TESTING A PULSATING BINARY MODEL FOR LONG SECONDARY PERIODS IN RED VARIABLES

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Received 2009 November 9; accepted 2010 March 1; published 2010 April 7

ABSTRACT

The origin of the long secondary periods (LSPs) in red variables remains a mystery until now, although many models exist. The light curves of some LSP stars mimic an eclipsing binary with a pulsating red giant component. To test this hypothesis, the observational data of two LSP variable red giants, 77.7795.29 and 77.8031.42, discovered by the MACHO project from the Large Magellanic Cloud, are collected and analyzed. The probable eclipsing features of the light curves are simulated by the Wilson–Devinney method. The simulation yields a contact and a semidetached geometry for the two systems, respectively. In addition, the pulsation constant of the main pulsating component in each binary system is derived. By combining the results of the binary model and the pulsation component, we investigate the feasibility of the pulsating binary model. It is found that the radial velocity curve expected from the binary model has a much larger amplitude than the observed one and a period double the observed one. Furthermore, the masses of the components based on the density derived from the binary orbit solution are too low to be compatible with both the evolutionary stage and the high luminosity. Although the pulsation mode identified by the pulsation constant which is dependent on the density from the binary model is consistent with the first or second overtone radial pulsation, we conclude that the pulsating binary model is a defective model for the LSP.

Key words: binaries: close – galaxies: individual (LMC) – stars: late-type – stars: oscillations

Online-only material: color figures

1. INTRODUCTION

Among the variable red giant stars, one sub-type exhibits long secondary periods (LSPs). The light curves of these stars exhibit not only a short primary period but also an LSP, which is approximately nine times longer than the short one. This phenomenon has been known for several decades (Payne-Gaposhkin 1954; Houk 1963). Some samples of these LSP variables are shown in Kiss et al. (1999). An interest in stars with LSPs has been renewed by the study of Wood et al. (1999). This paper shows that in the Large Magellanic Cloud (LMC), ∼25% of all variable asymptotic giant branch (AGB) stars show LSPs roughly nine times longer than the short primary period which is typically ∼30–200 days. Meanwhile, a study of the bright local pulsating red giants indicates that at least one-third of these stars exhibit LSPs (Percy et al. 2004). Soszyński also gives ∼30% of pulsating red giants in the LMC with LSPs (Soszyński et al. 2007). In the period–luminosity (P–L) diagram, it is interesting to see that the LSP variables follow a distinct sequence (sequence D), which is roughly parallel to the radial pulsation sequences A, B, and C for variable red giants.

The LSPs present in variable red giants have attracted a lot of attention since their discovery, but their origin still remains mysterious. Since the LSPs are several times longer than the fundamental radial periods, they could not be caused by normal radial pulsations. Moreover, Wood et al. (1999) and Wood et al. (2004) note that the LSPs cannot be explained by g+ mode for the oscillatory g− mode is evanescent in the convective region and it is unlikely to be observable in a red giant because of its convective envelope. The g− mode is dynamically unstable in the convection envelope, and unable to lead to any oscillation. Regarding the nonradial p modes, their periods are rather shorter than those of the fundamental radial modes, so they cannot explain the LSPs either. Alternatively, if the LSPs are caused by some strange modes, they would be extremely damped and should not be seen (Wood 2000). One more possible explanation is the rotating spheroid model, which can explain the shape of the velocity curve, but there is no reason for the rotating period to bring about the observed P–L relation.

It seems that variable red giants with LSPs (hereinafter referred to as LSPVs) cannot be easily interpreted as pulsating red giants. In this situation, a hypothesis of binarity arose. It has been suggested that the sequence D stars could be components of close binary systems, and the LSPs could be interpreted as the light variations caused by ellipsoidal binary motions or eclipses. Soszyński et al. (2004, 2007) and Derekas et al. (2006) find that the sequence D stars overlap with and have a direct continuation of the sequence E stars that are mostly confirmed to be binaries. Radial velocity variations on the timescale of LSPs have also been measured in a number of sequence D stars; such radial velocity variations are a requirement if the sequence D stars are binaries (Hinkle et al. 2002; Olivier & Wood 2003; Wood et al. 2004; Nicholls et al. 2009). Some observational arguments supporting the binary hypothesis have already been reviewed by Soszyński (2007).

