High resolution imaging of the molecular torus in NGC 1052 with VLBI

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(Sawada-Satoh et al. 2016, ApJL 830 L3; Sawada-Satoh et al. 2019, ApJL 872 L21)

Abstract

We present the first subparsec-scale imaging of HCN J=1-0 and HCO+ J=1-0 absorptions in the circumnuclear region of the nearby radio galaxy NGC 1052. Our 3-mm VLBI observations with the Korean VLBI Network have spatially resolved those absorptions against a double-sided nuclear jet structure. The absorption features show high optical depth concentrated on the receding jet side, where the free-free absorption occurred due to the circumnuclear torus. The size of the foreground absorbing molecular gas is estimated to be on approximately one-parsec scales. These results are most naturally explained by a circumnuclear torus that consist of several phase layers, perpendicular to the jet axis of NGC 1052. HCN and HCO+ absorbing gas could lie in the cooler molecular layer. The redshifted velocities of the absorption features account for the infall motion onto the central engine, such as an H2O maser emission.

Introduction

It is generally accepted that pronounced activity of an active galactic nucleus (AGN) is driven by the accretion of gas from its circumnuclear torus onto a supermassive black hole. Molecular gas in the central regions of extragalaxies provides important clues to the nuclear environment of AGNs. High angular resolution studies of molecular gas in the center of the external galaxies (<1kpc) have been obtained with millimeter and submillimeter interferometers. The size of the torus, however, is smaller than 10pc, and a milliarcsecond (mas) resolution is required to study its internal structure in nearby AGNs. VLBI observations have revealed the parsec- or subparsec-scale morphology of nearby AGNs. Although thermal emission lines from molecular gas are not luminous enough to detect with the VLBI, VLBI maps can display thermal absorption lines of the gas in silhouette against a bright background synchrotron radiation source with a mas resolution. To investigate the geometry and physical properties of the molecular gas in the circumnuclear region of NGC1052, we have performed high-resolution observations toward HCN J=1–0 and HCO+ J=1-0 absorption lines with the Korean VLBI Network (KVN).

About NGC 1052

NGC 1052 hosts a well-studied circumnuclear torus surrounding its central engine.

- A parsec-scale plasma torus, which obscure 0.1pc and 0.7pc of the eastern and western jets, respectively[1].
- Positionally coincidence of H2O maser emission and a plasma-obscuring torus[2].
- A torus model of several phase layers is proposed; a hot plasma layer at the inner surface, a warm molecular gas layer where H2O maser arises, a cooler molecular layer[2,3].
- Gases of H2O maser emission and OH absorption are located where the plasma torus obscure, which supports the torus model with several layer[2,4].
- The spectra of H2O maser and OH absorption are redshifted with respect to the systemic velocity of the galaxy, and the fact implies the on-going material infall onto the super massive black hole[2,4].
- HCN and HCO+ absorptions have been detected against an unresolved core with the IRAM PdBI, while it is unclear where they are associated with[5].

