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***A**strophysics*

Photometric investigation of the K-type extremely shallow contact binary V1799 Orion *

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Abstract New multi-color light curves of the very short period K-type eclipsing binary V1799 Ori were obtained and analyzed with the Wilson-Devinney code. The photometric solutions reveal that the system is a W-type shallow-contact binary with a mass ratio of $q = 1.335(\pm0.005)$ and a degree of contact of about $f = 3.5(\pm1.1)\%$. In general, the results are in good agreement with what is reported by Samec. Dramatic manifestations of the O'Connell effect that appear in the light curves can be explained well by employing starspots on the binary surface, which confirms that the system is active at present. Several new times of light minimum were obtained. All the available times of light minimum were collected, along with the recalculated and newly obtained values. Applying a least-squares method to the constructed $O - C$ diagram, a new ephemeris is derived for V1799 Ori. The orbital period is found to show a continuous weak increase at a rate of $1.8(\pm0.6) \times 10^{-8}$ d yr^{-1}. The extremely shallow contact, together with the period increase, suggests that the binary may be at a critical stage predicted by thermal relaxation oscillation theory.

Key words: binaries: close — binaries: eclipsing — stars: individual (V1799 Ori)

1 INTRODUCTION

K-type short-period contact binaries, especially those with periods shorter than 0.3 d, are most probably main-sequence objects and mostly convective (Bradstreet 1985). They are classified as W UMa type binaries in which both components share a common envelope lying between the inner and outer critical Roche-lobe surfaces. W UMa type binaries have been divided into two sub-groups: A-type and W-type according to Binnendijk (1970). Generally speaking, the A-type systems are more likely to have an earlier spectral type than the W-type systems (Rucinski 1974), so it is supposed that a large amount of K-type short-period contact binaries may be W-type systems. The majority of W-type contact binaries show characteristics of being in shallow contact (Zhu et al. 2010). Therefore, they are good targets for testing the thermal relaxation oscillation theory (TRO theory; e.g., Lucy 1976; Flannery 1976; Robertson & Eggleton 1977).

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V1799 Orion, or V1799 Ori (=GSC 00096–00175, $\alpha_{2000.0}$ = $04^{\rm h}47^{\rm m}18.19^{\rm s}$ and $\delta_{2000.0}$ = $+06^\circ40'56.1''$) is a very short period (with period shorter than 0.3 d) eclipsing binary. It was first suspected to show variability by Hanley & Shapley (1940) (the cross identification is HV 10397). However, it was neglected for a long time until the ROSTE survey (Akerlof et al. 2000) rediscovered it to be an eclipsing binary with EW type light curves (Khruslove Observations of Variables 2006) (the cross identification is NSV 1719). The following ephemeris was reported (Khruslove Observations of Variables 2006)

$$\mathrm{Min.I(HJD)} = 2451524.829 + 0^{\rm d}.29031 \times E\,. \tag{1}$$

It was then monitored many times by several researchers such as Diethelm (2009, 2010, etc.) and Nelson (2010). Recently, The $O-C$ gateway (*http://var.astro.cz/ocgate/*) published a more exact ephemeris,

$$\mathrm{Min.I(HJD)} = 2451524.829 + 0^{\rm d}.290304 \times E\,. \tag{2}$$

The first photometric analysis of V1799 Ori was given by Samec et al. (2010) as a student/professional collaborative program. Their photometric solutions depicted V1799 Ori as a W-type, extremely shallow contact, eclipsing binary. The degree of contact factor of $3\,\%$ is rather exceptional. Their solutions uncovered two hot spots on the components, which indicate the system is quite active at present.

In this paper, we present an analysis of newly obtained complete CCD light curves and compare the results with those given by Samec et al. The details of our observations are described in Section 2. In Section 3, we carry out a more exact period investigation of this system, using all the available times of light minimum. In Section 4, we study photometric solutions of the newly obtained light curves. Finally we will discuss the results and get into our conclusion in Section 5.

2 OBSERVATIONS

New CCD photometric observations of V1799 Ori in $BV(RI)_{\rm c}$ bands were carried out on 2012 December 15 with the 1.0-m reflecting telescope at Yunnan Observatories of Chinese Academy of Sciences. An Andor DW436 2K CCD camera equipped at the Cassegrain focus was used. A standard Johnson-Cousins-Bessel filter system that is mounted on the primary focus (Zhou et al. 2009) was used. The effective field of view was $7.3' \times 7.3'$. The integration times for each image were 40 s, 30 s, 15 s and 10 s in B, V, R and I bands, respectively. The stars 2MASS J04472543+0641432 and 2MASS J04472765+0638427 near the target were chosen as the comparison and check stars, respectively. Their brightness and color are similar to those of the variable. The raw images were reduced with the PHOT (magnitude measurements for a list of stars) task in the aperture photometry package IRAF. Complete $BVRI$ light curves were obtained and the original data describing the light curves are listed in Tables A.1–A.4 (see online version). The phased light curves are displayed in Figure 1. The phases were calculated with respect to the following ephemeris,

$$\mathrm{Min.I(HJD)} = 2456277.10109 + 0^{\rm d}.290304 \times E\,. \tag{3}$$

The initial epoch in this equation is the averaged time of min I (see Table 2, data with Hel. JD 2456277...). Some information about the light curves is listed in Table 1 to describe their main features. In addition, more CCD observations of V1799 Ori were made on two nights in December 2013 with the same telescope. These data were obtained around the times eclipses were occurring and were used to determine the times of light minimum (see Table 2).

The light curves displayed in Figure 1 show dramatic manifestations of the O'Connell effect (with different heights of light maximum, see O'Connell 1951a,b, Milone 1968), which we should take into account in deriving photometric solutions. The two deep eclipses displayed by the light curves will help us to derive more reliable parameters for the binary. Using a least-square parabolic fitting method, the new times of CCD light minimum were determined and are listed in Table 2.

