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Rapidly oscillating Ap stars versus non-oscillating Ap stars

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Abstract. The positions in the HR diagram and the kinematic characteristics of rapidly oscillating and non-oscillating chemically peculiar stars are obtained using new Hipparcos proper motions and parallaxes, and our own radial velocity measurements. We find that rapidly oscillating stars, as a group, are (-0.47 ± 0.34) mag above the zero-age main sequence (ZAMS), while the non-oscillating stars are (-1.20 ± 0.65) mag above the ZAMS and so appear slightly more evolved on average. From the comparison of the kinematical characteristics, we conclude that both groups are very similar. The results of radial velocity measurements indicate that there is a real deficiency of binaries among rapidly oscillating stars. Presently, no such star is known to be a spectroscopic binary.

Key words: stars: binaries: general – stars: chemically peculiar – stars: kinematics – stars: oscillations

1. Introduction

Rapidly oscillating Ap (roAp) stars are cool magnetic Ap SrCrEu stars which pulsate in high-overtone ($n \gg l$), low-degree ($\ell \leq 3$) p-modes with periods from 6 to 15 min and typical amplitudes of a few mmag. 31 such stars are currently known (Kurtz & Martinez 1993, 1994, 1995; Martinez et al. 1998; Handler & Paunzen 1999). Detailed reviews about roAp stars have been published by Kurtz (1990), Matthews (1991) and Martinez & Kurtz (1995a).

Determinations of asteroseismological luminosities (Kurtz & Martinez 1993; Martinez 1993; Matthews et al. 1999) suggest that roAp stars lie within the instability strip where the δ Scuti pulsating variables are found. This leads to the suspicion that the κ-mechanism operating on He II in the He II ionization zone is driving the pulsation.

Rapidly oscillating Ap stars are ideal targets for application of the techniques of asteroseismology. By comparing the observed frequency spectrum to the asymptotic pulsation theory, it is possible to specify their rotation periods, their temperatures, luminosities, radii, masses, their atmospheric structures, their evolutionary statuses, and geometries of their magnetic fields.

In terms of the Strömgren photometric indices, the currently observed limits of the roAp phenomenon are (Martinez 1993):

$$2.69 \leq \beta \leq 2.88\,, \quad (1)$$

$$0.08 \leq b-y \leq 0.31\,, \quad (2)$$

$$0.19 \leq m_1 \leq 0.33\,, \quad (3)$$

$$-0.12 \leq \delta m_1 \leq 0.02\,, \quad (4)$$

$$0.46 \leq c_1 \leq 0.88\,, \quad (5)$$

$$-0.31 \leq \delta c_1 \leq 0.04\,. \quad (6)$$

In terms of the dereddened parameters, the limits are:

$$0.22 \leq m_1 \leq 0.36\,, \quad (7)$$

$$0.40 \leq c_1 \leq 0.87\,, \quad (8)$$

$$0.98 \leq [u-b] \leq 1.34\,. \quad (9)$$

However, photometric indices in those ranges are not an unambiguous indicator of the roAp phenomenon. Other Ap stars co-exist in the same region of the parameter space, in which no pulsation could be detected, despite sometimes thorough searches (Martinez & Kurtz 1994).

Recent studies (e.g., Nelson & Kreidl 1993; Martinez 1993; Kupka et al. 1994; Kupka et al. 1996; Mathys 1993, 1994; Mathys et al. 1997; Mathys & Hubrig 1997) show that these Ap stars for which null results of searches for pulsations were reported (hereafter non-oscillating Ap stars, or noAp stars), are remarkably similar to the roAp stars in many respects (e.g. colour indices, abundances, magnetic fields). The first hint of a difference between the two groups was recently found through a study of their kinematical properties (Mathys et al. 1996, hereafter Paper I), based on proper motions taken from the Positions and Proper Motions Star Catalogue (PPM) (Röser & Bastian 1991; Bastian & Röser 1993) and measurements of radial velocities. It unveiled the existence of significant kinematical differences between roAp and noAp stars, suggesting that roAp stars are older than their non-pulsating counterparts. However, the conclusions drawn in that work were limited by the accuracy of the available astrometric data. In this paper we present the kinematical properties for roAp and noAp stars which we have determined by

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using new Hipparcos proper motions and Hipparcos parallaxes and our own radial velocity measurements.

The reader should keep in mind that we call “noAp stars” those stars in which no oscillations have been detected so far above a certain threshold (which typically differs from star to star), but that one cannot rule out that pulsations may be discovered in some of them in the future. Statistically speaking, though, noAp stars truly represent a group where pulsations have very small amplitudes, if they exist at all.

2. Kinematical properties

Of the 31 roAp stars known, 16 stars were observed by Hipparcos. As noAp we have selected all the Ap stars

- in which oscillations have been sought and have not been detected (Martinez & Kurtz 1994),
- whose photometric indices in the Strömgren system lie within the limits of occurrence of the roAp phenomenon (as defined by Martinez 1993),
- and for which Hipparcos data exist.

In relation with the second of those conditions, the photometric parameters were retrieved from Martinez (1993) or from the General Catalogue of Ap and Am stars (Renson et al. 1991). In the latter case, the indices were dereddened using the code of Moon & Dworetsky (1985). Martinez gives both the raw and dereddened indices. With respect to Paper I, the sample of noAp stars is larger in this study and consists now of 30 stars.

After completion of our study described in Paper I, we came to realize from the consideration of the data used in it that presently, none of the roAp stars is known to be a spectroscopic binary (SB) although several are members of wide, visual binary systems. We obtained at least two measurements of the radial velocity of 14 of the 31 roAp stars, but we found no evidence for variation in any of these stars. For the stars HD 134214, γ Equ (= HD 201601) and HD 137949, we have acquired respectively 34, 32 and 19 radial velocity measurements during the years 1989–1998. No long-term variations larger than the observational errors were found. Of the remaining 17 roAp stars, we have observed 15 only once and 2 have not been observed at all.

For the star γ Equ, radial velocity changes were reported by Scholz et al. (1997), but they were not confirmed by the observations at the same epoch by Mkrtichian et al. (1998). We have also obtained one measurement of the radial velocity around the same epoch (at HJD 2450345.728): it gives $V_{\rm r} = -17.0\,{\rm km\,s^{-1}}$, in full agreement with the radial velocity determined by Mkrtichian et al. (1998).

