Mauna Kea

Per Friberg
Head of Instrumentation JCMT

- Master degree in Engineering from Chalmers University of Technology (Sweden) - Theoretical Physics/Computers (1977).
- Ph.D .Onsala Space Observatory 1983. Spectroscopy of organic molecules in space.
- Post Doc. FCRAO, University of Massachusetts (Amherst)
- Researcher at Onsala Observatory.
- Staff member at the SEST telescope in Chile.
- Joined the JCMT staff in 1990.
- Head of Instrumentation JCMT since 1999.

JCMT
Telescope and Instrumentation
January 2015

Main Instruments:

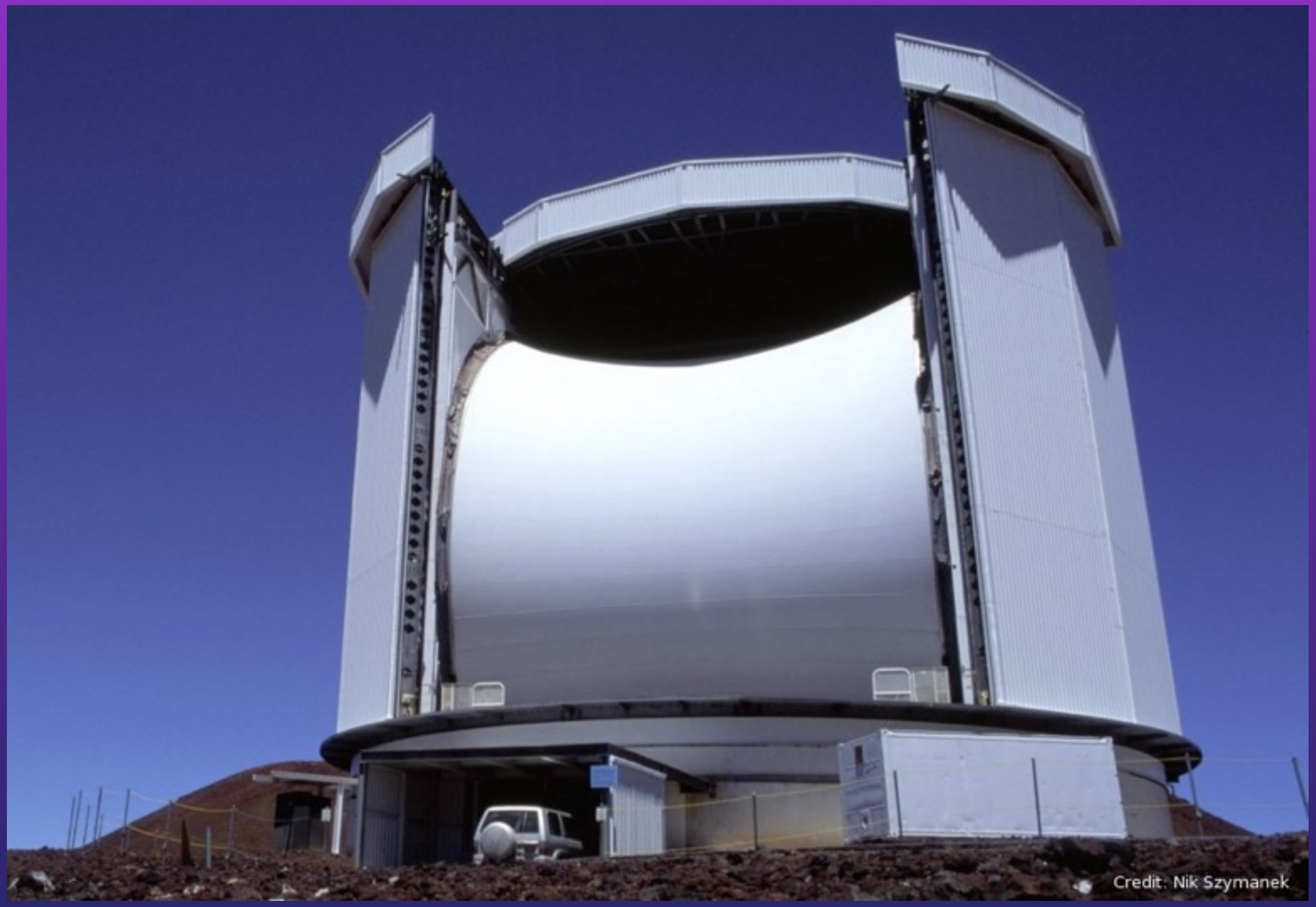
- SCUBA-2 - 10.000 pixel bolometer camera operating simultaneously at 450 and 850 μm
- HARP - 16 pixel 350 GHz band heterodyne array receiver
- RxA - Single pixel 230 GHz band heterodyne receiver (mmVLBI)
- ACSIS - 32 channel spectrometer used with the heterodyne inst.

Additional Instruments

- RxW - 660 GHz band heterodyne receiver. Out of service. Competes with SCUBA-2
- POL-2 - Polarimeter for the full field of SCUBA-2. Under commissioning. Operates at 450 and 850 μm
- FTS-2 - Fourier Transform Spectrometer for ~1/8 the SCUBA-2 field of view. Under commissioning. Operates at 450 and 850 μm
- Rover - Heterodyne Polarimeter. Partly Commissioned. Operates at the 230 and 350 GHz band.

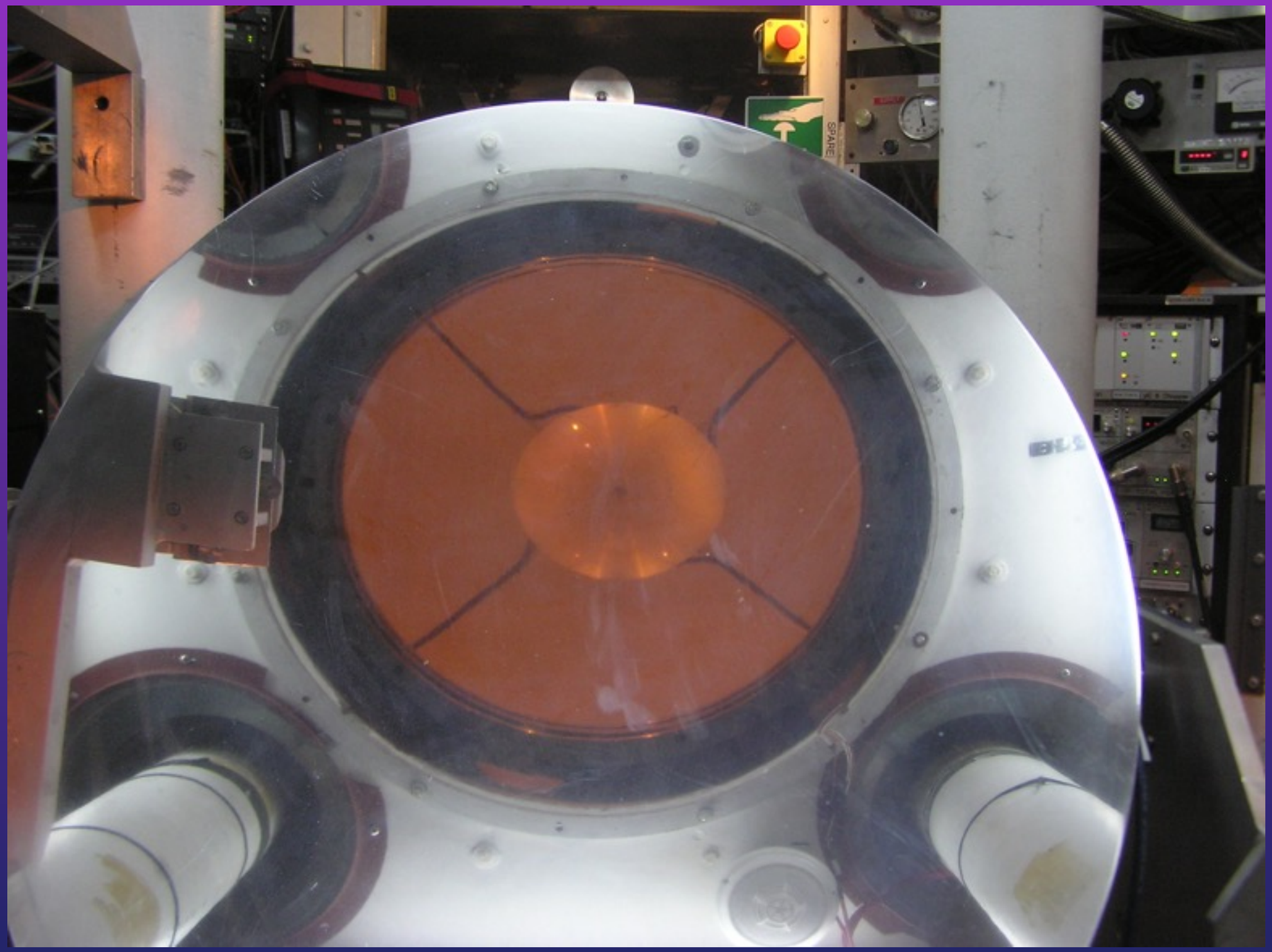
Helper Instruments

- Water Vapor Monitor. Looks at 183 GHz water line and measure atmospheric water vapor content. Used to and calculate the opacity (extinction). Critical for SCUBA-2 calibration.
- Access to SMA phase monitor data. Used for the submm seeing.
- Holography System (H3): 80/160 GHz source and receiver for measuring the dish surface. Used to maintain the surface accuracy.

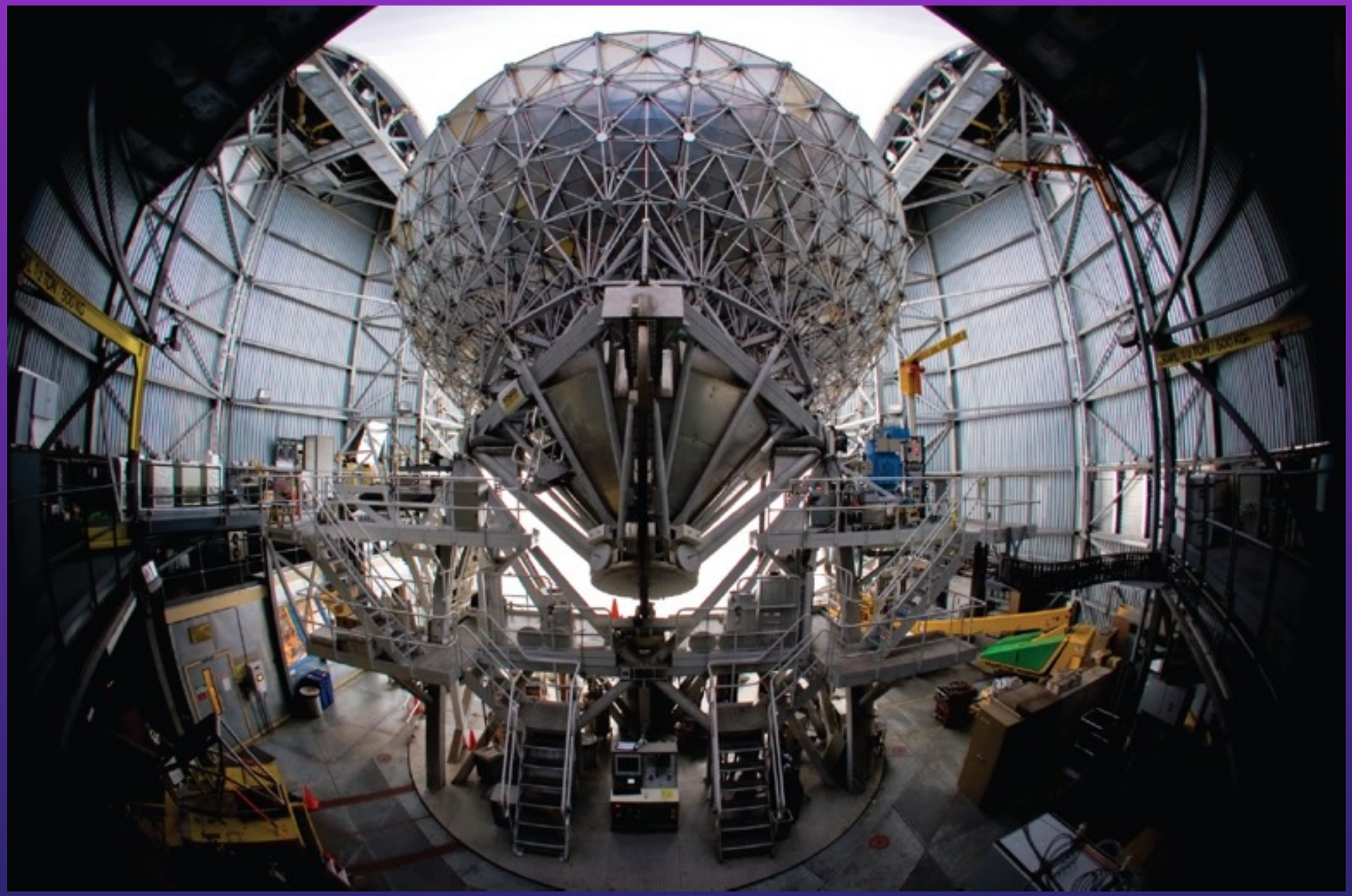


- Gortex membrane protects telescope when the building is open.
- Makes daytime observations possible - JCMT can observe the Sun
- Drawback losses, added noise and polarization.

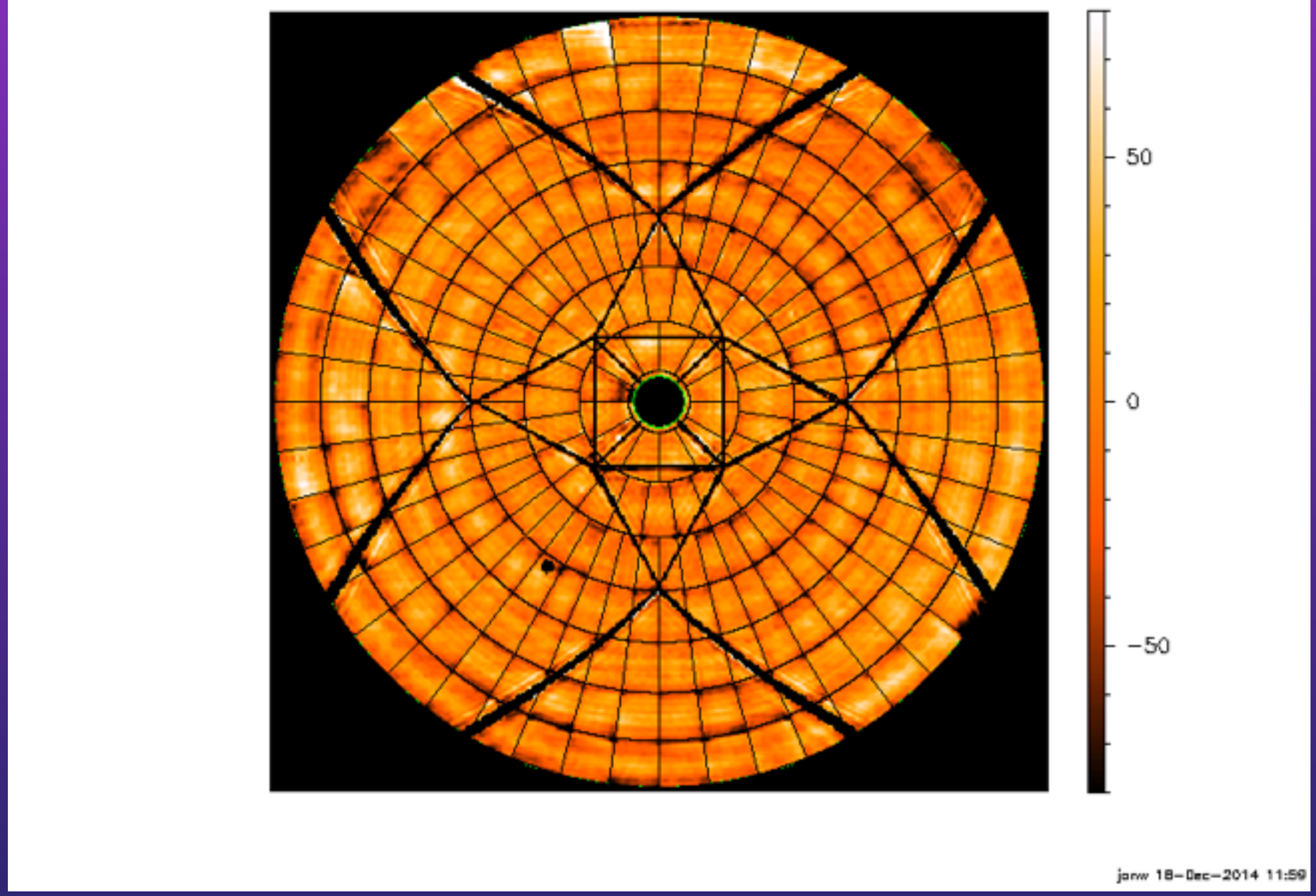
- Cassegrain design - 10’ FOV
- Focal Stations: Cass. cabin, Left & Right Nasmyth
- Chopping Secondary



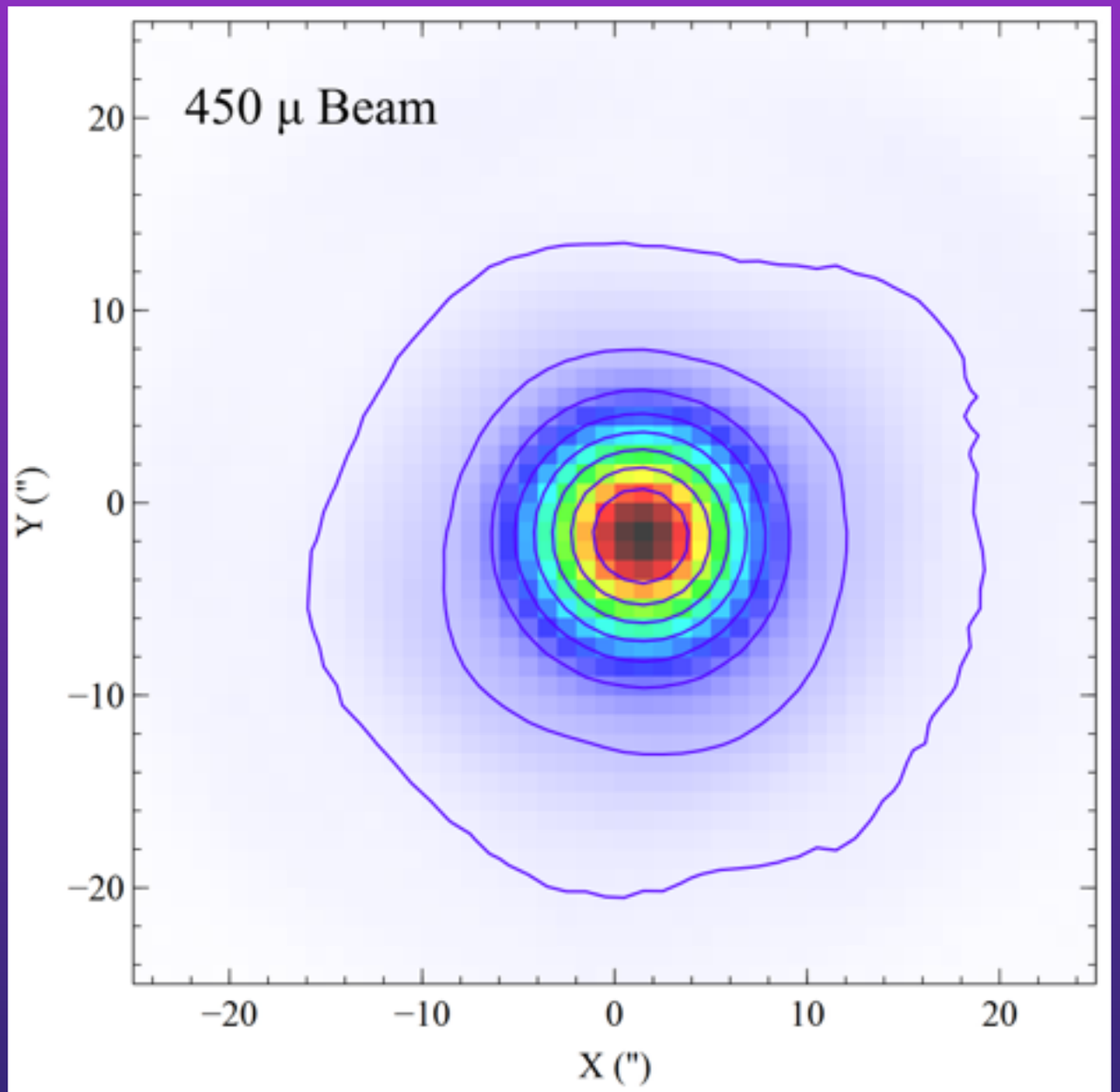
SCUBA-2 tertiary mirror with reflection of the secondary mirror and support.