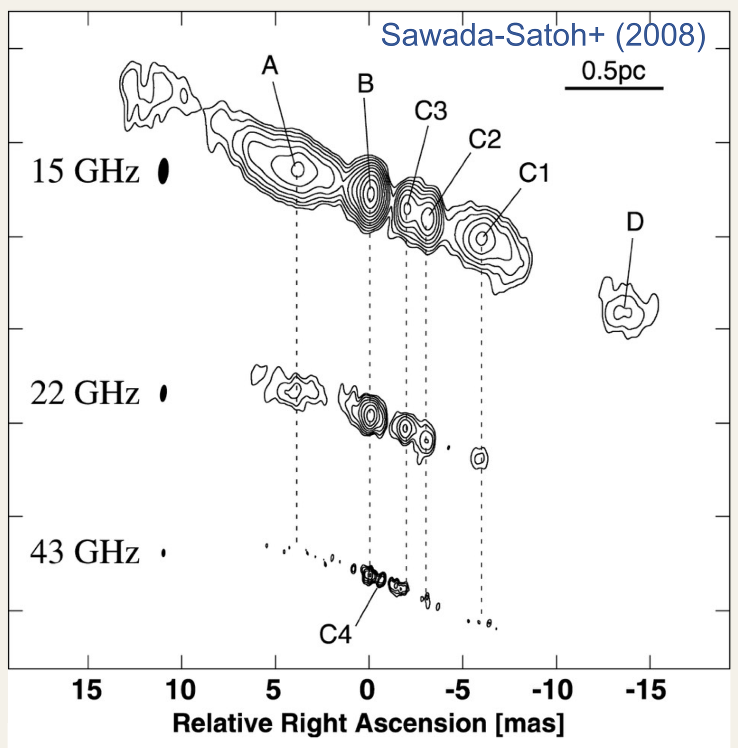

Fig.1 Double-sided radio jet of NGC 1052

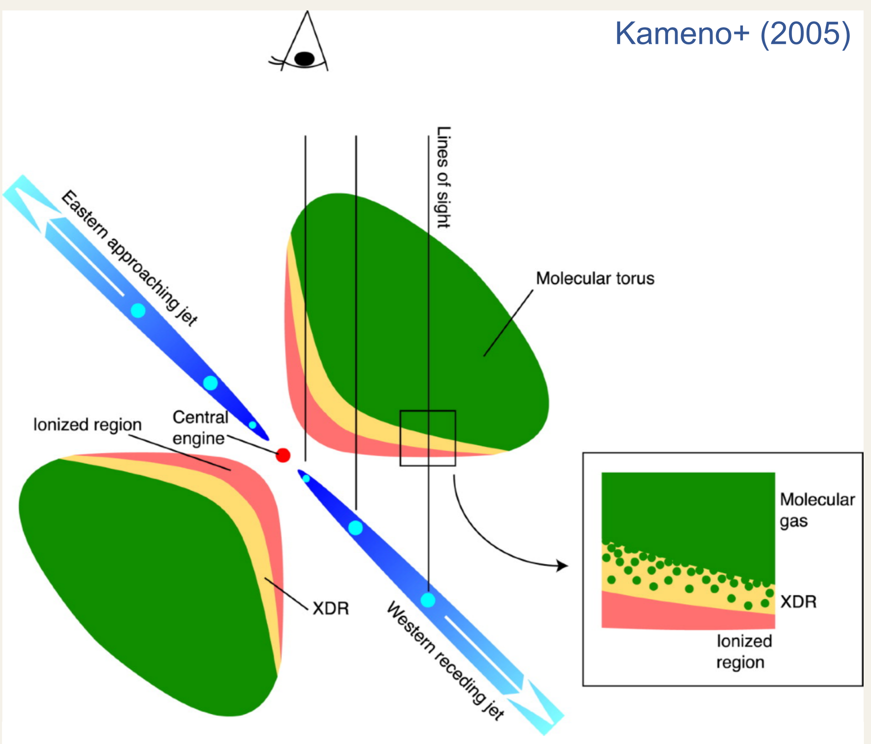

Fig.2 A torus model with several layers

Observations

To investigate distributions of HCN and HCO+ absorption in NGC 1052, KVN observations were carried out at 3-mm band. The resultant beam size was 1.5 x 0.9 mas (0.14 x 0.09 pc).

	HCN J=1-0	HCO+ J=1-0
Observation date	5 March 2015	17 June 2017
Bandwidth [MHz]	128	512
Rest frequency [GHz]	89.088	89.188

References

1. Kameno, S., et al. 2001, PASJ, 53, 169
2. Sawada-Satoh, S., et al. 2008, ApJ, 680, 191
3. Kameno, S., et al. 2005, ApJ, 620, 145
4. Impellizzeri, V., et al. 2008, Proc. 9th EVN Symposium, POS(IX EVN Symposium), 3
5. Liszt, H., & Lucas, R. 2004, A&A, 428, 445

HCN absorption

Two velocity features of HCN absorption (I & II) are detected with KVN (Fig.3), which are also found in the absorption profile from the IRAM PdBI data[5]. The absorption depths in the KVN spectral profile are deeper than those of the PdBI (2–6%). KVN images resolve the HCN absorption spatially, and show that high HCN optical depth is localized on the western receding jet side (Fig.4). HCN absorbing gas could be associated with the cooler molecular layer of the torus (Fig.5). The HCN absorbing gas is more likely to clumpy, rather than a large homogeneous structure with a single velocity.

