Data Analysis & Infrastructure

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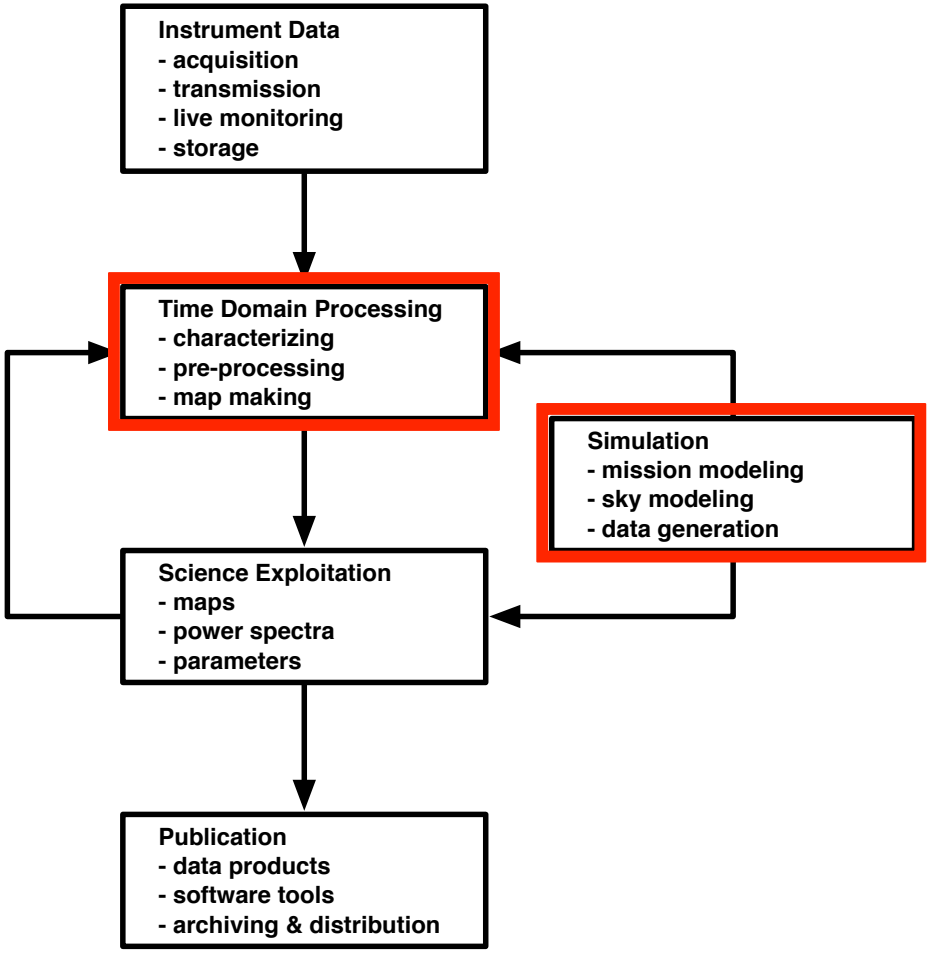
Data Management Overview

- Subdivide overall data management into 5 areas
  1. Instrument
  2. Time-Domain
  3. Science
  4. Publication
  5. Simulation
- Identify the key tasks & the human and computational resources for each.
- Now in the epoch of formal Data Project: WBS, Manager



