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Discovery of pulsations in the Am star HD 13079

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ABSTRACT

Pulsation in cool main-sequence Am stars is a rare phenomenon observed in a few marginal Am stars and only one classical Am star. The chemically peculiar star HD 13079 is shown to be pulsating with a 78-min period and a peak-to-peak B amplitude of 0.02 mag. The *Hipparcos* parallax, $uvby\beta$ photometry and pulsations together suggest that HD 13079 is an Am star near the zero-age main sequence, and that it is a fundamental-mode pulsator on the red edge of the instability strip.

Key words: stars: chemically peculiar – stars: individual: HD 13079 – stars: oscillations.

1 INTRODUCTION

The classical instability strip crosses the main sequence among the A and early F-type stars. About 30 per cent of the stars in this part of the Hertzsprung–Russell (HR) diagram are δ Scuti stars which pulsate with amplitudes ranging from a few mmag to almost a magnitude. Although most δ Scuti stars are chemically normal, there are also some chemically peculiar stars which exhibit δ Scuti pulsation. The pulsations are driven by the κ mechanism operating in the He II ionization zone. The chemical peculiarities are confined to the surface and are produced by diffusion: elements with many lines near flux maximum are pushed upward radiatively while elements with few lines near flux maximum, or with saturated lines, sink.

Among the chemically peculiar stars which exhibit δ Scuti pulsation are several luminous, cool evolved Am stars, a few marginal Am stars and one classical Am star, HD 1097 (Kurtz 1989). The classical Am stars are main-sequence stars of H-line spectral types A4–F1 in which the metallic-line and Ca II K line types differ by five or more spectral subclasses. The marginal Am stars (designated Am:) are those stars of similar spectral appearance to the classical Am stars, but in which the metallic and K line spectral types differ by less than the required 5 subclasses. As a group, Am stars are slowly rotating, in most cases as a result of their being members of close binaries.

The coexistence of pulsation and metallicism in Am stars is not fully understood. The partial He II ionization zone is the driving agent for δ Scuti-type pulsation. In the Am stars, sedimentation of elements owing to suppressed rotational velocities depletes He from the superficial layers. Earlier work by Cox, King & Hodson (1979) suggested that classical Am stars should not pulsate because their He II ionization regions should be fully depleted of He. The existence of subsequently discovered pulsating Am stars was attributed to residual He in the He II ionization zone being barely capable of exciting low-amplitude pulsation. However, more recent work by Gautschy, Saio & Harzenmoser (1998), incorporating an atmospheric temperature inversion in inhomogeneous envelope models, produces contradictory results. In these models, only the H/He ionization zone is deficient of He and the He II ionization region is unmodified. The hydrogen partial ionization zone has a damping influence which overcompensates the driving action of the He II ionization region, thus suppressing the low-overtone modes. In this scenario, the presence of pulsations in certain Am stars indicates that superficial He drainage is not sufficiently advanced in those stars to suppress pulsation. See Kurtz (1989, 1998) for additional discussions of the problems of pulsation and metallicism.

There is one other group of chemically peculiar pulsating stars, the rapidly oscillating Ap stars, which pulsate with periods in the range 6–16 min and amplitudes of a few mmag. The short periods imply pulsation in very high overtones: $n \simeq$ 10–40. See Kurtz (1990), Matthews (1991) and Martinez & Kurtz (1995) for reviews of these stars. In the context of this paper, the point we wish to note is that there is a well-documented exclusion of low-overtone (i.e. δ Scuti-like) pulsation in the Ap stars (Kreidl 1986). This is discussed in theoretical terms by Gautschy et al. (1998).

2 THE STAR HD 13079

HD 13079 (HIC 10023, CCDM 02090+3936) is a double star.

