Evolutionary Population Synthesis for Binary Stellar Population at High Spectral Resolution: Integrated Spectral Energy Distributions and Absorption-feature Indices

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ABSTRACT
Using evolutionary population synthesis we present high resolution (0.3 Å) integrated spectral energy distributions from 3000 to 7000 Å and absorption-line indices defined by the Lick Observatory image dissector scanner (referred to as the Lick/IDS system, for an extensive set of instantaneous burst binary stellar populations with binary interactions. The ages of the populations are in the range 1–15 Gyr and the metallicities are in the range 0.004–0.03. This high resolution synthesis results can satisfy the needs of modern spectroscopic galaxy surveys, and are available on request.

By comparing the synthetic continuum of populations at high and low resolution we show that there is a good agreement for solar metallicity and a tolerable disagreement for non-solar metallicity. The strength of the Balmer lines at high spectral resolution is greater than that at low resolution for all metallicities. The comparison of Lick/IDS absorption-line indices at low and high resolution, both of which are obtained by the fitting functions, shows that the discrepancies in all indices except for TiO$_1$ and TiO$_2$ are insignificant for populations with $Z = 0.004$ and $Z = 0.02$. The high resolution Ca4227, Fe5015 and Mg$_b$ indices are redder than the corresponding low resolution one for populations with $Z = 0.01$ and $Z = 0.03$, this effect lowers the derived age and metallicity of the population. The high resolution Mg$_1$, Fe5709 and Fe5782 indices are bluer than those at low resolution, it raises the age and metallicity. The discrepancy in these six indices is greater for populations with $Z = 0.03$ in comparison to $Z = 0.01$.

At high resolution we compare the Lick/IDS spectral absorption indices obtained by using the fitting functions with those measured directly from the synthetic spectra, and see that Ca4455, Fe4668, Mg$_b$ and Na D indices obtained by the use of the fitting functions are redder for all metallicities, Fe5709 is redder at $Z = 0.03$ and becomes to be bluer at $Z = 0.01$ and 0.004, and other indices are bluer for all metallicities than the corresponding values measured directly from the synthetic spectra.

Key words: Star: evolution – binary: general – Galaxies: cluster: general

1 INTRODUCTION
In the previous papers [Zhang et al. 2004, 2005], hereinafter Paper I, II), we took into account various known classes of binary stars in evolutionary population synthesis (EPS) models, presented integrated colours, integrated spectral energy distributions (ISEDs) and 21 absorption-line indices [following the definitions of Worthey et al. 1994] defined by the Lick Observatory image dissector scanner (referred to as the Lick/IDS system for an extensive set of instantaneous-burst binary stellar populations (BSPs) with binary interactions, investigated the influences of binary interactions and model input parameters on the results, and found that the inclusion of binary interactions makes the integrated $U - B$, $B - V$, $V - R$ and $R - I$ colours and the 21 Lick/IDS spectral indices substantially bluer. In Papers I and II the

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corrected BaSeL-2.0 (i.e., non-calibrated BaSeL-2.2) stellar spectra library of Lejeune, Cuisinier & Buser (1997, 1998) was used and low spectral resolution ISEDs (10 Å in the ultraviolet and 20 Å in the visible) were given.

In recent years, some spectroscopic galaxy surveys at intermediate spectral resolution (such as the Sloan Digital Sky Survey, SDSS) have been undertaken, and the data has been analyzed with EPS models to understand galaxy formation and evolution. Therefore, a EPS model that can predict the ISEDs at intermediate and high spectral resolution is required. The high spectral resolution of ISEDs can be used to predict the strength of numerous weak absorption lines and the evolution of the properties of the strongest lines over a wide range of ages (González Delgado et al. 2005; Munari et al. 2005; Murphy & Meiksin 2004; Zwitter, Castelli & Munari 2002,Murphy, Meiksin 2004; Zwitter, Castelli & Munari 2002,)(2004) used the library of Munari et al. (2005) and presented high resolution ISEDs and spectral absorption indices.