In this context, it is interesting to mention the gradual pulsation frequency changes found in in roAp stars by Martinez & Kurtz (1995b). At present 8 roAp stars exhibit such variations: HD 12932, HD 24712, HD 83368, HD 101065, HD 128898, HD 134214, HD 137949 and HD 217522. For 6 of 8 stars we have obtained at least two radial velocity measurements. Since we do not find radial velocity variations for any of these stars, it seems likely that the frequency variations are intrinsic to these stars. For HD 83368 the variations can be characterized as cyclic with a time-scale of 1.6 years. These variations cannot be easily explained as Doppler shifts caused by companions because many companions would need to be hypothesised (Kurtz 1998). Martinez & Kurtz (1995a) suggest that frequency variability indicates a magnetic cycle. Therefore, these frequency changes are compatible with roAp stars being single.

That until now, no roAp star is known to be a spectroscopic binary, is in direct contrast to the situation for noAp stars, in which a large fraction, specifically one third of stars in our sample, are SB systems, and for other types of pulsating variables (e.g., β Cep stars, δ Sct stars, or classical cepheids), which are frequently found in SB systems. Radial velocity data are scarce for noAp stars, due to the combination of their relative faintness (many have magnitudes between 8 and 10) and of the southern declination of most of them. However, all the noAp stars for which enough information is available, that is, 10 stars with radial velocity repeatedly measured, either are SBs or show hints of binarity. Since of these 10 stars, 8 stars possess well determined magnetic fields and the two remaining stars are typical Ap stars showing in their spectra anomalous strong lines of the elements Sr, Cr and Eu, we can exclude the possibility that binary noAp stars could be actually mis-classified Am stars (a class in which the majority of stars belong to binary systems). Three noAp stars have been observed only once by us and no radial velocity measurements exist for the remaining 17 noAp stars. This rather high frequency of binaries may appear surprising in view of the often quoted result of Abt & Snowden (1973) who had found only 20% binaries among all magnetic Bp-Ap stars. However Gerbaldi et al. (1985) found as many as 47% binaries among cool Ap stars – including, though, variable RV as a criterion, while it betrays sometimes only spots and rotation – and a long-term CORAVEL survey yielded 27% definite binaries (North et al. 1998) in magnetic Ap stars spanning a wider range of effective temperatures (7000-10000 K) than roAp stars. Mathys et al. (1997) found 18 binaries among 41 Ap stars (44%) with resolved Zeeman patterns, some of them with very long periods.[1] Therefore, the frequency of binaries among Ap stars seems higher than previously thought, especially when one takes into account the long period systems.

The present finding of a difference in duplicity between the group of roAp stars and the group of noAp stars raises the question whether the kinematical characteristics of field binaries generally differ from those of single stars. Unfortunately, there is no clear answer to this question. In particular, Gliese (1956) reported that the space velocities of nearby single and double stars are not strongly different. However, his study is not representative for the stars of spectral type A. Among 18 stars in the solar neighbourhood of spectral type A to F, only two stars are binary systems.

To take into account possible differences in kinematical characteristics between single and binary stars, we compared the sample of the roAp stars with the subsample of noAp stars con-

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[1] This binary fraction is even more remarkable in the present context considering that 6 of the non-binary stars from Mathys et al.'s study are roAp stars.

Table 1. Number of stars in the various samples and corresponding stellar data

Set	Stellar data	roAp	noAp	single noAp	binary noAp
(1)	Radial velocities and PPM proper motions	27	13		
(2)	PPM proper motions	28	65	52	13
(3)	Hipparcos proper motions and parallaxes	14	30	20	10
(4)	Radial velocities and Hipparcos proper motions and parallaxes	14	11	3	8

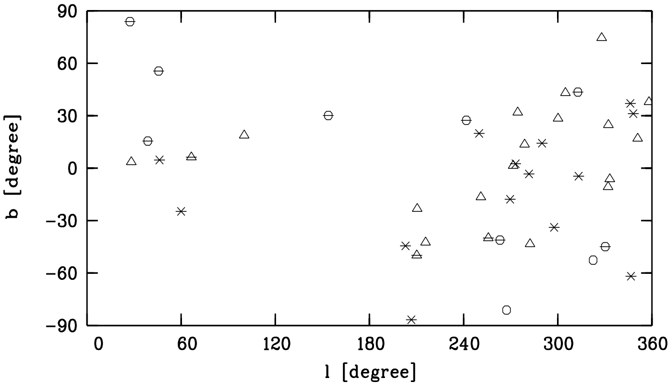

Fig. 1. Distribution of the stars of set 3 in the Galactic (l, b) coordinate system. The crosses, triangles and open circles correspond to the rapidly oscillating Ap stars, the non-pulsating single Ap stars, and the non-pulsating double Ap stars, respectively. The stars with known radial velocities are identified by a horizontal bar across the corresponding symbol

taining only recognized binaries (hereafter binary noAp stars) with the subsample of noAp stars for which no radial velocity study has been done until now (single noAp stars). Kinematical properties of noAp stars as a whole group were computed, too.

For the present kinematical study, we considered four different star samples, defined by the type of information available:

1. the sample studied in Paper I, for which PPM proper motions and radial velocities are available;
2. a set for which only PPM proper motions are considered;
3. one for which we have Hipparcos proper motions and parallaxes;
4. and a subsample of the latter, for which radial velocity measurements have been obtained.

The stellar contents of these four sets are summarized in Table 1.

The results of the kinematical study of set 1 have been reported in Paper I.

The positions in galactic (l, b) coordinates of the stars of set 3 are shown in Fig. 1.

Basic data for the stars of set 3 appear in Table 2: Hipparcos and HD numbers, apparent visual magnitude V, right ascension and declination (α_{2000} and δ_{2000}), Hipparcos parallax, Hipparcos proper motions with their mean errors and radial velocity (V_r). The uncertainties quoted for radial velocities correspond to internal errors, but they should be fairly representative of the actual measurement accuracy. In the subset of binary noAp stars, the radial velocity of the center of mass is known in one case only, HD 137909. Accordingly, for the other binary stars, the table just gives the average of the existing measurements of the radial velocity. We do not have spectroscopic observations for two binary stars, HD 7676 and HD 218994. HD 7676 was found to be a binary system by Strohmeier (1965). HD 218994 is a close visual binary system with a separation of $1\overset{''}{.}2$ (Renson et al. 1991).

In Fig. 2 we compare the accuracies of proper motions in the Hipparcos and PPM star catalogues. There is no obvious indication of a magnitude equation between Hipparcos and PPM proper motions (Figs. 2a, 2b). The errors of Hipparcos proper motions are smaller than those from the PPM catalogue by a factor of 3 (Figs. 2d, 2e).

The space distribution of the stars of set 3 in rectangular galactic coordinates X, Y, Z is shown in Fig. 3.

