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AN UPDATE OF THE EPHEMERIS OF V566 OPHIUCHI[1]

M.A. Hobart[2]

Instituto Nacional de Astrofísica, Optica y Electrónica
Tonantzintla, Pue. México, and
Facultad de Física, Universidad Veracruzana, México

T. Gómez

Instituto de Astronomía
Universidad Nacional Autónoma de México

and

J.H. Peña[3]

Instituto Nacional de Astrofísica, Optica y Electrónica
Tonantzintla, Pue., México

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RESUMEN

Se reportan observaciones fotométricas recientes del sistema V566 Ophiuchi. De los tiempos de mínimo obtenidos de estas observaciones junto con los reportados en la literatura, se determina la efemérides cuadrática

$$HJD_{min} = 24436744.4195 + 0.4096404\ E + (3.4092 \times 10^{-10})\ E^2/2$$
$$\pm 0.0035 \quad \pm 1.59 \times 10^{-7} \quad \pm 0.051 \times 10^{-10}$$

denotando un cambio contínuo en su período de 2.63 s/siglo.

ABSTRACT

Photoelectric photometry of the binary system V566 Ophiuchi is reported. From the times of minima obtained from these observations and those found in the literature, the following quadratic ephemeris is calculated

$$HJD_{min} = 24436744.4195 + 0.4096404\ E + (3.4092 \times 10^{-10})\ E^2/2$$
$$\pm 0.0035 \quad \pm 1.59 \times 10^{-7} \quad 0.051 \times 10^{-10}$$

implying a continuous change in the period of 2.63 s/century.

Key words: **STARS-BINARIES – STARS-VARIABLE – STARS-W URSAE MAJORIS**

I. INTRODUCTION

The contact binary system V566 Ophiuchi (HD 163611, BD + 5°3457) has been known to be an A-type W Ursae Majoris eclipsing variable with its secondary eclipse being total (Bookmyer 1969). The variability of V566 Ophiuchi was discovered by Hoffmeister (1935) and the first photoelectric observations were made by Fresa (1954). Since then, this system has been extensively observed. An excellent compilation of the times of minima observed until 1982 can be found in Lafta and Grainger (1985). Additional times of minima have been published by Niarchos (1983), Scarfe *et al.* (1984), Kennedy (1984) and Seeds and Dawson (1985). It has been stated in the literature (see for example, Bookmyer 1976) that the period of this system remained constant from 1952 to 1966, and then an abrupt change occurred. In order to increase the time span of observations and hence to decide on the variation of the period of this system, the authors of the present paper decided to re-observe this star.

II. OBSERVATIONS

The observations were carried out during the nights of June 15–16 and 16–17, 1987 in the Observatorio Astronómico Nacional at San Pedro Mártir with the 84-cm reflecting telescope. A dry-ice cooled RCA 31034 A photocell with a pulse counting system and a Johnson *V*

1. Based on observations collected at the Observatorio Astronómico Nacional of San Pedro Mártir, B.C., México.
2. On leave from Facultad de Física, Universidad Veracruzana.
3. On leave from Instituto de Astronomía, UNAM.

TABLE 1

CHARACTERISTICS OF THE OBSERVED STARS

Star	M_v	Sp. Type	α (1950)	δ	Type
V = BD+5°3457 (V 566 Oph)	7.85	F4	$17^h54^m25^s$	+4°59'25"	Variable
C_1 = BD+5°3553	8.10	K	17 53 45	+4 49 59	Constant
C_2 = BD+5°3544	8.00	K	17 53 36	+5 10 34	Constant

filter were used. Two comparison stars were chosen according to the usual criteria that they be of approximately the same magnitude as the variable star and that they be within two degrees of the program star. The stars BD+4°3553 and BD+5°3544, fulfilled these requirements and they remained constant during the two observing nights. The coordinates and magnitudes of each observed star are listed in Table 1. Figure 1 shows the light curve of V566 Oph for the night of June 15–16, 1987 while Figure 2 shows the light curve of this system for the night of June 16–17, 1987. In both cases each observation consisted of one 40 s integration on each star. The sequence of observations followed was C_1, C_2, V, V, V, C_1, C_2, etc. The photometric values plotted are the magnitude differences between the variable star and the average of the comparison stars interpolated at the time of the observation of the variable. Then an average of the differences was subtracted from each run to establish the zero baseline. The data points are accurate to $0^m.005$; the average span between successive sets of three points is $0^d.01$ while the accuracy in time for each point is $0^d.0014$. Figure 3 shows the two observed nights in phase, using the period $0^d.4096404$ obtained in the present paper.

