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Study of the variability of the Delta Scuti stars. VI. Pulsational behaviour of HR 1392 (69 Tau)

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Summary. — Photoelectric observations of the Delta Scuti star 69 Tau are presented. The analysis of the light curves shows a single sinusoidal component over the detectability threshold. The observed frequency does not agree with the fundamental pulsation mode.
The small observed amplitude is probably connected with the high rotational velocity. However the presence in the same region of the HR diagram of monopulsating Delta Scuti stars involving pulsational energies which differ by orders of magnitude, remains an open problem.

Key words : Delta Scuti stars ; 69 Tau — pulsation.

1. The observations.

69 Tau (F0III-IV) belongs to the Hyades cluster and shows the highest rotational velocity of any cluster member. Its variability was detected by Horan (1979) during three hours of observations : the tentative period and amplitude were $3^{\rm h}.2$ and $0^{\rm m}.025$ respectively.

We observed 69 Tau in V colour for seven nights between November '81 and February '82 (for instrumental equipment and procedure, see Bossi *et al.*, 1977). HR 1387 (K Tau — A7V) and HR 1388 (67 Tau — A5) were the comparison (c) and the check (c1) stars. The observational sequence consisted of 18 s integration of the variable (v) and the two comparison stars c, c1 in the order : c-v-c-c1-c-v-c. The observations of the variable and check stars were grouped into 97 and 86 normal points respectively. Table I shows the normal points ΔV for 69 Tau with the observational times and the standard errors σ.

2. Analysis of the data.

The search for the possible periodicities present in our observations was achieved in two ways.

First, the data were analyzed with the least-squares power spectrum method proposed by Vaníček (1971). This procedure weights the data as $1/\sigma^2$. In addition to the dominant frequency at 6.74 c/d, the power spectrum shows a small peak at low frequency, produced by different values of the night by night average magnitude. Taking into account these two known components, the power spectrum does not bear evidence of any other significant peak. The same analysis for ΔV's between c and c1 does not point out any significant features, with the exception of a low frequency signal, similar to that found for the variable star (even if the former seems of smaller amplitude : the contribution to the initial r.m.s. residual is $0^{\rm m}.0029$ for the comparison stars and $0^{\rm m}.0019$ for 69 Tau). Probably this low frequency feature cannot be attributed to the variable star. In any case f = 0.53 c/d is too low to be related to a Delta Scuti pulsational mode.

The second approach used the non linear least-squares period determination method PERDET (Breger, 1982) in connection with the Fourier method for unequally spaced data of Deeming (1975). In this procedure too, we found the low frequency signal. In consequence of that all the nights (with the exception of JD 44946 and 44992, which had too few measurements) were aligned to the same average value and then reanalyzed : the same results as in the first analysis came out, i.e. only a 6.74 c/d sinusoid. In any case, if in our data a second pulsation mode is present, it cannot have a semi-amplitude larger than $0^{\rm m}.002$. This result is common in both analysis procedures. Table II represents the adopted solution for 69 Tau light variations. The least-squares solution is fitted to the observations in figure 1, using one sinusoid to simulate the low frequency signal. As we can see, this fit is generally satisfactory with the exception of the night 990, in which however the measurements were poor.

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3. Discussion.

When only one frequency is known, the pulsation mode identification is very difficult because it is not possible to compare the observed period ratios with the theoretical ones. Using the formula (5) of Petersen *et al.* (1972) the frequency at 6.74 c/d gives the pulsation constant $Q = 0^{d}.027$. The physical parameters of this star ($M_V = 0^{m}.55$, log $T_e = 3.87$, log $g = 3.6$) have been derived from the *ubvy* indices (Hauck *et al.*, 1980) by means of the formula (3) of Petersen *et al.* (1972), Breger's (1974) calibration and assuming $BC = +0.02$ (Straizys *et al.*, 1981).

This Q-value excludes the possibility that 69 Tau is pulsating in the radial fundamental mode, but does not help us in identifying the true pulsational features.

Furthermore the case of 69 Tau is complicated by the fast rotation : i.e. $v \sin i = 195$ km/sec (Uesugi *et al.*, 1981). If we take into account the effect of this rotation on the pulsational periods, applying for example the formula (50) in Saio (1981), we introduce some new uncertainties in the Q determination, besides the usual internal error of about $0^{d}.003$ (Breger, 1975). The greatest uncertainty is due to the indetermination of the view angle, which prevents us to know the exact value of the stellar rotational frequency. Anyway the negative value of the C_2 parameter in aforesaid formula (50) strengthens the exclusion of the fundamental mode.

