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New pulsating variables discovered from the Naini Tal-Cape survey

S. Seetha[1], B. N. Ashoka[1], Santosh Joshi[2], V. Girish[1], Ram Sagar[2], U.S. Chaubey[2], S.K. Gupta[2]
[1] *ISRO Satellite Centre Airport Road, Bangalore 560 017*
[2] *State Observatory, Manora Peak, Naini Tal 263 129, Uttaranchal*

Abstract. The Naini Tal-Cape survey has been initiated to search for pulsations in chemically peculiar A and F type stars. Many of the magnetic A peculiar type stars exhibit rapid oscillations with periods ranging from 4-16 minutes. These stars are termed as rapidly oscillating Ap stars (roAp) stars. The oscillations are attributed to low order, high overtone p modes. In addition to the Ap stars, this region of the HR diagram also encompasses the non-magnetic 'Am' or metallic lined stars. Some of these Am stars exhibit low overtone δ Scuti type pulsations. The scientific motivation for a study of these oscillations is discussed along with the results on the variables discovered from the survey.

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1. Introduction

There are several classes of chemically peculiar (CP) main sequence stars (Wolff 1983). One of them is the A peculiar (Ap) stars, also termed as CP2 stars which exhibit surface overabundance of rare earth elements like Sr, Cr, Eu, etc. along with high magnetic field $\approx$ few kiloGauss and have effective temperatures in the range 7000 - 10000K.

In these stars the rotation period is observed as mean brightness modulation typically of the order of fractional magnitude. The magnetic field and spectrum also often indicate variations exhibiting the same period. They have been explained in terms of the oblique rotator model where the magnetic field axis of the star is inclined to its rotation axis (Wolff 1983 and references therein). The photometric and spectral variations are caused by the surface abundance of the rare earth elements predominantly around the magnetic poles, and as the star rotates about the rotation axis the magnetic field, brightness and the spectrum vary due to the varying aspect. In the early 1980s however, it was found that a subset of these Ap stars also exhibit pulsations with periods in the range of 4-16 minutes and amplitudes of few millimag (see Kurtz, 2000 for a review). This subset of Ap stars is termed rapidly oscillating Ap stars or roAp stars.

The pulsations are interpreted to be nonradial p modes of low degree ($l < 3$) and high overtone ($n \gg l$). The similarity of these pulsations and the evolutionary status of the roAp stars with respect to the corresponding properties of the Sun will be extremely useful to study the effects of strong magnetic field and surface abundance on stellar pulsation theory. Several of these stars exhibit multiple frequencies and a spacing of these frequencies could be due to odd/even l values or consecutive n values (Kurtz 1990 and references therein). The identification of the modes can lead to asteroseismological studies of these stars and hence provide fundamental properties like mass, luminosity and inclination of the magnetic field axis of these stars.

Out of the 32 known roAp stars 28 are in the southern hemisphere since most were discovered from the South African Astonomical Observatory (SAAO). A few surveys were also undertaken in the northern hemisphere to discover roAp stars and have met with limited success (Seetha et al, 2001 and references therein). These stars are fairly bright with apparent V magnitude < 11. The survey can be conducted with a one metre class telescope, located at a photometric site and attached with a photometer preferably consisting of three channels. The period range of 4-16 minutes is also conducive enough to be observed within a single night. The pulsations are in the frequency range of 1 mHz and above, hence it is necessary that the transparency of the observing site be steady in order to detect the pulsations. The location of the State Observatory, Naini Tal satisfies these criteria (Sagar, 1999). A survey to search for new variables amongst northern hemisphere CP stars was initiated between astronomers in India and South Africa. The collaborative initiative is between the State observatory of Naini Tal and the ISRO Satellite Centre at Bangalore on the Indian side and the SAAO and the University of Cape Town from the South African side. The survey was started in 1997 and regular observations have been conducted since 1999 (Martinez et al, 2001).

2. Observations

One week per month of observing time is allotted around full moon, at the 104 cm Sampurnanand telescope of State Observatory, Naini Tal. The observational responsibility is predominantly shared by two (SJ and VG) of us. A minimum of two channel photometer is used for the simultaneous measurement of (star + sky) and (sky) independently. A three channel photometer is preferred with simultaneous measurement of an additional comparison star. As the acquisition and centering of a comparison star in the second channel increases overhead on the observing time, hence the comparison star measurement is conducted only during follow-up observations of a likely variable.

