The A-Star Puzzle
Proceedings IAU Symposium No. 224, 2004
J. Zverko, J. Žižňovský, S.J. Adelman, & W.W. Weiss, eds.

DOI: 10.1017/S1743921305009567

A spectroscopic analysis of the metallic-line star 2 Ursae Majoris (A2m)

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Abstract. I derived the elemental abundances of metallic-line star 2 UMa, using high-dispersion, high signal-to-noise ratio spectra obtained from Dominion Astrophysical Observatory. This study used Kurucz's ATLAS9 and WIDTH9 programs. The star was selected as 1) it has not been the subject of a detailed elemental abundances analysis, and 2) it is relatively sharp-lined and hot enough so that the continuum can be well placed even in the blue. For even cooler Am stars determining the continium will be a major problem. As a guide for the broad-lined and cooler Am stars, a spectral line atlas of 2 UMa will be prepared.

Keywords. Stars: abundances, stars: chemically peculiar, stars: individual: (2 UMa)

1. Why study 2 UMa?

2 Ursae Majoris (HD 72037) is a metallic-line star of spectral type A2. This star has not been the subject of a detailed elemental abundances analysis, is relatively sharp-lined, and is hot enough so that the continuum can be well located in the blue. For even cooler Am stars finding the continuum will be a major problem. Once the continuum has been well determined then the abundance analysis can yield reliable results. In the sharp-lined stars it is possible to measure the weak lines and derive good quality elemental abundances. If the line identifications and elemental abundance analysis of 2 UMa are done very well, it may serve as a guide for other similar Am stars. Well determined abundances can be used for check the Am star theory. As a guide for broad-lined and cooler Am stars, a spectral line atlas of 2 UMa will be prepared.

2. Data description

Table 1.

Observatory	Dominion Astrophysical Observatory
Instrument	1.22-m. Coudè spectrograph
Detectors	RETICON, SITe2, SITe4
Wavelength Coverage	3825 Å - 4935 Å(total 14 spectra)
Dispersion	RETICON and SITe2: 2.4 Å mm^{-1} (total 10 spectra)
	SITe4: 2.4 Å mm^{-1} (4 spectra)
S/N	$>$ 200

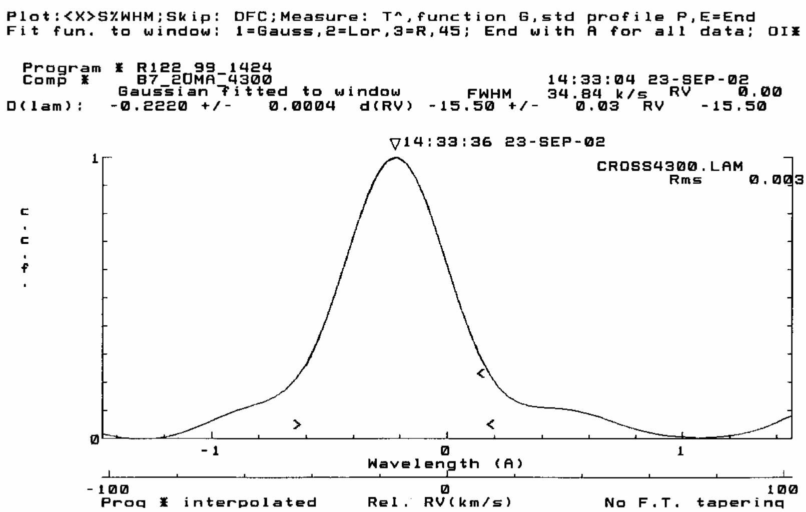

Figure 1. A Sample of radial velocity measurement using VCROSS.

3. Measurements

The continuum fitting, radial velocity measurements and equivalent width measurements have been done using the REDUCE (An Interactive Computer Graphics Program) (Hill & Fisher 1986) package.

3.1. *Radial velocities*

The radial velocities of the spectra have been obtained by cross-correlating each observed spectrum with a synthetic spectrum calculated for the same wavelength range. The synthetic spectra have been calculated using the program SYNTHE (Kurucz & Avrett 1981). The cross-correlation was achieved with the program VCROSS (Hill & Fisher 1986). The mean radial velocity from all spectra is $-17.04 \pm 0.04\,\mathrm{km\,s^{-1}}$ (see Figure 1).

3.2. *Continuum fitting and normalization*

Continuum fitting and normalization of each spectrum were made using the program REDUCE. The highest points and adjacent regions in the spectrum have been considered for determining the continuum. Then the spectrum has been divided by the spline fit through these points (see Figure 2).

