Sub-pc scale mm molecular clouds associated with the torus of NGC1052

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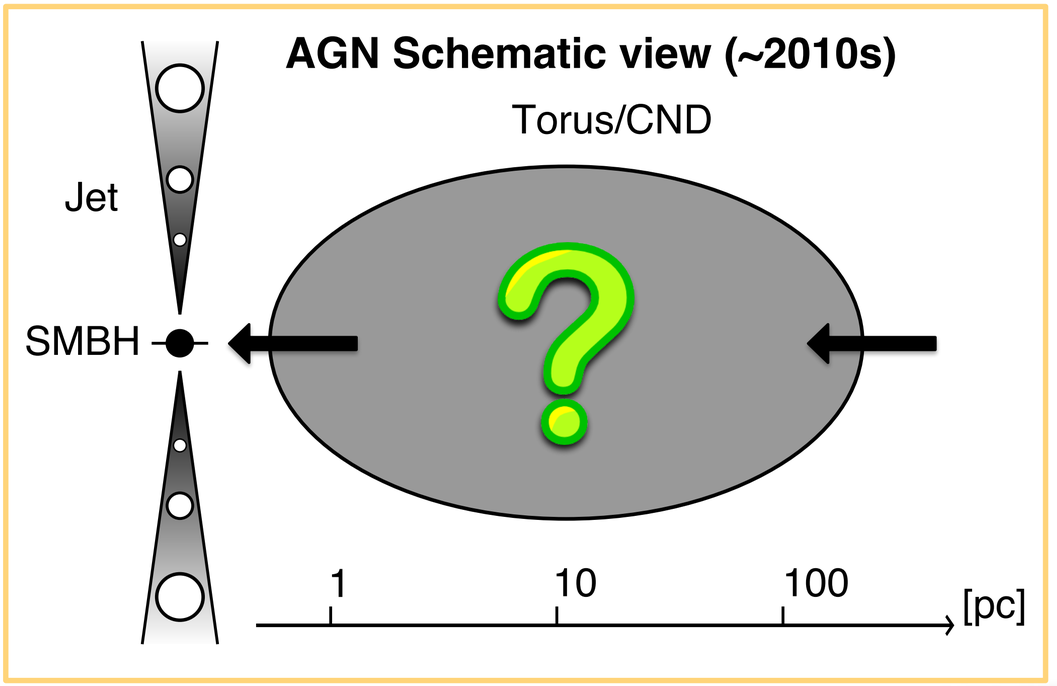
Questions to active galactic nuclei

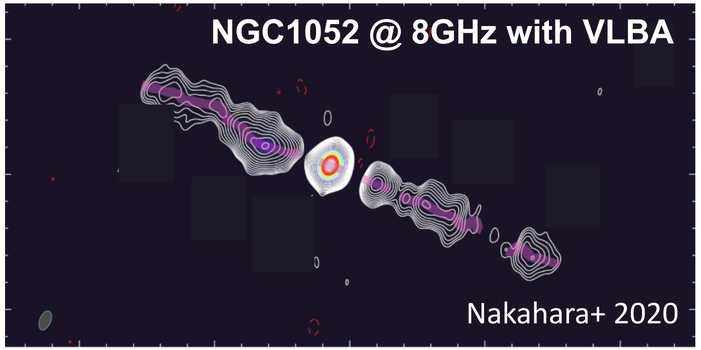
- Active galactic nuclei (AGNs) are powered by the accretion of matter onto a SMBH.
- Mass accretion process is still unclear.
  - What is the accretion matter ? gas, dust, or stars ?
  - Where does the accretion metter come from ?
  - How can the matter lose its angular momentum to accrete ?
  - etc.

High sensitivity VLBI observations of the vicinity of a SMBH is needed to understand the mass accretion process onto a SMBH.

