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A Model Atmosphere Analysis of Procyon (α CMi, F5 IV-V)

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Summary. The spectrum of Procyon (F5 IV–V) in the visual region is analysed relative to the Sun with a line-blanketed convective model atmosphere. Adopted atmospheric parameters are: an effective temperature $T_{\rm eff}=6650\pm150$ K, a surface gravity $\log g=4.0\pm0.1$, and a depth-independent microturbulent velocity $\xi_t=1.8\pm0.3$ km s^{-1}.

Chemical compositions determined for 30 elements, Na to Os, characterize Procyon as a normal Population I star. Only Ba is slightly overabundant with respect to the solar abundance.

Key words: abundances of elements – normal stars – fine analysis – stellar atmosphere

1. Introduction

The bright yellow star Procyon (αCMi) is one of the most frequently analysed stars in the solar neighbourhood. Recently, Philip and Egret (1980) derived the abundance of iron [Fe/H] = +0.14 from their calibration of *uvby* photometric data, and Nissen (1981) obtained a relative metal abundance of [M/H] = +0.02 from narrow-band photoelectric observations. Previous spectroscopic analyses will be briefly reviewed in the next section.

Procyon is a photometric and spectroscopic standard, and therefore it is very important to know its atmospheric parameters ($T_{\rm eff}$, $\log g$) and chemical compositions at the best. *A Photometric Atlas of the Spectrum of Procyon* has been published by Griffin and Griffin (1979). With this high quality Atlas, we can expect to determine its atmospheric parameters and chemical abundances with comparatively high accuracy. Additionally, realistic line-blanketed convective model atmospheres are now available. The structure of convective atmospheres of F-type stars has not been fully explored both theoretically and observationally so far. This work is intended as a further step in making Procyon as a reference star among middle F-type stars.

This paper describes an LTE line-blanketed model atmosphere analysis of Procyon relative to the Sun. Some basic data of this star are summarized in Table 1.

Table 1. Data for Procyon = α CMi = HR 2943 = HD 61421 = BD +5 1739

Property	Value	Author
Spectral type	F5 IV-V	1
Visual magnitude		
apparent (V)	0.34, 0.37	2, 3
absolute (M_V)	2.66, 2.71	3, 4
Parallax ["]	0.287 ± 0.004	3
Angular diameter ["]	$(5.50\pm0.17)\times10^{-3}$	5
Mass [$M_\odot$]	1.78	6
Radial velocity [km s^{-1}]	−3.25	7
Rotational velocity		
V sin i [km s-1]	6	8
Photometric data		
B-V	0.40, 0.43	1, 9
U-B	−0.01, 0.04	1, 9
b-y	0.272	10
m_1	0.167	10
c_1	0.532	10
β	2.671	10

Authors:
1 Johnson and Morgan (1953)
2 Hoffleit (1964)
3 Woolley et al. (1970)
4 Shallis (1981)
5 Hanbury Brown et al. (1974)
6 van de Kamp (1971)
7 Griffin and Griffin (1973)
8 Uesugi and Fukuda (1981)
9 Buscombe (1977)
10 Hauck and Mermilliod (1980)

2. Atmospheric Parameters

2.1. Review of Previous Spectroscopic Analyses

Previous spectroscopic analyses of Procyon are collected in Table 2, which is adapted from the catalogue of Cayrel de Strobel

Table 2. Summary of previous analyses of Procyon

Author	$T_{\rm eff}$	log g	[Fe/H]
Greenstein (1948)	5860*	3.7	+0.22
Wright (1948)	6725		−0.40
Talbert and Edmonds (1966)	6690	4.2	−0.29
Merchant (1966)	6300		+0.03
Powell (1970)	6630		+0.07
Griffin (1971)	6550		0.00
Hasegawa (1975)	6690		+0.74
Tomkin and Lambert (1978)	6600	4.0	−0.15

* Ionization temperature

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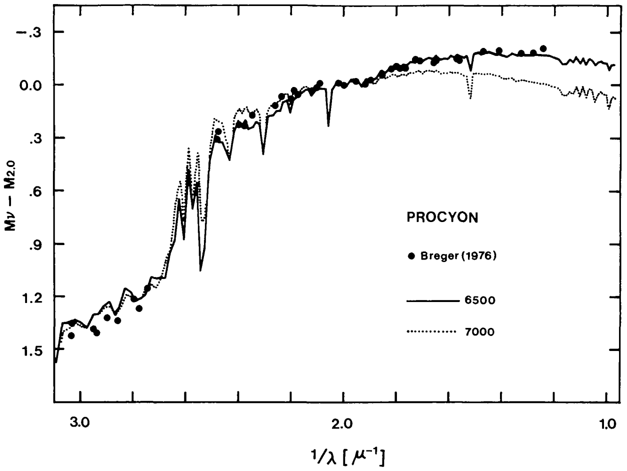

Fig. 1. Comparison between observed and predicted fluxes. The continuous line and dashed line represent the theoretical fluxes of the line-blanketed convective models (Kurucz, 1980) of $(T_{\rm eff}, \log g) = (6500, 4.0)$, and $(7000, 4.0)$, respectively. The ordinate is in magnitudes normalized to zero at 5000 A; the abscissa is in $1/\lambda$, where λ is the wavelength in μm

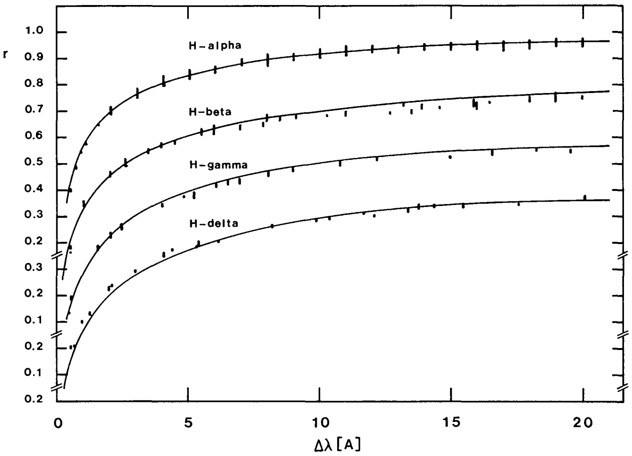

Fig. 2. Balmer lines of Procyon. Observed profiles (short vertical lines) of Procyon are compared with profiles computed from the model of $(T_{\rm eff}, \log g) = (6500, 4.0)$

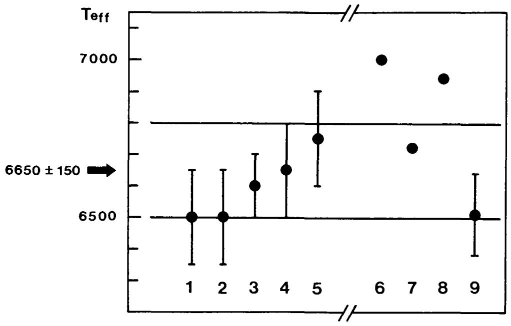

Fig. 3. Comparison of effective temperature resulting from various methods (**1**–**5**) and derived by other workers (**6**–**9**). The labels correspond to the methods and workers: **1** Continuum flux; **2** Balmer line profiles; **3** H_β-index; **4** Color indices; **5** Ionization balance; **6** Danziger (1966); **7** Dickens and Penny (1971); **8** Gray (1976); **9** Code et al. (1976). The adopted effective temperature and error limits are also indicated

et al. (1980). Among them, Griffin's (1971) careful analysis was made for 27 elements, and the first fine analysis was performed by Tomkin and Lambert (1978) for C, N, O, and Fe. Table 2 suggests that both the effective temperature and the resultant metal (iron) abundance have not been well defined yet, in spite of the efforts of previous workers. This is probably due to a lack of information on the atmospheric parameters, and due to the employment of the simplified curve-of-growth technique. Then, we tried to estimate the $T_{\rm eff}$ and $\log g$ using the best available data in the following.

