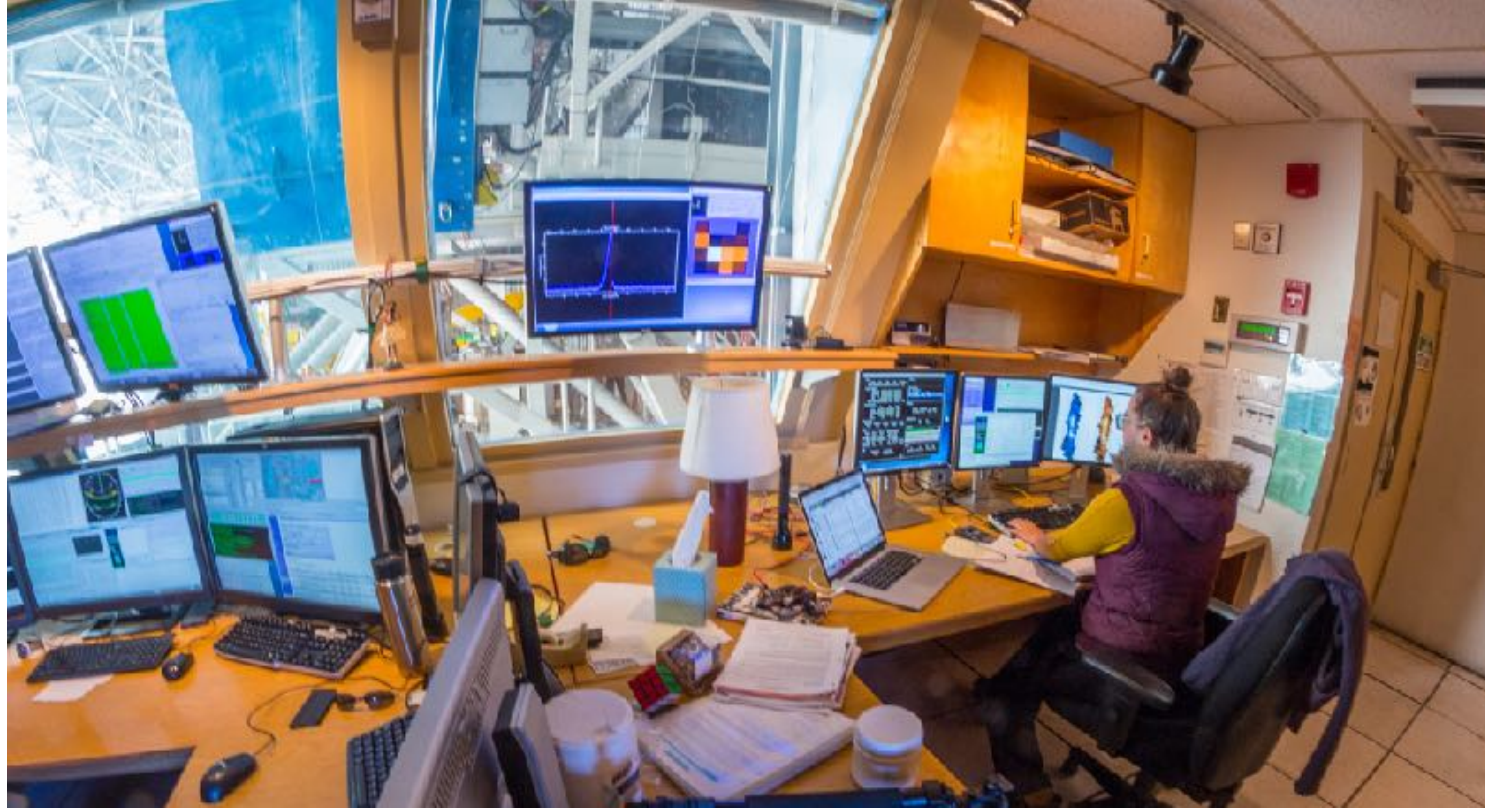


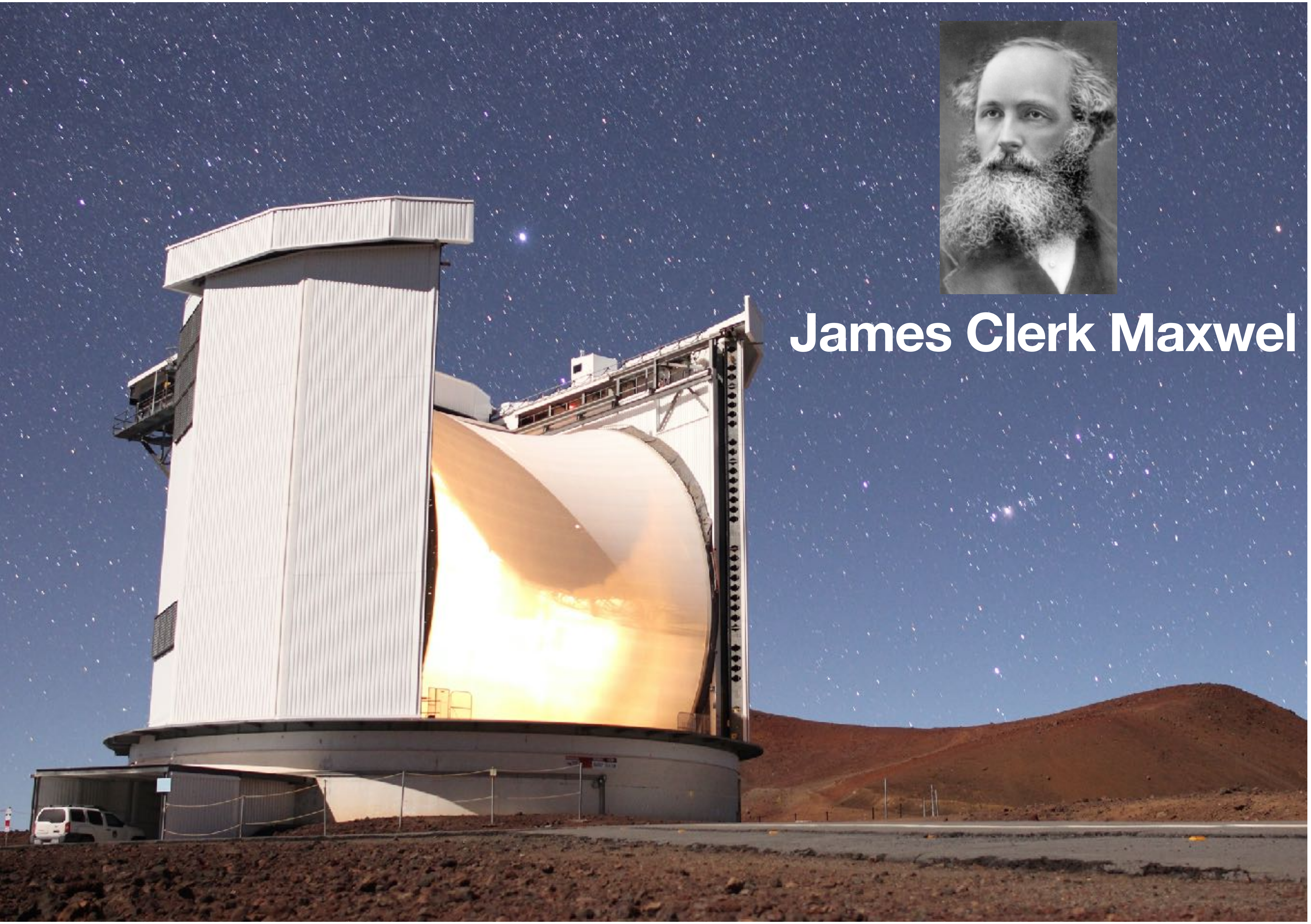
Introduction to the JCMT

James Clerk Maxwell Telescope (JCMT)
East Asian Observatory (EAO)

By Team EAO/JCMT

James Clerk Maxwell Telescope
East Asian Observatory

JCMT



- Operational in 1987
- Maunakea, Hawai`i
- Altitude 4,092m, 14,000’
- 15m dish
- 276 panels
- Surface accuracy typically 24μm
- Gore-Tex wind blind; transparent in sub-mm
- VLBI capabilities

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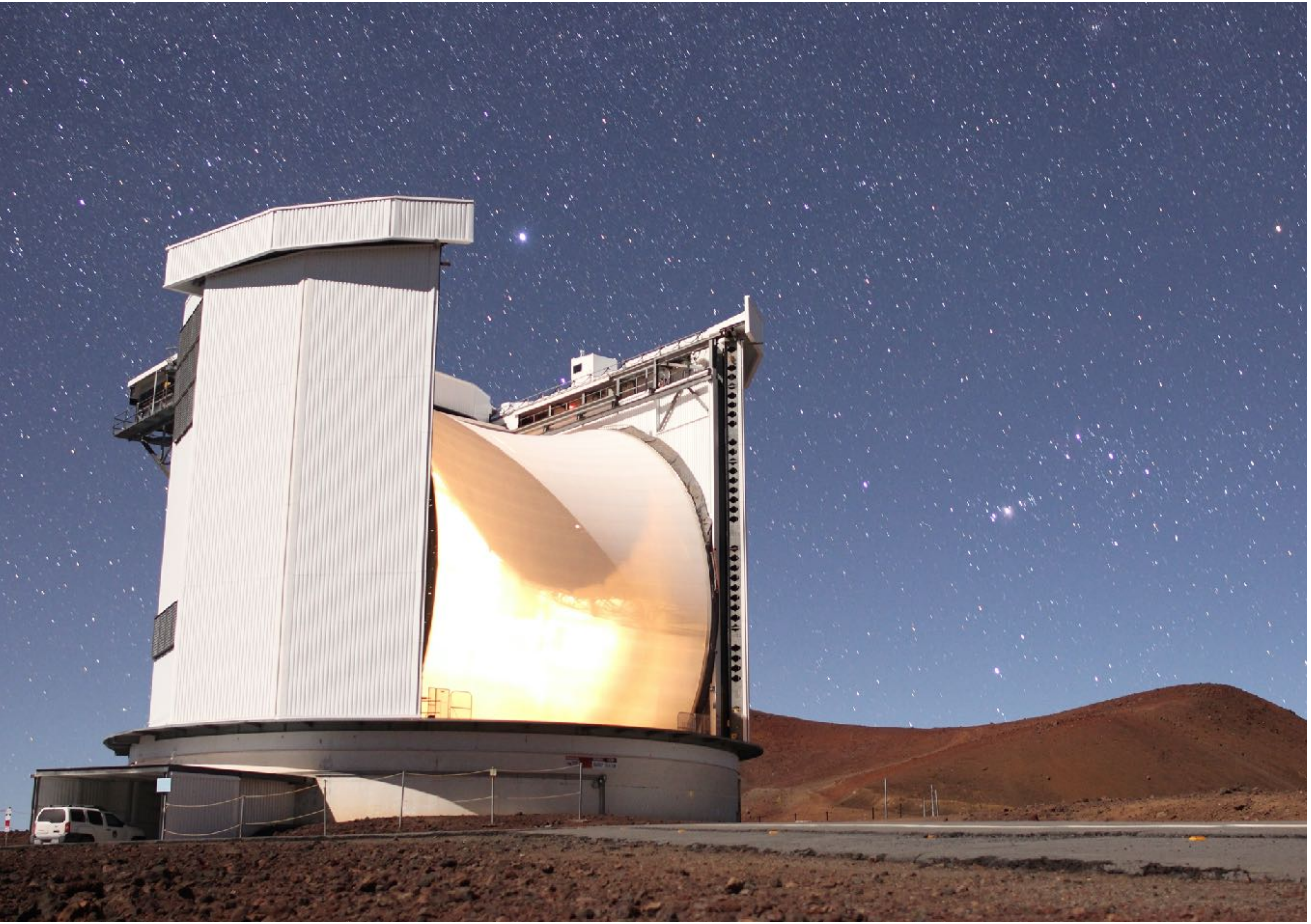

JCMT

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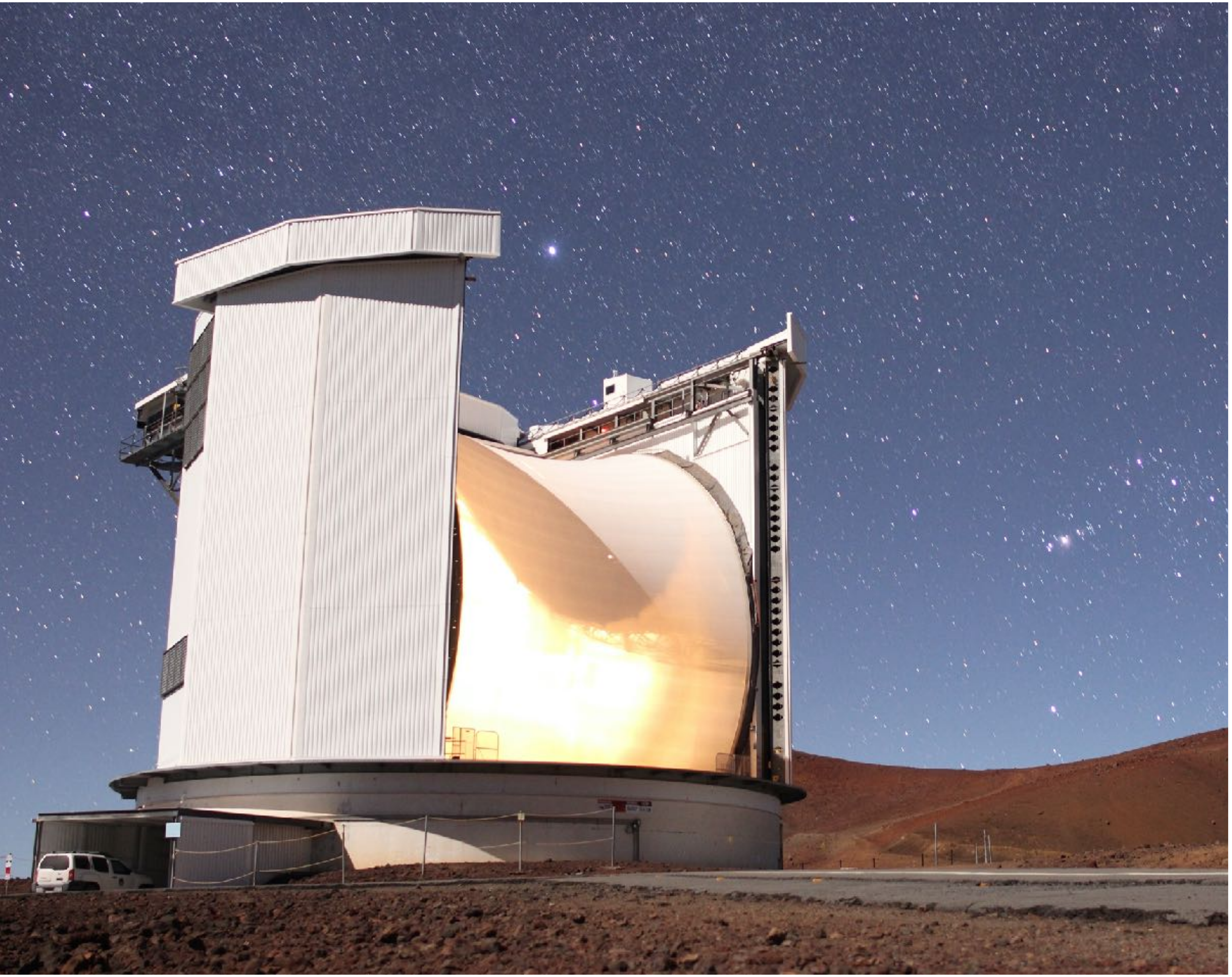


Instruments

- 4 instruments designed to make use of the sub-mm atmospheric windows
    - SCUBA-2
    - POL-2 (with SCUBA-2)
    - HARP
    - Nāmakanui

JCMT - Maunakea

- Altitude of 4,092m, 14,000’.
- inversion layer trapping moisture below 3000m
- latitude of 19.8 deg good for Northern and some souther hemisphere sources - overlap with ALMA
- Accessible/infrastructure - lodging 30 minutes, base facility 2 hours

Ric Noyle / W. M. Keck Observatory

Sub-mm atmospheric transmission as a function of frequency at the JCMT on Maunkaea

http://www.submm.caltech.edu/cso/weather/atplot.shtml

Sub-mm atmospheric transmission as a function of frequency at the JCMT on Maunkaea

Nāmakanui operating around 230GHz

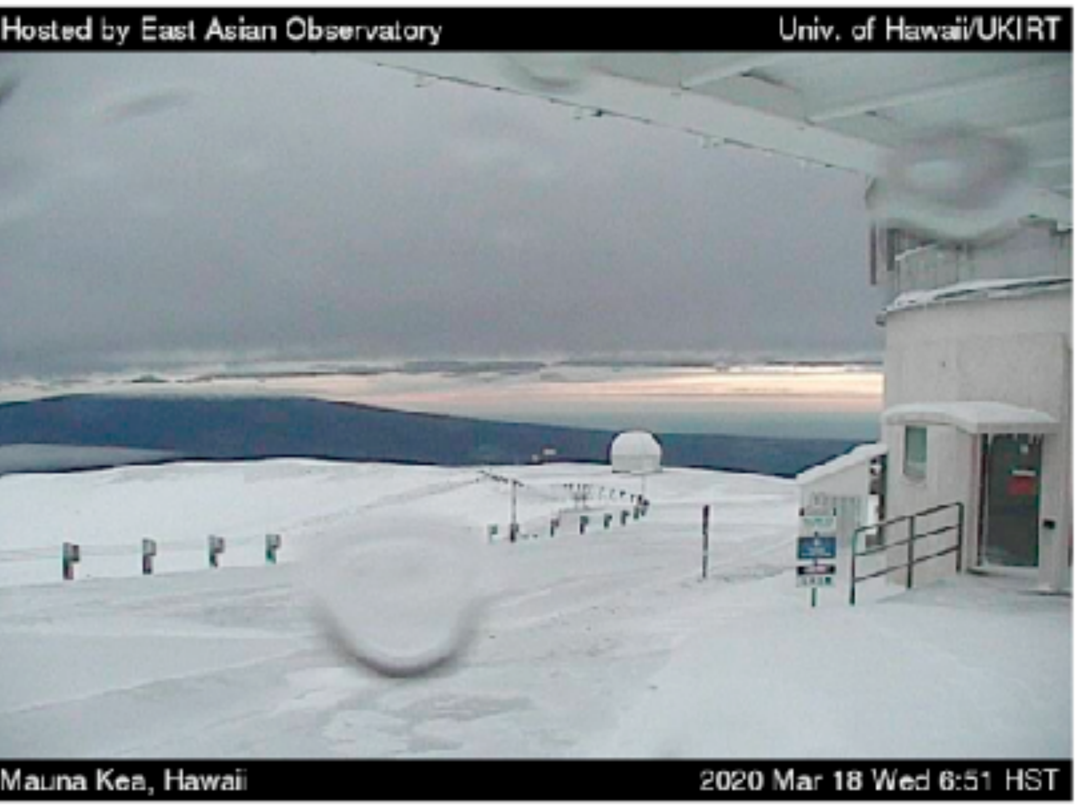
Nāmakanui HARP, SCUBA-2 and POL-2 345GHz

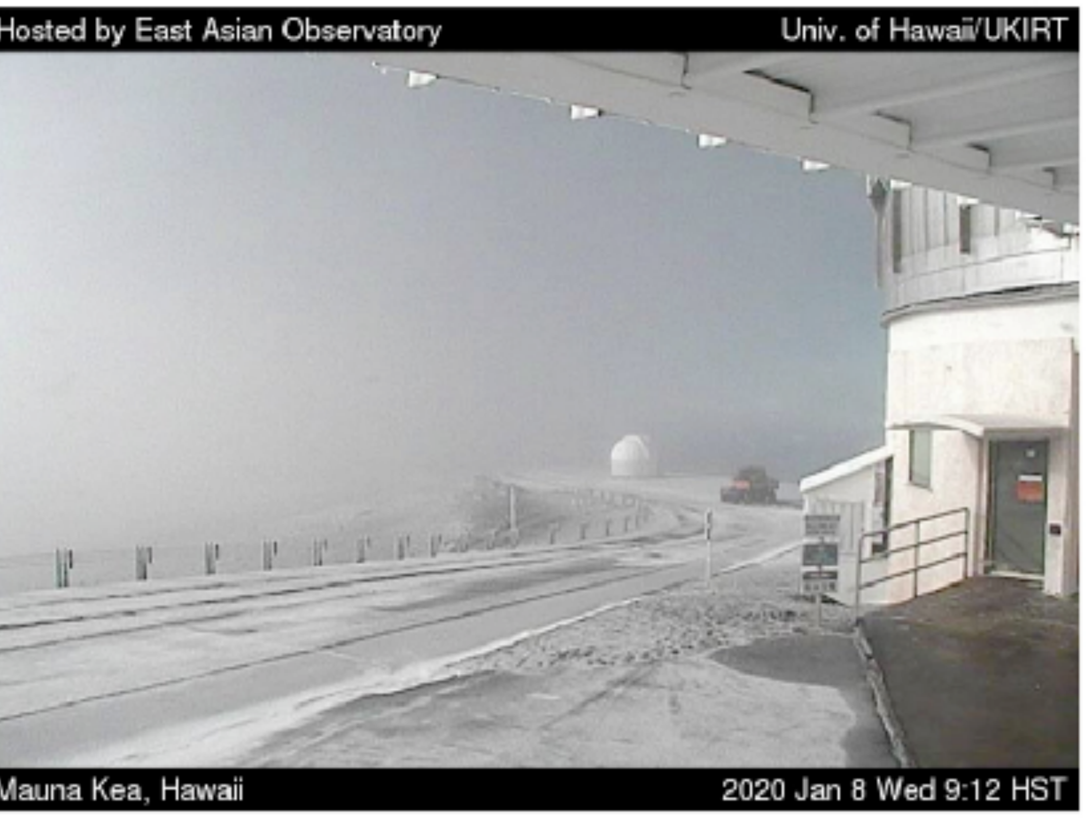
SCUBA-2 operating around 450microns ~660GHz

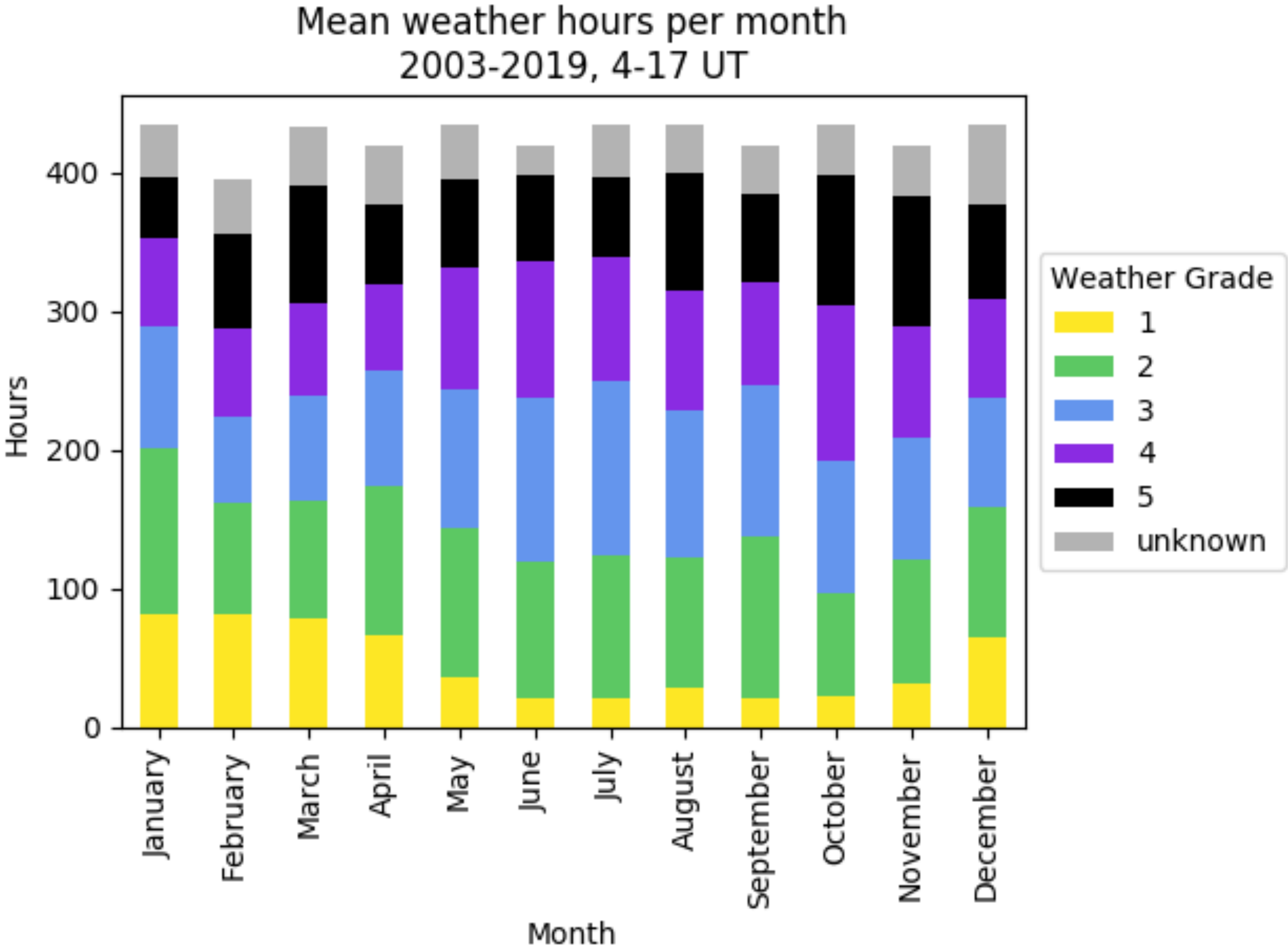
http://www.submm.caltech.edu/cso/weather/atplot.shtml

Sub-mm atmospheric transmission as a function of frequency at the JCMT on Maunkaea

http://www.submm.caltech.edu/cso/weather/atplot.shtml







https://www.eaobservatory.org/jcmt/observing/weather-bands/


SCUBA-2
450 & 850
microns
POL-2
450 & 850
microns
WVM
183GHz
Nāmakanui
86, 230, 345GHz
HARP
345GHz
Receiver Cabin
moves in elevation