In this study the initial mass of the primary is chosen from the approximation to the IMF of Miller & Scalo (1979) as given by (Eggleton, Fitchett & Tout 1989, hereinafter EFT).

\[ m_1 = \frac{0.19X}{(1 - X)^{0.75} + 0.032(1 - X)^{0.25}} \]  

where \( X \) is a random variable uniformly distributed in the range \([0,1]\), and \( m_1 \) is the primary mass in units of \( M_\odot \).

(ii) the initial secondary-mass distribution, which is assumed to be correlated with the initial primary-mass distribution in this study. So, it depends on the initial primary-mass (as set by equation 1) and the initial mass ratio, \( q \), distribution, which is assumed to be a uniform form (EFT 1989; Mazeh et al. 1992; Goldberg & Mazeh 1994).

\[ n(q) = 1, \quad 0 \leq q \leq 1, \]

where \( q = m_2/m_1 \),\( m_2 \) is the secondary mass in units of \( M_\odot \).

(iii) the distribution of orbital separations (or periods). It is taken as constant in \( \log a \) (where \( a \) is the separation) for wide binaries and falls off smoothly at close separations:

\[ a \approx \frac{a_0}{\psi} \]

where \( a_0 = 10R_\odot \) and \( \psi = 1.2 \).

(iv) the eccentricity distribution. A uniform form is assumed:

\[ e = X, \]

where \( X \) is a random variable, as in Eq. 1.

After the initial state (the masses of the component stars, \( m_1 \) and \( m_2 \), the separation \( a \) and eccentricity \( e \) of the orbit) of a binary system in a BSP is set, we also need to set the lower and upper mass cut-offs \( m_1 \) and \( m_2 \) to the mass distributions and assign a metallicity \( Z \) to the stars: \( m_1 \) and \( m_2 \) are set as 0.1 and 100 \( M_\odot \), respectively, \( Z = 0.004, 0.01, 0.02, 0.03 \). The relative age \( \tau \) of the BSP is assigned within the range of 1 – 15 Gyr.
2.2 Input physics, parameters and algorithm

We use the rapid binary star evolution (BSE) algorithm of Hurley, Tout & Pols (2002) to evolve each binary in the BSP to an age of $\tau$, which gives us evolutionary parameters such as the stellar luminosity $L$, effective temperature $T_{\text{eff}}$, radius $R$, current mass $m$ and the ratio of radius to Roche-lobe radius $R/R_L$ for the component stars. Next we use the high resolution HRES stellar spectral library of González Delgado et al. (2005) to transform the evolutionary parameters to stellar flux by interpolating the flux grid in the $\log T_{\text{eff}} - \log g - [\text{Fe/H}]$ plane, and then use equation (4) to obtain the monochromatic flux for an instantaneous BSP of a particular age and metallicity. For the spectral absorption-line indices in the Lick/IDS system, we assign the Lick/IDS absorption indices to a star with a set of given evolutionary parameters, and then use equations (5) to (8) to derive the indices for a BSP.

The integrated monochromatic flux of a BSP is defined as

$$F_{\lambda, \tau, z} = \sum_{k=1}^{n} f_{\lambda, k},$$

where $f_{\lambda, k}$ is the SED of the $k$th star.

The integrated absorption feature index of the Lick/IDS system is a flux-weighted one. For the $i$th atomic absorption line, it is expressed in equivalent width ($W_i$ in angstroms),

$$W_{i, \tau, z} = \sum_{k=1}^{n} \frac{w_i}{\sum_{k=1}^{n} f_{\lambda, C_{i, k}}},$$

where $w_i$ is the equivalent width of the $i$th index of the $k$th star, and $f_{\lambda, C_{i, k}}$ is the continuum flux at the midpoint of the $i$th ‘feature’ passband. The local continuum for the $i$-th index is the run of flux defined by drawing a straight line from the midpoint of the blue pseudocontinuum level to the midpoint of the red pseudocontinuum level, the flux at the midpoint of the pseudocontinuum is a average one and obtained by

