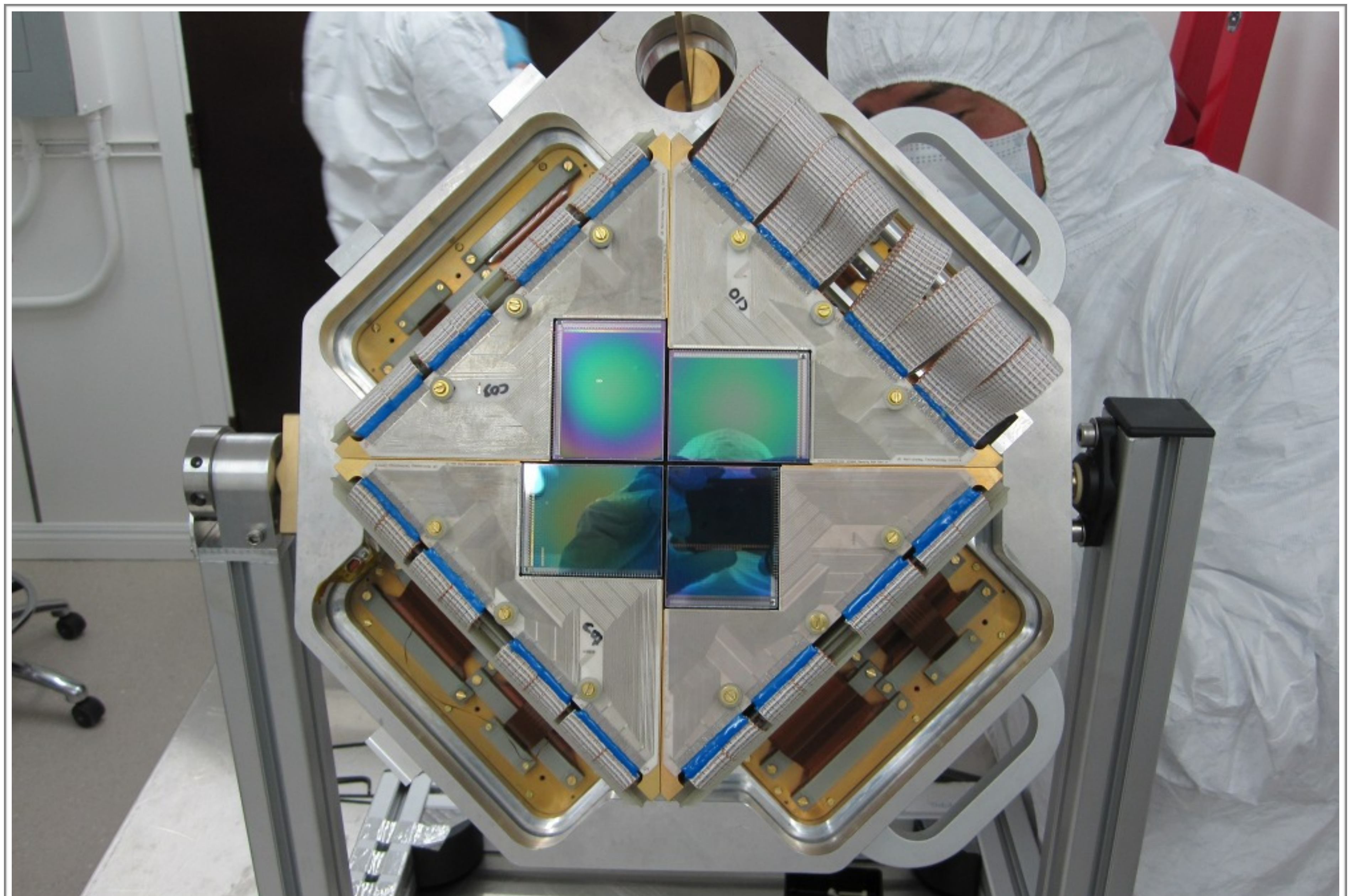
Assignment 1

SCUBA-2 Data Reduction



Dr. Steve Mairs (ASTR351L Spring 2019)

