Design Validation: Technical to Measurement

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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

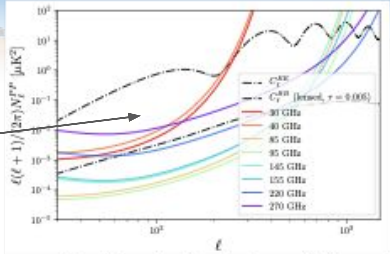

Figure 1: Required noise as a function of multipole for each frequency in polarization for the low-resolution, ultra-deep survey of 2.8% of the sky.

Delensing LAT temperature and polarization noise over 2.8% of sky

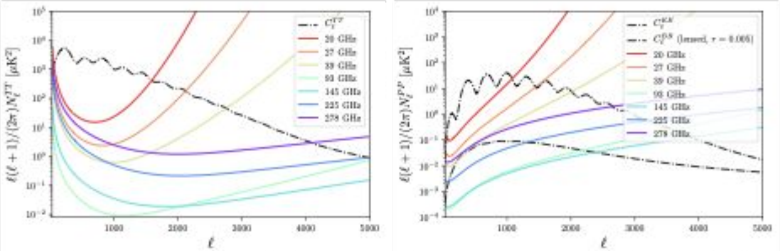

Figure 2: Required noise as a function of multipole for each frequency in intensity (left) and polarization (right) for the high-resolution, ultra-deep survey of 2.8% of the sky.

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

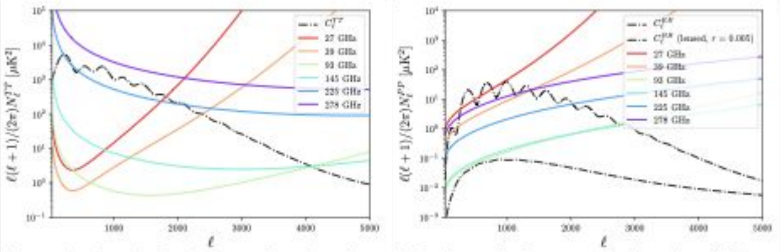

Figure 3: Required noise as a function of multipole for each frequency in intensity (left) and polarization (right) for the high-resolution, wide and deep survey of 68% of the sky.

+

Daily cadence, resolution and sensitivity requirements from transient science

From:
CMB-S4 Program Level Requirements

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

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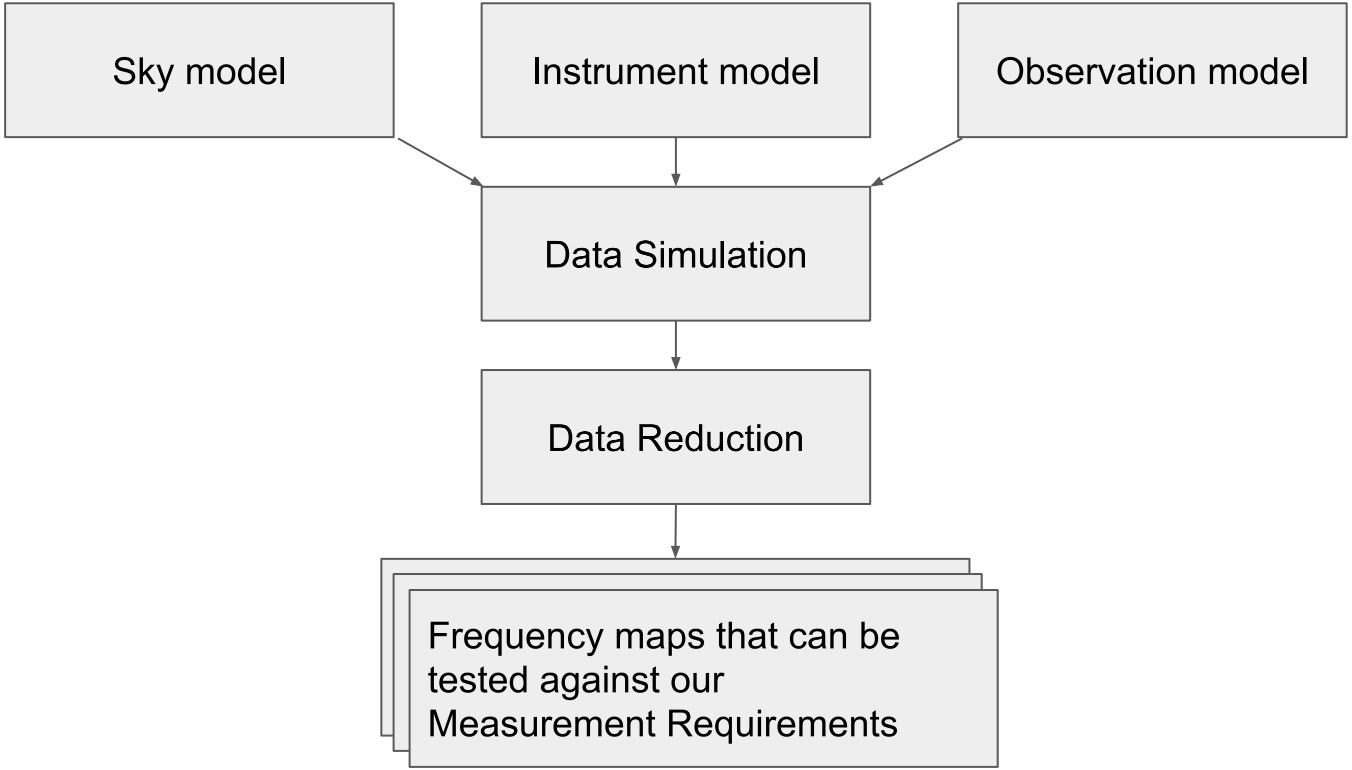
Desired outcome (2/2)

