Journal of the Korean Astronomical Society
48: 1 ∼ 7, 2015 February

http://dx.doi.org/10.5303/JKAS.2015.48.1.1
pISSN: 1225-4614 · eISSN: 2288-890X
http://jkas.kas.org

Mass Transfer and Light Time Effect Studies for AU Serpentis

S. M. Amin
National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Cairo, Egypt; dr_sayedama@yahoo.com

Received June 2, 2014; accepted October 7, 2014

Abstract: The orbital period changes of the W UMa eclipsing binary AU Ser are studied using the $(O-C)$ method. We conclude that the period variation is due to mass transfer from the primary star to the secondary one at a very low and decreasing rate $dP/dt = -8.872 \times 10^{-8}$, superimposed on the sinusoidal variation due to a third body orbiting the binary with period 42.87 ± 3.16 years, orbital eccentricity $e = 0.52 \pm 0.12$ and a longitude of periastron passage $\omega = 133^{\circ}.7 \pm 15$. On studying the magnetic activity, we have concluded that the Applegate mechanism failed to describe the cycling variation of the $(O-C)$ diagram of AU Ser.

Key words: binaries: eclipsing — binaries: close — stars: triple — stars: individual: AU Ser.

1. Introduction

AU Ser ($\alpha_{2000} = 15^h56^m49^s, \delta_{2000} = +22^{\circ}15^{'}42^{''}.3$) was discovered by Hoffmeister (1935) and classified as a W-type binary system according to Binnendijk (1972). It is a short period ($P = 0^{\rm d}.386$) W UMa system with magnitude $V_{max.} = 10^{\rm m}.9$ and spectral type G5V (Kukarkin, 1970).

Visual observations were made by Soloviev (1936, 1951), while photographic observations by Huth (1964). The radial velocity curve was obtained using the cross correlation technique by Hrivnak (1993). He found a mass ratio $q = m_2/m_1 = 0.71$. He also obtained a projected total mass of AU Ser of $(m_1 + m_2)\ sin^3\ i = 1.51\ M_{\odot}$, a value similar to that obtained by Pribulla et al. (2009) from their spectroscopic observations.

The first photoelectric observations were made by Binnendijk (1972) and subsequently Rucinski (1974), Kennedy (1985), Li, et al. (1992, 1998), Djurasevic (1993) and Gürol (2005). They obtained photoelectric light curves in different wavelengths. In addition, Gürol (2005) studied the period variation of the system suggesting its triplicity with a third body that orbiting the binary in about 94 years. However, many photoelectric and CCD minima times were observed and published during the last decade (39 minima) which motivated us to re-construct and analyze the $O-C$ diagram in order to obtain more precise orbital parameters for the third body. The goal of the present study is to discuss the causes of variation in the orbital period; mainly to re-determine the third body orbital parameters of AU Ser.

2. Period Variation

To investigate the period changes of the W UMa system AU Ser, we have collected all the available times of minima since HJD 2428318.5 (≡ 30 May 1936) until 2456034.5 (≡ 17 April 2012) which cover about 75.9 years. The times of minima are listed in Table 2 (Appendix). The successive columns of the table are: HJD, the number of integer cycles, type of the minimum, the O-C residuals and the references.

The $O-C$ residuals of Table 2 have been calculated using the ephemeris given by Kreiner et al. (2001):

$$\text{HJD(Min.I)} = 24\ 44722^{\rm d}.4660 + 0^{\rm d}.38650011\, E, \quad (1)$$

where E is the number of integer cycles.

To predict timing of new minima, the last 147 minima times, which cover the interval from June 1976 till April 2012, have been linearly fitted (Figure 1) and used to obtain the new light elements:

$$\text{HJD(Min.I)} = 24\ 44722^{\rm d}.5087 + 0^{\rm d}.38649967\, E, \quad (2)$$

with residual mean squares = 0.0002.

We have constructed the $(O-C)$ diagram of AU Ser (Figure 2). It shows complicated period variations, which may be due to a combination of more than one of the following effects: mass transfer, light time effect, magnetic activity. Thus, we examine each reason affecting orbital period behavior.

2.1. Mass Transfer

A quadratic least square fit concerning the first three terms of equation (5) has been performed. We obtained the coefficient of the quadratic term $Q = -4.69 \times 10^{-11}$ and consequently we calculated the rate of change of the orbital period $dP/dt = -8.872 \times 10^{-8}$ day/year. The quadratic fit is represented as the dashed line on Figure 2.

