BoloCalc: a sensitivity calculator for the design of Simons Observatory

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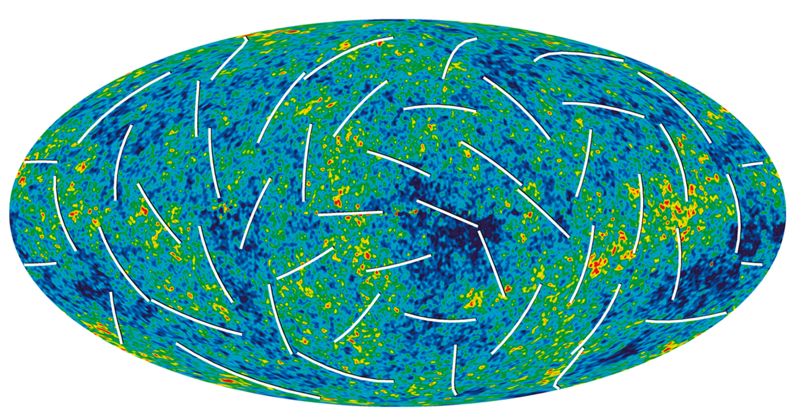
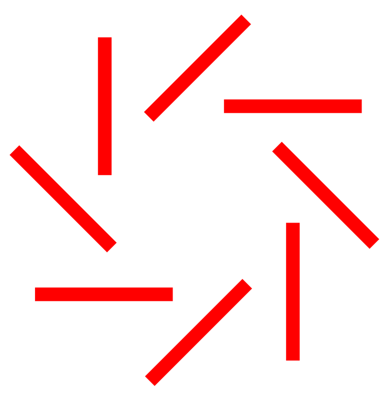
Simons Observatory Science Goals

Cosmic Microwave Background (CMB) Polarization



WMAP

B-modes



- Measure CMB polarization and temperature anisotropies to better constrain cosmological parameters
- Constrain the tensor-to-scalar ratio on large angular scales
- Study secondary distortions such as those generated by gravitational lensing on small angular scales
- Characterize galaxy clusters

Sensitivity Calculator Overview

- Python-based
- Calculates Noise Equivalent Power and Temperature (NEP and NET), detector parameters and optical power

$$\mathrm{NET_{det}} = \frac{\sqrt{\mathrm{NEP_{ph}^2} + \mathrm{NEP_{g}^2} + \mathrm{NEP_{read}^2}}}{\sqrt{2}\,(dP/dT_{\mathrm{CMB}})}$$

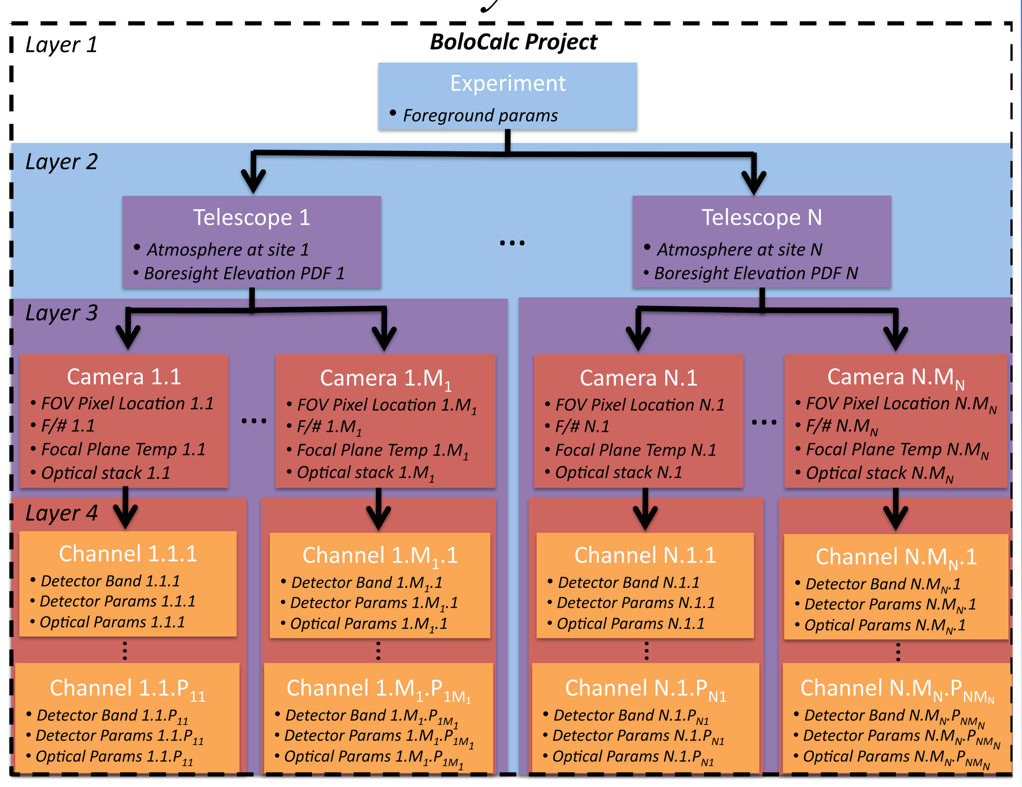
$$\mathrm{NET_{arr}} = \frac{\mathrm{NET_{det}}}{\sqrt{Y\, N_{\mathrm{det}}}}\,\Gamma$$

