

## CONTACT BINARIES IN THE FIELD OF STELLAR CLUSTERS

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### ABSTRACT

Several contact binary systems in four stellar clusters or their fields are reported here; NGC7789-V12, EP Cep and ES Cep in NGC188, NGC104-V95 and V710 Mon. Their multiple light curves were analyzed by the 2010 version of the W-D code, and their physical parameters were obtained.

*Key words:* Binaries: eclipsing— Stars: individual (NGC7789-V12, EP Cep, ES Cep, NGC104-V95, V710 Mon)— Stars: evolution

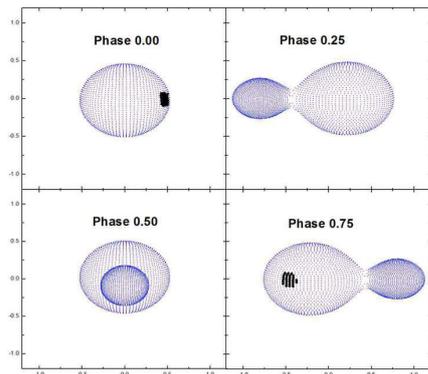


Figure 1. Geometrical structure of V12 at phases of 0.0, 0.25, 0.5, and 0.75, respectively. One dark spot on the secondary (the more massive component) is also shown in the panels.

### 1. BACKGROUND

Stellar clusters are good laboratories for determining the physical parameters of a contact binary system, whether the contact binary is a member or not. If it is a cluster member, obviously, the distance value of the cluster can be adopted for the binary system. Otherwise, we can use the extinction of the cluster and the color indices of the binary to estimate the binary's distance, under a linear extinction assumption. Here we reported several contact binary systems in four stellar clusters or in their fields.

### 2. CONTACT BINARIES IN THE CLUSTERS

When a contact binary is in a cluster, it should have the same distance as the cluster. The absolute mag-

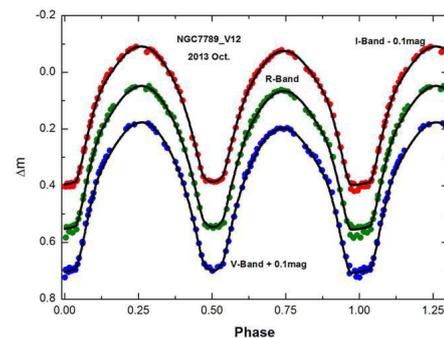


Figure 2. Observed (dots) and fitted (lines) light curves of NGC7789-V12.

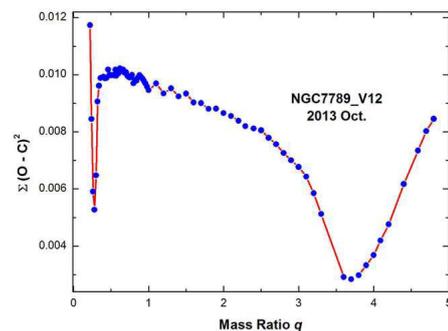


Figure 3. The relationship between  $q$  and  $\Sigma(O - C)^2$ .

nitudes can be computed by this well determined distance. On the other hand, the absolute magnitudes can also be calculated by photometric solutions with the W-D code. The set of parameters which makes these two distances equal should be a reasonable result. Thus, we can estimate the physical parameters of a cluster member contact binary without spectroscopic data. Af-

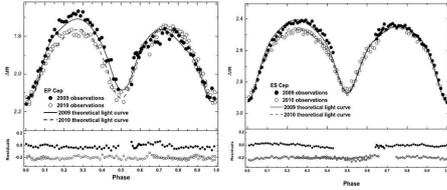


Figure 4. Comparison between the observed and theoretical light curves of EP and ES Cep. Left panel: the solid line represents the synthetic light curve with a dark spot on the secondary of EP Cep and the dashed line refers to the synthetic light curve with a dark spot on the primary of EP Cep. Right panel is the same as the left panel.

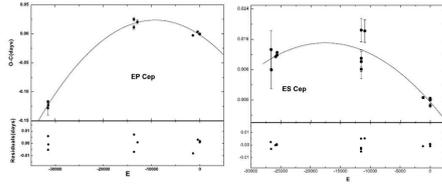


Figure 5. O-C curves of EP Cep (left) and ES Cep Per (right). The solid lines represent the quadratic fit curves. The dashed line refers to the linear fit. Dots in the upper panels represent residual CCD observations. All residuals are shown in the lower panels with dots (quadratic fit) and open circles (linear fit).

