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ORBITAL PERIOD VARIATION STUDY OF THE ALGOL ECLIPSING BINARY DI PEGASI

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ABSTRACT

We discuss the orbital period changes of the Algol semi-detached eclipsing binary DI Peg by constructing the $(O-C)$ residual diagram via using all the available precise minima times. We conclude that the period variation can be explained by a sine–like variation due to the presence of a third body orbiting the binary, together with a long-term orbital period increase ($dP/dt = 0.17$ sec/century) that can be interpreted to be due to mass transfer from the evolved secondary component (of rate $1.52 \times 10^{-8} M_\odot$/yr) to the primary one. The detected low-mass third body ($M_{3\ min.} = 0.22 \pm 0.0006$ $M_\odot$) is responsible for a periodic variation of about 55 years light time effect. We have determined the orbital parameters of the third component which show a considerable eccentricity $e_3 = 0.77 \pm 0.07$ together with a longitude of periastron $\omega_3 = 300° \pm 10°$.

Key words : binaries: eclipsing — binaries: close — binaries: Algol — stars: triple — individual: DI Peg

1. INTRODUCTION

DI Peg (BD+14°5006, HD 220619, HIP 116167, $\alpha_{2000} = 23^h\ 32^m\ 14^s.66924, \delta_{2000} = +14°\ 58'\ 08''.7408$, sp. F0IVn, mag$_v$ = 9.51 according to Simbad database) is a relatively short period ($P = 0^d.7118$) eclipsing binary, that has been discovered as an Algol type variable by Morgenroth (1934).

The system was observed by Jensch (1934) who published a photographic light curve. Subsequently, photoelectric light curves were observed by several authors; Kruszewski in 1962 (V filter), Chou & Kitamura (1968), and Binnendijk (1973) in B&V filters, and Chaubey (1982) in U, B&V filters.

High dispersion spectroscopic observations were conducted by Lu (1992) who presented the radial–velocity measurements of DI Peg and determined a K4 spectral type for the secondary component. He established the triplicity of the system confirming the earlier finding of Rucinski (1967) who suggested the presence of a third source of light based on an analysis of light curves contributing 24% of the total light of the system. Lu (1992) determined the radial velocity of the third component (+40.2 ± 0.3 km/s), and also carried–out a detailed analysis of the published photoelectric light curves with the Wilson–Devinney code (Wilson, 1979) setting the third light l_3 as a free parameter. He obtained the following absolute dimensions of DI Peg as: $A = 4.14 \pm 0.05$ R$_\odot$; $R_1 = 1.41 \pm 0.03$ R$_\odot$; $R_2 = 1.37 \pm 0.03$ R$_\odot$; $M_1 = 1.18 \pm 0.03$ M$_\odot$; and $M_2 = 0.70 \pm 0.02$ M$_\odot$.

The aim of this paper is to study the changes in the orbital period of this interesting system and to redetermine the third body orbital parameters using the photoelectric and CCD minima times obtained over the last two decades. All the available data covering about 84 years from 1928 to 2012.

2. PERIOD VARIATION STUDY

2.1 Light Elements

The light elements of DI Peg was first obtained by Jensch (1934):

$$\text{HJD(Min.I)} = 24\ 25644.315 + 0^d.711811\, E. \quad (1)$$

Later, several authors observed minima times visually (v), photographically (pg), photoelectrically (pe & CCD). They obtained different light elements that are listed in Table 1. We used Kreiner's (2004) light elements (see Table 1) to calculate the residual values of the $(O-C)$ diagram. For minima time detection, we used the last set of pe and CCD minima times of Table 7 (43 minima) starting from the Julian date 24 52567.3312 to JD. 24 56163.4447 to obtain the light elements:

$$\text{HJD(Min.I)} = 24\ 25918.21913 + 0^d.71181981\, E. \quad (2)$$

with standard deviation SD=0.0013 and regression r = 0.9643.

To study the period variation of DI Peg, one must first know the evolutionary status of the system through the spectroscopic and photoelectric light curves analysis of the previous studies. Second, one can construct

Table 1.

JD.+240000	Period (d)	Quad. term	Periodic term	Reference
25644.3150	0.71181100			Jensch (1934).
32441.4410	0.71181400			Jensch & Szafraniec (1951), SAC 22.
32441.4410	0.71181988			Gaposchkin (1952).
32441.4350	0.71181840			Rucinski (1967).
37522.3946	0.71181750			Chaubey (1982).
37983.6528	0.71181880			Chou & Kitamura (1968).
40114.8356	0.71181510			Binnendijk (1973).
25918.346	0.71181730		$a\ \sin[b\,(E\,+\,c)]^{\dagger}$	von Ahnert (1974).
42411.86193	0.71181612			Mallama (1980).
32441.4470	0.71181768	-0.194×10^{-9}	$a\ \sin(b\,E\,+\,c)^{\dagger\dagger}$	Rafert (1982).
25918.3597	0.71181663			Lu (1992).
45196.488	0.71181680			Kholopov et al., (1998).
25918.261	0.71181641			Kreiner (2004).
25918.23085	0.71181951			Present Work‡
25918.36771	0.71181545	1.901×10^{-11}		Present Work‡‡

