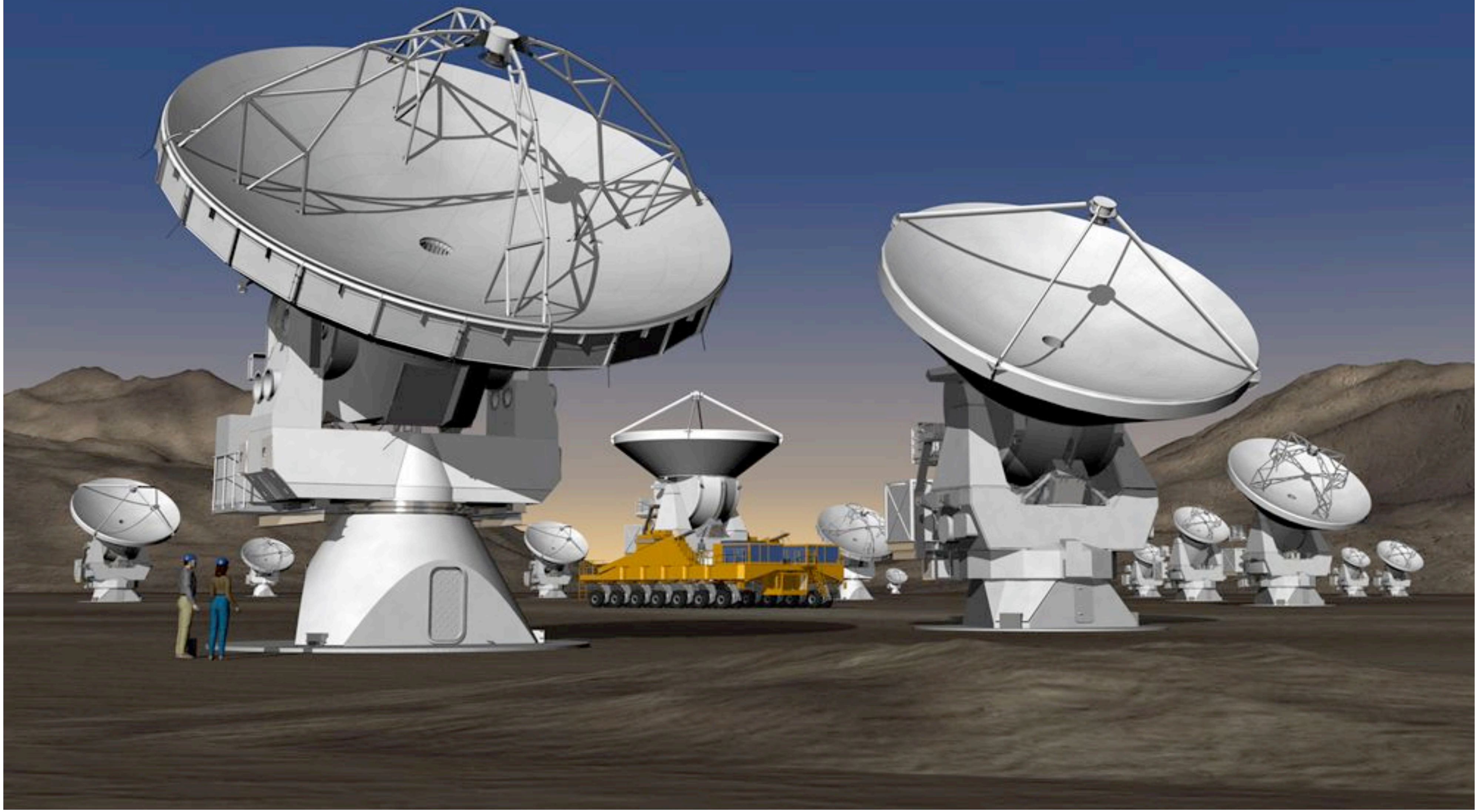
ALMA

The Atacama Large Millimeter/submillimeter Array



Brief history of ALMA

ALMA is the merger of three progects conceived in the 1980's and 1990's

MMA (USA, 1982)

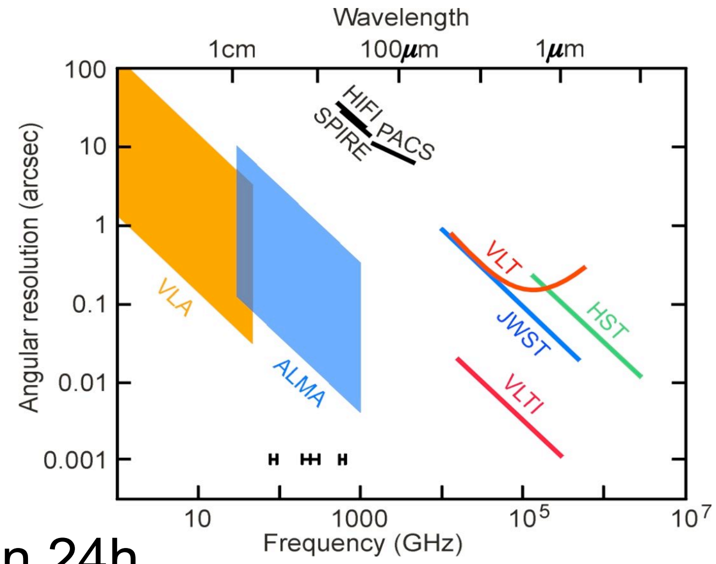
LSA (Europe, 1988)

LMSA (Japan,1983)

ALMA

1997

A Next Generation Millimeter Telescope

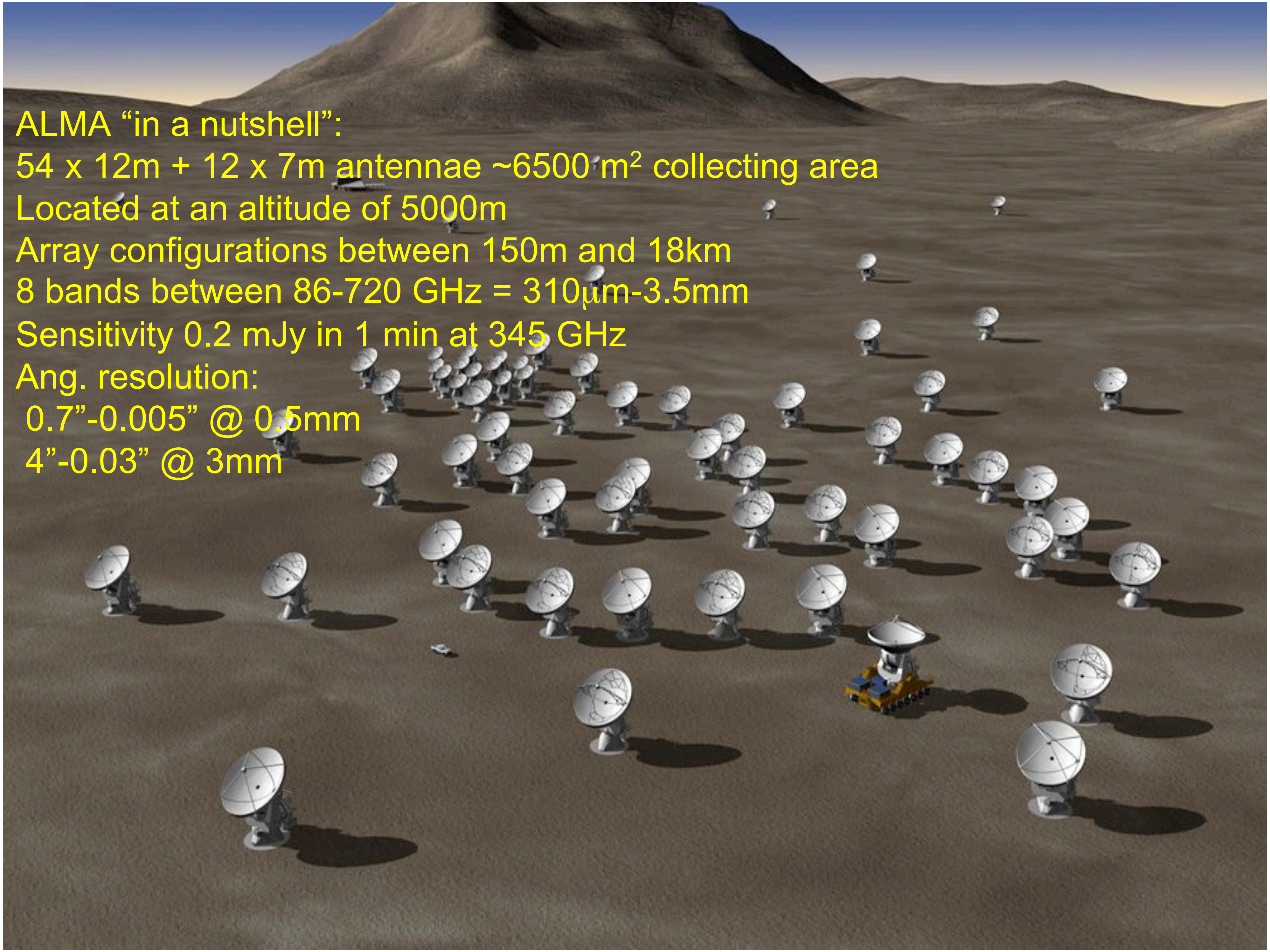


A major step in astronomy: a mm/submm equivalent of VLT, HST, JWST and EVLA.

Some key scientific drivers:
- Detect Milky Way-like galaxies at z~3 in less than 24h
- Image gas kinematics in protostars and protoplanetary disks at 150 pc (-> planets formation)
- Astrochemistry: new (pre-biotic) molecules

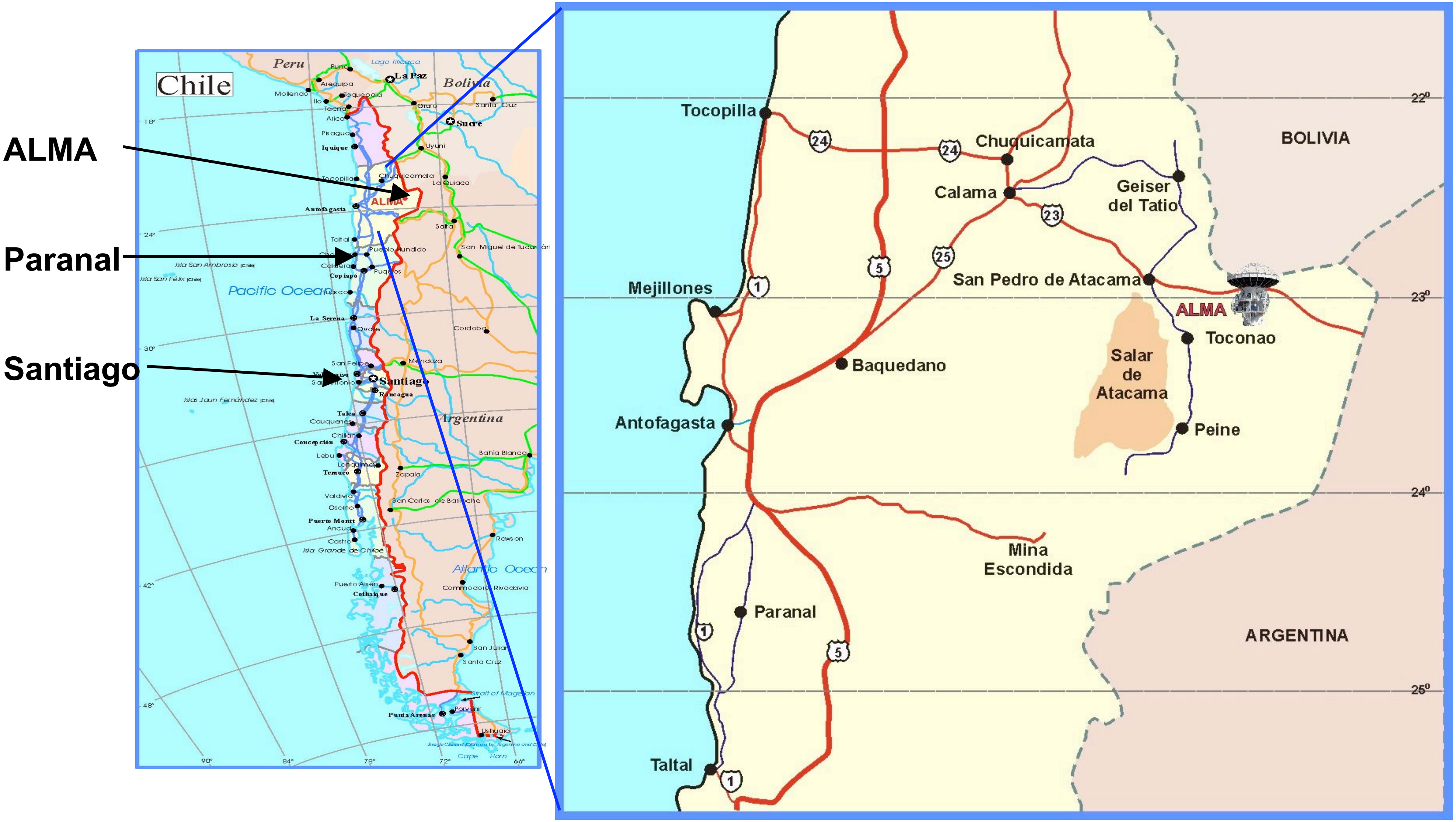
Requirements:
- High quality imaging with 0.1” resolution at 3 mm
- Continuum sensitivity ~ a few μJy
- Line sensitivity ~ a few μK
- Submm capabilities

These requirements imply:
- An array of antennas
- A collecting area > 5,600 m^2
- A site which is high, dry, large, flat

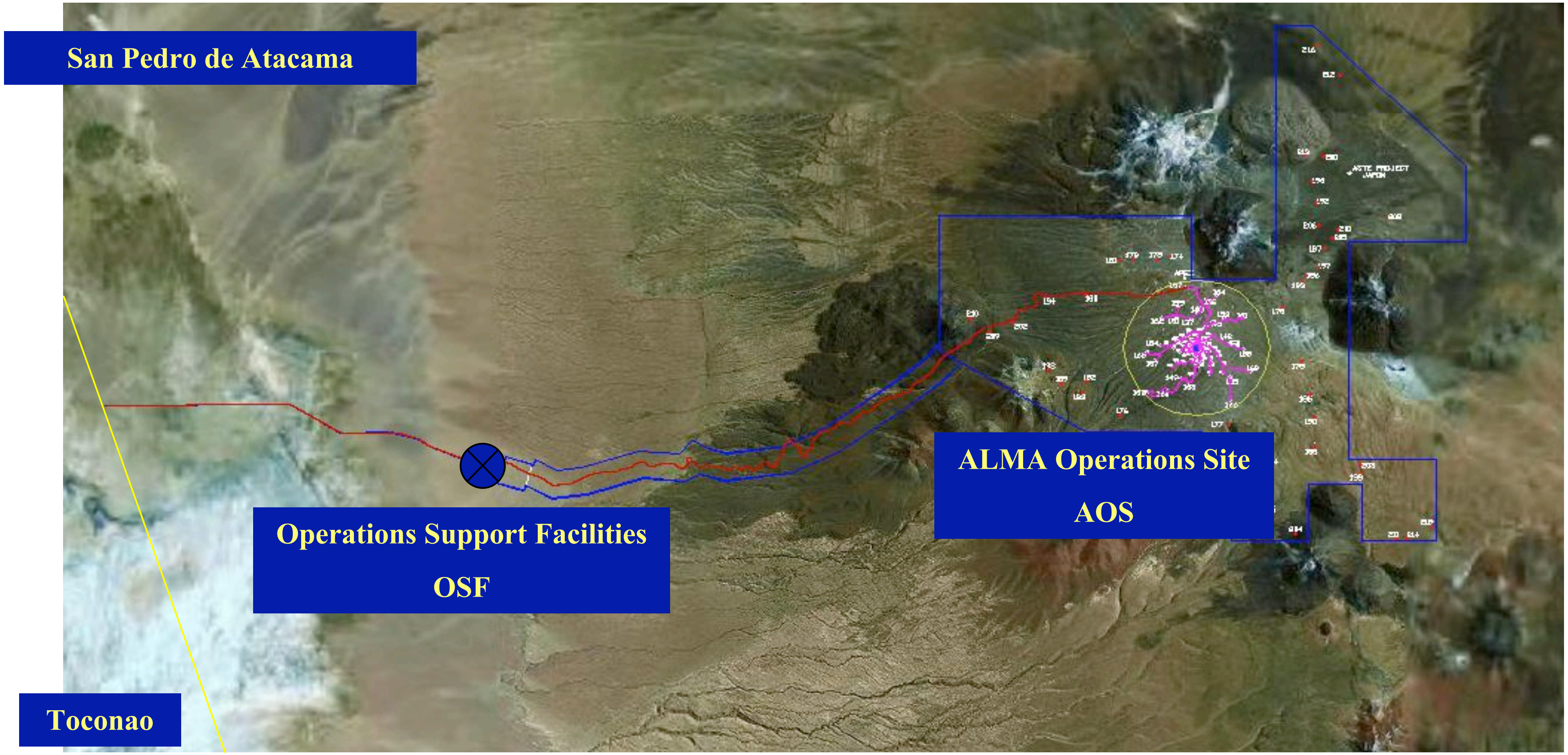

ALMA “in a nutshell”:
54 x 12m + 12 x 7m antennae ~6500 m^2 collecting area
Located at an altitude of 5000m
Array configurations between 150m and 18km
8 bands between 86-720 GHz = 310μm-3.5mm
Sensitivity 0.2 mJy in 1 min at 345 GHz
Ang. resolution:
0.7”-0.005” @ 0.5mm
4”-0.03” @ 3mm