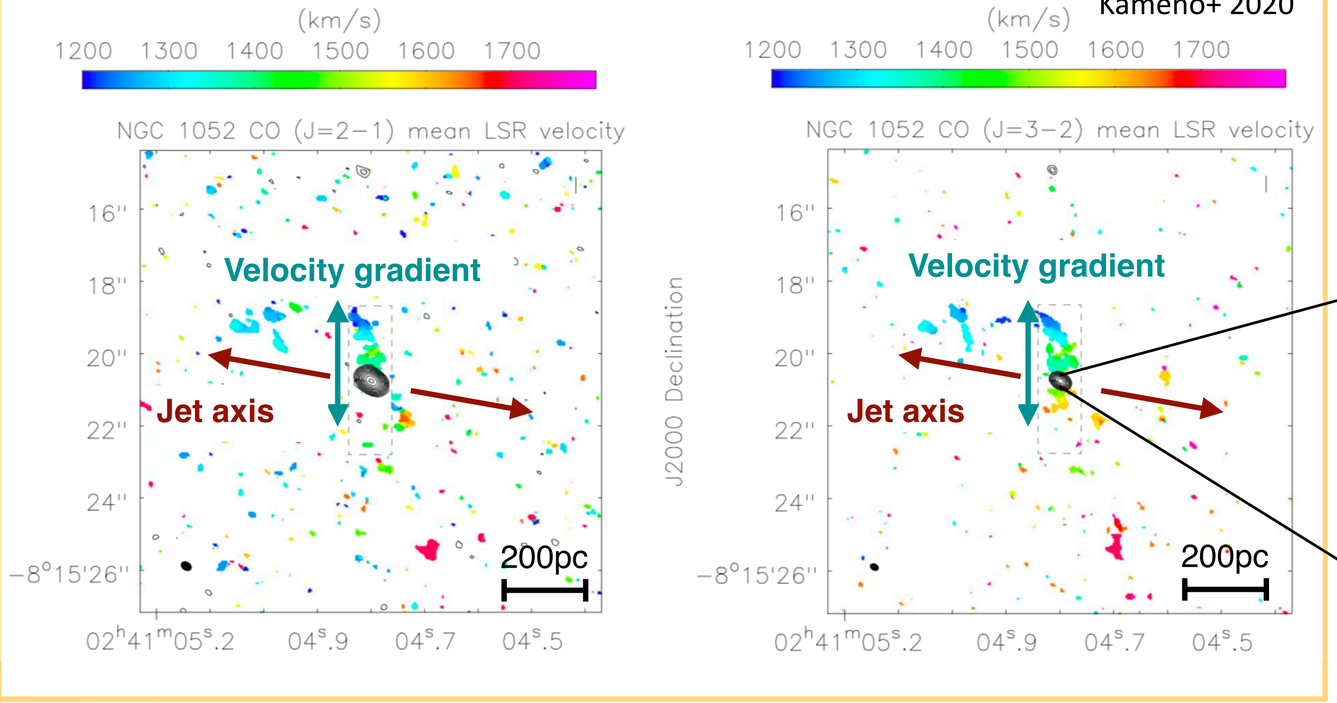


Current schematic view example : NGC1052

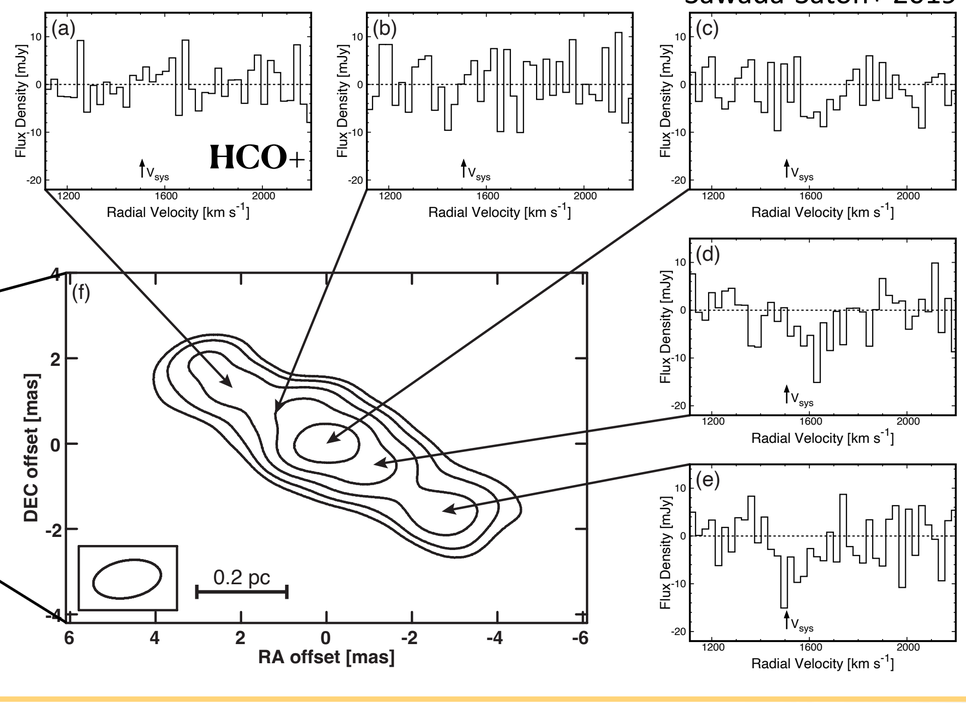
- NGC 1052 : studied well at 0.1—100 pc scales
  - Circumnuclear disk (CND) : ~100 pc scale in CO lines
  - Torus : ~ 1 pc scale in HCN & HCO+ absorption, H_2O maser, ionized gas



with ALMA

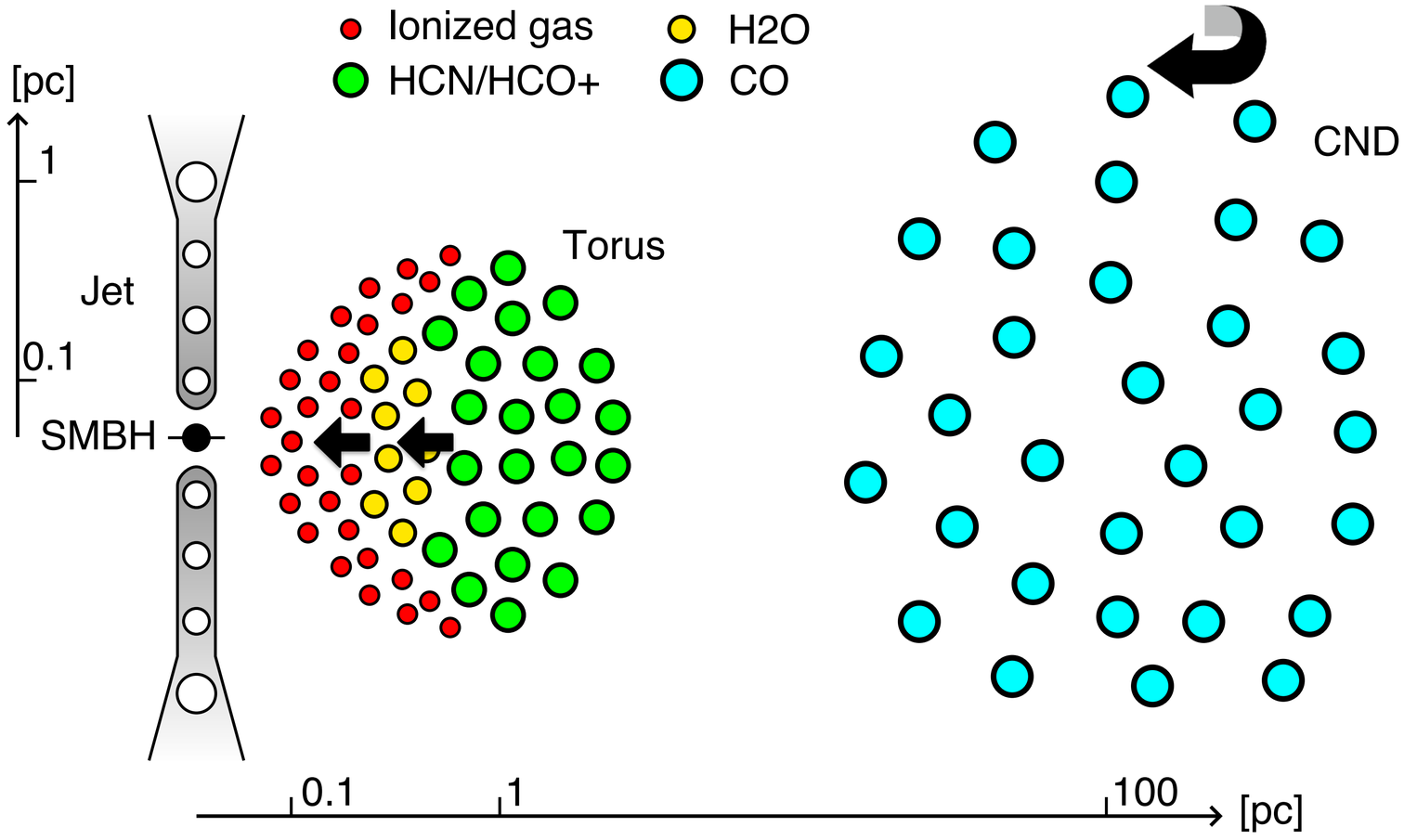


with KVN



Current schematic view example : NGC1052

- CND
  - CO molecular gas
- Torus
  - Multi-layer structure
  - Ionized gas
  - H_2O maser gas
  - HCN/HCO+ molecular gas
- Jet
  - cylindrical => conical
  - Pressure by Torus



