	1.23	−5.445
Ti II	104	436.7660	−0.860	PT	4.17	−4.996
Ti II	104	438.6844	−0.960	PT	3.15	−5.111
Ti II	105	417.4072	−1.260	PT	1.53	−5.245
Ti II	105	417.1910	−0.560	FW	4.62	−5.199
Ti II	106	406.4366	−1.614	CW	1.36	−4.952
Ti II	113	501.0210	−1.290	PT	3.99	−4.779
Ti II	113	506.9090	−1.820	PT	1.64	−4.417
Ti II	113	507.2280	−1.060	PT	4.61	−4.463
Ti II	113	491.1193	−0.340	FW	4.34	−5.244
Ti II	114	487.4010	−0.800	PT	3.25	−5.031
Ti II	115	448.8331	−0.510	PT	4.27	−5.099
Ti II	115	441.1074	−0.670	PT	4.14	−4.980
		log $N/N_T = -4.61 \pm 0.18$				
Ti III	-	388.1209	−0.380	NI	0.81	−4.574
Ti III	-	391.5471	0.730	NI	2.70	−4.672
Ti III	-	394.3554	−0.278	NI	1.28	−4.329
Ti III	-	394.8364	−0.559	NI	0.63	−4.520
Ti III	-	398.6393	−0.350	NI	1.13	−4.324
Ti III	-	406.0196	0.068	NI	1.00	−4.749
Ti III	-	406.9528	−0.231	NI	0.52	−4.861
Ti III	-	407.9958	−0.500	NI	0.48	−4.594
Ti III	-	411.9146	0.100	NI	0.85	−4.815
Ti III	-	419.1088	−0.200	NI	0.94	−4.422
Ti III	-	426.9833	0.710	NI	0.78	−4.491
Ti III	-	453.3263	0.370	NI	0.56	−4.680
Ti III	-	457.7962	−0.221	NI	0.31	−4.403
Ti III	-	465.2856	0.880	NI	0.73	−4.875
Ti III	-	530.1213	0.112	NI	0.90	−4.556
Ti III	-	534.9903	−0.169	NI	0.34	−4.848

Element	Multiplet	λ (nm)	log gf	Ref.	E.W.	log $N/N_{\rm tot}$
		log $N/N_T = -5.29 \pm 0.28$				
Cr II	18	421.7056	−2.809	K88	0.20	−5.512
Cr II	26	417.9421	−1.773	KX	1.03	−5.484
Cr II	26	407.2561	−2.407	KX	1.22	−4.810
Cr II	26	420.7363	−2.475	KX	1.06	−4.768
Cr II	26	408.6128	−2.422	KX	0.66	−5.095
Cr II	26	413.2410	−2.340	KX	1.84	−4.642
Cr II	30	481.2340	−1.995	K88	1.18	−5.185
Cr II	30	482.4130	−0.970	SL	4.56	−5.348
Cr II	30	483.6230	−2.000	SL	1.02	−5.256
Cr II	30	484.8230	−1.140	MF	3.02	−5.504
Cr II	30	485.6190	−2.260	KX	0.57	−5.276
Cr II	30	487.6410	−1.460	KX	3.30	−5.126
Cr II	30	488.4610	−2.080	MF	1.26	−5.069
Cr II	30	486.4326	−1.372	K88	2.72	−5.344
Cr II	31	426.1913	−1.340	SL	2.59	−5.398
Cr II	31	427.5567	−1.580	SL	1.72	−5.400
Cr II	31	428.4188	−1.670	SL	1.61	−5.348
Cr II	31	425.2632	−1.810	SL	1.27	−5.330
Cr II	31	424.2364	−0.590	BS	3.93	−5.850
Cr II	39	456.5740	−1.860	SL	0.92	−5.367
Cr II	43	530.8408	−1.810	MF	2.85	−4.779
Cr II	43	523.7330	−1.160	MF	2.40	−5.539
Cr II	43	527.4960	−1.290	KX	2.31	−5.433
Cr II	43	531.3560	−1.650	MF	1.99	−5.159
Cr II	43	533.4880	−1.560	KX	2.65	−5.076
Cr II	43	547.8365	−1.908	K88	1.82	−4.904
Cr II	44	455.8650	−0.410	SL	4.56	−5.819
Cr II	44	458.8199	−0.643	MF	4.32	−5.636
Cr II	44	455.4988	−1.380	MF	2.10	−5.401
Cr II	44	459.2050	−1.217	MF	2.59	−5.437
Cr II	44	461.6630	−1.291	MF	1.89	−5.551
Cr II	44	461.8800	−0.860	SL	3.56	−5.576
Cr II	44	463.4070	−0.990	SL	3.53	−5.453
Cr II	130	386.6523	−2.071	KX	0.71	−4.897
Cr II	162	422.4860	−1.726	KX	1.32	−4.779
Cr II	162	414.5781	−1.164	K88	2.27	−5.044
Cr II	167	386.5600	−0.780	KX	2.51	−5.362
Cr II	167	390.5644	−0.903	K88	2.82	−5.160
Cr II	183	397.9505	−0.731	K88	1.80	−5.465
Cr II	189	567.8420	−1.240	KX	0.38	−5.357
Cr II	190	490.1660	−0.830	KX	0.92	−5.371
Cr II	190	491.2460	−0.950	KX	0.33	−5.733
Cr II	194	403.7972	−0.557	KX	1.62	−5.364
Cr II	194	400.3283	−0.601	KX	1.02	−5.364
		log $N/N_T = -3.22 \pm 0.13$				
Fe I	4	385.9911	−0.710	NI	0.50	−3.435
Fe I	41	438.3544	0.200	NI	1.35	−3.253
Fe I	43	404.5813	0.280	NI	1.56	−3.246
Fe I	43	406.3594	0.070	NI	1.45	−3.045
Fe I	43	407.1737	−0.022	NI	0.98	−3.132
		log $N/N_T = -3.57 \pm 0.24$				
Fe II	3	394.5210	−4.440	N4	3.00	−3.009
Fe II	3	393.8290	−4.070	N4	3.46	−3.288
Fe II	22	412.4787	−4.160	N4	1.06	−3.522
Fe II	25	467.0182	−4.070	N4	1.69	−3.365
Fe II	27	441.6830	−2.600	N4	5.49	−3.877
Fe II	27	412.8748	−3.580	N4	2.21	−3.692
Fe II	27	430.3176	−2.610	N4	5.94	−3.798
Fe II	27	438.5387	−2.580	N4	4.96	−4.008
Fe II	27	427.3326	−3.340	N4	3.29	−3.627
Fe II	28	429.6572	−2.930	N4	4.41	−3.800
Fe II	28	436.9411	−3.580	N4	2.25	−3.603