The equatorial gravity of 69 Tau results in about 2/3 of the polar one, even if we assume $\sin i = 1$. This means that the stellar structure is strongly perturbed, and observational evidences suggest that non-radial modes are favoured in this condition (Fitch, 1980).

Finally, it should be necessary to explain why some low amplitude monopulsators, as perhaps 69 Tau (other examples may be HQ Hya and 21 Vul), bring into action pulsational energies some orders of a magnitude smaller than those related to some monopulsating Dwarf Cepheids, even if the two groups of stars have similar physical characteristics.

Perhaps, as Dziembowski (1980) supposes, non-radial modes with amplitude below our detectability threshold can be present in addition to the main discovered oscillation. Recently Breger (1982) showed a strong dependence of amplitudes on rotational velocities, in the sense that a large amplitude requires a small rotational velocity, and this is not the case of 69 Tau. This fact is certainly very important, especially in view of future interpretations, but it is not yet an explanation.

In conclusion, the problem of the low-amplitude monopulsators has to be added to those not yet resolved as regards the Delta Scuti stars.

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TABLE I. — *Normal points ΔV for 69 Tau with the observational times and the standard errors σ.*

Hel. J.D. 2400000+	ΔV	σ	Hel. J.D. 2400000+	ΔV	σ	Hel. J.D. 2400000+	ΔV	σ
44917.393	-0.076	.003	.576	-0.074	.001	.295	-0.087	.003
.402	-0.075	.002	.591	-0.083	.002	.302	-0.082	.003
.412	-0.072	.003	.605	-0.085	.002	.311	-0.074	.006
.431	-0.084	.003	.620	-0.080	.003	.319	-0.071	.003
.447	-0.084	.002	.634	-0.088	.004	.327	-0.074	.003
.454	-0.085	.003	.646	-0.084	.002	.336	-0.073	.003
.464	-0.077	.003	44919.474	-0.080	.003	.344	-0.073	.004
.475	-0.077	.002	.483	-0.087	.004	.350	-0.070	.002
.483	-0.075	.002	.492	-0.083	.003	.361	-0.059	.004
.491	-0.074	.002	.498	-0.085	.003	.369	-0.061	.003
.498	-0.074	.002	.505	-0.089	.003	.376	-0.066	.003
.505	-0.069	.002	.511	-0.088	.004	.384	-0.068	.003
.515	-0.069	.003	.518	-0.087	.003	.392	-0.072	.003
.531	-0.071	.003	.524	-0.094	.003	.402	-0.082	.003
.544	-0.078	.002	.531	-0.087	.004	.414	-0.080	.004
.552	-0.083	.002	.538	-0.088	.003	.427	-0.088	.006
.560	-0.082	.003	.544	-0.084	.004	.436	-0.091	.006
.568	-0.083	.003	.551	-0.079	.003	.444	-0.082	.004
.576	-0.083	.002	.559	-0.080	.004	.451	-0.077	.004
.584	-0.086	.002	.568	-0.077	.003	.460	-0.075	.006
.591	-0.088	.002	.577	-0.074	.003	44992.265	-0.071	.003
.598	-0.089	.002	.585	-0.072	.004	.276	-0.065	.003
.606	-0.088	.003	.591	-0.078	.003	.287	-0.070	.004
.614	-0.083	.002	.601	-0.078	.003	.324	-0.084	.003
.621	-0.080	.002	.613	-0.082	.003	45006.235	-0.065	.005
.630	-0.078	.003	.620	-0.086	.004	.251	-0.070	.003
.639	-0.077	.002	.630	-0.084	.004	.262	-0.075	.003
.651	-0.070	.003	44946.336	-0.082	.003	.269	-0.075	.003
44918.502	-0.077	.002	.345	-0.076	.007	.277	-0.080	.001
.518	-0.066	.003	44990.259	-0.081	.003	.288	-0.080	.004
.532	-0.071	.001	.269	-0.075	.003	.295	-0.087	.003
.547	-0.073	.002	.278	-0.080	.002			
.561	-0.069	.001	.286	-0.079	.003			

