Design Validation: Technical to Measurement

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CMB-S4

Context of this session

- Preliminary Baseline Design
  - Small Aperture Telescopes
  - Large Aperture Telescopes
  - Site Infrastructure, Integration & Commissioning
  - Detectors
  - Readout
  - Module Assembly & Testing
  - Data Acquisition & Control
  - Data Management
- Design Validation
  - **Technical to Measurement**
  - Measurement to Science
    - Galaxy Clusters
    - Tensor-to-Scalar Ratio
    - Light Relics
    - Transients

We are here.

Role of this session

- Ideally, **technical requirements** translate into an experiment that *inevitably* meets our **measurement requirements**.
- While the technical requirements are being refined, we must demonstrate that our **preliminary design**
    a. Complies with the current technical requirements
    b. Meets the measurement requirements
- With such a mechanism in place, we can discover designs that meet technical requirements but fail the measurement requirements. Each failure mode indicates a missing or insufficient technical requirement.

Technical requirements (examples)

- SAT Level 3 requirement STEL-0040 - Scan Speed:
  5 deg/s (on mount)
- Chile LAT Level 3 requirement CHLAT-005 - Aperture/resolution:
  6m aperture with 5-6m illuminated to achieve <= 1.4 arcmin resolution at 150GHz
- Detector Assembly requirements for transition temperature, operating resistance, Psat, bandpass and beam

Measurement requirements

SAT polarization noise over 2.8% of sky

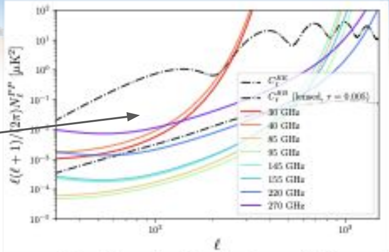


Figure 1: Required noise as a function of multipole for each frequency in polarization for the low-resolution, ultra-deep survey of 2.8% of the sky.

Delensing LAT temperature and polarization noise over 2.8% of sky

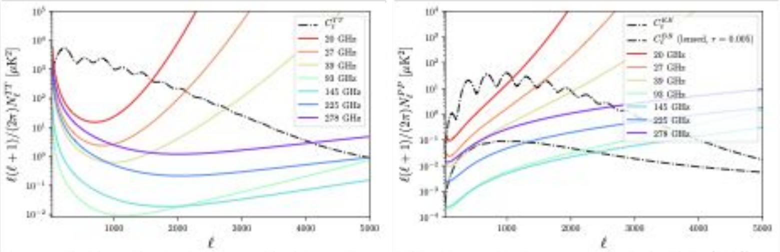


Figure 2: Required noise as a function of multipole for each frequency in intensity (left) and polarization (right) for the high-resolution, ultra-deep survey of 2.8% of the sky.

\+

Daily cadence, resolution and sensitivity requirements from transient science

Chile LAT temperature and polarization noise over 68% of the sky

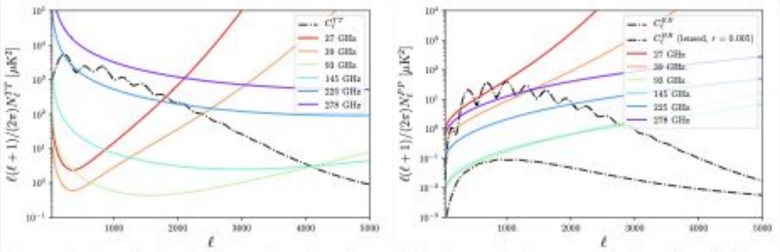


Figure 3: Required noise as a function of multipole for each frequency in intensity (left) and polarization (right) for the high-resolution, wide and deep survey of 68% of the sky.

From:
CMB-S4 Program Level Requirements

CMB-S4

Desired outcome (1/2)

After the parallel session, we will write in the Preliminary Baseline Design Report

1. Science Case
2. Science and Measurement Requirements
3. **Preliminary baseline design**
4. Science Analysis
5. Project Overview

Prepared in time for this meeting.

Appendix A : Design Validation

A.1 Technical Design to Measurement Requirements

A.2 Measured Maps to Science Requirements

Can only be written once the design is specified

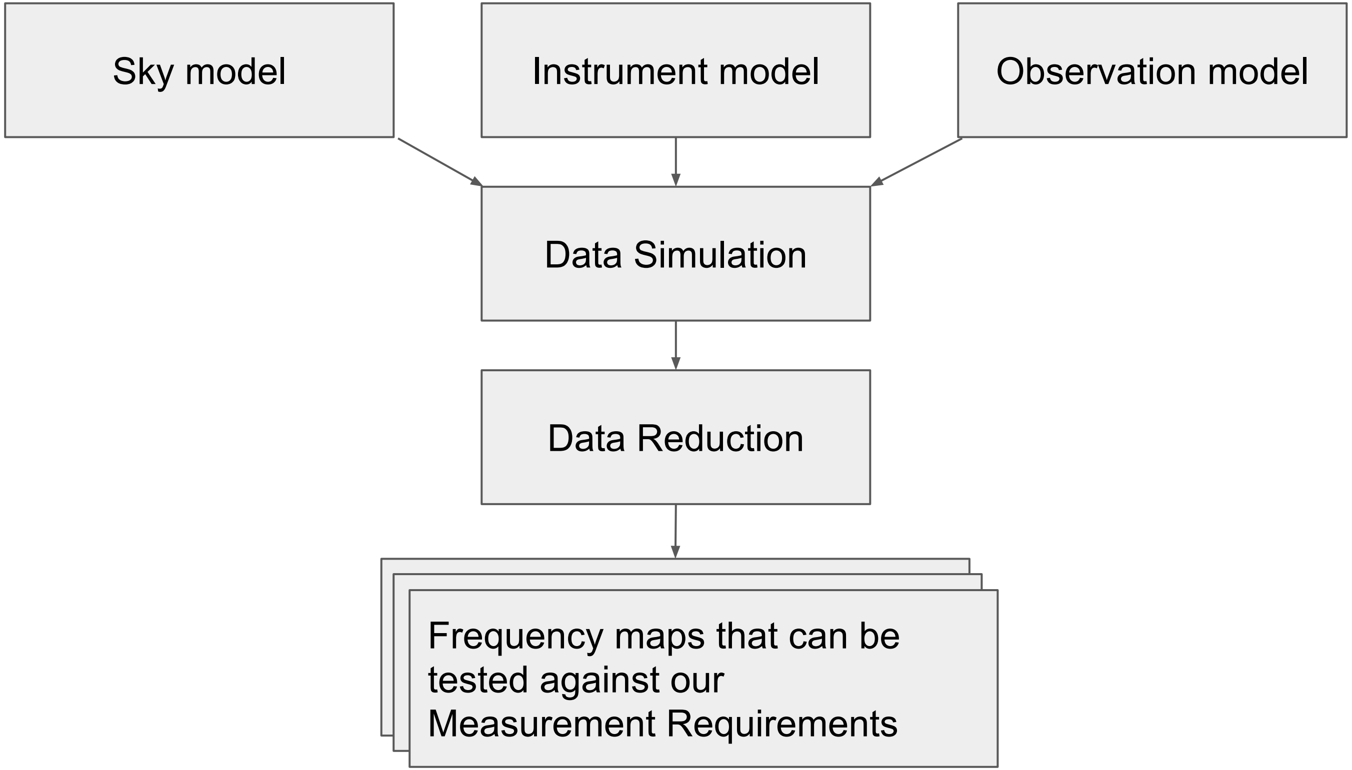
Desired outcome (2/2)

