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The multiple frequencies of the δ Scuti star V350 Peg*

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Abstract. V350 Peg is a δ Scuti star discovered by Hipparcos (ESA 1997). During 35 nights between July 1997 and December 2001 some 7500 CCD V observations were acquired at the Monegrillo and Esteve Duran observatories in Spain. The new data show that this star pulsates in a close doublet of frequencies separated by 0.17 c/d ($\Delta f/f = 3\%$) with similar amplitudes. More frequencies are excited but cannot be identified with certainty. The period as listed in the Hipparcos Catalogue is not confirmed.

Key words. δ Sct – stars: individual: V350 Peg

1. Introduction

V350 Peg (=HIP 115563) is a small-amplitude variable star discovered during the Hipparcos mission (ESA 1997). It was assigned to the δ Scuti class of pulsating stars with a period of 0.2012 days and a total amplitude of 0.05 mag, and included as such in the latest catalogue of δ Scuti variables (Rodríguez et al. 2000). There appears to be no further investigation of this star in the literature.

2. Observations and reduction

The star was observed in the V band by JV from Monegrillo Observatory on 31 nights between July 1997 and January 1998 (7131 observations during 175.7 hours and a total time span of 171 days), using a 40 cm Newtonian telescope. It was also observed on 4 nights in November and December 2001 by EG from Esteve Duran Observatory (381 observations during 21.8 hours), using a 60 cm Cassegrain telescope. Both telescopes are equipped with a SX Starlight CCD camera with a Sony ICX027BL chip cooled by a Peltier system to about −25 °C. Dark frames and flat fields were obtained, and image cleaning and aperture photomety was carried out using a software package called LAIA (Laboratory for Astronomical Image Analysis), developed by J. A. Cano. In the photometric analysis process a synthetic aperture differential magnitude extraction method was used.

Table 1. Catalogue data for the observed stars (ESA 1997).

Star	Identifier	Sp. T.	Hp	V_T	$(B-V)_T$
Var	HD 220564	F2	7.2894	7.233	0.397
Comp	HD 220538	K2	8.2370	8.180	1.074
Check	SAO 73234	F0	-	9.544	0.365

The brightness of the variable star was measured with respect to HD 220538 (=HIP 115545), while SAO 73234 served as a check star (cf. Table 1). Although the comparison star differs in colour with V350 Peg, it was preferred above the check star which is much fainter (resulting in a larger scatter) and which was not present on all images from 1997. This comparison star is furthermore reported to be found constant in the Hipparcos Catalogue with a standard deviation of only 1.6 mmag (ESA 1997). On the 12 nights in 1997 on which both objects could be measured, the difference between the comparison and the check star averaged $\Delta V = -1.429 \pm 0.013$, with the nightly standard deviations on ΔV ranging from 5 to 11 mmag only. For the 2001 data the difference between comparison and check star averaged $\Delta V = -1.424 \pm 0.009$, with a rms scatter between 8 and 11 mmag. The overall rms scatter on the differences between the variable and comparison star is 26 mmag.

At a first glance the light curve of V350 Peg displays strong changes from night to night. On some nights the peak-to-peak amplitude amounts to 0.15 mag while on others slight variations only are present. Figure 1 shows typical light curves on several consecutive nights.

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* Also based on data obtained by the Hipparcos astrometry satellite.

