ALMA: prospects for AGN studies

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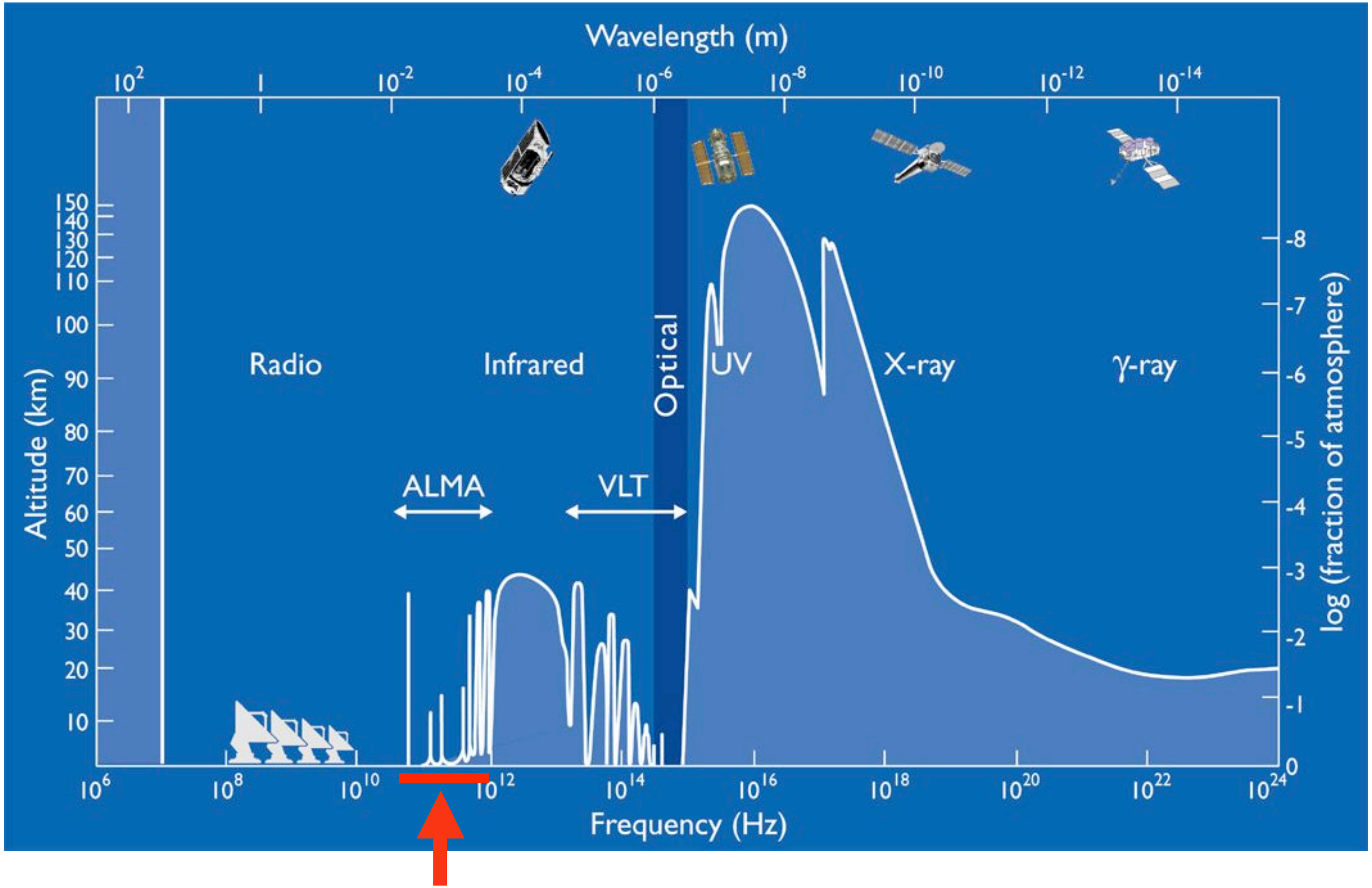
Outline:

Lecture 1
Short description of current sub/mm facilities
Short introduction to sub/mm extragalactic astronomy
Current/past sub/mm studies of AGNs

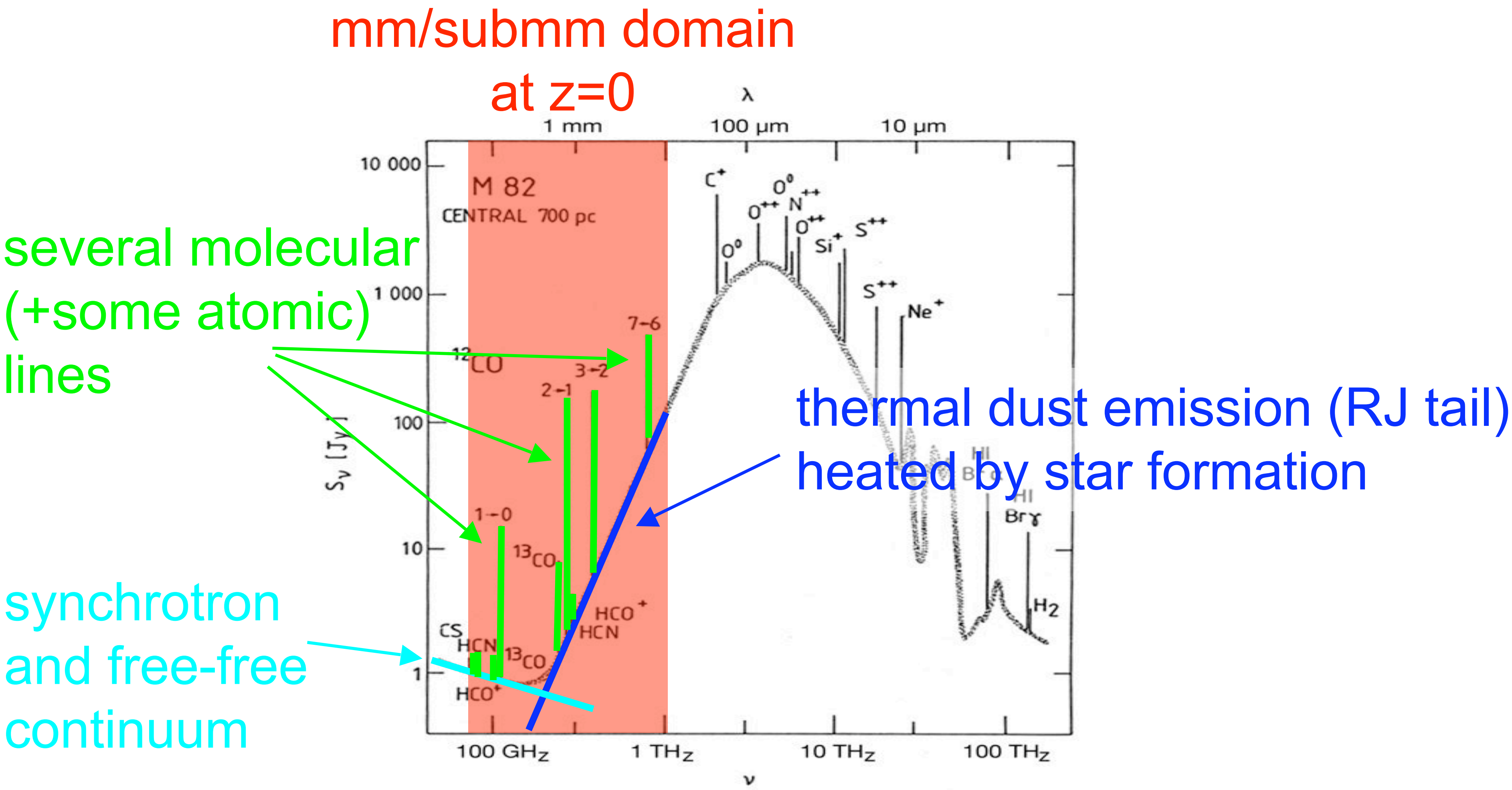
Lecture 2
ALMA description and capabilities
ALMA expectations for AGN studies

mm/submm astronomy

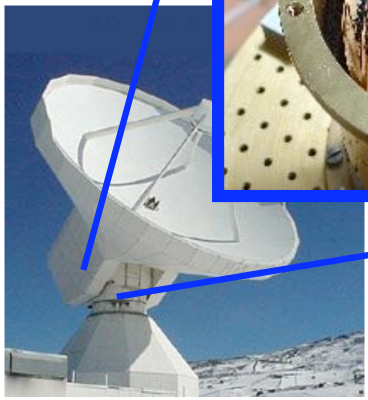
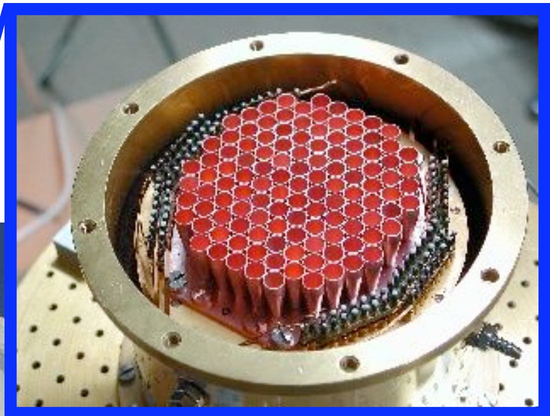


30-950 GHz = 10-0.3 mm

The IR-mm spectrum of a starburst galaxy

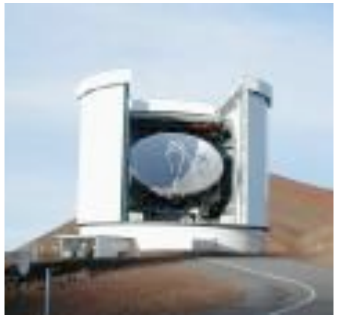


…acilities: single dish
…ontinuum mapping

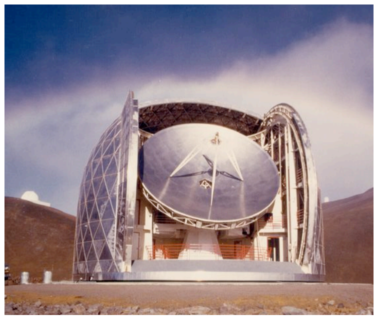
…1mm
het. receivers (spectr.)
MAMBO: 117 x bol. array
(cont.) FOV ~ 3 arcmin^2

APEX 12m
$\Delta\lambda$ = 350μm-1mm
beam ~ 18” at λ=870 μm
het. receivers (spectr.)
LABOCA: 295 x bol. array
(cont.) FOV ~ 11 arcmin^2

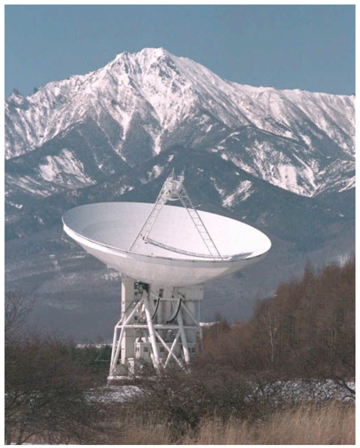


JCMT 15m
$\Delta\lambda$ = 450μm-1mm
beam ~ 15” at λ=850 μm
het. receivers (spectr.)
SCUBA-2: 10^4 x bol. array
(cont.) FOV ~ 50 arcmin^2
(12xSCUBA)

ASTE 10m
$\Delta\lambda$ = 350-850μm
beam ~ 17” at λ=870 μm
het. receivers (spectr.)



CSO 10.4m
$\Delta\lambda$ = 350μm-1mm
beam ~ 9” at λ=350 μm
het. receivers (spectr.)
SHARC-II: 384 x bol. array
(cont.) FOV ~ 2.5 arcmin^2



Nobeyama 45m
$\Delta\lambda$ = 3mm-1cm
beam ~ 15” at λ=3 mm
het. receivers (spectr.)

Current sub/mm facilities: interferometers

mostly, high resolution (& high sensitivity) line images

IRAM PdBI
6 x 15m antennas
max ang. res = 0.35”
λ= 1-3 mm
(highest sensitivity)

OVRO 6 x 10.4 ant.
λ = 1-3 mm

BIMA 10 x 6m ant.
λ = 1-3 mm

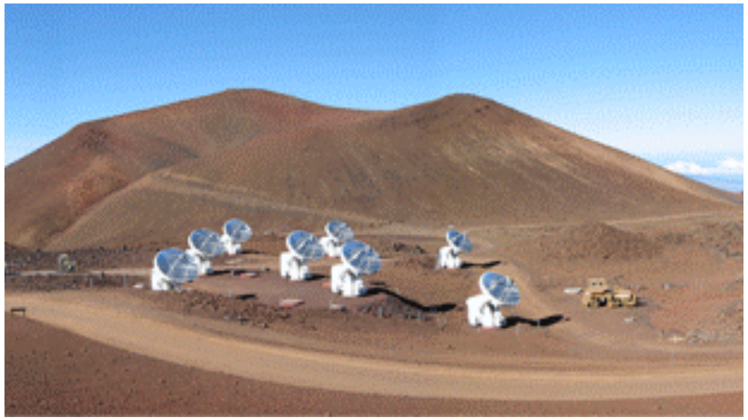
CARMA

max ang. res. = 0.1”

new wide band receivers (=> continuum)

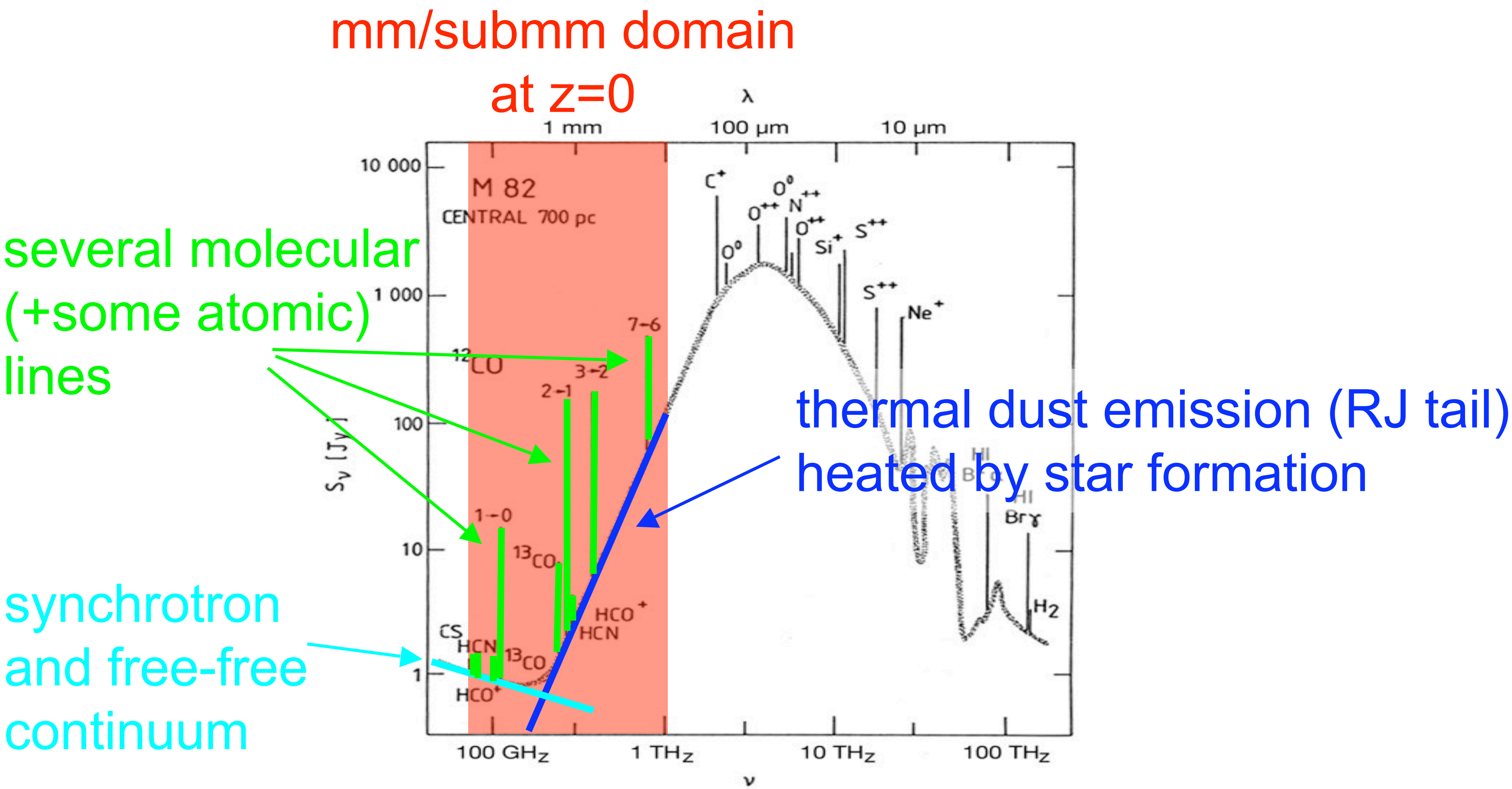
Current sub/mm facilities: interferometers