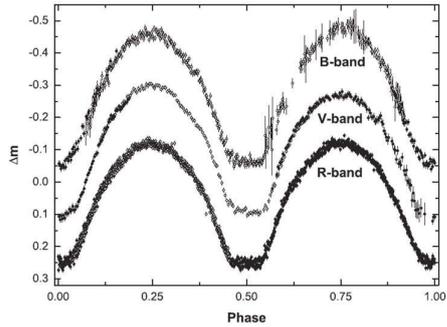


Figure 6. Observed light curves of V95 with errors.

ter all, spectroscopic observations are much harder than photometric observations, especially for the very distant faint contact binaries that are typical cluster members. We have observed the two open clusters, NGC7789 and NGC188, obtaining several light curves of contact binaries in them.

### 2.1. V12 in NGC7789

The NGC 7789 member V12 is a bright UMa-type binary star with an orbital period of 0.397 days. Its first complete light curves in V, R, and I bands have been analyzed with the W-D method. The results show that V12 is a W-type intermediate-contact binary ( $f = 43 \pm 2.2\%$ ) with a mass ratio of 3.848. The asymmetry of the light curves is explained by the presence of a dark spot on the more massive component. The possible long-term period increase at a rate of  $P = +2.48 \pm 0.17 \times 10^{-6}$  days/year reveals a rapid mass transfer from the less massive component to the more massive one. The presence of an intermediate-contact binary in an intermediate-age open cluster may suggest that some contact binaries have a very short pre-contact

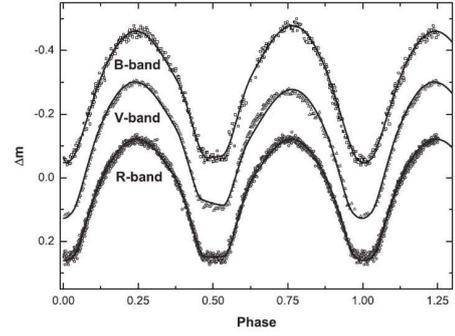


Figure 7. Observed (symbols) and theoretical (solid line, in case A) light curves of V95.

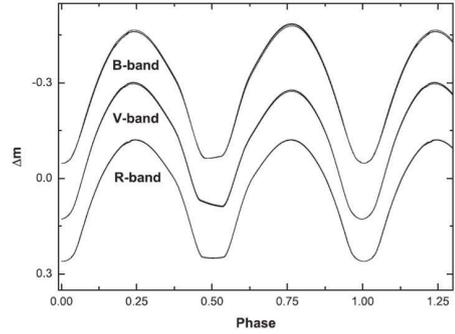


Figure 8. Comparison of light curves for the three cases. They are almost the same.

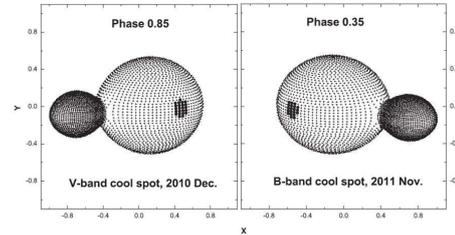


Figure 9. Geometrical structure of the high fill-out factor, extreme mass-ratio contact binary V95 with the changed cool spot. The spot is assumed to be on the more massive component.

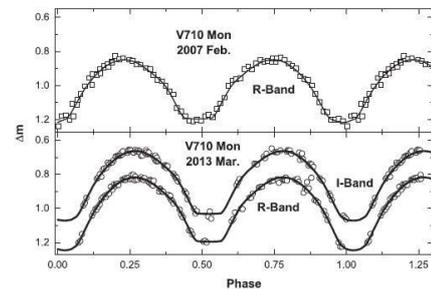


Figure 10. CCD photometric light curves of V710 Mon in R and I bands taken in (top) 2007 and (bottom) in 2013.

timescale. The presence of a third body or/and stellar collision may help to shorten the pre-contact evolution.

### 2.2. EP Cep and ES Cep in NGC188

The NGC188 members EP Cep and ES Cep are shallow-contact binaries (10.2%, 2.5%) with continuously de-

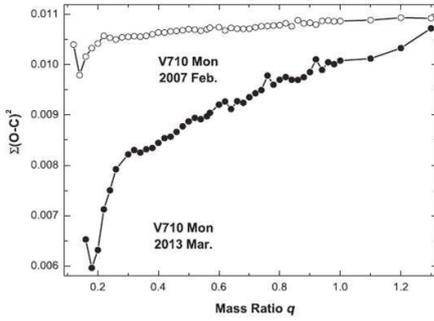


Figure 11. The fitting residuals versus the mass ratio.