© Copyright 2009: Instituto de Astronomía, Universidad Nacional Autónoma de México

TABLE 3 (CONTINUED)

Element	Multiplet	λ (nm)	log gf	Ref.	E.W.	log $N/N_{\rm tot}$	Element	Multiplet	λ (nm)	log gf	Ref.	E.W.	log $N/N_{\rm tot}$
Fe II	28	412.2668	−3.380	N4	4.76	−3.324	Fe II	205	507.4053	−1.973	KX	3.98	−3.090
Fe II	28	425.8154	−3.480	N4	3.55	−3.429	Fe II	212	396.0899	−1.420	KX	2.81	−3.760
Fe II	29	387.2766	−3.316	KX	4.14	−3.453	Fe II	212	405.7461	−1.545	KX	2.24	−3.779
Fe II	29	400.2083	−3.472	KX	1.77	−3.839	Fe II	213	435.4344	−1.395	KX	2.21	−3.780
Fe II	32	431.4310	−3.477	KX	3.07	−3.551	Fe II	213	450.7102	−1.918	K88	1.50	−3.426
Fe II	32	441.3601	−4.190	N4	1.04	−3.452	Fe II	219	459.8494	−1.497	KX	2.10	−3.639
Fe II	32	438.4319	−3.680	N4	3.72	−3.217	Fe II	219	462.8786	−1.737	K88	1.36	−3.626
Fe II	32	427.8159	−3.816	KX	1.47	−3.640	Fe II	220	431.9680	−1.758	K88	1.86	−3.443
Fe II	35	512.0352	−4.214	KX	0.53	−3.691	Fe II	220	432.1309	−1.830	K88	0.90	−3.746
Fe II	35	513.6802	−4.360	N4	0.90	−3.286	Fe II	222	428.6280	−1.622	KX	3.02	−3.325
Fe II	36	499.3358	−3.680	N4	2.04	−3.554	Fe II	222	435.7584	−2.113	KX	2.87	−3.528
Fe II	37	455.5893	−2.250	N4	6.12	−4.046	Fe II	222	445.1551	−1.844	KX	3.60	−3.607
Fe II	37	451.5339	−2.360	N4	6.84	−3.791	Fe II	J	390.3756	−1.495	KX	2.78	−3.588
Fe II	37	452.0224	−2.620	N4	4.83	−3.969	Fe II	J	392.2004	−1.072	KX	1.50	−3.759
Fe II	37	447.2929	−3.530	N4	2.58	−3.543	Fe II	J	445.5266	−2.143	KX	2.64	−3.496
Fe II	37	448.9183	−2.970	N4	4.29	−3.724	Fe II	J	459.6015	−1.837	KX	3.28	−3.647
Fe II	37	449.1405	−2.640	N4	4.03	−4.108	Fe II	J	482.6683	−0.442	KX	2.36	−3.608
Fe II	37	458.2835	−3.062	N4	3.04	−3.904	Fe II	J	490.8151	−0.304	KX	2.69	−3.636
Fe II	37	466.6750	−3.370	N4	3.15	−3.580	Fe II	J	491.3292	0.012	KX	4.78	−3.471
Fe II	38	450.8288	−2.350	N4	6.34	−3.912	Fe II	J	497.7035	0.041	KX	2.78	−3.939
Fe II	38	457.6340	−2.920	N4	4.39	−3.761	Fe II	J	498.4488	0.011	KX	4.45	−3.525
Fe II	38	454.1524	−2.970	N4	3.12	−3.974	Fe II	J	499.0509	0.195	N4	4.03	−3.803
Fe II	38	462.0521	−3.188	N4	2.67	−3.872	Fe II	J	500.1959	0.920	N4	8.02	−3.678
Fe II	40	643.2680	−3.500	N4	4.31	−3.154	Fe II	J	500.4195	0.497	KX	5.16	−3.867
Fe II	40	651.6081	−3.372	N4	2.92	−3.580	Fe II	J	500.9022	−0.415	KX	1.80	−3.766
Fe II	41	528.4109	−3.200	N4	5.43	−3.247	Fe II	J	502.1594	−0.300	KX	2.73	−3.637
Fe II	43	465.6981	−3.570	N4	4.38	−3.081	Fe II	J	502.6806	−0.222	KX	2.93	−3.656
Fe II	43	473.1453	−3.130	N4	3.73	−3.669	Fe II	J	503.0630	0.431	N4	4.61	−3.921
Fe II	46	599.1376	−3.557	KX	2.45	−3.405	Fe II	J	503.5708	0.630	N4	6.32	−3.735
Fe II	46	608.4111	−3.980	KX	0.58	−3.712	Fe II	J	506.1718	0.217	KX	4.18	−3.796
Fe II	48	526.4812	−3.233	N4	5.76	−3.374	Fe II	J	507.0899	0.242	KX	5.32	−3.563
