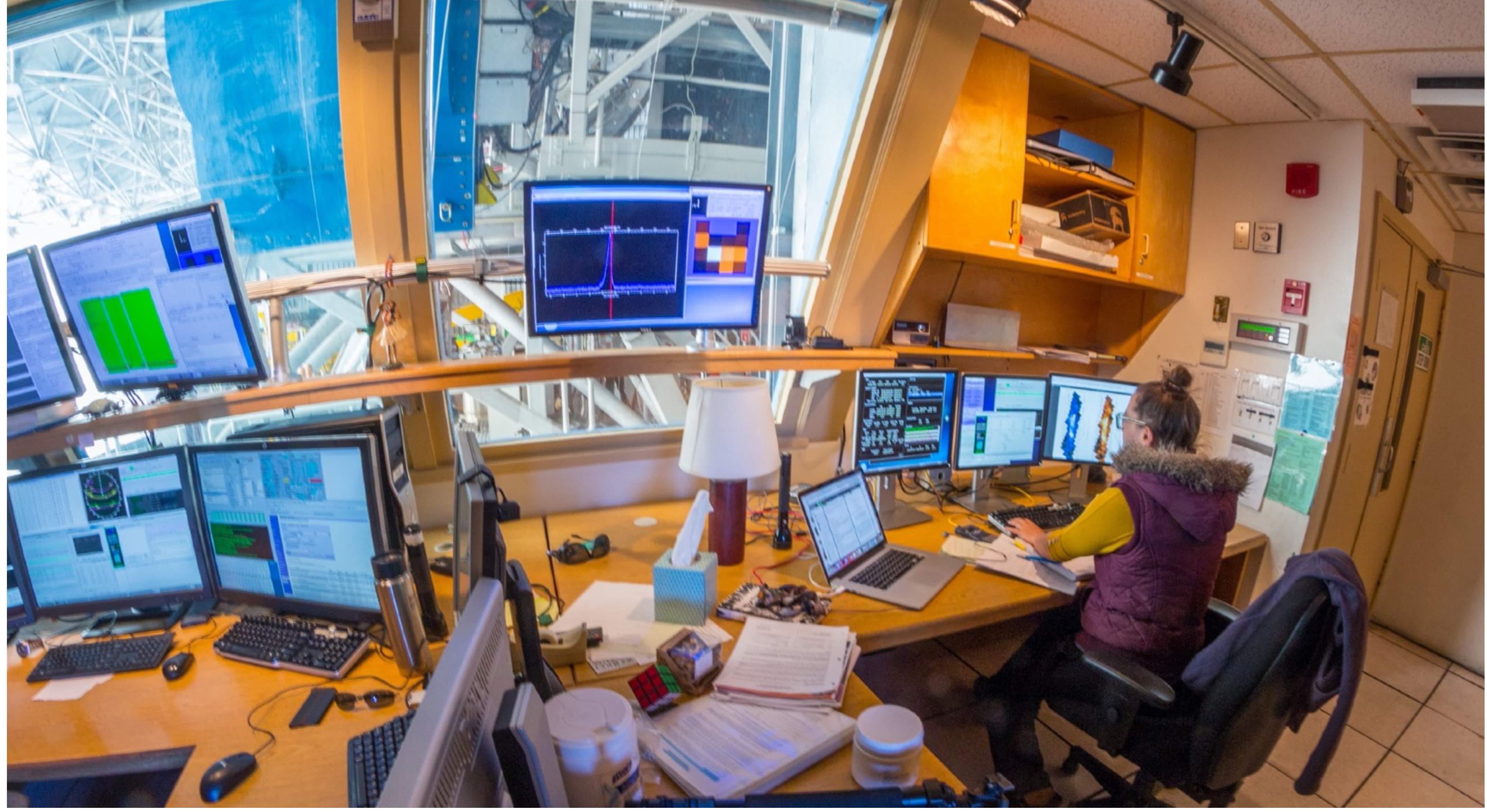


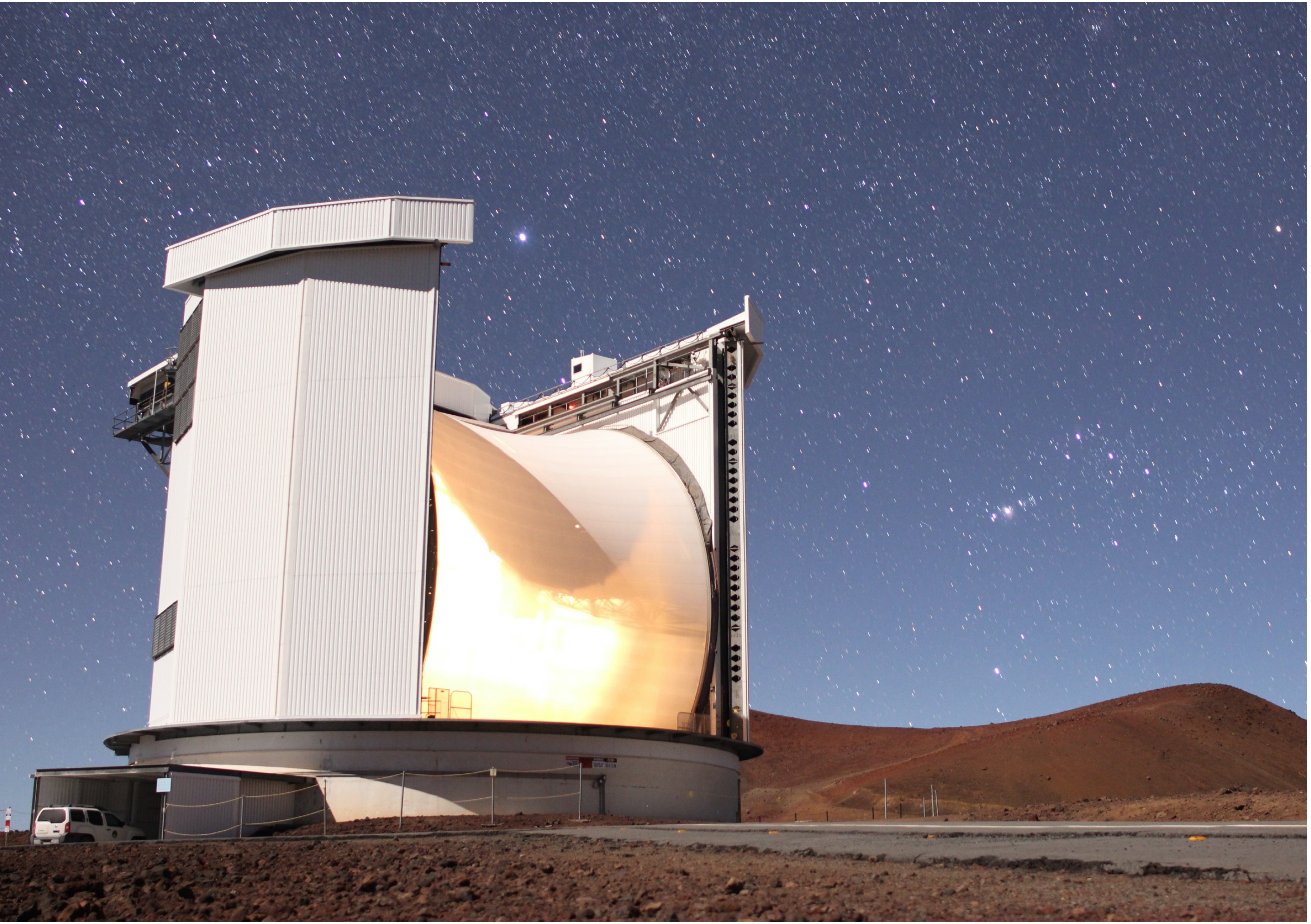
Introduction to the JCMT

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

By Team EAO/JCMT

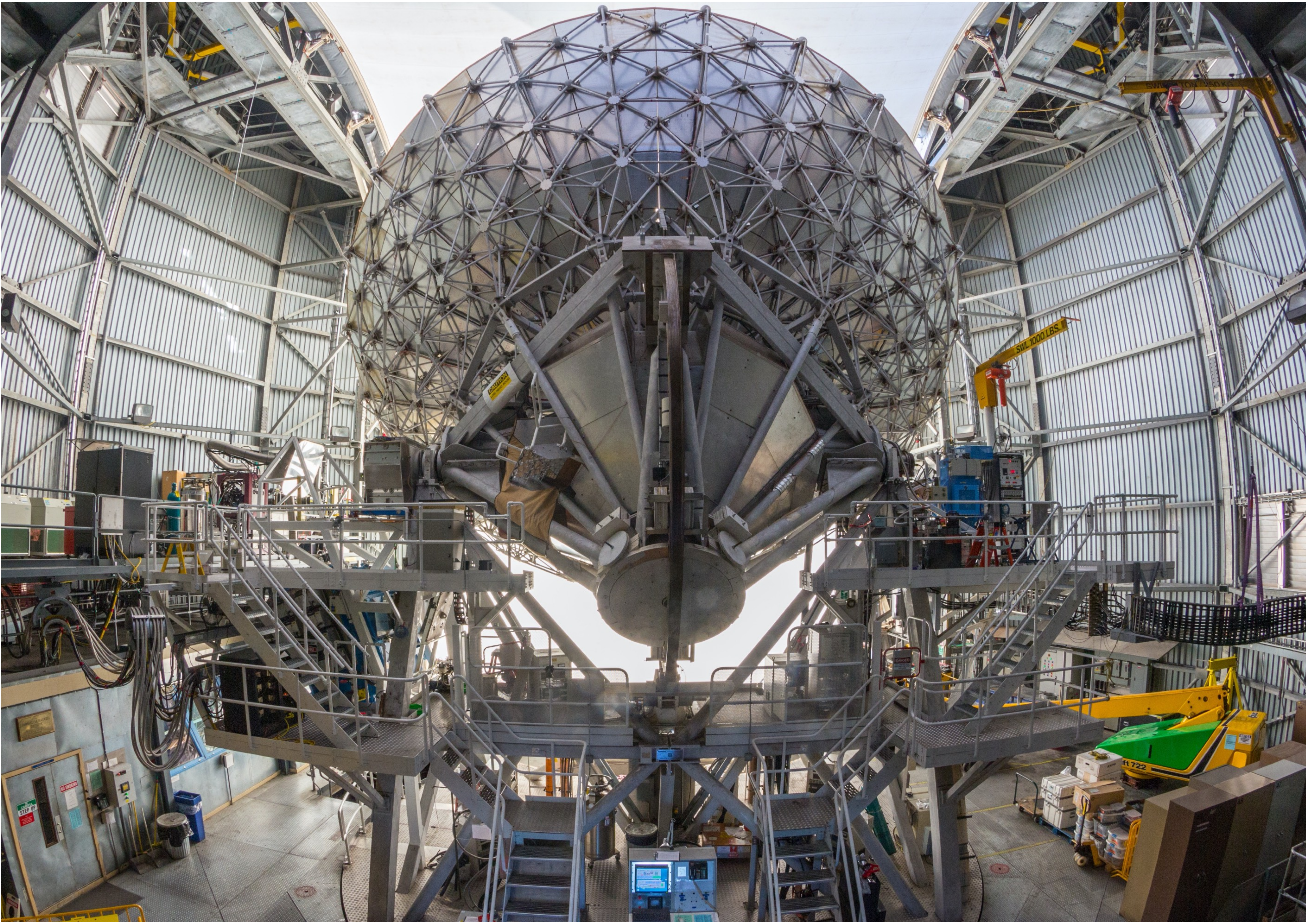
James Clerk Maxwell Telescope
East Asian Observatory


Kūlia i ka nu'u
`Olelo No`eau, Hawaiian saying: Strive for the summit
Image credit: Rita Morris, Subaru.



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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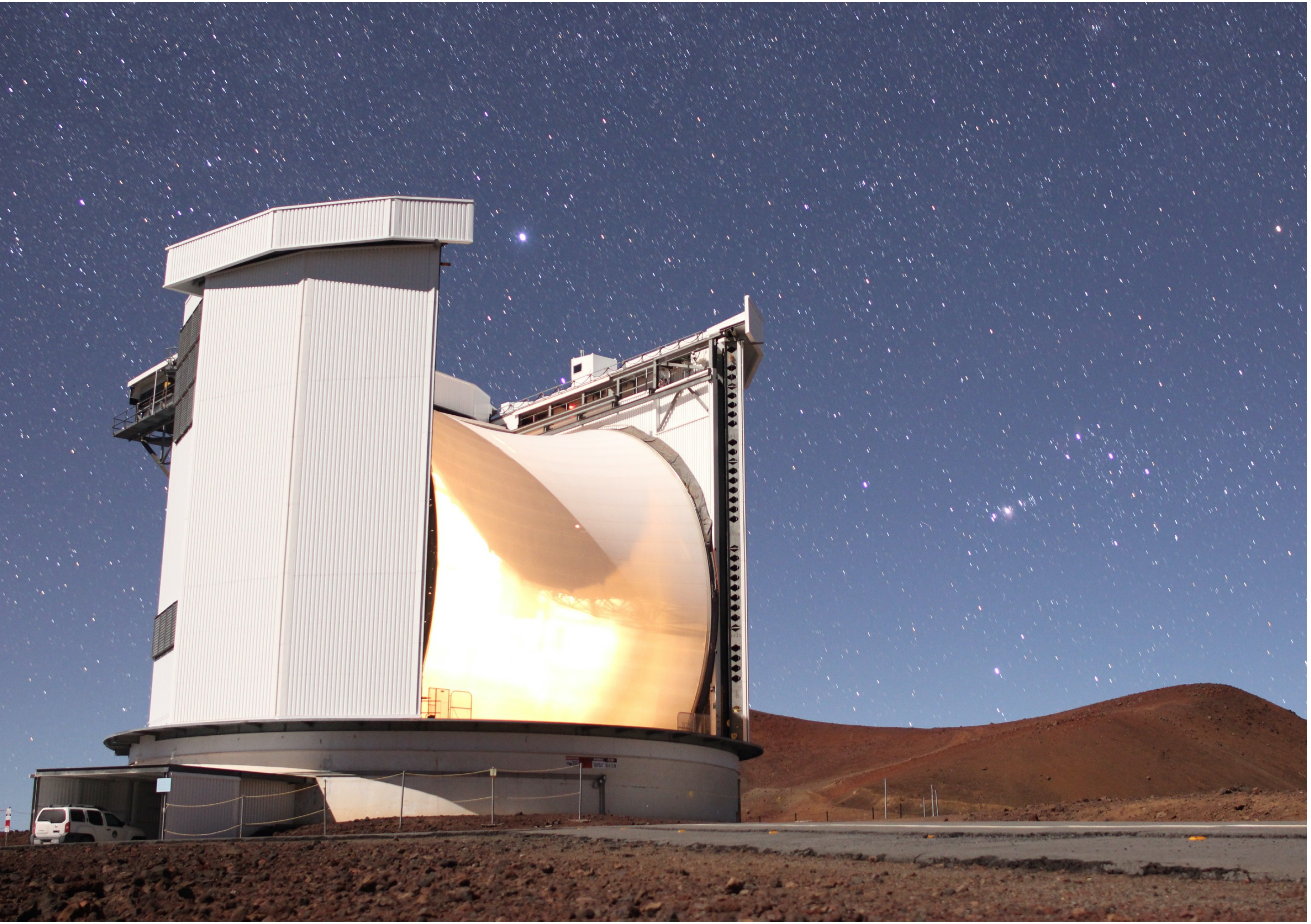

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James Clerk Maxwell

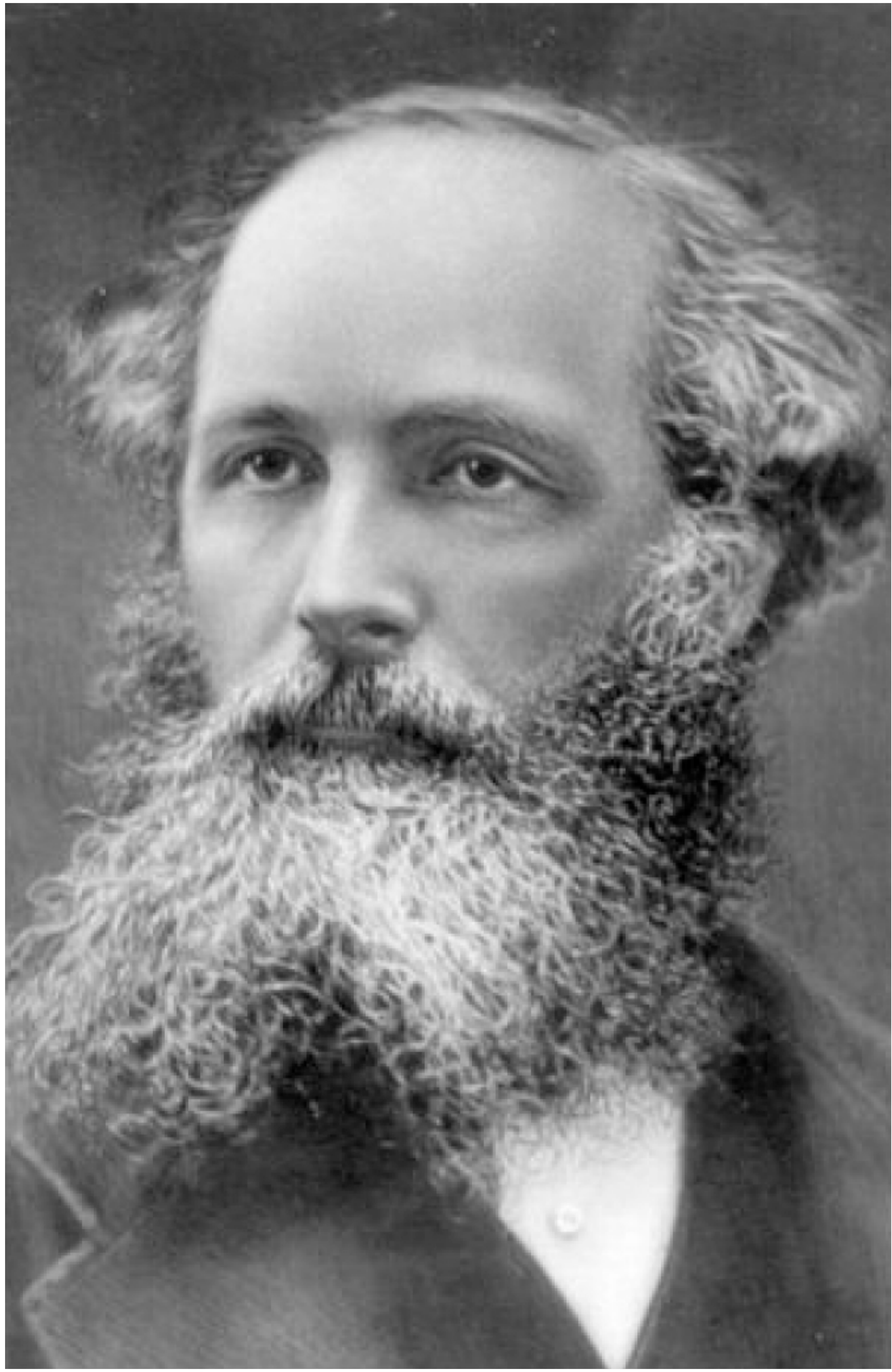
(1831 - 1979)

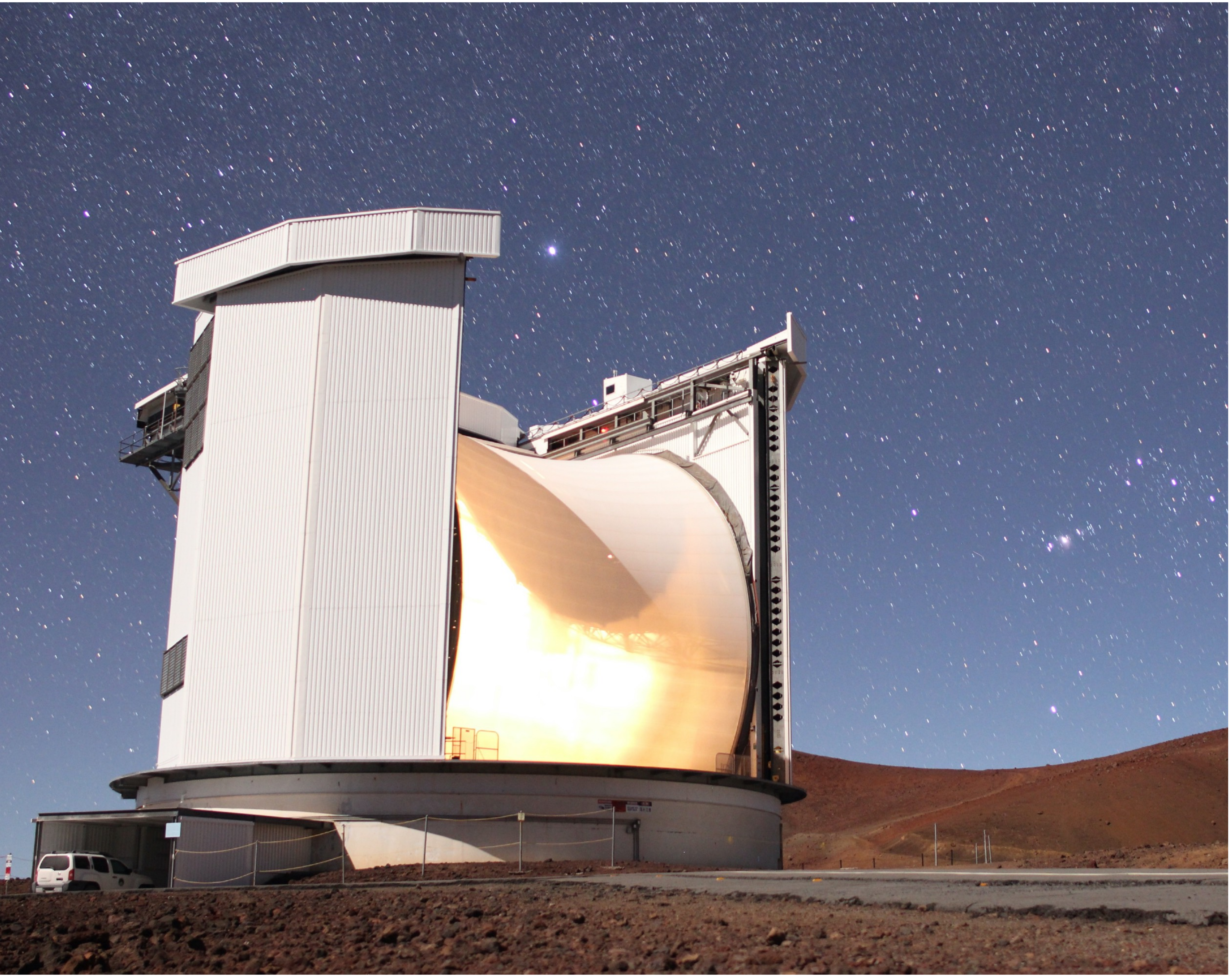
Name	Differential form	Integral form
Gauss's law	$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$	$\oiint_{\partial V} \mathbf{E} \cdot \mathrm{d}\mathbf{A} = \frac{Q(V)}{\varepsilon_0}$
Gauss's law for magnetism	$\nabla \cdot \mathbf{B} = 0$	$\oiint_{\partial V} \mathbf{B} \cdot \mathrm{d}\mathbf{A} = 0$
Maxwell–Faraday equation (Faraday's law of induction)	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$	$\oint_{\partial S} \mathbf{E} \cdot \mathrm{d}\mathbf{l} = -\frac{\partial \Phi_{B,S}}{\partial t}$
Ampère's circuital law (with Maxwell's correction)	$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$	$\oint_{\partial S} \mathbf{B} \cdot \mathrm{d}\mathbf{l} = \mu_0 I_S + \mu_0 \varepsilon_0 \frac{\partial \Phi_{E,S}}{\partial t}$

466 PROFESSOR CLERK MAXWELL ON THE ELECTROMAGNETIC FIELD.

as those of WEBER, which expresses the number of electrostatic units of electricity which are contained in one electromagnetic unit.

This velocity is so nearly that of light, that it seems we have strong reason to conclude that light itself (including radiant heat, and other radiations if any) is an electromagnetic disturbance in the form of waves propagated through the electromagnetic field according to electromagnetic laws. If so, the agreement between the elasticity of the





Instruments

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

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

Nāmakanui operating around 230GHz

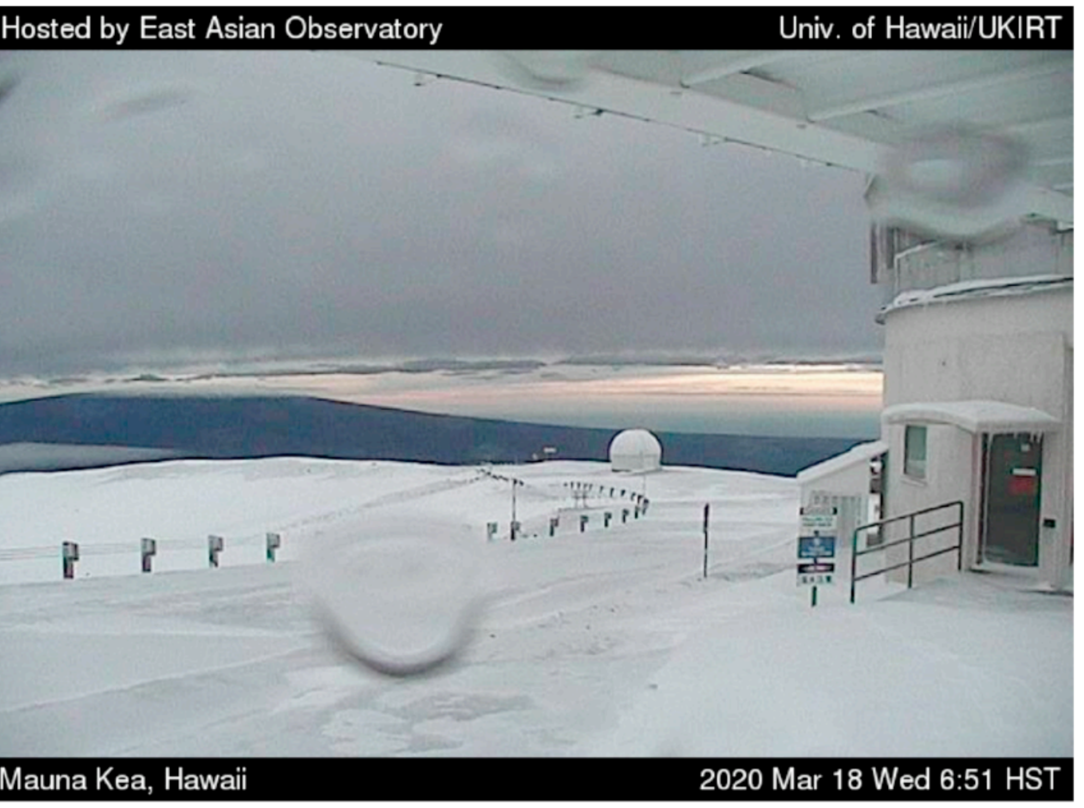
Nāmakanui HARP, SCUBA-2 and POL-2 345GHz

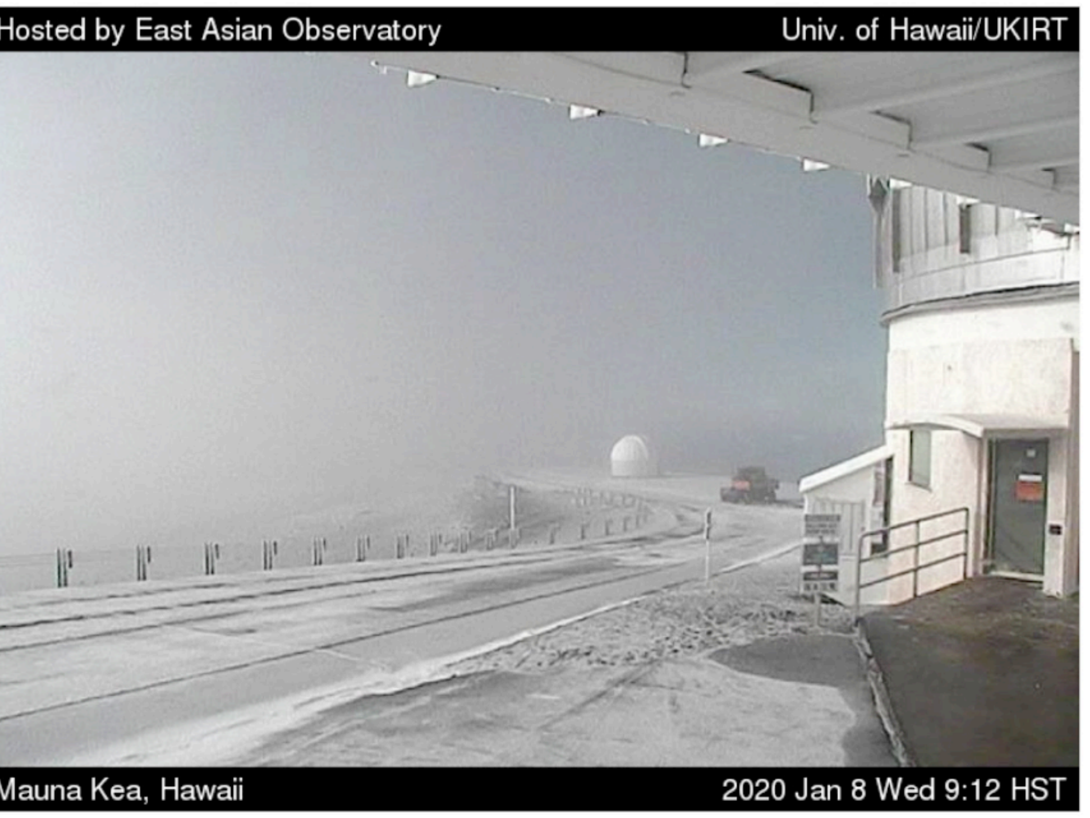
SCUBA-2 operating around 450microns ~660GHz

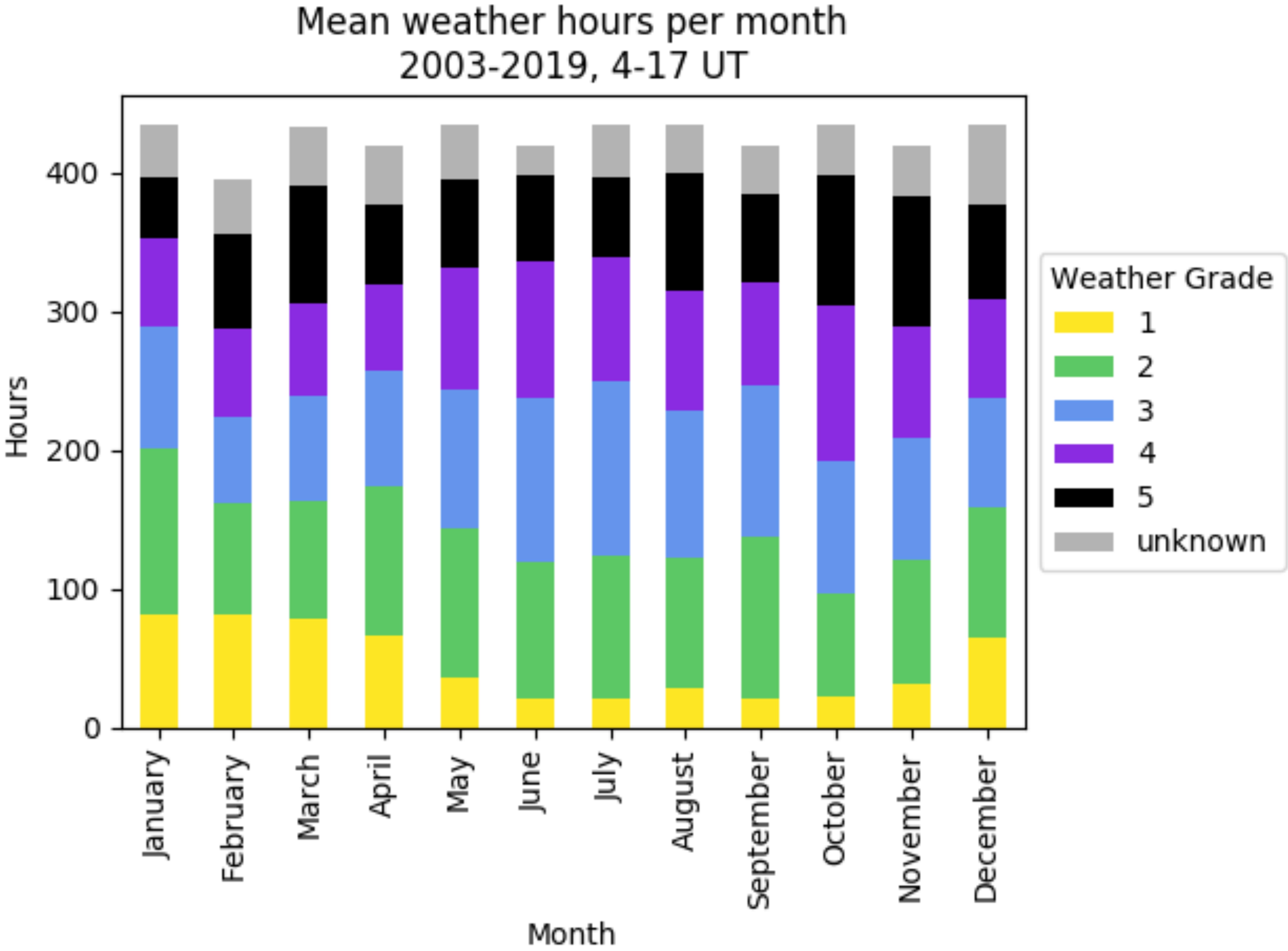
http://www.submm.caltech.edu/cso/weather/atplot.shtml

