Scienza extragalattica con ALMA

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Outline

I - Local galaxies

II - High redshift galaxies

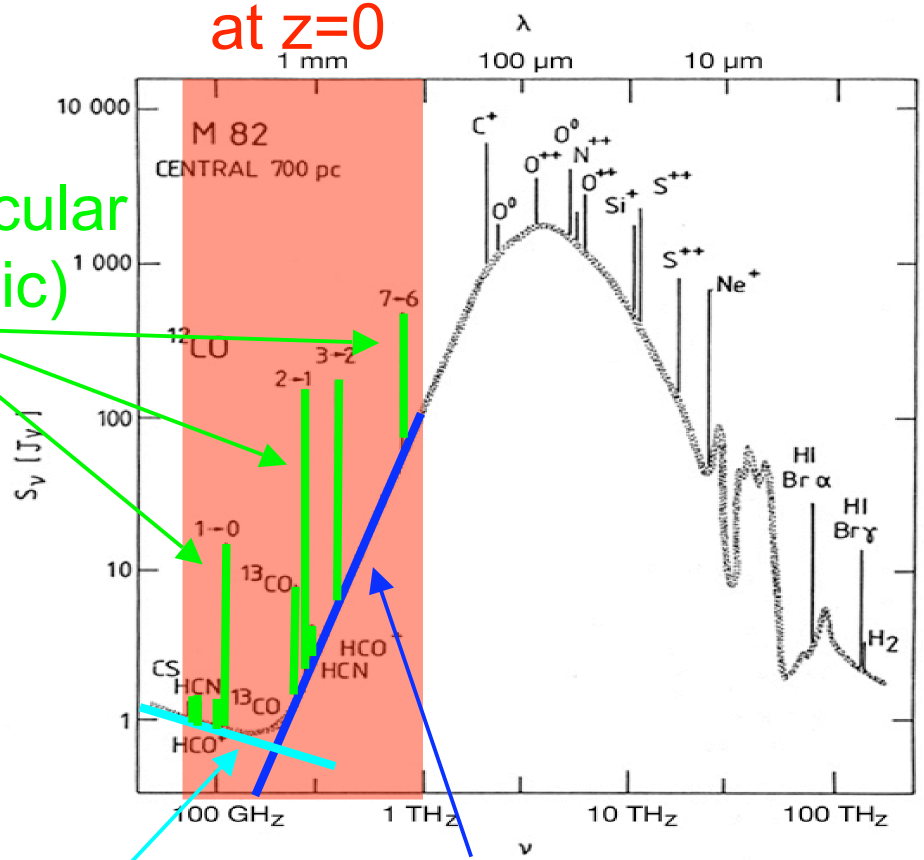
III - SZ effect

I

Local galaxies

IR-mm spectrum of a starburst galaxy

ALMA domain at z=0

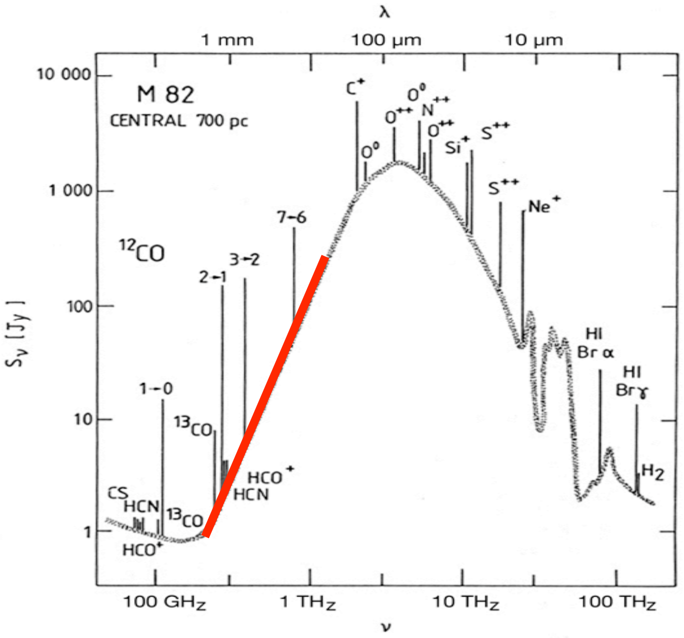


several molecular (+some atomic) lines

synchrotron + free-free

dust thermal emission (RJ tail)

Dust thermal emission



Dust is mostly heated by UV photons

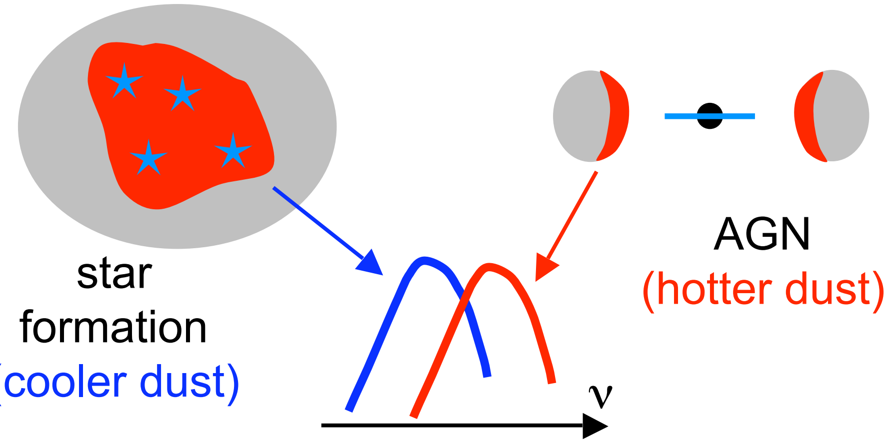
IR SED depends from:

emissivity

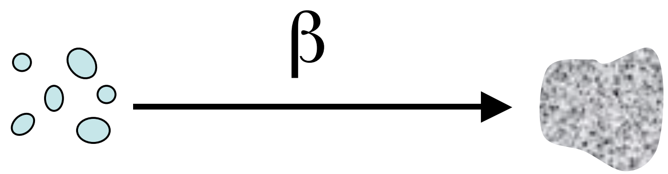
temperature distribution

$$S_\nu = \nu^\beta B(\nu,T)$$

Temperature depends on the strength of UV radiation field, but also on emissivity

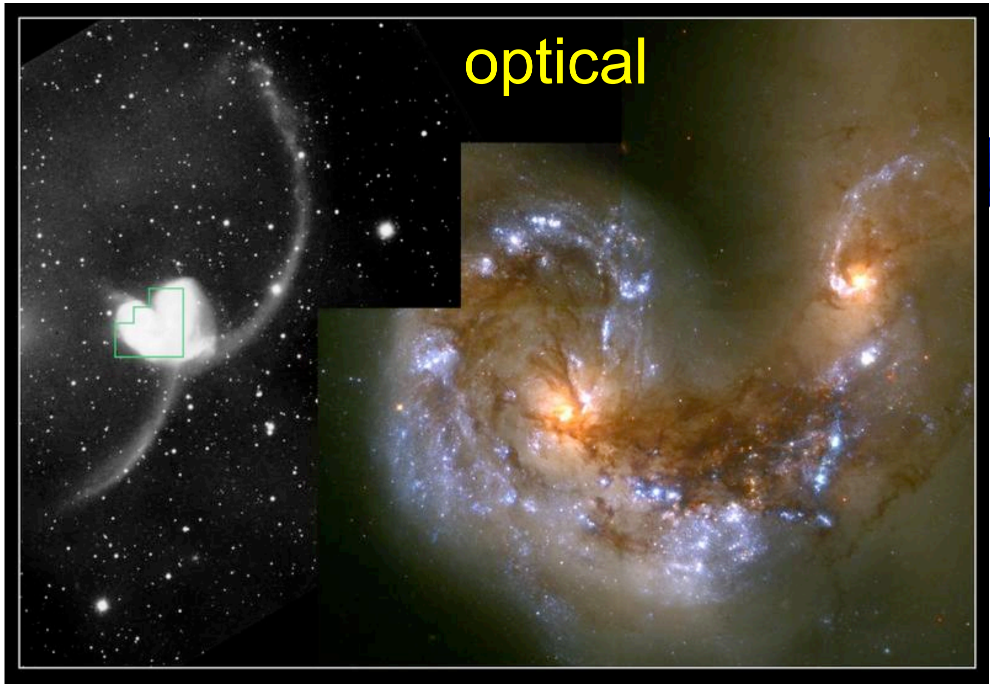


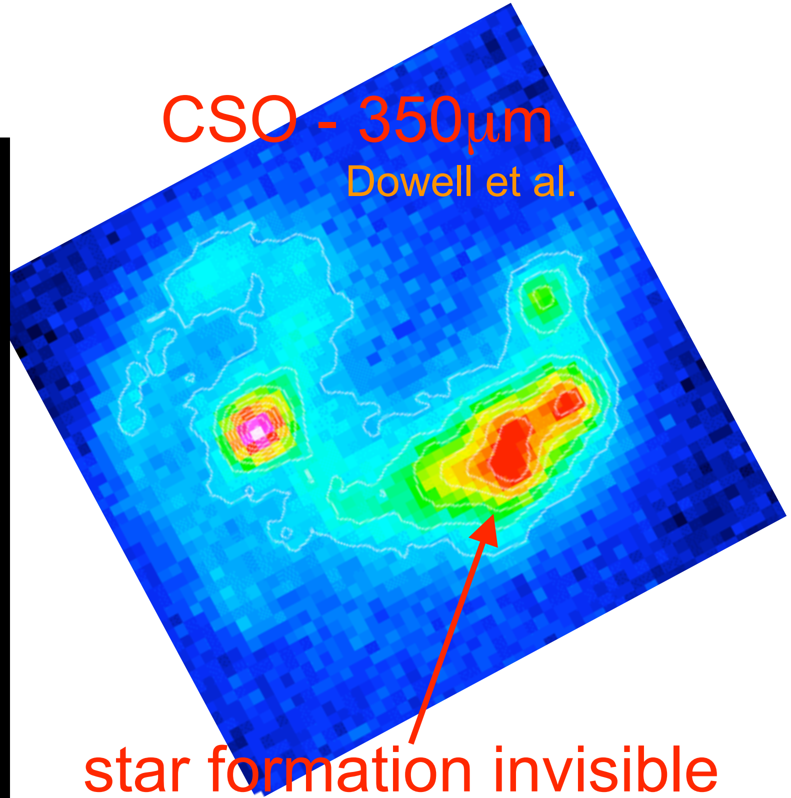
Emissivity depends on the dust grain properties (~size, to first order)



Dust thermal emission

It's an excellent tracer of star formation, not affected by extinction



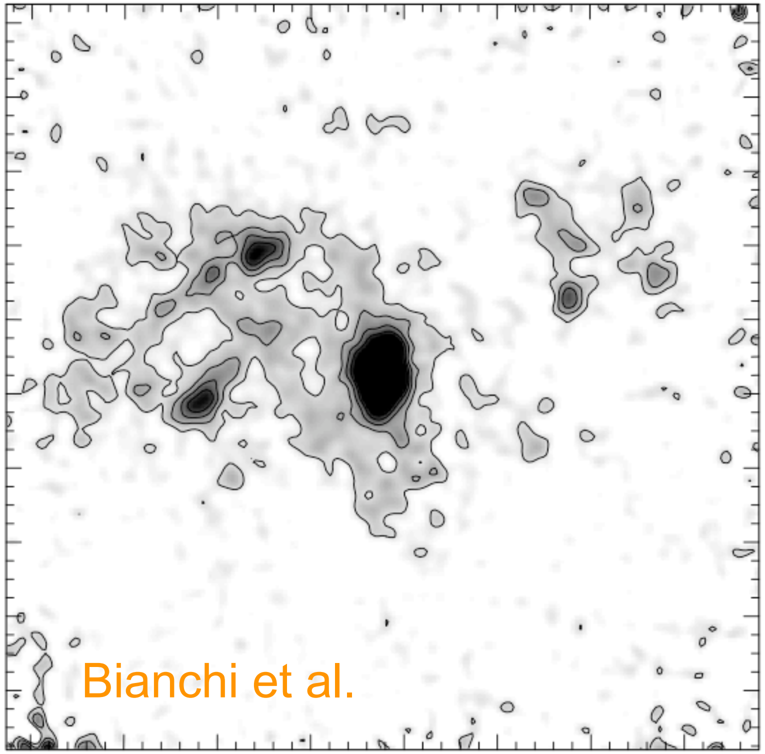


However current mm-submm facilities have poor angular resolution and poor sensitivity

