J. Astrophys. Astr. (2005) **26,** 203–211

HD 12098 and Other Results from Nainital–Cape Survey

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Abstract. Nainital–Cape Survey was started with an aim to search for new rapidly oscillating Ap stars in the northern hemisphere. We discovered one new mono-periodic roAp star HD 12098. The frequency separation of HD 12098 suggests a rotation period of 5.5 days for the star. We summarize here the observations of HD 12098 and briefly discuss the results of the multi-site observation campaign organized to resolve the ambiguity in the determination of the rotation period of HD 12098. Other interesting results like non-oscillating Ap stars discovered and two candidate stars in which roAp periodicity is seen but not confirmed are also discussed.

Key words. Stars: roAp stars—stars-individual: HD 12098—stars-individual: HD 207561—stars-individual: HD 17431—stars-individual: HD 25499—stars-individual: HD 38143—stars-individual: HD 38817.

1. Introduction

Nainital–Cape Survey is a program initiated with the main aim of detecting and studying new northern hemisphere rapidly oscillating Ap stars (roAp) stars. RoAp stars are short-period photometric variables with periods ranging from 5–21 minutes with typical amplitudes of few milli magnitude. Hence, the study of roAp stars requires a very stable site and atleast one meter class telescope. For these reasons, the 104 cm Sampurnanand telescope at ARIES, Nainital was selected for the survey. For a summary of the Nainital–Cape Survey, site characteristics and the facilities available at ARIES, Nainital for variable star research, see, Sagar & Mary (2005) in these proceedings.

Nainital–Cape Survey is an ongoing program. Till 2004, we have searched for short period variability in a total of 63 stars and detected rapid oscillations in HD 12098 (Girish *et al.* 2001) and δ Scuti oscillation in four stars (Joshi 2005). The selection of the candidate stars for the survey was made mainly on the basis of their Ap nature and Strömgren colours, and temperature whenever available. On the basis of known roAp stars, Matinez & Kurtz (1995) found that roAp stars fall in specific Strömgren colour space. To increase our chances of detecting new roAp stars, the candidates for the survey were selected mainly on these empirical limits on the six Strömgren colours. Since the limits are only empirical, the selection criteria is relaxed so as to include those stars which might lie just outside these limits. In fact one of the six Strömgren colours ($\delta m1$) of HD 12098, the first roAp star discovered under the survey falls outside of the corresponding limit.

Ap stars which share similar properties as that of roAp stars, but do not show rapid variability are called as non-oscillating Ap (noAp) stars. The noAp stars hold equal importance as the roAp stars for the understanding of roAp phenomenon. During survey, we found that three stars HD 25499, HD 38143 and HD 38817 fall under the category of noAp stars. The amplitude of variability, if any, is less than 0.2 mmag in these three stars in the frequency range 1–5 mHz. In addition, two stars HD 17431 and HD 207561 showed variability on a few nights, but the data are not enough to confirm variability in these stars. These results are discussed in the following sections.

2. Rapidly oscillating Ap stars

2.1 *HD 12098*

HD 12098 is the first roAp star discovered under the Nainital–Cape Survey. The star is a bright ($m_V = 7.9$) F0 star. The Strömgren colour indices of the star ($b - y = 0.191$, $m_1 = 0.328$, $c_1 = 0.517$ and $\beta = 2.796$, Hauck & Mermilliod 1998) combined with the de-reddened parameters estimated using the calibrations by Crawford (1975) falls within the empirical limits suggested for roAp stars except for δm_1. The discovery of roAp oscillations in HD 12098, hence extends the limits on δm_1 suggested by Martinez & Kurtz (1995) for probable roAp stars by a slight margin.

On the basis of Strömgren colours, HD 12098 was selected as a candidate for the survey and observed on the night of 21st November 1999. The discovery light curve plotted in Fig. 1 clearly shows variability around 7.1 minute. To confirm this variability, the star was observed on following nights.

The discovery and follow-up observations showed that the oscillation amplitude in HD 12098 varies from one night to the following night. This indicates plausible multi-mode oscillation and/or rotational modulation. To determine the nature of oscillation in HD 12098 it was observed on six nights continuously from Gurushikhar Observatory, Mt. Abu and Sampurnanand telescope, Nainital for a total of 65 hours.