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



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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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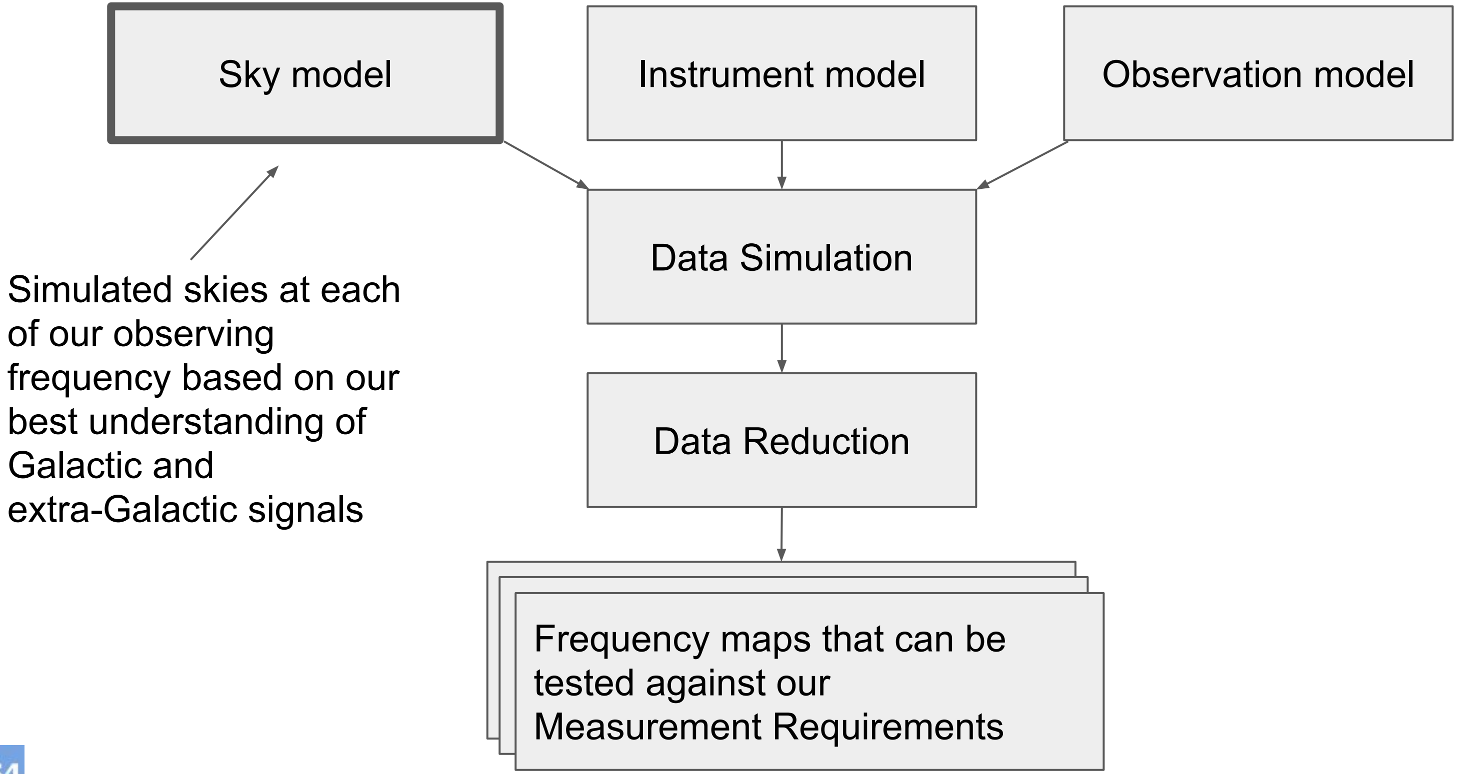

