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A binary origin for two sequences of blue stragglers in globular cluster M30

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Abstract. Two sequences of blue stragglers are observed in the colour-magnitude diagram of globular cluster M30, which provide an important clue to the origin of blue stragglers in globular clusters. We investigate the binary evolution channel for the formation of two blue-straggler sequences. In this channel, a star in binary system reaches the blue-straggler region by accreting matter from its companion. Employing Eggleton's stellar evolution code, we find that the binary-origin blue stragglers can appear on both sequences observed in the colour-magnitude diagram of M30 because their companions have different contribution on the total luminosity of the binary systems. Our results show that the companions of blue stragglers on the blue sequence are faint white-dwarf stars, while those on the red sequence are bright main-sequence or sub-giant stars. The binary evolution channel does not require a recent and short-lived dynamical event.

Key words. binaries: close – blue stragglers – globular cluster: individual (M30, NGC 7099)

1. Introduction

Blue stragglers are a class of anomalous stars that are brighter and bluer than the main-sequence turnoff stars in the colour-magnitude diagram of globular clusters. They should have already evolved away from the main sequence into red giant branch or white dwarf long ago. At present, blue stragglers are thought to be hydrogen-burning stars but more massive than normal TO stars of the host cluster (e.g. Shara et al. 1997). These anomalous objects are easily identified and also very common in other environments, such as open clusters, the Galactic field, and dwarf galaxies (e.g. Mathieu & Geller 2009; Preston & Sneden 2000; Momany et al. 2007).

Many scenarios have been proposed to explain the existence of blue stragglers. The currently favored mechanisms include mass transfer in binaries (McCrea 1964) and direct stellar collisions (Hills & Day 1976). These two mechanisms may be dominant in different environments. Mass transfer in binaries is believed to play an important role in open clusters and in the field, while direct stellar collisions are thought to dominate in more dense environments such as cluster core. However, the relative importance of these two mechanisms are still unclear (Knigge, Leigh & Sills 2009;

Mathieu & Geller 2009; Geller & Mathieu 2011).

The most exciting observation is the discovery of two separated sequences of blue stragglers in the Galaxy globular cluster M30 by Ferraro et al. (2009). Similar observations have been reported recently by Dalessandro et al. (2013) and Simunovic et al. (2014) for globular clusters NGC 362 and NGC 1261, respectively. The occurrence of two blue-straggler sequences in globular clusters has been explained by single short-lived dynamical events, such as core collapse event, which can boost the formation of blue stragglers from binary evolution (Xin et al. 2015) and direct stellar collision (Ferraro et al. 2009). Ferraro et al. (2009) suggested that the blue stragglers on the red sequence can well be reproduced by the products from binary mass transfer but those on the blue sequence are located outside the low-luminosity boundary determined by binary mass transfer by Tian et al. (2006). The blue stragglers on the blue sequence can be reproduced by 1-2Gyr old isochrones of stellar collision models from Sills et al. (2009). So, the presence of two separated sequences of blue stragglers in globular clusters is considered as the most striking evidence for the fact that binary evolution and stellar collision co-exist within the same cluster and dominate the formation of blue stragglers on the red sequence and blue sequence, respectively.

However, it should be noted that W Ursae Majoris (W UMa) contact binaries are found on both sequences of blue stragglers in M30 (Pietrukowicz & Kaluzny 2004; Ferraro et al. 2009). W UMa contact binaries are an important class of eclipsing binaries that are believed to be a typical product of mass transfer in binaries (Vilhu 2006; Jiang et al. 2009), and they are very common among blue stragglers in globular clusters (Rucinski 2000). The synthetic luminosity of W UMa contact binary becomes more and more similar to that of the bright component in such a binary with the mass ratio decreasing, since the contribution from the faint one becomes smaller and smaller (Rucinski 2004). So, it is very likely that the W UMa contact binaries appear on the blue sequence when their mass ratios are lower than a certain value. This provides a probability that the blue sequence of blue stragglers may be also related to the binary evolution. Meanwhile, Lu et al. (2010) found that some blue stragglers produced by mass transfer in binaries are outside the low-luminosity boundary given by Tian et al. (2006). Chen & Han (2008) showed that binary merger can produce single blue stragglers very close to or even below the zero-age main sequence (ZAMS), i.e. on the blue sequence. In addition, Stepien & Kiraga (2015) found that binary merger can form a blue sequence of blue stragglers while binary blue stragglers lead to a red sequence. Therefore, theoretical work is required to determine whether the binary evolution channel is able to produce blue stragglers on both sequences of blue stragglers observed in globular cluster M30.

2. The binary evolution channel

In the binary evolution channel for the production of blue stragglers, the primary of the initial binary first fills its Roche lobe and transfers the mass to the secondary. The secondary becomes the more massive component and evolve into the blue-straggler region in the colour-magnitude diagram. During the mass-transfer phase, the binary system will on the red sequence in the colour-magnitude diagram because the combined brightness of both components make the systems more luminous and redder than the single blue stragglers. However, the primary will become a faint white dwarf after the mass transfer stops, which is almost no change of the location of the binary systems relative to the single stars in the colour-magnitude diagram. Therefore the binary system will be like a single blue stragglers, e.g. on the blue sequence, if the secondary is still in the regions of blue stragglers.

