AN ANALYSIS OF THE SPECTRUM OF ALPHA URSAE MINORIS

B. B. SANWAL, B. S. RAUTELA, and G. C. JOSHI
Uttar Pradesh State Observatory, Manora Peak, Naini Tal, India

(Received 14 September, 1987)

Abstract. Three spectrograms of the cepheid Alpha Ursae Minoris (Polaris) taken at a dispersion of 17.8 Å mm^{-1} on 18, 19, and 20 January, 1971 have been analysed for the determination of the abundances of some elements. The analysis shows that the abundances of metals in the atmosphere of Polaris is similar to the Sun.

1. Introduction

Alpha Ursae Minoris is the nearest and apparently brightest of the cepheid variables. Its peculiar position in the sky contributed to the early discovery of the star as a variable. The cepheid nature of the star was suspected by Pannekoek (1913). Arellano Ferro (1983) has studied the period and amplitude variation of Polaris and concluded that the pulsation period of the star has been increasing steadily for the last 100 years and pulsational amplitude is decreasing. The decrease in pulsational amplitude has been confirmed by Kamper *et al.* (1984) with new radial velocity observations.

Luck and Bond (1986) and Giridhar (1985) have analysed the spectra of Polaris for the chemical composition of the atmosphere of the star, using the spectrum synthesis technique. They have calculated the oscillator strengths for metallic lines from solar equivalent widths, taking a solar model atmosphere and depth independent micro-turbulence. Using the oscillator strengths thus calculated the derived abundances of elements for a star depend on solar parameters also. Here we have attempted the analysis of the spectrum of Polaris using absolute values of oscillator strengths that were available and the model stellar atmospheres given by Kurucz (1979). The period of light cycle variation of α UMi is 3.96977 days and the spectral type varies from F7Ib–II to F8Ib–II (Kraft, 1960) during the pulsation cycle. This cepheid is with smallest light amplitude variation ($\Delta V \sim 0\overset{m}{.}05$).

2. Observational Material

The spectrograms used in this analysis were obtained by Schmidt *et al.* (1974) with the Coudé spectrograph of the Kitt Peak National Observatory 2.1 m telescope at a dispersion of 17.8 Å mm^{-1}. The spectrograms were taken on O98–O2 emulsion on 18, 19, and 20 January 1971. One of these plates taken on 19 January, 1971 had been measured by Schmidt *et al.* (1974) and line strengths of about 110 lines of 14 elements have been published. We have used these line strengths also in our analysis.

Astrophysics and Space Science **140** (1988) 131–135.

Density tracings for these plates have been obtained using Zeiss microphotometer. The continuum level on these tracings were located by drawing lines through points that have been located as line free or almost line free continuum points in the photometric atlas of the spectrum of Arcturus (Griffin, 1968). This atlas has also been used for the identification and selection of lines for our study.

The densities of the lines have been converted into intensities through calibrations provided with the spectrograms. The calibration curves for all the three plates were drawn using the available spot sensitometer calibration plates, appropriate to each spectrogram. We noticed that no appreciable difference in the characteristic curves was present in the entire wavelength region of interest. Hence, only one characteristic curve has been used for each plate. Schmidt *et al.* (1974) also used one calibration for entire wavelength range on similar grounds. The intensity curves of the lines of interest have been planimetered to get the equivalent widths.

3. Selection of Stellar Model Atmosphere

The selection of the model stellar atmosphere is usually done by the correct choice of the effective temperature, $\log g$ and chemical composition. We estimated the effective temperature of Polaris by using the $(B - V) - T_{\text{eff}}$ scale obtained by us on the basis of observed absolute energy distribution of a few cepheids. The effective temperature thus obtained is 6200 K $\pm$ 200 K. Parsons (1970), Arellano Ferro (1984), Giridhar (1985), and Luck and Bond (1986) have also estimated effective temperature for Polaris nearly similar to our values.

The variation of amplitude and colour of Polaris during its light cycle is very small and, hence, the effective temperature and gravity can also be taken as varying by very small amounts. Therefore, we adopted single values for the effective temperature and gravity namely $T_{\text{eff}} = 6000$ K; $\log g = 2.0$ (Luck and Bond, 1986) for the entire cycle and accordingly Kurucz (1979) model was selected.

4. Method of Analysis

To carry out an abundance analysis, detailed computations of the equivalent widths of selected lines have been done for different assumed abundances. The computed equivalent widths are then plotted against the assumed abundances. The observed equivalent width of a line of the element under investigation is then entered in this plot and the abundance is read out. The weak line method used by Waddell (1958) has been modified for the case of stars (Aller, 1960) and has been used in the present work (Sanwal *et al.*, 1986).