Heterodyne

Nāmakanui
operating around
86, 230 and 345GHz

HARP
operating around
345GHz

JCMT:
ACSIS
Digital backend
spectrometer

Heterodyne

Nāmakanui
operating around
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HARP
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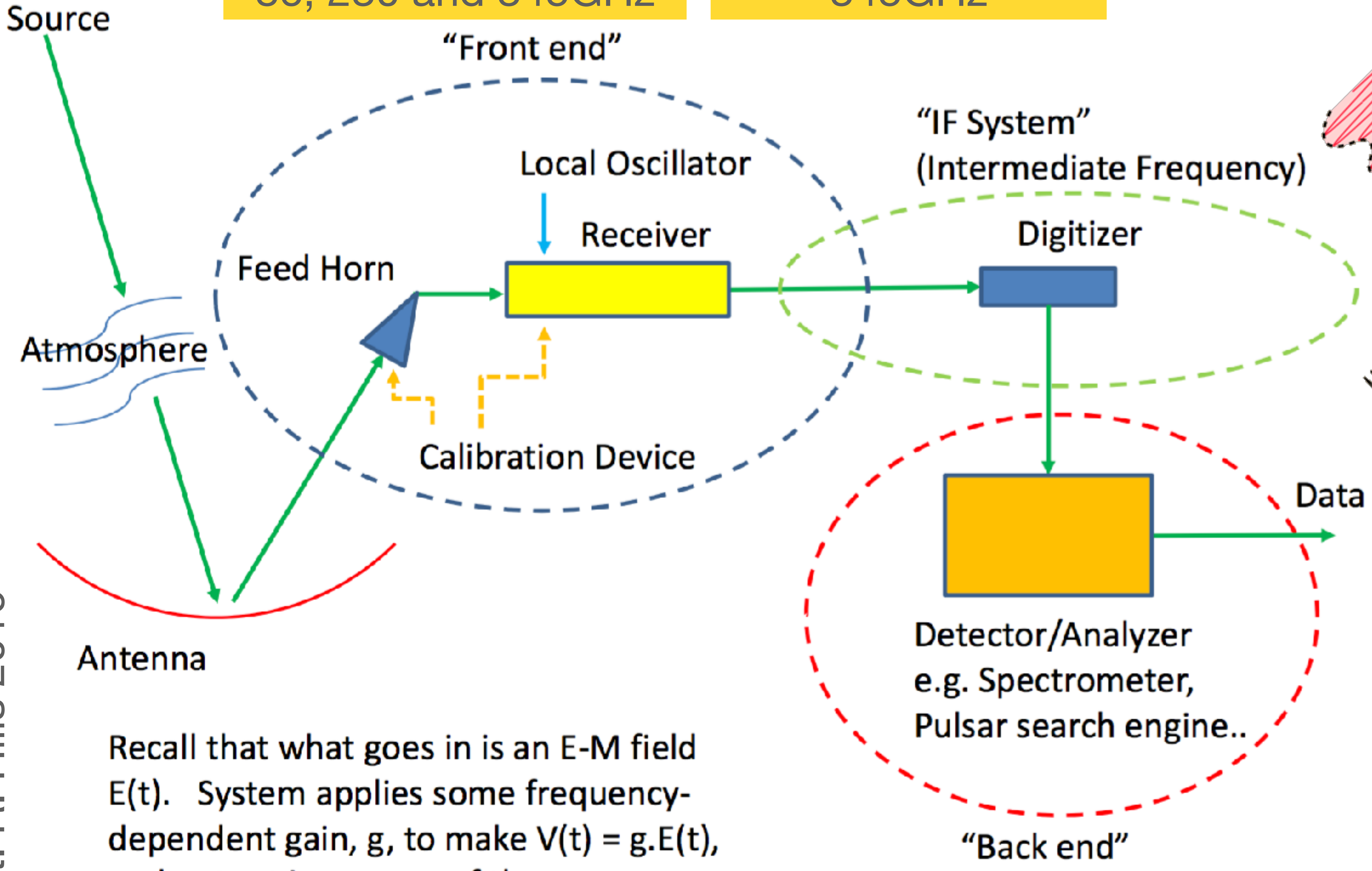
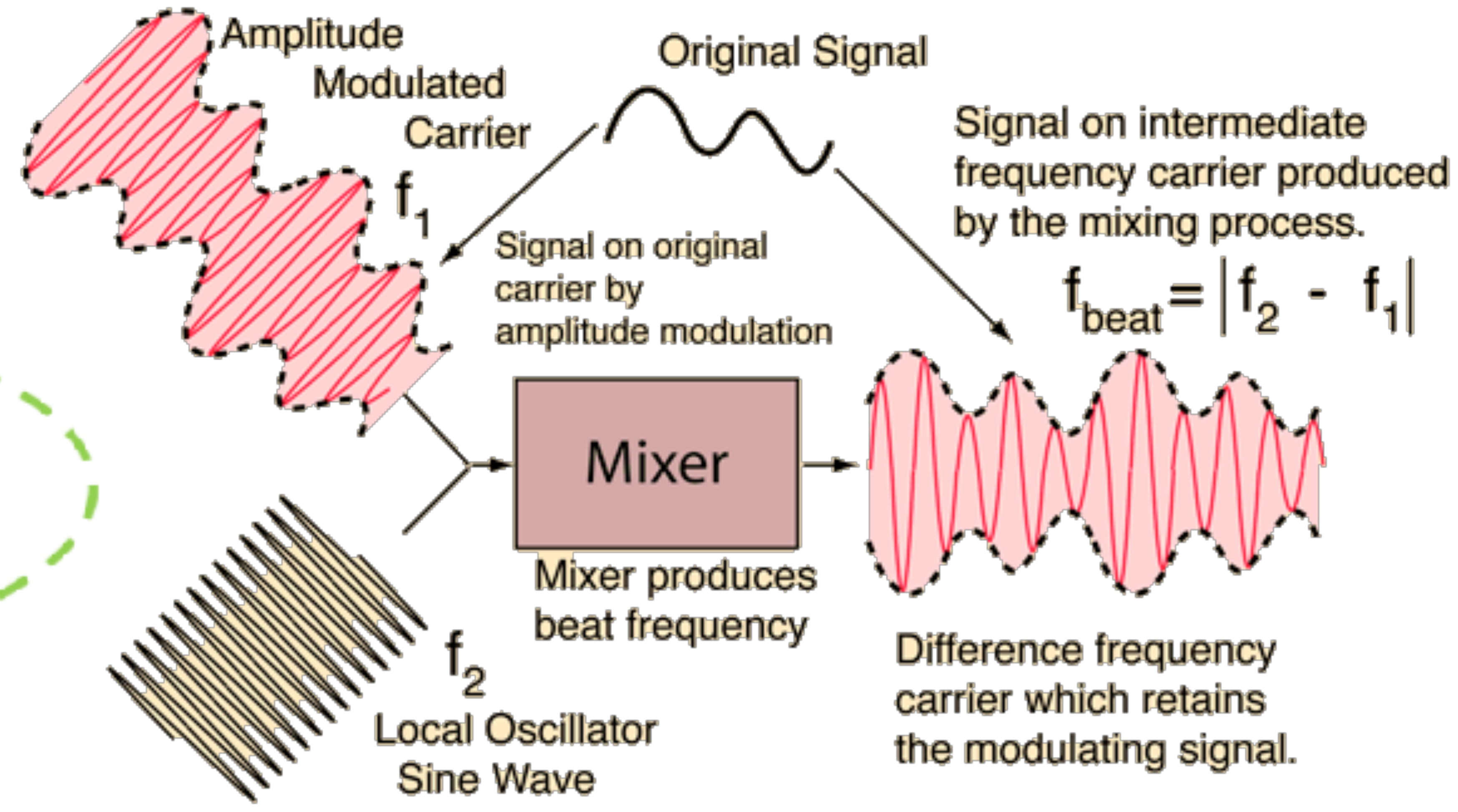




JCMT:
ACSIS
Digital backend
spectrometer

VLBI (EHT or EAVN)
R2DBE & Mark6

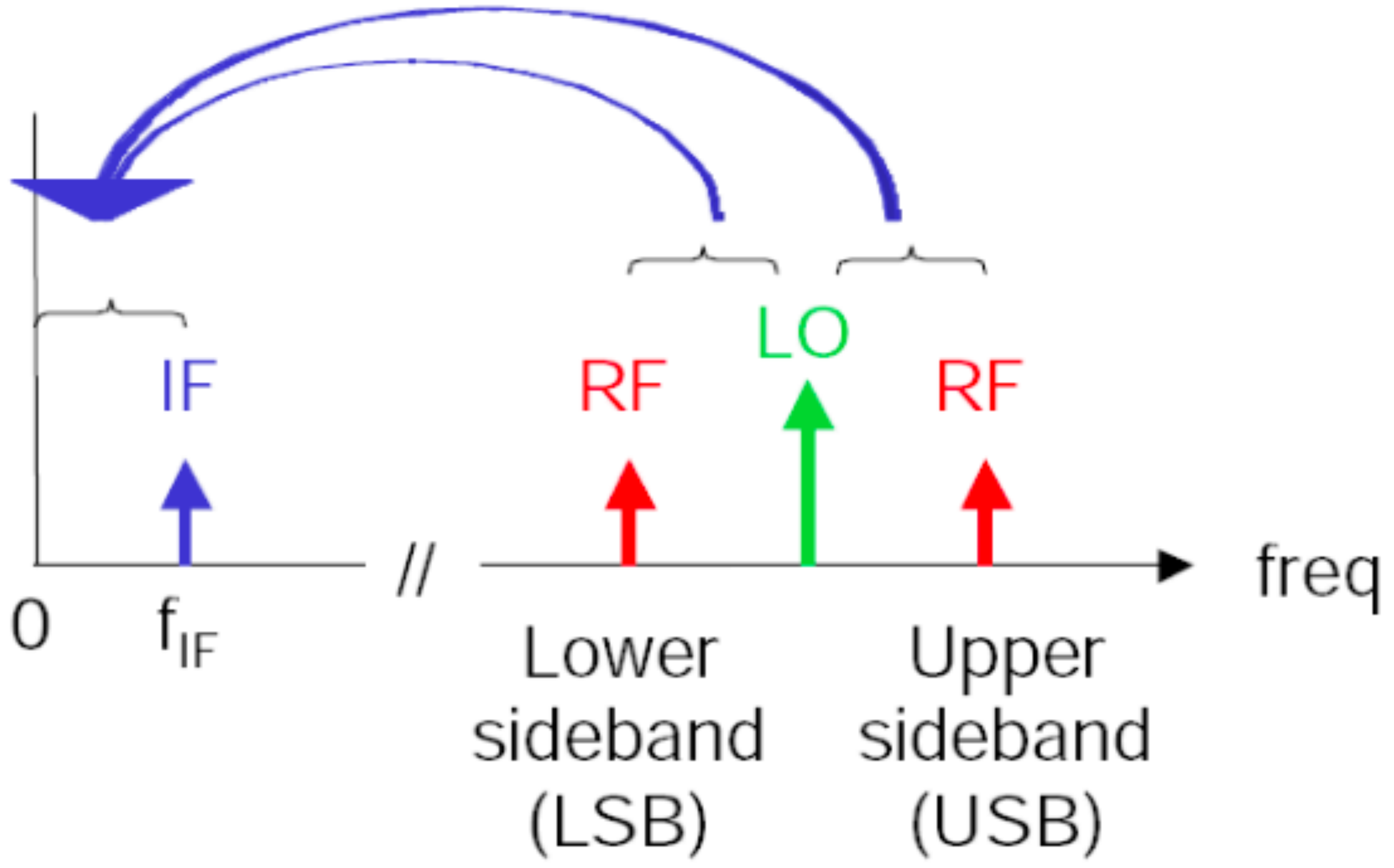
Recall that what goes in is an E-M field E(t). System applies some frequency-dependent gain, g, to make V(t) = g.E(t), and output is average of the power P = <V.V*> over some integration time τ.

Credit: R. Hills 2016

Mixer image: http://hyperphysics.phy-astr.gsu.edu/hbase/Audio/radio.html

Principle of Down-conversion

taken from: http://www.astro.umass.edu/~myun/teaching/radio/heterodyne_receivers_talk.pdf but many others on heterodyne receivers.



$$\nu_{IF} = |\nu_{LO} - \nu_{RF}|$$

SSB Receiver: Single Sideband

- Only one sideband makes it through the receiver. Other (image) sideband rejection (either quasi-optically or at mixer)

DSB Receiver: Both Sidebands are superimposed on each other at IF output

Sideband Separation Receiver: Both sidebands converted to different IF outputs

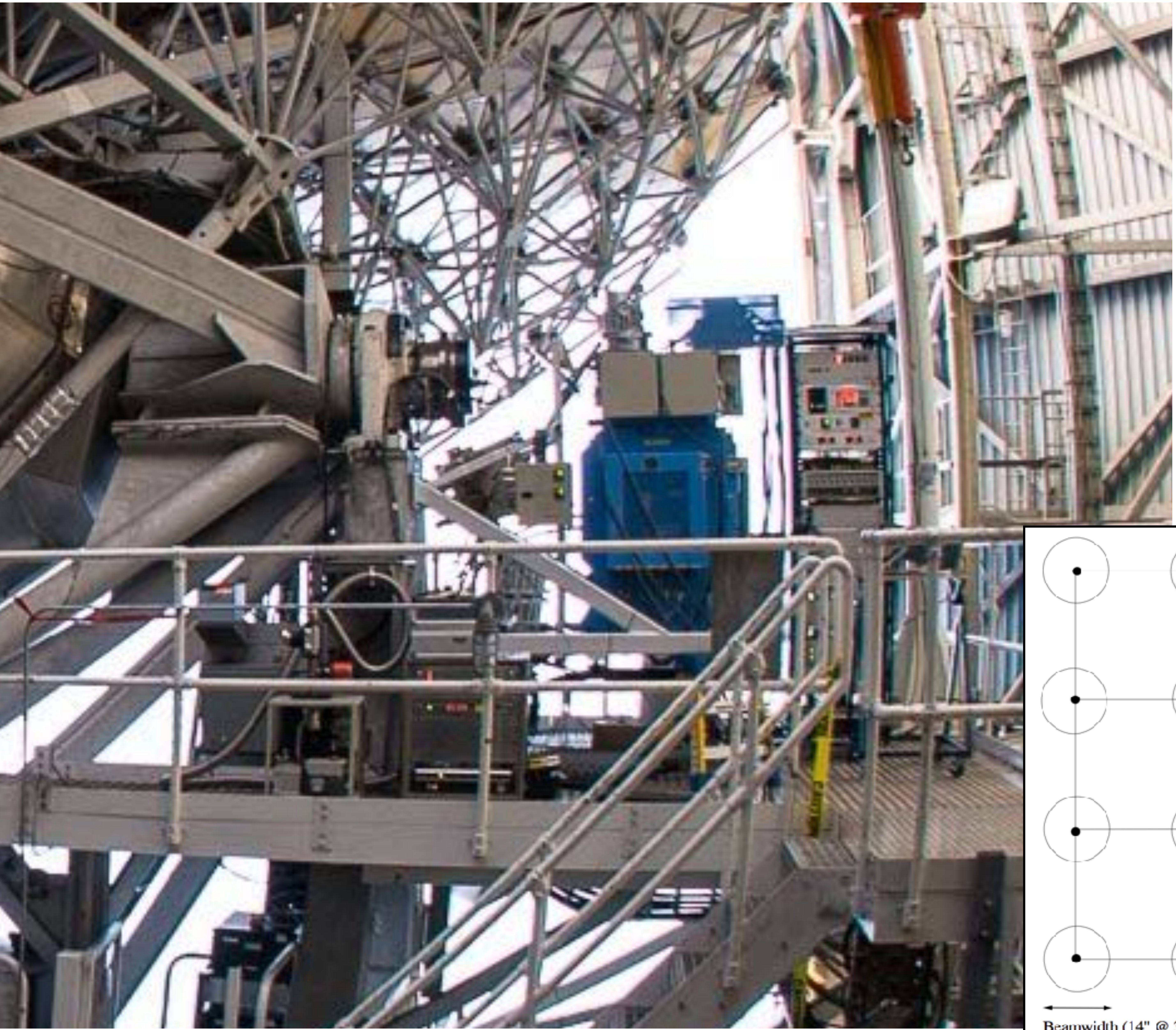
SSB at JCMT:
HARP
345GHz

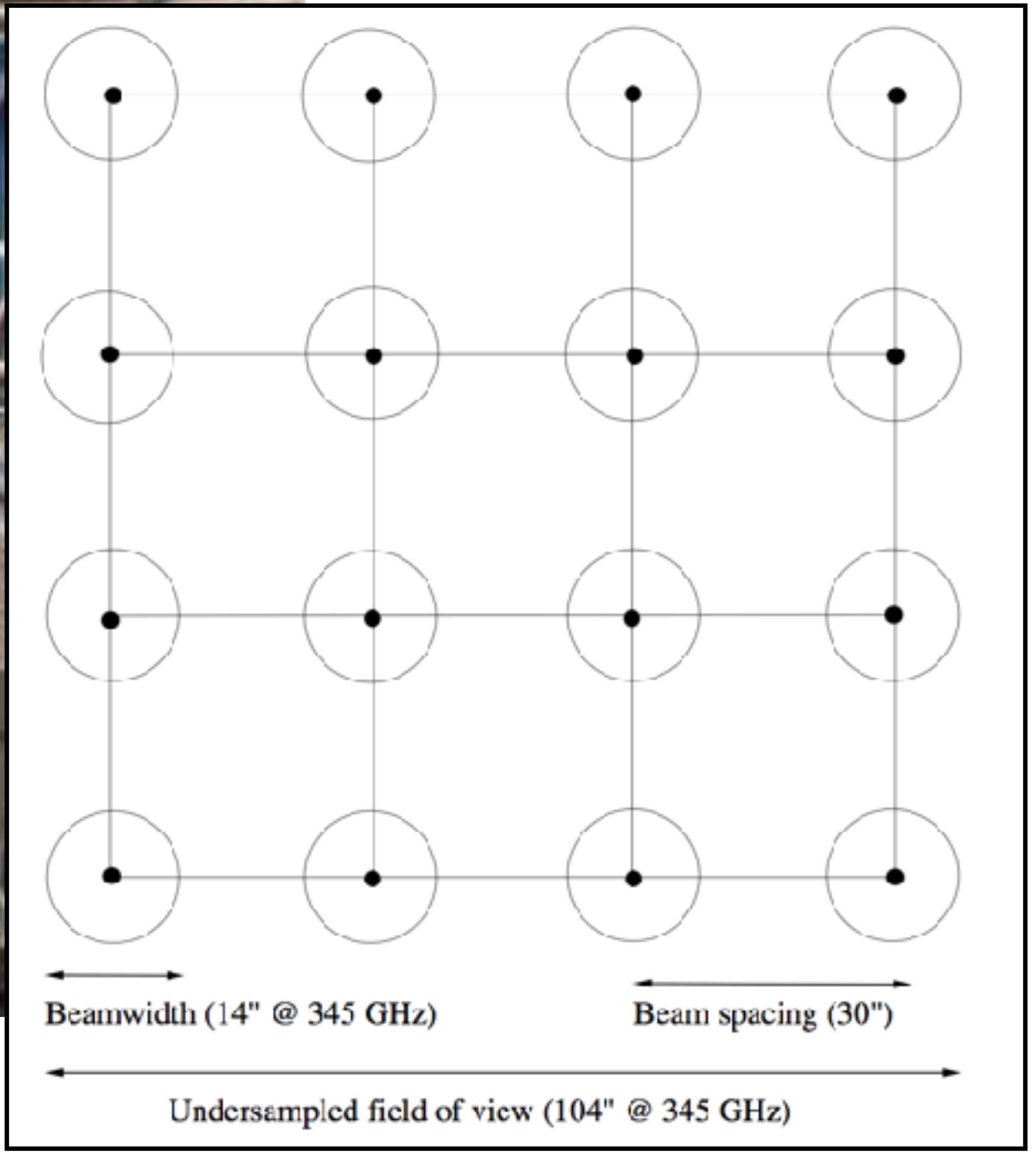
no DSB at JCMT

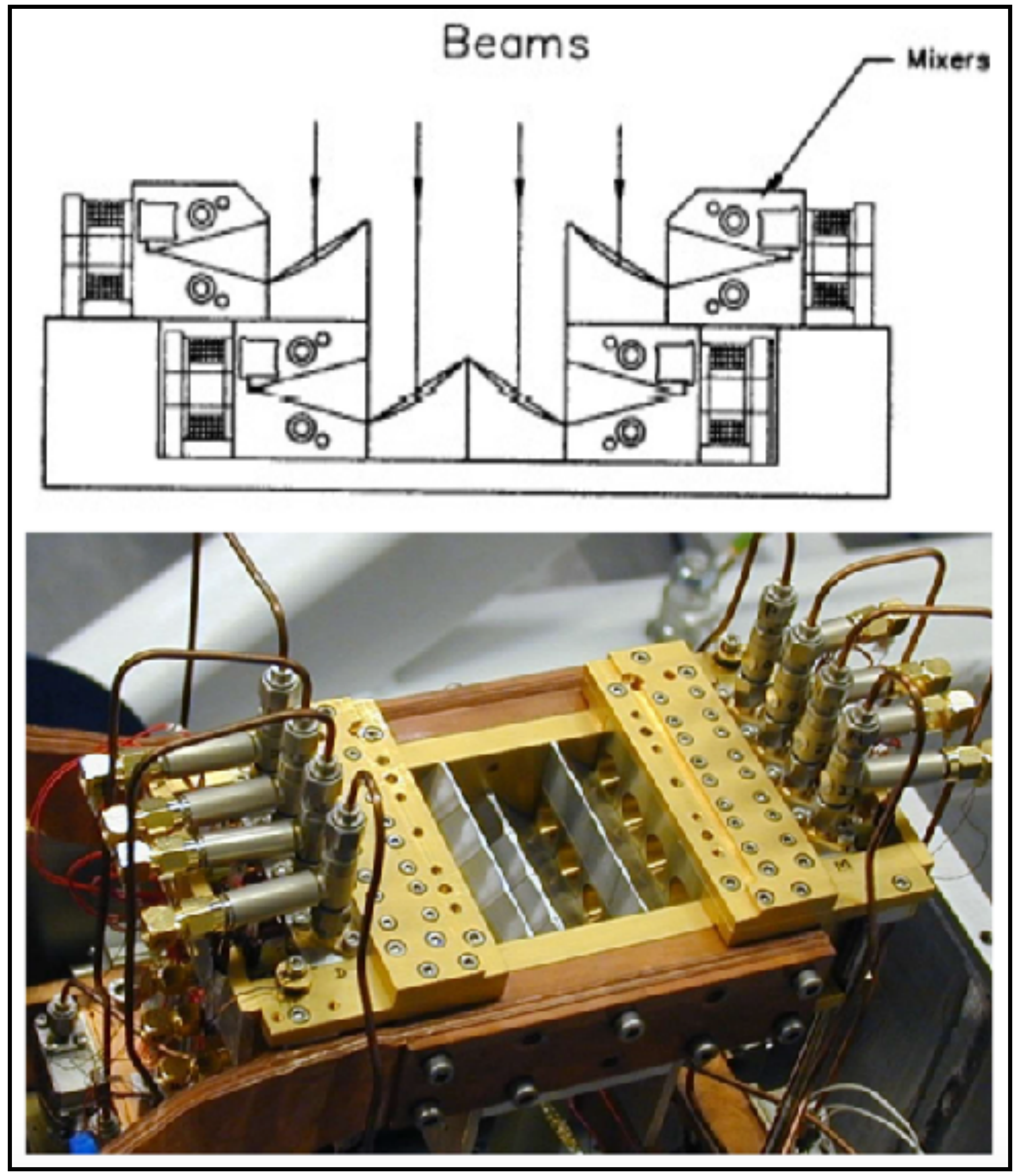
2SB at JCMT
Nāmakanui
86, 230 and 345GHz

HARP

- 16 receptors
- 325 - 375 GHz
- Single Side Band receiver (SSB)
- Intermediate Frequency (IF) of 5 GHz
- 14” beam