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

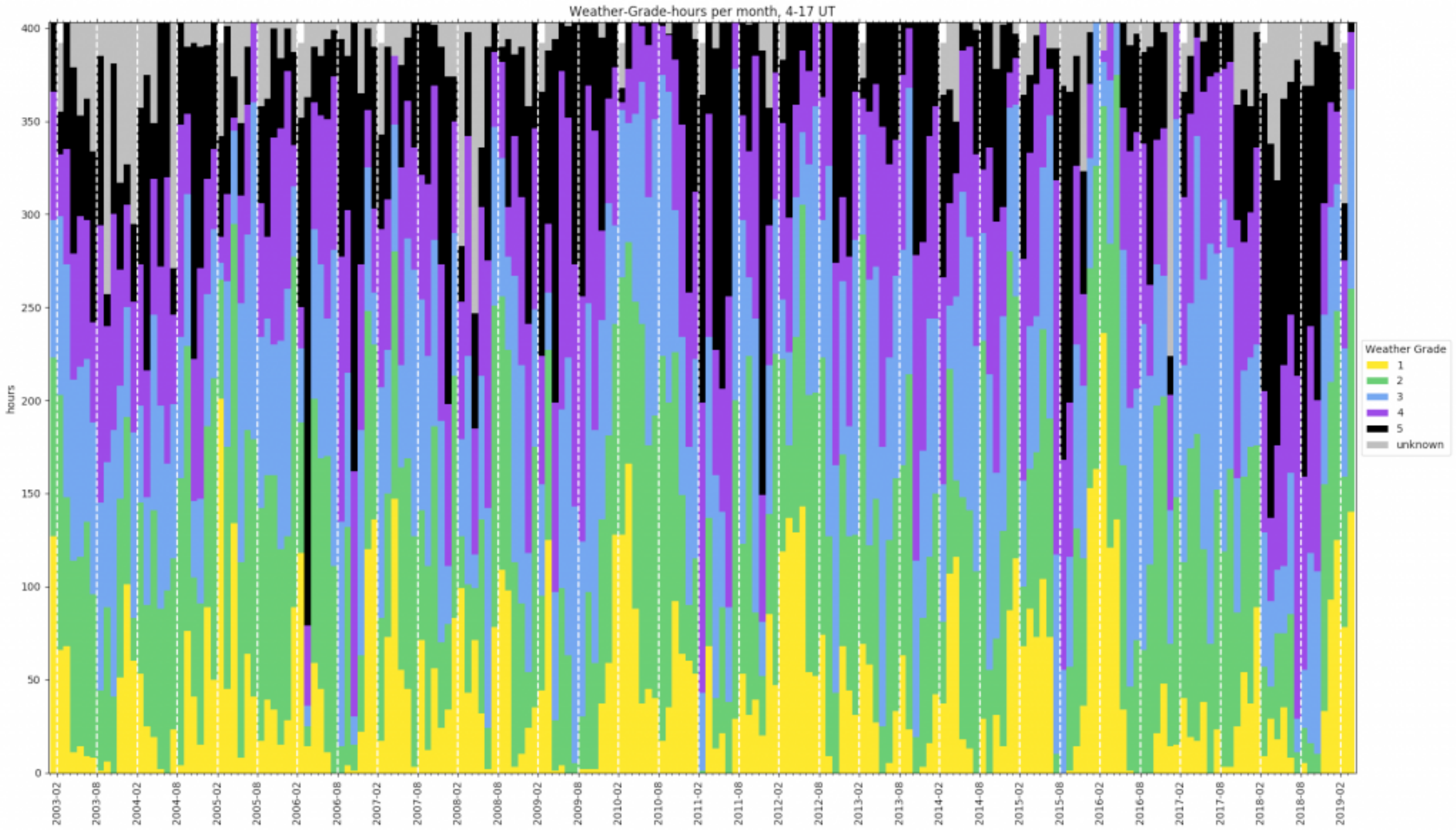
http://www.submm.caltech.edu/cso/weather/atplot.shtml







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



Weather-Grade-hours per month, 4-17 UT
hours
0
50
100
150
200
250
300
350
400
2003-02
2003-08
2004-02
2004-08
2005-02
2005-08
2006-02
2006-08
2007-02
2007-08
2008-02
2008-08
2009-02
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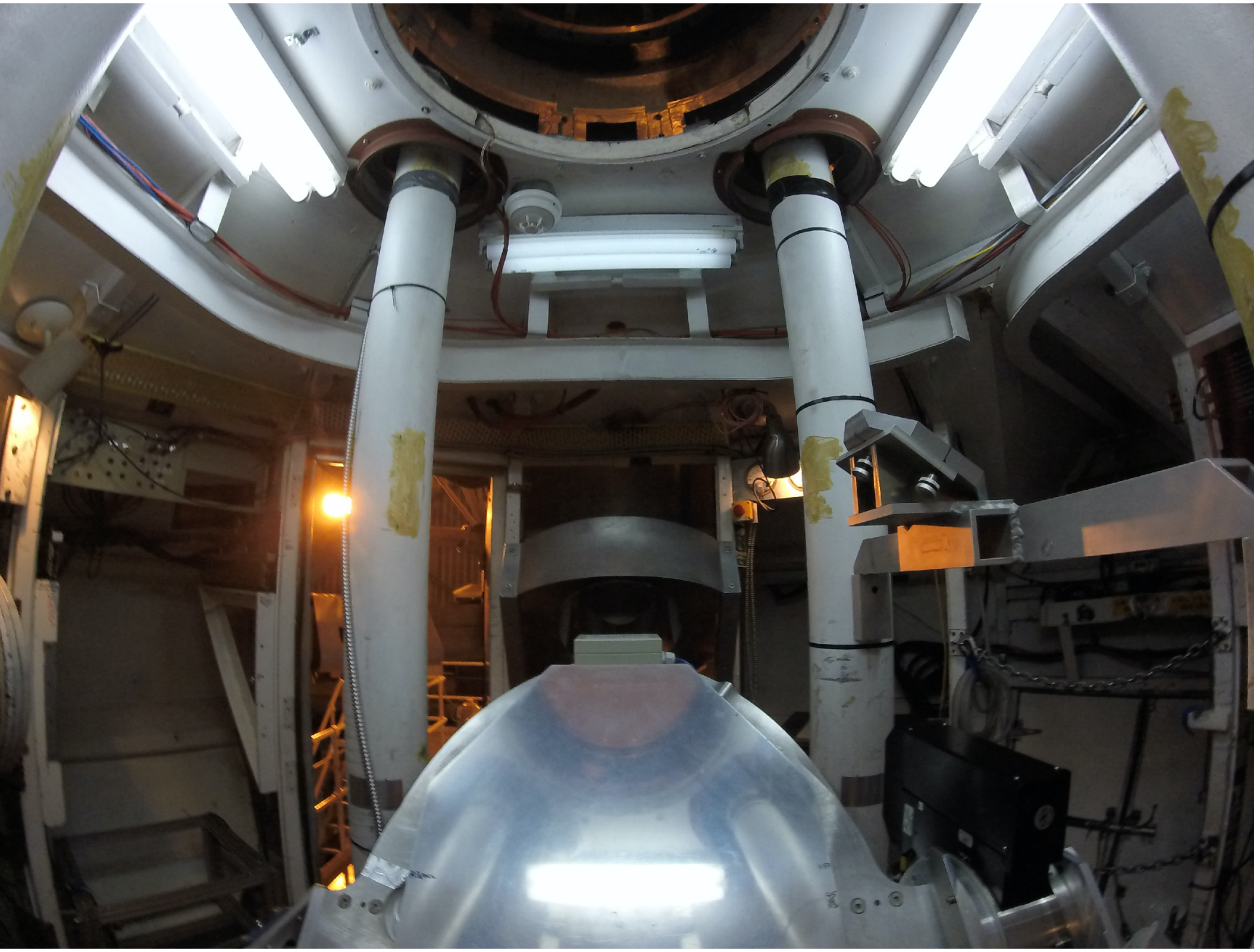
2014-08
2015-02
2015-08
2016-02
2016-08
2017-02
2017-08
2018-02
2018-08
2019-02
Weather Grade
1
2
3
4
5
unknown

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

WVM



- Measures the PWV (precipitable Water Vapor) at the JCMT using the 183GHz water line.
- Measured along the line of sight
- Generally reported as an opacity at 225GHz (for historic reasons)
- Sky opacity is required for SCUBA-2 data reduction and Nāmanakanui calibration
- Program selection during a night is based on science priority, instrument availability *and* sky opacity


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

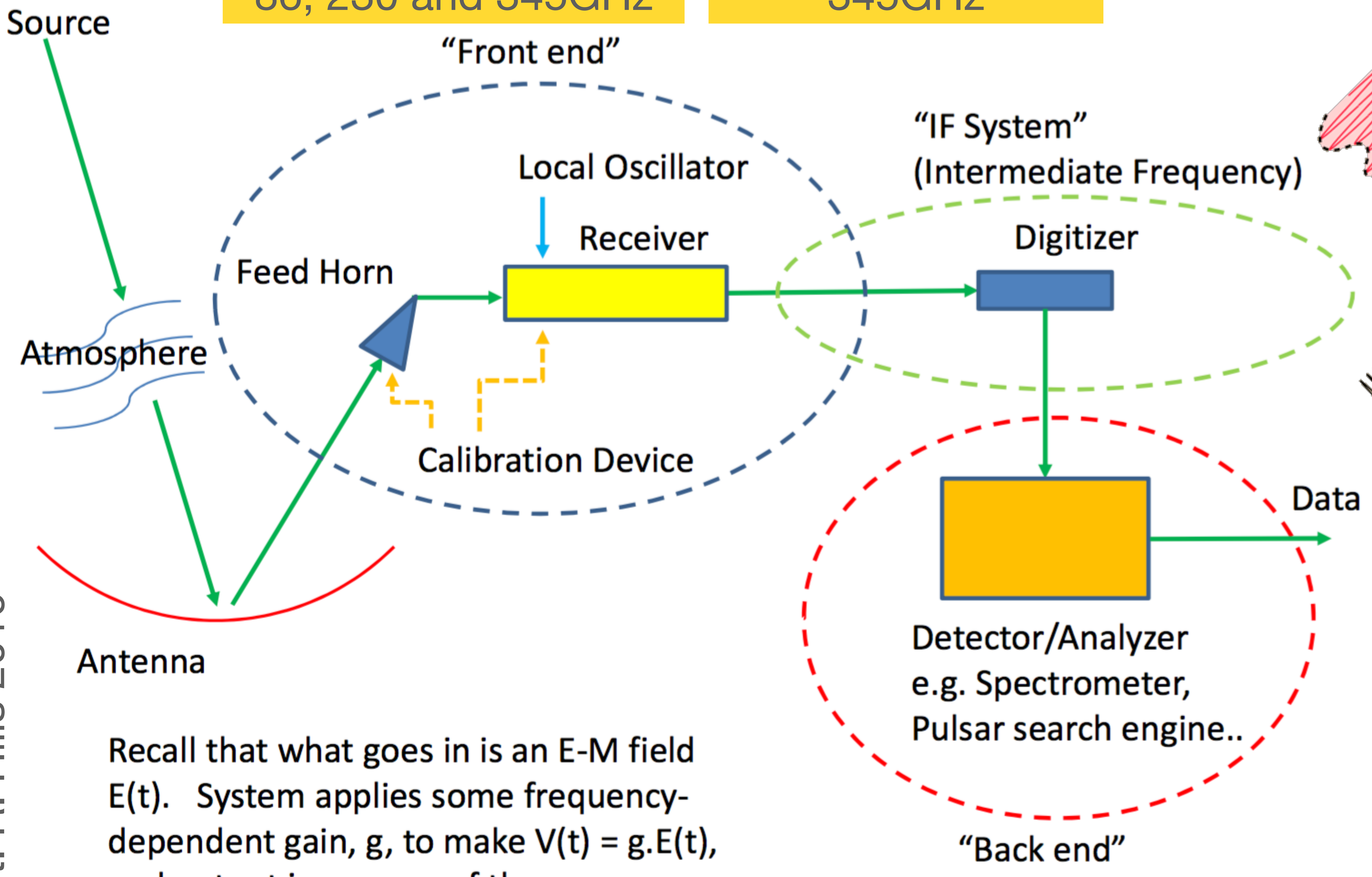
HARP
operating around
345GHz

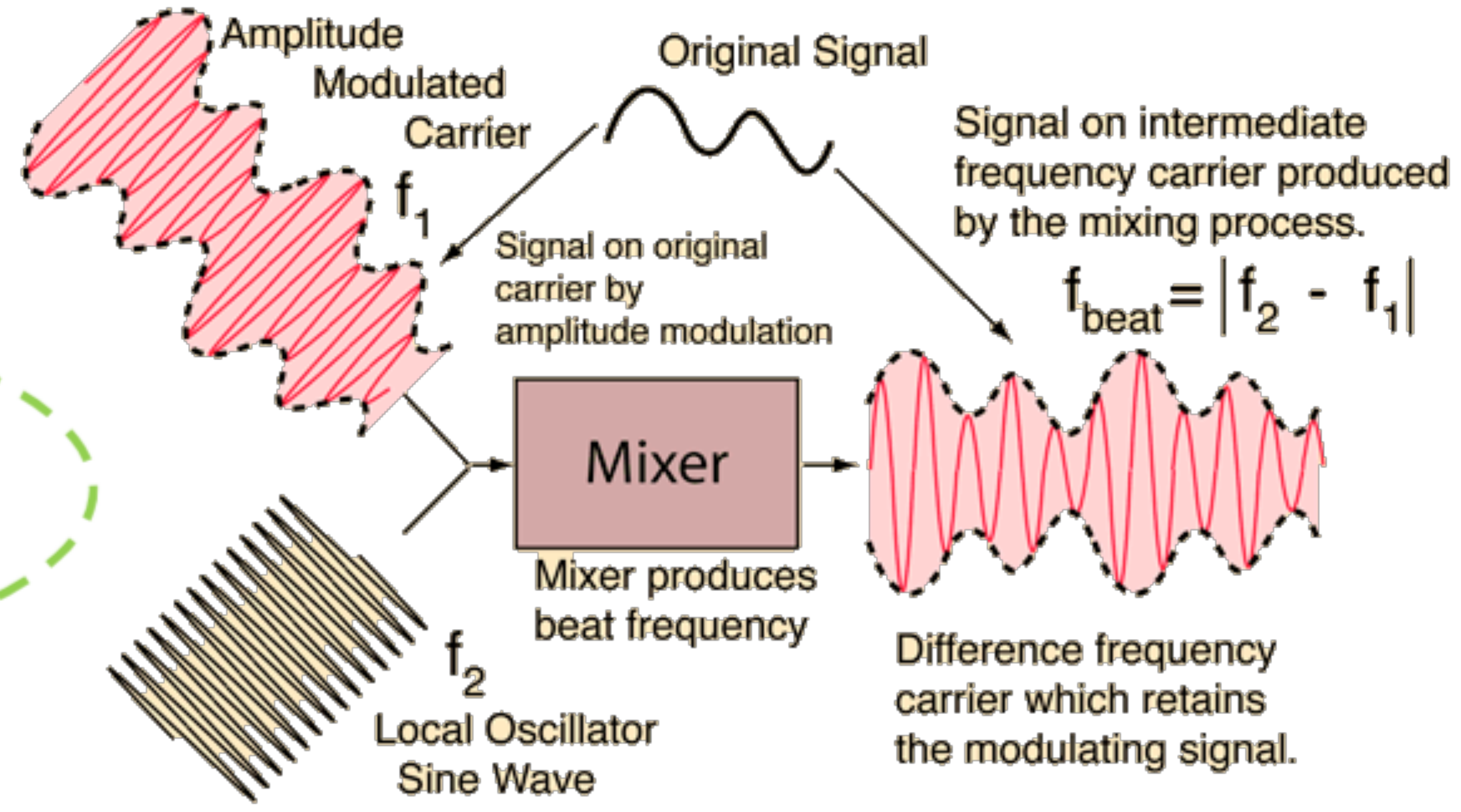
JCMT:
ACSIS
Digital backend
spectrometer

Heterodyne

Nāmakanui operating around 86, 230 and 345GHz

HARP operating around 345GHz





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.

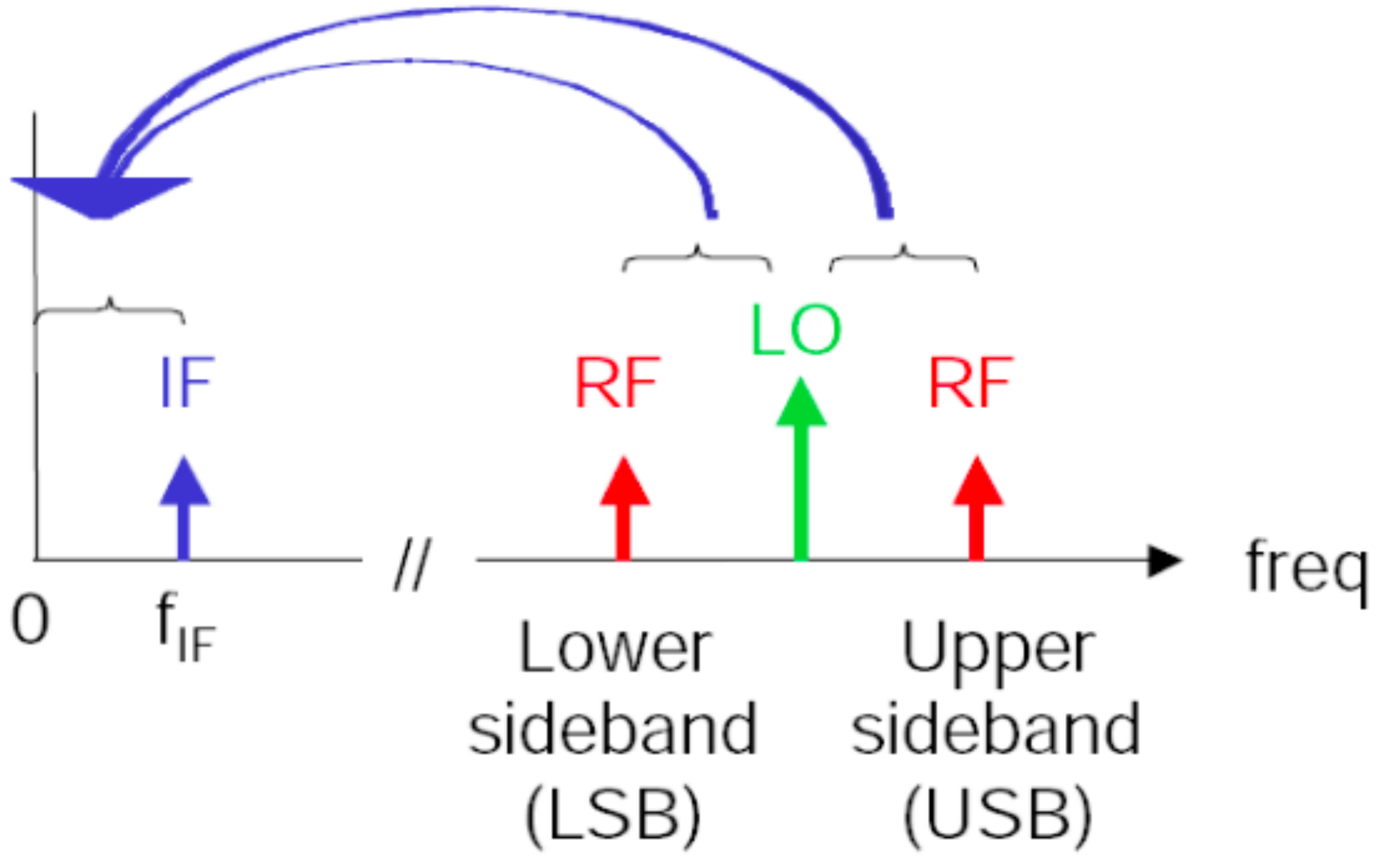
JCMT:
ACSIS
Digital backend spectrometer

VLBI (EHT or EAVN)
R2DBE & Mark6

Credit: R. Hills 2016

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

Principle of Down-conversion



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

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

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

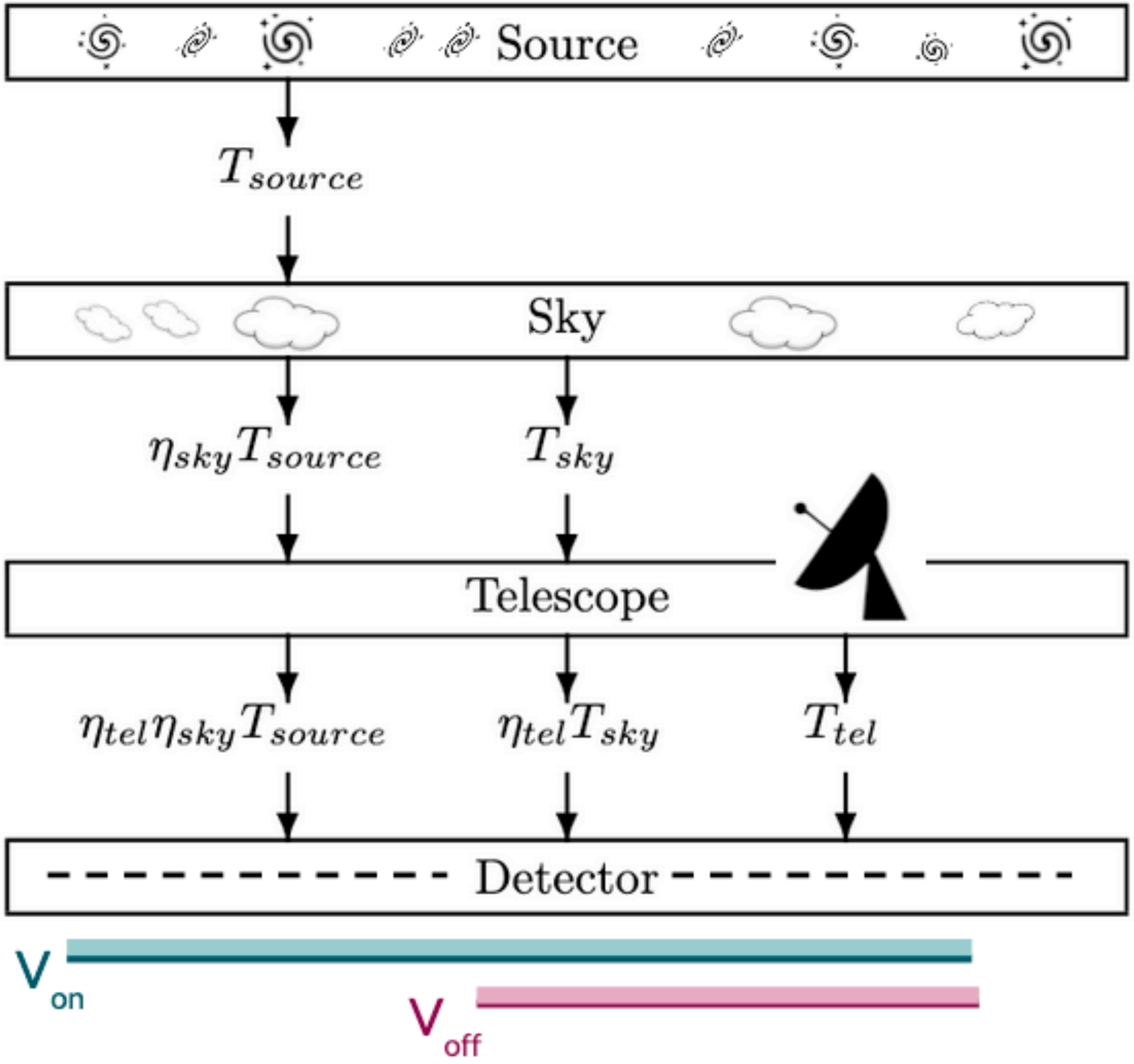
Switching - in position or frequency* between "on" and "off"

From our observations we get a normalized signal power (S_N) that is related to the power from the on (V_{on}) and off position (V_{off}). It is T_{sys} that converts this measurement in the raw data to and corrected antenna temperature.

$$S_N = V_{on} - V_{off} / V_{off}$$

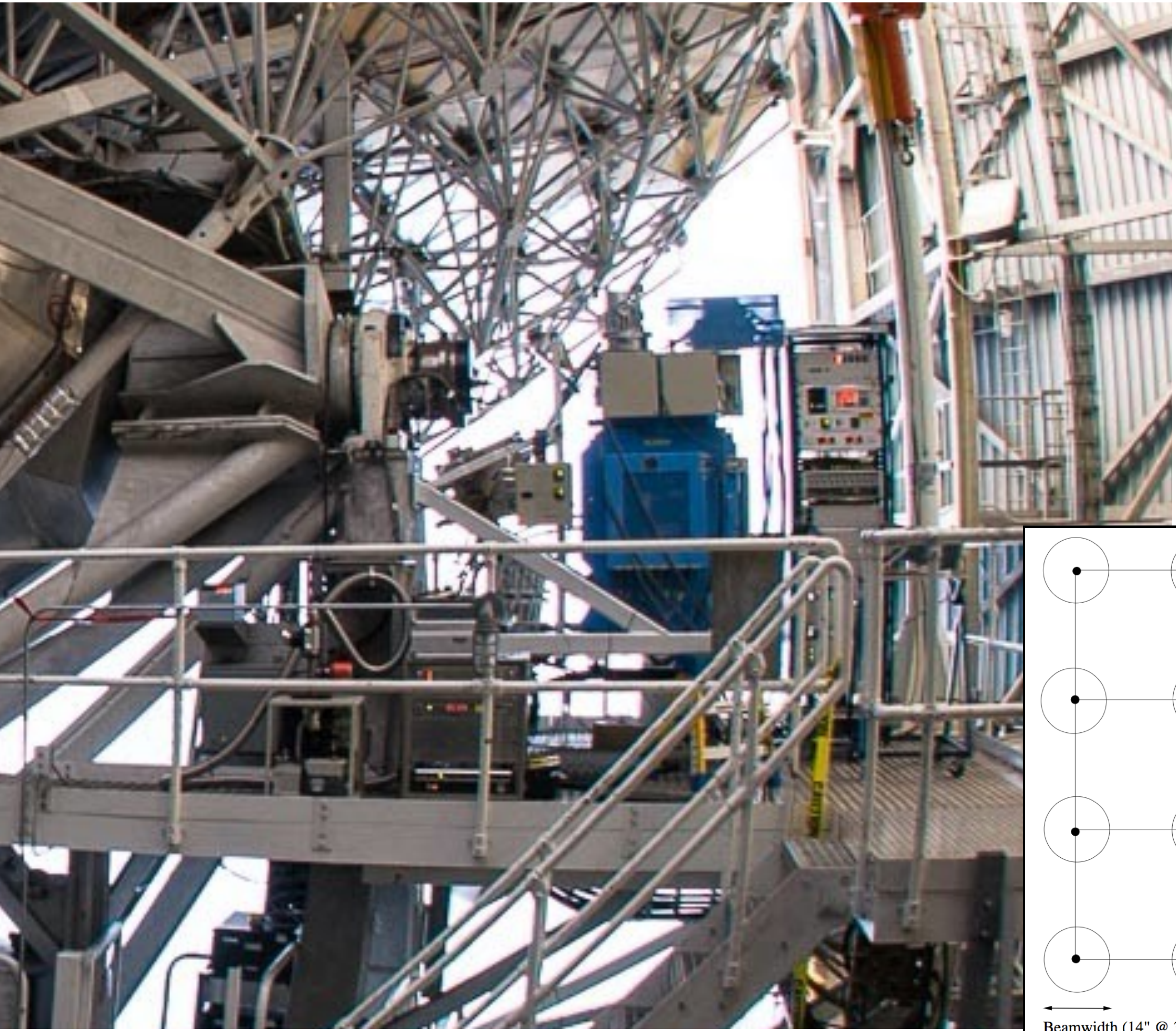
$$T_A^* = S_N . T_{sys}$$

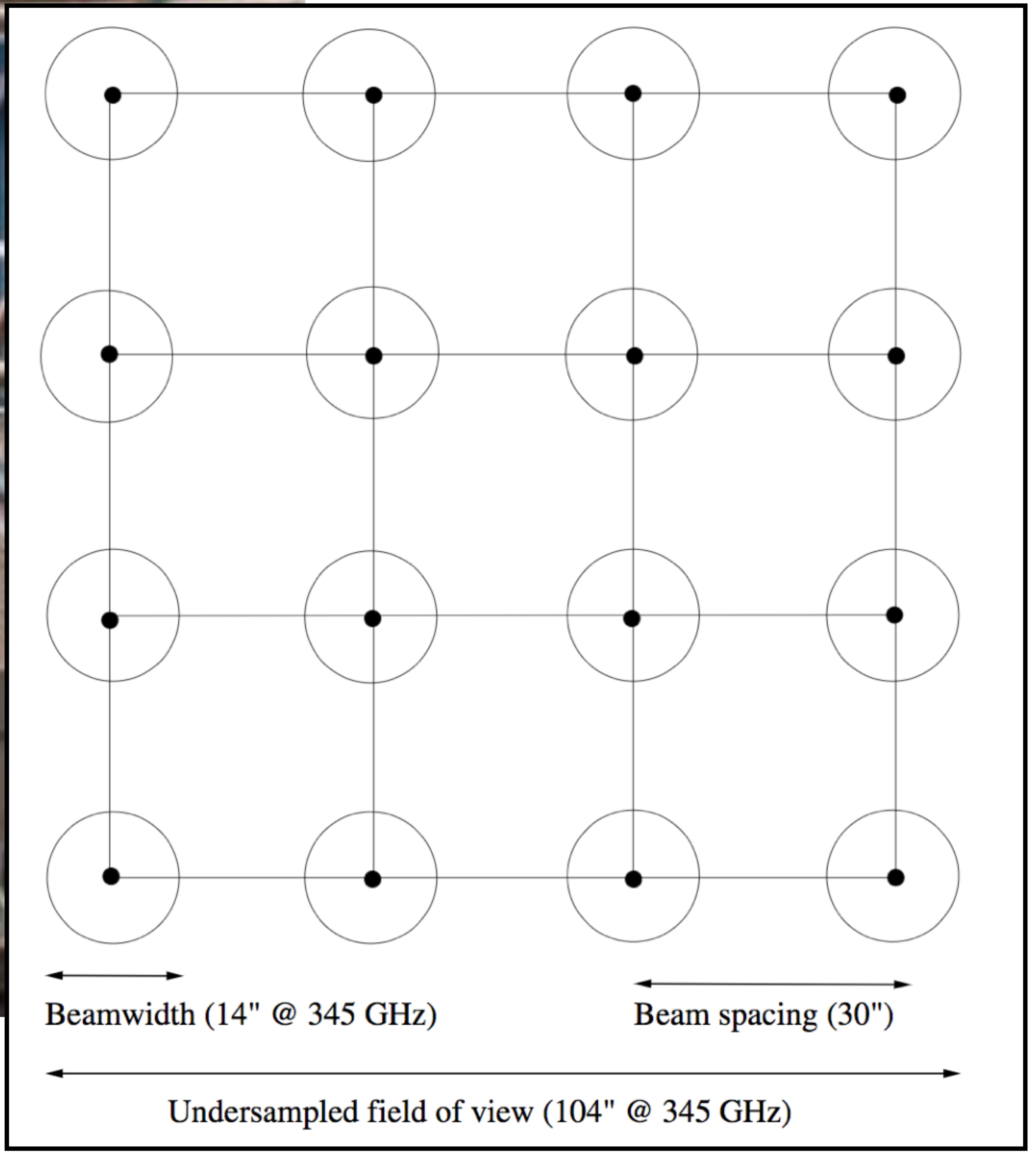
Obtaining T_{sys} and calibration is for another talk…