Kameno et al. 2001, 2005, 2020; Sawada-Satoh et al. 2008, 2016, 2019; Nakahara et al. 2020

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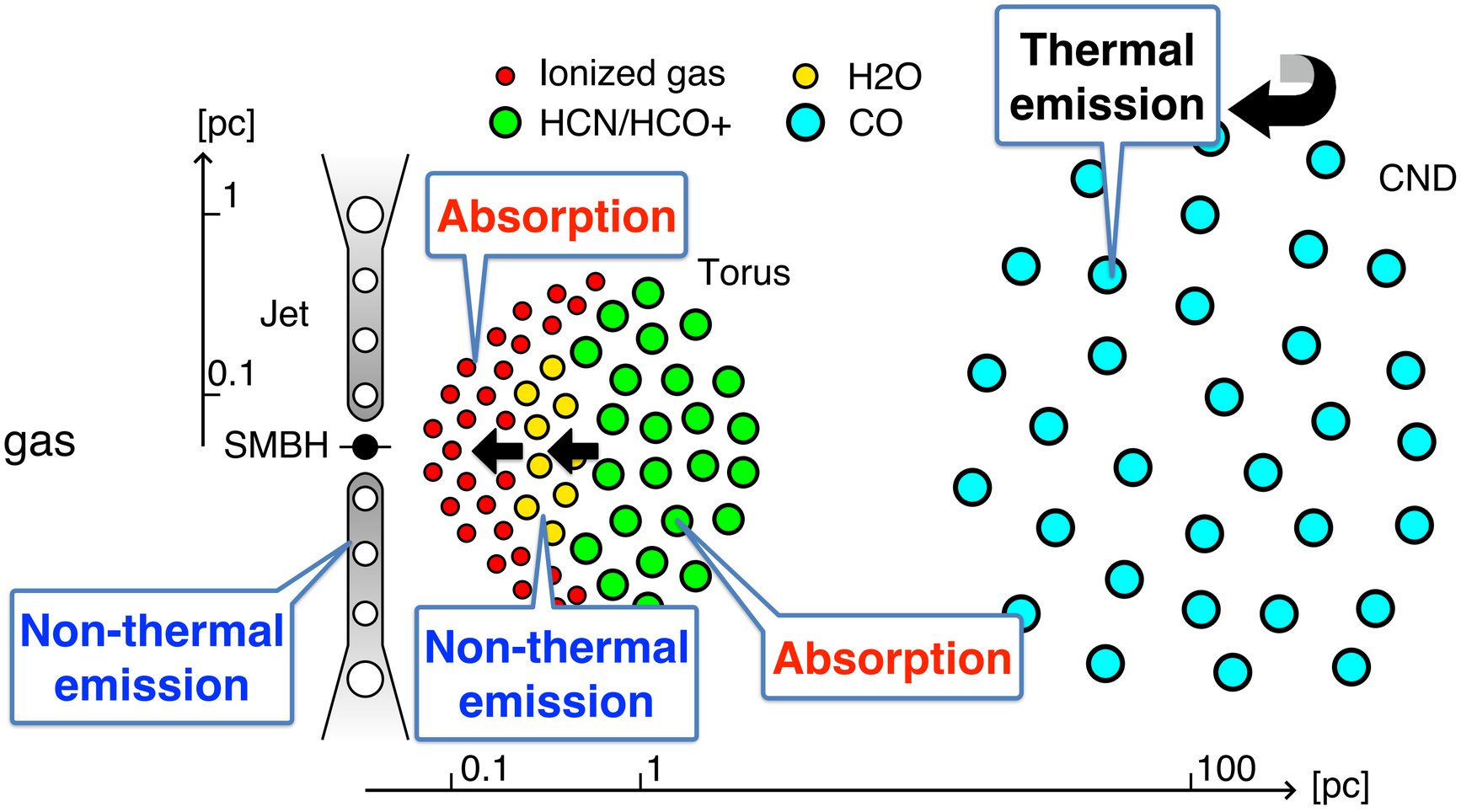

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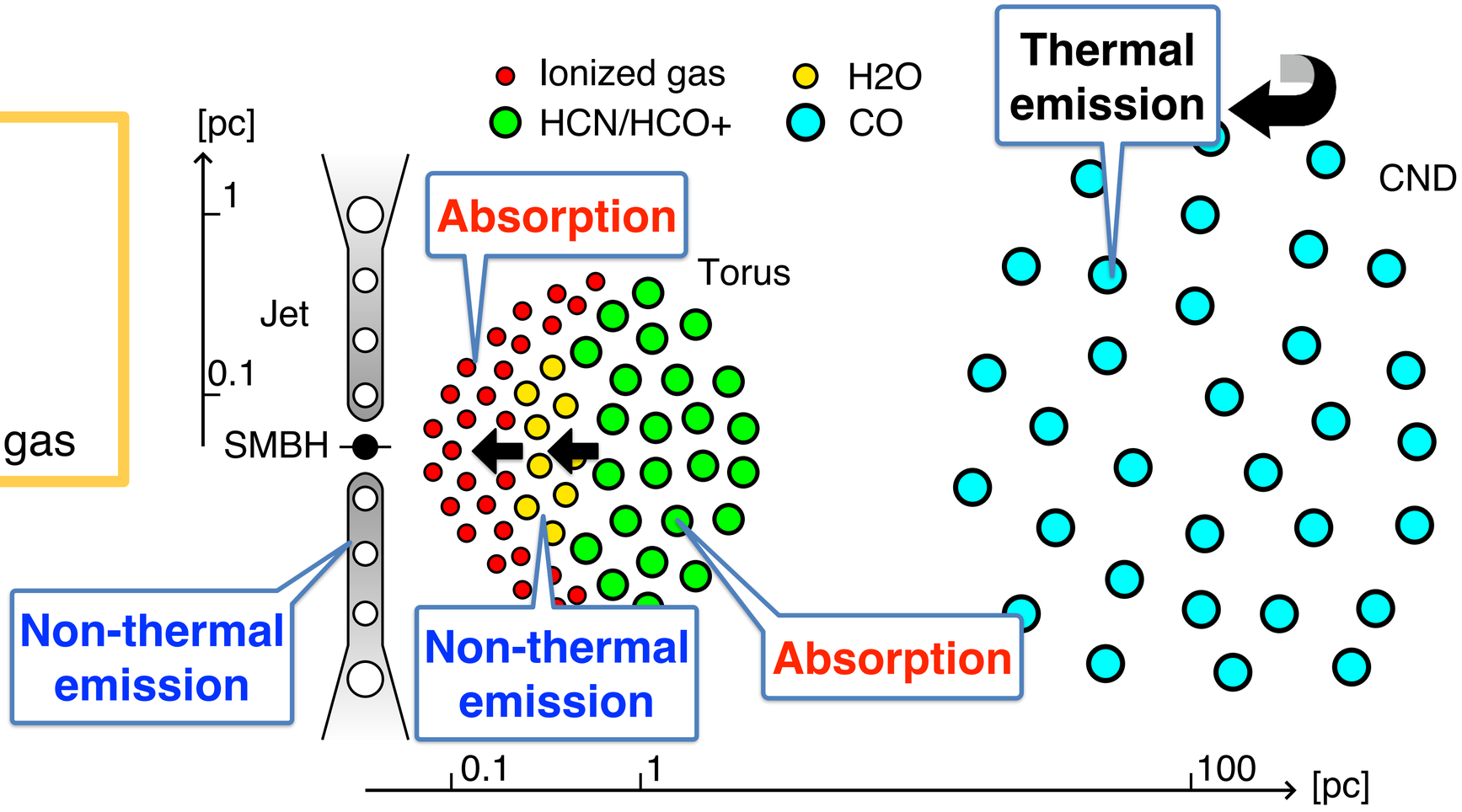

