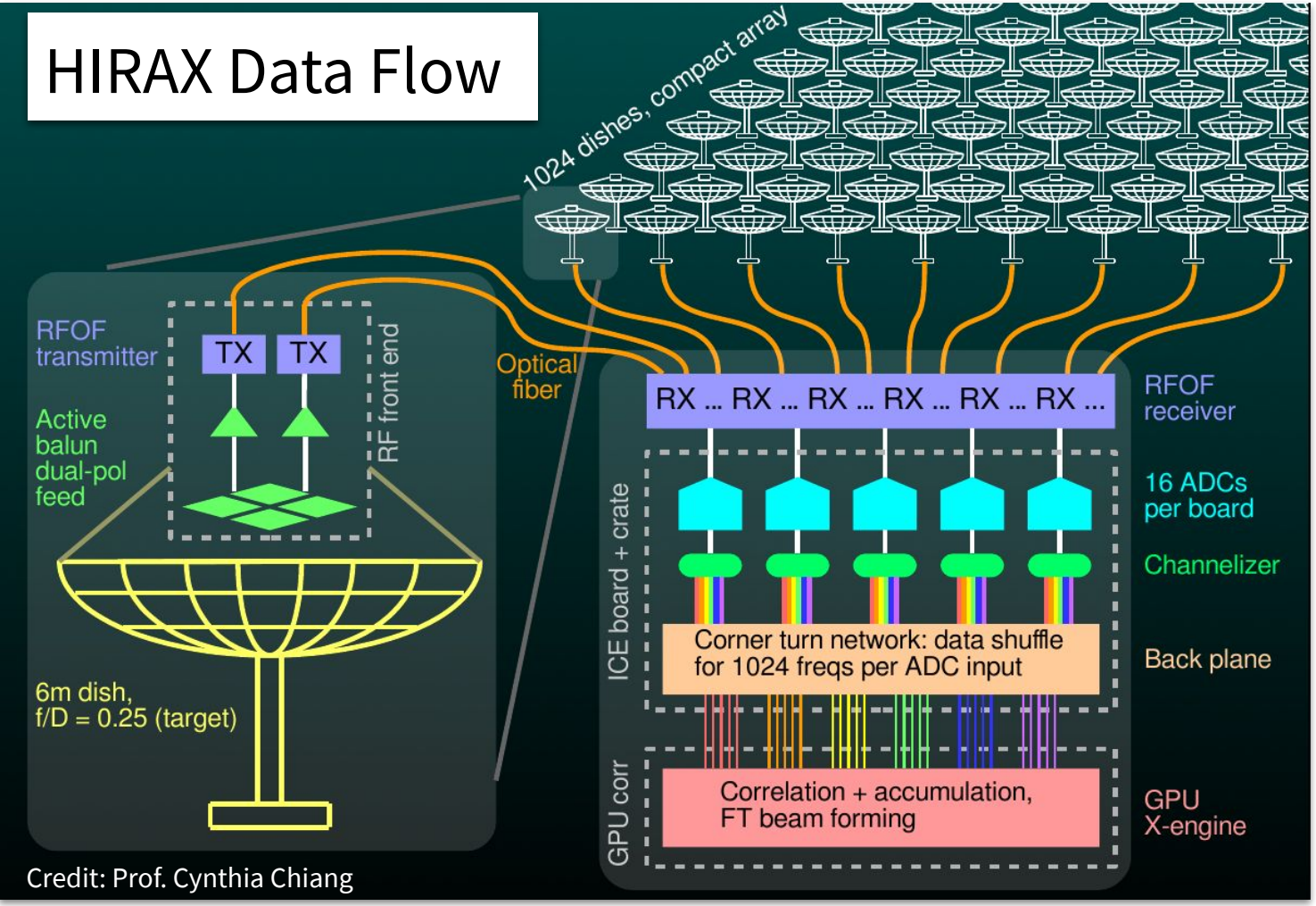
Data Analysis and Systematics

Swiss SKA Days - 08/09/2021

Devin Crichton - ETH Zürich

HIRAX Data Flow



Credit: Prof. Cynthia Chiang

Raw data rate:

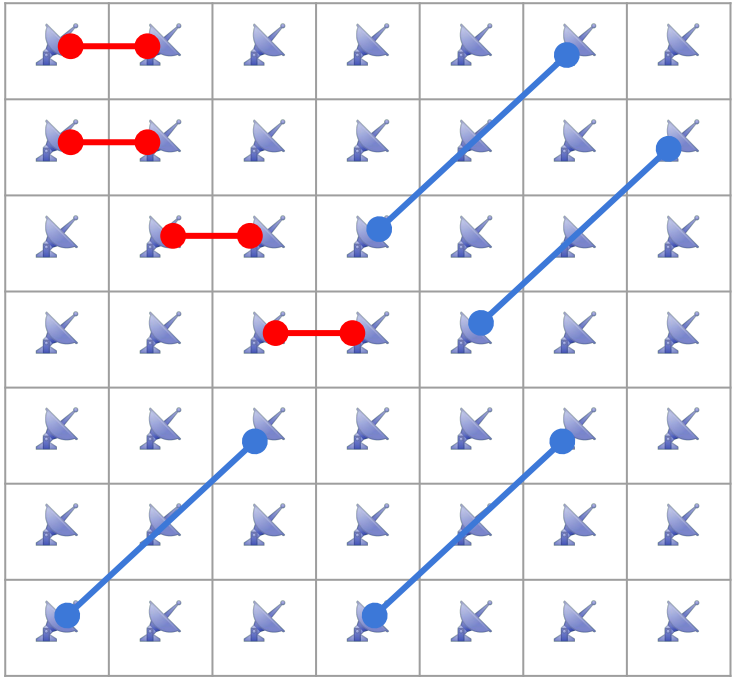
HIRAX-256:
1.6 Tbps
HIRAX-1024:
6.6 Tbps

Post-correlator:

HIRAX-256:
~9 TB/day
HIRAX-1024:
~150 TB / day

Leveraging Redundancy

- Each pair of dishes provides and independent measurement of the same signal on the sky as all other pairs with the same separation
- Regular layout provides significant redundancy in the signals that it measures allowing for significant raw data compressability, by a factor of 100-1000. Less than a ~TB per day after compression in ideal case
- **Requires well calibrated and characterised instrument**



Driftscan analysis - M-mode formalism

For cosmology and map-making, will use m-mode analysis:

- HIRAX does not track sky: fixed elevation pointing for ~weeks at a time
- Linearizes a drift-scan interferometer wrt sph. harmonic (l, m) coeff. on the sky
- **Analysis is separable in m-mode → the time-domain Fourier transform of drift scan visibilities maps to sky modes from single sph. harmonic m.**
- Efficient description of full mapping between the sky and the data as well as their 2-point statistics: tracking statistics of FG vs signal
- Allows use of the standard tools of linear algebra, SVD, filtering etc.

$$\boldsymbol{v} = \mathbf{B}\,\boldsymbol{a} + \boldsymbol{n}.$$

Data	Instrument and sky rotation	Sky
$(\boldsymbol{v}_m)_{(\alpha\nu)}$	$(\mathbf{B}_m)_{(\alpha\nu)(l\nu')}$	$(\boldsymbol{a}_m)_{(l\nu)}$