The interstellar extinction A_V was derived from the $uvby\beta$ colour excesses through application of the formula $A_V = 4.3E(b-y)$ (Shobbrook 1983). From the calculated distances and interstellar extinction values, the absolute magnitudes M_V^i were obtained. We adopted the effective temperatures determined by Martinez (1993) with the method of Moon & Dworetsky (1985).

Matthews et al. (1999) have shown that, if the interpretation of p-mode spacings in roAp stars is correct, then the Hipparcos parallaxes imply $T_{\rm eff}$ values significally lower than those derived by standard methods. The lower effective temperatures would make roAp stars more evolved from the zero-age main sequence (ZAMS). However, the low $T_{\rm eff}$ values they suggest are unrealistic in at least two cases, since a detailed spectral analysis of α Cir favours the higher classical value (and excludes the lower value), while HD 217522 would become a K0 dwarf if its $T_{\rm eff} = 5290$ K was taken at face value. In any case, even if the low $T_{\rm eff}$ scale was true, it would probably apply to all Ap stars, whether roAp or noAp, so it would not affect our results unduly.

To determine the evolutionary status of the samples of roAp stars and noAp stars, we calculated the differences $\Delta M_V^i = M_V^i - M_V^{{\rm ZAMS}i}$. Zero-age main sequence absolute magnitudes $M_V^{{\rm ZAMS}i}$ were derived from the grids of stellar models of Schaller et al. (1992) for the relevant effective temperatures.

Averages $\overline{\Delta M}_V$ were computed for each sample from the individual values of ΔM_V^i. The value of $\overline{\Delta M}_V$ found for the roAp stars is (-0.47 ± 0.34) mag, and for the noAp stars it is (-1.20 ± 0.65) mag. Hence, in agreement with previous results (Paper I), both the roAp stars and the noAp stars lie above

Table 2. Basic data for the stars of set 3

HIP	HD	V (mag)	α_{2000}	δ_{2000}	HIP paral. (mas)	HIP P.M.x (mas/y)	HIP P.M.y (mas/y)	V_r (km/s)
roAp								
5150	6532	8.44	1 5 55.703	−26 43 44.35	4.45 ± 1.3	−33.37 ± 1.37	−17.39 ± 1.13	2.2 ± 1.8
14026	19918	9.35	3 0 36.963	−81 54 7.88	3.82 ± 0.8	−26.24 ± 0.75	−17.14 ± 0.88	29.6 ± 0.7
18339	24712	5.99	3 55 16.129	−12 5 57.35	20.41 ± 0.8	−76.94 ± 0.96	−22.14 ± 0.86	23.2 ± 0.4
36537	60435	8.90	7 30 56.976	−57 59 28.36	4.28 ± 0.8	−12.76 ± 0.86	25.11 ± 0.93	18.8 ± 0.4
45658	80316	7.81	9 18 25.030	−20 22 16.15	7.48 ± 0.9	50.09 ± 0.77	−42.01 ± 0.62	9.5 ± 1.1
47145	83368	6.18	9 36 25.433	−48 45 4.57	13.80 ± 0.8	−8.01 ± 0.73	−7.70 ± 0.72	−1.9 ± 1.0
48619	86181	9.39	9 54 53.415	−58 41 45.52	4.14 ± 1.1	−11.59 ± 1.00	14.74 ± 1.02	7.9 ± 0.4
56709	101065	8.02	11 37 37.068	−46 42 34.80	7.95 ± 1.1	−47.30 ± 0.60	33.93 ± 0.81	12.4 ± 3.0
71908	128898	3.18	14 42 30.403	−64 58 30.51	60.97 ± 0.6	−192.64 ± 0.39	−234.07 ± 0.49	8.3 ± 0.6
74145	134214	7.47	15 9 2.392	−13 59 58.55	10.92 ± 0.9	−46.15 ± 1.02	13.25 ± 0.73	−14.7 ± 0.2
75848	137949	6.69	15 29 34.745	−17 26 27.39	11.21 ± 0.9	−67.68 ± 0.87	6.75 ± 0.63	−28.1 ± 0.5
93179	176232	5.91	18 58 46.924	13 54 24.22	13.45 ± 0.7	0.94 ± 0.72	−51.42 ± 0.58	17.9 ± 0.4
104521	201601	4.70	21 10 20.518	10 17 53.57	28.38 ± 0.9	49.07 ± 0.90	−151.85 ± 0.64	−16.6 ± 0.4
113711	217522	7.54	23 1 46.835	−44 50 27.01	10.49 ± 1.0	−91.93 ± 1.05	−45.55 ± 0.72	44.2 ± 0.5
single noAp								
16527	22488	7.51	3 32 46.312	−66 43 45.96	4.84 ± 0.6	25.19 ± 0.52	9.31 ± 0.57	–
17345	23207	7.56	3 42 44.557	−18 42 49.67	5.64 ± 1.0	−14.49 ± 1.12	−63.48 ± 0.91	1.2 ± 0.6
20033	27285	9.75	4 17 48.143	−19 52 59.07	2.31 ± 1.5	6.95 ± 1.00	−3.85 ± 1.44	–
22340	30849	8.86	4 48 38.556	−49 10 12.10	2.92 ± 0.8	−0.74 ± 0.83	−0.30 ± 0.84	4.6 ± 0.3
25227	35353	7.66	5 23 43.633	−8 17 22.55	7.30 ± 0.9	−1.70 ± 0.83	−1.87 ± 0.63	–
33375	51684	7.96	6 56 29.898	−40 59 25.48	3.73 ± 0.8	−8.84 ± 0.66	14.32 ± 0.87	–
46166	81588	8.46	9 24 54.445	−48 29 7.42	4.03 ± 0.9	−23.35 ± 1.05	8.48 ± 0.76	–
52218	92499	8.93	10 40 8.603	−43 4 50.83	4.46 ± 0.9	−12.03 ± 0.69	−7.18 ± 0.71	–
54215	96237	9.53	11 5 34.048	−25 1 9.15	1.96 ± 1.3	−5.74 ± 0.76	2.97 ± 0.91	–
61785	110072	10.10	12 39 50.247	−34 22 29.06	2.45 ± 1.4	−11.06 ± 1.26	−3.96 ± 0.90	–
63247	112528	8.27	12 57 35.315	−19 45 1.64	2.84 ± 1.2	−49.41 ± 1.03	4.94 ± 0.50	–
64886	115606	8.57	13 18 2.438	13 0 0.29	3.30 ± 1.2	−30.61 ± 1.01	3.67 ± 0.73	–
73098	131750	8.56	14 56 20.761	−30 52 37.89	2.86 ± 1.2	−18.47 ± 1.17	−10.12 ± 0.91	–
76245	138777	9.75	15 34 27.770	−6 53 16.34	1.33 ± 1.9	−4.88 ± 1.87	−2.44 ± 1.14	–
80027	146998	9.54	16 20 9.841	−25 51 26.44	4.40 ± 1.6	−35.49 ± 1.96	−22.28 ± 1.17	–
82340	151301	8.56	16 49 28.298	−54 26 48.33	3.56 ± 1.4	−6.47 ± 1.34	−15.79 ± 1.10	–
84017	154708	8.78	17 10 28.480	−58 0 17.55	7.10 ± 1.1	−19.81 ± 1.02	−36.23 ± 0.93	–
90680	170565	9.14	18 30 8.279	−2 35 27.47	2.72 ± 1.5	−4.17 ± 1.42	−21.60 ± 1.15	–
96177	184471	9.00	19 33 20.458	32 34 37.53	3.12 ± 1.0	2.82 ± 0.75	−16.30 ± 0.91	−40.4 ± 0.2
98357	190145	7.57	19 58 59.697	67 28 19.98	6.65 ± 0.6	25.96 ± 0.63	−6.02 ± 0.66	–
binary noAp								
5916	7676	8.40	1 16 6.818	−34 8 55.97	3.17 ± 0.9	19.36 ± 0.93	−6.30 ± 0.69	–
21460	29578	8.52	4 36 30.805	−54 37 16.17	3.37 ± 0.7	22.61 ± 0.80	32.30 ± 0.87	22.7 ± 0.2
37934	62140	6.50	7 46 27.398	62 49 49.92	12.32 ± 0.7	−36.98 ± 0.50	−61.01 ± 0.51	5.7 ± 0.7
45999	81009	6.51	9 22 50.859	−9 50 19.69	7.20 ± 0.8	−28.31 ± 0.78	−14.74 ± 0.54	28.9 ± 0.5
64936	115708	7.79	13 18 37.244	26 21 57.08	7.53 ± 1.1	4.19 ± 0.87	14.02 ± 0.62	3.9 ± 0.5
65203	116114	7.03	13 21 46.299	−18 44 31.68	7.12 ± 0.9	−46.29 ± 3.58	−13.63 ± 2.52	5.6 ± 0.2
75695	137909	3.66	15 27 49.739	29 6 20.59	28.60 ± 0.7	−181.39 ± 0.38	86.84 ± 0.57	−22.5 ± 0.5
88627	165474	7.45	18 5 43.282	12 0 14.09	7.69 ± 1.2	−2.48 ± 1.21	−2.83 ± 1.17	13.0 ± 0.4
108340	208217	7.20	21 56 56.756	−61 50 46.36	6.83 ± 0.9	23.46 ± 0.53	−39.24 ± 0.61	9.0 ± 0.5
114629	218994	8.57	23 13 16.103	−60 35 2.90	3.64 ± 2.1	39.72 ± 1.66	−21.51 ± 1.91	–

