SEQUOIA and 1 mm SIS Receiver WARES Spectrometer

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LMT Community Meeting #3

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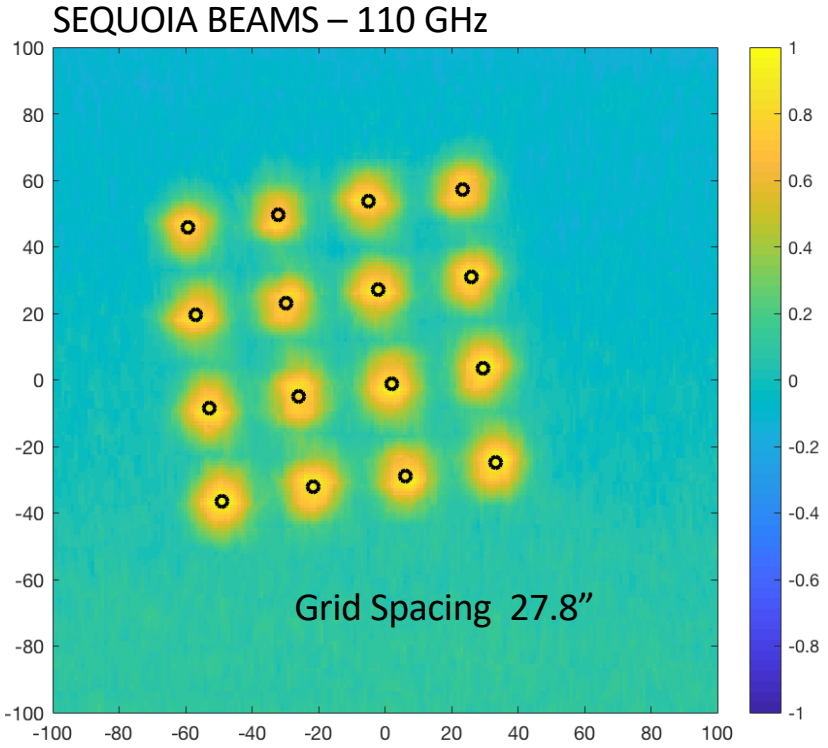
SEQUOIA

16-element Focal Plane Array

- 4 X 4 Array – 27.8” grid spacing
  - Field Rotates with Elevation Angle
- 15 GHz Instantaneous BW
  - 85-100 GHz (TRX ~ 55K)
  - 100-115 GHz (TRX 55-90K)
- Aperture Efficiency 55% at 100 GHz
- HPBW: 15.5”@86 GHz 13”@110 GHz
- Observing Modes:
  - On-the-fly Mapping
  - Position Switched Spectra
- WARES Spectrometer
- Sensitivity calculator verified with commissioning observations.



WARES

Digital Spectrometer

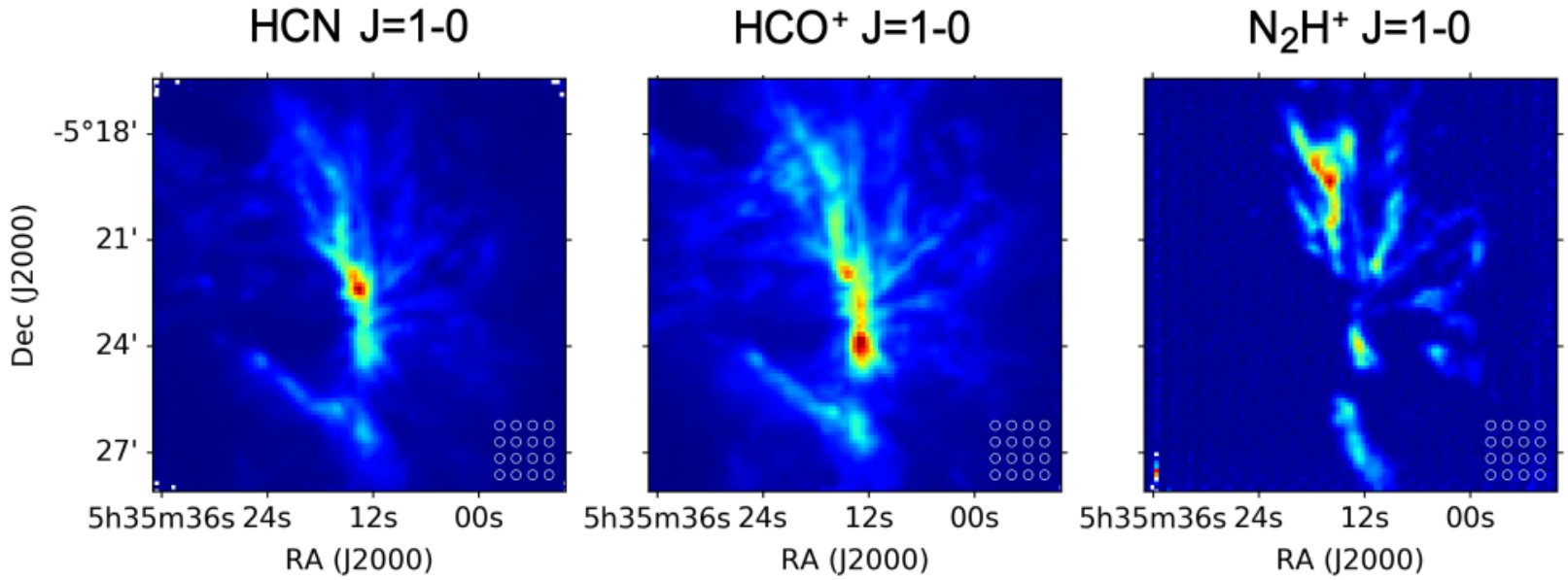
- Based on ROACH 2
- Modes:
  - Wide
  - Intermediate
  - Narrow
- Current Setup
  - 16 Spectrometers
  - 1 line per pixel
- Coming Soon
  - 32 Spectrometers
  - 2 lines in same SEQUOIA band per pixel

MODE	W	I	N
Bandwidth (MHz)	800	400	200
N Channels	2048	4096	8192
Resolution (kHz)	391	98	24
SEQUOIA *CO J=1-0 Line - 115.3 GHz*			
Bandwidth (km/s)	2082	1041	520
Resolution (km/s)	1.02	0.25	0.06
SEQUOIA *HCN J=1-0 Line - 88.6 GHz*			
Bandwidth (km/s)	2709	1354	677
Resolution (km/s)	1.32	0.33	0.08
1mm SIS Receiver *CO J=2-1 Line - 230.5 GHz*			
Bandwidth (km/s)	1041	521	260
Resolution (km/s)	0.51	0.125	0.03

