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The Hvar survey for roAp stars *(Research Note)*

I. The survey observations★

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ABSTRACT

Context. The rapidly oscillating Ap (roAp) stars exhibit short time scale photometric and/or radial velocity variations, which are most important to test current pulsation models as well as our assumptions of the atmospheric structure characteristics. In addition, their chemical peculiarity makes them very interesting for probing stellar formation and evolution in the presence of a global magnetic field. To date, only a limited number of about 45 roAp stars are known.

Aims. In order to increase the sample, we obtained photometric time series of 20 good roAp candidates to search for pulsations.

Methods. We present the time series analysis of about 60 h of CCD photometry taken at the 1 m Austrian-Croatian Telescope (Hvar Observatory) and derive effective temperatures for the programme objects.

Results. The upper amplitude limits of the Fourier spectra are typically below 2 mmag in Bessell B with one good candidate for follow-up observations to find possible pulsation. In addition, we present a list of further roAp candidates, worth to be (re)investigated.

Key words. stars: chemically peculiar – stars: variables: general – stars: early-type – stars: oscillations

1. Introduction

The rapidly oscillating Ap (roAp) stars are located within an area of pulsational instability in the Hertzsprung-Russell diagram, ranging in temperature from about 6600 K to 8500 K. Their luminosities place them between the zero age main sequence and the terminal age main sequence. Photometric investigations for these stars show a period range of five to twenty five minutes (Kurtz et al. 2011).

The driving mechanism for the roAp stars is believed to be the "classical" κ-mechanism operating in the hydrogen ionisation zone (e.g. Balmforth et al. 2001). The magnetic field plays an important role in mode driving and selection. However, Ap stars with strong magnetic fields in the range of temperature and luminosity of roAp stars may still be either roAp or non-oscillating Ap (noAp) stars.

In order to increase the available studied sample, we present 60 h of time series CCD Bessell B photometry for 20 CP stars located in the roAp spectral domain. Except one star, these were never investigated in this respect.

2. Target selection, observations, and reduction

The targets were selected from the catalogue of Ap, HgMn and Am stars by Renson & Manfroid (2009). Since most of the known roAp stars are classified as SrCrEu, we searched for such objects in the aforementioned reference. We discarded objects for which no suitable comparison star is located within the field-of-view of the telescope. In total, 20 stars were selected with $8.9 < V < 11.6$ mag.

The observations were performed from the 18th to the 30th of August 2011 at the Hvar Observatory, University of Zagreb, using the 1 m Austrian-Croatian Telescope (ACT). The telescope is equipped with a Apogee Alta U47 CCD camera of 1024×1024 pixels, resulting in a field-of-view of about 3′ square.

The integration times for the observations in the Bessell B filter system were set between 10 and 15 s, depending on the brightness of the target and comparison stars. In total, about 60 h of photometry were secured, whereas eight stars were observed twice in different nights.

After the basic CCD reductions (bias-subtraction and flat-fielding), for all frames we applied aperture photometry within IRAF[1]. To account for different seeing conditions, apertures with diameters of 24 and 32 pixels were used.

The reductions were performed using the standard technique for time series CCD observations. As final step, differential magnitudes of the target stars were calculated. If several comparison stars are available, these were checked individually to exclude variable objects. The final light curves were examined in more detail using the Period04 program (Lenz & Breger 2005),

★ The reduced photometric data are only available at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/542/A89

[1] Available from http://iraf.noao.edu/

Table 1. The basic data of the target stars and the results of the time series analysis.