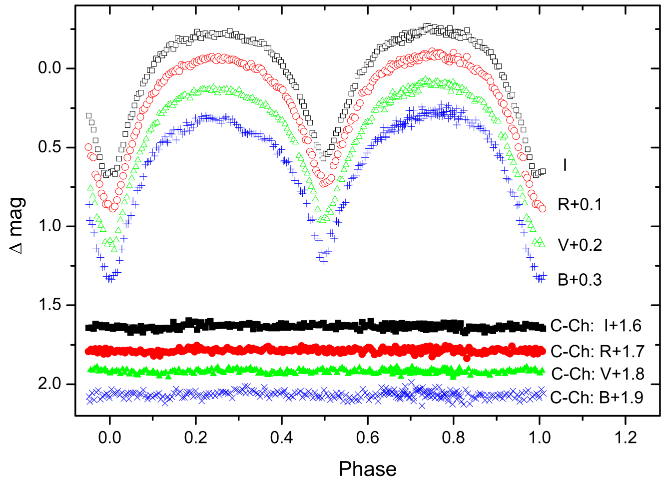

Fig. 1 Multi-color light curves of V1799 Ori obtained in 2012.

Table 1 Summary of the Multi-color Light Curves

Wave Band	Min.I-Min.II (mag)	Max.(0.25)–Max.(0.75) (mag)	Min.I–Max.(0.75) (mag)
B	0.15	0.05	1.08
V	0.18	0.04	1.03
R	0.13	0.03	0.98
I	0.10	0.03	0.93

Table 2 New Times of CCD Light Minimum

JD (Hel.)	Error (d)	Min.	Filter	NA
2456277.10131	0.00033	I	*B*	35
2456277.10091	0.00030	I	*I*	29
2456277.10110	0.00032	I	*R*	34
2456277.10105	0.00030	I	*V*	30
2456277.24598	0.00043	II	*B*	36
2456277.24612	0.00031	II	*I*	29
2456277.24600	0.00034	II	*R*	29
2456277.24648	0.00033	II	*V*	30
2456645.20608	0.00013	I	*N*	54
2456657.25337	0.00012	II	*I*	32
2456657.25374	0.00016	II	*N*	32

Notes: NA is the total number of data used to determine the times of light minimum.

3 ORBITAL PERIOD INVESTIGATION OF V1799 ORI

Times of light minimum are very useful for the study of orbital periods in eclipsing binaries. Therefore, we collected all the available times of light minimum with the help of the $O-C$ gateway[1]. They are listed in Table 3. Several times of light minimum from the INTEGRAL Optical Monitoring Camera (Alfonso-Garzón et al. 2012) Archive and ROTSE-I (Akerlof et al. 2000) are

[1] *http://var.astro.cz/ocgate/*

Table 3 Collection of Published or Reprocessed Times of Light Minimum

JD. Hel. 2 400 000+	Err. (d)	Epoch	$O-C$ (d)	Min	Method	Ref.	Notes
51524.10538	4.8×10^{-4}	−2.5	0.00214	II	ccd	[1]	reproc
51526.28195	3.5×10^{-4}	5	0.00143	I	ccd	[1]	reproc
53591.5061	0.003	7119.0	0.00295	I	V	[2]	newp, unused
53591.6487	0.002	7119.5	0.00034	II	V	[2]	newp, unused
54014.0306	0.003	8574.5	−0.01008	II	V	[2]	newp, unused
54530.3413	0.001	10353.0	−0.00502	I	V	[2]	newp
54756.9226	9×10^{-4}	11133.5	−0.00598	II	B	[3]	
54821.66301	1.6×10^{-4}	11356.5	−0.00337	II	$BVRI$	[4]	reproc
54821.80835	2.9×10^{-4}	11357.0	−0.00318	I	$BVRI$	[4]	reproc
54822.67936	2.1×10^{-4}	11360.0	−0.00308	I	$BVRI$	[4]	reproc
54822.82433	4.2×10^{-4}	11360.5	−0.00326	II	VRI	[4]	reproc
54824.71134	1.4×10^{-4}	11367.0	−0.00323	I	$BVRI$	[4]	reproc
54824.85607	7.1×10^{-4}	11367.5	−0.00365	II	V	[4]	reproc
54827.76016	2.2×10^{-4}	11377.5	−0.00260	II	BVR	[4]	reproc
54827.90541	1.5×10^{-4}	11378.0	−0.00250	I	BVR	[4]	reproc
55113.8532	5×10^{-4}	12363.0	−0.00415	I	ccd	[5]	
55135.7727	4×10^{-4}	12438.5	−0.00260	II	V	[6]	
55135.9187	5×10^{-4}	12439.0	−0.00176	I	V	[6]	
55506.9248	3×10^{-4}	13717.0	−0.00417	I	V	[7]	
55937.5900	0.003	15200.5	−0.00495	II	V	[8]	unused
55937.7353	8×10^{-4}	15201.0	−0.00480	I	V	[8]	
56237.9093	8×10^{-4}	16235.0	−0.00514	I	V	[9]	

Notes: ROTSE-I data can be retrieved from the NSVS database (*http://skydot.lanl.gov/nsvs/nsvs.php*). newp = Based on data from the OMC Archive at CAB (INTA-CSIC), pre-processed by ISDC, times of light minimum are newly calculated; reproc = data were reprocessed. Ref.: [1] Khrus1ov Observations of Variables (2006); [2] present paper; [3] Diethelm (2009); [4] Samec et al. (2010); [5] Nelson (2010); [6] Diethelm (2010); [7] Diethelm (2011); [8] Diethelm (2012); [9] Diethelm (2013).

also listed. They are recalculated by folding the original data according to the period and applying a least-square parabolic fitting method to the eclipsing part of the folded light curves. The resulting times are actually the average times of light minimum for each group of data. The HJD times of light minimum determined from the light curves observed by Samec et al. (2010) were reprocessed according to their observation times.

The times of light minimum that are collected from literature or from reprocessed data are listed in Table 3. The $O-C$ values calculated with respect to Equation (2) are shown in Figure 2 along with the epochs (data with errors larger than 0.001 d were not used). As seen in the upper panel of Figure 2, the general trend of $O-C$ shows an upward parabolic change without an obvious cyclic oscillation being superimposed. By using a weighted least square method, a new ephemeris was derived to be

$$\begin{aligned}\mathrm{Min.I(HJD)} = \ & 2451524.8307(\pm0.0003) + 0^{\mathrm{d}}.29030351(\pm0.00000005)\times E \\ & +7^{\mathrm{d}}.0(\pm2.4)\times10^{-12}\times E^2\,.\end{aligned} \tag{4}$$

The quadratic term in Equation (4) denotes a continuous increase in period at a rate of $\mathrm{d}P/\mathrm{d}t = 1.8(\pm0.6)\times10^{-8}$ d yr^{-1}. The residuals are also displayed in the lower panel of Figure 2. As shown in this figure, a few data points are not fitted well. This may be caused by occasional factors which would impact the shape of the light curves and therefore the determination of times of light minimum, e.g. the occurrence of solar-like activities and unstable weather conditions. Nevertheless, the general trend of $O-C$ data is well described by the upward parabolic fit.