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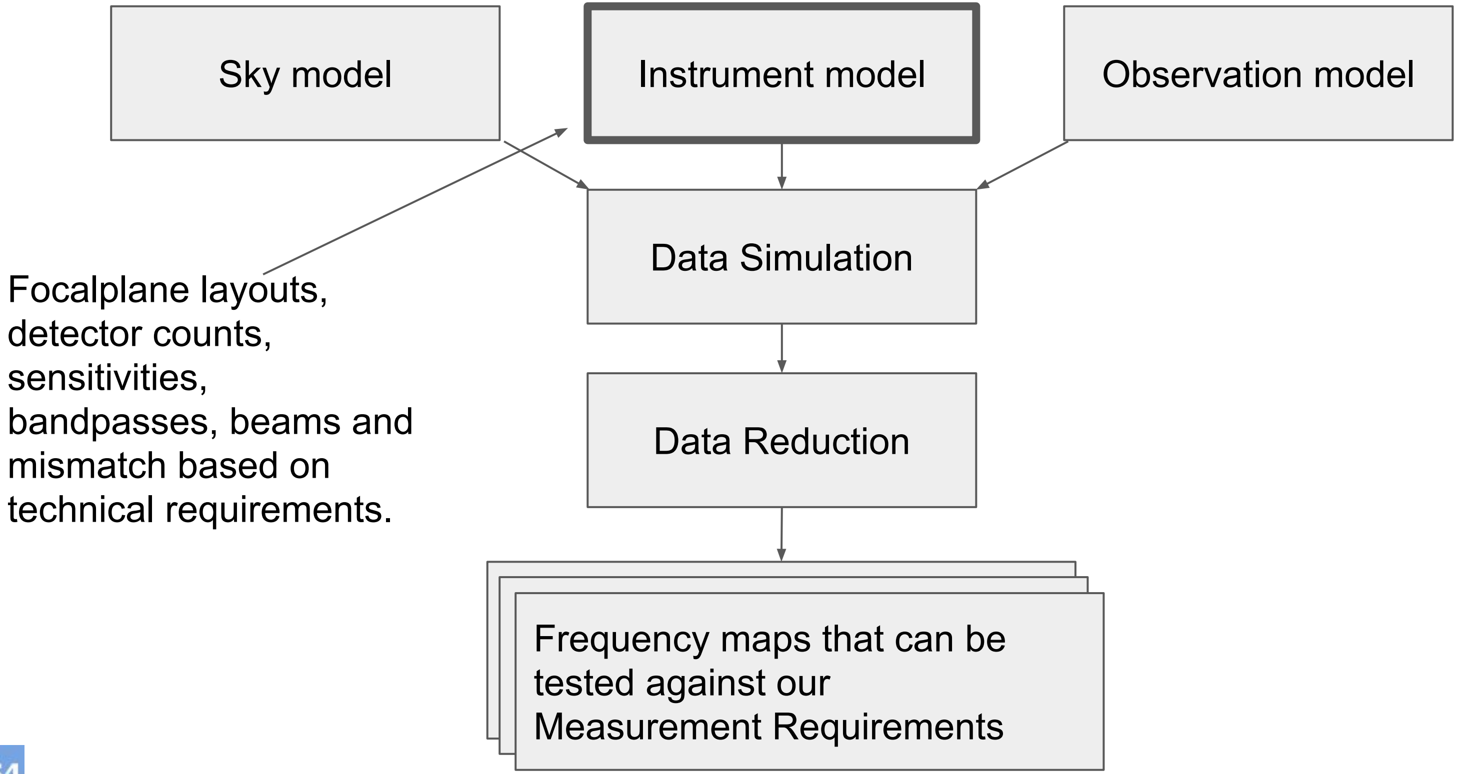

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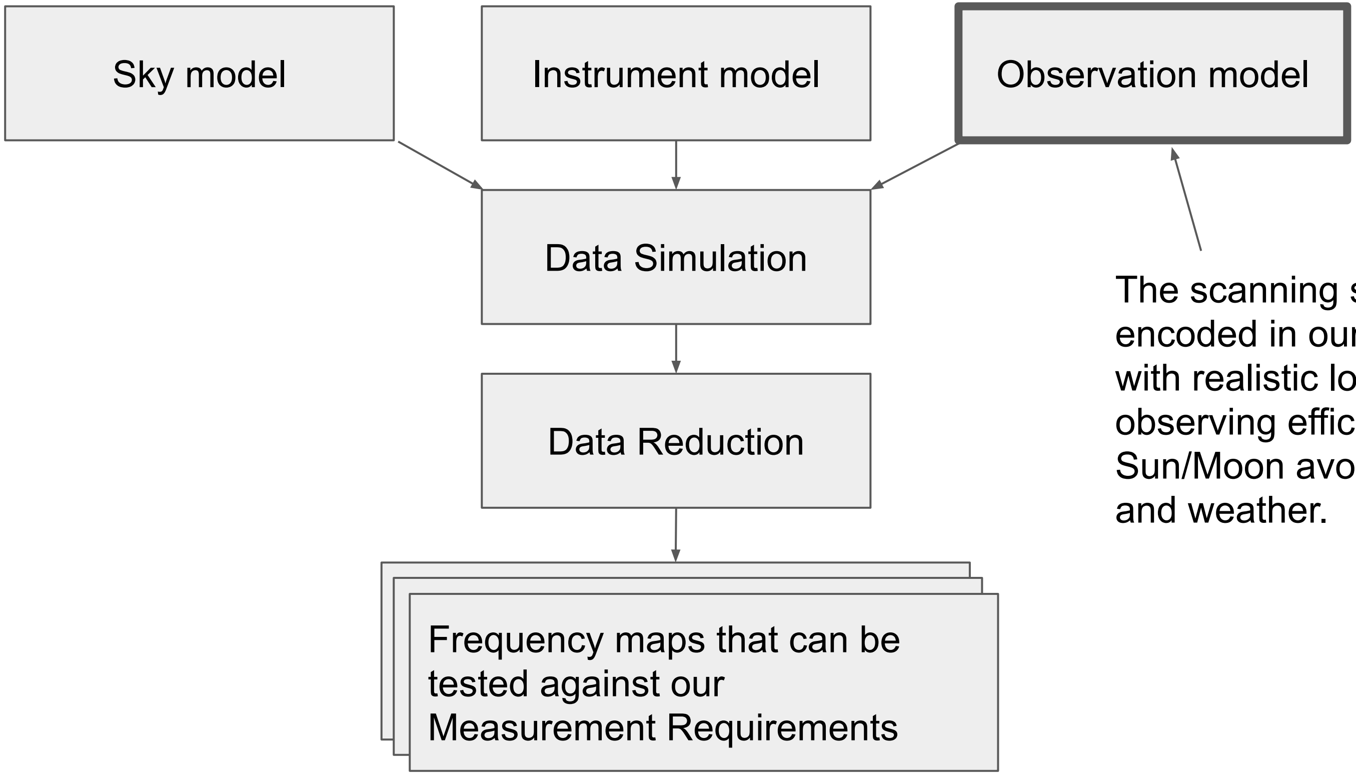

The scanning strategy encoded in our design with realistic loss of observing efficiency from Sun/Moon avoidance and weather.

