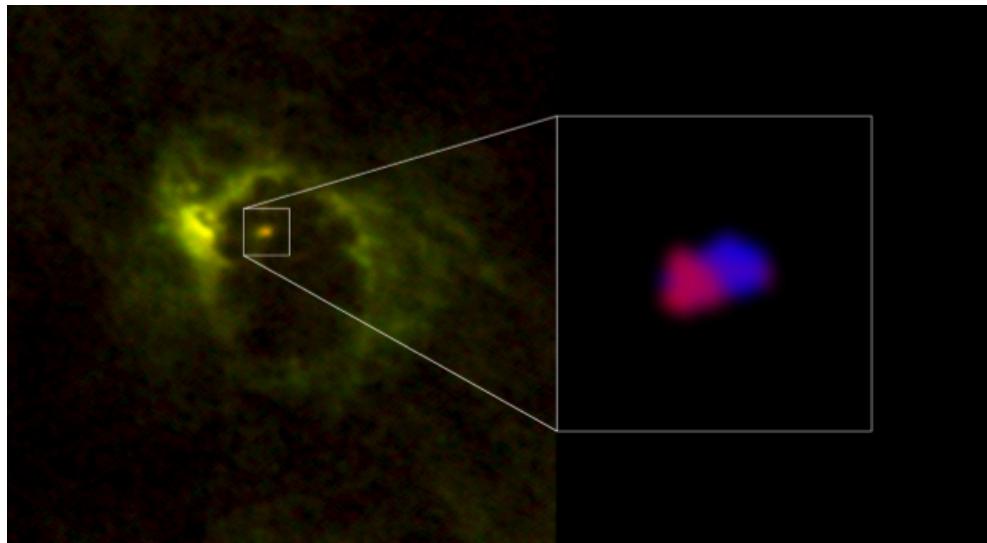


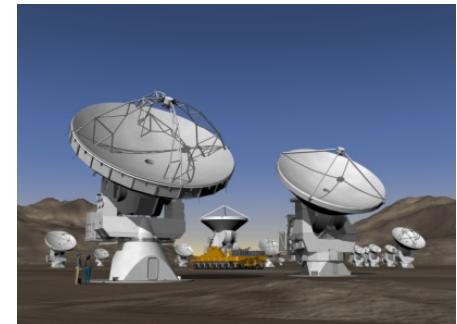
ALMA reveals a rotating dense molecular torus in the nearby AGN NGC 1068

ALMA Cycle 4 : HCN J=3-2, HCO⁺ J=3-2

Masa Imanishi (NAOJ)



ALMA



2018 Dec 13 @ Puerto Varas

NGC 1068 (14 Mpc)

