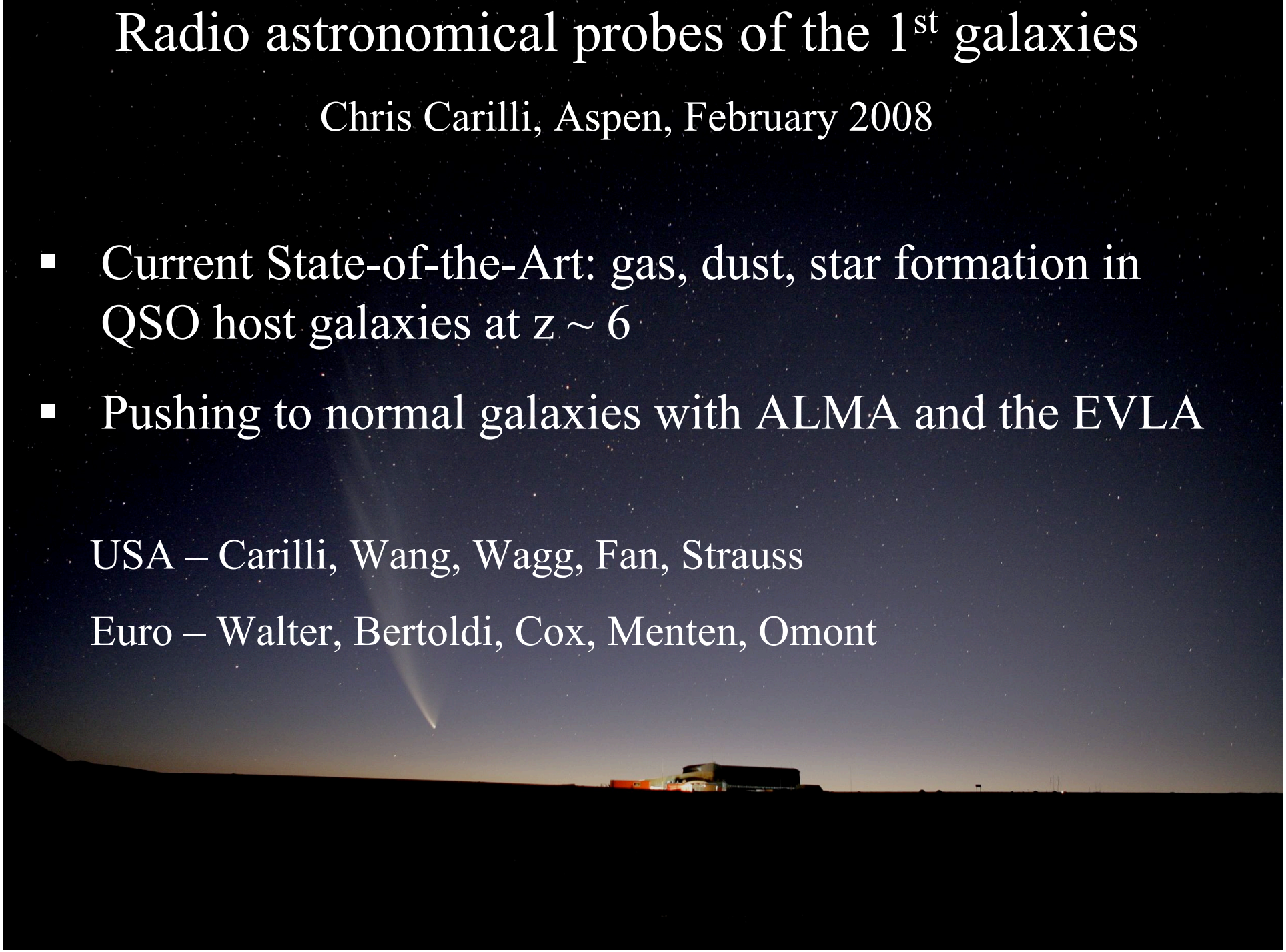
Radio astronomical probes of the 1st galaxies

Chris Carilli, Aspen, February 2008

- Current State-of-the-Art: gas, dust, star formation in QSO host galaxies at z ~ 6
- Pushing to normal galaxies with ALMA and the EVLA

USA – Carilli, Wang, Wagg, Fan, Strauss

Euro – Walter, Bertoldi, Cox, Menten, Omont



Why QSO hosts?

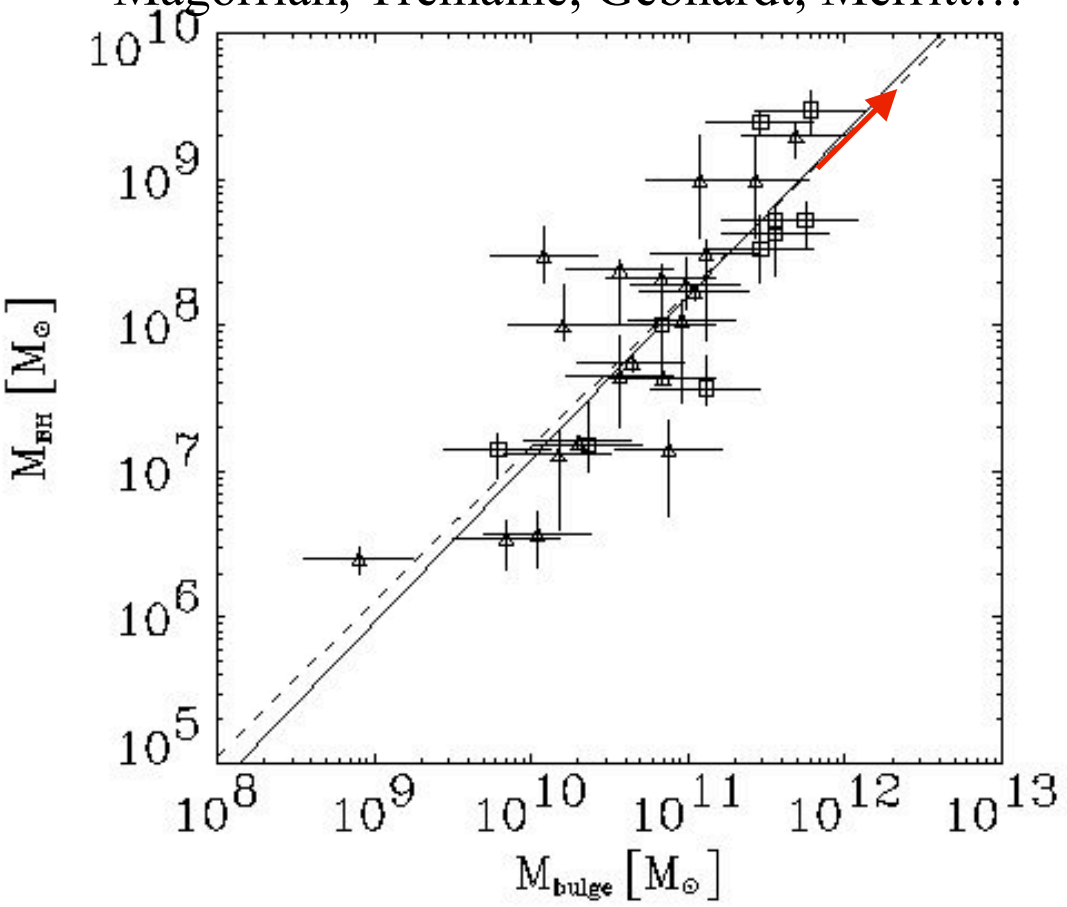
- Spectroscopic redshifts
- Extreme (massive) systems

