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The Nainital–Cape Survey: A Search for Variability in Ap and Am Stars

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Abstract. The "Nainital–Cape Survey" program for searching photometric variability in chemically peculiar (CP) stars was initiated in 1997 at ARIES, Nainital. We present here the results obtained to date. The Am stars HD 98851, HD 102480, HD 13079 and HD 113878 were discovered to exhibit δ Scuti type variability. Photometric variability was also discovered in HD 13038, for which the type of peculiarity and variability is not fully explained. The null results of this survey are also presented and discussed.

Key words. Stars: Ap—stars: Am—stars: δ Scuti-individual: HD 98851 —stars: individual: HD 102480—stars: individual: HD 13079— stars: individual: HD 13038—stars: individual: HD 113878.

1. Introduction

A collaborative survey program for searching variability in Ap (A-peculiar) and Am (A-metallic) stars between the Aryabhatta Research Institute of Observational Sciences, Nainital (formerly State Observatory Nainital), India and the South African Astronomical Observatory (SAAO) Cape Town, South Africa, was initiated in 1997 (Seetha *et al.* 2001). Prior to the Nainital–Cape Survey, a total of 31 rapidly oscillating Ap (roAp) stars were known, among which 28 belong to the southern sky. In order to investigate whether the difference in the observed number of roAp stars in both hemispheres corresponds to a reality or to an observational bias, the present survey was initiated to search for photometric variability in Ap and Am stars. The scientific goals of this survey were:

- to find a fresh perspective on the questions of variability in Ap and Am stars;
- to search for variability in stars lying in the same part of H–R diagram as that for roAp and δ-Scuti stars;
- to search for variability caused by g-modes, p-modes, or both; and
- to search for rapid oscillations in Am stars.

A number of other variability surveys are currently being performed, see, *e.g.,* Dhorokova *et al.* 2005, in this issue. To optimize the chances of discovering new variable stars, the strategy adopted in the Nainital–Cape Survey was to select candidates with Strömgren photometric indices similar to those of the known roAp stars (Martinez *et al.* 1991).

The Ap stars are characterized by anomalously strong lines of Si, Sr, Cr, Eu and rare earth elements in their optical spectra (North 1993). The effective temperature range of these stars varies from 7000 to 16,000 K. These stars possess relatively high magnetic fields (typically of the order of 1 to 10 kG). Ap stars have slow rotational velocities (< 100 km sec^{-1}) as compared to normal A type stars which rotate with velocities in the range of 250 to 300 km sec^{-1}. The magnetic field strength, the strength of the spectral lines and the luminosity of Ap stars are all observed to vary periodically on time scales of days to several decades. This is explained with the help of the *oblique rotator model* (Stibbs 1950). The Ap stars showing photometric variability with periods in the range of $\sim$ 5–21 min are known as rapidly oscillating Ap or roAp stars. In contrast to Ap stars, Am stars are non-magnetic stars with enhanced lines of metals in their spectra, as compared to normal stars of the same spectral classes (Titus & Morgan 1940; Roman *et al.* 1948; Smith 1974). Am stars are the coolest among chemically peculiar stars and have temperatures in a range of $\sim$6500–10,000 K. The majority of (and possibly all) Am stars with spectral types later than A4 are members of spectroscopic binary systems with periods less than 100 days, whereas only a few normal A type stars are binaries with periods generally longer than 100 days. Some Am stars exhibit photometric variability similar to the δ Scuti stars, with periods from 18 min to as long as 7 hr.

This paper presents the results obtained from "Nainital–Cape Survey". The paper is organized as follows. Section 2 summarizes the observations and the data analysis. The five variable stars discovered during the survey are presented in section 3, while the null results are presented and discussed in section 4. Conclusions are given in the last section.

2. Observations and data analyses

Most of the results presented here are based on the photometric observations. For some stars, we also carried out complementary spectroscopic observations. The photometric observations of the Ap and Am stars were carried out with a three-channel fast photometer (Ashoka *et al.* 2001; Sagar 1999) attached to the 104 cm Sampurnanand telescope at ARIES. Using this photometer, one can observe the programme star, a nearby comparison star and the sky-background measurement. As all the program stars for the survey are bright ($m_v < 10$ mag), it is very difficult to find a comparison star of similar magnitude and colour in the same field of view. Therefore, most of the time we decided to use only a single channel. The data reduction process comprised of four steps:

(1) Visual inspection of the light curve to identify and remove all the bad data points.
(2) Apply correction for the coincidence counting losses.
(3) Measurement of sky brightness produced by interpolating the points with a piecewise linear function.
(4) Apply correction for the atmospheric extinction.

