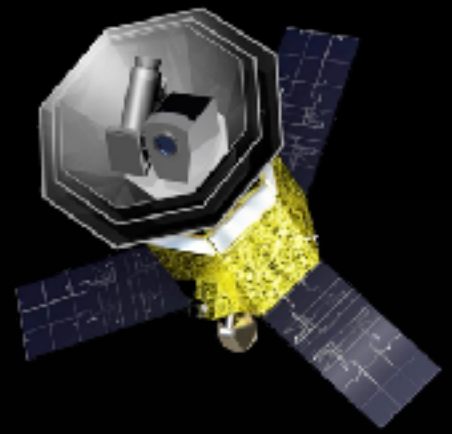
Credit : ESA and the *Planck* Collaboration

Probing the Early Universe

Simons Observatory and LiteBIRD

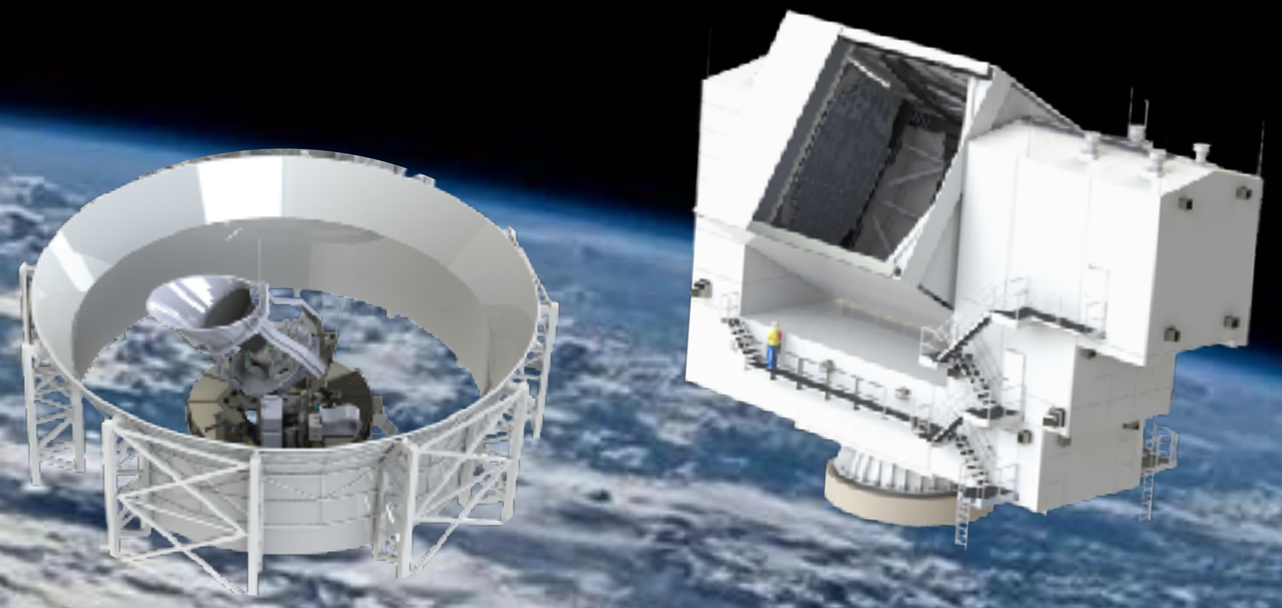


Benjamin Beringue
Postdoc @ APC-CNRS

October, 22nd 2024

Rencontres de Blois - 2024

SciPol
Science from the large scale cosmic microwave background polarization structure



Cosmic Microwave Background

Cosmic Microwave Background

Inflation

Radiation dominated expansion

CMB photons decoupling

Dark Ages

Structure formation and galaxy evolution

Cosmic Microwave Background

Inflation

- Large scale B-modes
- Primordial power spectrum (via TT,TE,EE)
- Primordial bispectrum

Radiation dominated expansion

- Y_p and $N_{\rm eff}$ (via damping tail)

CMB photons decoupling

- Imprints of ΛCDM

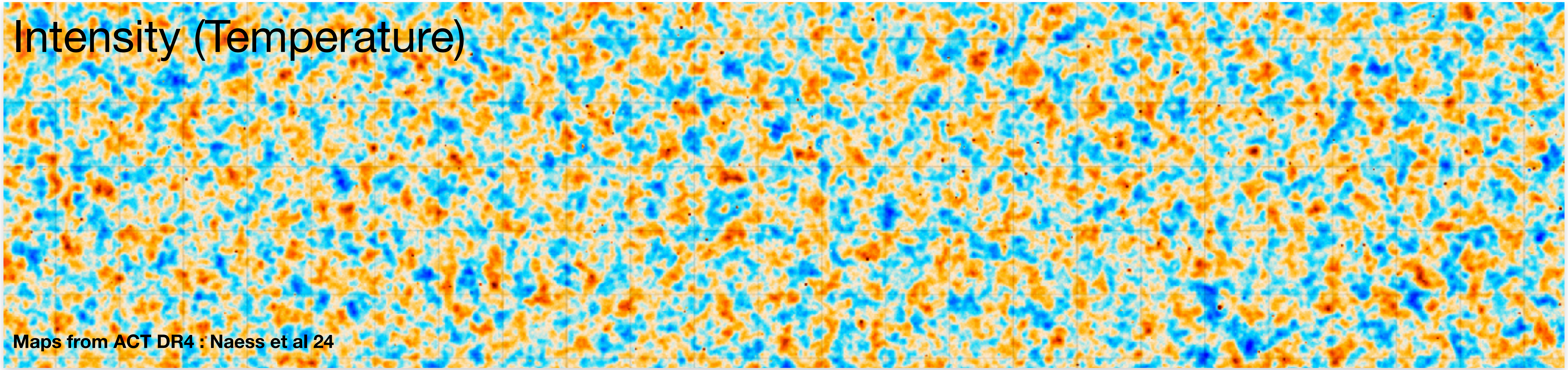
Dark Ages

Properties of reionisation:
- Duration (via kSZ)
- Mean free path of photons (via kSZ)

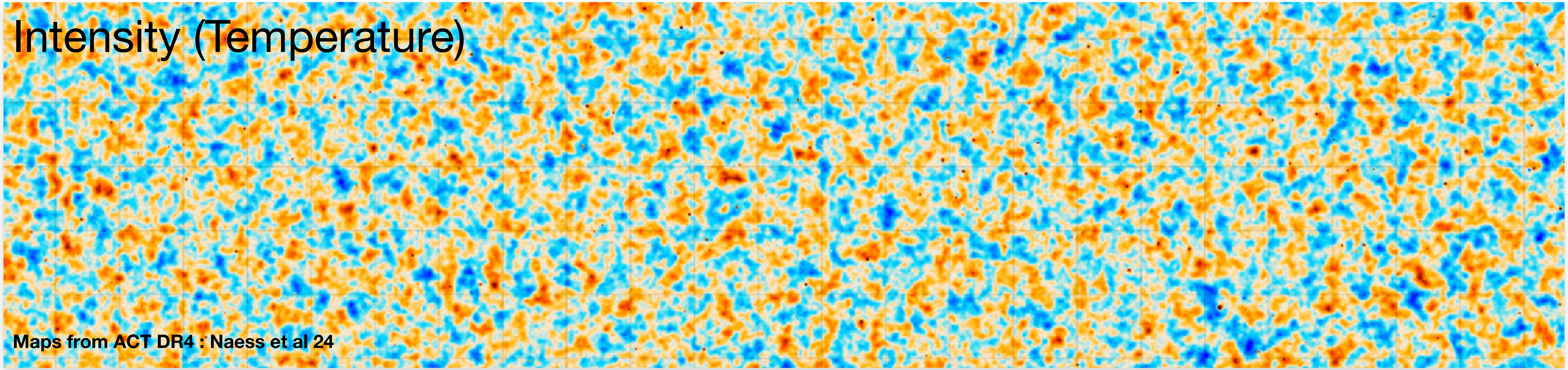
Structure formation and galaxy evolution

