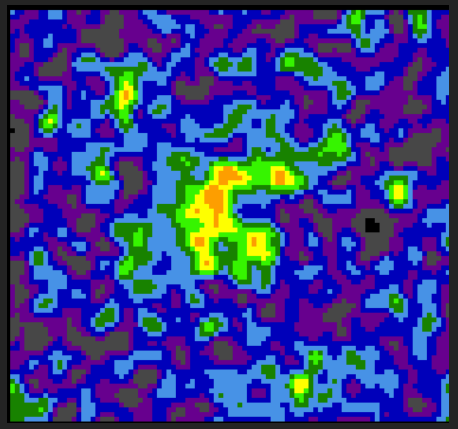

CO Tomography of the z=4.05 proto-cluster GN20

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Max Planck Institute for Astronomy (MPIA)

Collaborators:

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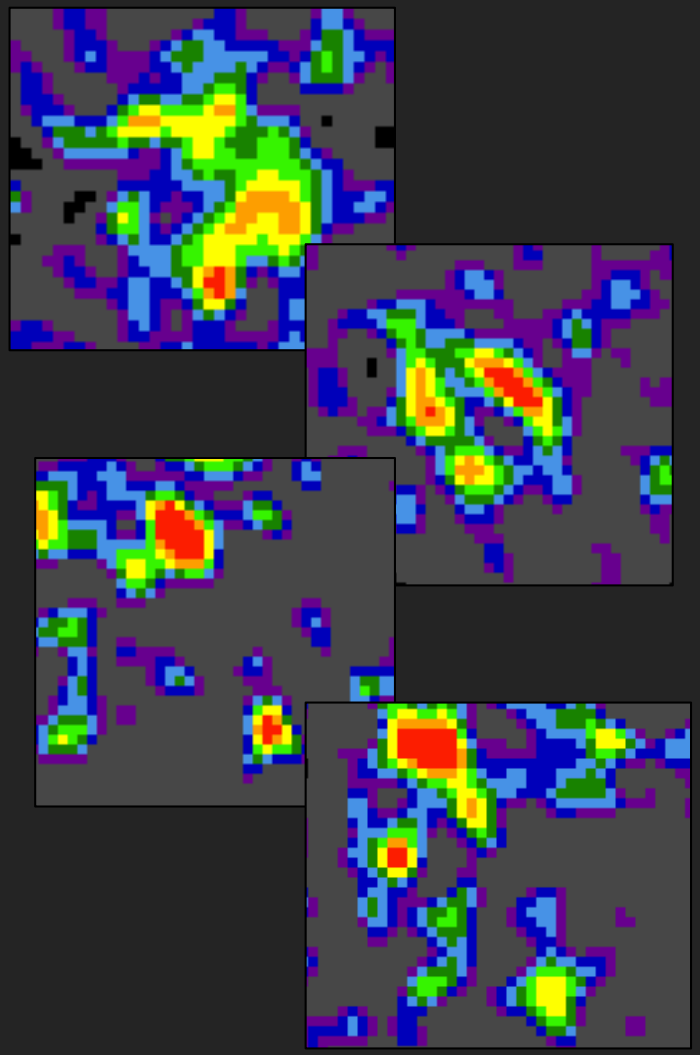
Fabian Walter (MPIA)

Dominik Riechers (Caltech)

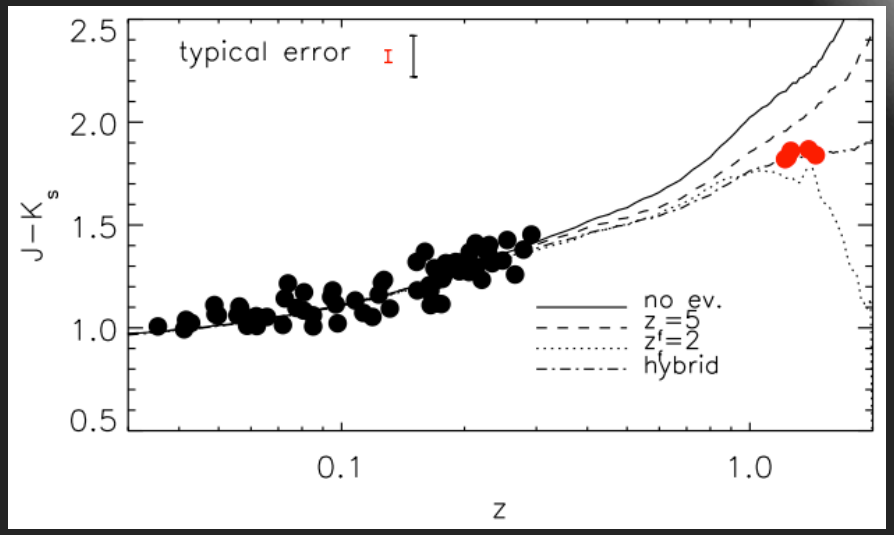
Overview

- Introduction to submillimeter galaxies
- The target: GN20
- The data: Old and New
- Results so far
- Preliminary analysis
- Conclusions

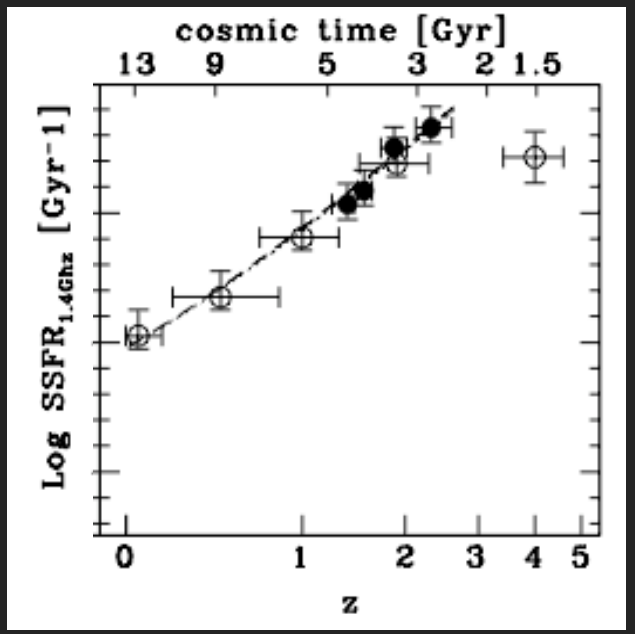


What We Observe

- The stars in massive ellipticals formed
  - quickly (timescales ≤ 1 Gyr)
  - at early times (z > 2)
- Old stellar populations observed in early-type galaxies at z ≥ 1 ➔ higher formation redshifts
- The more massive a galaxy, the earlier/faster the SF
  - SF preferentially quenched in more massive galaxies with cosmic time
- We should see population of intensely star forming, clustered galaxies at high-z