NMA
6 x 10m ant.
λ = 1mm-2mm-3mm
max ang. res. = 1”



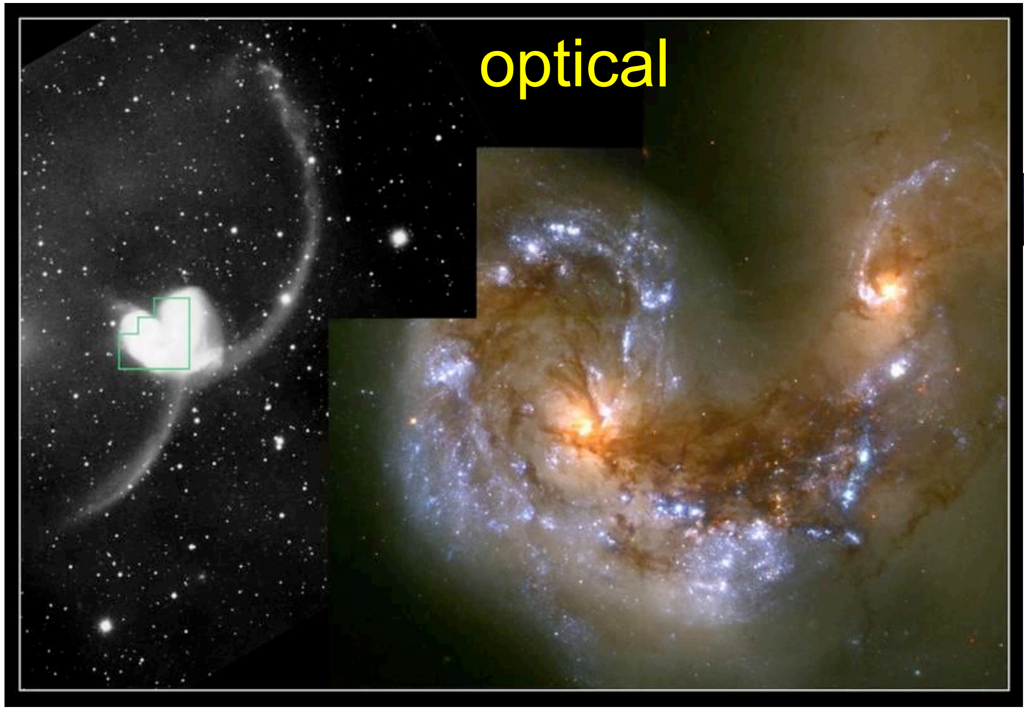
SMA
8 x 6m ant.
λ= 350μm-850μm-1mm
max ang. resol. = 0.1”

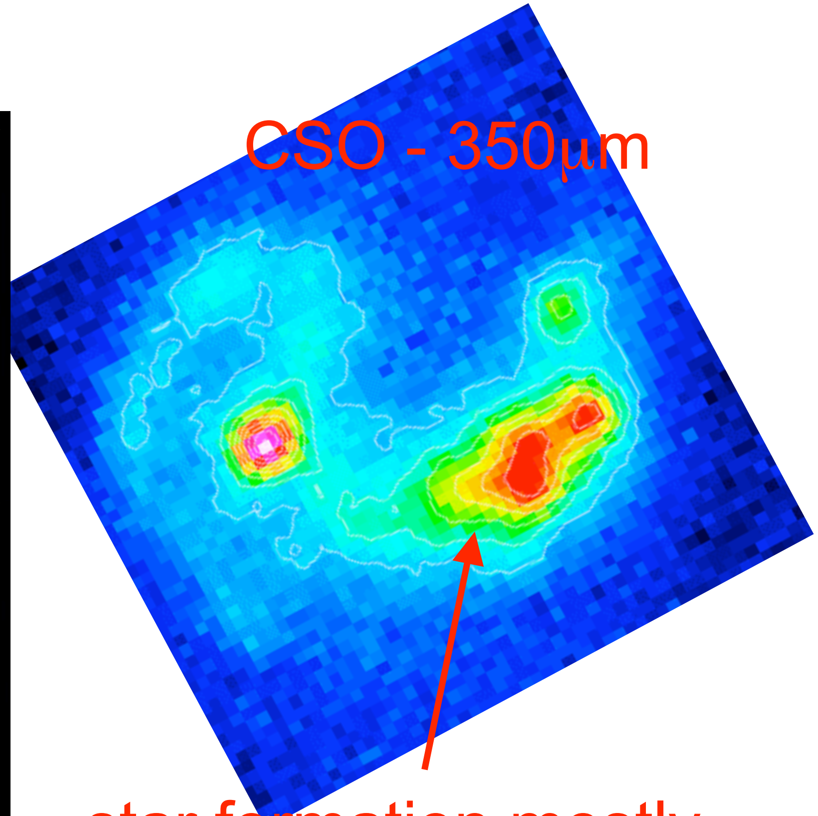
The IR-mm spectrum of a starburst galaxy



Dust thermal emission

Excellent tracer of star formation
not affected by dust extinction

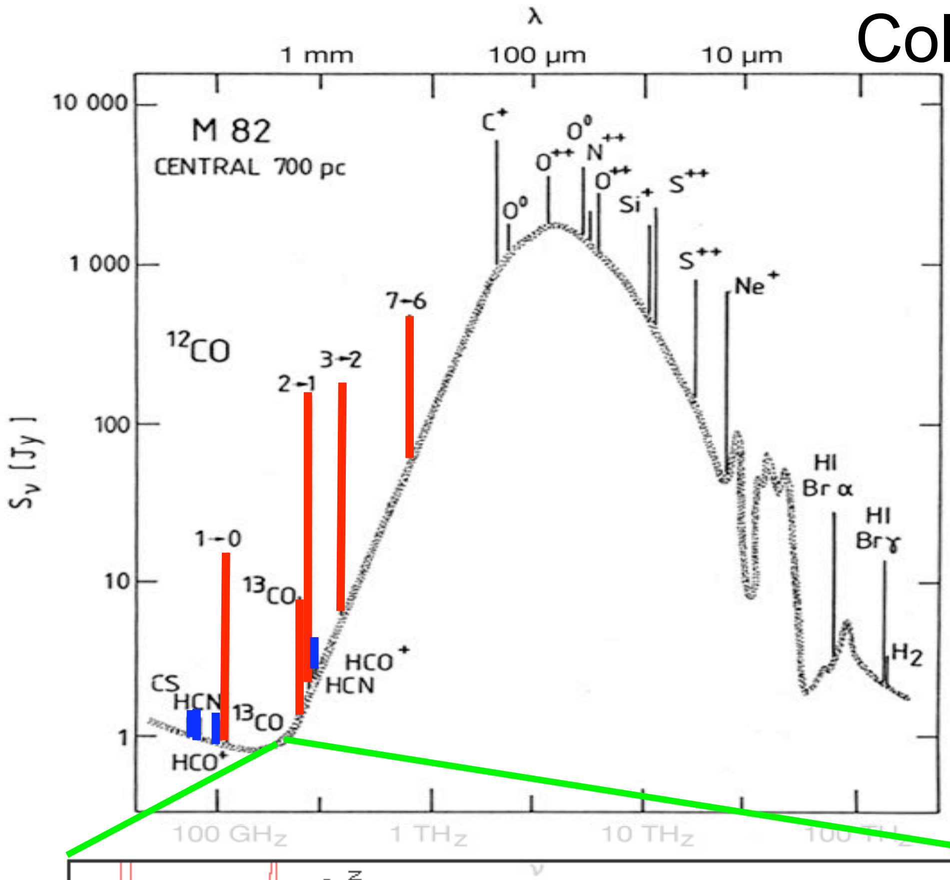


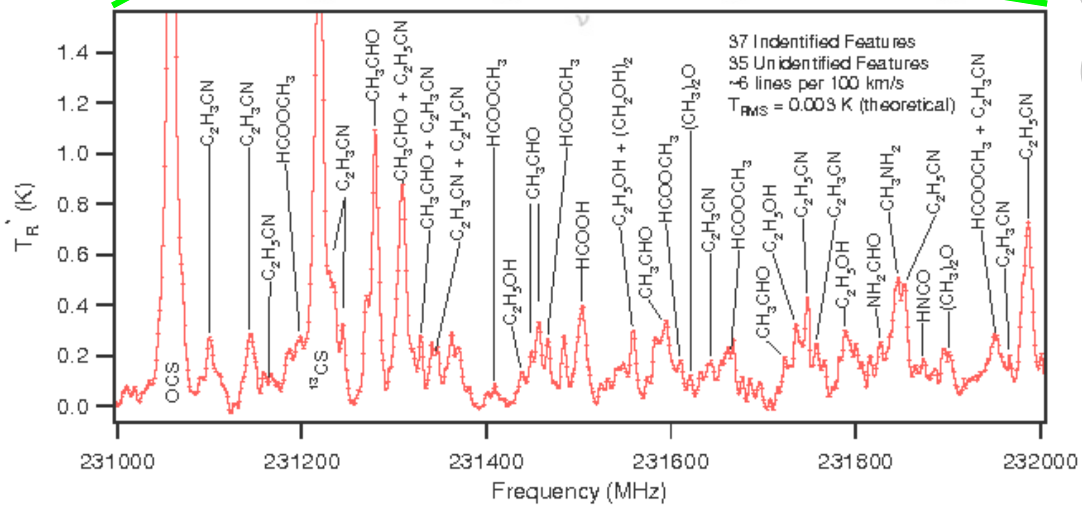


star formation mostly invisible at optical wavelengths

but current submm continuum observations have
poor angular resolution and little sensitivity (little dynamic range)

Molecular gas





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

CO second most abundant molecule (brightest mol. lines)

widely used as H_2 tracer

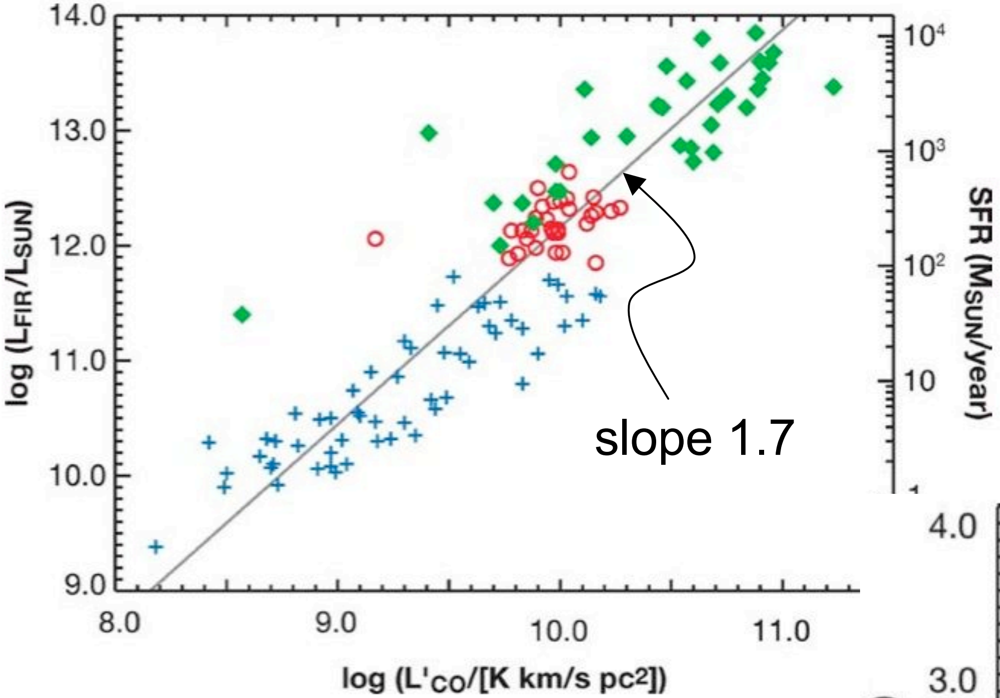
$$L_{CO} = \alpha\, M(H_2)$$

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

~120 additional molecules known in the ISM
most of their observed transitions lie in the mm/submm
~70 lines / GHz

