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THE EARLY A STARS. II. MODEL-ATMOSPHERE ABUNDANCE ANALYSIS OF EIGHT STARS IN THE PLEIADES*

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ABSTRACT

Stars near spectral type A0, showing anomalously low ratios of Sc II $\lambda 4246$/Sr II $\lambda 4215$, are found to be analogous to the classically defined Am stars. This result follows from a detailed model atmosphere study of eight sharp-lined A stars in the Pleiades. For the four Am analogues among these stars, the following anomalies are found: underabundances of carbon, calcium, and scandium; overabundances of strontium, yttrium, zirconium, and barium; and high microturbulent velocities. The analysis shows clearly that these anomalies cannot be attributed solely to inappropriate choices of atmospheric parameters. The normal A stars in our sample show excellent agreement in their element abundances with field A stars such as Vega.

I. INTRODUCTION

The classical definition of a metallic-line A star is based on the following spectroscopic criteria: (1) weakness of the K-line of Ca II for the hydrogen-line spectral type; and (2) strength of the metal lines, particularly those of the singly ionized metals, for the hydrogen-line spectral type. Use of these criteria at classification dispersions has served to identify Am stars in the spectral type range A5–F2.

Abundance analyses of Am stars (see Sargent 1964 and references therein; Conti 1965*a*) identified according to these criteria have revealed some or all of the following anomalies: (1) underabundances of scandium and calcium; (2) overabundances of strontium, yttrium, zirconium, and other heavy *s*-process elements; (3) overabundances of nickel and zinc; (4) enhancement of the Fe/H ratio; (5) high microturbulent velocities in the region of line formation; and (6) low electron pressure. Moreover, a survey by Abt (1962) has revealed a very high incidence of duplicity among these stars, and a characteristic low rotational velocity ($v \sin i$) has been pointed out by Slettebak (1954).

It is important to determine whether these anomalies associated with the Am phenomenon are restricted to the narrow range of effective temperature (T_{eff}) as implied by the surveys at classification dispersion. If this were the case, one might logically expect to attribute the presence of such anomalies to a set of atmospheric conditions that prevail only in this spectral type range (e.g., narrow convection zones) or to a particular stage in the evolutionary history of stars in this mass range.

However, detection of the Am anomalies at higher effective temperatures using classification dispersion is difficult for the following reasons: (1) The K-line is formed near the flat part of the curve of growth and hence its equivalent width is insensitive to relatively small changes in calcium abundance. (2) The hydrogen-line spectrum for stars near A0 is quite insensitive to small changes in temperature. The strength of the metal lines relative to the hydrogen lines (i.e., for a given temperature) is therefore no longer a measure of metal abundance alone but can also reflect a change in T_{eff}, which is not reflected by the character of the hydrogen-line spectrum.

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Recent analyses of sharp-line early A stars based on high-dispersion plate material, in particular of α CMa A1 V (Kohl 1964; Strom, Gingerich, and Strom 1966) and 68 Tau A2 IV (Conti, Wallerstein, and Wing 1965), have suggested that these stars have many of the abundance and atmospheric anomalies characteristic of the classical Am stars.

This work motivated Conti (1965*b;* Paper I of this series) to search for analogues of the Am stars among the sharp-line early A stars. He noted that both α CMa and 68 Tau show much lower values of the ratio

$$\alpha = \frac{W_\lambda(\text{Sc II } 4246)}{W_\lambda(\text{Sr II } 4215)}$$

(where W_λ is equivalent width) than those observed for early A stars such as Vega, which appear normal in both atmospheric parameters and abundance.

Conti's (1965*b*) survey of twenty-nine sharp-line early A stars in the field at 10 Å mm^{-1} dispersion revealed the following: (1) low K-line strengths for the lowest values of α, and

TABLE 1

SPECTROPHOTOMETRIC DATA FOR EIGHT PLEIADES A STARS

STAR		V	$(B-V)$	$(U-B)$	SP.	$v \sin i$	$(B-V)_0$	SP. BINARY?	ADS?
H II	HD								
	22615	6 51	0 15	+0 18	A0	10*	. .	. . .	
232	23194	8 06	20	+ 15	A5 V	20	0 15	Possible	
717	23387	7 18	16	+ 08	A1 V	15	03	Possible	. .
1362	23607	8 25	26	+ .10	A7 V	≤ 12	20	No	. . .
1397	23631	7 26	.05	+ 04	A2 V	≤ 10	.05	Possible	2767
2415	23924	8 10	22	+ 13	A7 V	100: †	20	No	. . . . . .
2507	23964	6 74	06	− 06	A0 V	15	0 00	16^{d}7	2795
. .	24368	6 36	0 12	+0 10	A0	10*	. .	. .	

