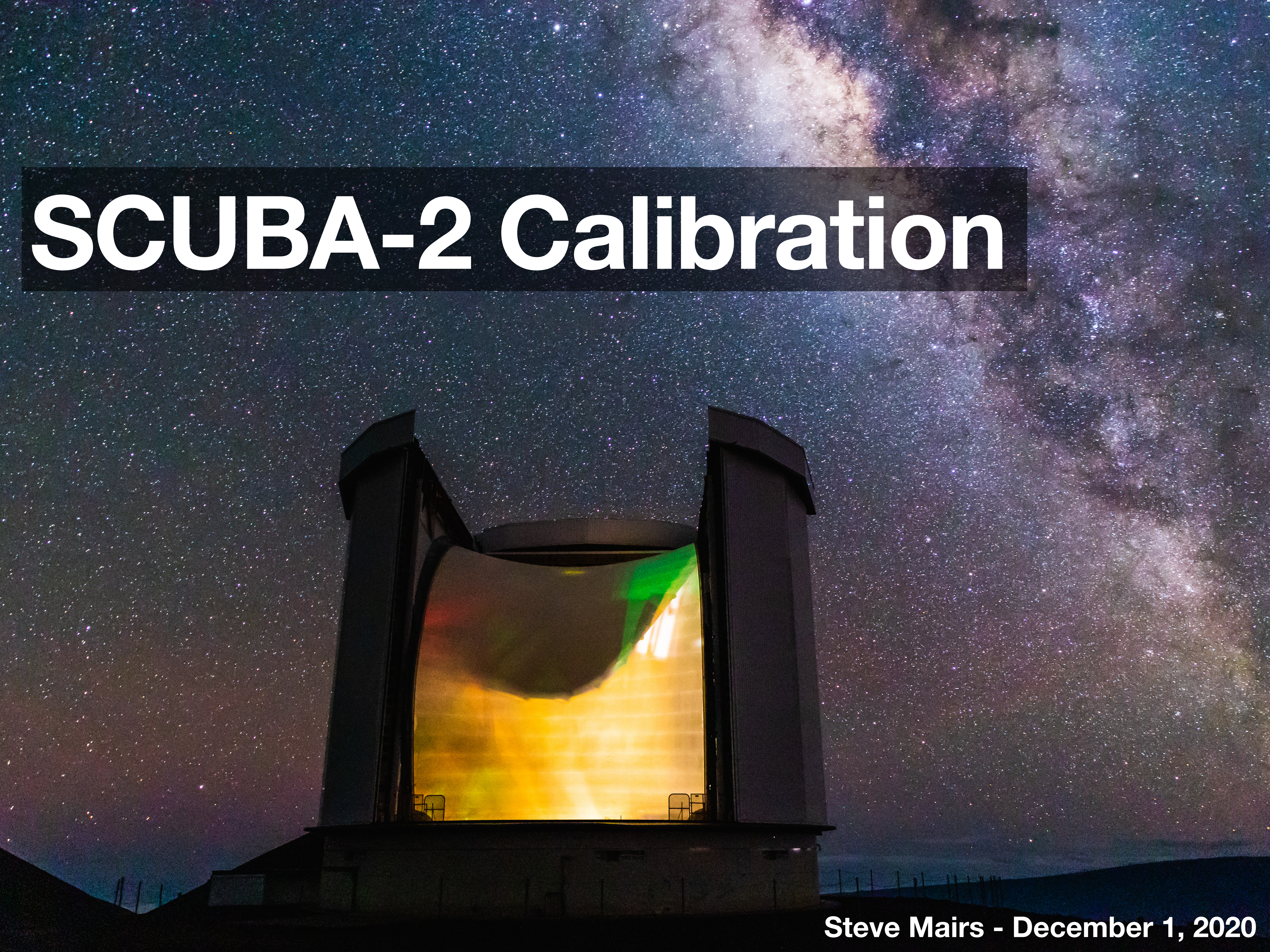
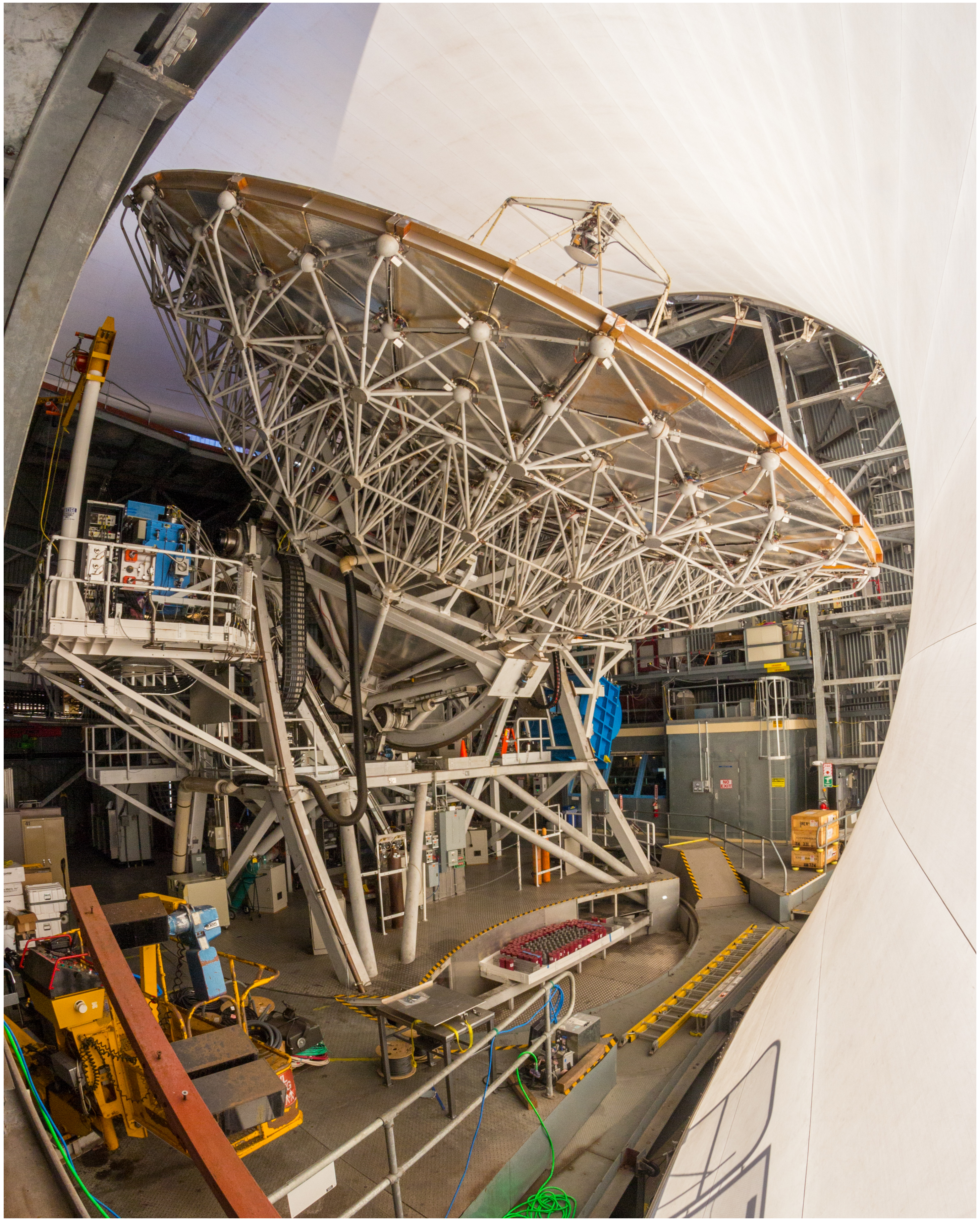
SCUBA-2 Calibration



Steve Mairs - December 1, 2020

Overview

1. **The “Beam” and Signal vs Noise**
2. **Data Reduction Methodology**
3. **Current Calibration Advice**
4. **Preliminary Calibration Advice**



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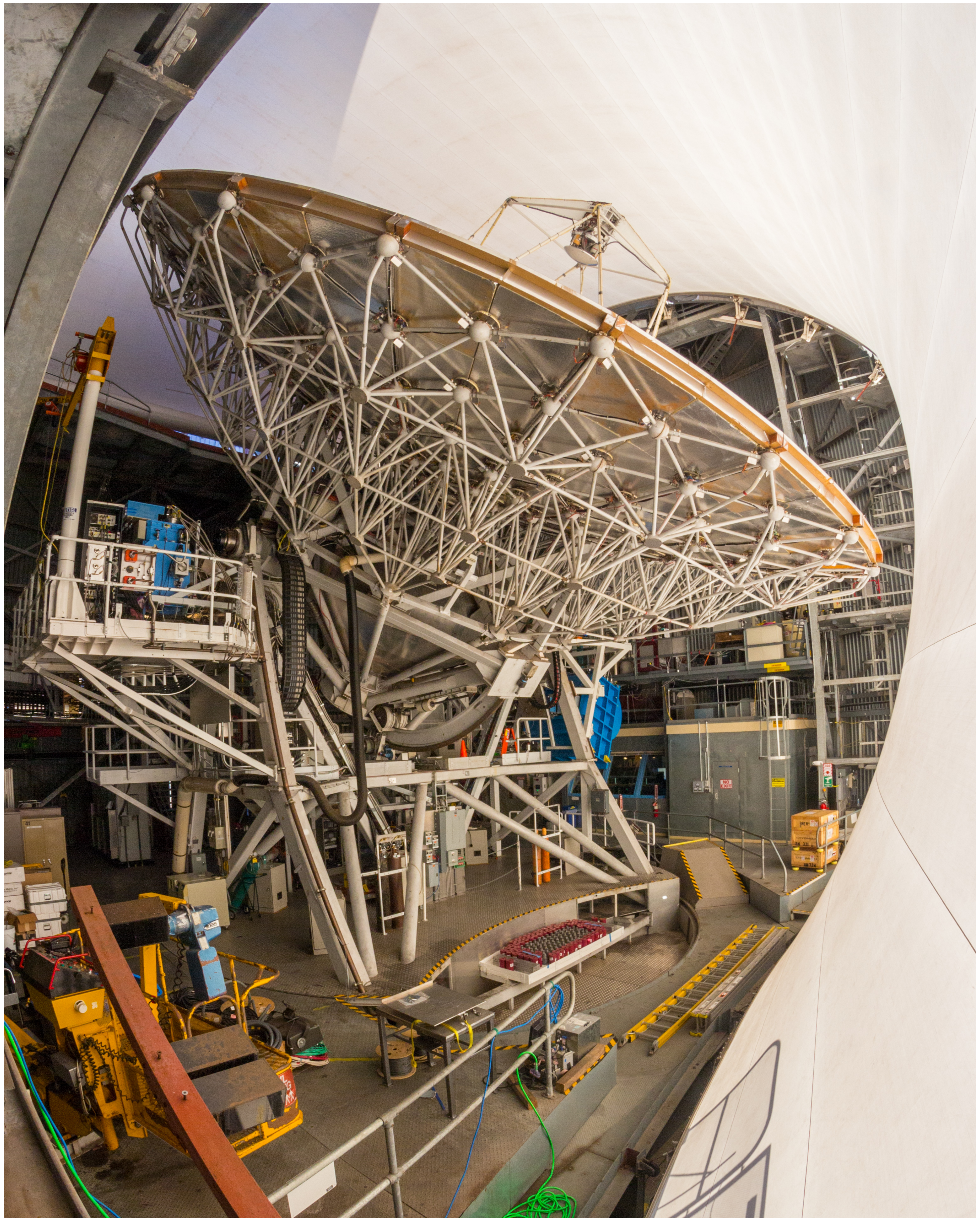
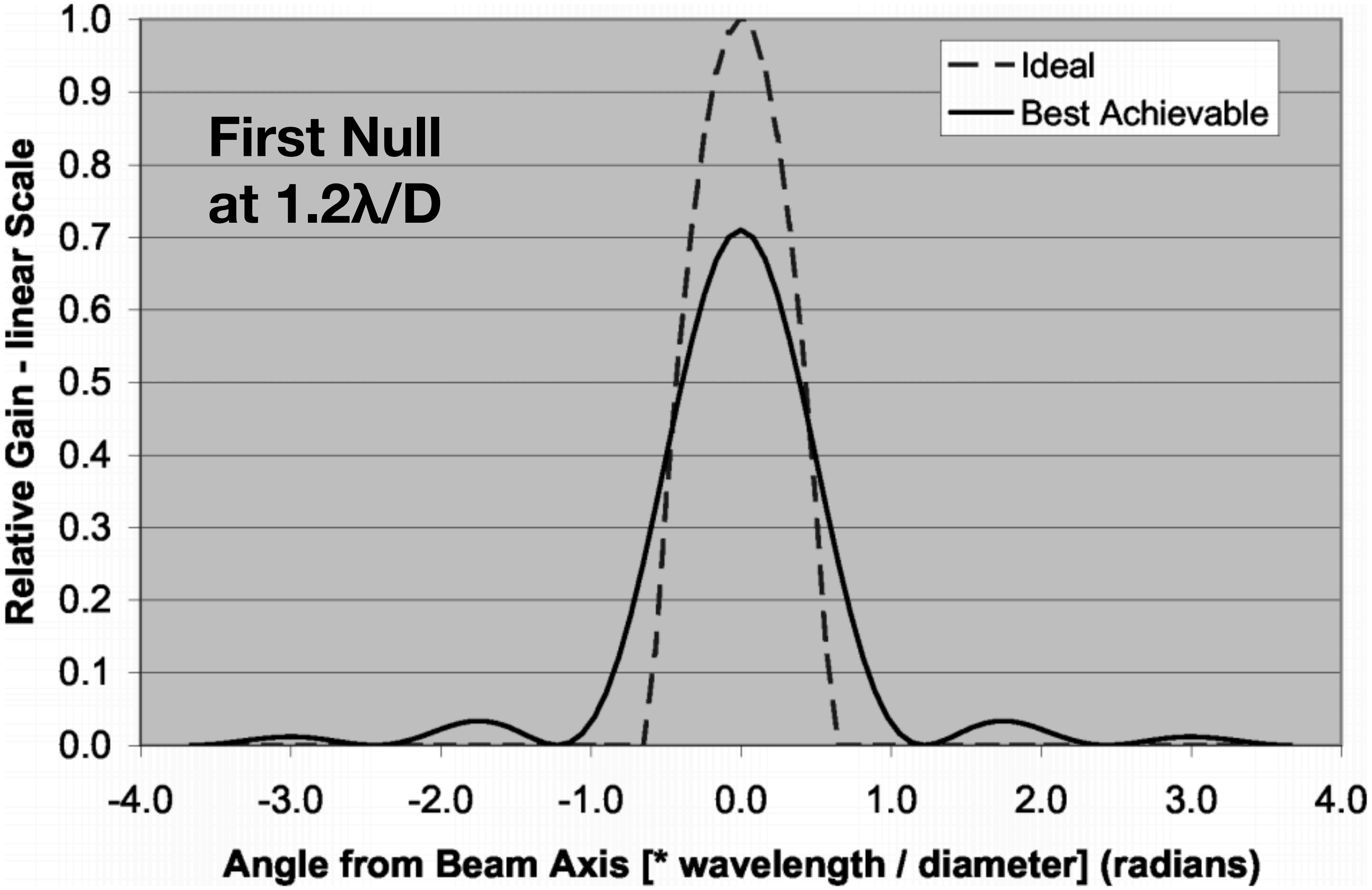


