SO:UK - A major UK contribution to Simons Observatory

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The SO:UK collaboration

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The Simons Observatory

- **10 Countries**
- **40+ Institutions**
- **306 Researchers**

United States

- Arizona State University
- Carnegie Mellon University
- Center for Computational Astrophysics
- Cornell University
- Florida State
- Haverford College
- Lawrence Berkeley National Laboratory
- NASA/GSFC
- NIST
- Princeton University
- Rutgers University
- Stanford University/SLAC
- Stony Brook
- University of California - Berkeley
- University of California – San Diego
- University of Michigan
- University of Pennsylvania
- University of Pittsburgh
- University of Southern California
- West Chester University
- Yale University

Japan

- KEK
- IPMU
- Tohoku
- Tokyo
- Kyoto

Canada

- CITA/Toronto
- Dunlap Institute/Toronto
- McGill University
- Perimeter Institute
- University of British Columbia

Chile

- Pontificia Universidad Catolica
- University of Chile

Europe

- APC – France
- Cambridge University
- Cardiff University
- Imperial College
- Manchester University
- Oxford University
- SISSA – Italy
- University of Sussex

South Africa

- Kwazulu-Natal, SA

Australia

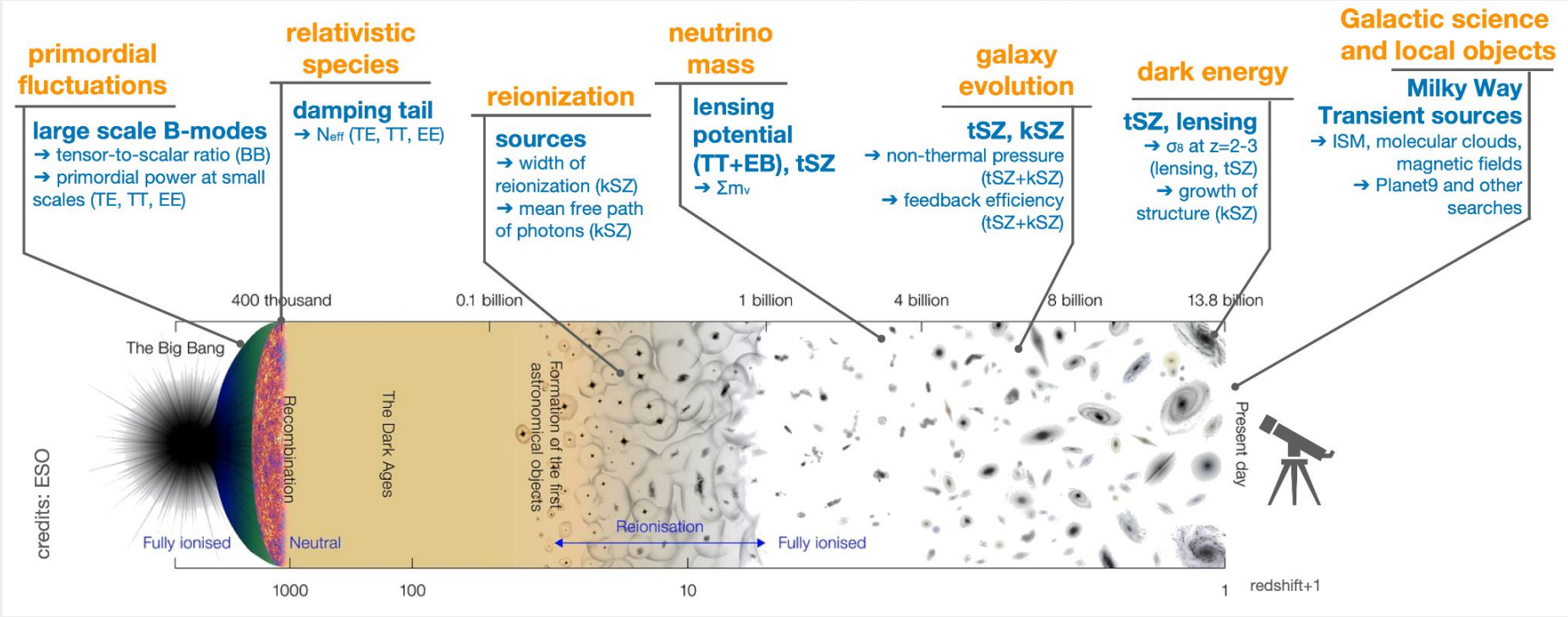
- Melbourne

Middle East

- Tel Aviv

Simons Observatory

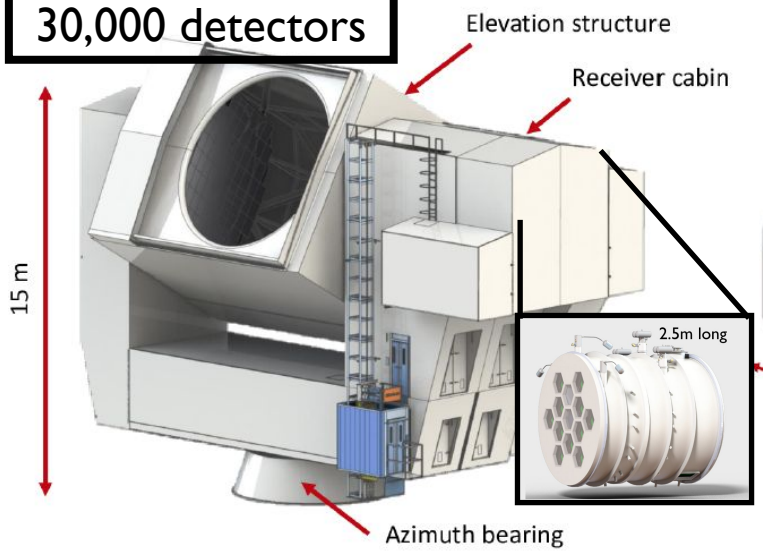
A next-generation **Cosmic Microwave Background (CMB)** observatory designed to provide breakthrough discoveries in fundamental physics, cosmology and astrophysics.



Simons Observatory telescopes

Large Aperture Telescope (LAT):

30,000 detectors



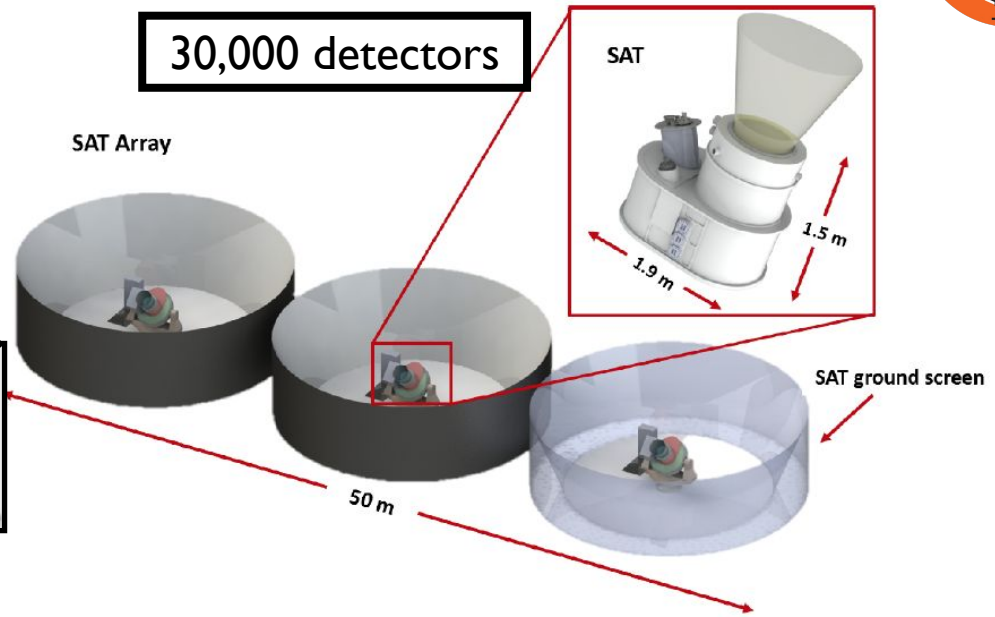
A 6m crossed-Dragone telescope feeding up to thirteen 38cm optics tubes. Baseline = 7 tubes.