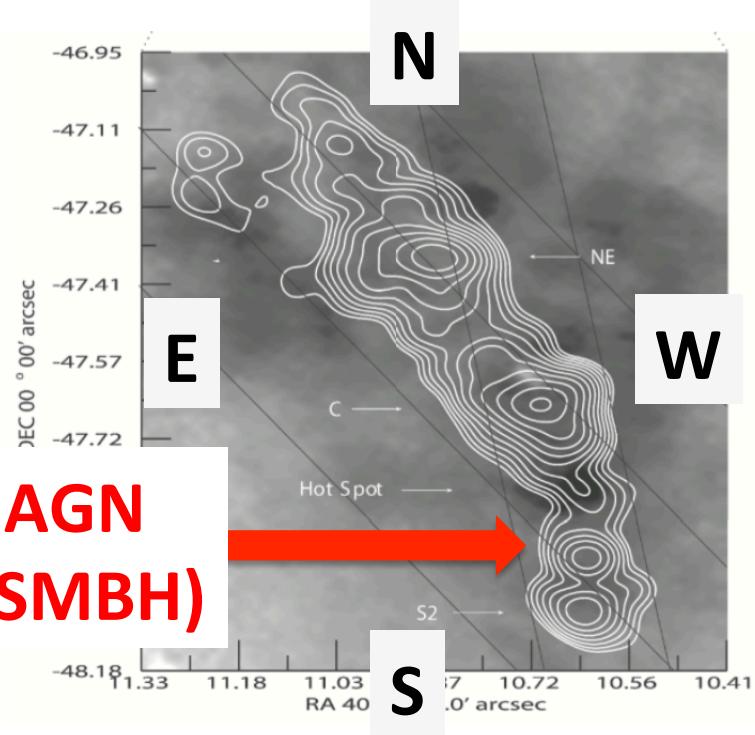


Image: [OIII] (NLR)
contour: radio

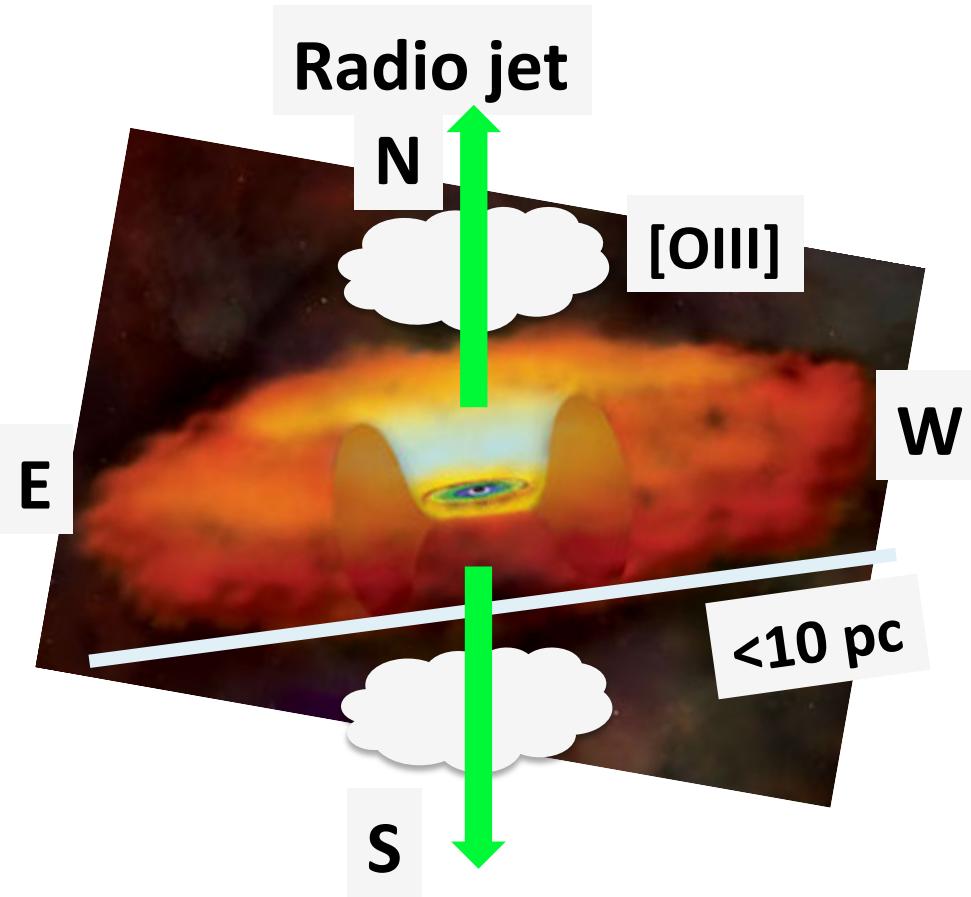
N-S elongated



Torus should be almost E-W

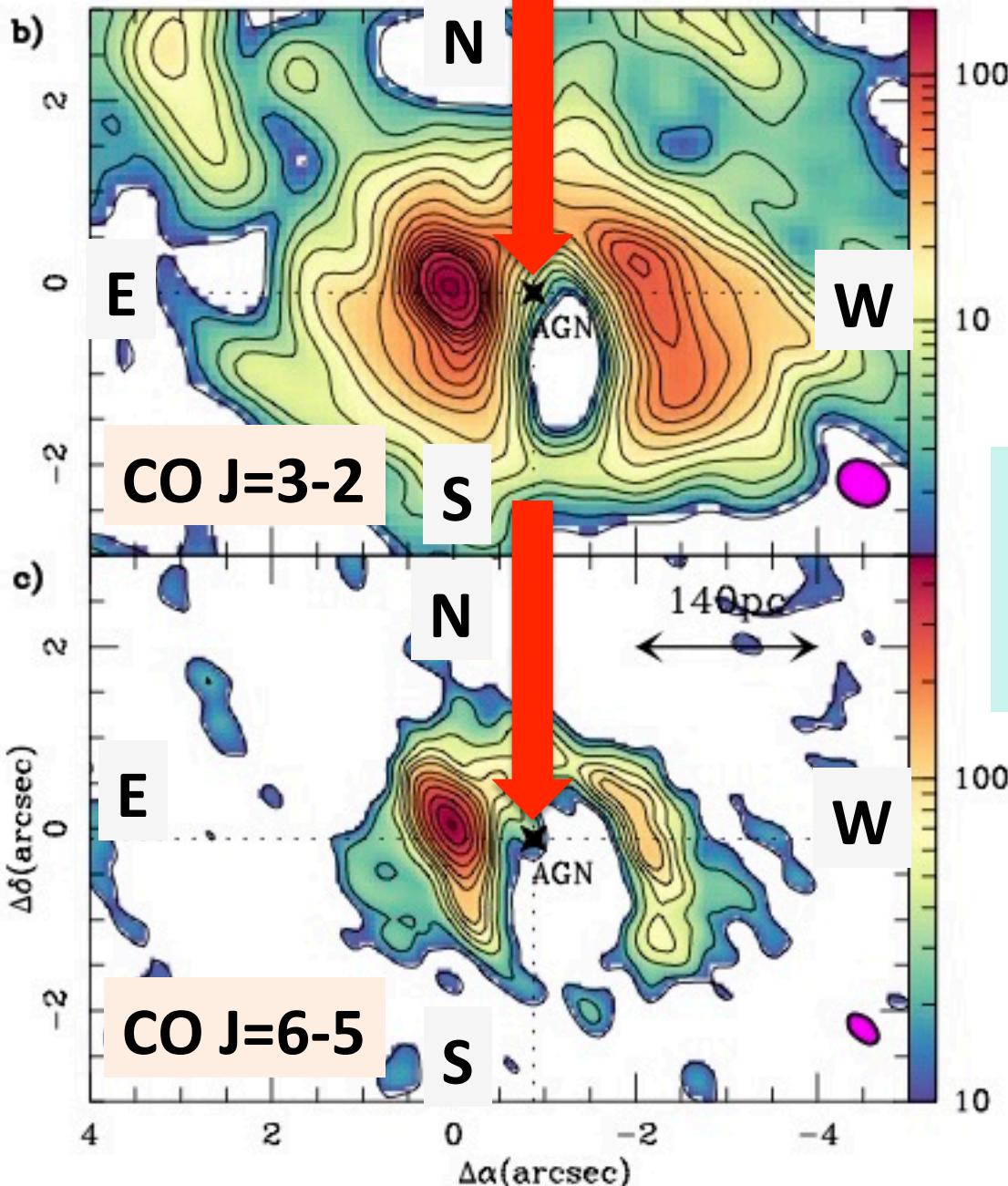
Das+06 AJ 132 620

Gallimore+04 ApJ 613 794



NGC 1068

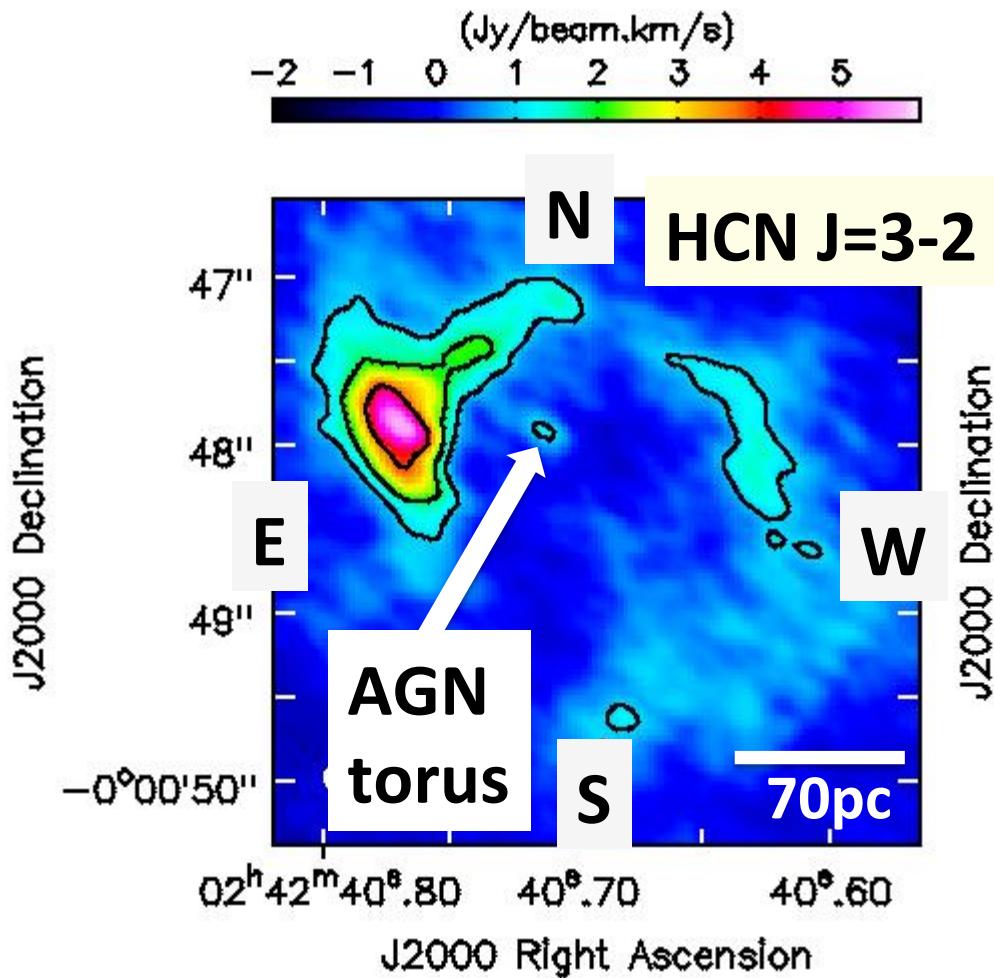
AGN torus position



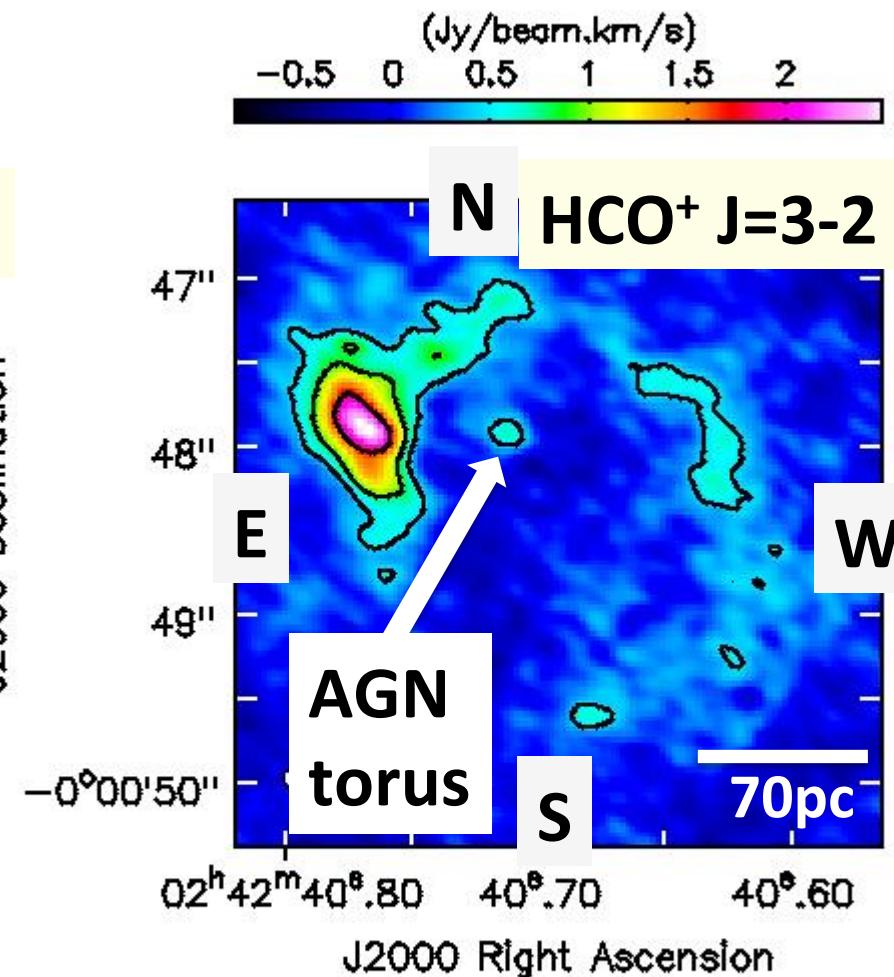
NGC 1068

Spatially isolate torus molecular emission from host galaxy