PSF = “Beam” in Radio Astronomy

The JCMT is sensitive to molecular clouds with large angular extent and to distant galaxies which appear as point sources

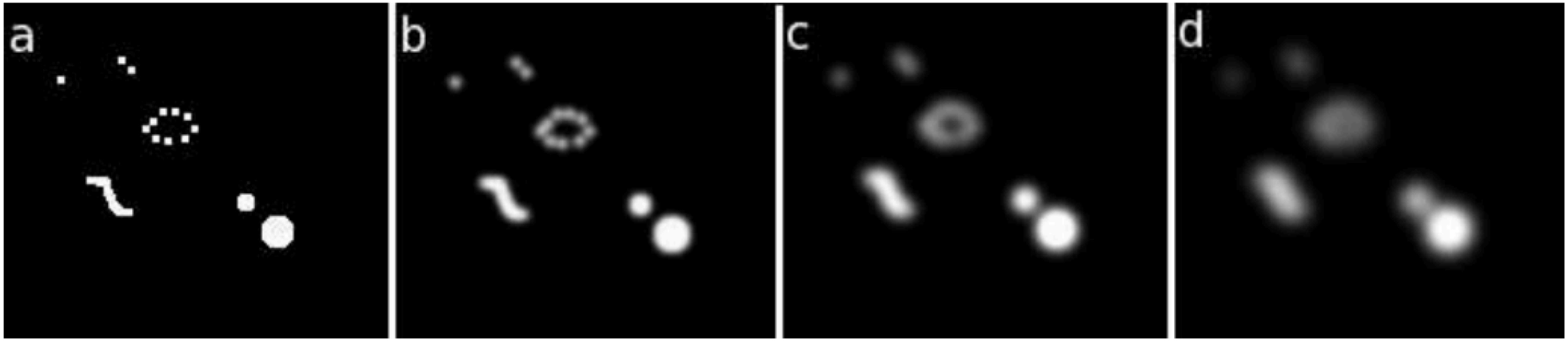


The beam defines the angular resolution of the image and how much power appears in the “Main beam” in contrast to the “Sidelobes”

PSF = Beam in Radio Astronomy

What the telescope sees is the actual radio brightness distribution in the sky smeared out by ("convolved") the beam of the telescope.

Larger Beam



The bigger the beam, the more it smears out,
the worse the resolution.

Brightness Unit: The Jansky

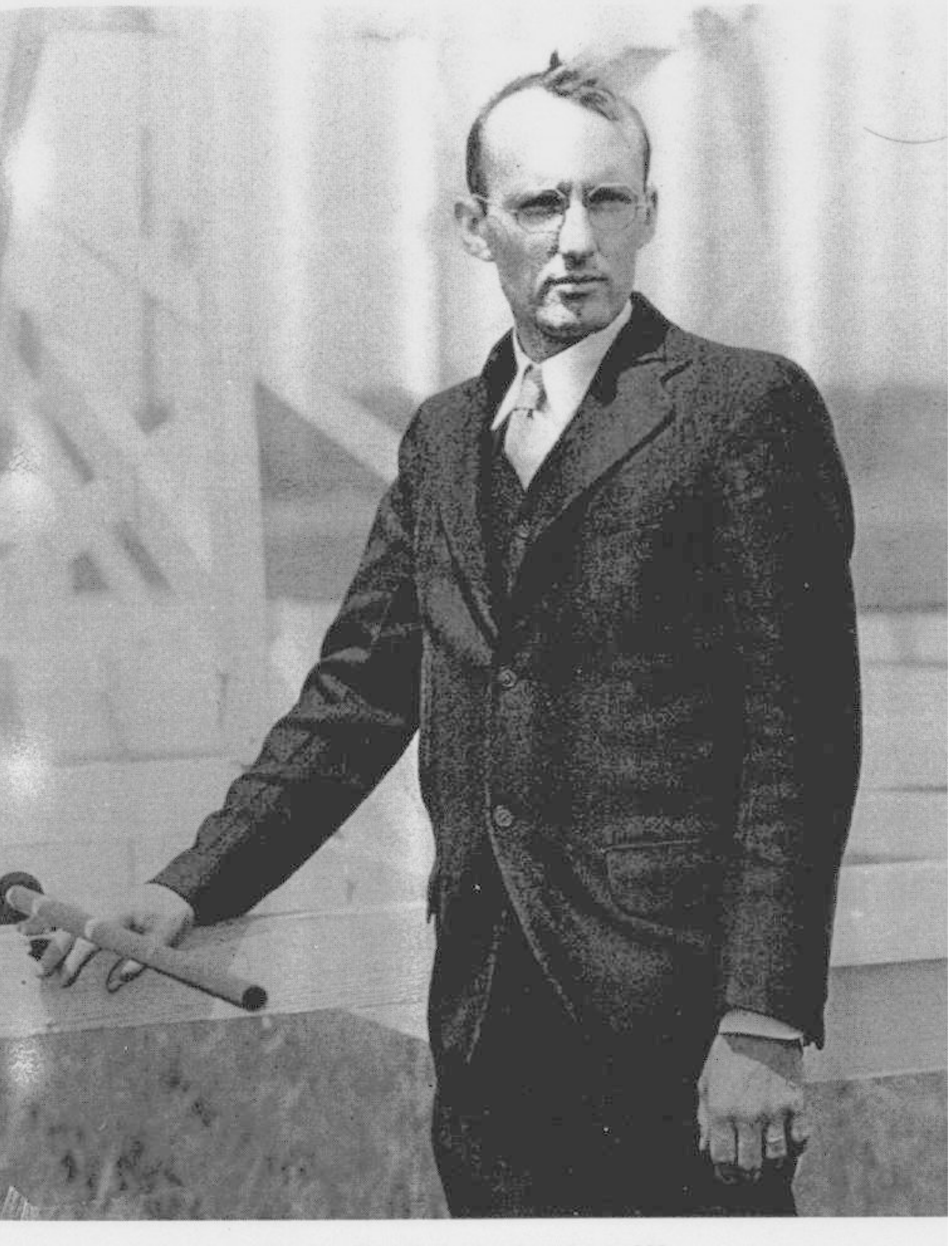


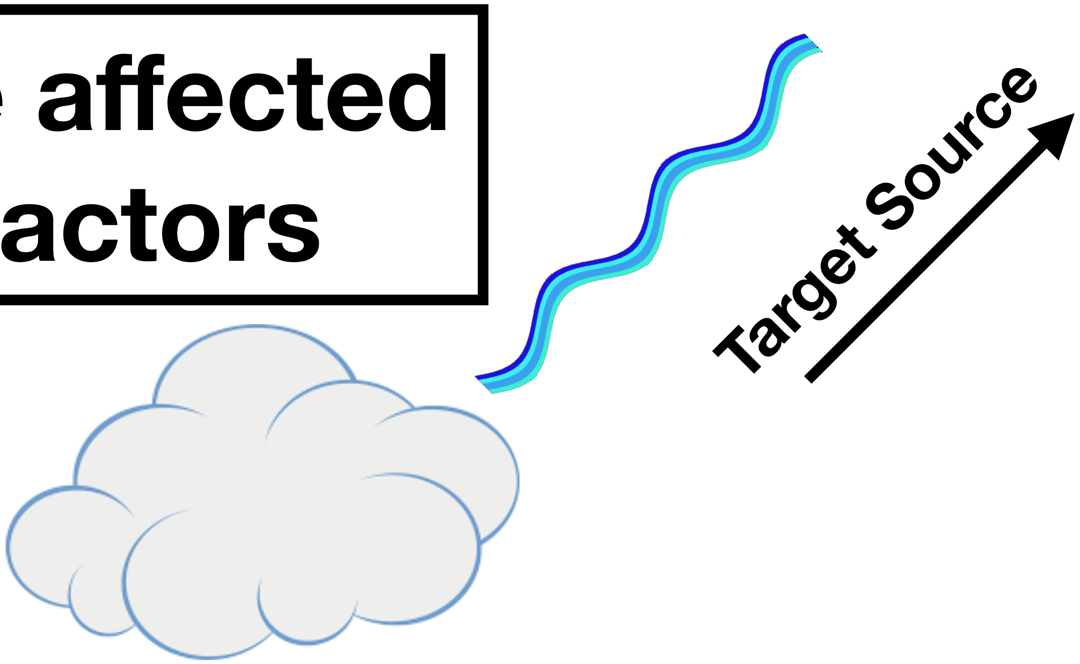
FIG. 1—Karl Guthe Jansky, about 1933.

Karl Guthe Janksy
first discovered
radio waves
in the Milky Way

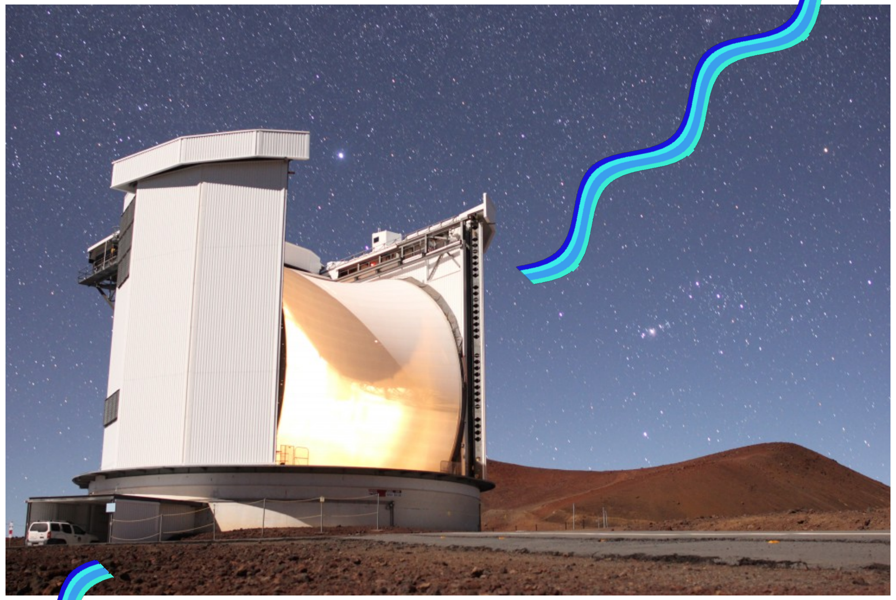
So we named
a unit after him!

$$\boxed{\begin{aligned} 1\ \mathrm{Jy} &= 1 \times 10^{-26}\ \mathrm{W\ m^{-2}\ Hz^{-1}} \\ &= \mathrm{J\ s^{-1}\ m^{-2}\ Hz^{-1}} \\ &= 1 \times 10^{-23}\ \mathrm{erg\ s^{-1}\ cm^{-2}\ Hz^{-1}} \end{aligned}}$$

Light can be affected by many factors



Atmosphere is bright and variable at submillimetre wavelengths.



