Rest-frame UV emission line diagnostics of ionized ISM properties in a Lyman-alpha emitter at z = 6.1

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Abstract

We investigate the photoionization models of the Lyman-alpha emitter at redshift z = 6.11 by modeling rest-frame ultraviolet (UV) emission lines using a public photoionization code. Our target, RXC J2248-ID3 (ID3), is abundant in observational photometric and spectroscopic data from rest-frame far-infrared to UV. A suite of multi-wavelength data sets obtained for ID3 allows us to reveal the physical properties of the galaxy in the reionization era. SED modeling with these observations reveals that ID3 has young and mature stellar populations. On the other hand, the best-fit model fails to reproduce the intensities of UV lines, implying that ID3 has extreme ISM properties. To investigate them, we construct a photoionization model that reproduces the observed UV line ratios. We find that ID3 favors density-bounded H II region models with a high ionization parameter larger than 10^{-2}. Our modeling shows that radiation-bounded models are insufficient to reproduce a bright C IV emission, suggesting the presence of additional ionizing mechanisms such as AGN or radiative-shock.

1. Introduction

- It is assumed that the galaxies at redshift z > 6 contributed the reionization, but **the nature of these galaxies and interstellar medium (ISM) are not well understood.**
  - Atacama Large Millimeter/submillimeter Array (ALMA) observations reveal that the [O III] 88 μm line is a good indicator for z > 6 galaxies.
  - Recent observations with ground-based telescopes (e.g., VLT) report that bright UV nebular emission lines from z = 6 - 7 galaxies.

➢ These emission lines contain a variety of information about the physical conditions in galaxies.

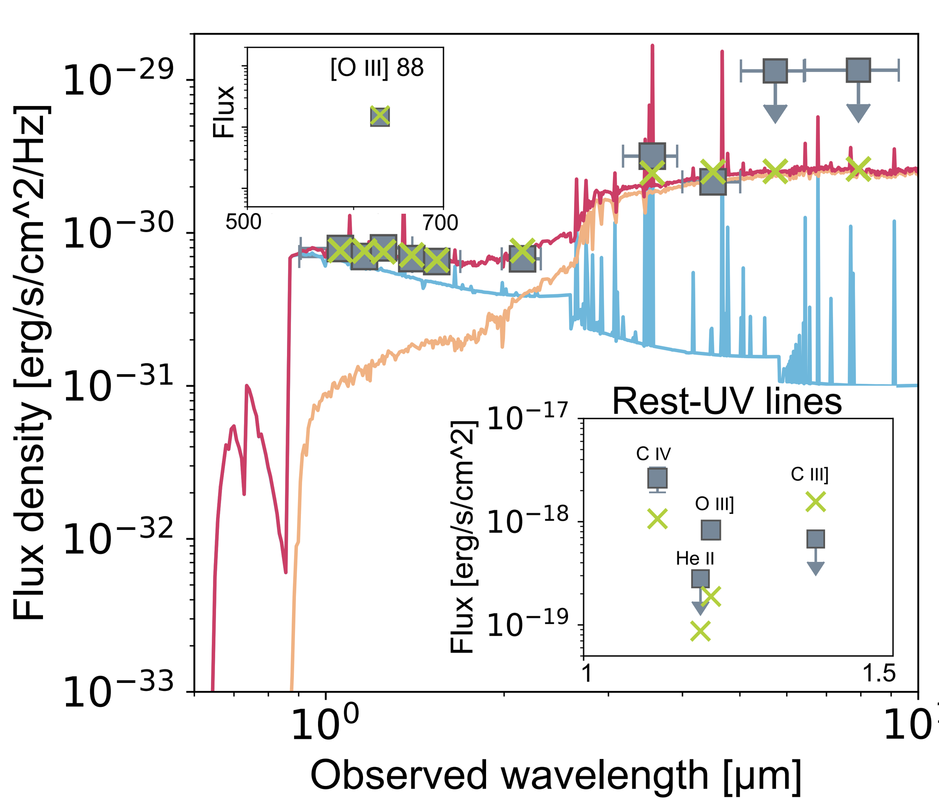
- Photoionization models with UV emission lines are well constructed at z = 2 - 4. (Byler et al. 2018, Nakajima et al. 2018)

➢ The strength of ratios of UV emission lines can be used to constrain the nature of ionizing source and physical properties of the galaxies.

