ALMA, SPICA and IXO:
Far-IR - X-ray synergies
to investigate galaxy evolution

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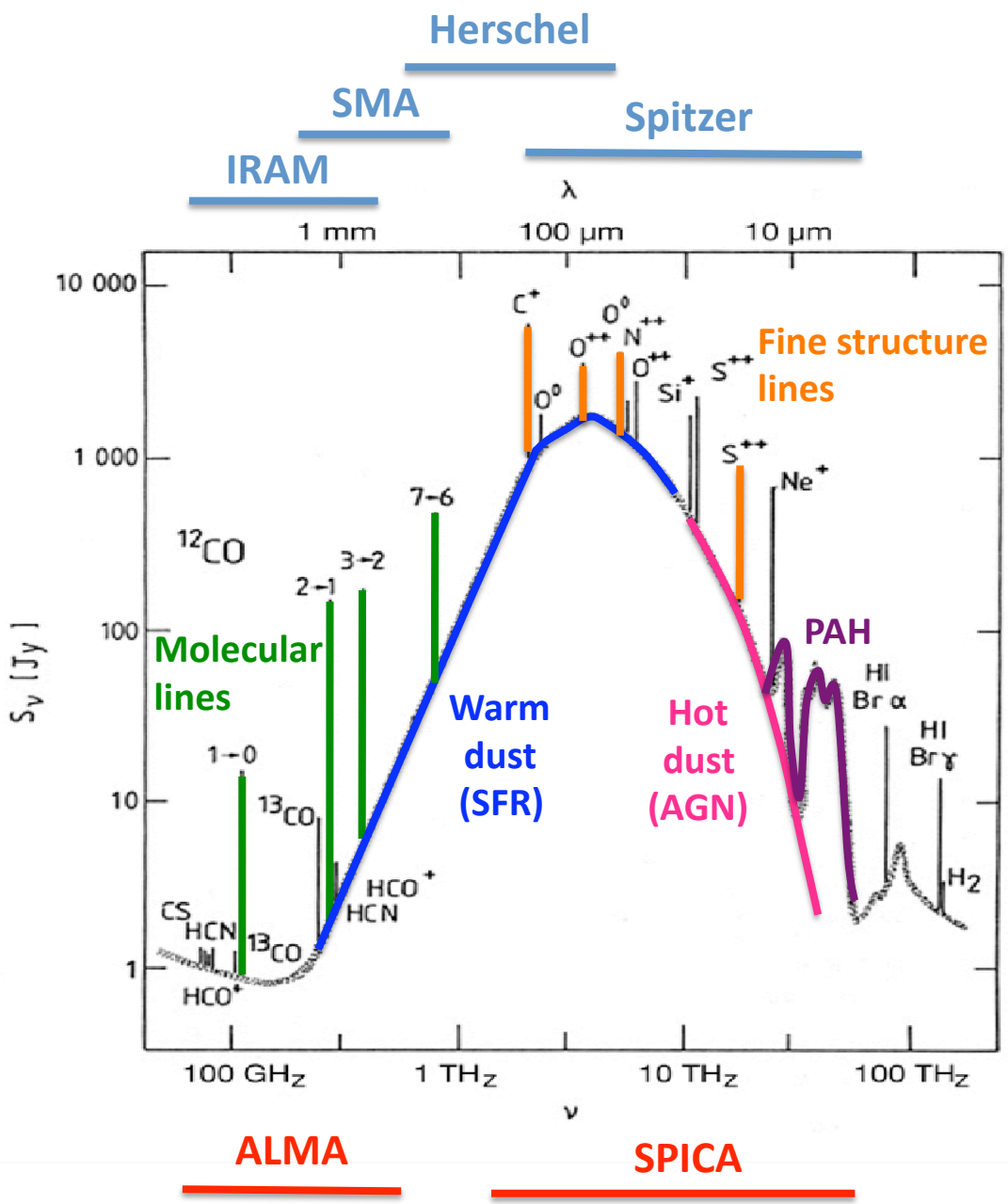
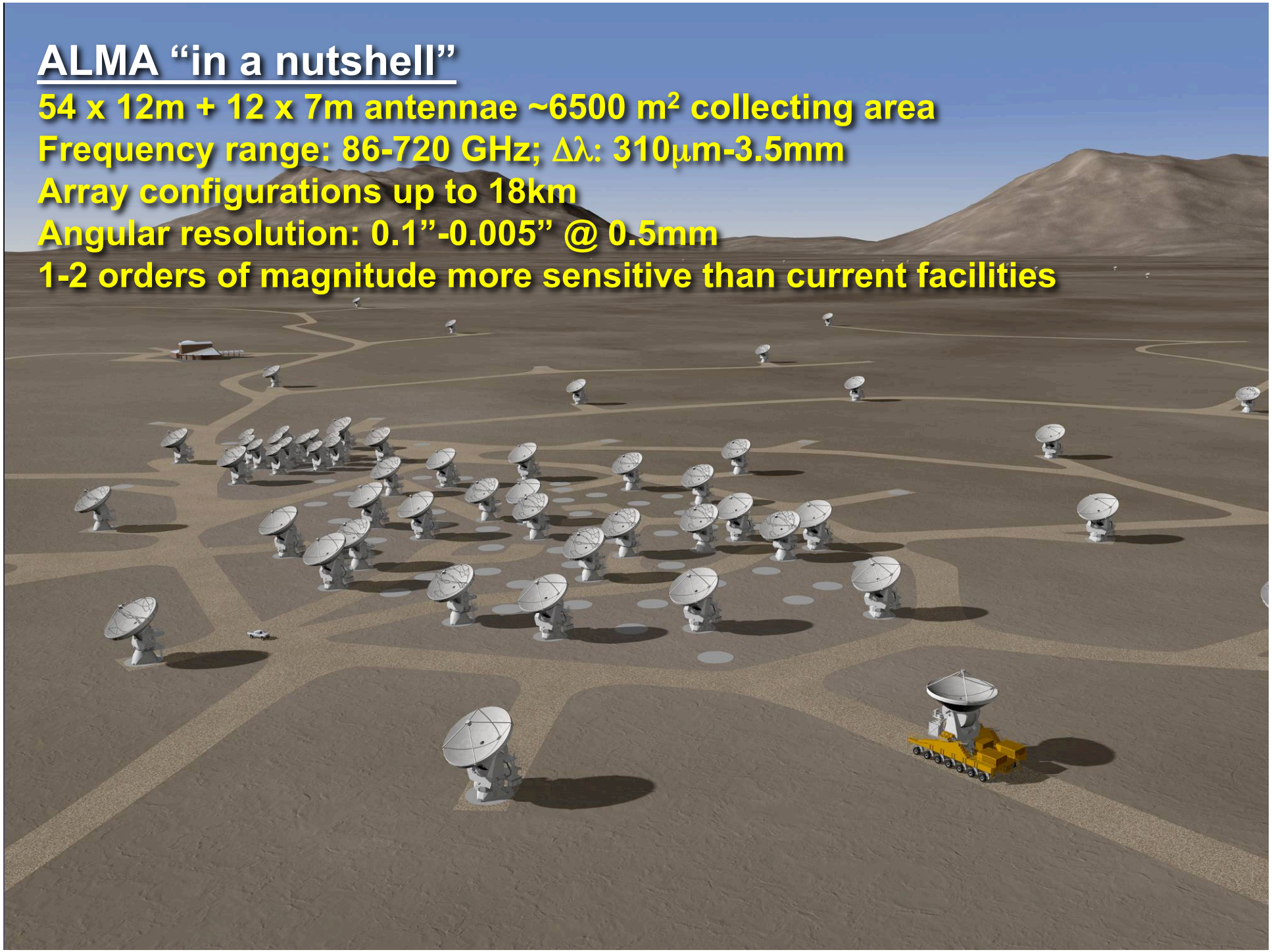
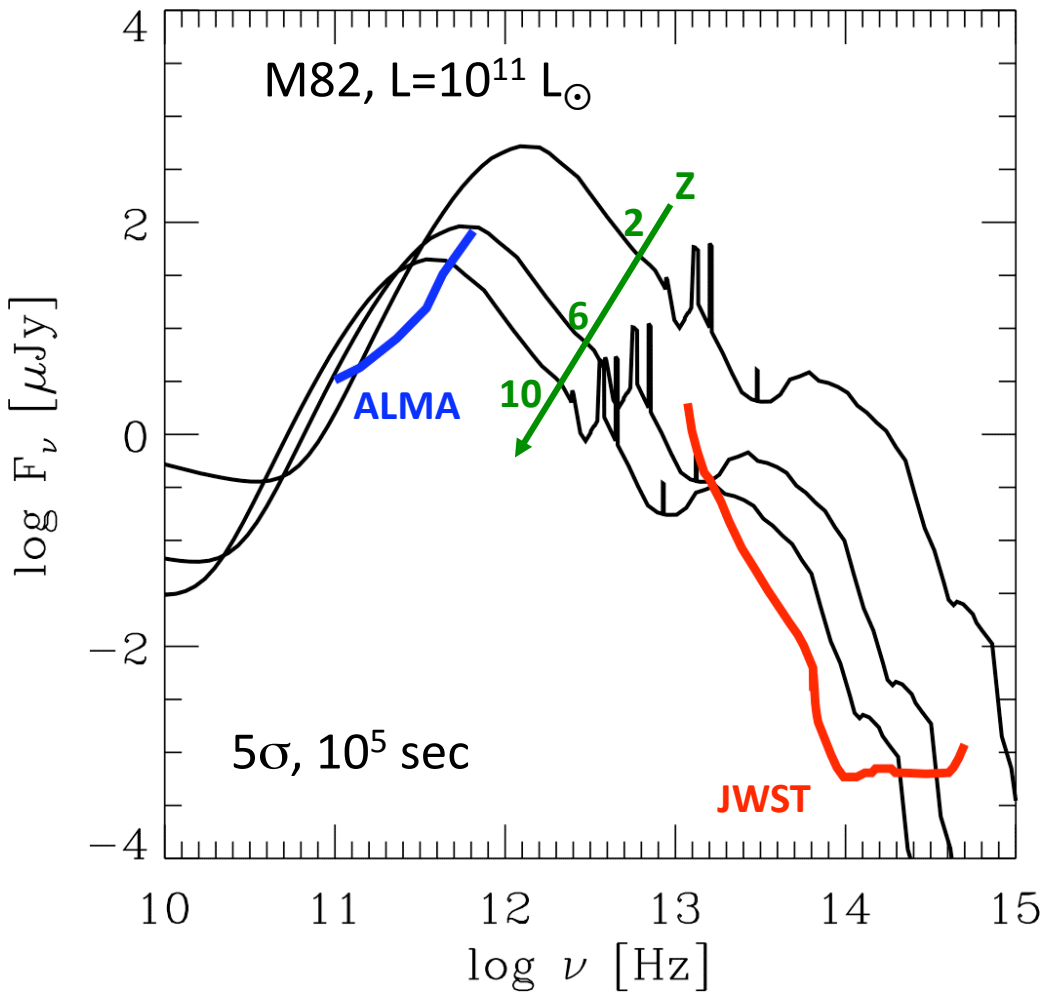

Herschel
SMA
Spitzer
IRAM
λ
1 mm
100 μm
10 μm
10 000
1 000
100
10
1
S_ν [Jy]
C^+
O^0
O^{++}
N^{++}
O^{++}
Si^+
S^{++}
S^{++}
Ne^+
Fine structure lines
7–6
^{12}CO
3–2
2–1
Molecular lines
1–0
^{13}CO
CS
HCN
^{13}CO
HCO^+
HCO^+
HCN
Warm dust (SFR)
Hot dust (AGN)
PAH
HI Br α
HI Br γ
H_2
100 GHz
1 THz
10 THz
100 THz
ν
ALMA
SPICA

ALMA "in a nutshell"

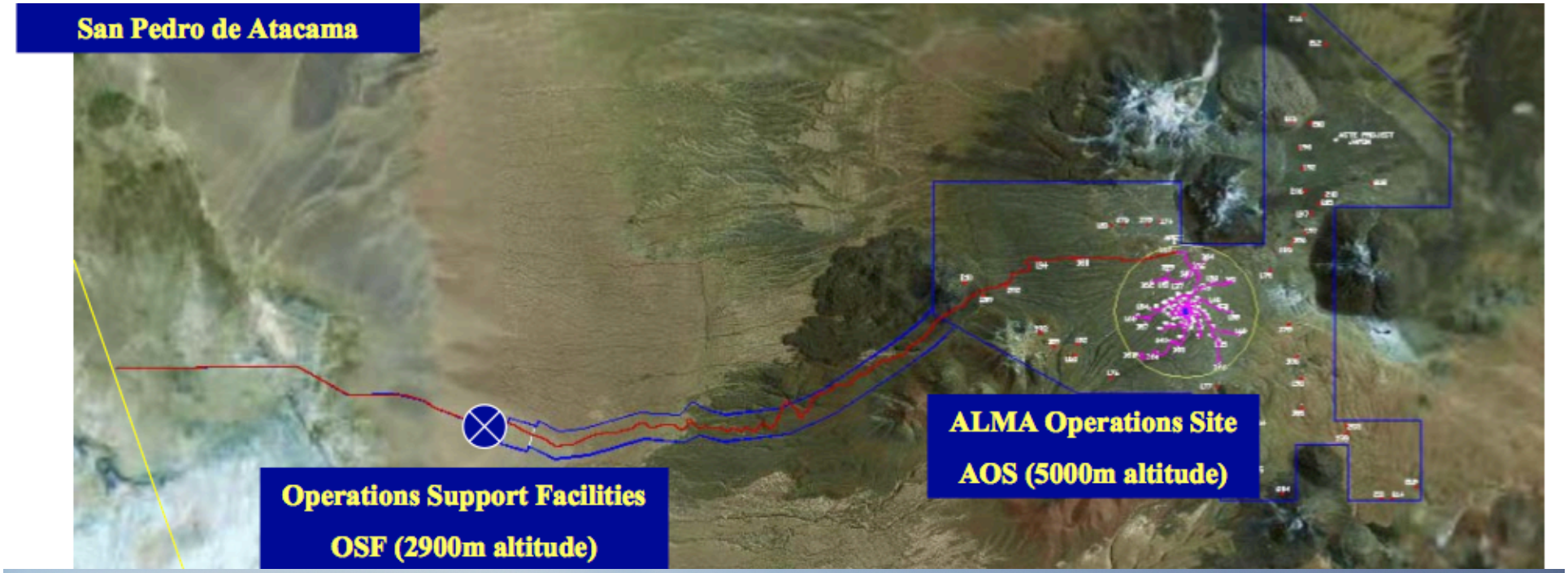
54 x 12m + 12 x 7m antennae ~6500 m^2 collecting area
Frequency range: 86-720 GHz; $\Delta\lambda$: 310μm-3.5mm
Array configurations up to 18km
Angular resolution: 0.1"-0.005" @ 0.5mm
1-2 orders of magnitude more sensitive than current facilities



