Astron. Astrophys. 334, 606–608 (1998)

ASTRONOMY AND ASTROPHYSICS

Discovery of p-mode oscillations in the Ap star HD 213637

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Received 29 December 1997 / Accepted 18 February 1998

Abstract. We announce the discovery of rapid p-mode oscillations in the A (p EuSrCr) star HD 213637. These variations are modulated in amplitude, which is consistent with rotational modulation, multi-mode oscillations or intrinsic mode growth/decay. A frequency analysis reveals that our data may be described by the combination of two oscillations with frequencies of 1411 and 1452 μHz. However, these frequency values suffer from 1 d^{-1} alias ambiguities, and require confirmation in a more detailed follow-up study.

Key words: stars: chemically peculiar – stars: individual: HD 213637 – stars: oscillations – stars: variables: other

1. Introduction

The rapidly oscillating Ap (roAp) stars are cool, magnetic, chemically peculiar A-type stars which exhibit broad-band light variations with periods in the range 6–16 min and Johnson B semi-amplitudes typically ≤ 0.008 mag (Kurtz 1990, Matthews 1991). These oscillations are caused by global non-radial acoustic pulsations, or 'p modes', of low degree ($\ell \leq 3$) and high overtone ($n \gg \ell$). The roAp stars are thus of considerable significance because they allow the use of asteroseismology as a tool in the study of the chemically peculiar stars of the upper main sequence.

In an ongoing programme to search for new rapidly oscillating Ap stars in the southern sky, HD 213637 came to our attention as a candidate roAp star. HD 213637 is classified by Houk & Smith-Moore (1988) as A(p EuSrCr). The Strömgren indices of HD 213637 were measured to be $V = 9.611$, $b - y = 0.298$, $m_1 = 0.206$, $c_1 = 0.411$ and $\beta = 2.670$. Our attention was particularly drawn to the dereddened indices, $[\delta m_1] = -0.089$ and $[\delta c_1] = -0.089$, both of which indicate very strong metallicity and line blocking in the v band. As these are characteristics that we associate with the roAp stars, we decided to search for rapid oscillations in HD 213637.

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2. Observations

HD 213637 was observed on seven nights during late July and early August 1997 using the Radcliffe Peoples Photometer attached to the 0.75-m telescope of the South African Astronomical Observatory at Sutherland. Our observations comprised continuous 10-s integrations in Johnson B light with occasional interruptions for sky background measurements. No comparison stars were observed. Fig. 1 shows the light curve we obtained on night 26/27 July 1997, JD 2 450 656.

The data where corrected for coincidence counting losses, sky background and extinction, respectively. Gradual extinction variations (T> $\frac{1}{2}$ hr) were removed in the Fourier domain, as described by Martinez (1993). The data were finally binned to 40-s integrations and the times were converted to Heliocentric Julian Dates to an accuracy of 10^{-5} day ($\sim$1 s).

Table 1 is a journal of our observations. For each night it lists the Heliocentric Julian Date (HJD) of the first and last observation, the duration in hr, the number of 40-s integrations, and the standard deviation, σ, of the observations with respect to the mean for the night. The quantity σ includes contributions from residual sky transparency variations, scintillation, photon statistics, as well as the actual variations in the star. Fig. 2 shows the Deeming (1975) Discrete Fourier Transform (DFT) for each light curve listed in Table 1, computed according to the prescription of Kurtz (1985). Inspection of this figure shows that the oscillations in HD 213637 are strongly modulated in amplitude on a night-to-night basis.

3. Frequency analysis

The DFT of the combined data in Table 1 was computed in the range $0 \leq \nu \leq 10$ mHz. This revealed that all oscillatory power is confined to the vicinity of 1.4 mHz and that no harmonics are present. Fig. 3 shows the DFT of the combined data in the narrower range 1–2 mHz. Owing to the short light curves, the spectral window of these data is very strongly aliased. The dominant window pattern in the top panel of Fig. 3 is centered at ν_1=1452 μHz. We fitted this frequency to the data by linear least squares to establish its amplitude and phase, with their respective fitting errors. The results of this fit were then used as initial values for an iterative non-linear least squares fit which

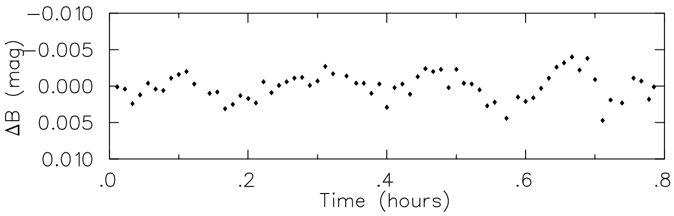

Fig. 1. The Johnson B light curve of HD 213637 on night 26/27 July 1997.

