THE VERY LARGE ARRAY
THE NEXT GENERATION

Galaxy assembly through cosmic time

Jacqueline Hodge
&
The high-z working group

US Radio/mm/sub-mm Science Futures II, Baltimore, 3 Aug 2016

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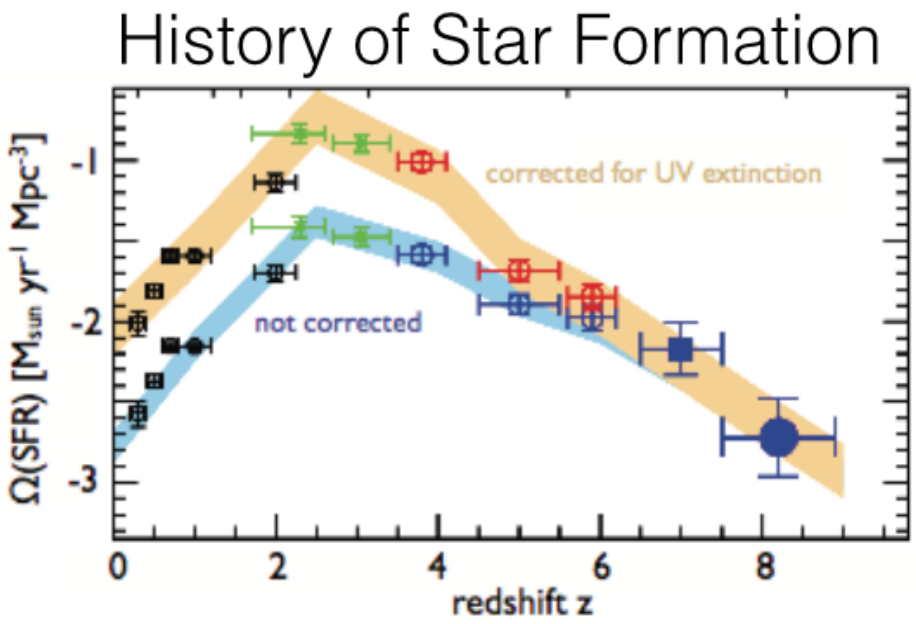
Key Science Projects:

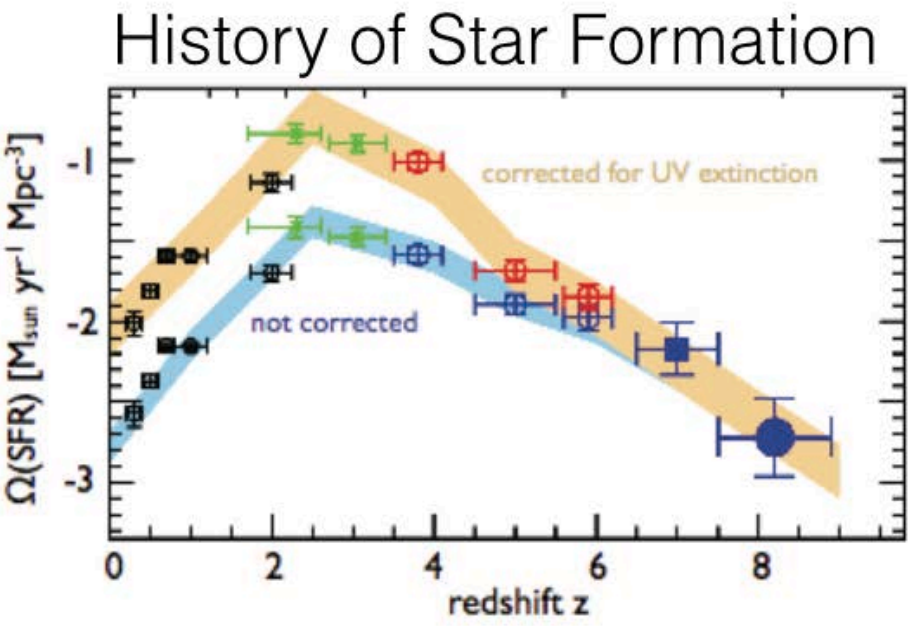
1. The cold gas history of the universe
2. Galactic dynamics at high-z
3. Tracing star formation in early galaxies with dense gas
4. Measuring dust-unbaised star formation with free-free emission
5. Magnetic fields in galaxies

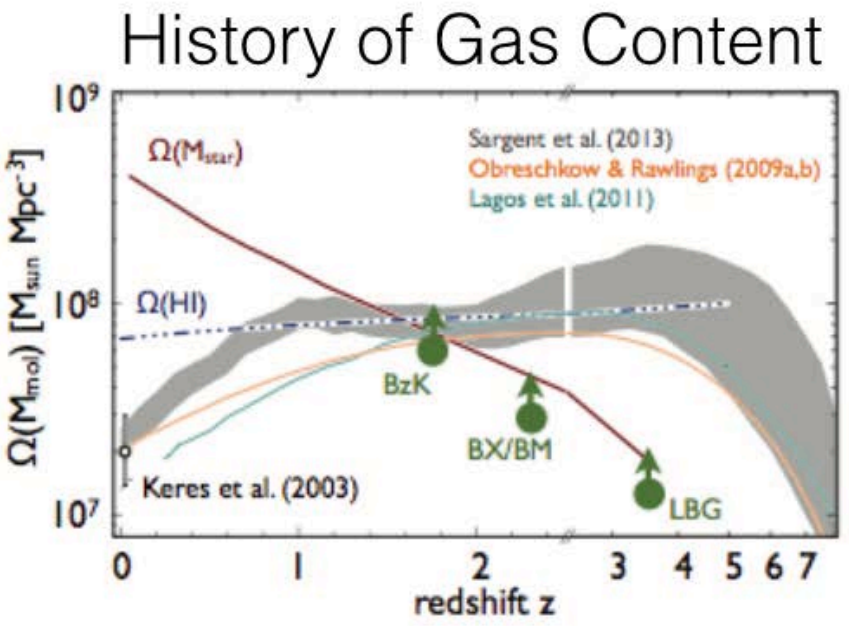
(See Casey, Hodge, Lacy et al. 2015 White Paper for further details)

Cold gas fuels galaxy evolution



Cold gas fuels galaxy evolution

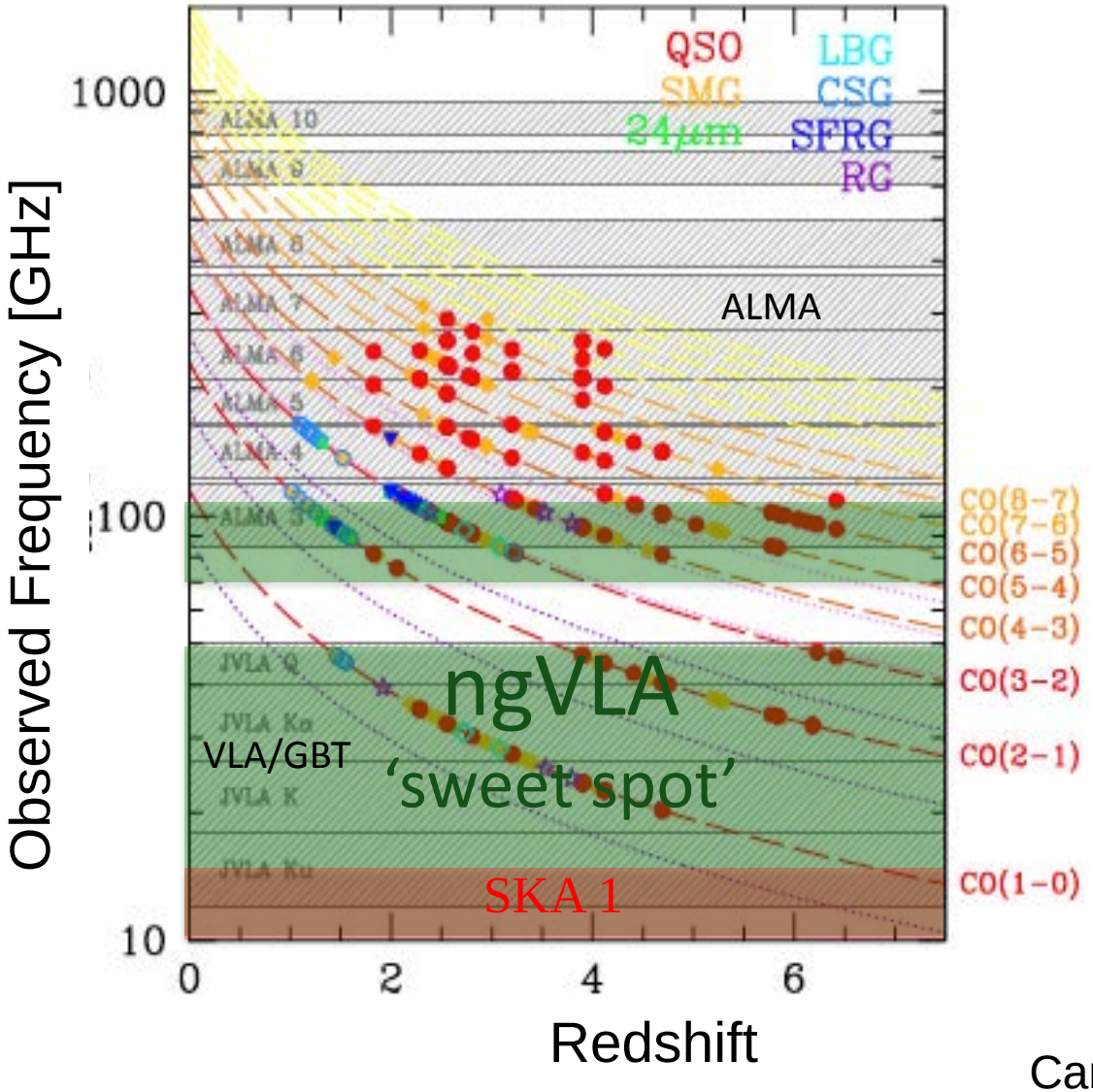




Carilli & Walter 2013 (ARA&A)