$$f_{i, p} = \frac{\int_{\lambda_{i-1}}^{\lambda_{i+1}} f_{\lambda} d\lambda}{\lambda_{i+1} - \lambda_{i-1}},$$

where $f_{\lambda}$ is the stellar flux, as in Eq. (5), $\lambda_{i-1}$ and $\lambda_{i+1}$ are the wavelength limits of the $i$-th pseudocontinuum sideband. For the $i$th molecular line, the feature index is expressed in magnitude,

$$C_{i, \tau, z} = -2.5 \log \frac{\sum_{k=1}^{n} 10^{-0.4 c_i} f_{i, C_{i, k}}}{\sum_{k=1}^{n} f_{i, C_{i, k}}},$$

where $c_i$ is the magnitude of the $i$th index of the $k$th star.

Detailed descriptions of the BSE package of Hurley et al. (2002) and the empirical fitting functions of Worthey et al. (1994) have been presented in Papers I and II, here we only mention several important input parameters required in the BSE code: the efficiency of common envelope ejection $\eta_{CE}$ is taken as 1.0, the Reimers wind mass-loss coefficient $\eta_1$ is set constant at 0.3, and the tidal enhancement parameter $B = 0.0$.

Following, we present a brief description of the HRES stellar spectral library of González Delgado et al. (2005). This library includes the synthetic stellar spectra from 3000 to 7000 Å with a final spectral sampling of 0.3 Å. The spectra span a range of effective temperature from 3000 to 55000K, with variable steps from 500 to 2500K, and a surface gravity $\log g = -0.5$ to 5.5 with dex steps of 0.25 and 0.5. For each temperature, the minimum gravity is set by the Eddington limit. The library covers several metallicities: twice solar, solar, half solar and 1/10 solar. Solar abundance ratios for all the elements, and a helium abundance of He/H $= 0.1$ by number are assumed. This high spectral resolution stellar library is based on Kurucz local thermodynamic equilibrium (LTE) atmospheres (Kurucz 1993), and the program SYNSPEC (Hubeny, Lanz & Jeffery 1995) for stars with $8000 \leq T_{\text{eff}} \leq 27000$ K, the program SPECTRUM (Gray & Corbally 1994) and Kurucz atmospheres for stars with $4750 \leq T_{\text{eff}} \leq 7750$ K, non-LTE line-blanketed models for hot ($27500 \leq T_{\text{eff}} \leq 55000$ K, Lanz & Hubeny 2003), and PHOENIX LTE line-blanketed models for cool stars ($3000 \leq T_{\text{eff}} \leq 4500$ K, Hauschildt & Baron 1999, Allard et al. 2001). This library is composed of 1650 spectra.

By adopting the above set of input distributions and parameters, in Fig. 4 we present the number of binary systems experiencing Roche lobe overflow (RLOF) as a function of time for solar-metallicity BSPs of $1 \times 10^6$ binaries. Because some binary systems would experience RLOF for several times, in Fig. 4 solid, dashed, dot-dashed, dotted and thick-dashed and thick-solid lines represent the 1st, 2nd, 3rd, 4th, 5th and all RLOF, respectively. From Fig. 4 we see that RLOF mainly happens at early age, and the number decreases with time. During the past 15 Gyr ~ 11.6 per cent of the binaries would experience RLOF.

Figure 1. Number of binary systems experiencing RLOF as a function of time for solar-metallicity BSPs of $1 \times 10^6$ binaries. Solid, dashed, dot-dashed, dotted, thick-dashed and thick-solid lines represent the 1st, 2nd, 3rd, 4th, 5th and all RLOF, respectively.
3 RESULTS

3.1 The integrated spectral energy distribution

In this part we present ISEDs covering the range 3000 – 7000 Å with a resolution of 0.3 Å for instantaneous burst BSPs with binary interactions over a large range of age and metallicity: \(1 \leq \tau \leq 15\) Gyr and \(-1.3 \leq [\text{Fe/H}] \leq +0.2\). For each model, a total of \(1.0 \times 10^6\) binaries are evolved according to the algorithm given in the previous section. The full set ISEDs are available on request from the authors.