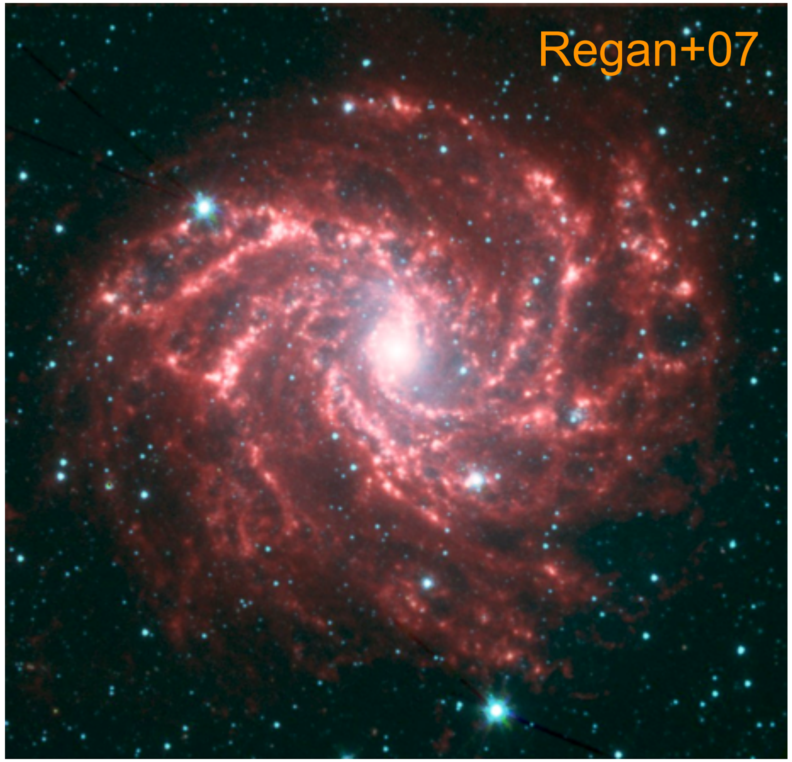
Dust thermal emission

ALMA will allow us to trace star formation in galaxies with an unprecedented sensitivity and angular resolution

NGC6946



850μm - JCMT

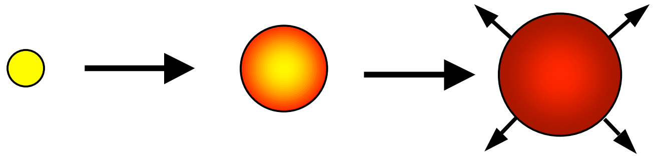


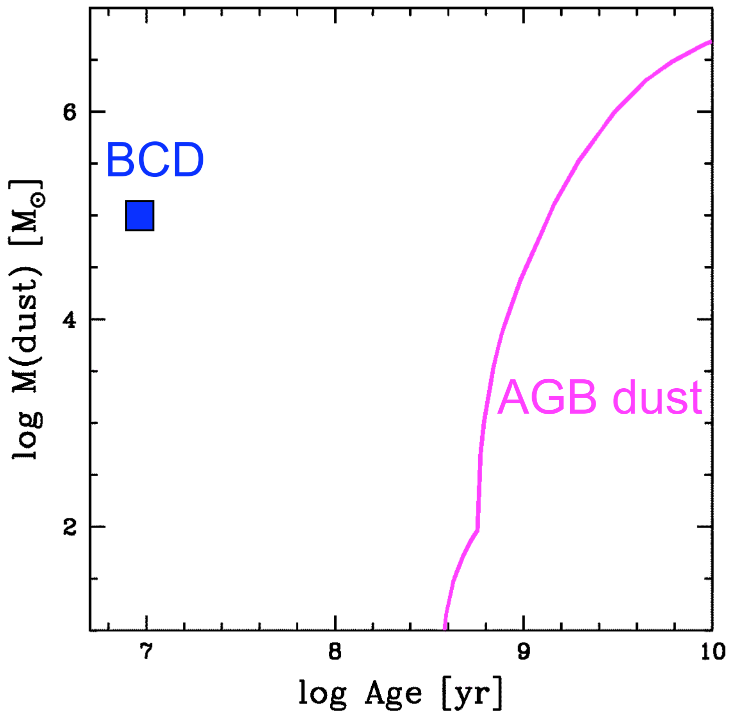
PAH - Spitzer ~ ALMA compact configuration

(~1/30 della massima risoluzione)

The origin of dust

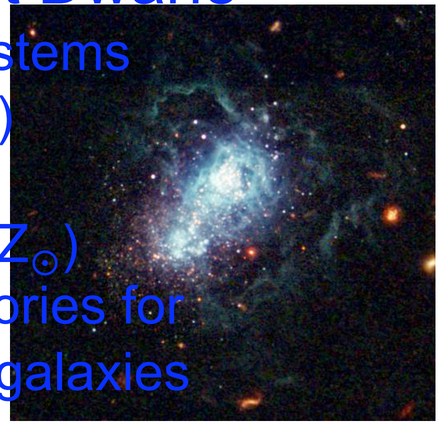
Standard scenario: atmospheres of evolved stars (AGB)





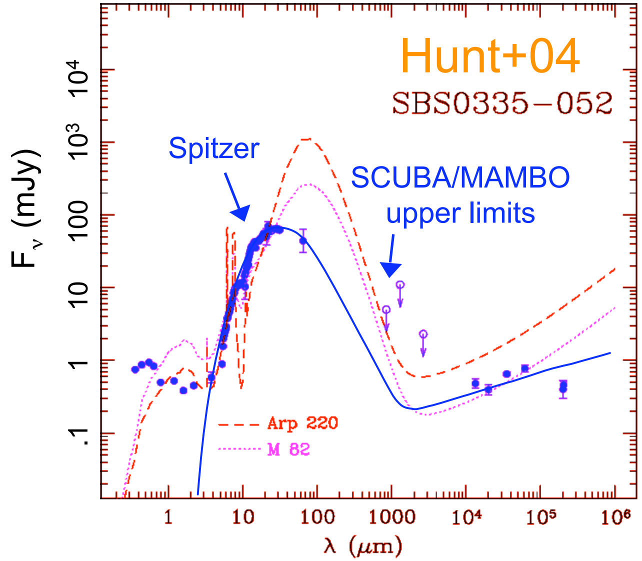
most of the AGB dust is formed after 1 Gyr

Blue Compact Dwarfs



- Very young systems (age ~10^7 yrs)
- Low metallicity (~1/10 - 1/50 $Z_\odot$)

⇒ Local laboratories for high-z primeval galaxies

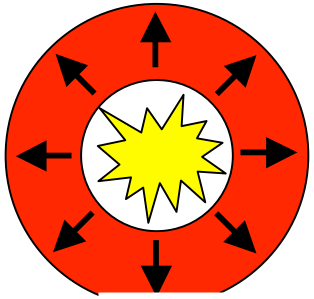


SED markedly different from classical starbursts

Dust mass ~ 10^5 $M_\odot$ (uncertain)

Origin of dust

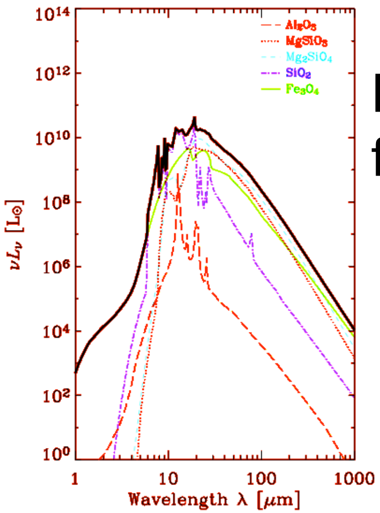
Dust from SNe -> short time scales



(dust yield hotly debated)

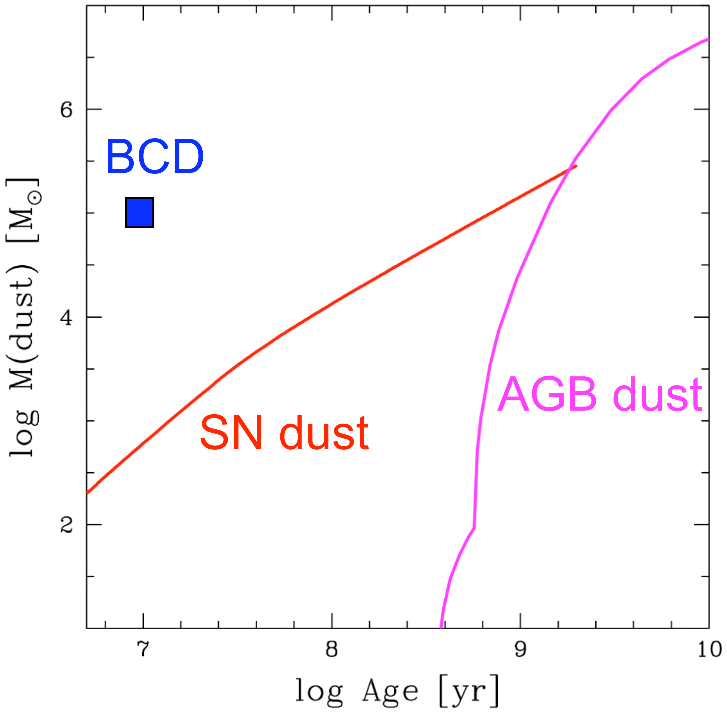
Different dust composition than ISM

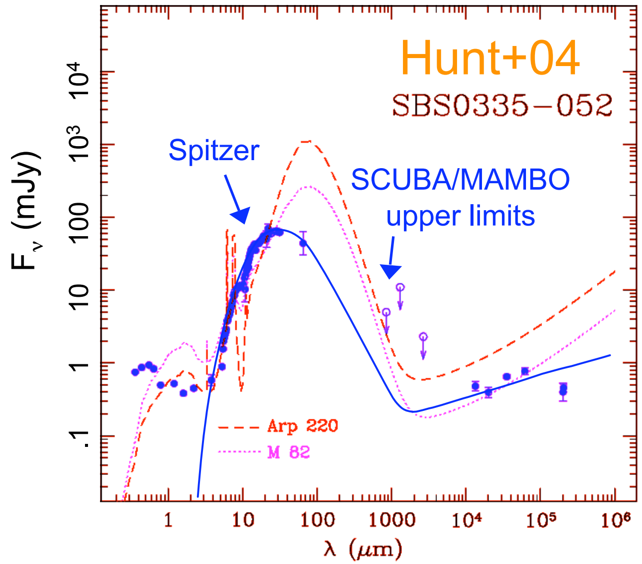
-> different emissivity



Expected SED from SN dust

Takeuchi+05





Even SN dust not fast enough!?

