Dynamical Properties of Submm Galaxies

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IRAM Plateau de Bure CO Interferometry of Submm Galaxies: First (Sub)arcsecond Imaging

SMG TEAM:
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&
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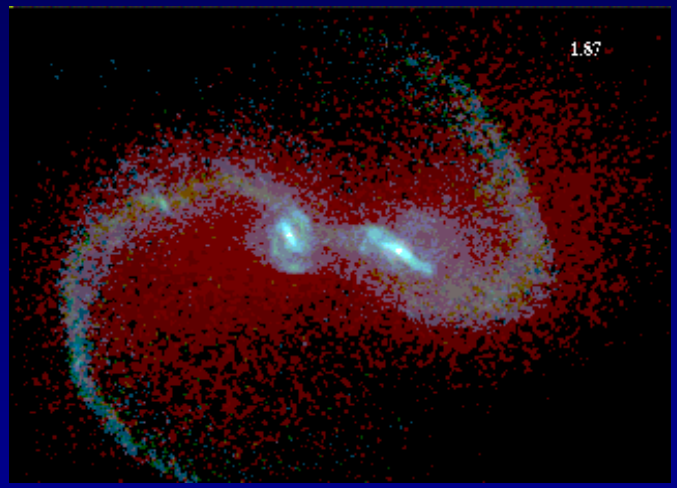
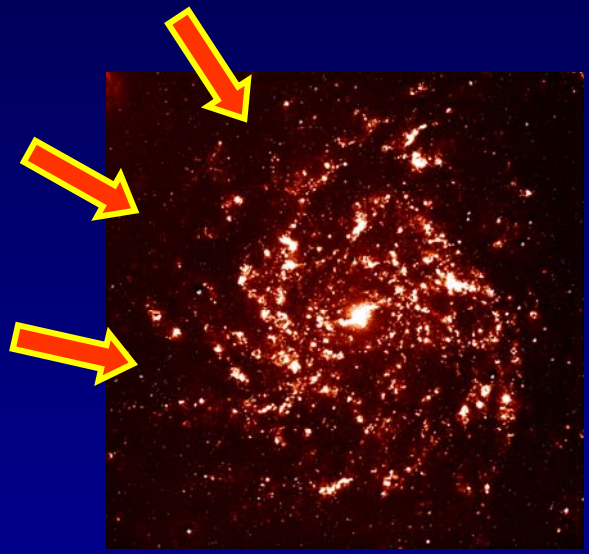
UC Berkeley Cosmology Seminar
19 February 2008

What Drives Star Formation at High-z ?

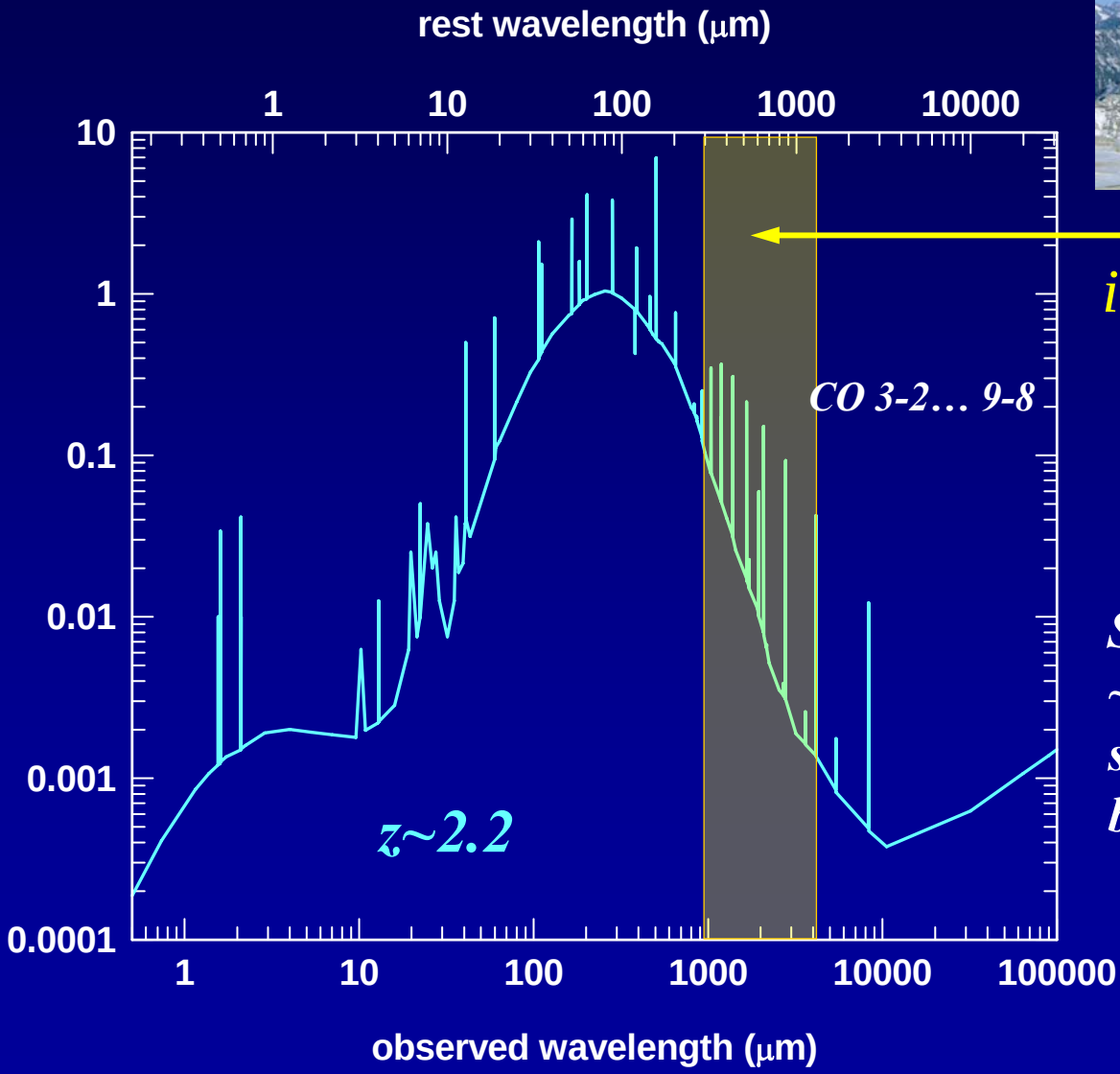


merger scenario (motivated by hierarchical merger model: Hernquist, Springel, di Matteo, Hopkins et al. 2003-2006



(rapid) inflow scenario: Dekel & Birnboim 2003,2006, Keres et al. 2005, Immeli et al. 2004, Nagamine et al. 2005, Davé 2007, Guo & White 2007, Naab et al. 2007

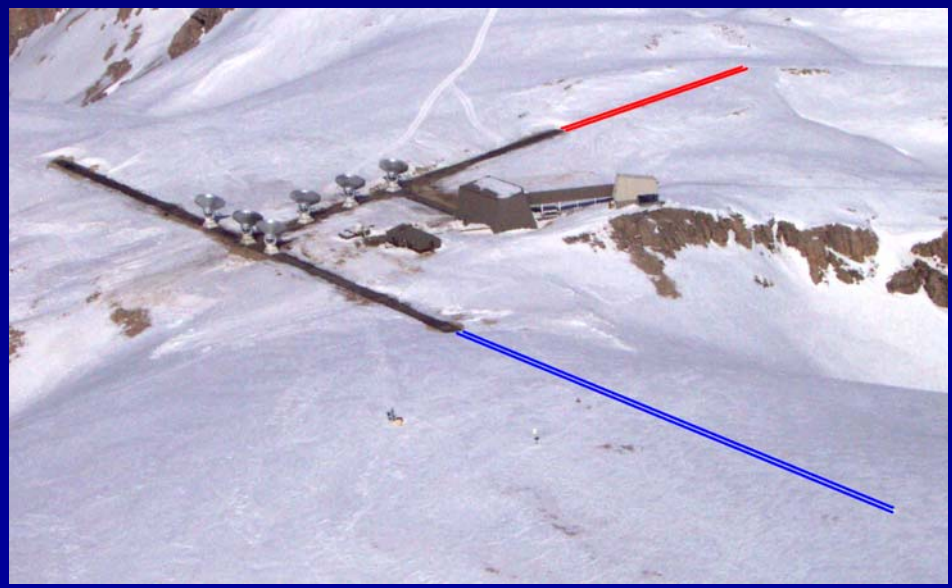
mm/submm Spectroscopy of Star-Forming z~1-3 Galaxies



mm-interferometry (PdBI)