In Fig. 4 we give the high spectral resolution ISED evolution for solar-metallicity BSPs at ages \(\tau = 1, 2, 4, 7, 13\) Gyr in the wavelength range of 3000 – 7000 Å. It shows that the continuum tends to be redder with increasing the age of the BSP, the variation in the shape of the continuum with time is significant at early age, and is almost constant at intermediate and late ages. Additionally, Fig. 2 shows that the strength of the Balmer lines decreases with the age of the BSP.

The metallicity effect on ISED evolution of BSPs is shown in the top panel of Fig. 3, which presents the ISEDs of young (\(\tau = 1\) Gyr) and intermediate-age (\(\tau = 7\) Gyr) BSPs at four different metallicities: \(Z = 0.004, 0.01, 0.02, 0.03\). The metallicity effect is also exhibited in the slope of the continuum and in the strength of the metallic lines. The continuum tends to be redder with increasing metallicity and metallic lines to be stronger. The bottom panel of Fig. 3 gives the evolution of Balmer lines with metallicity, it shows that their strength tends to be weaker when increasing metallicity.

In Fig. 4 we compare the ISEDs at high and low spectral resolution (10 Å in the ultraviolet and 20 Å in the visible) for solar-metallicity BSPs at ages \(\tau = 1, 2, 4, 7\) and 13 Gyr. These low resolution ISEDs are from Model A of Paper II, which includes binary interactions and adopts the same input parameters and distributions as this paper except for using the corrected BaSeL-2.0 (i.e., non-calibrated BaSeL-2.2) stellar spectral library of Lejeune et al. (1997, 1998). Fig. 4 shows that there is a good agreement in the continuum for solar-metallicity BSPs between two studies. Comparison
of the continuum for BSPs with non-solar metallicity shows that there is a difference existed at longer wavelengths for BSPs at ages $\tau = 1$ and 2 Gyr. In Fig. we give the ISEDs at high and low resolution for $\tau = 1$ Gyr BSP with four metallicities. It shows that at longer wavelengths the high resolution continuum is lower (redder) for BSPs with $Z = 0.004$, while greater (bluer) for BSPs with $Z = 0.01$ and 0.03 than that at low resolution.

3.2 Lick spectral absorption feature indices

At high spectral resolution we use two methods to obtain 25 Lick/IDS spectral absorption indices defined by Worthey et al. (1994) and Worthey & Ottaviani (1997): (1) directly compute them from the high-resolution synthetic spectra, (2) obtain them by using the empirical fitting functions of Worthey et al. (1994) and Worthey & Ottaviani (1997).

All the following results are for BSPs of $10^6$ binaries. To verify that our results are stable for $10^6$ binaries, we perform several simulations, the number of binaries in each simulation is $10^4$, $4 \times 10^4$, $1.6 \times 10^5$, $3.6 \times 10^5$ and $6.4 \times 10^5$, respectively. As an example, in Fig. we plot the evolution of Mg$_1$ index as a function of the number of binaries in the simulation, we see that the Mg$_1$ index fluctuates around the value for $10^6$ binaries when the number of binaries is not so enough, with the increase of the number of binaries the fluctuation would decrease. For $10^4$ binaries the discrepancy reaches to $\sim 0.05$ Å at $\tau = 12$ Gyr, for $3.6 \times 10^5$ binaries Mg$_1$ agrees with the value for $10^6$ binaries within a small range, and for $6.4 \times 10^5$ binaries the discrepancy is insignificant. Therefore the results for $10^6$ binaries in the simulation are stable.