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The *Hipparcos Hp* magnitudes for the two components are 8.989 ± 0.007 and 11.311 ± 0.057. The separation and position angle are $\rho = 6.173 \pm 0.017$ arcsec and $\theta = 254\overset{\circ}{.}4$, respectively. The Strömgren photometric indices for the combined light of the two stars are: $b - y = 0.203$, $m_1 = 0.211$, $c_1 = 0.672$, $\delta m_1 = -0.023$, $\delta c_1 = -0.028$ and $\beta = 2.759$. The dereddened indices are $[\delta m_1] = -0.060$ and $[\delta c_1] = -0.069$. These indices are typical of the strongly line-blanketed spectra of cool Ap and Am stars.

In this paper we report the discovery of low-overtone pulsation in HD 13079. Since there is a well-established exclusion of low-overtone pulsation in Ap stars, this argues that HD 13079 is probably an Am or Am: star.

The metal abundance may be determined from the photometry using the tight linear correlation determined by Smalley & Dworetsky (1993) $[\mathrm{M/H}] = -10.56\delta m_0 + 0.081$ which is valid for metal-rich stars, including classical Am stars. For HD 13079 we obtain $[\mathrm{M/H}] = 0.33$, a value typical of the Am stars.

The *Hipparcos* parallax of $\pi = 5.52 \pm 1.97$ mas indicates $M_V = 2.46^{+.66}_{-.96}$. At $(b - y) = 0.203$, this is about 0.5 mag above the main sequence, which places the star on the red edge of the instability strip (Breger 1979). The *Hipparcos* M_V is consistent with $M_V = 2.46 \pm 0.19$ derived from King's (1991) period–luminosity (P–L) relation for δ Scuti stars pulsating in the fundamental mode.

The $(B - V)$–$(b - y)$ calibration of Golay (1972) yields $(B - V) = 0.29$, in good agreement with the Tycho $(B - V)$ transformed to the Johnson system (ESA 1997); $(B - V) = 0.28 \pm 0.05$. These values are consistent with the hydrogen-line type of F0 given in the Henry Draper Catalogue.

Application of the *uvby*β photometry to the T_{eff}–$\log g$ grids of Moon & Dworetsky (1985) yields $T_{\mathrm{eff}} = 7350$ K and $\log g = 4.3$. Assuming a bolometric correction $\simeq -0.09$, and using the relation $\log M/\mathrm{M}_\odot = 0.46 - 0.10M_{\mathrm{bol}}$, the mass of the star is derived to be 1.7 $\mathrm{M}_\odot$, well within the range of masses of the δ Scuti stars.

For chemically normal A/F stars, $\delta c_1 = c_1 - c_1(\text{zero} - \text{age main sequence}, \beta)$ is a luminosity indicator. In the heavily blanketed metallic-line stars δc_1 is an unreliable luminosity indicator because c_1 is suppressed relative to the chemically normal stars. For Am stars, Gray & Garrison (1989) recommend the use of a δc_1 index based on the $(B - V)$ colour instead. Using the $(b - y)$–$(B - V)$ plot of Crawford, Barnes & Golson (1970) and Crawford's (1979) A-star calibration, we derived $\delta c_1(B-V) = 0.01$. Reference to fig. 5 of Gray & Garrison (1989) suggests that this is a luminosity class V star.

3 PHOTOMETRIC OBSERVATIONS AND ANALYSIS

In 1997 November we used the Indian Space Research Organisation (ISRO) high-speed photometer (Venkat Rao et al. 1990) attached to the 1-m Sampurnanand telescope of the Uttar Pradesh State Observatory (UPSO) at Naini Tal to search for high-overtone oscillations in Ap stars. The data were acquired as continuous single-channel 10-s integrations through a Johnson *B* filter. Photometric apertures of 30 arcsec or larger were used to minimize light losses arising from seeing effects and tracking drifts. The observations were interrupted for occasional sky background measurements to take account of changes in sky brightness during the night. Because the high-overtone pulsations in Ap stars have periods in the range 6–16 min, the candidates were monitored continuously and no comparison stars were observed. The data were corrected for coincidence counting losses, sky background and atmospheric extinction, respectively.

Table 1. Journal of time-series observations of HD 13079.

