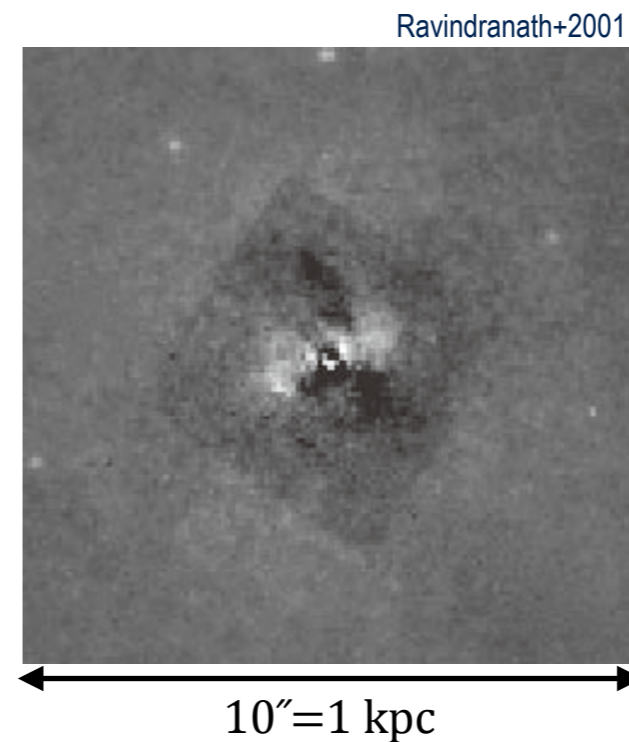
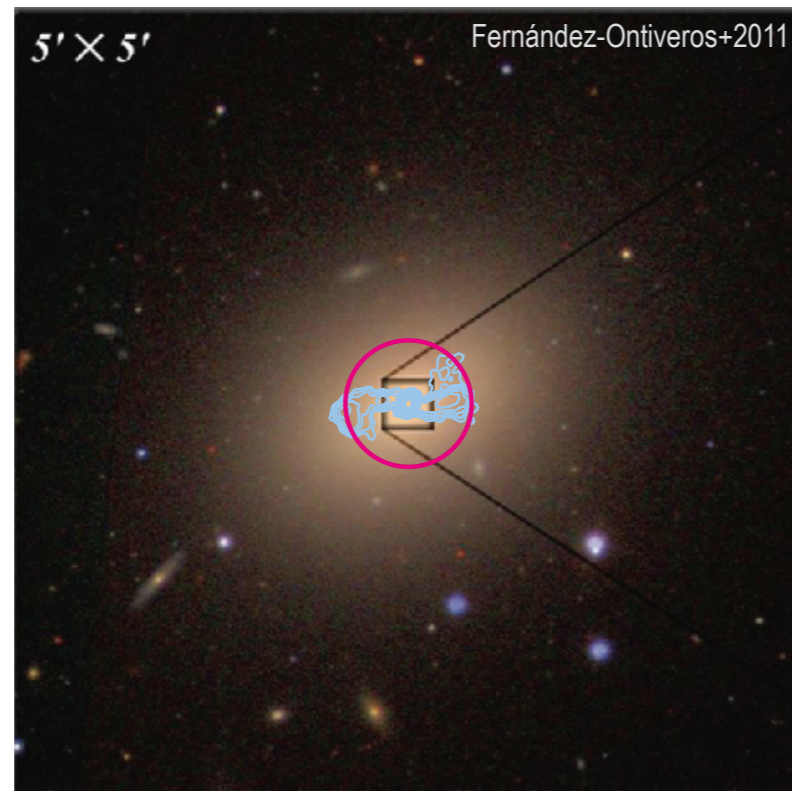


Molecular torus in the radio galaxy NGC 1052

Seiji Kameno (NAOJ / Joint ALMA Observatory) collaborated with
V. Impellizzeri, D. Espada, S. Martin, S. Sawada-Satoh, N. Nakai, H. Sugai, Y. Terashima, K. Kohno, L. Minju



Mass accretion in AGN

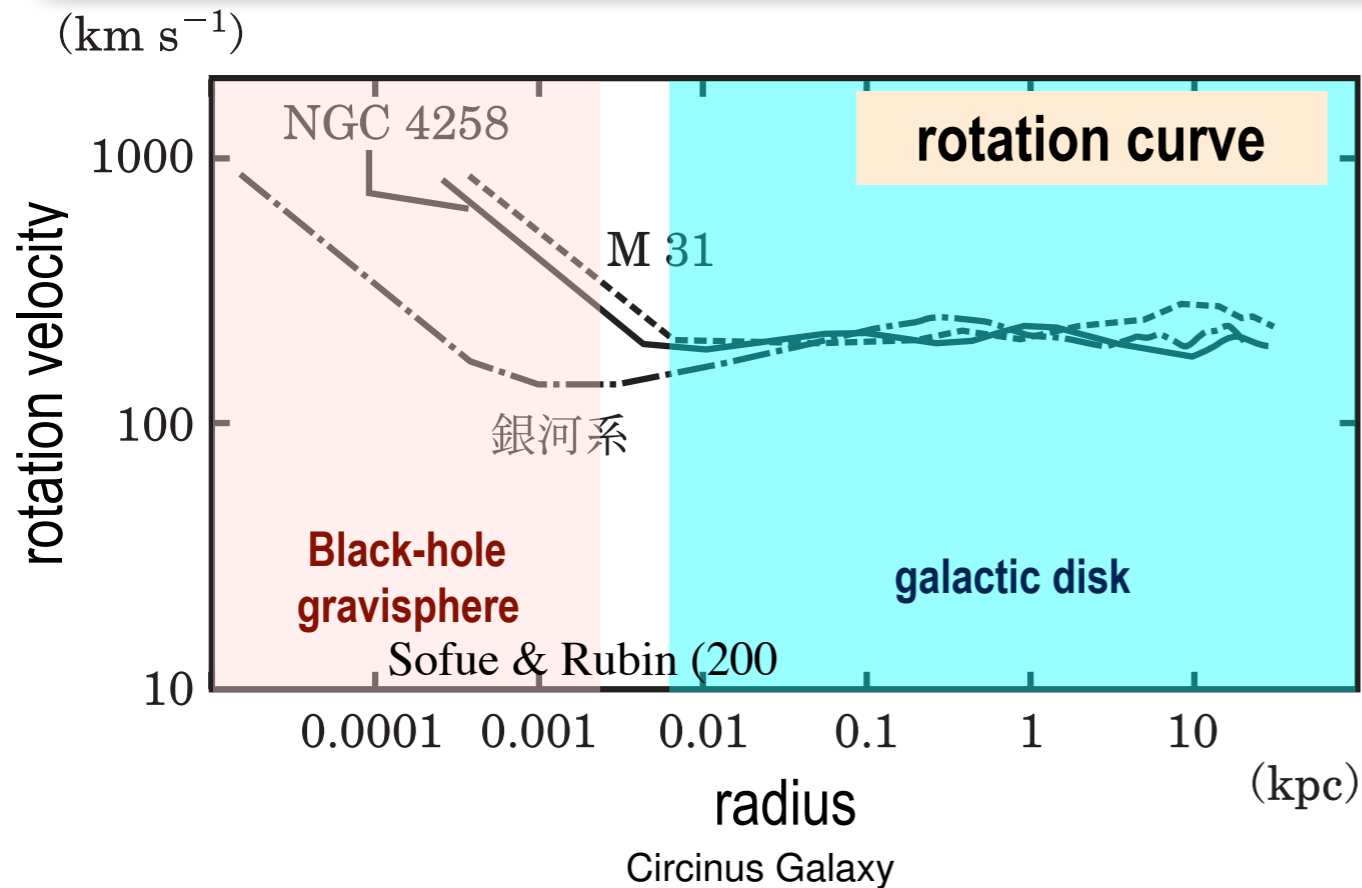


Artist's impression from NASA site

- Energy source $L = \eta \dot{M} c^2$
- Evolution of SMBH

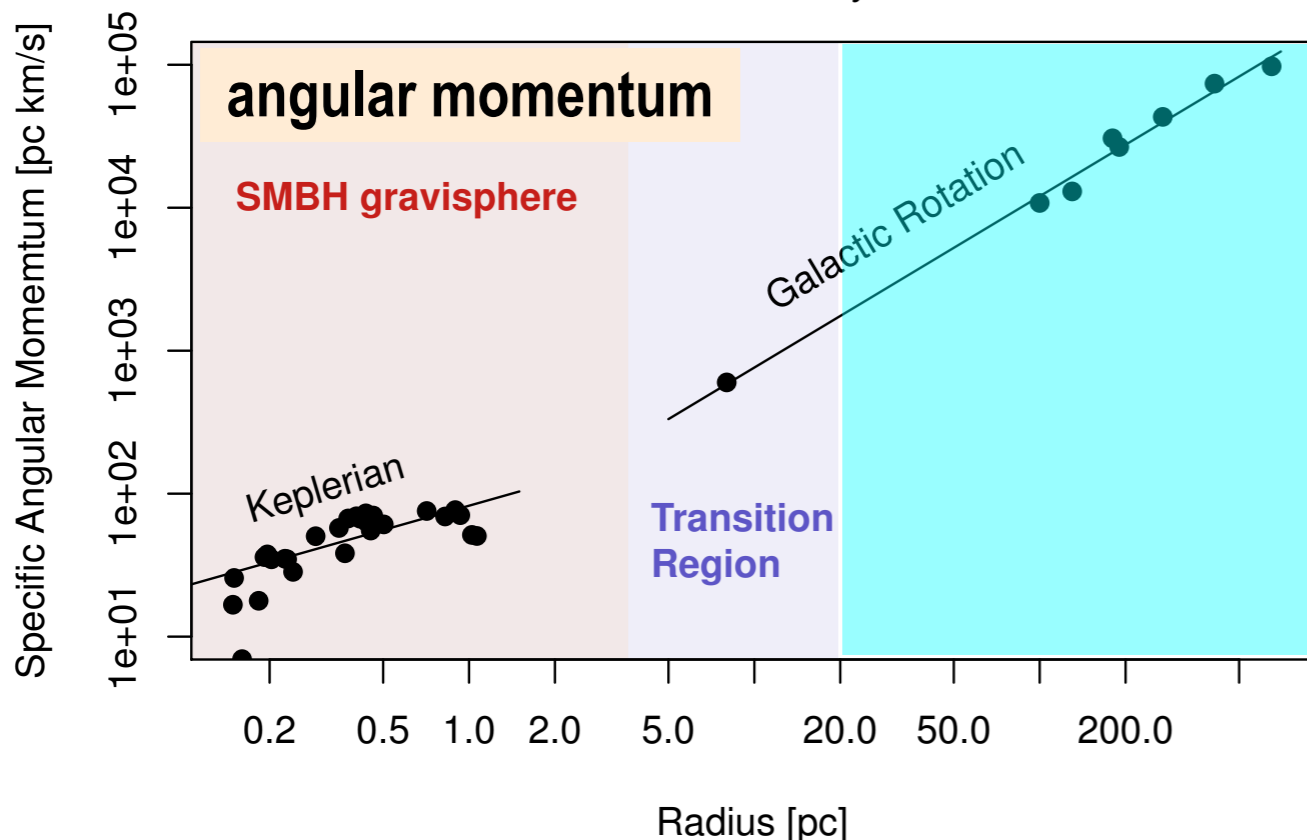
What controls the accretion rate?

Mass accretion from galactic disk into the center



The Transition Region between SMBH gravisphere (a.k.a. Sol) and galactic disk

- $M(R) \sim M_{BH}$
- $1 \text{ pc} < R < 10 \text{ pc}$
- Change in the rotation curve
- Change in the rotation axis



What is happening in the transition region (edge of Sol)?

