The Atacama Large Millimeter Array: Gas and dust in the most distant galaxies

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Spineto

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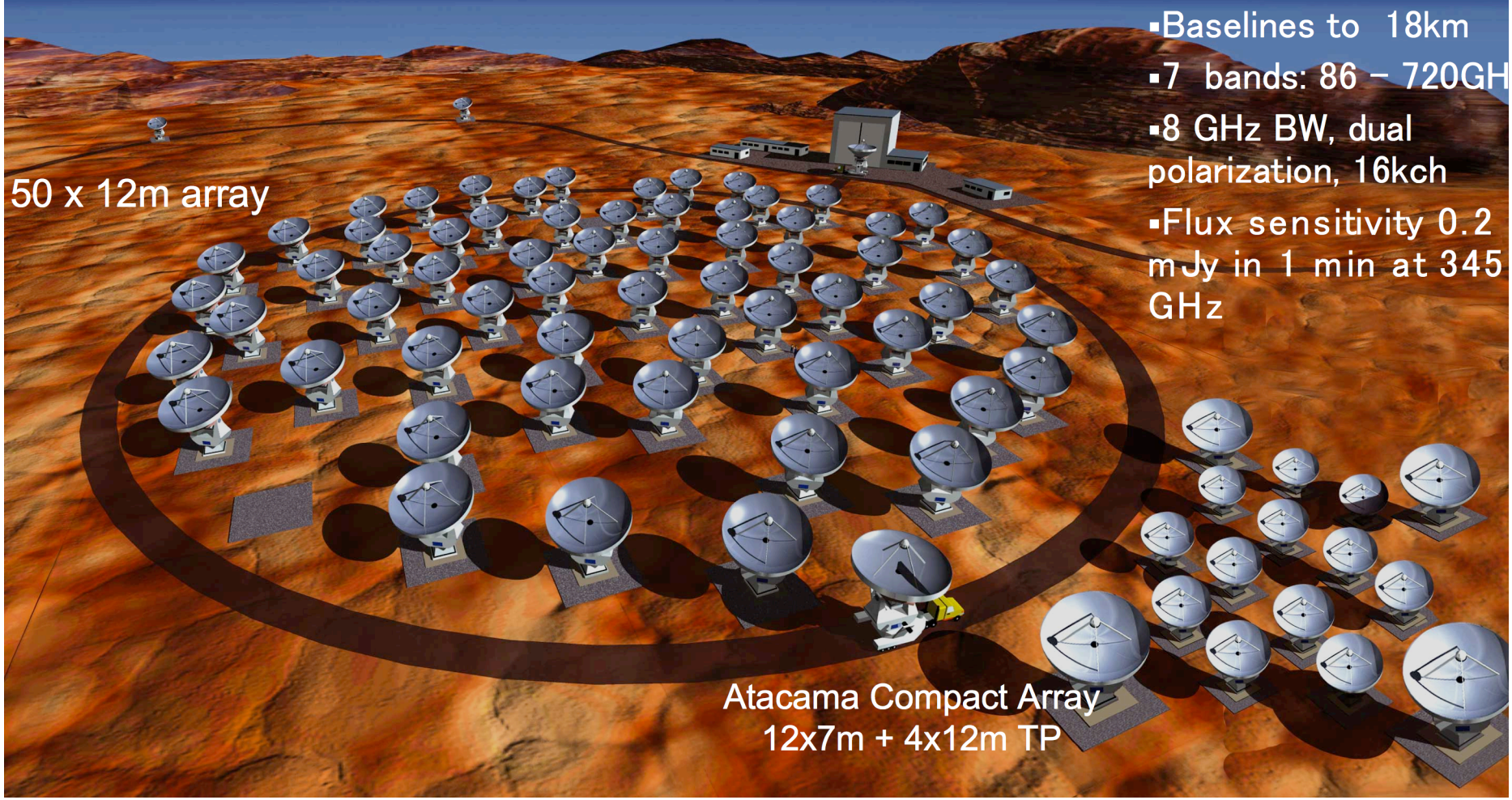
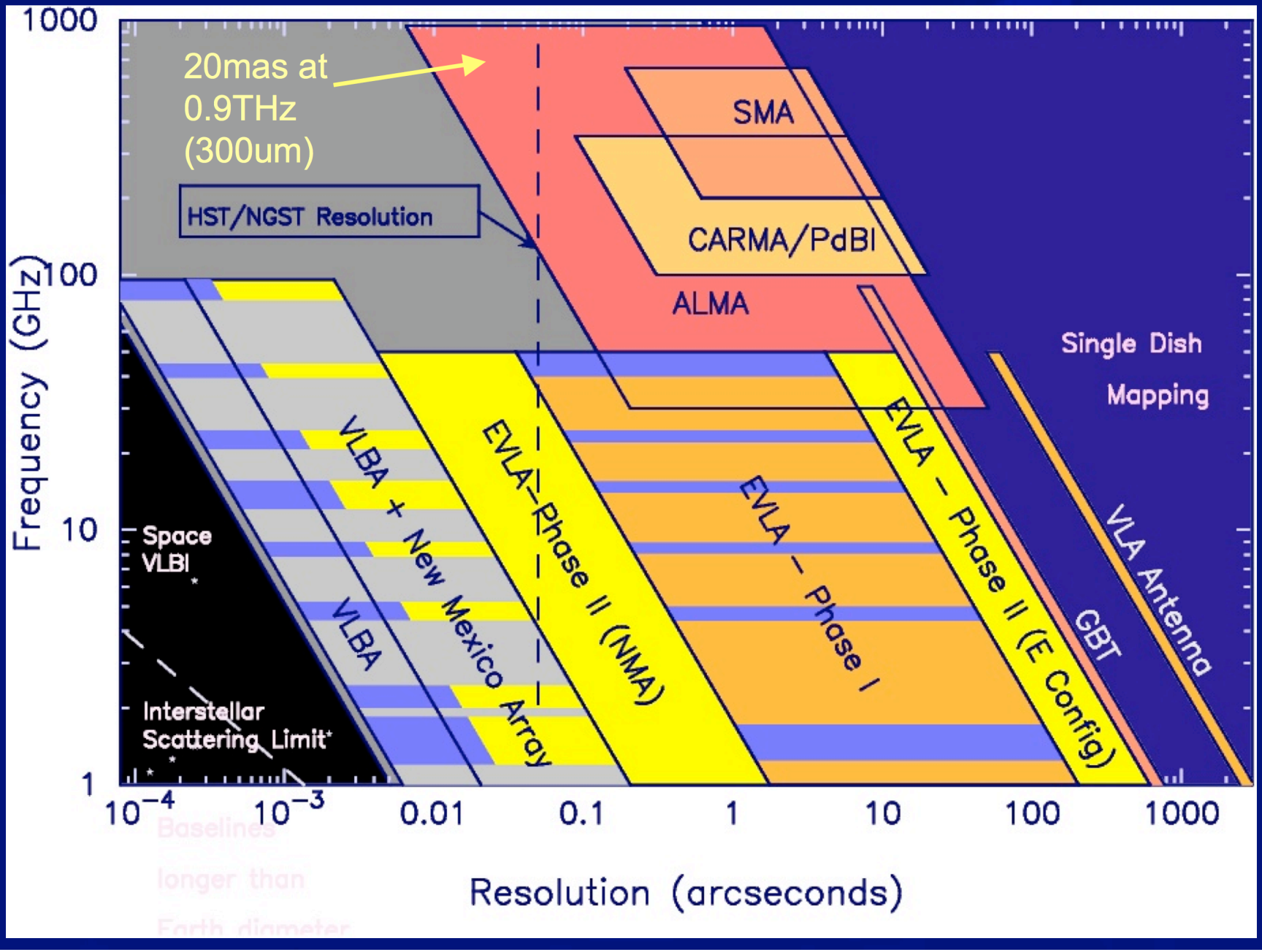
What is ALMA?

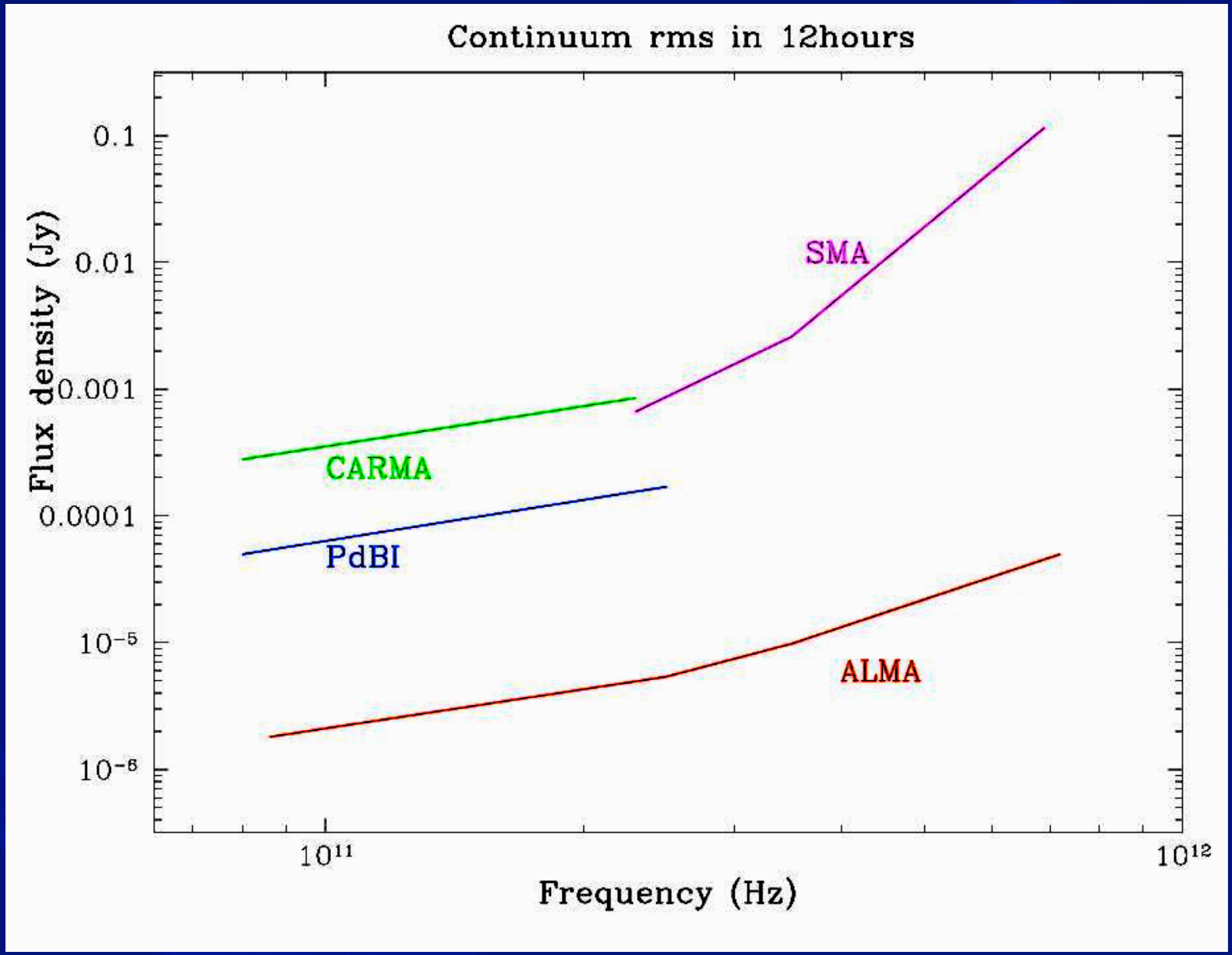
North American, European, Japanese, and Chilean collaboration to build & operate a large millimeter/submm array at high altitude site (5000m) in northern Chile -> order of magnitude, or more, improvement in all areas of (sub)mm interferometry, including resolution, sensitivity, and frequency coverage.