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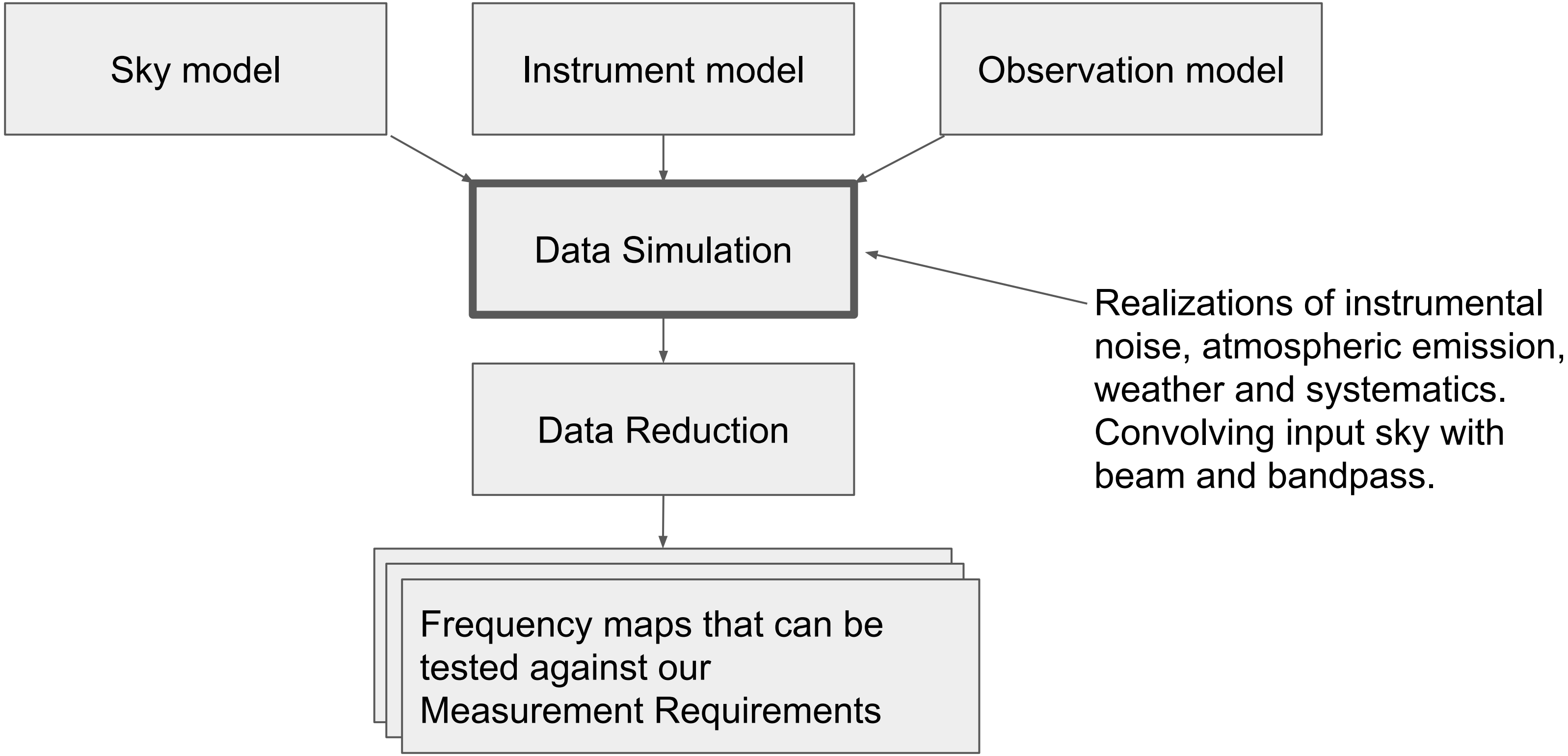

