Updates from Simons Observatory (SO)

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Overview

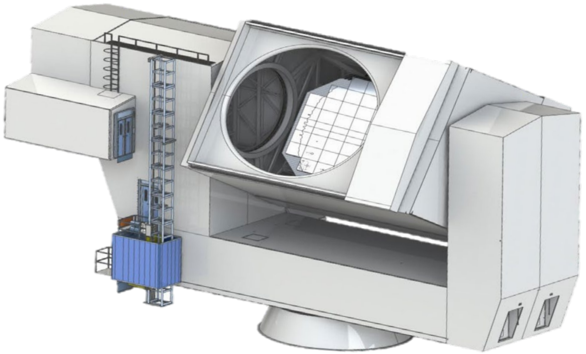
- Simons Observatory (SO) Introduction
- SO on-site updates
  - Large Aperture Telescope and Receiver (LAT/LATR)
  - Small Aperture Telescopes (SATs)
- SO pipeline updates
- SO Timeline and what’s next

Simons Observatory (SO)

- Atop Cerro Toco, Atacama Desert, Chile
  - 5200m above sea-level!
- Site as of 10/2023

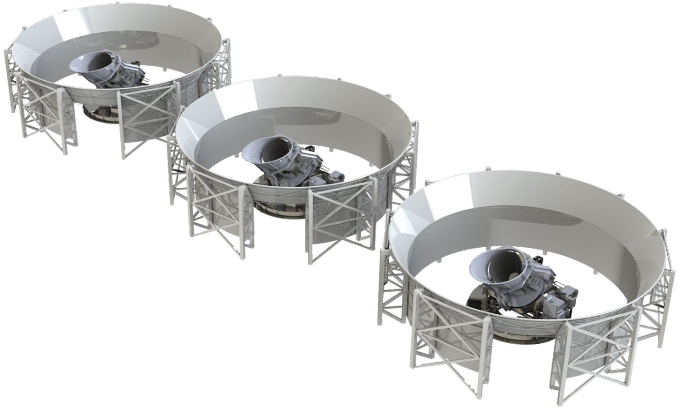
SO Telescopes

Large Aperture Telescope (LAT)



- 6m crossed-dragone telescope
- Large area scan strategy with high resolution (~arc minute)
- 6 frequency bands: (27, 39, 90, 150, 220, 280) GHz
- 30k TES detectors

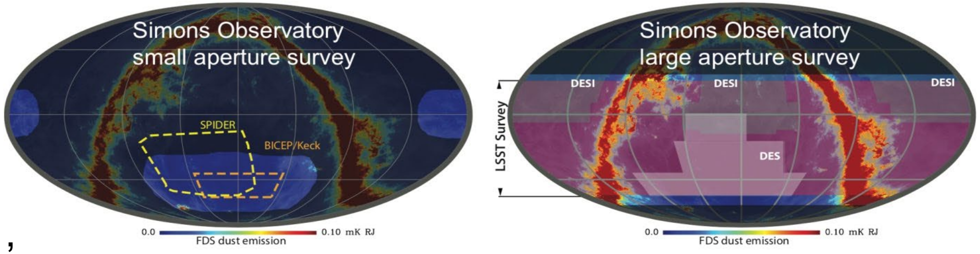
3x Small Aperture Telescopes (SATs)