ALMA will detect
CO in MW-like galaxies out to z<3 and
[CII] and/or continuum in moderately starburst galaxies at the re-ionization epoch

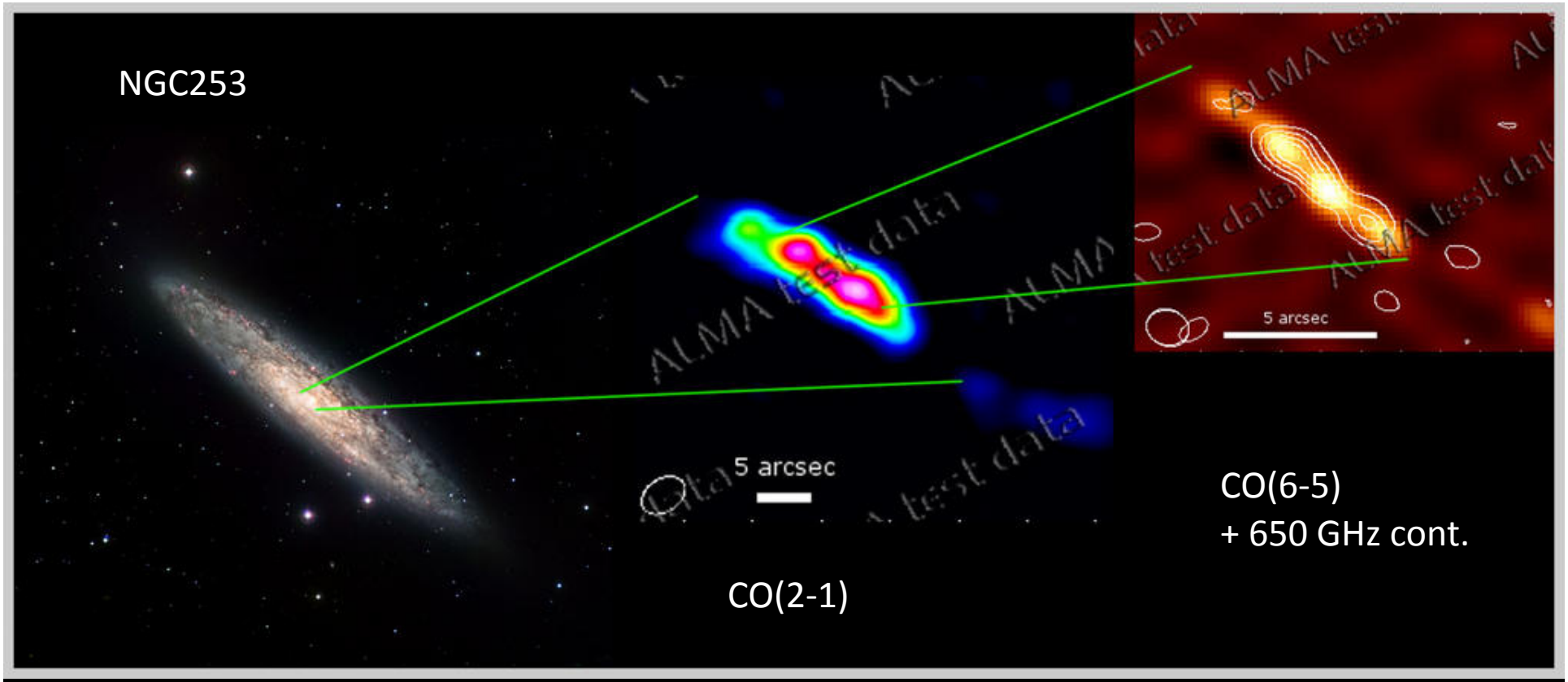


exploiting negative K correction

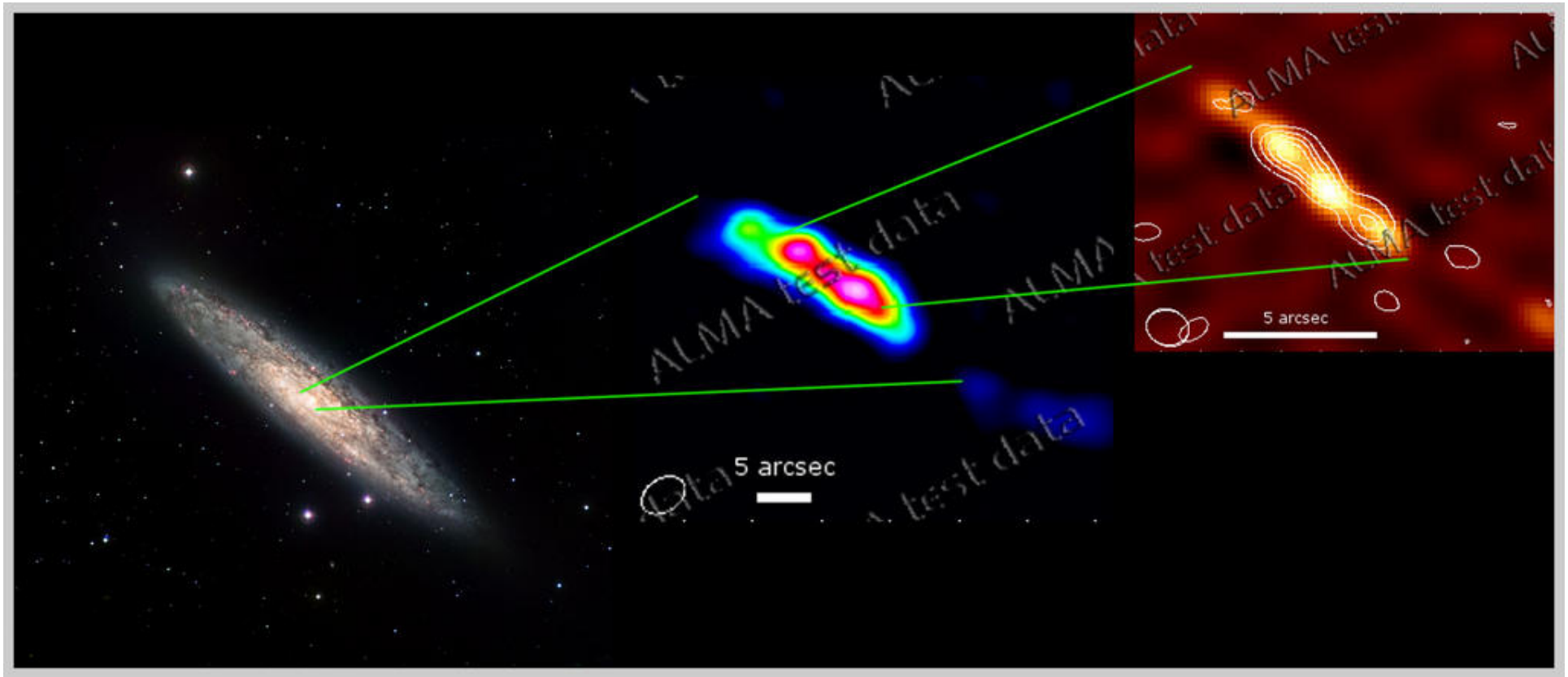

San Pedro de Atacama
ALMA Operations Site
AOS (5000m altitude)
Operations Support Facilities
OSF (2900m altitude)

23 anteannas at Operation Support Facility (OSF) 2900m

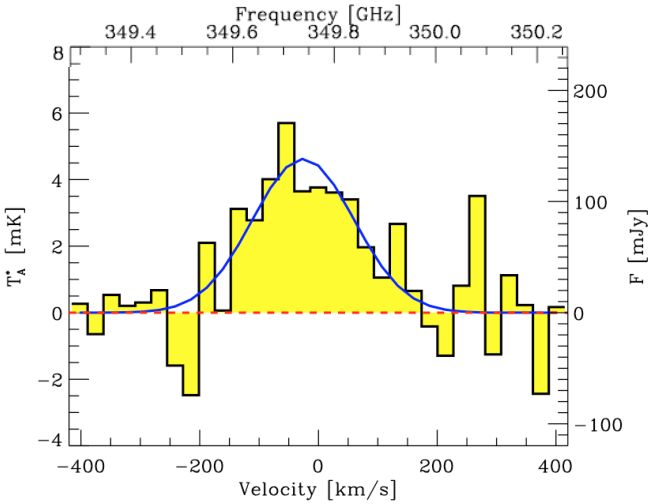
9 antennas at the ALMA Operations Site (AOS) 5050m



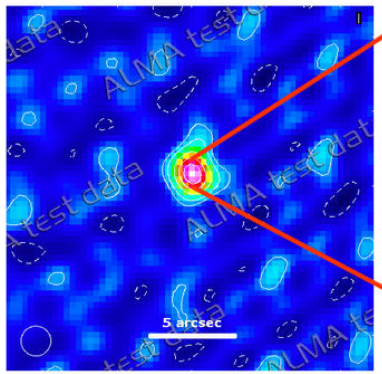
ALMA Science Verification test data



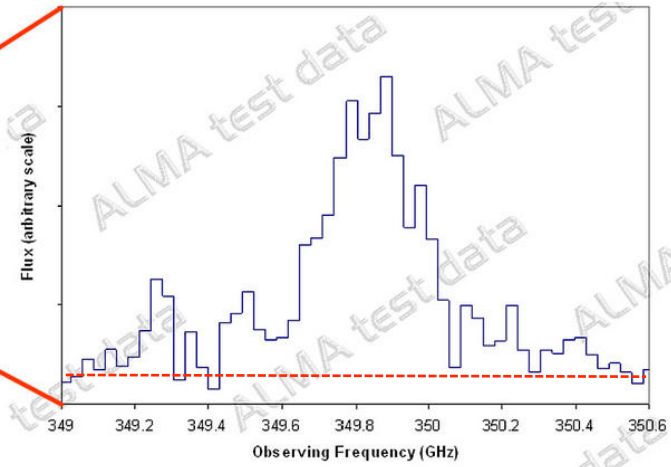
APEX - 5hr (Maiolino et al. 2009)



[CII]158μm z=4.8



ALMA Science Verification (8 ant.) - 1hr



CALL for ALMA EARLY SCIENCE in a few weeks:
16 antennas
4 bands (λ= 3, 1.3, 0.8, 0.45 mm)
baselines up to 250m

