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The variability of δ Ceti (*)

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Summary. — Differential *uvby* observations of the well-known β Cephei star δ Cet, obtained on seven nights in 1981 and on one night in 1982, are presented and analysed. Contrary to a recent report, no variation in the shape of the light curves is found. However, a marginal night-to-night variation of the 1981 amplitudes is noted. It is then demonstrated that the amplitude variation was caused either by a secondary short-period component with an amplitude not exceeding $0^{\mathrm{m}}.0016$, or by slow drifts in the differential magnitudes. In addition, it is shown that all available epochs of maximum light, except three unreliable ones, can be accounted for by a parabolic ephemeris which implies an increase of the period at a rate of 0.47 ± 0.09 sec/century. However, it is also shown that the epochs of maximum light from 1963 onwards can be satisfactorily represented with a constant period, equal to $0^{\mathrm{d}}.16113762 \pm 0^{\mathrm{d}}.00000002$. The available epochs of maximum radial-velocity are then examined. No compelling evidence for a variation of the phase lag between the light and radial-velocity curves is found. From modern radial-velocity data, a phase lag equal to 0.200 ± 0.005 is derived. Finally, it is shown that the available photometric observations are still not sufficient to detect a secular light amplitude change.

Key words : β Cephei stars — *uvby* photometry — pulsations.

1. Introduction.

As far as its variability is concerned, δ Cet = HR779 (*B2IV*, $V = 4^{\mathrm{m}}.07$) is remarkably devoid of complications. Unlike most other β Cephei stars, it does not show multiple periods or line-profile variations. The radial-velocity and light curves are sinusoidal in shape, with amplitudes (half-ranges) amounting to 7 km/sec and 12 milli-magnitudes (mmag) in the visual, respectively. The period is equal to $0^{\mathrm{d}}.161138$. As in other single-period variables of this type, maximum light occurs around the time when the velocity crosses the γ-axis from positive to negative values, so that the light-curve lags about a quarter period behind the velocity curve.

After these facts have been established by McNamara (1955) and Walker (1953), δ Cet was observed by a number of people. Most of them, however, contributed only one or two nights of spectrographic or photometric data, unfortunately not always of very high quality. New results were added by observations at ultraviolet wavelengths. In the Johnson *U* band the amplitude turned out to be 8 mmag greater than in the visual (Jerzykiewicz, 1971). It was found to further increase over the far ultraviolet, reaching 50 mmag at 1330 Å (Lesh, 1976 ; Beeckmans and Burger, 1977), and 70 mmag at 1120 Å (Hutchings and Hill, 1980).

The ground-based data, including the early radial-velocity observations of Frost and Adams (1903), Henroteau (1922), Crump (1934), and Marshall (1934), were used in several recent investigations of the long-term behaviour of the star's period by means of the (O-C) diagram. However, there is little agreement between results of different workers. Lane (1977) concluded that the period was constant until 1965 and that subsequently it increased at a rate of about 0.7 sec/century. Alternative interpretations of the (O-C) diagram, involving for example the light travel time effect due to a hypothetical binary motion, or several abrupt changes of period, she

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found less satisfactory. On the other hand, Ciurla (1979) argued that the period has been uniformly increasing since 1900 at a rate of 0.11 sec/century.

The slow rate of period increase was recently supported by Lloyd and Pike (1984), who contributed three nights of radial-velocity observations of the star. From all available radial-velocity data these authors derived the rate of period increase equal to 0.15 sec/century. However, they noted that up to 1952, when the first modern radial-velocity observations of δ Cet were made by McNamara (1955), there is little evidence to suggest a period variation. Furthermore, Lloyd and Pike (1984) pointed out that if only the modern velocity data — from McNamara (1955) onwards — were considered, a larger rate of period increase, equal to 0.28 sec/century, would result.

Ciurla's (1979) analysis yielded two by-products. One involved the phase difference between the light and radial-velocity curves, while the other, the radial-velocity amplitude. Instead of the above-mentioned phase lag of about 0.25, Ciurla (1979) derived 0.19 ± 0.04. Moreover, he found that the velocity amplitude has been increasing uniformly since 1900, the rate of increase being 3.9 km/sec/century. The latter result was also confirmed by Lloyd and Pike (1984). However, these authors suggested in addition that the phase lag changes slowly with time.

Another recent analysis of the long-term behaviour of the period of δ Cet is that of Chapellier (1985). Assuming the phase lag of 0.19, Chapellier (1985) plotted a single (O-C) diagram from both the radial-velocity and photometric data. He then tested the hypothesis of a uniform period increase against that of an abrupt change, finding the latter more satisfactory. According to Chapellier (1985), a 0.13 sec abrupt increase of the period of δ Cet had occurred in 1939, and after that the period remained constant. In a subsequent paper, Chapellier (1986) found a substantial variation in the phase lag between the light and radial-velocity curves, thus apparently confirming the earlier result of Lloyd and Pike (1984).

In none of the above-mentioned attempts to investigate the long-term behaviour of δ Cet, the essential simplicity of the star's variation has been questioned. On the contrary, they were all based on the assumption that the variation is strictly sinusoidal over, at least, each observing season. Exceptional in this respect is the recent paper by Sareyan *et al.* (1986), based on extensive photometric observations obtained in 1980, in which it is reported that « in the different light curves, large shape differences and some amplitude variations are easily seen from one night to another ». In spite of this, Sareyan *et al.* (1986) were able to discover a secular increase of the light amplitude with a rate of 7 mmag/century in the visual, and 13 mmag/century in the Johnson U band.

In the present paper we report *uvby* differential observations of δ Cet, carried out in 1981 and 1982 at the European Southern Observatory, La Silla, Chile. After briefly describing the observations and reductions in section 2, in section 3 we examine the shape of the light curves. In the next three sections we carefully analyse the night-to-night variations of the mean *uvby* differential magnitudes, the amplitudes, and the initial phases, devoting considerable attention to systematic effects that may produce spurious variations. In section 7 we investigate the wavelength dependence of the light amplitude and derive the amplitudes of b-y and c_1. Then, using all available data, we discuss in section 8 the photometric (O-C) diagram, the secular increase of the period, the phase lag between the light and radial-velocity curves, and the secular increase of the light amplitude. Finally, in section 9, we summarize main results of this work.

2. Observations and reductions.

The observations reported in the present paper were carried out on seven nigths in October 1981 by C.S., and on one night in October 1982 by M. K. Both observers used the same equipment, the simultaneous four-channel *uvby* photometer, attached to the Danish 50-cm telescope. In 1981 two comparison stars, ξ^2 and λ Cet, were used. An observation, consisting of a series of single 10-sec integrations on ξ^2, δ, and λ Cet, followed by 10-sec sky readings, resulted in the *uvby* differential magnitudes « δ minus a mean of ξ^2 and λ » and « λ minus ξ^2 ». For the 1982 observations, γ Cet was selected as the only comparison star, and shorter integration times, equal to 5 sec, were used. An observation yielded the magnitudes « δ minus γ ». The differential b-y and c_1 indices were also derived.

The differential magnitudes and colour indices were left on the instrumental system. However, they were carefully corrected for the atmospheric extinction by means of nightly extinction coefficients. In 1981 the extinction coefficients were determined in the usual way, from observations of the *uvby* standard stars over a range of air mass. In 1982 the extinction coefficients were derived as the rates of change with air mass of the observed magnitudes of the comparison star. The atmospheric extinction corrections will be discussed in some detail in section 4.

The differential magnitudes of the variable are listed in table I, at the end of this paper. In order to save space, we do not list the differential magnitudes « λ minus ξ^2 ». These data can be requested from the first author.

TABLE II. — *The standard deviations (in* mmag*).*

	δ Cet				λ Cet				
$JD_{\odot}$-2444800	u	v	b	y	u	v	b	y	N
83.6935^d-.7715^d	-	-	-	-	3.4	2.9	3.0	4.8	16
88.7042-.8537	3.1	2.5	2.9	3.2	4.0	3.1	3.4	3.4	46
89.6758-.8424	3.8	2.8	3.0	2.8	3.9	2.8	3.1	3.0	54
90.6767-.8407	4.3	3.3	3.4	3.3	4.7	3.5	3.3	3.7	56
91.6757-.8056	3.8	3.4	2.9	3.6	2.8	2.8	3.2	2.7	38
92.6659-.8351	3.9	3.1	3.1	3.4	4.1	2.9	3.4	3.7	52
96.6699-.8348	3.8	2.7	3.0	3.3	3.4	3.4	3.9	3.6	57

3. The light curves.

For two nights of 1981, JD 2444888 and JD 2444891, the differential magnitudes are plotted in figure 1 as a function of the time of observation, expressed in heliocentric Julian days. The 1982 differential magnitudes are shown in figure 2. The solid curves in figures 1 and 2 represent the $0^{d}.161138$ sinusoids :

$$\Delta x = \langle \Delta x \rangle + A_x \cos \left(2 \pi t / 0^{d}.161138 - \varphi_x\right), \quad (1)$$

fitted to each night's data by the method of least squares.