After examining the light curves of LSPVs collected from the MACHO database, we note that many of them show some nearly regular and stable, eclipse-like light variations at the LSPs with a large amplitude in comparison with that of the primary pulsation. It seems that the LSPs can be easily interpreted as eclipses by an orbiting component. If this can be shown to be the case, it would be direct evidence to support the binary hypothesis for the sequence D stars. To test this idea, we propose a model—pulsating binary, i.e., a binary system with a pulsating component. We begin with some very probable eclipsing LSP candidates whose light curves look like eclipsing binaries with primary and secondary minima. The light curves of two LSP stars are collected and analyzed by using the Wilson–Devinney (W–D, hereafter) code and the
power-spectrum method. Afterward, the proposed eclipsing and pulsating nature as well as their evolutionary properties are discussed.

2. THE DATA

Since the LSPs are sometimes as long as 1500 days, the candidate selection is based on the long-term MACHO survey. The MACHO project is a microlensing experiment that monitored numerous stars in the LMC, SMC, and Galactic Bulge over a time of ~3000 days. As the by-products of this survey, a large number of variables were discovered and monitored, including many LSPVs. From this database, two LSPVs in the LMC are selected as our program objects. Their field.title.sequence (F.T.S) numbers are 77.7795.29 and 77.8031.42, respectively. They are chosen as the working sample for the following reasons. (1) The time base of observations for both of the stars is long enough to cover at least a couple of LSPs. (2) Their light variations are both eclipse-like and symmetric over the LSP, and have distinct short primary variation. (3) These two stars are quite different from each other not only in their LSPs but also in the shapes of the light curves; they are expected to be different types of binaries.

The MACHO data are taken in non-standard red and blue bandpasses. The adopted transformation from the MACHO instrumental photometry to Kron–Cousins R and V are given in Alcock et al. (1999). However, it does not work well for our candidates in practice and brings about visible dispersion for the photometric points. Analyzing the data sets, we find the reason mainly being that the observed color index term “(V_{M.i} - R_{M.i})” in Alcock et al. (1999) brings in large dispersion as the raw red and blue magnitudes transfer their errors to each other. This term requires both measurements to be good at each time when adopting the transformation. In addition, the transformation has a term involving air mass. When the value of the air mass is greater than 2.0, the correction for the atmosphere extinction is rather uncertain. We adopt another transformation to avoid the above problems as Struble et al. (2006):

\[ R = R_{M.i} + 23.90 + 0.1825(V_{M.i} - R_{M.i}) \]
\[ V = V_{M.i} + 24.22 - 0.1804(V_{M.i} - R_{M.i}) \]

where the term “V_{M.i} - R_{M.i}” is the mean color index for a red giant instead of an individual measurement. Since color indexes of the red giants have a small scattering of about 0.2 mag, the adoption of the mean multiplied by a factor of 0.18 brings about a dispersion of only 0.04 mag, much smaller than the photometric uncertainty. The light curves of standardized R and V magnitudes for our two candidates are shown in Figure 1.

OGLE–II ( Udalski et al. 1997; Szymański 2005) also provides the light variation data for red giants in the I band, and the time span of the light curve overlaps the last half of the MACHO data, with ~300 days extension which is not long for the LSP. Besides and more importantly, the data are much sparser than the MACHO in the overlapping time range and it is of little help in analyzing the short primary pulsation. Thus we do not include the OGLE–II data for following analysis.

3. THE BINARY MODEL

Assuming that the phenomenon of the LSPs is caused by an orbiting component, we can employ some binary simulation method to analyze the LSP light curve. The W–D method, which consists of two main FORTRAN programs—LC and DC (short for Light Curve and Differential Correction, respectively)—is a simulation method producing the photometric solution for the binary system.