$L_{BH} > 1e14\ L_o$

$M_{BH} > 1e9\ M_o$

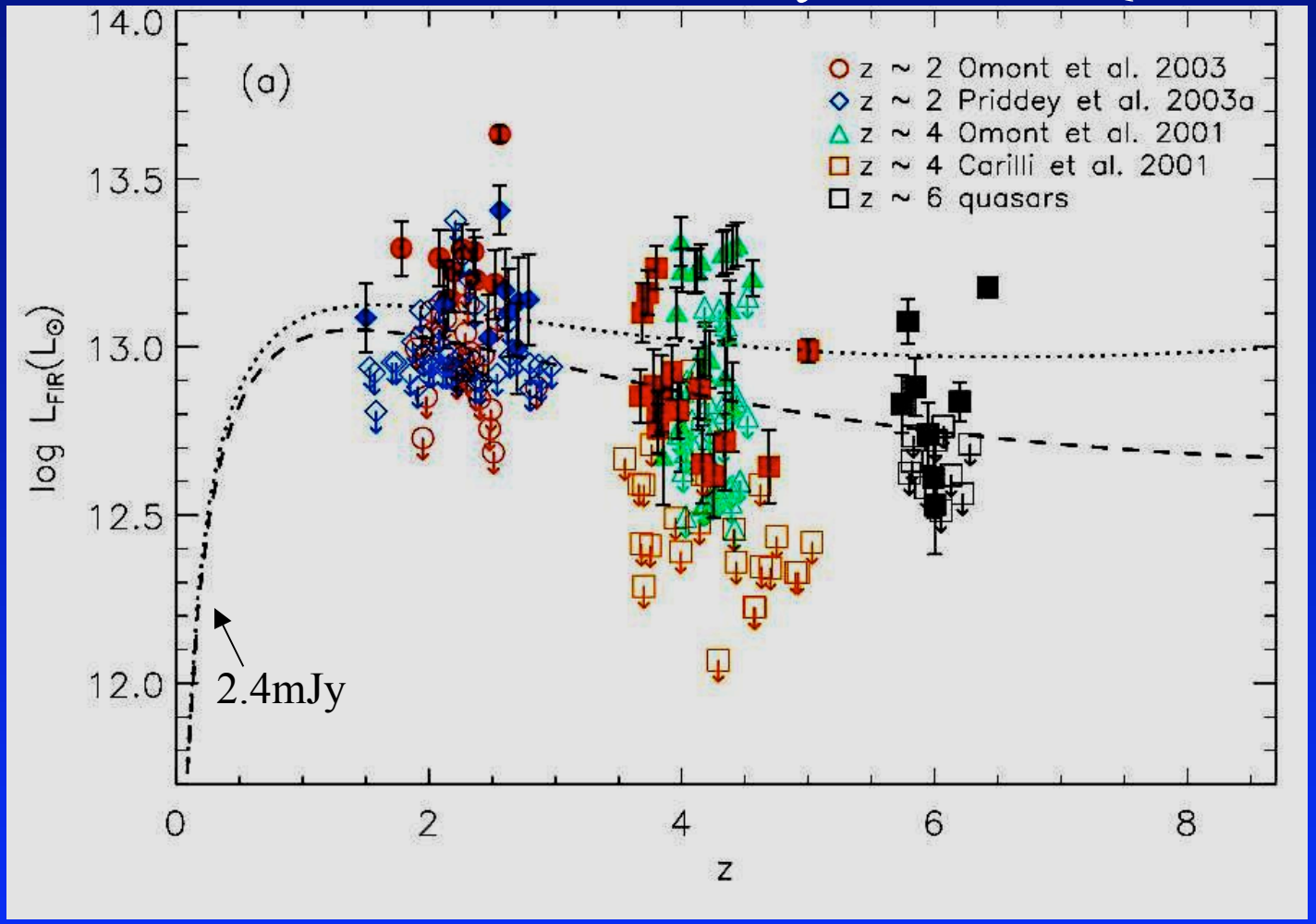
$\Rightarrow M_{host} > 1e12\ M_o$

Magorrian, Tremaine, Gebhardt, Merritt…



- All low z spheroidal galaxies have SMBH: $M_{BH}=0.002\ M_{bulge}$
- 'Causal connection between SMBH and spheroidal galaxy formation'
- Current mm/cm sensitivities require (very) extreme galaxies

MAMBO 250 GHz surveys of z>2 QSOs



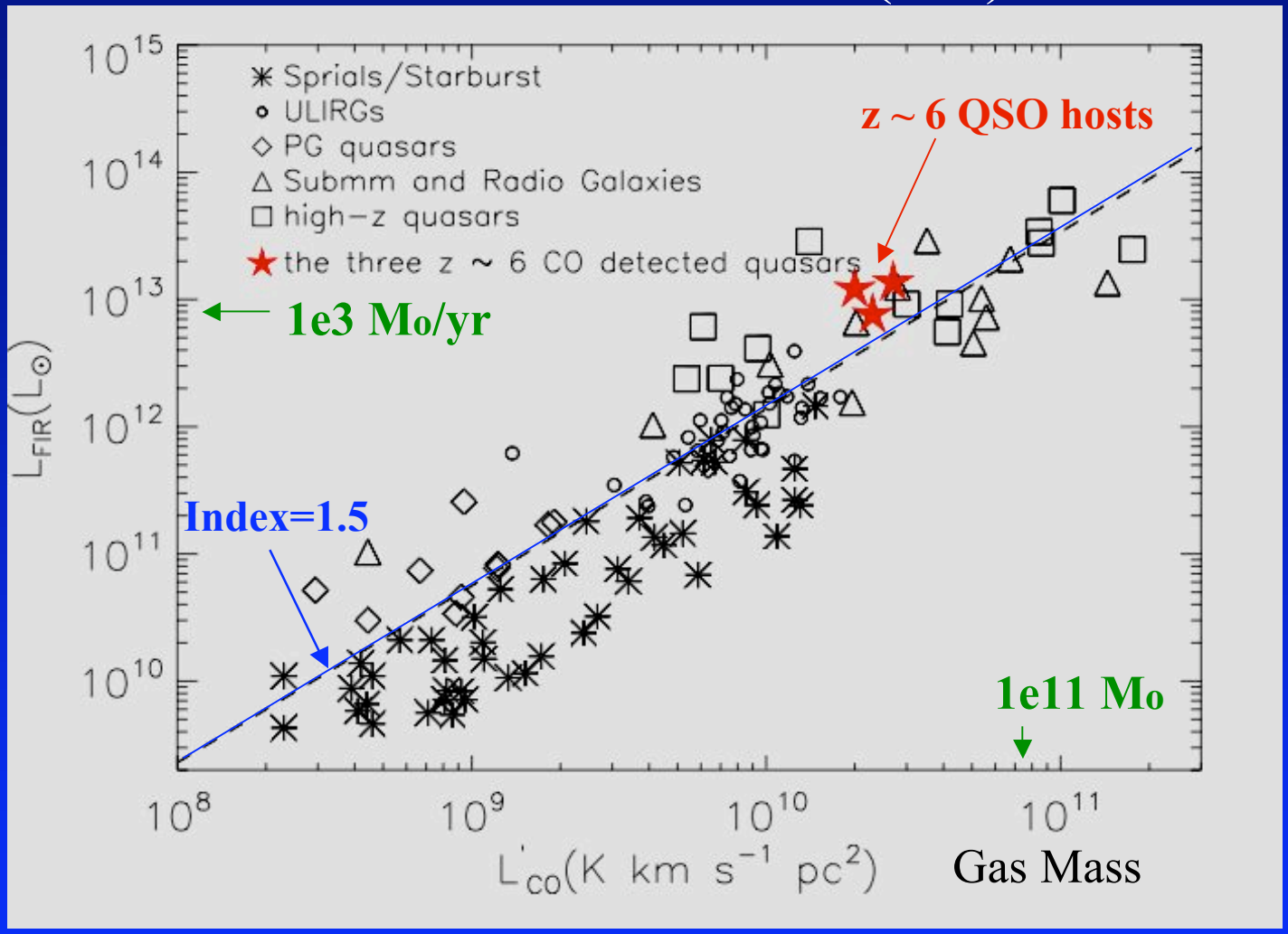
1e13 Lo

• 1/3 of luminous QSOs have $S_{250} > 2$ mJy, *independent of redshift* from z=1.5 to 6.4

• $L_{FIR} \sim$ 1e13 L_o (HyLIRG) ~ 0.1 x L_{bol} = thermal emission from warm dust: dust heating by starburst or AGN?

Dust => Gas: L_{FIR} vs L'(CO)

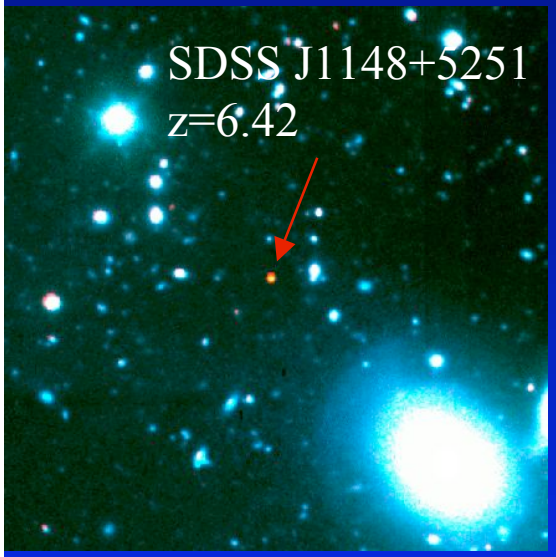
Star formation rate

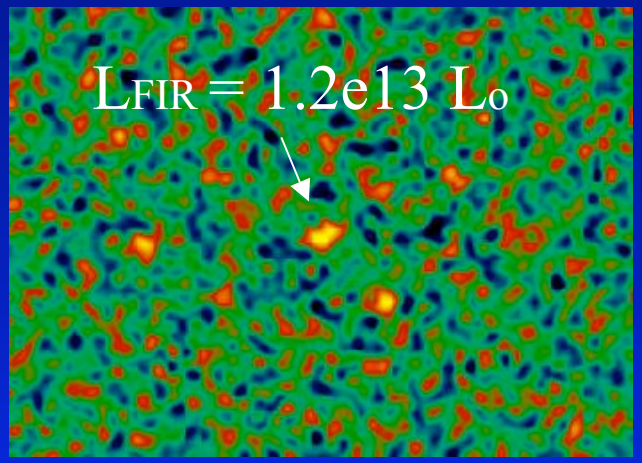


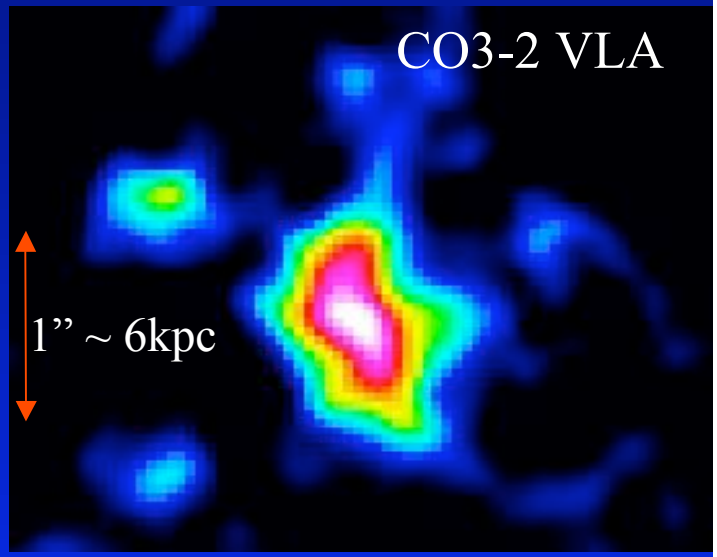
- non-linear => increasing SF eff (SFR/Gas mass) with increasing SFR
- SFR > 1000 Mo/yr, Gas masses > 2e10 Mo