ALMA Cycle 2 (2015)



0.13" x 0.23"
(9pc x 16 pc)



Imanishi+16 ApJL 822 L10

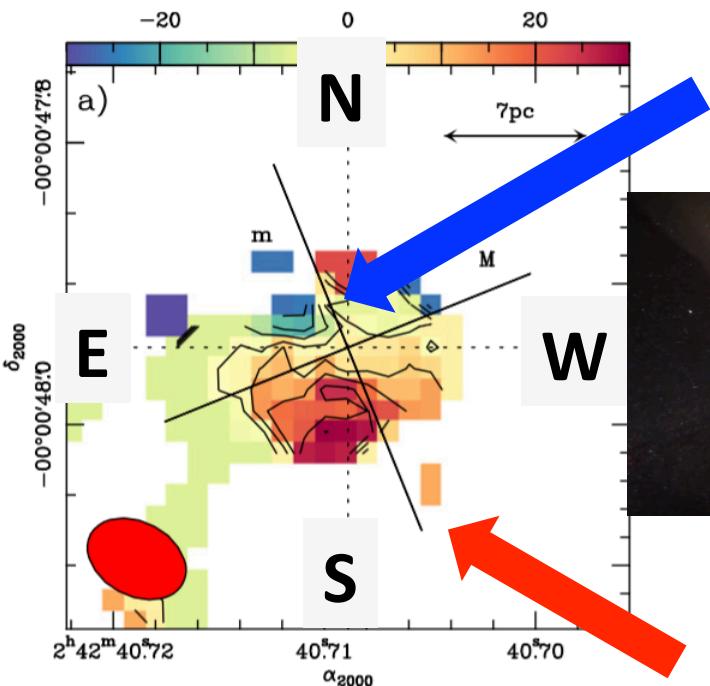
NGC 1068

CO J=6-5

Torus gas dynamics

Cycle 2 (2015)

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



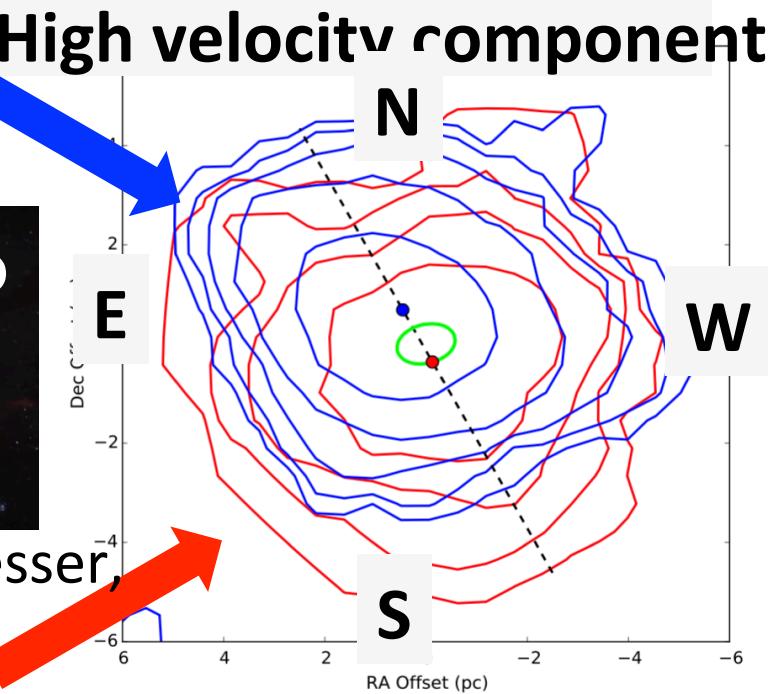
blueshifted



ESO/M. Kornmesser,
Nick Risinger

redshifted

$0.05'' \times 0.07''$
(3.5 pc x 4.9 pc)



