PS Vir: an Short-period Solar-like Contact Binary

Huiyu Yuan¹, Haifeng Dai², Yuangui Yang¹,²

¹ School of information, Huaibei Normal University, 235000 Huaibei, Anhui Province, China
² School of Physics and Electronic Information, Huaibei Normal University, 235000 Huaibei, Anhui Province, China

yygcn@163.com

Received 2018 February 24; accepted 2018 April 4

Abstract We presented multi-color photometric observations and one-dimension spectrum for the short-period eclipsing binary PS Vir, by using the 2.16-m, 85-cm and 60-cm telescopes at Xinglong station (XLs) of National Astronomical Observatories of China (NAOC) from March 2016 to May 2017. The spectral type was determined as G2V from the one-dimension spectrum. The photometric solution was reduced from $BVRC$ light curves. The results imply that PS Vir is a W-subtype contact binary with a mass ratio of $q = 0.305(\pm 0.008)$ and a fill-out factor of $f = 14.4(\pm 1.8)\%$. The orbital period may be undergoing a cyclic oscillation with an amplitude of $A = 0.0027(\pm 0.0001)$ days and a modulated period of $11.7(\pm 0.2)$ years, which may result from the light-time effect due to the third body. The lower mass for the assumed component is $0.12 \, M_\odot$. Moreover, the more massive component of PS Vir may be a bit evolved star from the mass-luminosity diagram.

Key words: binaries: close — binaries: eclipsing — stars: individual (PS Vir) — stars

1 INTRODUCTION

W UMa contact binaries (i.e., EW-type) are eclipsing systems in which both stars overflow their Roche lobes, sharing a common envelope (Lucy 1968). They are formed from nearly normal main-sequence stars with spectral types usually between F and K. Their light amplitudes are usually $< 0.8$ mag in $V$ band and the depths of both eclipsing minima are almost equal (Samus et al. 2017), implying that two component possess almost identical temperature. The mass ratio generally ranges from 0.2 to 0.5, but reported values are almost as high as unity for GU Mon (Lorenzo et al. 2016) and as low as 0.065 for V857 Her (Qian et al. 2005). The extreme mass-ratio may preliminarily be $0.044(\pm 0.007)$ from a statistical analysis of 46 deep, low mass-ratio overcontact binaries (Yang & Qian 2015). The orbital periods are usually smaller than one day. According to the newest statistics based on LAMOST data (Qian et al. 2017), the peak of period distribution is near to 0.29 day, and the short-period cut-off at 0.2 day. Although the EW-type binaries have recently been detected by several surveys, i.e., the Robotic Optical Transient Search Experiment (ROTSE; Akerlof et al. 2000), the Optical Gravitational Lensing Experiment (OGLE; Szymański et al. 2001), and the All Sky Automated Survey (ASAS; Pojmanski 2002), the high-precision photometry and spectroscopy for individual stars are necessitated in order to study the intrinsic light variability, such as DZ Psc (Yang et al. 2013) and V410 Aur (Lou et al. 2017), and determine the absolute parameters.

* Supported by the National Natural Science Foundation of China NO. 11473009 and U1231102
PS Vir (=GSC 00279-00321) is a W UMa-type binary from the automated variable star classification using the Northern Sky Variability Survey (Woźniak et al. 2004). Hoffman et al. (2009) obtained an orbital period of 0.28982 days and a light variable amplitude of 0.423 mag by the Fourier analysis method. From the VizieR Online Data Catalog 3, the magnitude and colors for this star are $J = 10.719(\pm 0.021)$ mag, $J - H = 0.428(\pm 0.022)$ mag and $H - K = 0.066(\pm 0.021)$ mag, respectively. Koppelman & Terrell (2002) identified that its light curve belongs to the characteristic shape of a W UMa binary from their unfiltered observations. This binary system shows a large asymmetry of about 0.1 mag between the maxima, which may be attributed to the X-ray emission arising from coronal activity.