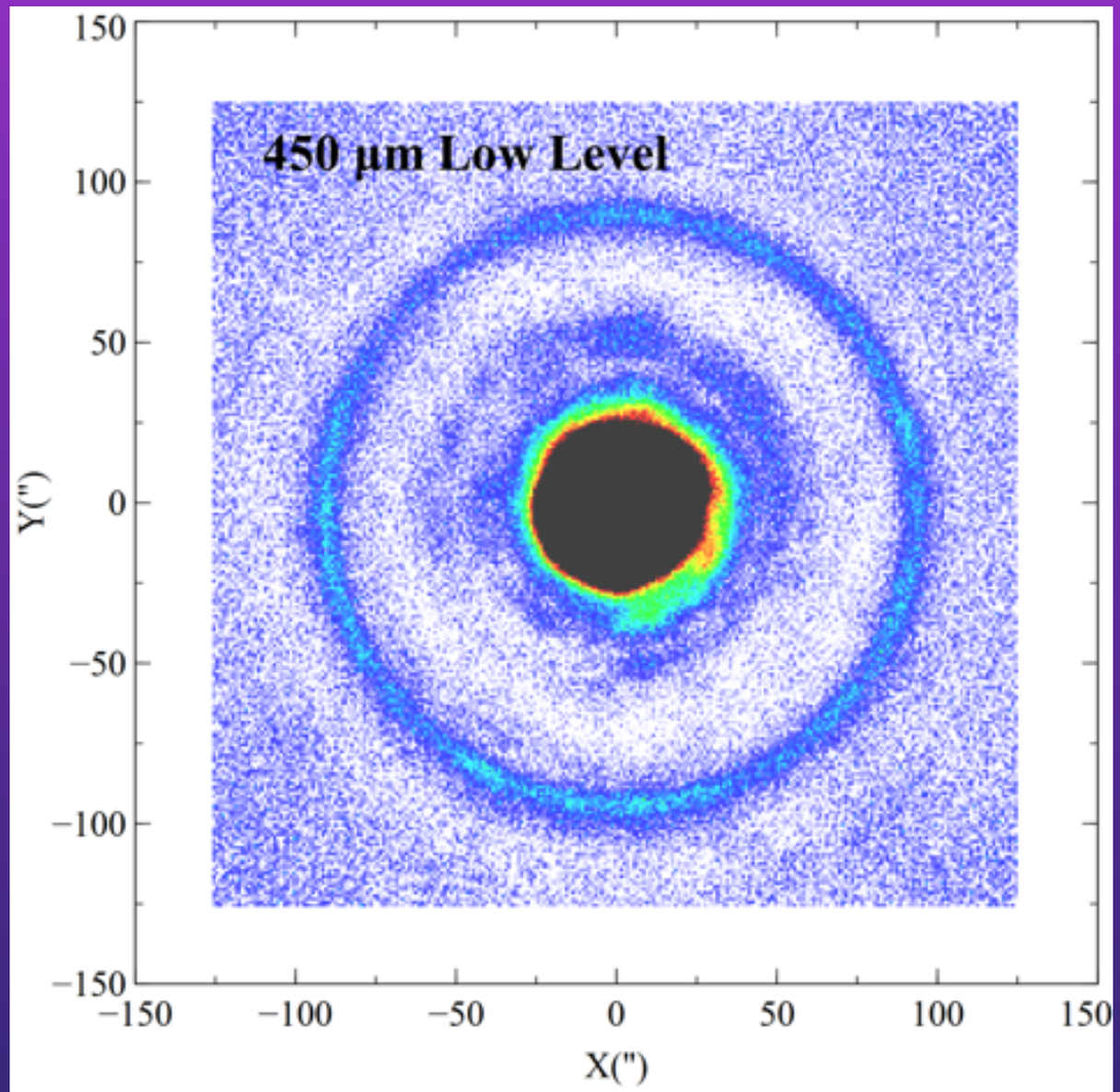


Backup structure and surface consiting of 276 panels - adjusted by 828 stepper motors.

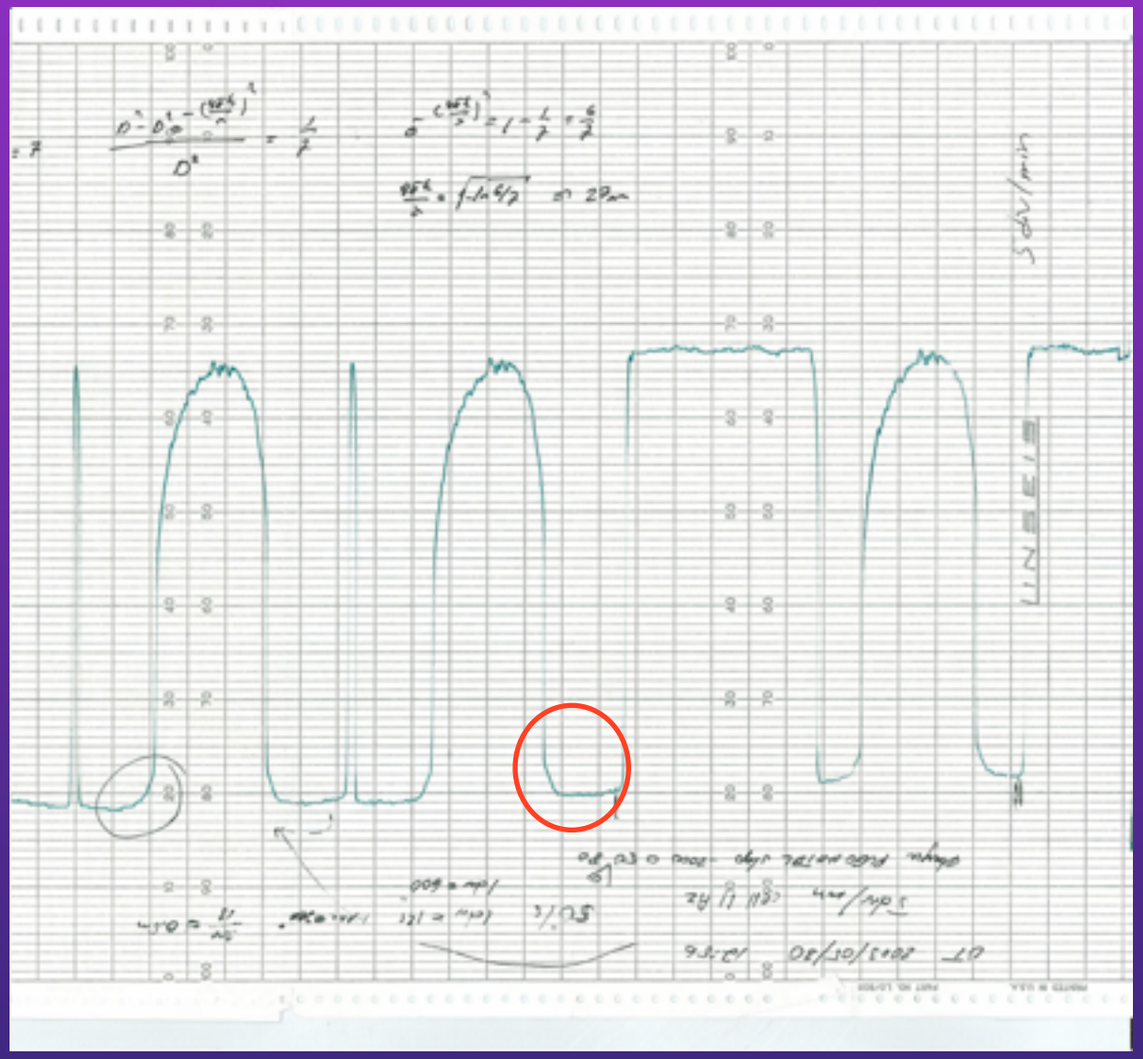


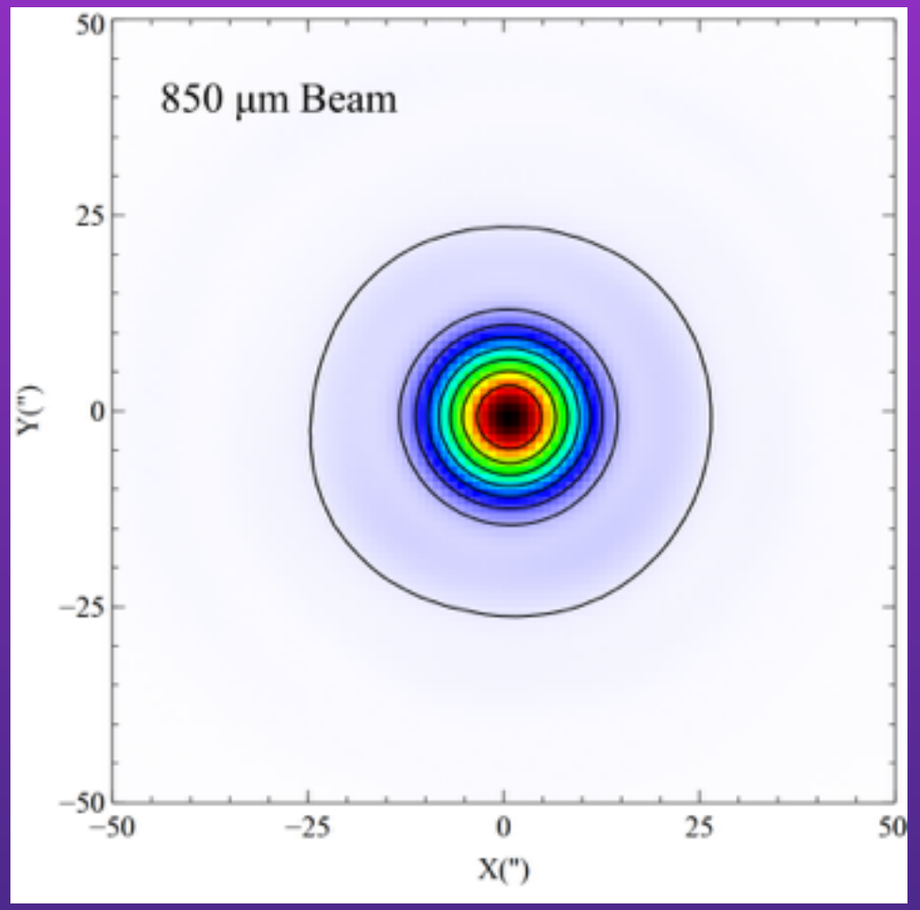
160 GHz surface map from December 18th. 2014
Measured rms 23.4 micron.
Panels and shadows from secondary as it's support visible.
Map takes 2 hours and is obtained during night time due to thermal issues.

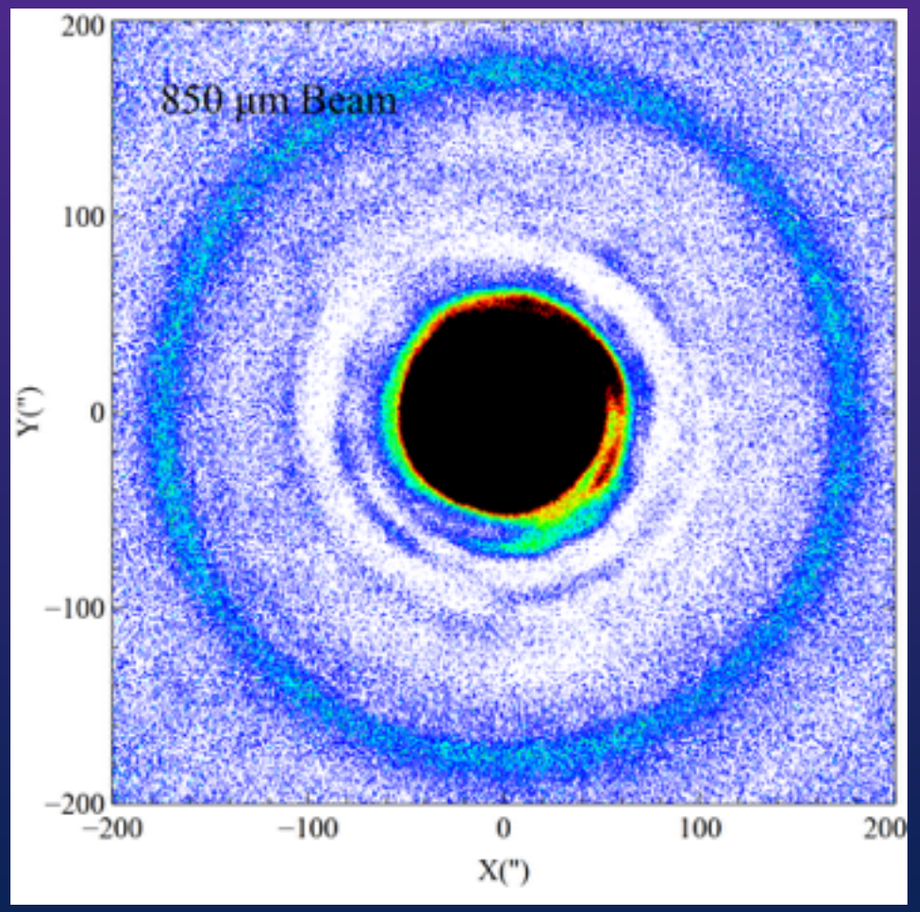




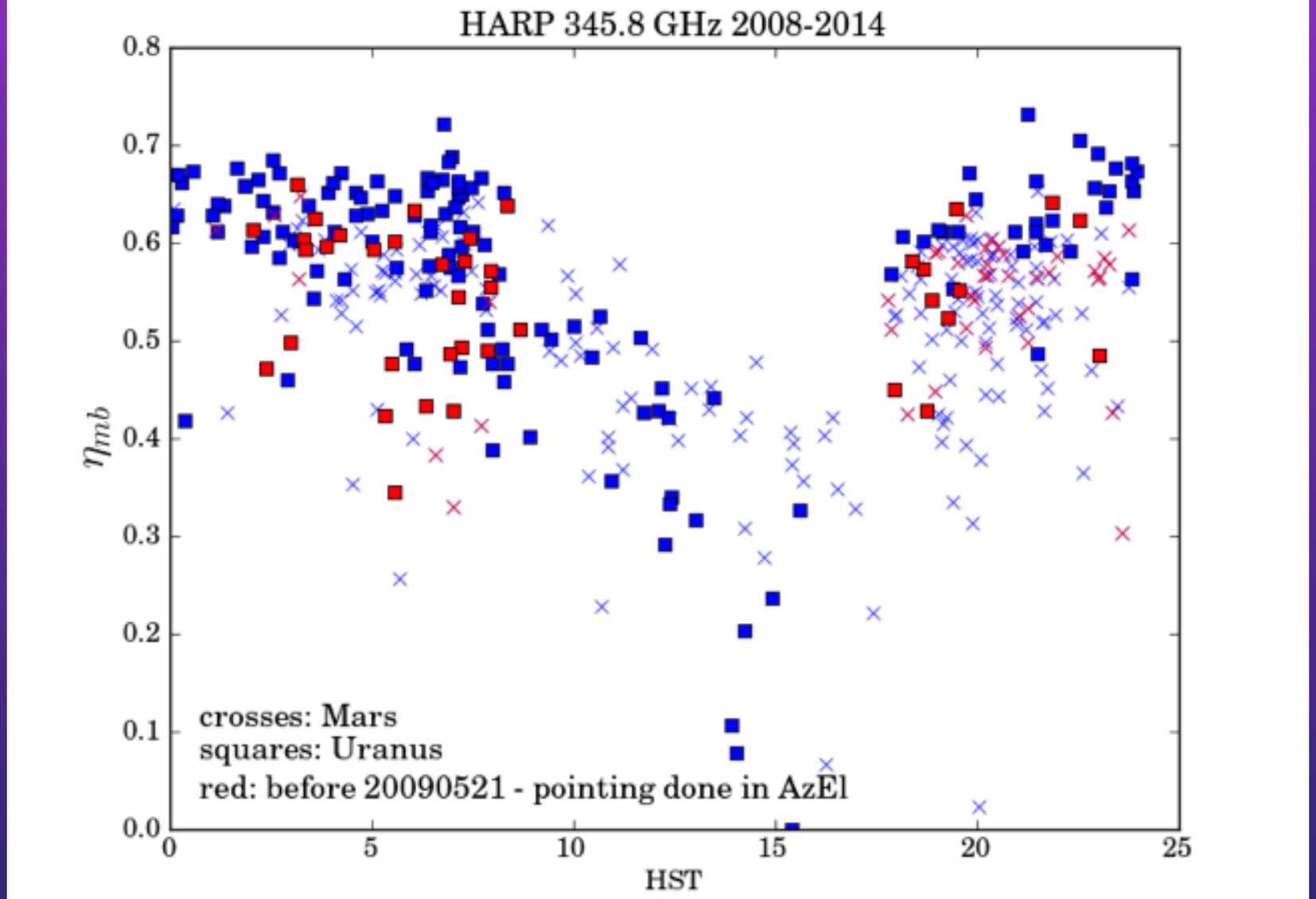
- Beam maps at 450 micron
- Core beam Gaussian HPBW 7.9” with a lower pedestal HPBW 25”
- Ring ~ 183” diameter at low level





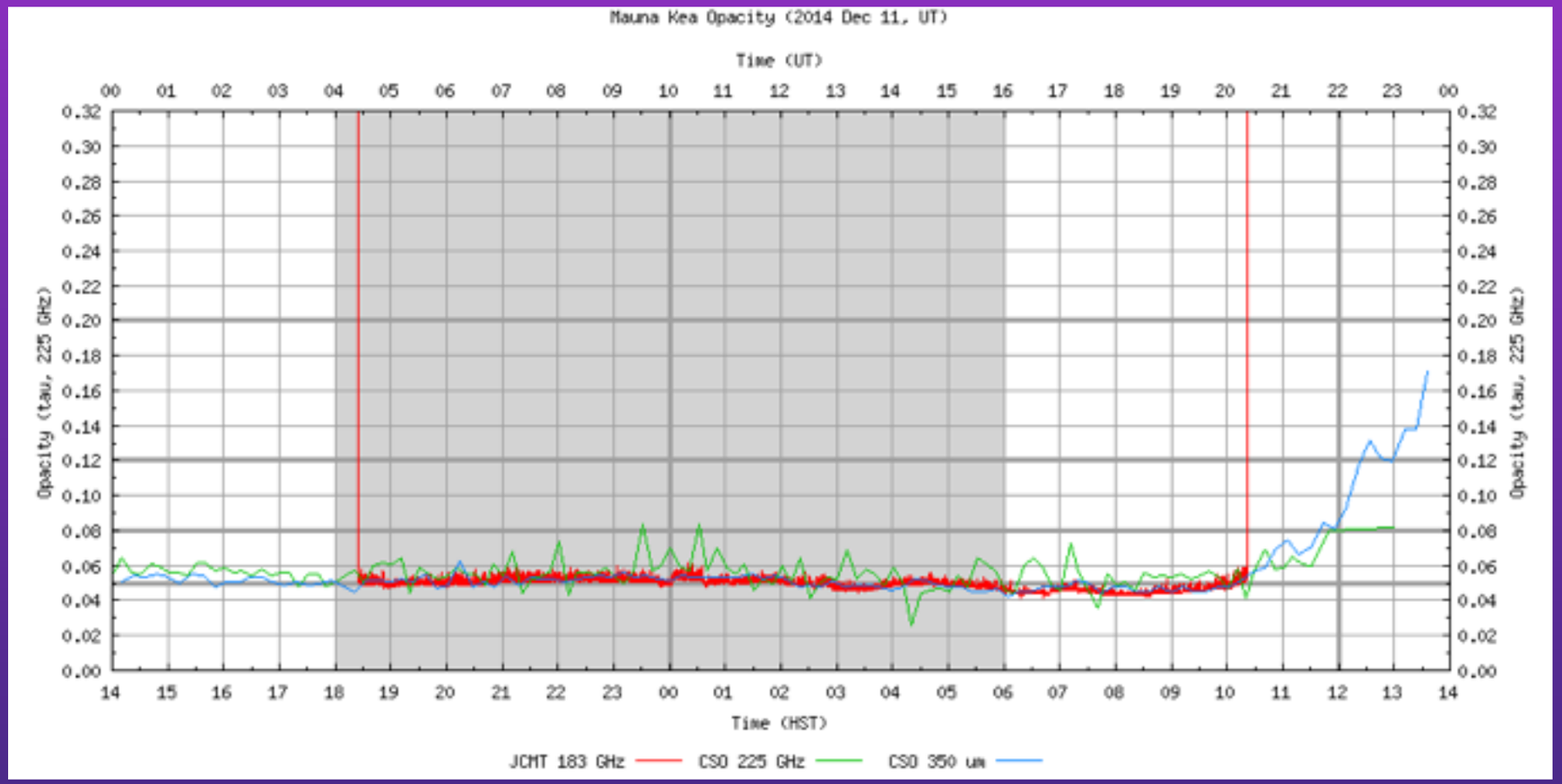


Moon Scan with 350 GHz receiver. Sensitive to more extended beam contributions.