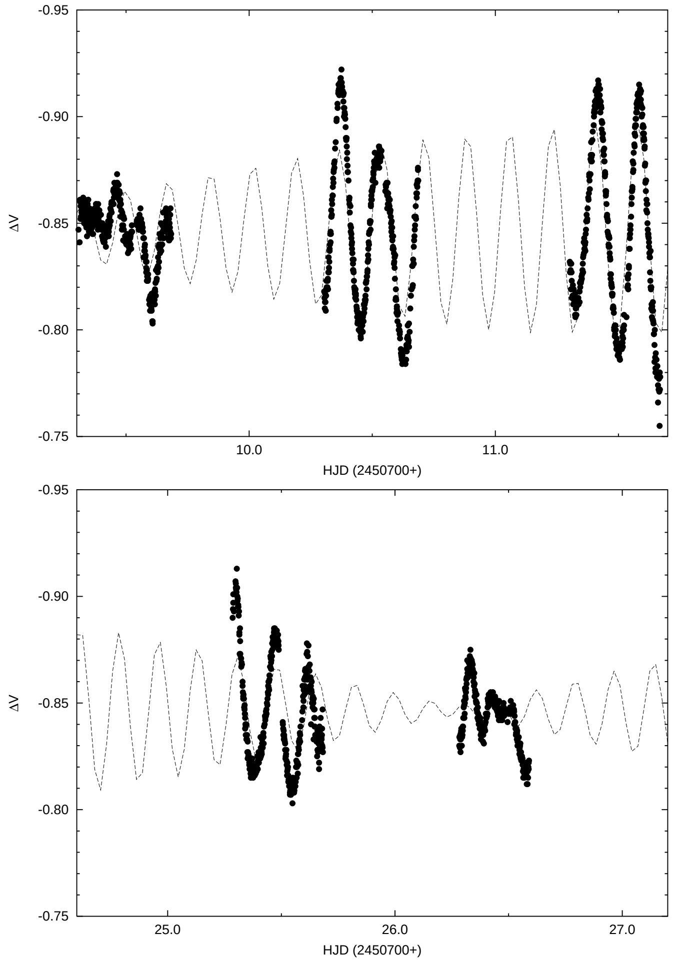

Fig. 1. Observations of V350 Peg on consecutive nights, together with a fit for the two main frequencies.

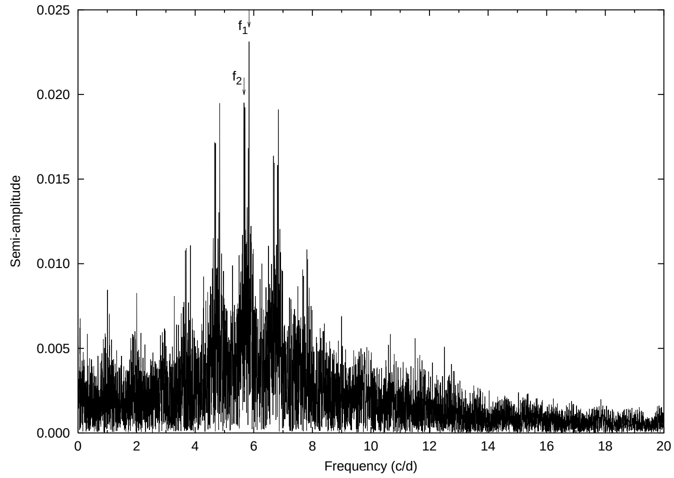

Fig. 2. Fourier spectrum of the 1997–98 data.

3. Frequency analysis

3.1. Data from the Spanish observatories

A Fourier analysis was performed using Period98 (Sperl 1998). The amplitude spectrum (see Fig. 2) shows a strong peak at 5.840 ± 0.002 c/d, together with its day^{-1} aliases, and a somewhat lesser peak at 5.668 ± 0.002 c/d and its aliases. The expected error in frequency may be computed by using the formula in Cuypers (1987) with $\alpha = 2/\pi$ (Montgomery & O'Donoghue 1999). We then obtain 0.0002 c/d. However, we prefer to adopt a more conservative error estimation of 0.002 c/d (i.e. 10 times larger) considering that the halfwidth at half maximum of the peaks in the periodogram is of order 0.004 c/d. This could be explained by the fact that the noise is correlated over an interval of about 10. δt, where δt represents the mean observing time spacing and probably also by the close proximity of the dominant frequencies. In Fig. 3 phase diagrams for f_1 and f_2 are given, after removal of the variation at the other frequency (to avoid overloading of the diagram, only 1 in 5 data points is shown).

Since the (fitted) semi-amplitudes of these frequencies are quite similar (27 and 24 mmag respectively), an obvious beat phenomenon can be seen in the light curve: during the beat cycle of 5.81 days the total amplitude of the star varies between almost zero and a maximum of about 0.15 mag (see Fig. 4, lower panel). A plot of the difference between the observed and the predicted times of maxima with a frequency of 5.840 c/d, against the beat period (Fig. 4, upper panel), shows the characteristic of two interfering frequencies: at the beat phase where the combined amplitude is minimal (i.e. between day 4 and 5 in Fig. 4), there is a jump in the (O–C) values (Breger 2001).