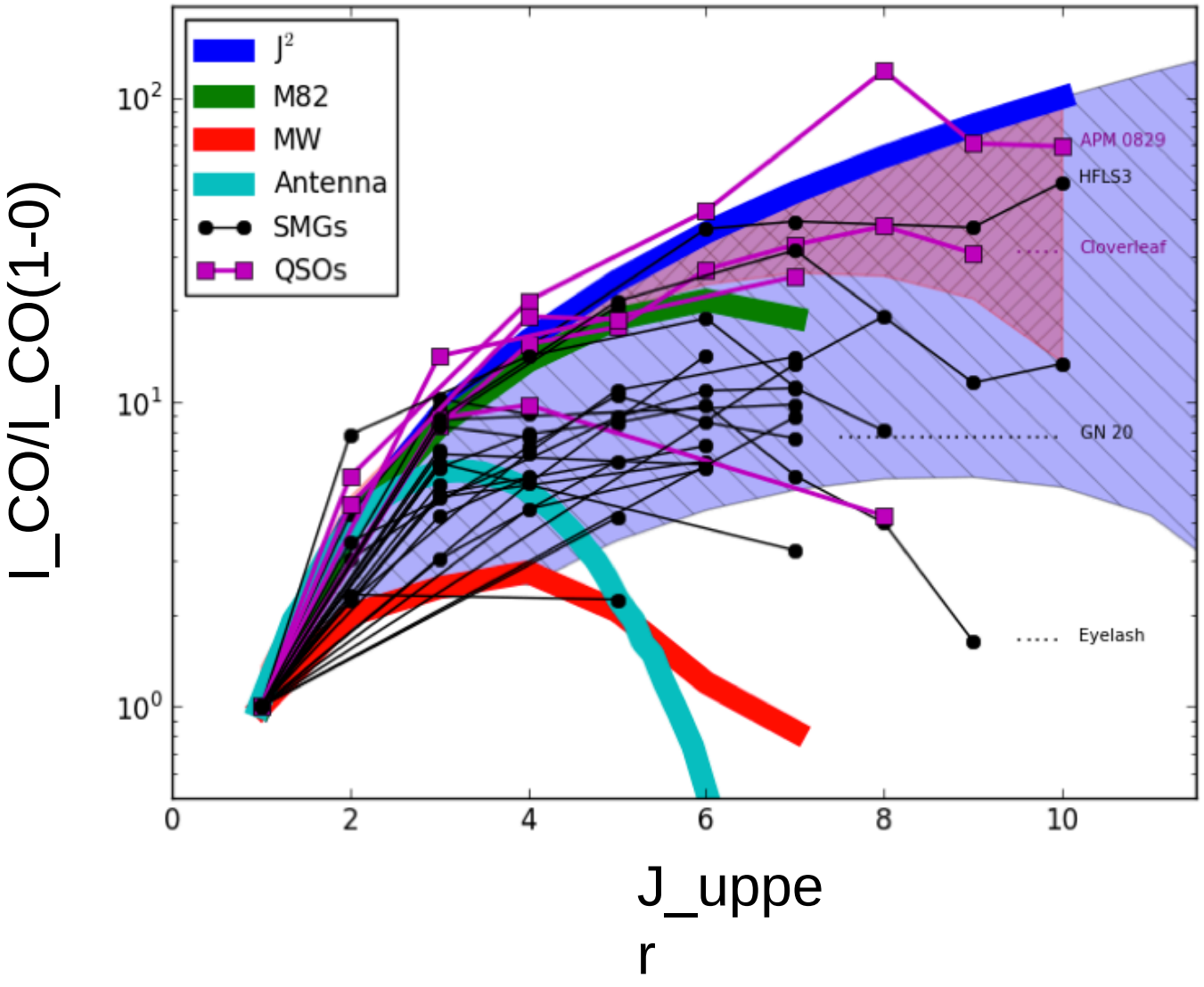
Cold gas fuels the growth of galaxies, yet the cold gas content in high-z galaxies is still poorly understood

Tracing molecular gas with CO



Carilli & Walter 2013

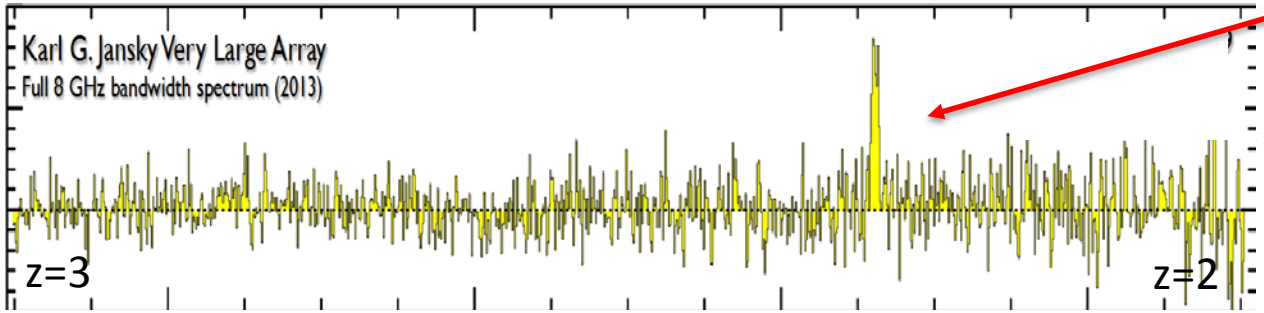
Low-J CO is critical

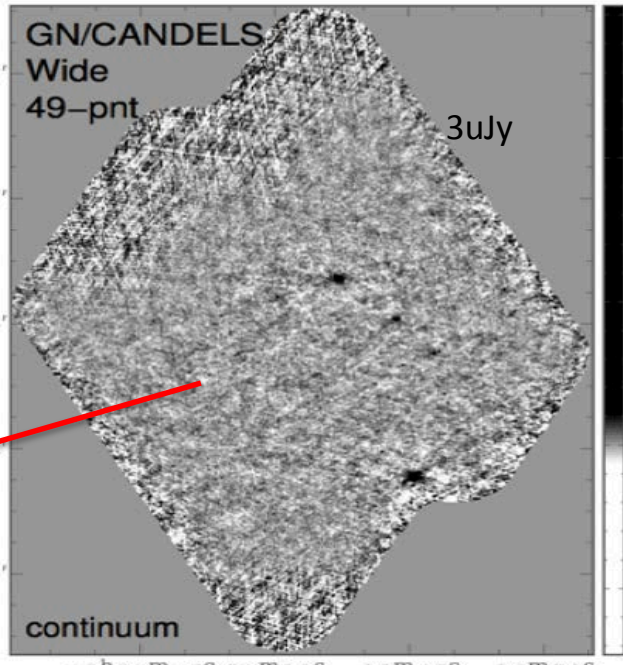


State of the art:

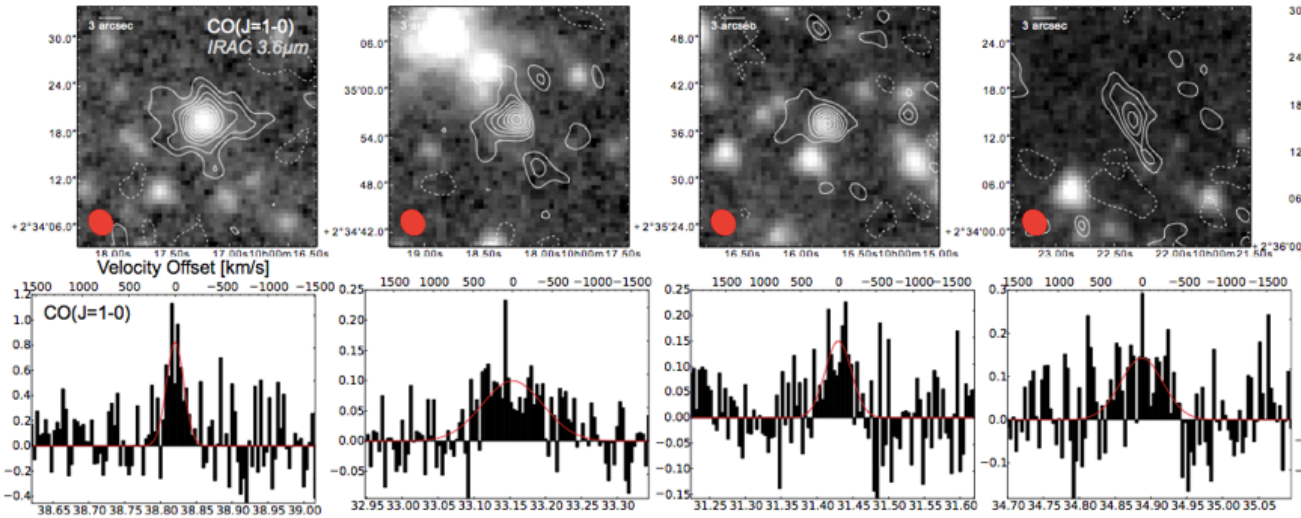
JVLA, ALMA CO Deep Fields

- JVLA 350hrs: 30-38GHz
- ALMA 40hrs: 82-115, 212 – 272



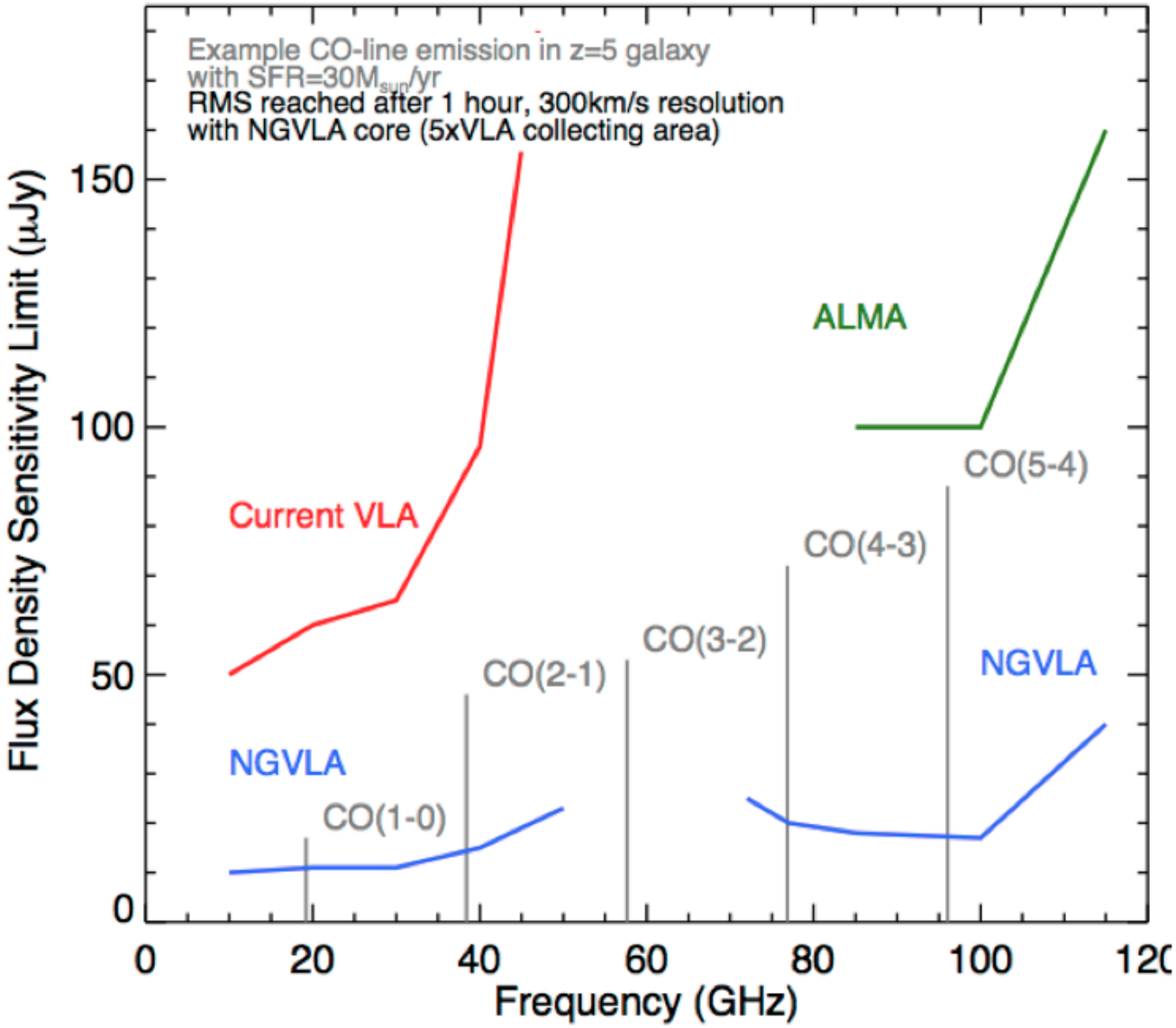


- Field sizes ~ 1 to 50 arcmin^2
- ~ 20 CO galaxies per survey, M_{H2} ~ 10^{10} M_o
- Main sequence: SFRs ~10-100 M_o/yr

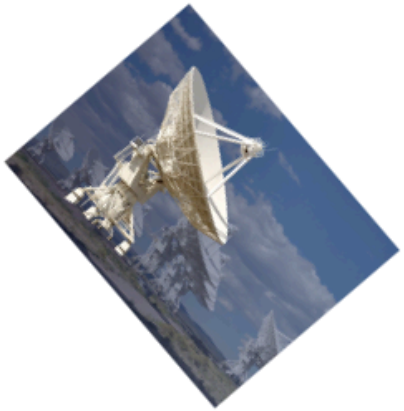


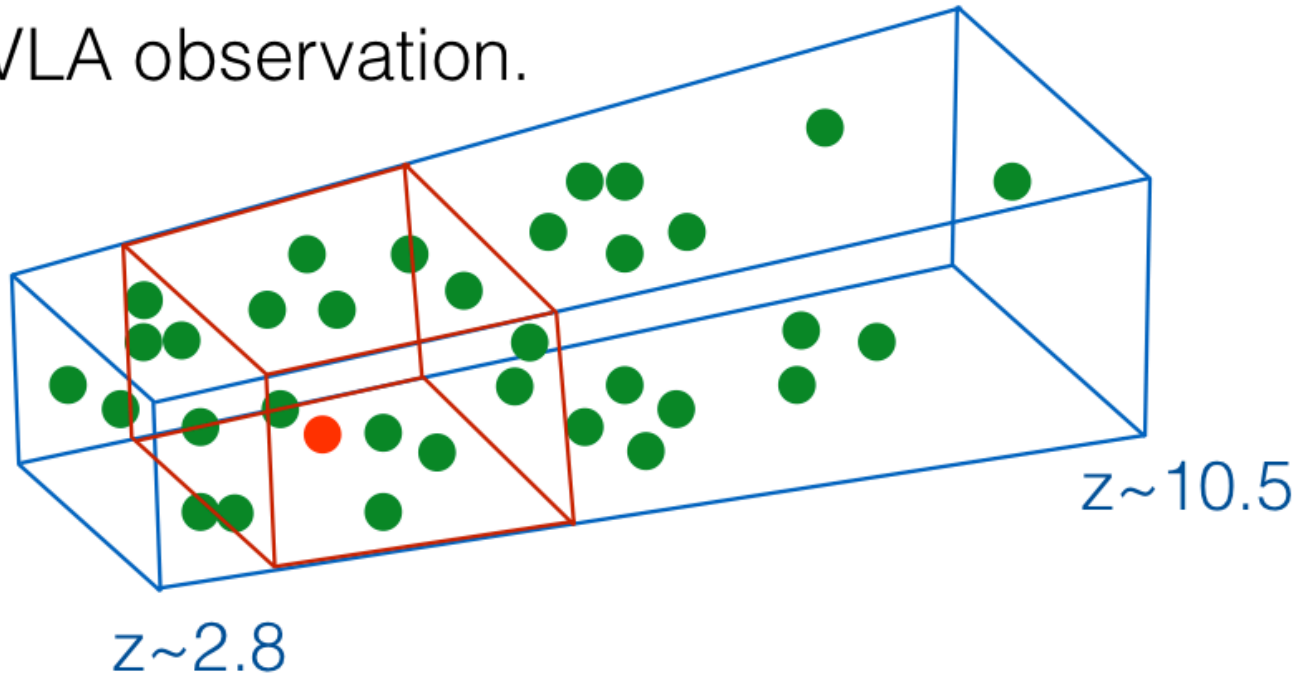
See Lentati+15; Walter+16a,b; Aravena+16a,b; Decarli+16a,b

Comparison for z=5 galaxy



An example ngVLA observation.