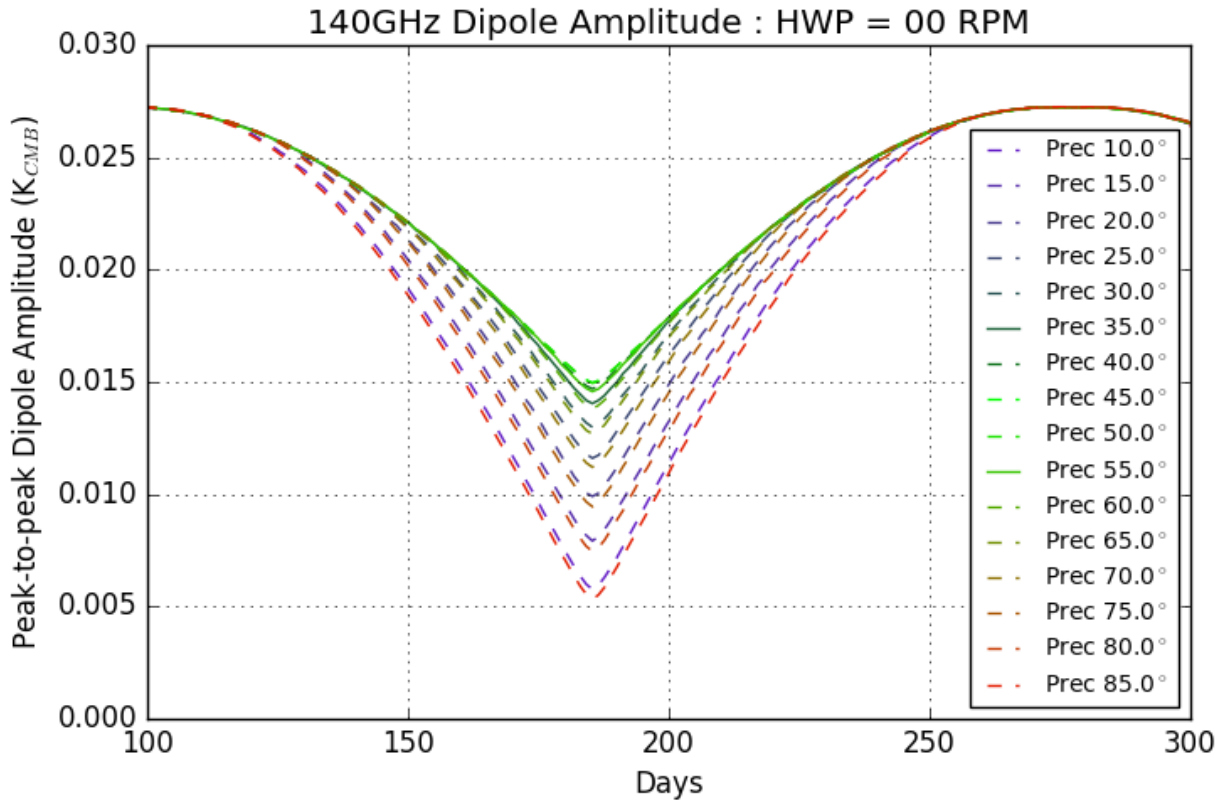
Simulations

Overview

- Given a sky model
  - Scalar, tensor & non-Gaussian CMB
  - Extragalactic foregrounds & lensing
  - Galactic foregrounds
- Given a mission model
  - Instrument
  - Observation
- Apply the mission to the sky to generate a synthetic mission dataset in the time, map, or spectral domain and analyze it
  - Trade cost against realism in selecting domain
  - Define simpler metrics as proxies for final parameter constraints

Example Metric

- Daily peak-to-peak dipole variation as a function of satellite scanning angles (fixed α + β)
  - Defines ability to perform daily dipole calibration



Sky Modeling

- A number of multi-frequency next-generation missions are in design & development
  - Suborbital – Simons Observatory, CCAT-p, CMB-S4
  - Space – LiteBIRD, ~~CORE~~, PICO

- Common sky models
  - Across scales: coherent low- and high-ell science
  - Across missions: comparison and combination
  - Across disciplines: CMB x LSS

Current Status

- With WMAP & Planck, these missions currently span 73 bands
  - Band definitions here

- Modelers are being asked to generate their sky in all bands
  - Tophat & delta bandpassed skies delivered to NERSC.
  - Mostly PySM to date; others for specific subsets.

- Most missions are using NERSC as a central repository
  - /project/projectdirs/{sobs, cmbs4, litebird, core, pico, …}

Wish List

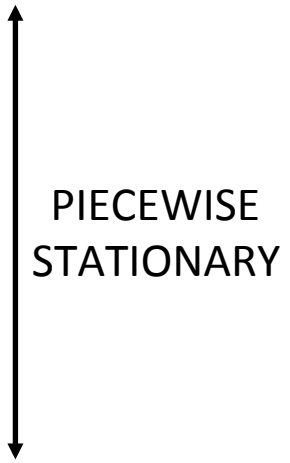
1. **More representative sky models**
   - PICO-sponsored sky modeling workshop: UCSD, 10/30-11/1

2. **Comprehensive sky maps**
   - Goal is (i) full-sky, (ii) IQU, (iii) nside ≥ 8192

3. **Sky models as callable functions of frequency**
   - Needed for on-the-fly band integration, to enable full exploration of band-space including intra-frequency bandpass mismatch.

Mission Modeling

- Instrument
  - Individual detector beams, band-passes
  - Auto- and cross-correlated noise components
    - detector, pixel, wafer, readout, telescope
  - Absolute & relative calibration
  - Polarization modulation systematics
  - Other
- Observation
  - Scanning strategy
  - Environment (atmosphere, ground-pickup; cosmic ray flux, …)



Wish List

- **Define mission parameter *distributions* to sample from.**
  - Required to simulate full missions before exhaustive characterization

- **Define *comprehensive* mission definitions and then derive reduced approximations**
  - Map domain: band-averaged noise, bandpass, symmetric beam
  - Spectral domain: spectra of residuals
  - Required for meaningful comparison of simulations in different domains.

Time Domain

Overview

- Fundamental mission deliverable is the reduction of the time-ordered data to a set of well-characterized frequency maps.

- Despite their expense, time-domain simulations are absolutely necessary
  - Design and development (after optimization in cheaper domains)
  - Pipeline validation & verification
  - Monte Carlo data characterization (10^4 x data!)

- Time domain analyses introduce their own systematic effects.

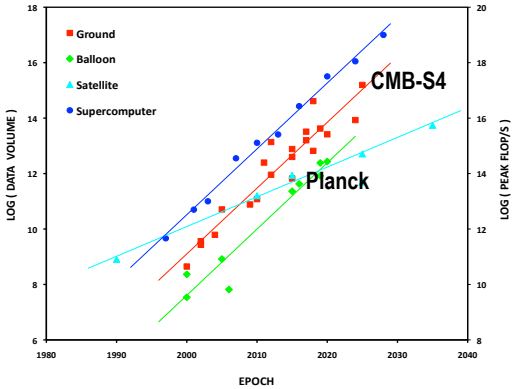
TOD Challenges

REALISM: ALGORITHMS

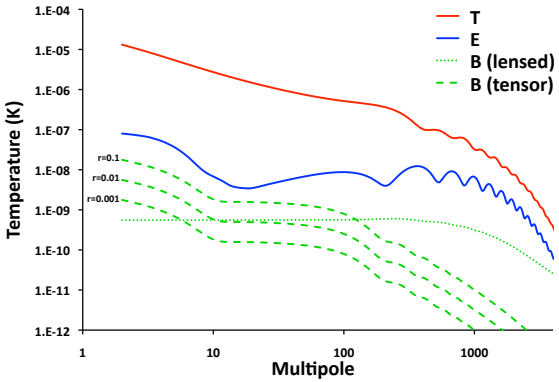
- 1000x systematics sources
  - Atmosphere
  - Ground pickup
  - Advanced instrumentation
  - Cross-correlated noise
  - …