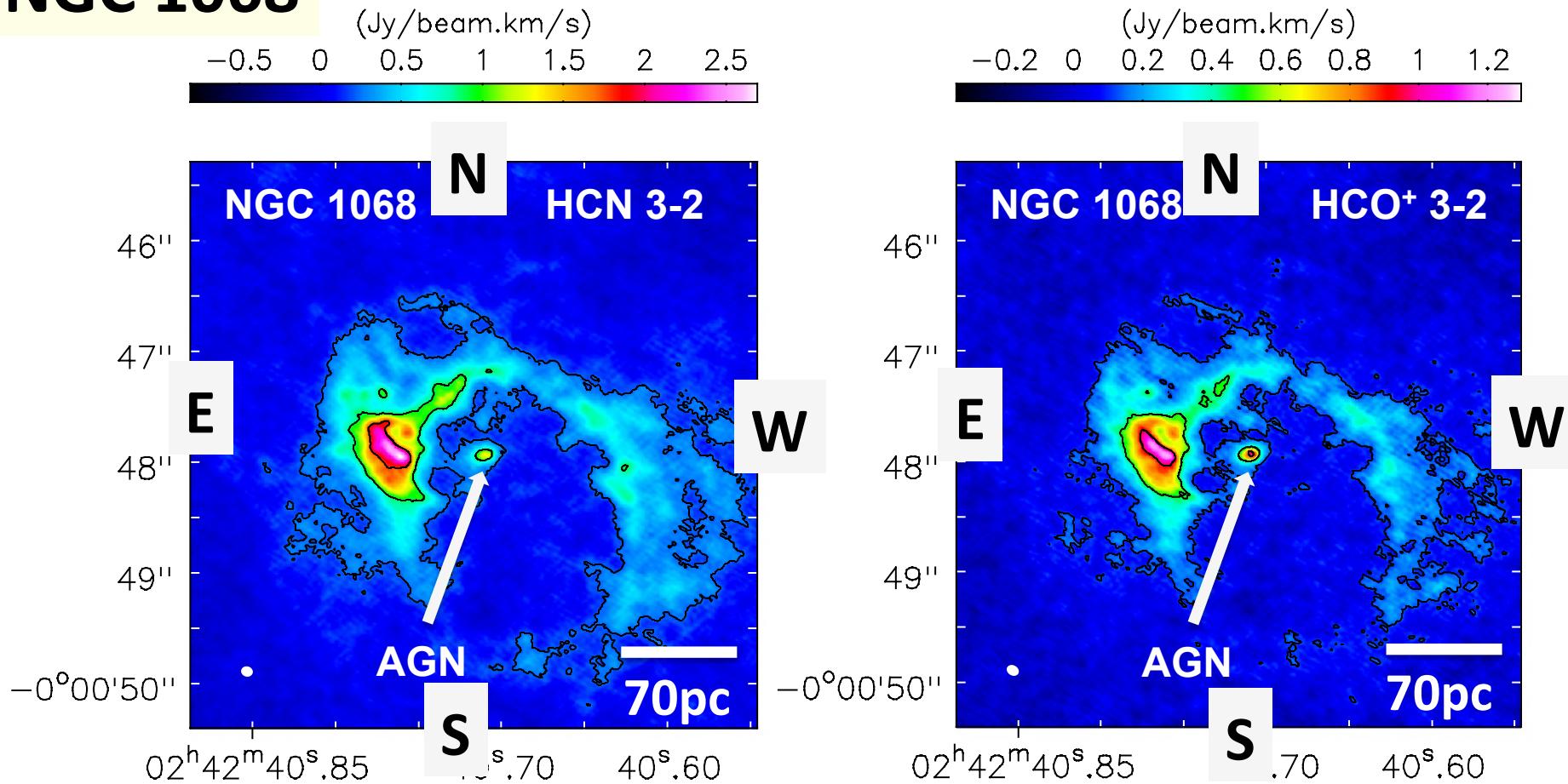
$0.08'' \times 0.06''$
(5.6 pc x 4.2 pc)

ALMA Cycle 4 (2017)

HCN, HCO⁺ J=3-2

1'' = 70 pc

NGC 1068

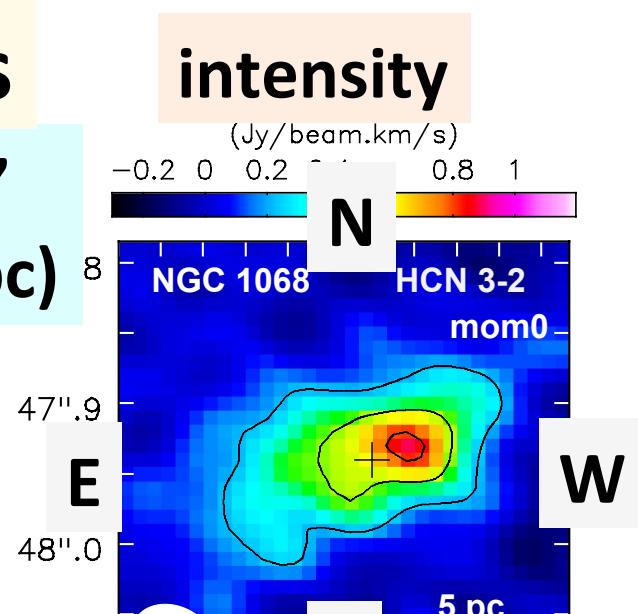


AGN torus

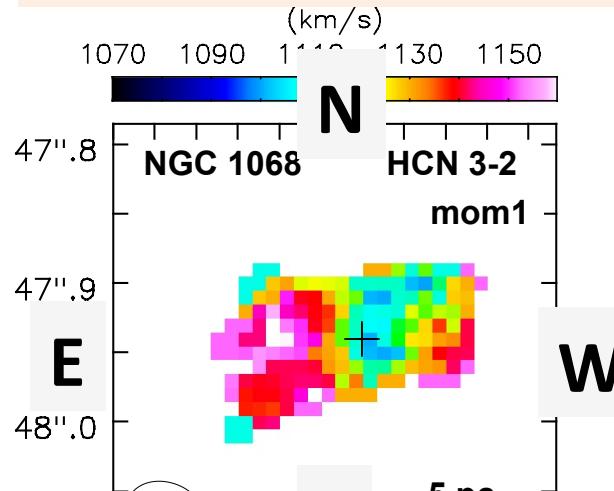
0.04" x 0.07"

(2.8pc x 4.9pc)

HCN J=3-2



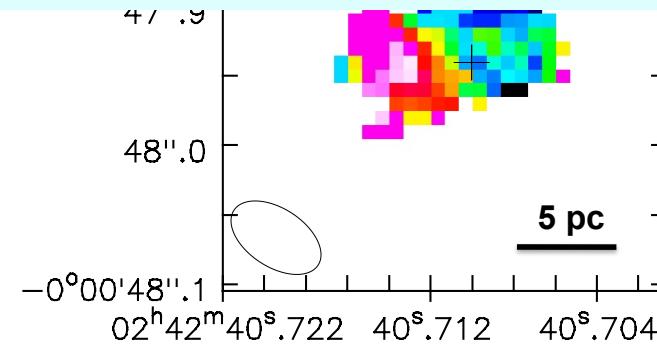
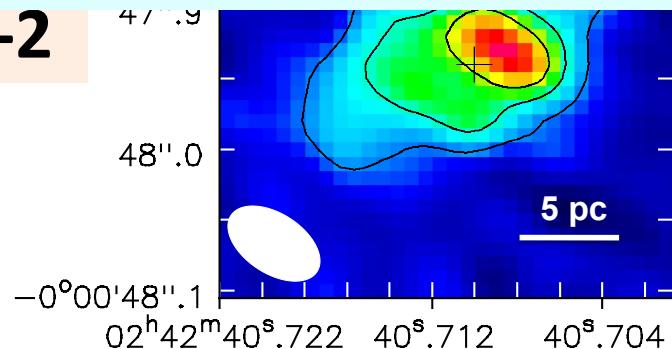
Velocity (rotation)



Den Torus is elongated along E-W
track
morphologically and dynamically !