In present paper, we describe the observational data and their reductions of PS Vir in Section 2. The complete light curves and one-dimension spectrum are presented. Two possible period studies are listed in Section 3, while we model $BVR_c$ light curves in Section 4. Finally, we give some discussions including the evolutionary state and the interpretations on the possible period variations.

2 OBSERVATIONS

2.1 Spectroscopy

The spectrum of PS Vir was taken at XLs of NAOC with the 2.16-m telescope attached with Beijing-Faint Object Spectrograph and Camera (BFOSC). We chose a 1.8 arcsec slit, and a $Grism - 3$ with a wavelength range from 3300Å to 6400Å. The exposure time of 600 seconds started at UT=12:26:10 of June 7, 2017 (i.e., HJD 2457941.0182). We extracted the one-dimensional spectrum and calibrated its wavelength according to the spectral atlas of BFOSC wavelength calibration lamps 4, after performing reduction including bias subtraction, flat-fielding, and cosmic-ray removal by IRAF packages. From the spectrum for PS Vir, it is easily to find some characteristic spectral lines, such as CaII (3934Å & 3968Å), CaI (4227Å), Hδ (4101Å), Hβ (4861Å), G-band (4308Å), which are shown in Fig.1. Comparing the

---

3 http://vizier.cfa.harvard.edu/viz-bin/VizieR?-source=II/246
Fig. 2 $BV_{Rc}$ light curves (a) and two eclipses (b) for the eclipsing binary PS Vir, observed by using the 60-cm and 85-cm telescopes, respectively. The computed light curves are plotted as continuous black lines by the photometric solution.

spectrum of PS Vir with the spectra in the stellar spectral flux library (Pickles 1998), we determined the spectral type of G2V by using the winmk software.

2.2 CCD Photometry

New photometry of PS Vir was carried out on March 23, 24 and 27, 2016 with the 60-cm telescope (Yang et al. 2010), and on April 30 and May 1, 2017 with the 85-cm telescope (Zhou et al. 2009) at XLS of NAOC. Those two telescopes are respectively equipped with the standard Johnson-Cousins-Bessel $UBV_{Rc}I_c$ systems. All effective CCD images were reduced by using the IMRED and APPHOT packages of IRAF in a standard mode. Differential magnitudes between the variable and comparison stars are obtained by aperture photometry.

In the observation process, TYC 0279-0536-1 and 2MASS J1157 3732+0620392 were chosen as comparison and check stars respectively. On 2016 March, we obtained a set of complete light curves, shown in Fig.2(a). The exposure times are 40s for $B$, 20s for $V$ and 10s for $R_c$ band, respectively. The individual magnitude differences versus heliocentric Julian dates (i.e., HJD vs $\Delta m$), are available on request. The standard derivations are estimated to be $\pm 0.024$ mag in $B$, $\pm 0.017$ mag in $V$ and $\pm 0.026$ mag in $R_c$ bands, respectively. From Fig.2(a), the multi-color light curves identify that PS Vir may be a W UMa-type eclipsing binary. The large asymmetry of about 0.1 mag between both maxima (Koppelman & Terrell 2002) disappears in the new light curves. On April 30 and May 1, 2017, moreover, two eclipses for PS Vir were observed as displayed in Fig.2(b). Using our new observations together Koppelman & Terrell’s (2002) data, we determined several light minimum times, which are listed in Table 1 including their observed errors and measured methods.

3 ORBITAL PERIOD VARIATIONS

In order to study the period changes for PS Vir, we compile all available eclipsing times from the O–C gateway. All those data with their errors are listed in Table 2, including 2 photoelectric and 23 CCD measurements.

---

5 http://www.appstate.edu/grayro/MK/winmk.htm
6 http://var2.astro.cz/ocgate/?lang=en
The $(O - C)$ diagrams for PS Vir. The solid circles represent photoelectric and CCD data. The continuous red lines in both upper panels are plotted by Eq.(2) and Eq.(3), respectively.