2.2. *Surface Gravity*, $\log g$

The surface gravity of Procyon can be obtained from its mass $1.78\,M_\odot$ (van de Kamp, 1971) and from its radius $2.06 \pm 0.09\,R_\odot$. This radius is calculated from the parallax of $0''.287 \pm 0.004$ (Woolley et al., 1970) and the angular diameter of 5.50 ± 0.17 milli-arcsec (Hanbury Brown et al., 1974). From these measurements, we can obtain the surface gravity as $\log g = 4.06 \pm 0.04$. Recently, Shallis and Blackwell (1980) determined its radius of $2.11 \pm 0.05\,R_\odot$ using the IR flux method. Taking into account of uncertainties in the determination of the binary mass ratio and in the measurement of the radius, we adopt the surface gravity of Procyon as

$$\log g = 4.0 \pm 0.1\,.$$

2.3. *Effective Temperature*, $T_{\rm eff}$

First, we compare in Fig. 1 the observed optical flux given in Breger's (1976) catalogue with predictions of line-blanketed models. The observed flux in the Paschen continuum agrees quite well with the prediction of the model of $(T_{\rm eff}, \log g) = (6500, 4.0)$.

Second, we use the profiles of hydrogen Balmer lines. A comparison was made between the profiles measured from the *Atlas* and a grid of theoretical ones computed with the new convective models (Kurucz, 1980). Our computations of the theoretical profiles were carried out using the "*unified theory*" Stark broadening of Vidal et al. (1973). Comparisons of the four Balmer lines are displayed in Fig. 2. The profile of H_α yields $T_{\rm eff} = 6500$ K, although a slightly higher temperature (~ 6600 K) seems to be better for H_β and H_γ. In addition, the H_β index of Procyon with the $\beta - T_{\rm eff}$ calibration of Schmidt (1979) indicates $T_{\rm eff} = 6600$ K.

The $b-y$ index of Procyon with the calibration of Relyea and Kurucz (1978) gives $T_{\rm eff} = 6600$ K, whilst Philip and Egret (1980) and Nissen (1981) derived $T_{\rm eff} = 6720$ K and 6640 K, respectively, from their own calibration systems. We take $T_{\rm eff} = 6650 \pm 150$ K from the comparison of the four-color indices.

Finally we examine the ionization equilibria of five elements (Si, Ca, Ti, Cr, and Fe). Temperature necessary to achieve ionization equilibria are found to range from 6600 K to 6900 K.

Effective temperatures estimated from the various methods noted above are summarized in Fig. 3 together with temperatures proposed earlier. The finally adopted effective temperature of Procyon is

$$T_{\rm eff} = 6650 \pm 150\,{\rm K}\,.$$

2.4. *Microturbulent Velocity*, ξ_t

A microturbulent velocity ξ_t is determined from the condition that the iron abundance derived from weak ($20 \sim 30$ mA) lines and medium strong (around 100 mA) lines be independent of equivalent widths. Those lines used in this analysis are presented in Table 3. Fe I and Fe II lines are selected from the lists of Mäckle et

Table 3. Lines used in the determination of the microturbulent velocity

Mult	λ (A)	χ (eV)	log gf	W_λ (mA)
Fe I				
13	6498.9	0.96	-4.81	17
39	4602.0	1.61	-3.34	44
62	6265.1	2.17	-2.78	62
168	6393.6	2.42	-1.93	104
686	5569.6	3.40	-0.69	112
687	4946.4	3.35	-1.35	72
786	5365.4	3.56	-1.53	66
843	5242.5	3.62	-1.34	75
1030	5464.3	4.12	-1.78	21
1064	5386.3	4.15	-1.95	13
1094	5074.8	4.20	-0.27	106
1097	4962.6	4.16	-1.45	35
Fe II				
22	4124.8	2.53	-4.20	49
25	4670.2	2.57	-4.22	44
	5000.7	2.77	-4.74	15
35	5136.8	2.83	-4.49	21
38	4508.3	2.84	-2.43	126
	4576.3	2.83	-3.08	93
40	6369.5	2.88	-4.36	33
46	6113.3	3.21	-4.31	21
49	5425.3	3.19	-3.36	67
74	6456.4	3.89	-2.30	99
--	6383.8	5.55	-2.27	18

al. (1975a) and Blackwell et al. (1980), respectively. The solar *gf* values of Fe I lines are calculated assuming the solar iron abundance to be $\log\varepsilon(\mathrm{Fe}) = 7.69$ (Blackwell et al., 1980) and those of Fe II lines are taken from Blackwell et al. (1980). Best values found from Fig. 4 are $\xi_t = 2.0\,\mathrm{km\,s^{-1}}$ for Fe I and $1.8\,\mathrm{km\,s^{-1}}$ for Fe II. Our value of ξ_t agrees well with the recent result by Smith (1981) within an error limit. We obtain the microturbulent velocity of $\xi_t = 1.8 \pm 0.3\,\mathrm{km\,s^{-1}}$.

3. Analysis

3.1. Line Data

All the equivalent widths of atomic lines are measured from the *Atlas* of Procyon with a planimeter. Errors in the continuum placements may play an important role in degrading the accuracy of the equivalent width measurements. In fact, the drawn continuum lines of some charts of the *Atlas* seem to be slightly higher or lower than the plausible levels. For example, the measured profile of H_β has a red/blue asymmetry by a few percent. However, we measured equivalent widths without changing the continuum level drawn on the *Atlas*.

In the process of line selection, weaker absorption lines longward of about 4000 A are preferred except for a few cases where not enough lines are available. Measured equivalent widths are found to be in good agreement with those given by Wright et al. (1964) and by Tomkin and Lambert (1978).

3.2. Method of Analysis

The abundance calculations were performed with the program WIDTH 5, the companion to the program ATLAS (Kurucz, 1970). Model atmospheres were taken from the grid of new convective models computed by Kurucz (1980). We selected two solar composition models with effective temperatures $T_{\mathrm{eff}} = 6500$ K and 7000 K, and with surface gravity $\log g = 4.0$. After the abundances are computed for these two models, interpolations are made to the adopted temperature (6650 K). When no data of damping constants are available in literature, ten times the classical damping is assumed. This approximation is usually good for weak lines. Data for radiation and electron damping constants and correction factors to the van der Waals damping constants are taken from the sources quoted by Sadakane and Nishimura (1979) or by Ishikawa (1975). Effects of hyperfine structure (*hfs*) are also taken into account for some elements. Sources for the data of *hfs* can be found in Mäckle et al. (1975b).

