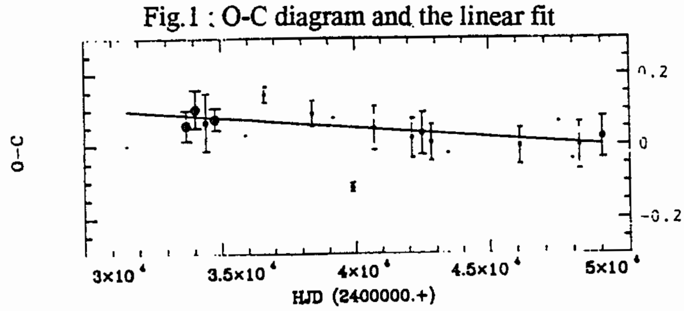
A PERIOD STUDY OF VZ CNC : A NEW HYPOTHESIS

Summary : processing 46 new visual maxima of VZ Cnc obtained in 1996-1997 together with the older maxima, we got a confirmation of the trend of O-C and of the variation of the beat period. To comprehend what mechanism causes such variations the hypothesis of the orbital motion and another new hypothesis based on the oscillation of one of the two periods of VZ Cnc (or both) have been briefly discussed. It was proved that the only light-time effect could not explain the observed beat period variation.

Introduction

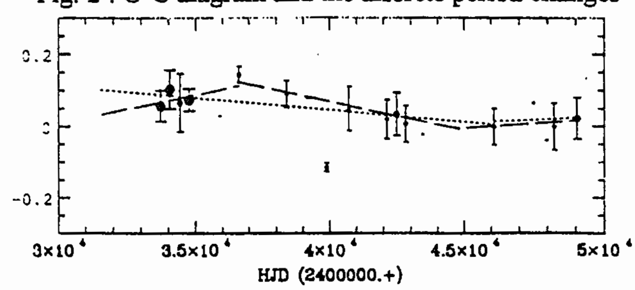
VZ Cnc is one of the most bright delta Scuti-type variable star in the sky with a large amplitude in the range 7.18-7.91 V, that makes it observable just by simple binoculars. Two periods are clearly evident in the light variation : the primary period of 0.17836376 d and the secondary period of 0.1428041 d are associated with the first and the second overtone and give rise to a well-developed beat period of 0.716292 d. This phenomenon causes a sinusoidal shift in the residuals that must be corrected before analysing the O-C diagram to prevent the large scatter due to the beat effect. In the past many observers followed maxima of VZ Cnc, supplying more and more times of maximum and proposing several explanations in order to rationalise the O-C trend. Some researchers highlighted that the primary period of VZ Cnc is undergoing secular changes, exhibited in the O-C diagram. Particularly, before HJD 2444600 it was clear that the best fit in the O-C diagram was obtained by a parabolic arc, that is the primary period was decreasing at a constant rate (Percy et al., 1980). After further investigations, it was noticed that the parabolic arc failed to fit new data. Hence Piersimoni et al. in 1993 preferred a simple linear fit to a parabolic one, indicating that the primary period is constant but with a value minor than 0.17836376 d. In fig.1 the linear fit is reported :

Fig.1 : O-C diagram and the linear fit



Also, the same O-C diagram can be explained by one or two period changes occurred : the first near HJD 2446000 and the latter near HJD 2436600 and HJD 2445000. In fig. 2 this attempt of explanation has been reported :

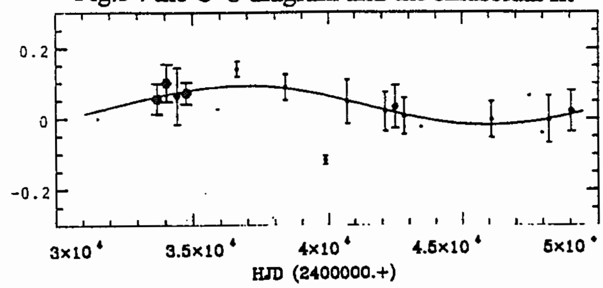
Fig. 2 : O-C diagram and the discrete period changes