* $v \sin i$ estimated.

† $v \sin i \sim 15$ from our spectra.

Source: *UBV:* Johnson and Mitchell (1958); Sp: Mendoza V. (1956) or *Henry Draper Catalogue; v* sin *i:* Anderson *et al.* (1966), Mendoza V. (1956); Sp. Binary: Abt, Barnes, Biggs, and Osmer (1965).

(2) low values of α for most of the spectroscopic binary systems observed. These results suggested that the phenomena associated with the classical Am stars are also found in stars of earlier spectral type. However, confirmation of this suggested extension of the Am stars would seem to require a detailed analysis of a sample of A stars with a range of Sc/Sr ratios.

II. OBSERVATIONAL DATA

In this paper we have chosen to perform a model-atmosphere analysis of eight sharp-line A stars in the Pleiades Cluster. These stars show a variety of Sc/Sr ratios (Conti 1967), and are the only sharp-line A stars in the cluster (Anderson, Stoeckly, and Kraft 1966). Presumably the initial composition of these stars was identical, and any anomalies that might be deduced from our analysis result from events occurring during the evolutionary history of individual stars. The spectrophotometric data for these stars are listed in Table 1. Variable reddening over the cluster renders straightforward interpretation of observed colors difficult. The reddening corrections are based only on the quoted spectral types and the unreddened colors are therefore somewhat uncertain.

A sharp-lined A star in Praesepe was also studied. This star, HD 73666 (= 40 Cnc),

TABLE 2 EQUIVALENT WIDTHS

LAMBDA	EP	MULT	-LOG(W/LAMBDA) 23607	23924	23194	22615	24368	23631	73666	23387	23964
C1											
4771.71	7.46	6	4.96	4.86A	4.95B	4.84	5.26	5.42	5.01B	5.30	5.61A
MG1											
4167.26	4.33	15	4.33	4.31	4.38	4.60	4.95	5.18	4.96	5.30	5.63A
4702.98	4.33	11	4.36	4.35	4.36	4.58	4.83	4.94	4.84	5.50B	5.68A
MG2											
4390.57	9.96	10	4.90	4.62	4.94	4.66	4.79	4.92	4.77	5.08	5.04
4481.19	8.83	4	3.93	3.86	3.93	3.93	4.02	4.05	3.92	4.08	4.09
AL1											
3944.00	0.	1	4.26	4.43	4.38	4.29	4.44	4.56	4.59	5.31B	4.91B
SI2											
4128.04	9.79	3	4.56	4.36	4.47	4.36	4.48	4.53	4.60	4.83	4.61
4130.87	9.80	3	4.95	4.58	4.87	4.43	4.48	4.56	4.53	4.76	4.52
CA1											
4226.72	0.	2	4.16	4.21	4.18	4.28	4.60	4.90	4.68	5.03	5.48