Continuous photometry through Johnson B filter for about 1-2 hours is conducted on any given target with an integration time of 10s. About 7-8 objects thus can be surveyed during a night. However, in many cases the pulsations may not show up in a single night observation because the amplitude of the oscillation undergoes modulation i) due the change in aspect of the pulsation axis with respect to the line of sight during a rotational cycle ii) due to multiple modes beating together and thus reducing the effective amplitude observed. Hence at least 3-4 sets of observations for every object are required on different nights before a star can be classified as a variable or a nonpulsator. The targets for observations are chosen based on the Strömgren temperature and color indices of the stars (Seetha et al. 2001). In case a target star is found to be variable, further follow-up observations are conducted. These are usually long term observations conducted probably for a week, to study the overall variation of the pulsational amplitude and to confirm the existence of any other frequencies with lower amplitudes. Follow-up observations are conducted with a three channel photometer (Ashoka et al, 2001) and simultaneous monitoring of a comparison star is performed in order to estimate transparency variations. At the end of the single site follow-up observations, spacing of multiple periods may still not be resolved due to aliasing caused by breaks in observations. This may further necessitate an additional multisite campaign.

3. Results

Four variables have been discovered so far from this survey. The details of the observations and results of these newly discovered pulsators are provided in this section.

3.1 Rapidly oscillating Ap stars

HD 12098: A new variable, HD 12098, was discovered in 1999, and it is the first and only roAp star discovered from the survey till now (Girish et al, 2001). This star is a far northern star with coordinates RA(2000) 02h 00.7m ; Dec(2000). 58.5 degree. It has a magnitude of $m_V \approx 7.97$ and its magnetic field is of the order of 2kG (Wade et al. 2001). During our observations in 1999, we detected a period of around 7.7 minute. The day to day variation in the amplitude was indicative of beating of more than one period and/or a rotation period of a few days. Figure 1 shows a panel of Fourier transforms (FT) of this object on different days. Based on these results we carried out a weeklong follow-up observations during Oct 18-24, 2000 using the 1.2 metre telescope at Gurushikhar, Mt. Abu. With the combined data sets of 7 nights we could resolve 2 independent frequencies. The main frequency was still at 2.174 mHz corresponding to a period of 7.67 minutes and an amplitude of 0.93 mmag. The second frequency could be either 2.164 mHz or 2.176 mHz. These being 1 day aliases of each other and since both have an amplitude of about