Pushing into Cosmic Reionization: J1148+5251 at z = 6.42

(t_{univ} = 870 Myr)







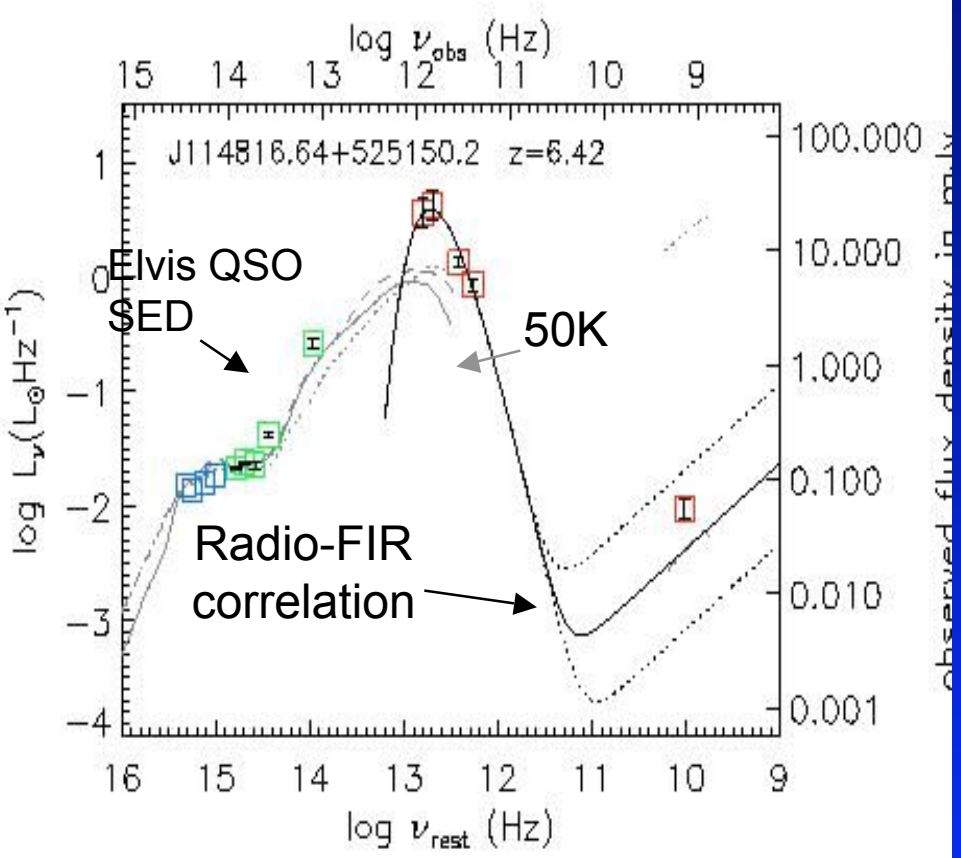
- Black hole mass ~3 x 10^9 M_o
- Dust mass ~ 7e8 M_o
- Gas mass ~ 2e10 M_o
- CO size ~ 6 kpc

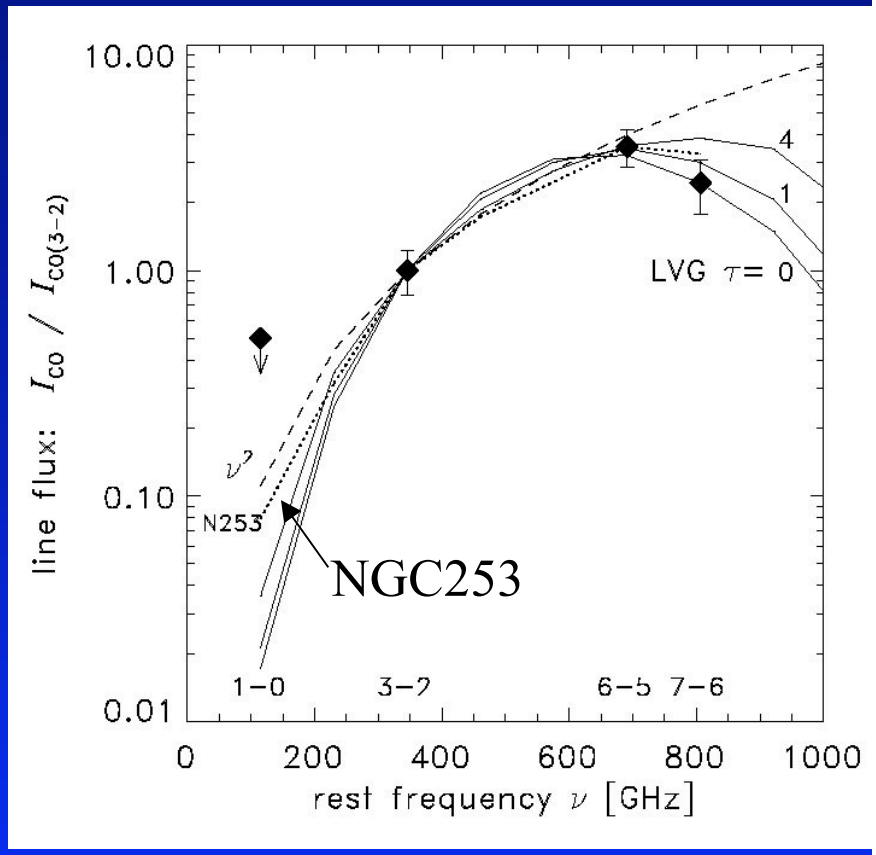
Note: low order molecular lines redshift to cm bands

Dust formation? AGB Winds take > 1.4e9yr > age Universe

=> dust formation associated with high mass star formation (Maiolino+ 07, Dwek+ 2007, Shull+ 2007)?

Continuum SED and CO excitation ladder





- FIR excess -- follows Radio-FIR correlation: SFR ~ 3000 $M_\odot$/yr
- CO excitation ~ starburst nucleus: T_{kin} ~ 100K, n_{H2} ~ 1e5 cm^-3

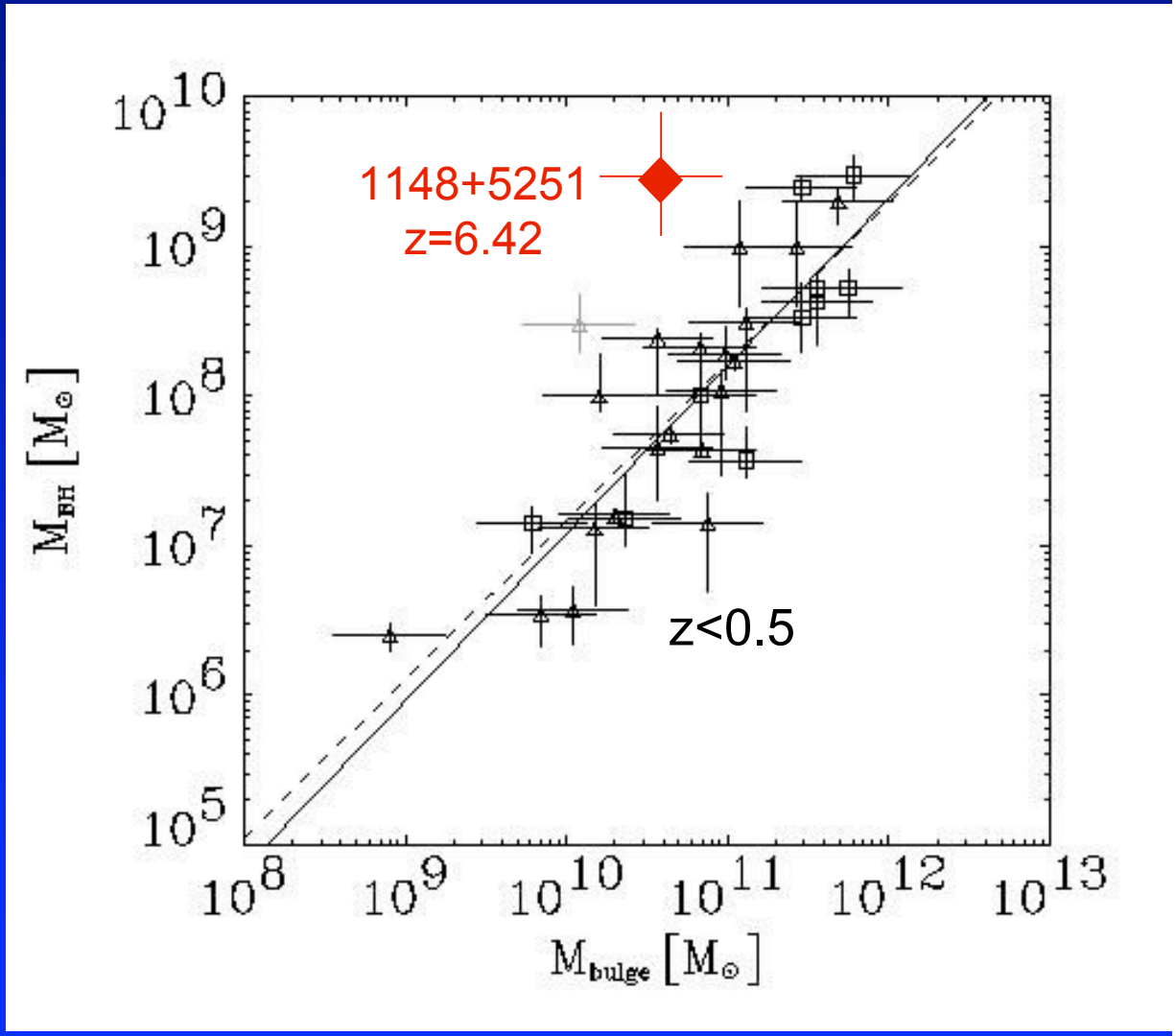
Gas dynamics: Potential for testing M_{BH} - M_{bulge} relation at high z. mm lines are only direct probe of host galaxies