III. ANALYSIS

For an accurate determination of the period, a long time span is required. If a smooth period variation is assumed then the following equations can be used

$$T = T_0 + P_0 E + (\alpha/2)E^2 \quad (1)$$

and

$$P = P_0 + \alpha E \quad (2)$$

and from them, if one supposes a fixed uncertainty in the determination of the times of minimum light, dT = $0^d.0035$, the accuracy of P and α can be obtained from the time coverage of the observations or equivalently from the number of cycles E covered in that time interval. For an assumed period of $0^d.409640$ the number of cycles is E = 31208.5 which allows an accuracy in the

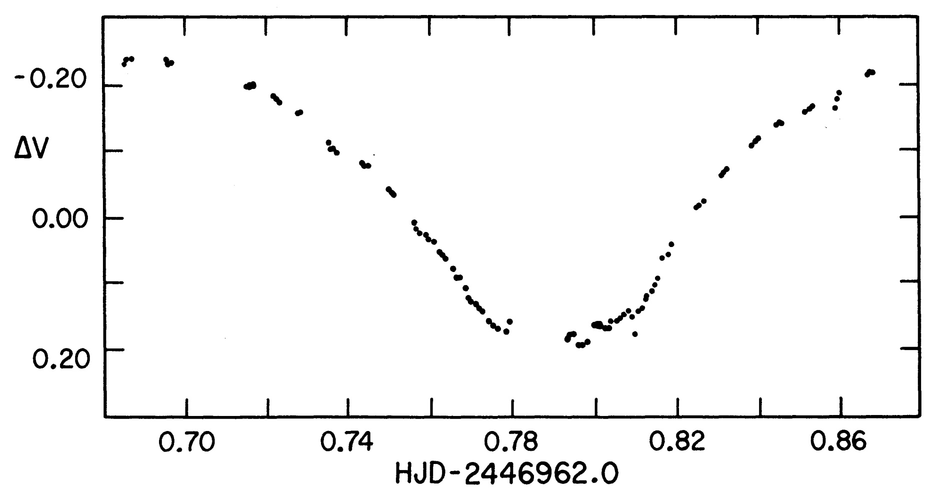

Fig. 1. Light curve of V566 Ophiuchi corresponding to the night of June 15 – 16, 1987. ΔV is given in magnitudes.

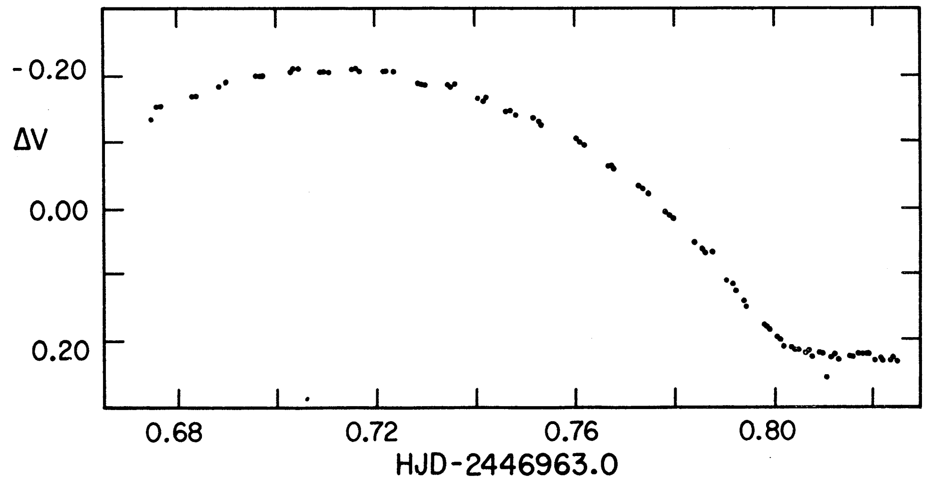

Fig. 2. Light curve of V566 Ophiuchi corresponding to the night of June 16 – 17, 1987. ΔV is given in magnitudes.

period of 1.59×10^{-7} and 5.1×10^{-12} in the quadratic coefficient.

