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Using colours to determine the stellar ages and metallicities of distant galaxies

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ABSTRACT

The determination of stellar populations of galaxies are important for studying the formation and evolution of galaxies, because all galaxies contain many stars and they evolve with galaxies. Spectra data are usually used to determine the stellar populations of nearby galaxies as they have the ability to disentangle the degeneracy between stellar age and metallicity. However, it is difficult to give similar studies to distant (e.g., $z > 0.3$) galaxies because of the lack of reliable spectra data. This is actually limited by current observational equipments and methods. In fact, the information of the stellar ages and metallicities of distant galaxies are crucial for solving the problem of galaxy formation and evolution. Colours can give us some information of the stellar populations of distant galaxies. In the paper, I introduce our works about using colours to estimate the ages and metallicities of the stellar populations of galaxies. Some potential colours for studying stellar-population parameters (age and metallicity) and their sensitivities to stellar-population parameters are reviewed. A new composite stellar population model that includes both single stars and binary stars is also introduced.

Key words: galaxies: stellar content, galaxies: evolution, galaxies: formation

1 INTRODUCTION

The formation of galaxies is one of the biggest challenges in astronomy and astrophysics. It is the golden era to solve this problem, because we have had good background of the formation and evolution of stars and the universe. In fact, many works have been done and some progress has been presented. However, it is far from well understanding galaxies and further researches are needed. Evolutionary stellar population synthesis is a widely used technique for studying galaxies. It can give reliable studies to galaxies via their stellar contents, because all galaxies contain a great deal of stars and stars contribute mainly to the light of galaxies. A lot of works studied galaxies using their stellar populations (see, e.g., Li et al. 2006). However, most previous works studied the stellar populations of nearby galaxies, via spectra-like methods, while optical colours are thought to be unusable for determining two stellar-population parameters (age and metallicity). This is very the well-known stellar age–metallicity degeneracy. However, some studies also showed that colours in different bands are sensitive to different stellar-population parameters and can possibly be used to give estimates to stellar populations of distant galaxies, and then investigations to galaxy formation and evolution. I will review our works on trying to use colours to study the stellar-population parameters of galaxies. This will be useful for future studies, because colours can be obtained much more easily than the spectra of galaxies.

The structure of the paper is as follows. In section 2, I introduce the sensitivities of colours to stellar-population parameters and some potential colours for stellar population studies. In section 3, I summary a few points that should be considered when using colours to study stellar populations. In section 4, I introduce a new stellar population model for using colours to study stellar populations of galaxies. Finally, in section 5, I give a short conclusion.

2 SENSITIVITIES OF COLOURS

Spectra line strength indices can be used to disentangle the stellar age–metallicity degeneracy because they have different sensitivities to the age and metallicity of stellar populations. However, optical colours are thought to be useless for disentangling stellar age–degeneracy because they have similar sensitivities to stellar-population parameters. In order to investigate the possibility of using colours in different bands to study the ages and metallicities of stellar populations, we investigated the sensitivities of colours to stellar-population parameters (Li et al. 2007). In that work, a simple stellar population model (Bruzual & Charlot 2003) and a relative sensitivity method were used. The results showed that colours in different bands have various sensitivities to the inputs of stellar populations. In detail, some colours related to optical bands, e.g., $(B-V)$, $(U-R)$, $(R-I)$ and $(V-I)$, are more sensitive to stellar age, while some other ones related to near-infrared bands, e.g., $(B-K)$, $(R-K)$, $(V-K)$ and $(I-K)$, to stellar metallicity. However, it showed that every colour is affected by both stellar age and metallicity. This suggests that it is impossible to determine stellar age or metallicity using one colour index. However, using a pair of colours that consist of an age-sensitive colour and a metallicity-sensitive colour, the stellar ages and metallicities of galaxies can be determined. One can refer to our paper (Li et al. 2007) for more details. When we tried to study the sensitivities of some colours (hereafter composite colours) including magnitudes on different photometry systems, we found that some composite colours [e.g., $(r-K)$, $(u-K)$, $(u-R)$ and $(i-I)$] have good sensitivities to stellar-population parameters. Thus they can be used for stellar population studies. If taken the usual observational errors for magnitudes, the abilities of different pairs of colours for disentangling the well-known stellar age–metallicity degeneracy can be valued (Li & Han 2008a). It is shown that pairs such as $[(r-K), (u-R)]$ and $[(r-K), (u-r)]$ are better for usual stellar population studies. However, the uncertainties in final stellar ages and metallicities are somewhat large (near 100%). This results from the large observational uncertainties in colours. Because different surveys have different observational uncertainties, the errors in the results of various surveys can be different a lot. In future surveys, because colour uncertainties will be possibly reduced, it will be possible to give more accurate constraints on stellar ages and metallicities of galaxies via colours.