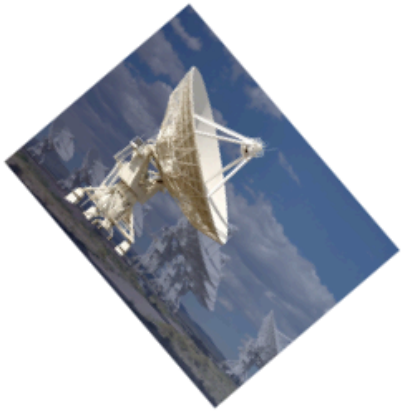
Detectable with current VLA

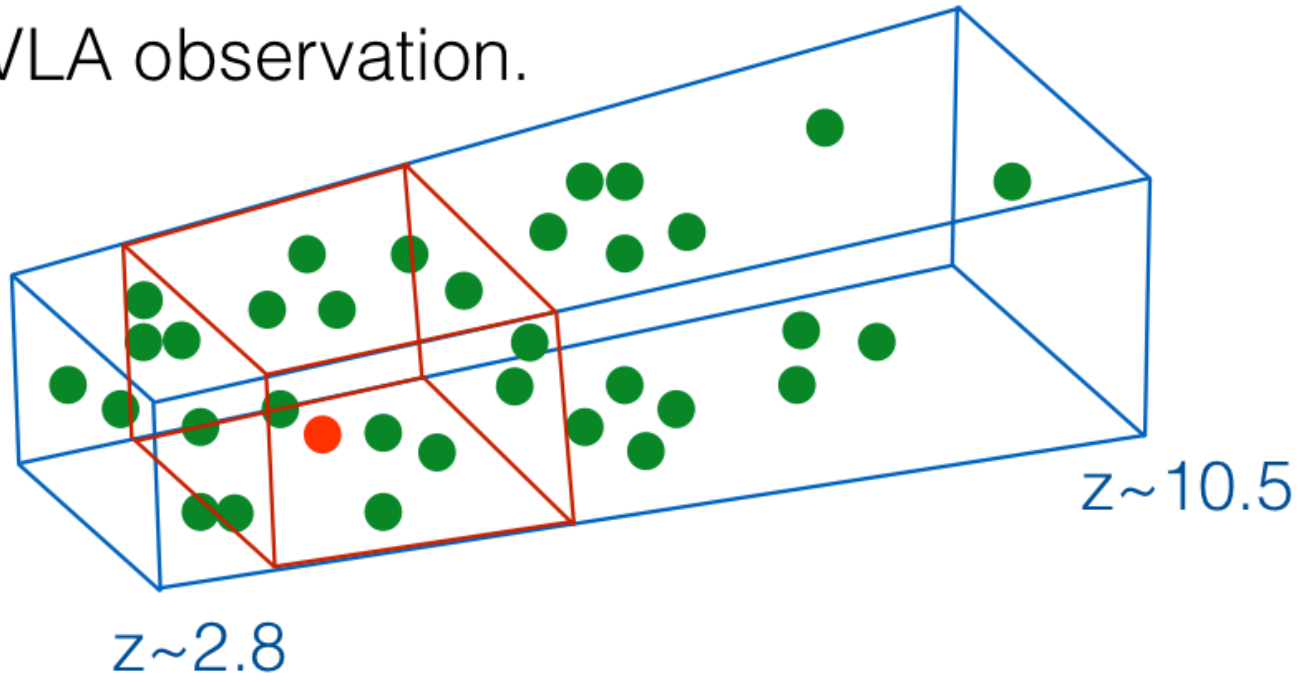
e.g. z=4.05 CO(1-0)
L'co~10^{10} Lsun
8GHz bandwidth
3.2<z<5.0

Detectable with ngVLA

2.8<z<10.5 CO(1-0)
L'co~2x10^{9} Lsun
3:1 bandwidth ratio
100s of blind CO(1-0) detections!

An example ngVLA observation.





Critical to complement e.g., JWST

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Detectable with ngVLA

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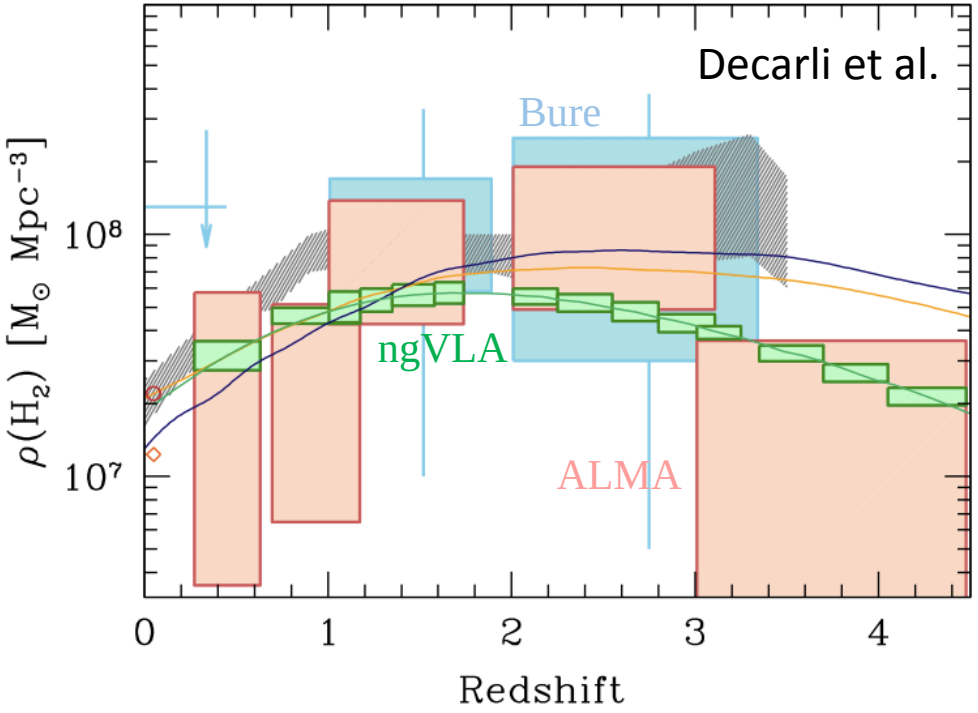
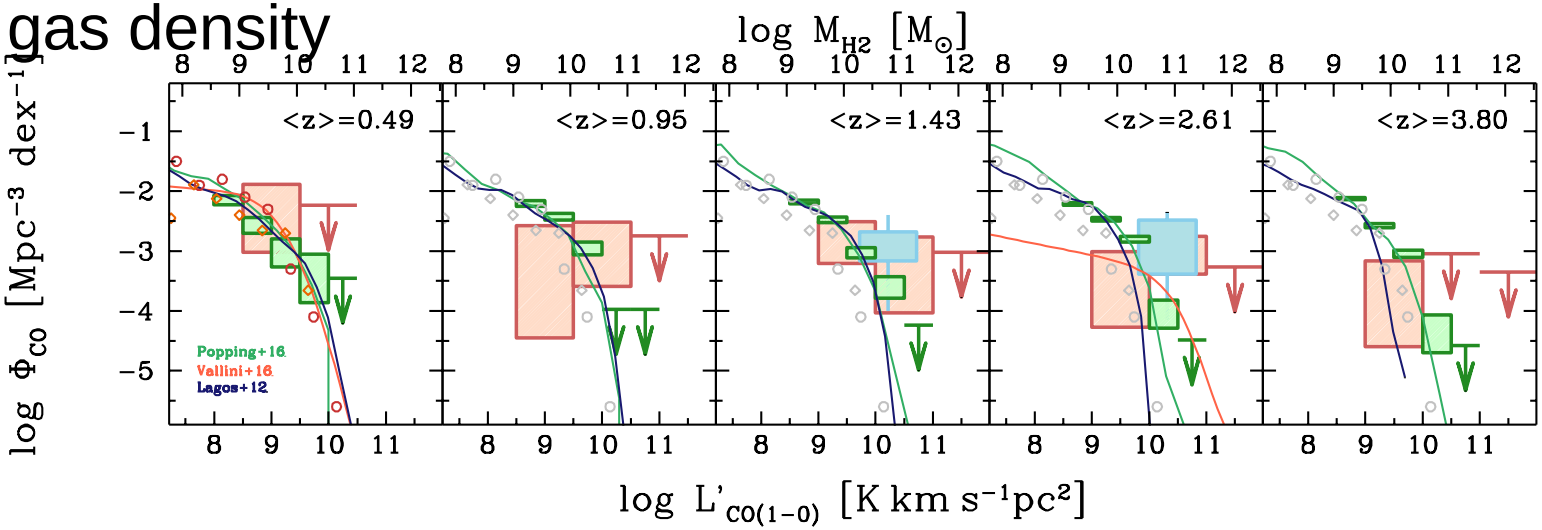
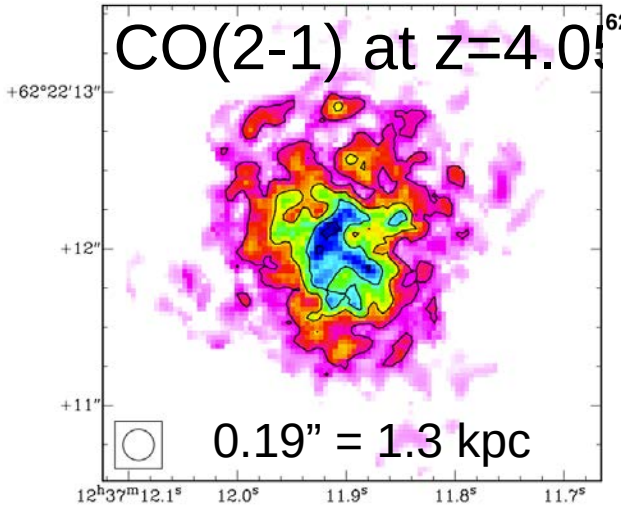
KSP#1: Cold gas history of universe

