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Application of Binary Evolution in Astrophysical Studies

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Abstract. Binary stars evolve differently from single stars, thus binary evolution is very useful for astrophysical studies. This paper discusses the application of binary evolution in the studies of stars, star clusters, galaxies, and cosmology. In particular, I concentrate on the use of binary evolution in colour-magnitude diagram and spectral energy distribution studies of star clusters and galaxies.

1. Binaries and Their Application in Astrophysical Studies

Binary stars are very common in the universe. For example, the Milky Way Galaxy includes more than fifty percent binary stars. A lot of astrophysical processes and properties can be investigated via binary stars. In fact, binary star is one of the most powerful tool for astrophysical studies. First, binary star is a good tool for studying many properties of stars. Usually, the luminosity, acceleration of gravity, effective temperature, and colours of stars in binaries are different from those of single stars. To investigate the properties of stars, the effect of binary interaction and binary evolution should be taken into account. Second, binary star is useful for stellar evolution study. Because there are many interactions between two components of a binary, the evolution of binary stars are different from single stars. The evolution of binary star has been the most important subject in studies about star evolution. In Figure 1, a comparison of the evolution of binary and single stars is shown. We see that in the binary and single evolution modes, stars evolve differently. Note that the evolution of stars are calculated via a rapid stellar evolution code (Hurley et al. 2002). Third, binary stellar evolution has an important role in studies of star clusters and galaxies. The reason is that star clusters and galaxies contain many binaries, and their integrated properties are related to binary evolution. Especially, when studying the stellar populations of star clusters and galaxies, binary evolution can affect the results obviously. Binary and single star evolution usually give different colour-magnitude diagrams (CMDs) and integrated spectral energy distributions (SEDs) for star clusters and galaxies. Fourth, binary evolution is helpful in cosmological studies. One method to constrain the age of the universe is to measure the correct ages of old globular star clusters and then give a lower-limit for the universe's age. The result is actually related to binary evolution, because binary evolution lead to different integrated specialties of stellar populations. In addition, binary evolution may also affect the studies like dark matter and star formation.

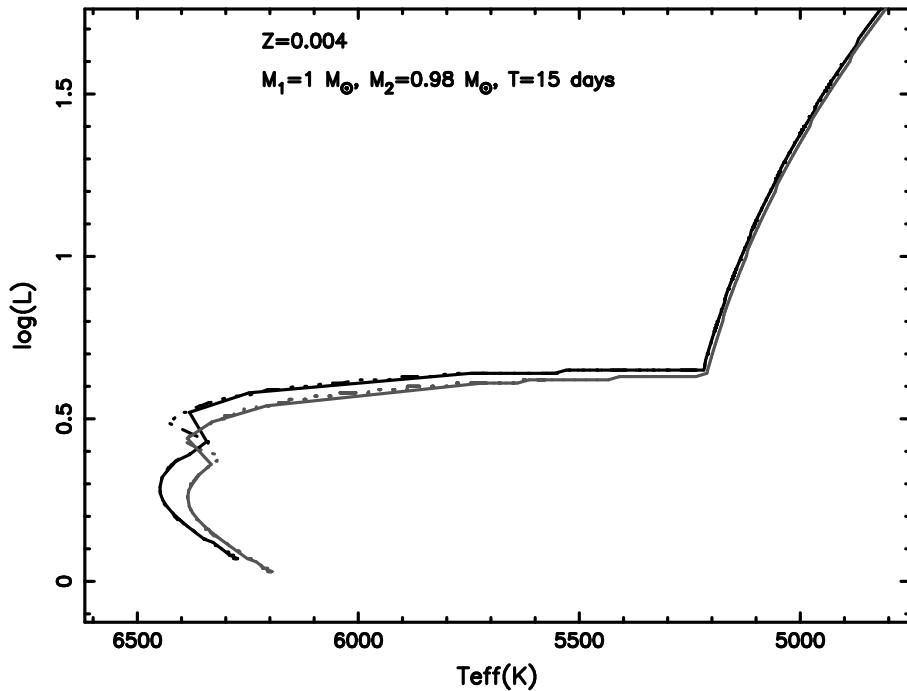


Figure 1. Comparison of single and binary stellar evolution of two stars with a metallicity of $Z = 0.004$. Two stars with 1.0 (star 1) and 0.98 (star 2) solar mass are investigated. Eccentricity of the binary is randomly set to be 0.7, and an orbital period of 15 days is taken. Solid lines are for single evolution of two stars, while dash-dot-dot lines for binary evolution. Stars 1 and 2 are shown in black and gray, respectively.