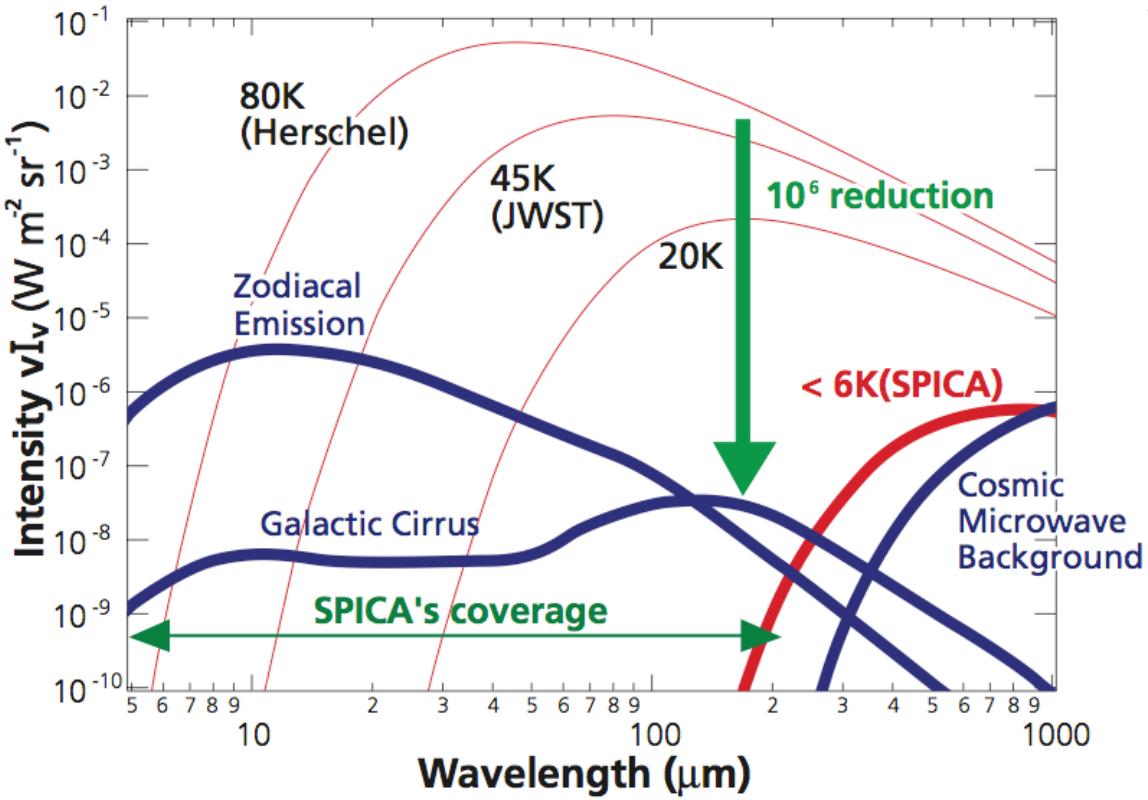
SPICA
JAXA + ESA Cosmic Vision

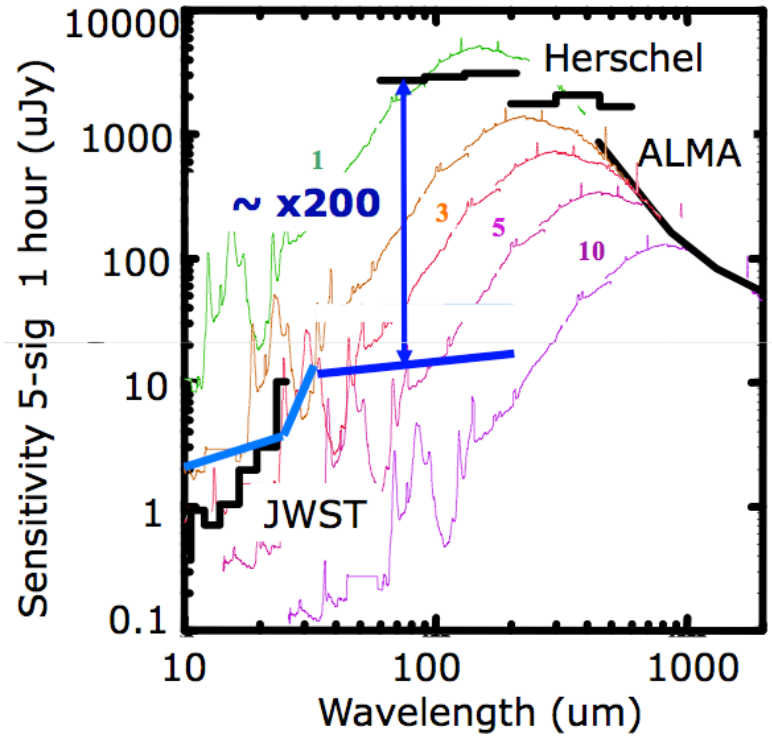
3.2m mirror cooled to ~ 6K

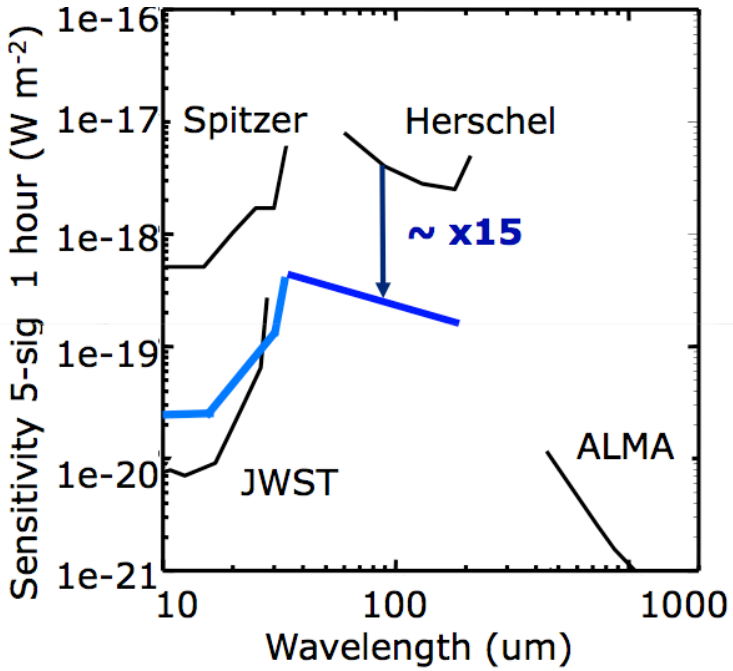
Instruments cover 5 - 210 µm

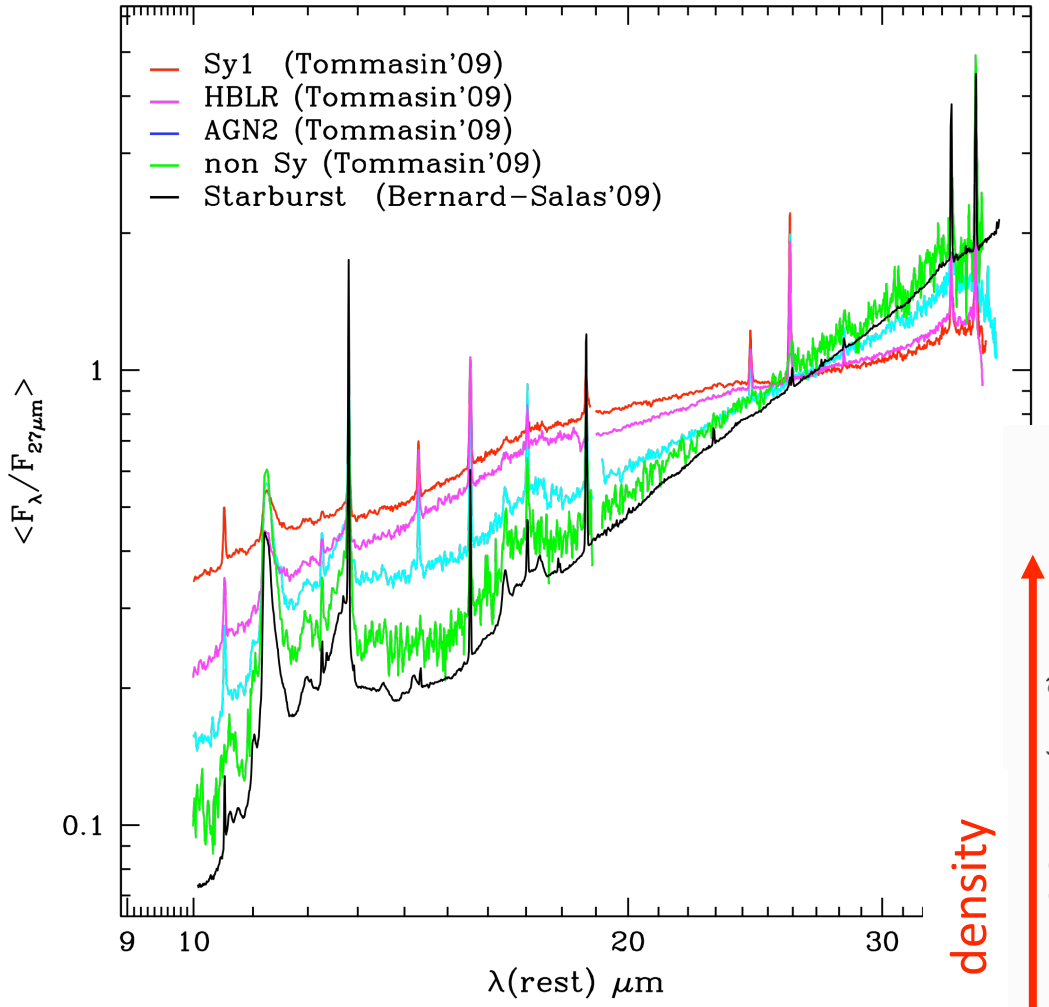
- -MIR spectro-photometer
- -FIR imaging spectrometer
- -MIR Medium/High Resolution Spectrometer
- -MIR coronagraph
- -FIR and sub-mm spectrometer – optional

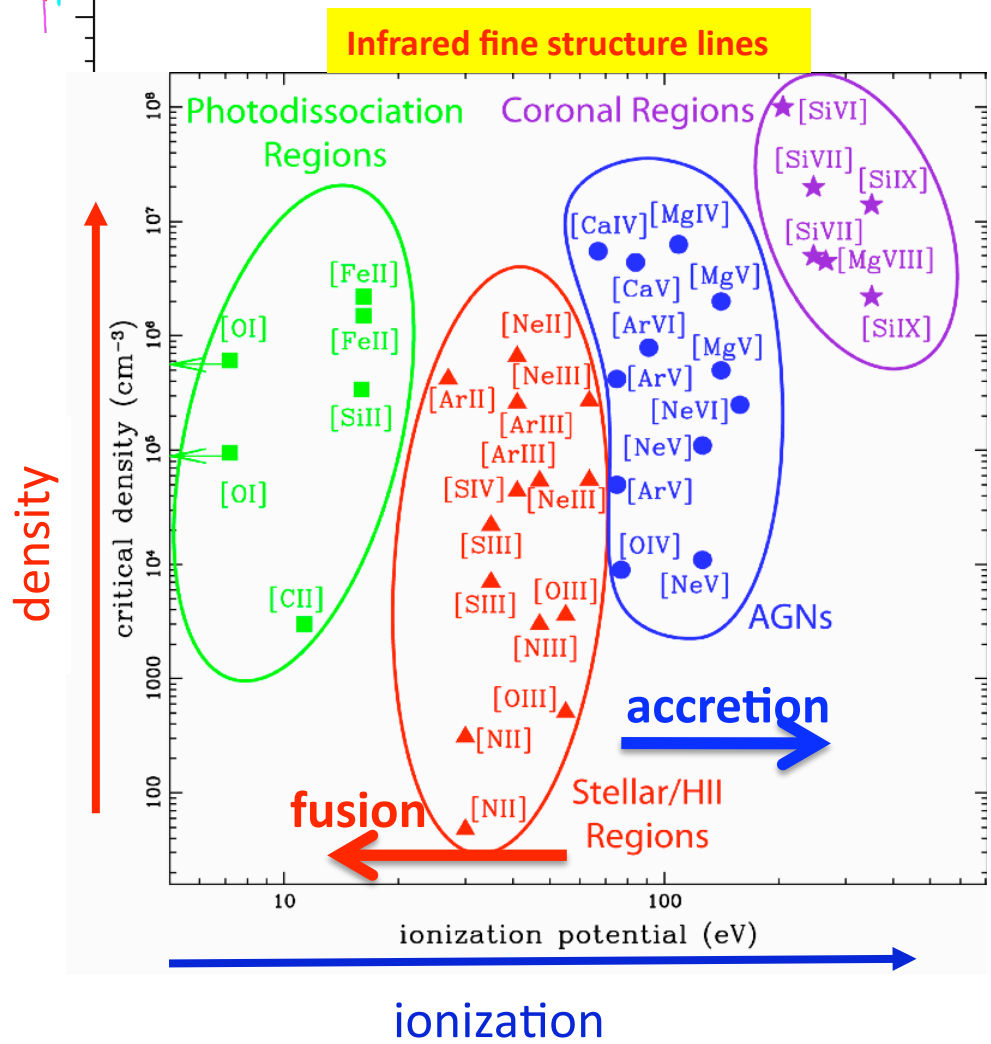
Sensitivity of a 6K FIR telescope



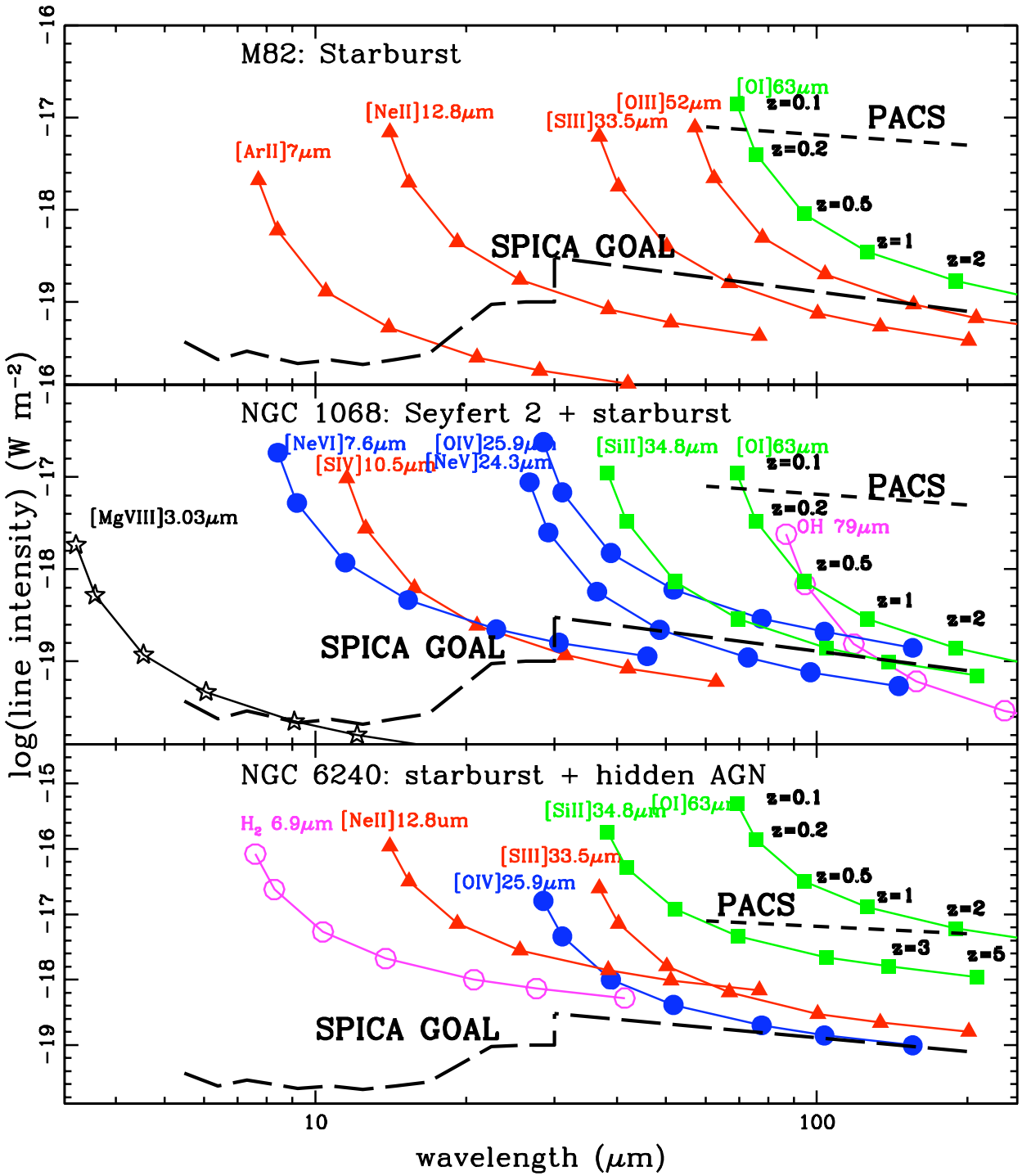








Mid-IR diagnostics (Spitzer spectra)

