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Discovery of unusual pulsations in the cool, evolved Am stars HD 98851 and HD 102480

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ABSTRACT

The chemically peculiar (CP) stars HD 98851 and HD 102480 have been discovered to be unusual pulsators during the 'Naini Tal–Cape Survey' programme to search for pulsational variability in CP stars. Time series photometric and spectroscopic observations of these newly discovered stars are reported here. Fourier analyses of the time series photometry reveal that HD 98851 is pulsating mainly with frequencies 0.208 and 0.103 mHz, and HD 102480 is pulsating with frequencies 0.107, 0.156 and 0.198 mHz. The frequency identifications are all subject to 1 d^{-1} cycle count ambiguities. We have matched the observed low-resolution spectra of HD 98851 and HD 102480 in the range 3500–7400 Å with theoretical synthetic spectra using Kurucz models with solar metallicity and a micro-turbulent velocity of 2 km s^{-1}. These yield $T_{\rm eff} = 7000 \pm 250$ K, $\log g = 3.5 \pm 0.5$ for HD 98851 and $T_{\rm eff} = 6750 \pm 250$ K, $\log g = 3.0 \pm 0.5$ for HD 102480. We determined the equivalent H-line spectral class of these stars to be F1 IV and F3 III/IV, respectively. A comparison of the location of HD 98851 and HD 102480 in the HR diagram with theoretical stellar evolutionary tracks indicates that both stars are about 1-Gyr-old, 2-$M_\odot$ stars that lie towards the red edge of the δ Sct instability strip. From comparison between the observed and calculated physical parameters, we conclude that HD 98851 and HD 102480 are cool, evolved Am pulsators. The light curves of these pulsating stars have alternating high and low amplitudes, nearly harmonic (or subharmonic) period ratios, high pulsational overtones and Am spectral types. This is unusual for both Am and δ Sct pulsators, making these stars interesting objects for further observational and theoretical studies.

Key words: stars: chemically peculiar – stars: individual: HD 98851 – stars: individual: HD 102480 – δ Scuti.

1 INTRODUCTION

The chemically peculiar (CP) stars lying in the temperature range $7400 \leqslant T_{\rm eff} \leqslant 10\,200$ K are identified by the presence of anomalously strong (and/or weak) absorption lines of certain heavy and rare-earth elements in their spectra. Two main classes of peculiarities are recognized among CP stars in the spectral range B5 to F5. The first class comprises the peculiar A type stars, designated as 'Ap', whose spectra are characterized by overabundances of Si, Mn, Cr, Sr and rare-earth elements. The other class comprises the metallic line stars, designated as 'Am' stars, whose spectra are characterized by an underabundance of Ca (and/or Sc) and/or an overabundance of the Fe group and heavier elements with respect to normal stars of same colour. Am stars with spectral types based on metallic lines and the Ca II K-line differing by five or more subclasses are called classical Am stars; otherwise they are called marginal Am stars (designated as 'Am:').

About 30 per cent of the stars in the lower classical instability strip with luminosities ranging from the zero age main sequence (ZAMS) to about 2 mag above the main sequence, with spectral types in the range late A to early F, and with masses of 1.5–2.5 $M_\odot$ are δ Sct stars. These stars pulsate in radial and/or non-radial p (and possibly g) modes driven by the κ mechanism, with periods between 30 min and 8 h and amplitudes varying from a few mmag to almost a magnitude.

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Table 1. Data for HD 98851 and HD 102480 taken from Hauck & Mermilliod (1998), Abt (1984) and ESA (1997).

Star	α_{2000}	δ_{2000}	m_v (mag)	$B–V$ (mag)	$V–I$ (mag)	$b–y$ (mag)	m_1	c_1	Sp. type based on K/H/metal lines
HD 98851	$11^h22^m48^s$	$31°49'32''$	7.40	0.33 ± 0.00	0.39 ± 0.01	0.199	0.222	0.766	F1/F1IV/F3
HD 102480	$11^h\ 47^m\ 52^s$	$53°00'54''$	8.40	0.36 ± 0.01	0.42 ± 0.02	0.211	0.204	0.732	F2/F4/F4

In the spectral range A to F, almost 70 per cent of non-CP stars are δ Sct variables at the current level of sensitivity. Most non-variables are Am stars. Therefore, the discovery of δ Sct pulsations in Am stars is very important because this type of pulsation and anomalous abundance are known to coexist in very few stars. Among the CP stars which exhibit δ Sct pulsations are several luminous, cool, evolved Am stars. The pulsations in evolved Am stars and marginal Am stars lying near the red edge of the instability strip are accounted for within the diffusion hypothesis; ZAMS Am stars are predicted not to pulsate (Turcotte et al. 2000). For a recent review of the different classes of CP stars and a discussion of pulsation in the presence of metallicism, the reader is referred to Kurtz & Martinez (2000), Kurtz (2000) and references therein.