3.3. *Equivalent widths and the first estimate of the rotational velocity*

The equivalent widths have been measured using the program VLINE (Hill & Fisher 1986). Because of 2 UMa is a slow rotating star, its spectrum has sharp lines. So that, while measuring the equivalent widths, Gaussian profiles have been fit to the lines. The rotational velocity (v sin i) has been estimated as $9\,\mathrm{km\,s^{-1}}$ from the FWHM's of the Gaussian fits which are made to the medium-strength and non-blended lines (see Figure 3).

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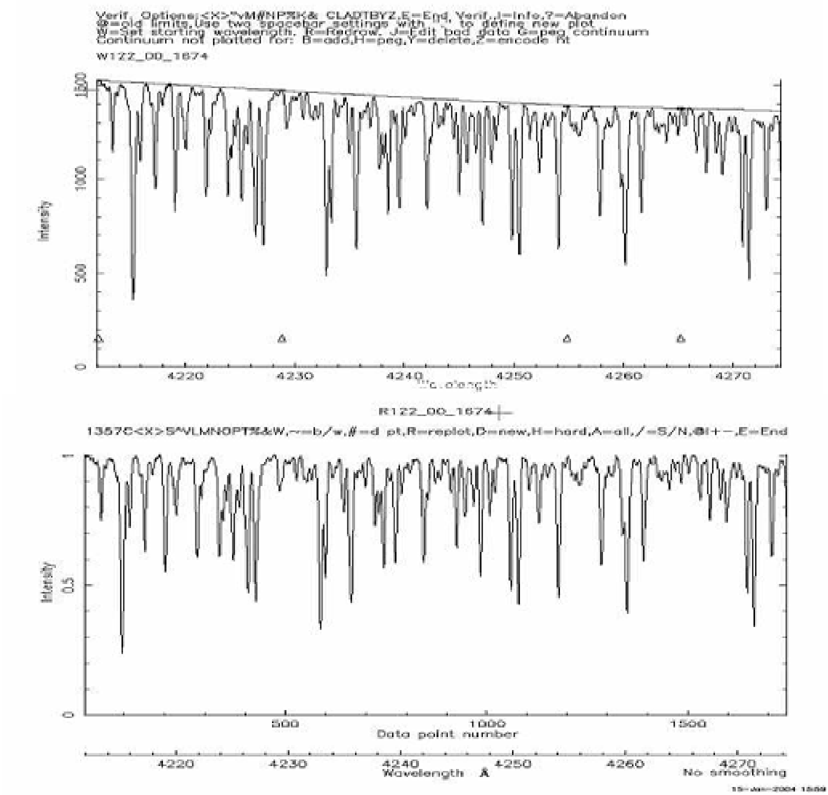

Figure 2. An example of continuum fitting using REDUCE.

Table 2. References used for line identifications to supplement Moore (1945).

C II, O II	Moore (1993)
Si I	Moore (1967)
Si II	Moore (1965)
S II	Pettersson (1983)
Ti II	Huldt *et al.* (1982), Litzen *et al.* (2002)
V II	Iglesias *et al.* (1988)
Cr I	Kiess (1953)
Cr II	Kiess (1951)
Mn I	Catalan *et al.* (1964)
Mn II	Iglesias & Velasco (1964)
Fe I	Nave *et al.* (1994)
Fe II	Dworetsky (1971), Johansson (1978), Guthrie (1985)
Y II	Nilsson *et al.* (1991)
Ba II	Klose *et al.* (2002)
La II, Ce II, Nd II, Sm II, Eu II, Gd II, Dy II, Er II, Yb II	Meggers *et al.* (1975)

4. Line identifications

The line identifications of the radial velocity corrected wavelengths were primarily made with the use of the RMT (Moore 1945) and its supplements. Newer line identification tables have been also used for the relevant elements (see Table 2).

Table 3 shows a sample page for line identifications of 2 UMa.