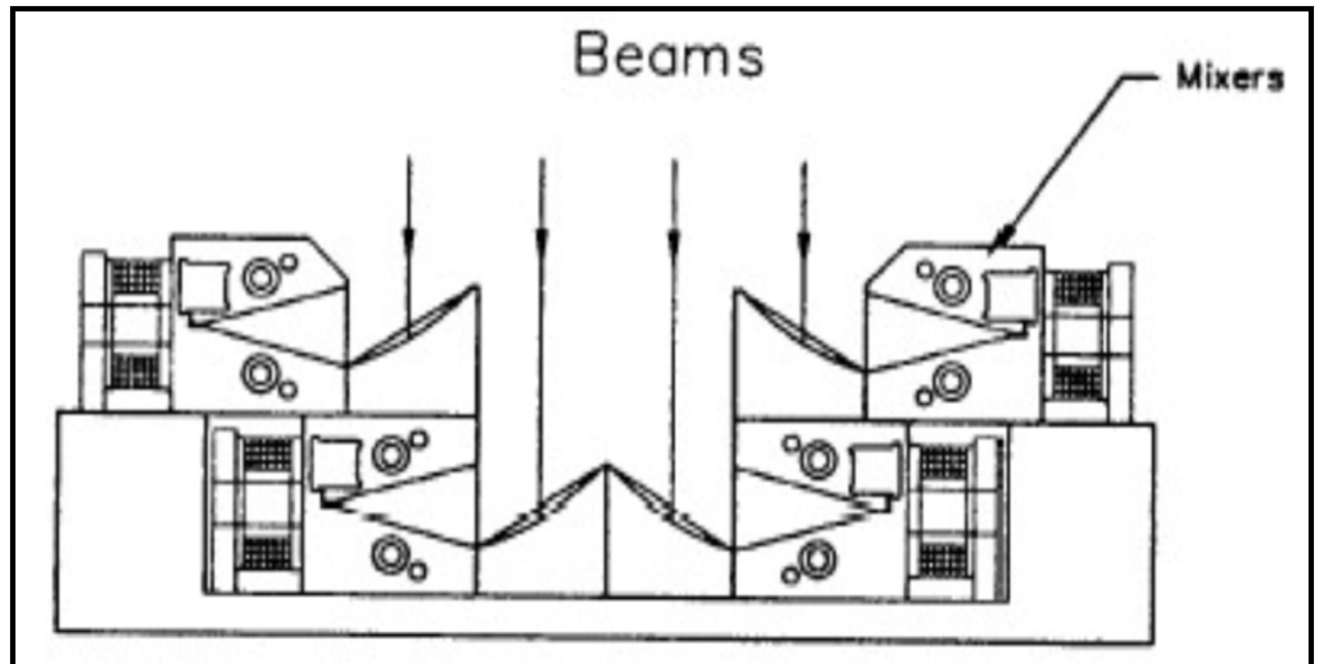


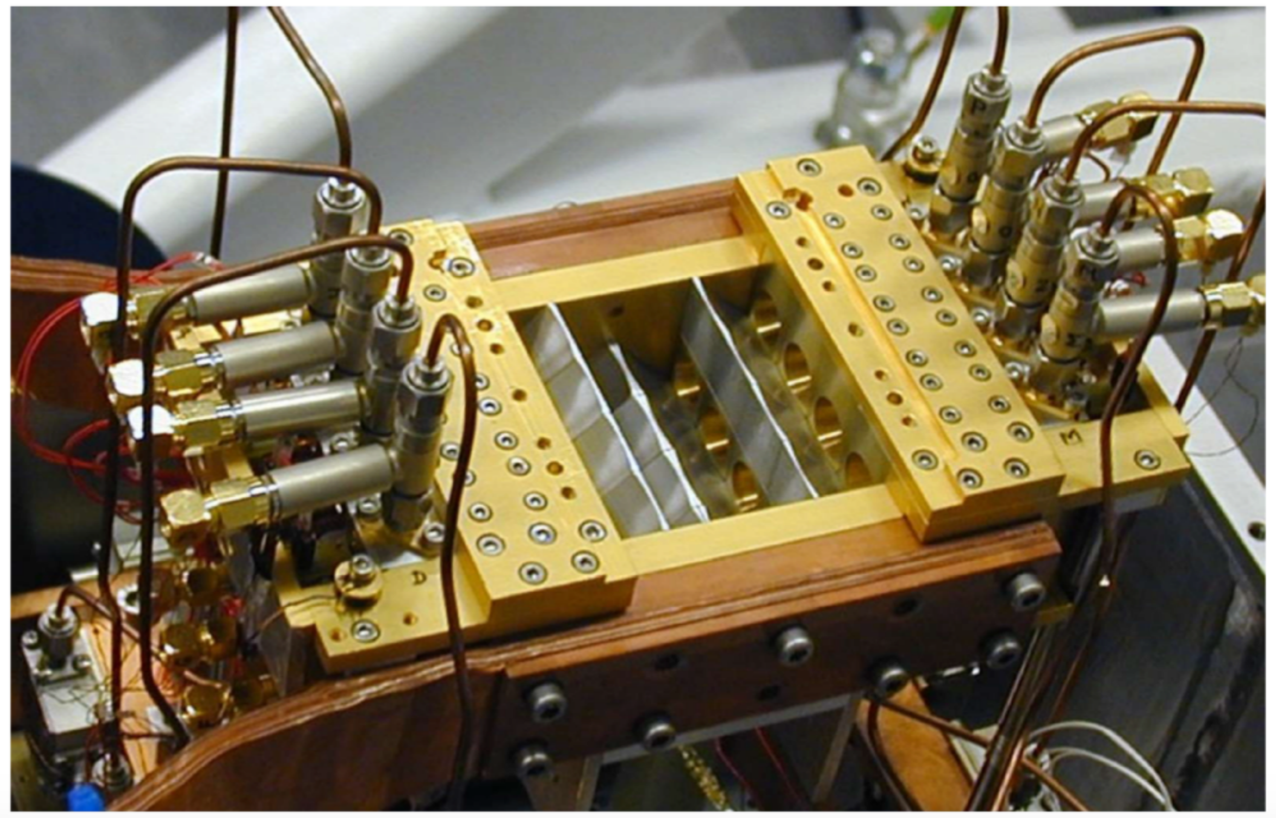
HARP

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





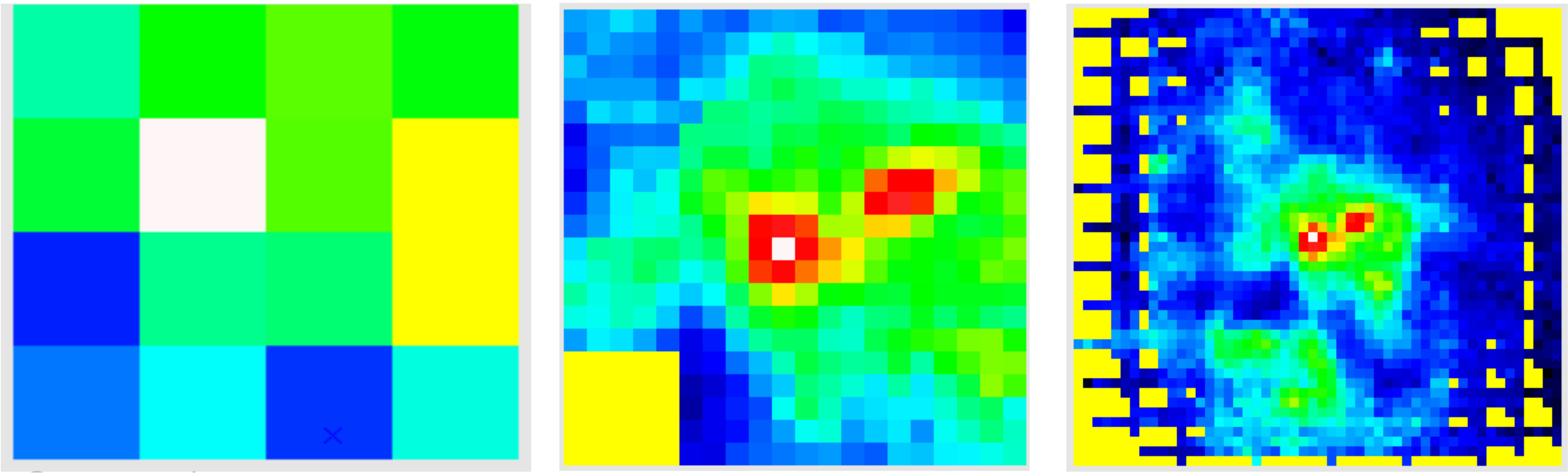




https://ui.adsabs.harvard.edu/abs/2009MNRAS.399.1026B/abstract

Observing Modes

HARP



2’ field,
30” pixels

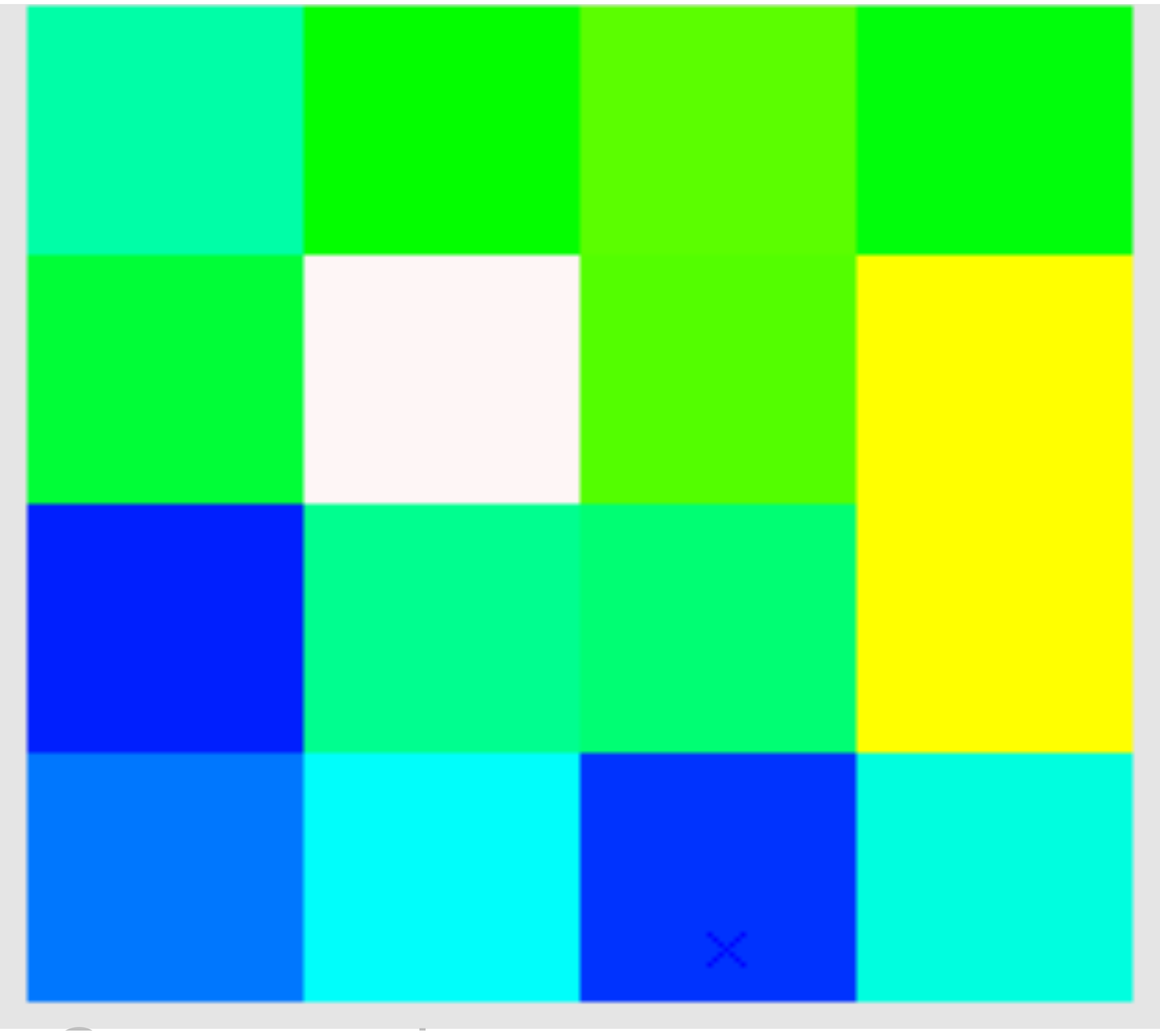
2’field,
6” pixels

6’ field,
7.25” pixels

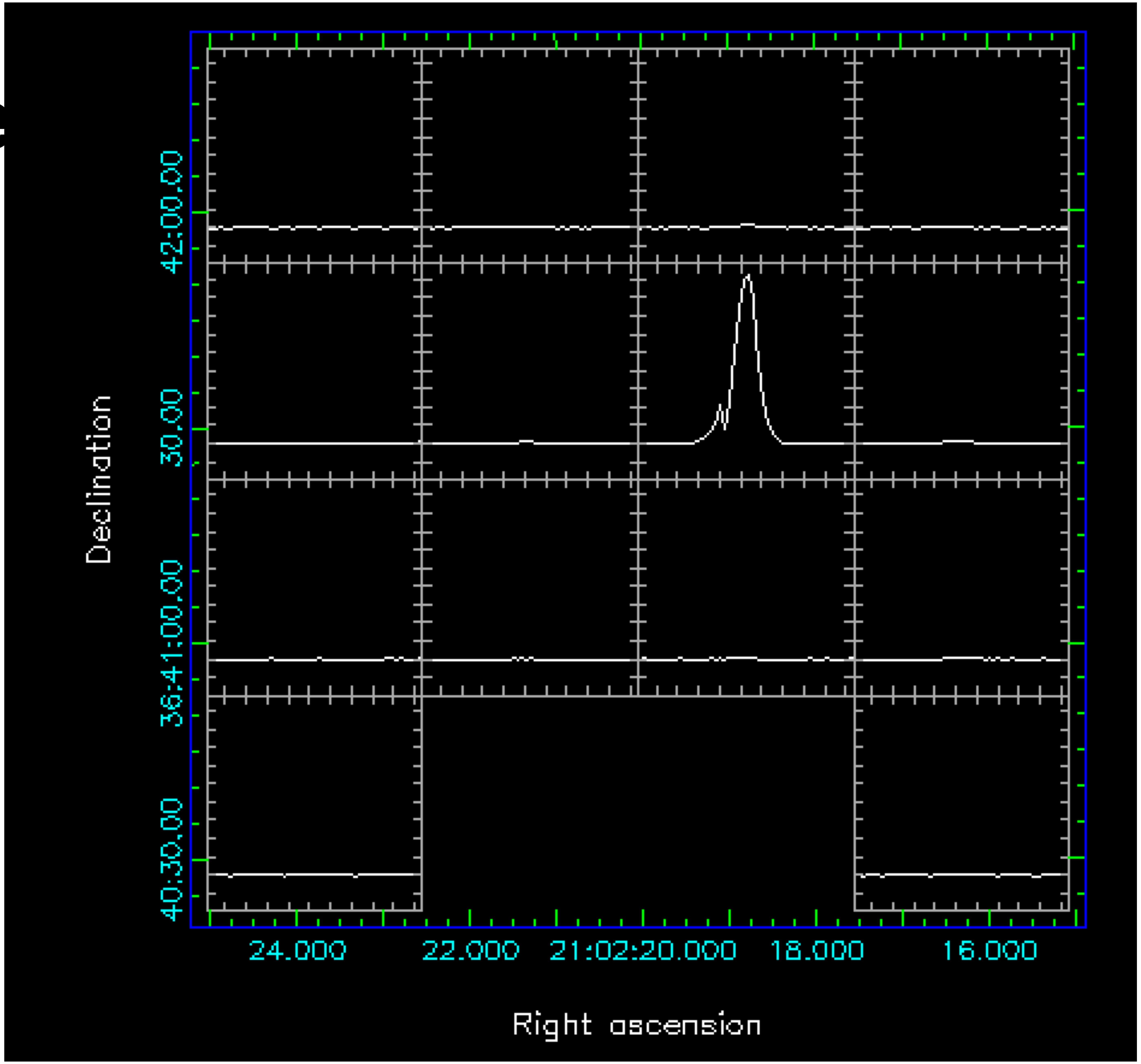
https://www.eaobservatory.org/jcmt/instrumentation/heterodyne/harp/

Obse

Stare



2’ field,
30” pixels



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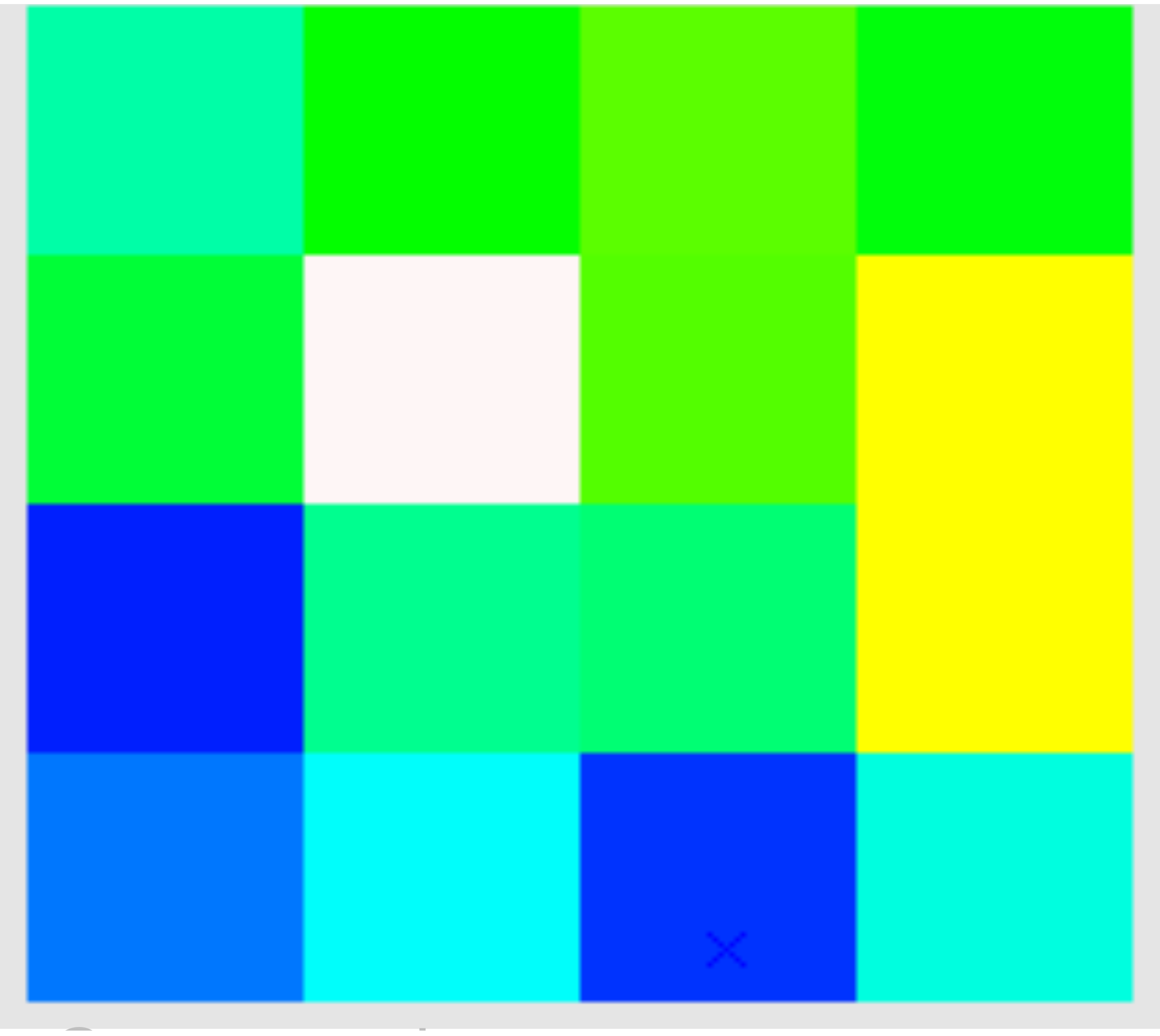
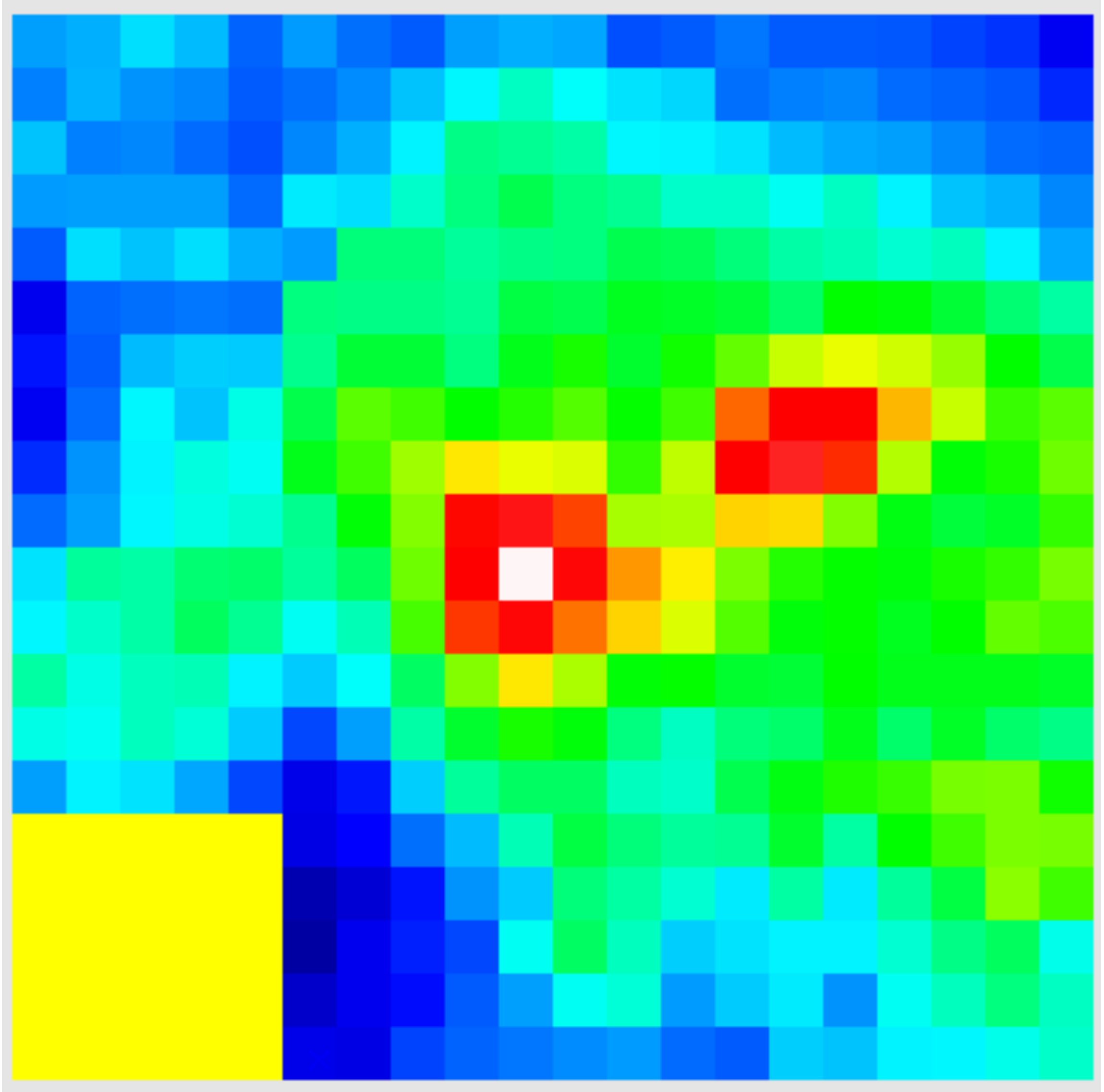
Observing Modes

HARP

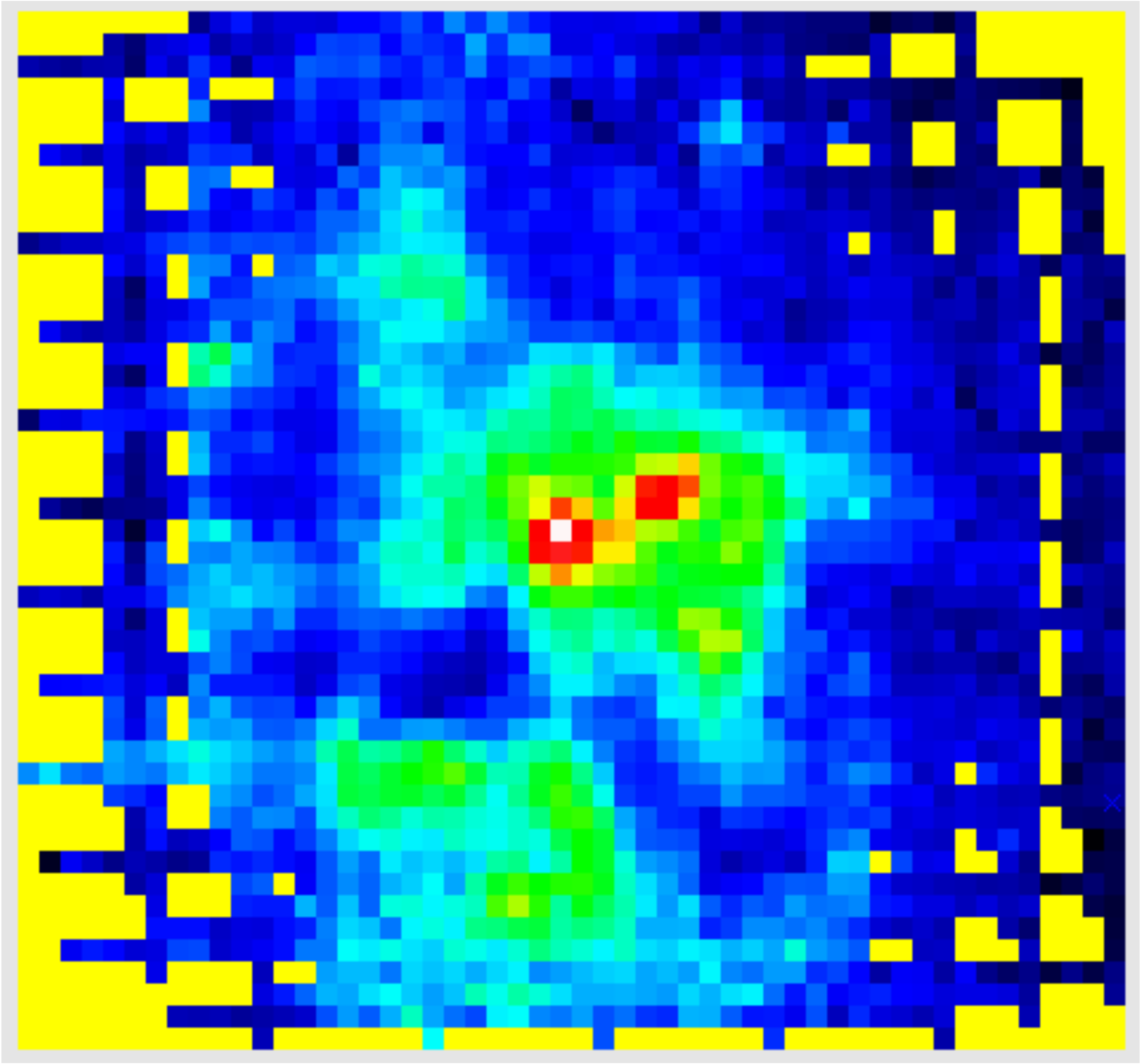
Stare



Jiggle



Raster



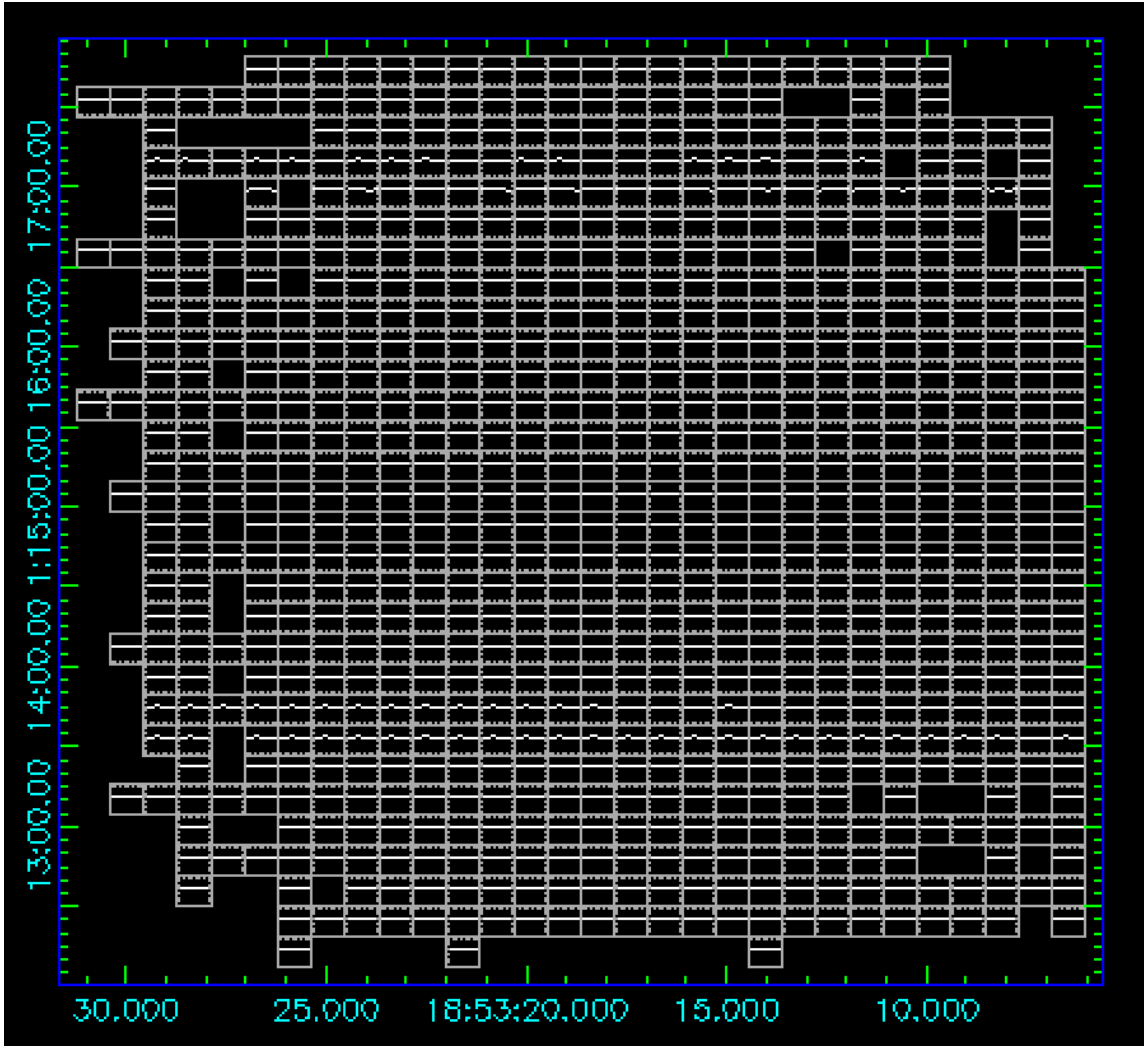
2’ field,
30” pixels

2’field,
6” pixels

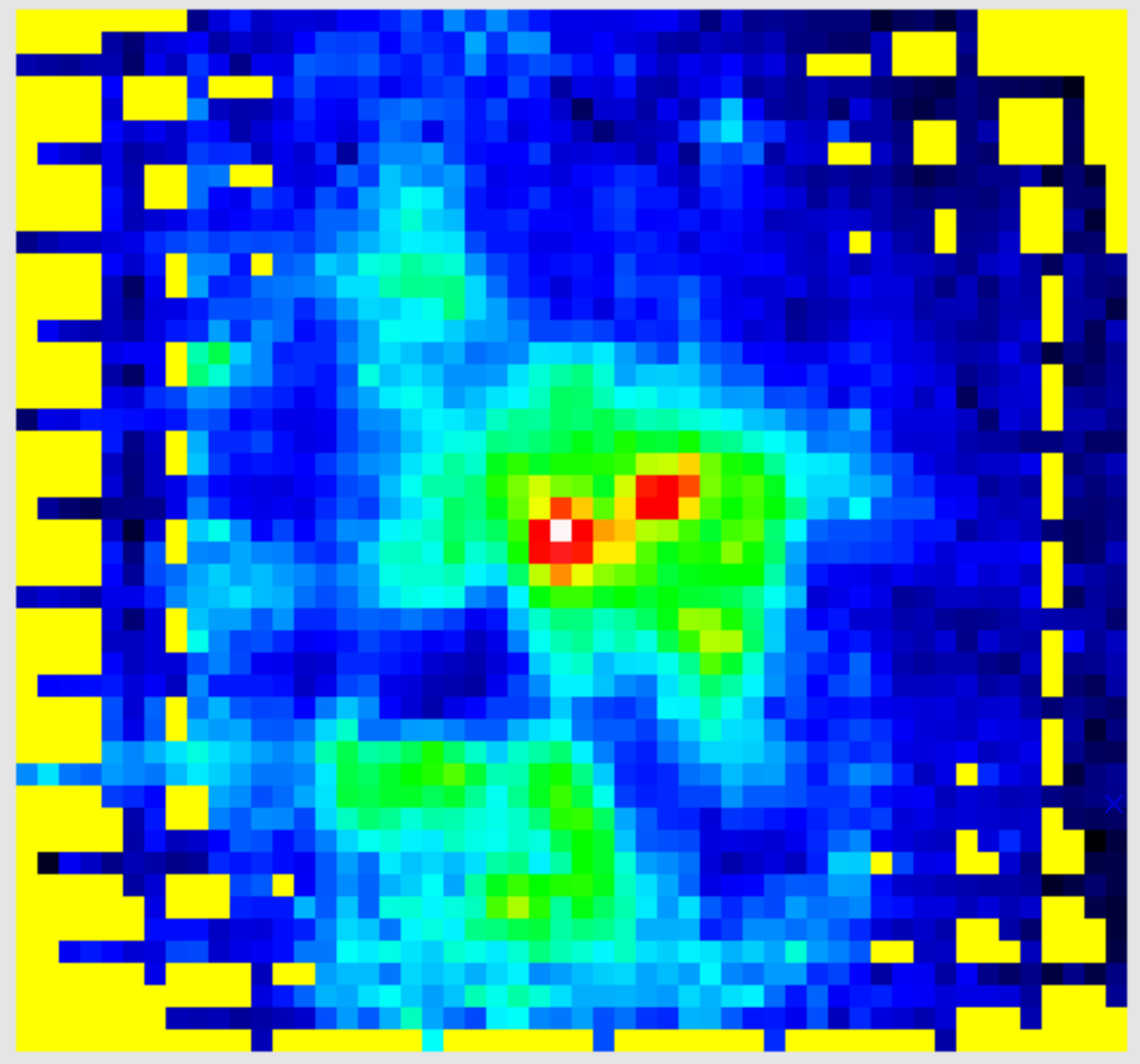
6’ field,
7.25” pixels

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

HARP



Raster

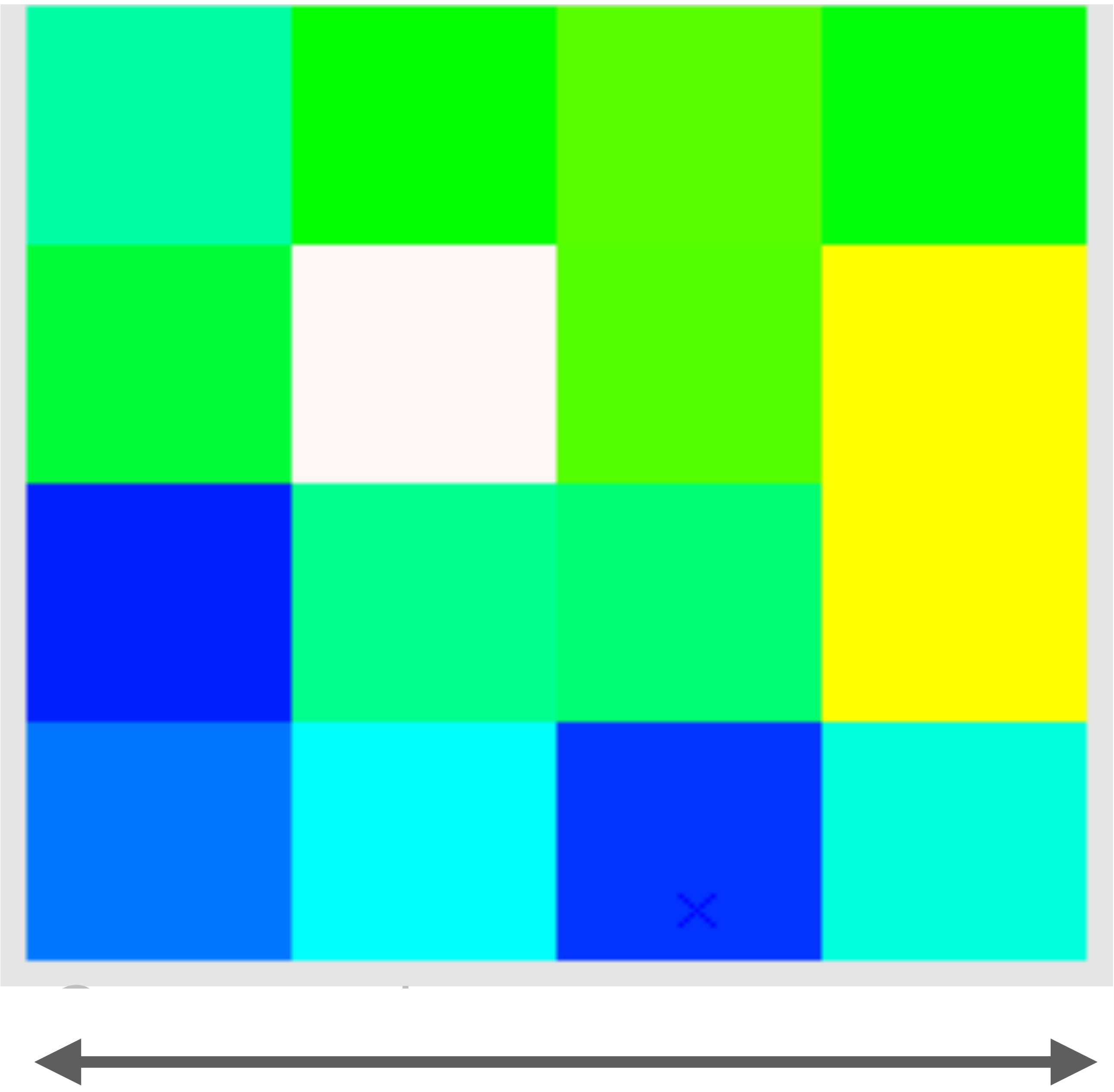


6’ field,
7.25” pixels

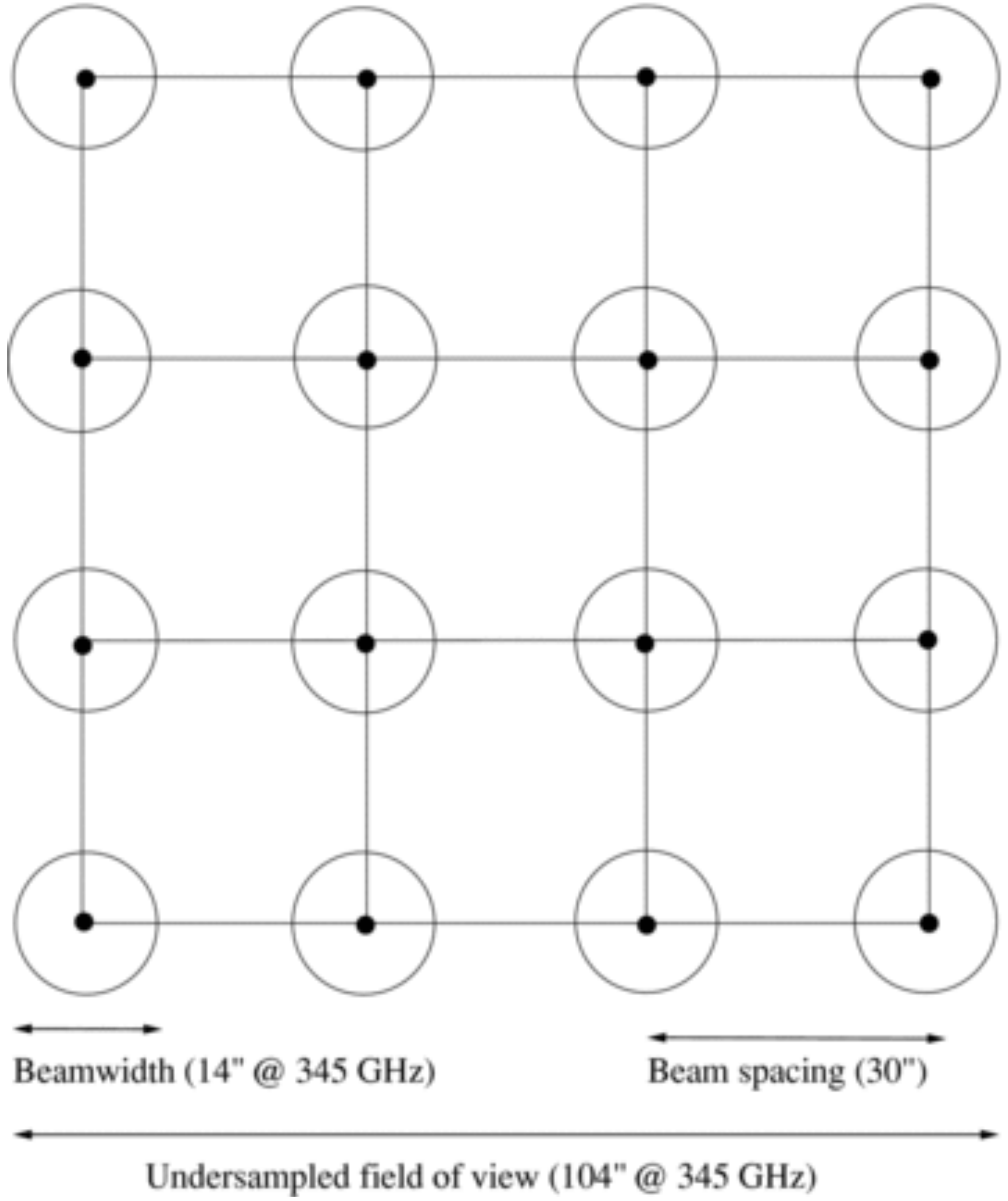
https://www.eaobservatory.org/jcmt/instrumentation/heterodyne/harp/

