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Metal abundances of A-type stars in galactic clusters*

II. Pleiades, Coma Berenices, Hyades, and Praesepe

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Abstract. A study of chemical composition for 23 A-type stars in four nearby open clusters (Pleiades, Coma, Hyades and Praesepe) has derived detailed abundances for Mg, Ca, Sc, Cr, Fe, and Ni from high resolution spectroscopy. These results are discussed using the microscopic diffusion model, which yields time-dependent element stratifications as in the case of Am stars. For the Pleiades, the youngest cluster, we find several atypical abundance patterns, which may be transient phases of the Am phenomenon. The members of the older clusters show globally more classical patterns.

Key words: open clusters: Pleiades; Coma; Hyades; Praesepe – stars: abundances; chemically peculiar

1. Introduction

Calcium and scandium are of special interest when one studies A-type stars since these elements are used to discriminate the metallic-lined stars (Am) from the normal ones. Indeed, the Am stars are usually defined through the weakness of their Ca or Sc lines with regard to stars of similar hydrogen line spectral type (see for instance Conti 1970; Preston 1974). These elements are thus deficient with respect to the solar value for Am stars. The microscopic diffusion process is now considered to be the main mechanism for building of these anomalies. There is a good qualitative agreement between the results from the computations of diffusion velocities of metals in Am stars and their observed abundances. Since the stratification process is time-dependent and influenced by the macroscopic motions in the superficial layers of the star, a more thorough understanding of the Am phenomenon requires time-dependent computations and more complex models for the stellar medium. Alecian (1996) has computed the behaviour of Ca and Sc in the superficial layers of A stars without the He convection zone (as suggested in the diffusion model for Am stars). The observable abundances of Ca and Sc depend on parameters such as the mixing layer's extent or the mass-loss rate. Overabundances of calcium and scandium occur shortly after the arrival on the main sequence of these stars (around log(years) ≈ 7), for some combinations of these parameters' values. Thus, the classical classification criteria of Am stars (underabundances of Ca or Sc) is questionable for the youngest of them. Abundance determinations in young main-sequence A stars can constrain such simulations, which should be completely self-consistent and include diffusion (see Richer et al. 1997). Open cluster stars are ideal targets since we know their age (under the assumption that all the stars of a cluster are born at the same time) and they form a homogeneous sample.

There is a poverty of abundance determinations in A-type stars of open clusters (Burkhart & Coupry 1997). Recently, Lithium values have renewed interest in studying open cluster stars. Coma has been treated by Boesgaard (1987), the Hyades by Burkhart & Coupry (1989), and the Pleiades by Burkhart & Coupry (1997). A series of studies focused on the abundances of Ca and Sc began with the work of Hui-Bon-Hoa et al. (1997, hereafter Paper I), which dealt with the stars of α Per, Coma, and Praesepe. This second paper of the series is concerned with the Pleiades, Coma, Hyades, and Praesepe clusters. The ages of these clusters are, respectively, 10^8 years (Meynet et al. 1993), $4.3\ 10^8$, $6.7\ 10^8$, and $7.6\ 10^8$ years (Boesgaard 1989).

2. Observations and reductions

2.1. The sample

The sample comprises 9 stars of the Pleiades, 4 of Coma Ber, 6 of the Hyades, and 4 of Praesepe. These targets were chosen using the same criteria as for Paper I, namely: (i) projected rotational velocities compatible with the determination of the abundances of Ca and Sc in the selected spectral range, and (ii) availability of *uvby* β data to allow precise determinations of

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[*] Based on observations collected at the Observatoire de Haute-Provence (France)

Table 1. Basic data for the programme stars.

Name	Cluster	HD	Sp. type	V mag.	Remarks
HII 5006	Pleiades	22615	A3m: (1)	6.5	non member?, Am (3)
HII 158	Pleiades	23156	A7V (2)	8.23	δ Scuti
HII 232	Pleiades	23194	A5V (2)	8.06	SB, Am? (6)
HII 531	Pleiades	23325	Am (2)	8.58	
HII 717	Pleiades	23387	A1V (2)	7.18	SB
HII 1362	Pleiades	23607	A7V (2)	8.26	δ Scuti, Am (6)
HII 1407	Pleiades	23610	Am (3)	8.13	
HII 1397	Pleiades	23631	A2V (2)	7.26	SB1, Am (7)
HII 2415	Pleiades	23924	A7V (2)	8.1	
Tr 62	Coma Ber	107168	Am (4)	6.3	
Tr 107	Coma Ber	107966	A3V (4)	5.18	Am (6)
Tr 139	Coma Ber	108486	Am (4)	6.75	
Tr 183	Coma Ber	109307	Am (4)	6.29	
63 Tau	Hyades	27749	A1m (1)	5.64	SB1, Am (8)
64 Tau	Hyades	27819	A7V (1)	4.8	
68 Tau	Hyades	27962	A2IV (1)	4.29	SB?, Am (9)
81 Tau	Hyades	28546	A5m (1)	5.5	
HR 1519	Hyades	30210	A2m (1)	5.57	SB?
16 Ori	Hyades	33254	A2m (1)	5.43	SB
KW 534	Praesepe	72942	A4Vvar. (5)	7.48	Am? (6)
KW 40	Praesepe	73174	Am (5)	7.77	SB1
KW 284	Praesepe	73712	A9V (5)	6.78	δ Scuti?
KW 286	Praesepe	73730	F2III (5)	8.02	Var., Am (6)

References: (1) Cowley et al. (1969); (2) Mendoza (1956); (3) Burkhart & Coupry (1997); (4) Mendoza (1963); (5) Bidelman (1956); (6) Renson (1990); (7) Abt & Levato (1978); (8) Roman et al. (1948); (9) Conti et al. (1965).

effective temperatures and surface gravities. Basic information concerning the sample is given in Table 1. The first column gives the HII number (Hertzsprung 1947) for the Pleiades, the Tr number (Trumpler 1938) for Coma, the names of the Hyades stars (except for HD 30210 = HR 1519, Hoffleit 1982), and the KW number (Klein Wassink 1927) for Praesepe.

2.2. Data collection and reduction

The spectra were obtained using the AURELIE spectrograph (Gillet et al. 1994) at the coudé focus of the 152 cm telescope of the Observatoire de Haute-Provence in December 1996. The settings were the same as in Paper I, giving an approximate spectral resolution of 34000 and a linear dispersion of 5 Åmm^{-1}. The spectral interval was 5495–5620 Å (typical spectra from this region are shown in Fig. 1 of Paper I). The detector, a linear diode array Thomson TH 7832 with 2036 13 by 750 μm pixels, was improved in March 1996 to obtain a better stability, in particular for the offsets. The dark current was negligible for the spectra of this run. The integration time varied from 10 minutes to 3 hours. The signal-to-noise ratios are typically around 300. The offset level was measured regularly during each night and we took exposures of a tungsten lamp and of a thorium-argon hollow cathode lamp for the flat-fields and the wavelength calibration, respectively.