The time of the mid-points of the integrations were converted into Heliocentric Julian Dates (HJD) with an accuracy of 10^{-5} day ($\sim$ 1 sec). The reduced data thus comprises a time-series of HJDs and corrected magnitude with respect to the mean of that for the entire observations. The time-series data for all the objects were then analyzed using an algorithm (Kurtz 1985) based on Deeming's DFT for equally spaced data (Deeming 1975).

The low resolution spectroscopic observations (in the spectral range of 3500–7400 Å) were also carried out from ARIES. We used for that purpose a 1 k × 1 k CCD detector of $24\mu \times 24\mu$ pixel size mounted on the HR-320 spectrograph with a linear dispersion of ∼2.4 Å per pixel. The spectra were taken using a 300 lines/mm grating and a 3 mm circular aperture. The intermediate resolution spectroscopic observations were obtained from the Vainu Bappu telescope at Kavalur, using the Opto-Mechanics Research (OMR) spectrograph. In this case, a grating of 1200 lines/mm and 2.5 mm long slit was used for intermediate resolution spectroscopy, which yields a dispersion of 1.3 Å per pixel. Preliminary spectroscopic data analysis was performed using IRAF, developed by the National Optical Astronomy Observations (NOAO).

3. Results

3.1 *HD 98851*

HD 98851 is of the spectral type F1 with a visual magnitude of 7.4. The Strömgren photometric indices for this star are: $b - y = 0.199$, $m_1 = 0.222$, $c_1 = 0.766$ (ESA 1997). HD 98851 was observed for a total of 10 photometric nights. The two main periods of 75 min and 150 min were discovered by Joshi *et al.* (2000). Figure 1 shows one light curve of this star. The alternating high and low amplitude cycles indicate a nearly sub-harmonic period ratio of 2:1. Such a phenomenon was not known in any Am or δ Scuti stars and to our knowledge this was disovered for the first time. The complementary spectroscopic analyses show that HD 98851 is of spectral type F1IV (Joshi *et al.* 2003). A similar type of the light curve and identical periodicity was reported from Xinglong Station of the National Astronomical Observatory, China (NAOC), using a three-channel fast photometer attached to an 85 cm telescope (Zhou 2001).

3.2 *HD 102480*

HD 102480 has F1 spectral type and a visual magnitude of 8.40. The Strömgren photometric indices for this star are $b - y = 0.211$, $m_1 = 0.204$, $c_1 = 0.732$ (ESA 1997). Variability in HD 102480 was discovered and confirmed from ARIES by Joshi *et al.*

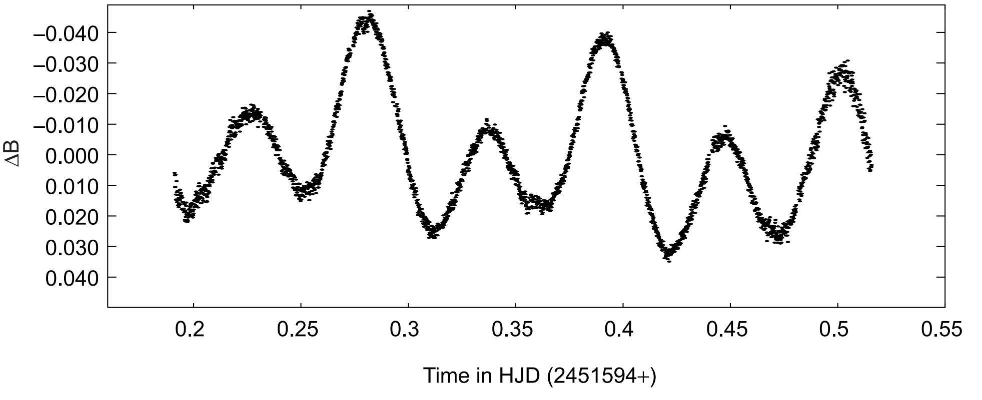

Figure 1. A light curve of HD 98851 obtained on HJD 2451594.