the ZAMS, and roAp stars are found to be less luminous than their non-oscillating counterparts. This is also consistent with the result obtained recently by North et al. (1997). The difference in the absolute magnitudes between roAp and noAp stars found here is 0.73 magnitude. The averages $\overline{\Delta M_V}$ for different samples are presented in Table 3.

The results in Table 3 show that the study based on less accurate PPM proper motions only (set 2), gives results that are

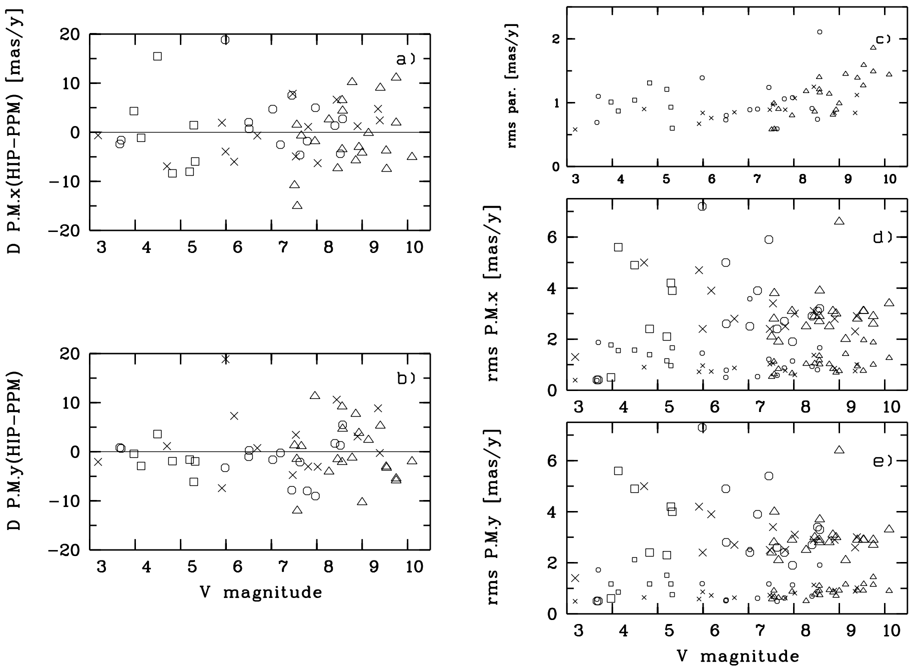

Fig. 2a–e. Differences of stellar proper motions in the Hipparcos and PPM catalogues (**a**, **b**), rms errors of Hipparcos parallaxes (**c**) and rms errors of Hipparcos (small symbols) and PPM (large symbols) proper motions (**d**, **e**). The symbols are the same as in Fig. 1

