Sub-mm Broad Band CO Emission Line Observation Towards NGC 7479 by SMA

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ABSTRACT

We have performed ^{12}CO$(2-1)$ continuum observations towards NGC 7479, a Seyfert 2 galaxy, at ∼230 GHz using the Submillimeter Array. The main purpose of this project is to investigate interaction of the CO molecular gas around the center galaxy. Our observation with a $\theta_{\rm maj} \times \theta_{\rm min} = 1.''02 \times 0.''86$ (P.A.=89.67°) synthesized beam marginally resolved the surrounding area of the center region of the galaxy. The ^{12}CO$(2-1)$ emission line result is similar to that of Sempere et al. (1995). For the continuum map, the center core size was calculated from 2D Gaussian model fit, with size of $1.''02 \times 1.''15$ (173×195 pc). Also, the central coordinate is similar to the measurement by Gaia Collaboration (2020). However, we failed to perform moment maps in this report.

Keywords: Active Galactic Nuceli, Seyfer 2 galaxy, NGC 7479, CO molecular gas emission

1. INTRODUCTION

We proposed the Submillimeter Array (SMA) observation with extended array configuration (EXT) towards NGC 7479 at 230 GHz (z ≈ 0.007967, Haynes et al. 2018), a Seyfert 2 galaxy, which is approximately 35 Mpc away from us. This galaxy has also been classified as LINER (Keel 1983). As we all known, at center of active galactic nuclei (AGN) host a powerful super massive black hole (SMBH). According to the radio loudness definition, $R = \frac{F_{5\ \rm GHz}}{F_{4400\ \rm Å}}$, scientist can classify AGNs into radio loud or radio quiet. Seyfert 2 galaxy has been classified as radio quiet galaxy, indicating weak radio emission was detected. Besides of the radio quiet characteristic, spiral galaxies is another morphology characteristic of Seyfert 2 galaxy, showing only narrow lines at all species. In this study, we would like to investigate the ^{12}CO$(2-1)$ molecular gas around the most central region of NGC 7479. Also, we would like to study the interaction of ^{12}CO$(2-1)$ molecular gas with the central region of the SMBH.

Our target source, NGC 7479, was detected by IRAS, with intermediate far-infrared luminosity (Tinney et al. 1990). It has angular size of about $4.1' \times 3.1'$ (Sempere et al. 1995). In this study, however, we just want to investigate the CO molecular gas morphology around the core. Therefore, we only focus on the most central region of this galaxy, and its core region angular size is about $10.''0 \times 20.''0$ (Sempere et al. 1995). Though this source has been observed by Sempere et al. (1995) with IRAM 30m telescope at January, 1990. They observed both ^{12}CO$(1-0)$ at 115 GHz with $23''$ resolution, and ^{12}CO$(2-1)$ at 230 GHz with $13''$ resolution. Also, Young et al. (1986) studied NGC 7479 in 5 positions with the FCRAO $45''$ beam. Using the observed CO intensity to derive H_2 mass. Therefore, by using SMA EXT configuration, we think we can improve the imaging angular resolution of this source.

For the details of our SMA observations are introduced in section 2. The results and discussion will be presented in section 3.

2. OBSERVATIONS

We have performed the SMA observations at ∼1 mm band towards NGC 7479 in the EXT on 2022 November 09, which covered the baseline lengths of 10-150 $k\lambda$. The pointing and phase referencing centers are R.A. (J2000)=23$^{\rm h}$04$^{\rm m}$56.64$^{\rm s}$and Decl. (J2000)=+22°19′22.36″, respectively. We used the dual receivers mode supported with the SMA Wideband Astronomical ROACH2 Machine (SWARM) backend: The RxA receivers covered the frequency ranges of 207.5–219.5 GHz and 227.5–239.5 GHz in the lower and upper sidebands, respectively; the RxB receivers covered the frequency ranges of 223.5–235.5 GHz and 243.5–255.5 GHz, respectively. The intrinsic spectral channel width was 140 kHz. With this spectral setup, the CO(2-1) line was simultaneously covered by both the RxA and RxB receivers; the continuum emission was observed over a while range of frequency.

The data were manually reduced following the standard data calibration strategy of SMA. The application of Tsys information and the absolute flux, passband, and gain calibrations were carried out using the MIR IDL software package (Qi 2003). The absolute flux scalings were derived by comparing the visibility amplitudes of the gain calibrators with those of the absolute flux calibrator, Neptune. We nominally quote the ∼15% typical absolute flux calibration error of SMA.

After calibration, the continuum image and ^{12}CO$(2-1)$ spectral line image were performed using the Miriad software package (Sault et al. 1995). For the spectral line imaging, we set specific frequency interval (can use channel number or velocity as well), to plot the spectral line (figure 1). Because of the noisy continuum line result (upper panel of figure 1), we performed "hann smoothing" to smooth the spectrum, the result is presented in lower panel of figure 1. On the other hand, for the continuum imaging. We first used "invert" to performed inverse Fourier transform to the calibrated visibilities, using "clean" to do deconvolution of dirty images, then we can have real images. In some channels of our continuum images, noise tends to be larger than the true signal. Therefore, all of our continuum images has been normalized separately, then superimposed together, in order to reduce noise level. The achieved synthesized beam size is $\theta_{\rm maj} \times \theta_{\rm min} = 1\farcs02 \times 0\farcs86$ (P.A.=89.67°). We have root-mean-square (RMS) noise level of 0.52 mJy/beam.