Elemental abundances relative to the Sun are derived from the difference $gf\varepsilon_{\mathrm{Procyon}} - gf\varepsilon_{\odot}$ obtained for each line. The solar $gf\varepsilon$

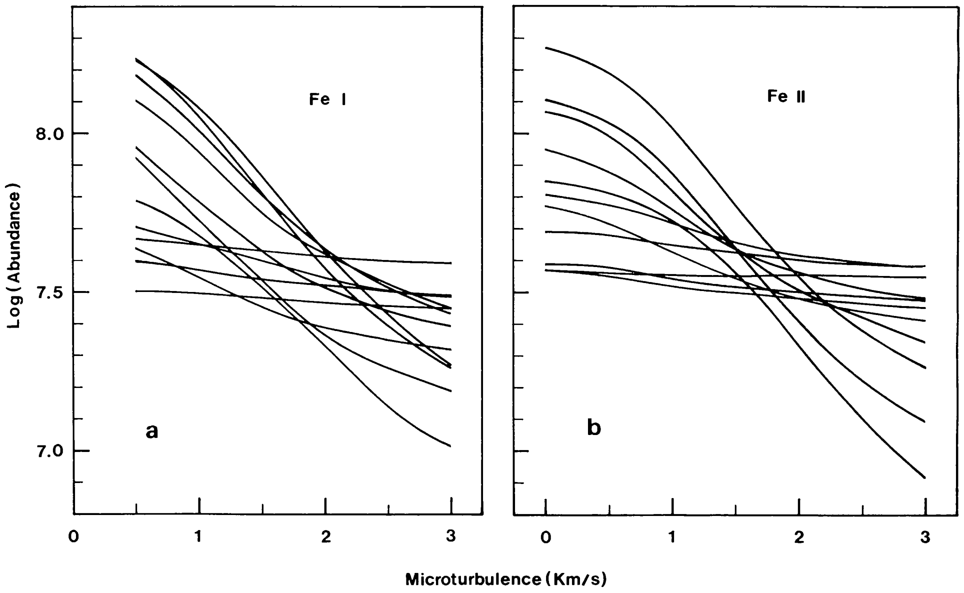

Fig. 4. The iron abundance of Procyon determined as a function of assumed microturbulence for the model of $(T_{\mathrm{eff}}, \log g) = (6500, 4.0)$. Abundance is on a scale where $\log\varepsilon(\mathrm{H}) = 12.00$, and solar gf-values are used

Table 4. Equivalent widths and elemental abundances for the finally used lines. $[\varepsilon]=\log(gf\varepsilon_{\mathrm{Procyon}})-\log(gf\varepsilon_{\odot})$