M_{dyn}~ 4e10 M_o

M_{gas}~ 2e10 M_o

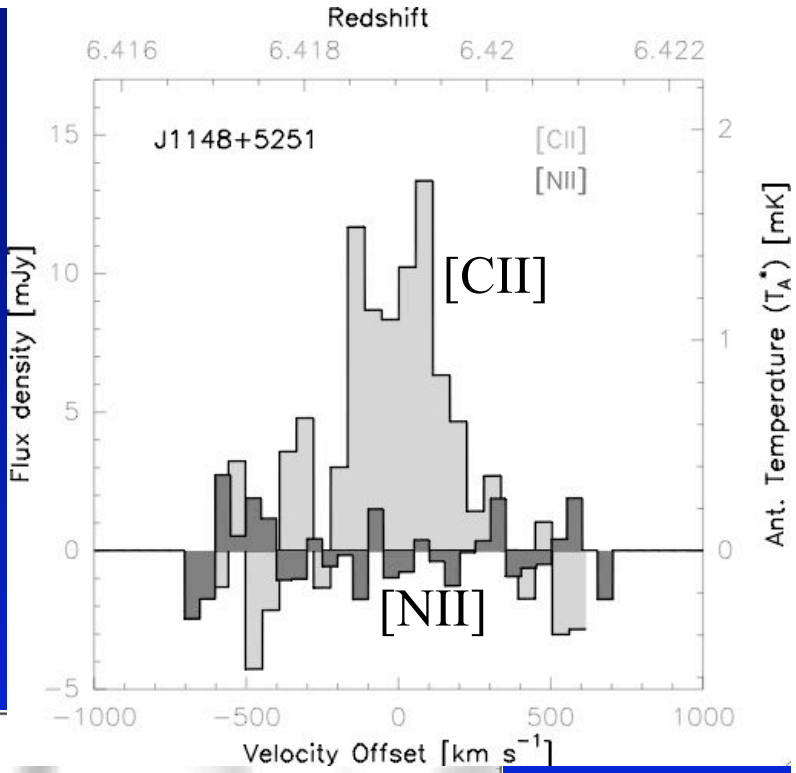
M_{bh} ~ 3e9 M_o =>

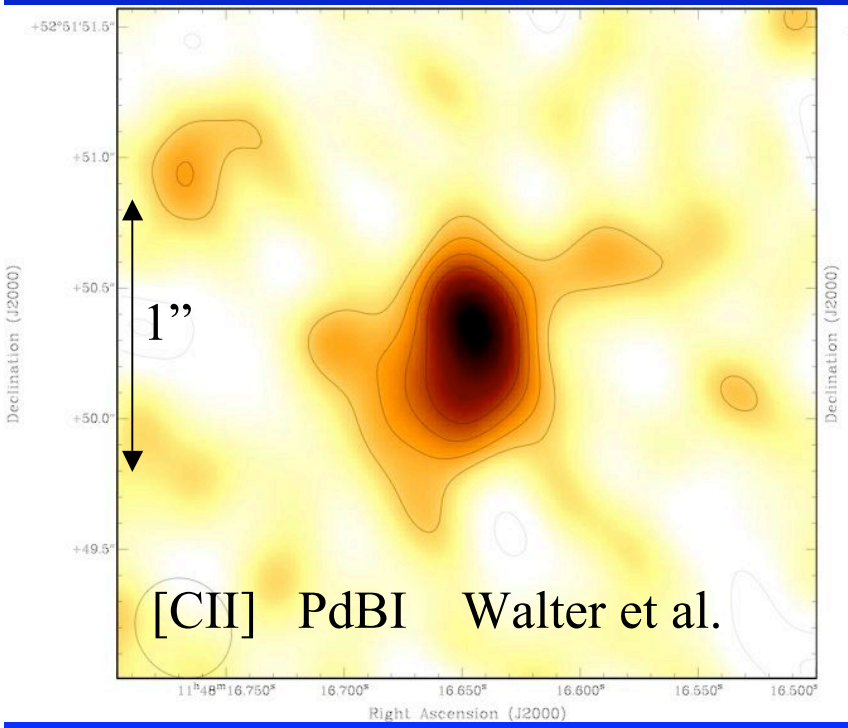
M_{bulge} ~1e12 M_o (predicted)

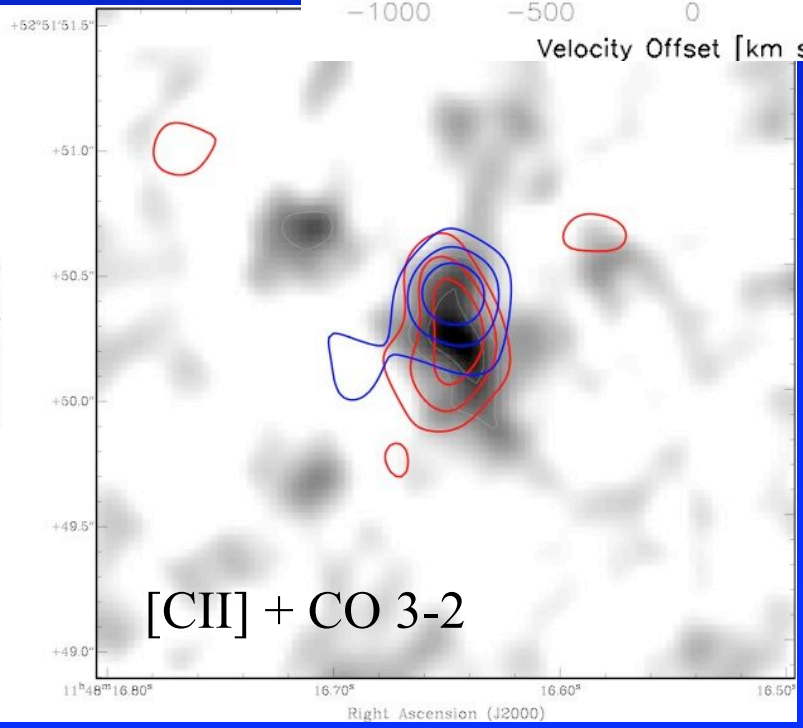


[CII] 158um at z=6.4: gas cooling

- z>4 => FS lines redshift to mm band
- [CII] traces star formation: similar extension as molecular gas ~ 6kpc
- $L_{[CII]} = 4x10^9 L_o$ ($L_{[NII]} < 0.1\ L_{[CII]}$)
- SFR ~ 6.5e-6 $L_{[CII]}$ ~ 3000 M_o/yr

