ALMA: Science at Band 10 and Beyond

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Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

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Brief history of Band 10

- 787 – 950 GHz (spec. $T_{Rx,DSB}$ = 230 K over 80% of band, 344 K over 100%)
- First band above the Niobium band gap (see Kerr, Lichtenberger talks)
- Dropped in 2000 when first light bands were cut from ten to four: 3,6,7,9
- In 2001, ASAC called "Band 10 and the ACA" the Top Priority for ALMA enhancements
- Japan joined ALMA in Sept. 2004, brought Bands 4, 8, 10
- Cold cartridge PDR held in Feb 2008
- First cartridge delivery to FEIC expected this year
- Surface σ=20μm yields aperture efficiency of 43-53%
  (compared to 56-63% across Band 9)
- Angular resolution and Primary beam:
- 12m array: 0.6" to 0.006" (PB ~ 7")
- ACA: 3" (PB ~ 12")

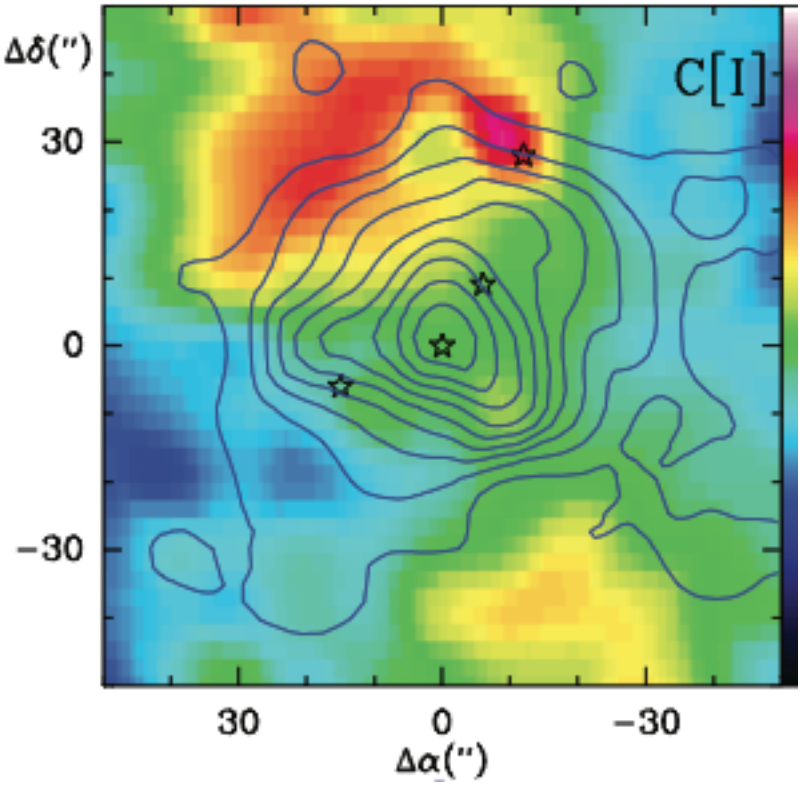
Band 10

Band 10 Science Drivers: Spectral lines

- **Many unique lines**
- Upper transition of [C I] at 809 GHz (62K), complements 492 GHz line (24K)
- HDO at 849 & 894 GHz (84K, 43K), complement 80 & 241 GHz (47K, 95K)
- HCN maser in 9-8 vibrational line
- CH^+, $^{13}CH^+$ (1-0) (835, 831 GHz); LiH 2-1 (887 GHz)
- **High-excitation lines of fundamental molecules**
- CO 7-6 (E_u=155K)
- HCN 9-8 and 10-9 (E_u=234 K, $n_{crit}=10^8$ cm^{-3})
- HCO+ 9-8 and 10-9 (E_u=235 K)
- **Redshifted lines**
- [C II] (z = 1.0 - 1.4)
- [N II] (z = 0.54 - 0.86) and (2.4 – 3.1)
- [O I] (z = 1.9 - 2.4) and (z = 5.6 - 6.9)

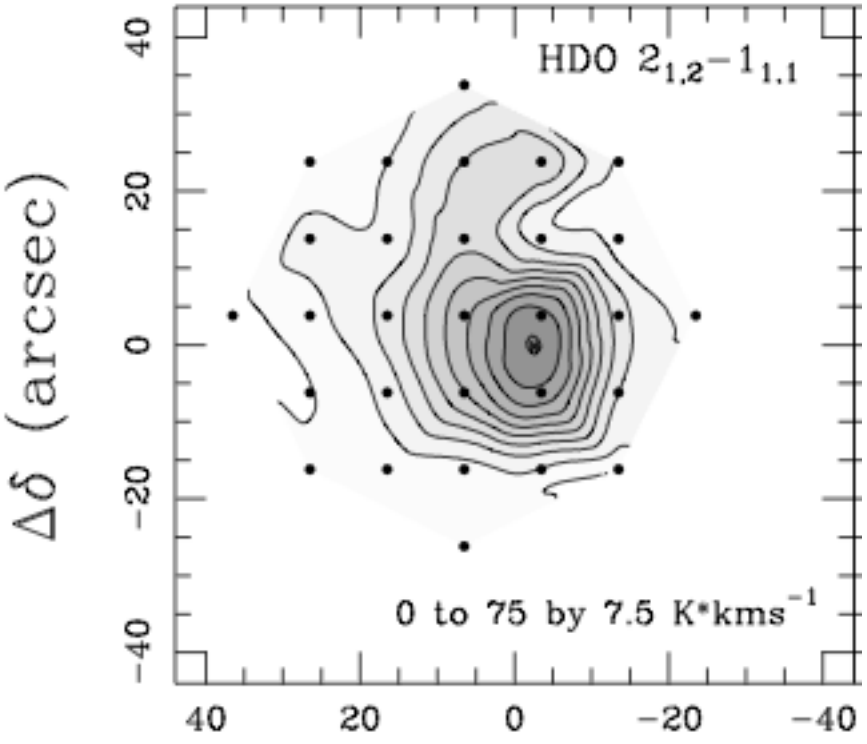
Band 10 unique lines: examples in Orion KL