Mult	λ(Å)	χ(eV)	W_λ	log gfε_*	log gf$\varepsilon_\odot$	[ε]	Remarks
Na I							
1	5890.0	.00	399	6.39	6.33	.06	M
	5895.9	.00	315	6.11	6.07	.04	M
5	6154.2	2.10	22	4.71	4.76	-.05	M
	6160.8	2.10	35:	4.98	5.01	-.03:	M
6	5682.6	2.10	86:	5.70	5.61	.09:	
	5688.2	2.10	111:	6.03	5.86	.17:	
12	4668.6	2.10	34	4.99	4.88	.11	
Mg I							
2	5172.7	2.70	456	6.95	7.16	-.21	M
	5183.6	2.70	606	7.22	7.29	-.07	M
8	5711.1	4.34	90	5.94	5.86	.08	M
9	5528.4	4.33	201	6.94	6.94	.00	M
10	4730.0	4.34	47:	5.31	5.48	-.17:	
11	4703.0	4.33	216	6.94	6.98	-.04	M
23	6318.7	5.11	27	5.55	5.55	.00	M
30	7387.7	5.75	51::	6.50	6.58	-.08::	M
Al I							hfs
1	3944.0	.00	270::	5.61	5.48	.13::	
5	6696.0	3.14	17:	4.73	4.87	-.14:	M
Si I							
10	5645.7	4.93	28::	5.50	5.42	.08::	M
	5665.6	4.92	26	5.44	5.60	-.16	
	5690.4	4.93	38:	5.69	5.75	-.06:	M
	5701.1	4.93	30:	5.54	5.51	.03:	M
11	5684.5	4.95	51:	5.92	5.84	.08:	M
17	5772.2	5.08	41	5.87	5.86	.01	M
27	6244.5	5.62	38:	6.25	6.19	.06:	M
28	6237.3	5.61	48:	6.42	6.45	-.03:	M
29	6145.0	5.62	31	6.12	6.06	.06	M
30	6142.5	5.62	31:	6.12	6.05	.07:	M
60	7003.6	5.96	55:	6.82	6.62	.20:	M
Si II							
2	6347.1	8.12	112	7.88	7.99	-.11	
	6371.4	8.12	83	7.52	7.58	-.06	
S I							
2	4694.1	6.52	20::	5.43	5.69	-.26::	
	4695.4	6.52	14:	5.23	5.37	-.14:	
8	6743.6	7.86	25::	6.64	6.63	.01::	M
	6757.2	7.87	44::	7.05	6.90	.15::	M
10	6046.0	7.83	28::	6.67	6.92	-.25::	
	6052.7	7.84	24	6.58	6.47	.11	M
Ca I							
3	6102.7	1.88	107	5.50	5.38	.12	M
	6122.2	1.89	150	6.04	5.88	.16	M
	6162.2	1.90	168	6.23	6.12	.11	M
4	4425.4	1.88	115	5.70	5.51	.19	
	4435.7	1.88	117	5.73	5.58	.15:	
5	4283.0	1.88	127	5.87	5.69	.18	
18	6439.1	2.52	146	6.41	6.36	.05	M
	6493.8	2.52	114	6.06	5.91	.15	M
	6499.7	2.52	72	5.56	5.47	.09	M
19	6449.8	2.51	88	5.72	5.44	.28	
	6455.6	2.52	30:	4.83	4.96	-.13:	M
20	6161.3	2.52	40	5.03	5.08	-.05	M
	6166.4	2.52	46	5.13	5.14	-.01	M
	6169.0	2.52	69	5.52	5.42	.10	M
21	5582.0	2.52	84	5.80	5.88	-.08	
	5588.8	2.53	141	6.39	6.28	.11	M
	5590.1	2.52	79	5.71	5.59	.12	M
36	4526.9	2.71	65	5.68	5.80	-.12:	
48	5513.0	2.93	68	5.77	5.99	-.22	M
51	4685.3	2.93	40	5.42	5.44	-.02	M
Ca II							
15	5001.5	7.50	33:	5.78	5.76	.02:	
	5021.1	7.51	8::	5.02	5.18	-.16::	
20	5339.2	8.44	20::	6.24	6.22	.02::	
Sc I							
7	4023.7	.02	19:	3.21	3.38	-.17:	
Sc II							
14	4420.7	.62	18	.82	.89	-.07	B
	4431.4	.61	37	1.22	1.31	-.09	B
15	4294.8	.61	82::	2.03	1.92	.11::	
19	6604.6	1.36	43	1.84	2.00	-.16	B
22	5318.4	1.36	17	1.36	1.37	-.01	
24	4670.4	1.36	83::	2.64	2.61	.03::	B
25	5552.2	1.45	8::	1.06	1.00	.06::	B
26	5239.8	1.45	69	2.42	2.35	.07	B
28	6245.6	1.51	42	1.98	2.00	-.02	B
	6300.7	1.51	8::	1.09	1.10	-.01::	B
	6320.8	1.50	10::	1.17	1.20	-.03::	B
29	5641.0	1.50	53	2.18	2.18	.00	B
	5667.2	1.50	41	1.98	1.96	.02	B
	5669.0	1.50	53:	2.17	2.05	.12:	B
Ti I							
4	5193.0	.02	48	3.83	4.04	-.21	
	5210.4	.05	54	3.97	4.17	-.20	
5	5040.0	.02	38::	3.67	3.88	-.21::	M
	5064.7	.05	50	3.91	4.05	-.14	
38	4981.7	.85	89	5.29	5.34	-.05	
	4999.5	.83	79	5.09	5.16	-.07	M
	5016.2	.85	29	4.22	4.40	-.18	M
	5022.9	.83	38	4.38	4.56	-.18	
	5024.8	.82	33	4.27	4.53	-.26	
42	4512.7	.83	35	4.35	4.56	-.21	M
	4548.8	.82	41	4.45	4.63	-.18	M
53	4840.9	.90	34	4.37	4.54	-.17:	M
72	5866.5	1.07	17	4.07	4.17	-.10	M
104	6258.1	1.44	18	4.42	4.63	-.21	M
	6261.1	1.43	17	4.37	4.53	-.16	
109	5087.1	1.43	13::	4.29	4.08	.21::	
110	5036.5	1.44	41::	4.95	5.03	-.08::	
	5038.4	1.43	34::	4.82	4.82	.00::	
126	4820.4	1.50	15	4.42	4.56	-.14	M
145	4617.3	1.74	36:	5.14	5.26	-.12:	M
157	4913.6	1.87	21	4.91	5.12	-.21	
200	4928.3	2.15	10	4.77	4.98	-.21	
233	4742.8	2.24	11::	4.90	5.05	-.15:	
	4758.1	2.25	21	5.24	5.29	-.05	
	4759.3	2.25	22	5.28	5.44	-.16	M
Ti II							
18	4493.5	1.08	46	2.16	2.11	.05	B
30	4506.7	1.13	20	1.66	1.55	.11	B
39	4583.4	1.16	39	2.10	2.14	-.04	B
	4609.3	1.18	15	1.57	1.61	-.04	B
40	4470.9	1.16	83	2.86	2.83	.03	M
49	4708.7	1.24	61	2.52	2.59	-.07	B
60	4544.0	1.24	48	2.32	2.43	-.11	B
61	4395.8	1.24	88:	3.10	3.01	.09:	
	4409.5	1.23	47	2.31	2.36	-.05	
69	5418.8	1.57	65	2.82	2.86	-.04	M
71	4981.4	1.57	10:	1.68	1.71	-.03:	B
	5005.2	1.57	30	2.25	2.30	-.05	B
91	6607.0	2.06	15::	2.23	2.09	.14::	B
113	5069.1	3.12	19:	3.31	3.46	-.15:	B
114	4911.2	3.12	69	4.29	4.40	-.11	B
V I							hfs
19	6216.4	.28	12	3.19	3.08	.11	M
22	4379.2	.30	68	4.27	4.15	.12	
	4390.0	.28	52::	4.19	4.46	-.27::	
	4408.2	.28	31::	3.81	3.98	-.17::	
34	6090.2	1.08	9	3.75	3.83	-.08	M
35	5703.6	1.05	9::	3.74	3.77	-.03::	M
	5727.0	1.08	11:	3.85	4.00	-.15:	M
92	5817.1	1.89	7::	4.33	4.15	.18::	M
V II							
9	4002.9	1.43	68	2.83	3.05	-.22	
	4036.8	1.48	39	2.35	2.50	-.15	B
10	3952.0	1.48	82::	3.17	3.23	-.06::	B
24	4234.2	1.69	15	1.95	1.86	.09	B
32	4005.7	1.82	107:	3.93	4.02	-.09:	
	4008.2	1.79	22::	2.27	2.23	.04::	B
	4023.4	1.80	85:	3.48	3.57	-.09:	
	4039.6	1.82	11	1.94	2.14	-.20	B
	4051.1	1.80	14::	2.04	2.08	-.04::	B
37	4225.2	2.03	44::	2.89	3.03	-.14::	B
54	5303.2	2.27	6::	1.94	1.96	-.02::	B
56	4564.6	2.27	33::	2.87	2.77	.10::	B
98	5928.9	2.52	12	2.46	2.32	.14	B