4283.01	1.88	5	4.57	4.79	4.65		5.63	5.50	5.14A	5.68	5.64A
4425.44	1.87	4	4.72	4.77	5.08	5.25	5.65	5.52B	5.63	5.42B	5.66
4434.96	1.88	4	4.59	4.56	4.75	5.03	5.39B	5.30B	5.45B	5.60	5.65A
4435.69	1.88	4	4.74	4.79	5.07	5.17	5.65	5.29	5.42B	5.47B	5.65A
CA2											
3933.65	0.	1	3.03	3.01	3.16	3.22	3.58A	3.72	3.51	3.78	4.10
SC2											
4246.82	0.31	7	4.38	4.30	4.35	4.51	4.64	5.33B	4.72	5.07	5.64
4325.01	0.59	15	4.42	4.59A	4.58	5.17	5.14B	5.48	5.25	5.53	5.64A
4400.35	0.60	14	4.68	4.58A	4.97		5.41	5.64	5.36B	5.27	5.66A
TI2											
4028.32	1.88	87	4.57	4.74	5.10	4.73	4.75	4.88	4.81	5.45	5.40
4163.63	2.58	105	4.43	4.51	4.55	4.43	4.61	4.65	4.67	4.98	5.04
4287.88	1.08	20	4.58	4.46	4.91	4.64	5.00	5.11	5.08	5.31	5.64
4290.22	1.16	41	4.27	4.14	4.23	4.23	4.45	4.56	4.54	4.95	5.05
4294.09	1.08	20	4.36	4.40	4.41	4.35	4.49	4.54	4.54	4.83	5.06
4300.04	1.18	41	4.35	4.36	4.37	4.31	4.43	4.48	4.47	4.78	4.72
4301.92	1.16	41	4.45	4.36	4.44	4.53	4.67	4.72	4.75	5.13	5.15
4312.85	1.18	41	4.45	4.50	4.59	4.73	4.62	4.71	4.72	5.02	5.11
4316.80	2.04	94	4.93	4.94	5.61	5.27	5.21	5.17	5.44	5.51	5.44B
4386.85	2.59	104	4.91	4.88	5.13B	4.93	5.08	5.13	5.10	5.47B	5.22A
4394.05	1.22	51	4.82	4.83	5.12	4.94	5.08	5.15	5.21	5.51	5.65
4395.02	1.08	19	4.29	4.32A	4.35	4.34A	4.46	4.51B	4.51A	4.85	4.90
4395.84	1.24	61	4.91	5.24		5.02	5.17	5.32	5.29	5.59	5.65
4399.76	1.23	51	4.52	4.42	4.50	4.48	4.69	4.76	4.74	5.22	5.12
4411.07	3.08	115	4.99	5.02B	5.45	5.03	5.10	5.27B	5.20	5.39	5.53
4417.71	1.16	40	4.55	4.61	4.73	4.47	4.76	4.64	4.81	5.14	5.25
4418.33	1.23	51	4.78A	5.13B		5.33A	5.35	5.53	5.29	5.69	5.66
4443.79	1.08	19	4.33	4.32	4.40	4.36	4.45	4.54	4.54	4.82	4.85
4450.48	1.08	19	4.56	4.68	4.75	4.56	4.84	4.85B	4.90	5.51B	5.13
4464.46	1.16	40	4.68	4.76B	4.79	4.73	5.08	5.15	4.99	5.59	5.47
4468.48	1.13	31	4.31	4.37	4.40	4.32	4.42	4.50	4.49	4.90	5.10
4488.31	3.11	115	4.82	4.78	5.22B	4.70	5.00	4.96B	4.98	5.33B	5.46
4501.26	1.11	31	4.36	4.36	4.36	4.36	4.58	4.57	4.58	5.00	4.84
4529.45	1.56	82	4.81	4.72	5.57	4.88	5.06	5.02B	5.22	5.63	5.25A
4563.75	1.22	50	4.34	4.47	4.51	4.42	4.55	4.65	4.62	5.11B	4.99
4571.96	1.56	82	4.26	4.37	4.37	4.29	4.43	4.54	4.53	4.91	4.76
4779.98	2.04	92	4.77	4.87A	5.08	4.73	5.09	5.11	5.14A	5.73	5.68A
4805.09	2.05	92	4.68	4.69A	4.66	4.56	4.96	4.94B	5.02	5.75A	5.45A