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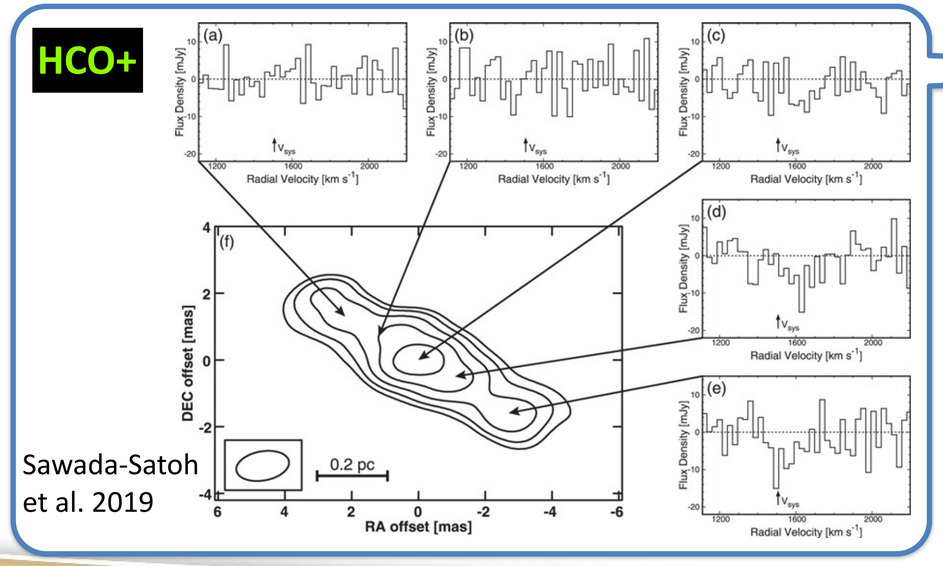
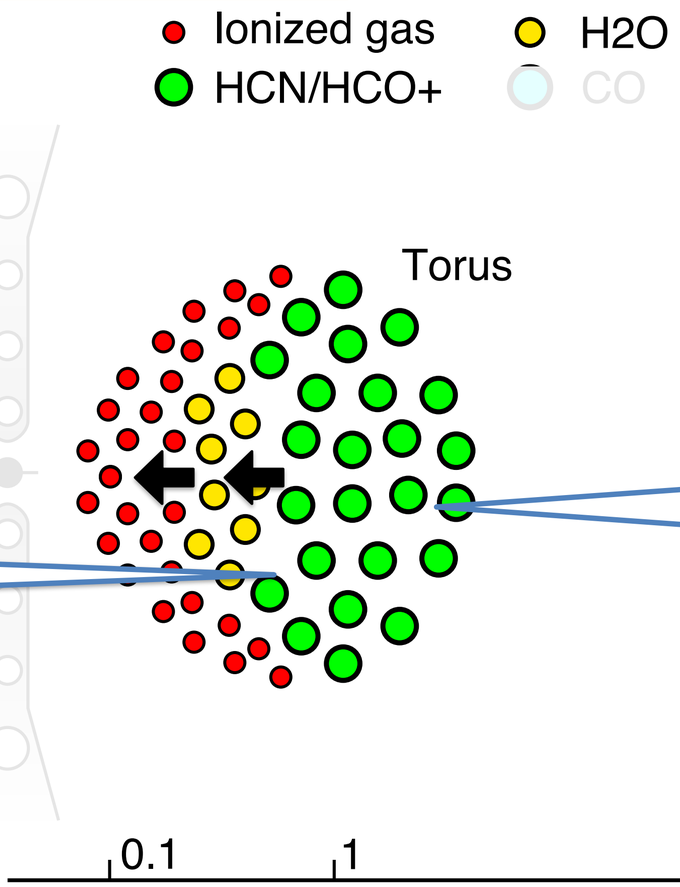
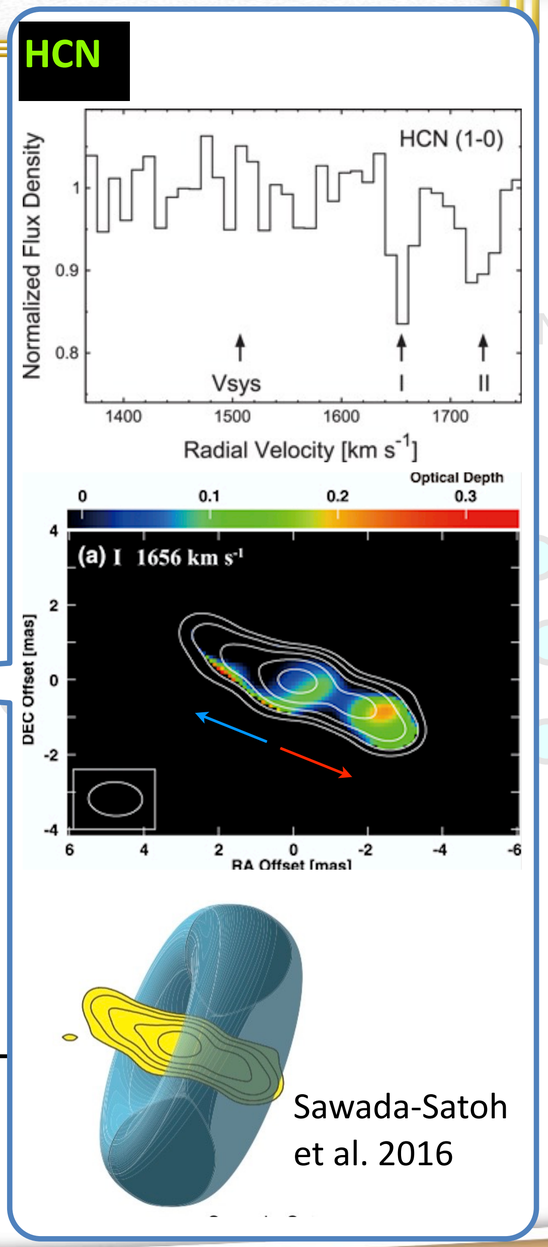
Revealing the torus with VLBI