HARP

Stare



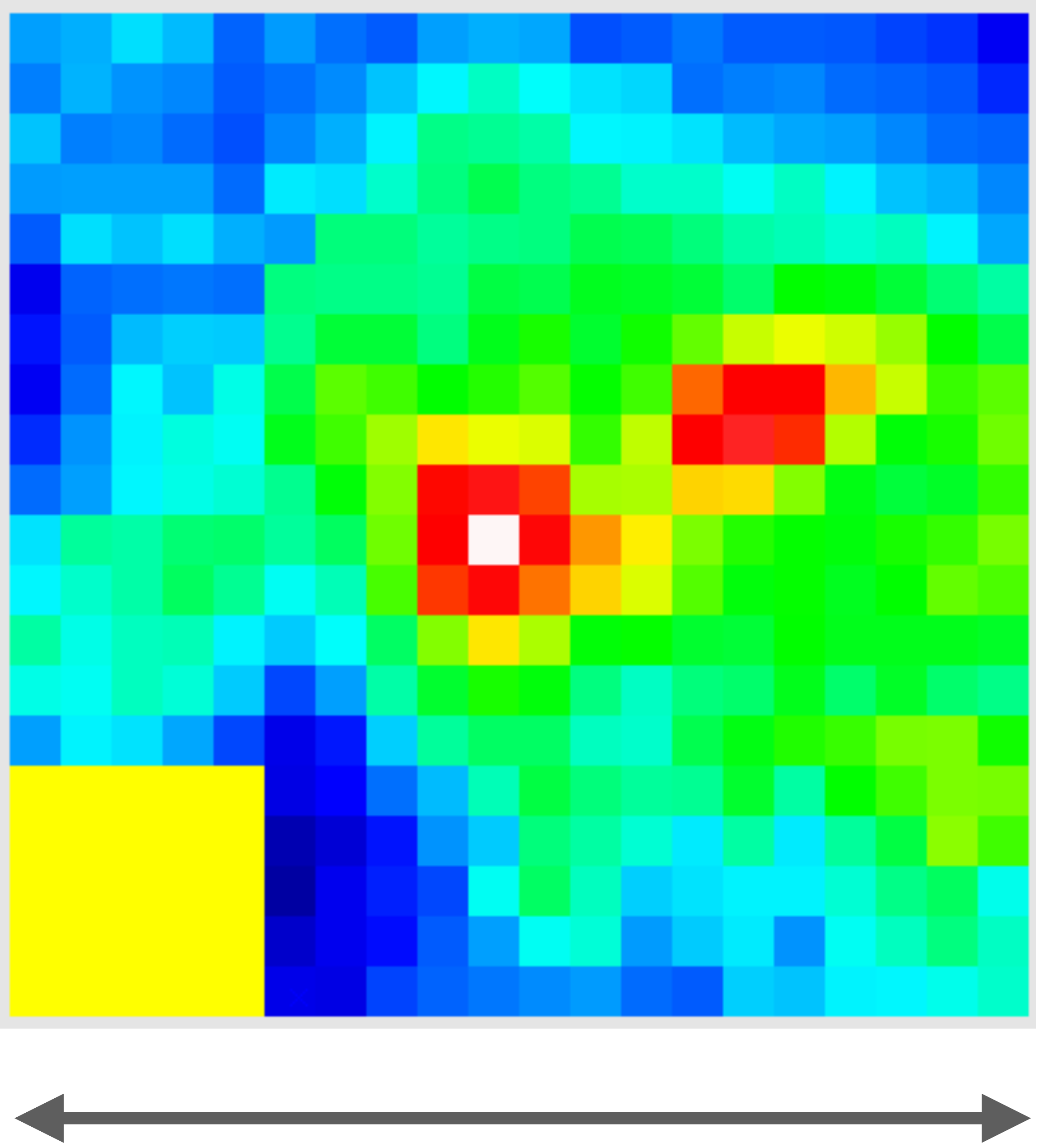
2’ field,
30” pixels



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

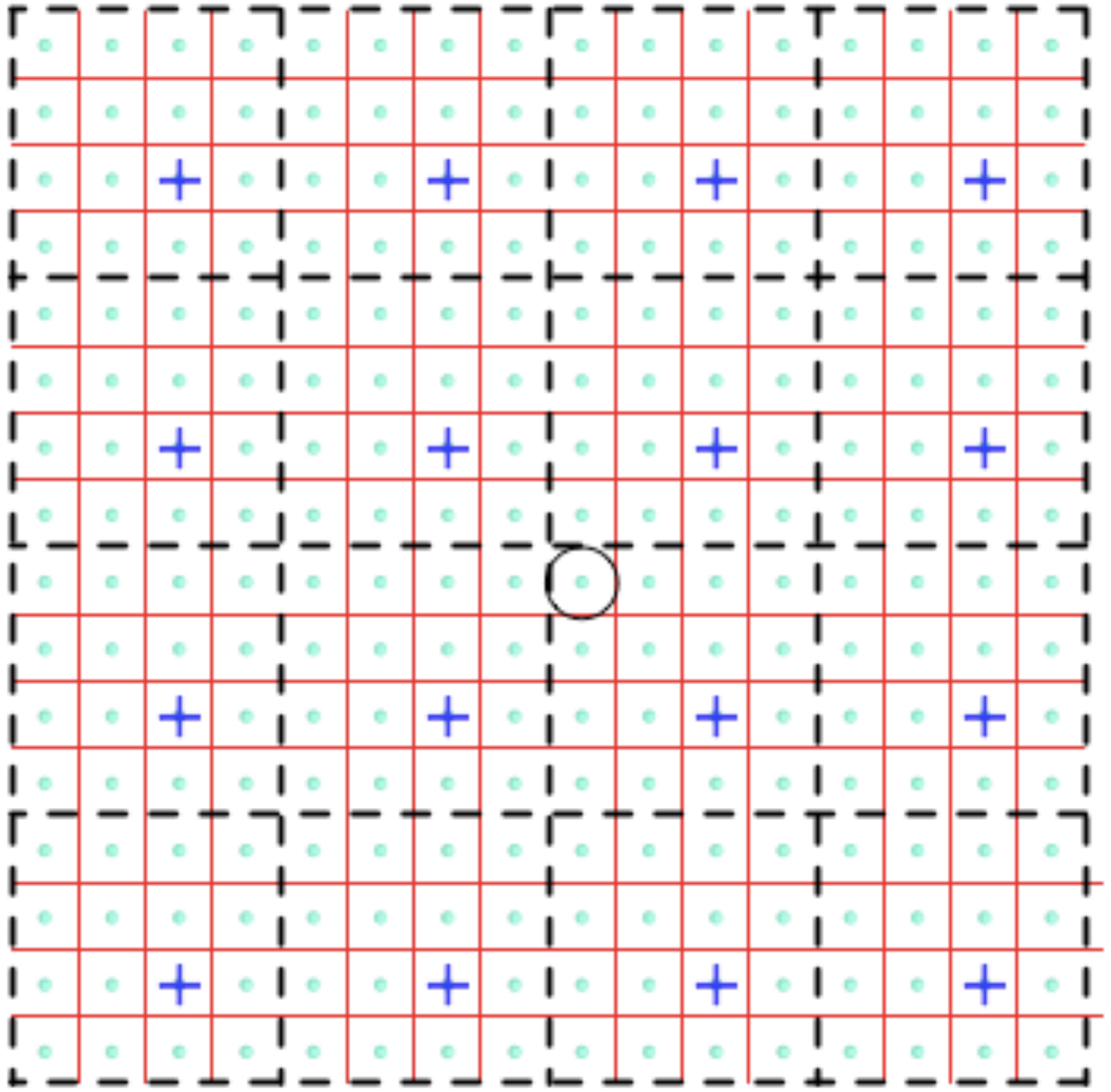
HARP

Jiggle



2'field,
6" pixels

HARP4 Jiggle Pattern

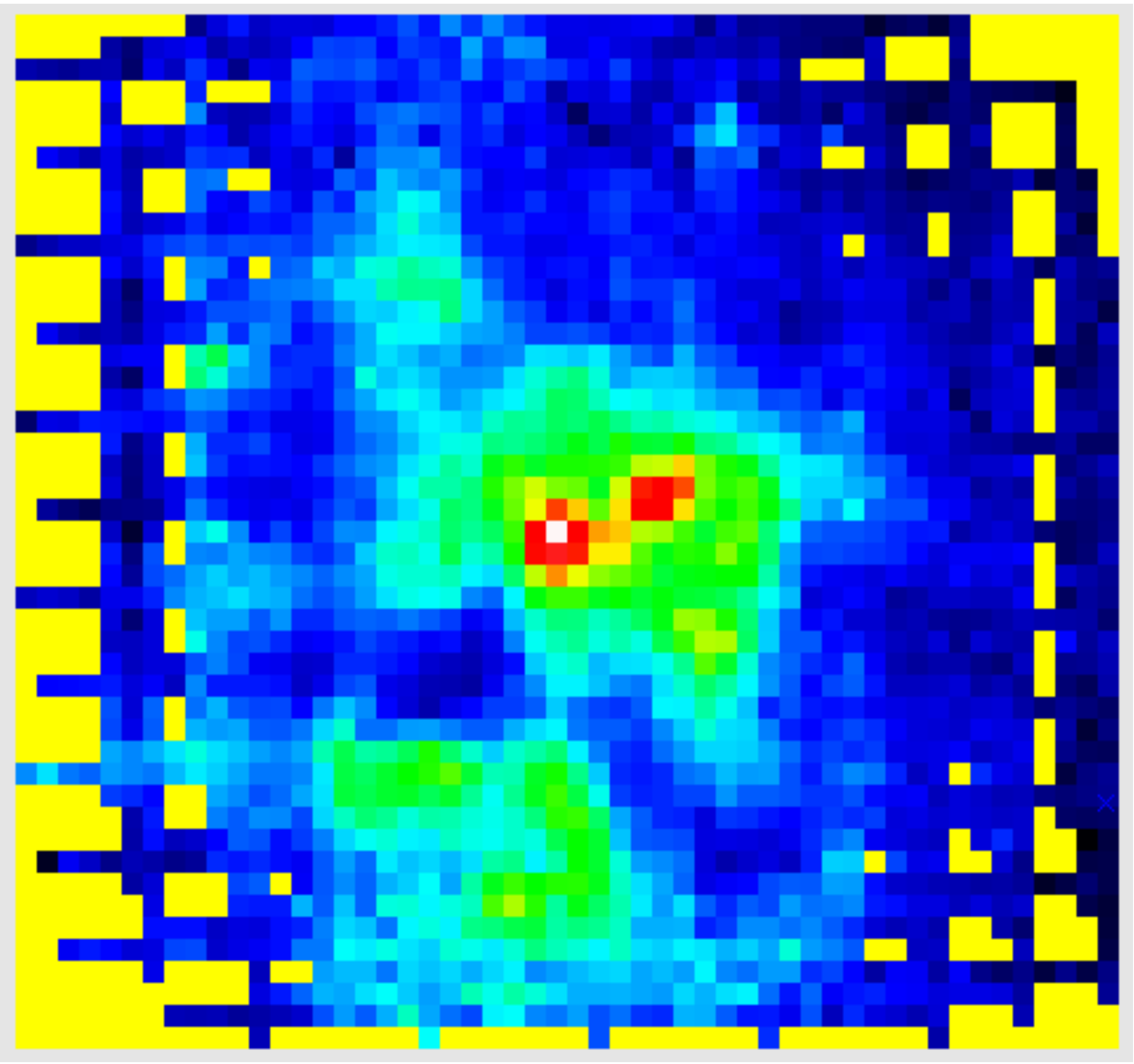


blue crosses = HARP receptors
red lines = pixels in the resultant map
grey dots = the HARP4 jiggle pattern
○ = the pointing centre

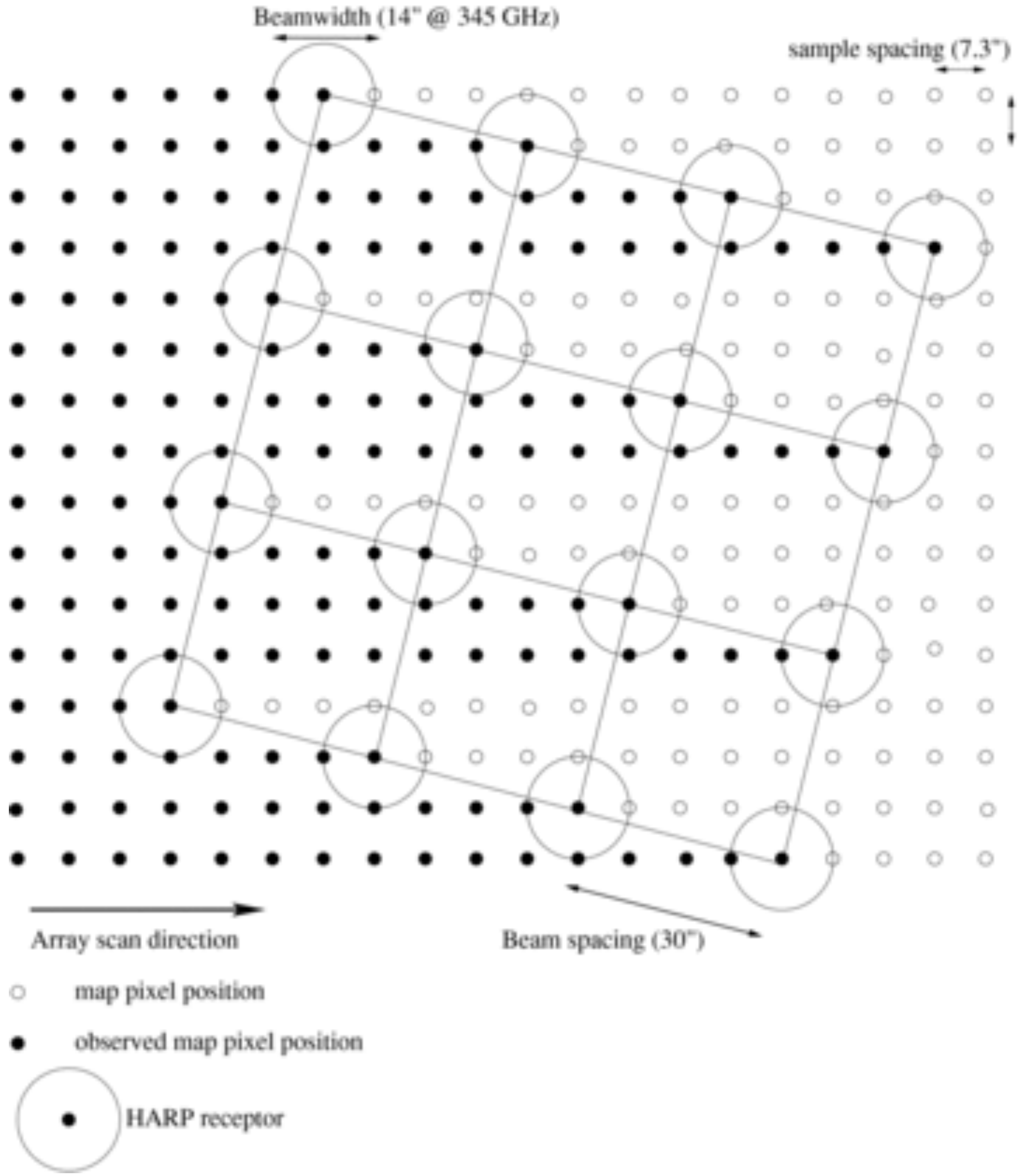
- Used for sources <2' in extent
- Moves secondary mirror to fill in 30" spacing between HARP receptors to make 2' × 2' map
- Two main spacings:
  - HARP4 – 4 × 4 jiggle, slightly undersampled. 7.25" pixels
  - HARP5 – 5 × 5 jiggle, oversampled, 6" pixels
  - (Also HARP3 - 3 × 3 jiggle, undersampled)

HARP

Raster

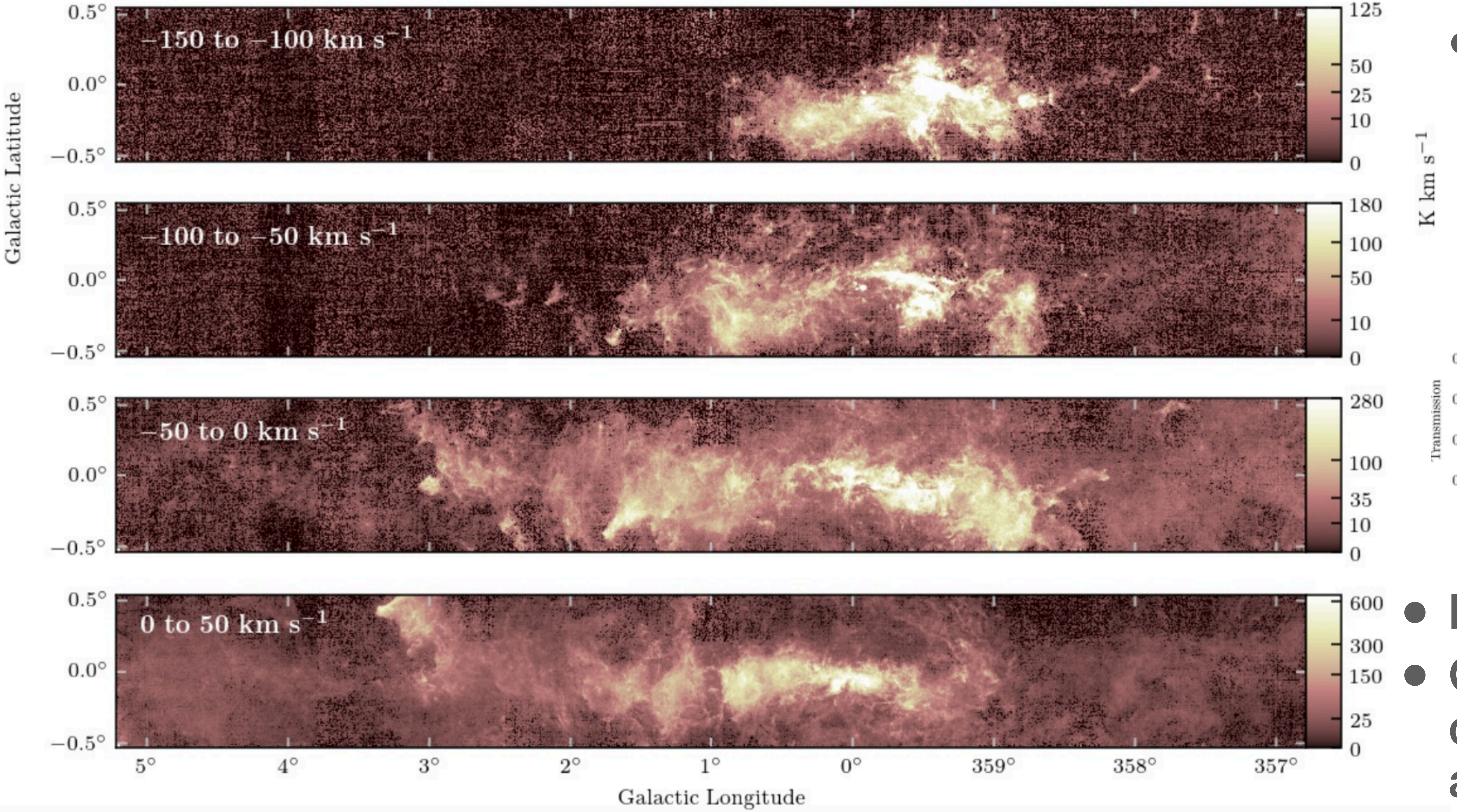


6’ field,
7.25” pixels



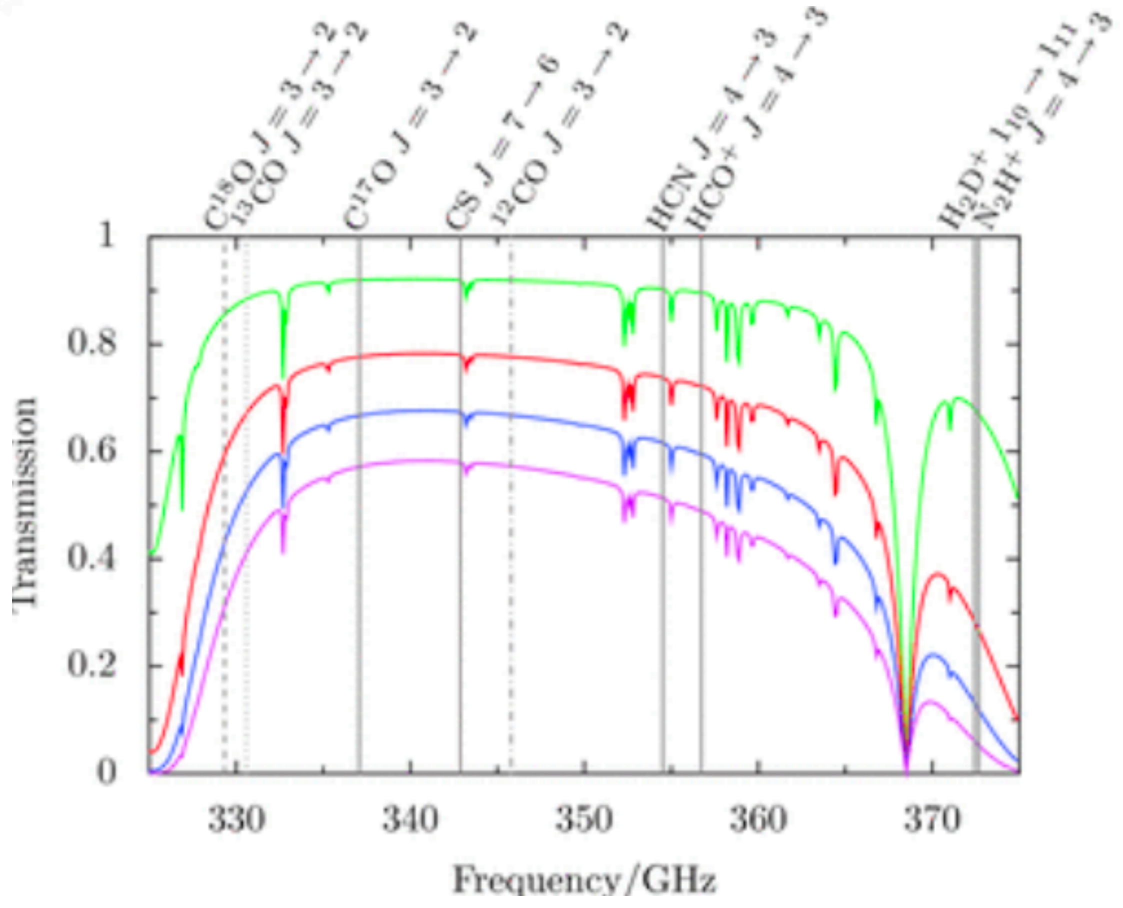
- sources > 2’
- Scan or 'on-the-fly' technique
- HARP array rotated at 14.04° to scan direction, with 7.3” pixels
- often repeated with 90° rotation to create ‘basket weave' maps

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

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

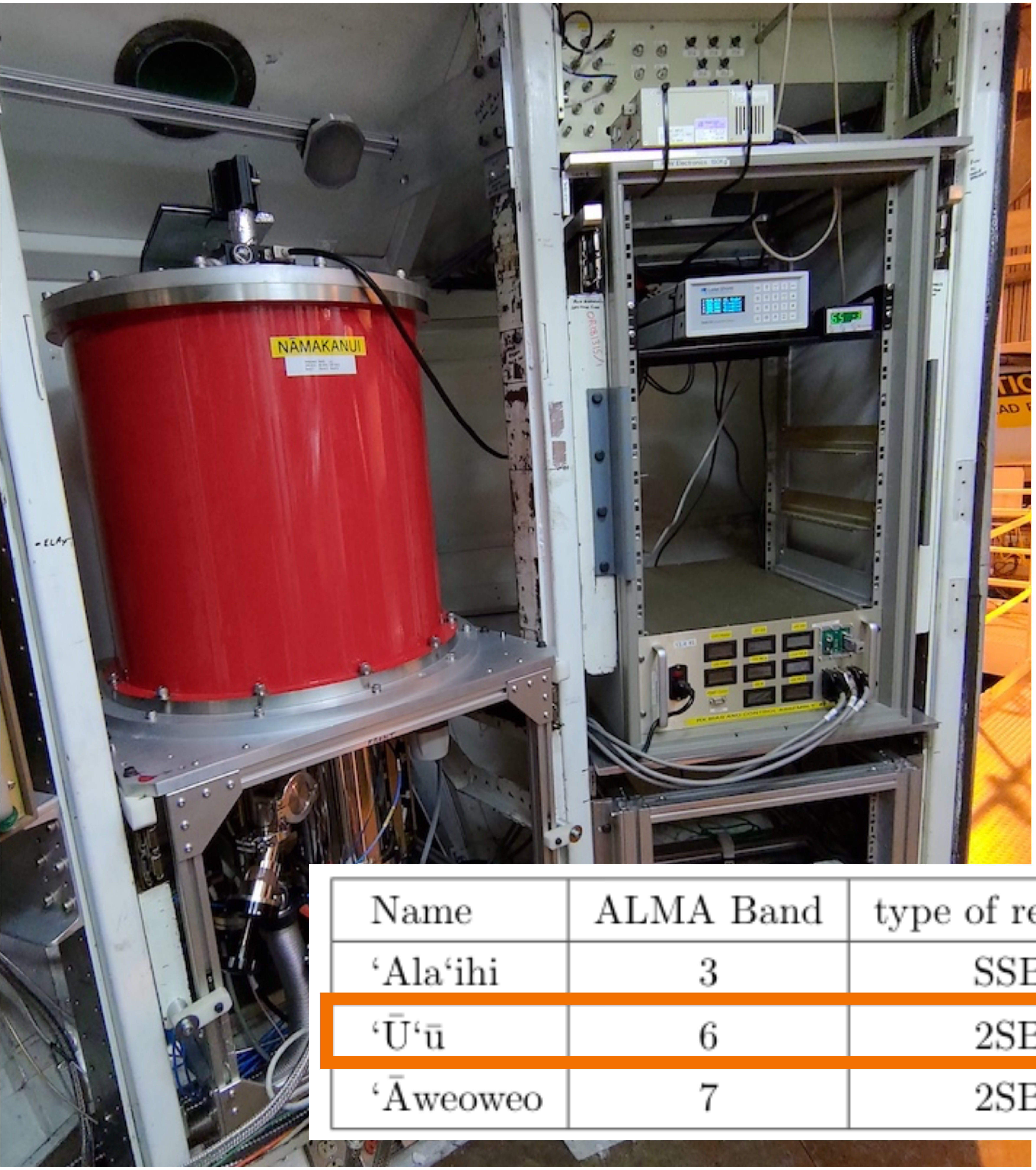
HARP

HARP
operating around 345GHz

Heterodyne

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

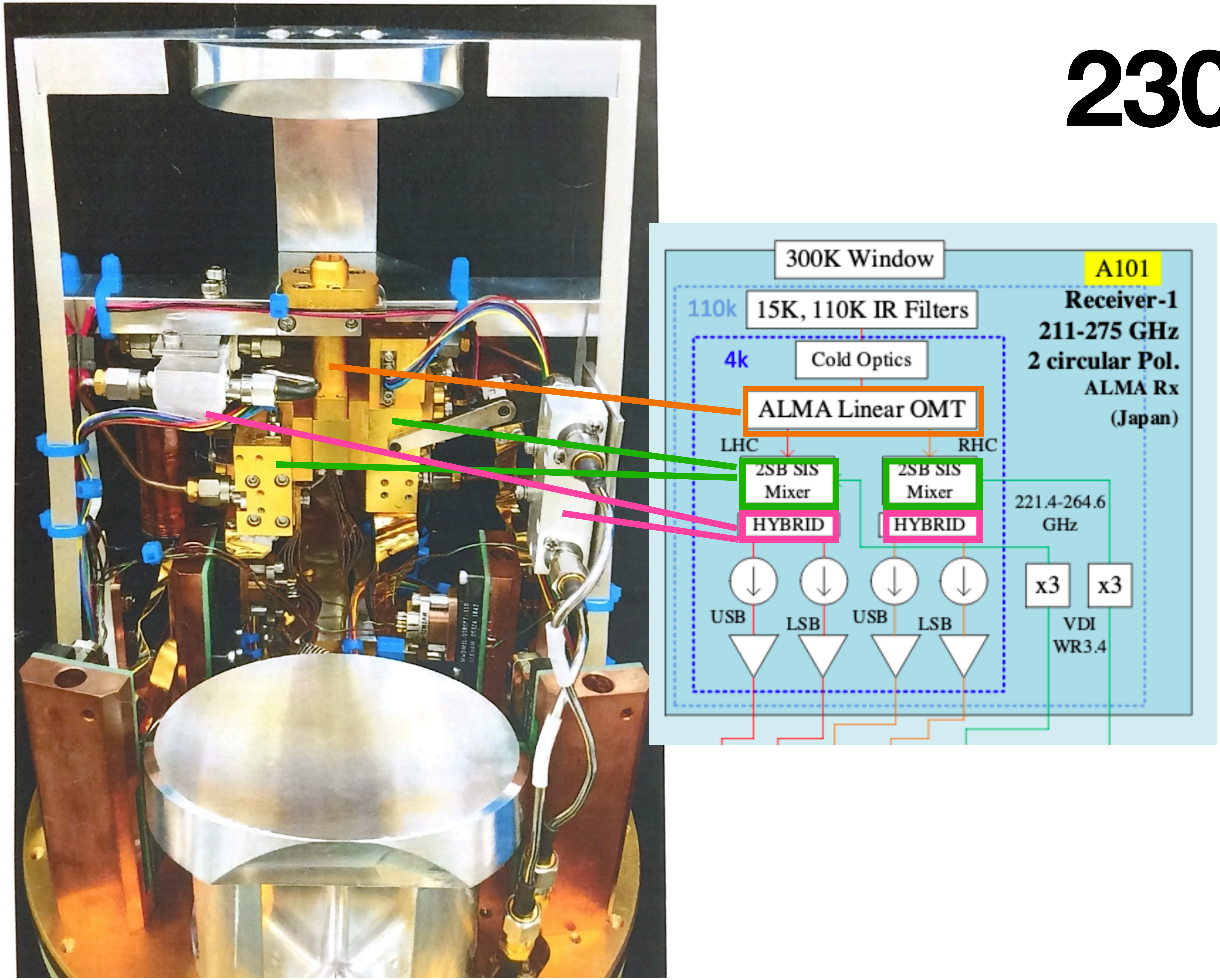
Nāmakanui



- 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 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)