TABLE II. — *Adopted solution for 69 Tau light variations.*

f = 6.74 ± 0.08 c/d
Amplitude = $0\overset{m}{.}0081$
Phase = + 0.046
DMϕ = 0.0776
Initial r.m.s. residual = $0\overset{m}{.}0065$
Final r.m.s. residual = $0\overset{m}{.}0034$

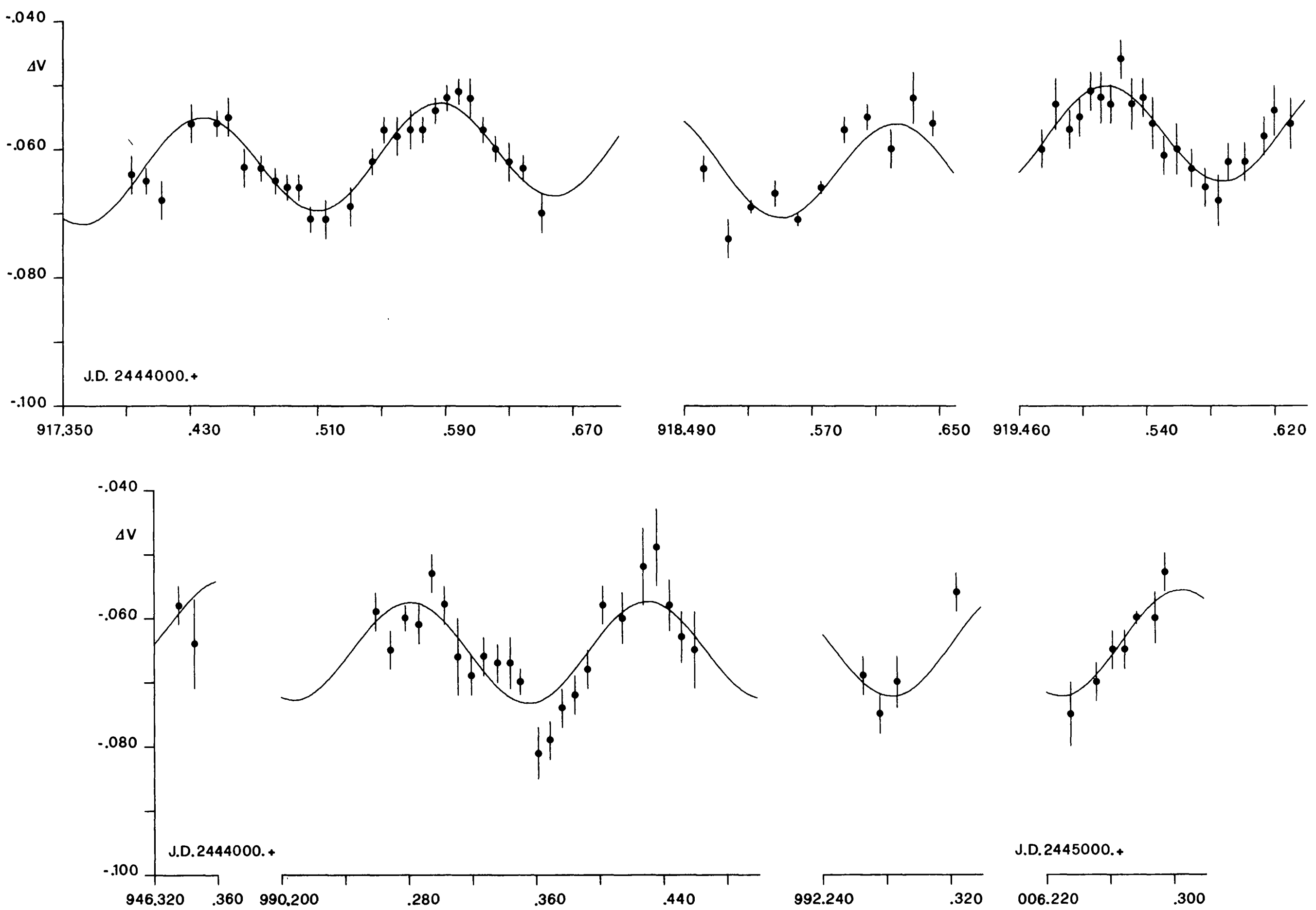

FIGURE 1. — Normal points and synthetic light curve for 69 Tau.

