THE FIRST PHOTOMETRIC ANALYSIS OF THE OVERCONTACT BINARY MQ UMa WITH AN ADDITIONAL COMPONENT

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ABSTRACT

The first $V$, $R_c$, $I_c$ band light curves of MQ UMa are presented and analyzed using the Wilson–Devinney (W–D) program. It is discovered that MQ UMa is an A-subtype contact binary with a high fill-out ($f = 82\%$) and a low mass ratio ($q = 0.195$), which indicates that it is in the late evolutionary stage of late-type tidal-locked binary stars. The mass of the primary and secondary stars is estimated and the evolutionary status of the two components are placed on the H-R diagram. The W–D solutions also indicate that MQ UMa may be a triple system with an additional F5V type component. A sample of 16 high fill-out, low mass ratio overcontact binaries is collected and their possible evolution scenarios are discussed. Using the five times of minimum light recently observed together with those collected from the literature, the authors find that the observed–calculated ($O – C$) curve exhibits cyclic period variation. The cyclic period change also reveals the presence of a tertiary component, which may play an important role in the formation and evolution of this binary system by drawing angular momentum from the central system.

Key words: binaries: close – binaries: eclipsing – stars: evolution – stars: individual (MQ UMa)

1. INTRODUCTION

W UMa type binaries are cool short-period (usually less than 1 day) binary systems with both components filling their critical Roche lobes and sharing a common convective envelope during their main sequence evolutionary stage. The formation and evolution of W UMa type binary systems are still unsolved problems in astrophysics. The most popular evolutionary scenario is that they are formed from initially detached systems via angular momentum loss by means of magnetic stellar wind (Vilhu 1982; Eggen & Iben 1989). Model calculations suggest that these binary stars will ultimately coalesce into single stars, which may be progenitors of the poorly understood blue stragglers and FK Com stars (Stepien 2006, 2011). It has been widely accepted that the eruption of V1309 Sco was the result of a cool short-period binary merging. In this paper, we focus on the high fill-out, low mass ratio overcontact binaries which are at the late evolutionary stages of the contact configuration.

MQ UMa, also named GSC 3015 0374, is a typical W UMa type contact binary. It was first discovered by CCD observations from large-scale automatic sky surveys in 1999 (Kazarovets et al. 2005). Since then, several times of minimum light have been published, and it is included in the Tycho-2 Catalog and 2MASS All Sky Catalog. The Tycho-2 Catalog gives the magnitude of MQ UMa, which are $11.77 \pm 0.09$ mag in $B$ band and $11.22 \pm 0.09$ mag in $V$ band. The 2MASS All Sky Catalog gives the magnitude of MQ UMa in the $J$, $H$, and $K$ band filters, which are $10.616 \pm 0.026$ mag in $J$ band, $10.402 \pm 0.028$ mag in $H$ band and $10.387 \pm 0.018$ mag in $K$ band. However, there is neither light curve (LC) photometric solution nor spectroscopic information about this target.

2. THE CCD PHOTOMETRIC LCs AND TIMES OF MINIMUM LIGHT

The $V$, $R_c$, and $I_c$ bands CCD observations of MQ UMa were carried out in three nights on 2014 January 19, March 7, and April 26 with an Andor DW436 1K CCD camera attached to the 85 cm reflecting telescope at Xinglong Observation Base. The coordinates of the variable star, the comparison star, and the check star were listed in Table 1. During the observation, the broadband Johnson–Cousins $V$, $R_c$, $I_c$ filters were used. The integration times were 60 s for $V$ band, 40 s for $R_c$ band, and 30 s for $I_c$ band, respectively. PHOT (measured magnitudes for a list of stars) of the aperture photometry package in the IRAF4 was used to reduce the observed images. The average observational errors were $0.002$ mag for $V$ band, $0.003$ mag for $R_c$ band, and $0.003$ mag for $I_c$ band, respectively. The LCs of those observations are displayed in Figure 1.