- HCN/HCO+ **The first imaging on sub-pc scales**
  - Redshifted with respect to Vsys
  - **In absorption**
  - Localized on the receding jet
  - Radius of torus: ~1pc,
  - Size of gas clump: <0.1pc
  - Temperature: ~200K



Sawada-Satoh et al. 2019



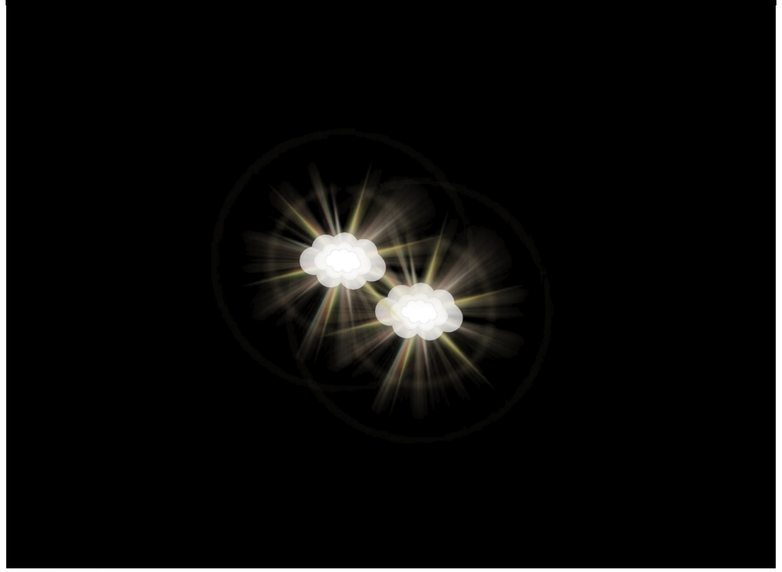


Sawada-Satoh et al. 2016

VLBI in a deep relationship with absorption

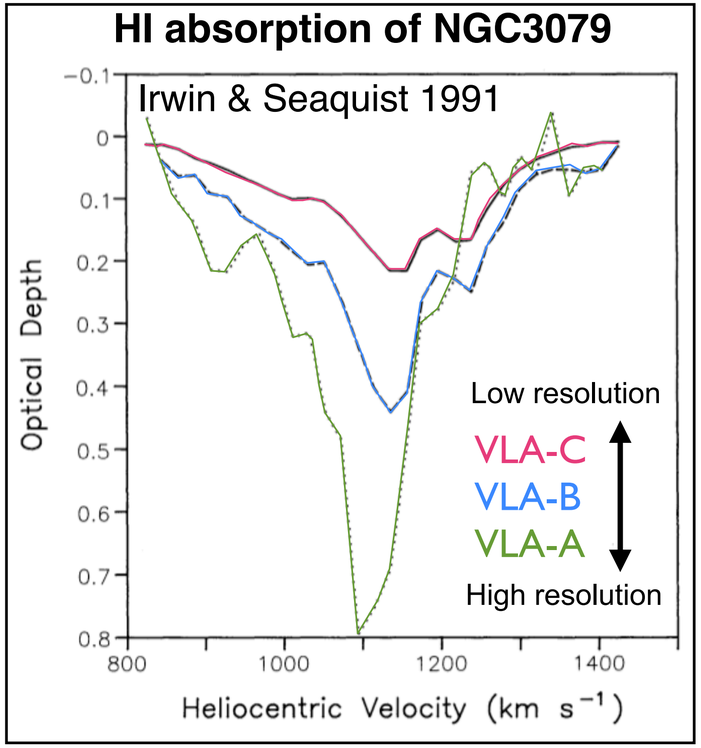
- Thermal gas often exists in galactic centers and is a good probe.
- Its emission has low brightness temperature, hard to detect with VLBI.
- Absorption against bright synchrtron emission is detectable.
- Compact absorbers need narrow VLBI synthesized beams.

Gas can emit thermal radiation, but too weak for VLBI detection.



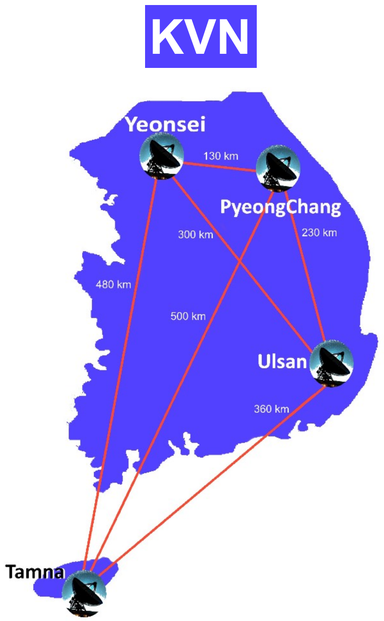
VLBI reveals gas via absorption against bright back ground.