UT date	HJD start 2 400 000+	T hr	N	% fill
12 Nov 1997	50765.15417	2.03	712	0.97
15 Nov 1997	50768.06686	2.52	866	0.96
18 Jan 1999	51197.09759	3.11	1119	1.00
19 Jan 1999	51198.07968	2.22	799	1.00
20 Jan 1999	51199.08145	2.58	929	1.00
	Σ	12.45	4425	

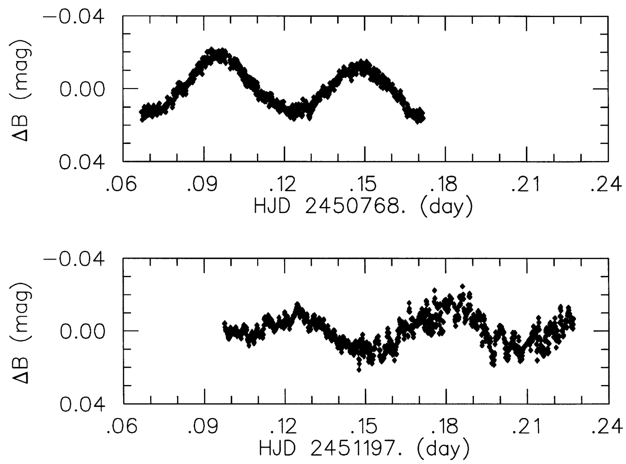

Figure 1. Johnson *B* light curves of HD 13079.

Low-overtone oscillations in HD 13079 with a period of ~ 80 min were discovered on the night of 1997 November 12/13 and subsequently confirmed with better signal-to-noise ratio data on the night of 1997 November 15/16. Additional multi-channel photometric observations of HD 13079 were subsequently acquired on 1999 January 18–20 using the same instrument attached to the 1-m telescope of the Vainu Bappu Observatory in Kavalur. The photometric observations are all listed in Table 1. The table lists the UT civil date, the heliocentric Julian date (HJD) of the first observation on each night, the duration in hours, the number of observations and the filling factor or 'duty cycle.' Fig. 1 shows two sample light curves of HD 13079.

Amplitude spectra of the light curves (Fig. 2) were computed using the Deeming (1975) discrete Fourier transform (DFT) algorithm as expressed by Kurtz (1985). These are 'raw' transforms in the sense that no low-frequency filtering has been applied to the data, other than a correction for mean extinction. Inspection of the nightly amplitude spectra shows that all the signal power is contained in the range 0–1 mHz and also suggests that the amplitude of the oscillations is modulated. This is especially evident in the three lower panels of Fig. 2, which refer to multi-channel data and should thus be relatively immune to sky transparency variations.

To refine our frequency determination for the oscillations in HD 13079 and to seek additional component frequencies, we computed the DFT of the multi-channel data combined from the three consecutive nights 1999 January 18–20. The top panel of

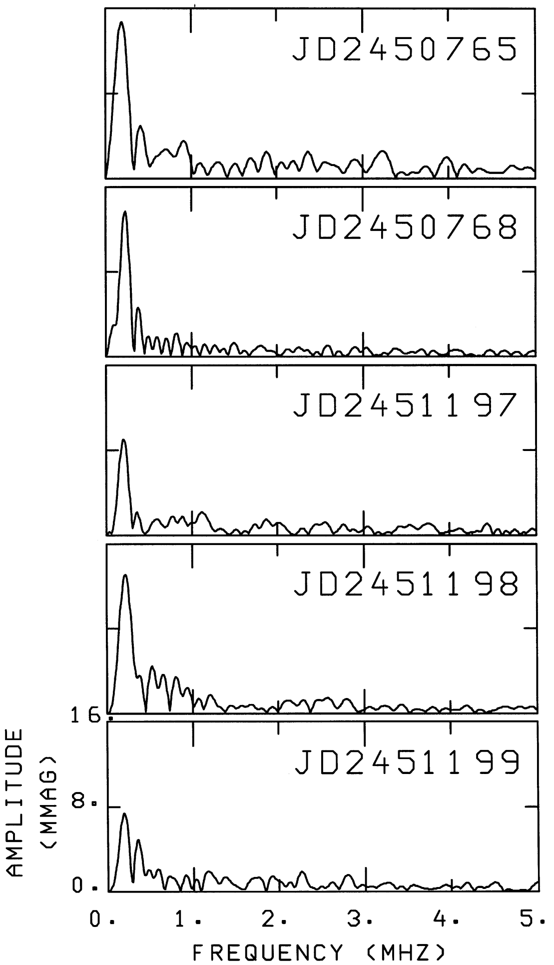

Figure 2. Discrete Fourier transforms of the light curves listed in Table 1.