$$P_{\mathrm{opt}} = \int_{-\infty}^{\infty} \left[\sum_{i=1}^{N_{\mathrm{elem}}} p_i(\nu)\right] B(\nu)\, d\nu$$

N_{det} = number of bolometers, Y = yield, Γ quantifies noise correlations between pixels, $p_i(\nu)$ is the spectrum from optical element i arriving at the detectors, $B(\nu)$ is the detector bandpass.

- NET per detector calculated from photon, thermal, and readout noise, plus factor to convert power fluctuations to CMB temperature units.

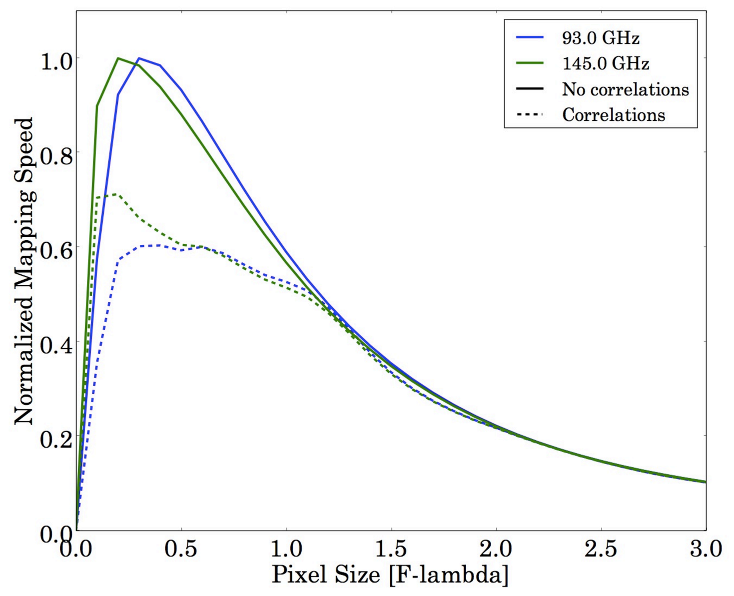
Calculator Layout



4 layers: Experiments, Telescopes, Cameras (Optics Tubes), Channels. N telescopes in each experiment, M cameras in each telescope, P channels in each optics tube.

