The Simons Observatory: next-generation CMB telescopes and science goals

Serena Giardiello, Cardiff University

Cosmology 2023 in Miramare, 28/08/2023

The Simons Observatory Collaboration

SIMONS FOUNDATION

HEISING-SIMONS FOUNDATION

2022 SO Collaboration meeting, San Diego

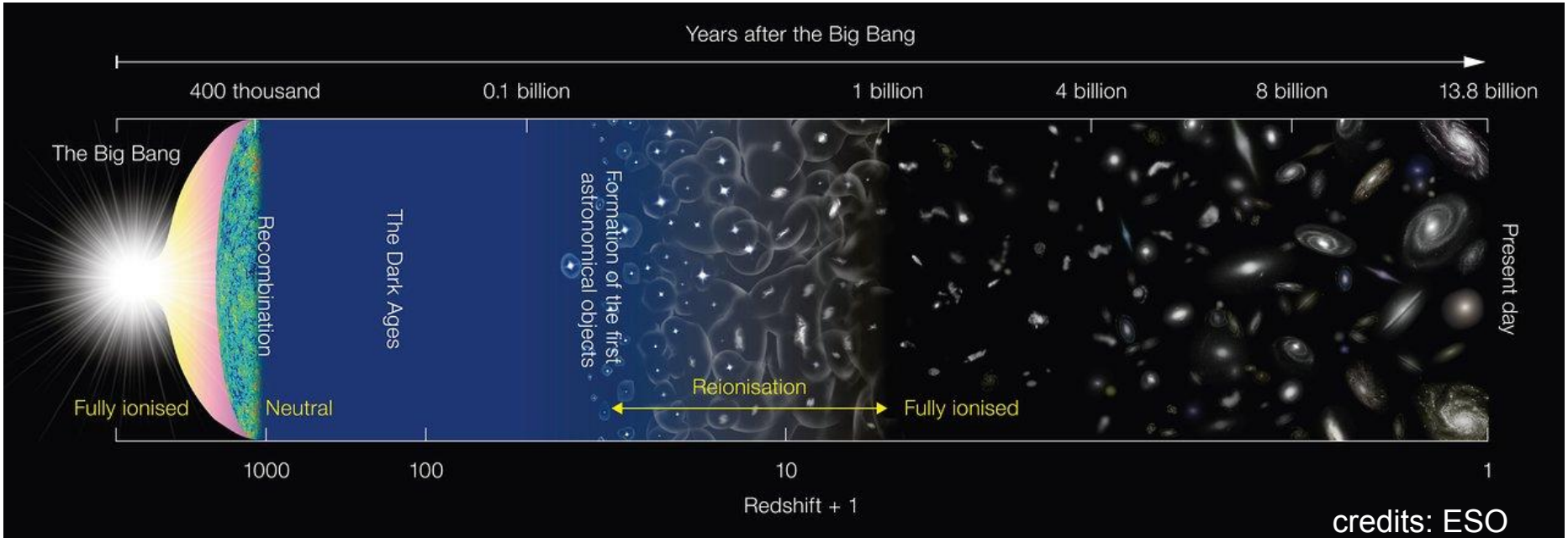
PARQUE ASTRONÓMICO ATACAMA, CHILE
SIMONS OBSERVATORY
22°57' S, 67°47' W
ELEVATION: 5190m
www.simonsobservatory.org

Construction of nominal project is funded privately and is fully under way.
300+ collaborators
40+ institutions
10 countries

The science goals of SO

SO is a next-generation, ground-based **cosmic microwave background (CMB)** experiment designed to provide breakthrough discoveries in fundamental physics, cosmology, and astrophysics. Now built in the Atacama desert. **First data in 2024!**

CMB radiation produced in the early Universe, affected by its propagation through evolving structures



The science goals of SO

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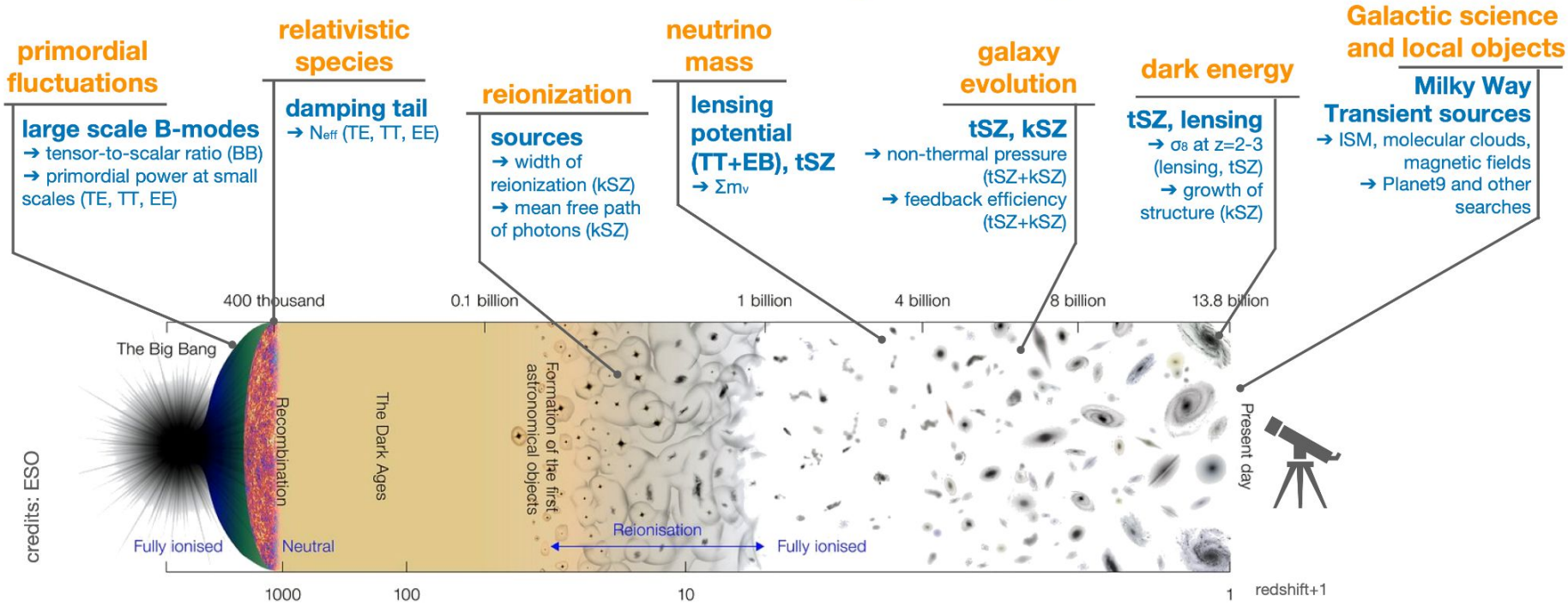
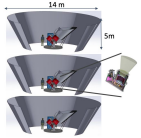