Besides of continuum imaging and ^{12}CO$(2-1)$ spectral line imaging. We also tried to plot channel maps, the method is similar to continuum imaging, but we failed. Moment 0 and moment 1 map is totally white when we open the file with DS9, and moments 2 map has a lot of noisy pattern.

3. RESULTS AND DISCUSSION

In this section, we are going to display our analysis results. Including ^{12}CO$(2-1)$ molecular gas emission line, as well as continuum imaging of NGC 7479. Also, we would like to compare our analysis result with previous study, i.e., ^{12}CO$(2-1)$ molecular gas spectrum from Sempere et al. (1995).

3.1. *CO Molecular Emission Line*

Figure 1 shows the 230 GHz ^{12}CO$(2-1)$ molecular gas emission line of NGC 7479, extracted from Rx230, upper side band, channel 1. Emission line figures before and after smoothing are provided. From the upper panel of figure 1, we extract frequency region between 227.5 to 229.5 GHz, with frequency resolution of 7.69 MHz. There are two local maximum in the spectrum, one has peak around 228.6-228.7 GHz, the other has peak around 228.8 GHz. We believe that these two peaks are the emission line produced by ^{12}CO$(2-1)$. Also, we calculate the redshift of our source by using the frequency of the peak of the spectrum, which is about 0.008311. Our calculation is 4.14% larger than the measurement of Haynes et al. (2018) ($z \sim 0.007967$).

After doing analysis, we compare our ^{12}CO$(2-1)$ molecular gas emission line spectrum with Sempere et al. (1995), which can be seen at figure 2. Sempere et al. (1995) presents ^{12}CO$(1-0)$ and ^{12}CO$(2-1)$ molecular gas study of NGC 7479, as well. The velocity interval in figure 2 ranging from 1800 $\sim$ 3000 km/s, and the unit of the emission lines are presented in temperature (Kelvin). The peak velocity of ^{12}CO$(2-1)$ is about 2400 km/s, using this velocity redshift is about 0.007556. Our measurement and calculation result is about 9.08% larger than that of Sempere et al. (1995). Form figure 2 we can also see two local maximum of ^{12}CO$(2-1)$.

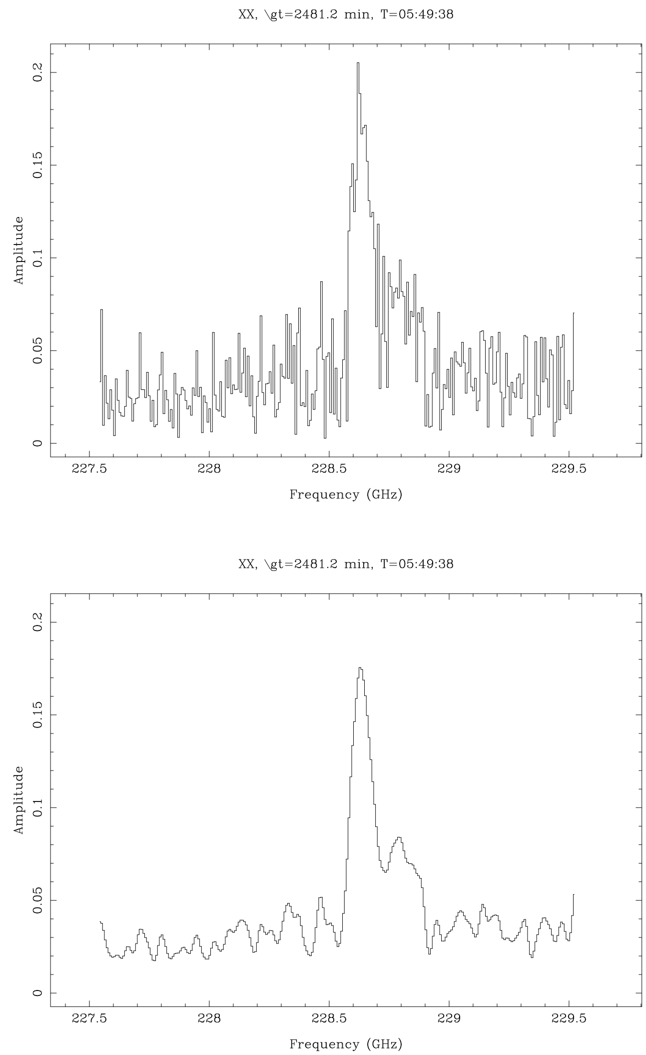

Figure 1. ^{12}CO$(2-1)$ molecular gas emission line before and after smoothing of NGC 7479. Upper panel shows spectral line before smoothing; lower panel displays spectral line after smoothing, where each point was using 10 bin-widths in upper spectral to smooth. The peak of ^{12}CO$(2-1)$ molecular gas emission line is located around 228.6-228.7 GHz.