The analysis of an individual nights' data clearly shows the modulation in the amplitude of oscillation. In roAp stars, the amplitude modulation can be caused either by the beating of close spaced periods and/or due to the rotation of the star explained by Oblique pulsator model (Kurtz 1982). To identify the nature of pulsations in HD 12098, we combined the data obtained from Mt. Abu on a common time scale and subjected

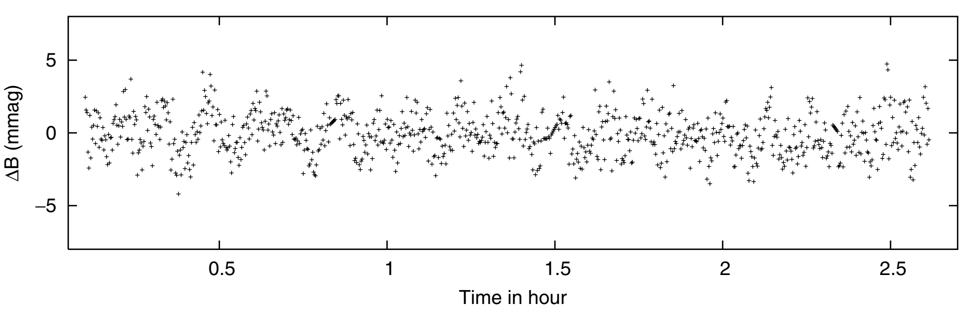

Figure 1. Discovery lightcurve of HD 12098 observed on the night of 21st November 1999. Each dot represents a 10-s integration.

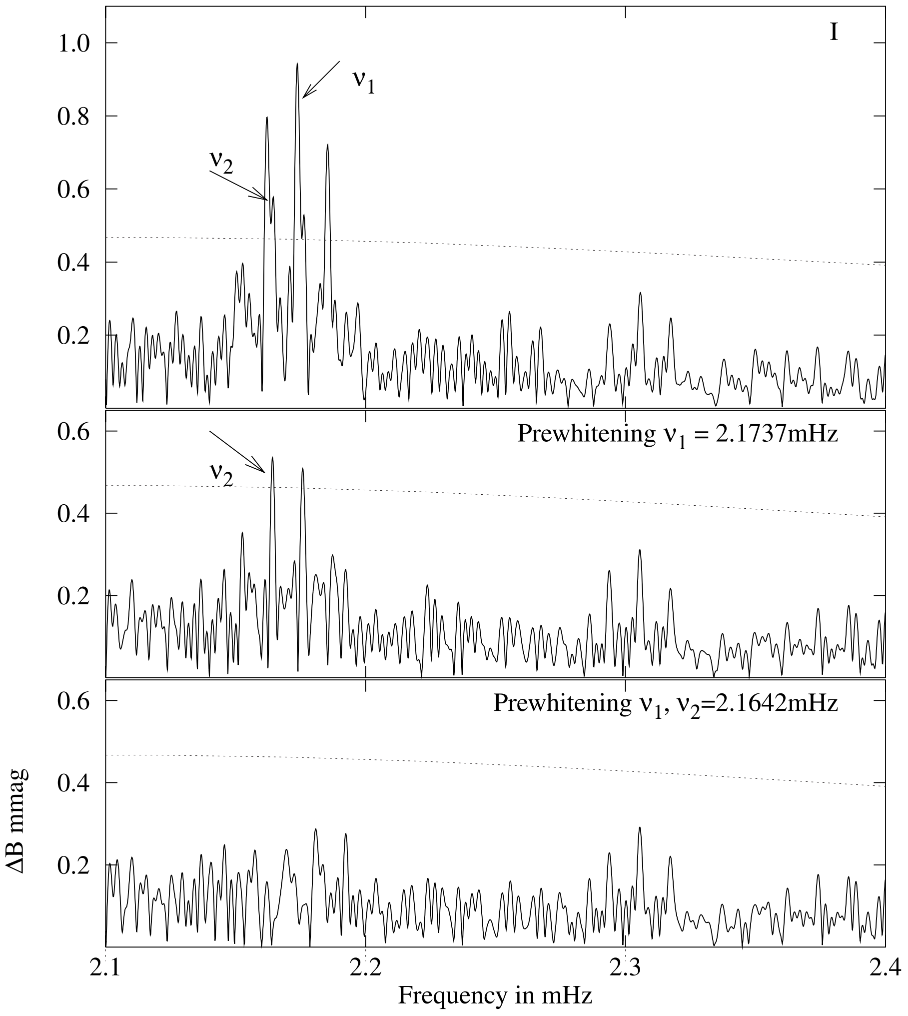

Figure 2. Amplitude spectra of the data obtained from Mt. Abu merged together. See text for details.

it to discrete Fourier transform (DFT). The resulting amplitude spectra shows a peak around 2.173 mHz. To avoid the identification of spurious peaks as real, the significance limit is set on the basis of local noise. The running average of amplitudes of a group of fifty frequencies are computed as the local noise assuming all the peaks in the data as noise. The significance level is set at four times the local noise level (see, Breger *et al.* 1996). Any peak lying above this limit is treated as being significant. In Fig. 2, this significance limit is shown as a dotted line.