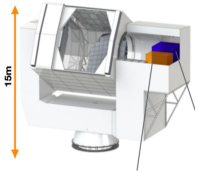
credits: J. Errard

The science goals of SO

Small Aperture Telescopes (SATs)



Large Aperture Telescope (LAT)



primordial fluctuations

large scale B-modes
➔ tensor-to-scalar ratio (BB)
➔ primordial power at small scales (TE, TT, EE)

relativistic species

damping tail
➔ N_{eff} (TE, TT, EE)

reionization

sources
➔ width of reionization (kSZ)
➔ mean free path of photons (kSZ)

neutrino mass

lensing potential (TT+EB), tSZ
➔ Σm_ν

galaxy evolution

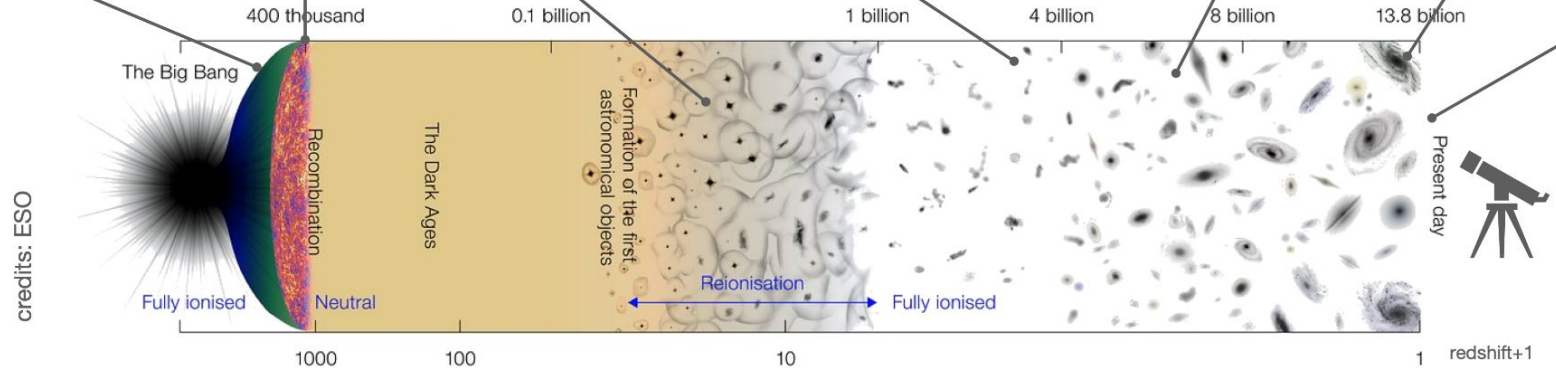
tSZ, kSZ
➔ non-thermal pressure (tSZ+kSZ)
➔ feedback efficiency (tSZ+kSZ)

dark energy

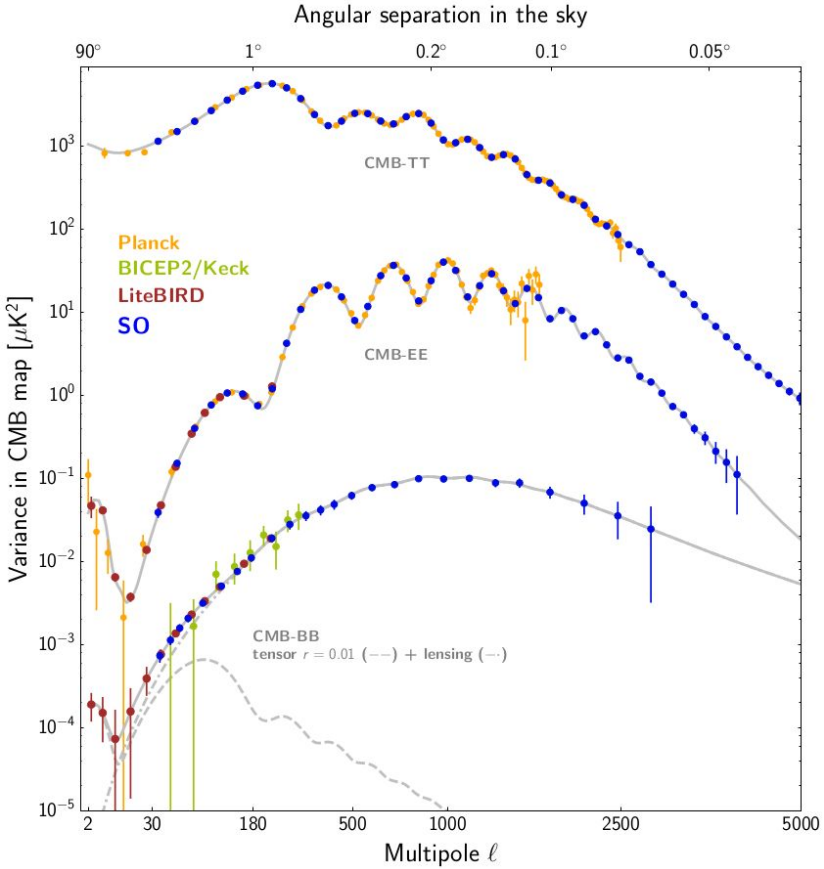
tSZ, lensing
➔ σ_8 at z=2-3 (lensing, tSZ)
➔ growth of structure (kSZ)