In the simplest case of conservative mass transfer, if the more massive component loses mass, the orbital size will decrease and the period of the system must decrease too (Pringle, 1985). So, the obtained orbital period decrease may be interpreted in terms of mass transfer from the more massive star to the less one (Kwee and van Woerden, 1958). The rate of mass transfer in the

Corresponding author: S. M. Amin

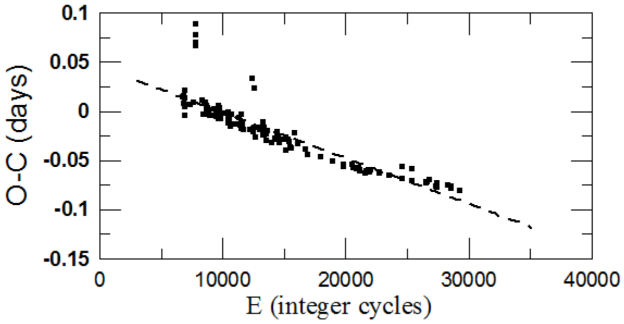

Figure 1. The (O-C) diagram. The dashed line represents the linear fit to the last 143 minimum data.

conservative case could be estimated by using the formula derived by Kreiner and Ziolkowski (1978):

$$\dot{M} \;=\; 243.5\,\frac{Q}{P^2}\;\frac{M_1\,M_2}{M_1-M_2}, \tag{3}$$

where the quadratic term coefficient Q, and the period P are in days. Adopting the values of the absolute parameters of AU Ser from Gürol (2005): $M_1 = 0.895$ M$_\odot$ and $M_2 = 0.635$ M$_\odot$, the rate of mass transfer:

$$\begin{aligned}\dot{M} &= -1.77\times 10^{-10}\ \mathrm{M_\odot/cycle}\\ &= -1.67\times 10^{-7}\ \mathrm{M_\odot/yr}.\end{aligned} \tag{4}$$

which is of the same order as the values given in the literature for contact binaries (see Liu & Yang 2003).

2.2. Light Time Effect

Observational detection of a periodic orbital period variation of a binary star system can be considered as a strong evidence of the existence of a third body around the binary system. This body causes the Light Time Effect (LITE) as displacement of the times of eclipse minimum light in a sinusoidal form with a period equal to the period of the third body, (Woltjer 1922; Irwin 1959).

At first, it may be noticed that both the primary and the secondary minima have the same trend on the $(O-C)$ diagram (Figure 2). The time of mid eclipse can be computed as follows:

$$\begin{aligned}\mathrm{Min.I} &= JD_0 + P\cdot E + Q\cdot E^2 + \frac{a_{12}\,\sin\,i}{c}\\ &\times\left[\frac{1-e_3^2}{1+e_3\,\cos\nu}\,\sin\left(\nu+\omega_3\right)+e_3\,\sin\omega\right],\end{aligned} \tag{5}$$

where e_3, ω_3, ν, a_{12} sin 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.

Gürol was the first who considered the sine-like variation of the $O-C$ curve of AU Ser. He calculated the light time effect (LITE) and obtained the orbital parameters of a third body of at least 0.53 solar mass orbiting the binary with an orbital period of 94.15 years. The recent photoelectric and CCD minima times (39

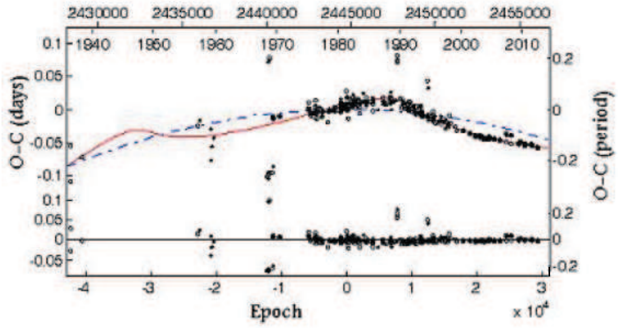

Figure 2. The $(O-C)$ variation with quadratic and sinusoidal fit and their residuals of AU Ser. Filled circles represent primary minima while open circles are for secondary minima.

minima) together with the earlier minima could enable us to re-calculate the LITE and obtain a more real and precise solution.

Using the program prepared by Zasche, et al. (2009), based on Irwin's method (1959), we have calculated the orbital parameters of the third body, and its LITE on the binary system. The program contains three modes 0, 1 and 2. These three modes correspond to computing the LITE due to the third body, the LITE together with the quadratic term and only the quadratic term, respectively.