(PA = 105-110 deg E of N)

HCO⁺ J=3-2



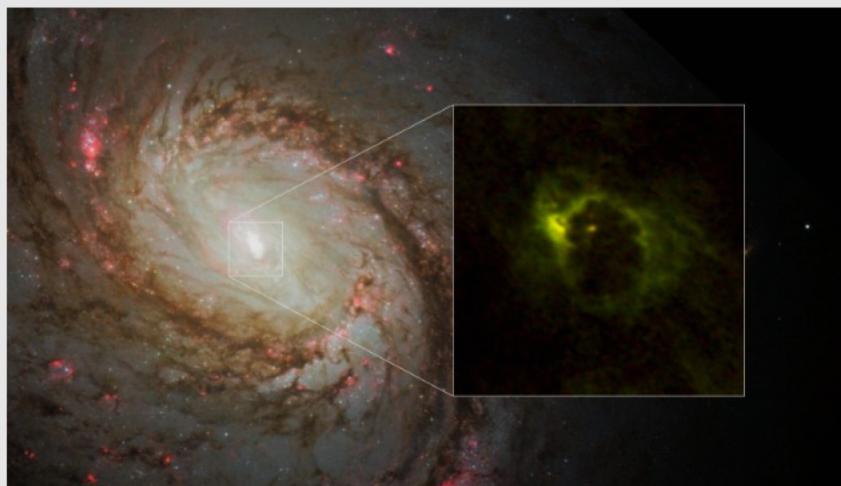
2018.02.14

Rotating Dusty Gaseous Donut around an Active Supermassive Black Hole

[f share](#)

[tweat](#)

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.



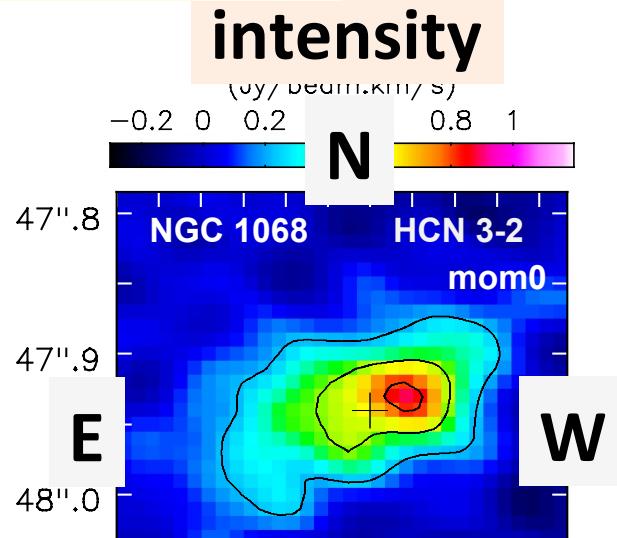
The central region of the spiral galaxy M77. The NASA/ESA Hubble

**Imanishi+18
ApJL 853 L25**

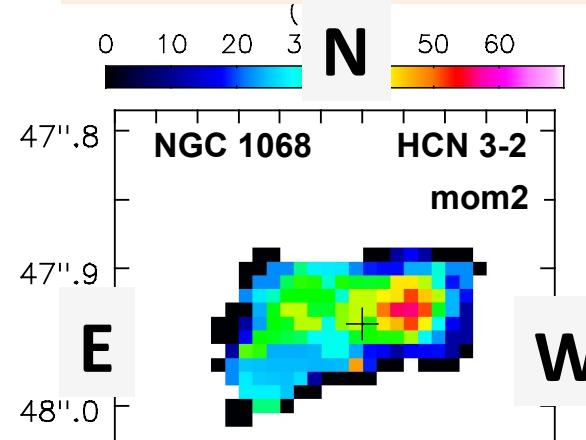
Surprising result 1

Asymmetric molecular emission

HCN J=3-2

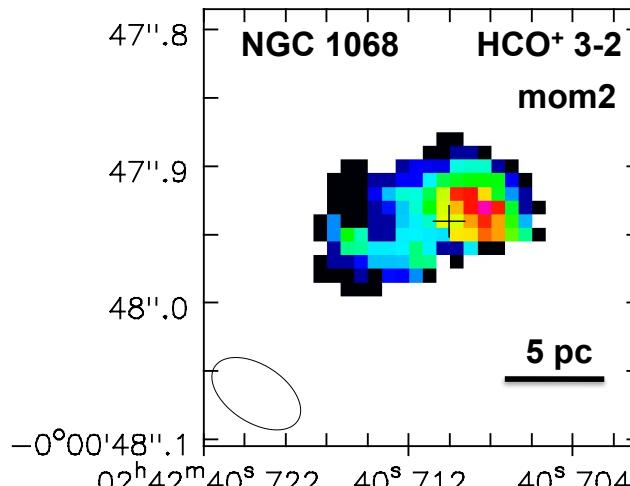
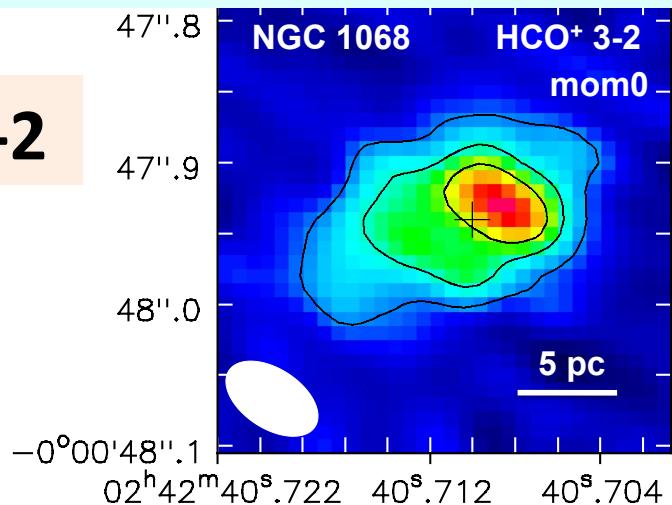


Velocity dispersion



West: high turbulence \rightarrow reduced line opacity
 \rightarrow stronger emission