† $a=0^d.0055$, $b=0^\circ.0221765$ and $c=3000$.
†† $a=0^d.0107$, $b=0^\circ.0001580$ and $c=6495$.
‡ Light elements obtained by using Pe and CCD minima starting from JD 24 52567.3312.
‡‡ Quad. light elements obtained by using all Pe and CCD minima only.

the $O-C$ diagram in order to:
(1) discuss the effect of mass transfer and/or lost from the system,
(2) to deduce the light time effect (LITE) due to the presence of a third body that has been already detected spectroscopically by Lu (1992), then calculating the third body orbital parameters, and
(3) to discuss the possibility of the presence of star–spots due to magnetic activity.

2.2 Previous Light Curve Studies

Rucinski (1967) used the unpublished light curve of Kruszewski's 1961 observations in the yellow band to obtain the geometrical elements of DI Peg. He introduced an additional (third) source contributing 24% of the light and identified a secondary minimum placed exactly at a phase of 0.5 (i.e., e=0), and obtained a F4IV spectral type for the primary component. He also suggested a semi–detached configuration of the system with two evolved components from the main sequence in which the fainter filled its Roche lobe.

Chou & Kitamura (1968) observed the system photoelectrically with B & V filters. They suggested a semi-detached Algol type configuration for DI Peg with sp. type K0+K2.

Binnendijk (1973) has also observed the system with B & V filters, and concluded that the extra light hypothesis of Rucinski (1967) is in conflict with his observations, but he agreed with him in the semi–detached property of the system.

Using Wood's (1972) model, Mardirossian et al. (1980) analyzed Binnendijk's (1973) two–color photometric observations and the photoelectric light curve obtained by Kruszewski and published by Rucinski (1967). Their analysis showed a cooler under–massive component which is a typical property of post–main sequence mass–exchange of Algol–type binaries.

Since the spectroscopic mass ratio q was unknown, Rucinski (1967) used $q=0.3$, while Mardirossian et al. (1980) used $q=0.6$ during their light curves analysis. Both studies agreed in their conclusion about the semi-detached configuration of DI Peg, but disagreed in the values for the orbital elements. They also disagreed about the necessity for the third light source.

Mardirossian et al. (1980) deduced the radii and the luminosities $R_1=1.4\,\mathrm{R}_\odot$, $R_2=1.1\,\mathrm{R}_\odot$, $Log\,(L_1/\mathrm{L}_\odot)=0.50$, $Log\,(L_2/\mathrm{L}_\odot)=-0.17$ under the uncertainty of their assumption that $M_1=1.4\,\mathrm{M}_\odot$.

Chaubey (1982) has observed DI Peg photoelectrically in the three UBV filters. The observed light curves showed luminosity at phase $0^{\mathrm{d}}.25$ to be greater than the luminosity at phase $0^{\mathrm{d}}.75$ in all the UBV filters. He argued that this phenomenon was either due to gas stream absorption or to electron scattering present in the system as noted by Piotrowski et al. (1974) in similar systems such as e.g., U Cep, U CrB, SW Cyg and S Equ. Another phenomenon that was seen in the light curves is that the shoulders of the primary minimum are depressed, which may be explained by a disc of circumstellar material surrounding the hotter component. The reduction in the light is then due to the eclipse of the disk by the subgiant component before and after the primary component is eclipsed (Chaubey, 1982). His orbital solution also suggested the semi–

detached configuration. Using the minima times available, Chaubey constructed the $O-C$ diagram and observed an inversion to the increase trend after 1969. He explained this change in the period with Biermann and Hall's (1973) model which incorporates mass transfer in the system.

The period variation of DI Peg have been observed by several authors (e.g., Rusinski 1967, Binnendijk 1973, Chaubey 1982, Kennedy 1982, Lu 1992 and Vinkó 1992), but few studies of these changes were performed in the literatures (e.g., Chou & Kitamura 1968, Lu 1992, and Vinkó 1992).

2.3 The $O-C$ Diagram

Kennedy (1982) observed four minima and combined them with other published minima. He constructed the $O-C$ diagram from data covering about 50 years. The diagram indicated two significant changes in the orbital period. A sudden period increase of $2^{\rm d}.4\times10^{-6}$ around 1946 and an almost identical sudden period decrease of $2^{\rm d}.2\times10^{-6}$ around 1969 (Kennedy 1982).

Besides the spectroscopic detection of a third body by Lu (1992), he established the $O-C$ diagram showing its sinusoid shape structure, but he did not use it to estimate the third body orbital parameters. However, the only study for determining the orbital parameter values of the third body was carried out by Vinkó (1992) (see Table 2). He suggested a third body orbiting the binary in 22 years, and reported that his derived orbital parameters are uncertain due to the shortness of the observed time interval.

Currently, more precise pe and CCD minima times are available since the last study of Vinkó in 1992. Hence, we aim to revisit the period variability of this interesting late type sd–Algol in order to calculate its third body orbital parameters as well as to discuss the other possible mechanisms that may affect the change in the period of DI Peg.