A.1 will tell the following story:

- We have presented a particular realization of the experiment and understand the envelope in which the design may evolve
- We understand or have strict limits to systematics and noise in our design
- We can project our noise and systematics budget onto science-ready deliverables that meet our measurement requirements.

How do we get there?

We propose an *ab initio* (from the beginning) simulation campaign



The Design Tool Working Group

- Darcy Barron
- Colin Bischoff
- Julian Borrill
- Brandon Hensley
- RK
- John Kovac
- Clem Pryke
- John Ruhl
- Sara Simon
- Kimmy Wu
- Andrea Zonca

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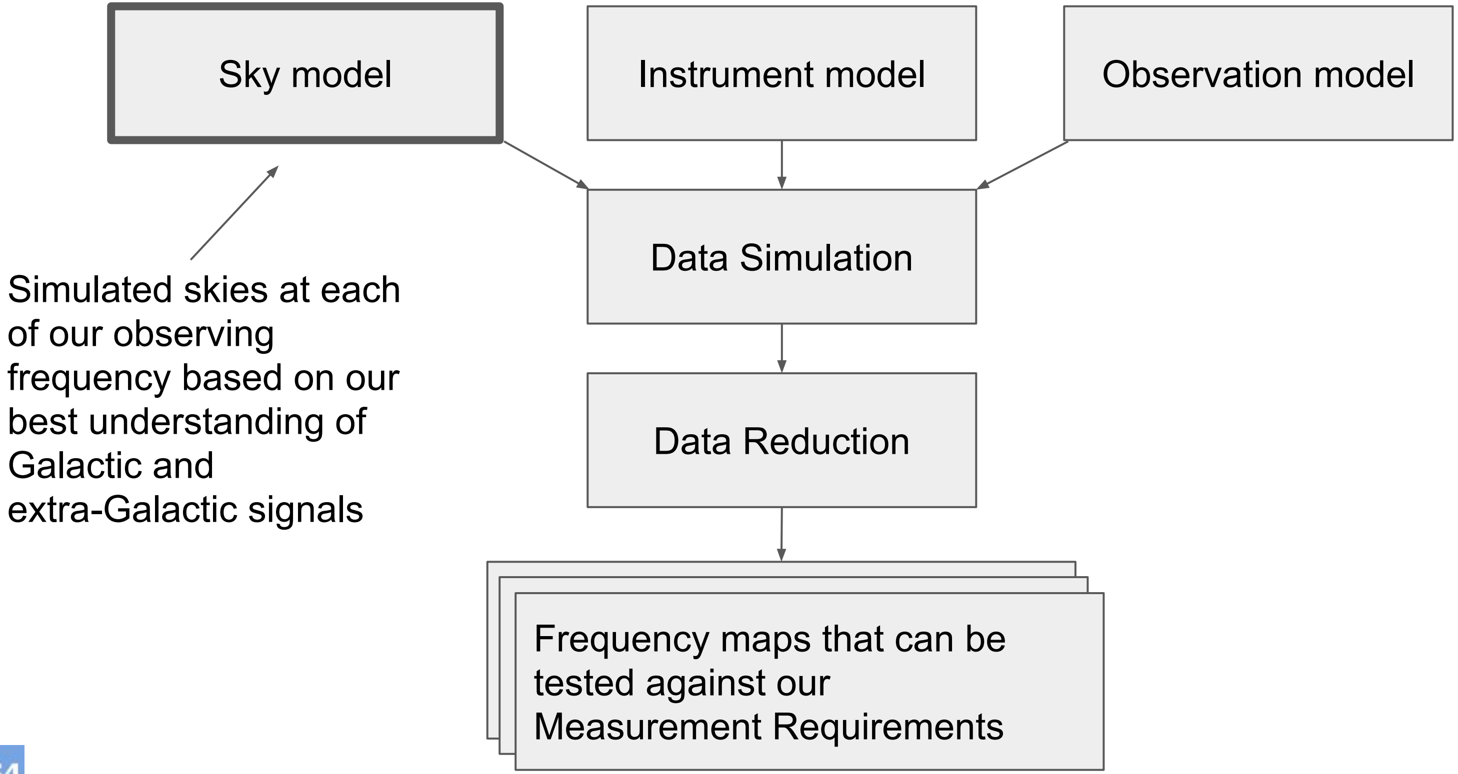

