ABSTRACT

Context. The 60 known rapidly oscillating Ap (roAp) stars are excellent laboratories to test pulsation models in the presence of stellar magnetic fields. Our survey is dedicated to search for new group members in the Northern Hemisphere.

Aims. We attempt to increase the number of known chemically peculiar stars that are known to be pulsationally unstable.

Methods. About 40 h of new CCD photometric data of 21 roAp candidates, observed at the 1 m Austrian-Croatian Telescope (Hvar Observatory) are presented. We carefully analysed these to search for pulsations in the frequency range of up to 10 mHz.

Results. No new roAp star was detected among the observed targets. The distribution of the upper limits for roAp-like variations is similar to that of previous similar efforts using photomultipliers and comparable telescope sizes.

Conclusions. In addition to photometric observations, we need to consolidate spectroscopic information to select suitable targets.

Key words. Stars: chemically peculiar -- variables: general

1. Introduction

The rapidly oscillating Ap (roAp) stars can be found within an area of the pulsational instability in the Hertzsprung-Russell diagram, between the zero-age main-sequence and terminal-age main-sequence, ranging in effective temperature from about 6600 K to 8500 K. They are characterized by overabundances of up to several dex of, for example, strontium, chromium, europium, and other rare-earth elements when compared to the Sun. The roAp stars show pulsational periods in the range of about 5 to 25 minutes with amplitudes of up to 10 mmag in Johnson $B$.

Since their first detection by Kurtz (1982), about 60 stars of this type have been discovered. Almost all members of this group have been found with ground-based photometric observations of known classical chemically peculiar (CP) stars. With the new high-precision space-based data, several new low-amplitude roAp stars have been detected (Holdsworth et al. 2014, and references therein). In addition to this, some roAp stars have been discovered by spectral line variations of elements such as cerium, neodymium, and samarium (Elkin et al. 2011).

Most, but not all, of the roAp stars exhibit strong global magnetic fields with values of up to 25 kG (Hubrig et al. 2012). Therefore, these stars are excellent test cases for studying the interactions between magnetic fields and stellar pulsation. The driving mechanism of their oscillations is most probably the classical $\kappa$-mechanism operating in the hydrogen ionisation zone (Balmforth et al. 2001). Recently, Cunha et al. (2013) suggested another excitation mechanism, however, where the pulsations are driven by the turbulent pressure in the convection zone.

We initiated a photometric survey to search for northern roAp stars at the Hvar observatory (Paunzen et al. 2012, Paper I). Together with the new observations, we collected 100 hours of time series in Bessell $B$ for 41 individual targets. Observations of three targets (Renson 1860, 58275, and 58777) were presented in both papers, but Renson 59590 is misclassified as a CP star. This left us with 40 potential roAp candidates. The accuracy of our data is similar to those of former, similar, efforts (Joshi et al. 2006). We did not detect any new roAp star, but were able to establish upper limits for variability.

2. Target selection, observations, and reduction

All targets were selected from the catalogue of Ap, HgMn, and Am stars by Renson & Manfroid (2009). Although most known roAp stars are classified as SrCrEu, we widened our list of targets to also include hotter spectral types, that is, silicon stars, to avoid missing any variables due to a bias in the selection process. In total, we selected 21 further objects for observations.

All observations were performed at the Hvar Observatory, University of Zagreb, using the 1 m Austrian-Croatian Telescope (ACT) with the following equipment:
Table 1. Basic data of the new target stars (upper panel), previously observed stars from Paper I (lower panel), and the results of the time-series analysis.