The period variability of DI Peg has been studied by means of an $O-C$ diagram analysis. We have used the following data reduction procedure. All the available times of mid eclipse have been gathered and examined carefully. A mean value of the observed time of minima, in the same epoch, for different filter bands, e.g., U, B and V has been used. The precise photoelectric and CCD times of minimum are used in our computations with weight 10. The three CCD times of minimum at JD 24 52542.7862, 24 52572.6843 and 24 52573.0329 (E=37403.5, 37445.5 and 37446) obtained by Karska and Maciejewski (2003) in addition to the pe secondary minimum 2454070.3254 (E=39549.5) by Şenavci et al. (2007) are excluded due to their very large deviations from the general trend of the $O-C$ diagram. They are typed in Table 4 in italics. The earlier pg data before the JD 2437196.391 are not used due to their large scatter, while the others are used with weight 3. Some visual minima are used with weight 1 to fill gaps in the diagram and the others are not used to minimize the

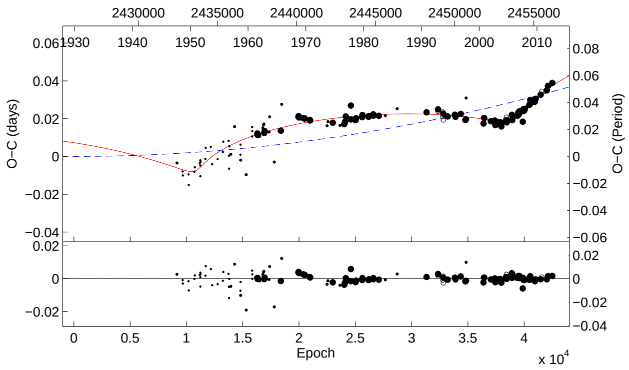

Fig. 1.— Raw $O-C$ diagram for DI Peg based on Kreiner's ephemeris (upper panel). The individual observations are shown as dots (primary) and open circles (secondary), the size is proportional to the statistical weight assigned to the individual minima (visual - 1; photographic - 3; photoelectric & CCD measurement - 10). The lower panel represents the residuals after the subtraction of the solution.

contamination of the data set. However, all the minima times used have been presented in Table 3. The unused data are listed in Table 4, for completeness. A total of 145 (70 pe, 28 CCD, 18 pg and 29 v) times of minima were used in our analysis. The $O-C$ values have been computed using the linear ephemeris of Kreiner (2004) (Table 1) and the resulting $O-C$ curve is displayed in the upper panel of Fig. 1.

2.3.1 Mass Transfer and Light Time Effect

On analyzing the $O-C$ diagram we used the standard approach (see, e.g., Mayer 1990 and Awadalla et al. 2004) assuming that the time of minima follow a quadratic ephemeris and are modulated by light time effect (LITE: see, e.g., Irwin 1959). The time of mid eclipse can be computed as follows:

$$\mathrm{Min.I} = JD_0 + P\cdot E + Q\cdot E^2 + \frac{a_{12}\,\sin \mathrm{i}}{c}\times [\frac{1-e_3^2}{1+e_3\,\cos\nu}\,\sin(\nu+\omega_3) + \mathrm{e}_3\,\sin\omega], \quad (3)$$

where e_3, ω_3, ν, $a_{12}\sin \mathrm{i}$ and c are the eccentricity, longitude of the periastron, true anomaly of the binary orbit around the center of mass of the triple system, projected semi-major axis, and the speed of light, respectively. We have used the computer programme written by Zasche et al. (2009). The quadratic ephemeris of the minima is represented by the first three terms of Eq. 3, and represented as the dashed line in Fig. 1, while the solid line fit represents the light time effect. The lower panel shows the residuals after the subtraction of the solution.

Table 2.

		Vinkó (1992)	Present Work
P_3 (period)	[yr.]	22.09	54.98 ± 0.76
A (semi-amplit.)	[day]	-	0.0101 ± 0.0068
e_3 (eccentricity)		0.66 ± 0.2	0.77 ± 0.07
ω_3 long. preias. pass.	[rad]	2.5 ± 0.4	5.25 ± 0.18
Time of periastron passage T_0	[HJD]	$24\,40612 \pm 400$	$24\,33702.022 \pm 344.419$
$a_{12} \sin i$ (projection of semi–major axis)	[AU]	0.77 ± 0.21	1.91 ± 0.13
$f(M_3)$	[$M_\odot$]	0.001 ± 0.001	0.0023 ± 0.000002
M_3 $_{i=90^\circ}$	[$M_\odot$]	-	0.22 ± 0.00006
$_{i=60^\circ}$		-	0.26 ± 0.00007
$_{i=30^\circ}$		-	0.48 ± 0.00015
a_3 angular distance of 3^{rd} component	[mas]	-	96.421
JD_0	[HJD]	-	$24\,25918.36771 \pm 0.00136$
P_{binary}	[day]	-	$0.711815447 \pm (0.5 \times 10^{-7})$
Q $(\times 10^{-11})$	[day]	-	1.901 ± 0.00071
Sum of the square residuals $\sum(O-C)^2$	[days^2]	-	0.0071