To search for pulsations in the CP stars, we started the 'Naini Tal–Cape survey' in 1997 November (Ashoka et al. 2000; Martinez et al. 2001, and references therein). During the survey the CP stars HD 13038, HD 13079, HD 98851 and HD 102480 have been discovered to be new δ Sct pulsating variables, while HD 12098 has been discovered to be a rapidly oscillating Ap star. The pulsation properties of HD 13038 (Martinez et al. 1999a), HD 13079 (Martinez et al. 1999b) and HD 12098 (Girish et al. 2001) have been reported earlier while those of HD 98851 and HD 102480 are presented here.

Joshi et al. (2000) discovered two main periods of 75 and 150 min for HD 98851. These pulsations were confirmed by Zhou (2001) with independent observations taken from the Xinglong Station of the National Astronomical Observatory, Chinese Academy of Sciences (NAOC). The spectral classifications of HD 98851 and HD 102480 are F1/F1IV/F3 and F2/F4/F4 on the basis of K-line, H-line and metal lines, respectively (Abt 1984). These classifications, as well as the presence of strong Sr II lines, weak Ca K-line, and other indications of general abnormality confirm that HD 98851 and HD 102480 are marginal Am stars. Here we present the new high-speed photometric and low-resolution spectroscopic observations of HD 98851 and HD 102480. The basic physical parameters and colour indices of both stars are given in Table 1. They are taken from Hauck & Mermilliod (1998), Abt (1984) and ESA (1997).

2 PHOTOMETRIC OBSERVATIONS

High-speed photometric observations of HD 98851 and HD 102480 were obtained using a three-channel fast photometer (Ashoka et al. 2001; Gupta et al. 2001) attached to the f/13 Cassegrain focus of the 104-cm Sampurnanand telescope of the State Observatory, Naini Tal. All the observations from Naini Tal were acquired as continuous 10-s integrations through a Johnson *B* filter. A photometric aperture of 30 arcsec was used to minimize light losses due to seeing fluctuations and tracking errors. We used the photometer in the single-channel mode as we were primarily searching for rapid oscillations in CP stars in the period range of 4–16 min, which is typical for rapidly oscillating Ap (roAp) stars. The observations were interrupted for occasional sky background measurements to take account of changes in sky brightness during the night. The observations reported here were carried out during photometric sky conditions. While single-channel high-speed photometry is not the ideal technique for studying the longer periods found in δ Sct stars, under good photometric conditions, it has been shown to be adequate. Indeed, the light curves in Figs 1 and 2 show this.

HD 98851 was also observed from NAOC, China, on two consecutive nights using a three-channel fast photometer attached to the 85-cm Cassegrain telescope. These observations comprised continuous 10-s integrations through a Johnson *V* filter, also with an aperture of 30 arcsec. Unlike the Naini Tal observations, these were simultaneous three-channel observations of HD 98851, a comparison star, SAO 62526, and the sky background.

Complete details of the photometric observations carried out from Naini Tal, India, and NAOC, China, are listed in Table 2. The data are available from the first author of this paper on request. The first column of Table 2 lists the name of the star, the second column

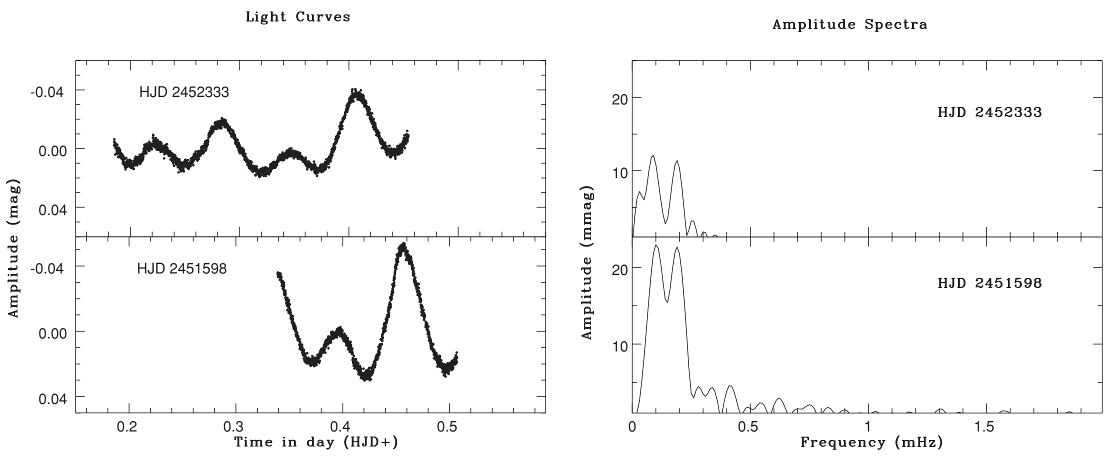

Figure 1. The Johnson *B* light curves of HD 102480 and their corresponding amplitude spectra. The upper panels are for 2002 February 27 (HJD 2 452 333) and the lower panels for 2000 February 23 (HJD 2 451 598). Both light curves were taken at Naini Tal. The amplitude spectra show two prominent peaks at 0.09 and 0.19 mHz.