230GHz - `Ū`ū



- 2 mixer blocks
- 2 polarizations
- 221 - 264.6 GHz
- 20” beam
- Side Band separating receiver (2SB)
- output: 4 pixels: LSB, USB P0 and P1 labeled: receiver, insert, sideband, polarization: **NUL0, NUL1, NUU0, NUU1**

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

`Ū`ū

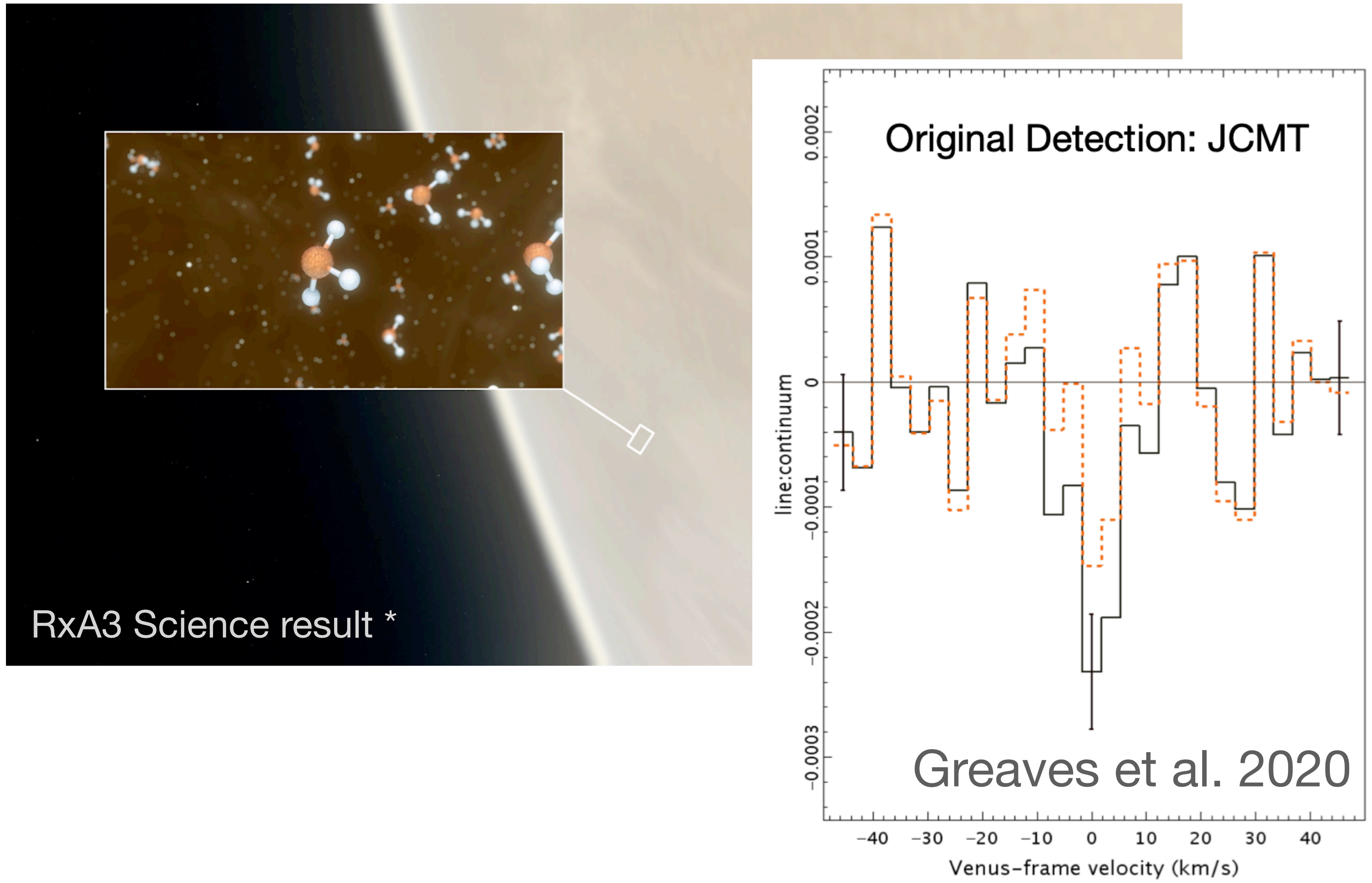
Nāmakanui
operating around 86, 230 and 345GHz

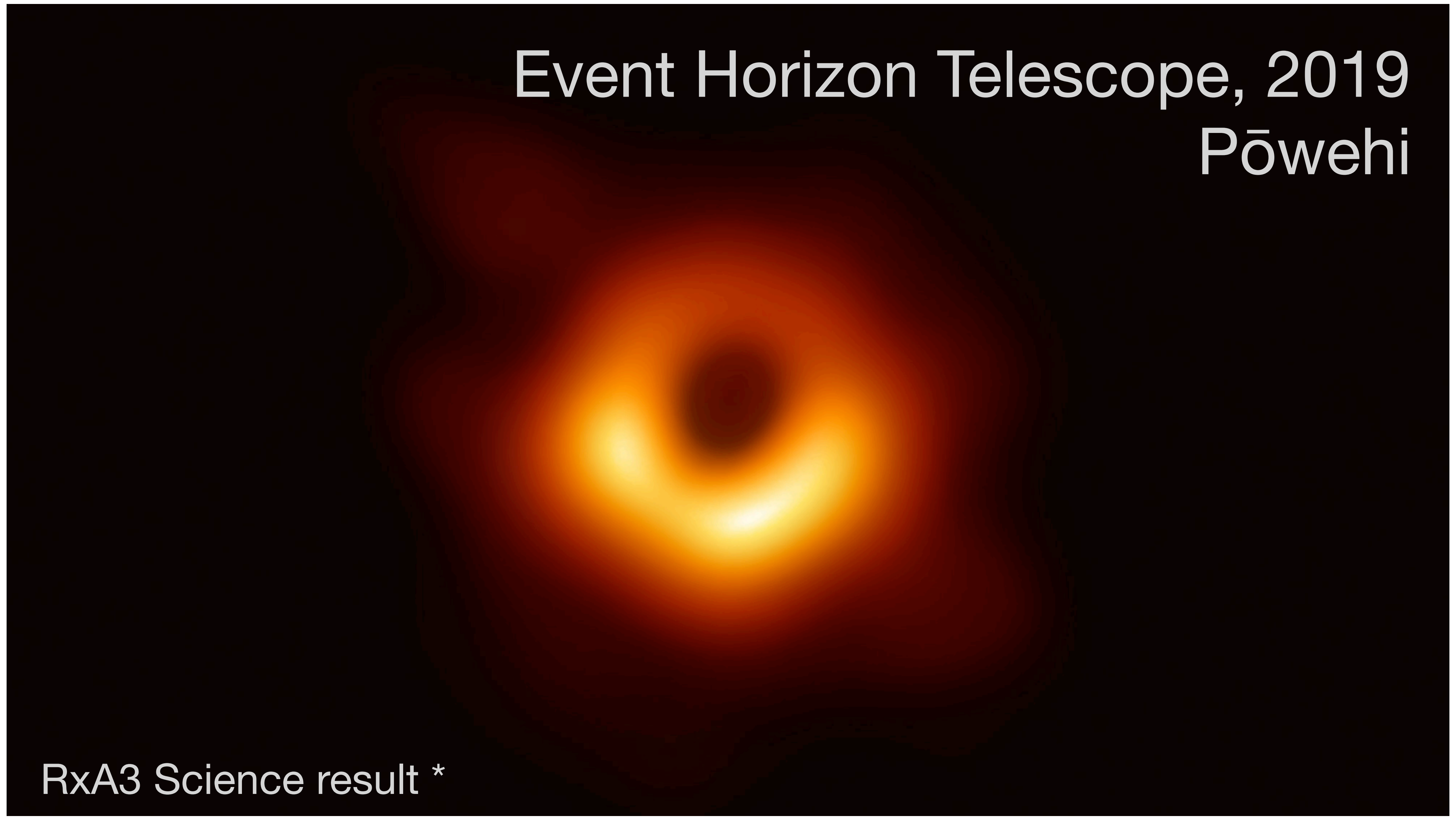
Heterodyne

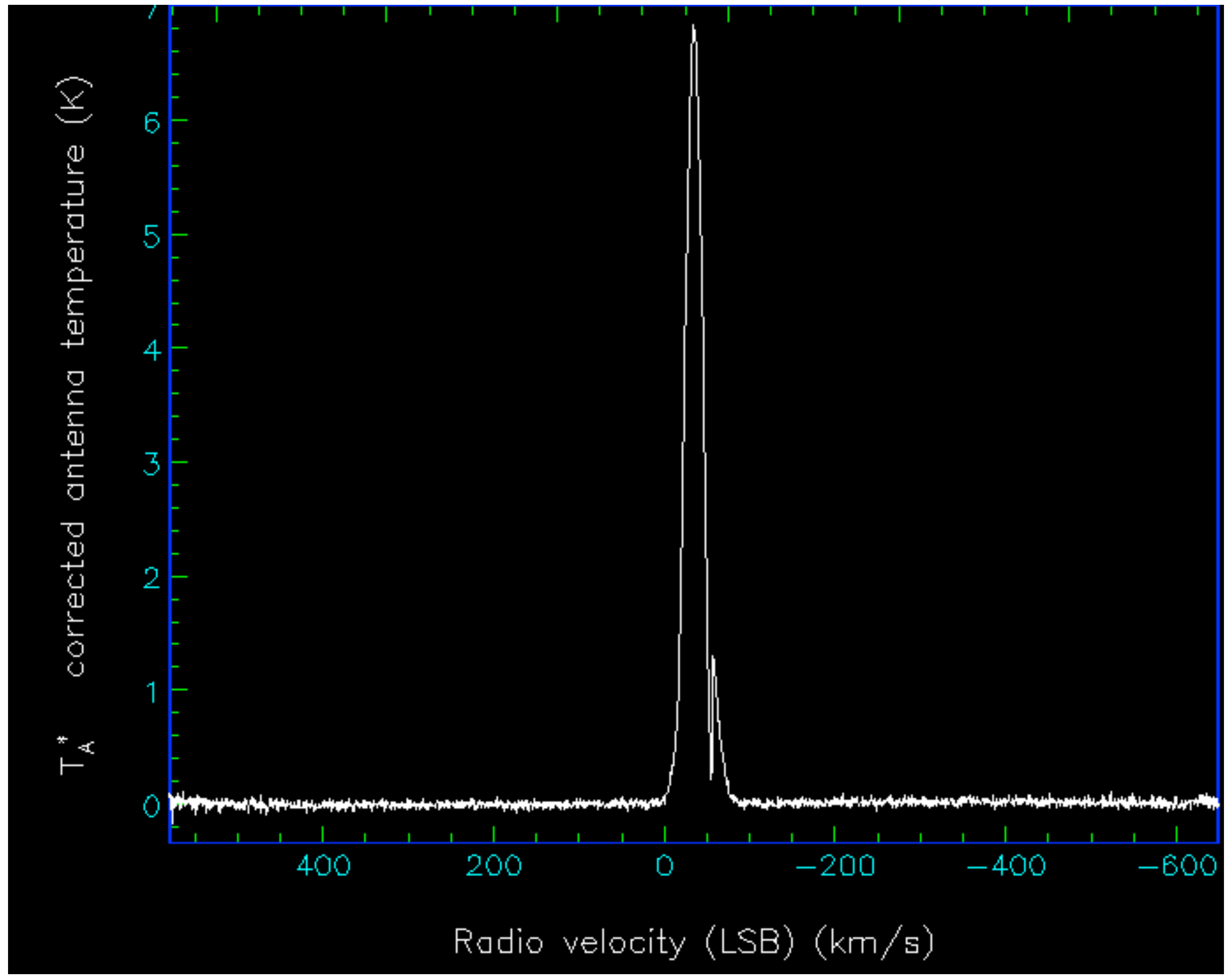
http://www.submm.caltech.edu/cso/weather/atplot.shtml

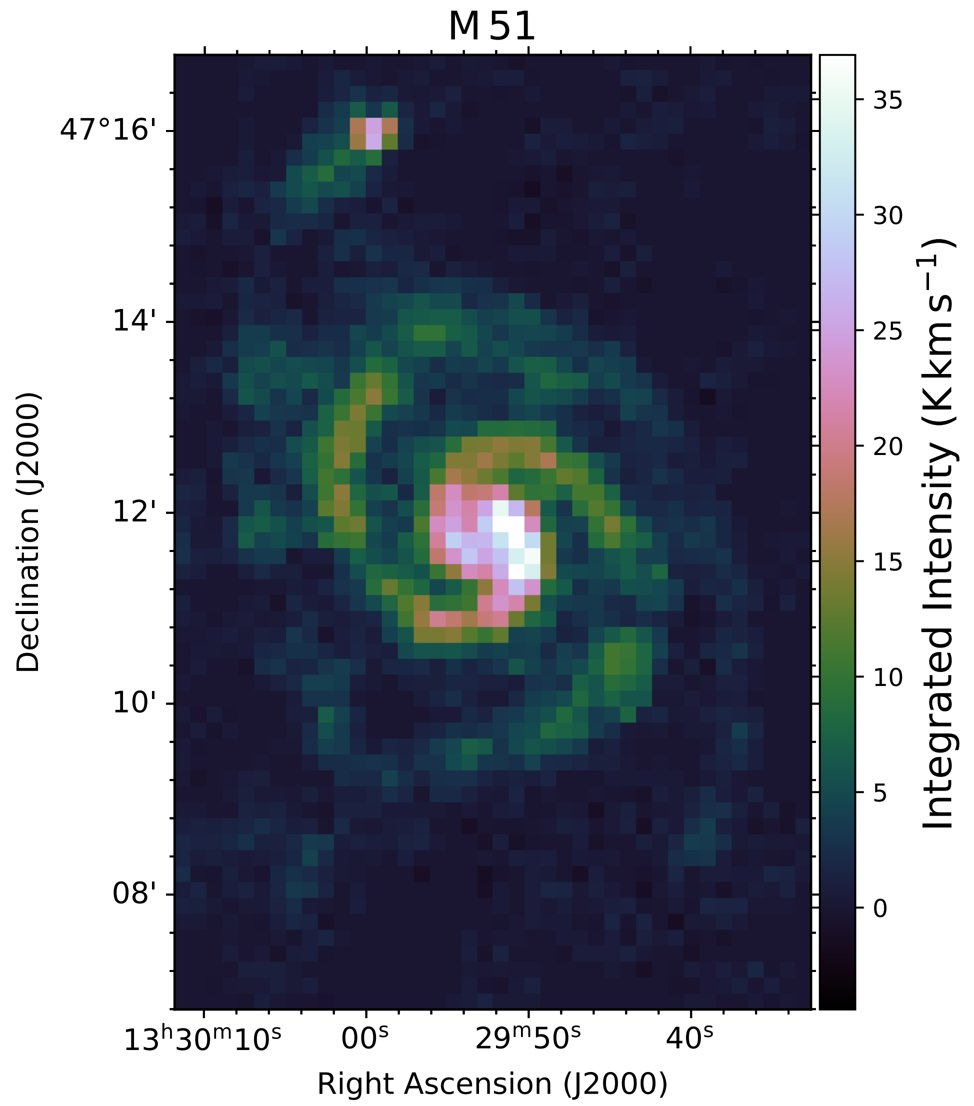
230GHz - ʻŪʻū

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

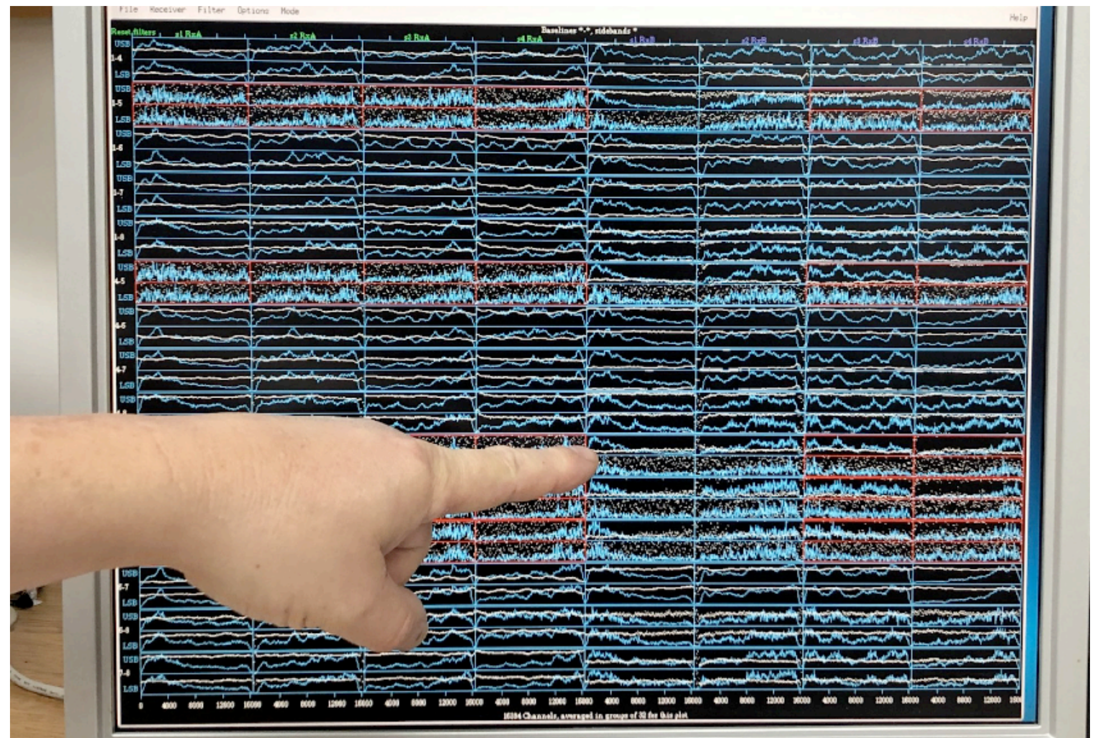








Above: first light spectrum - October 5th 2019
Above right: science image of M51
Right: First successful VLBI test with SMA December 13th 2019

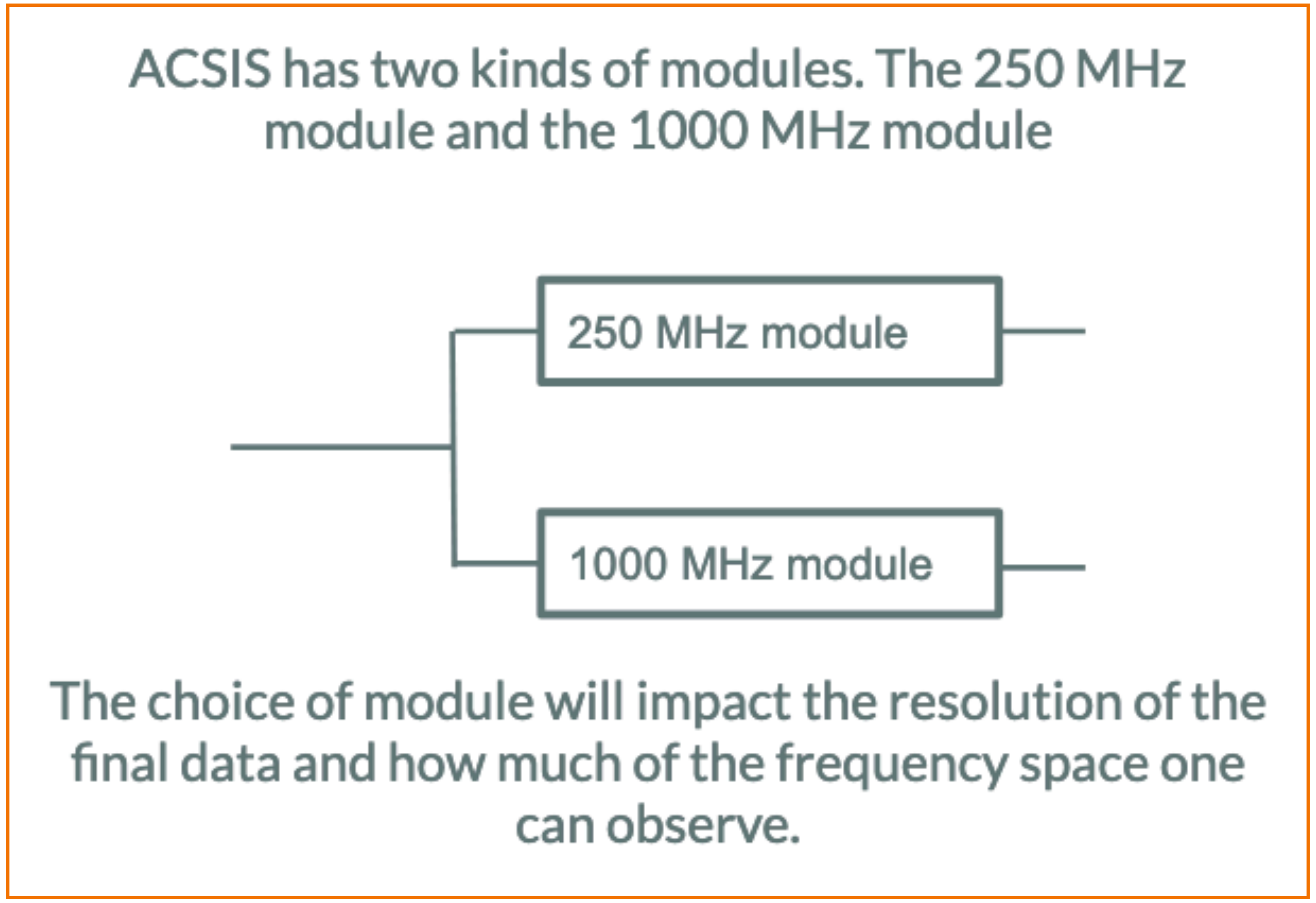


Backend digital spectrometer

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

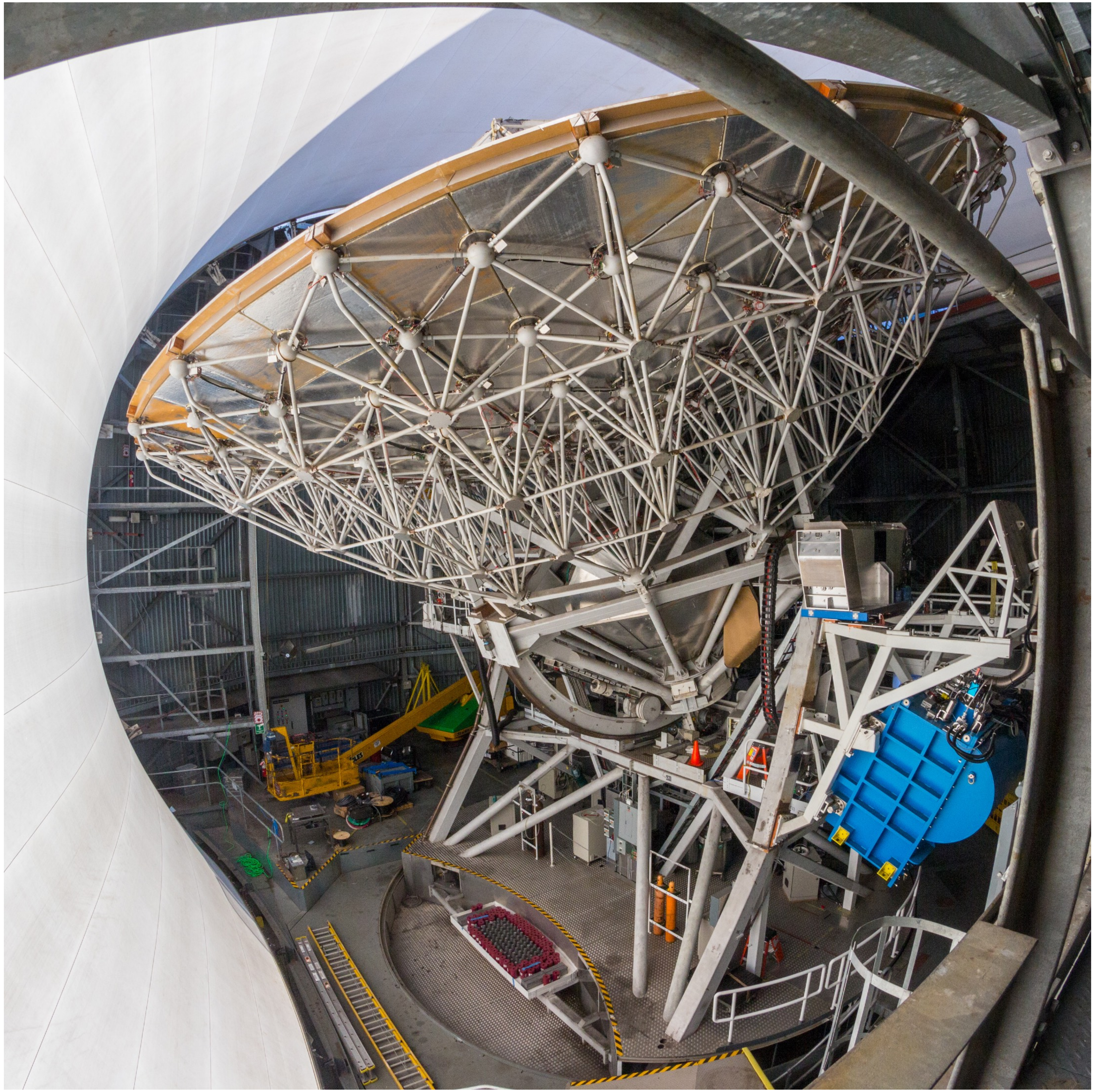


Backend digital spectrometer

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

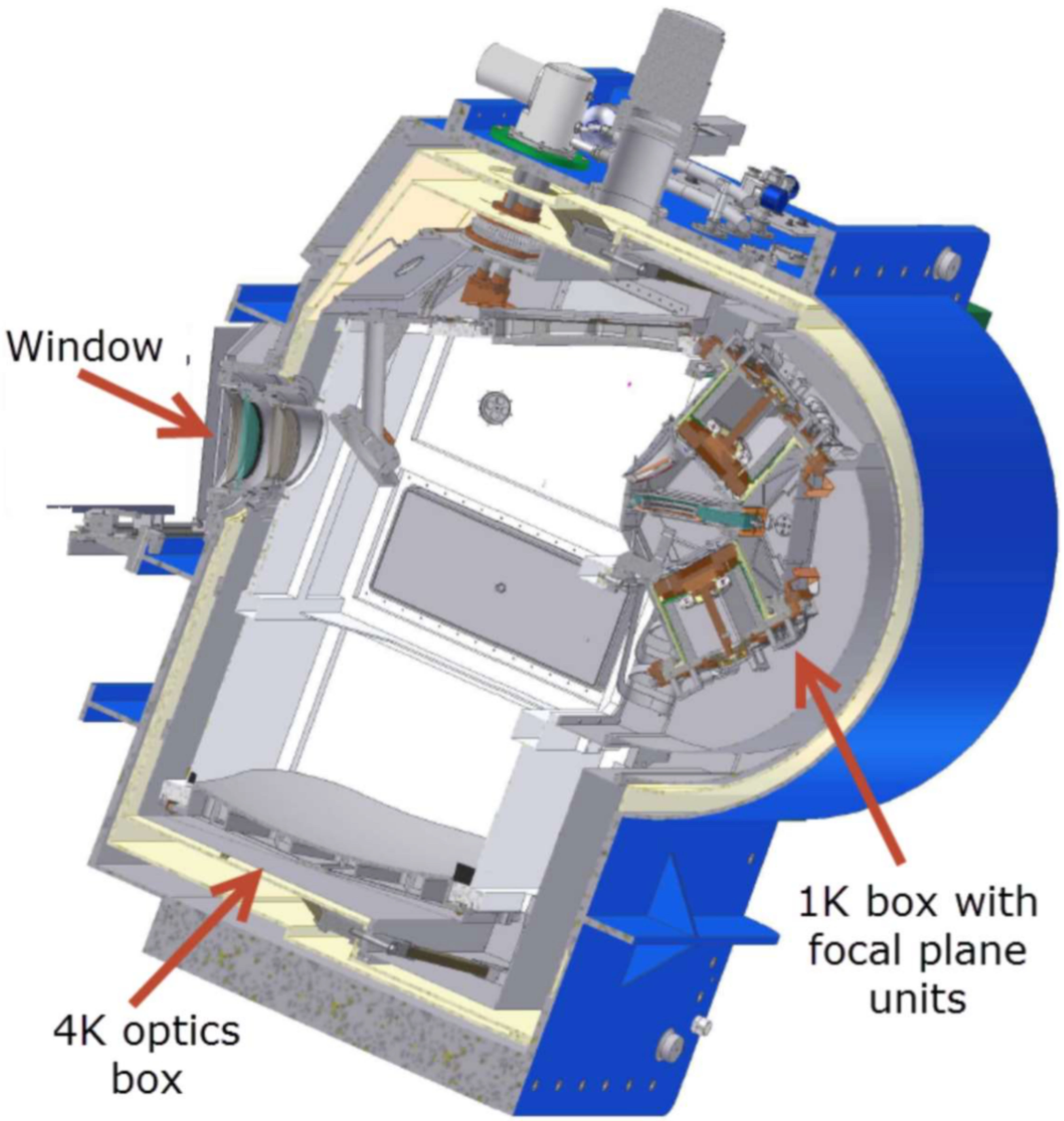


SCUBA-2

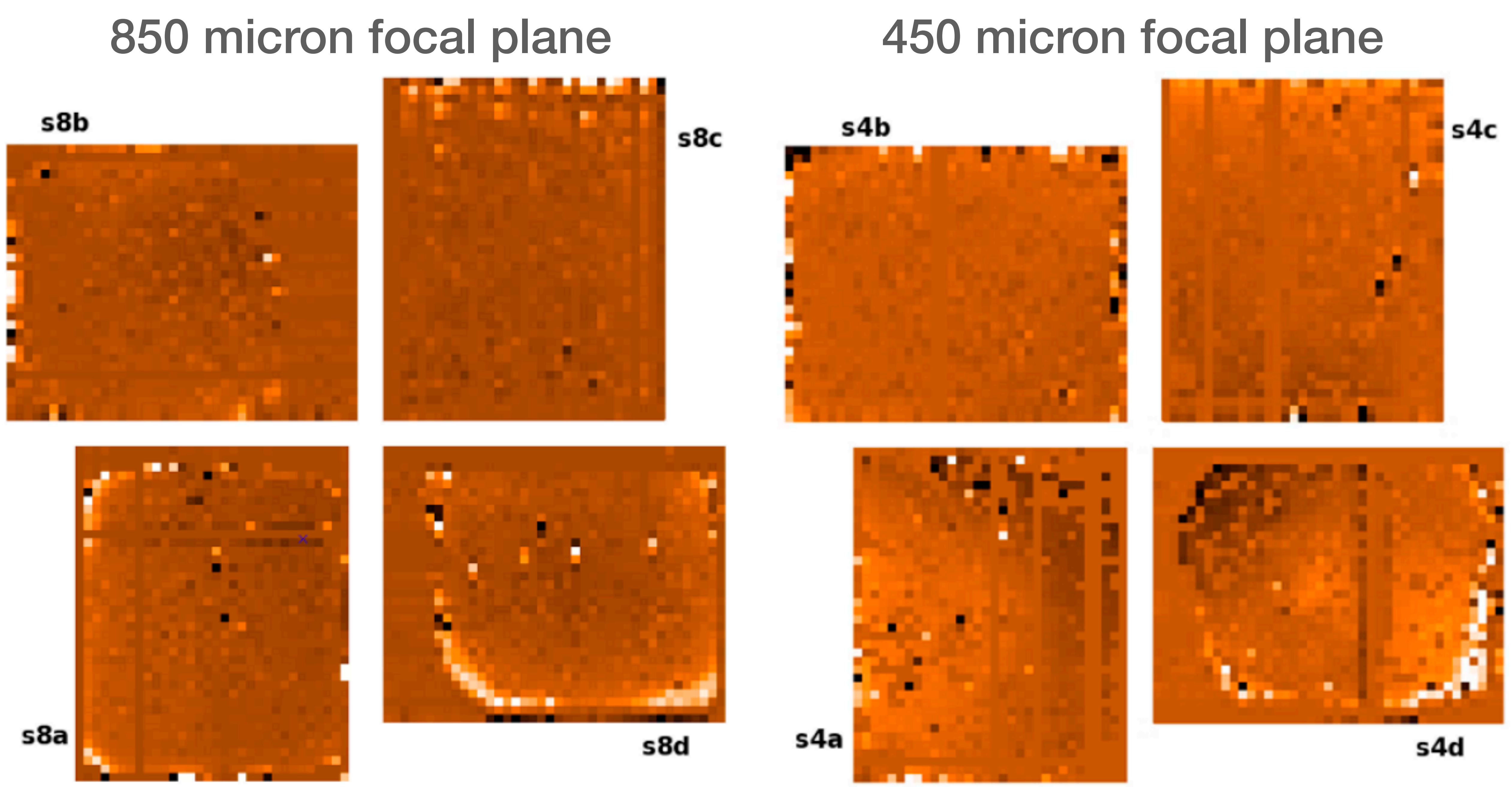
- Commissioned in 2011
- 10,240-pixel bolometer camera
- 450 μm & 850 μm
- 7.9” and 13” primary beam
- TES arrays
- Cooled by liquid ^{3}He

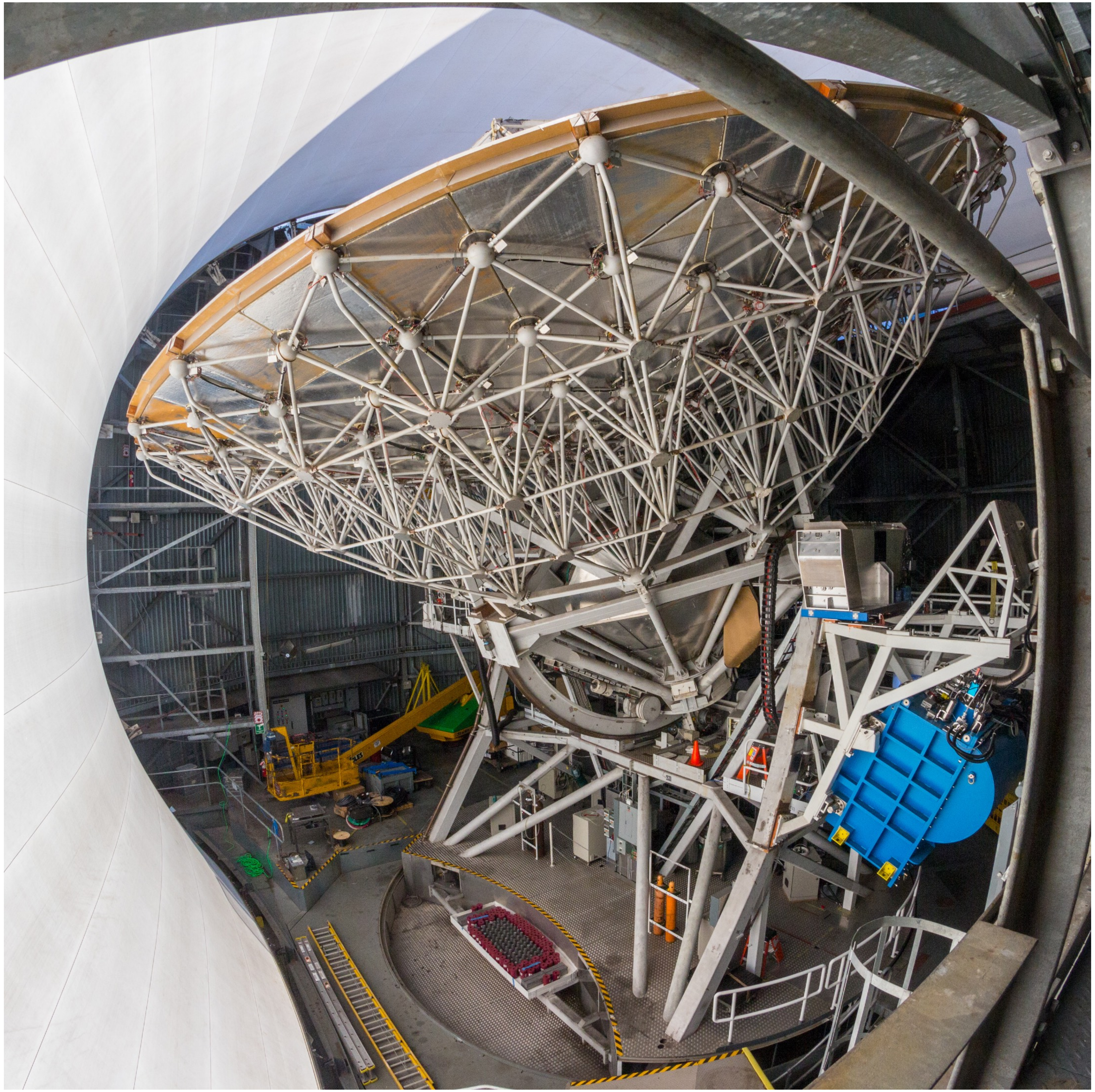
- Ancillary instruments:
  - POL-2
  - ~~FTS-2~~

SCUBA-2



- TES Transition edge sensors operating around 72mK
- Increase heat on the TES causes resistance to increase and drop in current
- Each focal plane is made up of 4 sub-arrays.

