ALMA Molecular Line Observations of Luminous Infrared Galaxies as a Tool to Detect Extremely Deeply Buried AGNs

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When gas-rich galaxies collide and merge, star-formation and AGN (= mass accretion onto a supermassive blackhole) are activated and generate energy at dust-obscured regions, and become luminous infrared galaxies (LIRGs). Since these energy sources are obscured by dust, observations at the wavelengths of low dust extinction effects are necessary. An AGN has two distinguished properties, when compared to a starburst (= active star-formation). First, an AGN can produce a larger amount of hot (> 100 K) dust, originating in the high radiative energy generation efficiency (6–42 % of Mc^2) by a mass-accreting supermassive blackhole, than a starburst. Second, the X-ray to UV luminosity ratio is much higher in an AGN than a starburst. Due to these different properties, an AGN and a starburst can input different physical/chemical effects to the surrounding molecular gas, and so can produce different molecular line flux ratios. Since there are rotational J-transition lines of many molecules at the almost dust-extinction-free (sub) millimeter wavelength, these molecular line flux ratios can be a powerful tool to scrutinize dust-obscured energy sources in LIRGs. High dipole moment molecules, such as HCN and HCO^+, can be particularly effective to probe how dense molecular gas at LIRG's nuclei are affected by dust-obscured energy sources.

Using ALMA, we have conducted HCN and HCO^+ J=3–2 observations, at the submillimeter 250 GHz range, of starbursts, optically-identified AGNs, and LIRGs whose energy sources were diagnosed based on previous infrared spectroscopy. We have confirmed that AGN-important galaxies identified through previous optical/infrared/X-ray spectroscopy tend to display higher HCN-to-HCO^+ flux ratios at J=3–2 than starburst-dominated regions (Figure 1) [1]. More importantly, our ALMA observations have discovered extremely deeply buried AGN candidates which do not show AGN signatures in the optical/infrared/X-rays, but do show in the (sub) millimeter. These LIRGs display elevated HCN-to-HCO^+ J=3–2 flux ratios and signatures of vibrationally excited (v_2=1f) HCN emission lines. Detection of the vibrationally excited (v_2=1f) HCN emission lines (T > 1000 K) requires the presence of strong infrared 14 μm continuum emission, most likely originating in AGN-heated hot dust. We argue that (sub)millimeter molecular line observations can be the most powerful way to elucidate deeply buried AGNs in LIRGs, thanks to much lower dust extinction effects than other methods (infrared or hard X-rays). Further systematic ALMA molecular line observations are important to better understand the energetic role of elusive deeply buried AGNs in LIRGs.

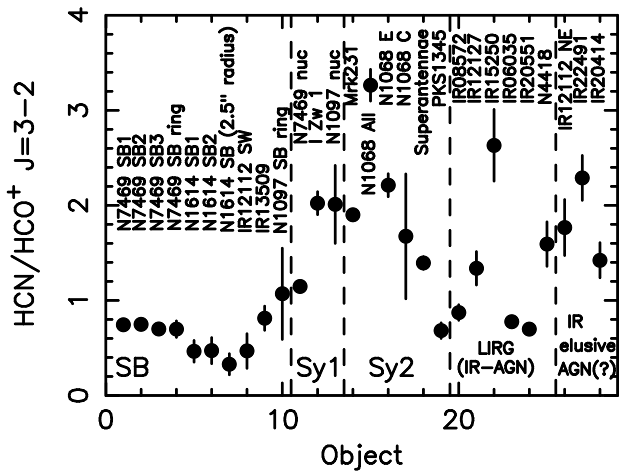

Figure 1: The observed HCN-to-HCO^+ flux ratios at J=3–2 (modified from [1]). "SB", "Sy1", "Sy2", "LIRG (IR-AGN)", and "IR elusive AGN(?)" mean starburst-dominated regions, optically identified Seyfert 1 type AGNs, optically identified Seyfert 2 type AGNs, luminous infrared galaxies with optically-elusive, but infrared-detectable buried AGN signatures, and candidates of infrared-elusive, but (sub)millimeter-detectable extremely deeply buried AGNs, respectively. Sources with AGN signatures tend to show elevated HCN-to-HCO^+ J=3–2 flux ratios, compared to starbursts [1].

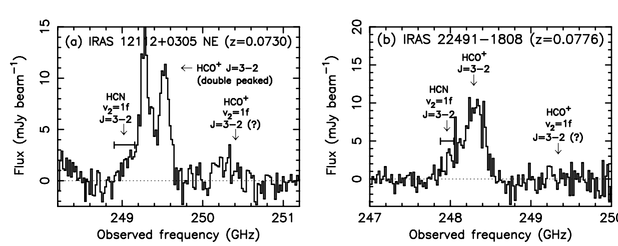

Figure 2: Zoom-in spectra of two LIRGs which show the signatures of vibrationally excited (v_2=1f) HCN emission lines. The extended tails at the lower frequency side of the bright HCO^+ J=3–2 emission lines at the vibrational ground level (v=0) are usually interpreted as the contribution from the HCN v_2=1f J=3–2 emission lines. Both of these sources show high HCN-to-HCO^+ J=3–2 flux ratios (second and third objects from the right in Figure 1).

Reference

[1] Imanishi, M., et al.: 2016, *AJ*, **152**, 218.