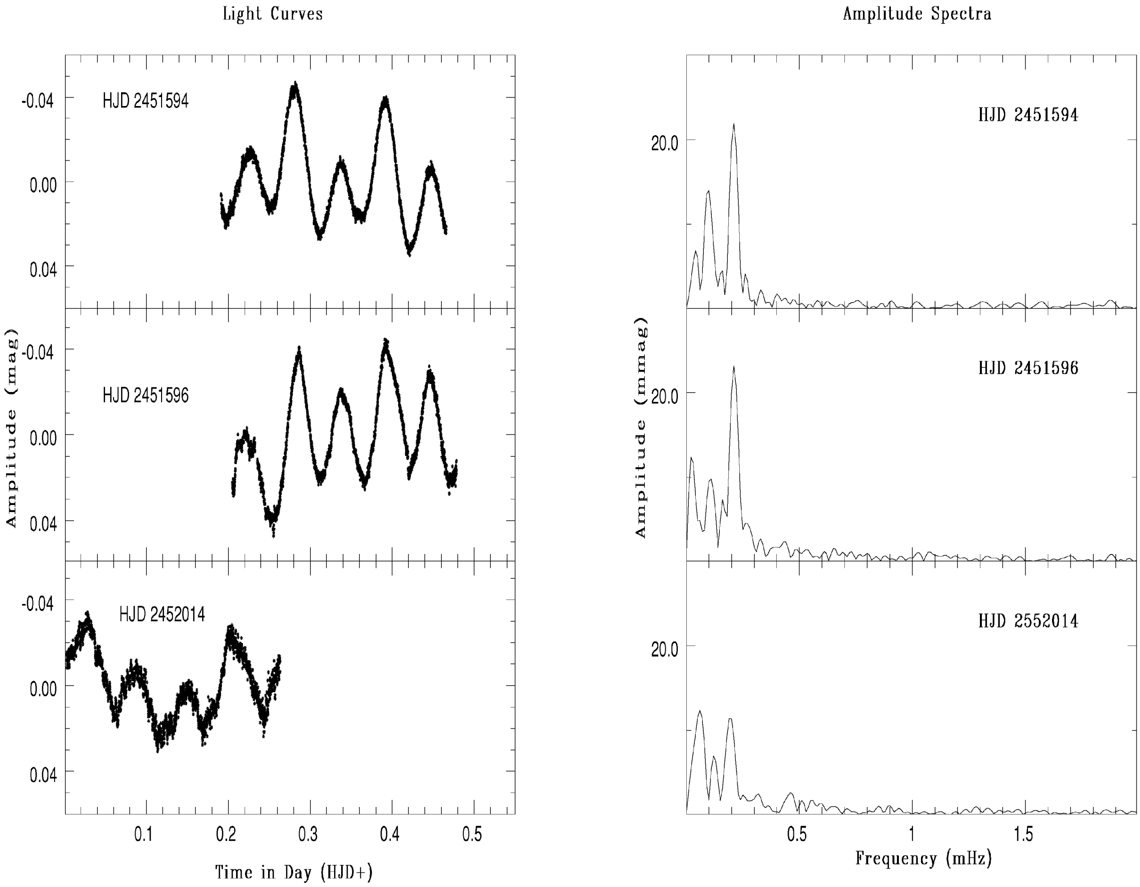

Figure 2. Typical light curves of HD 98851 and their corresponding amplitude spectra. The top two panels are the light curves obtained in Johnson *B* from Naini Tal. The third panel shows the Johnson *V* data from Xinglong.

lists the Universal Time (UT) date on which the observations were obtained, the third column lists the Heliocentric Julian Date (HJD) of the start of each run, the fourth column gives the total duration of observations in hours and the fifth column lists the total number of 10-s integrations obtained. The sixth column lists the passband of the observations. The seventh and eighth columns list the frequency and amplitude of the dominant oscillations detected in a given light curve, as described in Section 4. The photometric observations of HD 98851 taken from the NAOC are marked with asterisks; the rest are Naini Tal observations. In total, observations were obtained on 10 nights for HD 98851 and six nights for HD 102480. Most of the observations spanned more than one hour on a given night, thus covering at least one cycle of the variation.

3 PHOTOMETRIC DATA REDUCTION

The photometric data reduction procedure was standard and consisted of the following steps: dead-time correction to the count rates, subtraction of the linearly interpolated sky background at the time of each observation and extinction correction as a function of air mass. The HJD at the mid-point of each integration was calculated to an accuracy of 10^{-5} d ($\sim$1 s). Some typical light curves of HD 102480 are shown in Fig. 1 along with their amplitude spectra. The light curve obtained on HJD 2451598 is about 4 h duration, while the light curve obtained on HJD 2452333 is around 6 h duration. For both light curves, it is clear that there is more than one frequency present in the data. In fact, the alternating high and low amplitude cycles are indicative of the nearly-harmonic relation of the two highest amplitude frequencies.