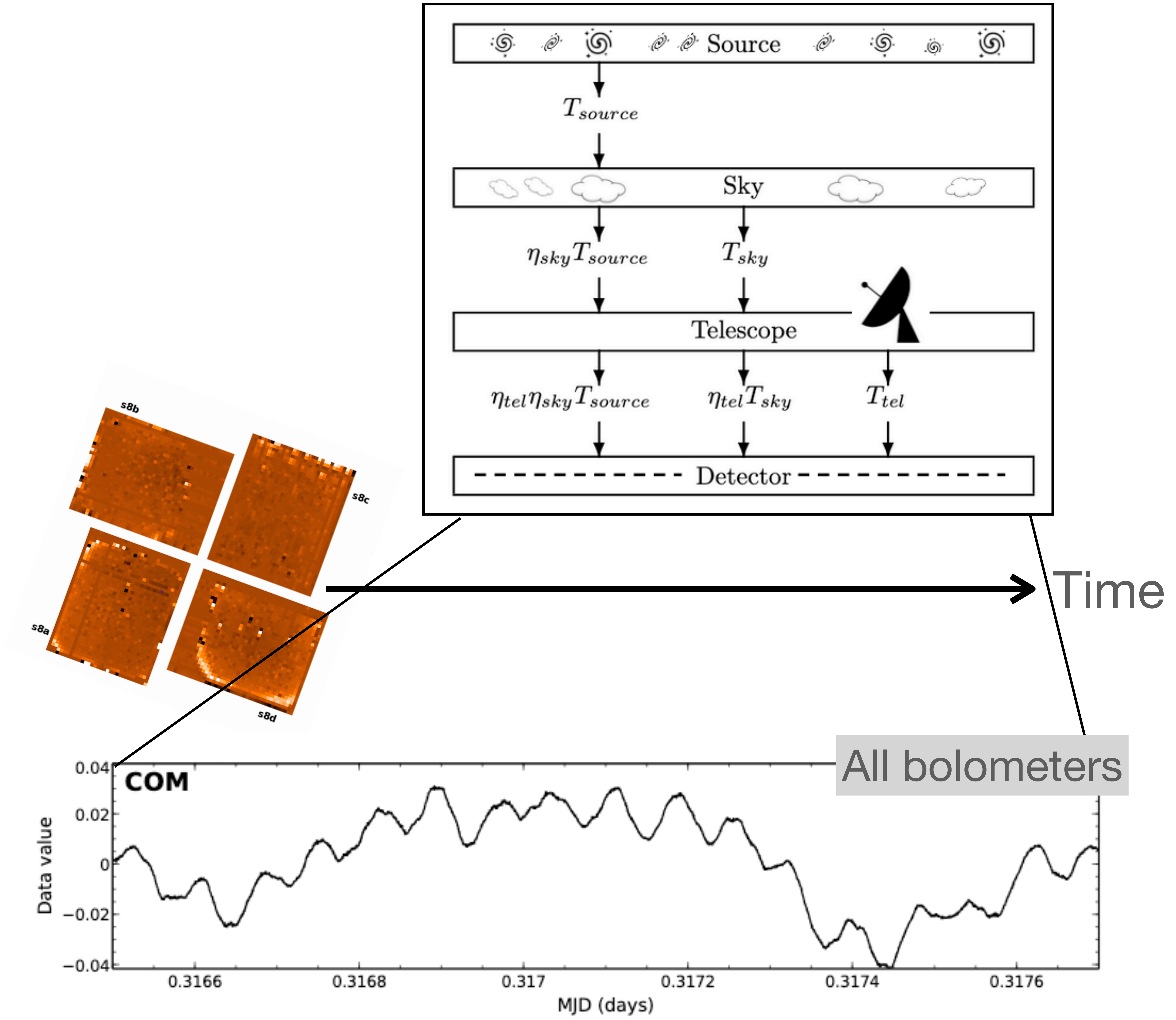




SCUBA-2

- 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



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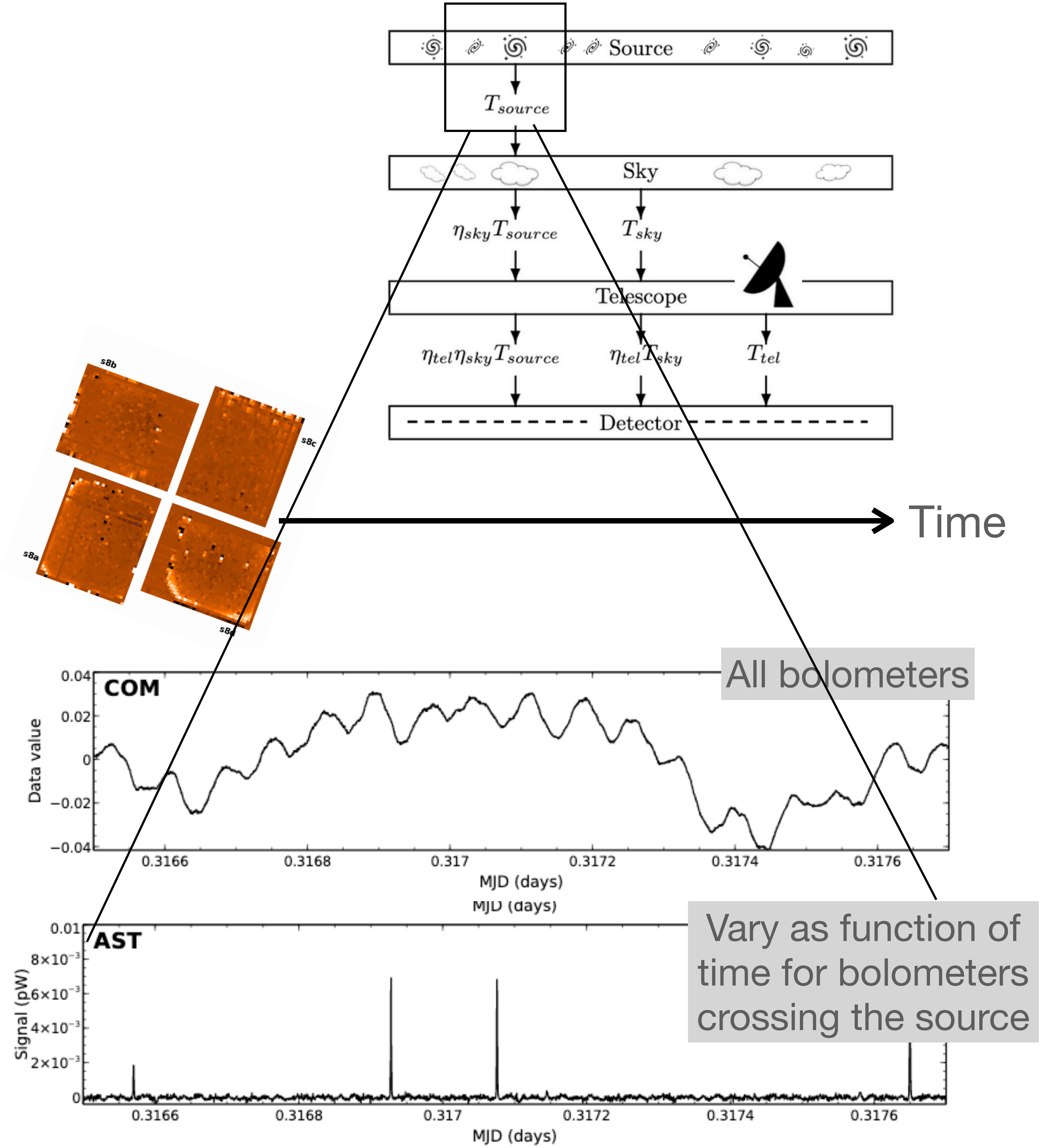
- This leads to higher efficiency, although some loss of spacial sensitivity.
- Requires creative ways of obtaining data with multiple bolometers covering the same patch of sky in a single observation.

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



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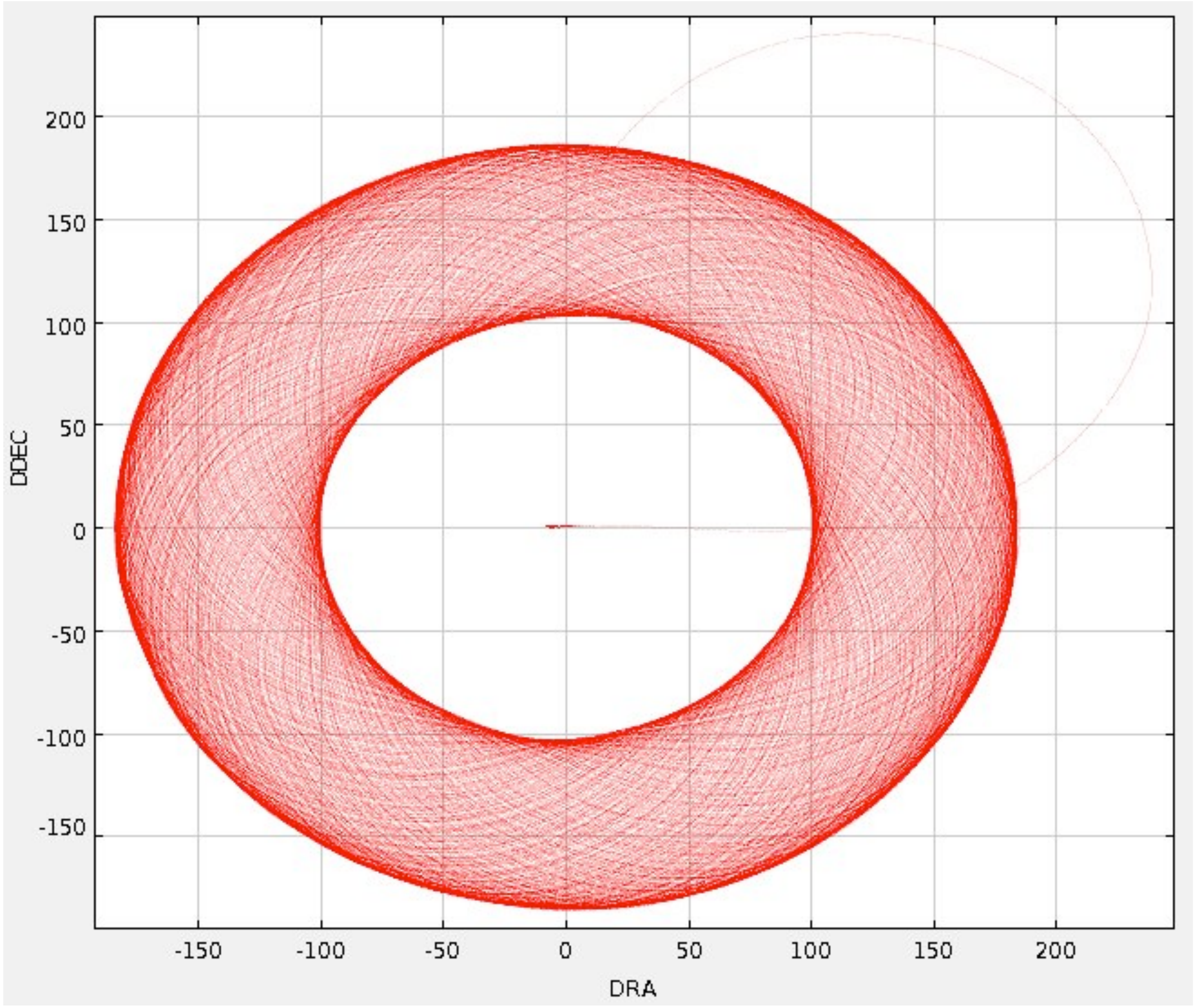
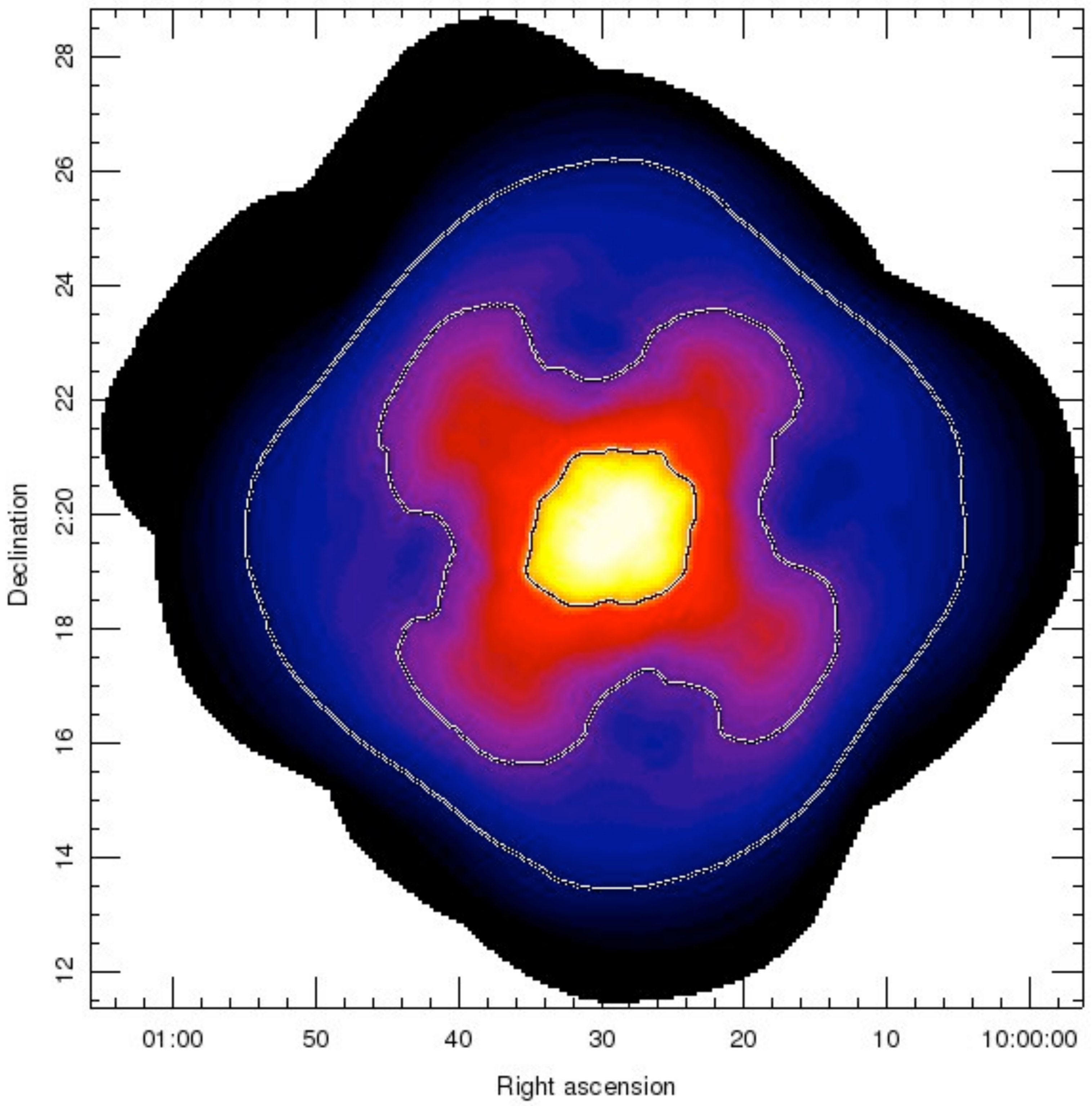
http://starlink.eao.hawaii.edu/devdocs/sc21.pdf

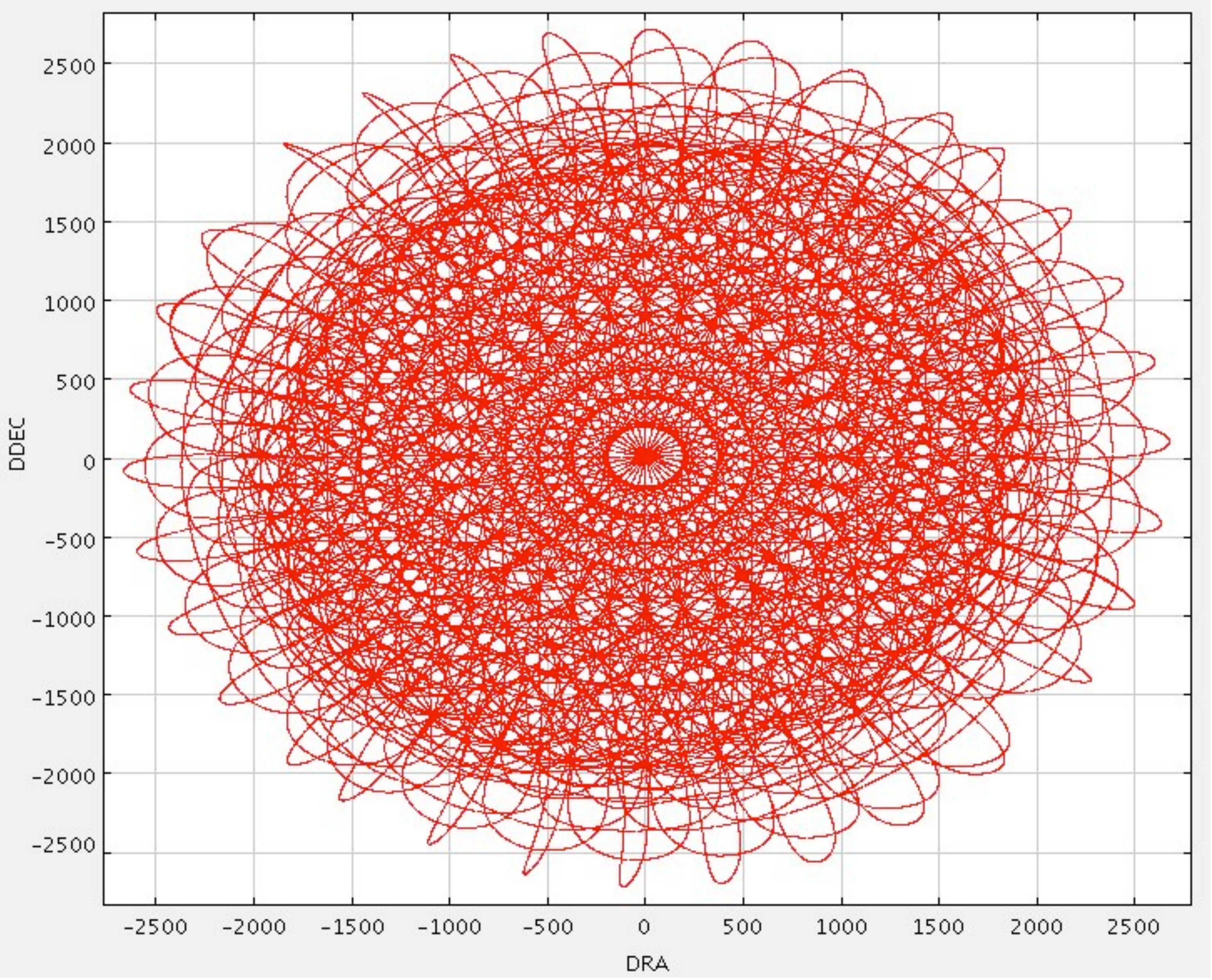
SCUBA-2

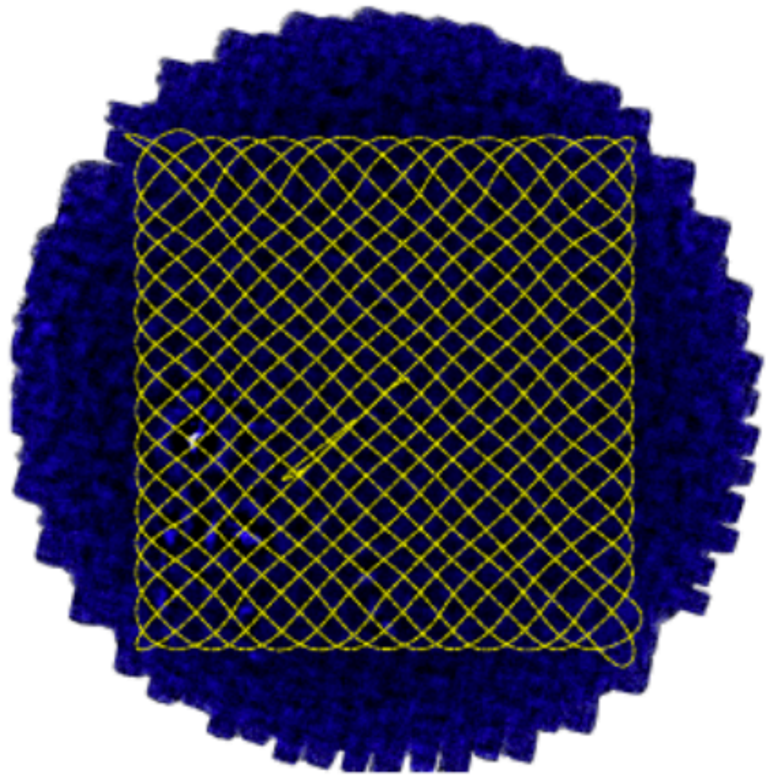
CV_Daisy Scan Pattern

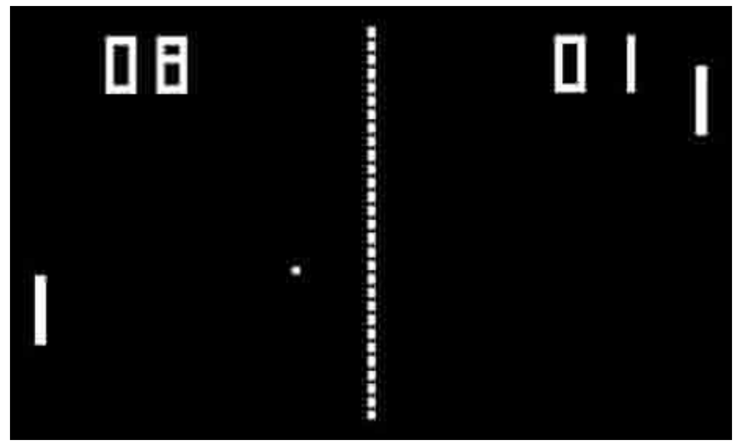




- “CV” = Constant Velocity***
- Ensure coverage of sky both in time and spacial domain
- Covers same positions at different angles
- Maximizes central exposure time but less-uniform depth
- Good for (e.g.) point sources
- High sensitivity in 3’
- Uneven coverage but still good to 12’



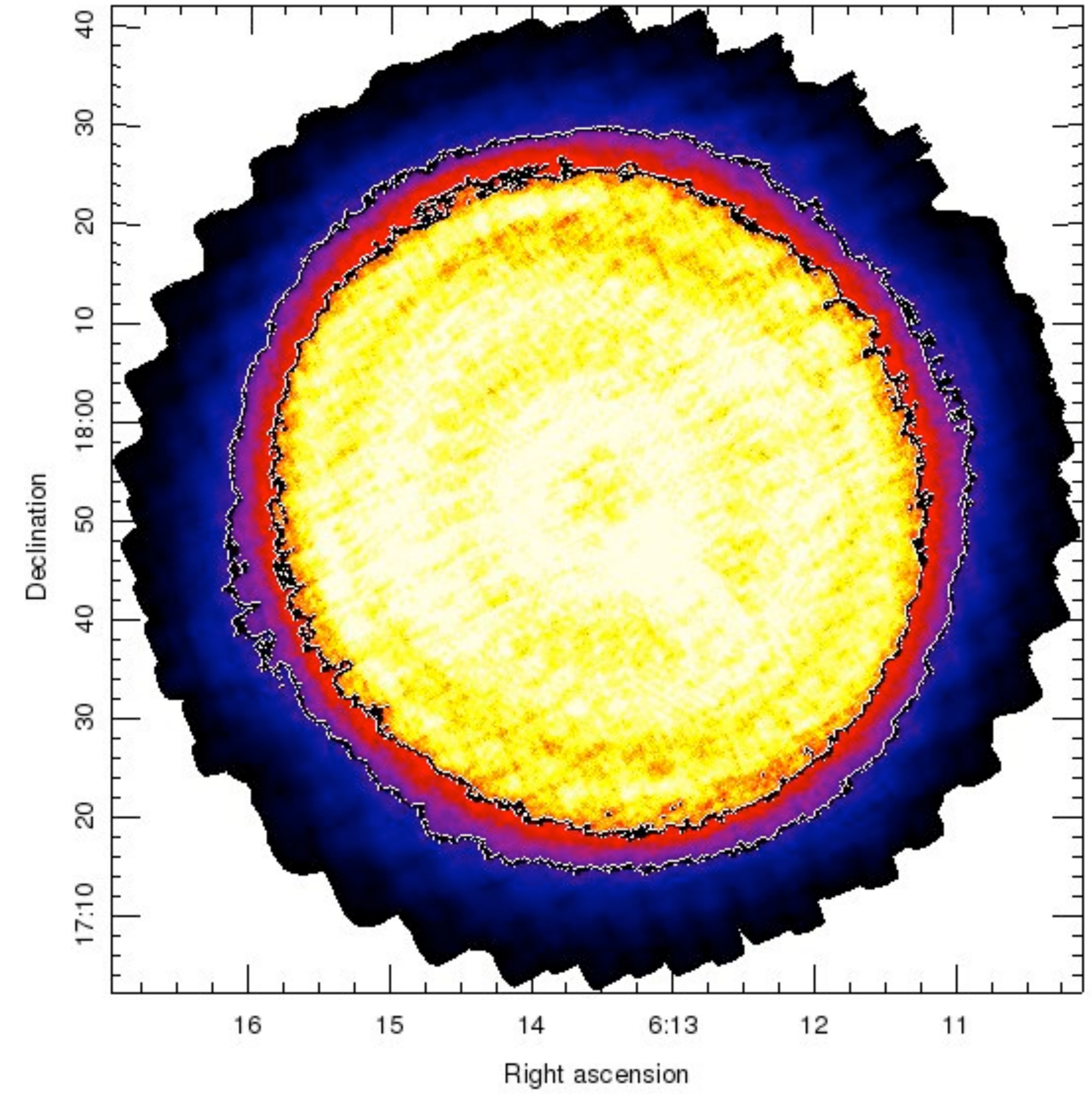




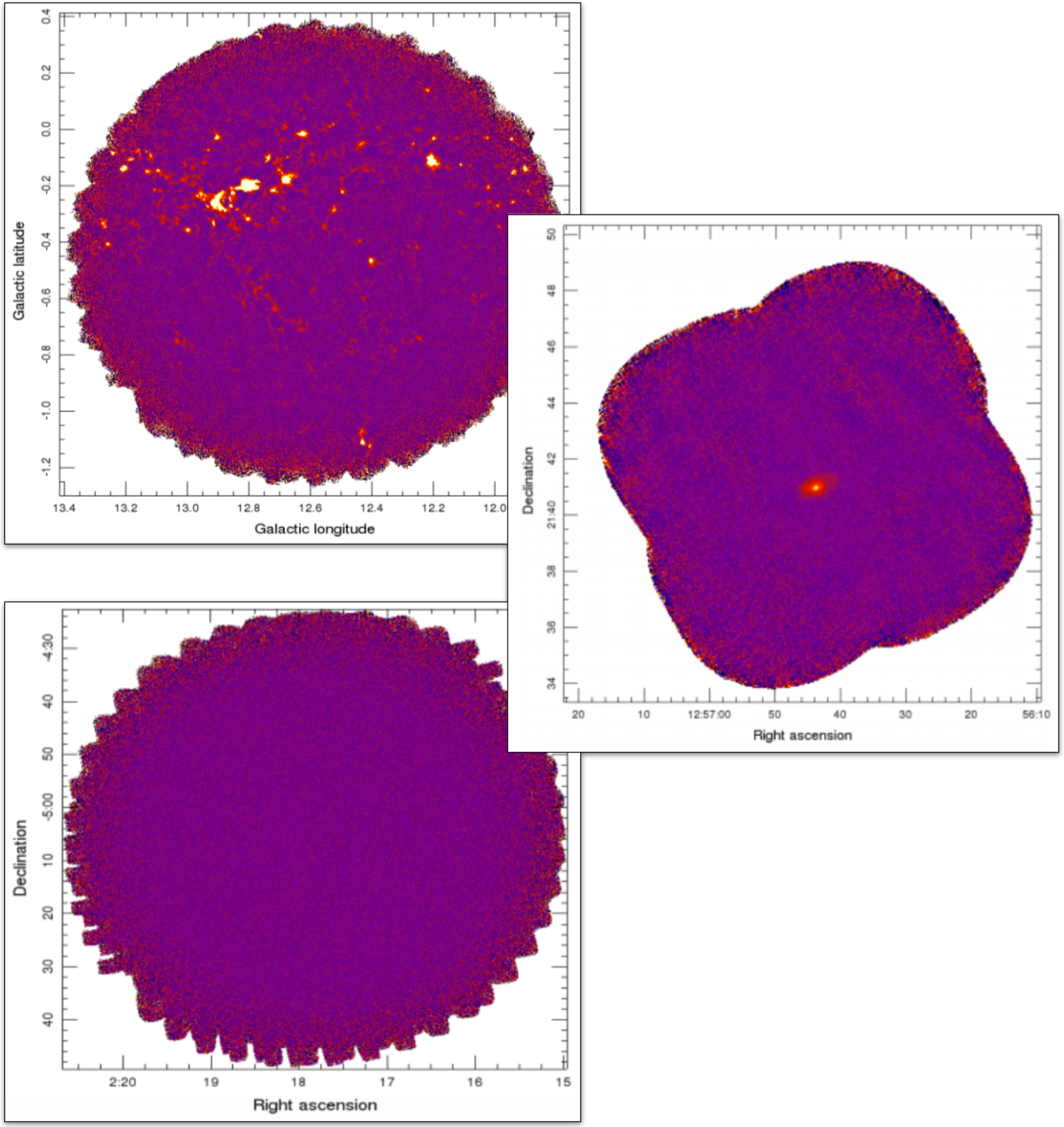
SCUBA-2

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

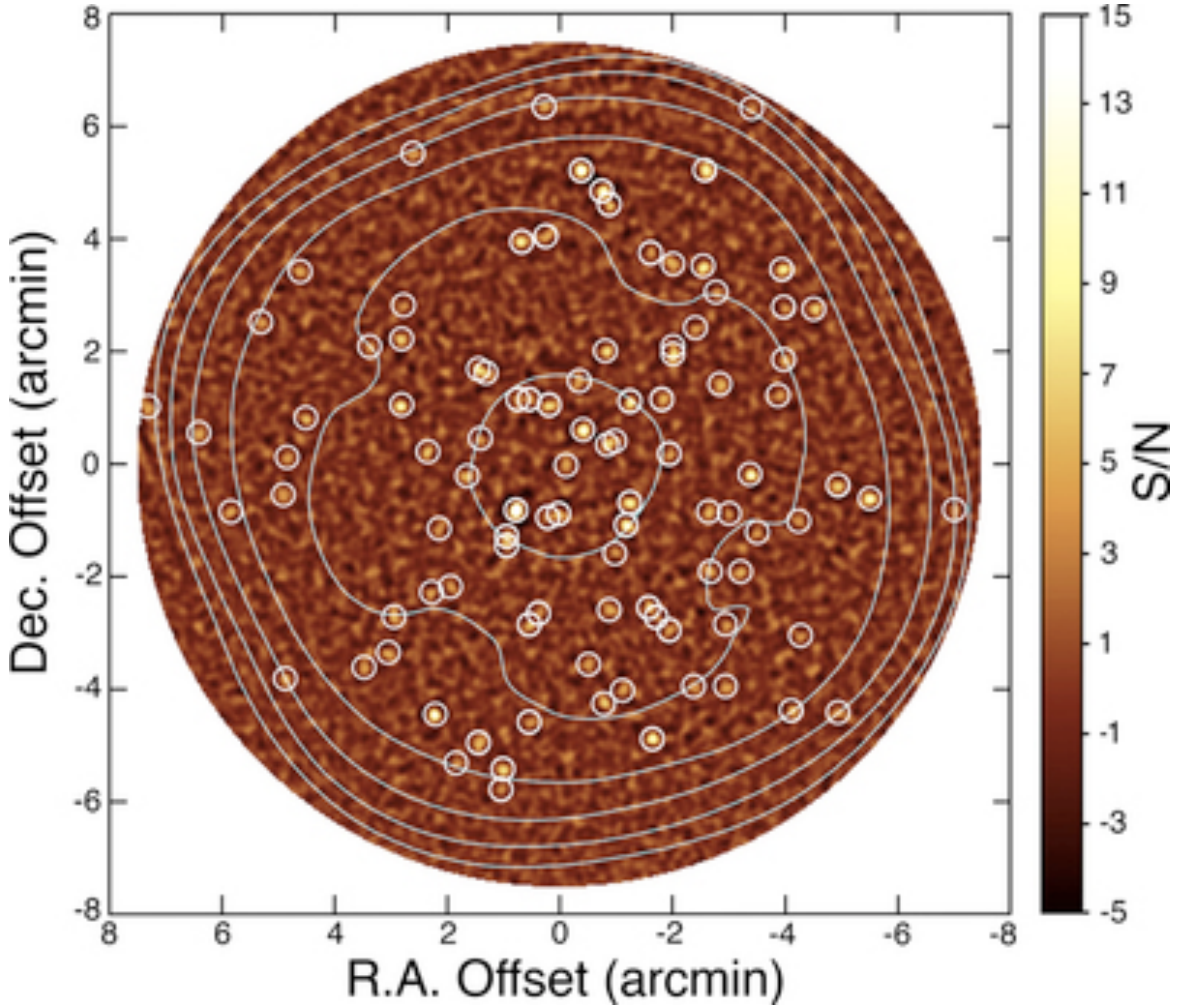
SCUBA-2 and POL-2 operating at 450micron and 850microns

