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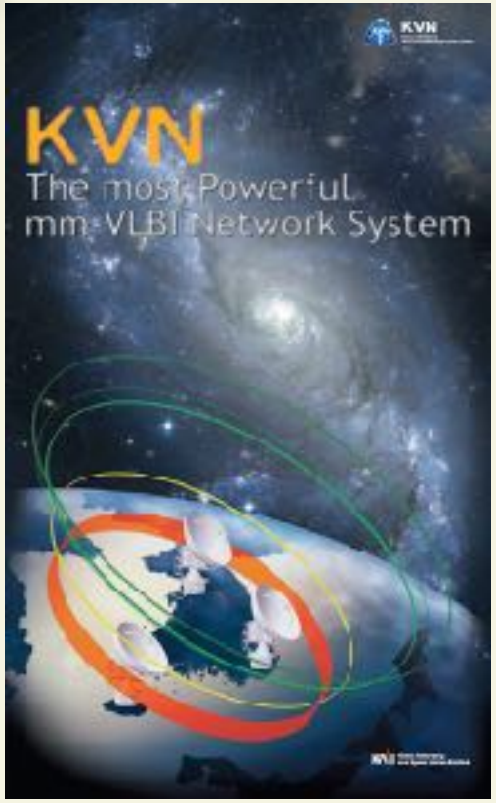
Molecular Absorption Lines in the Circumnuclear Region



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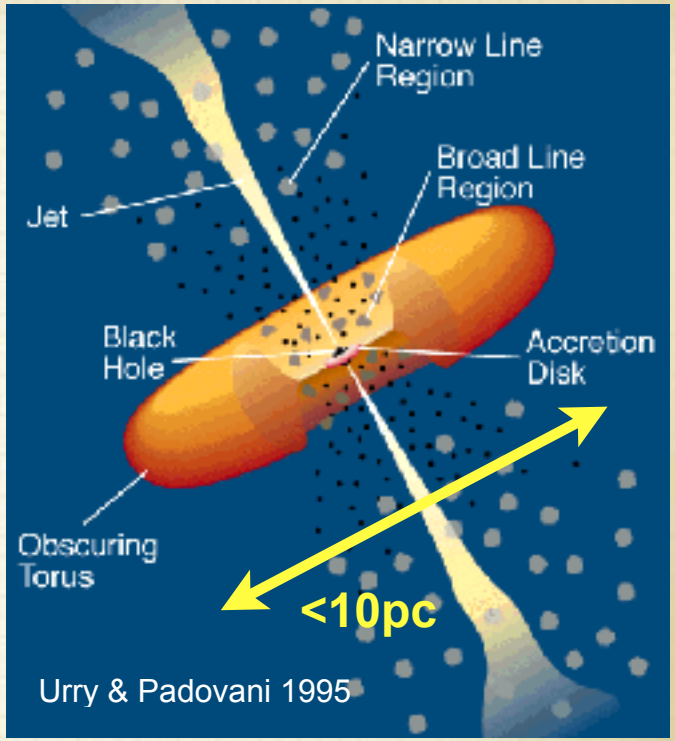
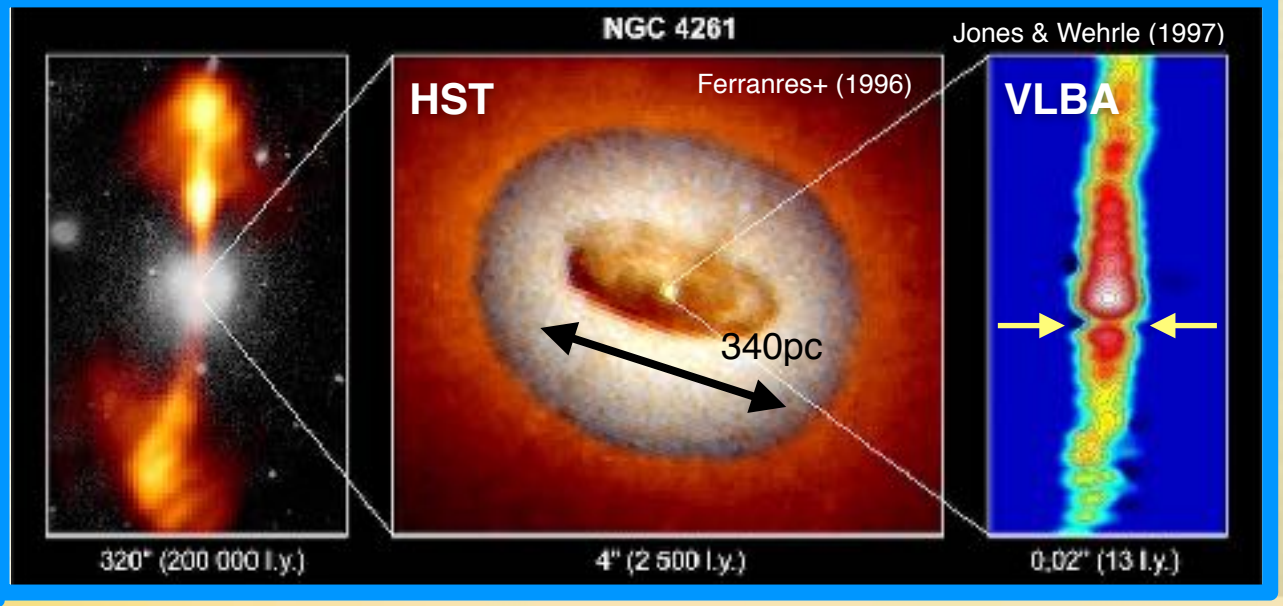
Background & Motivations