Frequencies:

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

Small Aperture Telescopes (SATs):

30,000 detectors



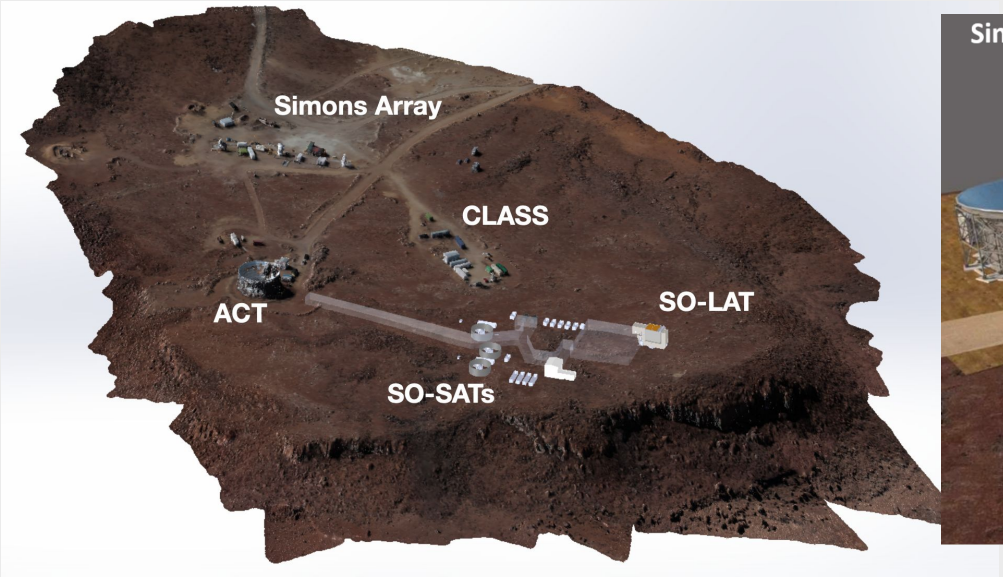
An array of 42cm refractors. Baseline for SO = 3 telescopes and 4 receivers:

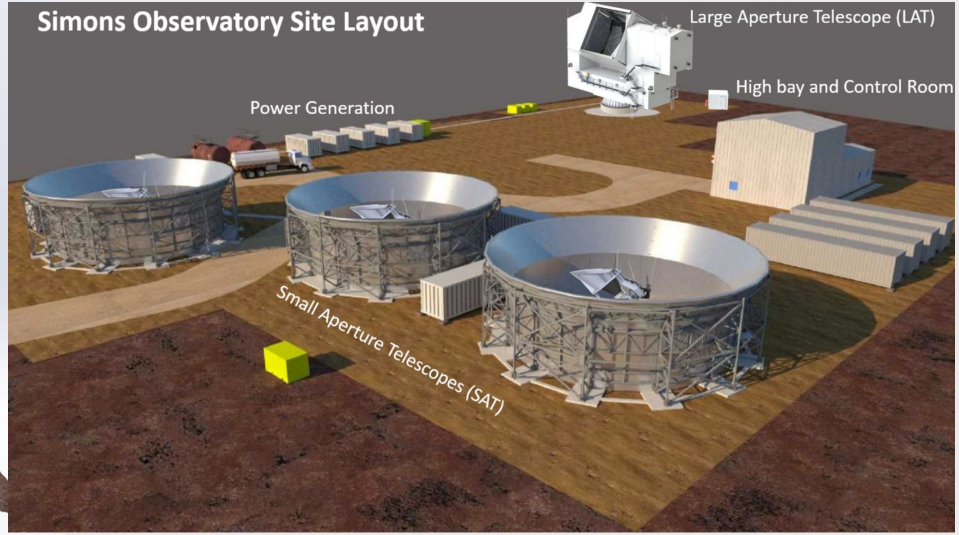
Frequencies:

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

Simons Observatory site

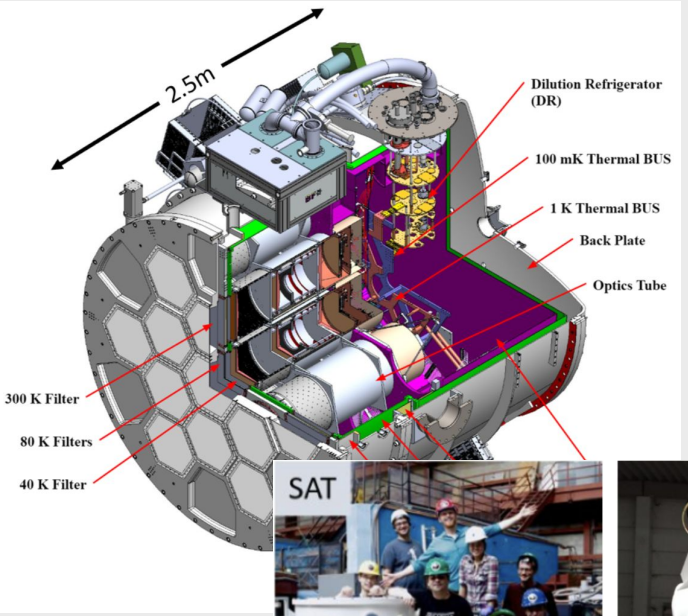
- Cerro Toco, Atacama Desert, Northern Chile, close to the ACT, Simons Array and CLASS CMB experiments.





Simons Observatory hardware

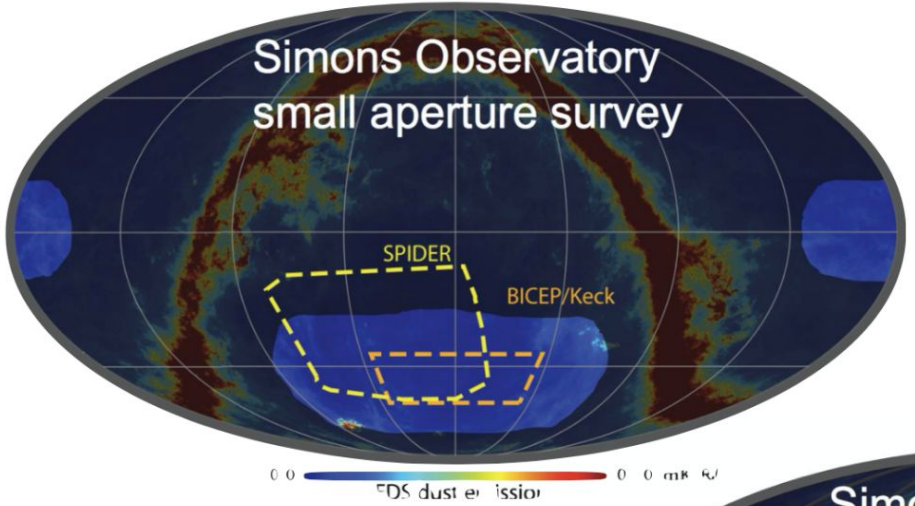
SO LAT receiver at The University of Pennsylvania



SO SAT platform (alt-az mount) at VERTEX in Germany

SO SAT telescope at UCSD

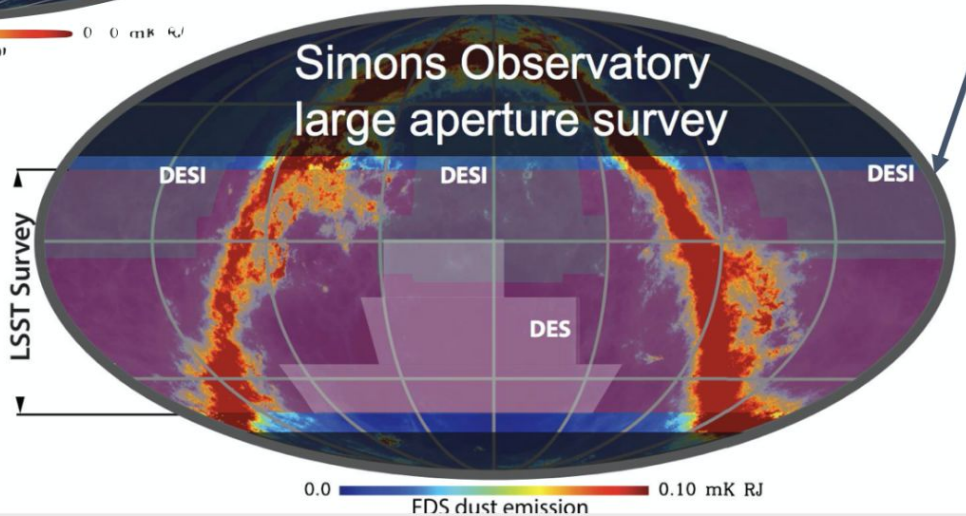
Two Surveys to Maximize the Science Return