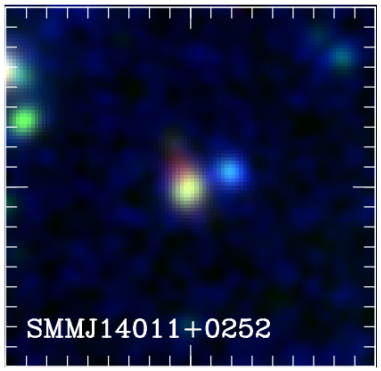
SMG survey: ~30 z~1.2-3.5 submillimeter bright galaxies

The IRAM Interferometer at Plateau de Bure

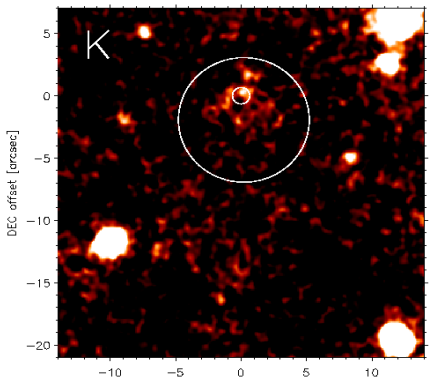


- *located in south of French Alps at 2552 m altitude*
- *funded by CNRS, MPG & IGN*
- *6x 15-meter antennas*
- *longest baselines – 368 m x 760 m (NSxEW)*
- *up to 0.3" spatial resolution*
- *observations in 3, 2 and 1 mm atmospheric windows*
  - *3mm covers 81-116 GHz*
  - *2mm covers 129-168 GHz*
  - *1mm covers 201-256 GHz*

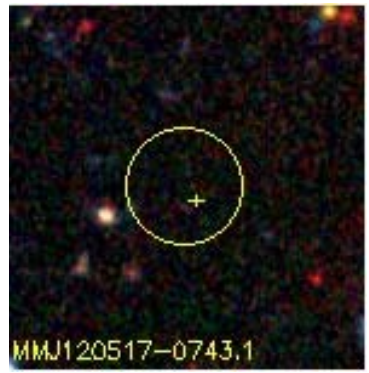
Submm Selected Galaxies



UV detected



ERO



Empty field

- *>1000 well detected sources > a few mJy (850μm or 1.1mm) (positional accuracy 5")*
- *Make up a significant fraction of the submm background and energy release at redshift 1-4*
- *Likely trace the massive tail of galaxy evolution*

Barger et al. 2001, Smail et al. 2001, Lutz et al. 2001, Dannerbauer et al. 2002, 2004, Ivison et al. 2002, 2005, Blain et al. 2002, Bertoldi et al. 2000,2007, Wilson et al. 2008; Younger et al. 2007, 2008

PdBI CO Survey of Submillimeter Galaxies (SMGs)

- *submm sources with VLA 1.4 GHz counterparts (tens of μJy)*

- *Keck follow up spectroscopy with LRIS-B: 85 redshifts: <z>~2.3 (Chapman et al. 2003,2005)*

- *PdBI CO to confirm redshift (10-20 hours on source)*

- *high resolution PdBI follow-up for spatially resolved CO emission (another 10-20 hours on source)*

- *~20 CO detections of SMGs between z~1 and 3.5 (out of ~30 sources)*

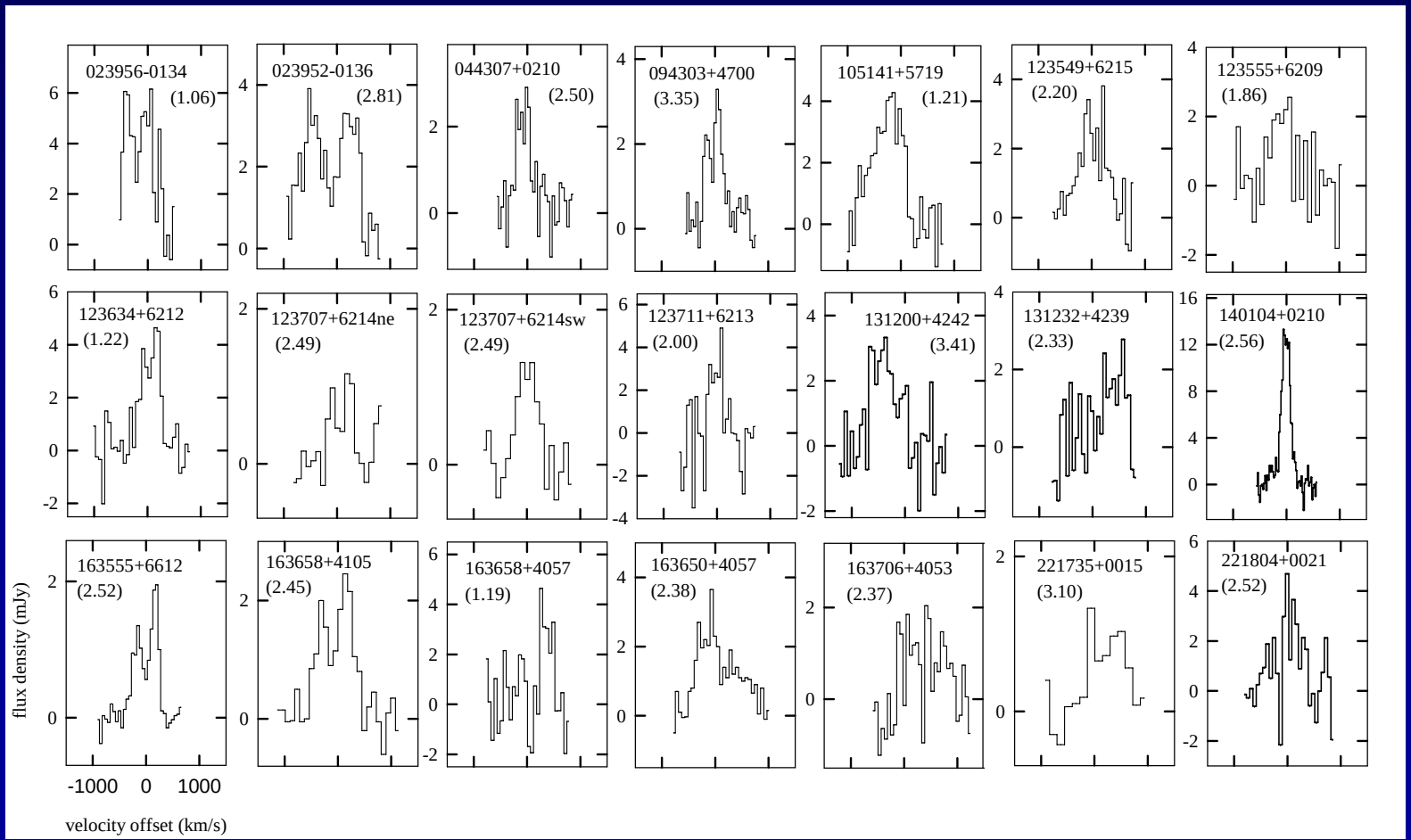
This Survey: Neri et al. 2003, Greve et al. 2005, Tacconi et al. 2006, 2008, Smail et al. 2008
Other high resolution CO/submm continuum work: Frayer et al. 1998, 1999, Andreani et al. 2000, Ivison et al. 2002, Downes & Solomon 2003, Genzel et al. 2003, Sheth et al. 2004, Kneib et al. 2005, Solomon & Vanden Bout 2005, Hainline et al. 2006, Iono et al. 2006, Wang et al. 2007, Younger et al. 2007, 2008…