- AGN circumnuclear torus
  - Fuel tank of mass accretion onto SMBH
  - Invented by astronomers, to explain Seyfert 1 & 2
  - The size : < 10pc
- How can we confirm it ?
  - Requirement of 1 milliarcsec (mas) resolution to image
  - VLBI can acheive it



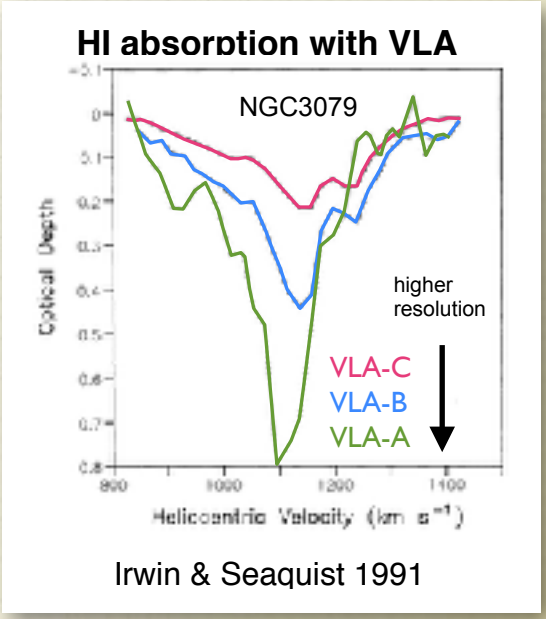
AGN torus/disk & VLBI

- 1990s mid ~ :
  - A pc-scale masering molecular disk surrounding a SMBH.
  - A pc-scale dense absorbing gas torus.
- 2000s ~ :
  - A torus model with several physical-phase layers inside.



