Challenges in Panchromatic Modelling with Next Generation Facilities
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First galaxy SED: Contribution from pre-main-sequence stars

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Abstract. We calculate the spectral energy distribution of the first galaxies which contain pre-main-sequence stars by using the stellar evolution code Modules for Experiments in Stellar Astrophysics, the spectra model BT-Settl, and the stellar population synthesis code PEGASE. We calculate the galaxy spectral energy distribution for Salpeter Initial Mass Function. We find that very young first galaxies are bright also in mid-infrared, and the contribution of pre-main-sequence stars can be significant over 0.1 Myr after a star-formation episode.

Keywords. galaxies: high-redshift, stars: pre–main-sequence, stars: formation

1. Introduction

Reionization is thought to be triggered by the first stars (at z∼20) with the contribution of first galaxies (z∼10) in the early Universe. Revealing the nature of these first objects is of great interest in astronomy. It is expected that the first objects will be observed by the next generation telescopes such as NASA's James Webb Space Telescope (JWST). In the conventional calculations of spectra of the first galaxies, pre-main-sequence (PMS) stars are not included (Bromm & Kudritzji (2001); Tumlinson, Giroux & Shull (2001); Schaerer (2002); Zackrisson *et al.* (2001)). In nearby galaxies, this is usually assumed because PMSs are hidden by dust grains. However, the light from PMS stars in the first galaxies where dust grains do not exist, can be directly observed. For very young ($\sim 10^5$ yr) first galaxies, which contain PMSs, contribution from PMS stars can be important in spectra of galaxies.

2. Results, Discussion

We calculate the spectral energy distribution (SED) from PMSs as well as from main-sequence (MS) stars. In order to calculate the contribution from PMSs, we calculate a number of PMS evolutions by using Modules for Experiments in Stellar Astrophysics (MESA, Paxton *et al.* 2011). The right panel of Fig. 1 shows the evolutionary tracks of PMSs. The mass range is from $0.1 M_\odot$ to $100\ M_\odot$. We obtained properties for each PMSs from MESA then used to calculate each star spectra by using the BT-Settl prescription, (Allard & Freytag 2012). Summing up the PMS spectra for an assumed initial mass function (IMF), we can then derive the PMSs contribution.

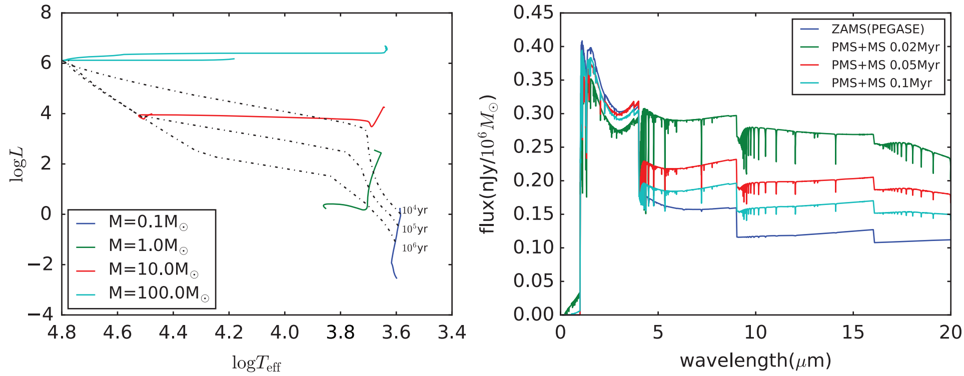

Figure 1. *left panel*: PMSs evolution in the HR diagram. Evolutionary track (solid curve) and isochrones (dotted curve) are also displayed. *right panel*: SED with PMSs at redshift $z = 10$. Observed flux (in nJy per $10^6 M_\odot$ stellar mass) vs. observed wavelength (in μm). The Blue curve represents the SED of the galaxy which consists of ZAMS and other curves represent SED with young PMSs. We assume the Salpeter IMF and instantaneous star burst galaxy at redshift $z = 10$. PMS contribution in mid-infrared ($\sim 10\mu$m) decreases with time.

In the calculation of the MS component, we use the stellar population synthesis code PEGASE (Fioc & Rocca-Volmerange (1997)). In the MS component, we also include the contribution of nebular continuum emission (Osterbrock & Ferland (2006)). We set electron temperature to be 20000K and we use zero age main-sequence (ZAMS) instantaneous star burst galaxy SEDs.

We combine the results of two components (i.e. the MS component and the PMS component) so that the mass distribution becomes Salpeter IMF, then we get the galaxy SED with PMSs contribution. The right panel of Fig. 1 shows the young galaxy SEDs with PMSs. The difference between the blue line (ZAMS) and the green line (0.02 Myr) is due to PMSs. The PMS contribution is important in mid-infrared wavelength because PMSs are low temperature and high luminosity. We find that PMSs can be significant red sources in the very young high-redshift galaxies. In the nearby galaxies, red components represent old stars, but in the distant galaxies, we may overestimate the galaxy ages and the stellar mass without considering PMSs in the SED fitting. The SED of the very young galaxies dramatically change in about 0.1 Myr. The flux of the first galaxy which have a stellar mass of $10^6 M_\odot$ and a Salpeter IMF at redshift $z = 10$ is about 0.3 nJy. It is difficult to detect such small and distant galaxies even if we use JWST, because the flux limit for the NIRCam imaging is about 10 nJy. However, if there is such a galaxy at redshift $z = 5$ and the light is magnified 10 times by gravitational lensing, we can detect not only the MS contribution but also the PMS contribution whose flux is about 10 nJy by using JWST. We thus conclude that the effect of the PMS contribution is indeed significant in the SED modeling of distant and young galaxies.

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