Overview

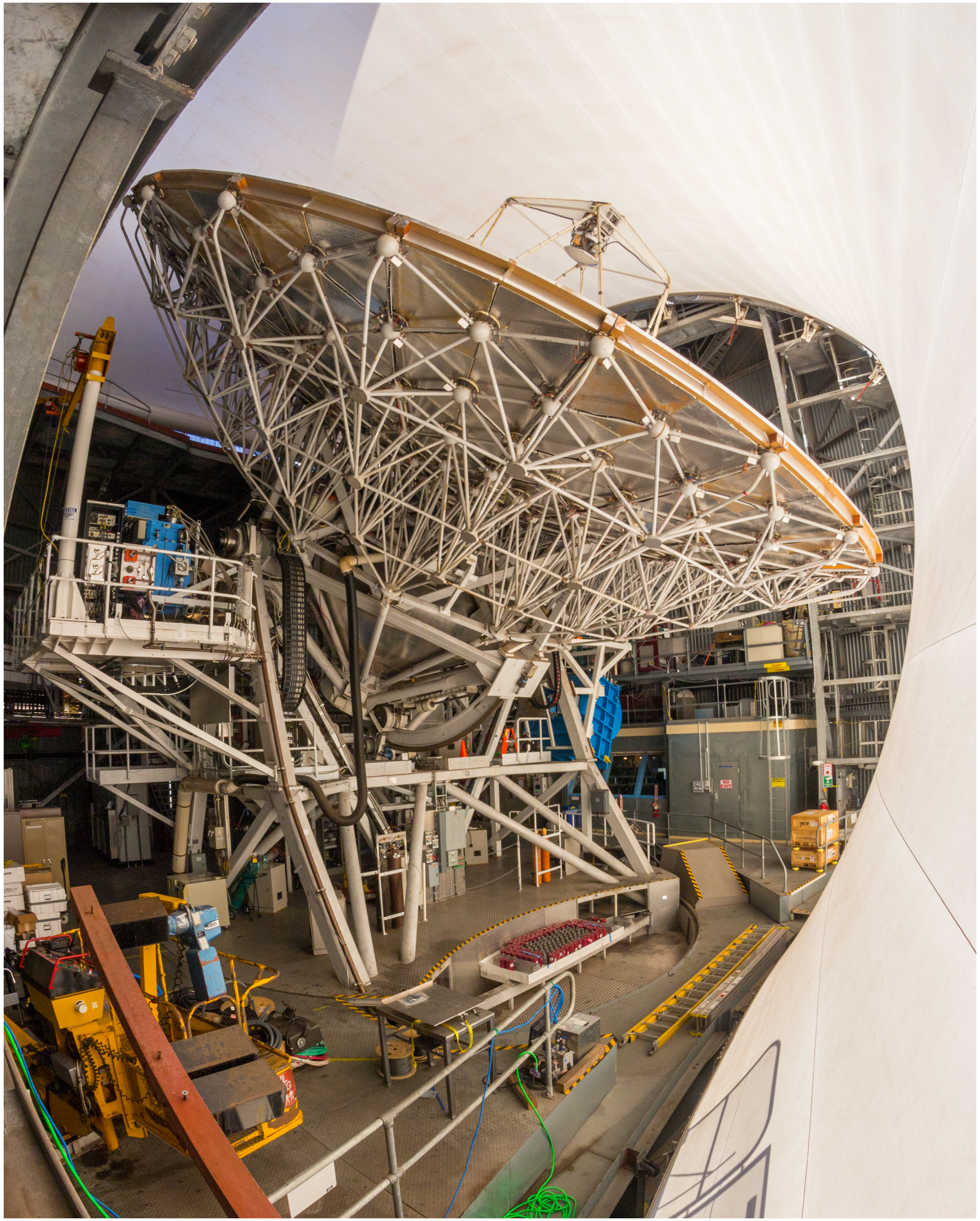
1. Signal vs Noise

2. Data Reduction Methodology

3. Point Spread Function: Submillimetre Style

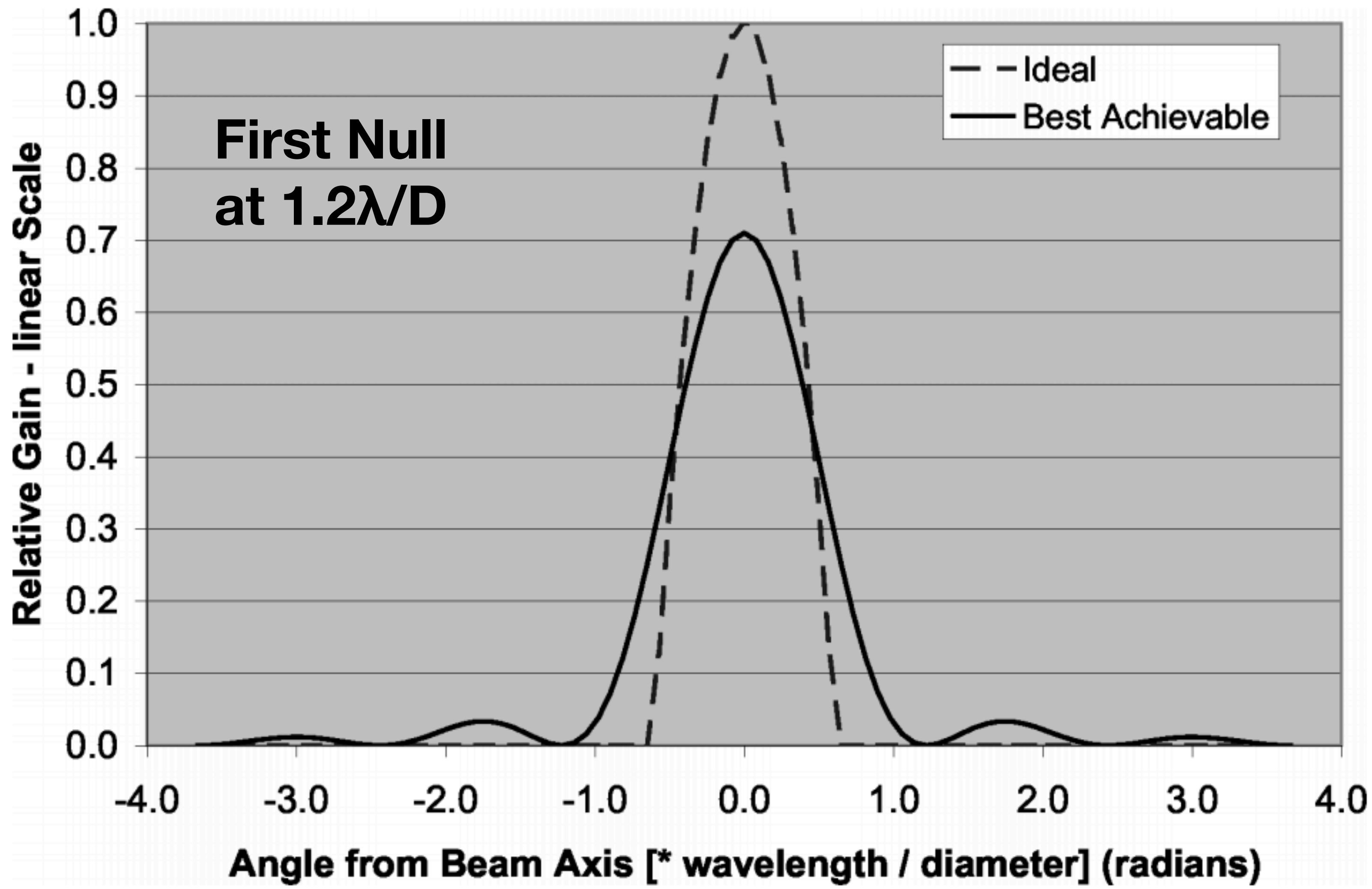
4. Units and Calibration

5. Demonstration



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

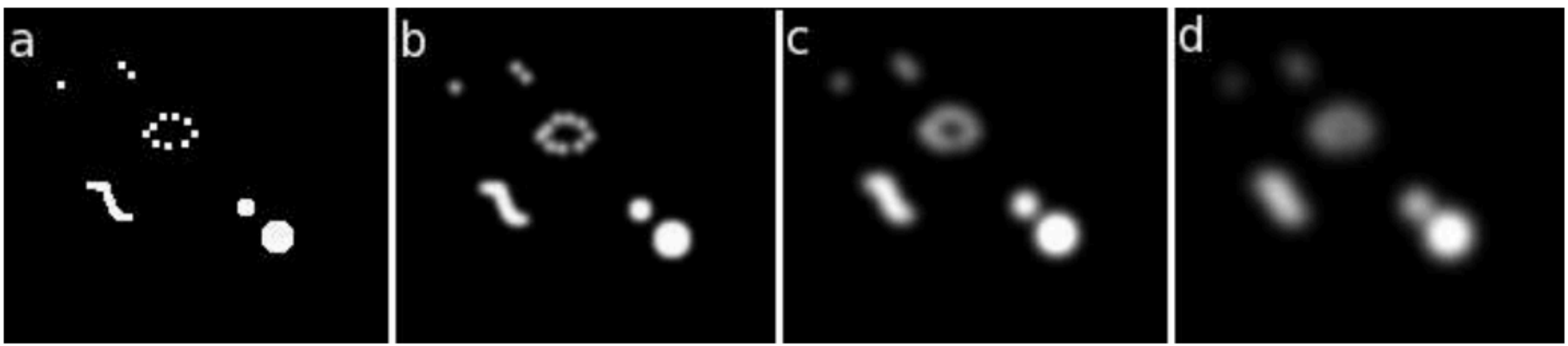


The beam defines the angular resolution of the image and how much power appears in the “Main beam” in contrast to the “Sidelobes”

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

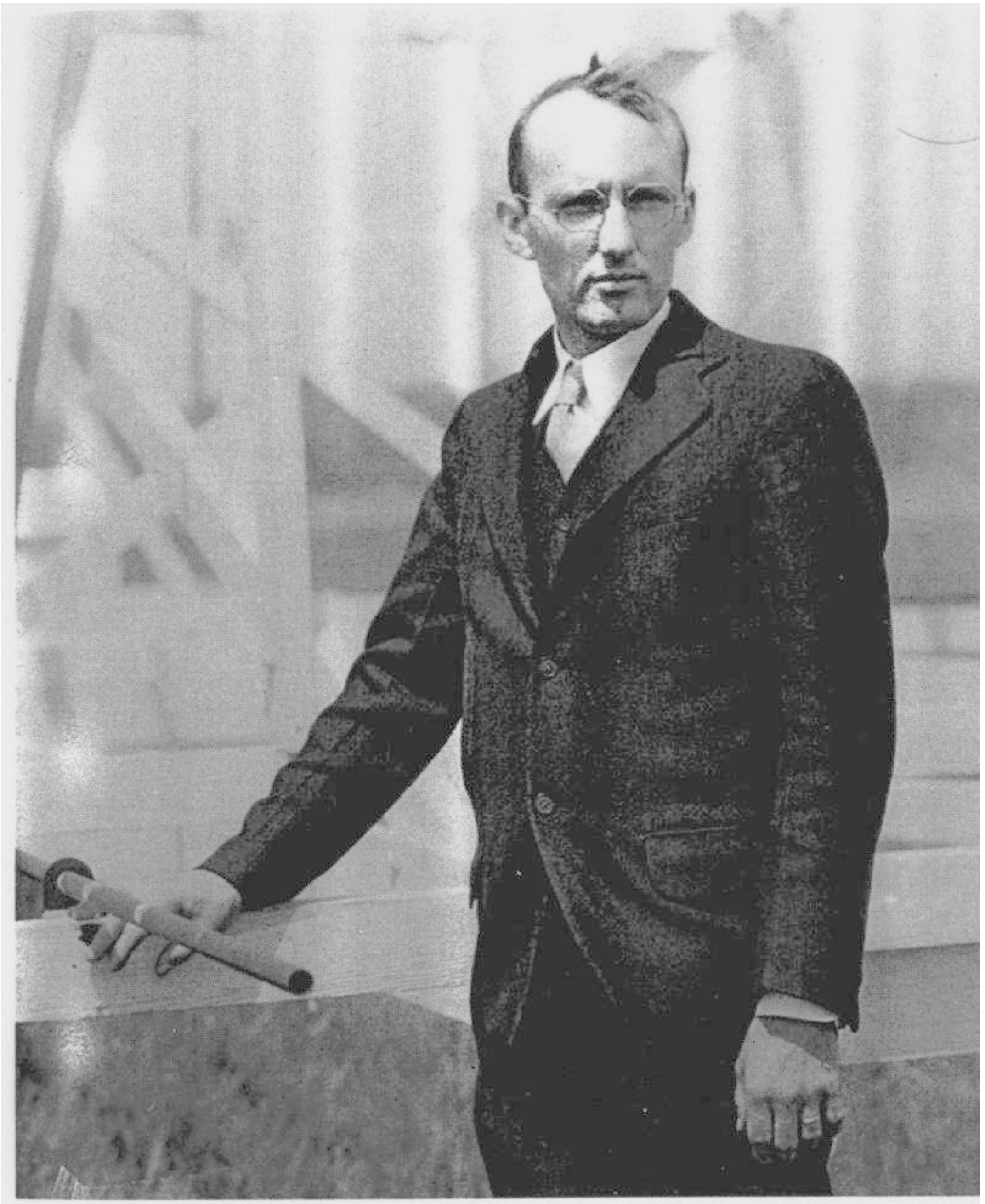


FIG. 1—Karl Guthe Jansky, about 1933.

Karl Guthe Janksy first discovered radio waves in the Milky Way

So we named a unit after him!

The amount of energy collected from space by all the radio telescopes ever used to explore the sky would not light a single lightbulb.

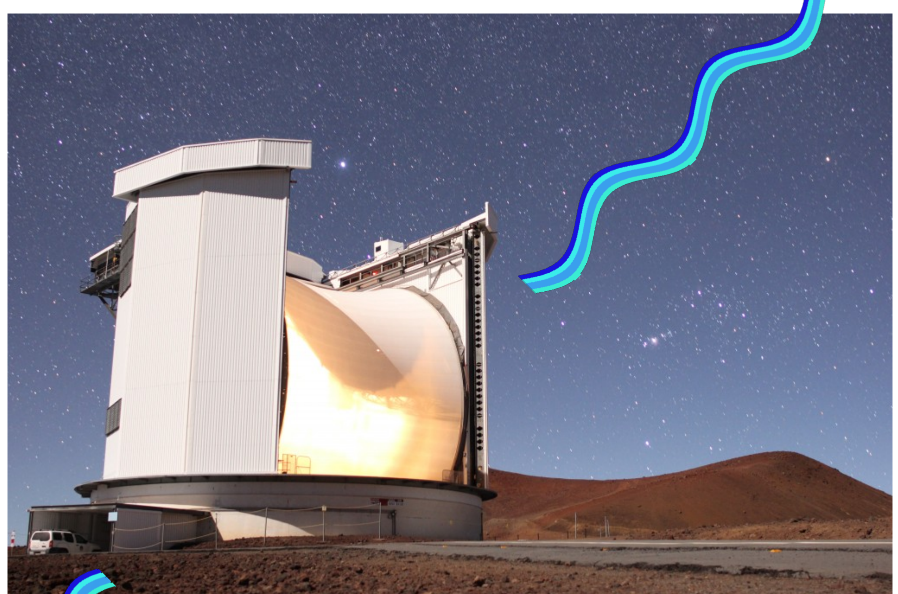
$$1\ \mathrm{Jy} = 1 \times 10^{-26}\ \mathrm{W\ m^{-2}\ Hz^{-1}} \qquad = \mathrm{J\ s^{-1}\ m^{-2}\ Hz^{-1}}$$

$$1\ \mathrm{Jy} = 1 \times 10^{-23}\ \mathrm{erg\ s^{-1}\ cm^{-2}\ Hz^{-1}}$$

Light can be affected by many factors

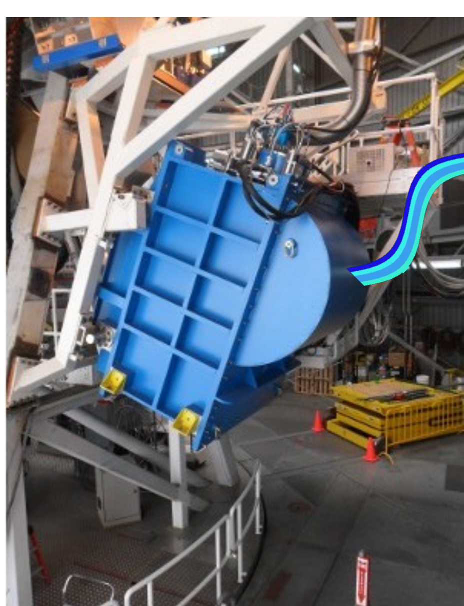
Some Space thing

Atmosphere is bright and variable at submillimetre wavelengths.



