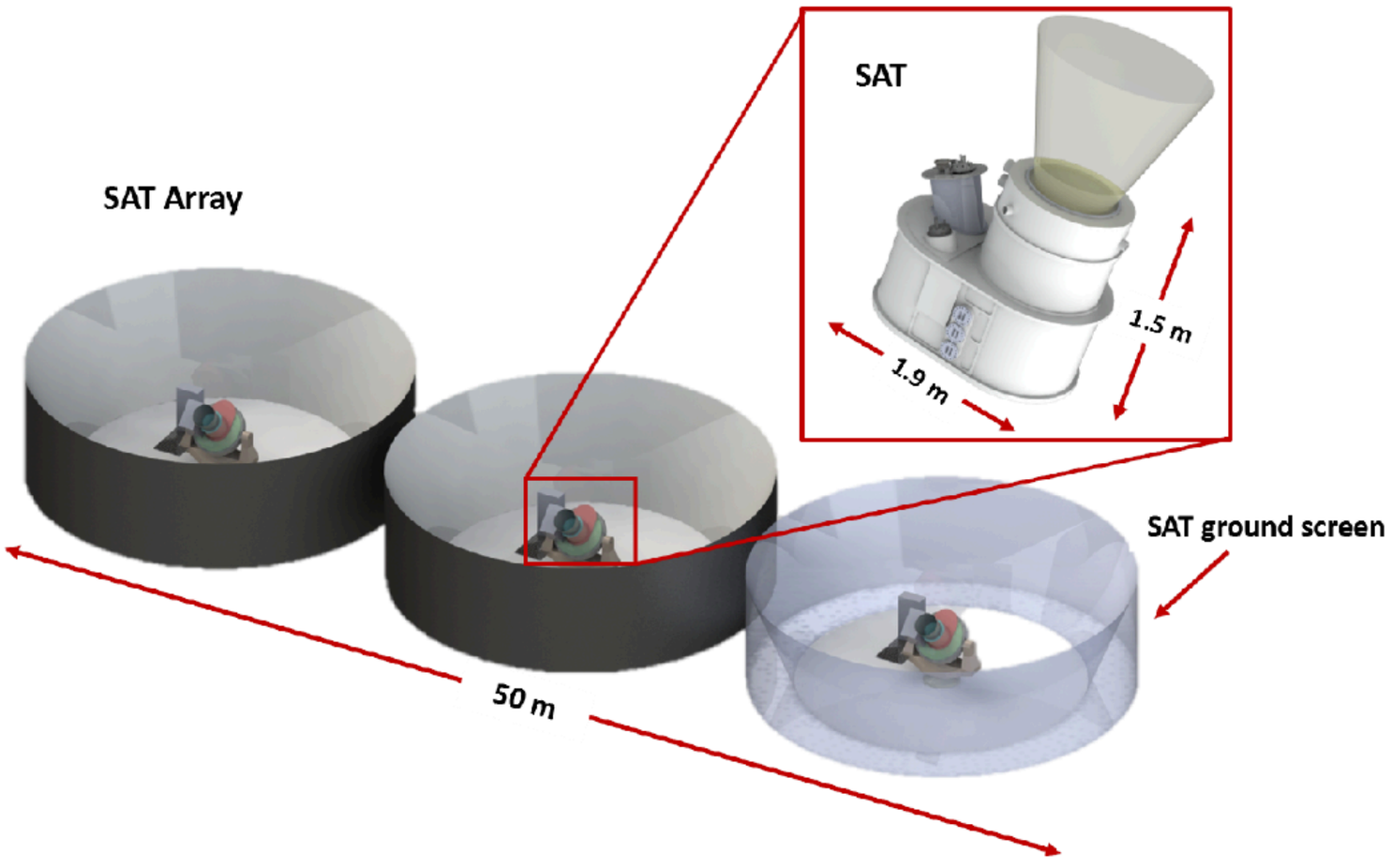
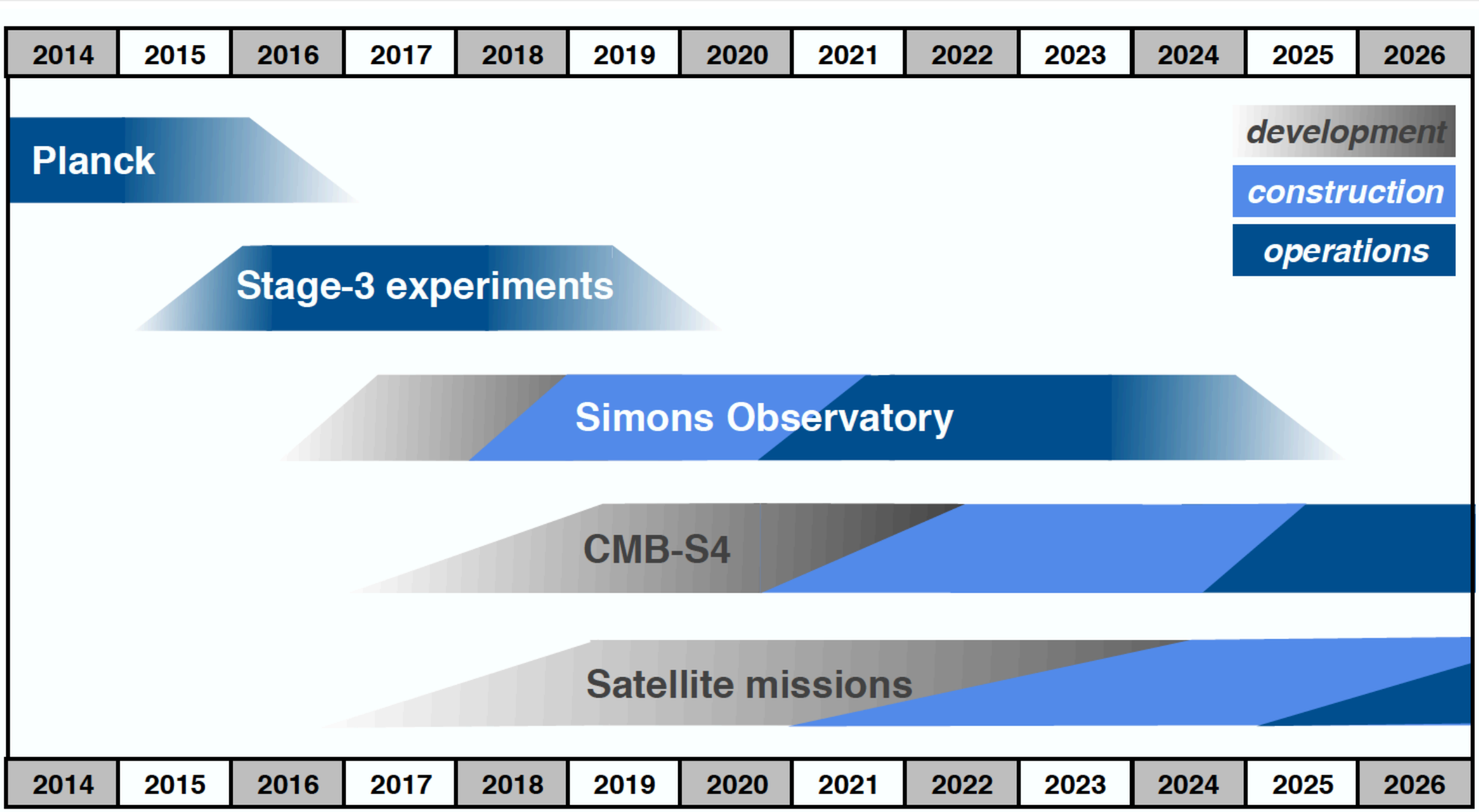
SO:UK - A major UK contribution to the Simons Observatory



Michael Brown (University of Manchester)
for the SO:UK collaboration

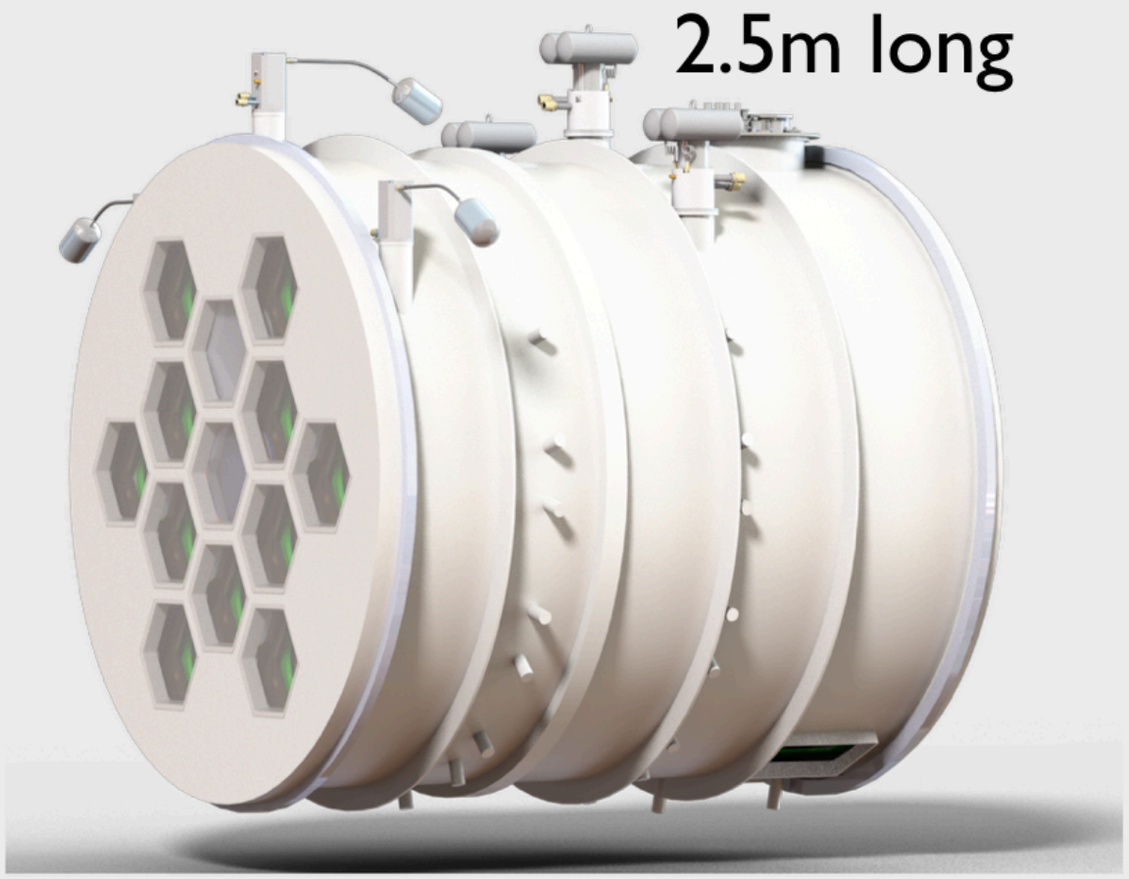
Background

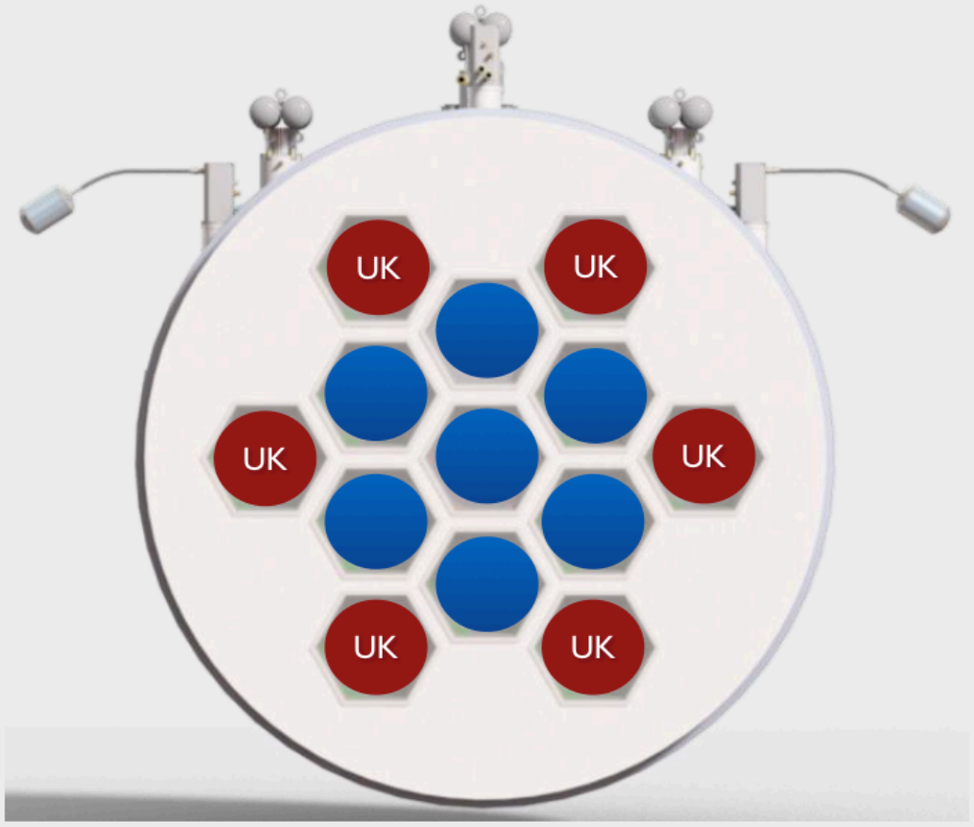
- **2016:** UK CMB community wrote a **white paper** outlining a proposed future roadmap, submitted to STFC Balance of Programs review. Several **UK groups join SO** collaboration.