| Renson HD/BD/Tycho | V Spec | T eff [K] | σT eff [K] | E(B−V) [mag] | JD(start) [d] | Δt [min] | UL [mmag] |
|---------------------|---------|-----------|------------|-------------|--------------|----------|---------|
| 680 2852            | 8.954   | A5 Sr Eu  | 8700       | 190 (3)     | 0.16         | 1888.57737| 0.16    |
| 45762 162162        | 9.328   | A3 Sr Eu  | 7410       | 250 (4)     | 0.15         | 1892.27993| 0.22    |
| 45763 162177        | 8.645   | A4 Sr Eu  | 8190       | 310 (4)     | 0.22         | 1888.27779| 0.22    |
| 47940 +17 3622      | 8.821   | A2 Sr Eu Cr | 8720     | 160 (3)     | 0.01         | 1895.27950| 0.15    |
| 48750 174021        | 9.797   | F − Sr    | 7960       | 180 (3)     | 0.15         | 1887.20577| 0.15    |
| 49170 337282        | 9.419   | A0 Si     | 9440       | 300 (3)     | 0.10         | 1896.27083| 0.10    |
| 49830 +44 3622      | 9.944   | A3 Si     | 8820       | 380 (4)     | 0.10         | 1885.31381| 0.10    |
| 50160 344100        | 9.099   | A3 Si     | 8540       | 220 (3)     | 0.01         | 1887.36799| 0.01    |
| 50600 +35 3616      | 9.477   | F0 Sr Eu  | 8630       | 410 (3)     | 0.08         | 1899.33105| 0.08    |
| 50924 234924        | 9.473   | A2 Sr     | 9460       | 140 (3)     | 0.00         | 1892.35595| 0.00    |
| 52200 339199        | 10.142  | A0 Si Sr  | 9140       | 660 (3)     | 0.27         | 1888.42960| 0.27    |
| 52670 189919        | 8.980   | A1 Si     | 10180      | 490 (3)     | 0.00         | 1887.44724| 0.00    |
| 53542 192060        | 8.762   | A5 Y Sr   | 7770       | 230 (4)     | 0.14         | 1895.36030| 0.14    |
| 54440 332312        | 9.722   | A4 Sr     | 8200       | 580 (3)     | 0.17         | 1886.47754| 0.17    |
| 54800 196542        | 8.896   | A4 Sr Cr Eu | 8620     | 340 (4)     | 0.05         | 1895.43588| 0.05    |
| 55130 341037        | 9.435   | F0 Sr Cr Eu | 8040     | 160 (3)     | 0.03         | 1887.39451| 0.03    |
| 59590* +38 4163     | 11.123  | A7 Sr Si  | 8180       | 770 (3)     | 0.15         | 1887.51775| 0.15    |
| 59910 +46 3884      | 9.137   | F0 Cr Eu  | 7660       | 220 (4)     | 0.14         | 1888.50305| 0.14    |
| 59980 +62 2151      | 9.805   | A1 Sr     | 9370       | 250 (3)     | 0.21         | 1895.51014| 0.21    |
| 60972 +51 3678      | 9.984   | A2−       | 8910       | 210 (3)     | 0.00         | 1887.57091| 0.00    |
| 1860 7410           | 9.076   | A5 Sr Cr Eu | 7920     | 160 (3)     | 0.02         | 1879.49306| 0.02    |
| 58275 +46 3543      | 9.728   | A2 Si     | 8660       | 340 (3)     | 0.08         | 1887.39956| 0.08    |
| 58777 3982-4172-1   | 10.737  | A3 Sr     | 7930       | 410 (3)     | 0.19         | 1839.35921| 0.19    |

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 Figs. 1 and 2. (e) Probably misclassified, see text.

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- August, September, and October 2011: Apogee Alta U47 CCD camera, 1024x1024 pixels, a field of view of about 3′.
- August 2014: Moravian instrument, G2-1600 KAF1603ME CCD camera, 1536x1024 pixels, a field of view, using a focal reducer, of about 10′x8′.

The integration times for the observations in the Bessell B filter system were set to between 10 and 45 seconds, mainly depending on the brightness of the target and comparison stars as well as the seeing.

The data reduction and differential photometry were performed using the C-Munipack package. If several comparison stars were available, these were checked individually to exclude variable objects. We compared the results of the final differential light curves using the aperture photometry routine from IRAF. We found no differences above the photon noise.

The final light curves were examined in more detail using the program Period04 (Lenz & Breger 2005), which performs a discrete Fourier transformation. Significant peaks exceeding the noise level of more than 4σ with periods of more than one hour were subtracted. The results were checked with those from the phase-dispersion method computed within the program package Peranso. No significant differences were noticed.

1 http://c-munipack.sourceforge.net/
2 Available from http://iraf.noao.edu/
3 http://www.peranso.com/
3. Analysis and discussion

Figure 3 shows the distributions of the apparent brightness and effective temperature for the 40 investigated targets. The detailed observational dates and results of the Fourier time-series analysis for all targets are listed in Table I and shown in Figs. 1 and 2.

