# Data Challenge 2 Plan and Prioritizations

**Input from analysis and technical groups**
**Overview by Sara Simon** *(she/her)*

CMB-S4

# Data Challenge 2 Overview

- DC2 will simulate two full years of observation data with the full CMB-S4 experiment
- In preparation for DC2, we can do smaller simulation runs to test codes, which can be used to:
  - Inform the instrument design
  - Inform the observation strategy
  - Inform systematic and calibration studies
- Today's discussion will be used to inform our plans for DC2, which will guide our simulation priorities over the next ~2 years
  - What do AWGs need the simulations to include to assess them?
  - What improvements and changes do we need in the experiment model?
  - Where can smaller time domain simulations leading up to the DC2 run be most useful?
  - Feel free to reach out with feedback beyond today's discussion!

# Planned DC2 Sky Model

- CMB sky with $r = 0$ and $r = 3e\text{-}3$
- 3 Galactic foreground models from the PanEx GFWG
- 1 Extragalactic foreground model from Alvarez et. al.
- TOAST atmosphere

Additional documentation and details for the previous design tool run are here

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# Maps2Cell

Ideally nside=4096, 2048 ok.

O(100) splits w. noise

# Clusters

- Nside=4096 (or 8192?).
- Consistent WebSky unlensed and lensed CMB; i.e., same CMB and WebSky cosmological parameters and CMB lensed with WebSky potential.
    - More than one realization, if possible.
- Multiple realisations of halo-correlated radio/dusty galaxies.
- Beam errors (for SPLAT).

# Maps to Other Statistics

- O(500) lensed CMB and realistic noise realizations with different splits.
- Consistent WebSky unlensed and lensed CMB with correlated foregrounds at least for a few realizations if possible; i.e., same CMB and WebSky cosmological parameters and CMB lensed with WebSky potential
- Galactic foreground sims capturing small-scale non-Gaussianity of foregrounds as well as possible
- Patchy kSZ realization with best-fit Planck tau (uncorrelated with z<5 LSS)
- Correlated galaxy and lensing survey sims for cross-correlations?

# Low-ell BB

- Nside: 512 for SAT maps, 2048 for LAT maps.
- N splits/realizations:
  - At least O(100) CMB and noise realizations.
  - Multiple CMB to be lensed by Gaussian phi with phi spectrum consistent with Websky’s.
  - Gaussian realizations of correlated (polarized/extragalactic) foregrounds
  - Ideally, O(500) realizations/splits.
- Observing matrix for SATs (and LAT if possible).
- Maybe good to have instrumental systematics effects (okay if not).
- Good to have small-scale (ell>1000) non-Gaussianity from the Galactic foreground models.

# AWG Feedback Summary

- Nside=4096 for LATs, 512 for SATs
- Consistent lensed/unlensed sky simulations
- Hundreds of realisations/splits
- Some systematics (especially beams)
- Small-scale non-Gaussianity in foreground models
- Observing matrices
- Patchy kSZ
- Correlated galaxy and lensing survey sims for cross-correlations

# Instrument Model

- Current DC1 instrument model was described in the DC1 session
- Instrument definition is the preliminary baseline design
  - Detector and telescope information from pBD spreadsheet (frozen version from DC1)
  - Detector noise and noise vs. elevation values from jbolo (LATs +SAT MF/HF, SAT MF)
  - Platescales from SAT/LAT groups
- Observation Definition
  - Observation Efficiency from survey strategy group with time domain breakdown
  - Scan Strategy parameterization from survey strategy group
    - SAT - BICEP/Keck-like scans
    - SPLAT- SPT-like raster scans
    - CHLAT-variable speed, constant elevation scans

# Detectors

- Reducing number of different wafer types will reduce risk, cost and schedule. Are there any further simplifications possible?
  - Can SAT and LAT HF detectors be exactly the same?  Currently only difference is Psat
  - Though may be better determined by ongoing sensitivity calculator work
- Updated detector layouts as the designs mature
- More realism in the detector response (e.g. saturation, non-linearity) to help inform detector requirements

# Readout

- TMUX structure in readout
- Crosstalk
  - Could likely assume uniform crosstalk level on nearest neighbor channels at this stage
  - Row-switching crosstalk and mitigation modeling could be particularly well-suited to a TOD sims.
- If there is a full bolometer model implemented with optical loading, could include:
  - Detector+readout stability
  - Time constant effects
- If above and detector/readout non-uniformity effects are implemented, could include:
  - Variation in gains and responsivity for fixed column biases.