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Study of the variability of the Delta Scuti stars. VII. The problem of stability and monoperiodicity in 20 CVn

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Summary. — We can confirm the long term stability of the Delta Scuti star 20 CVn on the ground of 17 hours of observation obtained in 1982. However we suspect the presence of a second pulsational mode although this star was so far claimed as a monopulsator.
The small pulsational amplitude, like that of many other similar variable stars, still needs an exhaustive explanation. In this case, it may be connected with the excitation of several high order modes, which would be photometrically undetectable, and/or with a possible peculiar metallicity.

Key words : Delta Scuti stars — pulsation — variable stars — 20 CVn.

1. Introduction.

20 CVn (HR 5017, F0II-III) was classified as a Delta Scuti star by Wehlau (1966). There are several controversial assertions about its metallicity : following some authors, it presents normal chemical abundances as the Hyades ; according to other people, it is a Delta Delphini star (Dickens *et al.,* 1971 ; Morgan and Abt, 1972 ; Kurtz, 1976). Recently M. Jaschek (1982) did not include 20 CVn among the sure Delta Delphini stars.

This object was suitably observed for the search of periodicities in 1969 (Shaw, 1976) and in 1980 (Peña and Gonzales, 1981, hereafter called PG). According to the data analyses of these authors, 20 CVn is a monoperiodic oscillator with a frequency of 8.22 c/d. The light variation amplitudes are practically the same in both sets of data : Shaw (1976) gives a semi-amplitude of $0^{m}.0098$ in V colour and we obtain a value of $0^{m}.011$ from PG's curves, hand-drawn with poor accuracy. So 20 CVn has behaved like a stable pulsator in a time interval of 11 years.

The steadiness of the pulsational behaviour of Delta Scuti stars is still an open matter. There are only a few objects observed in different epochs with the required precision, and they show different behaviours : e.g. 21 Mon (Stobie *et al.,* 1977) shows two completely different sets of frequencies at a distance of two years ; 38 Cnc (Breger, 1980) shows stable frequencies during a period of eight years, but with changing amplitudes and finally DQ Cep (Pena *et al.,* 1983) and HR 6434 (Breger, 1982a) have stable frequencies and amplitudes. So we decided to check the stability of 20 CVn further on observing it for three nights in 1982, in V colour, for a total of 17 hours, which correspond to about 6 periods.

2. Observations and data analysis.

For the instrumental equipment and reduction techniques, see Bossi *et al.* (1977). The comparison (c) and the check (c1) stars were HR 5004 (A5) and HR 4997 (K0III) respectively. The measurements were made adopting the sequence c-v-c-c1-c-v-c.... In order to improve the detection efficiency of periodicities (Scargle, 1982) the ΔV values were grouped into normal points (reported in table I and fig. 1). The mean luminosity of the variable in the third night is lower than that of the other two of about 0.014 magnitudes. A careful inspection of the data concerning the variable and the comparison stars allows us to exclude with some confidence that this can be due to instrumental, reduction, or sky effects, or to a variability of the comparison star.

So it seems that it could be a real phenomenon associated to the variable star : unfortunately we are unable to explain that in this context.

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The observations were analyzed adopting the Fourier transform for unequally spaced data (Deeming, 1975) in connection with the non-linear least-squares fit of sinusoids PERDET (Breger, 1982b).

Our results confirm definitely the pulsational stability of 20 CVn : we found a frequency of 8.21 ± 0.06 c/d with a semi-amplitude of $0^{m}_{.}0087$. The same analysis procedure, applied to the differences of magnitudes between the comparison and the check stars, gives only a noise spectrum. In figure 1 the solid line represent the computed sinusoid which gives the best least-squares fit. Its mean value has been adjusted night by night in order to answer for systematic shifts.

However the monoperiodicity of this star cannot be asserted with the same confidence. All the three considered major sets of observations (Shaw, 1976 ; PG and the present) seem to show in several nights, also at a mere glance, clues of modulation in the amplitude, which may be due to a beat between two close frequencies. Such a fact, if real, would complicate to some extent the interpretation of the results. With the aim to throw light on this problem, we reanalyzed with the above said procedure the PG data, which constitute the best group both quantitatively and qualitatively. Beside the frequency found by the authors it seems to present a second one at 6.99 c/d. The simultaneous least-squares fit for both frequencies gives the following semi-amplitudes : $0^{m}_{.}0100$ and $0^{m}_{.}0027$ respectively. The upper part of figure 2 shows a power spectrum computed using the PG data pre-whitened by subtracting out the sinusoid of 8.22 c/d and with the sets of data of each night reduced to the same mean value. The spectrum of a pure sinusoid with frequency at 6.99 c/d, sampled with the same times of PG observations, is drawn at the bottom of the same figure. As it can be seen, the two figures look very similar, except for the presence of some noise in the upper one. This test gives also confidence that the true frequency is at 6.99 and not at 7.99 c/d.