We also got three times of minimum light on 2014 January 19 and April 26 while doing LC observations. After that, one time of minimum light was obtained on 2015 January 3 using the 60 cm reflecting telescope in Yunnan Observatories (YNOs), and another TOM was obtained on 2015 January 12 using the 1 m reflecting telescope in YNOs. Using the least-squares parabolic fitting method, five new CCD times of minimum light were determined and listed in Table 2.

3. ORBITAL PERIOD CHANGE OF MQ UMa

The study of orbital period change is very important for contact binary stars. However, the period change investigation of MQ UMa has been neglected since it was discovered. During the present work, all available times of minimum light are collected and listed in Table 3. Using the following linear
The comparison GSC 3015 0367 deviations of the comparison-check observations are 0.015 mag for $\alpha$ targets.

The new ephemeris is

$$\text{Min. } I \left( \text{HJD} \right) = 2451312.851 + 0^d4760666 \times E,$$

(1)

the $O-C$ (observed times of minimum light–calculated times of minimum light) values are calculated and listed in the fourth column of Table 3 and plotted in the upper panel of Figure 2. Minimum times with the same epoch have been averaged, and only the mean values are listed in Table 3. The general $O-C$ trend of MQ UMa shown in the upper panel of Figure 2 indicates a cyclic change in its orbital period. Based on the least-square method, a sinusoidal term is added to the linear ephemeris of Equation (2). The new ephemeris is

$$\text{Min. } I = 2451312.85732 \pm \text{0.00029}$$

$$+ 0.47606620(\pm 0.00000003) \times E$$

$$+ 0.005646(\pm 0.0001355) \sin \left[ 0.03438 \times E + 264.4293(\pm 1:356) \right].$$

(2)

The sinusoidal term reveals a cyclic change with a period of 13.6 years and an amplitude of 0.0056 days. The residuals from Equation (2) are displayed in the lowest panel of Figure 2.

It has to be mentioned that the data point at $E = 0$ seriously affect the $O-C$ fitting since there is no other time of minimum light between data points at $E = 0$ and $E = 6049$. Thus we check the first data carefully. Although the data point at $E = 0$ does not give its observational error, it was observed by CCD camera. We believe that it has a high time precision as other CCD data. So we add it to the $O-C$ fitting and give the results as above. The cyclic period change in Equation (2) may be caused by the light travel time effect of the third component.

Actually, we can only ensure the existence of a tertiary component. The exact orbit period of the third body can not be determined for the absence of data point between $E = 0$ and $E = 6049$. In the present work, we just estimate a typical period which gives a very nice fitting results in Figure 2. In order to verify the periodic variations presented here, more determinations of minimum lights are required in the future.

### Table 1

| Targets       | Name           | $\alpha_{2000}$ | $\delta_{2000}$ |
|---------------|----------------|-----------------|-----------------|
| Variable      | MQ UMa         | 1h29m41.1      | +43°36’52”38’’ |
| The comparison| GSC 3015 0367  | 1h29m19.2      | +43°38’09”9”   |
| The check     | GSC 3015 0408  | 1h29m19.2      | +43°31’51”4”   |

### Table 2

| JD (Hel.) | Error (days) | Min. Filter | Method | Telescopes |
|-----------|--------------|-------------|--------|------------|
| 2456677.1653 | ±0.0004 | I         | VR,c   | CCD       | 85 cm  |
| 2456677.4031 | ±0.0005 | II        | VR,Ic  | CCD       | 85 cm  |
| 2456774.0451 | ±0.0003 | II        | VR,Ic  | CCD       | 85 cm  |
| 2457026.3616 | ±0.0006 | II        | VR,Ic  | CCD       | 1 m    |
| 2457035.4084 | ±0.0004 | II        | Ic     | CCD       | 60 cm  |

**Notes.** 60 cm and 1 m denote the 60 cm and 1 m reflecting telescope in Yunnan Observatories, and 85 cm denotes the 85 cm reflecting telescope in Xinglong Observation base.