Many semi-detached Algol binary systems exhibit increase in orbital periods during their evolution, while others show decrease. Generally, it has been thought that conservative mass transfer in Algol binaries causes their orbits to be wider because mass transfers from the evolved less massive secondary star to its more massive main sequence companion (e.g., AK Ser in Qian 2000; W Del in Hanna 2006; CL Aur in Wolf et al. 2007; RR Dra and TZ Eri in Zasche, et al. 2008). In case of Algols that show orbital period decrease (e.g., RZ Dra in Kreiner et al. 1994; UX Her in Tremko et al. 2004; AT Peg in Hanna 2012), authors (e.g., Kreiner et al. 1994; Pribulla, 1998) have attributed such decrease to mass loss from the system (non–conservative) via the lagrangian point L_2.

As one can see from the quadratic term in Eq. 3 (see Table 2), there is a long–term evolution of the orbital period represented by the dashed line in Fig. 1. It may be identified as a period increase caused by slow mass transfer rate dP/dt (=0.17 sec/century) from the evolved less massive secondary component to its more massive companion star. The rate of mass transfer in the conservative case can be estimated by using the formula derived by Kreiner and Ziolkowski (1978):

$$\dot{M} = 243.5 \frac{Q}{P^2} \frac{M_1 M_2}{M_1 - M_2}, \qquad (4)$$

where the quadratic term coefficient Q, and the period P are in days. Adopting the masses obtained by Lu (1992), $M_1 = 1.18\,M_\odot$ and $M_2 = 0.69\,M_\odot$, the rate of mass transfer $\dot{M}$=1.52×10^{-8} $M_\odot$/yr is obtained. Our calculations yield a relatively slower rate than that derived by Chaubey (1993) ($3.94\times10^{-7} M_\odot$/yr) by about one order of magnitude.

The light time effect due to the presence of the third body is clearly visible in the upper panel of Fig. 2 after the removal of the parabola. The residuals are also presented in the lower panel of the Fig. 2. The final solution of the orbital parameters are listed in the Table 2. The results show significant differences from those obtained earlier by Vinkó (1992).

2.3.2 Magnetic Activity

The quasi–sine variation shown in Fig. 1 may result from cyclic magnetic activity, proposed by Applegate (1992). Magnetic activities seen in low–mass late–type stars may produce this kind of period variation because of their rapid rotation and outer convective layers (Richards & Albright 1993). Changes of the magnetic field distribution result in changes of angular momentum distribution. Gravitational quadrupole coupling produces changes in the internal structure of the active star which results in a period variation. To compute the amplitude of the period oscillation, one could use the following equation (Rovithis-Livaniou et al. 2000),

$$\Delta P = A\sqrt{2[1 - cos(2\pi P_e/P_3)]}, \qquad (5)$$

as $\Delta P = 2.25 \times 10^{-6}$ with $P_3 = 20081.4$ days. Thus, the rate of period variation is found to be $\Delta P/P = 3.161 \times 10^{-6}$. Following Lanza & Rodonò (2002),

$$\frac{\Delta P}{P} = -9\frac{\Delta Q}{Ma^2}, \qquad (6)$$

the variation in the quadrupole moment can be estimated to be $\Delta Q = 6.5 \times 10^{49}\,\mathrm{g \cdot cm^2}$ for the secondary evolved late type component; where M is the mass of the active star and the separation a between both components can be determined with the Kepler's third low,

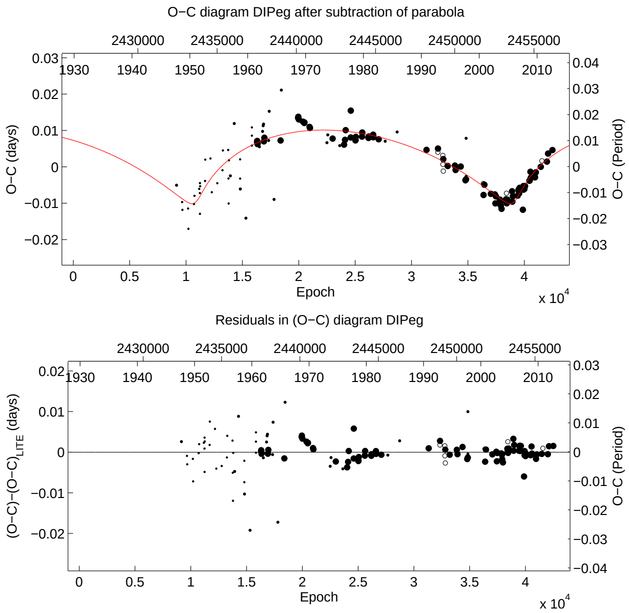

Fig. 2.— LITE solution made after the removal of a parabola (upper panel) and residuals (lower panel) for DI Peg.

$$a = [74.5 \cdot P^2(M_1 + M_2)]^{1/3}. \qquad (7)$$

Assuming conservation of the orbital angular momentum, Lanza & Rodonó (1999, 2004) have argued that magnetic variation could be detectable if the quadrupole moment ΔQ is of the order $10^{51} - 10^{52}$ g cm^2 for Algol–type binaries, which indicating that the obtained ΔQ value of the secondary component of DI Peg is not typical value for the close binaries. Therefore, the magnetic activity proposed by Applegate is not a possible mechanism to explain the cyclic variation of DI Peg. In addition, magnetic activity cycle of 55 years is considerably longer than expected in such low mass solar type stars in comparison to our sun.