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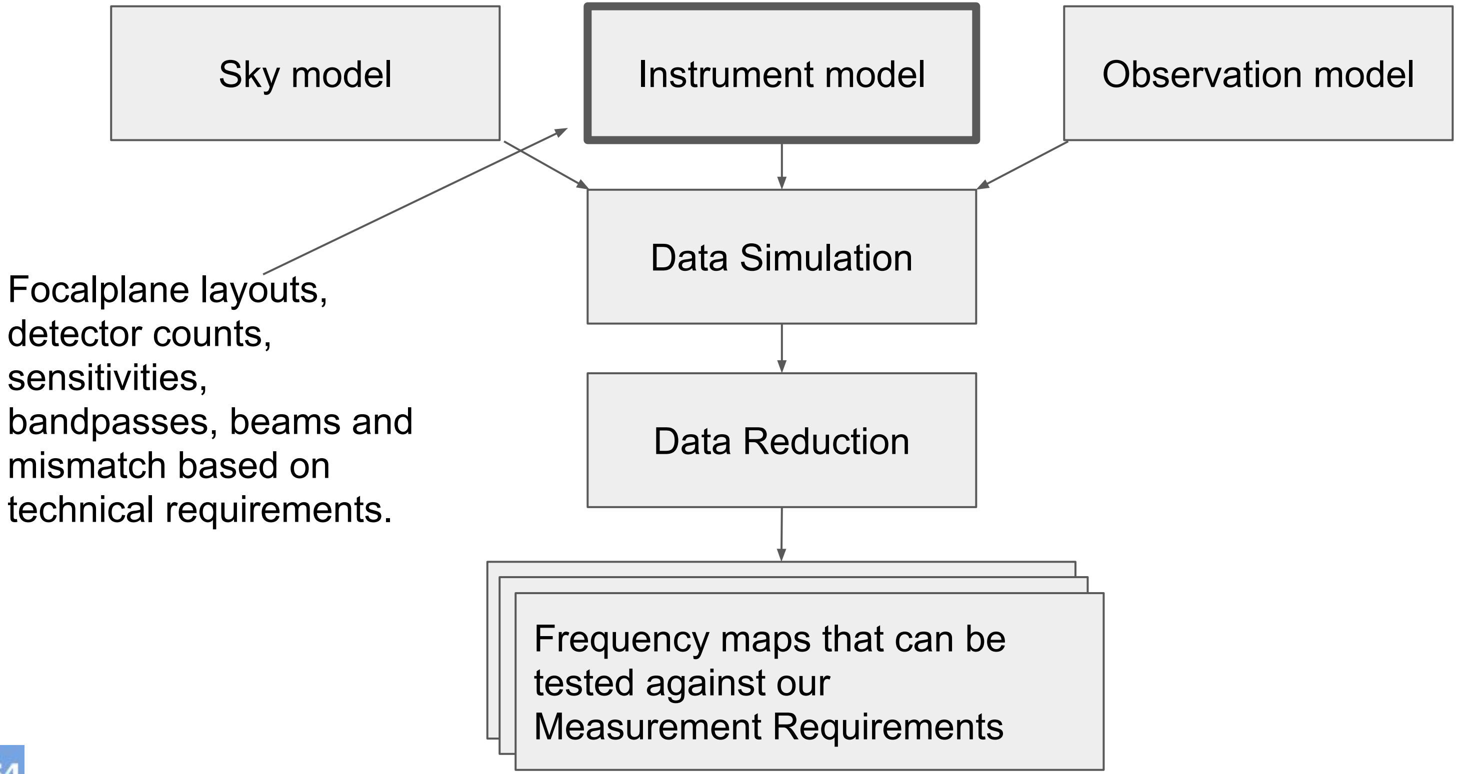

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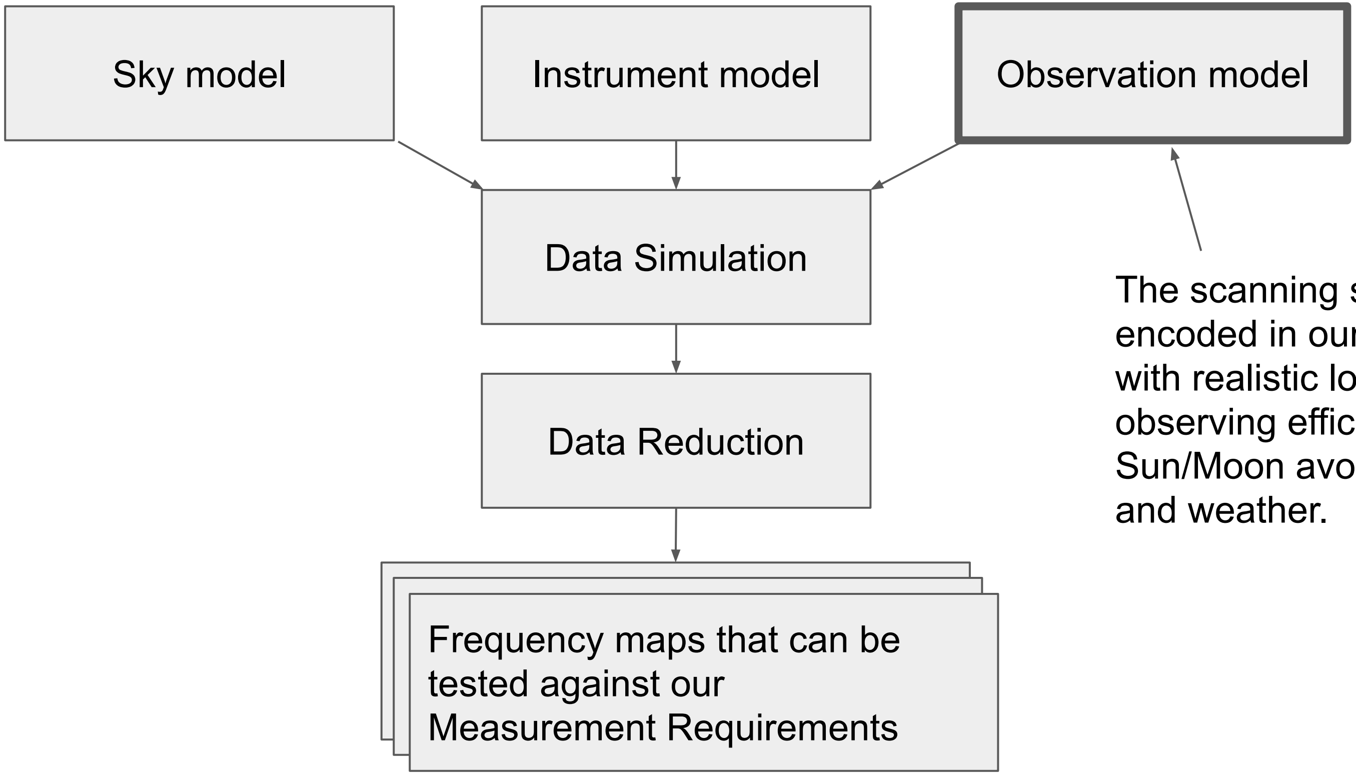

The scanning strategy encoded in our design with realistic loss of observing efficiency from Sun/Moon avoidance and weather.