Collins et al. 2009



Pannella et al. 2009

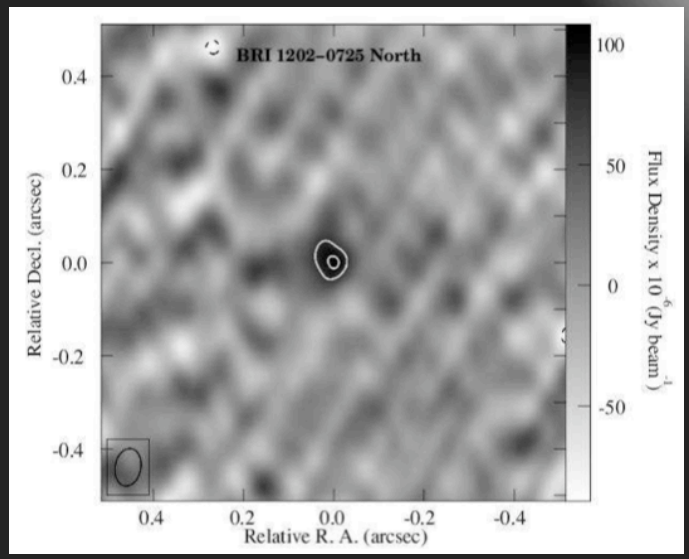
Submillimeter Galaxies (SMGs)

- Dusty, luminous starburst galaxies found in wide-field submillimeter surveys
- Gas-rich
- Relatively rare (10^{-5}-10^{-6} Mpc^{-3})
- Luminosities ~10^{13} $L_\odot$
- SF-dominated, SFRs ~ 10^3 $M_\odot$ yr^{-1} (Alexander+2005, Menendez-Delmestre+2007, Pope+2008, Clements+2008)
- May trace high over-densities (Stevens+2003, Aravena+2010)
  - Formation of clusters/massive ellipticals
- Space density peaks around z ~ 2.3 (Chapman+2003, Wagg+2009)
- High-redshift tail extends above z = 4 (Schinnerer+2008,2009, Coppin+2009)
- Likely numerous enough above z=3.5 to account for massive galaxies between z=2 and z=3 (Daddi+2009)

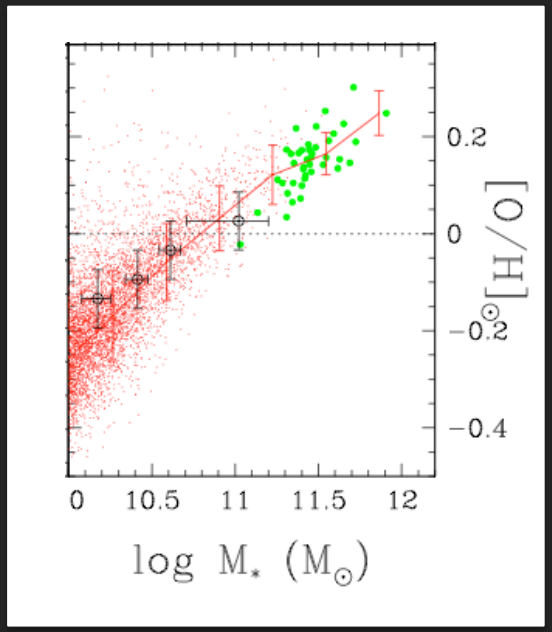
The Big Question

What is driving the intense star formation?

- **Gas-rich mergers** (Tacconi+2006,2008, Narayanan +2010)
  - Starburst-dominated, early stage
  - Scales ~few kpc, in nuclei
  - Timescale ~10^7 yr



Momjian et al. 2005

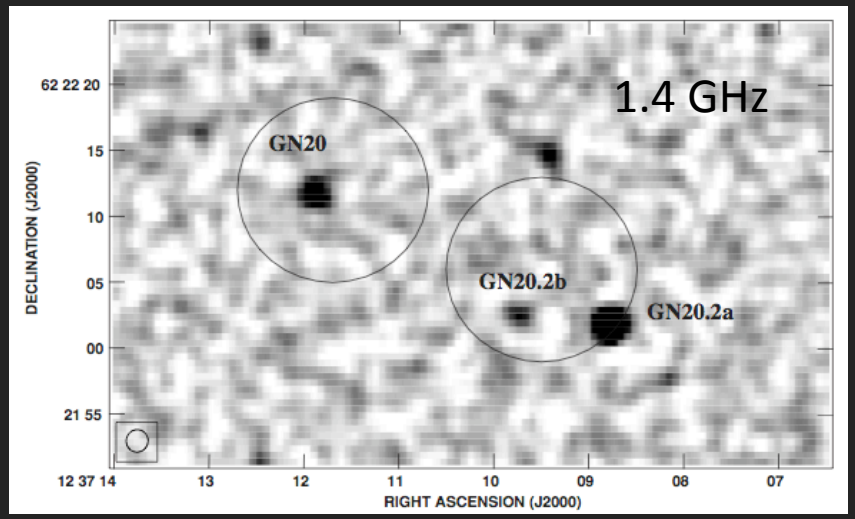


Dave et al. 2010

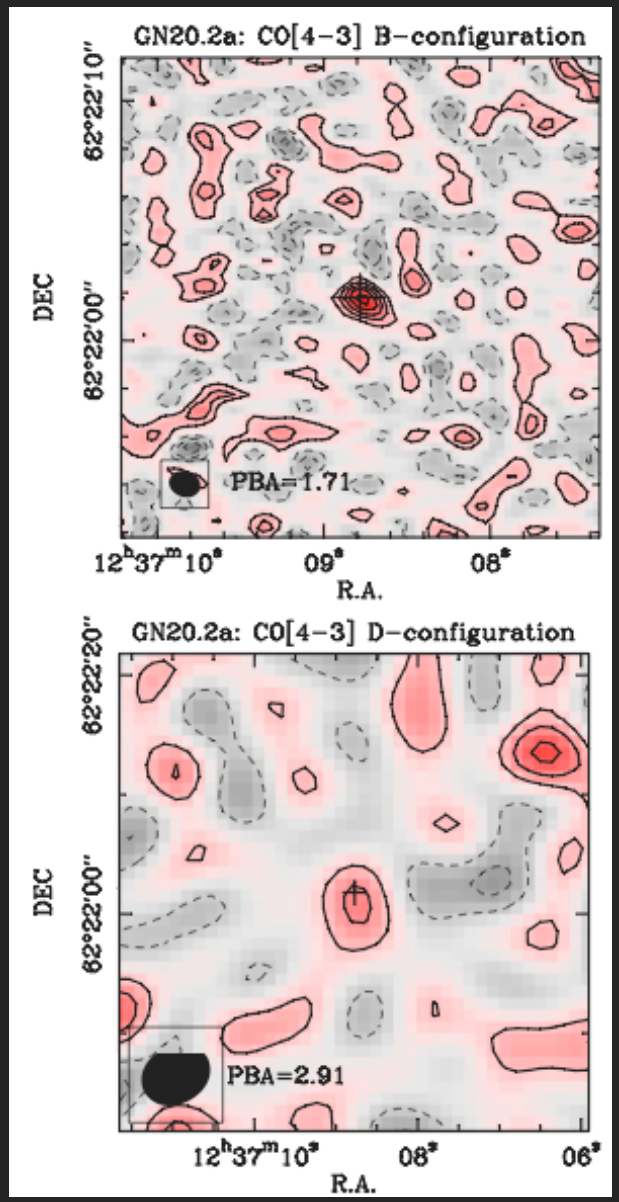
- **Cold-mode accretion (CMA)** (Dave+2010)
  - Gas flows in along cold, dense filaments from IGM
  - Continuously streams in, cooling rapidly (no shock-heating)
  - Clouds of enhanced SF occur every few kpc across disk, eventually migrating to center to form stellar bulge
  - Timescales ~1 Gyr