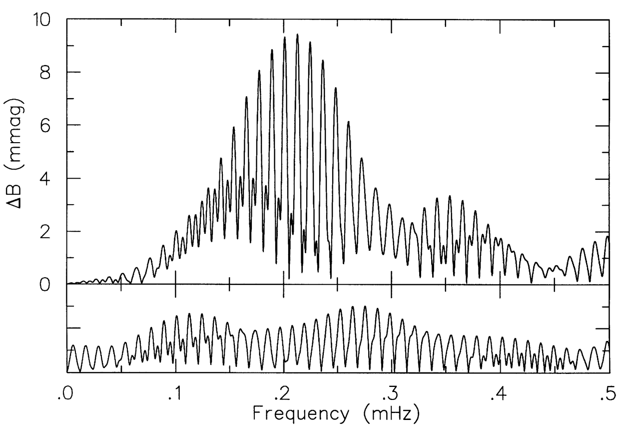

Figure 3. Discrete Fourier transform of combined light curves for JD 2451197–99.

Fig. 3 shows the DFT of the combined data for the range 0.0–0.5 mHz. This Fourier amplitude spectrum is dominated by a prominent window pattern of amplitude $A_1 = 9.4$ mmag, centred at frequency $\nu_1 = 0.2129$ mHz ($18.39\,\mathrm{d}^{-1}$) with daily alias ambiguities. The lower panel in the figure shows the residuals after prewhitening a sinusoid $A_1 \sin(2\pi\nu_1 t + \phi)$ from the data. The window patterns in these residuals are not sufficiently pronounced to warrant further frequency identifications and serve instead to define an upper limit of 3 mmag on the amplitude of further frequency components.

4 NEW SPECTROSCOPIC OBSERVATIONS OF HD 13079

Spectroscopy of HD 13079 in the 585–665 nm region was performed on 1998 November 24–25 with the 91-cm telescope at the Catania Astrophysical Observatory equipped with the REOSC spectrograph (Frasca & Catalano 1994). The data reduction performed with the IRAF package shows that the linear dispersion is $7.5\,\mathrm{Å\,mm^{-1}}$, the instrumental profile is represented by a full width at half-maximum Gaussian of 0.42 Å and a signal-to-noise ratio of ~ 95.

The observed spectra were analysed using (a) ATLAS9 (Kurucz 1993) to compute the stellar atmosphere models and (b) SYNTHE (Kurucz & Avrett 1981) to identify spectral lines and match the observations. The iterative procedure described by Leone & Manfrè (1997) was applied to determine the stellar parameters of HD 13079. We find that the H_α line profile can be matched assuming an effective temperature $T_{\mathrm{eff}} = 7200$ K, the solar metal opacity scale and $v_e \sin i = 45\,\mathrm{km\,s^{-1}}$. Because of the lack of a large number of unblended lines of a given chemical species necessary to measure the microturbulent velocity, a value of $2\,\mathrm{km\,s^{-1}}$ was assumed. Given that the Balmer lines are very weakly dependent on gravity, log g was fixed at 4.0.

As for metal abundances, the iron peak element abundances are not larger than solar values. Calcium, from the blended Ca I 639.4602, 643.9075, 644.9808, 646.2567, 649.9650 nm lines, appears to be underabundant. A quantitative evaluation has not been attempted because of the large number of free parameters involved and which cannot be separated at our spectral resolution. We also searched for lines of those other elements which characterize Am stars, such as scandium and strontium, but could not find them in our spectra.