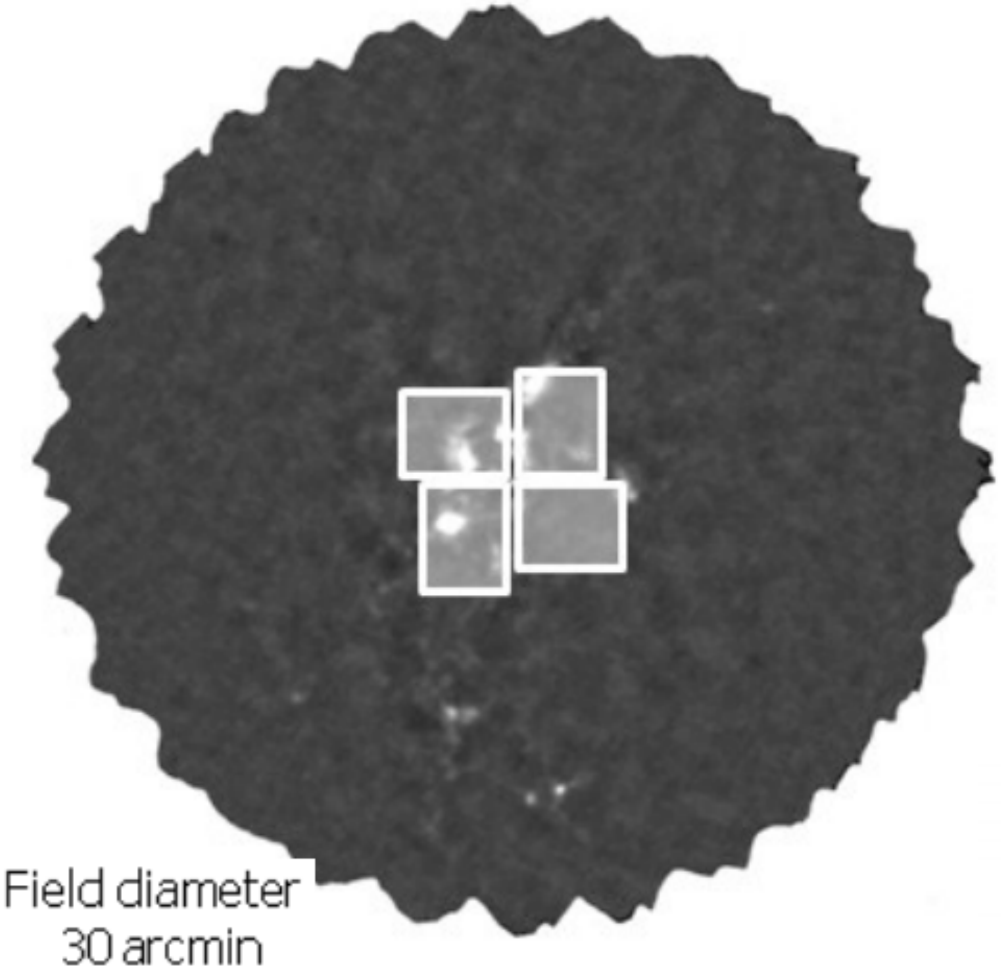
The JCMT is **not 100% reflective**, It is also covered with gore-tex!

Pointing and focus uncertainties!

There is electronic noise. Focal planes must be kept extremely cold. Temperature fluctuations and power glitches affect data!

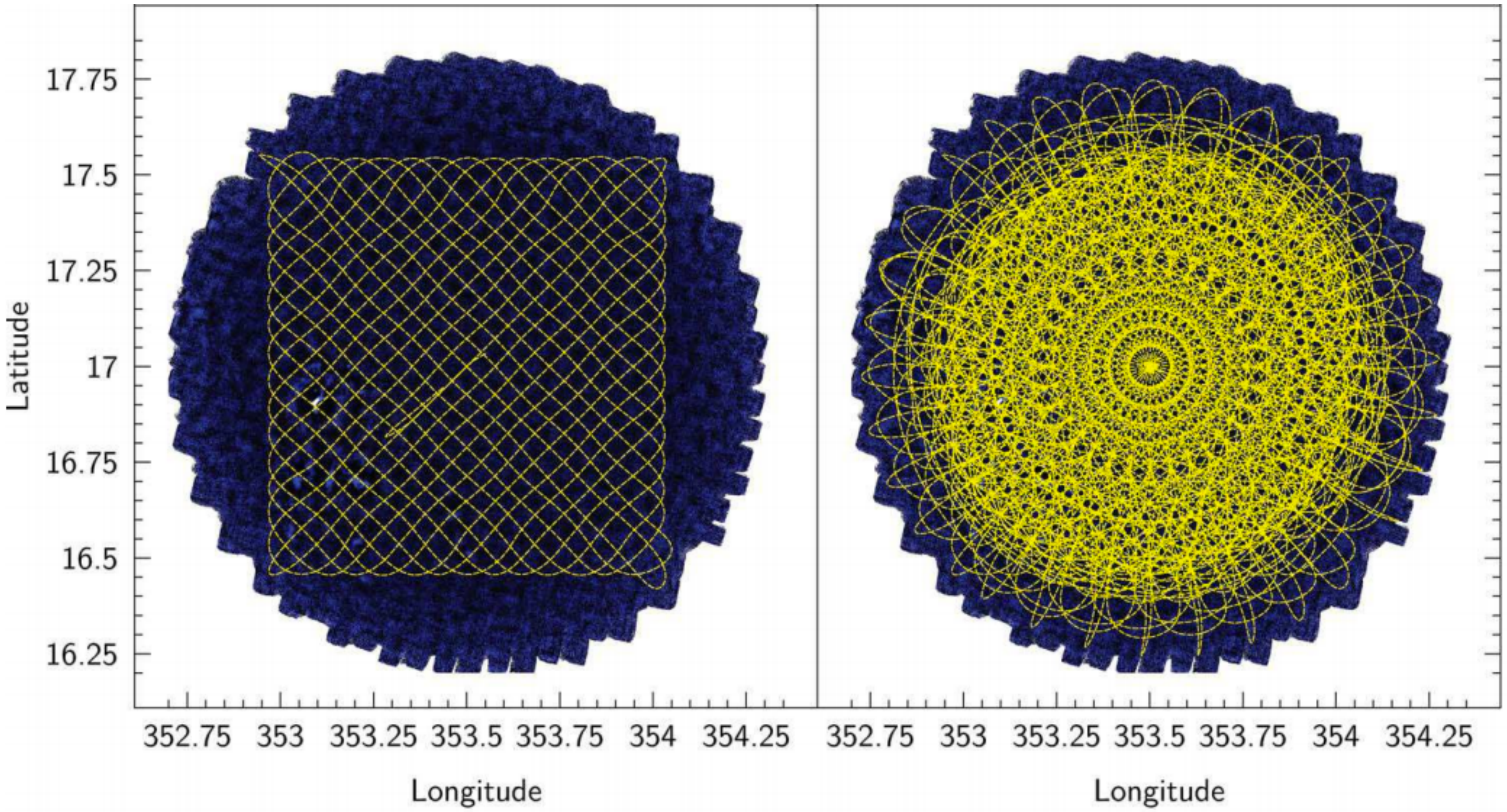
***Data Reduction Seeks to Remove All That is *Not* Real Astronomical Signal**

Removing the Atmosphere



The telescope scans across the sky and across the same region at many different position angles - this is how we can tell what is atmosphere and what is in space!

The flux that changes is atmosphere,
the flux that stays the same must be stable, astronomical signal

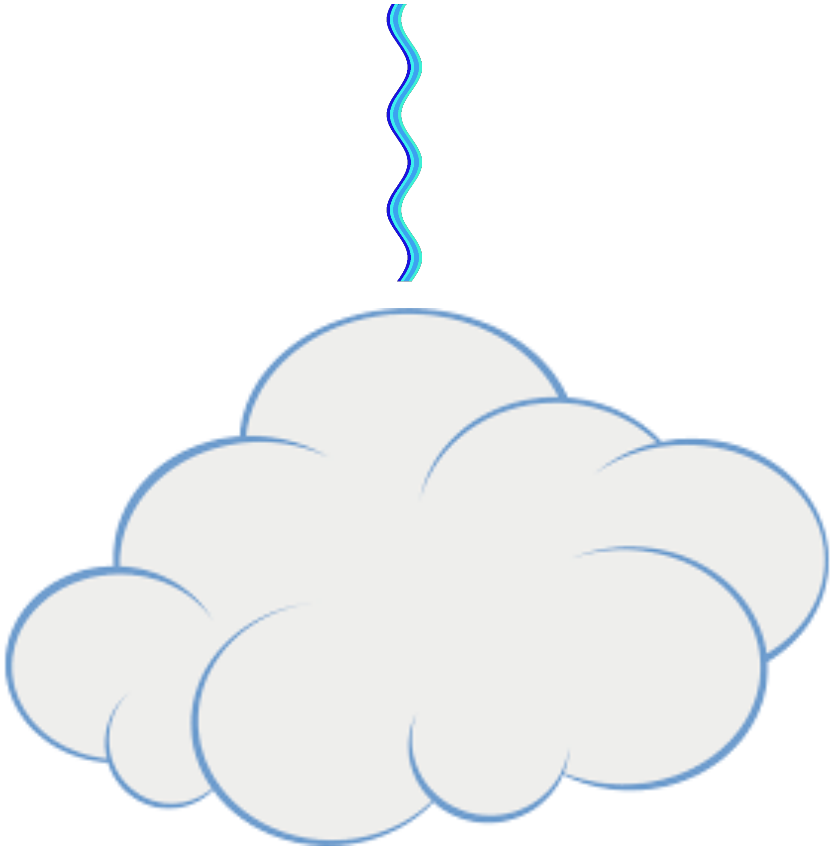


Figures From:
Holland et al. 2013

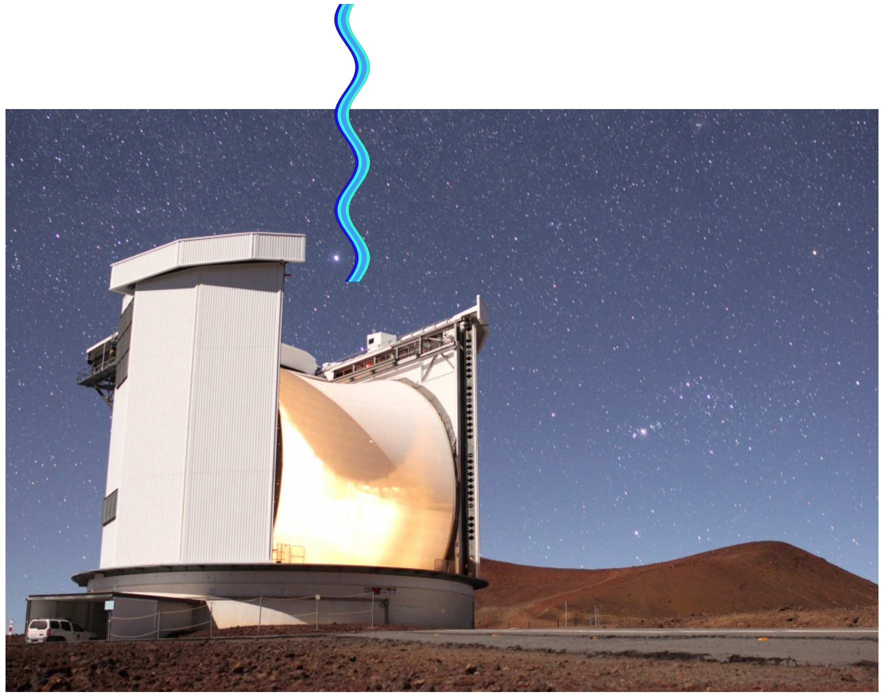
Data Reduction Seeks to Remove All That is Not Real Astronomical Signal

Once we remove the signal from the bright and variable atmosphere…

We need to correct for the astronomical light that was lost through its journey from the top of the atmosphere to the telescope!