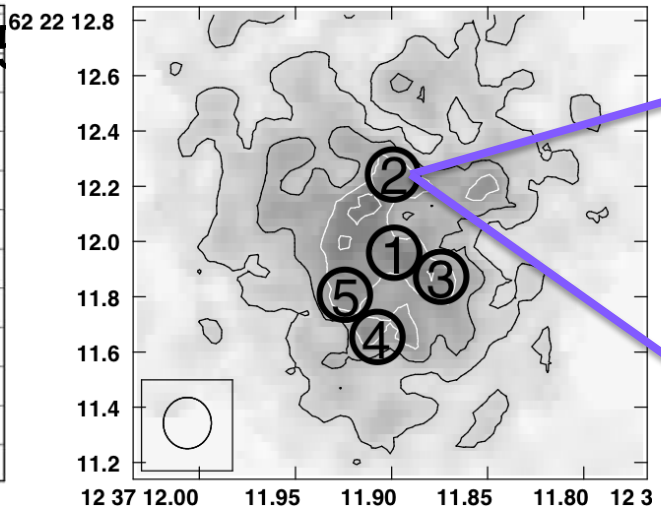
- 10's galaxies JVLA, ALMA: first-pass at CGHU
- NGVLA => 1000's of galaxies
- Quantitative evolution of CO luminosity function and cosmic gas density

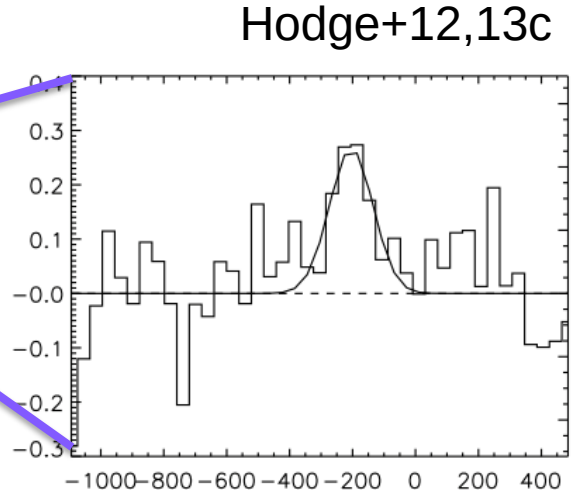


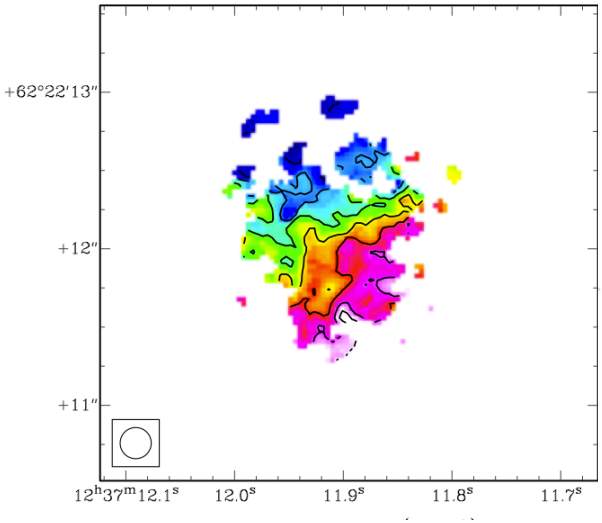


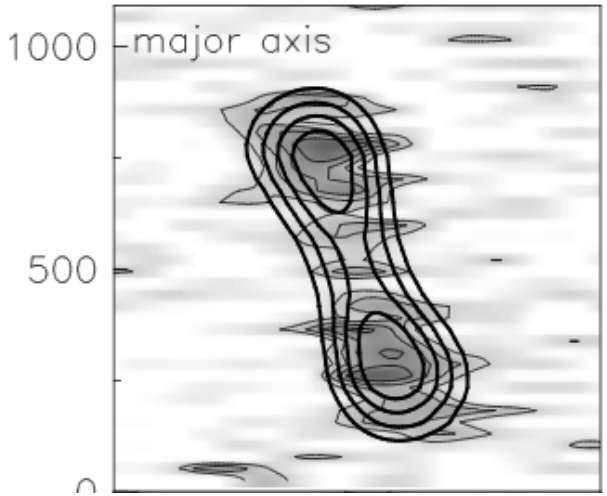
KSP#2: Galactic dynamics at high-z







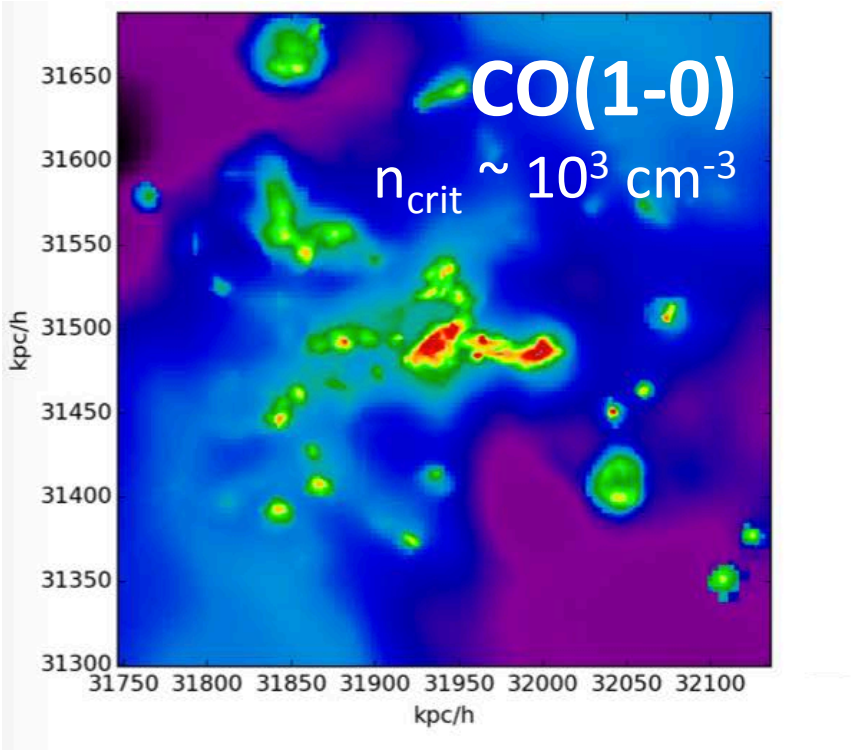


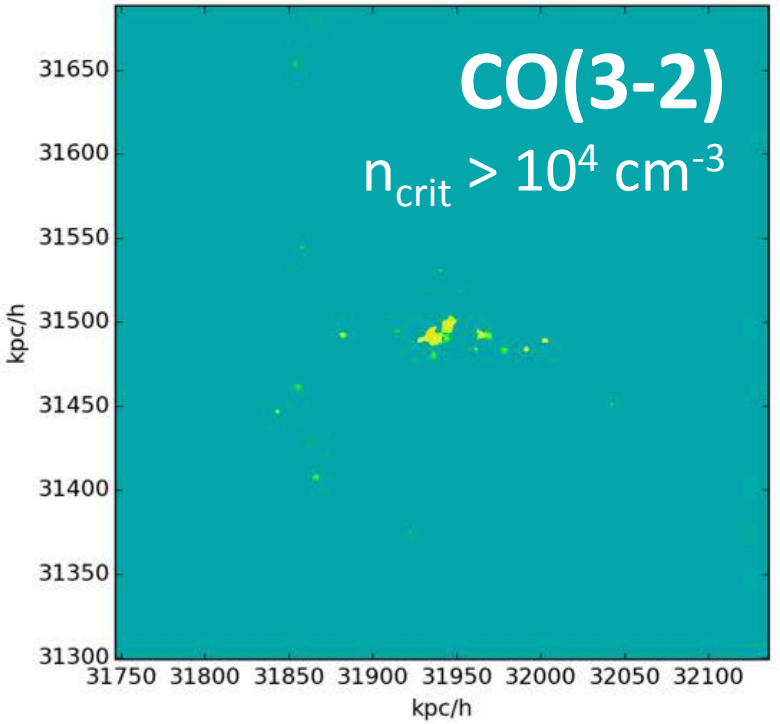


- Identify molecular gas clumps & quantify properties
- Model dynamics: mergers or disks?