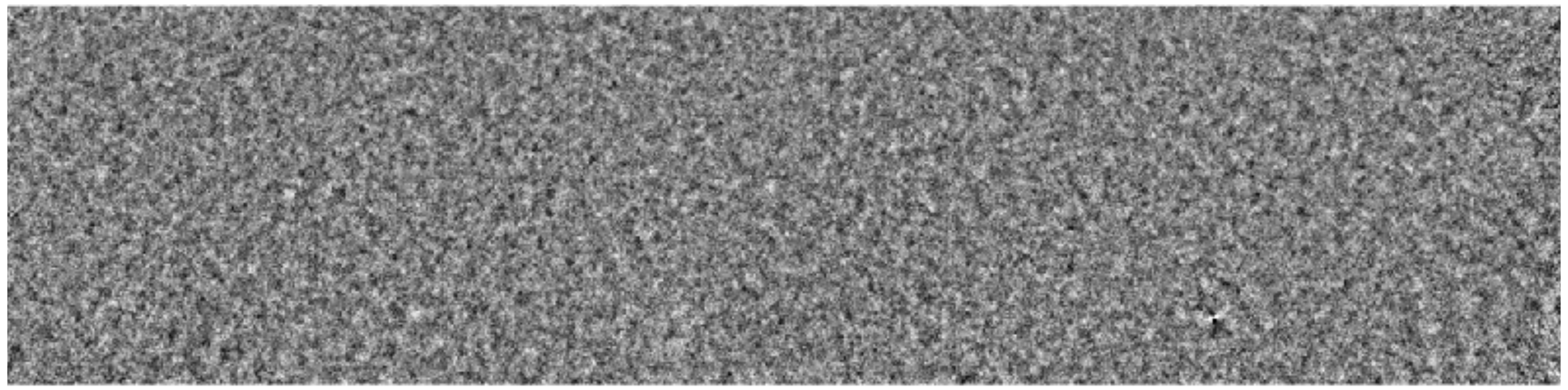
- Σm_ν (via lensing potential)
- Galaxy evolution
  - cluster properties (via tSZ)
  - feedback efficiency (via tSZ)
- Properties of Dark energy:
  - σ_8 (via lensing and tSZ)