The remaining two sets of data are insufficient to verify this result. In order to get a final answer, a further compact set of observations distributed over about ten nights would be necessary.

3. Discussion.

As regards the pulsational characteristics of 20 CVn we can limit ourselves to some simple considerations :

1) The pulsational mode could be the second radial overtone (PG, 1981). This assignment is however very uncertain, due either to the indetermination present in the computed Q value or to the impossibility to obtain the ratios between the frequencies corresponding to different modes, in the case of a virtual monopulsator. If the second frequency at 6.99 c/d was confirmed, we could furthermore affirm that its ratio with the first one, i.e. 0.85, do not fit in a satisfactory way the hypothesis of the excitation of the two first radial overtones (Fitch, 1981).

2) The low light amplitude classifies 20 CVn as a member of the group of those monopulsators which show a behaviour very different to that of the dwarf Cepheids lying in the same region of HR diagram. This fact is not yet exhaustively explained (PG, 1981 ; Breger, 1982a ; Bossi *et al.,* 1983). Taking into account the exiguity of the involved energies, the presence of a second periodicity with a small amplitude would not appreciably change the problem.

3) The projected rotational velocity of this star is 15 km/s (Uesugi and Fukuda, 1981). This value prevents to connect the low light amplitude with the high rotation (Breger, 1982a), even if we cannot exclude that the star could be a fast rotator seen pole-on.

4) It is possible to explain the pulsational characteristics of 20 CVn by hypothesizing the excitation of several modes, mainly non-radial, with amplitudes below the detectability threshold (Dziembowski, 1980). On the other hand this star is, probably, not a monopulsator.

5) The chemical composition could be an alternative or even a complementary factor which limits the pulsational amplitude. As we saw in the introduction, the spectral peculiarities of 20 CVn are at least controversial ; we observe that a possible peculiar metallicity could strengthen the hypothesis that this star is a slow rotator.

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TABLE I.— *Normal points ΔV for 20 CVn with the observational times and the standard errors σ.*

Hel. J.D. 2400000 +	ΔV	σ	Hel. J.D. 2400000 +	ΔV	σ	Hel. J.D. 2400000 +	ΔV	σ
45040.412	.914	.002	.689	.927	.003	.646	.913	.002
.428	.920	.002	45043.412	.918	.003	.665	.906	.003
.450	.920	.003	.427	.914	.003	45044.400	.893	.004
.478	.912	.002	.444	.911	.003	.418	.899	.003
.507	.911	.003	.468	.919	.003	.437	.915	.002
.529	.916	.003	.501	.927	.003	.461	.912	.002
.551	.921	.002	.527	.918	.003	.484	.906	.002
.573	.923	.002	.538	.910	.003	.510	.893	.002
.588	.912	.002	.555	.906	.003	.527	.885	.002
.607	.915	.002	.574	.911	.003	.537	.893	.002
.633	.908	.002	.599	.925	.003	.552	.902	.002
.655	.909	.003	.616	.925	.001	.567	.909	.003
.669	.926	.001	.629	.917	.002			

