# The First CO (1-0) Detections of High-Redshift Galaxies with the Zpectrometer


Chelsea E. Sharon (Rutgers), Andrew I. Harris (U. of Maryland),
Andrew J. Baker (Rutgers), and Stephanie G. B. Zonak (U. of Maryland)




## Motivation

### Why CO (1-0)?

-CO is a stable and abundant tracer for moecular gas.

-Rotational transitions in CO are easily excited by collisions with $H_2$.

-Analyses based on mid-J lines fail to account for possible extended, massive cold gas components, best traced by the J=1-0 line.

-For objects at z=2-3, the J=1-0 transition of CO is observed at ~1 cm wavelengths (Ka band).

### CO in Submillimeter Galaxies:

-Star formation in dusty, high-redshift submillimeter galaxies (SMGs) is fueled by molecular gas.

-Nearly all previous CO detections of SMGs have been in mid-J transitions.

-Only prior CO (1-0) detection in an SMG (Hainline et al. 2006) had broadened profile compared to mid-J lines, indicating a different dynamical state for the coldest gas component.

-This would be contrary to the single, thermalized component model advocated for SMGs based on the results of Large Velocity Gradient models of CO spectral line energy distributions (Weiss et al. 2005).

## The Zpectrometer

The Zpectrometer is an ultra-wideband spectrometer for the Robert C. Byrd Green Bank Telescope (GBT) in West Virginia, optimized for the detection of low excitation CO lines at high redshifts.

### Stats:

-25.6-37.7 GHz range of the Ka band

-20 MHz resolution

-CO (1-0) line within bandpass for galaxies at z=2.2-3.6

-CO (2-1) line within bandpass for galaxies at z=5.4-8.2

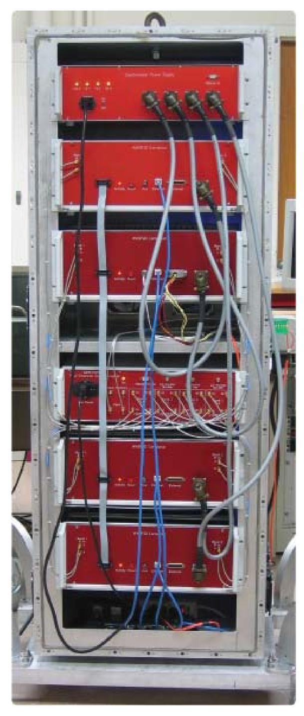
### Naturally flat, stable baselines:

-4x2 WASP2 analog lag cross-correlators (Harris & Zmuidzinas 2001) span the Ka band.

-Located in receiver cabin eliminating IF transport problems.

-Combination of subreflector nodding and position switching to a partner object results in the removal of nearly all baseline structure.

For more information, see:
http://www.astro.umd.edu/~harris/kaband



The Zpectrometer opened up in lab at UMD.

## Sources

### HH 1413+117 (Cloverleaf Galaxy)

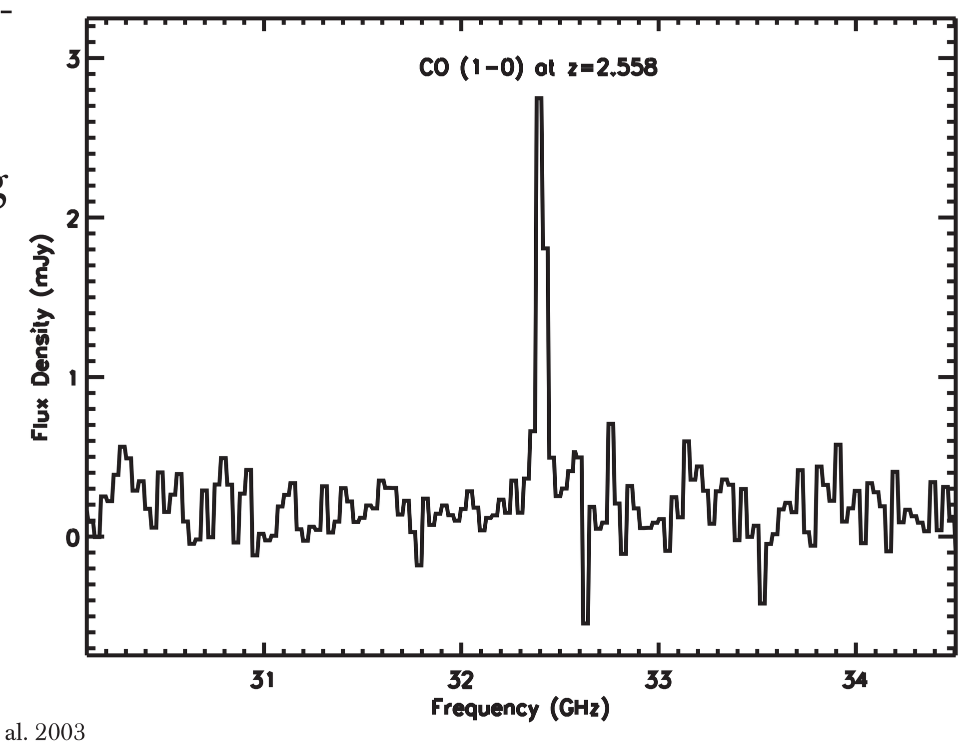
-A wider-bandwidth spectrum complementing the spectrometer detection of Vanden Bout & Maddalena (2009).