Continuum + linear polarizer

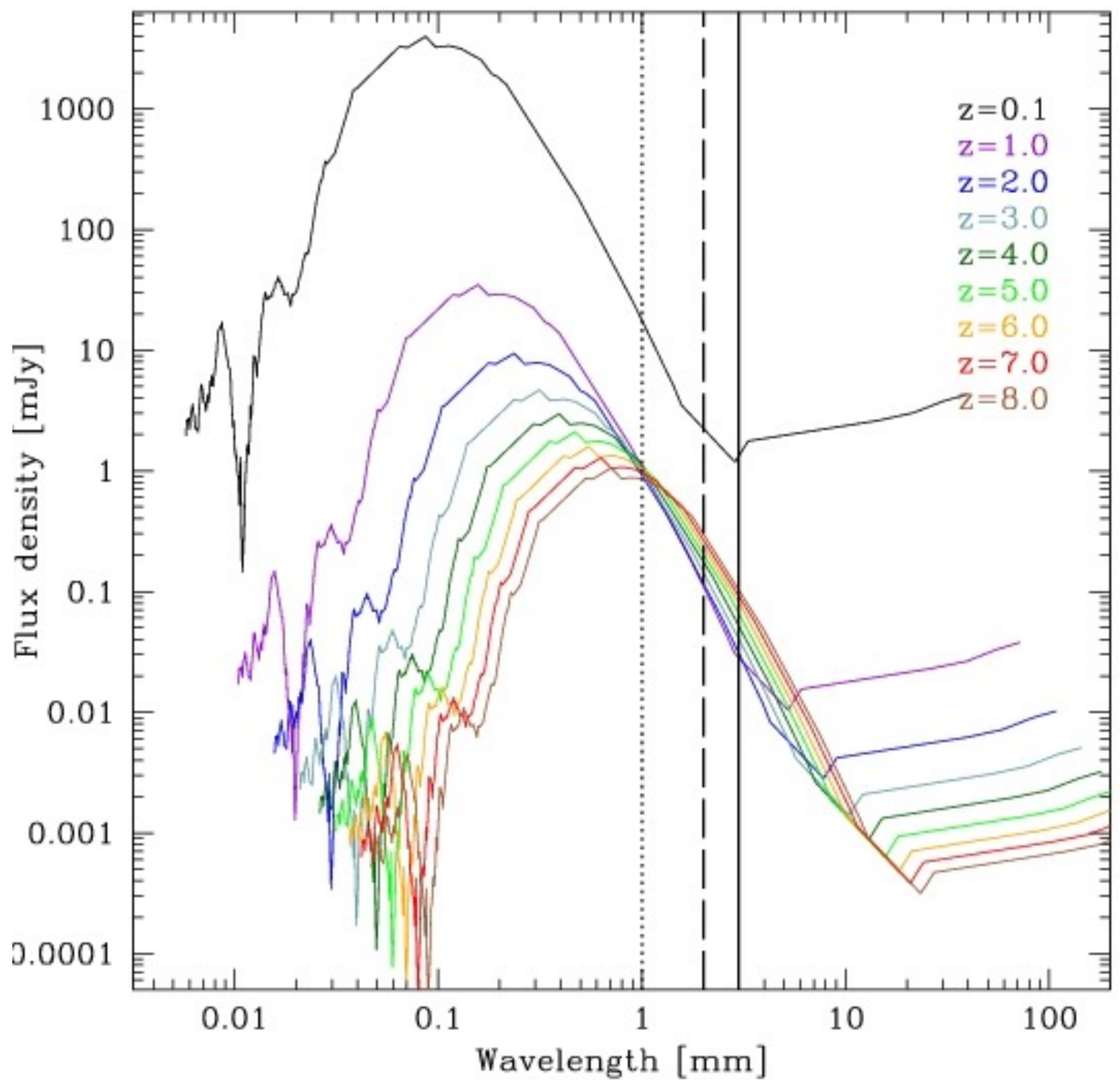
http://www.submm.caltech.edu/cso/weather/atplot.shtml

SCUBA-2

- Powerful galaxy mapping machine
- Ideal for ALMA follow up



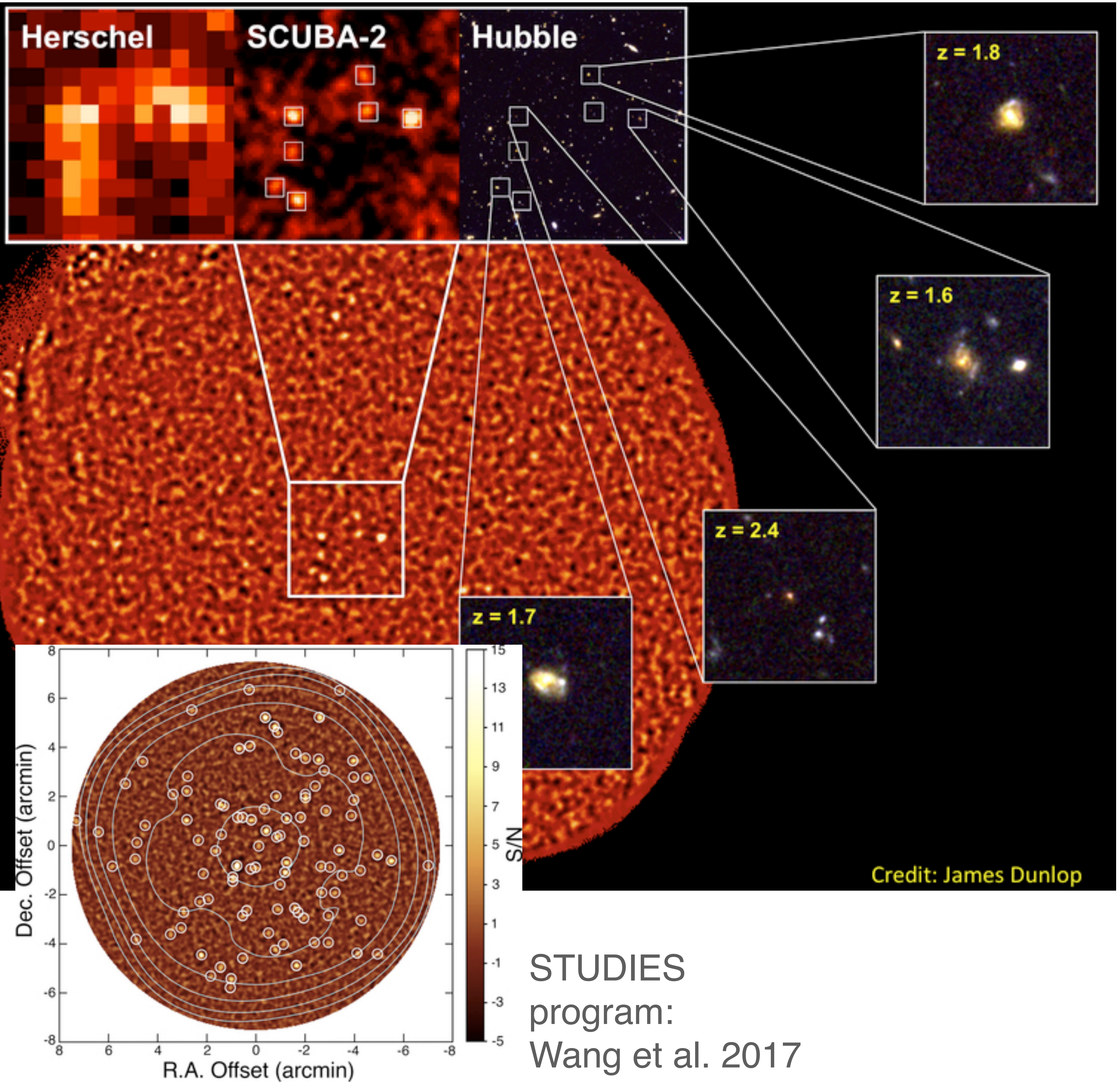
STUDIES (sub-mm galaxies): Wang et al. 2017



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.

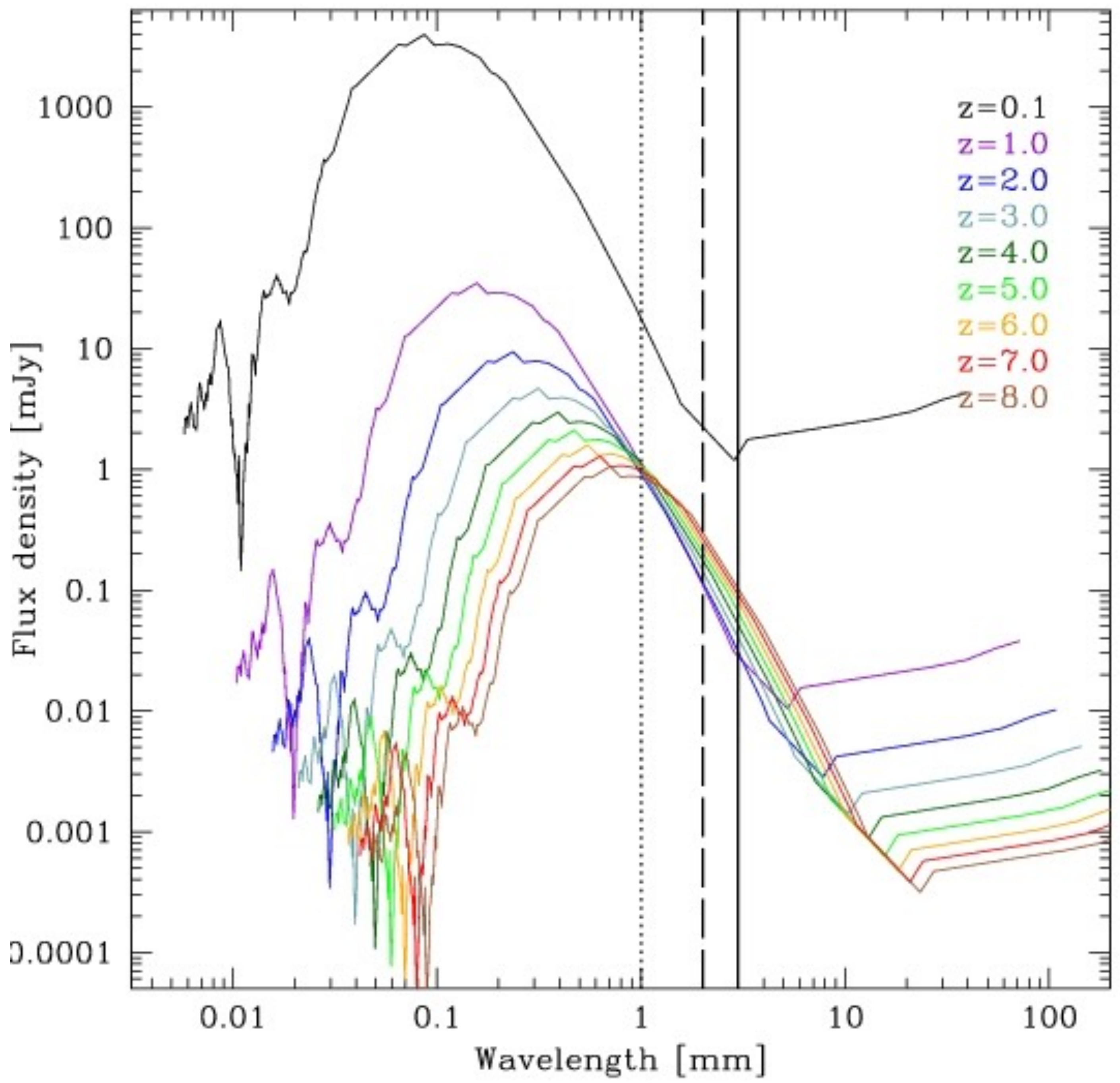
https://www2.mpia-hd.mpg.de/homes/decarli/science.html

SCUBA-2



STUDIES program: Wang et al. 2017

- Powerful galaxy mapping machine
- Candidates for ALMA follow up



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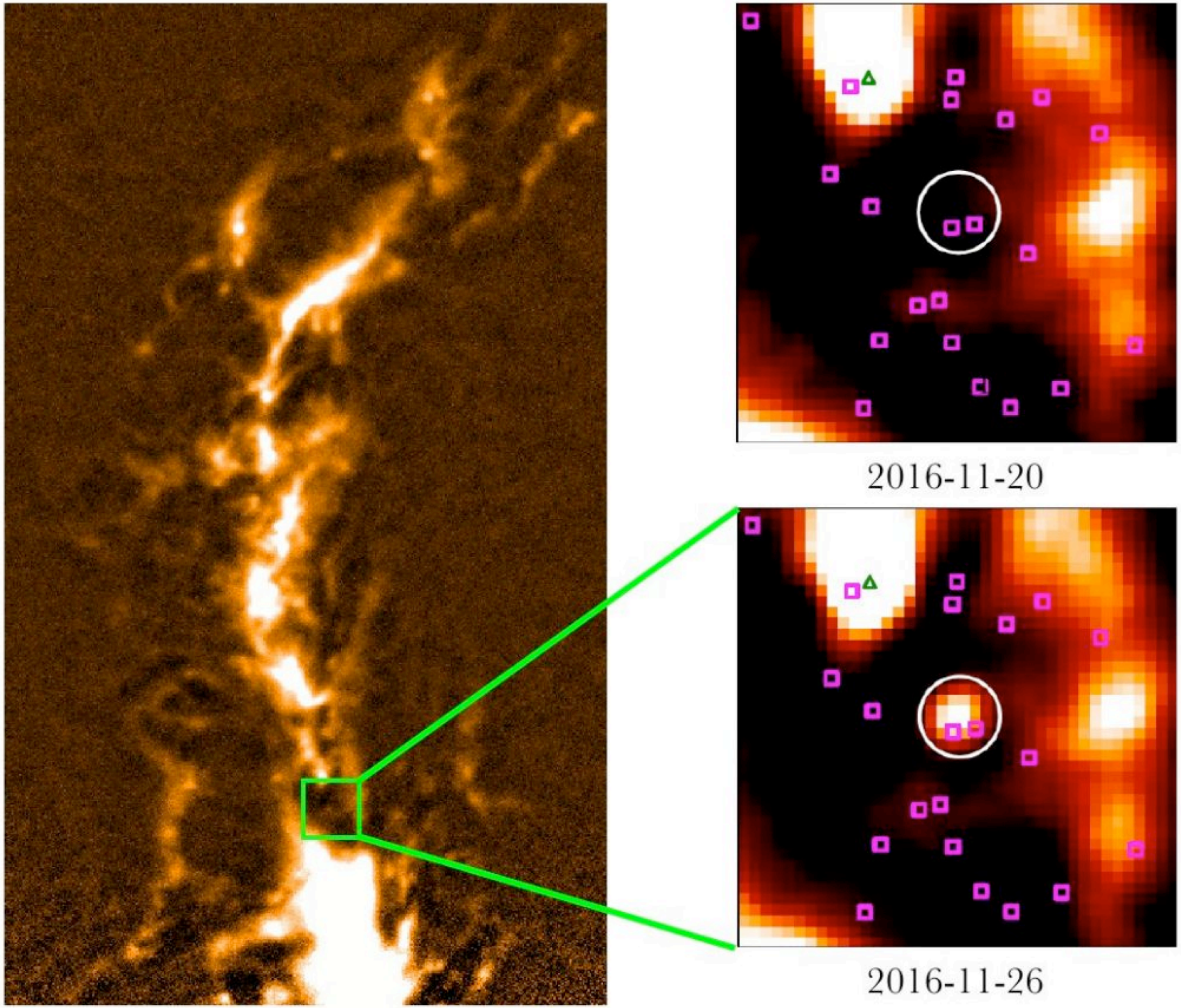


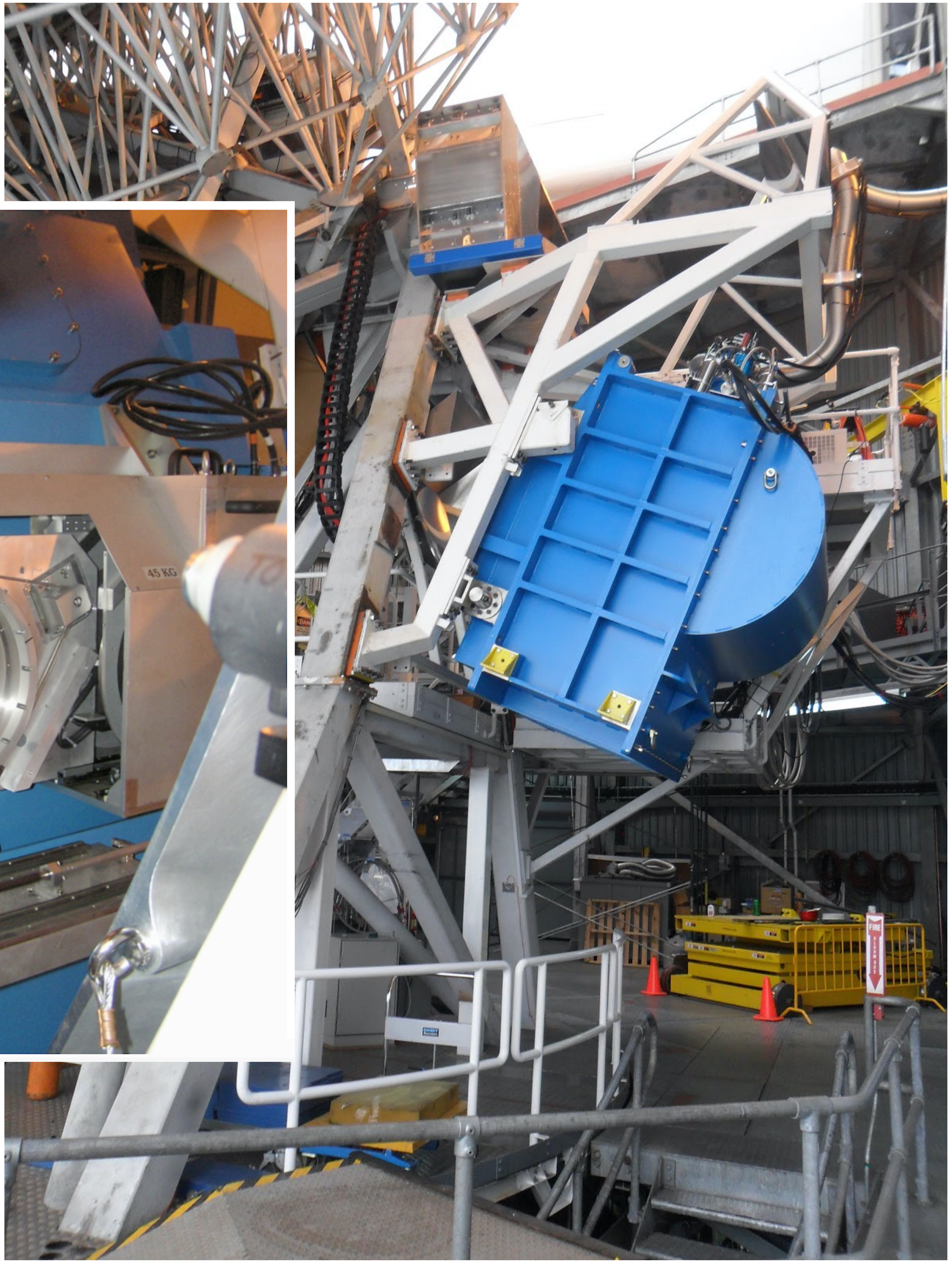
SCUBA-2

- Program started in 2016 at the observatory "Transient program" has lead to new field in sub-mm astronomy - cadence observations

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

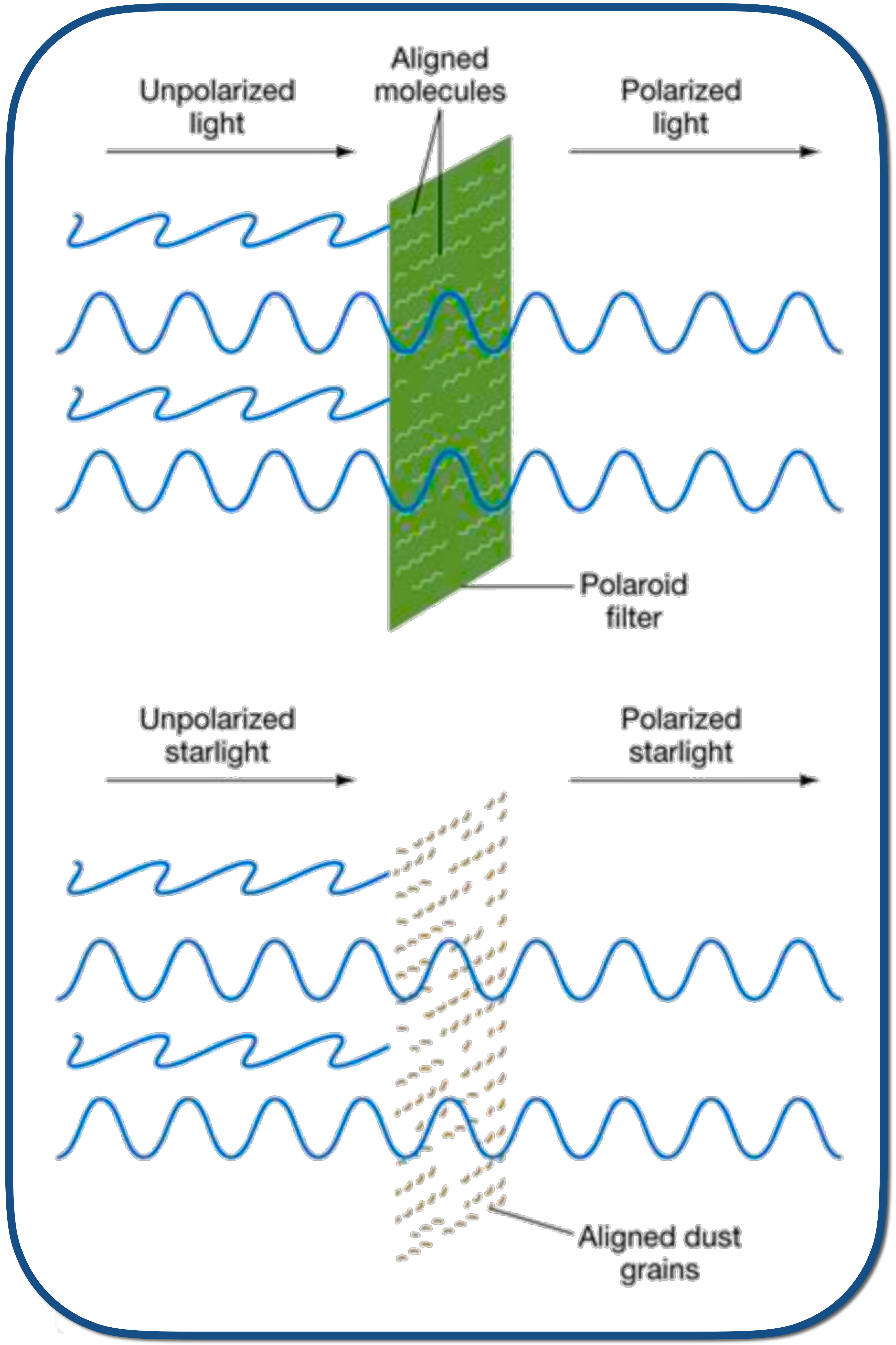
Mairs et al. 2018
T Tauri Binary System
JW 566

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%

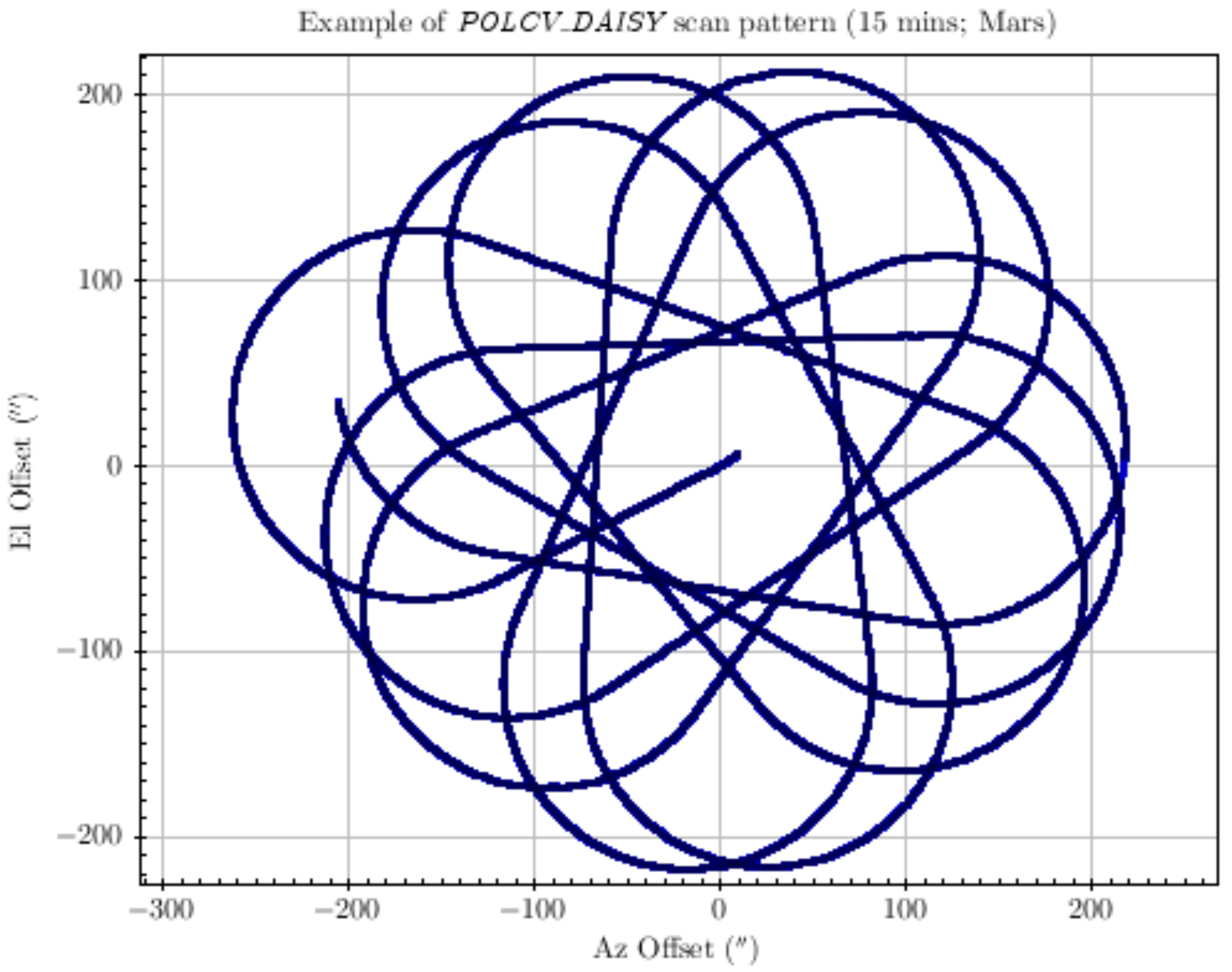
POL-2

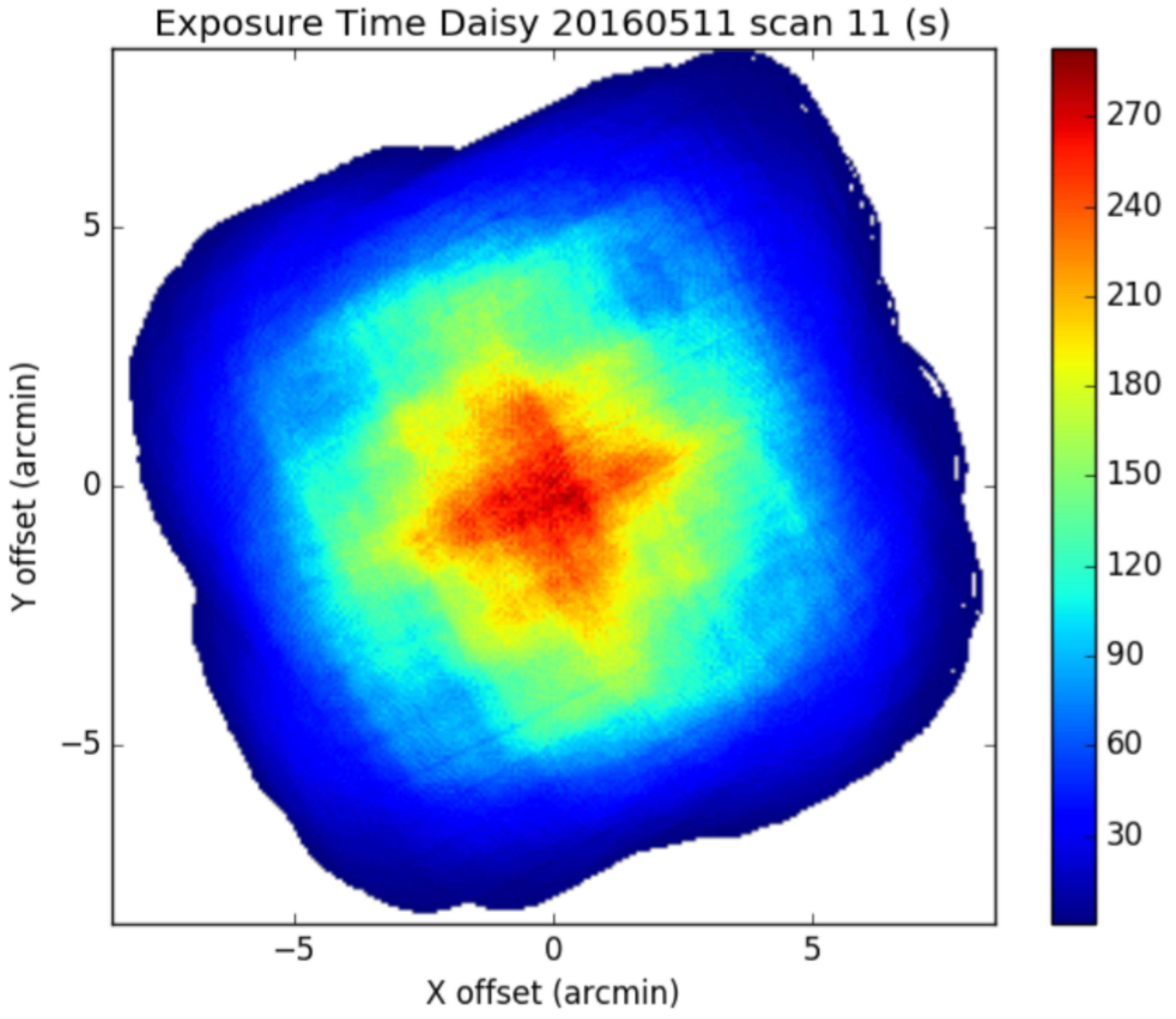


- Magnetic Fields Align Non-Spherical Dust Grains
- By looking at polarized light, we can “see” magnetic fields.
- True for visible, IR, sub-mm, etc - with the caveat that the polarization we detect at sub-mm wavelengths is perpendicular to the magnetic field direction.