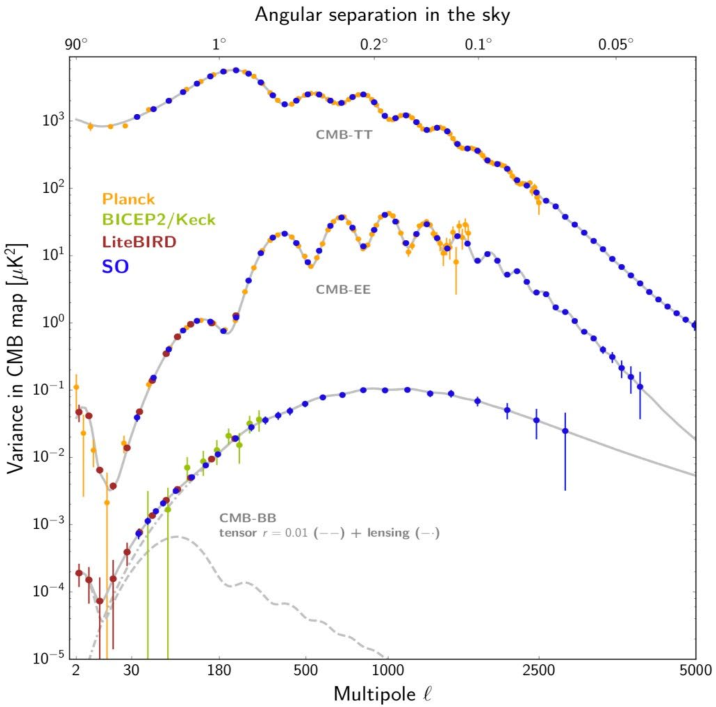
- Refractive telescopes with 42cm aperture
- Deep scan with ~degree resolution
- 6 frequency bands, same as LAT
  - Split amongst 3 SATs
- 30k TES detectors total

Overview of SO

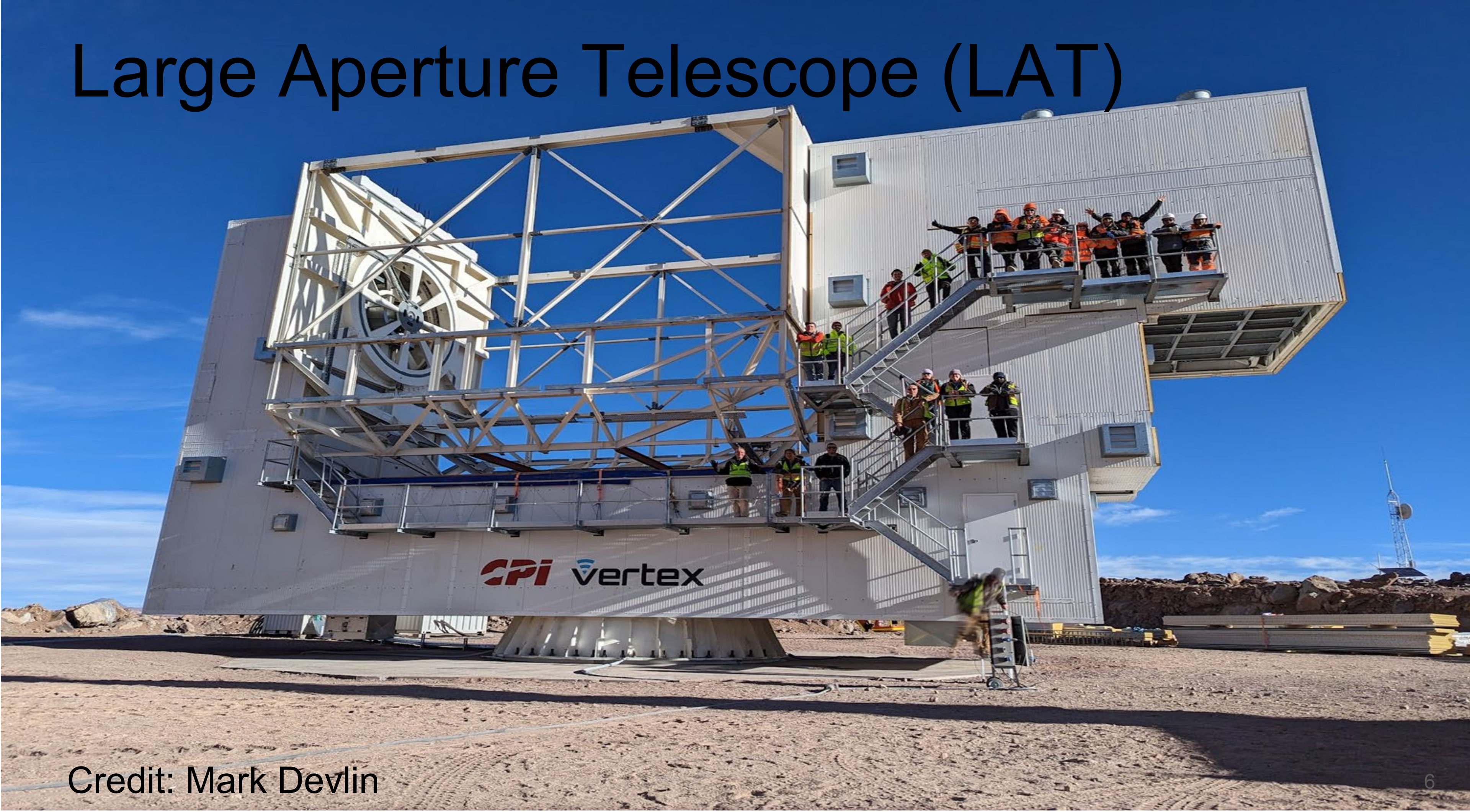
[SO Website](#)