The spectra were reduced using codes written by M. Spite (1967, 1996 private communication). Details are provided in Paper I.

The agreement of the equivalent width measurements obtained with the improved detector with previous studies is very good. The comparison of 7 solar lines with the data of Rutten & Van der Zalm (1984) yields

$$\begin{array}{lclcl} W_{\lambda\,(\mathrm{this\ study})} & = & 0.93\,W_{\lambda\,(\mathrm{Rutten})} & + & 2.12 \\ & \pm & 0.11 & \pm & 5.23 \end{array}$$

3. Analysis

3.1. Effective temperature and surface gravity

Effective temperatures and gravities are derived using *uvby* β photometry (Moon & Dworetsky 1985; Moon 1985). The values of effective temperature obtained this way are quite reliable for single stars (Napiwotski et al. 1993). The errors are mostly due to the uncertainties in the photometric measurements and are ±200 K for $T_{\rm eff}$ and 0.14 for log g. The photometric data are from the compilation of Hauck & Mermilliod (1980).

But, van't Veer-Menneret & Mégessier (1996) found lower temperatures in their study of two cool Am stars. They used two independent methods which are in very good agreement with each other. For the star we have in common, HD 27749 (63 Tau), the discrepancy amounts to 380 K. This reduces the

Table 2. Equivalent widths in mÅ for the sample stars (HD numbers).

λ (Å)	Element	22615	23156	23194	23325	23387	23607	23610	23631	23924	107168	107966	108486	109307
5501.47	Fe I	28.5	42.8	23.2	67.4	1.5	46.4	46.7	2.5	49.6	44.7	-	37.3	22.5
5502.09	Cr II	51.1	35.4	23.1	31.6	7.3	35.4	47.8	16.9	41.2	69.2	24.8	34.4	29.2
5506.79	Fe I	46.5	55.3	31.0	58.6	-	62.8	66.9	6.7	67.8	60.6	20.5	50.1	27.8
5508.64	Cr II	-	-	-	-	-	26.1	35.1	14.8	29.1	57.8	-	-	18.7
5512.99	Ca I	16.3	39.7	-	-	-	-	22.8	3.9	41.7	32.3	13.0	-	18.2
5526.82	Sc II	36.6	87.3	59.7	60.7	15.4	86.4	65.9	5.4	88.5	67.2	56.9	23.9	85.8
5528.42	Mg I	122.1	154.1	127.1	144.7	30.7	166.9	139.3	43.1	162.7	171.2	102.9	118.9	120.1
5543.20	Fe I	-	-	-	-	-	31.1	-	-	-	33.9	-	-	-
5543.95	Fe I	-	-	-	-	-	29.1	33.1	-	-	36.9	-	-	-
5554.90	Fe I	36.9	46.7	26.1	-	6.4	51.4	57.6	11.0	54.3	58.4	22.9	44.3	27.8
5560.22	Fe I	9.5	15.3	-	-	-	20.2	17.0	2.8	17.9	19.5	-	13.0	7.7
5569.63	Fe I	64.6	83.5	55.1	93.0	7.6	89.0	94.4	17.3	84.3	94.5	40.3	73.8	47.1
5576.10	Fe I	42.0	60.5	37.3	69.3	-	66.4	66.9	9.0	61.4	68.1	25.3	51.4	31.7
5578.73	Ni I	-	-	-	-	-	4.6	5.9	-	-	8.4	3.1	6.0	3.3
5581.98	Ca I	15.5	42.1	26.9	-	3.7	54.3	20.9	2.5	44.7	42.8	-	12.5	24.6
5586.77	Fe I	109.9	124.0	85.6	-	18.4	134.0	133.3	33.7	126.5	158.5	-	107.4	88.9
5588.77	Ca I	73.2	126.7	-	101.4	14.1	131.4	95.2	9.5	118.8	121.2	51.5	64.1	89.1
5589.37	Ni I	-	-	-	-	6.7	-	6.2	1.9	-	11.2	-	6.9	2.3
5590.13	Ca I	-	27.7	-	34.0	-	49.8	25.8	1.9	-	39.4	-	11.5	23.1
5593.75	Ni I	14.6	20.9	9.7	37.8	6.7	11.4	16.5	3.1	17.5	21.6	7.6	11.7	6.4
5601.29	Ca I	25.1	59.1	33.3	36.3	7.4	61.0	45.2	5.0	61.0	56.8	22.7	25.9	32.0

Table 2. (continued)

λ (Å)	Element	27749	27819	27962	28546	30210	33254	72942	73174	73730
5501.47	Fe I	95.9	35.9	12.2	69.9	53.4	78.5	27.5	45.2	54.1
5502.09	Cr II	83.4	34.9	34.1	54.9	73.0	74.8	29.0	50.8	59.9
5506.79	Fe I	113.4	48.9	-	85.6	-	96.0	-	57.0	73.0
5508.64	Cr II	68.9	-	27.4	43.6	-	59.7	-	41.9	-
5512.99	Ca I	9.6	33.0	7.1	32.2	-	11.2	-	14.0	-
5526.82	Sc II	21.2	102.5	6.2	48.9	$\leq$1.1	8.1	68.9	4.8	5.2
5528.42	Mg I	140.3	148.1	75.6	155.5	159.6	135.8	116.0	133.8	138.4
5543.20	Fe I	65.6	-	-	-	-	45.9	-	29.4	-
5543.95	Fe I	63.9	-	-	-	-	45.9	-	30.9	-
5554.90	Fe I	92.7	33.0	18.8	63.5	53.2	75.2	-	47.3	60.6
5560.22	Fe I	43.7	10.2	-	24.4	12.3	36.5	-	17.2	-
5569.63	Fe I	139.6	-	36.2	110.7	114.3	116.1	63.1	84.7	106.9
5576.10	Fe I	112.6	43.2	21.3	82.9	75.1	91.9	34.9	57.5	76.4
5578.73	Ni I	32.1	-	3.2	17.6	-	28.2	-	8.4	11.5
5581.98	Ca I	11.2	32.9	6.9	36.8	8.8	14.9	12.4	14.3	-
5586.77	Fe I	191.0	-	69.7	155.0	143.2	168.7	-	139.0	163.0
5588.77	Ca I	49.5	-	25.9	112.5	56.4	56.5	50.3	65.9	50.7
5589.37	Ni I	33.4	10.8	2.7	13.1	32.9	30.3	-	12.7	-
5590.13	Ca I	10.3	-	5.1	30.9	-	15.0	-	16.1	-
5593.75	Ni I	52.3	16.9	6.8	30.6	29.8	45.4	20.8	20.0	30.2
5601.29	Ca I	44.1	52.0	9.9	57.8	36.4	39.7	-	25.9	27.7

abundance value derived through neutral atoms by 0.2 dex, the singly ionized ions being almost unchanged. An important part of the reduction of $T_{\rm eff}$ is due to the metallicity of the model used, which amounts to [M/H] = +0.5 dex, a value consistent with the atmospheric metal enrichment in these stars. So, care should be taken in considering abundance values obtained through neutral atoms if this kind of correction were to be applied to all superficially metal-enriched stars over the range of effective temperatures of our sample.