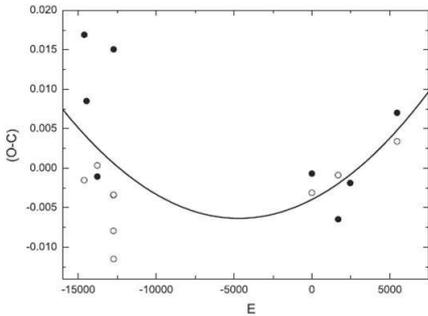


Figure 12. The (O-C) diagram of V710 Mon.

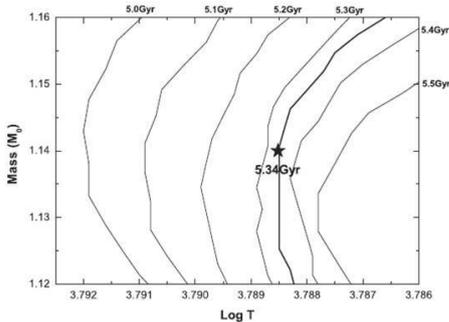


Figure 13. The Dartmouth model (Log T)-(M) isochrone diagram, with  $[Fe/H] = 0.0$  and  $[\alpha/Fe] = 0.0$ . The primary component is located along the 5.34 Gyr isochrone.

creasing periods ( $dP/dt = -3.73 \times 10^{-7}$  d/yr,  $dP/dt = -5.40 \times 10^{-8}$  d/yr). However, their mass ratios are quite different. EP Cep has an extremely low-mass ratio of  $q = 0.15$ , while ES Cep has a relatively high-mass ratio of  $q = 0.69$ , indicating that they lie in different evolutionary stages. The former is an evolved system and may be experiencing oscillations caused by the combined effect of the thermal relaxation oscillation and the variable angular momentum loss, while the latter is likely a newly formed contact binary via a Case A mass transfer.

### 3. CONTACT BINARIES IN THE FRONT OF THE CLUSTERS

When a contact binary is not in a cluster, it seems there is no connection with the cluster at all. However, we discovered that they can be connected via reddening. Once the contact binary and the cluster are in the same sight line, they are possibly reddened by the same matter. Their reddening should be the same if both of them are

behind the interstellar matter, or the reddening obeys a linear law if the interstellar matter is uniformly distributed. Under the linear extinction law, the reddening is proportional to the distance. The distance and reddening of the cluster are known so that we assume the reddening of the contact binary and compute a corresponding distance with the law. On the other hand, we can repeat this computation with the W-D code (Wilson & Devinney, 1971; Wilson, 1979; Wilson, 1990; Wilson, 2008; Van Hamme and Wilson, 2007). We get the final results when the outcomes of the two isolated method are equal. Here we show two examples.

#### 3.1. V95 in the Field of NGC104

Because V95 is not thought to be a member of NGC104 according to the Rucinski relationship (Rucinski, 1995) which produces uncertainty. We used three assumptions in our solutions; V95 is a field contact binary; V95 is a field contact binary with the same reddening as NGC104; V95 is a member of NGC104. Having compared with the statistical result of Li et al. (2007), we excluded the latter two assumptions. The reasonable result is Case A. Cool spots were found in the BV-band light curves. We compared the size, temperature and position of these two spots, thinking that they could be a single spot. If this conclusion is true, we have captured a starspot migration where cool spot on the surface of the more massive component shifted 126 degrees along the latitude line from west to east in a year.

#### 3.2. V710 Mon in the Field of Berkeley39

To find out the reddening of V710 Mon, we tested a series of reddenings with a step size 0.001 and found that an  $E(B-V)$  of 0.112 is the most reasonable value. The final photometric solution shows that V710 Mon is an extreme mass ratio (0.143 - 0.183), deep (59.5 - 62.7%) contact binary system. Its period increase, a rate of  $dP/dt = +1.95 \pm 0.06 \times 10^{-7}$  days/year, might be due to an expanding post-main-sequence component in the system. The time scale of the orbital increase is nearly equal to the time for the post-main-sequence star to evolve into a subgiant. The age of the primary is estimated to be 5.34 Gyr using the Dartmouth model isochrones (Dotter et al., 2008). This work is partly supported by Chinese Natural Science Foundation (Nos. 11103074, 11133007, 11325315, 10973037 and 10903026), the National Key Fundamental Research Project through grant 2007CB815406, the Yunnan Natural Science Foundation (No. 2008CD157 and by West Light Foundation of the Chinese Academy.

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