ALMA site

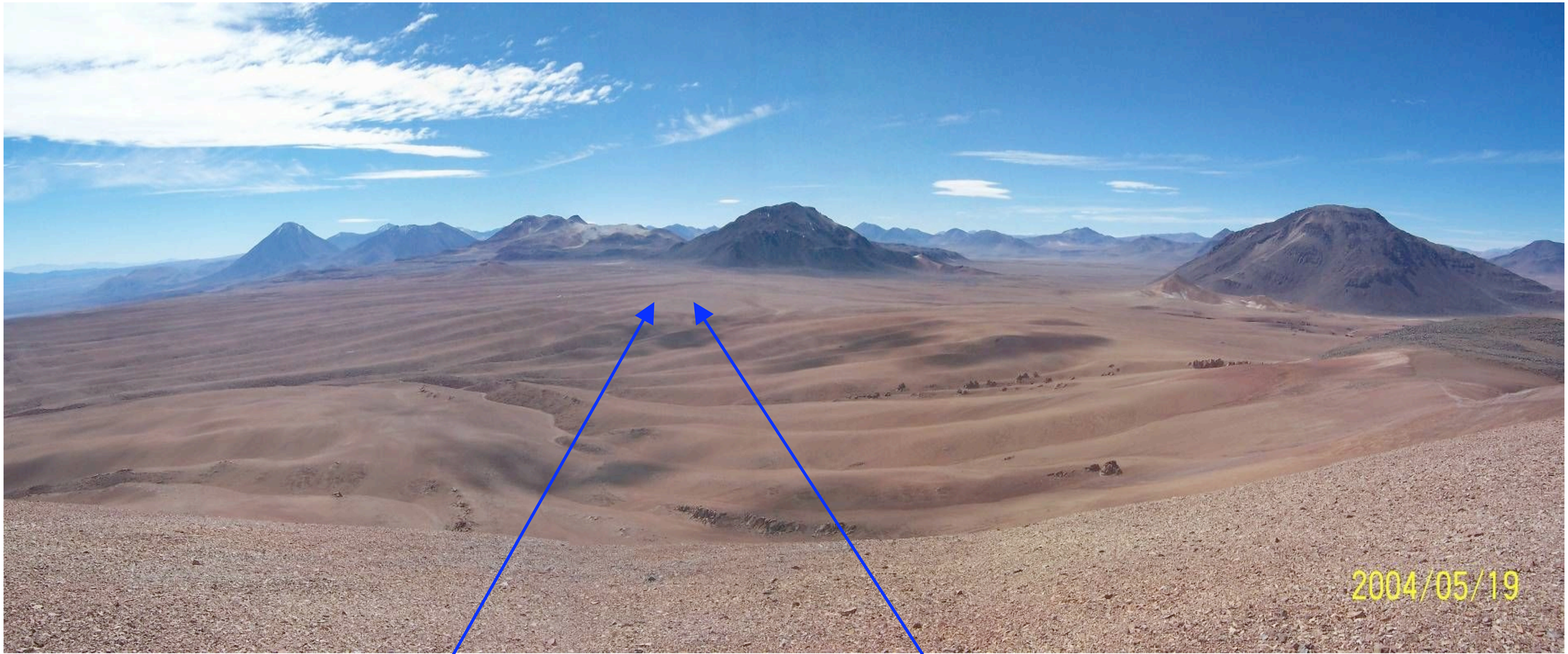
ALMA site


ALMA
Paranal
Santiago
Chile
Peru
Bolivia
Argentina
Pacific Ocean
Atlantic Ocean
Tocopilla
Chuquicamata
Calama
Geiser
del Tatio
BOLIVIA
San Pedro de Atacama
Mejillones
ALMA
Toconao
Baquedano
Salar
de
Atacama
Antofagasta
Peine
Mina
Escondida
Paranal
ARGENTINA
Taltal
22º
23º
24º
25º

ALMA site


San Pedro de Atacama
Operations Support Facilities
OSF
ALMA Operations Site
AOS
Toconao

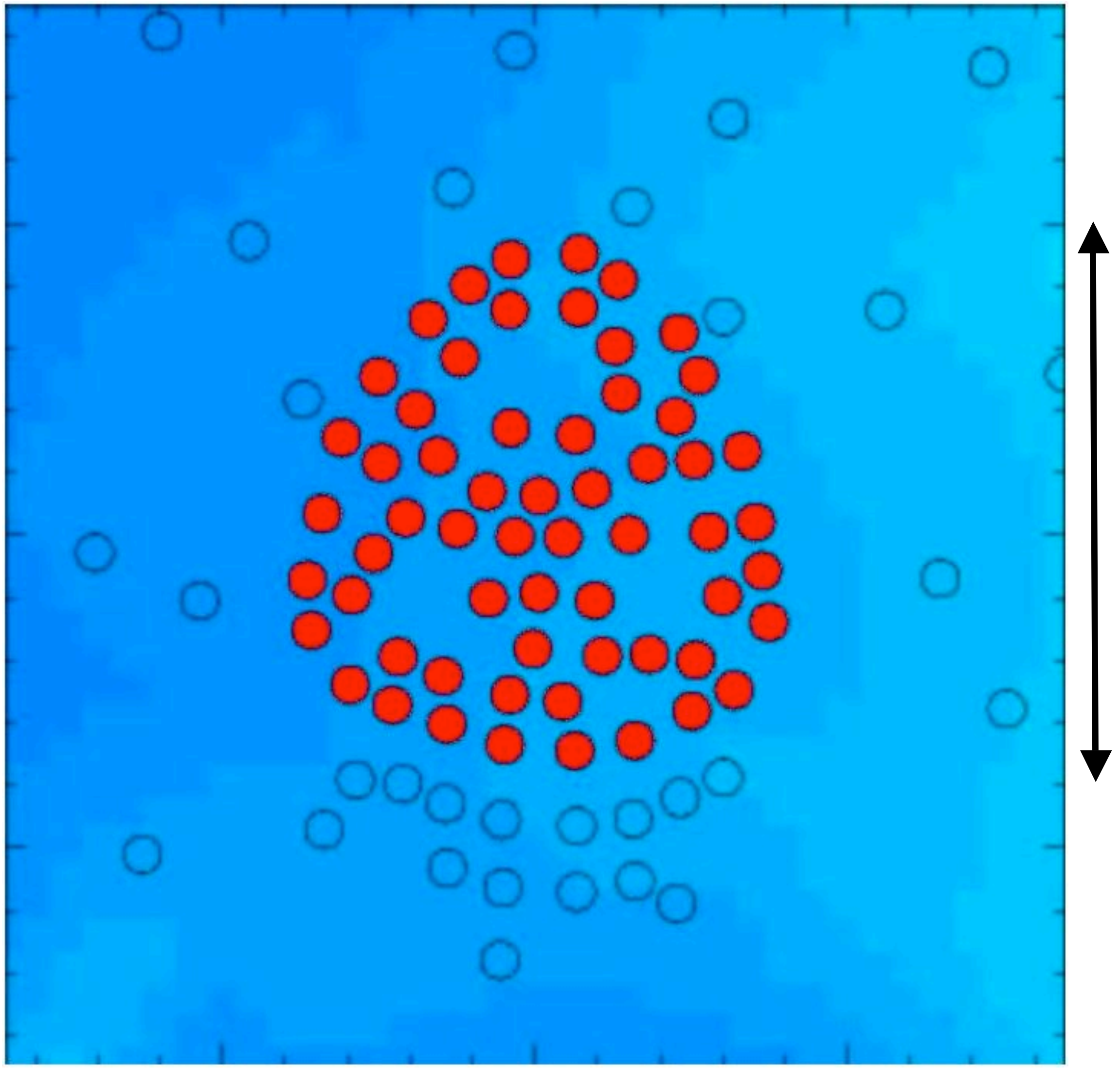
Chajnantor Plateau (5000m) – looking north