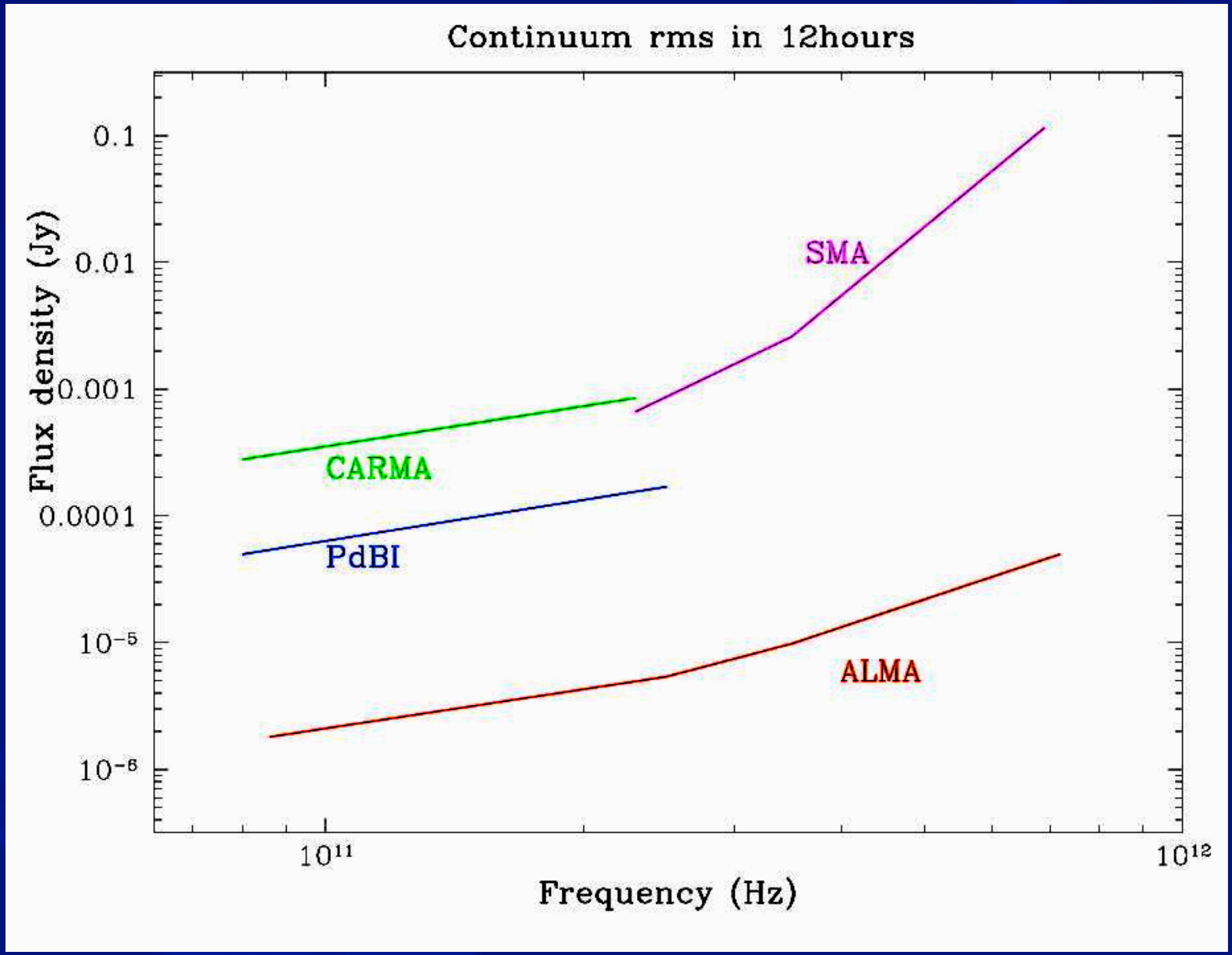
Giant Steps I: Frequency and resolution



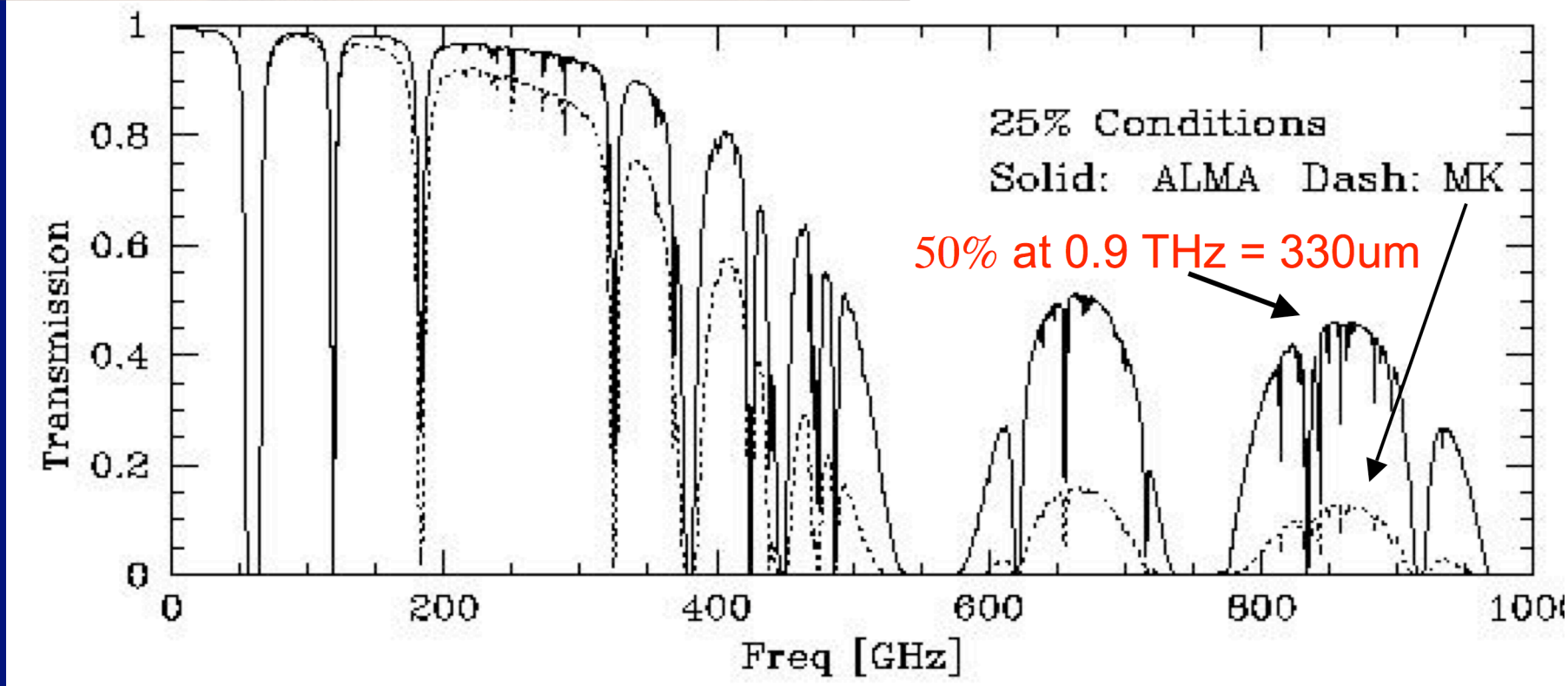
Giant Steps II: Sensitivity



Giant Steps II: Sensitivity



Giant Steps III: Site qualit

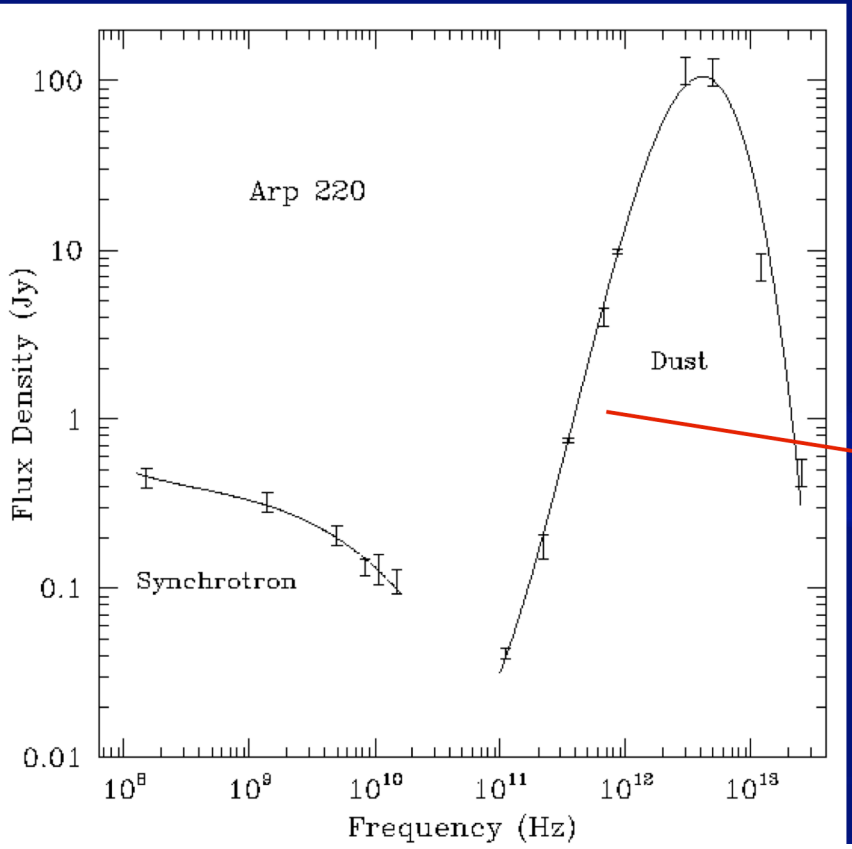


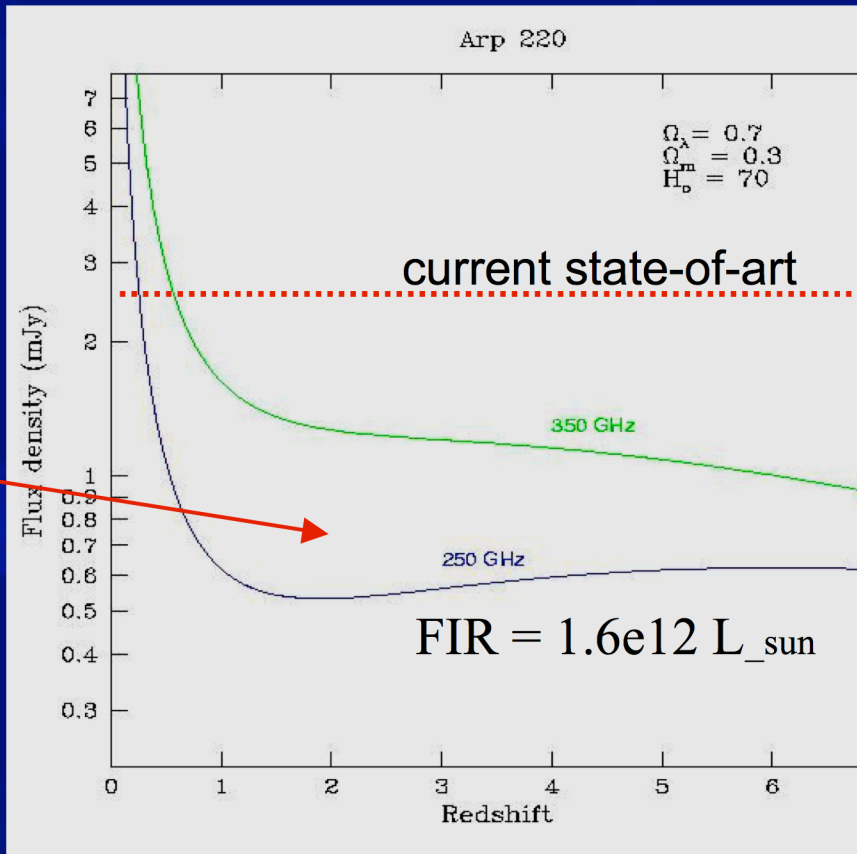
Gas and dust in the most distant galaxies