SMG Survey

IRAM PdBI

2002-2006

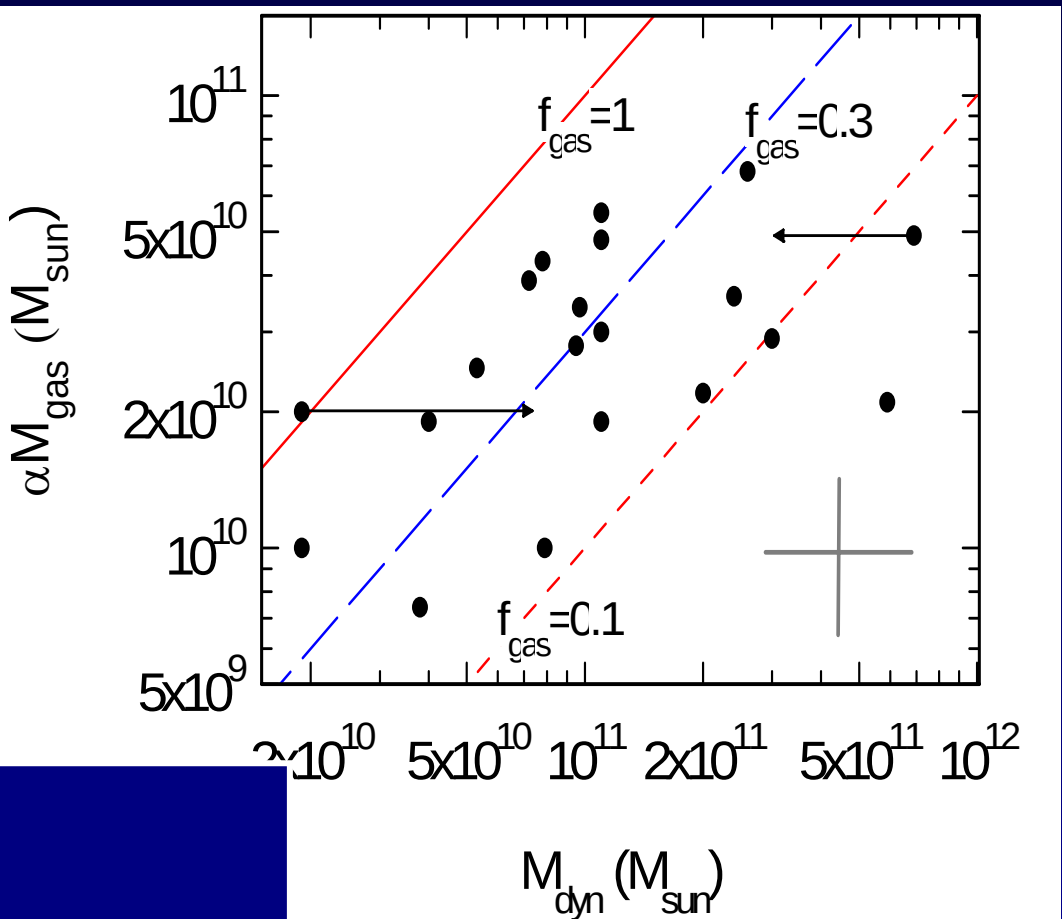
Downes & Solomon 2003, Genzel et al. 2003, Neri et al. 2003, Kneib et al. 2005, Greve et al. 2005, Tacconi et al. 06, 08, Smail et al. 2008



SMG Survey

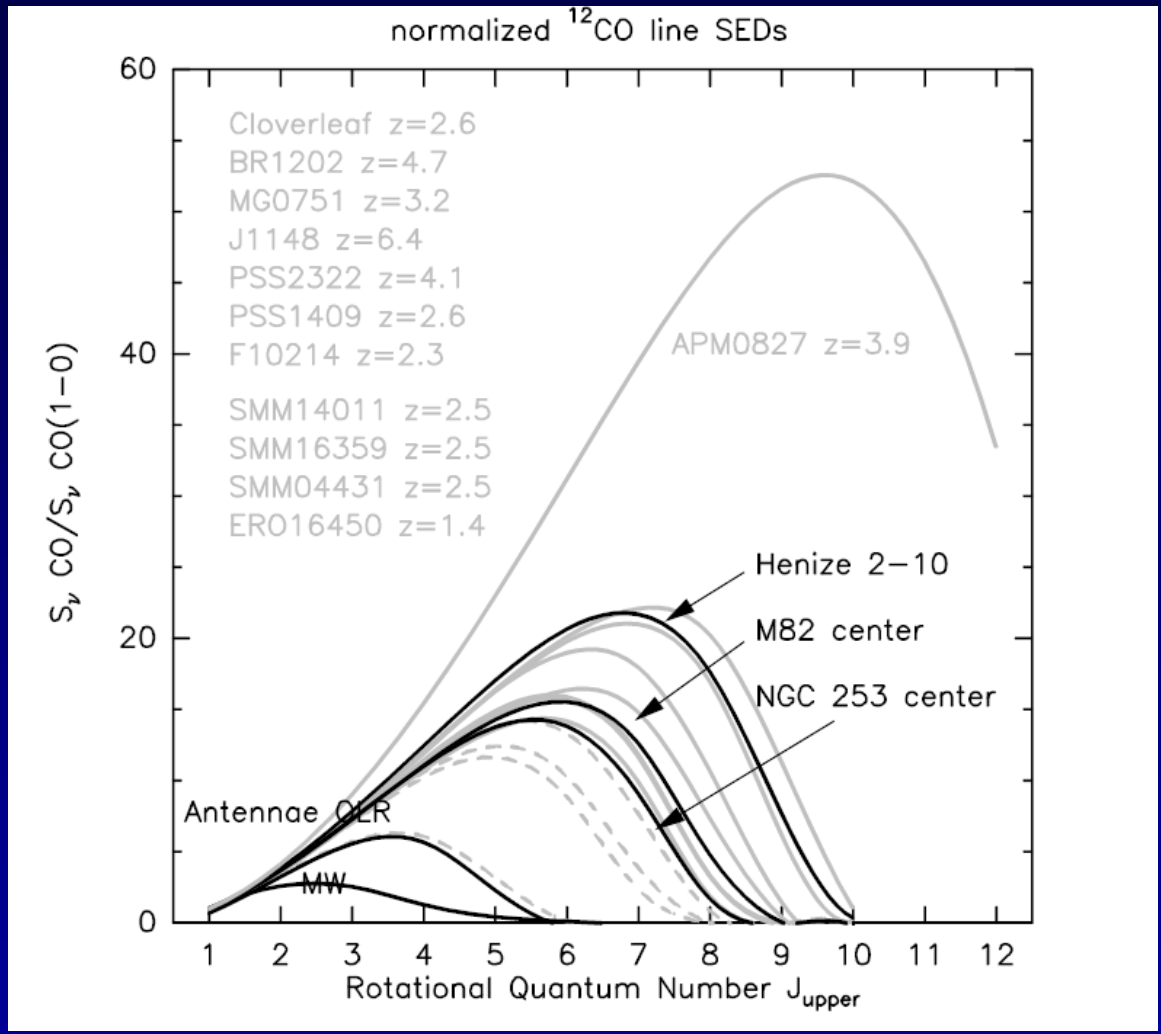
IRAM PdBI
2002-2006

Downes & Solomon 2003, Genzel et al. 2003, Neri et al. 2003, Kneib et al. 2005, Greve et al. 2005, Tacconi et al. 06, 08, Smail et al. 2008



- $\langle v_c \rangle$=400 km/s
- $M_{dyn} \sim 10^{11}\ M_\odot$ within CO regions
- $\langle M(H_2) \rangle = 3.0 \pm 1.6 x 10^{10}\ M_\odot$
- $f_{gas} \sim 0.2\text{-}0.5$
- $\langle R \rangle_{1/2} < 0.25$" (2 kpc)