Renson	BD/Tycho	V [mag]	Spec[a]	$T_{\rm eff}$ [K]	$\sigma T_{\rm eff}$[b] [K]	$E(B-V)$ [mag]	JD(start)[c]	Δt [min]	UL[d] [mmag]
1860	+32 213	9.076	A5 Sr Cr Eu	7920	160 (3)	0.02	800.5045	190.7	1.1
							801.6294	31.0	4.5
45690	+28 2829	8.992	A7 Eu Cr Sr	7610	180 (5)	0.10	796.2976	132.6	2.0
							804.2640	65.2	3.6
47048	+31 3215	9.573	A Sr	8760	120 (4)	0.11	800.2868	133.4	2.4
							801.2747	93.5	1.0
49240	+29 3427	9.676	A6 Cr Sr	8820	180 (4)	0.12	792.3666	92.7	1.2
49390	+29 3448	9.529	A9 Sr	7980	210 (3)	0.11	793.2910	123.0	2.0
							802.2768	65.2	2.6
51470	+34 3688	9.061	A5 Sr	8290	60 (4)	0.12	795.2967	130.9	1.6
52870	+39 4014	10.101	A2 Sr	8560	440 (4)	0.11	798.3517	131.2	1.3
							801.3686	130.5	1.2
53610	+36 3941	9.072	A7- Sr	7690	140 (3)	0.10	800.4331	67.3	2.3
55060	+21 4333	9.907	A2 Sr	8480	150 (3)	0.09	794.4382	125.9	2.5
55697	+33 4115	10.571	A7 Si Sr	8050	360 (3)	0.12	796.4467	119.8	2.9
55850	+37 4152	10.110	F0 Si Sr	7330	360 (3)	0.02	795.4371	129.1	3.2
							804.4079	65.2	1.3
56141[e]	2713-2426-1	11.619	A2 Si	6270	30 (2)	0.17	797.4572	130.8	2.6
56261	+35 4422	9.435	A5 Si	7830	130 (3)	0.02	799.4577	120.0	1.5
56543	+41 4078	9.377	A5 Si Cr	8110	180 (3)	0.10	793.4555	121.4	1.5
58275	+46 3543	9.728	A2 Si	8660	340 (3)	0.08	795.5449	130.7	1.4
58773	+54 2730	10.488	F0 Si Sr	7710	240 (3)	0.06	796.5473	125.4	1.6
58777	3982-4172-1	10.737	A3 Sr	7930	410 (3)	0.19	793.5602	112.4	3.0
59825	+57 2636	9.532	A Sr Cr Eu	7720	200 (3)	0.13	797.5622	108.8	2.0
							802.5654	94.3	2.3
61344	+50 4176	9.435	A2 Sr Eu	8510	120 (3)	0.13	799.5697	109.3	1.8
							801.5232	65.1	1.5
61420	+61 2565	9.940	A8 Sr Eu Cr	7270	290 (4)	0.09	798.5415	115.3	1.8

Notes. [(a)] Renson & Manfroid (2009). [(b)] The number of temperature calibrations used are given in parenthesis. [(c)] JD−2 455 000. [(d)] Upper limit in Fig. 2. [(e)] See discussion in Sect. 3.

which performs a discrete Fourier transformation. Significant peaks with periods of more than one hour were subtracted.

All large ground based surveys for the detection of roAp stars were conducted with photomultipliers (e.g., Joshi et al. 2006). This technique allows, in principle, to carefully select comparison stars with comparable magnitudes to that of the target. With a multichannel photomultiplier it is even possible to measure a comparison and a target simultaneously. This comes already very close to the CCD technique. However, for a significant amount of targets published in Joshi et al. (2006), no comparison stars were used due to the absence of proper objects in the vicinity of the bright programme stars and because the time scale of roAp variability is shorter than that of sky transparency variations under photometric conditions.

We present here the results of CCD observations within a very limited field-of-view. The detailed observational dates and results of the Fourier time series analysis for the 20 target stars are listed in Table 1 and shown in Fig. 2.

The individual time series span a range from 30 to 190 min. For eight stars, observations in two nights are available. The upper limits of the Fourier spectra are typically below 2 mmag. This value is well in the range or even below the ones published by Joshi et al. (2006).

One of our programme stars (Renson 45690) was already studied by Nelson & Kreidl (1993) for rapid variations, also without a sign of oscillations.

According to our measurements, only Renson 58777 is a good candidate for follow-up observations (see Fig. 1). Although not statistically significant, several peaks are visible around 2 mHz which is well in the range of known frequencies. Its effective temperature places this star where roAp stars are found.