Wang, Walter, Bertoldi, Cox, Fan, Strauss, Menten, Wagg, Omont

Magic of (sub)mm 'cosmology': distance independent method of studying objects in universe from z=0.8 to 10

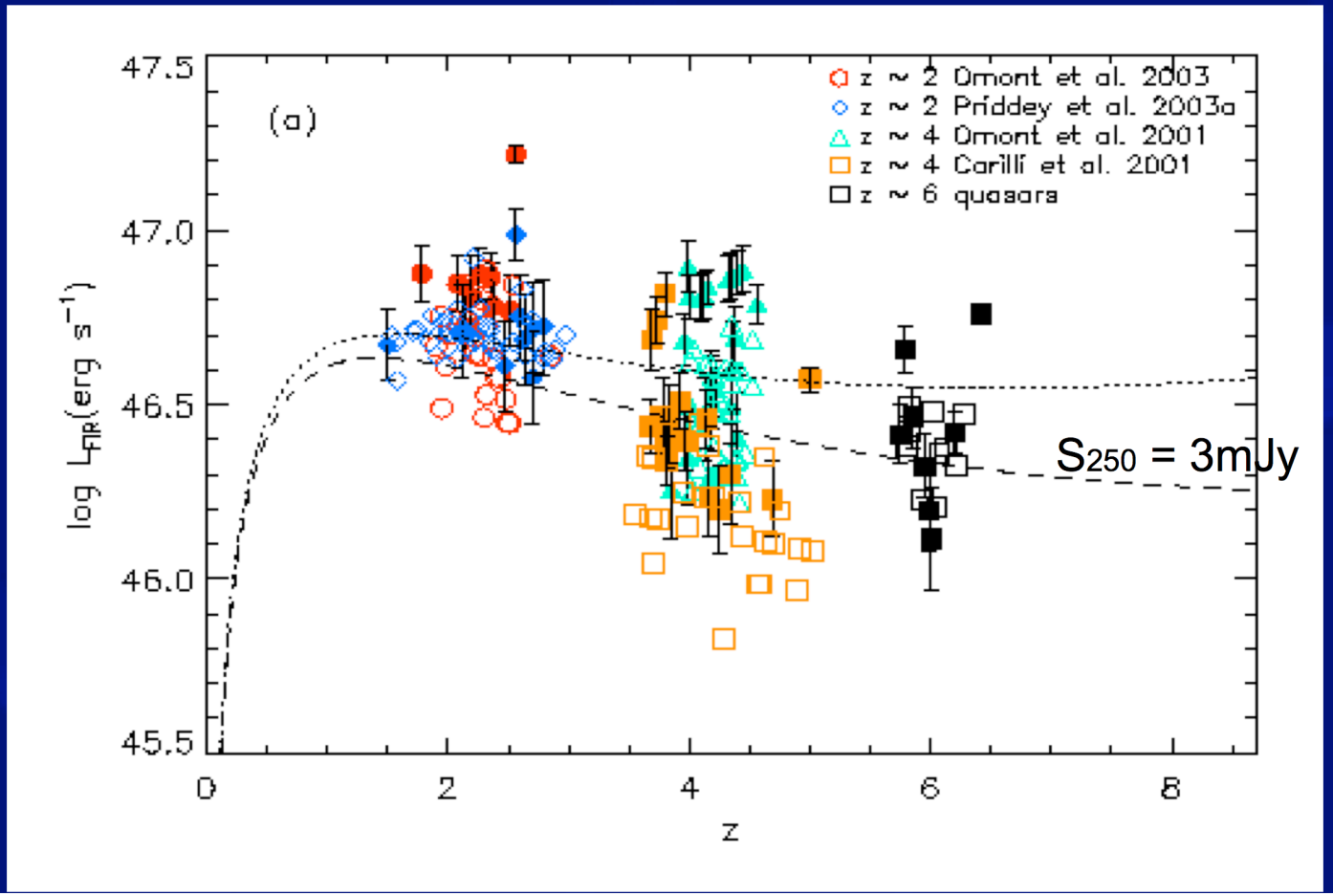
$L_{FIR} \sim 4e12 \times S_{250}(mJy)\ L_o \Rightarrow SFR \sim 1e3 \times S_{250}\ M_o/yr$



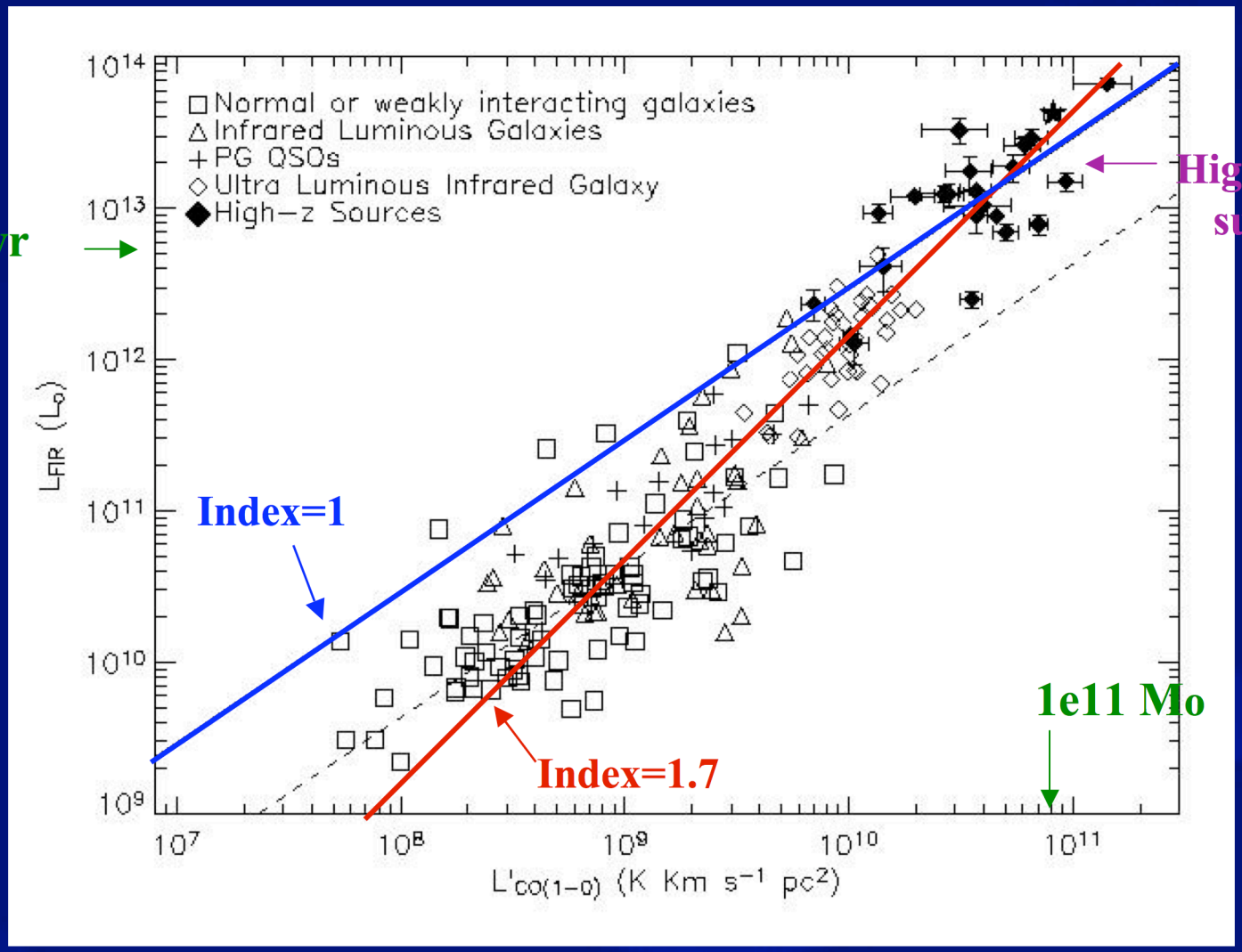


Dust in z ~ 2 to 6 QSO host galaxies
MAMBO/SCUBA suverys

- 30% of QSO host galaxies from z=1.5 to 6.4 have $S_{250} > 3$mJy => HyLIRGs: $L_{FIR} \sim 1e13\ L_o$
- $M_{dust} \sim$ few e8 M_o
- $L_{FIR} \sim 0.1 \times L_{bol}$: Dust heating by starburst or AGN?