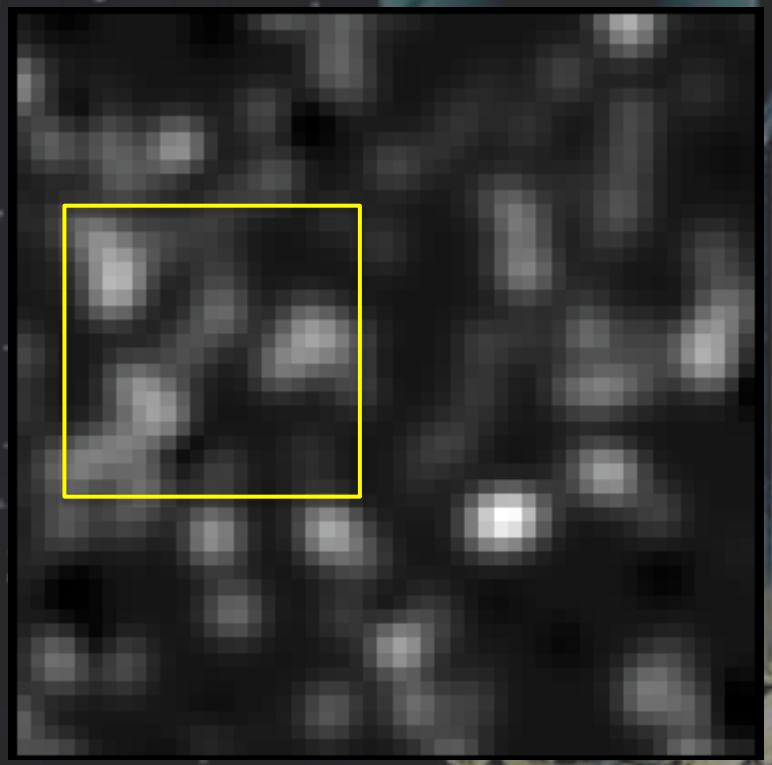


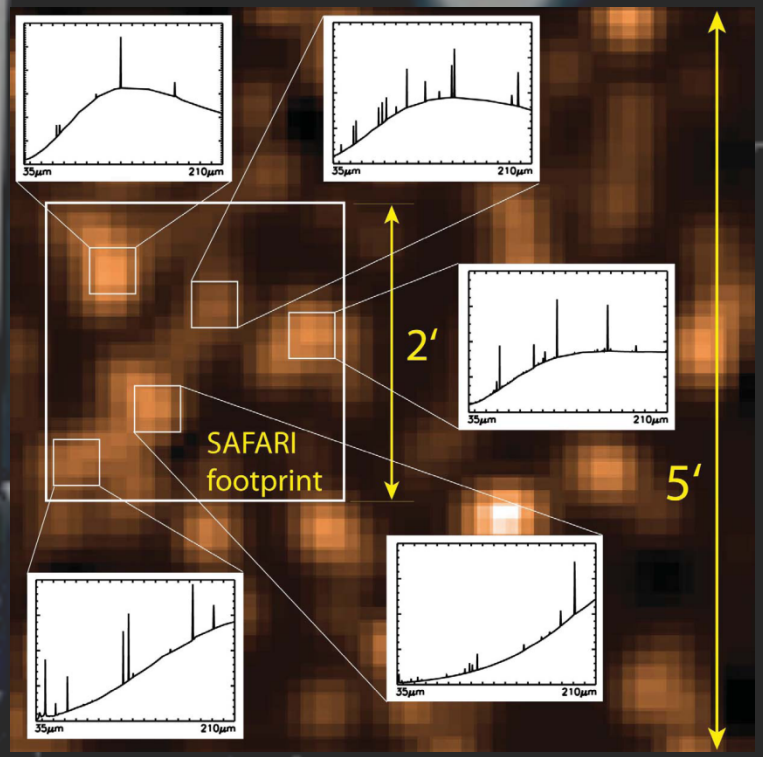
M82-like galaxies up to z~2

N1068-like galaxies up to z>5

The Multiplex Advantage

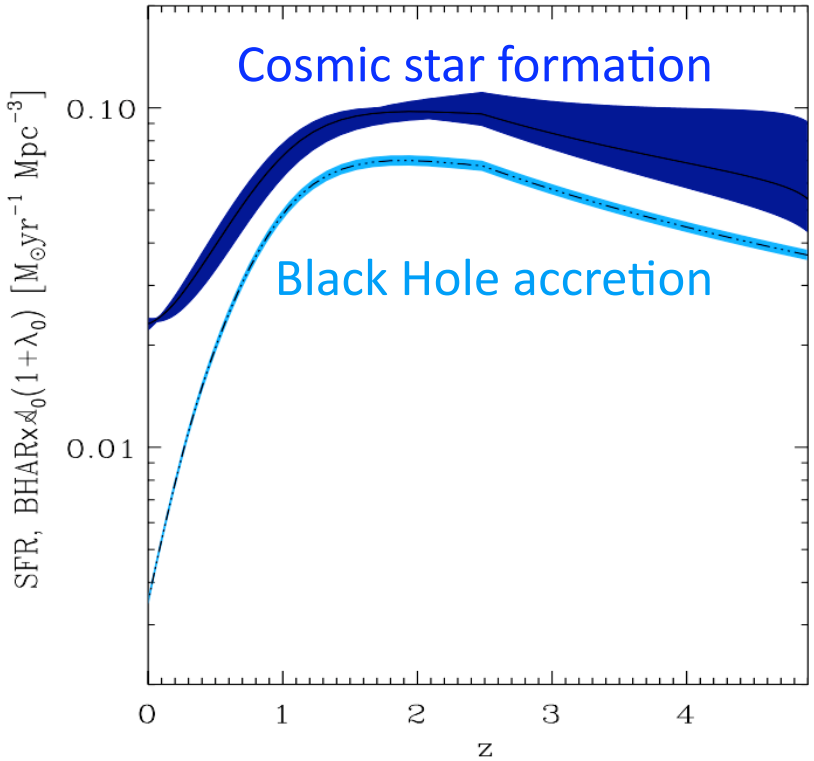
Complete characterization of the Herschel sources





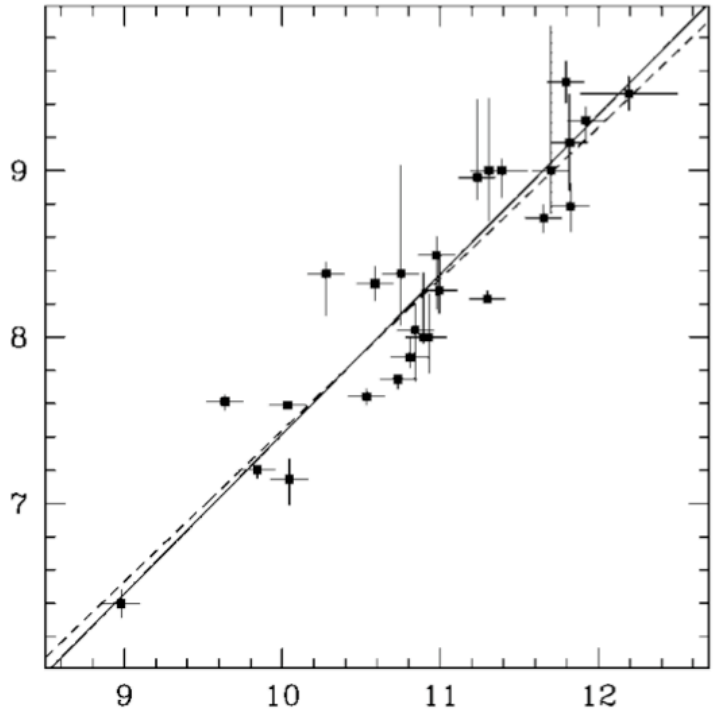
SPICA FIR FTS will take spectra of 7-10 sources/field

Images Rosenbloom, Oliver, Smith, Raab private communication



Merloni+06

Marconi & Hunt+04



M_{BH}

$\dot{M}_{BH}$

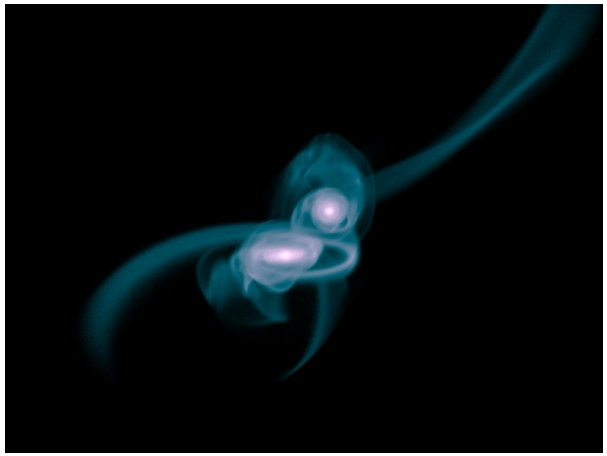
(L_{AGN})

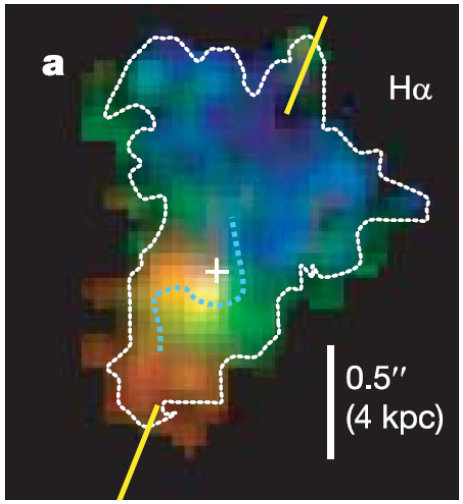
IXO

M_{bulge}

$\dot{M}_{star}$= SFR

ALMA - SPICA





Merger scenario

- Correlation $\dot{M}_{BH}$-SFR
- Irregular dynamics
- BH form faster than galaxy

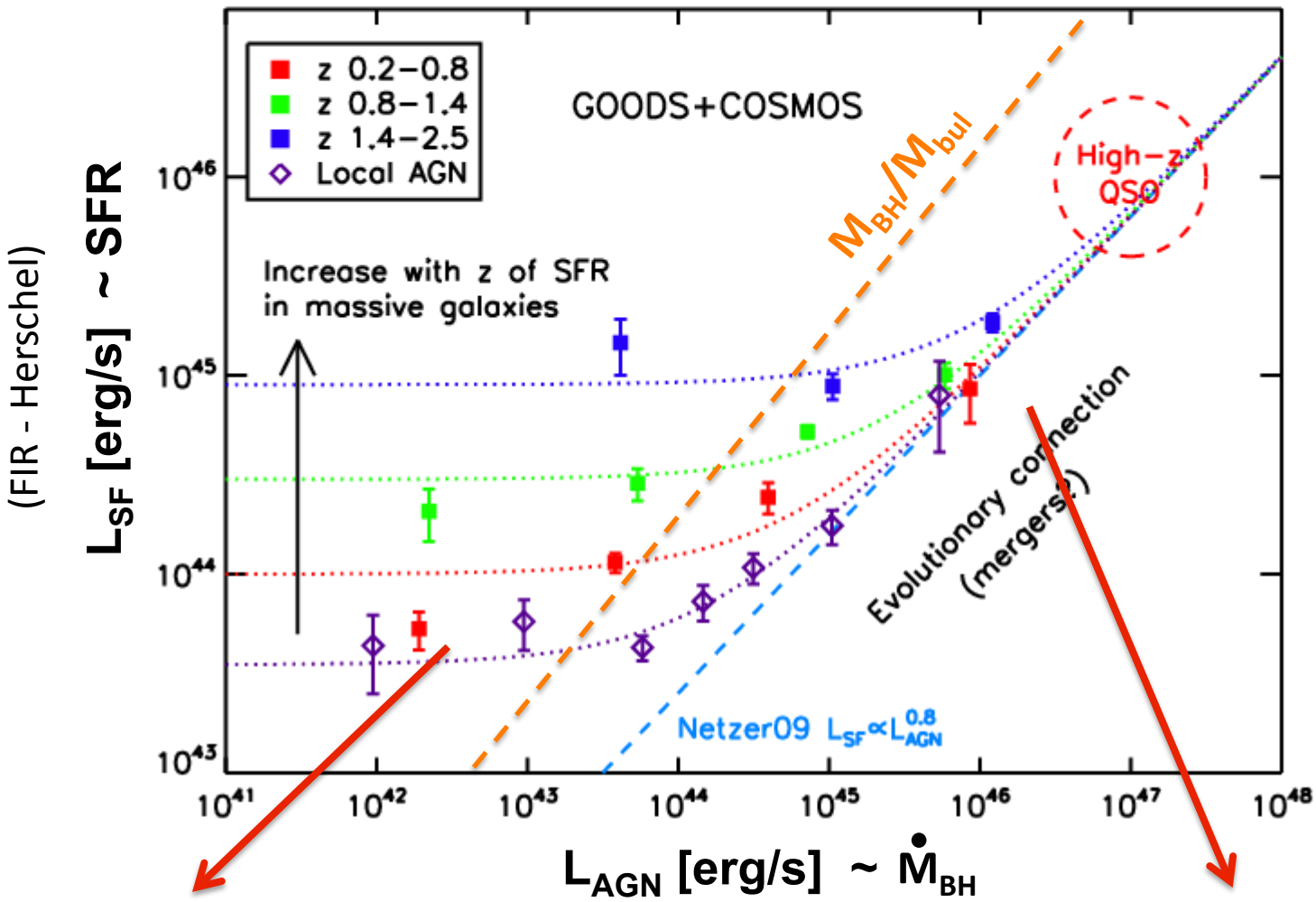
Secular scenario

- No correlation $\dot{M}_{BH}$-SFR
- Rotating (turbulent) disks
- Galaxies form faster than BH or coeval

AGN feedback

Low luminosity AGN hosts (bulk of BH accretion): no correlation between BH accretion and SFR

X-ray selected AGNs from COSMOS (Brusa+10) and GOODS (e.g. Bauer+09)