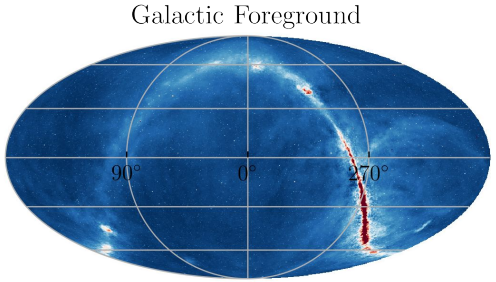
Shaw et al. arXiv: 1302.0327, 1401.2095

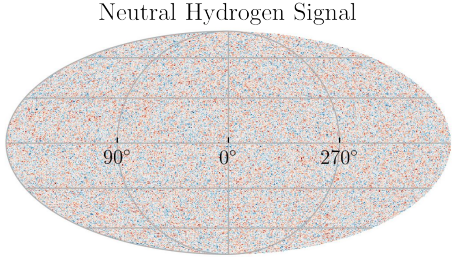
M-mode Analysis

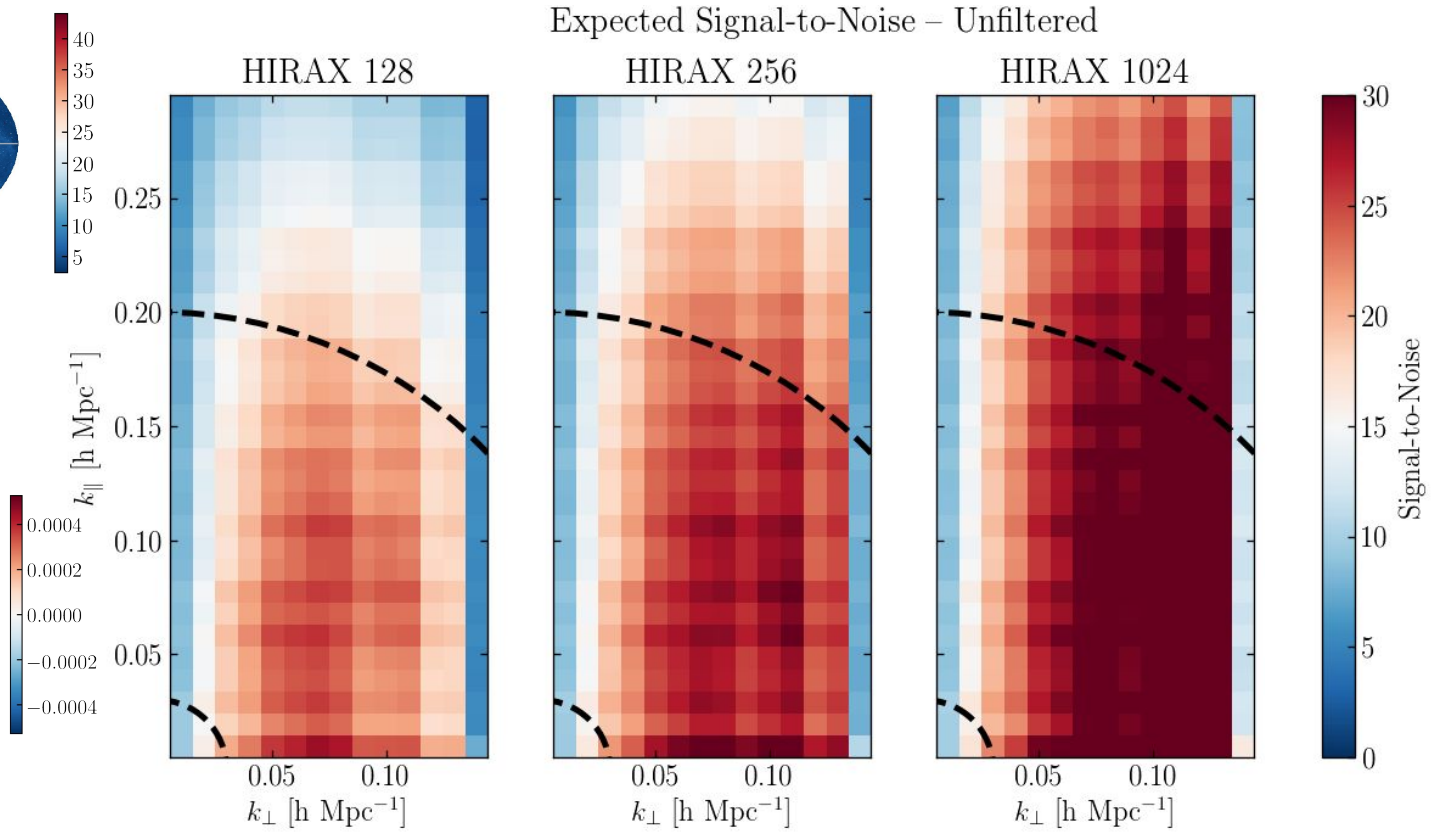
$$(\mathbf{B}_m)_{(\alpha\nu)(l\nu')}$$

- Keeping track of these transfer matrices is a significant computational challenge
- For HIRAX-256, analysing 10 pointings up to l_{max} ~ 1000 in a 100MHz sub-band
  ~ 2000 x [(10^6) x ($2x10^5$)] complex matrices
- Significant sparsity can be found → a single pointing only measures a fraction of the sky, therefore many linear combinations of l,m modes that we are insensitive to. Well suited to SVD based compression
  - Further sparsity can be found if you only want to recover unpolarised sky signals (e.g. for 21cm cosmology)
- Formalism used to simulate visibilities, map-making and quadratic power spectrum estimation with foregrounds filtered based on propagating 2-point statistics (Karhunen–Loève Filter)