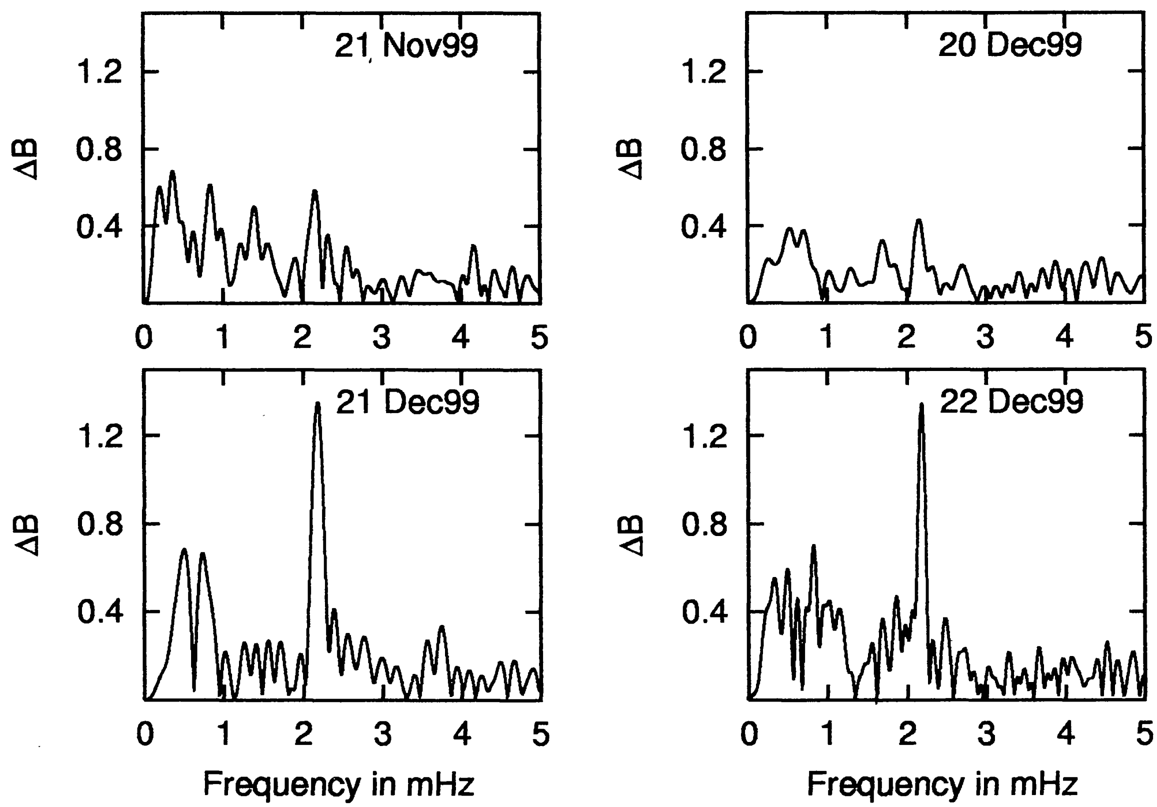

Figure 1. The Fourier transforms of HD 12098 showing the amplitude modulations.

0.5 mmag the real peak cannot be identified with our data set (Girish et al, 2001). The most likely interpretation of the transform is that the star is an oblique rotator and the second frequency is the rotational sidelobe of the main frequency. This implies a rotational period of ≈1.2 day or 5.5 day depending on which frequency is the rotational sidelobe.

We propose to determine the rotation period of the star independently by UBV measurements. A multisite campaign is also planned for Oct 2002, which may provide an answer not only to the rotational period of the star but also to the presence of additional low amplitude frequencies in the system.

3.2 Other variables

Apart from Ap stars, there exist in the same part of the HR diagram other stars which are slightly different in their spectroscopic or variability characteristics. Since the spectral classification of these stars may not be perfect and also since the selection criteria for the roAp stars is not very stringent, often variables of other types are also detected during our search for roAp stars.

Am stars: The Am stars have similar temperatures as roAp stars but do not have any measurable magnetic field. They too exhibit spectral peculiarity but of a different kind. The spectral classification of Am stars is based on Ca II and metal lines which differ by more than 5 subclasses. The periods they exhibit are usually longer, of the order of few tens of minutes, and are attributed to low degree delta Scuti type pulsations.

δ Scuti Stars: Whereas the Am and Ap stars are identified spectroscopically, δ Scuti stars are classified based on their variability. They are usually normal A or B stars without any peculiarity. These stars pulsate predominantly in the fundamental mode with successive overtone values. A few of them also exhibit nonradial pulsational modes.

The additional three variables discovered from this survey belong to the above two categories. The observations are detailed below.

HD 13079 Discovered as a pulsator on November 12/13, 1997, it indicates pulsations around 80 minutes. Further observations from Naini Tal and Kavalur, confirm that the pulsation frequency is 18.39 cycles d^{-1} (78.3 min) (Martinez et al, 1999). Figure 2 (top panel) shows a light curve and FT for the star. Spectroscopic observations conducted with the 91 cm telescope at Catania Astrophysical Observatory confirms that the effective temperature of the star is 7200 K. The Calcium lines are underabundant implying that it is likely to be an Am star.

HD 98851 Discovered as a pulsator in January, 2000, it is likely to be a marginal Am star as per catalog (Abt 1984). It exhibits a double humped profile. The Fourier transform of the light curve indicates frequencies at 0.11 and 0.22 mHz. (Joshi et al, 2000). Figure 2 (middle panel) shows a light curve and FT of the same. The ambiguity as towhich of frequencies is fundamental, is yet to be resolved, commensurate with the Hipparcos results. Spectroscopic measurements are planned to obtain H_β values to obtain an independent measure of temperature.

HD 13038: Classified as an A3 star, it exhibits strong line blanketing. Discovered as a variable with a period of 28.7 min.(Ashoka et al 2000), it is unique because this period is short compared to δ Scuti stars but too long compared to a roAp star. Amplitude modulation within a night is indicative of close multiple periods. Figure i2 (bottom panel) shows a llight curve and FT of the star. Further observations have been conducted in Nov. 2001, from Gurushikar Observatory. The data is under analysis.

