ALMA reveals a rotating dense molecular torus in the nearby AGN NGC 1068

ALMA Cycle 4 : HCN J=3-2, HCO⁺ J=3-2

Masa Imanishi (NAOJ)

2018 Dec 13 @ Puerto Varas
NGC 1068 (14 Mpc)

AGN (SMBH)

Image: \[\text{[OIII]}\] (NLR)

contour: radio

N-S elongated

Radio jet

\[\text{[OIII]}\] (NLR)

<10 pc

Torus should be almost E-W

Das+06 AJ 132 620

Gallimore+04 ApJ 613 794
AGN torus emission is overwhelmed by bright host galaxy emission

Garcia-Burillo+14
AA 567 A125

NGC 1068

AGN torus position

ALMA Cycle 0 (2012)
0.6” x 0.5” (42 pc x 35 pc)

CO J=3-2

CO J=6-5
Spatially isolate torus molecular emission from host galaxy

NGC 1068

ALMA Cycle 2 (2015)

HCN $J=3-2$

0.13” x 0.23”
(9pc x 16 pc)

HCO$^+$ $J=3-2$

Imanishi+16 ApJL 822 L10
NGC 1068

CO J=6-5

Torus gas dynamics

Cycle 2 (2015)

N-S rotation (?), not E-W torus direction

ESO/M. Kornmesser, Nick Risinger

High velocity component

redshifted

blueshifted

Garcia Burillo+16 ApJL 823 L12

Gallimore+16 ApJL 829 L7

0.05” x 0.07”
(3.5 pc x 4.9 pc)

0.08” x 0.06”
(5.6pc x 4.2pc)
ALMA Cycle 4 (2017)

NGC 1068

HCN, HCO$^+$ J=3-2

1" = 70 pc

Imanishi+18 ApJL 853 L25
AGN torus

0.04” x 0.07”
(2.8pc x 4.9pc)

HCN J=3-2

HCO⁺ J=3-2

Dense gas tracers

Velocity (rotation)

intensity

Torus is elongated along E-W morphologically and dynamically!

(PA = 105-110 deg E of N)
ALMA release (2018 Feb 14)

Rotating Dusty Gaseous Donut around an Active Supermassive Black Hole

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.

The central region of the spiral galaxy M77. The NASA/ESA Hubble
**Surprising result 1**

Asymmetric molecular emission

**Velocity dispersion**

**intensity**

**HCN J=3-2**

**West: high turbulence -> reduced line opacity**

**-> stronger emission**

**HCO+ J=3-2**
Surprising result 2

Much slower rotation than Keplerian motion by the central SMBH (1 x 10^7 Mo)

Keplerian rotation velocity = ±120 km/s at 3 pc
Surprising result 3

Dynamical decoupling of molecular gas between outside and inside torus

Host: E is blueshifted

Torus: E is redshifted

HCN $J=3-2$

HCO$^+$ $J=3-2$
Position–Velocity (PV) diagram

HCN J=3-2

Position (pc)

HCO⁺ J=3-2

Position (pc)

E

W

Gallimore+04

H₂O maser
NGC 1068: minor galaxy merger?

Subaru deep optical image (Tanaka+17)
Next step (NGC 1068)

ALMA Cycle 6

1. **Mass** distribution: symmetric or asymmetric?

   **Optically thin** isotopologue $\text{H}^{13}\text{CN}$, $\text{H}^{13}\text{CO}^+$ $J=3-2$ lines

2. Origin of high turbulence in the torus (W)

   **Nuclear starburst** in the torus?
1. Rotating dense molecular torus clearly detected along the E-W torus direction for the first time

2. Gas emission and dynamics are not as simple as expected from the classical AGN torus model

Origins need to be understood

End