Commissioning Observations

Orion Molecular Cloud

OTF Mapping Example: Data Cube

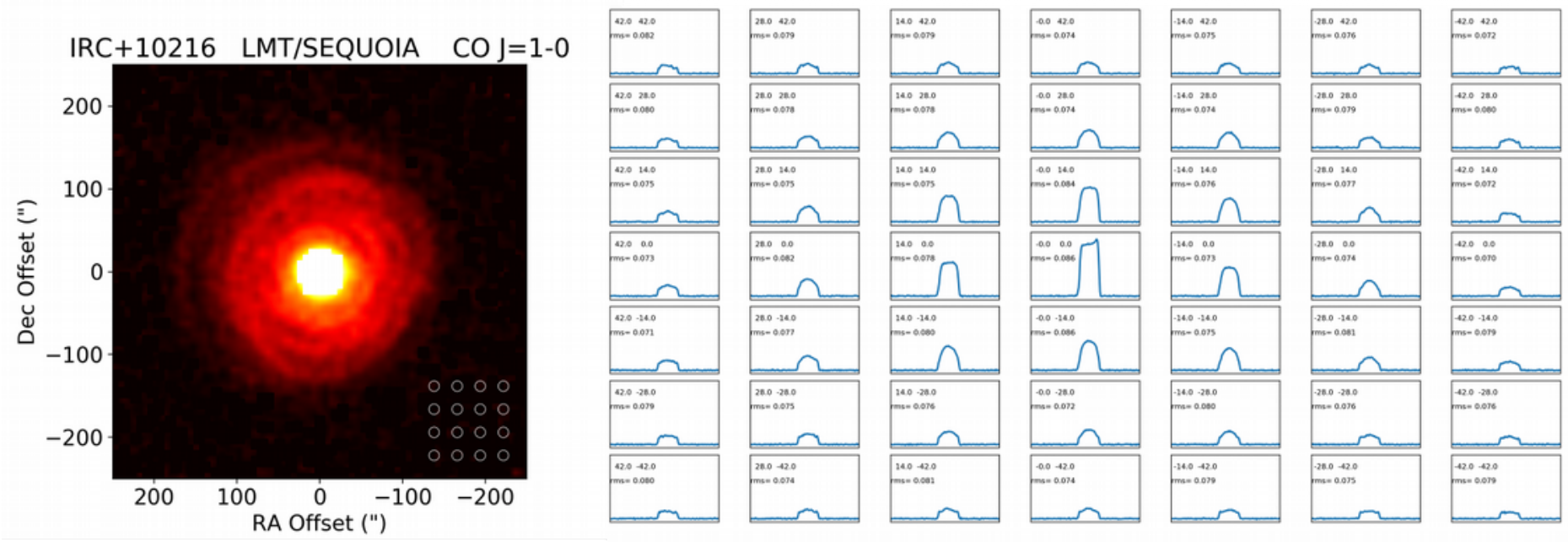


10’ X 10’ Maps required 2200 s *elapsed telescope time* to complete

65 mK rms in 1.3 km/s channel

Commissioning Observations
IRC+10216

OTF Mapping Example: Data Cube

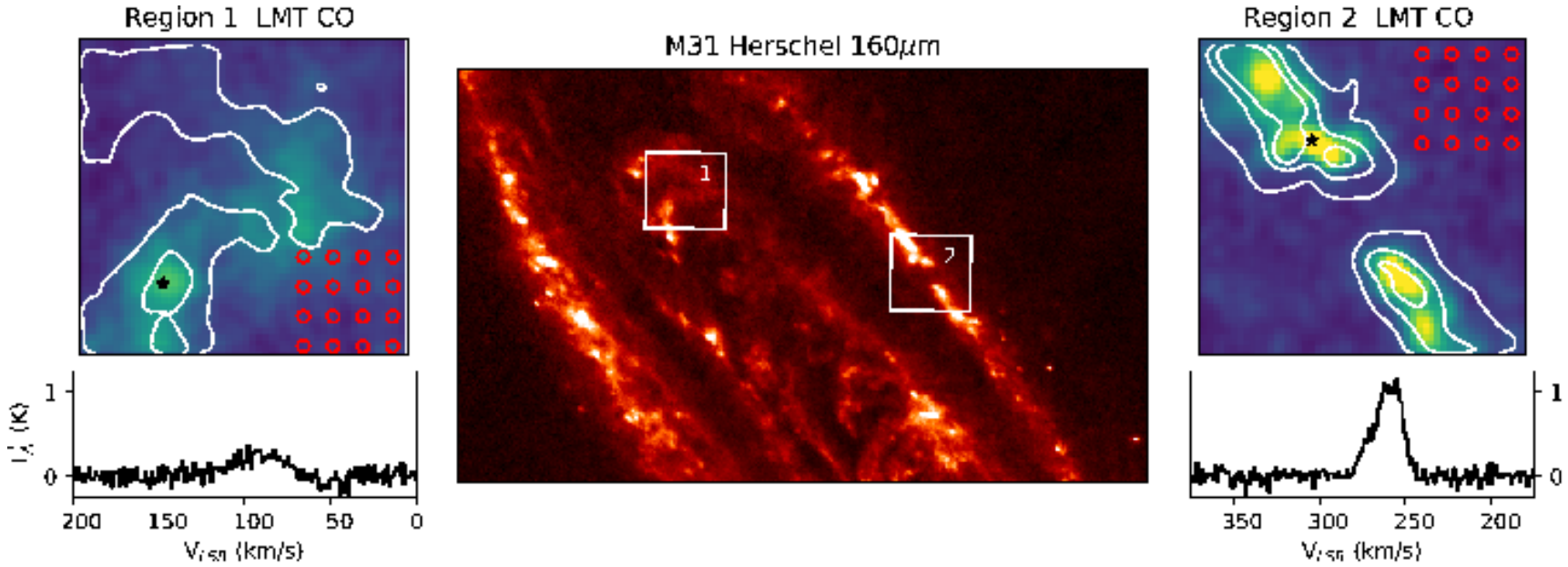


Average of four 10'x10' Maps – 7" Nyquist Pixel Cells – *0.08K rms in 1 km/s channel*
Each map required 2200s of *elapsed telescope time* to complete.

Observations from 2018-S1 Program

GMC's in M31 – Loinard et al.

OTF Mapping Example: Data Cube

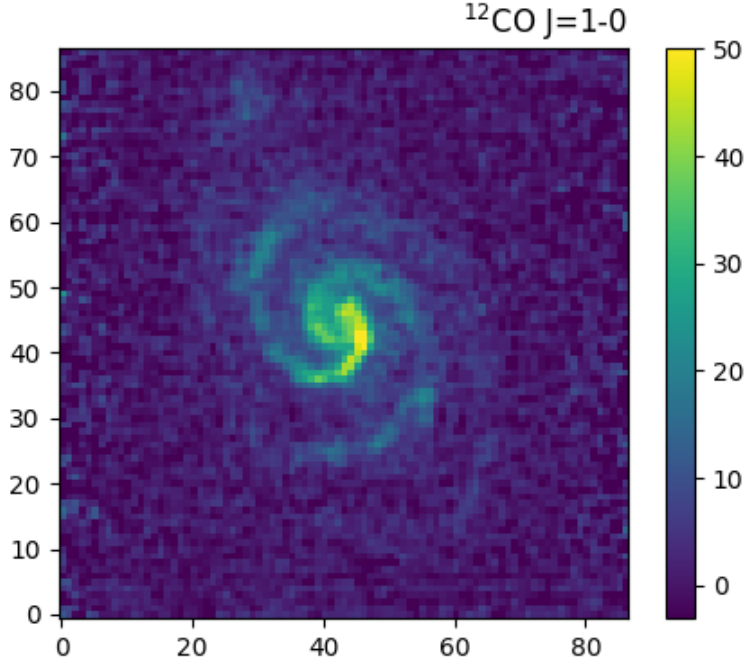


Each map has about 1 hour of observing time

Observations from 2018-S1

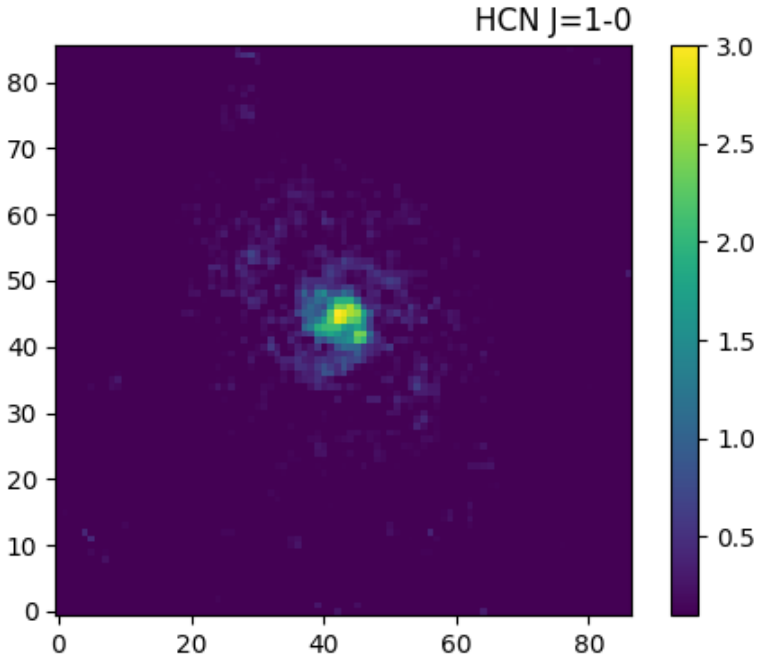
M51 Maps – Calzetti et al.