Molecular gas as the reservoir for star formation

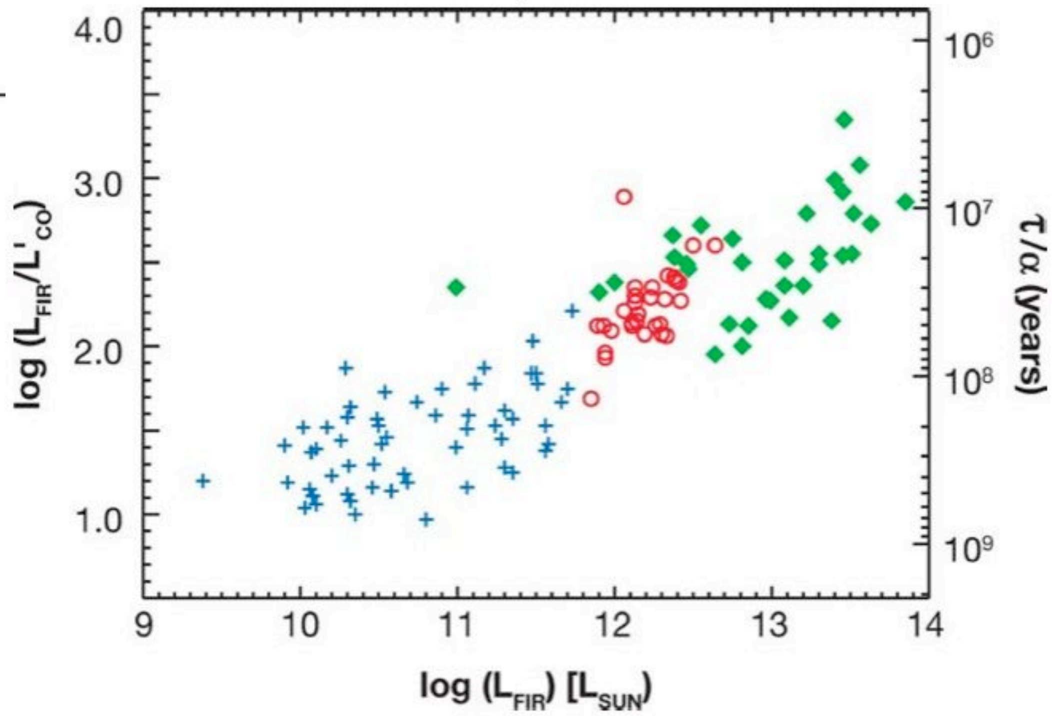
L_{FIR}-L_{CO} non-linear relation



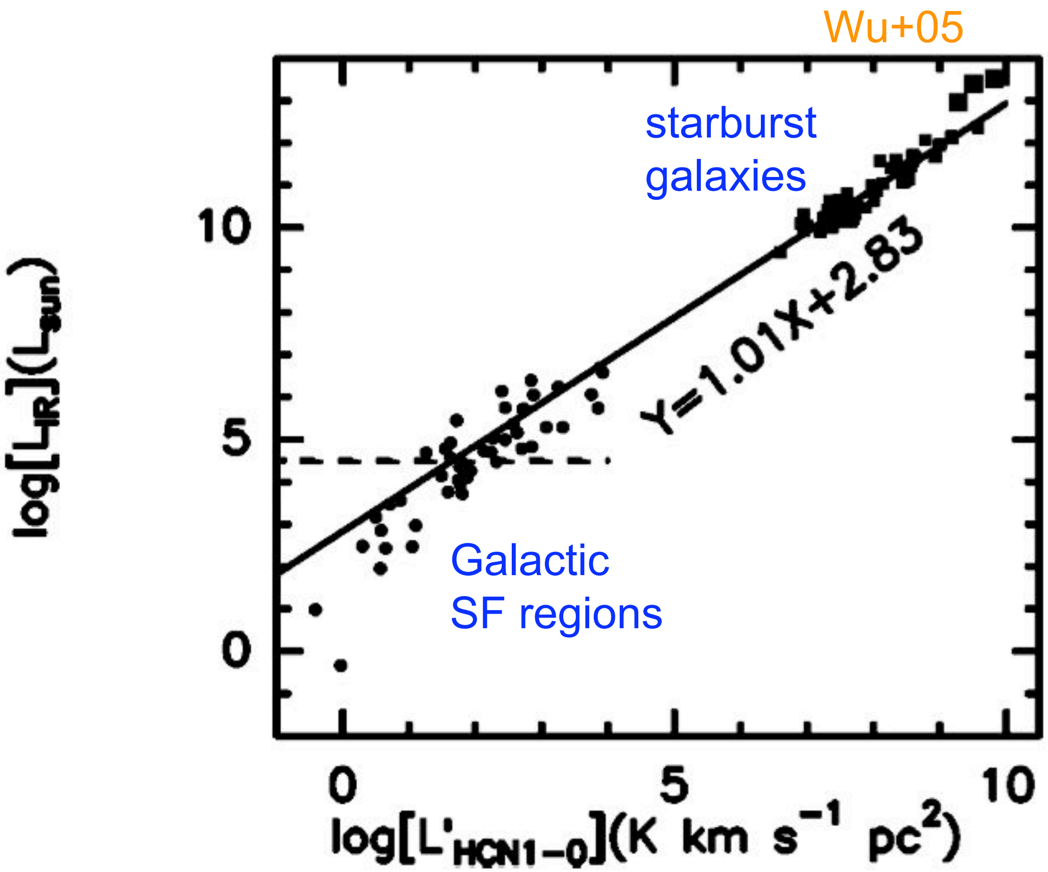
Star formation efficiency
SFE = SFR / M(H_2)
increases with luminosity

Solomon+05

Gas exhaustion time scale as short as $\tau \sim 10^7$yrs
$\Rightarrow$ powerful starbursts very short lived



L_{FIR}, i.e. SFR,
tight and linear correlation with L(HCN), i.e. dense gas

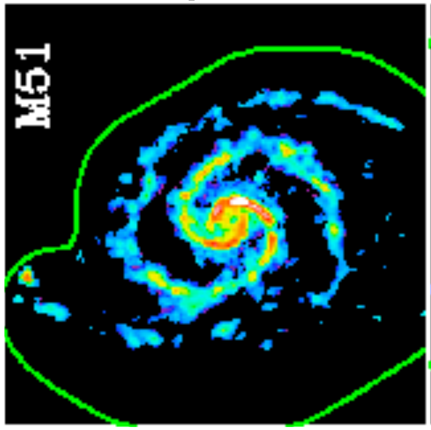


⇒ in starbursts star formation occurs in dense molecular clouds
⇒scaled-up version of Galactic star formation

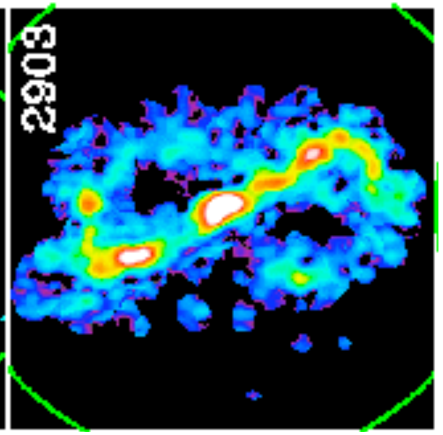
Molecular gas distribution in galaxies

A variety of morphologies

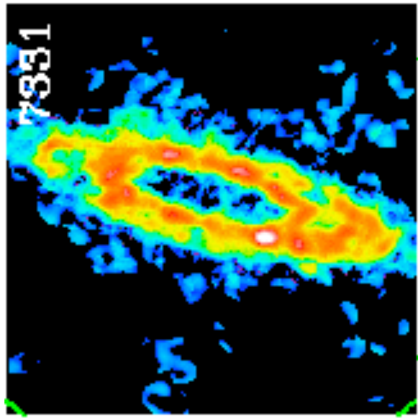
Spiral



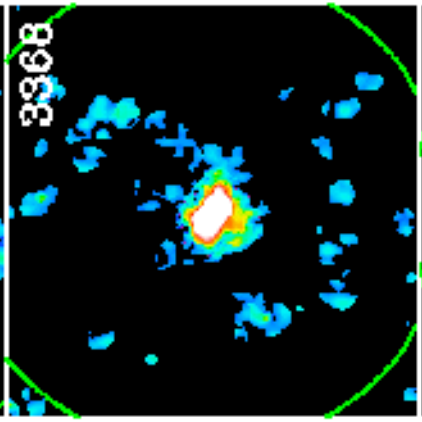
Barred



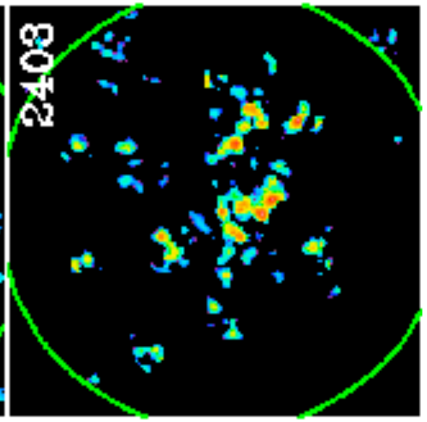
Ring



Nuclear

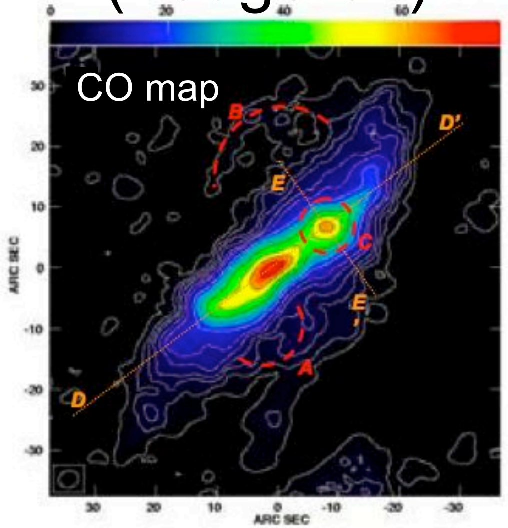


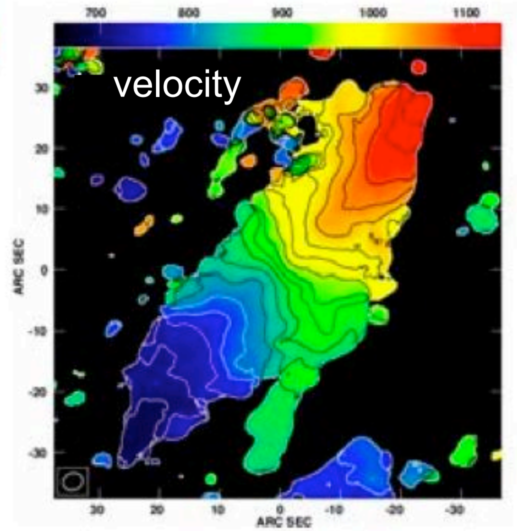
Irregular



Molecular gas kinematics

galaxy disk
(~edge-on)

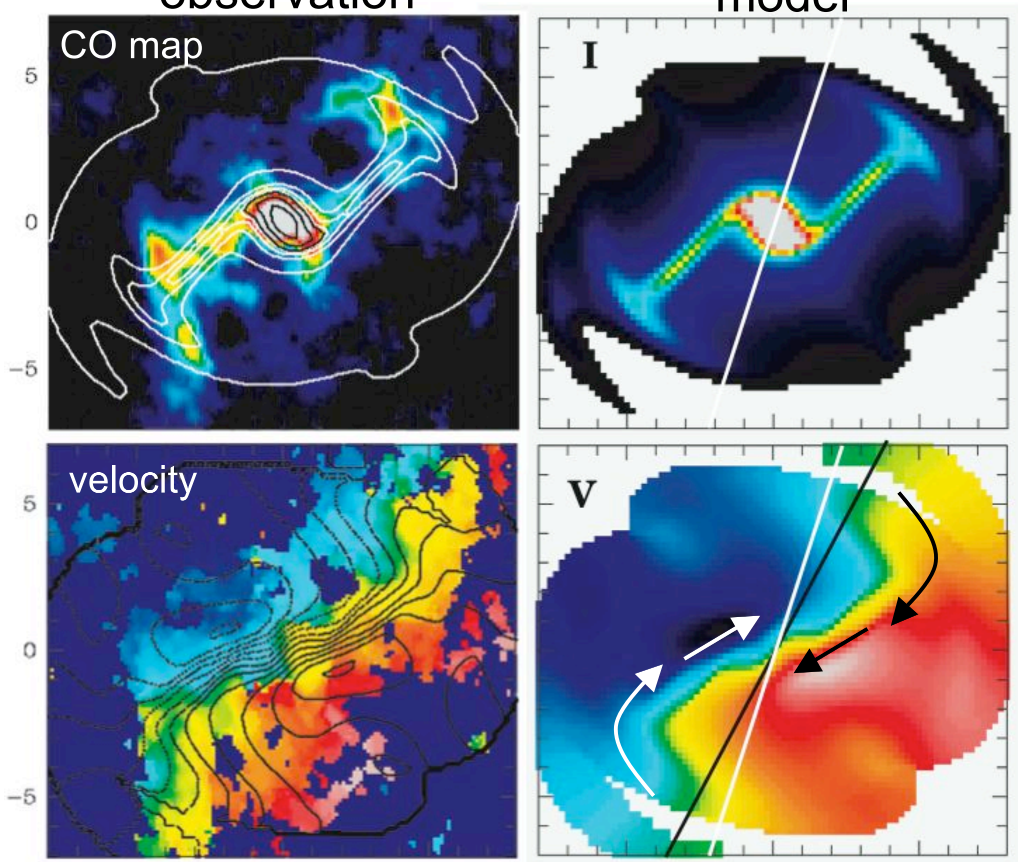




barred galaxy

observation

model



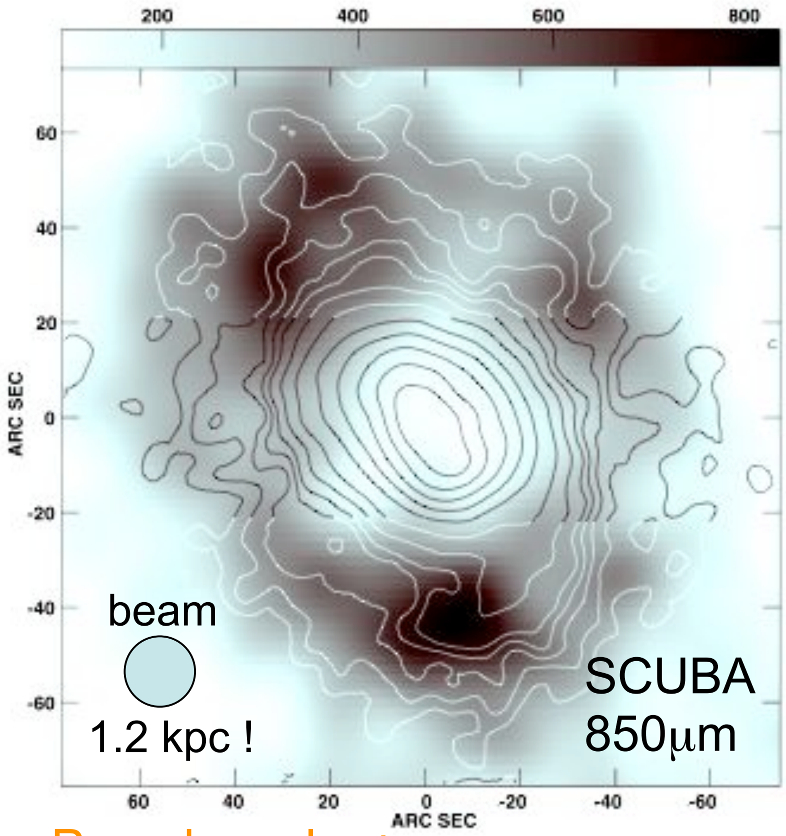
the bar potential drives
gas into the center

mm-submm observations of local AGNs

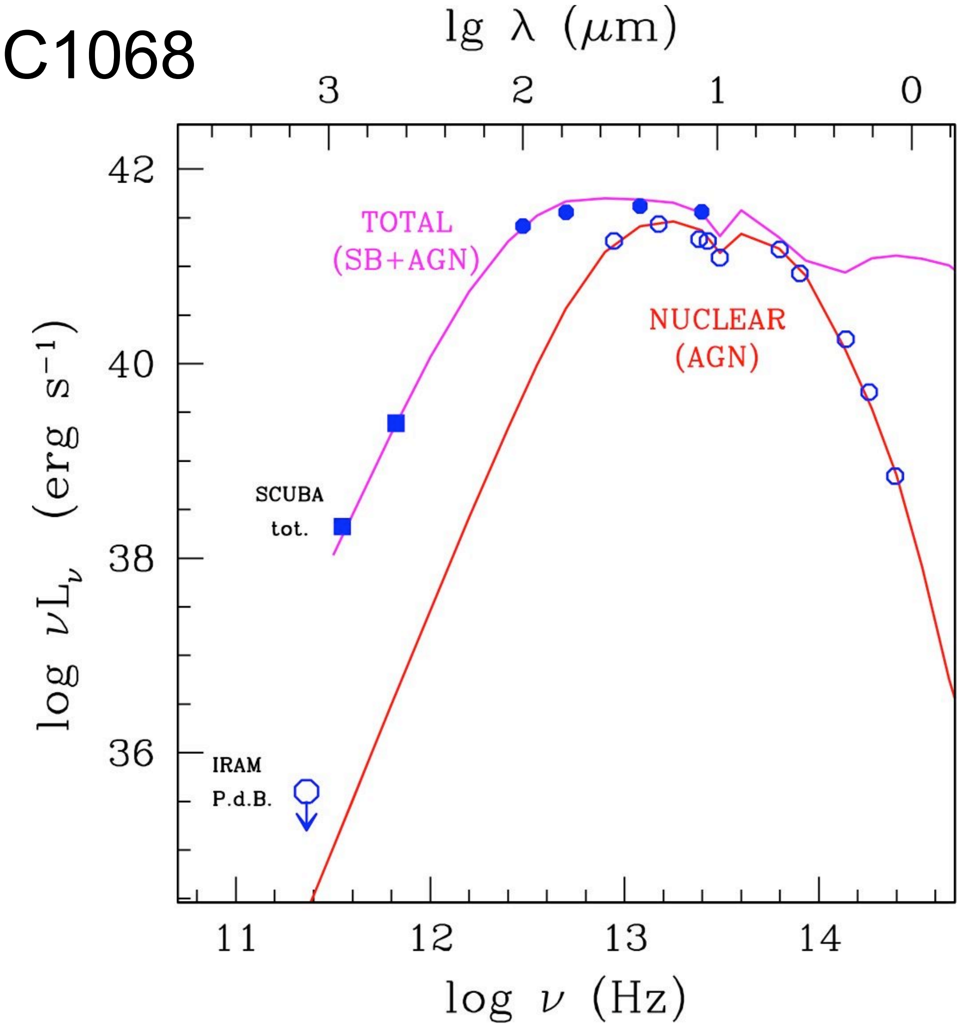
Continuum: nuclear AGN SED generally much "hotter" than star forming/quiescent galaxies