-Amplification by gravitational lensing (factor $\mu > 1$) makes sources such as the Cloverleaf ideal candidates for line detection experiments.

$z = 2.558,\ \mu = 7 - 10^{a,b,c}$

| Transition | FWHM (km $s^{-1}$) |
|---|---|
| **CO (1-0)** | **$434 \pm 14$** |
| CO (3-2)[d] | $416 \pm 6$ |
| CO (4-3)[a] | $375 \pm 16$ |
| CO (5-4)[a] | $398 \pm 25$ |
| CO (7-6)[b] | $\sim 450$ |

[a] Barvainis et al. 1997; [b] Kneib et al. 1998; [c] Venturi & Solomon 2003; [d] Weiss et al. 2003




### SMM J00266+1708

-The first SMG to be detected in the J=1-0 line before any other CO line.

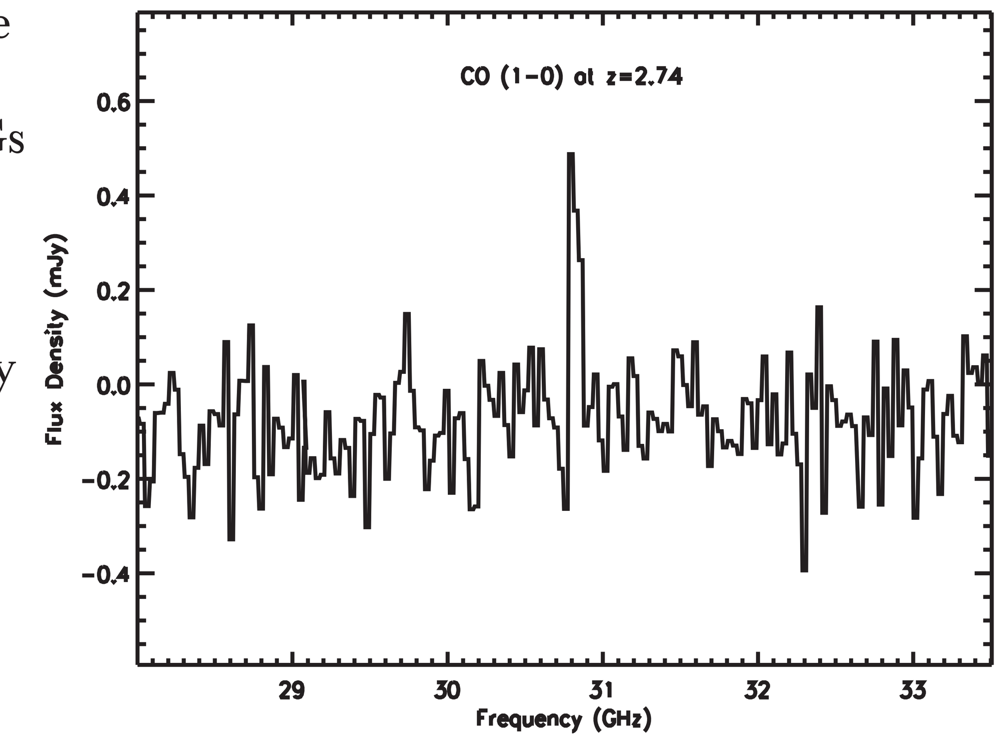
-Among the most obscured of SMGs (faint in K band; Frayer et al. 2004); redshift from PAH spectroscopy.