CO Line SEDs of High Redshift QSOs and SMGs



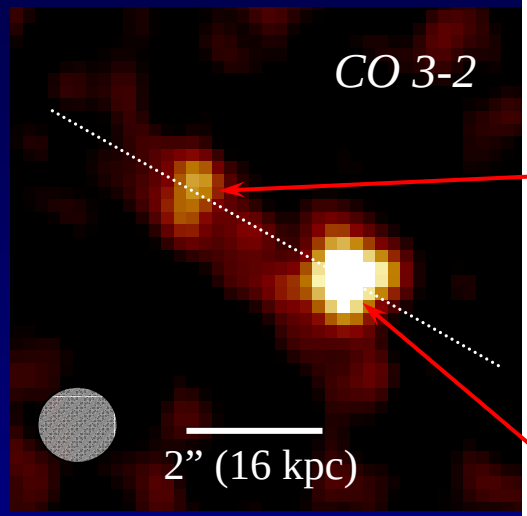
- *Multi-J CO Observations*
- *Single T, n LVG models*
- *QSOs – higher excitation gas than SMGs*
- *Both similar to starburst regions of nearby galaxies*
- *SMGs observed so far are lensed, intrinsically lower L*

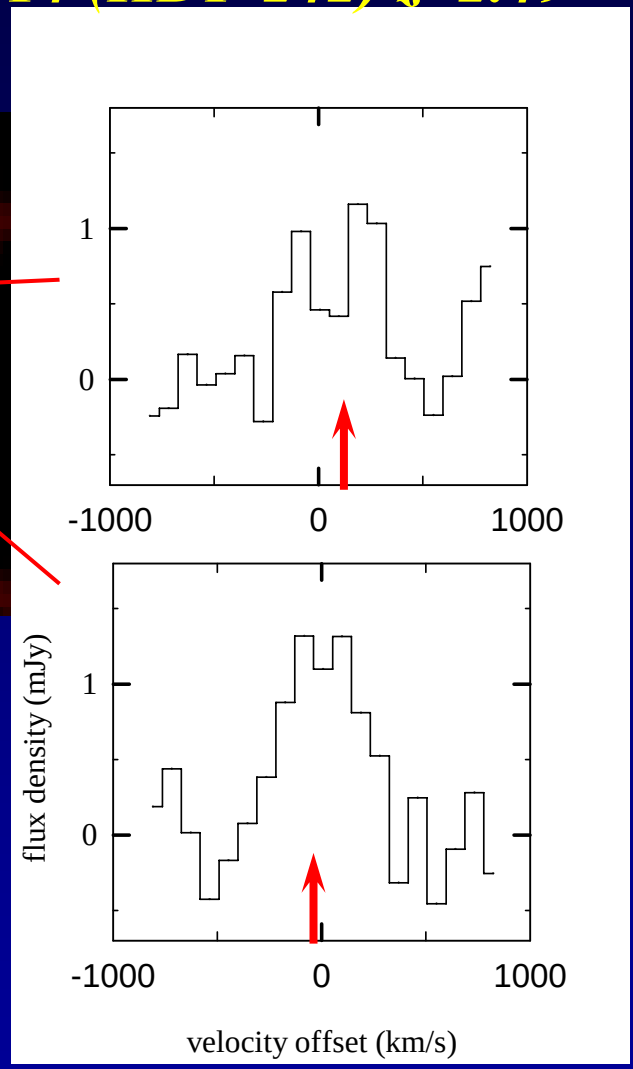
from Weiss et al. 2007

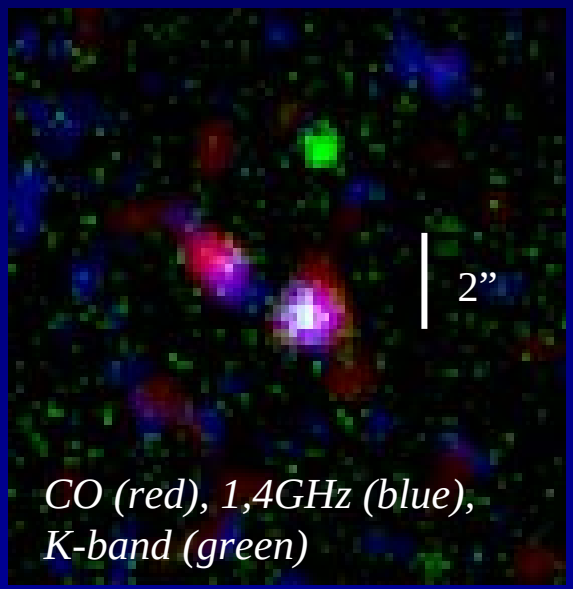
see also: Weiss et al. 2005.2007; Bayet et al 2004; Bradford et al. 2003; Ward et al 2003, Mao et al 2000

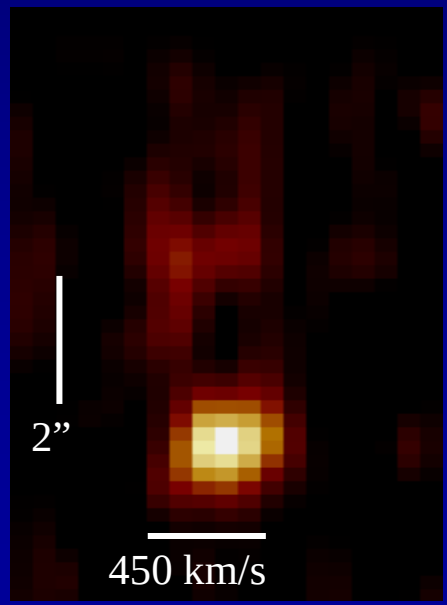
HDF 242: An Early Stage Merger?

SMMJ123707+6214 (HDF 242) z=2.49







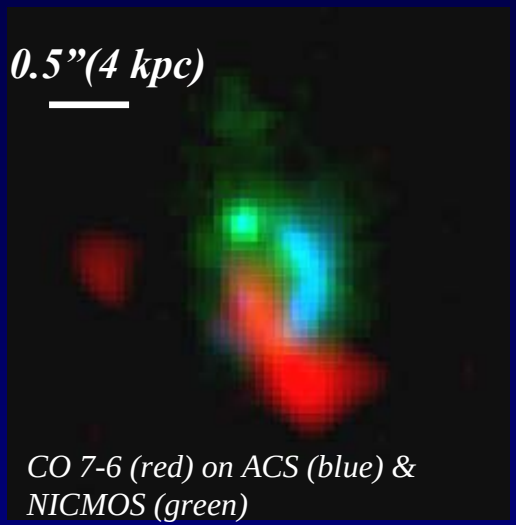


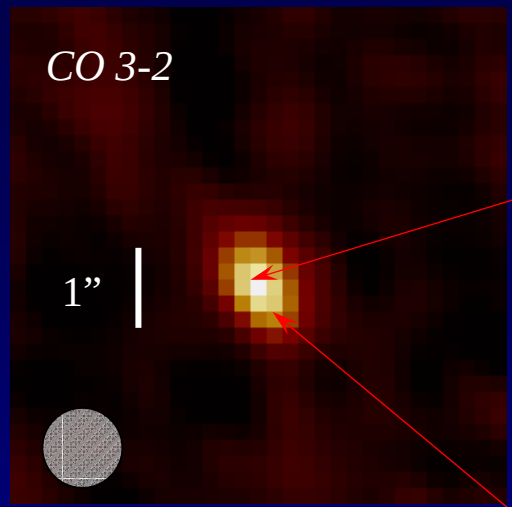
CO components:

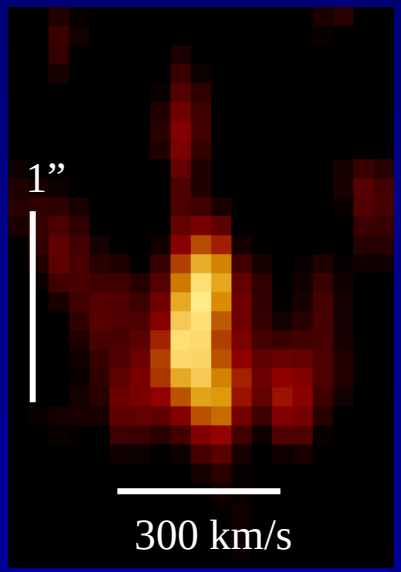
- *projected separation ~16 kpc*
- *velocity difference 100-150 km/s*

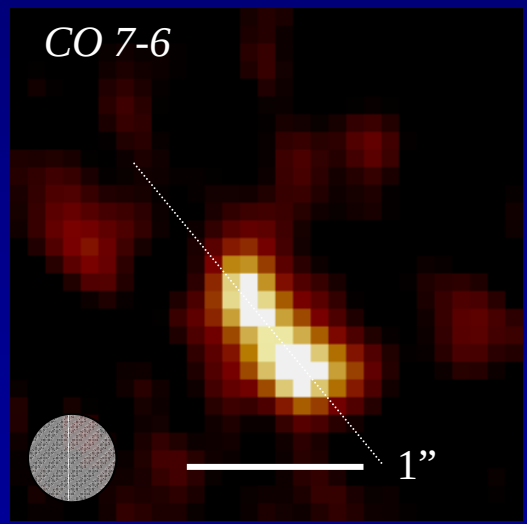
Tacconi et al. 2008

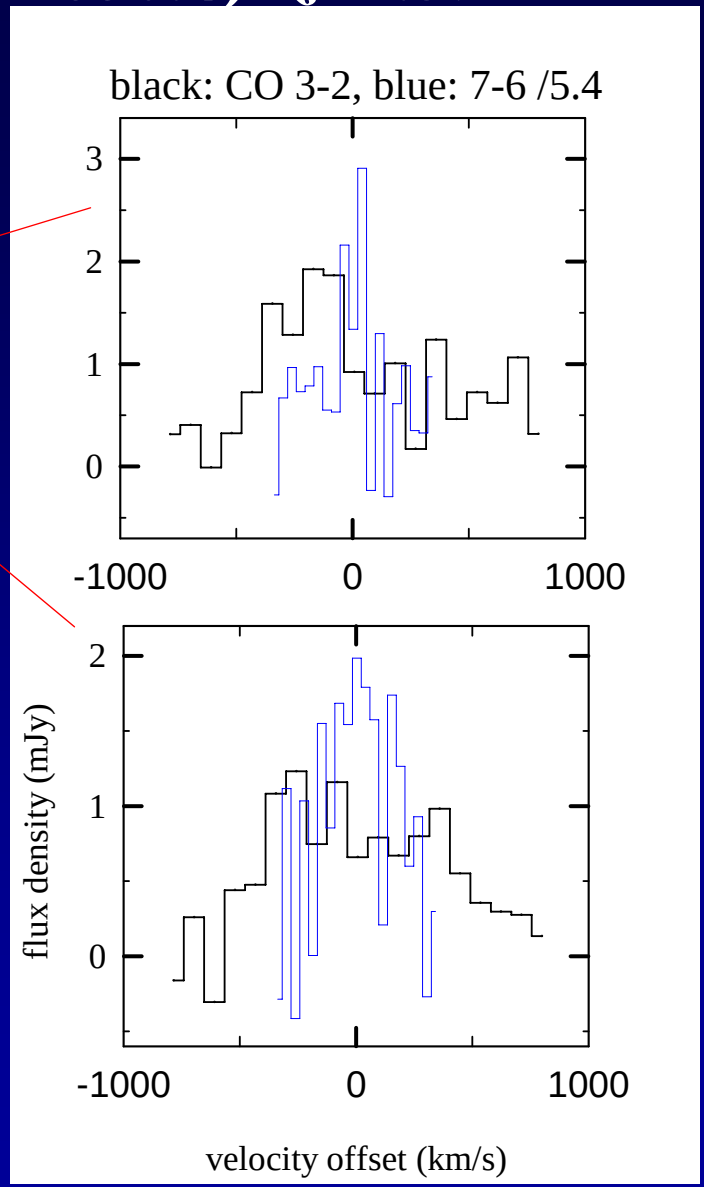
SMMJ163650+4057 (N2 850.4) z=2.39





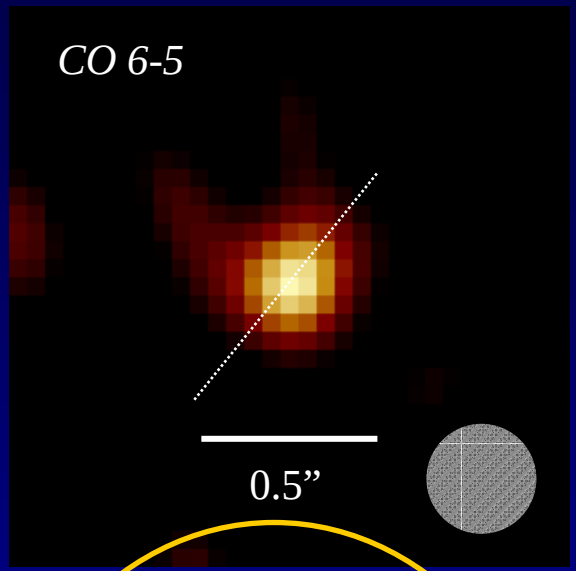


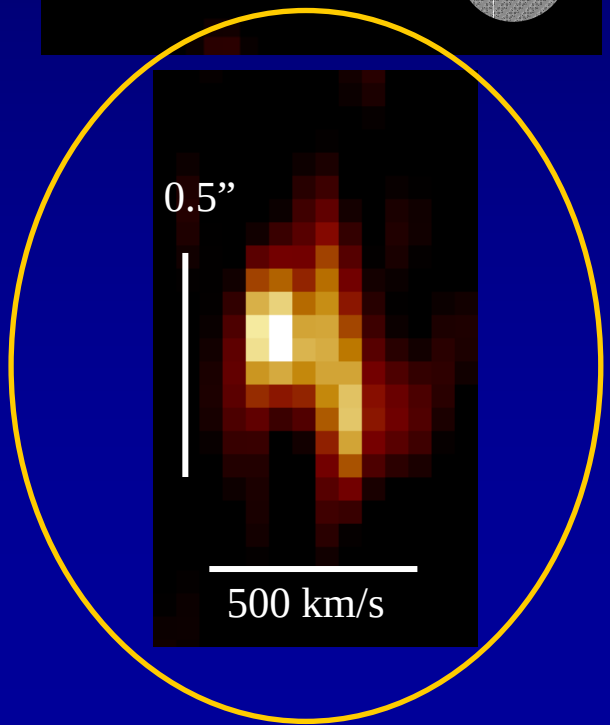


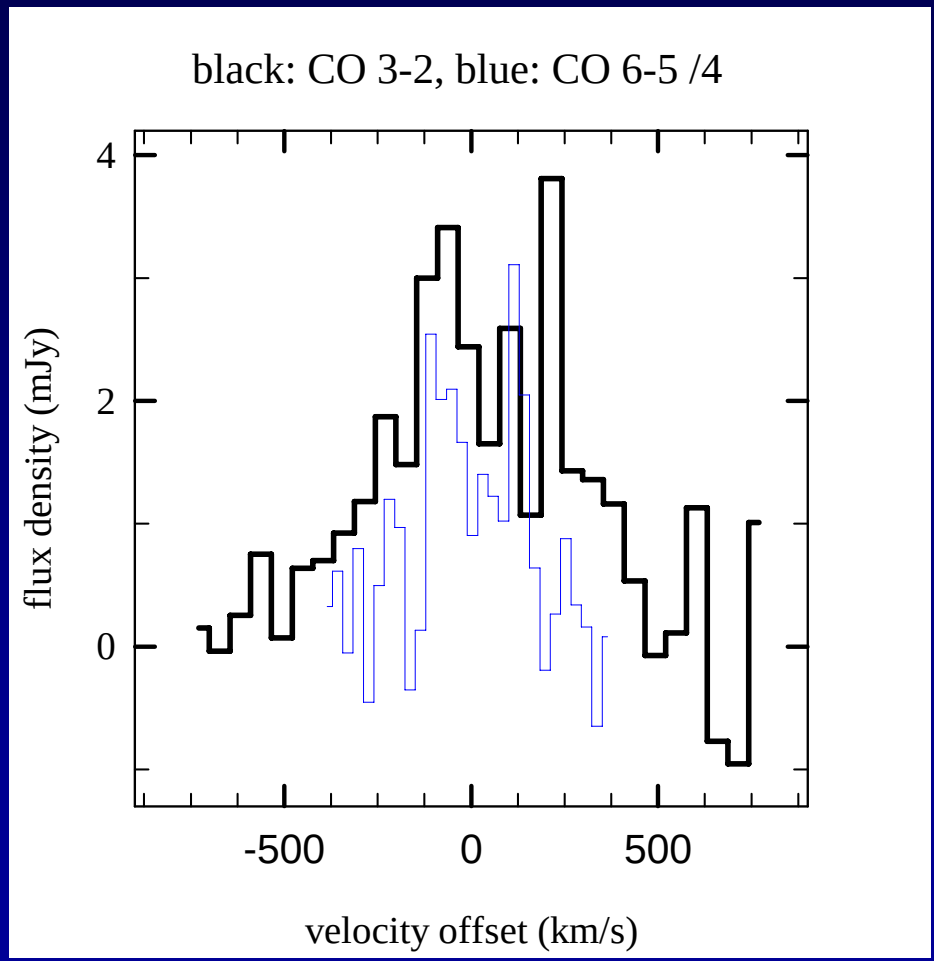


Smail et al. 2005, 2007 Swinbank et al. 2005, Tacconi et al. 2006, 2008

SMMJ123549+6215 (HDF76) z=2.20

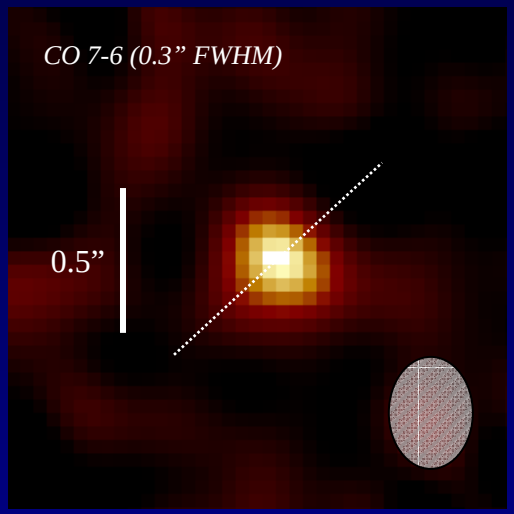


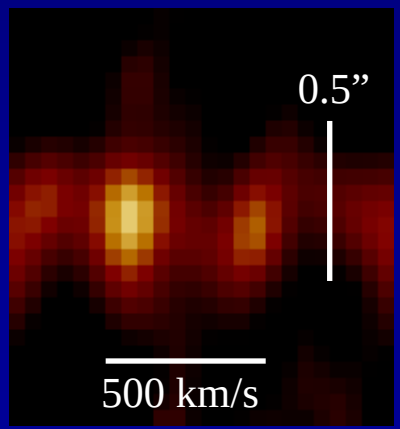


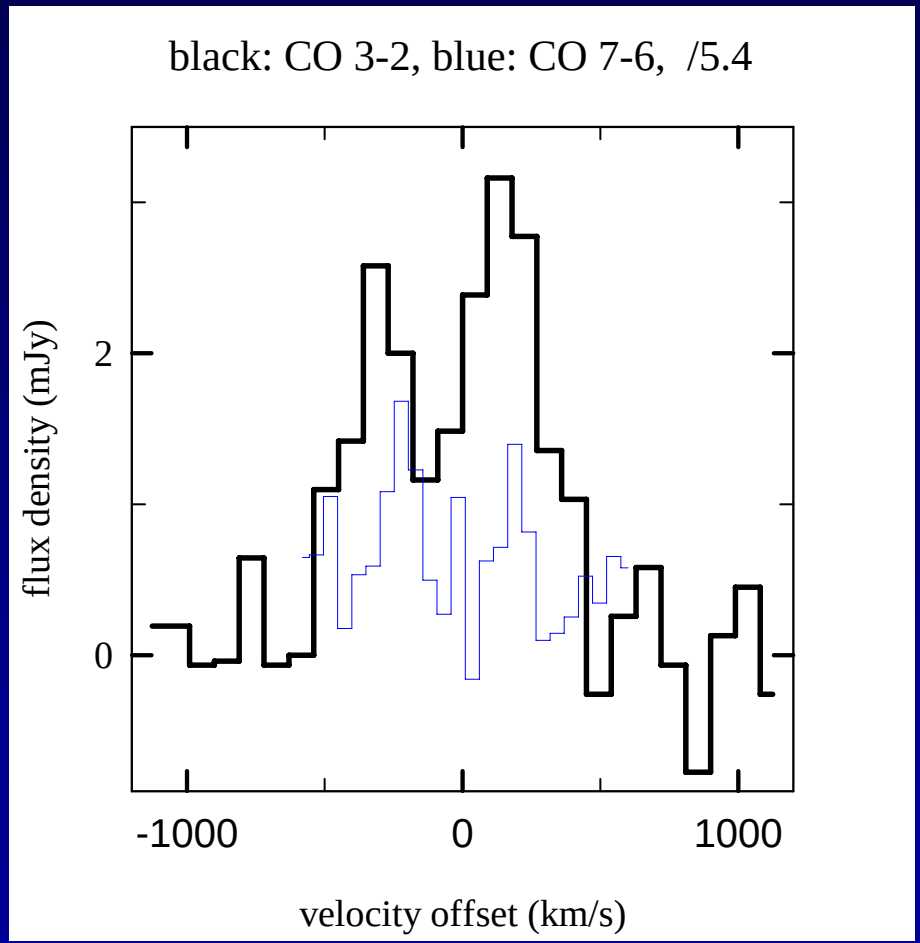


IRAM Plateau de Bure
resolution = 0.4”x0.3”FWHM

SMMJ16358+4105 (N2850.2) z=2.45







IRAM Plateau de Bure resolution = 0.3”FWHM

CO Size ~0.25” FWHM (1.6 kpc)

Submillimeter Galaxies Are Dense Gas Rich "Maximum Starbursts" Undergoing Major Mergers

- ***<M(H$_2$)>=3.0±1.6x10^{10} M$_\odot$***
- ***f_{gas}~0.2-0.5; high dense gas fractions***
- ***SFR~500-1000 M$_\odot$/yr***
- ***global SFR/M$_{gas}$ comparable to Galactic star formation regions W49 or W51***

Neri et al 2003, Greve et al. 2005, Tacconi et al. 2006, 2008, Gao et al. 2007, Smail et al. 2008

- *global instability to collapse (Q≤1)*

$$\Sigma_{gas,crit} \geq 2.9x10^3 \frac{\sigma_{100} v_{400}}{R_{1.6}} \qquad [M_\odot pc^{-2}]$$