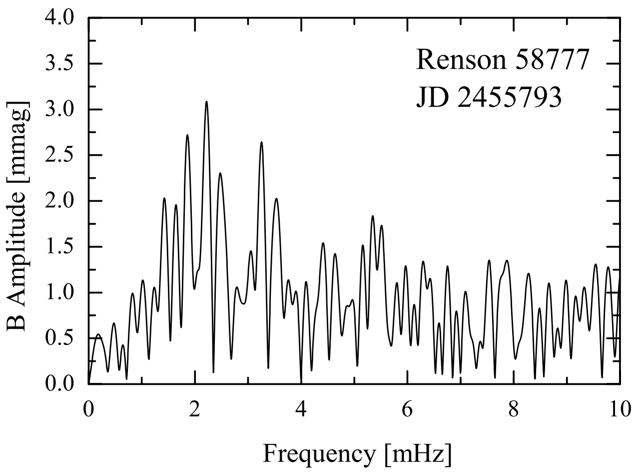

Fig. 1. The Fourier spectra of the light curve of Renson 58777.

3. Astrophysical parameters

In order to derive effective temperatures for the programme stars, we compiled all available photometric data using the General Catalogue of Photometric Data (GCPD). Unfortunately, for only six objects Strömgren, Geneva, or UBV photometry is available therein. We therefore proceeded like Wraight et al. (2011) and searched for additional data listed in