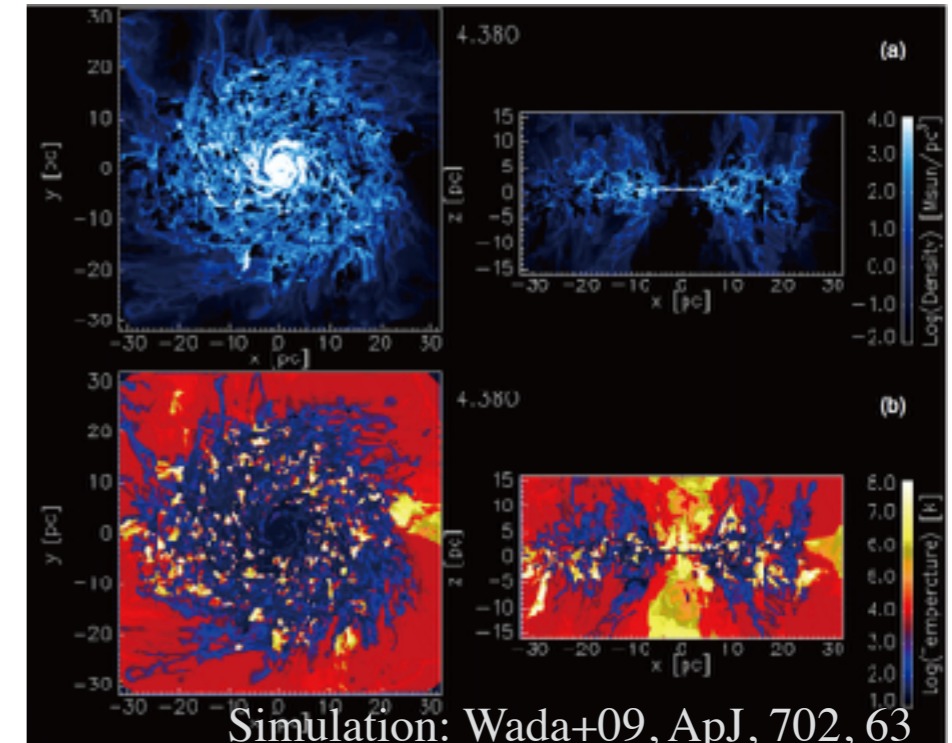
- ~ 0.1 arcsec in nearby AGNs
- VLBI resolution is crucial.
- Now ALMA is accessible there!

Parsec-scale mass accretion mechanism in AGN

Question: What is the key mechanism of angular momentum transfer?

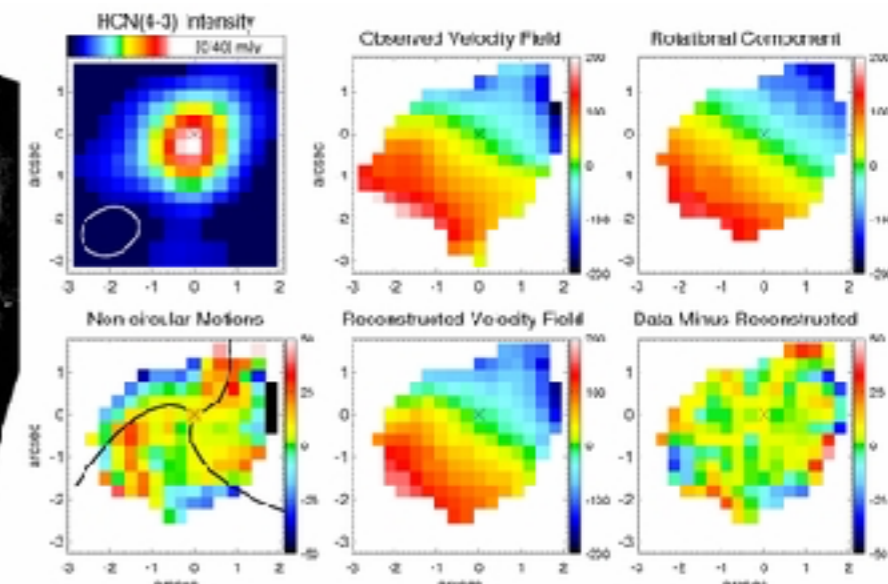
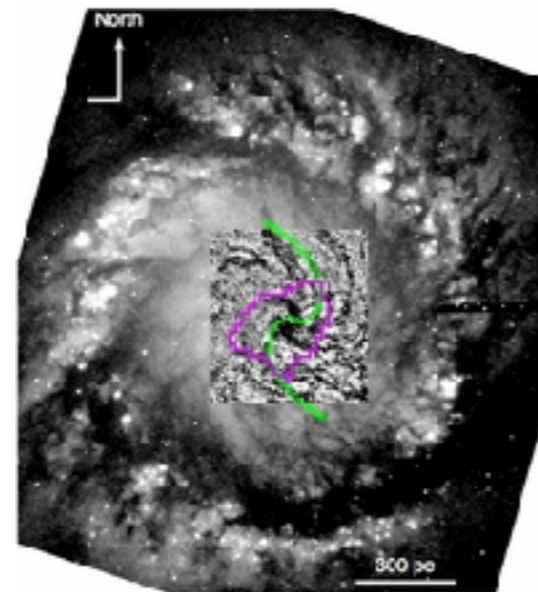
Starburst-AGN connection

- nuclear starburst
- turbulence by supernovae



What about non-starburst AGNs?

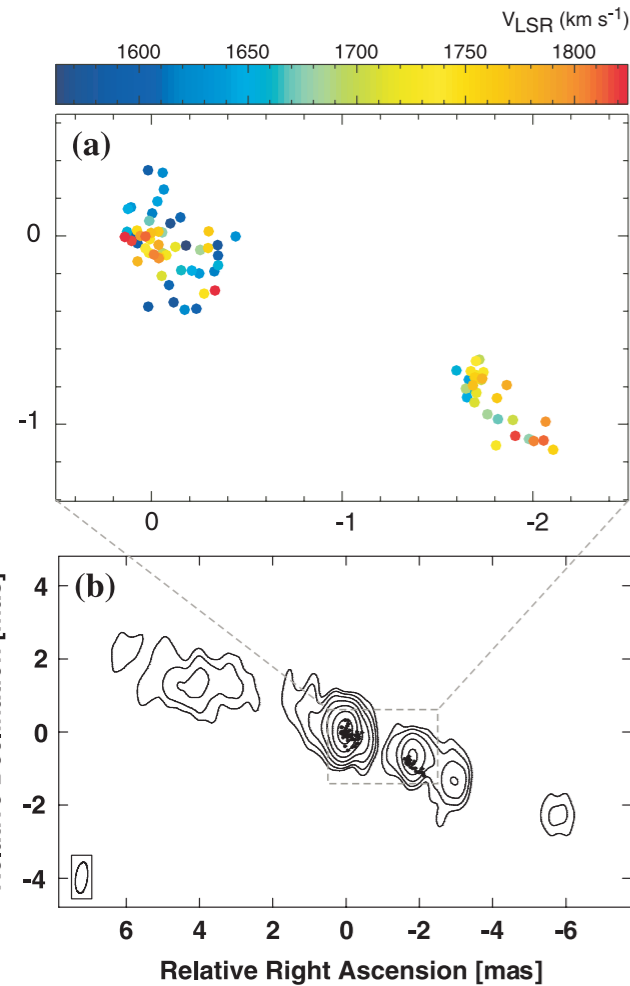
- Turbulent gas?
- Radiation drag?
- Dynamical friction of star clusters?



