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Elemental abundance analyses with Complejo Astronomico El Leoncito REOSC echelle spectrograms*

IV. Extensions of nine previous analyses

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Abstract. Using new CASLEO echelle spectrograms, we extended our elemental abundances of the sharp-lined Mercury-Manganese stars μ Lep, 14 Hya, κ Cnc, HR 4487, HR 4817, 28 Her, and HR 7245, the closely related star 3 Cen A, and 7 Sex an A0 V star with Population I abundances, but with Population II star space motions. The $\lambda\lambda$4500-6200 region contains a sufficient number of lines to derive high-quality abundances of these stars. For most stars, the new spectra provide additional lines for the analyses which improve their quality as well as help fill in the periodic table.

Key words: stars: abundances – stars: chemically peculiar

1. Introduction

Pintado & Adelman (1996), Adelman & Pintado (1997), and Pintado et al. (1998) performed elemental abundances analyses of 10 sharp-lined B and early A stars with spectrograms obtained with the 2.15-m telescope of the Complejo Astronomico El Leoncito (CASLEO) and a REOSC echelle spectrograph, which is on loan from the Institute Astrophysique de Liege, Belgium, and a TEK 1024 CCD. The cross dispersers were gratings with 1200 and 300 lines mm^{-1}. The equivalent width scale of these spectrograms for lines whose equivalent widths are $\geq$ 15 mÅ is marginally greater than those for Kitt Peak National Observatory (KPNO) coudé feed CCD and Dominion Astrophysical Observatory (DAO) Reticon spectrograms. Further the $\lambda\lambda$4500-5600 region for Mercury-Manganese (HgMn) and A0 V stars contains a sufficient number of unblended lines for high quality abundance analyses. Now we use additional spectrograms to extend nine of the 10 studies of our first three papers further into the red, a process which also makes them somewhat more uniform.

2. Reduction of spectrograms

The spectra reductions were made using IRAF. [1] Each night we produced a combined flat field from bias and flat frames and used it to divide the spectra to remove the pixel-to-pixel variations. The extraction was done with APALL and the wavelength calibration with ECIDENTIFY and DISPCOR using the ThAr comparison spectra.

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 for P II (Svendenius et al. 1983), P III (Magnusson & Zetterberg 1977), Mn II (Iglesias & Velasco 1964), Fe II (Johansson 1978), and Ga II (Isberg & Litzen 1985).

Table 1 lists the spectral regions of both our previous studies and the new extensions. Lines of additional atomic species found in the extensions are those of O I for μ Lep, O I and Mg I for 14 Hya, and of O I and Ne I for κ Cnc. In the spectra of HR 4487, HR 4817, 3 Cen A, and 28 Her the Na I D lines were seen, but these are probably of an interstellar origin. Newly found species for HR 4487 are Al I and P II as well as a confirmation of Hg I by the identification of a second line. For 3 Cen A O I and Ne I

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* Table 5 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr(130.79.128.5) or via http://cdsweb.u-strabg.fr/Abstract.html

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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 1. Spectral regions studied

Star	Previous Regions(Å)	New Region (Å)
μ Lep	4522-5589	7769-7781
14 Hya	4434-5076	5076-6131
		7731-7777
κ Cnc	4650-5110	5110-6150
7 Sex	4450-5057	5057-6140
HR 4487	4121-4130	5544-6127
	4170-5614	7703-7850
HR 4817	4422-5607	5607-6150
3 Cen A	3849-3868	5508-6147
	3906-3936	
	3991-4685	
	4712-4860	
	5010-5508	
28 Her	4521-5617	5617-6135
		7769-7781
HR 7245	3830-4485	5102-6683
	4500-5102	

lines were seen and for HR 7245 Ne I and Mg I lines. No new species were found for 7 Sex.

3. Effective temperatures and surface gravities

We used the homogeneous *uvby*β colors of Hauck & Mermilliod (1990) with the calibration of Napiwotzki et al. (1993) to obtain preliminary values of the effective temperature and surface gravity for each star. Then for those stars with published spectrophotometry and Hγ profiles these values were compared with the predictions of Kurucz (1995) ATLAS9 models to obtain best fits and hopefully better effective temperature and surface gravity estimates. Recently Adelman & Rayle (2000) found slight systematic differences as large as a few hundred K which are important especially for the hottest HgMn stars. Thus we used their corrected values for those stars whose parameters are found only via photometry. Table 2 lists the stars of this paper and the sources of their effective temperatures and surface gravities. The changes relative to our original analyses are as large as 300 K in effective temperature and in log g are usually only a few hundredths of a dex.