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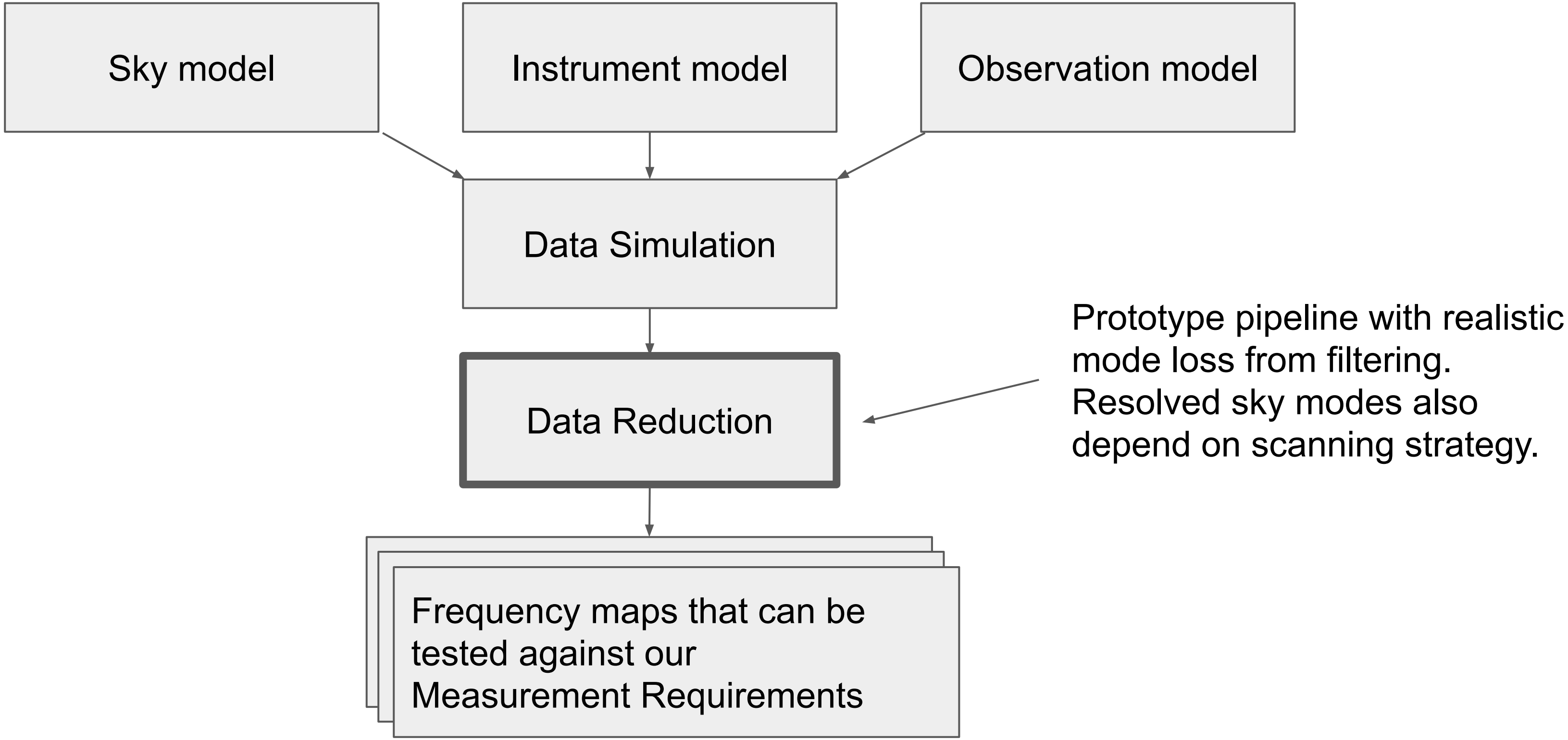

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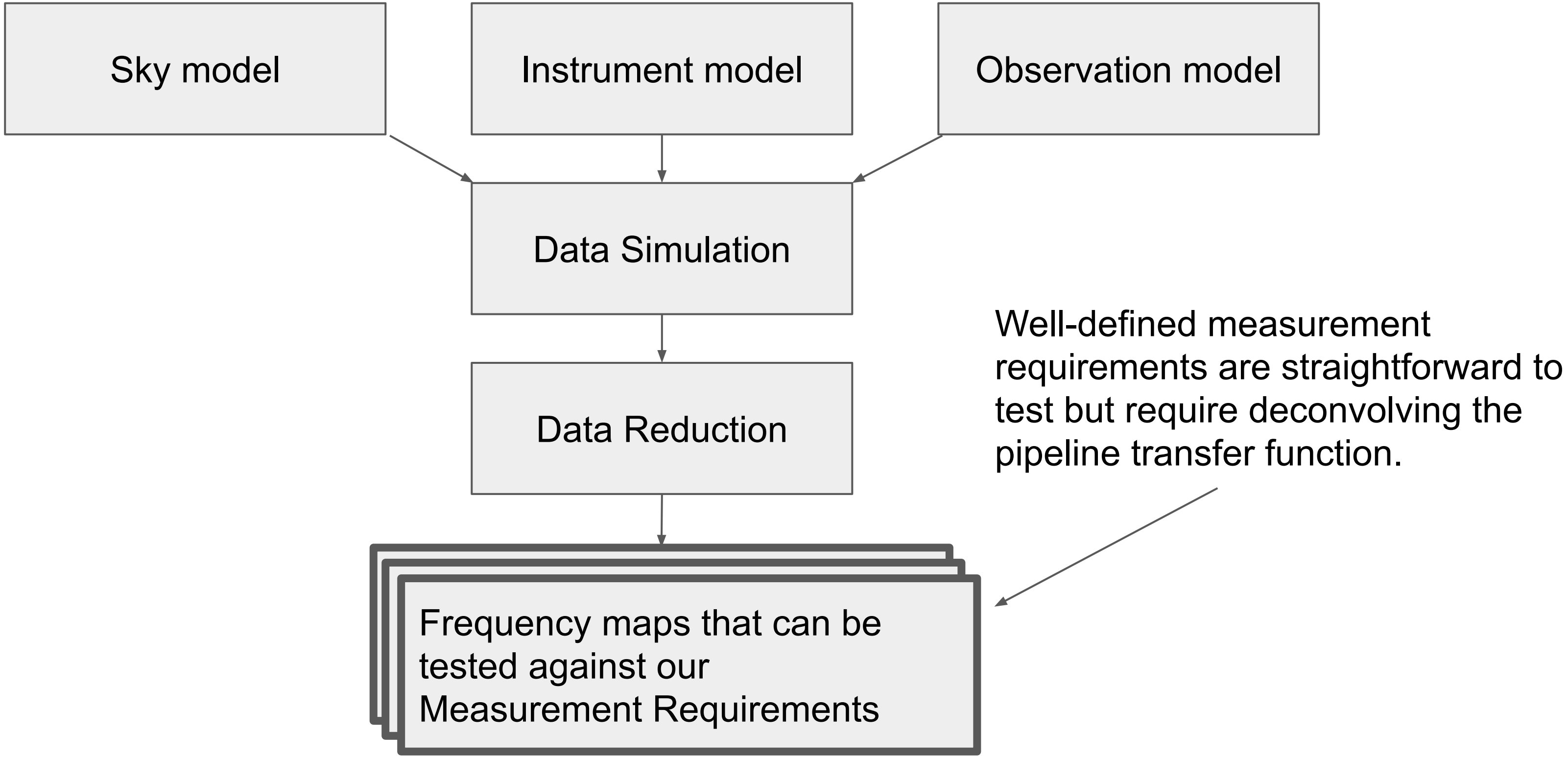