- Studies anisotropies in CMB
  - Science Goals:
    - Primordial B-modes, with tensor-to-scalar ratio, $r < 0.01$, $\sigma(r) < 0.003$
    - Neutrino Mass Hierarchy, Neff, + many others! [(SO forecast paper)](#)
- Nominally 4 telescopes sensitive to 6 frequency bands to observe extremely faint signal and to remove sources of galactic noise
  - LAT focuses on high ℓ science
  - 3x SATs focus on primordial B-modes (low ℓ)



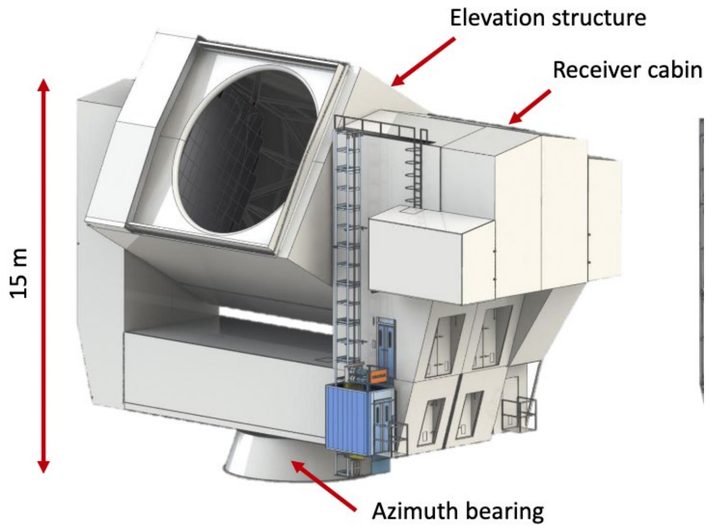
Large Aperture Telescope (LAT)



Credit: Mark Devlin

Large Aperture Telescope (LAT)

- Platform on site 06/2023
- Cryogenic Receiver installed 08/2023
  - Dark Tests performed last quarter of 2023
  - 2/7 optics tubes installed
- Mirrors to be installed midway through 2024
  - 7/7 optics tubes installed by 02/2024



Credit: Gakitzki SPIE 2018

Small Aperture Telescope - Middle Frequency 1, 2 and Ultra High Frequency (SAT-MF1, MF2, UHF)

Credit: Sam Day-Weiss

Credit: Adrian Lee

SAT-MF1

- Finished in-lab testing at UCSD
- Installed on Platform (08/2023)
- On-sky testing on-going