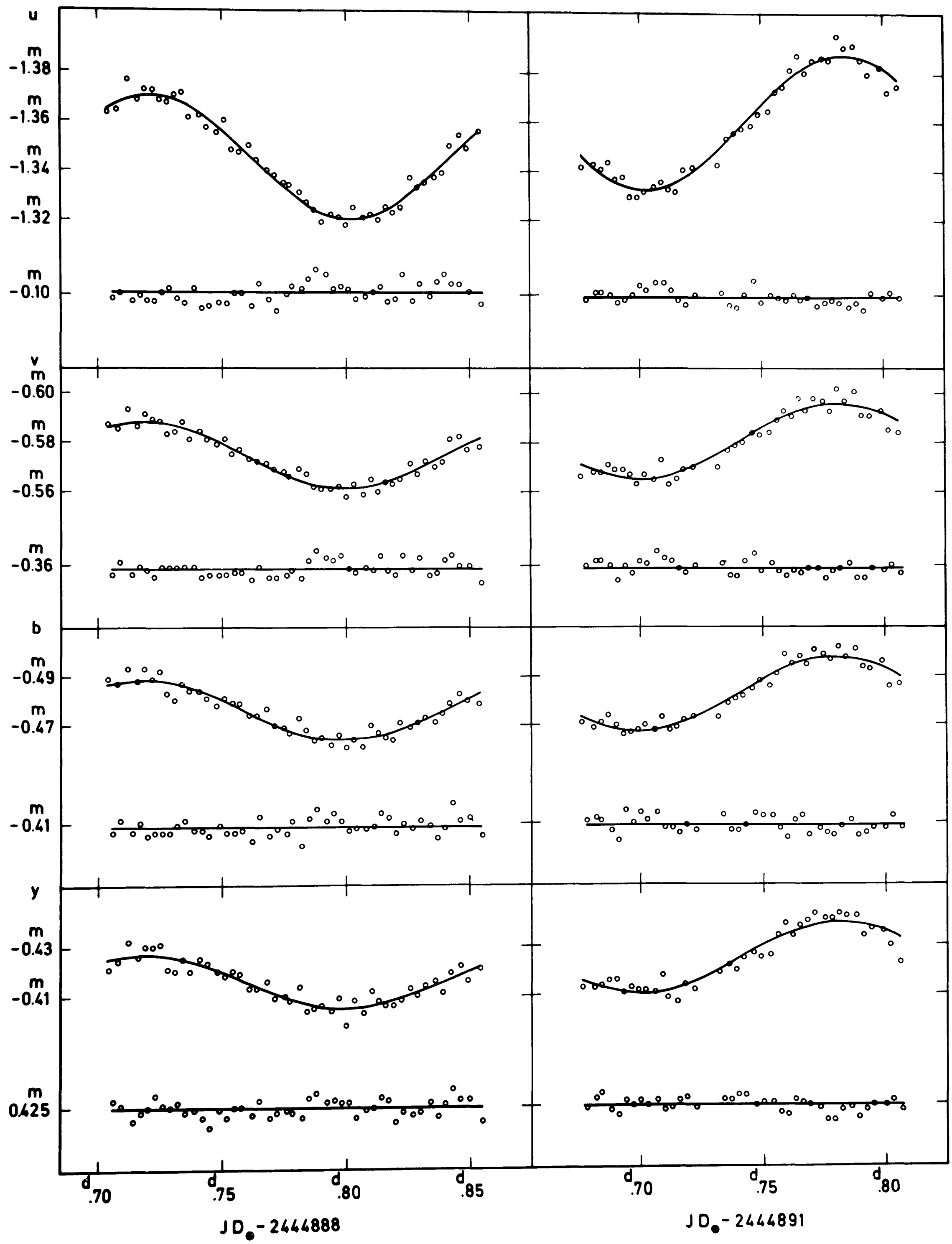

FIGURE 1. — Differential *uvby* magnitudes « δ minus a mean of ξ^2 and λ Cet » (top each panel) and « λ minus ξ^2 Cet » (bottom each panel) on two nights in 1981, plotted as a function of the heliocentric Julian Date. The solid curves represent the $0^{d}.161138$ sinusoids, and the horizontal straight lines, the mean differential magnitudes of the comparison stars.

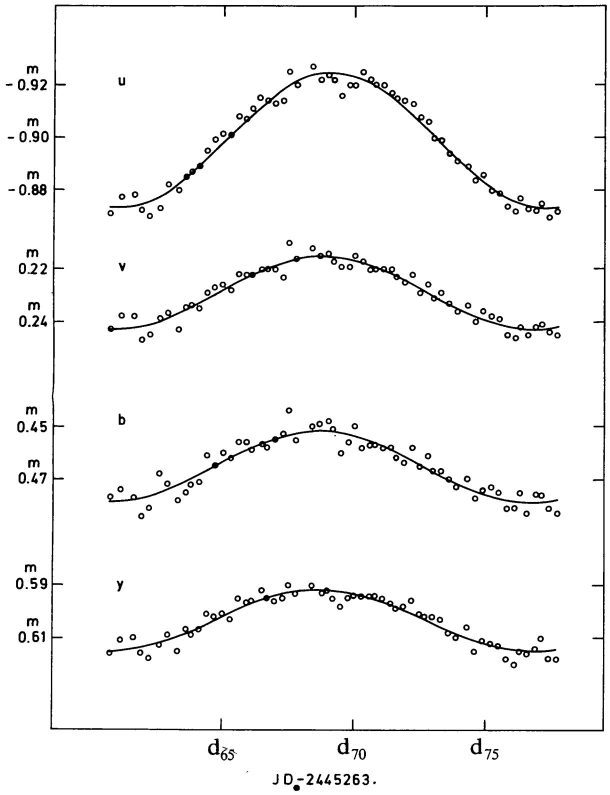

FIGURE 2. — The 1982 differential *uvby* magnitudes « δ minus γ Cet » plotted as a function of the heliocentric Julian day. The solid curves represent the 0ᵈ.161138 sinusoids.

In this equation, x denotes u, v, b, or y, t is reckoned from an arbitrary initial epoch, and the remaining symbols have their usual meaning. In figure 1 are also shown horizontal straight lines, Δx = const., corresponding to the nightly mean magnitudes of the comparison stars.

As can be seen from figures 1 and 2, the 0ᵈ.161138 sinusoids fit the data very well. In fact, the scatter of the variable star observations around them looks the same as the scatter of the comparison star observations around the Δx = const. lines. In this respect the nights shown are typical of our data. Quantitatively this is demonstrated in table II, which contains the standard deviations of the least-squares fits of equation (1) to the differential magnitudes « δ minus a mean of ξ^2 and λ » (in columns from second to fifth), along with the standard deviations of the differential magnitudes « λ minus ξ^2 » (in columns from sixth to ninth). In addition, the first column of table II gives the epochs of the first and last observation of the variable, while the last column contains the number of observations. Note that from the first night's data the « δ minus a mean of ξ^2 and λ » standard deviations could not be derived, because on this night the time interval covered by observations was too short.

The numbers in table II show that on each night the light curves are sinusoidal in shape to within the errors of measurement. In agreement with the earlier results of

TABLE III. — *Mean epochs of maximum light of δ Cet.*

$JD_{\odot}$ - 2400000		N	Author	E	(O - C)
34286ᵈ.8545 +	0ᵈ.0022	2	Walker (1953)	-25437	0ᵈ.0192
36163.9424	0.0027	1	Sato (1958)	-13788	0.0181
38338.4765	0.0020	6	Van Hoof (1968)	-293	0.0036
38656.5605	0.0021	5		1681	0.0025
38385.6861	0.0009	4	Jerzykiewicz (1971)	0	0
39013.9636	0.0006	10		3899	0.0030
40558.9497	0.0020	1	Watson (1971)	13487	0.0042
42393.3487	0.0005	5	Tunca (1977)	24871	0.0156
43101.3882	0.0005	2		29265	0.0176
43061.8957	0.0023	1	Lane (1977)	29020	0.0037
43794.2670	0.0021	4	Mohan (1979)	33565	0.0057
43804.7462	0.0010	1	Rufener and Waelkens	33630	0.0110
44189.219	0.0010	1	Mohan (1981)	36016	0.0101
44516.9732	0.0013	6	Sareyan et al. (1986)	38050	0.0109
44888.7186	0.0005	6	This paper	40357	0.0125
45263.6876	0.0010	1		42684	0.0149

other workers, except those of Sareyan *et al.* (1986), we thus find no night-to-night variation in the shape of the light curves of δ Cet. This, however, does not imply that the light curves are absolutely stable. A variation of the mean brightness, $\langle \Delta x \rangle$, the amplitude, A_x, or the initial phase, φ_x, may be too slow to conspicuously affect the shape of a single cycle, but still fast enough to show up when $\langle \Delta x \rangle$, A_x, or φ_x, derived from different nights' observations, are compared. In the following three sections we shall therefore investigate the night-to-night variability of the mean brightness, the amplitude, and the initial phase.

4. The mean brightness.

The 1981 nightly mean differential magnitudes of the variable, $\langle \Delta x \rangle$ in equation (1), are shown in figure 3, together with the nightly mean differential magnitudes, « λ minus ξ^2 Cet ». As can be seen from the figure, the latter show no variation, whereas the former deviate on two nights, JD 2444891 and JD 2444892, from the average level, defined by the remaining nights' values. The deviations amount to 14.5 mmag and 5.7 mmag in u, and about half these numbers in the other bands. They are certainly significant, because the mean errors of the nightly mean magnitudes do not exceed 0.6 mmag. Taken at their face value, the deviations would indicate that on the above-mentioned two nights δ Cet was, on the average, somewhat brighter than on the remaining nights. However, on JD 2444891 and JD 2444892 the Moon, passing across Cetus, was within less than 10 degrees from the variable and the comparison stars. A question arises whether this could have somehow caused the deviations seen in figure 3.