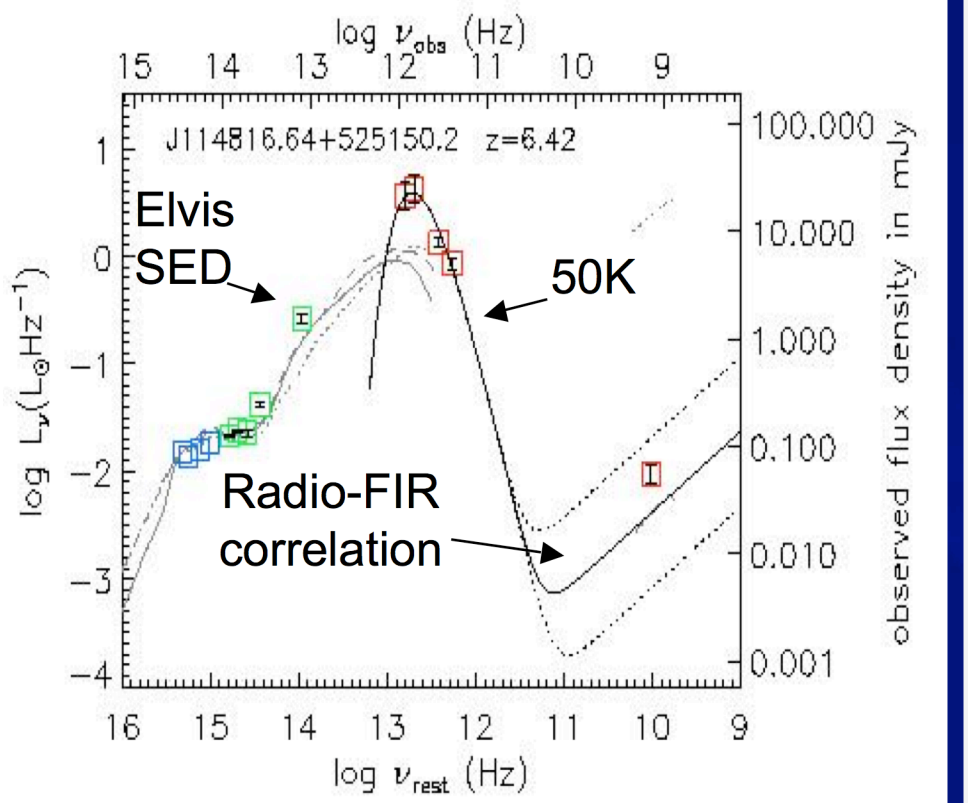


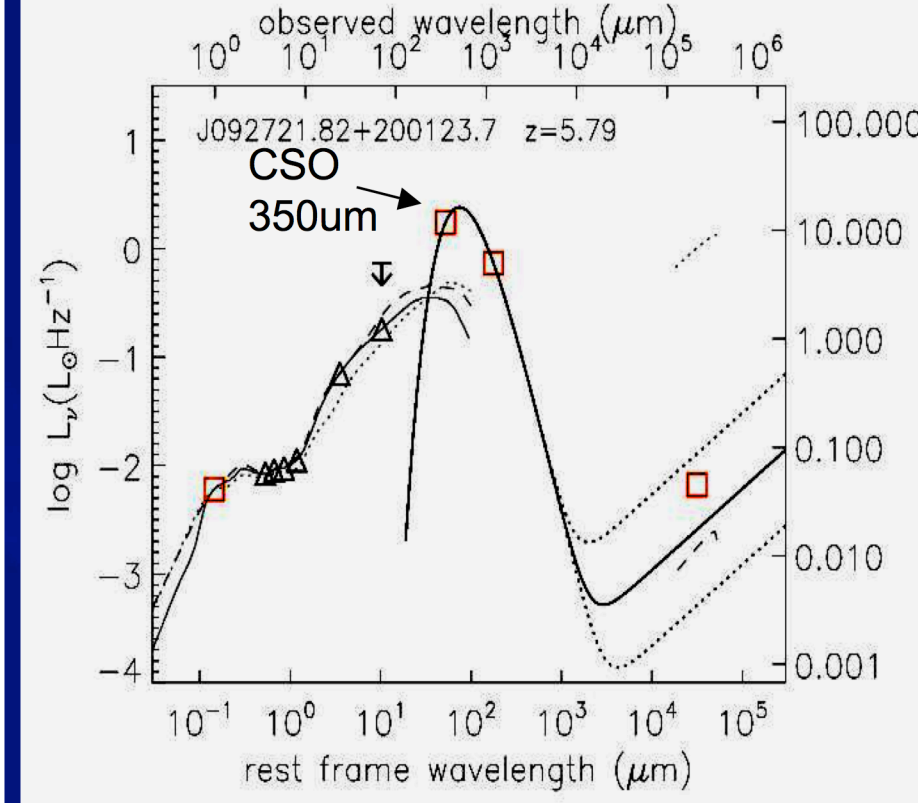
L_{FIR} vs L'(CO)



High-z sources = 10 -- 100 x M_{gas} of Milky Way

z~6 QSO host galaxies: dust into cosmic reionization (t_{univ} < 1Gyr)

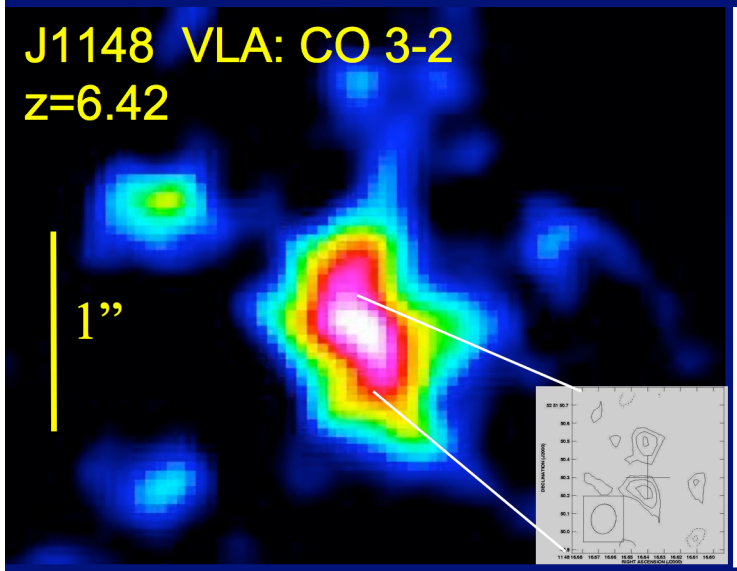


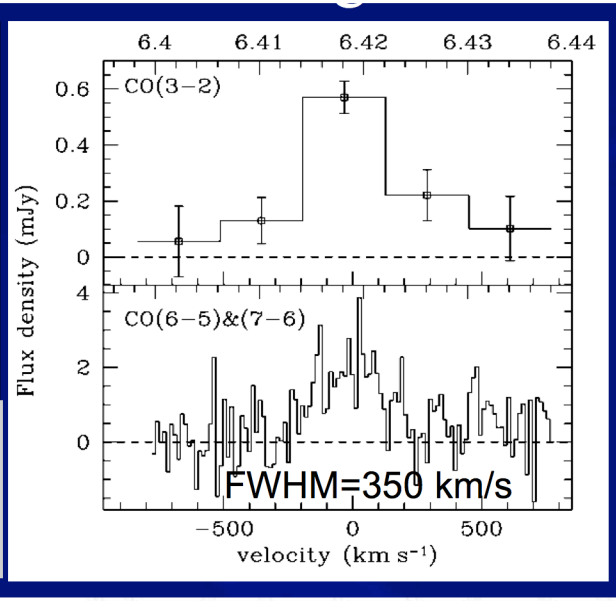


- FIR ~ 2e13 L_o
- Follows Radio-FIR correlation: SFR ~ 3000 M_o/yr

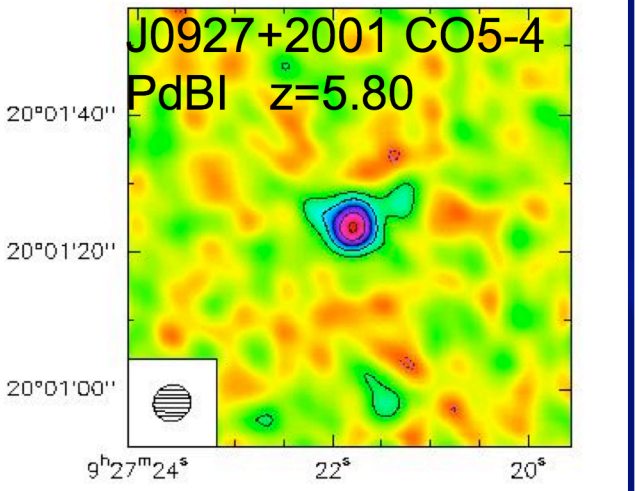
- $t_{univ} < t_{AGB}$ => Dust formation by massive stars (Dwek et al. 2007; Maiolino et al. 2005)?

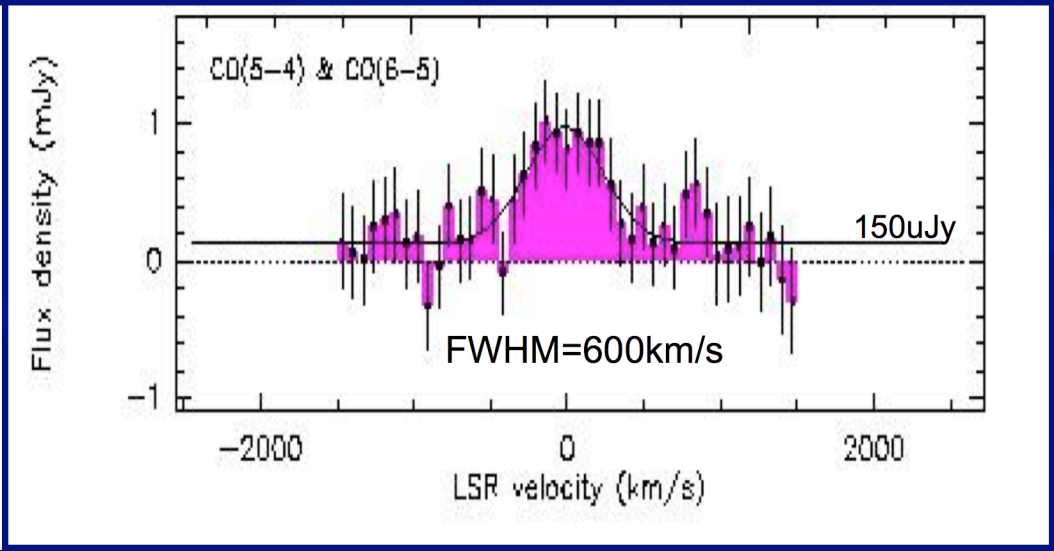
z ~ 6 QSO host galaxies: molecular gas into cosmic reionization





- Giant clouds of gas and dust (5kpc)
- 7e8 $M_\odot$ in dust
- 2e10 $M_\odot$ in gas
- T_B = 20K ~ ULIRG
- Gas/Dust ~ ULIRG





Early enrichment of heavy elements ($z_{sf} > 8$)

Accurate z_{host} => best measure of radius of CSS

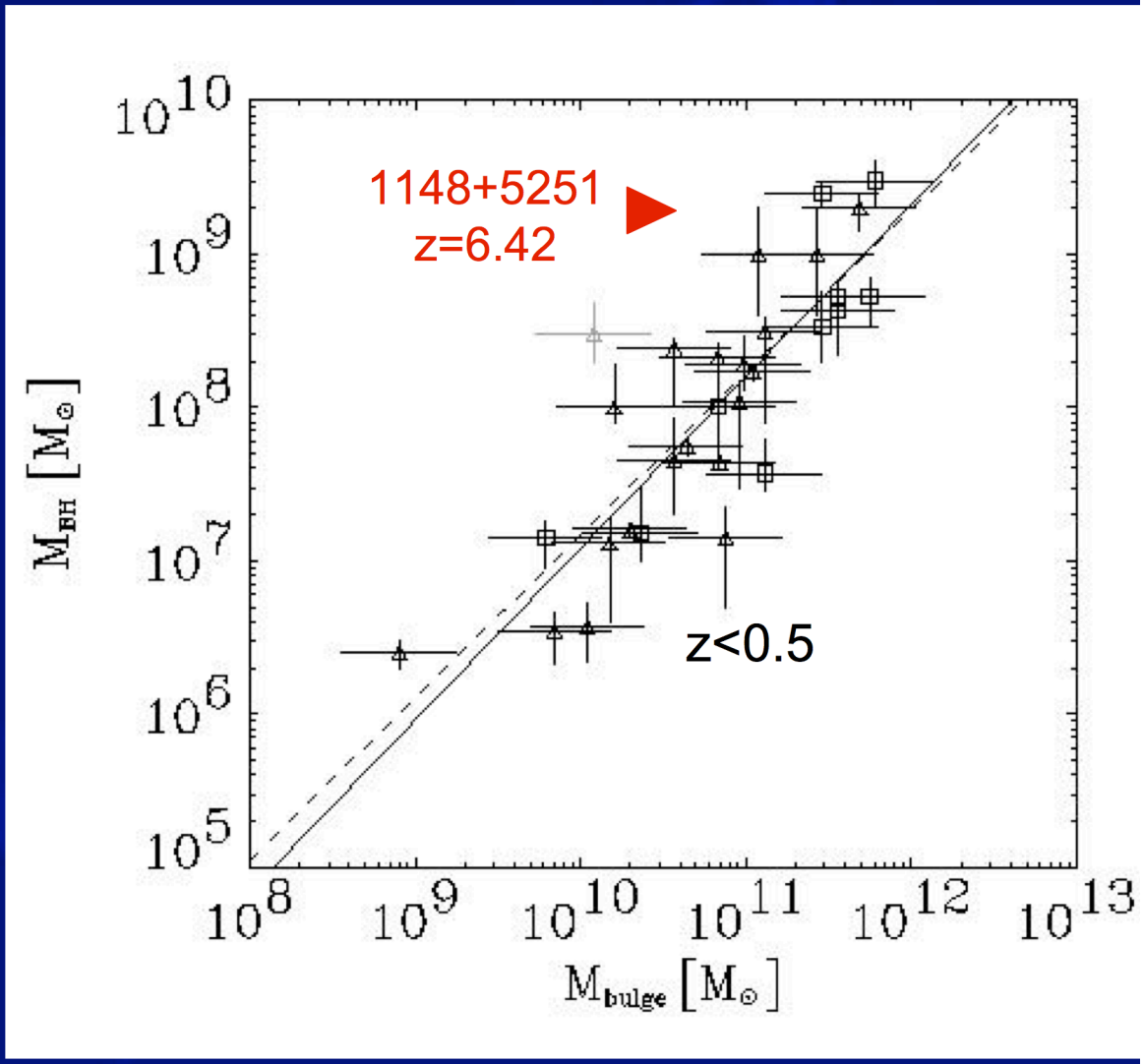
Testing M_{BH} - M_{bulge} relation at high z