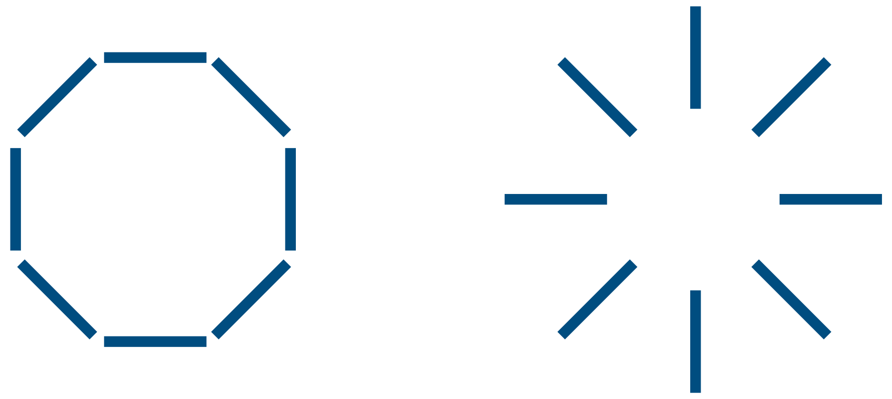
Cosmic Microwave Background



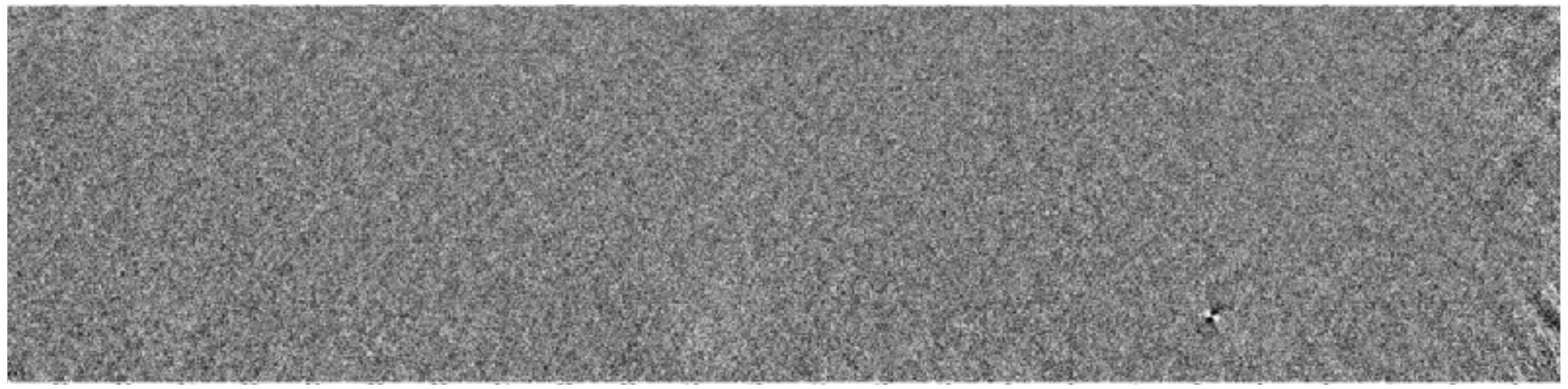
Cosmic Microwave Background

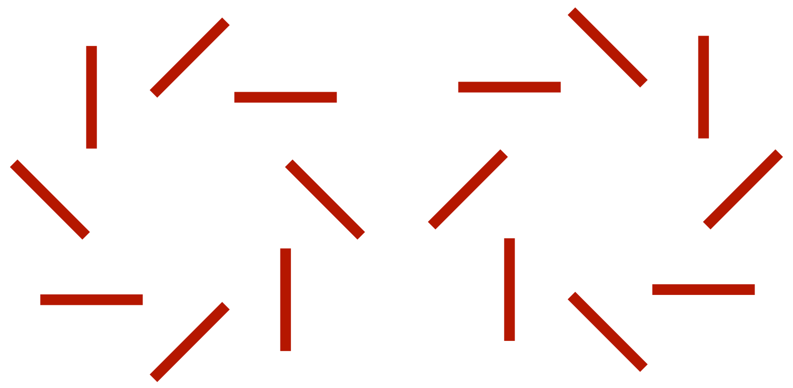






E-modes

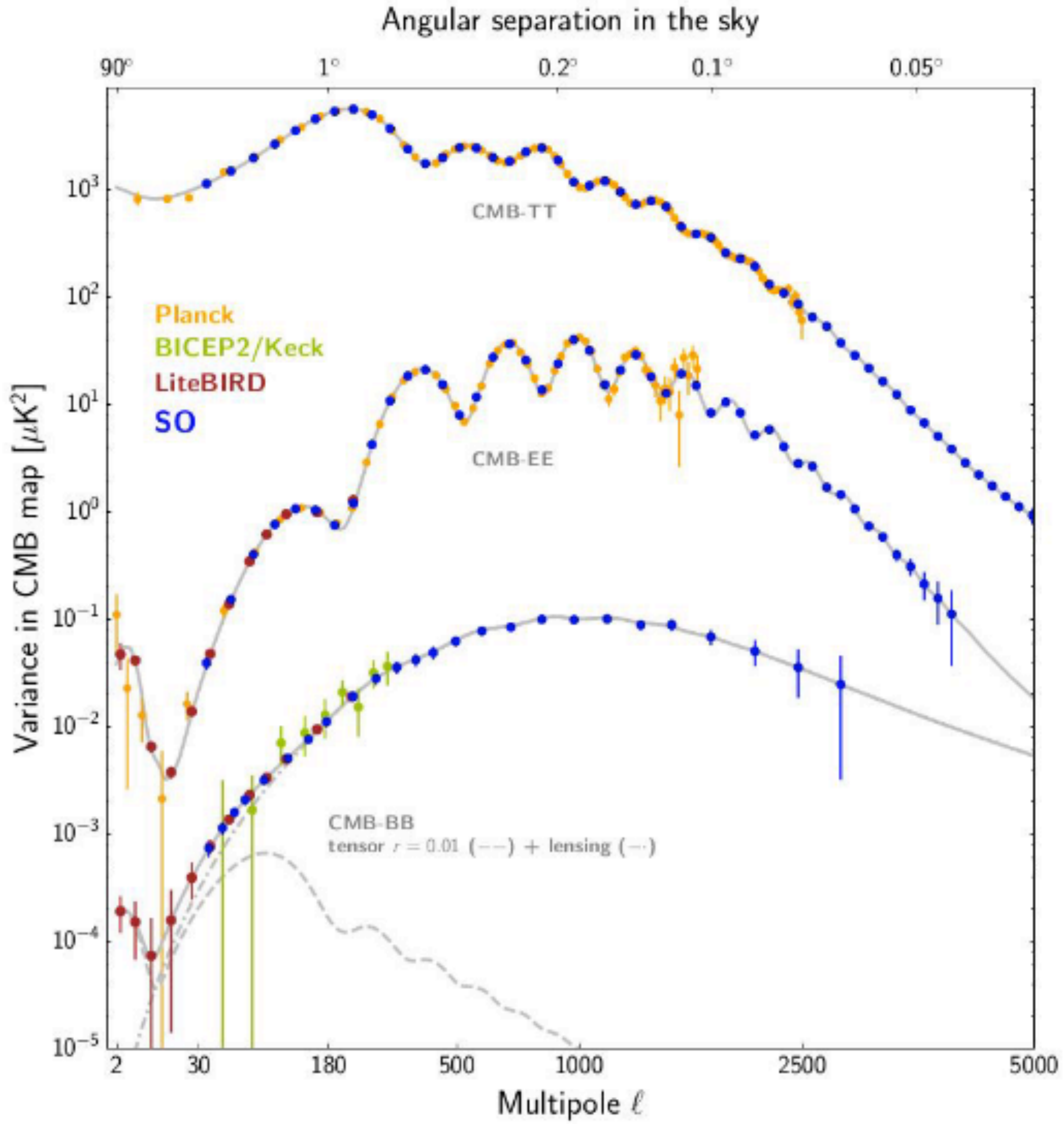


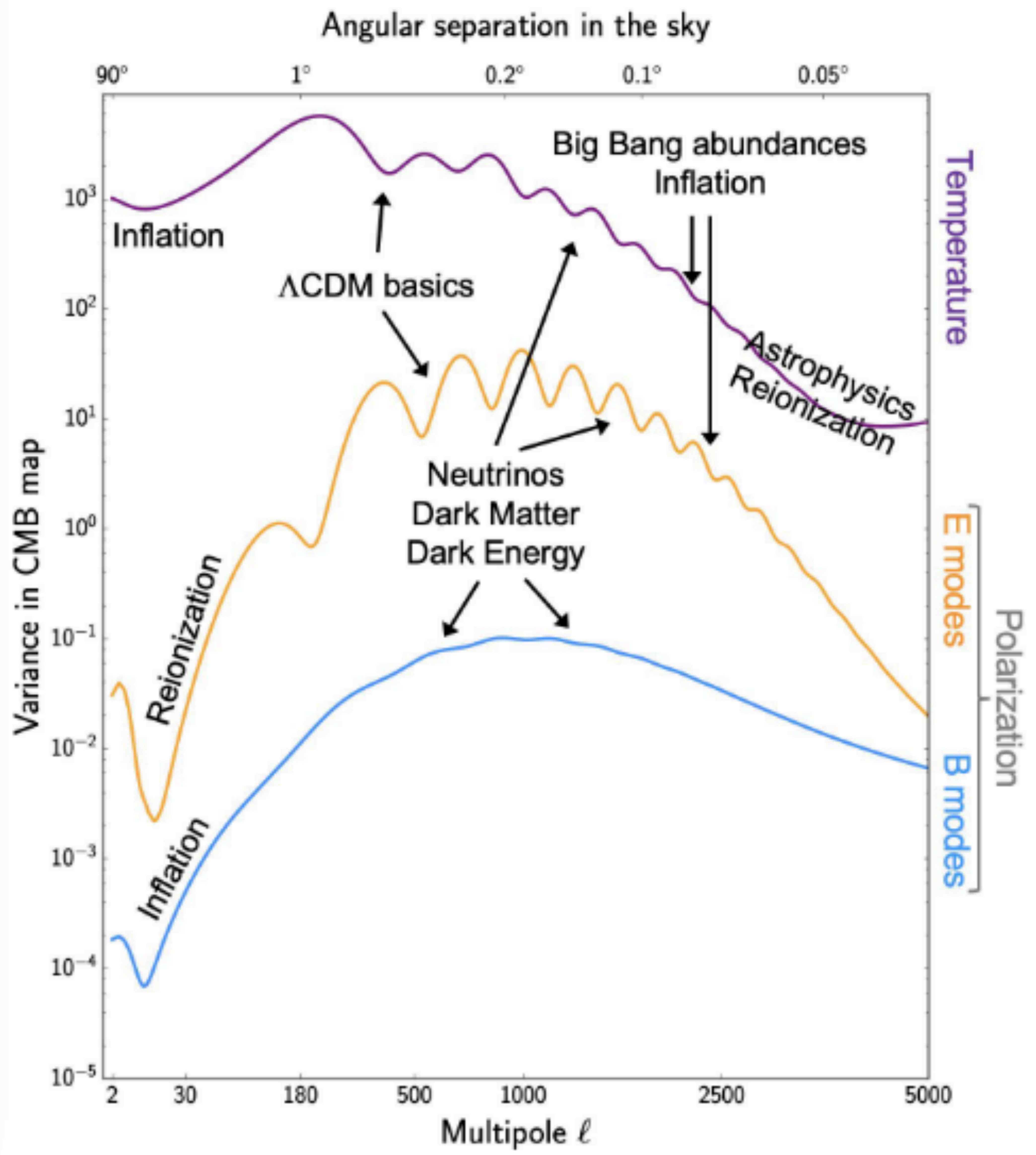


B-modes

The CMB is also polarised !

Cosmic Microwave Background





[Credit: E. Calabrese]

Simons Observatory

15+ Countries
60+ Institutions
375+ Researchers

Simons Observatory site

Chajnantor plateau (~5200m above sea level)