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

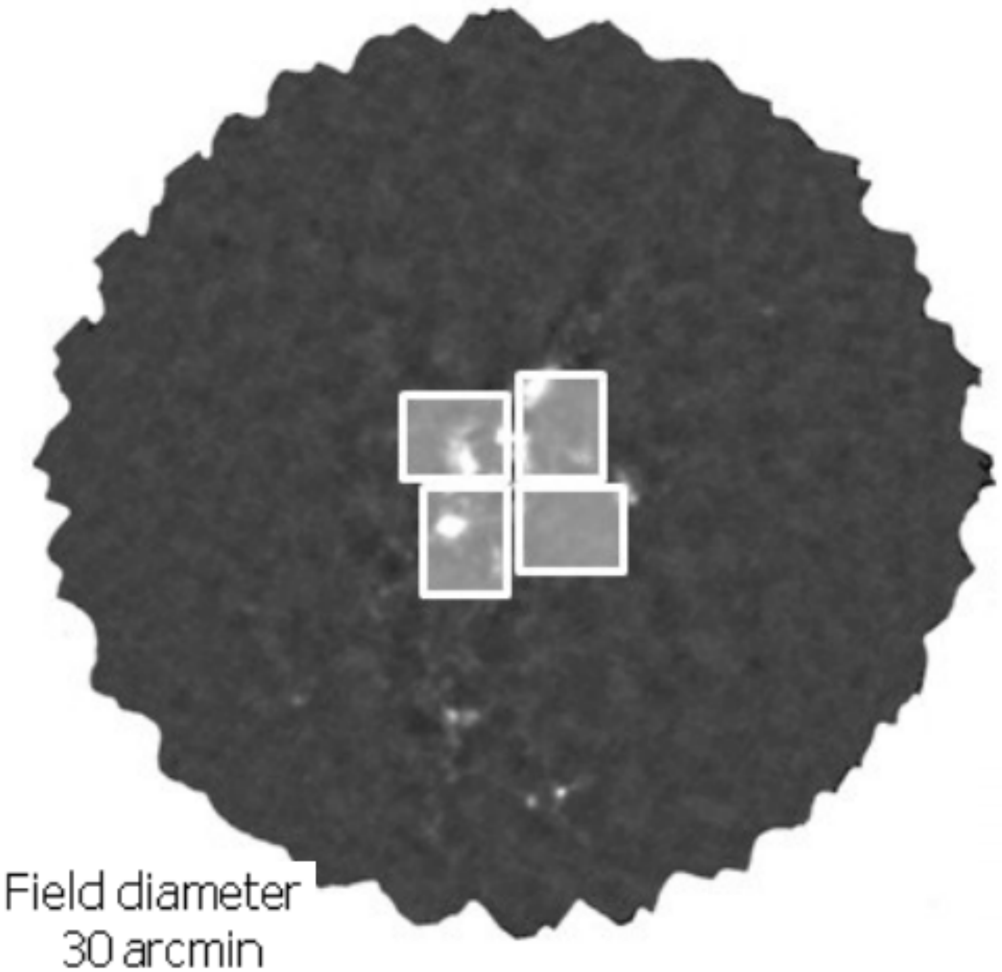
Pointing and focus uncertainties!



The instrumentation has electronic noise. Focal planes must be kept extremely cold. Temperature fluctuations and power glitches can affect data!

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

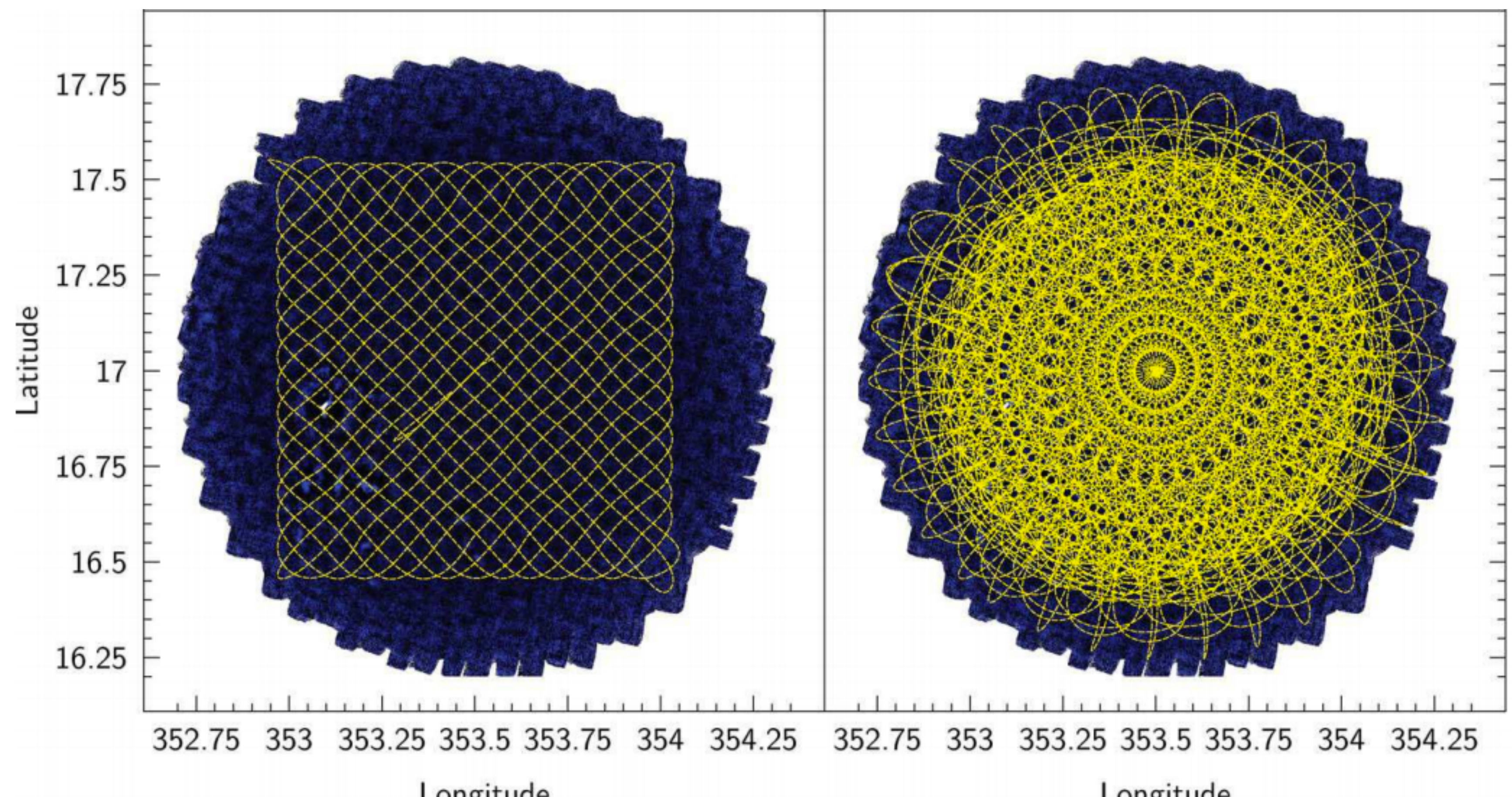
Getting Rid of the Atmosphere



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

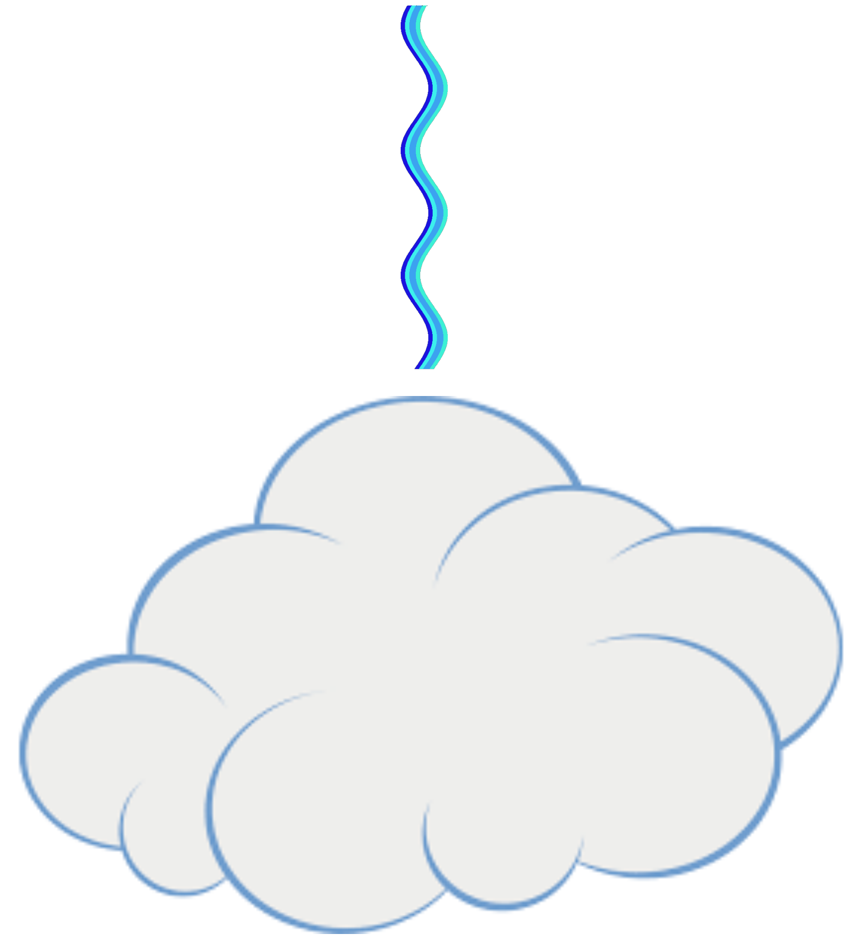
Once we get rid of the signal from the bright and variable atmosphere…