Inferred by spectral decomposition and correlations (see Netzer lectures), but still difficult to spatially disentangle SB and AGN components

NGC1068

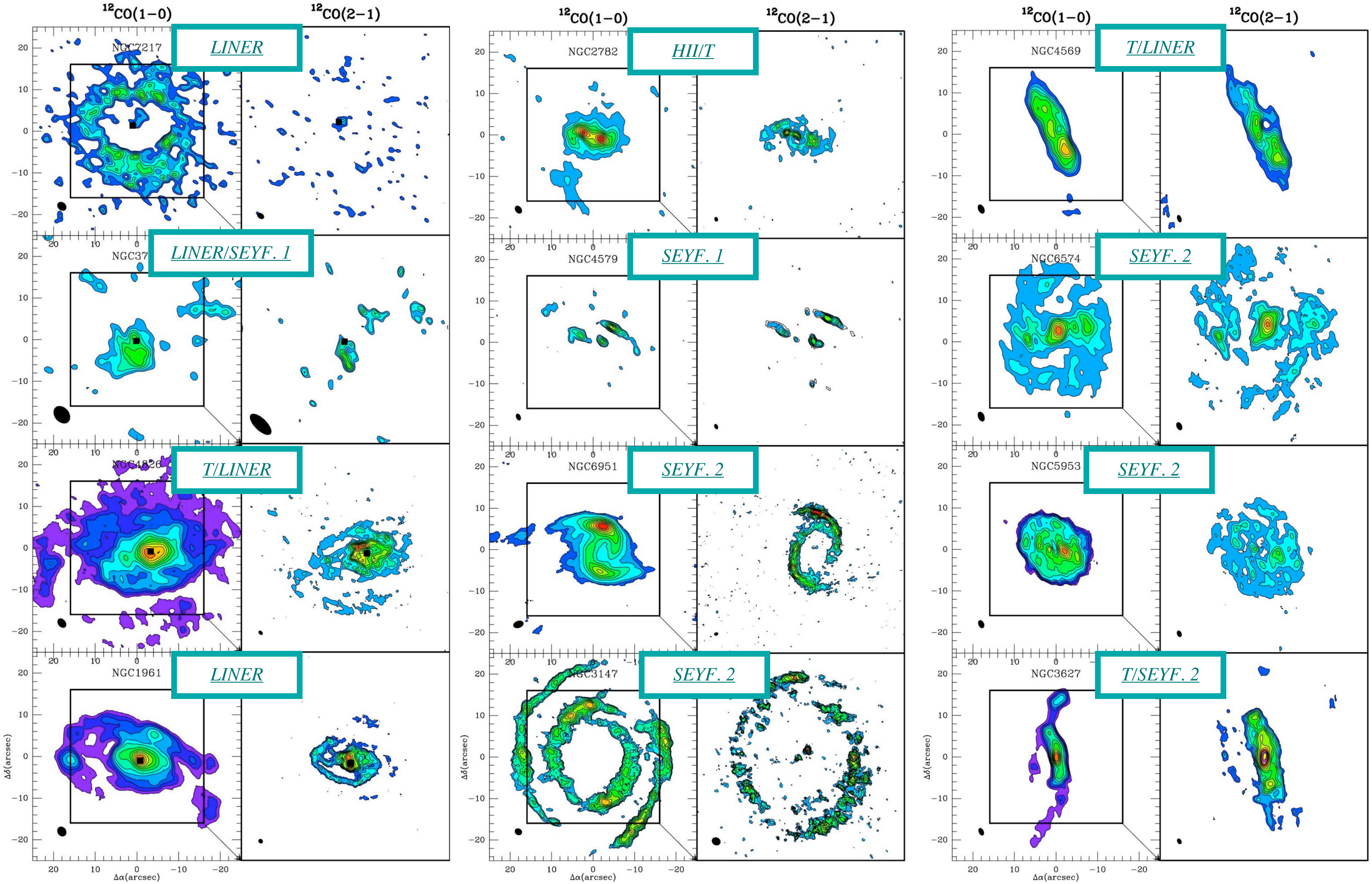


Papadopoulos+

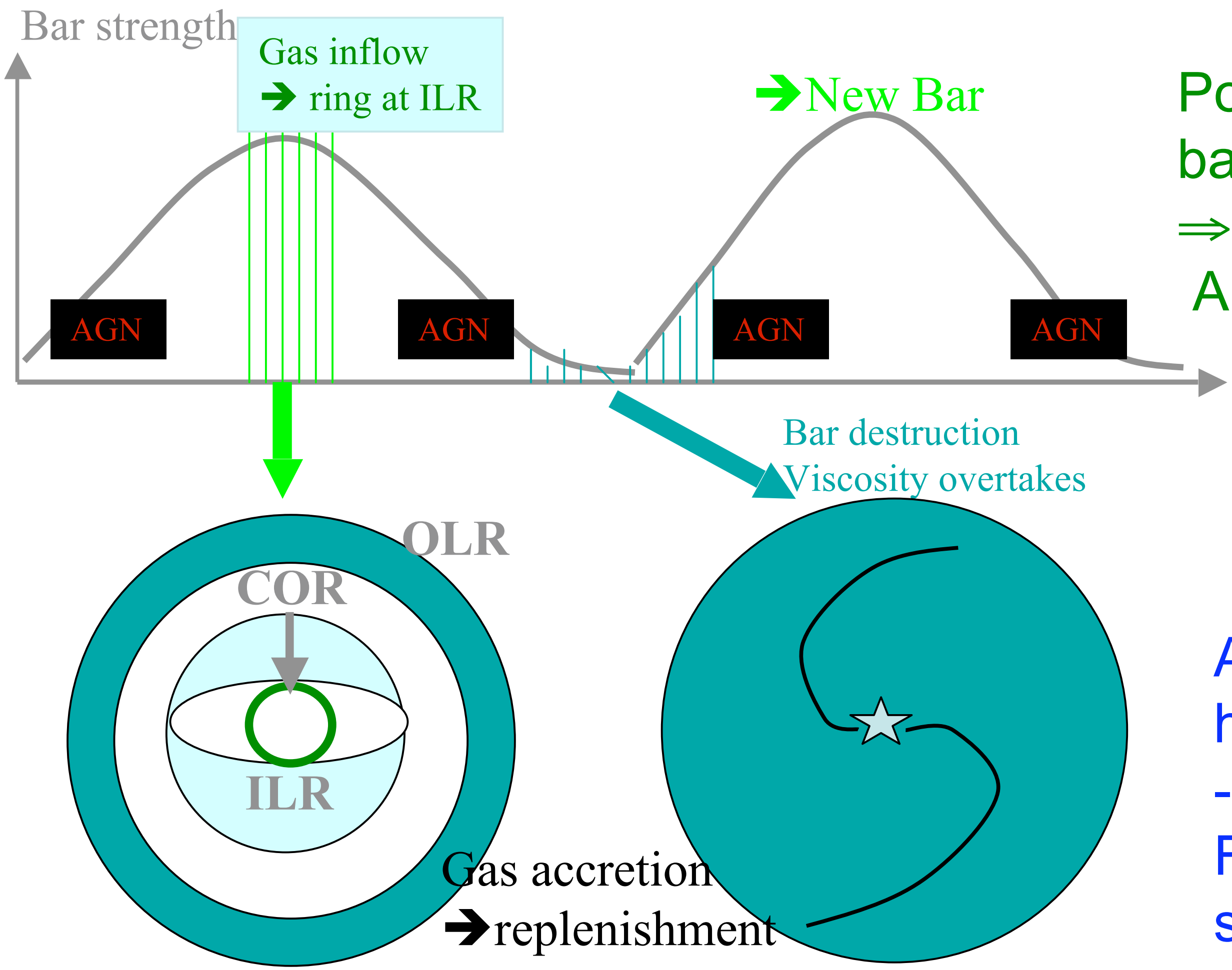


CO Images of AGNs: investigate AGN fuelling (NUGA project)

García-Burillo et al 2003a, 2003b, 2005; Combes et al 2004; Krips et al 2005, 2006; Boone et al 2006.



Variety of CO morphologies and dynamics in AGN hosts
Apparently no relation with the nuclear AGN activity
No ubiquitous evidence for current fuelling of the nucleus

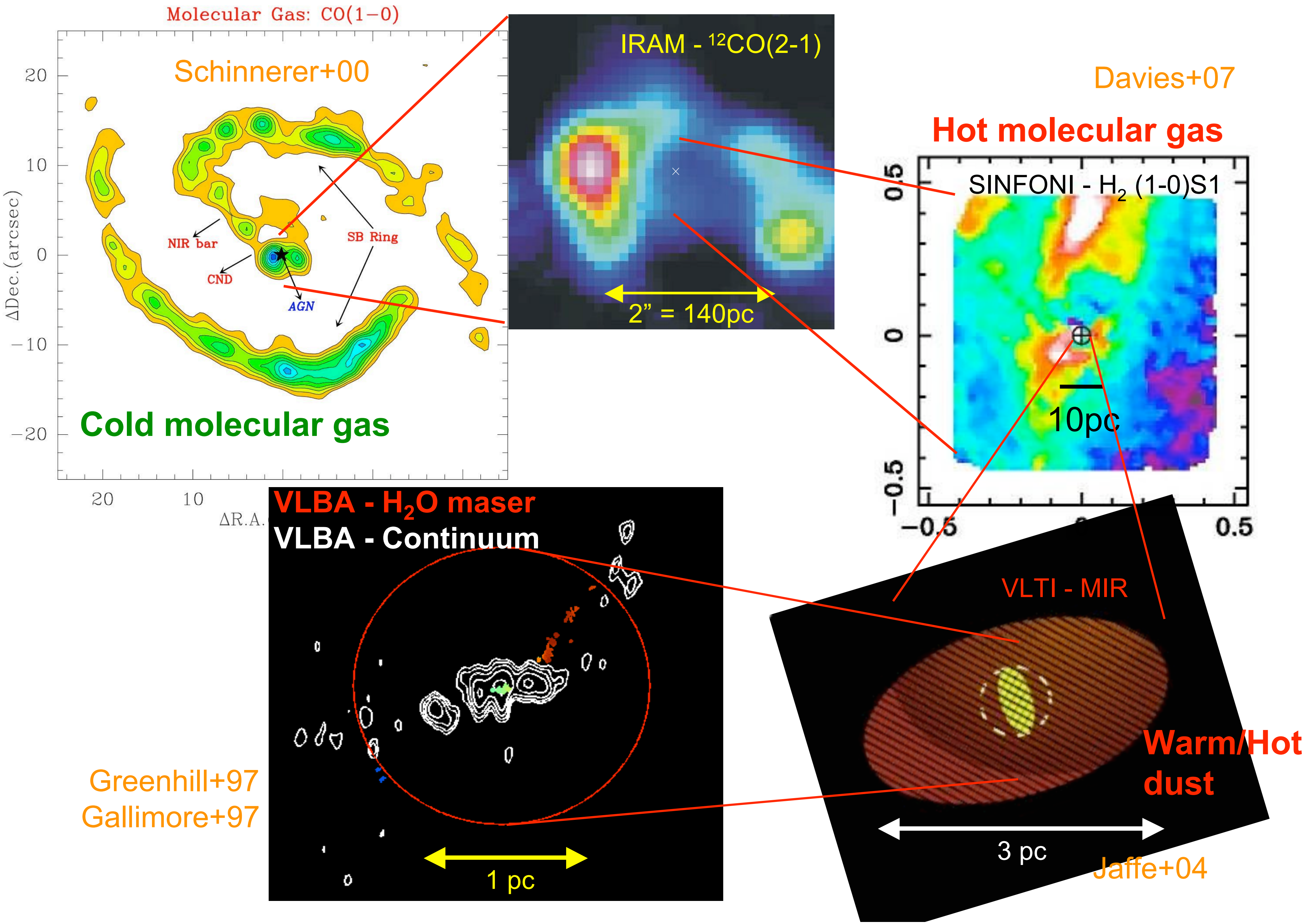


Possible cyclic fuelling by bars which self-destroy
⇒ large-scale fuelling agent and AGN phase not simultaneous

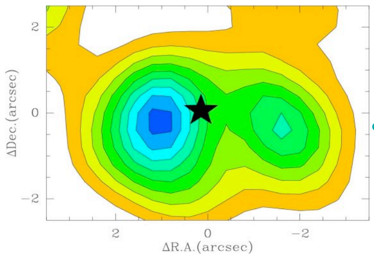
(curtesy of Garcia-Burrillo)

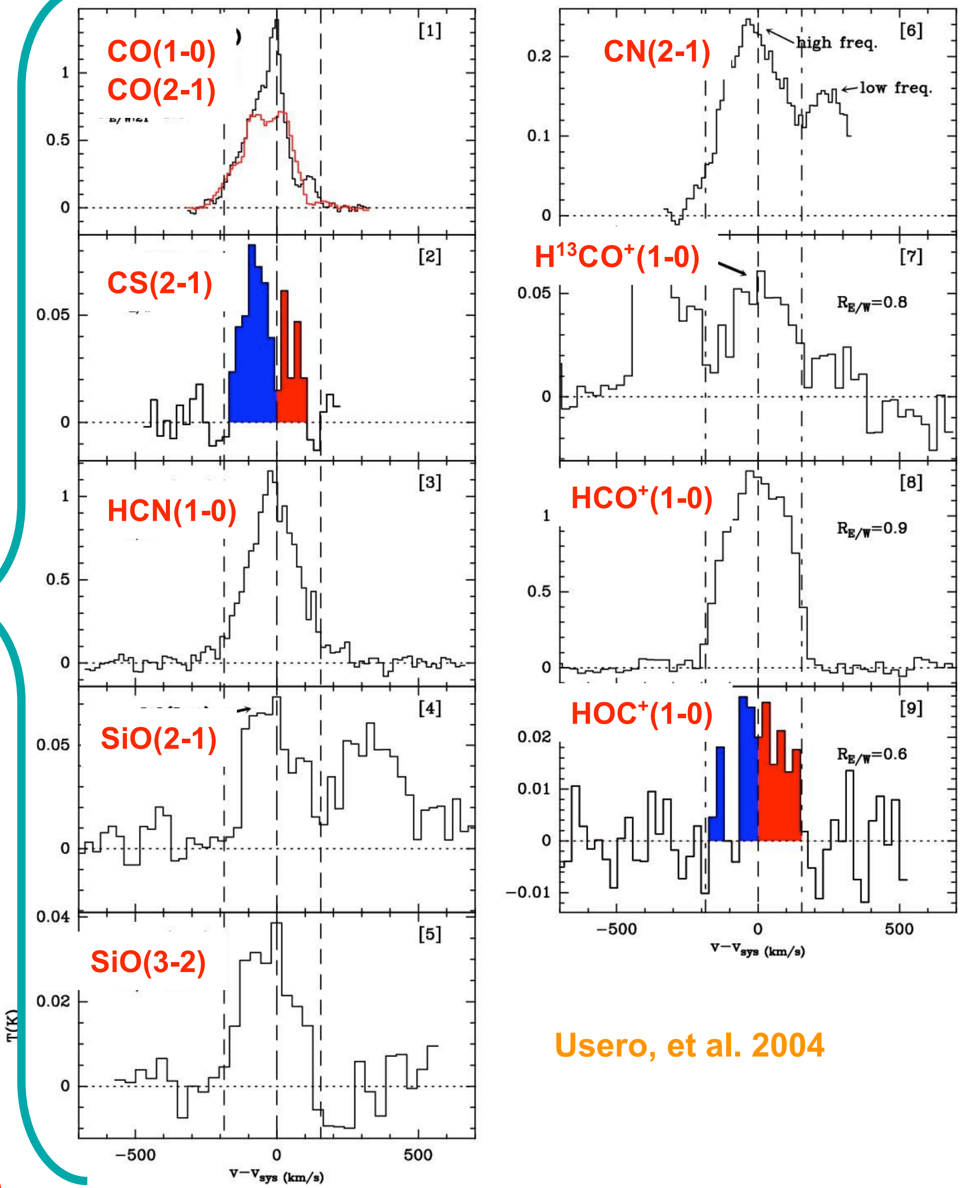
Also, nearby AGN have low luminosities
-> require little fuelling rate.
Fuelling problem more serious for QSOs, but more distant -> currently difficult to investigate in such a detail