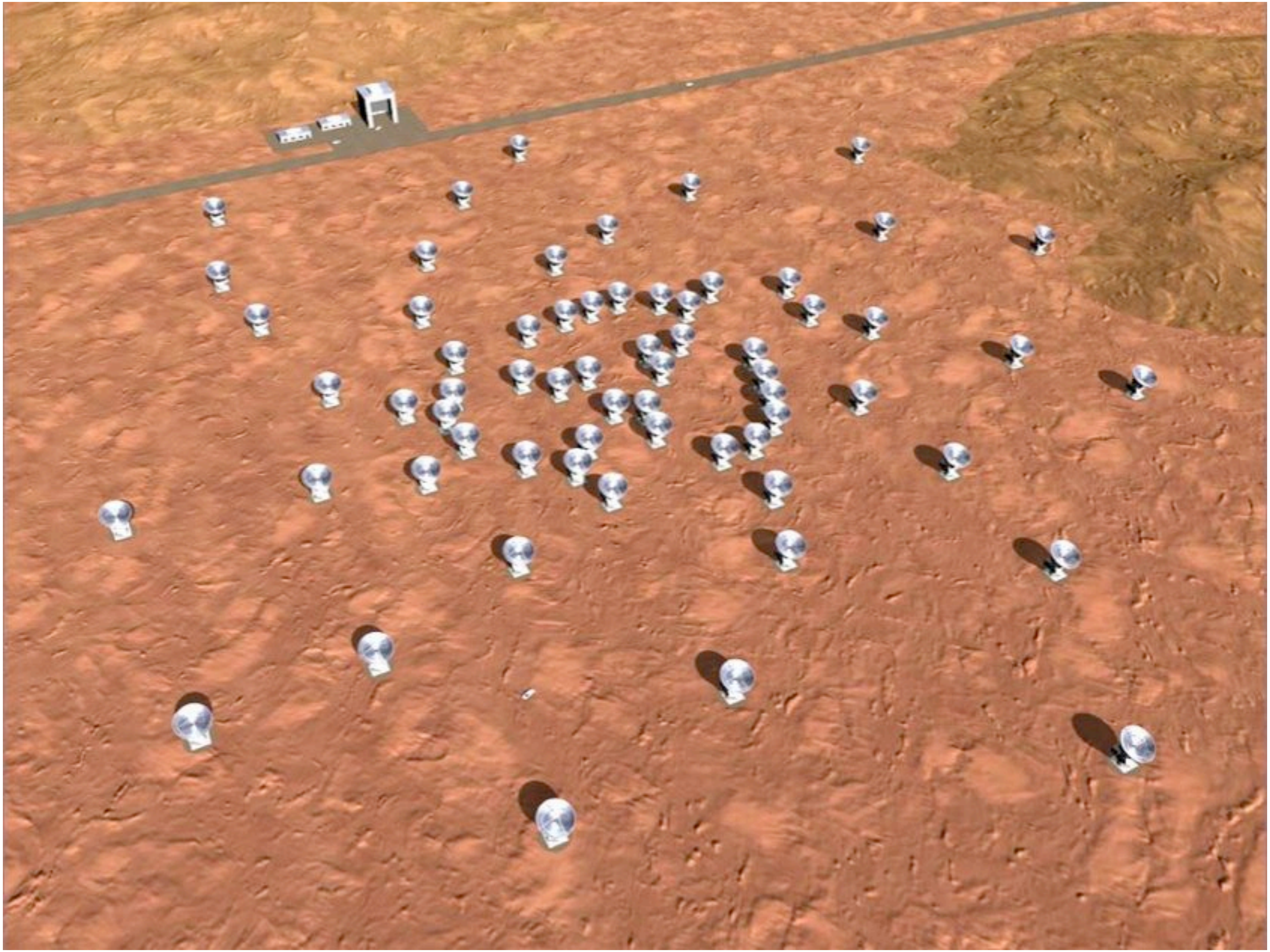


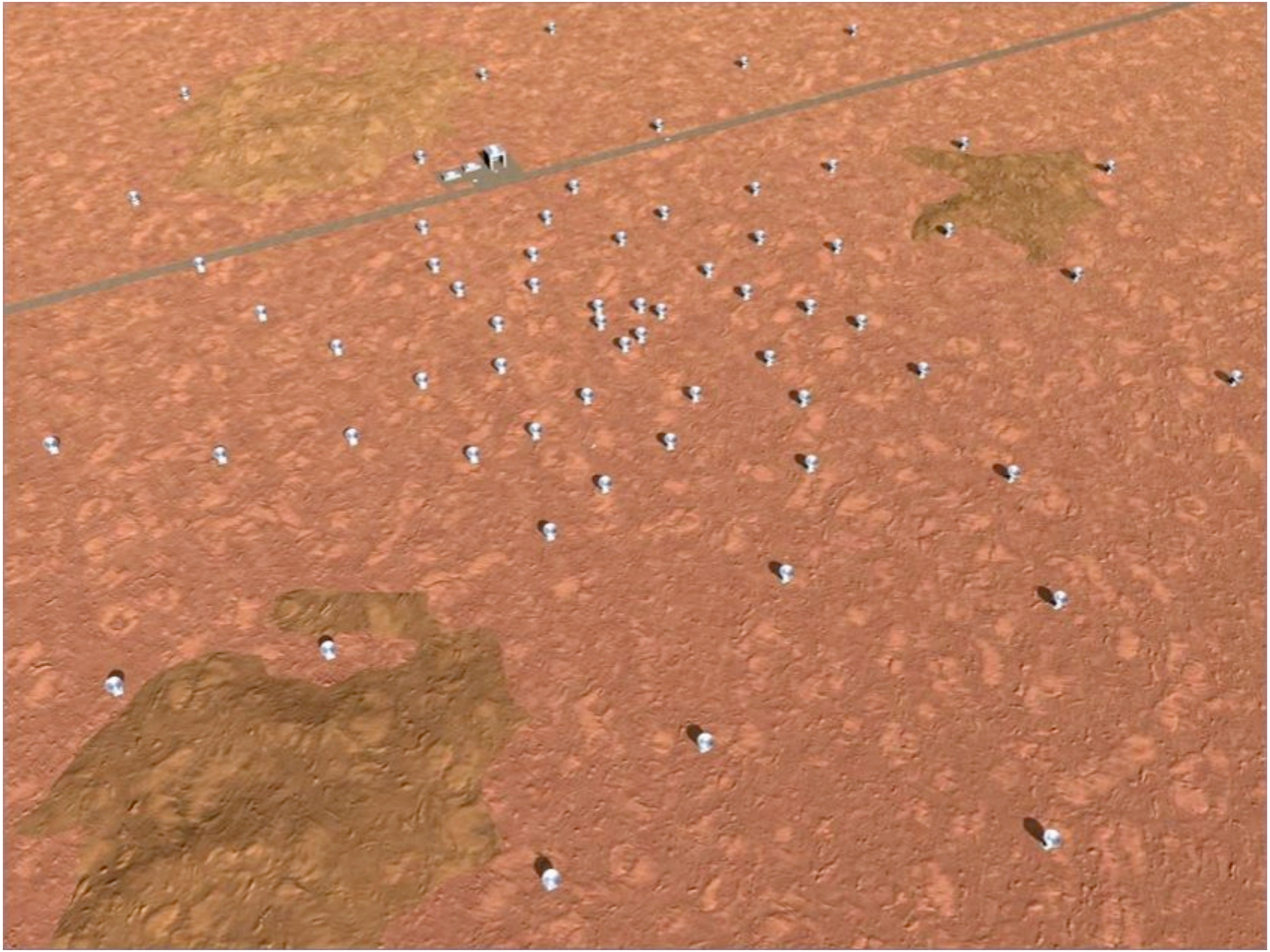
AOS TB

Center of Array

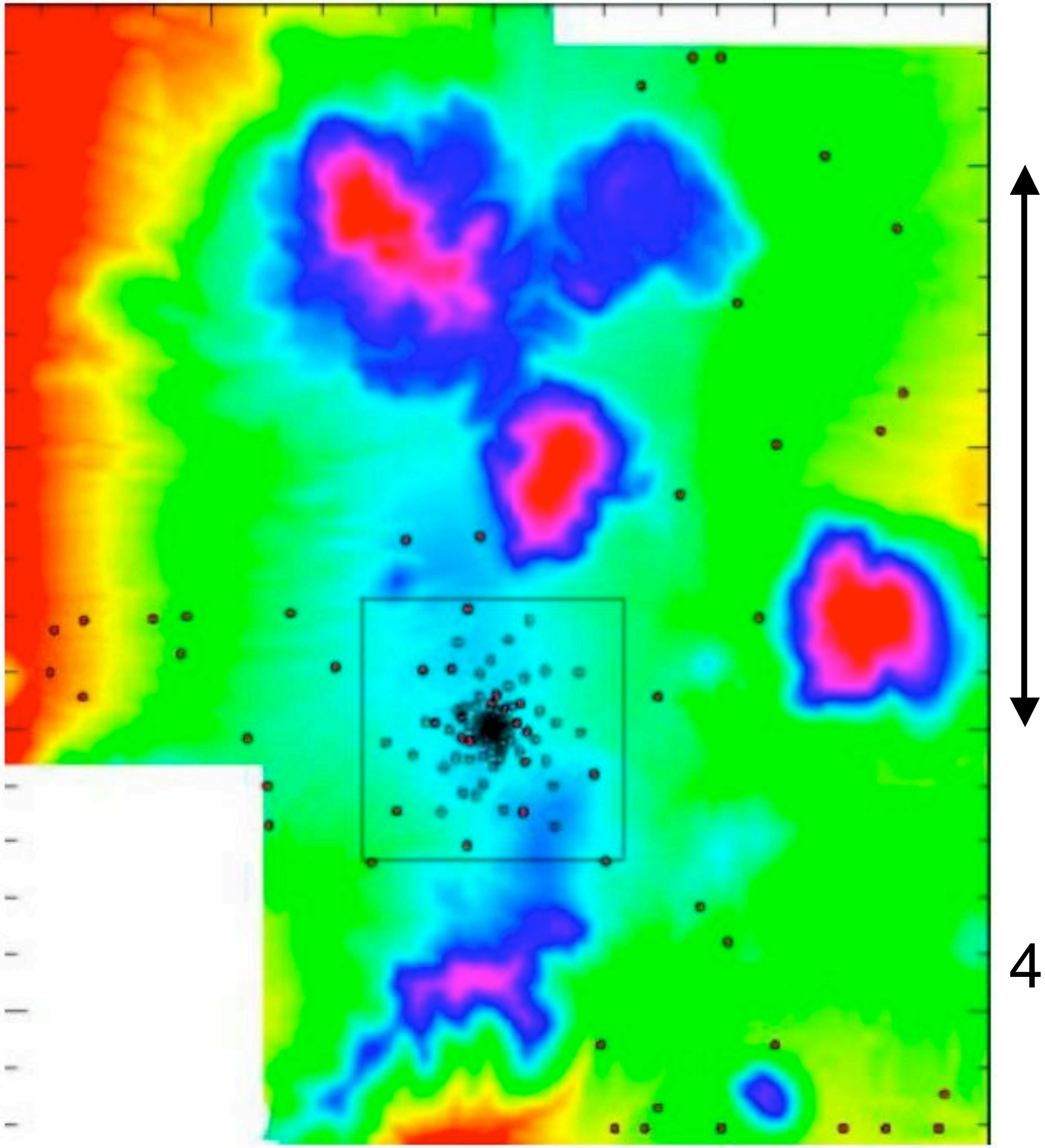
Antenna Configurations (compact)







Antenna Configurations (max, example)

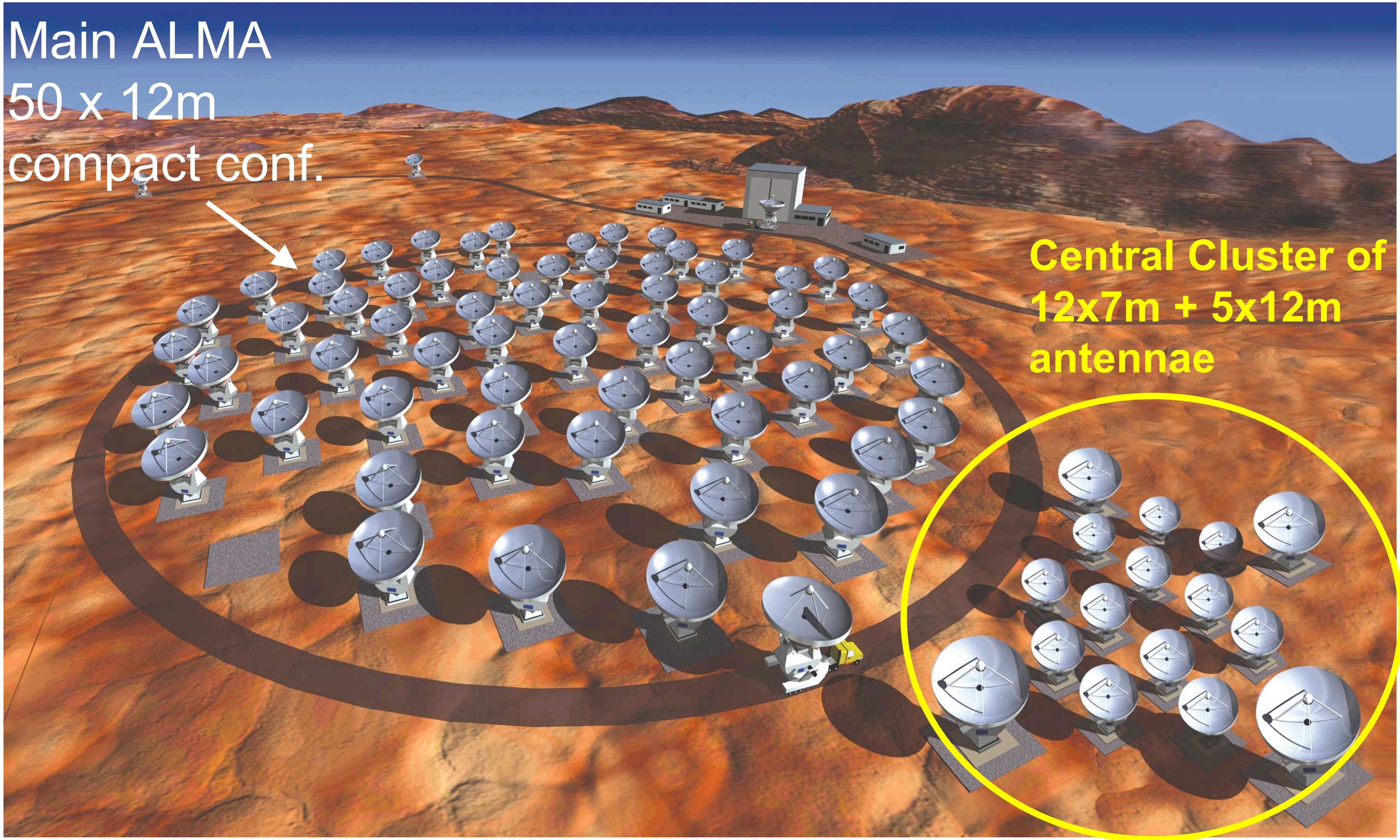


10 km

4 mas @ 950 GHz

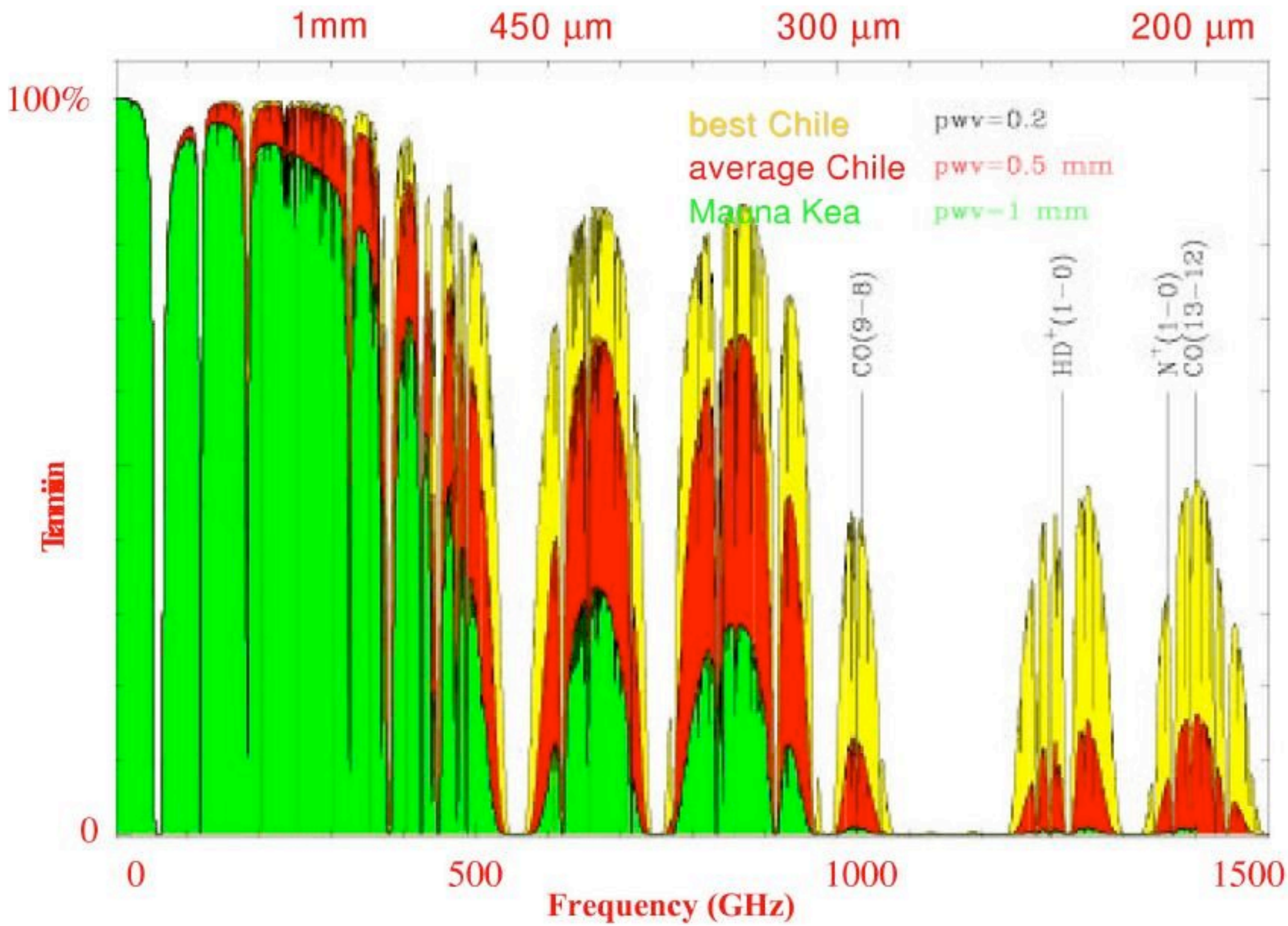
Moving the ALMA antennas

ACA: Atacama Compact Array

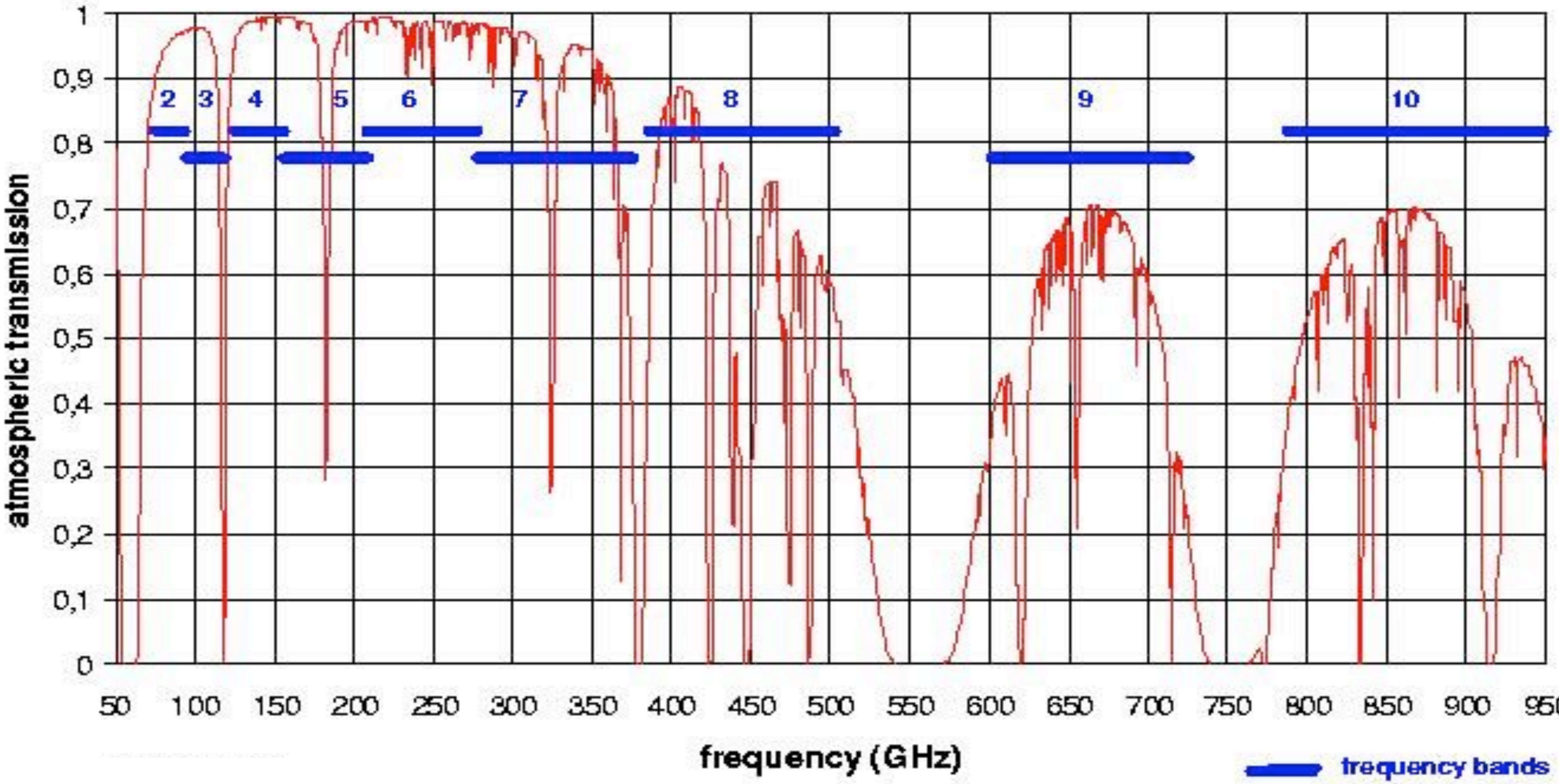


It will provide the ~"zero spacings" to detect diffuse emission on scales >~ 1"

Atmospheric transmission at Chajnantor



ALMA frequency bands



Maximum frequency simultaneous coverage: 8 GHz
⇒ each band can be fully covered with 3 frequency setups