Fig. 2 shows the light curves and the corresponding amplitude spectra of HD 98851 on three different nights. The light curves obtained on HJD 2451594 and HJD 2451596 are from Naini Tal, while that of HJD 2451014 is from NAOC. The presence of amplitude modulation is clear in all the light curves. The alternating high and low amplitude cycles are indicative of a nearly-harmonic relation of the two highest amplitude frequencies. This is very similar to the light curves seen for HD 102480 in Fig. 1, but is not at all typical of δ Sct stars in general.

4 FREQUENCY ANALYSIS

The time series data for both objects were analysed for periodic signals using a fast algorithm (Kurtz 1985) based on Deeming's discrete Fourier transform (DFT) for unequally spaced data (Deeming 1975). We adopted the criterion given by Breger et al. (1993) that a peak in the amplitude spectrum is intrinsic when the signal-to-noise (S/N) ratio is greater than 4; this can be lowered to 3.5 for multiperiodic variables.

The first step of our analysis was to inspect the DFTs for each individual light curve where the dominant frequency was identified. To identify other frequencies present in the data, a sinusoid, $A_1 \cos(2\pi f_1 t + \phi_1)$, corresponding to the dominant frequency, amplitude and phase was subtracted from the time series, a process we call 'pre-whitening.' The residuals to this fit were then used to compute

Table 2. Journal of observations of HD 98851 and HD 102480. On the two nights marked with asterisks the data were taken from NAOC, China, while on other nights they were taken from Naini Tal, India.

Star	UT date	HJD start of the run	Duration (h)	Total points	Filter	Freq. (mHz)	Amp. (mmag)
HD 98851	2000-01-24	2 451 568.365 43	0.81	294	*B*	0.23 ± 0.15	23.1
	2000-01-28	2 451 572.387 51	3.20	1155	*B*	0.16 ± 0.07	17.7
						0.06 ± 0.04	7.4
	2000-02-17	2 451 592.283 38	3.88	1400	*B*	0.20 ± 0.04	21.4
						0.05 ± 0.03	11.5
	2000-02-19	2 451 594.191 16	7.38	2660	*B*	0.21 ± 0.02	21.9
						0.10 ± 0.02	12.9
						0.13 ± 0.02	4.1
	2000-02-21	2 451 596.205 08	6.90	2484	*B*	0.21 ± 0.02	24.4
						0.11 ± 0.02	12.5
						0.03 ± 0.02	10.5
	2000-03-15	2 451 619.242 05	2.42	1169	*B*	0.19 ± 0.07	11.9
						0.07 ± 0.06	5.0
	2000-03-18	2 451 622.236 41	3.33	1201	*B*	0.06 ± 0.05	25.4
						0.21 ± 0.06	21.1
						0.11 ± 0.06	12.3
	2000-03-23	2 451 627.160 90	3.36	1212	*B*	0.19 ± 0.05	27.9
						0.12 ± 0.06	12.2
	2001-04-13*	2 452 013.012 64	6.68	2408	*V*	0.11 ± 0.03	16.8
						0.06 ± 0.03	13.9
						0.18 ± 0.02	7.6
	2001-04-14*	2 452 014.002 96	7.12	2564	*V*	0.06 ± 0.05	12.4
						0.20 ± 0.03	10.3
						0.12 ± 0.02	7.6
HD 102480	2000-01-19	2 451 563.411 89	0.95	343	*B*	0.20 ± 0.04	30.5
	2000-02-23	2 451 598.339 02	3.89	1400	*B*	0.10 ± 0.04	23.0
						0.19 ± 0.03	22.7
	2000-02-24	2 451 599.192 78	6.98	2684	*B*	0.16 ± 0.02	15.9
						0.10 ± 0.02	23.5
						0.20 ± 0.03	10.0
	2000-03-16	2 451 620.221 34	3.53	1269	*B*	0.19 ± 0.04	19.3
						0.07 ± 0.03	7.6
						0.13 ± 0.03	5.0
	2002-02-27	2 452 333.185 16	6.25	2249	*B*	0.09 ± 0.04	12.1
						0.19 ± 0.02	11.4
	2002-03-03	2 452 337.172 80	7.30	2628	*B*	0.10 ± 0.02	22.3
						0.18 ± 0.02	16.0

the DFT again, and the resulting dominant frequency was identified as f_2. The pre-whitening procedure was repeated until the residuals were judged to be only noise, or the remaining amplitude, even if real, was not identifiable with a particular frequency. The frequencies and the corresponding amplitudes thus obtained are listed in columns 7 and 8 of Table 2. We have listed here only the prominent frequencies. All these Fourier transforms are 'raw' transforms in the sense that no low-frequency filtering to remove sky transparency fluctuations was applied to the data, other than a correction for mean extinction. Inspection of the nightly amplitude spectra for both stars shows that all the signal power is contained in the range 0.0–0.5 mHz.