Low critical densities probe large-scale substructure

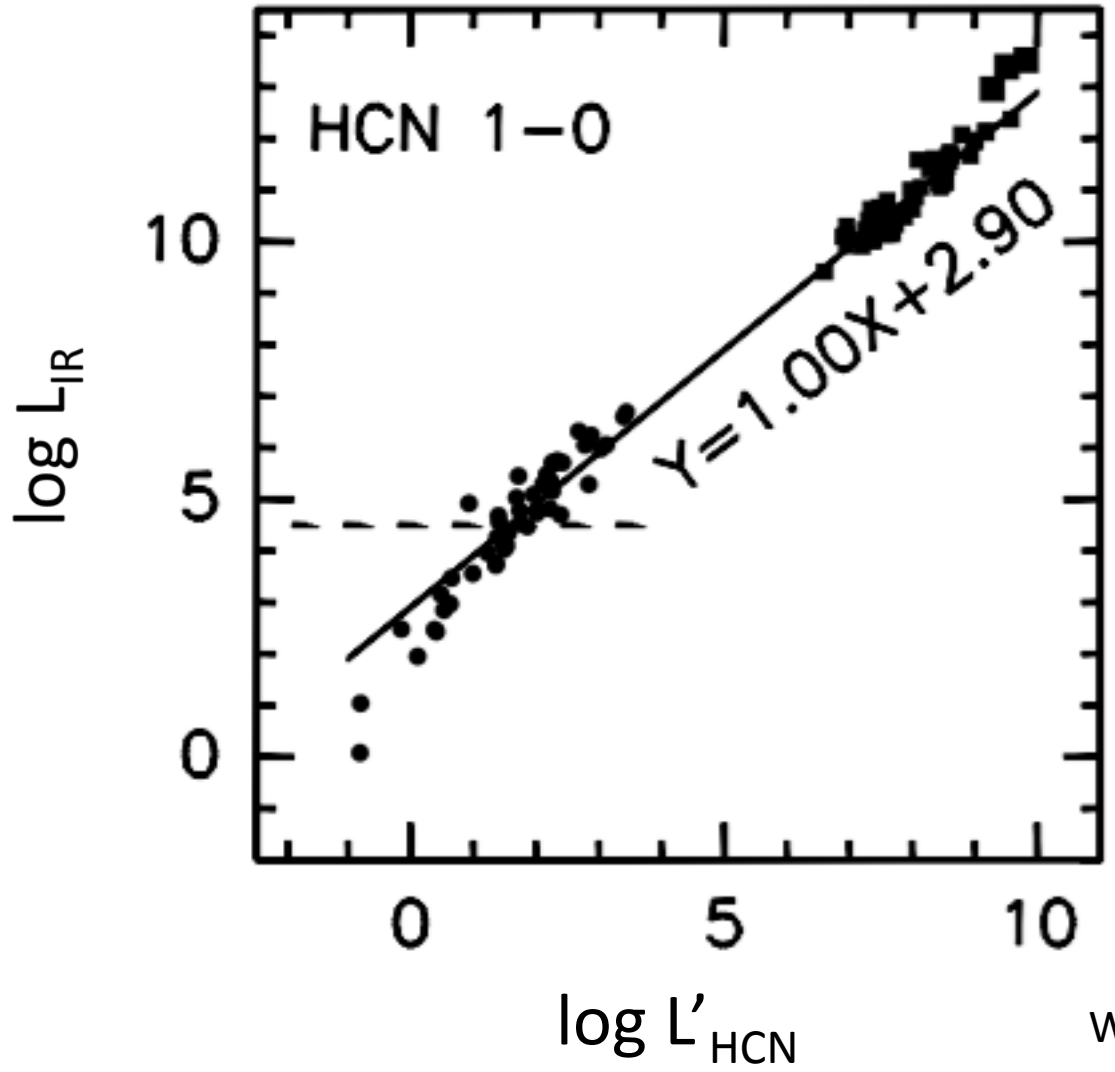
z ~ 3





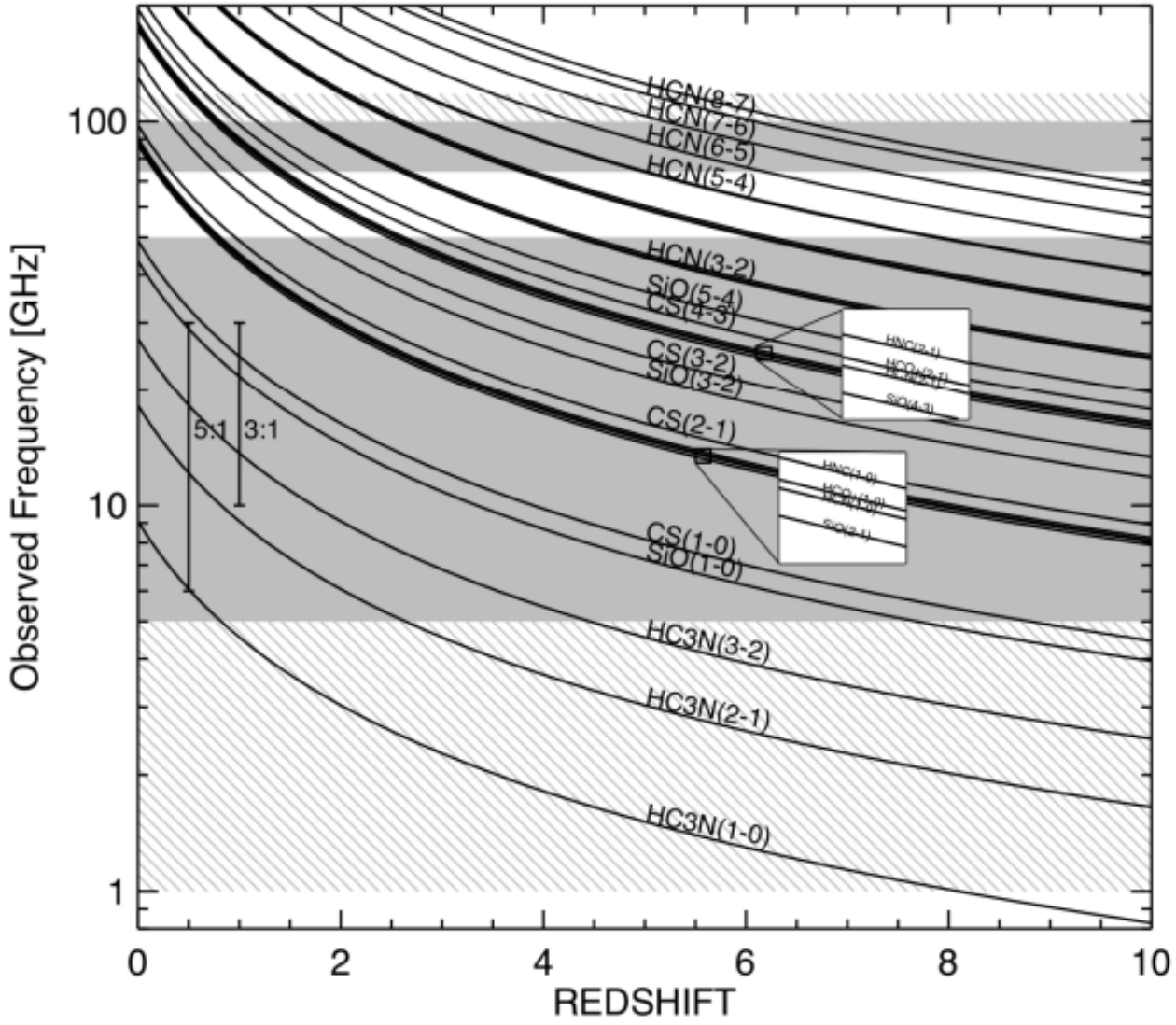
Narayanan Powderday RT code

Dense gas: a ‘fundamental unit’ of SF?

