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THE ABUNDANCES OF THE ELEMENTS IN SHARP-LINED EARLY TYPE STARS

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Since May 1 I have been working mainly with Dr. Scott Roby on obtaining final abundances from ultraviolet lines of nine stars for which we have coadditions. We presented a poster paper "N and Fe-peak Elemental Abundances from IUE Coadded Spectra of Hg-Mn and Normal Stars" at IAU Symposium 138 in Trieste, Italy in July 1992, a copy of which is attached as a supplement to this report. It will appear in the published proceedings. In the next few months we should complete three papers for publication in refereed journals. The first will focus on the results from lines of singly-ionized iron peak elements, the second on results from N I, and the third will deal with abundances from Mn III lines.

N AND FE-PEAK ELEMENTAL ABUNDANCES FROM IUE CO-ADDED SPECTRA OF HG-MN AND NORMAL STARS

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ABSTRACT Leckrone and Adelman have established an IUE observing strategy that has yielded co-added spectra with enhanced S/N ratios for several A and B stars. New observations by Roby and Adelman using the same technique have added two new Hg-Mn stars into this sample. We have begun a long-term study of elemental abundances in this uniform, high-quality set of IUE spectra for 13 stars. We report on the first stages of this project: abundances for N, Cr, Mn, Fe, Co, and Ni. The study of the Fe- peak elements show that our data set can provide accurate abundances and that abundances obtained from UV and optical spectra often are in good agreement. This study provides the groundwork for self-consistent abundance analyses of more exotic elements in our long term project.

INTRODUCTION

We have begun a long term project using a homogenously observed set of high quality co-added IUE spectra for late B and early A main-sequence stars. The primary goal is to perform a self-consistent UV and optical analysis of the chemical compositon of these stars. The first step in the UV portion of the project is a determination of Fe-peak (Cr, Mn, Fe, Ni, and Co) elemental abundances to check the accuracy of our techniques and data and to provide a foundation for removing the blends due to these elements when studying other species (C, O, Al, P, S, Cl, Cu and Zn) later on. We report here on this first phase of the project, which is nearing completion. We also report on two new N I abundances determined from two recently observed Hg-Mn stars. The details of this separate study are reported elsewhere (Roby, 1989; Roby, Leckrone, and Adelman, 1992).

OBSERVATIONS

The IUE telescope is ideally suited to this program in that extensive wavelength coverage is needed with at least moderate resolution to sample the largest number of UV transitions possible for each species. Leckrone and Adelman (1989) have acheived excellent (for IUE) S/N ratios of 25 - 50 by a suitable strategy of co-adding multiple spectra of the same target using different exposure times (to cover the dynamic range of the detector) and different offsets along the dispersion axis (to reduce fixed pattern noise). Roby and Adelman recently observed two more Hg-Mn stars using the same observing strategy. The program now contains SWP and LWP/LWR co-added images for eight normal stars, four Hg-Mn stars and one horizontal-branch field star. At this time, the Fe-peak analysis has been completed for five normal stars and the four Hg-Mn stars utilizng the LWP/LWR co-added spectra.

ANALYSIS

Adopted Parameters

The model atmospheres used were generated by Adelman using the ATLAS program and are based on his optical abundance studies of υ Her (Adelman, 1992), π Cet, 21 Aql, and ν Cap (Adelman, 1991), ι CrB (Adelman, 1989), μ Lep, κ Cnc, θ Leo, and o Peg (Adelman, 1988). The adopted atmospheric parameters are shown in Table 1.

TABLE I Atmospheric Parameters

star	T_{eff}(K)	log g	metallicity	ξ $km\,s^{-1}$	v sin i
π Cet	13150	3.65	opt. abund.	0	18
21 Aql	12900	3.35	opt. abund.	0	19
ν Cap	10250	3.90	opt. abund.	0	17
o Peg	9600	3.60	opt. abund.	1.7	9
θ Leo	9250	3.55	opt. abund.	1.8	18
κ Cnc	13125	3.45	opt. abund.	0	6
μ Lep	12500	3.50	opt. abund.	0	18
υ Her	11900	3.60	opt. abund.	0	7
ι CrB	11250	3.65	opt. abund.	0.2	3

The atomic data used for computing UV synthetic spectra are contained in Kurucz's extensive linelist (Kurucz and Peytremann, 1975; Kurucz, 1981, 1992), which include new calculations for the first nine ionization states of elements z = 20 - 28. Optical abundances from the previously cited studies of Adelman were used as the initial input for the synthetic spectra. For C, N, and O, the values of Roby and Lambert (1990) were used.