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

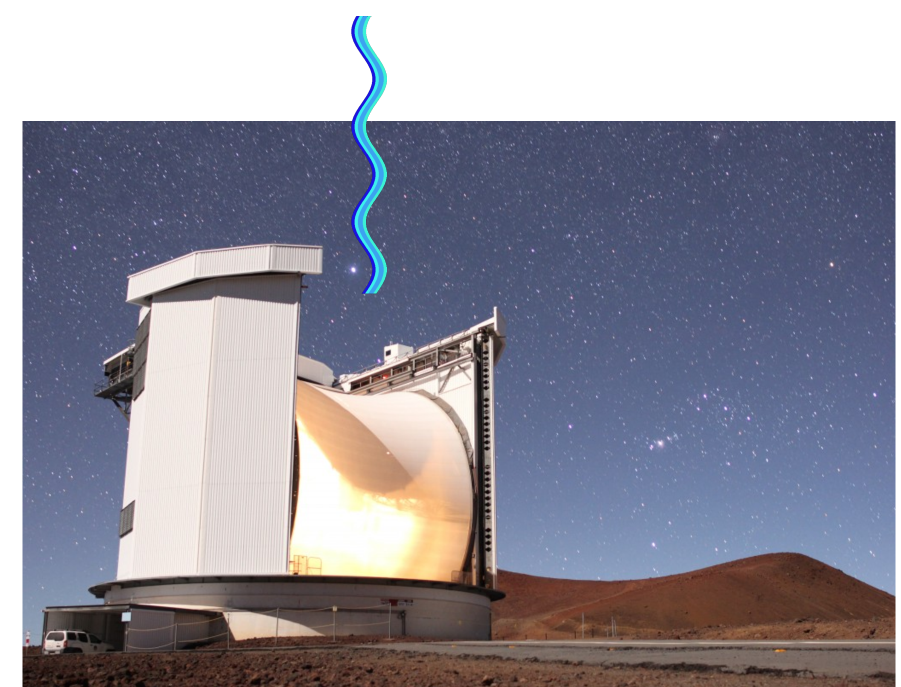
Extinction Correction

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

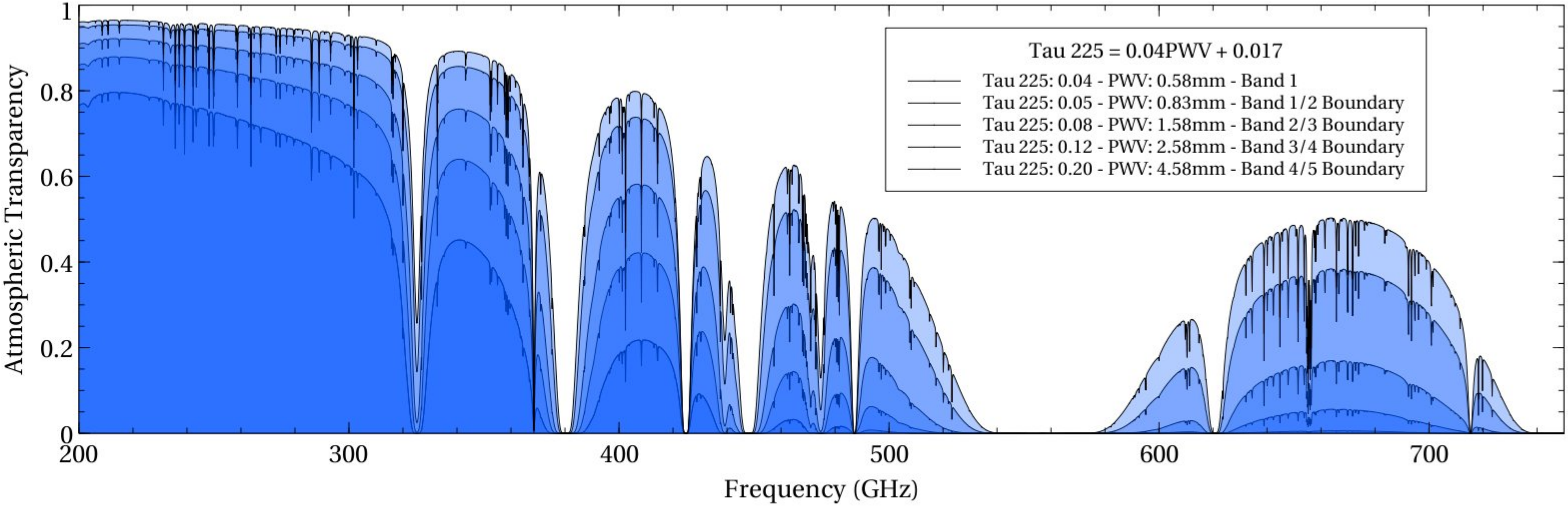
$$\mathbf{I_0 = I_{measured} / \exp(-\tau \times \mathit{Airmass})}$$

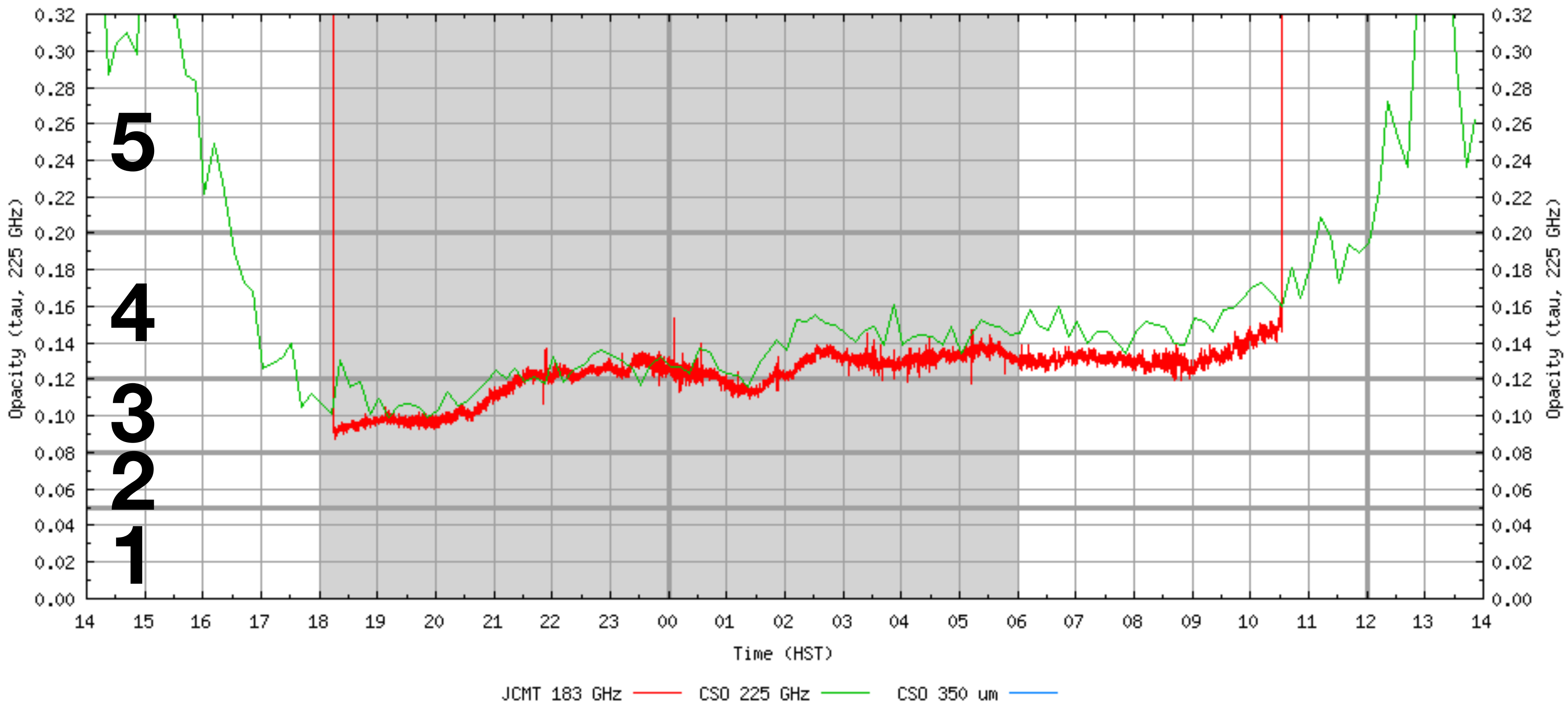


τ = Measure of PWV (Precipitable Water Vapour)