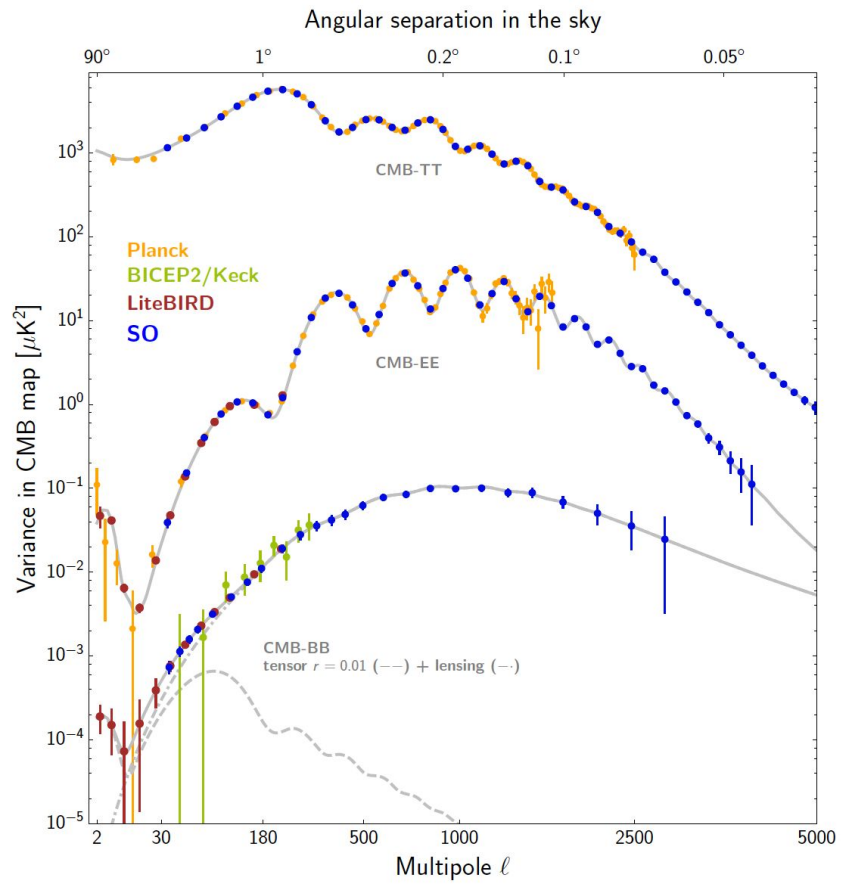
Effective f_{sky} ~ 10%
Optimised for Primordial B-modes

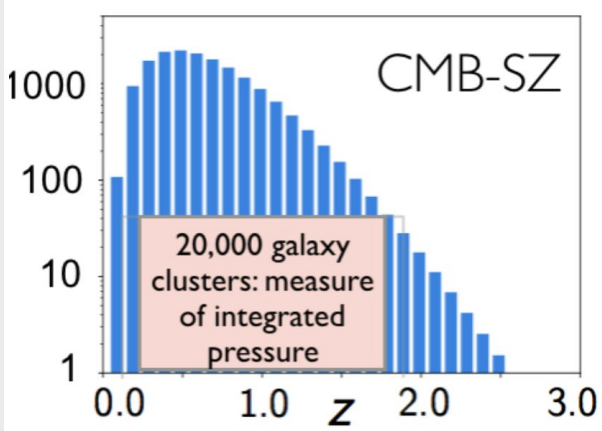
All SO science goals, except tensors, drive us to wide area, with maximum optical overlap

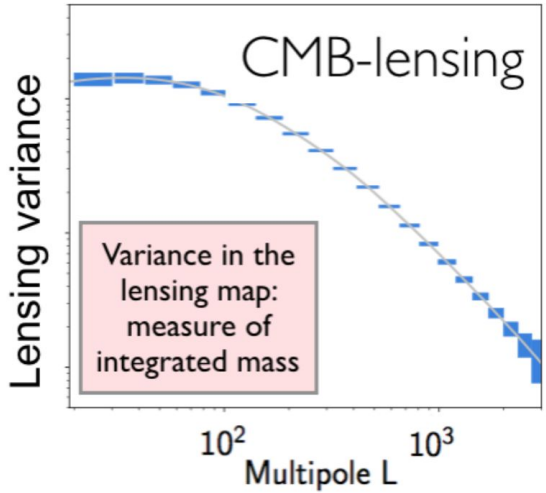
- Baseline f_{sky} ~0.4, Potentially as large as 0.7
- Overlap with Rubin-LSST, DESI, Euclid
- Observing cadence being refined for both cosmology and transient/Planet 9 searches



SO observables enable a wide range of science







ALSO:

- **kSZ**
- **Y-maps**
- **Millimetre sources and transients**
- **Planet 9**
- **Legacy arcmin resolution mm-wave sky maps**

SO observables enable a wide range of science

Table 1: Summary of SO-Nominal key science goals[a]

	Current[b]	SO-Nominal (2022-27) Baseline	Goal	Method[d]	SWP
Primordial perturbations (§2.1)					
r ($A_L = 0.5$)	0.03	0.003	0.002[e]	BB + external delensing	[12]
n_s	0.004	0.002	0.002	TT/TE/EE	[12]
$e^{-2\tau}\mathcal{P}(k = 0.2/\mathrm{Mpc})$	3%	0.5%	0.4%	TT/TE/EE	[13]
$f_{\mathrm{NL}}^{\mathrm{local}}$	5	3	1	$\kappa\times$ LSST-LSS	[14]
		2	1	kSZ + LSST-LSS	
Relativistic species (§2.2)					
N_{eff}	0.2	0.07	0.05	TT/TE/EE + $\kappa\kappa$	[15]
Neutrino mass (§2.3)					
Σm_ν (eV, $\sigma(\tau) = 0.01$)	0.1	0.04	0.03	$\kappa\kappa$ + DESI-BAO	[16]
		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	[17]
		2%	1%	tSZ-N $\times$ LSST-WL	
H_0 (km/s/Mpc, ΛCDM)	0.5	0.4	0.3	TT/TE/EE + $\kappa\kappa$	[18]
Galaxy evolution (§2.5)					
η_{feedback}	50-100%	3%	2%	kSZ + tSZ + DESI	[19]
p_{nt}	50-100%	8%	5%	kSZ + tSZ + DESI	[19]
Reionization (§2.6)					
Δz	1.4	0.4	0.3	TT (kSZ)	[20]

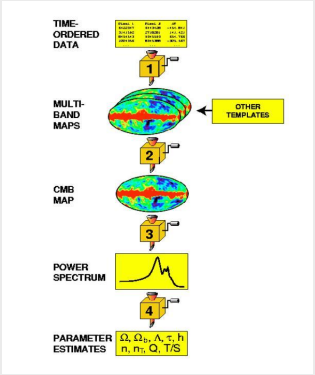
- Based on rigorous simulations-based forecasting pipelines (SO collaboration 2019)
- SO can also cross important thresholds in parameter space for some science cases.

SO:UK components

Data Centre

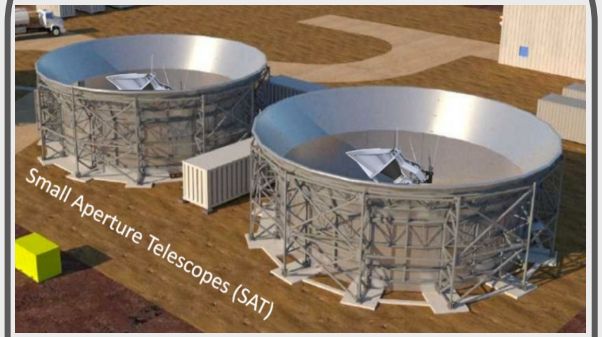
Delivering "Science Ready" Data Products for SO.

Algorithms



Analysis algorithms needed for SO data processing.

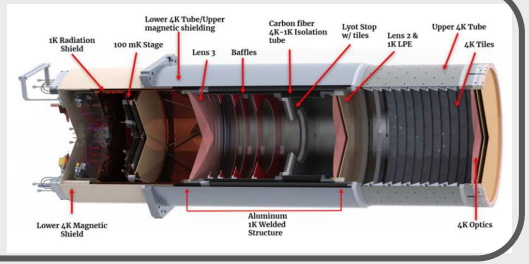
Two additional SATs



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.

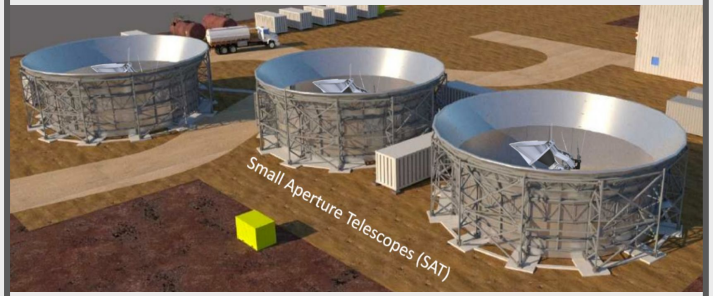


* Funding (£22.3M) has been awarded for all of these elements. Full project has now started (October 22).