SAT-MF2

- Finished in-lab testing at Princeton
- Installed on Platform (11/2023)
- Preparing for on-sky tests

Credit: Sam Day-Weiss

SAT-UHF

- Finished in-lab testing at Berkeley
- Shipped to Chile (12/2023)
- Begin unpacking and installation on platform
  - First quarter of 2024

Credits: Adrian Lee and Michael Randall

SO Pipeline Status

- SO makes use of multiple publicly available data processing pipelines
    - so-lenspipe, BBPower
- Large-scale B-mode signal pipeline validated using recent instrument data

The Simons Observatory: pipeline comparison and validation for large-scale B-modes

Kevin Wolz[1,2 ⋆], Susanna Azzoni[3,4], Carlos Hervías-Caimapo[5,6], Josquin Errard[7], Nicoletta Krachmalnicoff[1,2,8], David Alonso[3], Carlo Baccigalupi[1,2,8], Antón Baleato Lizancos[9,10], Michael L. Brown[11], Erminia Calabrese[12], Jens Chluba[11], Jo Dunkley[17,18], Giulio Fabbian[12,13], Nicholas Galitzki[14], Baptiste Jost[7,15], Magdy Morshed[7], and Federico Nati[16]

- LAT pipelines are being developed and tested on ACT data
    - DR6 Gravitational Lensing Map and Cosmological Parameters
    - Mitigating the impact of extragalactic foregrounds for the DR6 CMB lensing analysis

Future of SO

- SO:UK (United Kingdom), SO:JP (Japan)
  - 3 additional SATs (2x United Kingdom, 1x Japan)
  - 30k additional detectors
- Advanced SO (ASO)
  - Fully populate LAT Receiver with 6 additional optics tubes and 30k additional detectors
  - Additional 5 year observation time
  - Infrastructure upgrades to increase power efficiency via photovoltaic array