We analysed the frequency content of the data of both stars in a variety of ways but, for the sake of clarity, we will discuss only the most instructive analysis performed for each star. The data for each star were analysed in single nights, in groups of closely spaced nights, and as a whole. Although the combined full data sets had the highest frequency resolution, they also had the most complex window patterns, because of the sampling gaps in the data. Figs 3 and 4 present the particular data subsets for HD 98851 and HD 102480 which we found most instructive.

Fig. 1 shows two typical light curves of HD 102480, together with their amplitude spectra. There is a clear indication in these spectra of the presence of two main frequencies, $f_1 = 0.09$ mHz and $f_2 = 0.19$ mHz, of varying amplitude. Fig. 2 shows three typical light curves for HD 98851 and their amplitude spectra. The presence of at least two frequencies ($f_1 = 0.20$ mHz and $f_2 = 0.10$ mHz) of variable amplitude is indicated. To define these frequencies better, and to search for other frequencies present in the data, we computed the DFTs of combined data sets for each star in groups of consecutive, or closely spaced nights with long light curves. The iterative pre-whitening procedure described above was repeated until no more window patterns could be identified above the level of the noise in the amplitude spectrum.

Fig. 3 shows the analysis of three nights spanning 2451592–96 for HD 98851. Three frequencies were identified in these data. The frequencies f_1 and f_2 are real oscillations in the star, but our measurements of these frequencies suffer from a 1 d^{-1} alias ambiguity. The frequency f_3 is *very* tentative because, at such low frequencies, we cannot discriminate between real oscillations in the star and sky transparency variations in these single-channel data. We mention f_3 only because it appears in a number of the nightly amplitude

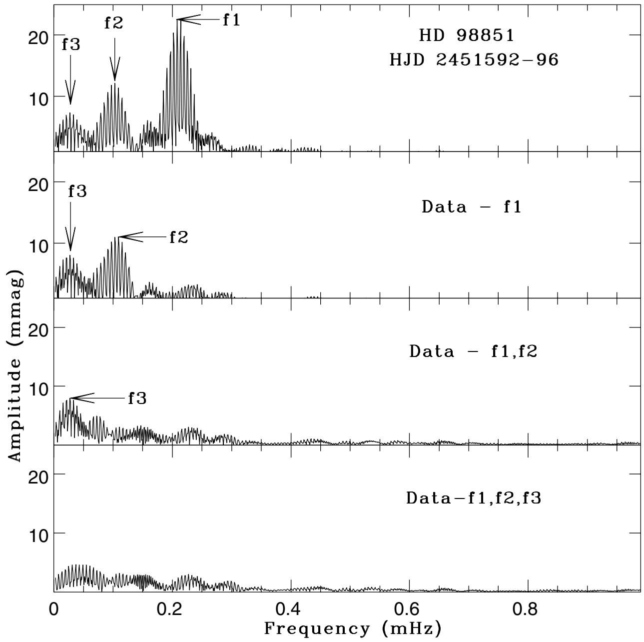

Figure 3. Identification of the frequencies present in HD 98851 for the combined data from nights JD 2 451 592–96, given in Table 2. The top panel shows the DFT for the data set. The subsequent panels display the DFT after successive pre-whitening of the frequencies f_1 to f_3 given in Table 3.

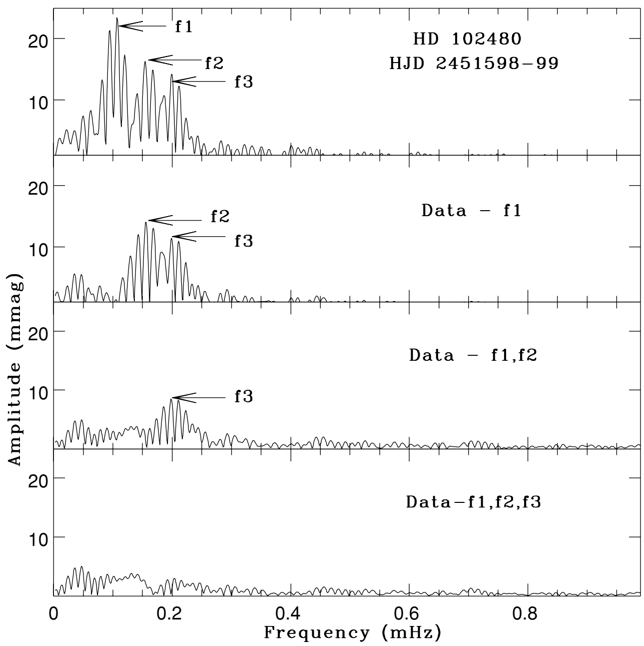

Figure 4. Identification of the frequencies present in HD 102480 for the combined data from nights JD 2 451 598–99, given in Table 2. The top panel shows the DFT for the data set. The subsequent panels display the DFT after successive pre-whitening of the frequencies f_1 to f_3 given in Table 3.

spectra listed in Table 2, and because we wish to draw attention to the need for a differential photometric study of the variations in HD 98851. Fig. 4 shows the analysis for the two nights 2451598–99 for HD 102480. In this star, too, our frequency identifications suffer from 1 d^{-1} alias ambiguities, particularly in the cases of f_2 and f_3.