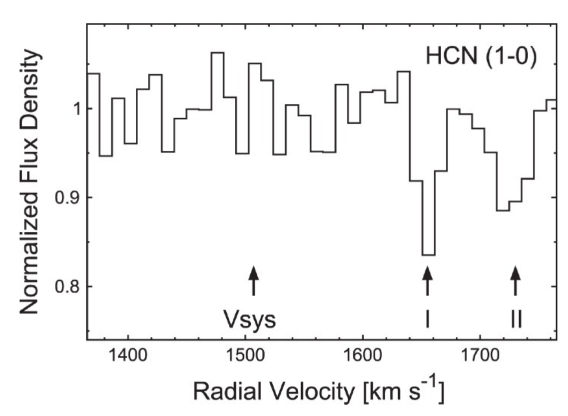

Fig.3 HCN absorption lines detected with KVN

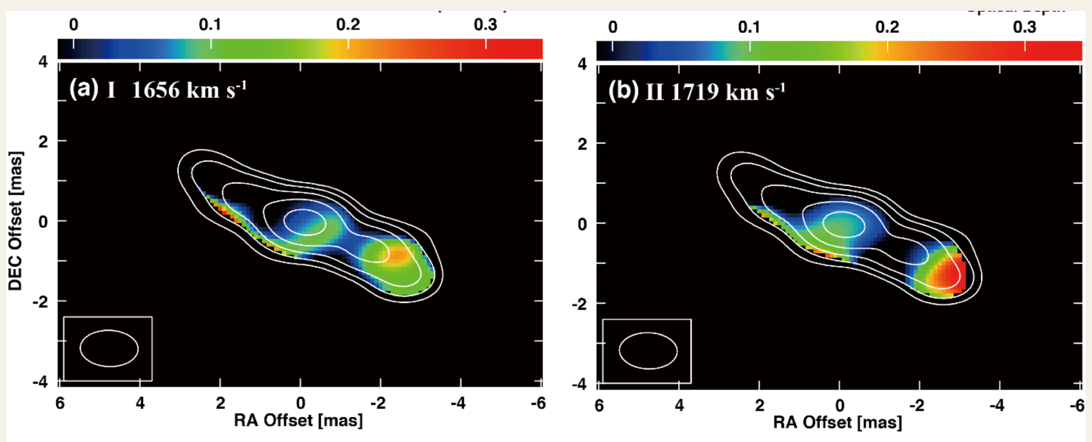

Fig.4 HCN optical depth maps (color), overlaid by a continuum map (contour)