CO FWHM + size =>

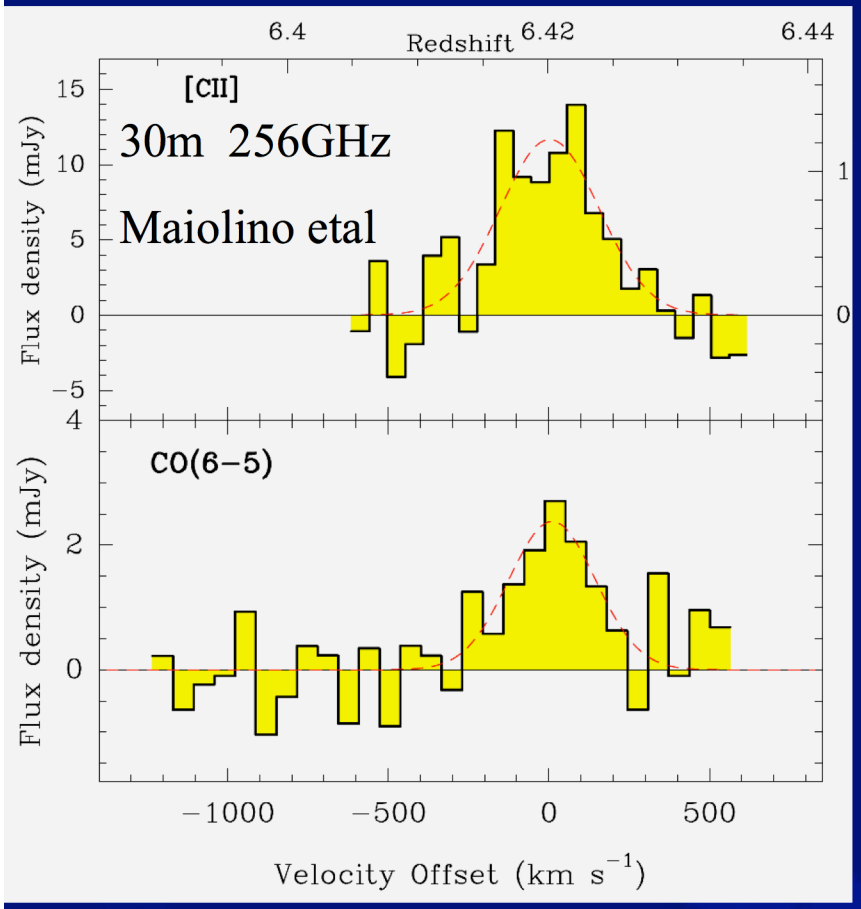
M_{dyn}~ 2e10/(sinθ)^2 M_o

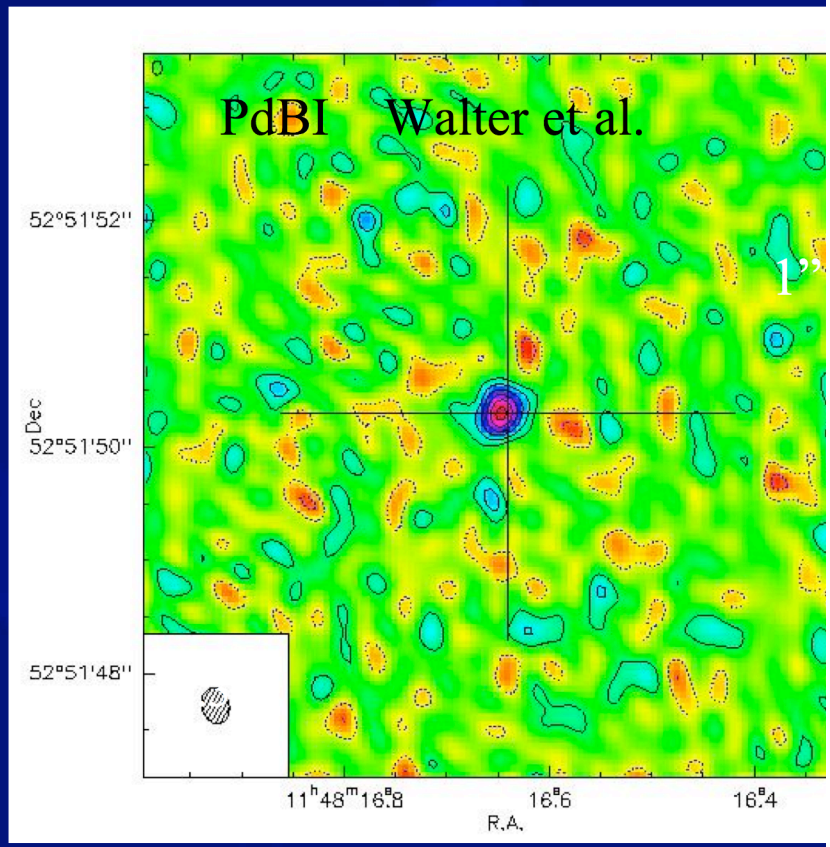
M_{gas}~ 2e10 M_o

M_{bulge} ~1e12 M_o
(predicted)



[CII] 158um PDR gas cooling line detected at z=6.4





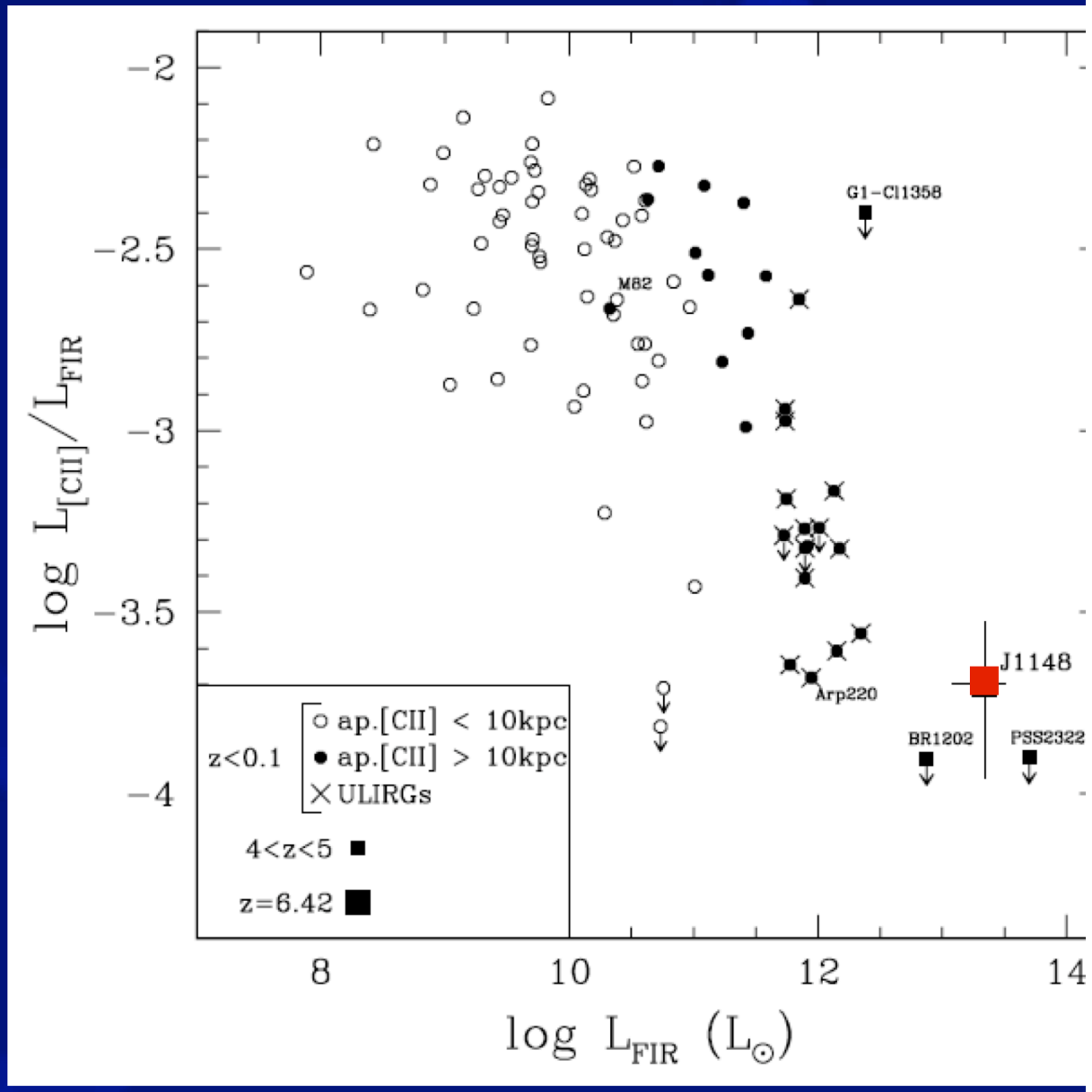
- $L_{[CII]} = 4x10^9\ L_o$
- $L_{[CII]}/L_{FIR} = 3x10^{-4} \sim$ ULIRG

- Size ~ 0.5" (~ 2.5kpc)
- Enriched ISM on kpc scales
- SFR ~ 6.5e-6 $L_{[CII]}$ ~ 3000 Mo/y

[CII] -- the good and the bad

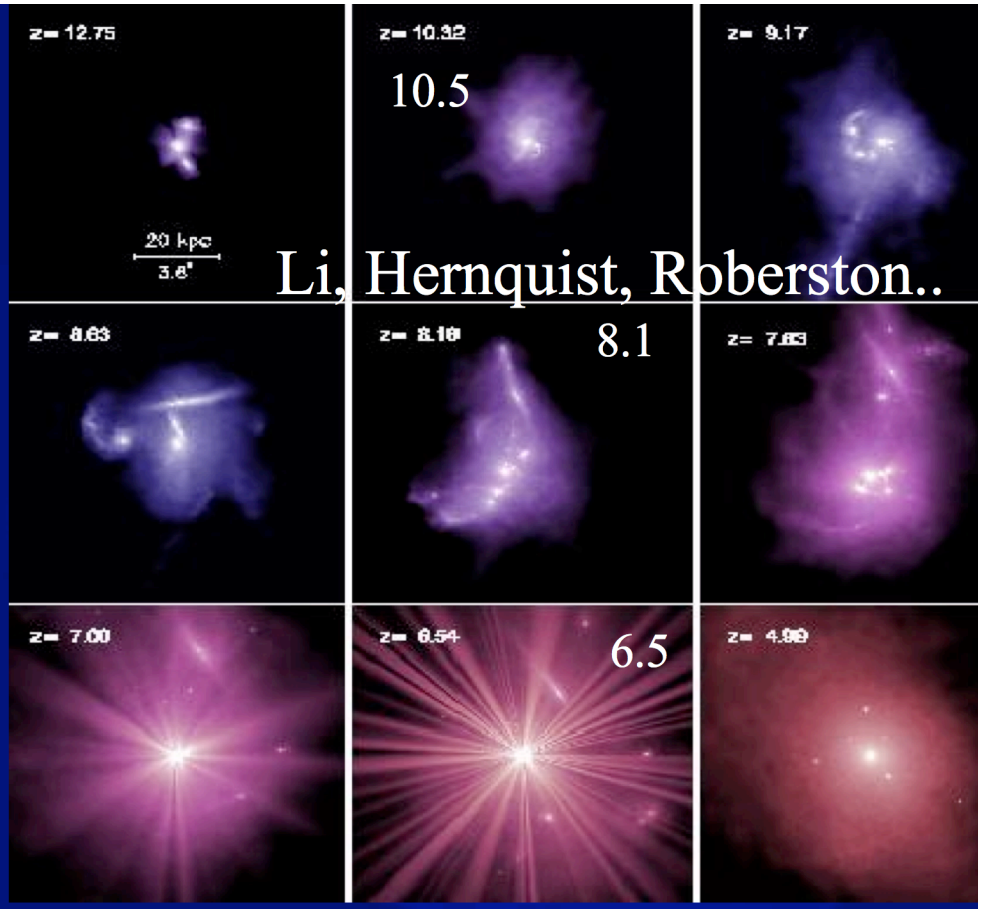
- [CII]/FIR decreases rapidly with L_{FIR} (lower heating efficiency due to charged dust grains?) => luminous starbursts are still difficult to detect in C+

- Normal star forming galaxies (eg. LAEs) are not much harder to detect!