All times of minima reported in Table 2 which cover a time span of 35 years, were used to analyze the period behaviour of V566 Oph. As a first step the times of minima between 1952 and 1966 (corresponding to the dates from HJD 2434179 to HJD 2439319) were examined. As mentioned already, there have been reports (Bookmyer 1969) that the system had maintained a constant period during these 14 years. The O–C residuals for this time interval were calculated according to the linear ephemeris ($\alpha = 0$)

$$HJD_{min} = 2436744.4195 + 0.4096409\,E$$
$$\pm 0.0035 \quad \pm 3.9\times10^{-7}$$

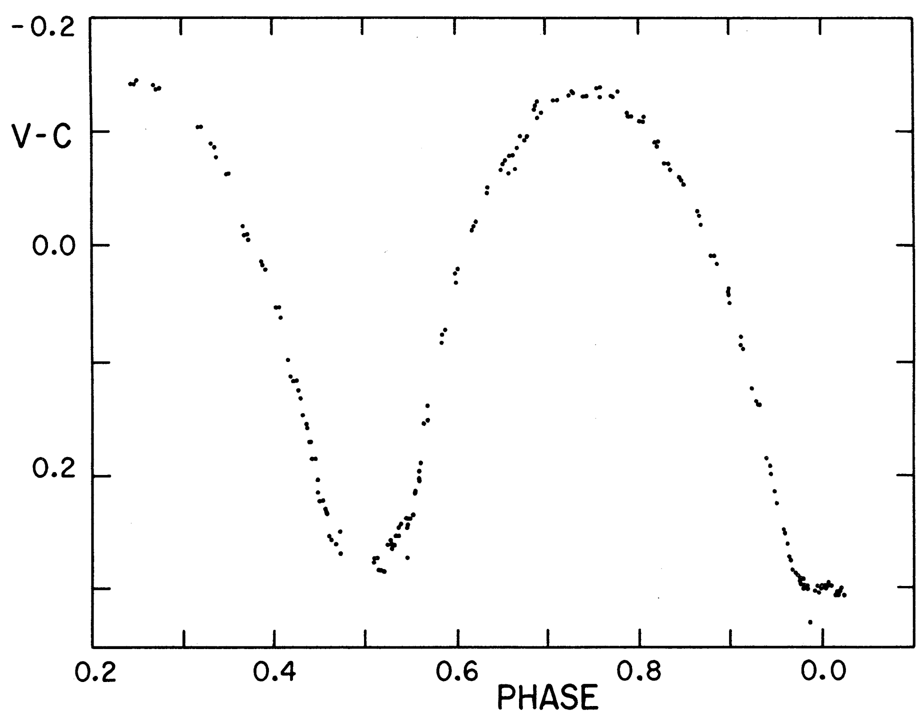

Fig. 3. Light curves in phase for the nights HJD 2446962 and HJD 2446963. The period used was P = 0.409640403 d found in the present paper.