Combining the observed emission lines, we can explore the physical conditions of the galaxies at the epoch of reionization using photoionization models.

2. Sample : RXC J2248-ID3 (ID3)

- Gravitationally lensed (magnification factor ~ 5.3) Lyman-α emitter at z = 6.105.
  - Detections of C IV λ 1550 Å, O III] λ 1663 Å and [O III] 88 μm
  - Upper limit of N V λ 1240 Å, He II λ 1640 Å and C III] λλ 1907,1909 Å
- Spectral energy distribution (SED) modeling with PANHIT (Mawatari in prep.) suggests that there are two populations; young (age ~ 2 Myr) and mature (age ~ 640 Myr).
- The best-fit model can not reproduce observed UV lines (bottom-right panel in Fig.1).



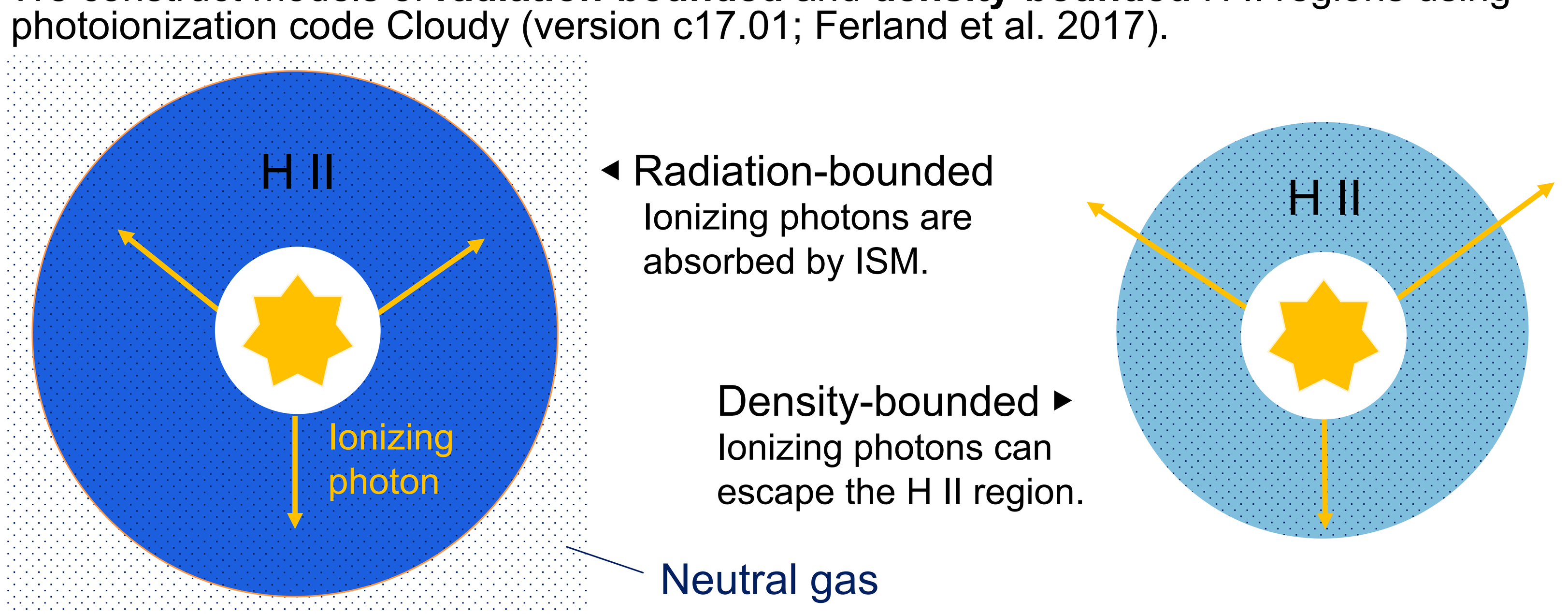
ISM properties differ from those that are often found in the local universe.

