Challenges in Panchromatic Modelling with Next Generation Facilities
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Panchromatic Analysis for Nature of HIgh-z galaxies Tool (PANHIT)

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Abstract. We have developed a new SED fitting tool specialized for frontier redshift galaxies. It is a common case for high-z galaxies that the available data are restricted to rich optical to near-infrared photometry and few far-infrared (FIR) data deep enough to detect the faint object (e.g., *HST*/WFC3 + *Spitzer*/IRAC + ALMA). In such situation, one cannot perform a complicated modeling of dust emission in FIR regime. We then adopt simple treatment for the dust emission using empirical LIRG templates. Instead, we adopt a sophisticated and physically motivated modeling for stellar and nebular emission parts in rest-frame UV-to-optical regime. Our new code fits not only broad band photometry but also spectral emission line flux. There is an option to fit observed SED with two templates with different physical properties. Our new code, PANHIT, is now in public, and was already applied to some high-z frontier galaxies.

Keywords. methods: data analysis, galaxies: high-redshift, early universe

1. Spectral model templates & Fitting algorithm

Our galaxy spectral models called as “SND” consist of the stellar continuum models (S: Bruzual & Charlot 2003), the nebular emission models (N: Inoue 2011), and the empirical dust emission templates (D: Rieke *et al.* 2009). Example of the three components are shown in Figure 1. Stellar continuum spectra are generated with a wide variety of age ($0.1\,\mathrm{Myr} \lesssim \mathrm{age} \lesssim 10\,\mathrm{Gyr}$), metallicity ($0.0001 \leqslant Z \leqslant 0.05$), and star formation history (Instantaneous burst, constant SFR, exponentially declining, and rising SFHs). User defined SFHs can also be adopted. The nebular continuum and emission line fluxes are calculated as functions of the ionizing photon production rate and metallicity of the stellar component (see Mawatari *et al.* 2016 for more detail). The escape fraction of ionizing photons is a free parameter. We follow an analytic model (Inoue *et al.* 2014) for the intergalactic medium attenuation. The same dust attenuation, A_V, is applied to both the nebular line flux and the stellar continuum, where users can select an attenuation law among the Calzetti *et al.* (2000) law, Small Magellanic Cloud law (SMC law; Prevot *et al.* 1984), and Milky Way law (MW law; Seaton 1979). The attenuated energy is re-radiated in the infrared wavelengths. The dust emission is described by the empirical templates of luminous infrared galaxies (LIRG) as a function of the dust emitting infrared luminosity (L_{IR}), where we assume L_{IR} is equal to the luminosity attenuated by dust.

In the template fitting, we followed the χ^2 minimization algorithm for data including flux density upper limits (Sawicki 2012). Not only broad band photometry but also

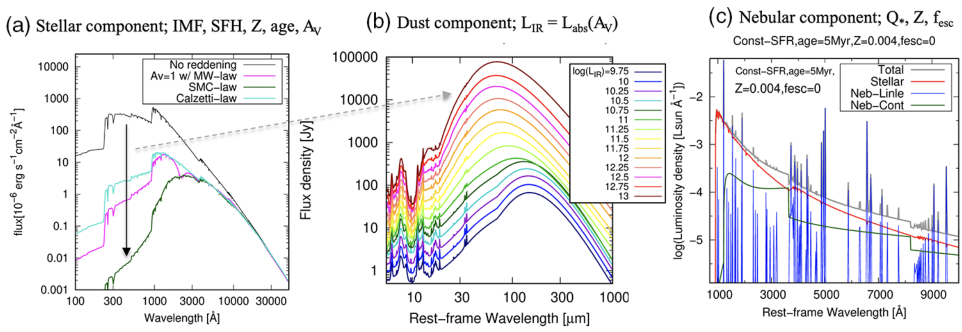

Figure 1. Our spectral models in the three components: (A) Stellar continuum with three dust attenuation laws, (B) Dust emission spectra that come from the empirical LIRG templates, and (C) Nebular continuum and line emissions.

spectral line flux can be fit. Fitting with a composite of two SND templates with different properties is available as an option, where fraction of two components' SFRs at their birth ages is parameterized (f_{SFR}). A Monte-Carlo (MC) technique is adopted to evaluate significance of the fitting solutions and uncertainties associated with the fitting parameters. The SND templates and fitting codes are available from our website: http://www.icrr.u-tokyo.ac.jp/~mawatari/PANHIT/PANHIT.html.

2. Applications

Hashimoto *et al.* (2018) applied PANHIT to the most distant spectroscopically confirmed galaxy at $z = 9.1$. Combining young and old components is required to explain the observed [O III]88μm line flux and *Spitzer*/IRAC red color, from which they suggest that this galaxy started the star-formation at $z \sim 15$. PANHIT also has been used in Hashimoto *et al.* (2019), Tamura *et al.* (2019), Mawatari *et al.* (2020), and Sunaga *et al.* (proceeding of IAU 341 symposium). These studies show that our new SED analysis tool is very useful to investigate detailed physical properties of frontier redshift galaxies.

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