TABLE 2

OBSERVED PHOTOELECTRIC MINIMA

HJD 2400000+	E	$(O-C)_1$	$(O-C)_2$	$(O-C)_3$	Source
34179.4534	-6261.5000	0.0005	0.0172	-0.0095	1
34181.5009	-6256.5000	-0.0002	0.0165	-0.0102	1
34226.3572	-6147.0000	0.0004	0.0168	-0.0093	1
34237.4178	-6120.0000	0.0007	0.0171	-0.0089	1
34515.5639	-5441.0000	0.0006	0.0152	-0.0073	2
34593.3956	-5251.0000	0.0005	0.0146	-0.0069	2
35245.7494	-3658.5000	0.0012	0.0110	-0.0030	3
35968.7655	-1893.5000	0.0011	0.0061	-0.0005	3
35987.8129	-1847.0000	0.0002	0.0051	-0.0014	3
36010.7534	-1791.0000	0.0008	0.0056	-0.0007	3
36395.4056	-852.0000	0.0002	0.0024	-0.0004	4
36404.4186	-830.0000	0.0011	0.0033	0.0005	4
36725.3717	-46.5000	0.0005	0.0006	0.0005	5
36728.4452	-39.0000	0.0017	0.0018	0.0017	5
36744.4195	0.0000	0.0000	0.0000	0.0000	5
36755.4810	27.0000	0.0012	0.0011	0.0012	5
38556.4671	4423.5000	0.0010	-0.0108	-0.0001	6
38557.4900	4426.0000	-0.0002	-0.0120	-0.0013	6
38589.4423	4504.0000	0.0001	-0.0119	-0.0011	6
38590.4633	4506.5000	-0.0030	-0.0150	-0.0042	6
39289.7240	6213.5000	0.0007	-0.0159	0.0028	7
39289.9288	6214.0000	0.0007	-0.0160	-0.0029	7
39294.4382	6225.0000	0.0040	-0.0126	0.0005	8
39297.7113	6233.0000	0.0000	-0.0167	-0.0036	7
39297.9170	6233.5000	0.0009	-0.0158	-0.0027	7
39319.4218	6286.0000	-0.0005	-0.0173	-0.0041	8
40047.3580	8063.000	-0.0395	-0.0178	-0.0033	9
40049.4057	8068.0000	-0.0400	-0.0183	-0.0038	9
40418.4931	8969.0000	-0.0439	-0.0198	-0.0051	9
40820.3490	9950.0000	-0.0510	-0.0242	-0.0097	10
40846.3686	10013.5000	-0.0439	-0.0170	-0.0024	11
40853.3280	10030.5000	-0.0485	-0.0215	-0.0070	11
41119.8018	10681.0000	-0.0496	-0.0209	-0.0066	12
41119.8070	10681.0000	-0.0444	-0.0157	-0.0014	13
41135.7800	10720.0000	-0.0476	-0.0188	-0.0045	13
41136.3852	10721.5000	-0.0569	-0.0281	-0.0138	14
41139.4564	10729.0000	-0.0580	-0.0292	-0.0149	14
41145.8170	10744.5000	-0.0470	-0.0181	-0.0038	12
41165.6840	10793.0000	-0.0478	-0.0188	-0.0045	13
41479.4703	11559.0000	-0.0506	-0.0195	-0.0058	15
41835.8616	12429.0000	-0.0515	-0.0181	-0.0052	12
41843.8498	12448.5000	-0.0514	-0.0179	-0.0051	12
41845.4890	12452.5000	-0.0508	-0.0173	-0.0045	15
41850.6089	12465.0000	-0.0515	-0.0179	-0.0051	16
41851.4283	12467.0000	-0.0514	-0.0178	-0.0050	15
41851.6327	12467.5000	-0.0518	-0.0183	-0.0055	16
41851.8381	12468.0000	-0.0512	-0.0177	-0.0049	16
41858.5968	12484.5000	-0.0517	-0.0181	-0.0053	16
41861.6690	12492.0000	-0.0518	-0.0182	-0.0054	16
41862.6934	12494.5000	-0.0515	-0.0179	-0.0052	16
41863.7179	12497.0000	-0.0512	-0.0175	-0.0048	16
41866.5848	12504.0000	-0.0518	-0.0181	-0.0054	16
41877.8505	12531.5000	-0.0514	-0.0176	-0.0049	12
41895.4680	12574.5000	-0.0486	-0.0148	-0.0021	15
42193.4828	13302.0000	-0.0515	-0.0157	-0.0040	17
42203.7230	13327.0000	-0.0525	-0.0166	-0.0049	18
42215.8078	13356.5000	-0.0522	-0.0163	-0.0046	19
42216.8320	13359.0000	-0.0522	-0.0162	-0.0046	19
42225.4170	13380.0000	-0.0697	-0.0337	-0.0221	20
42230.3329	13392.0000	-0.0696	-0.0336	-0.0219	20
42241.8201	13420.0000	-0.0525	-0.0164	-0.0048	19

TABLE 2 (CONTINUED)