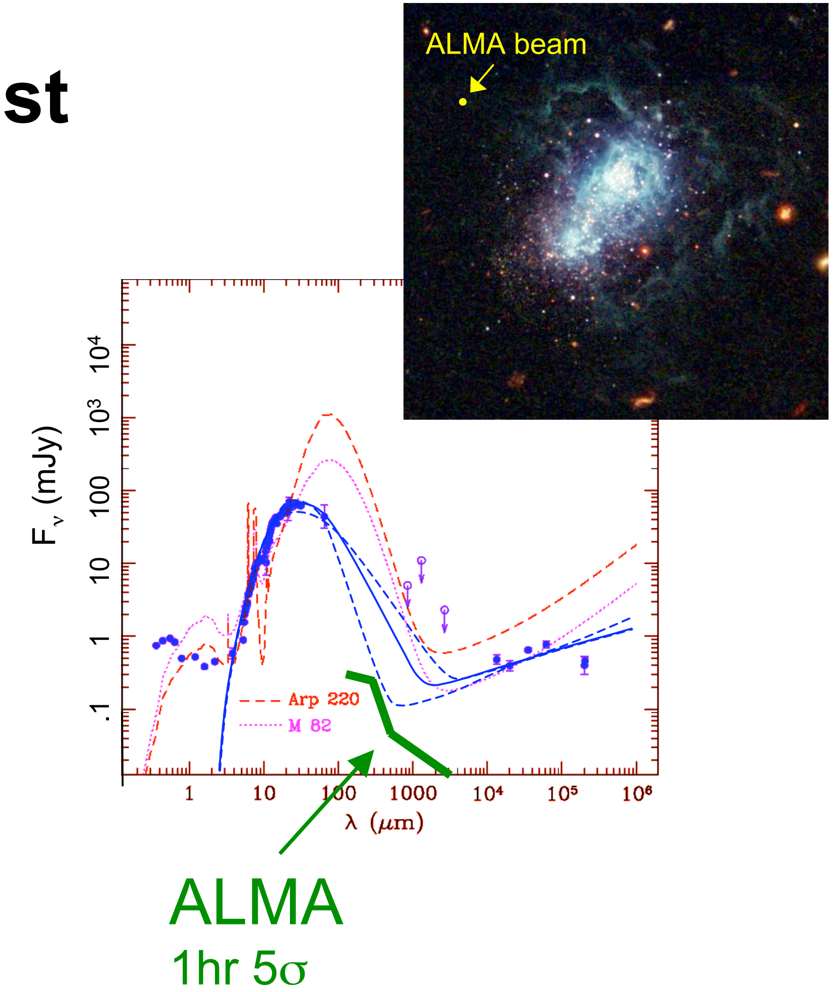
SED markedly different from classical starbursts

Dust mass ~ 10^5 $M_\odot$ (uncertain)

Origin of dust

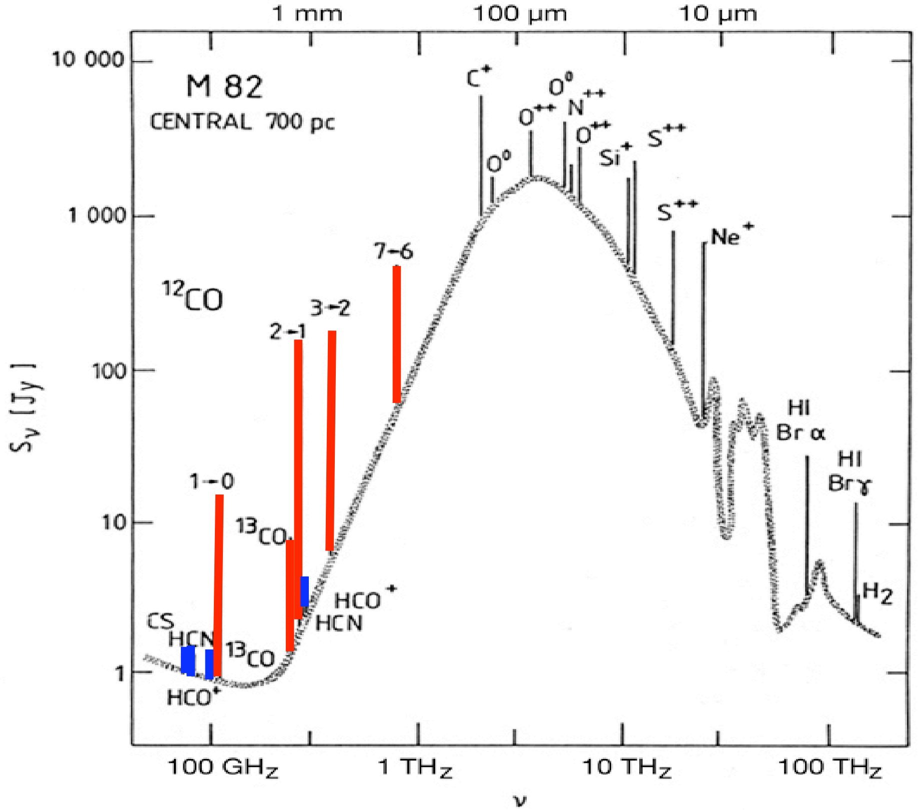
ALMA ~ at least 100 times more sensitive ⇒ will provide accurate dust masses and emissivities, and also locate dust production sites

⇒ pin-down dust formation mechanism and efficiency in the early stages of galaxy formation



(the submm region is the most sensitive to the dust mass and emissivity determination)

Molecular gas



Cold H_2 cannot be detected directly, because it has no dipole moment

CO second most abundant molecule, excited by collision with H2 (brightest mol. lines)

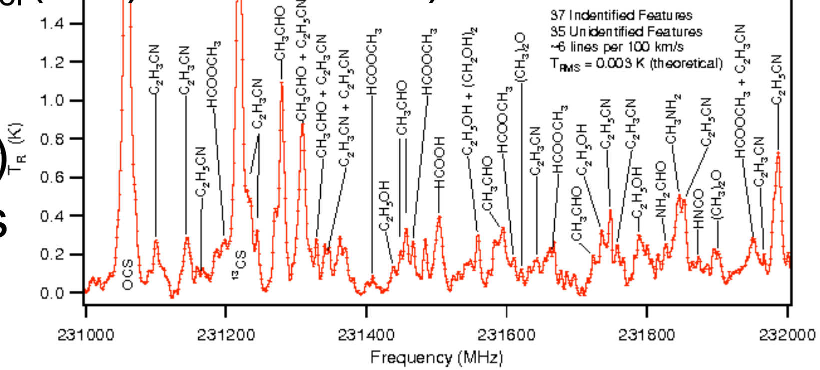
Widely used as H_2 tracer

$$L_{CO} = \alpha \, M(H_2)$$

(conversion factor depends on metallicity and temperature/density)

Tracers of high density gas: HCN, HCO+, ...
critical densities ~10^6-10^7 cm^{-3} (while n_{cr}(CO)~4×10^4 cm^{-3})

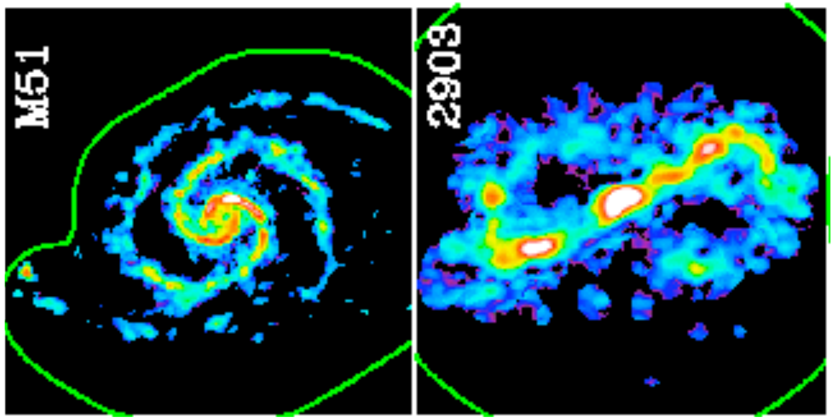
Forest of molecular transitions in high S/N spectra (~80 lines/1GHz) tracing different properties of the gas