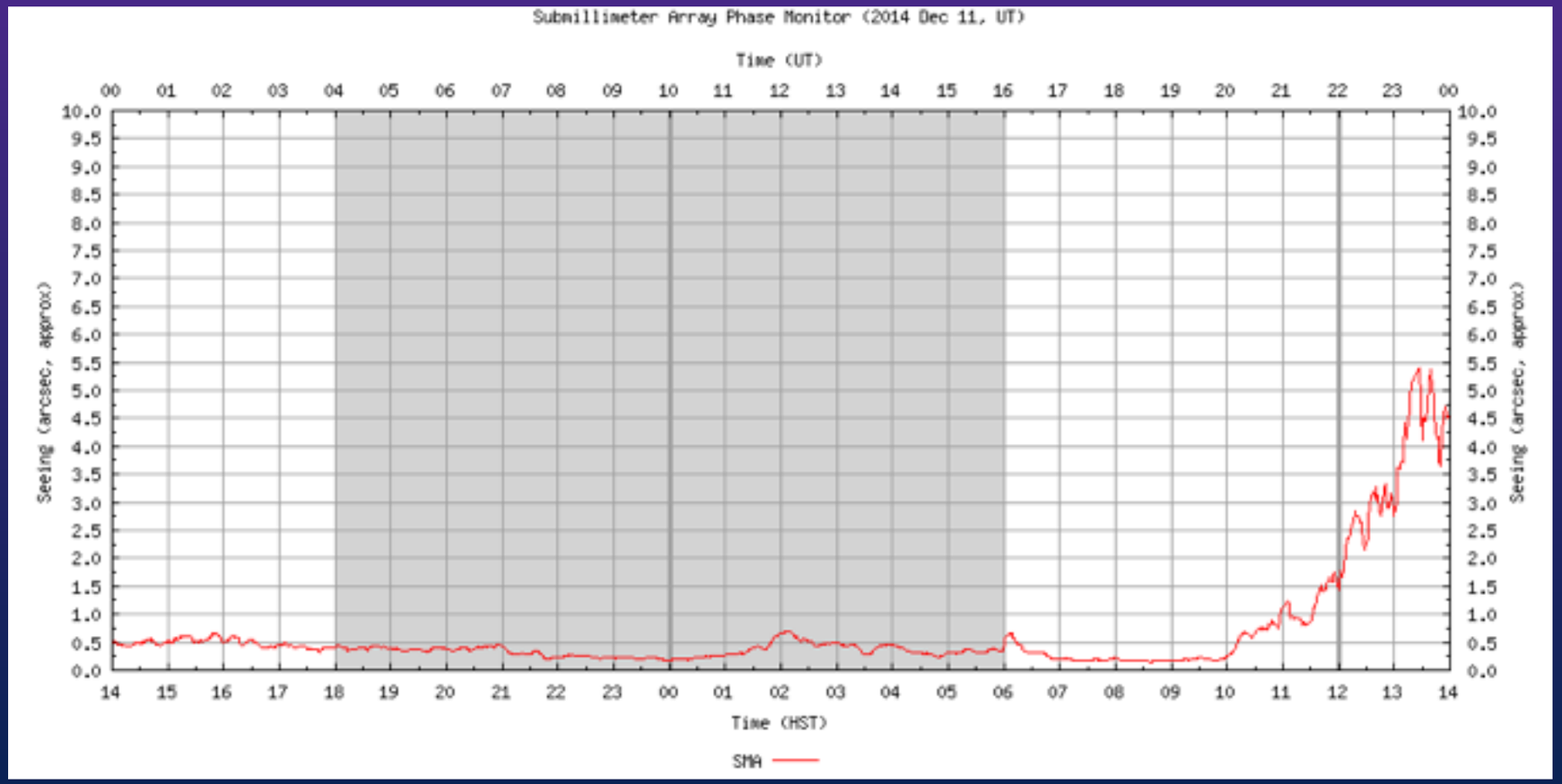


Daytime decrease in efficiency

- Cause - thermal distortions
- Also due to opacity variations and poor seeing



225 GHz
Opacity
wvm - red
CSO 225 -green
350μm-blue

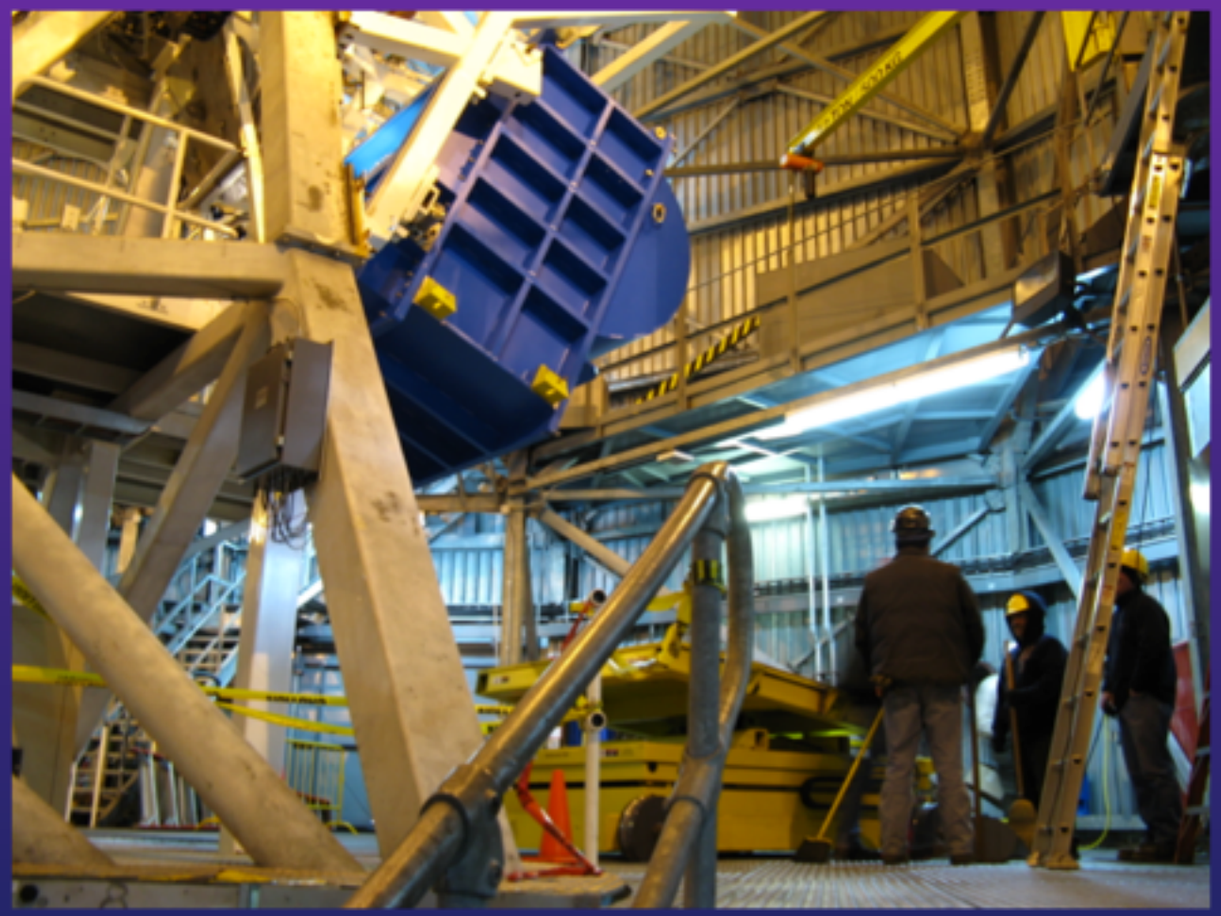


Seeing
SMA phase
monitor

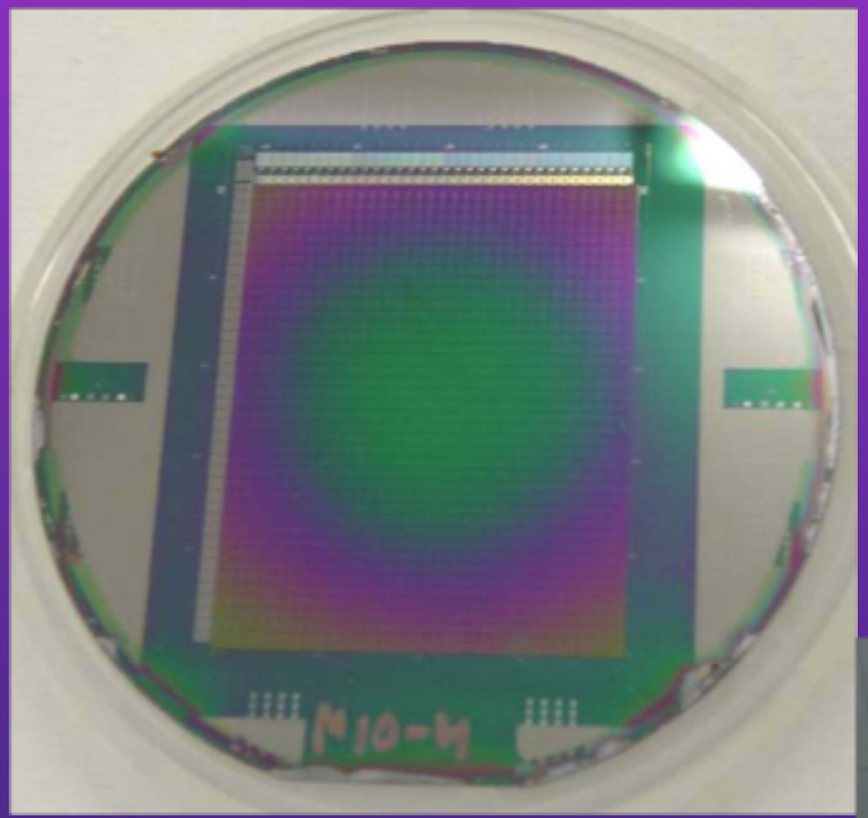
Seeing needed
for 450 < 1”
for 850 < 2”

SCUBA-2

10,000 pixel bolometer camera using Transition Edge Sensors (TES)



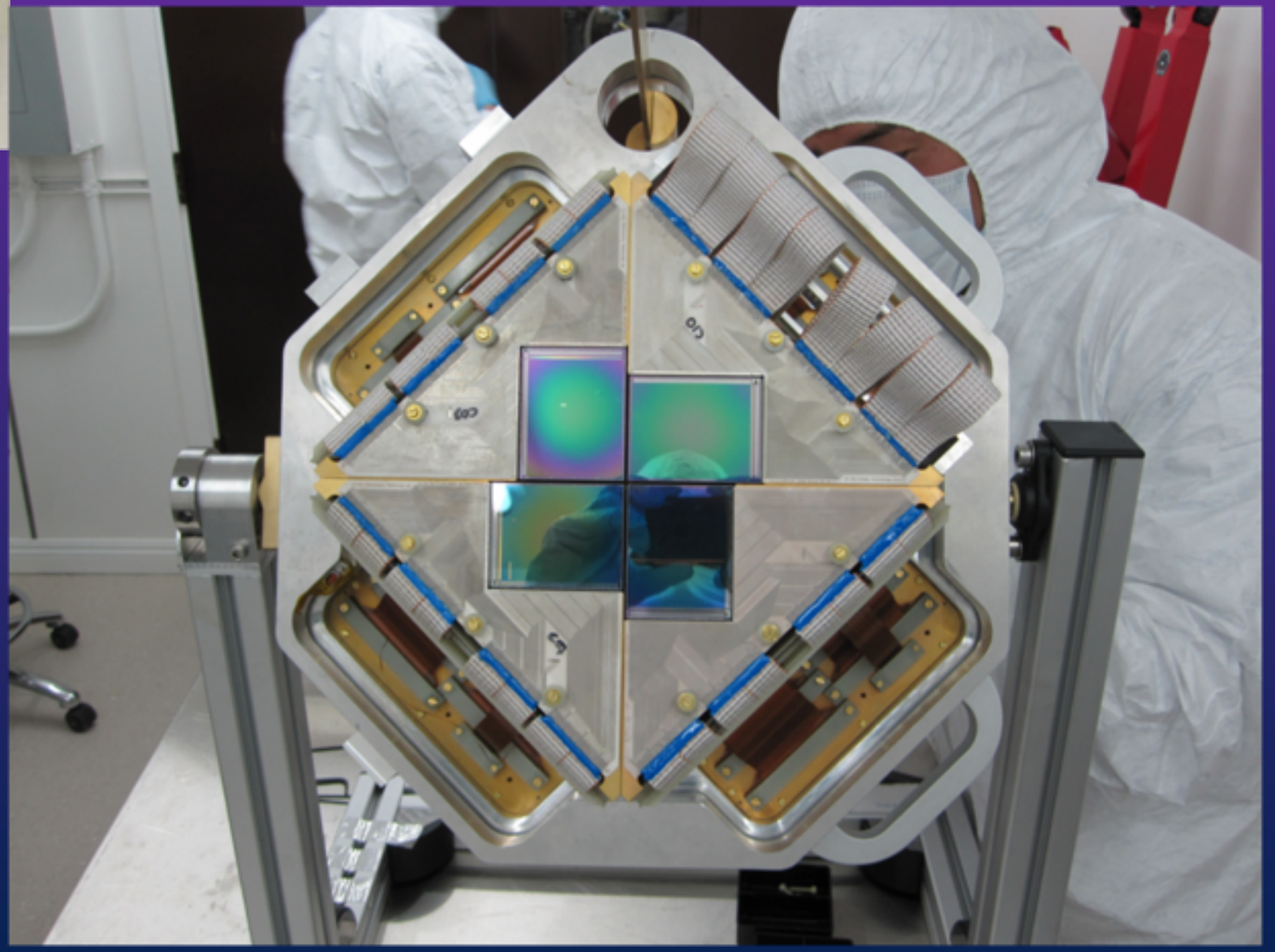
ATC, NIST, Cardiff University, Scottish Microelectronics Centre, UBC, Waterloo (Ca), Raethon …

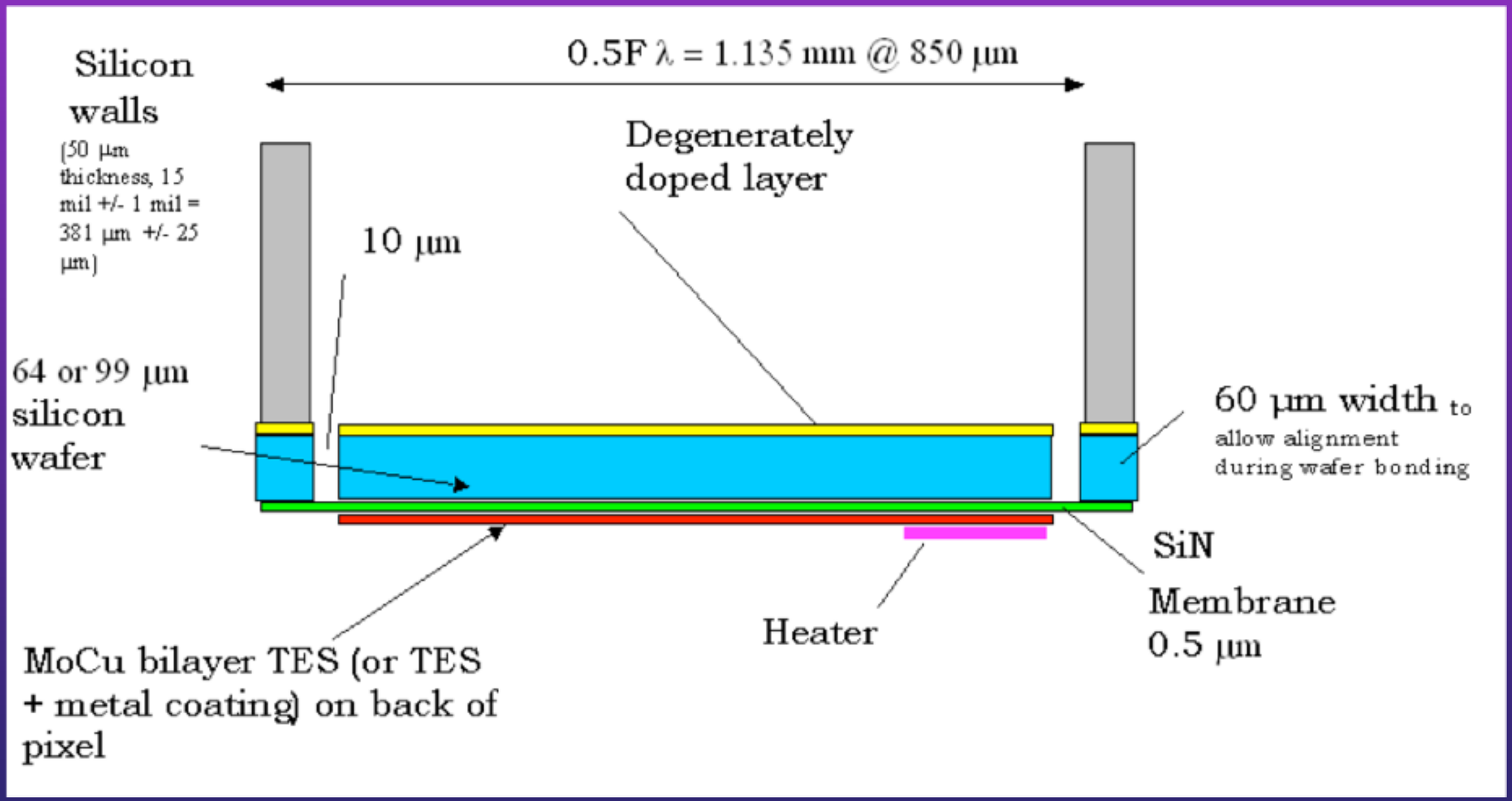


SCUBA-2
Lithographic Fabrication
“CCD like”