HDJ 2400000+	E	$(O-C)_1$	$(O-C)_2$	$(O-C)_3$	Source
42243.4608	13424.0000	-0.0504	-0.0143	-0.0027	21
42248.7844	13437.0000	-0.0522	-0.0160	-0.0045	19
42251.4448	13443.5000	-0.0545	-0.0183	-0.0068	17
42256.3680	13455.5000	-0.0470	-0.0108	0.0007	21
42257.3880	13458.0000	-0.0511	-0.0149	-0.0034	21
42258.4165	13460.5000	-0.0468	-0.0105	0.0010	21
42265.7848	13478.5000	-0.0521	-0.0158	-0.0043	19
42268.4474	13485.0000	-0.0522	-0.0159	-0.0044	17
42268.4480	13485.0000	-0.0516	-0.0153	-0.0038	17
42307.3612	13580.0000	-0.0548	-0.0183	-0.0069	21
42532.4640	14129.5000	-0.0526	-0.0146	-0.0042	21
42537.5770	14142.0000	-0.0602	-0.0221	-0.0117	21
42549.4593	14171.0000	-0.0576	-0.0195	-0.0091	21
42555.4039	14185.5000	-0.0529	-0.0147	-0.0044	21
42563.3940	14205.0000	-0.0509	-0.0127	-0.0024	21
42565.4320	14210.0000	-0.0611	-0.0229	-0.0126	22
42567.4800	14215.0000	-0.0614	-0.0231	-0.0128	22
42572.8131	14228.0000	-0.0537	-0.0154	-0.0051	19
42576.4964	14237.0000	-0.0572	-0.0189	-0.0086	21
42579.7790	14245.0000	-0.0518	-0.0134	-0.0032	23
42580.8014	14247.5000	-0.0535	-0.0151	-0.0049	23
42581.8262	14250.0000	-0.0528	-0.0145	-0.0042	19
42581.8263	14250.0000	-0.0527	-0.0144	-0.0041	23
42588.3797	14266.0000	-0.0536	-0.0153	-0.0050	21
42590.4300	14271.0000	-0.0516	-0.0132	-0.0030	21
42590.8385	14272.0000	-0.0527	-0.0143	-0.0041	23
42591.4547	14273.5000	-0.0510	-0.0126	-0.0024	21
42595.5490	14283.5000	-0.0531	-0.0147	-0.0045	22
42601.4860	14298.0000	-0.0560	-0.0175	-0.0074	24
42605.3790	14307.5000	-0.0547	-0.0162	-0.0060	21
42608.4600	14315.0000	-0.0460	-0.0075	0.0026	22
42609.4740	14317.5000	-0.0561	-0.0176	-0.0075	22
42609.4785	14317.5000	-0.0516	-0.0131	-0.0030	21
42610.5010	14320.0000	-0.0532	-0.0147	-0.0046	22
42614.8044	14330.5000	-0.0511	-0.0126	-0.0025	19
42617.4555	14337.0000	-0.0627	-0.0241	-0.0141	21
42618.4945	14339.5000	-0.0478	-0.0093	0.0008	21
42620.5300	14344.5000	-0.0606	-0.0220	-0.0119	22
42620.5350	14344.5000	-0.0556	-0.0170	-0.0069	22
42623.4060	14351.5000	-0.0521	-0.0135	-0.0034	21
42624.4277	14354.0000	-0.0545	-0.0159	-0.0058	21
42666.4175	14456.5000	-0.0534	-0.0146	-0.0047	21
42938.8340	15121.5000	-0.0517	-0.0110	-0.0025	19
42987.7861	15241.0000	-0.0524	-0.0114	-0.0030	19
43281.5037	15958.0000	-0.0511	-0.0082	-0.0015	25
43662.4770	16888.0000	-0.0489	-0.0034	0.0010	26
43671.7469	16910.5000	0.0040	0.0495	0.0538	35
43671.8964	16911.0000	-0.0513	-0.0059	-0.0015	27
43676.4026	16922.0000	-0.0513	-0.0057	-0.0014	28
43677.4272	16924.5000	-0.0508	-0.0052	-0.0009	28
44406.8073	18705.0000	-0.0459	0.0044	0.0034	31
44448.7922	18807.5000	-0.0497	0.0009	-0.0005	31
44750.4901	19544.0000	-0.0563	-0.0037	-0.0076	29
44750.4902	19544.0000	-0.0562	-0.0036	-0.0075	29
44751.5162	19546.5000	-0.0543	-0.0017	-0.0056	29
44751.5173	19546.5000	-0.0532	-0.0006	-0.0045	29
44780.8121	19618.0000	-0.0481	0.0047	0.0005	31
44781.8357	19620.5000	-0.0486	0.0041	0.0000	31
44795.3461	19653.5000	-0.0566	-0.0037	-0.0080	32
44796.3698	19656.0000	-0.0570	-0.0041	-0.0084	32
44798.4191	19661.0000	-0.0559	-0.0030	-0.0073	32
44799.4434	19663.5000	-0.0557	-0.0028	-0.0071	32
44825.2510	19726.5000	-0.0558	-0.0028	-0.0073	29
44825.2512	19726.5000	-0.0556	-0.0026	-0.0071	29