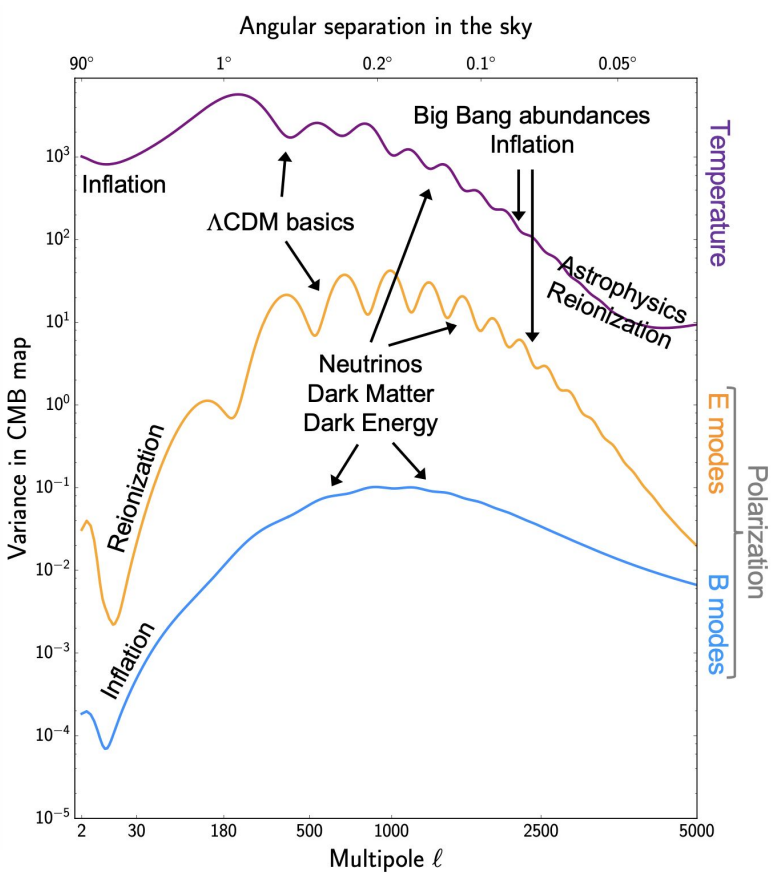
Galactic science and local objects

Milky Way Transient sources
➔ ISM, molecular clouds, magnetic fields
➔ Planet9 and other searches



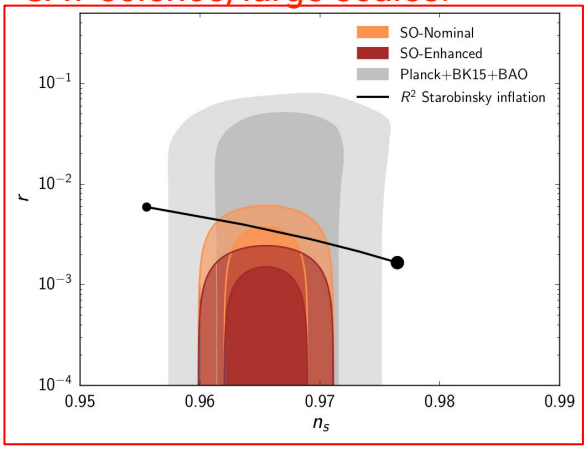
The science goals of SO

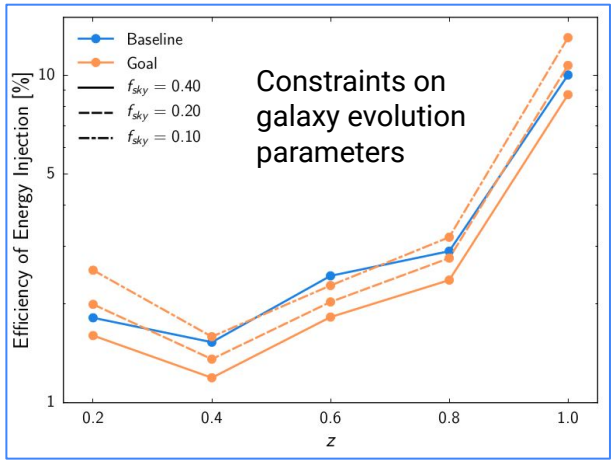


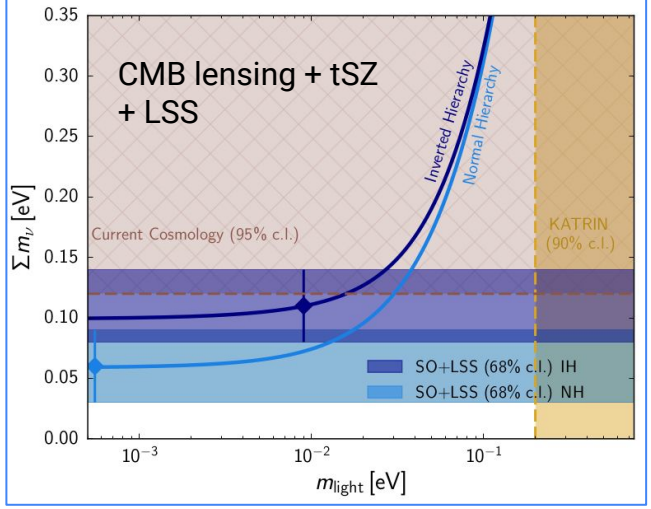


credits: Erminia Calabrese

SAT science, large scales:

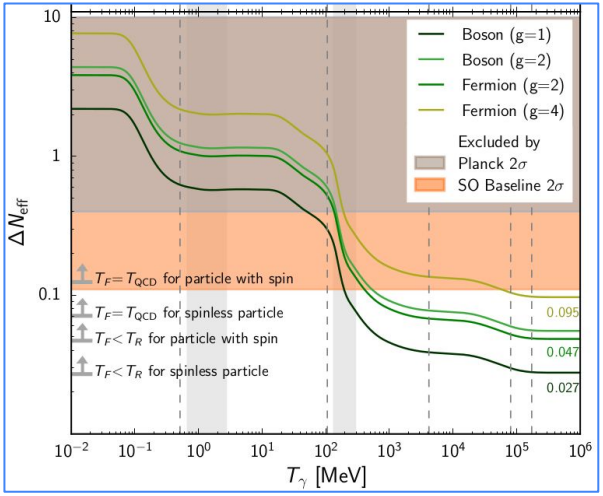






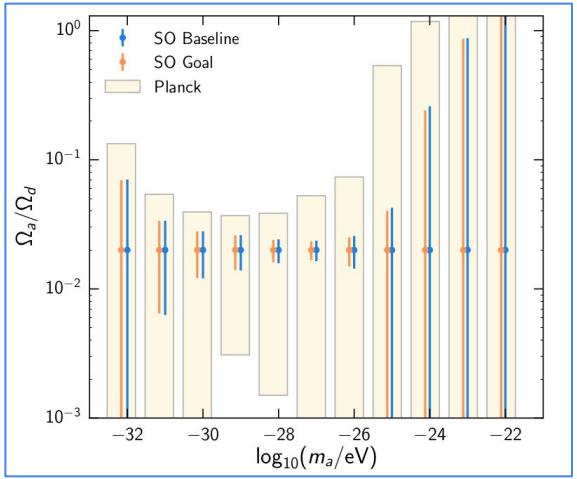
Forecasted sensitivity on neutrino masses

SO forecast paper 2019

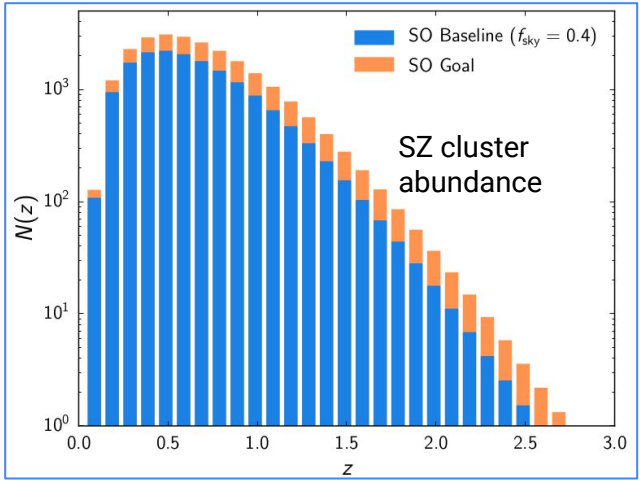


Constraints on Neff

LAT science, small scales:



Forecasted constraints on axion fraction



SO key science goals

From: The Simons Observatory: science goals and forecasts

Peter Ade, et al., JCAP02 (2019) 056

https://ui.adsabs.harvard.edu/abs/2019JCAP...02..056A/abstract

	Parameter	SO-Baseline[a] (no syst)	**SO-Baseline[b]**	SO-Goal[c]	Current[d] (2018-19)	Method	Sec.
Primordial perturbations	r	0.0024	**0.003**	0.002	0.03	BB + ext delens	3.4
	$e^{-2\tau}\mathcal{P}(k=0.2/\mathrm{Mpc})$	0.4%	**0.5%**	0.4%	3%	$TT/TE/EE$	4.2
	$f_{\mathrm{NL}}^{\mathrm{local}}$	1.8	**3**	1	5	$\kappa\kappa \times$ LSST-LSS + 3-pt	5.3
		1	**2**	1		kSZ + LSST-LSS	7.5
Relativistic species	N_{eff}	0.055	**0.07**	0.05	0.2	$TT/TE/EE + \kappa\kappa$	4.1
Neutrino mass	Σm_ν	0.033	**0.04**	0.03	0.1	$\kappa\kappa$ + DESI-BAO	5.2
		0.035	**0.04**	0.03		tSZ-N $\times$ LSST-WL	7.1
		0.036	**0.05**	0.04		tSZ-Y + DESI-BAO	7.2
Deviations from Λ	$\sigma_8(z=1-2)$	1.2%	**2%**	1%	7%	$\kappa\kappa$ + LSST-LSS	5.3
		1.2%	**2%**	1%		tSZ-N $\times$ LSST-WL	7.1
	H_0 (ΛCDM)	0.3	**0.4**	0.3	0.5	$TT/TE/EE + \kappa\kappa$	4.3
Galaxy evolution	η_{feedback}	2%	**3%**	2%	50-100%	kSZ + tSZ + DESI	7.3
	p_{nt}	6%	**8%**	5%	50-100%	kSZ + tSZ + DESI	7.3
Reionization	Δz	0.4	**0.6**	0.3	1.4	TT (kSZ)	7.6

SAT

LAT

[a] This column reports forecasts from earlier sections (in some cases using 2 s.f.) and applies no additional systematic error.

[b] This is the nominal forecast, increases the column (a) uncertainties by 25% as a proxy for instrument systematics, and rounds up to 1 s.f.

[c] This is the goal forecast, has negligible additional systematic uncertainties, and rounds to 1 s.f.

[d] Primarily from [44] and [287].

[44] BICEP2 and Planck collaborations, Joint Analysis of BICEP2/Keck Array and Planck Data, Phys. Rev. Lett. 114 (2015) 101301

[287] Planck collaboration, Planck 2018 results. VI. Cosmological parameters

Table 9. Summary of SO key science goals. All of our SO forecasts assume that SO is combined with *Planck* data.