In 1994 Arellano Ferro et al. proposed a new, more straightforward, explanation of the O-C diagram. They proposed a sinusoidal fit as reported in fig. 3, in which the following ephemeris was used for the calculation of the O-C :

$$\text{Max (HJD)} = 31550.71 + 0.17836376 * E \qquad (1)$$

Fig.3 : the O-C diagram and the sinusoidal fit



This fit provides a higher correlation coefficient than the linear and the parabolic one, and can be explained as a light-time effect, presumably due to an orbital motion of the star in a binary system. The authors remarked that if this hypothesis is true, the period of the sine wave fitting data and the orbital period of the binary system might have a value of 18000 ± 2000 days, about 50 years. Probably data collected until now are just sufficient to cover one orbital cycle, and surely they are still few to confirm this hypothesis and to reject the others.
Concerning the beat period, it was extensively studied by Todoran in 1976 who supplied the following ephemeris:

$$\text{Max (HJD)} = 33631.863 + 0.716292 * E_b \qquad (2)$$

In 1977 Cester et al. noted a small negative drift of the beat curve in the O-C vs beat phase diagram and in 1990 Quester et al. reported an increased negative drift, remarking the beat period was really decreasing. In 1995 Dalmazio confirmed that the beat period was shorter than the original value of 0.716292 d given by Todoran.

It is important to highlight that all workers studied the primary period and the beat period in a separate way, never keeping into account the correlation between such periods:

$$1/P_b = 1/P_2 - 1/P_1 \qquad (3)$$

where P_1 is the primary main period, P_2 is the secondary period and P_b is the beat period.

Results

Since 1995 two GEOS members visually observed VZ Cnc with the aim of obtaining additional maxima and confirming one of the previous hypotheses. About 800 visual estimates of VZ Cnc were obtained and 46 times of maximum were determined by SOP program (Gaspani, 1995). In the next tab.1 the observers (DDL=Dalmazio, DMT=Dumont), the heliocentric julian day and the error bars of the maximum, the O-C according to equation (1), the beat phase ψ_b according to equation (2) and the Argelander's degree at maximum, are reported. Due to different comparison stars used, the Argelander's degree estimated at maximum is different for both observers and so only for DDL's larger set of maxima it has been reported.

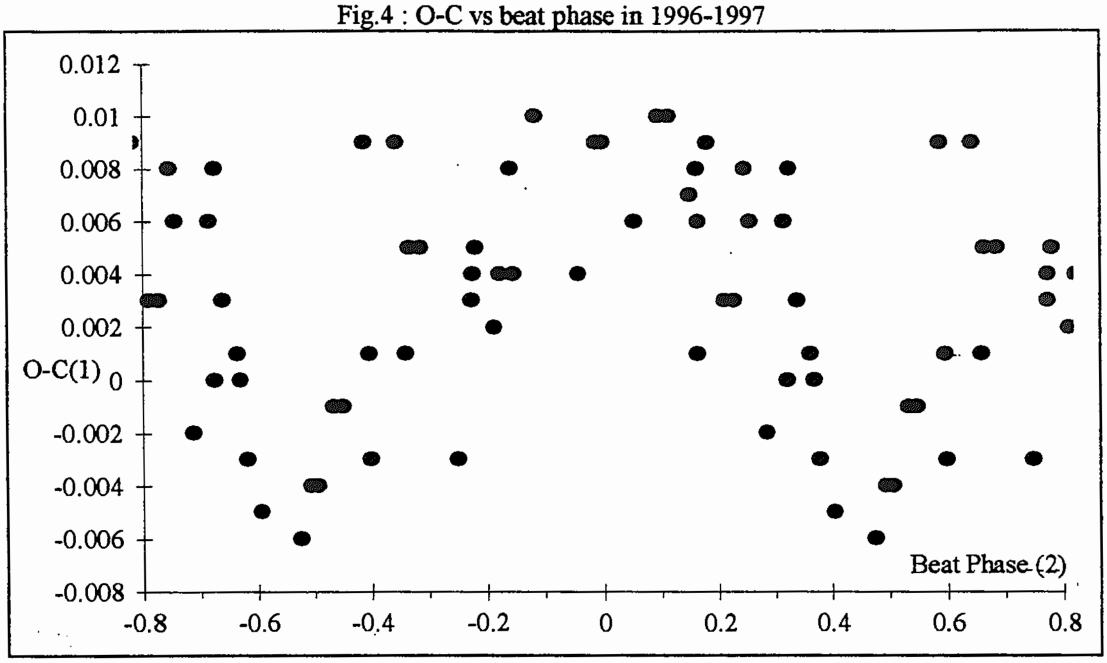
Tab.1 : times of maximum of VZ Cnc in 1996-1997