# Module Assembly & Testing

- Update module layouts (e.g. module pitch) as the designs mature
- More realism in the detector bandpasses to inform how well we need to measure them in initial testing (if not covered by map-based and power spectrum estimation tools)
- Need to define systems-level things like magnetic & RF shielding, temperature gradients, microphonics, but these are not currently understood well and/or may be able to be modeled with other calculations/simulation tools

# Integration & Commissioning

- Need information on integrated-system effects: microphonics, RF, ground pickup (but see point on MAT slide)
- Focal plane temperature gradients
- Most calibration is outside the scope of I&C, but knowing to what S/N level we need to measure beams, time constants, etc. will still be useful

# Systematics Group

*(Zoomcon:  Fridays, noon eastern, see CMB-S4 calendar)*

- The systematics working group is investigating a broad range of systematics using a combination of map-based and power-spectrum-based tools.  We expect that those analyses will provide valuable insight into which effects would benefit from more detailed timestream-based simulations.

- Systematics are inextricably linked with analysis algorithms, and often drive important choices in those algorithms that have consequences for map sensitivity.  It would be Very Good to probe the algorithms used in DC-2 by applying them to Stage-3 data sets.

# SAT

- Use of actual data
- See bullets from systematics group

# LAT/LATR

- Including more realistic beam sidelobes would be particularly interesting for LATs.
- Example simulations that could be used for the Chilean LATs are included in Gudmundsson et al. 2021 https://arxiv.org/abs/2009.10138
  - Beam spillover and far sidelobes
  - FWHM distributions
  - Ellipticity
  - Crosspol
- It may be challenging to assess the impact of these non-idealities without doing a simple on/off test for the simulations though, which would require a significant investment in this aspect of the simulations.
- Limits on overall gain variation and 1/f noise
- Add in spectrum of vibration to mimic microphonics?

# RFI

- The RFI group has been working on estimates of coupling to satellite constellations, and has identified a few potential areas for further study, potentially eventually in timestream simulations
  - Bright satellites coupling to instrument sidelobes
  - Satellite sidelobes coupling to main beam
  - Satellite signals can be bright (especially at LF) and complex (varying in time, pol.); measurements from radio telescopes in progress
  - LEO satellites will have highly uncertain and variable ephemerides
- RFI group could also help with calculations and empirical values for use in simulating time-varying ground pickup
  - Some satellite sources will be fixed in az/el (and varying in time)

# Instrument Feedback Summary

- Update instrument and observation plans as instrument model evolves
- Updated readout structure for TMUX
- More realism in bandpasses and beams
- Bolometer model with optical loading → stability/non-linearity studies
- Comparison and validation with real data
- Systematics
  - Crosstalk
  - Gain variation, temperature gradients, 1/f noise
  - Ground pickup framework
  - Other systematics prioritized by systematics group
- Understanding required S:N for calibration
- Effects from RFI
- Need more info on system level effects (microphonics, magnetic & RF shielding, ground pickup level), but may be better suited to other tools

# AWG feedback on DC2 plans

What would you like to see included in the DC2 plans?

Are there other components that need to be included in the simulations (e.g. transients)?

Requirements on Nside for the maps?

Are there requirements on the number of splits/realizations you need?

What additional information would you like/need about the plan?

Other thoughts?

# AWG Feedback Slides

Please add ~1 slide/AWG

# Potential Upgrades

- Full simulated bandpasses versus tophats
- Dark detectors
- Hex layout polarization angle patterns
- Pin/slot dead pixels
- Readout structure and mapping
- Detector saturation and non-linearity
- Non-Gaussian Beams
- Systematic position and beam variations across the focal plane from the optics (i.e. moving away from a simple platescale)
- Clocking of individual wafers and optics tubes
- Updated wafer pitches of designed wafers
- Systematic effects and mitigation

# Data Management: Potential thoughts on instrument DC2 plans

- Updates to match baseline design instrument changes (detector counts, wafer pitches, detector layouts, wafer clocking, pin/slot, hex Q/U patterning) and observation strategy
- Update readout structure for TMUX
- Add detector saturation
- More complexity in beams
- Detector non-linearity and gain variation systematic/calibration study
- Time-varying ground pickup framework (with dummy values)
- Other highly-prioritized systematic effects
- Full bandpasses vs. tophats (if useful)
- Distributions of optical properties across focal planes (if useful)

# Feedback on instrument plan

- What does your group think should be prioritized in the instrument model for DC2?
- These do not need to be things included in the current plan→ we want your input to inform our plans
- Systematic/Calibration studies can be smaller runs before DC2 to inform the design and instrument/calibration requirements→ especially good for time-varying/full focal plane effects
- Can also further study things like scan strategy (current strategies are here)