PERFORMANCE: IMPLEMENTATIONS

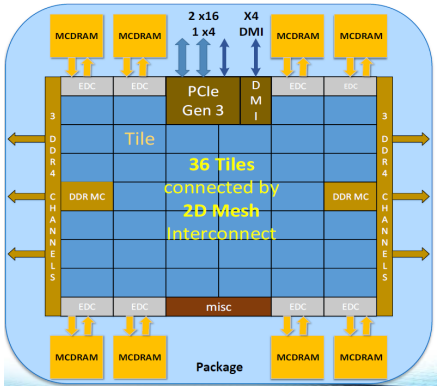
- 1000x data volume



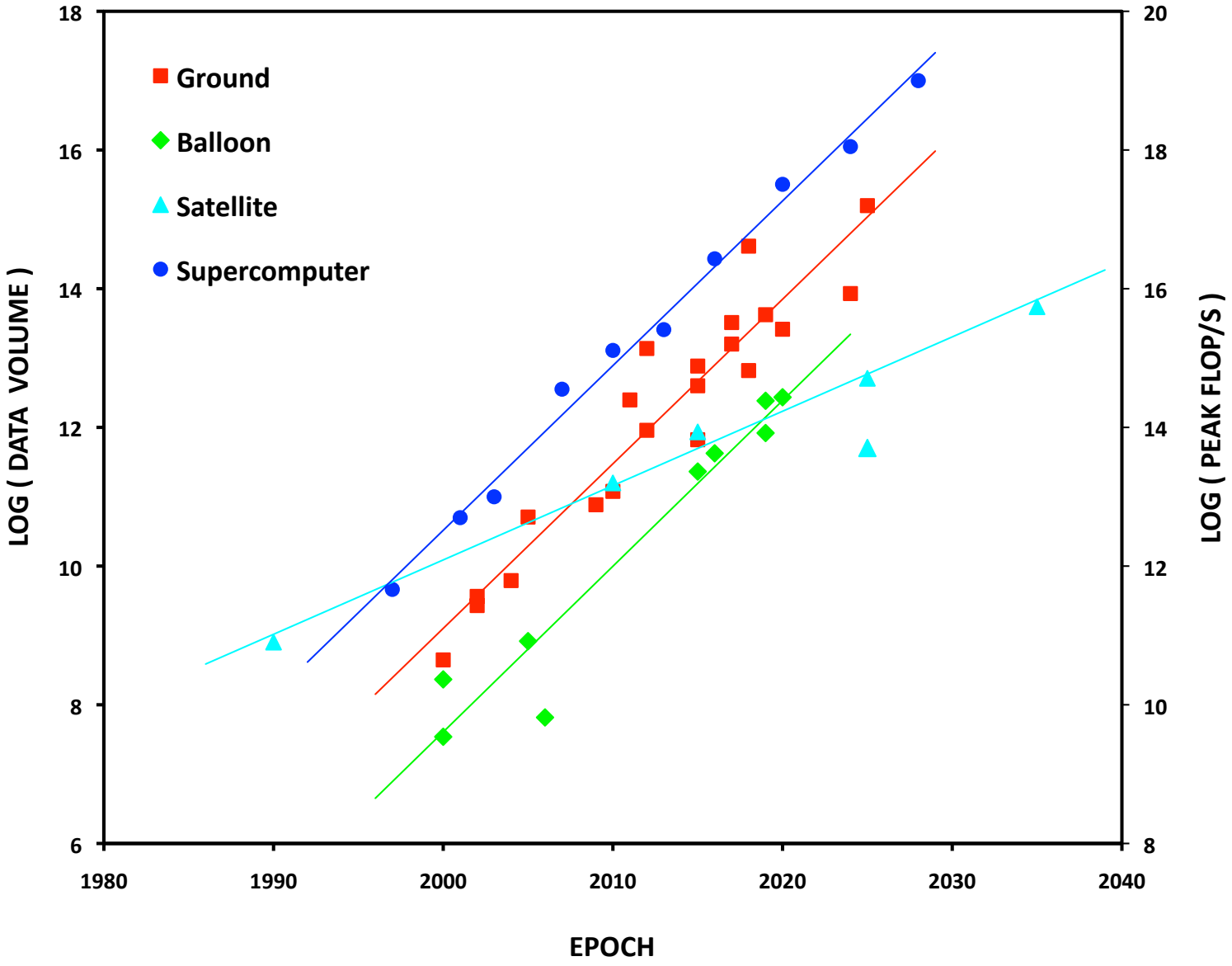
- 100x lower systematics threshold



- 100x fewer watts per FLOP



Moore's Law for CMB