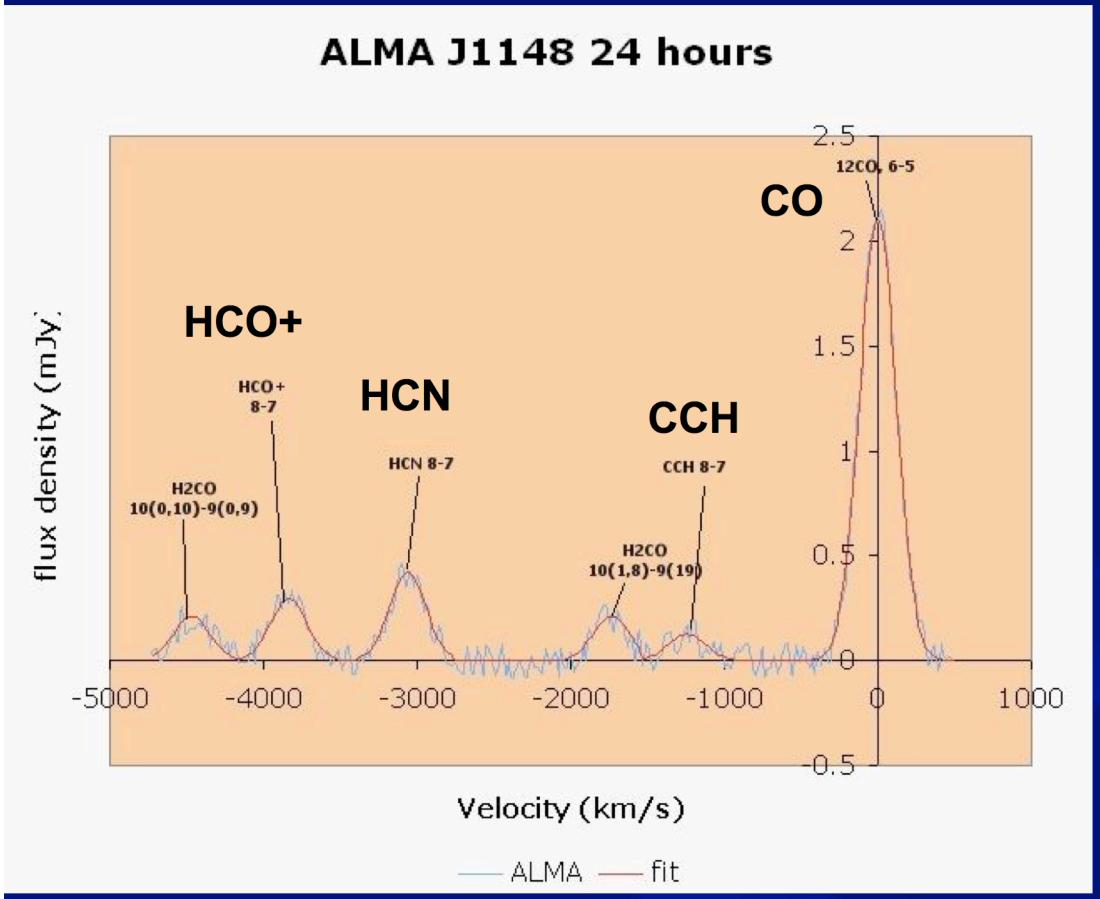
Building a giant elliptical galaxy + SMBH at $t_{univ} < 1$Gyr

- Multi-scale simulation isolating most massive halo in 3 Gpc^3 (co-mov)
- Stellar mass ~ 1e12 Mo forms in series (7) of major, gas rich mergers from z~14, with SFR ~ 1e3 - 1e4 Mo/yr
- SMBH of ~ 2e9 Mo forms via Eddington-limited accretion + mergers
- Evolves into giant elliptical galaxy in massive cluster (3e15 Mo) by z=0
- Consistent with 'downsizing' in SMBH and galaxy formation



- Extreme and rare objects: ~ 100 SDSS z~6 QSOs on entire sky
- Integration times: hours to days on HLIRGs

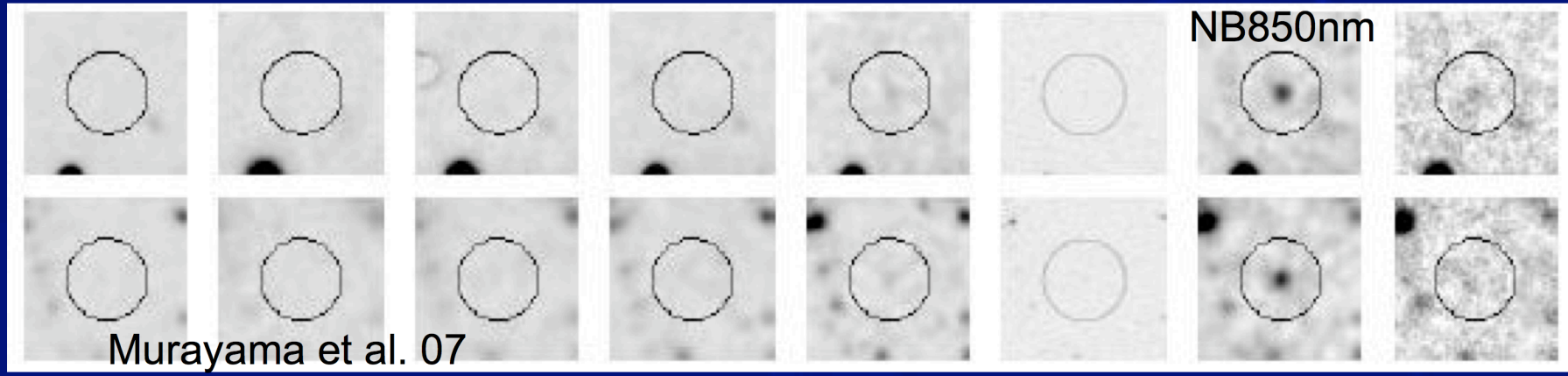
ALMA into reionization



Spectral simulation of J1148+5251

- Detect dust emission in **1se** (5σ) at 250 GHz
- Detect multiple lines, molecules per band => detailed astrochemistry
- Image dust and gas at sub-kpc resolution – gas dynamic

ALMA: Pushing to 'normal galaxies' during reionization, eg. z=5.7 Lyα galaxies in COSMOS

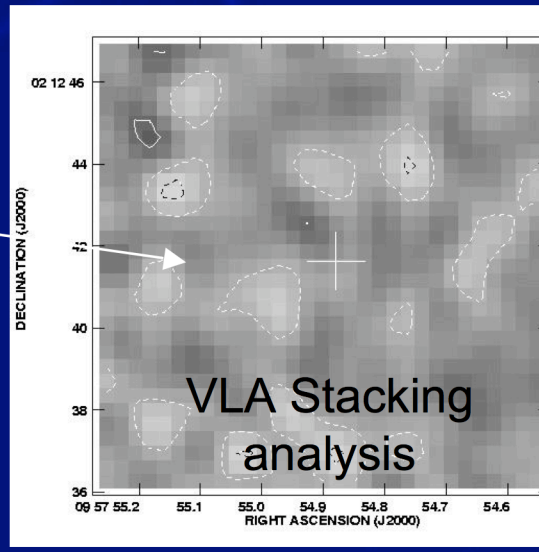


Murayama et al. 07

- SUBARU: Lyα => <SFR> ~ 10 Mo/yr
- 100 deg^-2 in Δz ~ 5.7 +/- 0.05
- Galaxies responsible for reionization?

ALMA: Pushing to 'normal galaxies' during reionization, eg. z=5.7 Lyα galaxies in COSMOS

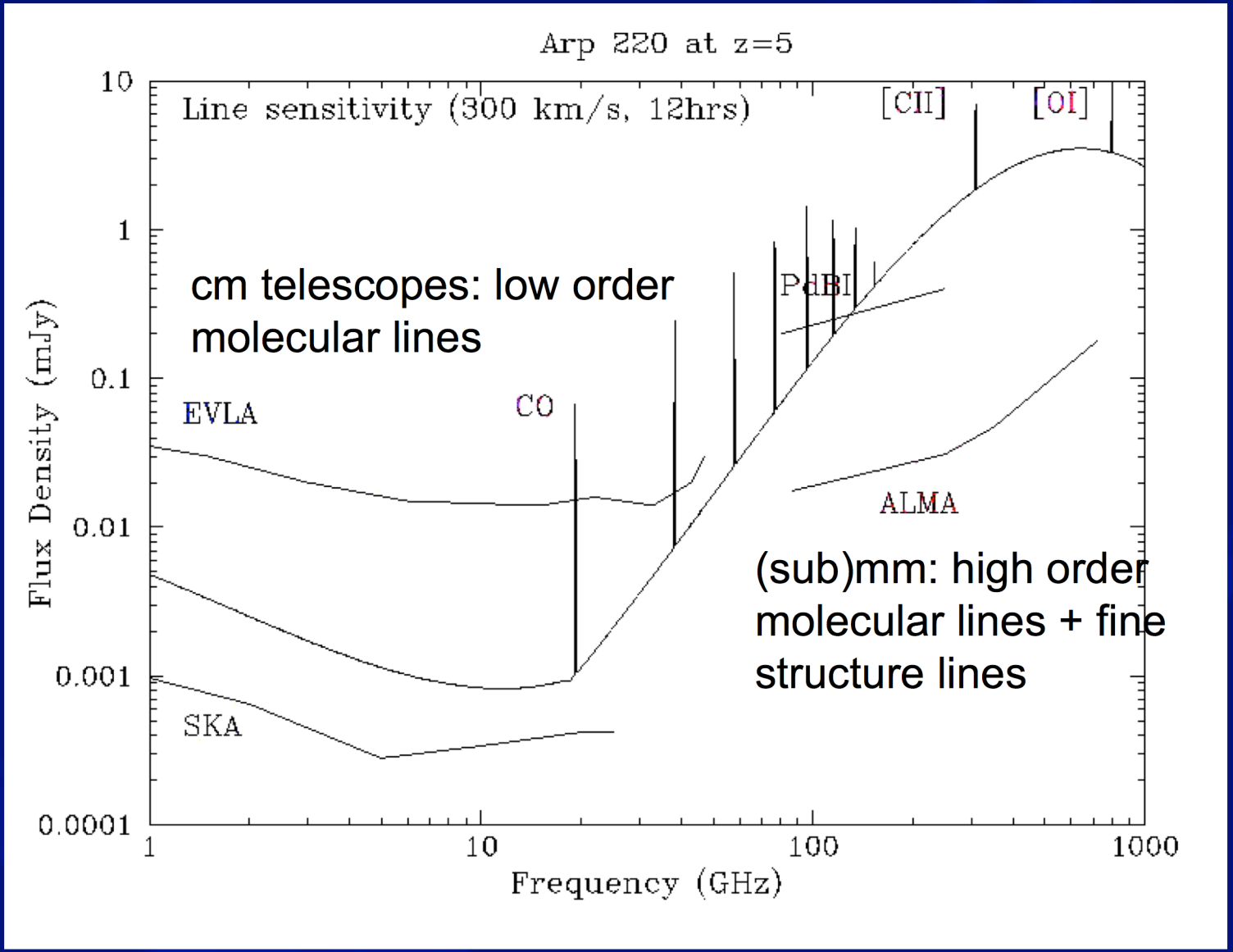
- MAMBO: $\langle S_{250} \rangle$ < 2mJy => SFR<300
- VLA: $\langle S_{1.4} \rangle$ < 2.5uJy => SFR<125