3.2.1 Results by the use of the fitting functions

Using the high resolution spectra and the fitting functions of Worthey et al. (1994) and Worthey & Ottaviani (1997), we obtain 25 Lick/IDS spectral absorption indices for the BSPs with binary interactions with four metallicities from
| Age (yr) | 1.00 | 2.00 | 3.00 | 4.00 | 5.00 | 6.00 | 7.00 | 8.00 | 9.00 | 10.00 | 11.00 | 12.00 | 13.00 | 14.00 | 15.00 |
|---------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| CN1     | 0.184| 0.136| 0.106| -0.079| -0.065| -0.051| -0.048| -0.051| -0.038| -0.034| -0.032| -0.044| -0.038| -0.035| -0.036|
| CN2     | 0.206| 0.171| 0.150| 0.129| 0.110| 0.093| 0.085| 0.080| 0.073| 0.069| 0.063| 0.062| 0.060| 0.059| 0.057|
| CN3     | 0.247| 0.197| 0.165| 0.138| 0.120| 0.107| 0.101| 0.097| 0.093| 0.089| 0.086| 0.085| 0.084| 0.082| 0.080|
| CN4     | 0.265| 0.205| 0.176| 0.153| 0.138| 0.124| 0.117| 0.111| 0.108| 0.104| 0.101| 0.099| 0.098| 0.097| 0.096|
| CN5     | 0.289| 0.229| 0.199| 0.177| 0.163| 0.149| 0.142| 0.137| 0.133| 0.129| 0.126| 0.125| 0.124| 0.123| 0.122|
| CN6     | 0.314| 0.254| 0.223| 0.202| 0.187| 0.174| 0.167| 0.162| 0.158| 0.155| 0.152| 0.151| 0.150| 0.149| 0.148|
| CN7     | 0.340| 0.280| 0.250| 0.229| 0.215| 0.202| 0.196| 0.192| 0.188| 0.185| 0.182| 0.182| 0.181| 0.180| 0.179|
| CN8     | 0.371| 0.311| 0.281| 0.262| 0.249| 0.237| 0.232| 0.228| 0.224| 0.221| 0.218| 0.218| 0.217| 0.216| 0.215|
| CN9     | 0.420| 0.370| 0.340| 0.322| 0.309| 0.298| 0.294| 0.291| 0.288| 0.285| 0.283| 0.283| 0.282| 0.282| 0.281|
| CN10    | 0.467| 0.417| 0.387| 0.369| 0.357| 0.347| 0.343| 0.340| 0.337| 0.335| 0.333| 0.333| 0.333| 0.333| 0.333|

Table 1. Lick/IDS spectral absorption feature indices of BSPs, derived by using the empirical fitting functions (Section 3.2.1).
In Figs. 8 and 9 we plot the theoretical age and metallicity if using high resolution Mg\(1\)Ca4227 (3), Fe5015 (10), Mg\(1\) (13), Fe5709 (17) and Fe5782 (18) indices. The symbols linked by a line denote the indices obtained by using the high resolution spectra of González Delgado et al. (2005), and those without a line are from the low resolution spectra of Lejeune et al. (1997, 1998). Different symbols are for different metallicity, from top to bottom, the metallicity \(Z\) is 0.03, 0.02, 0.01 and 0.004, respectively.

Figure 7. Evolution of absorption indices in the Lick/IDS system obtained by using the fitting functions for BSPs of various metallicity.

We compare them with those obtained by Model A of Paper II, which uses low resolution stellar spectral library and the fitting functions, and find that the evolution of TiO\(_1\) and TiO\(_2\) indices is not smooth for both two studies, the discrepancy in the rest 23 Lick/IDS spectral indices is small for metallicity \(Z\) = 0.004 and \(Z\) = 0.02, the synthetic Ca4227 (index 3), Fe5015 (10), Mg\(_1\) (11), Mg\(_0\) (13), Fe5709 (17) and Fe5782 (18) indices show much stronger discrepancy for metallicity \(Z\) = 0.01 and \(Z\) = 0.03.

In Fig. 8 we show the comparison of Ca4227 (index 3), Fe5015 (10), Mg\(_1\) (11), Mg\(_0\) (13), Fe5709 (17) and Fe5782 (18) indices between two studies. It shows that the high spectral resolution Ca4227 (3), Fe5015 (10) and Mg\(_0\) (13) indices are greater, Mg\(_1\) (11), Fe5709 (17) and Fe5782 (18) indices are less than those at low resolution for BSPs with \(Z\) = 0.03 and \(Z\) = 0.01, the discrepancy is greater for BSPs with \(Z\) = 0.03 in comparison to \(Z\) = 0.01. This discrepancy in the Lick/IDS spectral indices will directly influence the derived age and metallicity of a particular population, it will lower the age and metallicity if using high resolution Ca4227 (3), Fe5015 (10) and Mg\(_0\) (13) indices, and raise the age and metallicity if using high resolution Mg\(_1\) (11), Fe5709 (17) and Fe5782 (18) indices.