3.2. Abundance determinations

We used mainly the codes of M. Spite (1967, 1996 private communication) for the abundance analysis. The model atmospheres are obtained with Kurucz' ATLAS9 code (Kurucz 1992a, b). We

Table 3. Basic data for the clusters.

Cluster	Age (yr)	Metallicity ([Fe/H])
α Per	$5\,10^7$(1)	$4\,10^{-3} \pm 0.03$ (2)
Pleiades	10^8(1)	-0.03 ± 0.02 (3)
Coma Ber	$4.3\,10^8$(2)	-0.05 ± 0.03 (4)
Hyades	$6.7\,10^8$(2)	0.13 ± 0.02 (3)
Praesepe	$7.6\,10^8$(2)	0.04 ± 0.04 (4)

References: (1) Meynet et al. (1993); (2) Boesgaard (1989); (3) Boesgaard & Friel (1990); (4) Friel & Boesgaard (1992)

adopted the mixing length to pressure scale height ratio to be 1.25 since Michaud (1986) has suggested that this ratio should lie between 1.2 and 1.6 to explain the lithium depletion of the Hyades dwarfs. This also allows us to be more consistent with the results of Paper I for which the model atmospheres were interpolated in the grids. We have not used the overshooting option of ATLAS9, since Castelli et al. (1997) showed that the models computed with this option switched off generally match more observed quantities. For the microturbulent velocity, we choose the value that minimizes the dispersion among the abundance values obtained from the different lines of FeI since different lines of the same element should naturally yield the same abundance in our stars. This method could not be applied to HD 73712 for which we adopt the value given by Fig. 1 of Coupry & Burkhart (1992). Data for the lines considered for the abundance determination are the same as in Paper I.

The equivalent width measurements are shown in Table 2. The fitting method of Cayrel et al. (1985) is used with gaussian profiles for stars with $v \sin i \leq 30$ km/s and rotation profiles for the faster rotators. The lower limit of the values used is equal to the systematic error made on the equivalent width measurements for each star, estimated using the expression of Cayrel (1988). There are no telluric lines in this spectral region (Moore et al. 1966). The FeII line has been discarded from the analysis since it always yields an iron abundance much greater than the mean of the FeI lines. This may be due to the presence of a strong diffuse interstellar band around 5535 Å (Herbig 1995).

4. Results

Table 3 contains the basic data for the clusters studied in this paper and in Paper I.

Our abundance values are given in Table 4 along with parameters for the model atmospheres we used. The solar abundances are those of Grevesse & Noels (1993), namely: Mg, 7.58; Ca, 6.36; Sc, 3.17; Cr, 5.67; Fe, 7.50; Ni, 6.25. The script [X] for any quantity X means $\log(X)_* - \log(X)_\odot$. The dispersion of the values given by different lines is indicated for Ca and Fe when more than two lines are used for the estimate. The $v \sin i$ values are estimates from our data (see Sect. 4.5).

An Am star is usually classified as such as its spectral type given by the CaII-K line is earlier than that derived from the metallic lines, the hydrogen line type lying in-between (Roman et al. 1948). Conti (1970) introduced three groups of Am stars, which are relevant for sorting the stars of our sample: (a) stars with weak Ca (Sc) *and* strong metallic lines; (b) stars with *only* weak Ca (Sc) lines; (c) stars with *only* strong metallic lines. Column 14 of Table 4 indicates group to which an Am star belongs with an indication of weak Ca and/or Sc (for instance Am (a Sc) for an Am star with normal Ca, deficient Sc and enhanced metals). An abundance is considered as normal when its difference with regard to the solar value is less than 0.3 dex. The normal A stars (nl in Table 4) are those which exhibit abundance values within a factor 2 around the solar value (±0.3 dex) for Ca, Sc, and at least two of the elements Cr, Fe, or Ni. Stars that do not belong to the previous groups are denoted “atypical” (atyp in Table 4). HD 23387, the hottest star of our sample, has been classified as Ap (Si Cr) by Abt & Levato (1978) and will be discussed in more details in the next section.

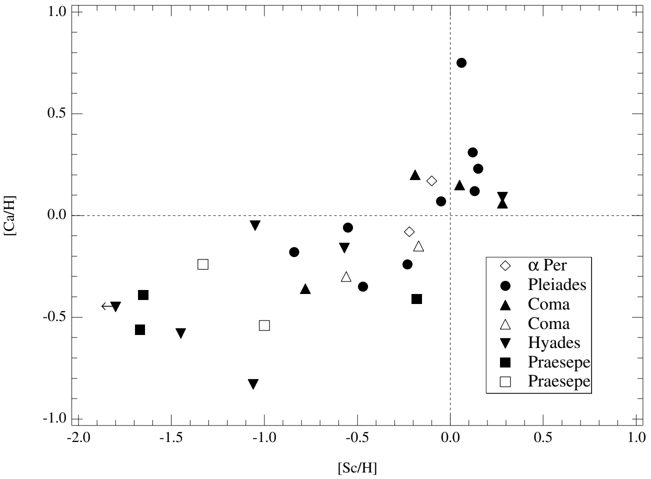

Fig. 1. [Ca/H] vs. [Sc/H] for the programme stars (filled symbols) and for stars of Paper I (open symbols). An arrow means an upper limit for the considered value (here [Sc/H]). The clusters are listed by order of increasing age.

Fig. 1 shows a loose correlation between the abundances of Ca and Sc. As the underabundance of Sc is always more pronounced than that of Ca, the Sc deficiency criterion discriminates more Am stars. This plot looks like Smith’s (1971) Fig. 6, but his slope was steeper. The scatter was also less important. Open symbols refer to the cluster stars studied in Paper I and closed symbols to those of the present one. We obtain the following relationship between these elements

$$\begin{array}{lcccc} [\mathrm{Ca/H}] & = & 0.39\,[\mathrm{Sc/H}] & + & 0.07 \\ & \pm & 0.07 & \pm & 0.06 \end{array}$$

The behaviour of magnesium is noteworthy (see Fig. 2a and 2b). As it is almost normal for the majority of our programme stars, the normal ones as well as the Am, we can see several stars for which this element is clearly overabundant, most of which belonging to the Pleiades. Except HD 107966, these stars, along with those which show a marginal enhancement of Mg, lie in a narrow temperature range, between 8000 and 8500 K. The Pleiades stars showing this peculiarity also have (for most of them) Ca and/or Sc (marginally) overabundant (see Fig. 3a). For the other elements, there is no clear dependence against