TABLE 2 (CONTINUED)

LAMBDA	EP	MULT	-LOG(W/LAMBDA) 23607	23924	23194	22615	24368	23631	73666	23387	23964
FE1 CONTINUED											
4282.40	2.17	71	4.51	4.48	4.77	4.61	4.92	4.98	5.02	5.50B	5.48
4299.24	2.42	152	4.26	4.26	4.41	4.43	4.86	4.91	4.97	5.34B	5.64
4383.55	1.48	41	4.13	4.29	4.30	4.28	4.45	4.50	4.58	4.83	4.84
4404.75	1.55	41	4.28	4.35	4.35	4.34	4.54	4.57	4.65	5.04	5.17
4415.13	1.61	41	4.28	4.27	4.31	4.40	4.81	4.70	4.82	5.15	5.24A
4447.71	2.21	68	4.72	4.87	5.06B	4.88	5.65	5.14	5.11A	5.62	5.65
4466.54	2.82	350	4.55	4.63	4.94	4.70	5.21	5.15	5.03	5.40B	5.66
4469.38	3.64	830	4.69	4.61	4.85	4.90	5.13	5.41B	5.50	5.54	5.66A
4494.56	2.19	68	4.64	4.59	4.93	4.73	5.30	5.07	5.32	5.70	5.66
4736.77	3.20	554	4.91	4.85	4.97	5.21	5.43	5.42	5.46B	5.73	5.38A
4871.32	2.85	318	4.35A		4.88	4.77A	5.13	5.26		5.74	5.19A
4890.76	2.86	318			4.86	4.84A	5.24	5.27		5.74	5.69A
4891.50	2.84	318			4.58B	5.36A	4.97	5.10		5.74	5.12A
FE2											
3938.29	1.66	3	4.52	4.37	4.56	4.40	4.69	4.88	4.81	5.65	5.02
4122.63	2.57	28	4.62	4.73	5.36B	4.66	4.79	4.93	5.03	5.26	5.22B
4178.84	2.57	28	4.35	4.32	4.40	4.27	4.50	4.53	4.61	4.92	4.71
4273.31	2.69	27	4.89	4.77	5.06	4.66	4.86	5.04B	4.92	5.28	5.12
4296.56	2.69	28	4.53	4.34	4.76	4.45	4.60	4.75	4.78	5.21	5.15
4303.19	2.69	27	4.52	4.51A	4.47	4.37	4.53	4.58	4.66	4.82	4.85
4413.60	2.66	32	5.47B	5.19	5.58	5.62	5.22	5.58	5.53	5.65	5.66A
4416.81	2.77	27	4.46	4.53	4.58	4.48	4.69	4.59	4.76	4.95	4.94
4472.91	2.82	37	4.93	4.85	4.96A	4.83	4.99	5.10	5.23	5.14	5.40B
4489.17	2.82	37	4.68	4.53	4.86	4.64	4.71	4.82	4.85	5.16	5.07
4491.39	2.84	37	4.66	4.63	4.74	4.59	4.65	4.61	4.74	4.95	4.95
4508.27	2.84	38	4.45	4.45	4.52	4.40	4.52	4.55	4.58	4.98	4.87
4515.33	2.83	37	4.45	4.49	4.68	4.47	4.60	4.58	4.70	5.07	4.78
4520.21	2.79	37	4.52	4.47	4.64	4.53	4.57	4.66	4.69	5.07	5.00
4522.62	2.83	38	4.42	4.37	4.47	4.29	4.46	4.52	4.54	4.95	4.84
4541.51	2.84	38	4.75	4.87	4.88	4.60	5.00B	4.78	4.97	5.55	5.05
4555.89	2.82	37	4.32	4.38	4.39	4.31	4.53	4.61	4.61	4.92	4.88
4576.32	2.83	38	4.64	4.71	4.73	4.67	4.76	4.85	4.92	5.32	5.10
4582.82	2.83	37	4.84	4.57A	5.18	4.69	4.89	4.91	5.06	5.14	5.19
4583.82	2.79	38	4.32	4.33	4.34	4.27	4.39	4.44	4.51	4.84	4.79
4620.50	2.82	38	4.80	4.80	5.43B	4.84	4.96	4.99	5.36B	5.43	5.67A
4629.33	2.79	37	4.43	4.48	4.43	4.41	4.53	4.63	4.69	5.51	4.89A
4666.75	2.82	37	4.76	4.55	4.78	4.83	4.98	5.08	5.03	5.35	5.09A
4731.43	2.88	43	4.83	4.70	4.95	4.70	4.85	4.91	5.09	5.24	5.16A
NI1											
4714.42	3.37	98	4.75	4.76	5.39B	4.88	5.38	5.48B		5.53B	5.68A
NI2											
4015.50	4.01	12	4.99	4.87	5.52	4.66	4.81	4.99	5.15	5.65	5.14
ZN1											
4722.16	4.01	2	5.39B	5.66	5.65A	5.17	5.23	5.34B		5.72	5.68A
4810.52	4.06	2	5.35B	5.13A	4.98	5.14	5.24	5.68		5.49B	5.69A
SR2											
4077.70	0.	1	4.13	4.27	4.23	4.07	4.22	4.44	4.63	4.94	4.99
4215.51	0.	1	4.16	4.27	4.26	4.13	4.37	4.52	4.70	5.16	5.11
Y2											
4177.53	0.41	14	4.35	4.30	4.51	4.21	4.47	4.82	4.91	5.18	5.23
4374.93	0.41	13	4.45	4.30	4.37	4.32	4.61	4.88	5.04	5.14	5.52
4883.68	1.08	22			4.99A	4.71A	5.05	5.62		5.74	5.69A

TABLE 2 (CONTINUED)