The 2007 version of the W–D code is used to analyze the eclipse-like light curves in R and V bandpasses of our two candidates. Nonlinear limb-darkening via a logarithmic form along with many other features (Wilson & Devinney 1971; Wilson 1979, 1990; Kallrath et al. 1998) are used in the code. Considering the likely close distance between the components, the effect of reflection is taken into account.

In computing the photometric solution, the important parameters adopted in the DC program are as follows. The orbital period for adjustment is computed by the Phase Dispersion Minimization (PDM) method (Stellingwerf 1978) and the Period04 software for double-check at the beginning. The value is about 970 days for 77.7795.29 and 1700 days for 77.8031.42. Note that these orbital periods are twice the normally adopted value for the LSP, the latter corresponding to one cycle of long-period variation apparent in the light curve. The temperatures of the two primary stars are both set to 3311 K according to Fox & Wood (1982) for long-period stars. The initial bolometric (X1,X2,Y1,Y2) and monochromatic (x1,y1,x2,y2) limb-darkening coefficients of the components are taken from Van Hamme (1993). The gravity darkening exponents are set to 0.32 for both the primary and the secondary component for convective envelopes according to Lucy (1967). The bolometric albedos are taken as A1 = 0.4 and A2 = 0.5 following Rucinski (1969).

The preliminarily estimated parameters are put in the first iteration of the DC code and after several iterations, a converged solution is reached. The photometric solutions are shown in Table 1, and the synthesized R-band light curves computed from the LC code are shown in Figure 1 together with the observed curves of the two candidates. The photometric solutions in the table provide insight into the orbital dynamics of the binary system. The orbit period (P_{orb}) adjusted by the DC code is consistent with the value from the PDM and Period04 method. The large angles of inclination (i), and argument of periastron (\omega) describe the orientation of the binary orbit, while the value of e reveals a nearly circular orbit. Moreover, we find that the secondary component is a low-mass M-type star, according to the mass ratio and effective temperature. All the binary modes, including detached mode, semidetached mode, and contact mode in the code are tried in the solution-seeking procedure, and it is found that only one mode can reach a converged solution for each candidate. For 77.7795.29, a contact configuration converges, and for 77.8031.42, a semidetached system with the primary component filling its Roche lobe converges.

| Parameter 77.7795.29 | Parameter 77.8031.42 |
|-----------------------|----------------------|
| Classification        | Contact              | Semidetached        |
| p_{orb} (day)         | 970.9                | 1700.9              |
| T_1 (K)               | 3311 (assumed)       | 3311 (assumed)      |
| T_2 (K)               | 3284                 | 3544 ± 48           |
| e                     | 0.0016 ± 0.0008      | 0.0123 ± 0.0164     |
| i (degree)            | 62.49 ± 0.27         | 63.19 ± 2.22        |
| \omega                | 3.64 ± 0.20          | 2.91                |
| q = m_2/m_1           | 0.608 ± 0.003        | 0.486 ± 0.029       |
| \psi_1                | 2.8359 ± 0.0041      | 2.8748              |
| \psi_2                | 2.8359 ± 0.0041      | 2.8943 ± 0.055      |
| L_1/(L_1 + L_2) (V band) | 0.609              | 0.561              |
implies that both of them have a mass exchange with their components due to Roche lobe overflow. No converged solutions were found for systems showing purely ellipsoidal variations, i.e., systems with an invisible secondary companion.

Using the photometric solutions, the theoretical radial velocities can also be simulated by the LC code. We try this in order to compare them with some observational facts. The bottom panel of Figure 1 shows the synthesized velocity curves for the primary components. The full amplitude of the velocity variation is about 11.0 km s$^{-1}$ for 77.7795.29, and 9.0 km s$^{-1}$ for 77.8031.42, where the value of the binary system mass is taken from Section 5 (but see discussion there for the problem of mass). Yet all the studies of radial velocity for LSPVs (Hinkle et al. 2002; Olivier & Wood 2003; Wood et al. 2004; Nicholls et al. 2009) show typical amplitudes of 3–4 km s$^{-1}$ and no objects with full velocity amplitude greater than 7 km s$^{-1}$ are found. Moreover, the synthesized velocity curves of the primary components have a period that is twice that of the light variation period. In contrast, all the observed radial velocities for the LSPVs have the same period as that of the light variation. The synthesized radial velocities for the second stars are also obtained from the LC code, and we find that the full amplitude is about 18.5 km s$^{-1}$ for 77.7795.29 and 18.3 km s$^{-1}$ for 77.8031.42. The large velocity separations between the primary and secondary stars would have been readily seen, while in the existing spectral observations there is no indication of this. Therefore, the synthesized velocity curve based on the binary model is inconsistent with the observation.