Fe II	48	541.4073	−3.482	N4	2.65	−3.411	Fe II	J	507.5764	0.277	KX	4.66	−3.681
Fe II	49	519.7577	−2.054	N4	7.03	−3.895	Fe II	J	508.2230	−0.099	KX	4.97	−3.255
Fe II	49	527.6002	−1.900	N4	7.41	−3.982	Fe II	J	509.7271	0.308	KX	5.99	−3.444
Fe II	49	532.5553	−2.570	N4	4.21	−3.980	Fe II	J	510.6109	−0.276	KX	2.65	−3.659
Fe II	49	542.7826	−1.580	N4	3.11	−3.701	Fe II	J	511.3004	−0.499	KX	3.03	−3.312
Fe II	55	553.4847	−2.860	N4	6.04	−3.296	Fe II	J	511.7034	−0.126	KX	2.83	−3.720
Fe II	74	614.9258	−2.724	KX	4.86	−3.391	Fe II	J	525.1233	0.424	N4	6.05	−3.483
Fe II	74	645.6383	−2.300	N4	5.92	−3.564	Fe II	J	525.3641	−0.091	KX	3.83	−3.489
Fe II	74	641.6919	−2.850	MF	5.16	−3.179	Fe II	J	525.7122	0.032	KX	4.97	−3.333
Fe II	127	402.4547	−2.440	N4	3.48	−3.721	Fe II	J	529.1666	0.575	KX	6.39	−3.593
Fe II	127	386.3951	−2.528	KX	2.30	−3.811	Fe II	J	538.7063	0.518	KX	5.37	−3.702
Fe II	151	403.1442	−3.115	KX	0.92	−3.723	Fe II	J	539.5857	0.358	KX	4.82	−3.637
Fe II	152	386.3386	−2.870	KX	1.23	−3.819	Fe II	J	540.2059	0.502	KX	6.67	−3.388
Fe II	167	516.0839	−2.641	K88	2.33	−3.334	Fe II	J	541.1375	−0.435	KX	2.62	−3.371
Fe II	168	501.9462	−2.697	KX	0.84	−3.834	Fe II	J	541.4850	−0.311	KX	3.82	−3.228
Fe II	168	495.3987	−2.757	K88	1.67	−3.417	Fe II	J	542.9988	0.458	KX	7.13	−3.235
Fe II	172	404.8832	−2.145	KX	2.98	−3.686	Fe II	J	544.4387	−0.185	KX	4.56	−3.151
Fe II	172	404.4012	−2.414	KX	1.56	−3.809	Fe II	J	544.5807	−0.106	KX	2.50	−3.754
Fe II	173	390.6035	−1.700	N4	4.26	−3.842	Fe II	J	545.0099	−0.530	KX	2.71	−3.246
Fe II	184	540.8811	−2.393	KX	1.70	−3.598	Fe II	J	545.7730	−0.168	KX	2.82	−3.573
Fe II	185	527.2397	−2.010	N4	4.69	−3.252	Fe II	J	547.5829	−0.176	KX	3.22	−3.521
Fe II	185	517.2990	−2.463	K88	2.10	−3.432	Fe II	J	548.2308	0.432	KX	4.93	−3.696
Fe II	186	463.5316	−1.580	N4	4.61	−3.721	Fe II	J	548.7619	0.357	KX	6.33	−3.294
Fe II	186	462.5893	−2.202	K88	1.60	−3.844	Fe II	J	548.8782	−0.466	KX	1.77	−3.587
Fe II	187	444.6237	−2.439	K88	1.26	−3.737	Fe II	J	549.8576	−0.393	KX	2.35	−3.485
Fe II	188	411.1877	−2.160	KX	1.94	−3.783	Fe II	J	550.2671	−0.137	KX	3.72	−3.408
Fe II	188	406.9883	−2.751	KX	1.42	−3.384	Fe II	J	550.3897	−0.645	KX	1.83	−3.417
Fe II	189	406.1782	−2.018	KX	1.74	−3.987	Fe II	J	550.6195	0.950	MF	7.09	−3.741
Fe II	190	400.2543	−1.709	KX	3.09	−3.937	Fe II	J	550.7072	−0.325	KX	3.88	−3.193
Fe II	190	393.8970	−1.930	N4	3.13	−3.724	Fe II	J	553.2088	−0.327	KX	3.34	−3.318
Fe II	191	397.5016	−2.005	KX	2.01	−3.917	Fe II	J	554.4196	−0.230	KX	3.25	−3.397
Fe II	199	644.6410	−2.080	N4	1.94	−3.679	Fe II	J	554.9001	−0.230	KX	3.03	−3.491
Fe II	200	604.5465	−2.419	KX	2.62	−3.176	Fe II	J	556.7842	−1.887	KX	3.43	−3.309
Fe II	201	444.4539	−2.535	K88	2.16	−3.233	Fe II	J	558.1628	−0.481	KX	1.99	−3.494