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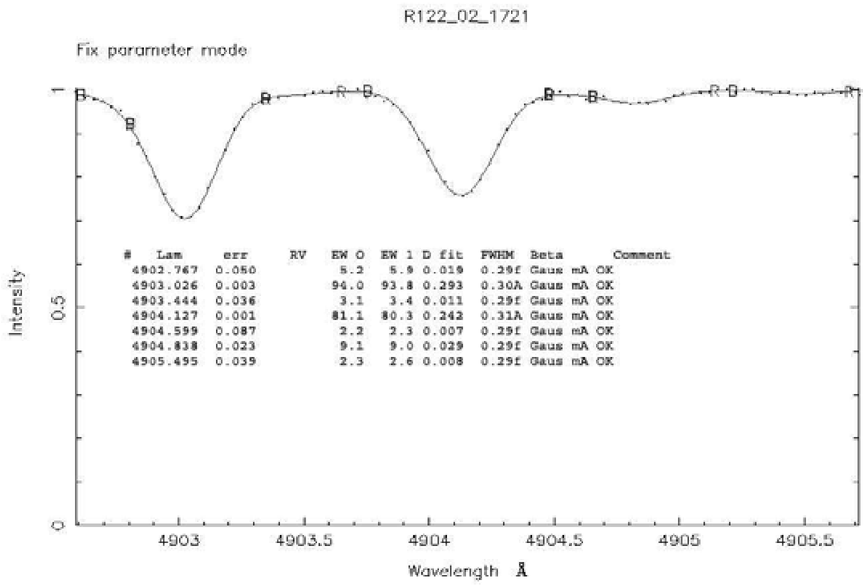

Figure 3. A sample equivalent width measurements using VLINE.

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Table 3. Sample of line measurements and identifications.

Measured Wavelength (Å)	Equivalent Width (m Å)	Line Depth	Line Width (Å)	Rest Wavelength (Å)	Identification
3874.490	19.6	0.079	0.23	3874.560	Cr I(138)3874.55(75W)
3874.705	6.5	0.026	0.23	3874.775	Ce II(MCS)3874.68(270)
3875.039	18.2	0.074	0.23	3875.109	Ce II(MCS)3875.06(140)
3875.569	11.3	0.046	0.23	3875.639	(V II(20)3875.656(20))
3875.807	14.5	0.059	0.23	3875.877	Ca I(26)3875.807((4))
3876.007	42.8	0.173	0.23	3876.077	Fe I(22)3876.040(4), Ce II(MCS)3876.12(170)
3876.692	9.8	0.039	0.23	3876.762	Co I(17,62)3876.831(20)
3876.882	19.2	0.078	0.23	3876.952	Ce II(82)3876.97(620)
3877.169	7.6	0.031	0.23	3877.239	Pr II(-)3877.18(1700)
3877.975	190.6	0.574	0.31	3878.045	Fe I(20)3878.0182(60)
3878.282	67.8	0.274	0.23	3878.352	Y II(7)3878.285(272), Ce II(48)3878.36(100)

5. Atmospheric analysis

5.1. *Determination of the effective temperature and surface gravity*

The initial effective temperature and surface gravity have been estimated as $T_{\rm eff} = 8053$ K and $\log g = 4.15$ with the help of the computer program of Napiwotzi *et al.* (1993) and the homogeneous $uvby\beta$ data of Hauck & Mermilliod (1998). These values have been refined to $T_{\rm eff} = 8050$ K and $\log g = 4.0$ by comparing the observed H_β and H_γ profiles to synthetic calculations (see Figure 4). We used ATLAS9 (Kurucz 1993) for calculating the model atmospheres. Our version of ATLAS9 includes the turbulent convection theory of Canuto & Mazzitelli (1991) which should be more realistic than mixing length theory. We have used the program SYNTHE for calculating the synthetic spectra.