ALMA

- Detect dust (30uJy) in ~ 1 hour
- Detect C+ (~ 0.5mJy) in ~ 1 hour => imaging gas dynamics in first galaxies
- Determine redshifts for dusty galaxies from mm spectroscopy

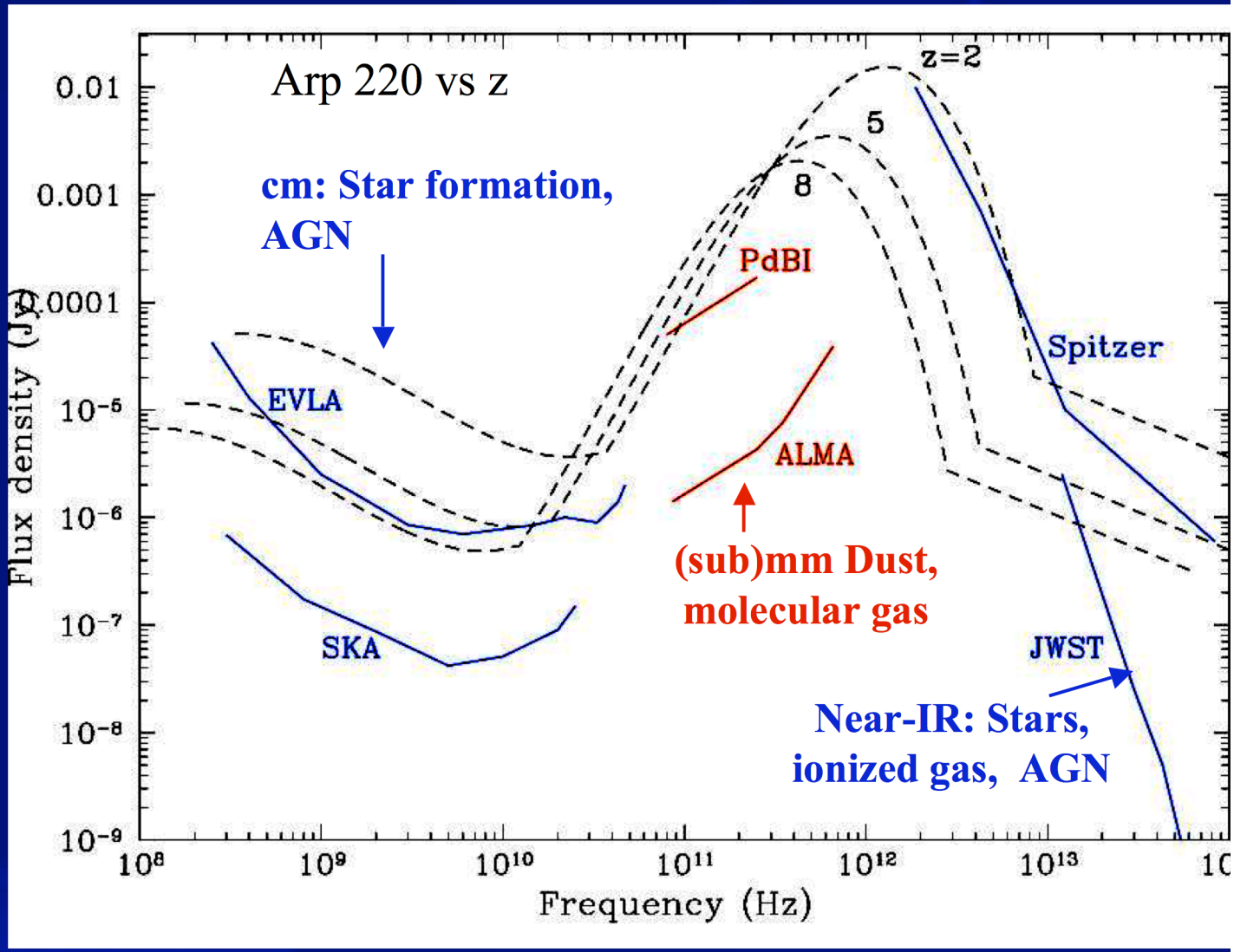
The ALMA revolution: spectral lines



The ALMA revolution: continuum

A Panchromatic view of galaxy formation

ALMA reveals the cool universe: dust and gas, the fundamental fuel for star formation



AOS Technical Building – March 2007

First Vertex Production Antenna in Chile

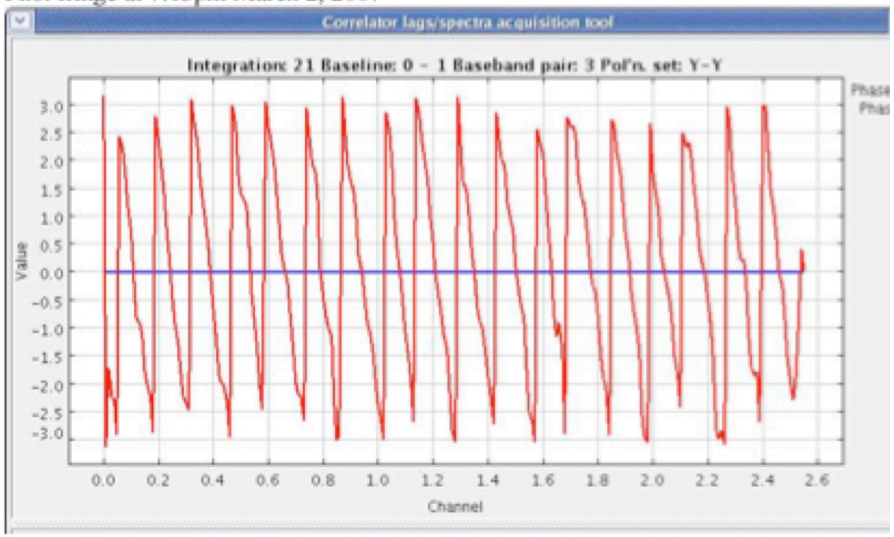
ALMA first fringes (Emerson +)