In addition, we should note that, among all the parameters derived from the DC code, some are highly reliable, including the orbital period, mass ratio, and temperature difference, if we admit the binary hypothesis, and some are relatively uncertain, such as the effective temperatures of the two components. Several parameters derived from the LC code, such as the mass

Figure 1. Light and velocity curves synthesized by the W–D code for 77.7795.29 and 77.8031.42. Also shown are the observed $R$- and $V$-band light curves from the MACHO project. Red asterisk represents the observed data point in $R$ band, while the blue one is the $V$-band data point. The black solid line in the $R$-band panel denotes the theoretical synthesized light curve. The bottom panel is the synthesized velocity curve.

(A color version of this figure is available in the online journal.)
and radius, are particularly uncertain for there are no radial velocities available for comparison, so they are not listed in Table 1. The synthesized radial velocities produced by the LC code are also very uncertain.

4. THE INTRINSIC PULSATION

For an eclipsing binary with a pulsating (primary) component, the observed light curve could be approximately interpreted as (Zhang et al. 2009)

\[ l_{\text{obs}} = l_1 f_{\text{pul}} + l_2, \]

where \( l_1 \) and \( l_2 \) are the calculated brightness contributed by the primary and secondary components, respectively, and \( f_{\text{pul}} \) denotes the pulsating variation of \( l_1 \). With the derived binary photometric solution, we could compute the brightness of the binary components separately at each observation epoch by using the LC code in the W–D code package, from which the "pure" pulsation light variation of the primary star could then be extracted. However, we do not use this approach, because the intrinsic pulsating amplitude of the primary component is so large that the theoretically synthesized light curve computed by the LC code would have up-down fluctuation and the extracted light curve would not be exactly equivalent to the true intrinsic pulsation variations. Instead, we make use of the original data sets to analyze the primary pulsation.

Period04, a commonly used technique for time series analysis, which utilizes Fourier transforms as well as multiple-least-squares algorithms, is applied to the power-spectrum analysis. In doing that, we use the R-band time series data which are brighter and with higher photometric accuracy than in the V band. We select only those peaks in the power spectrum with signal-to-noise ratio (S/N) larger than 4.0 for further discussion. Figures 2 and 3 show the first four-frequency solution of the data sets in the R band before and after subtraction of the most prominent remaining frequency (prewhitening). At the top of
the two figures, the spectral window based on the epochs of available observations is displayed. We notice that the alias patterns, including the 1 c d\(^{-1}\) daily alias, are quite low in power. The next four patterns in both figures are the step-by-step power spectrum derived from the pulsation data. The fitting is stopped when the light curve is well fitted. The results of the frequency analysis are given in Table 2. For 77.7795.29, nine frequencies are obtained, by using most parts of the MACHO data while the last part of the MACHO data is dropped because of a large gap. Among all the nine frequencies obtained, we find that the main power spectrum are dominated at \(f_1 = 0.0020\) c d\(^{-1}\) and \(f_2 = 0.0100\) c d\(^{-1}\). \(f_1\) is 2 times the assumed orbital frequency \(f_0 = 1/970 = 0.00103\) c d\(^{-1}\), it is not accepted as the real pulsating frequency, so only \(f_2\) remains as the intrinsic pulsating frequency. The other derived frequencies are found to be related to \(f_0\) and \(f_2\) as follows: \(f_1 = 2f_0\), \(f_3 = f_2 + 6f_0\), \(f_4 = f_0\), \(f_5 = 4f_0\), \(f_6 = f_2 + 1/365\), \(f_7 = f_2 + 7f_0\), \(f_8 = 3f_0\), \(f_9 = 5f_0\), all of them are aliases. For the other star 77.8031.42, we obtain \(f_2 = 0.0112\) c d\(^{-1}\), the real pulsating frequency, and the others have the relations of: \(f_1 = 2f_0\), \(f_3 = 4f_0\), \(f_4 = f_2 + 0.0004\), \(f_5 = 3f_0\), \(f_6 = 2f_0 + f_8\), \(f_7 = 4f_0\), \(f_8 = 1/365\), \(f_9 = f_2 + 10f_0\), \(f_{10} = f_2 - 0.0004\), \(f_{11} = f_0 + f_8\), \(f_{12} = 10f_0\), \(f_{13} = 12f_0\), \(f_{14} = f_0\), where \(f_0\) is the assumed orbital frequency. Here, 0.0004 c d\(^{-1}\), may be the rotation frequency of the LSPVs, in the theoretical range of 2400–10000 days for the rotation period of red giants (Kiss et al. 2000; Wood et al. 2004). Based on the above analysis, only one short primary pulsation is found for our two candidates, respectively, and the result is consistent with previous result from Wood et al. (1999) for LSPs stars.

