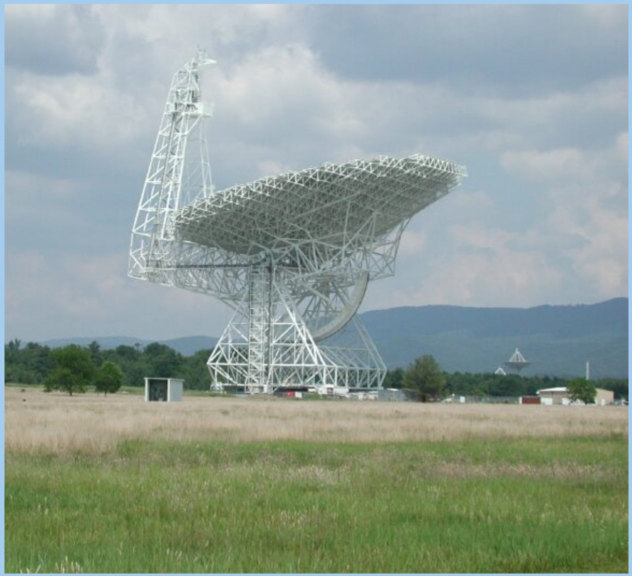
Beneath the Baselines:

Detecting Molecular Emission from Submillimeter Galaxies with the GBT



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CO: A Tracer of Cold H_2

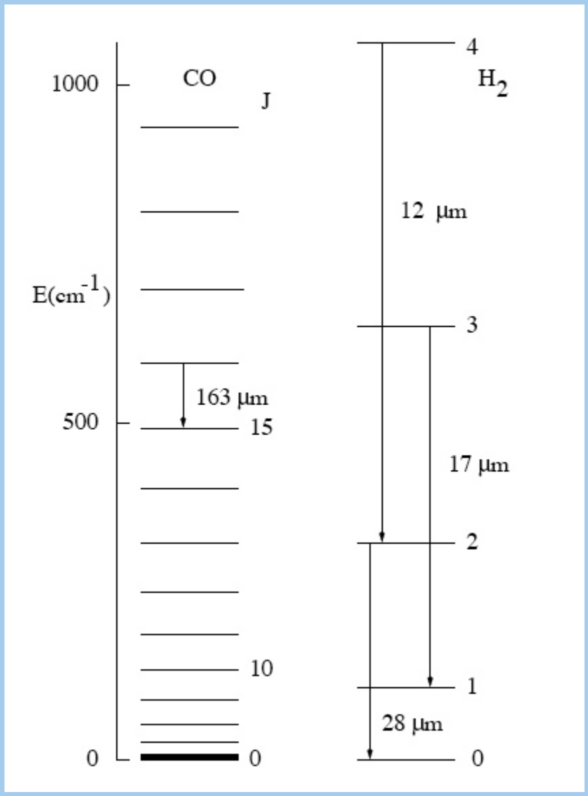
Important molecular properties:

- Linear, diatomic, heteronuclear
- Cosmically abundant
- Small T_{ex}

From CO rotational line emisson:

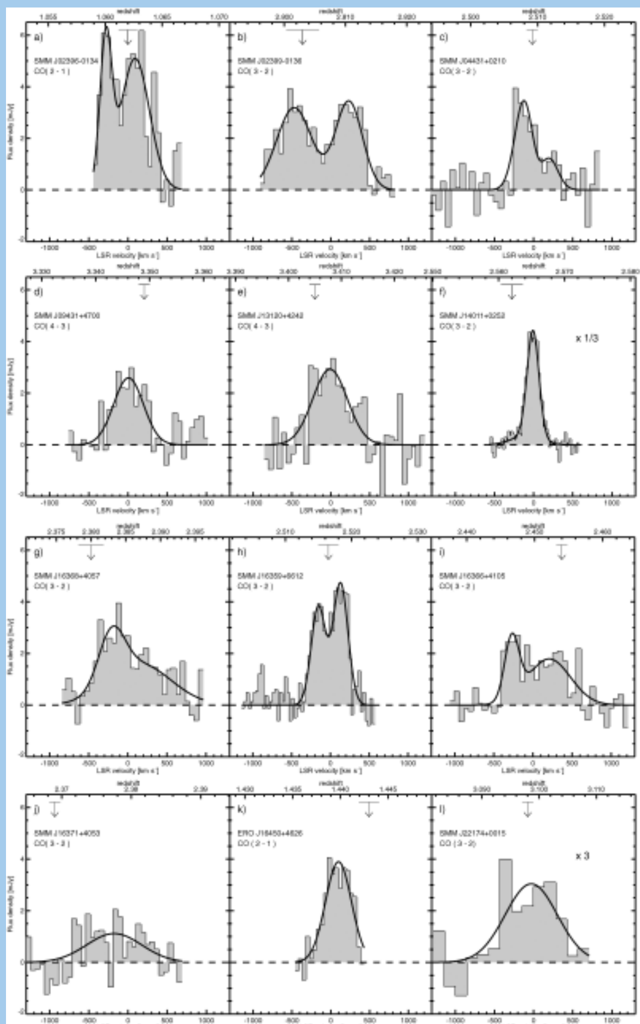
- Mass: $M(\mathrm{H}_2) = \alpha \times L'_{CO}$
- ISM conditions
- Dynamics
- Evolutionary State/Fuel for SF