Photoionization modeling offer a unique opportunity to unveil them.

Figure 1. Red line shows the best-fit SED. It has both young (blue) and mature (orange) stellar components. The gray squares are observed flux or flux density, and the crosses are model predictions. Right bottom panel shows UV lines. Upper left panel shows the [O III] 88 μm line.

3. Modeling Approach

We construct models of **radiation-bounded** and **density-bounded** H II regions using photoionization code Cloudy (version c17.01; Ferland et al. 2017).



Parameters

- Ionizing source: Binary stellar population using BPASS 2.1 (Eldridge et al. 2017)
- Gas density (n_H): 10^2, 10^3 cm^{-3}
- Ionization parameter (U): 10^{-3} to 10^0 with steps of 0.5 dex

$$U = \frac{Q(H)}{4\pi r_0^2 n_H c}$$

$Q(H)$: The number of ionizing photons
r_0 : The separation between center source to illuminated face [cm]
c : speed of light [cm/s]

- Gas metallicity Z: 0.2 Z_{sun} (obtained by SED model),
  - C/O, N/O and Si/O abundances are scaled by 0.15 (Berg et al. 2018)
- Grains: Orion abundances
- We adopted closed, spherical geometry
- CMB emission at z = 6.11
- magnetic field 10 μGauss

The calculations are stopped at

- (Radiation-bounded) the electron fraction to n_H falls below 1 %
- (Density-bounded) optical depth at 912 Å (τ_{912}) : log(τ_{912}) = 0.3, 0, -0.3, -0.5

Observed emission line ratios (Mainali et al. 2017) :
C IV/O III] = 3.2 ± 1.1, N V/O III] < 0.49, He II/O III] < 0.41, C III]/O III] < 0.98

Goal:
To construct photoionization models to reproduce observed UV line ratios.

4. Results

Radiation bounded model

- C IV λ 1550 Å has large discrepancies between observed data and model prediction.
- There is less dependence on gas density.

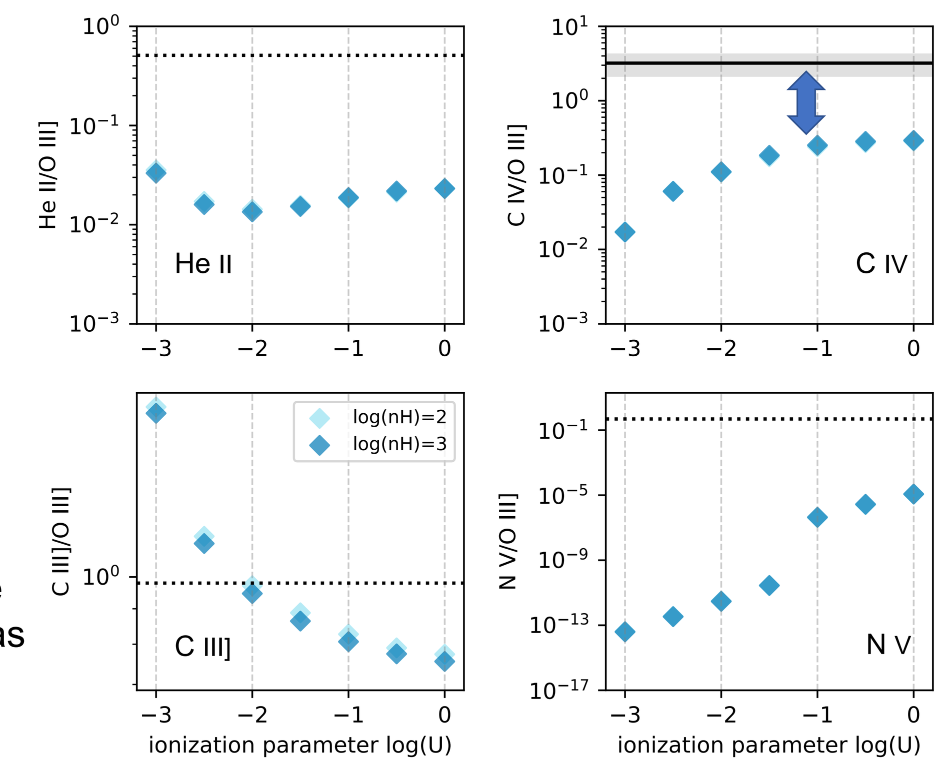


Figure 2. UV emission line ratios from radiation-bounded models. Observed line ratio and those uncertainties are plotted as solid line and gray shadow, respectively. Dashed line reproduce 2σ upper limit.