Figure 1. CCD photometric light curves in $V$, $R$, and $I$ bands. The magnitude difference between the comparison and the check stars is presented. The standard deviations of the comparison-check observations are 0.015 mag for $V$ band, 0.015 mag for $R$ band, and 0.017 mag for $I$ band. Crosses, open circles, and triangles correspond to the data observed on January 19, March 7, and April 26, respectively.

4. PHOTOMETRIC SOLUTIONS OF MQ UMa

MQ UMa is a newly determined binary system, and neither its LC photometric solution nor spectroscopic observation has been published since it was discovered in 1999 (Kazarovets et al. 2005). As shown in Figure 1, the LC variations in three colors are continuous and have very small magnitude differences between the depth of the primary and secondary minima. It means that MQ UMa ia a typical EW-type contact binary. In Figure 1, the LC data have been shifted vertically which make no difference to the results of Wilson–Devinney (W–D) program as differential photometry method is used. The phases are calculated with the following linear ephemeris:

$$\text{Min. } I(\text{HJD}) = 2456677.1653(4) + 0^d476058 \times E.$$

(3)

To understand its geometrical structure and evolutionary state, the $V R_c$ and $I_c$ LCs shown in Figure 1 are analyzed using the
2013 version of the W–D program (Wilson & Devinney 1971; Wilson et al. 2010; Wilson 1979, 1990, 2008, 2012; Van Hamme & Wilson 2007). The number of observational data points used in the W–D program are 377 in V band, 380 in R_c band, and 375 in I_c band, respectively. According to the Tycho-2 Catalog measurements, the color index of $B-V = 0.55$, which corresponds to a spectral type of F9, but the 2MASS All Sky Catalog gives the color index of $J-H = 0.214$, corresponding to a spectral type of F4 (Cox 2000). Thus the spectral type of MQ UMa ranges from F9 to F4, which means

| JD (Heli.) (2400000+.) | Min | Epoch | $(O - C)$ | Error | Method | Reference |
|------------------------|-----|-------|-----------|-------|--------|-----------|
| 51312.8513             | I   | 0     | 0.0003    | …     | CCD    | (1)       |
| 54192.5885             | I   | 6049  | 0.0143    | 0.0008| CCD    | (2)       |
| 54499.6476             | I   | 6694  | 0.0108    | 0.0030| CCD    | (3)       |
| 54518.9277             | II  | 6734.5| 0.0102    | 0.0005| CCD    | (4)       |
| 54912.3940             | I   | 7561  | 0.0080    | 0.0001| CCD    | (5)       |
| 54931.4375             | I   | 7601  | 0.0088    | 0.0007| CCD    | (6)       |
| 55259.4448             | I   | 8290  | 0.0066    | 0.0003| CCD    | (7)       |
| 55289.4355             | I   | 8353  | 0.0052    | 0.0003| CCD    | (7)       |
| 55311.5753             | II  | 8399.5| 0.0079    | 0.0025| CCD    | (7)       |
| 55625.2975             | II  | 9058.5| 0.0027    | 0.0010| CCD    | (8)       |
| 55644.5823             | I   | 9099  | 0.0068    | 0.0003| CCD    | (9)       |
| 55660.5289             | II  | 9132.5| 0.0052    | 0.0034| CCD    | (10)      |
| 55669.5757             | II  | 9151.5| 0.0067    | 0.0004| CCD    | (10)      |
| 55877.6101             | II  | 9588.5| 0.0003    | 0.0005| CCD    | (9)       |
| 55937.8357             | I   | 9715  | 0.0035    | 0.0004| CCD    | (11)      |
| 56003.5322             | I   | 9853  | 0.0029    | 0.0020| CCD    | (9)       |
| 56003.5325             | I   | 9853  | 0.0032    | 0.0003| CCD    | (9)       |
| 56011.6263             | I   | 9870  | 0.0039    | 0.0004| CCD    | (13)      |
| 56677.1653             | I   | 11268 | 0.0026    | 0.0004| CCD    | (14)      |
| 56677.4031             | II  | 11268 | 0.0023    | 0.0004| CCD    | (14)      |
| 56774.0451             | II  | 11471.5| 0.0030   | 0.0003| CCD    | (14)      |
| 57062.3616             | II  | 12001.5| 0.0042   | 0.0006| CCD    | (14)      |
| 57035.4084             | II  | 12020.5| 0.0057   | 0.0004| CCD    | (14)      |