LAMBDA	EP	MULT	-LOG(W/LAMBDA) 23607	23924	23194	22615	24368	23631	73666	23387	23964
V2											
3951.96	1.47	10	4.89	4.88	5.01	5.02	4.88	5.10	5.09	5.65	5.41
4002.94	1.42	9	5.18	5.08	5.26	5.40B	5.22	5.58	5.17	5.65	5.43
4005.70	1.81	32	4.95A	4.35A	5.57		4.76	4.98	4.92	5.39B	5.41
4023.38	1.80	32	4.80	5.26	5.55	4.77	4.93	5.10	5.10	5.52	5.19A
CR1											
4254.33	0.	1	4.33	4.42	4.65	4.38	4.91	4.89	4.95	5.48	5.43
4274.79	0.	1	4.41	4.44	4.80	4.64	5.08	5.02	5.04	5.49	5.47
CR2											
4145.76	5.30	162	5.01	5.06	5.46	5.10	5.16	5.10	5.14	5.67	5.28
4179.43	3.81	26	4.94A		5.59	4.65A	5.07	5.05	4.96	5.67	5.44
4242.37	3.85	31	4.67	4.56	4.81	4.59	4.75	4.70	4.82	5.31	5.03
4252.62	3.84	31	5.09B	5.04	5.54	4.95B	5.11	5.28B	5.20	5.62	5.63
4261.91	3.85	31	4.96	4.98B	4.92	4.72	4.86	4.73	4.88	5.63	5.08
4275.56	3.84	31	5.11B	4.76	5.61A	5.05	5.20	4.93	4.92	5.60	5.19
4284.20	3.84	31	5.10	4.92B	5.13	4.83	5.03B	5.04	5.16	5.63	5.46
4555.01	4.05	44	4.83	4.94	4.97	4.64A	4.90	4.87	4.96	5.53	5.04
4558.65	4.06	44	4.43	4.55	4.61	4.44	4.49	4.53	4.52	5.11	4.69
4588.21	4.05	44	4.45	4.52	4.71	4.45	4.66	4.60	4.63	5.00	4.84
4618.82	4.06	44	4.61	4.51	4.63	4.58	4.69	4.72	4.74	5.28	5.11A
4634.10	4.05	44	4.70	4.75	4.84	4.83	4.73	4.80	4.79	5.40	4.98A
4824.13	3.85	30		4.58A	4.66	4.51	4.69	4.82	4.67	5.73	4.75A
4848.24	3.85	30			5.66A	4.75	5.05	5.02	4.90A	5.74	5.69A
MN1											
4030.75	0.	2	4.20	4.25	4.38	4.25	5.04	5.12	5.00	5.50	5.45
4033.06	0.	2	4.31	4.34	4.60	4.33	4.81	5.00	4.93	5.47	5.18
4034.48	0.	2	4.54	4.73	5.06	4.81	5.61	5.59	5.53	5.54	5.62
FE1											
4005.25	1.55	43	4.19	4.15	4.24	4.21	4.67	4.79	4.74	5.05	5.15
4045.80	1.48	43	4.01	4.10	4.12	4.05	4.36	4.43	4.48	4.82B	4.78
4063.59	1.55	43	4.16	4.25	4.23	4.18	4.42	4.49	4.48	4.96	4.91
4067.97	3.20	559	4.66	4.77	4.99	4.94	5.04	5.37	5.23	5.51	5.57
4070.77	3.23	558	4.87	5.02	5.42	4.89	5.27	5.46	5.39B	5.66	5.61A
4071.73	1.60	43	4.21	4.37	4.33	4.28	4.57	4.56	4.63	4.88	5.07
4132.05	1.60	43	4.45	4.42	4.49	4.35	4.72	4.85	4.95	5.58	5.47
4157.78	3.40	695	4.78	4.86	5.45	5.32	5.22A	5.31	5.24A	5.67	5.39B
4175.63	2.83	354	4.68	4.81	5.08	4.92	5.13	5.32B	5.60	5.67	5.51
4181.75	2.82	354	4.34	4.33	4.51	4.44	4.93	5.03B	4.95	5.67	5.63
4187.03	2.44	152	4.48	4.56	4.55	4.56	4.99	4.98	5.03	5.59	5.63
4187.79	2.41	152	4.35	4.36	4.48	4.46	4.73	4.78	4.94	5.45B	5.16
4199.09	3.03	522	4.41	4.35A	4.53	5.30A	4.79	4.83	4.80	5.08	5.40
4202.02	1.48	42	4.31	4.32	4.39	4.34	4.65	4.70	4.84	5.26	5.47
4210.34	2.47	152	4.53	4.66	4.93B	4.92	5.11	5.13	5.24	5.68	5.63
4219.35	3.56	800	4.56	4.67	4.81	4.77	5.06	5.01B	5.17	5.68	5.52A
4222.21	2.44	152	4.57	4.59	4.97	4.91	5.19	5.20	5.26	5.68	5.64
4227.42	3.32	693	4.35	4.44A	4.05A	4.45A	4.71	4.81	4.86	5.27	5.14
4235.93	2.41	152	4.36	4.44	4.60	4.44	4.75	4.88	4.97	5.44B	5.20
4238.81	3.38	693	4.64	4.56	4.92	4.83	5.23	5.08	5.08	5.68	5.51
4247.43	3.35	693	4.64	4.89A	4.80	4.41A	5.14	5.07	5.29	5.58	5.64
4250.11	2.46	152	4.45	4.40	4.54	4.47	4.91	4.90	4.90	5.38	5.64
4250.78	1.55	42	4.32	4.42A	4.43A	4.45	4.77	4.80	4.86	5.52A	5.29
4260.48	2.39	152	4.26	4.22	4.33	4.29	4.68	4.68	4.71	5.07	5.15
4267.83	3.10	482	5.12	5.28		5.63	5.49	5.48B	5.59A		5.64A
4271.15	2.44	152	4.42	4.51A	4.63A	4.66	4.95	4.84	4.89		5.42
4271.75	1.48	42	4.21	4.22	4.26	4.26	4.53	4.57	4.59	4.91	5.00
ZR2											
3991.14	0.75	30	5.02B	5.06	5.54	4.90	4.90	5.31	5.28A	5.47	5.57A
3998.98	0.56	16	4.95	4.98	5.57A	4.76	4.87	5.47	5.20A	5.65	5.52
4211.87	0.52	15	5.21	5.23	5.60A	5.30	5.19	5.61	5.60	5.68	5.64
BA2											
4554.02	0.	1	4.37	4.48	4.48	4.41	4.50	4.67	4.92	5.71	5.13