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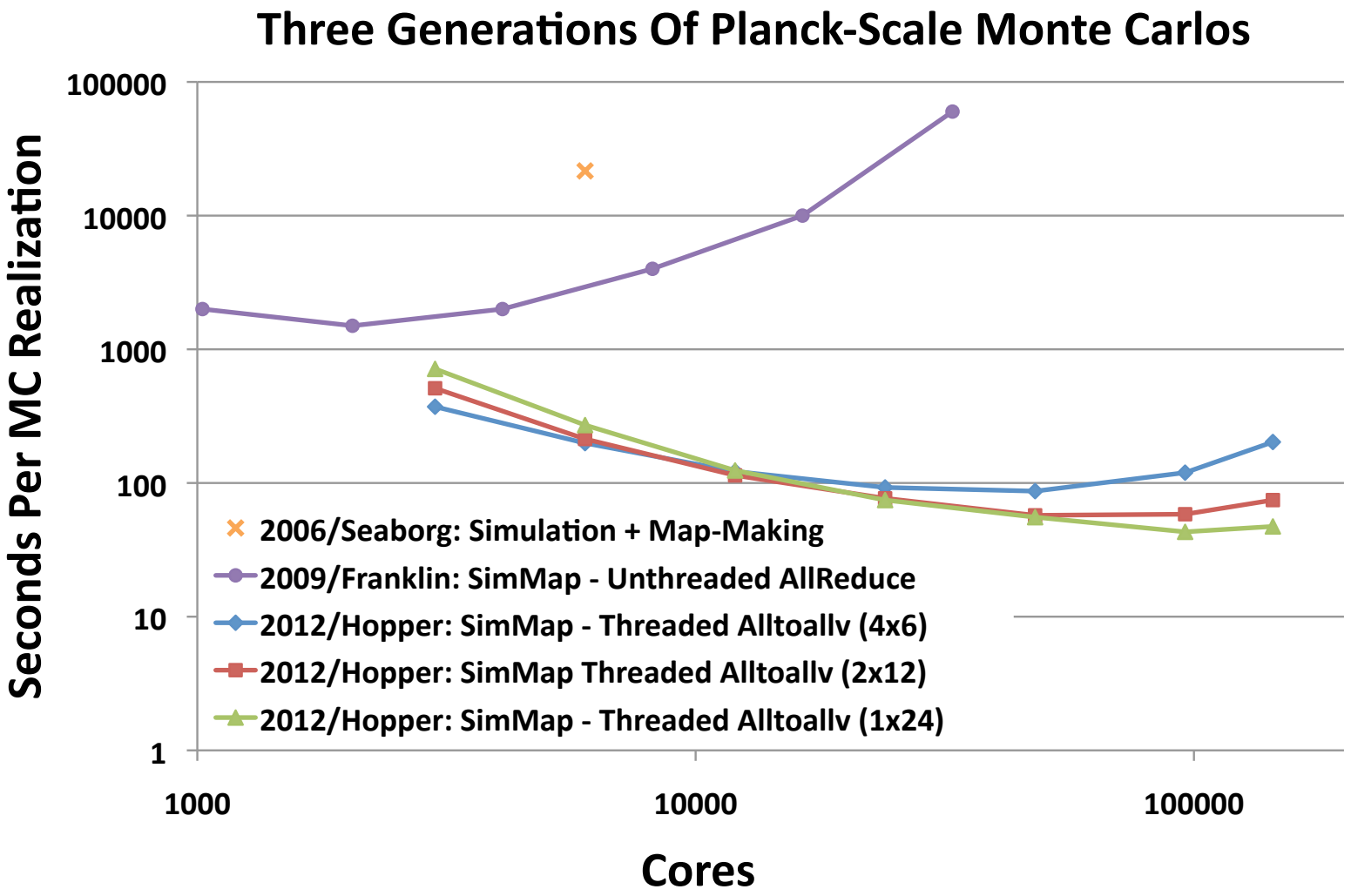
It's Déjà Vu All Over Again



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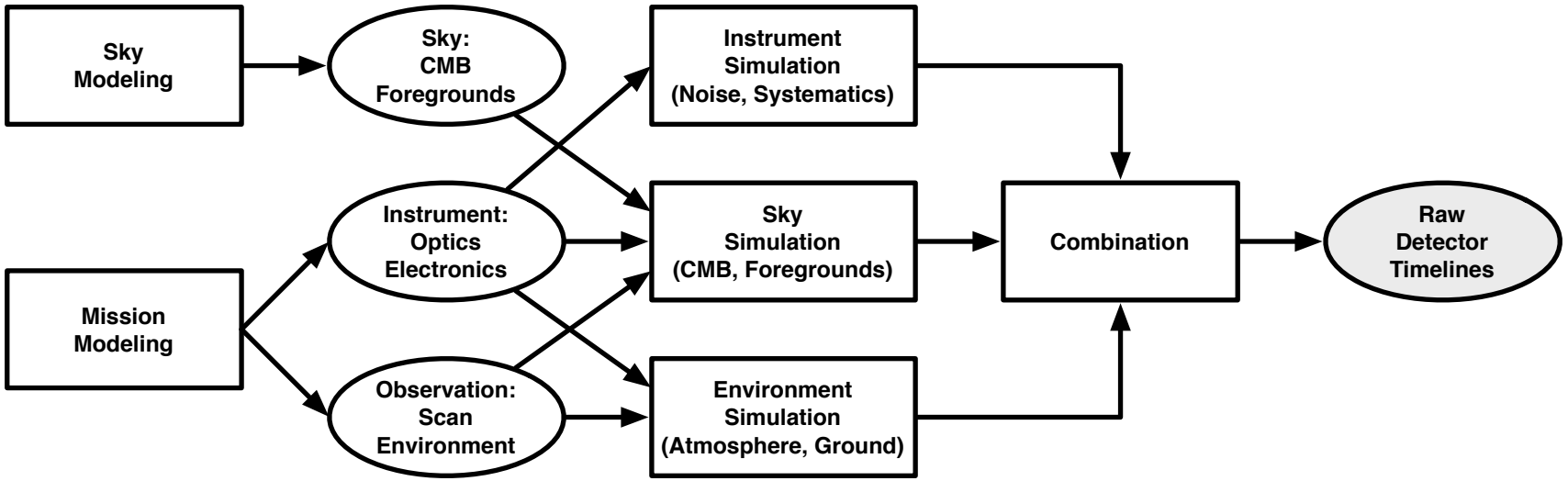
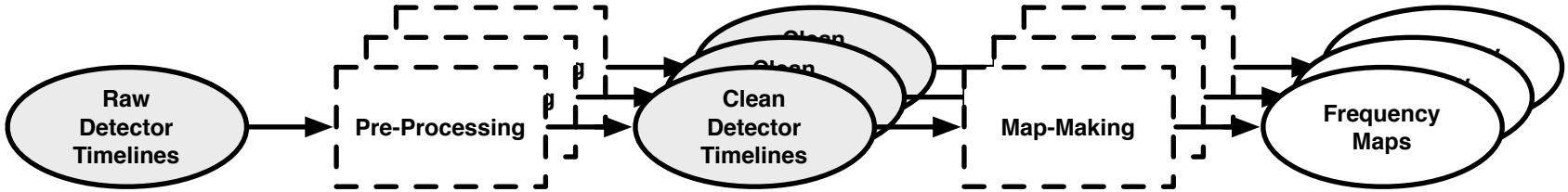
TOD Simulation Framework



