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Orbital period investigations of two short-period early-type overcontact binaries BH Cen and V701 Sco in two extremely young galactic clusters IC 2944 and NGC 6383

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Abstract

Both V701 Sco and BH Cen are two early-type short-period overcontact systems ($P = 0.^d762$ and $P = 0.^d792$, respectively). V701 Sco is a member of the young galactic cluster NGC 6383, while BH Cen is a component of a younger galactic cluster IC 2944 where star formation is in process. They provide good opportunity to understand the formation and evolution of binary stars. In the present paper, orbital period changes of the two binaries are investigated. It is discovered that the orbital period of BH Cen shows a long-term increase with a rate of $dP/dt = +1.70(\pm0.39) \times 10^{-7}$ days/year while it undergoes a cyclic oscillation with a period of 44.6 years and an amplitude of $A_3 = 0.^d0216$. For V701 Sco, its O-C curve reveals a periodic change with a period of 41.2 years and amplitude of $A_3 = 0.^d0158$. The mass ratio of BH Cen is 0.84, but V701 Sco contains twin B1-1.5V type stars with a mass ratio of unit. The continuous period increase of BH Cen is caused by the mass transfer from the less massive component to the more massive one at a rate of $dM_2/dt = 3.5 \times 10^{-6}$ days/year.

The cyclic period changes of both systems can be plausibly explained as the results of light-travel time effects suggesting that they are triple systems. The astrophysical parameters of the unseen tertiary components in the two systems have been determined. We think that the invisible tertiary components in both binaries played an important role in the formations and evolutions of the overcontact configurations by bringing angular momentum out from the central systems. For BH Cen, this process created the initial short period and will support its evolution into an overcontact configuration via a Case A mass transfer within the life time of the extremely young cluster IC 2944. For V701 Sco, two identical zero-age main-sequence components in an overcontact configuration suggest that it may have been formed by fission, possibly by the fission of the third body. The fact that no long-term continuous period variations were found for V701 Sco may suggest that an overcontact binary with the mass ratio of unity can be in an equilibrium revealing that the original configuration of the binary was overcontact as is its present state. It has been reported that faint stars in the two extremely young clusters are relatively scare. From the present study, it is shown that faint stars in young clusters are usually formed as companions of OB stars (including binaries). It is very difficult to detect them because of their low luminosity when compared with the more luminous OB stars.

Keywords: Stars: binaries: close; Stars: binaries: eclipsing; Stars: individual (BH Cen); Stars: individual (V701 Sco); Stars: evolution; Stars: early type

1. Introduction

The extremely young galactic cluster, IC 2944, is located in a very extensive H II region. It is dominated by a group of O bright stars and globules, suggesting that the process of star-formation in the cluster has not yet stopped (Thackeray and Wesselink, 1965). BH Cen is a member in this

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cluster (Cordoba XXVI). It was discovered to be a variable by Oosterhoff (1928, 1930) based on photographic observations that determined a period of $0.^d7915814$ from 10 times of light minimum. The first photoelectric light curves in UBV bands were obtained by Leung and Schneider (1977), and analyzed using the Wilson and Devinney (1971) code. It is shown that BH Cen is a zero-age overcontact binary. However, the light curves published by Leung and Schneider (1977) showed a large scatter, especially in U band. To obtain more reliable photometric parameters of the system, the light curves of Sistero et al. (1983) were analyzed by Leung et al. (1984). They found that this system is an overcontact binary with a degree of overcontact of 48% and a mass ratio of 0.84. Considering their membership in the very young galactic cluster IC 2944, absolute parameters of the binary system were estimated.

The light variability of the early-type eclipsing binary, V701 Sco, was discovered by Plaut (1948) using data derived from 301 photographic plates. He showed that the system is a short-period W UMa-type binary, later confirmed by Leung (1974) who obtained the first photoelectric light curves in B and V bands. Leung's light curves were analyzed by Wilson and Leung (1977) with the W-D code (Wilson and Devinney, 1971). Their solutions indicated that V701 Sco is an overcontact binary with a mass ratio of unity. The first radial velocity curves were published by Andersen et al. (1980). They determined a spectroscopic mass ratio of 0.98 ± 0.04. A detail spectroscopic and photometric analysis was given by Bell and Malcolm (1987) who derived absolute parameters of the system and confirmed that this binary contains identical components in an overcontact configuration. They pointed out that the system is in a temporary equilibrium state after the rapid phase of Case A mass transfer. Eggen (1961) suggested that V701 Sco is a member of the young open galactic cluster NGC 6383. This was later supported by the studies of Sahade and Cavila (1963) and Lloyd Evans (1978). They derived an upper age limit for the cluster of $4 - 5 \times 10^6$ year.