Background

- **2017:** UK institutes submit a **"Statement of Interest" (SoI) to STFC** proposing a large instrument contribution to SO LAT. Reviewed by STFC's Science Board but **full proposal not invited**.





2.4m diameter ~5,000 kg 30,000 → 60,000 detectors

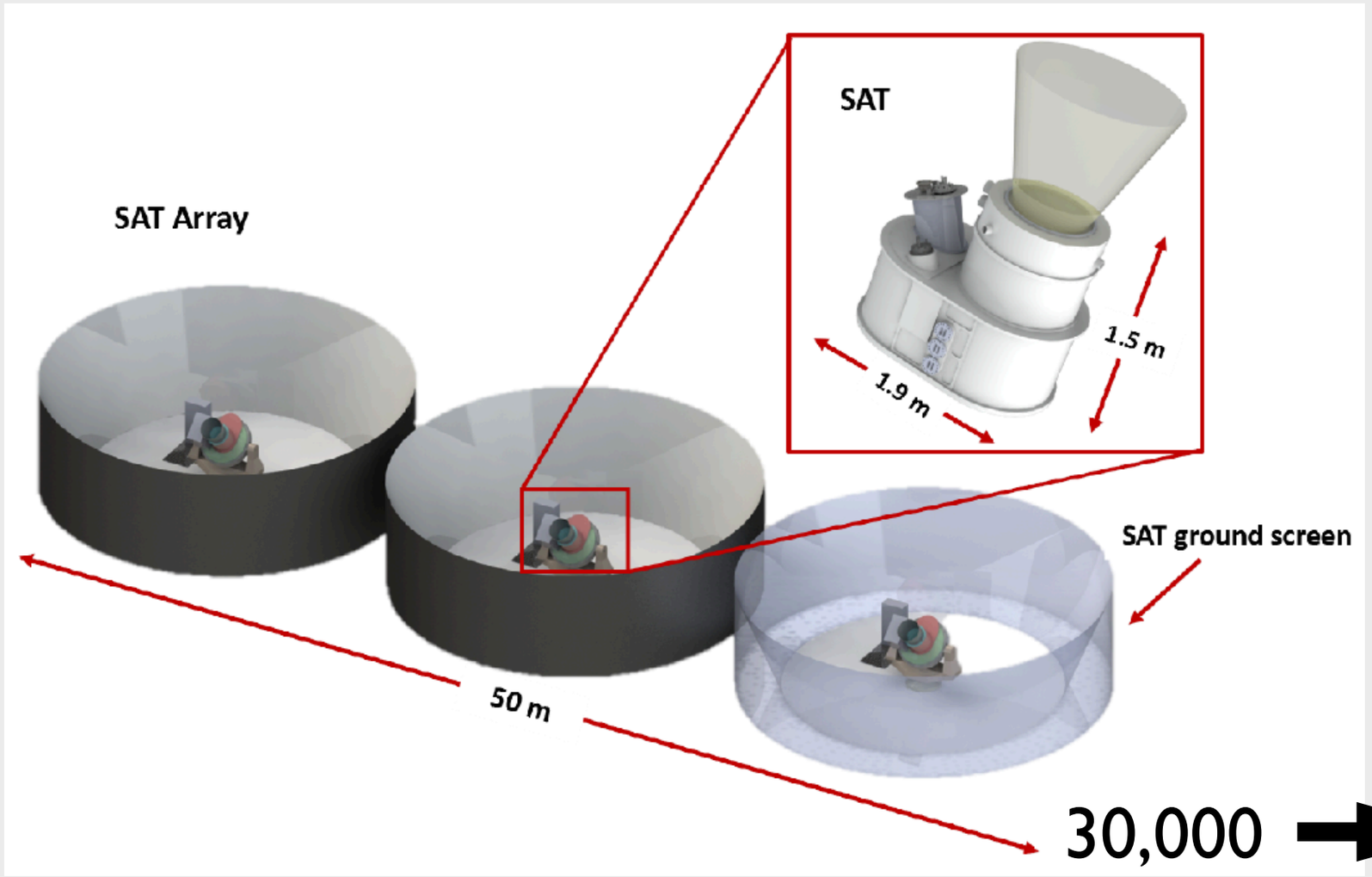
Background

- **2017/2018: ERC Synergy** application submitted for three SATs (on one mount), also **not successful**.

30,000 → 60,000 detectors

Background

- **2018:** STFC selects SO:UK as a **"High Priority Project"** (5 in Astronomy).
- **2018:** SO:UK proposed to STFC as a potential bid into UKRI's Fund for International collaboration (FIC). **STFC pre-selects SO:UK but bid is ultimately unsuccessful.**



30,000 → 60,000 detectors

Background

- **2019:** UK institutes submit a second **SoI to STFC**. Science Board **invites full proposal**.
- Submitted July 2019 and currently under review.

The SO:UK Collaboration

The University of Manchester

Richard Battye
Michael Brown
Jens Chluba
Simon Melhuish
Lucio Piccirillo
Neil Roddis
Bob Watson

Cardiff University
Prifysgol Caerdydd

Peter Ade
Erminia Calabrese
Simon Doyle
Peter Hargrave
Giampaolo Pisano
Rashmi Sudiwala
Carole Tucker

University of Cambridge

Anthony Challinor
James Fergusson
Paul Shellard
Blake Sherwin

Imperial College London

Dave Clements
Carlo Contaldi
Alan Heavens
Andrew Jaffe

University of Oxford

David Alonso
Mike Jones
Angela Taylor

University of Sussex

Antony Lewis

The SO:UK Collaboration

+ lots of help from members of the wider SO collaboration!

The U

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UNIVERSITY OF OXFORD

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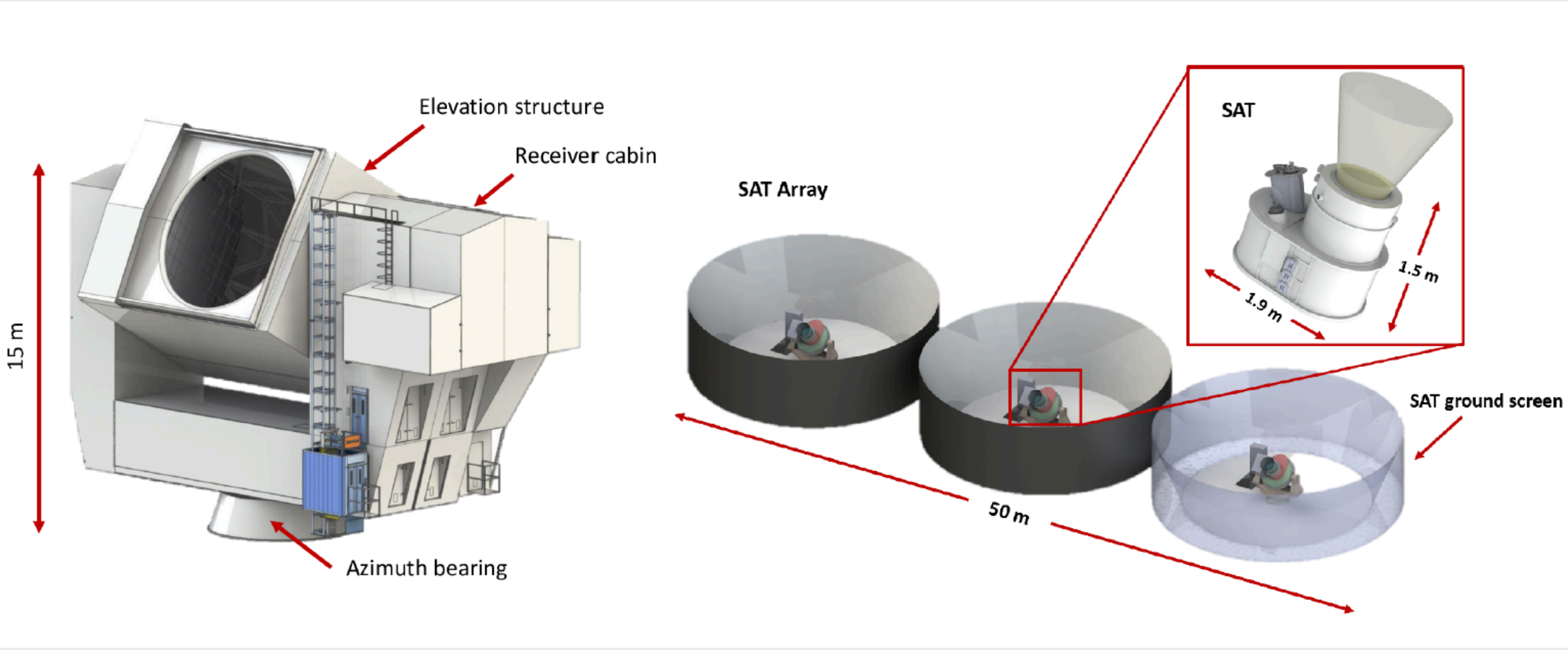
Instrument Concept

- Considered two possible options for a UK instrument contribution:
  - "filling out" the SO Large Aperture Telescope focal plane.
  - adding a further three Small Aperture Telescopes.