4. The elemental abundance analyses

We employed programs SYNSPEC (Hubeny et al. 1994) and WIDTH9 (Kurucz, private communication, respectively, to determine the helium and metal abundances. The adopted metal-line damping constants were those of Kurucz & Bell (1995). We applied a 3.5% scattered light correction to account for light scattered along the direction of the dispersion, which is an appropriate value for clean optical systems (Gulliver et al. 1996).

Table 3 contains the derived He/H ratios from new lines and a few older lines when there are changes of order 0.01 dex from our previously adopted values. For most stars no new analyzable He I lines are found and the changes in the stellar parameters are insufficient to change the derived He/H ratios. For HR 4817 the 300 K decrease in effective temperature increased the He/H ratio by 0.01. For HR 7245 the 240 K decrease in effective temperature increased the He/H ratio by 0.005.

Table 2. Effective temperatures and surface gravities

Star	$T_{\rm eff}$(K)	log g	Source
μ Lep	12400	3.70	1
14 Hya	12030	3.68	2
κ Cnc	13250	3.75	1
7 Sex	10135	3.70	3
HR 4487	10945	3.88	2
HR 4817	12600	3.68	2
3 Cen A	17500	3.80	4
28 Her	10845	3.82	2
HR 7245	12125	3.41	2

Sources: 1. Adelman & Rayle (2000) spectrophotometry and Hγ profile fitting, 2. Napiwotzki et al. (1993) program values using *uvby*β colors of Hauck & Mermilliod (1990) as corrected by Adelman & Rayle (1999), 3. Napiwotzki et. al (1993) program with *uvby*β colors from Hauck & Mermilliod (1990), 4. Castelli et al. (1997)

Table 3. New derived He/H ratios

Star	Wavelength (Å)	He/H
HR 4817	4144	0.07
	4472	0.05
	4713	0.05
Average		0.06
HR 7245	4026	0.020
	4472	0.025
	4713	0.015
	4921	0.025
	6678	0.025
Average		0.022

Table 4 summarizes the determination of the microturbulence using Fe I and Fe II lines. Those for ξ_1 were found by demanding that the derived abundances be independent of equivalent width and those of ξ_2 by minimizing the standard deviation of the mean. The differences with previous analyses are small. For μ Lep, 7 Sex, and 28 Her the adopted values decreased by 0.1 km s^{-1}, for 14 Hya it increased by 0.3 km s^{-1}, for κ Cnc by 0.7 km s^{-1}, for 3 Cen A by 0.1 km s^{-1}, and for HR 4817 it was unchanged. From Fe II lines, HR 4487, which previously had an undetermined microturbulence, now has a value of 0.9 km s^{-1} which somewhat large for HgMn stars. The 24 good Fe I lines yield a solution of order 2 km s^{-1}, but they did not include a sufficient number of strong lines. For 3 Cen A with the largest measured equivalent width of any Fe II line being less than 60 mÅ, the microturbulence is not well determined. For HR 7245 we found 0.5 km s^{-1} while previously it was not well determined and we used 0.0 km s^{-1} instead. There appears