was previously discussed by Conti *et al.* (1965). By means of a relative analysis, they concluded its metal content was normal. We used it here as a check on the absolute analysis in this paper.

Mount Wilson coudé spectra were obtained in the blue region (with baked IIaO emulsion) at a dispersion of 10 Å/mm. Two plates of each star were used to determine the equivalent widths (expressed as $-\log W/\lambda$) listed in Table 2. A mean relation between equivalent width and central depth was derived independently for each plate by measuring each quantity for about thirty representative lines. This relation permitted us to determine the equivalent widths of other lines from their measured central depths.

The average deviation of each plate from the mean for each line was about ± 0.1 in $\log W/\lambda$. Those lines labeled "A" in Table 2 were only measured on one plate; those lines labeled "B" had an individual deviation from their mean of more than 0.2 in $\log W/\lambda$. These lines were given less weight in the analysis. The measured equivalent widths less than -5.60 in $\log W/\lambda$ are to be considered upper limits.

TABLE 3

VALUES OF $T_{\rm eff}$ DEDUCED FROM SPECTROPHOTOMETRIC DATA

Star (HD)	$T_{\rm eff}$(° K)	Source of $T_{\rm eff}$
22614	8300	Hγ
23194	8500	Hγ
23387	9200	$(B-V)_0$
23607	7600	Hγ
23631	9100	$(B-V)_0$
23924	8250	Hγ
23964	9700	$(B-V)_0$
24368	9700	Sp.

III. CHOICE OF MODEL PARAMETERS

In order to perform a model atmosphere analysis of these stars, it is necessary to obtain trial values of the parameters specifying the model, namely, the effective temperature $T_{\rm eff}$ and the surface gravity g.

For $T_{\rm eff} \lesssim 8500°$ K, the Hγ profile provides a sensitive indicator of $T_{\rm eff}$. Moreover, the observed profile is virtually insensitive to reddening and hence provides the most accurate means of fixing the trial value of the temperature. The observed profiles used came from our spectra and were usually the result of averaging the profiles from two plates. Deane Peterson of Harvard University has kindly computed for us a set of hydrogen-line profiles in the $T_{\rm eff}$ range 7500°–10000° K based on the Griem (1964) theory of Stark broadening. We have used these profiles to deduce the $T_{\rm eff}$ values listed in Table 3.

In order to obtain estimates for stars having values of $T_{\rm eff}$ higher than 8500° K, we have used the relation between $T_{\rm eff}$ and $(B-V)_0$ determined by Oke and Conti (1966) and the deduced values of $(B-V)_0$. The values of $T_{\rm eff}$ so determined are listed in Table 3. These values carry considerably less weight than do the Hγ determinations for the cooler stars.

A direct estimate of surface gravities was made for stars having $T_{\rm eff} > 8500°$ K by comparing observed and computed Hγ profiles. The mean surface gravity obtained in this way is $\log g = 3.8 \pm 0.2$. This is about 0.2–0.3 in the log smaller than the values expected for unevolved early-A stars on the basis of analysis of eclipsing systems. However, it would clearly be of some importance from an evolutionary standpoint to determine a very accurate mean value for log g, particularly for the stars that exhibit Am characteristics. More accurate, preferably photoelectric profiles must be obtained and a critical comparison of theory and observation must be made for eclipsing systems before any definite conclusions can be drawn regarding the surface gravities deduced from Hγ profiles. However, no unusually large or small values of log g were deduced for any star that was analyzed. Uncertainties in both the theoretical profiles and the observations clearly admit the choice of log $g = 4$, and we adopt this value since we consider the directly determined surface gravities to be more reliable than theoretical values at present.