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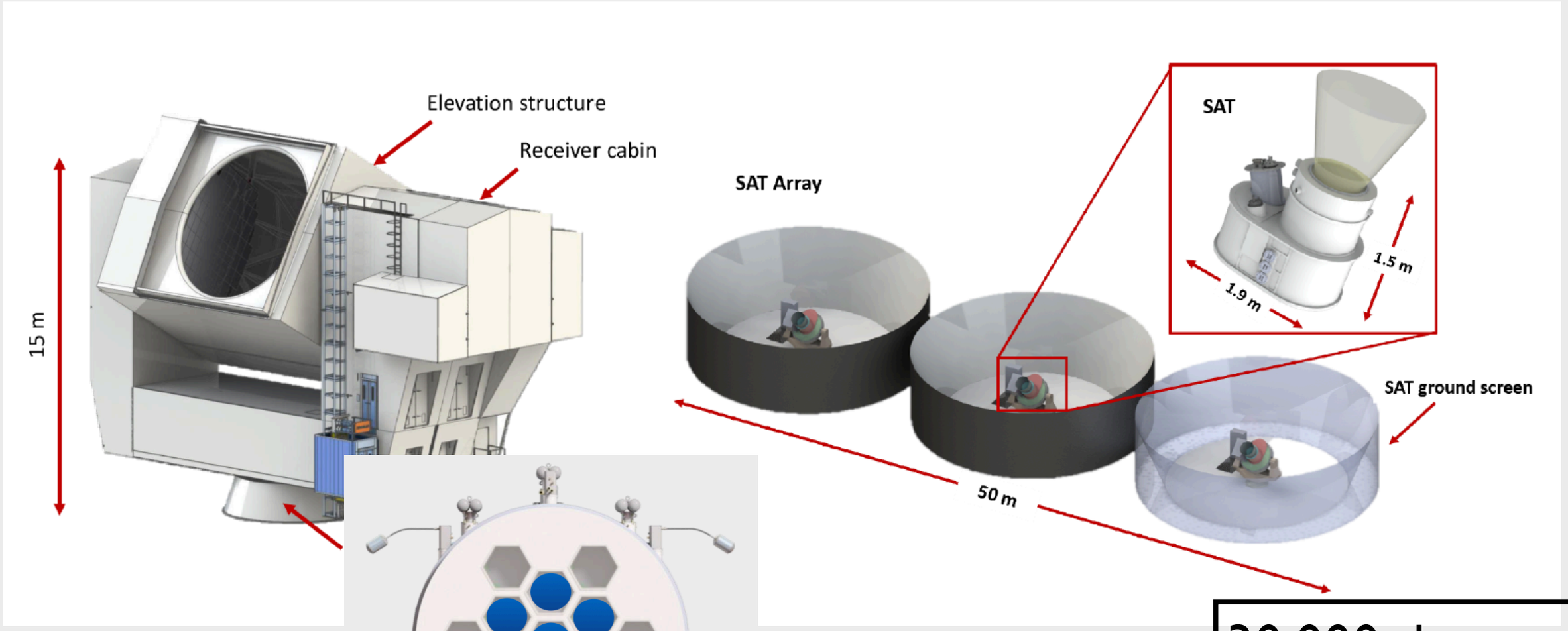


30,000 detectors

30,000 detectors

Instrument Concept

Option 2 (three additional SATs) selected.

- Considered various configurations for SO:UK frequency distribution. Ultimately chose to concentrate all sensitivity in 93 / 150 GHz frequency channels based on forecasts including foregrounds.

Table 2: Approximate number of detectors provided by the SO and SO:UK SATs in each of the six SO frequency channels. Also listed is the forecasted map-noise level for a 5-year deep survey covering ∼10% of the sky, with the SO + SO:UK combined instrument.

Freq. [GHz]	FWHM [arcmin]	SO detector count	SO:UK det. count	Map noise [μK-arcmin]
27	91	∼300	0	35
39	63	∼300	0	22
93	30	∼10,000	∼15,000	1.8
150	17	∼10,000	∼15,000	2.2
225	11	∼5,000	0	6.4
280	9	∼5,000	0	16

Scientific Justification

- Focussed on search for primordial gravitational waves.

Table 1: Tensor-to-scalar ratio forecasts for SO, and with the addition of SO:UK, for varying levels of the accuracy with which the contamination from lensing B-modes can be removed.

Delensing level	5-year mission		10-year mission	
	SO $\sigma(r)$	SO + SO:UK $\sigma(r)$	SO $\sigma(r)$	SO + SO:UK $\sigma(r)$
No delensing	3.1×10^{-3}	2.4×10^{-3}	2.4×10^{-3}	2.1×10^{-3}
50% delensing	2.3×10^{-3}	1.6×10^{-3}	1.6×10^{-3}	1.3×10^{-3}
70% delensing	2.0×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.0×10^{-3}

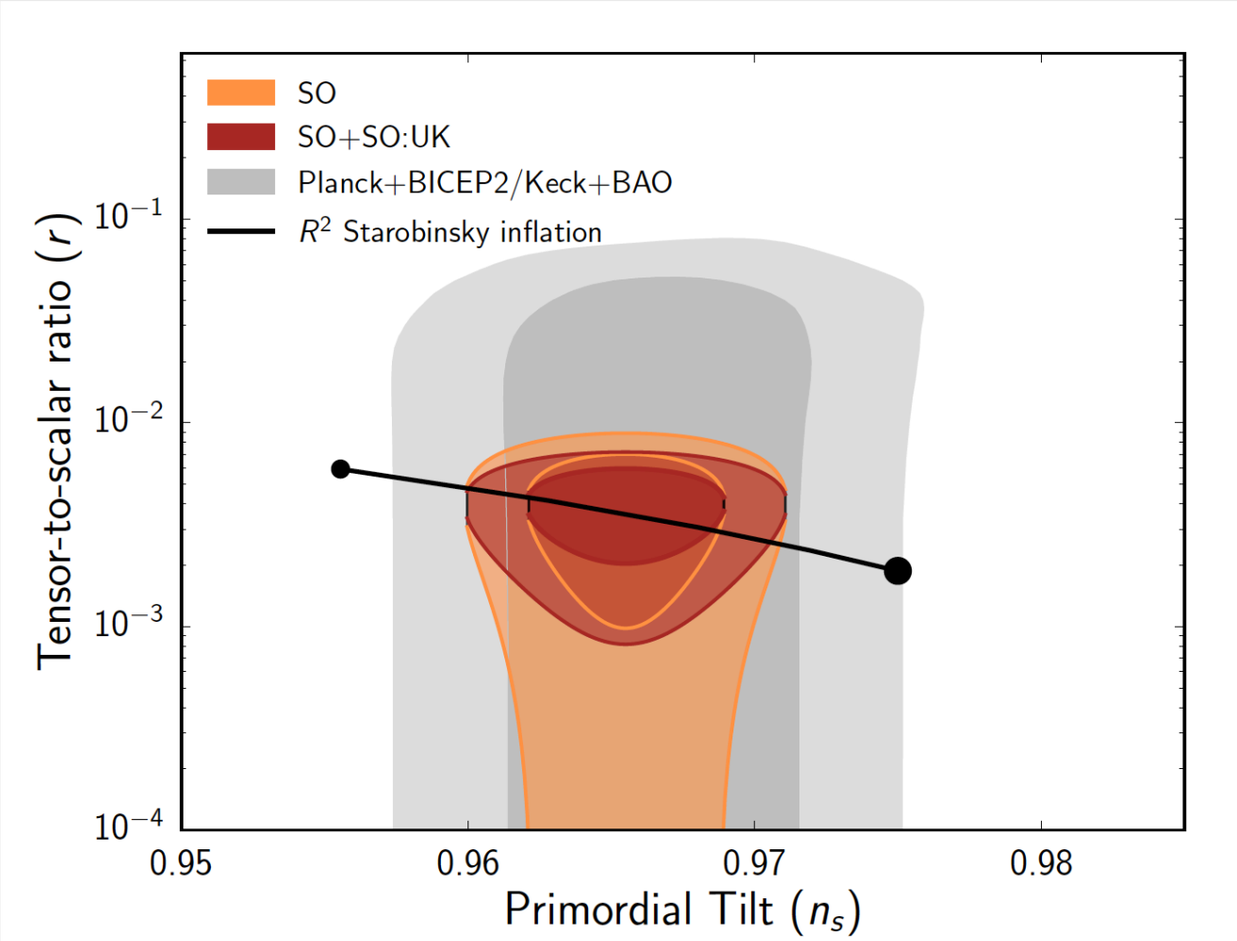
- 50% delensing probably achievable after 5 year mission.
- 70% delensing may be achievable after 10 year mission (with final LSST, Euclid maps).

Scientific Justification

- $1/N_*^2$ models (e.g. R^2 inflation) typically predict:

$$2 \times 10^{-3} < r < 5 \times 10^{-3}$$

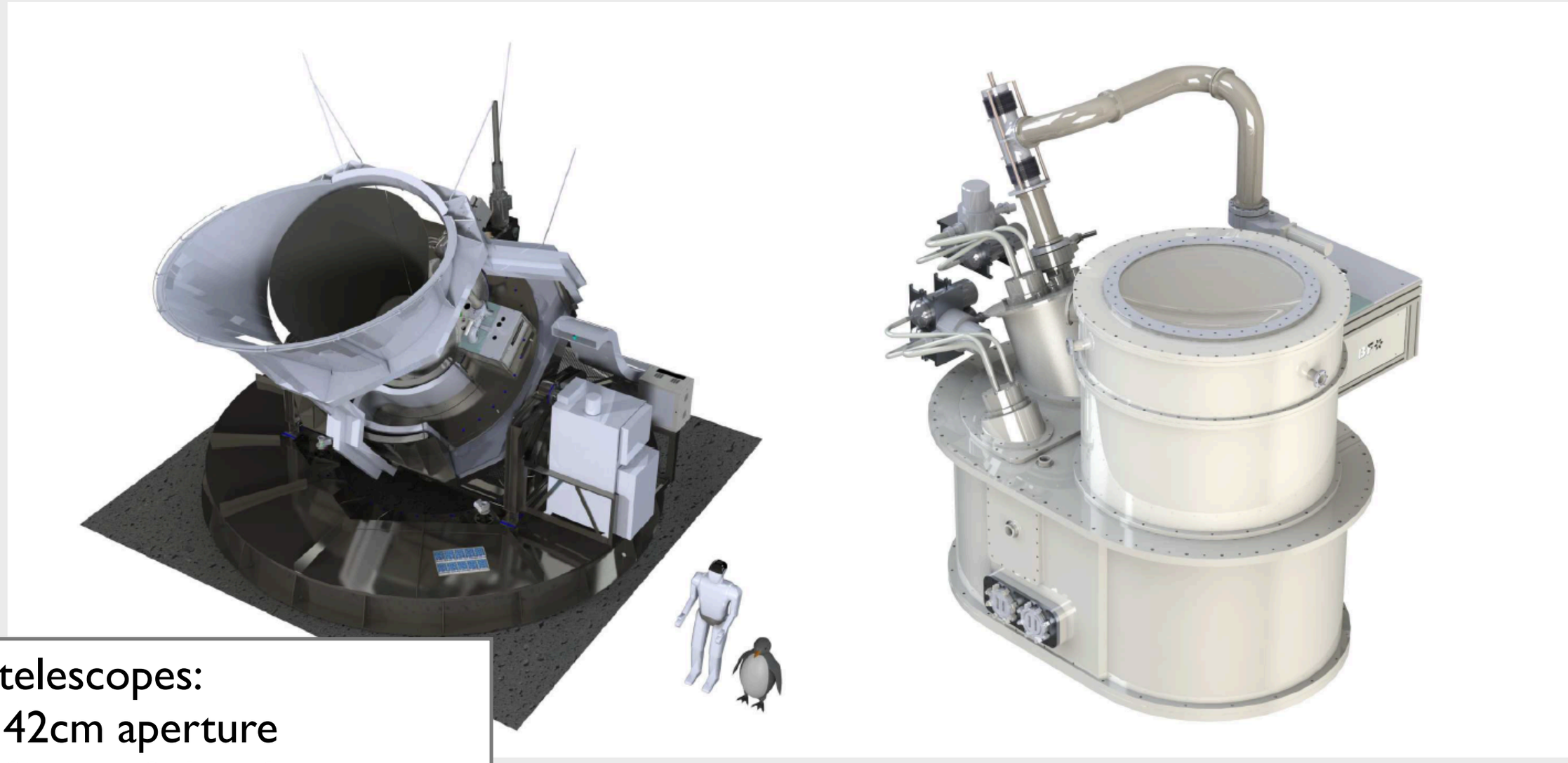
- UK SATs can potentially bring this important class of models within reach of SO.



- UK SATs providing ~50% of SO sensitivity to primordial B-modes and potentially bringing important candidate inflation models within reach.