Table 4. Determination of the microturbulences

Star	Species	gf values	n	ξ_1 (km s^{-1})	log Fe/N_T	ξ_2 (km s^{-1})	log Fe/N_T
μ Lep	Fe II	MF+KX	107	0.2	-4.62±0.23	0.2	-4.62±0.23
		MF	33	0.3	-4.70±0.23	0.3	-4.70±0.23
	adopted			0.2			
14 Hya	Fe II	MF+KX	54	0.5	-4.81±0.29	0.6	-4.83±0.29
	adopted			0.6			
κ Cnc	Fe II	MF+KX	236	0.7	-4.31±0.25	0.6	-4.30±0.25
		MF	57	0.8	-4.46±0.24	0.7	-4.45±0.24
	adopted			0.7			
7 Sex	Fe I	MF+KX	64	1.9	-4.17±0.26	1.6	-4.15±0.26
		MF	56	1.8	-4.20±0.24	1.7	-4.20±0.24
	Fe II	MF+KX	139	1.2	-4.25±0.25	1.2	-4.25±0.25
		MF	49	1.6	-4.42±0.20	1.5	-4.41±0.20
	adopted			1.6			
HR 4487	Fe II	MF+KX	132	0.9	-4.42±0.28	0.7	-4.41±0.28
		MF	36	1.0	-4.57±0.25	1.1	-4.58±0.25
	adopted			0.9			
HR 4817	Fe II	MF+KX	63	0.0	-4.87±0.27	0.0	-4.87±0.27
		MF	25	0.0	-5.00±0.23	0.0	-5.00±0.23
	adopted			0.0			
3 Cen A	Fe II	MF+KX	74	1.7	-4.34±0.28	1.4	-4.33±0.28
		MF	28	0.7	-4.27±0.25	0.8	-4.27±0.25
	adopted			1.2			
28 Her	Fe I	MF+KX	89	0.0	-4.43±0.19	0.0	-4.43±0.19
		MF	82	0.0	-4.44±0.19	0.0	-4.44±0.19
	Fe II	MF+KX	243	0.0	-4.34±0.25	0.0	-4.34±0.25
		MF	58	0.6	-4.44±0.21	0.5	-4.43±0.21
	adopted			0.1			
HR 7245	Fe II	MF+KX	219	0.4	-4.45±0.28	0.1	-4.45±0.28
		MF	39	0.7	-4.62±0.22	0.7	-4.62±0.22
	adopted			0.5			

gf value references: KX = Kurucz (1995), MF = Fuhr et al. (1988)

to be a tendency for lines in the yellow and red to give a slightly larger microturbulence than lines in the blue. This might be due to larger errors in the oscillator strengths.

Table 5 shows the elemental abundances from newly found lines [2] in our spectra. We give for each line 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. For each species with any newly found lines we give the mean abundance and its standard deviation. Table 6 summarizes the elemental abundances and compared them with solar values from Grevesse, Noels & Sauval (1996).

The changes for μ Lep with respect to our previous analysis are small. The ionization equilibria are slightly better. The new O abundance is greater than solar, but multiplet 1 of O I exhibits non-LTE effects and perhaps its values should be made smaller (see text below). For 14 Hya, the the values based on one Mg I and one Mg II line show large differences. We did not use the results from O I multiplet 1 as the lines of this multiplet gave larger results by order 0.60 dex. This also occurs for HR 4487. For 14 Hya P now is more overabundant while the abundances based on many lines are little changed. The changes for 7 Sex are due to new lines and to the reduction in microturbulence with those for C I, S II, and Y II being around 0.20 dex. For κ Cnc, the new abundances are greater; between 0.2 and 0.3 dex for P II, S II, Sc II, and Fe II, by typically 0.35 dex for Ca II, Mn I, and Mn II, and by 0.83 dex for Ni II relative to Adelman (1987). Relative to the values of Pintado & Adelman (1996) the changes are all less than 0.20 dex. These reflect more the changes in surface gravity than in effective temperature, but some may be due to improved oscillator strengths. Most of the new abundances of HR 4487 are slightly less than the previous values due to the larger adopted microtubulence, but Ca I is now greater making this star the most Ca overabundant HgMn star known. Lines in the blue need to be measured to confirm this value. As usually the neutral abundances are slightly greater than

[2] Table 5 is available only in electronic form at the CDS via anonymous ftp to 130.79.128.5.

Table 6. Summary of elemental abundances log (N/H)