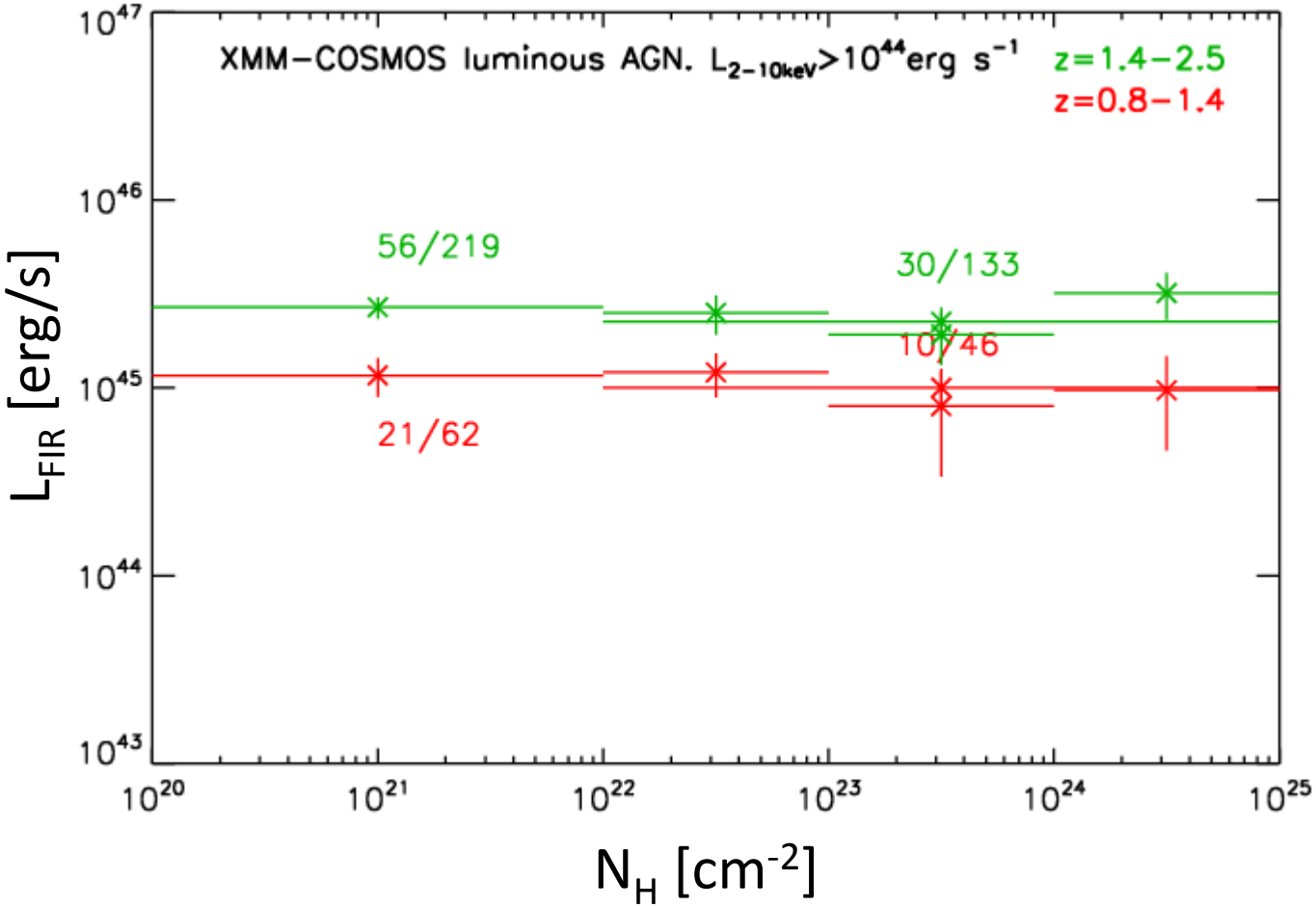


Shao+10
Lutz+11

ALMA CO maps: turbulent rotating disks?

ALMA CO maps: irregular dynamics?

SFR-obscuration connection?



… not what is suggested by the most simple version of a merger evolutionary pattern!

Current common tool investigate BH and galaxy evolution

$\dot{M}_{BH}$ → X-ray

SFR → FIR - Submm

Complementary tools in the ALMA-IXO era?

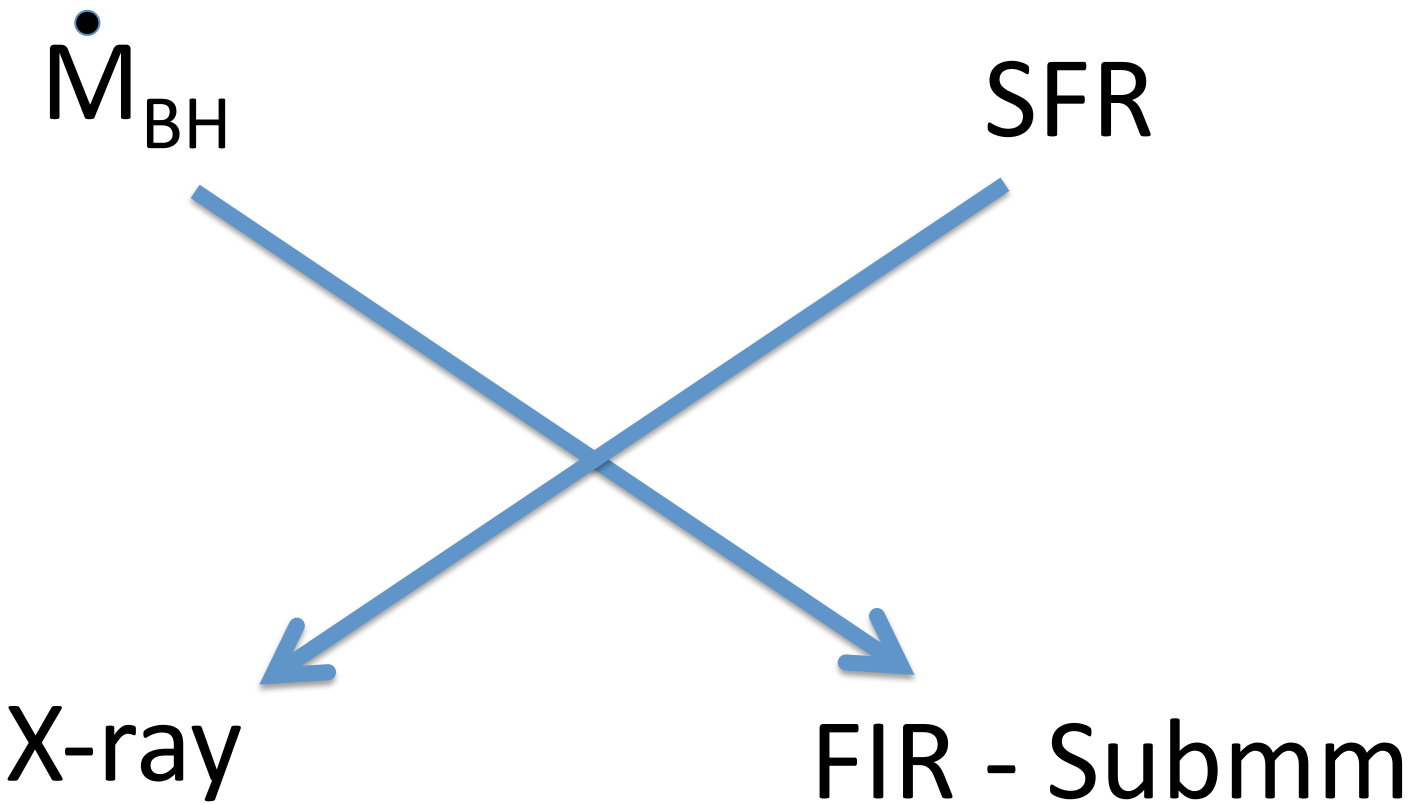
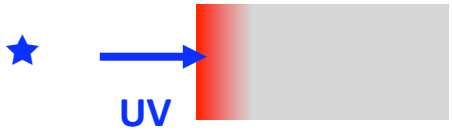
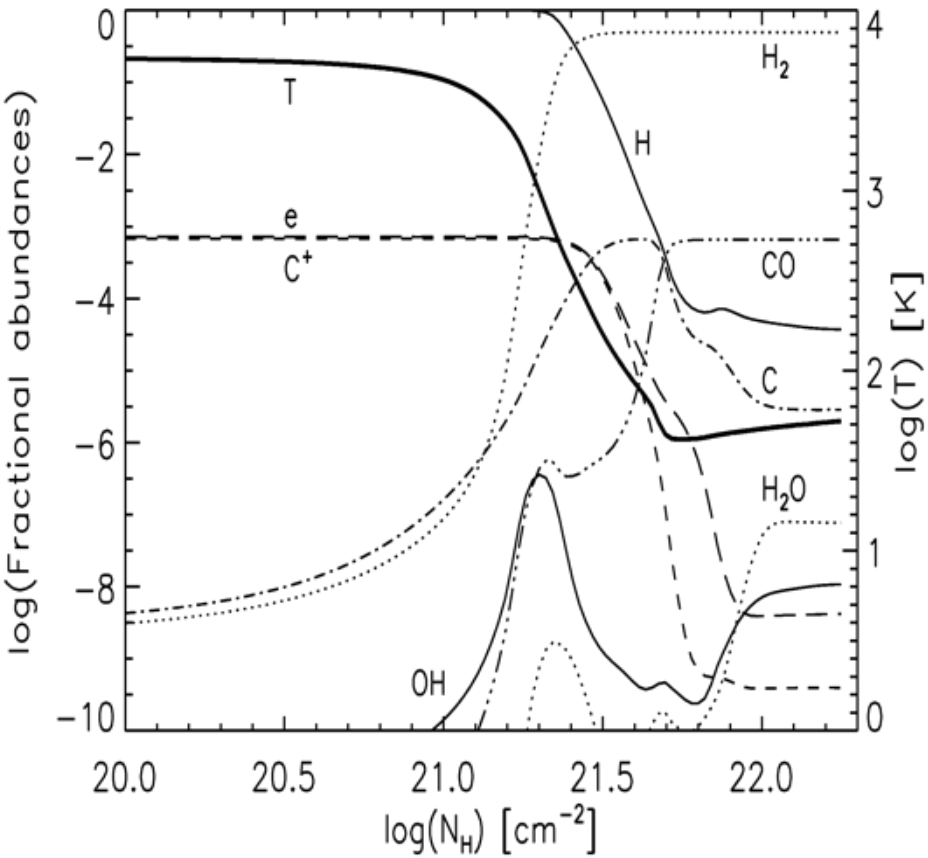


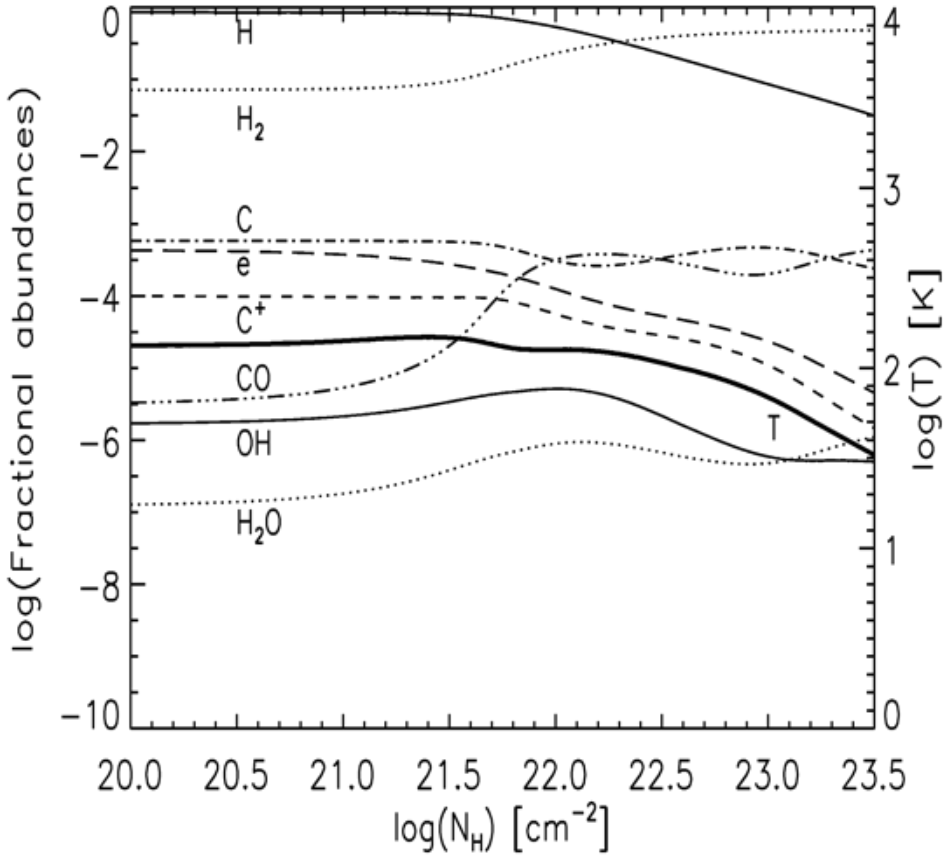
Photo Dissociated Regions (PDR's)





- **UV photons absorbed in the outer layer**
- **Heat the gas**
- **But also destroy most molecules**

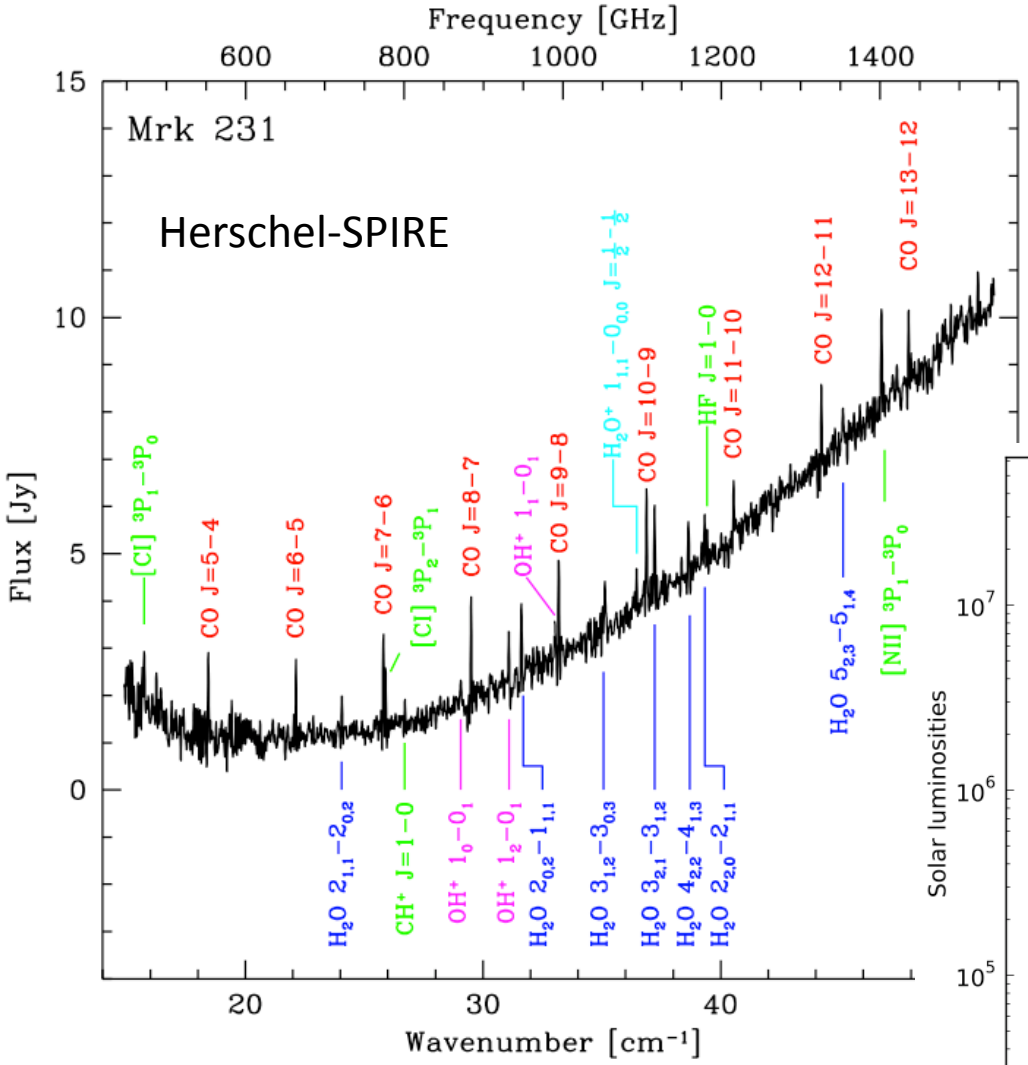
X-ray Dominated Regions (XDR's)