Max spectral resolution: 0.01 km/s

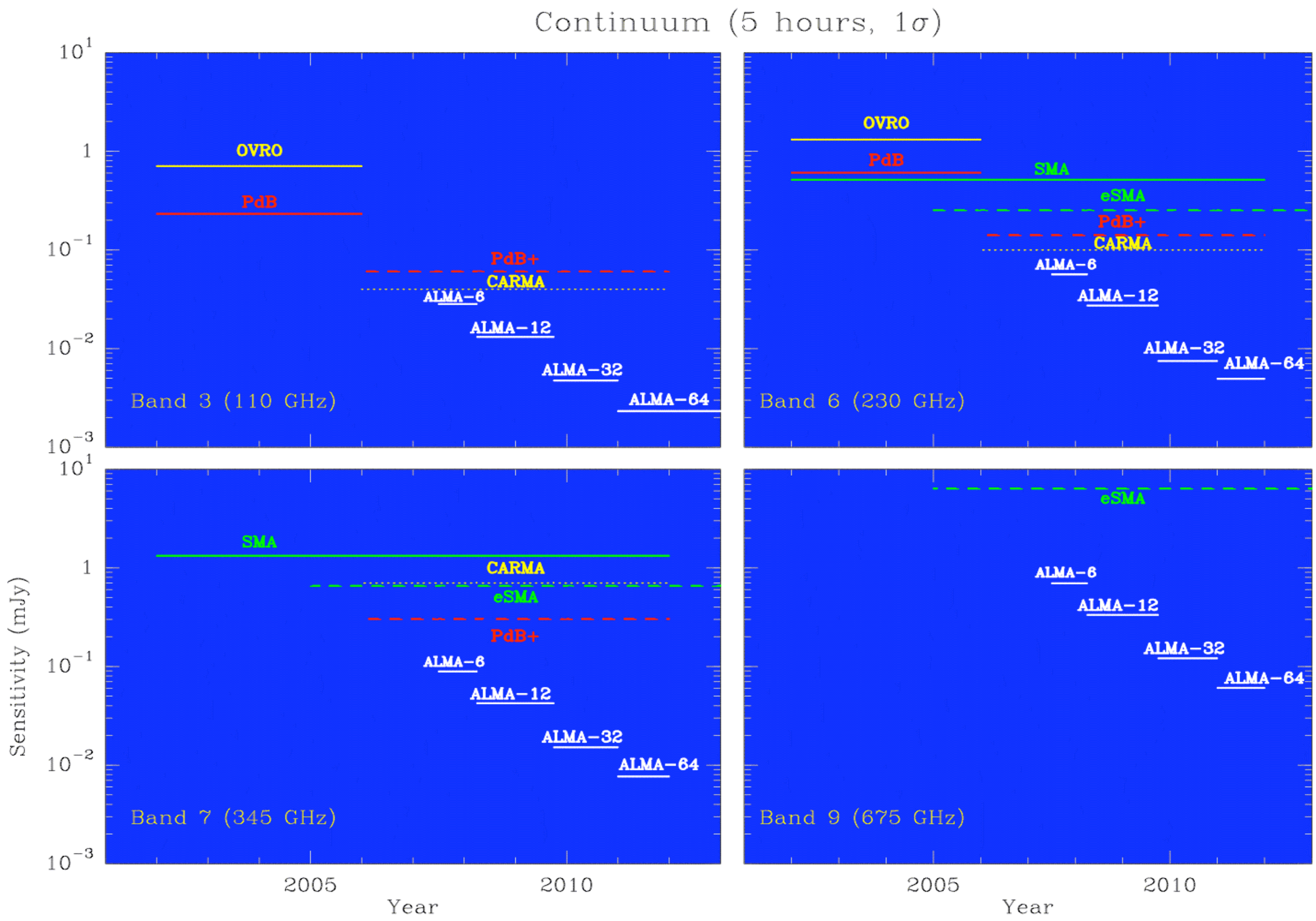
ALMA Median Continuum Sensitivity

(**1 minute**; AM=1.3; 75% Quartile opacities λ>1mm, 25% λ <1mm)

Frequency (GHz)	Wavelength (mm)	Continuum (mJy)
110	2.7	0.03
140	2.1	0.04
230	1.3	0.07
345	0.87	0.12
675	0.44	0.85
850	0.35	1.26

For comparison:
SCUBA ~1mJy
in 1 hours

Sensitivity comparison with previous facilities



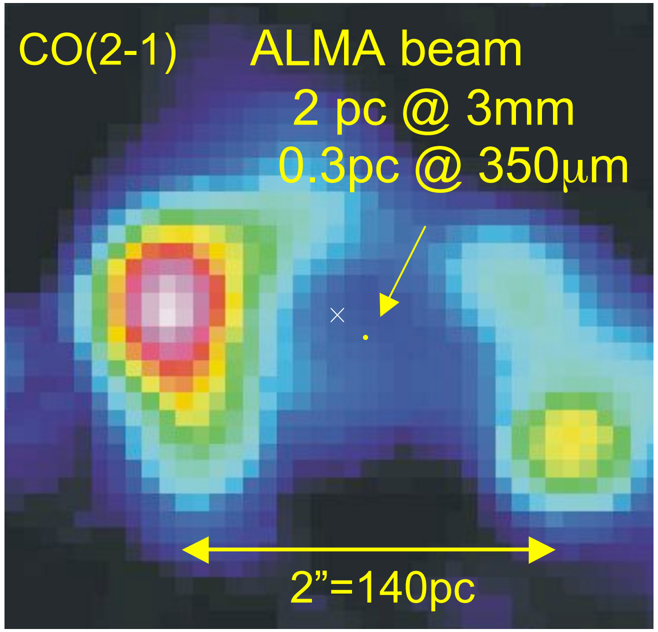
ALMA timeline

2007	First antennae arrival and testing at Chajnantor
Early 2009	Commissioning begins with 3-element array
Late 2009	Call for shared risk proposals - 6 antennae, 2 bands - Offline data reduction
2012	Pipeline images for standard modes
2012	Baseline ALMA construction complete

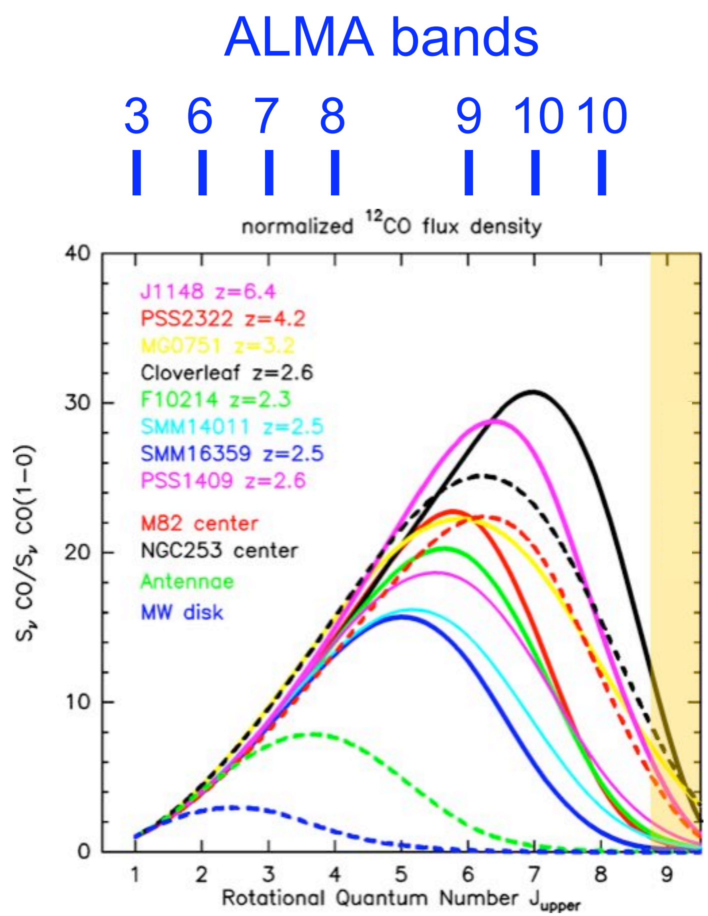
ALMA science
(AGN focused)

Resolve the innermost region of AGNs

NGC1068



Is there an innermost molecular structure? What is its morphology, dynamics and physical state?



Use high temperature and high density gas tracers, e.g. high CO transition, HCN, HCO+,...

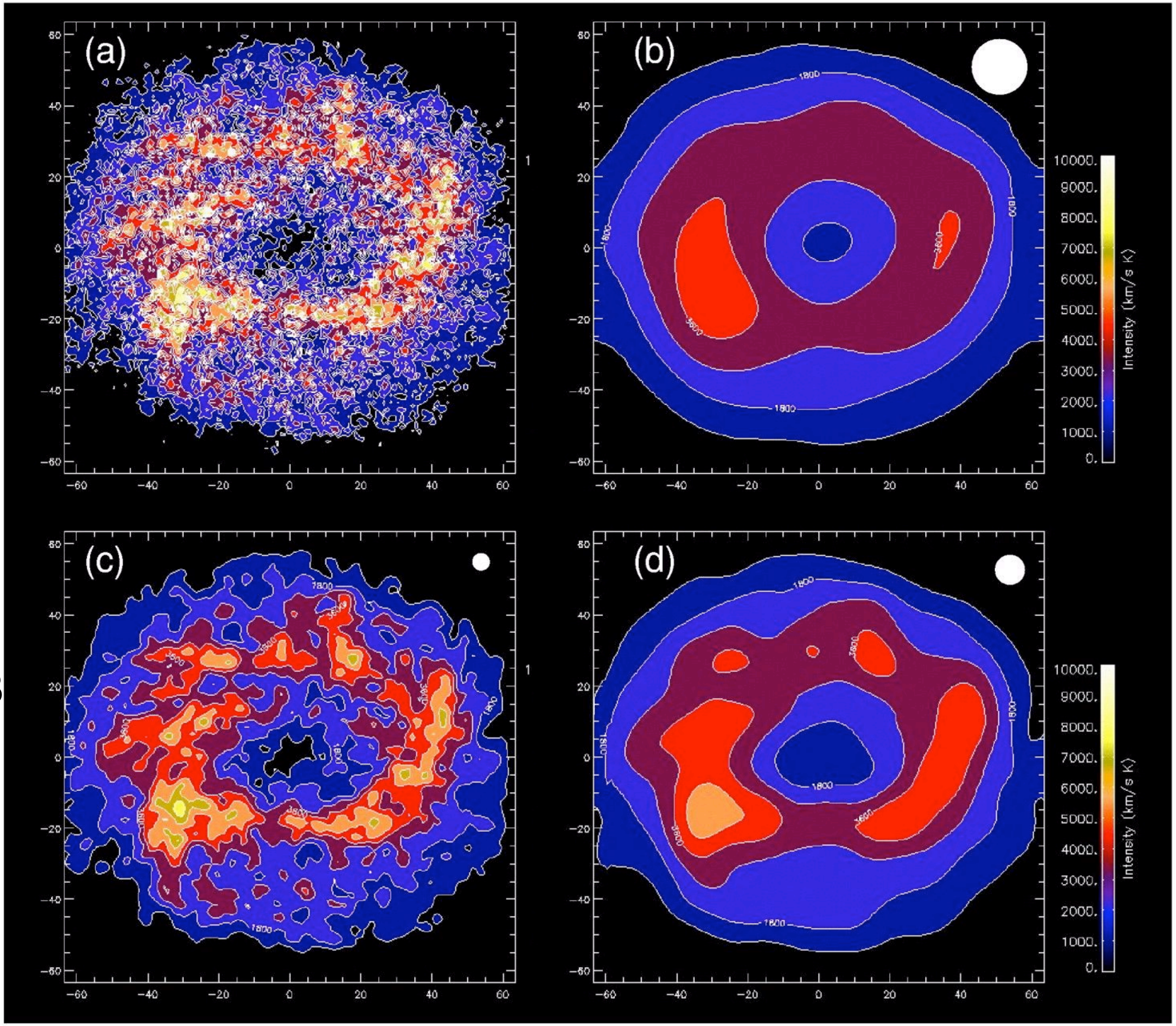
Wada+05

Clumpy torus (model)

70 pc

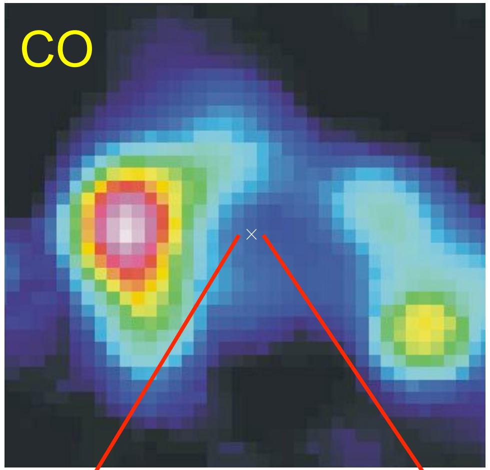
CO(2-1)

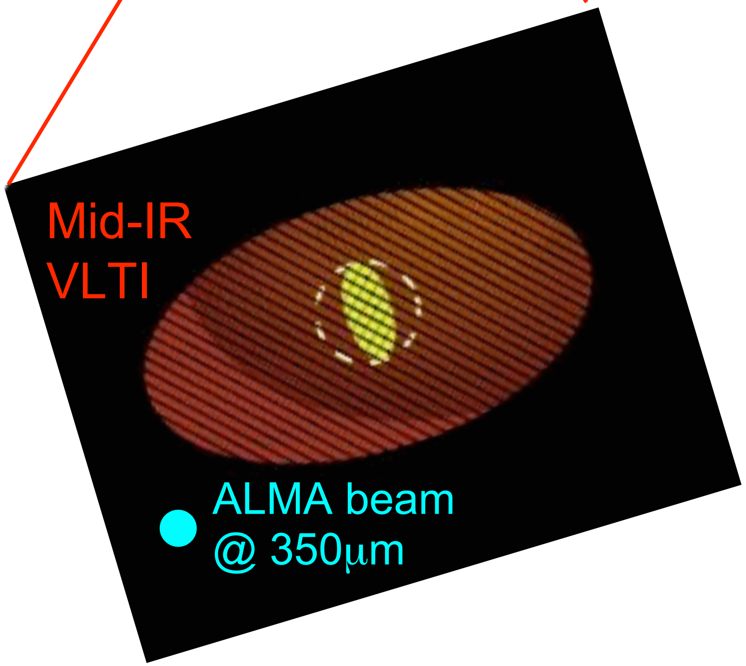
ALMA resolution @ NGC1068



Test clumpy model for nuclear dust thermal emission

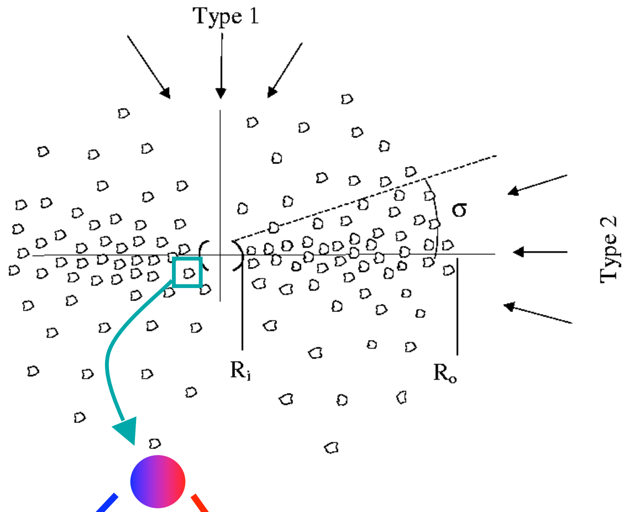
(see Elitzur's Lecture)

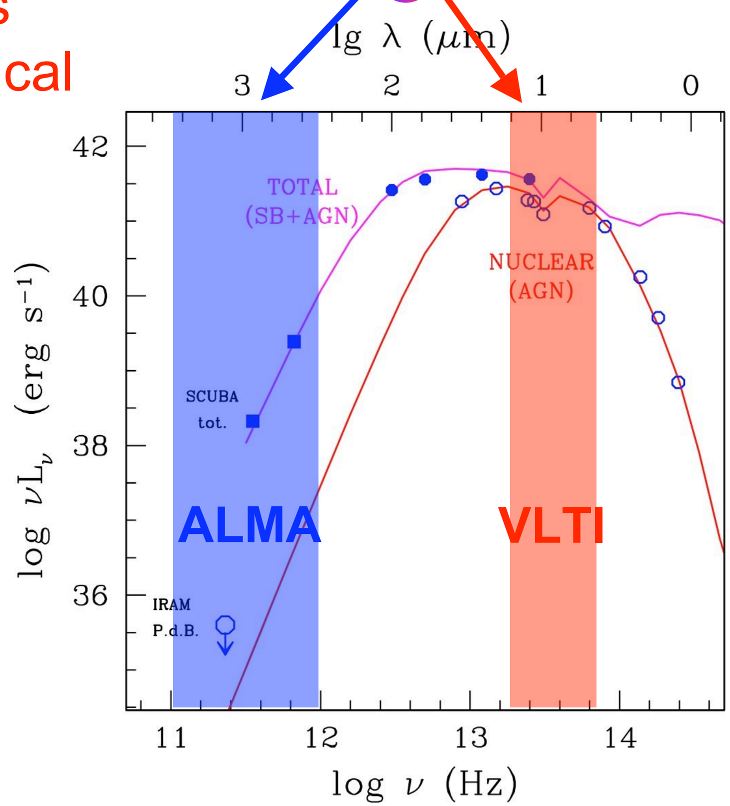




Nuclear small dusty clouds should emit both MIR and FIR

MIR and FIR morphologies should be identical





Identify hidden/elusive AGNs through their XDR's

Powerful, obscured AGNs without NLR (generally U/LIRGs)