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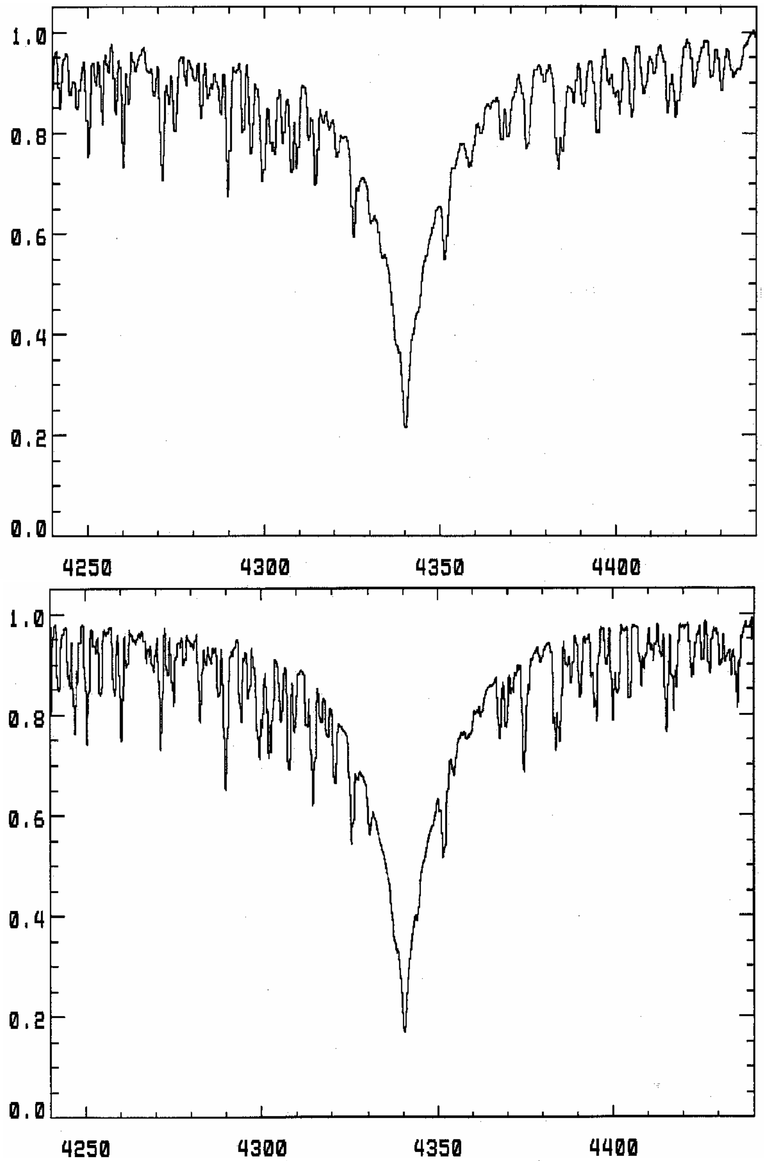

Figure 4. A sample comparison of the observational (top) and the synthetic (bottom) H_γ profiles.

5.2. *Determination of the microturbulent velocity and elemental abundances*

The program WIDTH9 (Kurucz 1993) has been used to determine the elemental abundances using the equivalent widths and the atomic data for each line. Abundances from Fe I, Fe II, Cr I and Cr II lines were derived for a range of possible microturbulences. The adopted values (see Table 4) are of which do not show a trend of values for lines of different equivalent widths and have minimal scatter about the mean (see Figure 5).

The abundances of all elements with observed lines have been calculated using the adopted value of the microturbulence. Table 5 compares the derived abundances of 2 UMa with the solar values from Grevesse *et al.* (1996).

Table 4. Determination of microturbulence.

Species	Number of Lines	ξ (km s^{-1})	gf - values
Fe I	320	2.60	Fuhr *et al.* (1988), Kurucz & Bell (1995)
Fe II	74	2.05	Fuhr *et al.* (1988), Kurucz & Bell (1995)
	Adopted mean 2.3		
Cr I	75	2.15	Martin *et al.* (1988), Kurucz & Bell (1995)
Cr II	36	2.50	Martin *et al.* (1988), Kurucz & Bell (1995)
	Adopted mean 2.3		

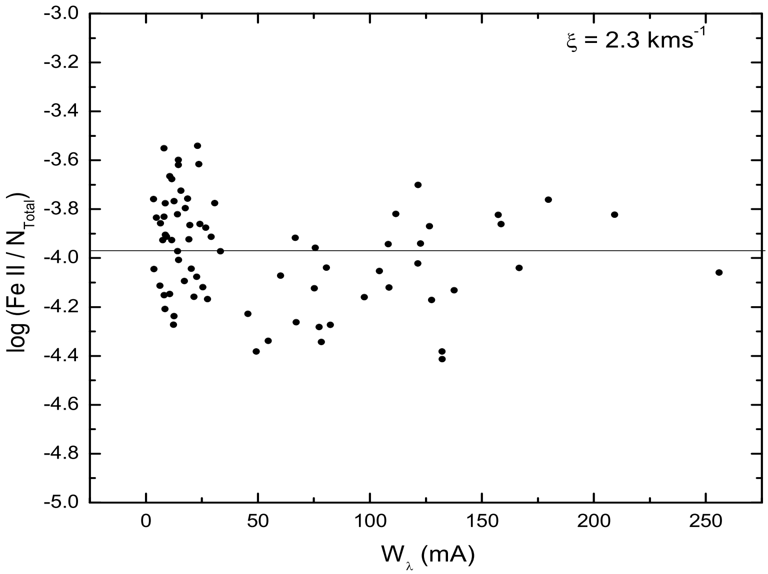

Figure 5. Fe II lines with the minimal scatter about the mean.