Three different weights 1, 5 and 10 were applied to the data points for: visual (v), photographic (pg) and photoelectric (pe) or CCD minima times, respectively. Applying code 1, we obtain the orbital parameters of the third body as in Table 1, and as represented by the solid sinusoidal (red) line in Figure 2.

On applying the well known mass function relation (cf., Albayrak et al., 1999):

$$f(M_3) = \frac{{M_3}^3\ \sin^3 i}{(M_{12}+M_3)^2} = \frac{(173.262\times A)^3}{P_3^2} \tag{6}$$

where M_{12} and M_3 are the masses (in solar units) of the eclipsing pair and the third body, A is the amplitude in days, and P_3 is the period of the third body in years. The inclination i of the third body orbit was assumed to be equal to the inclination of the eclipsing binary orbit. The minimal mass $M_{3\ min}$ is then corresponding to $i_3 = 90°$.

From our new analysis and including all the recent minima times, we obtain a third body orbital period of about 43 years instead of the very large period ($\simeq$ 94 yr.) given by Gürol (2005). Also, we obtain a significantly different value for the semi-amplitude. The comparison between the newly obtained set of parameters and those obtained earlier is given in Table 1.

2.3. Magnetic Activity and Star Spots

Kalužny (1986) analyzed the light curves that were made by Binnendijk (1972) using the W-D code. He reported that the depth of the primary and the secondary minimum differs by about 0.2 mag and such difference is unusually large for a W UMa-type system. He also

Table 1
The light–time effect solution and the corresponding quadratic ephemeris of the binary system is also presented

		Gürol (2005)	Present Work
P_3 (period)	[yr.]	94.1492	42.87 ± 3.16
A (semi-amplit.)	[day]	0.03546	0.0197 ± 0.0016
e_3 (eccentricity)		0.48	0.52 ± 0.12
ω_3 long. preias. pass.	[°]	147.7	133.70 ± 14.88
Time of periastron passage T_0	[HJD]	2444531.317	2448219.354 ± 507.641
$a_{12} \sin i$ (projection of semi–major axis)	[AU]	-	3.66 ± 0.30
$f(M_3)$	[$M_\odot$]	-	0.02662 ± 0.00013
M_3 $_{i=90°}$	[$M_\odot$]	0.53	0.475 ± 0.001
$_{i=60°}$		-	0.564 ± 0.0012
$_{i=30°}$		-	1.153 ± 0.0028
a_3 angular distance of 3^{rd} component	[mas]	-	84.329
JD_0	[HJD]	24 44722.4515	$24\,44722.46828 \pm 0.00142$
P_{binary}	[day]	0.38649922	$0.386499241707 \pm (1.1 \times 10^{-7})$
Q $(\times 10^{-11})$	[day]	-	-4.69
Sum of the square residuals $\sum(O-C)^2$	[days^2]	-	0.049

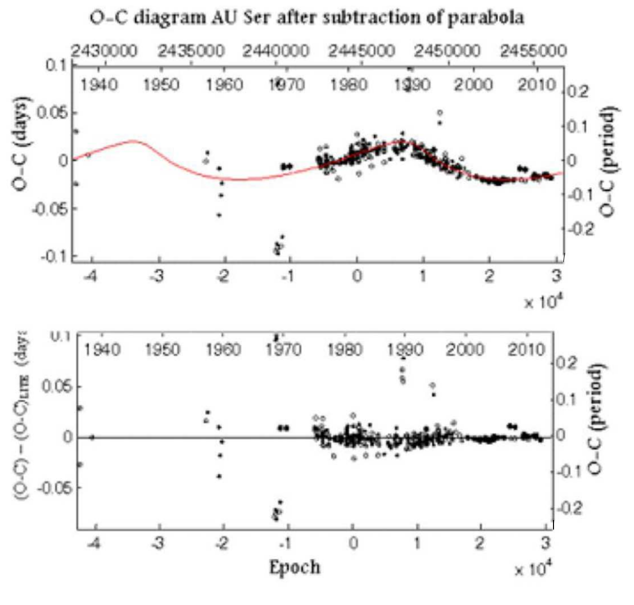

Figure 3. LITE solution made after the removal of a parabola (upper panel) and residuals (lower panel) for AU Ser.

noticed the degree of asymmetry in maxima of the light curve and suggested that such pronounced asymmetry of the light curves may be due to a hot spot located at the neck between the stars.