[C I] enhanced in dissociative shocks (beyond CO 7-6 contours)



Pardo et al. 2005 (CSO)

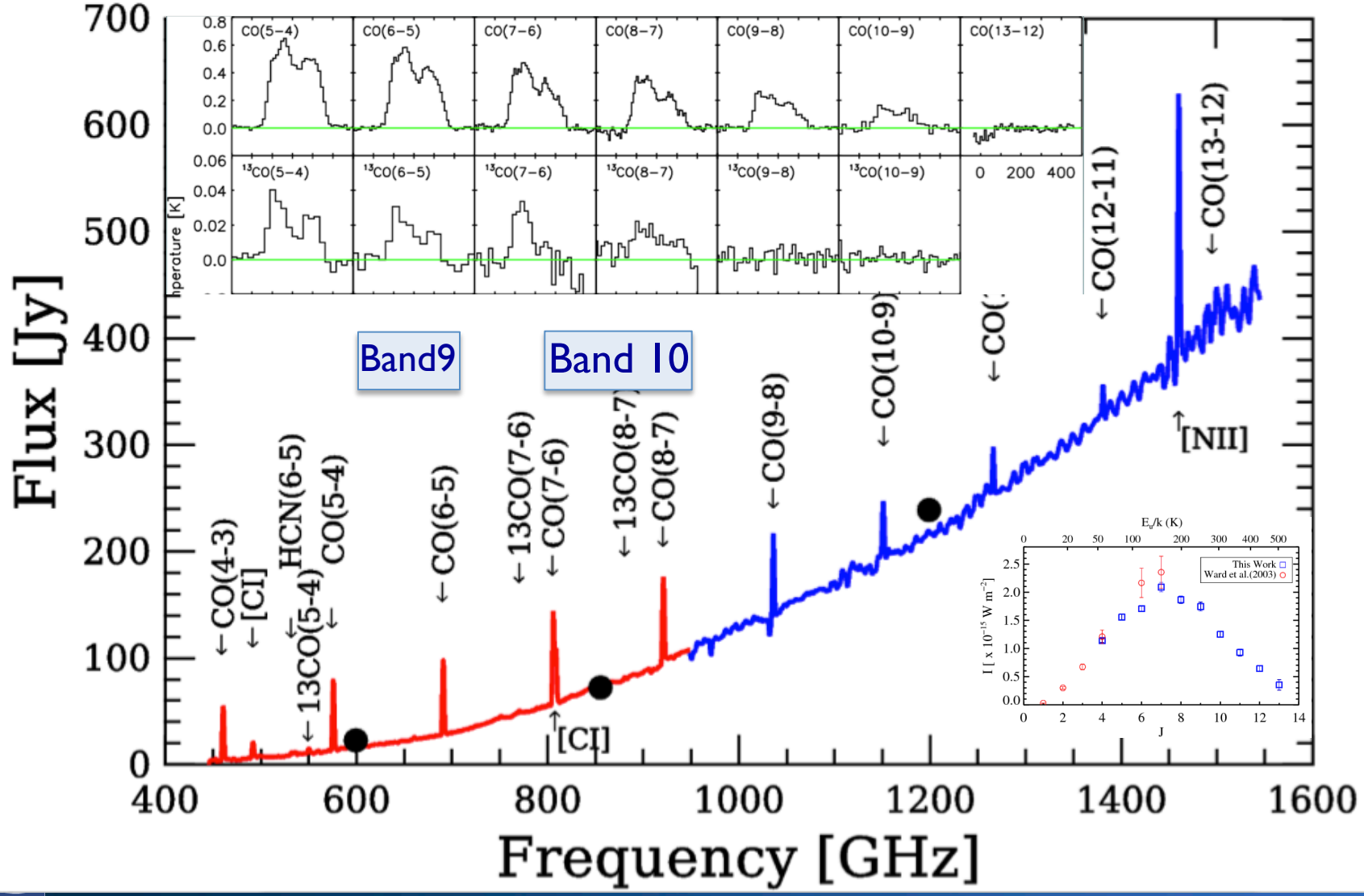
HDO line is compact and optically thick, D:H ratio ~ 0.01, grain evaporation



Pardo et al. 2001 (CSO)