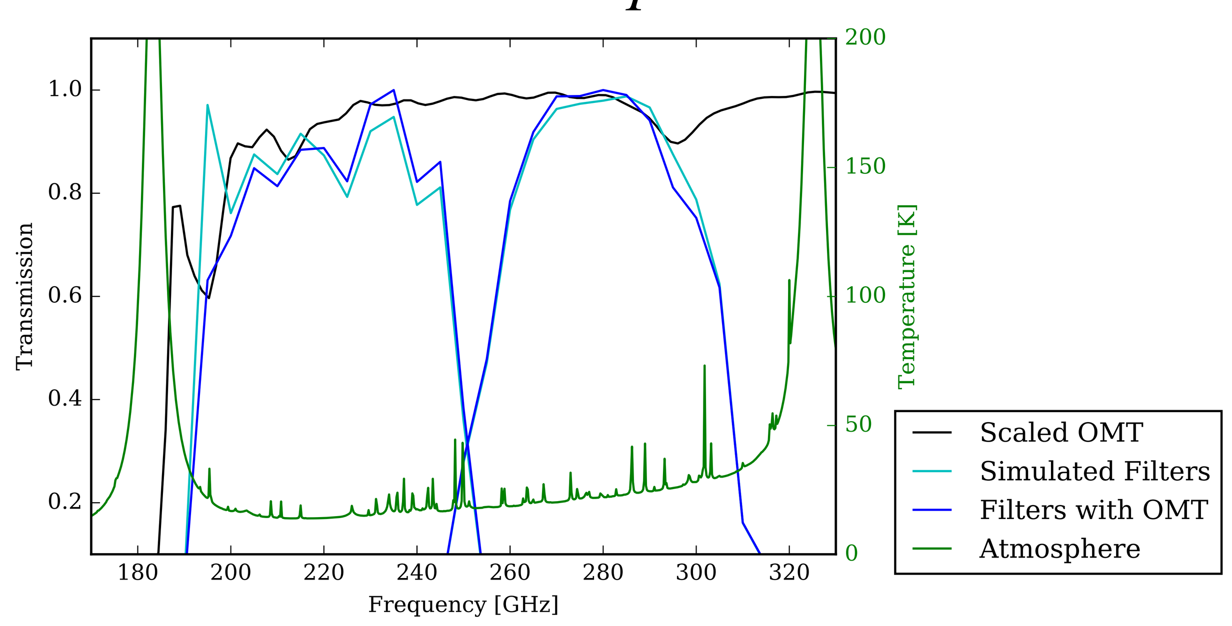
State-of-the-art Features

Correlated Noise



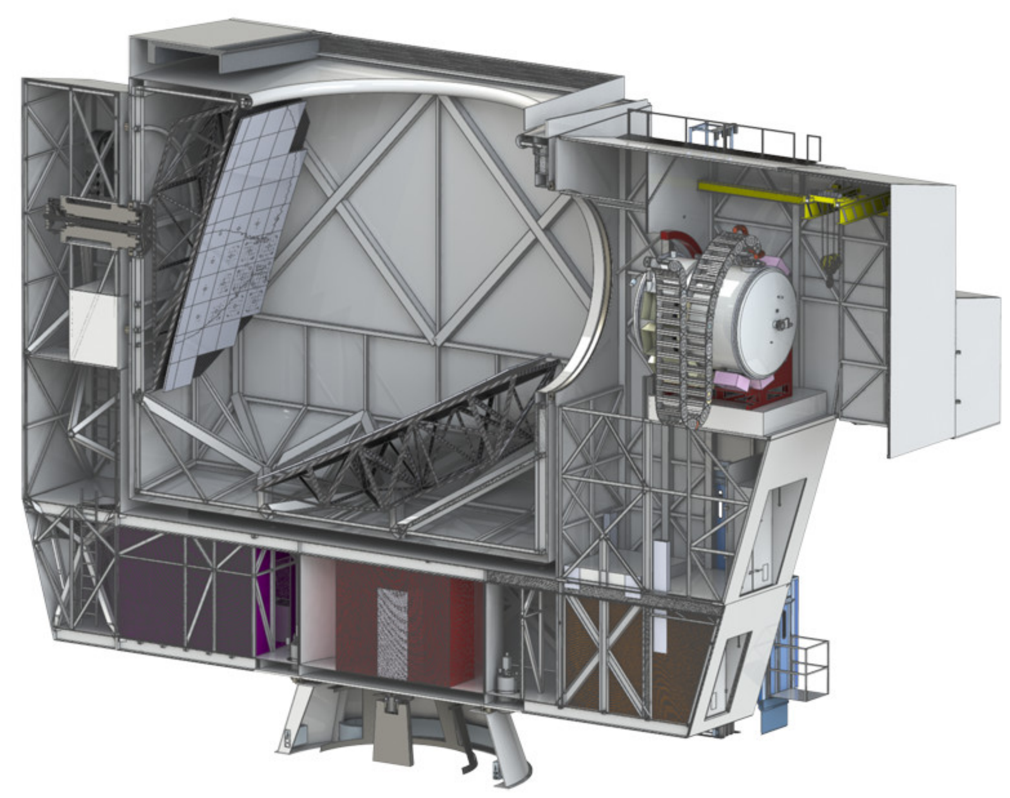
- BoloCalc implements correlated noise
- Close-packed pixels on the focal plane lead to optical white noise correlations between pixels