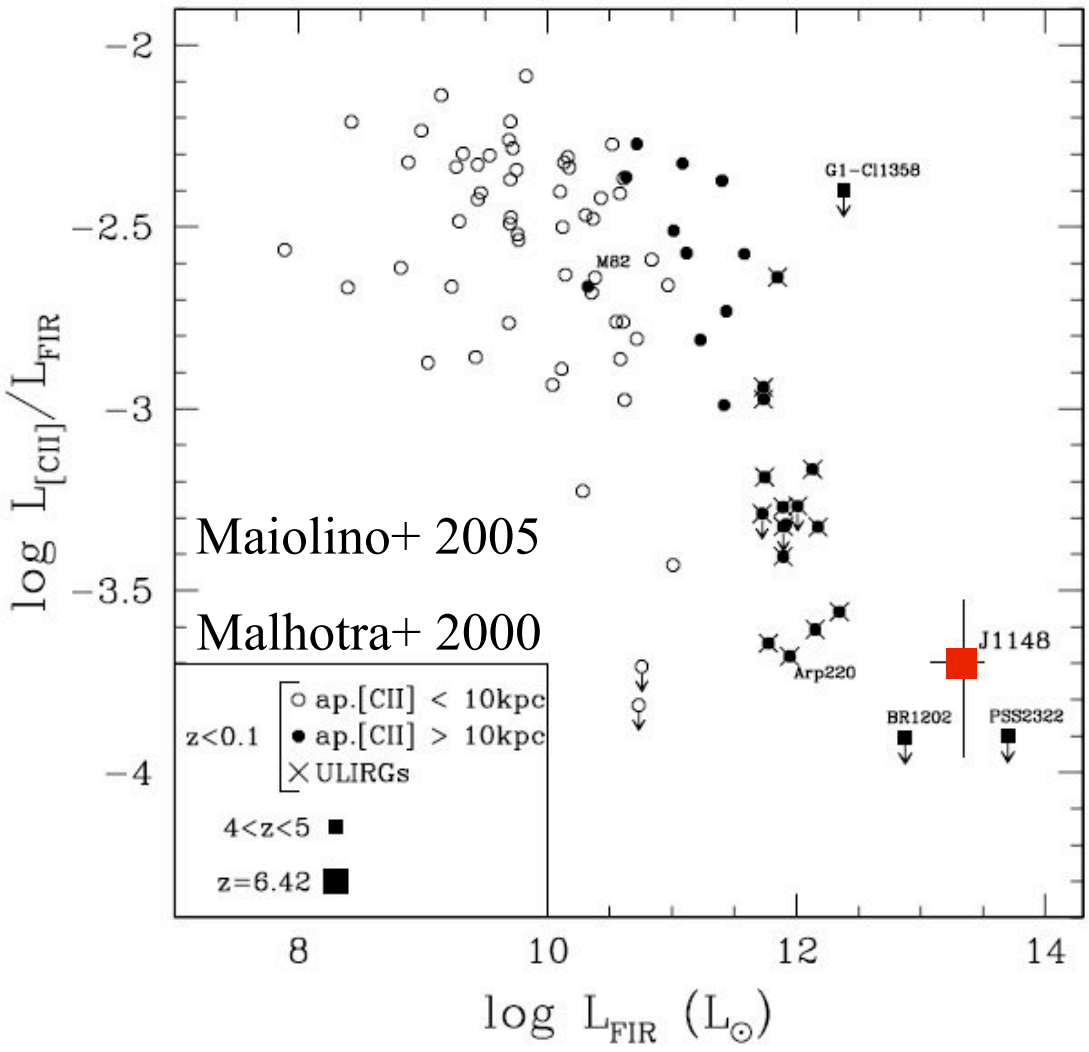






[CII] -- the good and the bad

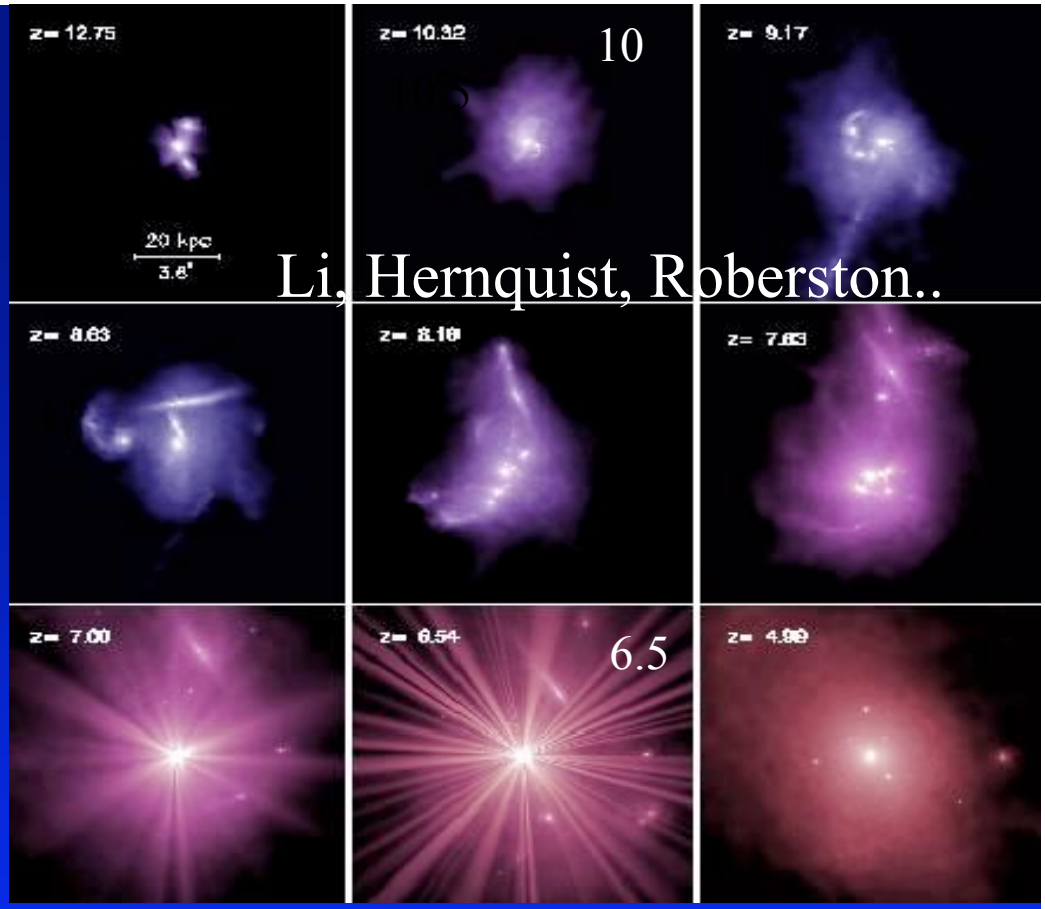
- [CII]/FIR decreases rapidly with L_{FIR} (lower heating efficiency due to charged dust grains?) => ultraluminous starbursts are still difficult to detect in C+
- Normal star forming galaxies (eg. LAEs) are not much harder to detect!



Current PdBI can detected 10x fainter [CII] source than 1148+5251 at z>6.4 => FIR ~ 1e11 L_o (SFR ~ 50 M_o/yr): any candidates with $\Delta z < 0.06$?

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



Li, Hernquist, Roberston..

- Rapid enrichment of metals, dust? molecules? in ISM
- Rare, extreme mass objects: ~ 100 SDSS z~6 QSOs on entire sky
- Integration times of hours to days to detect HyLIGRs

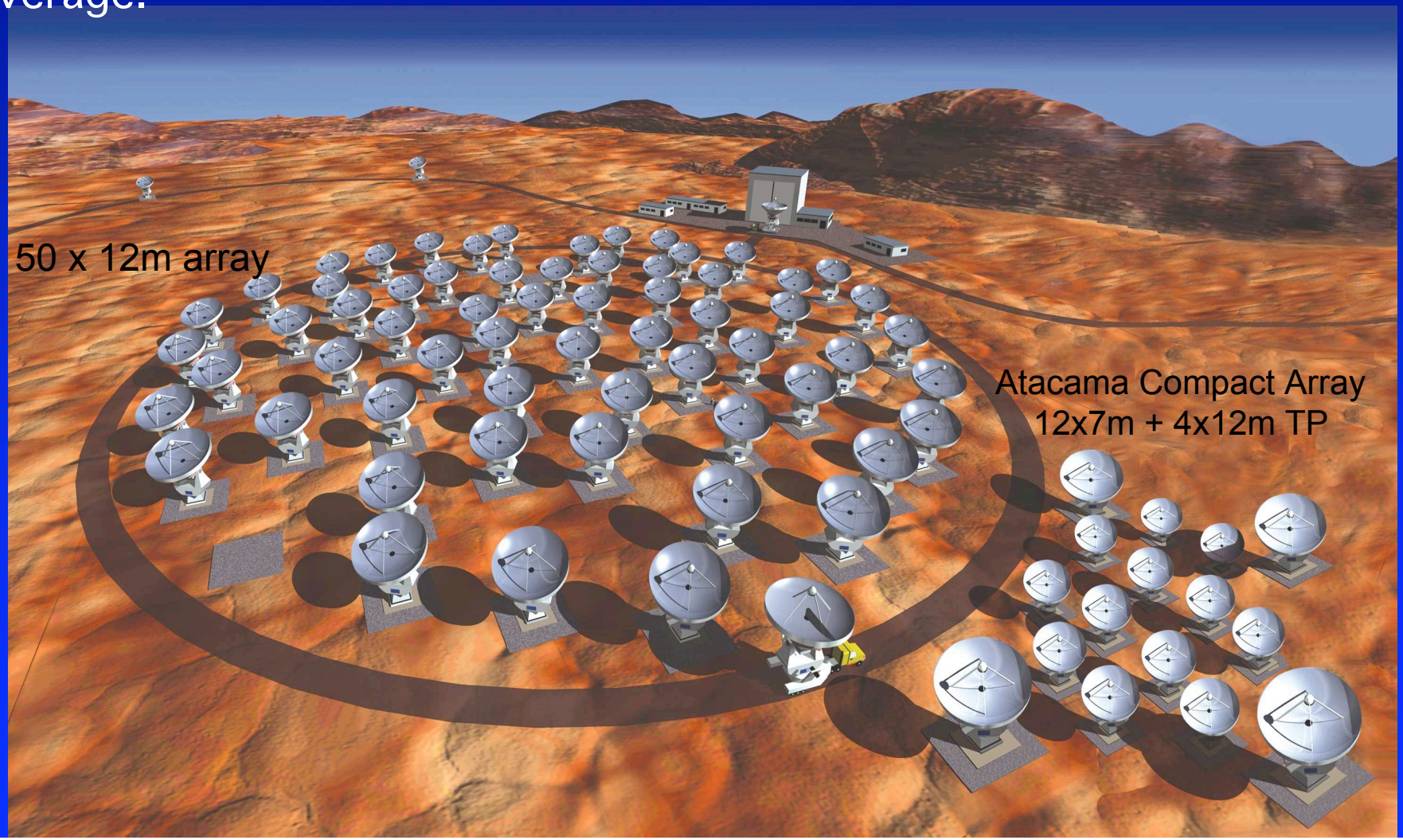
What is EVLA? First steps to the SKA

Full upgrade of 30 year old VLA electronics: multiply ten-fold the VLA's observational capabilities, including 10x continuum sensitivity (1uJy), full frequency coverage (1 to 50 GHz), 80x BW (8GHz)