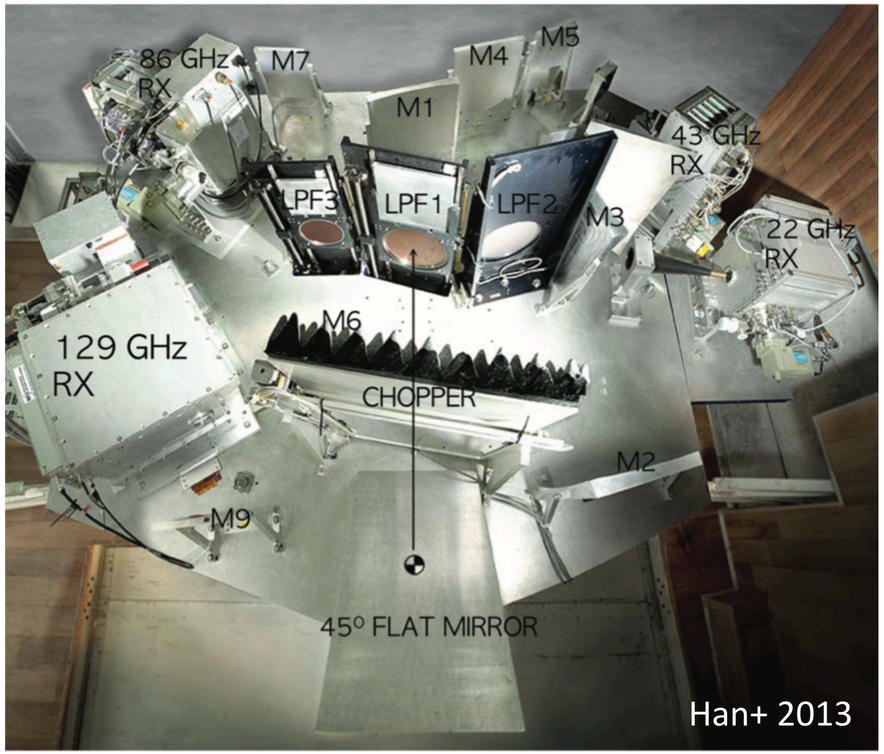
HI absorption of NGC3079

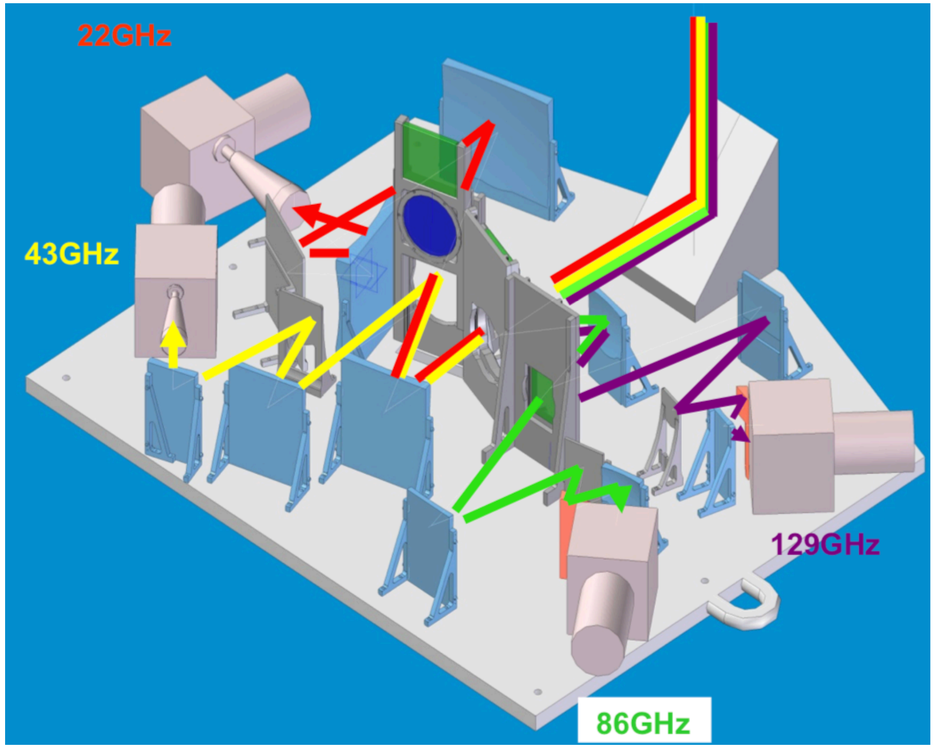


Why KVN ?

- Designed for high-resolution observations at mm wavelengths
- Capable of simultaneous observations at 22/43/86/129 GHz, enables effective atmospheric phase correction
- Improves coherence and image quality in high-frequency VLBI via FPT