- *star formation at maximum rate*

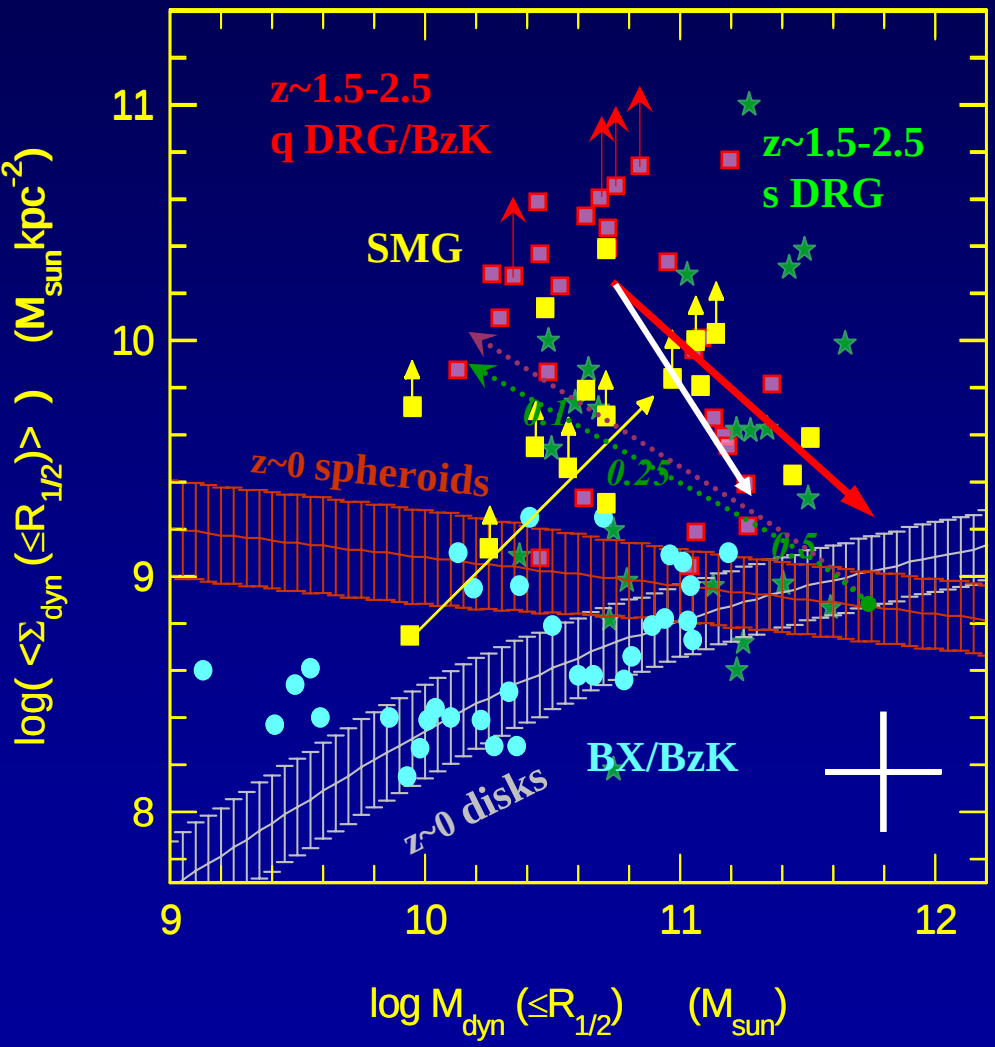
$$SFR_{\max} = \frac{\varepsilon f_g M_t}{t_{dyn}} = 620 \varepsilon_{0.1} f_{0.4} v_{400}^4 \qquad [M_\odot yr^{-1}]$$

- *stellar 'negative feedback is not sufficient to quench star formation*

$$SFR_{\max,feedback} \leq 9x10^3 f_{0.4} v_{400}^4 \qquad [M_\odot yr^{-1}]$$

Kennicutt 1998, Elmegreen 1999, Scoville 2003, Murray, Quataert & Thompson 2004, Thompson, Quataert & Murray 2005

Subsequent Evolution of SMGs



Daddi et al. 2005, Trujillo et al. 2006, Zirm et al. 2007, Toft et al. 2007, Bouche et al. 2007, Shen et al. 2003, Tacconi et al. 2008

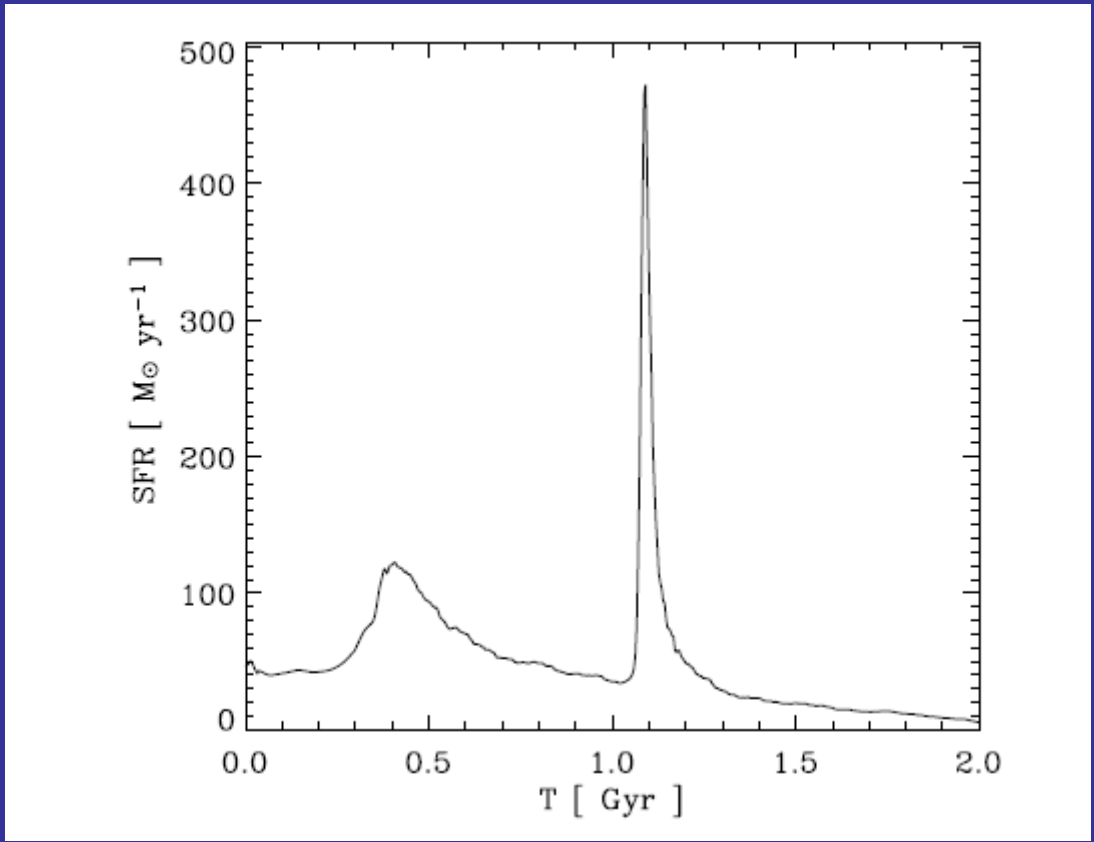
Lifetime of the SMG Phase

galaxy sample	*Φ (h_{70}^{-3} Mpc^{-3})*
SMGs: $S_{850\mu m}\geq$5 mJy, z=1-3.4 *OFRGs: z=1-3.4*	*$1.1\pm0.1\times10^{-5}$* *$\sim1\times10^{-5}$*
quiescent (passive) K≤20 BzK z=1.4-2 *quiescent (passive) K≤21.7 DRG z=2.0-2.6*	*$1.5\pm0.4\times10^{-4}$* *$6.5\pm2\times10^{-4}$*

→ ***SMG Duty Cycle ~0.1, or ~100 Myrs***
from: 1) SMG/red sequence volume densities
2) ratio of gas exhaustion timescale to merger time/ stellar pop age (~1 Gyr)