TABLE 2 (CONTINUED)

HDJ 2400000+	E	$(O-C)_1$	$(O-C)_2$	$(O-C)_3$	Source
44826.2739	19729.0000	-0.0571	-0.0040	-0.0085	29
44826.2742	19729.0000	-0.0568	-0.0037	-0.0082	29
44827.2992	19731.5000	-0.0559	-0.0028	-0.0074	29
44827.3005	19731.5000	-0.0546	-0.0015	-0.0061	29
45144.5759	20506.0000	-0.0502	0.0049	-0.0026	33
45169.9749	20568.0000	-0.0493	0.0060	-0.0017	34
45170.9988	20570.5000	-0.0495	0.0058	-0.0019	34
45172.6355	20574.5000	-0.0514	0.0040	-0.0038	33
45175.7085	20582.0000	-0.0507	0.0046	-0.0032	33
45183.4926	20601.0000	-0.0499	0.0055	-0.0024	30
45196.6001	20633.0000	-0.0511	0.0044	-0.0036	33
45197.0117	20634.0000	-0.0491	0.0064	-0.0016	34
45207.6598	20660.0000	-0.0518	0.0037	-0.0044	33
45512.8463	21405.0000	-0.0518	0.0058	-0.0054	31
45513.8700	21407.5000	-0.0522	0.0053	-0.0058	31
45554.6307	21507.0000	-0.0513	0.0065	-0.0051	33
45925.7694	22413.0000	-0.0522	0.0081	-0.0075	33
45928.6376	22420.0000	-0.0515	0.0088	-0.0068	33
45943.7952	22457.0000	-0.0508	0.0096	-0.0062	33
46318.4320	23371.5000	-0.0355	0.0273	-0.0072	36
46962.7900	24944.5000	-0.0511	0.0160	-0.0123	37
46963.8253	24947.0000	-0.0399	0.0272	-0.0011	37

1) Fresa (1954); 2) Kwee (1958); 3) Binnendijk (1959); 4) Purgathofer and Widorn (1959); 5) Purgathofer and Widorn (1964); 6) Schnell and Widorn (1965); 7) Bookmyer (1969); 8) Minti and Dinescu (1966); 9) Pohl and Kızılırmak (1970); 10) Popovici (1971); 11) Kızılırmak and Pohl (1971); 12) Scarfe and Barlow (1978); 13) Kaitchuk and Sprague (1974); 14) Pohl and Kızılırmak (1974); 15) Kızılırmak and Pohl (1974); 16) Bookmyer (1976); 17) Pohl and Kızılırmak (1975); 18) Kaitchuck (1975); 19) Scarfe and Barlow (1978); 20) Popovici (1974); 21) Pop and Torodan (1977); 22) *BBSAG Bull.*, No. 23; 23) Dawson and Nayaranaswamy (1977); 24) *BBSAG Bull.* No. 24; 25) Pohl and Gülmen (1981); 26) Ebersberger, Pohl, and Kızılırmak (1978); 27) Maddox and Bookmyer (1978); 28) Niarchos (1979); 29) Mahdy and Soliman (1982); 30) Pohl *et al.* (1983); 31) Scarfe *et al.* (1984); 32) Niarchos (1983); 33) Seeds and Dawson (1985); 34) Kennedy (1984); 35) Maddox and Bookmyer (1979); 36) von Huebscher, Lichtenknecker, and Meyer (1985); 37) this paper.

which was calculated by means of a computer program which sweeps an interval in period around a first test period with an established initial time. The most refined period is chosen as that with the smallest standard deviation. A finer interval in P is then swept in order to obtain a better value for the period. This procedure is followed as many times as necessary to reach the maximum possible accuracy. This ephemeris is in complete agreement with that presented by Bookmyer (1969). The residuals are shown in the third column of Table 2 under the heading $(O-C)_1$.

The times of minima from HJD 2440047 to HJD 2446963 (after the alleged change in period had occurred) were then used to calculated to O–C residuals by means of the linear ephemeris

$$HJD_{min} = 2436744.4195 + 0.4096463\ E$$
$$\pm 0.0035 \quad \pm 2.9 \times 10^{-7}$$

which was obtained in a similar way. The results are shown in the third column with the heading $(O-C)_1$ of Table 2.