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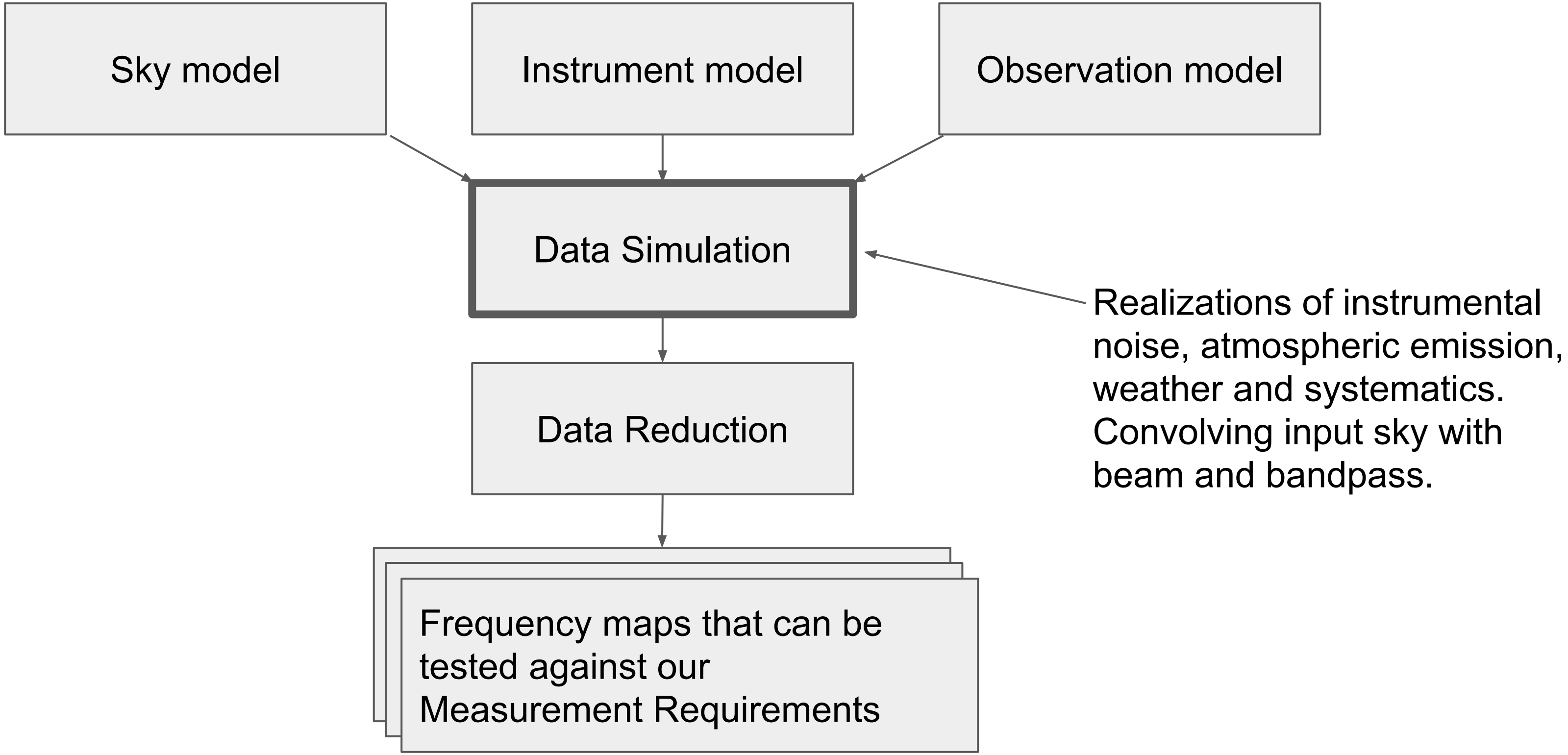

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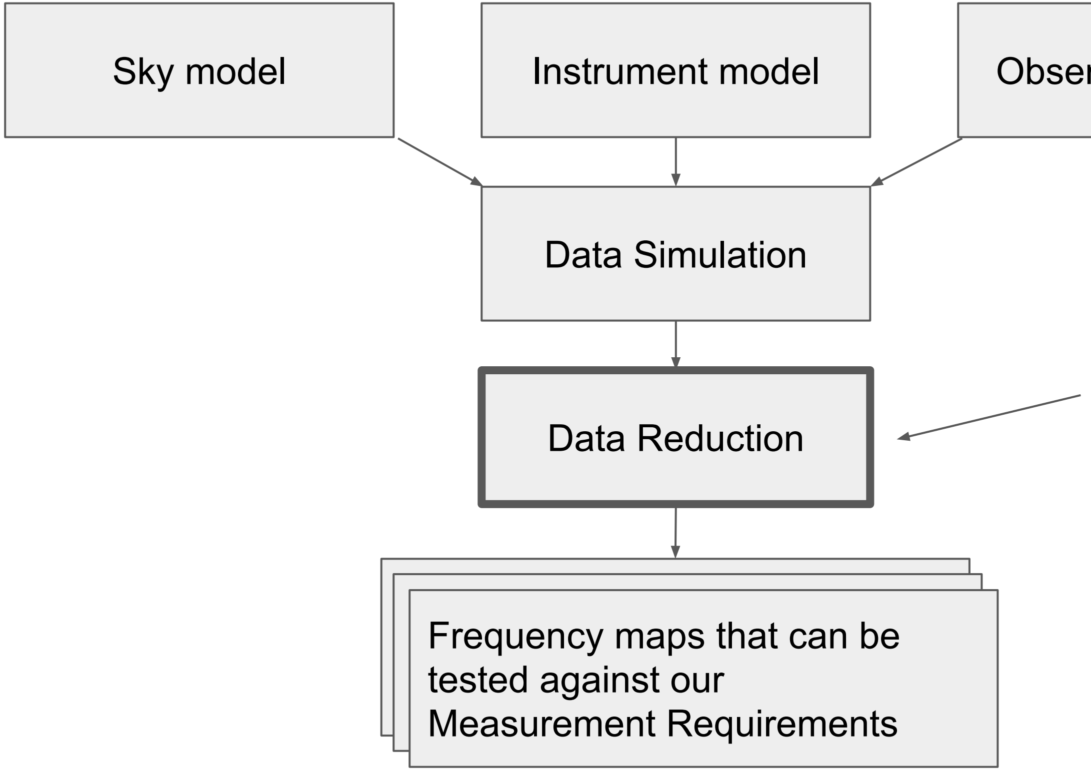