Done shot by Deborah Kellner

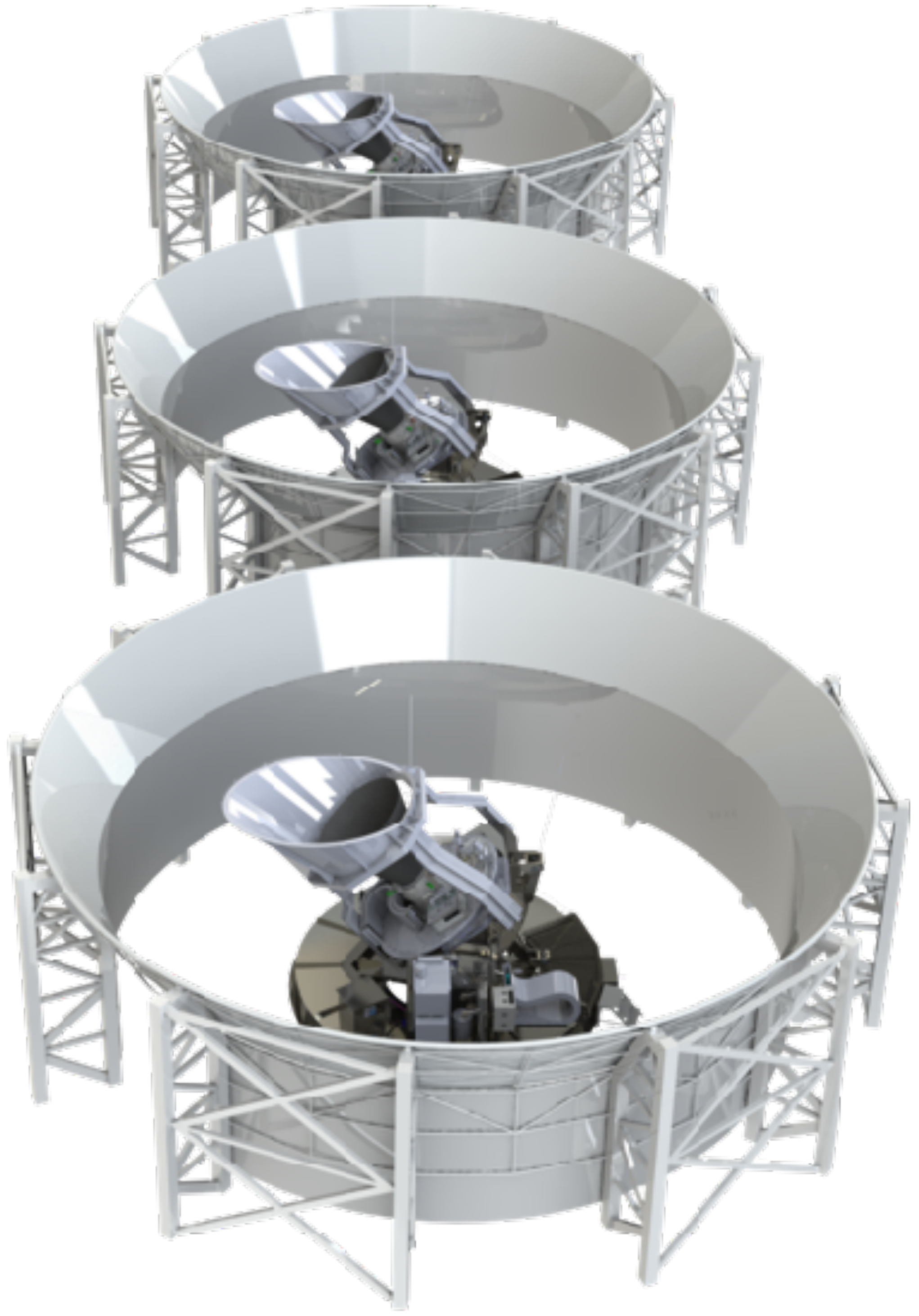
Done shot by Deborah Kellner

Done shot by Deborah Kellner

Simons Observatory

SO Small Aperture Telescopes (SATs)

- Nominally 3 telescopes
- **30.000** TES detectors
- **6 frequency** bands
- Focusing on **large scale polarisation modes**



Simons Observatory

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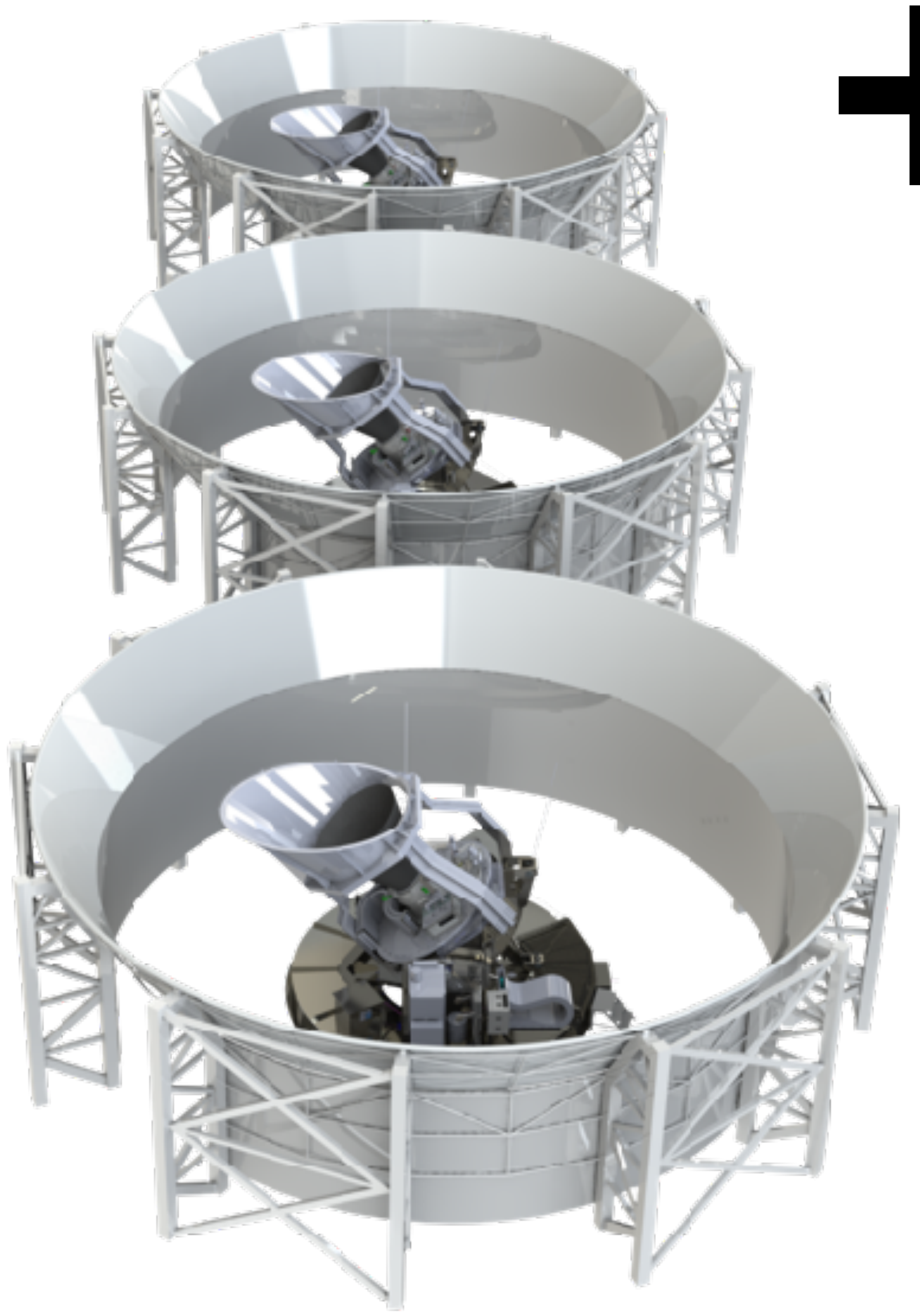