In Fig. 2, we can see an unresolved frequency very close to the alias peak (marked ν_2). To recover this frequency and to check for any other peaks that might be buried under the main frequency at ν_1, we subtracted a noise-free sinusoid with the amplitude and frequency corresponding to that of ν_1 from the time series. This process is typically referred to as prewhitening. The residual data are subjected to DFT again. The resulting amplitude spectra is plotted in the second panel of Fig. 2. We can see two peaks at the 2.1641, 2.1759 mHz with almost the same magnitude. The frequency difference between the two corresponds to $1c/d$ suggesting that one of them is the alias of the second frequency. Typically the real frequency will be of a higher amplitude and the aliases will be of a lower amplitude. But, for low amplitude peaks near the noise level, this will not be true and it will not be possible to identify the real peak from the alias.

The second frequency ν_2 is interpreted as the rotationally split component of the main frequency ν_1 (Girish *et al.* 2001). Assuming that $\nu_2 = 2.1641$ mHz is the real frequency, the authors predict a rotation period of 1.22 day for HD 12098. Instead, if $\nu_2 = 2.1759$ mHz, then the rotation period will be 5.5 day. The magnetic field measurements (Wade *et al.* 2001) also favour the longer period.

2.2 *Multi-site campaign*

From the single site observations it is found that the second frequency is the rotationally split component of the oscillation frequency of HD 12098. However, the second frequency has a 1 cycle/day alias ambiguity.

With the main aim of resolving the ambiguity in determining the second frequency and hence, rotation period of the star, we organized a multi-site observation campaign on HD 12098 in October/November 2002. The campaign involved a total of eleven observatories with ten observatories finally contributing to the data. A total of 394 hours of useful data extending over 28 nights with 45% duty cycle were obtained.

From the analysis of the multi-site data, we obtained mainly five frequencies separated by $\delta\nu = 2.14 \pm 0.02$ mHz. We have already ruled out the plausibility of such a small difference arising due to independently excited modes (Girish *et al.* 2001). The equal separation of the frequencies seen in the multi-site data gives a rotation period of $\Omega = 5.41 \pm 0.05$ day for HD 12098. This is very close to the 5.5 day rotation period predicted by Girish *et al.* (2001) assuming $\nu_2 = 2.1759$ mHz as the real frequency instead of 2.1641 mHz. The amplitude modulation of the pulsation of the individual nights data also favours a period close to 5.41 day. The detailed observation and results of the multi-site campaign will be published elsewhere (Seetha S. *et al.* 2005).

3. Non-oscillating Ap stars

Non-oscillating Ap stars hold equal value in the understanding of the roAp phenomena. The systematic difference between the noAp stars and roAp stars will help us in identifying the reasons why some of the stars which share similar properties of roAp stars do not show oscillations. During our survey, we observed three Ap stars which fit in to noAp star category. We discuss these noAp stars briefly.

3.1 *HD 25499*

HD 25499 satisfies all the six Strömgren colours used for identifying probable roAp stars. The star was observed on six occasions for a total of nine hours and found to show no oscillations with an amplitude limit of 0.2 mmag in the frequency range of 1–5 mHz. The amplitude of oscillations if any, would be below 0.2 mmag at 3σ level. The lightcurve and the amplitude spectrum of HD 25499 observed on 10th November 2003 are plotted in Fig. 3 and Fig. 4 respectively.

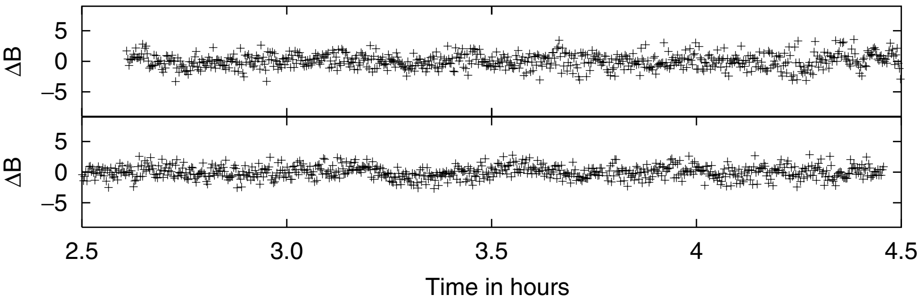

Figure 3. Lightcurve of HD 25499 observed on the night of 10th November 2003.