To discuss whether the difference of the coverage in the log\(g\)–log\(T_{\text{eff}}\) plane between HRES and BaSeL-2.0 libraries would cause the discrepancies in the Lick/IDS spectral absorption indices, in Figs. 8 and 9 we plot the theoretical isochrones of the bluest (i.e., the youngest [\(\tau\) = 1 Gyr] and lowest metallicity [\(Z\) = 0.004]) and the reddest (the oldest [\(\tau\) = 15 Gyr] and highest metallicity \(Z\) = 0.03) BSPs. In order to transform the evolutionary parameters of stars along the isochrones to stellar flux for \(Z\) = 0.004 BSPs in Fig. 8 we need to make interpolation in the flux grids between [Fe/H] = −1.0 and −0.5 because HRES spectral library only contains [Fe/H] = −1.0, −0.5, 0.0 and 0.3. While, the grid coverage in the log\(g\)–log\(T_{\text{eff}}\) plane between [Fe/H] = −1.0 and −0.5 is appreciably different, and the difference mainly concentrates in the low-temperature range. Within this low temperature range the denser stars (such as, low-mass MS stars) only give small contribution to the ISEDs (see Figs. 3 and 4 of Paper II), so we only interest in the difference of two libraries in the low-density range, in this range the grid coverage at [Fe/H] = −0.5 is smaller than that at [Fe/H] = −1.0, so in Fig. 8 we plot the boundary of HRES flux grid coverage at [Fe/H] = −0.5. Also we plot the boundary of BaSeL-2.0 flux grid coverage at [Fe/H] = −0.5, for this library the grid coverage in the log\(g\)–log\(T_{\text{eff}}\) plane for [Fe/H] = −1.0 and −0.5 is same in the low-temperature and low-density range. Similarly, for \(Z\) = 0.03 BSPs in Fig. 9 we plot the boundary of HRES flux grid coverage at [Fe/H] = 0.3 and BaSeL-2.0 library at [Fe/H] = 0.2.

Comparison of the coverage in the log\(g\)–log\(T_{\text{eff}}\) plane for two libraries in Figs. 8 and 9 shows HRES library extends to the higher temperature, in the log\(T_{\text{eff}}\) ≥ 4.43 range covers less gravity than BaSeL-2.0 library, while the latter covers...
lower temperature range. Although in the high temperature range the grid coverage of two libraries exists discrepancies, both grid coverage are enough to the BSPs we considered. In the lower temperature and lower gravity range, HRES library does not cover all cool AGB stars, it would cause the discrepancies in the Lick/IDS absorption line indices. Additionally, the differences in the spectral shape caused by the resolution also would cause to the discrepancies of the above several Lick/IDS absorption line indices.

3.2.2 Results computed from the high-resolution spectra

To compare theoretical results with observations, the Lick/IDS absorption indices also are measured directly from the high-resolution ISEDs using the passband definitions of Worthey et al. (1994) and Worthey & Ottaviani (1997), and are presented in Table 2. In Fig. 10 we compare them (except for TiO$_1$ and TiO$_2$) with those obtained by using the fitting functions of Worthey et al. (1994) and Worthey & Ottaviani (1997) (generated from Table 1), and find that Ca4455 (index 6, almost equal for $Z = 0.02$), Fe4668 (index 8, almost equal for $Z = 0.004$), Mg$_b$ (13) and Na D (19) are bluer than the corresponding ones obtained by using the fitting function for all metallicities. For Fe5709 (17) the discrepancy becomes from negative ($Z = 0.03$) to positive ($Z = 0.01$ and 0.004). Other indices are redder than the values from Table 1 for all metallicities.