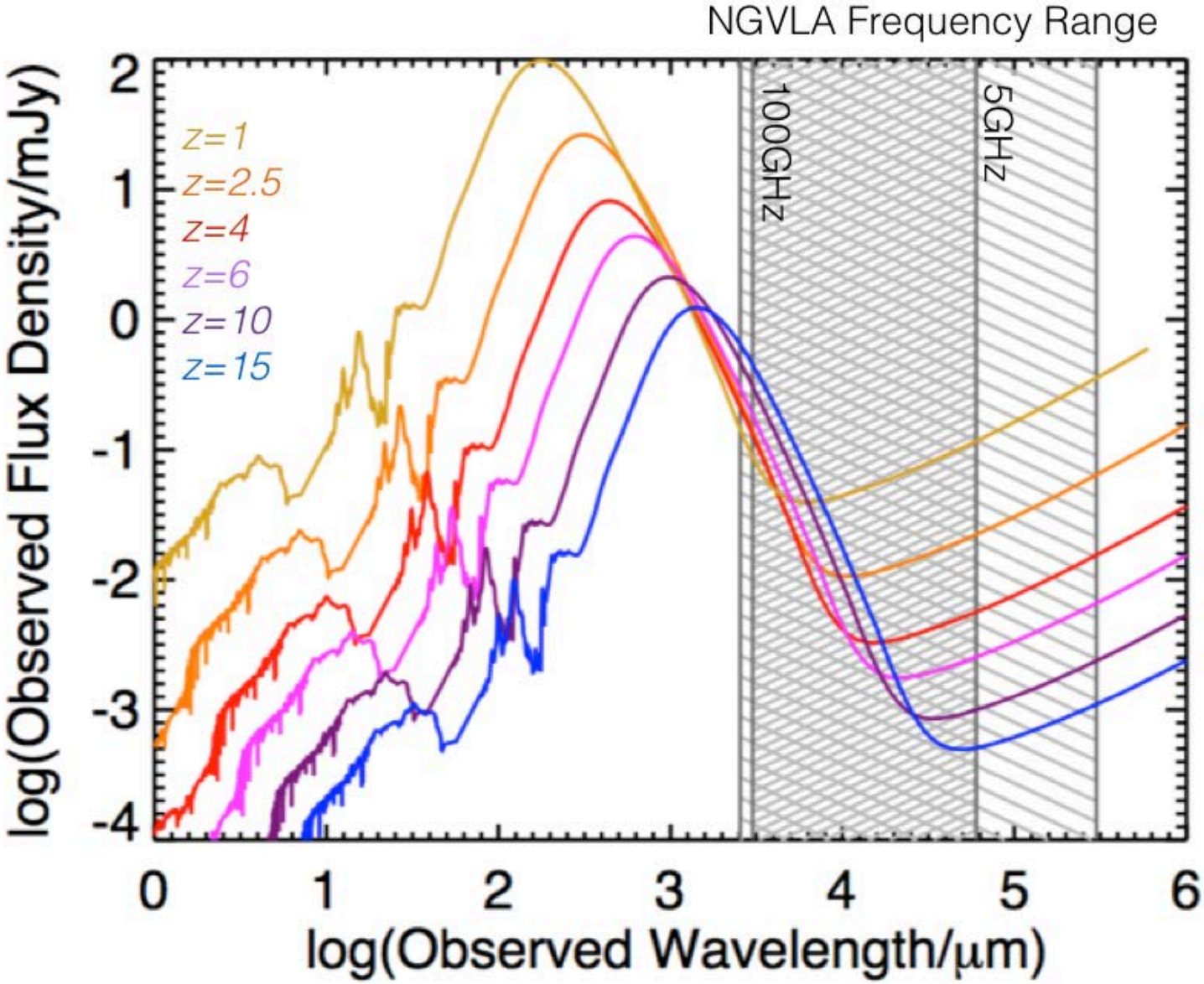


Wu et al. (2010)

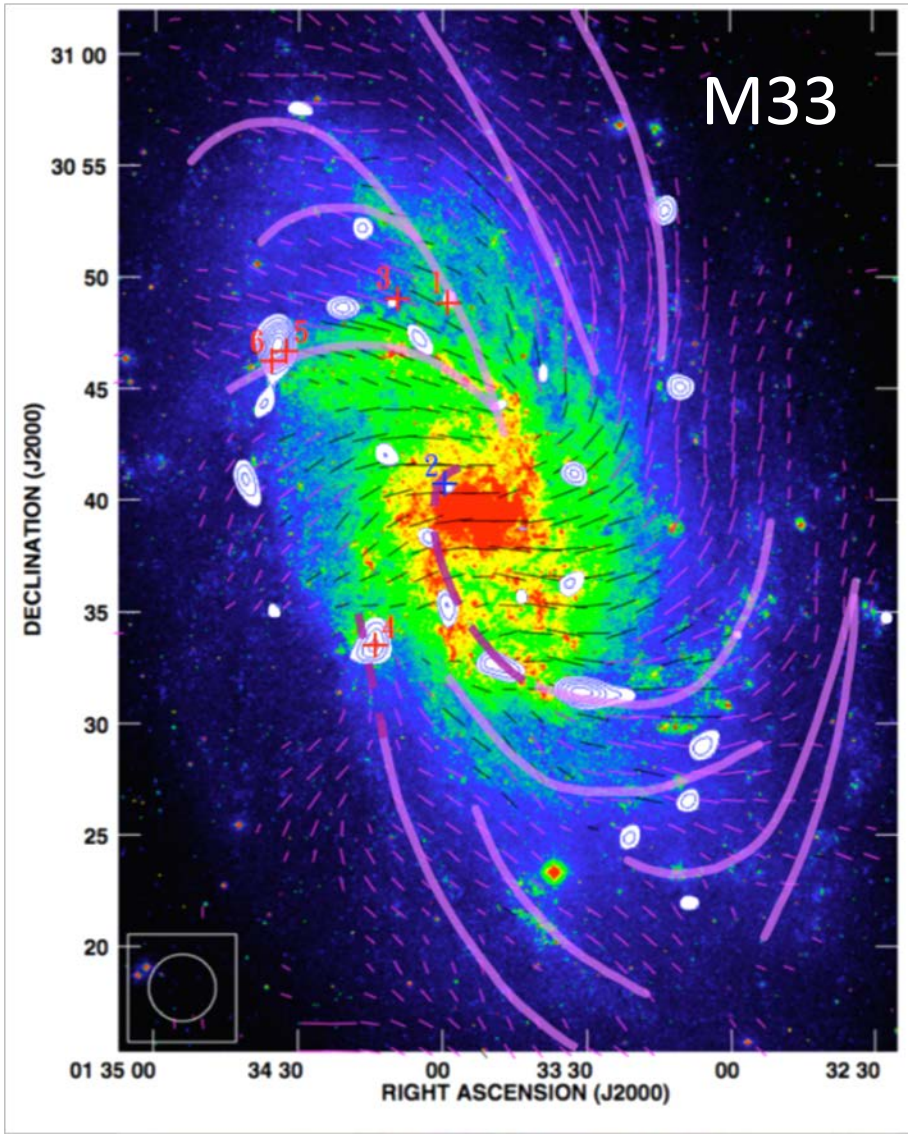
KSP#3: Tracing SF with dense gas



KSP#4: Continuum/Free-free emission



KSP#5: Polarimetry & cosmic magnetism



Li & Henning (2011)