Prototype pipeline with realistic mode loss from filtering. Resolved sky modes also depend on scanning strategy.

How do we get there?

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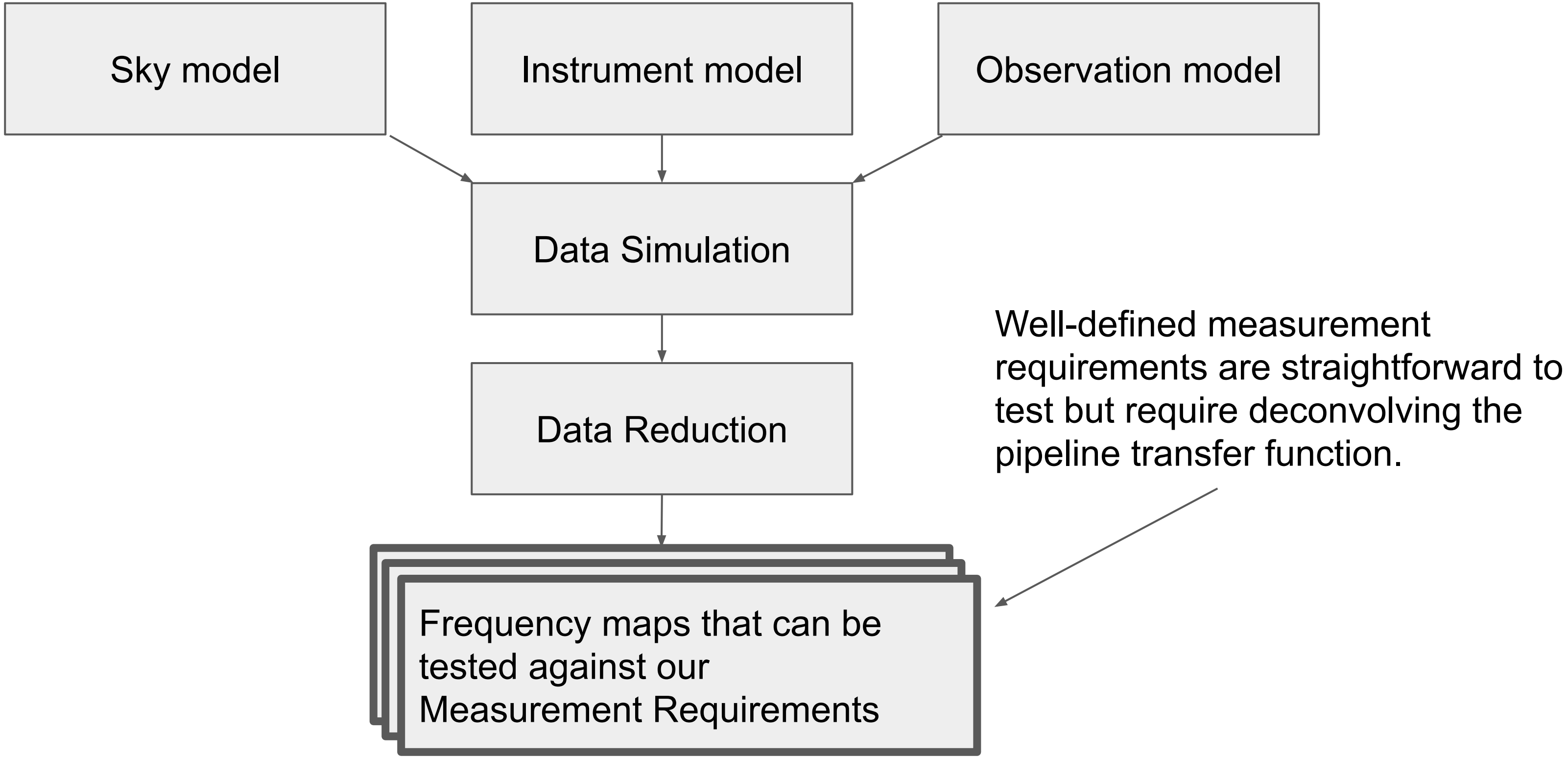


Parallel session

Thursday 3/11 at 3:30pm Eastern, 12:30pm Pacific

- Assess current readiness
  - Hardware model
  - Simulation and data reduction pipelines
- **Focus on systematics**
  - Blindspots
  - Technical requirements
  - How they complicate the validation process
- Draw from breadth of our collective experience
  - ACT
  - BICEP/Keck
  - POLARBEAR/Simons Array
  - SPT

Design tool simulations

Time permitting, we can take a quick look at the ongoing design tool simulation campaign. Mostly the following slides are provided for future reference.

The design tool simulation effort uses a lot of the same tools that are needed in the proposed ab initio simulations.