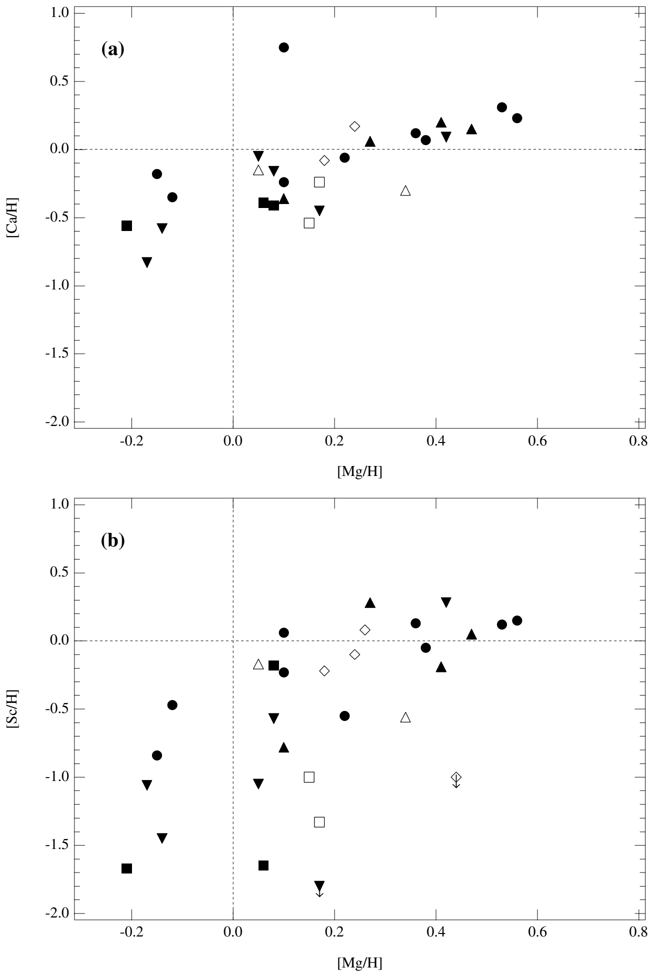

Fig. 2a and b. Same as Fig. 1 for: **a** [Ca/H] vs. [Mg/H] and **b** [Sc/H] vs. [Mg/H].

effective temperature, whatever the cluster. The 4 clusters will be reviewed in order of increasing age.

4.1. The Pleiades

The Pleiades, the youngest cluster of the present work, with an age of 10^8 years (Meynet et al. 1993) has a metallicity, of [Fe/H] = -0.03, which is almost solar (Boesgaard & Friel 1990). Fig. 4a shows the abundance patterns for the stars of this cluster. The sample has been splitted into two parts for sake of clarity and the temperature boundary (8250 K) has been arbitrarily set to yield an equal number of stars in each graph.

HD 22615, the only uncertain member of the Pleiades of our sample (Trumpler 1921), has been classified as Am by Conti & Strom (1968) because of the low Sc/Sr line strength ratio. The Am character is also pointed out by Renson (1990) and by Burkhart & Coupry (1997). Yet, this star is considered to be normal in the refined classification of Gray & Garrison (1989b). The present work shows it is an Am star showing weak Sc and overabundant Cr, Fe, and Ni. Calcium is almost normal. However, this star should be considered carefully since its membership is uncertain.

HD 23156 is a normal star according to Gray & Garrison (1989b) and Burkhart & Coupry (1997). Our results exhibit marginal overabundances of all elements except Mg and Ni which are clearly enhanced. The abundance pattern is thus nearly atypical.

The composition of HD 23194 is almost solar except obvious overabundances for Mg, as already noticed by Conti & Strom (1968), and for Ni. The marginal deficiency of calcium suggested by the spectral type of Abt & Levato (1978), K/H/M = A5/A7V/A7, is not observed. Gray & Garrison (1989b) consider it normal (A5V).

HD 23325 is an Am star of group b (Ca, Sc). Mendoza (1956) considered it as Am: (marginal Am star) and the Am character was confirmed by Abt & Levato (1978) and Burkhart & Coupry (1997).

The hottest star of our sample, HD 23387, appears to be an Ap star of the Cr, Si class (Abt & Levato 1978). Yet, our chromium abundance is normal and only two elements show obvious anomalies: Ca and Ni are in excess. The Si content derived by Conti & Strom (1968) is only slightly enhanced with regard to that of Vega (0.1 dex), their reference for normal A stars, but the abundance analysis of Adelman & Gulliver (1990) shows that Vega is metal-poor (-0.60±0.14 dex for 12 elements). Moreover, the temperature used by Conti & Strom (1968) is by 1000 K less than ours and thus certainly underestimated. Using their equivalent widths, the oscillator strengths of Lanz & Artru (1985) and our atmospheric parameters, we find that Si is marginally underabundant (-0.23 dex). So, the Ap character of HD 23387, at least the belonging to the Cr, Si subclass, seems to be questionable (see also Maitzen & Pavlovski 1987). Could this star could belong to the Hg-Mn group? It does not seem to be so as Mn is almost normal (+0.15 dex using the equivalent widths of Conti & Strom 1968 and the oscillator strengths of Martin et al. 1988), and the abundances of Mg and Ni are out of the range of values for these elements in Hg-Mn stars (see for instance Adelman 1994a). A more complete abundance study is needed to solve the classification problem for this star.

Although labelled A4-F2m in the catalog of Renson (1990), we find that HD 23607 is atypical. There is a general trend towards overabundances for all elements; Mg, Ca, and Fe are clearly in excess. Its pattern is similar to that of HD 23156 but with more enhanced anomalies.

HD 23610 is considered here as a normal star. Yet, its abundance pattern looks like that of a marginal Am with deficient Ca and Sc, and enhanced Cr, Fe, and Ni (see also Burkhart & Coupry 1997).

Abt & Levato (1978) considered HD 23631 as Am. According to our results, it is an Am of group b (Sc). The Ca abundance we obtain is slightly less than the solar value, in agreement with Burkhart & Coupry (1997).

We have classified HD 23924 as Am (c) according the enhancement of Fe and Ni. However, the marginal excesses of Ca and Sc make this pattern nearly atypical. The Mg abundance value is the highest observed for this cluster.

Different kinds of stars populate this cluster. One is almost normal, four are (marginally) Am (HD 22615 is excluded from