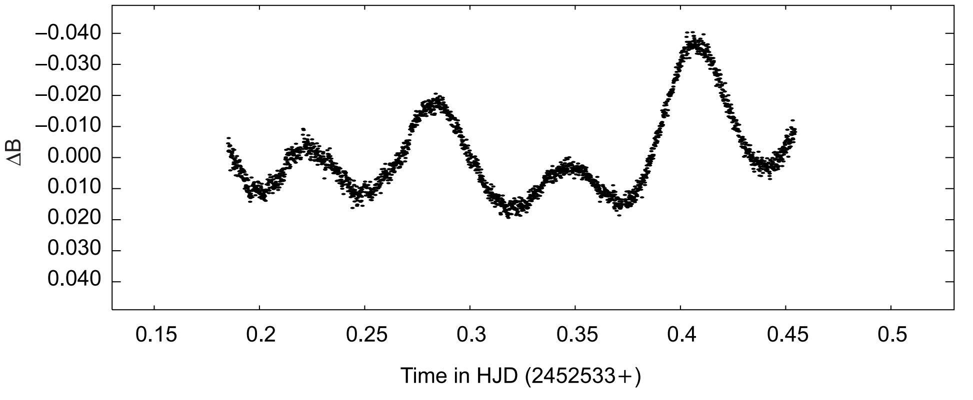

Figure 2. A typical light curve of HD 102480 obtained on HJD 2452533.

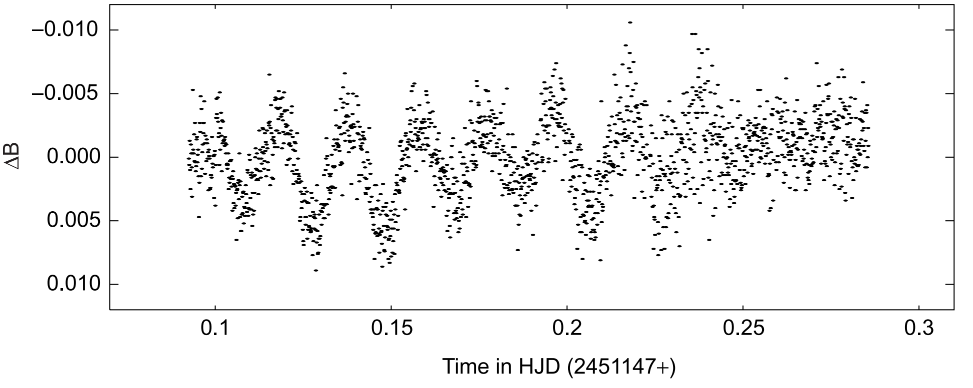

Figure 3. A typical light curve of HD 13038 obtained on HJD 2451147.

(2002). This star was observed for a total of 6 photometric nights. A typical light curve of this star is shown in Fig. 2. HD 102480 is pulsating with two main periods of 2.6 hr and 1.4 hr. The alternating high and low amplitude variations are similar to those of HD 98851. A nearly harmonic frequency ratio close to 2:1 is conspicuous. The complementary spectroscopic analyses shows that HD 102480 is of spectral type F3III/IV (Joshi *et al.* 2003).

3.3 *HD 13038*

HD 13038 is classified as a spectral type A3 star in the Henry Draper catalogue, having Strömgren colours $b - y = 0.105$, $m_1 = 0.220$, $c_1 = 0.848$ and $\beta = 2.86$ (ESA 1997). Variability in this star was discovered by Martinez *et al.* (1999a). HD 13038 was observed photometrically during 4 photometric nights from ARIES, see Fig. 3 for a typical light curve. This star is pulsating mainly with two close periods of 28 and 34 min. The amplitude modulation is caused by the beating of these periods, which lie between the typical pulsation period range of the roAp and δ Scuti stars. Recently, Elkin *et al.* 2005 have discovered a new luminous roAp star (HD 116114) with a pulsation period of 21 min, which is the longest period among all the known roAp stars.