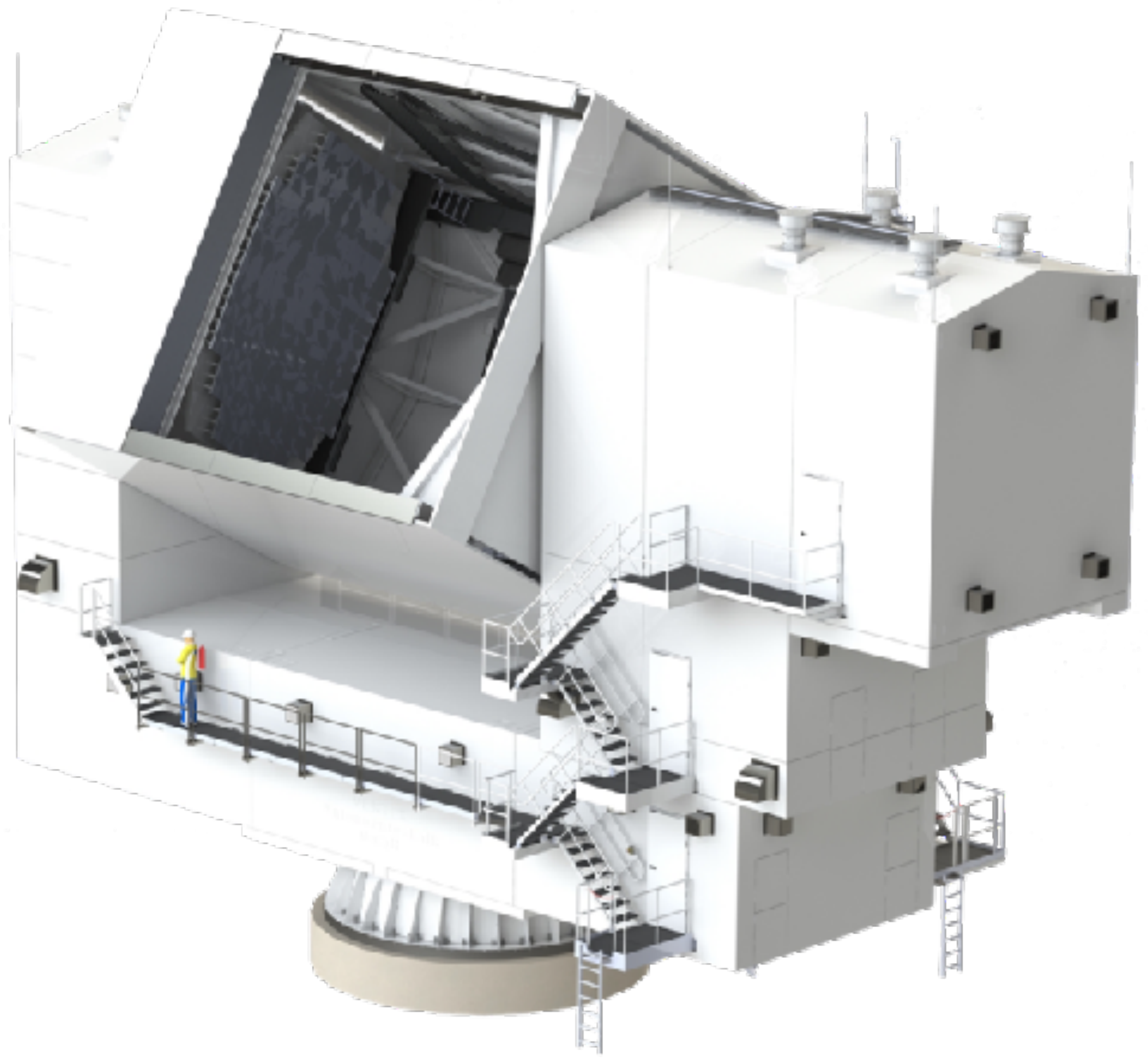

SO Large Aperture Telescope (LAT)

- **6m cross-Dragone** telescope
- **30.000** TES detectors
- **6 frequency** bands
- Observing **small scale anisotropies** over a large fraction of the sky

Simons Observatory

SO Small Aperture Telescopes (SATs)

- Nominally 3 telescopes
- **30.000** TES detectors
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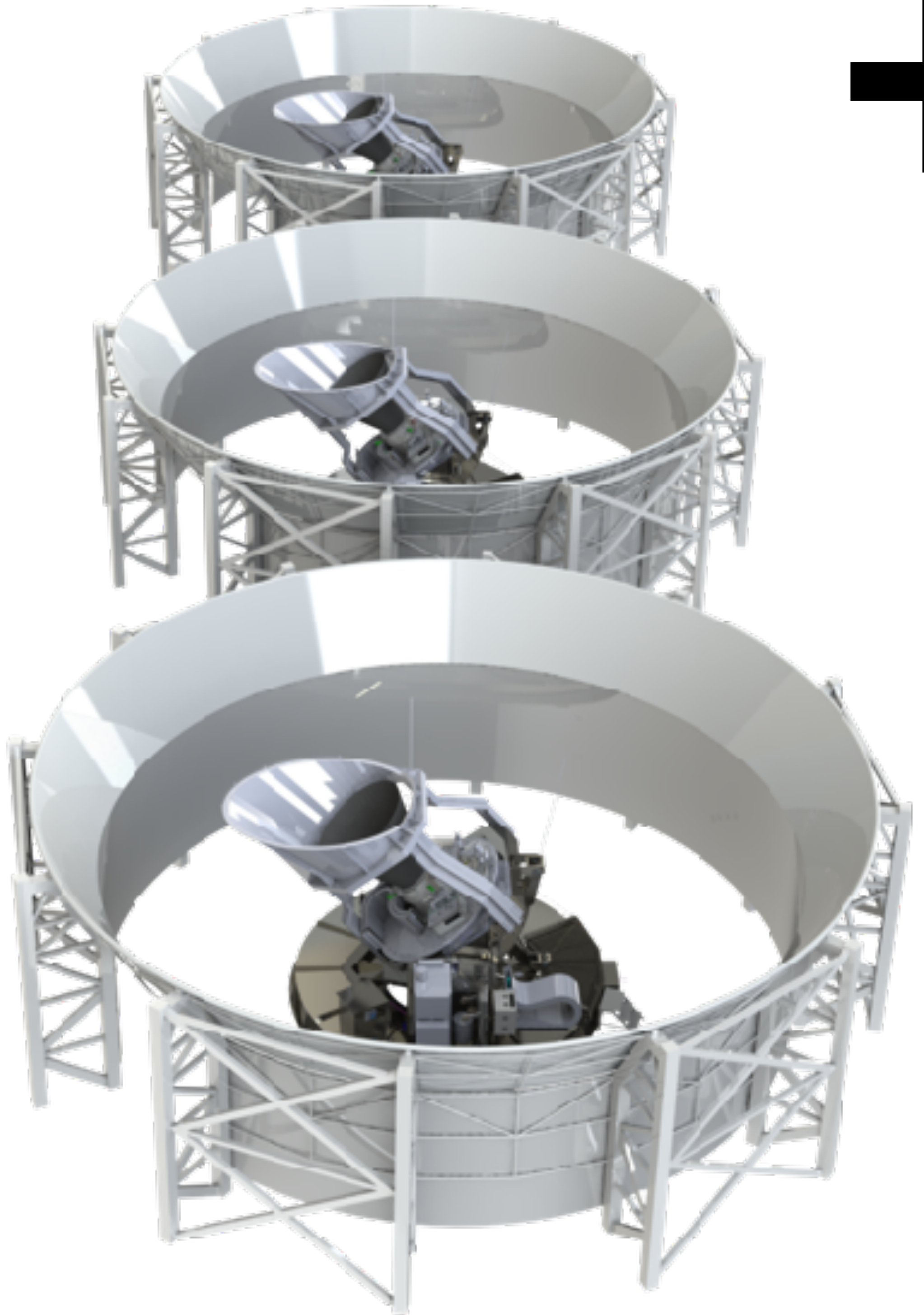
- Focusing on **large scale polarisation modes**

SO:UK + SO:JP

- 3 additional telescopes
- **30.000** TES detectors
- **Extended frequency range**