Realistic Bandpasses



- BoloCalc can implement realistic filter functions
- Useful for optimizing filter parameters
- Has informed design choices for the orthomode transducer (OMT) and the feedhorn waveguide cutoff
- Has been used to select optimal center frequencies and fractional bandwidths of the nominal SO bands.

Simons Observatory Instrument Overview



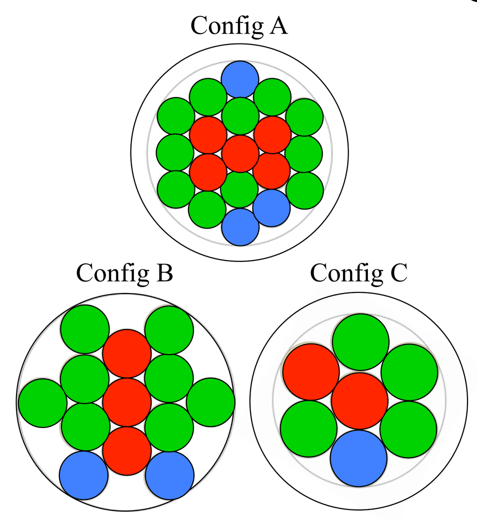
Rendering of the Large Aperture Telescope

- SO will observe temperature and polarization fluctuations in the CMB
- Will be located in the Cerro Toco Observatory in the Atacama Desert, Chile
- Frequency bands between 27 GHz and 270 GHz with most detectors 90/150 GHz dichroic
- Two types of instruments: Large Aperture Telescope (LAT) and array of Small Aperture Telescopes (SATs)
- LAT has a 6m primary reflector imaging a 7.8 degree field of view
- SATs are cryogenic refracting cameras with 0.5m apertures and 35 degree fields of view
- Total of 60,000+ detectors

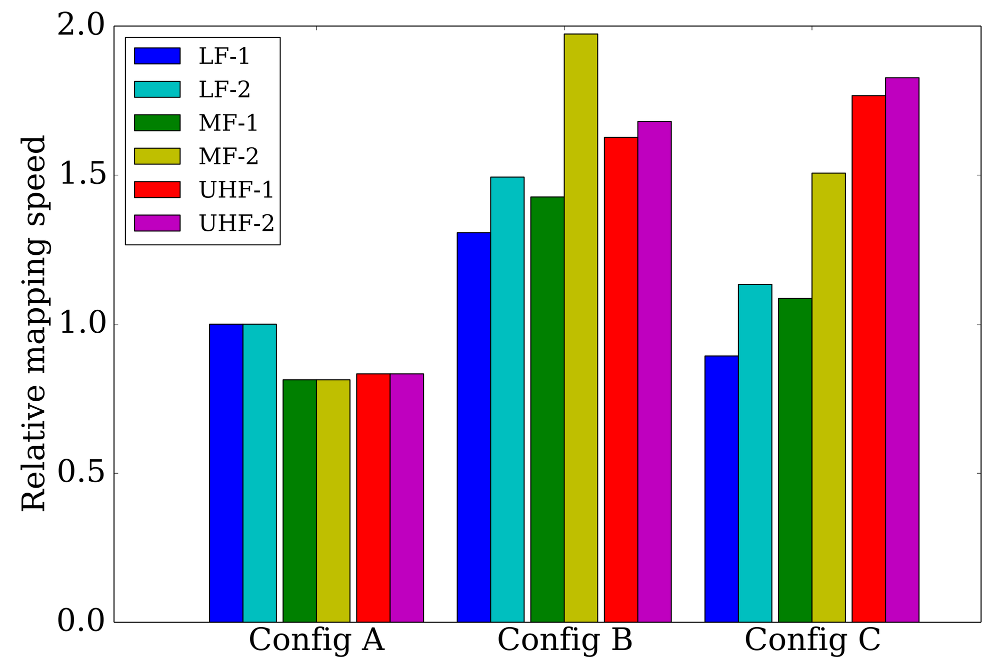
Applications: Informing the Design of SO