Inspection of the residuals in the light curve shows that a fit with only two frequencies does not explain all the variations (see Fig. 1): only 50% of the total variation is removed. The resulting residuals remain higher than the ones on the fainter check star. Furthermore, after prewhitening for these two main frequencies, there is still a lot of power in the amplitude spectrum (see Fig. 5). The next most dominant peaks are found at 1 and 2 c/d. These are probably artefacts of the Fourier analysis, because phase coverage is incomplete for these frequencies. In addition other peaks appear, mostly located between 6 and 11 c/d, of which the one at 6.374 c/d is the strongest, with a semi-amplitude of 6 mmag. The signal-to-noise ratio equals 4.4 (the noise was calculated within a box with a width of 5 c/d). According to Breger et al. (1993) this makes it a candidate for a genuine pulsation frequency. In order to verify the consistent appearance of this frequency, we also performed a Fourier analysis of four large data subsets (see Table 2): two data sets, A and B, were obtained by dividing the time string in two, two other data sets, I and II, by selecting alternating nights. In Table 2, the frequency, amplitude, phase and S/N-ratio for f_1 and f_2 are given after fitting both frequencies. Essentially the same results have been found when using the 12 nights of data with respect to the check star instead of the comparison star.

Whilst the two most important frequencies were always present in all cases, the frequency of 6.374 c/d (or an alias) showed up with $S/N > 4$ in only two subsets. In the spectral window of subset B for instance, there are prominent features at $n.7^{-1}$ c/d, with n a multiple. At the given resolution, the third frequency cannot be distinguished from $(5.668 + 5/7^{-1})$ c/d. In subset A these features are not present in the spectral window, so that the third frequency is resolved. Other frequencies which are marginally significant in the complete data set, after

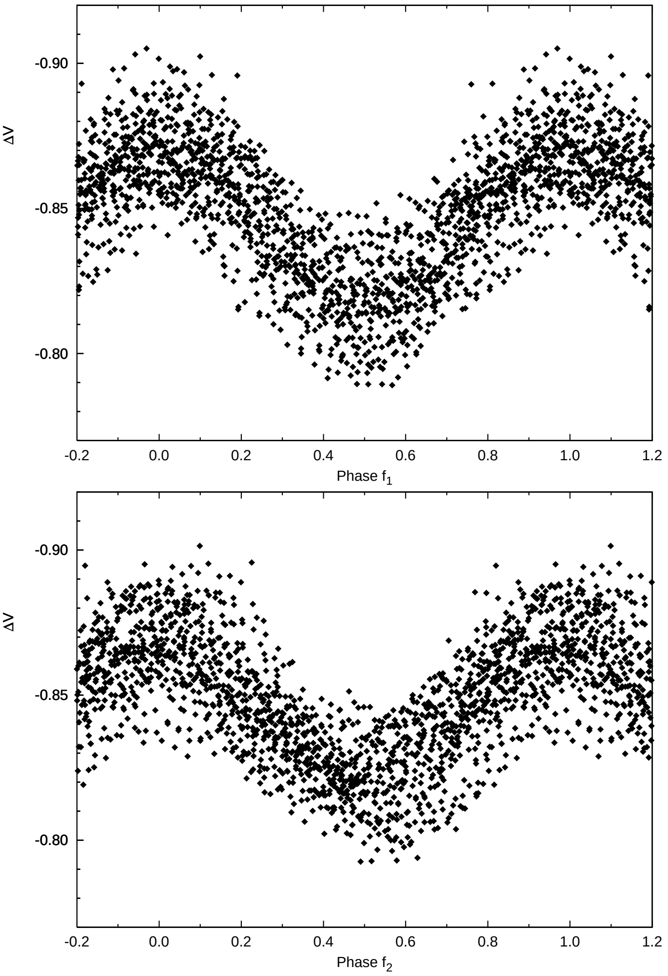

Fig. 3. Phase diagrams of V350 Peg against f_1 and f_2, after prewhitening for the other frequency (1 in 5 data points).