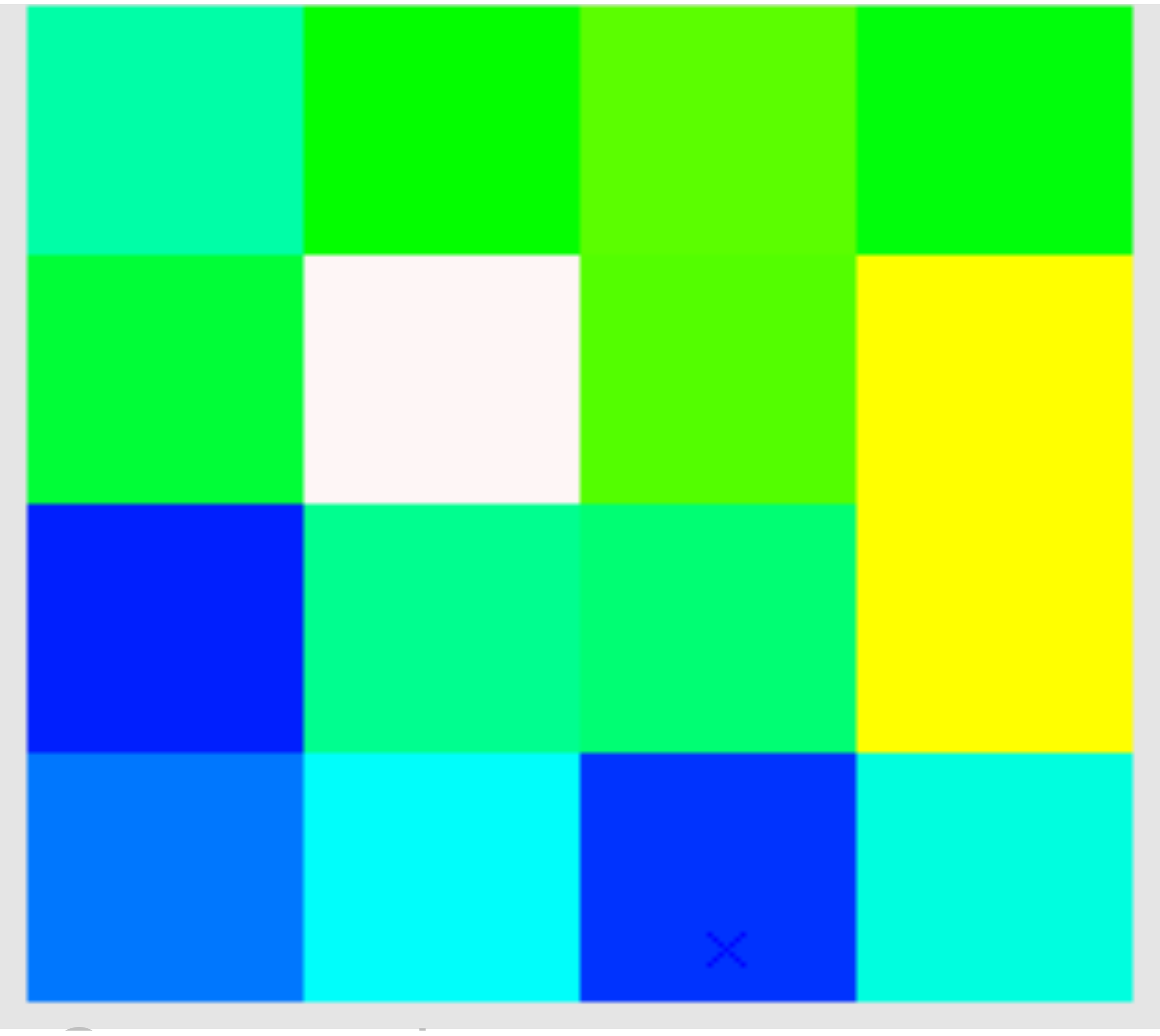


https://ui.adsabs.harvard.edu/abs/2009MNRAS.399.1026B/abstract

Observing Modes

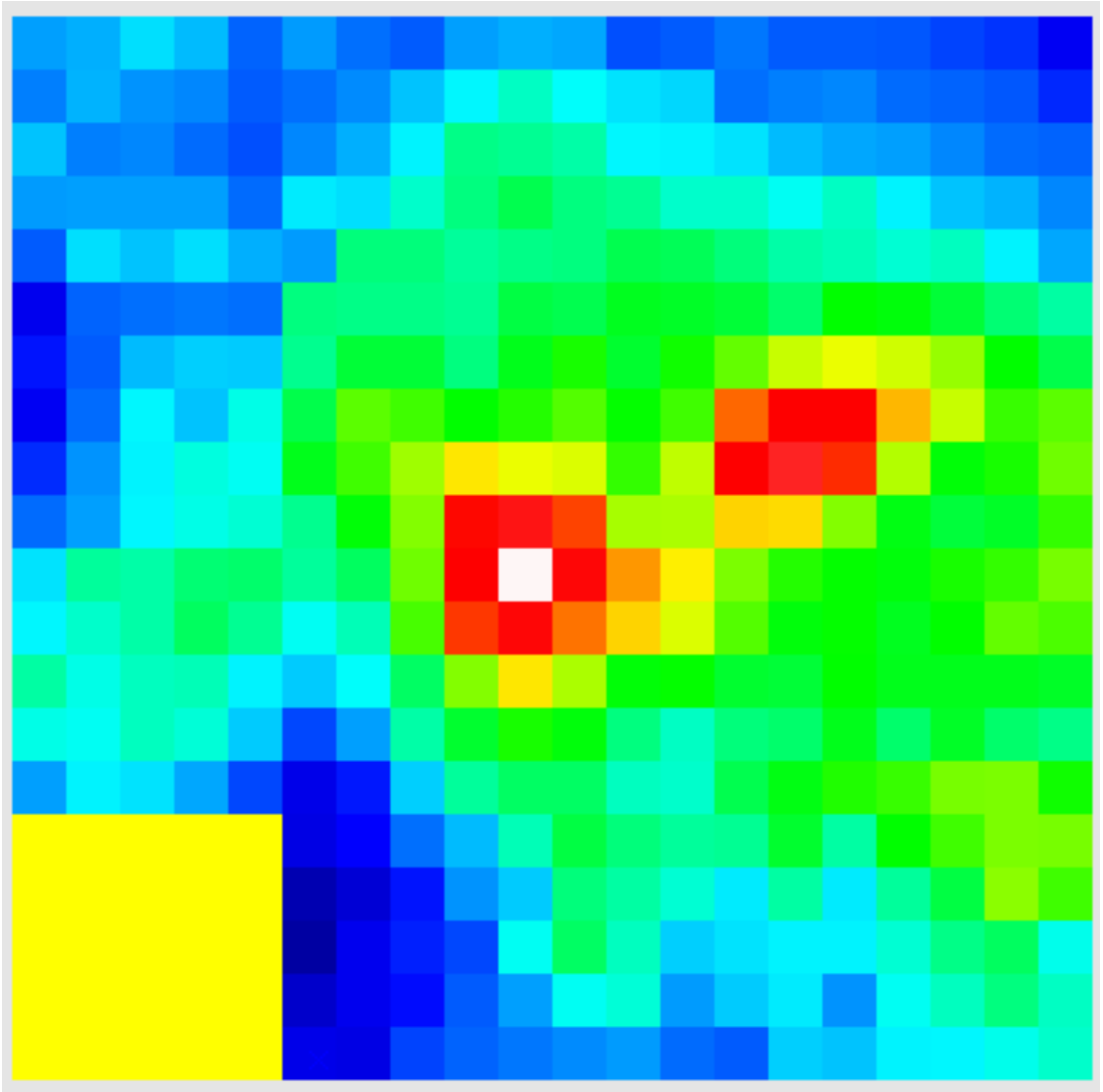
HARP

Stare



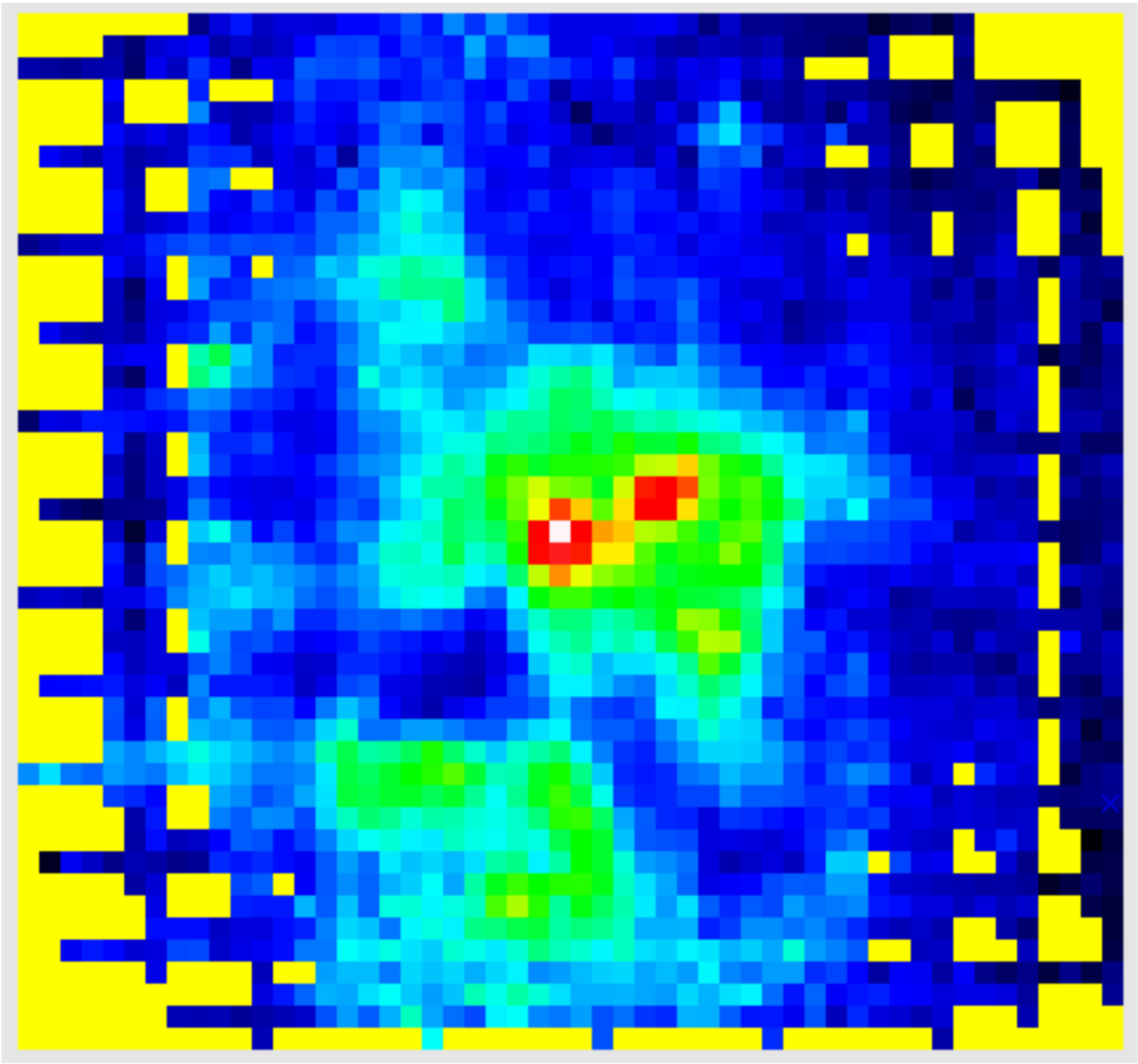
2' field,
30" pixels

Jiggle



2'field,
6" pixels

Raster

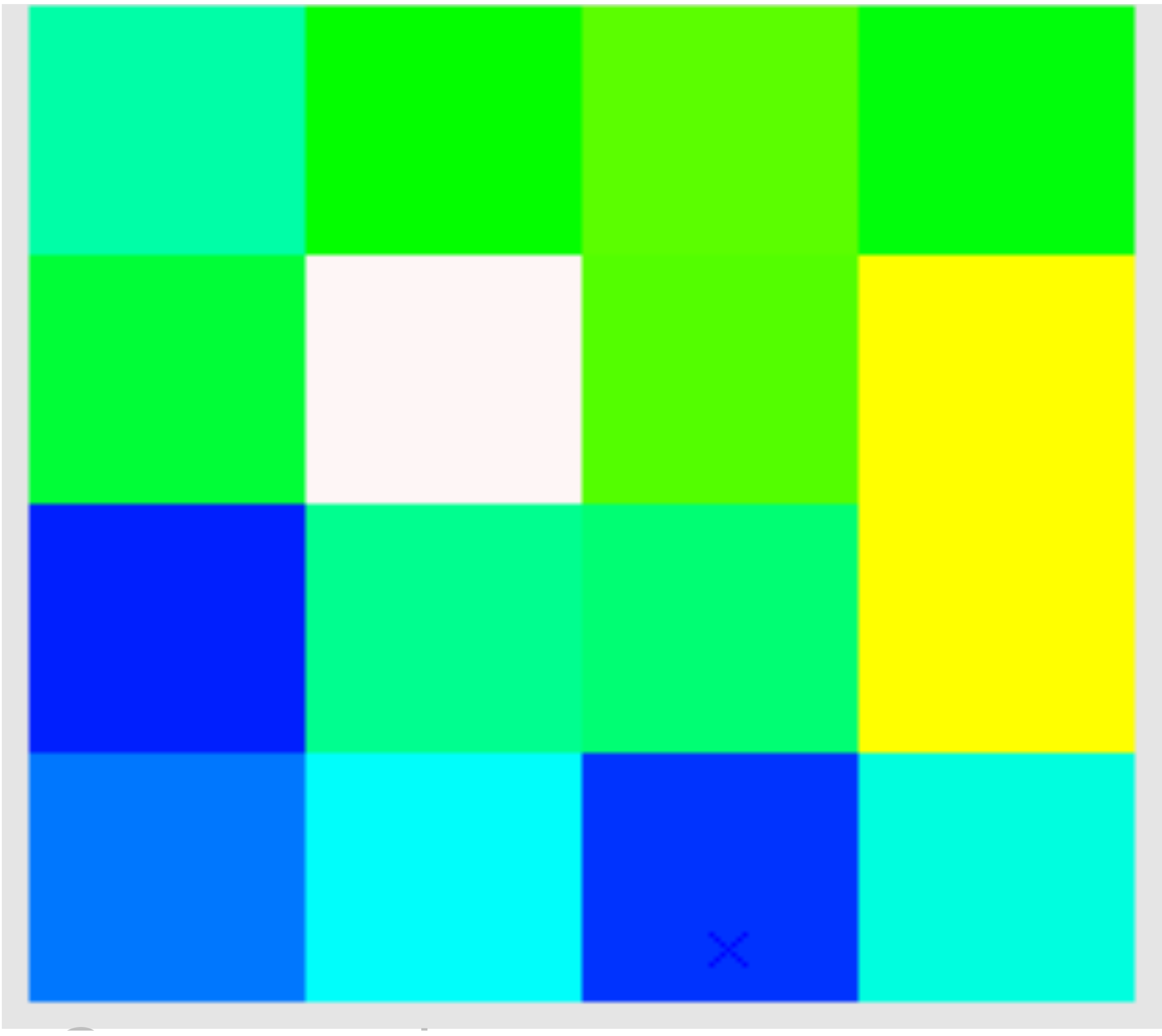


6' field,
7.25" pixels

https://www.eaobservatory.org/jcmt/instrumentation/heterodyne/harp/

Obse

Stare



2’ field,
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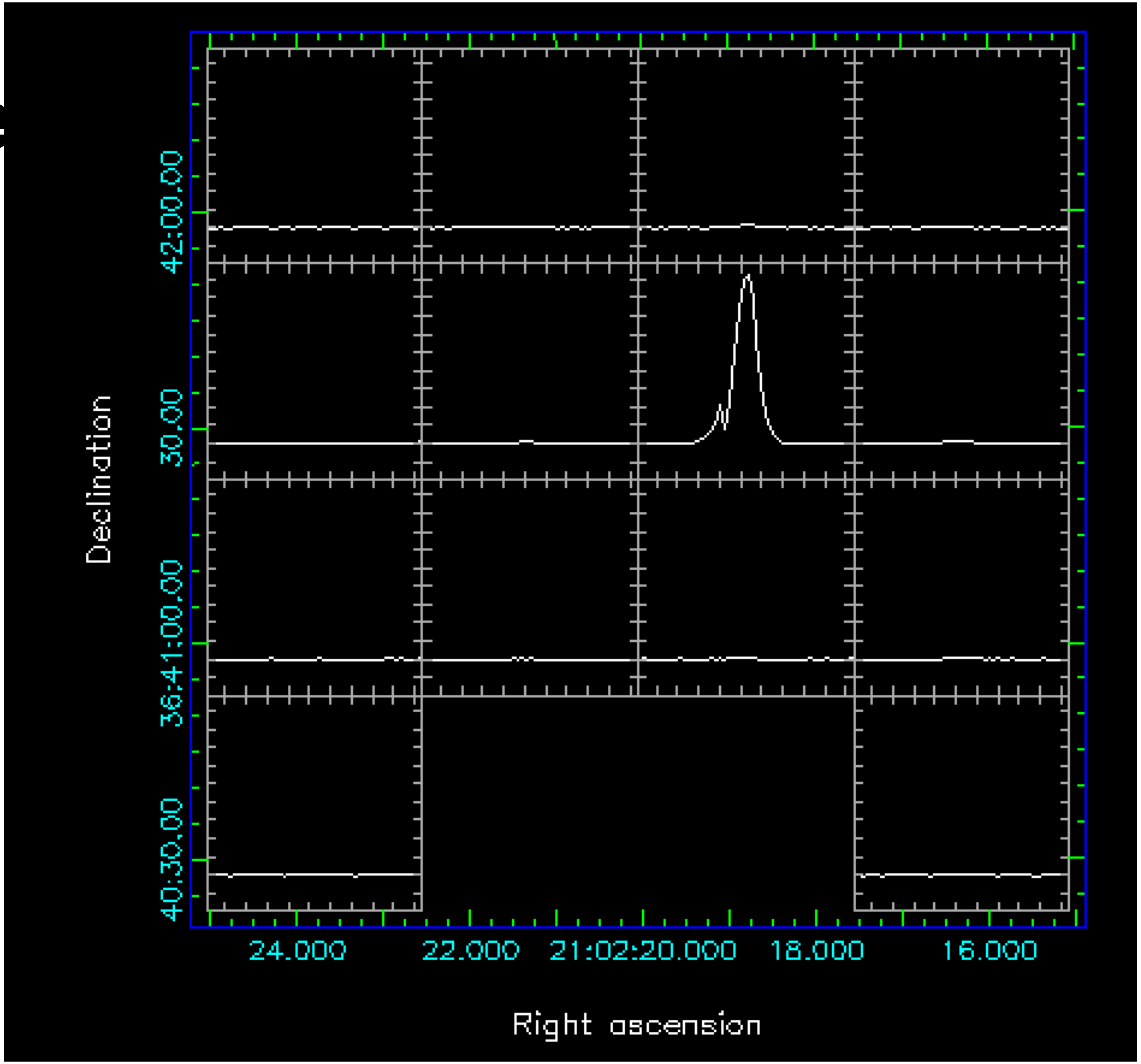

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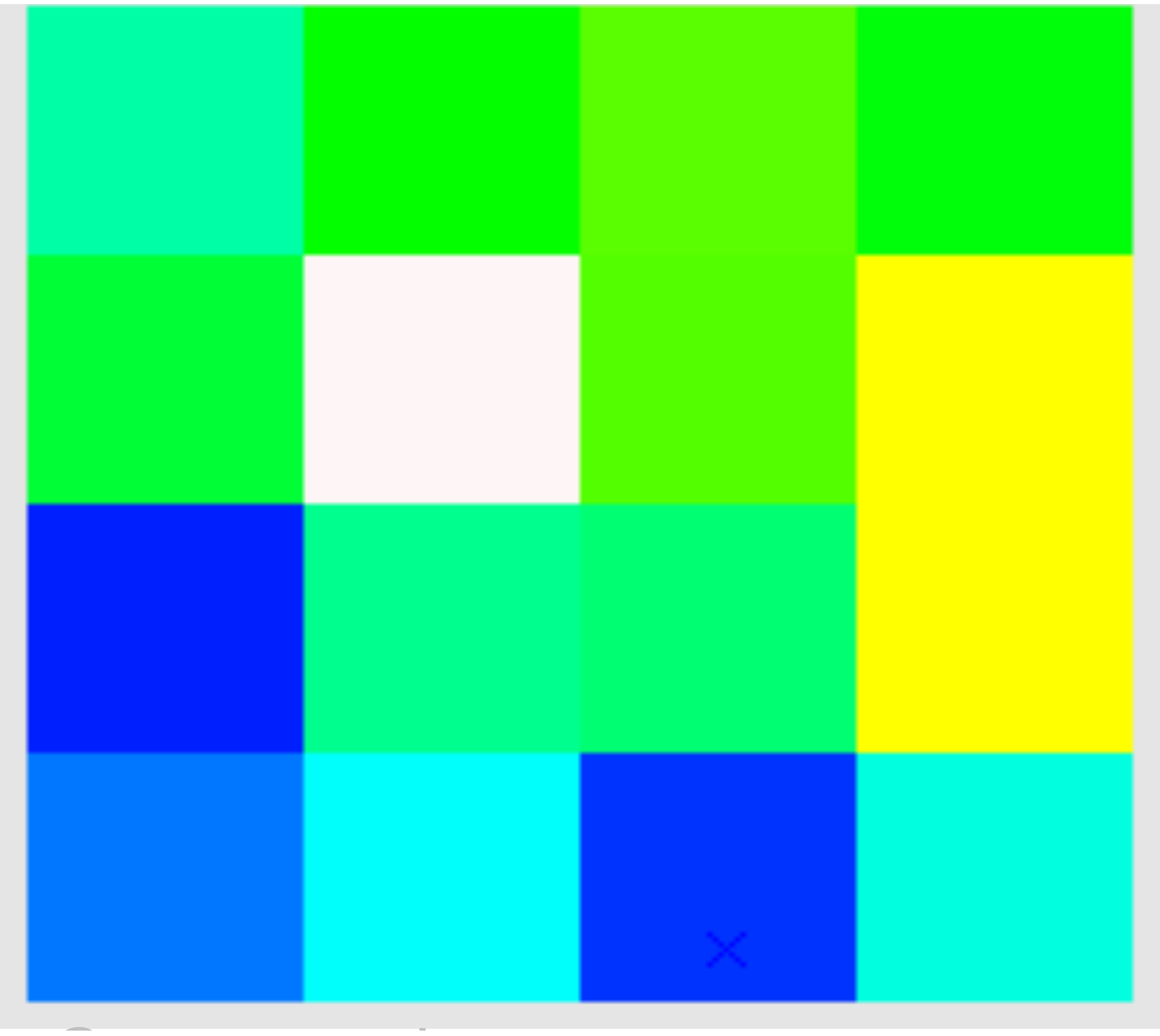
Observing Modes