Update: SO will still have six SATs in total

- Colleagues in **Japan** have secured funding for **one additional SAT**.

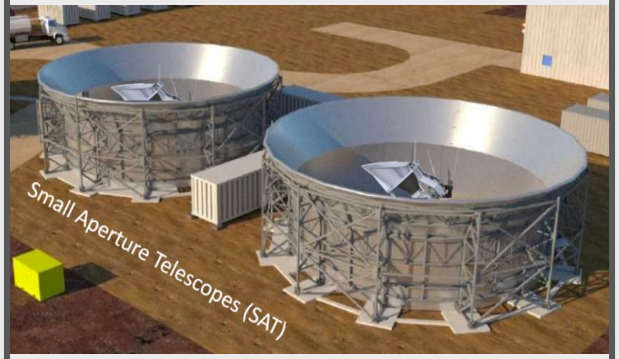
Three SATs



SO "Nominal"

Funded by Simons Foundation

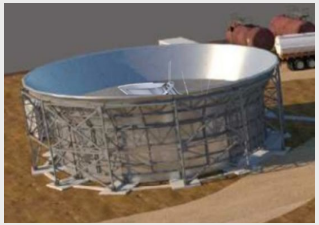
Two additional SATs



SO:UK

Funded by UKRI

One further SAT



SO:Japan

Funded by JSPS

Limitations and start dates

- SO:UK project **does not cover any science exploitation** (funded separately by UKRI/STFC through a different scheme).

- **Operations costs for SATs not included.** Funding will be sought in a future proposal. (UKRI/STFC will make provision for this in their future budget planning.)

- Data Centre, Algorithms and LAT Optics Tube programs started **April 2022**.

- SATs program started: **October 2022**.

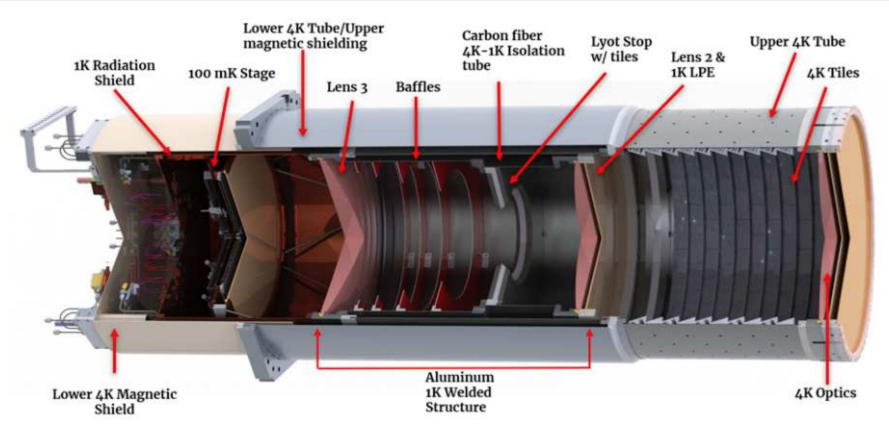
SO:UK Hardware

SO:UK LATR Optics Tube

- Primary role of SO:UK UHF (220/280 GHz) optics tube is as a **technology demonstrator** showcasing key UK technologies:

- **Metamaterial** based anti-reflection (AR) coating of large silicon lenses.

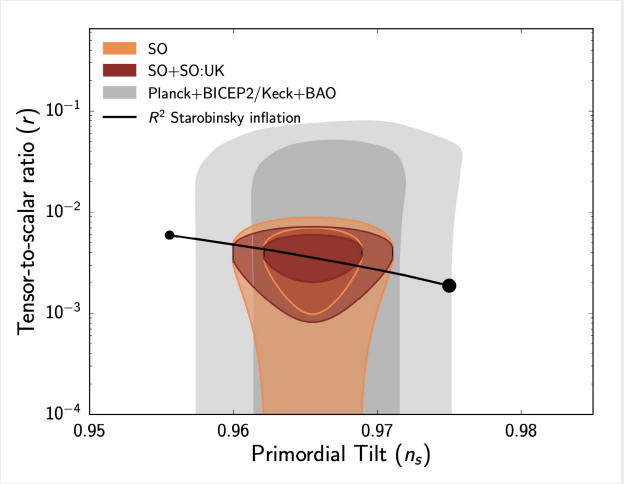
- The first deployment of arrays of dual-colour, dual polarisation **Kinetic Inductance Detectors (KIDs)**, plus associated readout, for CMB applications.



- Scheduled to install on LATR in Dec 2024 – Apr 2025 maintenance window.

SO:UK and SO:JP SATs science

- SO:UK (and SO:JP) SATs science case – push further on limits on tensor-to-scalar ratio, *r*:



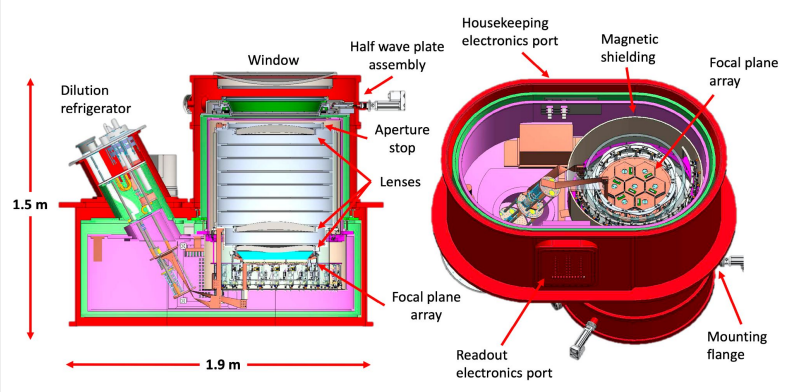
- Depending on foreground complexity and achieved UHF performance, fielding one SO:UK SAT @ UHF could play a crucial role.

SO:UK SATs

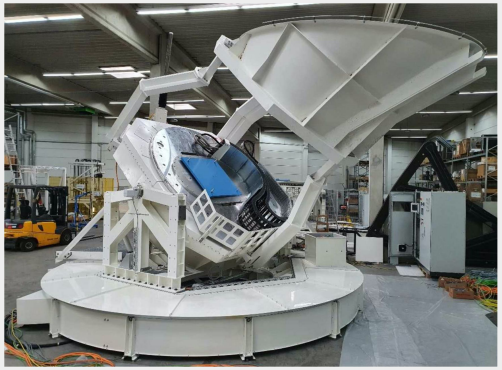
- Baseline is both SATs at MF (90/150 GHz). Will also explore one at MF and one at UHF (220/280 GHz) + other options.
- Identical to existing SO SATs apart from:
  - **MKIDs** (rather than TESs) + own warm readout (on RFSoCS).
  - **2-lens configuration** (as opposed to existing 3-lens system).
  - **A/R lens coating** following techniques demonstrated @ Cardiff.
  - Potentially **metal-mesh HWPs** instead of sapphire.
- UK funding covers: SATs, SATPs, ground screens, foundations (for SATPs and ground screens), site infrastructure expansion, local engineering support, deployment and commissioning.
- First science observations: **SAT4: Dec 2025** and **SAT5: Apr 2026**.

SO SATs and SATPs (mounts)

SAT (receiver)



SATP (alt-az mounts)

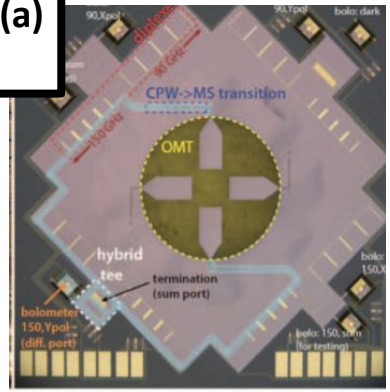


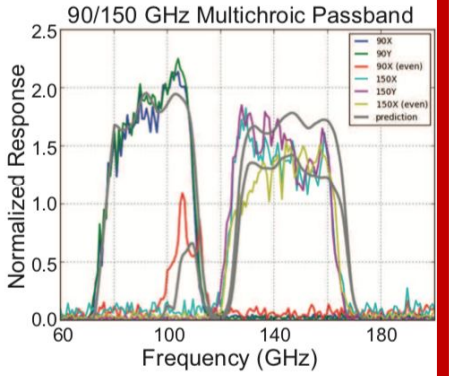
SAT MF1 receiver at UCSD

Three SATPs installed in Chile (May 2022)!

