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CCD PHOTOMETRY OF THE MULTI-MODE δ SCUTI STAR GSC 1730-1858

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The star ASAS 001856+2239.6 = GSC 1730-1858 (coordinates for equinox 2000.0: $\alpha = 00^h18^m55\overset{s}{.}87$, $\delta = +22^\circ39'40\overset{''}{.}2$) was found to be a new δ Scuti variable by the All Sky Automated Survey (*ASAS-3*; Pojmanski & Maciejewski, 2005) with a period of 0.0960 days. The phase plot of the *ASAS-3* data at this period shows an unusual amount of scatter. A close investigation of the available data as well as data from the Northern Sky Variability Survey (*NSVS*; Wozniak et al., 2004), showed two more excited modes with periods of 0.0920 and 0.0937 days, both close to the original period and amplitudes somewhat larger than half the main amplitude.

Follow-up observations of this object were then started at three private observatories. A total of 5109 data points in V were obtained during 46 different nights from September to November 2006. In addition, the star was observed simultaneously in B by SK, while FJH also observed in I_c. The observation log of the data is presented in Table 1, while the number of data points is given in Table 2. Schuler filters were used for all observations. All data are available electronically.

The comparison stars used were GSC 1730-2105 (adopted magnitude $V = 12.46$ from the YB6 catalogue; USNO, unpublished), GSC 1730-1709 and GSC 1730-2179. Unfortunately, all three are about two magnitudes fainter than the variable, limiting the precision of the observations. The average nightly standard deviation for the check stars was 0.02 mag in V. To remove small differences in the magnitudes of the variable between observers, the instrumental V magnitudes were shifted by a constant value.

Fig. 1 presents a sample of data from 15 nights showing obvious variations in the amplitude from night to night.

The data were then analysed using Period04 (Lenz & Breger, 2005). In addition to the three frequencies already found in the survey data, two more independent frequencies were found with a much smaller semi-amplitude of 7-8 mmag. Fig. 2 gives the frequency spectrum after prewhitening for the first three frequencies, together with the spectral window. All five frequencies lie between 10 and 11 c/d, with one very close pair: the main frequency f_1 and the frequency f_4, separated by only 0.03 c/d. The occurence of