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’

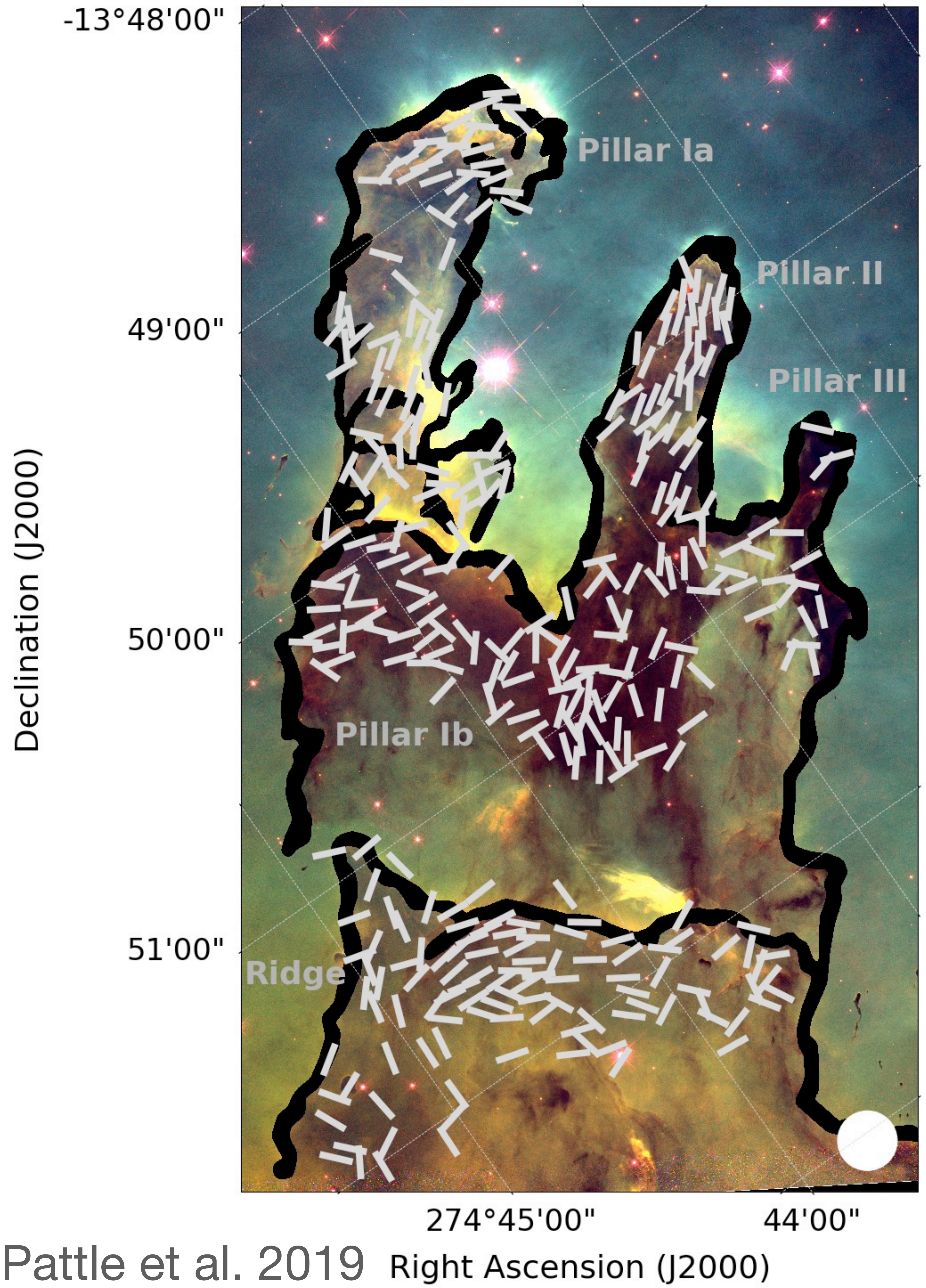
Sub-mm atmospheric transmission as a function of frequency at the JCMT on Maunkaea

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

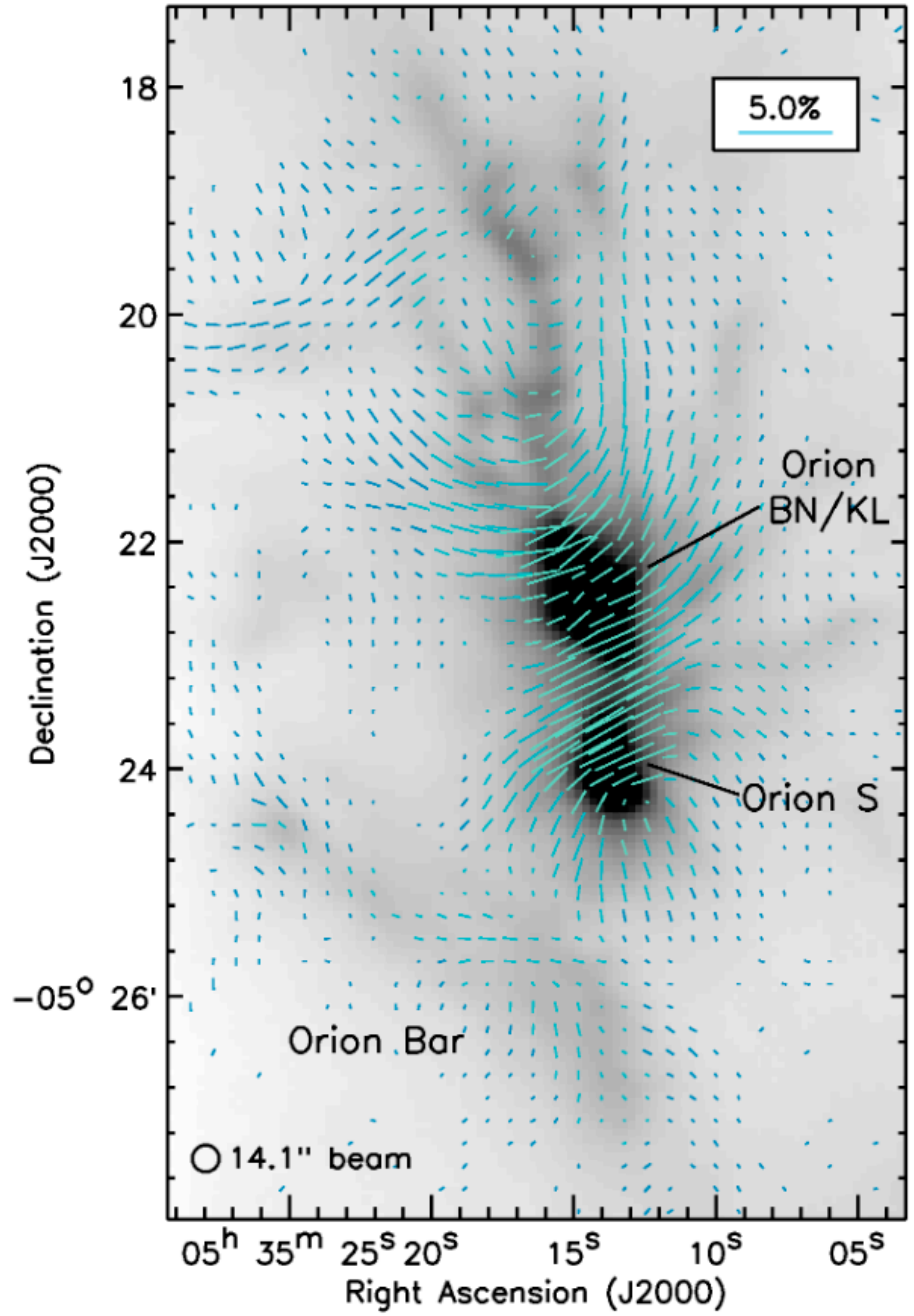
Continuum + linear polarizer

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

POL-2



Pattle et al. 2019



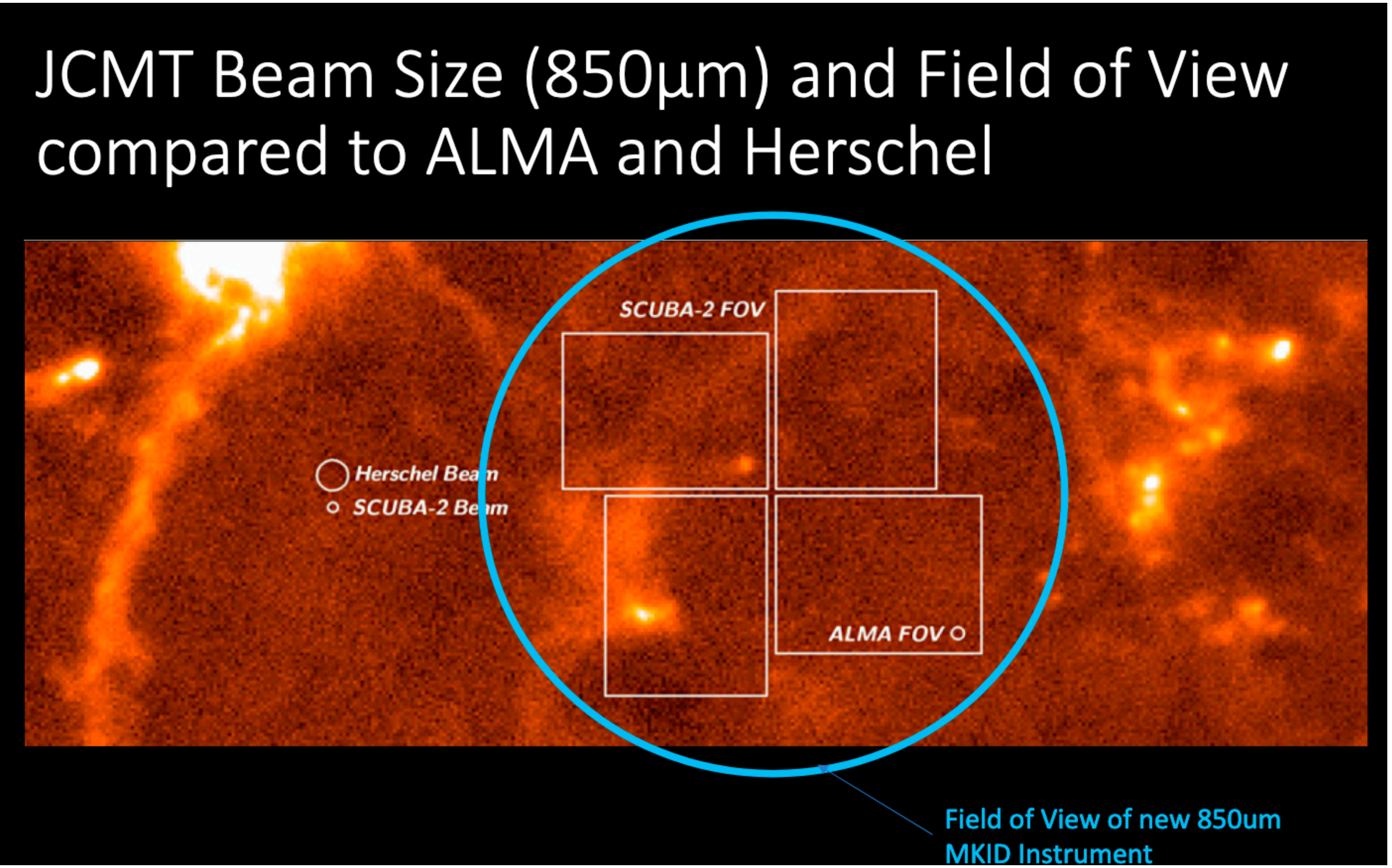
Pattle et al. 2017 - BISTRO

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

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

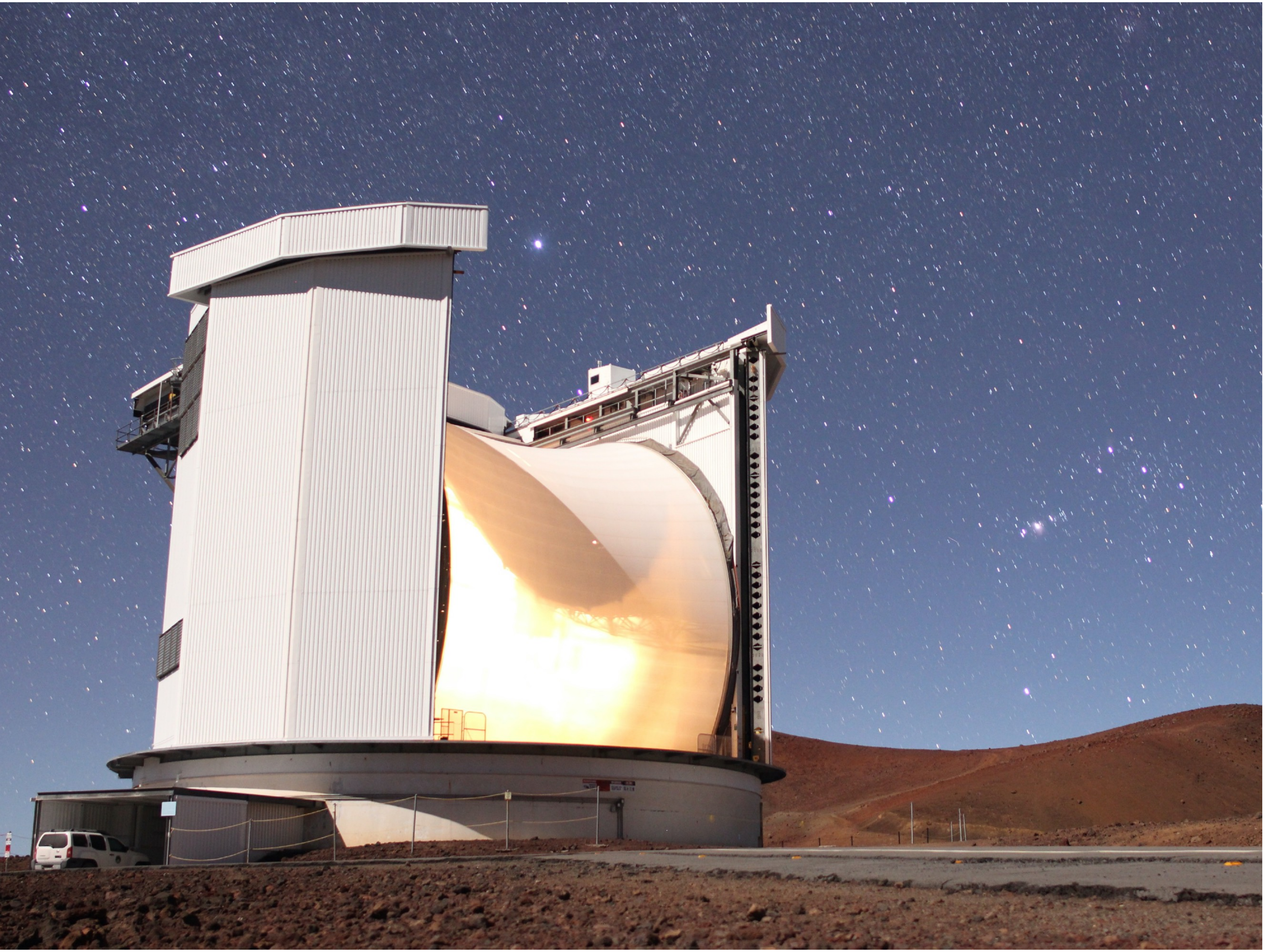
Primary and Secondary Mirrors
remote controlled
Tertiary Mirror Unit (TMU)
POL-2
SCUBA-2
HARP
Nāmakanui
ACSIS
inside the receiver cabin
outside the receiver cabin
Data ready for data reduction

Future Instrumentation



https://www.eaobservatory.org/jcmt/science/futures-2019/

- Current focus on the next generation of 850 micron wide field camera
- MKID detector design
- intrinsic polarization capabilities.
- single wavelength focus = faster delivery!
- Order of magnitude faster at mapping
    - 10 x faster than SCUBA-2
    - 20 x faster than POL-2



JCMT Operations

- Proposal Queues
- Flexible Observing
- Remote Operations

JCMT Proposal Queues

PI (principal investigator)	LAP (Large Program Queue)	Urgent Queue

JCMT Proposal Queues

PI (principal investigator)

- Call for Proposals issued every 6 months for “normal sized” projects (< 200 h, but typically ~ 3-50 hours) to be run during following semester
    - Current semester: 20B (1st August, 2020 — 31st January, 2021)
    - Next semester: 21A (1st February, 2021 — 31st July, 2021) - *Call Closed*
    - Next Call: 21B (1st August, 2021 — 31st January, 2022)
- Proposals competitively assessed by Time Allocation Committee (TAC)
- Successful projects run via PI queue

JCMT Proposal Queues

LAP (Large Program Queue)

- Call for Proposals issues periodically (in the past in 2016, 2017, 2020)
- large programs (> 200 h, multiple semesters)
- Proposals competitively assessed by Time Allocation Committee (TAC)
- Successful projects run via LAP queue
- Scheduled for same total time each semester as PI queue
- Due to large allocation observatory links time award to conditions:
    - Open Enrollment - any JCMT astronomer may join any *new* program
    - At least one member from every EAO region
    - Progress reports requested every 6 months
    - Clear publication roadmap

JCMT Proposal Queues

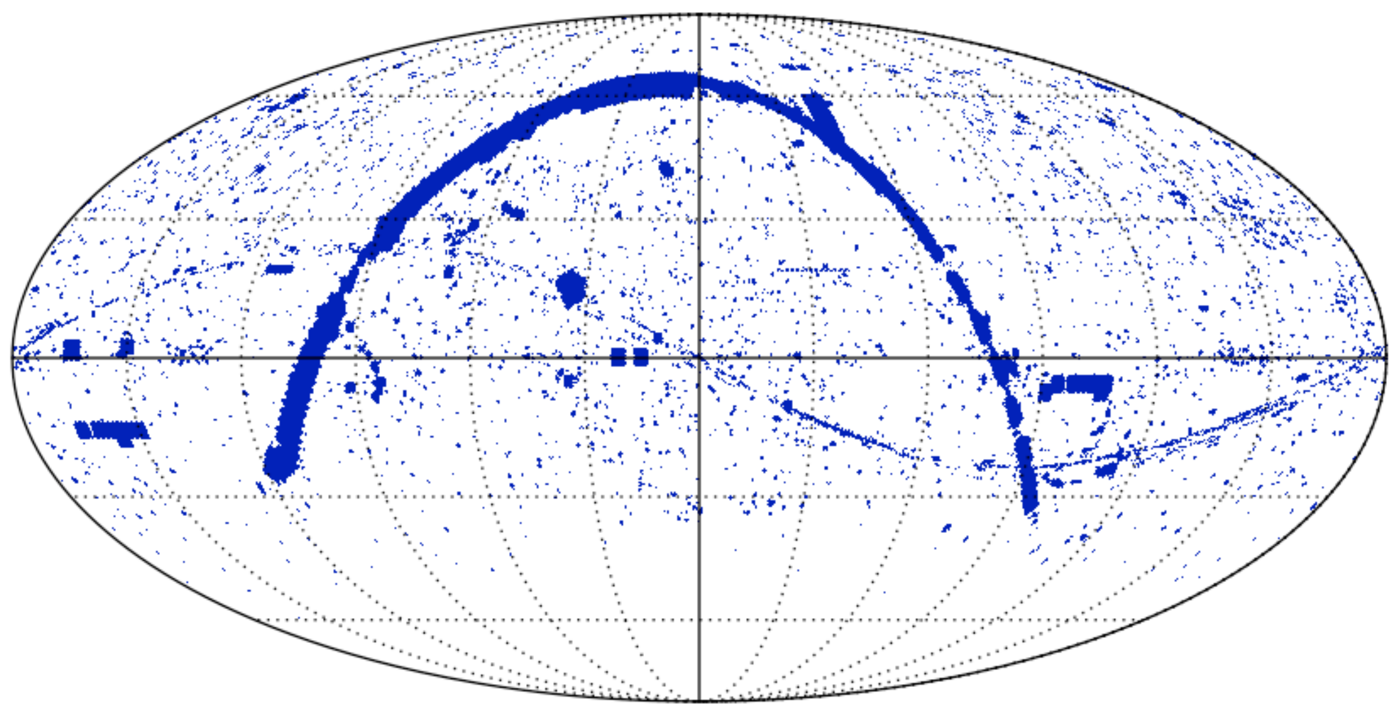
Urgent Queue

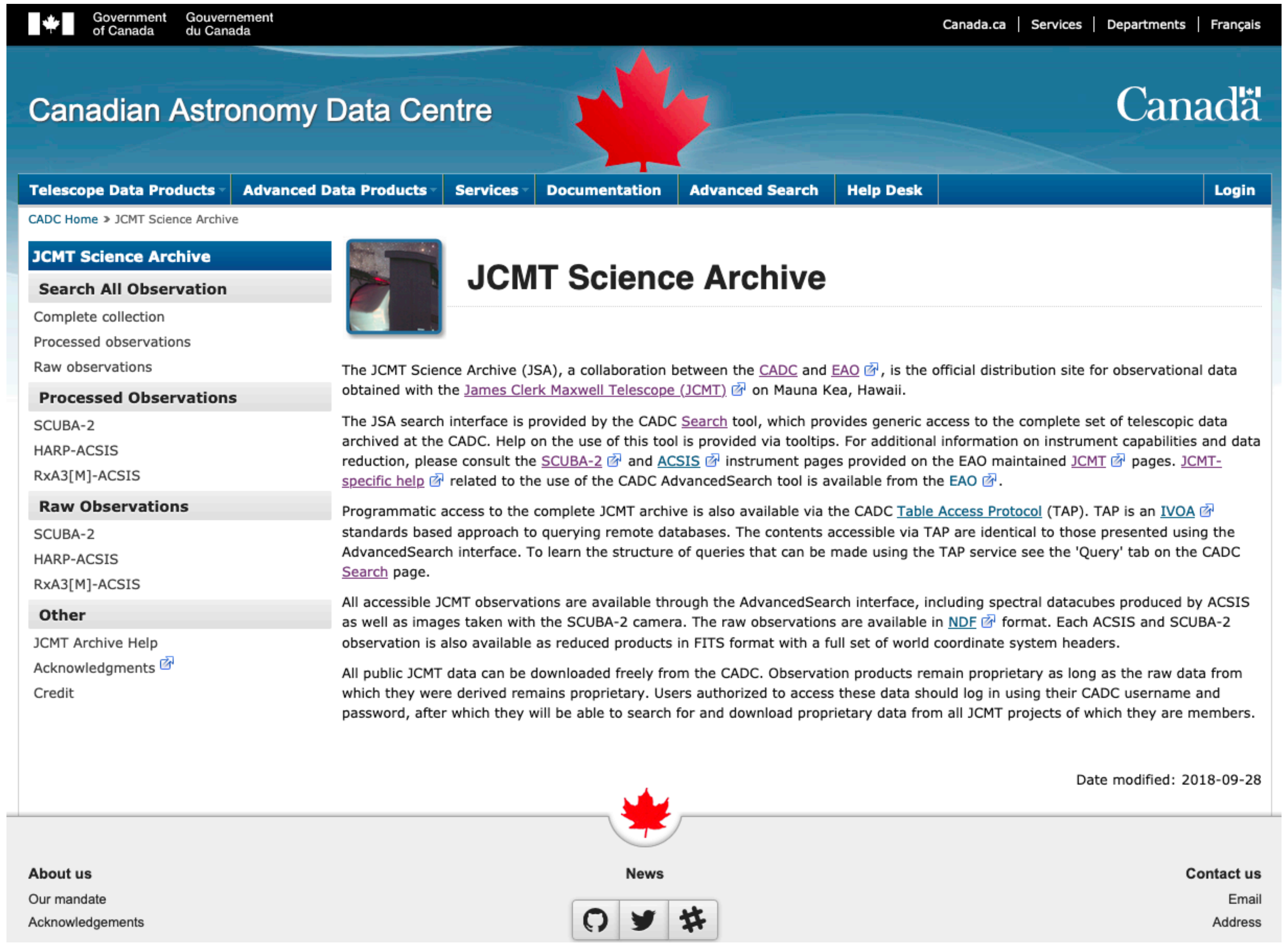
- Urgent queue always open for submissions for current semester
- For projects targeting phenomena that must be observed more urgently than normal; Typically ~ 2 — 12 hours (but may be longer)
- Assessed by same scientific TAC members as PI proposals
- Open to PIs from EAO partner regions

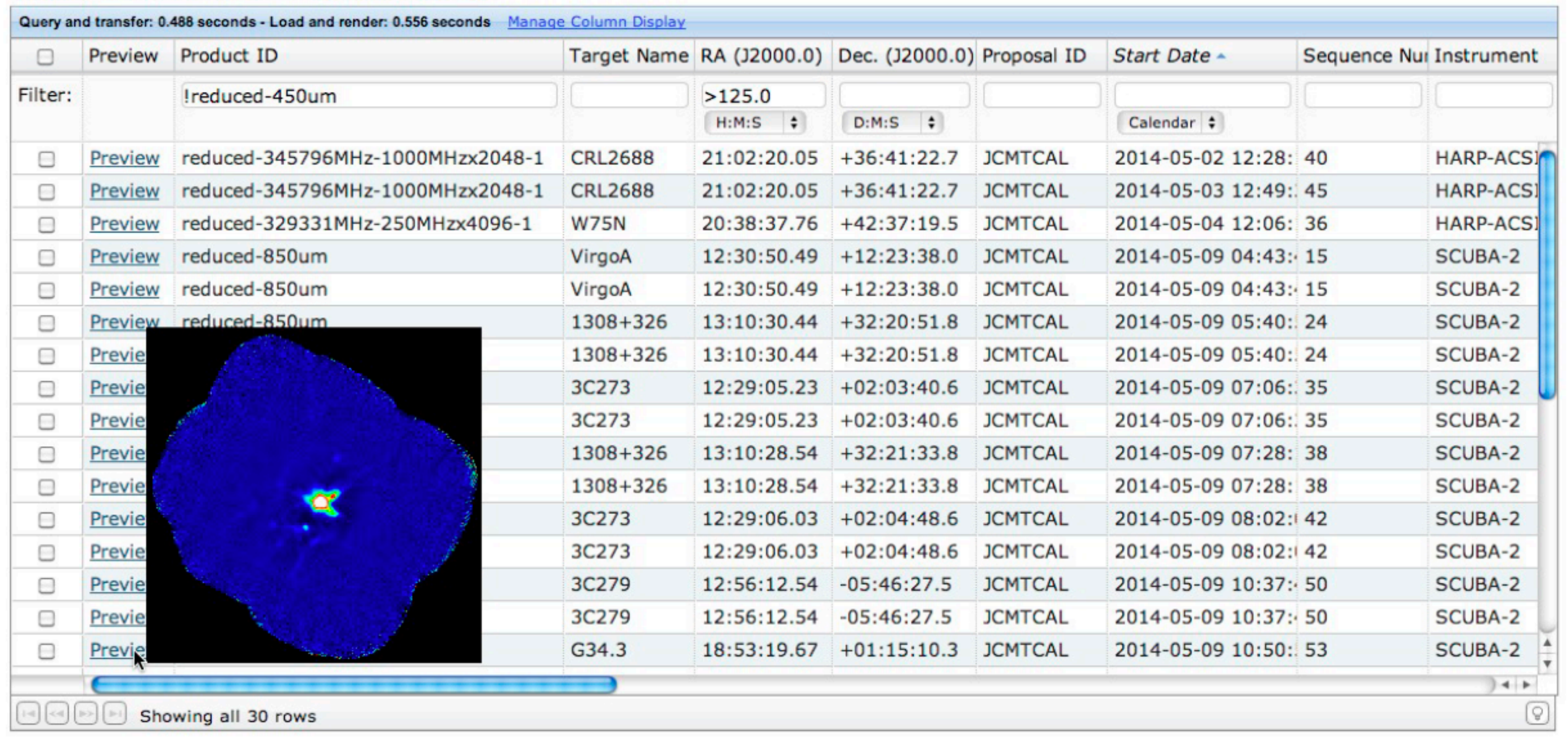
JCMT Proposal Queues

PI (principal investigator)	LAP (Large Program Queue)	Urgent Queue

- Data become public via the JCMT Science Archive one year after the semester in which it was observed. e.g. observed November 10th 2020. Data will become available February 1st 2022.







Query and transfer: 0.488 seconds - Load and render: 0.556 seconds Manage Column Display

	Preview	Product ID	Target Name	RA (J2000.0)	Dec. (J2000.0)	Proposal ID	Start Date	Sequence Nu	Instrument
Filter:		!reduced-450um		>125.0 H:M:S	D:M:S		Calendar		
☐	Preview	reduced-345796MHz-1000MHzx2048-1	CRL2688	21:02:20.05	+36:41:22.7	JCMTCAL	2014-05-02 12:28:	40	HARP-ACSI
☐	Preview	reduced-345796MHz-1000MHzx2048-1	CRL2688	21:02:20.05	+36:41:22.7	JCMTCAL	2014-05-03 12:49:	45	HARP-ACSI
☐	Preview	reduced-329331MHz-250MHzx4096-1	W75N	20:38:37.76	+42:37:19.5	JCMTCAL	2014-05-04 12:06:	36	HARP-ACSI
☐	Preview	reduced-850um	VirgoA	12:30:50.49	+12:23:38.0	JCMTCAL	2014-05-09 04:43:	15	SCUBA-2
☐	Preview	reduced-850um	VirgoA	12:30:50.49	+12:23:38.0	JCMTCAL	2014-05-09 04:43:	15	SCUBA-2
☐	Preview	reduced-850um	1308+326	13:10:30.44	+32:20:51.8	JCMTCAL	2014-05-09 05:40:	24	SCUBA-2
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☐	Previe		3C273	12:29:05.23	+02:03:40.6	JCMTCAL	2014-05-09 07:06:	35	SCUBA-2
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☐	Previe		3C273	12:29:06.03	+02:04:48.6	JCMTCAL	2014-05-09 08:02:	42	SCUBA-2
☐	Previe		3C279	12:56:12.54	-05:46:27.5	JCMTCAL	2014-05-09 10:37:	50	SCUBA-2
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☐	Previe		G34.3	18:53:19.67	+01:15:10.3	JCMTCAL	2014-05-09 10:50:	53	SCUBA-2

Showing all 30 rows

Flexible Queue Observing

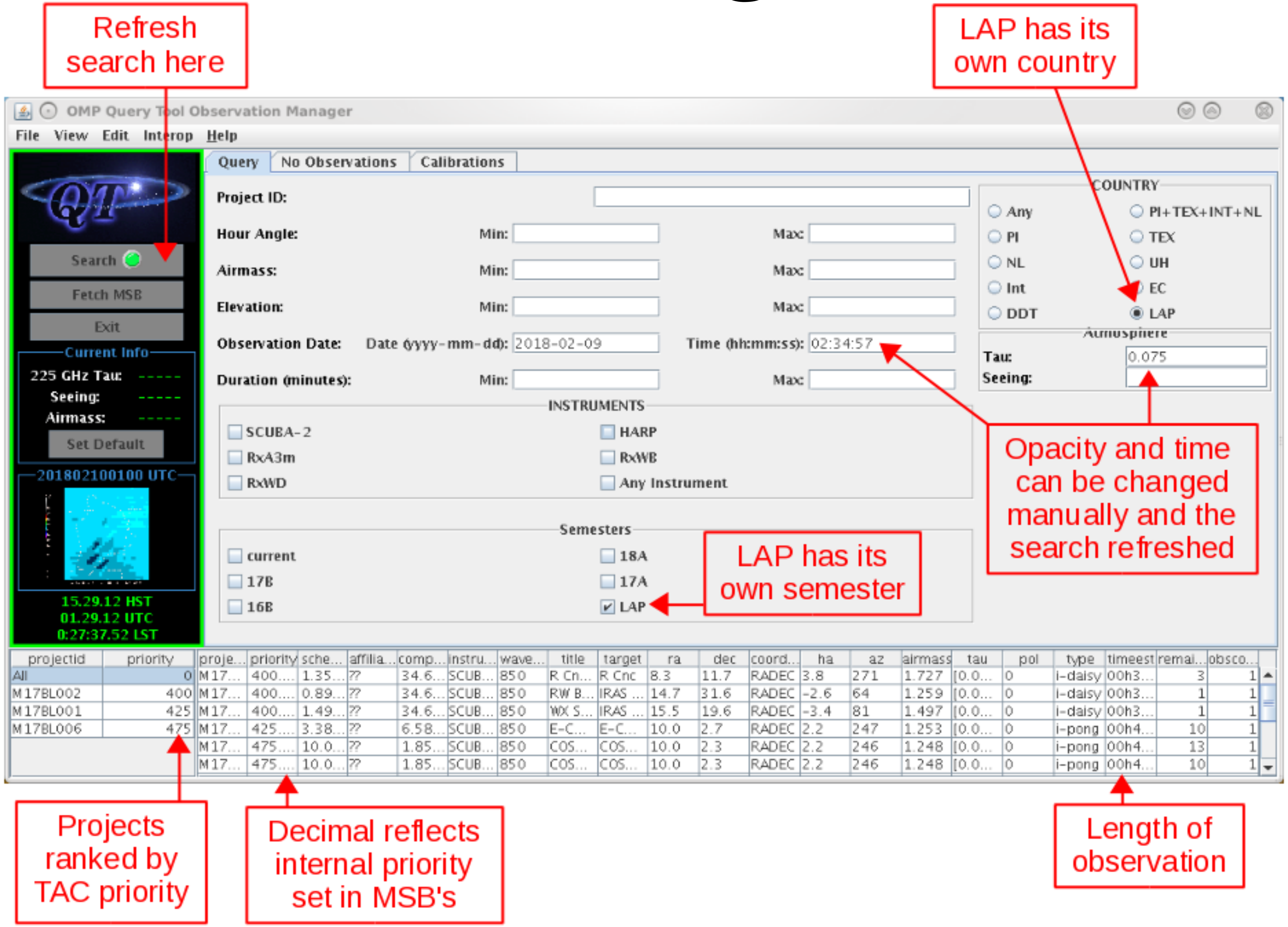
- Programs submitted to telescope in advance (e.g. start of the semester)
- Each night is assigned to a Queue
    - PI - Principle Investigator
    - LAP - Large Programs
    - UH - Uni. Hawaii (12%)
    - DDT - Directors Discretionary Time (3 nights/semester)
- During a night program observed according to TAC priority, instrument availability and atmospheric transparency.

JCMT Schedule for Semester 20B (November 2020)

TSS	Start Date	Notes	19:30 --------------- (P.I. ; Project ID) --------------- 07:30
AKA	s1		LAP Queue
AKA	2		"
KMS	h3		PI Queue
KMS/PMS	4		"
KMS/PMS	5		"
KMS/PMS	6		"
KMS/PMS	s7		"
CRM	s8		UH
CRM	9		"
CRM	10		"
AKA*	h11		LAP Queue
AKA*	12		"
AKA	13		"
AKA	s14	NOVEMBER	"
AKA	s15		"
AKA/PMS	16		DDT
AKA/PMS	17		PI Queue
KMS	18		"
KMS	19		"
KMS	20		"
KMS	s21		"
KMS	s22		LAP Queue
CRM/PMS	23		"
CRM/PMS	24	NOVEMBER	"
CRM/PMS	25		"
KMS*/PMS	h26		"
KMS*/PMS	27		PI Queue
AKA	s28		"
AKA	s29		"
AKA	30		"
@JROC	Election:	11th is Veteran's Day	unconfirmed Latest Update: 2020/10/13

Flexible Queue Observing

- Programs are selected by telescope operator using the JCMT Query Tool (QT)
- PI notified when data collection starts
- PI notified when data reduced and sent to CADC
- Telescope operator performs initial data Quality Assessment - ***but go check your data!***



JCMT Remote Observing

- Switched from summit observing + visiting scientist, to remote observing with no visiting scientist in **November 2019.**
- Programs observed according to flexible observing rules.
- Weather, systems and data quality monitored closely

JCMT `Ohana


660
East Asian Observatory
James Clerk Maxwell Telescope
UKIRT Observatory

Questions?