Design tool simulations

- The design tool combines short time domain simulations of sky signal, instrument noise and atmosphere into representations of DM deliverables.
- Users can set the distribution of frequencies across optics tubes, re-deploy portion of the SATs to Chile and adjust the frequency-specific observing efficiencies.
- Maps are accompanied with BICEP/Keck style observing matrix and estimates of white noise variance per pixel
- Scope of an additional CMB Monte Carlo is being discussed
- The design tool sims are a precursor for wider Data Challenge simulations

Elements of a design tool simulation (1/2)

Sky model (Andrea Zonca)

- foregrounds (dust, free-free, synchrotron, ame, Websky CIB/tsz/ksz)
- CMB scalar (Websky compatible cosmology, scalar modes and lensing with Websky potential)
- CMB tensor only (r=3e-3)

Instrument model (Sara Simon)

- Developed with technical working groups
- Up-to-date focalplane layout
- Physical estimates of detector sensitivity as a function of observing elevation

Elements of a design tool simulation (2/2)

Observing model (Sara Simon)

- Scanning strategy developed in a separate working group for all surveys
- Chile LAT observes according to the Az-modulated, high cadence strategy which produces uniform depth over maximum sky area
  - Requires varying scan rate along the scan
  - Observing at lowest possible observing elevation for larger sky coverage, impliest lower effective sensitivity

Noise and systematics (John Ruhl)

- 1/f, elevation-dependent instrument noise based on hardware model
- 3D atmospheric simulation calibrated for each site and against ACT, SPT and BICEP/Keck produces realistic detector-detector correlations
- Randomized 1% calibration errors for each detector

Simulating systematics

Facilities exist for simulating

- Beam asymmetry
- Bandpass mismatch
- Calibration errors
- Ground pick-up

These can be easily adapted from existing code:

- Time constants
- HWP-synchronous signal
- Gain drift

These are almost trivial to implement:

- Pointing errors

Data reduction pipeline

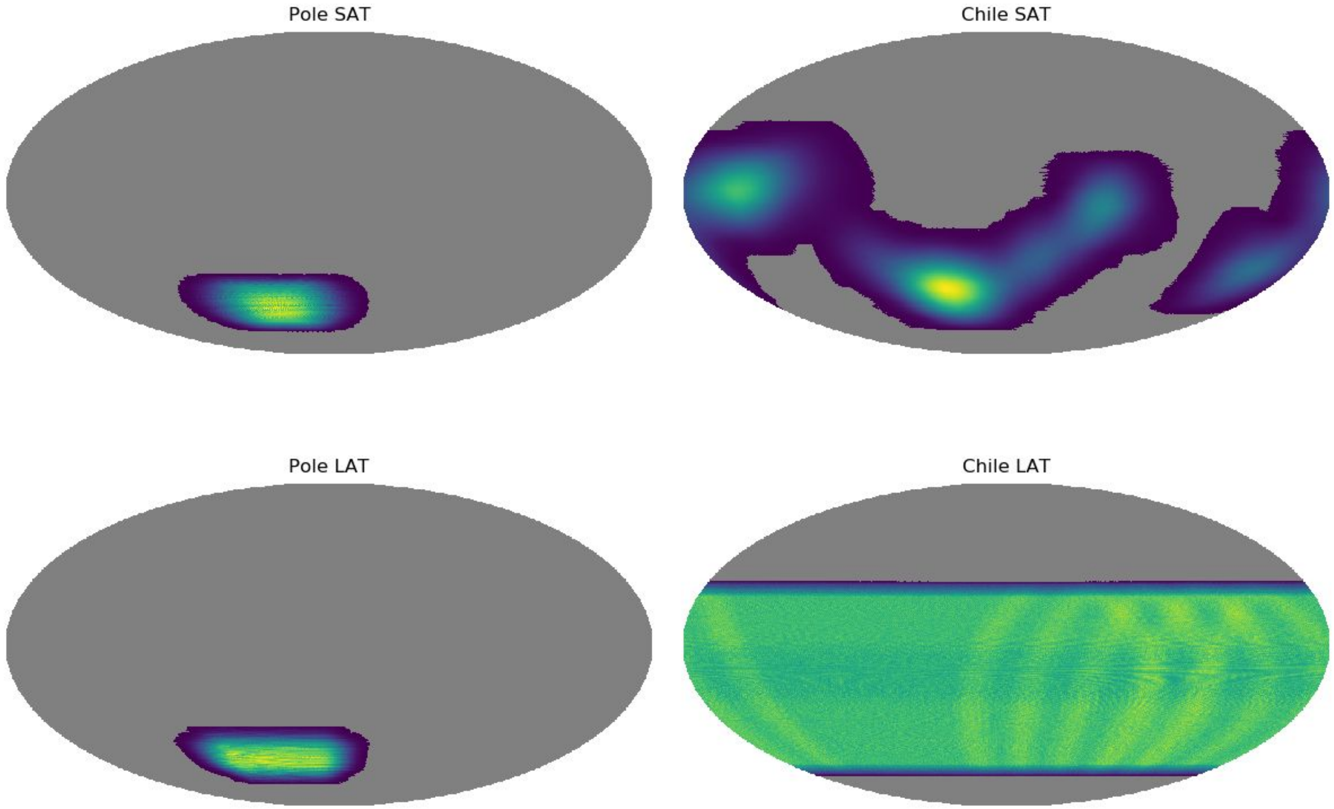
Currently applying a filter-and-bin scheme:

- Ground-synchronous signal filtering with Legendre polynomials
- Atmospheric filtering with
  - 2D polynomials across the focalplane at each sample (Chile LAT)
  - 1D polynomials for each subscan