The frequencies thus identified for both stars were fitted simultaneously to the combined data by the linear least-squares method, which assumes that the frequencies are perfectly known and adjusts the amplitudes and phases. The function

$$B = A_i \cos[2\pi f_i(t - t_0) + \phi_i]$$

was fitted by the least-squares method, where t_0 was taken as the time of first observation of the combined data set (Table 2). The fitted amplitudes and phases, along with their errors, are listed in Table 3. We caution that the frequencies listed in Table 3 are all subject to 1 d^{-1} cycle count ambiguities in the present study. A more extensive study would reduce these ambiguities, but to eliminate them altogether, a multisite campaign is necessary.

5 NEW SPECTROSCOPIC OBSERVATIONS AND DATA REDUCTION

To measure the effective temperatures and surface gravities of HD 98851 and HD 102480, we obtained low-resolution spectroscopic observations with the 104-cm Sampurnanand telescope (f/13) of the State Observatory, Naini Tal on 2002 April 18. We used a $1K \times 1K$ CCD detector and the HR-320 spectrograph, giving a linear dispersion of ~2.4 Å per pixel. The spectra were taken using a 300 line mm^{-1} grating and a 3-mm circular aperture. We covered a spectral range of 3500–7400 Å. Apart from the spectrophotometric standards, we also observed two standard stars of similar spectral type, HR 5447 (F2V) and HD 140283 (F5).

The spectroscopic data reductions were performed using the IRAF[1] software package (Tody 1993). To estimate the accuracy of the spectral data we determined synthetic Johnson *V* magnitudes for HD 98851 and HD 102480. Standard Kurucz models (Kurucz, private communication) with solar metallicity and microturbulent velocity of 2 km s^{-1} were used to match the observed spectra by normalizing the flux at 5500 Å. We considered our spectra to have zero reddening. The best matched T_{eff} and log g parameters for both stars are tabulated in Table 4. The best matched Kurucz models in both lines and continuum are shown in Fig. 5 along with the observed spectra. The log g estimates for both stars indicate that they are giants or subgiants of luminosity class III/IV.

On comparing our spectra with the observed stars of similar spectral type we estimate that HD 98851 and HD 102480 are of spectral type F1 and F3, respectively. In Fig. 5 it is notable that the Ca II H and K lines are weak compared to the Kurucz models, supporting the Am classification of these stars. We also estimated the equivalent spectral type by using the calibration of Schmidt-Kaler (1982) with the absolute colour (*B–V*) and T_{eff}. This comparison is consistent with our spectral types of F1 and F3 for HD 98851 and HD 102480, respectively, with luminosity class III or IV for both stars. Abt (1984) classified HD 98851 and HD 102480 with a Ca II K-line type, Balmer line type, metal line type as Am(F1/F1 IV/F3) and Am(F2/F4/F4), respectively; our spectral type estimates are in good agreement with his.

[1] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

Table 3. Simultaneous least-squares fits of the three most prominent frequencies fitted simultaneously to the JD 2451592–96 data for HD 98851 (top) and the JD 2451598–99 data for HD 102480 (bottom).

Star data set	Freq. (mHz)	Amp. (mmag)	ϕ (rad)	t_0 (d)
HD 98851	0.208 ± 0.001	22.35 ± 0.12	−2.37 ± 0.01	2 451 592.283 38
JD 2451592–96	0.103 ± 0.002	11.19 ± 0.12	−1.26 ± 0.01	
	0.027 ± 0.002	8.03 ± 0.11	−1.79 ± 0.02	
HD 102480	0.107 ± 0.002	20.77 ± 0.14	2.82 ± 0.01	2 451 598.339 02
JD 2451598–99	0.156 ± 0.002	12.50 ± 0.14	−1.49 ± 0.01	
	0.198 ± 0.003	9.28 ± 0.15	−3.08 ± 0.02	

Table 4. The physical parameters of HD 98851 and HD 102480 determined using our spectroscopic data and *Hipparcos* data.