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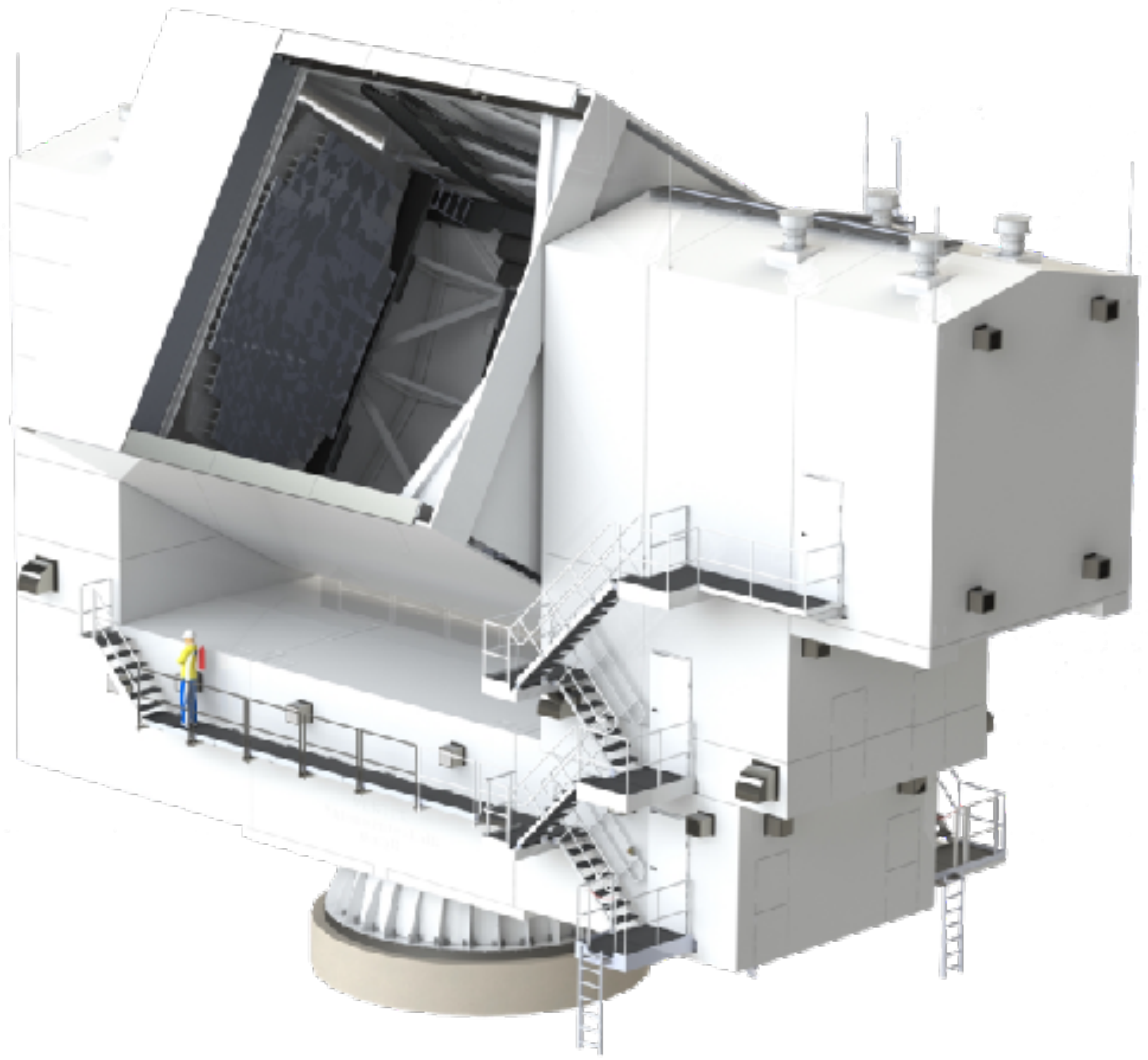

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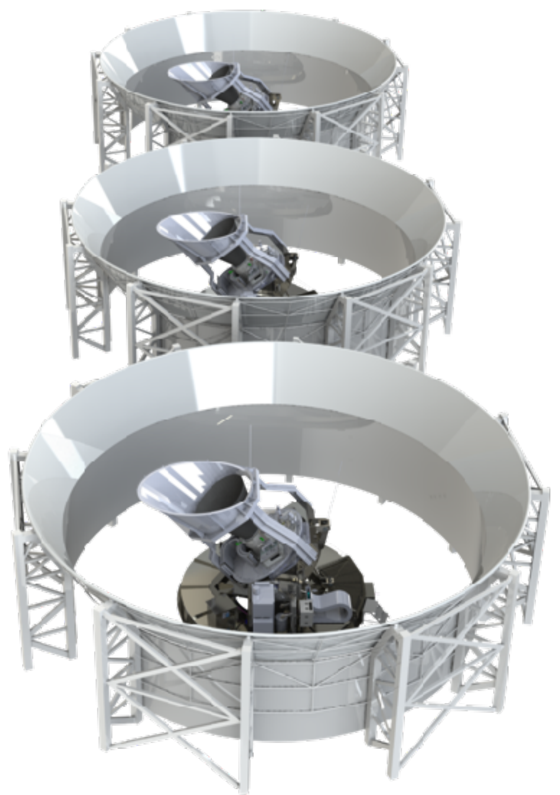

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Simons Observatory

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SO:UK + SO:JP + SO:FR ?

- 3 additional telescopes
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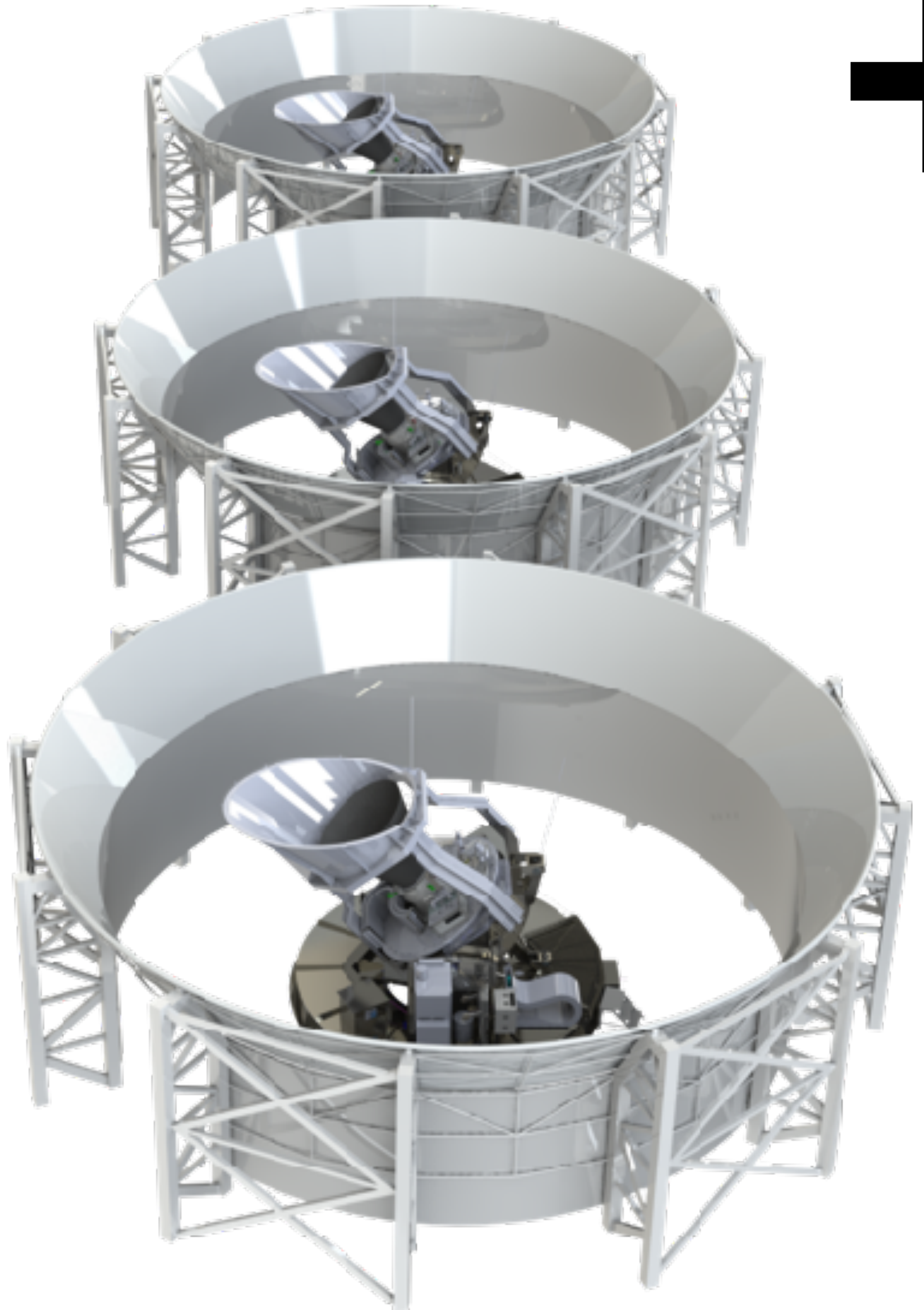