GN20

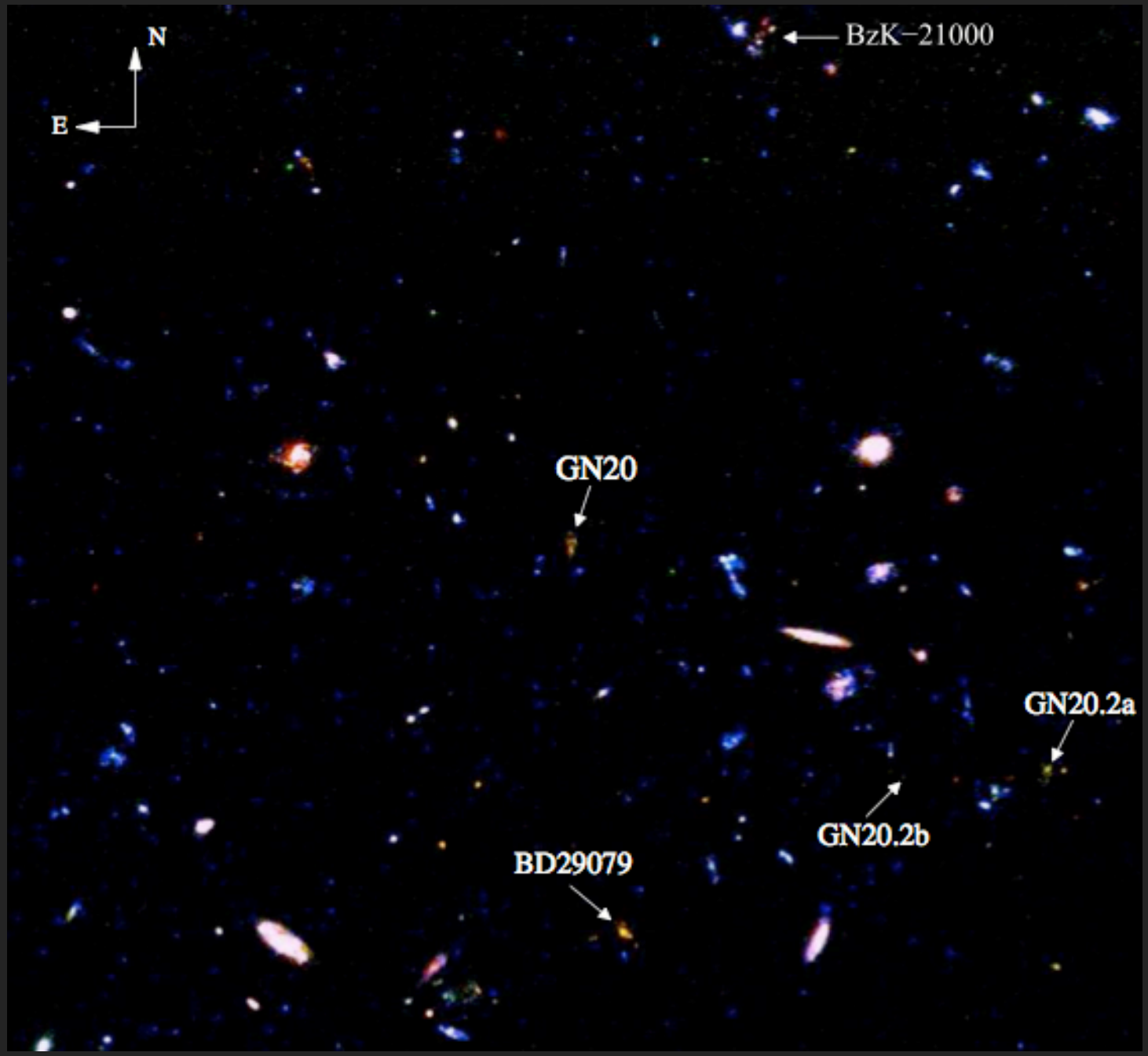
- Originally detected with SCUBA (Pope 2007)
- Discovered serendipitously in CO (Daddi et al. 2009)
- z = 4.05
- One of the most luminous starburst galaxies known at z > 4
- Field shows significant overdensity, indicating proto-cluster environment
- Contains three SMGs: GN20, GN20.2a, GN20.2b
- All within 20” (140 kpc projected)