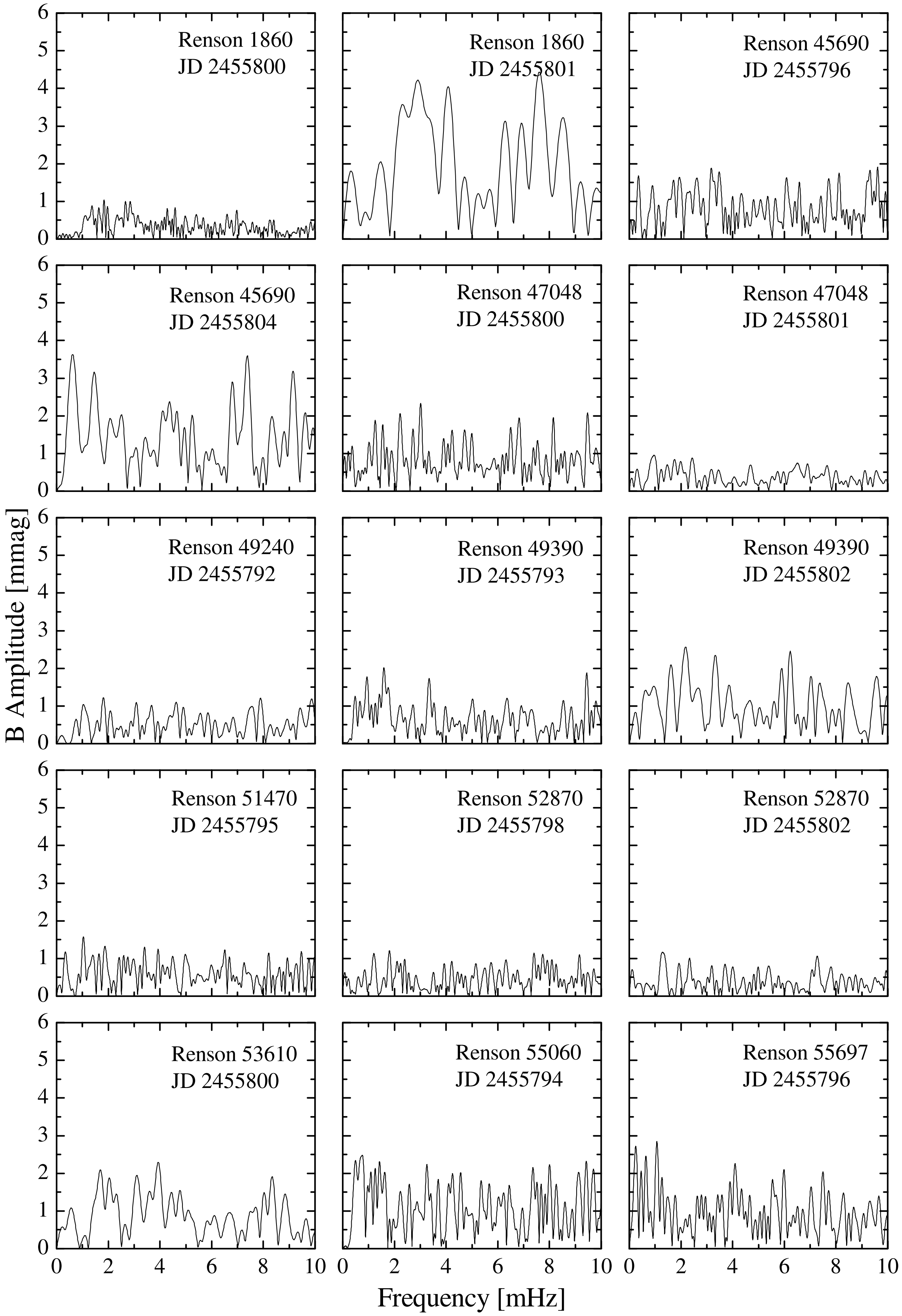

Fig. 2. The Fourier spectra of the target star light curves showing no sign of pulsation.

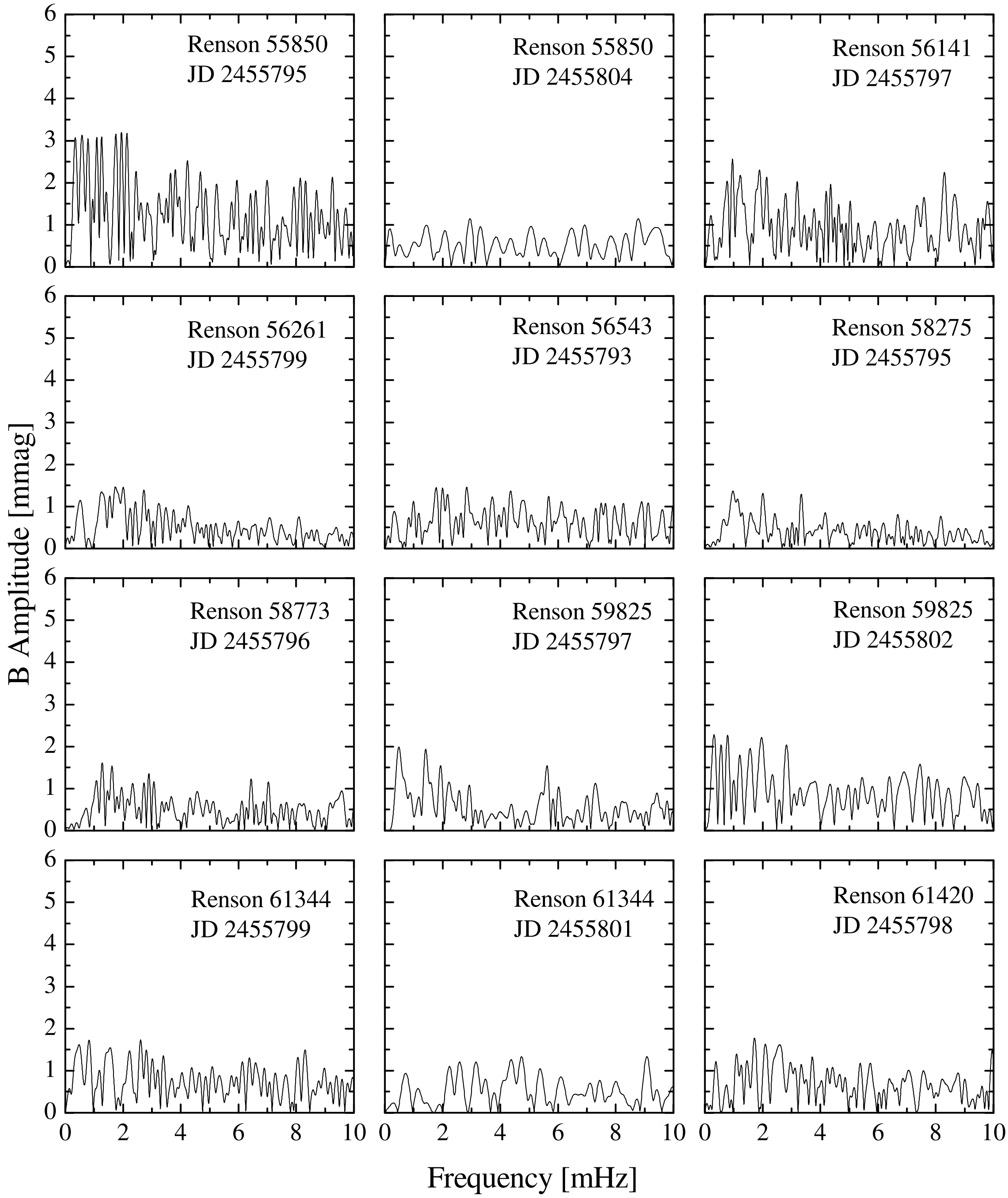

Fig. 2. continued.