Density bounded model

- To reproduce C IV/O III] ratio, high ionization parameter and small τ_{912} are preferred.
- The upper limit of C III]/O III] ratio gives a lower limit of the ionization parameter; **log (U) > -2**.

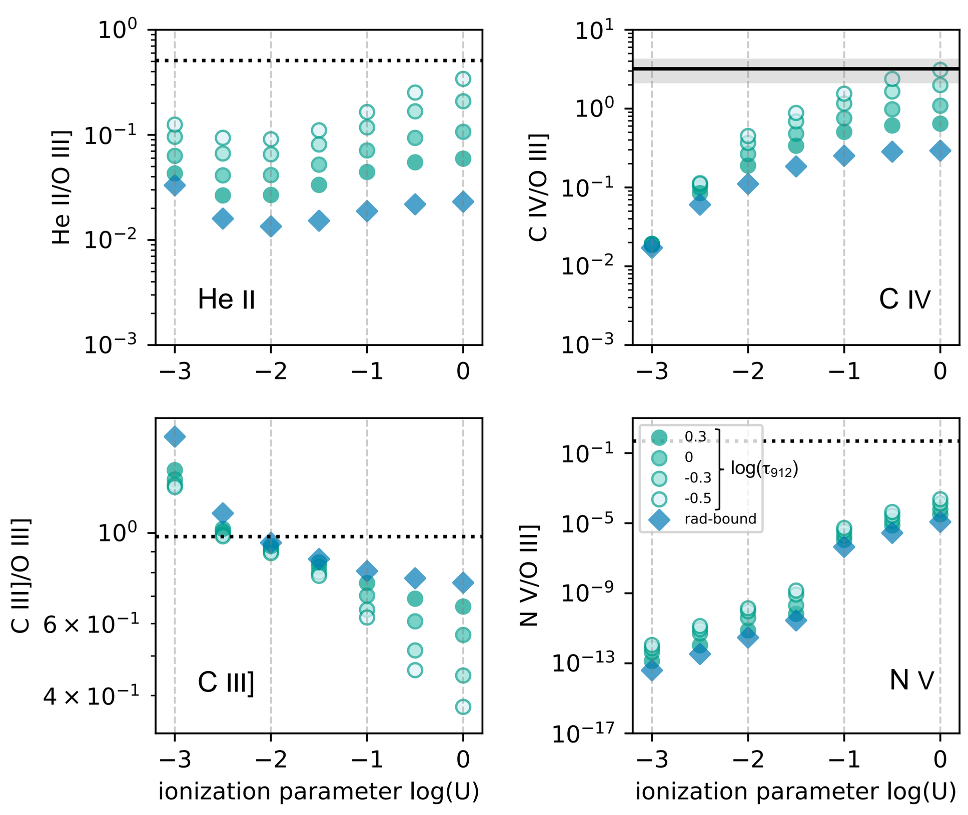


Figure 3. Circles show UV emission line ratios from density-bounded models with a fixed gas density $n_H = 10^3$ cm^{-3}. Triangles are radiation-bounded models with $n_H = 10^3$ cm^{-3}.

Density-bounded H II region models with high ionization parameters reproduce observed data well.

5. Multiple ionization sources

It is known that AGN and radiative-shock enhance high-ionization emission lines.

AGN + stellar models

- AGN broad line region models:
  - assuming power-law radiation fields, $n_H = 10^9$ cm^{-3} .
- Stellar models: same as Figure 2 with $n_H = 10^3$ cm^{-3}.