SO:UK Instrument

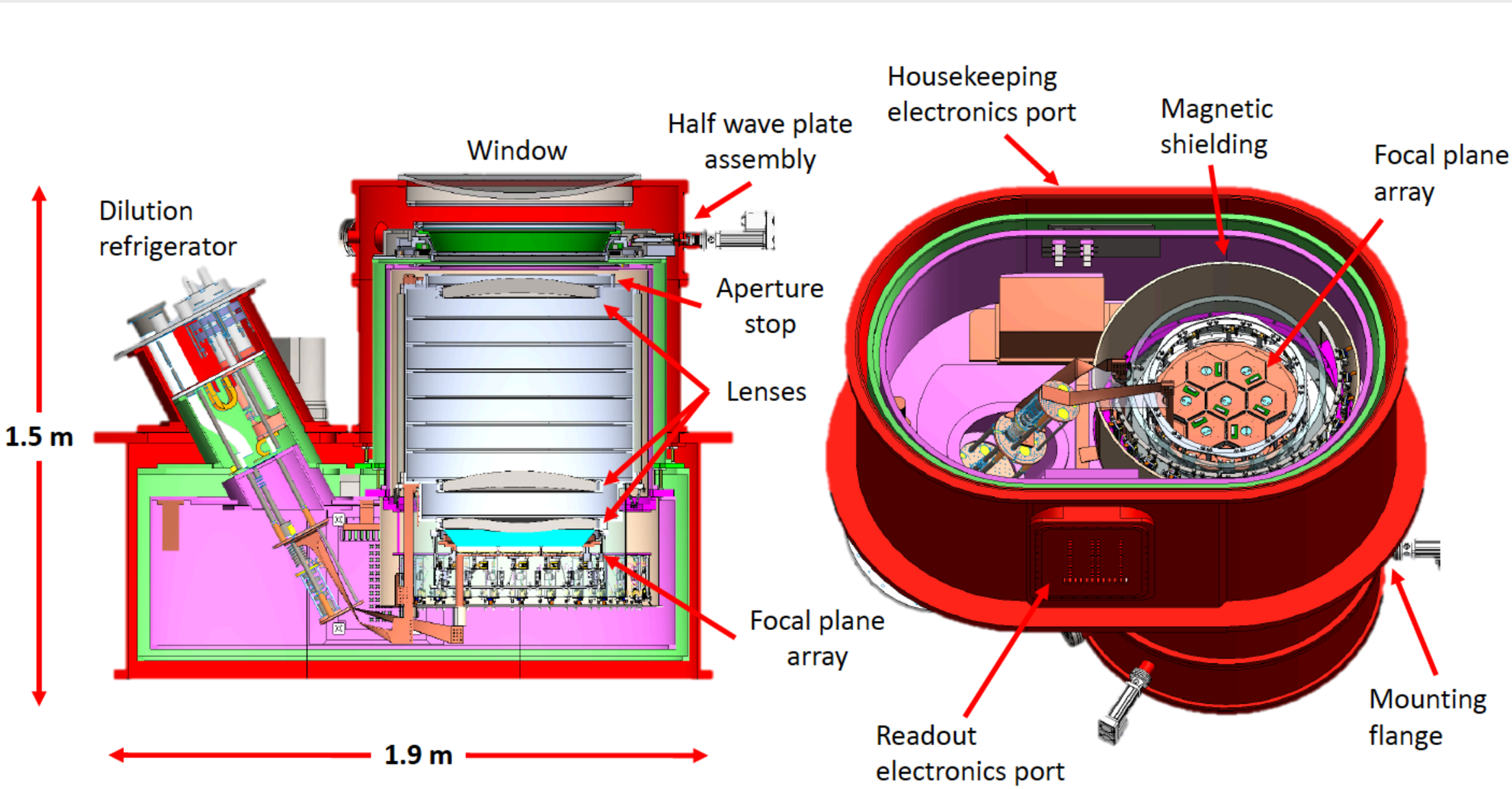
- Great deal of work already put into designing SO SATs. Will obviously want to (re-)use many aspects of that work…



3 telescopes:
- 42cm aperture
- 35 deg field-of-view
- 2 x 90/150 GHz
- 1 x 220/270 GHz
- + 27/39 GHz optics tube

SO:UK Instrument

- …but SO:UK SAT design also includes key distinguishing features:



SO:UK Instrument

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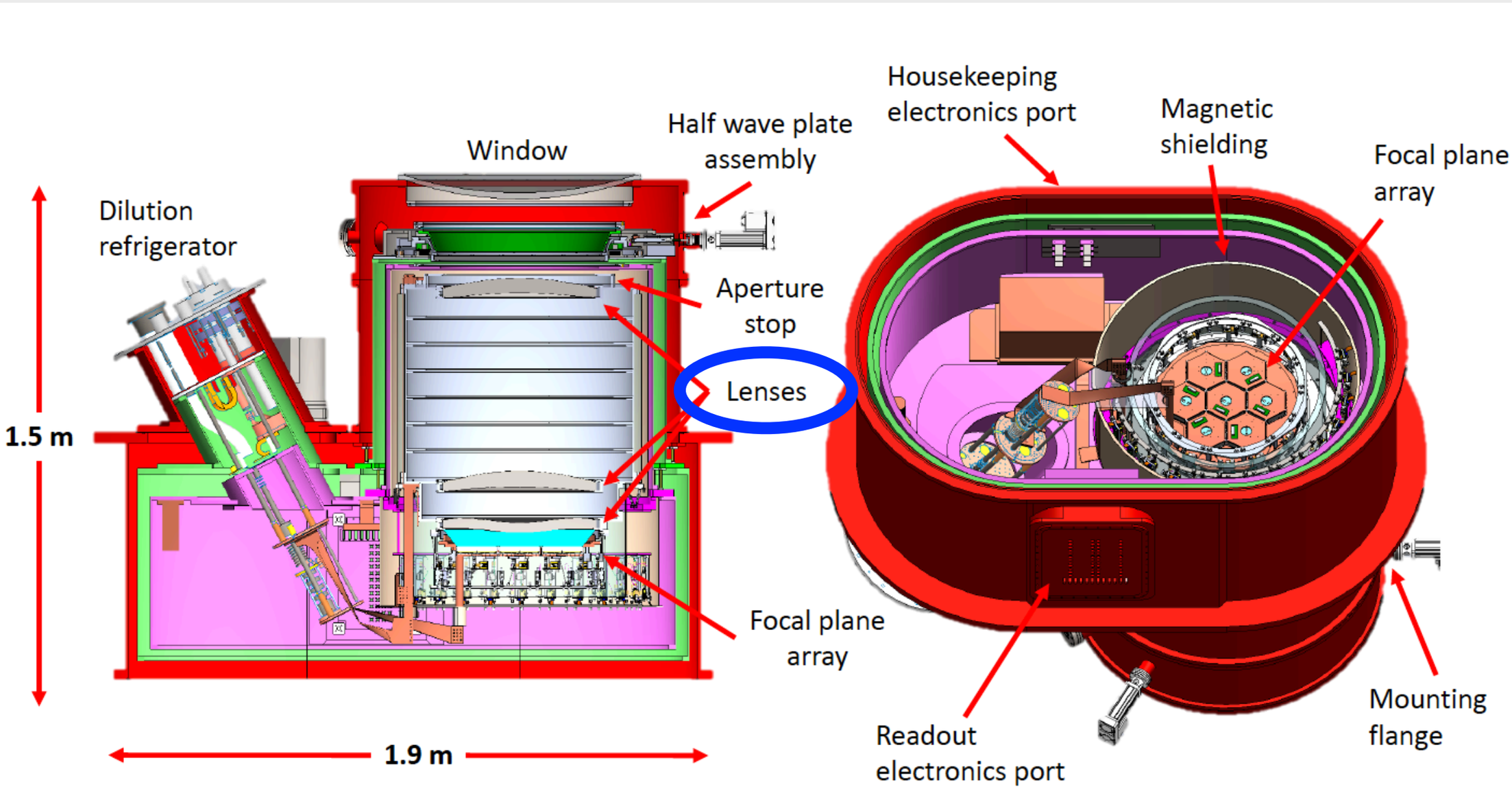
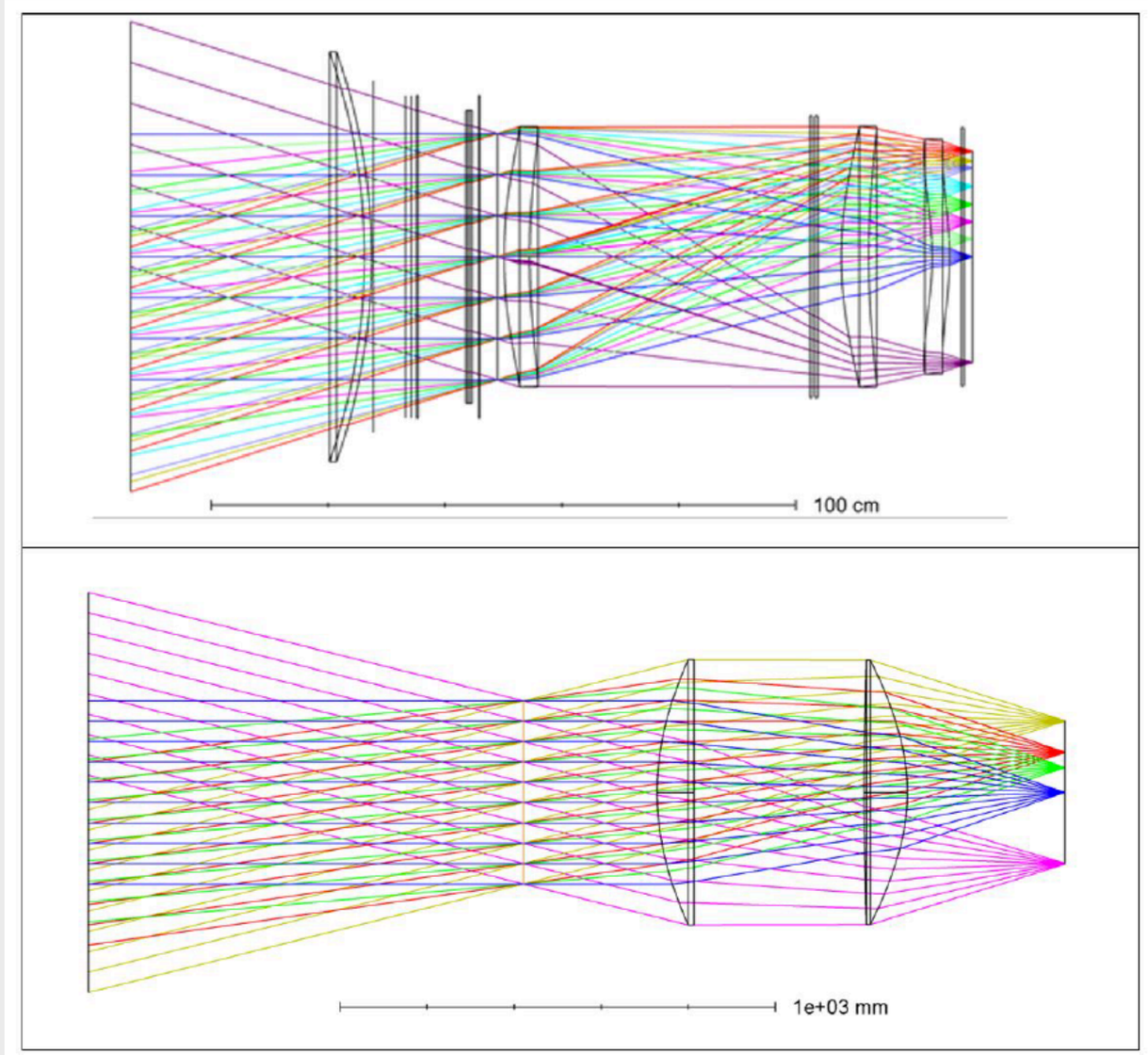


SO:UK Instrument

- …but SO:UK SAT design also includes key distinguishing features:

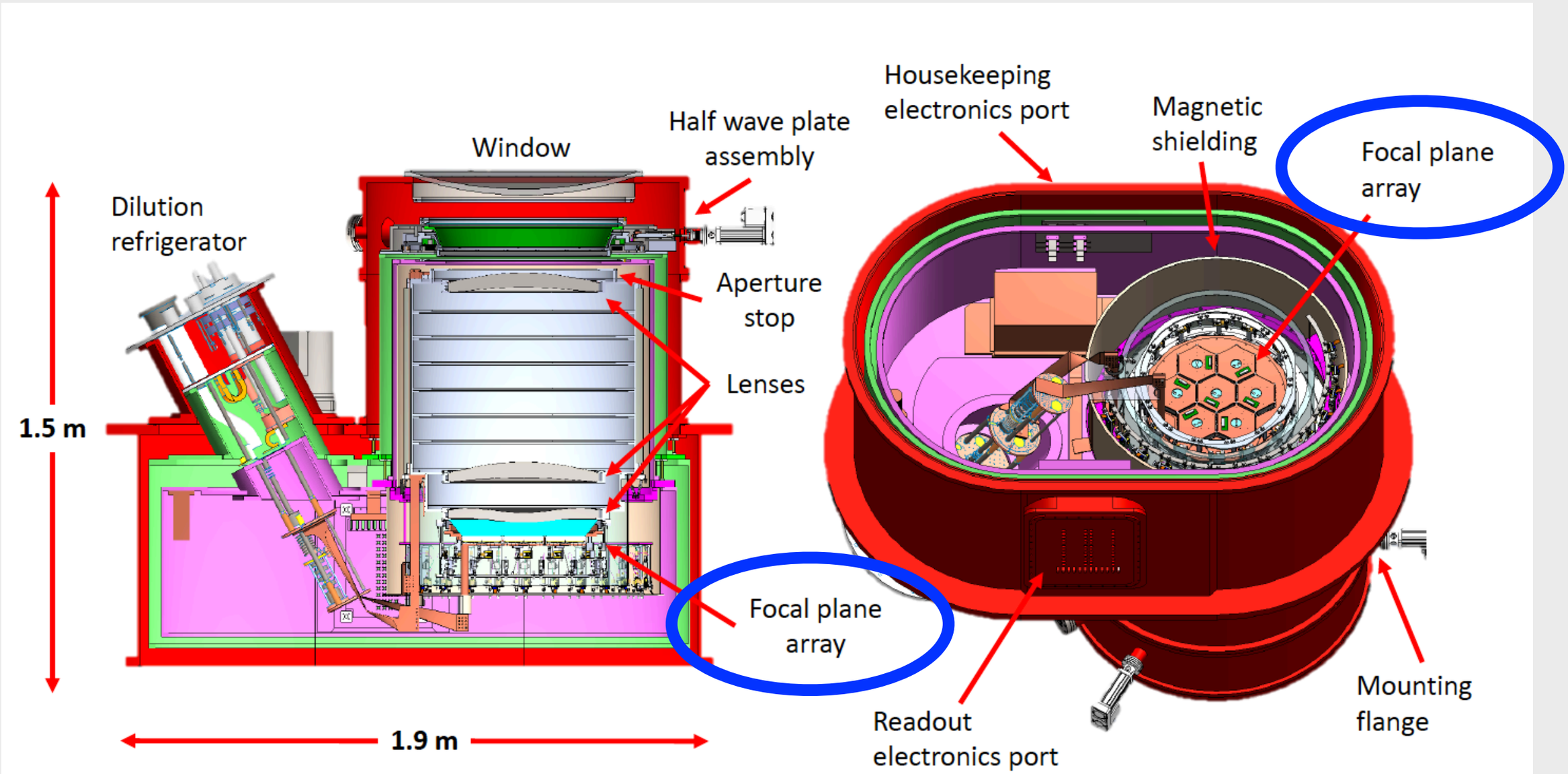
1. Optical components:



- Rather than traditional silicon lenses, will use **polypropylene (PP) lenses**. Allows for a much simpler optical design.
- Upgrade option to use MM lenses (fraction of mass of silicon lenses and are **flat ⇛ much easier to AR coat**.)
- Also use **metal-mesh filters** and **HWPs** - key technology developed in UK.

SO:UK Instrument

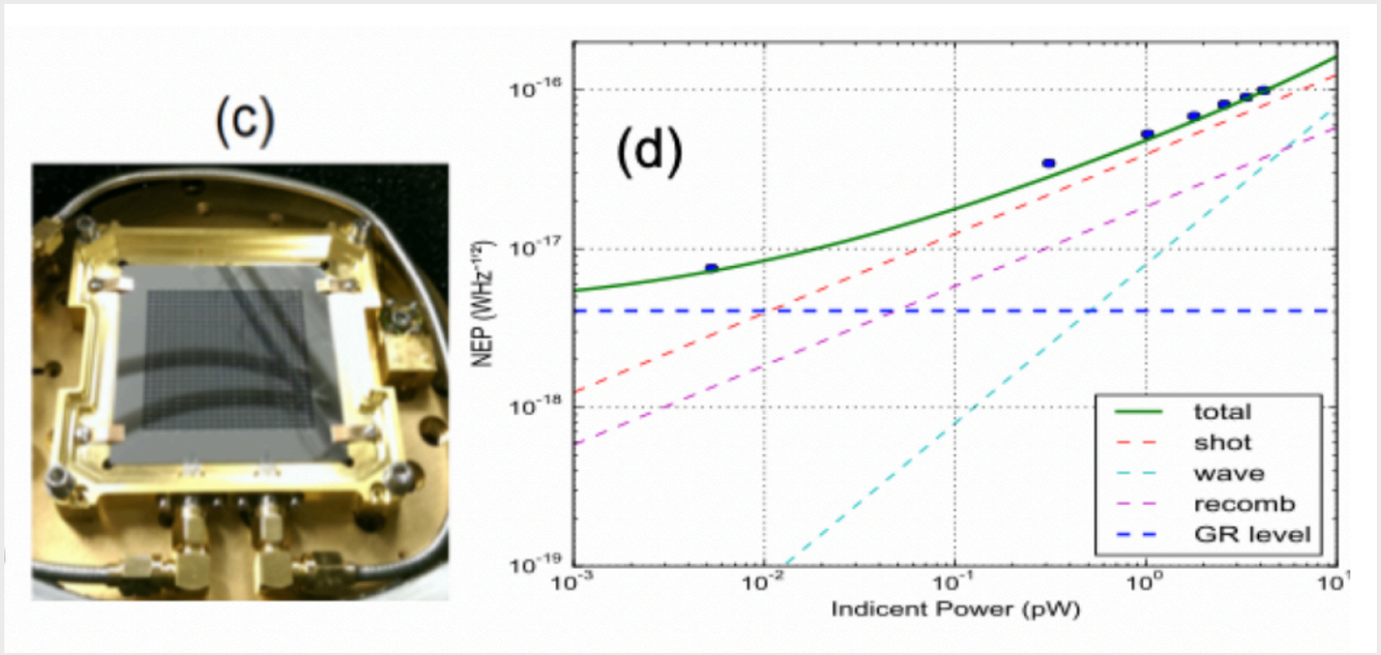
- …but SO:UK SAT design also includes key distinguishing features:



SO:UK Instrument

2. Kinetic Inductance Detectors for focal plane arrays:

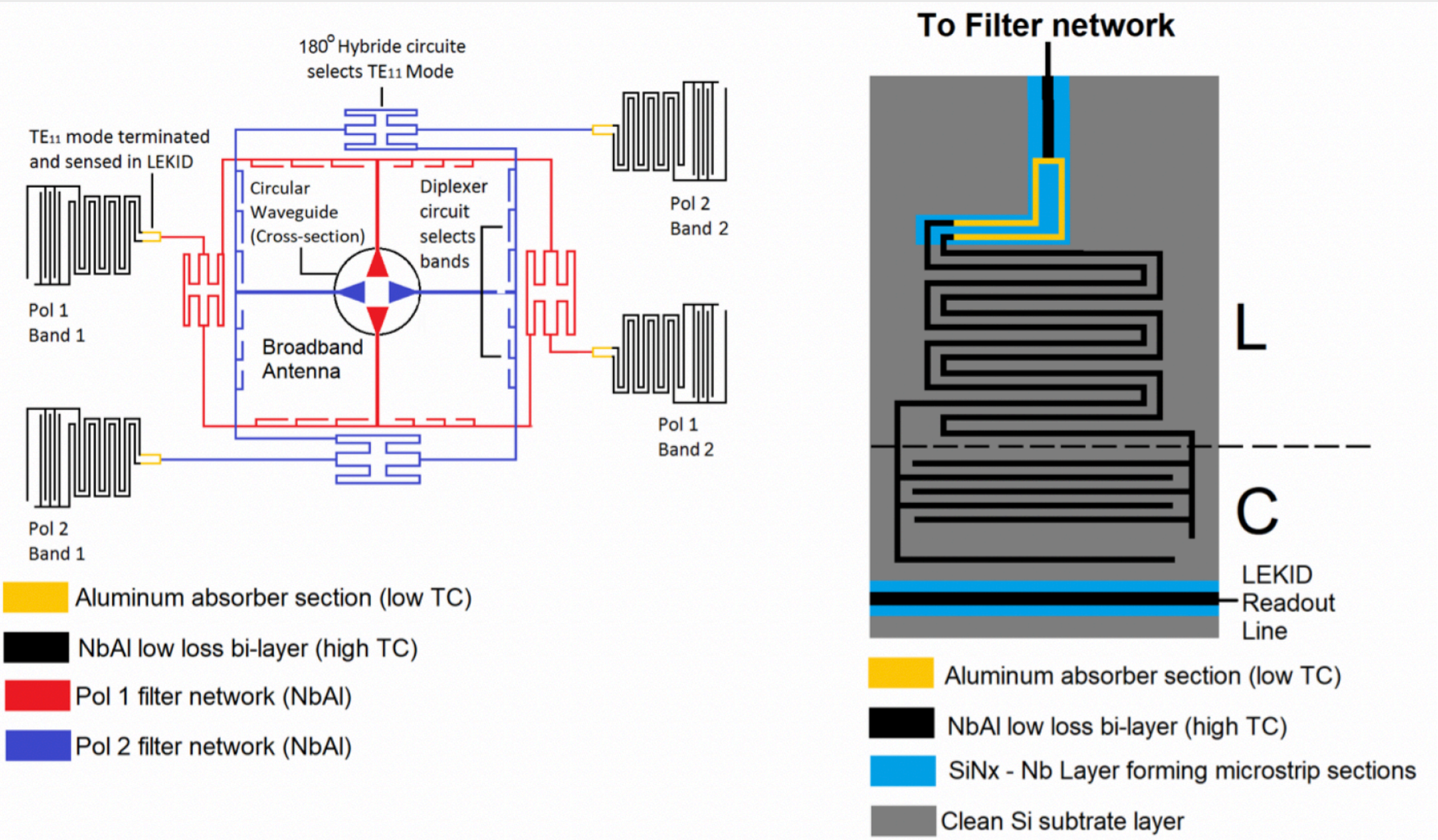
- Instead of TES detectors **SO:UK SATs will use** (LE)**KID** focal plane arrays.
- Much **easier to fabricate** than TESs.
- Much **easier to readout** than TESs - do not require complex SQUID readout systems.
- Multiple **UK and European** labs have world-leading **expertise in KIDs**.
- Potentially a **key enabling technology for CMB-S4**.