99	5819.9	2.52	6::	2.13	2.13	.00::	B
Cr I							
10	4546.0	.94	61	4.15	4.10	.05	
18	5247.6	.96	50	3.93	4.04	-.11	
	5300.7	.98	28	3.54	3.56	-.02	M
	5348.3	1.00	70:	4.30	4.39	-.09:	M
21	4616.1	.98	67	4.30	4.36	-.06	M
	4626.2	.97	60	4.15	4.17	-.02	M
	4651.3	.98	53	4.04	4.17	-.13	
31	4789.4	2.54	39:	5.12	5.14	-.02:	M
93	7355.9	2.88	30::	5.14	5.48	-.34::	M
	7400.2	2.89	46	5.44	5.57	-.13	M
96	4293.6	2.91	7:	4.52	4.57	-.05:	
127	4458.5	3.01	25:	5.25	5.47	-.22:	
145	4730.7	3.08	26	5.32	5.40	-.08	M
	4737.4	3.07	34	5.47	5.60	-.13	M
150	4511.9	3.09	20::	5.19	5.31	-.12::	M
	4540.7	3.10	41::	5.64	5.77	-.13::	
166	4936.3	3.11	18:	5.12	5.35	-.23:	M
168	4801.0	3.11	31	5.44	5.48	-.04	M
186	4708.0	3.17	37	5.62	5.67	-.05	M
	4718.4	3.19	46	5.78	5.86	-.08	M
188	5783.9	3.31	20	5.31	5.42	-.11	M
	5787.9	3.31	25	5.44	5.50	-.06	M
193	5214.1	3.35	7:	4.84	4.95	-.11:	M
197	4492.3	3.36	11	5.09	5.25	-.16	M
222	6882.5	3.42	14::	5.19	5.32	-.13::	M
	6883.1	3.42	11::	5.07	5.20	-.13::	M
	6925.3	3.43	20:	5.38	5.37	.01:	M
	6979.8	3.45	16::	5.28	5.33	-.05::	M
225	5340.4	3.44	6::	4.84	4.94	-.10::	
251	4039.1	3.85	23	5.91	6.06	-.15	
Cr II							
23	5246.8	3.71	28	3.23	3.19	.04	B
	5420.9	3.76	36::	3.43	3.30	.13::	B
24	5210.9	3.76	16	2.97	3.06	-.09	B
	5305.9	3.83	45	3.65	3.54	.11	B
	5346.1	3.83	19::	3.11	3.02	.09::	B
29	5369.4	3.87	8::	2.70	2.82	-.12::	B
30	4812.4	3.86	44	3.68	3.82	-.14	B
43	5279.9	4.07	37::	3.71	3.55	.16::	B
	5308.4	4.07	41	3.78	3.81	-.03	B
	5310.7	4.07	25	3.46	3.37	.09	B
	5313.6	4.07	59	4.11	3.95	.16	B
44	4555.0	4.07	73	4.40	4.24	.16	B
	4592.1	4.07	70	4.36	4.34	.02	B
	4616.6	4.07	65	4.26	4.27	-.01	B
	4634.1	4.07	81	4.54	4.63	-.09	
50	5502.1	4.17	35	3.76	3.65	.11	B
	5508.6	4.15	28	3.59	3.55	.04	B
Mn I							hfs
1	5432.5	.00	9:	1.48	1.59	-.11:	M
4	5420.4	2.14	26	3.83	3.93	-.10	M
5	4070.3	2.19	41	4.32	4.46	-.14	
21	4709.7	2.89	38	4.81	5.14	-.33	
	4739.1	2.94	27	4.62	5.04	-.42::	
	4761.5	2.95	50	5.08	5.19	-.11	M
	4765.9	2.93	62	5.27	5.33	-.06	M
	4766.4	2.91	76	5.54	5.67	-.13	M
22	4453.0	2.94	27	4.64	4.83	-.19	
	4470.1	2.94	31	4.73	4.89	-.16	M
	4502.2	2.91	33	4.73	4.97	-.24	M
23	4257.7	2.95	35	4.83	5.19	-.36	
	4265.9	2.94	37	4.85	5.10	-.25	
27	6013.5	3.06	42	4.97	5.25	-.28	M
42	5399.5	3.84	17	5.08	5.19	-.11	M
	5413.7	3.84	8	4.71	4.86	-.15	M
45	4141.1	4.26	7:	5.05	5.37	-.32:	
48	4626.5	4.71	12	5.66	5.88	-.22	
Mn II							
--	3419.4	4.93	9::	3.95	3.96	-.01::	
Fe I							
13	6498.9	.96	17:	2.95	2.88	.07:	M
14	5956.7	.86	19:	2.95	3.01	-.06:	M
15	5501.5	.95	96	4.48	4.41	.07	M
39	4602.0	1.61	44	4.20	4.35	-.15	M
62	6213.4	2.21	57	4.86	4.85	.01	M
	6219.3	2.19	68	5.02	4.99	.03	M
	6265.1	2.17	62	4.89	4.91	-.02	M
	6335.3	2.19	77	5.17	5.07	.10	M
	6430.9	2.17	91	5.41	5.40	.01	M
111	6945.2	2.41	52	4.91	5.05	-.14	M
168	6593.9	2.42	61:	5.09	5.04	.05:	M
169	6252.6	2.39	98	5.74	5.75	-.01	M
207	6065.5	2.60	99	5.95	5.81	.14	M
	6322.7	2.58	45	4.97	5.10	-.13	M
209	5701.6	2.55	64	5.31	5.32	-.01	M
342	6270.2	2.85	25:	4.81	4.95	-.14:	M
346	4741.5	2.82	50	5.33	5.62	-.29:	M
553	5217.4	3.20	88	6.34	6.36	-.02	M
633	4808.2	3.24	13	4.86	4.90	-.04	M
686	5576.1	3.42	92	6.54	6.51	.03	M
687	4946.4	3.35	72	6.19	6.34	-.15:	M
	4950.1	3.40	50	5.82	5.97	-.15	M
786	5365.4	3.56	66	6.22	6.16	.06	M
816	6246.3	3.59	89	6.65	6.66	-.01	M
	6301.5	3.64	91	6.72	6.75	-.03	M
	6411.7	3.64	96	6.81	6.84	-.03	M
843	5242.5	3.62	75	6.44	6.35	.09	M
868	5636.7	3.62	8	4.90	4.94	-.04	M
959	6003.0	3.86	58	6.31	6.47	-.16	M
971	4593.5	3.93	12	5.41	5.55	-.14	M
982	5809.2	3.88	25	5.71	5.80	-.09	M
1001	7219.7	4.06	30	5.93	5.94	-.01	M
1018	6027.1	4.06	48	6.33	6.26	.07	M
1030	5464.3	4.12	21	5.82	5.91	-.09	M
1051	6999.9	4.10	33	6.03	6.02	.01	M
	7130.9	4.20	70	6.81	6.87	-.06	M
1062	5543.9	4.20	46	6.41	6.41	.00	M
1064	5386.3	4.15	13	5.59	5.74	-.15	M
1086	5793.9	4.20	19	5.82	5.84	-.02	M
	5814.8	4.26	10	5.54	5.66	-.12	M
1087	5775.1	4.20	37	6.23	6.33	-.10	M
1089	5243.8	4.24	43	6.43	6.44	-.01	M
1097	4962.6	4.16	35	6.18	6.24	-.06	M
1108	5522.5	4.21	24	5.97	6.02	-.05	M
1144	5441.3	4.29	14	5.75	5.92	-.17	M
1148	5406.8	4.35	18	5.92	6.04	-.12:	M
	5417.0	4.40	17	5.94	6.04	-.10:	M
1159	5653.9	4.37	20	5.99	6.04	-.05	M
1161	5619.6	4.37	16	5.87	6.02	-.15	M
1173	6843.7	4.55	41	6.58	6.63	-.05	M
1175	5983.7	4.53	54	6.82	6.75	.07	M
1176	6079.0	4.63	28	6.40	6.45	-.05	M
1177	6093.7	4.59	15	6.01	6.12	-.11	M
1178	6008.0	4.63	43	6.70	6.72	-.02	M
	6024.1	4.53	94	7.57	7.50	.07	M
1180	5752.0	4.53	33	6.43	6.54	-.11	M
	5862.4	4.53	75	7.21	7.14	.07	M
	5930.2	4.63	74	7.27	7.13	.14	M
1181	5905.7	4.63	41	6.67	6.67	.00	M
1183	5679.0	4.65	42	6.71	6.71	.00	M
1195	6855.2	4.54	56	6.84	6.77	.07	M
1197	6820.4	4.62	24	6.28	6.30	-.02	M
1258	6420.0	4.73	71	7.29	7.22	.07	M
1259	6056.0	4.71	57	7.03	6.98	.05	M
	6078.5	4.77	62	7.17	7.14	.03	M
1260	5987.1	4.77	50	6.95	7.11	-.16:	M
Fe II							
22	4124.8	2.53	49::	3.41	3.39	.02::	B
25	4670.2	2.57	44::	3.30	3.36	-.06::	B
	5000.7	2.77	15:	2.79	2.88	-.09:	B
35	5100.7	2.79	34::	3.29	3.23	.06::	B
	5132.7	2.79	33:	3.30	3.40	-.10	B