In the calculating process, the individual weights are given inversely proportional to their uncertainties. The orbital period of PS Vir is updated to be as follows,

$$\text{Min.I} = \text{HJD} \ 2452425.7321(11) + 0.28980595(9) \times E,$$

where the numbers in brackets are given the errors in the last decimal place. Based on Eq.(1), we obtained the initial residuals, $(O - C)_i$, which are listed in Table 2 and also shown in the upper panels of Fig.3.

From this figure, we easily found that the $(O - C)_i$ curve may be described to be an upward parabola, which implies the existence a long-term period increase. So we yielded the following equation,

$$\hspace{0.5cm} (O - C)_i = +0.0026(\pm 0.0001) - 9.2(\pm 0.1) \times 10^{-7} \times E + 5.01(\pm 0.53) \times 10^{-11} \times E^2.$$  \hspace{1cm} (2)

The corresponding residuals, $(O - C)_q$, are listed in Table 2 and also displayed in the lower panel of Fig.3(a). The value of $\chi^2/N$ from Eq.(2) is 29.2. From the coefficient of the quadratic term, a period increase rate is computed to be $dP/dt = +1.26(\pm 0.13) \times 10^{-7} \text{d yr}^{-1}$. Eq.(2) is plotted as a solid line shown in its upper panel of Fig.3(a).

As shown in Fig.3, there exists a gap between HJD 2452431.6761 (Koppelman & Terrell 2002) and HJD 2454535.5201 (Brát et al. 2008) up to about 18 years. We assumed that the parabolic curve may be a part of a sine curve. Therefore, the residuals $(O - C)_i$ were fitted by a linear and sinusoidal ephemeris.

By using a nonlinear weighted least-squares method, we obtained the following equation,

$$\hspace{0.5cm} (O - C)_i = 0.0014(\pm 0.0002) + 0.0027(\pm 0.0001) \times \sin [4.26(\pm 0.07) \times 10^{-5} \times E + 0.228(\pm 0.065)].$$  \hspace{1cm} (3)

The corresponding residuals, $(O - C)_c$, are also listed in Table 2 and shown in the lower panel of Fig.3(b). The value of $\chi^2/N$ from Eq.(3) is 18.1. In its upper panel of Fig.3(b), a solid line is described by Eq.(3). By using the relation of $P_{\text{mod}} = 2\pi P/\omega$ with $\omega = 4.26(\pm 0.07)$ and $P = 0.28980595(9) \text{ days}$, a modulated period of $P_{\text{mod}} = 11.7(\pm 0.2) \text{ years}$ can be computed. The kind of case is similar to our previous studied binaries, WY Tau (Yang 2009) and AR Dra (Yang et al. 2016). The small value of $\chi^2/N$ from Eq.(3) may imply that it may represent the true period changes although it needs to be checked in the future observations.

Fig. 3
4 MODELING LIGHT-CURVES

Photometric solution for PS Vir is deduced from $BV R_c$ light curves in 2016 by the updated version of Wilson-Devinney program (Wilson & Devinney 1971; Wilson 1979; Wilson & van Hamme 2014), including Kurucz’s (1993) stellar atmosphere model. The albedos and gravity darkening coefficients are set to be $A_{p,s} = 0.5$ (Rucinski 1973) and $g_{p,s} = 0.32$ (Lucy 1967), which are appropriate for stars with convective envelopes. Following van Hamme’s (1993), we determined the logarithmic bolometric (i.e., $X$ and $Y$) and monochromatic limb-darkening coefficients (i.e., $x$ and $y$), which are based on the effective temperatures of the stars. During the calculation, the adjustable parameters are listed as follows, $i$, $q$, $T_s$, $\Omega_{p,s}$, $L_p$ and $\ell_3$.