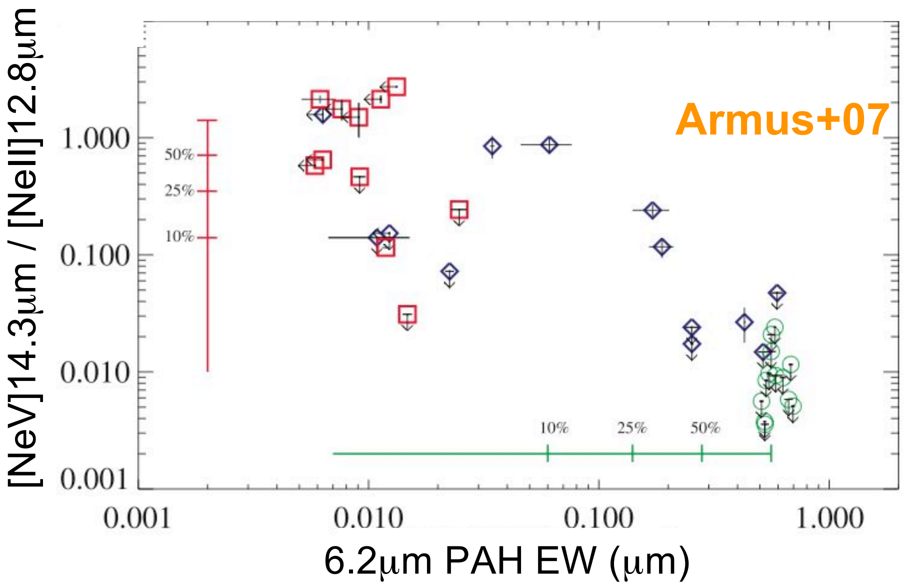
Imanishi+07,04, Franceschini+03, Maiolino+03, Ballo+04, Caccianiga+07...

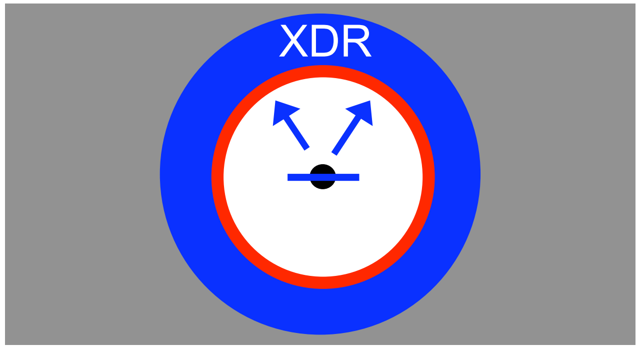
in some cases the NLR is obscured by dust in the host galaxy

Haas+06, Martinez-Sansigre+06, Polletta+06, Alonso-Herrero+06

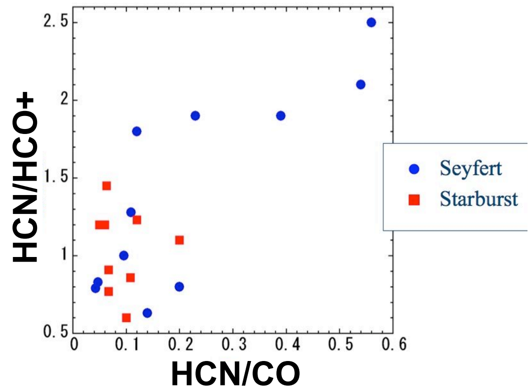
in some cases the NLR does not exist

4π nuclear obscuration?

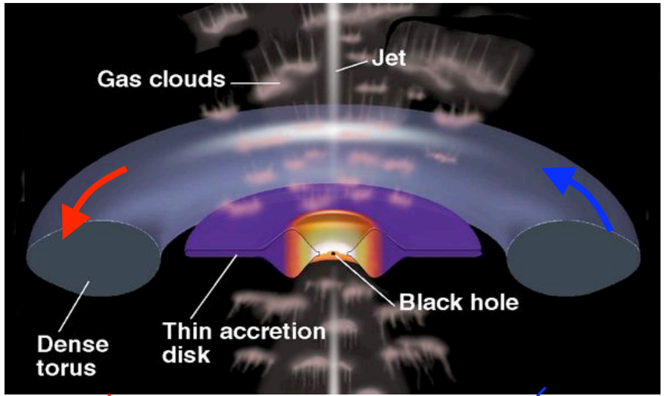


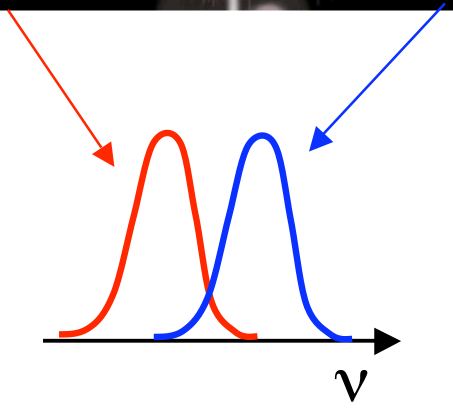


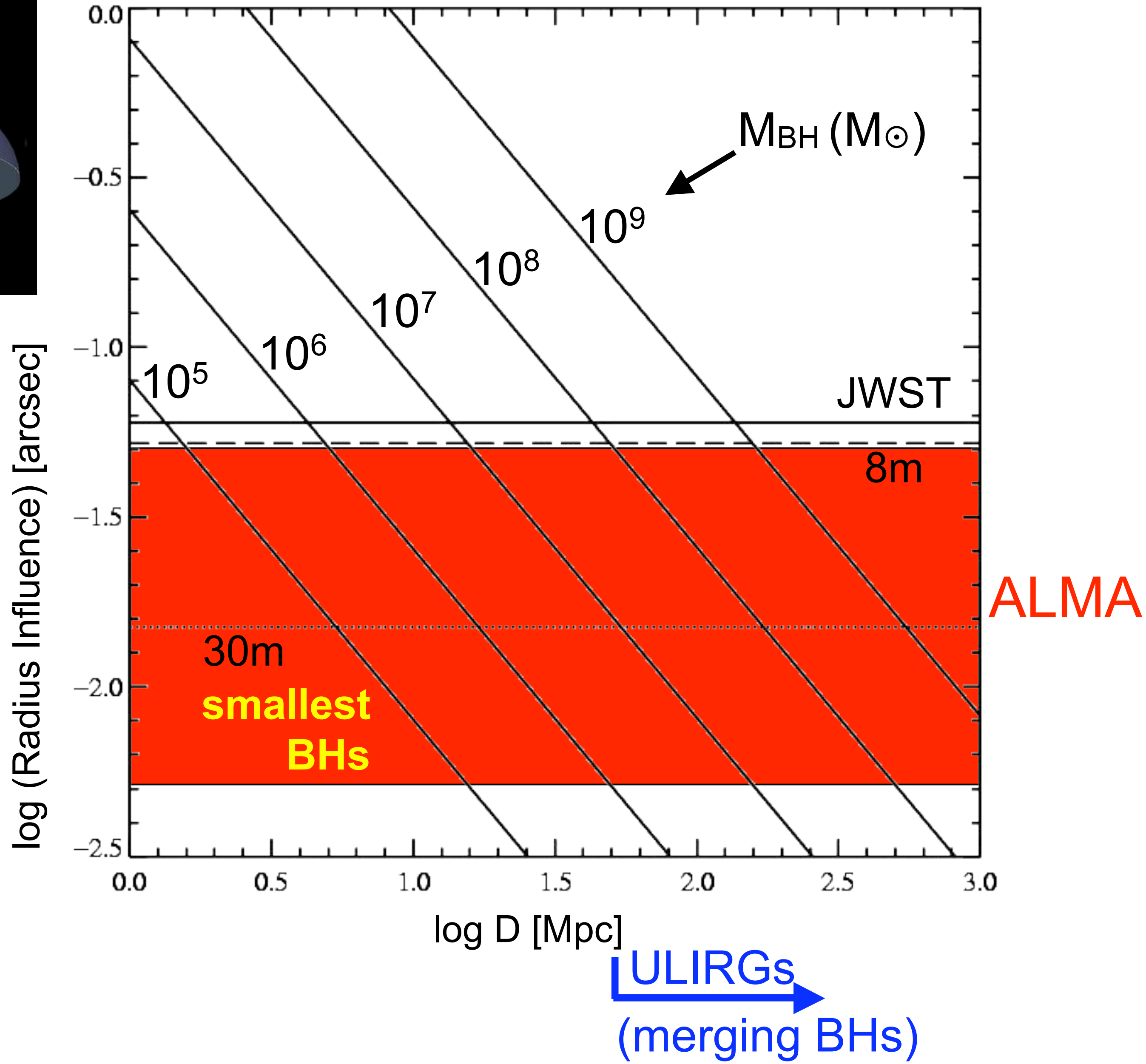
Exploit XDR tracers for a complete census of obscured AGNs (so far limited to powerful or nearby cases)



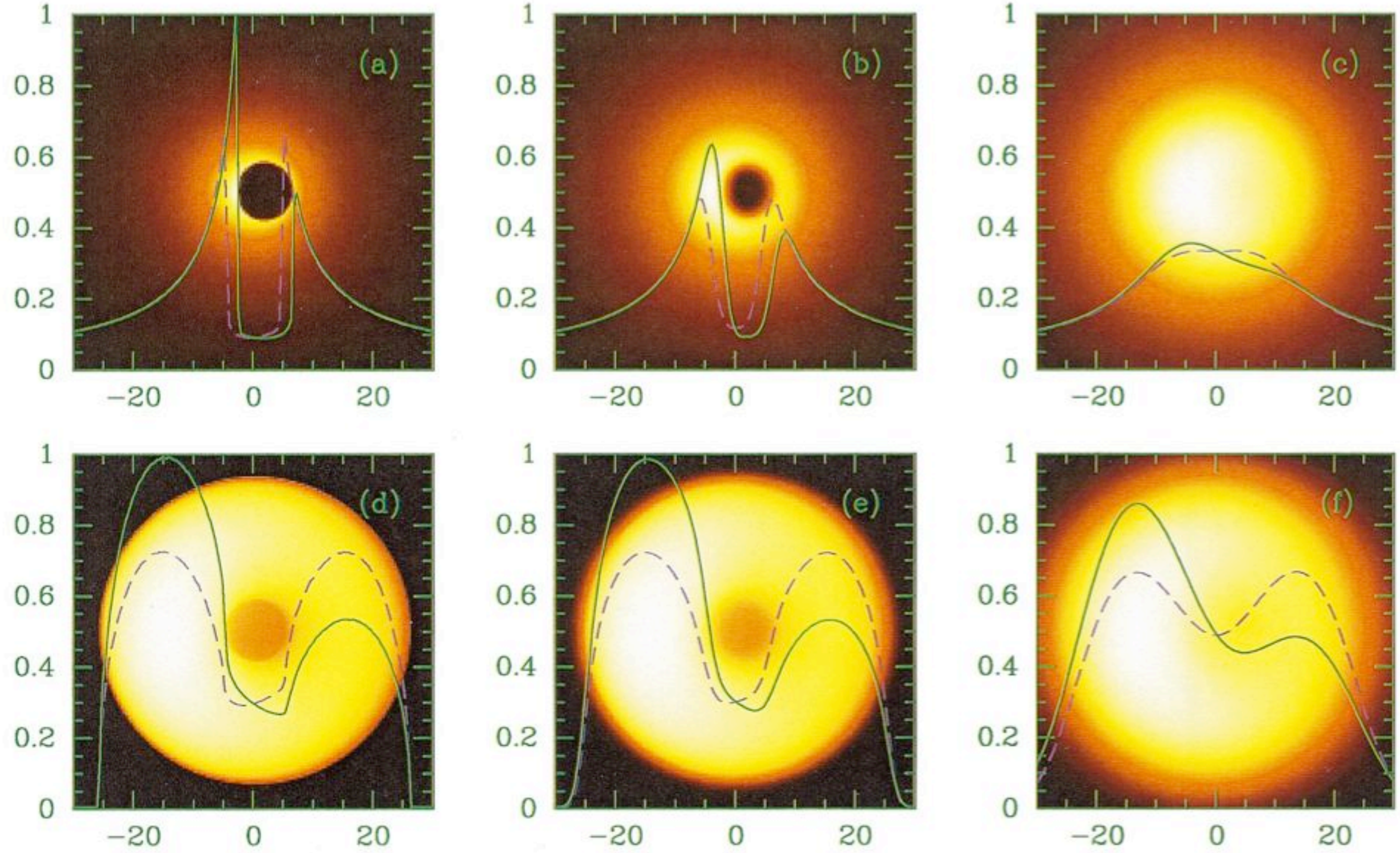
Measuring Black Hole masses in galactic nuclei







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



rotating BH

non-rotating BH

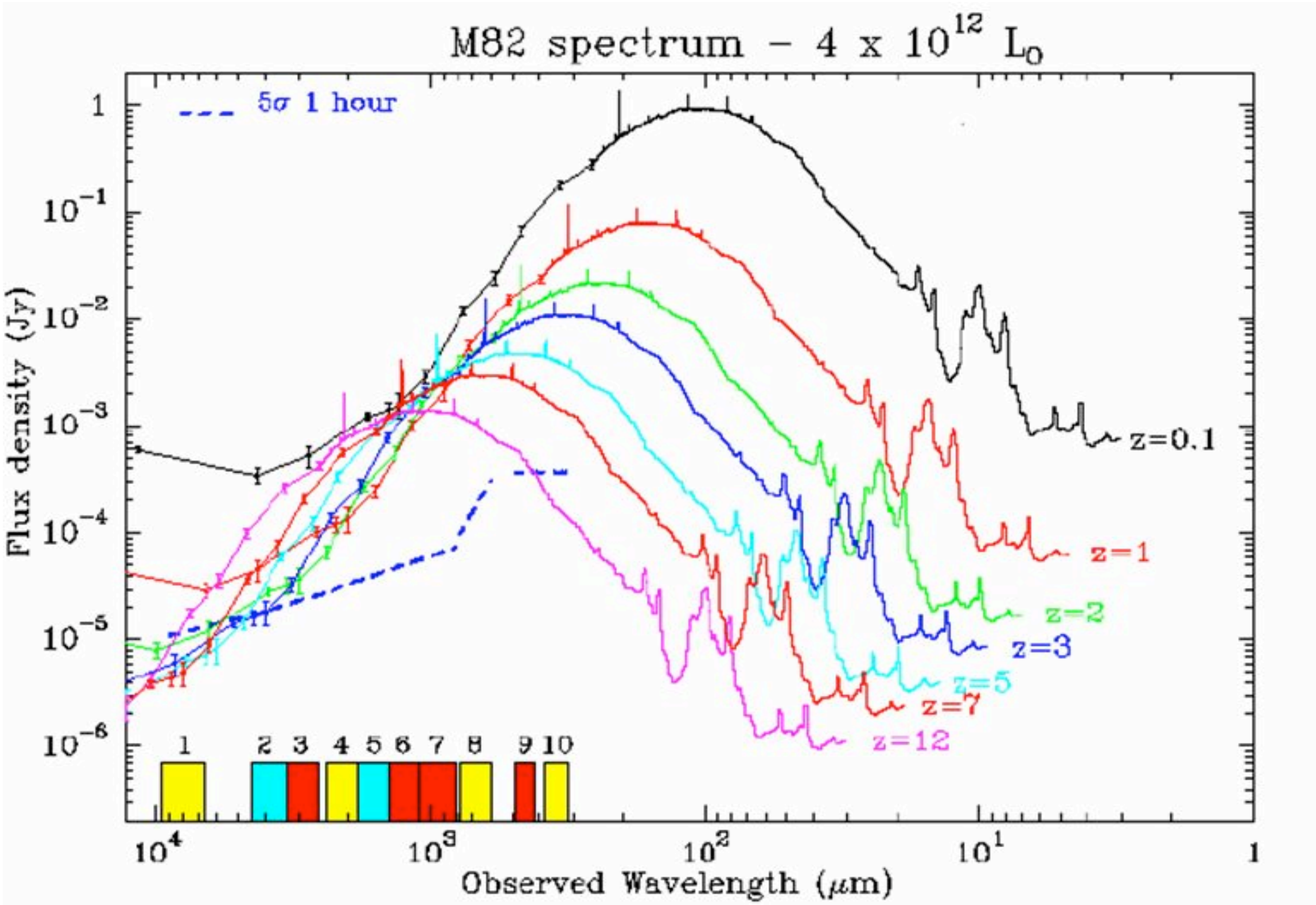
model

0.6 mm VLBI
16μarcs res.