In addition, a revised linear ephemeris was calculated to be

$$\mathrm{Min.I(HJD)} = 2451524.8303(\pm0.0002) + 0^{\mathrm{d}}.29030364(\pm0.00000002)\times E\,, \tag{5}$$

which can be used as a preliminary prediction for times of light minimum.

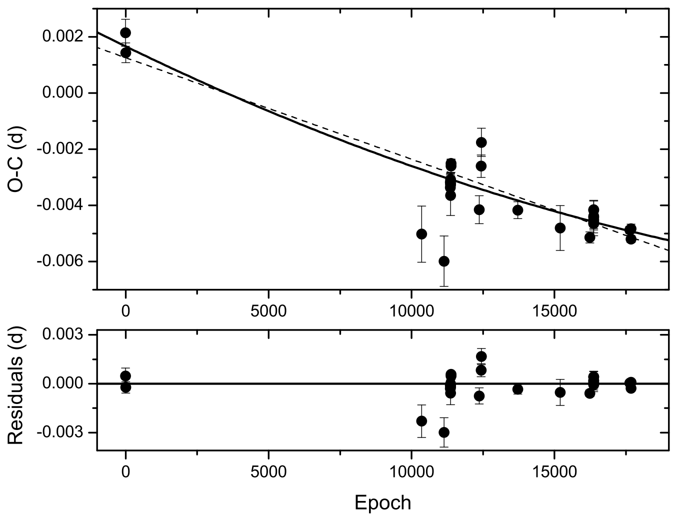

Fig. 2 *Upper panel*: the $O-C$ diagram calculated using the linear ephemeris in Eq. (2). The solid line indicates the upward parabolic trend, while the dashed line refers to a linear correction to the ephemeris. *Lower panel*: the residuals after the parabolic variation was removed.

4 PHOTOMETRIC SOLUTIONS WITH THE WILSON-DEVINNEY METHOD

The light curves displayed in Figure 1 show EW-type variation and a deep eclipsing feature in both minima. We can infer there is a high orbital inclination in the binary system, which enables a reliable photometric parameter determination. To understand the geometrical structure and evolutionary state, the multi-color light curves were analyzed with the Wilson-Devinney method (Wilson & Devinney 1971; Wilson 1979, 1990, 1994; Wilson & Van Hamme 2003). The temperature for star 1 (the star eclipsed at primary light minimum) was fixed as $T_1 = 5000$ K according to Samec et al. (2010). This is reasonable because the 2MASS color index $J - H = 0.448$ and $H - K = 0.089$ given in the VizieR database corresponds to a K0-K2 spectral type according to Allen's table (Cox 2000). The component eclipsed at the primary light minimum is usually the hotter one so we adopted the same temperature as Samec chose. The gravity-darkening coefficients were assumed to be $g_1 = g_2 = 0.32$ (Lucy 1967) and the bolometric albedo were assumed to be $A_1 = A_2 = 0.5$ (Rucinski 1969). Bolometric and bandpass square-root limb-darkening parameters were taken from van Hamme (1993). Mode 3 (contact model) was assumed during the process of calculation. The adjustable parameters were: the orbital inclination i; the mean temperature of star 2, T_2; the monochromatic luminosity of star 1, L_{1B}, L_{1V}, L_{1R} and L_{1I}; and the dimensionless potential ($\Omega_1 = \Omega_2$ for mode 3).

A q-search method was used in order to get the initial input parameters. A series of mass ratios ranging from less than 0.3 to larger than 3 were assumed as trial values. Calculations were carried out with these mass ratios. The resulting sum of weighted square deviations ($\Sigma w_i(O-C)_i^2$) along with mass ratios are plotted in Figure 3. The smallest Σ was achieved at $q = 1.3$ ($q = M_2/M_1$). Then, we treated q as an adjustable parameter and chose $q = 1.3$ as the initial value. We treated q as an adjustable parameter and chose $q = 1.3$ as the initial value and finally a set of converged solutions was obtained.

The obtained photometric solutions are listed in Table 5 (see Col. 2). However, the theoretical light curves obtained do not fit the observations very well because of the obvious asymmetry in the

Table 4 Comparison of Different Spot Scenarios

Model	Spot type	$\Sigma w_i(O-C)_i^2 \times 10^3$
0	no-spot	2.854
1	cool spot on C1	2.191
2	cool spot on C2	2.255
3	hot spot on C1	1.935
4	hot spot on C2	1.852

Notes: C1 and C2 represent component stars 1 and 2 respectively.

Table 5 Photometric Solutions for V1799 Ori from Different Spot Scenarios

Parameters	Model 0	Model 1	Model 4
	No-spot	Cool spot	Hot spot
(1)	(2)	(3)	(4)
$q\,(M_2/M_1)$	1.300 ± 0.003	1.300 ± 0.007	1.335 ± 0.005
$\Omega_{\rm in}$	4.2233	4.2233	4.2771
$\Omega_{\rm out}$	3.6571	3.6571	3.7087
T_2 (K)	4805 ± 5	4801 ± 4	4781 ± 4
$i\,(^\circ)$	89.8 ± 0.9	89.8 ± 0.8	89.7 ± 0.8
$L_1/(L_1+L_2)\,(B)$	0.5176 ± 0.0022	0.5196 ± 0.0019	0.5206 ± 0.0017
$L_1/(L_1+L_2)\,(V)$	0.5022 ± 0.0018	0.5038 ± 0.0016	0.5033 ± 0.0014
$L_1/(L_1+L_2)\,(R)$	0.4900 ± 0.0015	0.4914 ± 0.0015	0.4895 ± 0.0012
$L_1/(L_1+L_2)\,(I)$	0.4823 ± 0.0013	0.4835 ± 0.0014	0.4809 ± 0.0011
$\Omega_1 = \Omega_2$	4.1763 ± 0.0066	4.1695 ± 0.0119	4.2572 ± 0.0064
r_1 (pole)	0.3395 ± 0.0008	0.3403 ± 0.0015	0.3343 ± 0.0008
r_1 (side)	0.3564 ± 0.0010	0.3573 ± 0.0018	0.3504 ± 0.0010
r_1 (back)	0.3910 ± 0.0015	0.3924 ± 0.0029	0.3833 ± 0.0016
r_2 (pole)	0.3832 ± 0.0008	0.3839 ± 0.0014	0.3824 ± 0.0008
r_2 (side)	0.4048 ± 0.0010	0.4058 ± 0.0017	0.4037 ± 0.0010
r_2 (back)	0.4372 ± 0.0014	0.4385 ± 0.0025	0.4345 ± 0.0014
f (%)	8.3 ± 1.2	9.5 ± 2.1	3.5 ± 1.1
$\theta_s\,(^\circ)$	–	83.1 (trial)	74.5 (trial)
$\psi_s\,(^\circ)$	–	262 ± 17	246 ± 10
$r_s\,(^\circ)$	–	16.6 ± 6.1	10.8 ± 5.9
T_s/T_*	–	0.88 ± 0.11	1.20 ± 0.11
$\Sigma w_i(O-C)_i^2$	0.002854	0.002191	0.001852

