An evolutionary considerations for V228 from 47 Tuc

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Abstract

We perform evolutionary calculations of binary stars to find progenitors of system with parameters similar to the eclipsing binary system V228. We show that a V228 binary system may be formed starting with an initial binary system which has a low main sequence star as an accretor. The initial parameters for the evolutionary model are as follow: \( M_1 = 0.88 \, M_\odot, \, M_2 = 0.85 \, M_\odot, \, P_i = 1.35 \) days, \( f_1 = 0.05, \, f_2 = 4.65 \) and \( Z = 0.006 \) ([Fe/H] = –0.67). We also show that the best fitting model implies loss of about 50 per cent of initial total orbital momentum but only 5 per cent of initial total mass. The less massive component have a small helium core of mass \( 0.12–0.17 \, M_\odot \) and exchange mass in the nuclear time scale.

1 Introduction

Blue straggler (BS) stars are defined by their location on the color–magnitude diagram. These star lie above the main–sequence turnoff region, a region where, if the BS’s had been normally single stars, they should already have evolved away from the main sequence. The eclipsing binary V228 was discovered by Kałużny et al. (1998) during a survey for variable stars in the field of the globular cluster 47 Tuc, and classify as the eclipsing BS. Authors found an orbital period of \( P = 1.1504 \) days. On the colour–magnitude diagram of the cluster, the variable occupies a position near the top of BS sequence. Kałużny et al. (2007) concluded that, V228 has the same proper motion and radial velocity as 47 Tuc and is located at the cluster distance – member of the globular cluster 47 Tuc. However, an analysis of Kałużny et al. (2007) shows that V228 is a semi–detached Algol–type binary with the less massive component filling its Roche lobe. We know several system of such type: RY Aqr, S Cnc, R CMa, AS Eri (see Table 2).

In this paper we report results of an evolutionary considerations and their comparision with absolute parameters of V228 determined from observations (Kałużny et al 2007).

2 What do we know about V228 and 47 Tuc?

The absolute parameters of V228 from Kałużny et al. (2007) spectroscopic and photometric analysis are given in Table 1.
Table 1  Parameters of primary and secondary of V228

|        | mass [M\(_\odot\)] | radius [R\(_\odot\)] | luminosity [L\(_\odot\)] |
|--------|---------------------|-----------------------|---------------------------|
| Primary:| M\(_1\) : 1.512 ± 0.022 | R\(_1\) : 1.357 ± 0.019 | L\(_1\) : 7.02 ± 0.50     |
| Secondary: | M\(_2\) : 0.20 ± 0.007 | R\(_2\) : 1.238 ± 0.013 | L\(_2\) : 1.57 ± 0.09     |

Orbital period  P = 1.150686

For globular cluster 47 Tuc we know that age of the cluster is between 10 and 14 Gyr (Gratton et al. 2003, VandenBerg et al. 2006, Kałużny et al. 2007). Using VandenBerg et al. (2006) isochrones for the age of 14 Gyr implies turnoff masses of 0.868 and 0.852M\(_\odot\) for [Fe/H]= -0.606 and -0.707, respectively. We assuming metalicity value from Alves–Brito et al. (2005) [Fe/H]=–0.67 (Z=0.006).

3 Evolutionary model

While calculating evolutionary models of binary stars, we must take into account mass transfer and associated physical mechanism which lead to mass and angular momentum loss. We use a formula based on that used to calculate angular momentum loss via a stellar wind (Paczyński & Ziółkowski 1967; Ziółkowski 1985 and De Greve 1993). We can express the change in the total orbital angular momentum (\(J\)) of a binary system as

\[
\frac{J}{J_0} = f_1 f_2 \frac{M_1 M_2}{M_2 M_{tot}},
\]

where, \(M_1\), \(M_2\) and \(M_{tot}\) denote, respectively, the mass of the primary, secondary and the total mass of the system, \(f_1\) is the ratio of the mass ejected by the wind to that accreted by the primary component and \(f_2\) is defined as the effectiveness of angular momentum loss during mass transfer (Sarna & De Greve 1994, 1996).

Models of secondary stars filling their Roche lobes were computed using a standard stellar evolution code based on the Henyey-type code of Paczyński (1970), which has been adapted to low-mass stars (as described in detail in Marks & Sarna 1998). We use the Eggleton (1983) formula to calculate the size of the secondary’s Roche lobe.

For radiative transport, we use the opacity tables of Iglesias & Rogers (1996). Where the Iglesia & Rogers (1996) tables are incomplete, we have filled the gaps using the opacity tables of Huebner et al. (1977). For temperatures lower than 6000 K, we use the opacities given by Alexander & Ferguson (1994) and Alexander (private communication).