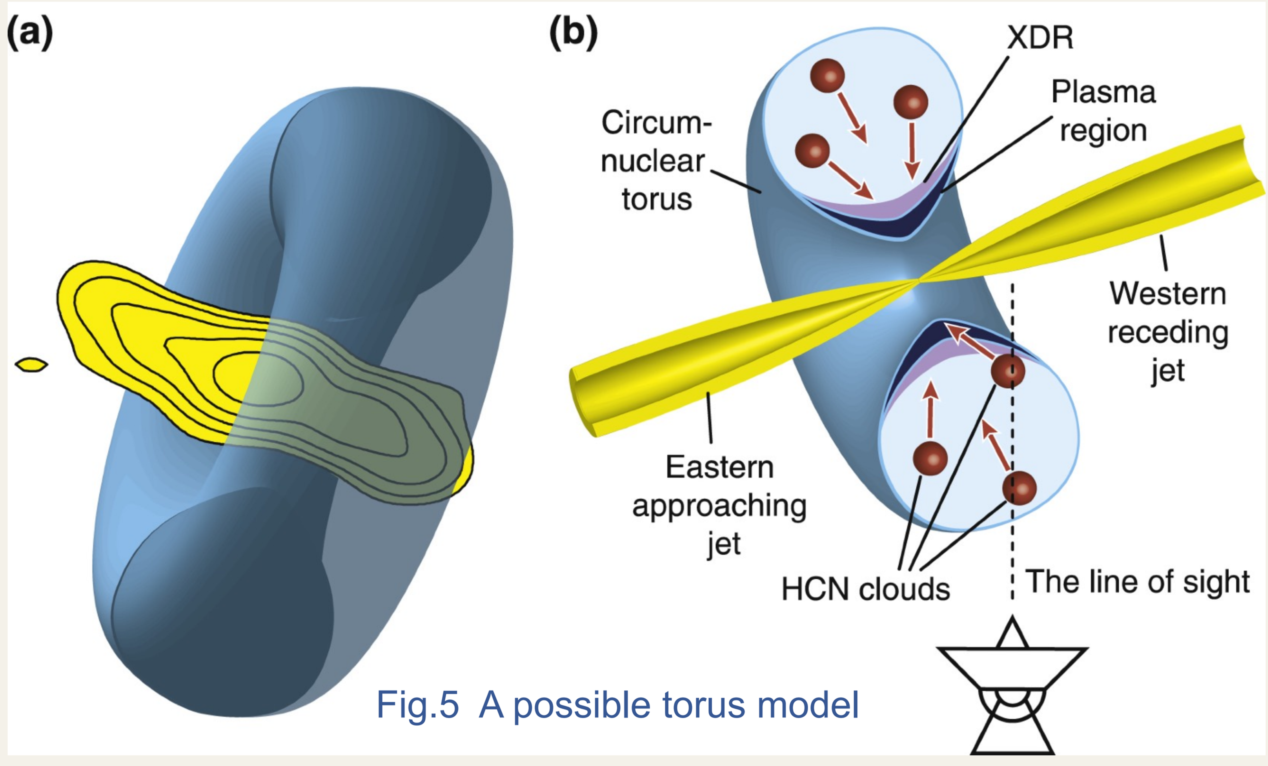

Fig.5 A possible torus model

HCO+ absorption

Broad HCO+ absorption is detected in the velocity range from 1350 to 1850 km s^{-1}, with the blueshifted part having more extended wing than the redshifted part. The HCO+ absorption is spatially resolved on subparsec scales. Concentration of high HCO+ opacity on the western receding jet component strongly suggests that HCO+ absorption is associated with the parsec-scale circumnuclear torus. The broad velocity width could be a complex of some rapid motion with multiple clumpy gas clouds at various different velocities, such as turbulence, interaction, and so on.