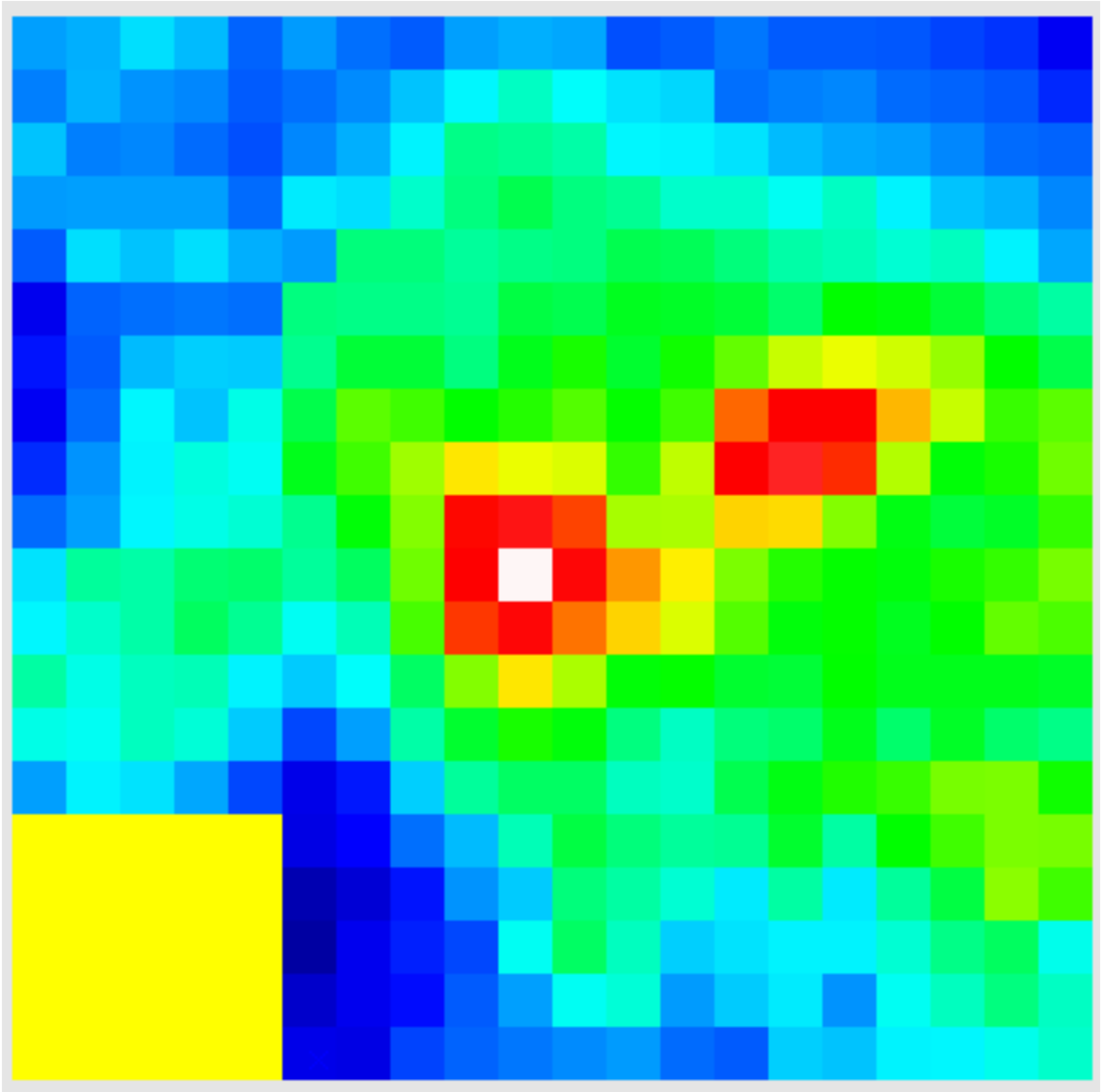
HARP

Stare



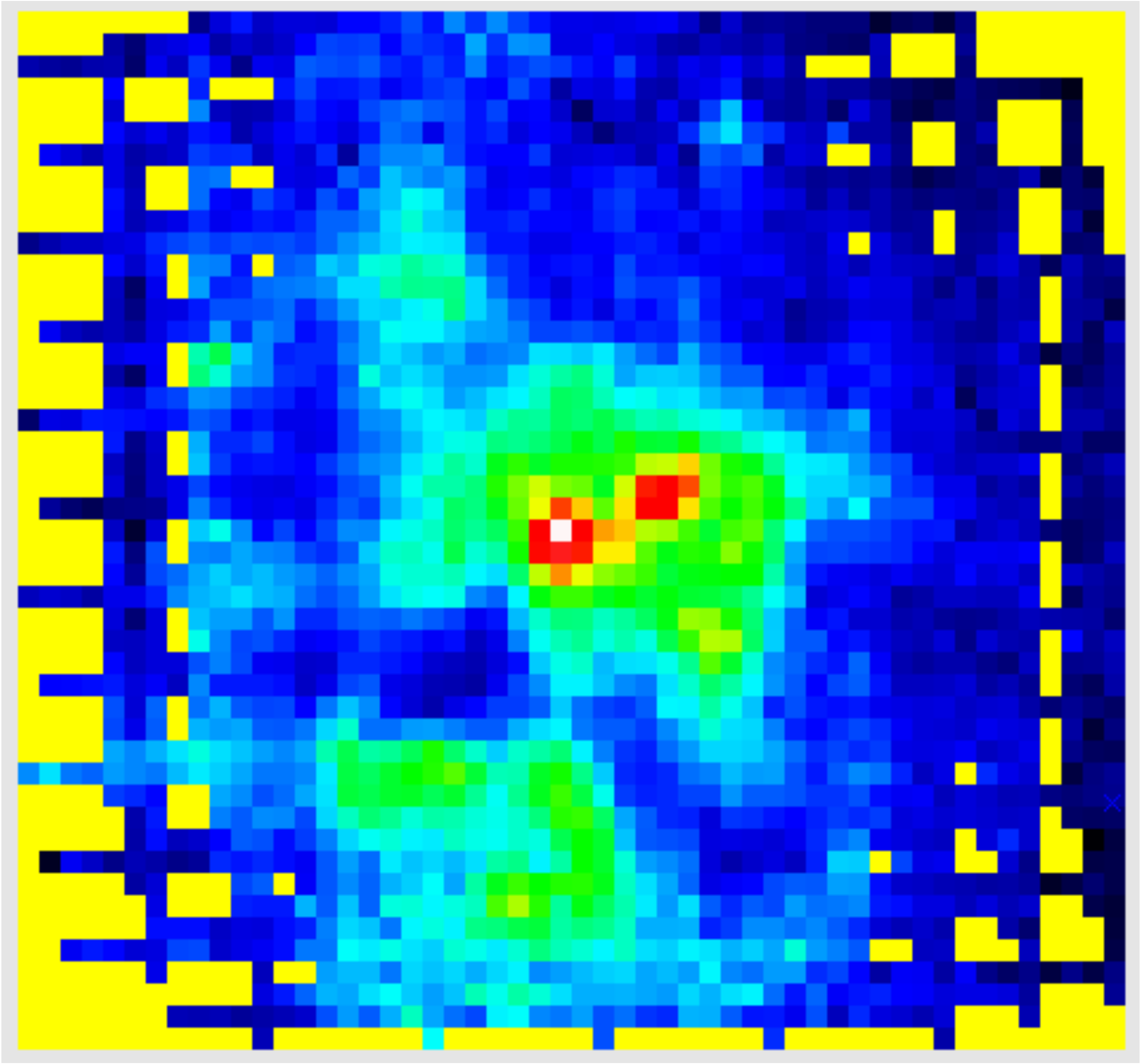
2’ field,
30” pixels

Jiggle



2’field,
6” pixels

Raster



6’ field,
7.25” pixels

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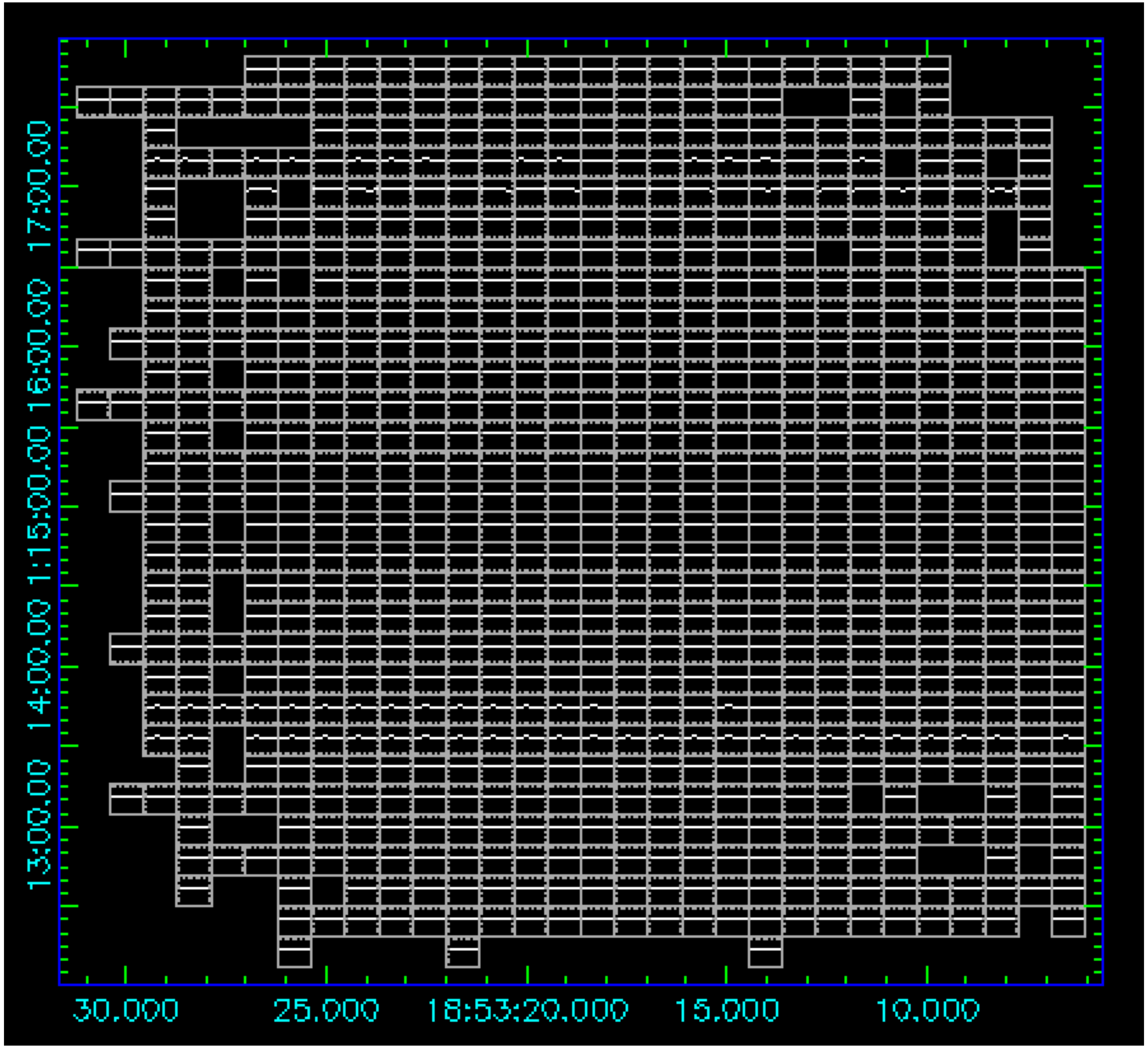
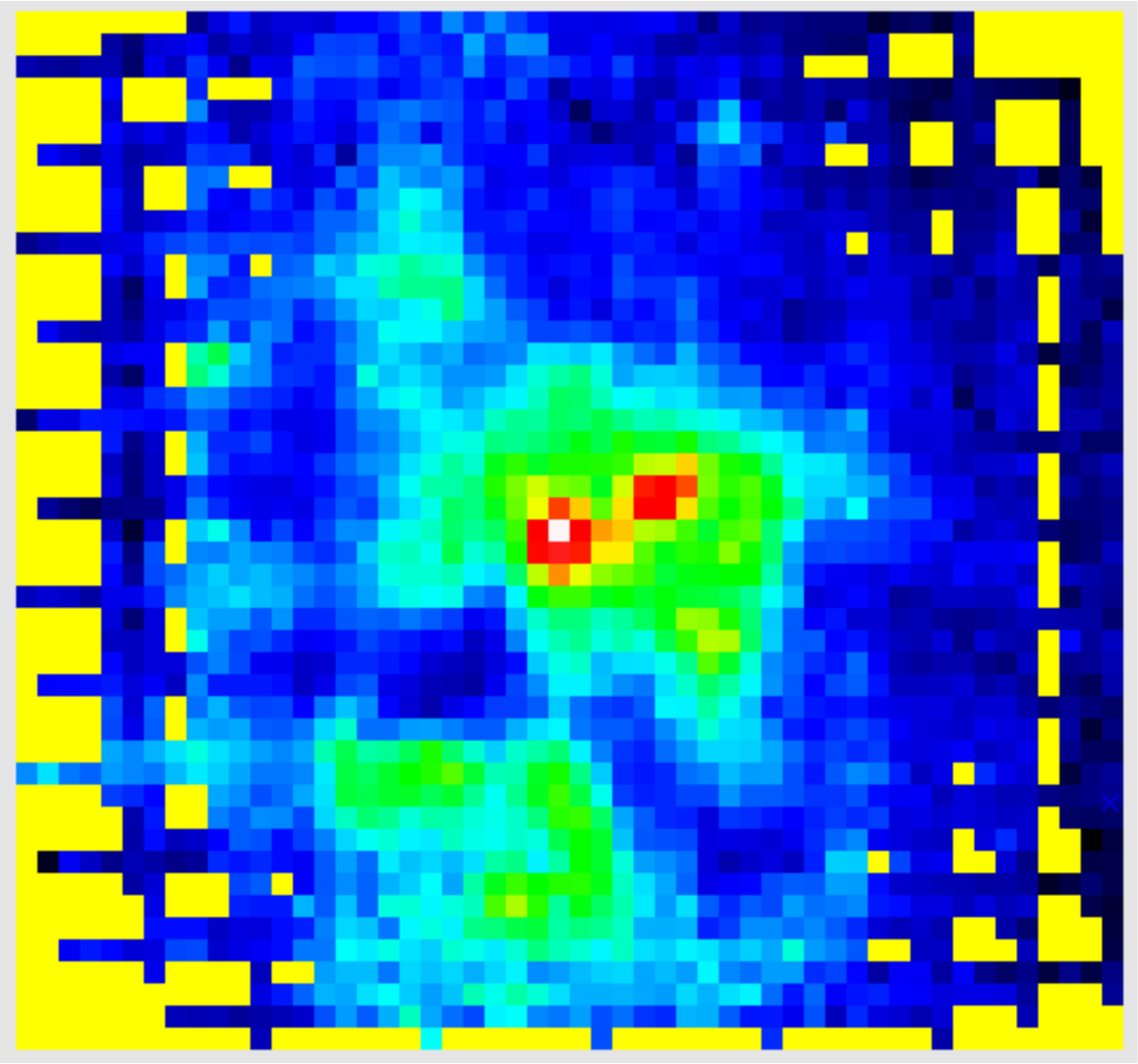
HARP



Raster



6’ field,
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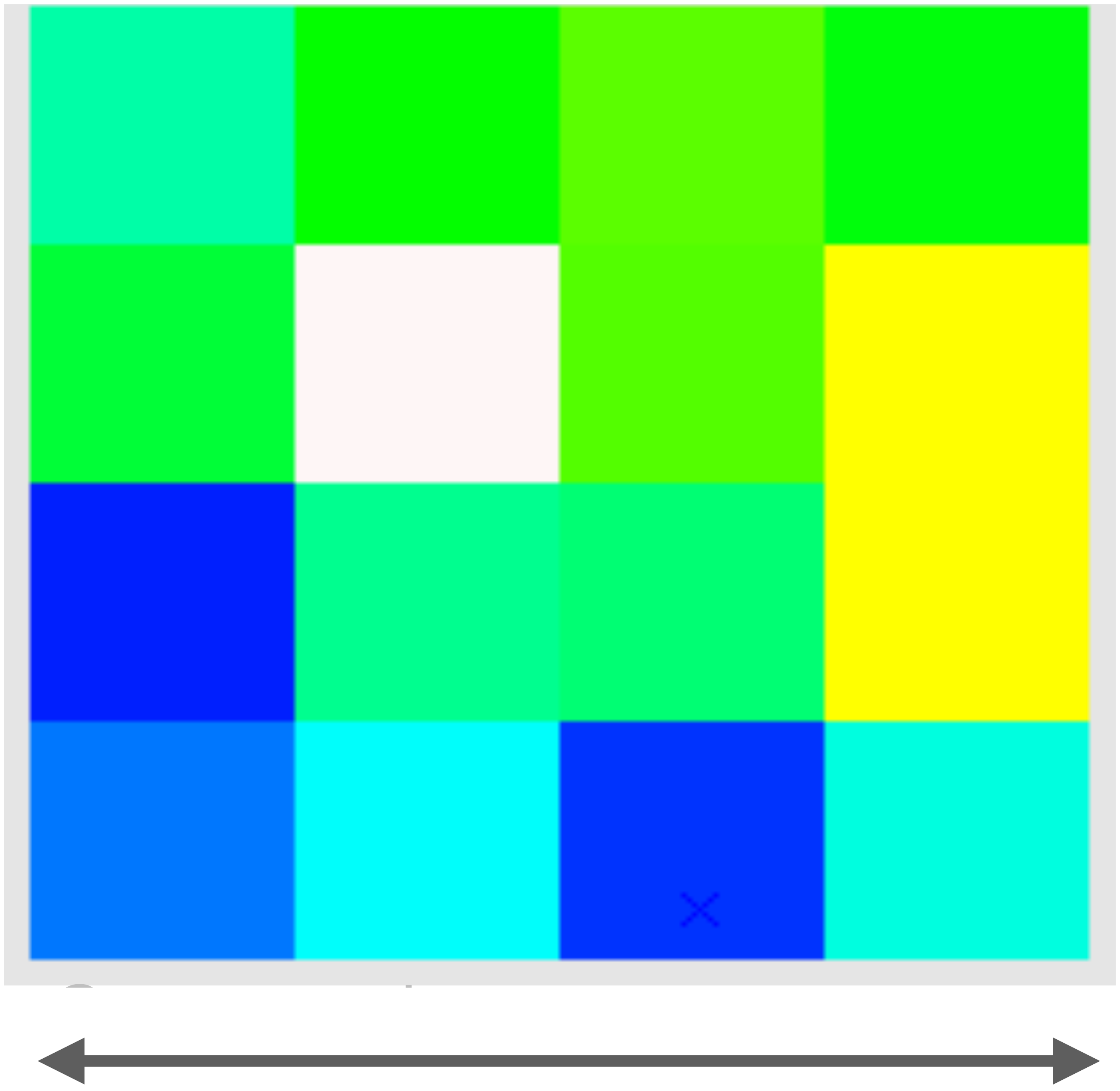
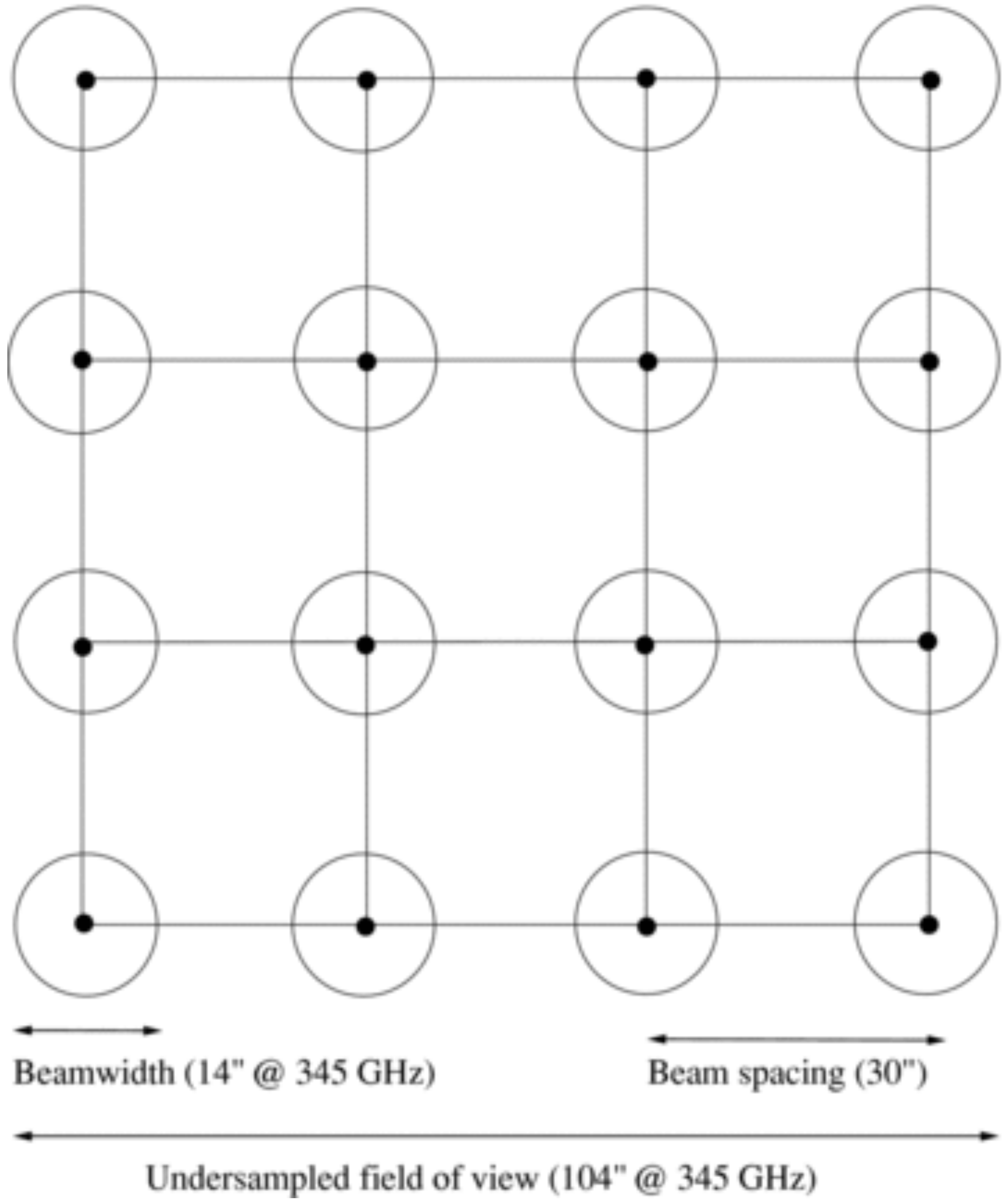
HARP

Stare



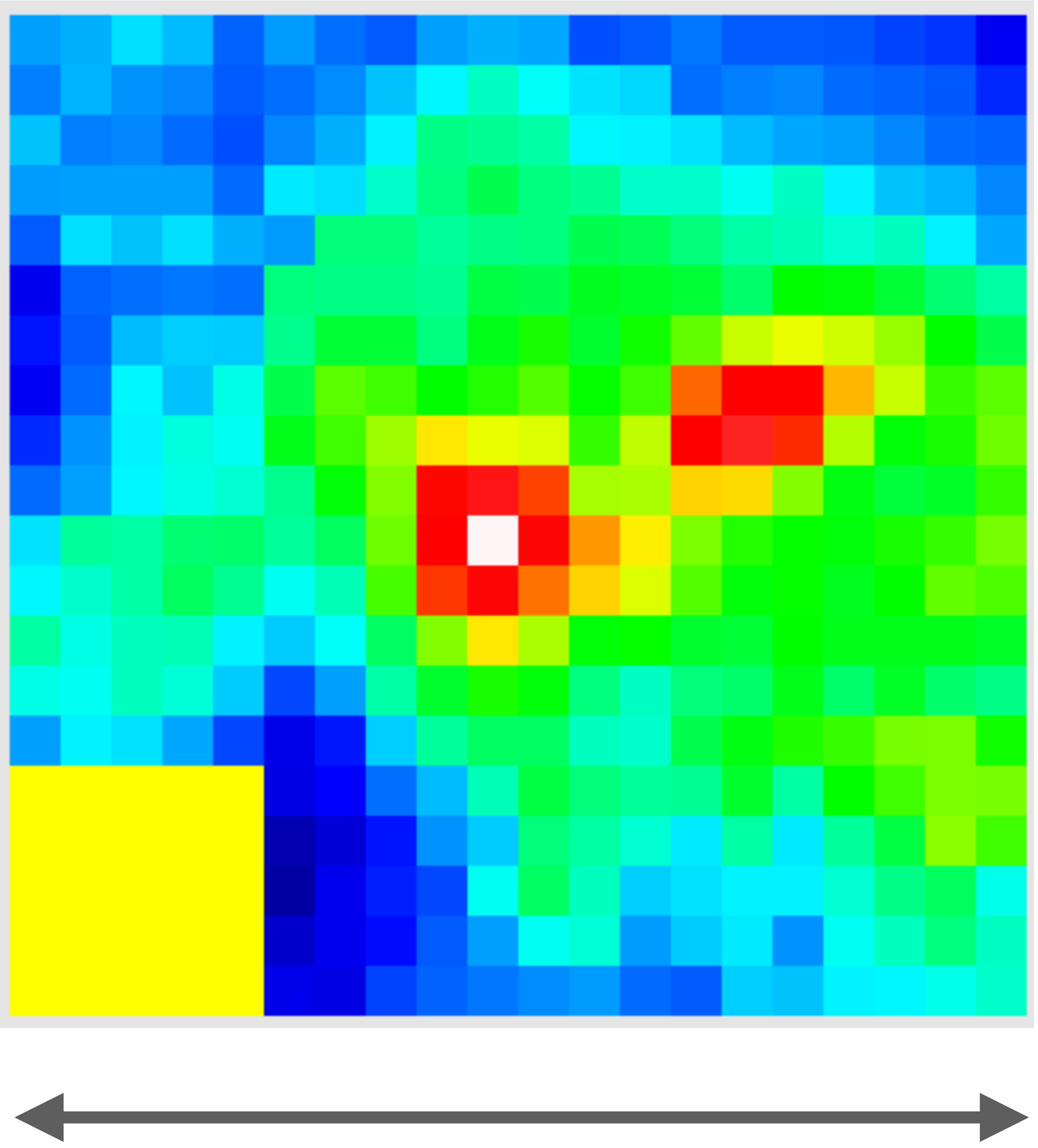
2’ field,
30” pixels



- simple mode
- good for a compact/point source
- center source of a single receptor

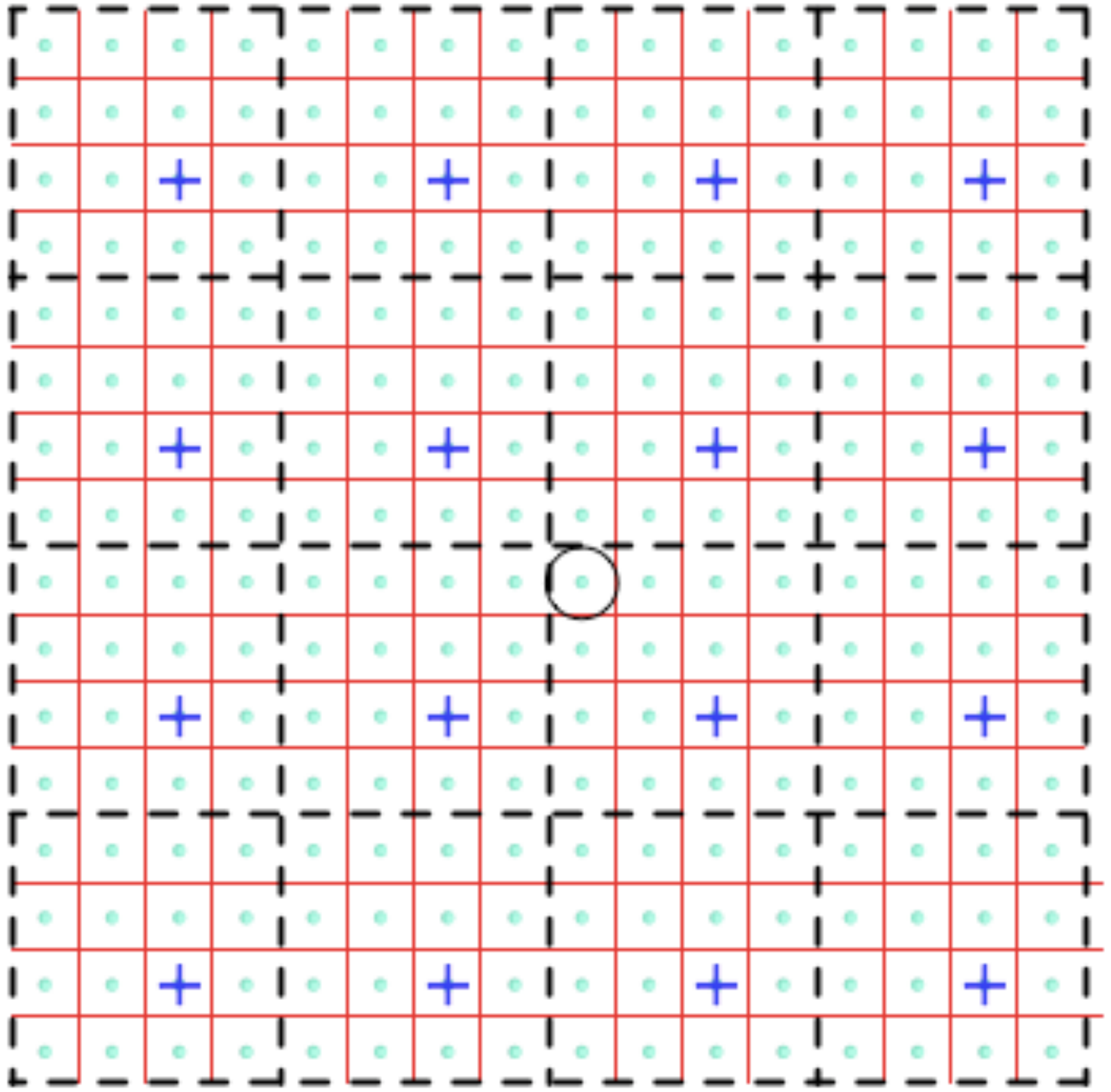
HARP

Jiggle



2'field,
6" pixels

HARP4 Jiggle Pattern

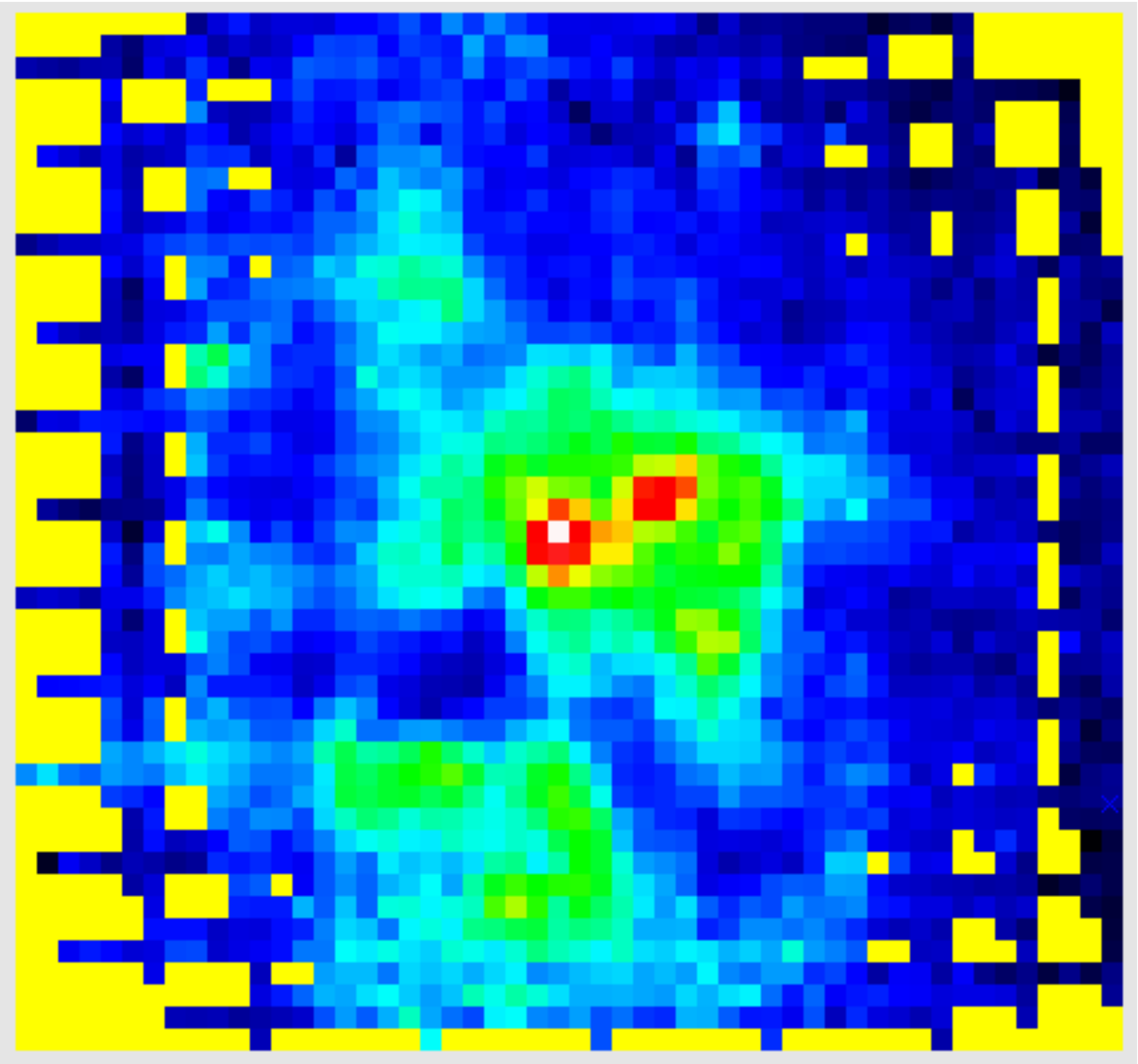


blue crosses = HARP receptors
red lines = pixels in the resultant map
grey dots = the HARP4 jiggle pattern
○ = the pointing centre