Observer	HJD	O-C(1)	ψ_b	Deg_{max}
DDL	50099.300 ± 0.010	0.008	0.838	2.87
DDL	50100.363 ± 0.014	0.000	0.322	0.53
DDL	50101.437 ± 0.002	0.004	0.821	3.19
DDL	50113.379 ± 0.005	-0.004	0.493	1.20
DDL	50122.305 ± 0.004	0.004	0.955	2.13
DDL	50126.409 ± 0.004	0.005	0.684	2.87
DDL	50130.334 ± 0.004	0.006	0.164	2.39
DDL	50137.294 ± 0.015	0.010	0.881	2.87
DDL	50138.355 ± 0.002	0.001	0.362	0.65
DDL	50140.326 ± 0.004	0.010	0.113	2.61
DDL	50141.387 ± 0.002	0.001	0.595	2.39
DDL	50142.282 ± 0.004	0.004	0.844	2.61
DDL	50143.351 ± 0.004	0.003	0.337	1.59
DDL	50148.349 ± 0.005	0.006	0.314	2.17
DDL	50154.412 ± 0.004	0.005	0.779	3.59
DDL	50156.365 ± 0.003	-0.004	0.505	2.61
DDL	50161.357 ± 0.009	-0.006	0.474	0.00
DDL	50163.328 ± 0.003	0.003	0.226	1.91
DDL	50178.315 ± 0.005	0.007	0.149	1.91
DDL	50194.359 ± 0.002	-0.001	0.548	3.59
DDL	50195.437 ± 0.001	0.006	0.053	3.59
DDL	50196.320 ± 0.001	-0.002	0.285	0.00
DDL	50211.308 ± 0.001	0.003	0.210	1.91
DDL	50219.326 ± 0.003	-0.005	0.404	1.20
DDL	50224.322 ± 0.001	-0.003	0.378	1.91
DDL	50476.361 ± 0.002	0.008	0.245	0.83
DDL	50478.324 ± 0.004	0.009	0.985	2.08
DMT	50486.500 ± 0.010	-0.020	0.400	-
DMT	50488.491 ± 0.001	0.009	0.179	-
DDL	50490.271 ± 0.002	0.005	0.664	3.57
DDL	50491.344 ± 0.001	0.008	0.162	0.60
DDL	50505.257 ± 0.001	0.009	0.586	2.08
DDL	50508.283 ± 0.004	0.002	0.810	3.13
DDL	50512.382 ± 0.003	-0.001	0.533	2.08
DMT	50515.418 ± 0.004	0.003	0.771	-
DDL	50515.419 ± 0.004	0.004	0.773	2.60
DDL	50518.266 ± 0.001	-0.003	0.747	2.08
DDL	50519.345 ± 0.003	0.006	0.254	1.04
DDL	50521.310 ± 0.004	0.009	0.997	1.79
DDL	50534.323 ± 0.005	0.001	0.164	1.04
DDL	50535.393 ± 0.002	0.001	0.658	2.78
DMT	50540.395 ± 0.004	0.009	0.641	-
DDL	50542.348 ± 0.002	0.000	0.368	1.67

Observer	HJD	O-C(1)	ψ_b	Deg_{max}
DMT	50545.377 ± 0.010	-0.003	0.597	-
DDL	50549.314 ± 0.003	0.010	0.093	2.08
DMT	50552.344 ± 0.004	0.008	0.323	-

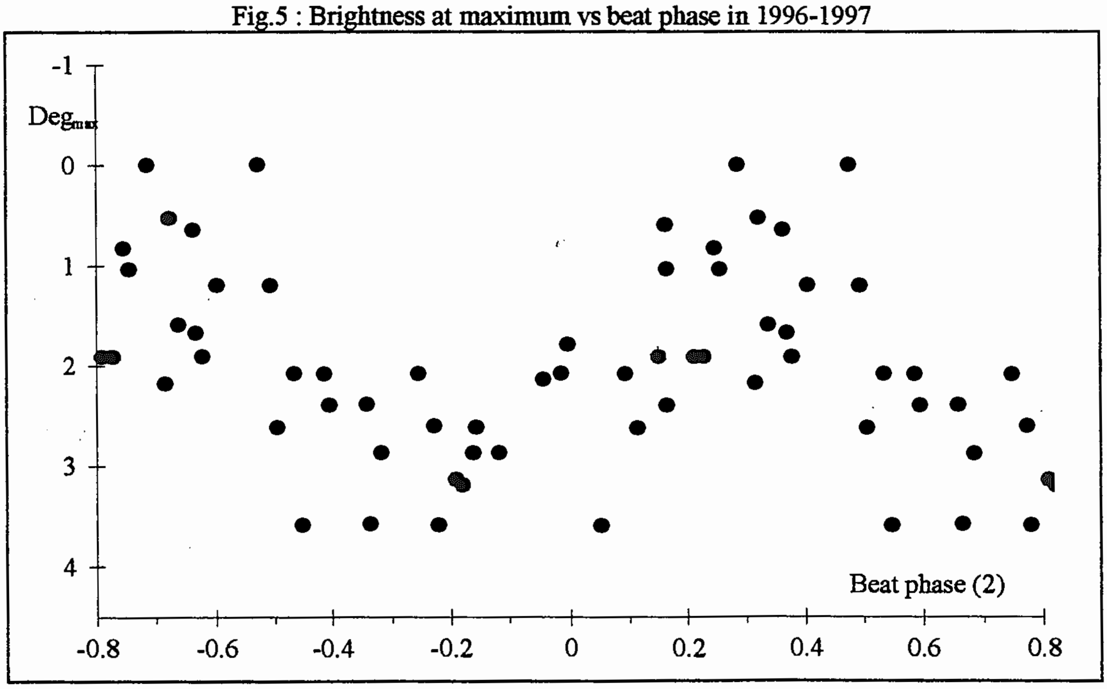
The figure 4 shows how the residuals are affected by the beat phase in a sinusoidal way:

Fig.4 : O-C vs beat phase in 1996-1997



The correlation between the brightness at maximum and the beat phase is evident in the next diagram, which shows the values of Deg_{max} vs ψ_b as reported in the table 1 :

Fig.5 : Brightness at maximum vs beat phase in 1996-1997



Three hypotheses

In the following discussion we will keep into account the equation (3) of the beat phenomenon. Apart from the linear trend of the O-C in time (see fig.1) which seems unlike, and the discrete period changes (see fig.2) which were discarded by Arellano Ferro et al., we are going to analyse the remaining hypothesis previously stated. The question is : the evident O-C trend, similar to a sine wave, has a geometric or an intrinsic nature? To discover what mechanism is active on VZ Cnc might be sufficient to observe how is the behaviour of the beat period. The possibilities are three :

a) *Geometric mechanism*

In this case the primary period, the secondary period, and obviously the beat period are all constant and the observed O-C diagram is caused by a light-time effect of a binary system in which VZ Cnc is : this is the Arellano Ferro et al.'s hypothesis.

b) *Intrinsic mechanism*

The primary (and the secondary) period of VZ Cnc oscillates with a well defined frequency. According to equation (3), this can cause the oscillation of the beat period and the sinusoidal appearance of the O-C diagram with the same frequency according to the equation (3).

c) *Both mechanisms a) and b) act*

This is the case of a different trend of the beat period other than sinusoidal (or a sinusoidal trend but with a different period of that one exhibited in the O-C diagram). So, the sinusoidal appearance of the O-C diagram is due to an orbital motion, and the non linear trend of the beat phase shift is due to the variation of the beat period.

If we detect that the beat period is constant, we can exclude the cases b) and c) and to confirm the Arellano Ferro et al.'s hypothesis of the binary system.

Data treatment

Now we have to find a technique to analyse all data (photoelectric and visual maxima) in order to investigate the trend of both primary and beat period separately. All photoelectric maxima reported by Arellano Ferro et al. in 1994 were collected together with visual maxima reported by Dalmazio in 1995 and the ones in this work, obtaining 213 maxima. Then, they were grouped to have, for each group, a consistent number of points generating a clear beat diagram in each epoch. One group at once was fitted by a sine wave like :

$$O\text{-}C = A \sin 2\pi (\psi_b - F) + T \qquad (4)$$

where O-C is the residual calculated by equation (1), A is the amplitude of the beat phenomenon, ψ_b is the beat phase calculated by equation (2), F is the shift of the beat curve for each group and T is the mean value of the O-C for each group. In this way we can monitor in each epoch the amplitude of the beat effect (A), the mean O-C (T), and the shift of the beat curve (F). The latter two parameters are strictly connected to respectively the primary period and the beat period. In the next table 2, all 15 groups with the number of maxima of each one, the average HJD, and the obtained values of A, F, T are reported :

Tab.2 : sinusoidal fit of the 15 group of maxima

Group	Nr maxima	Average HJD	A	F	T
1	20	33713	0.0060 ± 0.0008	0.059 ± 0.017	0.0065 ± 0.0005
2	18	34049	0.0065 ± 0.0018	0.069 ± 0.034	0.0076 ± 0.0012