τ = Opacity from measurement of Precipitable Water Vapour



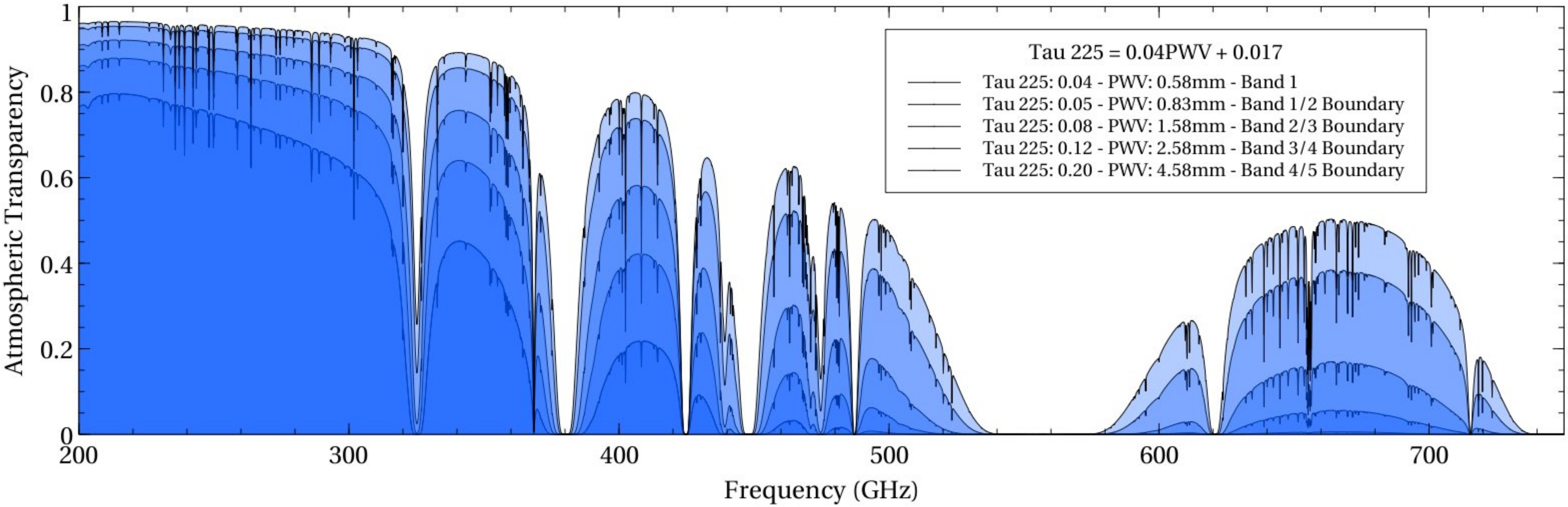
Extinction Correction

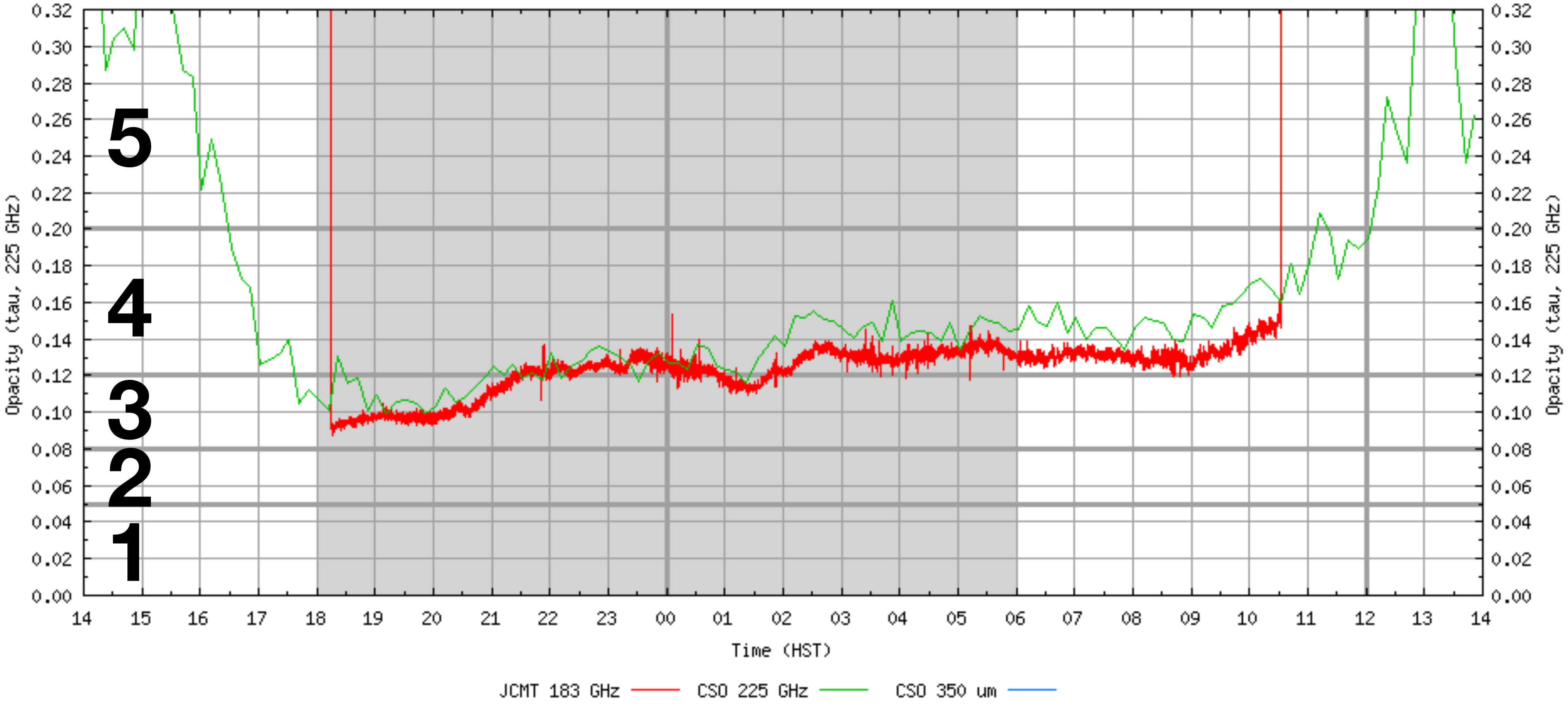
$$I_{\text{measured}} = I_0 \exp(-\tau \times \mathit{Airmass})$$

$$\mathbf{I_0 = I_{\text{measured}} / \exp(-\tau \times \mathit{Airmass})}$$

See Dempsey et al 2013 (10.1093/mnras/stt090) and Mairs et al (in prep)

Weather Grades





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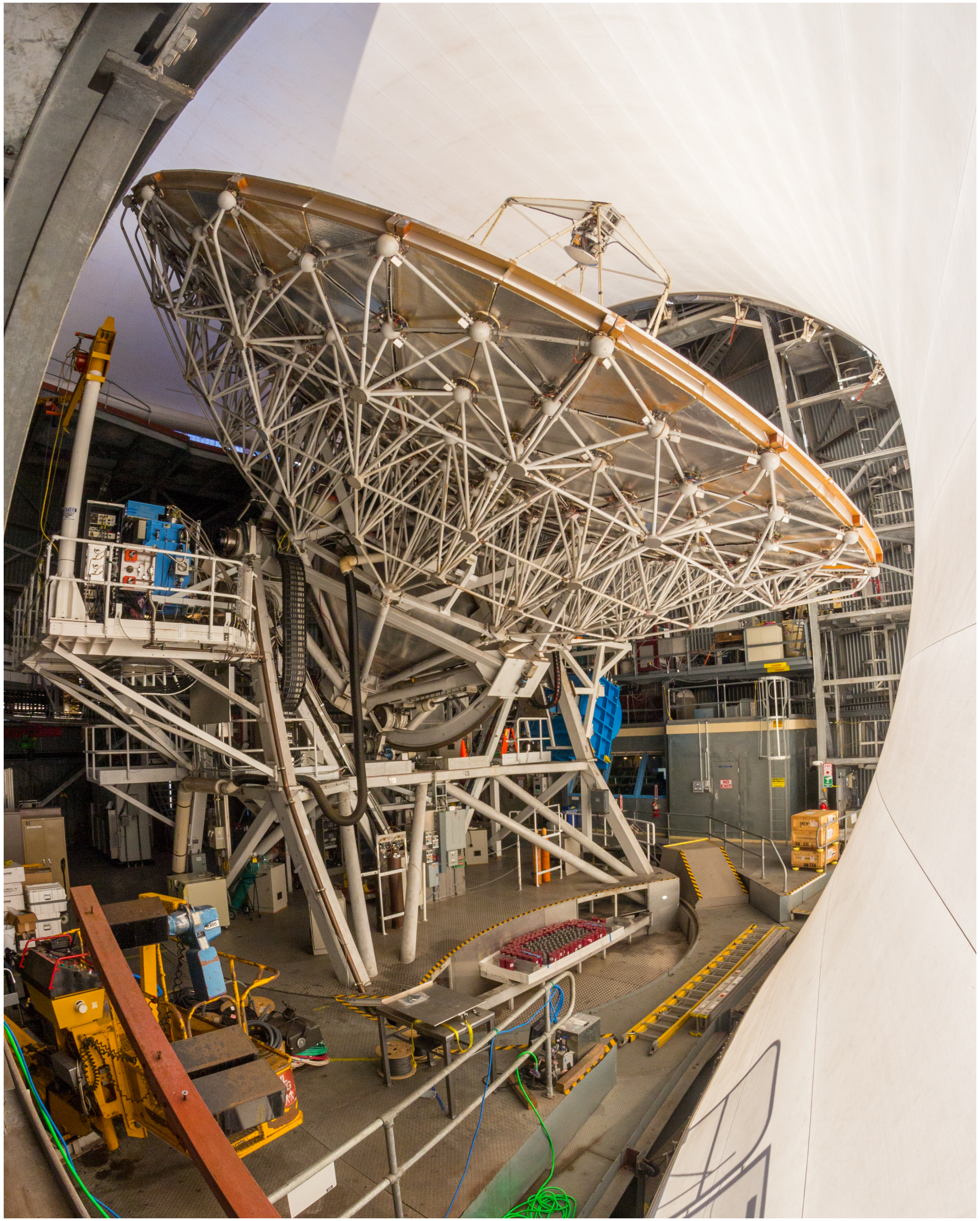
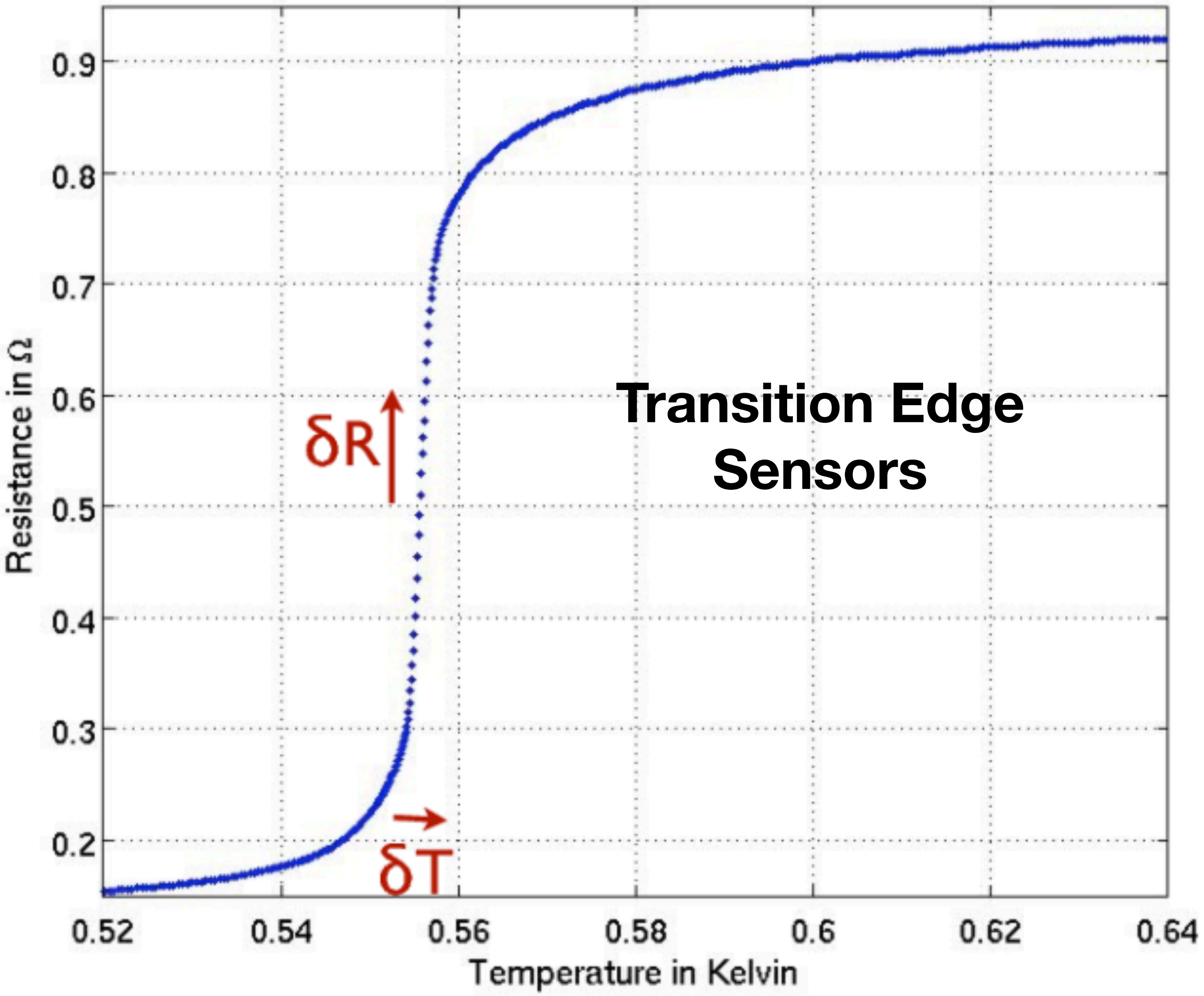


The Submillimetre Common User Bolometer Array 2

A bolometer is a super-cooled thermometer (0.075 K!)



Transition Edge Sensors

★ A small change in temperature = a large change in resistance

★ Light warms up the thermometers, the resistance changes, the current changes!

