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ELEMENTAL ABUNDANCES OF SHARP-LINED METALLIC-LINED AND COMPARABLE NORMAL STARS

DURSUN KOÇER*
Department of Astronomy, Istanbul University, 34452 University, Istanbul, Turkey

SAUL J. ADELMAN*
Department of Physics, The Citadel, Charleston, SC 29409 USA

ÇETIN BOLCAL*
Department of Physics, Istanbul University, 34459 Vezneciler, Istanbul, Turkey

GRAHAM HILL
Dominion Astrophysical Observatory, National Research Council of Canada, 5071 W. Saanich Road, Victoria, BC V8X 4M6 Canada

ABSTRACT We are performing elemental abundances of sharp-lined metallic-lined stars and normal late A through middle F stars using 2.4 Å mm^{-1} photographic region spectrograms taken with the coudé spectrograph of the 1.4-m telescope of the Dominion Astrophysical Observatory. Our initial studies of the Am stars 15 Vul and 32 Aqr and the normal stars θ Cyg (F4 V) and ι Psc (F7 V) showed that the elemental abundances of the normal stars were close to solar while 15 Vul shows smaller abundance anomalies than does 32 Aqr. These analyses are being done consistently with SJA's studies of the HgMn and hotter normal stars.

I. INTRODUCTION

We are analyzing the elemental abundances of several sharp-lined Am (metallic-lined) and comparable normal main sequence stars. This is the extension to cooler temperatures of the study of Mercury-Manganese and normal main sequence B and A type stars (see e.g. Adelman 1991). These complementary programs will allow us to evaluate the elemental abundances of both the nonmagnetic CP and normal upper main sequence stars over a considerable range of effective temperature.

The spectrographic material is being obtained with the coudé spectrograph of the 1.4-m telescope of the Dominion Astrophysical Observatory at a reciprocal dispersion of 2.4 Å mm^{-1}. Our initial studies of the normal stars θ Cyg (F4 V) and ι Psc (F7 V) Adelman et al. 1991) and of the Am stars 15 Vul and 32 Aqr (Bolcal et al. 1992) were based mainly

*Guest Investigator, Dominion Astrophysical Observatory, Hertzberg Institute of Astrophysics, National Research Council of Canada

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on coadded IIaO baked spectrograms which cover approximately λλ3700-4180 and λλ4190-4640. The coaddition procedure described by Adelman and Hill (1987) uses the REDUCE code (Hill and Fisher 1986). For our in progress and future studies, we will use spectra obtained with a Reticon. Our wavelength coverage will be approximately λλ3830-4770. We shifted the wavelength range to take advantage of the increased sensitivity of the Reticon to the red and to exchange a heavily line blanketed region for one with much cleaner and more analyzable lines. The signal-to-noise ratio of the Reticon material is typically 200 except for the very brightest stars while the coadded spectra have S/N ratios about 80 in the best exposed regions. In addition to these observations, Reticon exposures centered near Hγ are being made with a reciprocal dispersion of 19.6 Å mm^{-1}.

We have had some difficulties in measuring these spectra. The continuum is often hard to define, especially as one goes towards the blue in the spectra. The Reticon spectra appear to have more consistent continuum levels than the coadded spectra. This is clear when we have Reticon and coadded spectra of the same star in a given wavelength region. In the higher signal-to-noise ratio spectra, it is also easier to clearly identify blending components. But there is a wide range in difficulty in this regard. For example, Procyon and σ Boo are easier to measure than τ UMa and 60 Leo. Especially for complex spectral regions, analyses using synthetic spectra are probably more appropriate than those based on fine analysis techniques. But at present there are a several major obstacles to be surmounted to make such analyses in a routine manner. Thus we are using fine analyses techniques as a step in this direction.

II. MODEL ATMOSPHERES

Our analyses so far have used ATLAS6 metal-lined blanketed model atmospheres (Kurucz 1979). We plan to implement the ATLAS9 code for future analyses (Kurucz, private communication). This will permit a better match to the microturbulences and non-solar abundances. We also believe that a somewhat better match will be achieved especially for those stars which show molecular lines in their spectra. For some of these stars IUE low dispersion trailed observations with both LWP and SWP cameras have been obtained by SJA and Glenn M. Wahlgren. They plan to use these observations to improve the derived stellar parameters.