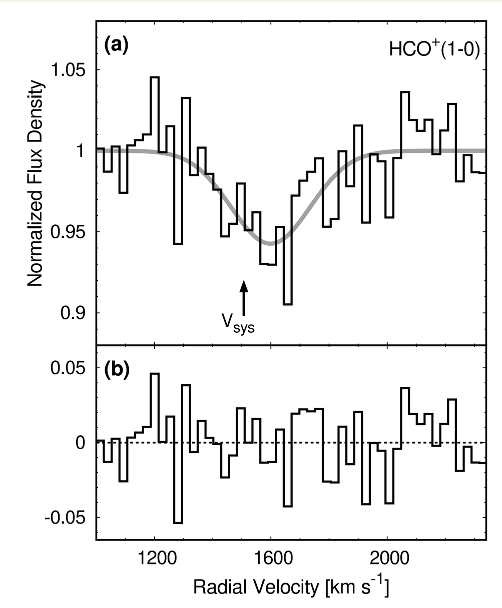

Fig.6 HCO+ spectral profile

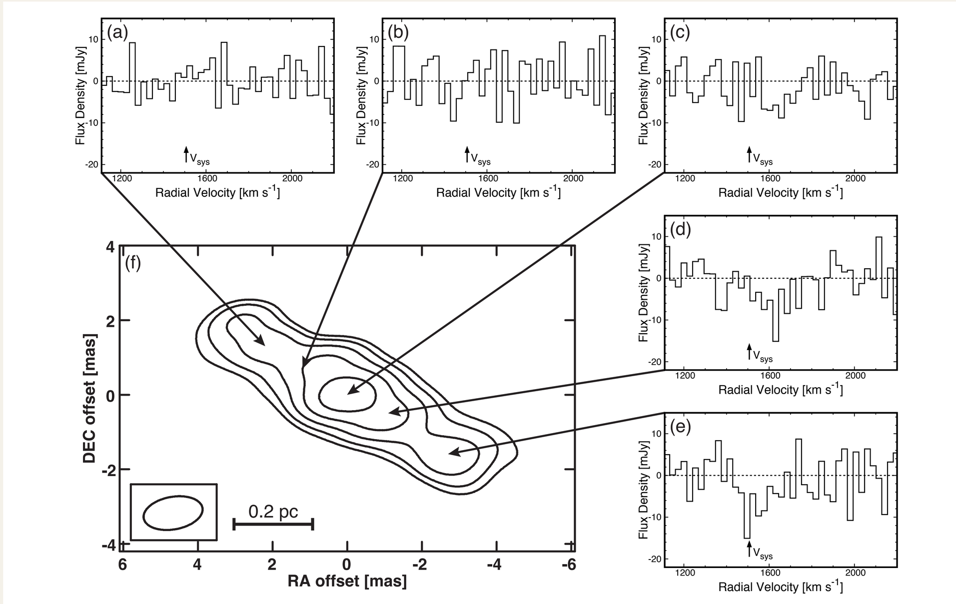

Fig.7 Spectra of HCO+ absorption at different locations

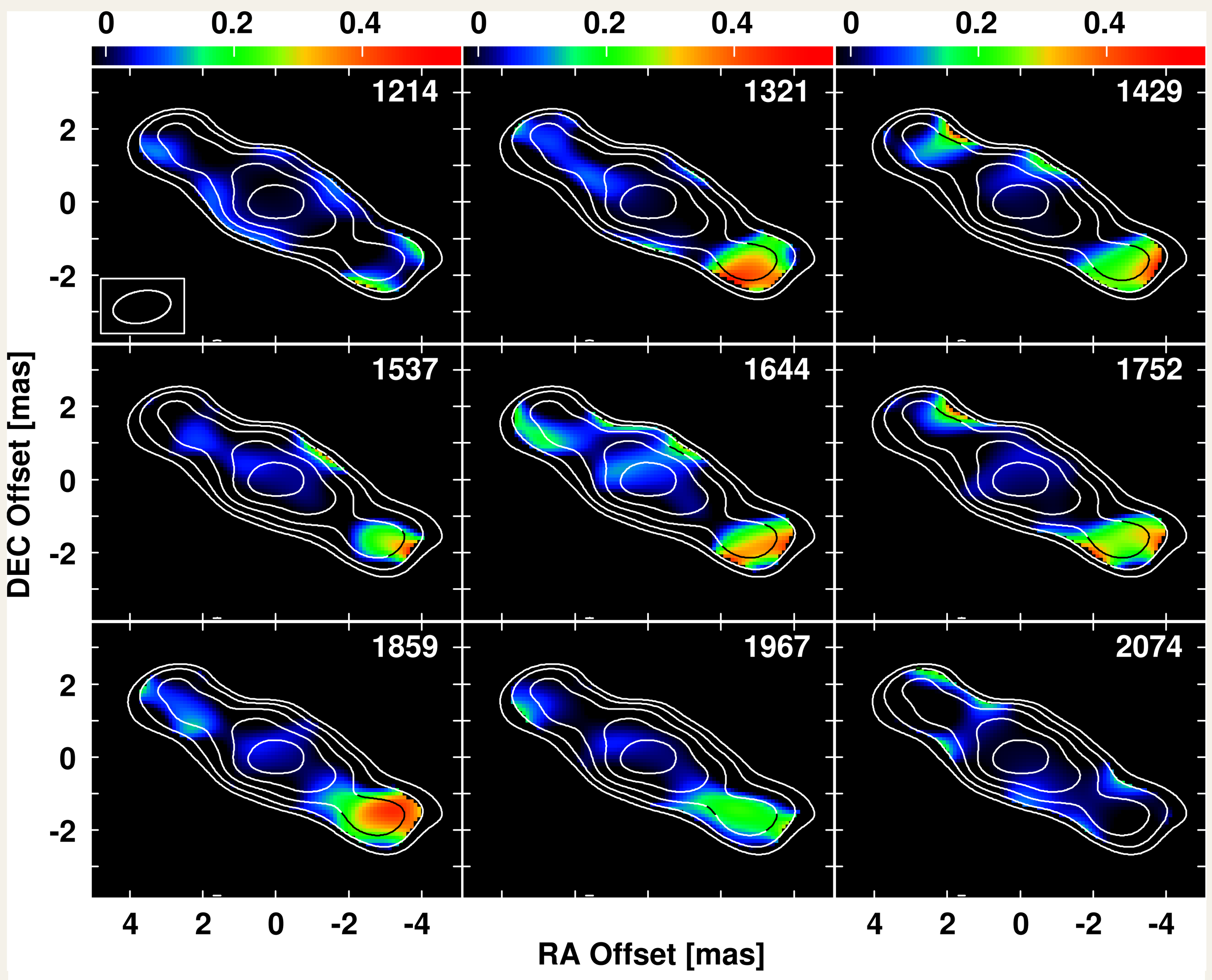

Fig.8 HCO+ opacity channel maps averaging every 108 km s^{-1}