Idealised Power Spectrum Forecasts

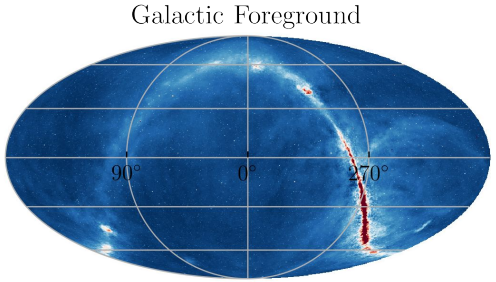


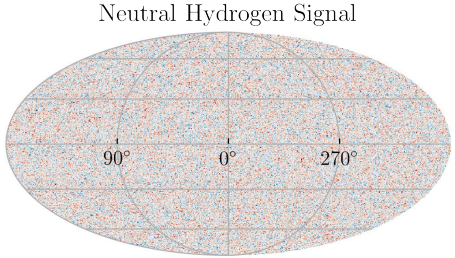


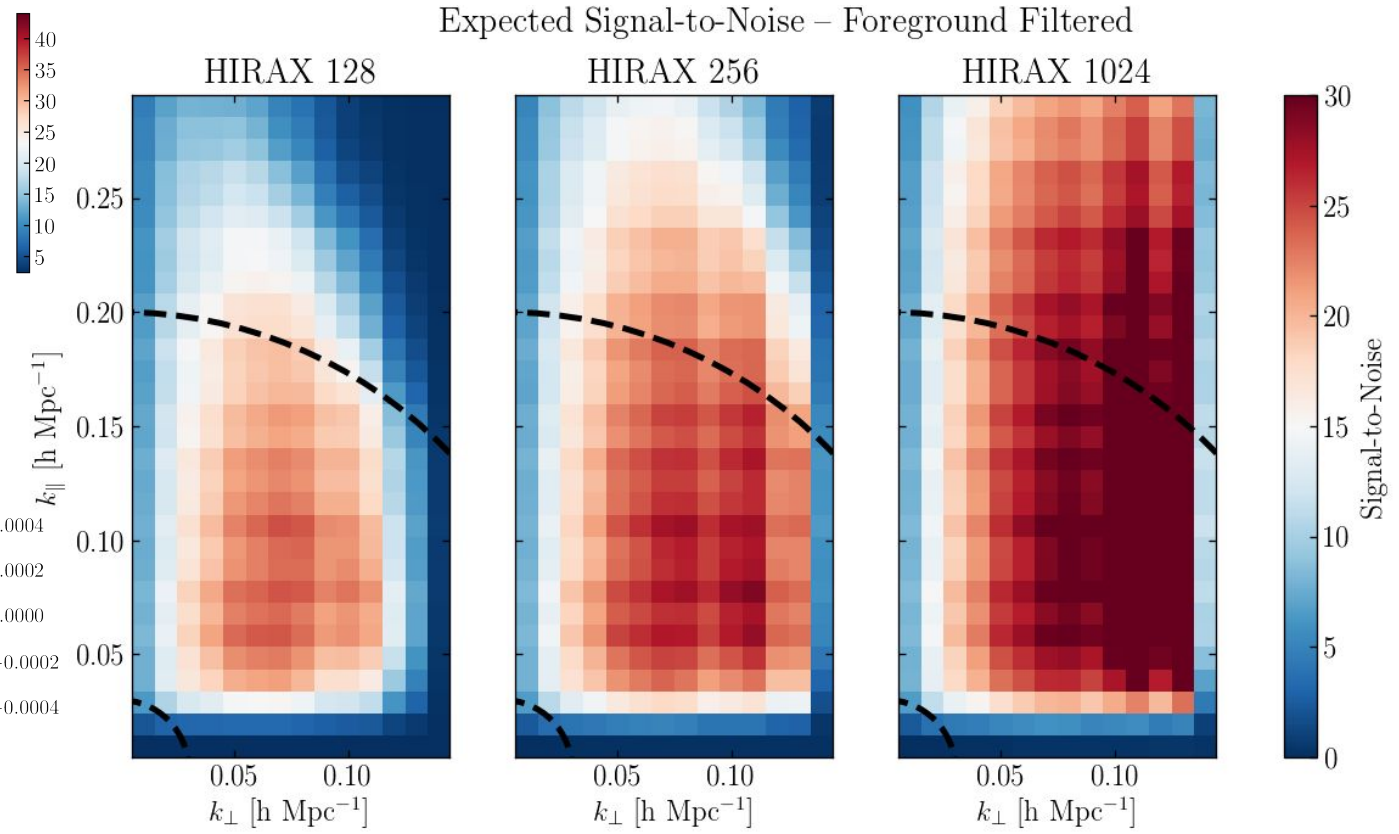


*Core baselines only, 550-650 MHz (¼ full bandwidth), ~6000 deg^2, artificial high resolution cut