3 POINTS SHOULD BE NOTED

Colours related to different bands have various sensitivities to stellar-population parameters and can help us to determine the stellar ages and metallicities of galaxies. However, some points should be noted, because simple stellar population models are usually used, but colours can be affected by, e.g., dust, young stars, and binary stars in galaxies, and observed colours are related to the distances of galaxies. In the following part, I will mention a few points.

3.1 Effects of young stars

Because early-type galaxies were thought to have some homogeneous and old stellar populations, some simple stellar population models were widely used in the studies of the stellar populations of early-type galaxies. However, more and more observations showed that there are recent star formations in those galaxies. It suggests that young stars are common in all type of galaxies and there should be more than one stellar populations in a galaxy. In this case, it is necessary to consider the effects of young stars on the determination of stellar ages and metallicities of galaxies, as young stars are usually bright and can contribute much to the light. One (Li & Han 2007) of our works studied how young stars can affect the stellar-population parameters determined by colours. That work shows that if there were two stellar populations (an old and a young one with the same metallicity) in a galaxy, the younger the age or the larger the mass fraction of the young component, the bluer the colours of the galaxy. When one gives estimates to stellar ages and metallicities via comparing a pair of colours of galaxies to those of theoretical simple stellar populations, younger ages and richer metallicities are usually obtained. Therefore, one should take the effects of young stars into account when studying stellar-population parameters using colours.

3.2 Effects of binary interactions

Because it is easier to model stellar populations via single stars, most widely used stellar population models are single-star stellar population models (ssSSPs), which do not take the effects of binary interactions into account. However, binary stars are common and they evolve differently from single stars. Two of our works (Li & Han 2008b; Li & Han 2008c) show that binary interactions make stellar populations less luminous, while making colours bluer, age-sensitive line strength indices larger and metallicity-sensitive indices less compared to ssSSPs. When using colours to determine the stellar-population parameters of galaxies, different stellar ages and metallicities will be obtained via ssSSPs and bsSSPs. Usually, poorer metallicities and similar ages will be given by ssSSP models, compared to the results obtained via bsSSP models. Therefore, when investigating the stellar metallicities of galaxies, the effects of binary interactions should be taken into account. In addition, although ssSSP and bsSSP models can give similar ages for galaxies, it is actually much more complicated in practical works, because the effects of binary interactions are degenerate with stellar-population mixing. This needs further investigations.

3.3 Effects of dust and corrections

Most stellar population models do not take the effects of dust into account, but dust exists in galaxies and can change the colours of galaxies. Therefore, the effects of dust should be considered. Many works about the dust of galaxies have been done, but there is a long way to go. Although it is difficult to give accurate corrections for the dust in galaxies, we can reduce the effects of dust in final results via defining our galaxy samples carefully. If we study luminous and relatively blue early-type galaxies, dust will affect our results much more slightly, because there is less dust in such galaxies. Moreover, there are larger uncertainties in the results of of galaxies with large (e.g., > 1) red shifts, because the corrections of the colours of such galaxies have much uncertainties and they can lead to large uncertainties in final results. However, this will possibly be improved in the future, following the development of telescopes and the process of observational data.

4 A NEW MODEL FOR STELLAR POPULATION STUDIES

Although there are many available stellar population models and some of them are widely used, there are some limitations in those models. It is necessary to build some new and more advanced models for stellar population studies and galaxy studies. I introduce a new model for studying stellar populations of galaxies via colours or low resolution spectral energy distributions (SEDs). This is a model that takes both the effects of binary interactions and population mixing into account. Because binary insteraction and population mixing