light curves. This arises from the so-called O'Connell effect. Therefore, we tried to employ starspots in the model. It should be noted that the spots would be cool spots, just like sunspots, or hot spots, which are hotter areas on the components. Since the masses of the components are close to each other ($q = M_2/M_1 \sim 1.3$), both of them may have the possibility of producing spots. To simplify the problem, we tried adding a single spot in the binary system. Together with the non-spot model, there are five scenarios to compare, which are listed in Table 4. The values in Column 3 are the sum of weighted squared residuals for the best solution of each scenario. It can be seen that values for the sum of squared residuals in spotted models are distinctively smaller than those of the non-spot model. When finding the converged solutions, we notice that these two kinds of cool spot models have similar parameters. The same situation was found with those two kinds of hot spot models. Thus we adopted model 1 and model 4 to give a detailed description. The parameters of model 0 (non-spot), model 1 (cool spot) and model 4 (hot spot) are listed in Table 5. The corresponding theoretical light curves of these models are plotted in Figure 4. In this figure, we can see that the observed light curves are fitted better by the hot spot model which reveals that V1799 Ori is a W-type shallow contact binary system with a degree of contact of $f = (\Omega - \Omega_{\rm in})/(\Omega_{\rm out} - \Omega_{\rm in}) = 3.5\% \pm 1.1\%$. The geometrical structure of the binary is shown in Figure 5.

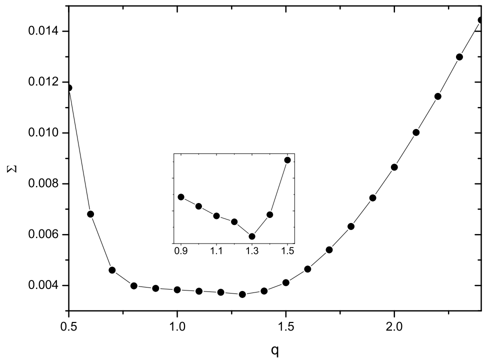

Fig. 3 Σ - q curves for V1799 Ori. Insert: an enlarged figure to show values around the minimum.

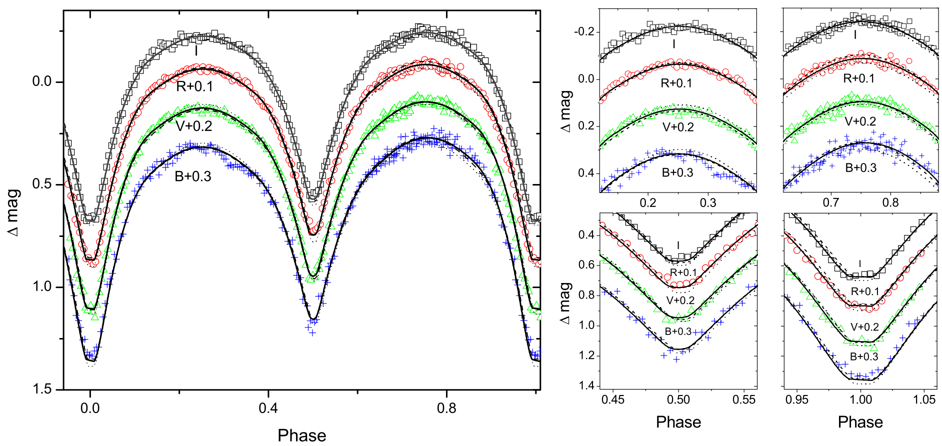

Fig. 4 Observed and theoretical light curves (lines) of V1799 Ori. Different colors and symbols represent observations in different bands. The solid line, dashed line and dotted line denote theoretical light curves calculated with hot spot model 4, cool spot model 1 and non-spot model 0, respectively. *Left panel*: the complete light curves. *Right panels*: the enlarged small part of the left panel at minimum and maximum phases.

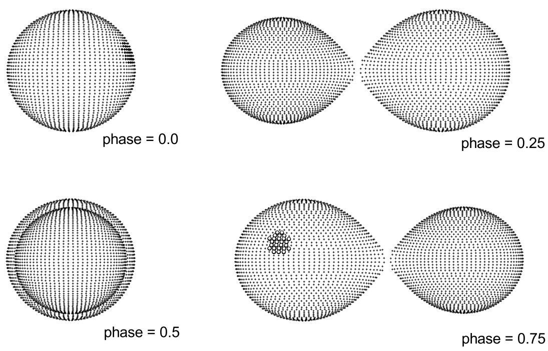

Fig. 5 Geometrical structure of V1799 Ori at phases 0.0, 0.25, 0.5 and 0.75.

5 CONCLUSIONS AND DISCUSSION

The deep eclipses in both primary and secondary light minima, which indicate there is a high inclination in the binary system, help us to derive reliable solutions for this system. Based on the complete $BV(RI)_{\rm c}$ light curves, the photometric solutions for V1799 Ori were carefully derived. We found that V1799 Ori is an extremely shallow contact binary system with a mass ratio of $q = M_2/M_1 = 1.335 \pm 0.005$ and a degree of contact of about $f = 3.5\% \pm 1.1\%$. It is a W-type system for which the less massive component is about 220 K hotter than the more massive one. The asymmetric light curves can be well modeled by employing a hot spot on the primary. Assuming that the primary component is a K0 type main-sequence star, its mass is roughly estimated to be $M_2 = 0.80\ M_\odot$ (Cox 2000). Then the mass of the other component can be estimated to be $M_1 = 0.60\ M_\odot$ by using the derived mass ratio.

