New Astronomy 31 (2014) 60–64

Contents lists available at ScienceDirect

New Astronomy

journal homepage: www.elsevier.com/locate/newast

A possible expanding component in the extreme mass ratio deep contact binary V710 Monocerotis

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HIGHLIGHTS

- The masses and the radii of each component for V710 Mon are determined.
- The age and distance of V710 Mon are estimated.
- We found that V710 Mon may contain a post-main-sequence component.
- The expansion of the primary component may cause the orbital period increase.

ARTICLE INFO

Article history:
Received 16 December 2013
Received in revised form 27 February 2014
Accepted 1 March 2014
Available online 12 March 2014

Communicated by P.S. Conti

Keywords:
Stars: binaries: close
Stars: binaries: eclipsing
Stars: binaries: evolution
Stars: individual: V710 Mon

ABSTRACT

We present CCD light curves of V710 Mon obtained in 2007 and 2013. By using the 2010 version of the W-D code, it is found that the star is a deep (59.5–62.7%) contact binary system, with an extreme mass ratio (0.143–0.183). The period of the system increases with a rate $dP/dt = +1.95(\pm 0.06) \times 10^{-7}$ days/year. We propose that the system contains a post-main-sequence component which may be in an expanding phase. The time scale of the orbital increase nearly equals 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.
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1. Introduction

Stellar clusters provide key information in the study of stellar evolution. Members of a star cluster have nearly the same age, distance, extinction, and chemical composition, so some stellar parameters, such as the distance and age are more readily determined than for isolated stars. Even if a star is not a member, but is known to be located in front of a star cluster, the range of the star's distance is restricted. Here we present such a case for the contact binary variable, V710 Mon, seen in the field toward the old open cluster Berkeley 39 (Be 39). The distance determination of Be 39 ranges from 3800 pc to 5248 pc, while the age ranges from 6 Gyr to 8 Gyr (see the summary in Table 1). We found the latest set of parameters by Bragaglia et al. (2012) to be most consistent with the Dartmouth isochrones (Dotter et al., 2008). These parameters for Be 39 are adopted in this paper.

V710 Mon is seen projected very close to the center of Be 39. The star was reported by Kaluzny et al. (1993) in a survey for variable stars in the field of Be 39. The star, with $(B-V) = 0.58$ mag and $(V-I) = 0.79$ mag, was classified as an EW type binary with a period of 0.4052 days on the basis of a complete I-band light

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http://dx.doi.org/10.1016/j.newast.2014.03.001
1384-1076/© 2014 Published by Elsevier B.V.

Table 1
Parameters of Berkeley 39.

E($B-V$)	D(kpc)	$(m-M)$	Age(Gyr)	Reference
0.12	4.786	13.4	8	Kaluzny and Richtler (1989)
0.11	5.248	13.6	6	Carraro et al. (1994)
0.12	3.8	12.9	6.5	Kassis et al. (1997); Krusberg and Chaboyer (2006)
0.12	4.40	13.2	7.4	Dutra and Bica (2000)
0.12	4.283	13.16	7.331	Paunzen and Netopil (2006)
0.17	3.872	12.94	6.3	Bragaglia et al. (2012)

curve. Adopted the distance modulus of Be 39, namely $m_v - M_v = 13.15$, these authors derived an absolute V-band magnitude of 2.2 mag. Mazur et al. (1999) later reported the V-band light curve and the color indexes $B-V = 0.66$ mag and $(V-I) = 0.72$ mag and $(B-V)$ of 0.66, which in turn, using the relationship reported by Rucinski and Duerbeck (1997), suggested a distance modulus of $m_v - M_v = 12.00$. Both these studies concluded that V710 Mon should not be a member of Be 39.

2. New CCD photometry for V710 Mon

We observed V710 Mon on five nights, February 17, 20, and 23 in 2007, and January 3 and 4 in 2009, with the 1.0-m reflecting telescope at the Yunnan Observatories in China. Images of the V and R bands were acquired for the 2007 run, for which a PI1024 TKB CCD was used, giving an effective field of view of $\sim 6.5 \times 6.5$ arcmin at the Cassegrain focus. The integration time was 200 s for both filters. In 2009, R-band images were obtained, with an integration time of 300 s, with the DW436 2048 × 2048 CCD. The field of view about this system is nearly 7.3 × 7.3 arcmin. The filters are very similar to the standard UBVRI set. From March 12 to 17, 2013, we observed this binary again, by using the 0.80-m telescope of the Tenagra Observatories in southern Arizona. The f/7 Ritchey–Chretien telescope was equipped with an SITe 1024 × 1024 pixel CCD, yielding a scale of 0.87″ pixel^{-1}, hence a field of view of $\sim 14.8 \times 14.8$ arcmin. The exposure time was 90 s for the R filter, and 120 s for the I filter.