3. CONCLUSIONS

The period variation of the Algol–type semi–detached eclipsing binary DI Peg was discussed using its $O-C$ diagram. Accurate pe and CCD minima collected during the last two decades were analyzed. The available collected times of minima covering about 84 years. We have applied the hypothesis of orbiting the system around the common center of mass with a third unseen companion, so–called light time effect, see Irwin (1959), together with a long term orbital period modualation increase shown, in Fig. 1, as a blue dashed parabolic curve. This approach was used in a programme by Zasche et al. (2009).

A quasi–sinusoidal variation, seen in Fig. 1, has a period of about 55 years, superimposed on a quadratic orbital period increase of rate $dP/dt = 3.8 \times 10^{-11}$ d/cycle (=1.9×10^{-8} d/yr), corresponding to a time scale of 3.65×10^7yr. This period increase can be interpreted to be due to mass transfer from the evolved secondary star to its primary more massive companion, which is a common mechanism in such Algol semi–detached eclipsing close binary systems.

The existence of the third component in the DI Peg system has been independently proven in three different ways: first, by Rucinski (1967) during his study to obtain the geometrical elements, he introduced an additional third light of about 24% in order to obtain the geometrical elements; second, by Lu (1992), who observed a direct spectral evidence by using high–dispersion spectrograph; he obtained a well determined radial velocity of +40± 0.3 Km/s for a third body; finally, through the present work, by studying the $(O-C)$ residual diagram. A well defined light time effect with a period of about 55 years and an amplitude of 0.02 days has been determined.

The Applegate (1992) mechanism was used in testing the probable presence of enough quadrupole momentum which may cause such cyclic variation in the $O-C$ diagram. The result shows that the mechanism of Applegate cannot explain the cyclical period variation of DI Peg.

