Challenges in Panchromatic Modelling with Next Generation Facilities
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ALMA detection of the [OIII] 88 μm line in a highly-magnified Lyman break galaxy at z = 6.1

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Abstract. We present a 4.7σ detection of the [OIII] 88 μm line in a gravitationally-lensed Lyman break galaxy, RXC J2248-ID3, using the Atacama Large Millimeter/submillimeter Array (ALMA). We did not detect [CII] 158 μm and rest-frame 90 μm dust continuum emission, suggesting that the bulk of the interstellar medium (ISM) is ionized. Our two-component SED model combining the previous Hubble Space Telescope (HST) data and new photometry obtained from Very Large Telescope (VLT), Spitzer and ALMA suggests the presence of young (~ 2 Myr) and mature (~ 600 Myr) stellar components with the metallicity of $Z = 0.2Z_{\odot}$. Our findings are in contrast with previous results claiming a very young, metal-poor stellar component.

Keywords. galaxies: high-redshift

1. Introduction

The [OIII] 88 μm far-infrared (FIR) fine structure line is expected to be bright enough to be detected in star-forming galaxies in the reionizaion era (Inoue *et al.* 2014). This line is a powerful probe to characterize the metallicity and the massive star formation activity. Furthermore, since the UV-to-optical nebular lines have a wide variety of ionization potentials and/or critical densities, the [OIII] 88 μm and the UV-to-optical lines will allow us to put a constraint on the physical properties of ISM even in $z > 6$ galaxies.

RXC J2248-ID3 (ID3) is a gravitationally-lensed (the lens magnification is 5.3) Lyman break galaxy at $z_{\mathrm{Ly}\alpha} = 6.110$ (Monna *et al.* 2014, Balestra *et al.* 2013). Monna *et al.* 2014 found that this object is a young (1.5 Myr), metal-poor ($Z = 0.005Z_{\odot}$) and low-mass ($M \simeq 2.1 \times 10^8 M_{\odot}$) star-forming galaxy by spectral energy distribution (SED) modeling in the rest-frame UV. In order to constrain more physical properties of ID3, UV-to-FIR SED is needed.

2. ALMA detection of [OIII] 88 μm and SED modeling

We searched for [OIII] 88 μm in ID3 using archival ALMA band 8 data (Cycle 2, PI: S. Madden) and detected it at $z_{\mathrm{[OIII]}} = 6.1051 \pm 0.0006$ at the 4.7σ significant level, with a line flux and luminosity of $F_{\mathrm{[OIII]}} = 0.587 \pm 0.074$ Jy km/s, $L_{\mathrm{[OIII]}} = 2.0 \times 10^8\ L_{\odot}$, respectively. The 90 μm dust continuum flux was not detected with a 3σ upper limit of $S_{90\,\mu\mathrm{m}} < 0.61$ mJy. We do not detect the [CII] 158 μm emission line (with a 3σ upper limit of $F_{\mathrm{[CII]}} < 0.17$ Jy km/s) suggesting a depletion of the neutral component in the ISM.

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Table 1. Best fit parameters.

parameters	best fit
Av [mag]	$0.00^{+0.02}_{-0.00}$
Metallicity [$Z_\odot$]	$0.2^{+0.04}_{-0.01}$
Escape fraction	$0.6^{+0.2}_{-0.1}$
Age (young) [Myr]	$2.2^{+0.2}_{-0.5}$
Age (old) [Myr]	641^{+86}_{-17}
SFH τ^{-1}(young)	0.10
SFH τ^{-1}(old)	10
Stellar mass [10^9 $M_\odot$]	$5.6^{+3.5}_{-2.6}$

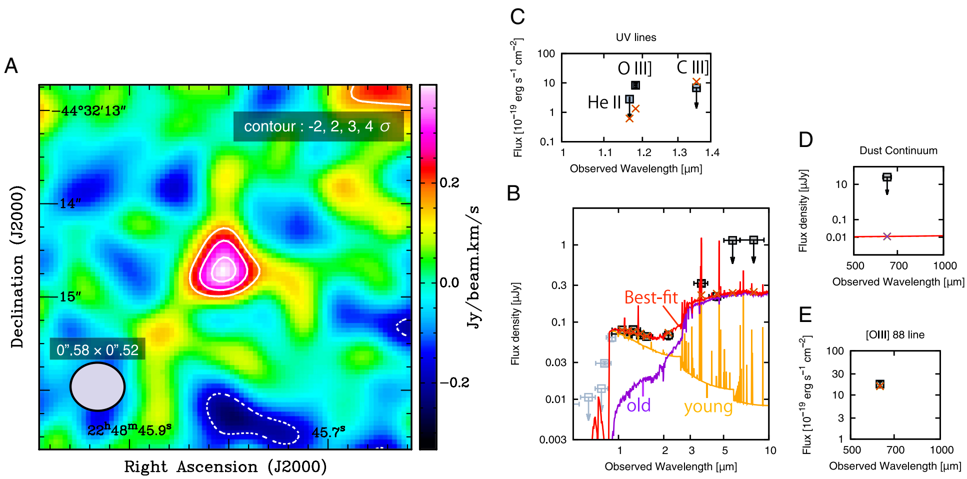

Figure 1. (A) [OIII] 88 μm integrated intensity map of ID3 obtained with ALMA. The ellipse at the bottom-left corner shows the synthesized beam size. The contours represent $(-2, 2, 3, 4) \times \sigma$. The panels from (B) to (E) show the optical-IR photometric data, UV lines, dust continuum, and [OIII] 88 μm line, respectively. Red lines show the best fit SED, while the orange and purple lines show the best fit young and old stellar component, respectively. The filled squares are observed line fluxes and continuum flux densities, while open squares are observed photometry that was not used for the SED fits. The crosses are the model predictions.

Then we perform stellar population synthesis modeling of ID3, where nebular emission and reprocessed dust emission are accounted for (PANHIT†). We use the [OIII] 88 μm flux and 90 μm upper limit in addition to the optical-to-near infrared broadband photometry obtained with HST, VLT/Hawk-I, and Spitzer/IRAC. We also account for UV line fluxes and upper limits, such as HeII λ1640, OIII] $\lambda\lambda$1661, 1666 and CIII] $\lambda\lambda$1907, 1909 (Mainali *et al.* 2017). We employ two stellar components with constant star-formation history (*cf.* Table 1), because a single component with any reasonable parameters cannot reproduce the observed SED. The best fit SED and parameters are shown in Figure 1 (B)-(E) and Table 1, respectively. The best-fitting model reproduces the broadband photometry and the [OIII] 88 μm line. However the UV lines are not reproduced very well, suggesting that the ISM has different properties from what is assumed in the model which is described by Mawatari *et al.* 2018. Photoionization modeling of the nebular emission lines will offer a unique opportunity to unveil the physical properties of ionized ISM.

† http://www.icrr.u-tokyo.ac.jp/mawatari/PANHIT/PANHIT.html

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