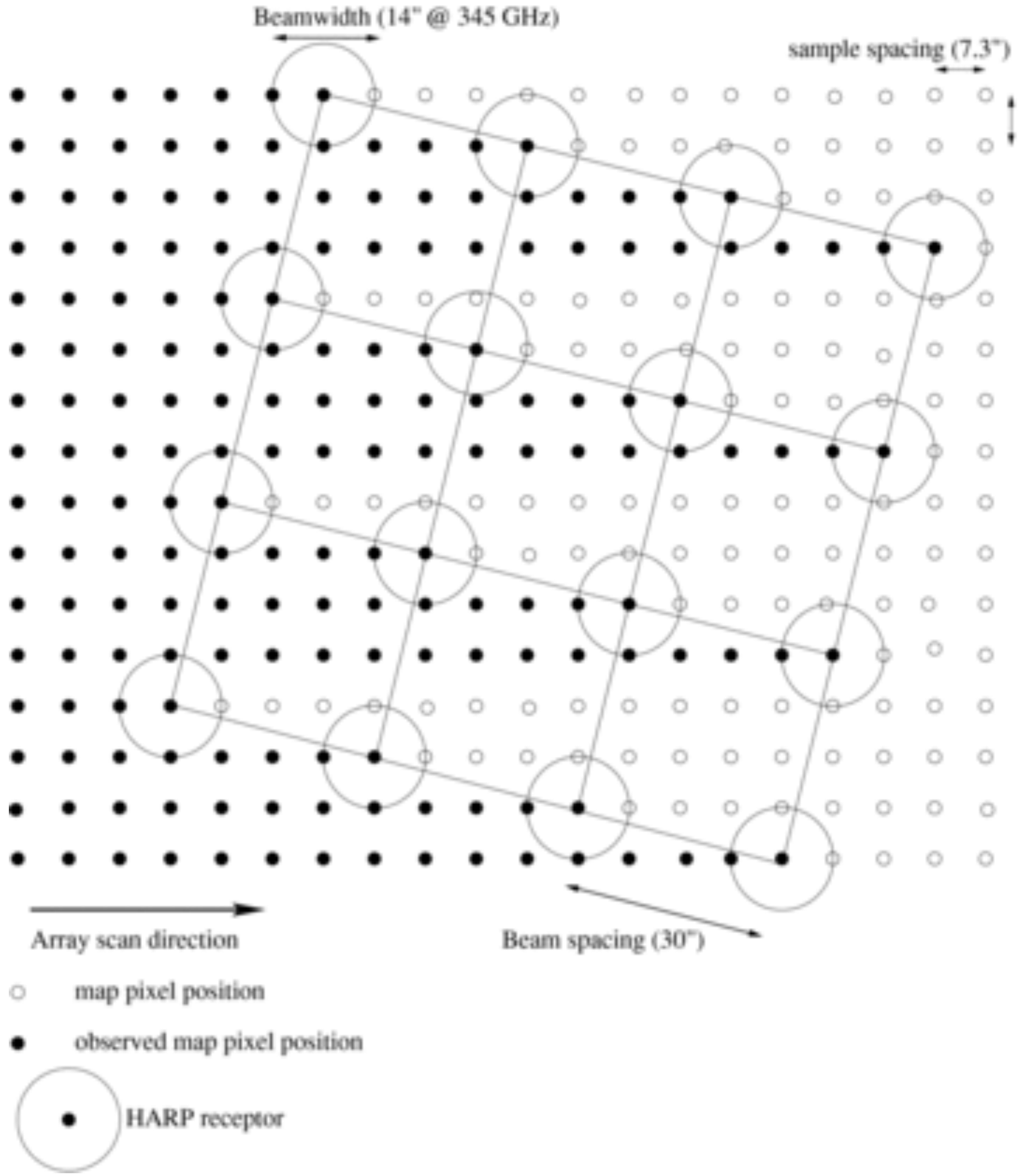
- Used for sources <2' in extent
- Moves secondary mirror to fill in 30" spacing between HARP receptors to make 2' × 2' map
- Two main spacings:
    - HARP4 – 4 × 4 jiggle, slightly undersampled. 7.25" pixels
    - HARP5 – 5 × 5 jiggle, oversampled, 6" pixels
    - (Also HARP3 - 3 × 3 jiggle, undersampled)

HARP

Raster

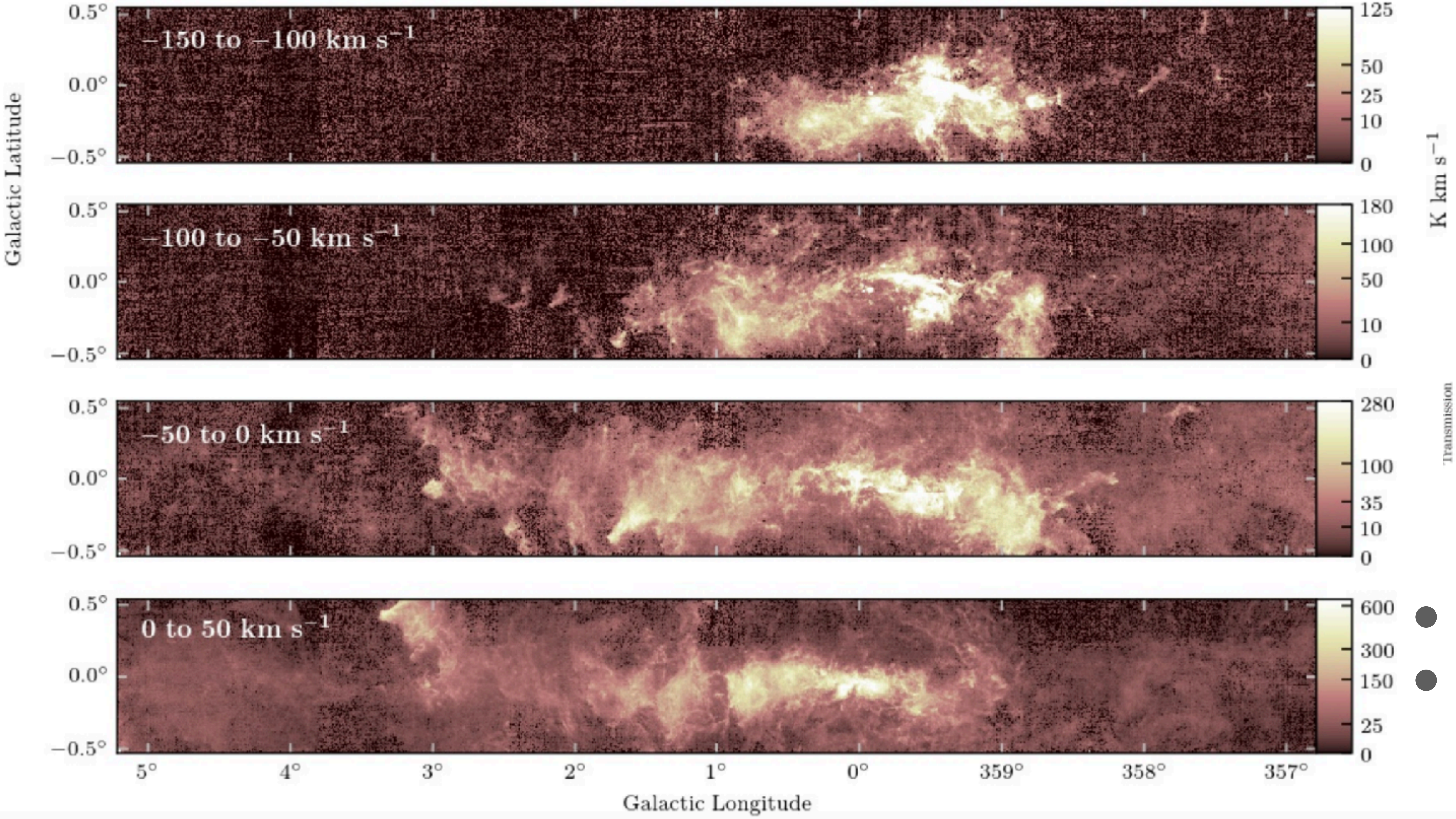


6’ field,
7.25” pixels



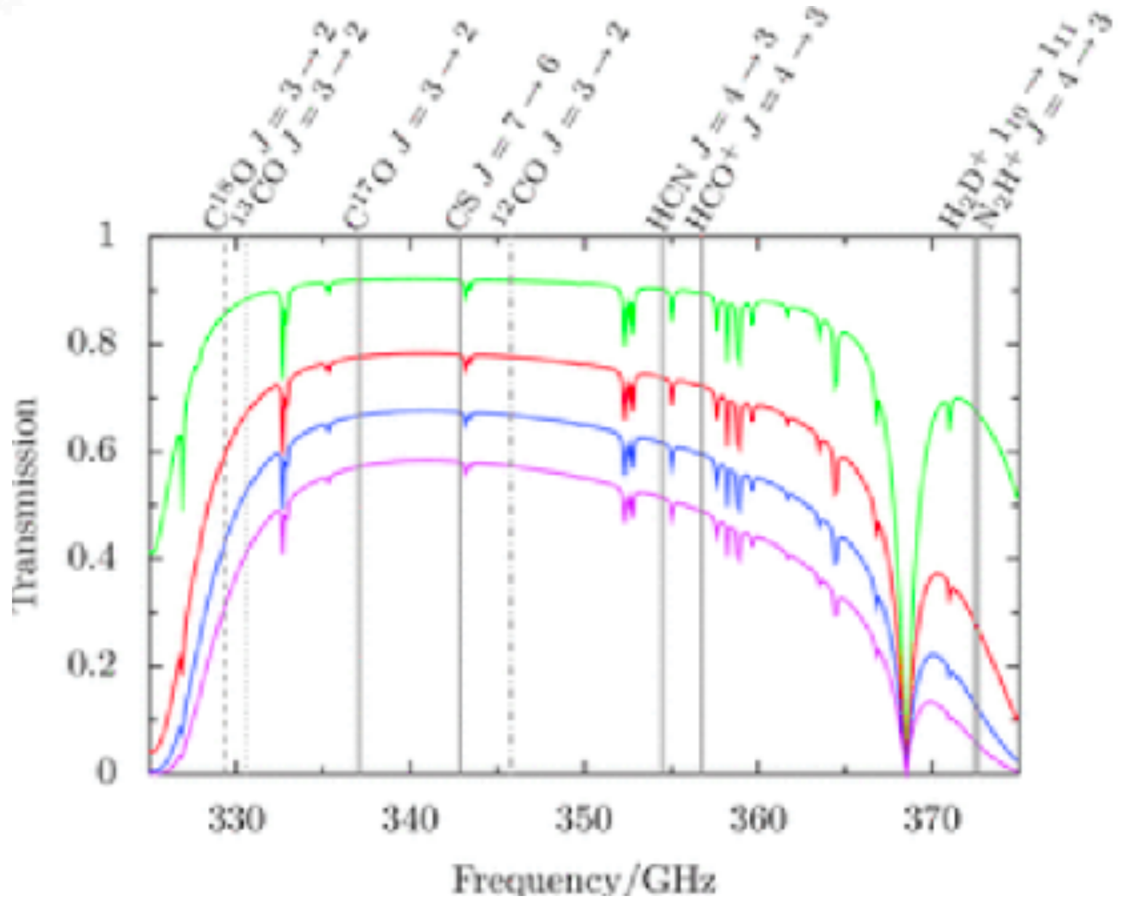
- sources > 2’
- Scan or 'on-the-fly' technique
- HARP array rotated at 14.04° to scan direction, with 7.3” pixels
- often repeated with 90° rotation to create ‘basket weave' maps

12CO emission towards the Galactic Centre



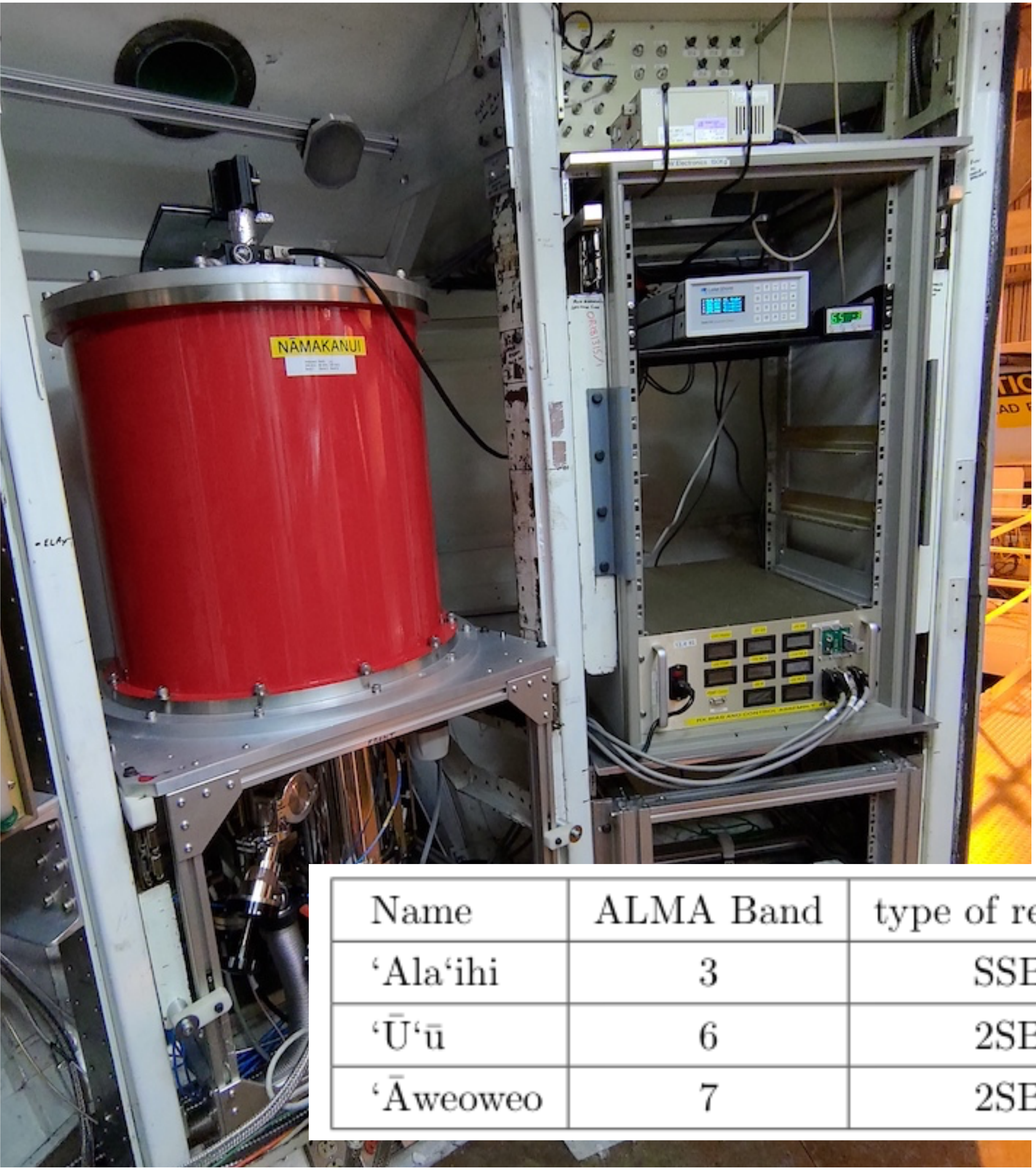
HARP

- Number of molecular lines of interest - chemistry



- kinematic data
- Complementary data for SCUBA-2 and POL-2 data analysis

Eden, et al. MNRAS, 498:4, 5936-5951. 2020



Nāmakanui

- Spare receiver for the GLT, on loan from ASIAA
- Three inserts operating around 86, 230 and 345GHz
- Used for PI science and VLBI science
- \`Ū\`ū operating at 230GHz is opened to the community from the 22B semester, while \`Aweoweo is currently in commissioning available for users under Shared Risk Observing

Name	ALMA Band	type of receiver	LO Frequency (GHz)*	Output IF
‘Ala‘ihi	3	SSB	80–88.2	2IF (two pol., USB)
‘Ū‘ū	6	2SB	221–264.6	4IF (two pol., two sidebands)
‘Āweoweo	7	2SB	283–365	4IF(two pol., two sidebands)

Sub-mm atmospheric transmission as a function of frequency at the JCMT on Maunkaea

`Ū`ū

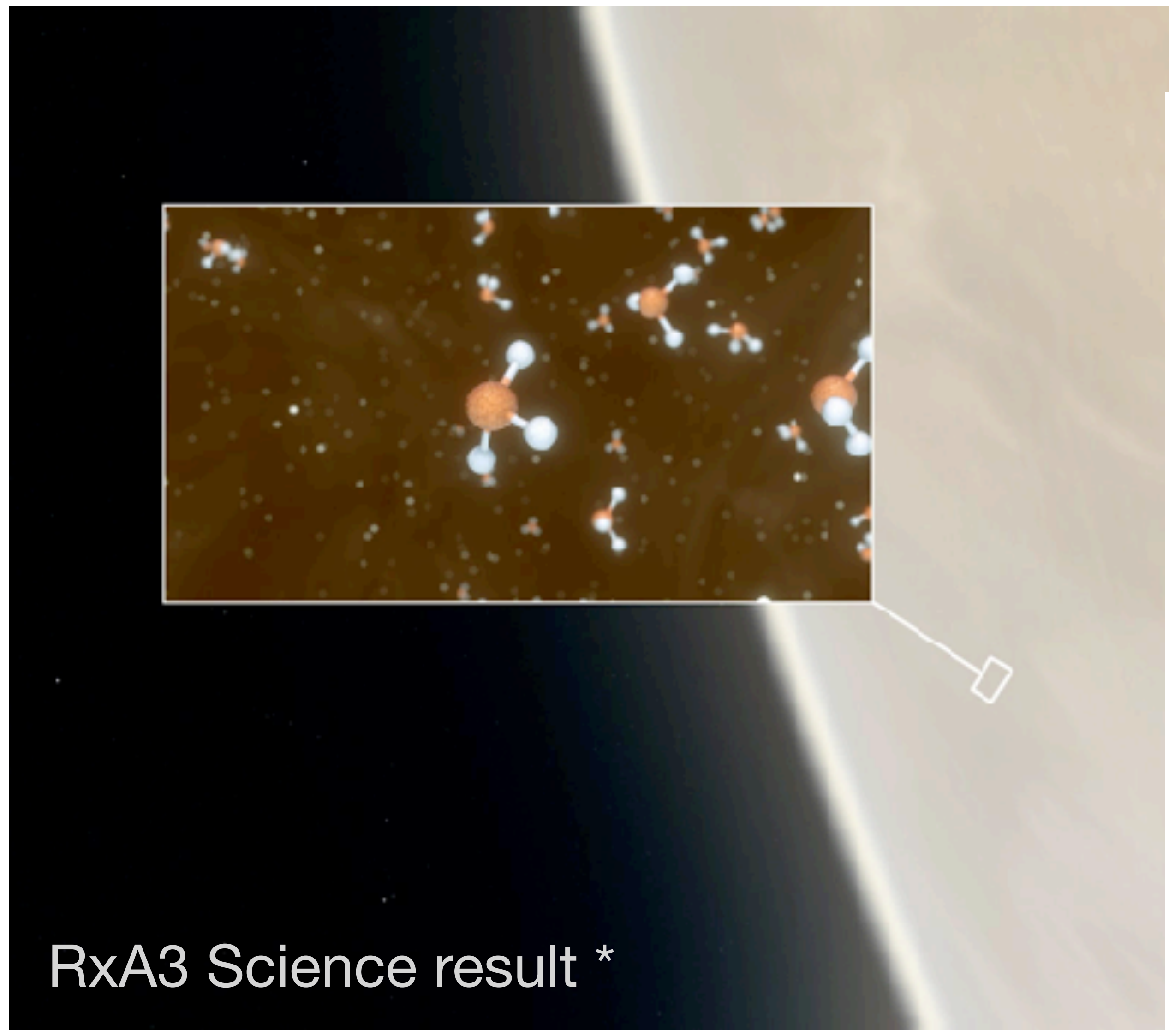
Nāmakanui
operating around 86, 230 and 345GHz

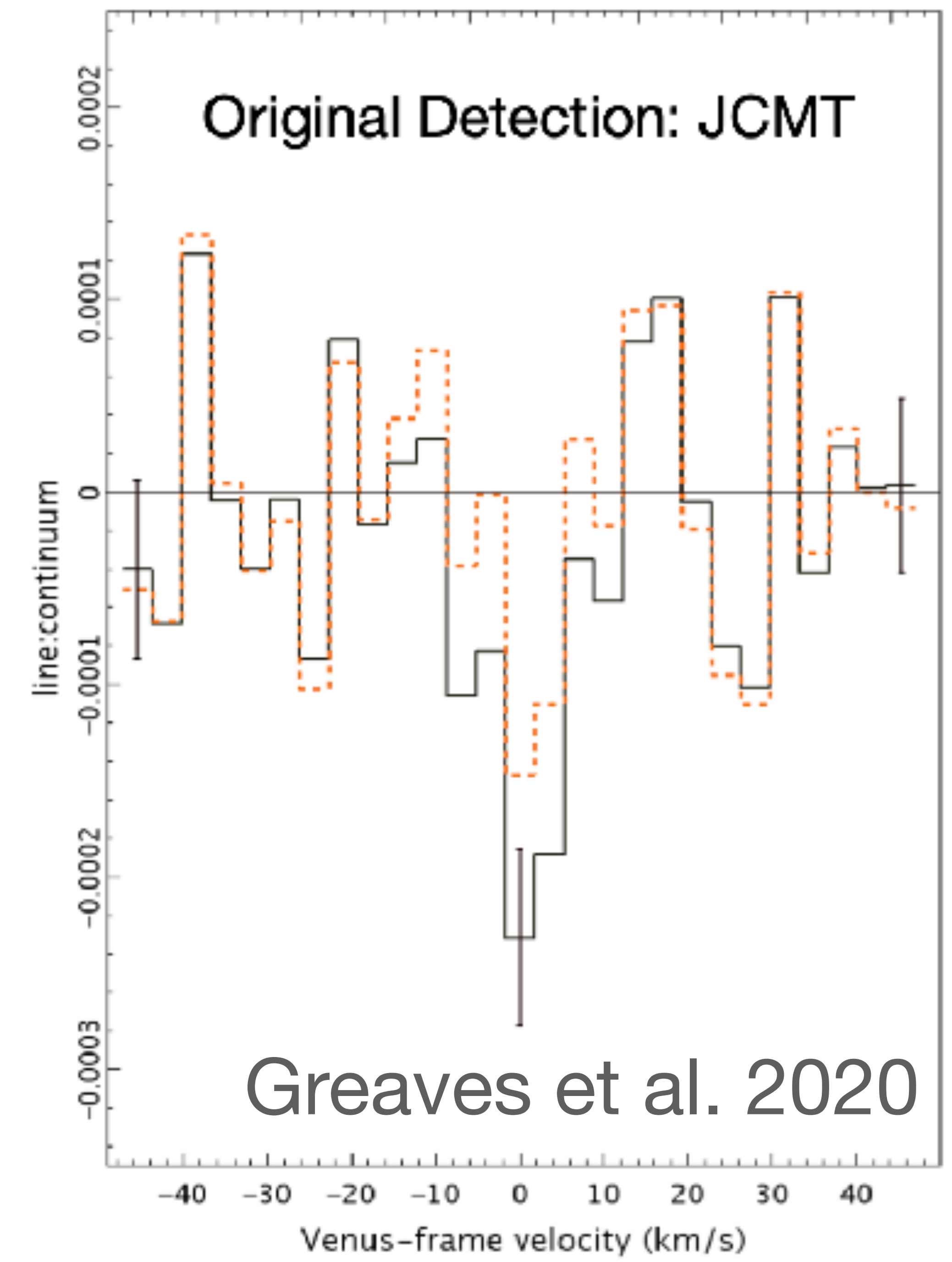
Heterodyne

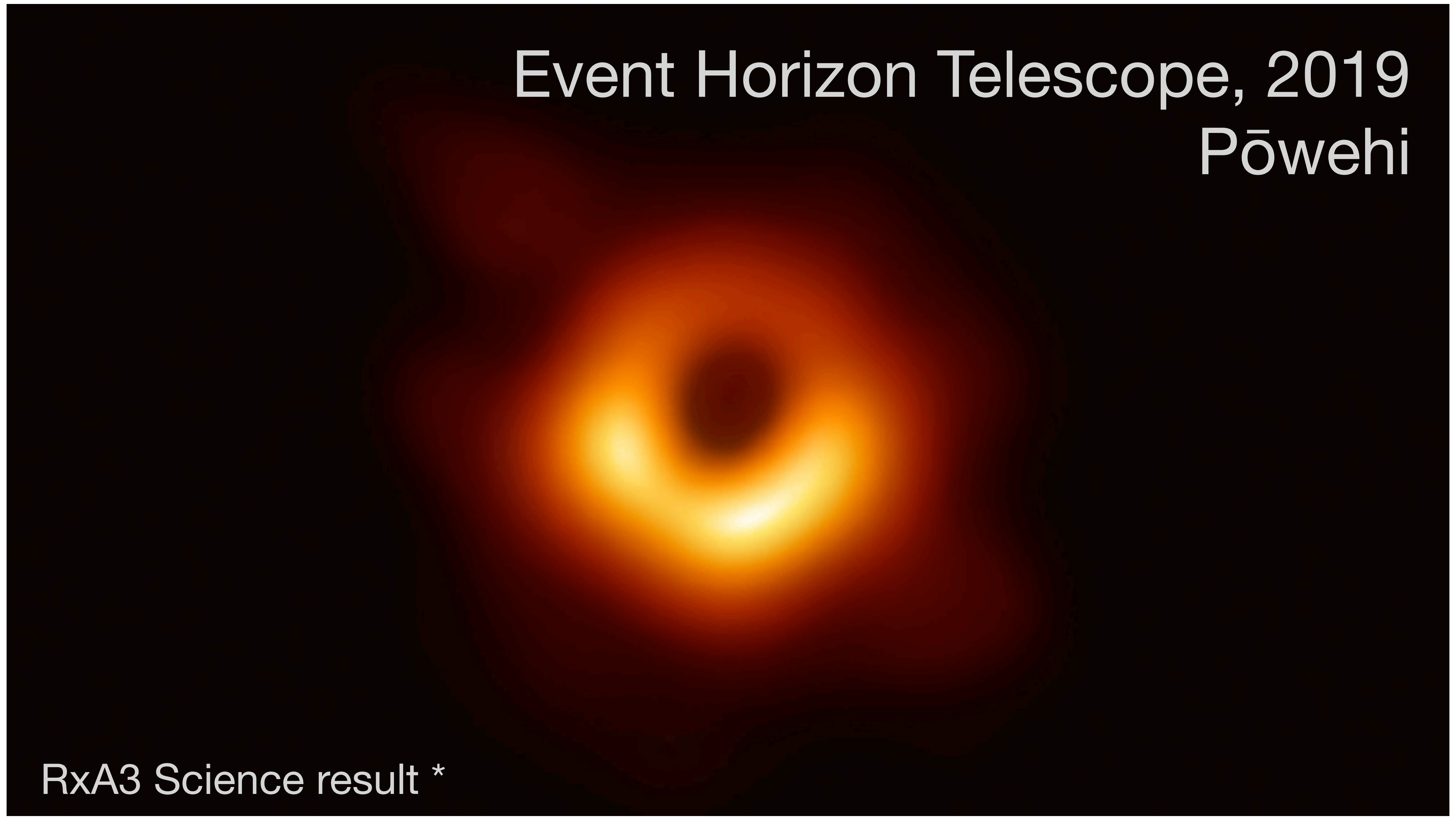
http://www.submm.caltech.edu/cso/weather/atplot.shtml