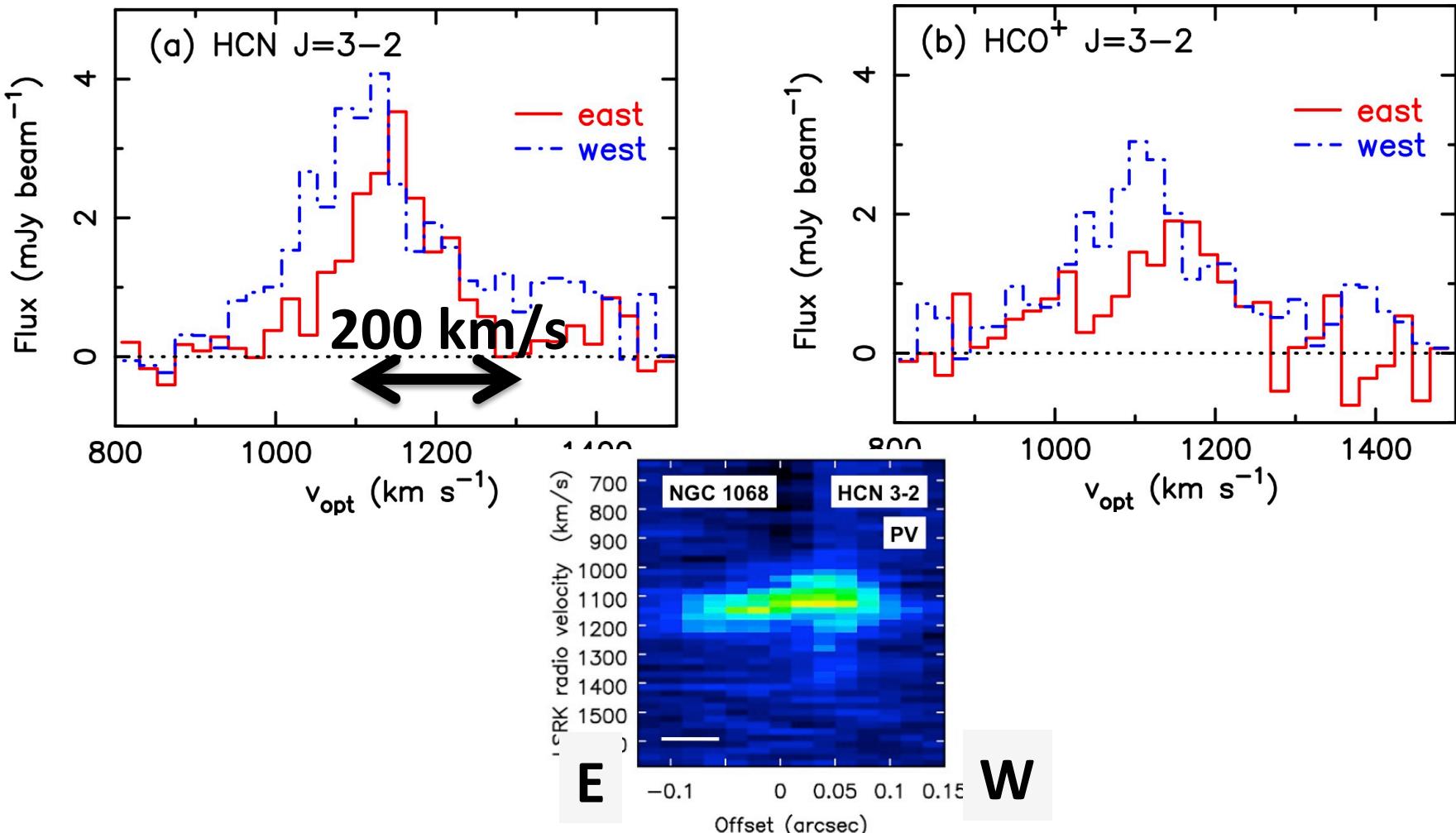
HCO⁺ J=3-2



Surprising result 2

Much slower rotation than Keplerian motion by the central SMBH ($1 \times 10^7 M_{\odot}$)

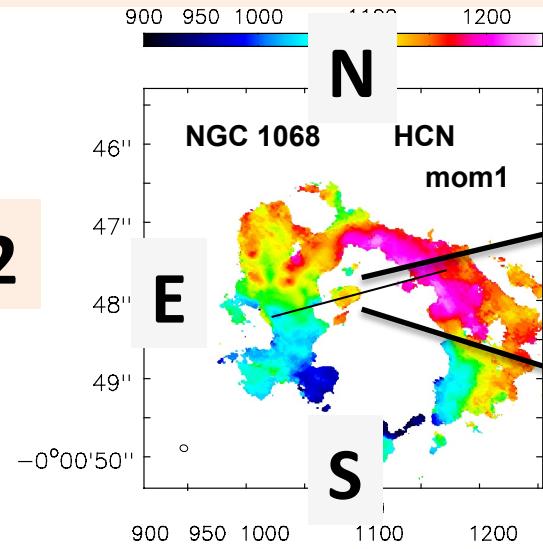
Keplerian rotation velocity = ± 120 km/s at 3 pc