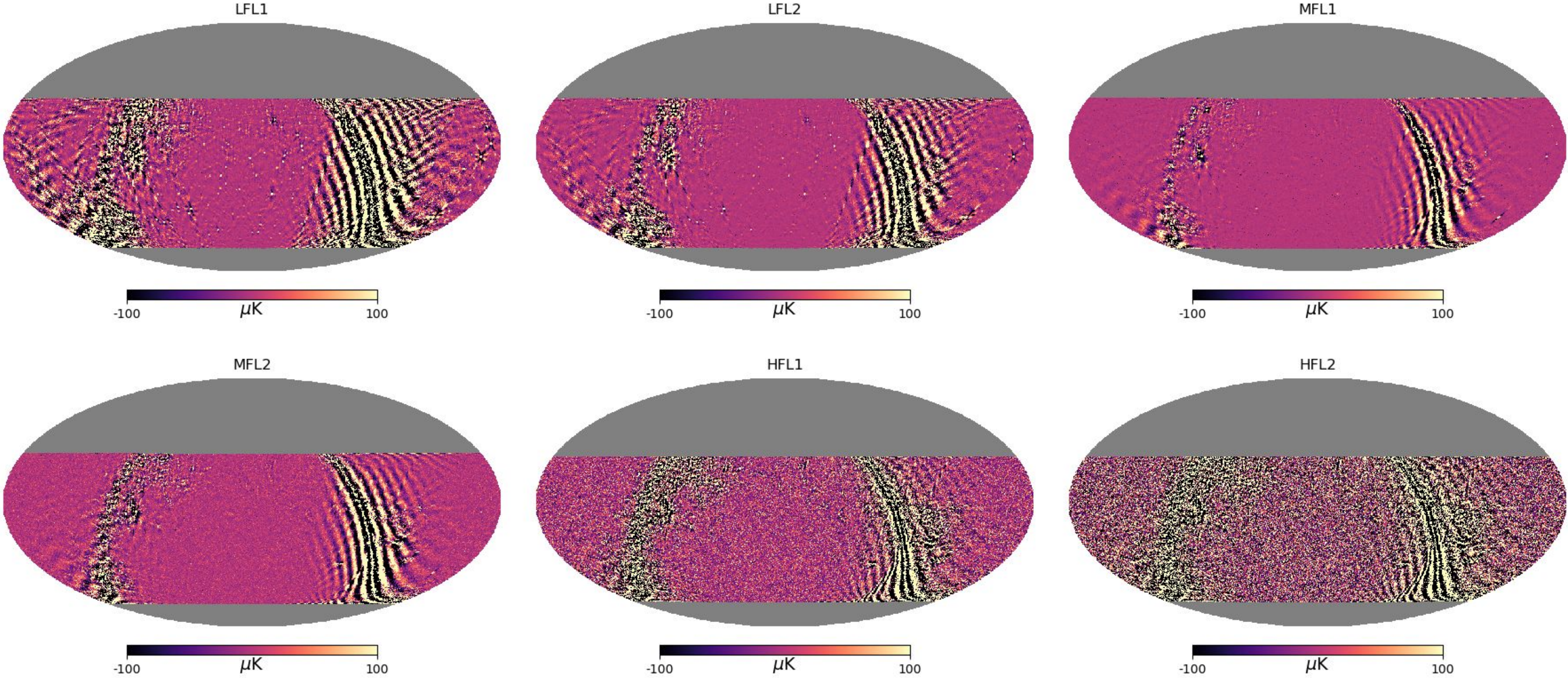
Could also deproject detector mismatch based on estimate of the sky signal

- NSide=4096 for LAT, NSide=512 for SAT

Both sites and telescope types (showing MF hit maps)

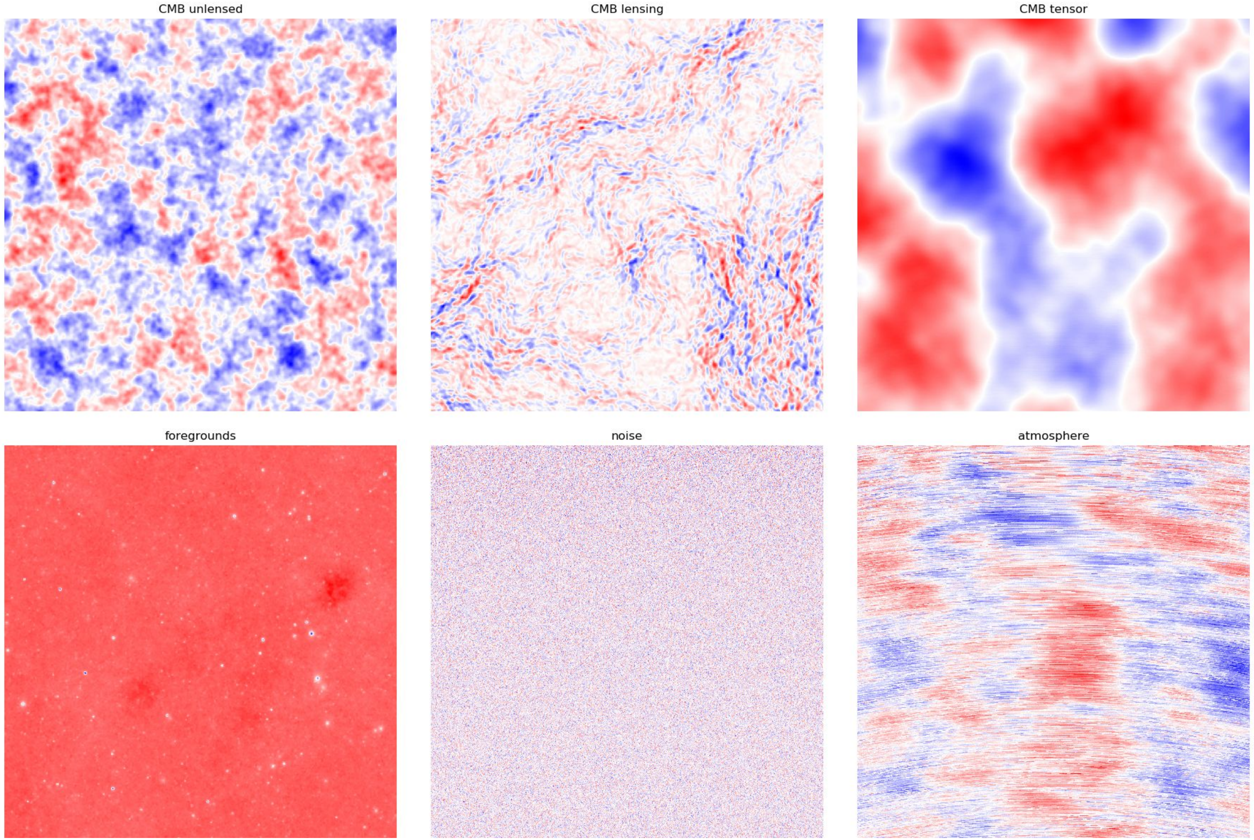


All CMB-S4 frequency bands (showing filtered Chile LAT foregrounds)