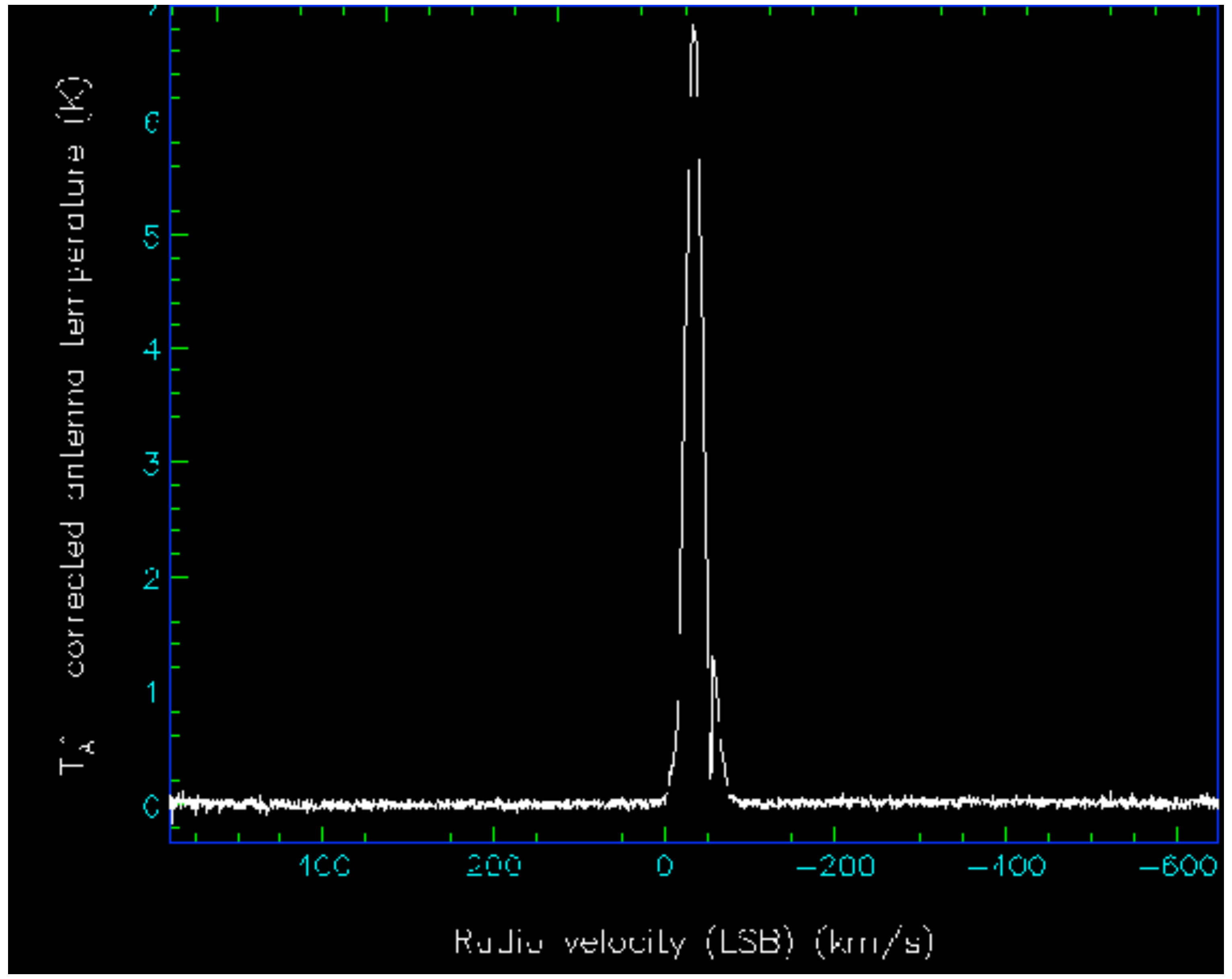
230GHz - `Ū`ū

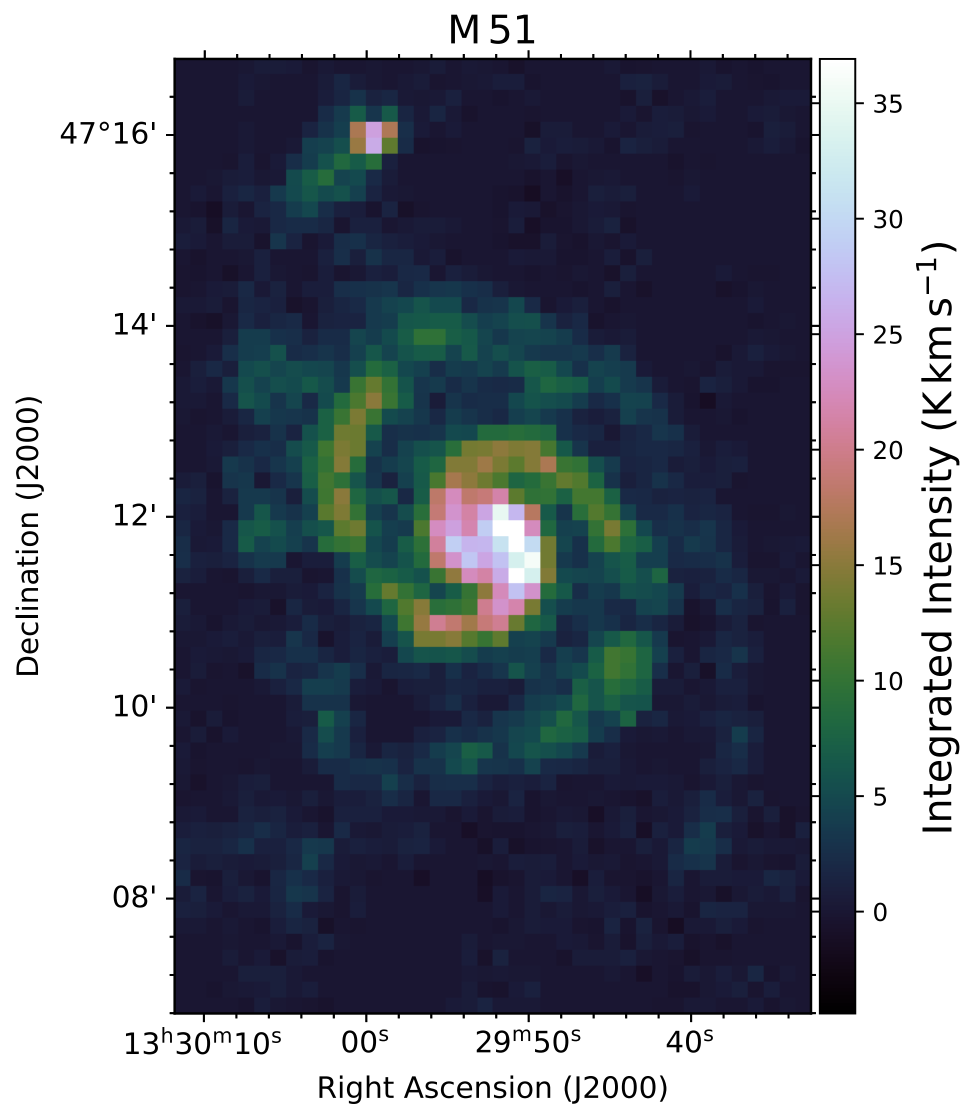
- Dual polarization means more sensitive than it’s predecessor - RxA3
- Currently demand seems dominated by nearby galaxy studies - gas estimates



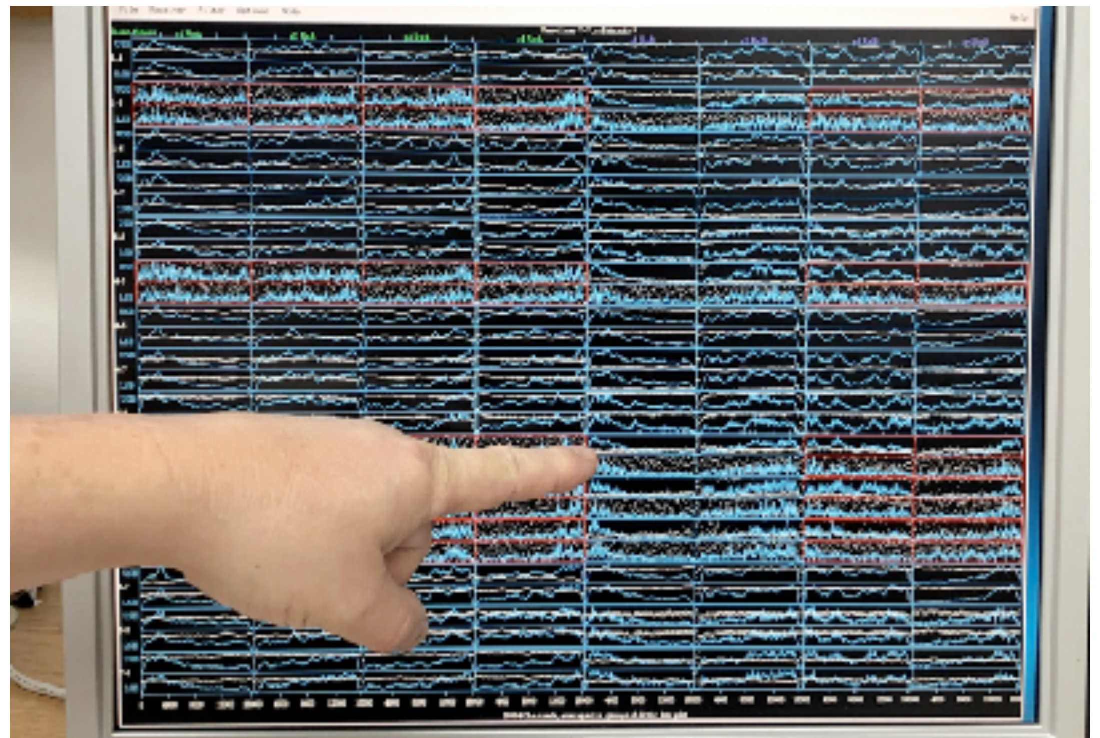








Above: first light spectrum - October 5th 2019
Above right: science image of M51
Right: First successful VLBI test with SMA December 13th 2019



Backend digital spectrometer

https://www.eaobservatory.org/jcmt/instrumentation/heterodyne/acsis/

ACSIS

- A maximum of 4 DCMs (down converter modules) can be fed from the same IF in a usable way
- 32 DCMs available.
- HARP can use 1-2 DCMs per receptor
- Nāmakanui can use 1-4 DCMs

ACSIS has two kinds of modules. The 250 MHz module and the 1000 MHz module

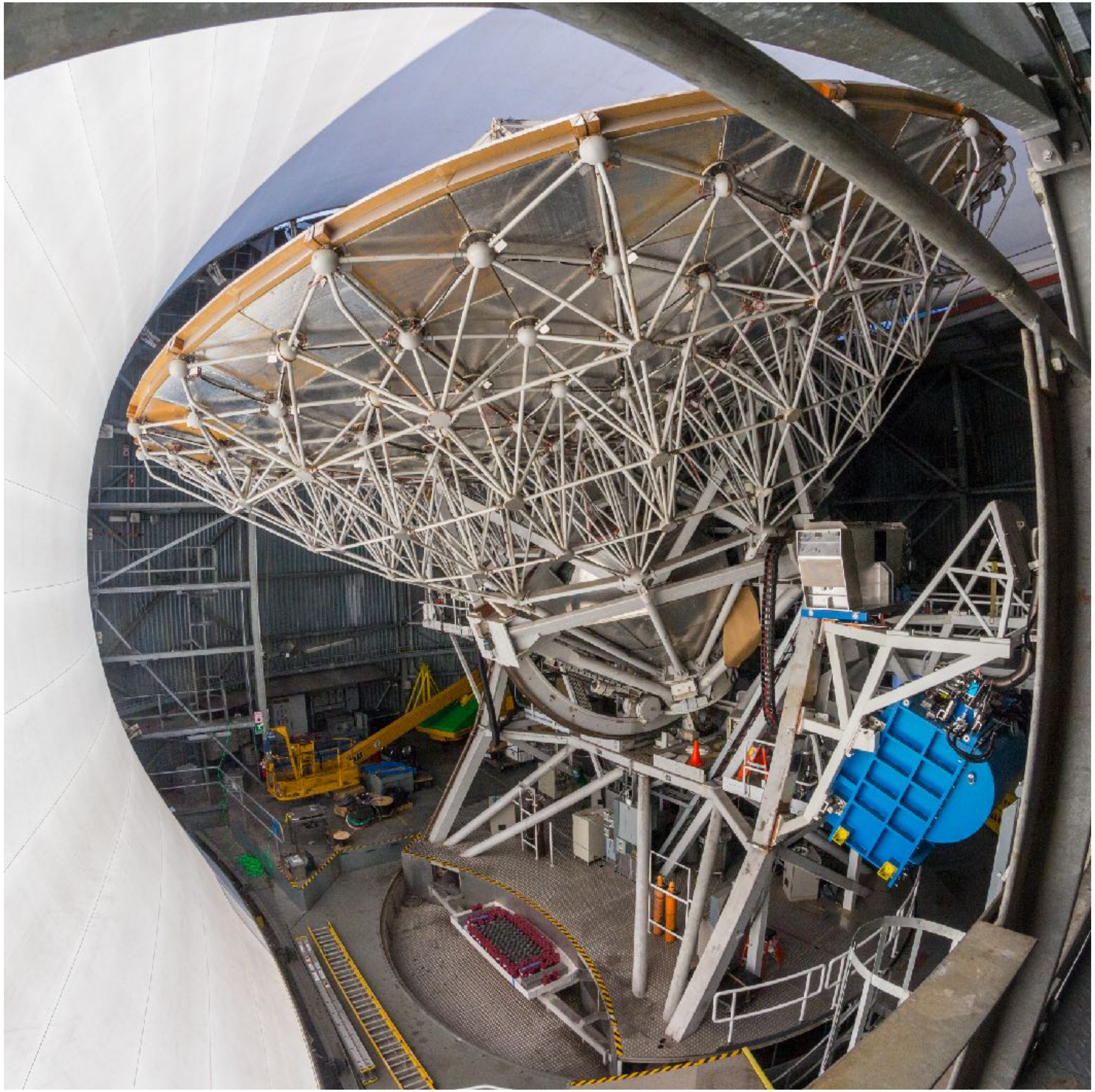
The choice of module will impact the resolution of the final data and how much of the frequency space one can observe.

Backend digital spectrometer

https://www.eaobservatory.org/jcmt/instrumentation/heterodyne/acsis/

ACSIS

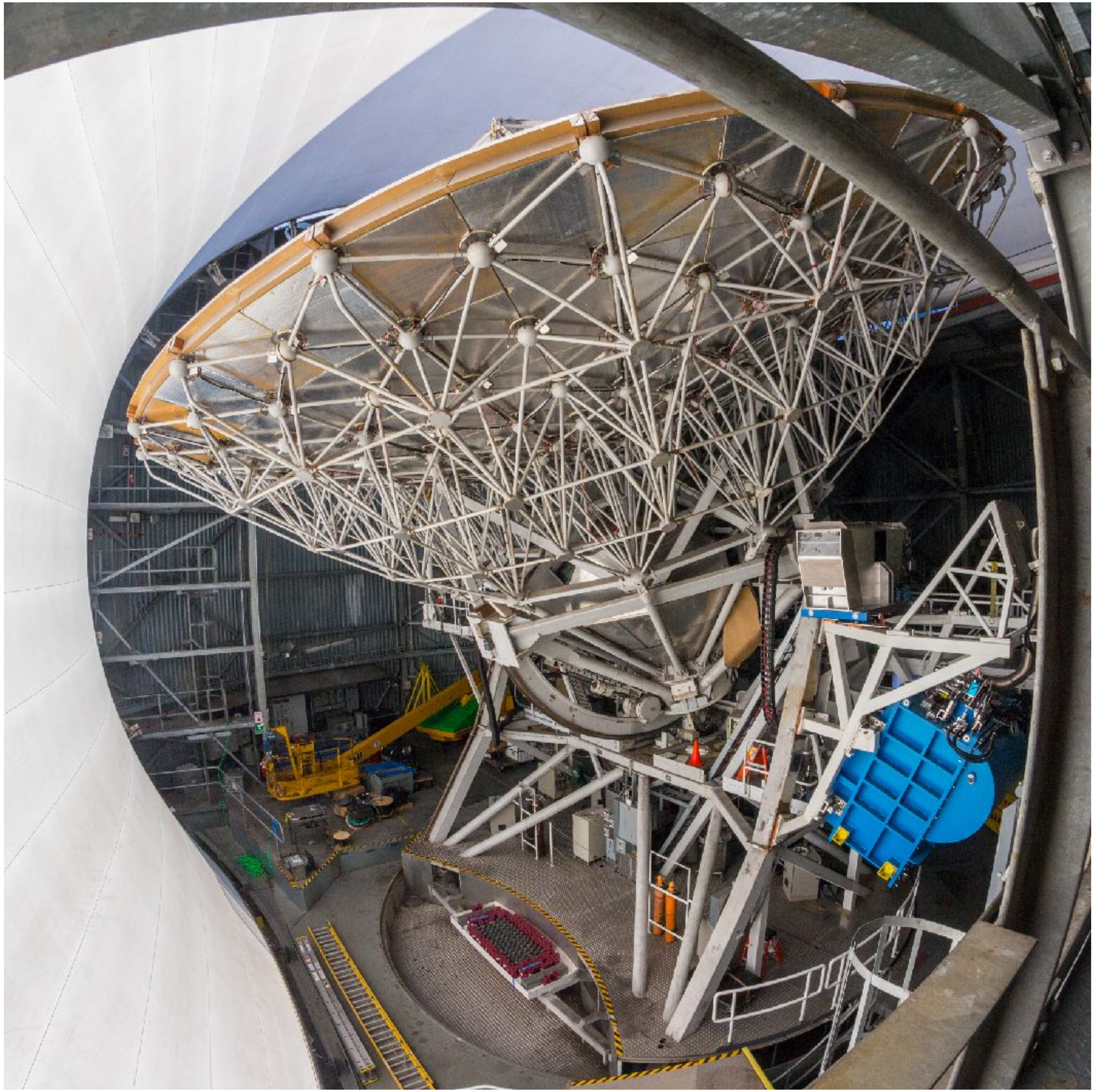
Spectral windows	BW mode	Channel Spacing	Usable Bandwidth	Channels
1	any 250	0.0305MHz	~220MHz	8192
	any 1000	0.488MHz	~930MHz	2048
	any 440	0.0305MHz	~440MHz	14417
	any 1860	0.488MHz	~1860MHz	3809
2	any 250	0.0305MHz	~220MHz	8192
	any 1000	0.488MHz	~930MHz	2048
	any 440	0.061MHz	~440MHz	7208
	any 1860	0.977MHz	~1860MHz	1904
3	A spectral window as in one of the four rows above			
	any other 250	0.061MHz	~220MHz	4096
	any other 1000	0.977MHz	~930MHz	1024
4	any 250	0.061MHz	~220MHz	4096
	any 1000	0.977MHz	~930MHz	1024



SCUBA-2

- Commissioned in 2011
- 10,240-pixel bolometer camera
- 450 μm & 850 μm
- 7.9” and 13” primary beam
- TES arrays
- Cooled by liquid ^{3}He

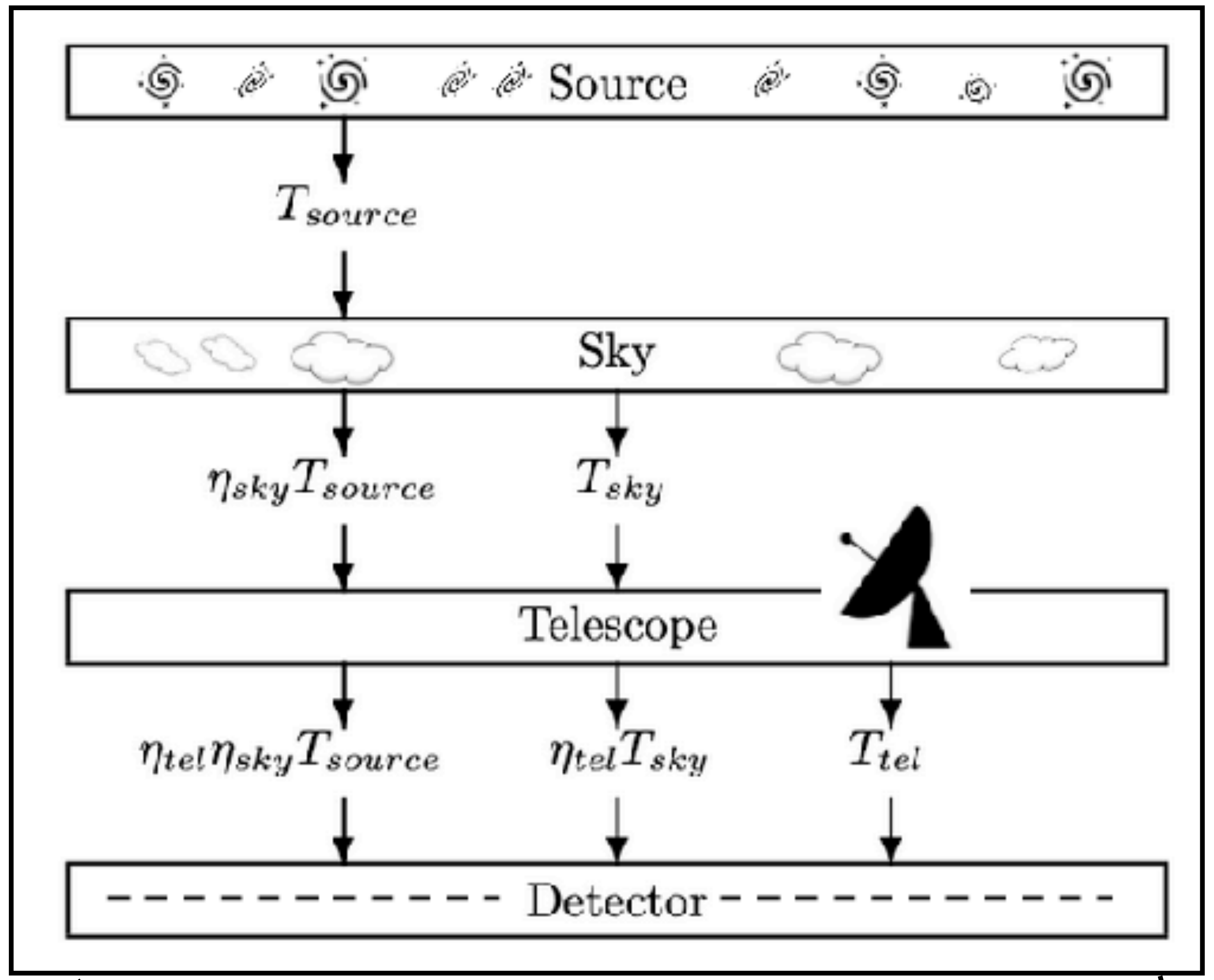
- Ancillary instruments:
  - POL-2
  - ~~FTS-2~~

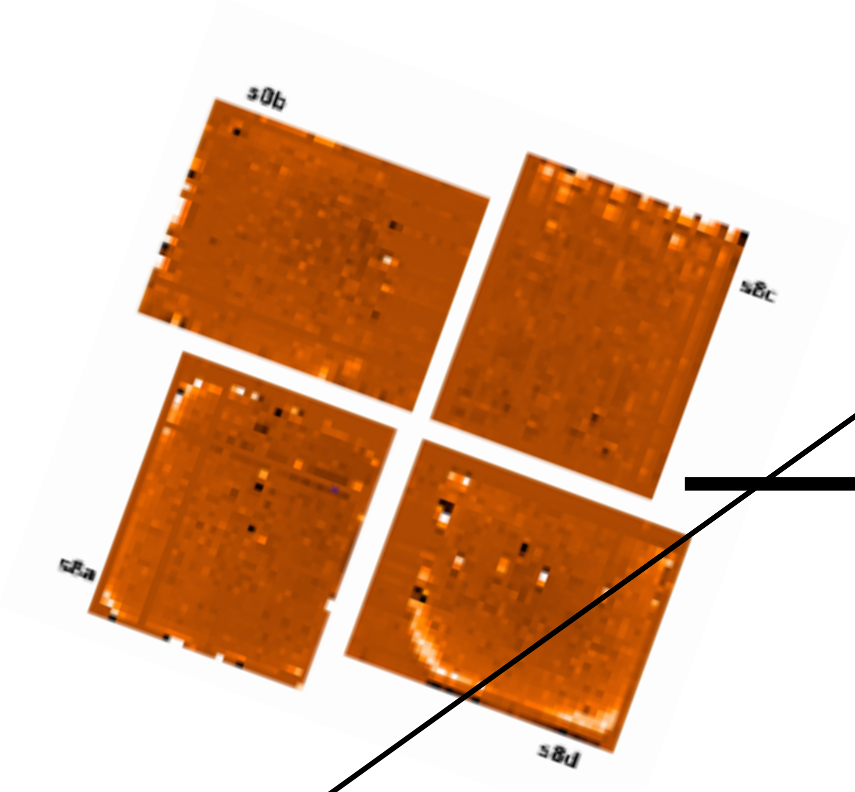


SCUBA-2

- Unlike other instruments at the JCMT sky subtraction is not performed by going to an “off position”.
- Sky subtraction comes from estimating the common mode - e.g. what the majority of bolometers see in a time series can be estimated to be sky background with variations within attributed to source signal.