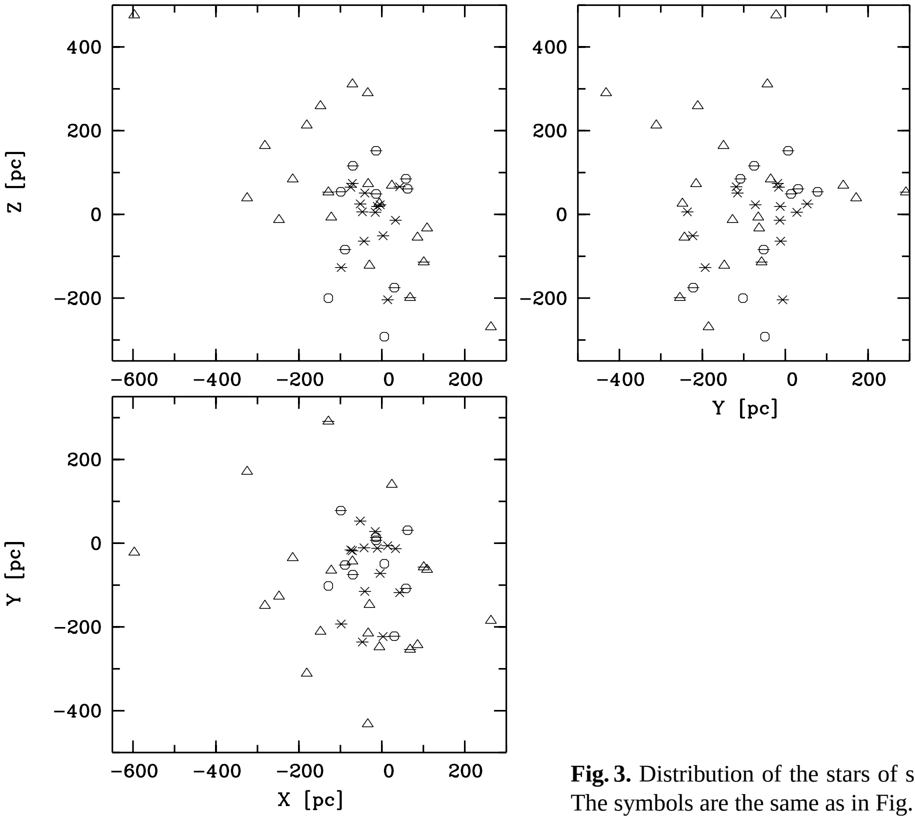

Fig. 3. Distribution of the stars of set 3 in the planes (X, Y), (X, Z) and (Y, Z). The symbols are the same as in Fig. 1

completely different from those of studies based on the datasets 1, 3 and 4.

For every star of the sample, the kinematic characteristics were computed at the distance R^i:

$$R^i = 10^{0.2[V^i - M_V^i - A_V + 5]}.$$

For the stars with known radial velocities (dataset 4), we have calculated the space velocity components U, V, W, their dispersions σ_U, σ_V, σ_W, the total space velocity $v_S = (U^2 + V^2 + W^2)^{0.5}$, and the elements of the galactic orbits: apogalactic distance R_a, orbital eccentricity e, and maximum distance $Z_{\max}$ from the galactic plane, that the star reaches in its orbital mo-

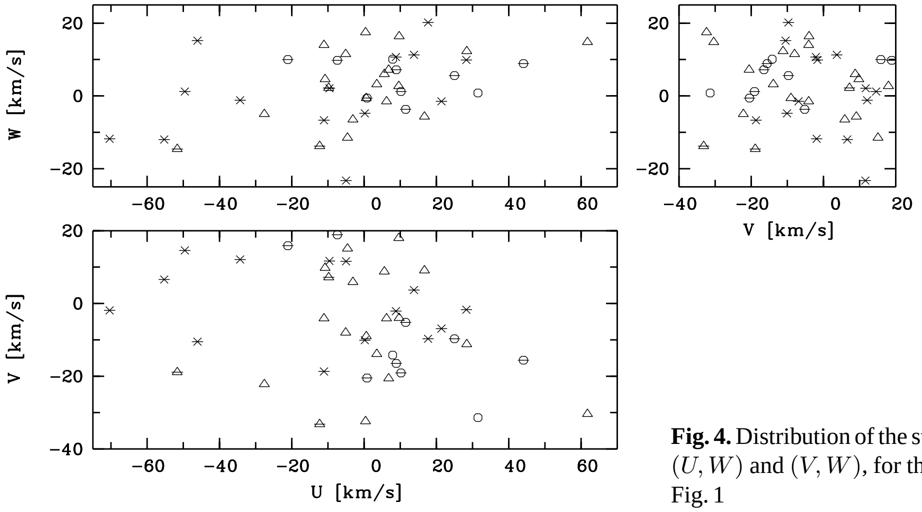

Fig. 4. Distribution of the stellar velocity components in the planes (U, V), (U, W) and (V, W), for the stars of set 3. The symbols are the same as in Fig. 1

Table 3. Averages $\overline{\Delta M_V}$ for the various stellar samples of Table 1

Set	roAp	noAp	single noAp	binary noAp
(1)	-0.64 ± 0.35	-0.96 ± 0.38		
(2)	-0.94 ± 0.36	$+0.55 \pm 0.54$	-0.02 ± 0.40	$+0.70 \pm 0.42$
(3,4)	-0.47 ± 0.34	-1.20 ± 0.65	-1.35 ± 0.70	-0.92 ± 0.42

Table 4. Space velocity data and mean orbital elements for sets 1 and 4

	Set 1		
Parameter	roAp	noAp	
$\overline{U}$ [km/s]	-4.4 ± 6.9	-1.3 ± 6.1	
$\overline{V}$ [km/s]	-4.4 ± 3.8	-9.2 ± 4.0	
$\overline{W}$ [km/s]	1.5 ± 2.5	2.4 ± 2.2	
$\overline{v}_S$ [km/s]	36.2 ± 4.4	25.9 ± 3.2	
σ_U [km/s]	35.2 ± 4.9	21.2 ± 4.3	
σ_V [km/s]	19.5 ± 2.7	14.0 ± 2.8	
σ_W [km/s]	12.6 ± 1.7	7.7 ± 1.6	
S_{tot} [km/s]	24.2 ± 3.3	15.3 ± 3.2	
$\overline{R}_a$ [kpc]	11.89 ± 0.28	11.07 ± 0.40	
$\overline{E}$	0.120 ± 0.020	0.109 ± 0.012	
$\overline{Z}_{max}$ [kpc]	0.58 ± 0.07	0.43 ± 0.06	
	Set 4		
Parameter	roAp	noAp	binary noAp
$\overline{U}$ [km/s]	-13.7 ± 8.5	-0.2 ± 7.6	9.0 ± 7.0
$\overline{V}$ [km/s]	-0.1 ± 2.0	-8.8 ± 5.0	-6.5 ± 5.5
$\overline{W}$ [km/s]	0.7 ± 3.2	1.1 ± 2.6	4.8 ± 1.8
$\overline{v}_S$ [km/s]	32.5 ± 4.9	28.0 ± 4.2	25.2 ± 3.6
σ_U [km/s]	31.9 ± 6.0	25.1 ± 5.3	19.8 ± 4.9
σ_V [km/s]	10.4 ± 1.4	16.4 ± 3.5	15.6 ± 3.9
σ_W [km/s]	12.0 ± 2.3	8.8 ± 1.9	5.2 ± 1.3
S_{tot} [km/s]	20.6 ± 3.8	18.0 ± 5.4	14.8 ± 5.2
$\overline{R}_a$ [kpc]	12.02 ± 0.38	11.30 ± 0.41	11.30 ± 0.53
$\overline{E}$	0.118 ± 0.019	0.104 ± 0.015	0.093 ± 0.018
$\overline{Z}_{max}$ [kpc]	0.45 ± 0.08	0.44 ± 0.07	0.37 ± 0.08

tion. For these calculations we have used the three-dimensional galactic potential model of Saio & Yoshii (1979). The velocity components are corrected for the solar motion with respect to the Local Standard of Rest, with the following values of parameters of the solar motion: $S_\odot = 15.5$ km s^{-1}, $L_\odot = 45°$, $B_\odot = 24°$.