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APPENDIX A. TIMES OF MINIMA

Table 3.
Photoelectric and CCD times of minima

J.D Hel.	type	wt	$O-C$	Ref.
32441.4370	v	1	-0.0098	[1]
32794.4970	v	1	-0.0105	[1]
32809.4430	v	1	-0.0127	[1]
33170.3340	v	1	-0.0126	[1]
33187.4120	v	1	-0.0182	[1]
33538.3440	v	1	-0.0117	[1]
33570.3780	v	1	-0.0094	[1]
33871.4780	v	1	-0.0077	[1]
33913.4740	v	1	-0.0089	[2]
33916.3240	v	1	-0.0062	[2]
33918.4510	v	1	-0.0146	[2]
33928.4240	v	1	-0.0071	[1]
34239.4890	v	1	-0.0058	[1]
34254.4430	v	1	0.0000	[1]
34580.4550	v	1	0.0001	[1]
34664.4400	v	1	-0.0092	[1]
35010.3850	v	1	-0.0070	[1]
35341.3830	v	1	-0.0036	[1]
35366.3020	v	1	0.0018	[1]
35699.4320	v	1	0.0017	[1]
35719.3550	v	1	-0.0061	[1]
35731.4490	v	1	-0.0130	[1]
35746.4090	v	1	-0.0012	[1]
35838.2290	pg	3	-0.0055	[3]
36079.5490	pg	3	0.0087	[3]
36450.3900	v	1	-0.0066	[1]
36455.3780	v	1	-0.0013	[1]
36462.4880	pg	3	-0.0095	[3]
36818.3880	pg	3	-0.0177	[3]
37193.5350	vis	1	0.0021	[1]
37193.5400	v	1	0.0071	[1]
37196.3850	v	1	0.0008	[1]
37522.3946	pe	10	0.0025	[4]
37523.4620	pe	10	0.0022	[4]
37527.3776	pe	10	0.0028	[4]
37544.4610	pe	10	0.0026	[4]
37559.4093	pe	10	0.0027	[4]
37668.3160	pg	3	0.0015	[3]
37870.4760	pg	3	0.0057	[3]
37907.4922	pg	3	0.0074	[3]
37932.4060	pg	3	0.0076	[3]
37956.6032	pe	10	0.0031	[1]
37983.6528	pe	10	0.0037	[1]
38255.5660	pg	3	0.0030	[3]
38290.4530	pg	3	0.0110	[3]
38591.5270	pg	3	-0.0134	[3]
39006.5324	pe	10	0.0031	[4]
39056.3730	pg	3	0.0165	[3]
40114.8356	pe	10	0.0081	[5]
40127.6488	pe	10	0.0086	[5]
40159.6796	pe	10	0.0077	[5]
40424.4746	pe	10	0.0070	[6]
40500.6394	pe	10	0.0074	[5]
40512.7402	pe	10	0.0073	[5]
40837.3269	pe	10	0.0058	[7]
40859.3930	pe	10	0.0056	[7]
41928.5370	pg	3	0.0013	[8]
41983.3490	pg	3	0.0034	[9]
42289.4285	pe B V	10	0.0019	[10]
42739.2950	pg	3	0.0004	[11]
43015.4802	pe	10	0.0008	[12]
43071.0029	pe	10	0.0019	[13]
43112.2910	pe	10	0.0046	[14]
43434.0295	pe	10	0.0021	[13]
43725.5179	pe V	10	0.0017	[15]
43729.4334	pe B V	10	0.0022	[15]
43756.48315	pe B V	10	0.0029	[15]
43780.3277	pe V	10	0.0016	[15]
44143.35645	pe B V	10	0.0040	[16]
44144.42295	pe B V	10	0.0028	[16]
44164.3545	pe	10	0.0035	[17]
44219.1650	pe	10	0.0041	[17]
44502.4654	pe	10	0.0016	[18]
44543.0401	pe	10	0.0027	[13]
44557.9879	pe	10	0.0024	[13]
44567.2420	pe	10	0.0029	[19]
44843.4272	pe	10	0.0033	[20]
44848.4102	pe	10	0.0036	[20]
44853.3920	pe	10	0.0027	[21]
45196.4870	pe	10	0.0022	[22]
45609.3400	pg	3	0.0017	[23]
46360.3090	v	1	0.0057	[24]
48219.5690	pe	10	-0.0001	[25]
48935.3002	pe	10	-0.0003	[26]
48939.2161	pe	10	0.0006	[26]
49246.3631	pe	10	-0.0012	[26]
49248.4963	pe	10	-0.0034	[26]
49276.2546	pe	10	-0.0060	[26]
49277.3259	pe	10	-0.0024	[26]
49553.5085	pe	10	-0.0046	[26]
50008.3599	pe	10	-0.0039	[27]
50008.3603	ccd	10	-0.0035	[28]
50050.3564	pe	10	-0.0045	[26]
50376.3686	pe	10	-0.0042	[29]
50672.4811	pe	10	-0.0074	[30]
50712.3428	pe	10	-0.0074	[31]
50717.3370	pg	3	0.0041	[32]
50719.4620	pg	3	-0.0066	[33]
51807.4721	pe	10	-0.0076	[34]
51818.5020	pe	10	-0.0109	[34]
51868.3321	pe	10	-0.0079	[34]
52278.3363	pe	10	-0.0100	[34]
52530.3191	pe	10	-0.0102	[35]
52567.3312	pe	10	-0.0126	[35]
52594.3820	pe	10	-0.0108	[36]
52843.5166	pe	10	-0.0119	[37]
52888.3606	pe	10	-0.0124	[38]
52903.3083	pe	10	-0.0128	[39]
52908.2924	pe	10	-0.0114	[39]
52950.2871	pe	10	-0.0139	[39]
53236.4400	pe	10	-0.0112	[40]

Table 3. — continued

J.D Hel.	type	wt	$O-C$	Ref.
53262.4225	pe	10	-0.0100	[41]
53265.6239	ccd	10	-0.0118	[42]
53267.7591	ccd	10	-0.0120	[42]
53272.7415	ccd	10	-0.0123	[42]
53282.7067	ccd	10	-0.0125	[42]
53325.4174	pe	10	-0.0108	[41]
53614.4169	ccd	10	-0.0088	[43]
53634.3450	ccd	10	-0.0116	[44]
53671.36089	ccd C	10	-0.0101	[45]
53967.4772	ccd	10	-0.0094	[46]
53991.3226	ccd	10	-0.0099	[47]
54024.4239	ccd	10	-0.0080	[48]
54027.27059	ccd R	10	-0.0086	[45]
54059.3020	pe B V	10	-0.0090	[49]
54096.31773	ccd R	10	-0.0077	[45]
54335.4878	pe	10	-0.0079	[50]
54335.48869	ccd R V I	10	-0.0070	[45]
54394.5693	ccd	10	-0.0072	[51]
54416.6361	ccd	10	-0.0067	[51]
54436.5670	ccd	10	-0.0067	[52]
54710.6180	ccd	10	-0.0050	[53]
54738.3787	ccd V	10	-0.0051	[54]
54799.5955	ccd	10	-0.0045	[55]
54774.6840	ccd	10	-0.0024	[56]
55044.4623	ccd V R	10	-0.0029	[57]
55064.3920	pe V	10	-0.0037	[58]
55064.3929	pe V	10	-0.0028	[58]
55085.7474	ccd	10	-0.0028	[59]
55116.3557	ccd C	10	-0.0026	[57]
55429.5569	ccd V	10	-0.0006	[60]
55498.2485	ccd R	10	0.0007	[61]
55561.2439	ccd V R	10	0.0004	[62]
55820.3461	pe	10	0.0013	[63]
55887.2592	pe	10	0.0037	[63]
56163.4447	ccd	10	0.0044	[64]