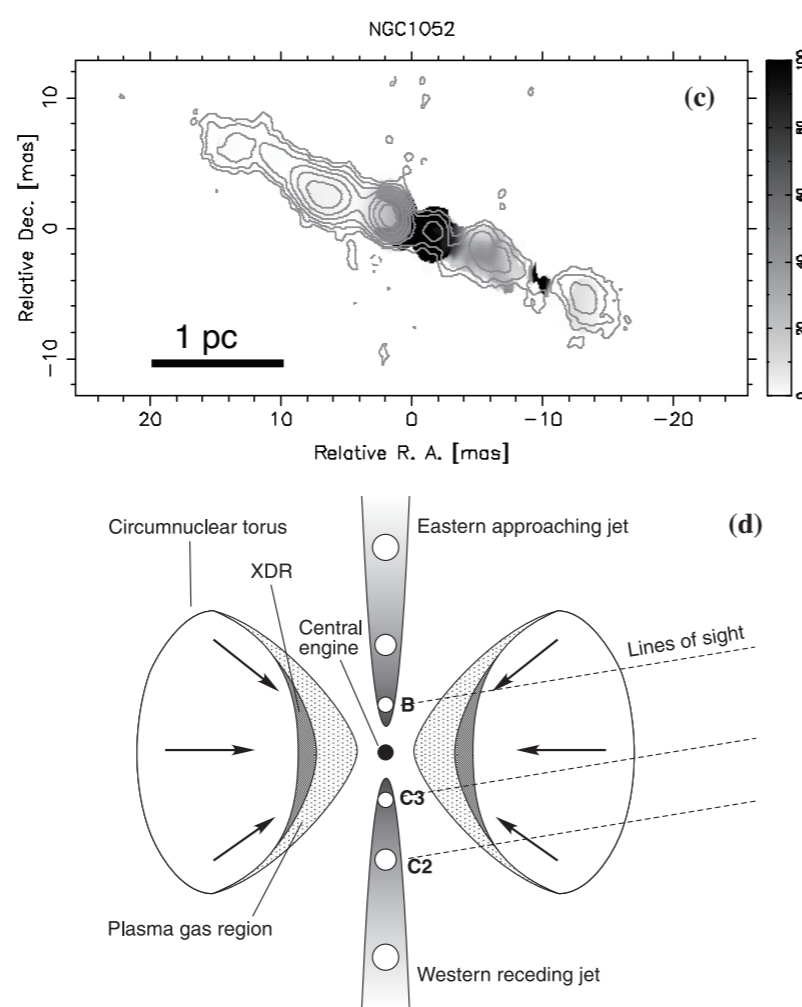
ALMA observations toward NGC 1052

Good target to observe
mass accretion in a molecular torus

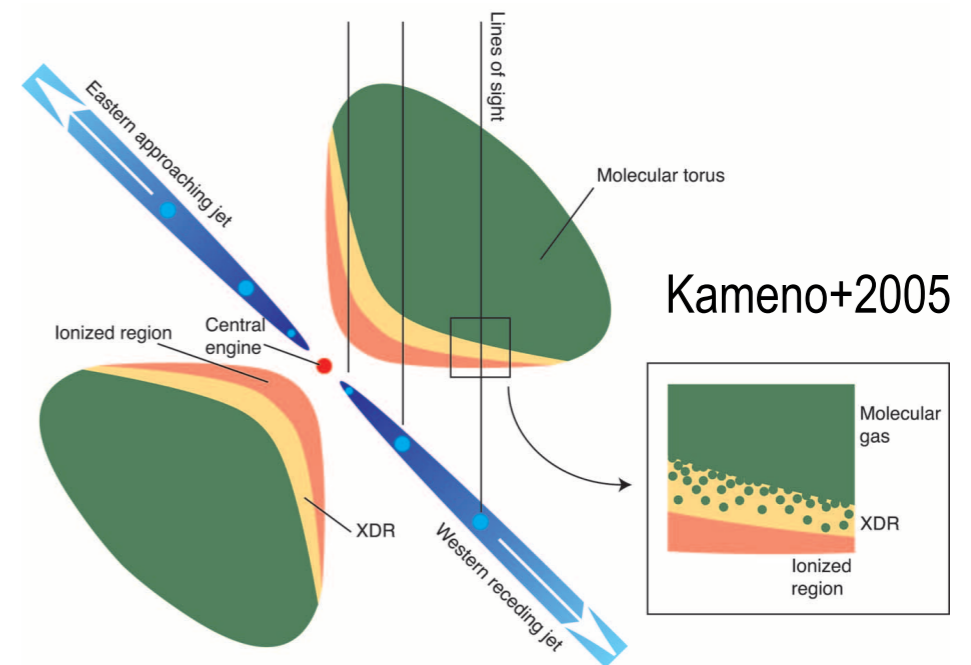
Sawada-Satoh+2008



Kameno+2003



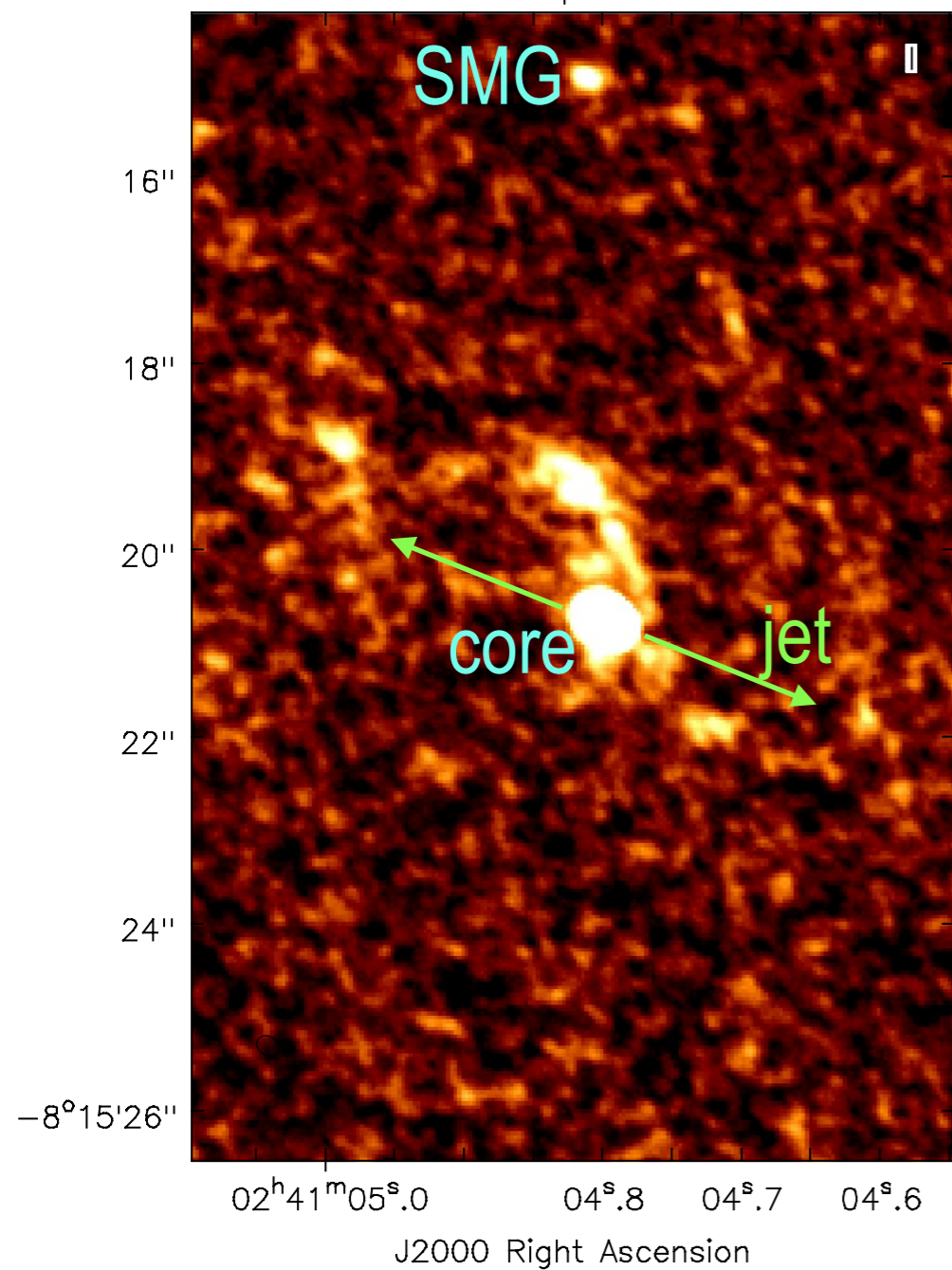
Host galaxy	E4 $B_T=11.41$ mag
Distance	20.3 Mpc, 1"=98 pc
Velocity	$V_{\text{sys}}(\text{LSR, Radio}) = 1471$ km s ⁻¹
Radio continuum	0.4 Jy@345 GHz
Radio Jet	$\beta = 0.25$, $i=62^\circ \pm 10^\circ$
H ₂ O maser	velocity = 1400 - 1850 km/s
Line absorption	HI, OH, HCO ⁺ , HCN, CO
Free-free absorption	



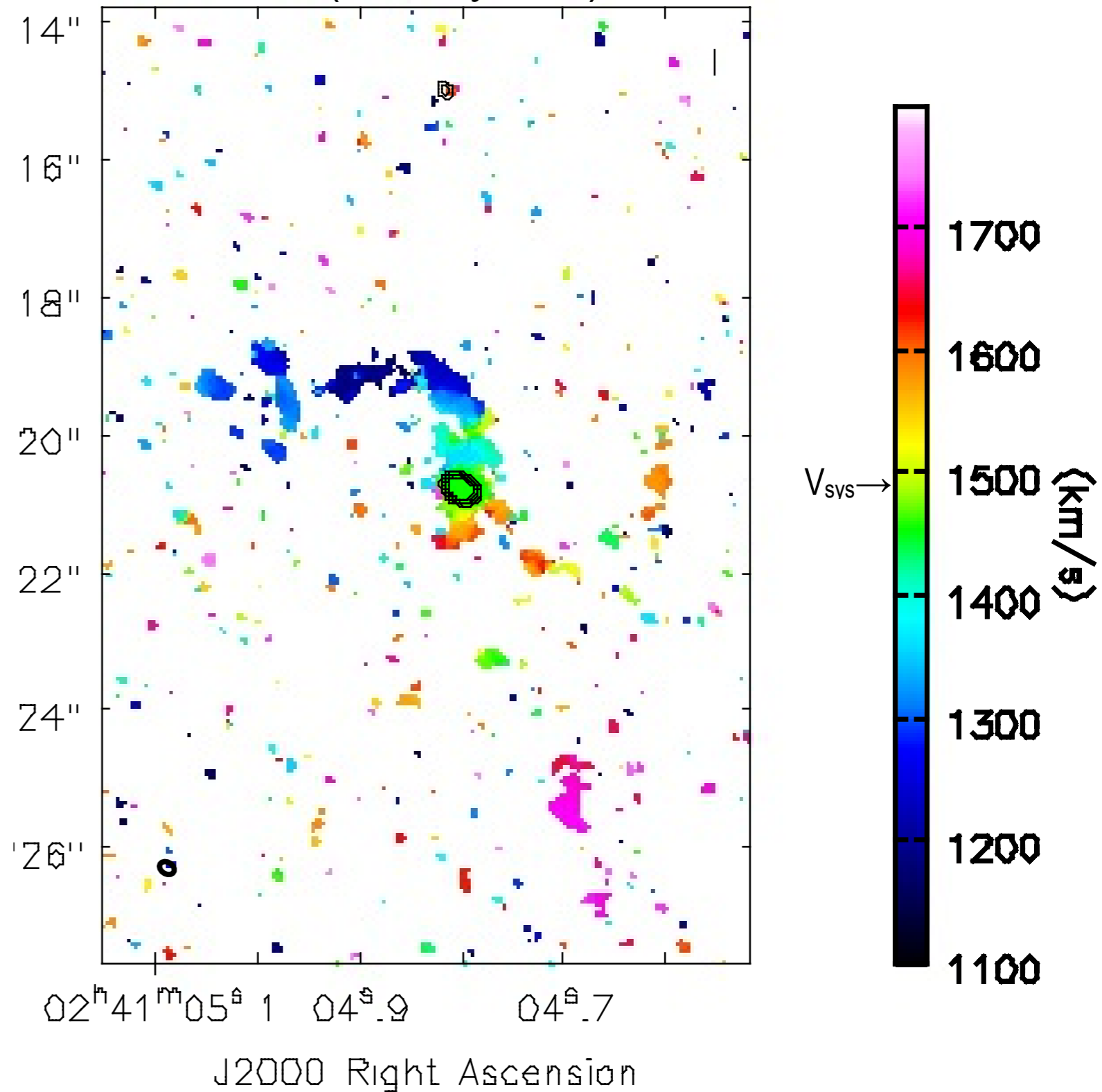
Kameno+2005

Molecular gas distribution and velocity (CO)

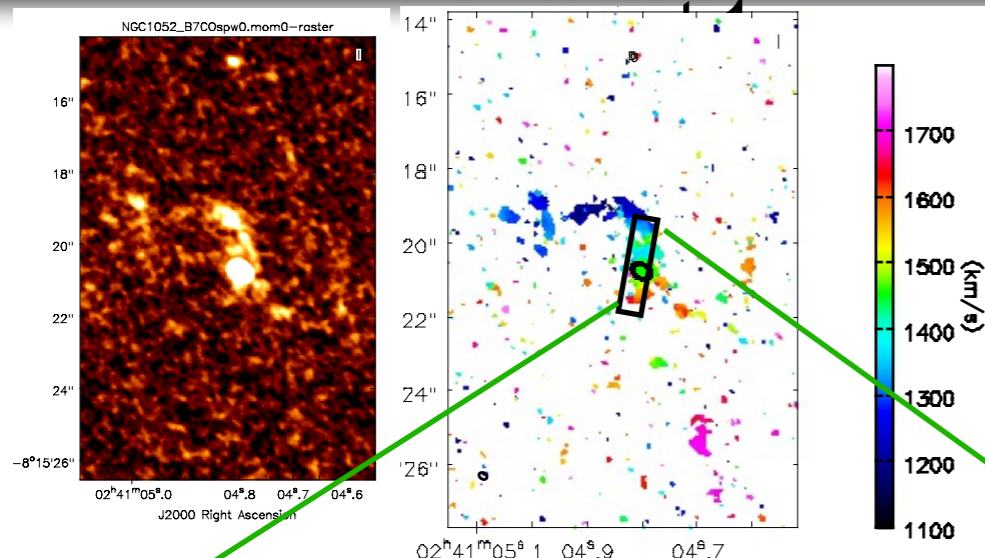
CO (3-2) total intensity map



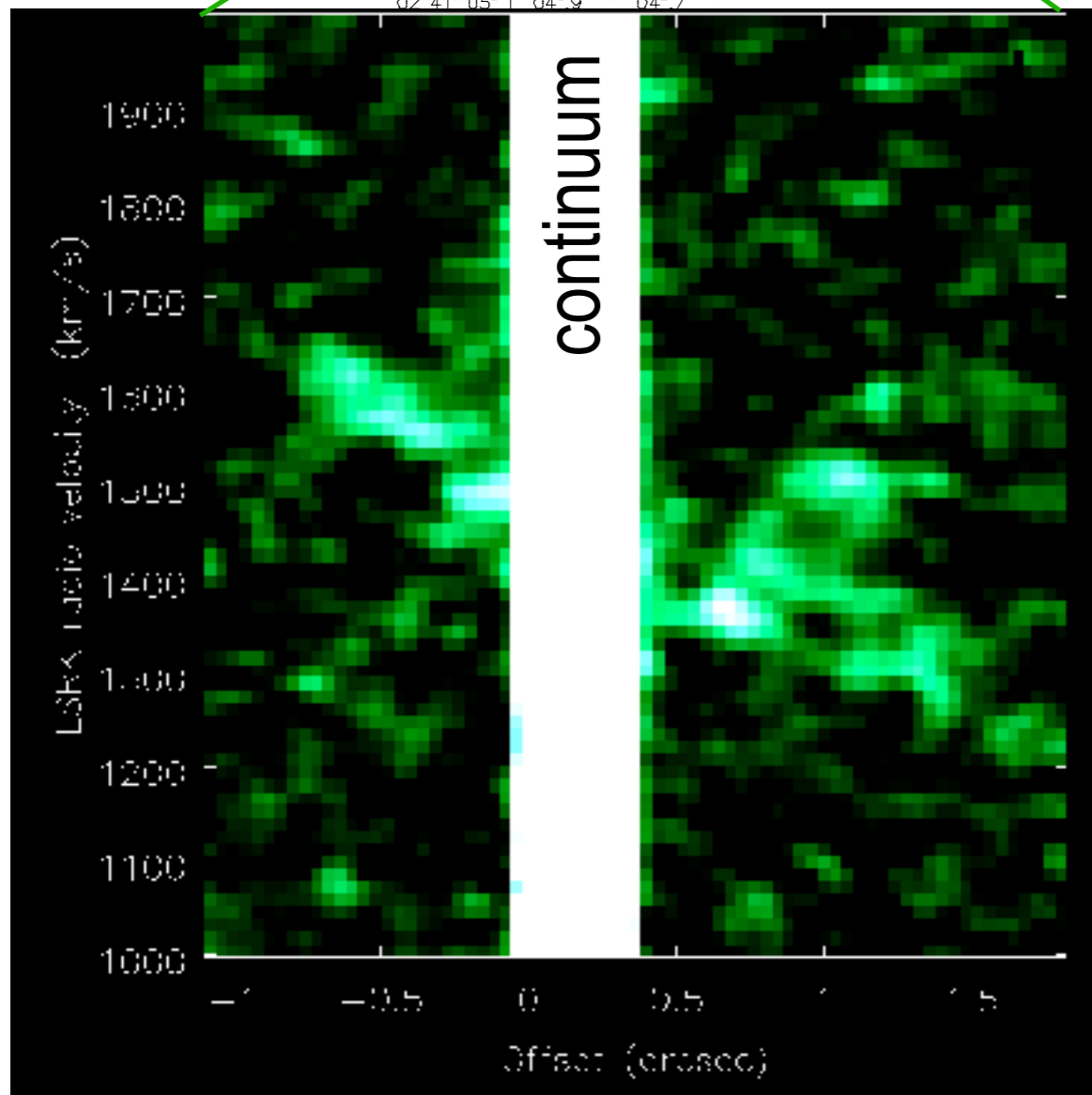
moment-1 (velocity field)



