

Detection of an oxygen emission line from a high-redshift galaxy in the reionization epoch

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The physical properties and elemental abundances of the interstellar medium in galaxies during cosmic reionization are important for understanding the role of galaxies in this process. We report the Atacama Large Millimeter/submillimeter Array detection of an oxygen emission line at a wavelength of 88 micrometers from a galaxy at an epoch about 700 million years after the Big Bang. The oxygen abundance of this galaxy is estimated at about one-tenth that of the Sun. The nondetection of far-infrared continuum emission indicates a deficiency of interstellar dust in the galaxy. A carbon emission line at a wavelength of 158 micrometers is also not detected, implying an unusually small amount of neutral gas. These properties might allow ionizing photons to escape into the intergalactic medium.

ISMの物理状態と組成を探りたい

- [CII] 158um from PDRs
 - Z=5-6 LAEからは検出されているが、z>6では受からない
- [OIII] 88um from HII regions
 - Hi-zでは装置がなくてこれまで試みられていない

Z=7.2 LAE(SXDF-NB1006-2)からの[OIII]88um emission

- 5.3sigma detection / 6.2e-21 W/m^2
 - [CII]は受からず (<5.3e-22 W/m^2 3sigma)
 - Continuumも受からず
- LyAにくらべてコンパクト
 - LyAからの速度オフセットは-110km/s => NHI<1e20(/cm^2)と小さい

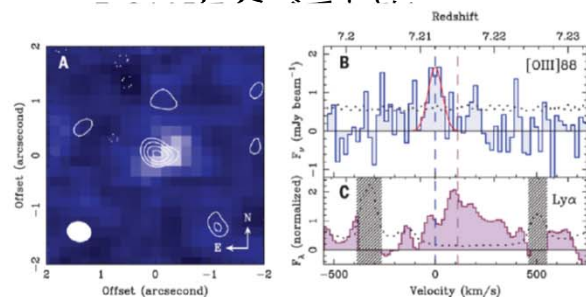


Fig. 1. [O III] 88- μm and Ly α emission images and spectra of SXDF-NB1006-2. (A) The ALMA [O III] 88- μm image (contours) overlaid on the Subaru narrow-band Ly α image (offsets from the position listed in Table 1). Contours are drawn at (-2, 2, 3, 4, 5) \times , where $\sigma = 0.0636 \text{ Jy beam}^{-1} \text{ km s}^{-1}$. Negative contours are shown by the dotted line. The ellipse at lower left represents the synthesized beam size of ALMA. (B) The ALMA [O III] 88- μm spectrum with resolution of 20 km s^{-1} at the intensity peak position shown against the relative velocity with respect to the redshift $z = 7.2120$ (blue dashed line). The best-fit Gaussian profile for the [O III] line is overlaid. The RMS noise level is shown by the dotted line. (C) The Ly α spectrum (17) shown as a function of the relative velocity compared to the [O III] 88- μm line. The flux density is normalized by a unit of $10^{-20} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ \AA}^{-1}$. The sky level on an arbitrary scale is shown by the dotted line. The velocity intervals where Earth's atmospheric lines severely contaminate the spectrum are flagged (hatched boxes). The Ly α line shows a velocity shift $\Delta v \approx +110 \text{ km s}^{-1}$ relative to the [O III] line (red dashed line).

SED Fitting

- Very blue UV (beta<-2.6) => Very young : 1Myr
- No dust continuum

Strong [OIII] => Z=0.05-1 Zsol : 現在の星形成より前に作られたもの
 Ionizing photon escape fraction : 50% => Low NHIの要因?

近傍dwarfとくらべる

- [OIII]/FUVは近い
- LIR or [CII]は非常によわい(一ケタ以上)
 - Metalの量に比べてdustが少ない
 - シミュレーションに比べても数倍以上少ない
 - => SNによるdust destructionがきているのか
 - => cold dense ISMがないせいでダスト形成がまだ進んでいないのか
 - HIガスの量が少ない(のでPDRができていない)

Ionization PhotonのEscape fraction x emission efficiency

- Log(fesc etaion)=25.44 : 非常に多い
- これまでに検出された銀河の明るさで(MUV<-17)Reionizationをおこすのに十分

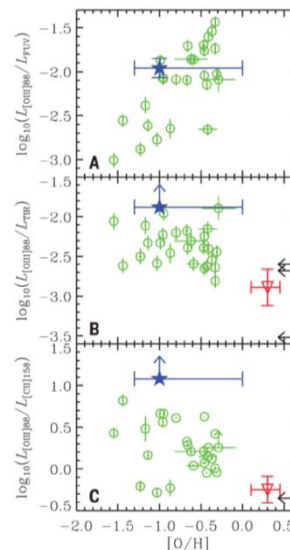
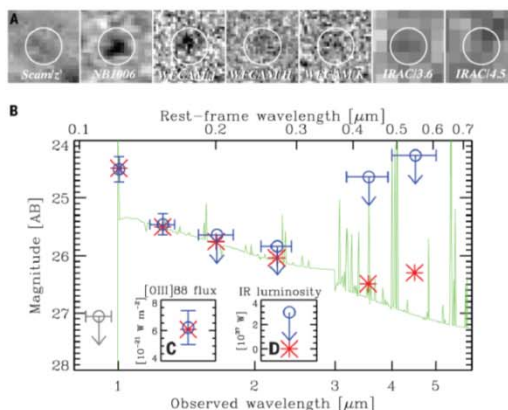


Fig. 3. Comparisons of SXDF-NB1006-2 and other galaxies detected in the [O II] line. The horizontal axis represents the oxygen abundance relative to the Sun on a logarithmic scale: $[O/H] = \log_{10}(n_O/n_H) - \log_{10}(n_O/n_H)_\odot$, where n_O and n_H are the number density of oxygen and hydrogen atoms, respectively, and the solar abundance is assumed to be $12 + \log_{10}(n_O/n_H)_\odot = 8.69$ (30). Circles with error bars represent data of nearby dwarf galaxies (9–11); inverted triangles with error bars are averages of nearby spiral galaxies (13). The arrows at the right-side axis show luminosity ratios of dusty galaxies at $z \sim 3$ to 4 whose oxygen abundances have not yet been measured (10, 14, 15). Data from SXDF-NB1006-2 are shown as five-pointed stars with error bars. (A) The [O III]/far-UV (FUV) luminosity ratio. The FUV luminosity is νL_ν at about 1500 \AA in the source rest frame. (B) The [O III]/total infrared (IR) luminosity ratio. The IR wavelength range is 8 to $1000 \mu\text{m}$ in the source rest frame. Because the IR continuum of SXDF-NB1006-2 is not detected, we show a 3σ lower limit with a dust temperature of 40 K and an emissivity index of 1.5. (C) The [O III]/[C II] luminosity ratio. Because the [C II] $158\text{-}\mu\text{m}$ line of SXDF-NB1006-2 is not detected, we show a 3σ lower limit.