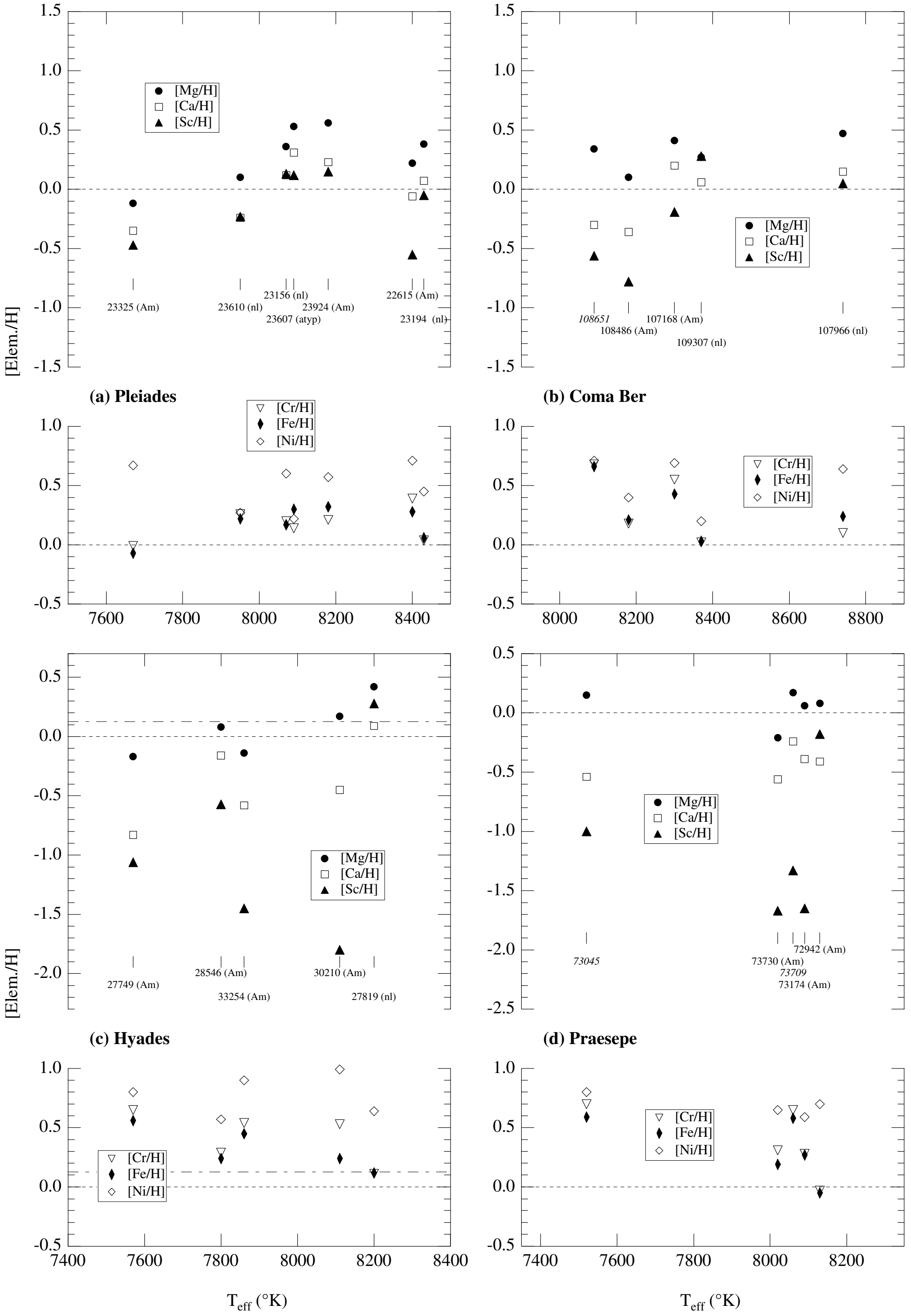

Fig. 3a–d. Abundances against effective temperature in the range 7500–9000 K for the stars of: **a** the Pleiades; **b** Coma; **c** the Hyades; **d** Praesepe (HD numbers followed by the type according to Table 4). Stars of Paper I are included (numbers in italics). The horizontal dash-dotted line in the Hyades plot shows the metallicity of this cluster.

this discussion) and three (marginally) atypical, HD 23387 being apart. Due to its particuliar pattern, HD 23924 is counted twice. The patterns of the atypical stars are very alike (see Fig. 4a). Their effective temperatures lie in a very narrow interval (between 8070 and 8180 K). Can this abnormality be related to the δ Scuti character presented by two of these stars? HD 23924 shows no detectable variability at this time. Concerning the Am stars, the situation is less homogeneous. However, the coolest members have relatively similar pattern whereas the hot Am stars exhibit more pronounced anomalies. Burkhart & Coupry (1997) noticed an iron enhancement for normal as well as Am stars, which is partly confirmed since 6 out of the 8 Pleiades members of our sample show a Fe content greater than solar, ranging from +0.15 dex to +0.32 dex.

In Paper I, we suspected the existence of atypical patterns in the young cluster α Per. Here we confirm that such anomalous patterns can actually occur for young cluster stars.