In the same fashion, the complete set of times of minima was employed to obtain the linear ephemeris

$$HJD_{min} = 243744.4195 + 0.4096436\ E$$
$$\pm 0.0035 \quad \pm 1.59 \times 10^{-7}$$

and the residuals are presented in the fourth column of Table 2 under the heading $(O-C)_2$ and are shown in Figure 4.

Finally, all the available times of maxima were used to calculate the O–C residuals with the quadratic ephemeris

$$HJD_{min} = 24436744.4195 + 0.4096404\ E +$$
$$\pm 0.0035 \quad \pm 1.59 \times 10^{-7}$$
$$+ (3.4092 \times 10^{-10})\ E^2/2$$
$$\pm 0.051 \quad \times 10^{-10}$$

where the coefficient of the quadratic term in E was obtained by using a linear ephemeris to calculate the epochs for each minima and then making a quadratic

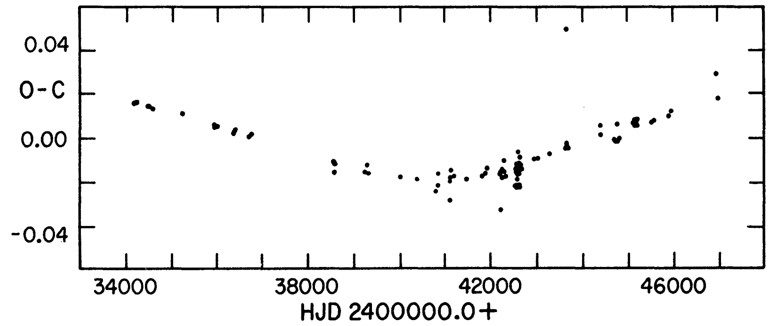

Fig. 4. O – C versus HJD using the linear ephemeris HJD 2436744.4195 + 0.4096436 E.

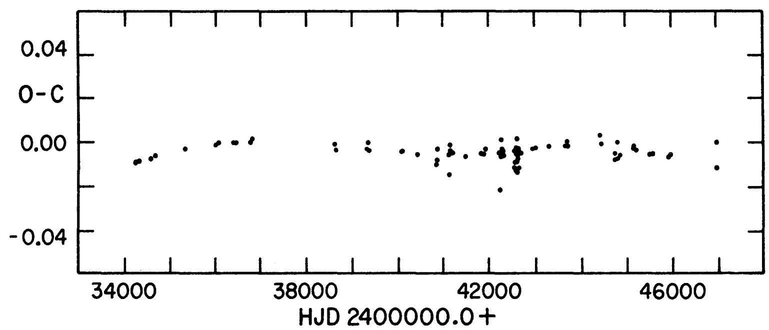

Fig. 5. O – C versus HJD, using the quadratic ephemeris HJD 2436744.4195 + 0.409640403 E + (3.40923) $E^2/2$ with the period and rate of change of the period deduced in the present paper.

least squares fit of the epochs versus the HJD of the times of minima. We thus obtained the result T = 243744.4153 + 0.4096404 E + 1.7046 × 10^{-10} E^2. Further the quadratic ephemeris was calculated with the method already described, with

$$1/2\,\alpha = 1.7046 \times 10^{-10}.$$

The residuals obtained are shown in the fifth column under the heading $(O-C)_3$ and presented in Figure 5.

IV. DISCUSSION

In order to decide on the nature of the period change, that is, if it was an abrupt change or if the change had been continuous, the dispersion of the residuals was calculated for the linear ephemeris and the quadratic ephemeris. In the former case the standard deviation was $\sigma_1 = 2.097 \times 10^{-2}$ while in the latter case, the standard deviation calculated was $\sigma_2 = 6.314 \times 10^{-3}$. From these values and the fact that there is no simple explanation for an abrupt change in the period of this kind of a system, one is tempted to believe that the period V566 has been changing smoothly and that the constant interval reported, simply corresponded to the time when the period change was near its minimum. From the coefficient of the second order term in E in the quadratic ephemeris, which represents the rate of change of the period, an increase of 2.63 seconds/century is calculated. More observations of this system are desirable in order to deduce beyond doubt the variation of this period.

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Teresa Gómez and José H. Peña: Instituto de Astronomía, UNAM, Apartado Postal 70-264, 04510 México, D.F., México.
Marco Antonio Hobart: Instituto Nacional de Astrofísica, Optica y Electrónica, Apartados Postales 51 and 216, 72000 Puebla, Pue., México.