Comparison of CO and H_2 excitation ladders



SMGs: Massive Galaxies in Formation?

Fig. 1 from Greve et al. (2005)



★★★How much fuel?★★★

Median values from CO survey of Greve et al. (2005): $(J_{upper} \geq 2)$

$$M(\mathrm{H}_2) = (3.0 \pm 1.6) \times 10^{10}\, M_{\odot}$$

$$\Delta V_{FWHM} = 780 \pm 320\ \mathrm{km/s}$$

$$M_{\mathrm{dyn}} = (1.2 \pm 1.5) \times 10^{11}\, M_{\odot}$$

What about the low-excitation gas?

Wanted: CO(1→0) Observations!

CO(1→0) observations crucial for SMGs:

- Trace **all** molecular gas
- Better comparison to local populations

GBT K and Ka-band well suited to detection:

- ν_{rest} = 115.271 GHz ⇒ 26-38 GHz at z ~ 2 - 3.5
- Wide bandwidth spectrometer

Our Goal: Detect CO(1→0) in SMGs at z > 3.4 using GBT!

- First experiments: SMGs with previous CO detections
  ⇒ limits sample to 2 SMGs (A851 & SSA 13)

Observations

Targets:

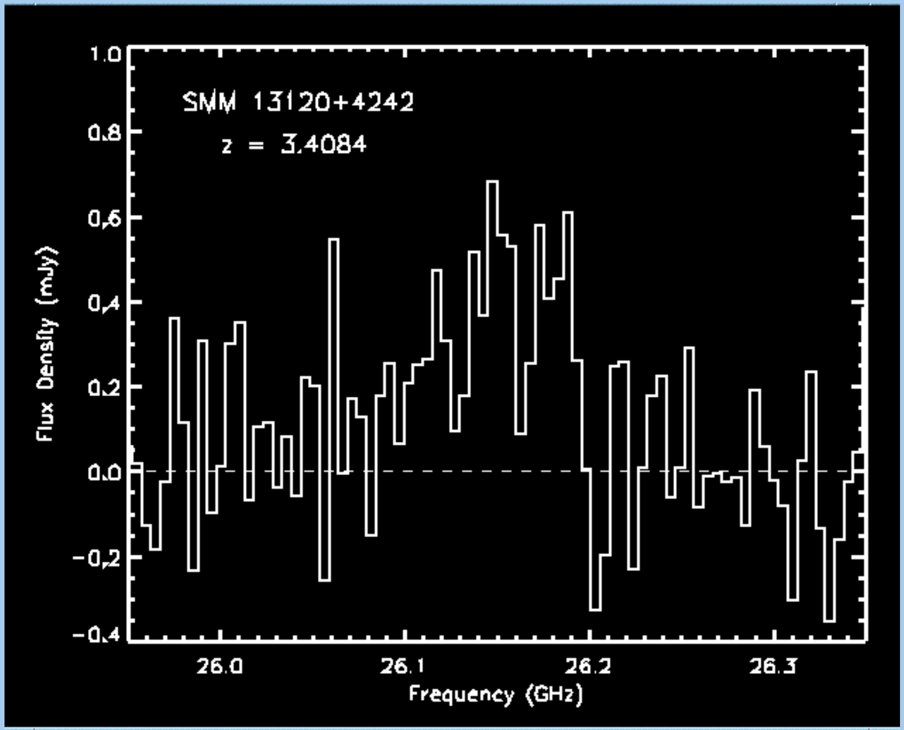
SMM J09431+4700 (z_{CO} = 3.346)

SMM J13120+4242 (z_{CO} = 3.408)

Data taken 1 Dec 2004 at GBT in excellent conditions:

- Dual-beam K-band receiver (18-26 GHz), 28″ beam
- ACS setup: 800 MHz BW, 2048 channels, centered at z_{CO}
- “Nod” observing pattern
- Total t_{int} ~ 6 hr (feed 2 data tossed so t_{eff} ~ 3 hr)

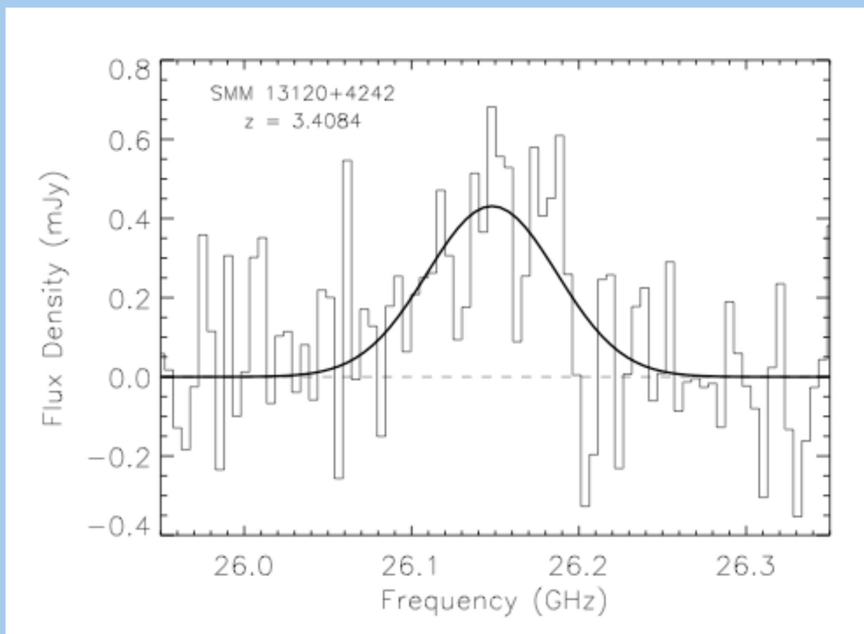
First CO(1→0) detection in a SMG!



SMM 13120+4242:

- In SSA 13, Hawaii Deep Field
- $S_{850\mu m}$ = 6.2 mJy, T_d = 47 K
- No evidence of lensing
- AGN lines in optical spectrum

CO(1→0) Line Parameters



$$\nu_{obs} = 26.1481\ \mathrm{GHz}$$

$$z = 3.408 \pm 0.004$$

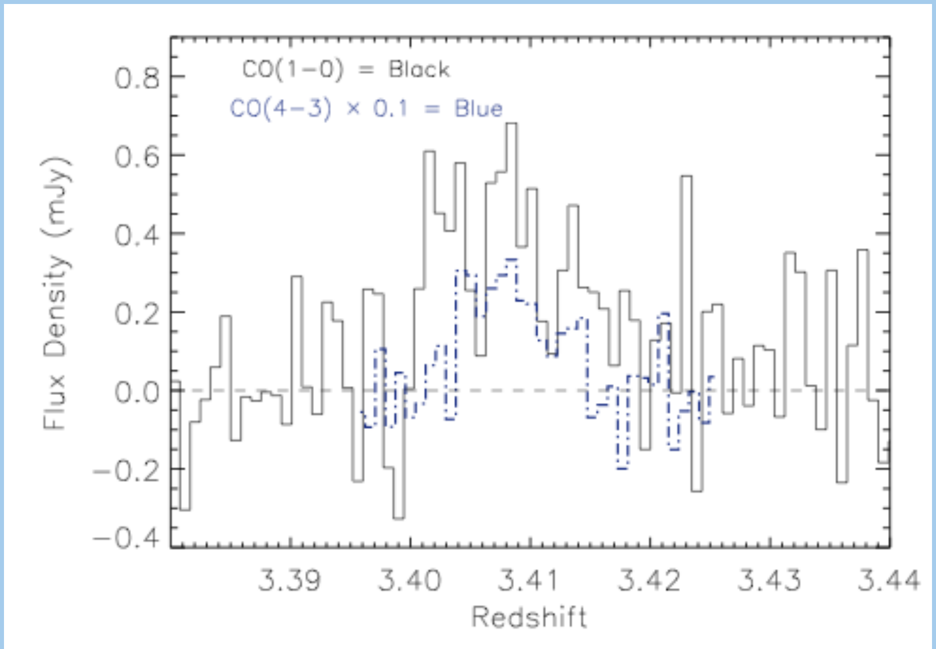
$$\Delta V_{FWHM} = 1040 \pm 120\ \mathrm{km\ s^{-1}}$$

$$S_{CO}\Delta V = 0.42 \pm 0.03\ \mathrm{Jy\ km\ s^{-1}}$$

$$L_{CO} = 1.0 \times 10^{7} L_{\odot}$$

Use = 0.8 $M_{\odot}$ (K km/s $pc^2)^{-1}$: $M(\mathrm{H_2}) = 1.6 \times 10^{11}\ M_{\odot}$