LAT Architecture

- BoloCalc helped determine the number of optics tubes on the LAT
- BoloCalc evaluated sensitivity for a study of three different configurations that were considered
- Config B is baselined

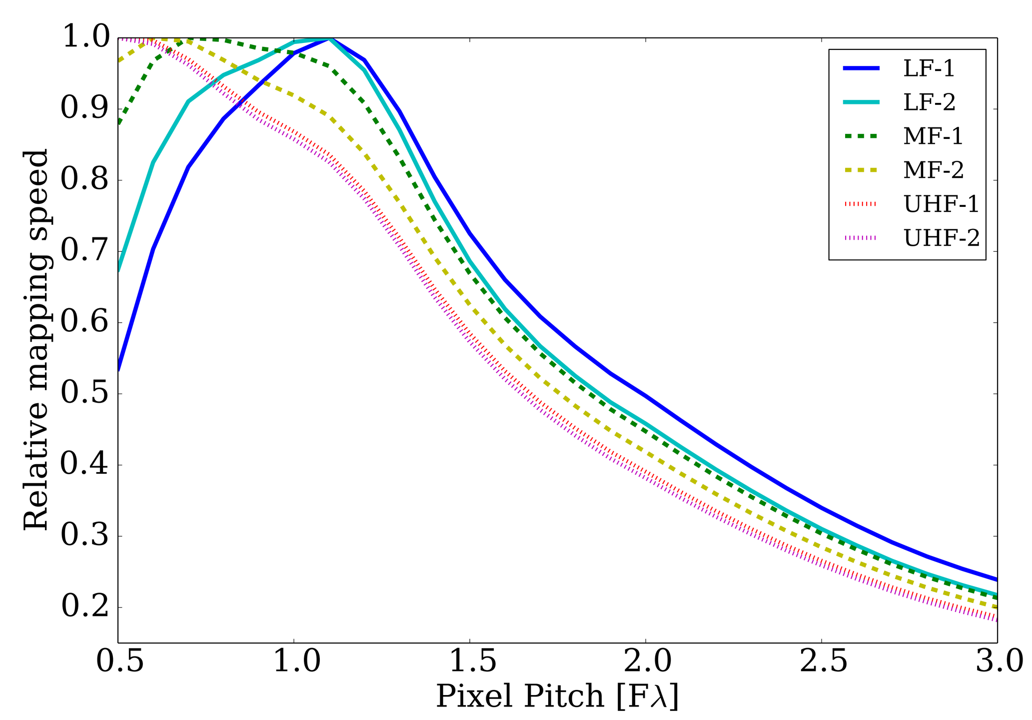


Frequency bands:
LF: 27/39 GHz
MF: 90/150 GHz
UHF: 220/270 GHz



Optimizing Pixel Size

- Optimized sensitivity as a function of pixel pitch in units of Fλ
- Smaller pixels resulted in a higher sensitivity up to a maximum
- As pixel pitch decreased below optimal, sensitivity degraded due to increased pixel-pixel noise correlations.



Moving Forward: Public Access

BoloCalc is available for download as a Python package and is supplemented with a detailed user manual and "quick start" guide. We invite you to download it here: https://github.com/chill90/BoloCalc.git BoloCalc has been a useful tool for SO, and we intend for it to benefit other future CMB experiments, including CMB-S4.

References

N. Galitzski and S. Observatory, "The simons observatory cryogenic cameras," Proceedings of SPIE Astronomical Telescopes + Instrumentation 10708, June 2018.

J. C. Mather, "Bolometer noise: nonequilibrium theory," Applied Optics 21, pp. 1125–1129, Mar. 1982.

J. Zmuidzinas, "Thermal noise and correlations in photon detection," Applied Optics 42, pp. 4989– 5008, Sept. 2003.

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