OTF Mapping Example: Data Cube



Single Map – 10’ X 10’

4k seconds integration time

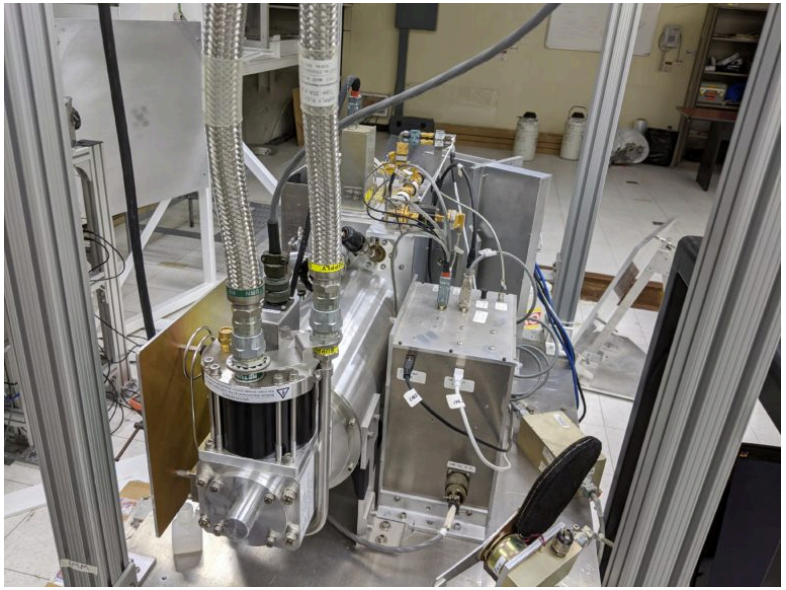


Multiple Maps

9.2 hours integration time – 4mk rms in 5km/s channel

1 mm SIS Receiver (“MSIP 1mm Receiver”)

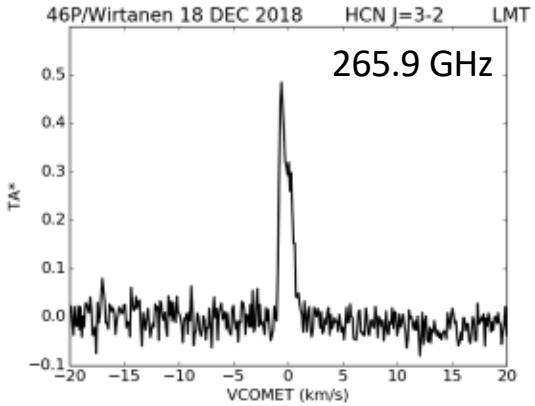
- Single Pixel Heterodyne Receiver
  - Dual Polarization
  - Sideband Separation
  - 4 IF’s – IF Band: 4-12 GHz
- Frequency Range: 210-280 GHz
- TRX: 60-75K
- Aperture Efficiency: 26% @ 230 GHz
- 6” HPBW Beam
- WARES Spectrometer
  - Current Setup: 2 spectral lines, with one in each sideband.
- Observing Modes: OTF and PS