III. EFFECTIVE TEMPERATURES AND SURFACE GRAVITIES

The determination of effective temperatures and surface gravities is a major problem for the Am and the late A and F stars. There are several ways of proceeding. In this temperature regime the effective temperature can be found by measuring a Balmer line profile (or equivalent width) and then the surface gravity can be found from the energy distribution. The problem is that when one does this using line profiles obtained at high dispersion and spectrophotometric measurements one obtains a different answer than using intermediate band photometry for which there are several inconsistent prescriptions, e.g. those of Moon and Dworetsky (1985) and Lane and Lester (1987). The use of ATLAS9 models and consistently measured Balmer line profiles should ameliorate this problem. We are comparing synthetic spectra calculated by the program SYNTHE (Kurucz, private communication) with the observations corrected for scattered light.

IV. MICROTURBULENCES

We derive microturbulences in two ways. After calculating abundances from Fe I and Fe II lines, atomic species with a large range in line strength and better quality gf-values than most other species, we find what microturbulences (ξ_1) result in no dependence of the derived abundances on equivalent width and (ξ_2) minimize the scatter about the mean. Usually the resulting values agree quite closely. Table 1 gives these values for our four stars assuming the Moon and Dworetsky (1985) values for effective temperature and surface gravity. These results are relatively insensitive to 10% changes in effective temperature and surface gravity. Note the calculations are done both for lines with gf-values in the critical compilation of Fuhr, Martin, and Wiese (1988) and those in this source along with those for which Kurucz (private communication) provides values. The normal and the Am stars show differences in the profiles of the strongest lines.

Table 1. Microturbulence results for iron species

Species	N	gfs	ξ_1	log Fe/H	ξ_2	log Fe/H
θ Cyg						
Fe I	310	MF&KX	1.4	-4.53±0.21	1.8	-4.67±0.19
	273	MF	1.5	-4.63±0.20	1.8	-4.73±0.18
Fe II	70	MF&KX	1.4	-4.45±0.24	1.3	-4.42±0.24
	38	MF	1.3	-4.44±0.20	1.3	-4.40±0.20
ι Psc						
Fe I	258	MF&KX	0.8	-4.51±0.26	1.4	-4.72±0.23
	232	MF	0.5	-4.45±0.28	1.4	-4.75±0.23
Fe II	42	MF&KX	0.9	-4.47±0.23	0.9	-4.72±0.23
	29	MF	1.1	-4.58±0.22	1.0	-4.58±0.22
15 Vul						
Fe I	170	MF&KX	3.9	-4.68±0.22	3.9	-4.68±0.22
	156	MF	3.9	-4.68±0.22	3.9	-4.68±0.22
Fe II	45	MF&KX	4.3	-4.71±0.25	4.4	-4.72±0.25
	33	MF	4.6	-4.75±0.22	4.5	-4.74±0.22
32 Aqr						
Fe I	220	MF&KX	4.4	-4.48±0.22	4.5	-4.49±0.22
	194	MF	4.4	-4.48±0.22	4.5	-4.49±0.22
Fe II	50	MF&KX	4.2	-4.34±0.27	4.5	-4.38±0.27
	29	MF	4.8	-4.48±0.18	5.0	-4.51±0.18

gf references: MF = Fuhr, Martin, and Wiese (1988)
KX = Kurucz (private communication)

V. RESULTS

Table 2 presents the abundances for our completed analyses. For effective temperatures and surface gravities, the normal stars analyses used the Moon and Dworetsky (1985) values while the Am star values used Balmer line profiles and spectrophotometry which gives values cooler by about 300 K. The solar abundances are from Anders and Grevesse (1989).

Table 2. Am and Normal Star Abundance Results (log N/H)