Molecular gas in AGNs: zooming into the nucleus of NGC1068



Little or no cold molecular gas within the nuclear few 10 pc
-> mostly dense/warm gas traced by other lines?
Problem of sensitivity and resolution
of current facilities to map lines fainter
than CO at high angular resolution

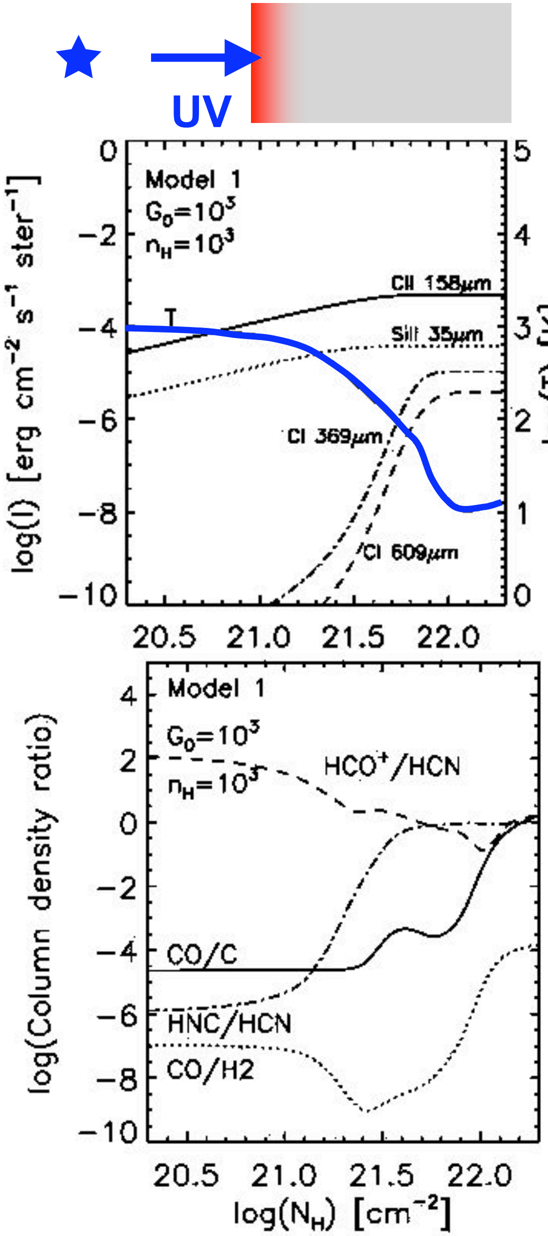




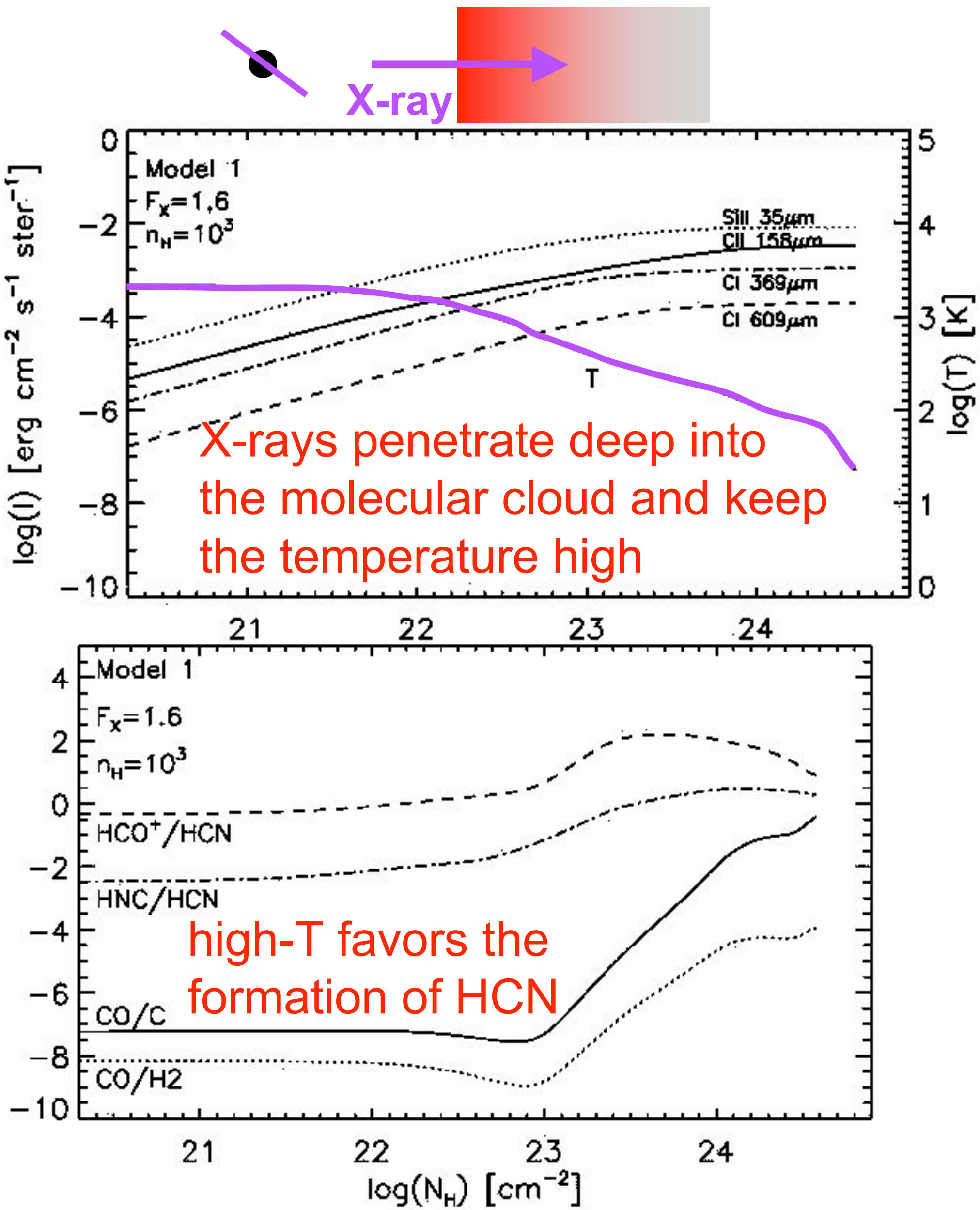
Usero, et al. 2004

Though not resolved yet,
mm observations of the nucleus
of NGC1068 do show evidence
for several molecular species tracing
not only dense gas,
but also very complex chemistry
-> Giant X-ray Dominated Region (XDR)

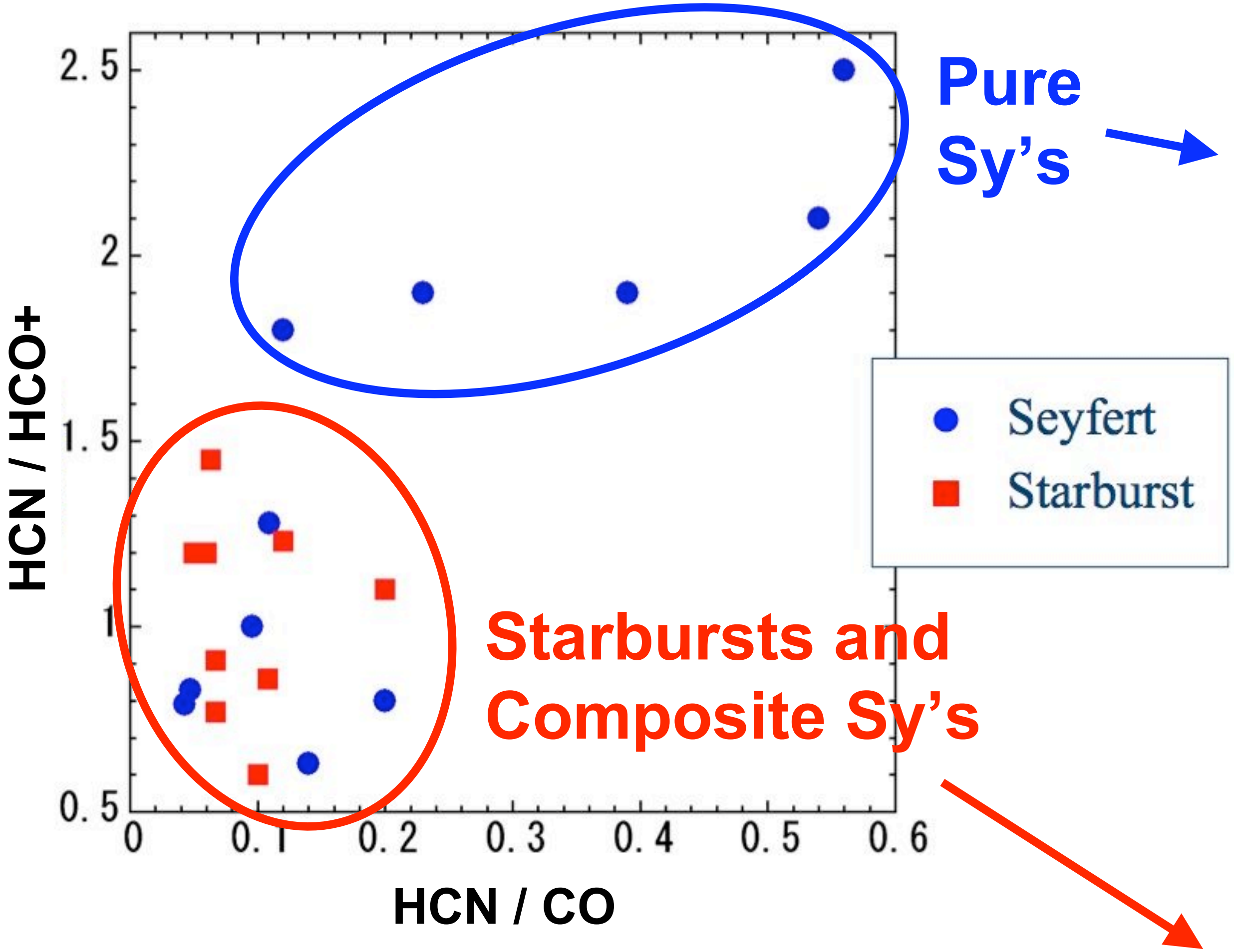
Photo Dissociated Regions (PDR's)

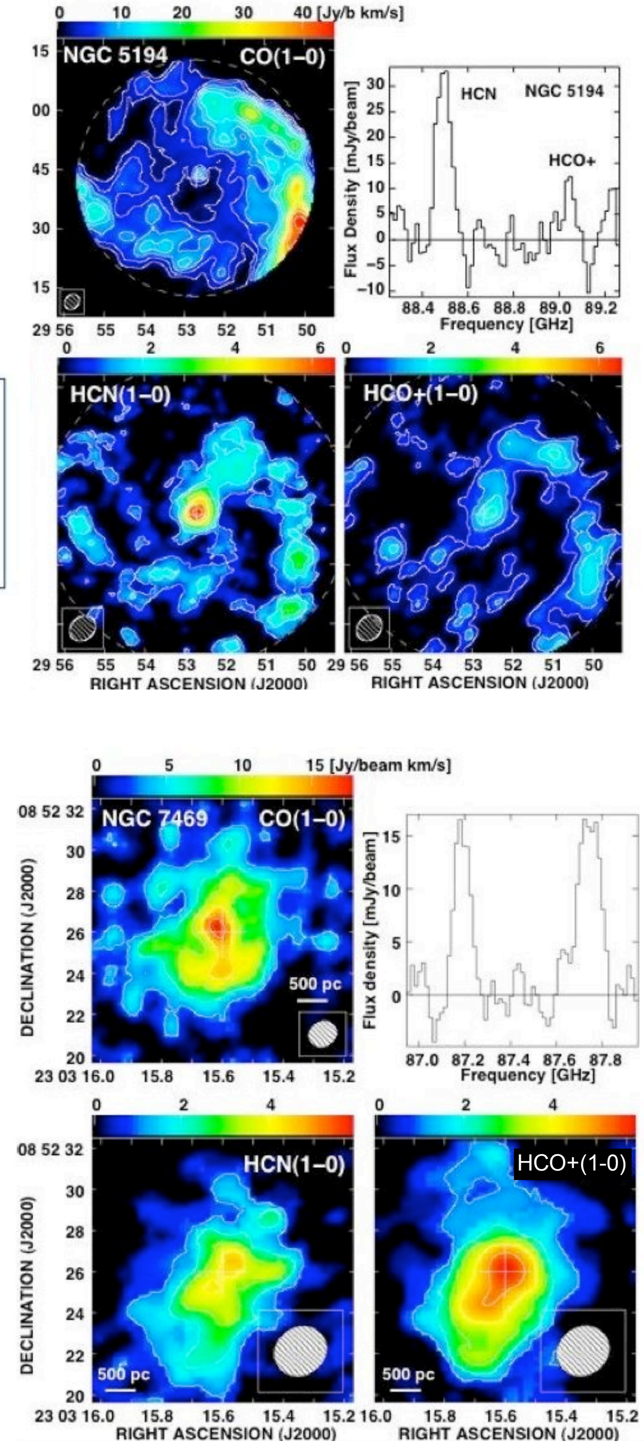


X-ray Dominated Regions (XDR's)