✓ The model with 40 % of AGN contribution to total emission reproduces a bright C IV emission line.

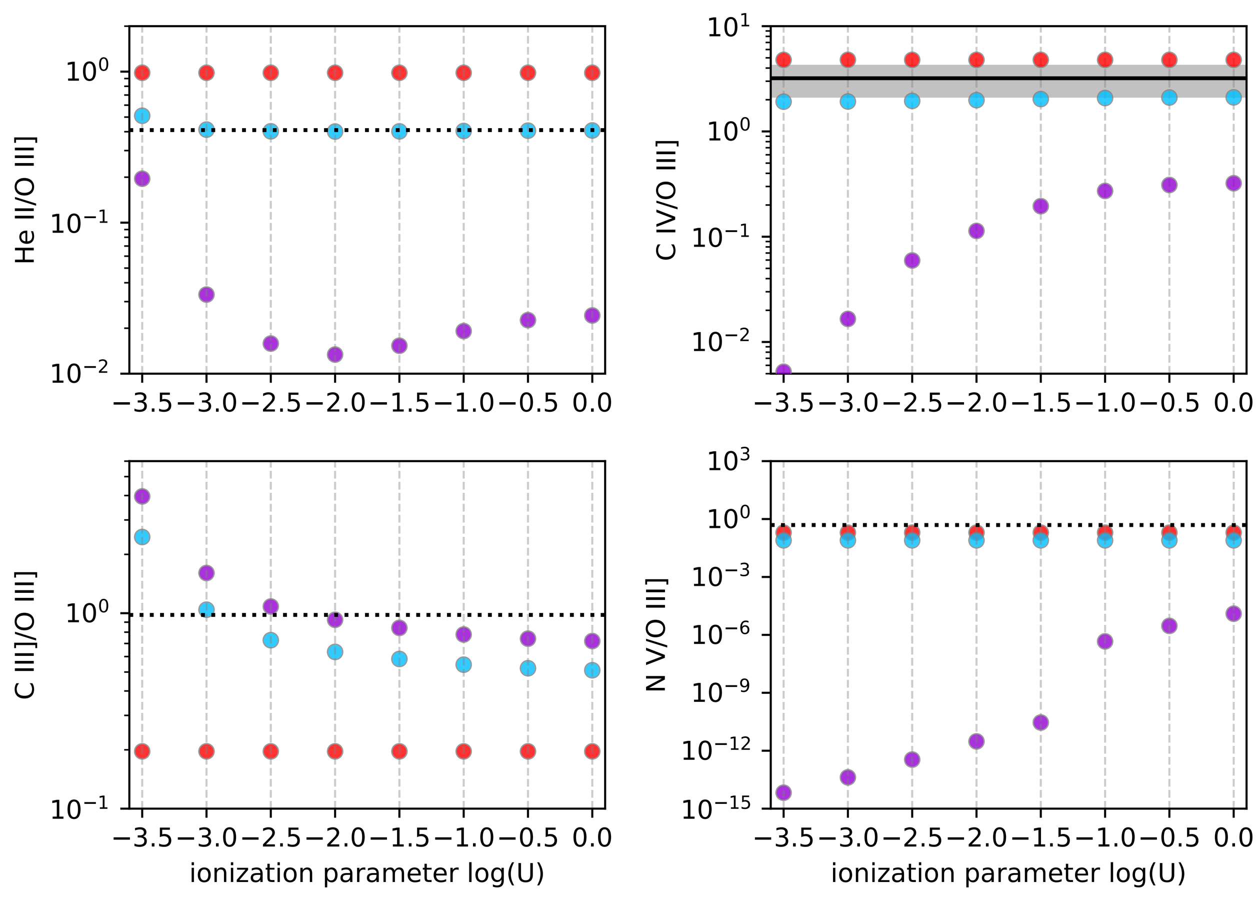


Figure 4. UV emission line ratios as a function of ionization parameters. Purple circles show pure stellar (BPASS) models, and red circles show pure AGN BLR models. Blue circles are the stellar (60 %) + AGN (40 %) models.

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