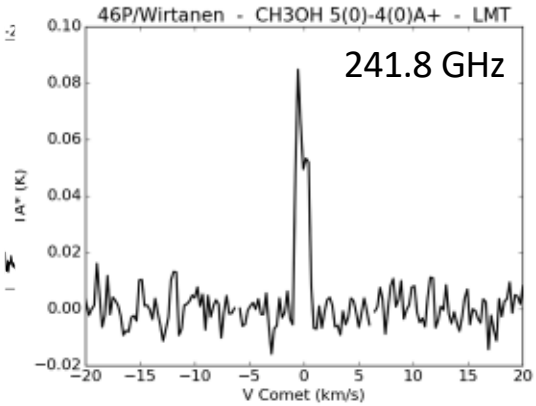
Commissioning Test

Observations of Comet 46P/Wirtanen

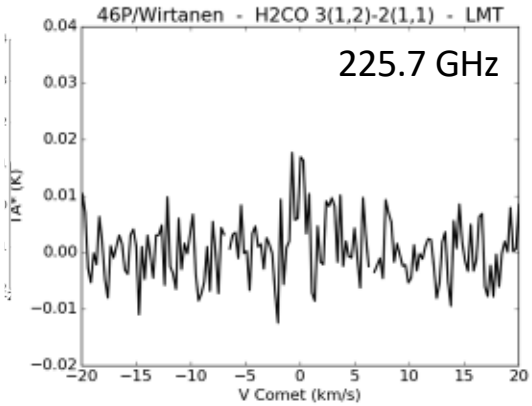
------- Observed Simultaneously ------



USB



LSB

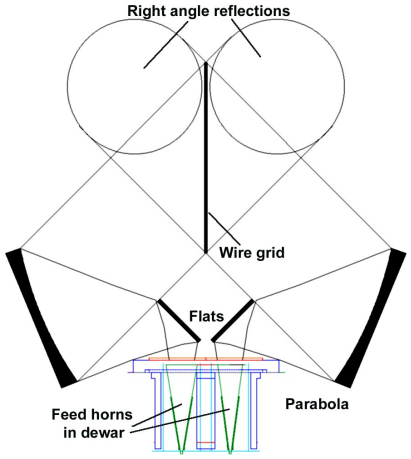


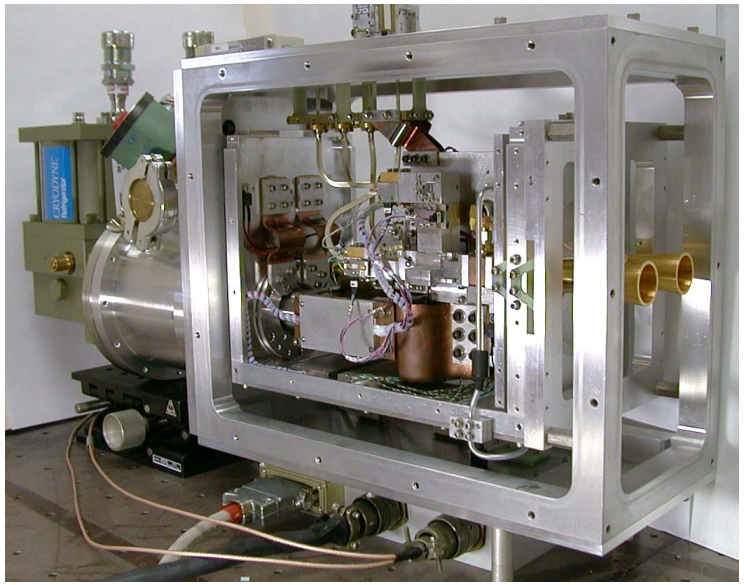
Narrow (200 MHz) Band Mode

16 minutes of integration time

Intermediate (400 MHz) Band Mode

60 minutes of integration time

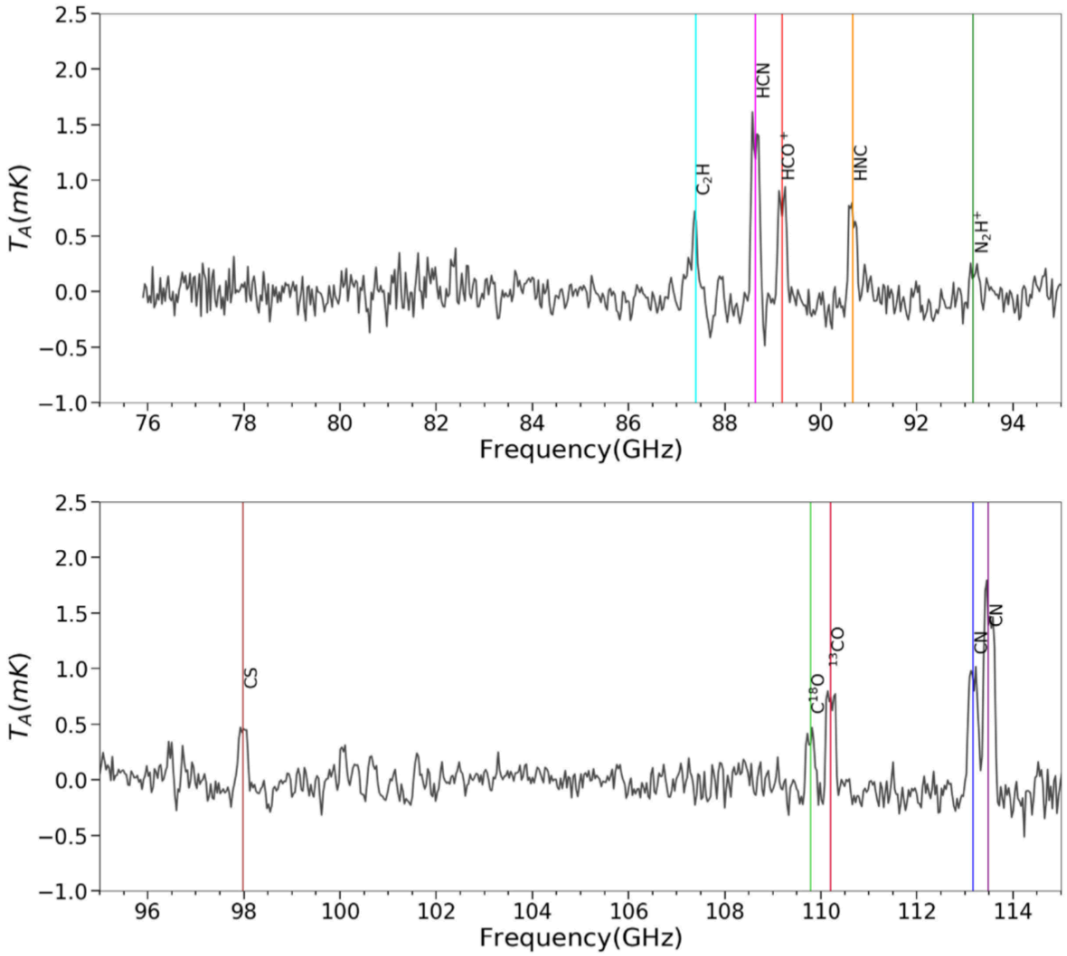


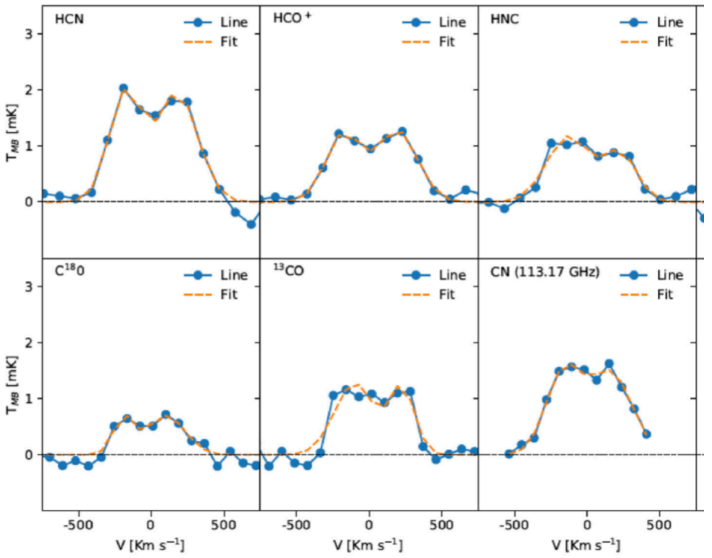


Redshift Search Receiver (RSR)

- Two receiver pixels with dual-polarization
- 1 kHz beam-switching to reduce 1/f noise
- 72 – 111 GHz instantaneous bandwidth at 31 MHz (~100 km/s) resolution
- Receiver temp ~ 60K; stable baselines
- detect multiple molecular-lines without prior information on galaxy redshift
- operational FCRAO-14m (2007-2008), LMT 32-m (2014-2017) , LMT 50-m (2018-present)

RSR Study of UGC 5101 by Cruz-Gonzalez et al. (2020)