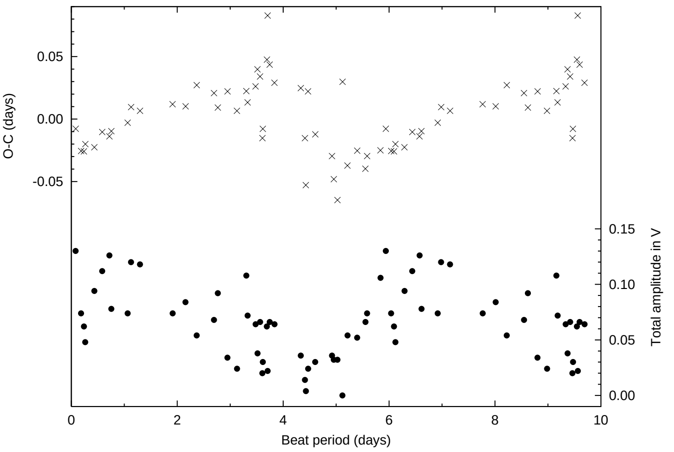

Fig. 4. (O–C) values (in days) between observed maxima and a monoperiodic signal with a frequency of 5.840 c/d (crosses), and total amplitudes (filled circles) plotted against the beat period (in days).

further prewhitening, are not present in all subsets either. Instead, some other apparently unrelated peaks appear in the subsets (all barely reaching significance level, if at all), but which are not detected in the complete data set. Therefore we cannot be confident about the correct identification of

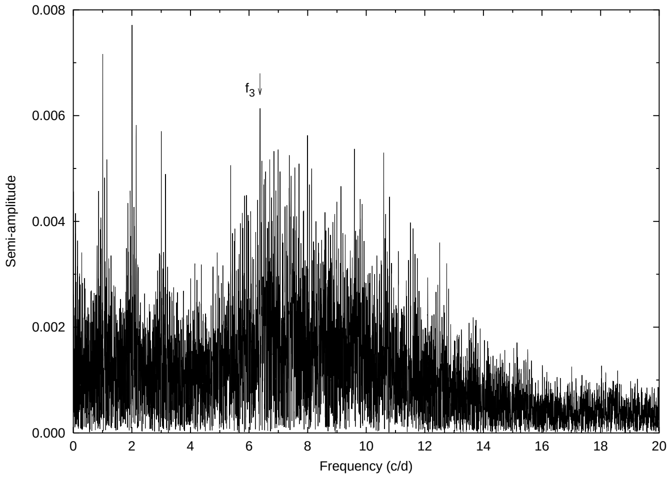

Fig. 5. Fourier spectrum of the 1997–98 data after prewhitening for the two main frequencies.

additional frequencies. Though it is clear from the amplitude spectrum that there are still a number of frequencies present, the spectrum is too complex (in part due to aliasing and artefacts), and the spectral window seems to determine which frequencies appear to be most easily detectable.

The frequency analysis of the data set obtained in 2001, did not allow to identify any of the frequencies discussed above, not even the principal ones. This is not necessarily an indication that these frequencies are no longer present. Picking four nights at random out of the 1997–98 data set will in most cases not be sufficient to identify these frequencies either. Longer data sets are required. The 2001 data do reveal a number of frequencies between 4 and 9 c/d, but the largest S/N is only 3.8, comparable to what can be found from a similar subset of the previous data.

3.2. HIPPARCOS data

A similar frequency analysis was performed on the Hipparcos Epoch Photometry data. These are less numerous but span a longer time base (1170 days). The period listed in the Hipparcos Catalogue (ESA 1997) does not appear in our analysis. Instead a frequency at 5.450 c/d appears to be dominant, followed by one at 5.840 c/d, and others at lower amplitudes (see Table 2). All of these frequencies are only slightly above noise level, which is very high, in particular between 4 and 8 c/d. The latter frequency corresponds to f_1 from our observations, but the former is not present.