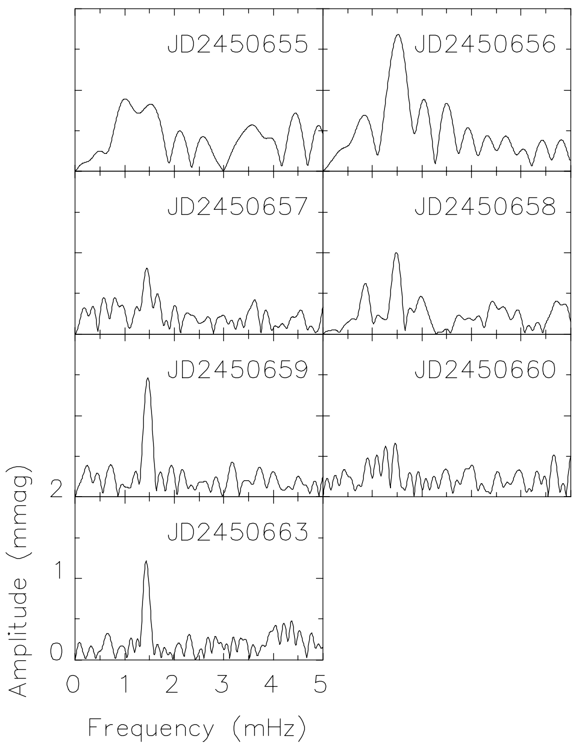

Fig. 2. Amplitude spectra of the Johnson B light curves of HD 213637. The frequency and amplitude scales are identical for all panels.

optimizes frequency, amplitude and phase together. A sinusoid with these optimized parameters was then subtracted from the data and the DFT of the residuals was calculated to produce the middle panel in Fig. 3. This suggests the presence of another frequency whose window pattern is centered at ν_2=1411 μHz. The two-stage least squares fitting procedure was repeated for both frequencies together (Table 2) and they were subtracted from the data to produce the residuals shown in the bottom panel of Fig. 3. This shows no further signals above the noise level of 0.2 mmag.

4. Discussion

We have demonstrated the presence of rapid photometric oscillations in the A (p EuSrCr) star HD 213637. These oscillations can be described by the superposition of two signals with frequency ν_1=1452 μHz and ν_2=1411 μHz. Owing to the sparse sampling in our data, both of these frequency identifications are subject to 1 cycle d^{-1} alias ambiguities.

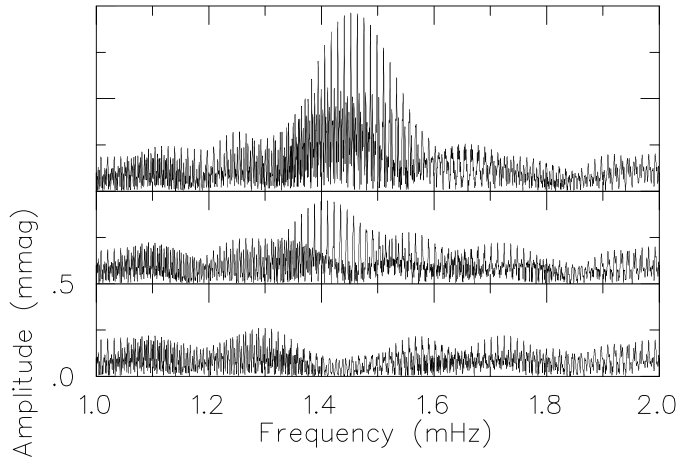

Fig. 3. *(Top)* The amplitude spectrum of the combined JD 2 450 655–663 data showing a dominant oscillation at ν_1=1452 μHz. *(Middle)* Residuals after prewhitening ν_1 reveal another oscillation at ν_2=1411 μHz. *(Bottom)* The amplitude spectrum of the residuals after removal of ν_1 and ν_2. The ordinate scale is identical for all three panels.

