ALMA Observations of Luminous Infrared Galaxies Using Dense Gas Tracers

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Luminous infrared galaxies (LIRGs) emit strong infrared radiation, and are usually formed by the collision and merger of gas-rich galaxies. The strong infrared emission is originated in thermal radiation from dust heated by dust-obscured starburst and/or AGN activity. Compared to normal quiescently star-forming galaxies, the fraction of dense gas is high in LIRGs. It is also predicted that since starburst and AGN activity have different effects to the surrounding dense gas, molecular emission line flux ratios can vary, depending on the primary energy source. Molecular rotational J-transition lines, seen in the (sub)millimeter wavelength range, usually do not suffer from significant dust extinction, so that these lines can be used to understand the physical and chemical properties deeply obscured by gas and dust at LIRGs' nuclei. In ALMA Cycle 0, we observed six LIRGs, using HCN, HCO^+, and HNC J = 4–3 lines, which are good tracers of dense gas. Results of two LIRGs have been published [1,2].

In the starburst-dominated LIRG, NGC 1614, the observed molecular lines are clearly spatially-resolved. The emission peak is separated from the nucleus by ~0.6" (Figure 1). This is the location where strong starburst activity is found. Our result supports the widely-argued scenario that stars are formed inside dense molecular gas. In NGC 1614, HCO^+ J = 4–3 emission is much stronger than HCN J = 4–3 emission (Figure 1).

In the starburst and AGN composite LIRG, IRAS 20551−4250, the HCN-to-HCO^+ J = 4−3 flux ratio is higher than NGC 1614 (Figure 2). It has been known that AGNs tend to show higher HCN-to-HCO^+ J = 1–0 flux ratio than starburst-dominated galaxies. The same trend is confirmed at the J = 4−3 transition line. Since the wavelength of J = 4−3 transition is shorter than J = 1−0 transition, we will be able to observe more distant galaxies at J = 4−3 with ALMA. Second, the vibrationally-excited HCN J = 4−3 emission line (v_2 = 1f) is detected (Figure 3). This is the second detection of this line in external galaxies. Infrared radiative pumping, by absorbing 14μm photons, is a plausible scenario for this vibrational excitation. Since an AGN can emit stronger infrared 14μm photons, due to AGN-heated hot dust, than starburst galaxies, HCN J-transition line emission in AGNs could be enhanced due to this infrared radiative pumping mechanism. Finally, in addition to the targeted lines, other lines, such as H_2S 3(2,1)–3(1,2) (369.1 GHz in rest-frequency) and CH_3CN v = 0 19(3)–18(3) (349.4 GHz in rest-frequency) emission lines, are clearly detected (Figure 2), demonstrating the high sensitivity of ALMA.

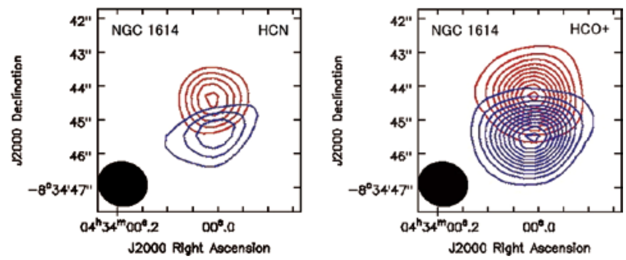

Figure 1: Spatial distribution of the red and blue components of HCN J = 4–3 (Left) and HCO^+ J = 4–3 (Right) in the LIRG, NGC 1614. For HCN, the contours start at 0.4 Jy km s^{-1}, and increases with 0.2 Jy km s^{-1}. For HCO^+, the contours start at 0.5 Jy km s^{-1}, and increase with 0.5 Jy km s^{-1}.

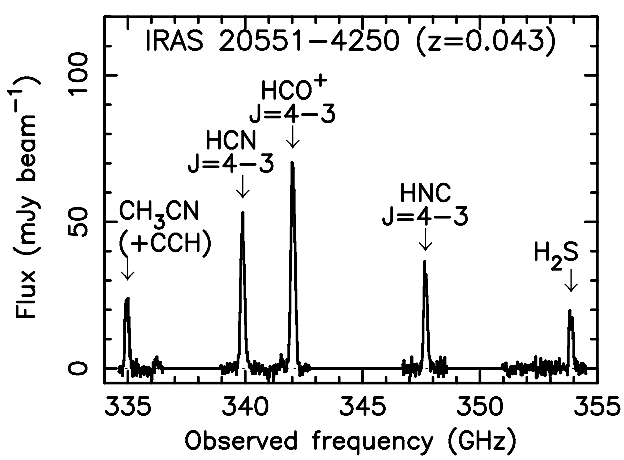

Figure 2: ALMA spectrum of the LIRG, IRAS 20551–4250. The ordinate is flux (mJy beam^{-1}), and the abscissa is observed frequency (GHz).

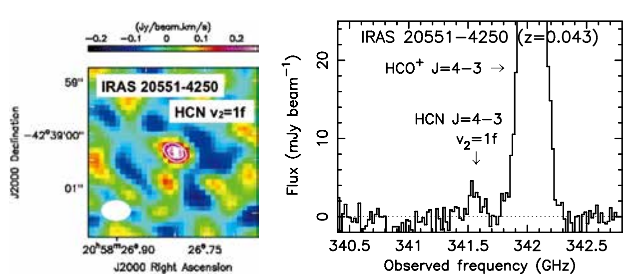

Figure 3: Integrated intensity map of the vibrationally-excited HCN J = 4–3 (v_2 = 1f) emission line and expanded spectrum around this line for IRAS 20551–4250.

References

[1] Imanishi, M., Nakanishi, K.: 2013, *AJ*, **146**, 47.
[2] Imanishi, M., Nakanishi, K.: 2013, *AJ*, **146**, 91.