Additional goals and Data combinations

[SO Collaboration (2019)]

Table 11
Catalogs and additional science from SO

LAT

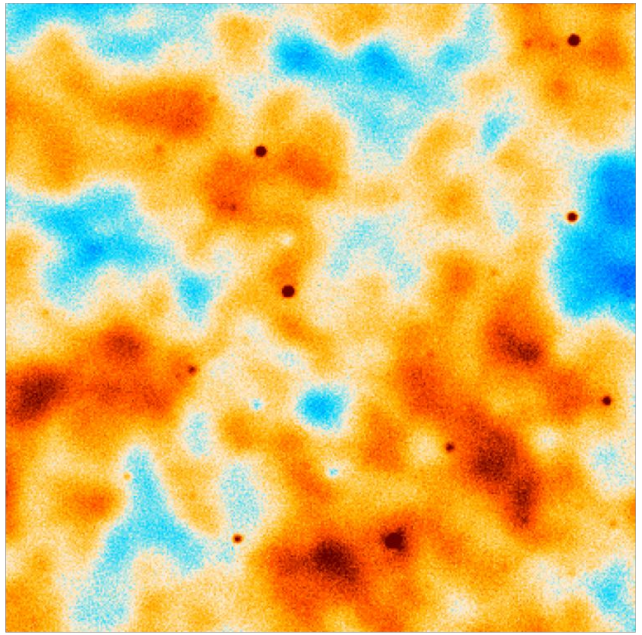
	Parameter	SO-Baseline	Method
Legacy catalogs	SZ clusters	20,000	tSZ
	AGN	10,000	Sources
	Polarized AGN	300	Sources
	Dusty star-forming galaxies	10,000	Sources
Primordial perturbations	$f_{\rm NL}$ (equilateral)	30	T/E
	$f_{\rm NL}$ (orthogonal)	10	
	n_s	0.002	$TT/TE/EE + \kappa\kappa$
Big bang nucleosynthesis	Y_P (varying $N_{\rm eff}$)	0.007	$TT/TE/EE + \kappa\kappa$
	$\Omega_b h^2$ (ΛCDM)	0.00005	$TT/TE/EE + \kappa\kappa$
Dark matter	DM–baryon interaction (σ_p, MeV)	5×10^{-27}	$TT/TE/EE+\kappa\kappa$
	UL axion fraction (Ω_a/Ω_d, $m_a = 10^{-26}$ eV)	0.005	$TT/TE/EE+\kappa\kappa$
Dark energy or modified gravity	w_0	0.06	tSZ +LSST
	w_a	0.2	tSZ + LSST
	Growth rate ($\Delta(\sigma_8 f_g)/\sigma_8 f_g$)	0.1	kSZ + DESI
Shear bias calibration	$m_{z=1}$	0.007	$\kappa\kappa$+LSST
Reionization	$\log_{10}(\lambda_{\rm mfp})$	0.3	$TT/TE/EE$ (kSZ)
	Ionization efficiency (ζ)	40	$TT/TE/EE$ (kSZ)

SO: New Opportunities in mm-Transient Science

Variable Active Galactic Nuclei:
track thousands daily/weekly/monthly at 1-10 mm.

Potential of mm transients:
e.g. orphan afterglows of Gamma Ray Bursts

Potential follow-up of Rubin Observatory optical transients



[Previous | Next | ADS]

ACT-T J061647-402140: a Strongly Variable, Flaring Source at 90, 150 and 220 GHz Positionally Coincident with the Transient Gamma-Ray Blazar, Fermi 0617-4026

ATel #12738; *Sigurd Naess (Center for Computational Astrophysics, Flatiron Institute) on behalf of the ACT Collaboration*
on 8 May 2019; 23:32 UT
Credential Certification: John P. Hughes (jph@physics.rutgers.edu)

Subjects: Millimeter, Gamma Ray, AGN, Blazar, Transient, Variables

In addition to wealth of CMB science (early and late-time signals), 30k high-z dusty galaxies, 20k clusters and Galactic science