Table 1. Journal of observations of HD 213637.

HJD start 2 450 000+	HJD end 2 450 000+	T hr	N_{40}	σ mmag
655.65435	655.68490	0.73	65	1.59
656.61029	656.64299	0.78	68	1.85
657.59298	657.67440	1.95	170	1.46
658.61142	658.67473	1.52	134	1.55
659.61528	659.68519	1.68	144	1.70
660.59611	660.68211	2.06	178	1.84
663.57863	663.67857	2.40	213	1.77
	Σ	11.13	972	

Table 2. The frequency solution for HD 213637.

	ν (μHz)	A (mmag)	ϕ^a (radian)
ν_1	1452.35 ± .06	0.96 ± .07	-0.35 ± .07
ν_2	1410.89 ± .11	0.50 ± .07	-1.59 ± .14

^{a} T_0=HJD 2 450 659.73368

Notwithstanding the uncertainties in our frequency identifications, the oscillations in HD 213637 are indisputably modulated in amplitude, as is evident in Fig. 2. This modulation may arise due to a number of causes, possibly acting in combination. These causes are rotation, the presence of multiple pulsation modes, and intrinsic growth or decay of pulsation modes. The presence of each of these factors yields further information about the star.

Rotational modulation arises in roAp stars because the pulsation axis is locked to the magnetic axis, which is generally inclined to the rotation axis. This causes non-radial modes to be viewed from variable aspect as the star rotates. The modulation clearly occurs with exactly the rotation frequency of the star, Ω_{rot}. The Fourier manifestation of this phenomenon is that each frequency ν is split into a multiplet of $(2\ell+1)$ frequencies with equal spacing Ω_{rot}. The components of these multiplets are usually asymmetric in amplitude as a consequence of the strong magnetic fields in Ap stars. The phenomenological model describing these rotationally induced modulations is called the *oblique pulsator* (Kurtz 1990). If such rotational splitting is observed in HD 213637, it could yield information on the rotation frequency of the star, its inclination, the degree ℓ of the pulsation mode, and an integrated measure of the internal magnetic field.

The possible presence of multiple pulsation modes offers the prospect of applying the techniques of p-mode asteroseismology to this star. The asymptotic theory of low-degree, high-overtone ($n >> \ell$) p modes (Tassoul 1990) predicts an eigenspectrum consisting of a comb of equally spaced frequencies $\nu_{n,\ell}$ given by

$$\nu_{n,\ell} = \Delta\nu(n + \frac{\ell}{2} + \epsilon)$$

to first order, where ℓ is the degree of the mode, n is the overtone, and ϵ is a constant which depends on the equilibrium structure of the star. The quantity $\Delta\nu$ is the spacing of consecutive overtones ($n, n+1, n+2, \ldots$) for a given ℓ. The overtone spacing may be expressed in terms of structural parameters as

$$\Delta\nu \propto \sqrt{\frac{GM}{R^3}}.$$

Using the mass-luminosity relation one may show that loci of constant $\Delta\nu$ are essentially lines of constant R in a theoretical H-R diagram (e.g. Shibahashi & Saio 1985). Thus, the detection of multiple modes in HD 213637 would allow the evolutionary stage of this star to be established.

The final cause for rapid amplitude modulation, intrinsic mode growth/decay, is more difficult to establish conclusively. The main difficulty here lies in disentangling the real modes from spurious frequencies introduced by the growth/decay of the modes, and also the aliases. Continuous multi-site data is required for this. Demonstrating intrinsic mode growth/decay in roAp stars is useful because it would constrain the mode selection and excitation mechanisms in these stars.

Future work on this star should concentrate on eliminating the alias ambiguities of the two identified frequencies. A definitive measurement of $\Delta\nu$, combined with Hβ photometry will allow a determination of the asteroseismological luminosity of this star. A more intensive study should reveal the rotational sidelobes of the pulsation frequencies if they are being modulated with rotation. A noise level lower than the 0.2-mmag level of the present study could result in the detection of additional frequency components. In order to meet these goals an intensive study spanning several weeks is required. This study should be conducted on 1-m class telescopes to improve photon statistics for this V=9.6 star and to minimize the scintillation noise.

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