Reference: (1) Kazarovets et al. (2005), (2) Hubscher et al. (2009), (3) Brát et al. (2008), (4) Nelson (2009), (5) Brat et al. (2009), (6) Hubscher et al. (2010), (7) Brat et al. (2011), (8) Hubscher & Monninger (2011), (9) Hoňková et al. (2013), (10) Hubscher & Lehmann (2013), (11) Hubscher et al. (2012), (12) Nelson (2013), (13) Hubscher (2013), (14) present work.

Figure 2. $(O - C)_1$ values of MQ UMa from the linear ephemeris in Equation (1) is presented in the upper panel. The solid line in the panel refers to the combination of a new linear ephemeris and a cyclic variation. The dashed line represents the new linear ephemeris. In the middle part of Figure 2, $(O - C)_2$ values calculated from the new linear ephemeris in Equation (2) are displayed. The solid line refers to a theoretical light travel time effect (LTTE) orbit of the tertiary component in the system. The residuals from the whole effect are displayed in the lowest panel.
the effective temperature of the primary star ranges from 6095 to 6670 K (Cox 2000). Meanwhile, we also use the following period–color relation derived by Deb & Singh (2011) to estimate the effective temperature of the primary star.

\[ J - K = (0.11 \pm 0.01) \times P^{-1.19 \pm 0.08}. \] (4)

The equation is derived from a total sample of 141 contact binaries, whose spectral type ranges from A2V to K5V, and has a period from 0.2211 to 1.1318 days. The sample has covered nearly all kinds of W UMa type contact binaries which means it is appropriate for MQ UMa. The period of MQ UMa is 0.476058 days, so the color index of \( J - K \) calculated using Equation (4) is 0.266 (±0.042), which corresponds to a spectral type of F5 to F7. Because the advantage of the \( J - K \) color is not affected by interstellar extinction and uncertain reddening corrections as compared to the \( B - V \) color, the period–color relation using the infrared color \( J - K \) will be much more accurate. According to the temperature estimated by the two methods, the authors argue that MQ UMa is a late-F type W UMa contact binary system and adopt F7V as the spectral type of the primary star.

During the W–D processing, the effective temperature of star 1 is chosen as \( T_1 = 6352 \) K according to the spectral type determined. Convective outer envelopes for both components are assumed. The bolometric albedo \( A_1 = A_2 = 0.5 \) (Ruciński 1969) and the values of the gravity-darkening coefficients \( g_1 = g_2 = 0.32 \) (Lucy 1967) are used. To account for the limb darkening in detail, logarithmic functions are used. The corresponding bolometric and passband-specific limb-darkening coefficients are chosen from Van Hamme’s (1993) table. During the calculation, it was found that the solution converges at mode 3, and the adjustable parameters are: the mass ratio \( q \) (\( M_2/M_1 \)); the orbital inclination \( i \); the mean temperature of star 2 (\( T_2 \)); the monochromatic luminosity of star 1 (\( L_{1V}, L_{1R} \) and \( L_{1I} \)); the dimensionless potential of star 1 (\( \Omega_1 = \Omega_2 \) in mode 3 for overcontact configuration); and the third light (\( l_3 \)). Since there are no radial velocity curves of MQ UMa, a \( q \)-search method is used to determine the initial mass ratio at first. Solutions with mass ratio from 0.1 to 8 are investigated, and the relation between the resulting sum of weighted square deviations \( \sum \) and \( q \) is plotted in Figure 3. The minimum values are found at \( q = 0.2 \), which indicates that MQ UMa is an A-subtype contact binary. Then \( q = 0.2 \) is set as the initial value and considered as an adjustable parameter. The final photometric solutions are listed in Table 4 and the theoretical LCs (with \( l_3 \)) are displayed in Figure 4. The contact configuration of MQ UMa is displayed in Figure 5.