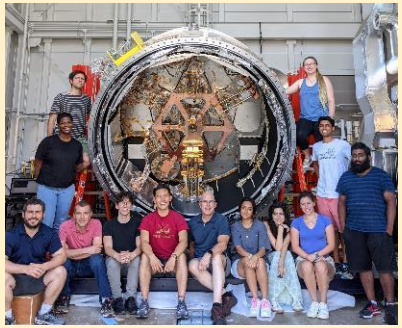
Time Domain Astrophysics

Tidal Disruption Events

Stellar Flares

Variable AGN

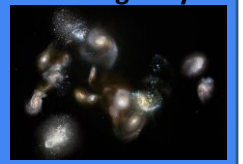
Training the Next Generation



Extragalactic Astronomy

Missing Baryons

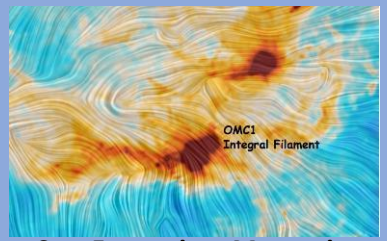
Sources



Galaxy Clusters

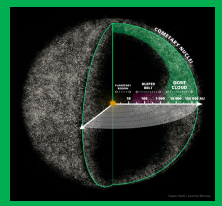
Galactic Astronomy

Interstellar Dust



Star Formation, Magnetic Fields and Turbulence

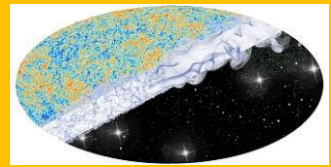
Planetary Science



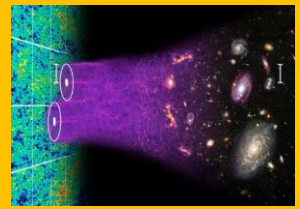
Exo-Oort Clouds

Planet 9

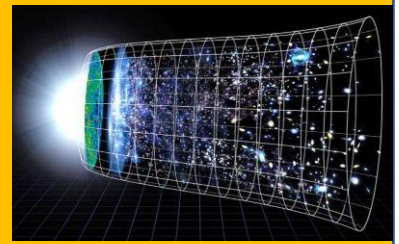
Cosmology and Particle Physics



H_0 Tension and New Physics



Light Relics and Neutrinos



The Evolution of the Universe Over Cosmic Time

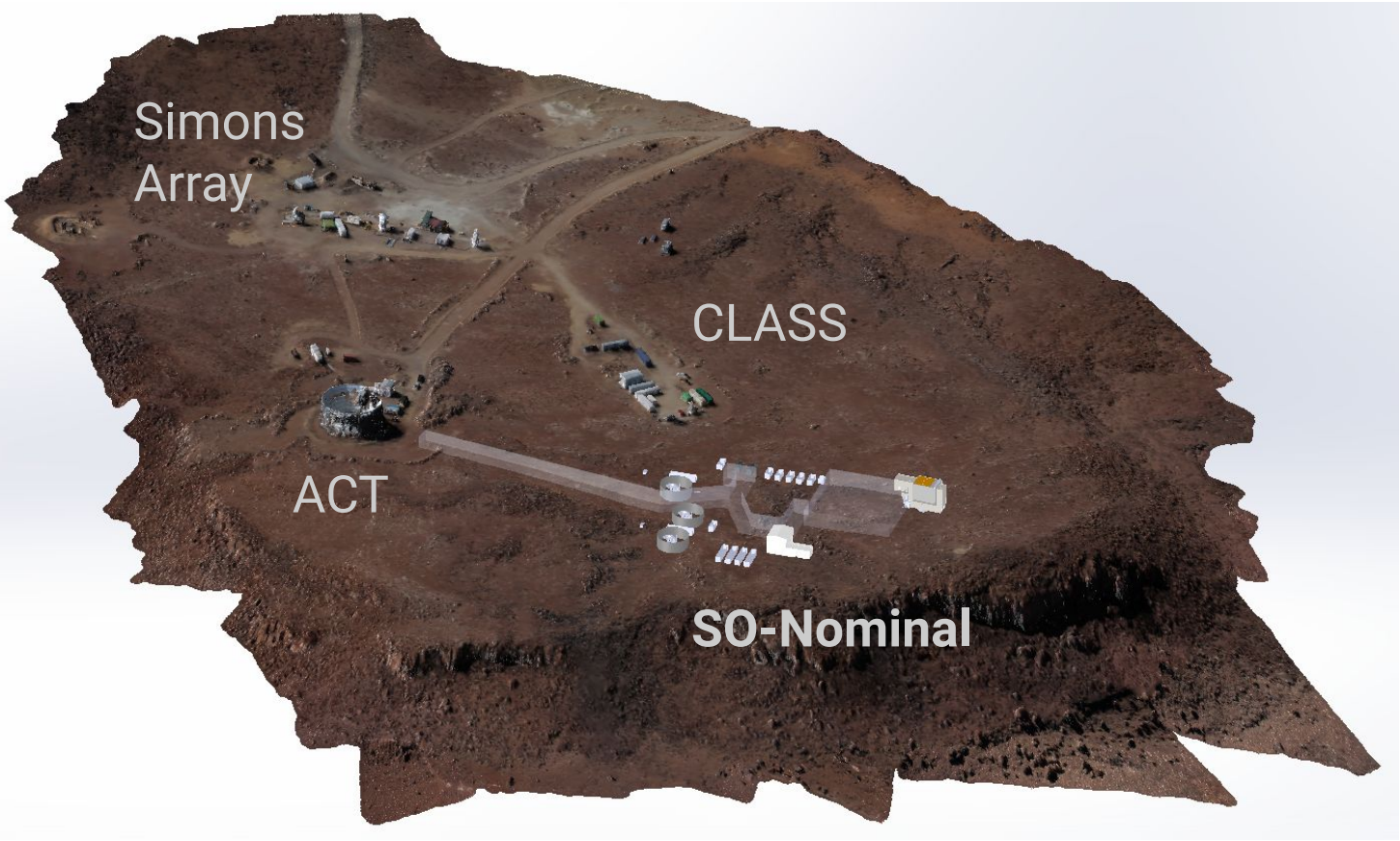
SO commitment to outreach & engagement

- Education
  - Undergraduate Summer Research (~30 students/summer)
  - Mentorship Program (~50 mentees, half from underrepresented minority)
  - Work with schools
    - Cosmology webinar for teachers (~100 teachers so far)
    - Skype a Scientist (>50 classrooms)
- Outreach
  - Average 75 events per year reaching 10s of thousands
  - Organized three Science/Astro on Tap Series
  - Recent event connecting 8th graders to Jessica Meir aboard Shuttle
- Engagement
  - Multiple “hack-a-thons” to transfer skills

Art & Science Book

STEM Camp in Trenton, NJ

The SO site



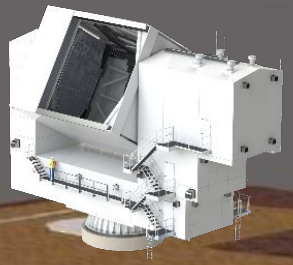
5,200 meters in the Atacama desert, in Northern Chile

23 degree South Latitude

Established site

Room for expansion

The SO-Nominal site



Large Aperture Telescope (LAT)

Power Generation

High bay and Control Room

Small Aperture Telescopes (SAT)


LAT
SAT


vertex

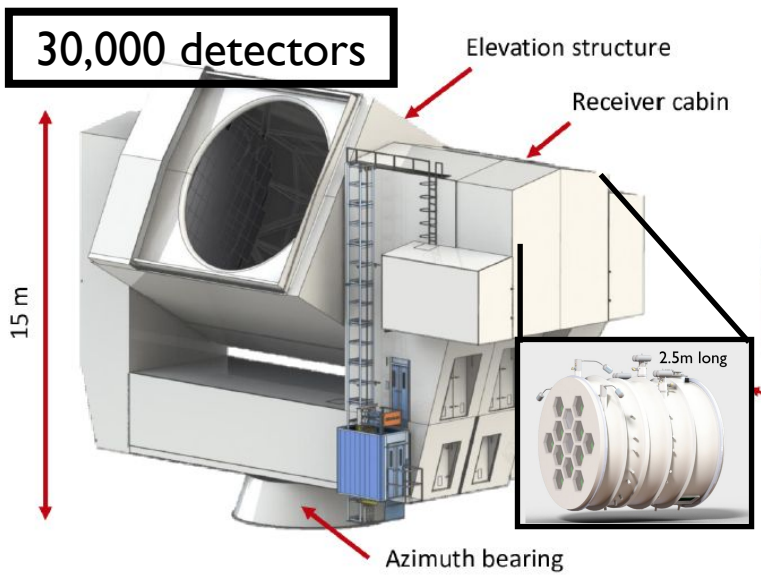

BEACON

Simons Observatory telescopes

credits: Michael Brown

Large Aperture Telescope (LAT):