Based on the spectral type of G2V, we adopted the effective temperature for the primary component to be $T_p = 5800(\pm 80)$K (Cox 2000). As shown in Fig.2(a), three color light curves for PS Vir include 319 in $B$, 341 in $V$ and 293 in $R_c$ band, which are simultaneously used to obtain the photometric elements. The calculation always uses Mode 3 (i.e., contact configuration). Due to lack of a spectroscopic mass ratio, we firstly search for a mass ratio, which ranges from 0.2 to 4.4 with a step of 0.1. After performing a series of solutions with fixed mass ratios, we obtained the relation of $q$ and $\Sigma(a-c)$, which are displayed in Fig.4. From this figure, we got a minimum value of $\Sigma(a-c)$ around $q = 3.4$. This implies that PS Vir is a W-subtype of contact binary. Then we considered $q$ and $\ell_3$ as free parameters. At last we got the best photometric solution, listed in Table 3.

The computed light curves are constructed as solid lines in Fig.2(a). The third lights in $BV R_c$ bands are $\ell_{3B} = 0.42\%$, $\ell_{3V} = 0.30\%$ and $\ell_{3R} = 0.33\%$, respectively. The mass ratio and fill-out factor for this binary are $q_{ph} = 0.305(\pm 0.008)$ and $f = 14.4(\pm 1.5)\%$, respectively. Therefore, PS Vir is a short-period solar-like shallow contact binary. It resembles another two binaries, DD Com (Zhu et al. 2010) and AD Cnc (Qian et al. 2007), whose period can show increase, decrease and cyclic change.

5 DISCUSSIONS

From the previous analysis, we deduced the photometric solution with a weak third light for $BV R_c$ light curves. The orbital period of PS Vir may be undergoing a secular period increasing or a periodic oscillation. Due to the small value of $\chi^2/N$, Eq(3) is accepted to be the final result for period variations, which
Fig. 5 Mass-luminosity diagram for PS Vir. The solid and open circles refer to the primary and secondary components for the W-subtype LTBs (Yakut & Eggleton 2005).

is similar to other eclipsing binaries such as WW Dra (Liao et al. 2010), BI Vul (Qian et al. 2013), IR Cas (Zhu et al. 2004), V401 Cyg (Zhu et al. 2013) and V1191 Cyg (Zhu et al. 2011). Based on the G2V-type star, we estimated the mass of the more massive component to be $M_p = 1.00(\pm 0.03) M_\odot$ (Cox 2000), whose error results from an uncertainty of a subtype spectral type. Combining the photometric elements, we can determine other absolute parameters, which are listed in Table 4. In order to describe the evolutionary status for PS Vir, we construct the mass-luminosity diagram in Fig.5. The zero-age main sequence (ZAMS) and the terminal-age main sequence (TAMS) are computed by the binary-star evolution code (i.e., BSE, Hurley et al. 2002). From this figure, the more massive component for PS Vir is between ZAMS and TAMS lines, which implies that it may be an evolved star. Meanwhile, the less massive star lies above the TAMS line. This may result from the energy transfer from the primary to the secondary, which is similar to other W-subtype LTBs (Yakut & Eggleton 2005).

For the eclipsing binaries, the observed period oscillations may be interpreted by either the cyclic magnetic activity (Applegate 1992) or light-time effect via the presence of the third body (Irwin 1952). Applegate (1992) pointed out that the period oscillation may be contributed to magnetic activity cycles through the variations of gravitational quadrupole moment, $\Delta Q$, in one or both components. With the relation of $\Delta Q = -9 M a^2 \Delta P / P$ (Lanza & Rodonò 2002), the variations of the quadruple moment $\Delta Q_{1,2}$ for both components are computed, and also listed in Table 4. For a contact binary, the typical value of $\Delta Q$ is of the order of $10^{51}-10^{52}$ (Lanza & Rodonò 1999). $\Delta Q_{1,2}$ from Table 4 are evidently much smaller than the typical value. Therefore we can remove this mechanism in the binary’s PS Vir.