To make the photometric solutions of MQ UMa more convincing, we also do a \( q \)-search of MQ UMa by giving the effective temperature of the primary star at \( T_1 = 6100 \) K, \( T_1 = 6300 \) K, \( T_1 = 6500 \) K, and \( T_1 = 6700 \) K, respectively. As shown in Figure 6, although the effective temperature of the primary star ranges from 6100 to 6700 K, the shape of the \( q \)-search curves do not have any significant changes. All of the \( q \)-search results get the best-fitting mass ratio at \( q = 0.20 \) (±0.02). The convergent photometric solutions (with \( l_3 \)) are listed in Table 5. As shown in the table, although there is some uncertainty in the \( T_1 \) estimate (6100–6700 K), the solutions give nearly consistent results, which mean the W–D program can tolerate the uncertainty of the primary star’s temperature estimated by us. Therefore, the solution of \( T_1 = 6352 \) K is acceptable and we will take the photometric solutions of \( T_1 = 6352 \) K as the final results for MQ UMa hereafter.

5. DISCUSSIONS AND CONCLUSIONS

LC solutions indicate that MQ UMa is an A-subtype overcontact binary system with a contact degree of \( f = 82\% \). The two components have nearly the same surface temperature (\( \Delta T = 128 \) K) in spite of their quite different masses and radii, which indicates that the system is under thermal contact. The obtained mass ratio is \( q = 0.195 \). If we assume that the mass of the primary component is \( M_1 = 1.33M_\odot \) (Cox 2000) according to its spectral type (F7V), then the mass of the secondary is estimated to be \( M_2 = 0.28M_\odot \). The evolutionary status of the primary and the secondary stars are plotted in the H-R diagram.
The evolutionary status of the primary star places it in the middle between the Zero Age Main Sequence and the Terminal Age Main Sequence (TAMS) lines of the H-R diagram. The secondary component is evidently more evolved than the primary star, and it is clearly overluminous and has a higher effective temperature for its present mass.

During photometric processing, the third light \( (I_3) \) is also included as an adjustable parameter, and the results suggest that the third light contributes nearly a quarter of the total luminosity in the triple system. According to the third light values in the \( V, R, I \) filters listed in Table 4, the color index of the tertiary component is calculated to be \( V - R_c = 0.39 \) and \( R_c - I_c = 0.24 \), which correspond to a spectral type of F5V. It means that MQ UMa has a quite massive and an early type tertiary component. In addition, the existence of the third component may probably be confirmed by spectroscopic observations in the future. As discussed in Qian et al. (2013, 2014), the existence of an additional stellar component in the binary system may play an important role in the formation and evolution by removing angular momentum from the central binary system during the early dynamical interaction or late evolution. The angular momentum and orbital period of the binary system will decrease, and the initially detached binaries can evolve into a contact configuration via case A mass transfer during their main sequence evolutionary stage.

High fill-out, low mass ratio overconact binary systems are at the final evolutionary stage of cool short-period binaries. They may merge into a single rapid-rotation star. As a consequence, high fill-out, low mass ratio overcontact binary stars may be the progenitors of blue stragglers and FK Com type stars. A sample containing 16 high fill-out, low mass ratio overcontact binaries are presented in Table 6. Most of them are triple systems and all of them are undergoing continuous long time period variations (decreasing or increasing). Systems with a decreasing period will evolve into single rapid-rotation stars when the photospheric surface of the binary systems is close to the outer critical Roche lobe, while systems with an increasing period may merge when it meets the more familiar criterion of the orbital angular momentum being less than 3 times the total

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**Figure 4.** Observed (open circles) and theoretical (solid lines) light curves in the \( V, R, I \) bands for MQ UMa. The standard deviation of the fitting residuals is 0.006 mag for \( V \) band, 0.007 mag for \( R \) band, and 0.008 mag for \( I \) band, respectively.