Ref. [1] cf, Chou, K. & Kitamura, M. (1968), JKAS 1, 1; [2] Kruszewski, A. (1956), AcA 6, 140; [3] Huth, H. (1966), Sonneberg 3,170; [4] Rucinski, S.M. (1967), AcA 17, 271; [5] Binnendijk, L. (1973), AJ. 78, 97; [6] IBVS 456; [7] IBVS 530; [8] AN 298, 121; [9] IBVS 978; [10] IBVS 1053; [11] AN 300, 165; [12] IBVS 1358; [13] IBVS 2118; [14] BBSAG Bull. 31; [15] IBVS 1495; [16] IBVS 1908; [17] Chaubey, U.S. (1982), Ap&SS 81, 283; [18] BBSAG Bull. 54; [19] BBSAG Bull. 51; [20] IBVS 2159; [21] BRNO 26; [22] IBVS 2385; [23] MVS 10, 104; [24] BAV-M 46; [25] AAVSO 2; [26] IBVS 4380; [27] IBVS 4382; [28] BBSAG Bull. 110; [29] IBVS 4562; [30] IBVS 4534; [31] IBVS 4562; [32] BAV-M 113; [33] IBVS 4606; [34] IBVS 5296; [35] IBVS 5484; [36] IBVS 5407; [37] IBVS 5791; [38] IBVS 5592; [39] IBVS 5643; [40] IBVS 5649; [41] IBVS 5657; [42] IBVS 5843; [43] IBVS 5662; [44] IBVS 5731; [45] Oejv 74; [46] IBVS 5777; [47] IBVS 5746; [48] IBVS 5761; [49] IBVS 5754; [50] IBVS 5801; [51] JAVSO 36, 171; [52] IBVS 5814; [53] JAVSO 36, 186; [54] IBVS 5898; [55] JAVSO 37, 44; [56] IBVS 5871; [57] IBVS 5924; [58] IBVS 5941; [59] JAVSO 38, 183; [60] IBVS 5988; [61] IBVS 5980; [62] BRNO 37; [63] IBVS 6026; [64] IBVS 6044;

Table 4.
Unused Data (see the text)

J.D Hel.	Ref.	J.D Hel.	Ref.	J.D Hel.	Ref.	J.D Hel.	Ref.	J.D Hel.	Ref.	J.D Hel.	Ref.
25644.315	[1]	42304.376	[16]	44134.458	[35]	44883.283	[46]	46290.538	[52]	48205.336	[59]
27738.474	[1]	42403.317	[17]	44164.3554	[36]	44890.41	[46]	46290.545	[52]	48266.552	[22]
28452.421	[1]	42403.322	[17]	44166.492	[36]	44893.255	[46]	46305.501	[52]	48480.814	[22]
31273.346	[1]	42403.324	[17]	44189.267	[37]	44900.387	[46]	46320.45	[52]	48481.524	[58]
38399.362	[2]	42739.3	[18]	44435.565	[38]	44910.33	[46]	46344.65	[22]	48506.423	[58]
39024.412	[3]	42754.247	[19]	44440.54	[38]	44925.284	[46]	46350.345	[53]	48545.587	[22]
39026.463	[2]	42776.296	[19]	44445.525	[38]	45170.858	[22]	46355.324	[54]	48859.497	[58]
39046.394	[2]	42786.271	[20]	44455.483	[39]	45201.469	[45]	46360.304	[55]	48859.5	[58]
39056.361	[2]	42786.275	[20]	44455.489	[39]	45201.47	[45]	46382.371	[55]	48859.507	[58]
39056.364	[2]	42796.24	[20]	44455.49	[39]	45201.472	[47]	46413.698	[22]	48859.512	[58]
39062.346	[2]	42990.57	[21]	44455.491	[39]	45228.52	[45]	46422.238	[53]	48863.766	[22]
39352.479	[4]	42993.412	[21]	44455.497	[39]	45228.523	[45]	46656.423	[56]	48873.733	[22]
39387.36	[4]	43013.351	[21]	44474.703	[22]	45231.369	[48]	46656.424	[56]	49215.413	[58]
39389.496	[4]	43034.701	[22]	44490.364	[40]	45235.645	[22]	46678.485	[57]	49224.65	[22]
39407.289	[4]	43040.398	[23]	44490.366	[40]	45258.408	[45]	46678.487	[57]	49241.735	[22]
40128.36	[5]	43069.57	[22]	44497.486	[41]	45258.418	[45]	46678.489	[57]	49333.56	[22]
40175.343	[4]	43069.583	[22]	44502.469	[40]	45258.422	[45]	46678.49	[53]	49543.544	[63]
40471.454	[6]	43134.36	[24]	44512.434	[40]	45554.521	[45]	46738.276	[57]	49543.55	[66]
40476.437	[6]	43154.288	[25]	44517.416	[41]	45554.522	[45]	46743.273	[58]	49602.63	[22]
41155.502	[7]	43311.594	[26]	44517.419	[42]	45554.527	[45]	46759.639	[22]	50396.3	[65]
41155.506	[7]	43371.387	[27]	44524.534	[41]	45579.447	[45]	46769.607	[22]	50423.356	[65]
41513.556	[8]	43391.319	[28]	44532.364	[43]	45609.344	[45]	46774.591	[22]	50672.4793	[66]
41550.562	[9]	43393.457	[28]	44567.245	[41]	45621.445	[45]	46779.564	[22]	50754.348	[67]
41563.381	[9]	43433.323	[29]	44593.584	[22]	45624.292	[49]	46999.52	[59]	*52542.7862*	[68]
41565.512	[9]	43435.461	[29]	44636.287	[42]	45671.275	[45]	47014.466	[60]	52848.5081	[69]
41580.46	[9]	43495.244	[30]	44823.49	[44]	45915.423	[50]	47054.333	[59]	*52572.6843*	[68]
41595.407	[10]	43517.318	[30]	44823.493	[44]	45976.643	[22]	47066.429	[59]	*52573.0329*	[68]
41605.373	[10]	43689.571	[31]	44823.494	[45]	45976.65	[22]	47091.346	[59]	52848.5024	[69]
41605.378	[10]	43776.414	[29]	44823.495	[45]	45981.629	[22]	47107.718	[22]	53236.44	[69]
41657.337	[11]	43791.354	[32]	44823.496	[45]	45992.303	[51]	47387.461	[61]	53236.4476	[69]
41928.537	[3]	43791.37	[32]	44823.497	[45]	46002.261	[51]	47464.344	[22]	53251.381	[70]
41931.375	[12]	43802.76	[22]	44823.498	[45]	46019.349	[52]	47469.315	[22]	53619.3969	[69]
41941.353	[12]	43803.465	[32]	44823.5	[45]	46028.609	[22]	47474.318	[62]	*54070.3254*	[71]
41988.321	[13]	43806.309	[32]	44823.503	[45]	46028.611	[22]	47794.62	[22]	54298.468	[62]
42008.263	[13]	43863.256	[33]	44853.392	[45]	46029.316	[51]	47851.561	[22]		
42274.486	[14]	43878.202	[33]	44853.392	[46]	46033.585	[22]	47853.693	[22]		
42289.427	[15]	44092.46	[34]	44853.395	[45]	46038.567	[22]	48123.473	[58]		
42301.54	[14]	44117.369	[34]	44853.396	[45]	46038.568	[22]	48123.479	[58]		
42304.396	[14]	44117.377	[34]	44853.398	[45]	46043.553	[22]	48148.395	[59]		