ATF, Socorro NM

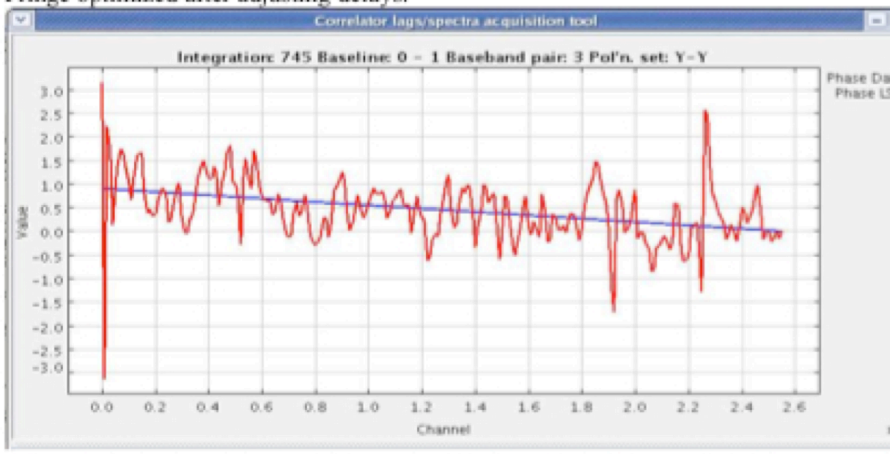
Saturn 90 GHz March 2, 2007

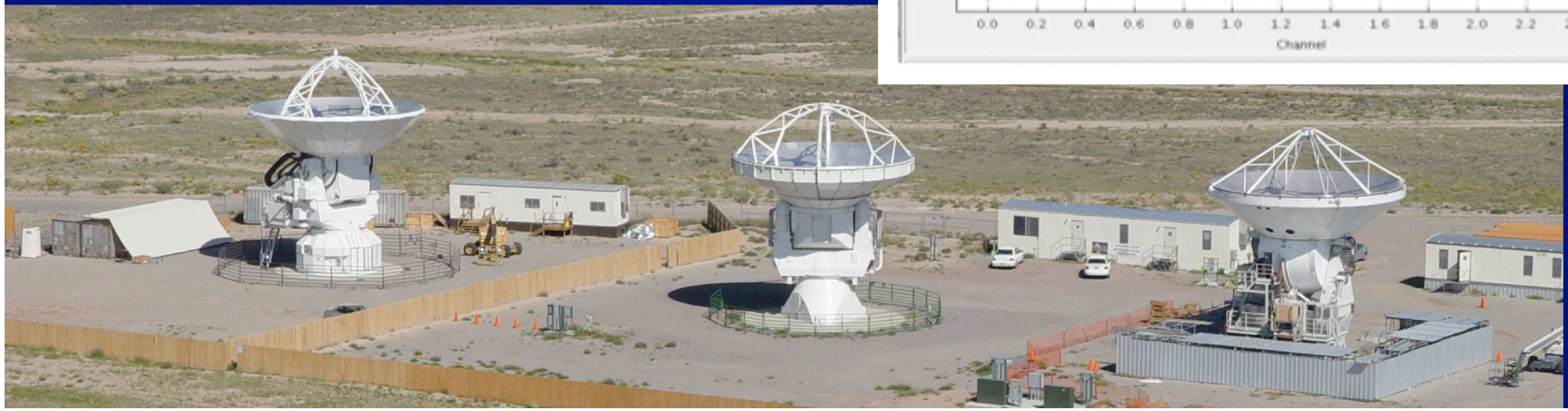
Used all ALMA electronics

First fringe at 7:13pm March 2, 2007



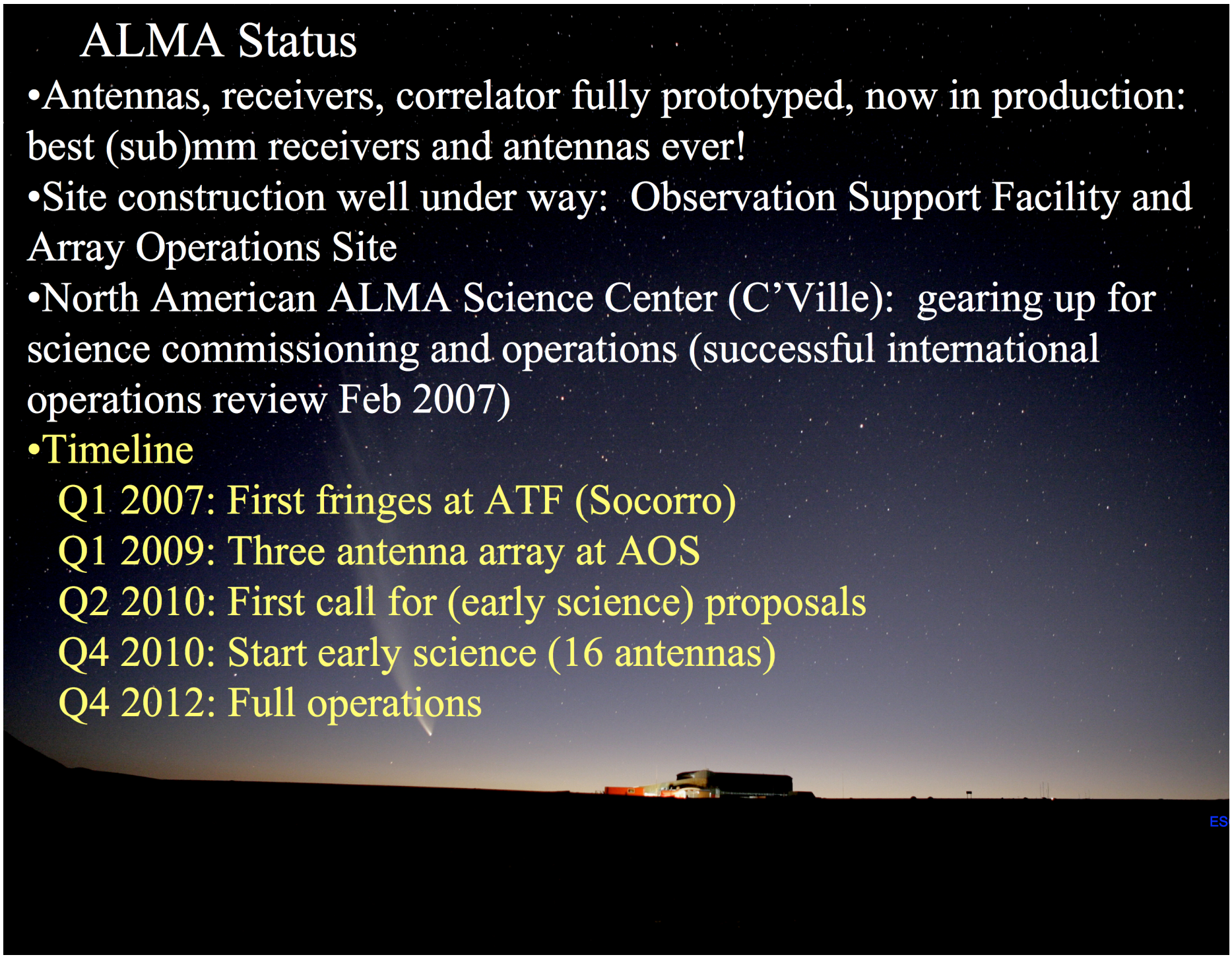
Fringe optimized after adjusting delays.





ALMA Status

- Antennas, receivers, correlator fully prototyped, now in production: best (sub)mm receivers and antennas ever!
- Site construction well under way: Observation Support Facility and Array Operations Site
- North American ALMA Science Center (C'Ville): gearing up for science commissioning and operations (successful international operations review Feb 2007)
- Timeline
  - Q1 2007: First fringes at ATF (Socorro)
  - Q1 2009: Three antenna array at AOS
  - Q2 2010: First call for (early science) proposals
  - Q4 2010: Start early science (16 antennas)
  - Q4 2012: Full operations

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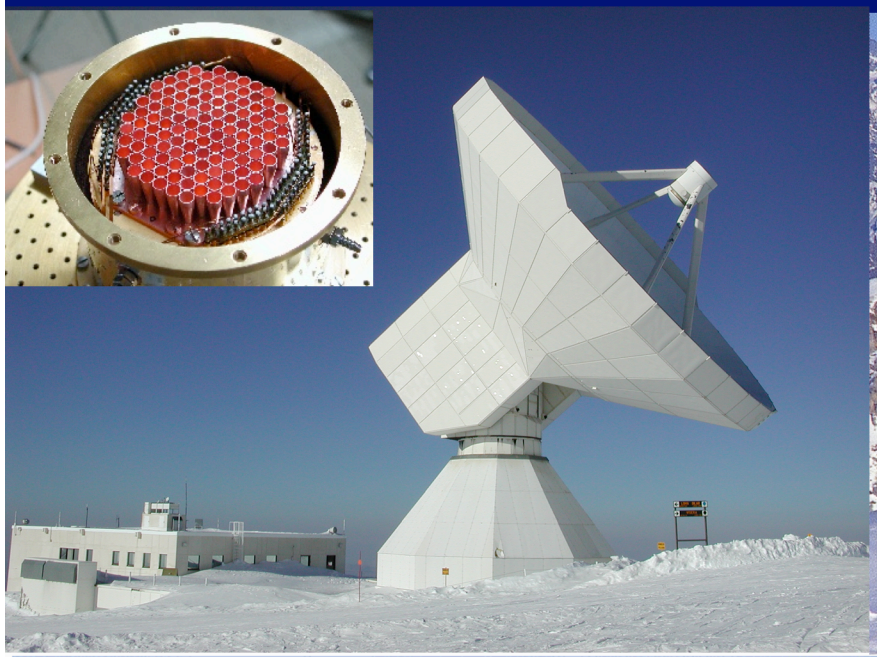
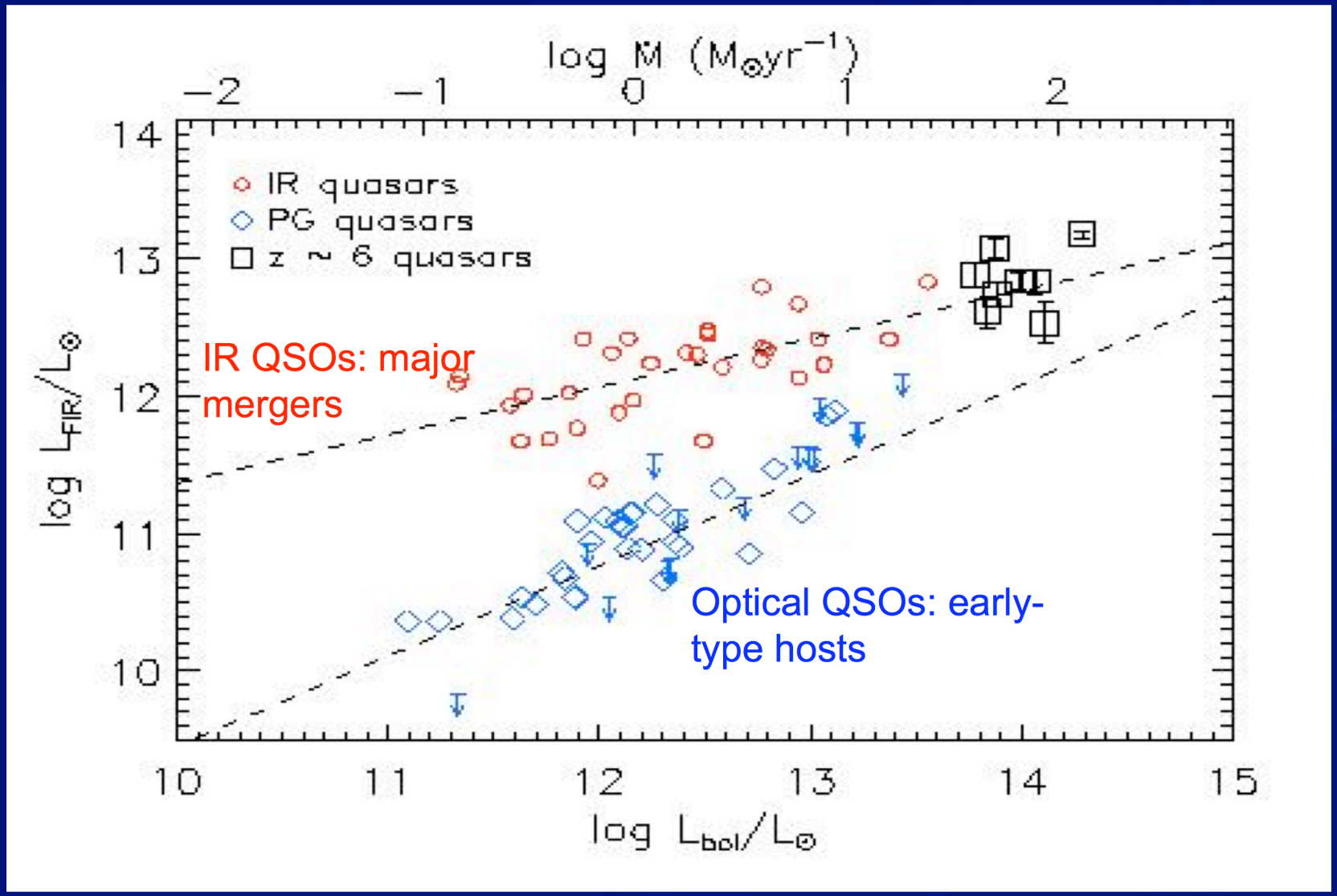
Radio observations of z ~ 6 QSO host galaxies



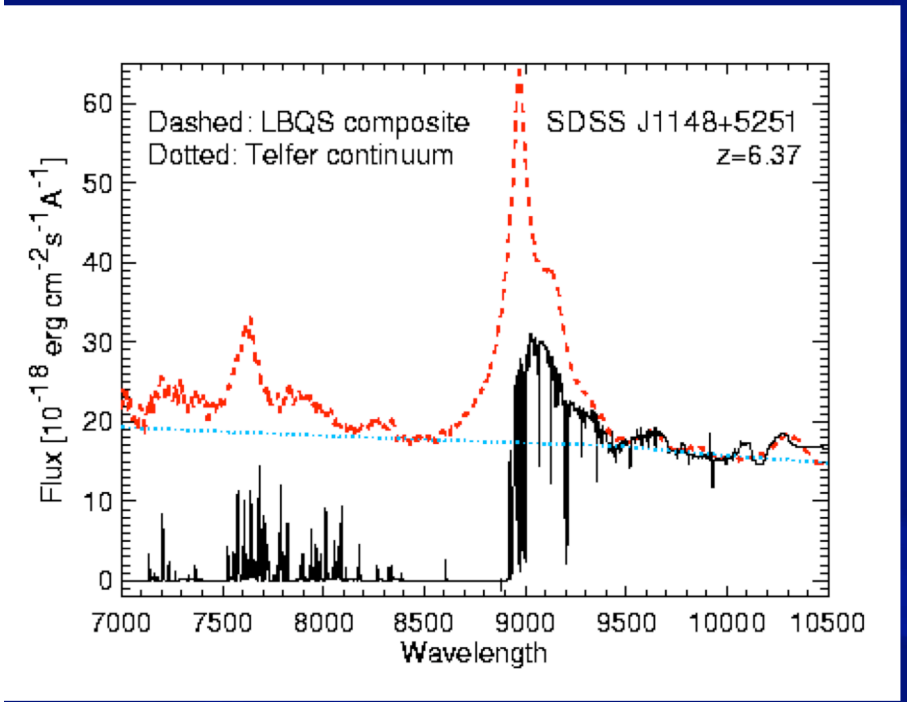
- IRAM 30m + MAMBO: sub-mJy sens at 250 GHz + wide fields → dust
- IRAM PdBI: sub-mJy sens at 90 and 230 GHz +arcsec resol. →mol. Gas, C+
- VLA: uJy sens at 1.4 GHz → star formation
- VLA: < 0.1 mJy sens at 20-50 GHz + 0.2” resol. → mol. gas (low order)

z=6 QSOs: Similar to IR-selected, low z QSOs, not optical (PG) QSOs



Pushing into reionization: Host galaxies of z~6 SDSS QSOS

- $t_{univ} < 1$ Gyr
- Gunn Peterson trough => probing tail-end of cosmic reionization
  -- last phase of cosmic evolution to explore
  -- first galaxies/BH



Why QSO host galaxies?

- Spectroscopic redshifts
- Extreme (massive) systems

  $M_B < -26 \Rightarrow L_{bol} > 1e14\ L_o$

  $M_{BH} > 1e9\ M_o$

- Rapidly increasing samples:

  z>5: ~100

  z>6: ~20

- Only currently viable samples (cf. submm galaxies at z<4)