Table 4 (continued)

Mult	λ(Å)	χ(eV)	W_λ	log $gf\varepsilon_*$	log $gf\varepsilon_\odot$	[ε]	Remarks
36	4993.4	2.79	56	3.70	3.73	-.03	B
37	4582.8	2.83	85	4.29	4.24	.05	B
38	4620.5	2.82	78	4.14	4.21	-.07	B
40	6432.7	2.88	66	3.86	3.84	.02	M
	6369.5	2.88	33	3.30	3.30	.00	M
43	4657.0	2.88	59::	3.84	3.77	.07::	B
46	5991.4	3.14	53	3.89	3.83	.06	B
	6084.1	3.19	37	3.66	3.61	.05	B
	6113.3	3.21	21	3.31	3.30	.01	B
48	5264.8	3.22	79	4.47	4.31	.16::	B
	5414.1	3.21	49	3.90	3.79	.11	B
49	5425.3	3.19	67	4.21	4.17	.04	B
	5325.6	3.21	74	4.35	4.19	.16	B
74	6149.2	3.87	67	4.78	4.61	.17	B
	6416.9	3.87	62	4.67	4.66	.01	B
199	6446.4	6.20	10	5.42	5.46	-.04	B
Co I							hfs
16	4020.9	.43	36	2.84	2.69	.15	
158	4792.9	3.24	13	4.71	4.86	-.15	M
	4813.5	3.20	22	4.95	5.04	-.09	M
172	5352.0	3.58	9:	4.78	4.90	-.12:	M
190	5342.7	4.00	16	5.44	5.52	-.08	M
Co II							
2	3501.7	2.24	93::	4.35	4.53	-.18::	
Ni I							
43	6643.6	1.68	59	4.05	4.23	-.18	M
44	6327.6	1.68	12	3.04	3.20	-.16	M
45	6108.1	1.68	30	3.55	3.70	-.15	M
47	5578.7	1.68	23:	3.42	3.57	-.15:	M
57	6767.8	1.83	54	4.08	4.07	.01	M
66	6482.8	1.93	14:	3.33	3.47	-.14:	M
70	5435.9	1.99	24	3.71	3.88	-.17	M
111	4953.2	3.72	30:	5.34	5.61	-.27:	M
	4998.2	3.59	32	5.27	5.49	-.22	M
131	5042.2	3.64	45	5.55	5.61	-.06	M
132	4914.0	3.73	35	5.45	5.62	-.17	M
143	5035.4	3.62	90	6.39	6.34	.05	M
144	5010.9	3.62	27	5.18	5.33	-.15	M
162	5084.1	3.66	78	6.19	6.17	.02	M
163	4807.0	3.66	42	5.53	5.68	-.15	M
164	5094.4	3.82	16	5.06	5.12	-.06	M
177	4935.8	3.92	41	5.72	5.88	-.16	M
	5115.4	3.82	58	5.94	6.08	-.14	M
192	5462.5	3.83	25	5.30	5.48	-.18	M
205	5589.4	3.88	14	5.02	5.10	-.08	M
206	5593.7	3.88	23	5.29	5.48	-.19	M
221	5625.3	4.07	24	5.47	5.55	-.08	M
230	6111.1	4.09	18	5.32	5.37	-.05	M
231	5760.8	4.09	18	5.33	5.51	-.18	M
232	5682.2	4.10	39	5.82	5.79	.03	M
234	5641.9	4.09	14	5.20	5.24	-.04	M
	5805.2	4.17	26	5.61	5.64	-.03	M
247	6378.3	4.14	15	5.25	5.43	-.18	M
248	6130.2	4.26	12	5.25	5.26	-.01	M
249	6086.3	4.25	24	5.61	5.75	-.14	M
Cu I							hfs
2	5105.5	1.38	50:	2.49	2.60	-.11:	M
	5782.1	1.64	30	2.36	2.36	.00	M
7	5218.2	3.80	36	4.40	4.44	-.04	M
Zn I							hfs
2	4722.2	4.03	64	3.92	4.08	-.16	M
	4810.5	4.08	67:	4.01	4.25	-.24:	M
6	6362.4	5.79	22:	4.63	4.62	.01:	M
Sr I							
2	4607.3	.00	25:	3.04	3.24	-.20:	M
Sr II							
1	4077.7	.00	339::	3.10	3.12	-.02::	
3	4161.8	2.94	53:	2.58	2.43	.15:	
Y II							
5	4398.0	.13	61	1.14	1.00	.14	M
20	4982.1	1.03	15::	.91	.85	.06::	
	5087.4	1.08	68	2.04	1.91	.13	M
	5119.1	.99	13:	.76	.96	-.20:	M
	5200.4	.99	49	1.60	1.53	.07	M
21	5123.2	.99	34::	1.32	1.29	.03::	
22	4900.1	1.03	76::	2.14	2.06	.08::	
35	5402.8	1.84	18	1.68	1.64	.04	M
Zr II							
11	3430.5	.47	64:	2.41	2.23	.18::	
41	4209.0	.71	52::	1.98	2.04	-.06::	M
43	4050.3	.71	26	1.48	1.43	.05	
88	4379.8	1.53	34:	2.33	2.33	.00:	
95	5112.3	1.66	11:	1.76	1.76	.00:	M
Nb I							
--	4606.8	.35	< 1	2.11	1.98	<.13	
Ru I							
4	3436.7	.15	2::	1.81	1.64	.17::	
	3498.9	.00	5::	2.09	2.18	-.09::	
Pd I							
2	3404.6	.81	6::	1.58	1.74	-.16::	
Ba II							hfs
1	4554.0	.00	182	2.12	2.03	.09	
2	5853.7	.60	79	1.24	1.12	.12	
	6141.7	.70	144	2.44	2.10	.34::	
	6496.9	.60	137	2.09	1.68	.41	
4	4130.6	2.72	50::	2.72	2.64	.08::	
La II							
8	4662.5	.00	7:	-.06	-.04	-.02:	M
27	3995.8	.17	>37	1.07	1.27	>-.20	
36	5123.0	.32	9::	.31	.24	.07::	M
66	4042.9	.92	21	1.36	1.38	-.02	
Ce II							
1	4562.4	.00	18	1.25	1.29	-.04	
	4628.2	.04	14	1.16	1.18	-.02	
2	4382.2	.20	8::	1.07	1.14	-.07::	
	4523.1	.52	10::	1.41	1.53	-.12::	
15	5274.2	.56	8::	1.28	1.41	-.13::	M
17	4773.9	.92	8	1.63	1.80	-.17	
57	4486.9	.30	10::	1.22	1.28	-.06::	
140	4042.6	.50	9::	1.33	1.51	-.18::	
203	4479.4	.56	14::	1.62	1.81	-.19::	
Nd II							
3	4811.3	.06	4::	.32	.70	-.38::	
36	4021.3	.32	8::	.94	1.28	-.34::	
48	5092.8	.38	4::	.57	.87	-.30::	M
49	4446.4	.20	6::	.65	.81	-.16::	
50	4463.0	.56	10::	1.21	1.35	-.14::	
75	5319.8	.55	7::	.96	1.24	-.28::	M
--	4023.0	.20	10::	.94	1.09	-.15::	
	5179.8	.74	4::	.88	1.08	-.20::	
Sm II							
3	4719.8	.04	3::	.13	.39	-.26::	M
32	4566.2	.33	3::	.11	.60	-.49::	
45	4538.0	.48	3::	.37	.65	-.28::	
49	4519.6	.54	4::	.52	.71	-.19::	
Eu II							
1	4129.7	.00	38::	.65	.92	-.27::	
8	6437.6	1.31	< 8	.76	.85	<-.09	M
Dy II							
--	3407.8	.00	37::	1.38	2.10	-.72::	
	3434.4	.00	7::	.40	.54	-.14::	
	3506.8	.10	22::	1.08	1.86	-.78::	
	3563.2	.10	9::	.60	.99	-.39::	
	3694.8	.10	18::	.79	1.03	-.24::	
	4073.2	.54	8::	.72	.87	-.15::	
	3550.2	.59	24::	1.57	2.20	-.63::	
Os I							
1	3528.6	.00	< 1	.28	.37	<-.09	