The eclipsing light curve synthesis has provided us some important parameters of the binary system such as the mass ratio and the unified radius \(r_1 = R_1/A\) which normalizes the radius to the semi-major axis (actually the accurate ratio can be obtained by the LC code). With these values, the mean density of the pulsating primary component can be precisely determined.
From Kepler's law

$$p_{\text{orb}}^2 = \frac{4\pi^2 A^3}{G(M_1 + M_2)}$$

and the density in solar units

$$\rho_1 / \rho_\odot = \frac{M_1 / R_1^3}{M_\odot / R_\odot^3},$$

we get

$$\rho_1 / \rho_\odot = \frac{4\pi^2 R_1^3}{M_\odot G(1 + q) r_1^2 p_{\text{orb}}^2},$$

where $p_{\text{orb}}$ is the orbit period of the binary system.

Substituting the values of $P_{\text{orb}}$, $q$, and $r_1$ from the W-D code analysis of the light curve into Equation (3), the mean density is computed, being $8.47 \times 10^{-3}$ and $3.67 \times 10^{-8}$ in solar unit, respectively, which agrees with the density of red giants. Then the pulsation constant can be easily calculated from $Q = P_{\text{pul}}(\rho_1 / \rho_\odot)^{1/2}$, where $P_{\text{pul}}$ is the “pure” pulsation period. The pulsation constant $Q$ is an important parameter to tell the intrinsic oscillation mode of a pulsating star, especially in normal radial mode. The $Q$ value calculated on the binary hypothesis, is shown in Table 3 and equal to 0.029 and 0.017 for our two candidates, respectively.

The values of $r_1$ calculated by the LC code in Table 3, 0.47 and 0.44, respectively, are consistent with that estimated in Soszyński et al. (2007), which notices $R_1/A \approx 0.4$ in the binary scenario. The result of mode identification shows agreement with the theoretical expectation for red giants (Fox & Wood 1982) and reveals that 77.7795.29 is a first overtone pulsating star while 77.8031.42 is a second overtone pulsating star. The pulsation properties derived from a binary model are reasonable for a pulsating red giant.

### 5. THE EVOLUTIONARY PROPERTY

A further analysis of the pulsating binary model is carried out from the evolutionary property of the components, as the stellar properties of the red giants are rarely known, by making use of the results derived in Section 4. From the Two Micron All Sky Survey (2MASS) near-infrared photometric data and the empirical bolometric correction factor $BC_K$ as a function of $(J-K)$ (Bessell & Wood 1984), and with a distance modulus of 18.54 for the LMC, the bolometric magnitude can be calculated, and the luminosity can thus be obtained. Applying the formula $L = 4\pi \sigma R^2 T_{\text{eff}}^4$, the equilibrium radius of the primary star can be computed. Here, $T_{\text{eff}}$ is an assumed value, 3311 K, which is the mean temperature for long-period variables in LMC. We do not calculate the temperature from the color index because the secondary component is not understood well and its contribution to the observed color index is not known. With the mean density and the radius, the mass of the primary star is derived. All these values are listed in Table 3.