Parallel session

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

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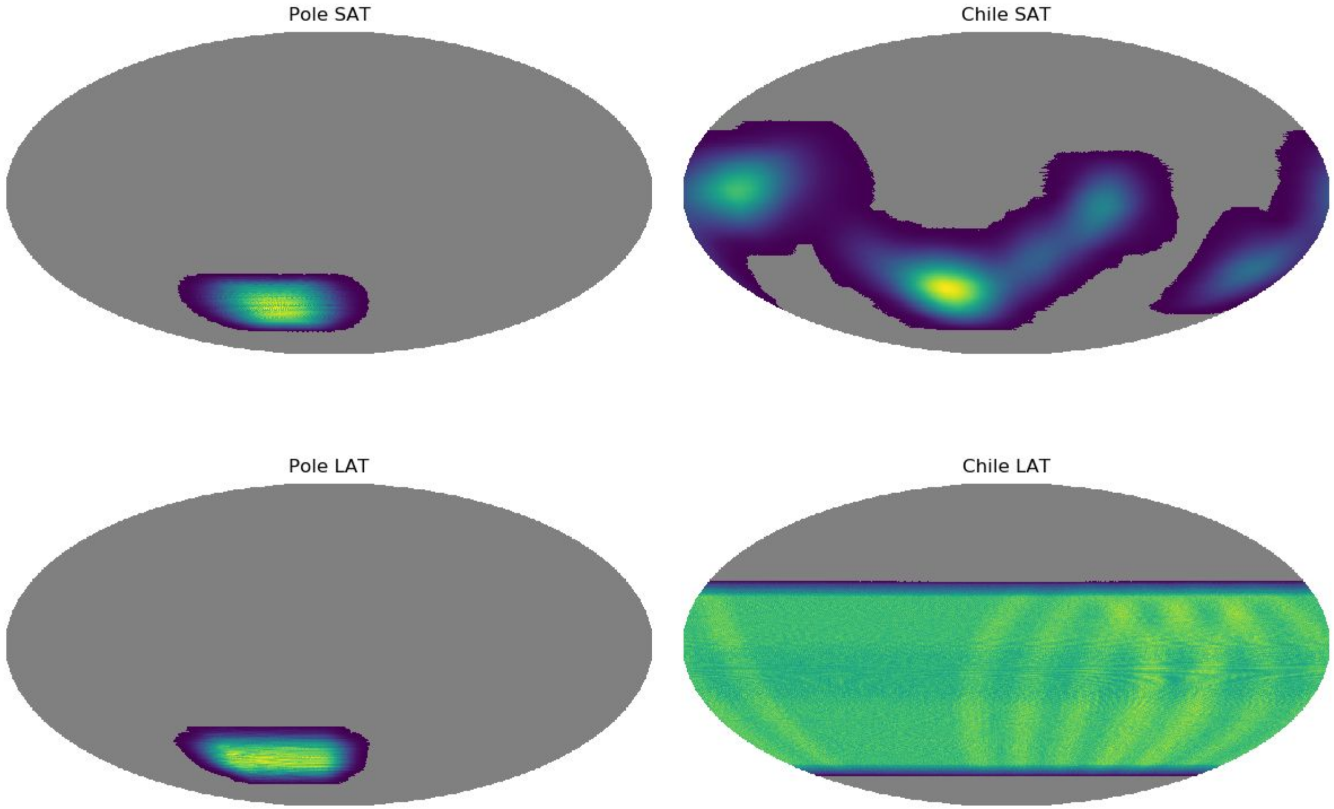
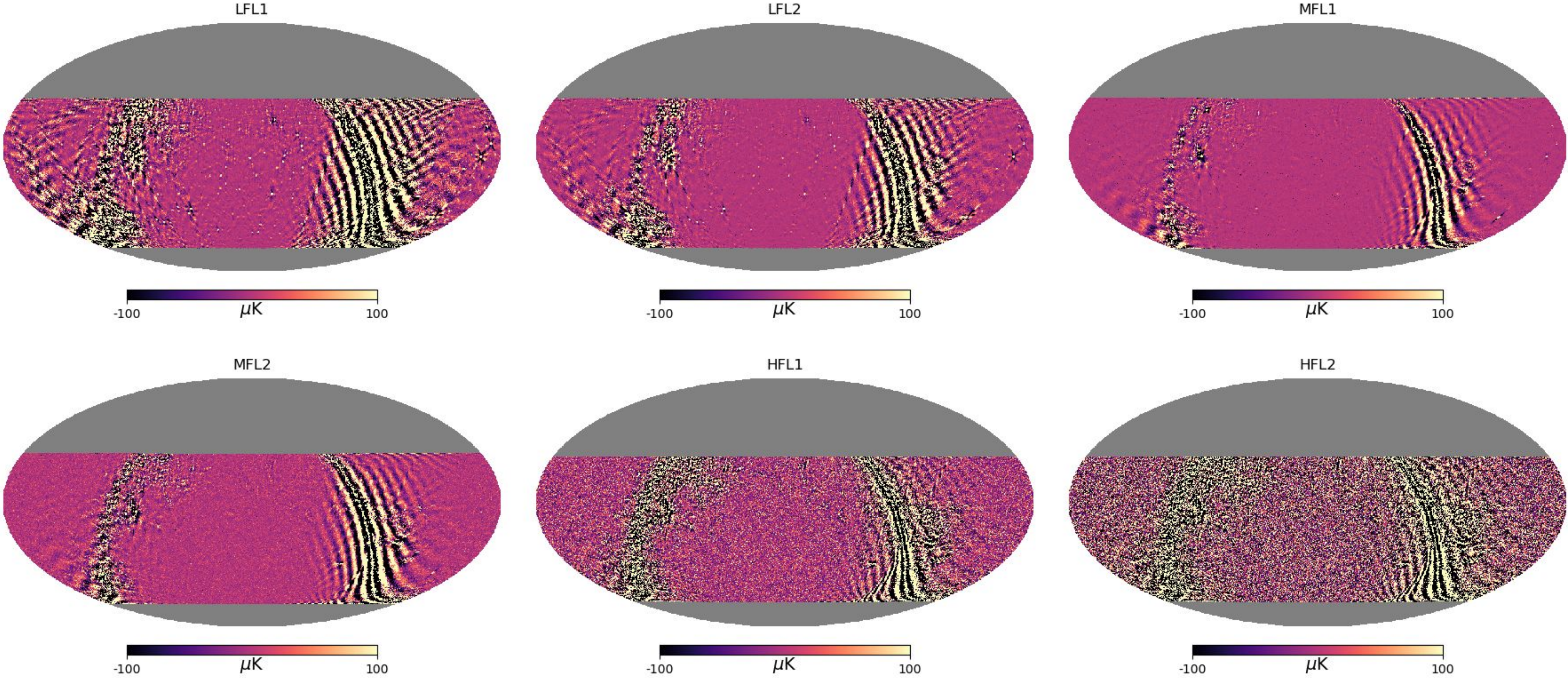
Both sites and telescope types (showing MF hit maps)