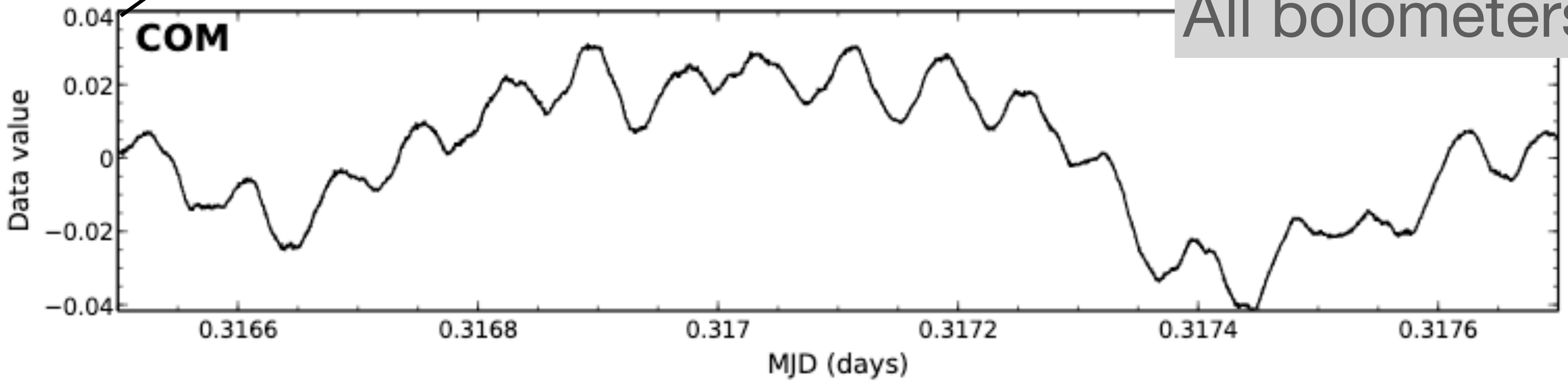
SCUBA-2





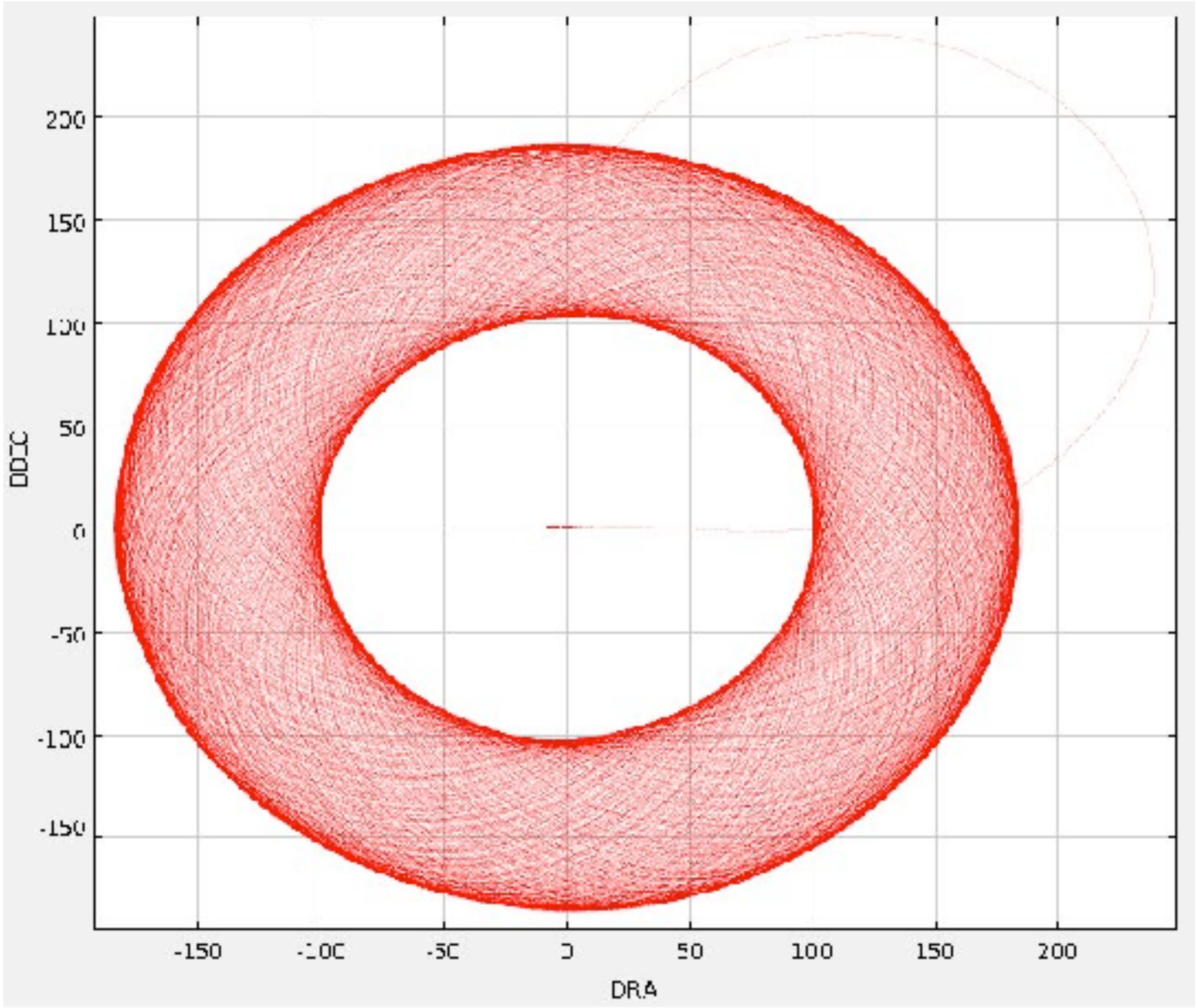
Time

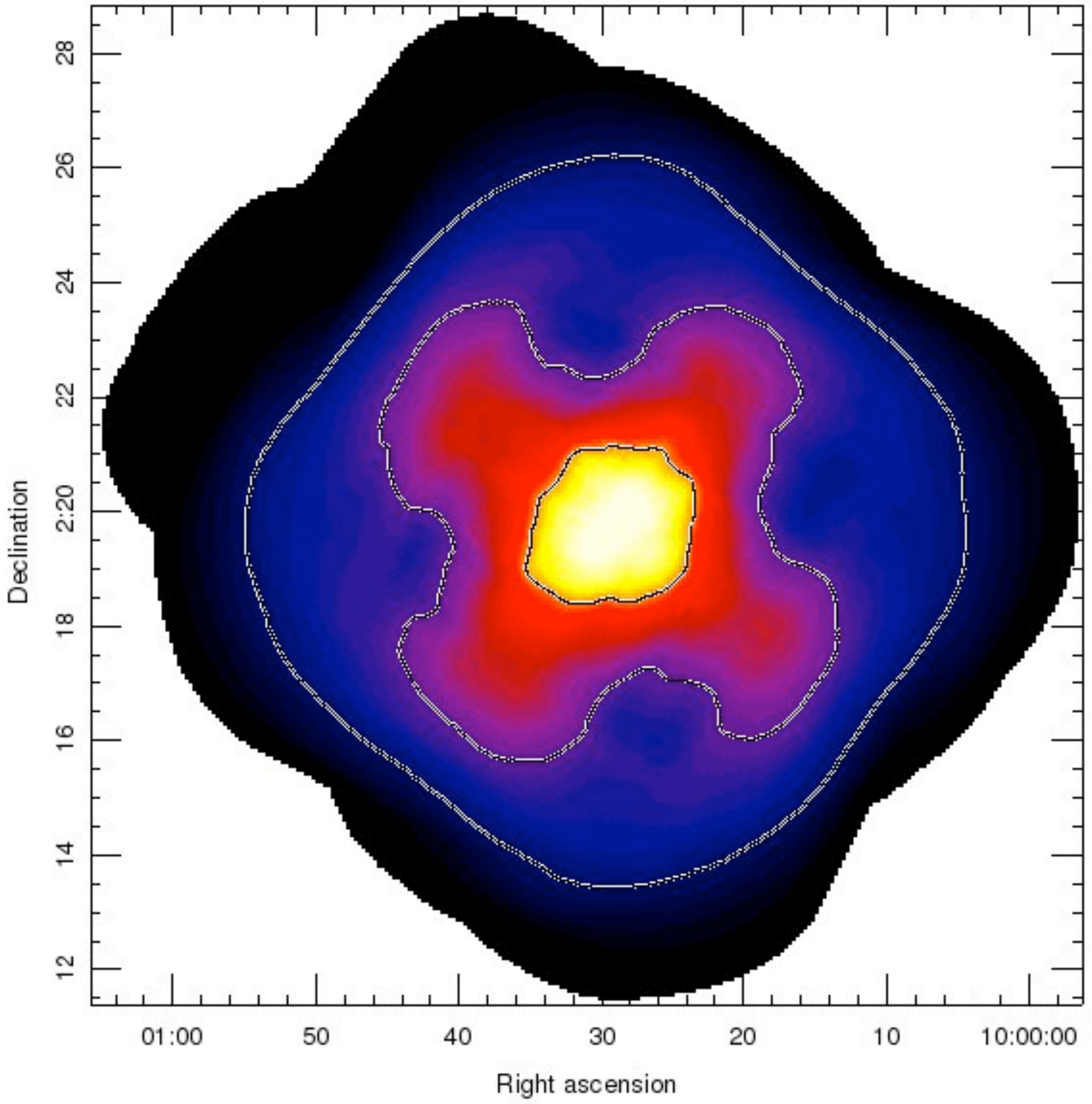
All bolometers



- Unlike other instruments at the JCMT sky subtraction is not performed by going to an “off position”.
- Sky subtraction comes from estimating the common mode - e.g. what the majority of bolometers see in a time series can be estimated to be sky background with variations within attributed to source signal.
- This leads to higher efficiency, although some loss of spacial sensitivity.
- Requires creative ways of obtaining data with multiple bolometers covering the same patch of sky in a single observation.

http://starlink.eao.hawaii.edu/devdocs/sc21.pdf

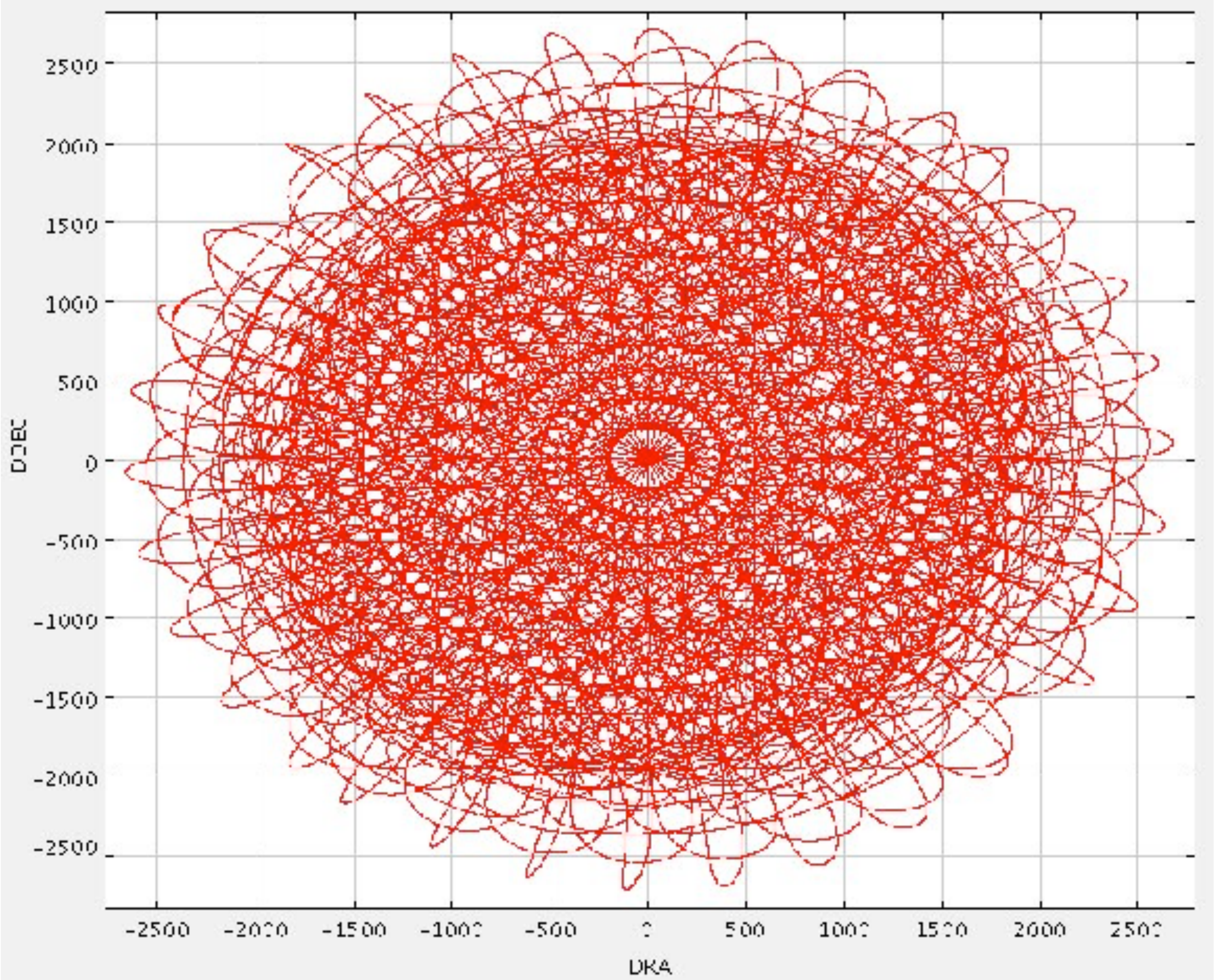


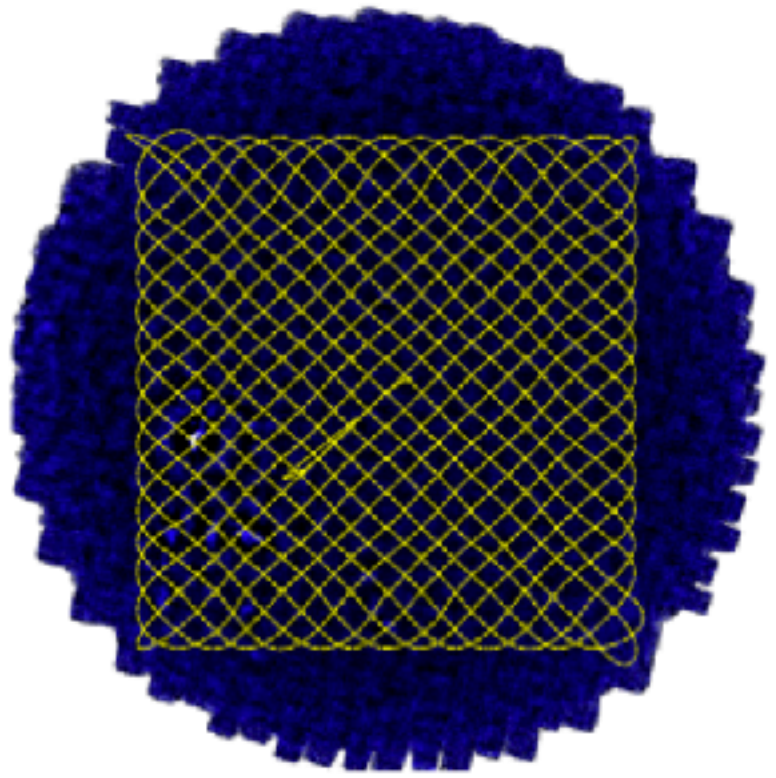


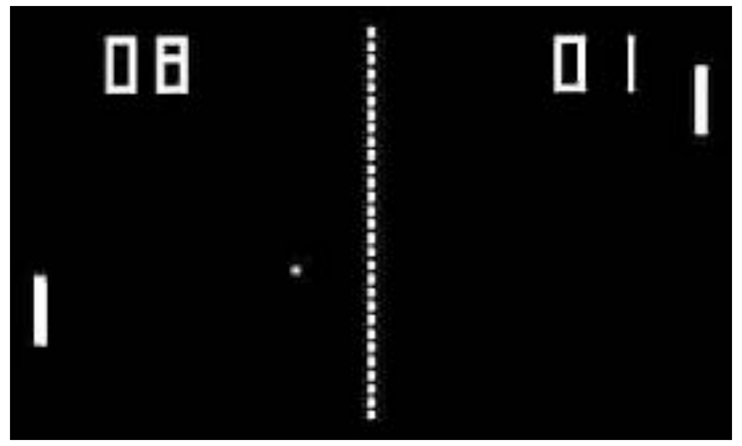
SCUBA-2

CV_Daisy Scan Pattern

- “CV” = Constant Velocity***
- Ensure coverage of sky both in time and spacial domain
- Covers same positions at different angles
- Maximizes central exposure time but less-uniform depth
- Good for (e.g.) point sources
- High sensitivity in 3’
- Uneven coverage but still good to 12’



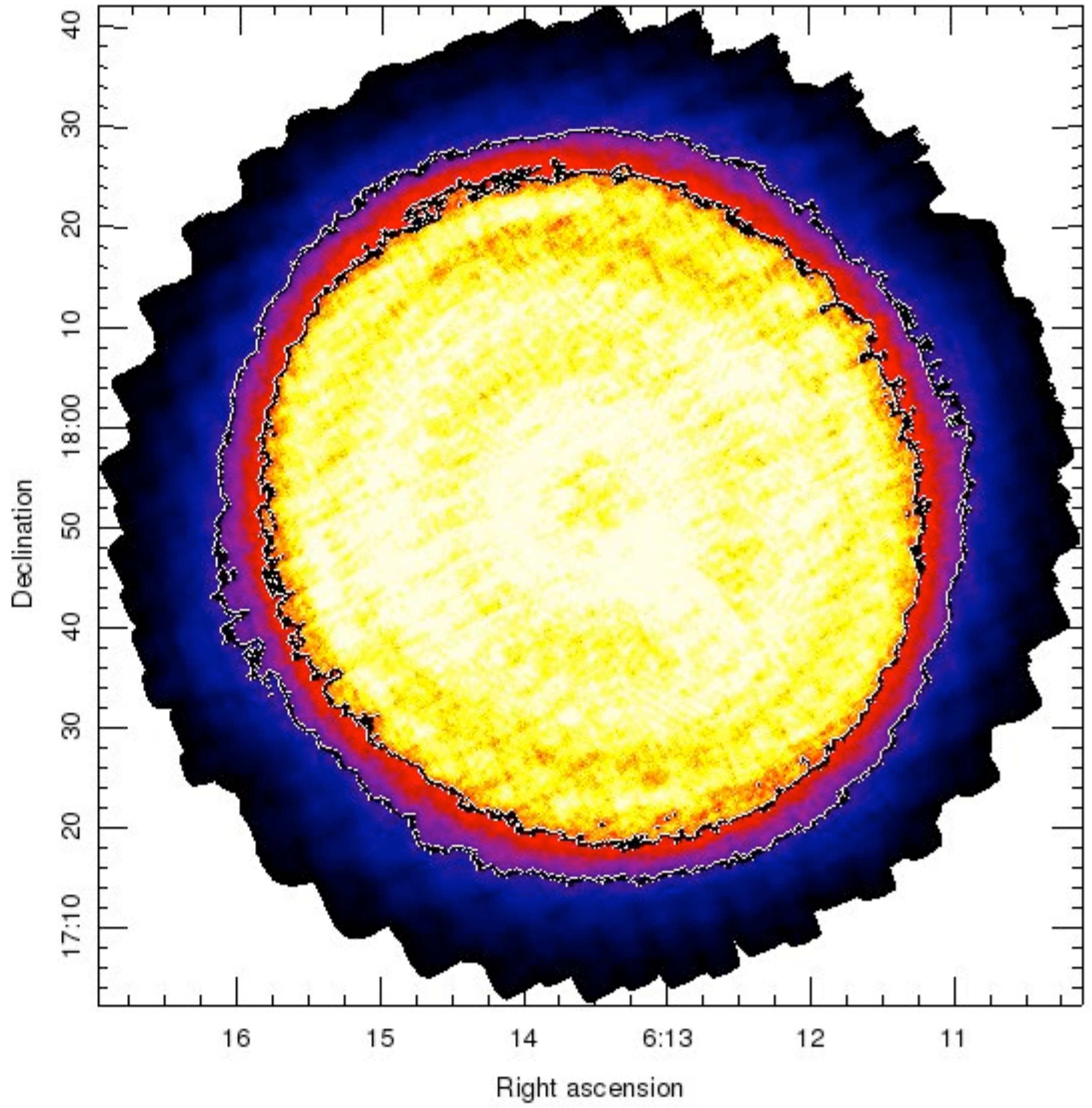




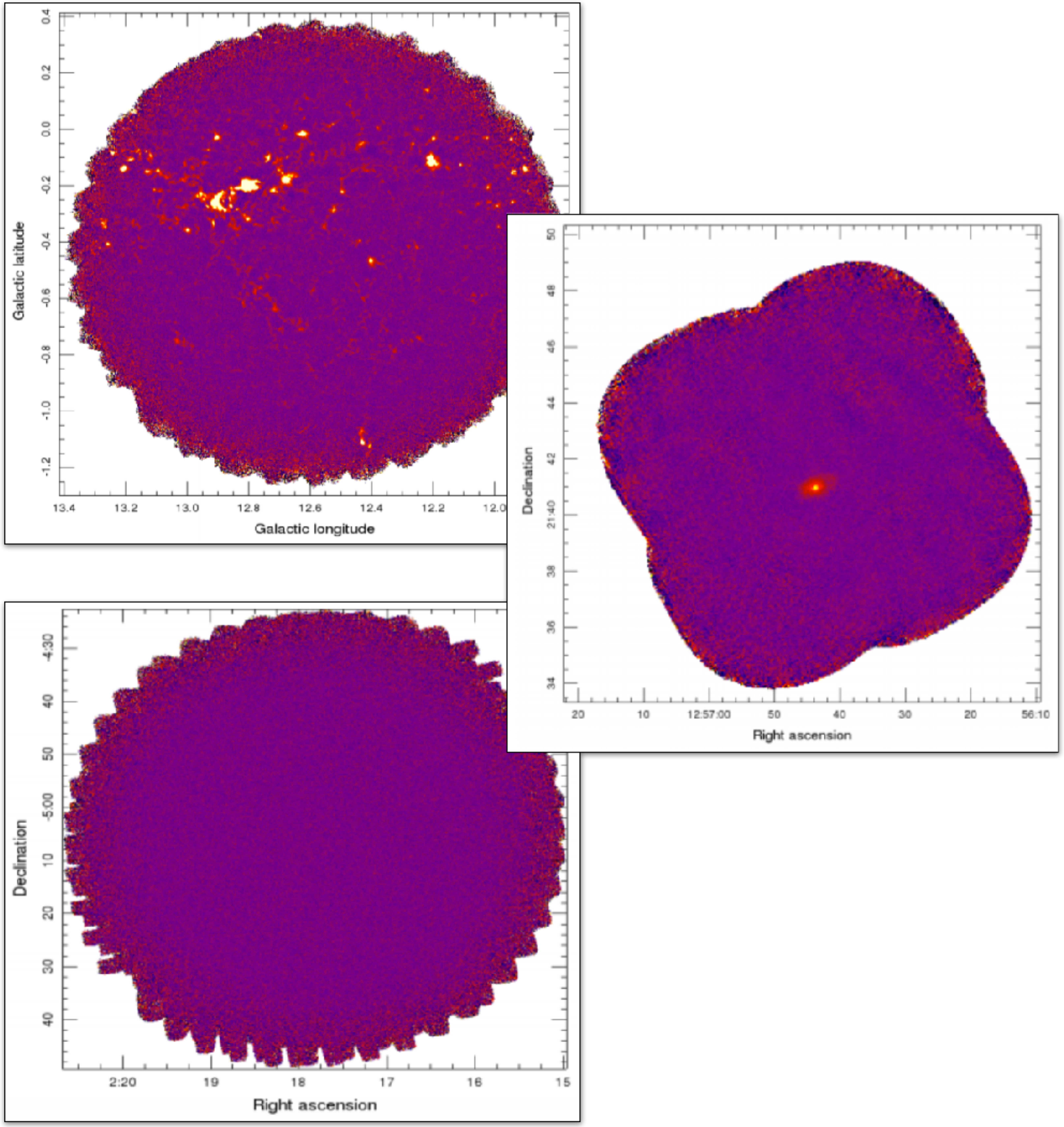
SCUBA-2

Pong Scan Pattern

- Ensure coverage of sky both in time and spacial domain
- Covers same positions at different angles & cross-links scans
- Maximize field coverage & provides more uniform exposure time across field; less central depth
- Good for (e.g.) extended sources
- Range of sizes: 900″, 1800″, 3600″ & 7200″



SCUBA-2



- Upper: Crowded Galactic Plane Field (JPS)
- Middle: Nearby Galaxy (NGLS)
- Lower: Cosmological Field (CLS)

Sub-mm atmospheric transmission as a function of frequency at the JCMT on Maunkaea

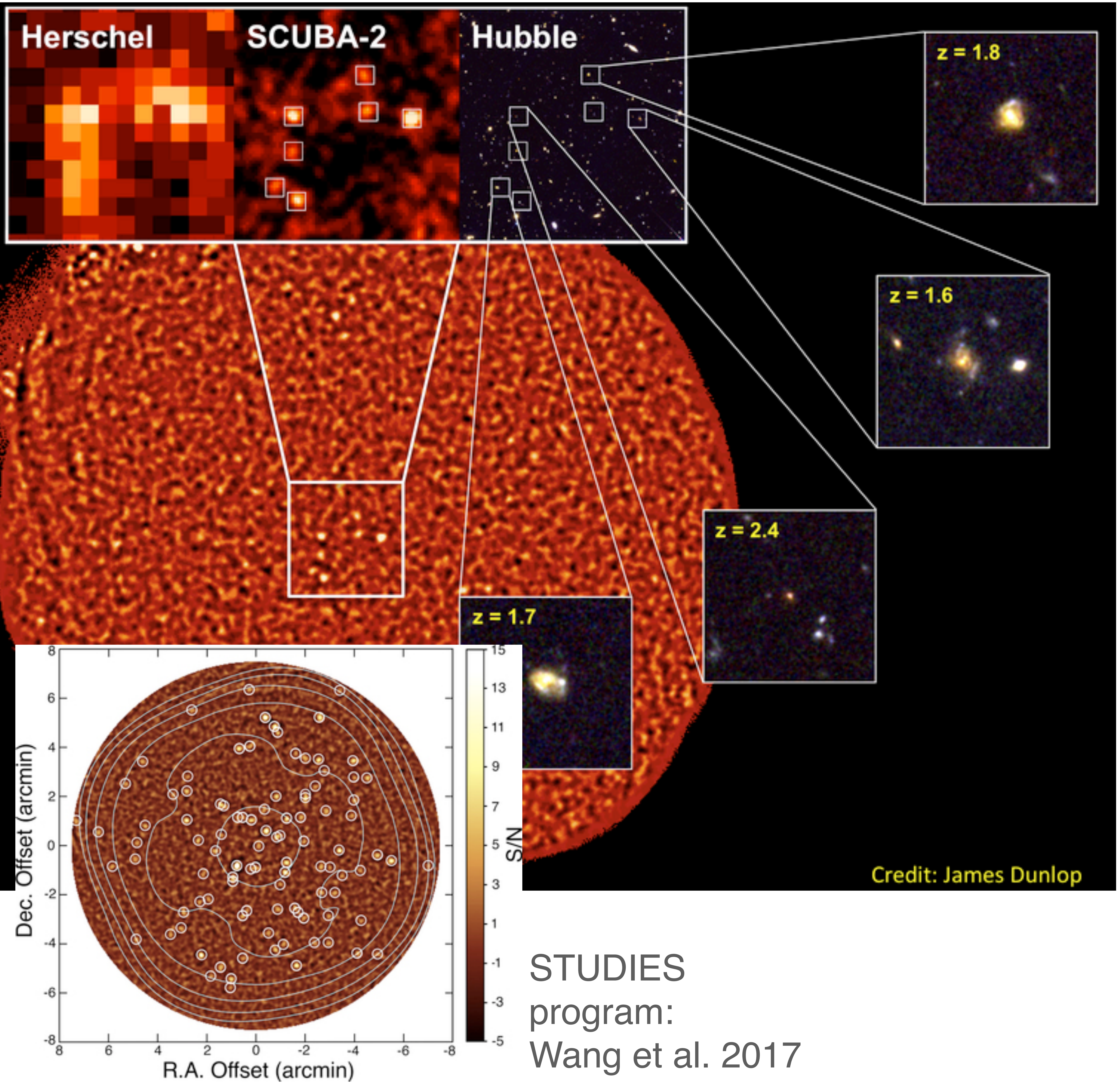
SCUBA-2

SCUBA-2 and POL-2 operating at 450micron and 850microns

Continuum + linear polarizer

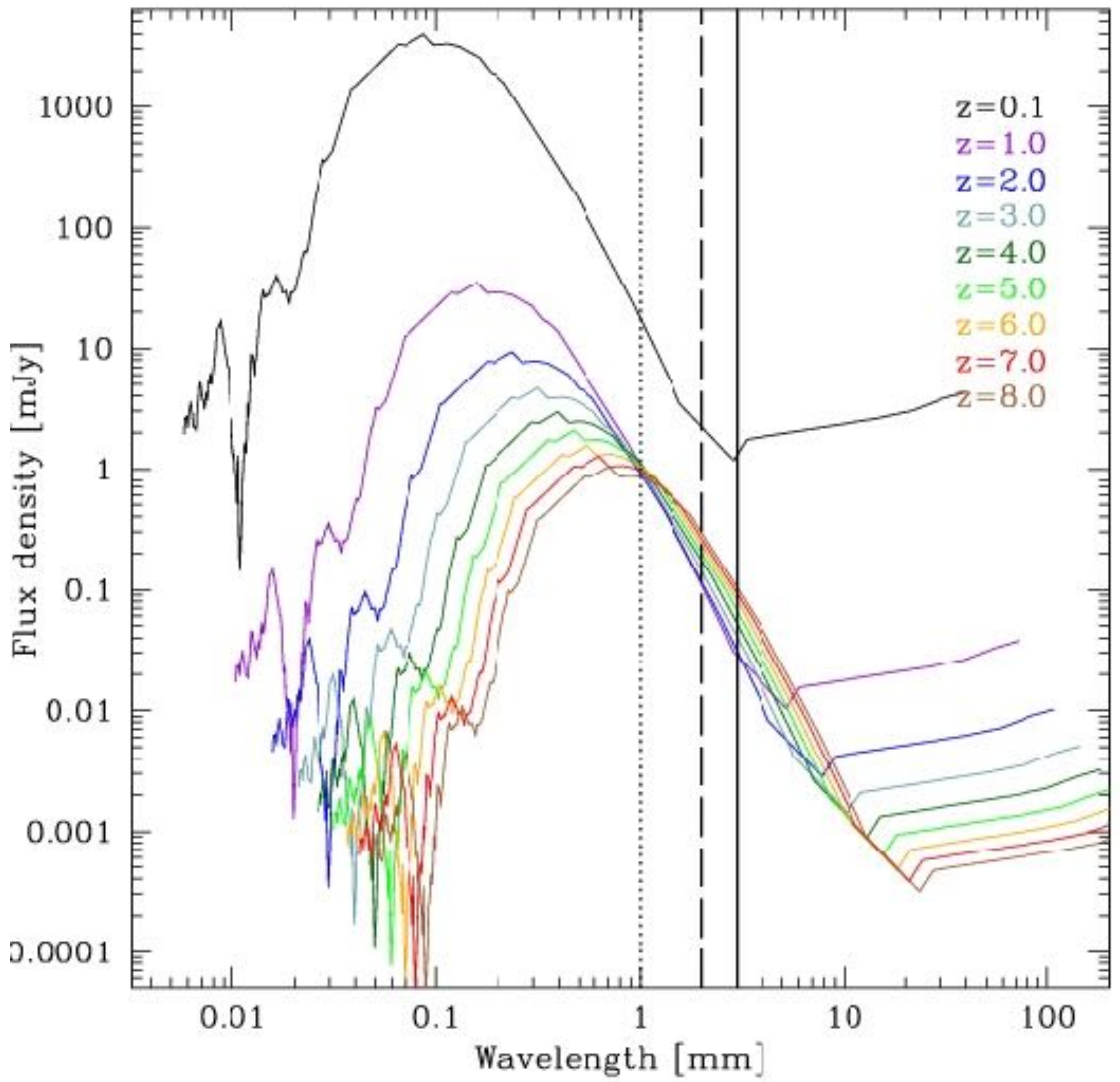
http://www.submm.caltech.edu/cso/weather/atplot.shtml