SO:UK Instrument

2. Kinetic Inductance Detectors for focal plane arrays:

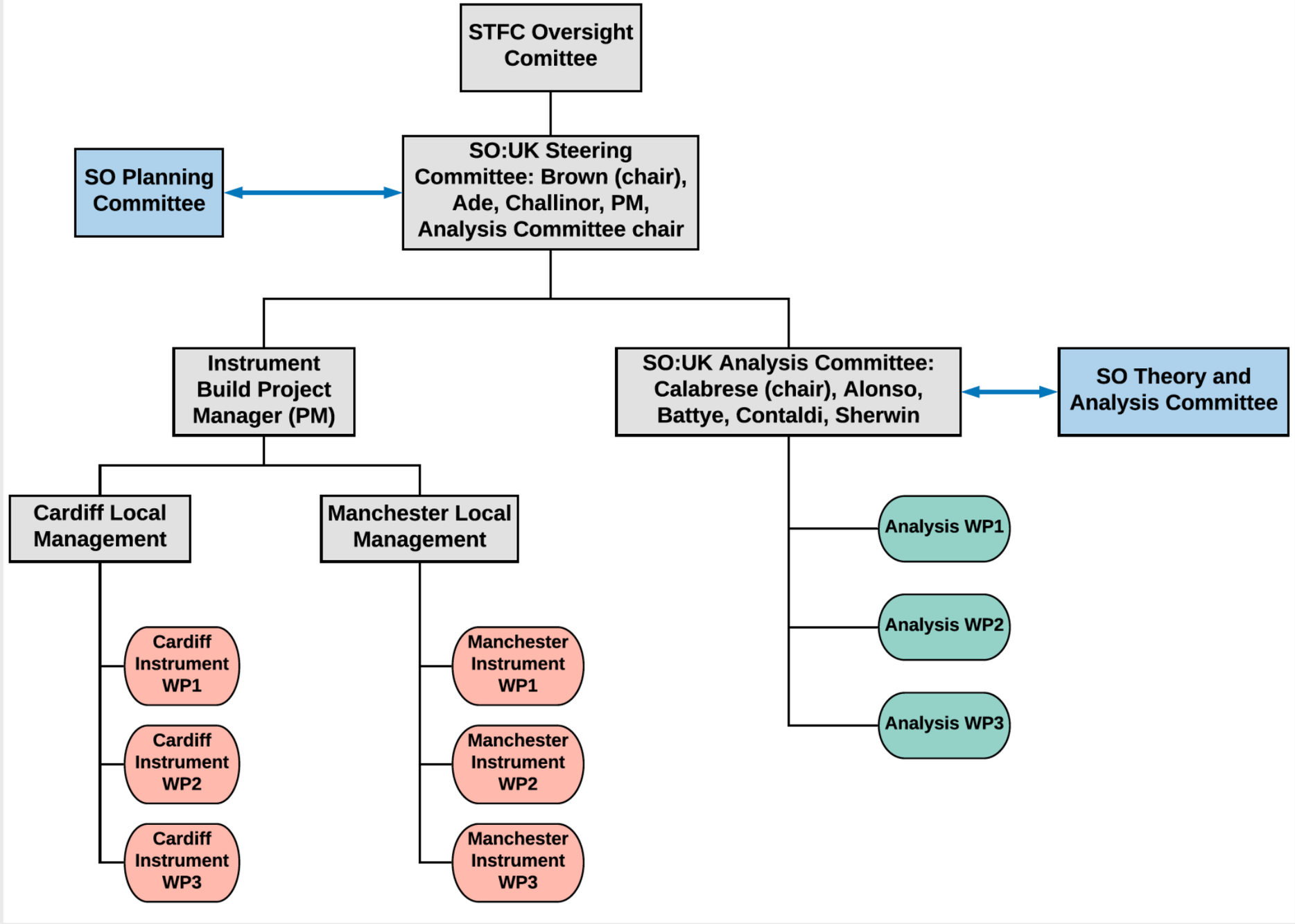
- A **dichroic dual-polarisation KID pixel** design for SO:UK:



SO:UK Analysis

- A major role in the SO data processing pipeline forms a critical part of the SO:UK proposal.
- Comprised of two components: (i) developing **low-level processing** functions specifically tailored **for KIDS** data (ii) more **general SO data processing** including for the data from the other SATs and the LAT.
- **Higher-level science exploitation** (which requires combination with other SO SATs and LAT) - and **publications** - will be done at the SO project-wide level.

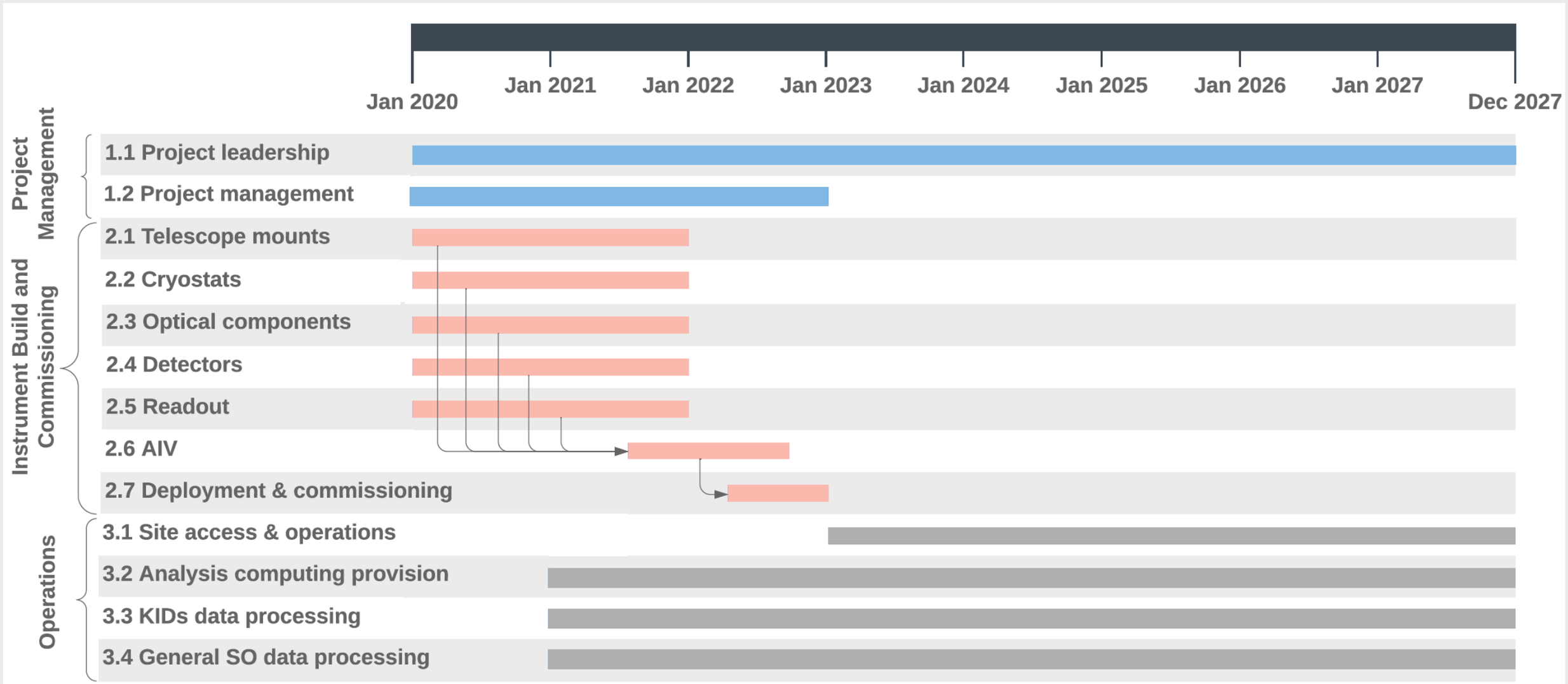
SO:UK Organisation



- Instrument work concentrated at Manchester and Cardiff; data processing work spread across all institutes.

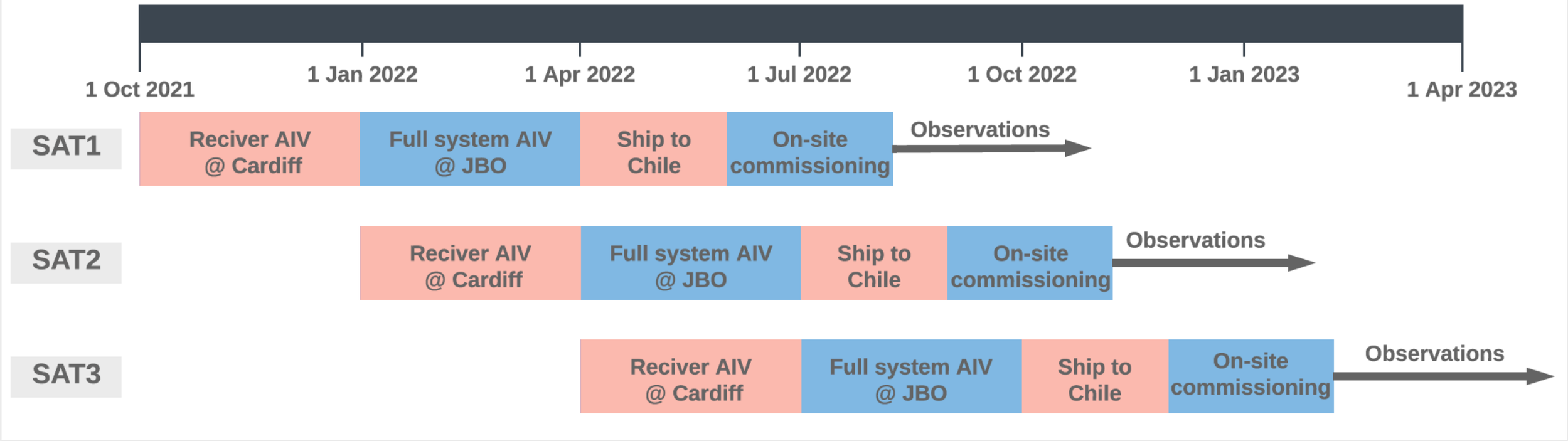
SO:UK Schedule

- Aiming for a **two-year build phase**, followed by a **phased deployment** of three SATs **during third year**.



SO:UK Schedule

- This is ambitious, but if achieved would result in the UK SATs providing **42% of the sensitivity for the 5-year SO "deep" survey**.

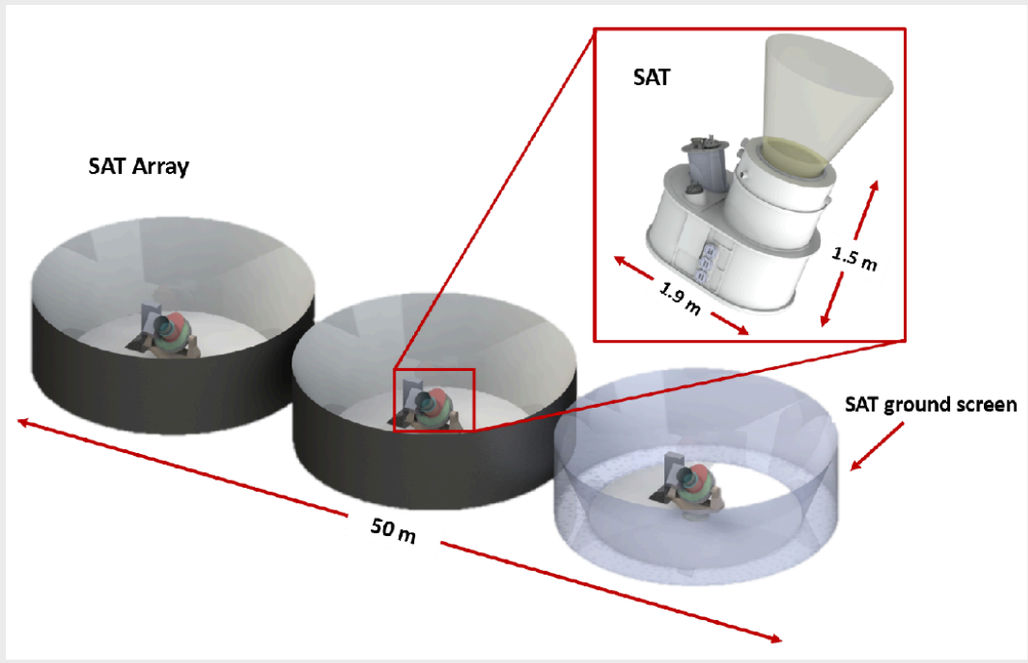


Current Status

- STFC's Science Board considered SoI in July and invited a full proposal to STFC's Project Peer Review Panel (PPRP).
- PPRP proposal has been submitted. Currently under review with applicant presentations and panel meetings happening this October/ November.
- If successful, likely project start date **~first quarter 2020**.