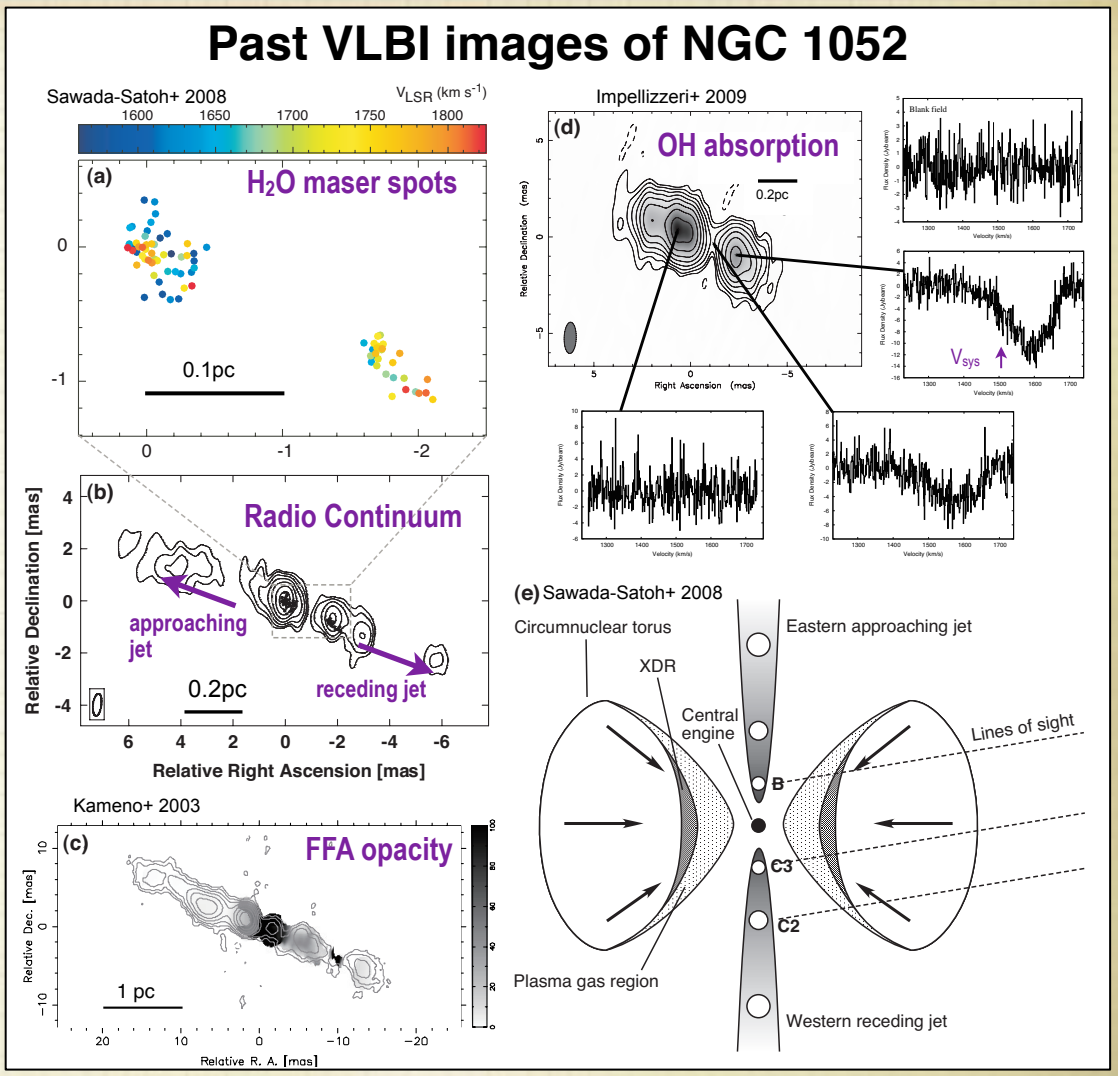
Molecular lines & VLBI

- Molecular gas in AGN region
  - Important clues to study AGN fueling
  - Compact (pc scale)
  - High column density ($10^{23\text{-}24}$ cm^{-2})
- Advantages of VLBI for absorption
  - Can display thermal absorption in silhouette against a background synchrtron emission.
  - Not detect the thermail emission
    - No contamination of emissions
  - Sensitive to detect the compact and dense absorbing gas
    - beam size smaller, filling factor larger