SCUBA-2



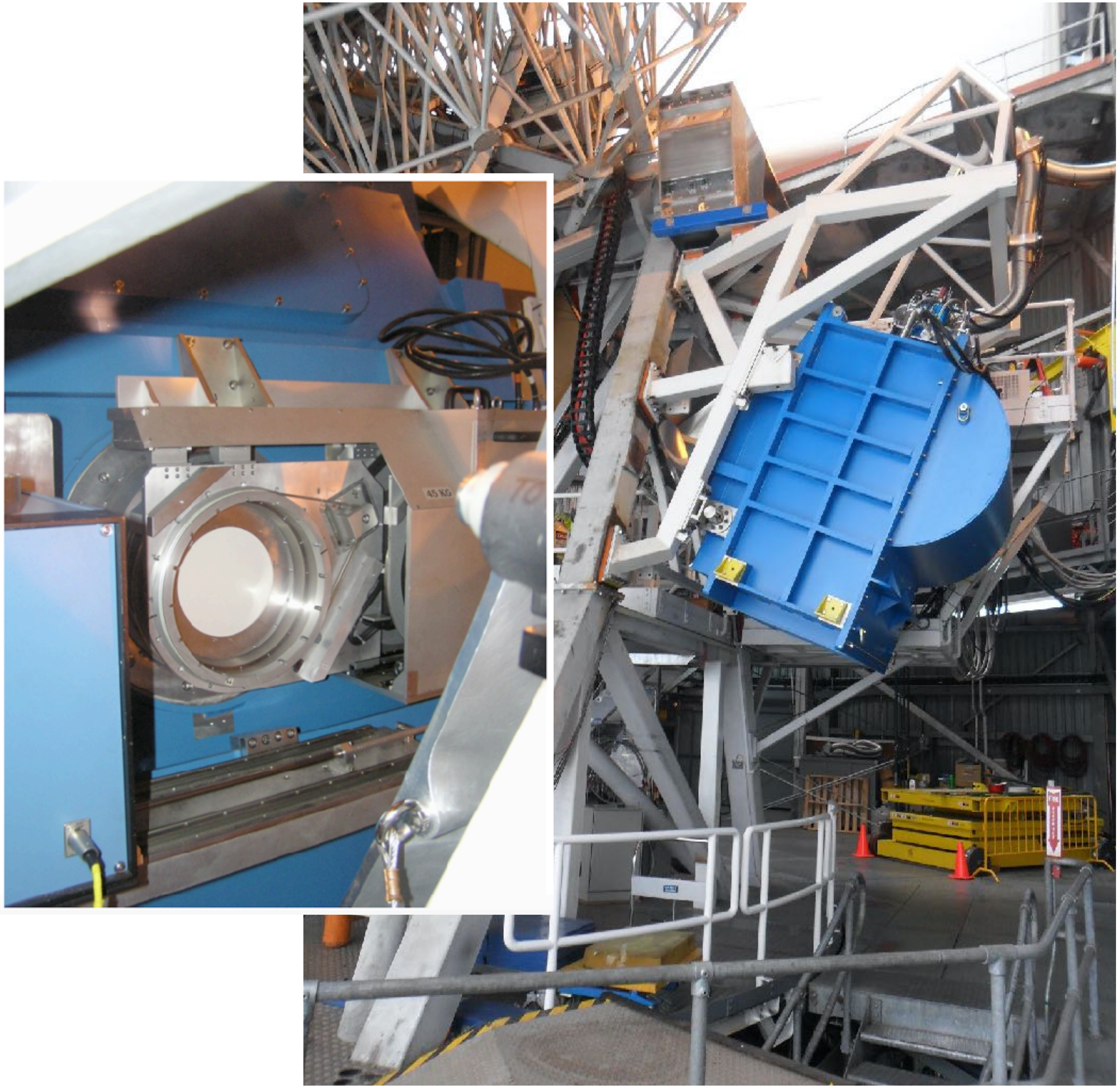
STUDIES program: Wang et al. 2017

- Powerful galaxy mapping machine
- Candidates for ALMA follow up



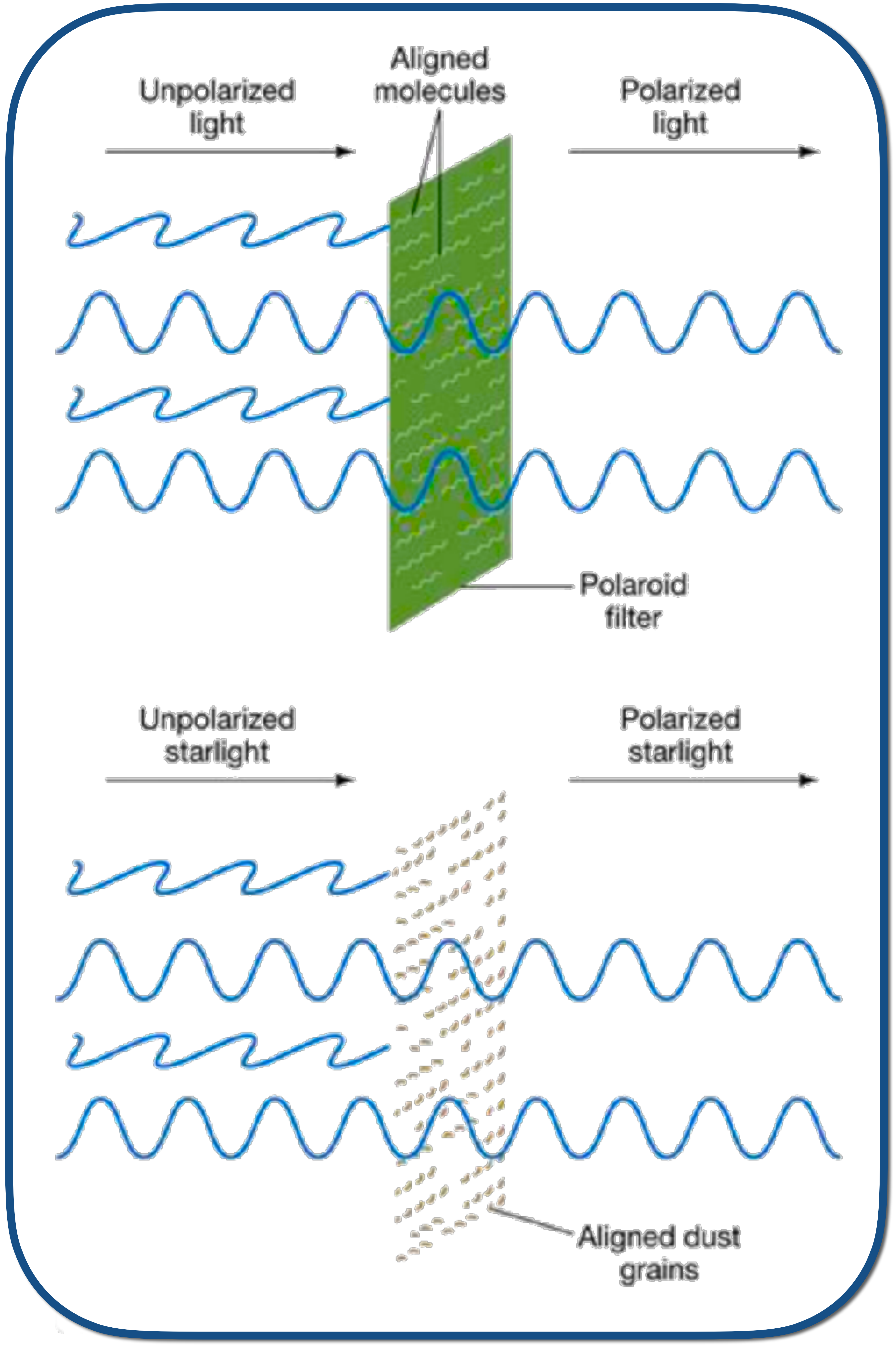
The continuum emission of Arp220 at mm-wavelengths, redshifted at various z. Because of the negative k-correction, which compensates the luminosity distance term at z>1, the flux density is constant at 1 mm.

https://www2.mpia-hd.mpg.de/homes/decarli/science.html



POL-2

- Linear polarimeter
- SCUBA-2 backend required
- 3 optical components in “blades”:
  - Calibrator (~100% polarization)
  - Half-wave plate (HWP). Continuous rotation of this modulates polarization, allowing removal of atmospheric effects. Transmission at 850μm ~ 86%
  - Analyser
- Total effective 850μm transmission ~ 74%

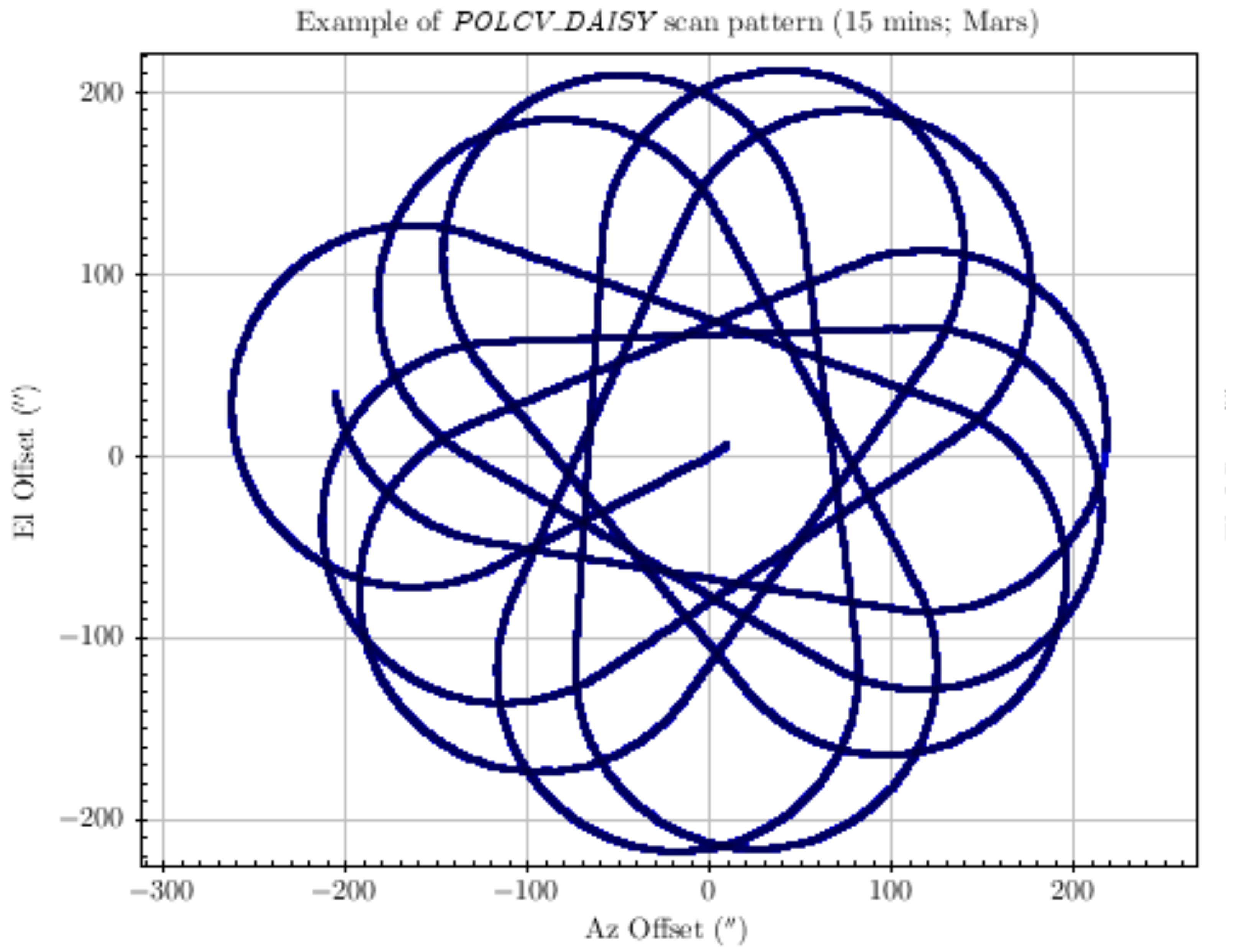


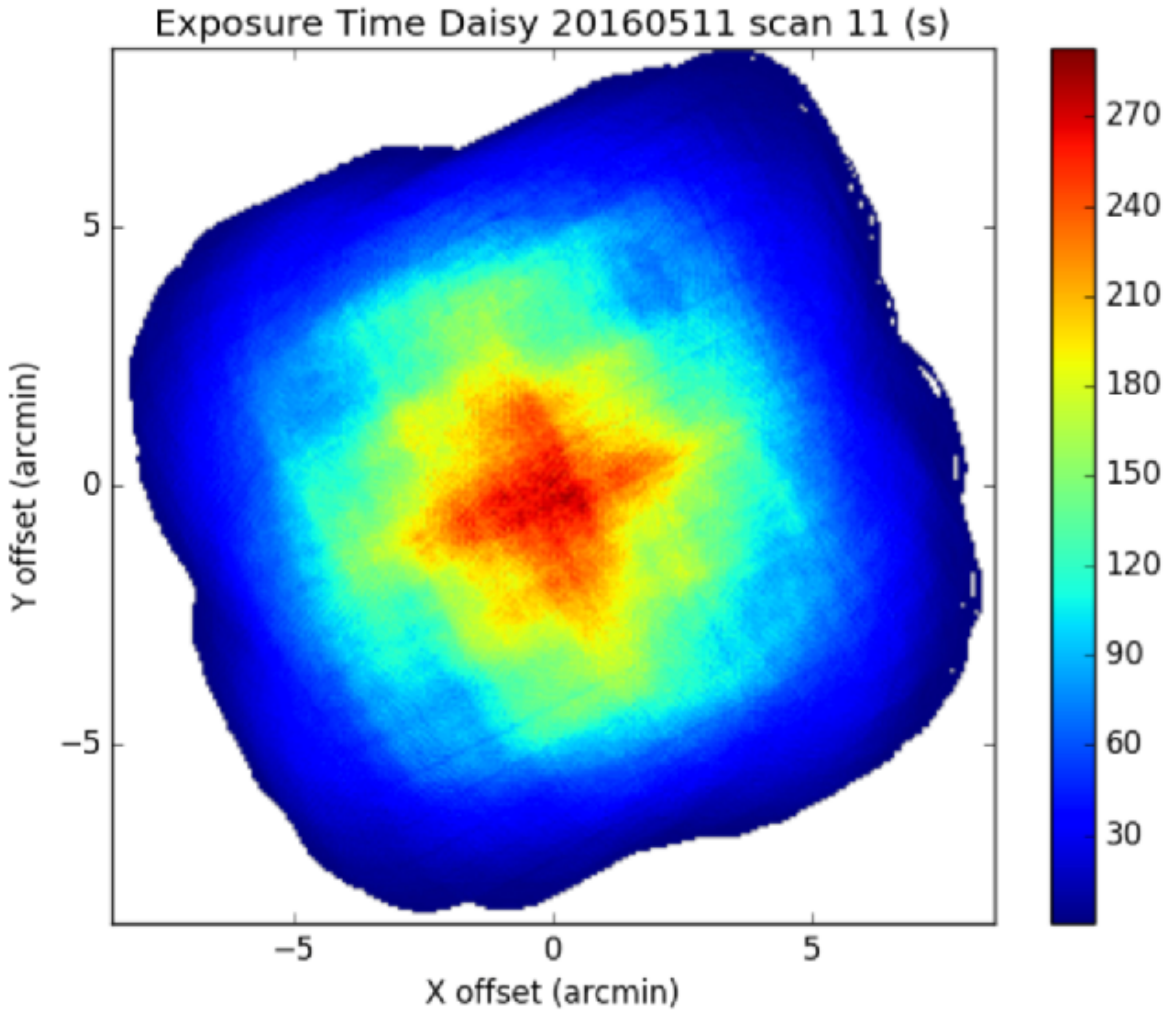
POL-2

- Magnetic Fields Align Non-Spherical Dust Grains
- By looking at polarized light, we can “see” magnetic fields.
- True for visible, IR, sub-mm, etc - with the caveat that the polarization we detect at sub-mm wavelengths is perpendicular to the magnetic field direction.

POL-2

POLCV_DAISY scan pattern





- With SCUBA-2 as the detector POL-2 requires constant scanning similar to SCUBA-2
- Covers same positions at different angles
- Motion of spinning wave plates means that SCUBA-2 must scan more slowly to enable good sampling.
- coverage area good for central 5’

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SCUBA-2 and POL-2 operating at 450micron and 850microns

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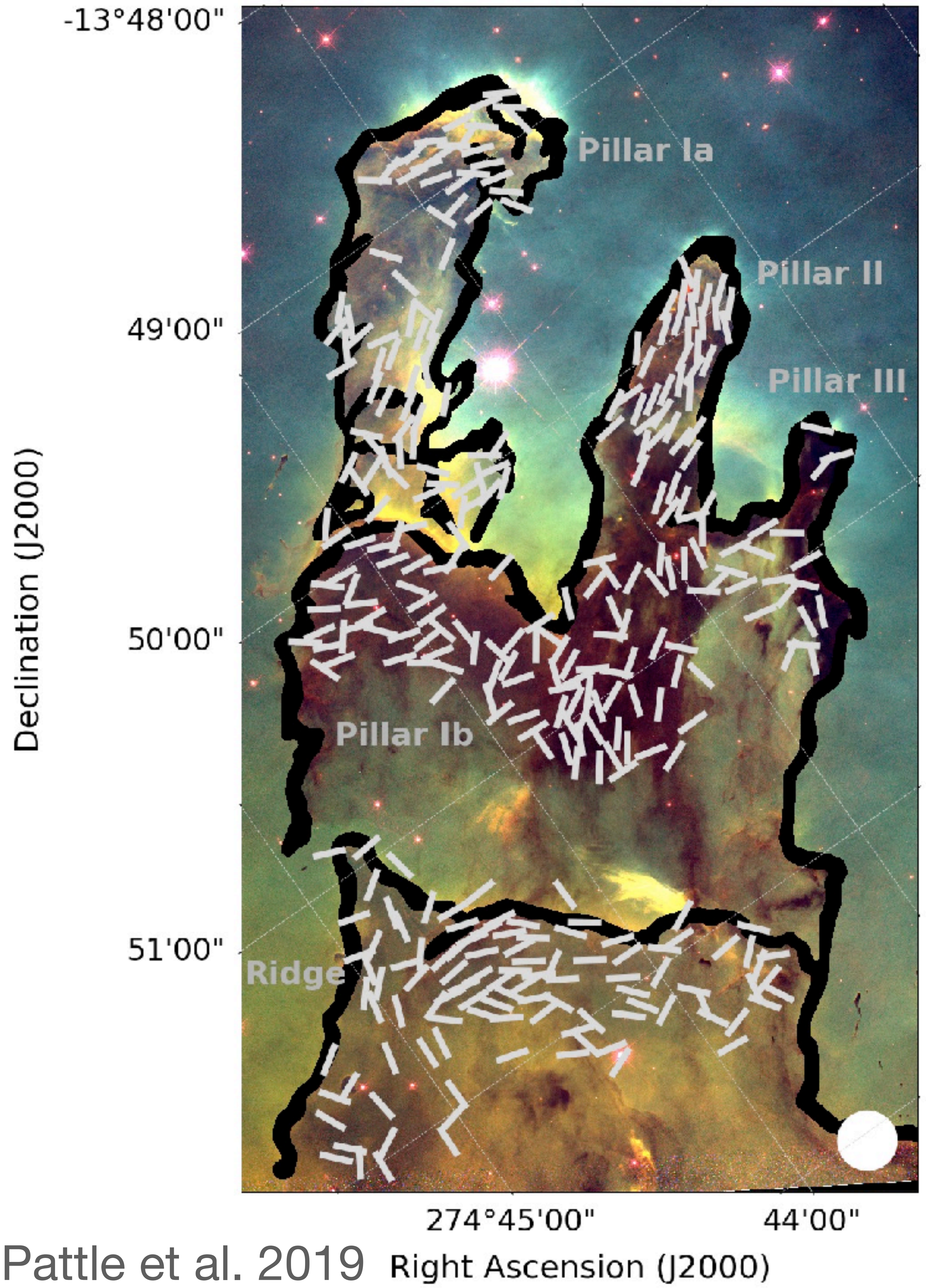
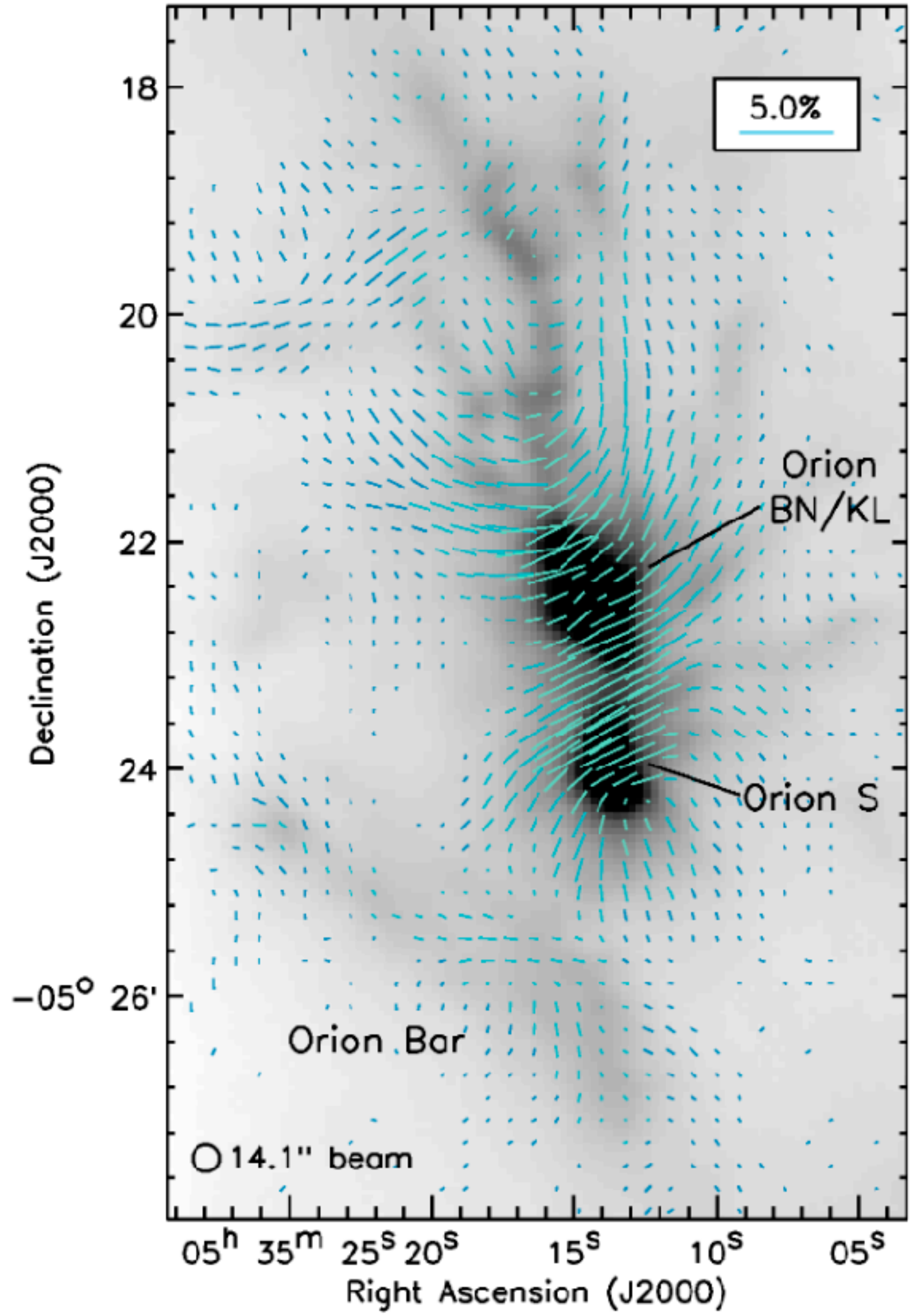
POL-2



Pattle et al. 2019



Pattle et al. 2017 - BISTRO

- Main area of focus understanding the role of magnetic fields in star forming regions.

https://www.eaobservatory.org/jcmt/science/large-programs/gb_bfields/


Primary and Secondary Mirrors
remote controlled
Tertiary Mirror Unit (TMU)
POL-2
SCUBA-2
HARP
Nāmakanui
ACSIS
Data ready for data reduction
inside the receiver cabin
outside the receiver cabin

JCMT `Ohana


660
East Asian Observatory
James Clerk Maxwell Telescope
UKIRT Observatory


Questions?