Summary

- The SO:UK will be a **distinctive facility** within the wider SO.
- SO:UK will provide ~50% of sensitivity for SO's deep survey. Major **enhancement of SO's science reach** in terms of primordial B-mode and inflation model constraints.
- Leverage leading role for Europe in SO (including **representation on SO Planning Committee / Executive Board**).
- Re-position the UK (and Europe more generally) for becoming major player in future ground-based experiments, e.g. **CMB-S4.**



THE END

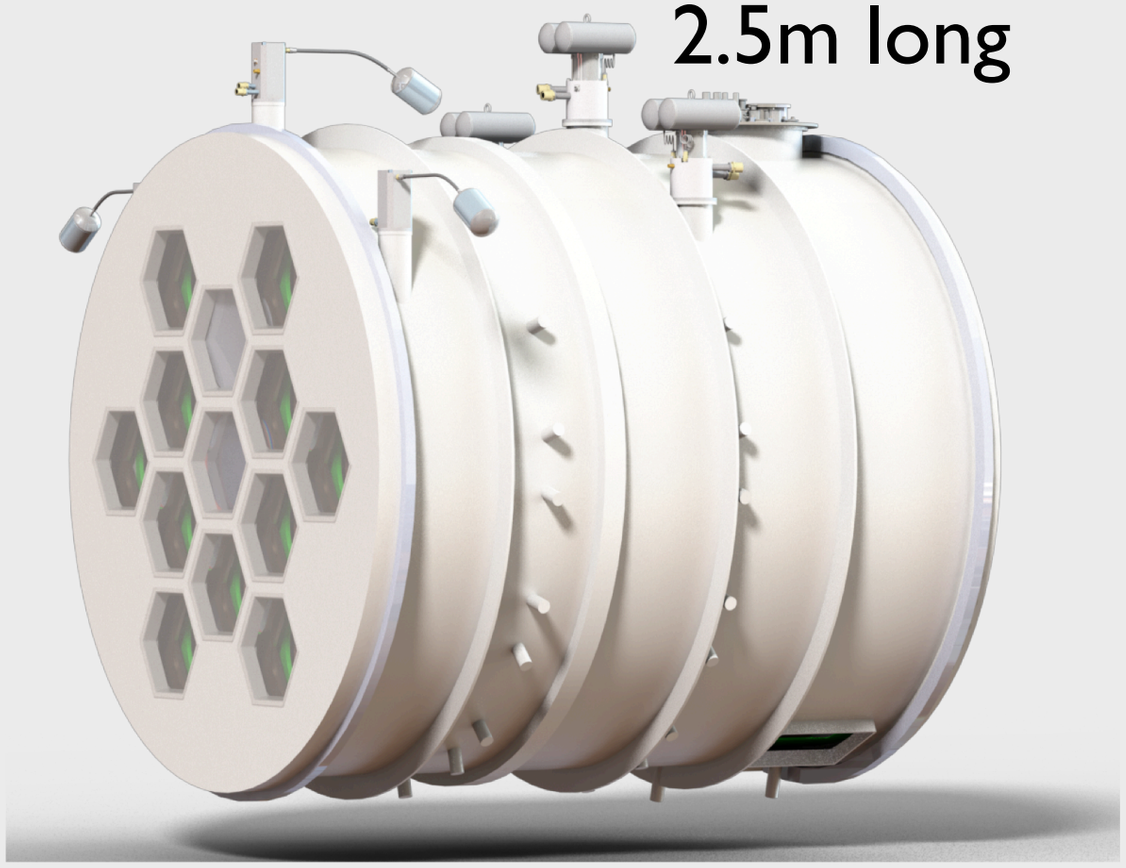
OLD SLIDES

Why small apertures?

- Have assessed the potential science impact of two options for a major European instrumental contribution to SO.
- Forecasts & conclusions that follow are not those of SO - they are those of the **UK/European proposal team**.

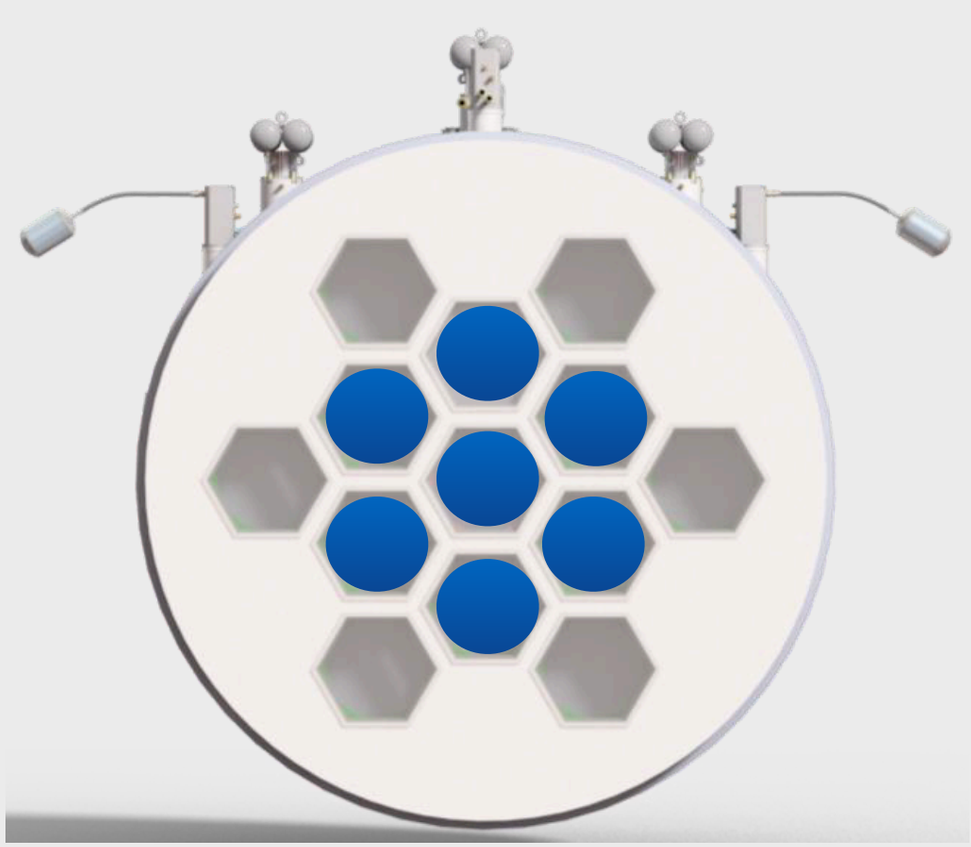
Option 1: Adding 6 European optics tubes to LAT receiver:

2.5m long



2.4m diameter

~5,000 kg



30,000 detectors

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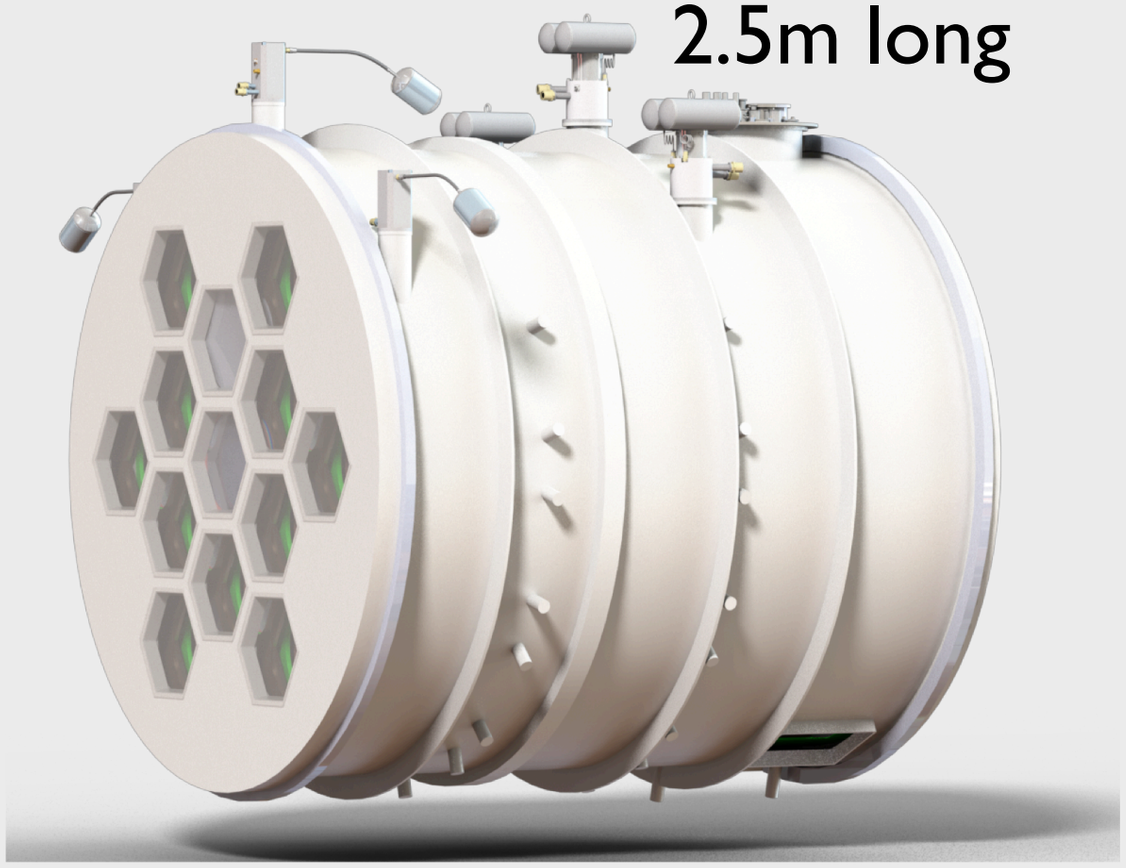

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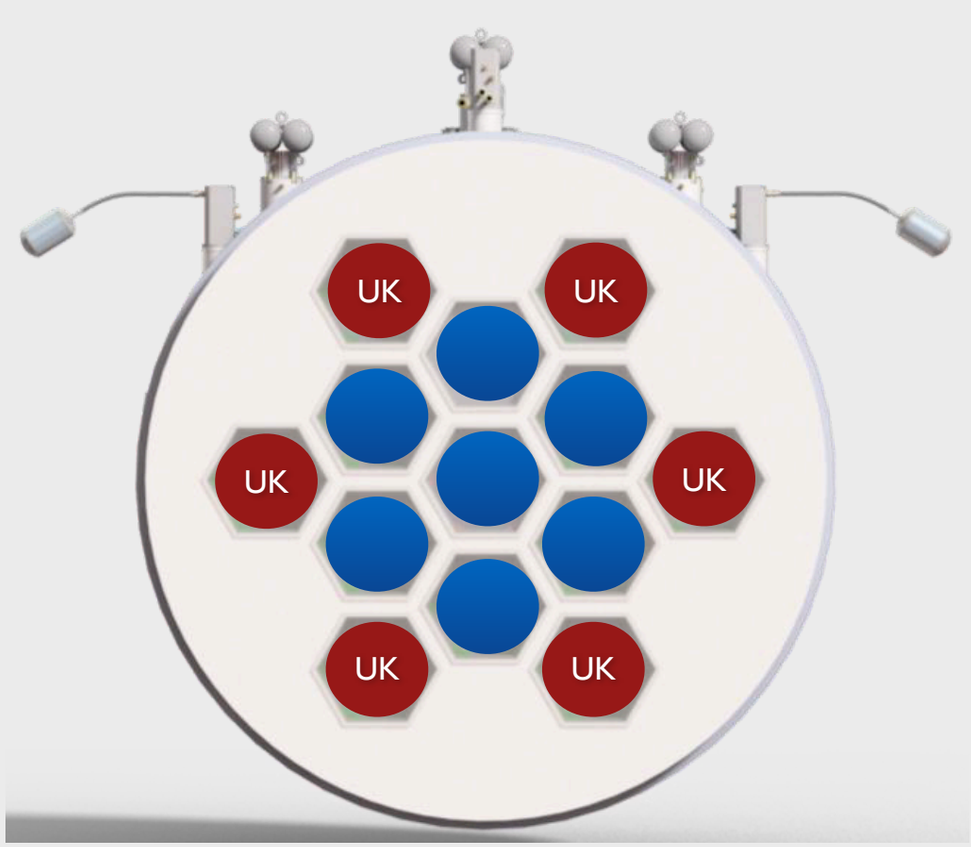


~60,000 detectors

Why small apertures?