Gürol (2005) has studied the published light curves (LCs) and reported that all the LCs can be modelled by hot or cool spots located on the secondary components. He also studied the O'Connell effect and attributed such complex nature of the light curve to variable starspot activity with 32 to 35 years as a probable period for the system. For a detailed discussion for the light curve analysis concerning the starspot activity one may review Gürol (2005).

Changes in 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. The Applegate (1992) model involves variations of the subsurface magnetic field. Such subsurface magnetic field may be compared to solar activity cycles. The model can give a plausible explanation of the cyclic period variations of late type active stars.

For AU Ser, the star-spots are expected to be presented on the cooler member i.e., the secondary less massive star (Sp. Type G5V) was considered as the active component when applying the Applegate (1992) mechanism. For more details about the mechanism see Applegate and Patterson (1987), Applegate (1992) and references therein. We applied the Applegate mechanism using of all data.

The present $(O-C)$ residual diagram for AU Ser contains a cycle of about 43 years. Assuming this long period P_3 to be the modulation period, P_{mod}, of the stellar magnetic activity of the convective secondary star, with semi amplitudes $O - C = 0.0197$ day, and accepting the parameters given by Gürol (2005) [$M_2 = 0.635\,M_\odot$, $R_2 = 0.94\,R_\odot$, $L_2 = 3.8\,L_\odot$ and the orbital semi-major axis $a = 1.19\,R_\odot$] one can follow the Applegate procedure (see Applegate 1992).

The observed amplitude of the period modulation of the cycle, $\Delta P/P = 2\pi(O-C)/P_{mod} = 7.92 \times 10^{-6}$ gives the variation of the orbital period $\Delta P = 0.264$ second. The angular momentum transfer is $\Delta J = 3.69 \times 10^{+46}$ g cm^2 s^{-1}. If the mass of the shell is $M_{shell} = 0.1\,M_2$, the moment of inertia of the shell is $I_{shell} = 3.604 \times 10^{+53}$g cm^2, and the variable part of the differential rotation of the active star is $\Delta\Omega/\Omega = 0.00036$. The energy budget needed to transfer the ΔJ is $\Delta E = 7.564 \times 10^{+39}$ ergs. The luminosity change is $\Delta L_{RMS} = 1.757 \times 10^{+31}$. This luminosity variation is $\Delta L_{RMS}/L = 0.0011 \simeq 0.0$ of the luminosity of the active star. This value is inconsistent with the values suggested by Applegate (1992) model which should be around 10% to prove the presence of magnetic activity on similar chromospherically active stars.

3. Discussion and Conclusions

In case of AU Ser especially for the observed light curves in 1992 and 1995, Kalimeris et al. (2002) studied the effects of star spots on the $(O-C)$ diagrams of eclipsing binaries and showed that migrating star spots can only introduce high frequency, low amplitude disturbances. Because of this Gürol (2005) deduced that the main causes of the $(O-C)$ variations of AU Ser may be only mass transfer between the two stars and/or light time effect due to the presence of a third body. This shows that our result is in agreement to that obtained by Gürol.

The present analysis of the $O-C$ diagram of AU Ser, suggests a decrease in the orbital period due to mass transfer from the more massive primary component to the less massive secondary one by a rate of about $dP/dt = -8.87 \times 10^{-8}$ day/year with a mass transfer rate of $dM/dt = -1.67 \times 10^{-7}\ M_{\odot}$/year. This period decrease is superimposed on a sinusoidal variation, as seen in Figure 2, due to the presence of a third body orbiting the binary AU Ser in about 42.9 years with an orbital eccentricity $e_3 = 0.52$ and a longitude of periastron passage $\omega_3 = 133.7°$.

Pribulla et al. (2009) observed the system spectroscopically to study its radial velocity. They did not see evidence for a third component when using the broadening functions technique described by Rusinski (2002). However, this result does not dismiss the third body hypothesis proposed in the present work and by Gürol (2005). Hence, more precise photoelectric and CCD observations are still needed to verify the obtained results.

Acknowledgments

I acknowledge the variable star observations from the BBSAG International Database, IBVS, and the NASA Astrophysics Data System Bibliographic Services. Thanks go also to Dr. Petr Zasche for his program for the determination of the LITE due to the presence of the third body.

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Appendix A. Times of Minima

Visual, photographic, photoelectric, and CCD times of minima follow on the next pages (Table 2).

Table 2
Visual, photographic, photoelectric, and CCD times of minima.