★ An alternating current = a magnetic field

★ We measure the magnetic field and convert it into a power (in units of picowatts)

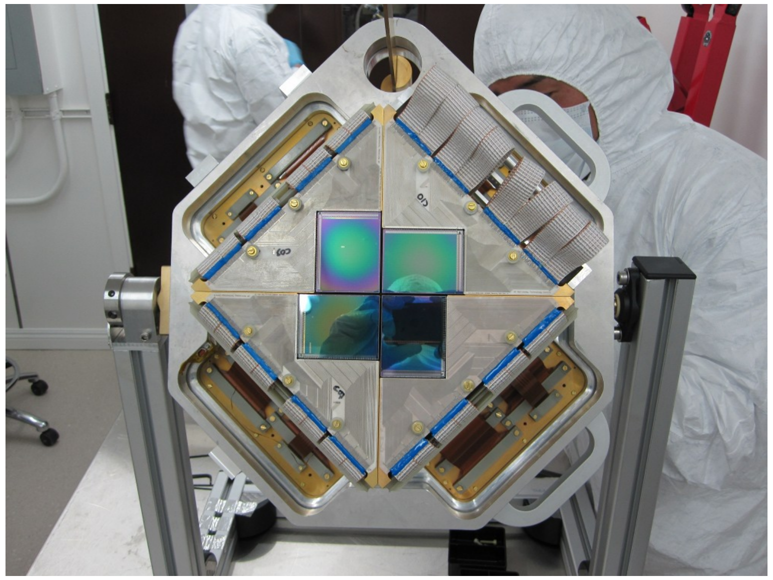
The Signal in a Single Bolometer

$$\boxed{\mathbf{b(t) = f \times [e(t) \times a(t) + n(t)]}}$$

b(t) = Signal Received by a Bolometer

f = Scaling Factor (pW -> Jy beam^{-1})

e(t) = Extinction Correction



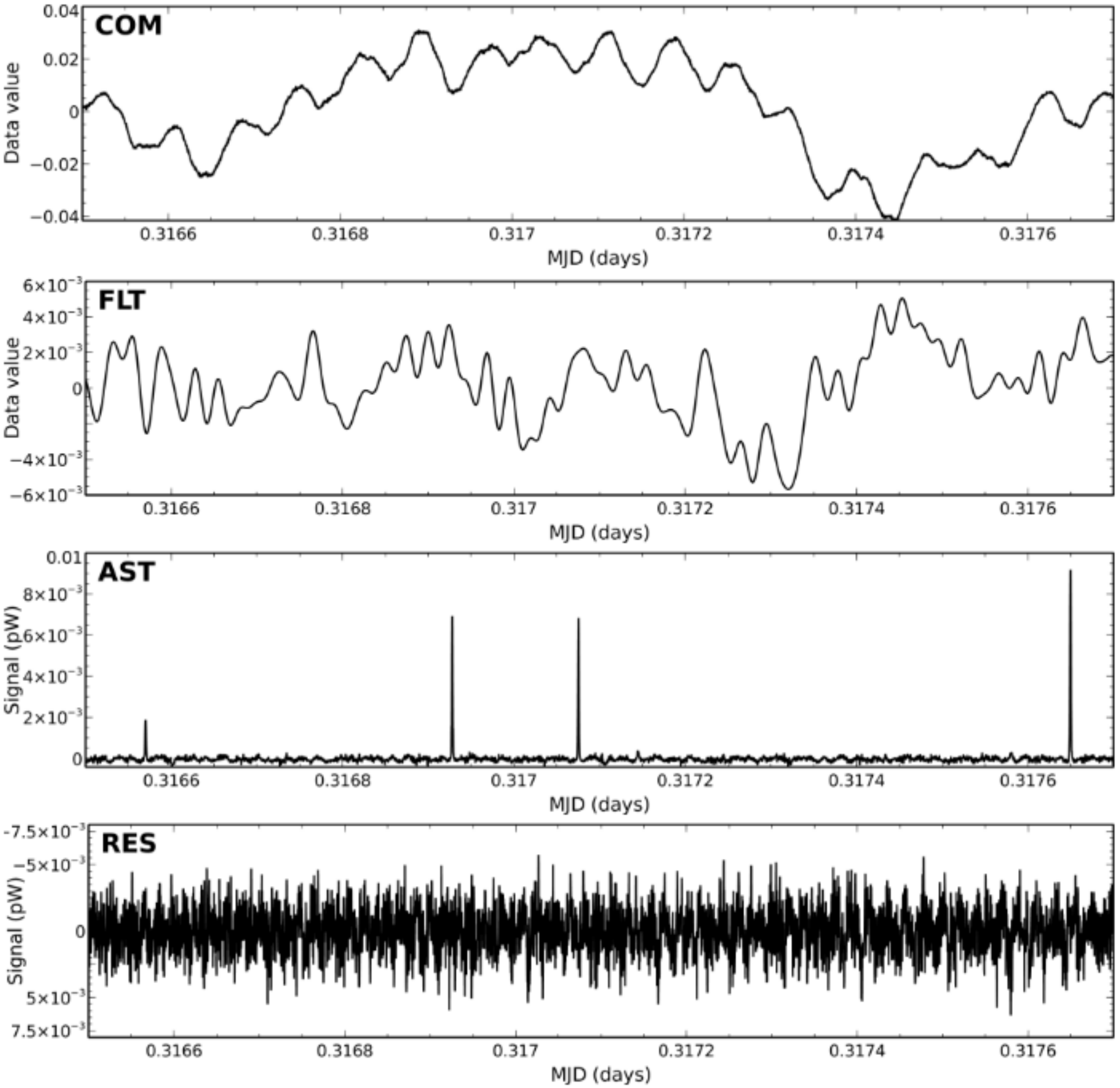
a(t) = Astronomical Signal

n(t) = Sources of noise:

$$\mathbf{n(t)} \begin{cases} 1.\ n_w = \text{Uncorrelated White noise} \\ 2.\ g \times n_c = \text{Common Mode noise + gain factor} \\ 3.\ n_f = \text{Excess noise (low freq.)} \end{cases}$$

An example of Real Time Stream Data
From the SCUBA-2 Data Reduction Handbook

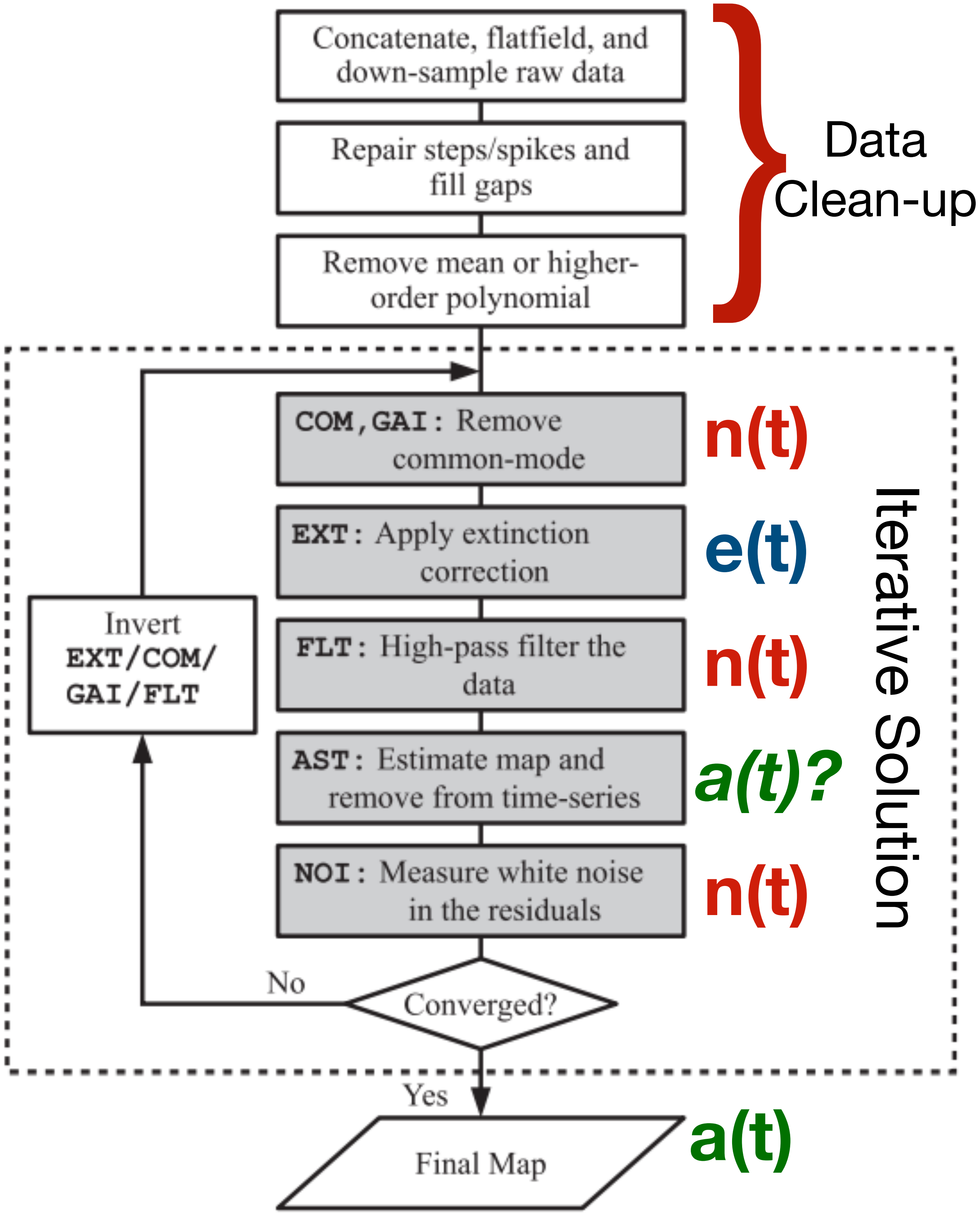
- **COM:** Signal common to all bolometers
- **FLT:** Low frequency noise (sky) missed by COM
- **AST:** Signal, spiking as the telescope scans across the source
- **RES:** Residual white noise (flat as expected)



SCUBA-2 Data Reduction Overview

- 5 main models applied to the data which separate sources of noise from astronomical signal
- More than 100 user defined parameters affect how each model is produced (see Mairs et al. 2015. MNRAS 454, 2557 for examples of DR tests)
- Noise models will be updated with each iteration until the solution converges

$$b(t) = f \times [e(t) \times a(t) + n(t)]$$



Chapin et al. 2013, MNRAS. 430, 2545–2573

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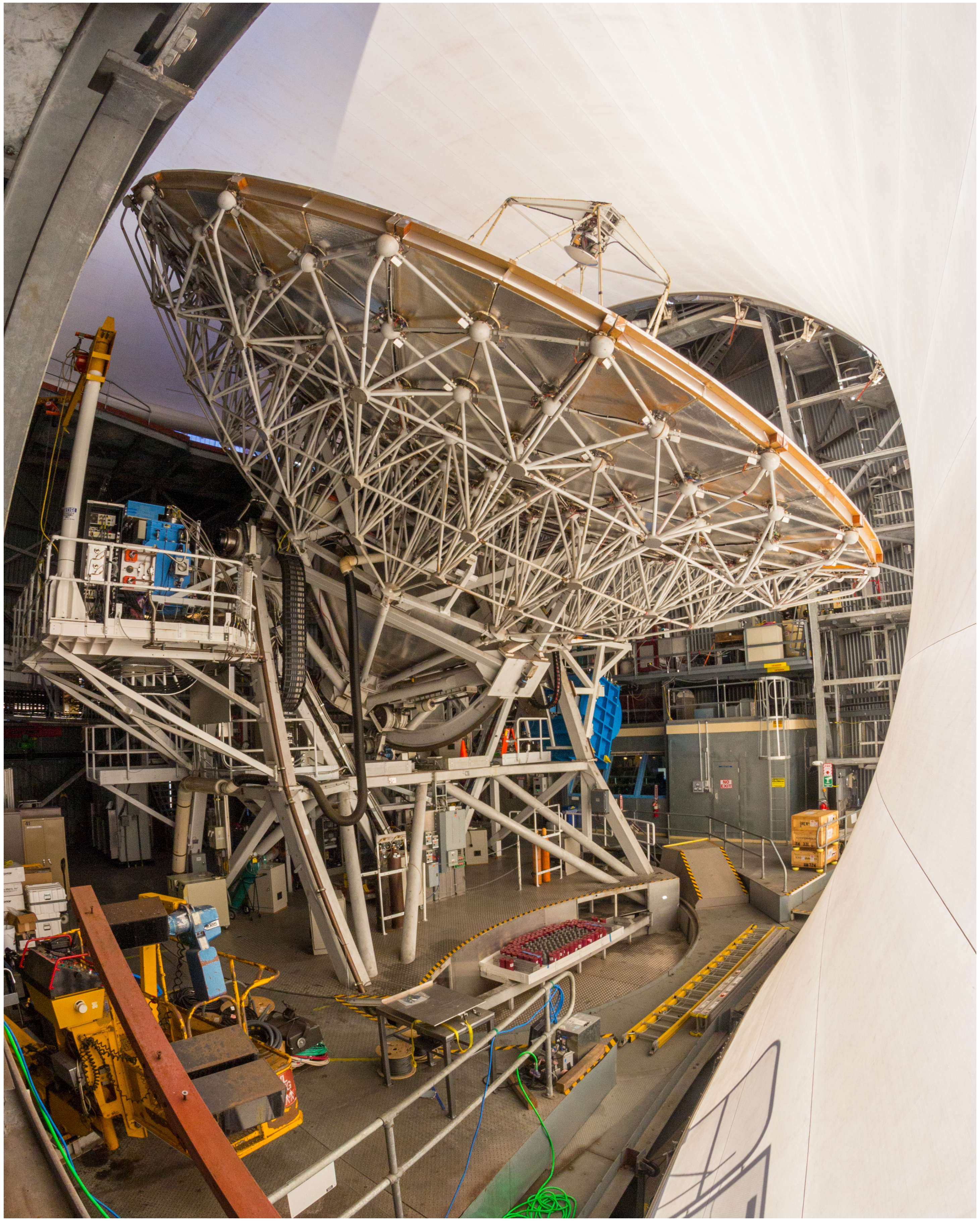
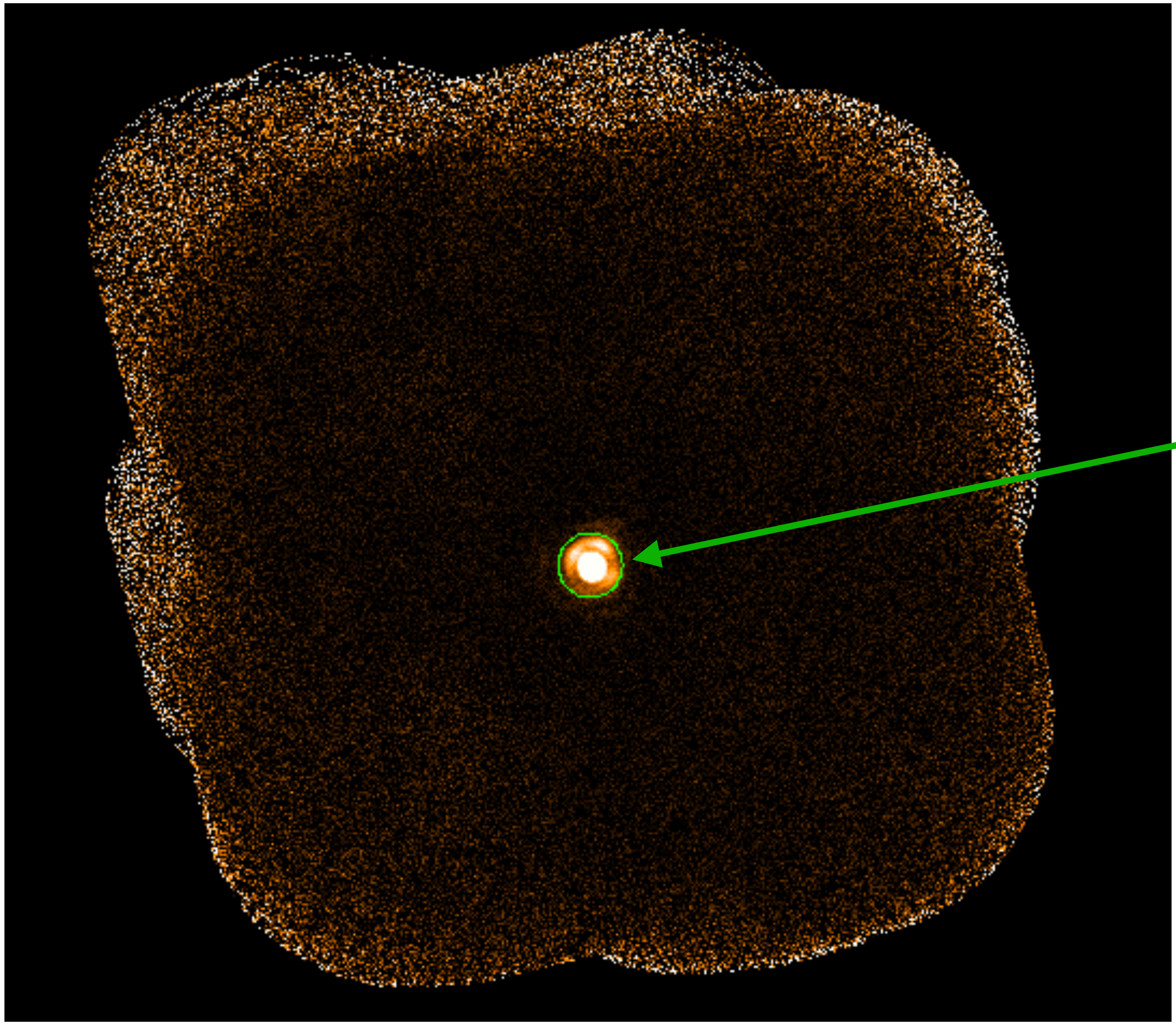