Molecular gas distribution in galaxies

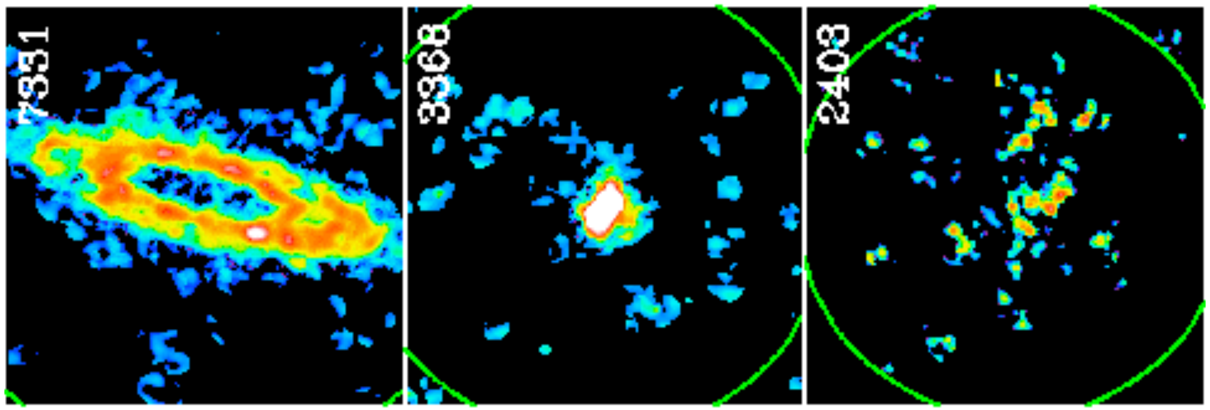
A variety of morphologies

Spiral Barred



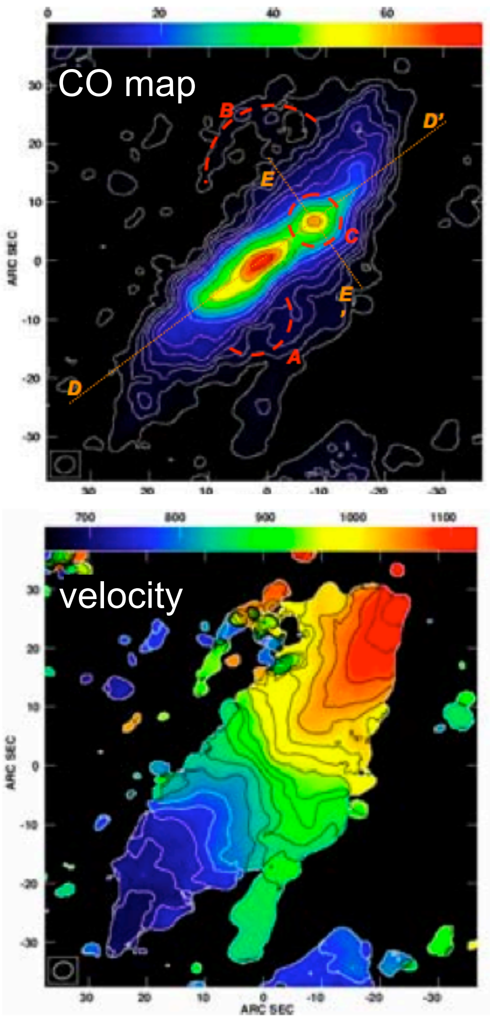
BIMA
SONG

Ring Nuclear Irregular



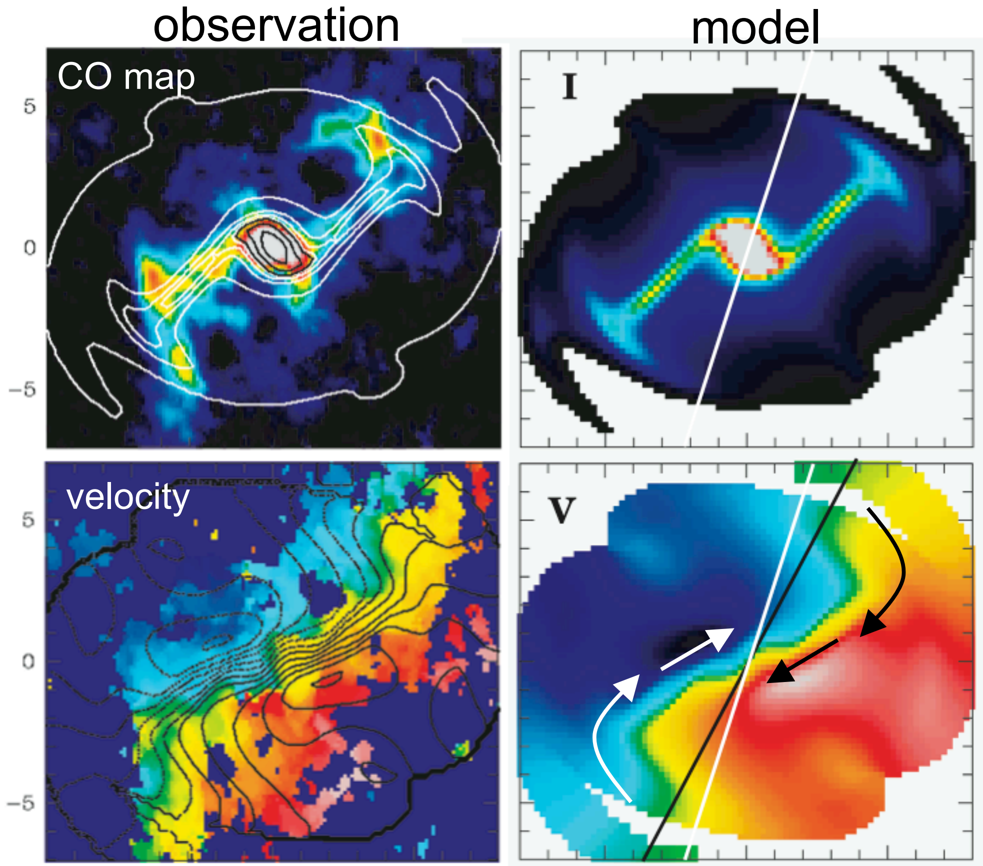
Molecular gas dynamics

disk rotation ($\Rightarrow M_{dyn}$)



Tsai+07

streaming motions in bars

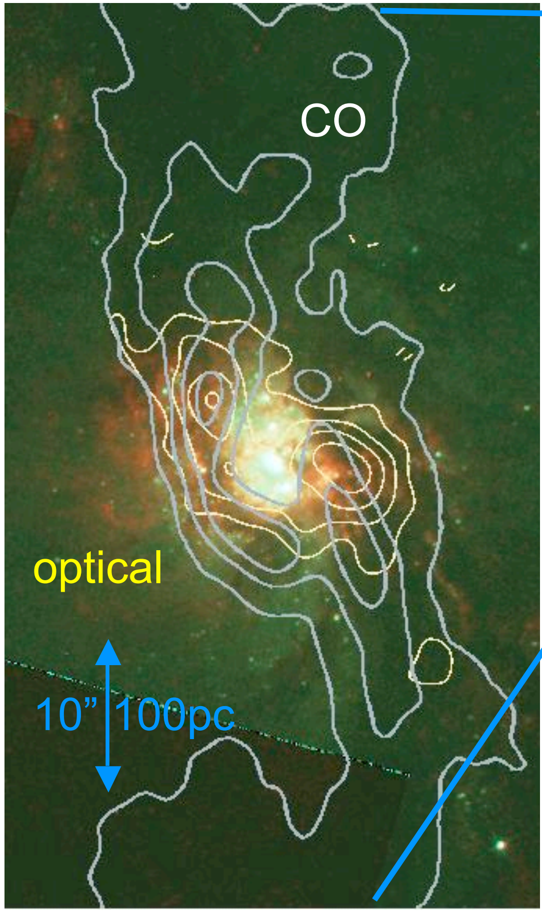


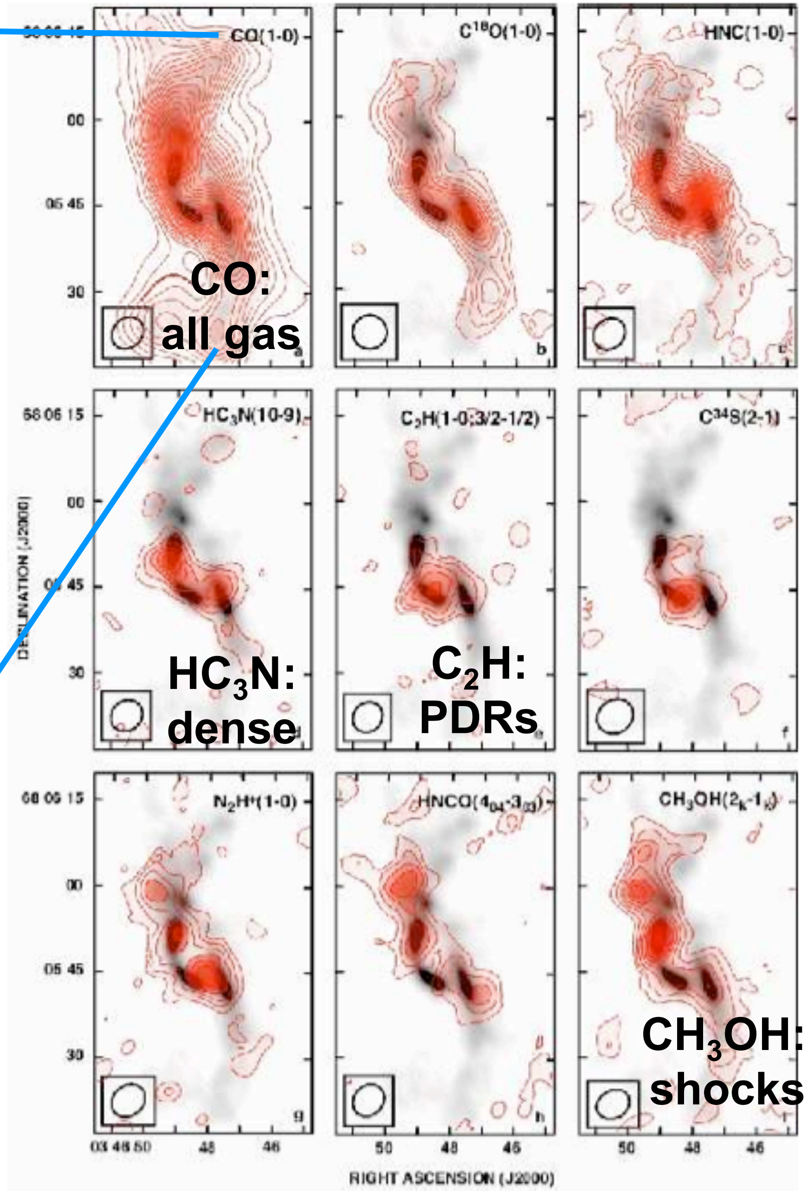
Schinnerer+07

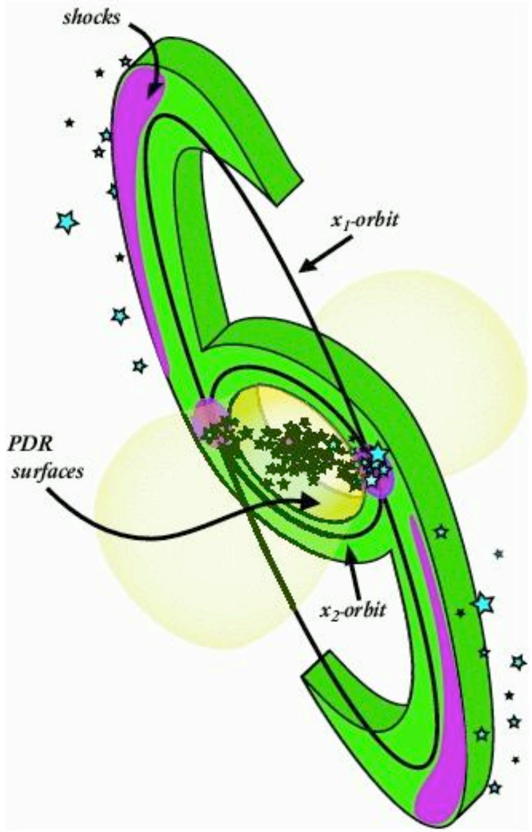
the bar potential drives
gas into the center

Astrochemestry -> diagnostic tool

IC342 D = 2 Mpc





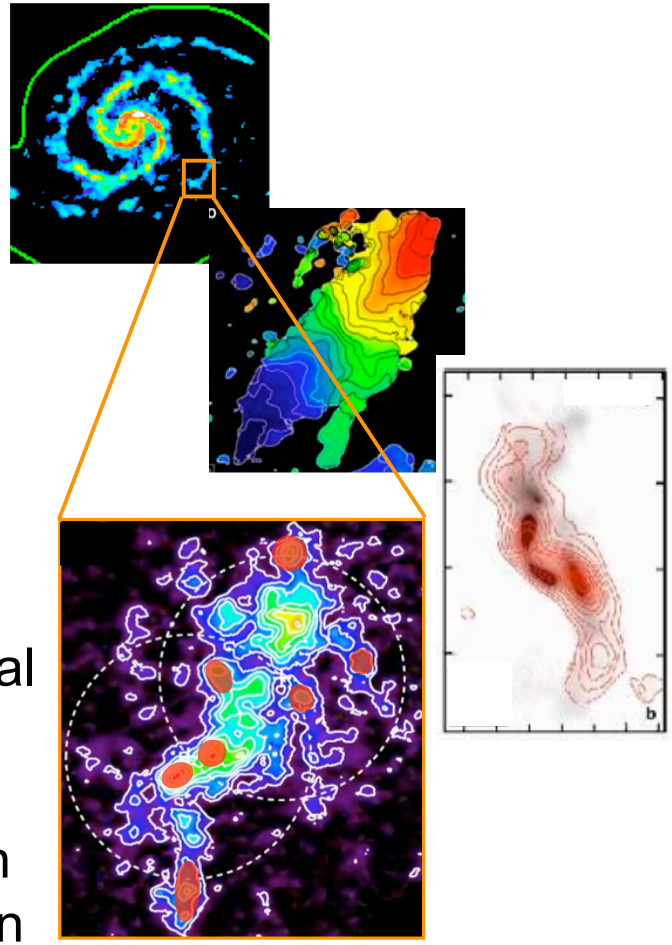


Meier & Turner 2004

ALMA will:

- Resolve these structures and kinematics in high-z galaxies

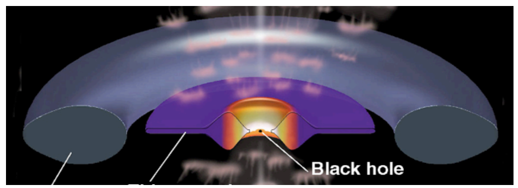
- The same detailed information currently obtained on nearby galaxies will be obtained in galaxies at ~100-500 Mpc (-> mergers, powerful starbursts, QSOs,...)