values are taken whenever possible from Biémont (1978) for lines of singly ionized iron peak elements and from Mäckle et al. (1975a) for other elements. Those lines contained in Biémont (1978) and in Mäckle et al. (1975a) are noted as "*B*" and "*M*" in Table 4. When no data can be found in these two sources, we computed solar $gf\varepsilon$ values using the Holweger-Müller (1974) solar model atmosphere. Equivalent widths of the solar absorption lines are measured on the *Jungfraujoch Solar Atlas* (Delbouille et al., 1973) or taken from the *Second Revision of Rowland's Preliminary Table* (Moore et al., 1966) for lines blueward of 4000 A. A depth-independent solar microturbulence of $\xi_t = 1.0\,\mathrm{km\,s^{-1}}$ is assumed in these computations.

The data for the individual line are listed in Table 4. The consecutive columns are as follows: (1) element and multiplet number, (2) wavelength λ in A, (3) lower excitation potential χ in eV, (4) measured equivalent width in mA, [equivalent widths with lower accuracy are marked with a colon (:), and those with the lowest accuracy are marked with two colons (::)], (5) derived log $gf\varepsilon_{\mathrm{Procyon}}$ and used log $gf\varepsilon_\odot$ values, [on the scale of log $\varepsilon(H) = 12.0$], (7) the difference in abundance [ε], and (8) remarks to each line.

4. Results and Discussion

4.1. Elemental Abundances

Final abundances relative to the Sun are summarized in Table 5 and Fig. 5. Higher weights are given to weak unperturbed lines having small or no hyperfine structure in averaging the individual value of [ε] in Table 4. Error limits in Fig. 5 are 1.4 times the rms deviations for each element except for Al, Co, Cu, Zn, Sr, Ru, Pd, Ba, La, and Eu. Error limits of 0.3 dex are given to these ten elements.

Abundances of nearly all of the observed elements in the spectrum of Procyon show the solar values. However, a slight overabundance of Ba seems to be real, since lines of Ba II in Table 4 are so fine that we can measure their profiles with high accuracy. On the other hand, slight underabundances of rare earth elements are rather uncertain. This is because of the intrinsic weakness of lines of rare earth elements and nearly all of these lines are affected by neighbouring lines. However, it is interesting to note here that Griffin (1971) also found underabundances of five rare earth elements.

4.2. Convective Model Atmospheres

In this study, we used Kurucz's (1980) new convective model atmospheres. The mixing length to scale height ratio of $l/H = 1$ is used in these models. On the other hand, the ratio of $l/H = 2$ is used in his previous models (Kurucz, 1979). Compared with the $l/H = 2$ models, the new models have steeper temperature gradients in the deeper layers ($\tau > 1$). There is only a little difference in the temperature structures in the outer layers. The convective energy transport strongly depends upon the choice of a value of

Table 5. Chemical composition of Procyon relative to the Sun (logarithmic units). I and II refer to neutral and singly ionized species, respectively. The number of lines used is given in the parentheses. Results of Griffin (1971) are listed in the last column for comparison

	I	II	mean	Griffin
Na	0.04(7)		0.04 ± .10	0.0
Mg	-0.04(8)		-0.04 ± .13	-0.1
Al	-0.05(2)		-0.05 ± .30	-0.1
Si	0.00(11)	-0.08(2)	-0.04 ± .11	0.0
S	-0.04(6)		-0.04 ± .21	-0.1
Ca	0.04(20)	-0.01(3)	0.02 ± .18	0.0
Sc	-0.17(1)	-0.00(14)	-0.00 ± .10	0.0
Ti	-0.15(25)	-0.02(15)	-0.05 ± .11	-0.1
V	-0.04(8)	-0.04(14)	-0.04 ± .18	-0.1
Cr	-0.10(30)	0.03(17)	-0.00 ± .13	0.0
Mn	-0.19(18)	-0.01(1)	-0.19 ± .13	-0.2
Fe	-0.01(66)	0.03(21)	0.02 ± .11	0.0
Co	-0.12(5)	-0.18(1)	-0.12 ± .30	-0.1
Ni	-0.10(30)		-0.10 ± .14	0.0
Cu	-0.04(3)		-0.04 ± .30	0.0
Zn	-0.16(3)		-0.16 ± .30	0.0
Sr	-0.20(1)	0.11(2)	0.03 ± .30	
Y		0.05(8)	0.05 ± .14	-0.1
Zr		0.02(5)	0.02 ± .08	0.0
Nb	0.13(1)		0.13$^{a)}$	
Ru	0.04(2)		0.04 ± .30	
Pd	-0.16(1)		-0.16 ± .30	
Ba		0.23(5)	0.23 ± .30	-0.1
La		-0.01(4)	-0.01 ± .30	-0.3
Ce		-0.09(9)	-0.09 ± .08	-0.2
Nd		-0.25(8)	-0.25 ± .11	-0.3
Sm		-0.31(4)	-0.31 ± .16	-0.4
Eu		-0.14(2)	-0.14 ± .30	-0.3
Dy		-0.40(7)	-0.40 ± .34	
Os	-0.09(1)		-0.09$^{a)}$	

a) upper limit

l/*H* in the mixing-length theory (e.g., Mihalas, 1978). However, how to choose an appropriate value of the ratio has been one of the fundamental uncertainties in the theory of convective model atmospheres. Now, we may estimate an appropriate value of *l*/*H* by comparing the models with observations. Examinations of the ionization balance of iron group elements are suitable for this purpose. If we use the $l/H=2$ models of Kurucz (1979), the ionization balance between Fe I and Fe II is obtained at $T_{\rm eff}=6900$ K instead of $T_{\rm eff}=6700$ K obtained with the new models. Other iron group elements also indicate temperatures around 7000 K, which are always higher by about 200 K than those obtained with the $l/H=1$ models. The effective temperature indicated by the ionization balance of iron group elements obtained with the new models shows closer agreement with those obtained from the continuum flux, the Balmer line profiles, and the color indices. Comparisons of the observed continuum flux and the Balmer line profiles with those predicted from both types of models give essentially the same temperature. Thus, we conclude that the new $l/H=1$ models used in this study are more consistent and better than the previous $l/H=2$ models.