[1] cf, Chou, K. & Kitamura, M. (1968), JKAS 1, 1; [2] Braune, W.& Hubscher, J. (1967), AN 290, 105; [3] Braune, W. et al., (1977), AN 298, 121; [4] Braune, J. et al. (1970), AN 292, 185; [5] IBVS 328; [6] Prerov, F.H. (1970), CoBrno 9; [7] IBVS 584; [8] BBSAG Bull. 4; [9] BBSAG Bull. 5; [10] BBSAG Bull. 6; [11] BBSAG Bull. 7; [12] BBSAG Bull. 11; [13] BBSAG Bull. 12; [14] Jiri, H. (1976), CoBrno 20; [15] BBSAG Bull. 17; [16] IBVS 1053; [17] BBSAG Bull. 19; [18] BBSAG Bull. 24; [19] BBSAG Bull. 25; [20] BBSAG Bull. 26; [21] BBSAG Bull. 29; [22] AAVSO 2.; [23] BBSAG Bull. 30; [24] BBSAG Bull. 31; [25] BBSAG Bull. 32; [26] BBSAG Bull. 33; [27] BBSAG Bull. 34; [28] BBSAG Bull. 35; [29] Braune, W. et al. (1981), AN 302, 53; [30] BBSAG Bull. 36; [31] BBSAG Bull. 37; [32] BBSAG Bull. 39; [33] BBSAG Bull. 41; [34] BBSAG Bull. 44; [35] BBSAG Bull. 45; [36] BAA 59, 16; [37] BBSAG Bull. 45; [38] BBSAG Bull. 49; [39] MAV 9, 18; [40] BBSAG Bull. 50; [41] BBSAG Bull. 51; [42] BBSAG Bull. 52; [43] BAV-M 32; [44] MVS 9, 89; [45] BRNO 26; [46] BBSAG Bull. 57; [47] BBSAG Bull. 62; [48] BBSAG Bull. 63; [49] BBSAG Bull. 69; [50] BBSAG Bull. 73; [51] BBSAG Bull. 74; [52] BRNO 27; [53] BBSAG Bull. 81; [54] BAv-M 43; [55] MvS 11, 19; [56] BAV-M 46; [57] CoBrno 28; [58] BRNO 31; [59] BBSAG Bull. 86; [60] BAV-M 50; [61] BAV-M 52; [62] BBSAG Bull. 90; [63] BBSAG Bull. 108; [64] BBSAG Bull. 107; [65] BAV-M 101; [66] IBVS 4606; [67] BAV-M 113; [68] Karska, A.& Maciejewski, G. (2003), IBVS 5380; [69] Lubos Bràt, et al. (2007), Oejv 74; [70] Hubscher, J. et al. (2008), PAV-M 202; [71] Şenavci, H. V. et al. (2007), IBVS 5754.