Object name	T_{eff} (K)	log g (cgs)	Spectral type	Distance (pc)	m_v (mag)	M_{bol} (mag)	log $(L/\mathrm{L}_{\odot})$	$M/\mathrm{M}_{\odot}$	$R/\mathrm{R}_{\odot}$
HD 98851	7000 ± 250	3.5 ± 0.5	F1IV	171 ± 25	1.2 ± 0.3	1.1 ± 0.3	1.5 ± 0.1	2.2 ± 0.2	3.6 ± 0.6
HD 102480	6750 ± 250	3.0 ± 0.5	F3III/IV	240 ± 60	1.5 ± 0.5	1.4 ± 0.5	1.4 ± 0.2	2.1 ± 0.3	3.5 ± 0.9

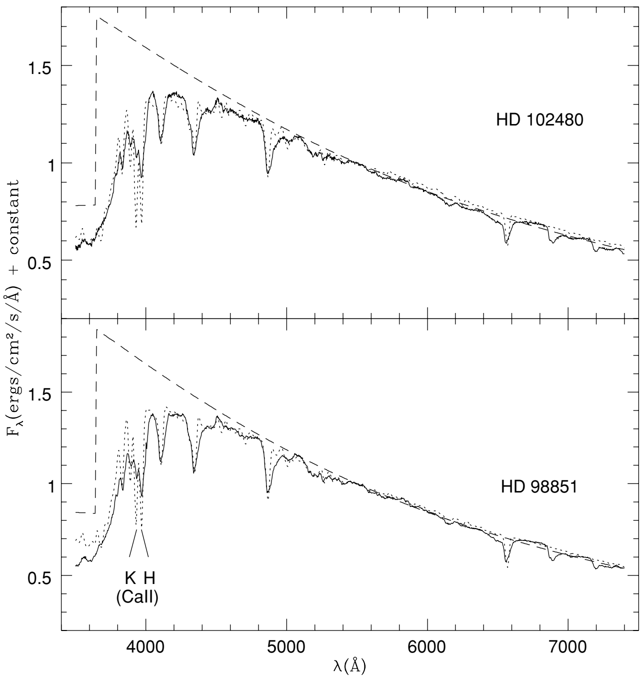

Figure 5. The best-matched synthetic spectra of Kurucz models, including continuum as well as lines, are overplotted with the observed spectra of the stars HD 98851 and HD 102480. The dotted and dashed lines represent line and continuum Kurucz models while the solid lines indicate our observed spectra.

6 PHYSICAL PARAMETERS AND EVOLUTIONARY STATUS OF HD 98851 AND HD 102480

We derived several physical parameters for HD 98851 and HD 102480 using *Hipparcos* data as well as our observational data. A comparison of the observed colours of HD 99851 and HD 102480 with those corresponding to the spectral types determined in the previous section indicates that both stars suffer little interstellar reddening. The *Hipparcos* parallaxes of HD 98851 and HD 102480 are 5.84 ± 0.87 mas and 4.17 ± 1.04 mas, respectively. The corresponding distances of these stars are 171 ± 25 pc and 240 ± 60 pc. At these distances, the absolute magnitudes of HD 98851 and HD 102480 are +1.23 ± 0.32 and +1.50 ± 0.54, respectively, as given in Table 4. Adopting a bolometric correction of −0.11 and −0.14 (Schmidt-Kaler 1982) for HD 98851 and HD 102480 respectively, we derived the corresponding luminosities $\log(L/\mathrm{L}_{\odot})$ as 1.12 and 1.36, respectively.

The masses for both stars were calculated using the following empirical relation (Schmidt-Kaler 1982):

$$\log(M/\mathrm{M}_{\odot}) = 0.46 - 0.1M_{\mathrm{bol}}.$$

It is worth noting that this relation is determined from well-observed eclipsing and visual binaries, and so does not depend on evolutionary models. The calculated masses of HD 98851 and HD 102480 are 2.2 and 2.1 $\mathrm{M}_{\odot}$ respectively, which are well within the range of masses for δ Sct stars. The radii of the stars can be derived according to the radiation law (Schmidt-Kaler 1982)

$$\log(R/\mathrm{R}_{\odot}) = -0.2M_{\mathrm{bol}} - 2\log T_{\mathrm{eff}} + 8.472,$$

giving 3.6 and 3.5 $\mathrm{R}_{\odot}$ for HD 98851 and HD 102480, respectively. From the spectroscopic observations we determined the effective temperatures of HD 98851 and HD 102480 to be 7000 ± 250 K and 6750 ± 250 K respectively, while the corresponding log g values are 3.5 ± 0.5 and 3.0 ± 0.5, respectively. All the physical parameters derived are listed in Table 4.

The positions of HD 98851 and HD 102480 in a theoretical HR diagram are shown in Fig. 6, along with the positions of other known pulsating Am stars taken from Turcotte et al. (2000). Stellar evolutionary model paths for 1.9-$\mathrm{M}_{\odot}$, 2.0-$\mathrm{M}_{\odot}$ and 2.2-$\mathrm{M}_{\odot}$ mass models are indicated in the figure where it is clearly seen that both HD 98851 and HD 102480 lie within the instability strip near the red edge.

Fig. 6 also indicates that both objects are probably near H core exhaustion, but within the errors they could be past it. The age of the model corresponding the calculated luminosities and effective temperatures is around 1.0 Gyr. Given their unusual pulsation characteristics, these would be interesting stars to model in more detail.