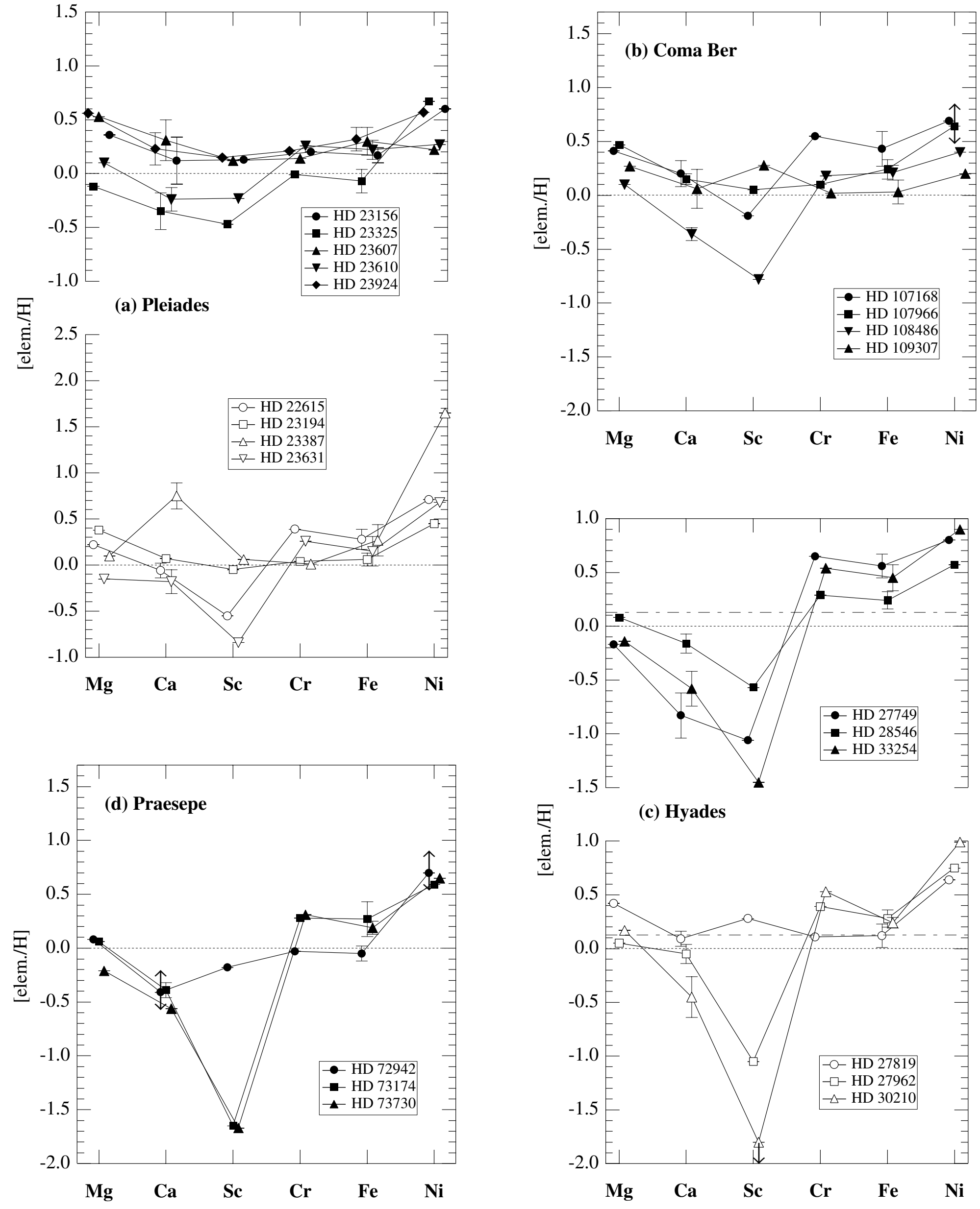

Fig. 4a–d. Abundance patterns for the stars of: **a** the Pleiades; **b** Coma; **c** the Hyades; **d** Praesepe. An arrow means upper limit and error bars ended by arrows denote very uncertain values. The metallicity of the Hyades is indicated by a dash-dotted line.

4.2. Coma

The metallicity of Coma is slightly below the solar value according to Friel & Boesgaard (1992) with a mean [Fe/H] of -0.05 dex. The patterns of Coma are shown in Fig. 4b.

HD 107168 (8 Com) has enhanced Mg, Cr, Fe, and Ni, slightly overabundant Ca and a slight deficiency of Sc. Thus this star is an Am of group c. Weaver (1952) classified it as A4ML3, denoting a strong metallic-line character, which was also observed by Barry (1970), who noticed that the K line was not weak. From the spectral type of Gray & Garrison (1989b), kA5hA5mF0 (III), the content of Ca should be nearly normal with respect to the hydrogen line type and metals enhanced. However, Abt & Levato (1977) found that the K-line spectral type was three subclasses earlier than the hydrogen line spectral type. But this last spectral type neither matches determinations from other authors nor the effective temperature we have estimated. Boesgaard (1987) obtained a slightly deficient value for Ca. Still, with her equivalent width for CaI λ 6717.69 (the line she used for the calcium abundance determination) and the oscillator strength of Smith & Raggett (1981), we obtain an abundance value for Ca (0.32 dex) much more in agreement with our determination. Yet, this value should be considered as an upper limit because of severe blending with a FeI line as stressed by Burkhart & Coupry (1989). An overabundance of calcium has already been suggested by Henry (1969) and by Smith (1971). Moreover, from Δa-photometry (Maitzen 1976), Maitzen & Pavlovski (1987) concluded that this star could be related to the CP-2 group (Ap stars). Still, the problems raised by the classification of this star cannot be solved yet.

Table 4. Abundance values for the programme stars. The row in italics denotes the uncertain membership of HD 22615.

Name	HD	Remarks	$v \sin i$ (km/s)	$T_{\rm eff}$ (K)	log g	$V_{\rm t}$ (km/s)	[Mg/H]	[Ca/H]	[Sc/H]	[Cr/H]	[Fe/H]	[Ni/H]	Type
HII 5006	*22615*	*non member ?, Am (1)*	*30*	*8400*	*3.80*	*2.5*	*0.22*	*-0.06* *(±0.08)*	*-0.55*	*0.39*	*0.28* *(±0.11)*	*0.71*	*Am (a Sc)*
HII 158	23156	δ Scuti	32	8070	4.4	2.5	0.36	0.12 (±0.22)	0.13	0.20	0.17 (±0.07)	0.60	nl
HII 232	23194	SB, Am ? (2)	37	8430	4.4	2.0	0.38	0.07	-0.05	0.04	0.06 (±0.07)	0.45	nl
HII 531	23325	Am (3)	70	7670	4.3	3.0	-0.12	-0.35 (±0.17)	-0.47	-0.01	-0.07 (±0.11)	0.67	Am (b Ca, Sc)
HII 717	23387	SB	21	10210	4.3	0.0	0.10	0.75 (±0.14)	0.06	0.01	0.27 (±0.17)	1.65	atyp
HII 1362	23607	δ Scuti, Am (2)	22	8090	4.4	2.5	0.53	0.31 (±0.19)	0.12	0.14	0.30 (±0.13)	0.22	atyp
HII 1407	23610	Am (1)	28	7950	4.3	2.5	0.10	-0.24 (±0.11)	-0.23	0.26	0.22 (±0.09)	0.27	nl
HII 1397	23631	SB1, Am (4)	≤10	9460	4.4	0.0	-0.15	-0.18 (±0.13)	-0.84	0.26	0.15 (±0.16)	0.68	Am (b Sc)
HII 2415	23924		33	8180	4.3	2.5	0.56	0.23 (±0.15)	0.15	0.21	0.32 (±0.11)	0.57	Am (c)
Tr 62	107168	Am (5)	16	8300	4.2	3.5	0.41	0.20 (±0.12)	-0.19	0.55	0.43 (±0.16)	0.69	Am (c)
Tr 107	107966	Am (2)	50	8740	3.8	1.5	0.47	0.15 (±0.05)	0.05	0.10	0.24 (±0.09)	0.64	nl
Tr 139	108486	Am (5)	37	8180	4.2	2.0	0.10	-0.36 (±0.06)	-0.78	0.18	0.21 (±0.07)	0.40	Am (b Ca, Sc)
Tr 183	109307	Am (5)	17	8370	4.1	2.0	0.27	0.06 (±0.18)	0.28	0.02	0.03 (±0.11)	0.20	nl
63 Tau	27749	SB1, Am (6)	16	7570	4.3	2.8	-0.17	-0.83 (±0.21)	-1.06	0.65	0.56 (±0.11)	0.80	Am (a Ca, Sc)
64 Tau	27819		45	8200	4.0	2.5	0.42	0.09 (±0.07)	0.28	0.11	0.12 (±0.11)	0.64	nl
68 Tau	27962	SB?, Am (7)	11	9030	4.1	2.0	0.05	-0.05 (±0.09)	-1.05	0.39	0.28 (±0.08)	0.75	Am (a Sc)
81 Tau	28546	A5m (8)	28	7800	4.3	3.0	0.08	-0.16 (±0.09)	-0.57	0.29	0.24 (±0.08)	0.57	Am (b Sc)
HR 1519	30210	A2m (8), SB?	55	8110	4.0	3.5	0.17	-0.45 (±0.19)	≤-1.80	0.53	0.24 (±0.05)	0.99	Am (a Ca, Sc)
16 Ori	33254	A2m (8), SB	16	7860	4.2	3.0	-0.14	-0.58 (±0.16)	-1.45	0.54	0.45 (±0.12)	0.90	Am (a Ca, Sc)
KW 534	72942	Am ? (2)	70	8130	3.8	2.0	0.08	-0.41	-0.18	-0.03	-0.05 (±0.07)	0.70	Am (b Ca)
KW 40	73174	Am (9), SB1	≤10	8090	4.0	2.8	0.06	-0.39 (±0.07)	-1.65	0.28	0.27 (±0.16)	0.59	Am (b Ca, Sc)
KW 284	73712	δ Scuti ?	180	7270	3.4	3.0	-	-	-	-	-	-	-
KW 286	73730	Var., Am (2)	32	8020	3.9	4.0	-0.21	-0.56	-1.67	0.31	0.19 (±0.06)	0.65	Am (a Ca, Sc)