To understand the evolution of close binary V228 we computed various evolutionary sequences: for different chemical compositions Z=0.006–0.2; initial secondary masses 0.85–1.35M\(_\odot\) and initial mass ratios \(q_i = M_{1,i}/M_{2,i}\) from 0.6 to 0.95. For each system the secondary fills Roche lobe with a small helium core (Hertzsprung gap).
The lower conservative limit for total mass of the system is about 1.7 \( M_\odot \), which infer that the original primary had a mass exceeding 0.85 \( M_\odot \).

4 Evolutionary status – results

From computed evolutionary sequences we predict that:
1. Initial mass of the primary and secondary was about 0.85–0.9 \( M_\odot \), and mass ratio around 1;
2. Current properties of the system indicate that the original primary filled Roche lobe in the Hertzsprung gap – early case B mass transfer;
3. The initial parameters for the evolutionary model are as follow: \( M_{1,i} = 0.88 \ M_\odot, M_{2,i} = 0.85 \ M_\odot, \)
\( P_i = 1.35 \) days, \( f_1 = 0.05, f_2 = 4.65 \) and \( Z = 0.006 ([\text{Fe/H}] = -0.67) \);
4. The best fitting model implies loss of about 50 per cent of initial total orbital momentum, but only 5 per cent loss of initial total mass;
5. The less massive component have a small helium core of mass 0.12–0.17 \( M_\odot \) and exchange mass in the nuclear time scale;
6. The best fitting model (0.88+0.85) spend about 10 Gyr in detached configuration, while 0.2–0.3 Gyr in semidetached.

5 Discussion

V228 is eclipsing binary system of the globular cluster 47 Tuc. An analysis of Kałuży et al. (2007) shows that V228 is a semidetached, low—mass Algol type binary with the less massive component filling its Roche lobe (mass transfer occurs on the nuclear timescale). According to accepted evolutionary scenarios, the Algol–type binaries forms by mass transfer from initially more massive star to less massive, leading to the reversal of the initial mass ratio of the binary. This provide a unique opportunity to look into stellar interiors and to observer the remnant products of past core hydrogen burning. The current secondary component of V228 is oversized and overluminous for its mass, which suggest a small mass helium core inside it. Several well–studied systems of this kind are known in the literature. In Table 2 we summarized some orbital and physical parameters for low–mass Algol–type binaries with orbital period shorter than 10 days.

| Name      | \( P_{\text{orb}} \) [d] | \( M_1/M_\odot \) | \( M_2/M_\odot \) | \( R_1/R_\odot \) | \( R_2/R_\odot \) | \( f_1 \) | \( f_2 \) | References        |
|-----------|--------------------------|-------------------|-------------------|-------------------|-------------------|--------|--------|------------------|
| S Cnc     | 9.48                     | 2.40              | 0.20              | 2.18              | 4.83              | 0.09   | 4.62   | 1, 2, 11            |
| AS Eri    | 2.66                     | 1.92              | 0.21              | 1.57              | 2.25              |        |        | 3, 4               |
| RY Aqr    | 1.97                     | 1.26              | 0.26              | 1.28              | 1.79              |        |        | 5, 6               |
| R CMa     | 1.14                     | 1.07              | 0.17              | 1.50              | 1.15              |        |        | 7, 8, 9            |
| V228      | 1.15                     | 1.51              | 0.20              | 1.36              | 1.24              | 0.05   | 4.65   | 10, see text       |

(1) Popper & Tomkin (1984); (2) Van Hamme & Wilson (1993); (3) Popper (1980); (4) Van Hamme & Wilson (1984); (5) Helt (1987); (6) Popper (1989); (7) Tomkin (1985); (8) Sarma et al. (1996); (9) Varricatt & Ashock (1999); (10) Kałużny et al. (2007); (11) Sarna & De Greve (1996).
As a result of recent analysis by Sarna et al. (1997, 1998), we should concluded that the physical conditions in mass losing star of mass ranging from 0.2 to 1.5 $M_\odot$ that have undergone low–mass Algol–type evolution are most favourable for the occurrence of intensive magnetic braking (Sukmanich 19972; Verbunt & Zwaan, 1981). In fact during evolution of S Cnc and V 228 binaries, systems loses only less than 5 and 9% (see table 2) of its total mass, respectively, but about more than 50% of its initial total angular momentum (Sarna & De Greve 1996). This lead to the conclusion that a possibility of cyclic dynamos is a more quantitative way to explain the observed status of systems presented in Table 2.

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