5.3. *Determination of the macroturbulence velocity and the final estimate of rotational velocity*

To estimate the macroturbulence and rotational velocity, the calculated abundances have been put into the model atmosphere and a new synthetic spectrum has been calculated to compare to the observed spectrum in $\lambda\lambda$4500-4540 (see Figure 6). Hence, only adjusting the macroturbulence and rotational velocity values, the macroturbulence and final rotational velocity of 2 UMa have been estimated as 5 km s^{-1} and 11 km s^{-1}, respectively.

6. Location of 2 UMa on the HR diagram

As 2 UMa has a well determined parallax from the HIPPARCOS Satellite (ESA 1997), it is possible to convert its apparent visual magnitude to absolute magnitude and compare with the stellar evolutionary calculations of Schaller *et al.* (1992) to find its mass and age since the ZAMS. Figure 7 shows the location of 2 UMa on the HR diagram with respect to the mentioned calculations. Using the $T_{\rm eff}$ value found in this study, the mass of 2 UMa has been estimated as 1.8 M$_\odot$ which is the same value found by Kunzli & North (1998).

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Table 5. Abundances of 2 UMa.

Species	Number of lines	$log(N/H)_{2\mathrm{UMa}}$	$log(N/H)_\odot$	$[N/H]^*$
O I	1	-2.44	-3.13	0.69
Na I	1	-5.03	-5.67	0.64
Mg I	3	-4.89±0.15	-4.42	-0.47
Mg II	1	-4.73	-4.42	-0.31
Al I	1	-4.99	-5.53	0.54
Si II	4	-4.52±0.23	-4.45	-0.07
S I	3	-4.70±0.12	-4.67	-0.03
Ca I	15	-6.31±0.19	-5.64	-0.67
Ca II	1	-6.52	-5.64	-0.88
Sc II	3	-10.28±0.11	-8.83	-1.45
Ti I	23	-6.76±0.20	-6.98	0.22
Ti II	36	-7.12±0.19	-6.98	-0.14
V I	6	-7.66±0.04	-8.00	0.34
V II	17	-7.42±0.17	-8.00	0.58
Cr I	75	-5.66±0.21	-6.33	0.67
Cr II	36	-5.77±0.24	-6.33	0.56
Mn I	22	-6.16±0.16	-6.61	0.45
Mn II	10	-6.09±0.17	-6.61	0.52
Fe I	320	-3.98±0.21	-4.50	0.52
Fe II	74	-3.93±0.21	-4.50	0.58
Co I	16	-5.97±0.21	-7.08	1.11
Ni I	62	-4.91±0.18	-5.75	0.85
Ni II	2	-4.95	-5.75	0.80
Zn I	2	-6.61	-7.40	0.79
Sr I	1	-7.21	-9.03	1.82
Sr II	2	-8.00	-9.03	1.03
Y II	9	-8.63±0.19	-9.76	1.13
Zr II	19	-8.72±0.19	-9.40	0.68
Ba II	2	-7.78	-9.87	2.09
La II	32	-9.28±0.20	-10.83	1.55
Ce II	111	-9.03±0.20	-10.42	1.39
Nd II	23	-9.45±0.22	-10.50	1.05
Sm II	6	-9.46±0.20	-10.99	1.53
Eu II	3	-10.22±0.12	-11.49	1.27
Gd II	1	-9.58	-10.88	1.30
Dy II	1	-9.94	-10.86	0.92
Er II	2	-10.09	-11.07	0.98
Yb II	1	-9.94	-10.92	0.98

$^*[N/H] = log(N/H)_{2\,\mathrm{UMa}} - log(N/H)_\odot$

7. Discussion

7.1. *Rotational velocity*

Table 6 summarizes the rotational velocity ($v \sin i$) studies of 2 UMa found in the literature. Fekel gives the same value as in this study. The differences between this and the other studies are mostly due to their lower dispersion spectra. Because of the high dispersion and the high signal-to-noise spectra used in this study, my rotational velocity should be more reliable.