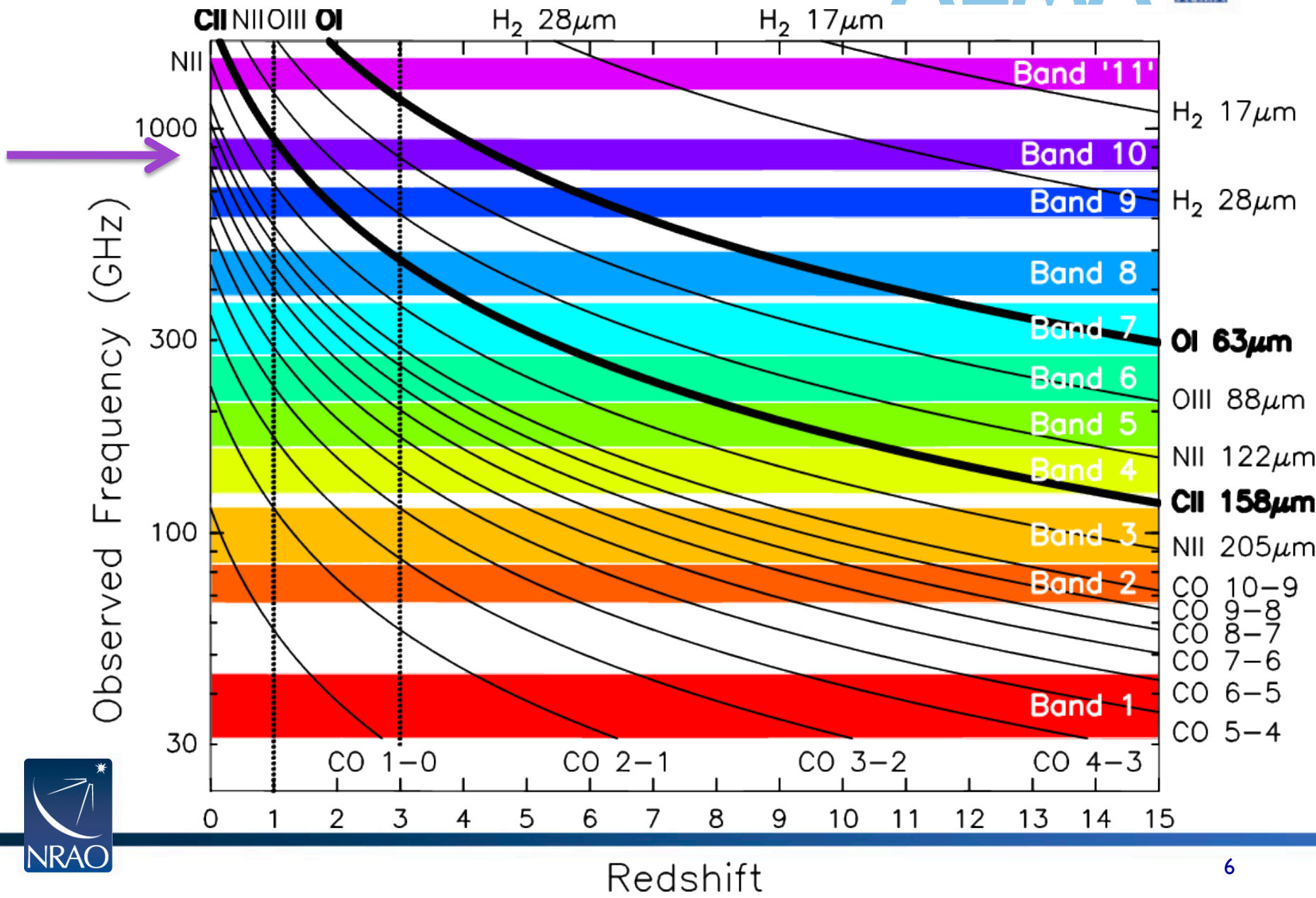
Band 10 High-J CO lines

- Herschel spectra of M82 (SPIRE: Panuzzo et al. 2010, HIFI: Loenen et al. 2010)