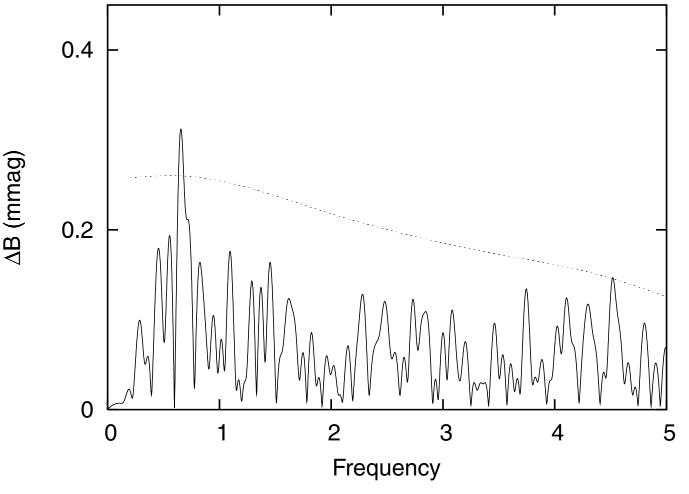

Figure 4. Fourier transform of the light curve of HD 25499 observed on 10th November 2003. The dashed curve represents three times the local noise level.

3.2 *HD 38143*

HD 38143 is classified as an A2 star whose Strömgren colour indices are well within the empirical limits suggested by Martinez and Kurtz (1995). The star was first observed on 23rd January 2000 and later, on three nights in 2002 and two nights in 2003 for a total of 22 hours. No variability is seen in all the runs with an amplitude limit of 0.3–0.4 mmag. The lightcurve of HD 38143 observed on 19th November 2003 is plotted in Fig. 5 with the corresponding amplitude spectra in Fig. 6. Our observations suggest that the star is a noAp star unless it has a very long rotation period of few years or the oscillations if any, have very small amplitudes (< 0.3 mmag).

3.3 *HD 38817*

HD 38817 is classified as an A2 star. Only three of the six Strömgren colours (H_β, m_1, dm_1) satisfy the limits suggested for a probable roAp star while one parameter, c_1 lies within 10% of the corresponding limiting value. The star was

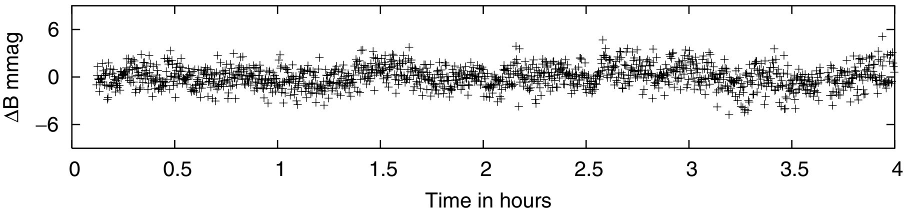

Figure 5. Amplitude spectra of HD 38143 observed on 19th November 2003.

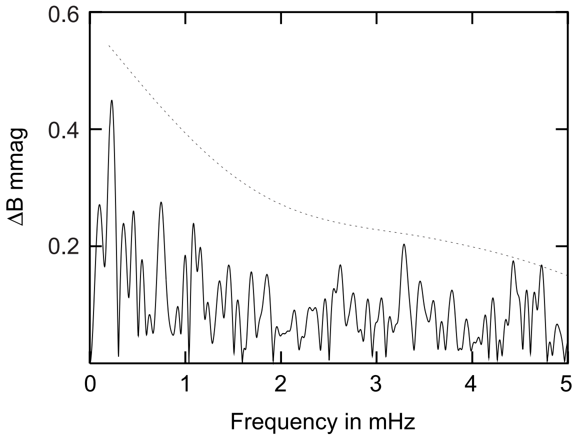

Figure 6. Amplitude spectra of lightcurve plotted in Fig. 5.