The photometric solution is in good agreement with that given by Samec et al. (2010) except for the configuration of starspots. This can be explained by activity of the components. The solar-like activities on the surface of the binaries are expected to change with time, which would cause different patterns of starspots. When examining the light curves obtained by Samec et al., we found their shapes are slightly different from ours. The difference between the two maxima in their light curves is about 0.03 mag (B,V), 0.02 mag (R) and 0.01 mag (I), which are distinctively smaller than those in the newly obtained light curves (see Table 1). This further confirms that the binary is highly active at present.

Based on the analysis of the $O-C$ diagram (Fig. 2), a general trend of long-term period increase at a rate of $1.8(\pm 0.6) \times 10^{-8}$ d yr^{-1} was derived. The period increase is insignificant (close to the error), making it very small compared with other shallow contact binaries (see table 7 in Zhu et al. 2010). This is in accord with the exceptionally low degree of contact, which also agrees with the fact that a system where the period is increasing usually has a lower degree of contact (Zhu et al. 2010). The long-term period increase, together with the exceptionally low degree of contact, suggests that the binary may be at a critical stage which is predicted by the TRO theory.

If the variation period is caused by conservative mass transfer, then using the well-known equation

$$\frac{\dot{P}}{P} = 3\frac{\dot{M}_2}{M_2}\Big(\frac{M_2}{M_1} - 1\Big), \tag{6}$$

the mass transfer rate is estimated to be ${\rm d}M_2/{\rm d}t = 1.4(\pm 0.5) \times 10^{-8}\ M_\odot$ yr^{-1}. However, the real mass transfer rate may be quite different from this value because of the contribution of angular momentum loss (Rahunen 1981; Qian et al. 2013). In addition, it is possible that the long-term increase may be only one part of a long cyclic oscillation. More observations are needed to clarify the nature of this variation in period.

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Appendix A:

Table A.1: The original B band data of V1799 Ori observed in 2012 (Hel. JD 456 200+).

Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm
76.9944	0.151	77.0629	0.090	77.1314	0.253	77.1998	0.111	77.2693	0.315
76.9958	0.074	77.0643	0.095	77.1328	0.198	77.2012	0.132	77.2707	0.310
76.9972	0.132	77.0657	0.146	77.1342	0.210	77.2026	0.113	77.2721	0.304
76.9986	0.092	77.0671	0.114	77.1356	0.170	77.2040	0.147	77.2735	0.264
77.0000	0.098	77.0685	0.165	77.1370	0.162	77.2054	0.143	77.2749	0.235
77.0014	0.085	77.0699	0.200	77.1384	0.128	77.2060	0.154	77.2763	0.207
77.0028	0.098	77.0713	0.184	77.1398	0.159	77.2074	0.152	77.2777	0.187
77.0042	0.027	77.0727	0.252	77.1403	0.170	77.2088	0.142	77.2791	0.186
77.0056	0.089	77.0741	0.237	77.1417	0.112	77.2102	0.156	77.2805	0.150
77.0070	0.036	77.0746	0.263	77.1431	0.115	77.2116	0.194	77.2819	0.162
77.0084	0.083	77.0760	0.280	77.1445	0.088	77.2130	0.181	77.2824	0.139
77.0090	0.053	77.0774	0.345	77.1459	0.152	77.2144	0.241	77.2838	0.137
77.0104	0.047	77.0788	0.397	77.1473	0.086	77.2158	0.228	77.2862	0.107
77.0118	0.022	77.0802	0.405	77.1487	0.084	77.2172	0.213	77.2876	0.136
77.0132	0.010	77.0816	0.481	77.1501	0.115	77.2186	0.286	77.2890	0.075
77.0146	0.068	77.0830	0.487	77.1515	0.100	77.2191	0.281	77.2904	0.107
77.0160	0.000	77.0844	0.509	77.1529	0.042	77.2205	0.295	77.2918	0.072
77.0174	0.025	77.0858	0.565	77.1534	0.061	77.2219	0.288	77.2932	0.062
77.0188	0.023	77.0872	0.561	77.1548	0.095	77.2233	0.337	77.2946	0.053
77.0202	−0.003	77.0878	0.663	77.1562	0.056	77.2247	0.359	77.2960	0.067
77.0216	−0.015	77.0892	0.688	77.1576	0.071	77.2261	0.410	77.2974	0.056
77.0221	−0.040	77.0906	0.741	77.1590	0.013	77.2285	0.428	77.2988	0.065
77.0235	−0.020	77.0920	0.837	77.1604	0.044	77.2299	0.476	77.3002	0.058
77.0249	−0.016	77.0934	0.862	77.1618	0.032	77.2313	0.490	77.3007	0.050
77.0263	−0.034	77.0948	0.896	77.1632	0.004	77.2327	0.469	77.3021	0.012
77.0277	−0.034	77.0962	0.957	77.1646	0.017	77.2341	0.554	77.3035	−0.034
77.0291	−0.032	77.0976	0.954	77.1660	−0.003	77.2355	0.641	77.3049	0.014
77.0305	−0.039	77.0990	1.016	77.1666	0.016	77.2369	0.662	77.3063	−0.036
77.0319	−0.013	77.1004	1.033	77.1680	0.014	77.2383	0.654	77.3077	0.017
77.0333	0.001	77.1009	1.028	77.1694	0.012	77.2397	0.759	77.3091	0.002
77.0347	−0.074	77.1023	1.035	77.1708	0.016	77.2411	0.779	77.3105	0.030
77.0352	0.002	77.1037	1.011	77.1722	0.023	77.2425	0.790	77.3119	−0.057
77.0366	−0.005	77.1051	0.991	77.1736	0.028	77.2430	0.896	77.3133	0.014
77.0380	−0.028	77.1065	0.991	77.1750	0.027	77.2444	0.863	77.3139	−0.002
77.0394	0.017	77.1079	0.915	77.1764	0.046	77.2458	0.921	77.3153	−0.014
77.0408	0.002	77.1093	0.844	77.1778	0.016	77.2472	0.870	77.3167	−0.023
77.0422	−0.033	77.1107	0.778	77.1792	0.008	77.2486	0.857	77.3181	0.005
77.0436	−0.020	77.1121	0.685	77.1797	0.006	77.2500	0.743	77.3195	−0.023
77.0450	−0.047	77.1135	0.685	77.1811	0.021	77.2514	0.742	77.3209	−0.010
77.0464	0.017	77.1140	0.659	77.1825	0.040	77.2528	0.778	77.3223	−0.006
77.0478	0.002	77.1154	0.631	77.1839	0.020	77.2542	0.667	77.3237	−0.044
77.0484	−0.021	77.1168	0.539	77.1853	0.041	77.2556	0.676	77.3251	−0.025
77.0498	−0.035	77.1182	0.563	77.1867	0.056	77.2561	0.600	77.3265	−0.021
77.0512	0.023	77.1196	0.472	77.1881	0.074	77.2575	0.582	77.3270	−0.009
77.0526	0.025	77.1210	0.451	77.1895	0.075	77.2589	0.562	77.3284	−0.054
77.0540	0.059	77.1224	0.441	77.1909	0.108	77.2603	0.548	77.3298	−0.065
77.0554	0.044	77.1238	0.384	77.1923	0.103	77.2617	0.442	77.3312	−0.031
77.0568	0.070	77.1252	0.309	77.1928	0.105	77.2631	0.438	77.3326	−0.009
77.0582	0.025	77.1266	0.292	77.1942	0.114	77.2645	0.397	77.3340	0.005
77.0596	0.068	77.1272	0.290	77.1956	0.101	77.2659	0.390	77.3354	0.057
77.0610	0.081	77.1286	0.284	77.1970	0.112	77.2673	0.380	77.3368	0.024
77.0615	0.059	77.1300	0.230	77.1984	0.114	77.2687	0.341		