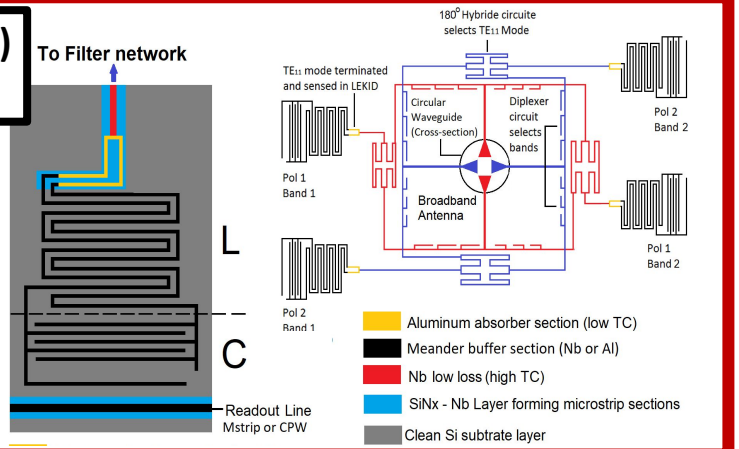
Using KIDs in Dual Pol, multi-chroic pixels

(a)

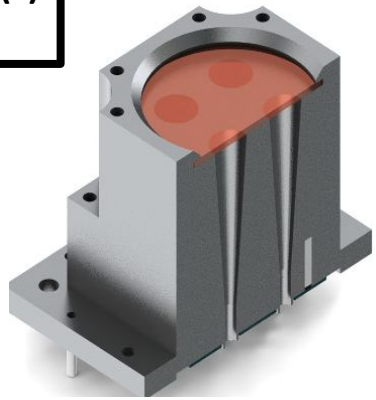


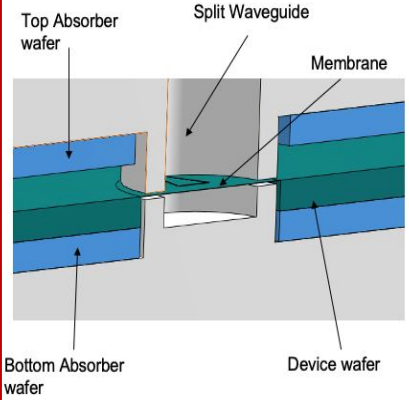


(b)



(c)





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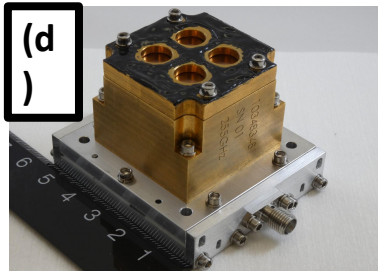
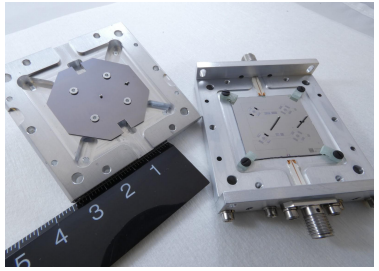
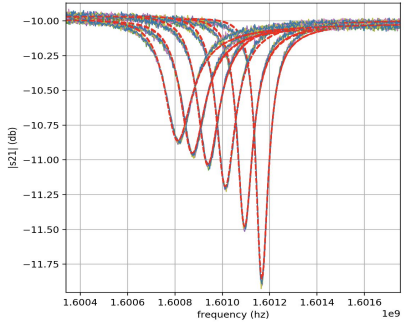


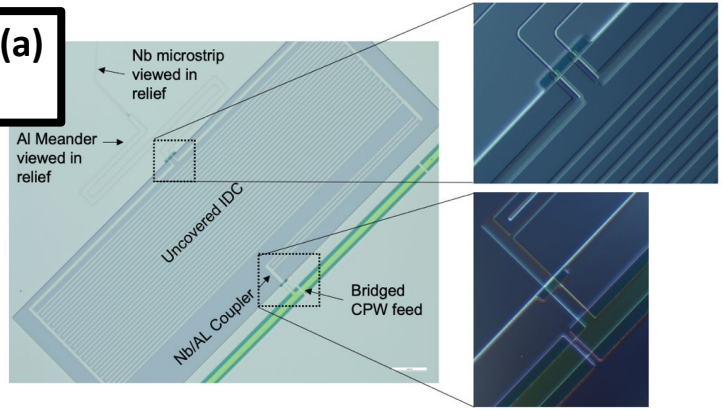


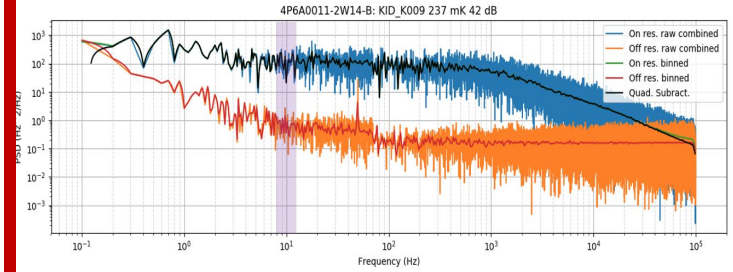


Simon Doyle

Process development– Fabrication at Cardiff ICS

(a)

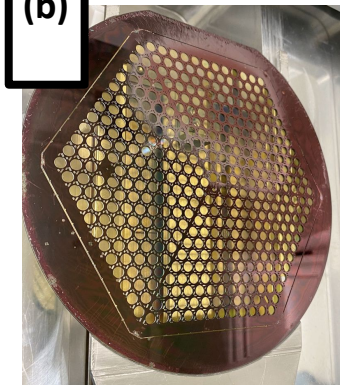


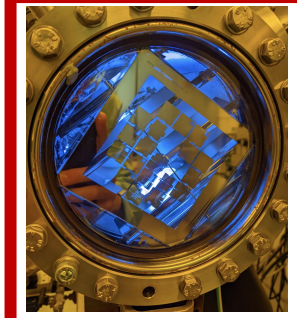


Frontside processing realized with the detector showing GR noise limited performance.

A rough estimate of NEP is of order < 1×10^{-17} W/Hz$^{0.5}$ @ 250mK

(b)





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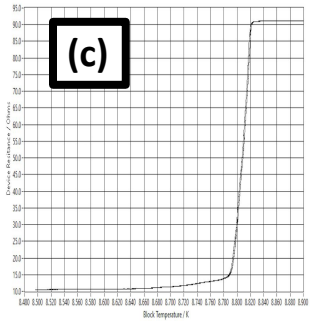
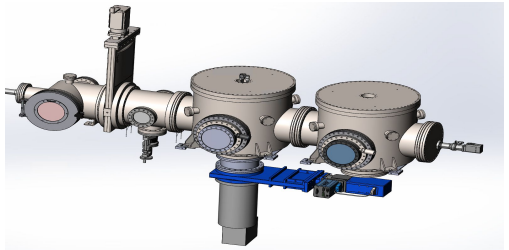
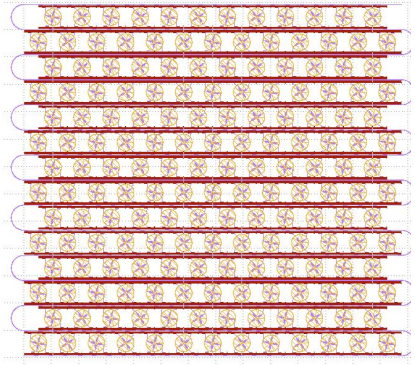
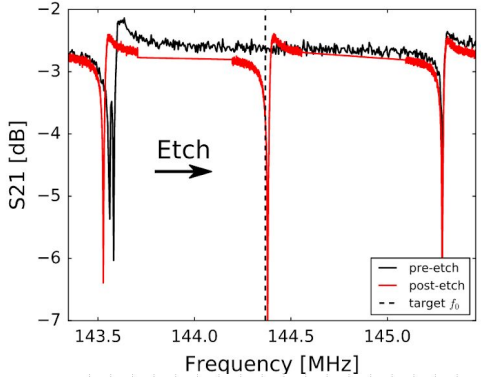