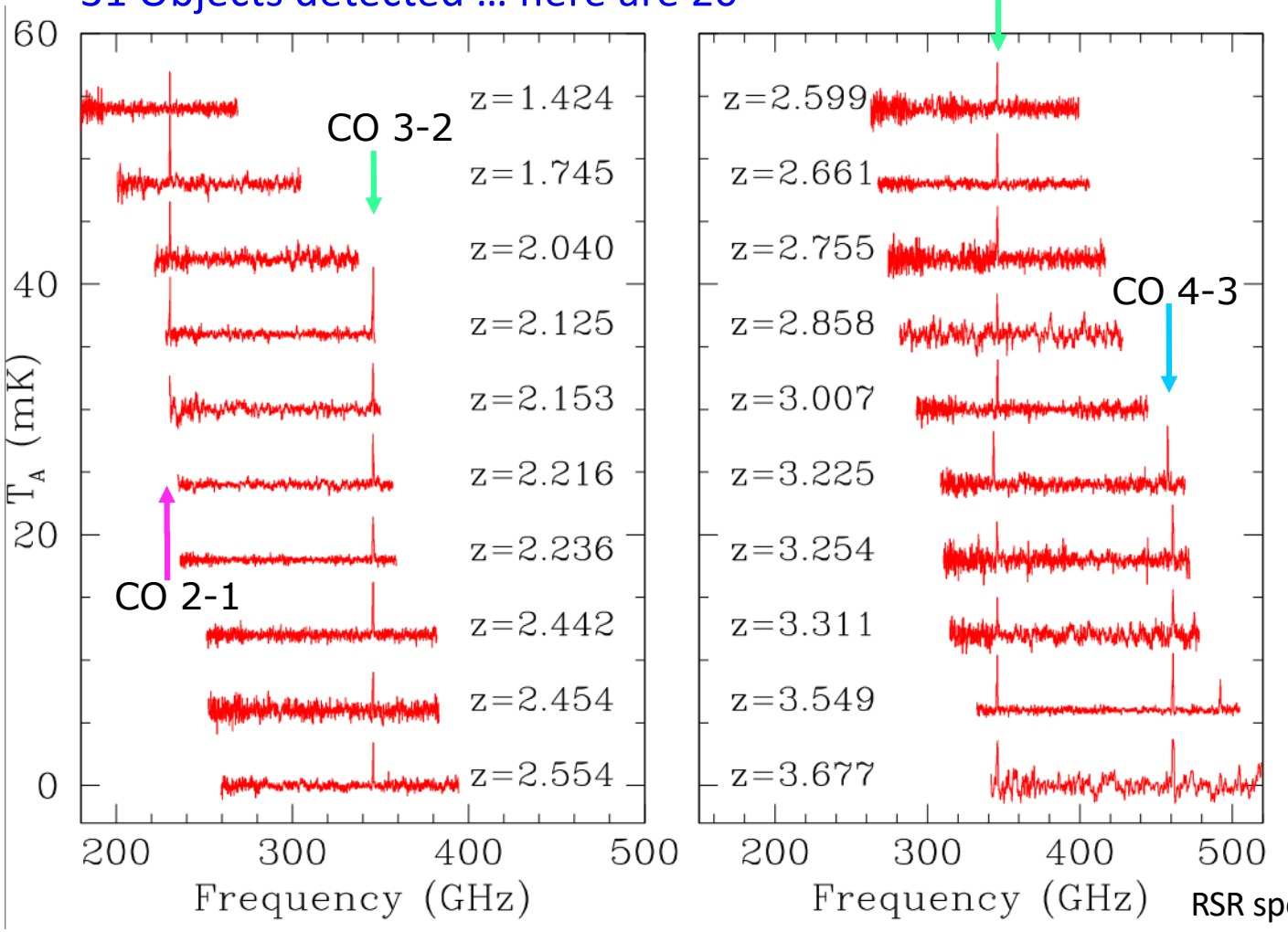
RSR spectrum from 32m LMT

Planck Selected SMG's

31 Objects detected … here are 20

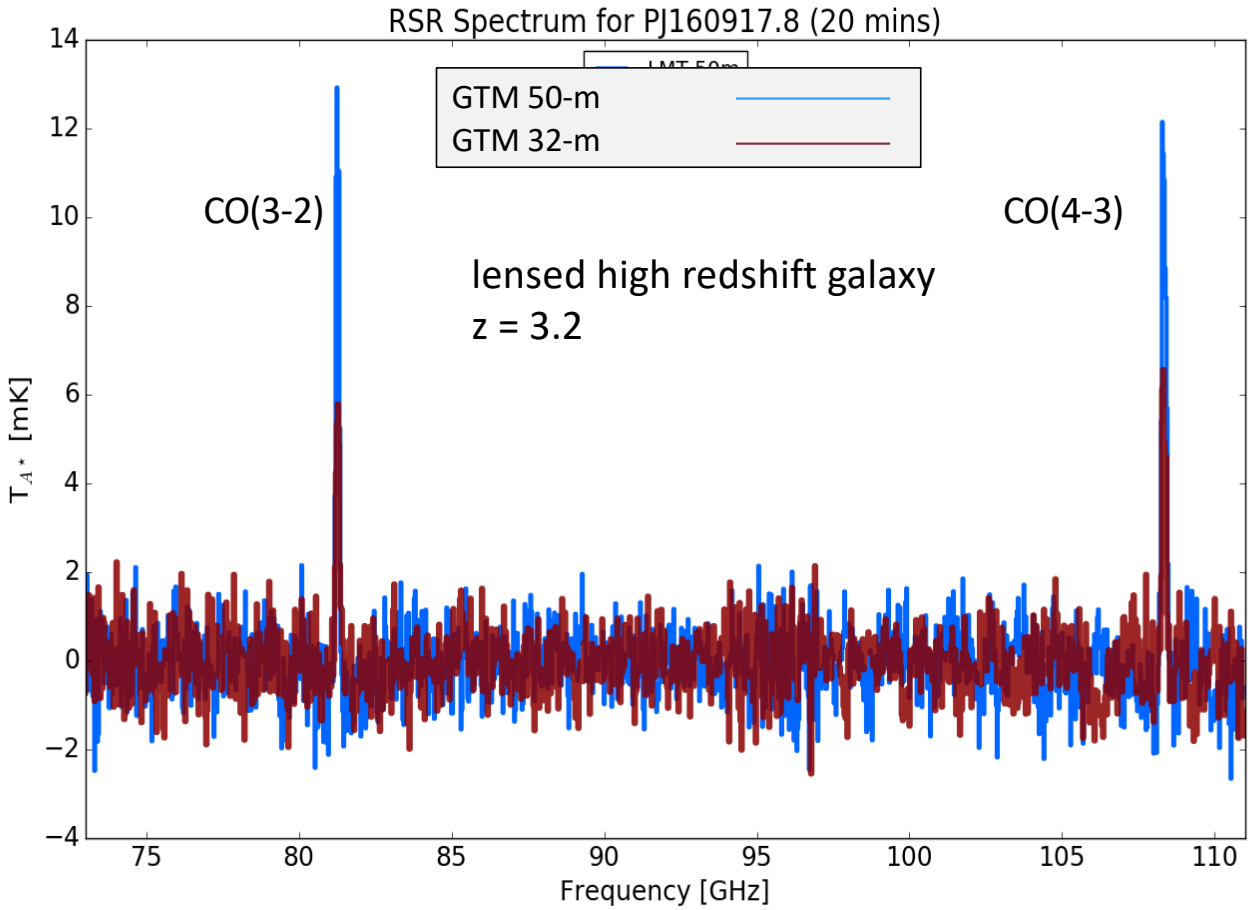
Harrington et al. (2016)

Berman et al., in prep



RSR spectra from 32m LMT

RSR: LMT 50-m vs. LMT 32-m



[Credit: D. Sanchez]

Band 4 Receiver (B4R)