the ASCC catalogue (Kharchenko 2001), providing TYCHO-2 transformed B, V photometry as well as 2MASS data (Cutri et al. 2003). Furthermore, the TASS survey (Droege et al. 2006) was queried for V, I photometry. Hence, for most stars at least the broad wavelength range with B, V, I, J, H, K_s magnitudes is covered. Using these datasets, we performed a spectral energy distribution (SED) fitting using the tool provided by Robitaille et al. (2007), which allows to set reddening as free parameter. A comparison to the reddening and temperatures deduced from available Strömgren photometry, which were treated as given in Netopil et al. (2008), provided a good agreement between the two methods. Applying the obtained reddening estimates, further temperatures were derived using the colour indices $(B-V)$ and $(B2-G)$ in combination with the calibrations for chemically peculiar stars listed by Netopil et al. (2008). Since the colours of CP stars cooler than about 9000 K do not differ significantly from normal ones, we did not apply the correction for the SED temperatures as given by Wraight et al. (2011). Additionally, we used $(V-K_s)$ as a further temperature indicator using the calibration by Di Benedetto (1998), the transformation of 2MASS nIR data to the Johnson-Glass system by Carpenter (2001), and the reddening ratios listed by Bessell et al. (1998). The averaged results for $T_{\rm eff}$, based on up to five determinations, the standard deviation, and the number of individual calibrations used are given in Table 1. Due to the faintness of the objects, for only three stars Hipparcos parallaxes (van Leeuwen 2007) are available. However, since the errors are between 30 to 150%, the calculation of luminosity would be erroneous. Especially for the object Renson 56141 we noticed a significant difference between the given spectral type (A2 Si) and the estimated temperature (6270 K). Using SED fitting we obtained a reddening of $E(B-V) = 0.17$, whereas the extinction maps by Schlegel et al. (1998) and Arenou et al. (1992) result in a only slightly larger value of ~0.25 mag. Since it is the faintest object and the available photometric data are rather poor (especially the *B* magnitude), at least additional Strömgren photometry would be helpful to obtain a better reddening and temperature estimate, but this comment applies to the majority of the programme stars.

4. Further roAp candidates

About 45 roAp stars are known so far, the latest discovered by Alentiev et al. (2012). However, due to the faintness of numerous objects, no Hipparcos parallaxes are available to deduce luminosity and to place them on the Hertzsprung-Russell diagram (HRD). Such information is important in order to check e.g. the theoretical instability strip by Cunha (2002), or to investigate evolutionary effects.

Several photometrically studied objects showing, a-priori, no signs of variability, are in the meanwhile classified as roAp. In this respect it is worth to mention e.g. HD 116114, studied photometrically over several hours and runs by Martinez & Kurtz (1994) and Nelson & Kreidl (1993), classified as noAp star by both references. Using high-resolution spectroscopy, then Elkin et al. (2005) detected a 21 min pulsation period with amplitudes in the radial velocity data up to 125 m s^{-1}. Later on, Lorenz, Handler, & Kurtz (2005) again monitored this object photometrically and found no pulsation within a limit of 0.6 mmag. Furthermore, as mentioned by Balona et al. (2011), the roAp stars detected by the *Kepler* satellite (except KIC 10195926) would have been classified as noAp via ground based photometric observations. Hence, there is a strong dependence on the accuracy of the measurements or method (photometric or spectroscopic), making the sample of noAp's probably rather contaminated, unless a considerable number is also investigated spectroscopically or via space missions. An additional difficulty arises that for numerous stars the classification as CP is still based on former studies using objective prism plates (e.g. Bidelman 1983), therefore a new inspection like by Paunzen et al. (2011) and/or an extensive polarimetric survey to measure magnetic fields is strongly needed to reject wrongly classified CP stars.