The first possibility which comes to mind is that the deviations on JD 2444891 and JD 2444892 were caused

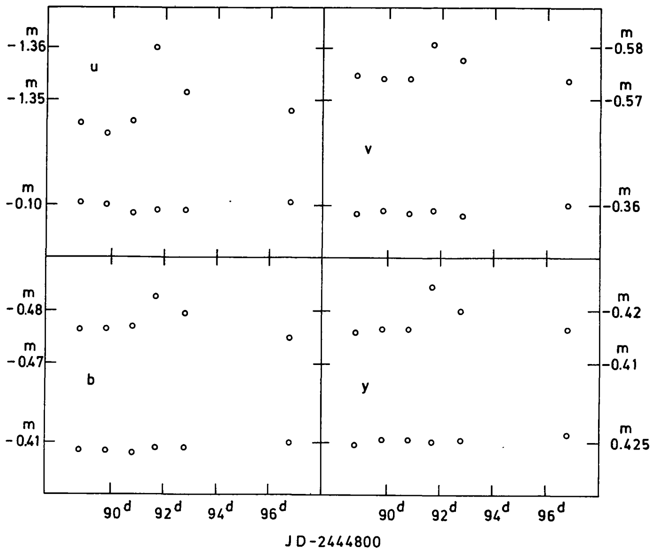

FIGURE 3. — The 1981 *uvby* nightly mean differential magnitudes « δ minus a mean of ξ^2 and λ Cet » (top each panel) and « λ minus ξ^2 Cet » (bottom each panel), plotted as a function of Julian date.

by inadequate sky corrections. This, however, is unlikely for the following reasons. The sky readings were taken immediately after every star reading. They showed no erratic behaviour or short-term variability. Furthermore, they were by no means excessive. For example, on JD 2444891 the sky readings in the *u* band amounted to 0.5, 1.0, and 0.8 percent of the corresponding star readings for δ, ξ^2, and λ Cet, respectively. In order to remove the 14.5 mmag deviation, one would have to artificially increase the sky readings for δ Cet to 1.9 percent, that is, almost four times, without changing the sky readings for ξ^2 and λ. The deviation would also be removed, without appreciably affecting the differential magnitudes « λ minus ξ^2», if all sky readings were decreased by the same number of counts, equal to the sky readings for δ Cet. This, however, would make the sky readings for the comparison stars negative, which is absurd. Moreover, in *v*, *b*, and *y* the differential magnitudes « λ minus ξ^2» were not all so insensitive to decreasing all sky readings by the same amount, as they were in *u*.

After making these and a number of other experiments, in which we altered not only the sky but also the star readings, we were forced to conclude that a consistent explanation of the deviations on JD 2444891 and JD 2444892 in terms of moonlight affecting the observations does not exist. We then examined the possibility that the deviations resulted from errors in the differential extinction corrections. On JD 2444891 the differential air mass « δ minus a mean of ξ^2 and λ» increased from − 0.16 for the first observation, to − 0.12 at the meridian passage, and then decreased to − 0.13 for the last observation. Deviations of about the same magnitude as observed would therefore result if the atmospheric extinction coefficients were in error by about 0.1 magnitude per air mass (mag/am) in *u*, and about 0.05 mag/am in *v*, *b*, and *y*. However, on the same night the differential air mass « λ minus ξ^2» decreased from 0.12 for the first observation to − 0.05 for the last one. If the extinction coefficients were indeed in error by the amounts mentioned above, the differential magnitudes « λ minus ξ^2» would decrease between the first and the last observation by almost 20 mmag in *u* and 10 mmag in *v*, *b*, and *y*. As can be seen from figure 1, this is not observed. In fact, the differential magnitudes « λ minus ξ^2» increased on JD 2444891 by about 3 mmag between the first and the last observation. In addition, by plotting differential magnitudes of the comparison stars as a function of the differential air mass, we found that the extinction coefficients used in the reductions were correct to within ± 0.02 mag/am. In a similar manner we found that the extinction coefficients on JD 2444892 were correct to within ± 0.01 mag/am. Thus, neither the larger deviations on JD 2444891, nor the smaller ones on JD 2444892, can be accounted for by errors in the extinction coefficients.

In spite of these negative results, we still hesitate to conclude that the deviations on JD 2444891 and JD 2444892 are due to a variation of the mean brightness of δ Cet, because of the possibility of an unknown instrumental effect. We plan to investigate this possibility in the future.

5. The amplitudes.

5.1 THE UPPER LIMIT OF THE AMPLITUDE OF A SECONDARY SHORT-PERIOD COMPONENT. — The nightly *uvby* amplitudes of δ Cet, A_x in equation (1), are displayed in figure 4. Note that in addition to the 1981 amplitudes, the 1982 ones are also shown. The horizontal straight lines represent the weighted means of the 1981 values.

In addition to the wavelength dependence, which will be discussed in section 7, the amplitudes show a marginal night-to-night variation. In order to find out whether a secondary short-period component were responsible for the variation, we carried out a frequency analysis of the 1981 data. A description of the analysis of the *u* data follows.

To begin with, we prewhitened the data with a sinusoidal component, corresponding to the primary frequency, $1/0\overset{d}{.}161138$. As was to be expected, the prewhitened data showed a night-to-night variation that reflected the variation of $\langle \Delta u \rangle$, discussed in the preceding section. In the amplitude spectrum this variation resulted in a considerable amount of low frequency noise. In particular, there was a 10 mmag peak at 0.933 c/d. Since the sideral day aliases of this peak could affect the amplitude spectrum at frequencies as high as 5 or even 6 c/d, we subtracted the nightly means from the data. In the amplitude spectrum of the data prepared in this way there was no peak at 0.933 c/d and very little low frequency noise. In the frequency range from 0 to 7 c/d, the highest peak occurred at 4.383 c/d.

Its height amounted to 1.6 mmag. However, the sidereal day aliases of this peak, at 5.378, 3.383, and 6.372 c/d, were almost as high. The beat-periods corresponding to these four frequencies are equal to 0^d549, 1^d21, 0^d354, and 6^d0. The last beat-period represents the nightly u amplitudes somewhat better than the shorter three ones do : while for the shorter three beat-periods the amplitude of the sine-curve fit to A_u amounts to 1.4 ± 0.4 mmag, for the 6^d0 one it is equal to 1.6 ± 0.4 mmag. This value is also equal to the height of the highest peak in the amplitude spectrum. It defines the upper limit of the amplitude of the secondary short-period component in the light variation of δ Cet.

5.2 AN ALTERNATIVE EXPLANATION OF THE NIGHT-TO-NIGHT AMPLITUDE VARIATION. — Any of the above-mentioned beat-periods would account for about half of the standard deviation of the night-to-night amplitude variation. On the other hand, a two-component fit to the differential magnitudes has a standard deviation only slightly smaller than a single component fit. For example, a sum of two sinusoidal components with frequencies $1/0^d161138$ and 6.372 c/d fits the 1981 differential u magnitudes — corrected for the $\langle \Delta u \rangle$ variation — with a standard deviation equal to 3.9 mmag, while the $0^d161138$ sine curve alone fits the same data with a standard deviation equal to 4.0 mmag.

The insignificant reduction of the standard deviation in the case of the two-component fit indicates that the peaks in the amplitude spectrum at 4.383, 5.378, 3.383, and 6.372 c/d may represent spurious periodicities, introduced by observational errors. If this were indeed so, the night-to-night amplitude variation would have to be accounted for without invoking a secondary short-period component.

The only solution of this problem we could find is the following. Suppose that on each night the light curve were slightly distorted by a slow drift, present for some reason in the differential magnitudes. Since on any night the observations cover no more than about one cycle of the short period variation, the drift would be difficult to notice. However, it would introduce an error into the amplitude of a sine curve, forced to fit the data. As can easily be verified, the magnitude of the error would depend not only on how much the differential magnitudes drifted during a night, but also on the phase of the first observation in the $0^d161138$ variation. Since the latter varies from night to night, the same drift will cause different errors on different nights. Therefore, a drift must exist for which the scatter of the nightly amplitudes would be minimum. As it turns out, the drifts which minimize the standard deviations of the nightly amplitudes around the 1981 means amount to 1.3, 1.0, 1.0, and 1.2 mmag per hour (mmag/h) for u, v, b, and y, respectively. Using these values, one gets the corrected amplitudes, represented in figure 4 by points without error bars.

As can be seen from figure 4, the corrected amplitudes show very little night-to-night variation. Note, moreover,

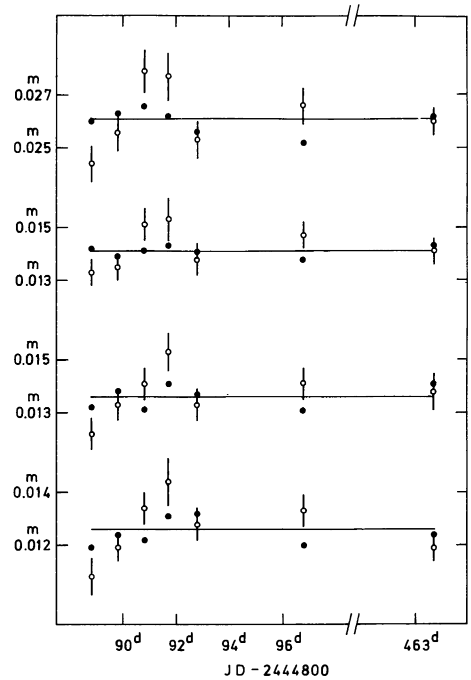

FIGURE 4. — The *uvby* (top to bottom) nightly amplitudes of δ Cet, plotted as a function of Julian date. The error bars are equal to twice the standard deviations. The rightmost points were derived from observations on the single night in 1982. The horizontal straight lines represent weighted means of the 1981 amplitudes. The points without error bars are amplitudes, corrected for hypothetical drifts in the data as explained in subsection 5.2.

that when the uncorrected amplitudes deviate most markedly from the means, as on JD 2444888, JD 2444890, and especially on JD 2444891, they are also most sensitive to drifts in the data. Consequently, the amplitude variation would also virtually disappear if the drifts were present on just these three nights.