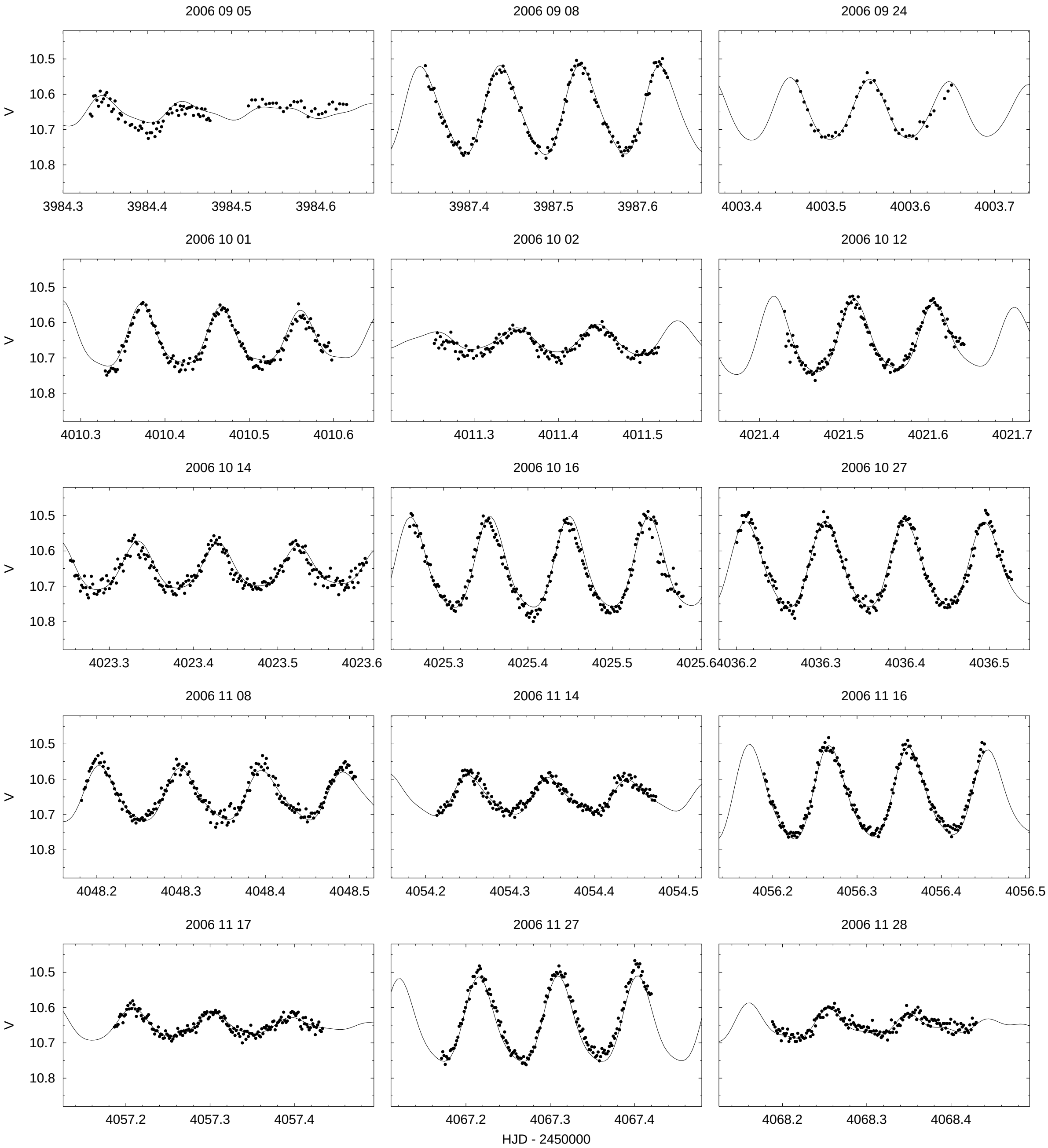

Figure 1. V light curve of GSC 1730-1858 on 15 nights. Also shown is a model plot with the nine frequencies found

Table 1: Observation log

Observer	Telescope	CCD camera	Filters	Timespan (JD − 2450000)	No. of nights	No. of hours
KB	20-cm C8	SX Starlight	V	3984-4064	22	68.3
FJH	35-cm C14	SBIG ST-8	V, I_c	4017-4066	10	57.8
SK	30-cm LX200	SBIG ST-7XMEI	B, V	3984-4068	21	124.1

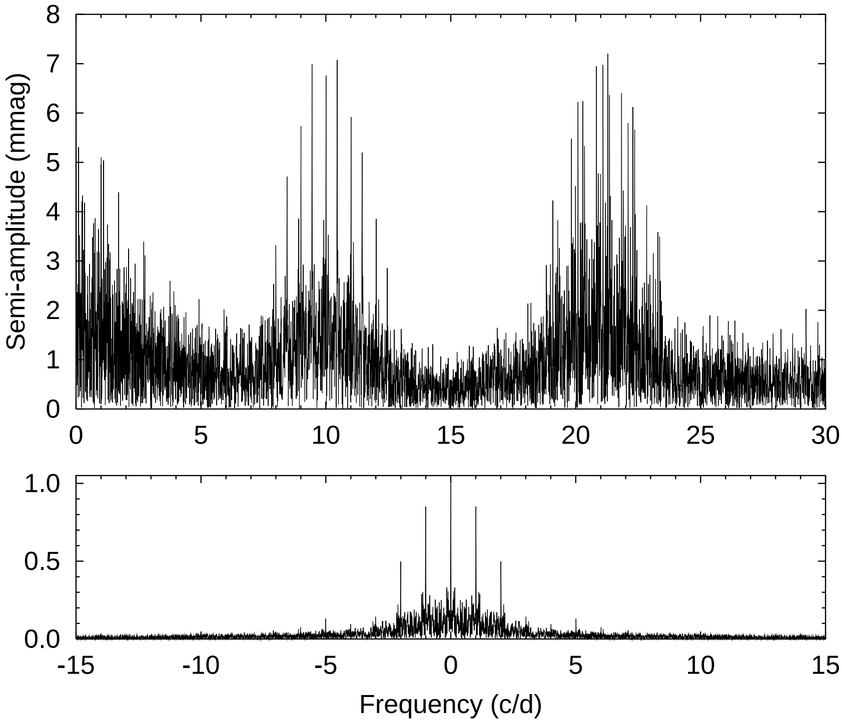

Figure 2. Frequency spectrum of GSC 1730-1858 after prewhitening for f_1 to f_3 (top panel) and spectral window (bottom panel)