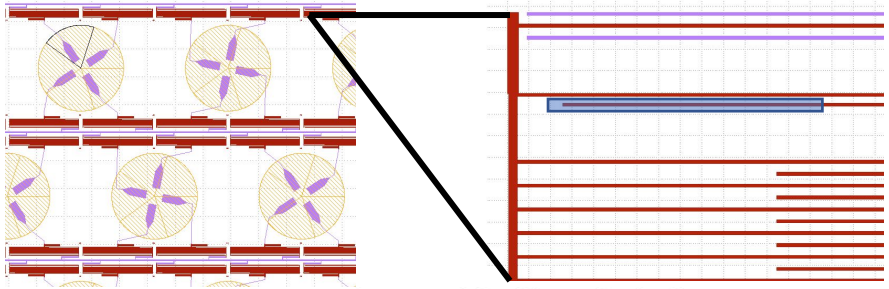


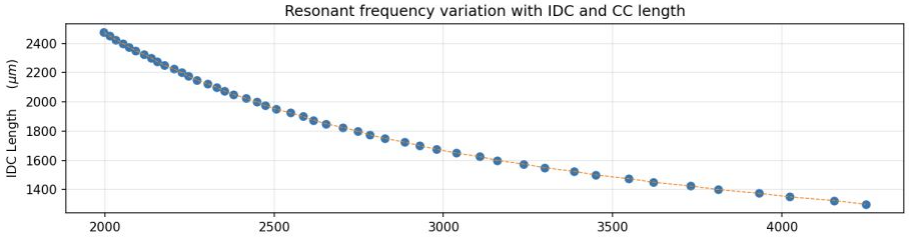
Simon Doyle

Design and test status now and looking forward









- Key fabrication processes proven in ICS.
- New fabrication facility and equipment due early (Jan/Feb) 2023
- Scaling to array scale – Design demonstrated in terms of MUX and wafer space on most challenging 90/150 GHz array. Compatible with baseline readout.
- Detector test and edit equipment almost in place. Plan to prove F0 editing at Cardiff by end of 2022
- Next 12 months will be used to refine processing for full array manufacture starting September 2023
- 2 **New** process engineers due to start October 2022.
- 2 **New** PDRA positions to be filled

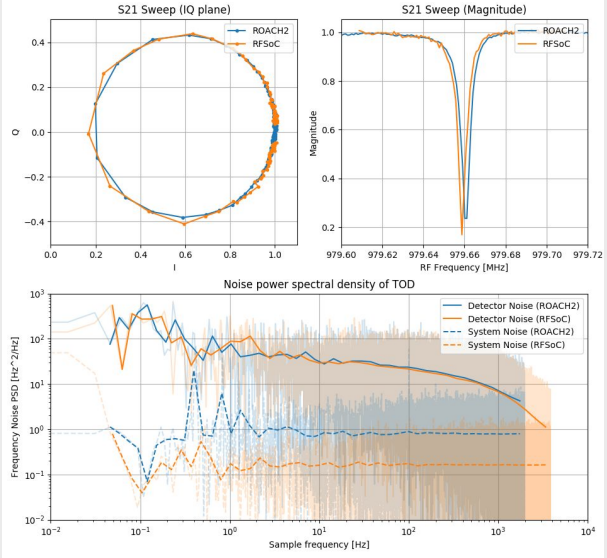
Simon Doyle

SO:UK warm readout on RFSoCs

- Key advantage of KIDS is the simplification of the readout system.
- Significant milestone achieved in June 2022: existing KID readout design successfully ported from (depreciated) Roach-2 boards to RFSoCs.

Reading out prototype KID array with ported RFSoC readout

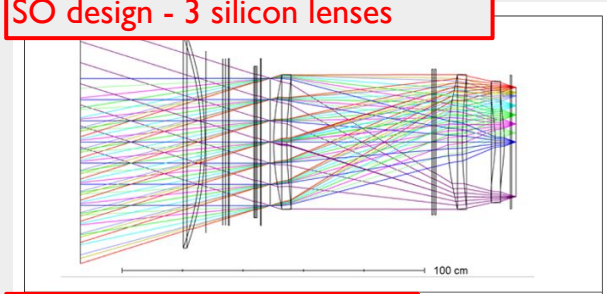
Comparison of Roach-2 readout (blue) with new RFSoC readout (orange)



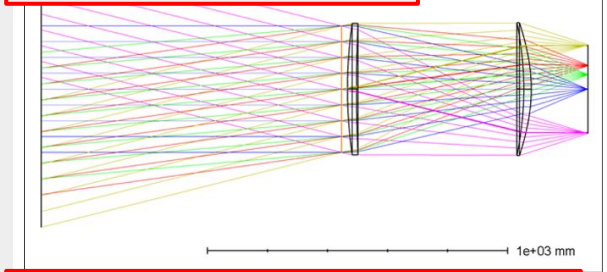
- Next steps: optimization of design using RFSoC board features, tone tracking functionality, interfacing with SO's Observatory Control System (OCS).

Optical designs, components & techniques

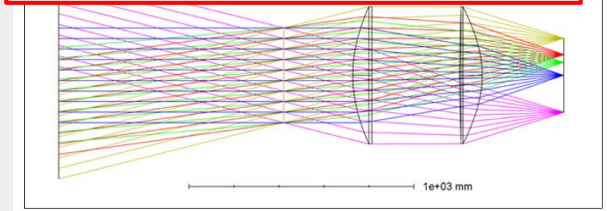
SO design - 3 silicon lenses



UK silicon option - 2 lenses

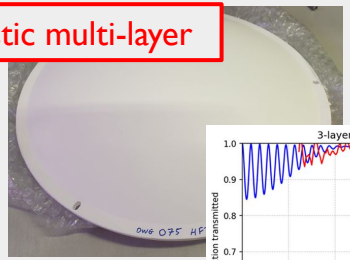


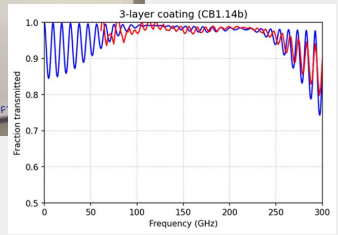
UK polymer-based option - 2 lenses



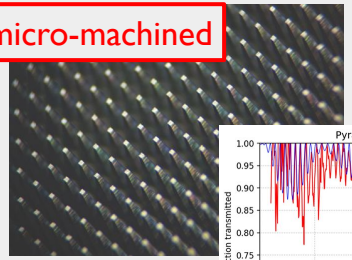
Anti-reflection (A/R) coatings:

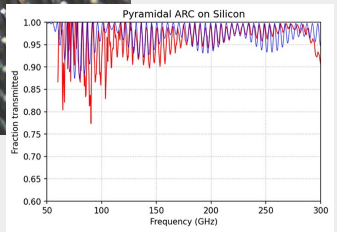
Plastic multi-layer



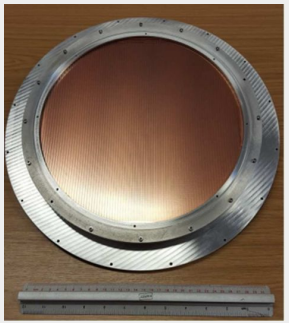


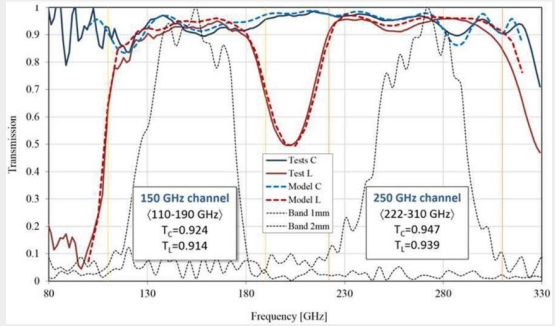
Silicon micro-machined





Large-diameter metal-mesh half-wave plates:

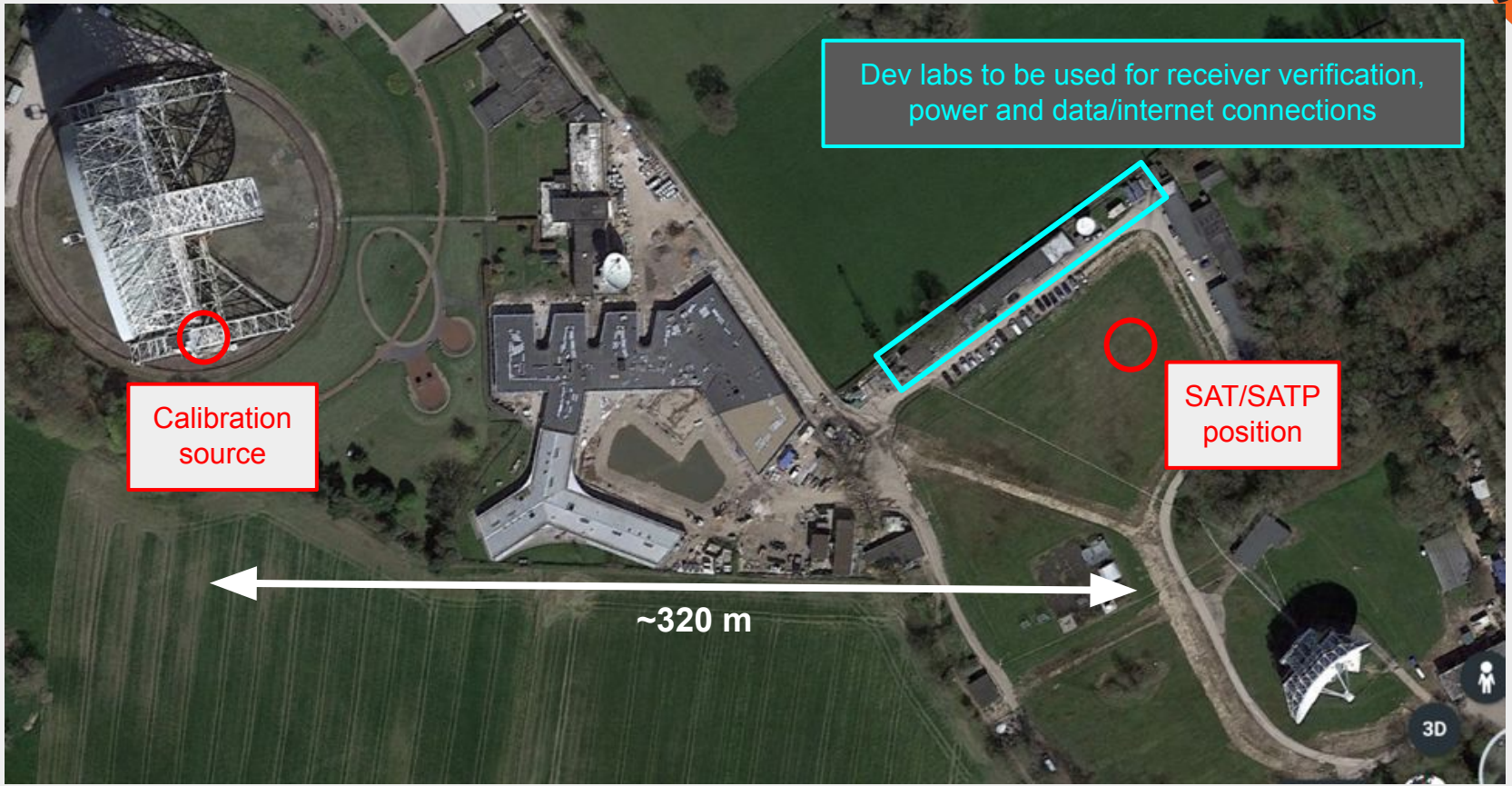




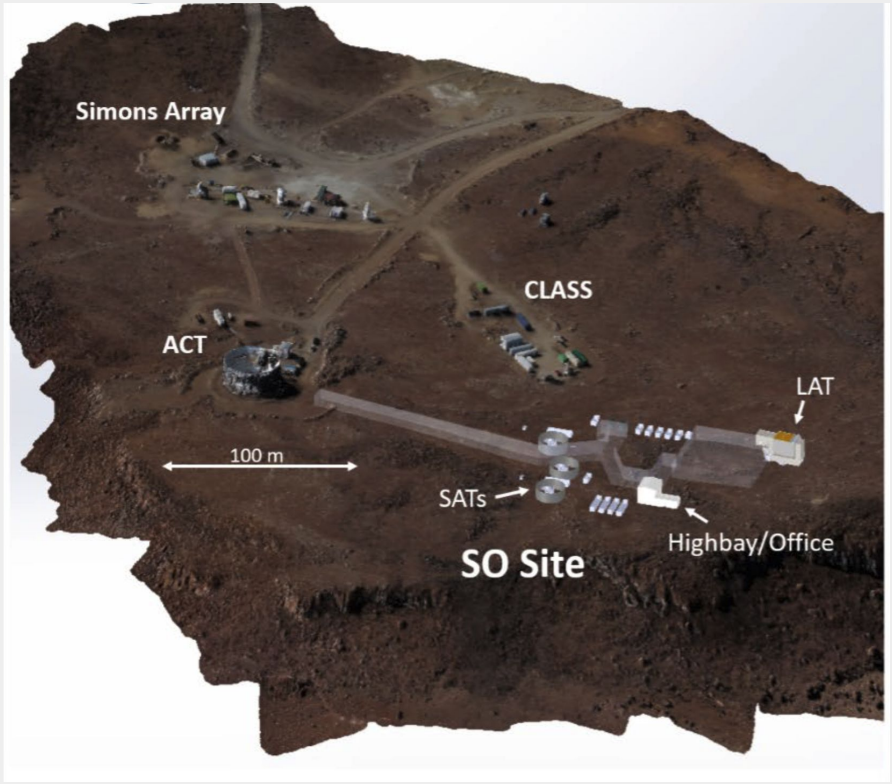
SO:UK SATs AIV plan

- First SATP delivered (by German manufacturer, VERTEX) to Jodrell Bank Observatory (JBO). Set up on concrete pad for further drive verification tests under representative loads. Second SATP shipped directly to Chile.
- SATs undergo *receiver-level AIV at Manchester and Cardiff*, then transfer to *JBO for full system AIV* and tests.
- For final calibration observations, we will mount a polarised source (IMPATT diode) on one of the Lovell telescope towers, in far-field of the SAT receiver (~160m).

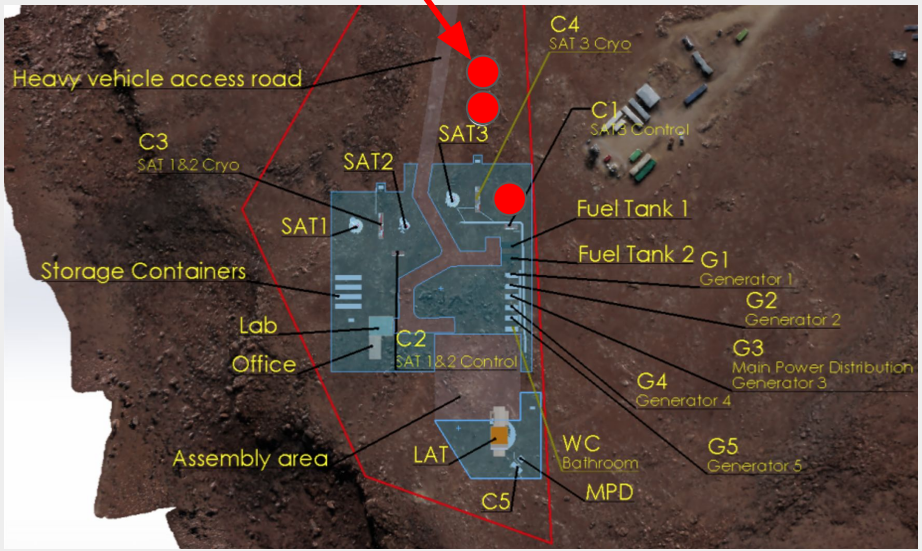
SO:UK SATs AIV plan



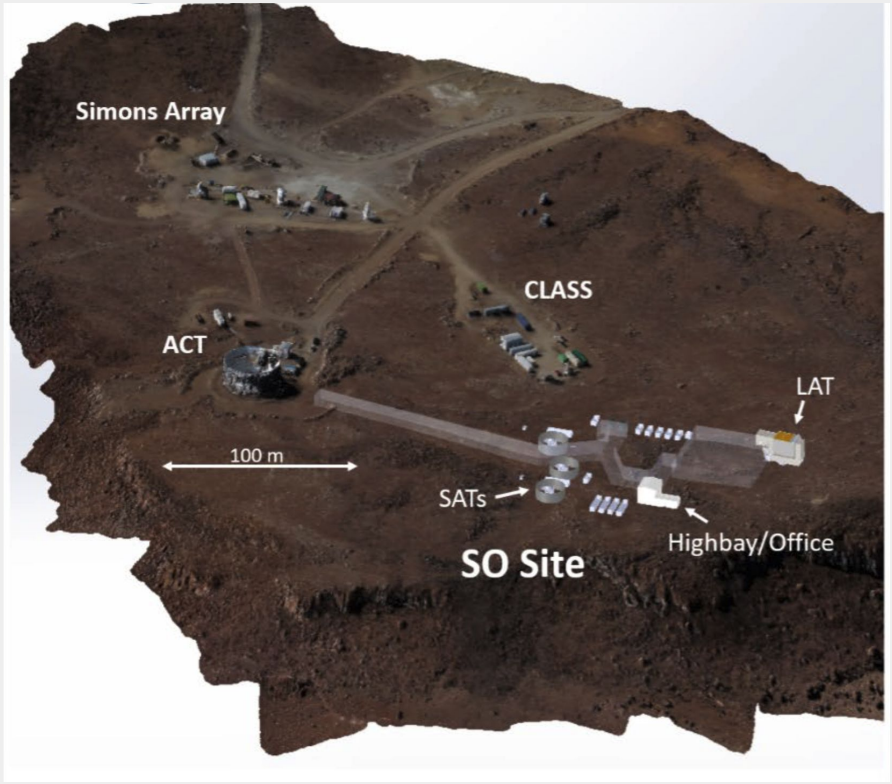
SO:UK and SO:JP SATs – site locations



Likely (preliminary) siting of three additional SATs (two SO:UK and one SO:Japan)