Drifts of the order of 1 mmag/h may be caused by small inhomogeneities of the atmospheric transparency over the sky. In fact, drifts of this magnitude are present on some nights in the differential magnitudes « λ minus ξ^2». An example was mentioned in the preceding section in connection with the deviant mean magnitudes on JD 2444891. Another possibility is a slow intrinsic variation of δ Cet, superimposed on the $0^d161138$ variation. On the other hand, an intrinsic variation of one of the comparison stars cannot be responsible for 1 mmag/h drifts in the differential magnitudes « δ minus a mean of ξ^2 and λ », because « λ minus ξ^2» would then show twice as large drifts in the opposite sense, contrary to what is observed.

6. The initial phases and the epochs of maximum light.

Our data do not indicate any night-to-night variation of the initial phases, φ_x in equation (1). Consequently, the observed epochs of maximum light, O, obey the following linear ephemeris :

$$C = \langle \mathrm{JD} \rangle + 0^d161138\, E\,, \qquad (2)$$

where C is the computed epoch of maximum light, $\langle JD \rangle$ denotes the mean epoch of maximum light, and E is the number of cycles which elapsed since $\langle JD \rangle$. That is, all (O-C) residuals are close to zero.

This is illustrated in figure 5, where the (O-C) residuals for $x = v$ are plotted as circles with error bars. The mean epoch used to compute the residuals, $\langle JD \rangle = 2444888^{d}_{.}7185 \pm 0^{d}_{.}0004$, was derived from the 1981 epochs of maximum light.

Also shown in figure 5 are the (O-C) residuals that are obtained when the hypothetical drifts, discussed in the preceding section, are taken into account. Correcting for a drift equal to 1.0 mmag/h results in the (O-C) residuals plotted as filled circles. Note that on most nights these residuals are shifted away from the (O-C) = 0 line. Thus,

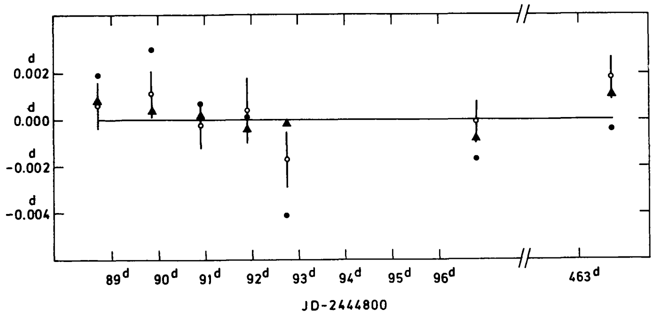

FIGURE 5. — The (O-C) residuals of the v light maxima, plotted as a function of Julian date. The error bars are equal to twice the standard deviations of the observed epochs of maximum light. Symbols without error bars represent the (O-C) residuals that resulted when the hypothetical drifts were corrected for as explained in section 6.

the 1.0 mmag/h drift, while minimizing the night-to-night variation of A_v, increases the scatter of the (O-C) residuals. However, by assuming different drifts on different nights it is possible to reduce the night-to-night scatter of both, the amplitudes and the (O-C) residuals. Indeed, drifts equal to 1.0 mmag/h on JD 2444890 and JD 2444891, 0.5 mmag/h on JD 2444888, – 1.0 mmag/h on JD 2444892, and zero drifts on the remaining three nights, reduce the variation of A_v below the level of observational scatter. At the same time, using these drifts one gets the (O-C) residuals — represented in figure 5 by triangles — that show even less scatter than those corresponding to the uncorrected data.

The foregoing discussion could be limited to the v data because in u, b and y the (O-C) residuals show the same behaviour as in v. In contrast, the epochs of maximum light are not entirely independent of wavelength. As can be seen from figure 6, where the 1981 mean epochs of maximum light are plotted as a function of effective wavelength of the *uvby* filters, the u maxima occur, on the average, about 3 min later than maxima in the other bands. Although the formal mean error of this value is equal to almost 30 percent, the effect may be real. Of course, it implies that the u curve lags behing the v, b, and y curves by the above mentioned amount. The effect is independent of drifts in the data.

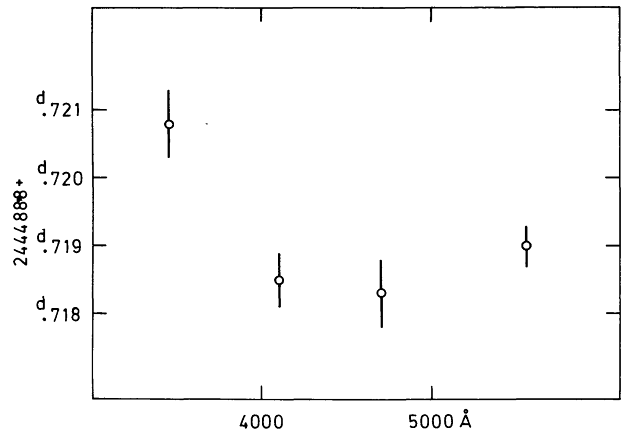

FIGURE 6. — The 1981 mean epochs of maximum light, $\langle JD \rangle$, plotted as a function of effective wavelength of the *uvby* filters. The error bars are equal to twice the mean errors of $\langle JD \rangle$.

The analysis carried out in this and the preceding three sections leads to the following conclusions. On any night the *uvby* light curves of δ Cet are sinusoidal in shape. The sinusoids show some night-to-night variation of the mean light level and the amplitudes. The former effect may have an instrumental cause. The latter is either due to a secondary short-period variation with an amplitude not exceeding 1.6 mmag, or results from slow drifts in the data. However, there is no evidence for a night-to-night phase variation. In addition, we found no amplitude or phase change between 1981 and 1982.

7. The wavelength dependence of the light amplitude and the amplitudes of *b-y* and c_1.

In figure 7, the amplitudes of the light variation of δ Cet are plotted as a function of the effective wavelength of the *uvby* filters. As can be seen from the figure, the 1981

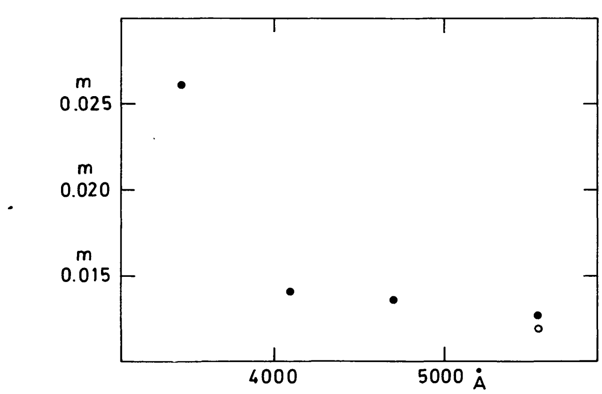

FIGURE 7. — The weighted means of the 1981 nightly amplitudes (filled circles) and the 1982 y amplitude (open circle), plotted as a function of the effective wavelength of the *uvby* filters. The diameter of the symbols is approximately equal to the standard deviations of the amplitudes. The 1982 u, v, and b amplitudes are not shown because they are equal to the 1981 values to within 0.2 mmag or less. The y amplitudes differ by 0.7 ± 0.7 mmag.

$\langle A_u \rangle$ is 13 mmag greater than $\langle A_y \rangle$. This is in a reasonably good agreement with the *UBV* results of Jerzykiewicz (1971), mentioned in the introduction. While, however, Jerzykiewicz (1971) was unable to detect a *B-V* variation, the 1981 amplitudes show a clear decrease over the Paschen continuum, implying a *b-y* variation. Since, as we have shown in the preceding section, the *b* and *y* curves are in phase, the *b-y* amplitude is equal to the difference of the *b* and *y* amplitudes. However, $\langle A_b \rangle - \langle A_y \rangle = 1.0$ mmag has a large mean error of 0.6 mmag. This can be traced to the night-to-night amplitude variation, discussed in section 5, which affects the mean errors of $\langle A_b \rangle$ and $\langle A_y \rangle$. A better estimate of the *b-y* amplitude can be obtained directly from the differential *b-y* colour indices, derived in section 2. Indeed, by fitting equation (1) to all 1981 differential *b-y* colour indices, including those derived from observations on JD 2444883, one gets $\langle A_{b-y} \rangle = 0.9 \pm 0.2$ mmag. The very good agreement between $\langle A_b \rangle - \langle A_y \rangle$ and $\langle A_{b-y} \rangle$ follows, of course, from the fact that A_b and A_y show similar night-to-night variations. Likewise, the c_1 amplitude, obtained directly from the 1981 differential c_1 indices, has a much smaller mean error than the c_1 amplitude, computed from the mean light amplitudes, but the amplitudes themselves are almost the same. In the first case one gets $\langle A_{c_1} \rangle = 11.1 \pm 0.3$ mmag, whereas in the second, $\langle A_u \rangle - 2\langle A_v \rangle + \langle A_b \rangle = 11.5 \pm 0.8$ mmag. Note that in deriving the c_1 amplitude from the light amplitudes we neglected the small phase lag of the *u* curve relative to the *v* and *b* curves, mentioned in the preceding section.