Ion	θ Cyg	ι Psc	15 Vul	32 Aqr	Sun
Mg I	-5.08±0.21	-5.10±0.17	-5.13:	-4.80	-4.42
Mg II	-4.99	-4.71	-4.36±0.30	-4.16±0.26	-4.42
Al I	-5.65	-6.24	-6.25:	-6.06:	-5.53
Si I	...	...	-5.06	-4.75	4.45
Si II	-4.34±0.06	-4.19±0.26	-4.77±0.33	-4.60±0.30	-4.45
Ca I	-5.77±0.21	-5.79±0.22	-6.12±0.17	-6.20±0.20	-5.64
Sc II	-8.88±0.12	-8.75±0.17	-9.59±0.13	-10.24±0.17	-8.90
Ti I	-7.21±0.26	-7.34±0.20	-7.33±0.15	-7.37±0.26	-7.01
Ti II	-6.98±0.26	-6.98±0.28	-7.46±0.29	-7.39±0.24	-7.01
V I	-8.13±0.27	-8.14±0.22	-8.34±0.26	-7.66±0.33	-8.00
V II	-7.63±0.23	-7.91±0.19	-7.98±0.22	-7.87±0.23	-8.00
Cr I	-6.49±0.27	-6.54±0.27	-6.52±0.32	-6.31±0.35	-6.33
Cr II	-6.18±0.26	-6.17±0.33	-6.56±0.23	-6.26±0.25	-6.33
Mn I	-6.69±0.23	-6.75±0.28	-6.89±0.19	-6.60±0.32	-6.61
Fe I	-4.60±0.20	-4.59±0.24	-4.94±0.22	-4.66±0.22	-4.33
Fe II	-4.48±0.23	-4.52±0.23	-4.87±0.26	-4.54±0.24	-4.33
Co I	-7.06±0.23	-7.06±0.27	-7.11±0.27	-6.93±0.22	-7.08
Ni I	-5.91±0.17	-5.97±0.15	-5.78±0.26	-5.48±0.26	-5.75
Ni II	-5.52±0.12	-6.04	-5.58±0.33	-5.20±0.16	-5.75
Sr II	-9.05±0.11	-9.31±0.21	-8.79±0.09	-8.54±0.08	-9.10
Y II	-9.66±0.14	-9.72±0.19	-9.57±0.24	-9.16±0.07	-9.76
Zr II	-9.15±0.23	-9.12±0.36	-8.97±0.19	-8.77±0.23	-9.40
Ba II	-9.64±0.10	-9.83±0.16	-9.47	-9.22±0.25	-9.77
La II	-10.77±0.25	-10.67	-10.61±0.21	-10.15±0.20	-10.78
Ce II	-10.14±0.16	-10.16±0.16	-9.72±0.18	-9.26±0.21	-10.45
Pr II	...	...	-9.02	-10.02±0.23	-11.29
Nd II	-10.52±0.29	-10.44	-10.27±0.19	-9.79±0.17	-10.50
Sm II	-10.97±0.21	-11.16	-10.52±0.11	-10.41±0.20	-11.00
Eu II	-11.44	-10.50±0.16	-10.88±0.14	-10.68±0.14	-11.49
Gd II	-11.20±0.20	-11.16	-10.14±0.24	-10.11±0.23	-10.88
Dy II	...	...	-10.99	-10.71	-10.90
Er II	...	...	...	-10.77±0.25	-11.07
Teff	6770	6170	7600	7500	
log g	4.41	4.18	3.20	3.40	

Relative to 32 Aqr, 15 Vul is a mild Am star. The normal stars exhibit less than solar Mg values while the Am stars have normal Mg values. For Si the normal stars show slightly greater than while the Am stars slightly less than solar values. The normal star Ca abundances are marginally less than solar while the Am stars show a greater deficiency. The normal stars have solar Sc abundances while the Am stars have sub-solar values. The Sr, Ba, La, Sm, and Gd abundances of the normal stars are solar while those of the Am stars are significantly greater than solar. The normal stars have marginally greater than solar Zr and Ce abundances while the Am stars are definitely Zr and Ce rich. The differences between the normal star values and solar may be due to problems with the

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gf values, the adopted effective temperatures and surface gravities, and/or to intrinsic differences between these F stars and the Sun. If such differences are real then the processes producing them may also be those affecting the Am stars albeit to a lesser extent. The Am star signature is more clearly seen in the Sc abundances than the Ca abundances.

VI. WORK IN PROGRESS

We are working on additional stars for which we have obtained most of the needed spectroscopic material with a Reticon. We are furthest along on with σ Boo (F2 V). We are measuring spectra of Procyon (F5 IV-V) which have S/N typically 500+. The continuum in the region longward of λ4500 appears to be well defined. Despite the problems cited earlier in measuring the spectra, the quality of the equivalent widths is comparable with that achieved with coadded spectra of hotter stars. This was not the case for our four initial studies. We are performing Wavelength Coincidence Studies (see e,g, Cowley and Adelman 1990 to aid in this work. This technique indicates that molecular lines are probably present in many of our program stars. The continuum of the Am star τ UMa is much less well defined than that of Procycon. In part this is may to its being cooler and/or more metal-rich. That of the Am star 60 Leo is difficult to measure as we see many weak features.

We plan fine analyses of all our stars and then to progress to synthesizing at least key feature in the spectra. To do this we will need improved values of effective temperature and surface gravity as well as more consistent gf-values. We will make our line identification lists including the line measurement information available to other investigators in the form of computer files as soon as each star's analysis is published. We will also make available the spectroscopic data mostly likely as FITS files at the end of our study.

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