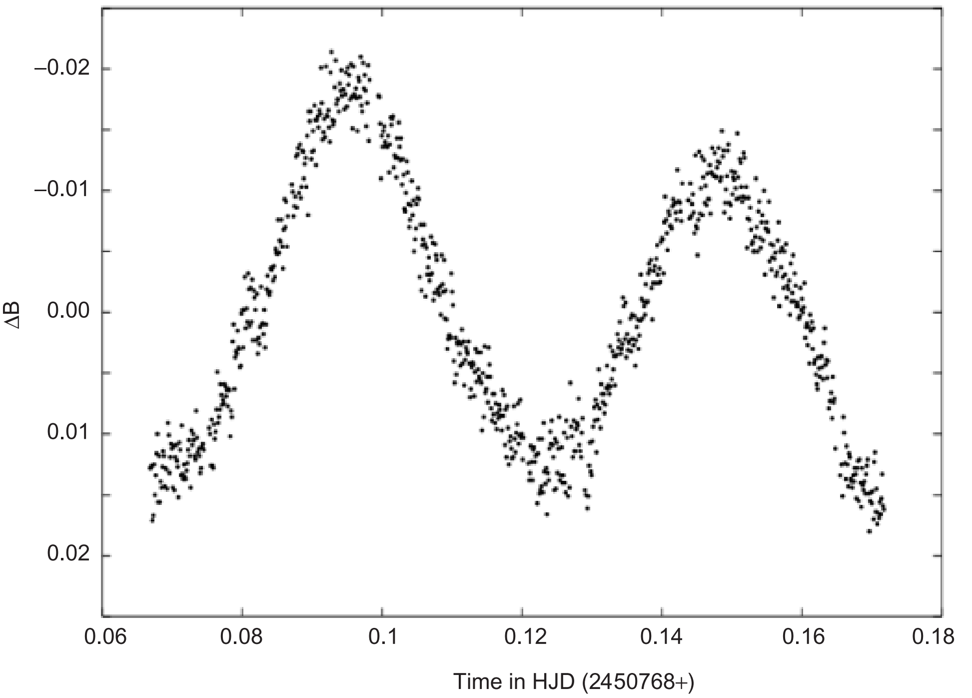

Figure 4. A typical light curve of HD 13079 obtained on HJD 2450768.

If HD 13038 is classified as an Ap star, then it will contribute in resolving a number of important questions related to the roAp and δ Scuti stars.

3.4 *HD 13079*

HD 13079 is a visual double star. The Hipparcos H_p magnitudes for the two components are 8.989 ± 0.007 and 11.31 ± 0.05. The spectral type of HD 13079 is F0, and the Strömgren photometric indices for the combined light of both stars are $b - y = 0.203$, $m_1 = 0.211$, $c_1 = 0.672$ and $\beta = 2.759$ (ESA 1997). HD 13079 was observed photometrically from ARIES and the Vainu Bappu telescope (VBT), for a total of 5 photometric nights. Figure 4 show a typical light curve of this star. The data analyses on HD 13079 show that this star is pulsating with a period of 78 min, which corresponds to a fundamental period of δ Scuti type variables. Spectroscopic analyses have shown that HD 13079 is an evolved Am star (Martinez *et al.* 1999b). The possible/probable change in the fundamental period will tell us more about the evolutionary state of this star, making this discovery very important from the asteroseismological point of view.

3.5 *HD 113878*

HD 113878 is a star of visual magnitude 7.8. The Strömgren photometric indices for this star are $b - y = 0.219$, $m_1 = 0.257$, $c_1 = 0.729$, $\beta = 2.45$ (ESA 1997). The spectral type of this star is F1/F3V/F3, on the basis of the CaII Kline, the H line and the metal lines respectively, suggesting that HD 113878 is a marginal Am star. HD 113878 was observed photometrically from ARIES, for a total of 8 photometric nights. The time-series analyses show that the star pulsates with a period of around 2.3 hr, which is again typical of δ Scuti stars, see Fig. 5 for a typical light curve. Abt (1984) has shown that the above stars HD 98851, HD 102480, HD 113878, as well as another one (HD 104202C) do not show the classical range of more than 0.5 spectral class between the K-line type and the metallic-line types. They are however classified as Am stars by their strong Sr II lines, weak λ4226 CaI line, and other indications of their general abnormality. Among these stars, HD 98851, HD 102480 and HD 113878 show photometric variability. The star HD 104202C has to be observed for variability. If this star exhibits variability patterns similar to the other three objects, then these variable stars