TOD Reduction Framework

- Feed the total timeline directly into multiple reduction pipelines to amortize the simulation cost – fully on-the-fly framework.
- Each map-making may use the same or different pre-processing.



TOAST Design Drivers

1. Must be easy to prototype algorithms
   - We don't yet know how to mitigate systematics to the level required to recover faintest signals.
2. Must be scalable to massive parallelism (both HPC & HTC)
   - We want to simulate/reduce a huge data volume on the fly.
3. Must be readily available & open to developers
   - We need a coordinated, community-wide effort

$\Rightarrow$ Python-wrapped, MPI/OpenMP hybridized, compiled libraries

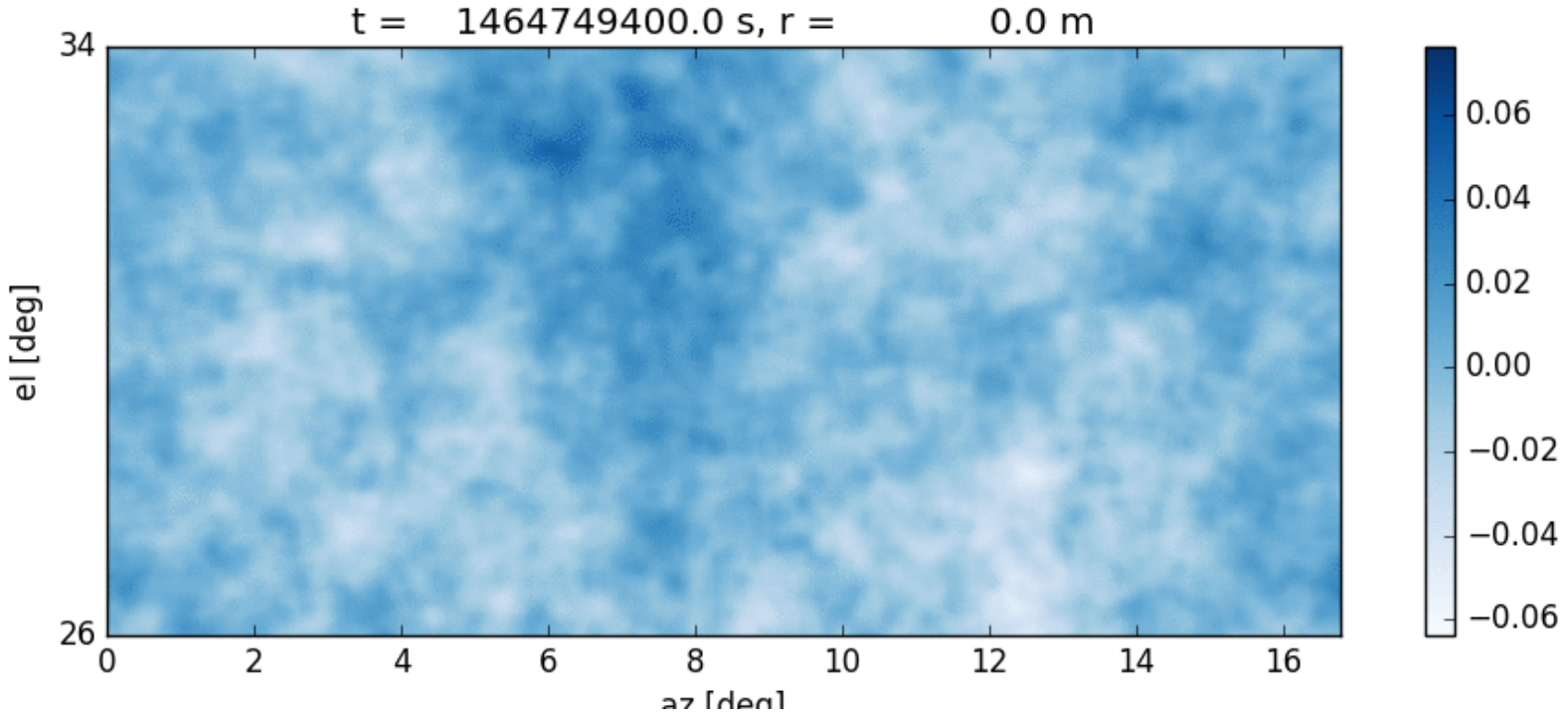
$\Rightarrow$ Code available on github, HPC resources available at NERSC