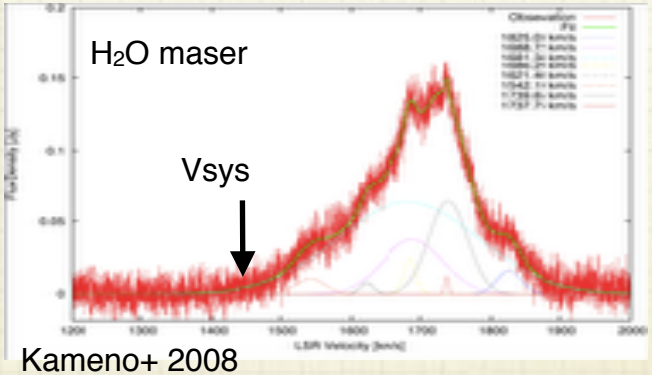
The target NGC 1052 (1)

- A nearby radio gal.
  - AGN : LINER/Sy2
  - Two-sided radio jet
- AGN torus suggested
  - Several layers
  - Free-free absorption (FFA) due to plasma
  - H_2O maser
  - OH absorption
  - Redshifted from V_{sys}
    - Ongoing infall ?

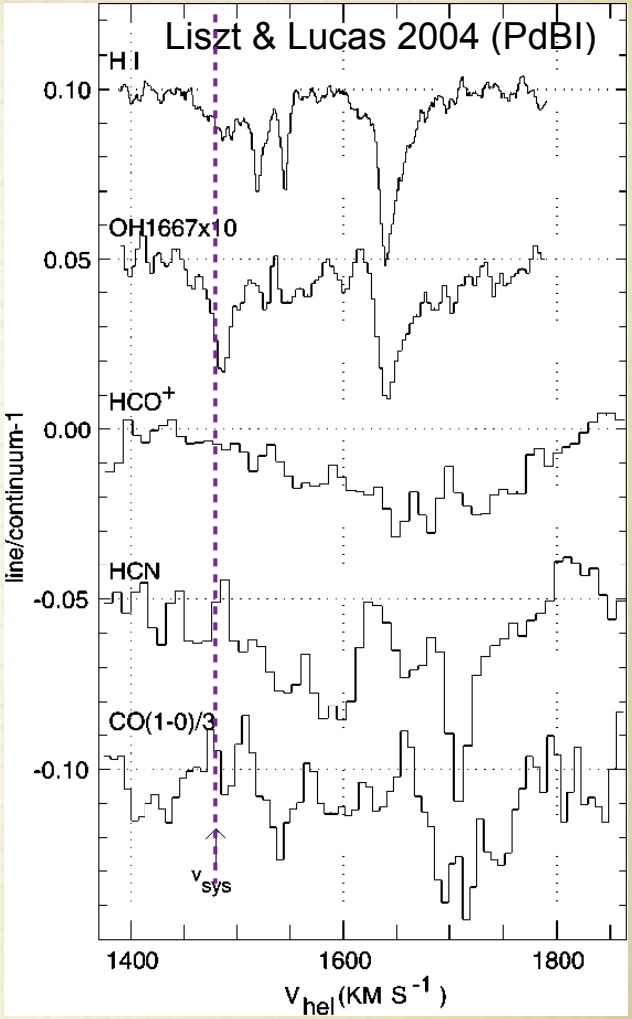


The target NGC 1052 (2)

- Molecular absorption at mm band
  - HCO+(1-0), HCN(1-0), CO(1-0)
  - Velocity: 1400-1800 km/s
  - Redshifted with respect to Vsys
    - Similar to OH and H_2O
    - Infall from the torus ? or, another motion ?
    - Location of the absorption is a key !
      - **Need a high resolution image**