Morrison et al. 2010



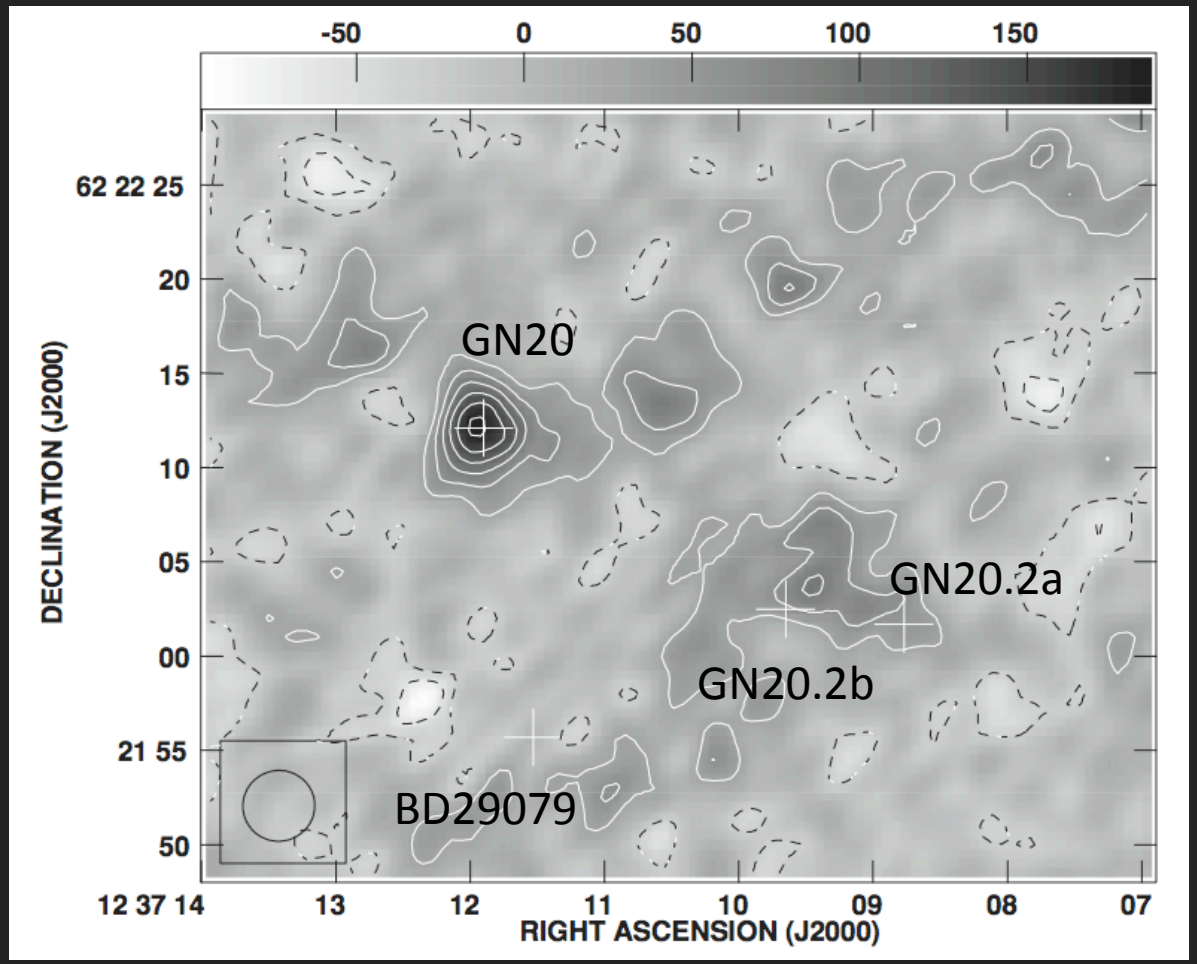
Daddi et al. 2009

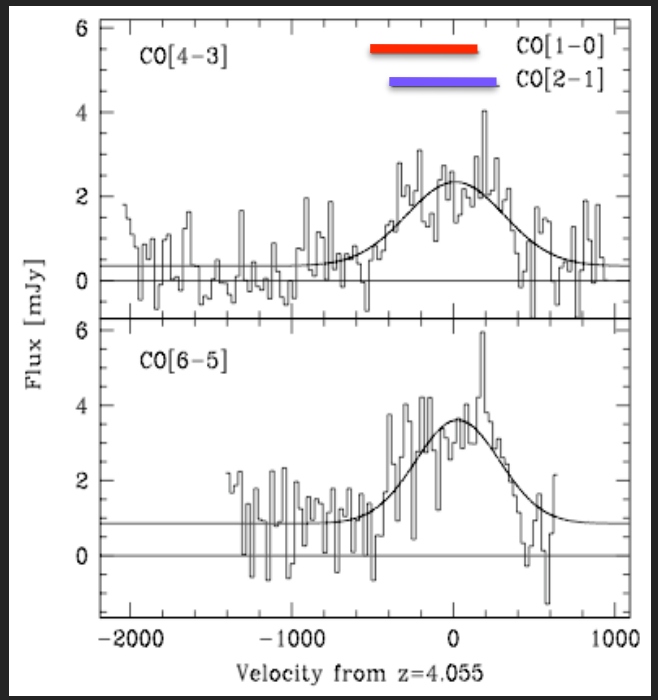


Daddi et al. 2009

Previous VLA Observations

GN20 field in CO 1-0



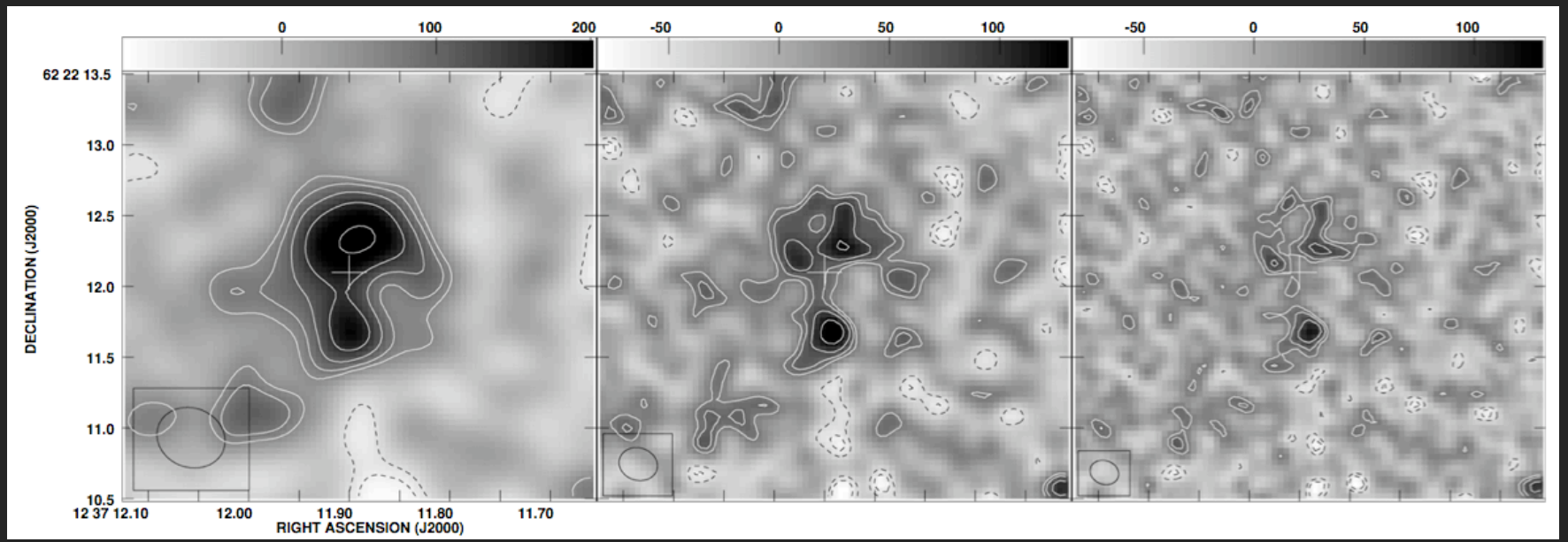


Carilli et al. 2010

Previous VLA Observations

CO 2-1, B+C+D

Carilli et al. 2010

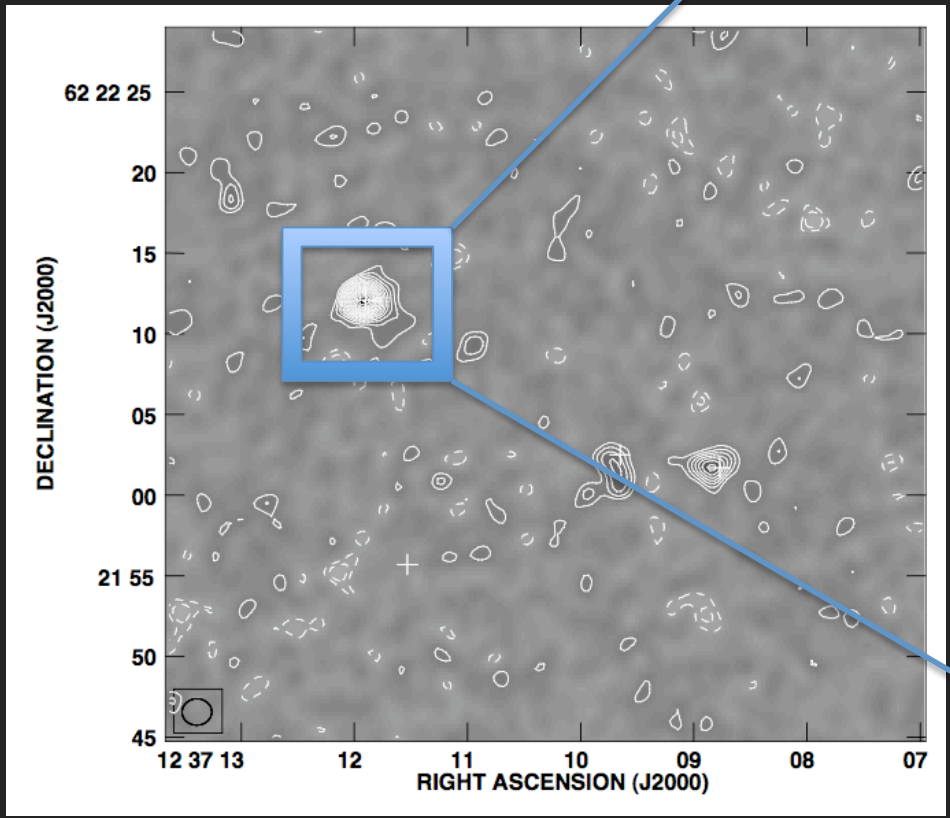


0.45” 0.25” 0.18”