Idealised Power Spectrum Forecasts







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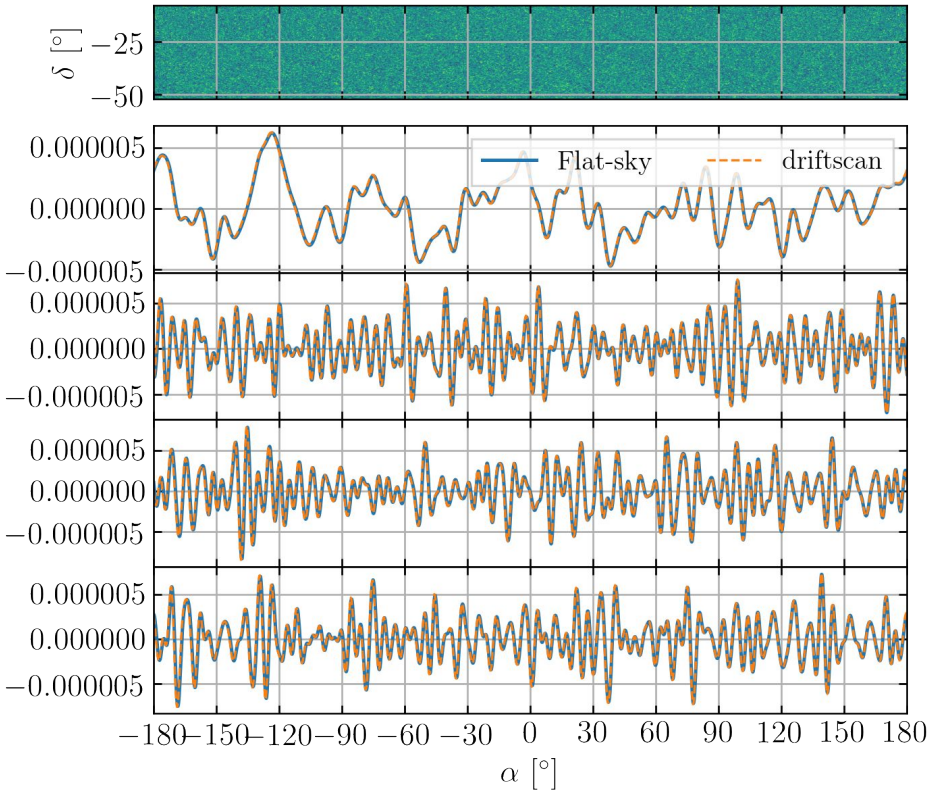
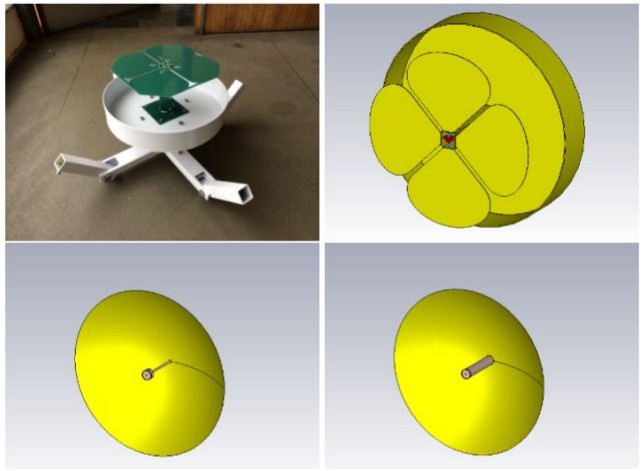
Spherical → Cylindrical Sky