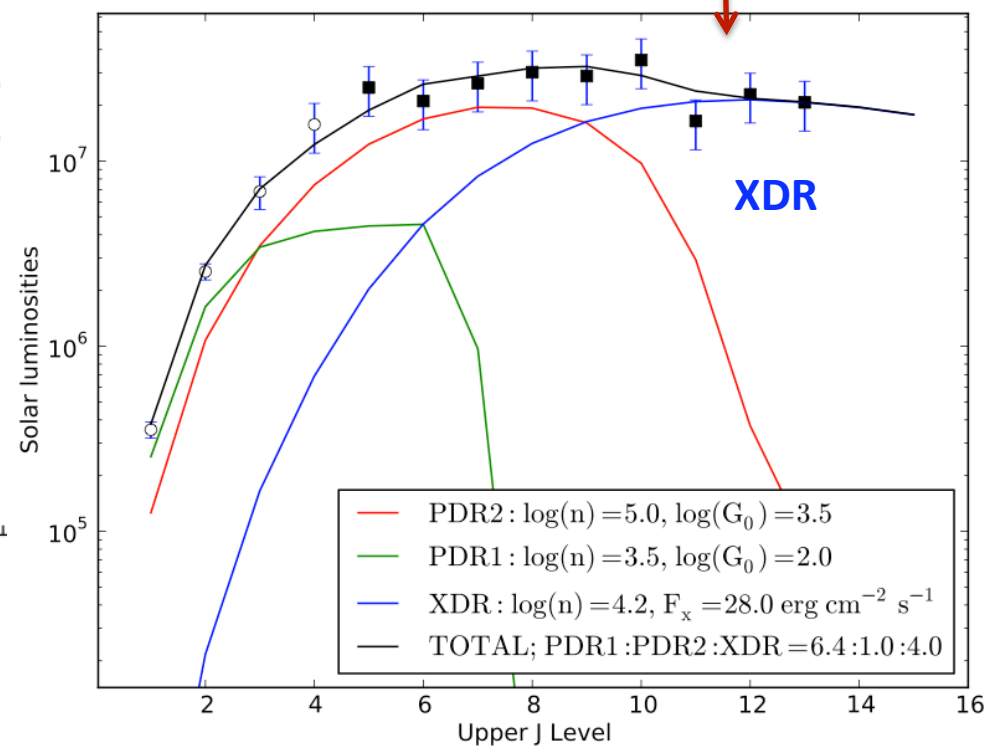
- **X-rays penetrate deep into the cloud**
- **Keep the gas warm (high excitation)**
- **Do not photo-dissociate molecules**

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

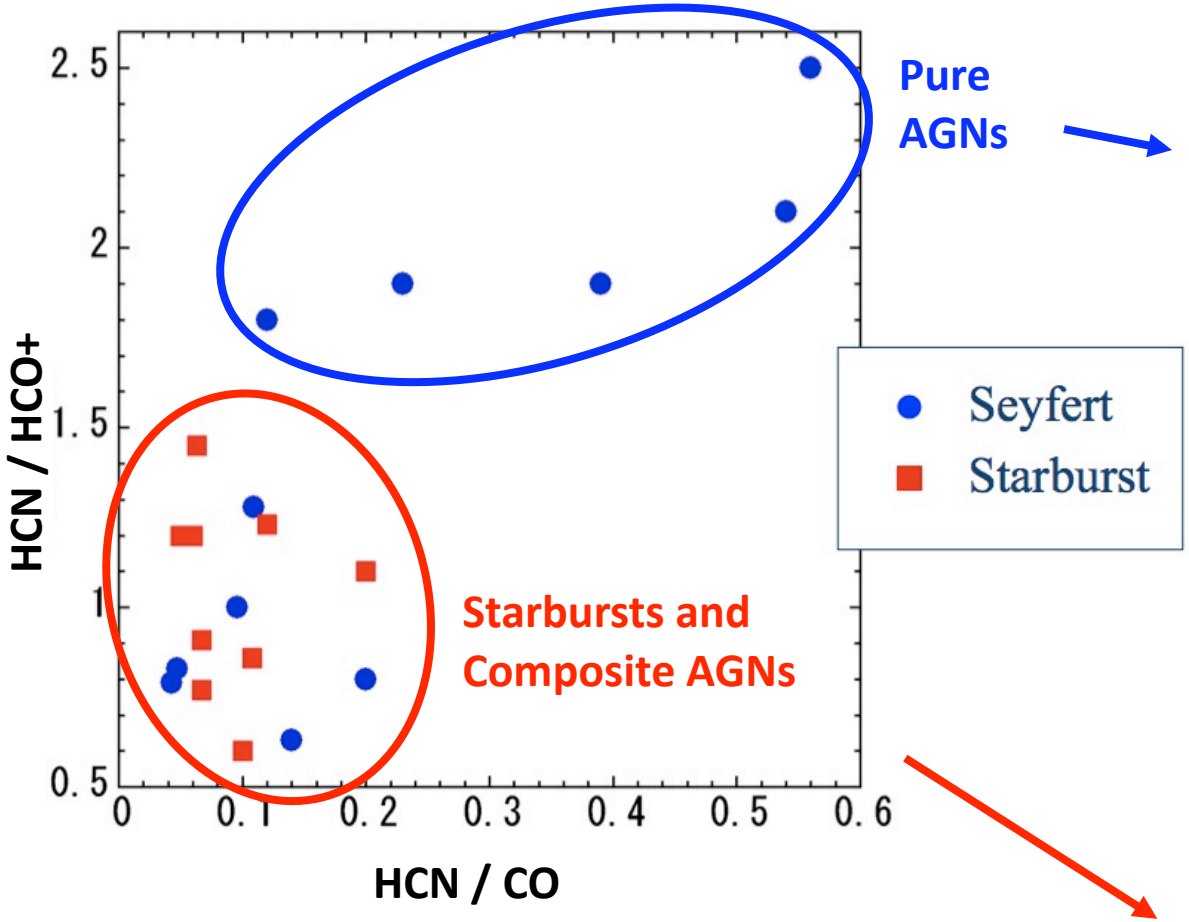
Mrk231 (Compton thick AGN)

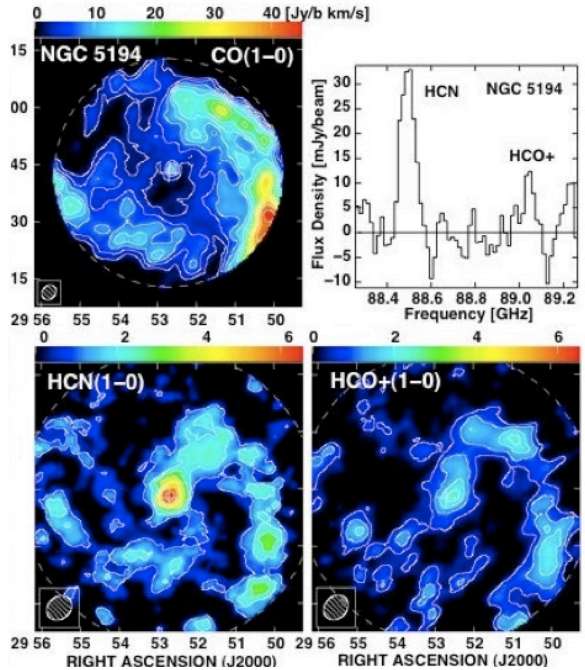


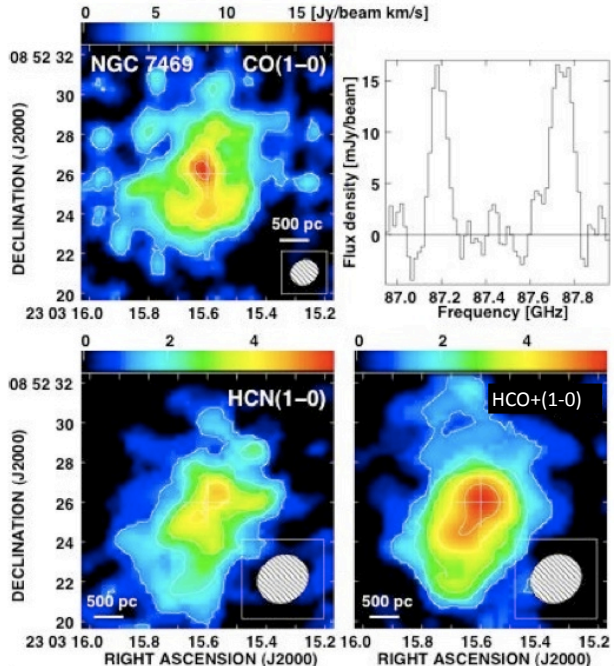
Powerful tool to identify totally obscured and embedded AGNs



Van der Werf+10



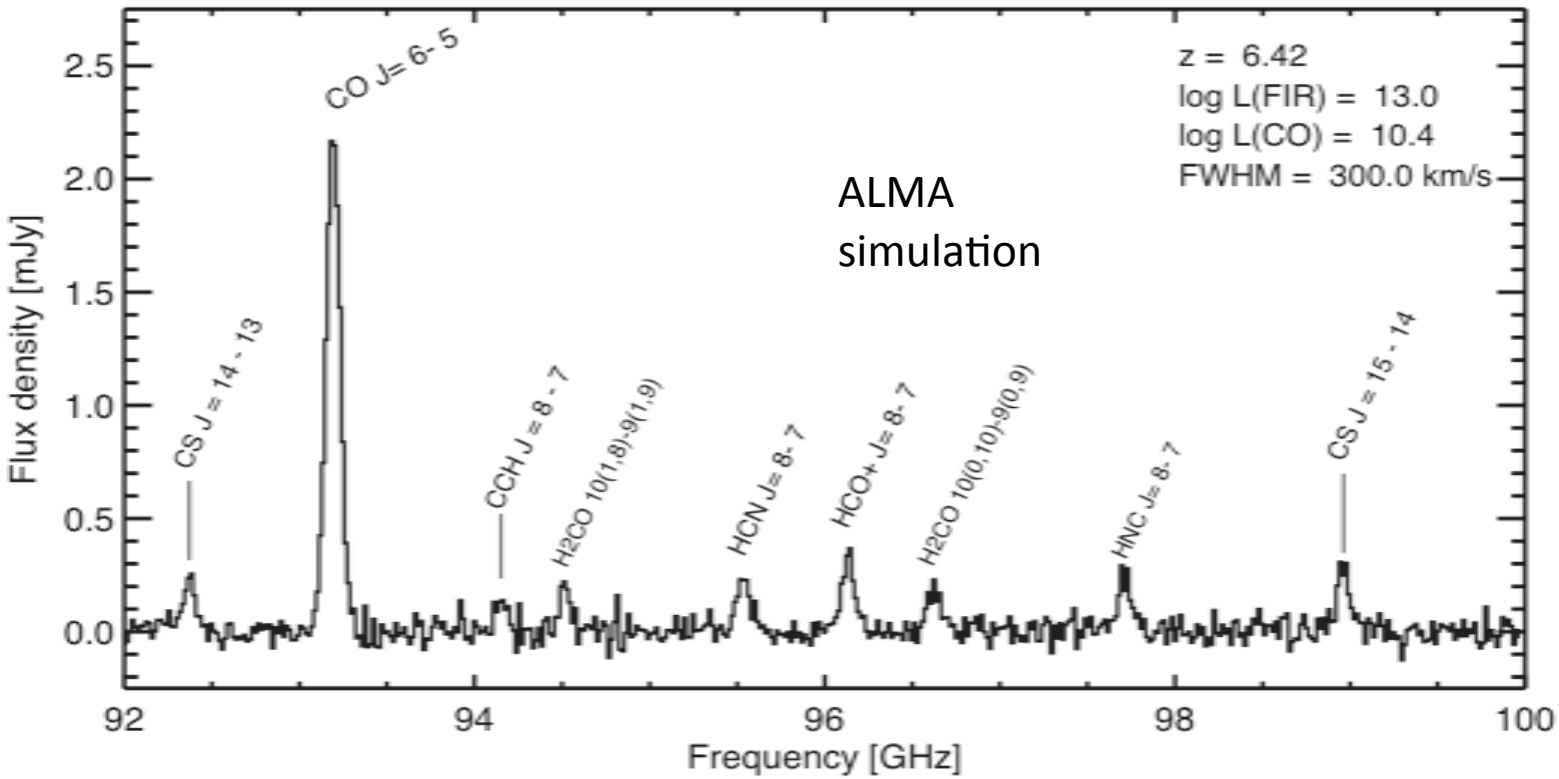




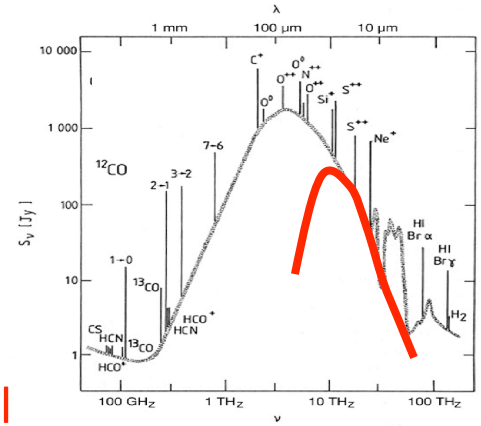
XDR-enhanced species can identify the presence of hidden/elusive AGNs