© Copyright 2009: Instituto de Astronomía, Universidad Nacional Autónoma de México

© Copyright 2009: Instituto de Astronomía, Universidad Nacional Autónoma de México

TABLE 3 (CONTINUED)

Element	Multiplet	λ (nm)	log gf	Ref.	E.W.	log $N/N_{\rm tot}$
Fe II	J	558.7114	−2.185	KX	2.84	−3.153
Fe II	J	564.5392	0.085	KX	3.99	−3.561
Fe II	J	564.8904	−0.242	KX	3.81	−3.267
Fe II	J	567.5248	−0.498	KX	0.57	−4.273
Fe II	J	573.7898	−0.536	KX	2.88	−3.116
Fe II	J	577.6756	−0.580	K88	0.80	−3.862
Fe II	J	578.3630	0.365	N4	3.62	−3.840
Fe II	J	578.4448	0.060	KX	3.31	−3.601
Fe II	J	581.1629	−0.492	KX	3.04	−3.136
Fe II	J	583.0341	−0.269	KX	3.12	−3.309
Fe II	J	606.9675	−0.371	KX	1.15	−3.829
Fe II	J	607.1426	−0.188	KX	2.83	−3.461
Fe II	J	623.3534	−2.939	KX	1.67	−3.231
Fe II	J	624.8898	−2.696	KX	1.79	−3.423
Fe II	J	635.7162	0.169	KX	5.07	−3.158
Fe II	J	638.3722	−2.410	N4	3.30	−3.287
Fe II	J	649.3035	−2.575	KX	2.25	−3.366
Fe II	J	654.8379	0.210	KX	4.71	−3.214
Fe II	J	658.6699	−2.767	KX	0.87	−3.678
log $N/N_T = -3.90 \pm 0.09$						
Fe III	4	436.564	−3.430	K88	0.92	−3.885
Fe III	4	441.960	−2.210	K88	3.77	−4.025
Fe III	4	438.251	−3.020	K88	2.01	−3.781
Fe III	4	443.102	−2.580	K88	2.84	−3.925
log $N/N_T = -5.96 \pm 0.00$[a]						
Ni II	11	406.7031	−1.834	K03	1.58	−5.960
log $N/N_T = -6.31 \pm 0.34$						
Ga II	-	425.1149	0.350	RS	0.44	−6.590
Ga II	-	425.4075	−0.230	RS	0.29	−6.202
Ga II	-	426.2014	0.980	RS	2.27	−6.301
Ga II	-	536.3595	0.060	NK	0.63	−5.768
Ga II	-	541.6318	0.640	RS	0.81	−6.202
Ga II	-	633.4069	1.000	RS	1.69	−6.792
Ga II	-	641.9239	0.570	RS	0.93	−6.706
Ga II	-	645.5923	−0.080	RS	1.12	−5.949
log $N/N_T = -6.70 \pm 0.23$						
Sr II	1	407.7709	0.150	NI	5.46	−7.024
Sr II	1	421.5519	−0.170	NI	6.02	−6.550
Sr II	3	416.1800	−0.470	NI	1.01	−6.512
log $N/N_T = -7.20 \pm 0.46$						
Y II	5	435.8728	−1.329	HL	0.13	−7.221
Y II	5	439.8013	−1.000	HL	0.18	−7.395
Y II	6	395.0352	−0.490	HL	0.52	−7.428
Y II	6	398.2592	−0.490	HL	0.15	−7.983
Y II	7	383.2899	−0.340	HL	0.68	−7.416
Y II	13	437.4935	0.160	HL	4.45	−6.625
Y II	20	520.5724	−0.342	HL	2.00	−6.481
Y II	22	490.0120	−0.090	HL	0.45	−7.510
Y II	34	572.8890	−1.120	HL	0.12	−6.717
log $N/N_T = -7.27 \pm 0.15$						
Zr II	7	384.2995	−0.641	GB	0.59	−7.024
Zr II	16	395.8230	−0.306	CC	0.55	−7.326
Zr II	17	391.5959	−0.815	CC	0.17	−7.351
Zr II	30	399.1152	−0.300	GB	0.39	−7.397
log $N/N_T = -5.51 \pm 0.32$						
Xe II	-	537.2390	−0.211	WM	1.28	−5.759
Xe II	-	553.1070	−0.616	WM	1.46	−5.233
Xe II	-	571.9600	−0.746	WM	1.25	−5.150
Xe II	-	699.0880	0.200	WM	1.05	−5.883
log $N/N_T = -8.50 \pm 0.03$[a]						
Ba II	1	455.4029	0.163	NB	0.27	−8.527
Ba II	1	493.4076	−0.150	NB	0.15	−8.466
log $N/N_T = -6.42 \pm 0.29$						
Ce II	-	394.2151	−0.280	MC	0.96	−6.155
Ce II	-	398.0890	−0.050	MC	0.34	−6.598
Ce II	-	399.3819	0.354	MC	0.43	−6.812
Ce II	-	399.9237	0.232	MC	0.48	−6.887
Ce II	-	413.3802	0.390	MC	0.67	−6.656
Ce II	-	420.2958	−0.191	MC	0.68	−6.236
Ce II	-	425.5782	−0.123	MC	0.66	−6.213
Ce II	-	442.7916	−0.460	MC	0.46	−6.115
Ce II	-	446.0207	0.171	MC	0.87	−6.460
Ce II	-	452.8473	0.075	MC	0.44	−6.535
Ce II	-	456.5840	−0.016	MC	0.92	−5.992
log $N/N_T = -7.61 \pm 0.04$[a]						
Ce III	-	452.1922	0.979	BC	0.18	−7.572
Ce III	-	453.5727	−1.913	BC	0.83	−7.651
log $N/N_T = -9.10 \pm 0.09$[a]						
Pr III	-	528.4681	−0.510	DR	1.09	−9.005
Pr III	-	595.6035	−0.700	DR	0.34	−9.195
log $N/N_T = -8.12 \pm 0.26$						
Nd III	-	4903.241	−1.830	DR	0.43	−8.430
Nd III	-	492.7488	−0.830	DR	2.07	−8.390
Nd III	-	510.2455	−0.380	DR	2.93	−8.496
Nd III	-	512.7044	−1.080	DR	2.33	−8.115
Nd III	-	528.6753	−1.510	DR	1.34	−7.889
Nd III	-	529.4113	−0.650	DR	3.71	−8.272
Nd III	-	567.7178	−1.410	DR	0.57	−8.411
Nd III	-	584.5020	−1.130	DR	2.46	−7.842
Nd III	-	598.7683	−1.220	DR	2.78	−7.724
Nd III	-	614.5068	−1.290	DR	1.66	−8.075
Nd III	-	632.7265	−1.360	DR	1.83	−8.002
Nd III	-	655.0231	−1.440	DR	2.25	−7.836
log $N/N_T = -6.84 \pm 0.10$						
Pt II	-	402.3823	−2.610	DW	0.12	−6.785
Pt II	-	414.8271	−2.300	DW	0.10	−6.978
Pt II	-	451.4124	−1.480	DW	1.34	−6.763
log $N/N_T = -4.89 \pm 0.28$						
Hg I	-	435.8320	−0.323	BL	0.45	−5.171
Hg I	-	546.0730	−0.185	BL	1.12	−4.613