Maloney+96, Lepp & Dalgarno 96, Meijerink+05,07





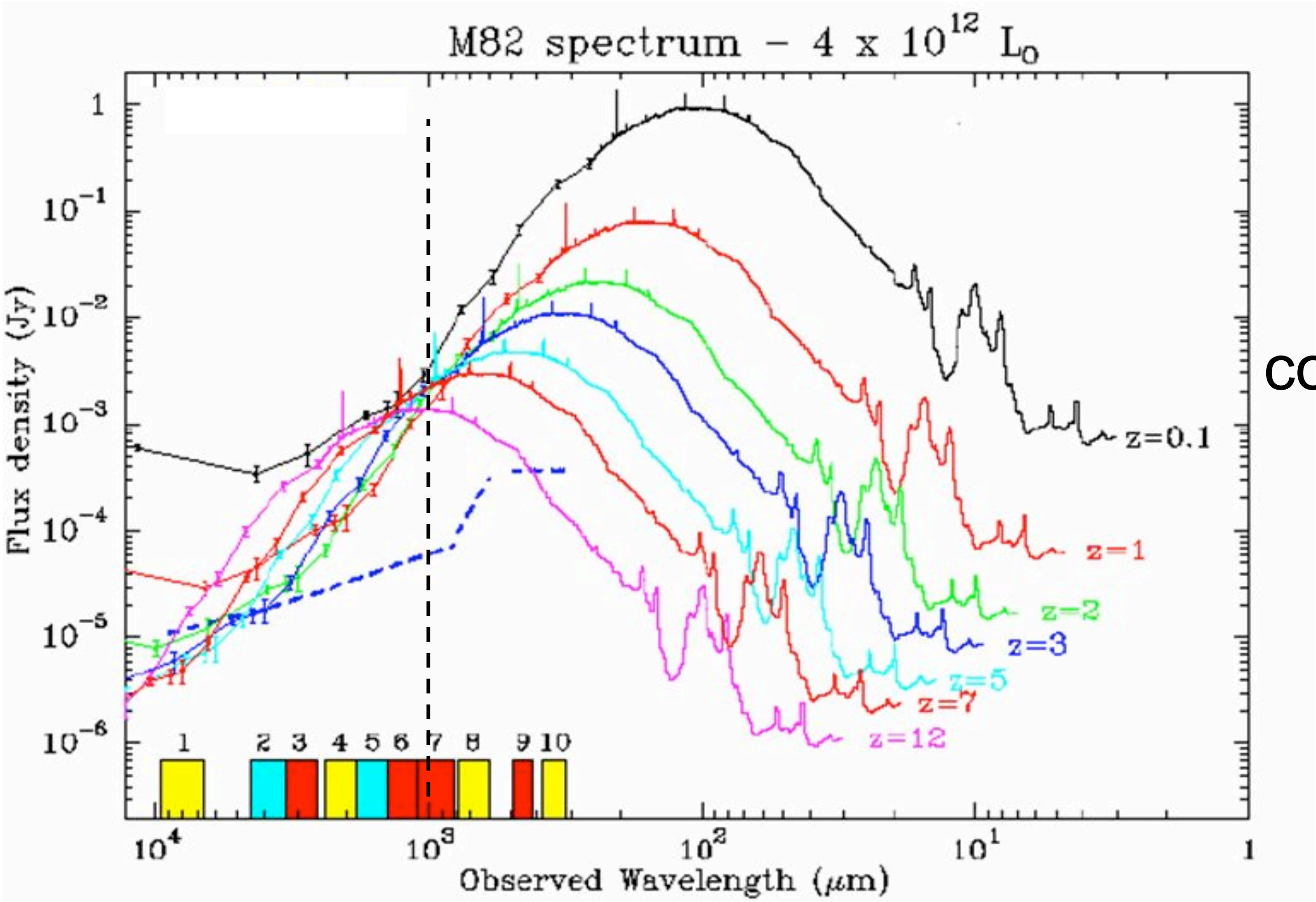
- Use of HCN as a tracer of dense molecular gas in questions when an AGN is present
- XDR-enhanced species can identify the presence of hidden/elusive AGNs (totally optically obscured, without NLR, Compton thick)

High-z galaxies

Premise: currently only very powerful sources have
been detected at high-z (the tip of the iceberg)...
not representative of the bulk of the galaxy population at high-z

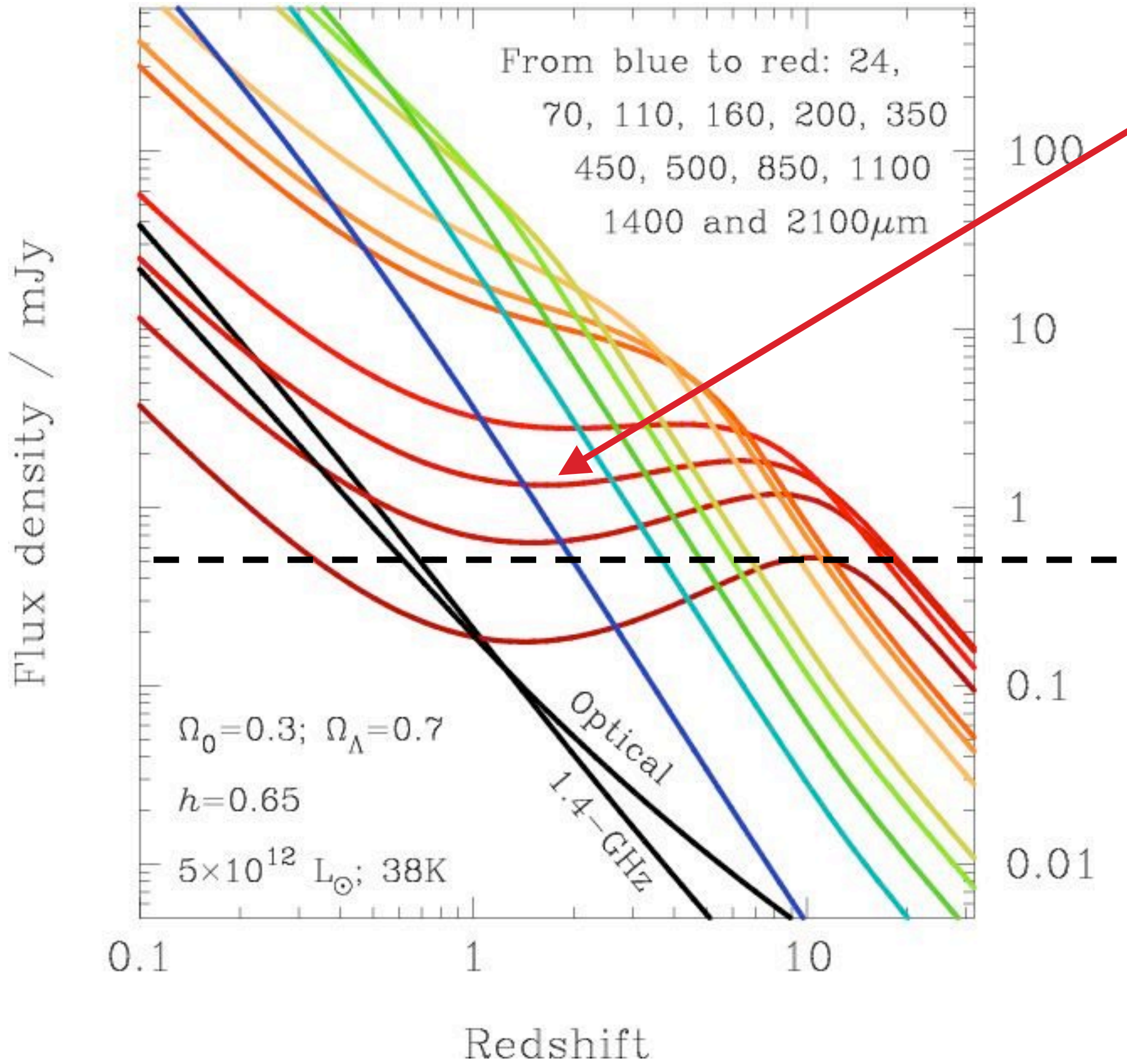
(this will change drastically with ALMA)

Strong negative K-correction at mm-submm wavelengths



The steep submm SED counteracts the $1/D^2$ cosmological dimming

Strong negative K-correction at mm-submm wavelengths



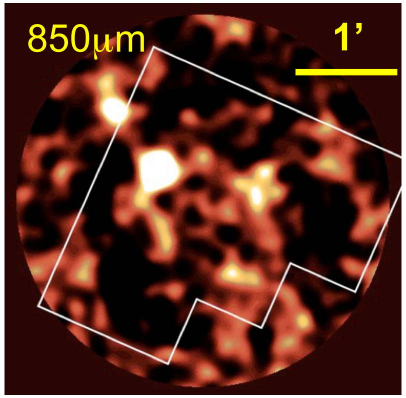
At $\lambda \sim 1$ mm detecting a source at z=10 is as easy as at z=1

~ limit of current surveys

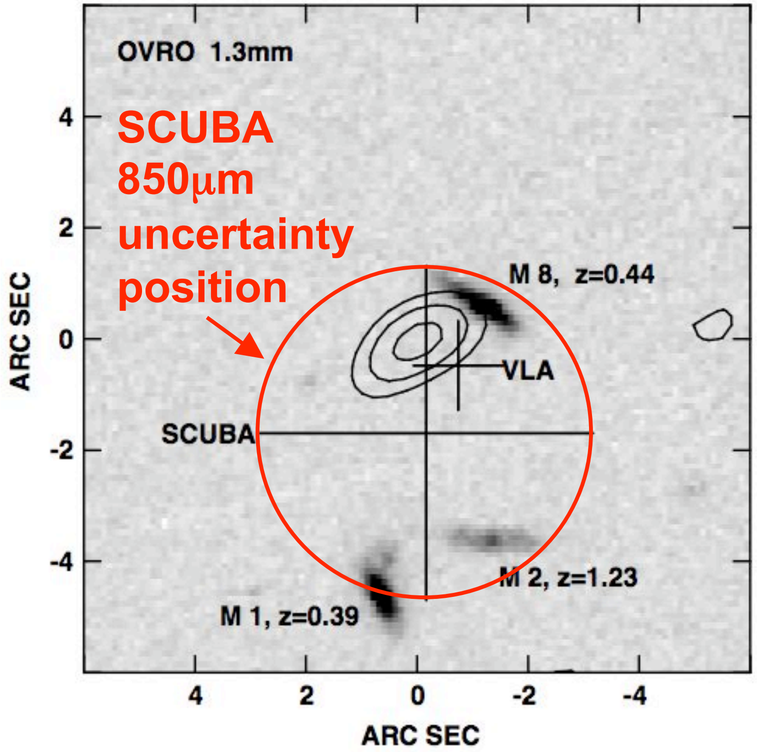
$\Rightarrow L>10^{12}\ L_{\odot}$ at $1<z<10$

The low angular resolution of past/current submm facilities has been a major problem for the optical and spectroscopic identification of high-z Submm Galaxies (**SMG**)

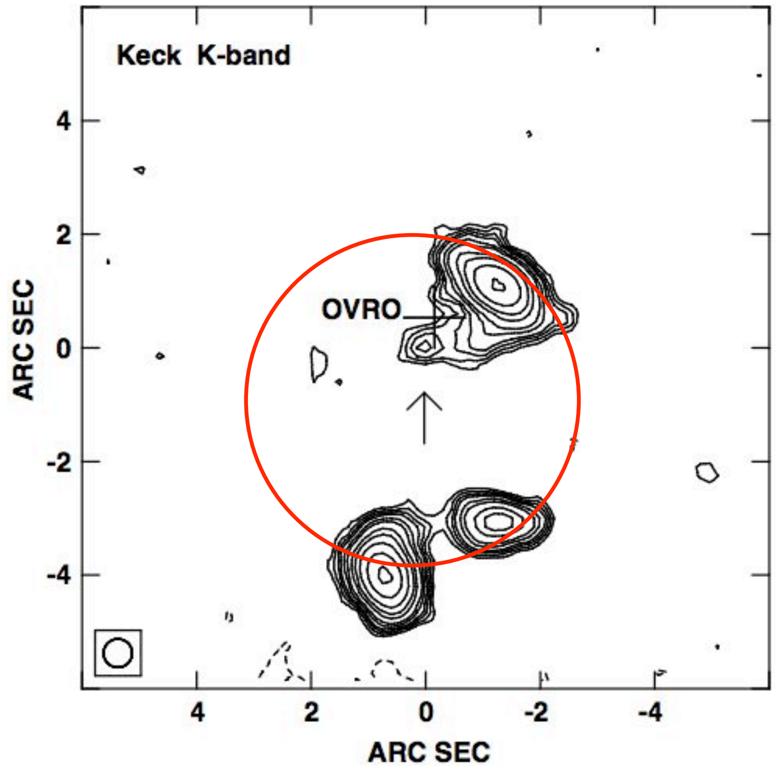
deep SCUBA map (HDF)



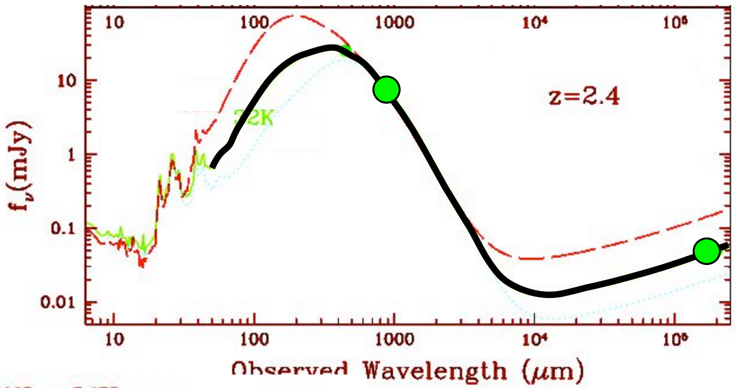
grayscale HST optical



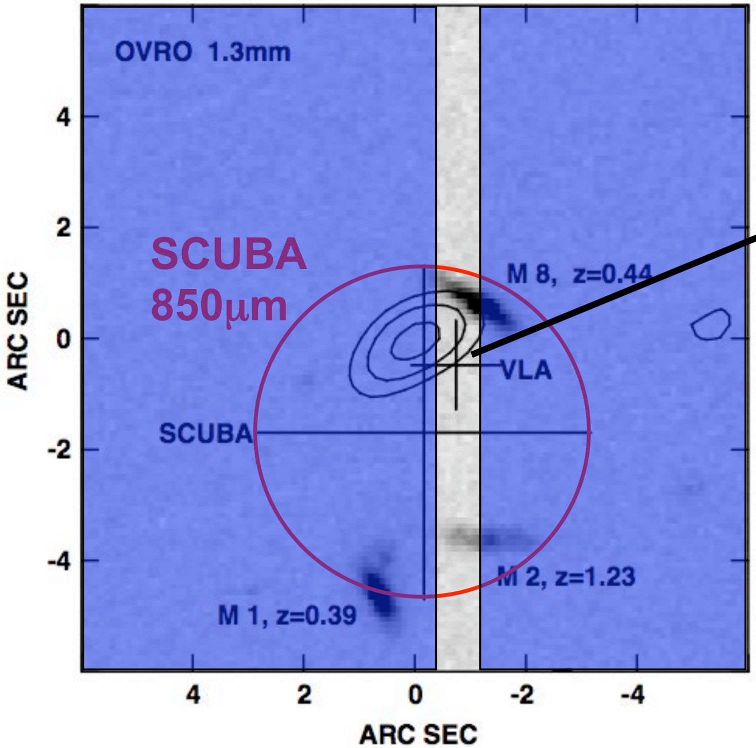
near-IR (2μm) image

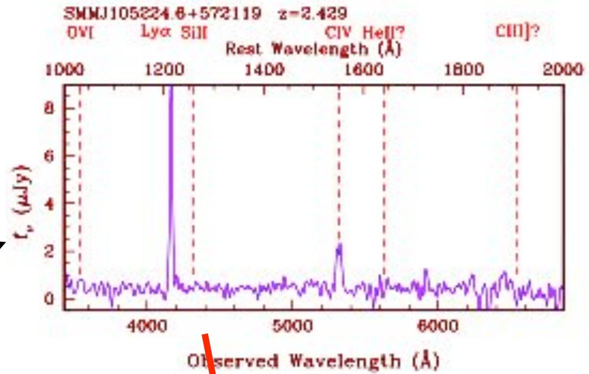


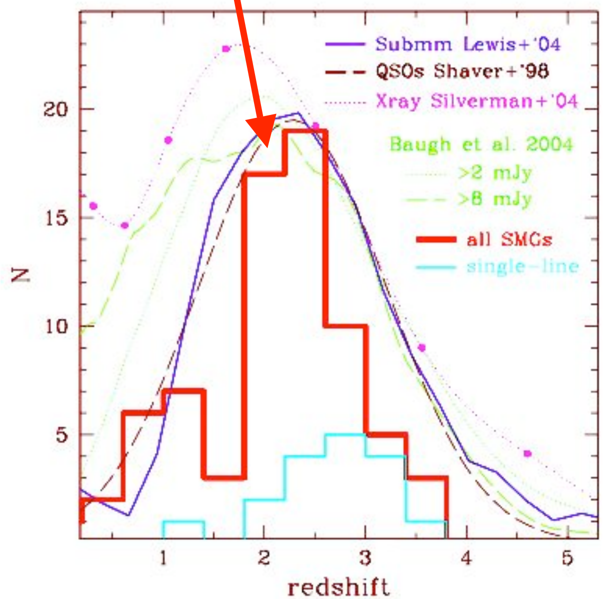
Chapman et al. (2004) exploit the FIR-radio correlation of galaxies to locate the source through the radio-VLA position and “blindly” place the slit for optical spectroscopy