Group	Nr maxima	Average HJD	A	F	T
3	8	34430	0.0113 ± 0.0017	0.039 ± 0.023	0.0059 ± 0.0012
4	25	34762	0.0042 ± 0.0005	0.065 ± 0.016	0.0068 ± 0.0003
5	9	36922	0.0075 ± 0.0026	0.109 ± 0.038	0.0076 ± 0.0016
6	7	40487	0.0090 ± 0.0019	0.051 ± 0.031	0.0068 ± 0.0010
7	19	42516	0.0074 ± 0.0007	0.020 ± 0.015	0.0025 ± 0.0005
8	6	43347	0.0068 ± 0.0007	0.021 ± 0.014	0.0033 ± 0.0005
9	11	47470	0.0084 ± 0.0011	-0.132 ± 0.011	0.0016 ± 0.0005
10	12	48071	0.0091 ± 0.0008	-0.157 ± 0.015	0.0006 ± 0.0006
11	10	49041	0.0082 ± 0.0009	-0.204 ± 0.018	0.0028 ± 0.0007
12	9	49427	0.0058 ± 0.0012	-0.148 ± 0.044	0.0002 ± 0.0011
13	13 (visual)	49790	0.0060 ± 0.0016	-0.263 ± 0.001	0.0037 ± 0.0012
14	25 (visual)	50154	0.0054 ± 0.0008	-0.264 ± 0.023	0.0030 ± 0.0006
15	21 (visual)	50515	0.0050 ± 0.0023	-0.251 ± 0.062	0.0038 ± 0.0014

Two beat diagrams with the related fitting sine waves are shown :

Fig.6 : sine wave fitting data of group 1

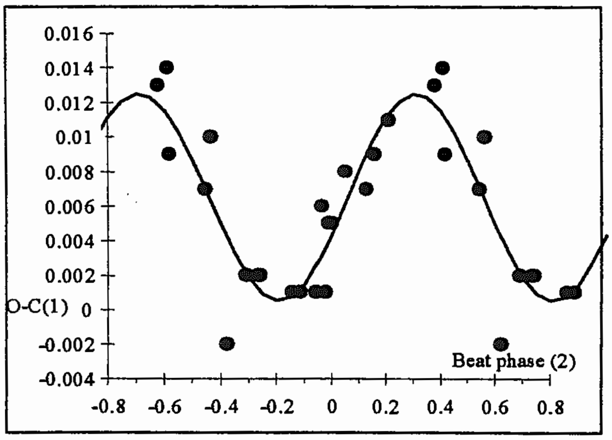
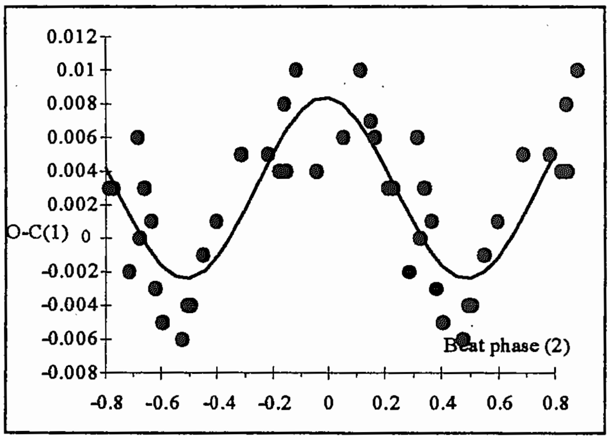


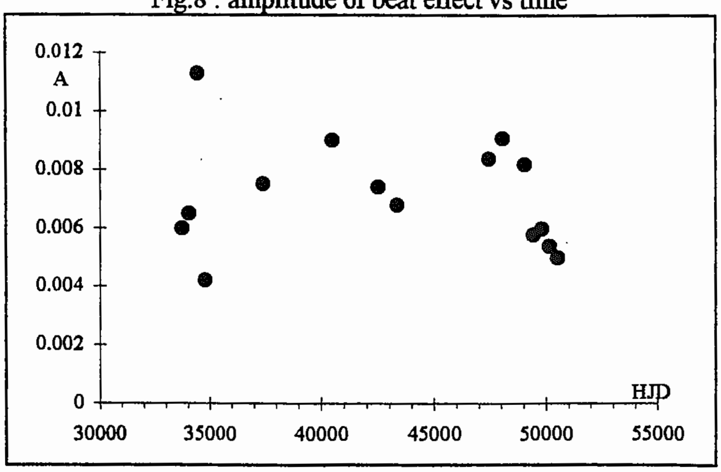
Fig.7 : sine wave fitting data of group14