Another possible mechanism is the light-time effect due to the third body, which may result in the cyclic variations. With the fitting parameters in Eq.(3), we can easily obtain a mass function of $f(m) = 7.46(\pm 0.83) \times 10^{-4} M_\odot$ for the assumed third body. Finally, we can obtain the minimum mass of $M_3 = 0.12(\pm 0.1) M_\odot$ at $a_{12} = 5.3(\pm 0.4)$ AU. This kind of effect may be efficient to detect low mass objects such as substellar objects in NN Ser (Qian et al. 2009) and HU Aqr (Qian et al. 2011). The kind of low-mass dwarf is difficult to find a direct evidence due to its extremely low luminosity, which is weakly identified by the third light from Table 3 (i.e., $l_3 < 0.5\%$). However, the small values of $\Delta Q_{1,2}$ imply that Applegate’s magnetic mechanism may not work. The observed periodic oscillation may result from light-time effect via the presence of an additional component, which implies that PS Vir may be a triple star. This may provide the observational evidence that contact binary stars exist in
multiple systems (D’Angelo et al. 2006; Pribulla & Rucinski 2006; Rucinski et al. 2007). In the future observation, it necessitates to obtain high-precision photometry and spectroscopy in order to check the period changes and to determine its absolute parameters.

Acknowledgements The research leading to the results has received funding from the National Natural Science Foundation of China (Nos. 11473009 and U1231102), and the Outstanding Young Talents Program of the Education Department of Anhui Province (Nos. gxyq2018161). Many thanks are given to the anonymous referee for his constructive comments and helpful suggestions. We acknowledge the support of the staff of the Xinglong 2.16m/85cm/60cm telescope. This work was partially supported by the Open Project Program of the Key Laboratory of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences.

References

Yang, Yuan-Gui, 2009, PASJ, 61, 1211
Yang, Yuan Gui, & Qian, Shengbang, 2015, AJ, 150: 69
Zhu, L.-Y., Qian, S.-B., & Xiang, F.-Y. 2004, PASJ, 56, 809
Table 1  New light minimum times of PS Vir

<table>
<thead>
<tr>
<th>JD(Hel.)</th>
<th>Error</th>
<th>Min.</th>
<th>Filter</th>
<th>Telescope</th>
</tr>
</thead>
<tbody>
<tr>
<td>2457471.25747</td>
<td>±0.00016</td>
<td>I</td>
<td>B</td>
<td>60cm</td>
</tr>
<tr>
<td>2457471.25745</td>
<td>±0.00017</td>
<td>I</td>
<td>V</td>
<td>60cm</td>
</tr>
<tr>
<td>2457471.25694</td>
<td>±0.00019</td>
<td>I</td>
<td>R</td>
<td>60cm</td>
</tr>
<tr>
<td>2457472.27085</td>
<td>±0.00015</td>
<td>II</td>
<td>B</td>
<td>60cm</td>
</tr>
<tr>
<td>2457472.27149</td>
<td>±0.00018</td>
<td>II</td>
<td>V</td>
<td>60cm</td>
</tr>
<tr>
<td>2457472.27104</td>
<td>±0.00022</td>
<td>II</td>
<td>R</td>
<td>60cm</td>
</tr>
<tr>
<td>2457475.16894</td>
<td>±0.00012</td>
<td>II</td>
<td>B</td>
<td>60cm</td>
</tr>
<tr>
<td>2457475.16912</td>
<td>±0.00015</td>
<td>II</td>
<td>V</td>
<td>60cm</td>
</tr>
<tr>
<td>2457475.16921</td>
<td>±0.00019</td>
<td>II</td>
<td>R</td>
<td>60cm</td>
</tr>
<tr>
<td>2457874.08541</td>
<td>±0.00020</td>
<td>I</td>
<td>B</td>
<td>85cm</td>
</tr>
<tr>
<td>2457874.08521</td>
<td>±0.00017</td>
<td>I</td>
<td>V</td>
<td>85cm</td>
</tr>
<tr>
<td>2457875.10064</td>
<td>±0.00014</td>
<td>II</td>
<td>B</td>
<td>85cm</td>
</tr>
<tr>
<td>2457875.10215</td>
<td>±0.00027</td>
<td>II</td>
<td>V</td>
<td>85cm</td>
</tr>
<tr>
<td>2452313.86998*</td>
<td>±0.00079</td>
<td>I</td>
<td>V</td>
<td>IBVS5299</td>
</tr>
<tr>
<td>2452313.86867*</td>
<td>±0.00049</td>
<td>I</td>
<td>Ic</td>
<td>IBVS5299</td>
</tr>
<tr>
<td>2452425.73392*</td>
<td>±0.00015</td>
<td>I</td>
<td>no</td>
<td>IBVS5299</td>
</tr>
<tr>
<td>2452426.74984*</td>
<td>±0.00026</td>
<td>II</td>
<td>no</td>
<td>IBVS5299</td>
</tr>
<tr>
<td>2452431.67610*</td>
<td>±0.00023</td>
<td>II</td>
<td>no</td>
<td>IBVS5299</td>
</tr>
</tbody>
</table>
Table 2 All Compiled Light Minimum Times for PS Vir