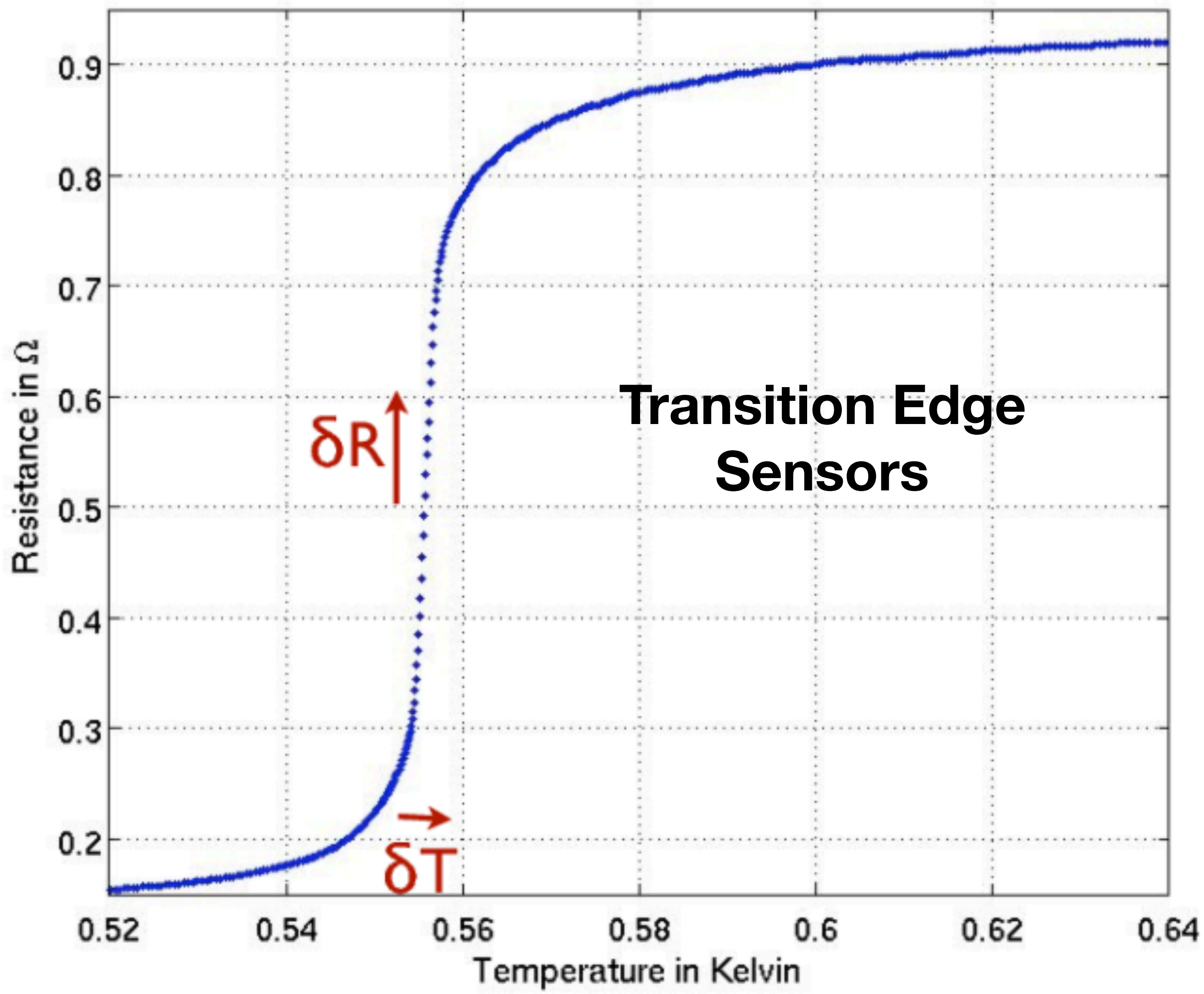
Weather Grades





Bolometers (Really Briefly)

A super-cooled thermometer (0.075 K!)



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 picowatts)

The Signal in a Single Bolometer

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

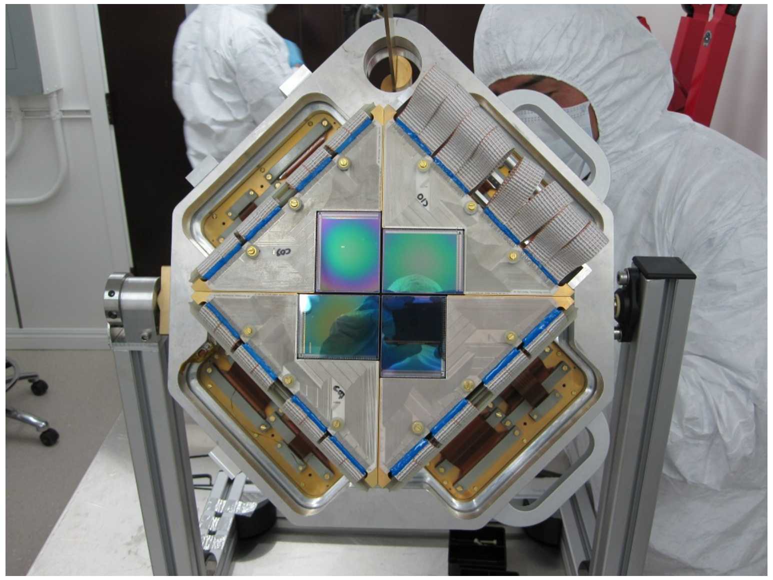
b(t) = Signal Received by a Bolometer

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

e(t) = Extinction Correction

a(t) = Astronomical Signal

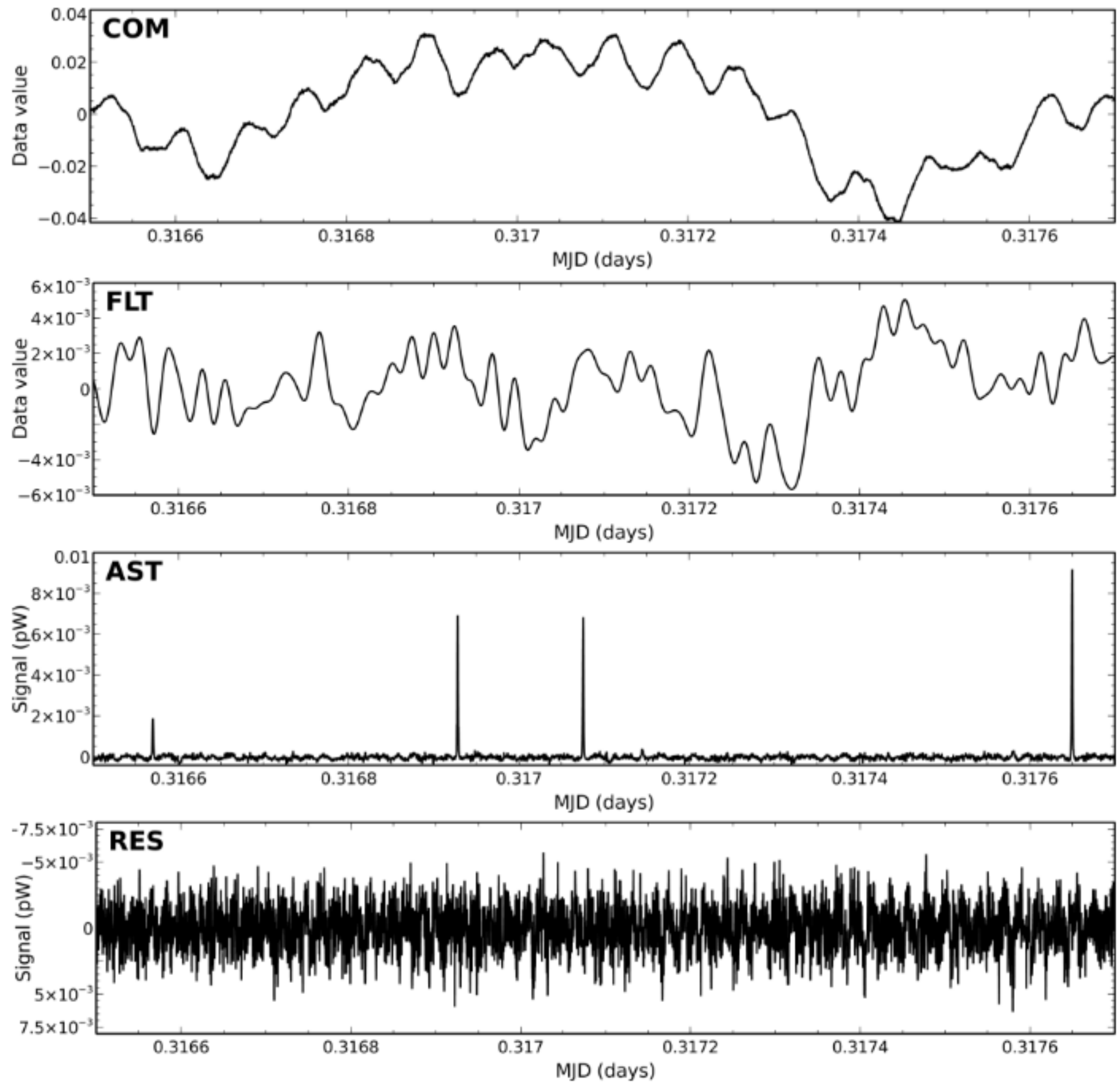
n(t) = Sources of noise:



n(t)
1. n_w = Uncorrelated White noise
2. $g \times n_c$ = Common Mode noise + gain factor
3. n_f = Excess noise (low freq.)

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

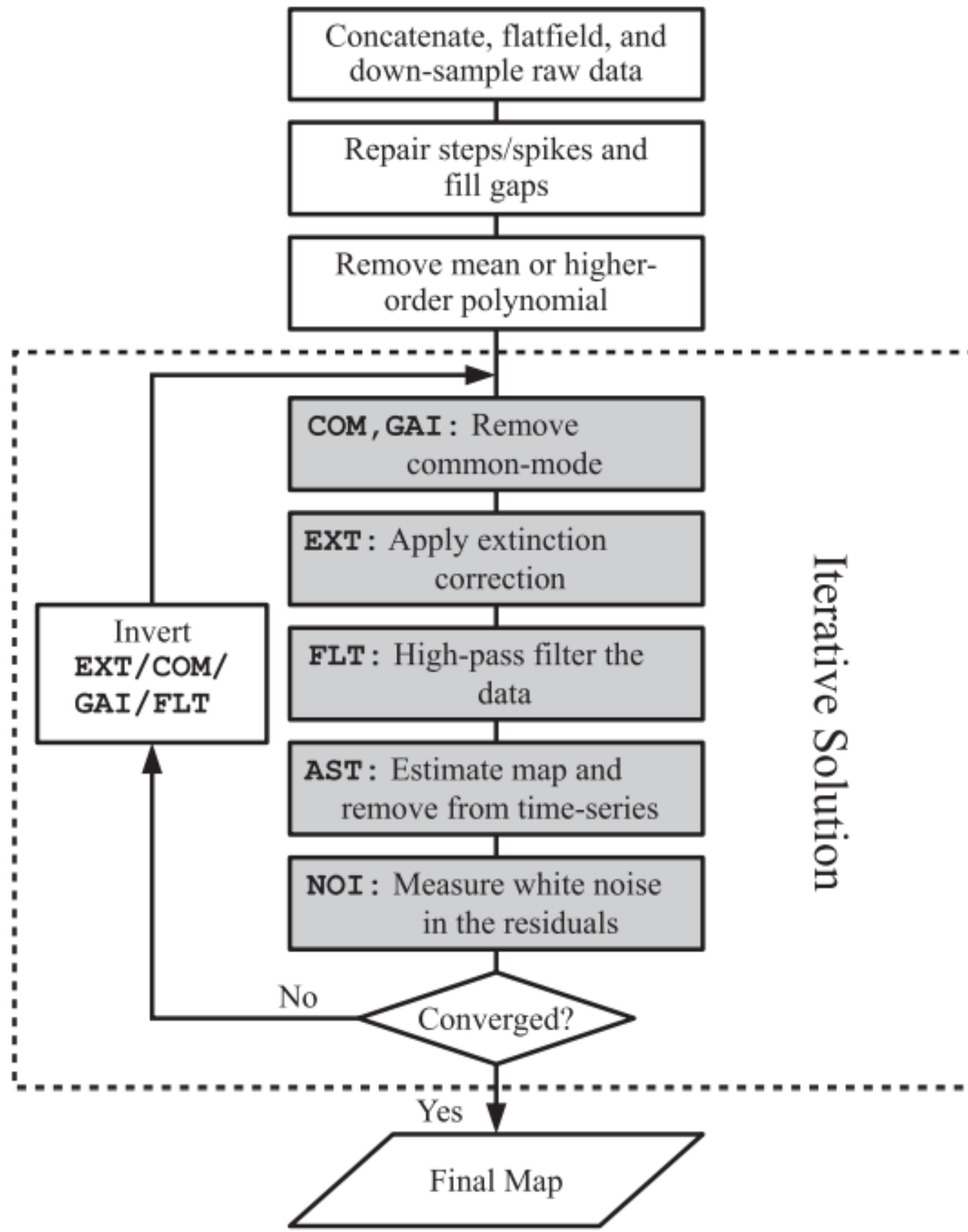
- **COM:** Signal common to all bolometers
- **FLT:** Low frequency noise (sky) missed by COM
- **AST:** Signal, spiking as the telescope scans across the source
- **RES:** Residual white noise (flat as expected)