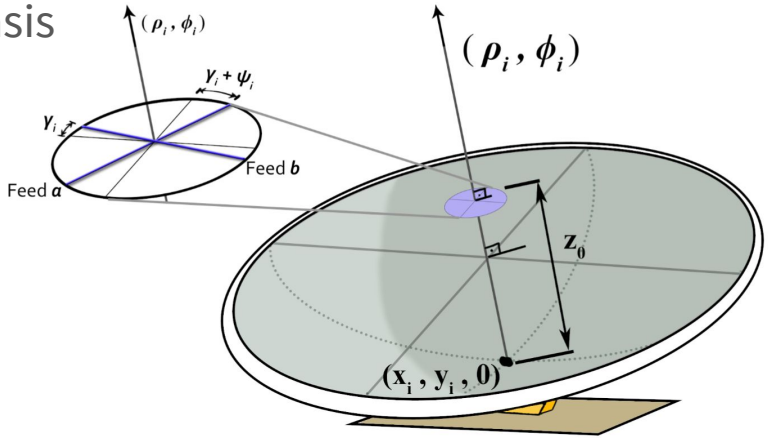
- Similar approach can be developed for cylindrical coordinate system
  - Well matched to ~ few degree strips of declination observed by single pointing of HIRAX
- SHTs → FFTs
- Separable in R.A. aligned Fourier modes (analogous to m-mode)
- Currently still testing accuracy of this for cosmological pipeline but well suited for simulating systematic perturbations



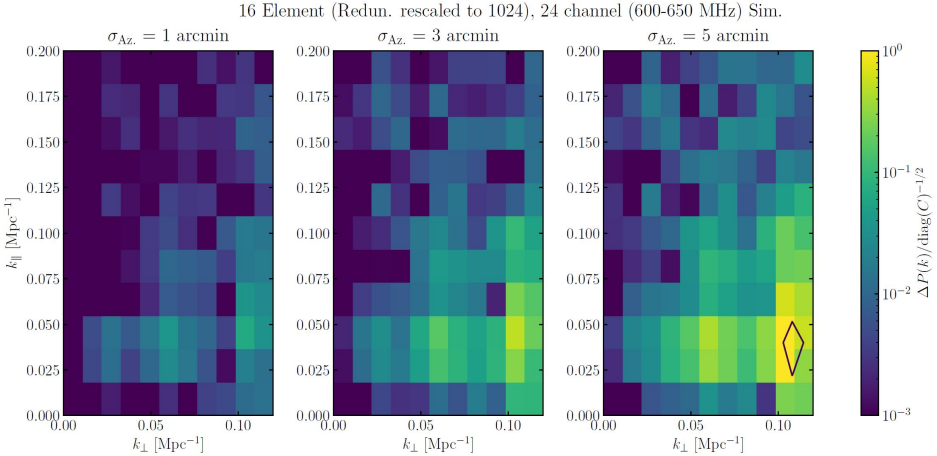
Systematics Analysis

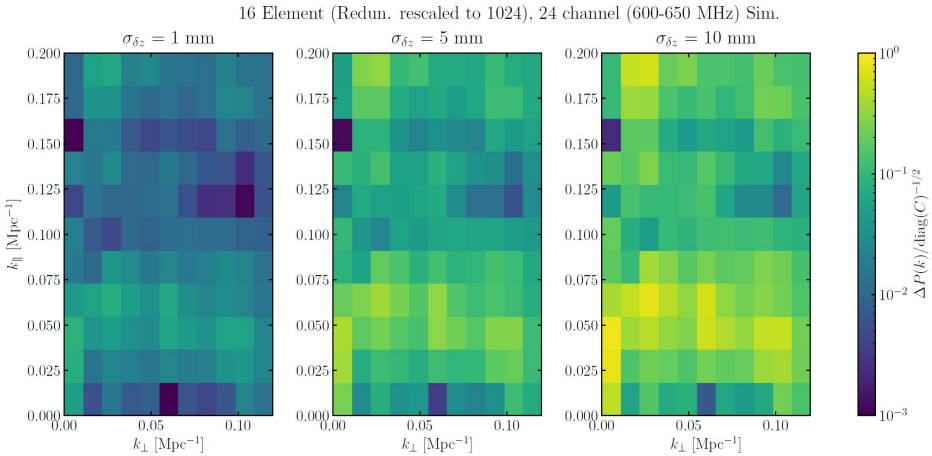
- Modeling primary beam using CST simulations of dish-feed system
- Parameter sweeps in tolerances used for design specification
- Linearised models of perturbations propagated into systematics pipeline on statistical, per feed basis