4. Conclusions

The Naini Tal-Cape survey has so far resulted in the discovery of four new variables. We propose to conduct rotation period measurements as an independent programme. Mul-

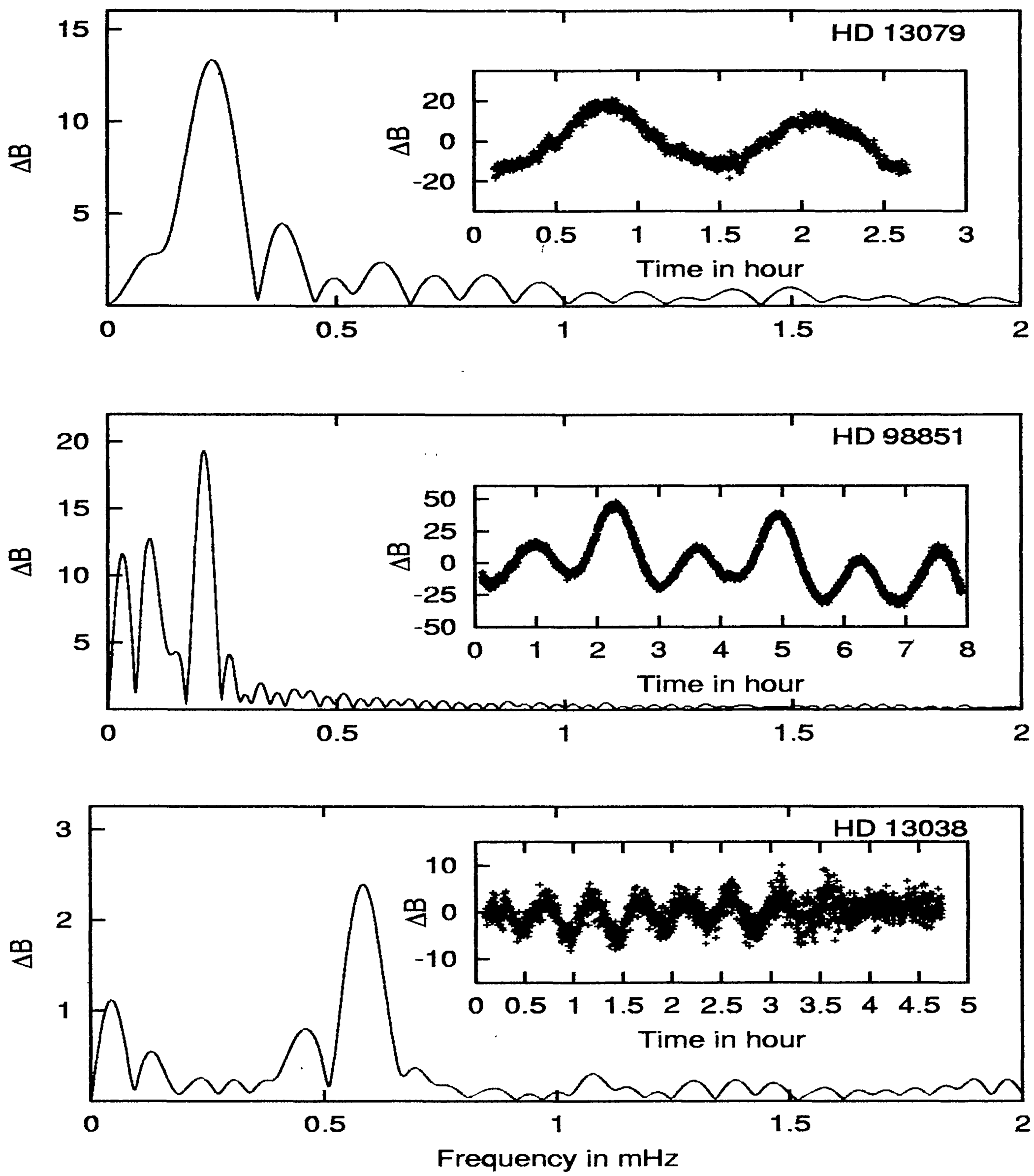

Figure 2. Lightcurve and FT of the other three variables discovered in the Naini Tal-Cape survey

tisite campaigns are also planned for the interesting variables where asteroseismological studies are likely to provide stellar parameters.

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