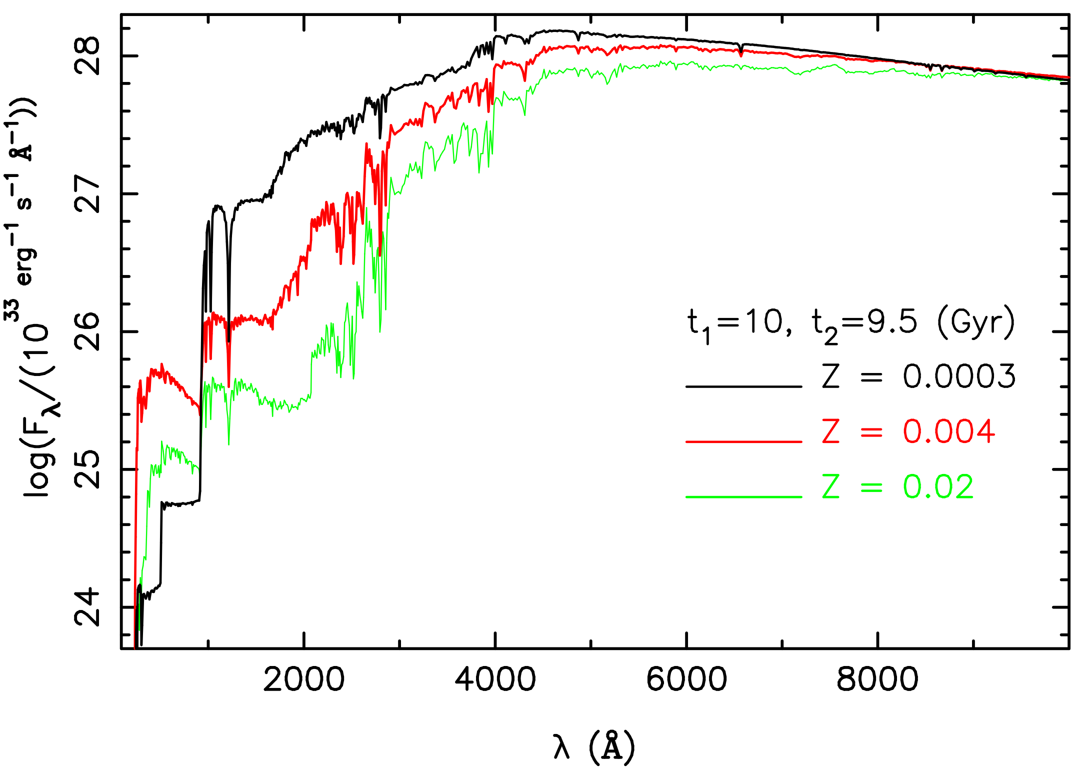

Figure 1. The spectral energy distributions of three composite stellar populations with different metallicities. A fraction of 50% is taken for binaries.

are common in galaxies, the theoretical populations of the new model are closer to those of galaxies.

The model is built using an isochrone database (Li & Han 2008d) of both single-star and binary-star stellar populations, in which the evolution of stars was calculated via the rapid stellar evolution code of Hurley et al. (2002). When building the new model, we used BaSeL 3.1 spectra library (Westera et al. 2002) to transform the results of stellar evolution into the SEDs of stellar populations. Although a galaxy may contains many populations, we build our population via two stellar populations (an old and a young one). This makes it easier to calculate the model and possible to estimate the characteristics of the main components of galaxies. Following the results of Thomas et al. (2005), a exponentially declining law with age is taken for the mass fractions of young components in our work. In such a case, when the model is used for studies, some mass-weighted stellar ages and metallicities will be obtained for the components of galaxies. As the main results, the SEDs and colours of composite stellar populations are calculated. In Fig. 1, the SEDs of a few populations are shown as an example. We see that the UV-upturns observed in elliptical galaxies are reproduced by our new model. In fact, UV SEDs are sensitive to the recent star formations of galaxies. When we try to study the sensitivities of colours to the inputs of stellar populations, photometries in different bands are found to be sensitive to different model inputs. This will be useful for studying the metallicities and the ages of the components of the stellar populations of galaxies, and then the star formation histories of galaxies.

5 CONCLUSION AND DISCUSSION

Colours can help us to explore the stellar populations of galaxies, because different colours have various sensitivities to the inputs of stellar populations. If the galaxy sample is well selected and suitable stellar population model is used, some credible results can be obtained via colours of galaxies. It is will be useful for studying the formation and evolution of galaxies. However, some points should be noted in studies.

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