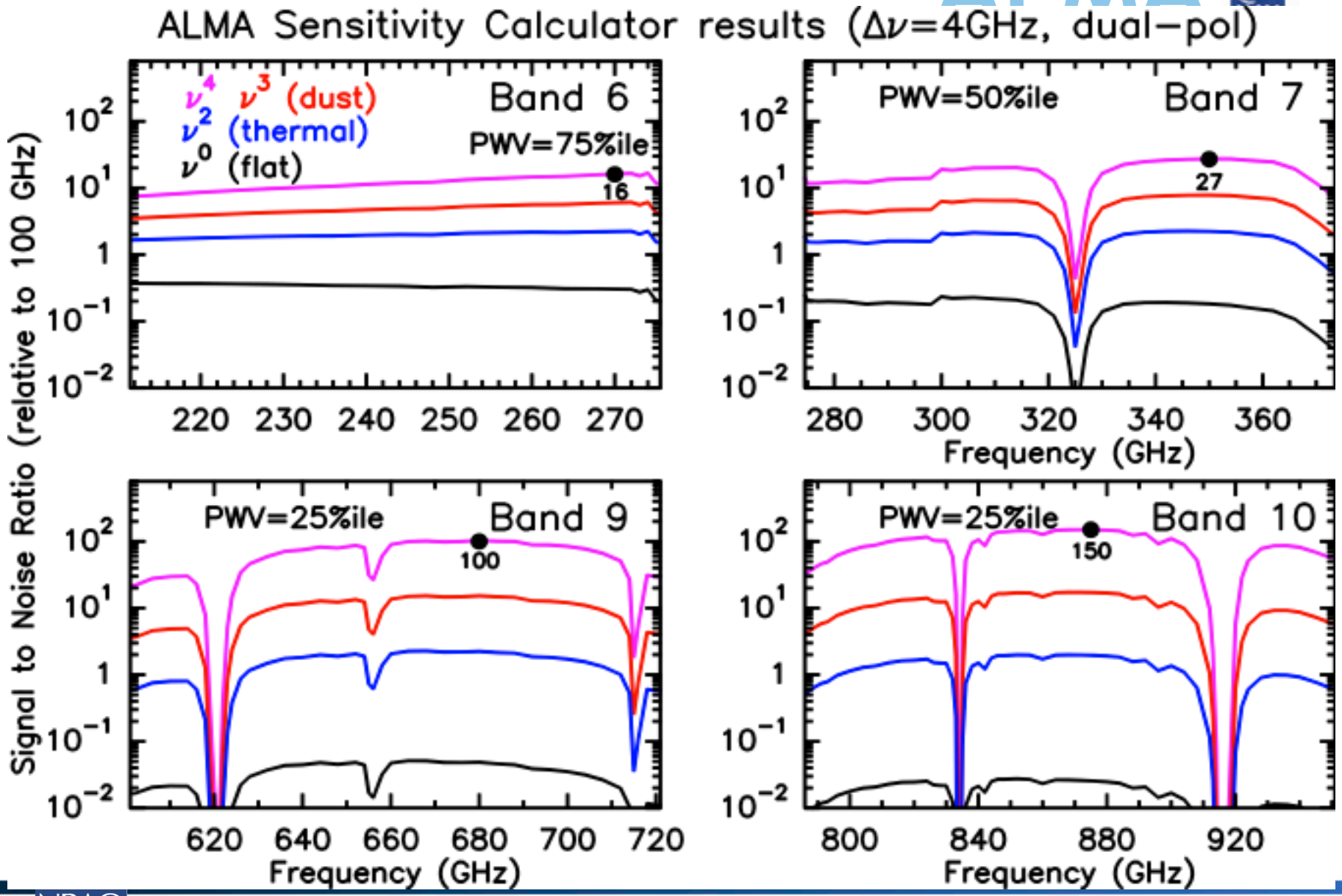


High-J CO and fine structure lines

ALMA

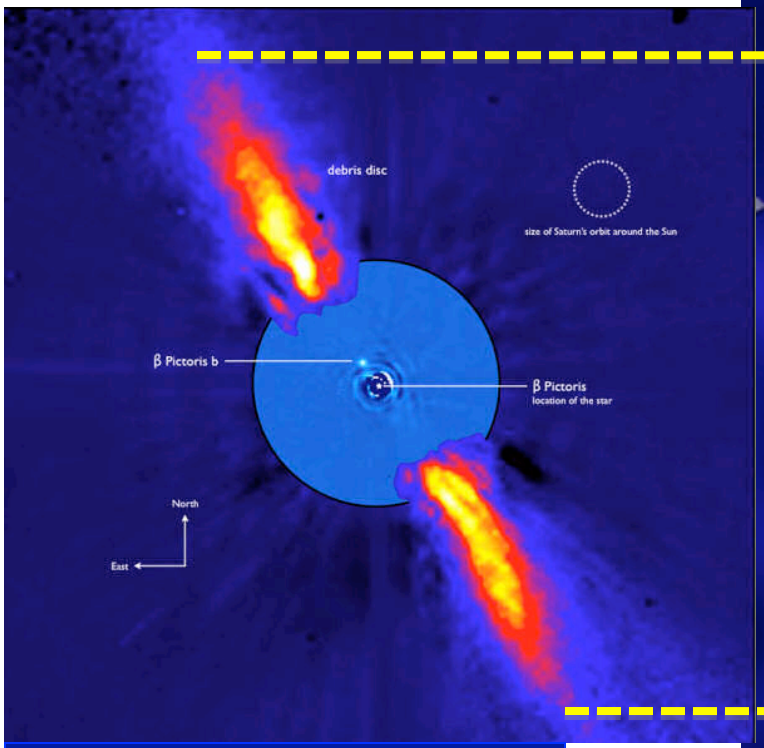


Band 10: Continuum Sensitivity

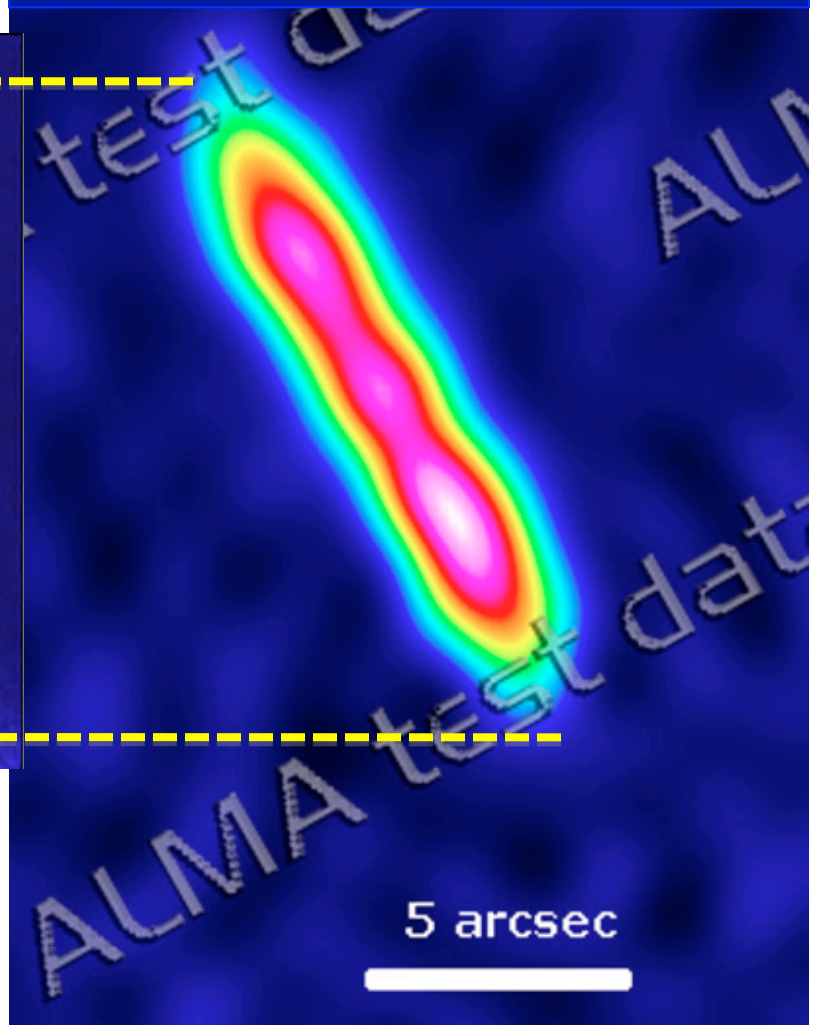


Band 10 Science Drivers: Dust Continuum

ALMA Band 9 Test Data



Near-IR ESO 3.6m & VLT



The "Lockman Hole" as seen by Herschel

Image scale:

500um (Band 9)

350um (Band 10)

250um (Band 11)