To estimate the continuous opacity, we have included negative hydrogen ion, neutral hydrogen, scattering due to H and H_2 and Thomson scattering. The general formulations given by Tsuji (1966) have been used to carry out continuous opacity calculation. A microturbulent velocity of 5 km/sec has been adopted from Giridhar (1985) in our calculations.

TABLE I

Measured equivalent widths ($-\log w/\lambda$) and derived abundances at various phases for alpha UMi (Relative to $\log N_H = 12$)

Wavelength	Measured equivalent widths at phases				Derived abundances at phases			
	0.516	0.775	0.015	0.775	0.516	0.775	0.015	0.775
				Fe I				
5417.03	4.95	4.98	5.08	4.98	7.73	7.70	7.57	7.70
5441.32	4.99	4.95	5.02	4.94	7.74	7.79	7.70	7.80
5554.90	4.61	4.54	4.47	4.59	7.00	7.23	7.46	7.06
5567.39	4.67	4.75	4.80	4.50	7.65	7.52	7.44	7.93
5618.65	4.73	4.90	4.83	4.67	7.76	7.51	7.61	7.84
5679.02	4.73	4.76	4.79	4.62	7.53	7.47	7.42	7.72
5717.84	4.74	4.62	4.71	4.69	7.50	7.71	7.55	7.59
5762.99	4.37	4.41	4.43	4.33	7.61	7.46	7.39	7.66
5793.93	5.00	4.98	5.02	4.68	7.61	7.63	7.59	7.94
5859.61	4.81	4.82	4.79	4.55	7.57	7.55	7.60	7.98
5883.84	4.66	4.67	4.70	4.52	7.47	7.45	7.38	7.77
5916.25	4.85	4.79	4.84	4.58	7.41	7.51	7.42	7.77
5976.78	4.70	4.68	4.67	4.52	7.48	7.52	7.54	7.83
6027.06	4.65	4.63	4.61	4.58	7.44	7.49	7.53	7.60
6055.99	4.70	4.68	4.70	4.59	7.38	7.43	7.38	7.62
6157.73	4.66	4.80	4.80	4.61	7.79	7.56	7.56	7.87
6180.22	4.74	4.84	4.90	4.61	7.64	7.49	7.39	7.85
6188.04	4.83	4.91	4.92	4.63	7.55	7.42	7.41	7.86
6200.32	4.71	4.70	4.63	4.66	7.25	7.28	7.44	7.37
6265.15	4.56	4.72	4.60	4.73	7.31	6.82	7.19	6.79
6297.80	4.63	4.57	4.61	4.58	7.42	7.56	7.47	7.54
6344.15	4.60	4.63	4.69	4.78	7.82	7.77	7.67	7.51
6355.04	4.79	4.71	4.67	4.74	7.27	7.43	7.51	7.37
6419.98	4.70	4.75	4.67	4.79	6.87	6.79	6.97	6.58
6518.38	4.67	4.74	4.82	4.77	7.83	7.73	7.60	7.68
6677.99	4.35	–	–	4.35	7.54	–	–	7.54
				Fe II				
6084.11	4.53	4.68	4.67	4.44	7.82	7.52	7.52	7.84
6149.24	4.46	4.49	4.50	4.34	7.56	7.47	7.44	7.93
6369.46	4.55	4.62	4.61	4.53	7.57	7.39	7.41	7.62
6416.91	4.44	4.47	4.50	4.50	7.58	7.48	7.38	7.38
6432.65	4.39	4.38	4.49	4.41	7.62	7.66	7.24	7.21
				Ba II				
5853.68	4.29	4.32	4.34	4.37	2.17	2.00	1.94	1.77
				Sc II				
5526.81	4.24	4.29	4.28	4.26	3.14	2.86	2.92	3.03
				Al I				
6698.63	5.22	5.29	5.31	5.33	6.39	6.31	6.28	6.26

Table I (continued)