Model atmospheres covering the range of T_{eff} and log g were computed. These models included as opacity sources H, H^-, H_2^+, He I, Mg I, Si I. No line blanketing was included in any of the models. Departures from LTE and the effects of convection were also ignored. From numerical trials performed by us, none of the above simplifying omissions is expected to affect the deduced abundances in any significant way.

IV. THE ABUNDANCE DETERMINATIONS

After choosing an appropriate model atmosphere we proceed in the following way: (1) Line profiles and resulting equivalent widths are computed from the model and the given atomic parameters for a range of trial abundances, A, and microturbulent velocities, v_t. (2) The observed equivalent widths and the data computed in step 1 allow us to obtain an abundance for each individual line. (3) A plot, for each value of v_t, of deduced abundance against observed equivalent width for Fe I lines allows us to choose the best value for the microturbulence from the condition that the slope of the A against W_λ relation must be zero. We estimate the accuracy of the v_t values deduced in this way to be ± 0.5 km/sec^{-1}. (4) A plot of A against χ, the lower excitation potential, for the observed Fe I lines permits an evaluation of the trial value of T_{eff}. The effective temperatures of the models are varied until the slope of this relation is zero. We estimate $\pm 250°$ K as the accuracy of this T_{eff} determination. Note that, while this procedure is analogous to choosing an excitation temperature from a curve of growth analysis, it makes complete use of the model atmosphere in determining the best value of T_{eff}. Steps 3 and 4 are not entirely independent, but there is no difficulty in achieving a unique solution in a few iterations. (5) The Fe I/Fe II ionization equilibrium was also used as a check on the accuracy of the T_{eff} determination. In no case did we find a discrepancy between the Fe I and Fe II abundances that exceeded 0.15 in the log after choosing T_{eff} from condition 4.

The T_{eff} values finally adopted in Table 3 are close to those indicated by the colors or by Hγ. The absolute f-value scale used for this determination was that of B. Warner (private communication) and checks on this scale using observed solar Fe I and Fe II lines (Cohen and Strom 1968) confirmed its essential accuracy.

In Table 4 we have chosen to present the results of our abundance analysis for each star in the form of the ratio log $(A_{\text{el}}/A_{\text{Fe}})$, since this ratio, for most elements, is quite insensitive to moderate changes in T_{eff} and v_t. In addition, we present the values of log (Fe/H) for what we consider to be the best choice of atmospheric parameters. The atmospheric parameters and abundance ratios for each of the eight Pleiades A stars are summarized in the table. In addition, we present abundance determinations made for two A stars that appear to have normal (i.e., solar) abundances: α Lyr (Vega) and HD 73666.

The results of Strom *et al.* (1966) and Hunger (1955) support the view that Vega has metal abundances almost identical to those of the Sun. For Vega, the Strom *et al.* analysis was based on the high-dispersion plate material of Hunger (1955). For HD 73666, the observed equivalent widths were obtained at the same 10 Å/mm dispersion used for all the Pleiades stars. The abundances obtained for these two normal A stars are remarkably similar; the differences almost never exceeded 0.2 in the log. (Barium is the

Table 4

Abundances Deduced for 10 A Stars

	α Lyr	HD 73666	HD 22615	HD 23194	HD 23387	HD 23607	HD 23631	HD 23924	HD 23964	HD 24368
T_{eff}	9500	9500	8500	8500	9250	7900	9500	8000	10000	9500
log g	4.0	4.0	4	4.0	4.0	4.0	4.0	4.0	4.0	4.0
v_t	3.0	4.0	10.0	9.0	2.5	9.5	4.5	9.5	4.0	5.0
α	1.4	1.0	0.4	0.8	1.2	0.6	0.2	0.9	0.3:	0.5
Log (Element/Fe)										
C	.....	+1.9:	+1.8:	+1.9:	+2.0:	+1.7:	+1.4:<	+1.9:	+1.6:<	+1.5:<
Mg	+0.7	+0.8	+0.7	+1.2>	+0.9	+1.2>	+0.6	1.0	0.3:<	+0.7
Al	-0.8:	-0.5:	-0.7	-0.8:	-1.1:	-1.1:	-0.6:	-1.3:<	-0.6:	-0.4:>
Si	+0.7	+1.0	+0.8	+0.9	+1.0	+0.8	+0.9	+1.1:	+1.1	+1.0
Ca	-0.8:	-1.1	-1.0	-0.8	....	-0.9	-1.5<	-0.8	....	-1.3<
Sc	-3.8	-3.8	-4.2<	-3.5	-3.6	-3.6	-4.3<	-3.5	-4.0:	-3.9
Ti	-2.2	-2.0	-2.0	-2.0	-2.0	-2.1	-2.0	-2.0	-2.2	-2.0
V	-3.1	-3.1	-3.3	-3.1	-3.2	-3.3	-3.3	-2.9	-3.1	-3.0
Cr	-1.2	-1.2	-1.4	-1.3	-1.3	-1.3	-1.2	-1.2	-1.2	-1.3
Mn	-1.3	-1.4	-1.5	-1.3	-1.4	-1.4	-1.5	-1.4	-1.2	-1.5
Ni	....	-1.6:	-1.2:>	-1.5:	-0.8:B>>	-1.5:	-1.2:>	-1.2:	-1.0:>	-1.1:>
Zn	....	....	-2.9	-2.5	-2.4	....	-2.7	-3.1	-2.5	-2.5
Sr	-3.7	-3.5	-3.0>>	-3.5	-3.7	-3.6	-3.2>	-3.9	-3.6	-2.8>>
Y	-4.0	-3.8	-3.3>>	-3.5>	-3.7	-3.7	-3.8	-3.6:>	-3.6>	-3.2>>
Zr	-3.7	-3.5	-3.3>	-3.9	-3.4	-3.7	-3.7	-3.6	-3.3>	-3.0>>
Ba	.....	-3.7:	-3.6:	-3.7:	-3.6B:	-4.0:	-3.3:>	-4.1:<	-3.3:>	-3.2:>
Fe/H	-5.5	-5.3	-5.3	-5.6	-5.7	-5.7	-5.5	-5.7	-5.5	-5.2