Continuum Fitting

The IUE/RDAF interactive normalization procedure NORM was modified by Roby to accommodate a scrolling graphic window so that a 500Å chunk of a high dispersion IUE spectrum can be scrolled horizontally with the user seeing only 20Å or so at a time. NORM was further modified to allow up to 150 points to be specified in normalizing these large chunks. Typically 100 points were required to fit a typical 500Å chunk. For late B and early A main-sequence stars, the high peaks in the observed spectrum very often lie 1 - 5 % below the true continuum. Thus it is necessary to do some modeling of the spectrum to determine the location of the continuum. For these calculations we adopted the initial parameters described in the previous section.

A major concern is that the abundances adopted (particularly Fe) for determining the continuum placement may effect the final abundance determinations. Fortunately, we have some evidence that the optical Fe abundance should be reliable in fitting the continuum. Two of us (Leckrone and Wahlgren) have observed χ Lup and κ Cnc with the Goddard High Resolution Spectrograph (GHRS) on the HST. The high resolution of these two sharp-lined spectra reveal the continuum quite readily. Analyses of this data shows that the optical Fe abundance requires adjustments of less than 0.1 dex in the log to model the GHRS spectra successfully. Our experience with IUE data shows that a 0.1 dex change in log Fe/H changes the location of the continuum with respect to high points in the spectrum by less than 1%. This is within our estimated range of internal accuracy (0.5 - 2.0%) in fitting the continuum with models.

Each coadded spectrum was given a trial normalization based on the high peaks found in the observed spectrum with the RDAF procedure NORM. This was then plotted along with an overlapping synthetic spectrum based on optical abundances. The original 500Å observed spectrum chunk was then normalized anew using this plot as a guide. When possible several lines over a small region were used to judge the placement of the continuum – in other cases a single feature or two dominates the only usable peak and a subjective judgment had to be made. A linear interpolation of the fitted continuum was then divided into the observed flux to get the final normalized flux used for subsequent abundance determinations. We note that the linear interpolation of the fitted continuum shows evidence of residual echelle ripples, which are not fully corrected for in current IUE reduction procedures.

Subsequent reviews of the continuum fit during the abundance determinations of individual lines revealed that the above technique yielded a continuum fit judged to be good about 95% of the time. In the few bad cases, the continuum was readjusted locally.

Line Analysis

To choose the least-blended lines for our analysis, we computed global synthetic spectra for the range 2000-3000Å in the Hg-Mn star, κ Cnc. For each of six elements (Ti, Cr, Mn, Fe, Ni, and Co) we also calculated spectra with their abundance set effectively to zero. Dividing these into the full element spectrum produces a synthetic spectrum showing only the lines of the chosen element. Thus, at a glance, we could quickly see which features involved blends of different species and which did not. We further examined sources of *gf* values, especially the compilations by Martin, Fuhr, and Wiese (1988) and Fuhr, Martin, and Wiese (1988), as we desired to use lines with the best quality *gf* values. We also used the completeness and symmetry of the line profile and the location of local continuum points as additional criteria in selecting lines. Abundances for indivdual lines were obtained by examining plots with overlaying synthetic spectra that bracketed the observed profile in strength. Two independent judgements were made for each line (by Roby and Adelman) of the abundance needed to make a fit. We usually agreed to within 0.05 dex, conversing by mail.

RESULTS

The abundance determinations are shown in Tables II and III. The abundances are relative to log H = 0. The internal rms scatter (std) of the individual abundances for the lines of each species is shown in parentheses, followed by the number of lines (n) used. For N I, the std and n columns have been left out to save space (n = 3 and std is typically (0.35)).