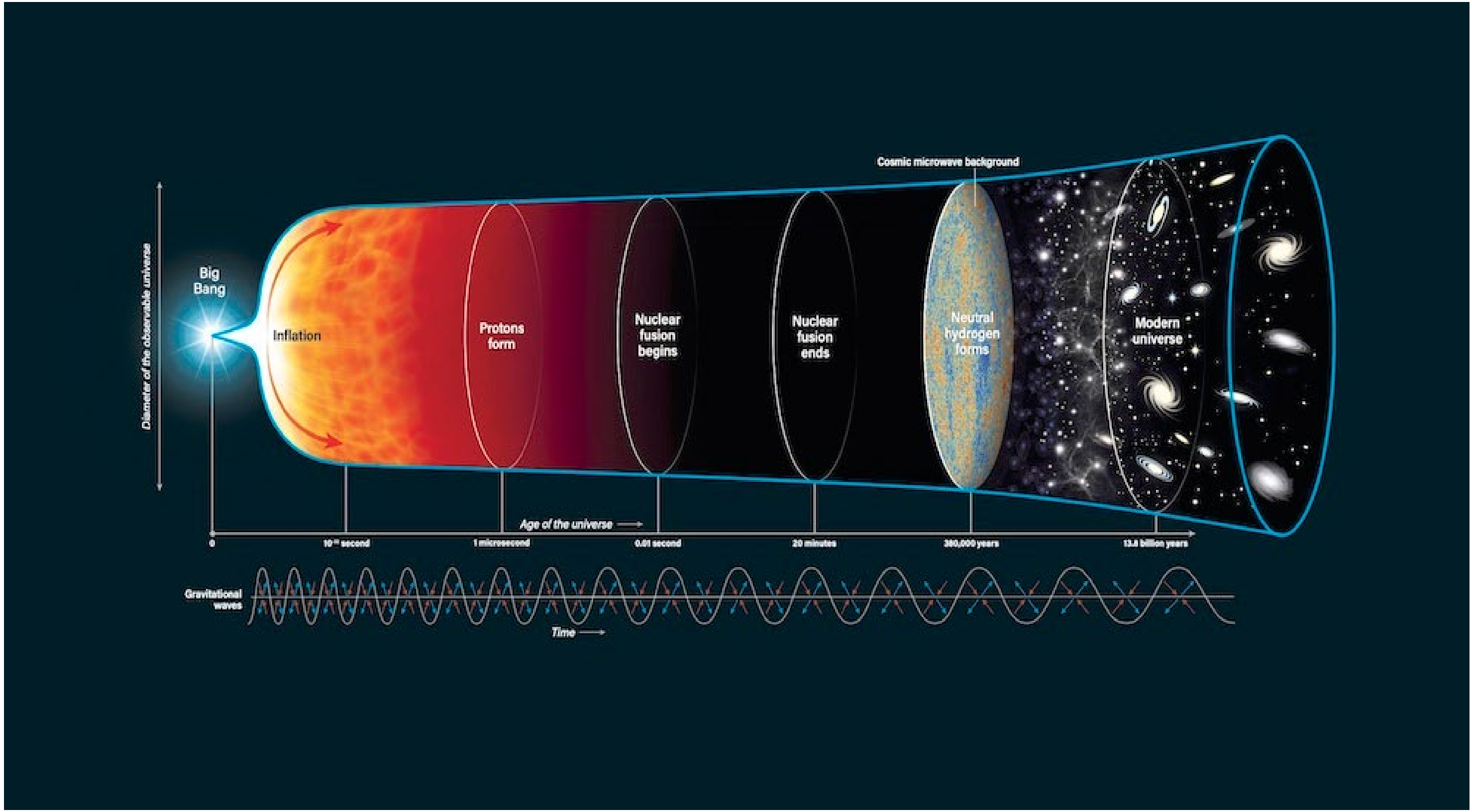
Credit: Benjamin Beringue

End

Extras

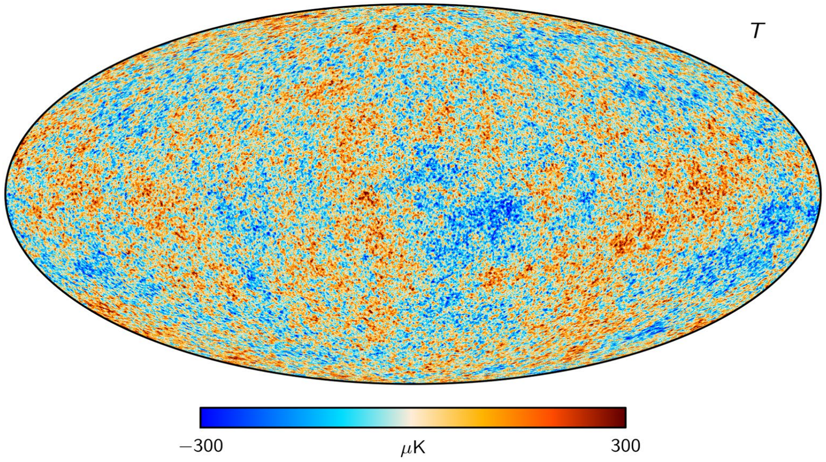
(Quick) History of the Universe

- Density perturbations in very early universe are *inflated* to cosmic scales
- These seed cosmic structure we see today
- Density perturbations imprinted in the cosmic microwave background (CMB)