grayscale HST optical

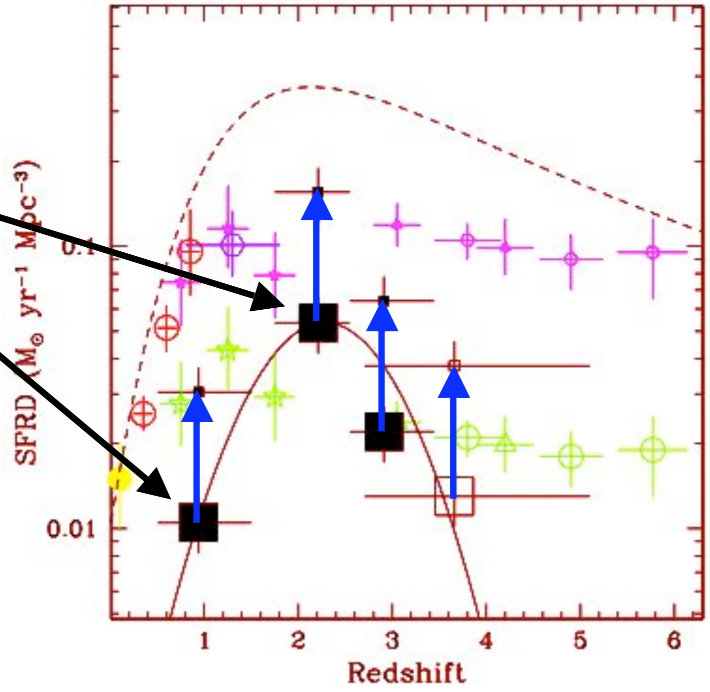






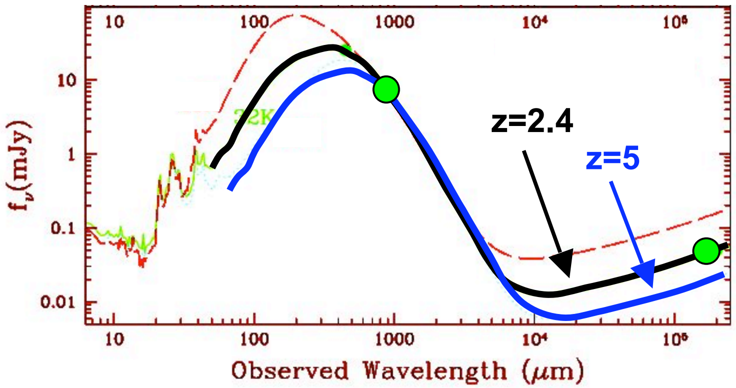
redshift distribution <z> ~ 2.5

Inferred evolution of the
cosmic star formation rate



Problems:

- Current submm surveys only sample extremely luminous objects (L_{IR}>10^{12} $L_{\odot}$, the tip of the iceberg) correct to “real” SFR with models



-Radio identification prevents the identification of high-z sources (radio K-correction goes other way)

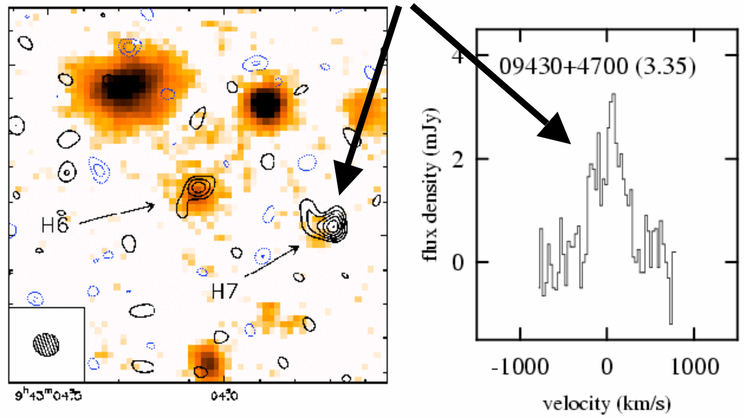
- Also bias against cool SED

-The optical (=UV rest frame) spectroscopic identification has missed the most obscured objects

Dynamics of high redshift galaxies traced by mm-submm spectroscopy

Genzel+04

CO(4-3) at z=3.35

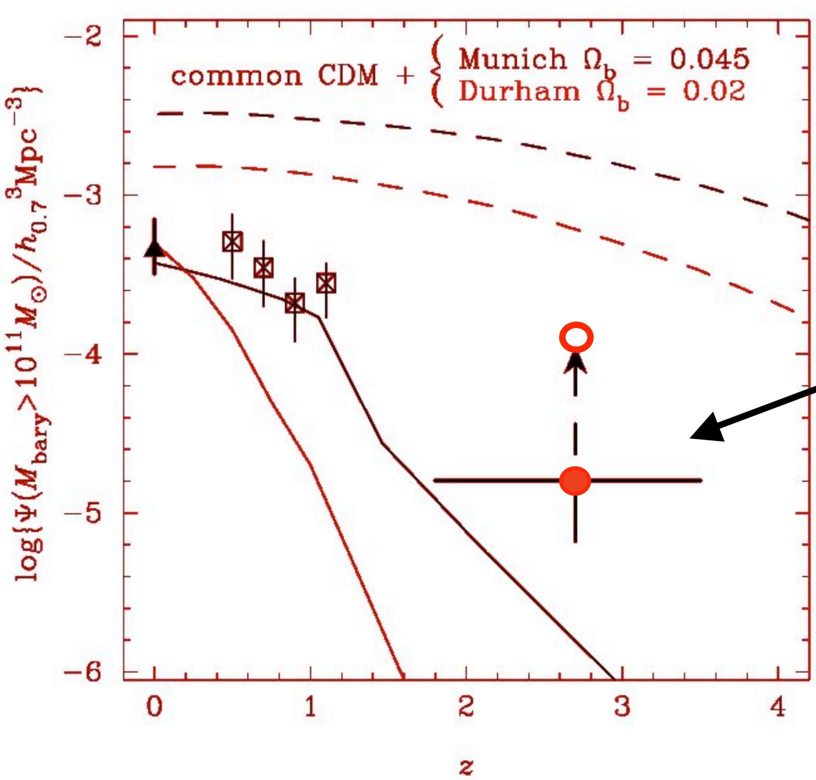


Currently obtained in few extremely luminous sources

Resolved line profile, but generally unresolved morphology

infer dynamical mass ~ $2\times10^{11}\ M_\odot$

infer density of massive galaxies ($>10^{11}\ M_\odot$) at $2<z<3$

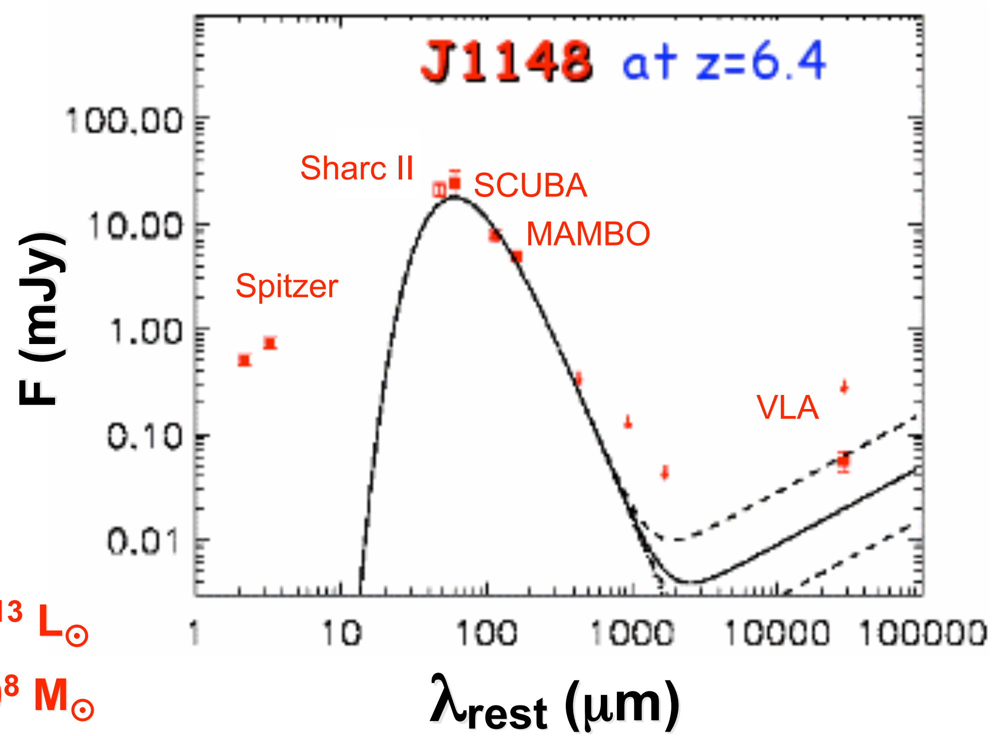


much higher than expected by classical hierarchical models

High-z AGNs

Most detections in luminous QSOs and powerful radio-galaxies

submm/mm (=FIR) continuum detected in ~60 optically selected QSOs and ~20 radio-galaxies at z>1, up to z=6.4



$L_{FIR} \sim 2 \times 10^{13}\ L_\odot$

$M_{dust} \sim 4 \times 10^{8}\ M_\odot$

SFR ~ 3000 $M_\odot$/yr

Beelen+06

Large masses of dust inferred even at high-z (important implications for origin of dust)

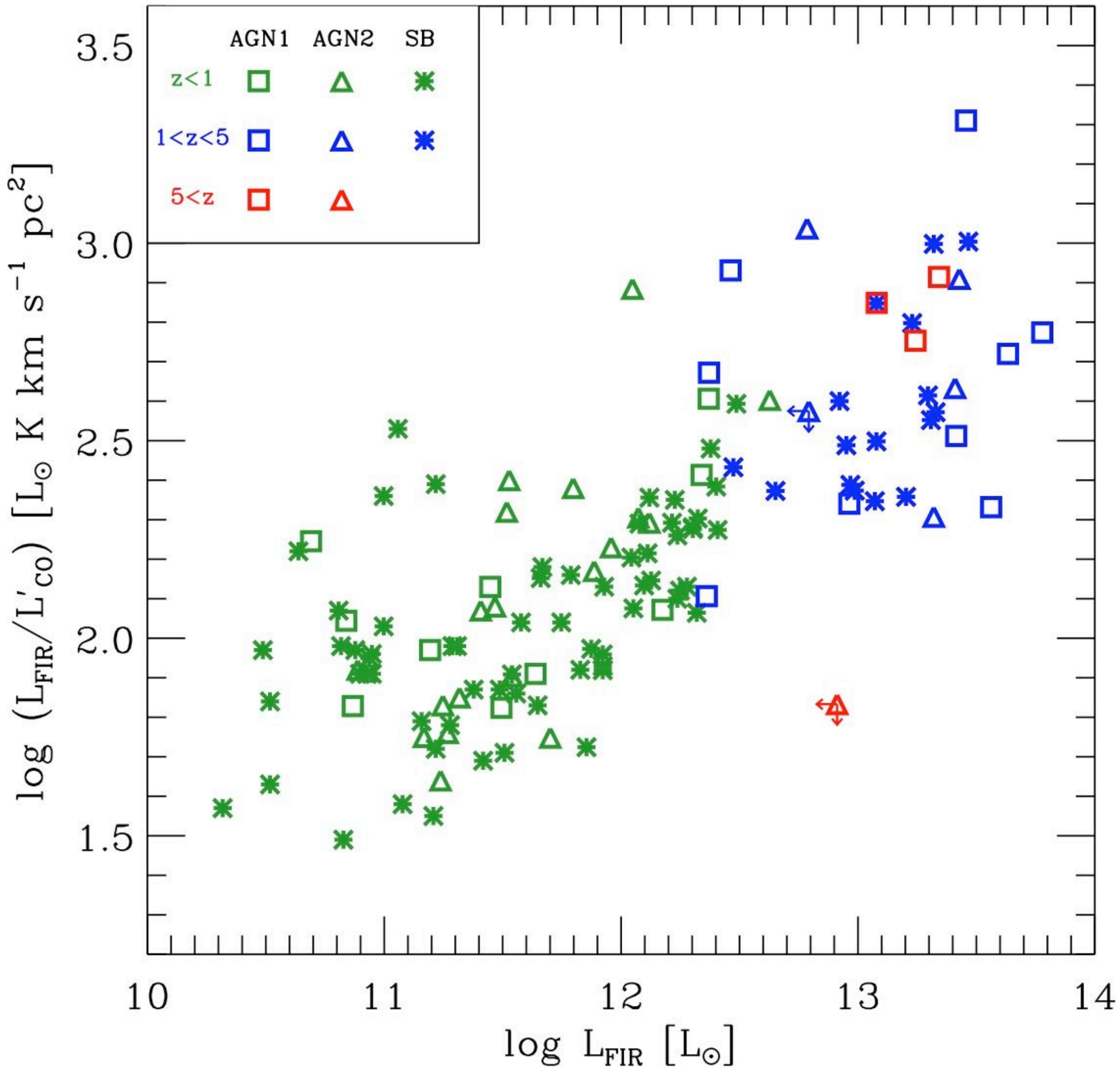
FIR-radio, FIR-CO, FIR-PAH correlations suggest QSOs FIR dominated by SFR
⇒inferred large SFR's ~1000 $M_\odot$/yr

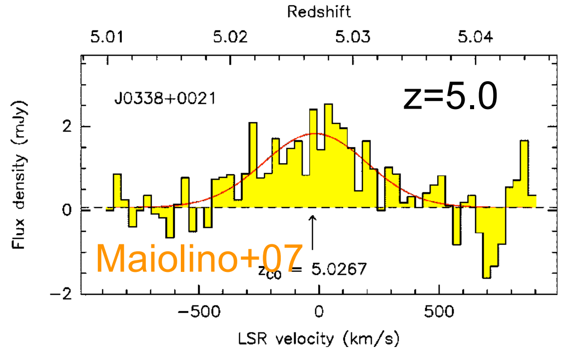
Molecular gas in high-z QSO radio galaxies

CO detected in ~23 QSOs and radio galaxies at z>1

(+some HCN,HCO+ detections)