**Table 4**

| Parameters | Values Without \( I_3 \) | Values With \( I_3 \) |
|------------|--------------------------|------------------------|
| \( \beta_1 \) | 0.32(fixed) | 0.32(fixed) |
| \( \beta_2 \) | 0.32(fixed) | 0.32(fixed) |
| \( \theta_1 \) | 0.50(fixed) | 0.50(fixed) |
| \( \theta_2 \) | 0.50(fixed) | 0.50(fixed) |
| \( q \) \( (M_2/M_1) \) | 0.211(±0.006) | 0.195(±0.008) |
| \( T_0 \) | 6352(fixed) | 6352(fixed) |
| \( \Omega_0 \) | 60.70(±0.20) | 65.58(±0.69) |
| \( \Omega_{out} \) | 2.259129 | 2.622506 |
| \( \Omega_2 = \Omega_3 \) | 2.125046 | 2.393652 |
| \( \Omega_3 \) | 2.203736(±0.001206) | 2.117244(±0.021541) |
| \( T_0(K) \) | 6116(±12) | 6224(±25) |
| \( L_1/(L_1 + L_2) (V) \) | 0.8211(±0.0009) | 0.8089(±0.0065) |
| \( L_1/(L_1 + L_2) (R) \) | 0.8172(±0.0009) | 0.8068(±0.0064) |
| \( L_1/(L_1 + L_2) (I) \) | 0.8138(±0.0009) | 0.8050(±0.0065) |
| \( L_1/(L_1 + L_2 + L_3) (V) \) | ... | 0.5970(±0.0102) |
| \( L_1/(L_1 + L_2 + L_3) (R) \) | ... | 0.6057(±0.0099) |
| \( L_1/(L_1 + L_2 + L_3) (I) \) | ... | 0.6103(±0.0100) |
| \( L_1/(L_1 + L_2 + L_3) (V) \) | ... | 0.2620(±0.0068) |
| \( L_1/(L_1 + L_2 + L_3) (R) \) | ... | 0.2492(±0.0064) |
| \( L_1/(L_1 + L_2 + L_3) (I) \) | ... | 0.2419(±0.0064) |
| \( \rho_i \) (pole) | 0.4963(±0.0023) | 0.5150(±0.0038) |
| \( \rho_i \) (side) | 0.5436(±0.0031) | 0.5710(±0.0055) |
| \( \rho_i \) (back) | 0.5707(±0.0030) | 0.6022(±0.0057) |
| \( \rho_i \) (pole) | 0.2510(±0.0115) | 0.2585(±0.0201) |
| \( \rho_i \) (side) | 0.2633(±0.0142) | 0.2735(±0.0257) |
| \( \rho_i \) (back) | 0.3114(±0.0330) | 0.3510(±0.1020) |
| \( \phi \) | 41.9%(±0.9%) | 825%(±17%) |
| \( \sum (O - C)^2 \) | 0.005077 | 0.004314 |
Figure 5. Contact configurations of MQ UMa at phase 0.0, 0.25, 0.5, 0.75.

Figure 6. $q$-search diagrams of $T_1 = 6100$ K (solid circles), $T_1 = 6300$ K (open circles), $T_1 = 6500$ K (solid squares), $T_1 = 6700$ K (open squares), and $T_1 = 6352$ K (triangles).

Table 5

| Parameters                  | Values     | Values     | Values     | Values     | Values     |
|-----------------------------|------------|------------|------------|------------|------------|
| $T_1$ (K)                   | 6700 (fixed) | 6500 (fixed) | 6300 (fixed) | 6100 (fixed) | 6352 (fixed) |
| $q$ ($M_2/M_1$)             | 0.202±0.005 | 0.212±0.004 | 0.216±0.007 | 0.208±0.005 | 0.195±0.008 |
| $i$ ($^\circ$)              | 63.09±0.66  | 61.10±0.58  | 61.33±0.60  | 61.24±0.60  | 65.58±0.69  |
| $\Omega_1 = \Omega_2$      | 2.158458±0.015663 | 2.202068±0.013527 | 2.209652±0.018830 | 2.193309±0.014472 | 2.117244±0.021541 |
| $T_2$ (K)                   | 6496±19    | 6270±18    | 6085±16    | 5898±16    | 6224±25    |
| $\Delta T$ (K)             | 204        | 230        | 215        | 202        | 128        |
| $T_2/T_1$                   | 0.970±0.003 | 0.965±0.003 | 0.966±0.003 | 0.967±0.003 | 0.980±0.004 |
| $\Sigma (O-C)^2$           | 0.004314   | 0.004317   | 0.004317   | 0.004321   | 0.004314   |