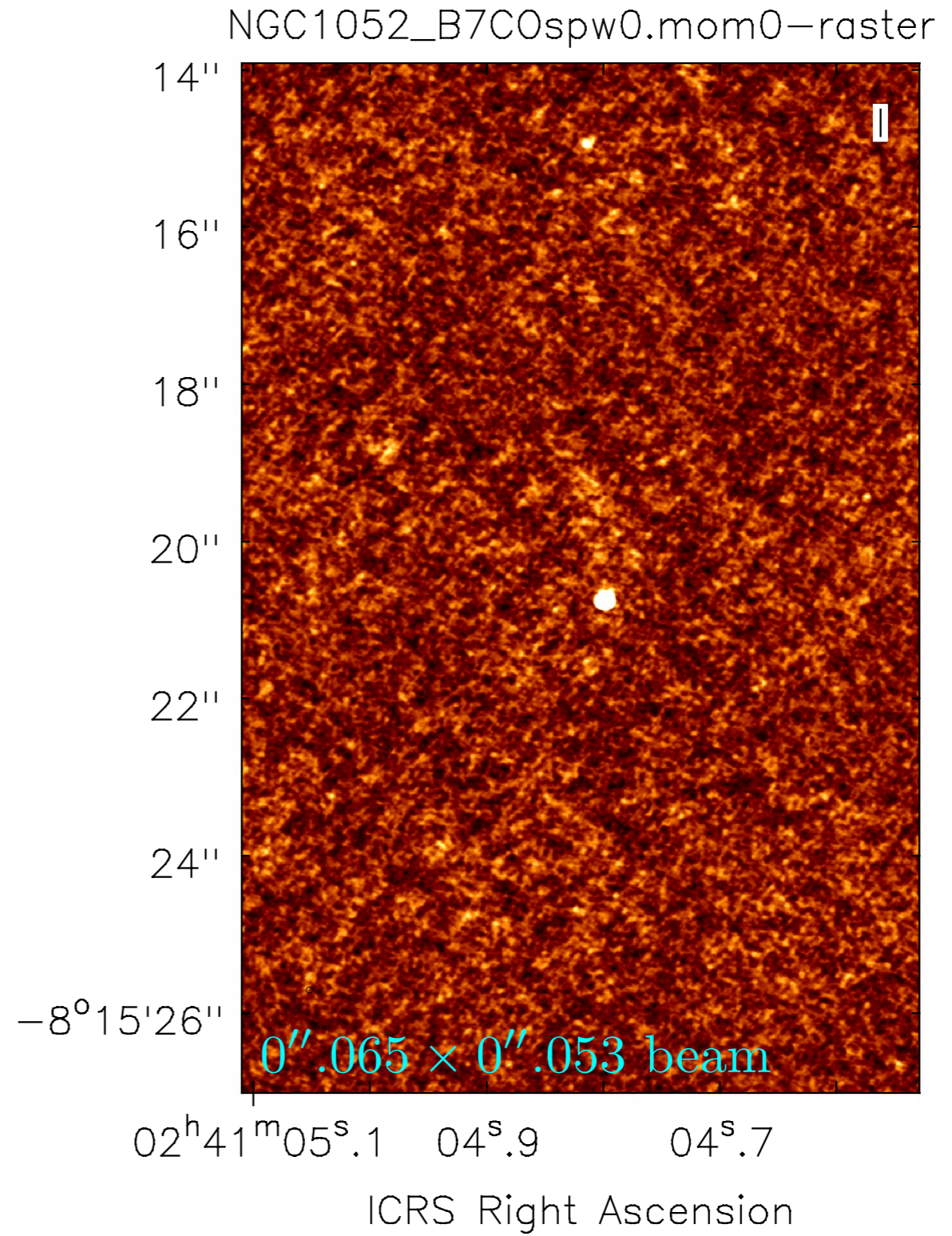
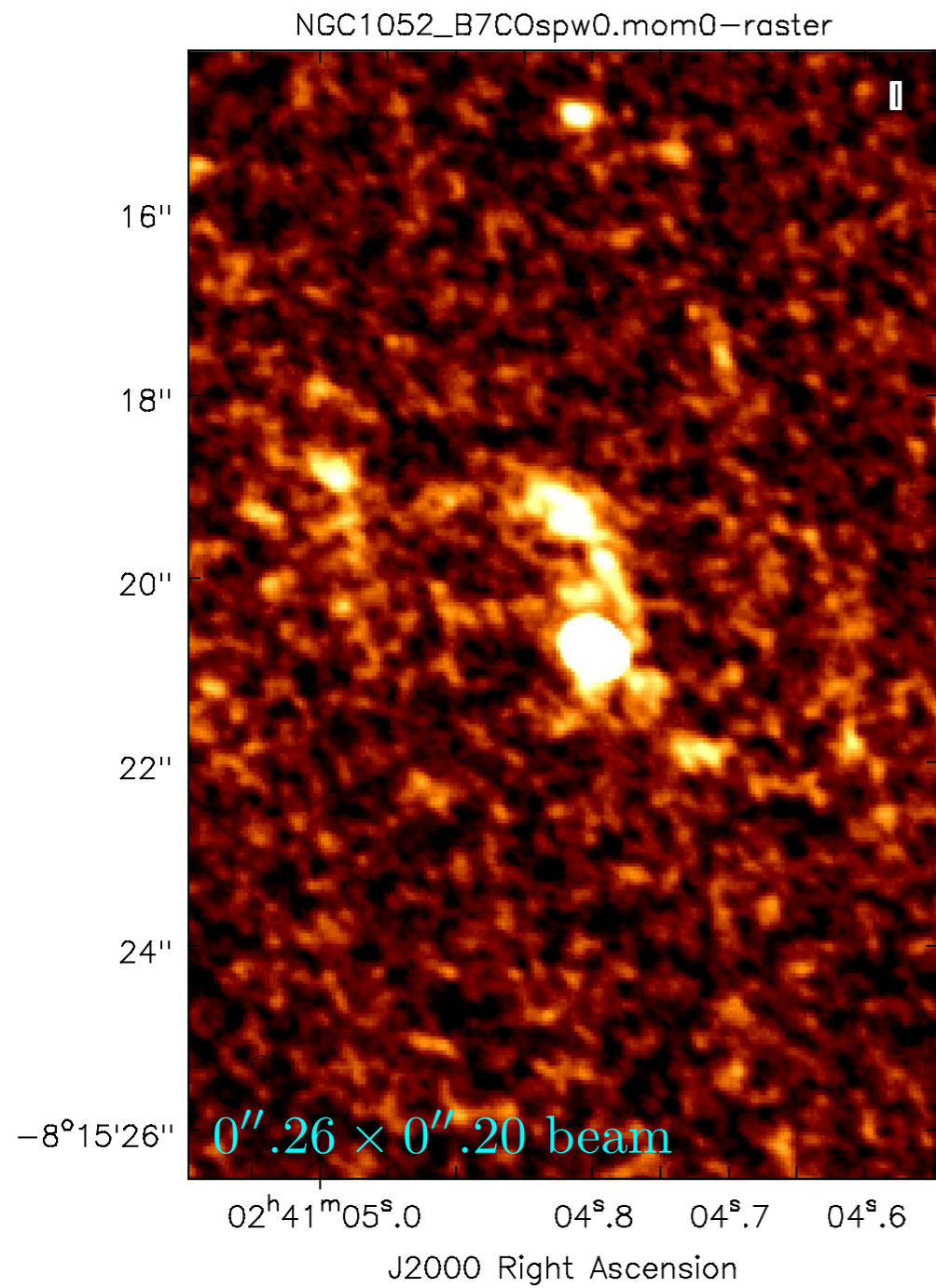
CND (CircumNuclear disk) rotation



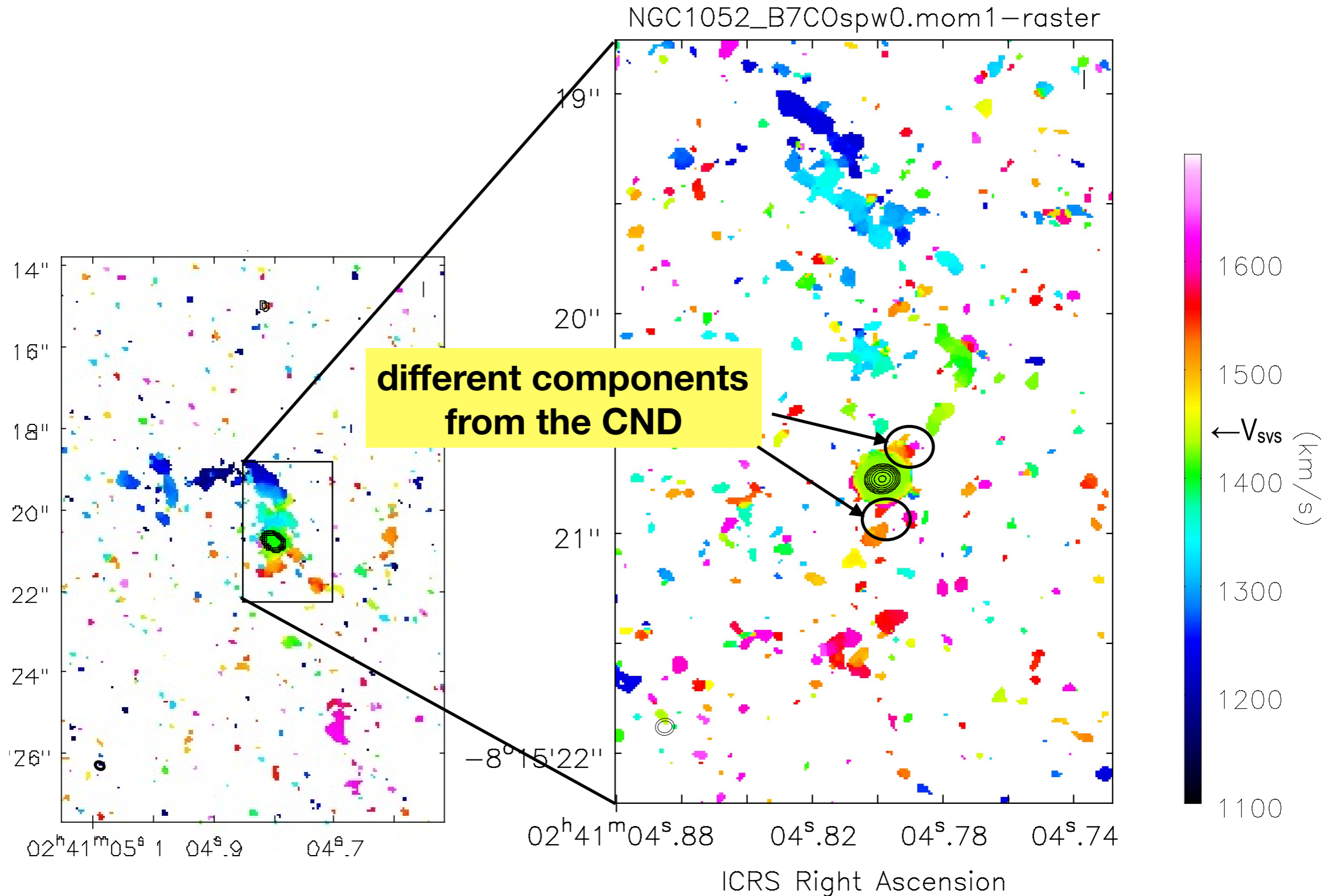
- radius ~ 100 pc
- rotation speed ~ 150 km s $^{-1}$
- enclosed mass = $5 \times 10^8 M_{\odot}$