J.D Hel.	E	type	$O-C$	Ref.
28318.801	-42441.5	pg	-0.02058	[1]
28334.267	-42401.5	v	-0.01459	[2]
29039.224	-40577.5	v	-0.03379	[3]
35899.632	-22827.5	pg	-0.00274	[4]
35984.477	-22608	pg	0.00549	[4]
36671.612	-20830	pg	-0.05671	[4]
36673.593	-20825	pg	-0.00821	[4]
36757.436	-20608	pg	-0.03573	[4]
36848.276	-20373	pg	-0.02326	[4]
40008.429	-12196.5	v	-0.08841	[5]
40059.427	-12065	v	0.08483	[5]
40059.45	-12064.5	v	-0.08542	[5]
40060.42	-12062	v	-0.08167	[5]
40101.38	-11956	v	-0.09068	[6]
40113.35	-11925.5	v	0.09106	[6]
40119.337	-11910	v	0.08731	[6]
40299.469	-11443.5	v	-0.08299	[7]
40353.395	-11304	v	-0.07376	[8]
40385.7421	-11220.5	pe	0.00058	[4]
40386.7074	-11218	pe	-0.00037	[4]
40386.9019	-11217.5	pe	0.00088	[4]
40387.8665	-11215	pe	-0.00077	[4]
40748.8592	-10281	pe	0.00083	[4]
40749.8264	-10278.5	pe	0.00178	[4]
42455.652	-5865	v	0.00915	[9]
42461.64	-5849.5	v	0.00639	[9]
42466.666	-5836.5	v	0.00789	[9]
42491.596	-5772	v	0.00863	[9]
42509.578	-5725.5	v	0.01838	[10]
42525.602	-5684	v	0.00263	[10]
42528.506	-5676.5	v	0.00787	[10]
42538.354	-5651	v	0.00012	[10]
42550.533	-5619.5	v	0.00437	[10]
42561.55	-5591	v	0.00612	[10]
42570.435	-5568	v	0.00161	[11]
42571.398	-5565.5	v	-0.00164	[11]
42623.386	-5431	v	0.00210	[11]
42629.375	-5415.5	v	0.00035	[11]
42787.648	-5006	v	0.00155	[12]
42866.496	-4802	v	0.00353	[13]
42867.468	-4799.5	v	0.00928	[13]
42869.59	-4794	v	0.00553	[14]
42878.477	-4771	v	0.00302	[13]
42886.409	-4750.5	v	0.01177	[13]
42887.365	-4748	v	0.00152	[13]
42888.332	-4745.5	v	0.00227	[13]
42900.331	-4714.5	v	0.01977	[15]
42904.368	-4704	v	-0.00148	[15]
42905.344	-4701.5	v	0.00827	[15]
42905.529	-4701	v	0.00002	[15]
42913.454	-4680.5	v	0.00176	[15]
42916.359	-4673	v	0.00801	[15]
42926.398	-4647	v	-0.00199	[15]
42926.404	-4647	v	0.00401	[15]
42938.387	-4616	v	0.00551	[15]
42948.43	-4590	v	-0.00050	[15]
42949.403	-4587.5	v	0.00625	[15]
42953.457	-4577	v	0.00200	[15]
42959.449	-4561.5	v	0.00325	[15]