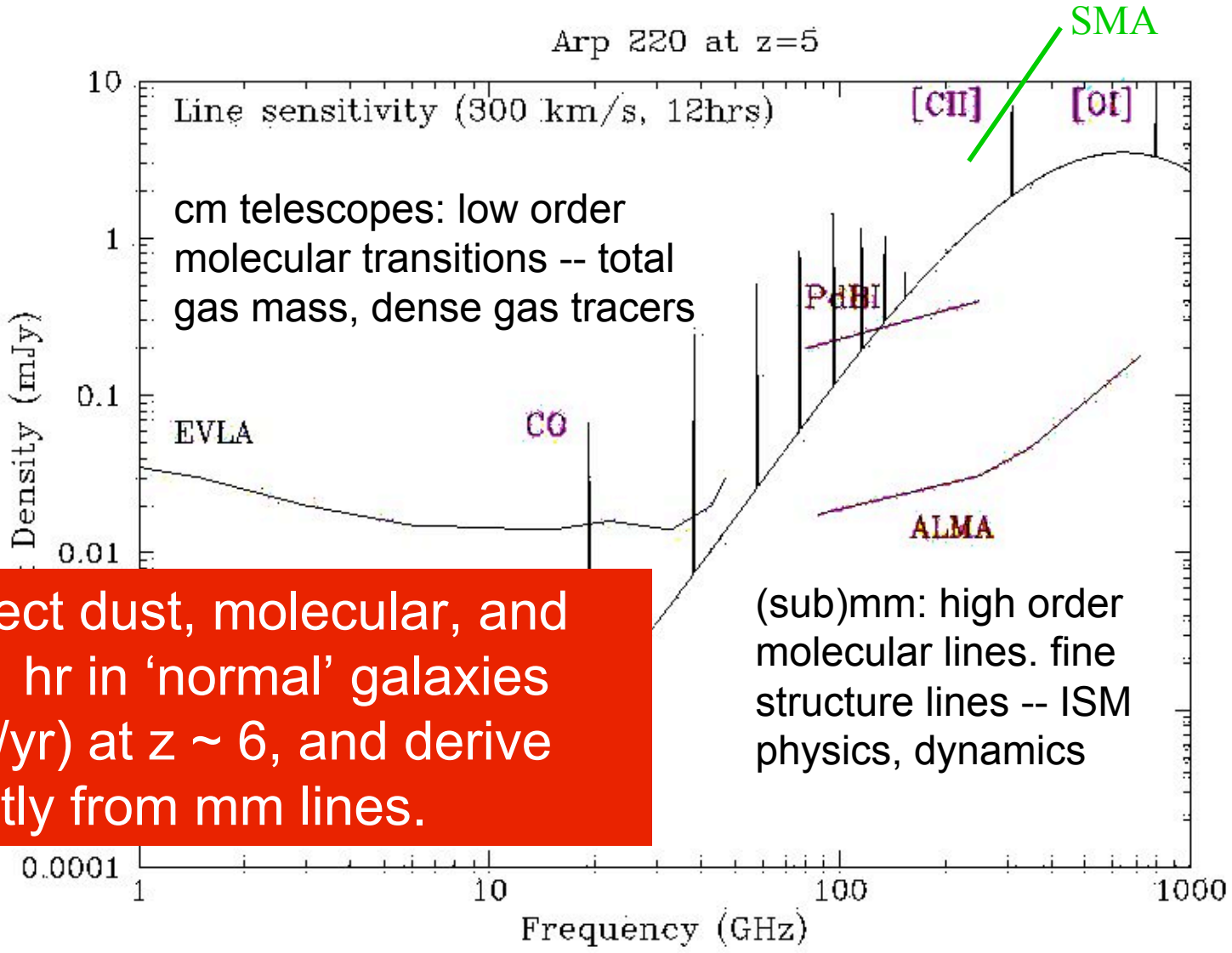
- Antenna retrofits now 50% completed.
- Early science in 2010, using new correlator.
- Project completed 2012.

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 astronomy, including resolution, sensitivity, and frequency coverage.



Pushing to normal galaxies: spectral lines

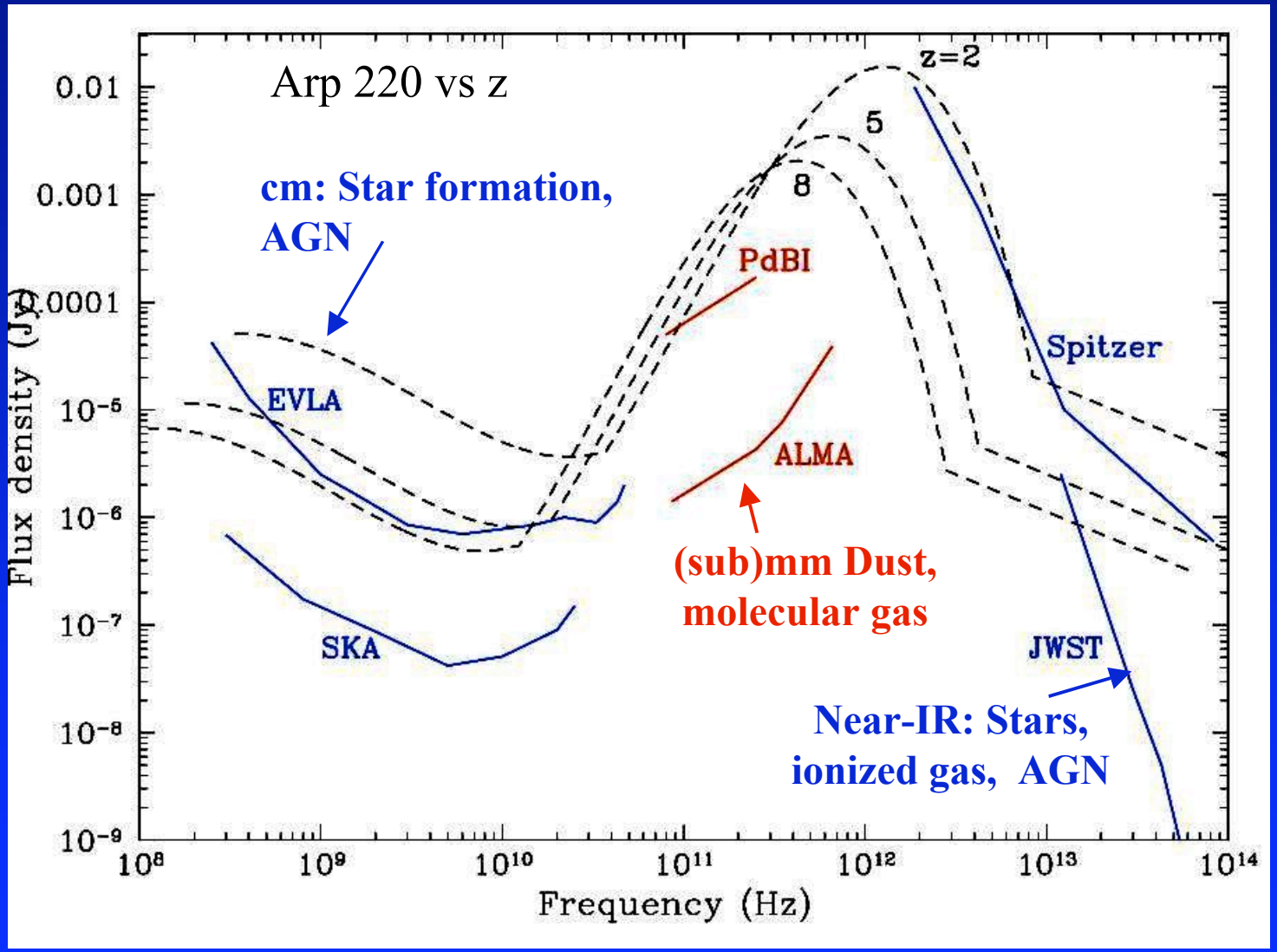


ALMA will detect dust, molecular, and FS lines in ~ 1 hr in 'normal' galaxies (SFR ~ 10 $M_\odot$/yr) at z ~ 6, and derive redshifts directly from mm lines.

- FS lines will be workhorse lines in the study of the first galaxies with ALMA.
- Study of molecular gas in first galaxies will be done primarily with cm telescopes

Pushing to normal galaxies: continuum

A Panchromatic view of galaxy formation



ALMA Status

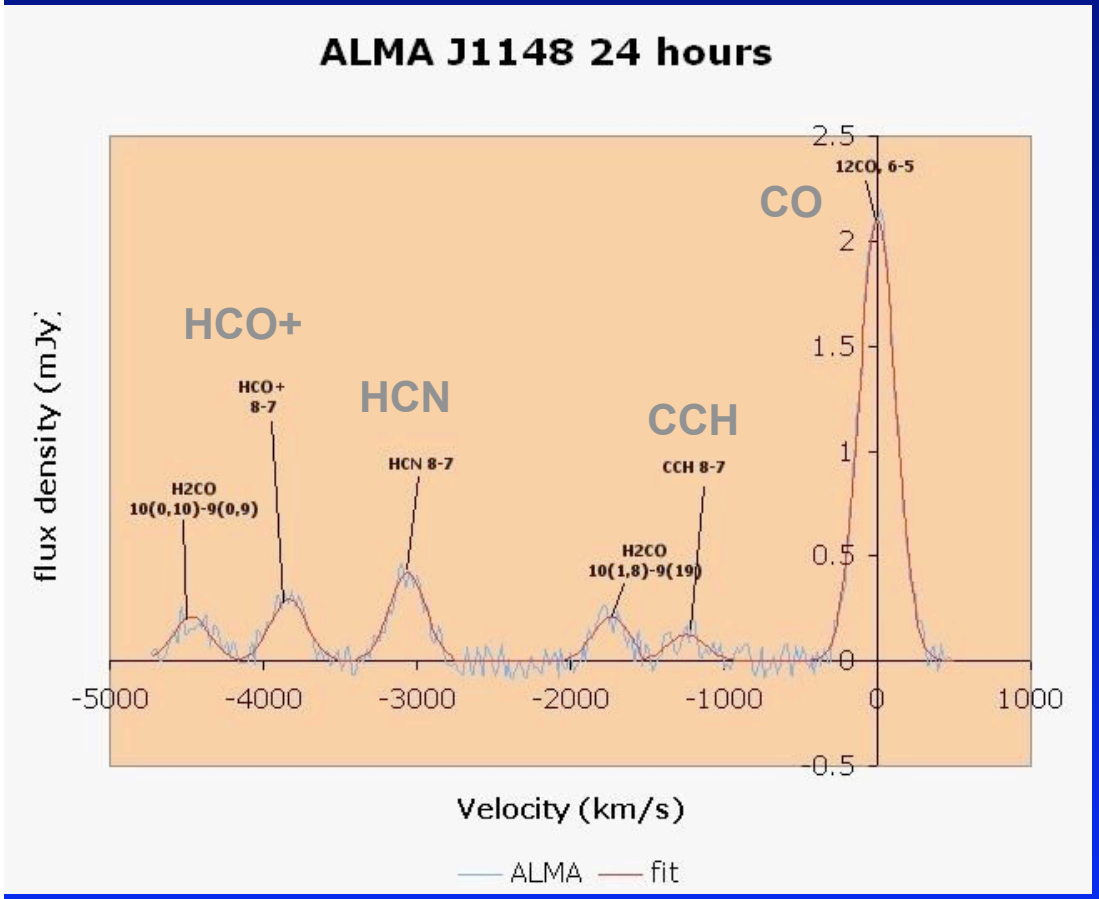
- Antennas, receivers, correlator fully prototyped, now in production: best (sub)mm receivers and antennas ever!
- Site construction well under way: Observation Support Facility and Array Operations Site
- North American ALMA Science Center (C'Ville): gearing up for science commissioning and early operations