1.3 mm VLBI
33μarcs res.

Falcke+2000

ALMA observations of high-z galaxies



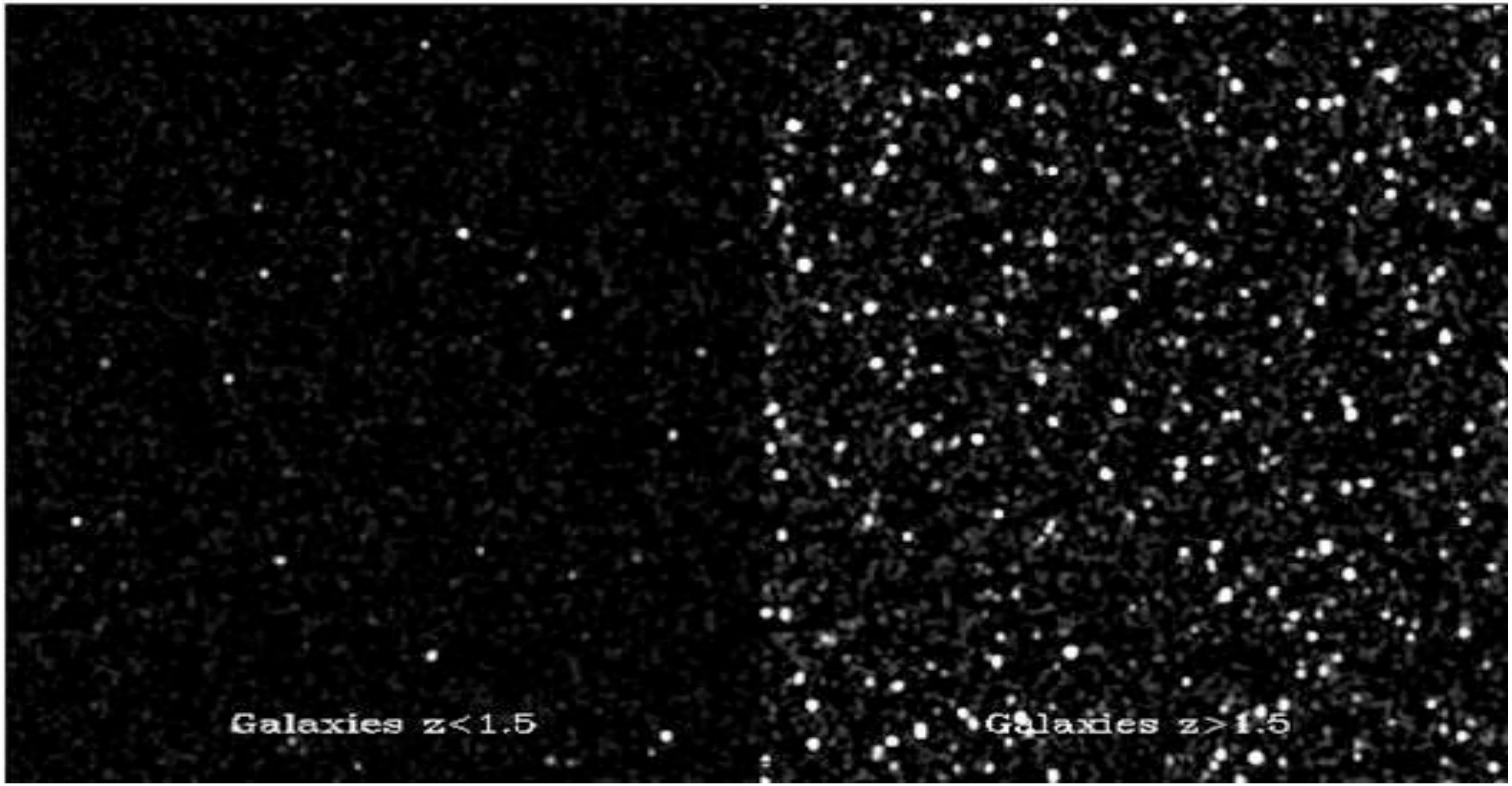
Deep optical field (HDF): rich in low-z galaxies, poor in high-z galaxies.

(12 days of integration)

$z<1.5$ $z>1.5$

ALMA deep field: poor in low-z galaxies, rich in high-z galaxies.

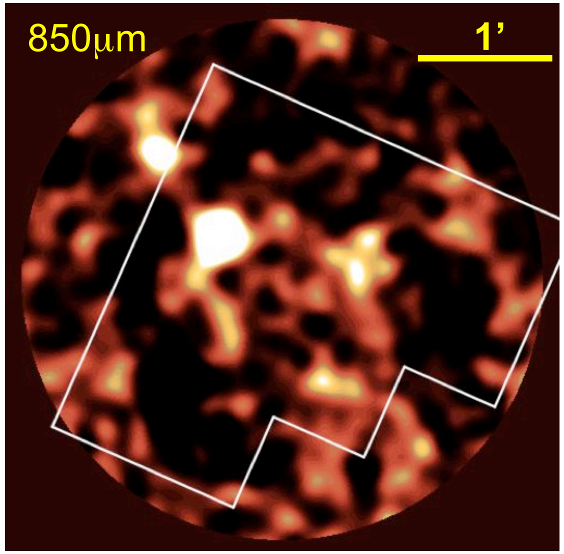
simulation 3 days of integration 4’x4’ arcmin

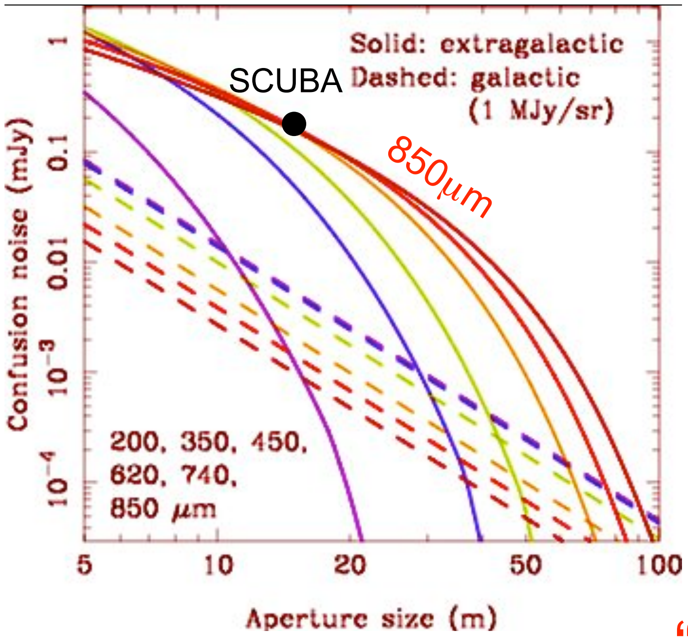


z<1.5 z>1.5

The main limit of past and current facilities (SCUBA) is "confusion": below a certain flux limit (which depends on the beam size) most sources blend together

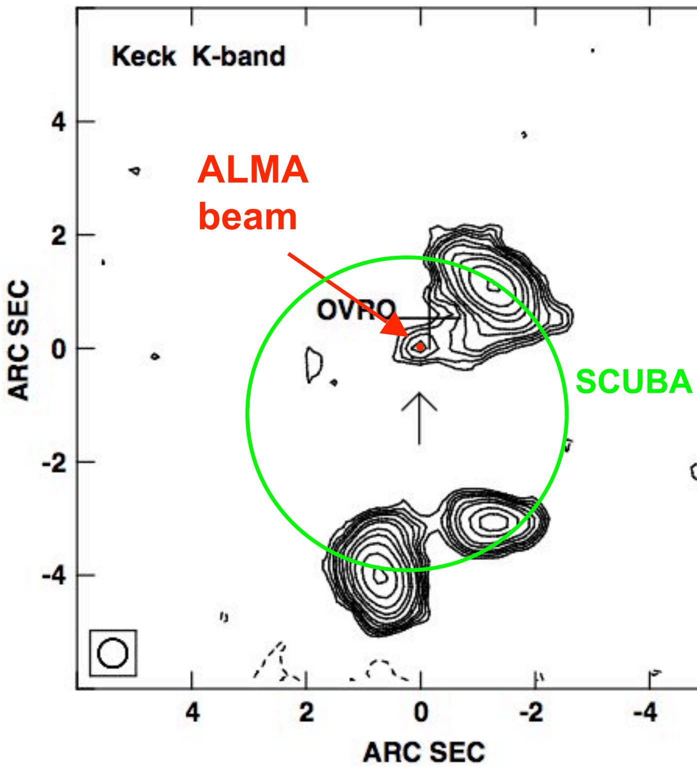
deep SCUBA map (HDF)





"confusion" will not be a problem for ALMA

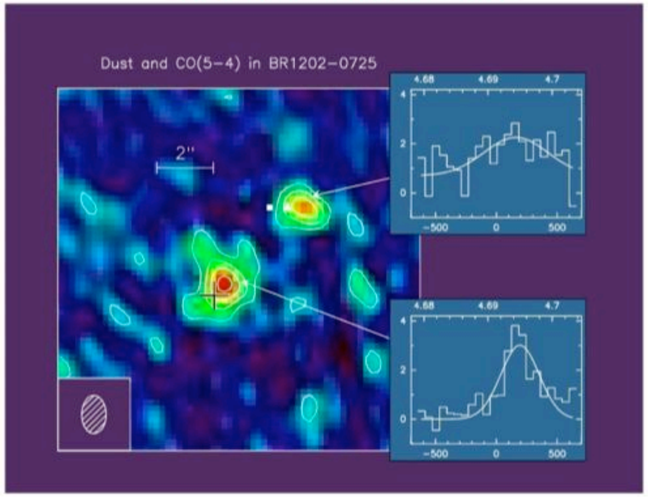
ALMA will provide accurate positions of mm-submm sources ⇒ unambiguos cross identification at other wavelengths



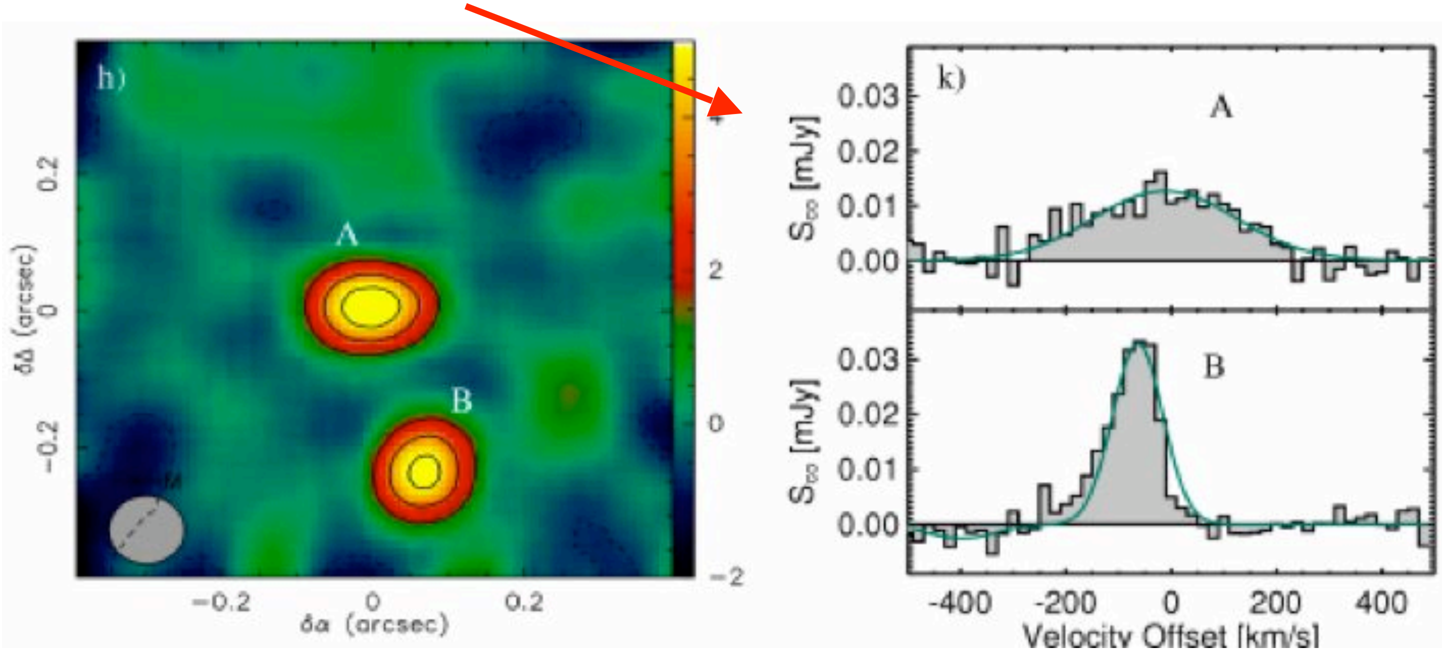
ALMA will directly provide the redshift of the sources by detecting their CO transitions

So far CO detections at high-z have been obtained only in extremely luminous sources (ULIRGs-QSOs)

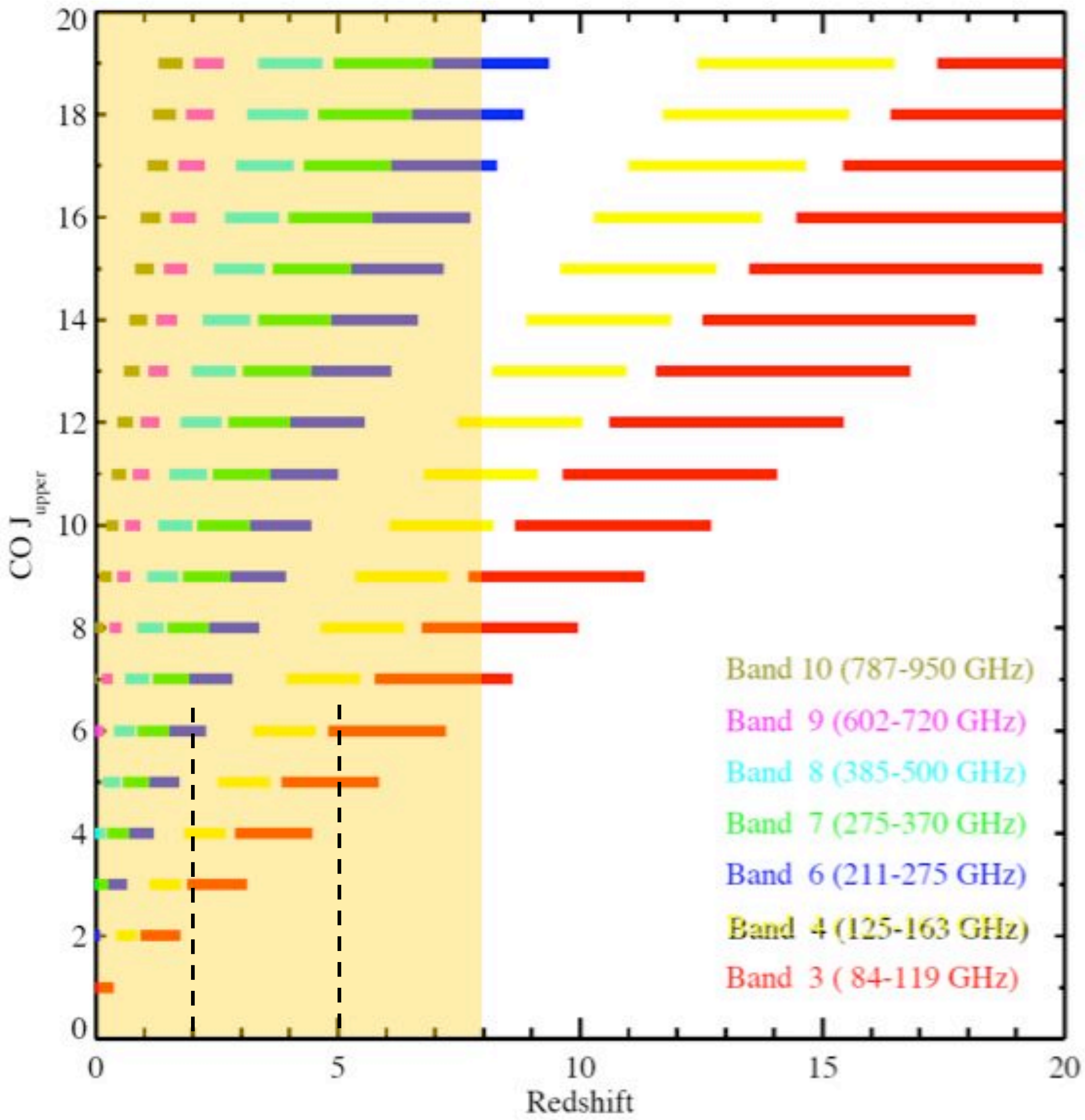
QSO BR1202-0725 at z=4.12



ALMA will be able to detect a Milky Way at z=3: CO(4-3) in 12 hours



Use of CO lines to identify the redshift of high-z galaxies

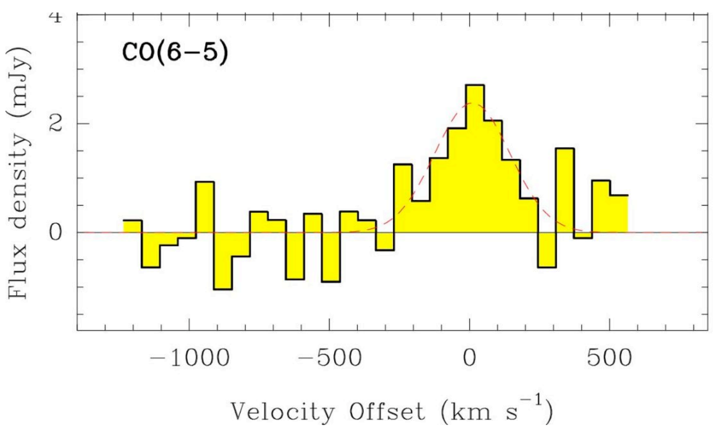


With 3 tunings it will be possible to fully cover band 3 (84-116 GHz)
⇒ at least one CO line