Proof-Of-Principle Run

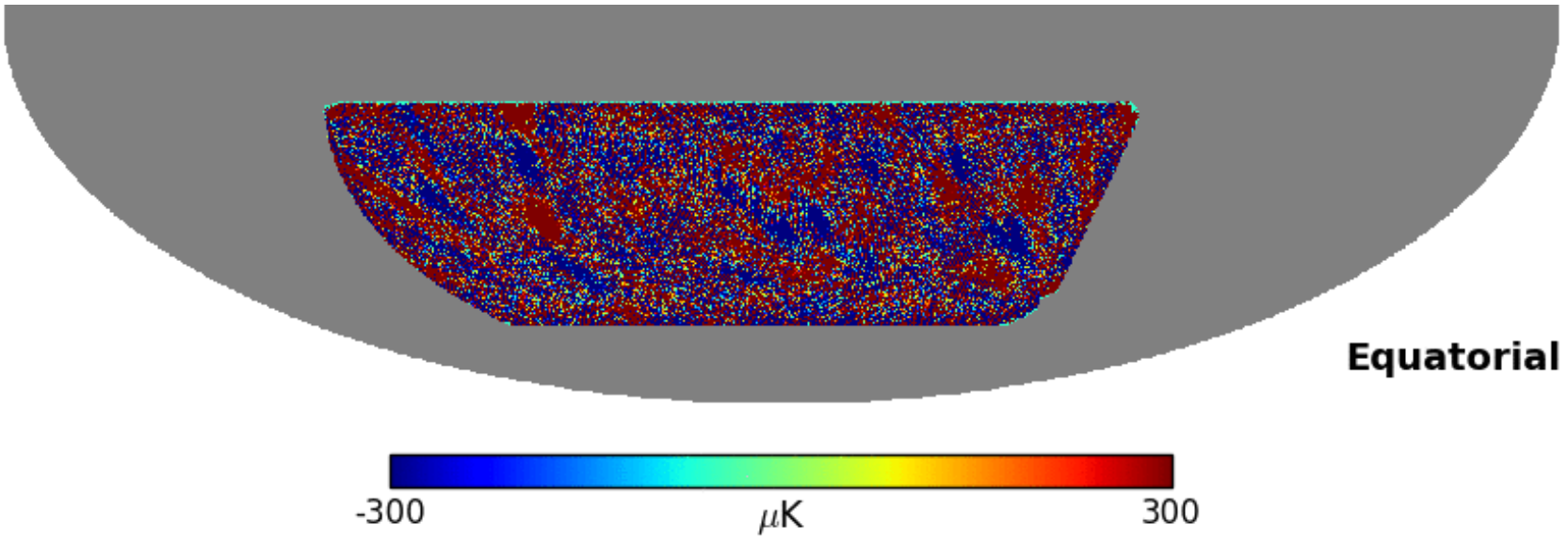
- Simulation:
  - 50K detectors; 7 frequencies; 20% of the sky;1 year: 35X Planck
  - Piecewise stationary atmosphere, noise + sky
  - Per detector calibration uncertainty
- Reductions:
  - 3rd order polynomial filter, bin to daily maps
  - 3rd order polynomial filter, bin to full-season maps
- Run on entire Cori-2 system at NERSC
  - 600,000 cores running 150,000 MPI-tasks each with 4 threads
  - Docker/Shifter to launch Python on 600,000 cores!

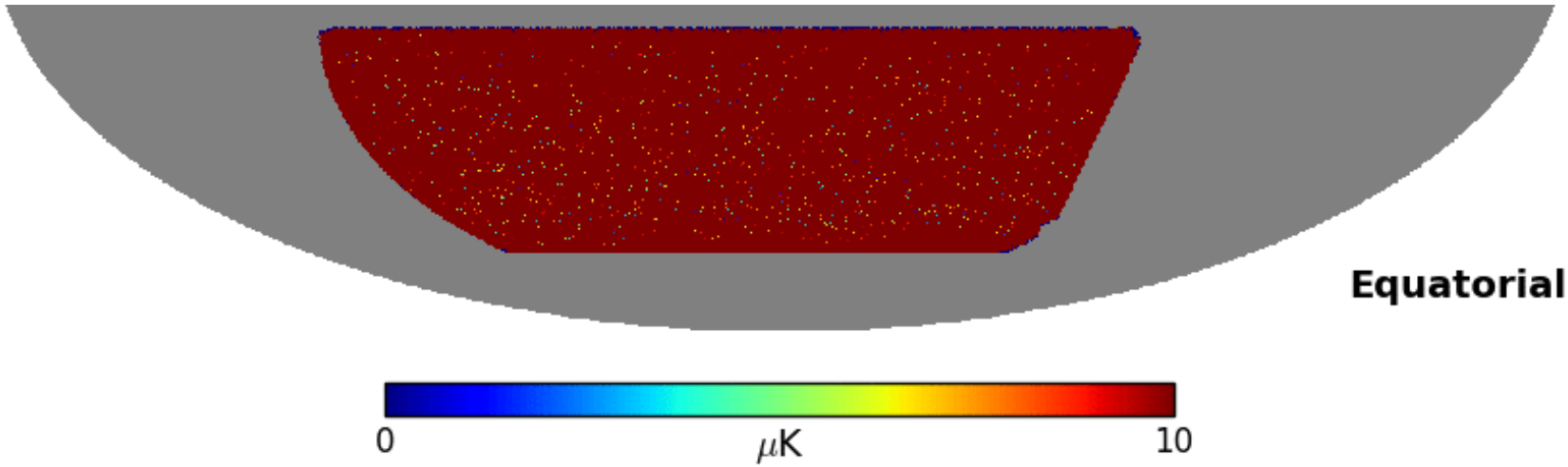
Atmospheric Realization

- Generate bounding volume of atmosphere seen by the telescope in one scan period (2- & 3-D Kolmogorov spectra)
- Perform line-of-sight integral for every observation.