- Timeline
  - Q1 2007: First fringes at ATF (Socorro)
  - Q1 2009: Three antenna array at AOS
  - Q2 2010: Early science call for proposals
  - Q4 2010: Start early science (16 antennas)
  - Q4 2012: Full operations

ESO


END
ESO

ALMA into reionization



Spectral simulation of J1148+5251

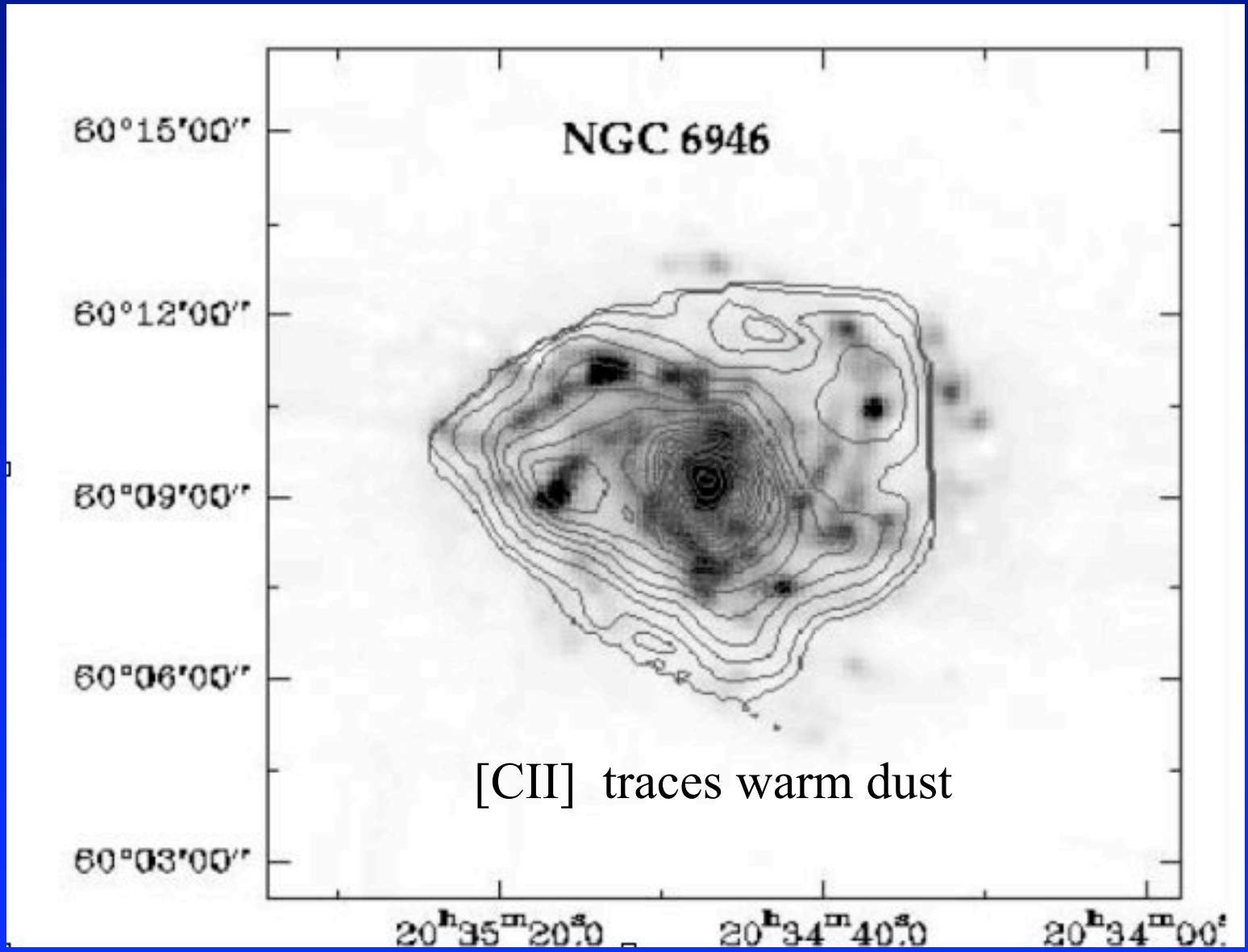
- Detect dust emission in 1sec (5σ) at 250 GHz
- Detect [CII] in 1min
- Detect multiple lines, molecules per band => detailed astrochemistry
- Image dust and gas at sub-kpc resolution – gas dynamics

ALMA Progress

Operations Support Facility, Dec 07

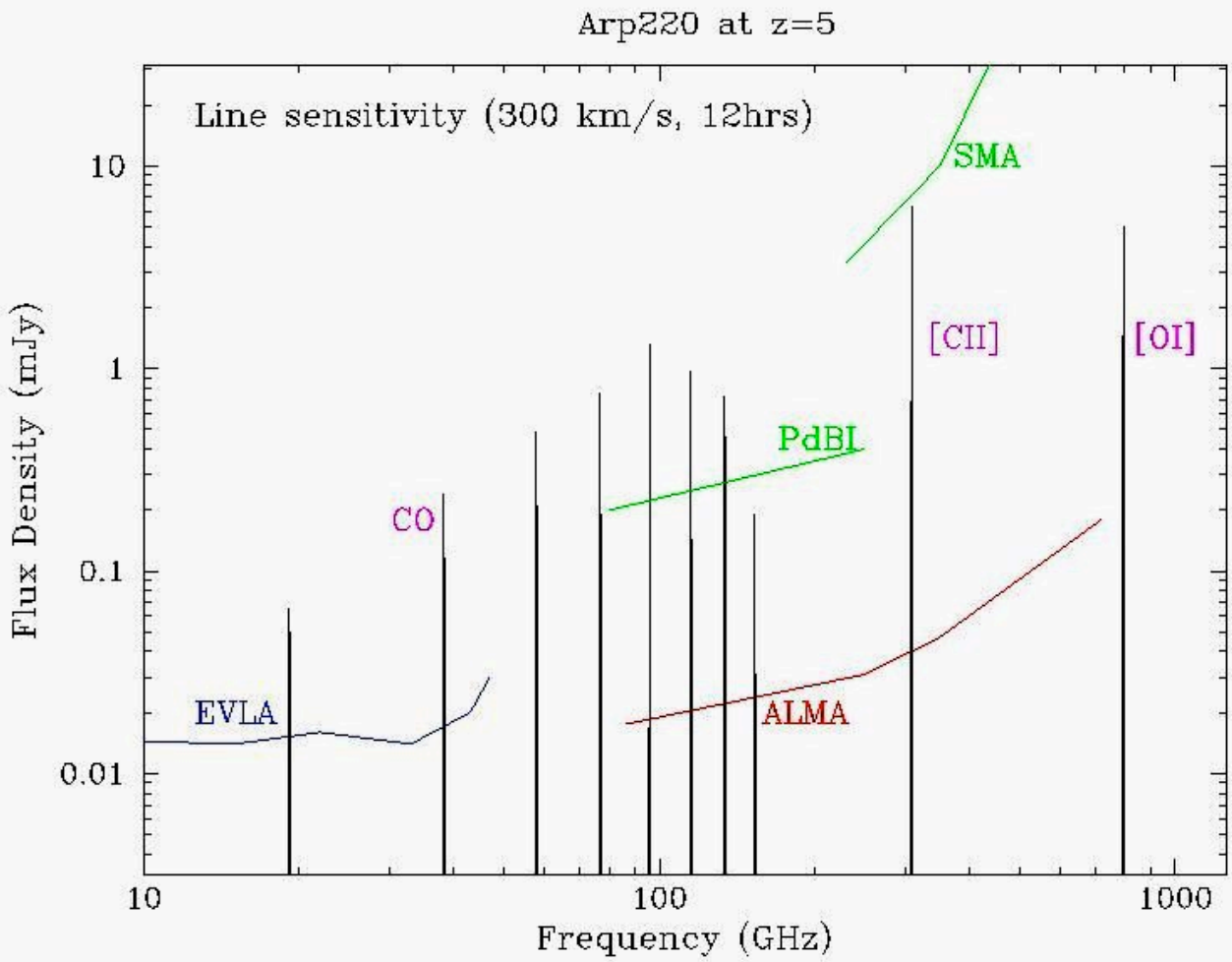
ALMA Operations Site

[CII] 158um fine structure line: dominant ISM gas cooling line



[CII] traces warm dust

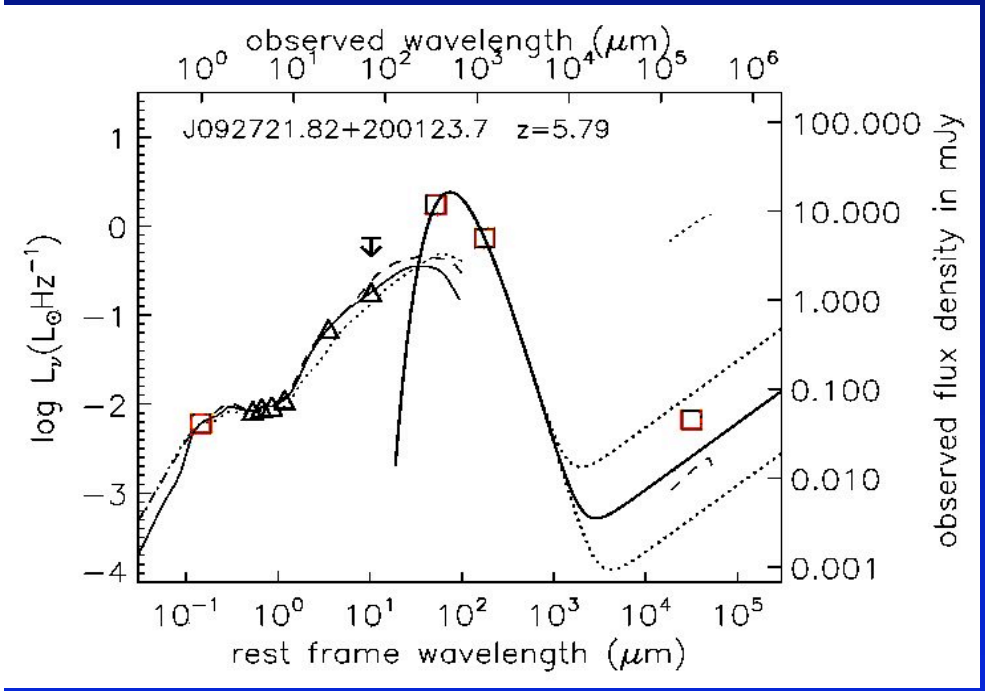
Pushing to normal galaxies: spectral lines