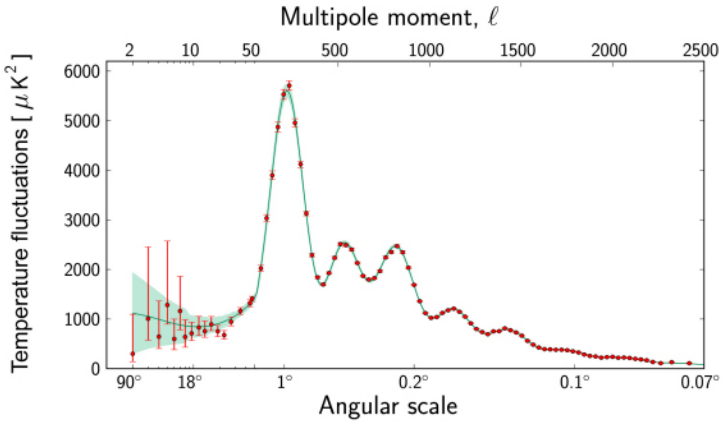


Information from the CMB

- CMB is mostly uniform in temperature, but there are anisotropies. ***Why?***
- Theory of inflation:
  - Temperature anisotropies caused by density perturbations
  - Polarization anisotropies as well!
- Study the CMB *statistics* via power spectra
  - In frequency and angular distance spaces