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)
- Currently testing 4 different methods based on the JCMT Gould Belt Survey and the JCMT Legacy Data Release

SCUBA-2 Data Reduction

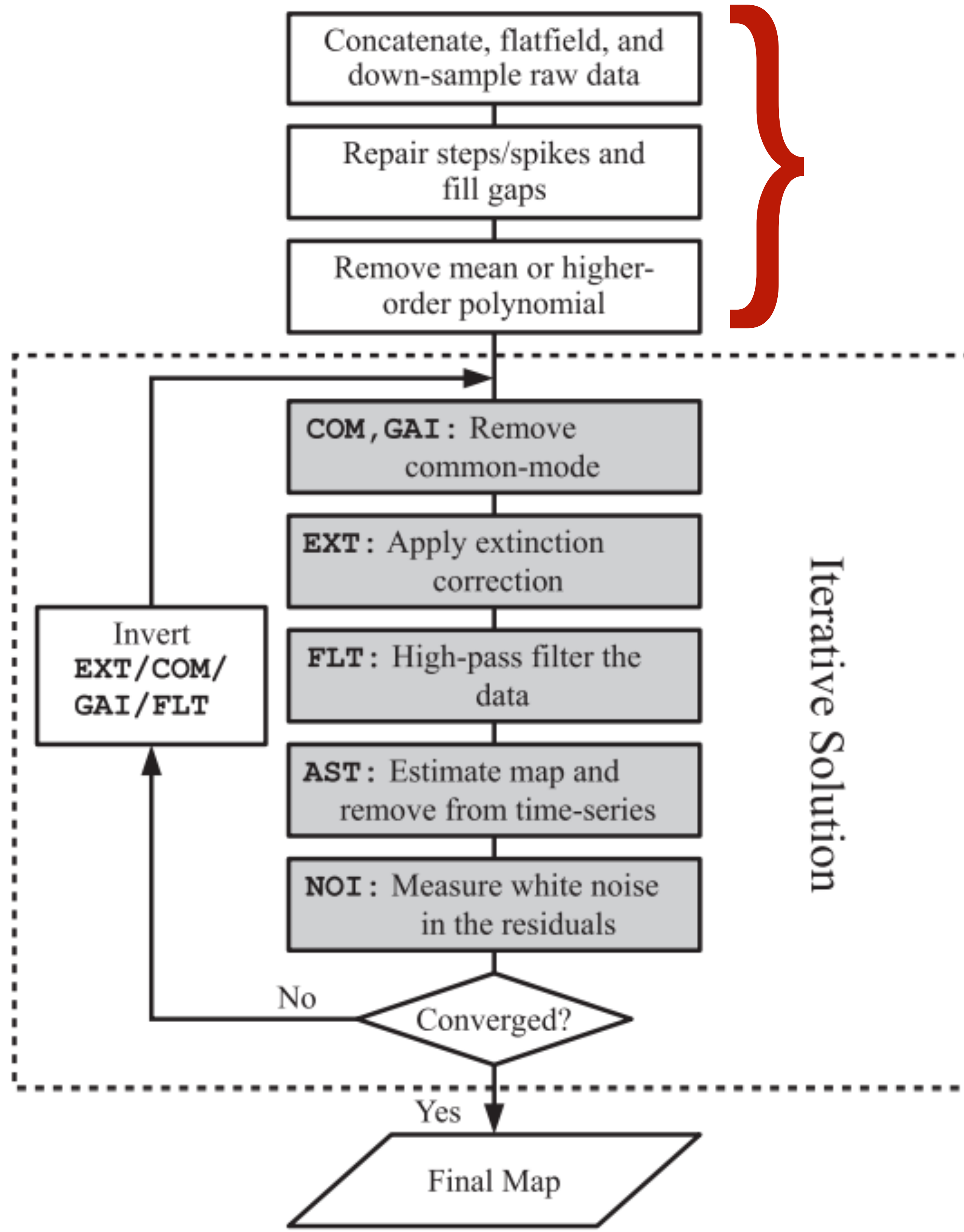


Chapin et al. 2013, MNRAS. 430, 2545–2573

SCUBA-2 Data Reduction

The Preliminaries

- General cleanup - bad pixels removed
- Data is flat fielded
- Short duration/high frequency spikes are removed
- Large “steps” caused by cosmic rays are removed
- Beginning/end of time series are smoothed



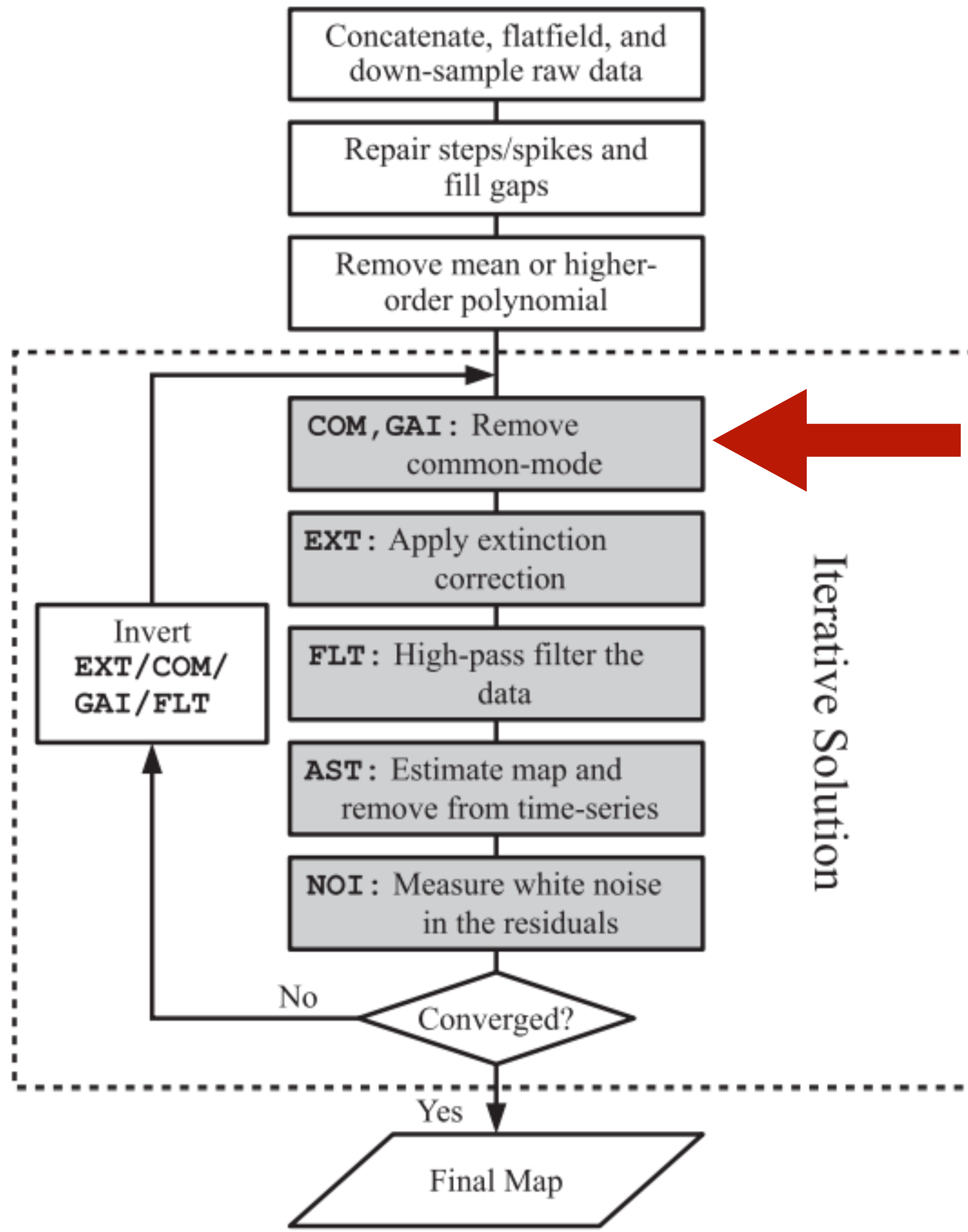
Chapin et al. 2013, MNRAS. 430, 2545–2573

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

SCUBA-2 Data Reduction

The COM/GAI Models

- The Common Mode (COM) is similar signal which appears across the majority of the bolometers
- A consequence of variations in the atmosphere
- The sensitivity of each bolometer varies from detector to detector
- The GAI model corrects for the varying sensitivities by comparing a bolometer's time stream to the common mode