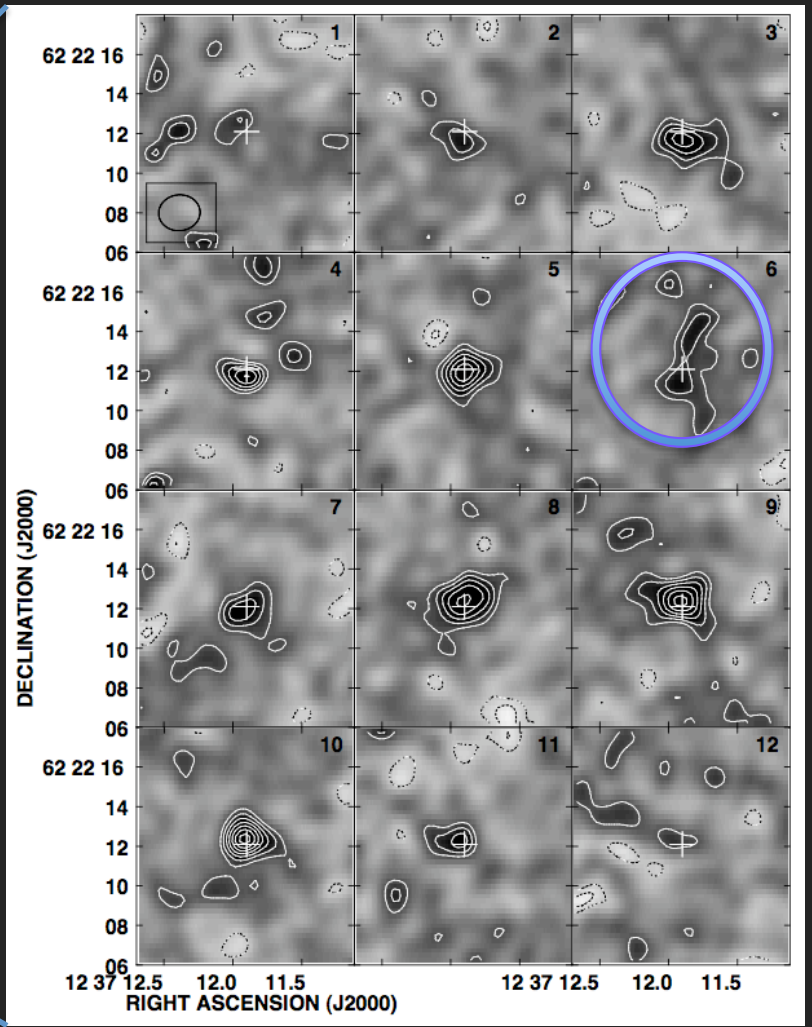
EVLA: D-Array

- CO 2-1

GN20 Field



GN20

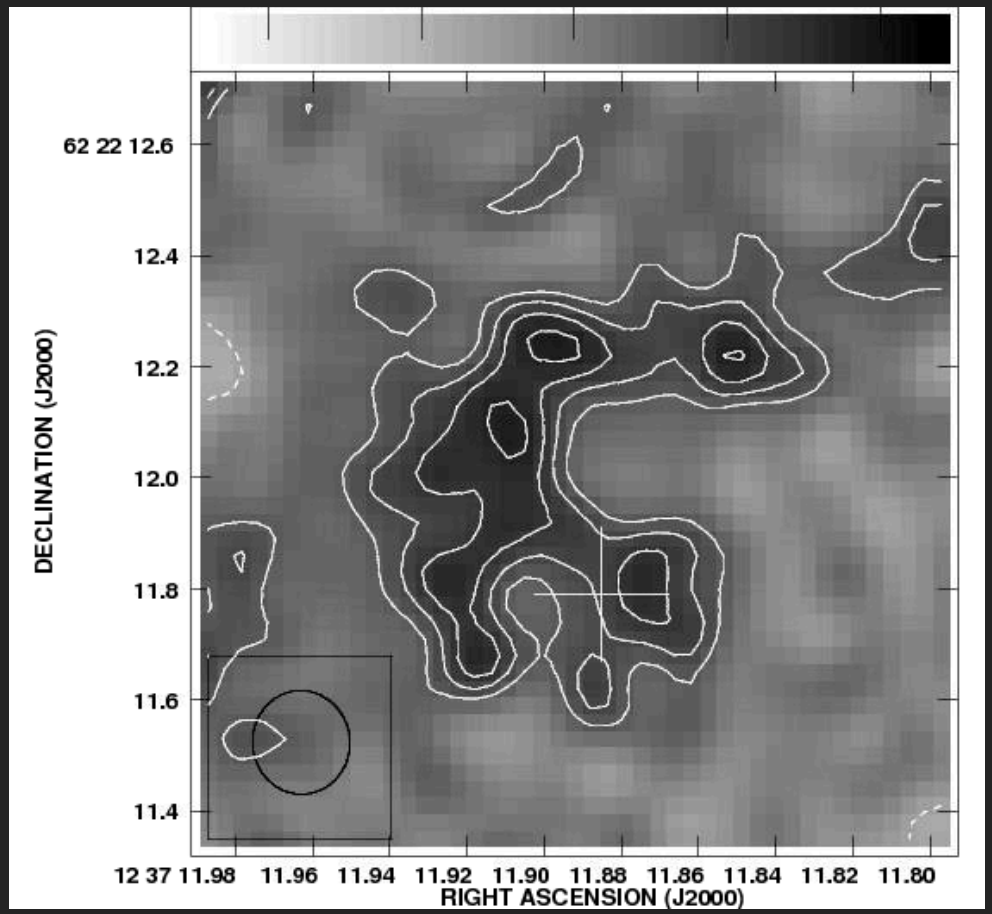


Carilli et al. 2011

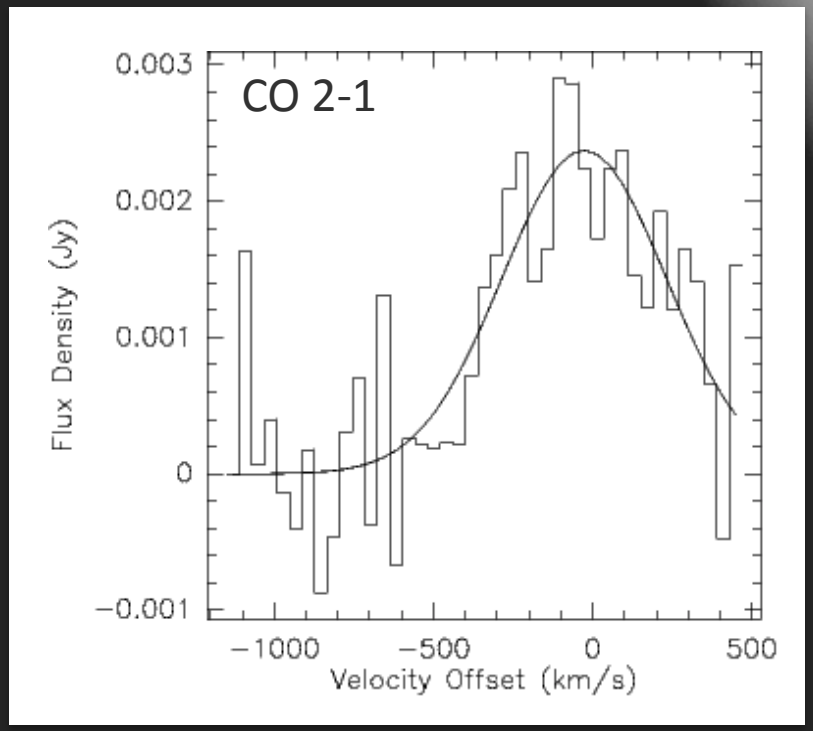
EVLA: B+D-Array