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spin angular momentum (Hut 1980). As for MQ UMa, the orbital period analysis based on observations collected from publicly available data and our own observations reveals that it is a triple system. However, we cannot determine the exact orbital period of the third component and it is unclear whether it is undergoing long time period variations (decreasing or increasing). Since the period variations are very important to understand their formation and evolution scenarios, those binary systems listed in Table 6 together with MQ UMa will be long-time monitored in the future.

Figure 7. The two components of MQ UMa are plotted on the H-R diagram. The solid line represents the Zero Age Main Sequence (ZAMS) and the dashed line represents the Terminal Age Main Sequence (TAMS).

Table 6
Parameters of High Fill-out, Low Mass Ratio Overcontact Binaries

| Star Name | T1   | T2   | Period | q   | f | i     | dp/dt | Cyclic | Ref. |
|-----------|------|------|--------|-----|---|-------|-------|--------|------|
| FG Hya    | 5900 | 6012 | 0.32783| 0.112| 85.6| 85:25 | -1.96 | yes    | (1)  |
| GR Vir    | 6300 | 6163 | 0.34698| 0.122| 78.6| 83:36 | -4.32 | yes    | (2)  |
| IK Per    | 9070 | 7470 | 0.67503| 0.191| 52.0| 77:75 | -2.50 | yes    | (3)  |
| CU Tau    | 5900 | 5938 | 0.41254| 0.177| 50.1| 73:95 | -18.1 | no     | (4)  |
| TV Mus    | 5980 | 5808 | 0.44586| 0.166| 74.3| 77:15 | -2.16 | yes    | (4)  |
| XY LMi    | 6144 | 6093 | 0.43689| 0.148| 74.1| 81:04 | -1.67 | ...    | (5)  |
| V410 Aur  | 6040 | 5915 | 0.36635| 0.143| 52.4| 78:6  | +8.22 | ...    | (6)  |
| XY Boo    | 6324 | 6307 | 0.37055| 0.186| 55.9| 69:0  | +6.25 | ...    | (6)  |
| V857 Her  | 8300 | 8513 | 0.38223| 0.065| 83.8| 85:43 | +2.90 | ...    | (7)  |
| AH Cnc    | 6300 | 6265 | 0.36044| 0.168| 58.5| 90:00 | +3.99 | yes    | (8)  |
| VX And    | 6500 | 6217 | 0.41217| 0.233| 58.9| 56:20 | +2.48 | ...    | (9)  |
| EM Psc    | 5300 | 4987 | 0.34396| 0.149| 95.3| 88:60 | +39.7 | yes    | (10) |
| V345 Gem  | 6115 | 6365 | 0.27477| 0.142| 72.9| 73:3  | +0.59 | yes    | (11) |
| V1191 Cyg | 6500 | 6626 | 0.31338| 0.107| 68.6| 80:4  | +4.5  | yes    | (12) |
| CK Boo    | 6380 | 6340 | 0.35515| 0.111| 71.7| 65:9  | +0.98 | yes    | (13) |
| DZ Psc    | 6210 | 6195 | 0.36613| 0.136| 89.7| 78:97 | +7.42 | yes    | (14) |

Reference: (1) Qian & Yang (2005), (2) Qian & Yang (2004), (3) Zhu et al. (2005), (4) Qian et al. (2005a), (5) Qian et al. (2011), (6) Yang et al. (2005), (7) Qian et al. (2005b), (8) Qian et al. (2006), (9) Qian et al. (2007), (10) Qian et al. (2008), (11) Yang et al. (2009), (12) Zhu et al. (2011), (13) Yang et al. (2012), (14) Yang et al. (2013).
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