B4R Team

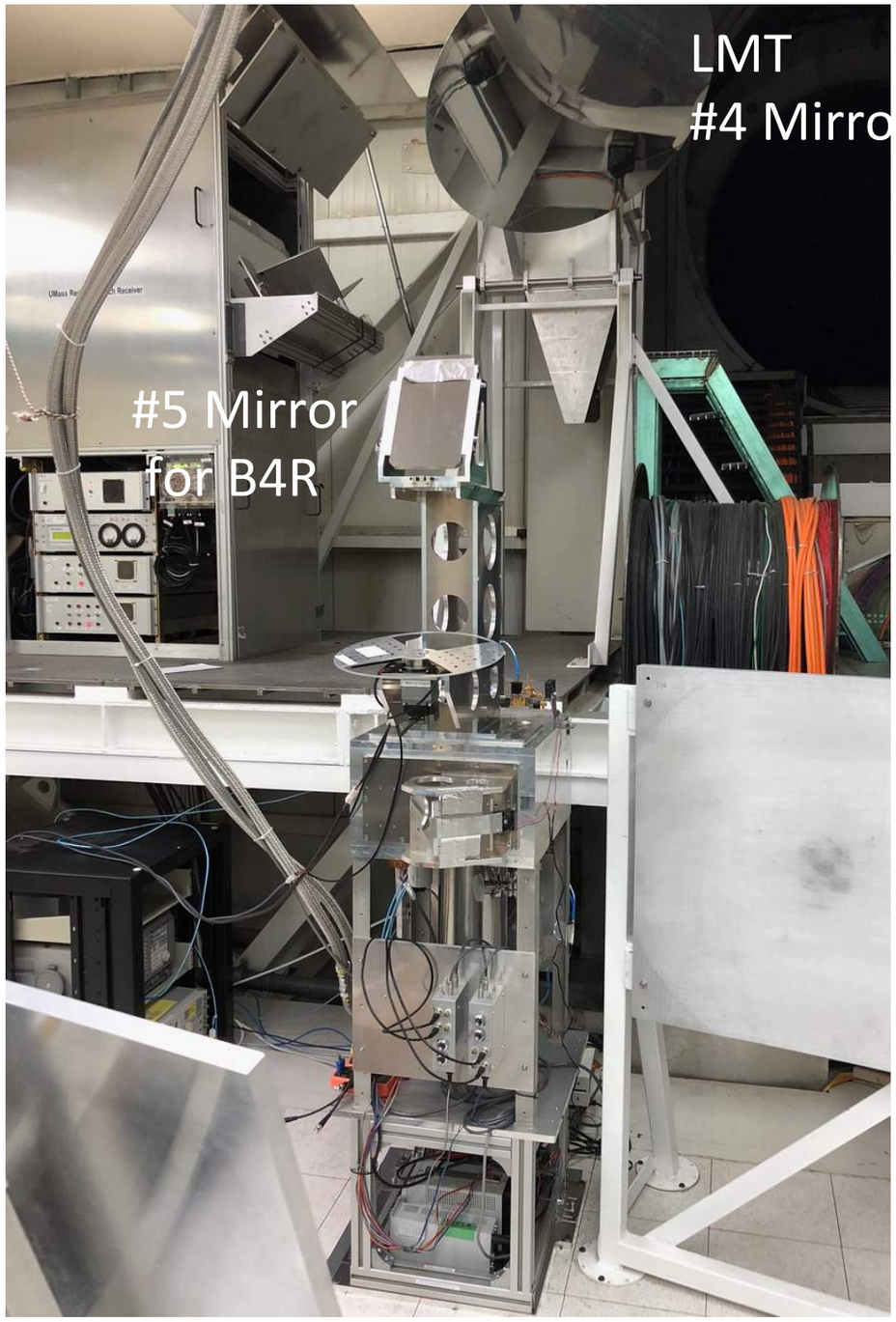
PI: Ryohei Kawabe(NAOJ)
Project Scientist: Bunyo Hatsukade (U. Tokyo)
Receiver Leader: Takeshi Sakai (UEC Tokyo)
BE leader: Kunihiko Tanaka (Keio University)
Science Advisors: Yoichi Tamura (Nagoya U.) and Kotaro Kohno (U. Tokyo)
Technical Advisor: Tai Oshima (NAOJ)
Other members: Akio Taniguchi, Masato Hagimoto, Keiichi Matsuda, Yohei Togami (Nagoya University), Yuki Yoshimura (U. Tokyo), Tatsuya Takekoshi (Kitami Tech/U. Tokyo), Teppei Yonetsu, Hiroyuki Maezawa (Osaka Pref. Univ), and Yoshito Shimajiri (NAOJ)

B4R

- Single-beam two-polarization 2mm-band receiver and dedicated digital spectrometer composed of four XFFTS boards

- Based on ALMA band-4 “2SB”, re-designed to fully use the 50m diameter of the LMT

- Installed and commissioned in 2018, science demonstration observations during fall 2019



Specifications

Commissioning results:

Aperture Efficiency

48 ± 6 % (133 GHz)
46 ± 6 % (147 GHz)

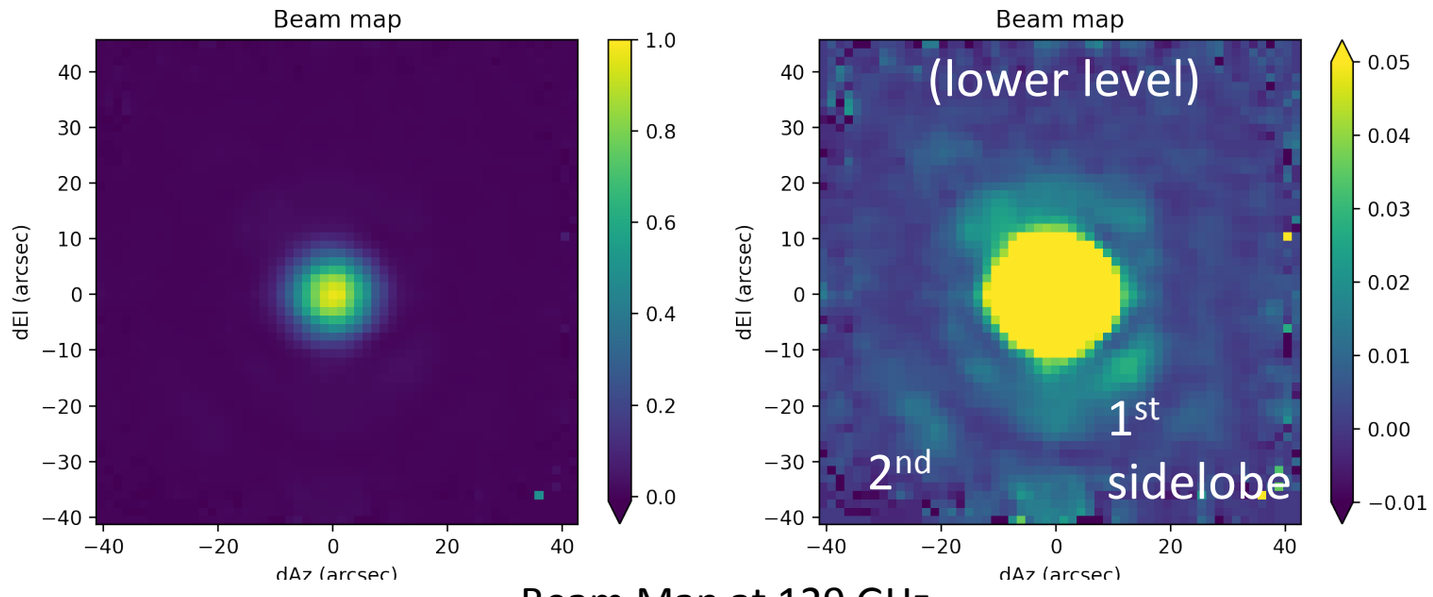
Tsys = 90 – 120 K
for tau_{225GHz} ~ 0.2
(toward targets)

Items	Specification	Comment
RF Frequency	125 – 163 GHz	ALMA Band-4 spec
# of Beam and Polarization	Single and Two pols	ALMA Band-4 spec
Sidebands Image Rejection Ratio	Two single sidebands > 13 dB	ALMA Band-4 spec
Trx (receiver noise)	< 60 K	ALMA Band-4 spec
IF Frequency	4-8 GHz	ALMA Band-4 spec
Spectrometer (XFFTS) Bandwidth/board # of freq channels/board freq. resolution	4 XFFTS boards 2.5 GHz/board 32,768 channels/board 76.3 kHz/channel	expandable to 8 boards (20 GHz in total) (131,072 channels) ~ 0.18 km/s in velocity

Table 1. Specifications of the B4R system.

