ALMA Reveals a Rotating Dense Molecular Torus in NGC 1068

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Active galactic nuclei (AGNs) emit strong radiation from the compact nuclear regions of galaxies. It is widely believed that a mass-accreting supermassive black hole (SMBH) is present at the center, surrounded by toroidally distributed (torus shaped) gas and dust which are thought to be rotating under the gravitational potential of the central SMBH. If this kind of gas and dust torus is present, various observational results of AGNs can naturally be explained (the so-called AGN unified model), so that researchers believe that such a torus is present. However, since the torus is spatially very compact, < 10 pc in physical size or < 0.15 arcsec at the distance of 15 Mpc, its observational understanding is still highly incomplete. Thanks to the advent of ALMA with high spatial resolution observing capability, our understanding of the AGN torus is expected to improve a lot.

NGC 1068 (z=0.0037, distance ~14 Mpc) is a nearby well-studied AGN. From previously revealed spatial distribution of optical ionized gas emission and radio jet, there is a consensus that the torus should be located along the almost east-west direction. ALMA high-spatial-resolution CO J=6–5 observational results were reported, but its dynamical direction is along the almost north-south direction, rather than the expected east-west torus direction. The results are largely different from the classical torus picture.

We have observed NGC 1068, with 0.04 arcsec × 0.07 arcsec resolution, in the HCN J=3–2 (265.89 GHz) and HCO^+ J=3–2 (267.56 GHz) lines, both of which are known to be good dense gas tracers. We have detected east-west oriented dense molecular emission and rotation (Figure 1), as expected. However, the observed rotation is slower than that expected from Keplerian motion dominated by the gravity of the central SMBH. Dense molecular emission and velocity dispersion are asymmetric. We interpret that the dense molecular emission is brighter at the western part of the central mass-accreting SMBH, due to higher turbulence and resulting reduced line opacity. We have also found that dense gas at the eastern (western) part of the torus is redshifted (blueshifted) (Figure 1), while that at the central part of the host galaxy outside the torus, along the torus direction, is counter-rotating (i.e., eastern region is blueshifted and western region is redshifted) (Figure 2), suggesting that some external process happened in the past. This may be the result of a minor galaxy merger [1].

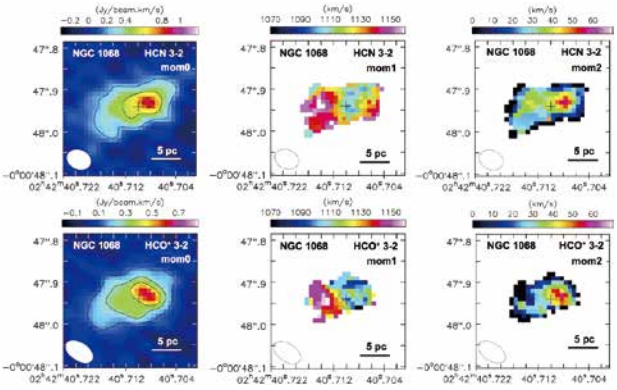

Figure 1: Integrated intensity (Left), intensity-weighted mean velocity (Middle), and intensity-weighted velocity dispersion (Right) maps of the HCN J=3–2 (Top) and HCO^+ J=3–2 (Bottom) emission lines in the torus region with ~10 pc scale around the mass-accreting SMBH (denoted as the "+" mark). Gas at the eastern part (left side of the figures) is redshifted, and that at the western part (right side of the figures) is blueshifted. At the western part, both lines are brighter and velocity dispersion is larger.

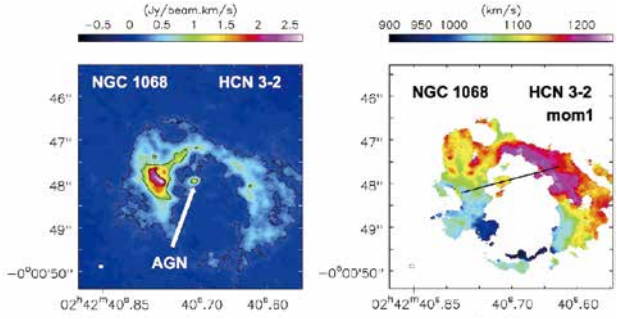

Figure 2: Integrated intensity (Left) and intensity-weighted mean velocity (Right) maps of the HCN J=3–2 emission line at the central ~350 pc region of the host galaxy. The mark "AGN" (in the left panel) corresponds to the torus in Figure 1. Dense molecular gas at the eastern (western) part outside the torus along the torus direction (solid line in the right panel) is blueshifted (redshifted), suggesting counter-rotation of dense gas inside and outside the torus. The HCO^+ line also shows virtually the same properties.

Reference

[1] Imanishi, M., et al.: 2018, *ApJL*, **853**, L25.