- In nearby galaxies ALMA will resolve individual molecular clouds (~1pc) -> mass function

- Trace at the same time star formation through continuum emission -> map the star formation efficiency (SFE)

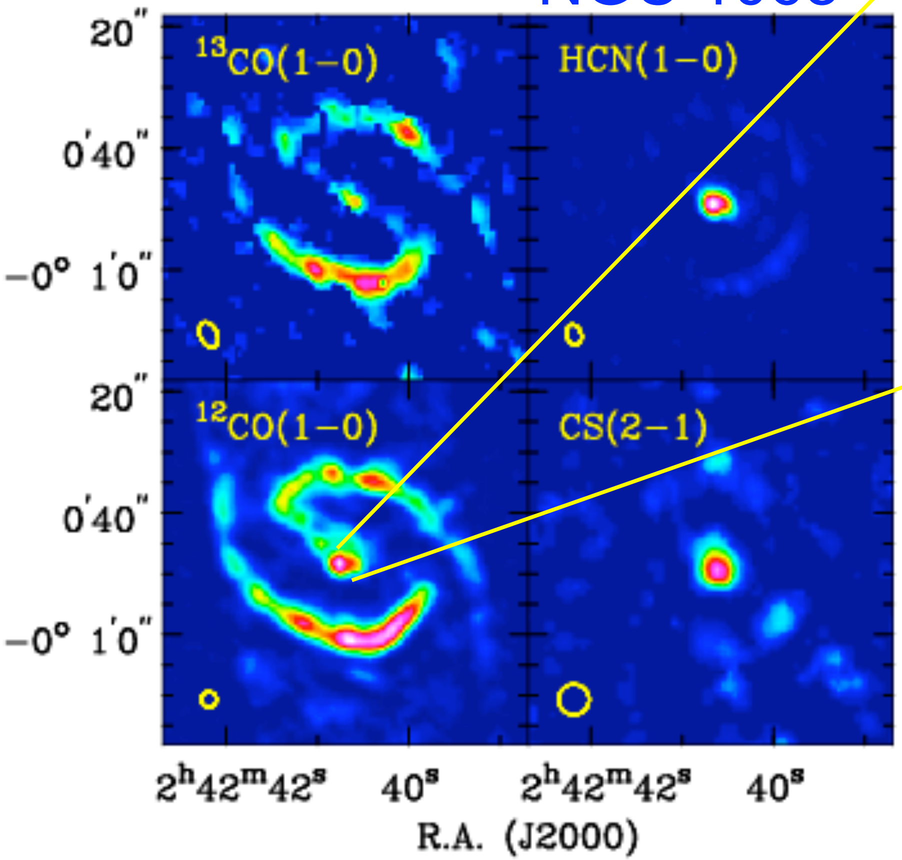
-Trace molecular gas around AGN and supermassive black holes (unified model, BH feeding and masses)

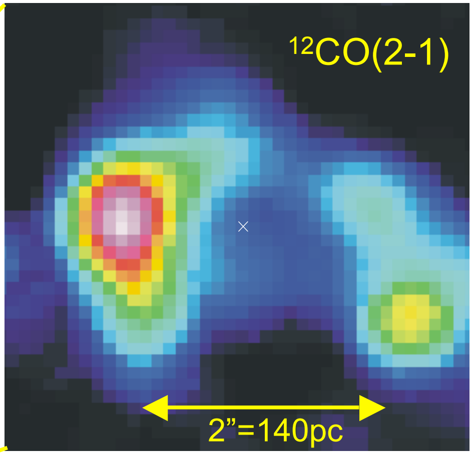


The feeding of Active Galactic Nuclei is still a puzzle

specially from the ~100pc to the ~1 pc scale

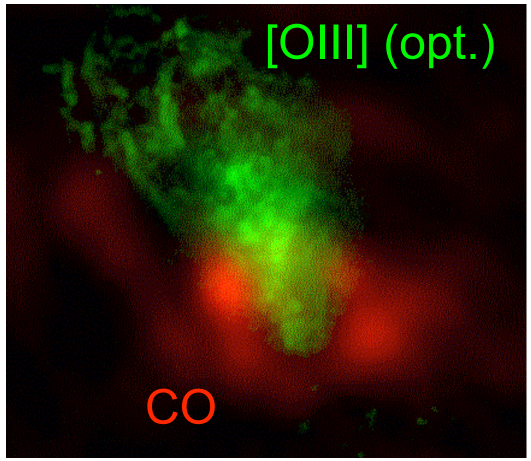
NGC 1068



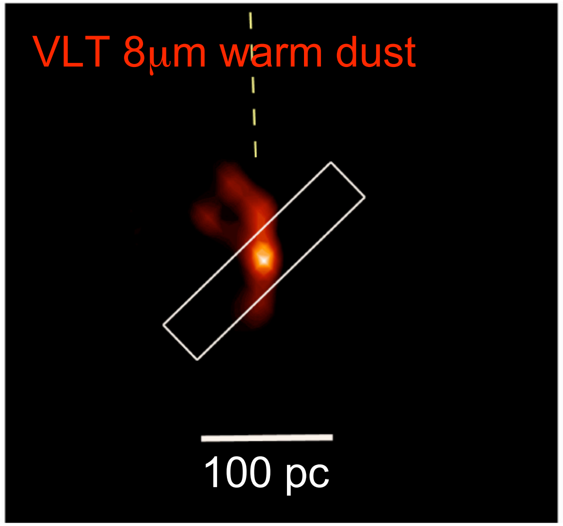


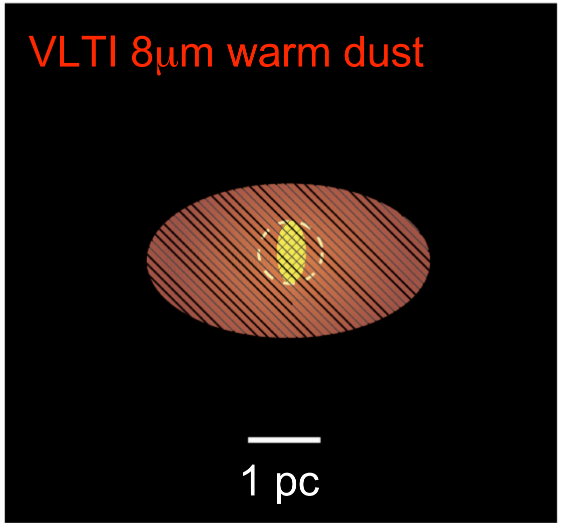
molecular “hole”
inside the
100pc ring

Schinnerer+00

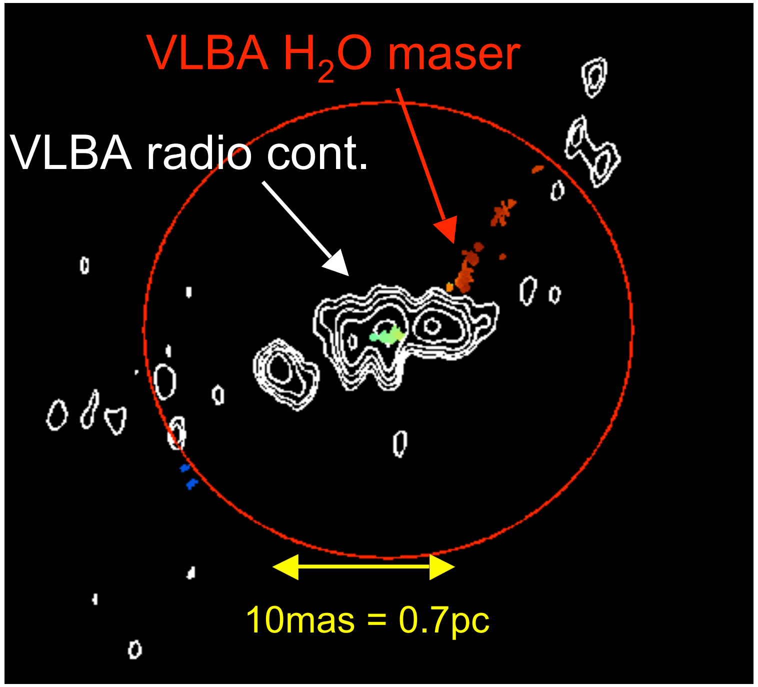


But we know that inside the central parsec there is a strong concentration of gas/dust





powerful nuclear (pc-scale) warm dust emission

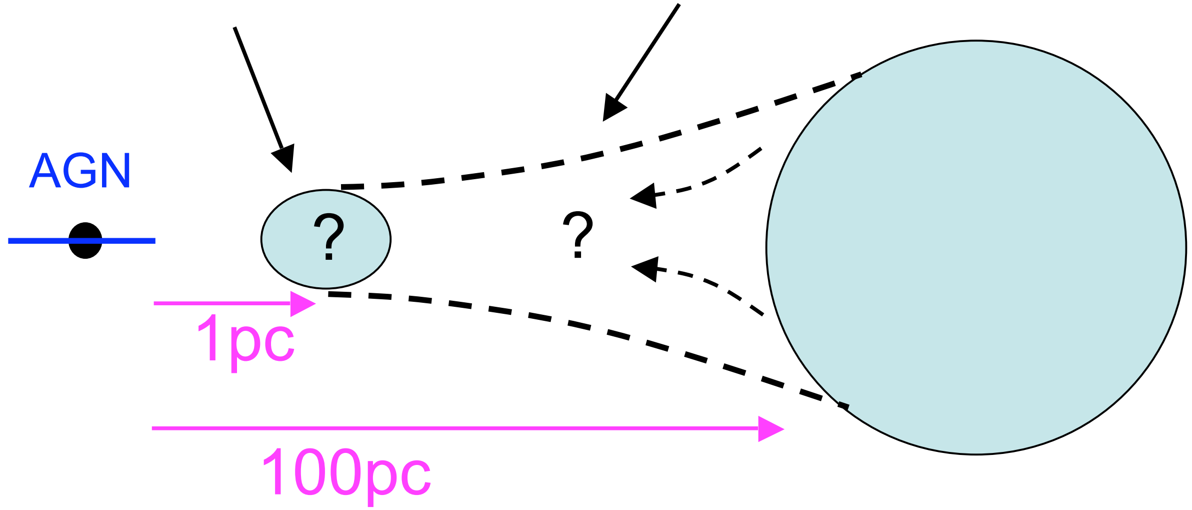


nuclear (pc-scale) H_2O maser disc

Gallimore+97
Greenhill+97

Why the nuclear component is not detected in CO?

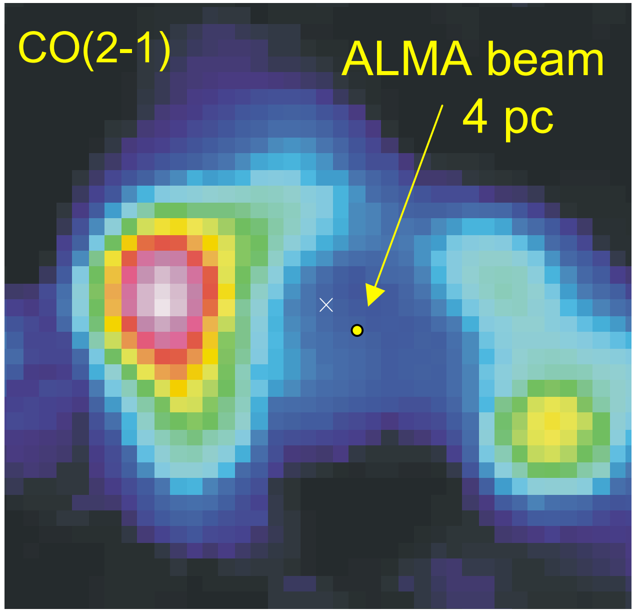
How does the molecular gas manage to flow from the 100pc ring/torus to the inner pc?



Beam dilution?
Hot and dense gas?
Totally dissociated?