>100 hours

GN20: Resolution 0.18”/1.2 kpc



Hodge et al. in prep



Molecular Gas Mass:

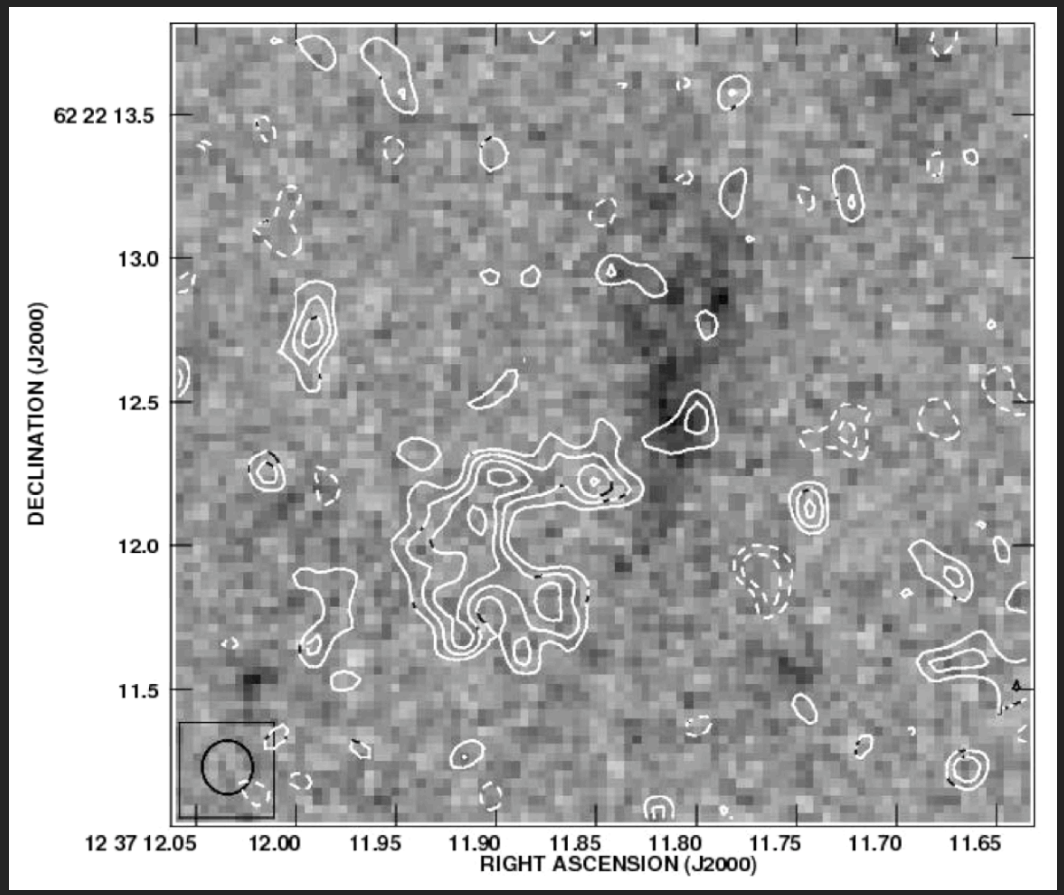
- $M_{H2} = 1.9 \times 10^{11}\ M_{\odot}$ ($\alpha = 0.8$)