As far as the wavelength dependence is concerned, the 1982 amplitudes behave in the same manner as the 1981 ones do, except that they indicate a somewhat larger *b-y* amplitude of 1.9 ± 0.9 mmag. Almost the same *b-y* amplitude, equal to 2.1 ± 0.5 mmag, is obtained by fitting equation (1) to the 1982 differential *b-y* colour indices. However, the difference between these and the 1981 values is probably insignificant.

8. Discussion.

8.1 THE PHOTOMETRIC (O-C) DIAGRAM AND THE RATE OF PERIOD INCREASE. — The epochs of maximum light of δ Cet, derived from all available photometric observations of the star, are listed in the first column of table III. Most of them are mean values, based on several nights observations ; the number of nights, N, is given in column two. Table III contains also the number of cycles, E, counted from the arbitrarily chosen initial epoch, JD 2438385.6861, and the (O-C) residuals, computed with the photometric period of $0^{d}\!.16113735$, due to Ciurla (1979).

The first eleven epochs of maximum light in table III, from Walker (1953) to Mohan (1979), are from table IV of Lloyd and Pike (1984), except that in a few cases, including the multicolour observations of Sato (1958) and Watson (1971), individual epochs of maximum light have been replaced by mean values. Of the remaining five epochs of maxima, that of Mohan (1981) is taken

TABLE IV. — *Mean epochs of maximum radial-velocity of δ Cet based on modern data.*

$JD_{\odot}$ - 2400000		N	Author	E	(O - C)
d	d				d
34288.9136	+ 0.0013	4	McNamara (1955)	-25424	-0.0324
34630.8475	0.0016	2		-23302	-0.0302
34724.6267	0.0017	3	Jorgensen (1966)	-22720	-0.0326
39778.6905	0.0006	1	Ciurla (1979)	8645	-0.0297
42662.7256	0.0012	2	Lane (1977)	26543	-0.0343
43736.5485	0.0008	3*	Lloyd and Pike (1984)	33207	-0.0339
43747.8180	0.0017	4	Campos and Smith (1980)	33277	-0.0440

* Four nights, but only eight radial velocity measurements.

from his paper, whereas the other four have been derived by the present authors. The method used consisted in calculating the epoch of maximum light from a least-squares fit of equation (1) to the observations on each night separately, and then computing a mean epoch if more than one night was available. Rufener and Waelkens's epoch has been derived from their unpublished observations in the *V*-band of the Geneva system. The epoch of Sareyan *et al.* (1986) is based on these authors' observations, carried out between JD 2444514 and JD 2444519. Finally, the last two epochs of maximum light have been obtained from the *v*, *b*, and *y* observations reported in the present paper.

The (O-C) residuals from the last column of table III are displayed in figure 8 as a function of the number of cycles. It is immediately clear from the figure that a model capable of accounting for all photometric (O-C)

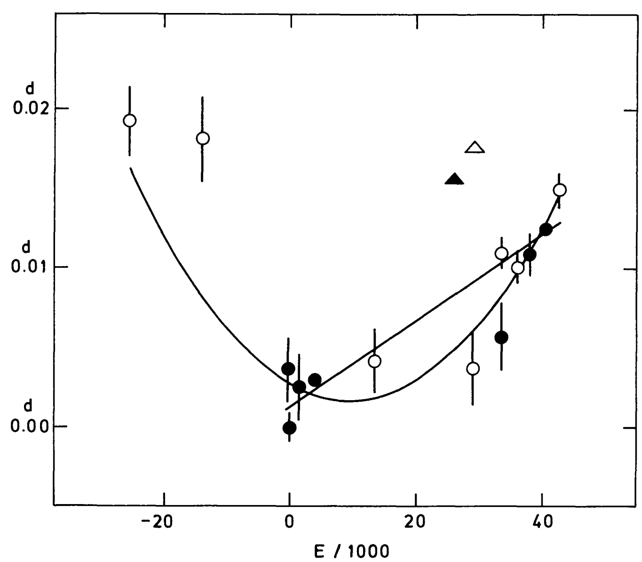

FIGURE 8. — The photometric (O-C) residuals of δ Cet plotted as a function of the number of cycles. The error bars are equal to twice the mean errors, but no error bar is shown if the mean error was less than $0^{d}\!.0007$. Open symbols represent the (O-C) residuals based on observations from only one or two nights, whereas filled symbols, those from observations on at least four nights. Triangles correspond to Tunca's (1977) epochs of maximum light. The ephemerides given by equations (3) and (4) are shown as the straight line and the parabola, respectively.

1988A&AS...72..449J

residuals of δ Cet does not exist. However, the data from Van Hoof (1968) onwards could be satisfactorily represented with a constant period if Tunca's (1977) residuals (triangles in Fig. 8) were spurious. In fact, Ciurla (1979) had rejected these residuals on the grounds that Tunca (1977) may have been influenced by earlier work. This, of course, can neither be proved nor disproved. Note, however, that Tunca's (1977) residuals fall exactly on the straight line defined by the (O-C) residuals of Jerzykiewicz (1971), which does seem suspicious. Following Ciurla (1979), we shall henceforth disregard the (O-C) residuals of Tunca (1977).

The linear ephemeris, which can now be fitted by the method of least squares to the (O-C) residuals from Van Hoof (1968) onwards, will depend slightly on the weights assigned to the data. We decided to compute the weights from the mean errors and then, in addition, double the weights of the (O-C) residuals based on observations from four or more nights. As a result, we obtained the following ephemeris :

$$C = \mathrm{JD}_{\odot}\ 2438385.6875 + 0^{\mathrm{d}}.16113762\ E \pm \pm 0.0006 \pm 0.00000002 \qquad (3)$$

This equation, or any other linear ephemeris, does not account for the earliest two photometric (O-C) residuals, that is, those of Walker (1953) and Sato (1958). If, however, Sato's (1958) residual were disregarded, the data could be fitted with the following parabolic ephemeris :

$$\begin{aligned} C = \mathrm{JD}_{\odot}\ 2438385.6888 &+ 0^{\mathrm{d}}.16113713\ E \\ &\pm 0.0040 \pm 0.00000020 \\ &+ 11^{\mathrm{d}}.7 \times 10^{-12}\ E^2 \\ &\pm\ 2.2 \times 10^{-12} \end{aligned} \qquad (4)$$

In deriving this equation the weights were computed in the same way as before.

As far as we are aware, equation (4) represents the first successful attempt to reconcile Walker's (1953) observations with the more recent ones. Unfortunately, it leaves the (O-C) residual of Sato (1958) unaccounted for. This objection, however, is less serious than it appears at first sight. Indeed, as has been pointed out by Lloyd and Pike (1984), Sato's (1958) light curves show amplitudes 2 to 3 times larger than are usually observed. It is extremely unlikely that this was due to an increase of the pulsation amplitude of the star. An explanation in terms of systematic errors, perhaps caused by inadequate extinction corrections, would be much more plausible, especially that Sato (1958) used only one comparison star, λ Cet, which is about 10 degrees from δ Cet. But then the observed epoch of maximum light would also be affected. Of course, systematic effects leading to a factor of two or three increase of the observed amplitude would have to be much larger than those discussed in subsection 5.2.

The rate of period increase, implied by equation (4), is equal to 0.47 ± 0.09 sec/century, approximately halfway between the small value of Lloyd and Pike (1984) and the large one of Lane (1977). However, the latter author's result is almost certainly spurious, because in her analysis she used the epochs of maximum light of Sato (1958) and Tunca (1977), which have just been shown to be unreliable. Lloyd and Pike's (1984) rate of period increase will be discussed in the next subsection.

As has been mentioned in the introduction, Chapellier (1985) maintains that all modern data can be represented with a constant period. In view of the above discussion this statement is invalid, even if one bears in mind that Chapellier (1986) has also rejected Tunca's (1977) epochs of maximum light.

8.2 THE PHASE LAG. — Lloyd and Pike (1984) have provided a list of all available epochs of maximum radial-velocity of δ Cet. Taking from this list the epochs based on the modern radial-velocity data, from McNamara (1955) onwards, we have determined the mean epochs, as given in table IV. This table is analogous to table III, except that the (O-C) residuals, listed in the last column, have been computed from the parabolic ephemeris, derived in the preceding subsection.

In order to investigate the secular variation of the phase lag between the light and radial-velocity curves, found by Lloyd and Pike (1984), and confirmed by Chapellier (1986), we have plotted in figure 9 the (O-C) residuals from the last column of table IV as a function of the number of cycles. Also shown in the figure is a horizontal straight line, representing the mean (O-C) residual, computed without the deviant point at upper right, and two parabolas, corresponding to the two

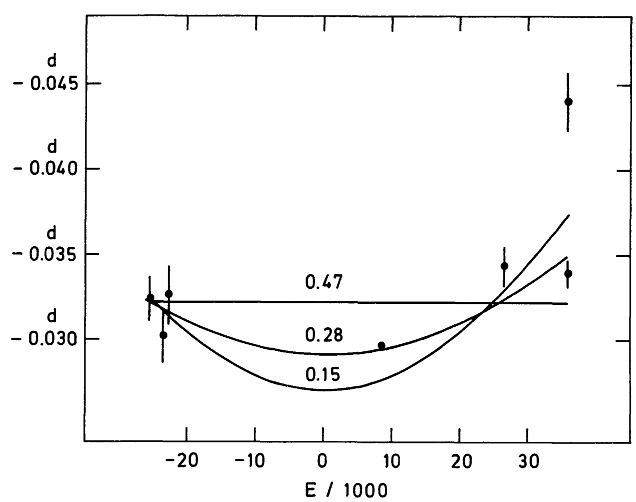

FIGURE 9. — The (O-C) residuals of the observed epochs of maximum radial-velocity from the parabolic ephemeris in figure 8, plotted as a function of the number of cycles. The error bars are equal to twice the mean errors of the observed epochs. The horizontal line represents the mean residual, computed without the deviant point at upper right, whereas the parabolas correspond to the two ephemerides of Lloyd and Pike (1984), one derived from only the modern radial-velocity data, and the other, from all data. The straight line and the parabolas are labelled with the rates of secular period increase, in sec/century, which they entail.

ephemerides of Lloyd and Pike (1984), one derived from only the modern radial-velocity data, and the other, from all data. The straight line and the parabolas are labelled with the rates of secular period increase they entail.