References: (1) Burkhart & Coupry (1997); (2) Renson (1990); (3) Mendoza (1956); (4) Abt & Levato (1978); (5) Mendoza (1963); (6) Roman et al. (1948); (7) Conti et al. (1965); (8) Cowley et al. (1969); (9) Bidelman (1956)

Except for Mg and Ni, which are clearly overabundant, the composition of HD 107966 (13 Com) is almost normal. As for the previous star, it shows a strong excess of Mg. We can notice a slight overabundance of Ca. The statement of Renson (1990) that this star is an Am is not confirmed.

HD 108486 belongs to the Am b (Ca, Sc) subgroup. Our deficiency in Ca is less pronounced than Boesgaard's (1987) with -0.36 dex instead of -0.65. Yet, as we did for HD 107168, the use of her equivalent width for the Ca line yields a value in very good agreement with ours. On another hand, the iron content is very similar. The other elements are slightly enhanced.

HD 109307 (22 Com) is of special interest. Its pattern is almost atypical according to the overabundance of scandium. Indeed, this peculiarity has already been noticed (Smith 1971; Cowley 1981). Moreover, we find that the calcium content is normal. Boesgaard (1987) derived a marginal underabundance for Ca (-0.11 dex) but, as for the previous stars we have in common, we obtain a value through Ca I λ 6717.69 which is in very good agreement (0.06 dex) with that of our Ca lines. Therefore the classification as Am by several authors (Weaver 1952; Renson 1990) is somewhat surprising. The abundances of the iron peak elements have been questioned by Cowley (1981) who did not observe the enhancement reported by Smith (1971). The values we obtain are nearly normal.

Our results indicate only one definite Am star in our sample of Coma cluster stars, namely HD 108486. The pattern of this star is quite different from that of HD 108651 (Paper I) which is only by 90 K cooler and has almost the same surface gravity. These differences may thus arise from other atmospheric parameters and/or from a different rotational velocity.

4.3. The Hyades

This cluster has often been studied along with the previous one owing to similarities in their ages and H-R diagrams. Still, its metallicity is much greater with [Fe/H] = 0.13 (Boesgaard &

Friel 1990). The patterns for the Hyades stars are presented in Fig. 4c. Again, the sample has been divided for clarity.

HD 27749 (63 Tau) is a well-known Am star (of group a (Ca, Sc)), already considered as a standard for spectral classification by Roman et al. (1948). Burkhart & Coupry (1989) obtained a slightly higher abundance for calcium than ours but, as already mentioned, the value derived through Ca I λ 6717.69 must be considered as an upper limit.

The situation for HD 27819 (64 Tau) is less clear. Conti et al. (1965) showed that this star was normal, apart from a marginal underabundance of Ca. Our overabundance of scandium indicates it is nearly atypical. Its pattern looks like that of HD 109307. This is even more amazing when one sets the zero point of the abundance scale according to the enhancement of iron in the Hyades, assuming that the other elements are enriched by the same amount.

The hottest Hyades star, HD 27962 (68 Tau), is a blue straggler, located above the cluster turn-off point in the H-R diagram (see Fig. 1 of Conti et al. 1965, who found it Am). Our results show a strong deficiency of scandium and enhanced iron peak elements. Mg and Ca are normal. This latter element has also been found normal by Smith (1971) and Burkhart & Coupry (1989). This justifies its classification as Am a (Sc). There is an excellent agreement with the results of Adelman (1994b).

The classification of HD 28546 (81 Tau) used to be controversial (see Conti 1965). However, it has been often regarded as Am (Smith 1971; Burkhart & Coupry 1989). In this last paper, Ca is marginally deficient and Fe mildly enhanced. This agrees with our results. The Am character is stated through the Sc underabundance. The iron peak elements are all enhanced but only Ni shows an excess of more than 0.3 dex.

HD 30210 (HR 1519) is another standard Am star of Roman et al. (1948). We observe a typical Am star (a (Ca, Sc)) pattern with underabundant Ca and Sc and (mildly) enhanced iron peak elements. The scandium abundance value is an upper limit (denoted by the downward arrow) since we could not observe the line in our spectrum.

Another Am standard is in our sample, HD 33254 (16 Ori). As for the previous star, it shows typical anomalies for an Am star.

The close link between the Am a (Ca, Sc) subgroup and the standard stars of Roman et al. (1948) is not surprising since this class is that of the "classical" Am stars. The classification of Gray & Garrison (1987, 1989a, b) is also well-correlated with this subgroup. Moreover, almost all the Am stars of the Hyades we studied are of subgroup a. This would mean that the enhancement of the iron peak elements is more important than for the younger clusters but if we take the Fe enrichment of this cluster into account, two stars are in subgroup b. This illustrates the problem of the zero point abundance value.

4.4. Praesepe

The metallicity of this cluster is slightly enhanced with [Fe/H] = 0.04 (Friel & Boesgaard 1992). The patterns for the Praesepe stars are presented in Fig. 4d.

HD 72942 appears to be an Am star. It exhibits a strong underabundance of Ca and a milder one for Sc. This is to be related to the Am character of Renson (1990).

The Am character of HD 73174 has already been stated by Bidelman (1956). We classified it in group b (Ca, Sc) but its pattern is very close to that of group a (Ca, Sc) since Cr, Fe, and Ni are enhanced.

We have included HD 73712 in our sample because Uesugi & Fukuda (1970) give 55 km/s and Bernacca & Perinotto (1970) 20 km/s for its rotational velocity. Only Treanor (1960) had suggested that the rotational velocity was high (200:). Also, several authors have remarked that the spectral lines of this star were nebulous (Abt 1986; Gray & Garrison 1989a). We find $v \sin i$ is around 180 km/s. Thus we could only estimate the content of Mg and Sc through spectrum synthesis method. The values seem normal but are very uncertain.

With clearly deficient Ca and Sc and enhanced Cr, Fe, and Ni, HD 73730 is a classical Am of group a (Ca, Sc). Kocer et al. (1988) have also performed a spectroscopic study. Except Cr, abundance values for the other elements in common show strong differences. The trend of some anomalies can even be reversed as they find Fe and Ni underabundant. These discrepancies can be explained neither by the differences in the parameters for the model atmosphere they used nor the use of an ATLAS6 model (Kurucz 1979) instead of ATLAS9. Using their data (equivalent widths, oscillator strengths) and atmospheric parameters, we obtain quite different abundance values. For instance, Ca, Sc, Fe, and Ni are almost normal whereas Mg and Cr are clearly overabundant. Besides, there seems to be systematic discrepancies in the equivalent width measurements since the abundance patterns are different between their study and the present one whatever the set of atmospheric parameters used.