In Fig. 4 we show the distribution of the stellar velocity components U, V, W in the $(U - V)$, $(U - W)$ and $(V - W)$ planes. The stars with known radial velocities for which spatial velocity components were calculated are marked by an horizontal bar.

In Table 4, we give the space velocity data and the mean orbital elements characterizing the motion of the stars of the various samples in the Galaxy. The sample of the stars for which only one radial velocity measurement is available is too small (with 3 stars), so that kinematical parameters were not calculated separately for that group. The value $S_{\rm tot} = [(\sigma_U^2 + \sigma_V^2 + \sigma_W^2)/3]^{0.5}$ is the dispersion of the space velocity components. This value, in general, is a reasonable indicator of the kinematical and evolutionary status of different stellar groups. For instance, Mihalas & Binney (1981) give for A5 and F0 dwarfs velocity dispersions of 14 and 17 km s^{-1}, respectively. For comparison, we also give in Table 4 the results of our previous kinematical study of roAp stars based on PPM motions and radial velocity measurements (Paper I).

For the datasets 2 and 3, only tangential velocity components and their dispersions were computed, making the assumption that the mean radial velocity of the stars is zero. Corresponding space velocity data are presented in Table 5. Large scatter of velocity components for different stellar samples is due to the small number of stars in our samples. Notice that our S_{tot} values listed in Table 5, Set 3, are very close to those found by Gomez et al. (1998): 17.0 and 15.8 km s^{-1} for 12 roAp and 9 noAp stars respectively. Our results for kinematical properties of roAp and noAp stars based on PPM proper motions datasets show significant differences between roAp and noAp stars and are inconsistent with those based on Hipparcos parallaxes. We explain this inconsistency by the limited accuracy of the astrometric data in the PPM Star Catalogue.

Table 5. Tangential velocity data for sets 2 and 3

Parameter [km/s]	roAp	noAp	single noAp	binary noAp
Set 2				
$\overline{U}$	-13.6 ± 6.5	-5.8 ± 1.7	-3.1 ± 1.7	-6.1 ± 1.6
$\overline{V}$	3.4 ± 3.1	6.1 ± 1.4	4.2 ± 1.5	6.4 ± 1.3
$\overline{W}$	6.1 ± 3.8	5.4 ± 1.2	4.0 ± 0.9	5.4 ± 1.2
$\overline{v}_S$	36.2 ± 5.2	12.9 ± 1.4	16.6 ± 1.2	12.7 ± 1.3
σ_U	33.9 ± 4.6	6.5 ± 1.2	12.1 ± 1.2	6.0 ± 1.1
σ_V	16.3 ± 2.2	5.2 ± 1.0	10.6 ± 1.1	4.9 ± 0.9
σ_W	19.6 ± 2.7	4.8 ± 0.9	6.8 ± 0.7	4.5 ± 0.8
S_{tot}	24.5 ± 3.6	5.5 ± 1.1	10.1 ± 1.2	5.2 ± 1.0
Set 3				
Parameter [km/s]	roAp	noAp	single noAp	binary noAp
$\overline{U}$	-14.1 ± 7.1	3.4 ± 4.0	3.6 ± 5.4	10.2 ± 5.2
$\overline{V}$	5.3 ± 2.7	-5.0 ± 2.7	-6.4 ± 4.1	-5.3 ± 4.6
$\overline{W}$	-7.0 ± 3.2	4.1 ± 1.9	3.3 ± 3.4	6.2 ± 3.6
$\overline{v}_S$	30.2 ± 4.3	24.1 ± 2.8	26.2 ± 3.2	23.9 ± 4.0
σ_U	26.4 ± 5.0	21.3 ± 2.8	20.1 ± 3.8	16.4 ± 3.7
σ_V	10.1 ± 1.9	15.5 ± 1.9	15.5 ± 2.9	14.4 ± 3.2
σ_W	12.1 ± 2.3	10.2 ± 1.3	12.7 ± 2.4	11.5 ± 2.6
S_{tot}	17.8 ± 3.4	16.0 ± 2.9	16.4 ± 2.9	14.2 ± 4.5

3. Discussion

In Fig. 5 we show the distribution of roAp and noAp stars in the special version of the H-R diagram proposed by Arenou & Luri (1999) and called by them "astrometric H-R diagram": instead of considering the absolute visual magnitude (or the logarithm of the luminosity), we use what these authors call the Astrometry-Based Luminosity (ABL) which is written

$$a_V = 10^{0.2M_V} = \pi 10^{\frac{m_V - A_V + 5}{5}} \tag{10}$$

where M_V is the absolute magnitude, m_V the apparent one and A_V is the visual interstellar absorption. This quantity has the advantage that the error bars are essentially symmetrical (the error on the apparent visual magnitude may be neglected) and that no Lutz–Kelker bias (Lutz & Kelker 1973) occurs. Therefore, all stars may be represented, since there is no reason to impose any limit on the relative error of the parallaxes.

The evolutionary tracks for theoretical stars of 1.5, 1.7, 2.0 and 2.5 solar masses and the isochrones $\log t = 8.75$, 9.0 and 9.2 computed by Schaller et al. (1992) are also shown.