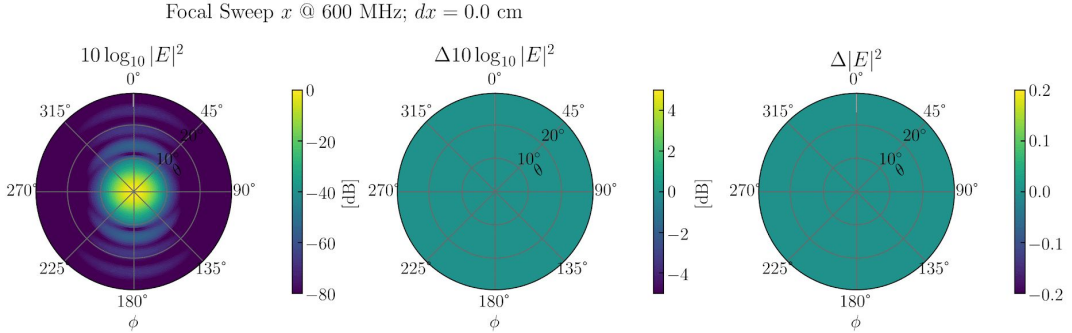




Simulating systematics







Flat-sky simulator allows allows for perturbation on a dish by dish basis

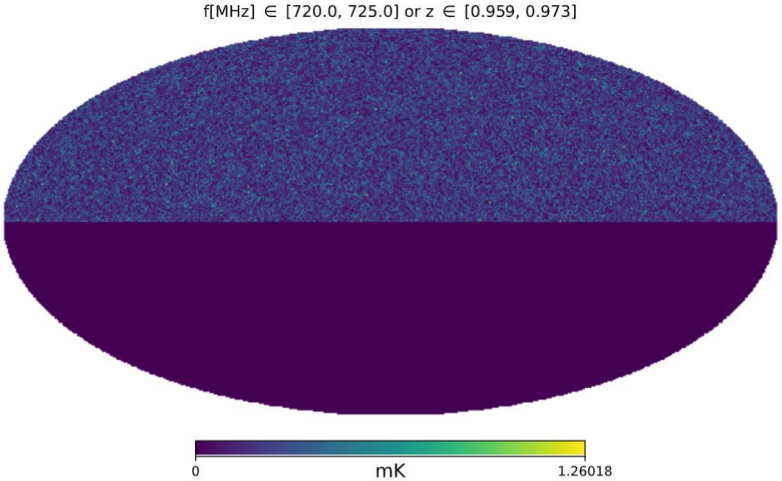
This allows us to evaluate the effect of physical instrument systematics (and their distribution across the entire array) on the extracted power spectra.

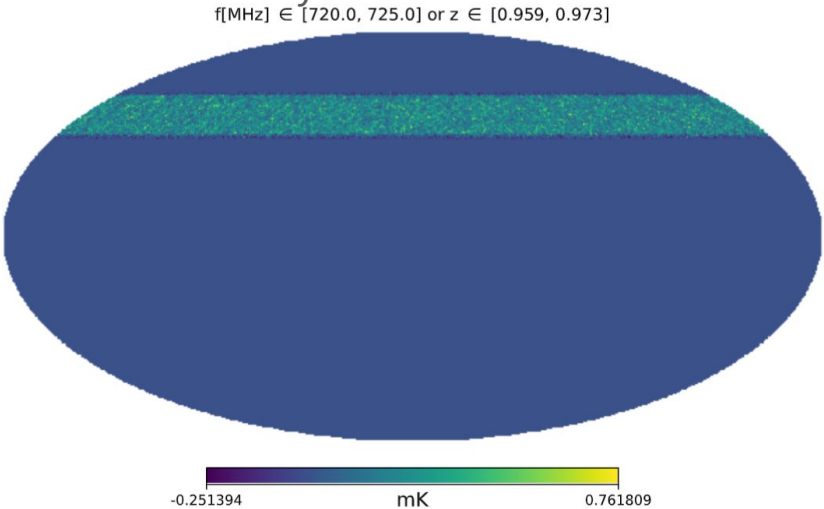
- Future work will involve accounting for models of systematics in power spectrum estimation

Simulated 21cm sky Maps

- Developing 21cm sky simulations suitable for testing cross-correlation
- PINNOCHIO LPT halo-mock catalogs + HI halo model → Simulated sky maps
  - Use empirical halo model from Padmanabhan et al. 2017
- Goal to test cross-correlation analyses with other probes using consistent LSS.

Example of map-making pipeline run on simulated map for HIRAX-like survey





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Thanks!