7.2. *Elemental abundances*

Since there is no other detailed elemental abundance analysis of 2 UMa in the literature, Table 7 shows only some values from different studies to compare with this study. Cowley

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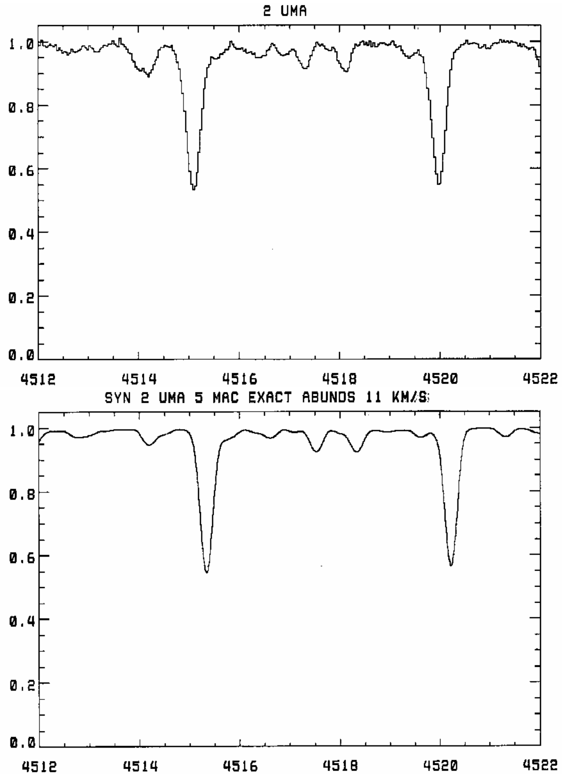

Figure 6. A sample comparison of observational (top) and synthetic (bottom) spectra to determine the macroturbulence and the rotational velocity.

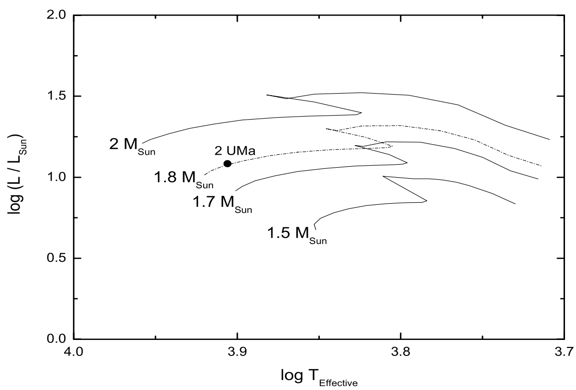

Figure 7. Location of 2 UMa on the HR diagram

& Aikman (1980) used their own calibration formulae based on the line statistics to derive the abundances and as they noted their method does not give very accurate results. Guthrie (1987) used Ca II K line photometry to obtain the equivalent widths and calculated the Ca II abundance using a differential analysis method. Kunzli & North (1998) used spectrum synthesis techniques while Adelman *et al.* (2000) fine analysis techniques similar to this study.

Compared with the solar values, 2 UMa shows considerable underabundances of Ca and Sc, as expected for an Am star. Mg is underabundant while Ti, Si and S show nearly

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Table 6. v sin i determinations.

Reference	$v \sin i$ (km s^{-1})
Abt & Moyd (1973)	<10
Uesugi & Fukuda (1982)	15
Hoffleit (1982)	17
Abt & Morrell (1995)	18
Royer *et al.* (2002)	26
Fekel (2003)	11
This Study	11

Table 7. Comparison of abundance determinations.

	Cowley & Aikman (1980)	This Study
Cr II	-6.5	-5.77±0.24
Mn II	-6.5	-6.09±0.17
Fe II	-5.0	-3.93±0.20
	Guthrie (1987)	This Study
Ca II	-6.22	-6.52
	Kunzli & North (1998)	This Study
Ca II	-6.22	-6.52
	Adelman *et al.* (2000)	This Study
Co I	-6.35 to -6.94	-5.97±0.21
	(for Am stars including 2 UMA)	

solar abundances. V, Mn and Fe have been found to be overabundant while Al, Cr, Na, Zr, Zn and Ni shows considerable overabundances. Rare earths are also considerably overabundant as expected.

Acknowledgements

This poster is the summary of the author's PhD. thesis, completed on February 19, 2004 at the Istanbul University and supervised by Dr. H. Gokmen Tektunali (Istanbul University, Astronomy Dept.) and Dr. Saul J. Adelman (The Citadel, Physics Dept.). I thank Dr. James E. Hesser, Director, Dominion Astrophysical Observatory, Herzberg Institute of Astrophysics, for the observing time used by Dr. Adelman to obtain the spectra I analyzed. This work was supported by the Research Fund of The University of Istanbul, Project number : UDP-313/25052004.

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