Dynamical Mass:

- $M_{Dynamical} = 8.3 \times 10^{10}\ M_{\odot}$

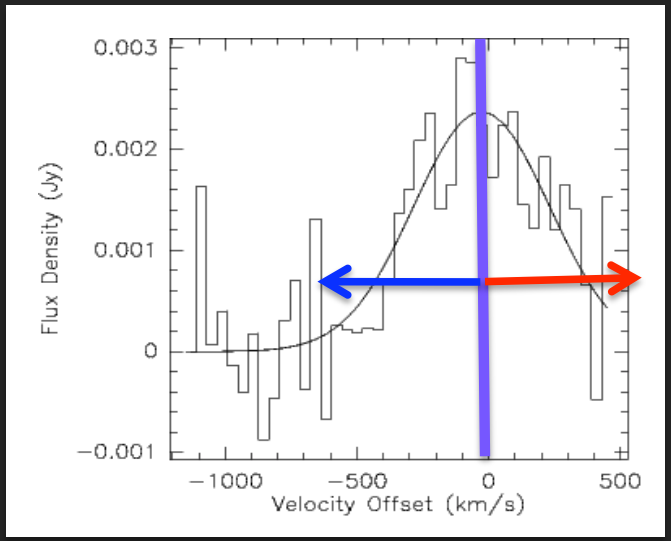
Gas Versus Stars

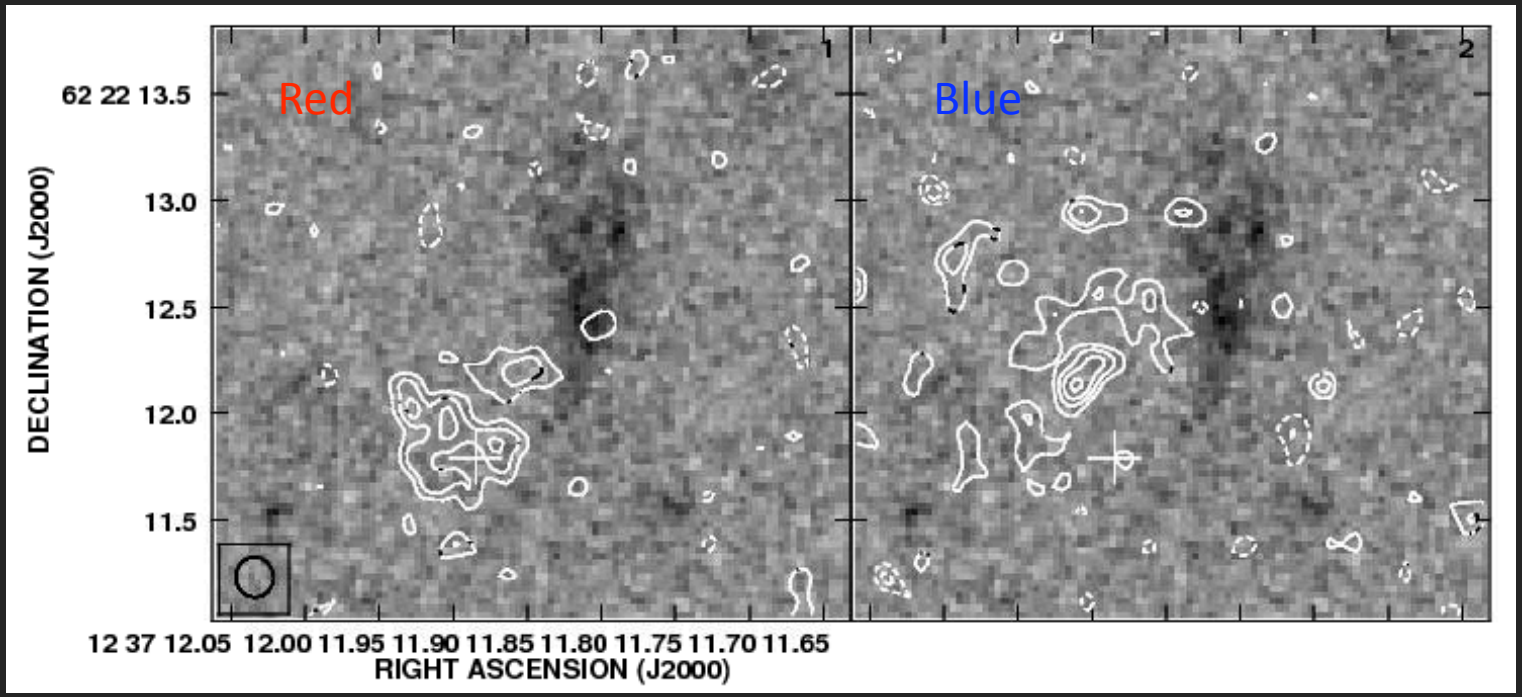
- Obscuration?
- Or due to astrometric uncertainty…