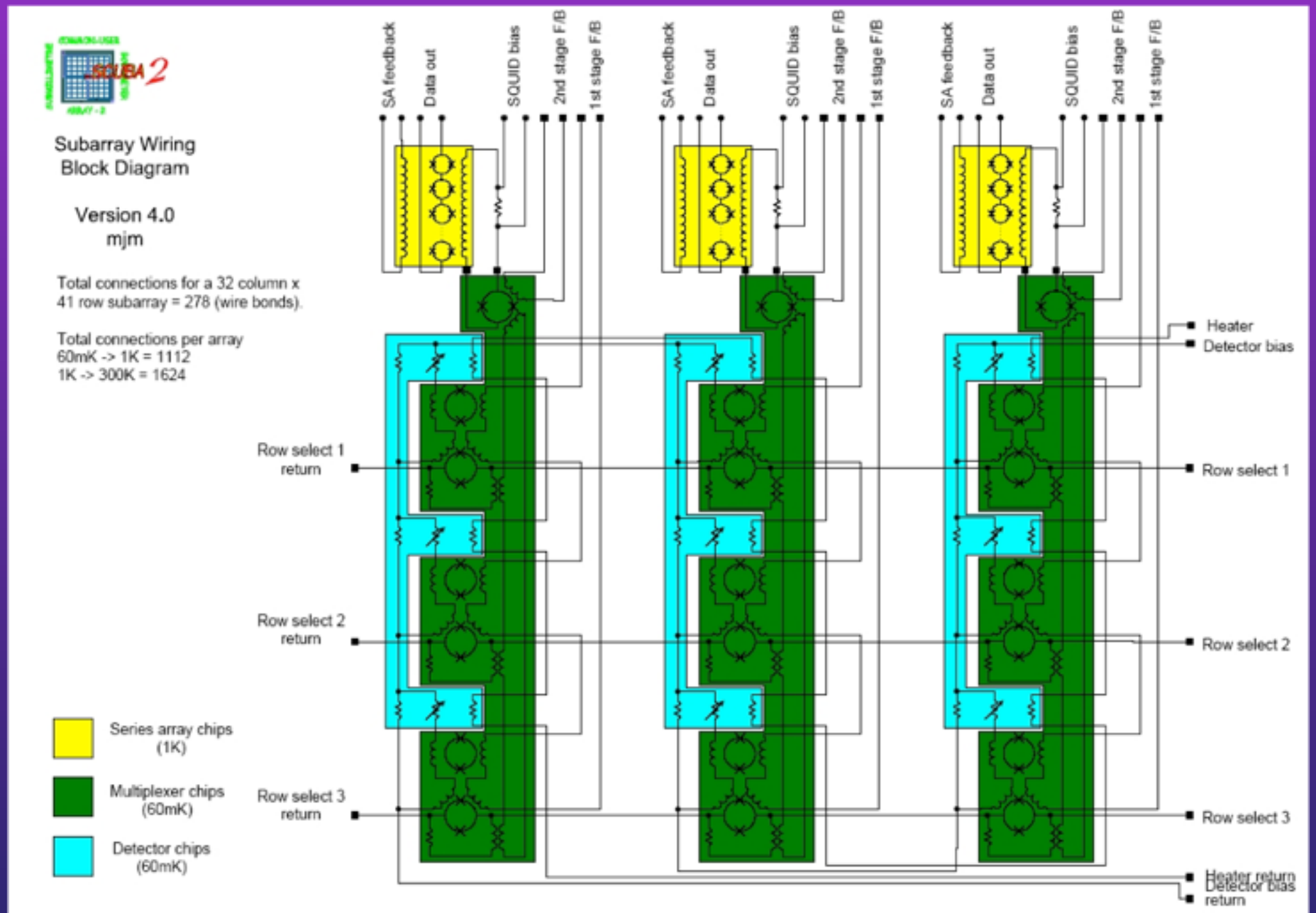
Single subarray on 3” wafer. 32 columns x 40 rows => 1280 pixels

Focal Plane with four arrays





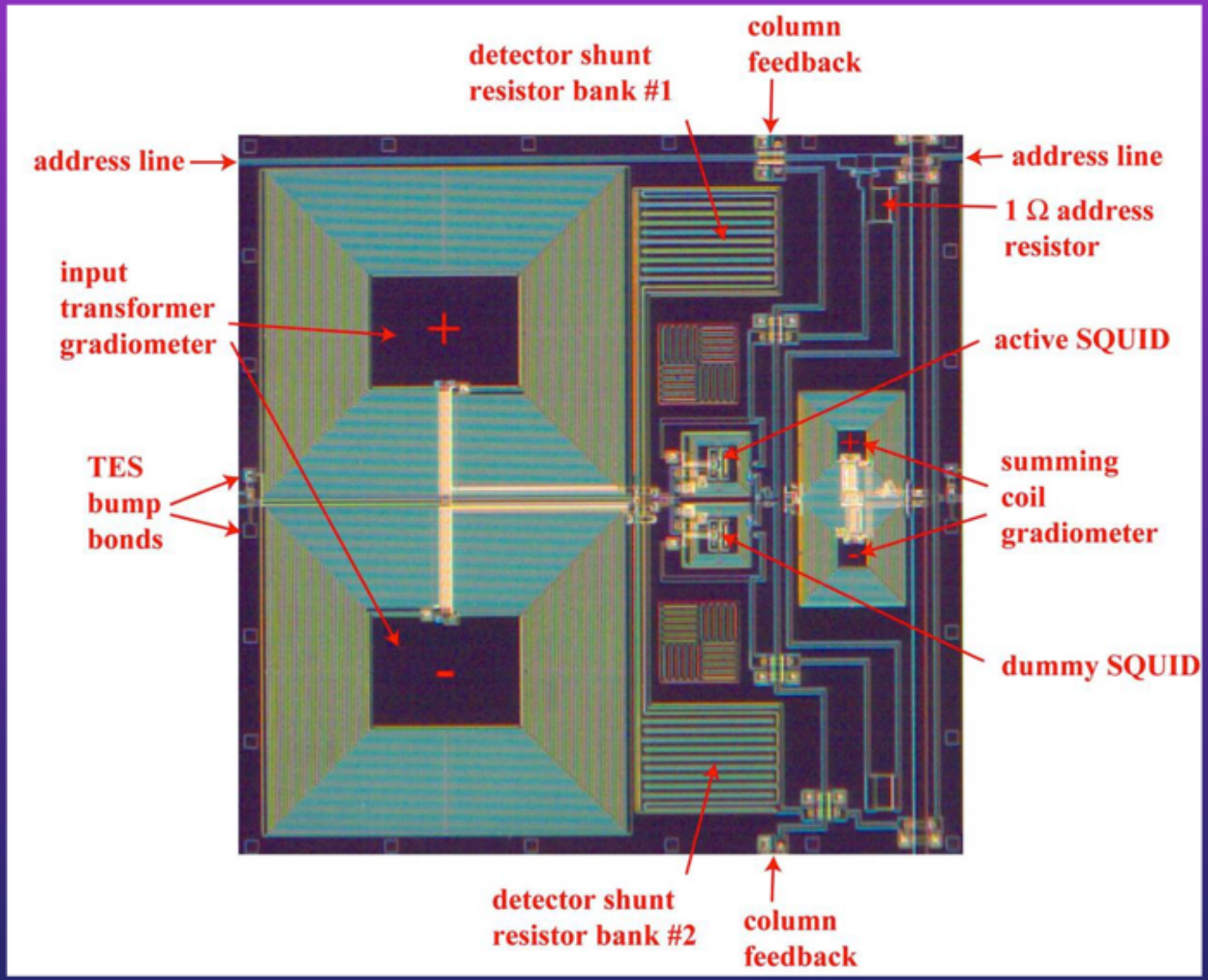
- Single pixel Bolometer schematics. Fλ/2 @ 850 Fλ @ 450
- TES Tc 140 mK @ 850 Tc 180 mK @ 450



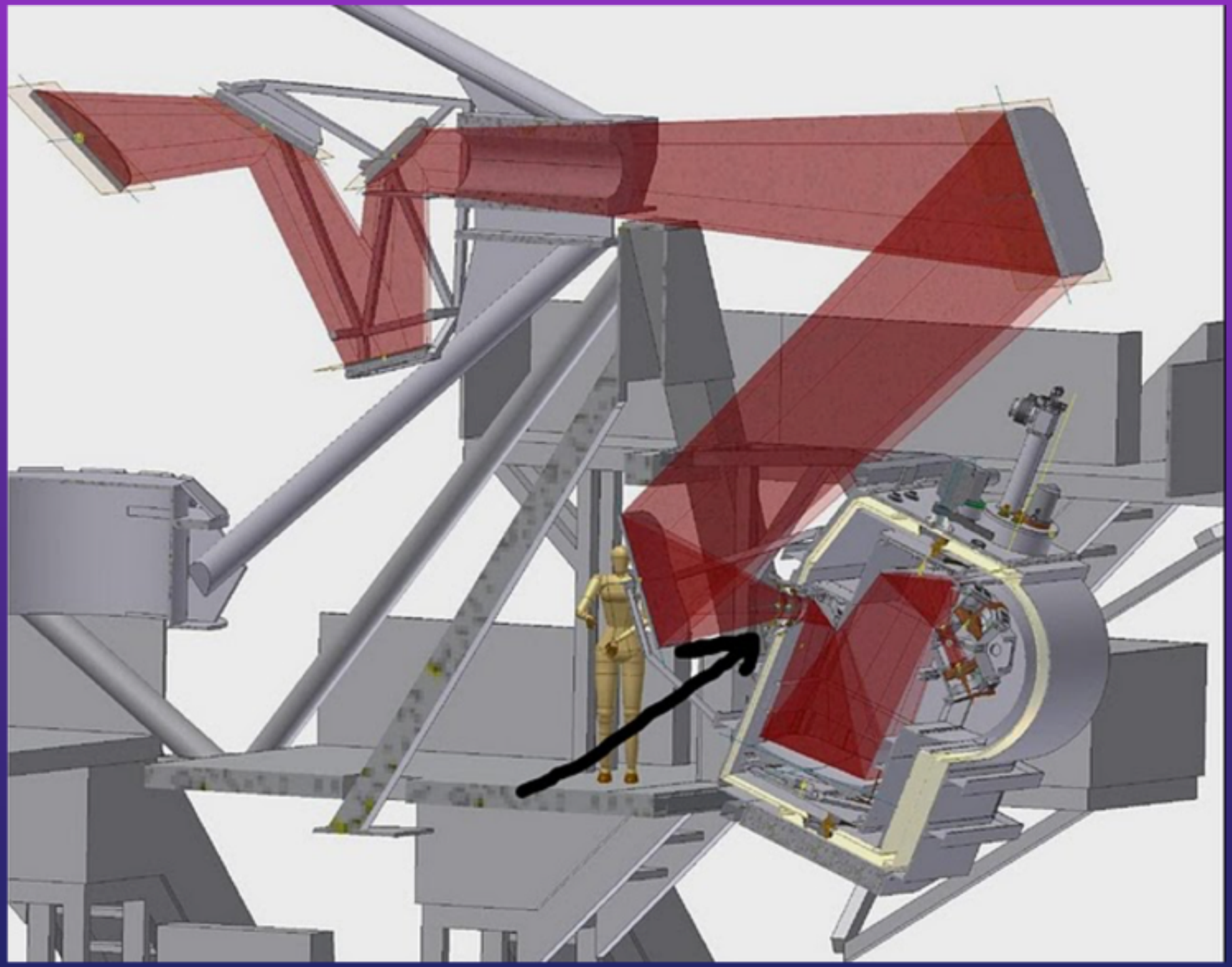
Simplified schematics of SQUID multiplexer with 3 rows 3 columns

Colors different wafers - detector (blue), multiplexer (green), yellow (SQUID amp)

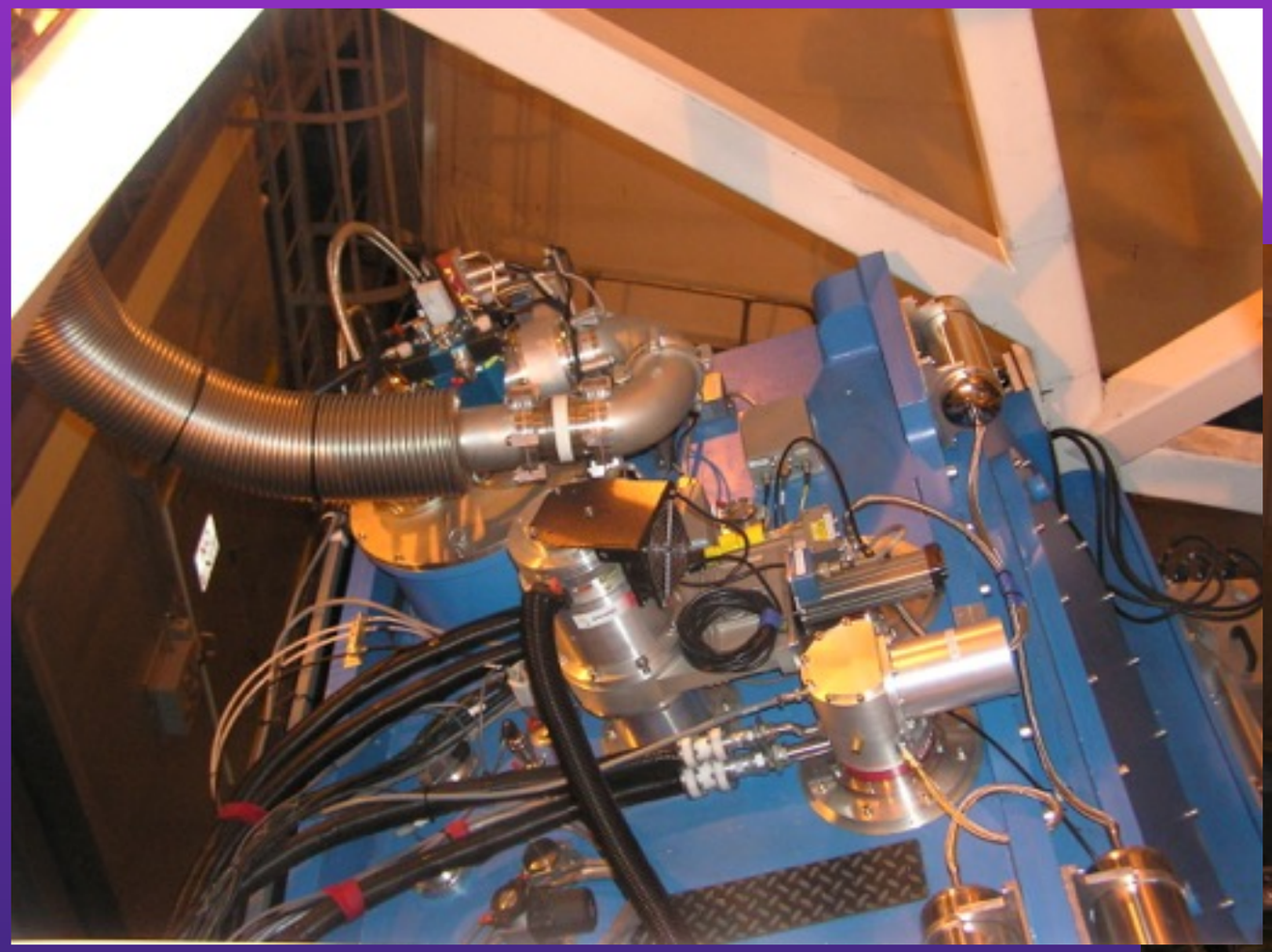
Only one bias and one heater connection per array.

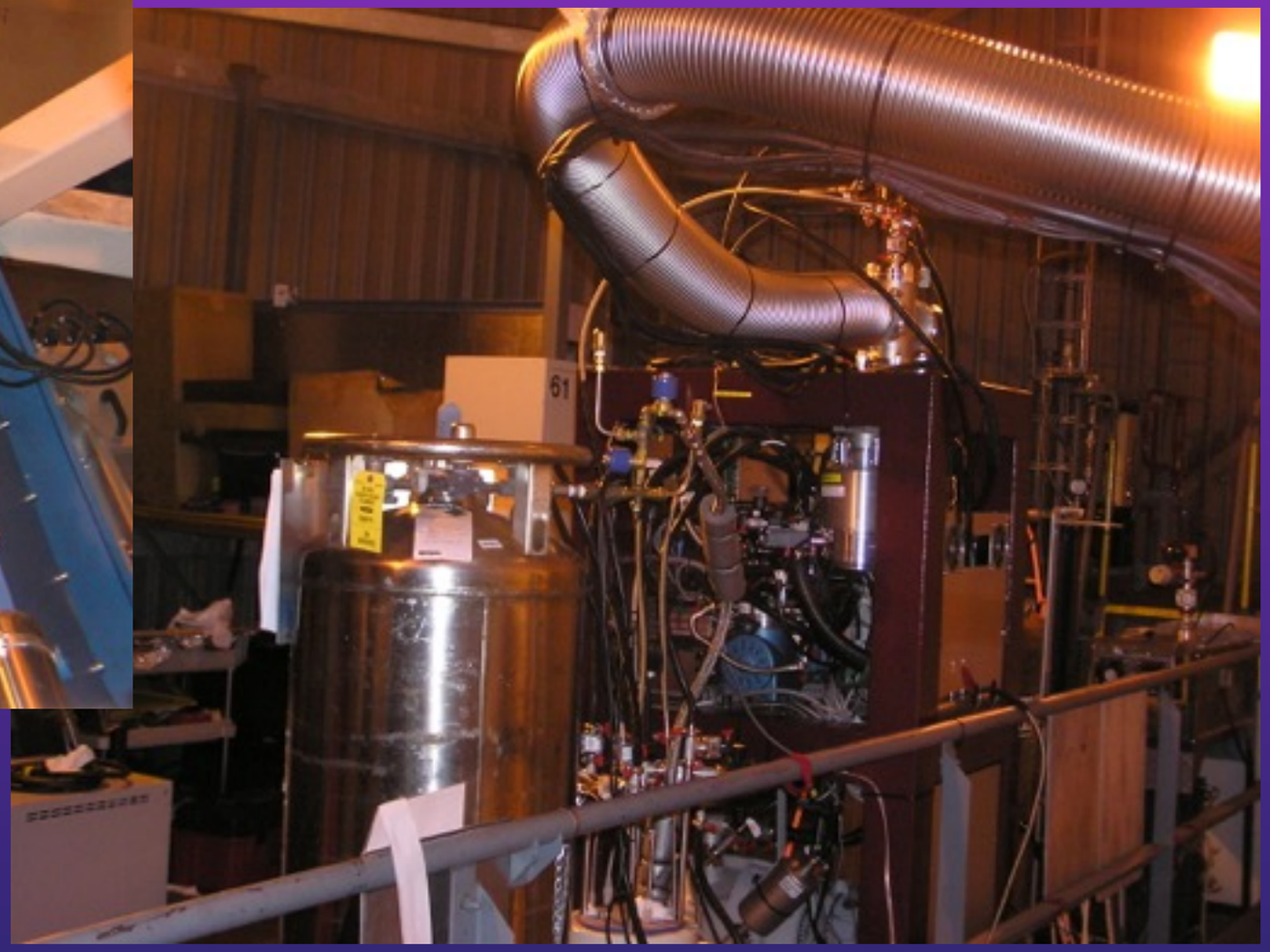


- Layout of one SQUID readout cell
- One cell ~ 1x1 mm behind each bolometer



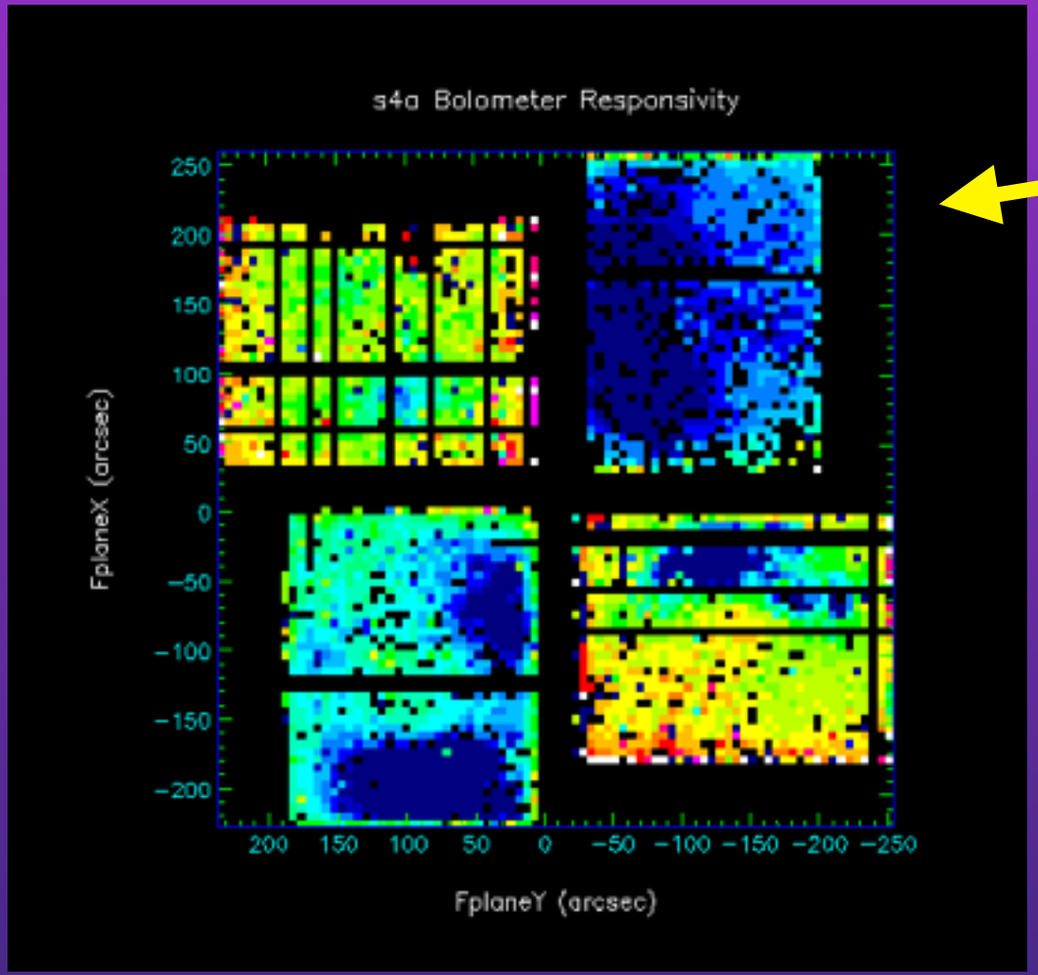
- SCUBA-2 optics





SCUBA-2 fridge - we can keep SCUBA-2 cold for over a year.