Table A.2: The original V band data of V1799 Ori observed in 2012 (Hel. JD 2 456 200+).

Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm
76.9949	0.004	77.0634	0.017	77.1318	0.149	77.2003	0.007	77.2697	0.234
76.9963	0.063	77.0648	0.051	77.1332	0.143	77.2017	0.015	77.2711	0.201
76.9977	0.012	77.0662	0.066	77.1346	0.083	77.2031	0.020	77.2725	0.168
76.9991	0.023	77.0676	0.064	77.1360	0.086	77.2045	0.036	77.2739	0.145
77.0005	0.017	77.0690	0.091	77.1374	0.069	77.2064	0.026	77.2753	0.137
77.0019	−0.050	77.0704	0.116	77.1388	0.051	77.2078	0.042	77.2767	0.138
77.0033	−0.035	77.0718	0.133	77.1408	0.031	77.2092	0.068	77.2781	0.114
77.0047	−0.020	77.0732	0.135	77.1422	0.026	77.2106	0.081	77.2795	0.067
77.0061	−0.017	77.0751	0.223	77.1436	0.035	77.2120	0.092	77.2809	0.067
77.0075	−0.058	77.0765	0.241	77.1450	0.017	77.2134	0.087	77.2829	0.024
77.0094	−0.023	77.0779	0.228	77.1464	−0.003	77.2149	0.110	77.2843	0.039
77.0108	−0.055	77.0793	0.294	77.1478	−0.008	77.2163	0.129	77.2867	0.028
77.0122	−0.040	77.0807	0.339	77.1492	−0.021	77.2177	0.127	77.2881	0.003
77.0136	−0.059	77.0821	0.366	77.1506	−0.029	77.2196	0.153	77.2895	−0.001
77.0150	−0.033	77.0835	0.395	77.1520	−0.037	77.2210	0.183	77.2909	0.005
77.0164	−0.086	77.0849	0.445	77.1539	−0.024	77.2224	0.209	77.2923	−0.014
77.0178	−0.049	77.0863	0.474	77.1553	−0.012	77.2238	0.229	77.2937	−0.020
77.0192	−0.057	77.0882	0.560	77.1567	−0.046	77.2252	0.252	77.2951	−0.023
77.0206	−0.095	77.0896	0.609	77.1581	−0.060	77.2266	0.268	77.2965	−0.035
77.0226	−0.118	77.0910	0.653	77.1595	−0.041	77.2289	0.353	77.2979	−0.049
77.0240	−0.099	77.0924	0.742	77.1609	−0.044	77.2303	0.371	77.2993	−0.072
77.0254	−0.108	77.0938	0.759	77.1623	−0.063	77.2317	0.408	77.3012	−0.059
77.0268	−0.117	77.0952	0.795	77.1637	−0.069	77.2331	0.439	77.3026	−0.087
77.0282	−0.092	77.0966	0.822	77.1651	−0.070	77.2345	0.465	77.3040	−0.073
77.0296	−0.091	77.0980	0.900	77.1670	−0.065	77.2359	0.509	77.3054	−0.086
77.0310	−0.117	77.0994	0.914	77.1684	−0.070	77.2373	0.548	77.3068	−0.075
77.0324	−0.099	77.1014	0.891	77.1698	−0.059	77.2387	0.578	77.3082	−0.089
77.0338	−0.102	77.1028	0.919	77.1712	−0.082	77.2401	0.628	77.3096	−0.104
77.0357	−0.087	77.1042	0.949	77.1726	−0.064	77.2415	0.692	77.3110	−0.113
77.0371	−0.092	77.1056	0.887	77.1740	−0.045	77.2435	0.759	77.3124	−0.115
77.0385	−0.107	77.1070	0.826	77.1754	−0.066	77.2449	0.765	77.3143	−0.132
77.0399	−0.107	77.1084	0.761	77.1768	−0.061	77.2463	0.743	77.3157	−0.117
77.0413	−0.055	77.1098	0.715	77.1782	−0.069	77.2477	0.753	77.3171	−0.114
77.0427	−0.115	77.1112	0.647	77.1802	−0.069	77.2491	0.696	77.3185	−0.099
77.0441	−0.094	77.1126	0.615	77.1816	−0.046	77.2505	0.713	77.3199	−0.103
77.0455	−0.086	77.1145	0.544	77.1830	−0.068	77.2519	0.657	77.3213	−0.090
77.0469	−0.075	77.1159	0.495	77.1844	−0.057	77.2533	0.628	77.3227	−0.119
77.0488	−0.078	77.1173	0.451	77.1858	−0.046	77.2547	0.564	77.3242	−0.102
77.0502	−0.062	77.1187	0.422	77.1872	−0.041	77.2566	0.500	77.3256	−0.106
77.0516	−0.059	77.1201	0.380	77.1886	−0.065	77.2580	0.505	77.3275	−0.113
77.0530	−0.037	77.1215	0.330	77.1900	−0.031	77.2594	0.443	77.3289	−0.081
77.0544	−0.028	77.1229	0.307	77.1914	−0.027	77.2608	0.411	77.3303	−0.101
77.0558	−0.020	77.1243	0.285	77.1933	−0.014	77.2622	0.373	77.3317	−0.091
77.0572	0.008	77.1257	0.248	77.1947	−0.011	77.2636	0.349	77.3331	−0.080
77.0586	−0.003	77.1276	0.198	77.1961	−0.007	77.2650	0.316	77.3345	−0.085
77.0600	−0.003	77.1290	0.186	77.1975	−0.014	77.2664	0.271	77.3359	−0.080
77.0620	0.002	77.1304	0.159	77.1989	0.006	77.2678	0.262	77.3373	−0.046