Beam size~ 10” at 150 GHz

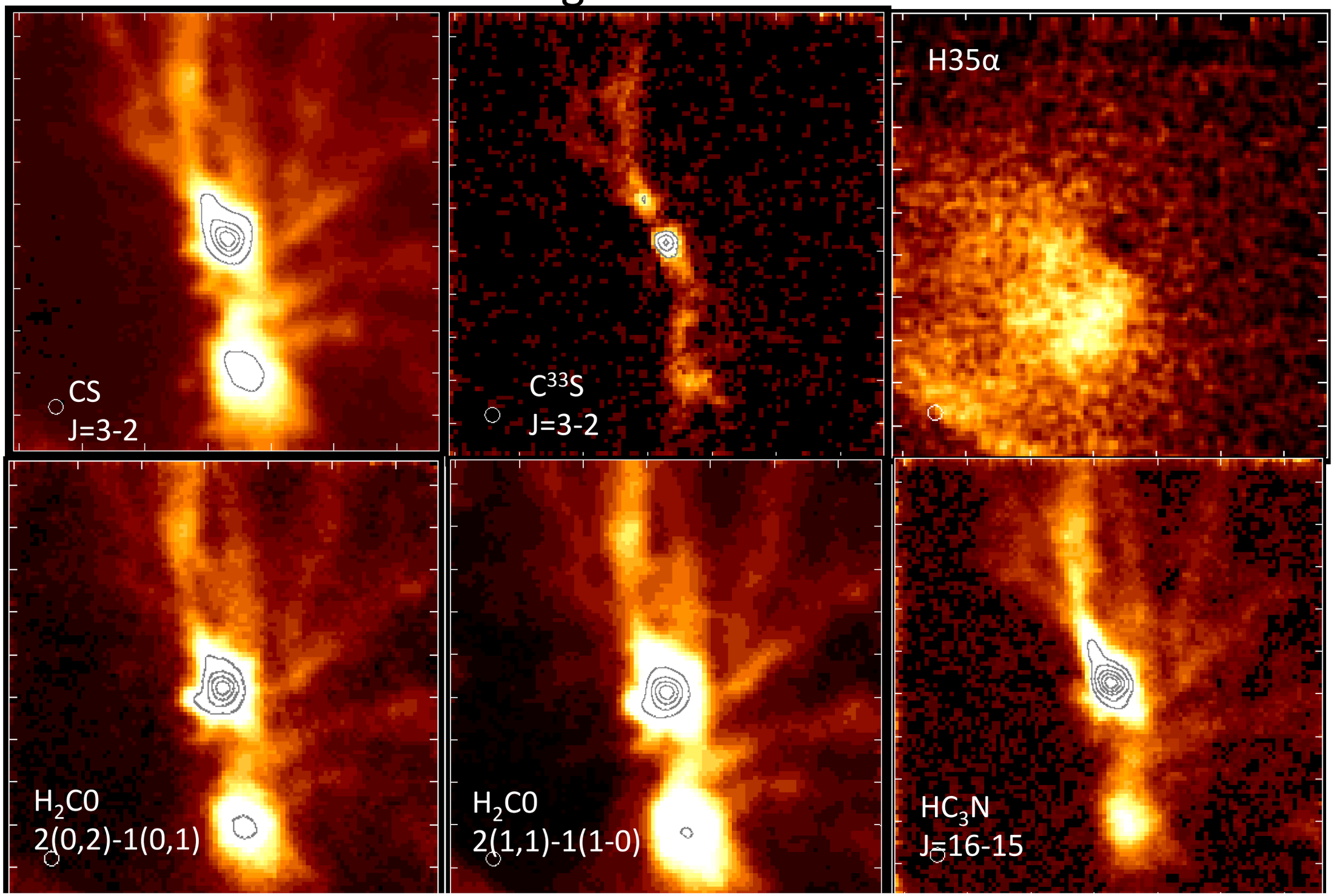
1st sidelobe < 3% of peak



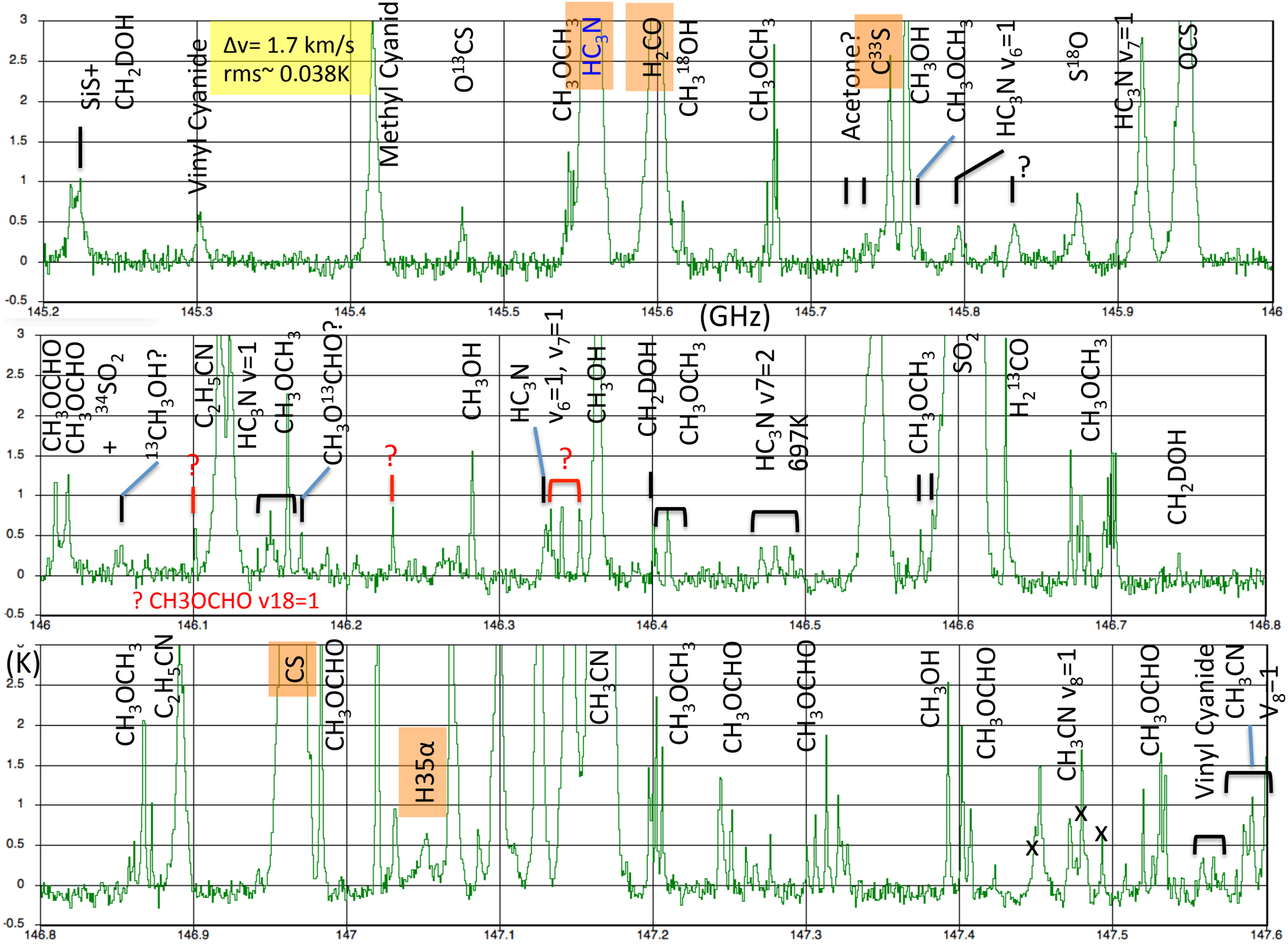
Beam Map at 129 GHz

Demo Science:
OTF images: OMC-1 5'x5'