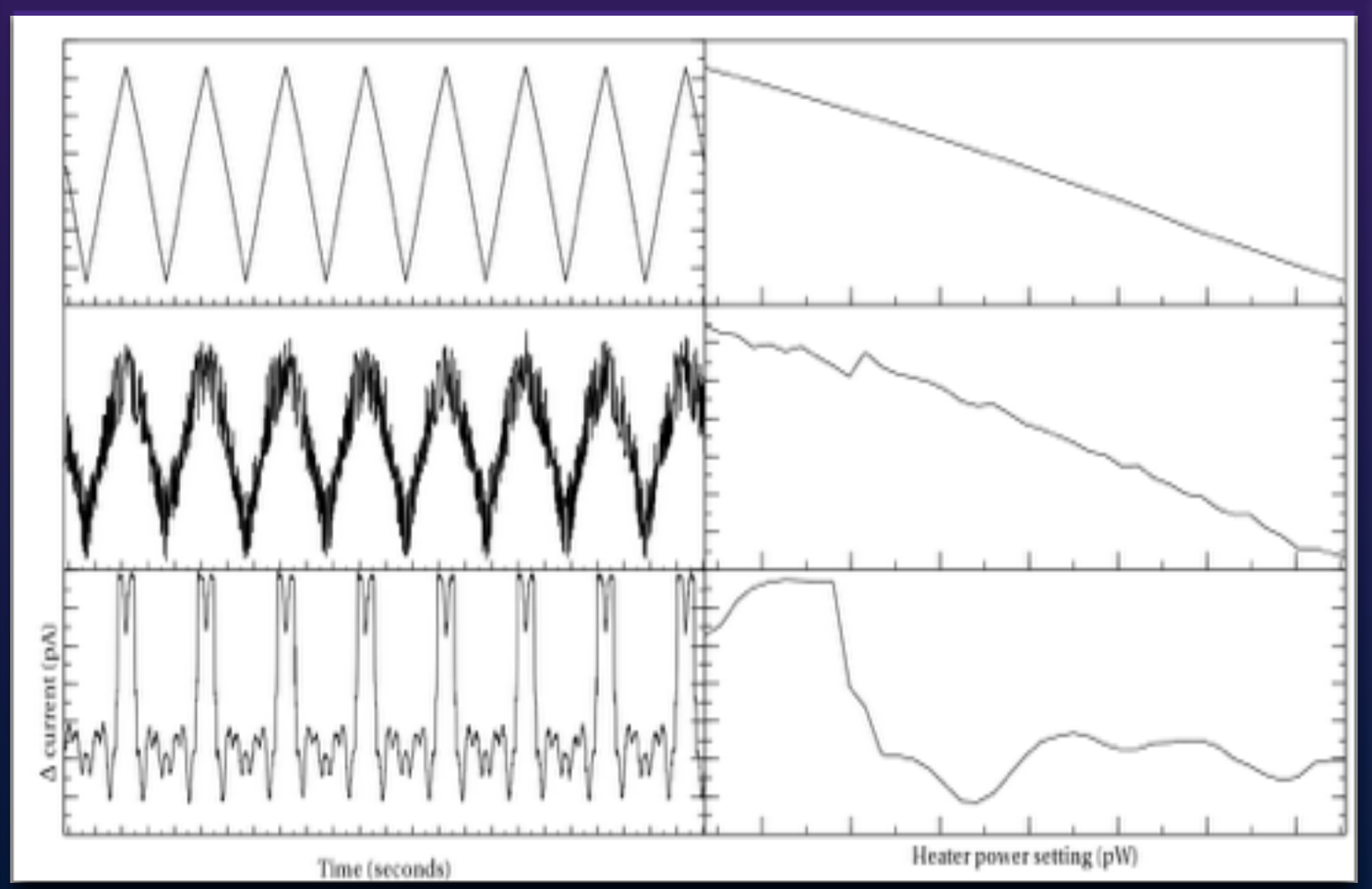
Dilution fridge base temperature ~ 50 mK

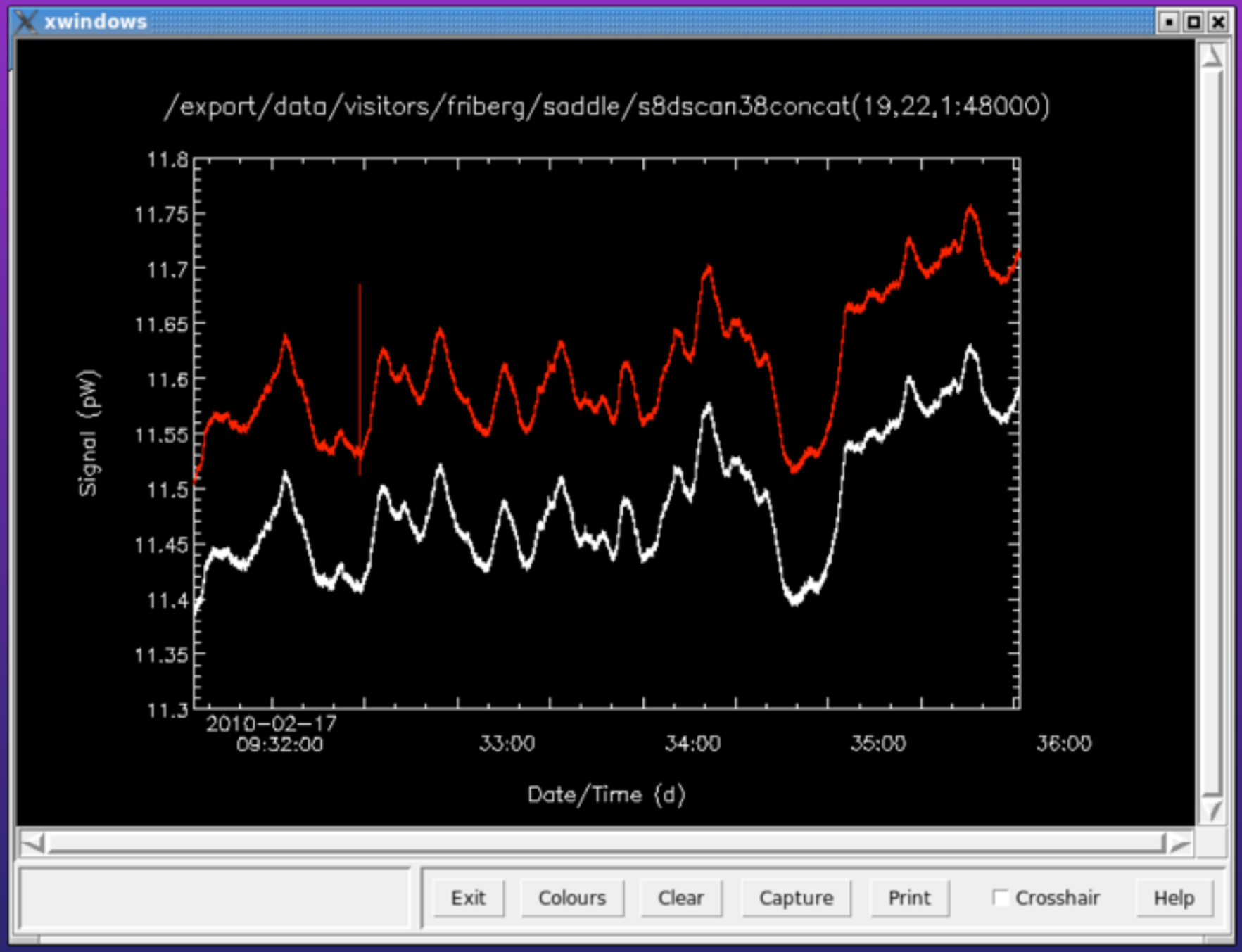


Array responsitivity or flat filed @ 450 micron

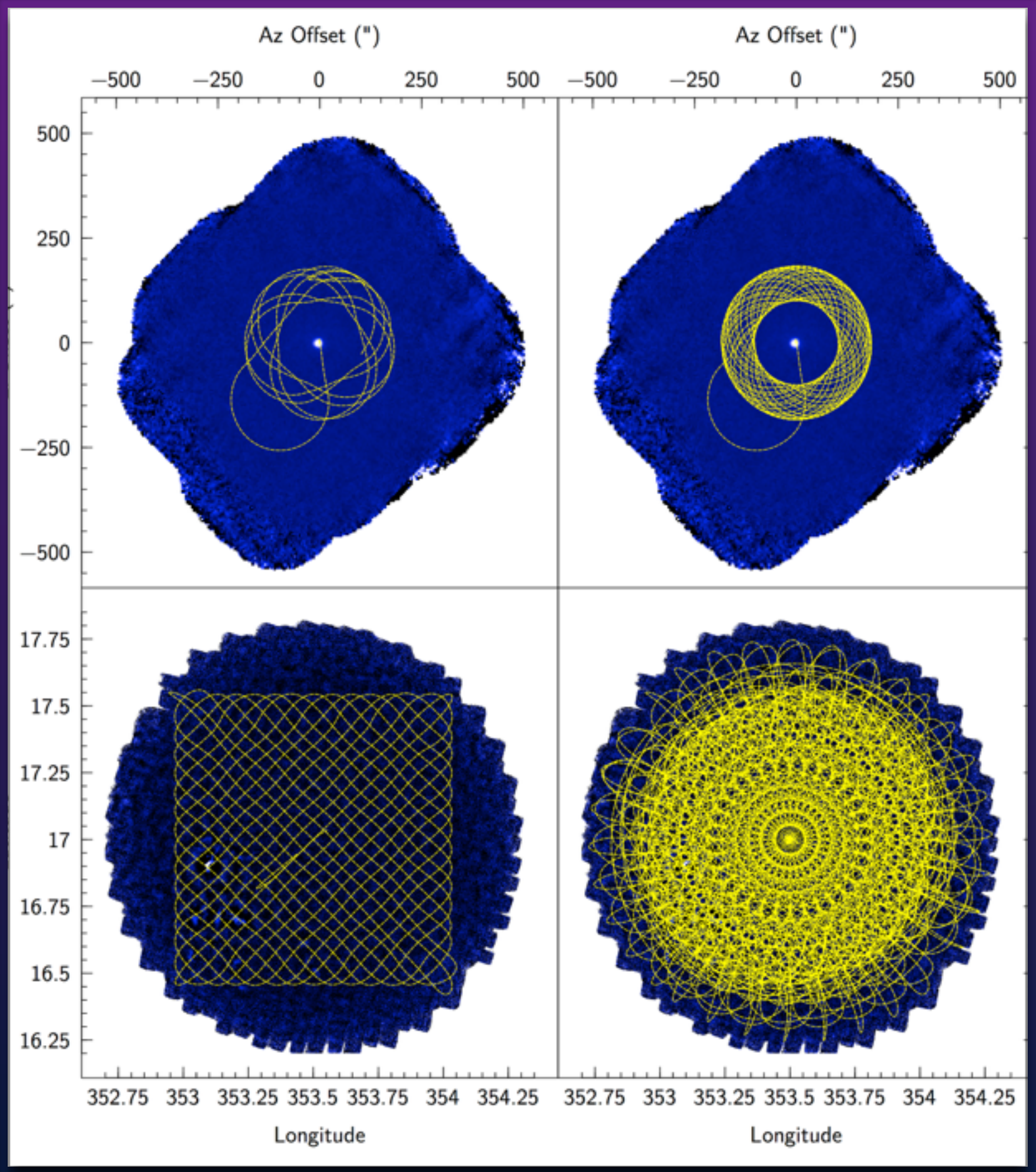
Flat fielding by ramping the heater.

The flat field ramps calibrates the data and is used to identify noisy and non-linear bolometers for removal.





- SCUBA-2 flat field time series data from two bolometers
- Signal dominated by common mode from atmosphere, temperature drifts, magnetic pickup …



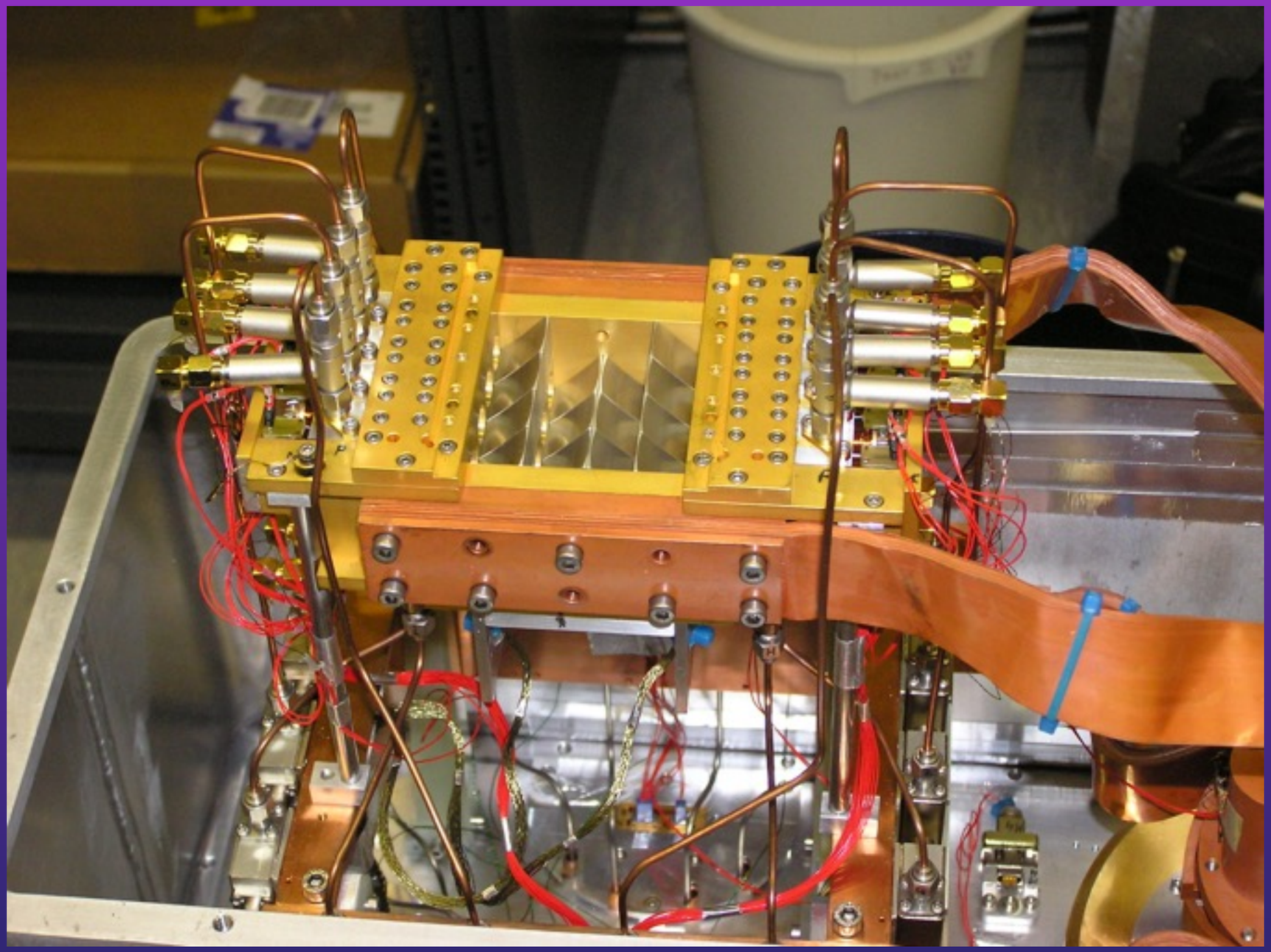
- **Daisy'**: small fields (< 8 arcmin)
  - *Constant speed, size and turning radius optimised for maximum on-source integration time*
- **'Pong'**: large fields (0.25 < deg < 2)
  - *Speed, spacing, rotation number and angle optimised for most even exposure time over widest possible field*

SCUBA-2 NEP

Wavelength	Yield	NEP ($W\sqrt{s}$)	Responsivity (A/W)
850μm (dark)	3430	9.3×10^{-17}	1.4×10^{6}
850μm (sky)	3339	1.48×10^{-16}	1.4×10^{6}
450μm (dark)	3540	2.36×10^{-16}	6.1×10^{5}
450μm (sky)	3434	3.4×10^{-16}	6.1×10^{5}

HARP
16 Pixel
350 GHz
Band
Array

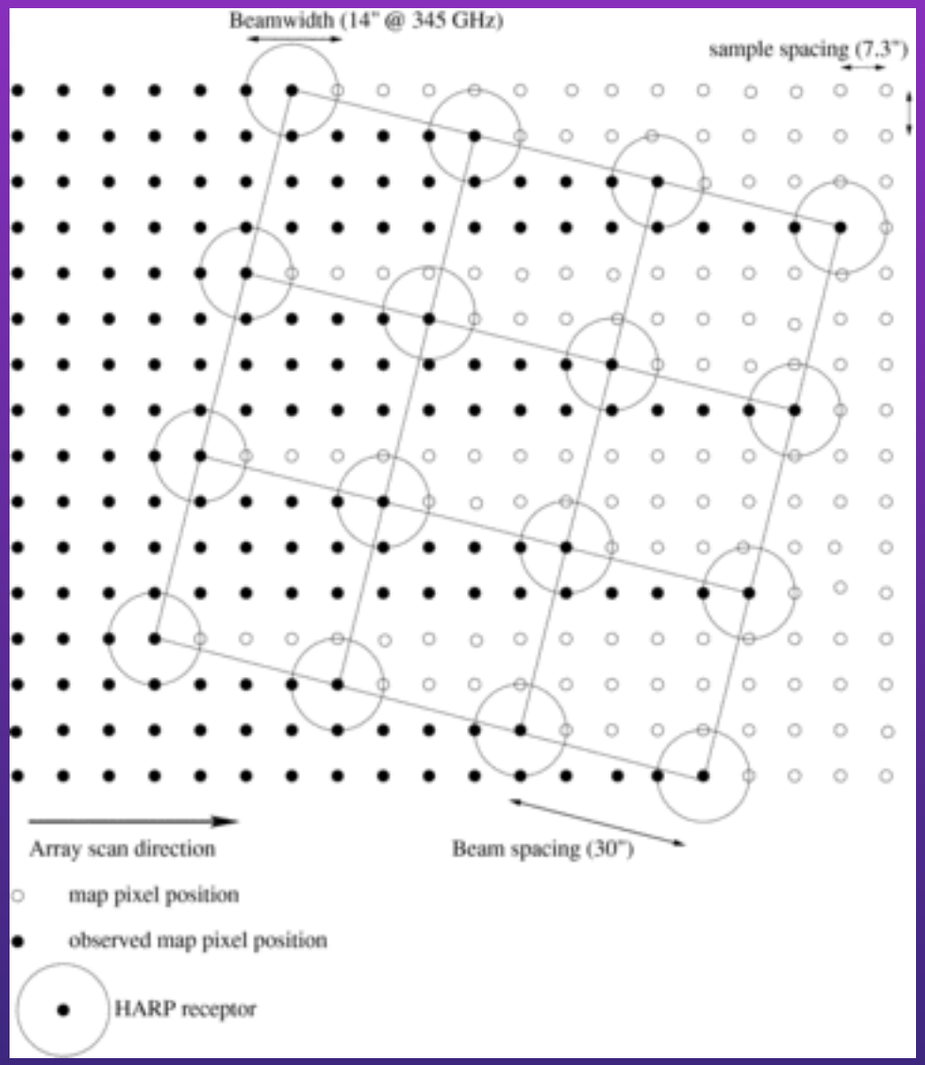
- Trx 100-150 K, IF bandwidth 2 GHz
- SSB mode with cold load termination.
- no Dual SideBand possible
- Automatic Tuning