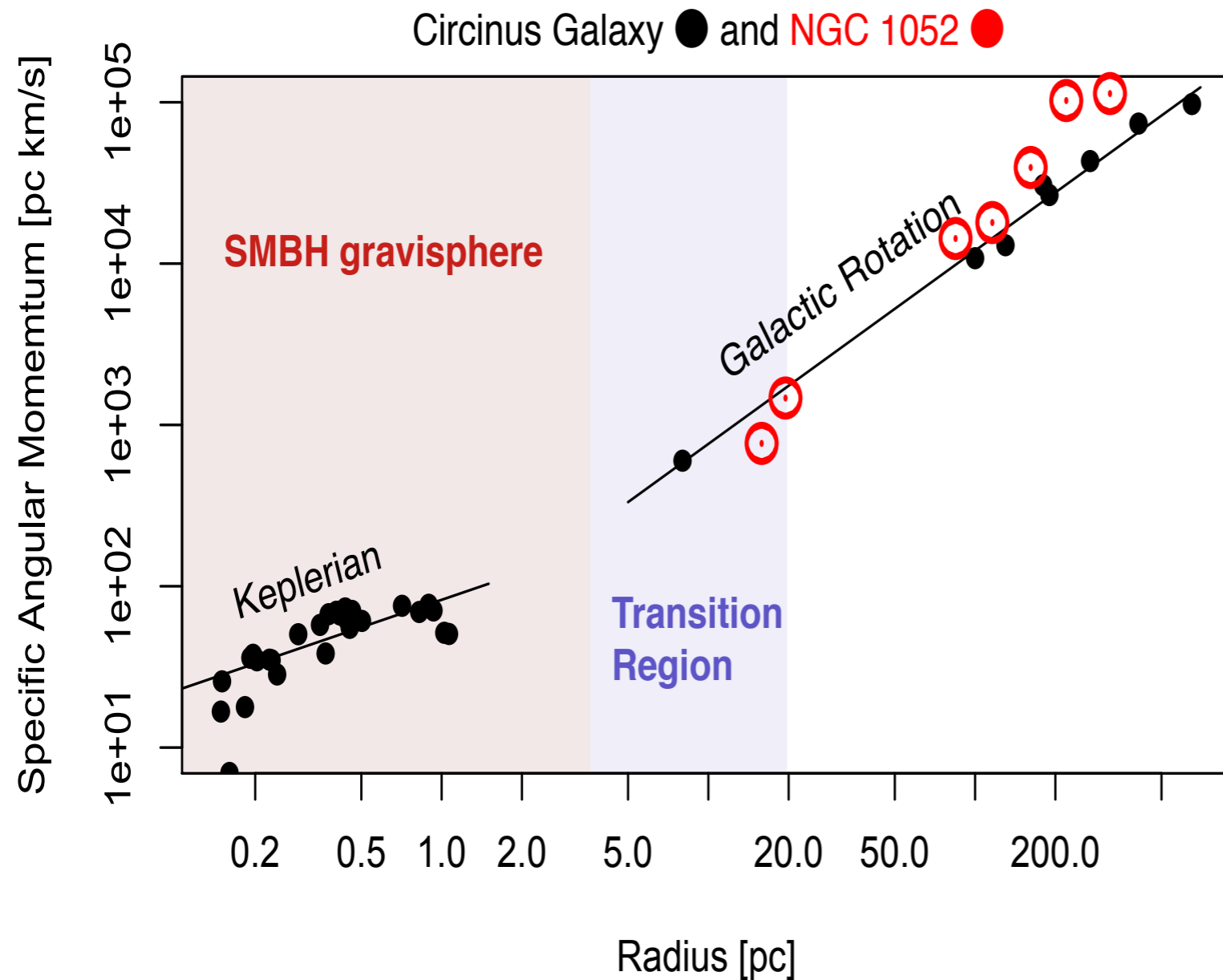
Long-baseline view



High-resolution velocity field



Angular momentum plot

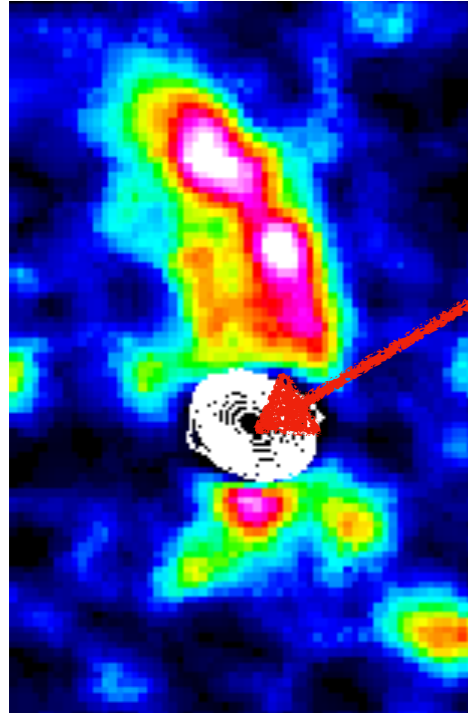


- Still outside of gravisphere
- Need higher resolutions!