Solomon & Vanden Bout '05, Omont '07





Same L_{FIR}/L_{CO} ratio as in powerful starbursts

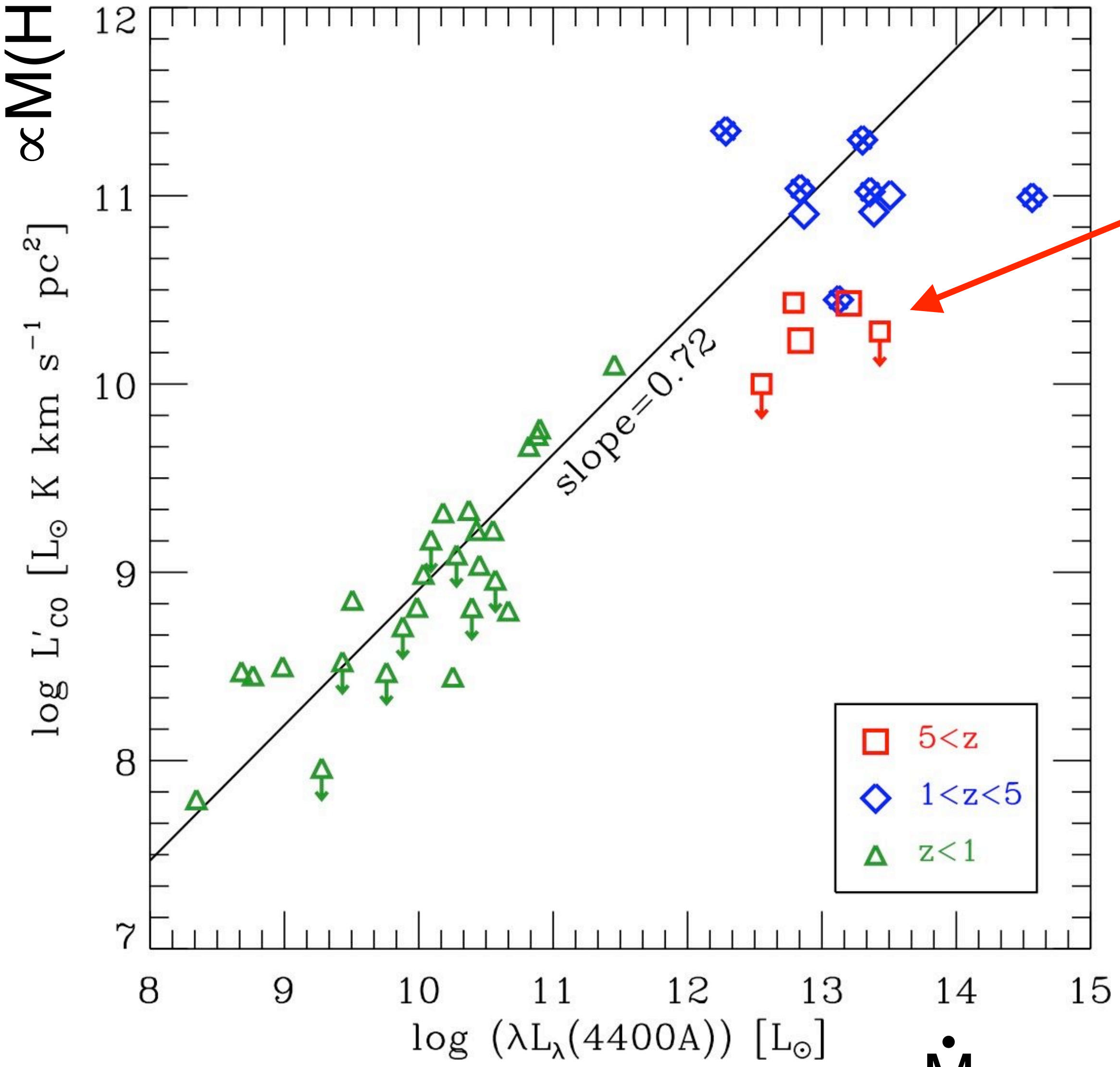
QSO hosts characterized by intense, short-lived (~10^7 yrs) starbursts

↓

Tracing early, co-eval formation of BH and galaxies?

But non-linear relation between L_{CO} (H_2 mass = SF fuel) and QSO optical luminosity (BH accretion rate)

$\propto M(H_2)$



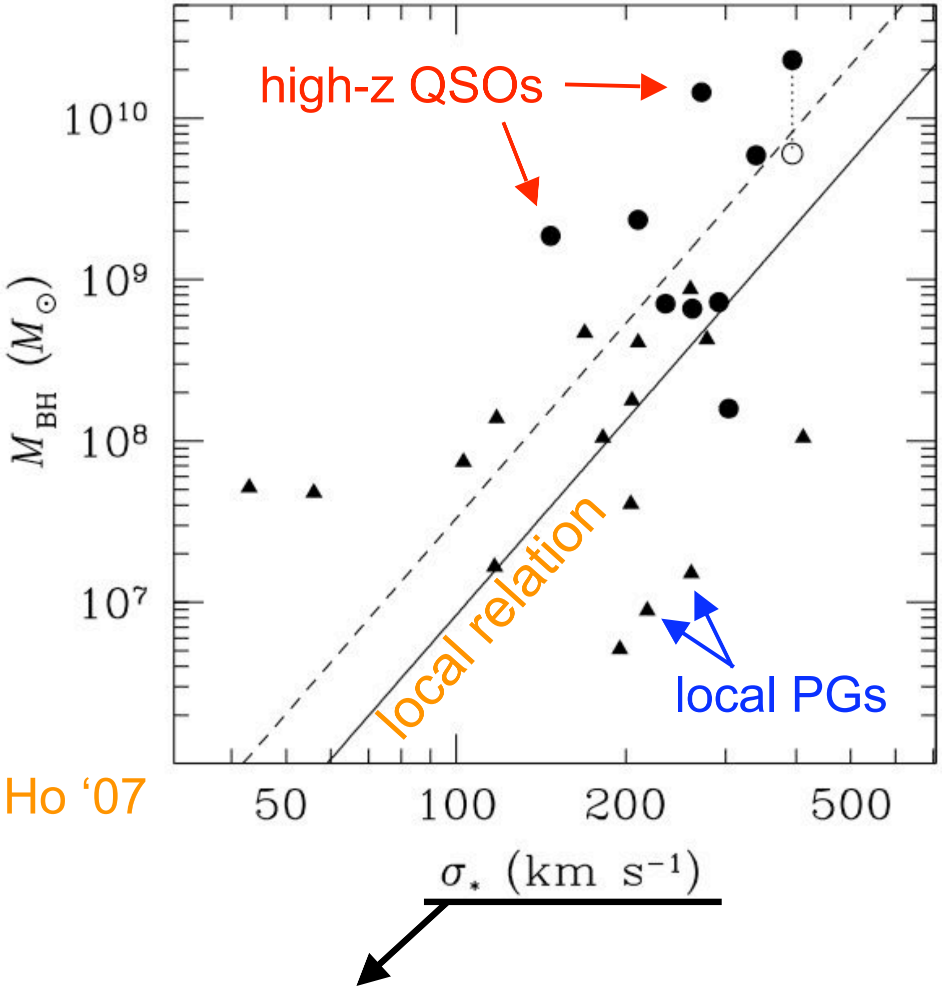
$\propto \dot{M}_{BH}$

especially at z>5

BH may form faster and earlier than their bulges

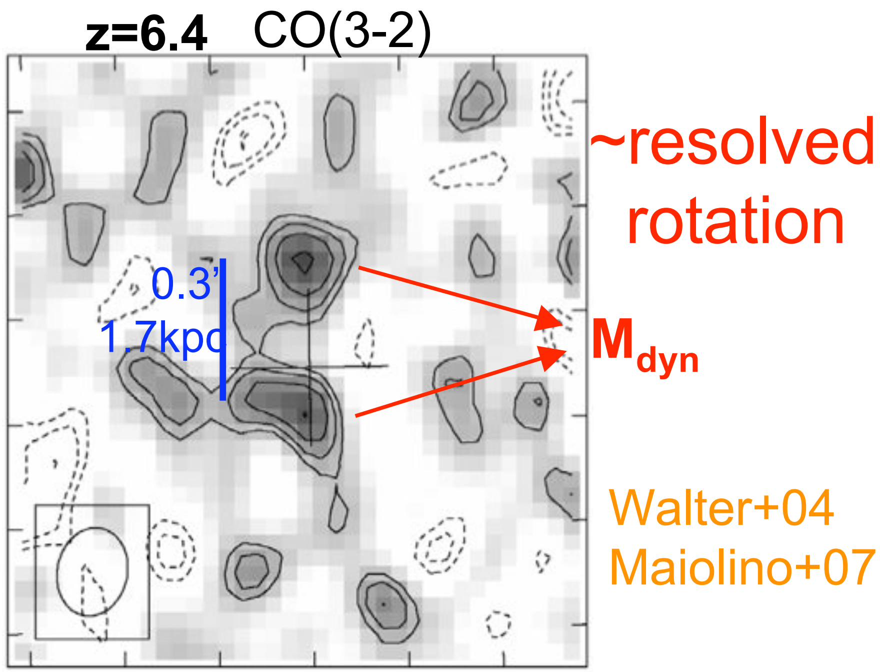
In keeping with recent indications that the M_{BH}-M_{bulge} relation is offset in high-z QSOs...

CO dynamics provides a powerful tool to investigate QSO host dynamics (no issues of continuum contrast)



from CO width... very dangerous... QSO1's biased against edge-on systems **(see Carilli & Wang '06, Wu '07)**

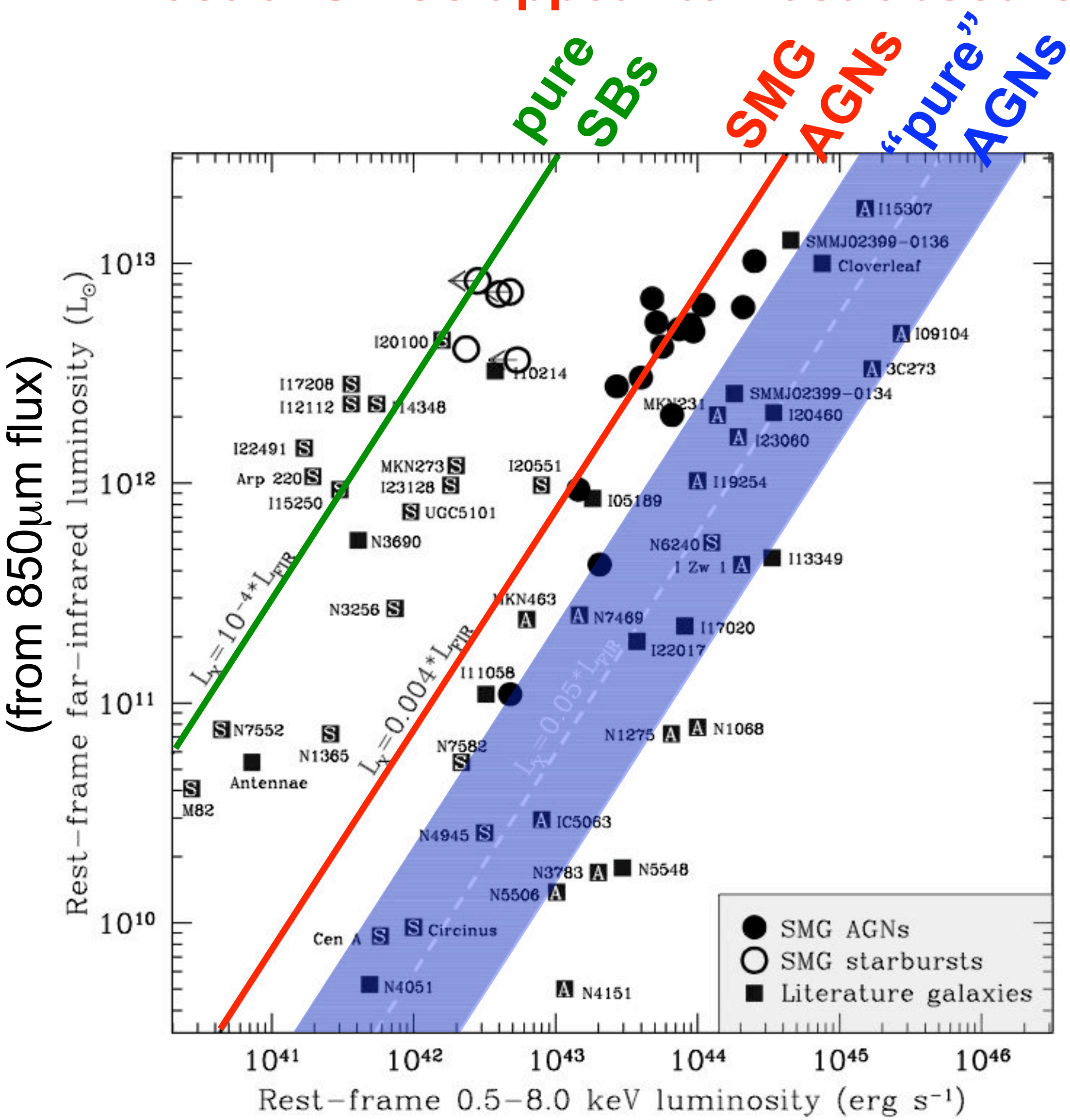
Indications for an offset M_{BH}/M_{bulge} relation at high-z



Also high-z CO resolved hosts support M_{BH}/M_{bulge} >> 0.002 (local)

What about submm/mm observations of low luminosity (~Sy like) AGNs at high-z?

Most of them out of reach of current facilities... but (viceversa) most of SMGs appear to host obscured, low-luminosity AGNs

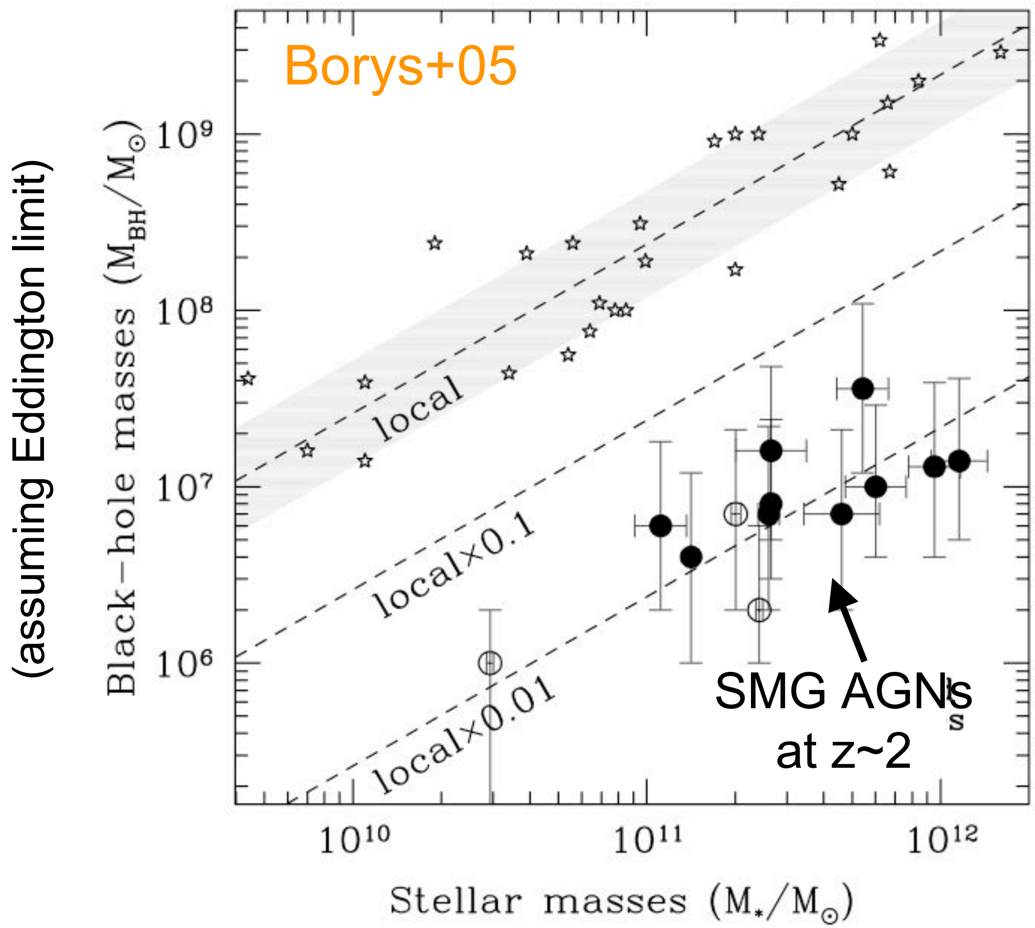


Little AGN contribution to L_{FIR}

Interpreted as progenitors of QSOs... growing BH, still low M_{BH}

Alexander+04,05

Attempt to locate SMG-AGNs on the M_{BH}-M_{Gal} relation at z~2



(from near-IR data)

Opposite trend with respect to high-z QSOs !!!???

Possible explanations:

- Sampling different populations?
- In both samples only the tip of the iceberg observed...
- Huge differences between M_{DYN} and M_{STAR} of host galaxies??
- Large uncertainties and several, heavy assumptions...

Very confusing so far...

...need to obtain better data on more representative samples of high-z AGNs

...need ALMA!