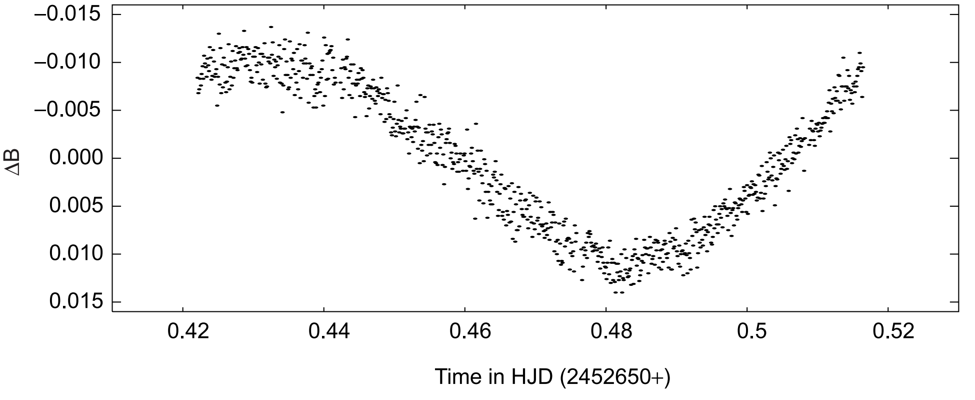

Figure 5. A typical light curve of HD 113878 obtained on HJD 2452650.

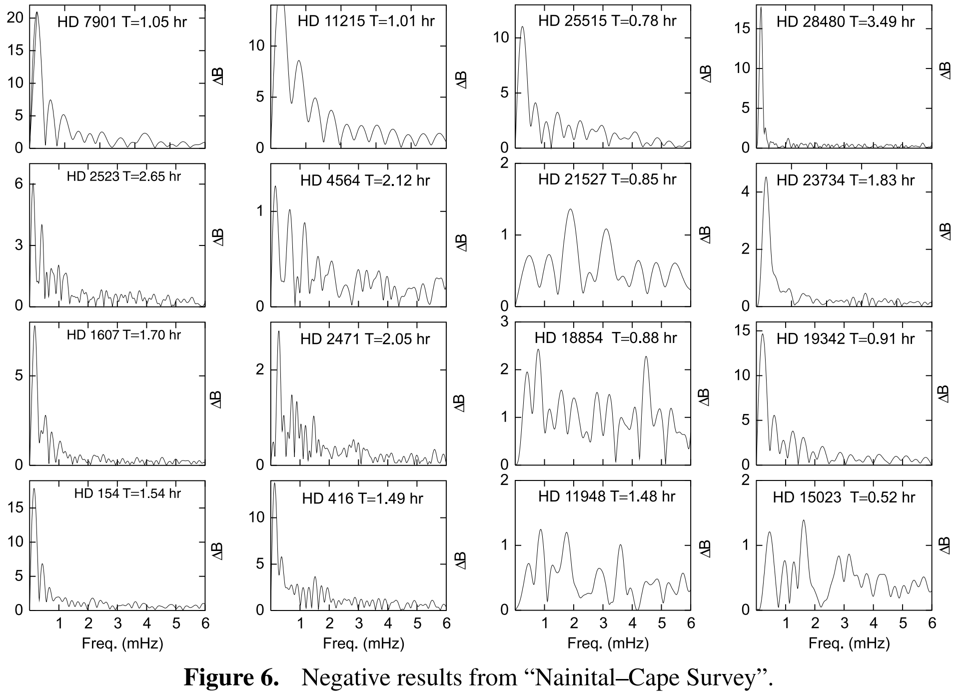

Figure 6. Negative results from "Nainital–Cape Survey".