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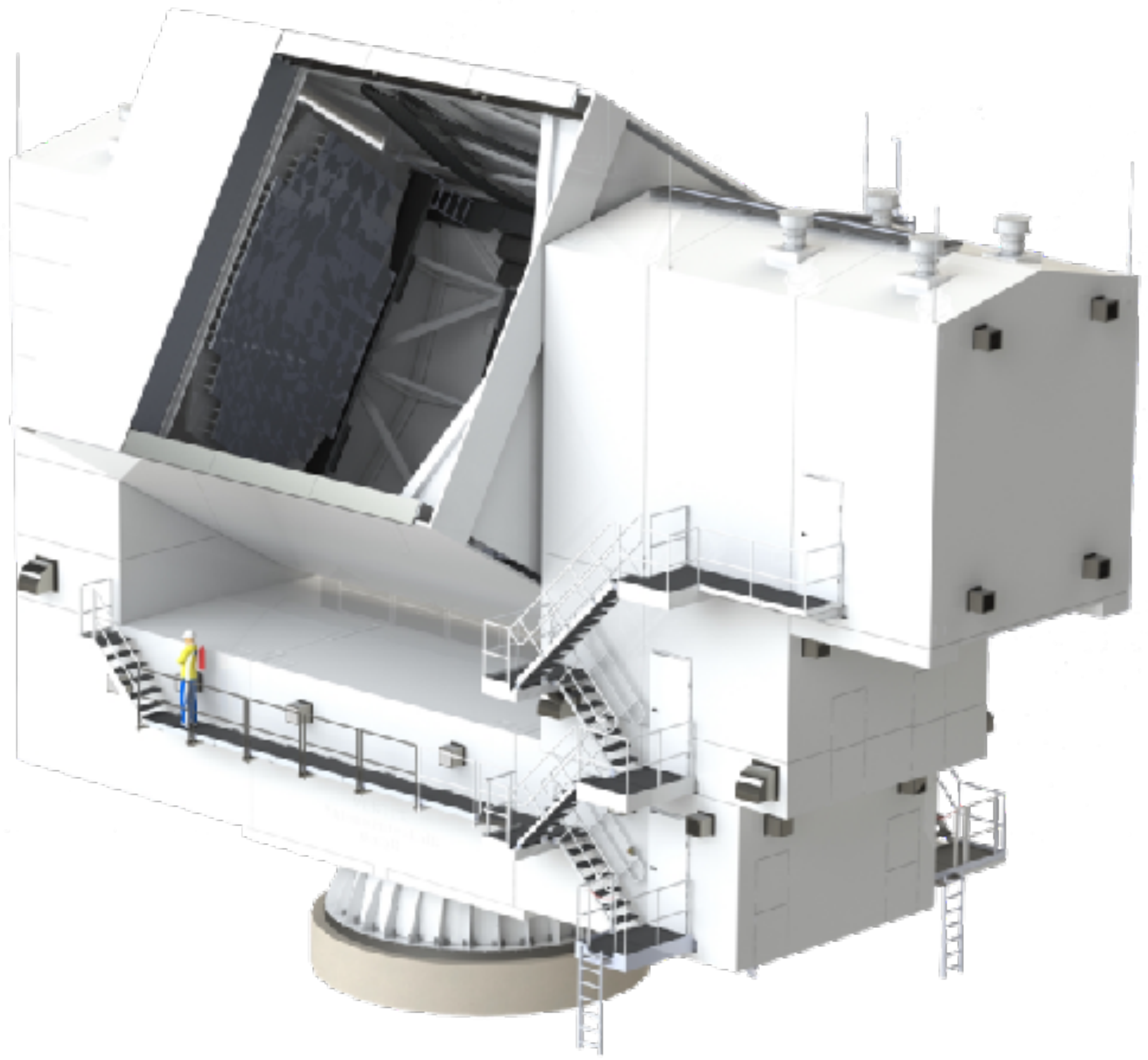

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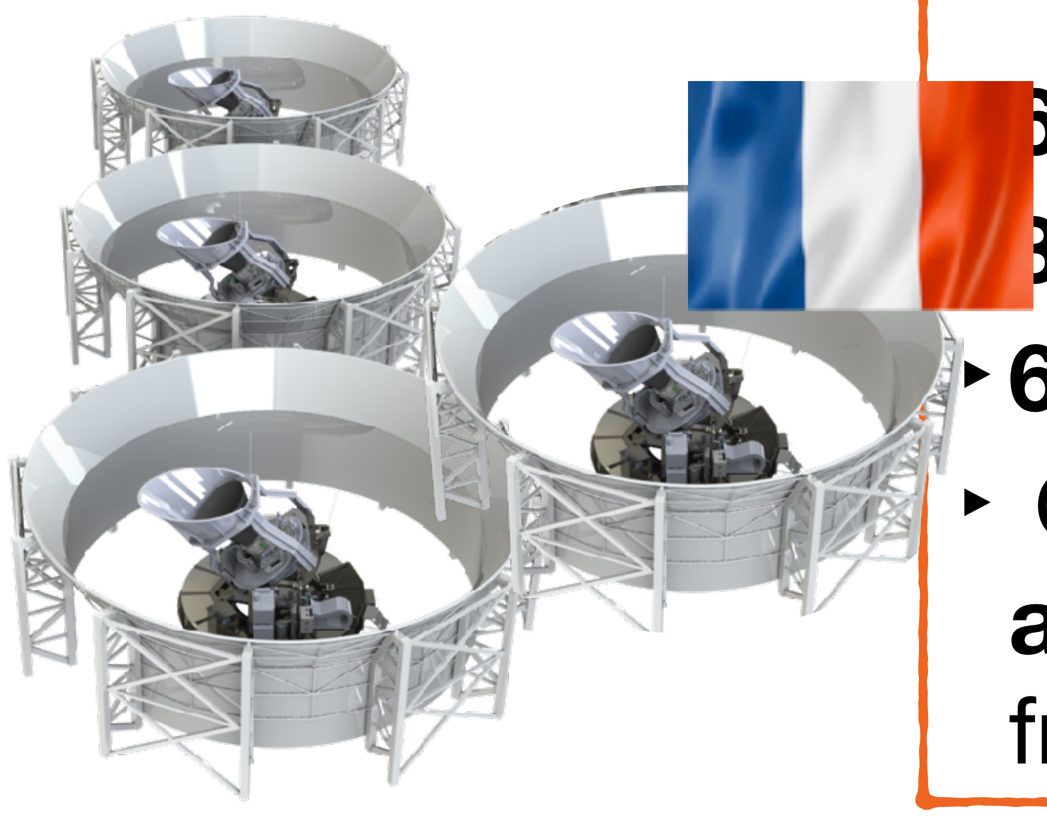

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Simons Observatory

SO Small Aperture Telescopes (SATs)