The peak with lower local maximum is close to 2500 km/s, where our lower peak (lower panel of figure 1) is relatively apparent than theirs.

3.2. *NGC 7479 Continuum Imaging*

Figure 3 displays continuum imaging of NGC 7479, which superposed over 24 images, including Rx230 and Rx240, both lower and upper side bands, as well as six different channels. The central region of NGC 7479 is displays at the center of the map, with peak intensity about 150 $\sim$ 175 mJy beam^{-1}, which translates sigma level is approximately 11.4σ, with $\sigma \sim 13.46$ mJy beam^{-1}. We performed 2D Gaussian model fitting to measured its

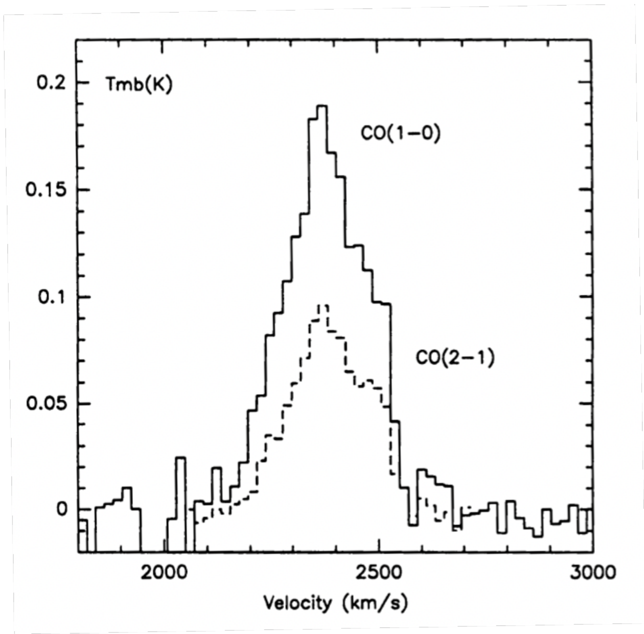

Figure 2. NGC 7479 $^{12}CO(2-1)$ molecular gas emission line from Sempere et al. (1995), which vertical axis is in the unit of temperature (Kelvin), and horizontal axis is in the unit of velocity (km/s). $^{12}CO(2-1)$ molecular gas emission line is presented in dashed line, while $^{12}CO(1-0)$ molecular gas emission line is conferred as solid line.

core size, which is about $1.''02 \times 1.''15$ (173×195 pc). Also, from 2D Gaussian model fit, we can obtain the central coordinate of the source, which is (R.A., DEC) = $(23^{h}04^{m}56.^{s}66, +12^{\circ}19'22.''92)$. Compare to the coordinate from Gaia Collaboration (2020), measured in optical, which is (R.A., DEC) = $(23^{h}04^{m}56.^{s}64, +12^{\circ}19'22.''35)$. Our calculation is quite similar compare to theirs.

However, in our analysis we cannot produce moment maps of the source. Therefore, we are not able to analyze the CO molecular gas morphology around the source.

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Facilities: SMA

Software: astropy (Astropy Collaboration et al. 2013), Numpy (van der Walt et al. 2011), APLpy (Robitaille & Bressert 2012), MIR IDL (Qi 2003), Miriad (Sault et al. 1995)

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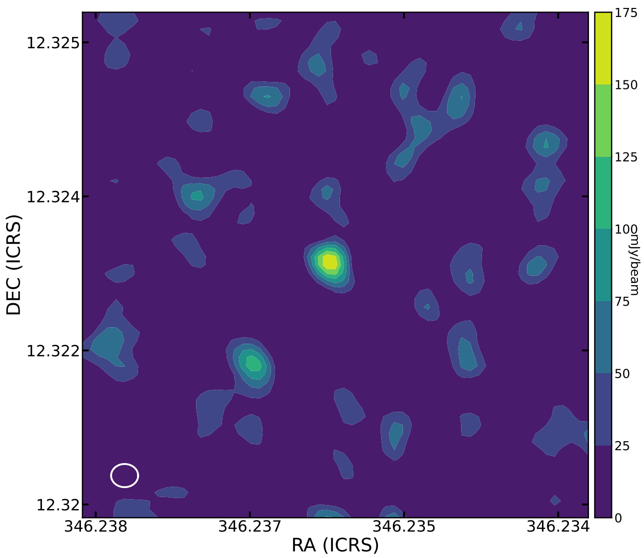

Figure 3. NGC 7479 continuum imaging of 230 GHz ^{12}CO$(2-1)$ with contour levels of 1.89σ, 3.72σ, 5.57σ, 7.43σ, 9.29σ, 11.4σ, with $\sigma \sim 13.46$ mJy beam^{-1}. This imaging has a size of $19\farcs16 \times 18\farcs72$. The synthesized beam size is located at the lower-left corner of the map, which is about $1\farcs02 \times 0\farcs86$ (P.A.=89.67°).