Comparing the discrepancies in the Lick/IDS spectra indices caused by the difference in the metallicity, we find that the discrepancies in Ca4455 (index 6), Mg$_2$ (12), Mg$_b$ (13) and Na D (19) indices introduced by using the different computation method are smaller.
| CN   | 1.00  | 2.00  | 3.00  | 4.00  | 5.00  | 6.00  | 7.00  | 8.00  | 9.00  | 10.00 | 11.00 | 12.00 | 13.00 | 14.00 | 15.00 |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 0.005 | 1.00  | 2.00  | 3.00  | 4.00  | 5.00  | 6.00  | 7.00  | 8.00  | 9.00  | 10.00 | 11.00 | 12.00 | 13.00 | 14.00 | 15.00 |
| 0.004 | 1.00  | 2.00  | 3.00  | 4.00  | 5.00  | 6.00  | 7.00  | 8.00  | 9.00  | 10.00 | 11.00 | 12.00 | 13.00 | 14.00 | 15.00 |
| 0.003 | 1.00  | 2.00  | 3.00  | 4.00  | 5.00  | 6.00  | 7.00  | 8.00  | 9.00  | 10.00 | 11.00 | 12.00 | 13.00 | 14.00 | 15.00 |
| 0.002 | 1.00  | 2.00  | 3.00  | 4.00  | 5.00  | 6.00  | 7.00  | 8.00  | 9.00  | 10.00 | 11.00 | 12.00 | 13.00 | 14.00 | 15.00 |
| 0.001 | 1.00  | 2.00  | 3.00  | 4.00  | 5.00  | 6.00  | 7.00  | 8.00  | 9.00  | 10.00 | 11.00 | 12.00 | 13.00 | 14.00 | 15.00 |

**Table 2.** Lick/IDS spectral absorption feature indices of BSSPs, as measured directly from the high-resolution ISEDs (Section 3.2.2.).
Figure 10. Absorption indices in the Lick/IDS system computed directly from the high-resolution ISEDs (symbols + line) and by using the fitting functions (only symbols) for BSPs of various metallicity. The symbols have the same meaning as in Fig. 7.
4 SUMMARY AND CONCLUSIONS

We have simulated realistic stellar populations composed of 100 per cent binaries by producing $1 \times 10^6$ binary systems using a Monte Carlo technique. Using the EPS method we present the high spectral resolution (0.3 Å) ISEDs over the wavelength range 3000–7000 Å and 25 Lick/IDS spectral absorption indices, for an extensive set of instantaneous burst BSPs with binary interactions over a large range of age and metallicity: $1 \leq \tau \leq 15$ Gyr and $0.004 \leq Z \leq 0.03$. This set of high spectral resolution ISEDs fully satisfies the need of studying the formation and evolution of galaxy by analyzing the data of modern spectroscopic galaxy surveys, and can be available on request.

By comparing the synthetic continuum at high and low resolution, we show that there is a good agreement for BSPs with $Z = 0.02$ and smaller discrepancy for BSPs with non-solar metallicity. And, the comparison of the Lick/IDS spectral indices at low and high resolution, both of which are obtained by using the fitting functions, shows that the high resolution Ca4227, Fe5015 and Mg indices are redder, Mg1, Fe5709 and Fe5782 indices are bluer than those at low resolution for BSPs with $Z = 0.01$ and 0.03. The high spectral resolution Ca4227, Fe5015 and Mg indices act to lower the age and metallicity, and the high resolution Mg1, Fe5709 and Fe5782 indices will raise the age and metallicity.

At high resolution we compare the Lick/IDS spectral absorption indices obtained by using the fitting functions with those measured directly from the synthetic spectra, and find that Ca4455, Fe4668, Mg and Na D indices are redder for all metallicities, Fe5709 is redder at $Z = 0.03$ and becomes to be bluer at $Z = 0.01$ and 0.004, other indices are bluer for all metallicities than the corresponding values computed from the high-resolution ISEDs.

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