[a]Indicates that the abundance is determined from one or two lines only.

References. BB: Berry et al. (1971); BC: Bord et al. (1997); BG: Biémont et al. (1982); BL: Benck, Lawler, & Dakin (1989); CC: Cowley & Corliss (1983); CW: Cowley et al. (2000); DR: http://www.umh.ac.be/astro/dream.shtml; DW: Dworetsky, Storey, & Jacobs (1984); FM: Fuhr, Martin, & Wiese (1988); GB: Grevesse et al. (1981); G74: Griem (1974); HL: Hannaford et al. (1982); KX: Kurucz & Bell (1995); K88: Kurucz (1988); K03: Kurucz (2003, private comm.); LA: Lanz & Artru (1985); MF: Martin et al. (1988); MC: Magazzu & Cowley (1986); NB: Miles & Wiese (1969); N4: Fuhr (2005); NK: Nielsen, Karlsson, & Wahlgren (2000); NI: http://physics.nist.gov/cgi-bin/AtData/lines_form; PT: Pickering, Thorne, & Pérez (2002); RS: Ryabchikova & Smirnov (1994); SG: Schulz-Gulde (1969); SL: Sigut & Landstreet (1990); WD: Ward (1985); WF: Wiese, Fuhr, & Deters (1996); WM: Wiese & Martin (1980); WS: Wiese, Smith, & Glennon (1966).

© Copyright 2009: Instituto de Astronomía, Universidad Nacional Autónoma de México

The helium abundance was found by comparing the profile of λ 4426, λ 4387, λ 4471 and λ 4922 lines with theoretical ones computed using SYNTHE code, with approximate Stark damping constants yielded by the SYNTHE code. We used a model for HD 168733 having parameters $T_{\rm eff}$ = 14000 K, log g = 3.70, microturbulent velocity $\xi = 1.5$ km s^{-1}. The synthetic profile was also broadened for $v \sin\, i$ = 10 km s^{-1} and for a Gaussian instrumental profile with 40000 resolving power. A rotation velocity of 10 km s^{-1} was taken from a recient paper of Hubrig et al. (2007) and was verified by us in our spectra. We did not consider any Zeeman effect in the computed spectrum and we have supposed that its effect is taken into account in the microturbulence velocity adopted. Although the He/H values are not consistent from line to line, all of them show a great underabundance. Figures 1-3 show the comparison between synthetic and observed profiles for λ 4471 for three different He abundances. A mean value of −3.00 was adopted. This star shows then a marked deficiency of helium.

