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First [N II] 122 μm line detection in a starburst pair at $z = 4.7$

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Abstract. We report the first detection of [N II] 122 μm line toward a QSO-SMG pair, BRI 1202-0725, at $z = 4.7$ using ALMA. Combining with [N II] 205 μm line detection and taking the line ratio of [NII]122/[NII]205, we constrain electron densities of both galaxies. The derived electron densities are 26^{+12}_{-11} and 134^{+50}_{-39} cm^{-3} for the SMG and the QSO, respectively, which are the first measurements for galaxies at $z > 4$. The electron density of the SMG is comparable to the Galactic plane and the average of local spiral galaxies, while the value for the QSO is comparable to local starbursts and optical-line based measurements for star-forming galaxies at $z \sim 2-3$. Considering the similar star-formation rates (SFRs) of $\approx$1000 $M_\odot$ yr^{-1} for both galaxies, our results suggest a large scatter of electron densities at fixed SFR and caution against using optical lines for dusty starbursts. The details of this report are presented in Lee *et al.* 2019 (submitted).

Keywords. galaxies: evolution – galaxies: high-redshift – galaxies: ISM – galaxies: starburst – submillimeter – ISM: evolution

1. Introduction

Fine structure line transitions at far-infrared (FIR) and sub-millimeter wavelengths are a powerful tool to probe dusty star-forming galaxies that form stars at a rate of ≈ 1000 M$_\odot$ yr^{-1} or even above, because they are less affected by dust extinction compared optical and ultra-violet emission lines. Two FIR fine-structure lines of [N II] (at 122 μm and 205 μm) originate from fully ionized gas with the ionization potential of 14.5 eV and the combination of these lines can be used as a probe of electron density.

BRI 1202-0725 at $z = 4.7$ is a pair system of two starburst galaxies (a QSO and a SMG) that remains the archetype of gas-rich mergers. Extremely high FIR luminosities of the QSO and the SMG (Omont *et al.* 1996; Iono *et al.* 2006; Yun *et al.* 2000, $\sim 10^{13}$ $L_\odot$) imply vigorous star formation rate of ≈ 1000 $M_\odot$ yr^{-1}. This unique system is an ideal target for probing ISM conditions of dusty starbursts at high-z with rich ancillary data sets. Here, we report the first detection of [N II] 122 μm with ALMA observations.

2. ALMA detection of [N II] 122 μm line from the QSO and the SMG

We detected [N II] 122 μm line from the QSO and the SMG with $> 4\sigma$. This is the first detection for $z > 4$ galaxies so far. Combining with [N II] 205 μm line detection for both galaxies (Pavesi *et al.* 2016) and taking the [N II] line ratio, we derived the electron

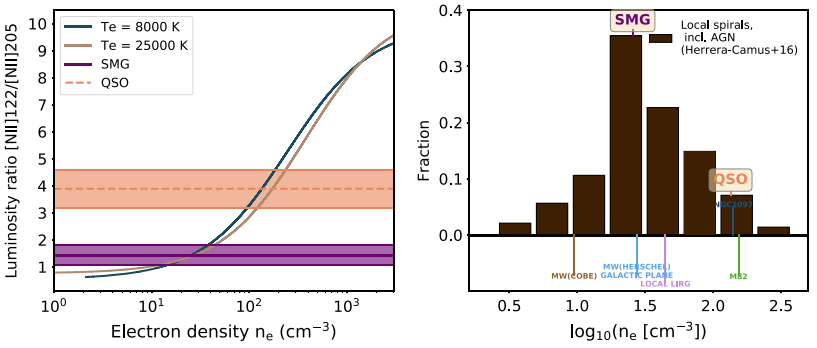

Figure 1. Left : The [NII] line luminosity ratio as a function of electron density. The two solid curves are for different electron temperatures (T_e = 8000 K and 25000 K). The line ratios for the SMG and the QSO are shown as purple solid and dark orange dashed lines, respectively. Right : The histogram for the distribution of electron density, based on the observed line ratio of local spirals from Herrera-Camus *et al.* (2016) to compare with the BR1202-0725 system. The remaining measurements are from Bennett *et al.* (1994) (MW:COBE), Goldsmith *et al.* (2015) (MW : galactic plane), Petuchowski *et al.* (1994) (M82), Beirão *et al.* (2012) (NGC1097), Díaz-Santos *et al.* (2017) (local LIRGs) (figures modified from the original in Lee *et al.* 2019, submitted)

densities for both galaxies. We used the PYNEB package (Luridiana *et al.* 2015) to perform the calculation. The derived electron densities are 26^{+12}_{-11} and 134^{+50}_{-39} cm^{-3} for the SMG and the QSO, respectively. Considering the similar star-formation rates of these galaxies, our results suggest a large scatter of electron densities at fixed SFR in global scale. The electron density of the SMG is comparable to the Galactic plane and local spirals whereas the QSO has a similar value to local starburst galaxies (Figure 1). The enhanced value for the QSO is also consistent with the measurements of high-z star-forming galaxies at $z = 2-3$ (e.g., Sanders *et al.* 2016) which are obtained from rest-frame optical lines, and with the lower limit obtained from the stacking analyses of lensed starburst galaxies at $z = 1-3.6$ using the same [NII] tracers (Zhang *et al.* 2018). Provided the varying degree of electron densities at similar SFR, our results demonstrate the power of using the FIR [N II] lines in future systematic surveys for probing electron densities of dusty starburst galaxies. The details are presented in Lee *et al.* 2019 (submitted).

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