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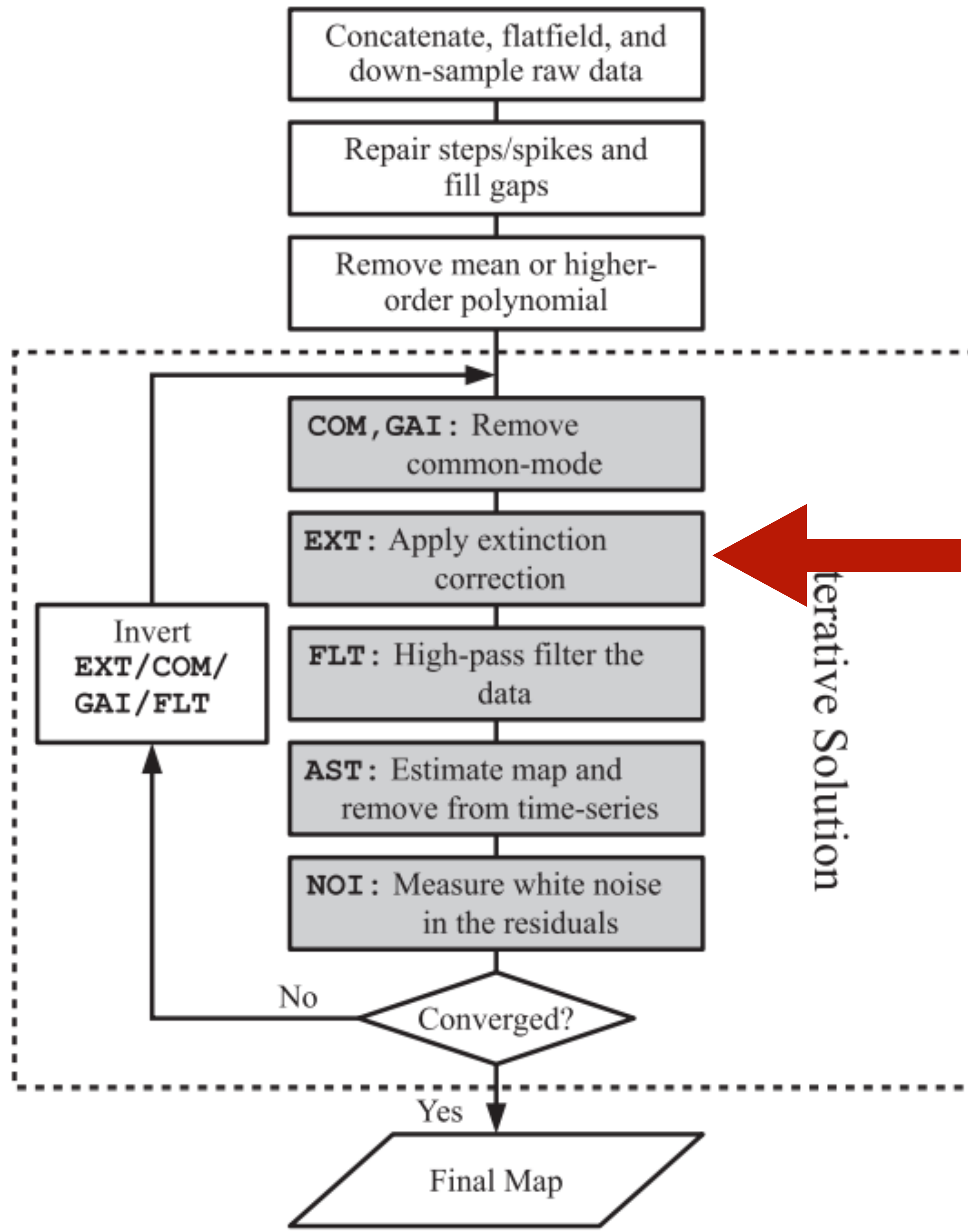
$b(t) = f \times [e(t) \times a(t) + n(t)]$

SCUBA-2 Data Reduction

The EXT Model

- EXT refers to the atmospheric extinction caused by water vapour
- $\mathrm{Signal}_{meas} = \mathrm{Signal}_0\, e^{-\tau A}$
- τ = extinction coefficient (see Dempsey et al. 2013 MNRAS 430:2534.)
- The JCMT has a water vapour monitor which is active throughout the observation



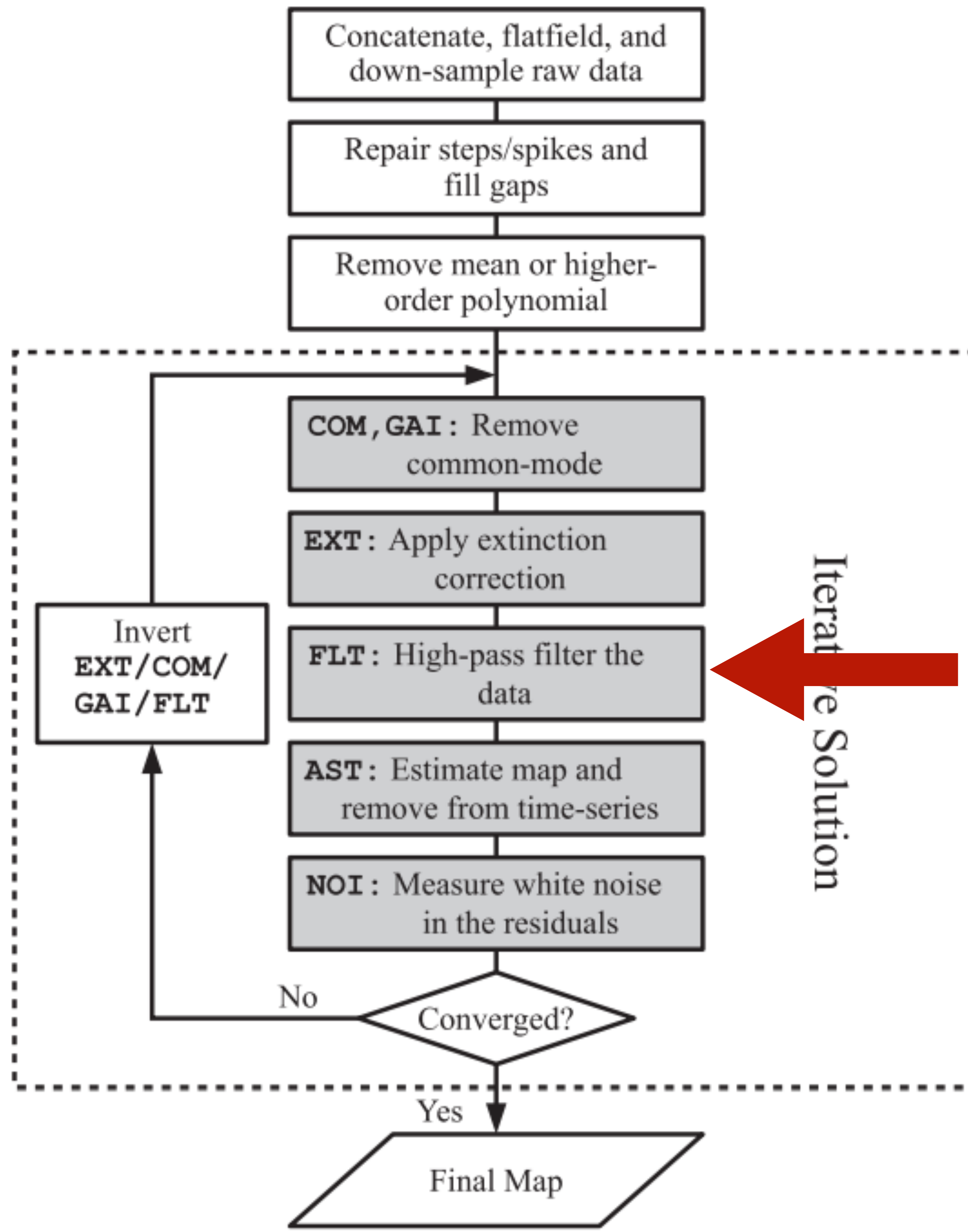
Chapin et al. 2013, MNRAS. 430, 2545–2573

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

SCUBA-2 Data Reduction

The FLT Model

- This model takes the FFT of the bolometer time series data
- A high pass filter is then applied to remove the residual 1/f noise after the common mode has been subtracted
- Regridding the map to a specific pixel size effectively lowpass filters the data below a frequency hat corresponds to the crossing time of a pixel



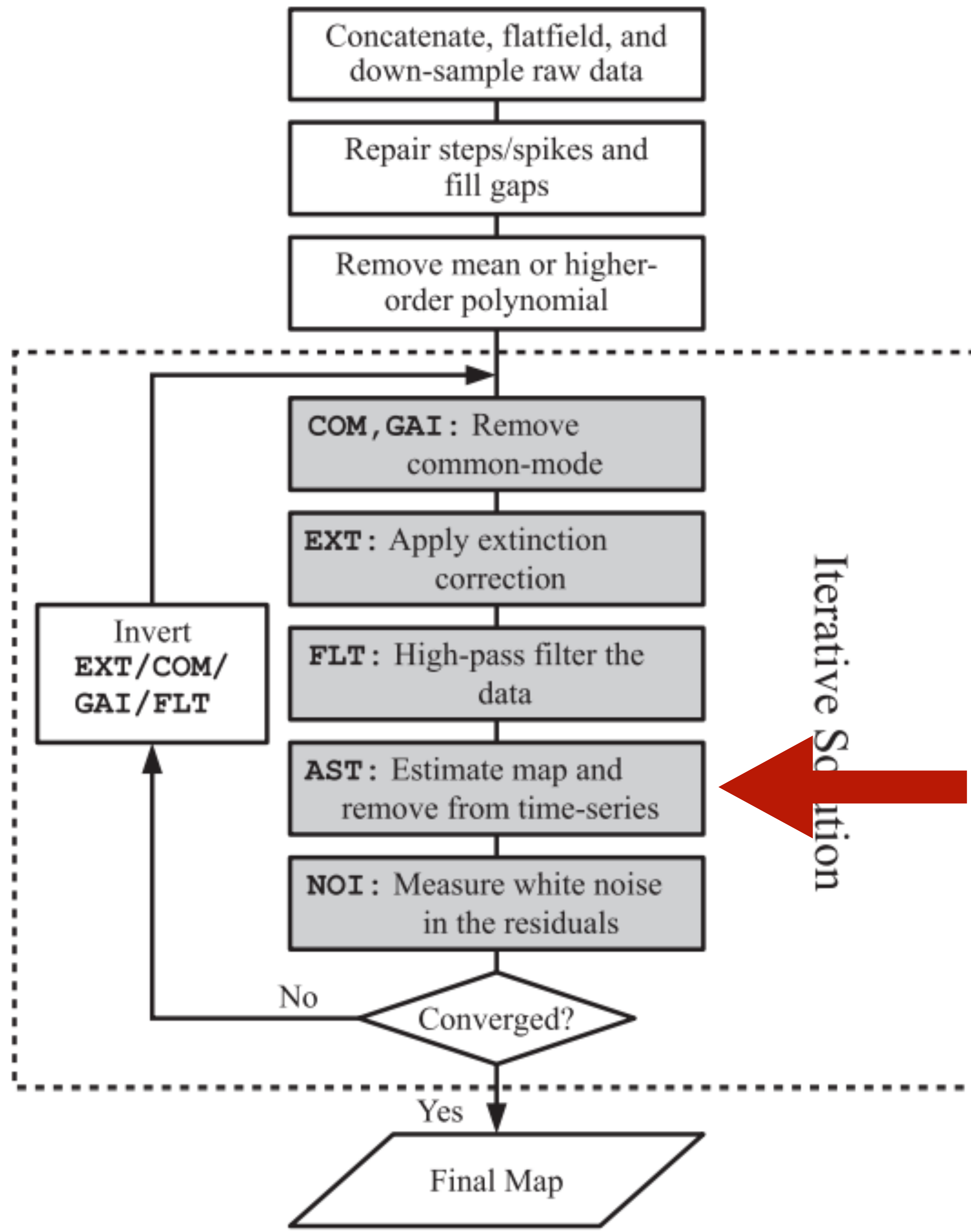
Chapin et al. 2013, MNRAS. 430, 2545–2573