Because the errors on the Hipparcos parallaxes are gaussian (Arenou et al. 1995), the average ABL may be estimated using the weighted mean

$$\langle a_V \rangle = \frac{\sum_i \frac{a_i}{\sigma^2_{a_i}}}{\sum_i \frac{1}{\sigma^2_{a_i}}}\,, \tag{11}$$

while the average absolute magnitude is (Arenou & Luri 1999)

$$\langle M_V \rangle = 5 \log(\langle a_V \rangle)\,. \tag{12}$$

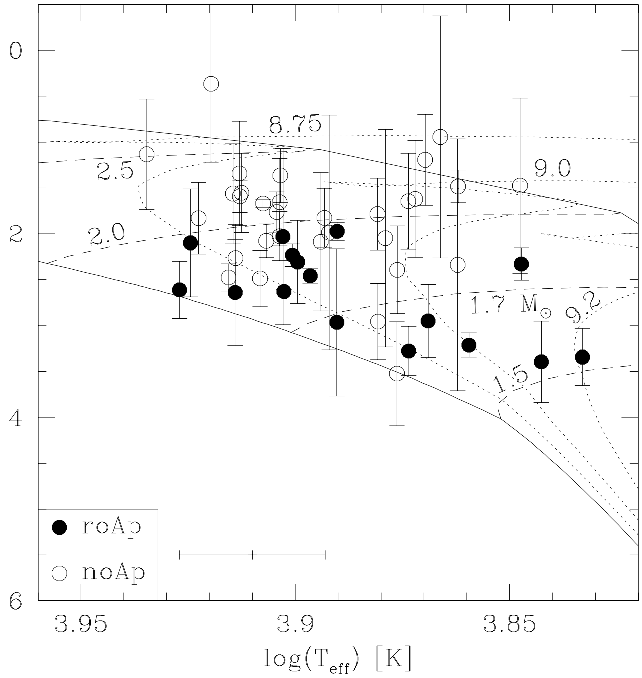

Fig. 5. "Astrometric" HR diagram (with $a_V = 10^{0.2M_V}$, see text) of the roAp (full dots) and of the noAp stars (open dots); the recently discovered roAp stars HD 99563 and HD 122970 are included in this plot. The horizontal segment at the lower left indicates the typical error on $\log T_{\rm eff}$ (±300 K in $T_{\rm eff}$), its total length being $2\,\sigma$. The lower continuous curve (ZAMS) is an isochrone at $\log t = 5.7$ based on the models of Schaller et al. 1992 for $Z = 0.020$ while the upper curve (TAMS) links the 11th points of Schaller et al.'s evolutionary tracks. The dotted curves are the isochrones at the indicated $\log t$, while the dashed curves are the main sequence parts of the evolutionary tracks for masses between 1.5 and 2.5 $M_\odot$.

The result that we obtain in this way is $\langle a_V(\mathrm{roAp})\rangle = 2.591$, $\langle a_V(\mathrm{noAp})\rangle = 1.748$ and $\langle M_V(\mathrm{roAp})\rangle = 2.07$, $\langle M_V(\mathrm{noAp})\rangle = 1.21$, including the two new roAp stars HD 99563 and HD 122970 (Dorokhova & Dorokhov 1998; Handler & Paunzen 1999). HD 99563 is a close visual double with $\rho = 1\farcs7$ and $\Delta m_V = 1.7$, so its visual magnitude and colours are affected. Its $uvby\beta$ colours have been used to estimate $T_{\rm eff} \sim 8000$ K, neglecting the influence of the companion: this estimate should rather be a lower limit. The apparent magnitude has been corrected for the presence of the companion, which results in $V = 8.58$ instead of 8.32, and a very uncertain $A_V = 0.2$ was assumed from $E(b-y) = 0.045$ estimated from the colours. This value of A_V should be regarded as an upper limit, considering the rather high galactic latitude ($b = 48.63$ deg) of the star, which in any case has a very uncertain parallax ($\sigma(\pi)/\pi = 0.473$). HD 122970 has a much better parallax, and its $uvby\beta$ colours (the only ones available) yield $T_{\rm eff} = 6960$ K – in good agreement with its F0 type – and $E(b-y) \sim 0.023$, hence $A_V \sim 0.1$. If these two stars are not taken into account, the average absolute magnitude of the sample is not significantly affected: one gets $\langle a_V(\mathrm{roAp})\rangle = 2.590$ and $\langle M_V(\mathrm{roAp})\rangle = 2.07$.

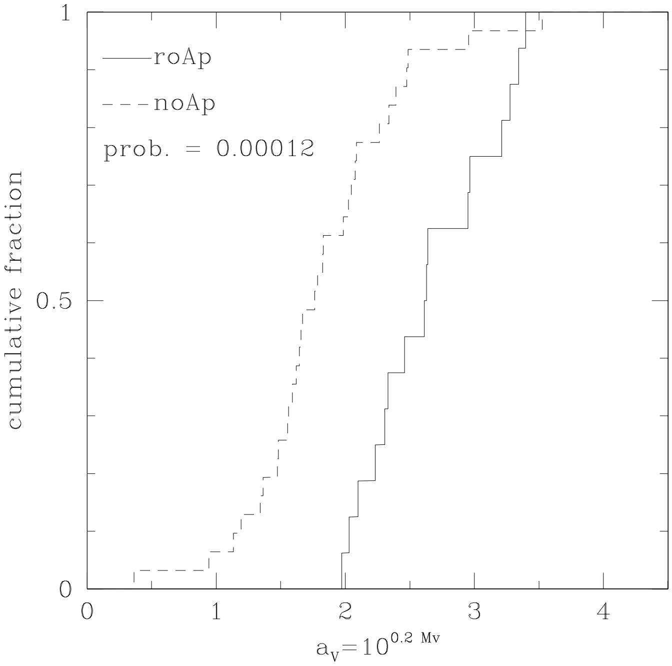

Fig. 6. Cumulative distributions of the "Astrometry-Based Luminosities" a_V of the roAp stars (continuous line) and of the noAp stars (broken line). The "prob." number is the probability given by the KS test, that both distributions are drawn from the same parent distribution.

Although noAp stars are similar to roAp stars in their colour indices, abundances and magnetic fields, the roAp stars as a group are less luminous and less evolved, consistently with the results obtained by North et al. (1997). The noAp stars are also more massive on average than the roAp stars, since their masses range from about 1.6 to $2.5\ M_\odot$ instead of 1.5 to $2.0\ M_\odot$ (see Fig. 5). The absolute magnitude difference between roAp and noAp stars found in this study is 0.86 mag.

From comparison of the kinematical characteristics calculated from Hipparcos data, we conclude that both groups are very similar. We see in Table 4 that kinematical study for the set 4 gives somewhat higher values for the dispersion of the space velocity components $S_{\rm tot}$ for roAp stars compared to that for noAp stars. It can be understood as some hint of older kinematics for roAp stars. On the other hand, within the uncertainties, this result can also be consistent with the view that both roAp and noAp stars are of the same or only slightly different age, approximately that described by the isochrone $\log t = 8.85$.

A plot of the cumulative distributions of a_V for roAp and noAp stars shows very clearly two parallel curves (Fig. 6), and the Kolmogorov-Smirnov test indicates that the two distributions differ at the significance level of 99.98%. Although this seems highly significant, it is necessary to keep in mind two possible observational biases:

(1) Most of the roAp stars were discovered by Kurtz and Martinez. They found that looking for roAp stars among candidates with a negative value of δc_1 was especially efficient. δc_1 is sensitive to line blanketing, which is heavy for cool Ap stars, but also to luminosity through the Balmer jump. Therefore, such a selection criterion for detecting roAp stars would certainly lead to select also lower luminosity stars. One may fear, then, that we simply have detected this bias.