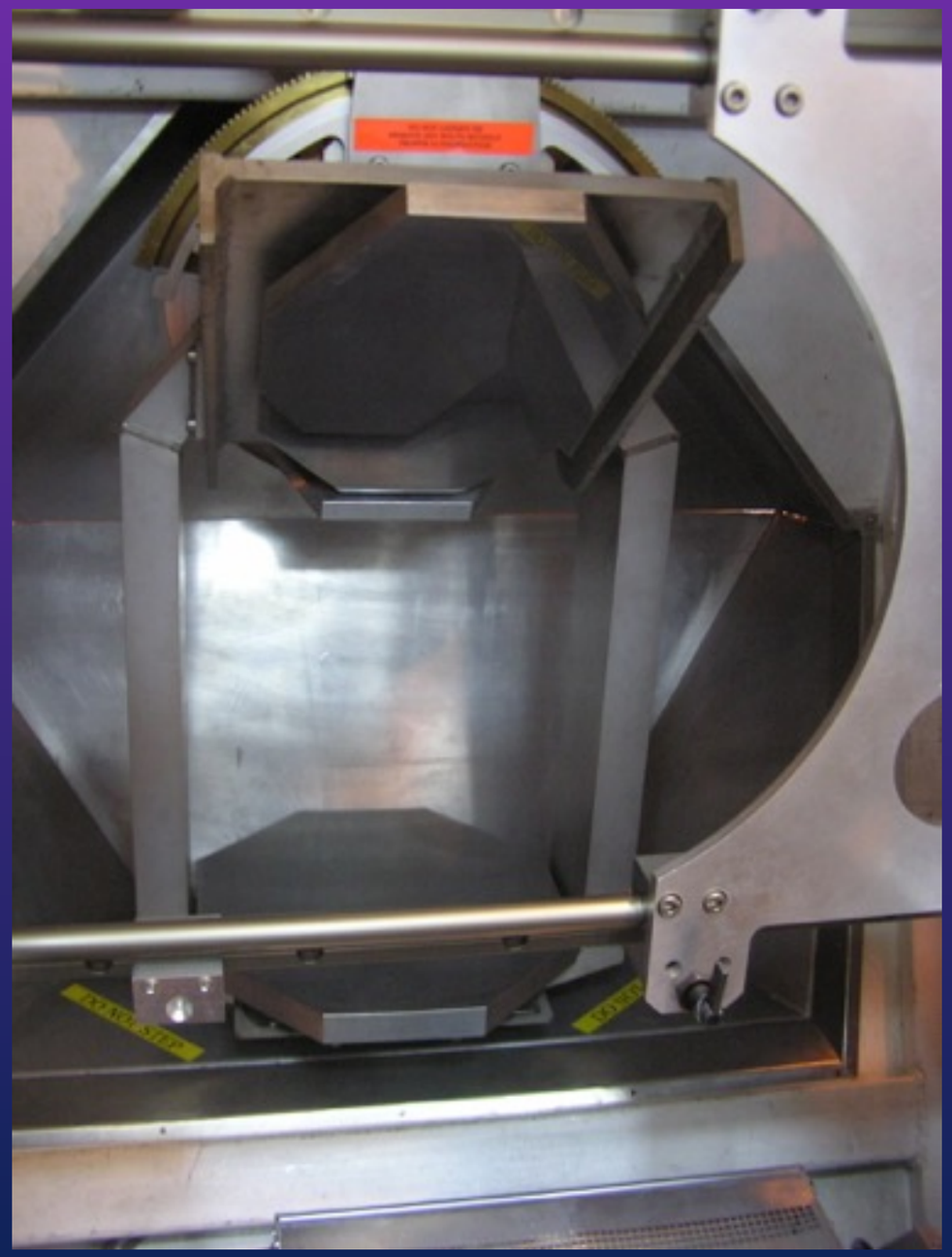


HARP Mixers

- Mixer block with integrated feed horns
- Refocusing mirrors
- LO injection (not shown) by mylar
- Pixels separated by 30” on the sky (2x HPBW)

Raster mapping (OTF) with HARP: 350 GHz Band





K-mirror rotates array 14.3 degrees relative the scan direction

230 GHz Band RxA

- Tuning ranger 211-272 GHz (gap around 252 GHz)
- Trx 50-150 K
- Auto tuning & Dual sideband operation - no SSB

ACSIS
Correlator

- 32 channels
- 250 or 1000 MHz bandwidth
- 2 GHz samplers
- Temperature stabilized
- Fast - 0.1 s dump time for large scale mapping

Science Program

Open | Cut | Copy | Paste | Save | Image | Prioritize | Validation

OR Folder
AND Folder
Survey Container
MSB Folder
Observation
Note
Library
Component
Iterator
Observe

- Science Program
  - *MSB Folder (1X)*
    - Site Quality
    - Sched. Constraints
    - Target Information
    - DRRecipe
    - *Het Setup (HARP)*
    - Observation
      - Sequence
        - *Scan*

JCMT Heterodyne

The Heterodyne instrument is configured with this component.

Front End Configuration

Fron... (•) HARP ( ) A3M ( ) A3 ( ) WB ( ) WD

Sp. ... (•) 2 ( ) 1 ( ) 3 ( ) 4 Special ... None

Mode: (•) ssb ( ) dsb

Side... (•) best ( ) usb ( ) lsb

Front End S...
Low li... 325
High li... 375

Bandwidths
250.0
✓ 1000.0
250.0
250.0

Frequency Setup

☑ Default tuning velocity to target radial velocity

Velocity 0 Definition radio Frame LSRK

CO | 3 – 2 | 345.7959899 GHz Accept

Show Frequency Editor | Hide Frequency Editor

Frequency Configuration

Region	Species	Trans.	Rest. Freq.	Centre F...	BW	res	overlap	channels
0	CO	3 – 2	345.79...	5.0E9	2.5E8	61	0.0	4096
1	CO	3 – 2	345.79...	5.0E9	1.0E9	977	0.0	1024

Undo

Science Program

Open | Cut | Copy | Paste | Save | Image | Prioritize | Validation

OR Folder
AND Folder
Survey Container
MSB Folder
Observation
Note
Library
Component
Iterator
Observe

- Science Program
  - *MSB Folder (1X)*
    - Site Quality
    - Sched. Constraints
    - Target Information
    - DRRecipe
    - *Het Setup (HARP)*
    - Observation
      - Sequence
        - *Scan*

JCMT Heterodyne

The Heterodyne instrument is configured with this component.

Front End Configuration

Fron... ○ A3M ○ A3 ○ WB ○ WD ● HARP

Sp. ... ● 1 ○ 2 ○ 3 ○ 4 Special ... None

Mode: ● ssb ○ dsb

Side... ● best ○ usb ○ lsb

Front End ...
Low l... 325
High ... 375

Bandwidths
✓ 250.0
440.0
420.0
400.0
1000.0
1860.0
1800.0
1600.0

Frequency Setup

☑ Default tuning velocity to target radial velocity

Velocity 0 Definition radio Frame LSRK

CO | 3 – 2 | 345.7959899 GHz Accept

Show Frequency Editor | Hide Frequency Editor

Frequency Configuration

Region	Species	Trans.	Rest. Freq.	Centre F...	BW	res	overlap	channels
0	CO	3 – 2	345.79...	5.0E9	2.5E8	31	0.0	8192

Undo

Science Program

Open | Cut | Copy | Paste | Save | Image | Prioritize | Validation

OR Folder
AND Folder
Survey Container
MSB Folder
Observation
Note
Library
Component
Iterator
Observe

- Science Program
  - *MSB Folder (1X)*
    - Site Quality
    - Sched. Constraints
    - Target Information
    - DRRecipe
    - *Het Setup (A3)*
    - Observation
      - Sequence
        - *Scan*

JCMT Heterodyne

The Heterodyne instrument is configured with this component.

Front End Configuration

Fron... (•) A3 — A3M ( ) WB ( ) WD ( ) HARP ( )

Sp. ... (•) 3 — 1 ( ) 2 ( ) 4 ( ) Special ... None

Mode: (•) dsb — ssb ( )

Side... (•) lsb — best ( ) usb ( )

Front End S...
Low li... 215
High li... 272

Bandwidths

250.0
250.0
420.0
1000.0

Frequency Setup

[x] Default tuning velocity to target radial velocity

Velocity 0 Definition radio Frame LSRK

H2CO 3 0 3 – 2 0 2 218.222186 GHz Accept

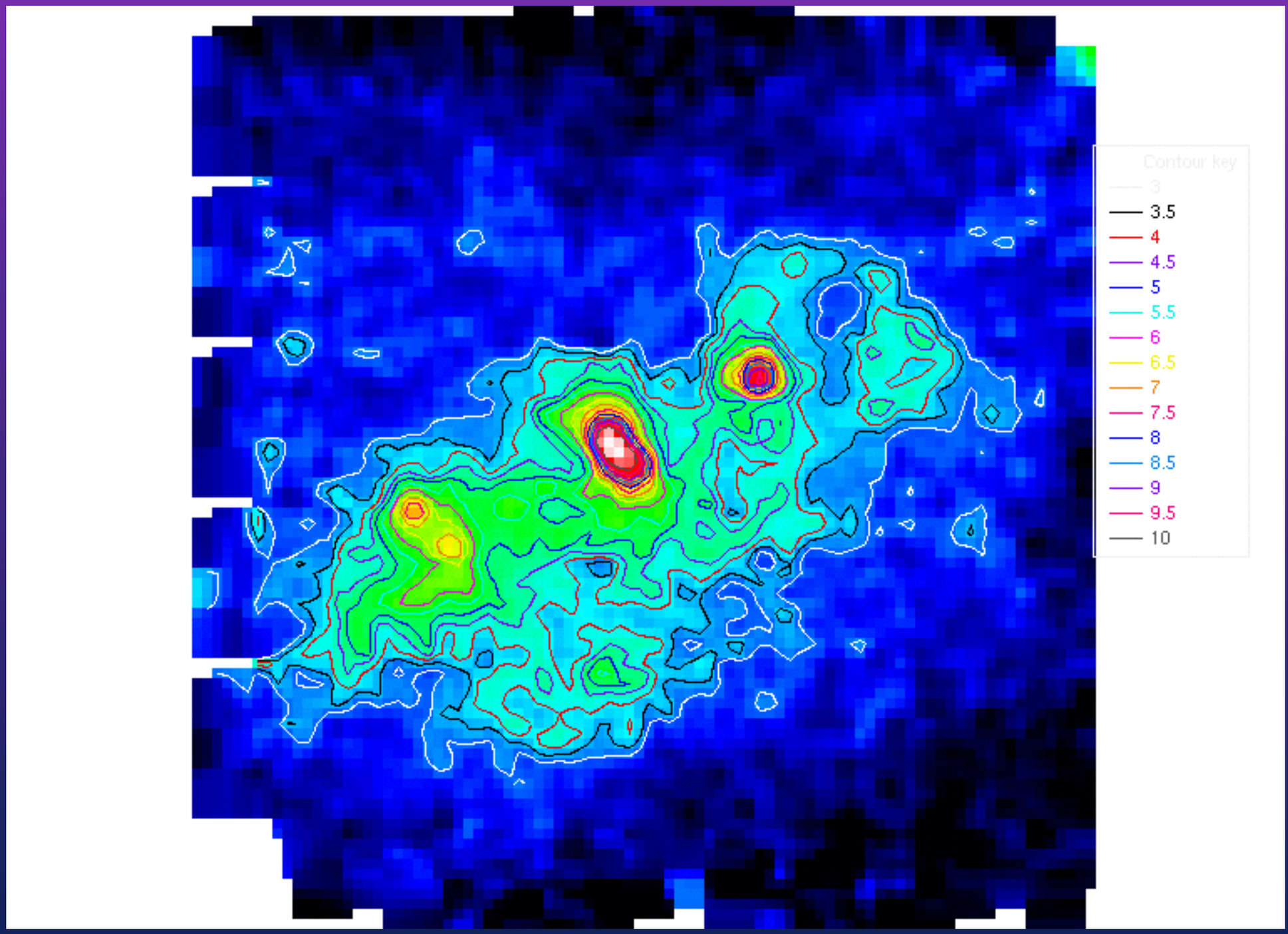
Show Frequency Editor Hide Frequency Editor

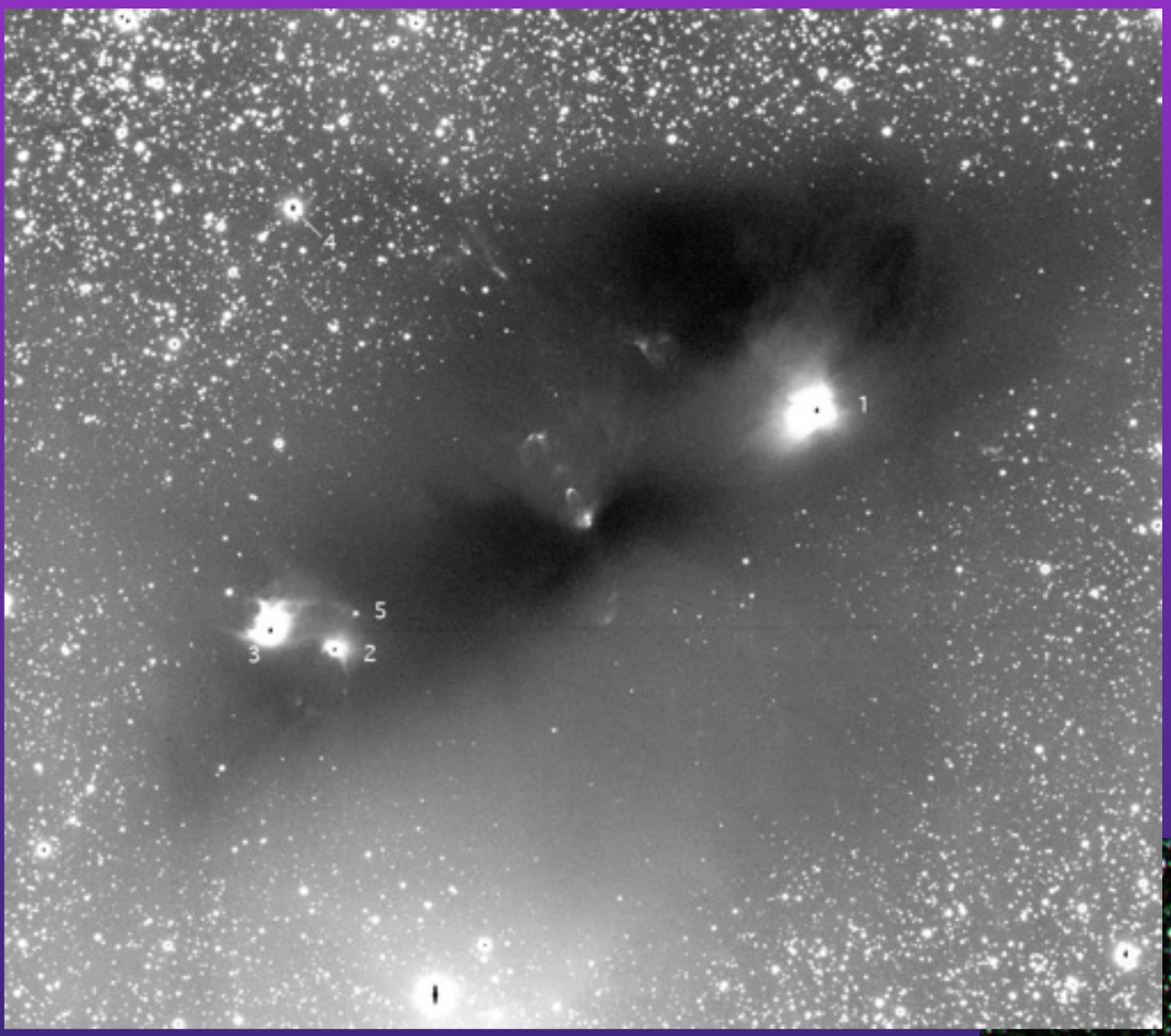
Frequency Configuration

Region	Species	Trans.	Rest. Freq.	Centre F...	BW	res	overlap	channels
0	H2CO	3 0 3 –...	218.22...	4.2278...	2.5E8	61	0.0	4096
1	H2CO	3 2 2 –...	218.47...	3.9744...	2.5E8	61	0.0	4096
2	H2CO	3 2 1 –...	218.76...	3.6899...	4.2E8	61	40.0	6881

Undo

B62 CO 3-2 9’x9’





Subaru Hα

UKIRT WFCAM

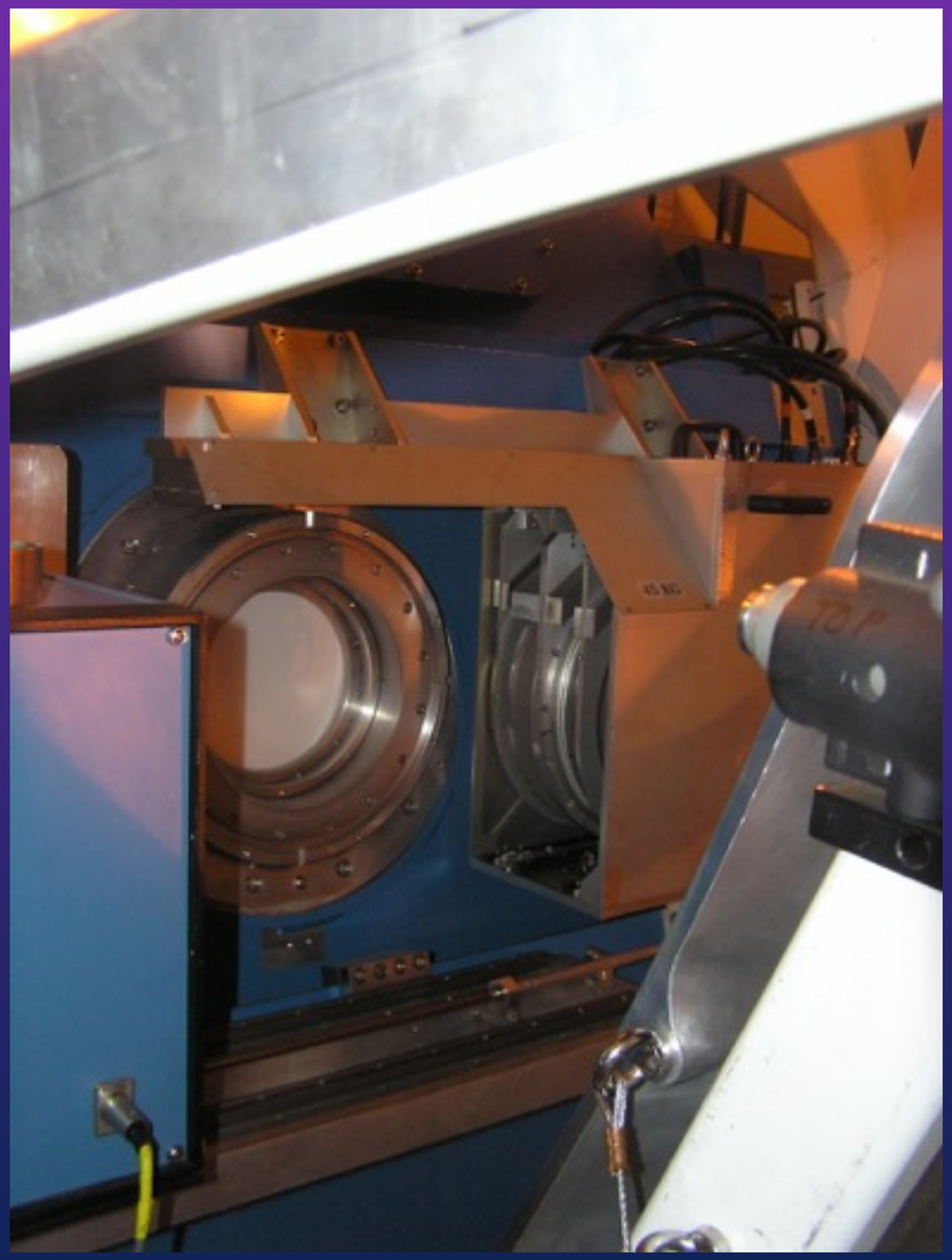
JHK composite

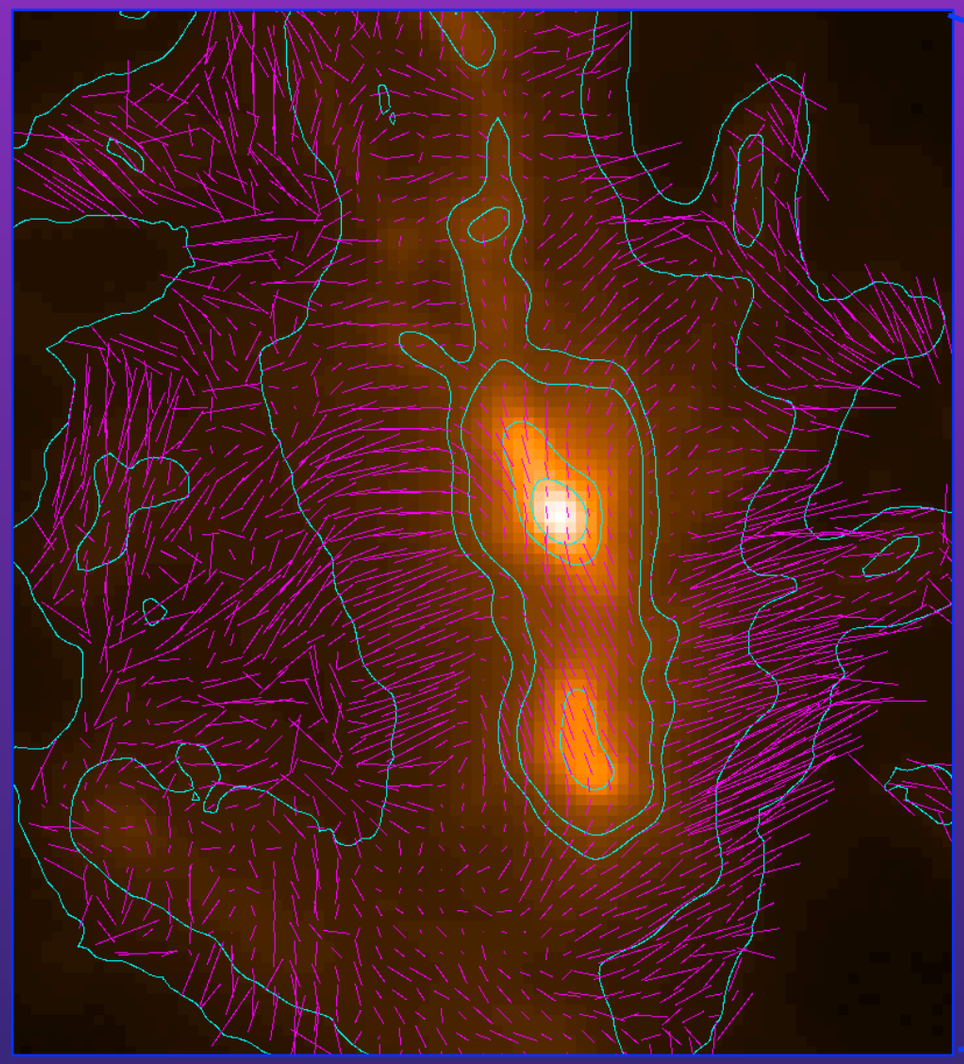
RxW 660 GHz

- Out of operation, can be repaired and reinstated if there is interest
- Need good weather
- Partial manual tuning - cumbersome and time consuming to tune
- Trx 500-700 K tuning range 630-700 GHz
- Dual mixer per frequency band/ dual Frequency bands.
- Single Sideband and Dual Sideband operation. In SSB mode the unwanted sideband is dump on cold load