Khono+08
Krips+09

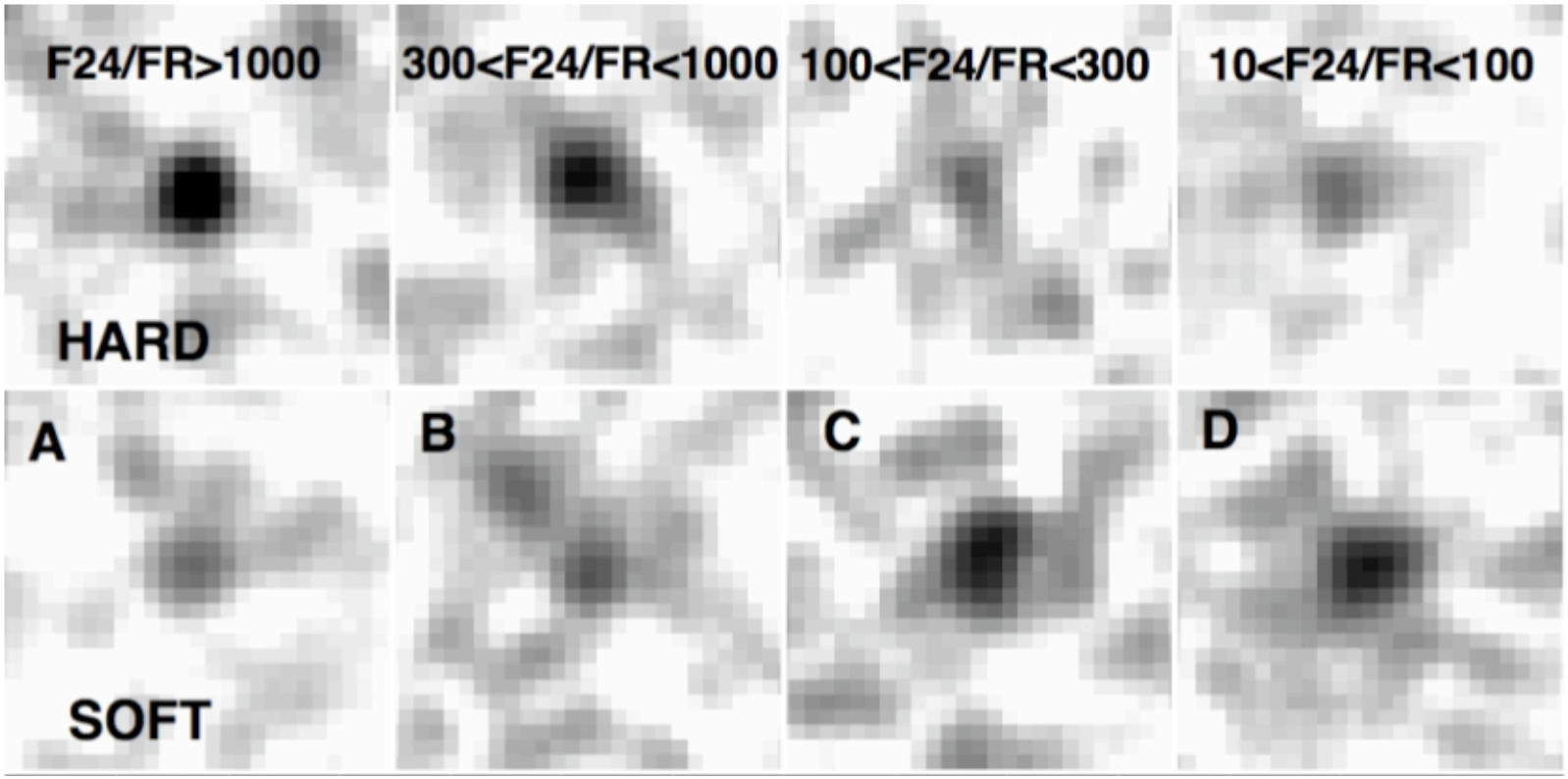
ALMA will probably allow us to identify Compton thick AGN out to the re-ionization epoch



Compton thick AGN identified through their hot dust emission



Mid-IR/optical

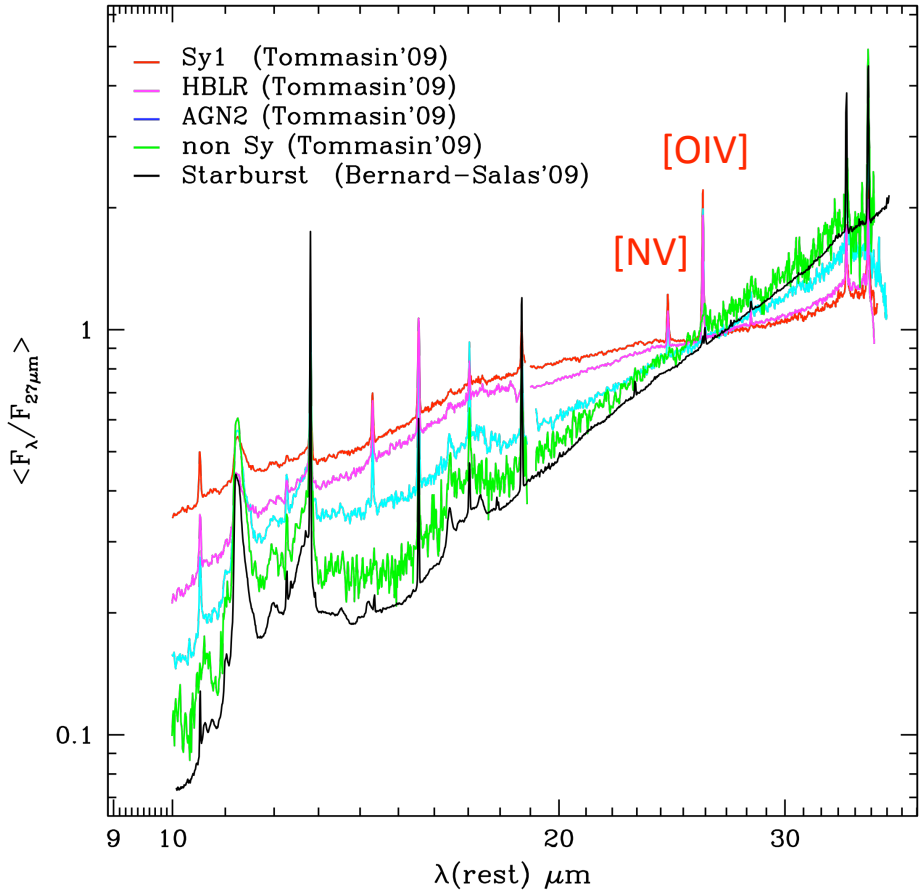


1.5-6 keV stacked

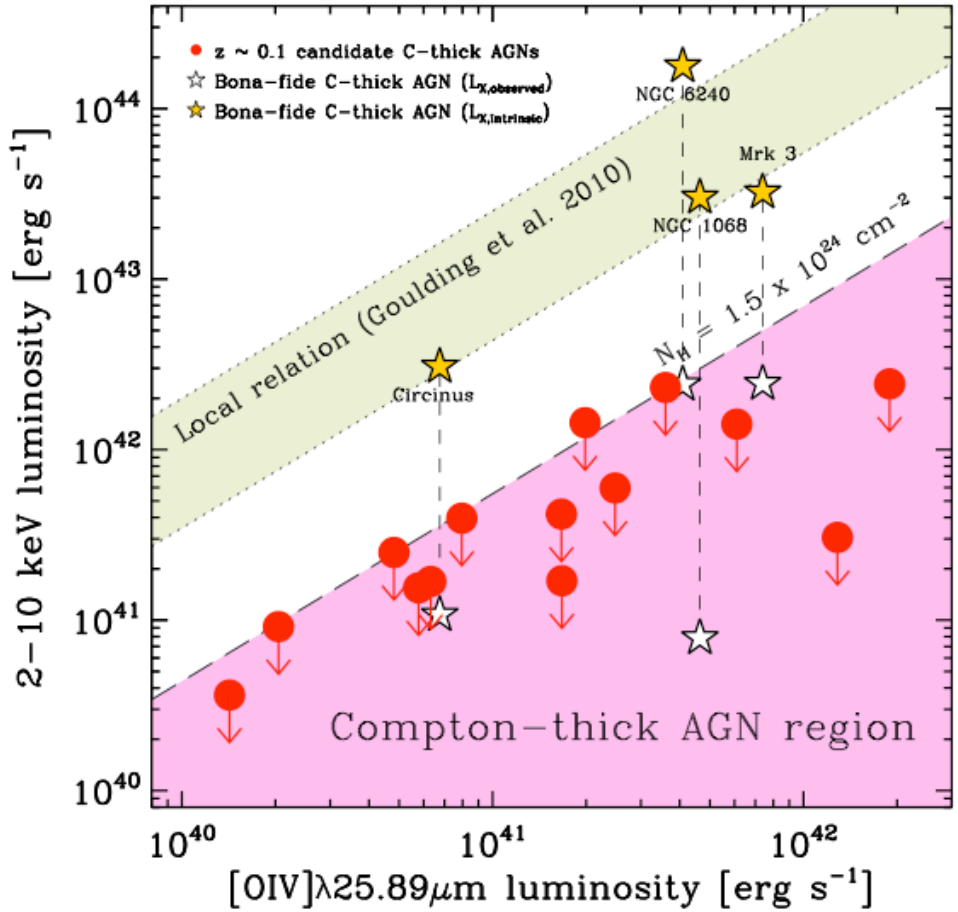
0.3-1.5 keV stacked

Fiore+2008,2010, Daddi+08

Identifying Compton thick AGN through high ionization mid-IR lines



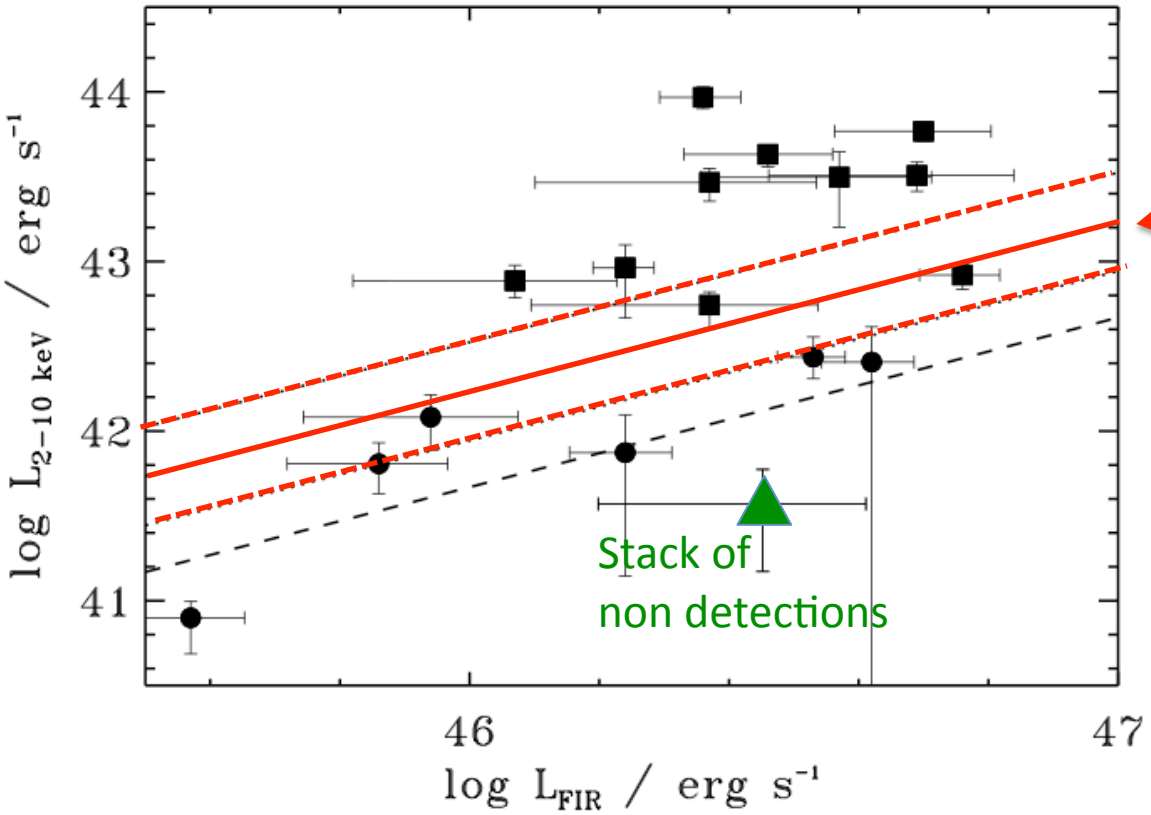
Gouldin+11



SPICA can detect these high ionization lines up to z~6

Detecting high-z infrared star forming galaxies through their X-ray emission...