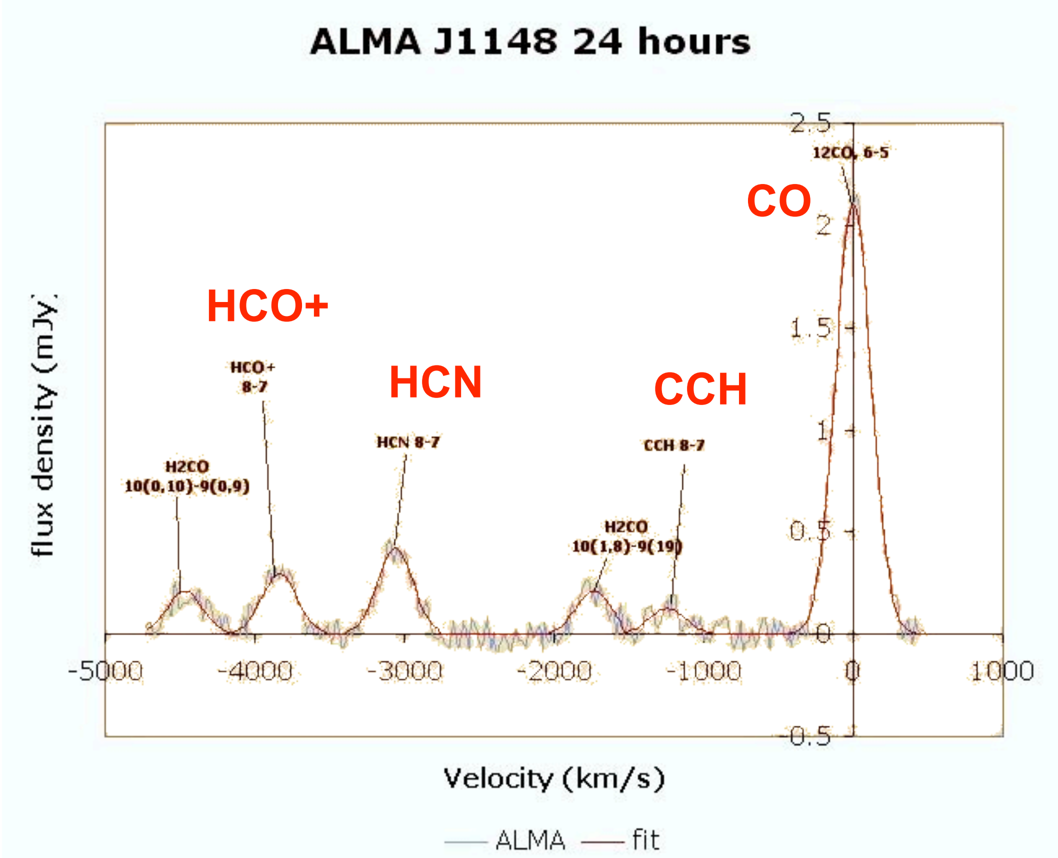
At z>3 at least 2 CO lines within band 3,
else (z<3) observe another band to confirm redshift

Example of QSO at z=6.4

IRAM ~16 hours

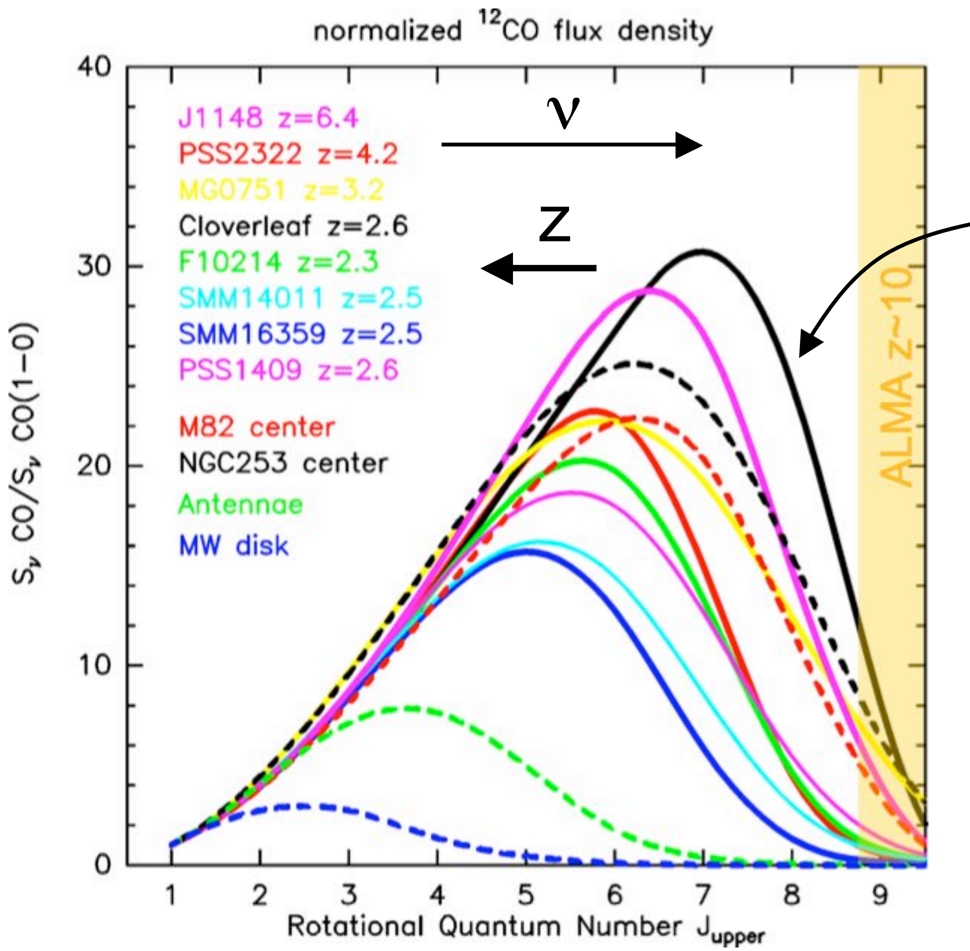


Bertoldi+03

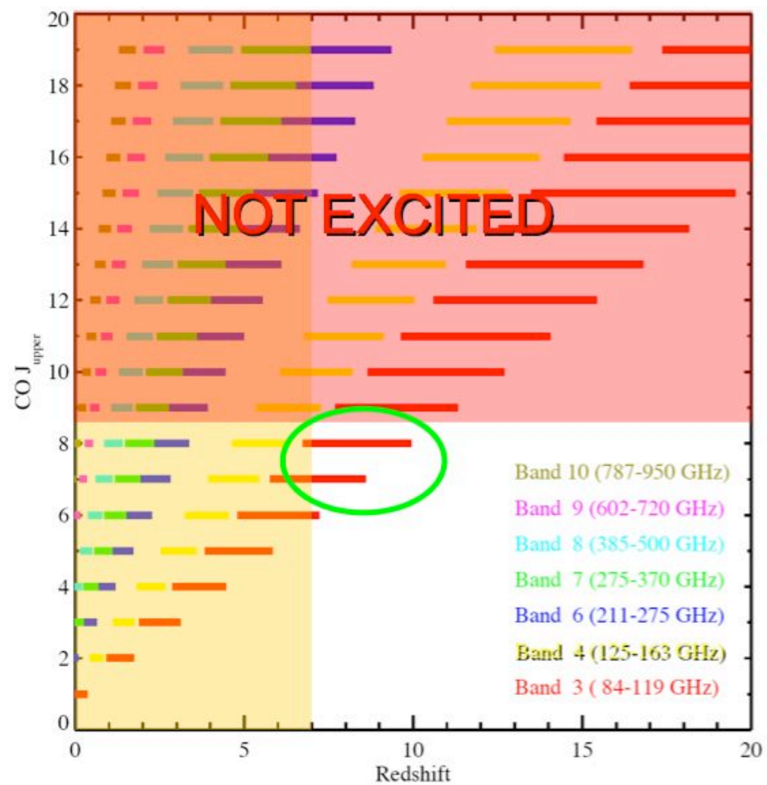


Not only ~∞ S/N on CO line (⇒ detailed dynamical studies, see discussion later on), but also several other molecular lines -> astrochemistry -> **XDR tracers**

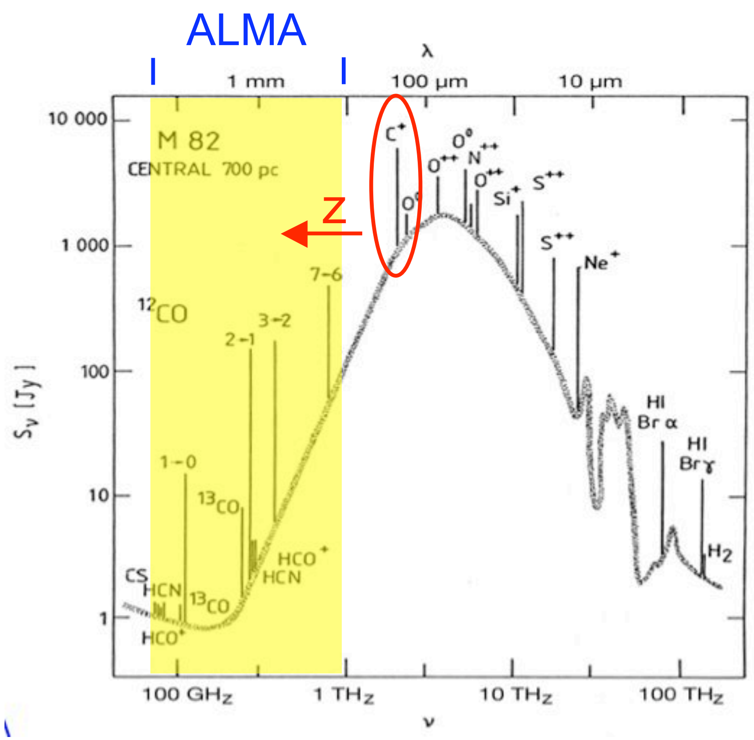
At **z>7** galaxies can be identified through the detection of high order CO lines, J_{upper}>7... are these transitions excited?



at high J rapid drop of intensity... bad news for ALMA: difficult to use CO at z>7, unusable at z>10



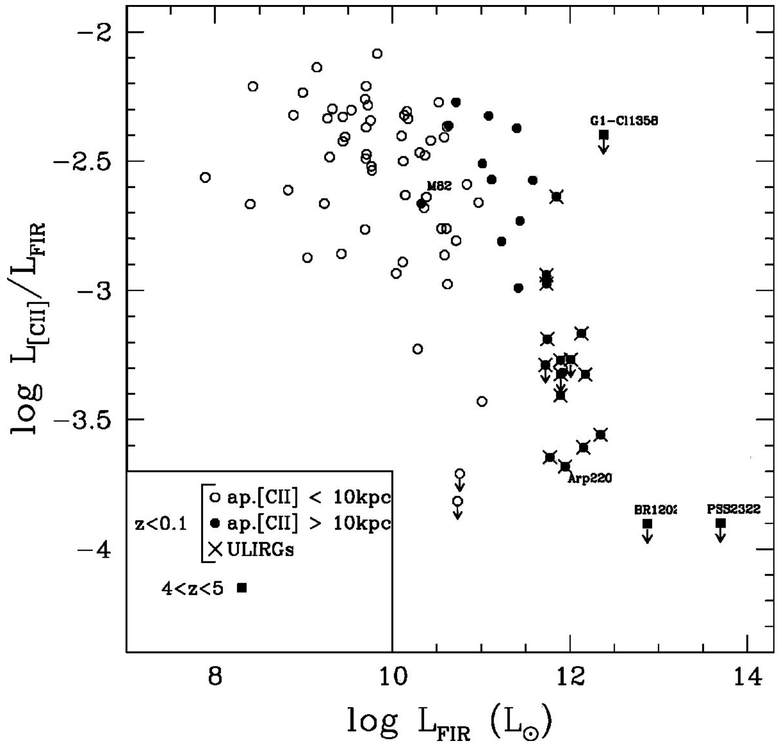
[CII]158μm line: the main coolant of the ISM



Emitted in PDR's ⇒ tracer of star formation

Generally the strongest line in the spectrum of galaxies
(~5-100 times stronger than CO lines)

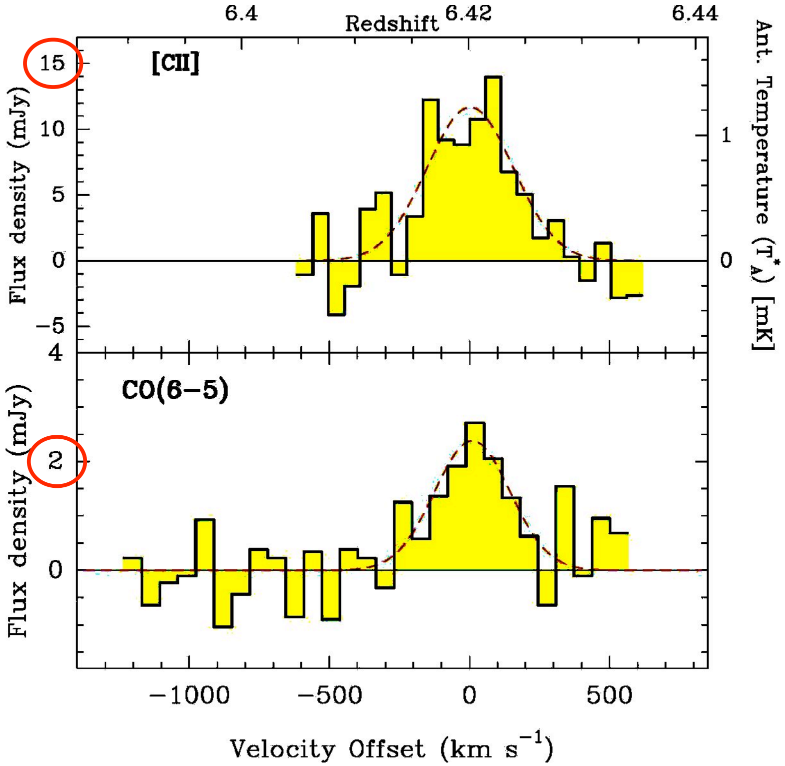
~1% of the whole bolometric luminosity is emitted in this single line