Wavelength	Measured equivalent widths at phases				Derived abundances at phases			
	0.516	0.775	0.015	0.775	0.516	0.775	0.015	0.775
				Ca I				
6122.22	4.30	4.18	4.27	4.23	6.41	6.61	6.46	6.52
6471.66	4.48	4.50	4.45	4.58	6.28	6.21	6.38	5.92
				Tl I				
5868.44	5.00	5.07	5.12	4.91	5.12	5.05	5.00	5.20
5899.30	5.21	4.95	5.17	4.67	4.99	5.24	5.03	5.51
5978.54	4.99	4.90	5.01	4.87	5.20	5.29	5.18	5.37
6091.18	5.23	5.01	5.17	4.69	5.11	5.32	5.17	5.64
5922.11	5.30	5.23	5.27	5.19	5.18	5.25	5.21	5.29
				Mn I				
5516.77	4.80	4.78	4.75	4.78	5.41	5.43	5.46	5.43
6013.50	4.69	4.75	4.80	4.58	5.50	5.41	5.33	5.68
				Ni I				
5578.73	4.37	4.40	4.39	4.94	6.23	6.10	6.14	–
5892.88	4.82	4.71	4.79	4.43	6.32	6.48	6.37	6.87
6108.12	4.60	4.69	4.65	4.70	6.07	5.84	5.94	5.81
6643.64	4.71	4.60	4.67	4.63	6.06	6.29	6.16	6.25
6767.78	4.58	4.57	4.53	4.60	6.29	6.31	6.41	6.25
				V I				
5727.02	4.91	4.93	4.99	4.91	4.20	4.18	4.10	4.20
6119.50	5.42	5.30	5.37	5.05	4.06	4.19	4.12	4.46
6292.86	4.69	4.79	4.80	4.77	4.08	3.99	3.88	4.00

5. Results and Discussions

Measured equivalent widths and derived abundances at various phases are given in Table I. The results of our analysis are given in Table II along with other published results. Our analysis shows that the atmosphere of Polaris has solar like abundance of metals. Luck and Bond (1986) also found similar conclusion, however, Giridhar (1985) found calcium to be under abundant and chromium slightly enhanced with respect to the solar values.

Luck and Bond (1986) found that Polaris shows carbon depletion and Nitrogen enhancement, typical of F–G supergiants and attributed this to the mixing up of CN processed material with the surface layers. The oxygen content is lower than solar, but it is not readily understood, since the dredge up is not expected to reach material that has undergone ON-cycling.

TABLE II

Mean abundances relative to $\log N_H = 12$ and (M/H) with respect to solar values

Element	Solar (Grevesse, 1984)	This study		Giridhar (1985)	Luck and Bond (1986)
		$\log N_H = 12$	(M/H)	(M/H)	(M/H)
Al	6.47	6.3 ± 0.1	-0.17	–	0.05
Ca	6.36	6.4 ± 0.2	$+0.04$	-0.20	0.10
Sc	3.10	3.0 ± 0.1	-0.10	-0.10	0.70
Ti	5.02	5.2 ± 0.2	$+0.18$	$+0.10$	0.08
V	4.00	4.1 ± 0.1	$+0.10$	–	0.17
Mn	5.45	5.5 ± 0.1	$+0.05$	–	0.03
Fe	7.67	7.5 ± 0.2	-0.17	$+0.10$	0.05
Ni	6.25	6.2 ± 0.2	-0.05	–	0.02
Ba	2.13	2.0 ± 0.1	-0.13	–	–

Acknowledgement

We are thankful to Dr S. C. Joshi for guidance and helpful discussions.

References

Aller, L. H.: 1960, in J. L. Greenstein (ed.), *Stellar Atmospheres*, p. 156.

Arellano Ferro, A.: 1983, *Astrophys. J.* **274**, 755.

Arellano Ferro, A.: 1984, *Monthly Notices Roy. Astron. Soc.* **209**, 481.

Giridhar, S.: 1985, 'Cepheids: Theory and Observations', in B. F. Madore (ed.), *IAU Coll.* **82**, 100.

Griffin, R. F.: 1968, *A Photometric Atlas of the Spectrum of Arcturus 3600–8825 Å*, Cambridge Philosophical Society.

Grevesse, N.: 1984, *Phys. Scripta* **8**, 49.

Kamper, K. W., Evans, N. R., and Lyons, R. W.: 1984, *J. Roy. Astron. Soc. Can.* **76**, 173.

Kraft, R. P.: 1960, *Astrophys. J.* **131**, 330.

Kurucz, R. L.: 1979, *Astrophys. J. Suppl.* **40**, 1.

Luck, R. E. and Bond, H. E.: 1986, 'Space Telescope Science Institute', Preprint No. 96.

Pannekoek, A.: 1913, *Koninkl. Akad. Van. Wetenschappen, Amsterdam* **15**, 1192.

Parsons, S. B.: 1970, *Astrophys. J.* **159**, 951.

Sanwal, B. B., Rautela, B. S., and Joshi, G. C.: 1986, *Astrophys. Space Sci.* **123**, 183.

Schmidt, E. G., Rosendhal, J. D., and Jewsbury, C. P.: 1974, *Astrophys. Space Sci.* **29**, 397.

Tsuji, T.: 1966, *Publ. Astron. Soc. Japan* **18**, 134.

Waddell, J. H.: 1958, *Astrophys. J.* **127**, 284.