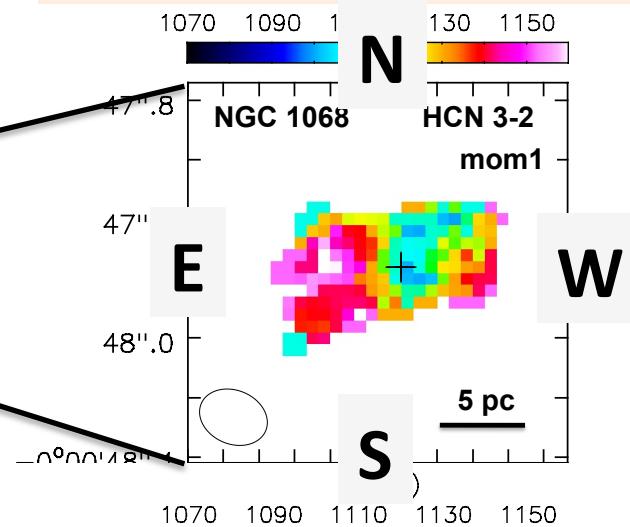
Surprising result 3

Dynamical decoupling of molecular gas between outside and inside torus

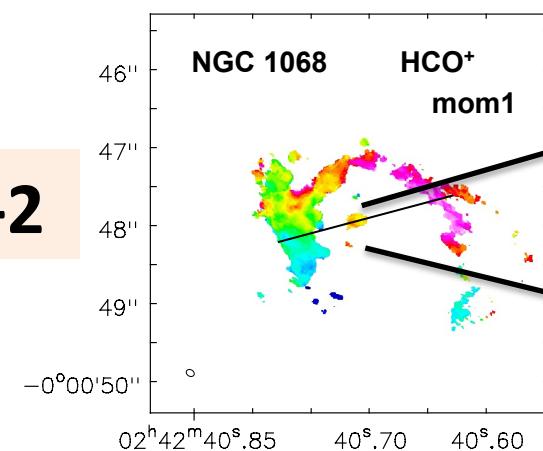
Host: E is blueshifted



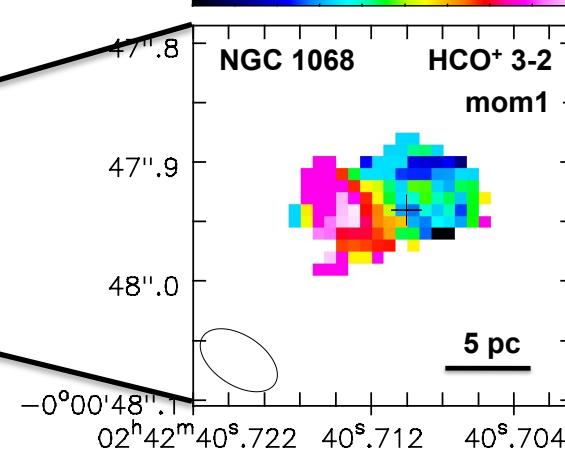
Torus: E is redshifted



HCN J=3-2



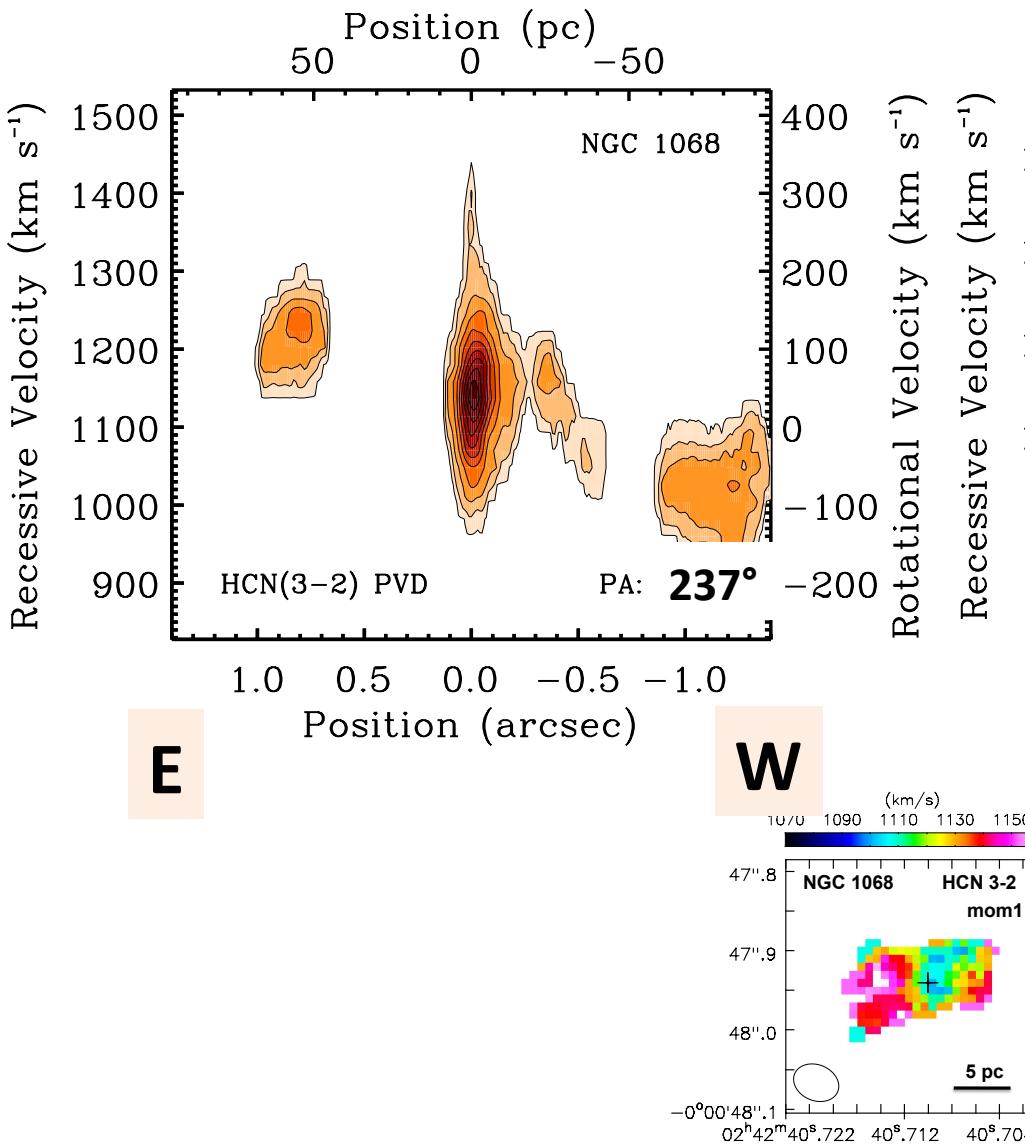
HCO⁺ J=3-2



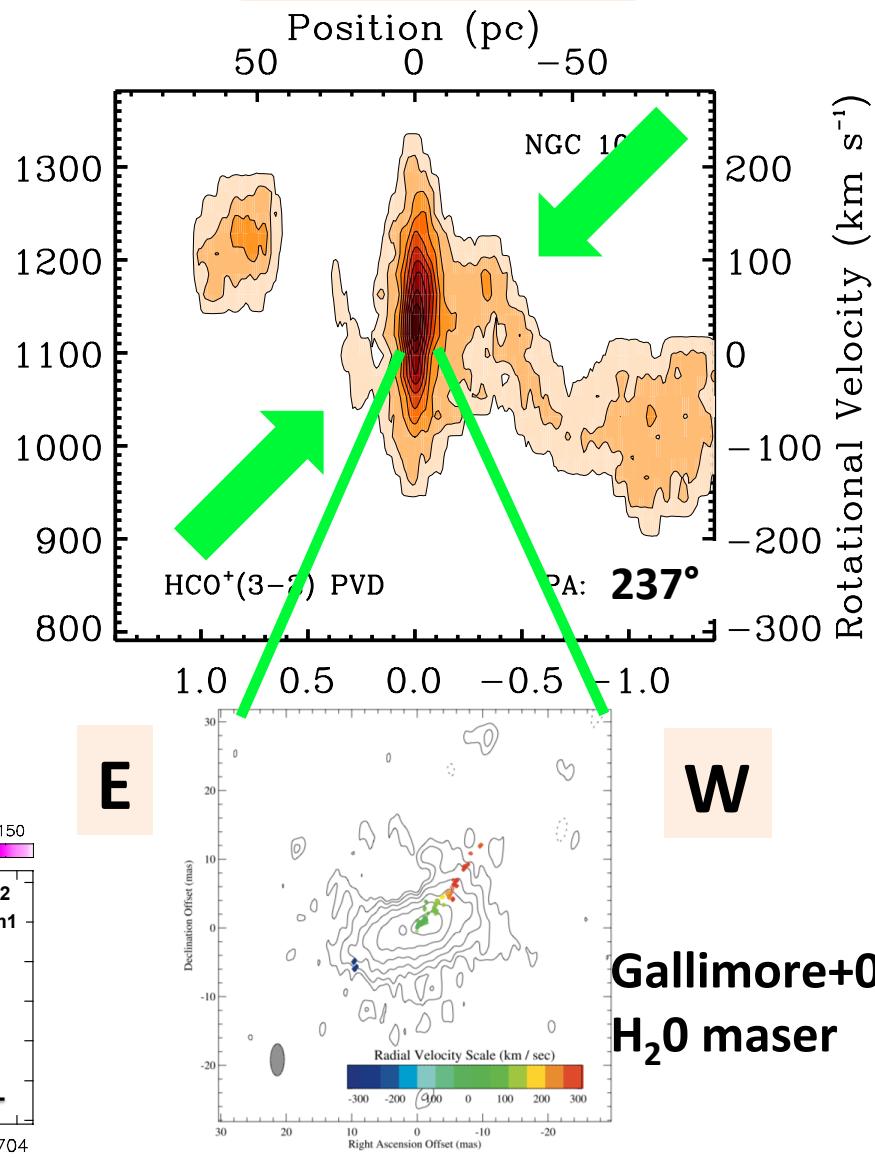
Position–Velocity (PV) diagram

D. Nguyen (NAOJ)

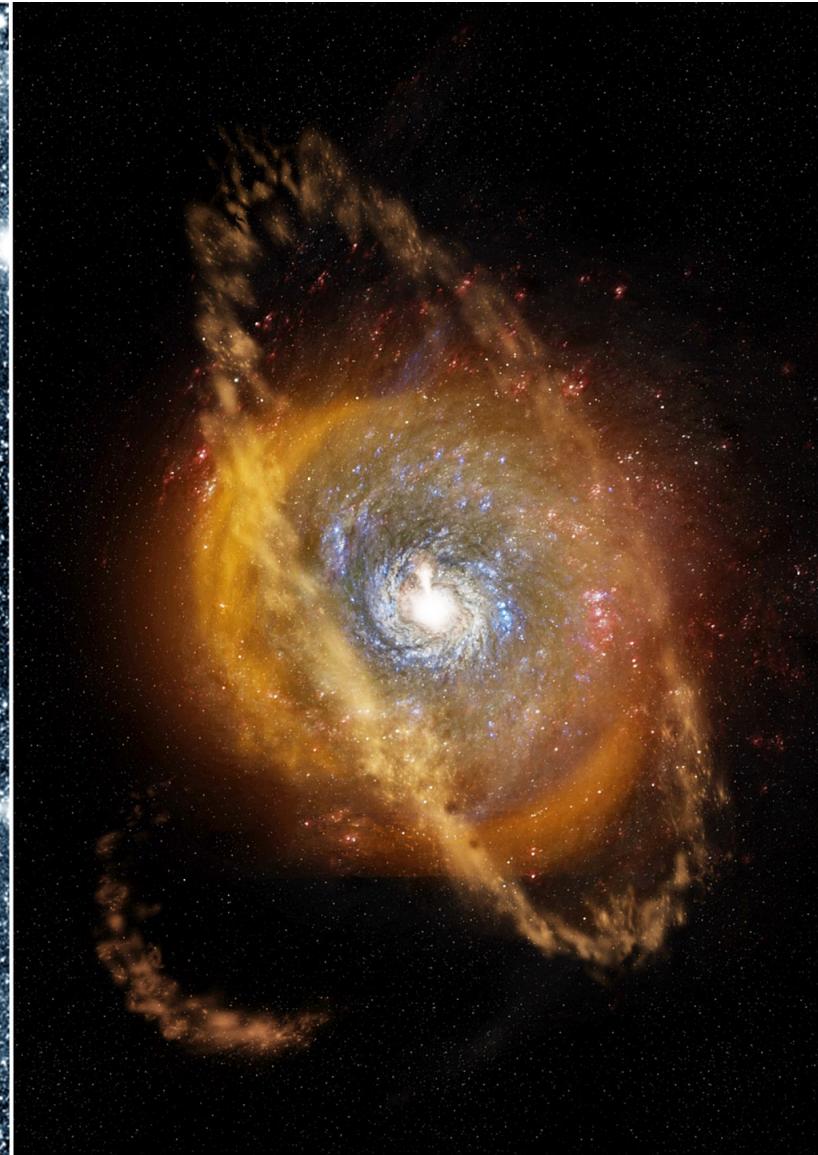