Issue: its luminosity drops at high bolometric luminosities ($L_{FIR} > 10^{11.5}\ L_{\odot}$)

First detection of [CII]158μm at high-z

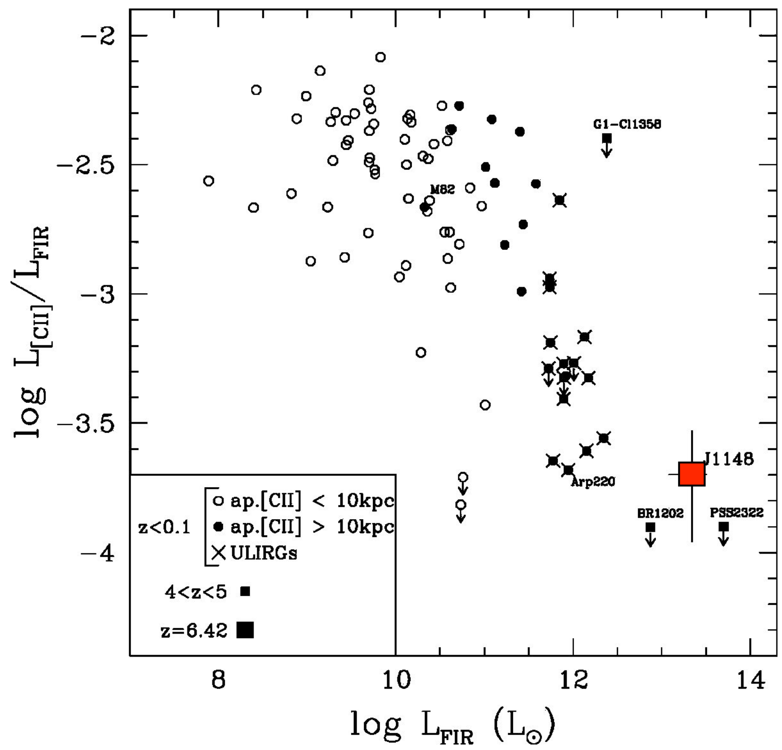
QSO at z=6.4



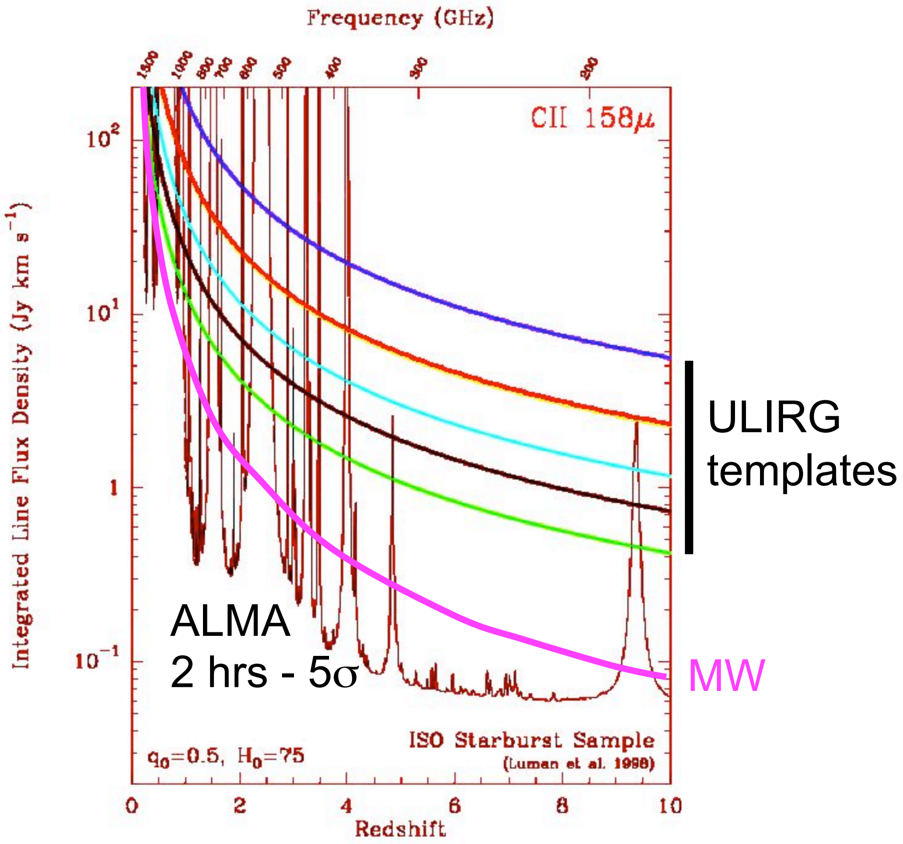
Maiolino+05

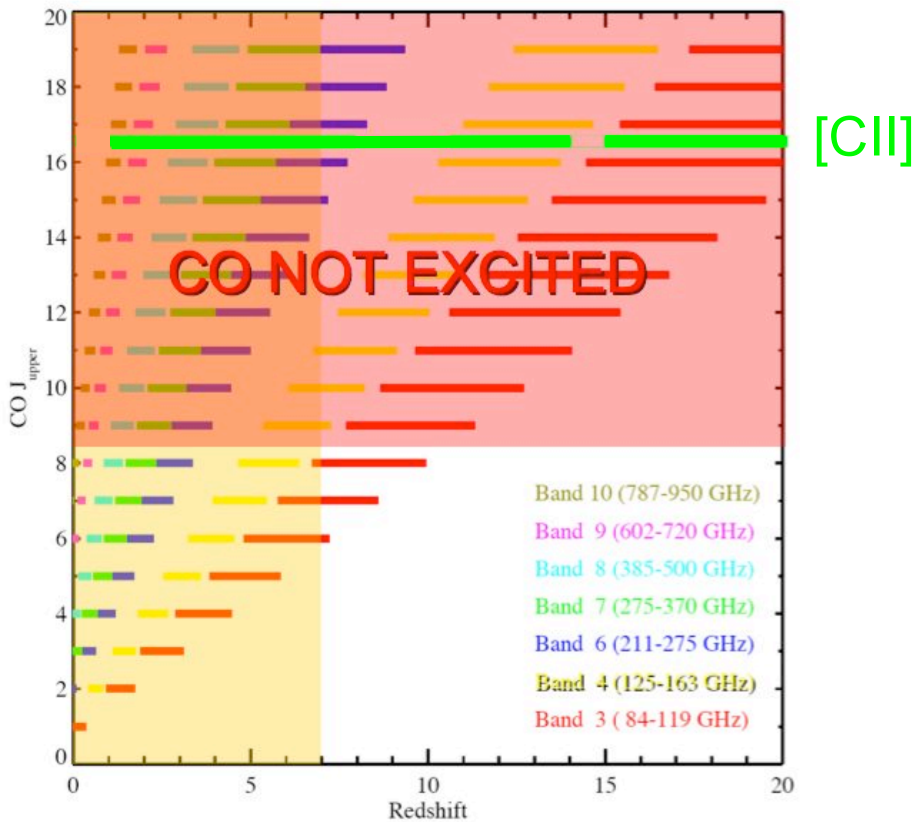
Six time brighter than CO

Even if in worse case still detectable



[CII]158μm: main ALMA tool to investigate high-z galaxies

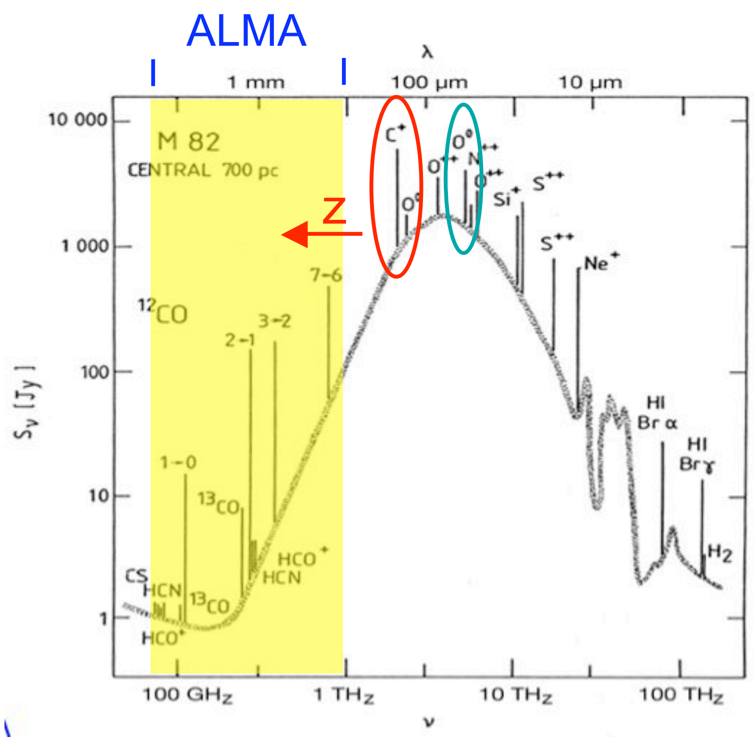


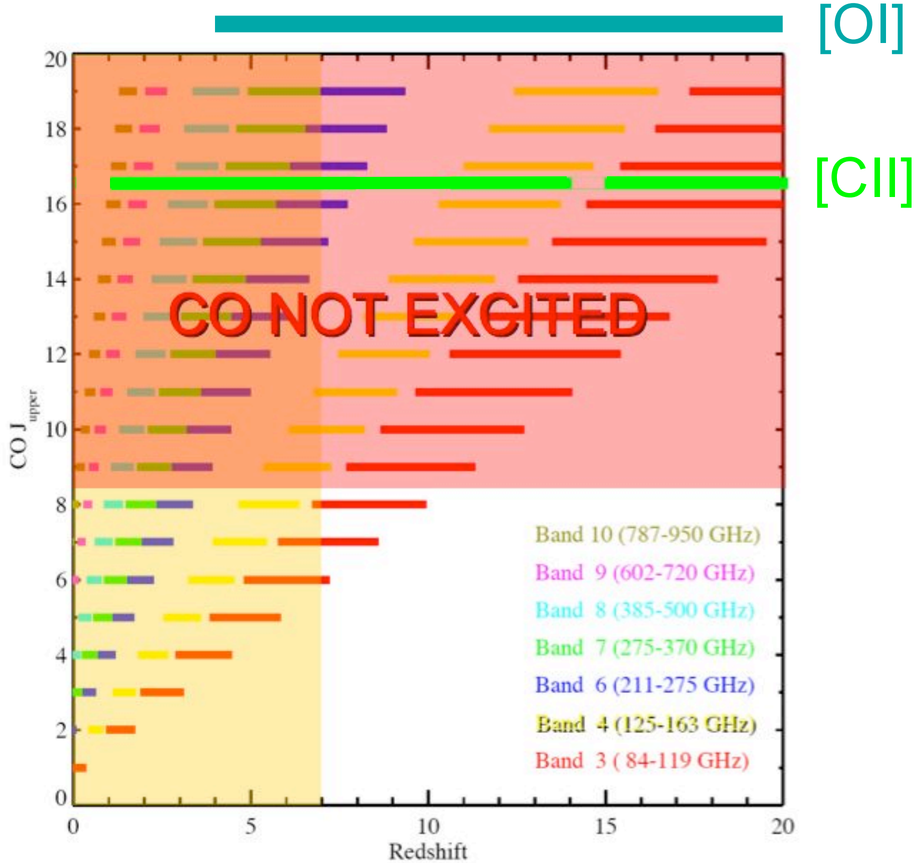


Relative to CO lines (besides being brighter)
[CII]158μm has also the advantage of being observed at
higher frequencies ⇒ higher angular resolution (~ factor of 2-3)

[CII]158μm will provide the redshift, but also SFR and kinematics (-> M_{dyn})

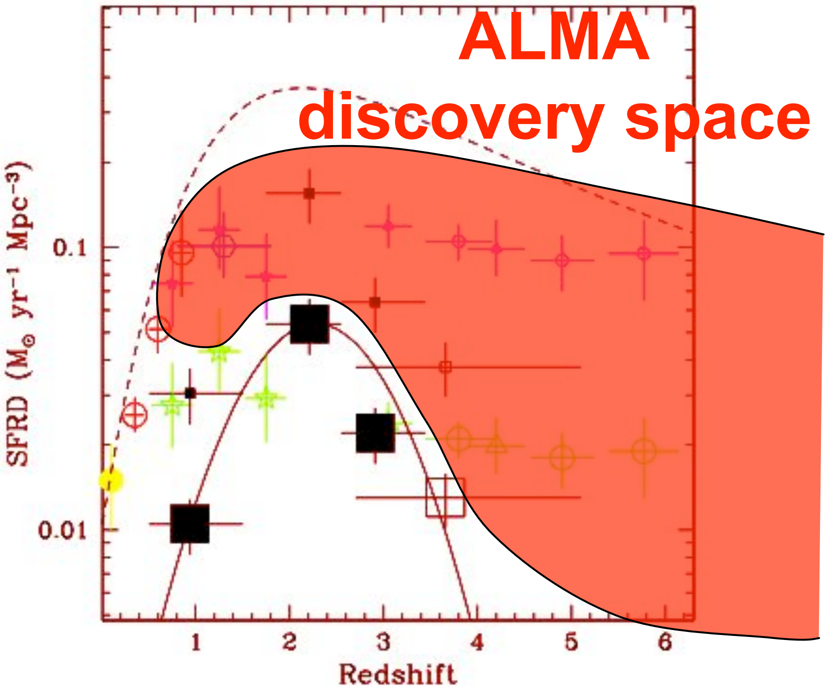
[OI]63μm: second brightest line in galaxies, but is expected to be even stronger than [CII]158μm in young, high-z galaxies





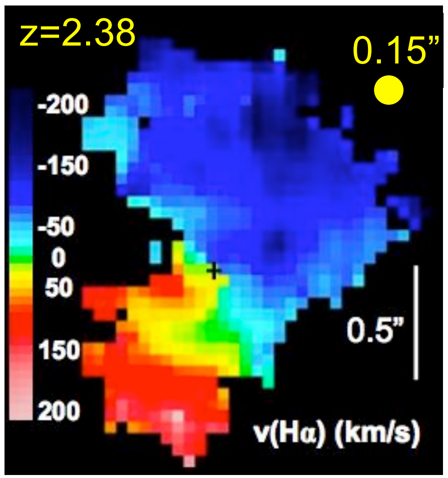
[OI]63μm additional ALMA tool to investigate high-z galaxies:

- redshift
- [OI]+[CII] -> Star Formation Rate
- [OI]/[CII] -> chemical enrichment

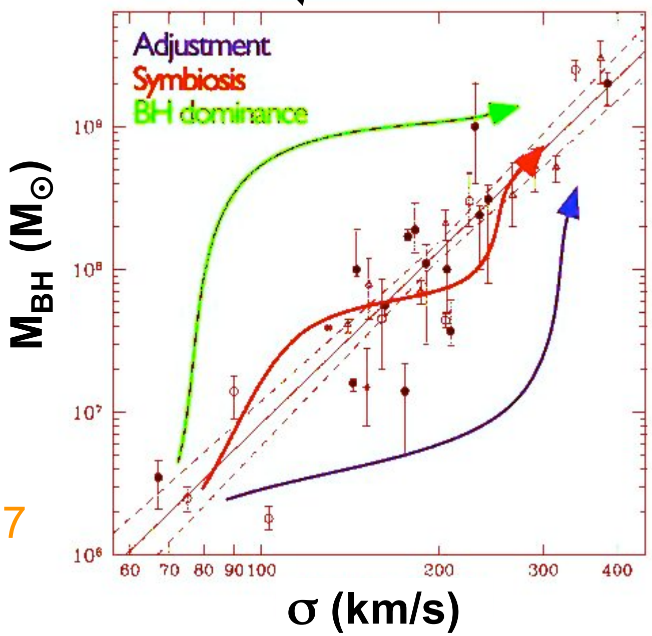


For these galaxies ALMA will provide:

- SFR, also in AGN hosts,
  -> galaxy-AGN co-evolution
- Molecular gas content
  -> SFE
- Identify hidden AGNs (XDRs)
- Dynamical masses
  -> evolution of mass function
  -> evolution of M_{BH}-M_{gal} relation



Genzel+07



Colpi'07

Finally...

YOU are expected to provide new, fresh ideas to best exploit the unprecedented capabilities of ALMA