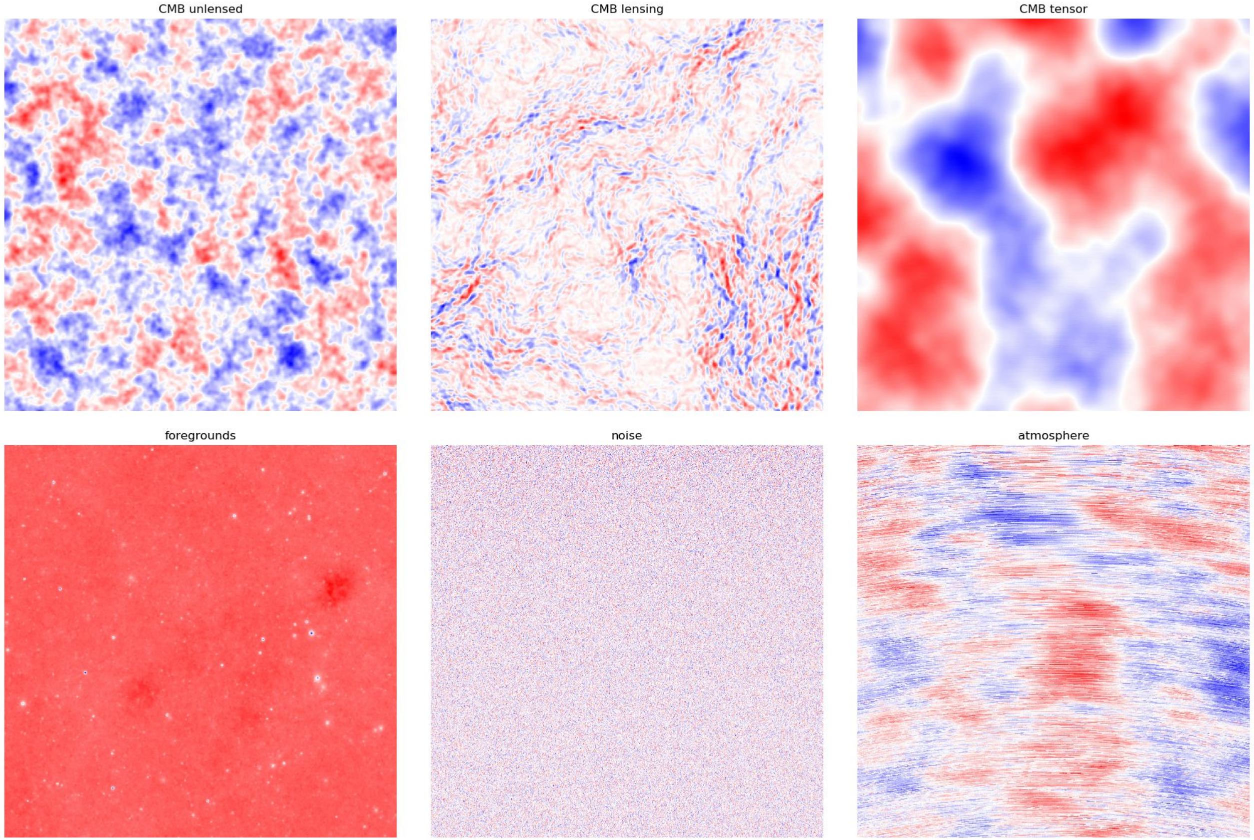


All CMB-S4 frequency bands (showing filtered Chile LAT foregrounds)



Six different components (showing Pole LAT 93GHz)