SCUBA-2 Calibration: FCFs

Uranus: The Primary Calibrator



The raw data is in units of picowatts (pW)

We observe *calibrators* throughout the night, measuring the peak flux and the total flux

By comparing the calibrators' known peak and total flux to the received power, we can measure *Flux Conversion Factors* (FCFs)

Information on our Primary and Secondary calibrators (known fluxes) can be found here:
http://www.eaobservatory.org/jcmt/instrumentation/continuum/scuba-2/calibration/calibrators/

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http://www.eaobservatory.org/jcmt/instrumentation/continuum/scuba-2/calibration/

SCUBA-2 Calibration: FCFs

2 types of FCF = Flux Conversion Factor

$\mathrm{FCF}_{\mathrm{beam}}$

$\mathrm{pW} \longrightarrow \mathrm{mJy\ beam^{-1}}$

$$\mathrm{FCF}_{\mathrm{beam}} = \frac{S_{\mathrm{peak}}}{I_{\mathrm{peak}}}$$

S_{peak} = The known calibrator peak flux
I_{peak} = The measured peak flux

$\mathrm{FCF}_{\mathrm{arcsec}}$

$\mathrm{pW} \longrightarrow \mathrm{mJy\ arcsec^{-2}}$

$$\mathrm{FCF}_{\mathrm{beam}} = \frac{S_{\mathrm{total}}}{I_{\mathrm{total}}\,A}$$

S_{total} = The known calibrator total flux
I_{total} = The measured total flux
A = The pixel area in arcsec^{-2}

Information on our Primary and Secondary calibrators (known fluxes) can be found here:
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SCUBA-2 Calibration: FCFs

2 types of FCF = Flux Conversion Factor

$\mathrm{FCF}_{\mathrm{beam}}$

$$\mathrm{pW} \longrightarrow \mathrm{mJy\ beam}^{-1}$$

$$\boxed{\mathrm{FCF}_{\mathrm{beam}} = \frac{S_{\mathrm{peak}}}{I_{\mathrm{peak}}}}$$

The number by which to multiply your map if you wish to measure absolute peak fluxes of discrete sources.

$\mathrm{FCF}_{\mathrm{arcsec}}$

$$\mathrm{pW} \longrightarrow \mathrm{mJy\ arcsec}^{-2}$$

$$\boxed{\mathrm{FCF}_{\mathrm{beam}} = \frac{S_{\mathrm{total}}}{I_{\mathrm{total}}\,A}}$$

The number by which to multiply your map if you wish to use the calibrated map to do aperture photometry.

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Current SCUBA-2 Calibration Advice

Extinction Correction is **Automatically applied to the data!**

$$\text{Reduced Data} = \frac{\text{Raw Data}}{\exp(-\tau_\lambda A)}$$

where

$$\tau_{450} = 26.0\,(\tau_{225} - 0.012)$$

$$\tau_{850} = 4.6\,(\tau_{225} - 0.0043)$$

τ_{225} and Airmass are recorded in the header!

FCF$_{\text{beam}}$

450 microns: 491 ± 67 Jy pW^{-1} beam^{-1}
850 microns: 537 ± 26 Jy pW^{-1} beam^{-1}

The number by which to multiply your map if you wish to measure absolute peak fluxes of discrete sources.

FCF$_{\text{arcsec}}$

450 microns: 4.71 ± 0.50 Jy pW^{-1} arcsec^{-2}
850 microns: 2.34 ± 0.08 Jy pW^{-1} arcsec^{-2}

The number by which to multiply your map if you wish to use the calibrated map to do aperture photometry.

For More Information, See: Dempsey et al. 2013. MNRAS 430:2534 and http://www.eaobservatory.org/jcmt/instrumentation/continuum/scuba-2/calibration/

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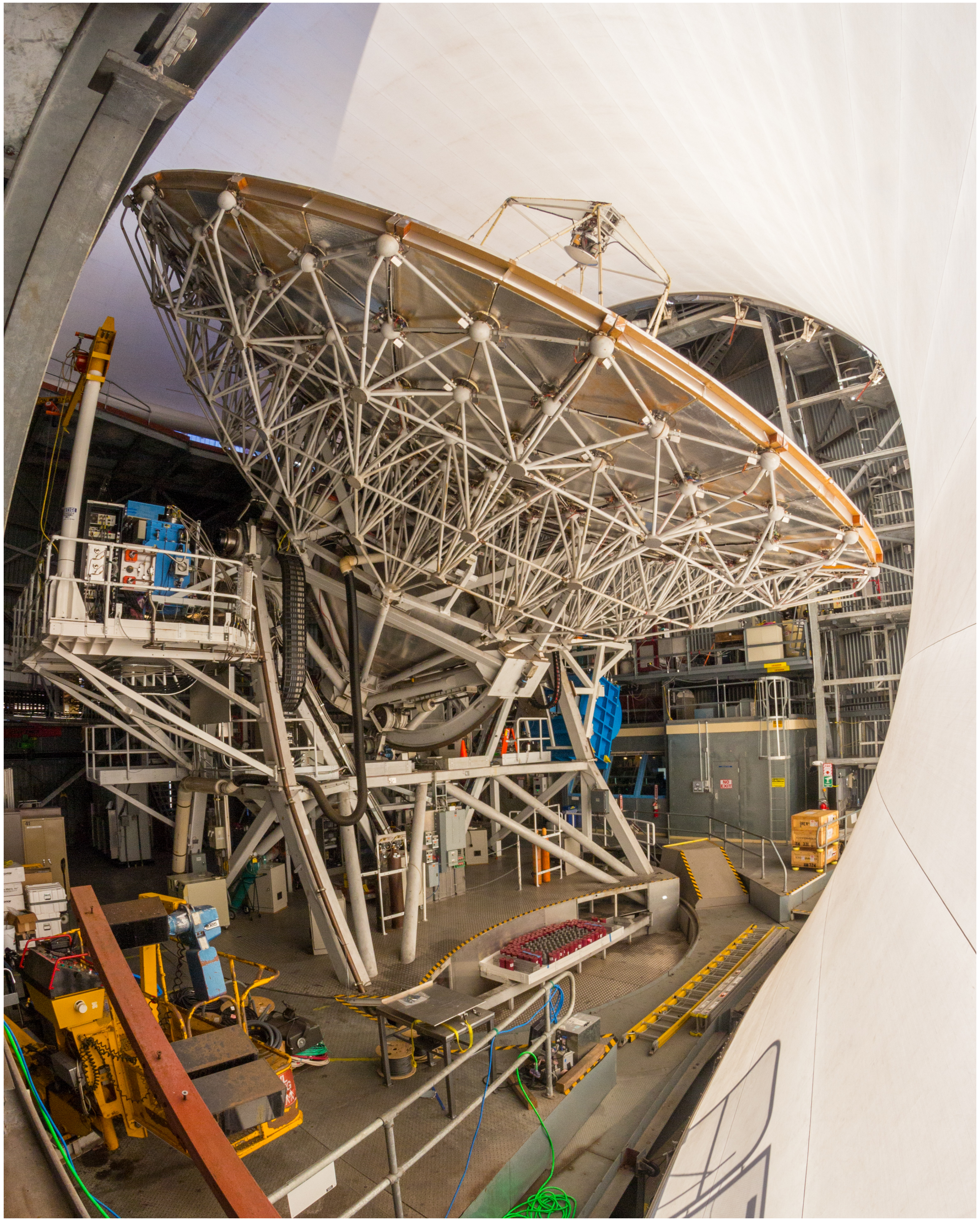
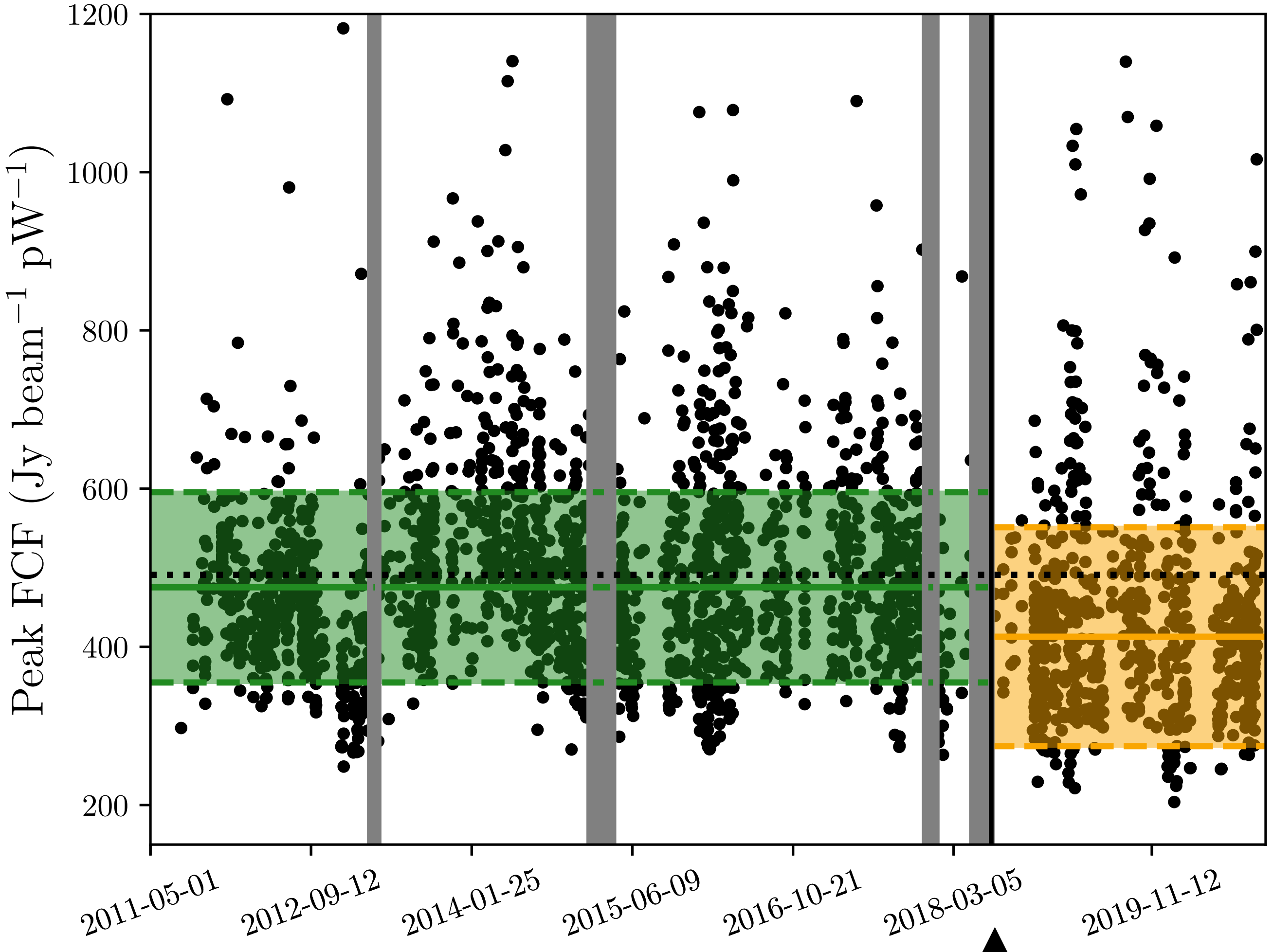
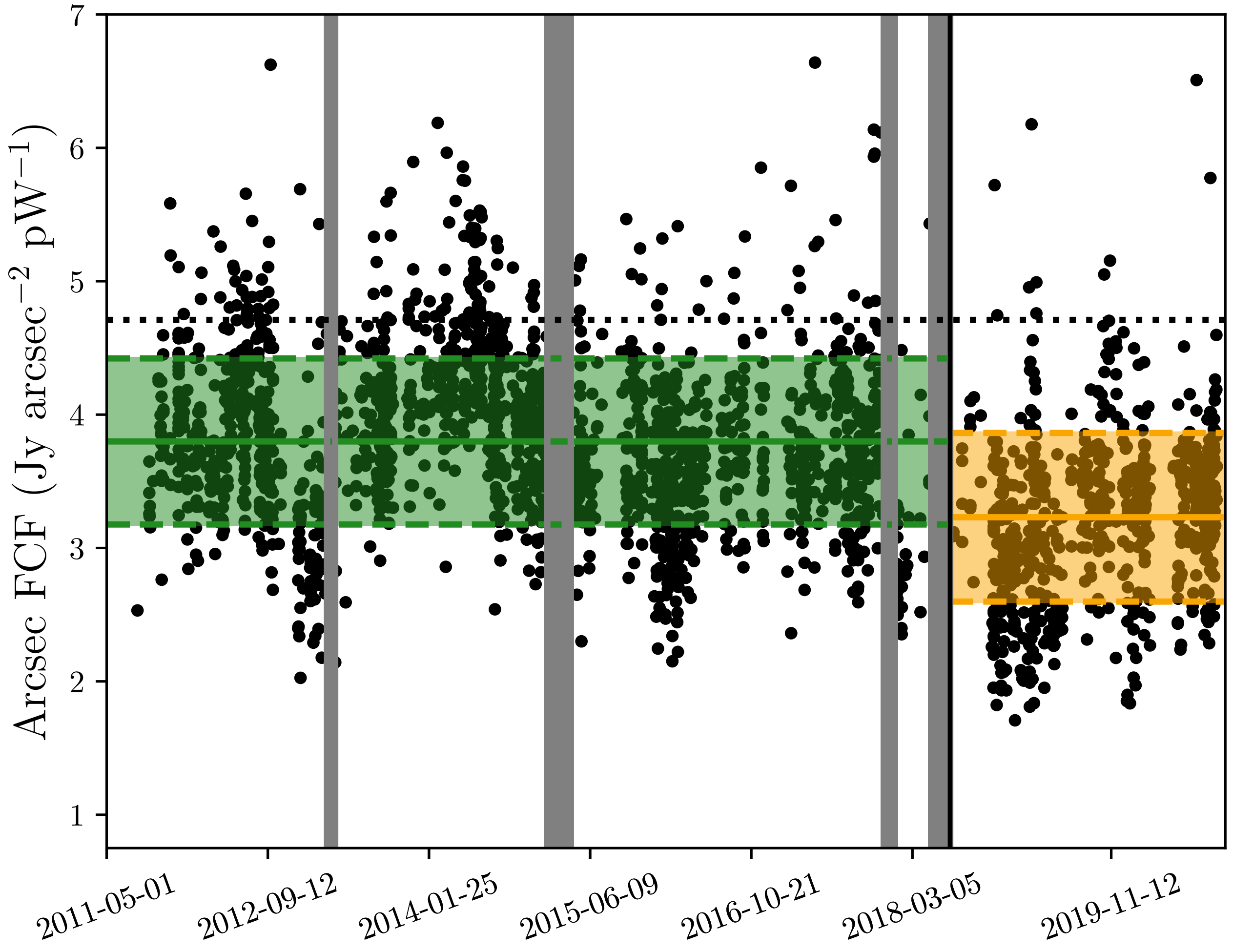