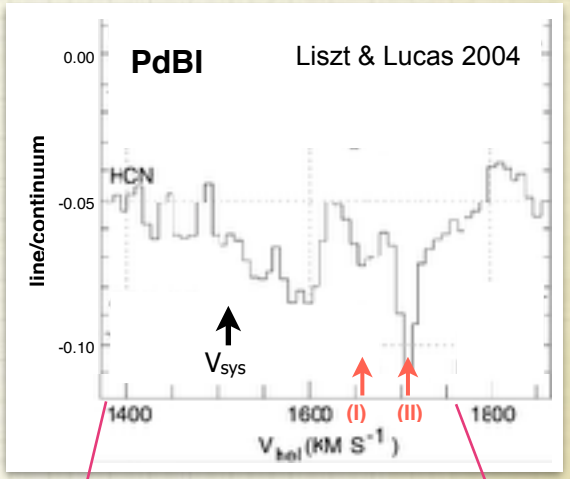


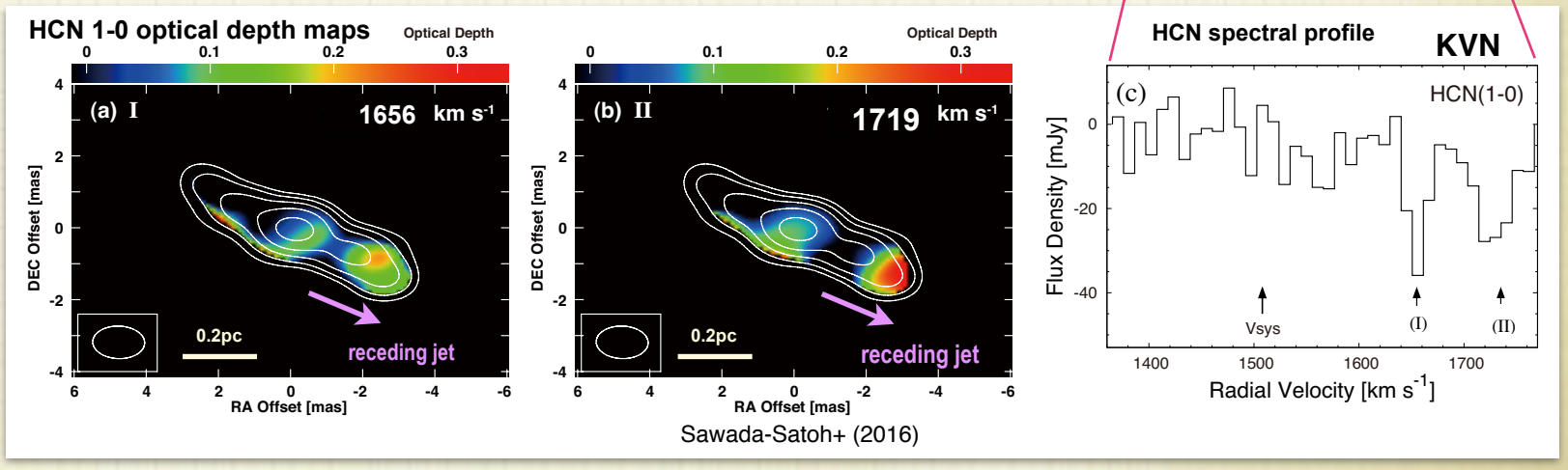
Kameno+ 2008



HCN (1-0) absorption

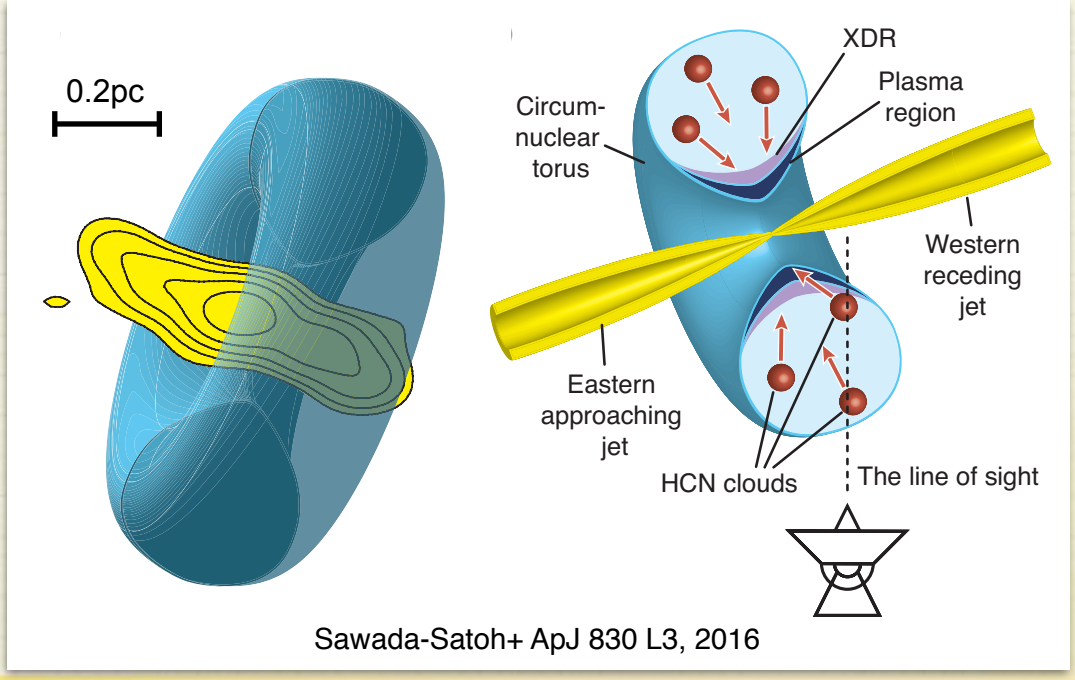
- The first VLBI map of HCN (1-0) (Sawada-Satoh+ ApJ 830 L3, 2016)
  - Two redshifted features, detected.
  - The features around V_{sys}, not detected.
  - Localized on the receding jet side.
  - A depth of >10%, deeper with PdBI





A possible model

- Several layers + clumpy HCN clouds (Sawada-Satoh+ 2016)
  - High opacity localized on the receding jet => Inclined torus
  - At least two narrow absorptions => Inhomogeneous, clumpy
  - Redshifted velocity => Ongoing infall onto SMBH



Sawada-Satoh+ ApJ 830 L3, 2016

Physical properties

Column density of HCN 1-0 absorption

Sawada-Satoh+ ApJ 830 L3, 2016

Label	V_p [km/s]	V_p-V_{sys} [km/s]	Δv [km/s]	N_{HCN}(T=100K) [10^{14} cm^{-2}]	N_{HCN}(T=230K) [10^{14} cm^{-2}]
I	1656	149	31.7	9.5	50
II	1719	212	52.9	20	101