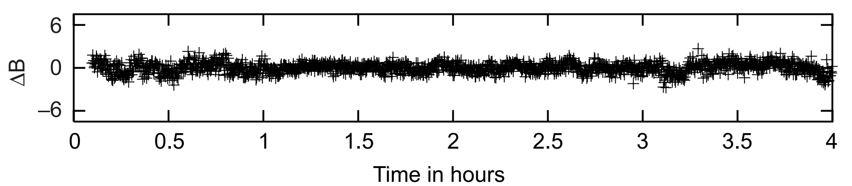

Figure 7. Lightcurve of HD 38817 observed on the night of 9th November 2003.

selected as a candidate star for Nainital–Cape Survey to check the possible extension of these limits, but turned out to be a non-variable at a limiting amplitude of 0.2 mmag. The star was observed for a total of 14 hours over four nights with the last three nights' observations extending for more than three hours each. The lightcurve and the corresponding amplitude spectrum of HD 38817 observed on 9th November 2003 are plotted in Figs. 7 and 8 respectively. From the analysis of the data we conclude that HD 38817 is a noAp star at a limiting amplitude of 0.4 mmag at 3σ confidence level.

4. Probable roAp stars

In the course of our survey, we observed variability in the frequency range of 1–5 mHz in two stars, HD 207561 and HD 17431. But, the data on hand are not sufficient to

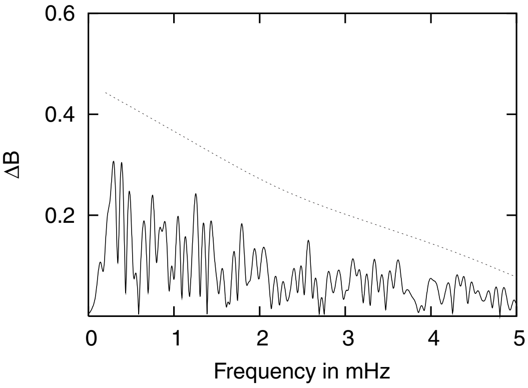

Figure 8. Plot of amplitude spectrum of the lightcurve plotted in Fig. 7.

confirm oscillations in these stars. HD 207561 is classified as an Am star and the detection of rapid variability will make it the first Am star showing roAp type variability. For the benefit of the others who may be interested in these stars, we briefly describe them.

4.1 *HD 207561*

HD 207561 is an F0 III star which falls well within the empirical limits for probable roAp stars (Martinez *et al.* 1995). The star was observed on 16th December 2000 for the first time and on several nights later. The lightcurve and the corresponding Fourier spectrum of HD 207561 obtained on two consecutive nights on 6th and 7th December 2002 plotted in Fig. 9 show regular variations which were absent in the comparison star data observed in the second channel. HD 207561 is classified as an Am star (Floquet 1975) and pulsations in this star if confirmed, will make HD 207561 the first Am star to show rapid oscillations similar to roAp stars.

Both the lightcurve and the amplitude spectrum of HD 207561 plotted in Fig. 9 clearly show regular variability around six minutes on two different nights. The absence of similar variation in the comparison star rules out the possibility of local effects. But the absence of the six minute period in the follow-up observations stops us in confirming rapid oscillations in the star. Also the period is very close to six minutes. Whenever periodicity of the integral multiple of a minute is detected, care should be taken to rule out the plausibility of drive error or other instrumental effects mimicking regular variability. Another likely reason for the non-detection of oscillations in the follow-up nights might be due to mis-identification of the star. However, the confirmation of the presence or absence of oscillations in HD 207561 will be important as it will make HD 207561 the first Am star with roAp type variability.

4.2 *HD 17431*

HD 17431 is classified as an A3 star. The Strömgren colour indices of the star satisfy all the six Strömgren parameters suggested for a probable roAp star. The star was first observed on the night of 9th October 2000. The Fourier transform of the data showed a