The deviant point at upper right represents the residual based on the radial-velocity data of Campos and Smith (1980). It falls above the point corresponding to the residual of Lloyd and Pike (1984), which has been derived from observations made at almost the same time as those of Campos and Smith (1980). Clearly, one of these residuals contains a substantial systematic error. We believe that it is the deviant residual which is in error, because Campos and Smith's (1980) data consist of only eight measurements that barely cover the full cycle of the short-period variation, whereas those of Lloyd and Pike (1984) include nearly 60 observations and provide adequate phase coverage.

The 0.28 sec/century parabola in figure 9 fits the modern data very well but it does not account for the older radial-velocity observations of Frost and Adams (1903), Henroteau (1922), Crump (1934), and Marshall (1934). An attempt to reconcile the old and modern velocity data, resulting in the 0.15 sec/century parabola, makes the fit to the modern observations somewhat worse. In fact, the straight line accounts for these observations equally well. In addition, the straight line has an important advantage over the parabolas of implying a constant phase lag between the light and radial-velocity curves. However, the straight line also leaves the old data unexplained. One is thus faced with the dilemma of either putting up with a phase-lag variation, for which there seems to be no easy explanation, or leaving the old radial-velocity observations unaccounted for. Unfortunately, the 0.28 sec/century parabola is defective on both these scores, and therefore should probably be rejected.

The mean (O-C) residual, computed without the deviant value of Campos and Smith (1980), amounts to $-0\overset{d}{.}0322 \pm 0\overset{d}{.}0008$. This corresponds to the phase lag of the light curve behind the velocity curve equal to 0.200 ± 0.005, in good agreement with Ciurla's (1979) 0.19 ± 0.04. Note, however, the order-of-magnitude improvement in accuracy between the old and new value.

8.3 THE SECULAR INCREASE OF THE LIGHT AMPLITUDE. — As has been mentioned in the introduction, Sareyan *et al.* (1986) maintain that the amplitude of δ Cet increases at a rate of 7 mmag/century in the visual, and 13 mmag/century in the Johnson *U* band.

In our opinion, these numbers are very uncertain for the following reasons.

In the ultraviolet, Sareyan *et al.* (1986) have derived the rate of the amplitude increase from their own 1980 data and from the 1965 observations of Jerzykiewicz (1971). Sareyan *et al.* (1986) have apparently found that the difference between the 1980 and 1965 amplitudes amounts to 2 mmag. However, both sets of data consist of only two nights of observations each. Consequently, systematic effects such as those discussed in subsection 5.2 would not be averaged out. As was noted by Jerzykiewicz (1971), substantial systematic errors were probably present in his observations because of the $1\overset{m}{.}0$ difference in the *U-B* colour index between δ Cet and the comparison star, HR 732. The same comparison star was also used by Sareyan *et al.* (1986). In addition, on either night in 1980 the observations covered less than 0.7 of the full cycle of the short-period variation, so that the 1980 amplitudes must be quite uncertain. Thus, the above-mentioned 2 mmag difference between the 1980 and 1965 *U* amplitudes may be entirely due to errors.

As far as the rate of increase of the visual amplitude is concerned, Sareyan *et al.* (1986) have given high weight to the 1952 yellow magnitude observations of Walker (1953), and to their own 1980 observations, carried out with blue filters (see their Fig. 2). The difference between the 1980 and 1952 amplitudes is equal to 2.5 mmag. However, about half of this value may be accounted for by the wavelength dependence of the light amplitude, discussed in section 7, and the other half, by observational errors. Note, moreover, that Walker's (1953) yellow amplitude, as derived by Lloyd and Pike (1984), is equal to 12 ± 1 mmag, whereas from figure 4 it can be seen that the 1981 and 1982 y amplitudes amount to 12.6 ± 0.4 and 11.9 ± 0.5 mmag, respectively, both in excellent agreement with the 1952 value. Clearly, the available data are still not sufficient to detect a secular light amplitude change.

9. Summary of the main results.

In addition to the conclusions, set forth at the end of section 6, the most important results of the present work are the following.

The *uvby* variations are in phase, except that the *u* curve lags slightly behind the other ones. The amplitudes of *b-y* and c_1 amount to 0.9 ± 0.2 mmag and 11.1 ± 0.3 mmag, respectively.

All available epochs of maximum light, except three clearly unreliable ones, can be accounted for by means of a parabolic ephemeris that implies an increase of the period at a rate of 0.47 ± 0.09 sec/century. However, the epochs of maximum light from 1963 onwards can also be satisfactorily represented with a constant period, equal to $0\overset{d}{.}16113762 \pm 0\overset{d}{.}00000002$.

There is no compelling evidence for a variation of the phase lag between the light and radial-velocity curves, unless one insists on fitting the old and modern radial-velocity maxima with a single ephemeris. Modern radial-velocity data, from 1952 onwards, lead to a phase lag equal to 0.200 ± 0.005. There is also no evidence for a secular variation of the light amplitude.

The question how common are β Cephei stars with secular variations of the amplitudes may have some bearing on the problem of what makes these variables pulsate. Therefore, observations of δ Cet and other well-known β Cephei stars should continue. Hopefully, future observations will also help understand the long-term behaviour of the periods.

Acknowledgements.
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TABLE I. — *The differential magnitudes of δ Ceti.*