Table 2
Continued

J.D Hel.	E	type	$O-C$	Ref.
42971.42	-4530.5	v	-0.00725	[16]
43013.365	-4422	v	0.00249	[16]
43177.634	-3997	v	0.00894	[17]
43188.647	-3968.5	v	0.00669	[17]
43211.639	-3909	v	0.00193	[18]
43275.406	-3744	v	-0.00359	[18]
43275.406	-3744	v	-0.00359	[18]
43281.395	-3728.5	v	-0.00534	[18]
43288.362	-3710.5	v	0.00466	[18]
43344.402	-3565.5	v	0.00214	[19]
43348.46	-3555	v	0.00189	[19]
43611.457	-2874.5	v	-0.01443	[20]
43657.467	-2755.5	v	0.00205	[20]
43659.401	-2750.5	v	0.00355	[20]
43709.454	-2621	v	0.00479	[21]
43711.387	-2616	v	0.00529	[21]
43735.346	-2554	v	0.00128	[21]
43904.634	-2116	v	0.00223	[22]
44008.409	-1847.5	v	0.00195	[23]
44008.413	-1847.5	v	0.00595	[23]
44016.531	-1826.5	v	0.00745	[23]
44024.448	-1806	v	0.00120	[23]
44036.429	-1775	v	0.00070	[24]
44048.413	-1744	v	0.00319	[24]
44069.479	-1689.5	v	0.00494	[24]
44082.426	-1656	v	0.00418	[24]
44271.622	-1166.5	v	0.00838	[25]
44303.504	-1084	v	0.00412	[26]
44320.517	-1040	v	0.01111	[27]
44340.61	-988	v	0.00611	[26]
44341.377	-986	v	0.00011	[26]
44344.482	-978	v	0.01311	[26]
44344.485	-978	v	0.01611	[26]
44360.52	-936.5	v	0.01135	[26]
44370.372	-911	v	0.00760	[27]
44403.41	-825.5	v	-0.00016	[27]
44409.42	-810	v	0.01909	[27]
44425.444	-768.5	v	0.00333	[28]
44425.445	-768.5	v	0.00433	[28]
44432.402	-750.5	v	0.00433	[29]
44438.389	-735	v	0.00058	[29]
44442.456	-724.5	v	0.00933	[29]
44450.377	-704	v	0.00708	[29]
44480.328	-626.5	v	0.00432	[28]
44480.333	-626.5	v	0.00932	[28]
44491.349	-598	v	0.01007	[28]
44595.698	-328	v	0.00404	[30]
44648.653	-191	v	0.00852	[31]
44707.616	-38.5	v	0.03025	[32]
44708.572	-36	v	0.02000	[32]
44711.462	-28.5	v	0.01125	[32]
44722.4745	0	pe	0.00850	[33]
44734.448	31	v	0.00050	[32]
44750.497	72.5	pe	0.00974	[33]
44787.403	168	v	0.00498	[34]
44793.409	183.5	v	0.02023	[34]
44815.422	240.5	v	0.00272	[34]
44816.408	243	v	0.02247	[34]
44817.353	245.5	v	0.00122	[34]
44838.426	300	v	0.00997	[34]

Table 2
Continued

J.D Hel.	E	type	$O-C$	Ref.
44845.384	318	v	0.01097	[34]
45014.666	756	v	0.00592	[35]
45022.597	776.5	v	0.01366	[35]
45067.425	892.5	v	0.00765	[36]
45077.486	918.5	v	0.01965	[36]
45079.41	923.5	v	0.01115	[36]
45087.346	944	v	0.02390	[36]
45101.442	980.5	v	0.01264	[36]
45103.562	986	v	0.00689	[36]
45115.364	1016.5	v	0.02064	[36]
45142.0227	1085.5	pe	0.01083	[37]
45142.9884	1088	pe	0.01028	[37]
45145.503	1094.5	v	0.01263	[38]
45159.416	1130.5	v	0.01163	[38]
45182.417	1190	v	0.01587	[38]
45200.377	1236.5	v	0.00361	[39]
45200.388	1236.5	v	0.01461	[39]
45212.373	1267.5	v	0.01811	[39]
45231.305	1316.5	v	0.01161	[39]
45380.686	1703	v	0.01031	[40]
45386.672	1718.5	v	0.00556	[40]
45441.374	1860	v	0.01780	[41]
45496.445	2002.5	v	0.01253	[42]
45504.553	2023.5	v	0.00403	[42]
45530.439	2090.5	v	-0.00548	[42]
45555.384	2155	v	0.01026	[43]
45717.716	2575	v	0.01222	[44]
45504.553	2023.5	v	0.00403	[42]
45530.439	2090.5	v	-0.00548	[42]
45555.384	2155	v	0.01026	[43]
45717.716	2575	v	0.01222	[44]
45743.624	2642	v	0.02471	[45]
45810.475	2815	v	0.01119	[46]
45815.499	2828	v	0.01069	[47]
45815.499	2828	v	0.01069	[46]
45818.592	2836	v	0.01169	[45]
45868.451	2965	v	0.01217	[46]
45874.439	2980.5	v	0.00942	[46]
45878.494	2991	v	0.00617	[14]
45884.489	3006.5	v	0.01042	[14]
45886.418	3011.5	v	0.00692	[14]
45915.416	3086.5	v	0.01741	[14]
45946.33	3166.5	v	0.01140	[48]
46101.703	3568.5	v	0.01136	[49]
46259.392	3976.5	v	0.00831	[50]
46264.422	3989.5	v	0.01381	[50]
46269.429	4002.5	v	-0.00369	[50]
46269.444	4002.5	v	0.01131	[50]
46270.416	4005	v	0.01706	[50]
46298.427	4077.5	v	0.00680	[51]
46607.425	4877	v	-0.00204	[52]
46884.364	5593.5	v	0.00963	[53]
46908.333	5655.5	v	0.01563	[54]
46910.449	5661	v	0.00588	[53]
46939.438	5736	v	0.00737	[54]
46939.439	5736	v	0.00837	[54]
46946.397	5754	v	0.00937	[54]
47038.381	5992	v	0.00634	[55]
47057.317	6041	v	0.00384	[56]
47229.705	6487	v	0.01279	[57]