The abundance patterns of the Am stars in the present work and in Paper I are remarkably close to each other. This is particularly striking when we consider HD 73174, HD 73709, and HD 73730, which share almost the same temperature. Thus, the Am stars of Praesepe we observed form a very homogeneous group.

4.5. The projected equatorial velocities

As a by-product of our analyses, we consistently estimated the $v \sin i$ of our stars by synthesizing Fe I lines. Values of (projected) rotational velocities are often poorly known and the available data generally come from various sources. The instrumental profile is assumed to be gaussian and its width is 0.13 Å (FWHM). No macroturbulence is introduced. The uncertainties range from 1 km/s for small $v \sin i$ (around 20 km/s) up to 5 km/s for $v \sin i$ = 70 km/s. For HD 73712, the iron lines cannot be used and the rotational velocity is estimated through the Sc-Mg blend.

5. Discussion

As in Paper I, we discuss our results in the framework of the diffusion process utilizing radiative accelerations and simulations performed by Alecian (1996) and Richer et al. (1997). We will mainly stress on the new results. Since the abundances of stars of Paper I have been determined the same way as in the present work, they are included in Fig. 1 to 3 to increase the sample with homogeneous data.

The stars of our sample have sufficiently low *v* sin *i* values ($\leq$70 km/s) to permit abundance determinations and are objects with spectral types corresponding to the Am star temperature range. To see possible transient phases of the Am phenomenon, especially in the youngest clusters, all the cluster stars matching these criteria were retained, regardless of their detailed classification. However, as seen in Table 4, there are many more peculiar stars in our sample than the ratio found through spectral classification (see for instance Abt 1979). This is undoubtedly due to the observational fact that Am stars are slow rotators and then the *v* sin *i* criterion introduces a bias.

The correlation in Fig. 1 between Ca and Sc confirms that their abundances are affected by the same physical process, which is consistent with the radiative accelerations calculated by Alecian (1996): calcium and scandium are not (or are weakly) supported by the radiation field just below the superficial convection zone for Am stars, but both are more or less supported in deeper layers. According to time-dependent calculations by the same author, both might be slightly overabundant for young stars (the detailed evolution depending on the thickness of the mixing zone and the mass-loss rate) and Ca must be underabundant in all cases for old Am stars. The theoretical computations suggest that Sc should be underabundant only for some values of the thickness of the mixing zone and mass-loss rate. According to our abundance determinations, as shown in Fig. 1, the stars presenting weak underabundances or slight overabundances (right part of the plot) are rather found in the Pleiades and α Per clusters (the youngest targets of this work), while stars with the strongest underabundances (left part of the plot) are old stars (in Hyades and Praesepe). As stressed by Alecian (1996), the radiative acceleration of Sc is presently less accurate than that of Ca (because of a lack of accurate atomic data for scandium), and we need a more precise theoretical study of this element to go further in the discussion.

The situation is less clear for magnesium for which a correlation with respect to Ca and/or Sc cannot be excluded from Fig. 2. According to computations by Richer et al. (1997), Mg is not supported just below the convection zone of stars with $T_{\rm eff}$ around 10000 K (it is supported deeper in the star, more than Ca and Sc). This suggests that systematic underabundances of this element might be predicted, at least in hot young Am stars, and some correlation of Mg with Ca and Sc might be observed for young stars. This is in agreement with the loose correlations in Fig. 2. No detailed computation is available for this element in Am stars.

In Fig. 3, an interesting correlation seems to appear in the Pleiades (Fig. 3a) for some elements (Mg, Ca, Sc) versus temperature: there is a quasi-systematic underabundance for $T_{\rm eff}$ smaller than 8000 K, and a bump around 8200 K. We suspect also another correlation (different from that of the Pleiades) in the Hyades (Fig. 3c): a bump around 7700 K and a hole around 8100K. We have enough stars in our sample to consider that these behaviours are significant. We have not found any bias in our abundance determination to explain these correlations. Such an effect, if real, may be interpreted as due to the position of the bottom of the superficial mixing zone, which is very sensitive to the effective temperature (its depth decreases when $T_{\rm eff}$ increases). That the correlation appears mostly for Pleiades, the youngest cluster, cannot be explained safely in view of existing theoretical computations. We can only speculate on the transient nature of these abundances, and assert their compatibility (at least for Ca and Sc) with existing computations. Moreover, temperature is not the only parameter that can affect the thickness of the mixing zone: other physical processes can alter the structure of the superficial layers (like rotation for instance), and then the building up of the anomalies. This could account for the differences between stars of similar effective temperatures. At this time the effects of these other mechanisms are poorly known and observational data are lacking.

To analyze abundance evolution in A stars, or presumably Am stars, in each cluster, we use the abundance pattern plots shown in Fig. 4. As stressed in Paper I, some Am stars show a very typical pattern such as HD 73174 or HD 73730 in Praesepe, and stand out easily from these plots. This pattern looks like a large "square root" symbol in the figures. One remarkable result of the abundance determinations in our sample, is that the older is the cluster (Hyades and Praesepe), the more frequent the typical Am pattern is encountered. In the youngest cluster (Pleiades), the Am pattern is almost absent despite the relatively large number of stars studied, except for two stars which have actually a peculiar status compared to the others: HD 22615 (for which the membership to the cluster is doubtful), HD 23631 which is probably a hot Am star. One star has also a peculiar pattern: HD 23387 which is suspected to be a cool Ap star. The lack of typical Am pattern is very noticeable for the coolest stars of the Pleiades (upper series of Fig. 4a), while the patterns are more emphasized for hotter ones and this may be understood in the framework of the time-dependent diffusion model. According to the calculations of Alecian (1996), the age of the Pleiades is comparable with the time scale of appearance of the first phases of the Am phenomenon based on Ca and Sc abundances. On another hand, this time scale is shorter for hotter stars since their convection zone is thinner and this is in accordance with the more emphasized patterns of hot stars in Fig. 4a. Therefore, we tend to confirm that Am stars in clusters as young as the Pleiades (about 10^8 years old) might be in a transient phase of the building up of element stratifications.

The small overabundances found for Ca in some Pleiades stars are not strong enough to confirm the phase of overabundance predicted by the Alecian (1996). Either this cluster is not young enough and has passed the predicted phase of overabundance, or the mixing depth and mass-loss rate are such that this phase does not exist. In this last case, and in view of our measures, we may infer that the extension of the convection zone is smaller than one pressure scale height and the mass-loss rate is close to 10^{-14} solar mass per year.

This quantitative prediction, as well as the correlation with respect to $T_{\rm eff}$ (Fig. 3) pointed out previously, are far from being definite since much more accurate time-dependent computations (including evolutionary effects such as the ones started by Richer et al. 1997), and many more studies of young clusters are needed to draw any firm conclusion.

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