To verify whether the Hipparcos frequencies are convincing, we created simulated data based on the Hipparcos observing times, using the two most dominant frequencies from the 1997–98 data set, and adding random noise of the same order as the residuals after prewhitening for the Hipparcos frequencies. For some of these artificial data sets the Fourier analysis produced spurious peaks with a similar separation from the original frequencies as the 5.450 c/d peak. This shows that a false peak may be produced by random observational errors and the particular observing window. In addition, when keeping only those observations with the error flag equal to 0,

Table 2. Frequency analysis of V350 Peg.

Data set name No of data	Timespan days	Freq.	Frequency c/d	Semi-ampl. mag	Phase[(1)] 2πrad	S/N Coding	Explained variation	Remaining var. (mag)
1997–98	171	f_1	5.840	0.027	0.55	16.5	21%	0.021
7131		f_2	5.668	0.024	0.82	14.7	50%	0.013
		f_3	*6.374*	*0.006*	*0.70*	*4.4*	*53%*	*0.013*
A	64	f_1	5.840	0.024	0.53	11.5	19%	0.021
4186		f_2	5.668	0.025	0.80	11.8	52%	0.013
		f_3+1	*7.374*	*0.008*	*0.25*	*4.1*	*56%*	*0.011*
B	100	f_1	5.840	0.030	0.57	14.6	24%	0.021
2945		f_2	5.667	0.024	0.89	12.1	54%	0.013
I	171	f_1	5.840	0.028	0.57	10.8	20%	0.021
3246		f_2	5.668	0.024	0.82	9.3	52%	0.013
II	168	f_1	5.839	0.026	0.54	13.2	22%	0.021
3885		f_2	5.668	0.025	0.82	12.3	53%	0.013
		f_3	*6.380*	*0.008*	*0.85*	*5.2*	*58%*	*0.012*
Hipparcos	1170	?	5.450	0.022	0.42	5.8	21%	0.024
99		f_1	5.840	0.020	0.98	5.1	36%	0.020

[1] The zero-point in time corresponds to HJD = 2450716.0 for the observations presented in this paper, and to HJD = 2448427.0 for the Hipparcos data.

leaving 74 observations, the frequency at 5.668 c/d turns out to have the largest amplitude.

4. Some physical parameters

The Hipparcos parallax of V350 Peg is 6.96 ± 0.82 mas (ESA 1997). Considering that $V_J = 7.20$ mag leads to an absolute visual magnitude of $M_V = 1.41 \pm 0.26$ mag. Strömgren indices are also available: $(b - y) = 0.229$, $m_1 = 0.196$ and $c_1 = 0.771$ mag (Olsen 1994; Rodríguez et al. 2000). Assuming insignificant reddening ($E(b-y) = 0.0$), the variable is located inside the δ Scuti instability domain and rather close to the observed red edge for evolved stars (see Fig. 6 in Pamyatnykh 2000). Using the calibrations in effective temperature and surface gravity for solar abundances (Smalley & Kupka 1997), values of $T_{\rm eff} = 6800 \pm 100$ K and $\log g = 3.5 \pm 0.2$ dex can be derived. Given these errors but assuming a zero error on the frequency, the corresponding error on the pulsation constant Q is of the order of 15% at least, which is too large to be of any help in the mode determination (see also Breger 2000).

5. Conclusion

In conclusion it can be stated that the main period of V350 Peg as given by the Hipparcos Catalogue is not confirmed, neither in the Hipparcos data, nor in the new data. Instead we identified two frequencies of almost similar amplitude: one at 5.840 c/d (0.1712 d), and one at 5.668 c/d (0.1764 d). The ratio of these frequencies ($f_2/f_1 = 0.97$) indicates non-radial pulsation for at least one of the corresponding modes. Since the semi-amplitudes are very similar, it is furthermore probable that both modes are non-radial. Follow-up observations are necessary to extract the additional frequencies, which are probably lying in a narrow range of the frequency spectrum. Though the data set used here is a very extensive one, the fact that it is collected from a single site prevents reaching further conclusions with respect to the multiperiodic character (note that these data will be available upon request from the Archives of Unpublished Observations of IAU Commission 27). The multiperiodicity combined with the short beat period and the fact that several non-radial modes are possibly excited, make this star a worthwhile target for a multisite campaign.

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