As an important part, this paper will show some new results about how binary evolution can give explanation to the observational CMDs and SEDs of stellar populations.

2. Binary Evolution Explanation to CMDs

CMD is well known as one of the best information desk for studying stars, star clusters, galaxies and the universe. I tried to explain the CMDs of stellar populations via binary evolution in my work. According to the observational results, I aims to reproduce the observational shape and blue stragglers in CMDs. In this work, I assume that all stars in a simple stellar population form in a star burst, and stars in a composite stellar population form in different star bursts. The masses of stars are generated randomly via some widely used initial mass functions. Then all stars are evolved by a rapid star evolution code of Hurley et al. (2002). Finally, the stellar evolution parameters of stars are transformed into CMDs of stellar populations via a BaSeL library (Westera et al. 2002). Some results can be seen in Figures 2, 3, and 4.

Figure 2 shows a V versus $(B - V)$ CMD of a simple stellar population including 50% binary stars with orbital period less than 100 days. The typical observational uncertainty in B and V magnitudes have been taken into account via an uniform distribution. We find that the shape of the CMD is close to the observational ones of star clusters, and binary evolution generate some blue stragglers naturally. This suggests that binary evolution is much better for CMD studies compared to single evolution. Binary evolution should be taken into account all astrophysical studies respecting to stars.

For a comparison purpose, a CMD of a simple stellar population consisting of single stars is also shown in Figure 3. It shows that blue stragglers can not be formed via single stellar evolution. In addition, there are clear differences between the CMDs of simple stellar populations basing on binary and single stellar evolution.

In Figure 4, a CMD of a composite stellar population with 50% binary stars is shown. It consumes that stars in the population have the same metallicity but different ages. We see that the CMD is very complicated. If it is compared to the CMDs of some galaxies, we will find that the CMD shown here is similar to the observational CMDs of some galaxies. Note that in order to make it easier to plot the CMD, observational uncertainties are not taken into account in this Figure. In fact, observational uncertainty has obvious effect on modeling CMDs.

One can refer to one of our previous work (Li et al. 2010) to see how we can use stellar population model basing on binary evolution for CMD studies of star clusters.

3. Binary Evolution Explanation to Stellar Population SEDs

Besides CMDs, SEDs are of special importance for astrophysical studies. SEDs can be used for studying the element abundances, stellar ages, distances and many other astrophysical properties of objects. Here I show how binary evolution can give explanation to SEDs of stellar populations. I pay attention to some UV-upturn SEDs, because such SEDs are observed in most of elliptical galaxies and it seems difficult to be explained via single stellar evolution under nature assumptions. Figure 4 shows the results. We can see that UV-upturn SEDs are generated naturally by binary evolution for some stellar populations (see also Han et al. 2007). Therefore, binary evolution are possibly the