The short periods, early spectral types, overcontact configurations and the membership of two extremely young galactic clusters all suggest that they are very interesting systems to study. In the paper, orbital period variations of the two systems were analyzed. Based on the properties of period changes, the triplicity, formation and evolutionary states of the two binaries were investigated.

2. Orbital period change of BH Cen

Epochs and orbital periods of BH Cen have been determined by several investigators (see Table 1). The period change of BH Cen was first suspected to be variable by Sistero et al. (1979). Since no linear ephemeris of the observations taken between 1920 and 1979 fits, they pointed out that the O-C residuals may be caused by a light-time effect with a period of 50 years and a projected radius $R\sin i = 6 \times 10^8$ km. Herczeg (1984) obtained two photoelectric times of light minimum, and analyzed the light-time effect of the system proposed by Sistero et al. (1979). By assuming a period of 50 years and a total mass of $20M_\odot$, a lowest mass of $3.6M_\odot$ was obtained for the third body. Subsequently, several possibilities of the period changes were discussed by Pfleiderer and Pfleiderer (1985) indicating that the period changes of BH Cen is complex and needs to be investigated in detail. Pfleiderer and Pfleiderer (1985) derived a lowest mass of $5M_\odot$ for the tertiary component and a long-term period increase rate of $dP/dt = +9.2 \times 10^{-7}$ days/year.

Table 1
Several epochs and orbital periods of BH Cen

Epochs	Orbital period	Reference
2439621.7975	0.791616	Leung and Schneider (1977)
2444018.28888	0.7915942	Sistero et al. (1979)
2424260.3709	0.7915877	Sistero et al. (1979)
2431748.7478	0.79158298	Sistero et al. (1979)
2444208.27094	0.79159210	Sistero et al. (1983)
2444028.5796	0.79158298	Herczeg (1984)

All available times of light minimum were compiled by Kreiner et al. (2001). Early photographic (hereafter "Pg") times of light minimum were obtained by Oosterhoff (1928, 1930), Hertzsprung (1928), and Guthnick and Prager (1929). Those listed in Table 2 are the photoelectric and CCD times of light minimum. The $(O\text{-}C)_1$ values of those times of light minimum were computed with the following linear ephemeris given by Kreiner et al. (2001)

$$\text{Min.I} = 2431748.7483 + 0^d.79158345 \times E. \quad (1)$$

The corresponding $(O\text{-}C)_1$ curve is displayed in the upper panel of Fig. 1 and is shown in the fifth column of Table 2. Those shown in the third column of Table 2 are the observational methods where "Pe" refers to photoelectric and "CCD" to charge-couple device photometry. The crosses in the upper panel of Fig. 1 represent "Pg" data, solid and open circles represent the primary and the secondary eclipse times observed with the methods of photoelectric or CCD (hereafter "PC") photometry, respectively.

Orbital period changes are not unusual among late-type (W UMa-type) overcontact binary stars (e.g., Qian, 2001a,b, 2003a; Kreiner et al., 2001). Some systems are observed to have a complex period change where periodic changes are usually found to be superimposed on a secular period change. Some such recently studied systems are V839 Oph (Akalin and Derman, 1997), YY Eri (Kim et al., 1997), V417 Aql (Qian, 2003b), BX Peg (Lee et al., 2004), FG Hya (Qian and Yang, 2005), CE Leo (Kang et al., 2004), GR Vir (Qian and Yang, 2004), AK Her (Awadalla et al., 2004), CK Boo (Qian and Liu, 2000), ER Ori (Kim et al., 2003), and XY Leo (Yakut et al., 2003). For the early-type overcontact system, BH Cen, the $(O\text{-}C)_1$ curve displayed in Fig. 1 indicates that the change of the orbital period may be continuous and its variation is also very complex. A sinusoidal variation may exist in the change of the $(O\text{-}C)_1$ curve. Therefore, a sinu-