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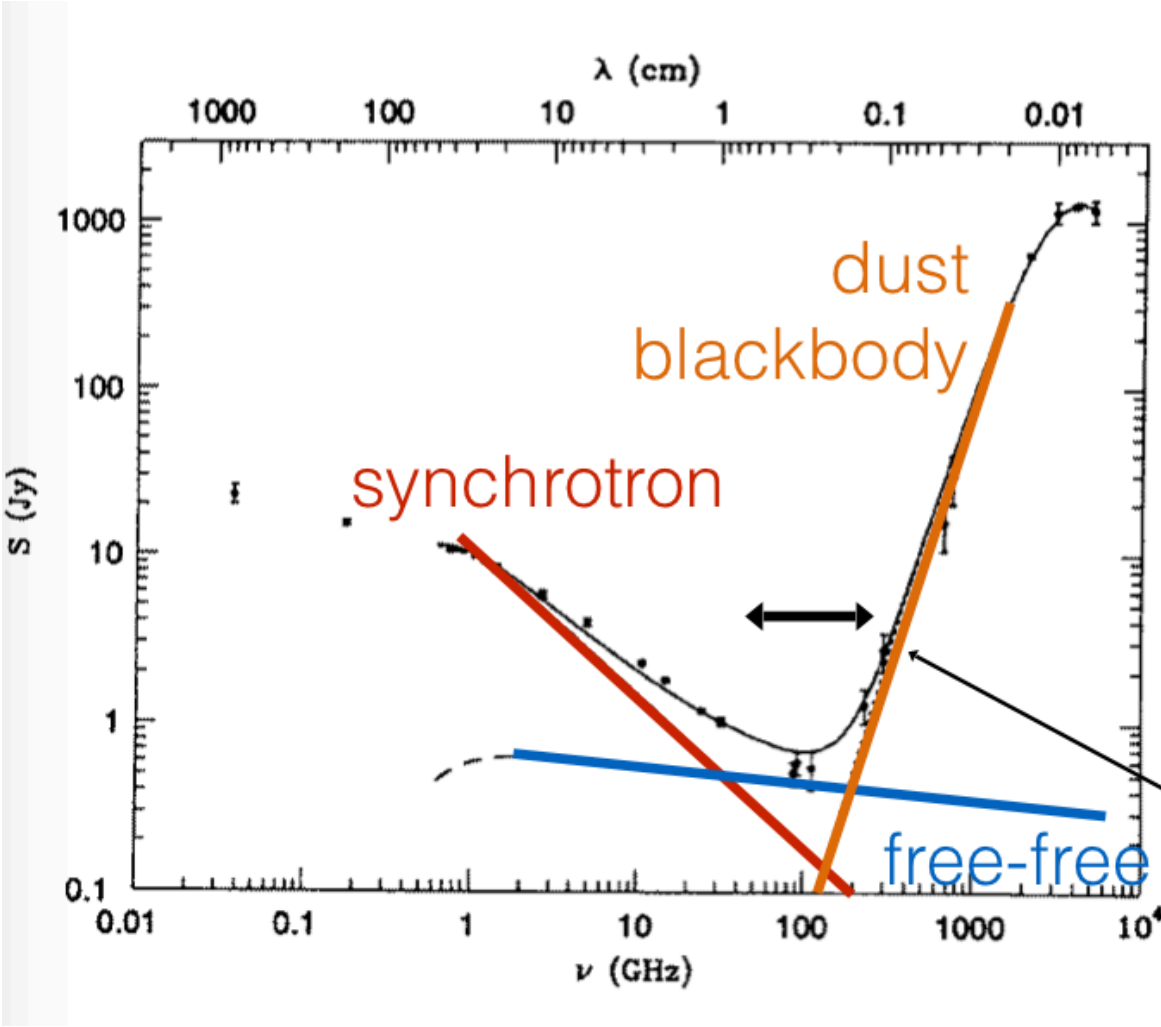
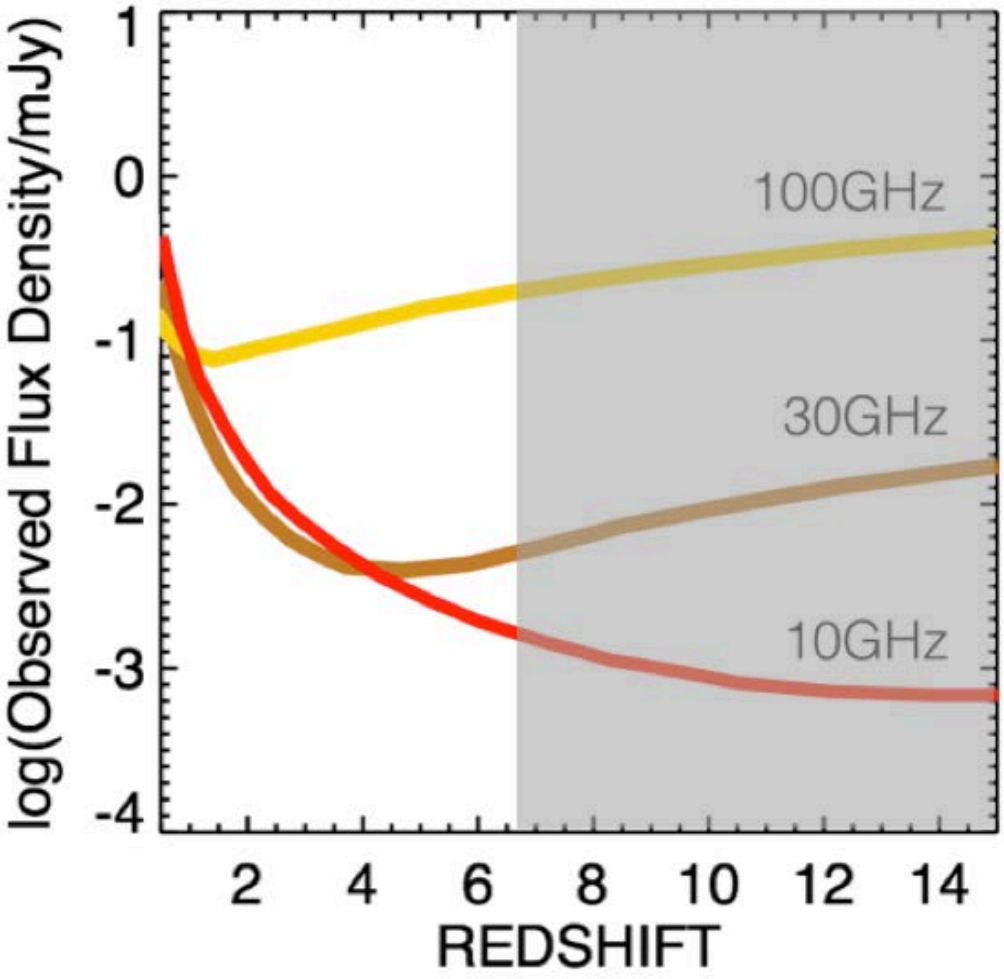
Continuum



Continuum emission from 5-100GHz: synchrotron emission, free-free, and cold dust emission. Wide-bandwidth observations will be critical to disentangling the spectrum.

example 5:1 bandwidth for z=2-3 galaxy
(observed frequency 10-50GHz)

Continuum

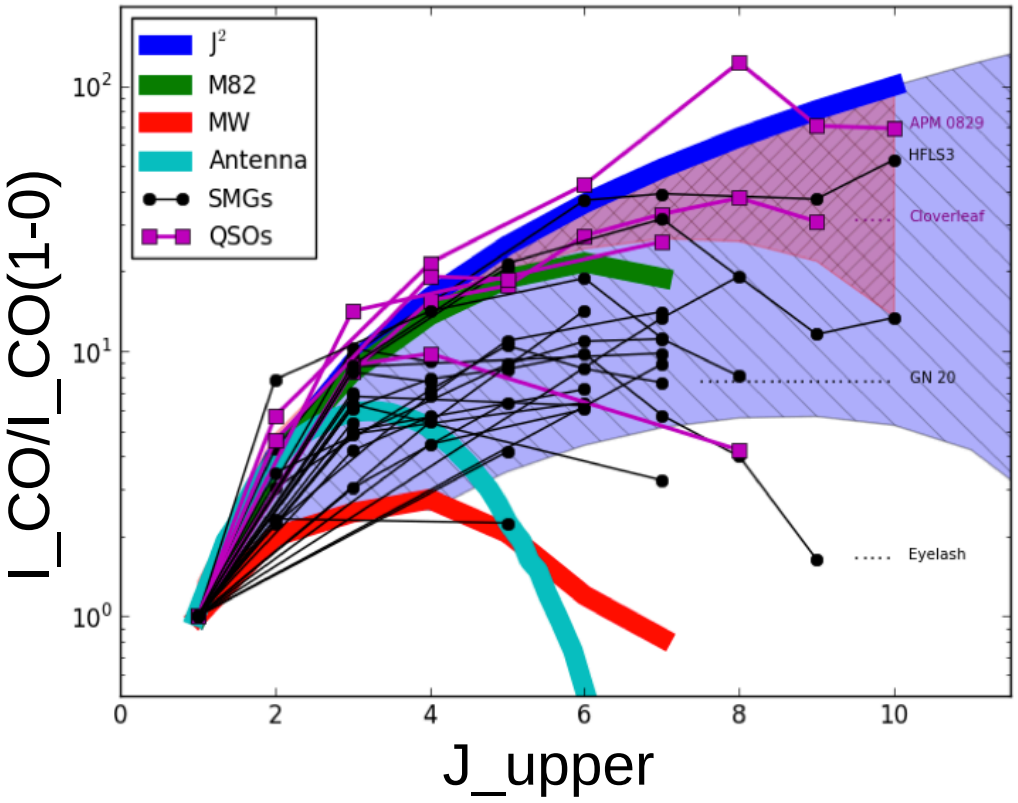

log(Observed Flux Density/mJy)
1
0
-1
-2
-3
-4
2
4
6
8
10
12
14
REDSHIFT
100GHz
30GHz
10GHz

We need low-J CO because:

1. CO excitation is highly variable galaxy to galaxy
   - adds a factor of ~5 uncertainty to gas masses

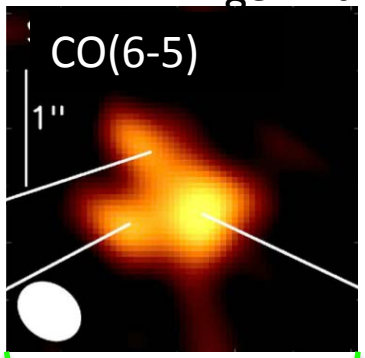
2. High-J CO transitions do not probe the entire molecular gas potential well, spatially or by mass
   - Could lead to underestimates in dynamical mass, gas surface density; problems interpreting dynamics!

Low-J CO is critical

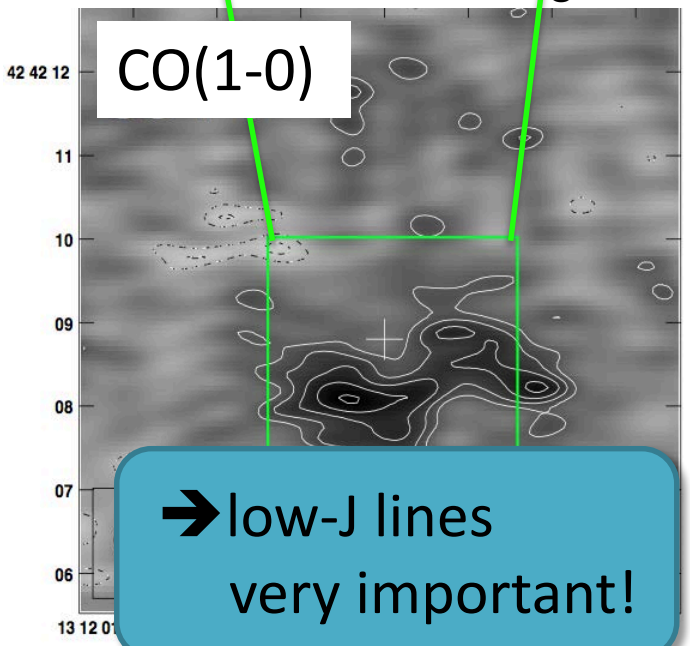


Casey, Narayanan & Cooray 2014

Engel+10



Riechers, Hodge+11



➔low-J lines very important!