FCF Results over Time (Mairs et al. in Prep)

450 µm, Peak FCF



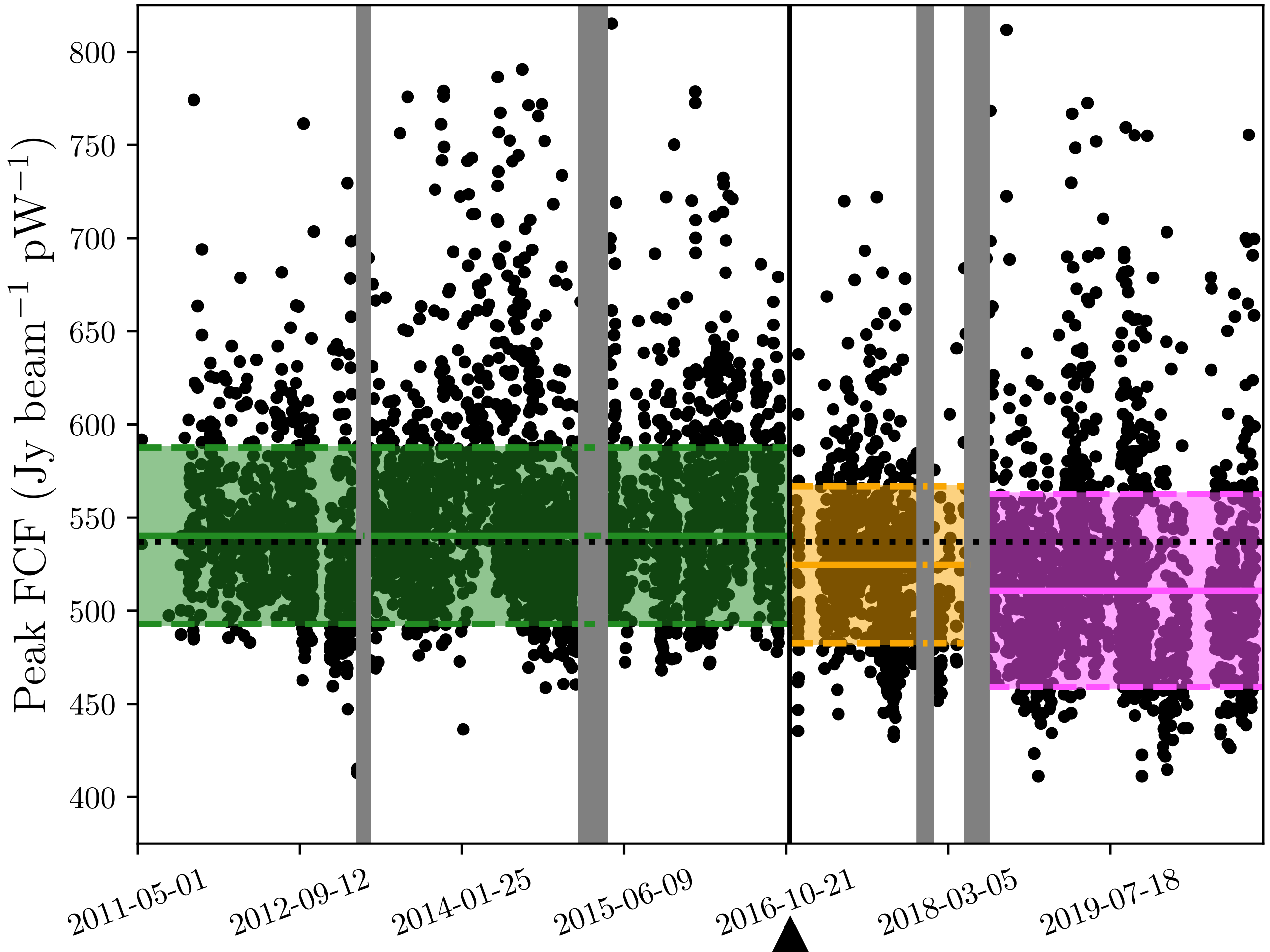
450 µm, Arcsec FCF



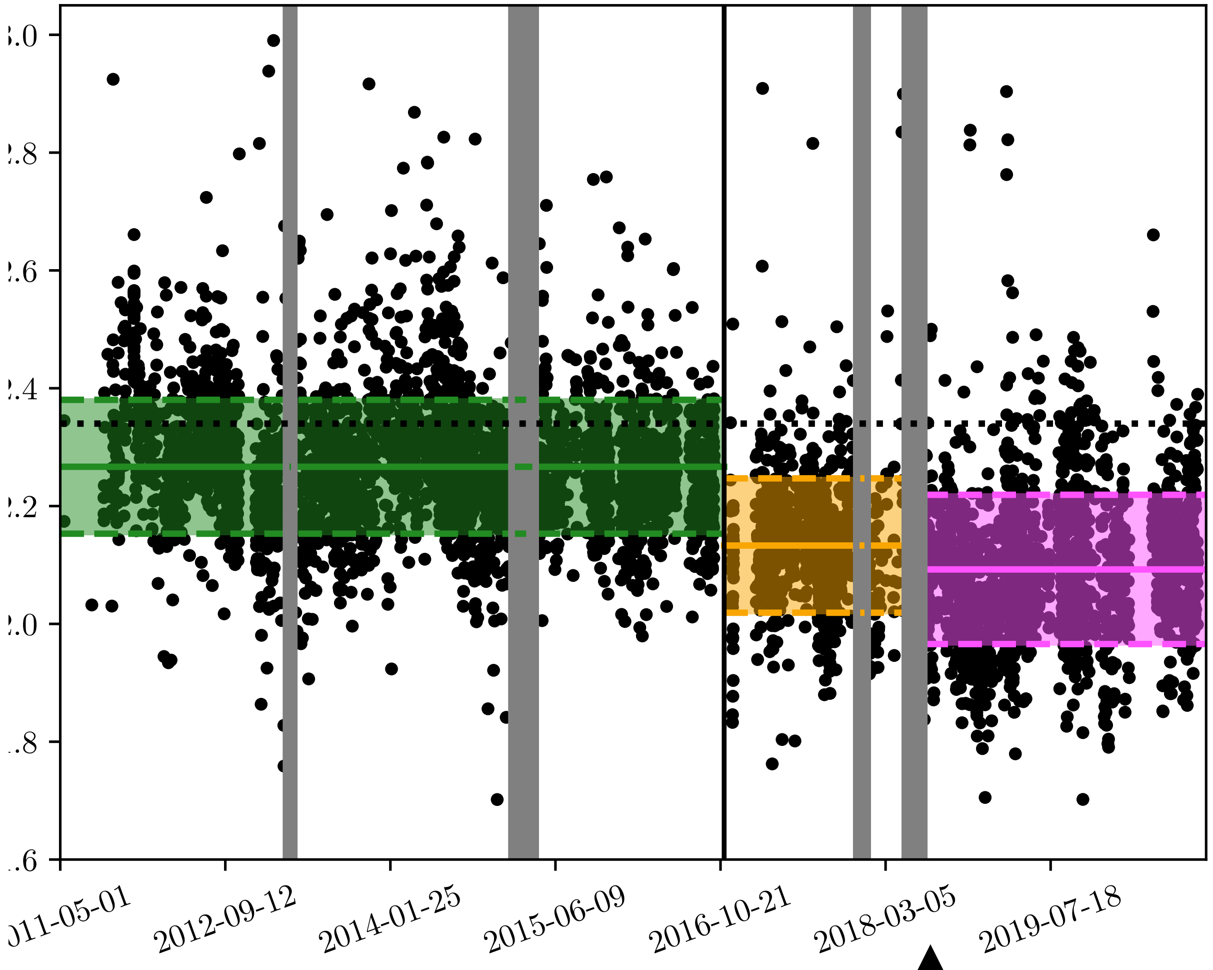
Changes to the Secondary Mirror Unit.
The flux became more concentrated
in the beam, lowering the FCFs

FCF Results over Time (Mairs et al. in Prep)