Option 1: Adding 6 European optics tubes to LAT receiver:

- Focussed on high-ell science and de-lensing for "r".
- Forecasts for neutrino mass and N_{eff} after five year survey covering 40% of sky:

Baseline SO:		+ Euro tubes:
$\sigma(\Sigma m_\nu) = 74$ meV	→	$\sigma(\Sigma m_\nu) = 71$ meV
$\sigma(N_{\rm eff}) = 0.055$		$\sigma(N_{\rm eff}) = 0.050$

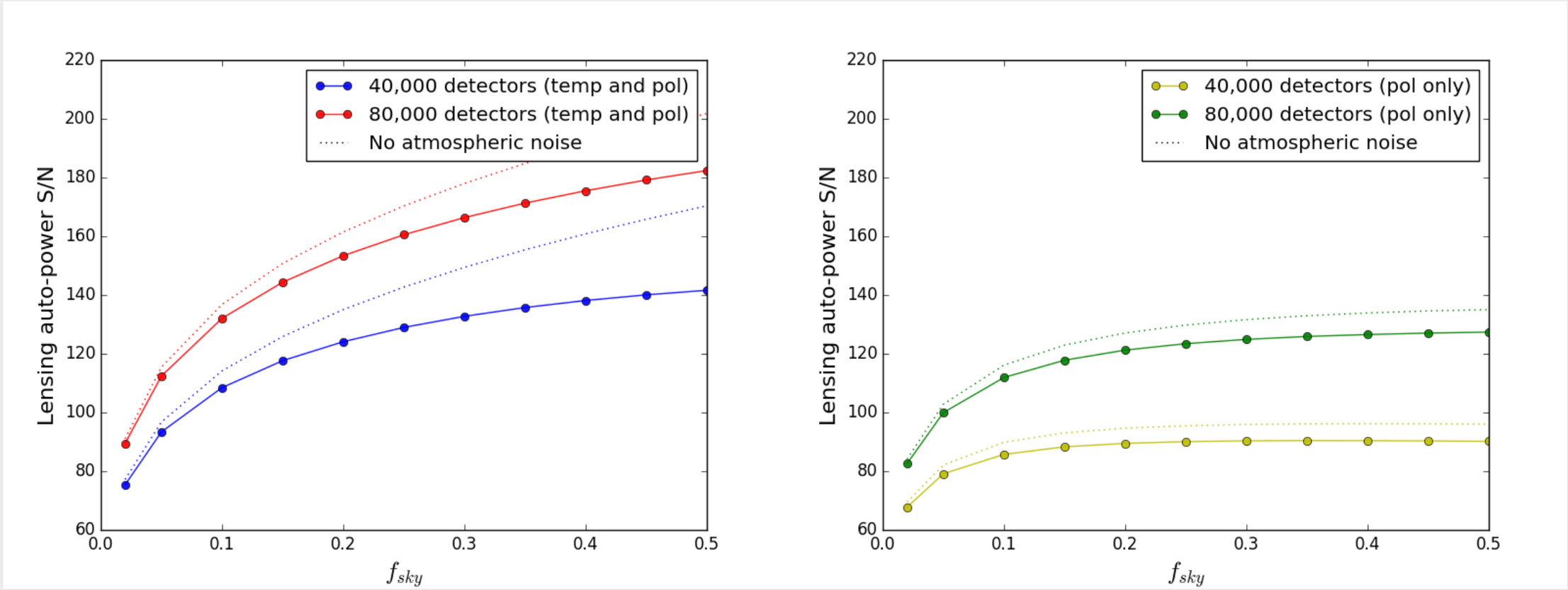
(E Calabrese)

- Even doubling the mapping speed of the LAT, difficult to make a large impact on headline science goals.
- Sample variance dominated at these noise levels so going deeper doesn't help much. (Also limited by external degeneracies, e.g. with optical depth, τ.)

Why small apertures?

Option 1: Adding 6 European optics tubes to LAT receiver:

- Improvement looks better in terms of S/N ratio of lensing potential reconstruction:



(D Han)

- Doesn't translate to better neutrino mass constraints, but useful for cross-correlations with LSS surveys.

Why small apertures?

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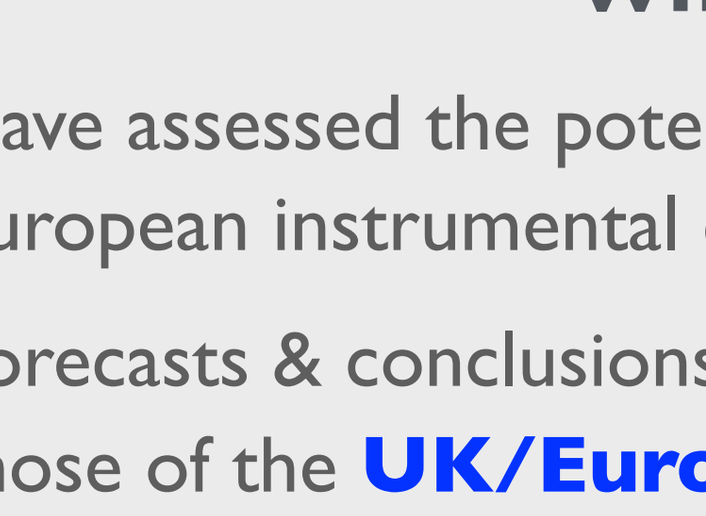
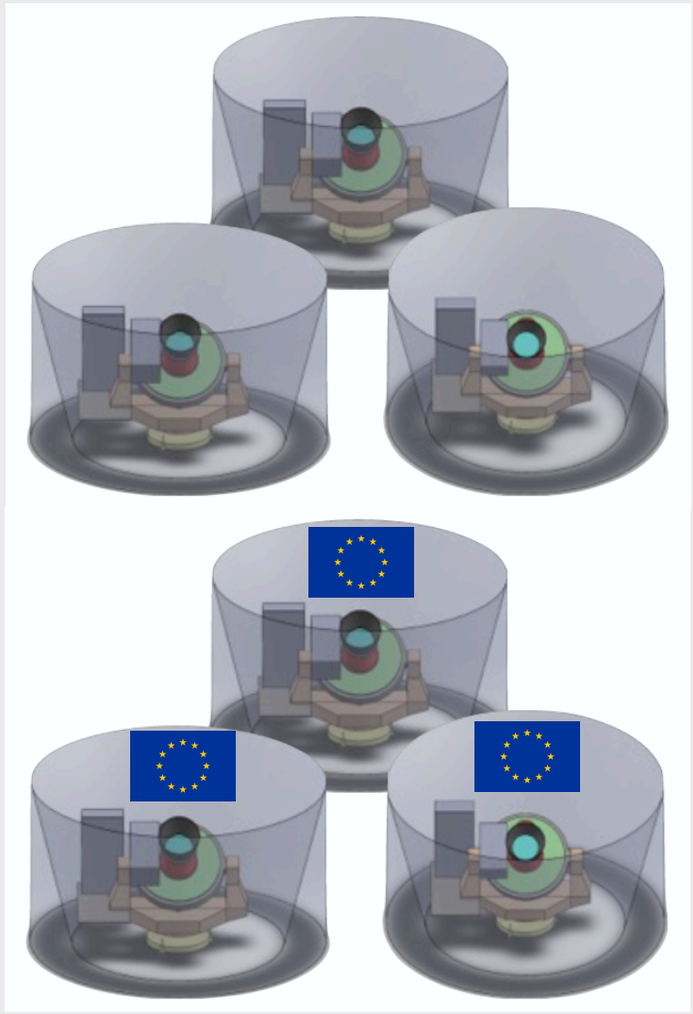
Option 2: Adding three European SATs:



30,000 detectors



60,000 detectors

Why small apertures?

Option 2: Adding three European SATs:

- Focussed on search for primordial gravitational waves.
- Forecasts for "r" after five year survey covering 5% of sky:

Instrument Configuration	SO $\sigma(r)$	SO + SO-EBT $\sigma(r)$
No delensing:	4.8×10^{-3}	3.3×10^{-3}
50% delensing:	3.5×10^{-3}	2.1×10^{-3}
75% delensing:	2.8×10^{-3}	1.4×10^{-3}

Based on three forecasting pipelines:

- D Alonso
- J Errard
- C Hervias-Caimapo

- These results are for case where all Euro SATs are at 90/150 GHz (and existing SO SATs are spread across the $27 < \nu < 280$ GHz range).
- Also explored other options for Euro SAT frequencies but above was best-performing configuration.

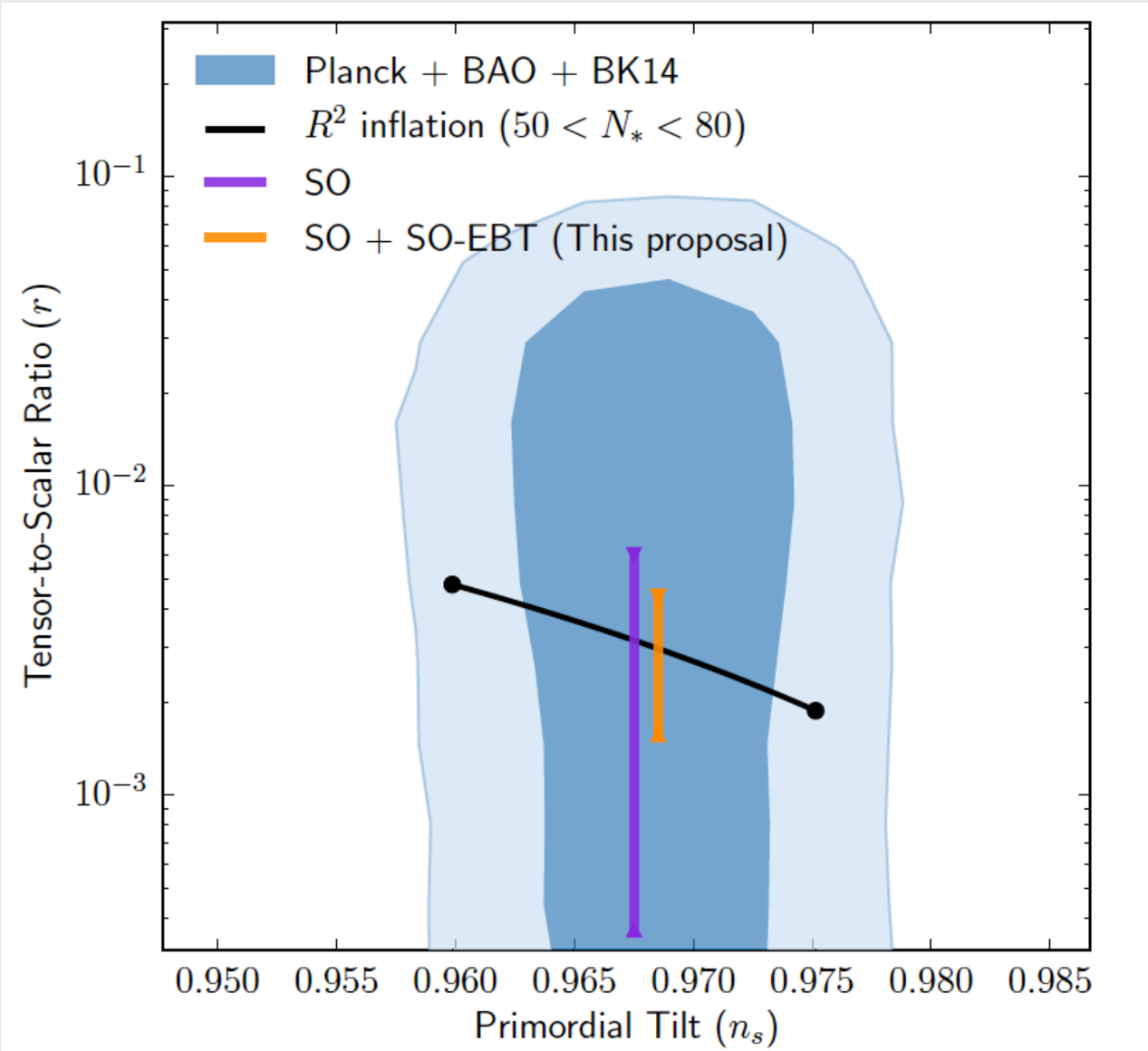
Why small apertures?

Option 2: Adding three European SATs:

- $1/N_*^2$ models (e.g. R^2 inflation) typically predict:

$$2 \times 10^{-3} < r < 5 \times 10^{-3}$$

- Euro SATs can potentially bring this important class of models within reach of SO.



- Euro SATs providing 50% of SO sensitivity to primordial B-modes and potentially bringing important candidate inflation models within reach.