HJD-2440000	Δu	Δv	Δb	Δy
	m	m	m	m
4883.6935	-1.351	-0.582	-0.484	-0.427
.6970	-1.356	-0.583	-0.484	-0.424
.6996	-1.351	-0.581	-0.482	-0.423
.7070	-1.356	-0.583	-0.487	-0.427
.7137	-1.373	-0.593	-0.493	-0.432
.7162	-1.376	-0.594	-0.493	-0.434
.7191	-1.380	-0.599	-0.498	-0.436
.7286	-1.374	-0.596	-0.493	-0.430
.7327	-1.380	-0.598	-0.496	-0.437
.7446	-1.367	-0.586	-0.486	-0.429
.7475	-1.366	-0.584	-0.485	-0.425
.7504	-1.373	-0.591	-0.488	-0.431
.7576	-1.357	-0.580	-0.481	-0.420
.7654	-1.349	-0.582	-0.487	-0.427
.7684	-1.347	-0.576	-0.480	-0.415
.7715	-1.346	-0.576	-0.474	-0.414
4888.7042	-1.363	-0.587	-0.489	-0.421
.7082	-1.364	-0.585	-0.487	-0.424
.7123	-1.376	-0.593	-0.493	-0.432
.7157	-1.368	-0.586	-0.488	-0.426
.7188	-1.372	-0.591	-0.493	-0.430
.7219	-1.372	-0.589	-0.489	-0.430
.7253	-1.368	-0.588	-0.492	-0.431
.7283	-1.367	-0.583	-0.483	-0.421
.7314	-1.370	-0.584	-0.480	-0.420
.7343	-1.371	-0.588	-0.487	-0.425
.7374	-1.361	-0.581	-0.484	-0.420
.7407	-1.362	-0.584	-0.484	-0.425
.7439	-1.357	-0.581	-0.481	-0.423
.7480	-1.355	-0.579	-0.478	-0.420
.7512	-1.360	-0.581	-0.481	-0.418
.7542	-1.348	-0.575	-0.479	-0.420
.7574	-1.347	-0.577	-0.479	-0.419
.7608	-1.350	-0.573	-0.474	-0.413
.7640	-1.344	-0.572	-0.474	-0.413
.7679	-1.340	-0.571	-0.477	-0.416
.7714	-1.338	-0.569	-0.470	-0.409
.7746	-1.335	-0.568	-0.469	-0.410
.7774	-1.334	-0.566	-0.467	-0.408
.7806	-1.331	-0.569	-0.473	-0.414
.7838	-1.327	-0.567	-0.468	-0.404
.7870	-1.324	-0.562	-0.464	-0.405
.7904	-1.319	-0.561	-0.465	-0.406
.7936	-1.322	-0.561	-0.462	-0.404
.7968	-1.321	-0.562	-0.466	-0.409
.8001	-1.318	-0.558	-0.461	-0.398
.8032	-1.325	-0.563	-0.464	-0.408
.8066	-1.321	-0.559	-0.461	-0.403
.8098	-1.322	-0.565	-0.470	-0.412
.8127	-1.320	-0.560	-0.467	-0.408
.8160	-1.325	-0.564	-0.465	-0.406
.8192	-1.323	-0.563	-0.464	-0.406
.8223	-1.325	-0.565	-0.471	-0.408
.8257	-1.337	-0.571	-0.469	-0.413
.8290	-1.333	-0.567	-0.471	-0.410
.8325	-1.335	-0.572	-0.473	-0.414
.8357	-1.337	-0.570	-0.471	-0.416
.8388	-1.339	-0.572	-0.475	-0.411
.8422	-1.350	-0.581	-0.479	-0.419
.8455	-1.354	-0.582	-0.483	-0.422
.8487	-1.349	-0.577	-0.480	-0.416
.8537	-1.356	-0.578	-0.479	-0.421
4889.6758	-1.375	-0.593	-0.496	-0.430
.6791	-1.367	-0.588	-0.488	-0.426
.6821	-1.374	-0.593	-0.497	-0.431
.6851	-1.373	-0.590	-0.493	-0.432
.6880	-1.369	-0.589	-0.490	-0.432
.6912	-1.370	-0.589	-0.492	-0.432
.6942	-1.369	-0.588	-0.487	-0.430
.6974	-1.370	-0.586	-0.487	-0.424
4889.7004	-1.361	-0.581	-0.487	-0.427
.7035	-1.369	-0.589	-0.490	-0.426
.7067	-1.372	-0.588	-0.487	-0.421
.7098	-1.363	-0.582	-0.485	-0.423
.7130	-1.359	-0.581	-0.483	-0.421
.7159	-1.348	-0.573	-0.474	-0.416
.7193	-1.351	-0.578	-0.479	-0.418
.7222	-1.344	-0.574	-0.481	-0.419
.7251	-1.341	-0.570	-0.473	-0.417
.7281	-1.341	-0.570	-0.474	-0.415
.7317	-1.341	-0.574	-0.477	-0.413
.7360	-1.330	-0.566	-0.467	-0.411
.7385	-1.331	-0.566	-0.468	-0.407
.7419	-1.333	-0.568	-0.470	-0.410
.7449	-1.331	-0.566	-0.465	-0.410
.7478	-1.330	-0.567	-0.469	-0.409
.7507	-1.326	-0.563	-0.465	-0.410
.7537	-1.326	-0.564	-0.463	-0.404
.7567	-1.322	-0.562	-0.467	-0.407
.7598	-1.318	-0.561	-0.465	-0.405
.7628	-1.320	-0.562	-0.466	-0.404
.7660	-1.321	-0.562	-0.465	-0.407
.7692	-1.320	-0.562	-0.463	-0.403
.7721	-1.316	-0.561	-0.464	-0.404
.7755	-1.317	-0.560	-0.462	-0.405
.7786	-1.320	-0.563	-0.463	-0.406
.7818	-1.322	-0.563	-0.467	-0.410
.7852	-1.324	-0.564	-0.467	-0.409
.7883	-1.328	-0.567	-0.469	-0.412
.7913	-1.327	-0.567	-0.471	-0.414
.7942	-1.332	-0.571	-0.474	-0.413
.7973	-1.329	-0.566	-0.472	-0.410
.8003	-1.333	-0.570	-0.472	-0.412
.8034	-1.340	-0.572	-0.472	-0.411
.8063	-1.336	-0.571	-0.472	-0.411
.8093	-1.339	-0.572	-0.473	-0.410
.8123	-1.344	-0.575	-0.475	-0.417
.8155	-1.341	-0.573	-0.477	-0.417
.8188	-1.347	-0.574	-0.477	-0.420
.8222	-1.355	-0.584	-0.486	-0.426
.8255	-1.360	-0.584	-0.484	-0.423
.8293	-1.359	-0.585	-0.487	-0.423
.8326	-1.362	-0.585	-0.486	-0.431
.8359	-1.364	-0.584	-0.488	-0.425
.8392	-1.365	-0.585	-0.489	-0.430
.8424	-1.369	-0.586	-0.487	-0.429
4890.6767	-1.370	-0.588	-0.488	-0.426
.6796	-1.360	-0.581	-0.485	-0.424
.6826	-1.353	-0.574	-0.479	-0.419
.6856	-1.357	-0.581	-0.484	-0.423
.6890	-1.350	-0.576	-0.477	-0.417
.6916	-1.352	-0.575	-0.477	-0.413
.6944	-1.344	-0.571	-0.474	-0.413
.6974	-1.346	-0.569	-0.473	-0.411
.7004	-1.342	-0.571	-0.478	-0.417
.7033	-1.326	-0.562	-0.466	-0.406
.7062	-1.334	-0.566	-0.471	-0.408
.7089	-1.331	-0.568	-0.473	-0.412
.7116	-1.319	-0.556	-0.460	-0.404
.7142	-1.327	-0.566	-0.471	-0.414
.7173	-1.319	-0.561	-0.467	-0.404
.7200	-1.313	-0.552	-0.453	-0.397
.7230	-1.324	-0.561	-0.463	-0.406
.7258	-1.327	-0.566	-0.469	-0.410
.7287	-1.317	-0.557	-0.462	-0.402
.7314	-1.324	-0.560	-0.465	-0.406
.7345	-1.318	-0.559	-0.460	-0.398
.7372	-1.322	-0.562	-0.465	-0.403
.7402	-1.326	-0.564	-0.466	-0.407
.7432	-1.324	-0.564	-0.469	-0.408

TABLE I (*continued*).

HJD-2440000	Δu	Δv	Δb	Δy	HJD-2440000	Δu	Δv	Δb	Δy
	m	m	m	m		m	m	m	m
4890.7463	-1.322	-0.559	-0.464	-0.404	4892.6659	-1.327	-0.568	-0.470	-0.409
.7494	-1.323	-0.564	-0.469	-0.408	.6701	-1.331	-0.569	-0.470	-0.411
.7522	-1.324	-0.562	-0.465	-0.406	.6730	-1.331	-0.568	-0.471	-0.414
.7554	-1.324	-0.564	-0.468	-0.410	.6760	-1.334	-0.570	-0.471	-0.412
.7583	-1.327	-0.565	-0.469	-0.409	.6791	-1.328	-0.564	-0.465	-0.404
.7614	-1.334	-0.569	-0.470	-0.410	.6823	-1.336	-0.568	-0.468	-0.413
.7642	-1.329	-0.567	-0.470	-0.407	.6853	-1.328	-0.563	-0.468	-0.406
.7676	-1.343	-0.574	-0.475	-0.413	.6883	-1.336	-0.570	-0.475	-0.415
.7704	-1.338	-0.567	-0.469	-0.410	.6918	-1.343	-0.576	-0.476	-0.416
.7733	-1.343	-0.572	-0.474	-0.414	.6953	-1.339	-0.571	-0.471	-0.417
.7761	-1.347	-0.573	-0.473	-0.411	.6983	-1.345	-0.575	-0.478	-0.415
.7795	-1.350	-0.579	-0.484	-0.423	.7013	-1.346	-0.573	-0.475	-0.413
.7823	-1.354	-0.582	-0.485	-0.422	.7042	-1.350	-0.576	-0.479	-0.419
.7854	-1.351	-0.577	-0.481	-0.420	.7073	-1.349	-0.578	-0.482	-0.421
.7885	-1.359	-0.581	-0.485	-0.427	.7135	-1.354	-0.582	-0.483	-0.424
.7915	-1.366	-0.585	-0.486	-0.425	.7165	-1.354	-0.578	-0.481	-0.421
.7945	-1.363	-0.583	-0.487	-0.427	.7201	-1.366	-0.589	-0.493	-0.431
.7975	-1.366	-0.584	-0.487	-0.429	.7230	-1.366	-0.585	-0.486	-0.423
.8007	-1.372	-0.588	-0.487	-0.426	.7264	-1.374	-0.591	-0.490	-0.430
.8038	-1.376	-0.592	-0.490	-0.428	.7293	-1.374	-0.589	-0.489	-0.430
.8071	-1.369	-0.586	-0.488	-0.430	.7323	-1.362	-0.583	-0.485	-0.424
.8101	-1.373	-0.591	-0.495	-0.433	.7356	-1.374	-0.592	-0.494	-0.437
.8133	-1.375	-0.590	-0.492	-0.428	.7391	-1.370	-0.587	-0.489	-0.431
.8162	-1.378	-0.591	-0.492	-0.433	.7423	-1.374	-0.590	-0.493	-0.436
.8201	-1.371	-0.588	-0.492	-0.426	.7462	-1.374	-0.588	-0.492	-0.432
.8232	-1.379	-0.592	-0.492	-0.431	.7507	-1.383	-0.596	-0.496	-0.433
.8263	-1.375	-0.590	-0.492	-0.428	.7540	-1.381	-0.592	-0.493	-0.433
.8293	-1.365	-0.583	-0.485	-0.428	.7573	-1.377	-0.594	-0.496	-0.440
.8323	-1.371	-0.586	-0.489	-0.428	.7602	-1.372	-0.589	-0.490	-0.427
.8350	-1.368	-0.586	-0.487	-0.426	.7635	-1.379	-0.592	-0.493	-0.432
.8378	-1.355	-0.578	-0.481	-0.422	.7666	-1.370	-0.585	-0.487	-0.425
.8407	-1.360	-0.579	-0.483	-0.427	.7698	-1.364	-0.584	-0.485	-0.427
4891.6757	-1.342	-0.566	-0.471	-0.413	.7738	-1.368	-0.584	-0.485	-0.430
.6806	-1.343	-0.568	-0.469	-0.413	.7770	-1.363	-0.583	-0.487	-0.423
.6835	-1.341	-0.568	-0.471	-0.414	.7803	-1.361	-0.581	-0.482	-0.424
.6868	-1.344	-0.571	-0.474	-0.416	.7835	-1.351	-0.577	-0.479	-0.420
.6900	-1.337	-0.569	-0.470	-0.416	.7875	-1.350	-0.574	-0.475	-0.418
.6929	-1.338	-0.569	-0.466	-0.411	.7906	-1.349	-0.578	-0.480	-0.416
.6961	-1.330	-0.567	-0.467	-0.413	.7936	-1.345	-0.572	-0.475	-0.419
.6992	-1.330	-0.563	-0.468	-0.412	.7970	-1.336	-0.567	-0.465	-0.408
.7022	-1.332	-0.567	-0.470	-0.412	.7998	-1.340	-0.569	-0.471	-0.416
.7056	-1.334	-0.565	-0.468	-0.411	.8032	-1.336	-0.568	-0.471	-0.412
.7089	-1.336	-0.573	-0.473	-0.418	.8063	-1.334	-0.568	-0.469	-0.412
.7118	-1.333	-0.563	-0.468	-0.409	.8094	-1.333	-0.566	-0.468	-0.408
.7147	-1.332	-0.565	-0.469	-0.407	.8124	-1.327	-0.563	-0.464	-0.410
.7176	-1.341	-0.569	-0.472	-0.414	.8165	-1.327	-0.561	-0.464	-0.405
.7224	-1.342	-0.570	-0.473	-0.412	.8194	-1.327	-0.567	-0.471	-0.408
.7325	-1.343	-0.570	-0.473	-0.419	.8228	-1.328	-0.565	-0.468	-0.409
.7357	-1.354	-0.577	-0.479	-0.422	.8257	-1.327	-0.563	-0.465	-0.405
.7387	-1.356	-0.579	-0.481	-0.420	.8289	-1.322	-0.559	-0.463	-0.404
.7418	-1.358	-0.580	-0.482	-0.425	.8320	-1.321	-0.560	-0.464	-0.405
.7465	-1.359	-0.584	-0.485	-0.427	.8351	-1.323	-0.564	-0.469	-0.408
.7493	-1.364	-0.583	-0.488	-0.425	4896.6699	-1.335	-0.566	-0.467	-0.408
.7527	-1.365	-0.584	-0.486	-0.426	.6725	-1.334	-0.567	-0.469	-0.407
.7556	-1.373	-0.589	-0.491	-0.434	.6751	-1.324	-0.561	-0.461	-0.405
.7587	-1.375	-0.593	-0.499	-0.439	.6781	-1.325	-0.559	-0.461	-0.402
.7618	-1.382	-0.591	-0.495	-0.434	.6807	-1.323	-0.558	-0.461	-0.400
.7651	-1.388	-0.598	-0.498	-0.438	.6829	-1.324	-0.564	-0.468	-0.413
.7682	-1.381	-0.593	-0.495	-0.440	.6856	-1.324	-0.562	-0.466	-0.409
.7714	-1.386	-0.598	-0.501	-0.443	.6879	-1.320	-0.552	-0.453	-0.398
.7749	-1.387	-0.597	-0.499	-0.441	.6904	-1.325	-0.561	-0.462	-0.408
.7780	-1.386	-0.593	-0.497	-0.441	.6934	-1.320	-0.556	-0.458	-0.401
.7814	-1.396	-0.602	-0.502	-0.443	.6970	-1.318	-0.557	-0.463	-0.400
.7845	-1.391	-0.597	-0.498	-0.442	.6996	-1.313	-0.555	-0.458	-0.398
.7876	-1.392	-0.601	-0.501	-0.442	.7022	-1.321	-0.560	-0.461	-0.402
.7908	-1.386	-0.591	-0.494	-0.434	.7046	-1.326	-0.563	-0.463	-0.405
.7941	-1.380	-0.591	-0.493	-0.437	.7072	-1.326	-0.560	-0.461	-0.408
.7991	-1.383	-0.593	-0.496	-0.436	.7103	-1.330	-0.563	-0.462	-0.406
.8024	-1.373	-0.585	-0.486	-0.430	.7131	-1.326	-0.560	-0.463	-0.404
.8056	-1.375	-0.584	-0.487	-0.423	.7168	-1.335	-0.569	-0.473	-0.410