In order to present an additional list of proper roAp candidates, worth to be re-investigated, we compiled the the lists given by Martinez & Kurtz (1994, their Tables 1 and 2), which provide either the null-results of their photometric survey as well as an additional literature compilation. Furthermore, the results by Handler & Paunzen (1999) and the Nainital-Cape Survey (Joshi et al. 2006, 2009) were incorporated, excluding a considerable number of normal or metallic line Am stars from the latter survey, which were also investigated by them to cover a broad range of star classes. They already provide a classification for the stars, which were re-checked using the additional literature. This way we found some objects classified as normal although a magnetic field was detected (e.g. for HD 62140). We noticed that 11 objects of the former photometric nullresults are in the meanwhile classified as roAp by means of spectroscopic investigations. In total, we compiled 124 noAp stars which have sufficient photometry and Hipparcos parallaxes (van Leeuwen 2007), in order to derive their fundamental properties. Beside Strömgren data, which are available for all objects in GCPD and the additional literature, we used also Geneva and/or *UBV* data together with the respective temperature calibration by Netopil et al. (2008). If temperature determinations apart from photometric ones are available in the latter reference, these were adopted.

Table 2. Selected roAp candidates for deeper investigations[a].

Star ID	Spec[b]	$T_{\rm eff}$[c] [K]	$\log(L/L_\odot)$
HD 21190	F2 Sr Eu Si	7050(360)/2	1.62(15)
HD 38823	A5 Sr Eu Cr	7270(600)/2	0.92(10)
HD 51684	F0 Sr Eu Cr	7820(70)/2	1.62(17)
HD 62140[d]	A8 Sr Eu	7800(140)/2	1.30(7)
HD 96707	A8 Sr	7820(230)/3	1.55(6)
HD 112528	A3 Sr Eu Cr	7160(90)/2	1.34(23)
HD 115606	A2 Sr	7880(250)/2	1.20(21)
HD 115708[d]	A3 Sr Eu	7760(350)/2	0.90(10)
HD 165474	A7 Sr Cr Eu	7930(220)/3	1.29(15)
HD 94427[d]	A5 Sr Eu Cr	7500/1	1.29(10)
HD 105999	F1 Sr Cr	7070(380)/3	1.05(8)
HD 160468	F2 Sr Cr	6640(120)/2	1.30(10)
HD 168481	A7 Sr Cr	7860(120)/2	1.96(13)
HD 189832	A6 Sr Cr Eu	7790(100)/2	1.63(12)

Notes. [(a)] Upper/lower part: stars investigated/not investigated so far for rapid variability. [(b)] Renson & Manfroid (2009). [(c)] Average temperature (standard deviation)/number of determinations. [(d)] Temperatures adopted from Netopil et al. (2008).

In Table 2 (upper panel) we list the most promising roAp candidates with respect to temperature, which were classified as noAp so far, and for which further spectroscopic time series are desirable. To exclude probable misclassified objects (see discussion above), we selected only those with a magnetic field measured so far. Two of these stars (HD 62140 and HD 115708) were already proposed as roAp candidates by Ryabchikova et al. (2004), whereas for the latter object a preliminary investigation was presented by Semenko et al. (2008).

In addition to the sample compiled above, we also investigated CP objects not included in the used noAp references. We therefore queried the catalogue by Renson & Manfroid (2009), excluding questionable stars using their flags, and found about 220 additional stars with accurate parallaxes (error ≤15%) and sufficient photometry to estimate temperature and luminosity. However, only six of them are within the temperature domain of roAp objects (see Table 2). One of them (HD 21190) was already studied spectroscopically by González et al. (2008), but with a cadence of only three to four minutes. We therefore kept this object in our list and moved it to the compilation of already investigated ones, worth for a deeper follow-up investigation. This star is also a known δ Scuti variable (Koen et al. 2001), making it to an interesting target anyway. The small number of additional roAp candidates indicates that within the solar neighbourhood probably almost all roAp stars are already known.

Hence the sample of roAp stars can probably only be increased by a closer look at the objects given in Table 2. All the stars listed in Table 2 are closer than 300 pc, with distance errors less than about 20%, making them ideal targets to enhance the roAp sample for which accurate luminosities can be deduced, to be able to investigate their properties (pulsation period, amplitudes etc.) e.g. against parameters like mass or evolutionary stage in more detail.

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