Species	3 Cen A	κ Cnc	HR 4817	μ Lep	HR 7245	14 Hya	HR 4487	28 Her	7 Sex	Sun
He I	-1.70	-2.22	-1.15	-1.57	-1.66	-1.40	-1.53	-2.00	-1.00	-1.01
C I	...	...	...	...	...	...	-3.46	...	-3.30	-3.45
C II	-4.38	-3.79	-3.63	-3.61	-3.85	...	-2.95	-3.88	-2.67	-3.45
N II	-3.90	...	...	...	...	...	...	...	...	-4.03
O I	-3.66	-3.46	-3.05	-2.52:	-3.22	-3.08	-3.22	-3.37	-2.95	-3.13
Ne I	-3.55	-3.38	...	...	-4.48	...	...	...	...	-3.92
Mg I	...	...	-4.64	-5.10	-4.43	-4.90	-4.82	-5.52	-3.93	-4.42
Mg II	-5.08	-5.05	-4.11	-4.61	-4.27:	-4.06	-5.22	-5.04	-4.09	-4.42
Al I	...	...	...	...	...	...	-4.37	...	-5.81	-5.53
Si II	-4.54:	-4.37	-4.39	-4.47	-4.06	...	-4.22	-4.65	-4.31	-4.45
Si III	-4.81	-4.31	-4.73	-4.22	...	...	...	...	...	-4.45
P II	-4.84	-4.51	-6.06	-5.34	-5.21	-5.63	-5.43	-5.57	...	-6.55
S II	-5.15	-5.32	-4.95	-4.70	-5.42	-4.71	-3.80	-4.45	-4.19	-4.67
Ar II	-5.37	...	...	...	...	...	...	...	...	-5.48
Ca I	...	...	...	...	...	...	-4.07	-6.14	-4.93	-5.64
Ca II	-6.54	-5.65	-5.49	-5.26	-4.91	...	...	-5.59	-5.27	-5.64
Sc II	...	-8.12	-7.79	-8.41	-8.67	...	-8.18	...	-8.56	-8.83
Ti II	...	-6.74	-5.62	-6.39	-6.37	-5.73	-6.81	-6.86	-6.74	-6.98
V II	...	-7.70	...	...	...	...	...	...	-7.71	-8.00
Cr I	...	...	...	...	...	...	...	-5.92	-5.69	-6.33
Cr II	-5.77	-6.27	-5.50	-5.89	-5.85	-5.60	-5.45	-6.19	-5.98	-6.33
Mn I	...	-4.13	-4.10	-4.56	-4.44	-4.42	-4.38	-5.64	...	-6.61
Mn II	-4.80	-4.34	-4.12	-4.50	-4.86	-4.46	-5.14	-5.48	-5.65	-6.61
Fe I	...	-4.47	...	-4.72	-4.39	...	-4.11	-4.43	-4.12	-4.50
Fe II	-4.30	-4.37	-4.90	-4.63	-4.50	-4.80	-4.46	-4.39	-4.31	-4.50
Fe III	-4.23	-4.31	...	-4.72	-4.79	...	...	-4.30	...	-4.50
Ni I	...	...	...	...	...	...	-4.94	...	...	-5.75
Ni II	-5.61	-6.25	...	-6.34	-6.47	...	-5.45	...	-5.54	-5.75
Ga II	-5.66	-4.77	-5.72	-4.81	-5.90	...	...	...	...	-9.12
Sr II	...	-8.48	...	-7.30	-8.81	...	-7.37	-6.63	-9.11	-9.03
Y II	...	-8.39	-7.62	-7.09	-7.88	-7.03	-6.99	-6.68	-9.15	-9.76
Zr II	...	...	...	...	-7.79	...	-6.86	-8.57	-8.92	-9.40
Ba II	...	...	...	...	...	...	-8.65	-9.84	-9.68	-9.87
Ce II	...	...	...	...	-6.81:	...	...	...	...	-10.44
Hg I	...	...	...	-5.68	...	...	-6.53	...	...	-10.83
Hg II	...	-5.98	...	-5.63	-6.65	...	...	-7.77	...	-10.83
T_{eff}	17500	13250	12600	12400	12125	12030	10945	10845	10135	

those from the singly-ionized species, some slight adjustment in the stellar parameters are probably necessary but we lack sufficient information on how to do this. The new abundances for HR 4817, 3 Cen A, and 28 Her are generally similar to our previous values. The largest changes for 28 Her are between 0.10 and 0.20 dex for Mg II, Si II, and S II. Most of the abundances of HR 7245 have changed only slightly, but those of Si II and P II have changed by over 0.25 dex due to the inclusion for Si II of λ3853.66 and for P II of many additional lines.

5. Discussion

The lines from the spectra used to extend the analyses of this paper have both improved the quality of the derived abundances and helped to fill in the table of known abundances for these stars. Table 6 shows that 7 Sex is slightly metal-rich relative to the Sun. A major difference between 3 Cen A and the cooler HgMn stars is that its N abundance is normal while they are extremely N poor (Roby et al. 1999). As 3 Cen A is much hotter than the typical HgMn star, this may reflect a dependence of the N abundance on temperature for this sequence. Ne abundances are found for three stars. Additional determinations may help connect 3 Cen A with the cooler HgMn stars. Ga II lines are found in the hottest five stars while Zr II lines in the cooler stars. Iron peak elements can have large overabundances. When Mn has an abundance similar to that of iron, it could have an observable effect on the energy distribution. Other elements such as Si have values only in more limited ranges. Only when they are only very overabundant do Ga and Hg have observable lines.

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