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Development of Calibration Strategies for the Simons Observatory

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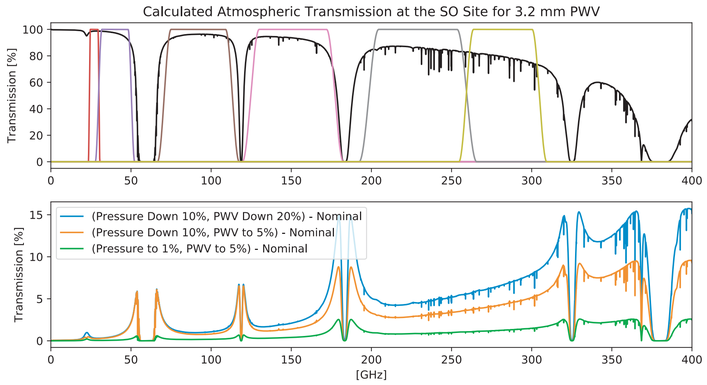
Bandpass Requirements

The spectral shape of each frequency band must be known to reach the Simons Observatory (SO) science goals. Incorrect measurements of the passbands can result in incorrect foreground separation, which contaminates the B-mode signal.

The end-to-end passband has two contributions:
- Instrument passband measured with the FTS
- Time-varying atmospheric transmission



Simulations of the atmospheric transmission at the site show that accurate measurements of the precipitable water vapor (PWV), ground temperature, and ground barometric pressure are needed to know the band centroids to better than the required 0.5% error.

Band Centroid Uncertainty	39 GHz	90 GHz	150 GHz	220 GHz	270 GHz
Pressure to 10%, PWV to 20%	0.075%	0.001%	0.184%	0.026%	0.058%
Pressure to 10%, PWV to 5%	0.074%	0.009%	0.112%	0.018%	0.038%
Pressure to 1%, PWV to 5%	0.008%	0.002%	0.036%	0.005%	0.011%
(Maximum Permissible from Requirements)	0.500%	0.500%	0.500%	0.500%	0.500%

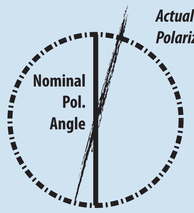
Directly Measuring Atmospheric Transmission

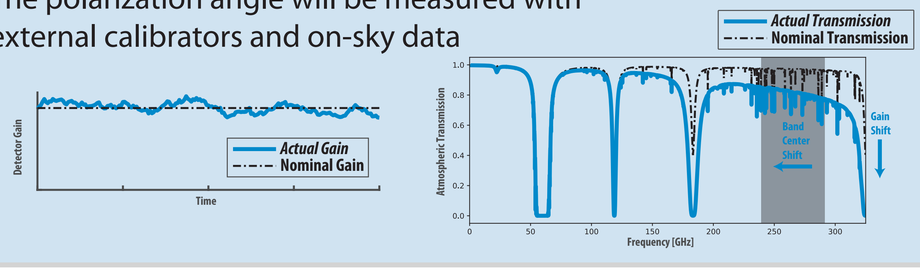
Future experiments like CMB-S4 may require better atmospheric monitoring than SO. Anticipating these future requirements, we have studied a multiband atmospheric sounding radiometer to directly measure the full atmospheric transmission spectrum without relying on modeling or historical weather data.

Unprecedented Sensitivity Requires Better Calibration

Cosmic Microwave Background (CMB) experiments are becoming increasingly sensitive, requiring improved calibration techniques to mitigate systematic effects. We highlight a few of the most important instrument calibrations, their requirements for SO, and the novel experimental calibration techniques we plan to use to mitigate them.

Weather measurements and atmospheric models will yield data to monitor and remove the impact of atmospheric transmission.
Gain drifts will be monitored with external calibrators and detector readout electronics.
The polarization angle will be measured with external calibrators and on-sky data





Radiometer + Weather Station

To measure the PWV and weather, SO will use a 183 GHz atmospheric radiometer and a precise weather station. This data will be used as inputs to the *am* atmospheric model code to calculate the atmospheric transmission spectrum needed for foreground subtraction.

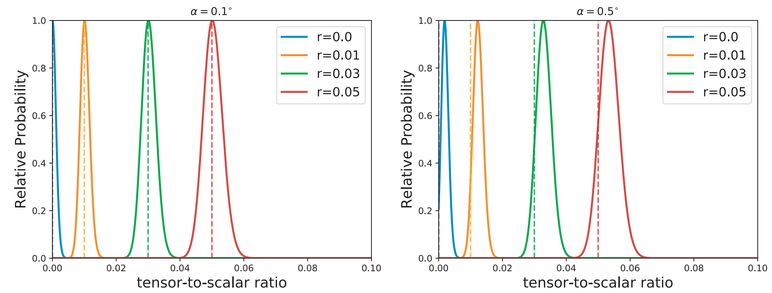
Gain Stability Requirements

Detector responsivity varies due to:
- Atmospheric fluctuations
- Temperature drifts in the instrument
- Intrinsic detector noise
- ...

Our simulations show that the random variation largely averages down, leaving the mean drift across the entire array as the dominant contaminant. This must be continuously measured to ~0.5%.
Bias steps such as those used in SPIDER and ACT, and IV curves will track the detector gain. Atmospheric fluctuations will be monitored with the detector DC level and/or the HWP second harmonic.

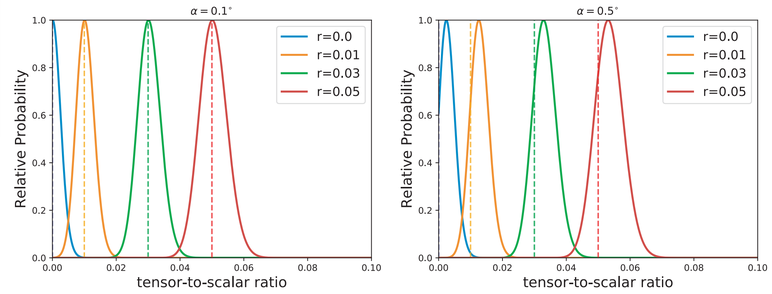
Polarization Angle Requirements

Error in the polarization angle converts E-modes into B-modes, contaminating the B-mode spectra and degrading lensing reconstruction. Driven mostly by the inflation science, for SO the angle error requirement is ~0.1˚, 5-10x stricter than previous experiments.



Bias in *r* from a angle miscalibration of 0.1˚ (left) and 0.5˚ (right) for SO with a pessimistic noise level of 3 μKarcmin with ellknee=50 (top)

and an optimistic noise level of 2 μKarcmin with ellknee=25 (bottom).



SO will achieve this precision in angle calibration through a combination of near-field and far-field calibration sources, drone or balloon flights with sources, and on-sky measurements.

Conclusions

The calibration technologies and analyses developed for SO will represent a critical step toward the next generation of CMB experiments like CMB-S4.

Selected References

- Ward, et al., "The Effects of Bandpass Variations on Foreground Removal Forecasts for Future CMB Experiments," Submitted to ApJ, arxiv/1803.07630 (2018).
- Aumont, J. et al.., "Absolute calibration of the polarisation angle for future CMB B-mode experiments from current and future measurements of the Crab nebula," ArXiv e-prints (May 2018).
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