Many 1000's of potential galaxies to study with ALMA

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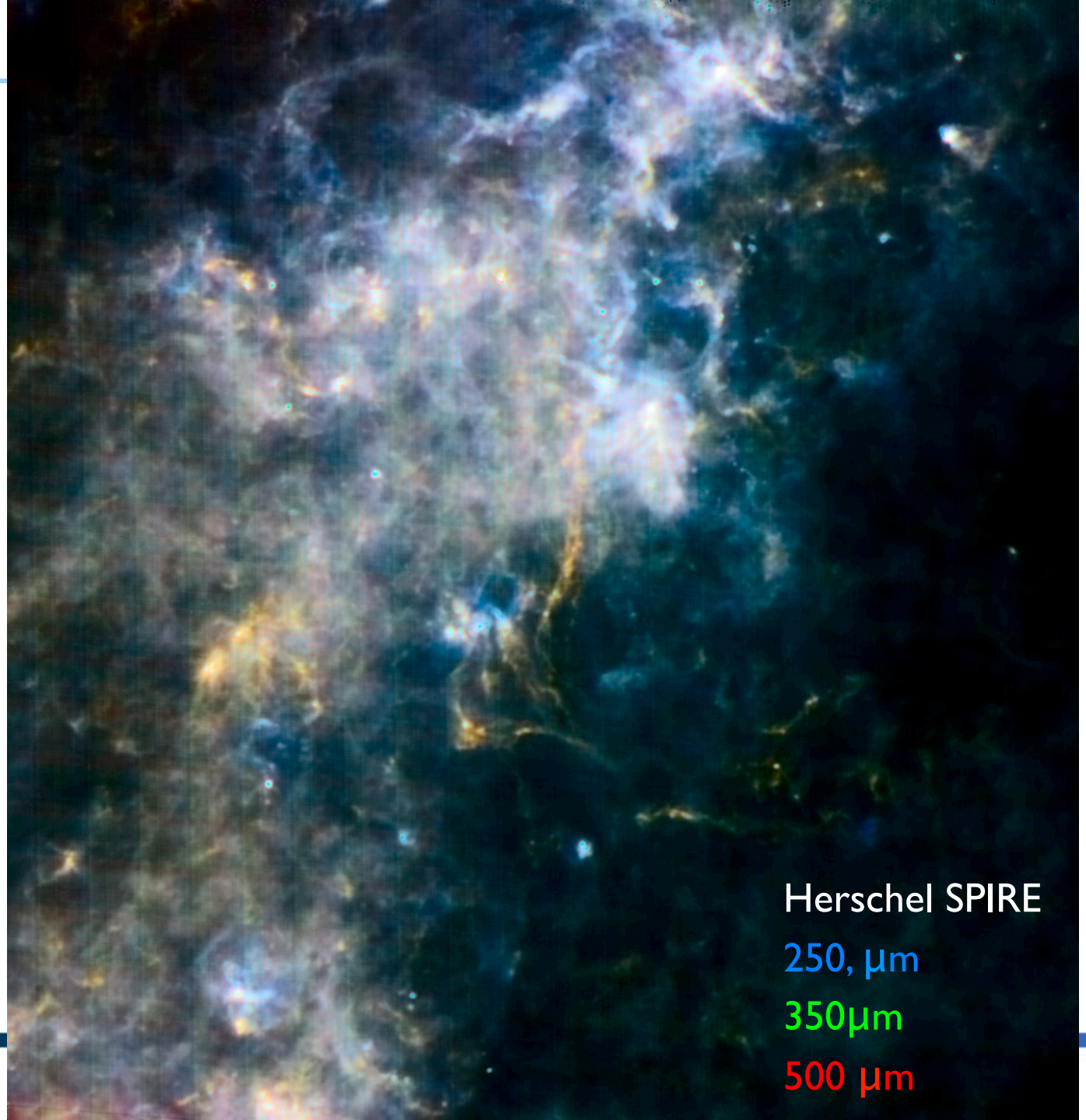
Band 11: Continuum?

Image size: 2°x2°,
Resolution ~ 20”

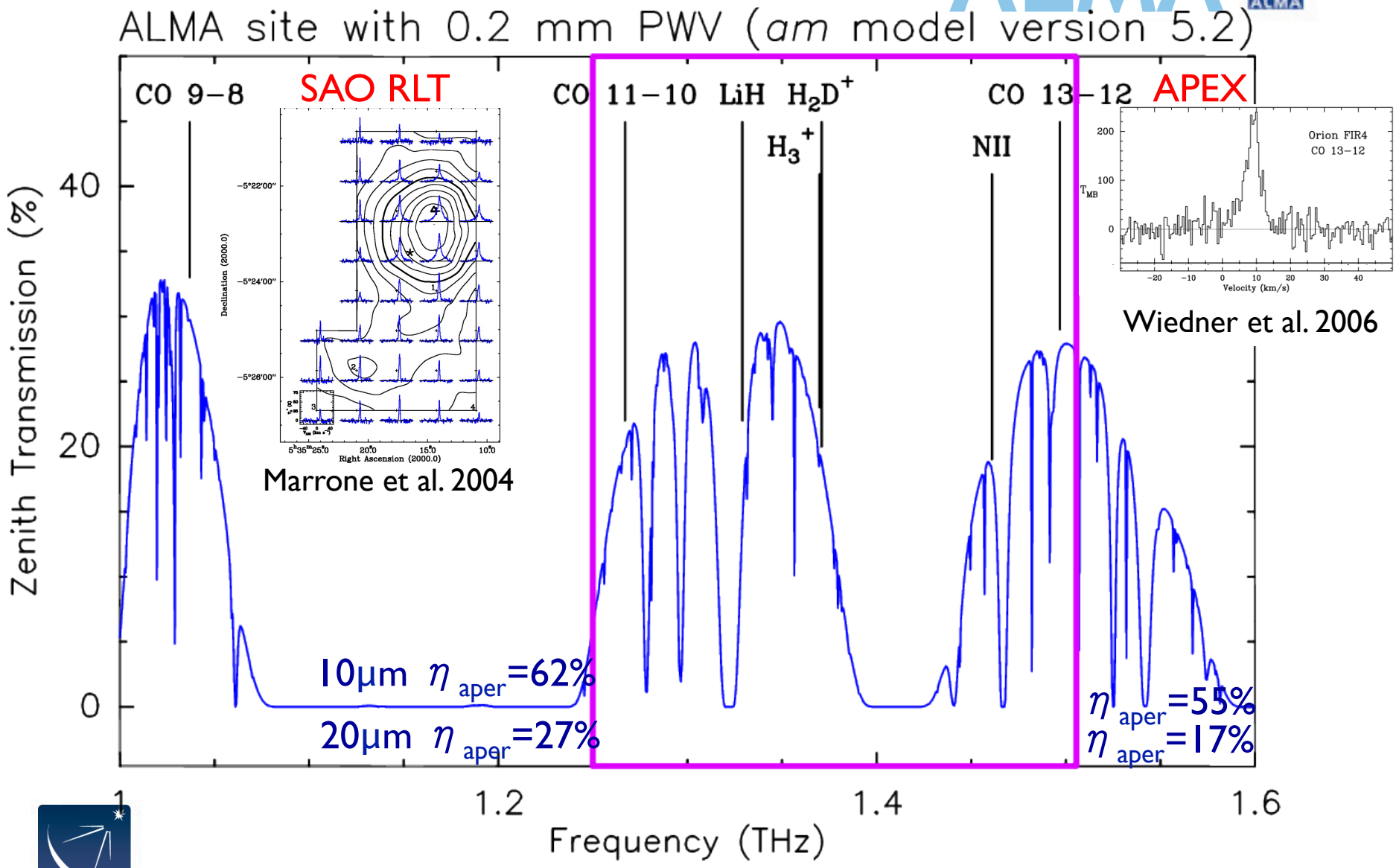
Primary beam
on ACA at
1.3 THz = 8”,
FPA!!