ALMA will allow us to tackle these issues

e.g. NGC1068

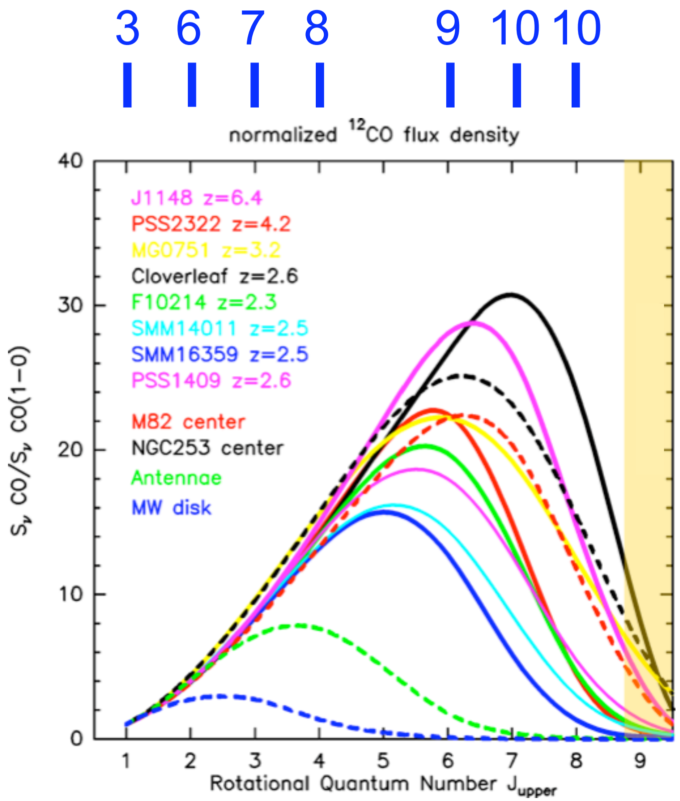


Resolve the innermost region

Trace high temperature and high density gas tracers

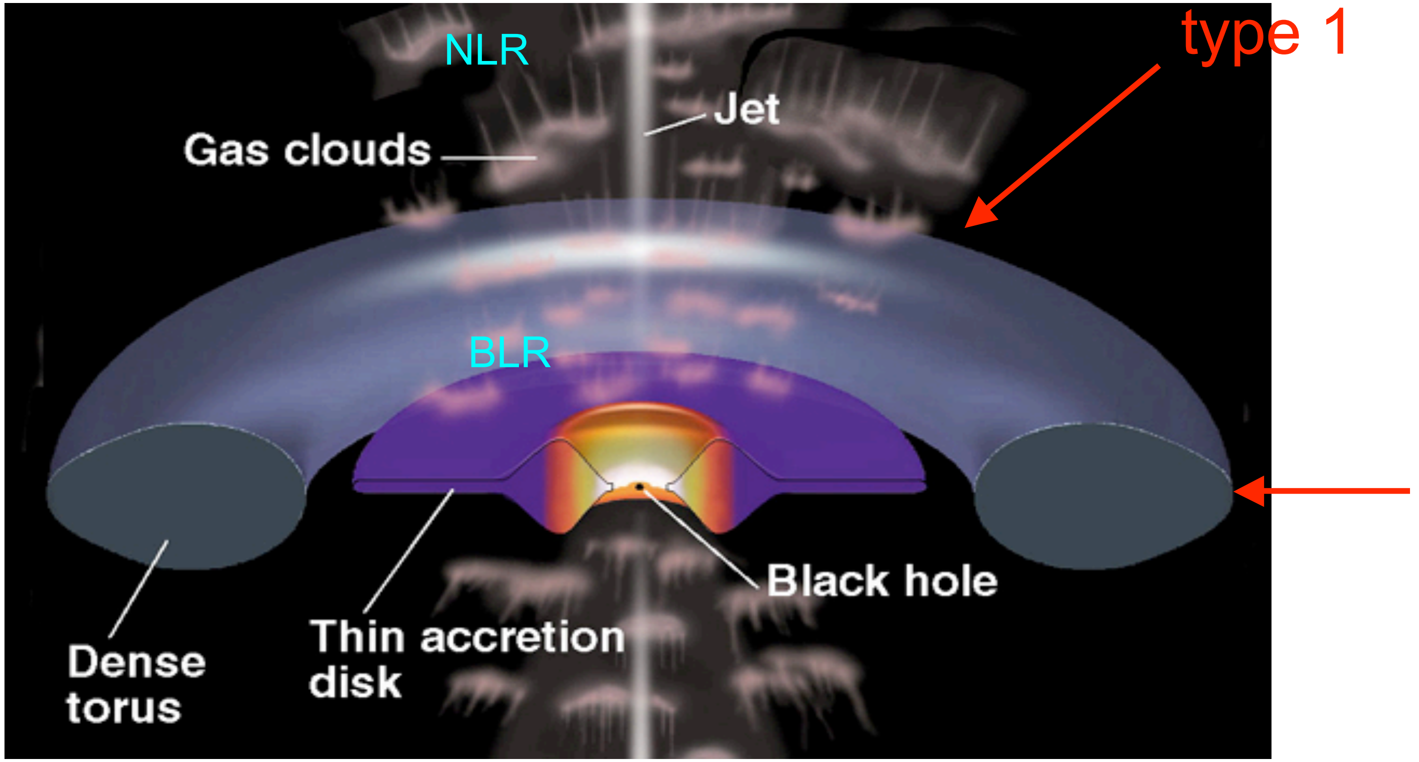
(also HCN, HCO+...)

ALMA bands



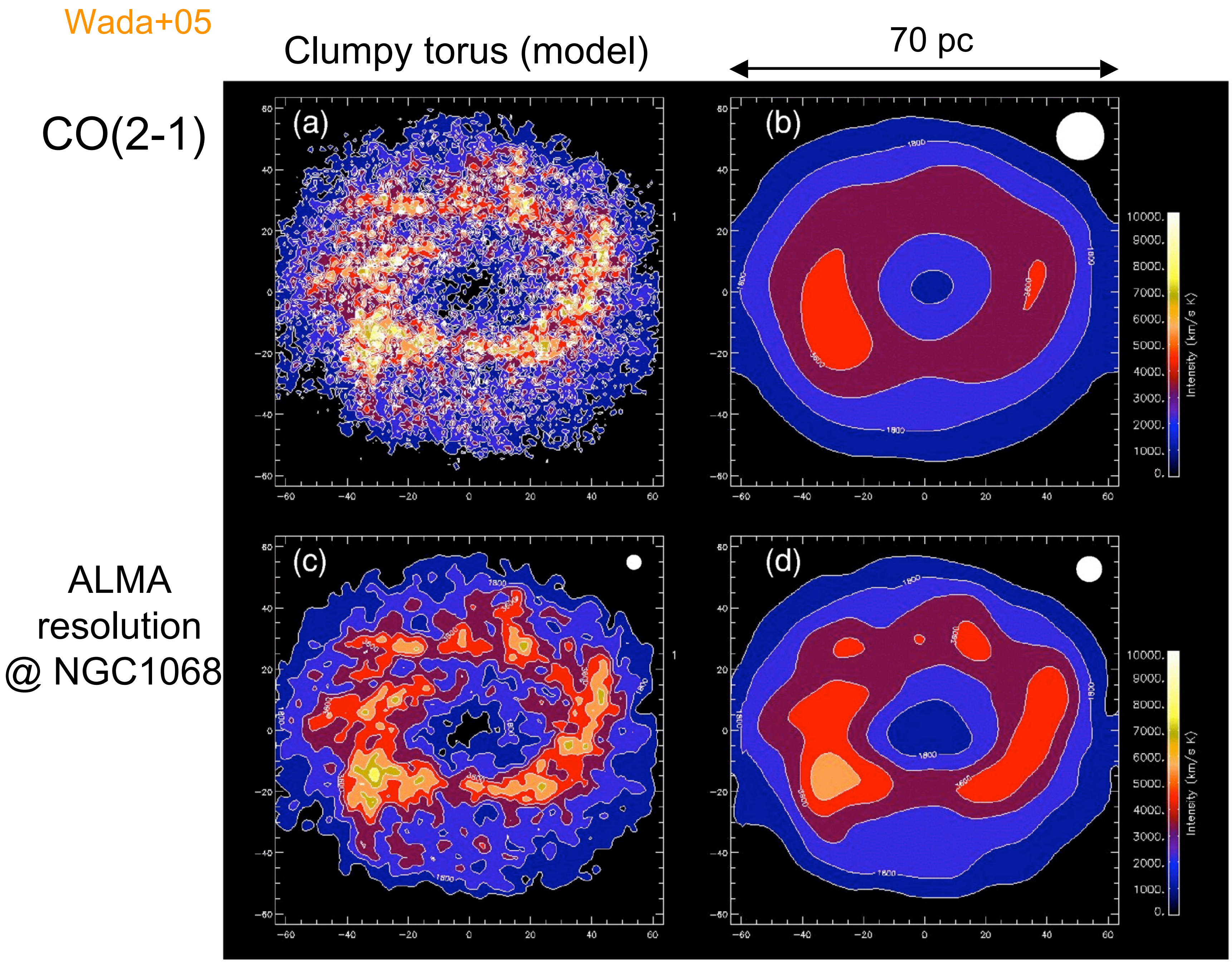
Weiss+07

Related issue: the obscuring torus in the unified model of AGNs

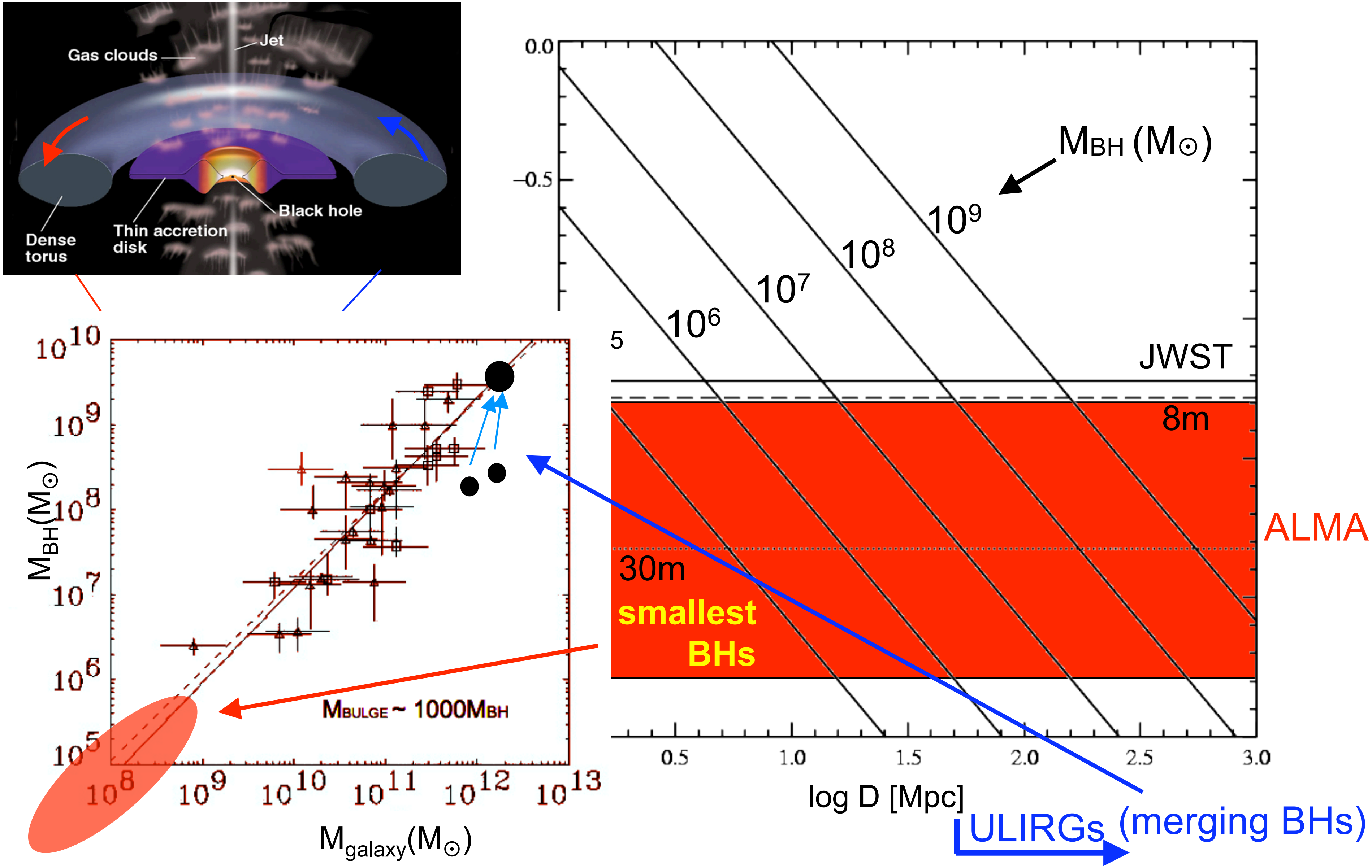


Several (competing) models:

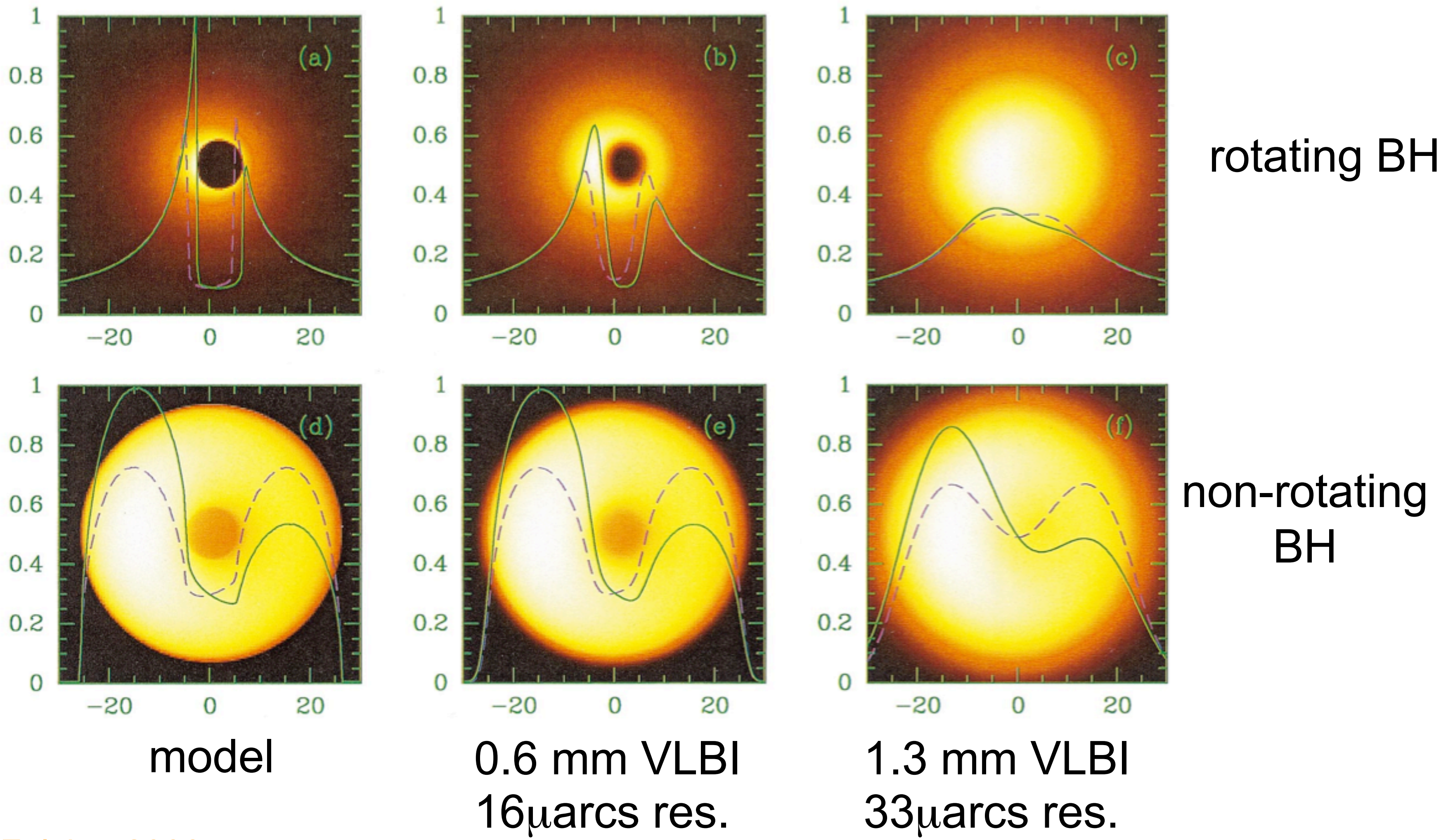
Geometry		Dynamics		Structure	
large ~100 pc	small ~1 pc	rotation	rotation and outflow	cont./diff. medium	clumpy medium
(observed)	**(ALMA)**	**(ALMA)**		**(ALMA)**	


Wada+05
Clumpy torus (model)
70 pc
CO(2-1)
ALMA
resolution
@ NGC1068
(a)
(b)
(c)
(d)
Intensity (km/s K)
1800
3600

Measuring Black Hole masses in galactic nuclei



A “picture” of the Galactic Center Black Hole taken with ALMA + mm VLBI



Falcke+2000

Merging of galaxies

Main triggering mechanism of strong starburst galaxies

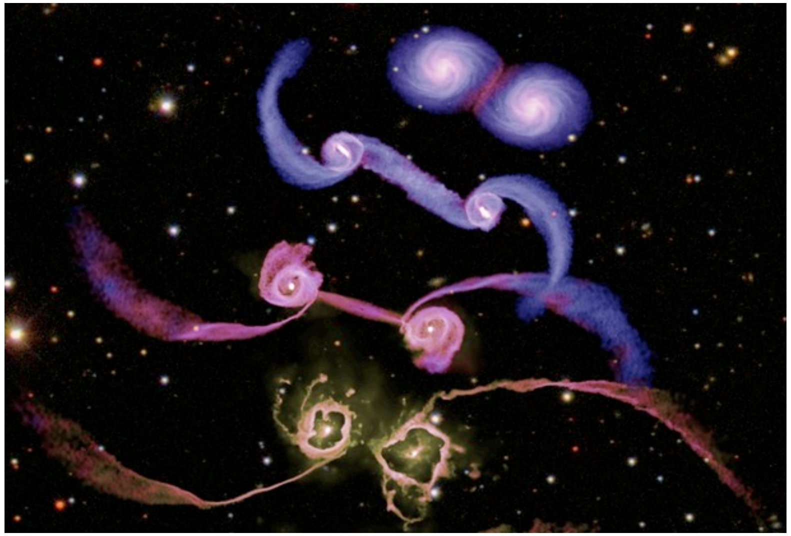
(all galaxies with SFR>100 Msun/yr are merging strongly interacting)

Triggering mechanism of AGN

(most merging systems host an AGN)

Crucial phase of galaxy evolution (“hierarchical” formation of gals.)

Galaxy merger simulations: behaviour of gas



Di Matteo+05

(see movie)

- Extended, diffuse tidial tails, but most of the gas collapses towards the nuclei (see also Barnes & Hernquist 1996)

- Strongly enhanced star formation
  -> starburst winds

- Black-Hole accretion -> AGN

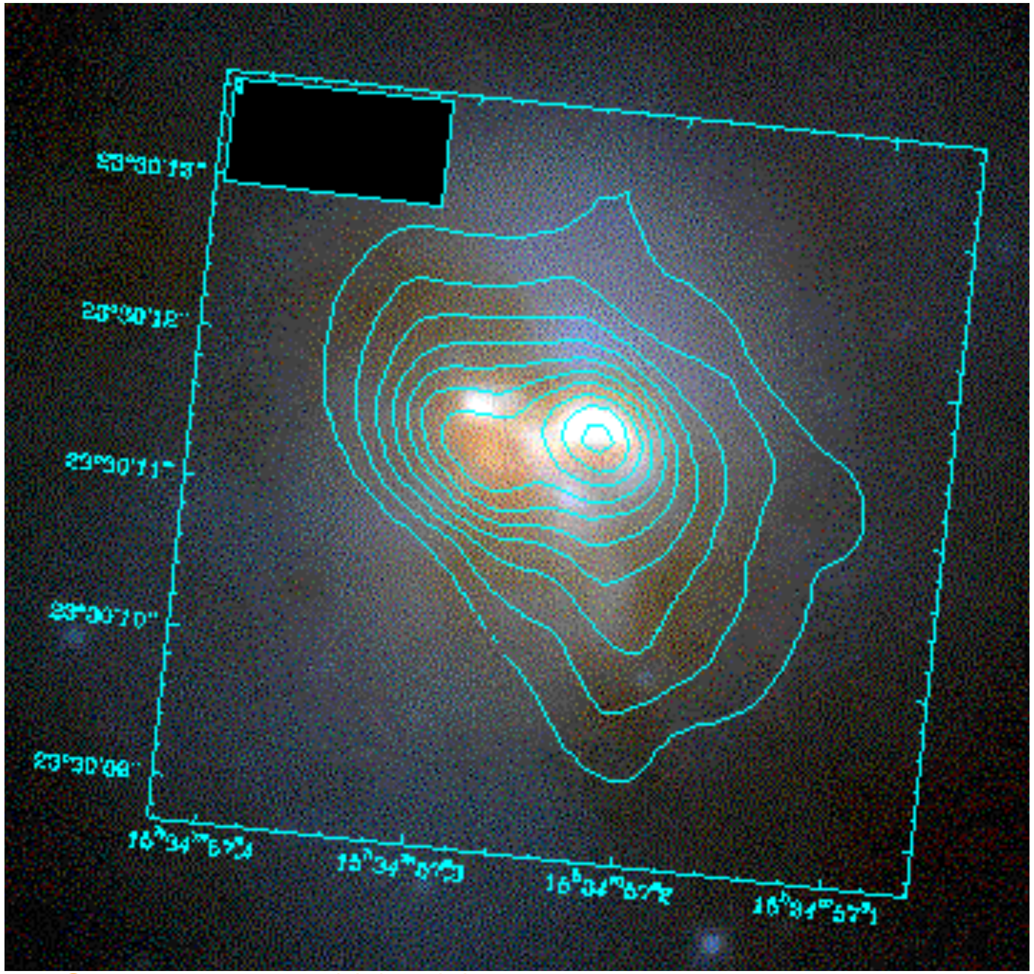
- QSO winds eject most of the gas in the galaxy -> stops star formation (see also Granato et al. 2004)