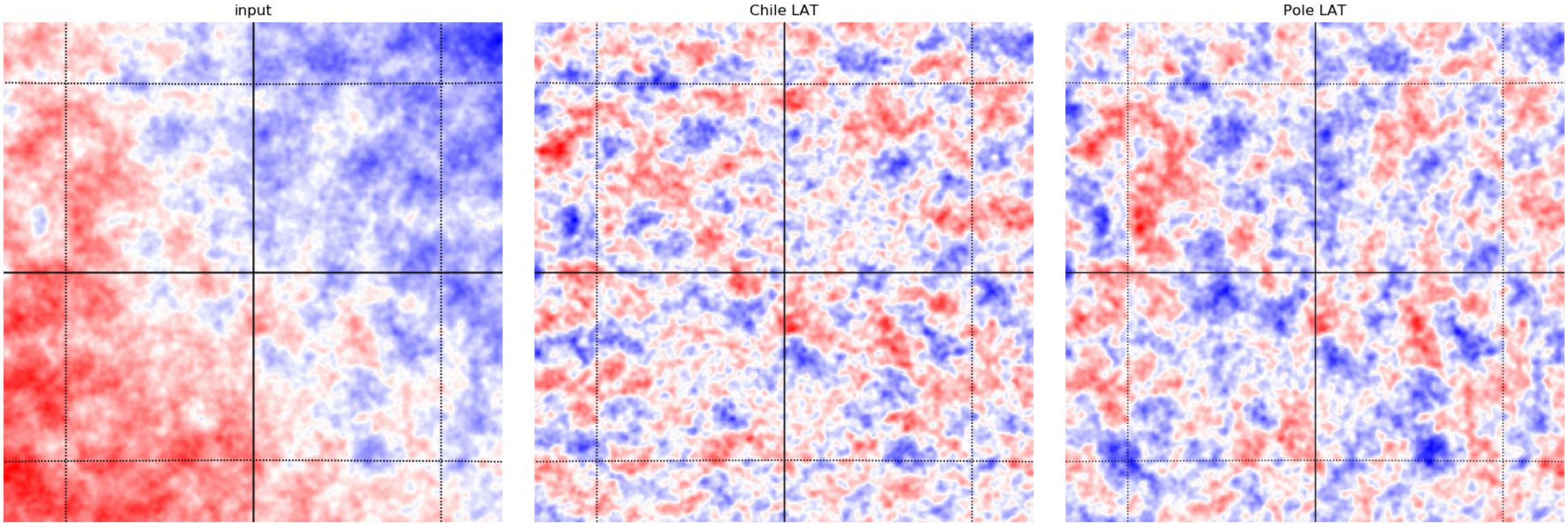


Six different components (showing Pole LAT 93GHz)

Each panel is 13x13 degrees



Realistic mode loss (scalar CMB, Chile and Pole LAT)

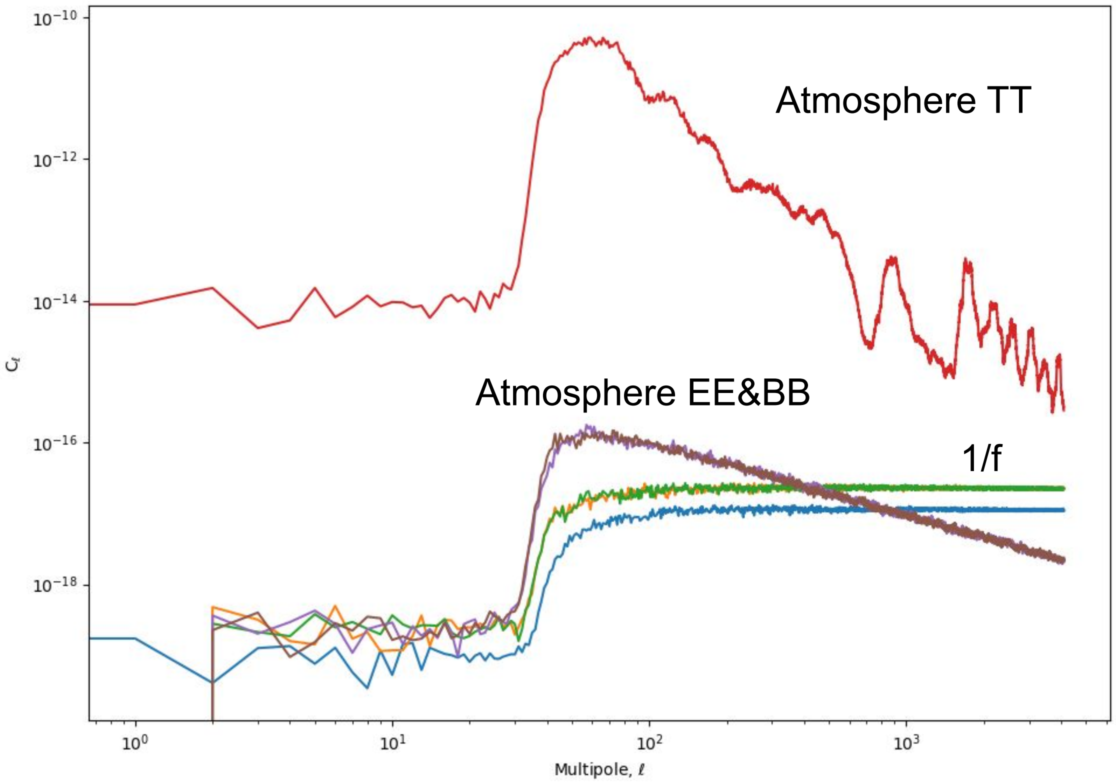


Each panel is 13x13 degrees

1/f and atmosphere scale differently

Showing instrumental 1/f and atmospheric noise TT, EE and BB spectra.

Atmosphere only presents in polarization through detector mismatch.



Where can I find them?

Please keep an I eye on

https://github.com/CMB-S4/s4mapbasedsims/tree/master/202102_design_tool_run

the CMB-S4 log book

https://cmb-s4.atlassian.net/wiki/spaces/XC/pages/370770139/Logbook

And our Slack channel

https://cmb-s4.slack.com/archives/C01DM8YGARG (design-tool)