30,000 detectors



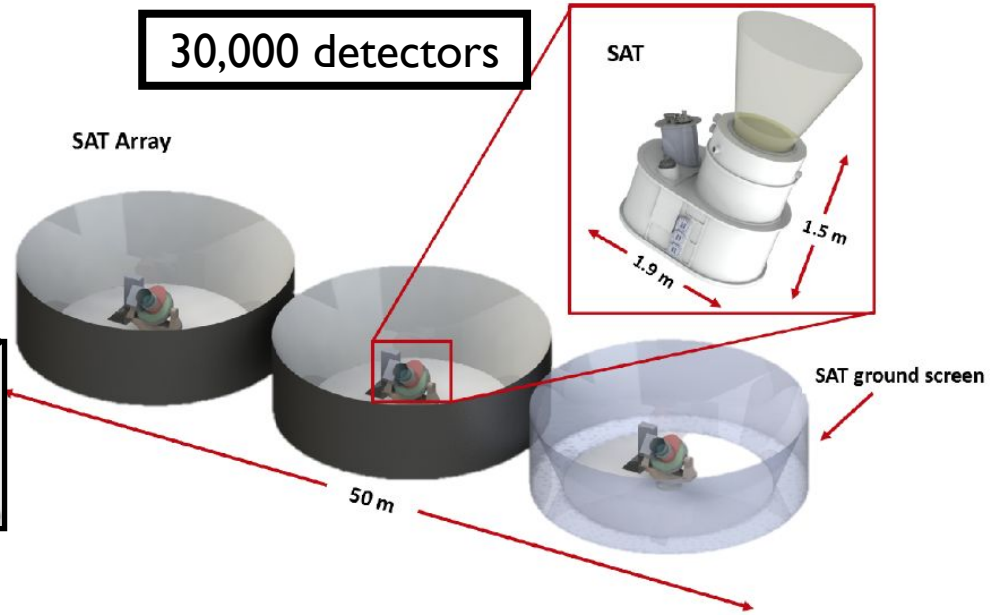
A 6m crossed-Dragone telescope feeding up to thirteen 38cm optics tubes. Baseline = 7 tubes.

Frequencies:

- 27/39 GHz: 1 tube
- 93/150 GHz: 4 tubes
- 220/280 GHz: 2 tubes

Small Aperture Telescopes (SATs):

30,000 detectors

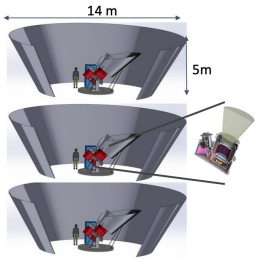


An array of 42cm refractors. Baseline for SO = 3 telescopes and 4 receivers:

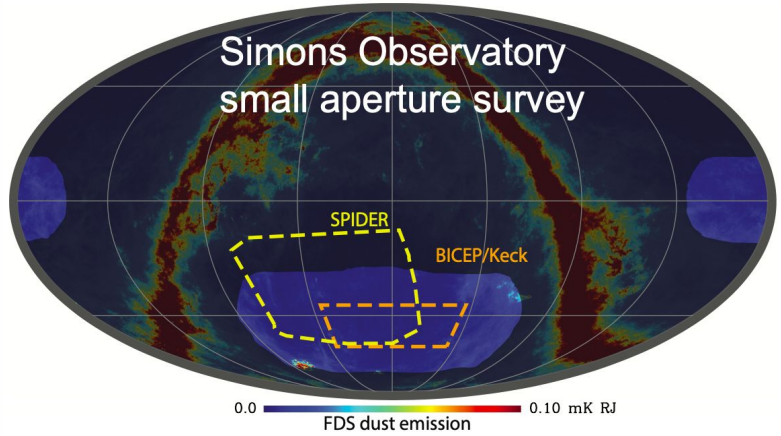
Frequencies:

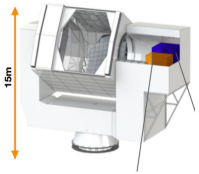
- 27/39 GHz: 1 receiver
- 93/150 GHz: 2 receivers
- 220/280 GHz: 1 receiver

SO Surveys

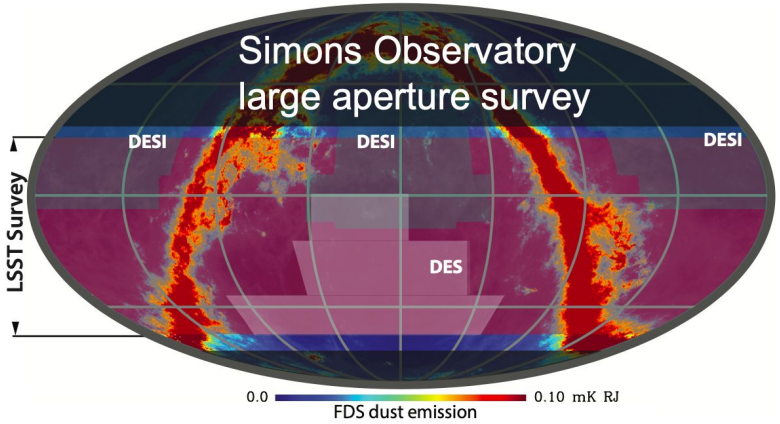


- f_{sky} ~ 0.1
- 0.5° angular resolution at 93 GHz
- 2 μK-arcmin noise level coadded over 93 and 150 GHz channels
- **optimized for *B*-modes observation** (avoiding Galactic plane, limited range of elevations)