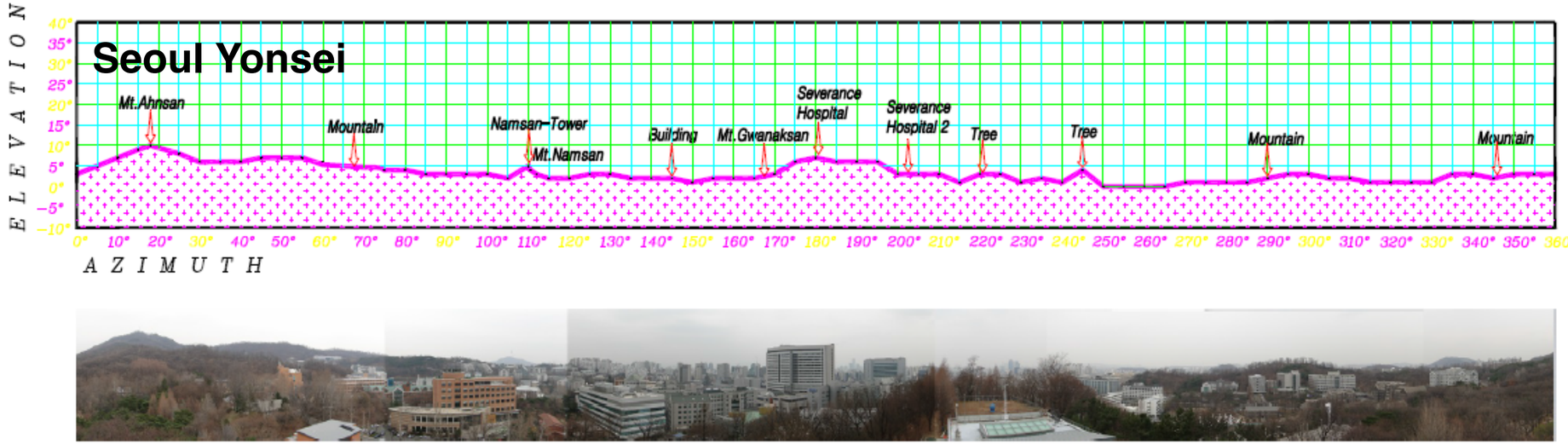




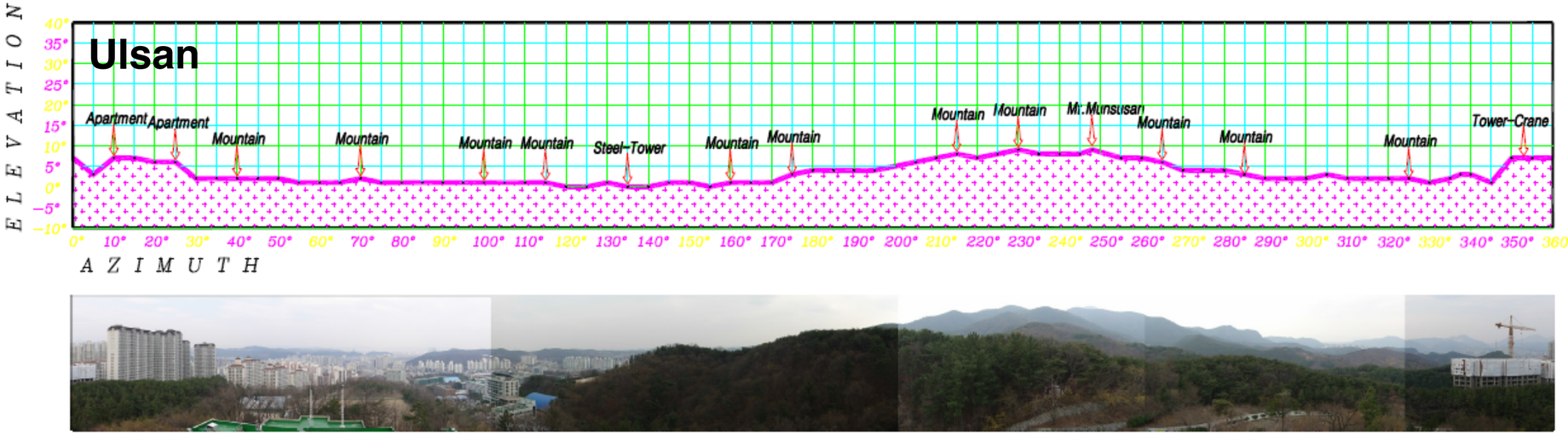


Antennas located in urban areas

Seoul Yonsei



Ulsan



The power of FPT

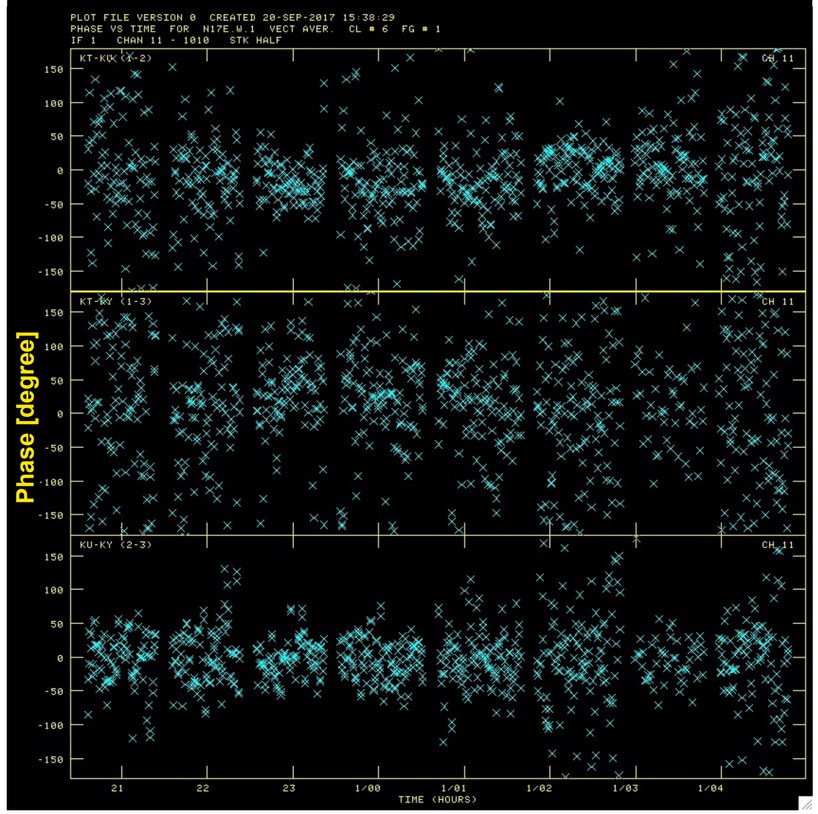
- The case of our KVN observation (22 & 88 GHz)
  - The rms phase fluctuation is reduced by ~50% for all of three baselines.