Resolution ~ 3”
(ACA16 ~ 1”)

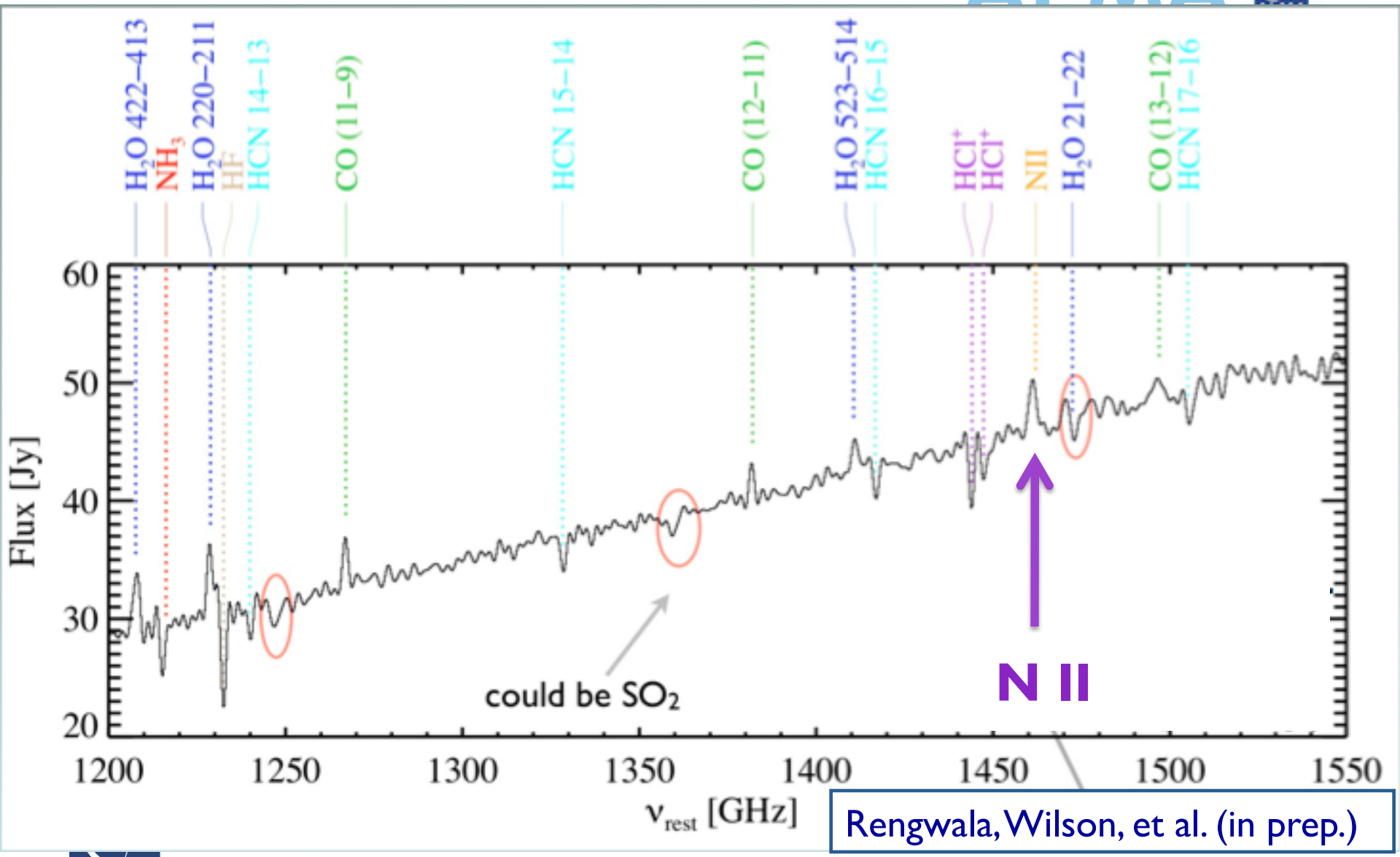
ALMA can match this beamsize all the way to Band 1