Table A.3: The original R band data of V1799 Ori observed in 2012 (Hel. JD 2 456 200+).

Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm
76.9952	−0.069	77.0637	−0.059	77.1322	0.047	77.2006	−0.096	77.2701	0.118
76.9966	−0.084	77.0651	−0.048	77.1336	0.017	77.2020	−0.106	77.2715	0.054
76.9980	−0.082	77.0665	−0.044	77.1350	−0.012	77.2034	−0.097	77.2729	0.047
76.9994	−0.078	77.0679	−0.019	77.1364	−0.010	77.2048	−0.076	77.2743	0.033
77.0008	−0.132	77.0693	0.019	77.1378	−0.022	77.2068	−0.046	77.2757	0.044
77.0022	−0.121	77.0707	0.029	77.1392	−0.049	77.2082	−0.043	77.2771	0.016

Table A.3: (Continued)

Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm
77.0036	−0.122	77.0721	0.054	77.1411	−0.065	77.2096	−0.024	77.2785	−0.017
77.0050	−0.133	77.0735	0.072	77.1425	−0.076	77.2110	−0.009	77.2799	−0.037
77.0064	−0.156	77.0754	0.115	77.1439	−0.084	77.2124	−0.011	77.2813	−0.050
77.0078	−0.140	77.0768	0.125	77.1453	−0.082	77.2138	0.016	77.2832	−0.070
77.0098	−0.124	77.0782	0.171	77.1467	−0.098	77.2152	0.019	77.2846	−0.066
77.0112	−0.158	77.0796	0.184	77.1481	−0.084	77.2166	0.025	77.2870	−0.088
77.0126	−0.154	77.0810	0.225	77.1495	−0.124	77.2180	0.036	77.2884	−0.082
77.0140	−0.134	77.0824	0.279	77.1509	−0.117	77.2199	0.077	77.2898	−0.110
77.0154	−0.148	77.0838	0.295	77.1523	−0.117	77.2213	0.090	77.2912	−0.100
77.0168	−0.175	77.0852	0.329	77.1542	−0.124	77.2227	0.114	77.2926	−0.125
77.0182	−0.151	77.0866	0.397	77.1556	−0.113	77.2241	0.137	77.2940	−0.117
77.0196	−0.152	77.0886	0.454	77.1570	−0.127	77.2255	0.170	77.2954	−0.125
77.0210	−0.178	77.0900	0.463	77.1584	−0.143	77.2269	0.202	77.2968	−0.132
77.0229	−0.192	77.0914	0.570	77.1598	−0.141	77.2293	0.233	77.2982	−0.141
77.0243	−0.191	77.0928	0.591	77.1612	−0.153	77.2307	0.279	77.2996	−0.159
77.0257	−0.183	77.0942	0.631	77.1626	−0.151	77.2321	0.299	77.3015	−0.150
77.0271	−0.179	77.0956	0.690	77.1640	−0.164	77.2335	0.351	77.3029	−0.167
77.0285	−0.210	77.0970	0.712	77.1654	−0.158	77.2349	0.355	77.3043	−0.158
77.0299	−0.195	77.0984	0.760	77.1674	−0.166	77.2363	0.425	77.3057	−0.169
77.0313	−0.182	77.0998	0.756	77.1688	−0.171	77.2377	0.448	77.3071	−0.178
77.0327	−0.201	77.1017	0.772	77.1702	−0.175	77.2391	0.501	77.3085	−0.168
77.0341	−0.198	77.1031	0.788	77.1716	−0.163	77.2405	0.544	77.3099	−0.174
77.0360	−0.187	77.1045	0.774	77.1730	−0.152	77.2419	0.567	77.3113	−0.174
77.0374	−0.170	77.1059	0.733	77.1744	−0.174	77.2438	0.577	77.3127	−0.182
77.0388	−0.151	77.1073	0.678	77.1758	−0.158	77.2452	0.630	77.3147	−0.169
77.0402	−0.144	77.1087	0.636	77.1772	−0.153	77.2466	0.625	77.3161	−0.184
77.0416	−0.177	77.1101	0.580	77.1786	−0.171	77.2480	0.618	77.3175	−0.183
77.0430	−0.200	77.1115	0.524	77.1805	−0.164	77.2494	0.610	77.3189	−0.184
77.0444	−0.168	77.1129	0.464	77.1819	−0.154	77.2508	0.592	77.3203	−0.176
77.0458	−0.175	77.1148	0.417	77.1833	−0.159	77.2522	0.515	77.3217	−0.193
77.0472	−0.145	77.1162	0.377	77.1847	−0.158	77.2536	0.486	77.3231	−0.179
77.0492	−0.149	77.1176	0.325	77.1861	−0.152	77.2550	0.442	77.3245	−0.196
77.0506	−0.129	77.1190	0.299	77.1875	−0.144	77.2569	0.384	77.3259	−0.180
77.0520	−0.176	77.1204	0.261	77.1889	−0.135	77.2583	0.379	77.3278	−0.158
77.0534	−0.119	77.1218	0.207	77.1903	−0.135	77.2597	0.325	77.3292	−0.165
77.0548	−0.110	77.1232	0.165	77.1917	−0.130	77.2611	0.288	77.3306	−0.164
77.0562	−0.091	77.1246	0.154	77.1936	−0.108	77.2625	0.284	77.3320	−0.160
77.0576	−0.083	77.1260	0.126	77.1950	−0.115	77.2639	0.230	77.3334	−0.162
77.0590	−0.100	77.1280	0.100	77.1964	−0.132	77.2653	0.206	77.3348	−0.157
77.0604	−0.085	77.1294	0.064	77.1978	−0.109	77.2667	0.212	77.3362	−0.156
77.0623	−0.067	77.1308	0.057	77.1992	−0.097	77.2681	0.144	77.3376	−0.133

Table A.4: The original I band data of V1799 Ori observed in 2012 (Hel. JD 2 456 200+).

Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm
76.9954	−0.131	77.0639	−0.130	77.1324	−0.065	77.2009	−0.160	77.2703	0.024
76.9968	−0.133	77.0653	−0.116	77.1338	−0.057	77.2023	−0.157	77.2717	0.022
76.9982	−0.147	77.0667	−0.100	77.1352	−0.092	77.2037	−0.167	77.2731	0.008
76.9997	−0.165	77.0681	−0.105	77.1366	−0.083	77.2051	−0.158	77.2745	−0.026
77.0011	−0.156	77.0695	−0.073	77.1380	−0.098	77.2070	−0.130	77.2759	−0.041
77.0025	−0.187	77.0709	−0.046	77.1394	−0.121	77.2084	−0.129	77.2773	−0.027
77.0039	−0.188	77.0723	−0.011	77.1413	−0.147	77.2098	−0.102	77.2787	−0.064
77.0053	−0.176	77.0737	−0.014	77.1427	−0.156	77.2112	−0.089	77.2801	−0.086
77.0067	−0.170	77.0756	0.041	77.1441	−0.125	77.2126	−0.059	77.2815	−0.108
77.0081	−0.162	77.0770	0.056	77.1455	−0.151	77.2140	−0.079	77.2834	−0.138
77.0100	−0.225	77.0784	0.104	77.1469	−0.193	77.2154	−0.057	77.2848	−0.127
77.0114	−0.198	77.0798	0.127	77.1483	−0.177	77.2168	−0.041	77.2872	−0.143
77.0128	−0.181	77.0812	0.175	77.1497	−0.186	77.2182	−0.018	77.2886	−0.164

Table A.4: (Continued)

Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm	Hel. JD	Δm
77.0142	−0.194	77.0827	0.165	77.1511	−0.173	77.2201	0.023	77.2900	−0.155
77.0156	−0.212	77.0841	0.235	77.1525	−0.186	77.2215	0.038	77.2914	−0.170
77.0170	−0.216	77.0855	0.262	77.1545	−0.162	77.2229	0.056	77.2928	−0.165
77.0184	−0.210	77.0869	0.298	77.1559	−0.184	77.2243	0.081	77.2942	−0.179
77.0198	−0.222	77.0888	0.341	77.1573	−0.198	77.2257	0.105	77.2956	−0.182
77.0212	−0.247	77.0902	0.387	77.1587	−0.197	77.2271	0.118	77.2970	−0.187
77.0231	−0.243	77.0916	0.456	77.1601	−0.235	77.2295	0.178	77.2984	−0.212
77.0245	−0.271	77.0930	0.512	77.1615	−0.220	77.2309	0.210	77.2998	−0.196
77.0259	−0.269	77.0944	0.561	77.1629	−0.193	77.2323	0.237	77.3018	−0.209
77.0273	−0.258	77.0958	0.618	77.1643	−0.221	77.2337	0.280	77.3032	−0.204
77.0287	−0.247	77.0972	0.660	77.1657	−0.223	77.2351	0.315	77.3046	−0.229
77.0301	−0.265	77.0986	0.675	77.1676	−0.209	77.2365	0.343	77.3060	−0.234
77.0315	−0.237	77.1000	0.665	77.1690	−0.210	77.2379	0.407	77.3074	−0.227
77.0329	−0.252	77.1019	0.655	77.1704	−0.227	77.2393	0.422	77.3088	−0.229
77.0343	−0.258	77.1033	0.651	77.1718	−0.201	77.2407	0.481	77.3102	−0.232
77.0362	−0.233	77.1047	0.668	77.1732	−0.219	77.2421	0.499	77.3116	−0.236
77.0376	−0.235	77.1061	0.629	77.1746	−0.217	77.2440	0.551	77.3130	−0.233
77.0390	−0.246	77.1075	0.570	77.1760	−0.220	77.2454	0.569	77.3149	−0.247
77.0404	−0.257	77.1089	0.513	77.1774	−0.221	77.2468	0.538	77.3163	−0.249
77.0418	−0.228	77.1103	0.482	77.1788	−0.225	77.2482	0.541	77.3177	−0.256
77.0432	−0.226	77.1117	0.414	77.1807	−0.213	77.2496	0.529	77.3191	−0.235
77.0446	−0.235	77.1131	0.358	77.1821	−0.239	77.2510	0.497	77.3205	−0.240
77.0461	−0.231	77.1151	0.309	77.1835	−0.209	77.2524	0.455	77.3219	−0.237
77.0475	−0.228	77.1165	0.287	77.1849	−0.211	77.2538	0.410	77.3233	−0.226
77.0494	−0.224	77.1179	0.234	77.1863	−0.220	77.2552	0.388	77.3247	−0.236
77.0508	−0.198	77.1193	0.187	77.1877	−0.202	77.2571	0.324	77.3261	−0.236
77.0522	−0.244	77.1207	0.160	77.1891	−0.204	77.2585	0.298	77.3280	−0.214
77.0536	−0.203	77.1221	0.153	77.1905	−0.201	77.2599	0.272	77.3294	−0.227
77.0550	−0.183	77.1235	0.095	77.1919	−0.177	77.2613	0.234	77.3308	−0.226
77.0564	−0.178	77.1249	0.076	77.1939	−0.179	77.2627	0.210	77.3322	−0.212
77.0578	−0.156	77.1263	0.051	77.1953	−0.176	77.2641	0.159	77.3336	−0.207
77.0592	−0.143	77.1282	0.011	77.1967	−0.171	77.2655	0.123	77.3350	−0.211
77.0606	−0.170	77.1296	0.012	77.1981	−0.184	77.2669	0.111	77.3364	−0.200
77.0625	−0.133	77.1310	−0.029	77.1995	−0.162	77.2683	0.044	77.3378	−0.193