Grey scale: HST+ACS I band; contours: CO 2-1

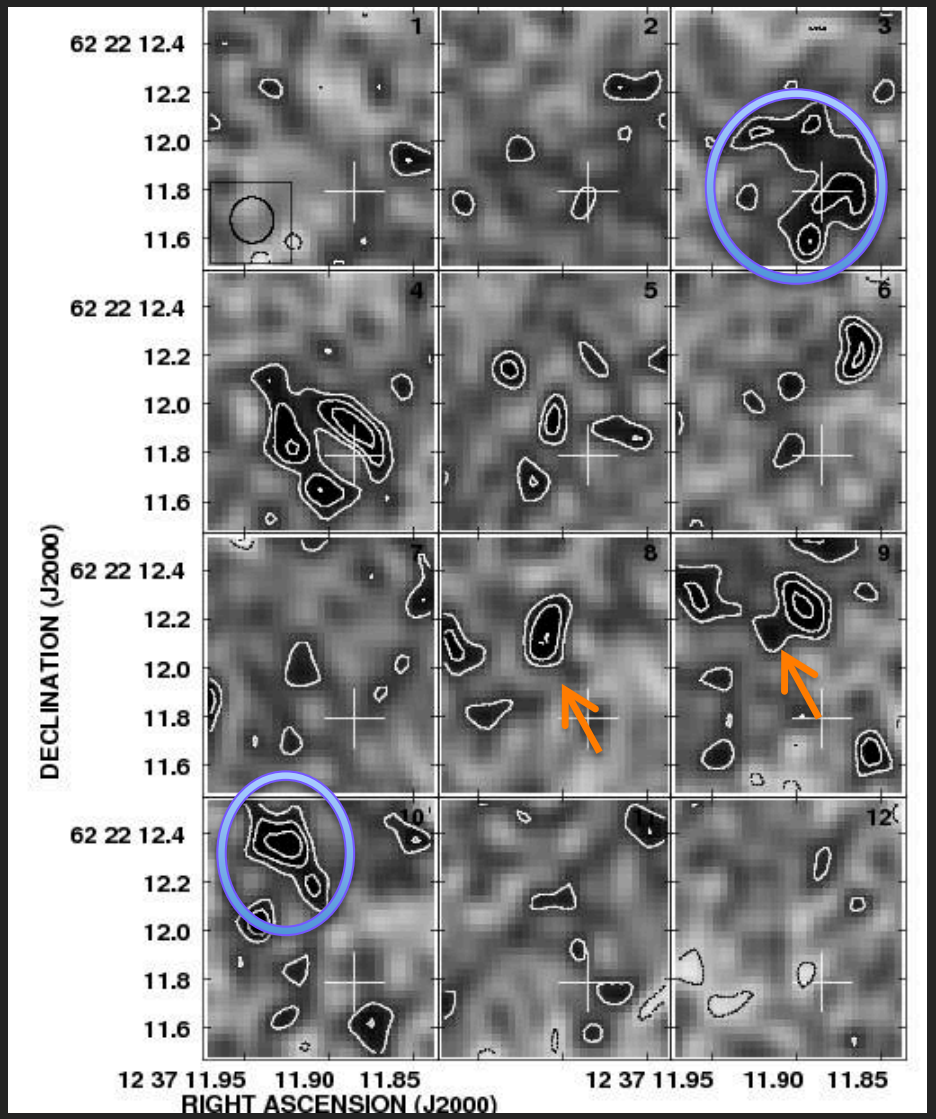
Gas Versus Stars





Grey scale: HST+ACS I band; contours: CO 2-1

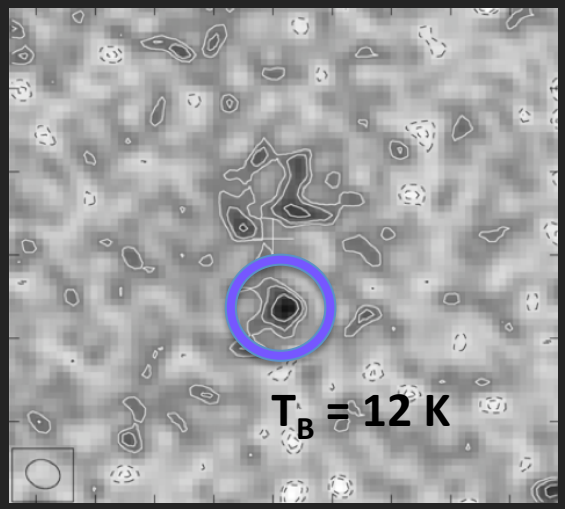
KINEMATICS



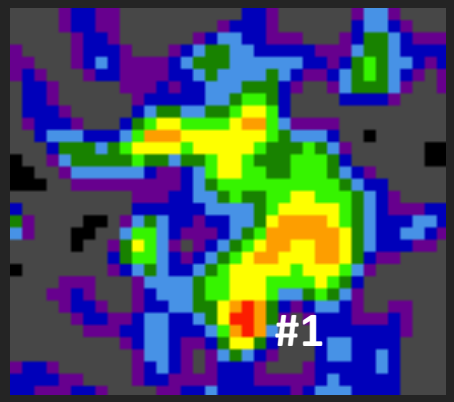
(80 km/s channels)

Brightness Temperatures

Previous VLA Data:

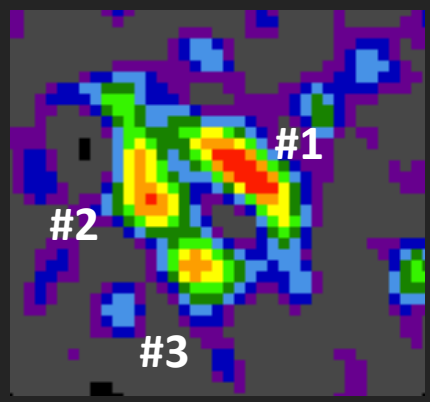


Channel 3 of 12



#1: T_B = 24K

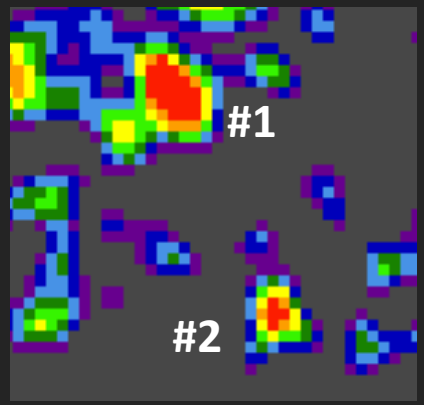
Channel 4 of 12



#1: T_B = 25K
#2: T_B =22K
#3: T_B =21K

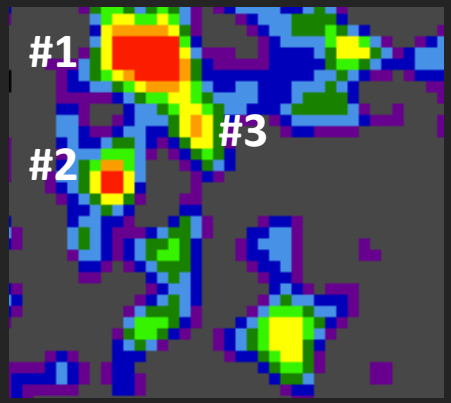
New EVLA Data:

Channel 9 of 12



#1: T_B =22K
#2: T_B =19K

Channel 10 of 12



#1: T_B =25K
#2: T_B =20K
#3: T_B =17K

Conclusions

- This is some of the highest quality data on a high-z SMG to date
- Because of the spatial/spectral resolution, we are able, for the first time, to investigate the brightness temperatures of individual gas clumps
- Despite being one of the brightest sources out there, we still needed a huge investment of EVLA time to get only to this low S/N regime
- This high spectral and spatial resolution data gives a preview of what will become possible on a regular basis with ALMA