-Our more accurate redshift allows for follow-up studies of this potentially unique source.

$z = 2.742,\ \mu = 2.4^{a}$

| Transition | FWHM (km $s^{-1}$) |
|---|---|
| **CO (1-0)** | **$334 \pm 59$** |

[a] Frayer et al. 2000



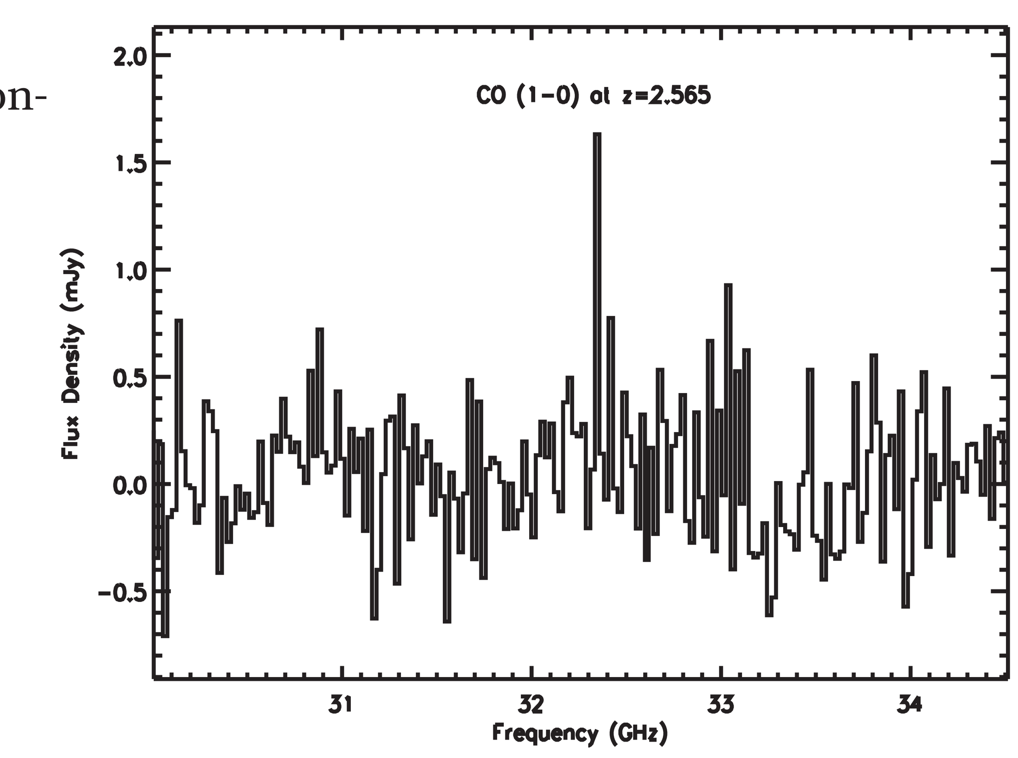

### SMM J14011+0252

- Extremely narrow line width is consistent with observations of the mid-J lines.

$z = 2.565,\ \mu \sim 5^{a}$

| Transition | FWHM (km $s^{-1}$) |
|---|---|
| **CO (1-0)** | **$186 \pm 22$** |
| CO (3-2)[b] | $190 \pm 11$ |
| CO (7-6)[b] | $170 \pm 30$ |