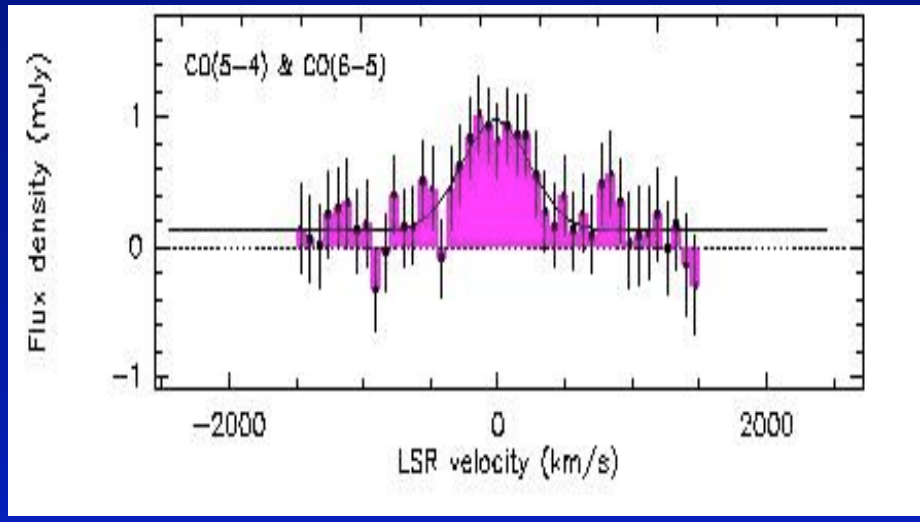


- ALMA will detect dust, FS lines in 1 to 3 hours in normal galaxies at z ~ 6: LAEs, LBGs
- cm telescopes: low order molecular transitions -- total gas mass, dense gas tracers
- (sub)mm: high order molecular lines. fine structure lines -- ISM physics, dynamics

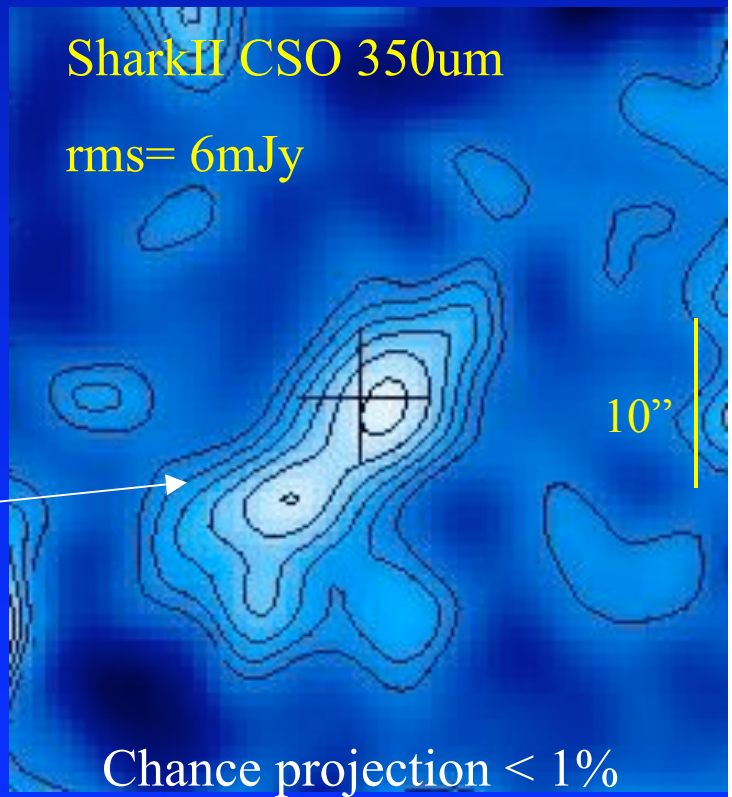
- FS lines will be workhorse lines in the study of the first galaxies with ALMA.
- Study of molecular gas in first galaxies will be done primarily with cm telescopes

SDSS J0927+2001 z=5.8

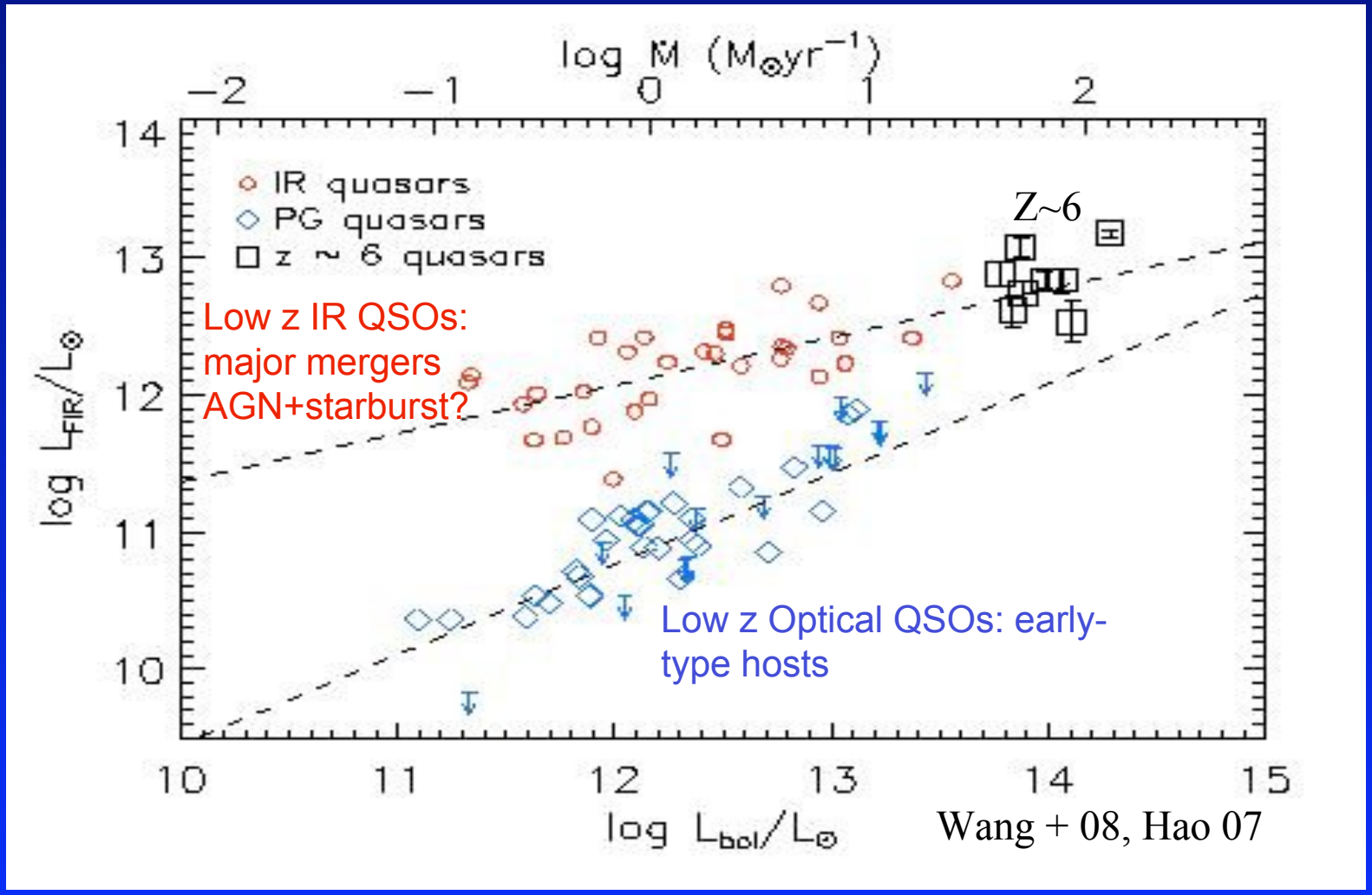




- L_{FIR} ~ 1e13 $L_\odot$ => SFR ~ 2500 $M_\odot$/yr
- M(H_2) ~ 2e10 $M_\odot$
- HyLIRG QSO host + 'submm galaxy' companion, separation = 87kpc
- Biased massive galaxy formation?



FIR - L_{bol} in QSO hosts



FIR luminous z ~ 6 QSO hosts follow relation establish by IR-selected QSOs at low z => (very) active star forming host galaxies?