Table 2
Continued

J.D Hel.	E	type	$O-C$	Ref.
47304.489	6680.5	v	0.00902	[58]
47310.477	6696	v	0.00626	[58]
47326.518	6737.5	v	0.00751	[58]
47330.391	6747.5	v	0.01551	[59]
47334.442	6758	v	0.00826	[58]
47353.388	6807	v	0.01575	[59]
47368.468	6846	v	0.02225	[59]
47371.35	6853.5	v	0.00550	[59]
47381.407	6879.5	v	0.01349	[60]
47387.38	6895	v	-0.00426	[59]
47412.321	6959.5	v	0.00748	[59]
47563.636	7351	v	0.00769	[61]
47668.379	7622	v	0.00916	[62]
47713.475	7738.5	v	0.07790	[62]
47723.516	7764.5	v	0.06990	[62]
47737.427	7800.5	v	0.06689	[62]
47743.44	7816	v	0.08914	[62]
47925.597	8287.5	v	0.01134	[63]
47968.485	8398.5	v	-0.00217	[63]
48002.497	8486.5	v	-0.00218	[64]
48010.431	8507	v	0.00856	[64]
48016.423	8522.5	v	0.00981	[64]
48058.544	8631.5	v	0.00230	[64]
48068.404	8657	v	0.00655	[64]
48085.408	8701	v	0.00454	[65]
48121.35	8794	v	0.00203	[65]
48163.279	8902.5	v	-0.00423	[65]
48323.684	9317.5	v	0.00323	[66]
48356.3364	9402	pe	-0.00363	[67]
48357.301	9404.5	pe	-0.00528	[69]
48358.468	9407.5	v	0.00222	[69]
48404.462	9526.5	v	0.00270	[69]
48405.421	9529	v	-0.00455	[69]
48429.381	9591	v	-0.00756	[69]
48440.41	9619.5	v	0.00619	[69]
48475.378	9710	v	-0.00407	[69]
48486.401	9738.5	v	0.00368	[69]
48504.363	9785	v	-0.00658	[70]
48639.643	10135	v	-0.00161	[71]
48739.361	10393	v	-0.00064	[72]
48742.252	10400.5	pe	-0.00839	[68]
48743.219	10403	pe	-0.00764	[68]
48761.381	10450	v	-0.01115	[72]
48761.387	10450	v	-0.00515	[72]
48766.41	10463	v	-0.00665	[72]
48783.411	10507	v	-0.01166	[72]
48795.396	10538	v	-0.00816	[72]
48817.422	10595	v	-0.01267	[72]
48830.368	10628.5	v	-0.01442	[72]
48840.429	10654.5	v	-0.00242	[73]
48859.367	10703.5	v	-0.00293	[73]
48992.7	11048.5	v	-0.01247	[74]
49077.537	11268	CCD	-0.01224	[75]
49092.423	11306.5	v	-0.00649	[75]
49132.419	11410	v	-0.01326	[75]
49137.444	11423	v	-0.01276	[75]
49147.503	11449	v	-0.00276	[75]
49166.433	11498	v	-0.01126	[75]
49172.422	11513.5	v	-0.01302	[75]
49173.384	11516	v	-0.01727	[75]