Absorption Studies with ALMA and KVN



CO line profile toward the nucleus

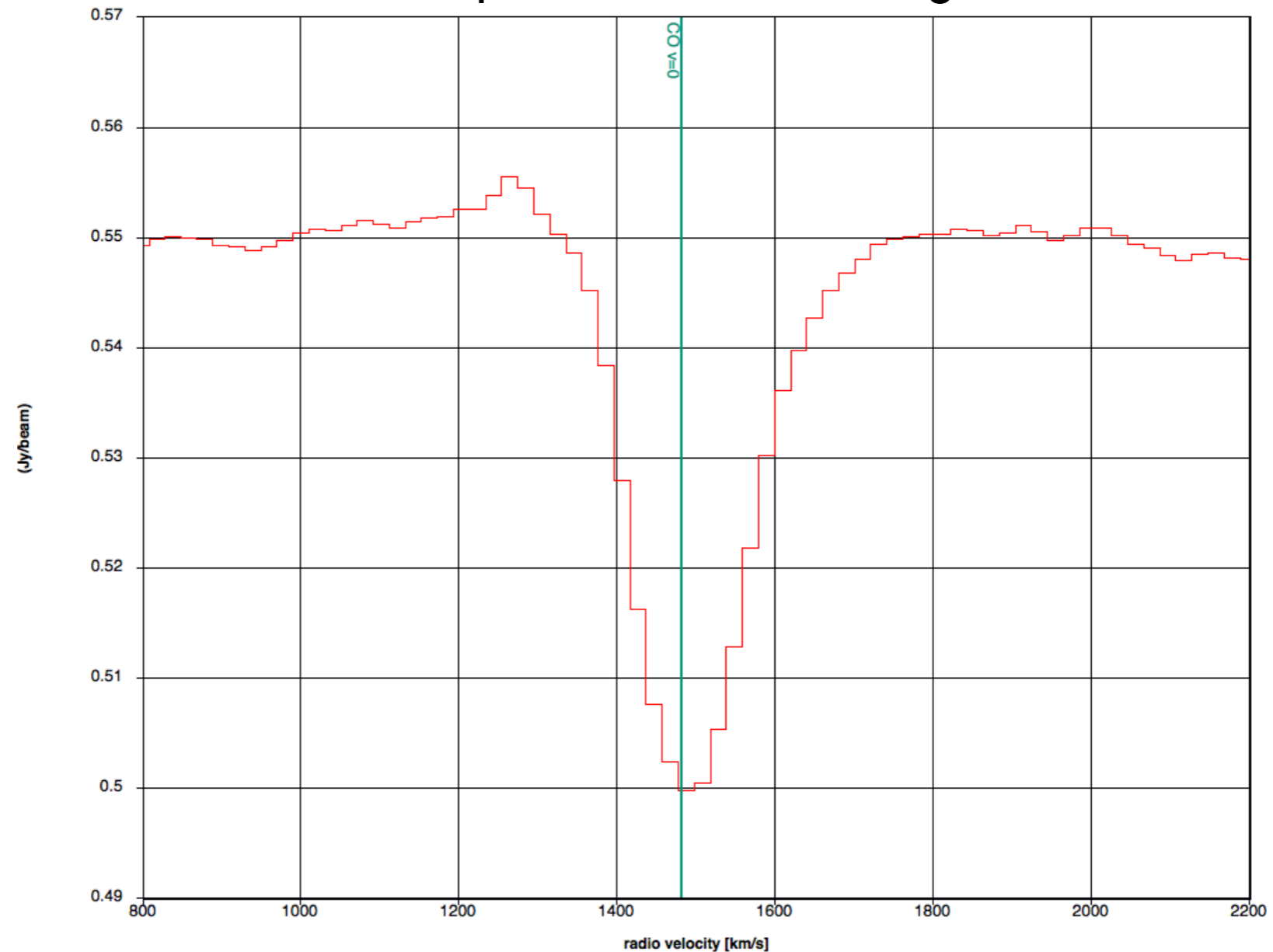


Spectra toward
the nucleus

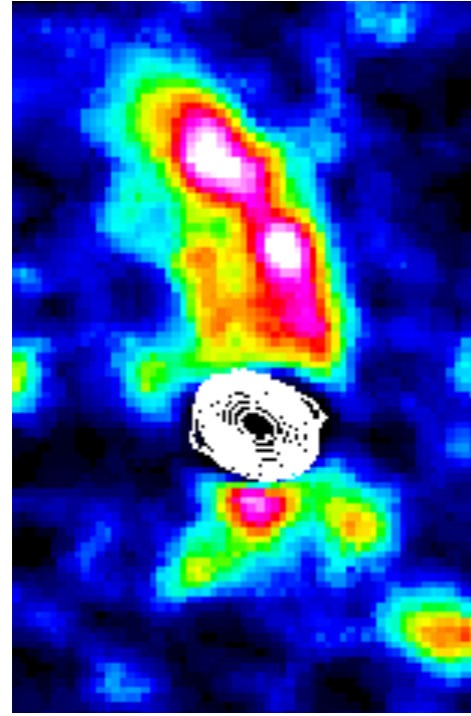
CO (J=2-1) : inverse P-Cyg profile

blue emission + red absorption

implication of inward gas motion



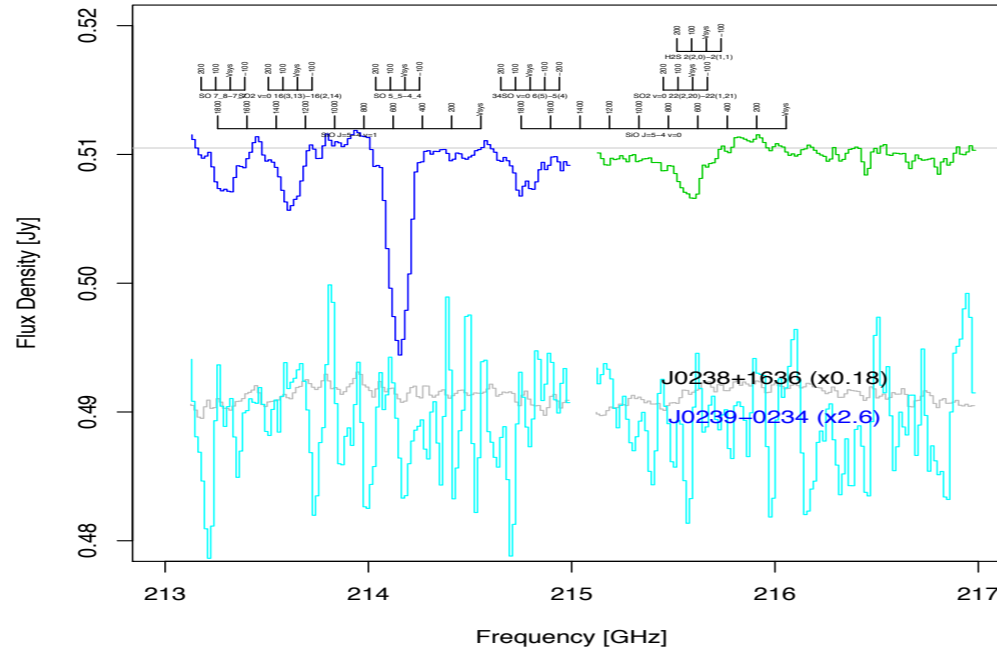
Absorption features



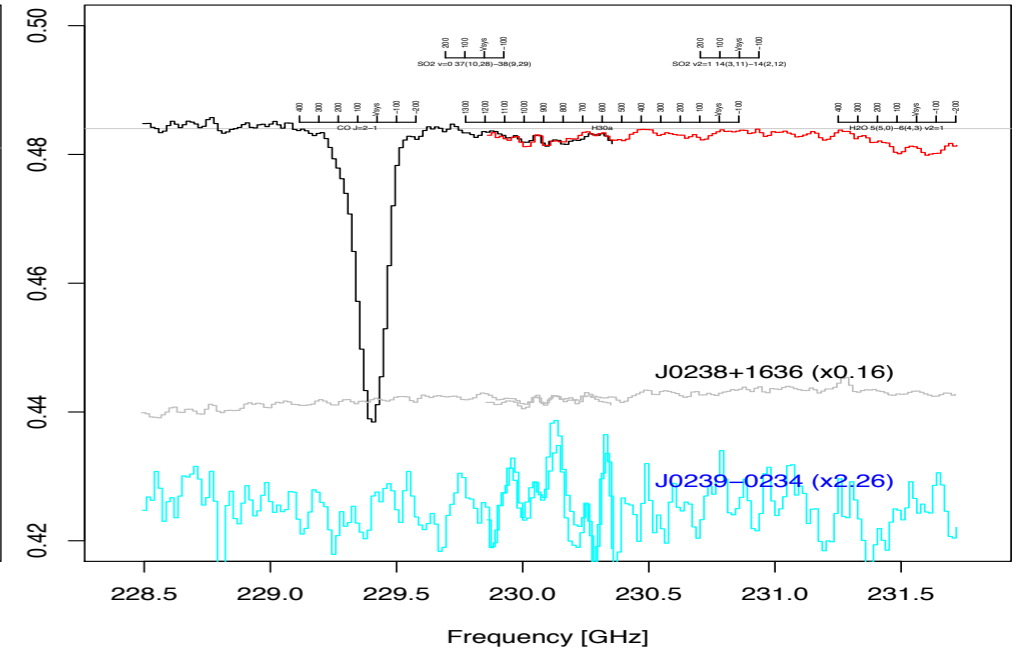
Spectra toward the nucleus

CO, HCN, HCO+, CS, SO, and CN
 - isotopologues : H¹³CN, HC¹⁵N
 - vib-excited HCN, HCO+