To determine the evolutionary tracks of blue stragglers produced by mass transfer in binaries, we use Eggleton's Stellar evolution code (Eggleton 1971, 1972; Eggleton et al. 1973). This code has been updated during the last four decades (Han et al. 1994; Pols et al. 1995; Nelson & Eggleton 2001; Eggleton & Kiseleva-Eggleton 2002). Figure 1 and 2

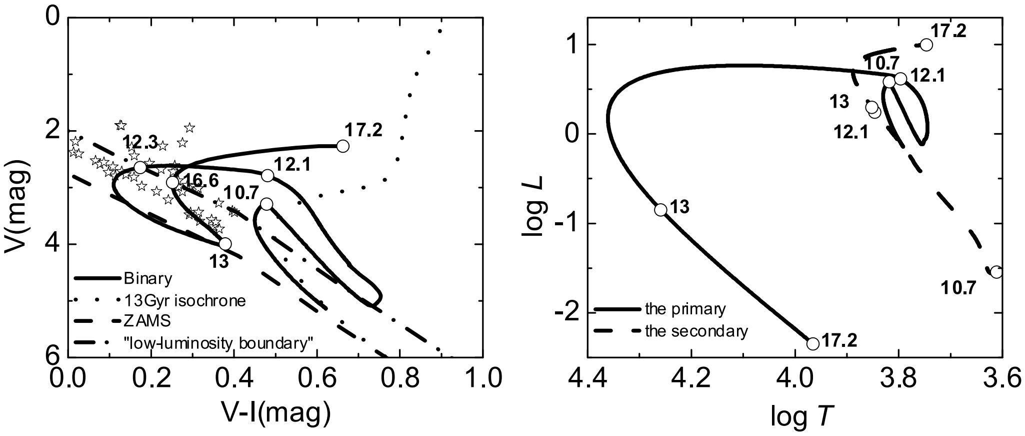

Fig. 1. The evolutionary track of a binary system that produces a blue straggler on the blue sequence at 13 Gyr. Left panel: the synthetic evolutionary track (solid line) of a binary system (M_{10}=0.83 $M_\odot$, M_{20}=0.37 $M_\odot$, P_0 = 0.647 d) in the colour-magnitude diagram. Open circles show its positions at different ages (in Gyr). Dotted, dashed and dash-dot lines correspond to the single-star isochrone of 13 Gyr, the the zero-age main sequence (ZAMS) and the "low-luminosity boundary"(Tian et al. 2006) (the ZAMS shifted by 0.75mag to brighter luminosities), respectively. Right panel: the evolutionary tracks of the primary (solid lines) and the secondary (dashed lines) for this system in the effect temperature-luminosity plane. Mass transfer begins at 10.7 Gyr after central hydrogen of the primary is exhausted (Case B), and ends at 12.1 Gyr after the primary passes the tip of the red giant branch. This binary system evolves to the blue sequence at 13 Gyr because the primary becomes a faint white dwarf.

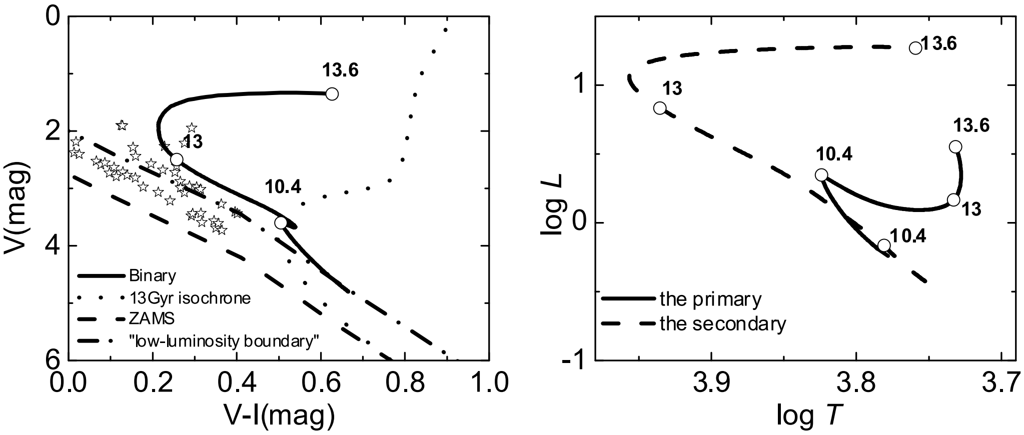

Fig. 2. Similar to Figure 1, but for a binary system (M_{10}= 0.81 $M_\odot$, M_{20}= 0.72 $M_\odot$, P_0 = 0.456 d), which is on the red sequence at 13 Gyr. Mass transfer begins at 6.8 Gyr when the primary is on main sequence (Case A), and mass transfer is in progress at 13 Gyr.

present two binary evolution calculations to illustrate how mass transfer in binary system leads to blue stragglers on two sequences. Figure 1 shows the evolutionary tracks of a binary system that produces a blue straggler on the blue sequence at 13 Gyr, include the synthetic evolutionary track of the binary system and the evolutionary tracks of the primary and the secondary. This binary evolves into the region of the red sequence at about 12 Gyr as a result of Case B mass transfer. However, it runs across the "low-luminosity boundary"(Tian et al. 2006) and reaches to the blue sequence. This is because the mass-donor star (the primary) evolves from the red giant branch to a helium white dwarf and cools before the accretor (the secondary) leaves MS. This binary has been below the "low-luminosity boundary" for about 4 Gyr, and then turns back the red sequence and leaves the blue straggler region finally. Figure 2 shows the evolution of a binary system that produces a blue straggler on the red sequence at 13 Gyr from Case A mass transfer. This binary evolves into blue straggler region along parallel to the "low-luminosity boundary", and does not run cross this boundary.

3. Conclusions

Using Eggleton's Stellar evolution code, we carried out the binary evolution calculations for the production of blue stragglers from the binary evolution channel. We find that the binary-origin blue stragglers can appear in different locations in the colour-magnitude diagram, e.g. on both sequences observed in M30, because the companions of blue stragglers have different contribution to the total luminosity of the binary systems. This suggests that both sequences of blue stragglers observed in globular cluster M30 maybe have the same origin, mass transfer in binaries.

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