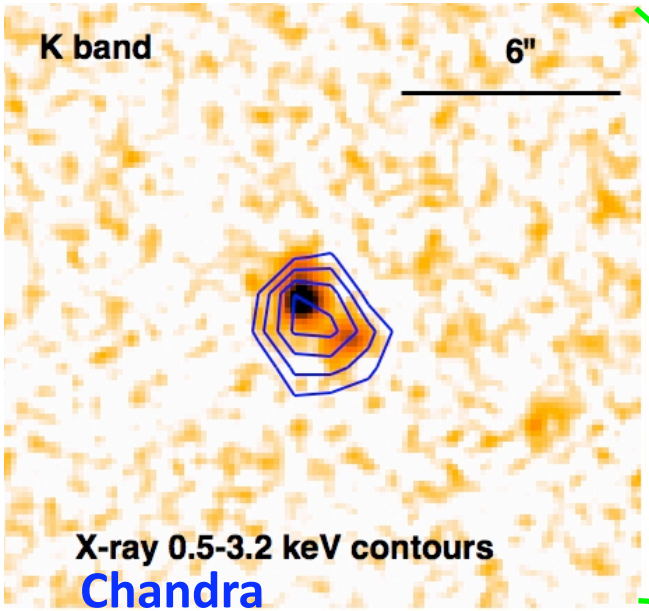
Laird+10, Georgantopoulos+10

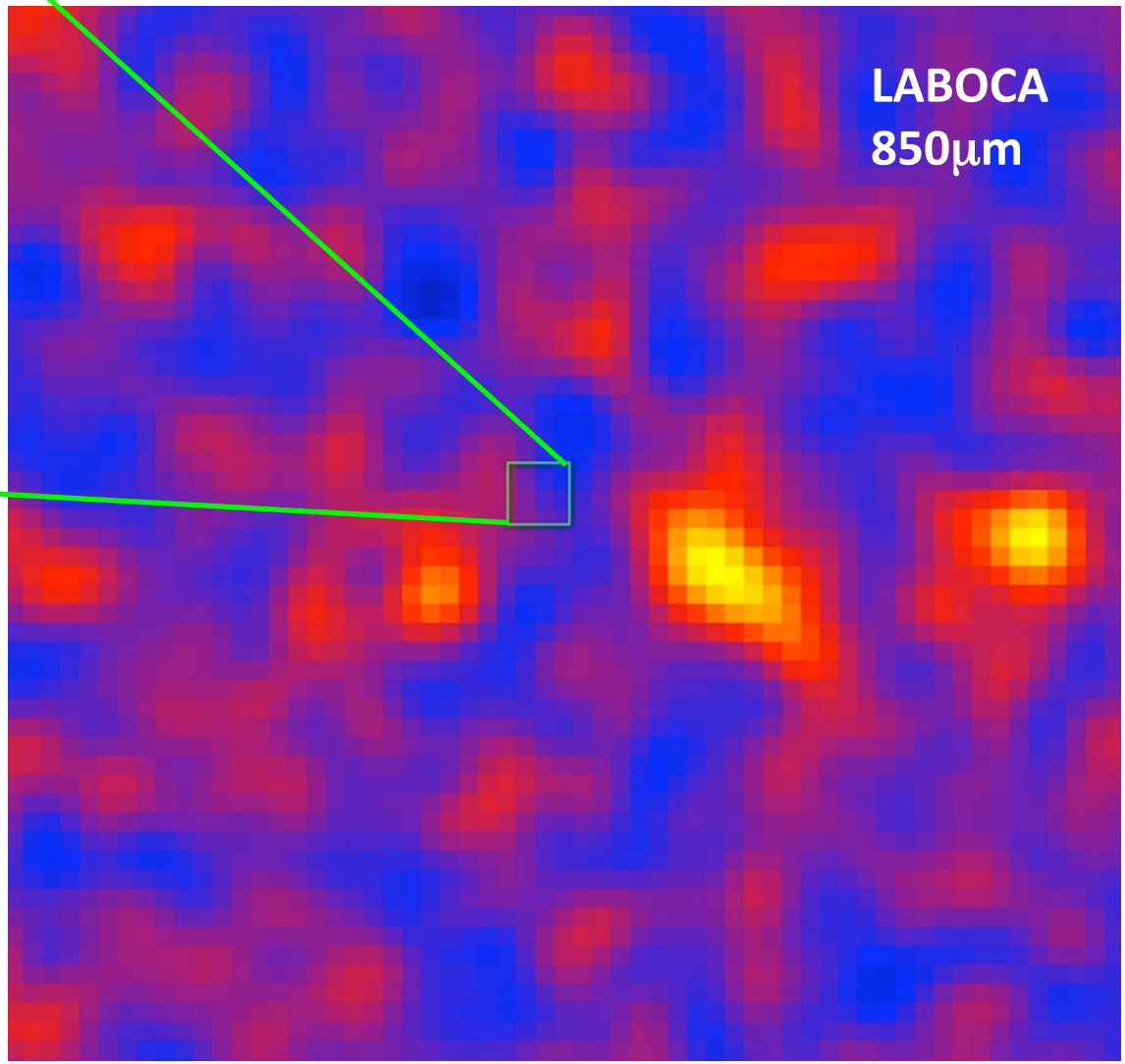


Starburst relation

Fiore+11

...even star forming galaxies NOT detected in the FIR-submm



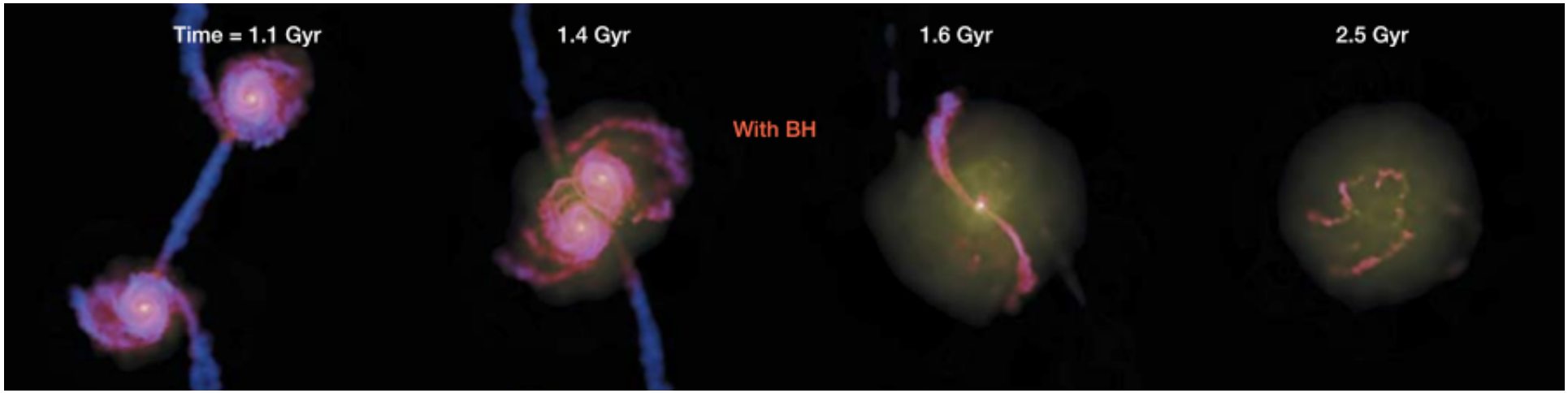


z=3.47
SFR~440 Msun/yr

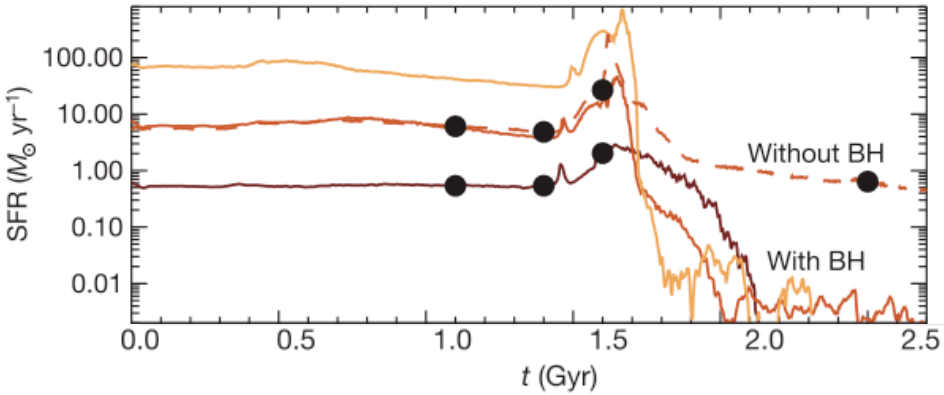
Dust poor (metal poor) galaxies may be easier to detect in X-rays than in FIR-submm bands

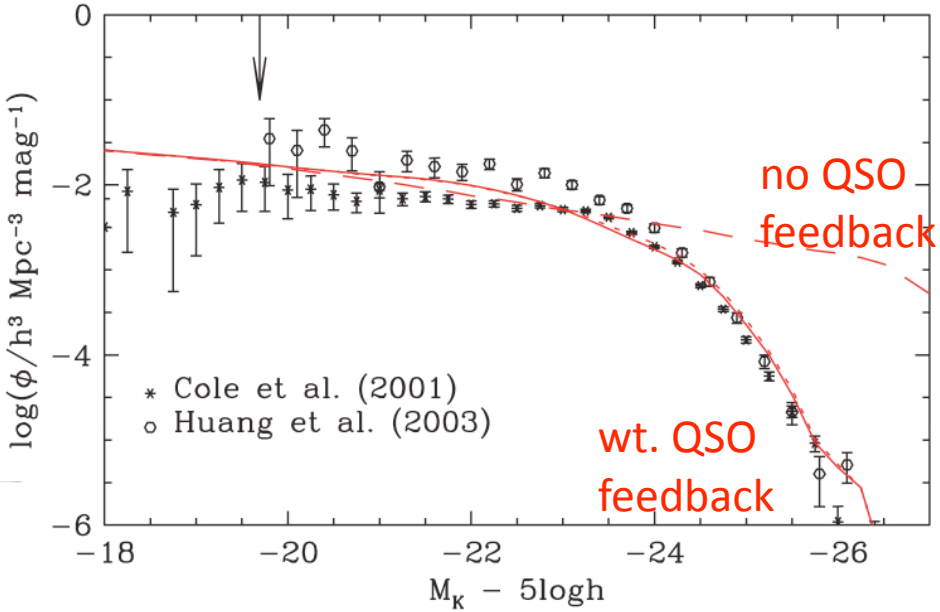
Quasar feedback

Invoked by both scenarios to quench star formation in massive galaxies



Di Matteo+05, Granato+04, Springel+08, Menci+06,08, Narayanan+06,08, Bower+06, Hopkins+08, Lapi+06



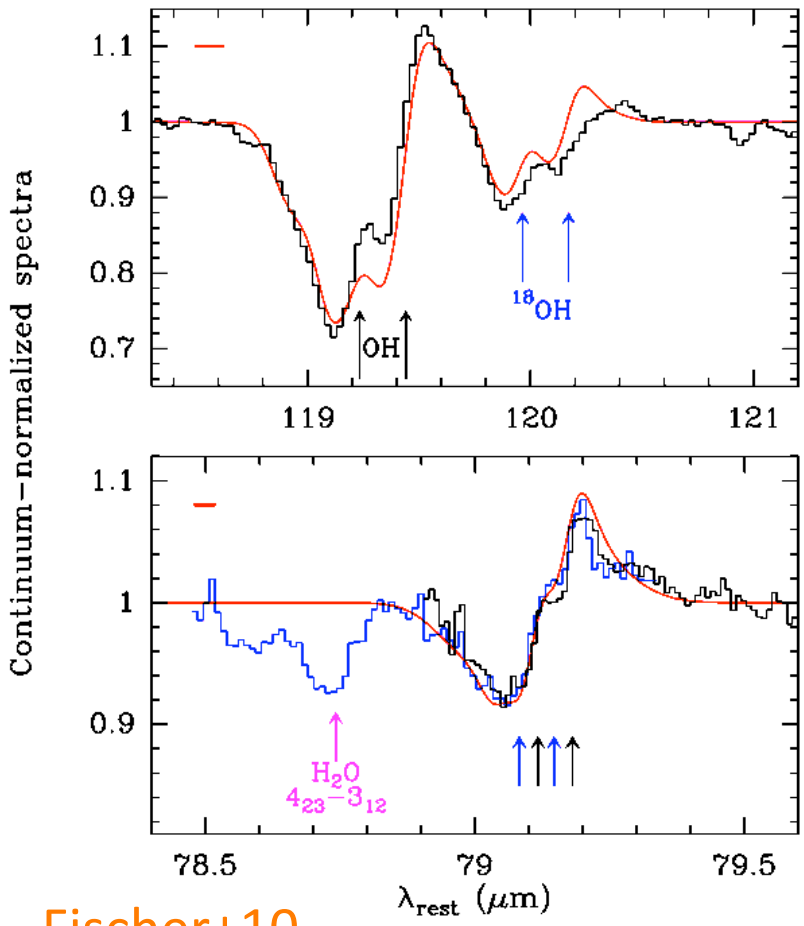


No direct observational evidence until recently

Explains the steep decline of the density of local massive galaxies and their red colors

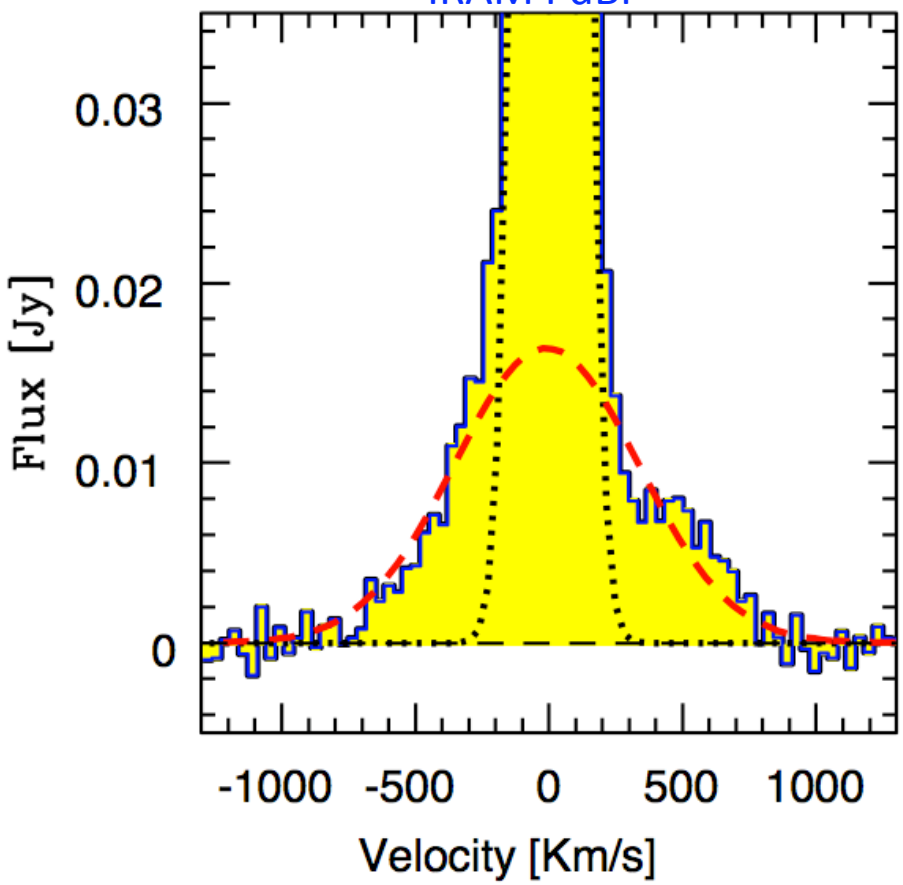
Massive molecular outflow in Mrk231 (local)

Herschel+PACS



Fischer+10

IRAM PdBI



Feruglio+10

Kinetic power ~ 2 10^{44} erg/s ➔ ~ 0.05 x L_{AGN}

...as expected by AGN feedback models

ALMA+SPICA+IXO will reveal quasar feedback at z~1-6