Table 2: Number of data points per filter

Observer	B	V	I_c
KB	-	671	-
FJH	-	1347	1109
SK	2975	3091	-

Table 3: Detected frequencies in V

	Frequency c/d	S/N	Semi-ampl. V mmag
f_1	10.41632(5)	90.0	58.0
f_2	10.86918(7)	57.6	36.4
f_3	10.67766(7)	52.8	33.9
f_4	10.44804(34)	12.4	8.0
f_5	10.00745(38)	11.0	7.2
$2f_1$	20.83264(9)	8.4	5.9
f_1+f_2	21.28550(9)	7.9	5.5
f_1+f_3	21.09398(9)	7.8	5.5
$2f_3$	21.35532(15)	7.3	5.1

Table 4: Amplitude ratios and phase differences for B and I_c

Frequency	Ampl. ratio B/V	Ampl. ratio V/I_c	$\phi_B - \phi_V$ degrees	$\phi_V - \phi_I$ degrees
f_1	1.31 ± 0.02	1.66 ± 0.08	0.8 ± 0.7	7 ± 3
f_2	1.22 ± 0.03	1.50 ± 0.09	−2.5 ± 1.3	1 ± 3
f_3	1.33 ± 0.03	1.78 ± 0.12	−3.7 ± 1.3	2 ± 4
f_4	1.32 ± 0.12	2.40 ± 1.16	27.6 ± 5.3	−34 ±25
f_5	1.14 ± 0.13	1.15 ± 0.25	18.9 ± 6.5	−1 ±12
$2f_1$	1.74 ± 0.18	2.60 ± 1.42	1.4 ± 5.9	−51 ±25
$f_1 + f_2$	1.17 ± 0.17	0.80 ± 0.17	−22.3 ± 8.6	−10 ±13
$f_1 + f_3$	1.06 ± 0.17	0.78 ± 0.15	−1.3 ± 9.1	−21 ±10
$2f_3$	1.09 ± 0.18	1.22 ± 0.44	4.9 ± 9.6	22 ±19

close frequencies may be an artifact resulting from the use of inhomogeneous data sets, especially when observations from different instruments are combined. This is not the case here however, because all frequencies found in the aggregated data set were also found in the three longest data sets separately. In addition the data for the check star do not show any frequency with an amplitude above the noise at 2 mmag in the frequency range concerned (at low frequencies the noise is somewhat larger). Four linear combinations of the independent modes were found as well in the frequency spectrum of GSC 1730-1858. These are centered around 21 c/d in Fig. 2. In the low frequency range (less than 3 c/d), none of the frequencies rise significantly above the noise.

An overview of all frequencies found in the V data, is presented in Table 3. The uncertainties of the frequencies given in the table are the errors of the least squares solution. The real uncertainties may be larger. The uncertainties of the V semi-amplitudes are all of the order of 0.4 mmag. No additional frequencies with semi-amplitudes above 2 mmag, other than those listed, could be detected up to 25 c/d. All independently excited frequencies are therefore situated in a narrow band between 115 and 125 μHz. Most other δ Scuti stars with many excited modes show a much broader range of independent modes. At higher frequencies, near 30 c/d, again multiples of the independent frequencies are found. However, their signal to noise ratio is small and they are hard to distinguish from their 1-day aliases. They were therefore not included here.

After fitting the 9 detected frequencies, the average residual is 18 mmag, which may be compared to the standard deviation of the check star. A model plot using those 9 frequencies is shown in Fig. 1.

Amplitude ratios and phase differences for the frequencies in B and I_c, compared to V are presented in Table 4. Because there were less data points for these filters, the amplitudes and phases were calculated using the frequencies obtained from the V data. This table may assist in the identification of the excited modes.

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