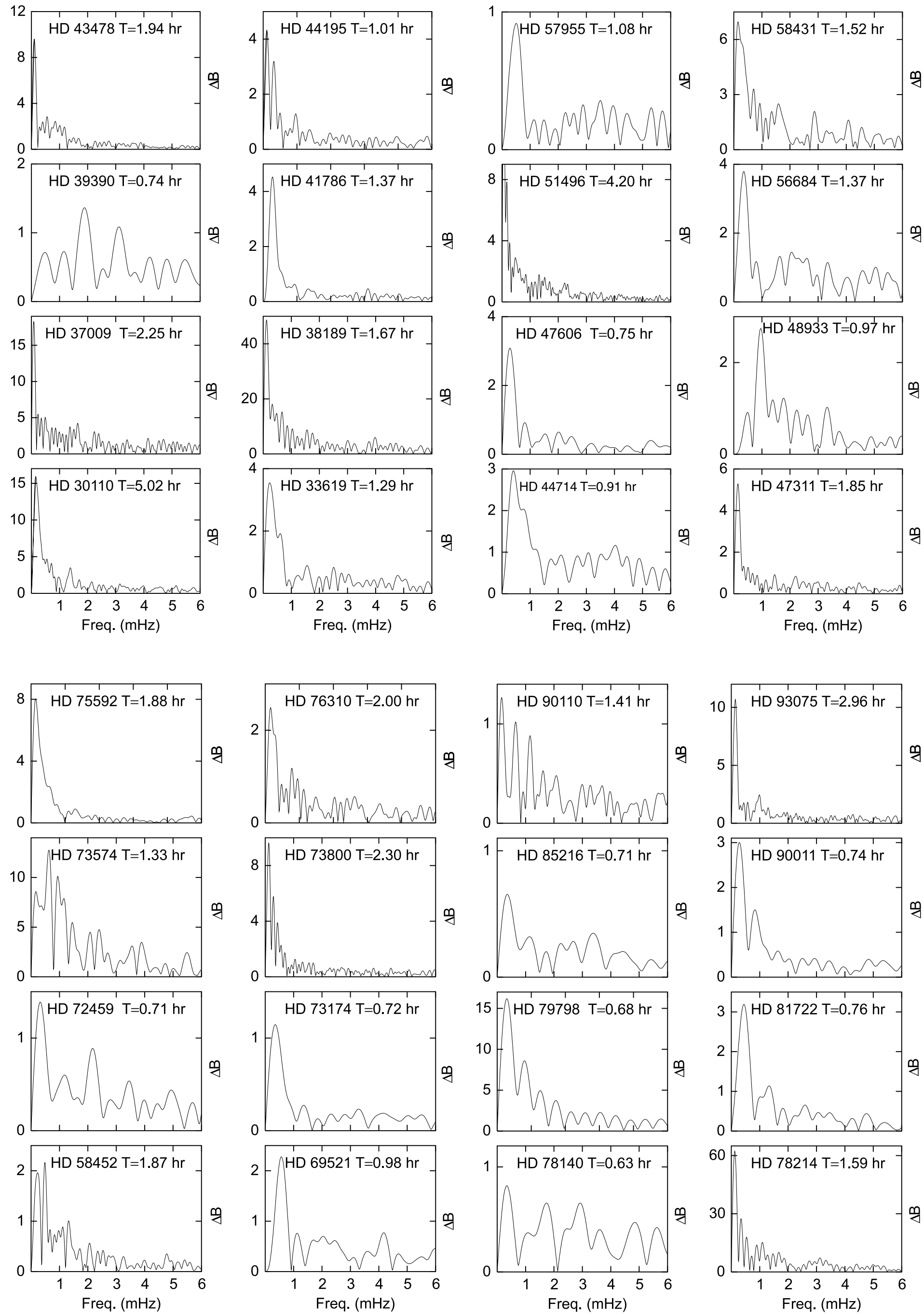

Figure 6. (*Continued*)

will have a great importance towards the field of asteroseismology of peculiar stars. HD 104202C is, therefore an interesting candidate for the ongoing Nainital–Cape survey for Ap and Am stars.

4. Null results

The amplitude spectra of the other 48 candidates are shown in Fig. 6. Each panel covers the frequency range 0–6 mHz and an amplitude range of several milli-magnitude, depending upon sky background and scintillation noise. We caution that the appearance of a star in our list of negative results does not exclude it from being a variable star. The star may have been non-variable for the duration of these particular observations, or the noise level was sufficiently high to hide the variability. Apart from this, it must be kept in mind that the peak corresponding to the main frequency in the roAp pulsation spectra can appear and disappear on a time scale of days (Handler 2004). Furthermore, the beating between close frequencies may interfere destructively to hide the variability. Hence, these results can be used as an informative reference, but all these stars should be observed again in future to check for variability. The Nainital–Cape survey is an on-going project. In addition to the main-sequence stars – Ap and Am stars – luminous peculiar stars have been included in our list of variable candidates, according to the "p" peculiarity criterion defined by Masana *et al.* (1998).

5. Conclusions

HD 98851 and HD 102480 are variables with unusually high overtones having nearly harmonic (or sub-harmonic) period ratios of 2:1. Two close pulsation periods in HD 13038 (28 min and 34 min), with a beat period of 2.78 hr have been observed. HD 13079 appears to be an Am star pulsating in the fundamental mode with a period of 78 min. A δ Scuti type variability was discovered in HD 11378, with a period of approximately 2.3 hr. All the negative results of our observations have been presented and can be used as an informative reference for further observations.

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