Table 2
Continued

J.D Hel.	E	type	$O-C$	Ref.
49201.409	11588.5	CCD	-0.01352	[76]
49206.436	11601.5	v	-0.01103	[76]
49232.324	11668.5	v	-0.01853	[76]
49441.614	12210	v	-0.01834	[77]
49511.43	12390.5	v	0.03439	[78]
49520.461	12414	v	-0.01737	[79]
49544.421	12476	v	-0.02037	[79]
49544.423	12476	v	-0.01837	[79]
49549.447	12489	v	-0.01887	[79]
49567.422	12535.5	v	-0.01613	[79]
49568.428	12538	v	0.02362	[78]
49609.348	12644	v	-0.02539	[79]
49731.682	12960.5	v	-0.01868	[78]
49836.426	13231.5	v	-0.01621	[80]
49841.456	13244.5	v	-0.01071	[80]
49852.458	13273	v	-0.02396	[80]
49860.189	13293	pe	-0.02296	[68]
49861.155	13295.5	pe	-0.02321	[68]
49861.348	13296	pe	-0.02346	[68]
49894.401	13381.5	v	-0.01622	[81]
49899.422	13394.5	v	-0.01972	[80]
49917.394	13441	v	-0.01998	[82]
49928.407	13469.5	v	-0.02223	[82]
49952.363	13531.5	v	-0.02924	[82]
49970.345	13578	v	-0.01949	[82]
50103.676	13923	v	-0.03103	[83]
50210.354	14199	v	-0.02706	[84]
50244.559	14287.5	v	-0.02732	[84]
50249.389	14300	v	-0.02857	[84]
50283.409	14388	v	-0.02058	[84]
50300.41	14432	v	-0.02559	[81]
50313.356	14465.5	v	-0.02734	[81]
50337.315	14527.5	v	-0.03135	[81]
50343.309	14543	v	-0.02810	[81]
50507.571	14968	v	-0.02865	[85]
50546.417	15068.5	v	-0.02591	[86]
50560.511	15105	v	-0.03916	[86]
50638.402	15306.5	v	-0.02793	[86]
50671.445	15392	v	-0.03069	[86]
50702.36	15472	v	-0.03570	[87]
50727.288	15536.5	v	-0.03696	[87]
50821.61	15780.5	v	-0.02099	[88]
50942.573	16093.5	v	-0.03252	[89]
51180.652	16709.5	v	-0.03759	[90]
51252.535	16895.5	v	-0.04361	[91]
51648.88903	17921	CCD	-0.04544	[92]
52028.8138	18904	CCD	-0.05028	[93]
52041.5684	18937	pe	-0.05018	[94]
52354.2438	19746	CCD	-0.05337	[95]
52365.4503	19775	pe	-0.05538	[96]
52365.6449	19775.5	pe	-0.05403	[96]
52367.578	19780.5	v	-0.05343	[97]
52652.622	20518	v	-0.05326	[98]
52673.8759	20573	pe	-0.05686	[99]
52714.6513	20678.5	pe	-0.05722	[100]
52782.0949	20853	CCD	-0.05789	[101]
52821.5178	20955	CCD	-0.05801	[102]
52843.3551	21011.5	pe	-0.05796	[103]
52843.3562	21011.5	pe	-0.05686	[103]
52873.3071	21089	pe	-0.05972	[103]
52873.3081	21089	pe	-0.05872	[103]
53040.659	21522	v	-0.06237	[104]

Table 2
Continued

J.D Hel.	E	type	$O-C$	Ref.
53069.2623	21596	pe	-0.06008	[105]
53165.5019	21845	pe	-0.05900	[106]
53196.4199	21925	CCD	-0.06101	[107]
53215.3608	21974	CCD	-0.05862	[108]
53482.4294	22665	pe	-0.06159	[109]
53510.4501	22737.5	pe	-0.06215	[106]
53817.5223	23532	pe	-0.06429	[110]
54206.3504	24538	pe	-0.05530	[111]
54225.8558	24588.5	CCD	-0.06815	[112]
54507.6122	25317.5	CCD	-0.07033	[113]
54508.5903	25320	CCD	-0.05849	[113]
54952.8579	26469.5	CCD	-0.07276	[114]
54955.3711	26476	CCD	-0.07181	[113]
54959.429	26486.5	Pe	-0.07226	[115]
54978.368	26535.5	CCD	-0.07167	[116]
55059.342	26745	CCD	-0.06944	[117]
55267.852	27284.5	CCD	-0.07595	[118]
55309.405	27392	Pe	-0.07251	[115]
55309.594	27392.5	Pe	-0.07656	[115]
55651.4545	28277	CCD	-0.07511	[119]
55654.5464	28285	Pe	-0.07521	[120]
55656.8658	28291	CCD	-0.07481	[121]
55693.3885	28385.5	CCD	-0.07637	[119]
55730.492	28481.5	CCD	-0.07708	[122]
55731.459	28484	CCD	-0.07583	[122]
55739.381	28504.5	CCD	-0.07749	[122]
55740.349	28507	CCD	-0.07604	[122]
56034.857	29269	CCD	-0.08072	[123]
56065.3904	29348	Pe	-0.08083	[120]

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