We conclude that the solar abundances of the iron peak elements exclude HD 13079 being an Ap star and that the calcium underabundance suggests that it is an Am star.

5 DISCUSSION

We have presented evidence for the existence of chemical peculiarities in HD 13079 and the presence of low-overtone pulsations in this star. However, the exact peculiarity class of HD 13079 is unclear. Given the pulsation period, the calcium underabundance and the peculiar colours, the star is most likely an Am, Am:, or ρ Pup (evolved Am) star. Indeed, the β index indicates a somewhat higher effective temperature than $(b-y)$, as is generally observed in Am stars. The Am and Am: stars are main-sequence objects, whereas the ρ Pup stars are cooler and considerably more luminous (Gray & Garrison 1989). We will argue that the balance of evidence indicates a main-sequence luminosity for HD 13079, and hence an Am character.

The standard pulsation relation

$$Q = P\sqrt{\bar{\rho}/\bar{\rho}_\odot}.$$

may be expressed in terms of observable quantities as

$$\log Q = -6.454 + \log P + 0.5 \log g + 0.1 M_{\mathrm{bol}} + \log T_{\mathrm{eff}},$$

where the pulsation period P and pulsation constant Q are in units of days, and g is in cgs units. The value of Q is not too sensitive to

Table 2.

$\log g$	Q (days)
4.3	0.034
4.0	0.024
3.5	0.014
3.0	0.008

$M_{\rm bol}$ or $T_{\rm eff}$, but it is sensitive to $\log g$, which is our most uncertain quantity. Table 2 shows the Q values computed for a variety of possible $\log g$ values. The Q values are almost all identical to three decimals for $T_{\rm eff}(b-y) = 7200\,{\rm K}$ and $T_{\rm eff}(\beta) = 7350\,{\rm K}$. For standard late-A and early-F star models we expect $Q = 0.033$ for fundamental-mode pulsation and $Q = 0.025$ for first-overtone pulsation (Stellingwerf 1979). Breger & Bregman (1975) demonstrated that for $T_{\rm eff} < 7800\,{\rm K}$, the highest amplitude mode tends to be the fundamental mode, whereas for hotter temperatures the first overtone is prevalent. This is consistent with Stellingwerf's (1979) computed blue edge for fundamental-mode pulsation near the zero-age main sequence (ZAMS). If one admits this as a probabilistic argument for fundamental-mode pulsation in HD 13079, then Table 2 is consistent with HD 13079 being near the ZAMS, as indicated by the *Hipparcos* parallax and the photometry.

It is instructive to compare this result with the luminosity calculated from Breger's (1979) empirical δ Scuti P–L–C relation

$$M_V = -3.052 \log P + 8.456(b-y) - 3.121,$$

which yields $M_V = 2.46 \pm 0.31$, in good agreement with the value derived from the *Hipparcos* parallax. The above relation does not take account of the pulsation mode. King (1991) derived P–L relations for the fundamental, first overtone, second and third overtone pulsators. Reference to fig. 2 of King (1991) suggests that HD 13079 is a fundamental-mode pulsator. This is consistent with the observed tendency for variables near the red edge of the instability strip to show a fundamental-mode Q value. This in itself does not constitute a definitive mode identification of the pulsations in HD 13079. If additional pulsation frequencies can be measured in this star, the period ratios will allow further comparisons with period ratios expected for radial modes.

The coexistence of pulsation and metallicism in Am stars is important for our understanding of abundance anomalies in the A-type stars and of diffusion processes in general. HD 13079 appears to be an Am or Am: fundamental-mode pulsator on the red edge of the instability strip. It would be instructive to perform a more detailed spectroscopic analysis of this star. It would also be useful to obtain more extensive pulsation data to search for further pulsation modes. The star is situated at declination $+30°$ and would thus be a good target for a short multi-site campaign with 0.5- to 1-m telescopes. The fainter star in this double is 6 arcsec from HD 13079. This separation is too small to exclude that star in conventional aperture photometry. The companion is only 2.3 mag fainter, and could be used as the on-chip comparison for differential CCD photometry.

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