The question is whether most noAp stars have suffered the same selection bias than the roAp stars. The simplest way to answer this is to plot the cumulative distribution of δc_1 for both groups. The result is that both distributions do not differ, according to the Kolmogorov-Smirnov test (probability level: 64% that both distribution are drawn from the same parent distribution). A slightly higher proportion of noAp stars have positive values of δc_1, but removing them would make no significant difference on Fig. 6, the probability level becoming 0.0005 instead of 0.00012. In conclusion, this possible bias does not really exist.

(2) The noAp stars are systematically fainter – in apparent magnitudes – than the roAp stars, by roughly one magnitude on average (the difference, judged from cumulative distributions of m_V, ranges from ~ 1.5 mag around $m_V = 7.0$ to ~ 0.5 mag around $m_V = 9.0$). This difference is seen also in the Hipparcos parallaxes, which are systematically smaller for the noAp stars than for the roAp ones. Therefore, one may fear that minute variations of 1-2 mmag may have simply escaped detection in these fainter stars, which we would, then, have unduly put into the "noAp" category. Non-oscillating Ap stars are also farther away on average, and more numerous: then, they have a good chance to span the whole width of the main sequence. The roAp stars, on the contrary, are rarer, and since the lifetime is longer near the ZAMS than near the terminal-age main sequence (TAMS), these few objects would tend to cluster near the ZAMS. In the end, one may have the impression that noAp stars are intrinsically brighter on average than roAp stars.

The only way to decide whether or not this bias holds is to show that the noise does not increase with apparent magnitude in a significant way. This test is delicate, because the detection of oscillations depends on many factors, such as telescope aperture, sky transmission stability, total duration of the monitoring, and even rotational phase of the star. We have estimated the noise level on the periodograms published by Martinez & Kurtz (1994) for frequencies larger than 1 mHz and plotted it against the apparent visual magnitude to see whether any correlation appears. In cases where there are several periodograms (i.e. several observing runs) per star, the one giving the smallest noise was retained. The result is shown on Fig. 7 as full dots. The open dots in Fig. 7 are taken directly from Nelson & Kreidl (1993), who give the noise in tabulated form and have about the same criteria of noise definition.

A slight correlation emerges, showing that the above mentioned bias might be real. A more thorough investigation is required in order to check its significance for the detection of rapid oscillations in noAp stars.

The difference between the masses of roAp stars and noAp stars may be important for the understanding of the origin of their oscillations. Plausibly, convection starts becoming efficient for the roAp stars. More generally, the difference of internal structure associated with the mass difference can probably explain why oscillations are observed only in the roAp stars. On the other hand, the domains of the roAp and noAp stars in the

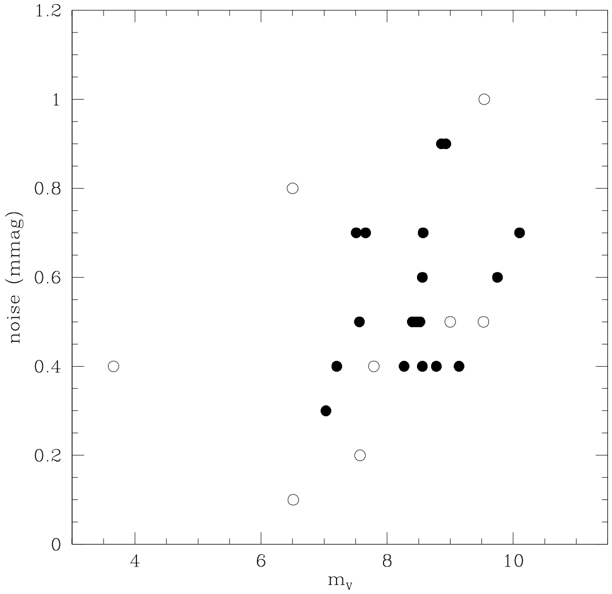

Fig. 7. Noise level versus apparent magnitudes for noAp stars. Full dots: data from Martinez & Kurtz (1994). Open dots: data from Nelson & Kreidl (1993)

H-R diagram largely overlap. This shows that mass and internal structure differences between the roAp and noAp stars cannot be the only decisive factor in their respective evolution.

As mentioned above, none of the roAp stars is known to be a spectroscopic binary. With respect to this, it is noteworthy that also no pulsating white dwarf is known to be a spectroscopic binary (Koester 1999). In one case, GW Lib, the dwarf primary of a cataclysmic variable star shows non-radial pulsations (Warner & van Zyl 1998). However, this is a special case where the white dwarf has been pumped in $T_{\rm eff}$ into the instability strip by accretion heating.

On general grounds, the issue of whether duplicity affects pulsation through tidal interaction is unsettled. From the theoretical point of view, while some authors (e.g., Cowling 1941; Zahn 1977) have conjectured that tides in close binary systems may act as an external perturbing force driving oscillations, the question whether tidal interaction may also be efficient in damping already existing pulsations does not seem to have ever been addressed. Observationally, in the same region of the parameter space in which pulsations were detected, there is only one binary system with a noAp primary presently known, in which the two components are close enough so that significant tidal interaction occurs between them (Giuricin et al. 1984): HD 200405 (SB1, $P = 1.63$ days, North 1994). This star does not appear in Table 2 because its proper motion and parallax were not measured by Hipparcos.

Tidal forces might conceivably also play a non-negligible rôle in systems with a larger average separation, provided that their eccentricity is large enough. Interaction would then occur mostly on the part of the orbit when the components are closest, since tidal forces are strongly dependent on the distance between the components. At present, though, almost nothing is known about the orbital eccentricities of the noAp binaries.

In other words, neither theoretically nor observationally is our present knowledge sufficient to decide confidently whether tidal interaction in binaries may reduce the amplitude of or inhibit pulsation in cool Ap stars. To establish this, a necessary condition would be to show that essentially all noAp stars are binaries. Although this is not inconsistent with the information available so far, the latter is too incomplete to draw any more definite conclusion. To gain further insight, it will be important to establish if *no* roAp star is a binary (except for very wide visual binaries). Another potentially fruitful investigation would be to search for binarity among the noAp stars in the region of overlap, since among the stars of this region in which pulsations have been sought and not found, only three are not definite binaries.

Answering those questions will require a major additional observational effort. Future observations aimed at determining the orbital elements of the noAp binaries should also contribute to a better knowledge of the interaction between binarity and pulsation. Such observations will help to establish which conditions must prevail for the appearance of rapid oscillations in cool Ap stars.

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