We did not then make any correction to convert log N/N_T values to log N/H. The analysis of the metal line spectra, Table 3, contains for each line the multiplet number (Moore 1945), the laboratory wavelength, the logarithm of the *gf*-value and its source, the equivalent width in units of 0.01 Å as observed, and the deduced abundance. References for the *gf* values are given at the end of Table 3.

TABLE 4

COMPARISON OF PRESENT RESULTS WITH PREVIOUS ONES

Element	Little	M&C	This Paper	Sun
He I	...	...	−3.00	−1.07
C II	−2.69	...	−3.52	−3.71
N II	−3.06	−3.20	−3.93	−4.22
O I	...	...	−2.89	−3.34
Na I	...	...	−4.47[a]	−5.73
Mg I	...	...	−2.88[a]	−4.47
Mg II	−4.75	...	−5.03	−4.47
Al I	...	...	−5.05	−5.63
Si II	−4.50	−4.00	−4.48	−4.49
Si III	−3.71	−4.30	−4.65	−4.49
P II	...	...	−6.15	−6.64
S II	−5.36	...	−5.20	−4.86
Cl II	−4.84	−4.30	−5.13	−6.27
Sc II	−4.90[a]	...	−7.74	−8.95
Ti II	−4.85	−4.50	−4.97	−7.10
Ti III	−3.51	−3.90	−4.61	−7.10
Cr II	−5.54	−4.90	−5.29	−6.36
Fe I	−3.79	−3.10	−3.22	−4.55
Fe II	−4.02	−3.20	−3.57	−4.55
Fe III	−3.08	−2.80	−3.90	−4.55
Ni II	−5.30	...	−5.96[a]	−5.78
Sr II	−6.82	...	−6.70	−9.08

[a]Indicates that the abundance is determined from one or two lines only.

5. DISCUSSION

Table 4 compares our results with the previous ones obtained by Little (1974, L), Muthsam & Cowley (1984, M&C) and the Sun (Asplund, Grevesse, & Sauval 2005). We can see that, in general, they are in agreement with the results obtained by L and M&C.

Table 5 shows a comparison between our derived abundances and the ones of κ Cnc, a typical HgMn star (Adelman & Pintado 2000), HD 206653, a CP2 star (Albacete-Colombo et al. 2002), HD 65949 wich is similar to HD 168733 in the sense that it is neither a silicon nor a mercury-manganese star (Cowley et al. 2006), but it has perhaps the highest mercury abundance of any known star. We do not identify in HD 168733 exotic elements such as Re II, Os II, Te II that are present in HD 65949.

Compared to the Sun, C and N are slightly overabundant by factors of 1.5 and 2 respectively, a result not shared by the HgMn or the Si stars where the light elements are in general deficient. Mg is deficient, Si shows a solar value, while Si III shows a small deficiency, confirming that HD 168733 is not a silicon star.

P is overabundant by a factor 3. It is overabundant in the HgMn stars and rarely present in the CP2 group. S is deficient by a factor 2 as in the HgMn and Si stars. Cl is overabundant, showing a behavior similar to other silicon stars. The “iron peak” elements are all overabundant, Sc, Ti, Cr, and Fe by factors 16, 135, 10 and 10 respectively. One can see that Ti is strongly present; some lines of Ti III are also present, showing an overabundance similar to that of Ti II. Fe is present in the three ionization stages, as Fe I, Fe II and Fe III. It is overabundant by a factor 10, greater than the observed in the stars of the other groups. Fe III, present with only 4 lines gives an overabundance by a factor 5, but confirms the great overabundance of Fe in HD 168733. Mn is definitely not present and we identified only one line of Ni II.

The average abundance of gallium is log $N_{Ga}/N_H = -6.31 \pm 0.34$, corresponding to an over-

TABLE 5

COMPARISON OF ABUNDANCES OF HD 168733, κCNC, HD 206653, HD 65949 AND THE SUN ($\log N/H$)

Element	HD168733	κCnc	HD206653	HD65949	Sun
He I	−3.00	−2.22	···	···	−1.07
C II	−3.52	−3.79	−4.70	···	−3.71
N II	−3.93	···	···	Poss.	−4.22
O I	−2.89	−3.46	···	···	−3.34
Mg I	−2.88[a]	···	···	···	−4.47
Mg II	−5.03	−5.05	−4.55	···	−4.47
Al I	−5.05	···	−4.20	···	−5.63
Si II	−4.48	−4.37	−3.73	···	−4.49
Si III	−4.65	−4.31	−4.50	···	−4.49
P II	−6.15	−4.51	···	Pres.	−6.60
S II	−5.20	−5.32	−5.52	Pres.	−4.84
Cl II	−5.13	···	···	···	−6.27
Sc II	−7.74	−8.12	···	Poss.	−8.95
Ti II	−4.97	−6.74	−5.33	Pres.	−7.1
Ti III	−4.61	···	···	···	−7.10
Cr II	−5.29	−6.27	−4.97	Pres.	−6.36
Mn I	···	−4.13	···	···	−6.61
Mn II	···	−4.34	···	Pres.	−6.61
Fe I	−3.22	−4.47	···	···	−4.55
Fe II	−3.57	−4.37	−3.51	Pres.	−4.55
Fe III	−3.90	−4.31	−4.66	···	−4.55
Ni II	−5.96[a]	−6.25	−5.15	Poss.	−5.78
Ga II	−6.31	−4.77	···	···	−9.12
Sr II	−6.70	−8.48	−5.80	Pres.	−9.08
Y II	−7.20	−8.39	−6.60	Pres.	−9.79
Zr II	−7.27	···	−5.71		−9.41
Xe II	−5.57	···	···	Pres.	−9.73
Ba II	−8.53	···	−7.39	···	−9.84
Ce II	−6.42	···	−5.48	Poss.	−10.42
Ce II	−7.61	···	···	Poss.	−10.42
Pr II	−9.10	···	···	Pres.	−11.25
Nd III	−8.12	···	···	Pres.	−10.55
Pt II	−6.84	···	···	−7.49	−10.36
Hg I	−4.89	···	···	···	−10.87
Hg II	?	−5.98	−6.11	−4.60	−10.87
$T_{\rm eff}$	14000	13250	14000	13600	