The comparison star is 2MASS07465356-0442217 and the check star is 2MASS07465199-0441557. All images were reduced by the PSF photometry using IRAF. Five isolated bright stars in each image were chosen as PSF stars. Every observed image yielded a PSF image by using the AUTO profile, with which the photometric magnitudes of the targets were corrected. A least-squares parabolic fitting was used to obtain the times of minima because the light curves around minima are ought to symmetric. A new ephemeris was obtained, and the phases were derived. The complete phased light curves observed in 2007 and 2013 are displayed in Fig. 1.

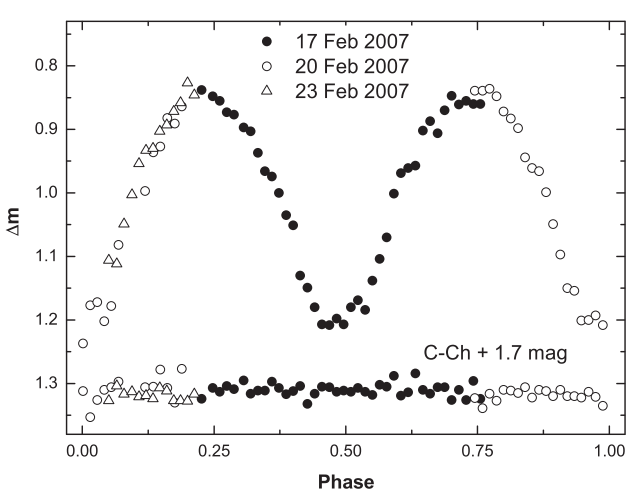

Fig. 1. CCD photometric light curve of V710 Mon in R band obtained in 2007.

3. Orbital period variations of V710 Mon

There was no period analysis for V710 Mon before. We collected its times of minima published from 1989 to 2013, as listed in Table 2. Starting with an initial period of 0.4052 days as declared by Kaluzny et al. (1993), we derived a new linear ephemeris with all available minima,

$$\text{Min. I} = 2454152.2236 \pm 0.0025 + 0^d.40519638 \pm 0.00000024 \times E. \quad (1)$$

However, the $(O-C)$ diagram derived with the ephemeris shows a long-term period increase, as seen in Fig. 2. Hence, a parabola term was then used to fit the $(O-C)$ diagram, which led to

$$\text{Min. I} = 2454152.2196(\pm 0.0002) + 0^d.40519739(\pm 0.00000003) \times E + 1.08(\pm 0.03) \times 10^{-10} \times E^2. \quad (2)$$

With the quadratic term in this improved ephemeris, a secular period increase rate is determined to be $dP/dt = +1.95(\pm 0.06) \times 10^{-7}$ days/year.

4. Photometric solutions

We analyzed the light curves with the 2010 Version of the W-D code (Wilson and Devinney, 1971; Wilson, 1979; Wilson, 1990; Wilson, 2008; Van Hamme and Wilson, 2007). Unlike the case of NGC 104-V95 (Liu et al., 2014), V710 Mon is close to the galactic disc ($b = +10.0854$) where the interstellar extinction cannot be neglected. If these dust and gas distribute homogeneously along the line of sight, the extinction in this direction should increase with the distance. To find a reasonable extinction value, we tried

Table 2
Times of light curve minima of V710 Mon.

JD. Hel. 2400000+	Min.	E	$(O-C)$	Ref.*
48226.8328	II	−14623.5	−0.0015	(1)
48227.8642	I	−14621	0.0169	(1)
48285.7989	I	−14478	0.0085	(1)
48567.8060	I	−13782	−0.0011	(1)
48568.8204	II	−13779.5	0.0003	(1)
48985.7592	II	−12750.5	−0.0079	(1)
48988.8027	I	−12743	−0.0034	(1)
48989.8076	II	−12740.5	−0.0115	(1)
48992.6521	II	−12733.5	−0.0034	(1)
48993.6835	I	−12731	0.0150	(1)
54149.1815	II	−7.5	−0.0031	(2)
54152.2229	I	0	−0.0007	(2)
54835.1812	II	1685.5	−0.0009	(2)
54836.1886	I	1688	−0.0065	(2)
55147.3840	I	2456	−0.0019	(2)
56365.8184	I	5463	0.0070	(2)
56366.8278	II	5465.5	0.0034	(2)

* (1) Kaluzny (private communations); (2) This work.

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