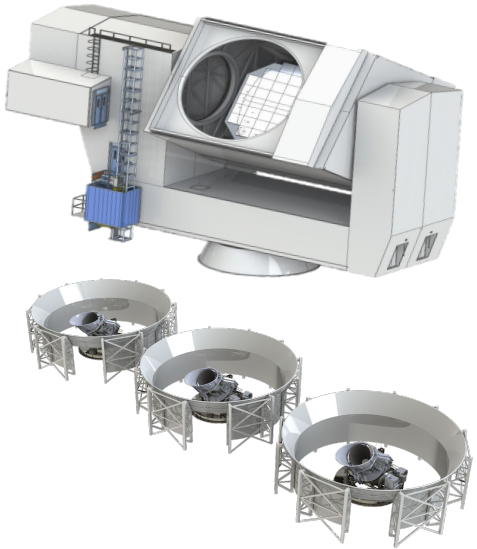


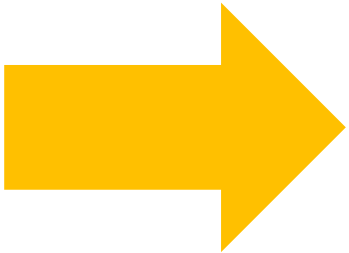


- f_{sky} ~ 0.4
- 2.2’/1.4’ resolution at 93/150 GHz
- 6.5 μK-arcmin noise level coadded over 93 and 150 GHz channels
- **overlap with LSST and DESI is optimized**



+3 SATs with UK and Japan funds





Twice better sensitivity to primordial gravitational waves

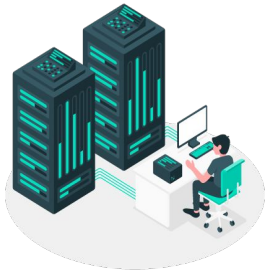
~60,000 detectors

~90,000 detectors

credits: Michael Brown

SO:UK components

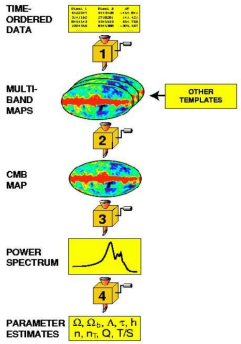
Data Centre



Delivering "Science Ready" Data Products for SO.

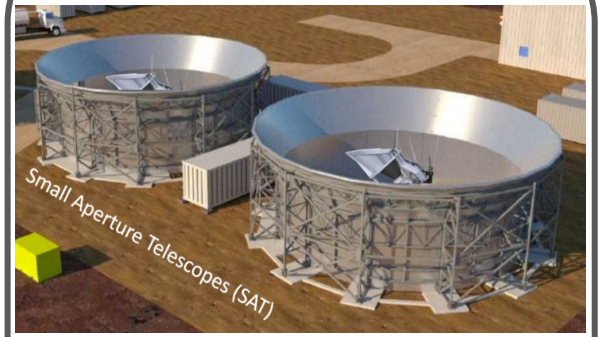
SAT/LAT commissioning: 2025-2026

Algorithms



Analysis algorithms needed for SO data processing.

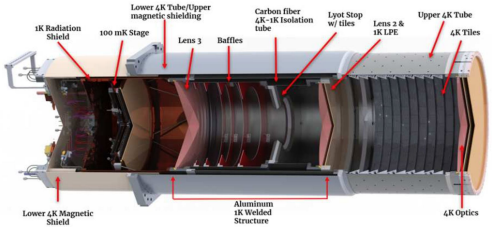
Two additional SATs



Baseline is for both SATs to be MF. As a goal, will also explore one MF and one UHF.

LAT Optics Tube

A single ultra-high frequency (UHF) optics tube for the LATR.

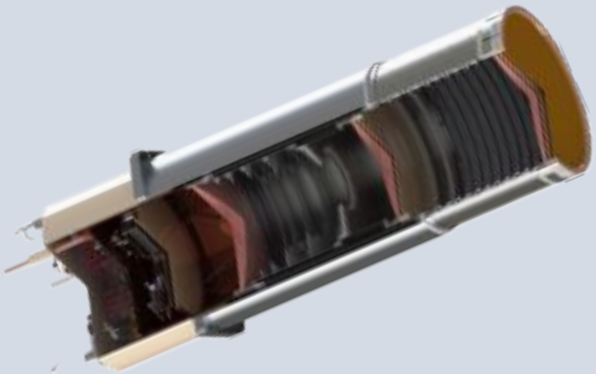


Science and Technology Facilities Council

* Funding (£22.3M) has been awarded for all of these elements. Full project has now started (October 22).

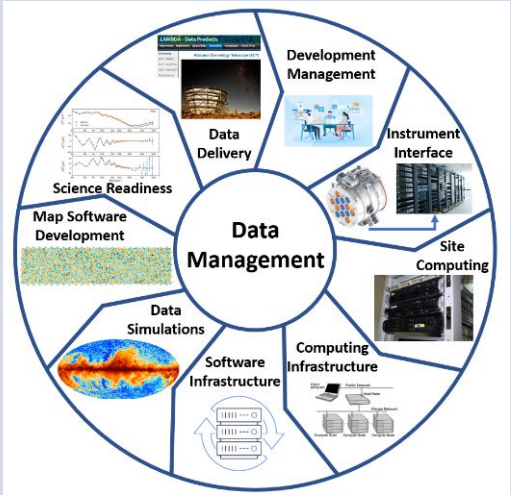
Advanced SO – Project Definition

Optics Tubes



- Six New Optics Tubes
- Double Mapping Speed
- Enable Transient Detection
- No Development Required

Data Management



- Full Maps Processed in 6 Months
- Daily Transient Alerts
- Verification and Systematics Mitigation

Photo Voltaic Array

- 9% increase in Observing Efficiency
- Reduced Carbon Footprint (reduce diesel-generated power by 70%)
- Reduced Maintenance Costs


Thanks for your attention!