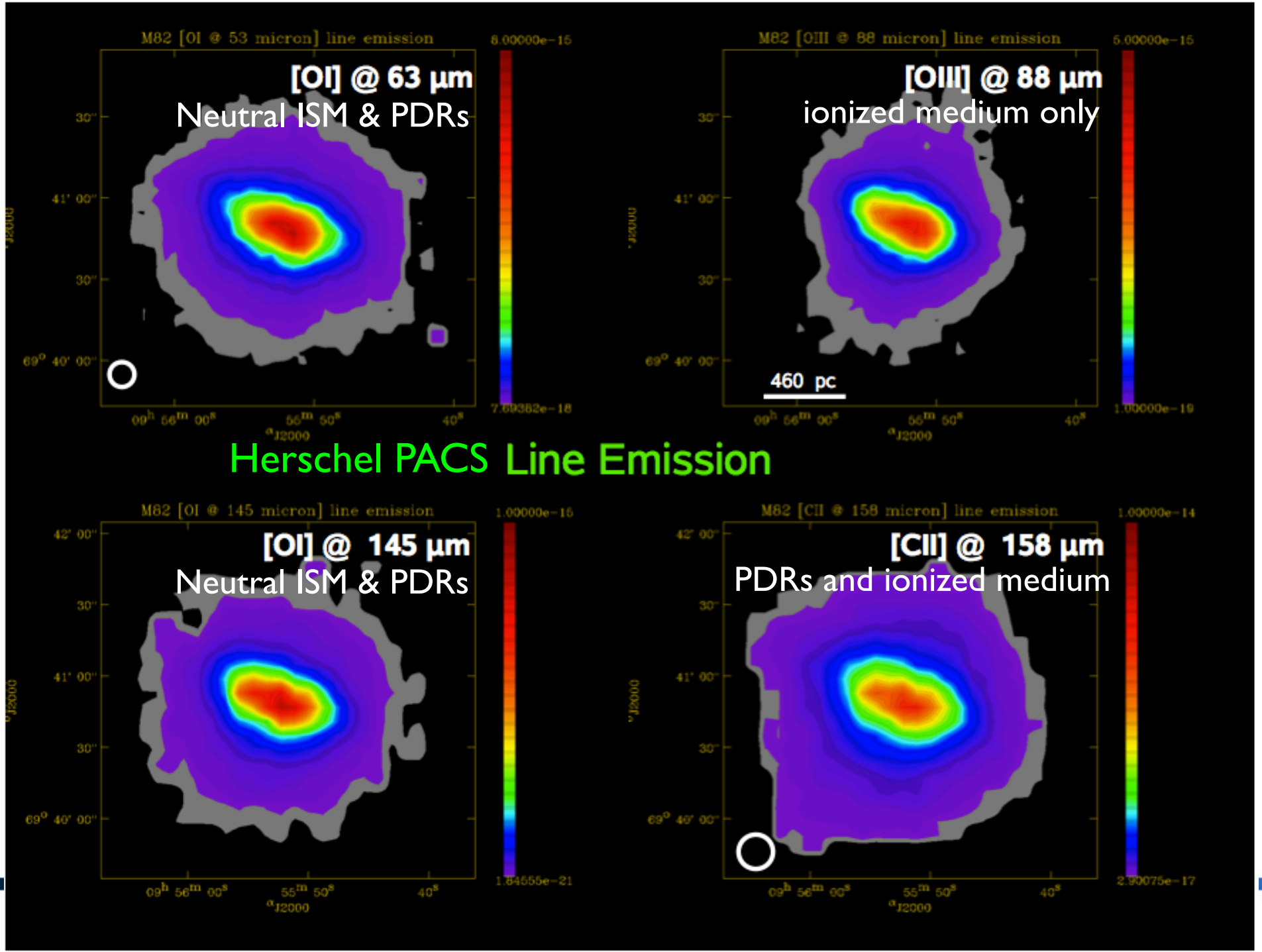
Band 11: Spectral Lines?