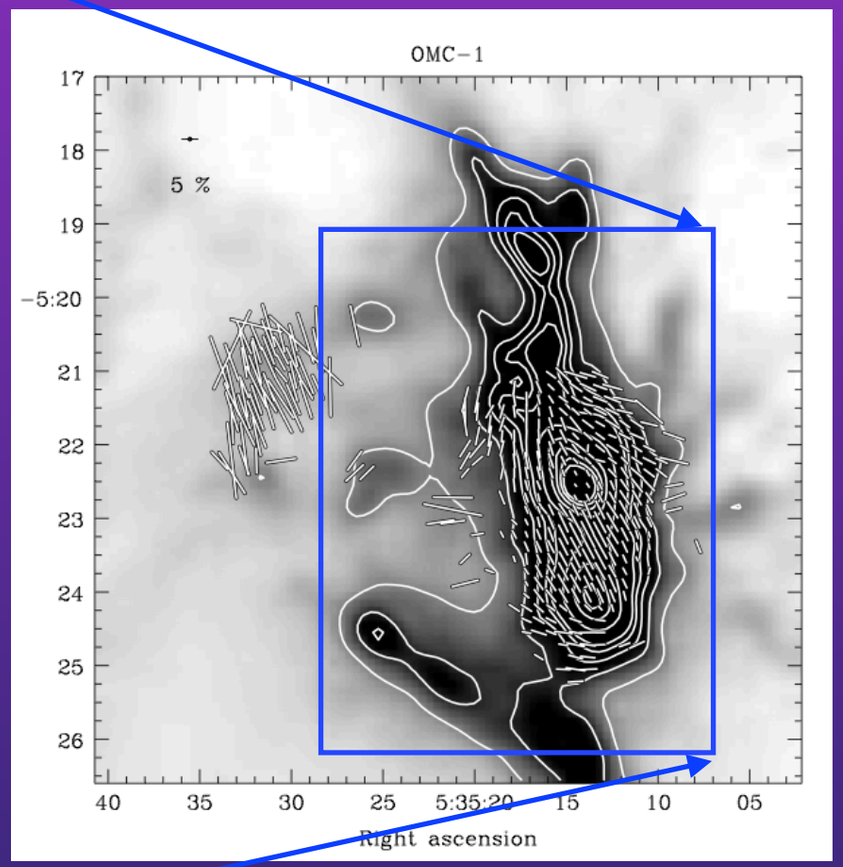
POL-2 on SCUBA-2

- Fast spinning achromatic λ/2 plate
- Analyzer - grid
- Calibrator - grid
- 450 and 850 μm
- Covers full SCUBA-2 field of view

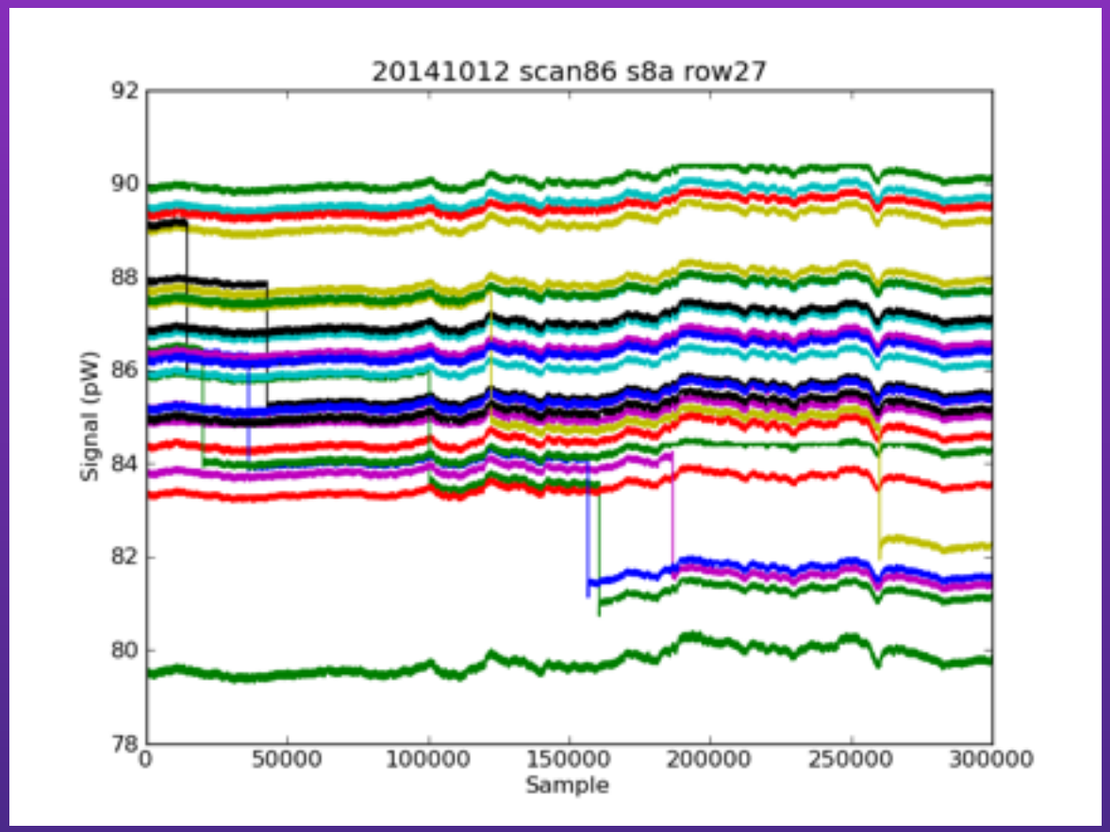




POL-2 OMC-1
Commissioning
Data



SCUBA Pol.
Matthews et.al
2009

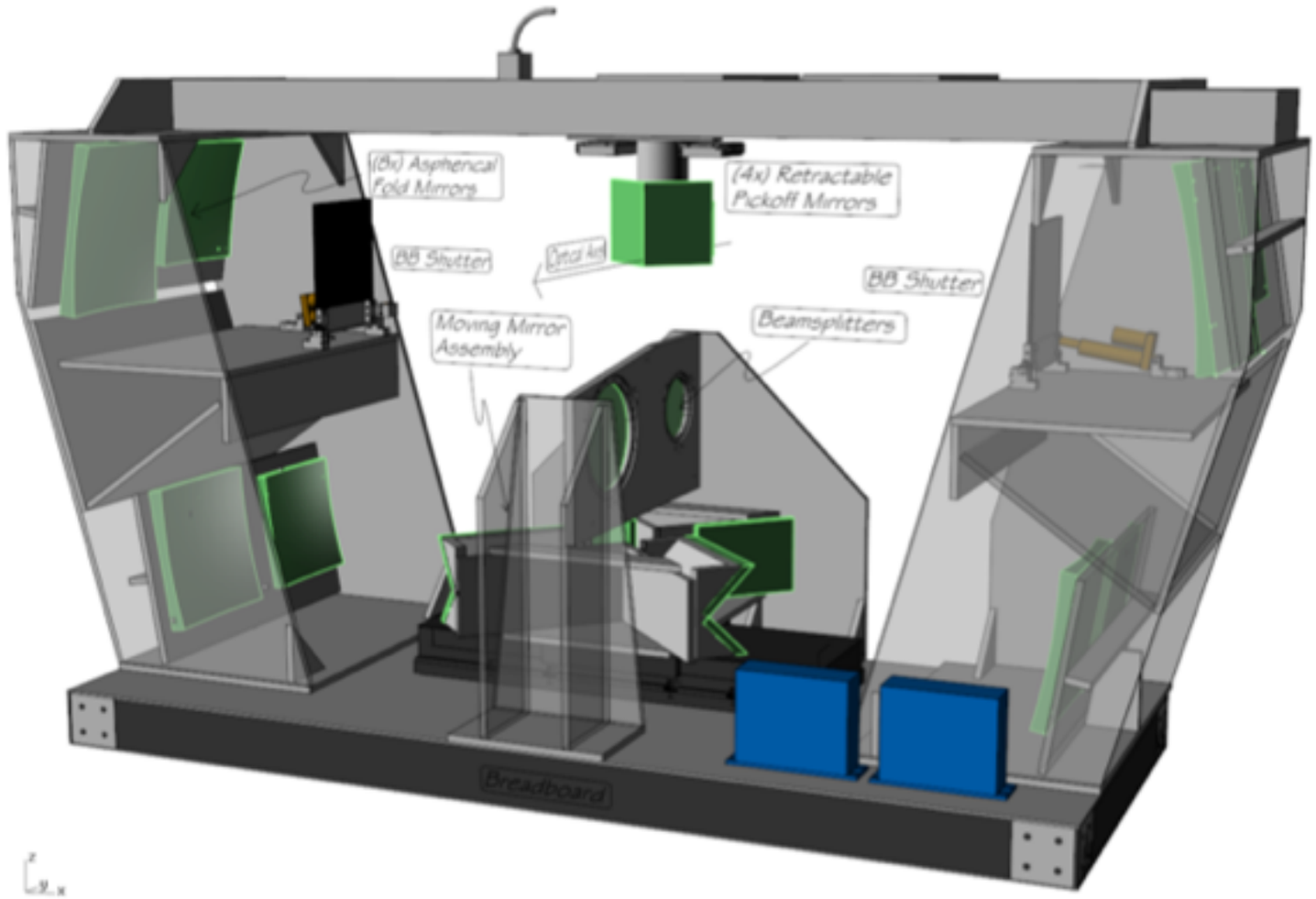


Flat fielded time series data from POL-2 (few bolo-meters)

Needs work on

- Wave plate reflections (loading variation with 2 x spin rate)
- Data defects
- Observing method (sky background removal)
- Data reduction
- IP model/removal

FTS-2



Inserted in the SCUBA-2 optical path in on the Nasmyth platform.

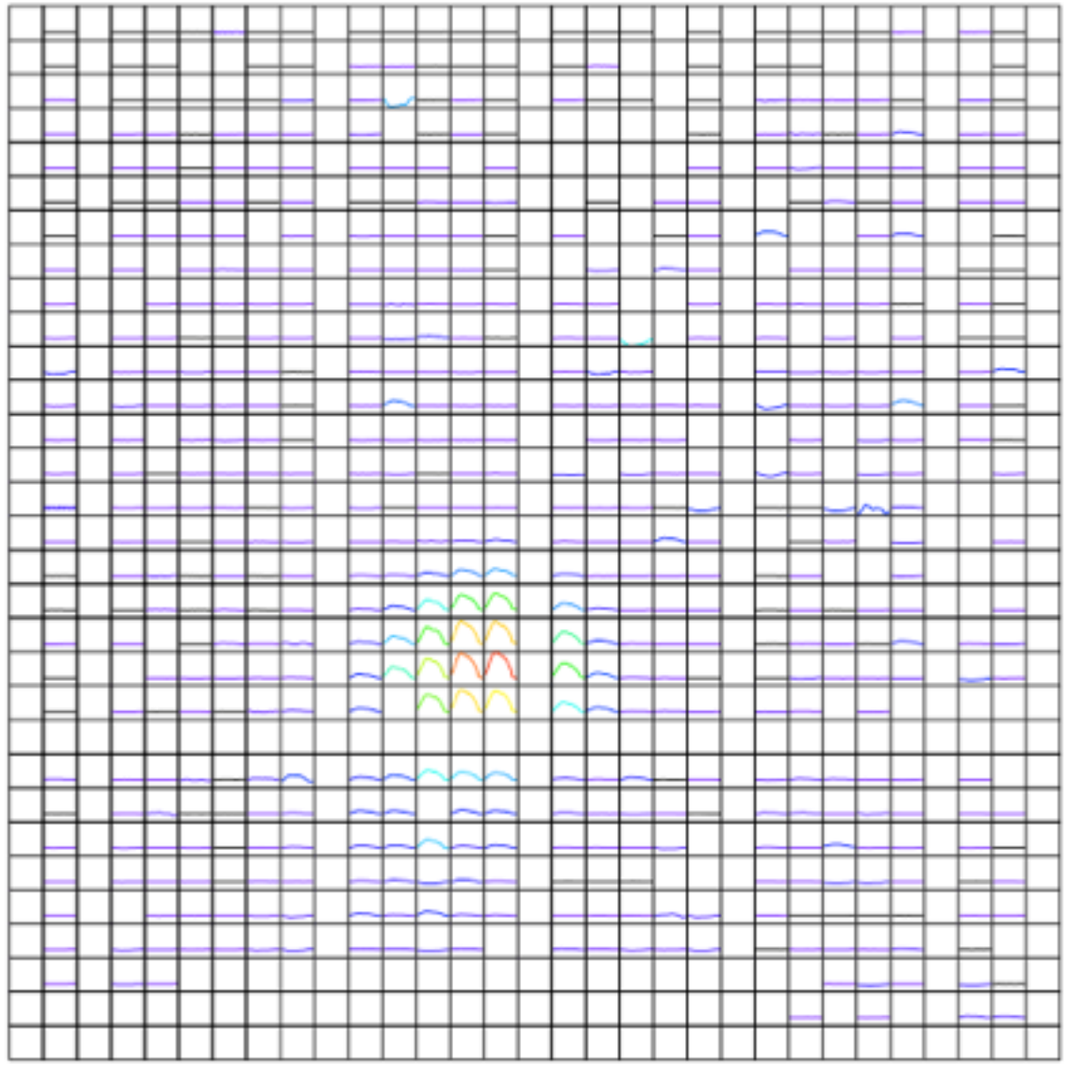
R ~10-5000

Two main modes:
SED (low resolution)
@
High ReSolution (HRS)

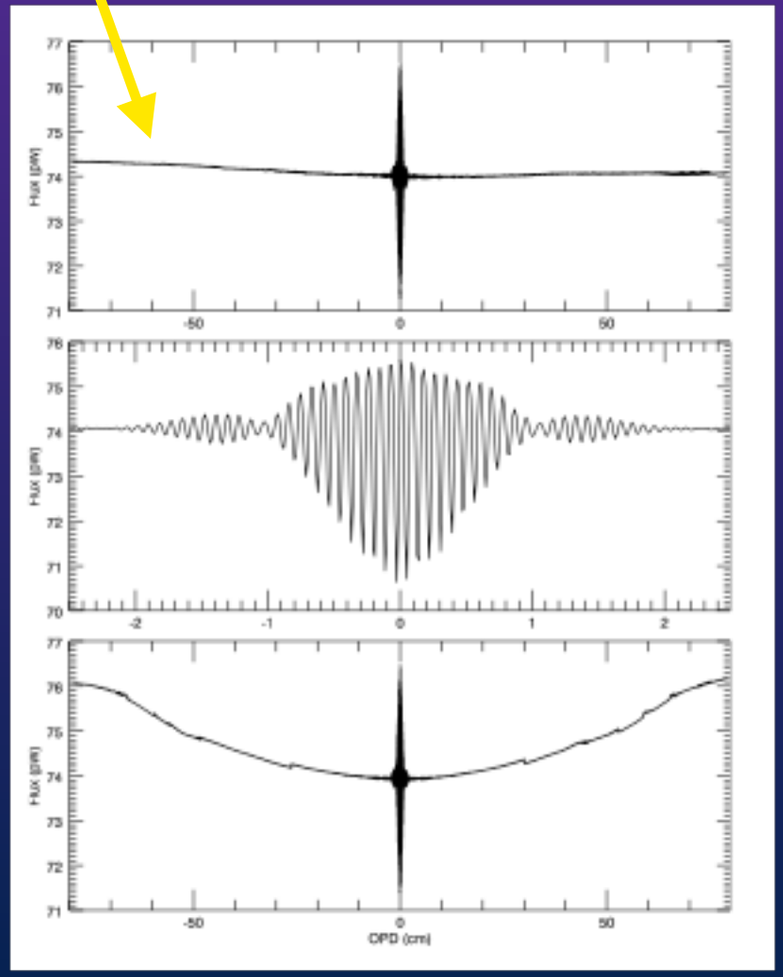
- Field of view ~ 5 arcmin^2 in low resolution SED mode
- Field of view ~ 1 arcmin^2 in HRS mode

FTS-2

Spectra map of Jupiter



Interferograms



Issues:
Dynamical range
Linearity
Flux jumps
port imbalance

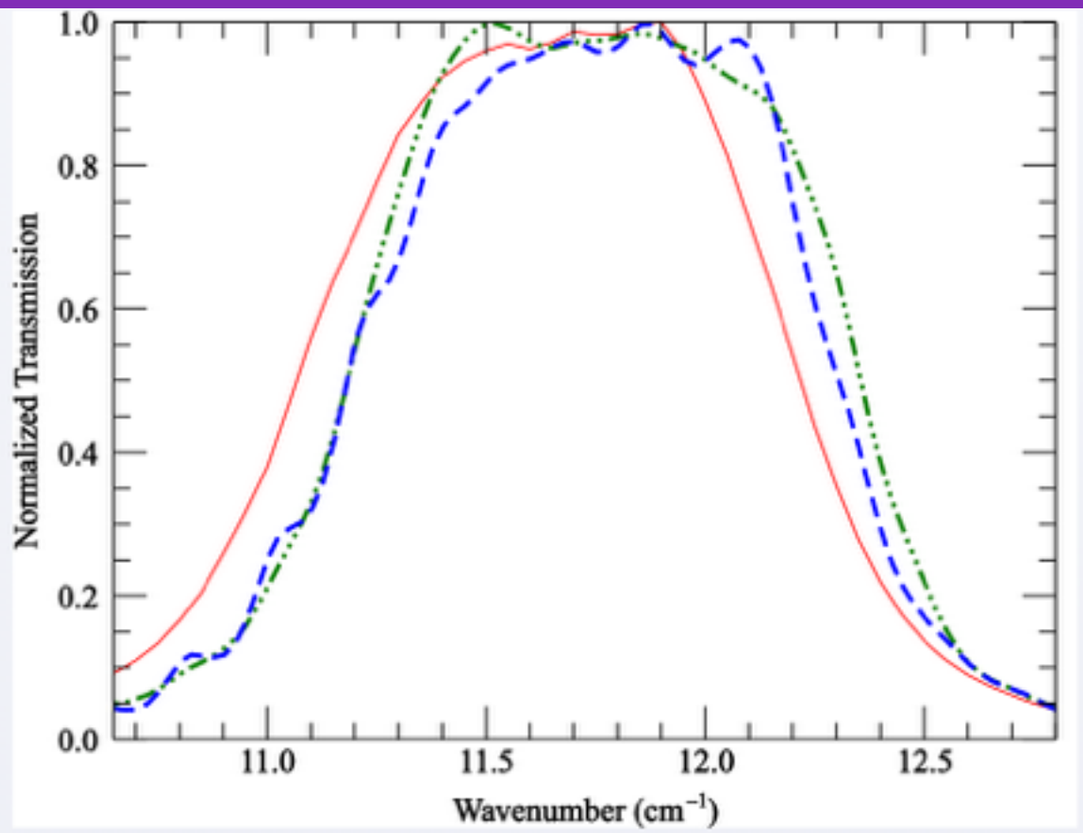


Figure 9. Comparison of theoretical SRF (solid red) calculated from room temperature measurements of individual filters and the SRF measured by FTS-2 (dash-dot green: s8c, dashed blue: s8d) for the 850 μm band.