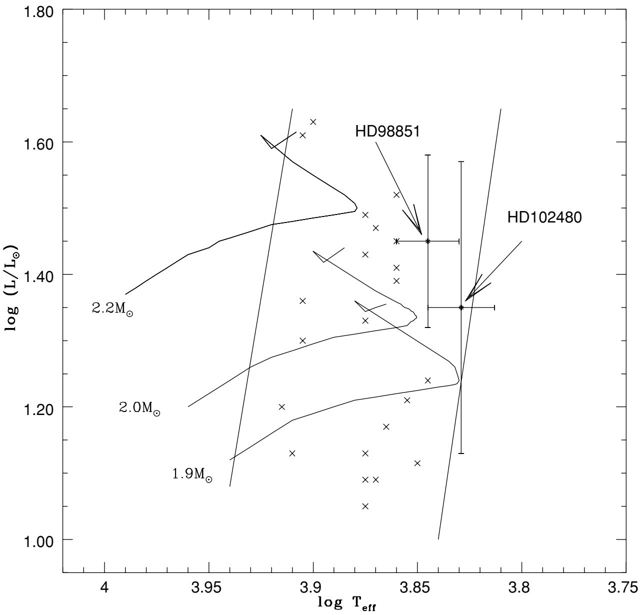

Figure 6. An HR diagram showing the positions of HD 98851 and HD 102480 in relation to the borders of the instability strip. The crosses indicate the positions of other known pulsating Am stars (Turcotte et al. 2000). Three evolutionary model tracks for 1.9-$M_{\odot}$, 2.0-$M_{\odot}$ and 2.2-$M_{\odot}$ stars are shown.

7 DISCUSSION

The unusual pulsations in the cool, marginal, evolved Am stars HD 98851 and HD 102480 are very interesting. The alternating high and low amplitude variations with nearly harmonic (or subharmonic) frequency ratio close to 2:1 are conspicuous. In some δ Sct stars, a 2:1 frequency ratio is seen, and in others a pattern of alternating high and low amplitude peaks with longer periods is observed. The coexistence of both these phenomena has not previously been observed in chemically peculiar stars.

Arentoft, Sterken & Handler (2001) found that XX Pyx shows a near 2:1 frequency ratio, and suggested that XX Pyx is a δ Sct star in a binary system, in which the companion is a low mass or compact object. A similar scenario cannot be excluded for HD 98851 and HD 102480, because the spectroscopic and photometric evidence suggests that they are Am stars, and it is known that Am stars are almost all in short-period known binary systems. In the case of these two stars, radial velocity observations are required to demonstrate their binarity. This, in turn, would constitute additional support for the Am classification for these two stars.

The locations of HD 98851 and HD 102480 in the HR diagram are consistent with the theoretical work of Turcotte et al. (2000), which shows that young Am stars are stable against κ-mechanism pulsation, and that as they evolve towards the red edge of the instability strip they become unstable. However, the ratio of two prominent periods for HD 98851 and HD 102480 has an intriguing value which is far from the ratio 0.75 to 0.79 associated with the radial fundamental and first overtone pulsation for a large sample of double-mode δ Sct stars.

Among the low-amplitude δ Sct stars which exhibit near 2:1 frequency ratios are AN Lyn (Rodriguez et al. 1997; Zhou 2002), V663 Cas (Mantegazza & Poretti 1990) and 63 Her (Breger et al. 1994). In all these cases the authors concluded that a mixture of radial and non-radial modes is needed to explain the non-standard frequency ratio. Therefore, in both HD 98851 and HD 102480 there may be a mixture of radial and non-radial modes.

8 CONCLUSIONS

In this paper, we have presented the results of high-speed photometric and low-resolution spectroscopic observations of the Am stars HD 98851 and HD 102480. Analyses of the available data show that HD 102480 is pulsating mainly in two frequencies, 0.107 and 0.198 mHz, corresponding to periods 2.6 and 1.4 h. Similarly, HD 98851 is pulsating mainly with two frequencies 0.208 and 0.103 mHz, corresponding to periods 1.34 and 2.70 h. Beside the two main frequencies, we can see evidence of one other frequency in the amplitude spectra of both stars.

The effective temperature and log g for the stars are determined to be 7000 ± 250 K, 3.5 ± 0.5 and 6750 ± 250 K, 3.0 ± 0.5 for HD 98851 and HD 102480, respectively. The corresponding equivalent hydrogen line spectral types are found to be F1IV and F3III/IV.

We conclude that HD 98851 and HD 102480 are unusual variables lying near the red edge of the instability strip. Their Am spectral types are securely established; given their luminosities these stars belong to the ρ Pup group (previously known as δ Del) of evolved Am stars. Their unusual nearly harmonic (or subharmonic) period ratios, unusually high overtones and Am spectral types make these stars especially interesting objects for further observational and theoretical studies.

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