Band 11: Arp220 with SPIRE

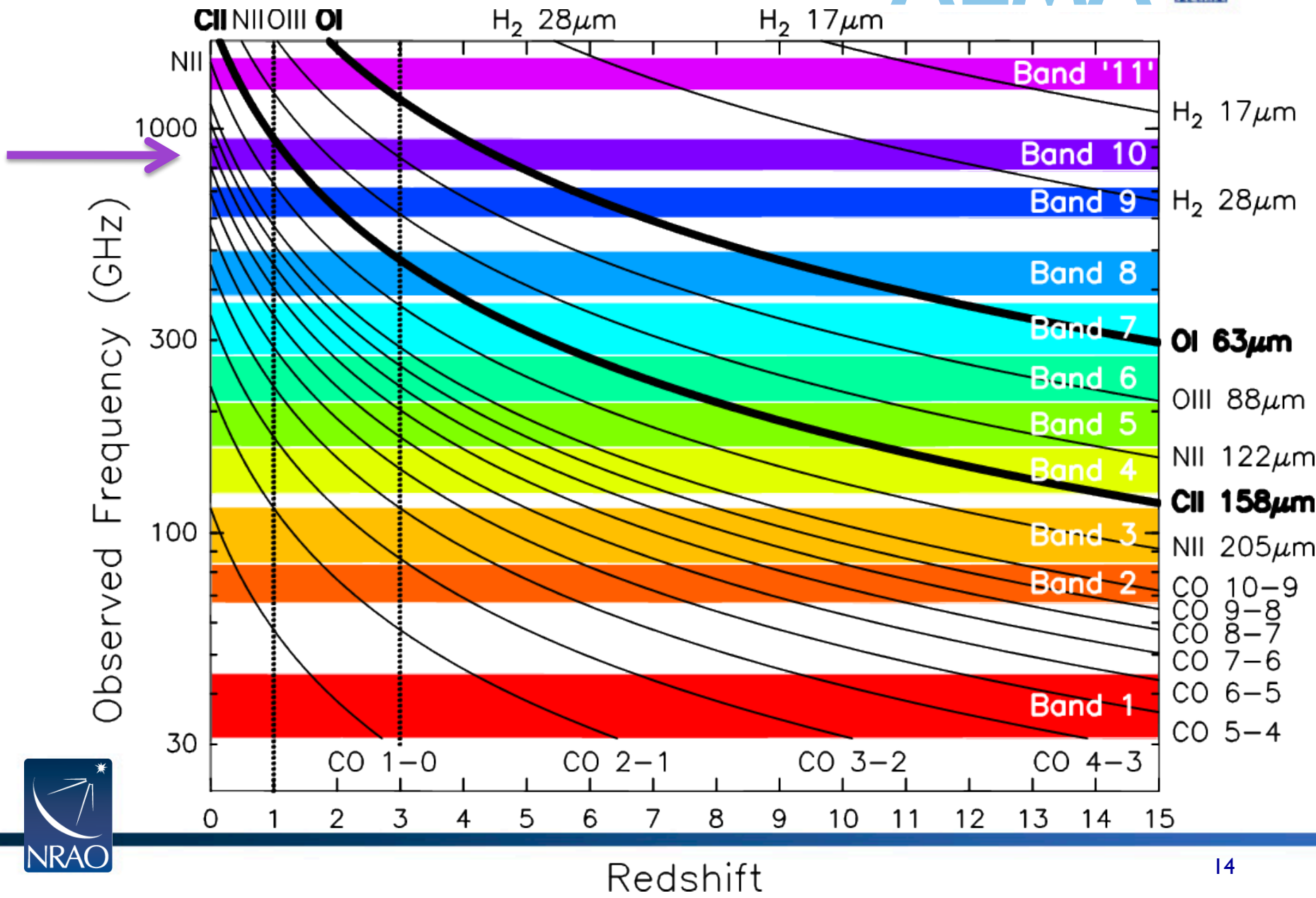


Rengwala, Wilson, et al. (in prep.)


M82 [OI @ 53 micron] line emission
[OI] @ 63 µm
Neutral ISM & PDRs
M82 [OIII @ 88 micron] line emission
[OIII] @ 88 µm
ionized medium only
460 pc
Herschel PACS Line Emission
M82 [OI @ 145 micron] line emission
[OI] @ 145 µm
Neutral ISM & PDRs
M82 [CII @ 158 micron] line emission
[CII] @ 158 µm
PDRs and ionized medium

High-J CO and fine structure lines

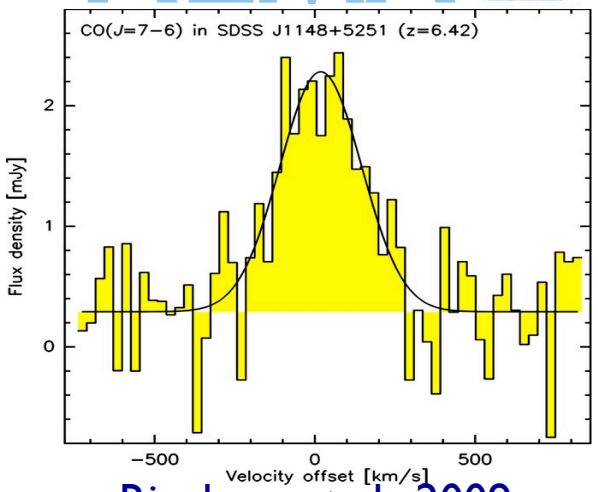
ALMA



Band 11: H_2 at z ~ 6-7 or 11-13?

J1148+5251 (z=6.42; 0.8 Gyr)
an early massive, hyperluminous and high metallicity galaxy with an extended region of tremendous star formation

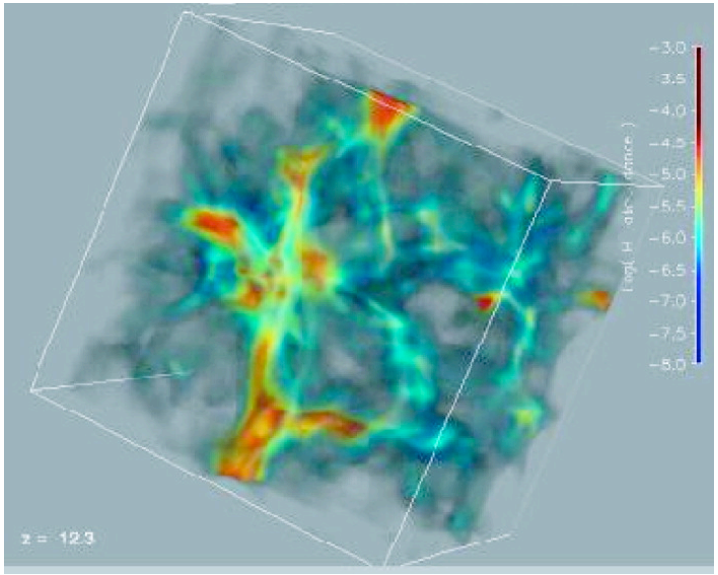
- SFR ~1000 M_{sun}/yr/kpc^2
- Size ~750 pc radius
- Lum ~ 2 10^{13} L_{sun}, Mass ~2 10^{10} M_{sun}



Riechers et al. 2009

At some point, higher z objects will have little carbon so we will be forced to search for H_2 itself via its rest frame mid-infrared lines: 0-0 S(1) at 17μm or 0-0 S(0) at 28 μm.

See Astro2010 white paper: **"The Dark-side of Reionization: Probing Cooling in the Early Universe" by Appleton et al.**



H_2 simulation at z=12.3 (Ricotti, Gnedin, Shull 2002)

Summary

- **Band 10: Many unique lines**
- [C I], HDO, ground state of CH^+ & $^{13}CH^+$, LiH 2-1
- **High-excitation lines of high density tracers**
- CO, HCN, HCO+, etc.
- **Redshifted fine-structure lines**
- [C II], [N II], [O I]

- **Band 11 possibilities**
- ACA antennas potentially offer very high efficiency (>50%) at 2-3" resolution
- CII at z~0.5, NII at z~0.8, and OI at z~3
- H_2 at z ~ 7-13

www.almaobservatory.org

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership among Europe, Japan and North America, in cooperation with the Republic of Chile. ALMA is funded in Europe by the European Organization for Astronomical Research in the Southern Hemisphere, in Japan by the National Institutes of Natural Sciences (NINS) in cooperation with the Academia Sinica in Taiwan and in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC). ALMA construction and operations are led on behalf of Europe by ESO, on behalf of Japan by the National Astronomical Observatory of Japan (NAOJ) and on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI).

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