- An elliptical galaxy is formed

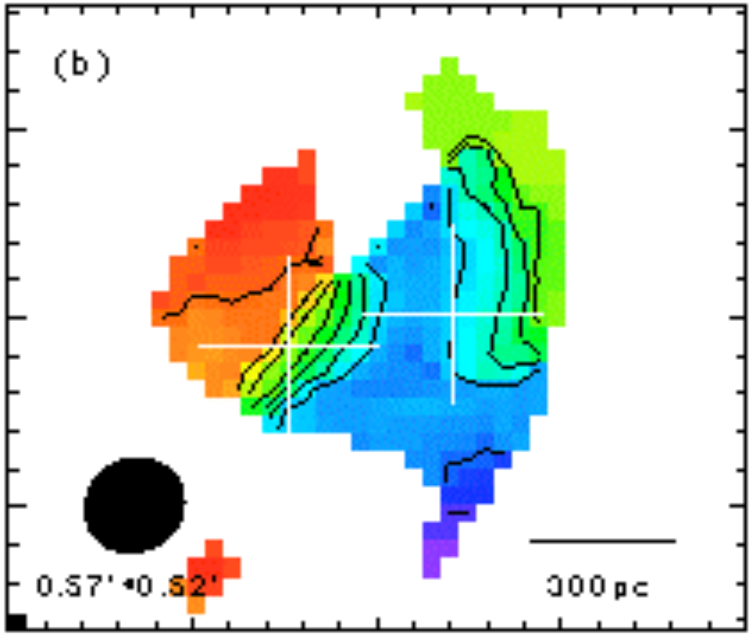
- The QSO feedback manages to keep $M_{BH} \propto M_{gal}$ (for experts: it also accounts for downsizing)

Preliminary tests with current facilities

Arp220: the closest (D=75Mpc) strongly merging system



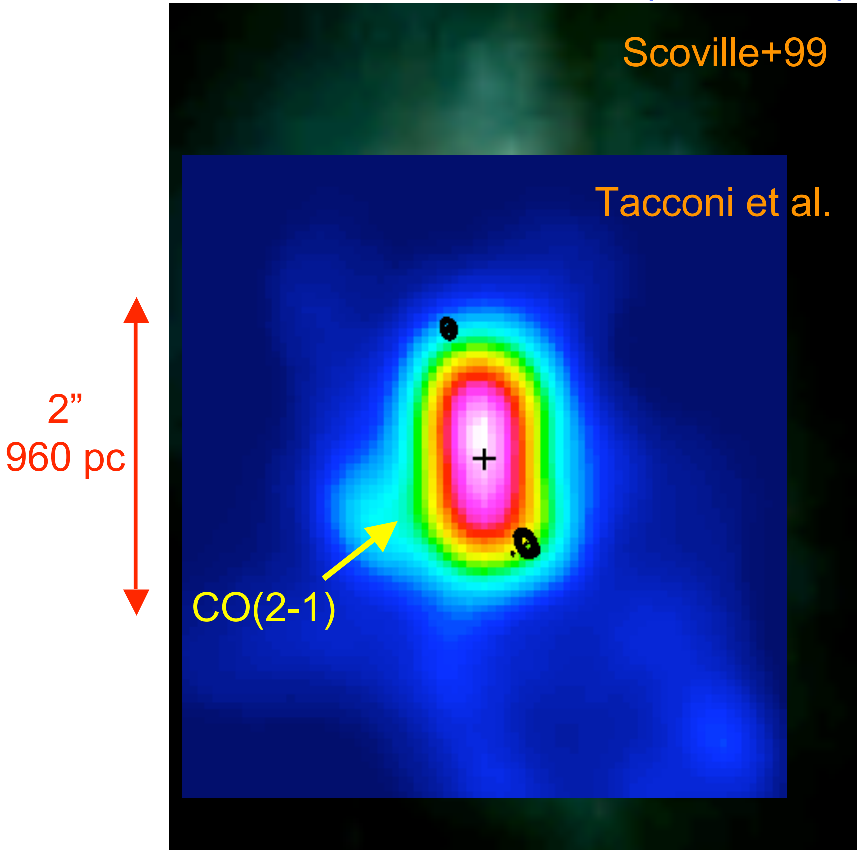
Scoville et al. 1997,98,
Downes and Solomon 1998
Sakamoto et al. 1999

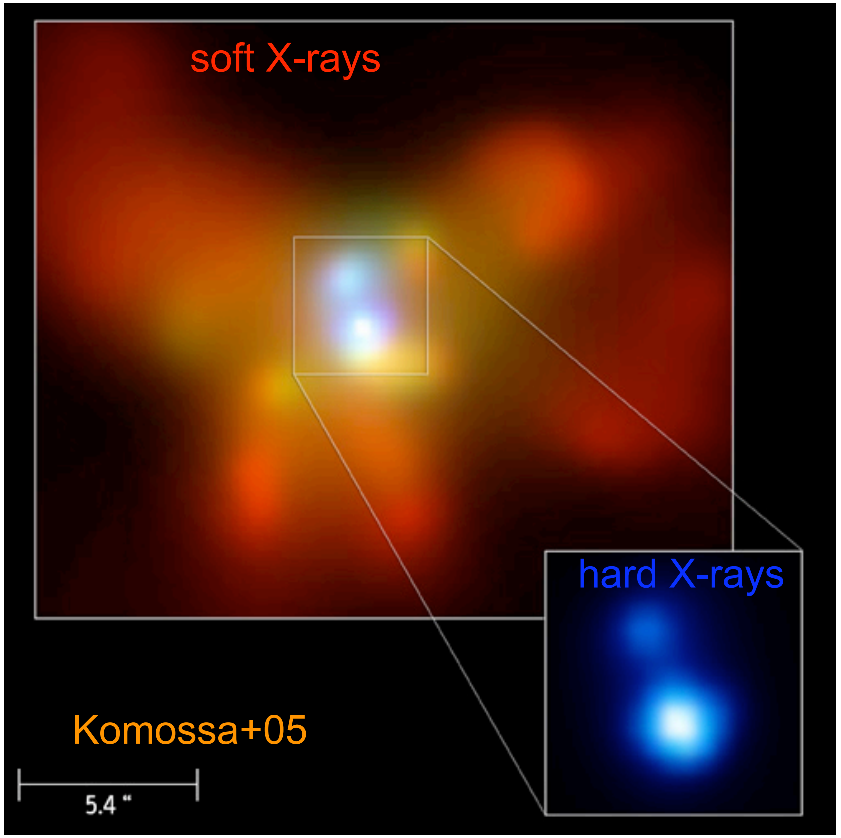


gas accumulated onto the two nuclei in thick rotating disks (in agreement with simulations)

NGC6240: strongly, advanced merging system

Huge amount of molecular gas, most of it in the region
between the two nuclei (probably the center of mass) NOT on the nuclei



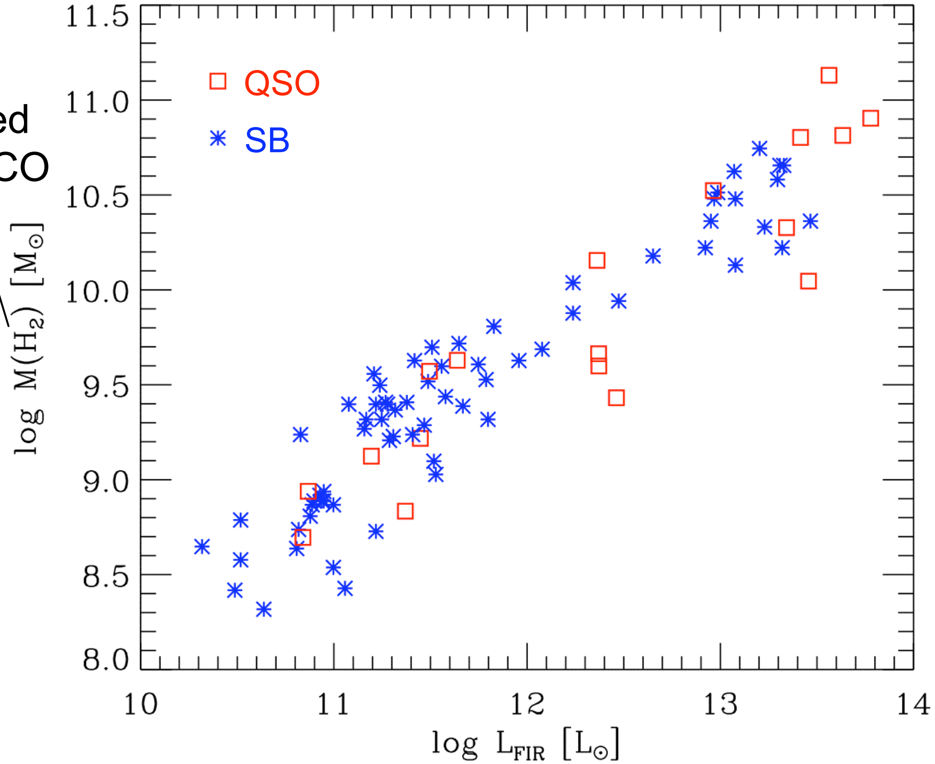


It hosts two QSOs (as expected by
simulation in the advanced merging phase)
but both of them are heavily obscured (N_H>10^{24} cm^{-2})
-> QSO wind/feedback seems little effective here

Additional issue

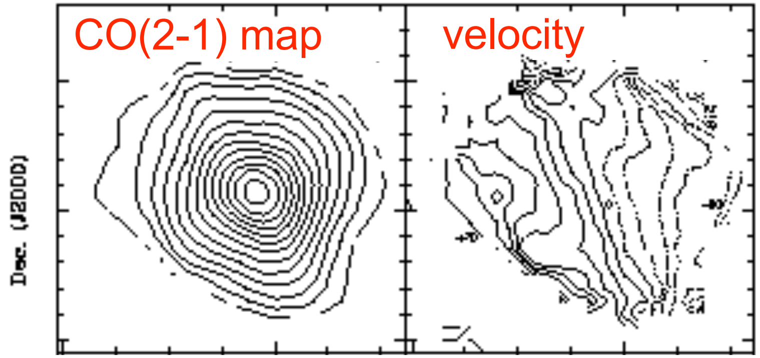
Many (unobscured) QSOs show large quantities of molecular gas

derived from CO



Models expect little redisual gas during the QSO phase

Mkn231, the closest ~QSO

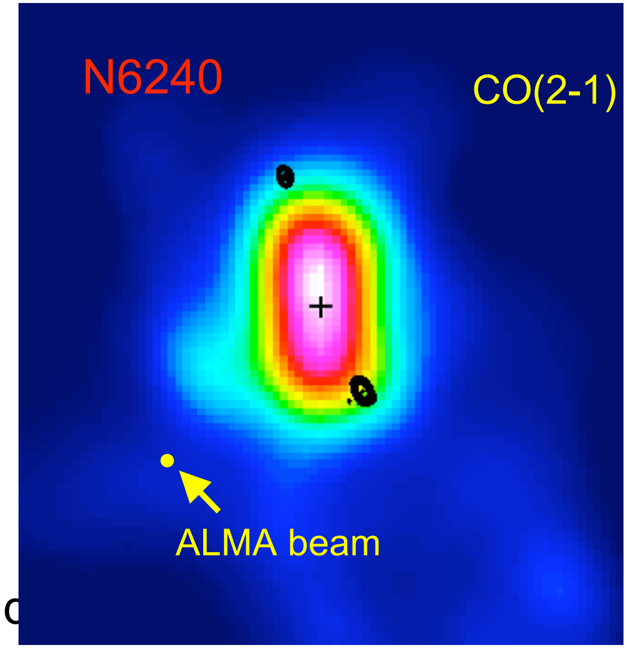


regular rotation...

models expect strongly distorted, post-merging morphology and velocity field (but poor resolution)

ALMA will allow us to tackle these issues:

by providing detailed molecular gas maps in merging / interacting systems



- Do the merging nuclei have dense concentrations of molecular gas?
- Measure multiple transitions-species: is the conversion factor CO-> H_2 much higher than "stand
- Is the gas in the center of star forming stars? (avoiding the feedback from the QSOs). Or low SFE

by obtaining detailed information of molecular gas properties in powerful of QSOs

- Kinematical evidence for recent merger?
- Large population of gas-poor QSOs?

HST / IRAM-PdBI CO(2-1) images of a powerful QSO