Two Freq. Settings
Nov., 2019 **40 min x 2**



Spectral line survey

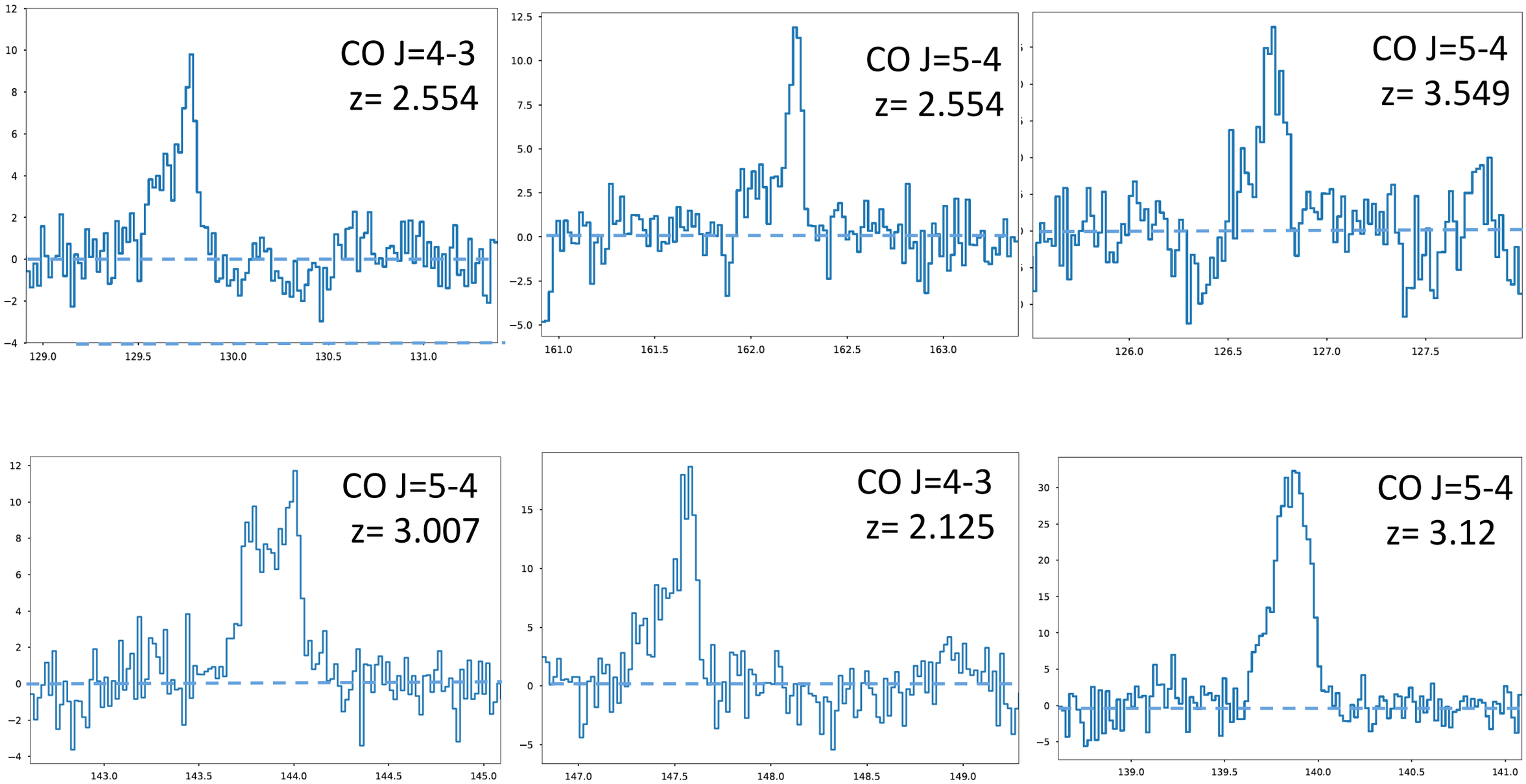


13” diameter region around Orion KL; ~ 2-3 sec integration

Demo Science:
CO Detections for high-z bright SMGs

On-source ~ 5-10 min.

Nov., 2019



B4R webpage

Large Millimeter Telescope *Alfonso Serrano*

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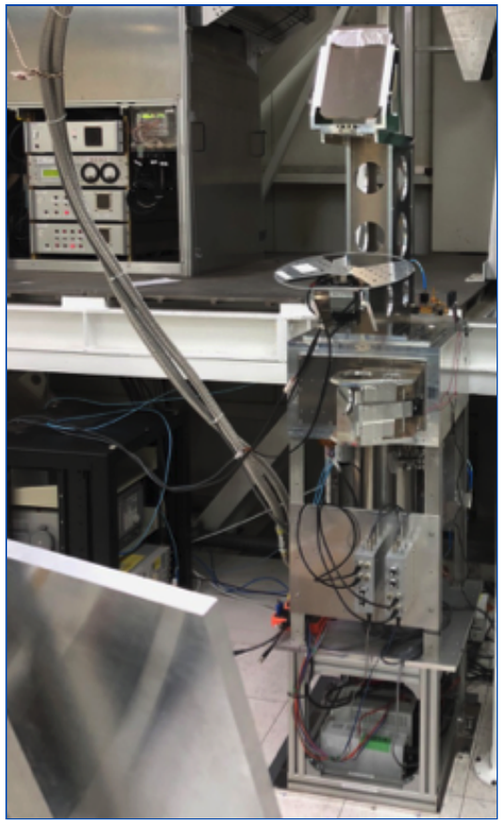


The 2mm B4R installed in the instruments room of the LMT.

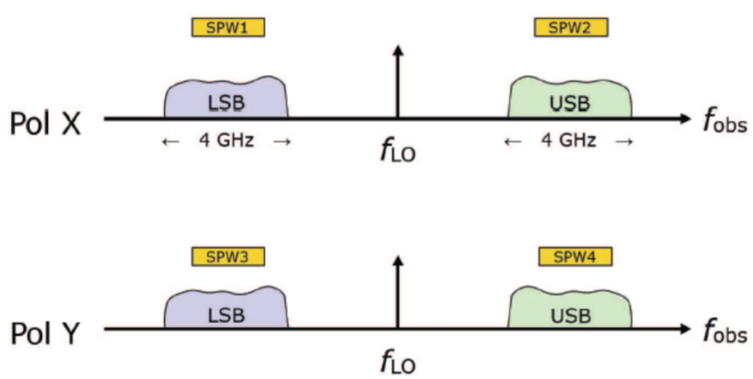
B4R

The 1st IF is 4 to 8 GHz, and the 1st LO composed of a synthesizer and multiplier chain. The first IF is down-converted using the 2nd LO (or 2nd IF reference) signal from other synthesizers to the final IF signal DC-2.5 GHz. The four sets of the IF signals are fed to the spectrometer via bandpass filters. The observing frequencies at the USB (f_{USB}) and the LSB (f_{LSB}) are calculated as follows:

$$f_{\rm USB} = f_{\rm LO} + f_{\rm IFref} - f_{\rm USB,XFFTS},$$
$$f_{\rm LSB} = f_{\rm LO} - f_{\rm IFref} + f_{\rm LSB,XFFTS},$$

where f_{LO} is the 1st LO frequency, f_{IFref} is the 2nd IF frequency (8.1 GHz for the default frequency setting), and $f_{USB,\ XFFTS}$ or $f_{LSB,\ XFFTS}$ are the XFFTS frequencies.

For example, if we select f_{LO} = 140 GHz, the observing frequencies are f_{USB} = 145.6-148.1 GHz and f_{LSB} = 131.9-134.4 GHz. Note that both band edges at the final IF at the spectrometer (i.e. 0.0 – 2.5 GHz), 0.0 – 0.1 MHz and 2.4 – 2.5 GHz are contaminated by out-band spectral signals due to aliasing of AD converter in the XFFTS board and the 2nd down conversion, respectively.



Spectrometer: “XFFTS”

Basic Specifications for single XFFTS board

Bandwidth: 2.5 GHz/each board

Total Number of frequency channels: 32,768 ch./each board

Freq Resolution: 1.16 ch x 76.3 kHz/ch = 88.5 kHz

Velocity Resolution/Coverage: 0.177 km/s & ~ 5,800 km/s at 150 GHz

Frequency Configuration for B4R

Four XFFTS boards for two pols & two sidebands (one each IF output)

=> upgrade to 8 XFFTS boards to cover full IF=4-8 GHz

(currently additional two XFFTS boards purchased)

Spectrometer with FFTS boards and FFT controller