[a] Smail et al 2004; [b] Downes & Solomon 2003




### SMM J04431+0210

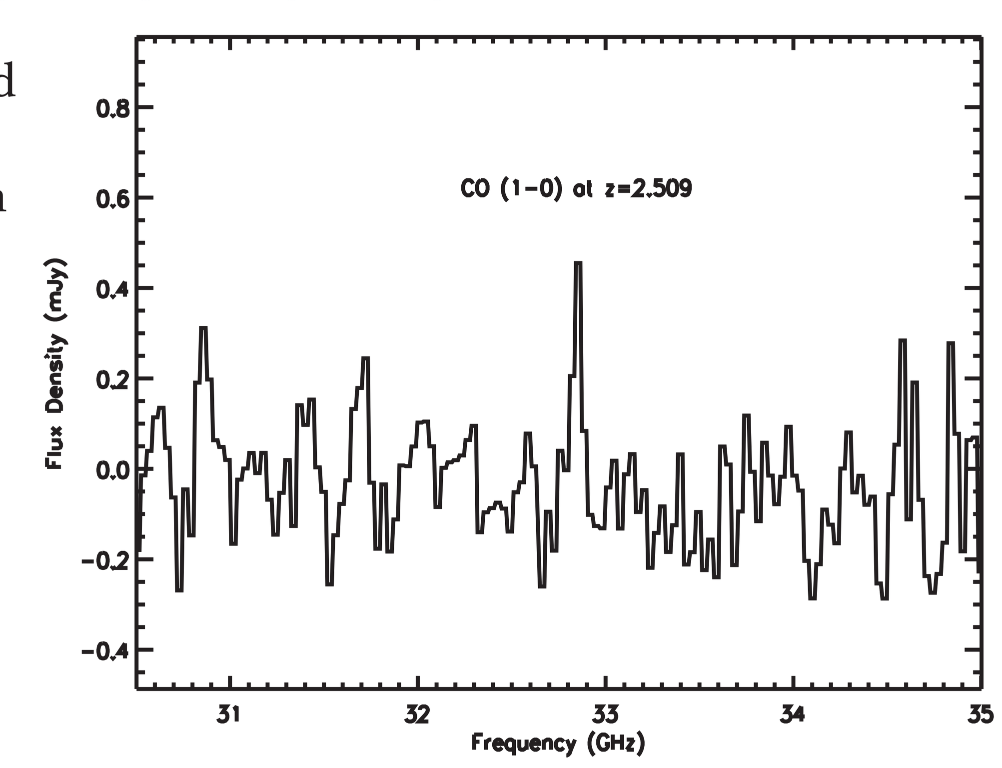
-Also classified as an Extremely Red Object (J-K=3.2; Frayer et al. 2003).

-Remnants of a baseline ripple from the Ka receiver (undergoing repair) can be seen in this spectrum.

$z = 2.509,\ \mu = 4.4^{a}$

| Transition | FWHM (km $s^{-1}$) |
|---|---|
| **CO (1-0)** | **$415 \pm 62$** |
| CO (3-2)[b] | $350 \pm 60$ |

[a] Smail et al. 1999; [b] Neri et al . 2003




## Conclusions

The detection of SMM J00266+1708 at z = 2.742 validates the use of template fitting to polycyclic aromatic hydrocarbon (PAH) emission features as an estimate of the redshift (PAH estimate: z = 2.73 ± 0.02; Valiante et al. 2007).

Our line profiles do not show the broadened, extended wings seen by Hainline et al. 2006 in SMM J13120+4242 .

It is not clear that our detections support or refute the single thermalized component model of SMGs; differential lensing and limited data can cause degenerate results. Additional mid-J observations and resolved maps of these sources are necessary to break these degeneracies.


References: Barvainis, R. et al. 1997, ApJ, 484, 695; Downes, D. & Solomon, P. M. 2003, ApJ, 582, 37; Frayer, D. T. et al. 2000, AJ, 120, 1668; Frayer, D. T. et al. 2003, AJ, 126, 73; Frayer, D. T. et al. 2004, AJ, 127, 728; Hainline, L. J. et al. 2006, ApJ, 650, 614; Harris, A. I. & Zmuidzinas, J. 2001, Review of Scientific Instruments, 72, 1531; Kneib, J. P. et al. 1998, A&A, 339, L65; Neri, R. et al. 2003, ApJ, 597, L113; Smail, I. et al. 1999, MNRAS, 331, 495; Smail, I. et al. 2004, ApJ, 616, 71; Valiante, E. et al. 2007, ApJ, 660, 1060; Vanden Bout, P. A. & Maddalena, R. J. 2009 (in preparation); Venturi, S. & Solomon, P. M. 2003, ApJ, 590, 740; Weiss, A. et al. 2003, A&A, 409, L41; Weiss, A. et al. 2005 A&A, 440, L45


Zpectrometer NRAO NSF UNIVERSITY OF MARYLAND RUTGERS UNIVERSITY

Zpectrometer construction and operation have been funded by NSF grants AST-0503946 and AST-0708653.