The luminosity of the primary stars in the table is a few hundreds of solar luminosity, consistent with the red giant luminosity. The radii of both candidate stars are on the order of hundreds of solar radius, which are consistent with red giants. However, the masses of the two LSPVs are too low, and the masses of their components would be even lower, according to the mass ratios in Table 1. Moreover, these low-mass stars have very high luminosities, which seems impossible. For the star 77.7795.29, the mass is $0.31 M_\odot$ and its luminosity is $2502 L_\odot$. In the age of universe, such a low-mass star is impossible to evolve up to the red giant branch. For the secondary component, the mass is about $0.188 M_\odot$, while its luminosity is $1607 L_\odot$, the value of which is computed from the data of “$L_1/(L_1 + L_2)$” in Table 1. It is hard to imagine how such low-mass stars in a binary system exchange their masses. It is difficult to find an evolutionary path to satisfy this situation. This problem is also present in the star 77.8031.42, with a mass of $0.36 M_\odot$.

### Table 3

Parameters of the Primary Stars

| Star          | Frequency (c d$^{-1}$) | $R_1/A$ | $\rho_1/\rho_\odot$ | $Q$ | Mode | $M_{\text{bol}}$ (mag) | $L/L_\odot$ | $R/R_\odot$ | $M/M_\odot$ |
|---------------|------------------------|--------|---------------------|-----|------|------------------------|-------------|-------------|-------------|
| 77.7795.29    | 0.0100                 | 0.47   | 8.47E−8             | 0.029 | 1H   | −3.75                  | 2502        | 153         | 0.31        |
| 77.8031.42    | 0.0112                 | 0.44   | 3.66E−8             | 0.017 | 2H   | −4.46                  | 4839        | 213         | 0.36        |

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### Table 2

Results of Fourier Analysis for Stars 77.7795.29 and 77.8031.42

| Frequency (c d$^{-1}$) | Amplitude (mag) | Phase | S/N |
|------------------------|-----------------|-------|-----|
| $f_1$                  | 0.0020          | 0.2138| 0.3144| 21.6279 |
| $f_2$                  | 0.0100          | 0.0529| 0.6576| 22.4815 |
| $f_3$                  | 0.0162          | 0.0327| 0.0015| 13.9081 |
| $f_4$                  | 0.0011          | 0.0363| 0.9538| 15.4348 |
| $f_5$                  | 0.0041          | 0.0280| 0.6792| 11.9004 |
| $f_6$                  | 0.0130          | 0.0205| 0.8848| 7.0696  |
| $f_7$                  | 0.0174          | 0.0189| 0.4320| 8.1379  |
| $f_8$                  | 0.0031          | 0.0199| 0.0318| 8.0322  |
| $f_9$                  | 0.0049          | 0.0199| 0.6315| 8.4640  |

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The values of $r_1$ calculated by the LC code in Table 3, 0.47 and 0.44, respectively, are consistent with that estimated in Soszyński et al. (2007), which notices $R_1/A \approx 0.4$ in the binary scenario. The result of mode identification shows agreement with the theoretical expectation for red giants (Fox & Wood 1982) and reveals that 77.7795.29 is a first overtone pulsating star while 77.8031.42 is a second overtone pulsating star. The pulsation properties derived from a binary model are reasonable for a pulsating red giant.
and a luminosity of $4839 \, L_{\odot}$, whose component has about 0.175 $M_{\odot}$ and 3790 $L_{\odot}$. If a reasonable mass is expected, the density should be upgraded by a factor of 4 or the radius be upgraded by a factor of 1.4. Recalling the determination of the density from Equation (5), the density is calculated from the parameters, $q$, $r_1$, and $P_{\text{orb}}$ all of which have relatively small errors which will not bring about a density uncertainty of a factor of 4. Besides, the density is reasonable for a red giant. On the other hand, the radius is derived from the luminosity and effective temperature. The luminosity has uncertainty from the bolometric correction and the neglect of interstellar extinction, and the effective temperature also has some uncertainty. If the luminosity is higher or the effective temperature lower, the radius would be larger and so the mass. However, if the mass is indeed higher, the system would then have a large separation from Equation (3) and an even more serious problem with the large velocity amplitude. In summary, the pulsating binary model requires a low mass incompatible with an evolved stellar stage having the observed high luminosity.