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

SCUBA-2 Data Reduction

The AST Model

- AST is the astronomical signal
- The data is gridded onto a map. The brightness of a given pixel is the weighted average of all the bolometer samples contributing to that pixel. A variance map is also constructed.
- If the SNR of a pixel is above a specified value, it is included in the AST model
- The AST mode is removed and saved, leaving a residual map



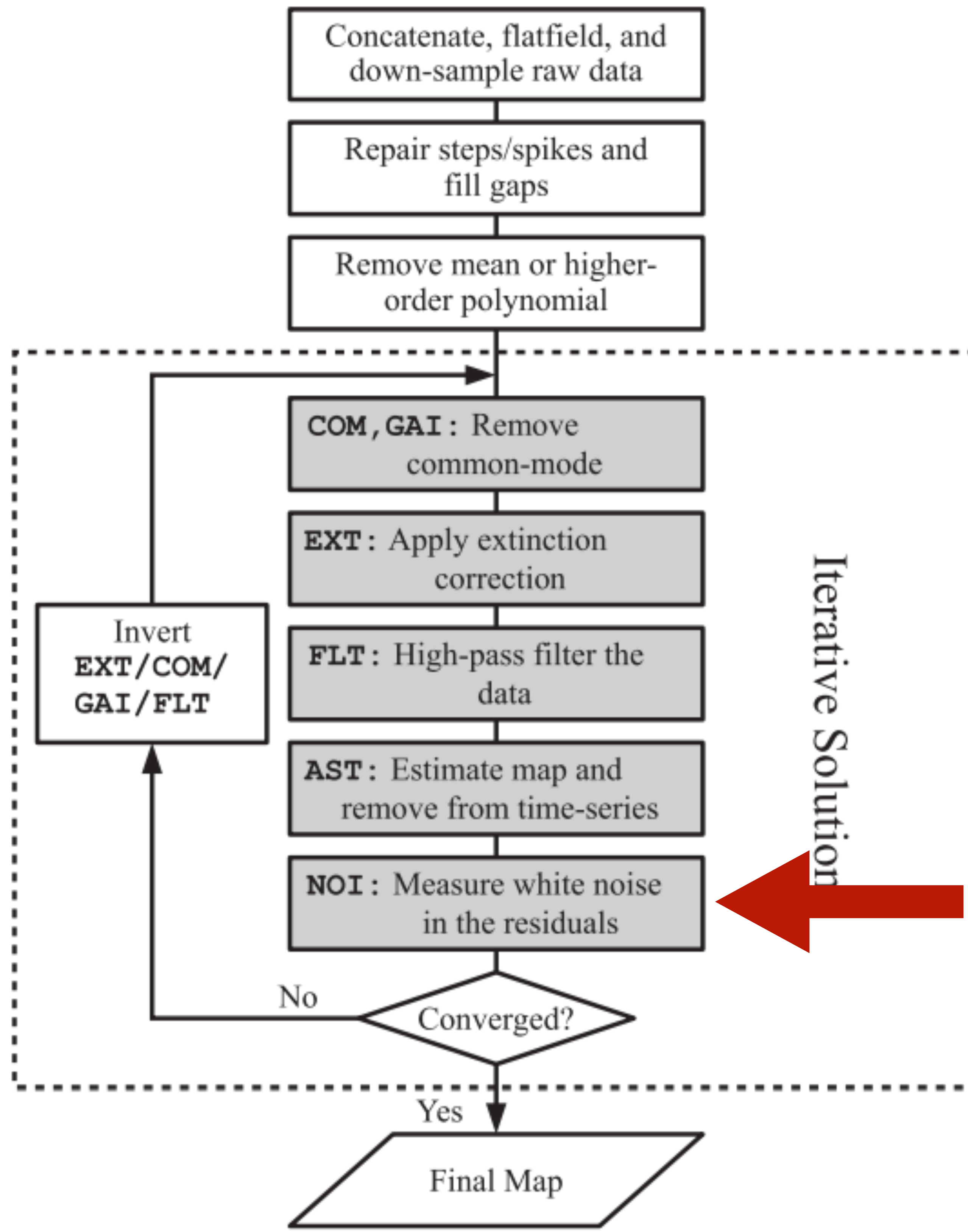
Chapin et al. 2013, MNRAS. 430, 2545–2573

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

SCUBA-2 Data Reduction

The NOI Model

- After all of the other noise and the astronomical signal have been removed, a measurement is made of the residual white noise
- If the white noise converges to a user-specified tolerance, the final map is produced
- If convergence hasn't been achieved, the algorithm begins again at the common mode



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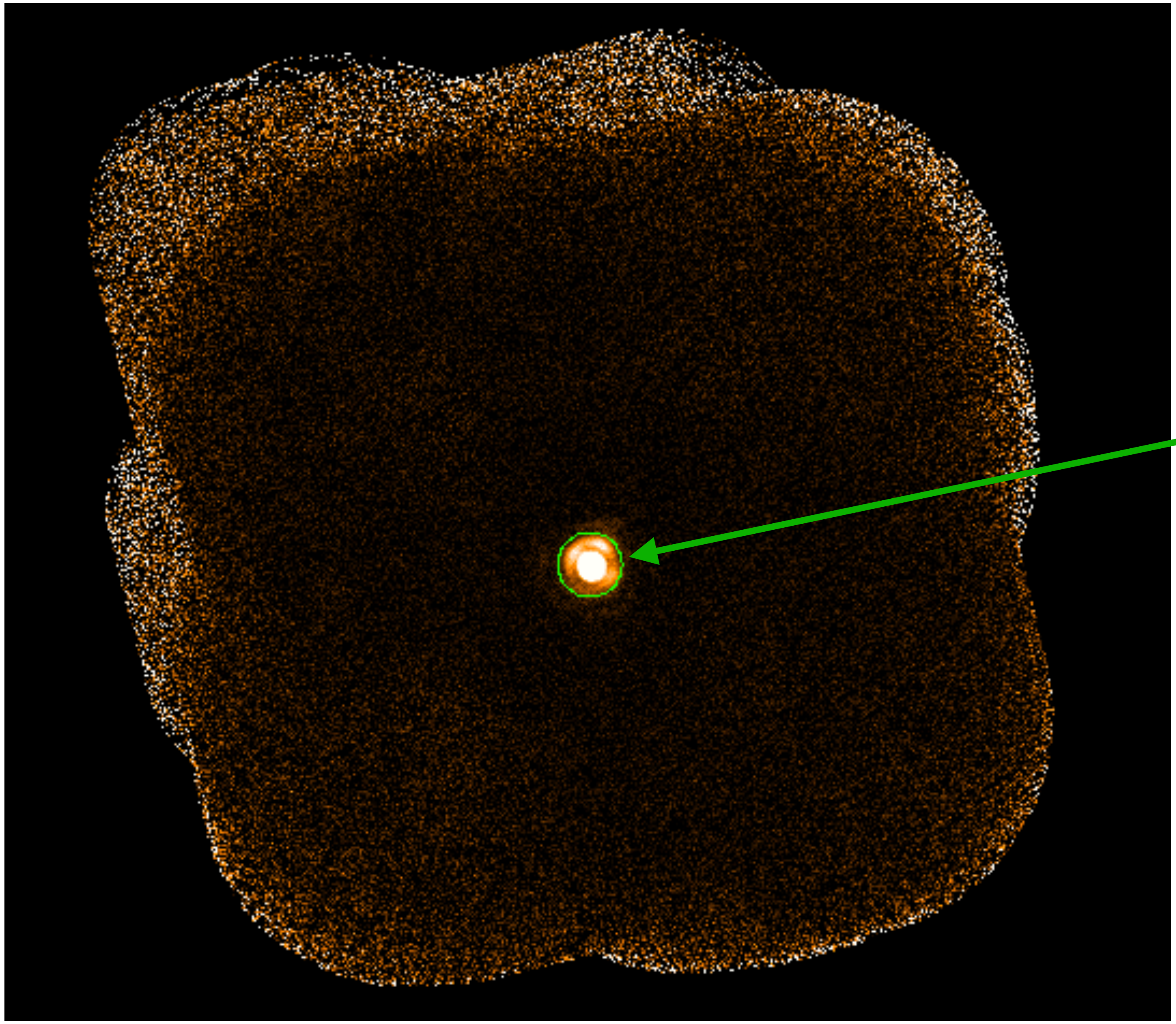
SCUBA-2 Calibration: FCFs

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 values 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/

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

SCUBA-2 Calibration: FCFs

FCF = Flux Conversion Factor

Reduce your calibrator data in the same manner as your observations

FCF_{beam}

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

$$FCF_{beam} = \frac{S_{peak}}{I_{peak}}$$

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

FCF_{arcsec}

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

$$FCF_{beam} = \frac{S_{total}}{I_{total}\,A}$$

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

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SCUBA-2 Calibration: FCFs

FCF = Flux Conversion Factor

The observatory has measured FCFs over a long period of time to publish nominal values which should work for most observing programs.

$\mathbf{FCF_{beam}}$

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

Nominal Values:

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.

$\mathbf{FCF_{arcsec}}$

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

Nominal Values:

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/

The anatomy of a Raw SCUBA-2 File

In “tutorial/”, there are 3 directories:

raw/
reduced/
example_reduced/

List the contents of the “raw/” directory:

<u>SCUBA-2</u>

Filename: s8a_20120501_00068_0004.sdf

s8a = SCUBA-2, 850 microns, Subarray “a”

20120501 = YYYYMMDD

00068 = Scan Number

0004 = Subscan number (30 seconds of raw power)