Credit: Planck Legacy Archive



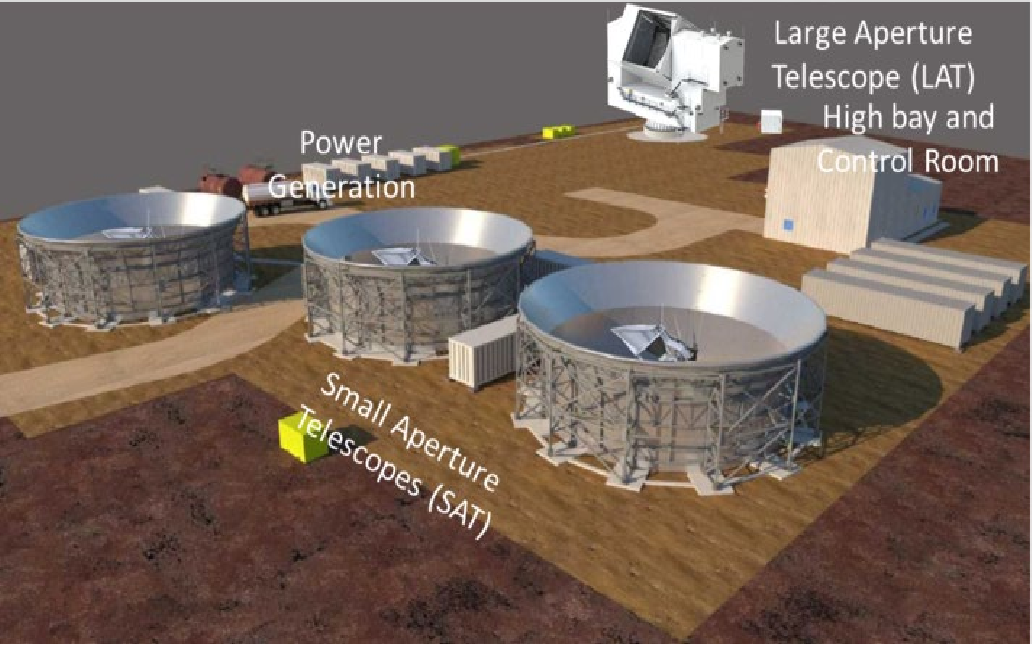
Credit Planck Legacy Archive

SO-Nominal Key Science Goals

	Current[b]	SO-Nominal (2022-27)		Method[d]
		Baseline	Goal	
Primordial perturbations (§2.1)				
r ($A_L = 0.5$)	0.03	0.003	0.002[e]	BB + external delensing
n_s	0.004	0.002	0.002	TT/TE/EE
$e^{-2\tau}\mathcal{P}(k = 0.2/\mathrm{Mpc})$	3%	0.5%	0.4%	TT/TE/EE
$f_{\rm NL}^{\rm local}$	5	3	1	$\kappa\kappa \times$ LSST-LSS
		2	1	kSZ + LSST-LSS
Relativistic species (§2.2)				
$N_{\rm eff}$	0.2	0.07	0.05	TT/TE/EE + $\kappa\kappa$
Neutrino mass (§2.3)				
Σm_ν (eV, $\sigma(\tau) = 0.01$)	0.1	0.04	0.03	$\kappa\kappa$ + DESI-BAO
		0.04	0.03	tSZ-N $\times$ LSST-WL
Σm_ν (eV, $\sigma(\tau) = 0.002$)		0.03[f]	0.02	$\kappa\kappa$ + DESI-BAO + LB
		0.03	0.02	tSZ-N $\times$ LSST-WL + LB
Beyond standard model (§2.4)				
$\sigma_8(z = 1 - 2)$	7%	2%	1%	$\kappa\kappa$ + LSST-LSS
		2%	1%	tSZ-N $\times$ LSST-WL
H_0 (ΛCDM)	0.5	0.4	0.3	TT/TE/EE + $\kappa\kappa$
Galaxy evolution (§2.5)				
$\eta_{\rm feedback}$	50-100%	3%	2%	kSZ + tSZ + DESI
$p_{\rm nt}$	50-100%	8%	5%	kSZ + tSZ + DESI
Reionization (§2.6)				
Δz	1.4	0.4	0.3	TT (kSZ)

From Astro2020 talk (A. Lee, S. Staggs)

Render of site to Current site status



From Mark Devlin; SO

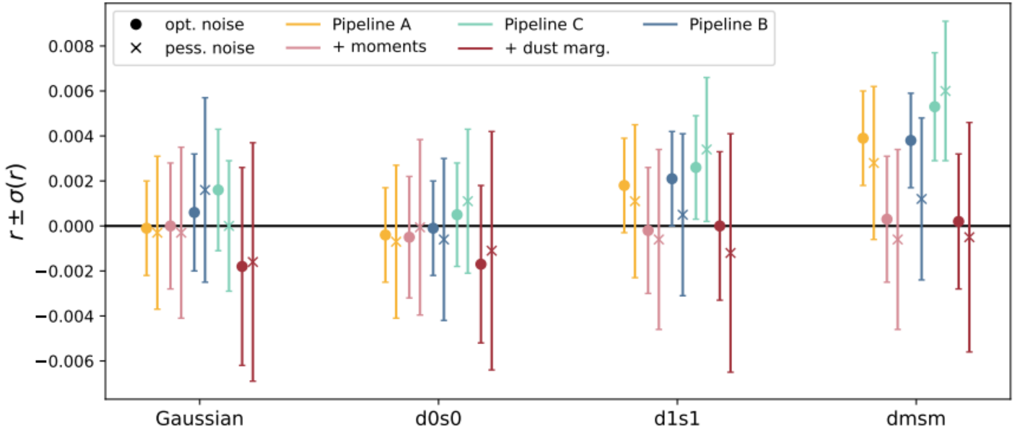
Advanced Simons Observatory (ASO)

- Doubles mapping speed and increases number of detectors
  - Fully populate LAT Receiver (from 7/13 to 13/13 Optics Tubes, additional 30k detectors)
- Adds 5 years of observations

	SO-Nominal (Goal)	SO-Enhanced (Goal)
Lensing and SZ (LAT)		
Minimal neutrino mass detection (Σm_ν=0.06 eV)[a]	3σ	4σ
Lensing detection (polarization-only)	160σ (110σ)	220σ (180σ)
Number of SZ clusters	20000	33000
Kinematic SZ detection (DESI cross-correlation)	190σ	240σ
Measurement of Optical Depth from kSZ, $\sigma(\tau)$ [b]	0.007	0.003
Primordial polarization (SATs)		
Tensor-to-scalar ratio	$\sigma(r) = 0.002$	$\sigma(r) = 0.001$[c]

SO Pipeline Status

- Validated analysis pipeline for B-mode search based on SAT instrumentation data



[SO large scale B-mode pipeline validation paper]

- LAT data analysis pipelines have been tested on recent ACT data release (DR6)