6. DISCUSSION AND CONCLUSION

The origin of the LSPs is unknown and there exist many explanations. The light curves of some LSPVs are eclipse-like and it seems that this phenomenon is due to an invisible component orbiting around the pulsating red giant. To test this hypothesis, we propose a model—pulsating binary, and select two LSP stars to analyze their orbit motions and pulsation nature.

On the assumption of binarity, we simulate the photometric light curves of the systems by using the W–D method. The photometric solutions give us a configuration for the binary system: a contact system for 77.7795.29 and a semidetached system for 77.8031.42. It means that the LSP star may have strong interaction and very probably mass transfer with the other component via Roche lobe overflow. However, Roche lobe overflow will rule out the binary hypothesis if we accept the view of Wood et al. (2004), which states that the mass transfer of Roche lobe will result in a short merger timescale of about 1000 yr. Moreover, the calculated effective temperatures and the “$L_1/(L_1 + L_2)$” values in Table 1 suggest that the secondary star is also a red giant with a similar temperature and luminosity to that of the primary red giant. This would lead to a double-lined spectroscopic binary. However, no observer of radial velocities in these systems has reported seeing spectral lines from the secondary star (Hinkle et al. 2002; Olivier & Wood 2003; Wood et al. 2004; Nicholls et al. 2009). There are also some serious problems about the synthesized velocity curves. The simulation produces one cycle of velocity curve for two cycles of the light curve, while the observed velocities show one cycle of the radial velocity curve for one cycle of the light curve. The synthesized full velocity amplitudes for the star 77.7795.29 and 77.8031.42 are much greater than the typical values of other LSPVs. The full amplitudes of the secondary components are even larger and would lead to great velocity separations between the primary and the secondary stars, which have never been found by spectral observations.

Fourier analysis is applied to investigate the intrinsic oscillations of the LSPVs over the raw data sets. Using the parameters ($R_1$/$A$ and $q$) obtained from the W–D code, the mean densities of the LSPVs are deduced and they are consistent with the red giant phase. Then the pulsation constants are obtained by using the classical equation $Q = P_{\text{orb}}(p_1/p_0)^{1/2}$ to identify the pulsation mode. For star 77.7795.29, one pulsating frequency is detected and it is caused by the first overtone radial pulsation, and for star 77.8031.42, the only pulsating frequency is caused by the second overtone radial pulsation. These agree with the theoretical value for red giants and the conclusion of Wood et al. (1999).

The stellar properties of LSPVs are derived by using the information from the pulsating binary model. We calculate the bolometric magnitude, luminosity, radius, and mass of the primary star, and find some of them conflict very seriously with the evolutionary properties of red giants. In particular, the masses for the star 77.7795.29 and 77.8031.42 are both less than 0.4 $M_{\odot}$, and their luminosities are too high for such low masses. It is difficult to imagine how such low-mass stars could have such large luminosities. The situation gets even worse if we apply the mass ratio and the value of “$L_1/(L_1 + L_2)$” to calculate the mass and luminosity of the secondary star.

Therefore, the radial velocities and the masses computed from the pulsating binary model do not agree with some observations and facts about red giants. We conclude that the model “pulsating binary” has some deficiencies in dealing with the observed properties of LSPVs and that the binary hypothesis for explaining the LSPs seems unreasonable.

The authors are very grateful to Prof. Peter Wood for very constructive suggestions and helpful discussion. They also thank the anonymous referee for helpful suggestions to improve the work significantly. This research is supported by the National Natural Science Foundation of China (NSFC) through grant 10778601 and the Ministry of Science and Technology of the People’s Republic of China through grant 2007CB815406.

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