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References

Biémont, E.: 1978, *Monthly Notices Roy. Astron. Soc.* **184**, 683

Blackwell, D.E., Shallis, M.J., Simmons, G.J.: 1980, *Astron. Astrophys.* **81**, 340

Breger, M.: 1976, *Astrophys. J. Suppl.* **32**, 7

Buscombe, W.: 1977, MK Spectral Classifications, Third General Catalogue, Northwestern University, Evanston

Cayrel de Strobel, G., Bentolila, C., Hauck, B., Curchod, A.: 1980, *Astron. Astrophys. Suppl.* **41**, 405

Code, A.D., Davis, J., Bless, R.C., Hanbury Brown, R.: 1976, *Astrophys. J.* **203**, 417

Danziger, I.J.: 1966, *Astrophys. J.* **143**, 591

Delbouille, L., Roland, G., Neven, L.: 1973, Photometric Atlas of the Solar Spectrum from λ3000 to λ10000, Institut d'Astrophysique de l'Université de Liège

Dickens, R.J., Penny, A.J.: 1971, *Monthly Notices Roy. Astron. Soc.* **153**, 287

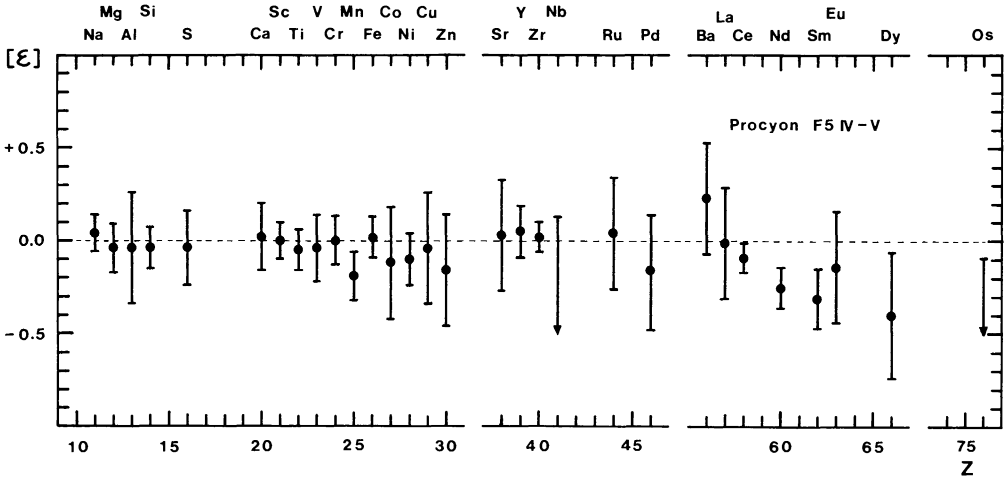

Fig. 5. Chemical composition of Procyon. Abundances relative to the Sun (logarithmic units)

Gray, D.F.: 1976, The Observation and Analysis of Stellar Photospheres, Wiley, New York, p. 214

Greenstein, J.L.: 1948, *Astrophys. J.* **107**, 151

Griffin, R.: 1971, *Monthly Notices Roy. Astron. Soc.* **155**, 139

Griffin, R., Griffin, R.: 1973, *Monthly Notices Roy. Astron. Soc.* **162**, 243

Griffin, R., Griffin, R.: 1979, A Photometric Atlas of the Spectrum of Procyon, R. & R. Griffin, Cambridge, England

Hanbury Brown, R., Davis, J., Allen, L.R.: 1974, *Monthly Notices Roy. Astron. Soc.* **167**, 121

Hauck, B., Mermilliod, M.: 1980, *Astron. Astrophys. Suppl.* **40**, 1

Hasegawa, T.: 1975, Sendai Astronomiaj Raportoj, N-ro 164

Hoffleit, D.: 1964, Catalogue of Bright Stars, Yale University Observatory, New Haven

Holweger, H., Müller, E.A.: 1974, *Solar Phys.* **39**, 19

Ishikawa, M.: 1975, *Publ. Astron. Soc. Japan* **27**, 1

Johnson, H.L., Morgan, W.W.: 1953, *Astrophys. J.* **117**, 313

Kurucz, R.L.: 1970, *Smithsonian Ap. Obs. Spec. Rept.*, No. 309

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

Kurucz, R.L.: 1980, private communication

Mäckle, R., Griffin, R., Griffin, R., Holweger, H.: 1975a, *Astron. Astrophys. Suppl.* **19**, 303

Mäckle, R., Holweger, H., Griffin, R., Griffin, R.: 1975b, *Astron. Astrophys.* **38**, 239

Merchant, A.E.: 1966, *Astrophys. J.* **143**, 336

Mihalas, D.: 1978, Stellar Atmospheres, Second Edition, Freeman, San Francisco, p. 187

Moore, C.E., Minnaert, M.G.J., Houtgast, J.: 1966, *Natl. Bur. Stand. Monogr.*, No. 61

Nissen, P.E.: 1981, *Astron. Astrophys.* **97**, 145

Philip, A.G.D., Egret, D.: 1980, *Astron. Astrophys. Suppl.* **40**, 199

Powell, A.L.T.: 1970, *Monthly Notices Roy. Astron. Soc.* **148**, 477

Relyea, L.J., Kurucz, R.L.: 1978, *Astrophys. J. Suppl.* **37**, 45

Sadakane, K., Nishimura, M.: 1979, *Publ. Astron. Soc. Japan* **31**, 481

Schmidt, E.G.: 1979, *Astron. J.* **84**, 1739

Shallis, M.J.: 1981, *Astron. Astrophys.* **97**, 203

Shallis, M.J., Blackwell, D.E.: 1980, *Astron. Astrophys.* **81**, 336

Smith, G.: 1981, *Astron. Astrophys.* **103**, 351

Talbert, F.D., Edmonds, F.N., Jr.: 1966, *Astrophys. J.* **146**, 177

Tomkin, J., Lambert, D.L.: 1978, *Astrophys. J.* **223**, 937

Uesugi, A., Fukuda, I.: 1981, Revised Catalogue of Stellar Rotational Velocities, C.D.S., Strasbourg

van de Kamp, P.: 1971, *Ann. Rev. Astron. Astrophys.* **9**, 103

Vidal, C.R., Cooper, J., Smith, E.W.: 1973, *Astrophys. J. Suppl.* **25**, 37

Woolley, R., Epps, E.A., Penston, M.J., Pocock, S.B.: 1970, *Roy. Obs. Ann.*, No. 5

Wright, K.O.: 1948, *Publ. Dominion Astrophys. Obs.* **8**, 1

Wright, K.O., Lee, E.K., Jacobson, T.V., Greenstein, J.L.: 1964, *Publ. Dominion Astrophys. Obs.* **12**, 173