[a]Indicates that the abundance is determined from one or two lines only.
Pres= Present, Poss= Possible.

abundance [+ 2.81], approximately 650 times the solar value. In the HgMn stars Ga is generally overabundant by a factor of 3000. It is not present in HD 65949 nor in the silicon stars. Sr, Y and Zr are all overabundant by factors of 240, 390 and 140, respectively. This behavior is similar to that found in the other stars. For Ba II we have identified only two lines.

We have identified four lines of Xe II. This element shows a high overabundance as in some HgMn stars and also is present in HD 65949. Of the rare earths, we identified Ce II, Ce III, Pr III and Nd III; the presence of these elements in the second ionization stage is normal for the HgMn stars. Pt II is also identified in our spectra with a great overabundance, 3000 times the solar one. Pt is identified in the HgMn objects with a similar overabundance. We used two lines of Hg I to calculate its abundance. It shows an overabundance of the order of 9.5×10^4 times the solar value, similar to the value found in HgMn stars. The Hg II line λ 3984 shows a complicated structure and is not useful for an abundance measurement.

We have improved previous abundance analyses of HD 168733, extending the number of identified elements and resolving the ionization balance problem for elements present in two ionization stages, using better model atmospheres that include blanketing of numerous metallic lines and more realistic abundances, greater than the solar values. We think that for some elements such as Si III, Ti III and Fe III it is necessary to take into account better determinations of the log gf.

The authors thank the night assistants of CASLEO for their help during the observing runs. A.E.C. appreciates useful discussions about data reduction with Dr. F. González, and thanks Dr. S. Malaroda and Dr. R. Gamen for their help in preparing the manuscript. This research was supported by a grant from CICITCA, UNSJ. We are grateful to the anonymous referee for valuable comments, corrections and suggestions which helped improve the paper.

REFERENCES

Adelman, S. J. 1987, MNRAS, 228, 573
Adelman, S. J., & Pintado, O. I. 2000, A&A, 354, 899
Adelman, S. J., & Rayle, K. E. 2000, A&A, 355, 308
Albacete-Colombo, F., López-García, Z., Levato, H., Malaroda, S. M., & Grosso, M. 2002, A&A, 392, 613
Asplund, M., Grevesse, N., & Suval, J. 2005 in ASP Conf. Ser. 336, Cosmic Abundances as Records of Stellar Evolution and Nuclear Synthesis, ed. F. N. Bash & T. G. Barnes (San Francisco: ASP), 25
Benck, E. C., Lawler, J. E., & Dakin, J. T. 1989, J. Opt. Soc. Am. B., 6, 11
Berry, H. G., Bromander, J., Curtis, L. J., & Buchta, R. 1971, Phys. Scr., 3, 125
Bidelman, W. P., & Aller, L. 1963, AJ, 68, 273
Biémont, E., Grevesse, N., Kwiatkovski, M., & Zimmermann, P. 1982, A&A, 108,127
Bord, D. J., Cowley, C. R., Hubrig, S., & Bidelman, W. P. 2003, BAAS, 35, 744
Bord, D. J., Cowley, C. C., & Norquist, P. L. 1997, MNRAS, 284, 869
Cowley, C. R., & Corliss, C. H. 1983, MNRAS, 203, 651
Cowley, C. R., Hubrig, S., González, J. F., & Núñez, N. 2006, A&A, 455, L21

© Copyright 2009: Instituto de Astronomía, Universidad Nacional Autónoma de México