Each panel is 13x13 degrees



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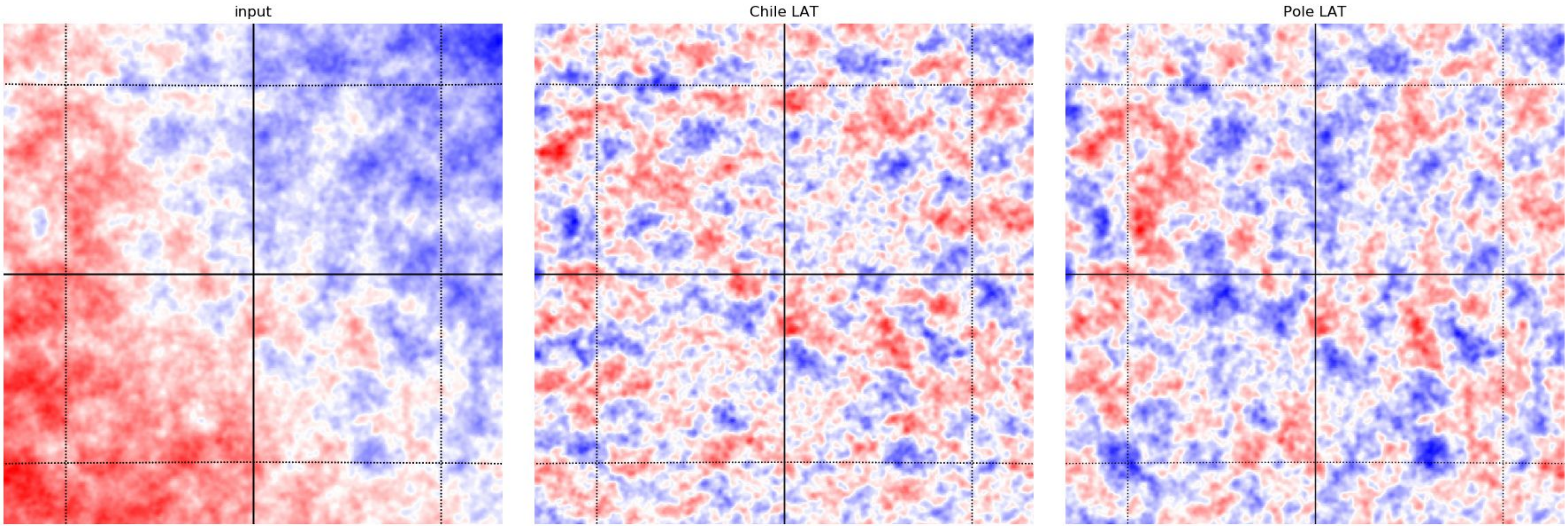
Realistic mode loss (scalar CMB, Chile and Pole LAT)

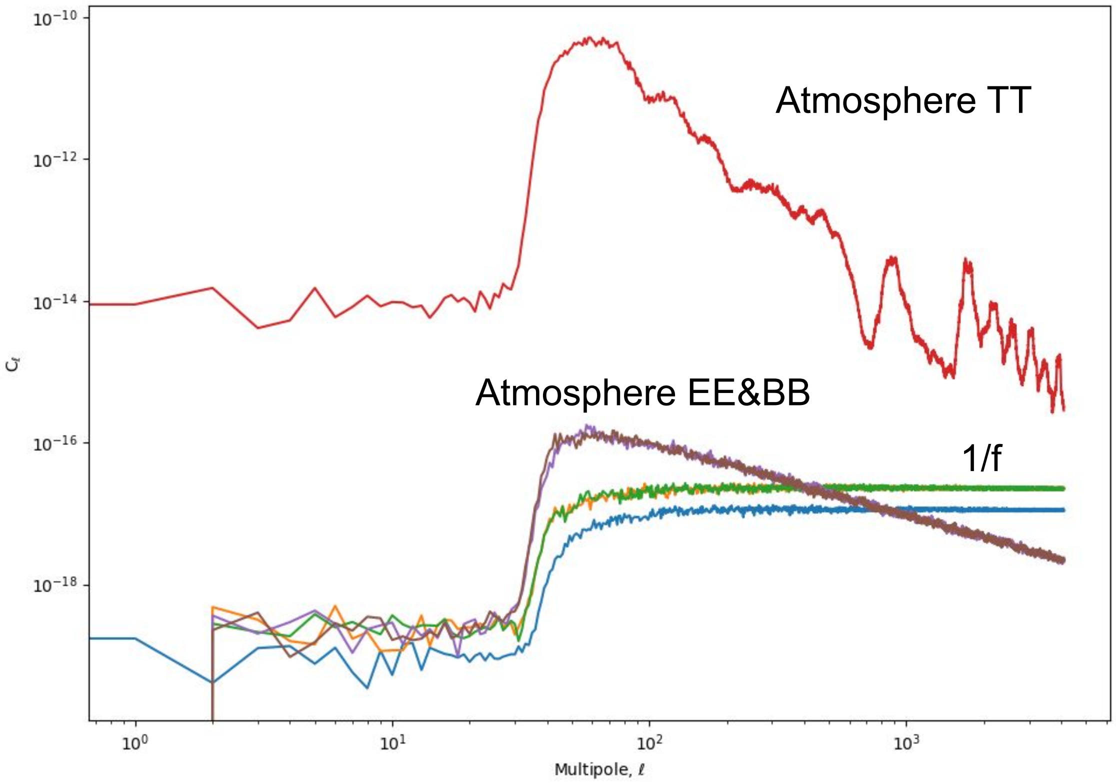


Each panel is 13x13 degrees

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.



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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)