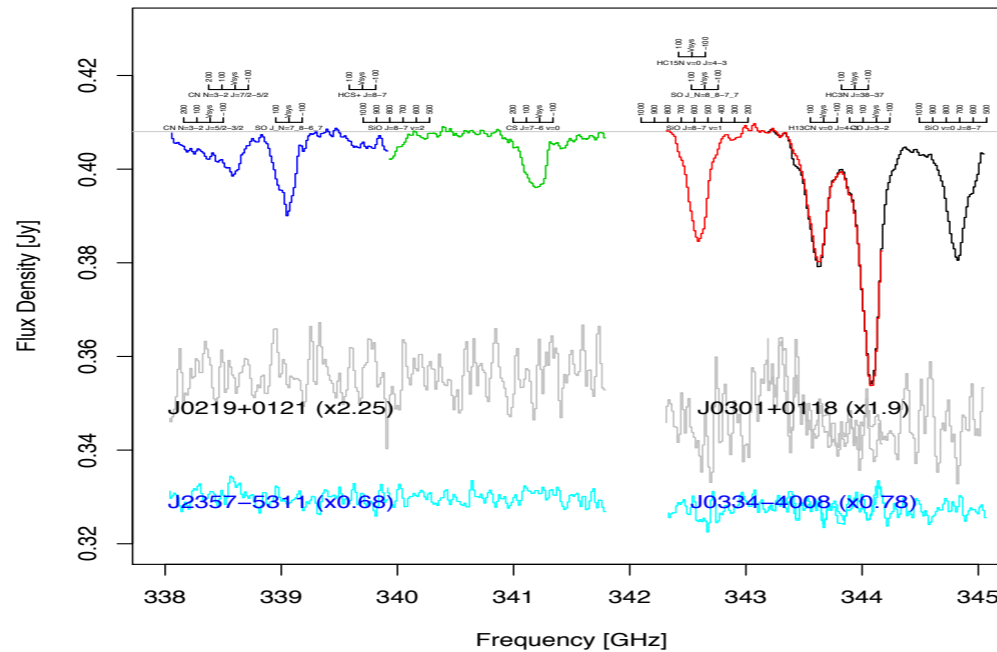
NGC 1052 Cycle 2 Band 6



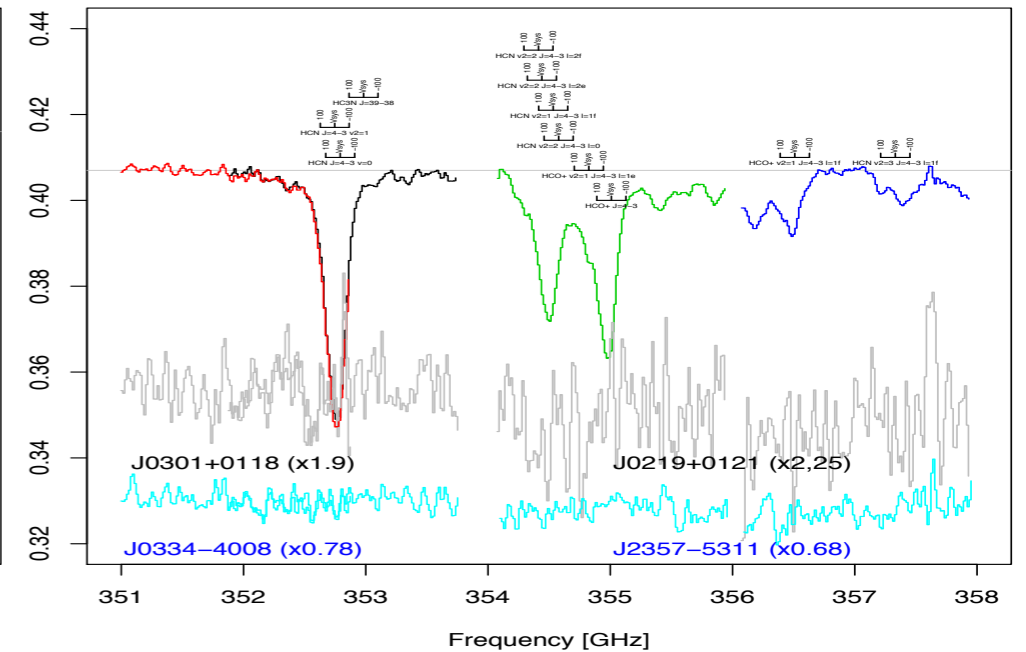
NGC 1052 Cycle 2 Band 6



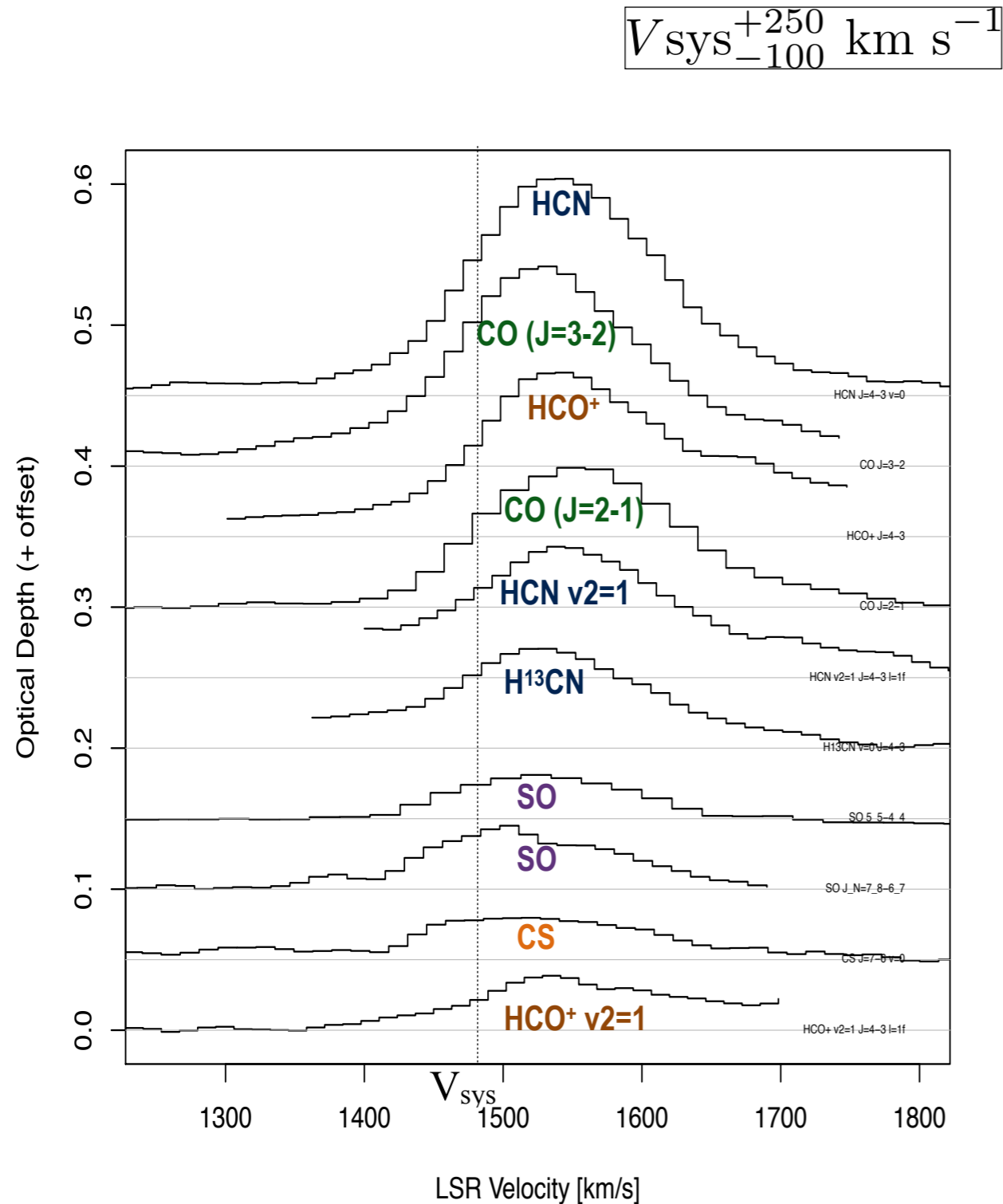
NGC 1052 Cycle 2 Band 7



NGC 1052 Cycle 2 Band 7



Optical depths



- Mostly redshifted w.r.t. V_{sys}
- Wider than CNS
- HCN deeper than CO

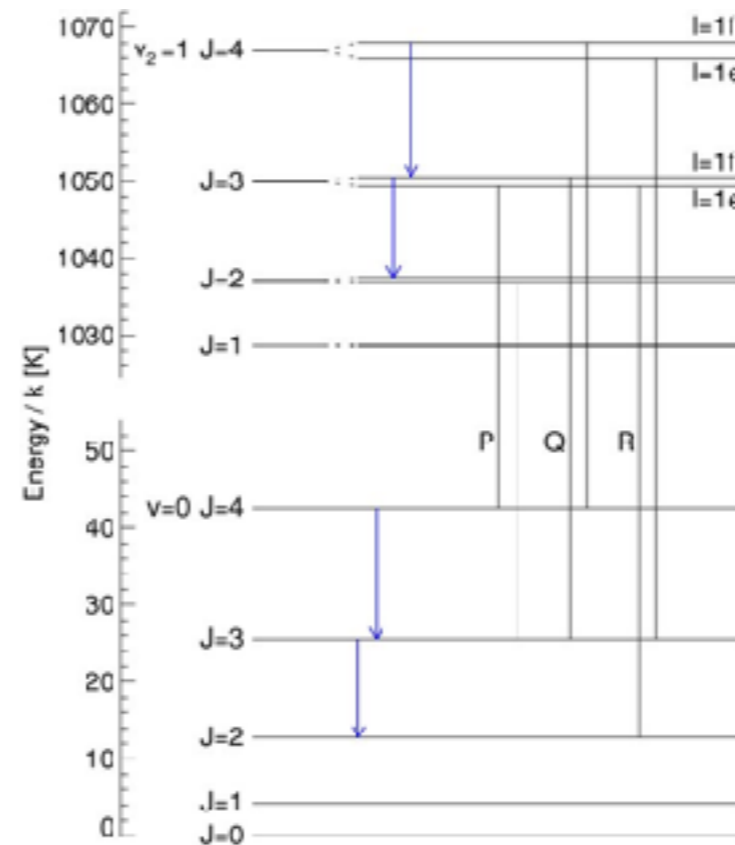
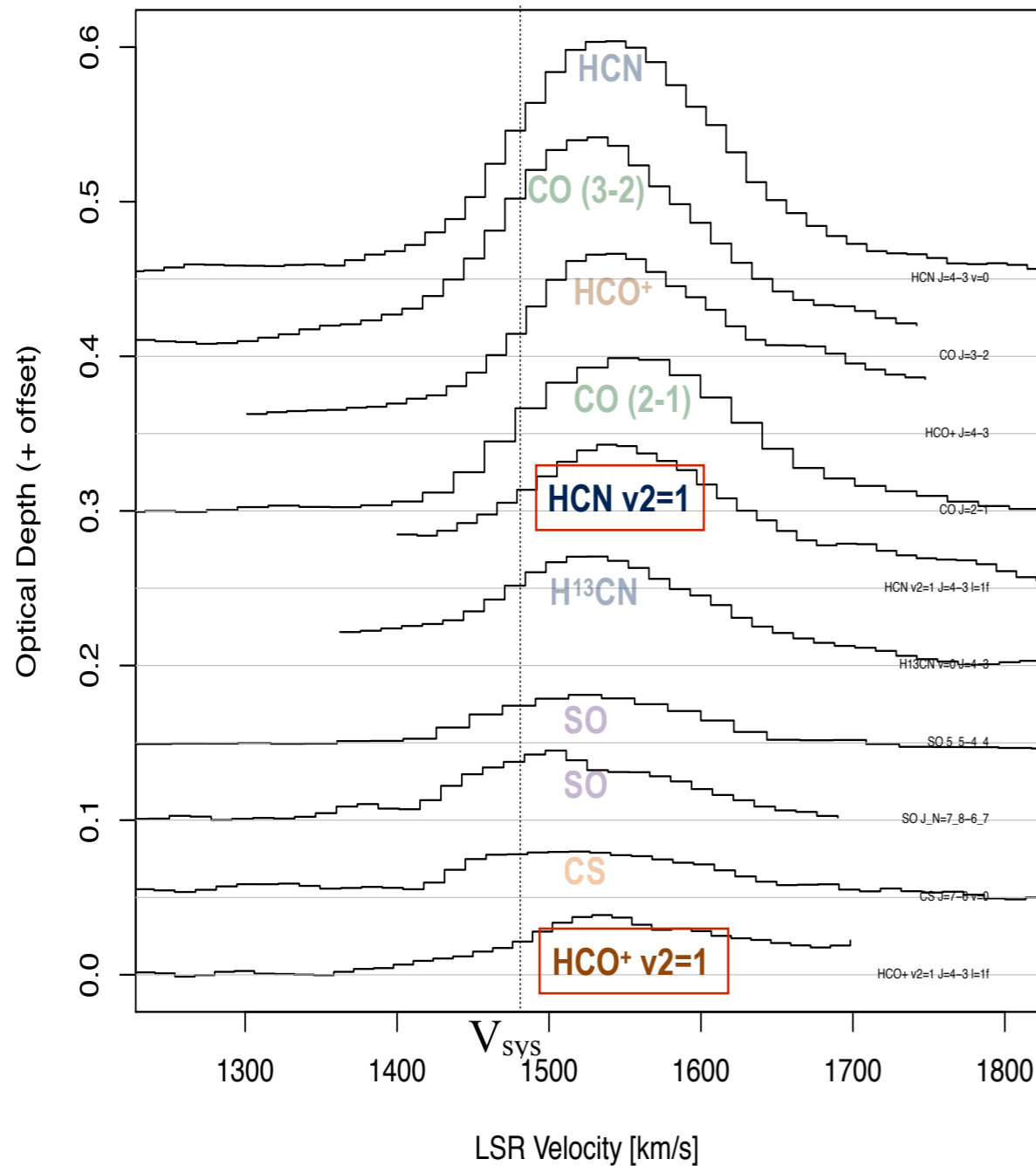
$$EW = \int \tau(v) dv = 24.4 \text{ kms}^{-1}$$

Absorption features are likely to originate in a molecular torus

Presence of vibrationally excited lines

HCN J=4-3 and HCO⁺ J=4-3

- line ratio ($v=0$ to $v_2=1$) : $R=0.6$
- if optically thin, $T_{\text{ex}} = 520$ K
- IR ($14 \mu\text{m}$) pumping from hot dust?

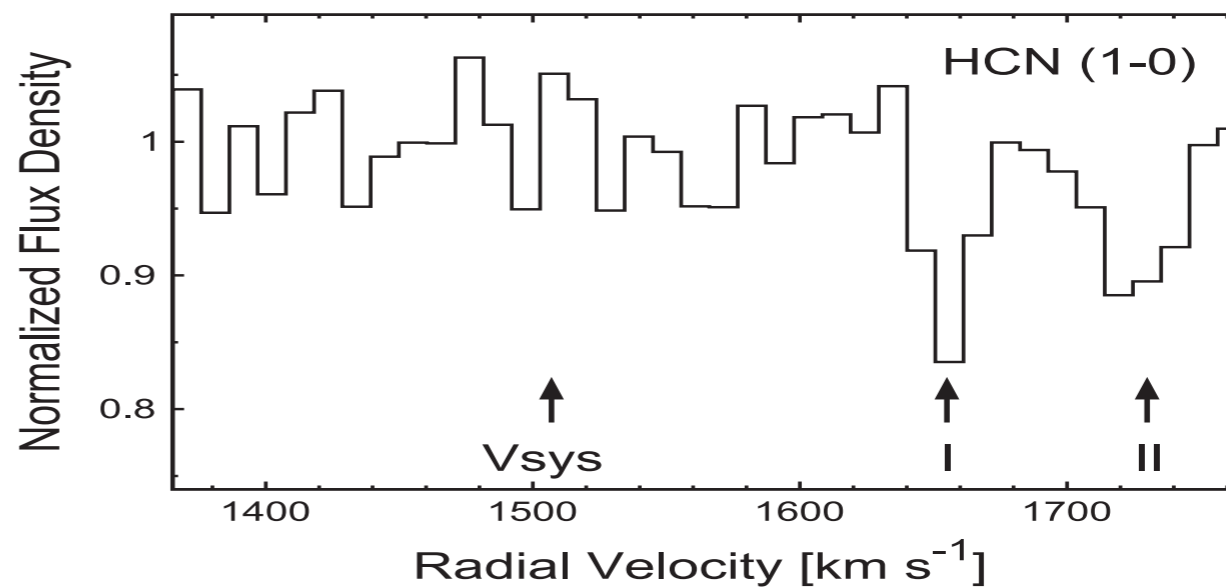
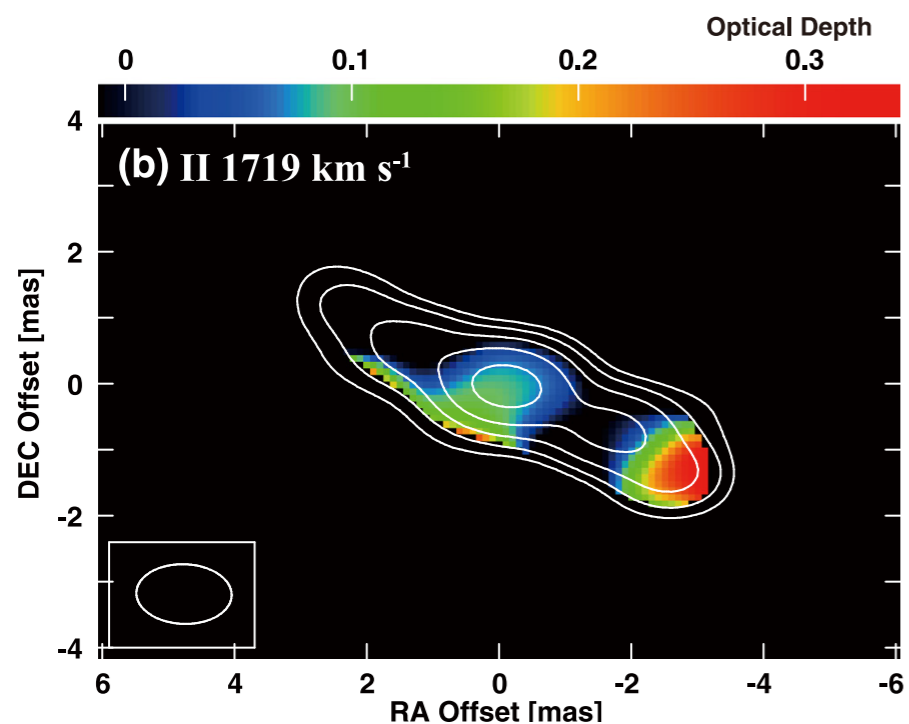
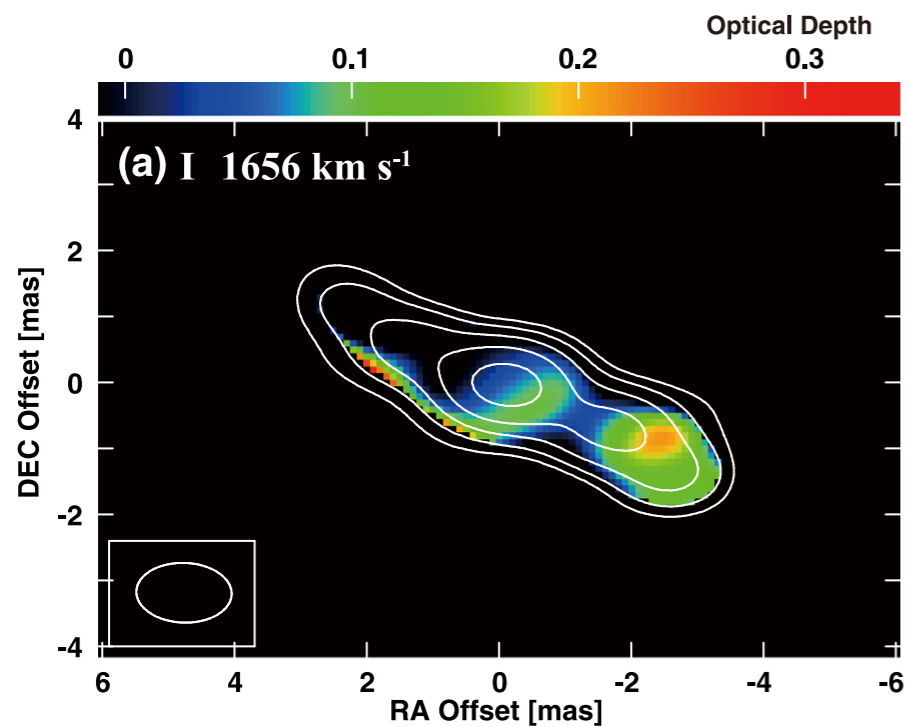