850 µm, Peak FCF



850 µm, Arcsec FCF

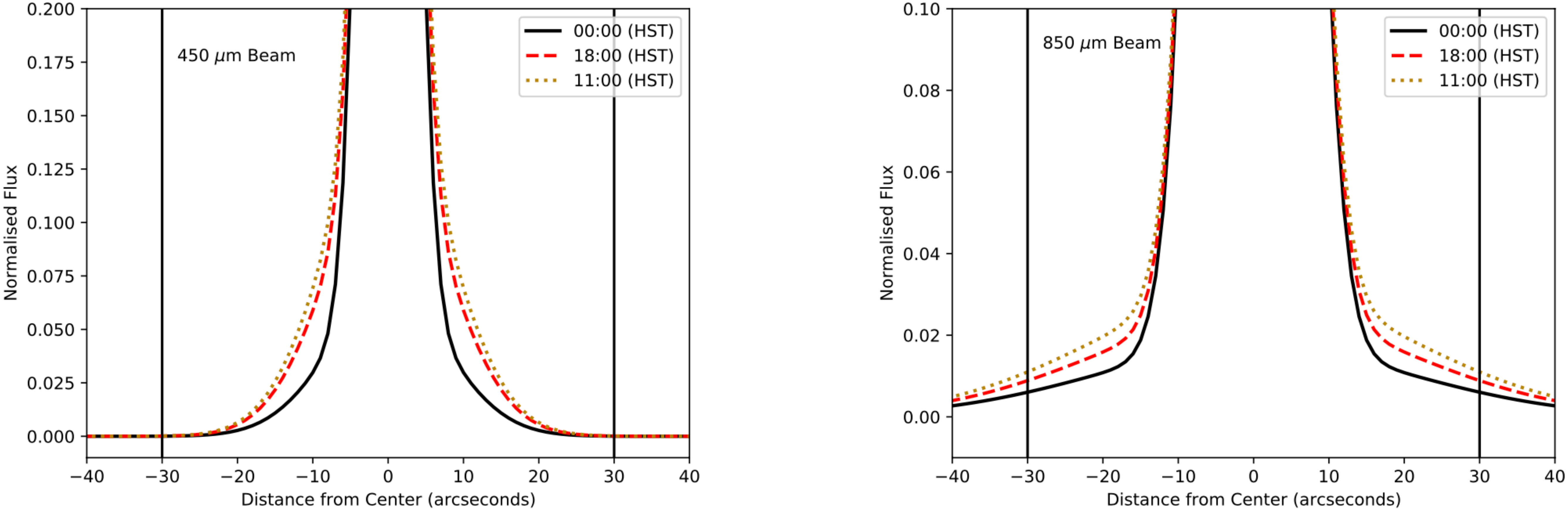


New thermal filter stack installed.
This increased throughput of camera.
Less scatter at 850 µm makes
change apparent.

Changes to the
Secondary Mirror Unit.
The flux became more
concentrated in the beam,
lowering the FCFs

Peak FCFs Vary Over the Course of One Night

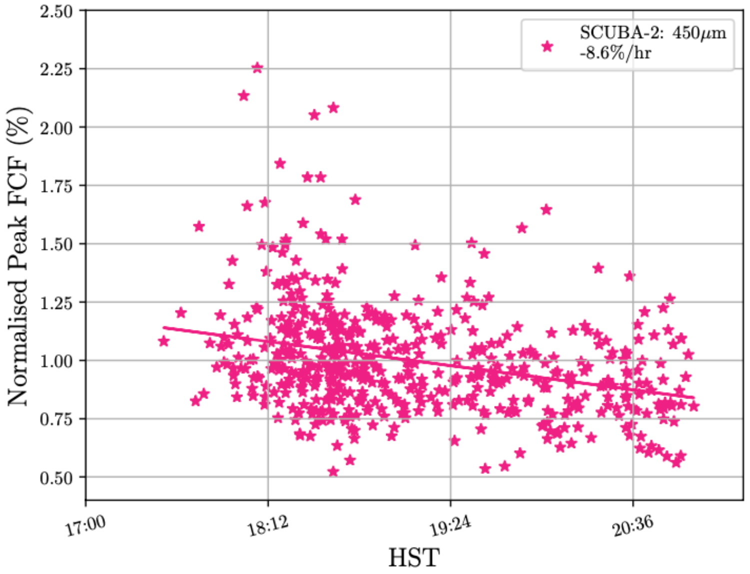
As the telescope cools down in the evening, or warms up in the morning, the physical structure of the dish changes



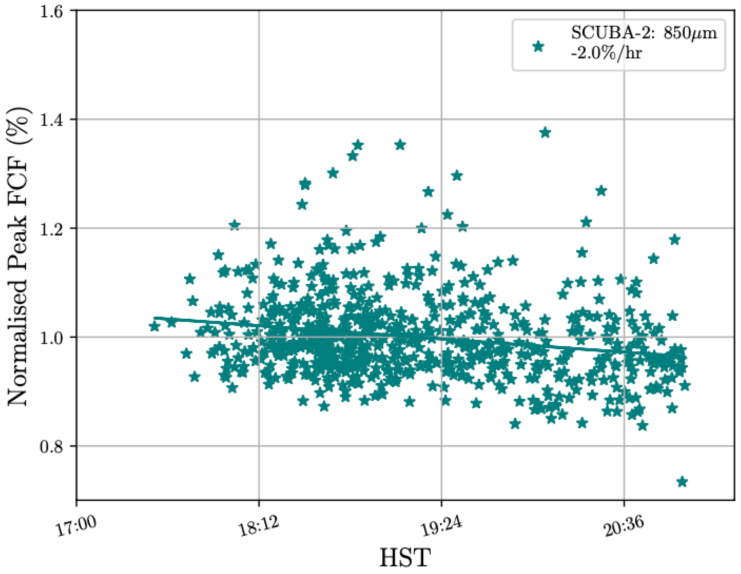
This surpasses the peak flux and distributes it into the "shoulders" of the beam profile

The Peak FCFs, therefore, change with time in the early evening and late morning while the Arcsecond FCFs stay the same

450 µm Flux Improves by 8.6% per hour

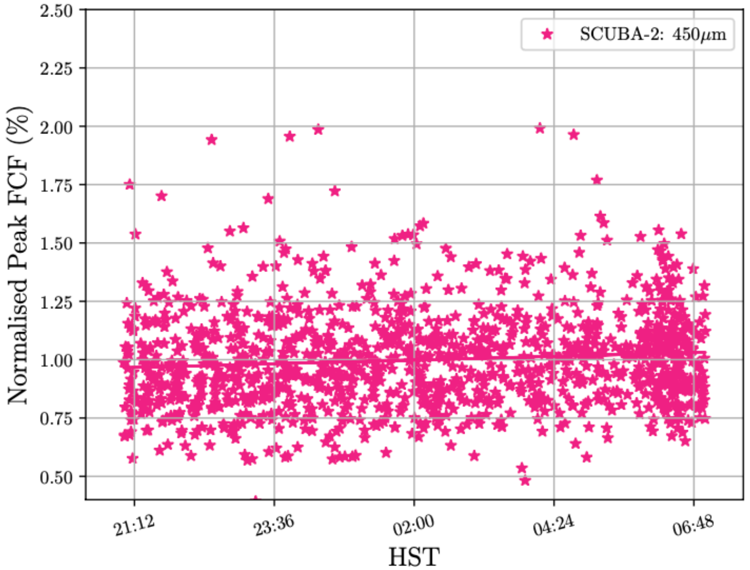


850 µm Flux Improves by 2.0% per hour

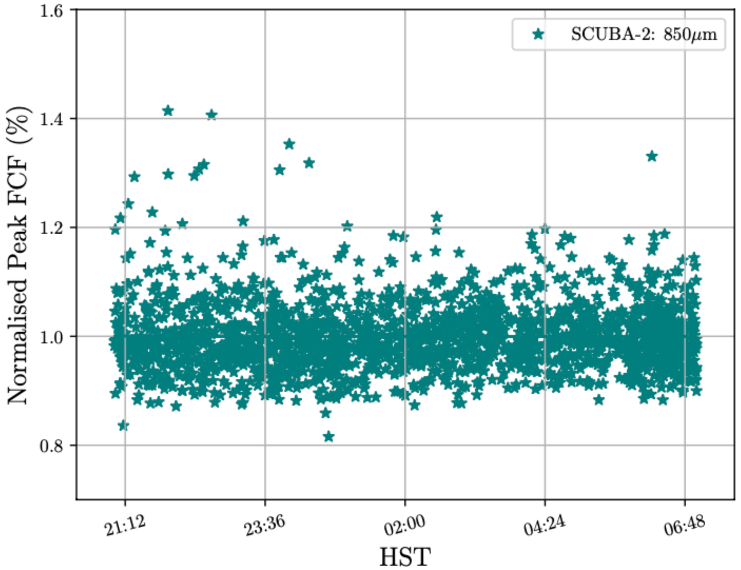


17:00 - 21:00 Hawaii Time
(03:00 - 07:00 UT)

450 µm Flux is stable

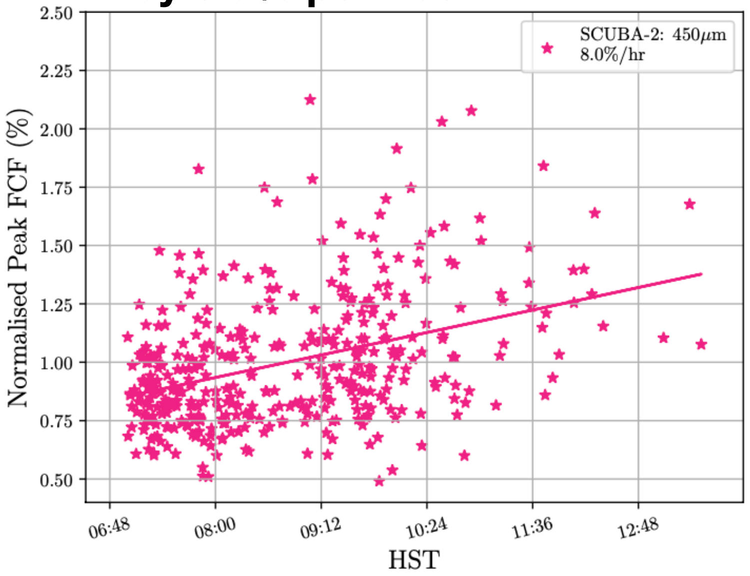


850 µm Flux is stable

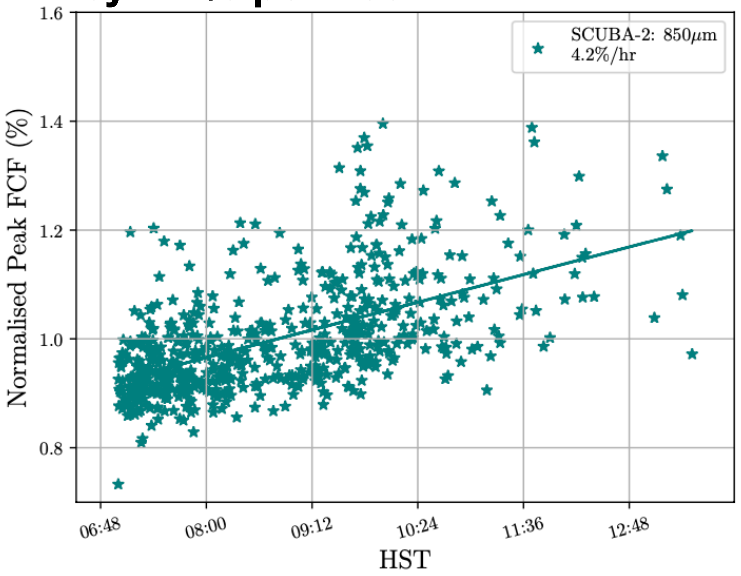


21:00 - 07:00 Hawaii Time
(07:00 - 17:00 UT)

450 µm Flux Degrades by 8.0% per hour



850 µm Flux Degrades by 4.2% per hour



07:00 - 13:00 Hawaii Time
(17:00 - 23:00 UT)

Preliminary SCUBA-2 Calibration Advice

New extinction corrections

$$\text{Reduced Data} = \frac{\text{Raw Data}}{\exp(-\tau_\lambda A)}$$

where

$$\tau_{450} = 25.25 \times \left(\tau_{225} - 0.0104 + 0.00343 \times \sqrt{\tau_{225}}\right)$$

$$\tau_{850} = 3.71 \times \left(\tau_{225} - 0.0400 + 0.201 \times \sqrt{\tau_{225}}\right)$$

$\boldsymbol{\tau}_{225}$ and Airmass are recorded in the header - must undo original correction first!

Stable FCF values between 21:00 - 07:00 Hawaii Time (07:00 - 17:00 UT)

***These FCFs assume the extinction corrections, above**

	$\mathrm{FCF}_{\mathrm{peak}}$	$\mathrm{FCF}_{\mathrm{arcsec}}$
450 μm, Pre 2018-06-30	470 ± 66	3.84 ± 0.34
450 μm, Post 2018-06-30	408 ± 71	3.23 ± 0.37
850 μm, Pre 2016-11-01	539 ± 25	2.27 ± 0.06
850 μm, 2016-11-01 to 2018-06-30	522 ± 21	2.14 ± 0.06
850 μm, Post 2018-06-30	504 ± 23	2.09 ± 0.05

17:00 - 21:00 Hawaii Time

(03:00 - 07:00 UT)

450 µm *Peak FCF* Reduces by 8.6% per hour until stable

850 µm *Peak FCF* Improves by 2.0% per hour until stable

07:00 - 13:00 Hawaii Time

(17:00 - 23:00 UT)

450 µm *Peak FCF* Increases by 8.0% per hour from stable

850 µm *Peak FCF* Improves by 4.2% per hour from stable