<table>
<thead>
<tr>
<th>JD(Hel.)</th>
<th>Error</th>
<th>Epoch</th>
<th>Type</th>
<th>Method</th>
<th>((O - C)_e) (days)</th>
<th>((O - C)_y) (days)</th>
<th>((O - C)_c) (days)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2452313.8693</td>
<td>±0.0006</td>
<td>−386.0</td>
<td>I</td>
<td>CCD</td>
<td>+0.0022</td>
<td>−0.0008</td>
<td>+0.0006</td>
<td>(1)</td>
</tr>
<tr>
<td>2452425.7339</td>
<td>±0.0001</td>
<td>+0.0</td>
<td>I</td>
<td>CCD</td>
<td>+0.0017</td>
<td>−0.0009</td>
<td>−0.0004</td>
<td>(1)</td>
</tr>
<tr>
<td>2452426.7498</td>
<td>±0.0003</td>
<td>3.5</td>
<td>II</td>
<td>CCD</td>
<td>−0.0033</td>
<td>+0.0007</td>
<td>+0.0012</td>
<td>(1)</td>
</tr>
<tr>
<td>2452431.6761</td>
<td>±0.0002</td>
<td>20.5</td>
<td>II</td>
<td>CCD</td>
<td>+0.0029</td>
<td>+0.0003</td>
<td>+0.0008</td>
<td>(1)</td>
</tr>
<tr>
<td>2454535.5201</td>
<td>±0.0002</td>
<td>7280.0</td>
<td>I</td>
<td>CCD</td>
<td>+0.0006</td>
<td>+0.0020</td>
<td>+0.0002</td>
<td>(2)</td>
</tr>
<tr>
<td>2454583.3377</td>
<td>±0.0002</td>
<td>7445.0</td>
<td>I</td>
<td>CCD</td>
<td>+0.0002</td>
<td>+0.0017</td>
<td>+0.0000</td>
<td>(2)</td>
</tr>
<tr>
<td>2454863.8671</td>
<td>±0.0002</td>
<td>8413.0</td>
<td>I</td>
<td>CCD</td>
<td>−0.0025</td>
<td>−0.0009</td>
<td>−0.0016</td>
<td>(3)</td>
</tr>
<tr>
<td>2454924.4284</td>
<td>±0.0005</td>
<td>8622.0</td>
<td>I</td>
<td>CCD</td>
<td>−0.0007</td>
<td>+0.0009</td>
<td>+0.0004</td>
<td>(4)</td>
</tr>
<tr>
<td>2455267.7136</td>
<td>±0.0003</td>
<td>9806.5</td>
<td>II</td>
<td>CCD</td>
<td>−0.0006</td>
<td>+0.0010</td>
<td>+0.0013</td>
<td>(5)</td>
</tr>
<tr>
<td>2455318.2827</td>
<td>±0.0001</td>
<td>9981.0</td>
<td>I</td>
<td>CCD</td>
<td>−0.0026</td>
<td>−0.0010</td>
<td>−0.0006</td>
<td>(6)</td>
</tr>
<tr>
<td>2455318.4291</td>
<td>±0.0001</td>
<td>9981.5</td>
<td>II</td>
<td>CCD</td>
<td>−0.0011</td>
<td>+0.0005</td>
<td>+0.0009</td>
<td>(6)</td>
</tr>
<tr>
<td>2455605.9142</td>
<td>±0.0015</td>
<td>10973.5</td>
<td>II</td>
<td>CCD</td>
<td>−0.0035</td>
<td>−0.0020</td>
<td>−0.0014</td>
<td>(7)</td>