Tamna & Ulsan

Tamna & Yonsei

Ulsan & Yonsei

Calibrated visibility phases @ 88 GHz without FPT



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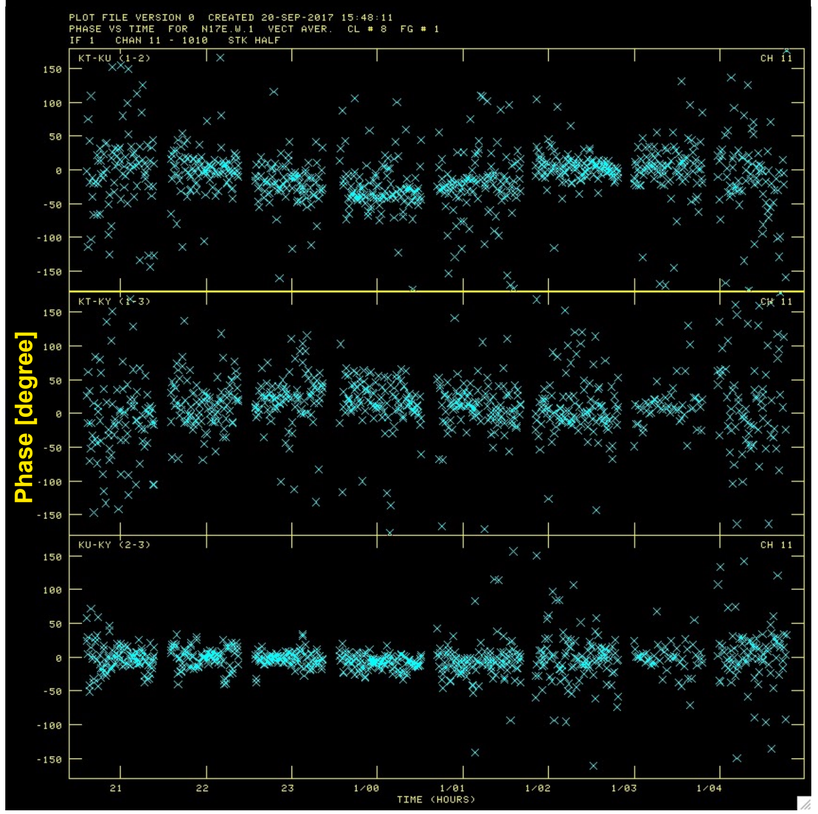
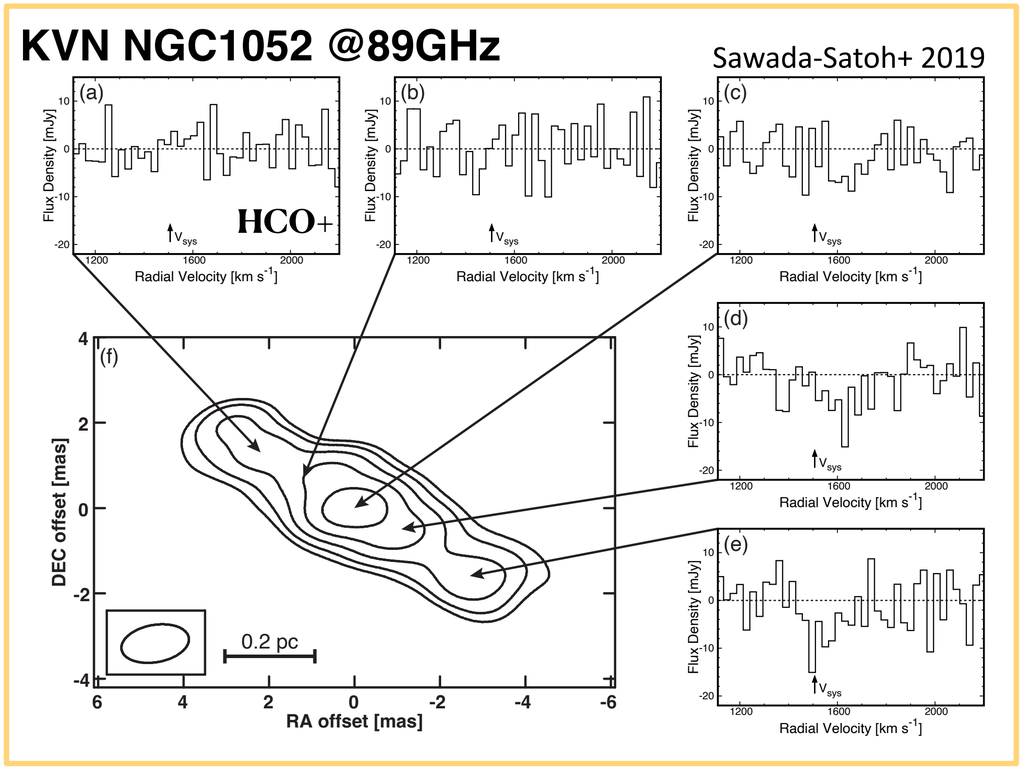
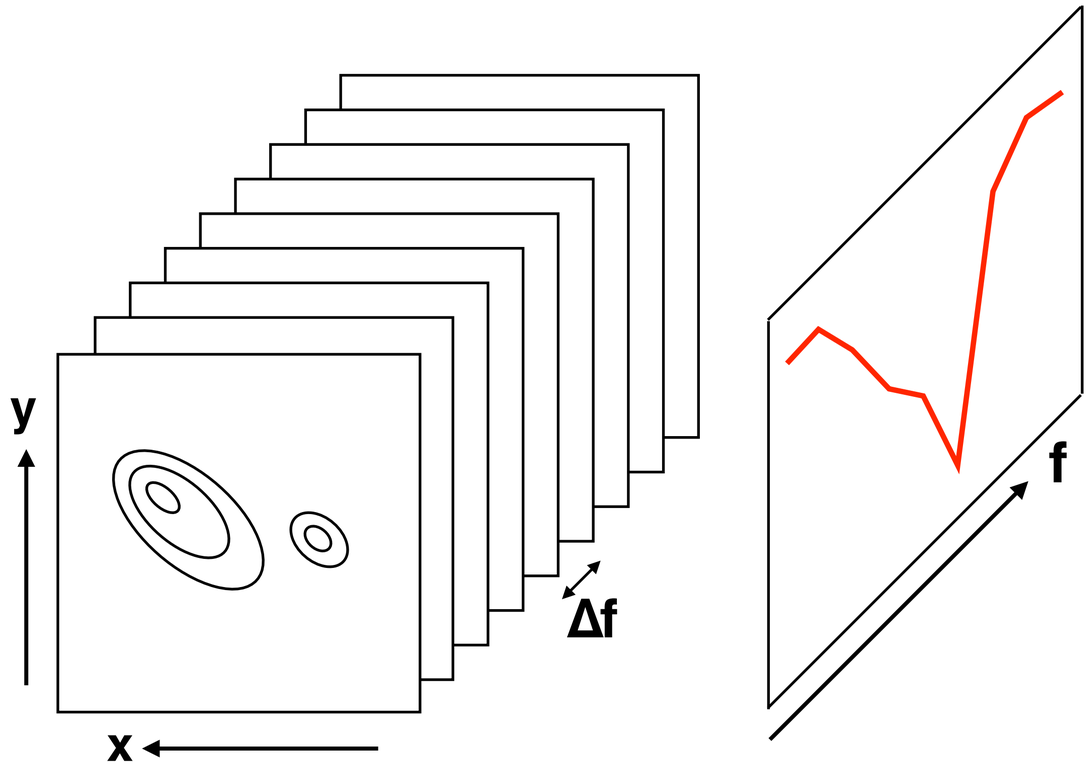


The power of FPT

- KVN's high sensitivity enabled to make a absorption-line channel map.
  - Significant detection of continuum emission at all Δf channels.





Summary

- High sensitivity VLBI observations of the vicinity of a SMBH is essential for understanding the mass accretion process onto a SMBH.
- A simultaneous multi-frequency receiving system and FPT technique can improve coherence and image quality in high-frequency VLBI.
- Applying FPT to our KVN data at K/W bands, the rms fluctuation of visibility phase at W band was reduced by ~50% for all of three baselines.
- Taking advantage of KVN's high sensitivity by FPT, molecular absorption lines in the AGN region were spatially resolved on sub-pc scales.
- To explain our KVN results of NGC 1052, we propose a circumnuclear torus model.