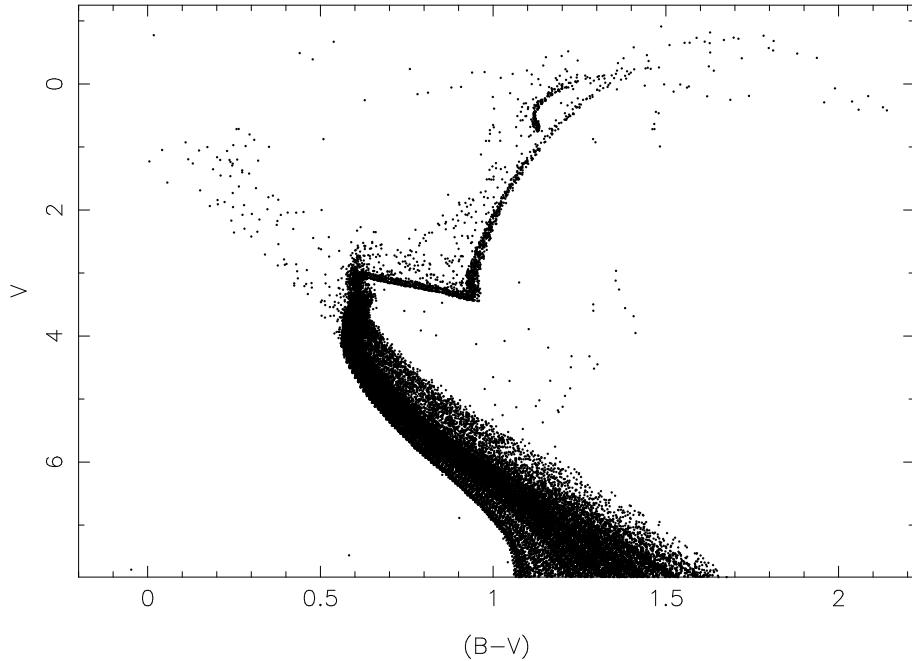


Figure 2. Theoretical CMD of a simple stellar population (50 000 stars) with 50% binary stars. The metallicity (Z) and age of the population are 0.02 and 4.6 Gyr, respectively.

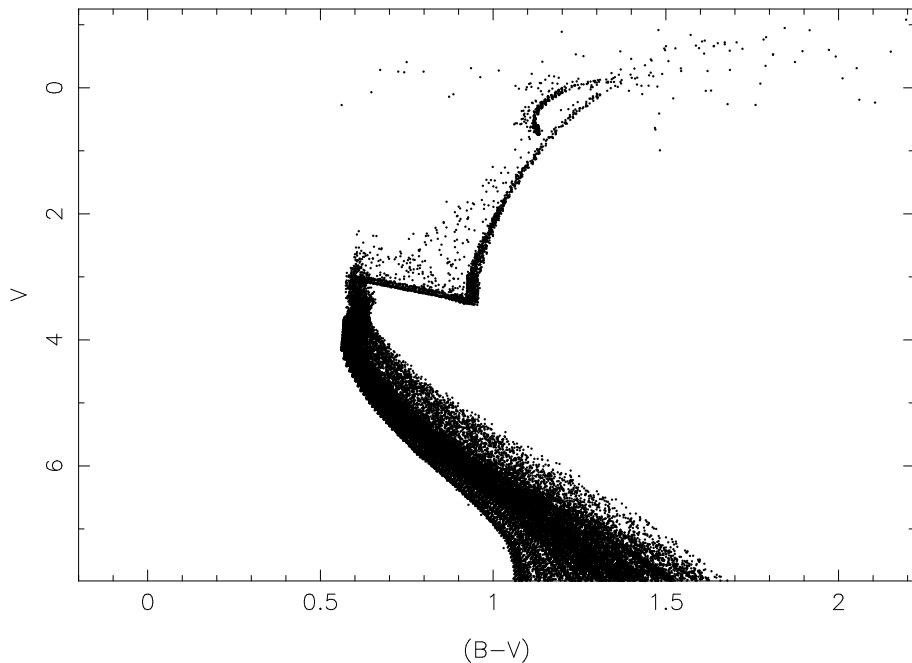


Figure 3. Similar to Figure 2, but for a stellar population without binary stars.