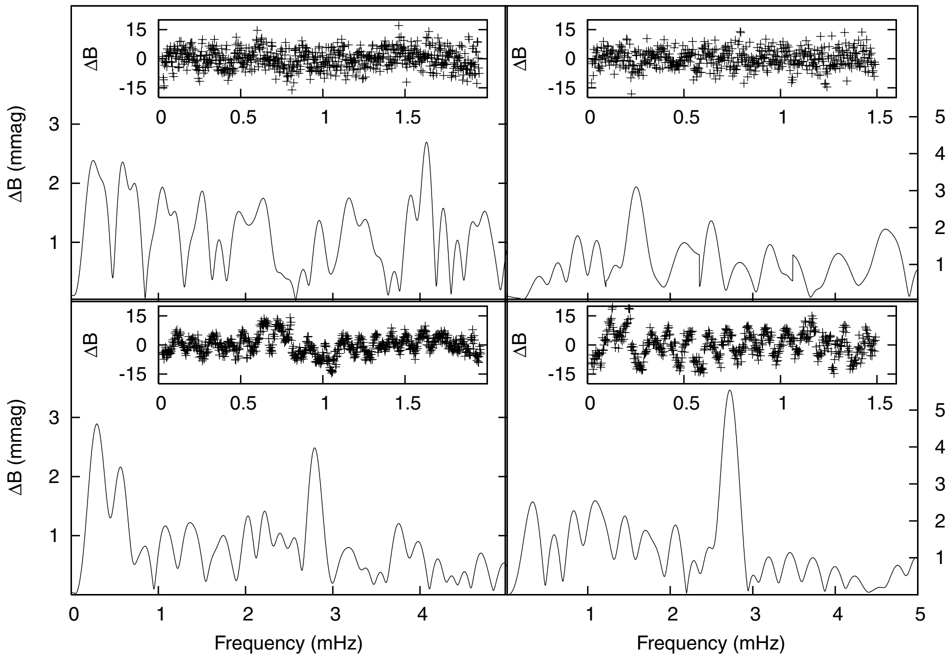

Figure 9. Amplitude spectrum of HD 207561 observed on the nights of 6th December 2000 (left panels) and 7th December 2000 (right panels). The top two panels show the plots of the comparison stars while the bottom panels correspond to HD 207561 data. A peak around 6.1 minute period is clearly seen in both amplitude spectrum and lightcurve of HD 207561 which is absent in the comparison star.

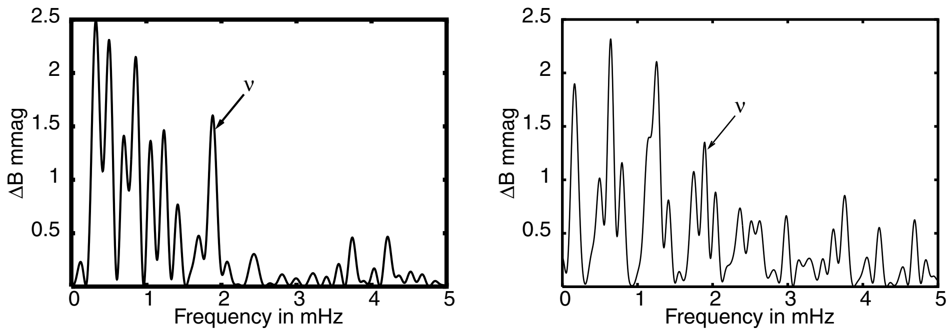

Figure 10. Amplitude spectrum of HD 17431 observed on 10th October 2000 and 6th December 2001. The peaks marked as ν correspond to $\sim$ 8.8 minutes.

peak around 8.8 minutes. A similar period was observed on the follow-up observations though not with very good signal except on 10th October 2000. In Fig. 10, we plot the amplitude spectrum of the data obtained on 10th October 2000 and 6th December 2001 which indicate the presence of a period around 8.8 minutes. Though, similar variability near this period is seen on few other nights, the nights were not photometric which prevents us from making any statement on this star.

5. Conclusions

We presented a brief summary of the main results of the Nainital–Cape Survey conducted from late 1999 to early 2004. During this period we have discovered one roAp star HD 12098 which is a single periodic oscillator. The amplitude modulation of the pulsation frequency and frequency splitting observed in HD 12098 suggest a rotation period of ~ 5.4 days for the star. We classify three stars HD 25499, HD 38143 and HD 38817 as non-oscillating Ap stars which can be useful in understanding the differences between roAp and Ap stars which share similar properties of roAp stars but do not oscillate. We also presented two interesting objects HD 17431 and HD 207561 which showed variability on few occasions. Further observations on the two may confirm the roAp variability in the two. The confirmation of oscillations in HD 207561 may be a very useful result as it will be the first Am star showing roAp type variability.

Acknowledgements

The author would like to acknowledge Dr. S. Seetha for the opportunity to work in the exciting field of roAp stars and who was also instrumental in organizing the multi-site campaign on HD 12098. Thanks are due to Prof. Ram Sagar for all the support at ARIES, Nainital. The author would like to acknowledge the help and support of Dr. Santosh and all the other observatory staff of ARIES, Nainital without whose help this survey would have been impossible.

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