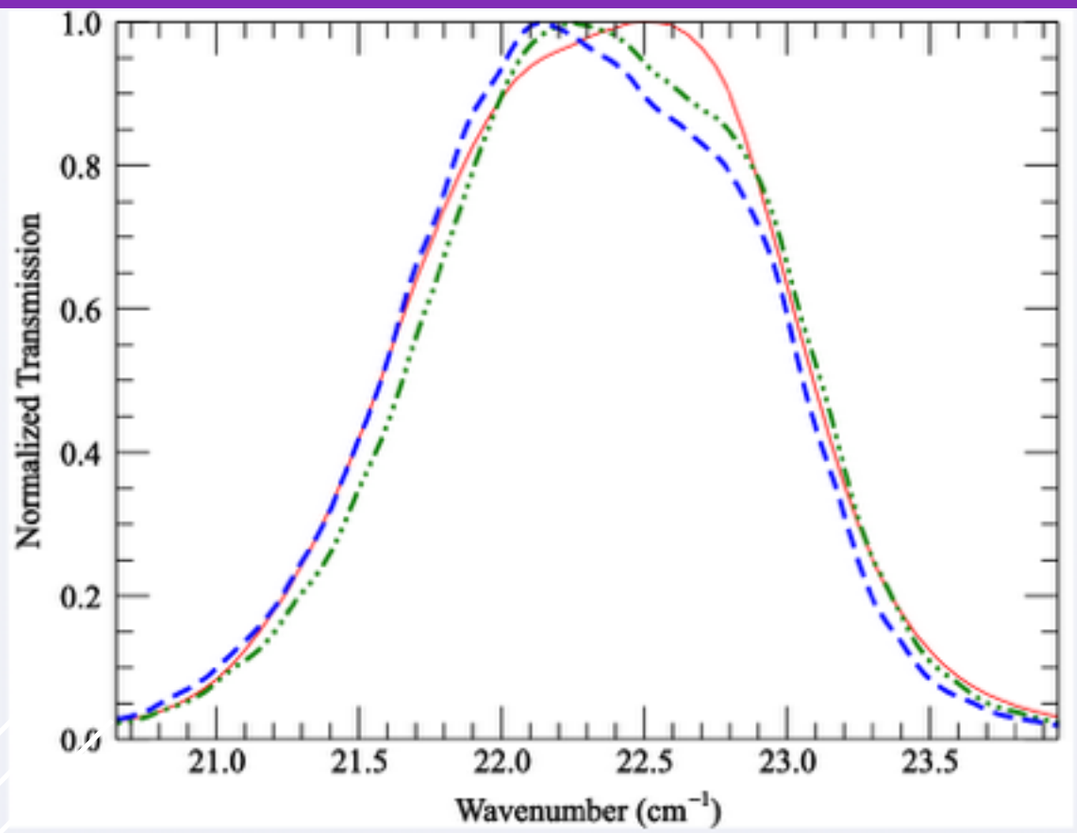
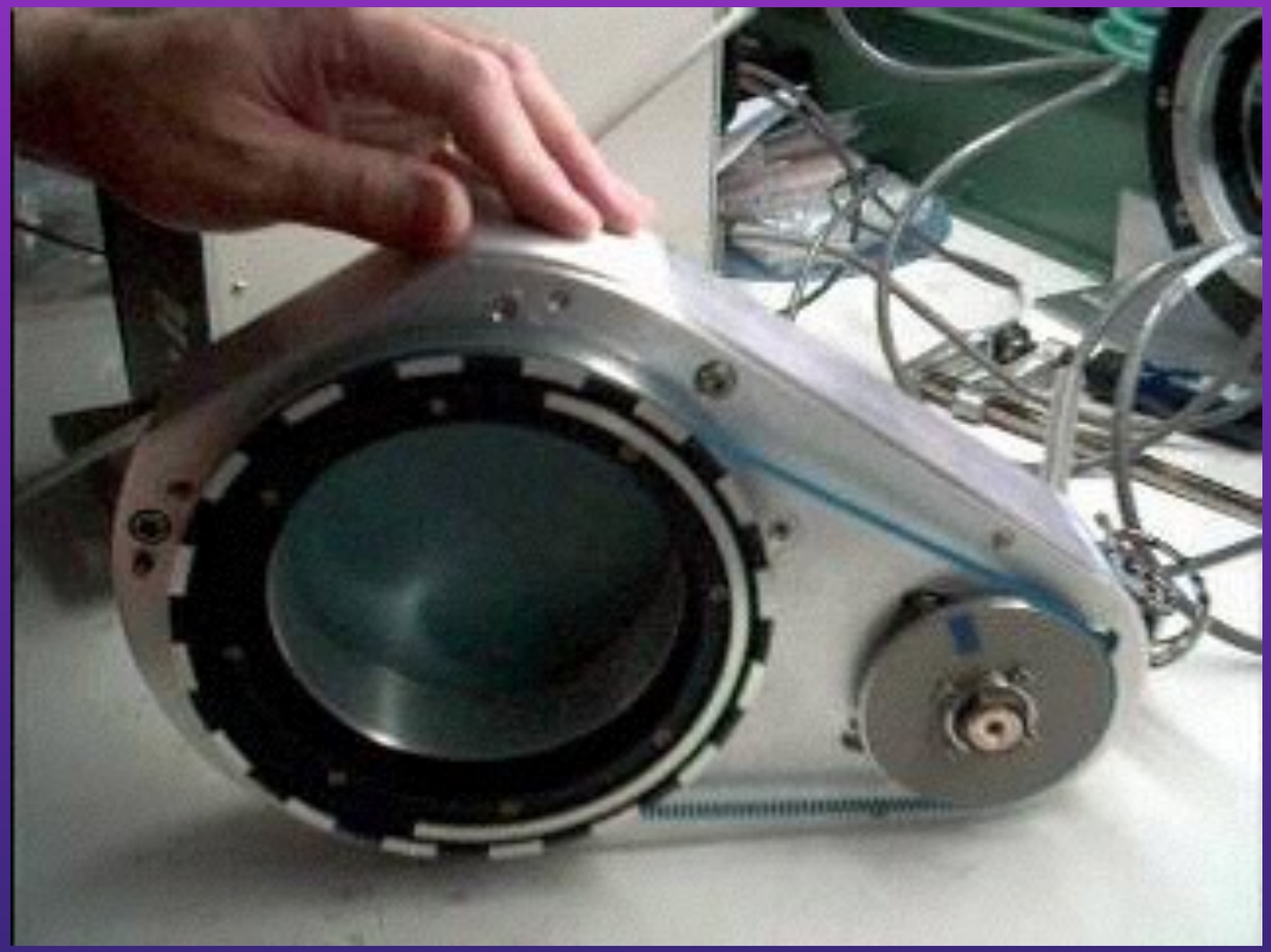


Figure 10. Comparison of theoretical SRF (solid red) calculated from room temperature measurements of individual filters and the SRF measured by FTS-2 (dash-dot green: s8c, dashed blue: s8d) for the 450 μm band.

FTS-2 measurements of SCUBA-2 filter profiles

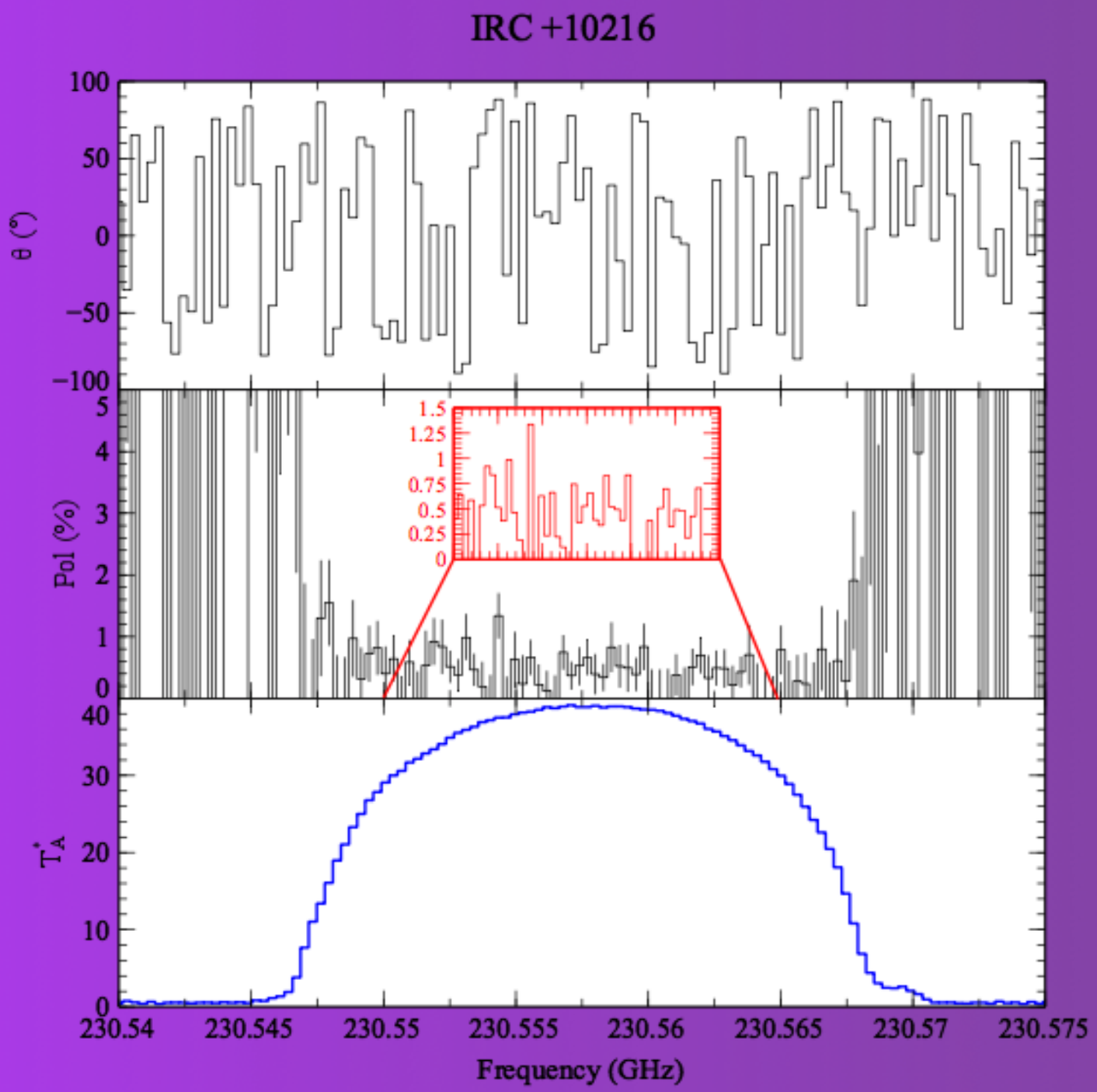
- 850 profile shifted 0.1 cm^-1 compared to predictions
- 450 profile agrees well with predictions



ROVER

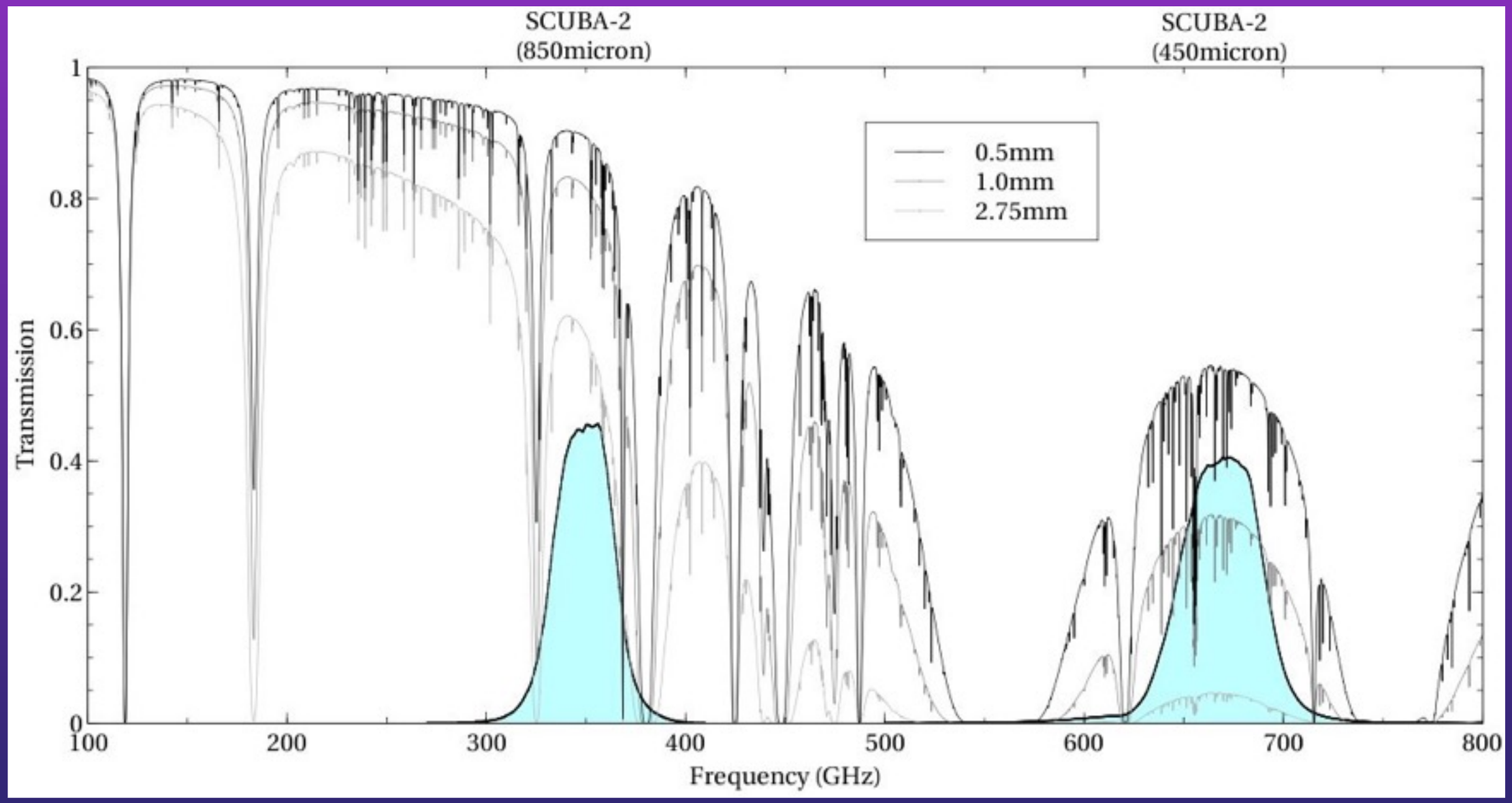
Heterodyne polarimeter

- Achromatic λ/2 plate - 230 & 350 GHz band, Also used for the VLBI λ/4 plate.
- Using the 0.1 s dump time of ACSIS to read out spectra fast.
- Tested at 230 GHz but not 350 GHz



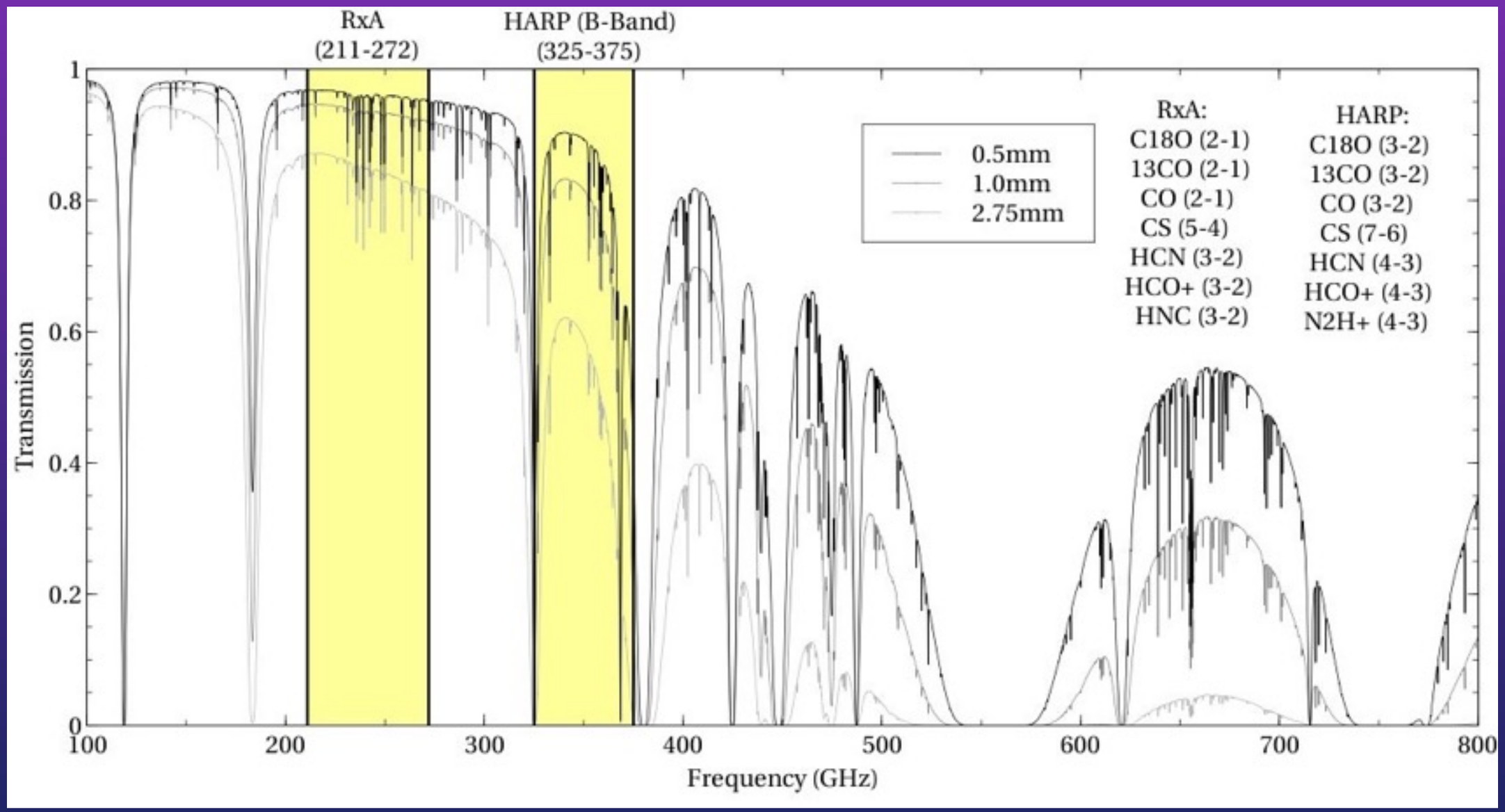
Test data from ROVER Commissioning

IRC+10216 CO 2-1 Slight polarization detected



- SCUBA-2 Filter witdhs & atmosphere
- The 692 GHz CO line one edge of 450 filter

Heterodyne Bands JCMT



Different names than ALMA & SMA