Notation

: Determination based on only one line

B Upper limit

\> Abundance increased by 0.3 to 0.6 dex compared to normal A stars

\>> Abundance increased by >0.6 dex compared to normal A stars

< Abundance decreased by 0.3 to 0.6 dex compared to normal A stars

only exception to this otherwise encouraging picture; the Ba II λ4554 line is observed in HD 73666 while it is absent in Vega's spectrum.) We feel that the generally very close agreement of the abundances deduced here from both these normal stars provides us with a solid basis for support of the reality of any abundance anomalies in the Pleiades stars.

We should note, however, that we have made no attempt here to discuss the scale of absolute transition probabilities for each element, but relied instead on defining the abundances of Vega and HD 73666 as "normal." A thorough discussion of the scale and accuracy of absolute transition probabilities is sorely needed but is beyond the scope of this paper.

We consider abundance anomalies significant if they are at least a factor 2 different from the average of Vega and HD 73666. Examination of the abundances listed in Table 4 reveals the following: (1) There is a close agreement between the abundances obtained for the Pleiades stars HD 23194, HD 23387, HD 23607, and HD 23924, and those determined from the two normal A stars. All these stars have measured Sc/Sr ratios within a factor 2 of unity. This result supports the hypothesis that stars showing Sc/Sr ratios near unity are those with normal metal abundances. (2) We find some, but not all, of the following anomalous element/Fe ratios in the four stars having Sc/Sr ≤ 0.5: (*a*) low C, Sc, and Ca; (*b*) enhanced Sr, Y, Zr, and Ba (*s*-process elements); (*c*) enhanced Ni. (3) All the Pleiades stars, except HD 23387, have high microturbulence. (4) The Fe/H ratio is higher for the group of low Sc/Sr stars than it is for the normal stars. The average Fe/H ratio for *all* Pleiades stars is the same as for Vega and HD 73666. It is possible that the normal A stars *may* have slightly lower Fe/H ratios than is the case for Vega, HD 73666, and the Hyades. However, we regard such a conclusion as extremely tentative at this time and we must await the results of analyzing many more Pleiades before the reality of such an effect can be confirmed.

We feel confident in the reality of the abundance anomalies since (*a*) changing T_{eff} by 1000° K, log g by 0.5, and v_t over a wide range fails to change the essential character of the abundance anomalies; (*b*) the abundance ratios for the "normal" A stars are consistent for the Pleiades stars, Vega, and HD 73666.

V. CONCLUSIONS

We have found that in the four Pleiades A stars with the λ4246/λ4215 ratio significantly lower than unity, a detailed model atmosphere analysis reveals that other Am abundance anomalies are found. In addition, these stars all have high turbulence, and at least one is a spectroscopic binary. This would suggest that these are earlier-type analogues of classical Am stars and that the Am phenomenon extends to A0 spectral type.

On the other hand, three of the four Am stars studied here give no firm evidence of duplicity (although only one was studied by Abt *et al.* 1965). Also, three of the four *normal* Pleiades A stars show high turbulence. It is not completely conclusive here, therefore, that these Pleiades stars are Am *by definition*. In any case, they share the *abundance* anomalies of the classical Am stars. As such, their presence in this young cluster containing B stars poses problems of their origin.

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