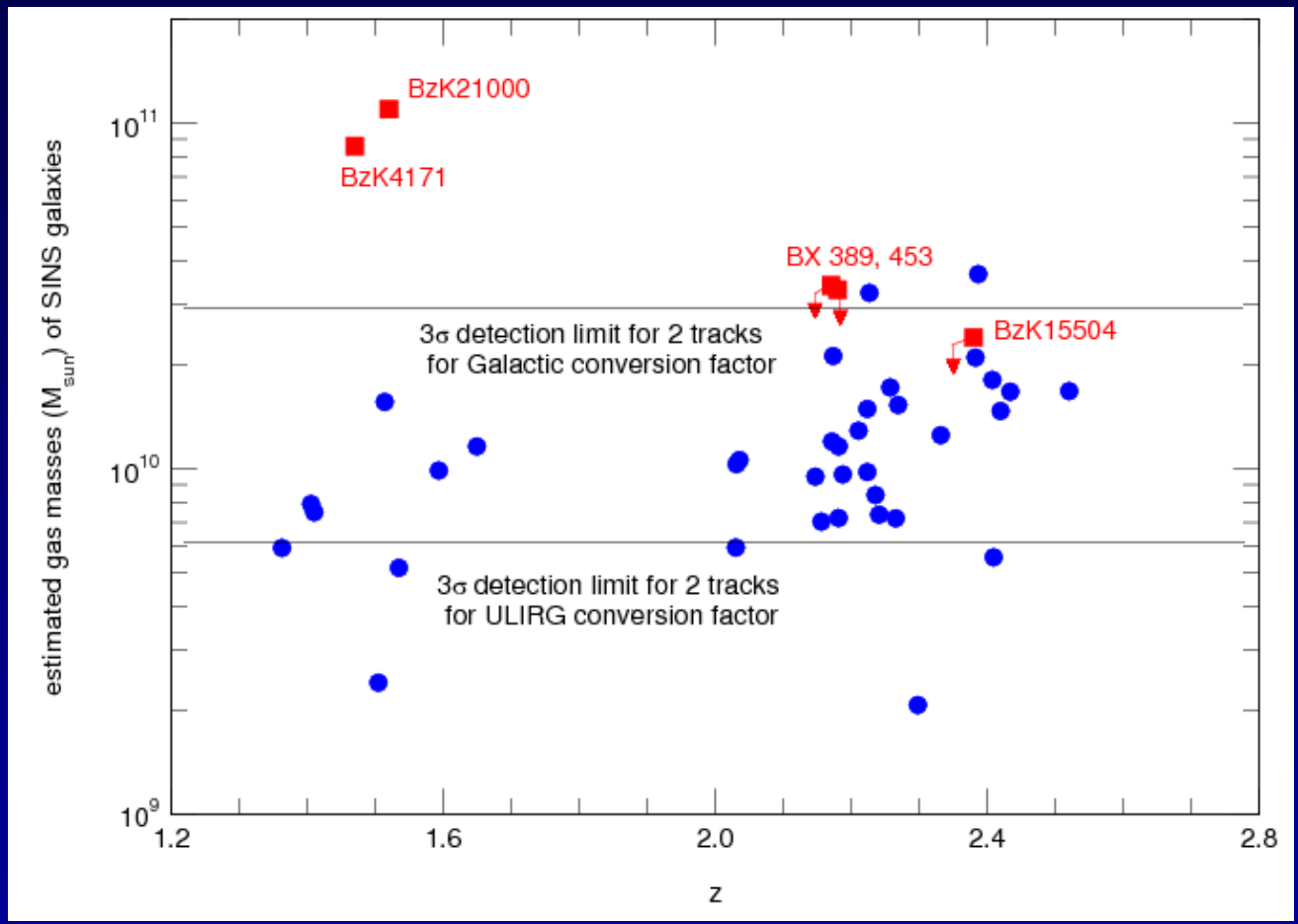
Chapman et al 2005a,b, Reddy et al. 2005, Daddi et al. 2004, 2005, Kong et al. 2006, Grazian et al. 2007, Zirm et al. 2006, Toft et al. 2007

Lifetime of the SMG Phase



Springel et al. 2005, Mihos and Hernquist 1996

Molecular Gas Estimates in Lower Luminosity High-z Star Forming Galaxies: Detection Limits with Current PdBI

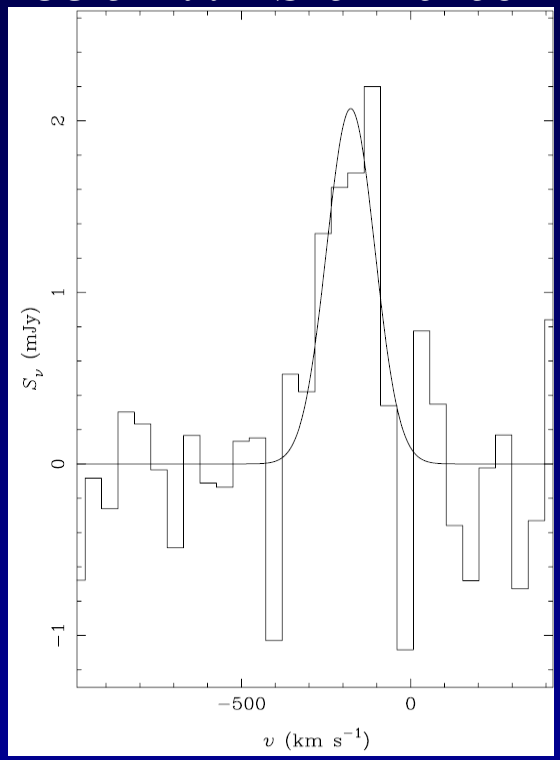


Assumes:

- ***6 hours on source per track***
- ***summer weather conditions***
- ***spectrally resolving line***

Molecular Gas in Gravitationally Lensed Lyman-Break Galaxies

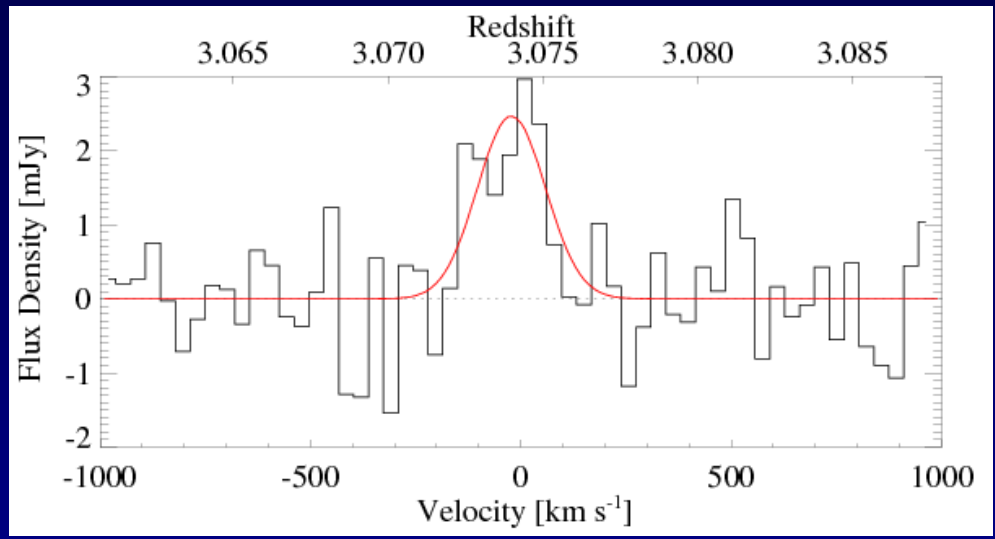
CO 3-2 in MS1512-cB58



- *z=2.7*
- *M_{H2}~2.3x10^9 $M_\odot$*
- *30 hours PdBI*

Baker et al 2004

CO 3-2 in the "Cosmic Eye"



- *z-=3.07*
- *M_{H2}~2.4x10^9 $M_\odot$*
- *magnification 8x*
- *10 hours PdBI*

Coppin et al. 2007

Summary

- *SMGs are compact & massive with 20-50% gas fractions*
- *SMGs are dissipative major mergers*
- *SMGs are very gas rich, 'maximum' starbursts that can convert a large fraction of their original gas mass to stars in a few hundred Myrs*
- *Comparison with compact red sequence objects implies SMGs rapidly form compact M* spheroids at z~2-3*
- *SMG phase must be short-lived ~100 Myrs*