SO:UK and SO:JP SATs – site locations



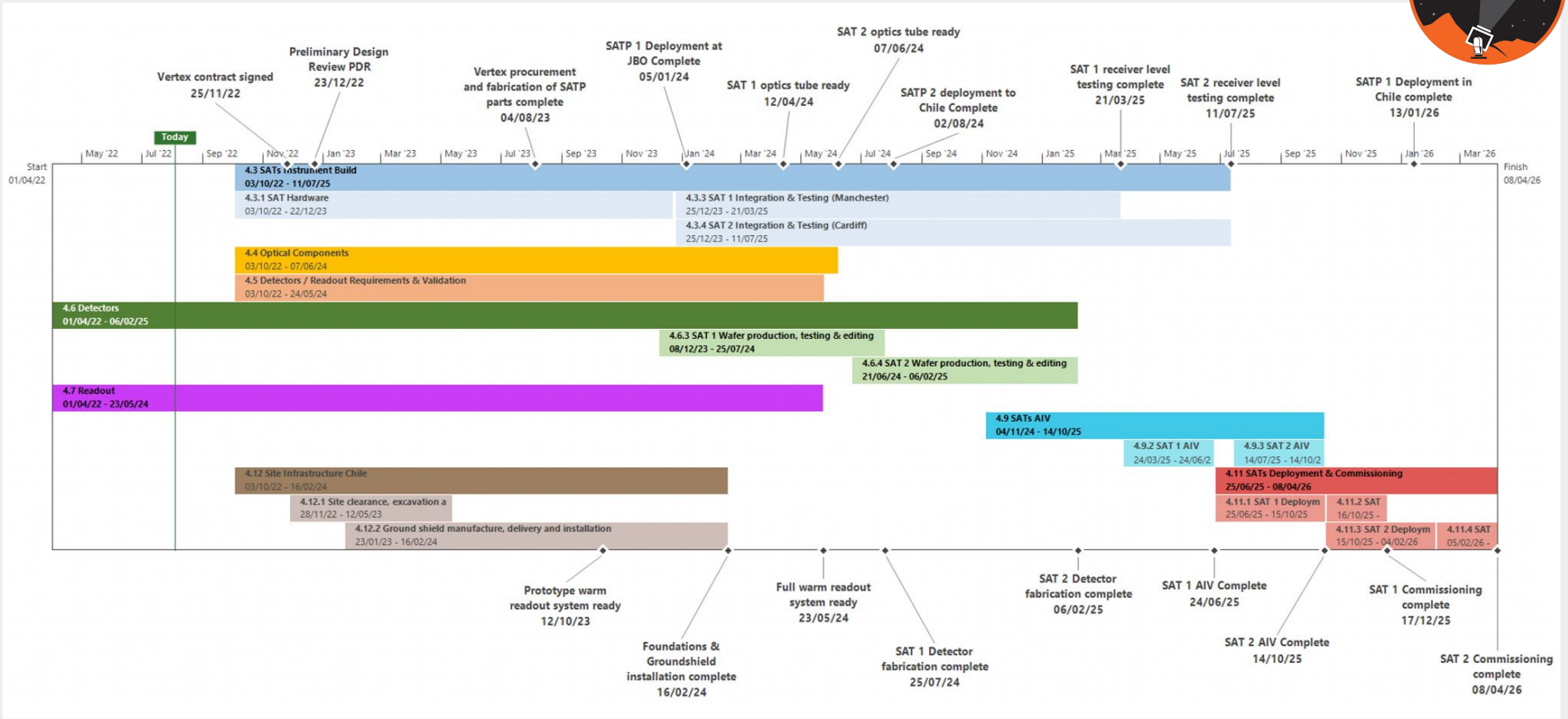
Likely (preliminary) siting of three additional SATs (two SO:UK and one SO:Japan)

Preliminary

Site infrastructure (Chile)

- HEF infrastructure (expansion of site electrical distribution and cooling system).
- Ground screens.
- Foundations for telescopes and ground screens.
- Site access and telescope installation.
- Telescope ops (power) during commissioning.
- Local engineering support.

Project schedule (SATs only)



SO:UK Data Management

SO:UK Data Centre

- A lead role in delivering the "Science Ready Data Products" (SRDPs):
  - **Per-frequency maps**, fully validated for subsequent science analysis, for SO wide and deep surveys.
  - **Prompt products** (transient alerts & light curves).

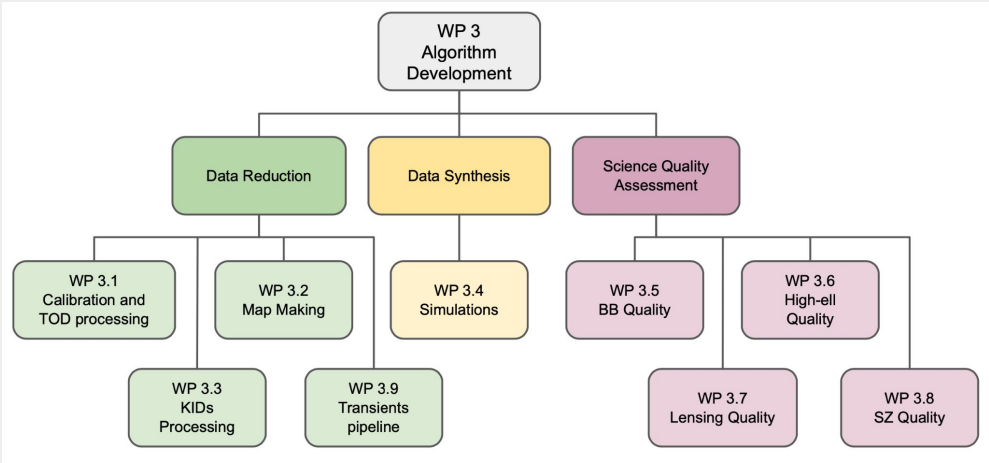
- **Software engineering support** for SO Data Management tasks, pipeline working groups (PWGs) and analysis working groups (AWGs).

- **Data access service** (both internal and, ultimately, external to SO).

- Includes **HPC infrastructure** for use by entire SO collaboration. SO:UK software engineers will help SO members access UK facility.

SO:UK Algorithm Development

- Primarily postdoc effort distributed across five primary SO:UK institutes to develop and optimise algorithms for SO data processing.
- Major focus on developing tools needed to deliver UK data centre activities (e.g. validation tools for delivering SRDPs).
- Fully integrated within SO's DMG and WBS.
- Contributions to SO's "Data Reduction" (WBS 1.6.7), "Data Synthesis" (WBS 1.6.6) and likely new "Data Delivery and Science Readiness" Level-3 WBS elements.



Announcements

- **Job opportunities in SO:UK Instrumentation at Manchester:**

  - Senior Research Fellow (lead role in SATs delivery): https://jobregister.aas.org/ad/8369017c

  - Research Associate/Fellow (Detectors/Readout testing and HWP rotation mechanism development): https://jobregister.aas.org/ad/9c37814d

  - Senior Technician (at Jodrell Bank Observatory): https://www.jobs.ac.uk/job/CUX489/senior-technician-simons-observatoryuk-project

Summary

- SO will be one of the **leading CMB experiments of the 2020s**.
- UK will play a leading role:
    - **Data centre** (UK delivering primary SO data products).
    - **Algorithm development** (leveraging key UK expertise to develop SO data pipeline algorithms).
    - **A KIDs-based UHF optics tube for the SO LAT** (demonstrating UK tech, in advance of future experiments).
    - **Two additional SATs** (pushing further on primordial *B*-modes).
- SO:UK positions UK CMB community well to pursue leading roles in future experiments (CMB-S4, CMB-HD, ESA Voyage 2050 etc.)