</tr>
<tr>
<td>2455629.3898</td>
<td>±0.0003</td>
<td>11054.5</td>
<td>II</td>
<td>pe</td>
<td>−0.0022</td>
<td>−0.0008</td>
<td>−0.0001</td>
<td>(8)</td>
</tr>
<tr>
<td>2455650.4024</td>
<td>±0.0002</td>
<td>11127.0</td>
<td>I</td>
<td>pe</td>
<td>−0.0006</td>
<td>+0.0008</td>
<td>+0.0015</td>
<td>(9)</td>
</tr>
<tr>
<td>2455677.7865</td>
<td>±0.0003</td>
<td>11221.5</td>
<td>II</td>
<td>CCD</td>
<td>−0.0031</td>
<td>−0.0017</td>
<td>−0.0011</td>
<td>(7)</td>
</tr>
<tr>
<td>2455978.8938</td>
<td>±0.0005</td>
<td>12260.5</td>
<td>II</td>
<td>CCD</td>
<td>−0.0042</td>
<td>−0.0031</td>
<td>−0.0027</td>
<td>(10)</td>
</tr>
<tr>
<td>2456011.3540</td>
<td>±0.0002</td>
<td>12372.5</td>
<td>II</td>
<td>CCD</td>
<td>−0.0023</td>
<td>−0.0012</td>
<td>−0.0009</td>
<td>(11)</td>
</tr>
<tr>
<td>2456011.5006</td>
<td>±0.0003</td>
<td>12373.0</td>
<td>I</td>
<td>CCD</td>
<td>−0.0006</td>
<td>+0.0005</td>
<td>+0.0008</td>
<td>(11)</td>
</tr>
<tr>
<td>2456026.7135</td>
<td>±0.0002</td>
<td>12425.0</td>
<td>II</td>
<td>CCD</td>
<td>−0.0025</td>
<td>−0.0014</td>
<td>−0.0011</td>
<td>(12)</td>
</tr>
<tr>
<td>2456063.7135</td>
<td>±0.0006</td>
<td>12460.0</td>
<td>I</td>
<td>CCD</td>
<td>+0.0010</td>
<td>+0.0021</td>
<td>+0.0024</td>
<td>(10)</td>
</tr>
<tr>
<td>2457471.2575</td>
<td>±0.0006</td>
<td>17410.0</td>
<td>I</td>
<td>CCD</td>
<td>+0.0038</td>
<td>+0.0020</td>
<td>+0.0010</td>
<td>(1)</td>
</tr>
<tr>
<td>2457472.2711</td>
<td>±0.0002</td>
<td>17413.5</td>
<td>II</td>
<td>CCD</td>
<td>+0.0031</td>
<td>+0.0013</td>
<td>+0.0003</td>
<td>(1)</td>
</tr>
<tr>
<td>2457475.1691</td>
<td>±0.0001</td>
<td>17423.5</td>
<td>II</td>
<td>CCD</td>
<td>+0.0030</td>
<td>+0.0012</td>
<td>+0.0002</td>
<td>(1)</td>
</tr>
<tr>
<td>2457874.0853</td>
<td>±0.0002</td>
<td>18800.0</td>
<td>I</td>
<td>CCD</td>
<td>−0.0013</td>
<td>−0.0017</td>
<td>−0.0013</td>
<td>(1)</td>
</tr>
<tr>
<td>2457875.1014</td>
<td>±0.0002</td>
<td>18803.5</td>
<td>II</td>
<td>CCD</td>
<td>+0.0031</td>
<td>+0.0001</td>
<td>+0.0005</td>
<td>(1)</td>
</tr>
</tbody>
</table>