Sakamoto+2010, ApJL, 725, L228

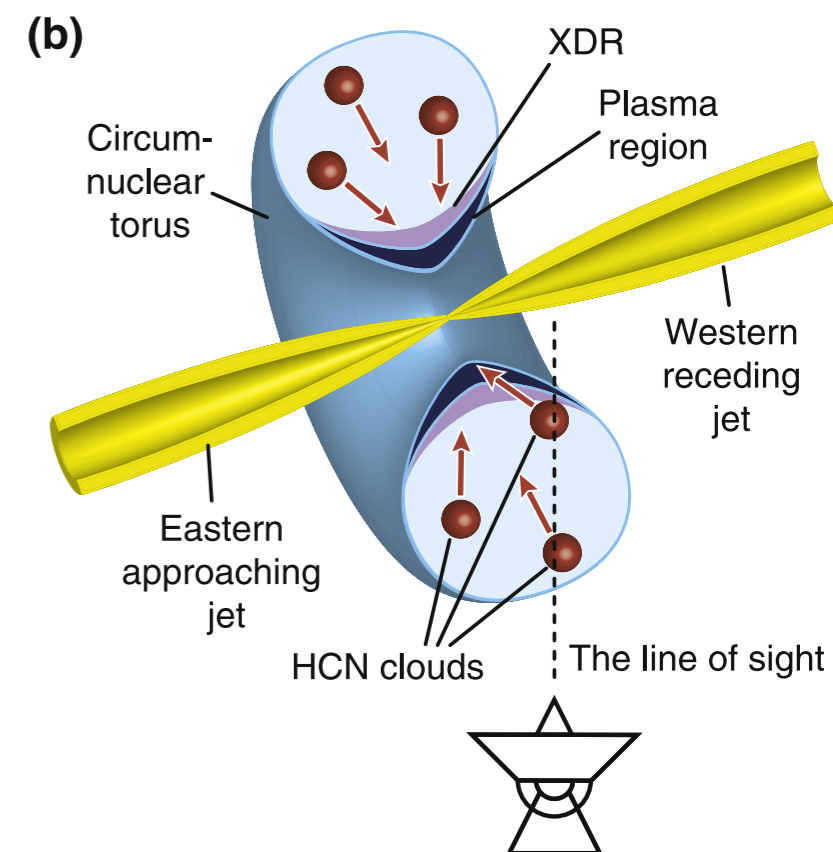
Locating HCN absorption with KVN

Sawada-Sato+2016: HCN absorption with KVN

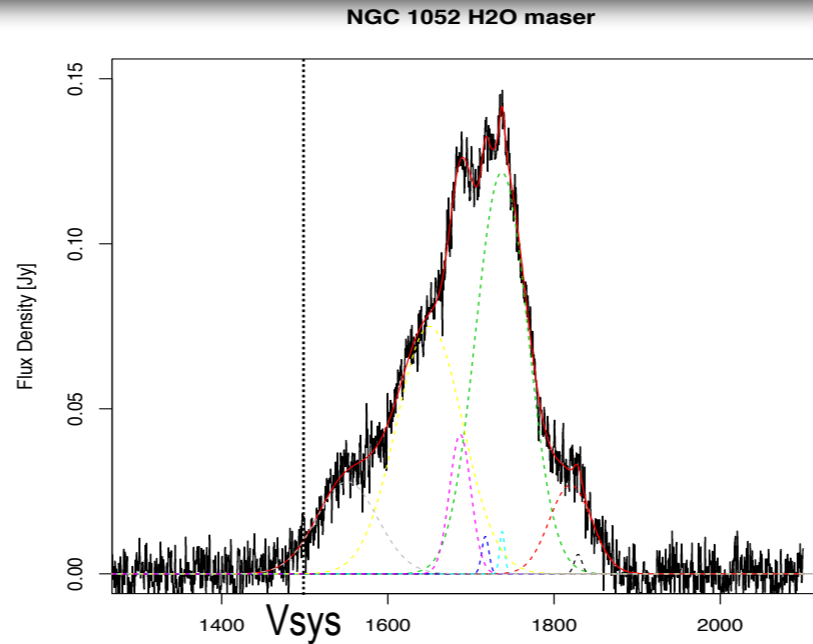
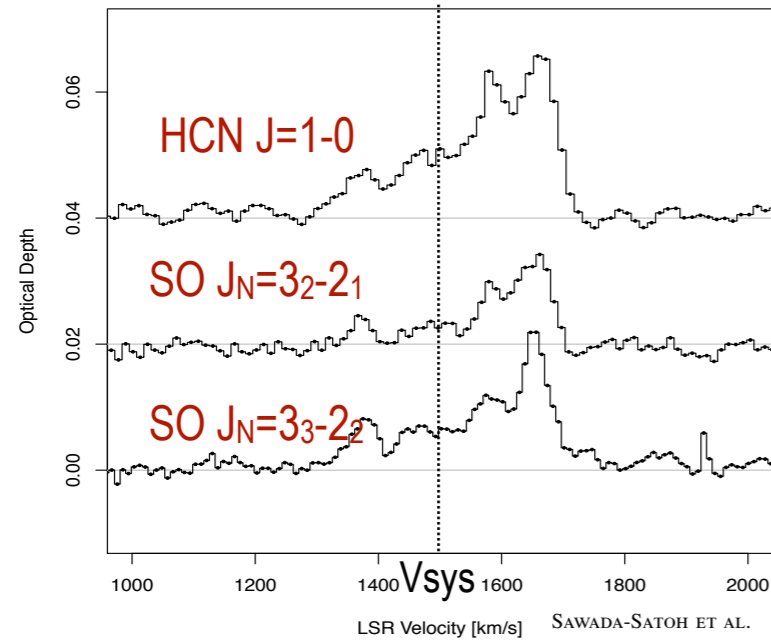
SAWADA-SATOH ET AL.



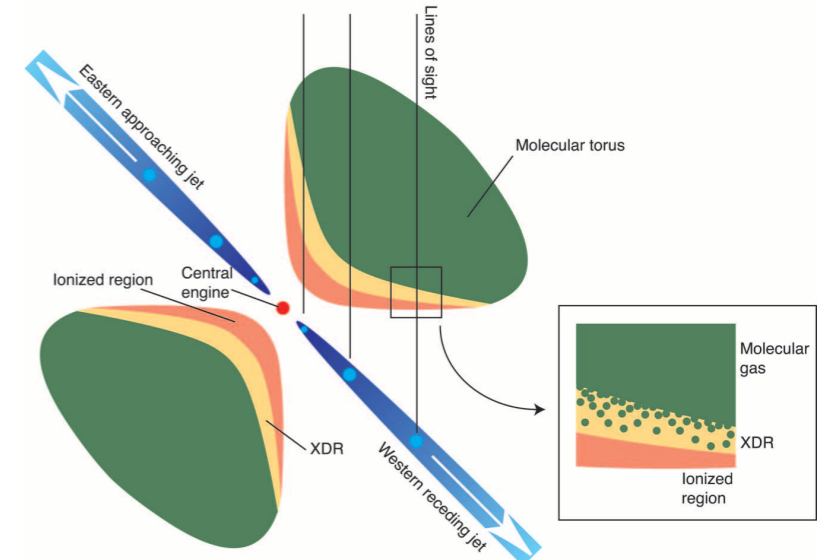
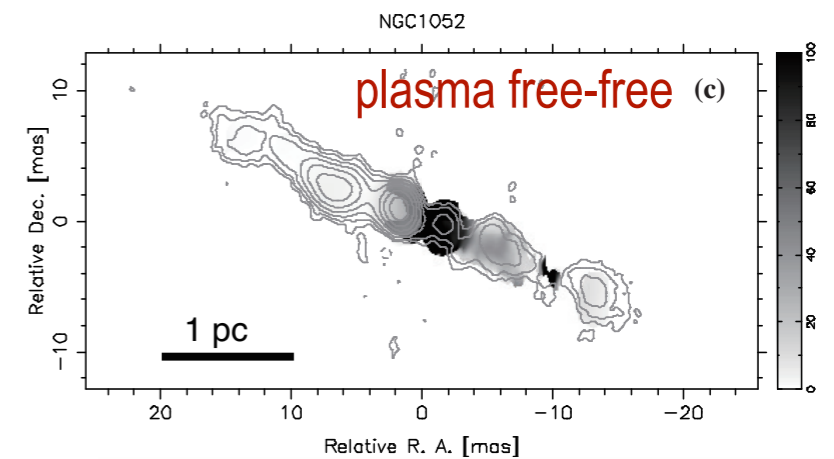
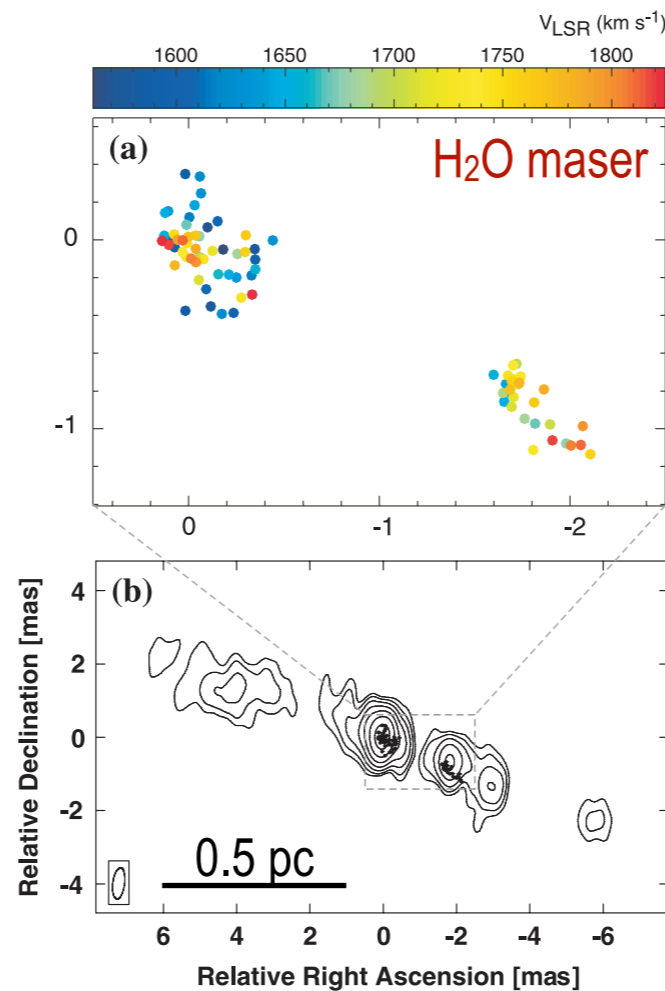
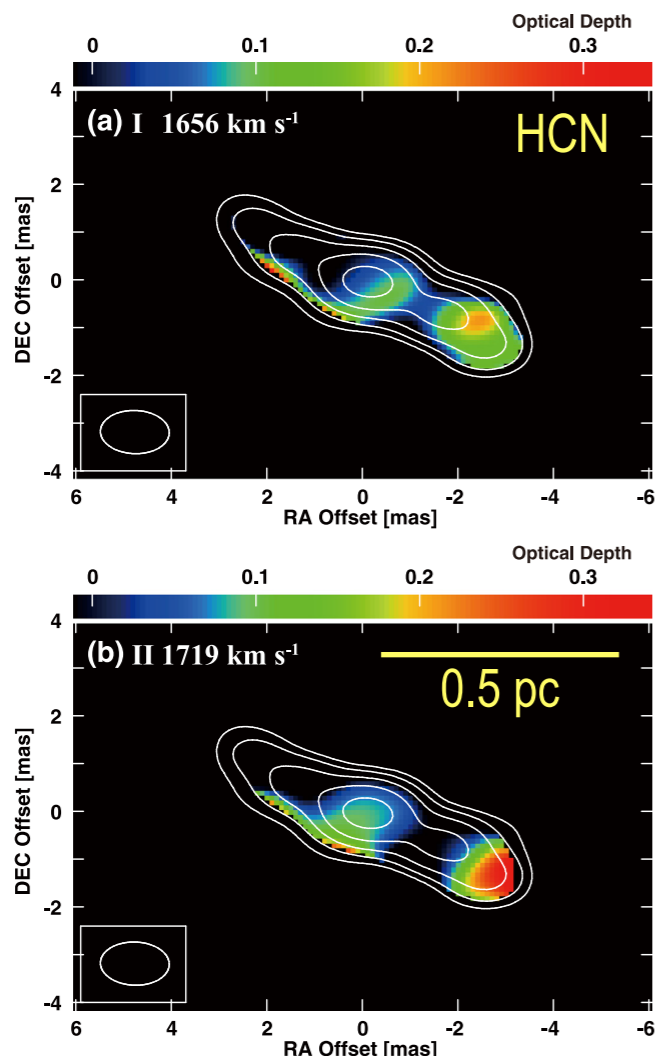
- absorption feature toward receding jet
- clumpy, with a filling factor ~ 0.03



Absorption features and H₂O maser



- Asymmetric profile
- sharp red edge
- Less redshifted than H₂O maser
- Inside molecular torus?



Summary

ALMA + KVN is the best combination to quest mass accretion in radio galaxies

- Molecular emission/absorption line with ALMA
- Locating absorbers with KVN

Discoveries from NGC 1052

- CND (radius~100 pc, $V_{\text{rot}} \sim 150$ km/s)
- Absorption by accretion matter in molecular torus
 - CO, HCN, HCO⁺, CS, SO, and CN
 - isotopologues : H¹³CN, HC¹⁵N
 - vib-excited HCN, HCO⁺
- Vertical structure of a geometrically thick torus
 - Molecular + XDR + plasma
 - Clumpy molecular clouds