Compare to CO(4→3) Detection



From Greve et al. (2005):

$$z_{4-3} = 3.408 \pm 0.002$$

$$\Delta V_{FWHM,4-3} = 530 \pm 50 \text{ km s}^{-1}$$

$$S_{CO}\Delta V_{4-3} = 1.7 \pm 0.3 \text{ Jy km s}^{-1}$$

$$M(\mathrm{H}_2) = (4.2 \pm 0.7) \times 10^{10}\ M_\odot$$

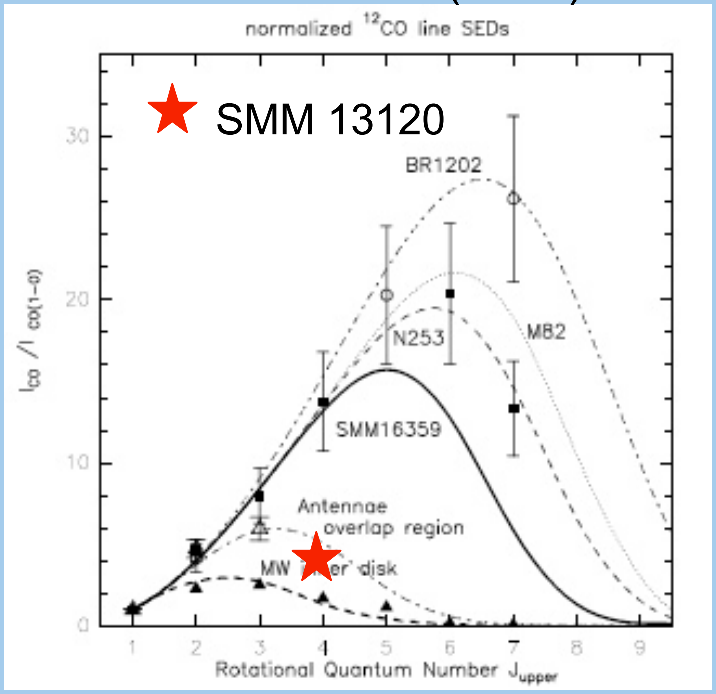
$$M_{dyn} < 1.2 \times 10^{11}\ M_\odot$$

- Line profile ~ similar, but CO(1→0) line wider ⇒ Why?
- Common fit to both spectra: $z = 3.4078, \Delta V = 680 \text{ km s}^{-1}$
- 4x more mass implied by (1-0) ⇒ High-*J* line missing mass

Spatial data for (1→0) needed ⇒ EVLA!

Implications: Gas Density & Temp

Weiss et al. (2005)



Line ratio: $$\frac{T_b(4 \rightarrow 3)}{T_b(1 \rightarrow 0)} = 0.26 \pm 0.05$$

(Assume D = 0.5″ following Tacconi et al. 2005)

Standard LVG models fit to line ratio:

- Best fit model: $n(H_2) > 300$ cm^{-3}, $T_k = 67$ K ($X_{CO} = 10^{-4}$)
- Fix $X_{CO} = 10^{-5}$, $T_k = T_d \sim 50$ K: $n(H_2) > 10^3$ cm^{-3}

T_b ratio, $n(H_2)$ lower than high-z QSOs! Diffuse gas?

Implications: Continuum-to-Line Ratio

Take L_{FIR} from Chapman et al. (2005): $$\frac{L_{FIR}}{L'_{CO}} = 100$$

Previous high-z CO(1→0) detections: $$\frac{L_{FIR}}{L'_{CO}} \sim 200 - 300$$

Implications for SMGs:

- More cold gas?
- Less L_{FIR} from AGN effects?
- Subthermal excitation?

Summary

With GBT K-band, first detection of CO(1→0) emission from SMG SMM 13120+4242!

- $\Delta V_{CO(1-0)} > \Delta V_{CO(4-3)}$
- (1→0) mass ~ 4x (4→3) mass
- $n(H_2) > 10^{2-3}$ cm^{-3}
- r_{43}(SMM 13120) < r_{43}(QSO)
- Subthermal excitation important?