Rotating gaseous donut around an active supermassive black hole

February 14 2018

The central region of the spiral galaxy M77. The NASA/ESA Hubble Space Telescope imaged the distribution of stars. ALMA revealed the distribution of gas in the very center of the galaxy. ALMA imaged a horseshoe-like structure with a radius of 700 light-years and a central compact component with a radius of 20 light-years. The latter is the gaseous torus around the AGN. Red indicates emission from formyl ions (HCO+) and green indicates hydrogen cyanide emission. Credit: ALMA (ESO/NAOJ/NRAO), Imanishi et al., NASA/ESA Hubble Space Telescope and A. van der Hoeven

High-resolution observations with the Atacama Large Millimeter/submillimeter Array (ALMA) imaged a rotating dusty gas torus around an active supermassive black hole. The existence of such rotating donuts-shape structures was first suggested decades ago, but this is the first time one has been confirmed so clearly. This is an important step in understanding the co-evolution of supermassive black holes and their host galaxies.

Almost all galaxies hold concealed monstrous black holes in their centers. Researchers have known for a long time that the more massive the galaxy is, the more massive the central black hole is. This sounds reasonable at first, but host galaxies are 10 billion times bigger than the central black holes; it should be difficult for two objects of such vastly different scales to directly affect each other. So how could such a relation develop?

Aiming to solve this shadowy problem, a team of astronomers utilized the high resolution of ALMA to observe the center of spiral galaxy M77. The central region of M77 is an "active galactic nucleus," or AGN, which means that matter is vigorously falling toward the central supermassive black hole and emitting intense light. AGNs can strongly affect the surrounding environment, therefore they are important objects for solving the mystery of the co-evolution of galaxies and black holes.

The team imaged the area around the supermassive black hole in M77 and resolved a compact gaseous structure with a radius of 20 light-years. And, the astronomers found that the compact structure is rotating around the black hole, as expected.

"To interpret various observational features of AGNs, astronomers have assumed rotating donut-like structures of dusty gas around active supermassive black holes. This is called the 'unified model' of AGN," explained Masatoshi Imanishi (National Astronomical Observatory of

Japan), the lead author on a paper published in the *Astrophysical Journal Letters*. "However, the dusty gaseous donut is very tiny in appearance. With the high resolution of ALMA, now we can directly see the structure."

Many astronomers have observed the center of M77 before, but never has the rotation of the gas donut around the black hole been seen so clearly. Besides the superior resolution of ALMA, the selection of molecular emission lines to observe was key to revealing the structure. The team observed specific microwave emission from hydrogen cyanide molecules (HCN) and formyl ions (HCO+). These molecules emit microwaves only in dense gas, whereas the more frequently observed carbon monoxide (CO) emits microwaves under a variety of conditions. The torus around the AGN is assumed to be very dense, and the team's strategy was right on the mark.

"Previous observations have revealed the east-west elongation of the dusty gaseous torus. The dynamics revealed from our ALMA data agrees exactly with the expected rotational orientation of the torus," said Imanishi.

Interestingly, the distribution of gas around the supermassive black hole is much more complicated than what a simple unified model suggests. The torus seems to have an asymmetry and the rotation is not just following the gravity of the black hole but also contains highly random motion. These facts could indicate the AGN had a violent history, possibly including a merger with a small galaxy. Nevertheless, the identification of the rotating torus is an important step.

The Milky Way Galaxy, where we live, also has a supermassive black hole at its center. This black hole is, however, in a very quiet state. Only a tiny amount of gas is accreting onto it. Therefore, to investigate an AGN in detail, astronomers need to observe the centers of distant

galaxies. M77 is one of the nearest AGN and a suitable object for peering into the very center in detail.

More information: Masatoshi Imanishi et al. ALMA Reveals an Inhomogeneous Compact Rotating Dense Molecular Torus at the NGC 1068 Nucleus, *The Astrophysical Journal* (2018). DOI: 10.3847/2041-8213/aaa8df