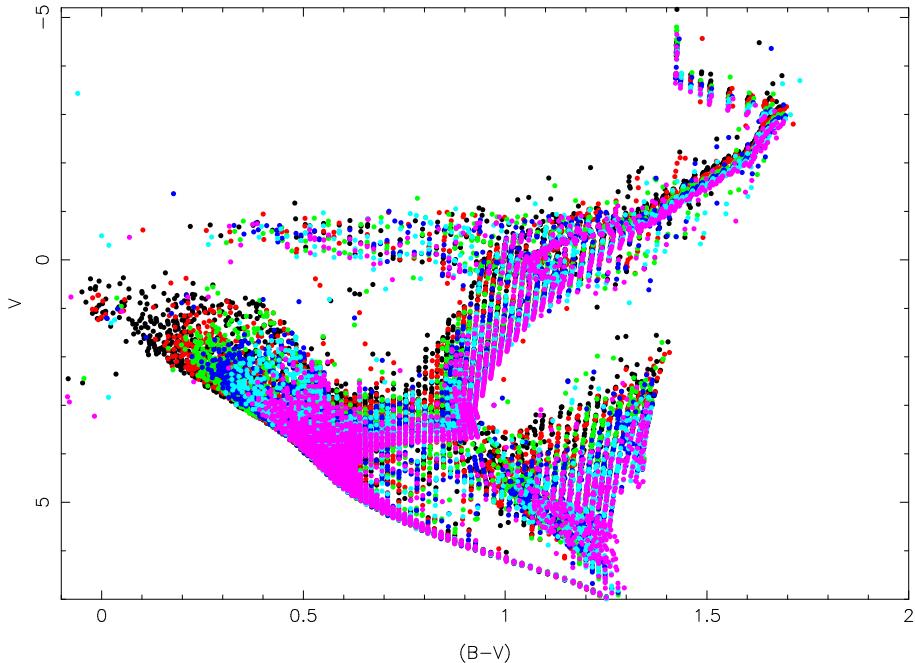


Figure 4. CMD of a composite stellar population with 50% binary stars. Stars are assumed to form between 10 and 5 Gyr. The stellar metallicity (Z) of the population is 0.02. Effects of observational uncertainty is not taken into account.

main reason for causing UV-upturn SEDs. In addition, the figure shows that the age of young component affects SEDs significantly.

4. Discussion

Although this paper discusses the application of binary evolution in studies of stars, star clusters and galaxies, it needs deeper investigations. First, all stellar populations take a binary fraction of 50%, but the fractions may be different for various objects. Thus it is necessary to investigate how binary fraction affect astrophysical studies and build stellar population models with wide binary fractions. Second, the effect of mass ratio of two components of a binary should be studied according to observational results. Third, the metallicity difference in stars of a stellar population should be noted. This will be important for objects that have long star formation histories. Finally, a lot of processes in binary evolution remains unclear. Thus the uncertainty in binary evolution should be taken into account.

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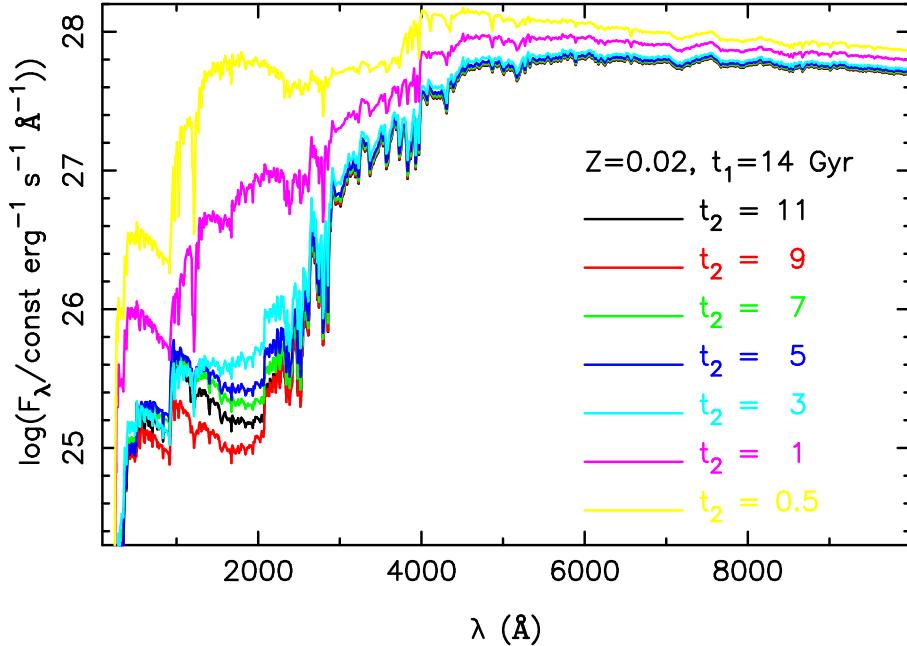


Figure 5. SEDs of a few composite stellar populations with solar stellar metallicity. Each composite stellar population contains an old and a young component. All populations have the same age (14 Gyr) for their old components but different ages for their young components.

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