Cowley, C. R., Wiese, W. L., Fuhr, J., & Kuznetsova, L. A. 2000, in Astrophysical Quantities, ed. A. N. Cox (4th ed.; New York: Springer), 53
Dolk, L., et al. 2002, A&A, 385, 111
Dworetsky, M. M., Storey, P. J., & Jacobs, J. M. 1984, Phys. Scr., T8, 39
Engleman, R. 1989, ApJ, 340, 1140
Fuhr, J. R. 2005, J. Phys. Chem. Ref. Data, submitted
Fuhr, J. R., Martin, G. A., & Wiese, W. L. 1988, J. Phys. Chem. Ref. Data, 17, 4
Glagolevskij, Yu. V. 1994, Bull. Spec. Astrophys. Obs., 38, 152
Grevesse, N., Biémont, E., Hannaford, P., & Lowe, R. M. 1981, in Upper Main-Sequence CP Stars, 23rd Liége Astrophys. Coll. (Liége: Université de Liége), 211
Griem, H. R. 1974, Spectral Line Broadening by Plasmas (New York: Academic Press)
Guthrie, B. N. G. 1984, MNRAS, 206, 85
Hannaford, P., Lowe, R. M., Grevesse, N., Biémont, E., & Whaling, W. 1982, ApJ, 261, 736
Hauck, B., & Mermilliod, M. 1998, A&AS, 129, 431
Hubrig, S., North, P., & Schöeller, M. 2007, Astron. Nachr., 328, 475
Huldt, S., Johansson, S., Litzen, U., & Wyart, J. F. 1982, Phys. Scr., 25, 401
Iglesias, L., & Velasco, R. 1964, Publ. Inst. Opt. Madrid, 23
Isberg, B., & Litzén, U. 1985, Phys. Scr., 31, 533
Johansson, S. 1978, Phys. Scr., 18, 217
Jones, T. J., & Wolff, S. C. 1974, PASP, 86, 67
Kurucz, R. L. 1970, SAO Special Report 309 (Cambridge: SAO)
__________. 1988, in Trans. IAU, XXB, ed. M. McNally (Dordrecht: Kluwer), 168
Kurucz, R. L., & Bell, B. 1995, Atomic Line Data, CD-ROM 23 (Cambridge: SAO)
Lanz, T. 1987, PhD Thesis, University of Geneva
Lanz, T., & Artru, M.-C. 1985, Phys. Scr., 32, 115
Lanz, T., Dimitrijević, M. S., & Artru, M.-C. 1988, A&A, 192, 249
Little, S. J. 1974, ApJ, 193, 639
Little, S. J., & Aller, L. H. 1970, ApJS, 22, 157
Magazzu, A., & Cowley, C. R. 1986, ApJS, 308, 254
Manfroid, J., & Renson, P. 1994, A&A, 281, 73
Martin, G. A., Fuhr, J. R., & Wiese, W. 1988, J. Phys. Chem. Ref. Data, 17, 3
Mathys, G., & Hubrig, S. 1997, A&AS, 124, 475
Miles, B. M., & Wiese, W. L. 1969, Atomic Data 1 (NBS Tech. Note 474; Washington: US GPO), 1
Moore, C. E. 1945, A Multiplet Table of Astrophysical Interest (Princeton: Princeton Univ. Obs.)
Muthsam, H., & Cowley, C. 1984, A&A, 130, 348
Nave, G., Johansson, S., Learner, R. C. M., Thorne, A. P., & Brault, J. W. 1994, ApJS, 94, 221
Nielsen, H., Karlsson, H., & Wahlgren, G. M. 2000, A&A, 363, 815
Nilsson, A. E., Johansson, S., & Kurucz, R. L. 1991, Phys. Scr., 44, 226
Osawa, K. 1965, Ann. Tokyo Astron. Obs., Ser., 9, 123
Pettersson, J. E. 1983, Phys. Scr., 28, 421
Pickering, J. C., Thorne, A. P., & Pérez, R. 2002, ApJS, 138, 247
Reader, J., & Corliss, C. H. 1980, Wavelengths and Transition Probabilities for Atoms and Atomic Ions, Part I (NSRDS-NBS 68; Washington: US GPO)
Renson, P. 1978, Inf. Bull. Variable Stars, 1391
Rogers, N. Y. 1995, Communications in Asteroseismology, 78, 1
Rosberg, M., & Wyart, J. F. 1997, Phys. Scr., 55, 690
Ryabchikova, T., & Smirnov, Y. 1994, Astron. Rep., 38, 70
Schulz-Gulde, E. 1969, J. Quant. Spectrosc. Radiat. Transfer, 9, 13
Shallis, M. J., & Blackwell, D. E. 1979, A&A, 79, 48
Sigut, T. A. A., & Landstreet, J. D. 1990, MNRAS, 247, 611
Svendenius, N., Magnusson, C. E., & Zetterberg, P. O. 1983, Phys. Scr., 27, 339
Ward, L. 1985, MNRAS, 213, 71
Wiese, W. L., Fuhr, J. R., & Deters, T. M. 1996, J. Phys. Che. Ref. Data, 7, 21
Wiese, W. L., & Martin, G. A. 1980, Wavelengths and Transition Probabilities for Atoms and Atomic Ions, Part II (NSRDS-NBS 68; Washington: US GPO)
Wiese, W. L., Smith, M. W., & Glennon, B. M. 1966, Atomic Transition Probabilities, Vol. I (NSRDS-NBS 4; Washington: US GPO)

Ana Collado: Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de San Juan, Av. Ignacio de la Roza 590 (O), Rivadavia, San Juan, Argentina, CPA: J5402DCS (zlgarcia@casleo.gov.ar).
Zulema López-García: Complejo Astronómico El Leoncito, CASLEO, CONICET and Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de San Juan, Argentina (zlgarcia@casleo.gov.ar).

© Copyright 2009: Instituto de Astronomía, Universidad Nacional Autónoma de México