The internal scatter for individual lines of Fe II and Cr II are in the range 0.1 - 0.2 dex, and slightly larger for Ni II. Comparison with the optical abundances for these three species usually show a difference that is the same or smaller than the internal scatter. In the worst cases the difference is about two standard deviations.

TABLE II Cr II, Fe II, and Ni II Log N/H Abundances

star	Cr II	std	n	FE II	std	n	Ni II	std	n
π Cet	-6.09	(0.17)	5	-4.61	(0.16)	25	-5.80	(0.24)	6
21 Aql	-6.58	(0.24)	7	-4.69	(0.29)	22	-6.07	(0.32)	9
ν Cap	-5.72	(0.24)	7	-4.57	(0.09)	24	-5.40	(0.12)	9
o Peg	-6.20	(0.19)	7	-4.62	(0.11)	24	-5.17	(0.15)	8
θ Leo	-6.08	(0.23)	7	-4.82	(0.09)	26	-5.40	(0.22)	8
κ Cnc	-6.28	(0.22)	7	-4.53	(0.17)	26	-5.87	(0.22)	9
μ Lep	-5.64	(0.19)	7	-4.79	(0.12)	26	-6.33	(0.50)	8
υ Her	-5.91	(0.24)	6	-4.92	(0.15)	25	-6.19	(0.29)	9
ι CrB	-5.95	(0.19)	6	-4.46	(0.12)	25	-6.04	(0.26)	9

TABLE III Mn II, Mn III, Co II, and N I Log N/H Abundances

star	Mn II	std	n	Mn III	std	n	Co II	std	n	N I
π Cet	-5.97	(0.23)	8	-5.38	(0.21)	2	-6.54	(0.53)	3	-4.70
21 Aql	-6.23	(0.22)	9	-6.46	(0.07)	2	-6.84	(0.71)	4	-4.45
ν Cap	-5.90	(0.25)	5	-	-	-	-6.94	(0.32)	2	-4.92
o Peg	-6.20	(0.23)	8	-	-	-	-6.37	(0.17)	4	-4.20
θ Leo	-6.31	(0.25)	7	-	-	-	-6.91	(0.40)	4	-4.60
κ Cnc	-3.98	(0.32)	9	-3.65	(0.27)	7	<-7.36?	(0.77)	2	<-6.12
μ Lep	-4.29	(0.24)	8	-3.68	(0.17)	5	<-8.31?	~~(0.14)~~	2	<-6.19
υ Her	-4.44	(0.15)	8	-4.00	(0.40)	5	<-8.16?	-	1	<-6.43
ι CrB	-5.00	(0.28)	8	-4.58	(0.44)	4	<-8.06?	~~(0.14)~~	2	<-6.55

For the two normal stars o Peg and θ Leo) where Mn II and Co I have been reliably measured in the optical, we find good agreement with the UV results. However, in the Hg-Mn stars, the UV abundance is noticeably larger (+0.30 dex on average) than the optical abundance for Mn II. The discrepancy is perhaps related to the enhanced strength of Mn II lines in these stars and may be a signature of non-LTE effects, inadequate knowledge of the atomic parameters, or additional contributions from unaccounted for weaker lines in the UV spectrum.

Also in the Hg-Mn stars, we find a very large internal scatter for the individual line abundances of Mn III and Co II. We suspect that unaccounted for line blends are primarily responsible, as these lines are very weak, and therefore more susceptible to contributions from weak, unidentified lines. The lack of detection of some of the Co II lines while others in the same star appear to be much stronger requires further attention. We also note that the Mn III lines yield abundances systematically higher (about 0.45 dex) than the Mn II lines in the same stars. This also may be a signature of non-LTE.

The N I results for μ Lep and υ Her are reported here for the first time. They are upper limits, but more confining than those provided by near-IR studies, due to the larger intrinsic strength of the UV lines. All four Hg-Mn stars consistently suggest that the N I abundance is extremely depleted, by factors of 40 - 100 relative to the normal stars (4 - 10 times more depleted than indicated by less stringent near-IR upper limits).

The implications of these results will be discussed in forthcoming papers (Fe-peak abundances; Adelman *et al.*, 1992, N I; Roby *et al.*, 1992).

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