TABLE I (*continued*).

HJD-2440000	Δu	Δv	Δb	Δy
	m	m	m	m
4896.7207	-1.331	-0.566	-0.469	-0.413
.7234	-1.333	-0.566	-0.466	-0.412
.7261	-1.336	-0.569	-0.473	-0.413
.7296	-1.341	-0.570	-0.472	-0.413
.7323	-1.342	-0.573	-0.476	-0.418
.7350	-1.344	-0.570	-0.472	-0.413
.7377	-1.351	-0.576	-0.478	-0.424
.7406	-1.353	-0.577	-0.478	-0.418
.7433	-1.361	-0.584	-0.485	-0.424
.7463	-1.357	-0.581	-0.481	-0.421
.7490	-1.368	-0.587	-0.487	-0.425
.7526	-1.360	-0.582	-0.485	-0.424
.7556	-1.365	-0.582	-0.483	-0.421
.7585	-1.359	-0.581	-0.482	-0.423
.7615	-1.365	-0.584	-0.485	-0.428
.7645	-1.366	-0.582	-0.486	-0.425
.7674	-1.370	-0.584	-0.486	-0.427
.7703	-1.374	-0.589	-0.489	-0.430
.7733	-1.375	-0.587	-0.487	-0.427
.7764	-1.379	-0.588	-0.489	-0.430
.7796	-1.373	-0.590	-0.493	-0.433
.7827	-1.368	-0.587	-0.493	-0.430
.7855	-1.369	-0.587	-0.489	-0.431
.7902	-1.373	-0.586	-0.485	-0.430
.7928	-1.370	-0.584	-0.483	-0.428
.7956	-1.372	-0.586	-0.486	-0.427
.7986	-1.370	-0.582	-0.479	-0.424
.8019	-1.368	-0.581	-0.482	-0.425
.8046	-1.362	-0.581	-0.482	-0.421
.8075	-1.361	-0.580	-0.482	-0.422
.8106	-1.350	-0.573	-0.476	-0.416
.8135	-1.356	-0.580	-0.481	-0.421
.8168	-1.353	-0.573	-0.473	-0.420
.8196	-1.341	-0.570	-0.473	-0.415
.8226	-1.345	-0.570	-0.473	-0.420
.8259	-1.342	-0.570	-0.473	-0.411
.8290	-1.338	-0.565	-0.466	-0.406
.8318	-1.334	-0.563	-0.467	-0.410
.8348	-1.334	-0.564	-0.465	-0.412
5263.6072	-0.871	0.243	0.477	0.616
.6108	-0.877	0.238	0.474	0.611
.6157	-0.878	0.238	0.477	0.610
.6192	-0.872	0.247	0.484	0.616
.6224	-0.870	0.245	0.481	0.618
.6257	-0.873	0.239	0.468	0.613
.6289	-0.882	0.237	0.472	0.609
.6327	-0.880	0.243	0.478	0.615
.6358	-0.885	0.235	0.475	0.607
.6385	-0.887	0.234	0.472	0.609
.6413	-0.889	0.235	0.471	0.607
.6441	-0.895	0.229	0.461	0.601
.6469	-0.899	0.227	0.465	0.602
.6500	-0.901	0.226	0.460	0.601
.6526	-0.901	0.228	0.462	0.603
.6557	-0.908	0.222	0.456	0.595
.6586	-0.907	0.222	0.456	0.597
.6614	-0.911	0.222	0.459	0.596
.6645	-0.915	0.220	0.457	0.592
.6674	-0.914	0.220	0.458	0.595
.6699	-0.913	0.220	0.455	0.596
.6726	-0.914	0.223	0.453	0.595
.6752	-0.925	0.210	0.444	0.590
.6779	-0.920	0.216	0.455	0.593
.6844	-0.927	0.212	0.450	0.590
.6870	-0.922	0.215	0.449	0.593
.6896	-0.924	0.214	0.448	0.592
.6923	-0.922	0.217	0.451	0.595
.6949	-0.916	0.219	0.460	0.598
.6975	-0.920	0.219	0.456	0.595
5263.7002	-0.920	0.215	0.450	0.594
.7027	-0.925	0.217	0.458	0.594
.7056	-0.922	0.220	0.457	0.594
.7081	-0.920	0.220	0.457	0.594
.7108	-0.920	0.220	0.458	0.595
.7136	-0.917	0.220	0.458	0.597
.7163	-0.915	0.223	0.462	0.599
.7191	-0.914	0.225	0.464	0.598
.7218	-0.913	0.222	0.458	0.596
.7247	-0.908	0.229	0.465	0.601
.7277	-0.906	0.226	0.461	0.602
.7304	-0.900	0.231	0.467	0.602
.7332	-0.899	0.229	0.467	0.603
.7360	-0.894	0.233	0.470	0.608
.7387	-0.891	0.236	0.473	0.610
.7431	-0.889	0.234	0.470	0.606
.7461	-0.884	0.240	0.477	0.615
.7488	-0.886	0.236	0.474	0.611
.7518	-0.880	0.238	0.473	0.612
.7551	-0.879	0.239	0.475	0.613
.7581	-0.874	0.245	0.481	0.618
.7607	-0.872	0.246	0.481	0.620
.7633	-0.877	0.242	0.475	0.615
.7660	-0.873	0.245	0.483	0.616
.7688	-0.872	0.242	0.476	0.614
.7713	-0.875	0.241	0.476	0.610
.7741	-0.870	0.244	0.481	0.618
.7768	-0.872	0.245	0.483	0.618