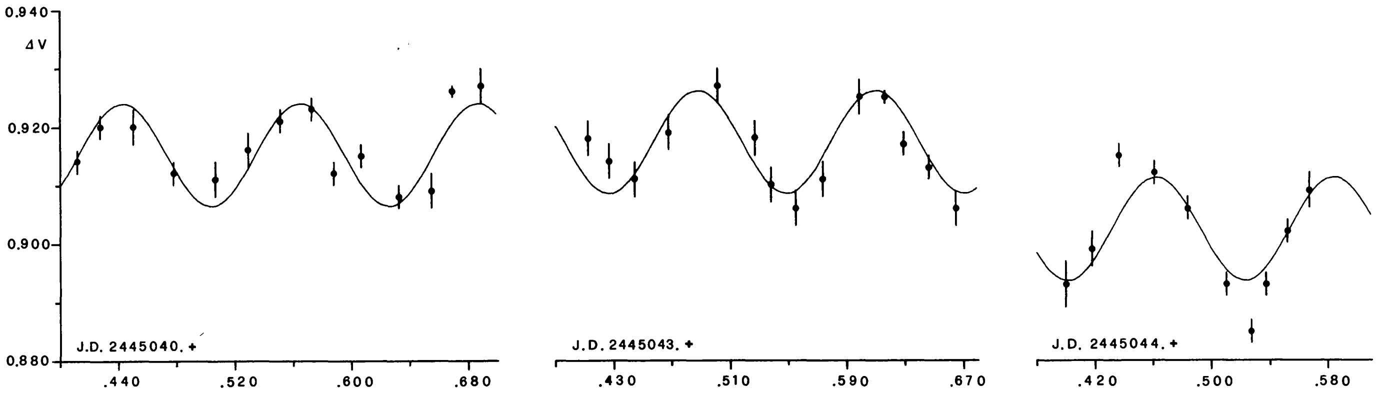

FIGURE 1. — Our measurements and the related synthesized light curve ; bars represent the double standard errors σ.

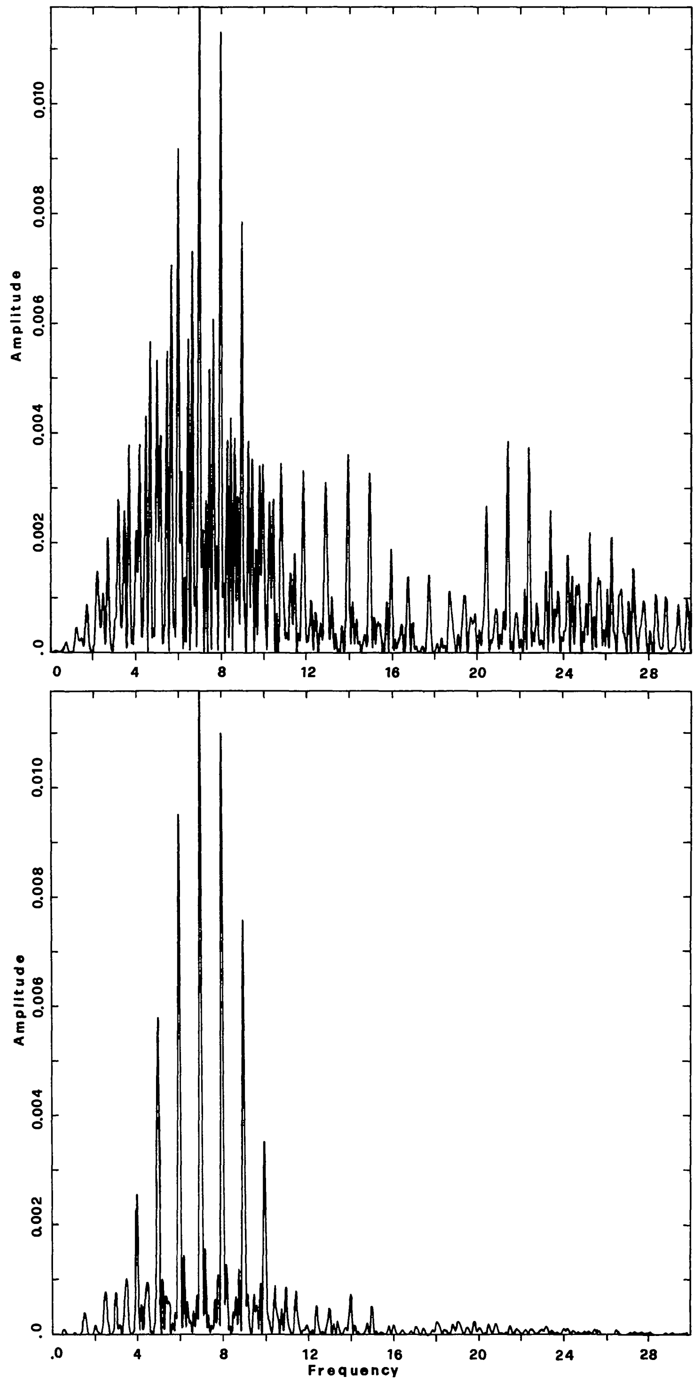

FIGURE 2. — *Top :* Power spectrum of PG data, prewhitened by the 8.22 c/d sinusoid and with the sets of observations of each night reduced to the same mean value. *Bottom :* Power spectrum of a pure 6.99 c/d sinusoid, sampled with the same times of PG observations.