Discussion

Now we can plot diagrams concerning the amplitude, the beat phase shift and the mean O-C in time (average HJD for each group), and look at the trend of both primary and beat period:

Fig.8 : amplitude of beat effect vs time



The behaviour of the beat amplitude is rather irregular, due to random variations around a mean value. We prefer to go on and to discuss the next two diagram :

Fig.9 : beat phase shift vs time

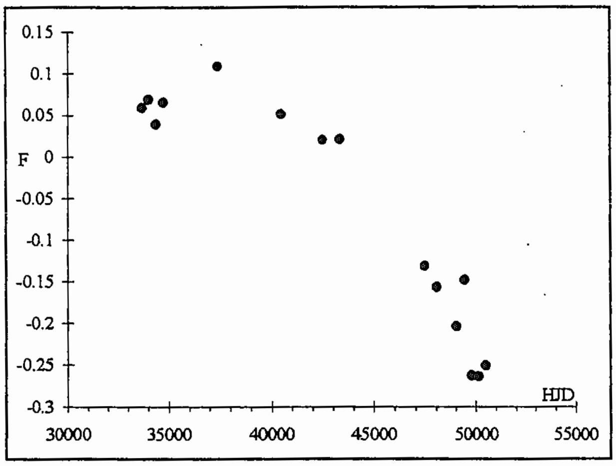
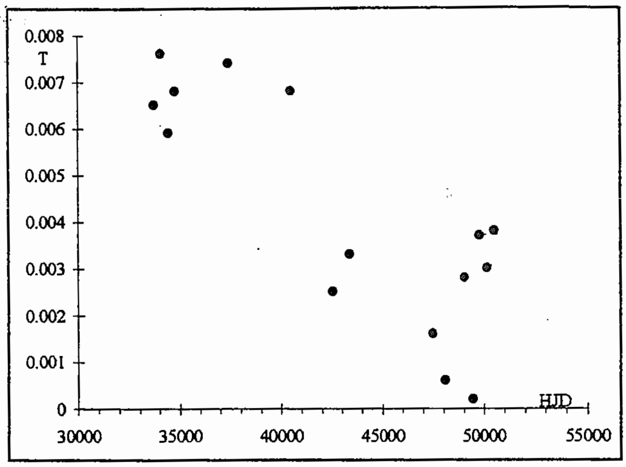


Fig.10 : mean O-C vs time



The fig.10 confirms that the mean O-C varies in time. We will assume that the variation is cyclical according to Arellano Ferro et al., even if the observations cover only approximately a cycle of variation. About the mechanism which produces such a phenomenon we cannot conclude that it depends only by an hypothetical light-time effect since even the beat period varies. Infact in fig.9 we can look at the non linear trend of the beat phase shift (the F value).

It is important to remark that a simple orbital motion causes an apparent oscillation of the beat phase shift, too, but it is negligible. Numerically, if the mean O-C oscillates of ± 0.004 d in 18000 days, we can calculate that the F value will oscillate of ± 0.005 phase (± 0.004/P_b) in the same range of time. Even invoking a consistent negative drift of the F values, corresponding to a value of P_b shorter than 0.716292 d, it seems that the F oscillation is however much greater than ± 0.005 phase.

Furthermore, keeping into account the only orbital motion without invoking variations of the primary period or both primary and secondary period, we would have to expect the F curve and the T curve phased. Infact when VZ Cnc is far from earth, its light spends more time to arrive to us, and the mean O-C is positive. In addition, the beat phase curve is positively shifted : hence the trend of the two curves goes together. Watching the fig. 9 and the fig.10, both F and T curves are phased until HJD 2447000, but in the recent past (up to HJD 2447000) they diverge, indicating that the only light-time effect could not be sufficient to explain the observations.

Conclusions

46 visual maxima of VZ Cnc carried out by GEOS in 1996-1997 confirmed the oscillation of the O-C and the decreasing trend of the beat phase shift, previously remarked by other authors. In order to explain if such a behaviour is caused by an orbital light-time effect, or by an oscillation of the primary period or both periods, 213 maxima were processed, proving that the only orbital motion could not be sufficient to explain the trend of the beat phase diagram. More interesting is another hypothesis of an intrinsic mechanism, or of two mechanisms independently affecting the O-C diagram and the beat period. It is still early to say what hypothesis is more credible because the observations do not cover an entire cycle of variation. Therefore further observations of maximum times in the future will secure what mechanism generates the mean O-C diagram and the beat phase shift diagram.

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