Table 3 Photometric Elements of the Contact Binary PS Vir

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Primary</th>
<th>Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>q = (M_p/M_\star)</td>
<td>0.305(±0.008)</td>
<td>(M_\star)</td>
</tr>
<tr>
<td>T(K)</td>
<td>5800(±80)</td>
<td>5976(±8)</td>
</tr>
<tr>
<td>(X, Y)</td>
<td>+0.649, +0.220</td>
<td>+0.660, +0.210</td>
</tr>
<tr>
<td>(x_B, y_B)</td>
<td>+0.837, +0.158</td>
<td>+0.830, +0.187</td>
</tr>
<tr>
<td>(x_V, y_V)</td>
<td>+0.761, +0.238</td>
<td>+0.749, +0.257</td>
</tr>
<tr>
<td>(x_R, y_R)</td>
<td>+0.609, +0.254</td>
<td>+0.657, +0.267</td>
</tr>
<tr>
<td>(\Omega_B = \Omega_\star)</td>
<td>2.4505(±0.0034)</td>
<td>(L_\star)</td>
</tr>
<tr>
<td>(L_\star + L_\star + L_\star + L_\star)</td>
<td>0.2926(±0.0018)</td>
<td>(L_\star)</td>
</tr>
<tr>
<td>(L_\star + L_\star)</td>
<td>0.2831(±0.0017)</td>
<td>(L_\star)</td>
</tr>
<tr>
<td>(L_\star + L_\star)</td>
<td>0.2776(±0.0024)</td>
<td>(L_\star)</td>
</tr>
<tr>
<td>(L_\star + L_\star)</td>
<td>0.42(±0.05)%</td>
<td>(L_\star)</td>
</tr>
<tr>
<td>(L_\star + L_\star)</td>
<td>0.33(±0.07)%</td>
<td>(L_\star)</td>
</tr>
<tr>
<td>(r_{pole})</td>
<td>0.6404(±0.0005)</td>
<td>0.2688(±0.0003)</td>
</tr>
<tr>
<td>(r_{side})</td>
<td>0.4963(±0.0005)</td>
<td>0.2808(±0.0003)</td>
</tr>
<tr>
<td>(r_{back})</td>
<td>0.5235(±0.0006)</td>
<td>0.3187(±0.0004)</td>
</tr>
<tr>
<td>(f)</td>
<td>14.4(±1.8)%</td>
<td>(f)</td>
</tr>
</tbody>
</table>

* Note: the third light \(L_3\) is \(L_3/(L_1 + L_2 + L_3)\).
Table 4 Absolute Parameters and Related Deduced Values for PS Vir

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Primary</th>
<th>Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$ (AU)</td>
<td>2.01(±0.03)</td>
<td></td>
</tr>
<tr>
<td>$M$ ($M_\odot$)</td>
<td>1.00(±0.03)</td>
<td>0.31(±0.02)</td>
</tr>
<tr>
<td>$R$ ($R_\odot$)</td>
<td>1.10(±0.03)</td>
<td>0.58(±0.02)</td>
</tr>
<tr>
<td>$L$ ($L_\odot$)</td>
<td>1.24(±0.06)</td>
<td>0.39(±0.02)</td>
</tr>
<tr>
<td>$\Delta P/P^*$</td>
<td>3.97(±0.15)</td>
<td>$\times 10^{-6}$</td>
</tr>
<tr>
<td>$\Delta Q$ ($\times 10^{49}g$ cm$^2$)</td>
<td>1.72(±0.07)</td>
<td>0.53(±0.02)</td>
</tr>
<tr>
<td>$a_{12}$ sin $i'$ (AU)</td>
<td></td>
<td>0.467(±0.017)</td>
</tr>
<tr>
<td>$f(m)$ ($M_\odot$)</td>
<td>7.46(±0.83)</td>
<td>$\times 10^{-4}$</td>
</tr>
</tbody>
</table>