The effective temperatures were calibrated as described in Paper I. In short, they are mean values from different photometric calibrations and fitting the individual spectral energy distributions (SED). Almost all targets are between 8.5 and 10.5 magnitude in Johnson V. Taking into account the reddening values from Table I and corresponding isochrones (Bressan et al. 2012), a mean distance modulus of 8 mag (or a distance of 400 pc) places all targets between the zero- and terminal-age main-sequence. The range of effective temperatures is broader than the values of known roAp stars.

The distributions of the upper limits for roAp-like variations and the length of observation for the 45 individual data sets (about 100 hours, in total) are shown in Fig. 4. We compared the results of the time series limits with the distribution of the peak-to-peak variations of known roAp stars from Kurtz et al. (2006). The latter are also for B magnitudes. Additional later detected roAp stars were either found spectroscopically (e.g., Kochukhov et al. 2013) or are low-amplitude stars in a different filter (e.g., Holdsworth et al. 2014). No attempt was made to transfer amplitudes from other photometric system to B magnitudes. Figure 4 shows the comparison of both distributions. Nine known roAp stars exceed a peak-to-peak variation of 5 mmag. Therefore, we conclude that there might be bona-fide roAp stars among our sample that were not detected because of their low photometric amplitudes (several members do not even show photometric variation at all).

In the following, we discuss the results for some individual stars in more detail.

Renson 1860 and 58275: results for both stars were presented in Paper I. We re-observed them on four nights, each, to investigate their long-term (in)stability.
and currently listed as HD 399199 in Simbad. This ID is most likely a typographical error in Simbad/CDS, because the number exceeds the entries in the HD catalogues. The star is actually HD 339199 according to the catalogue by Fabricius et al. (2002), for example.

**Renson 54800**: This is a very interesting close binary system (separation of about 3") consisting of a CP1 and a CP2 star (Abt & Cardona 1984), for which Cowley & Cowley (1964) reported possible spectrum variability. The two components were not resolved, therefore our observations are for the combined flux.

**Renson 58777**: In Paper I, we stated that this is a good candidate for follow-up observations. Here, we present one additional data set (Fig. 2). No statistically significant variability with an upper limit of 2.9 mmag was detected. However, this limit is just 0.1 mmag lower than previously. Therefore, this star is still worthy of further follow-up observations.

**Renson 59590**: From the available photometry we conclude that this object is an early G-type dwarf. But it was classified as ‘A7 Sr’ by Zirin (1951). He listed a photographic magnitude of 8.5 mag, while $B/V$ is 12.09/11.12 mag, respectively. We checked some other listed magnitudes and compared them to more recent magnitudes for stars with similar spectral types (for example, HD 188854) and found an excellent agreement. In the vicinity of Renson 59590, there are no other bright stars of eighth to ninth magnitude, however. We conclude that there is probably a typographical error of the stellar designation in Zirin (1951). This object is certainly no CP star.

**Renson 59980**: The star is located in the area of the Cep OB3 association, but very probably a nonmember based on kinematic and photometric data (Kharchenko et al. 2004). The reddening of the star is lower than that of other members of the association (e.g., Garrison 1974), which confirms this classification.

### 4. Conclusions

We presented our efforts to search new northern roAp stars in two papers. In total, 65 individual data sets with about 100 hours of CCD photometry for 40 stars were analysed without detecting a statistically significant signal. The upper limits for the variability range are between 1 to 5 mmag with a peak at about 2 mmag.

Further high-precision photometric observations are needed to detect new roAp stars to initiate spectroscopic follow-up observations to model their stellar atmospheres in more detail (Nesvadba et al. 2013). As a first step, however, the only source for good candidate targets, the catalogue by Renson & Manfroid (2009), has to be consolidated and updated. In addition, even for bright stars, we lack modern classification resolution spectroscopy (Pauzen et al. 2011). We will continue our efforts to contribute to these different tasks in the future.

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Fig. 1. Fourier spectra of target star light curves first investigated for roAp oscillations in this paper.
Fig. 1. continued.
Fig. 2. Fourier spectra of the target star light curves previously investigated for roAp oscillations.