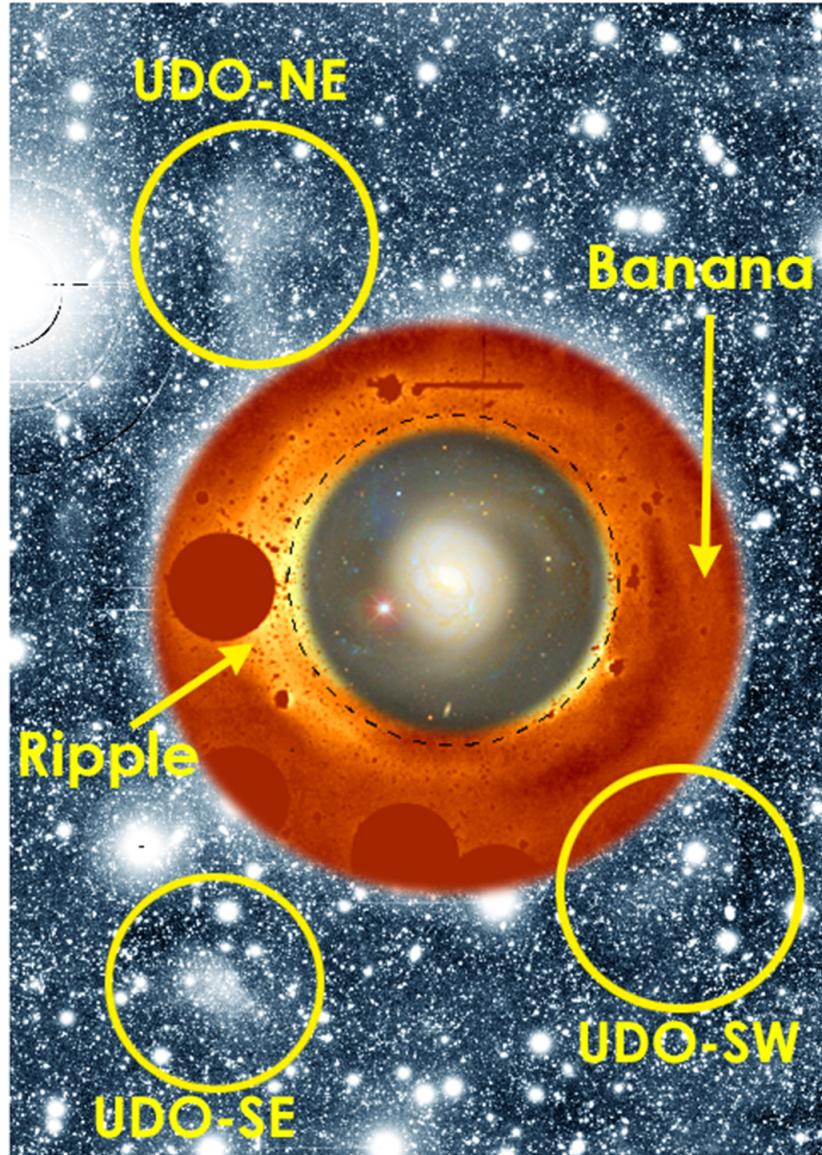
HCN J=3-2



HCO⁺ J=3-2



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 H¹³CN, H¹³CO⁺ J=3-2 lines

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

Nuclear starburst in the torus ?

Summary

**ALMA 0.04" x 0.07" observations of NGC 1068
in the HCN and HCO⁺ J=3-2 lines (dense molecular tracers)**

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

Imanishi+16 ApJL 822 L10, Imanishi+18 ApJL 853 L25

End