- $N(H_2)$: 10^{24}-10^{25} cm^{-2} (HCN-to-H_2 ratio of 10^9; Smith & Wardle 14)
  - 1-2 order higher than N(e) by FFA opacity (~10^{23}; Kameno+ 01)
- Infall rate : ~0.05-0.5 M_{sun}/yr $\dot{M} = f_v R_{\rm in} N_{\rm H} m_{\rm H} V_{\rm in} \Omega$
  - Comparable to the rate estimated from X-ray luminosities (~0.04 ; Wu & Cao 06)

Summary

- Conducted KVN observations of the HCN(1-0) & HCO+(1-0) absorption in NGC 1052.
- Our HCN results are naturally explained by an AGN tors
  - Two HCN absorption features are identified at redshifted velocities.
  - Reached a depth of >10%, deeper than that of PdBI.
  - Found N(H_2) of 10^{24}--10^{25} cm^{-2} (HCN-to-H_2 ratio of 10^9), assuming a Tex of 100--200 K
  - High opacity of HCN absorption localized on the receding jet
  - HCN gas is clumpy, and traces ongoing infall onto SMBH.
- The first VLBI detection of HCO^+(1-0) absorption
  - A broad absorption feature (~500km/s), unlike HCN
  - Localised on the receding jet side. Torus ?