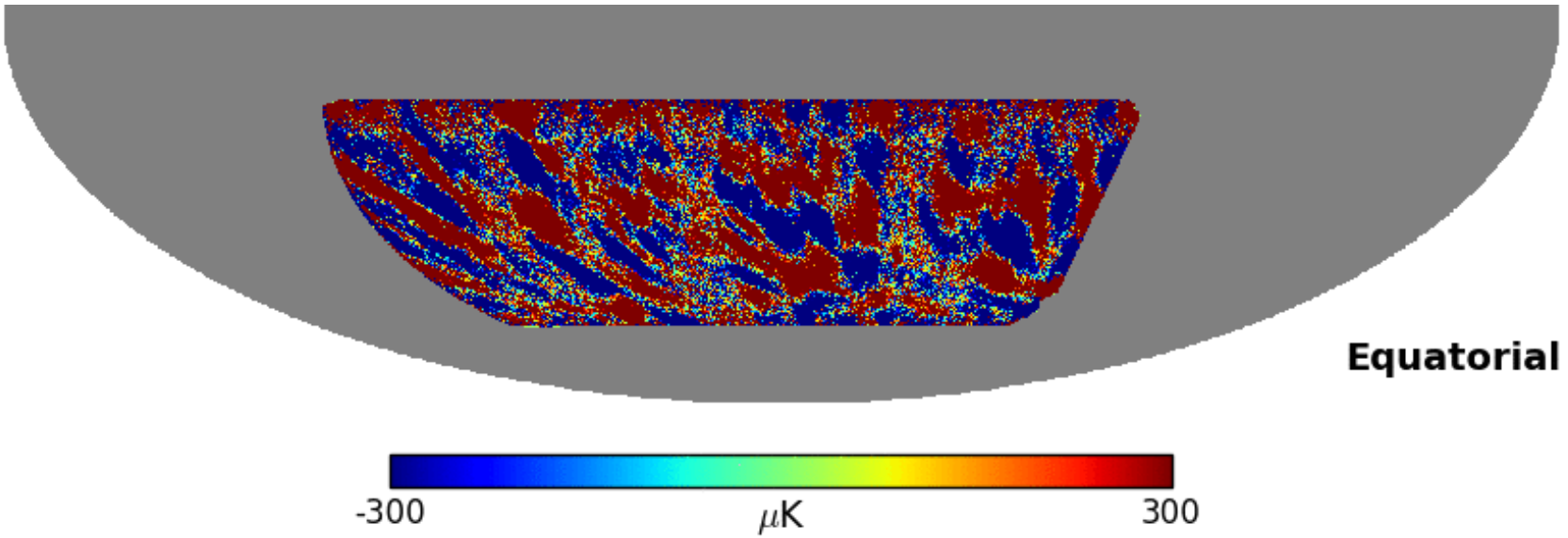


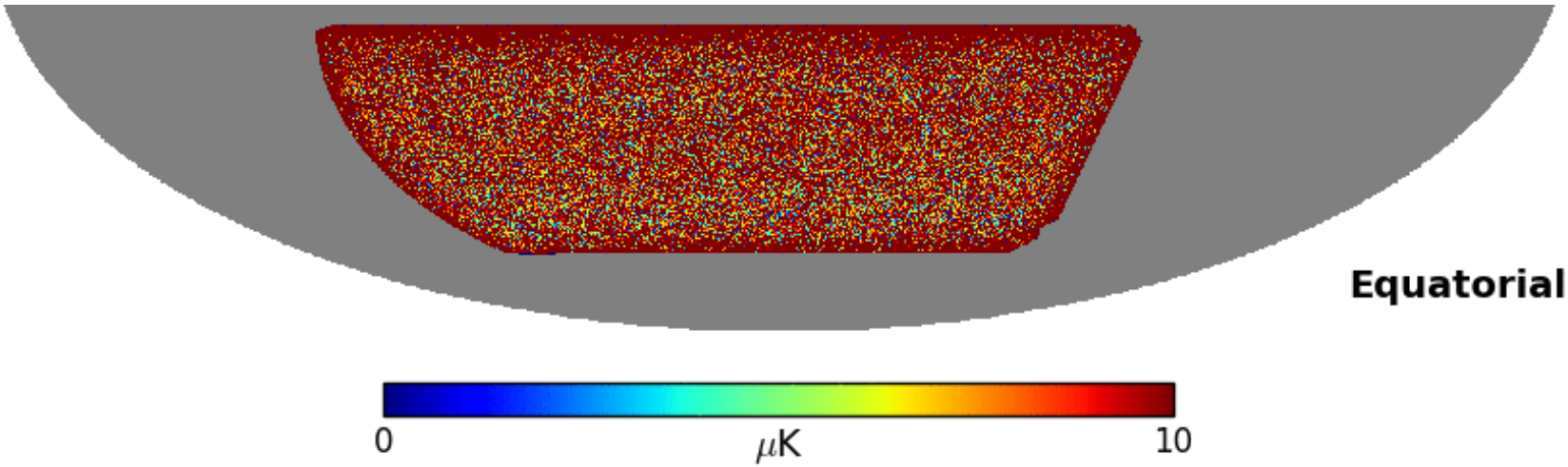
Cumulative T & P Maps: 20 GHz



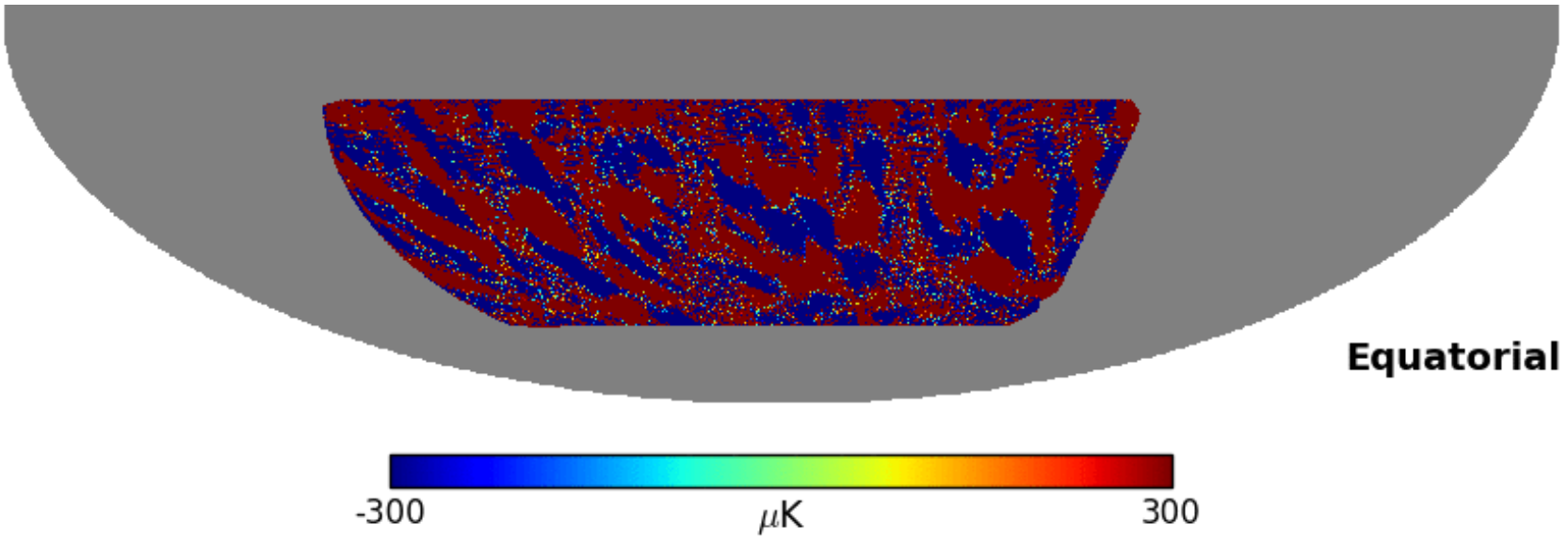


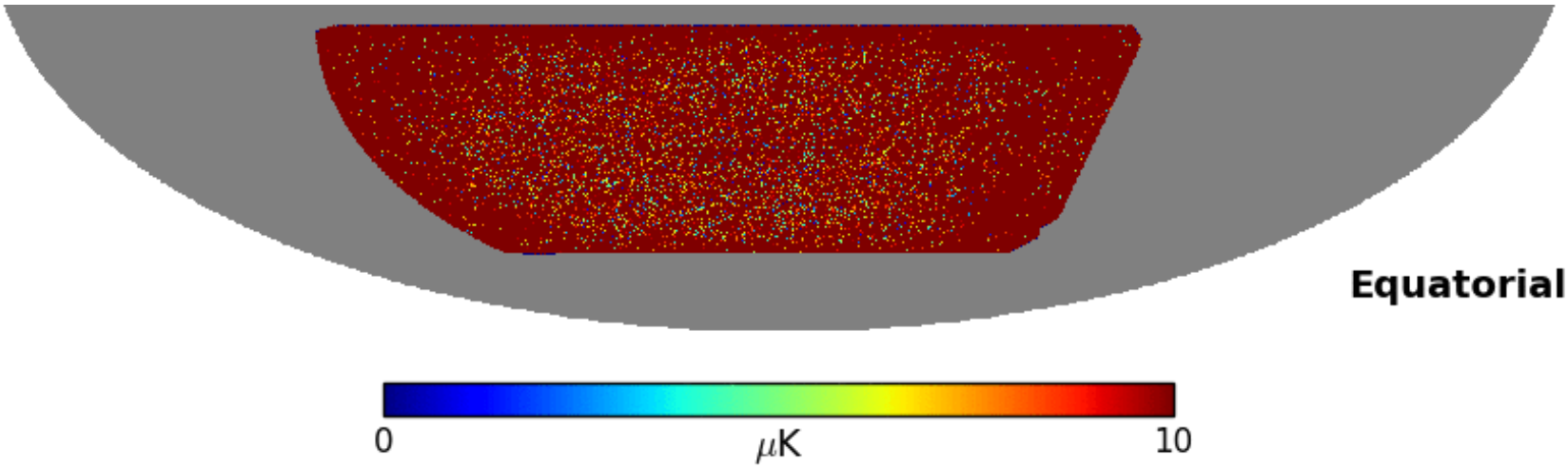
Cumulative T & P Maps: 95 GHz





Cumulative T & P Maps: 270 GHz





Collaboration & Coordination

- We have limited human and computational resources; we must make the most effective use of them across all the proposed missions.
- Multiplicity is valuable, but not at the cost of completeness or consistency.
- Global collaboration on generic issues:
  - Sky modeling
  - Reduced metrics & common requirements
  - TOD framework development & deployment
  - Science analyses
  - HPC, especially Xeon Phi efficiency:
    - NERSC (#6: Cori), ALCF (#16: Theta, Aurora), JCAHPC (#7: Oakforest), CINECA (#14: Marconi), CSC (?)