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SO:UK + SO:JP

- 3 additional telescopes
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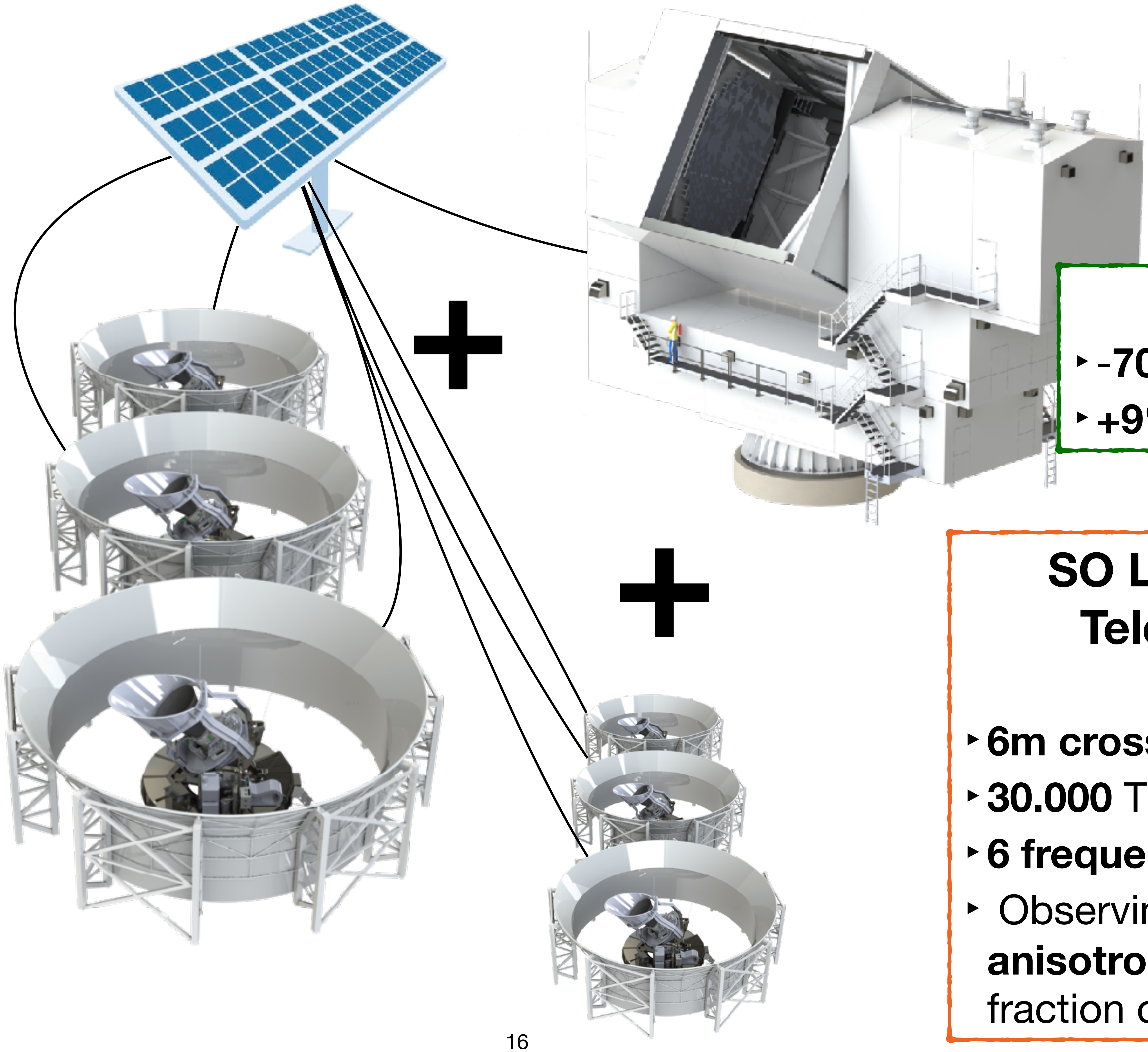

SO PV array

- **-70% diesel consumption**
- **+9% efficiency**

SO Large Aperture Telescope (LAT)

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Simons Observatory

SO Small Aper
Telescopes (S

- Nominally 3 telesc
- **30.000** TES detect
- **6 frequency** band
- Focusing on **large**
polarisation mod

SO:UK + SO:

- 3 additional telesc
- **30.000** TES detect
- **Extended frequen**
range

SO PV array
diesel consumption
efficiency

rge Aperture
cope (LAT)

Dragone telescope
detectors
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small scale
es over a large
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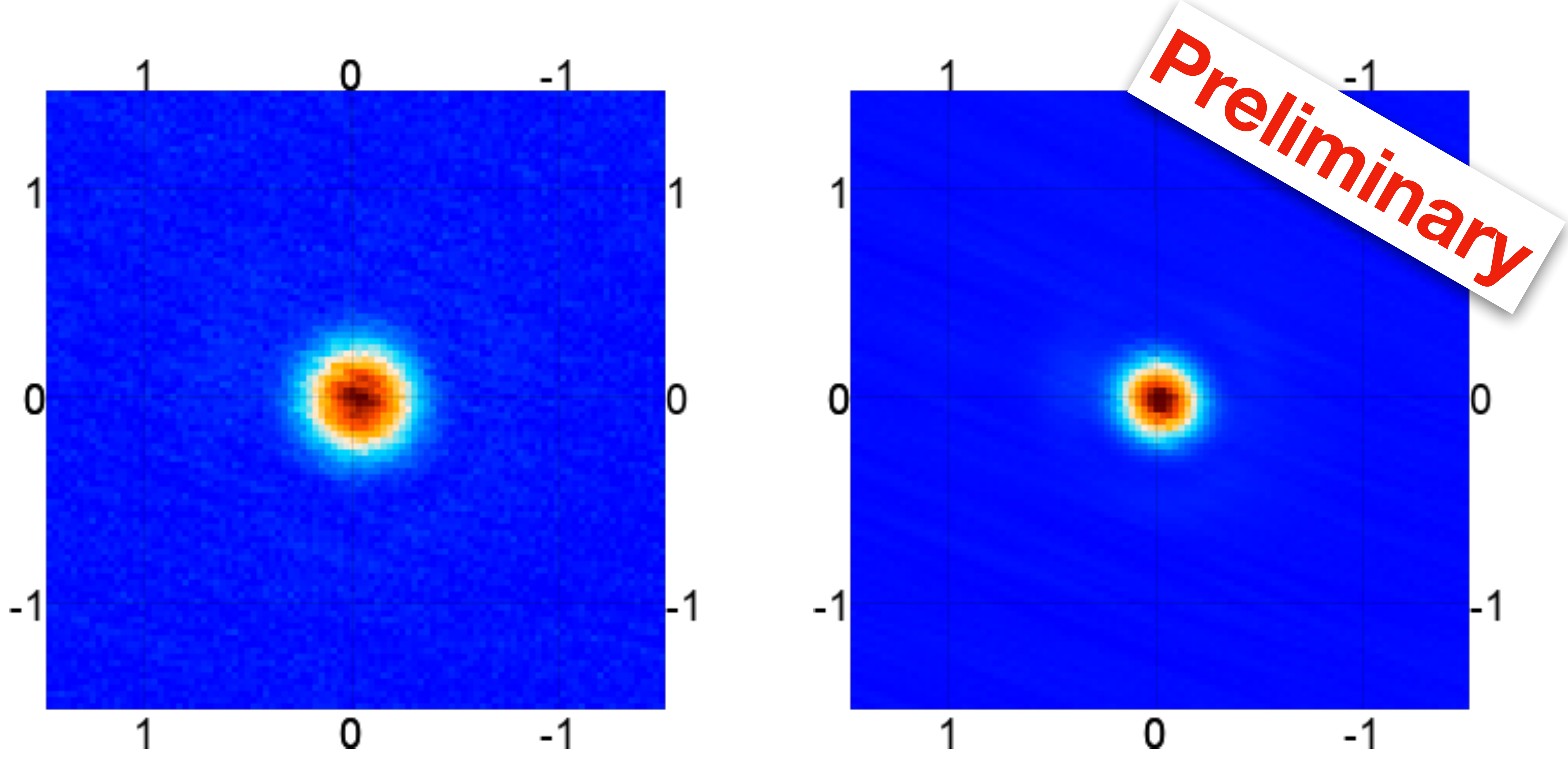
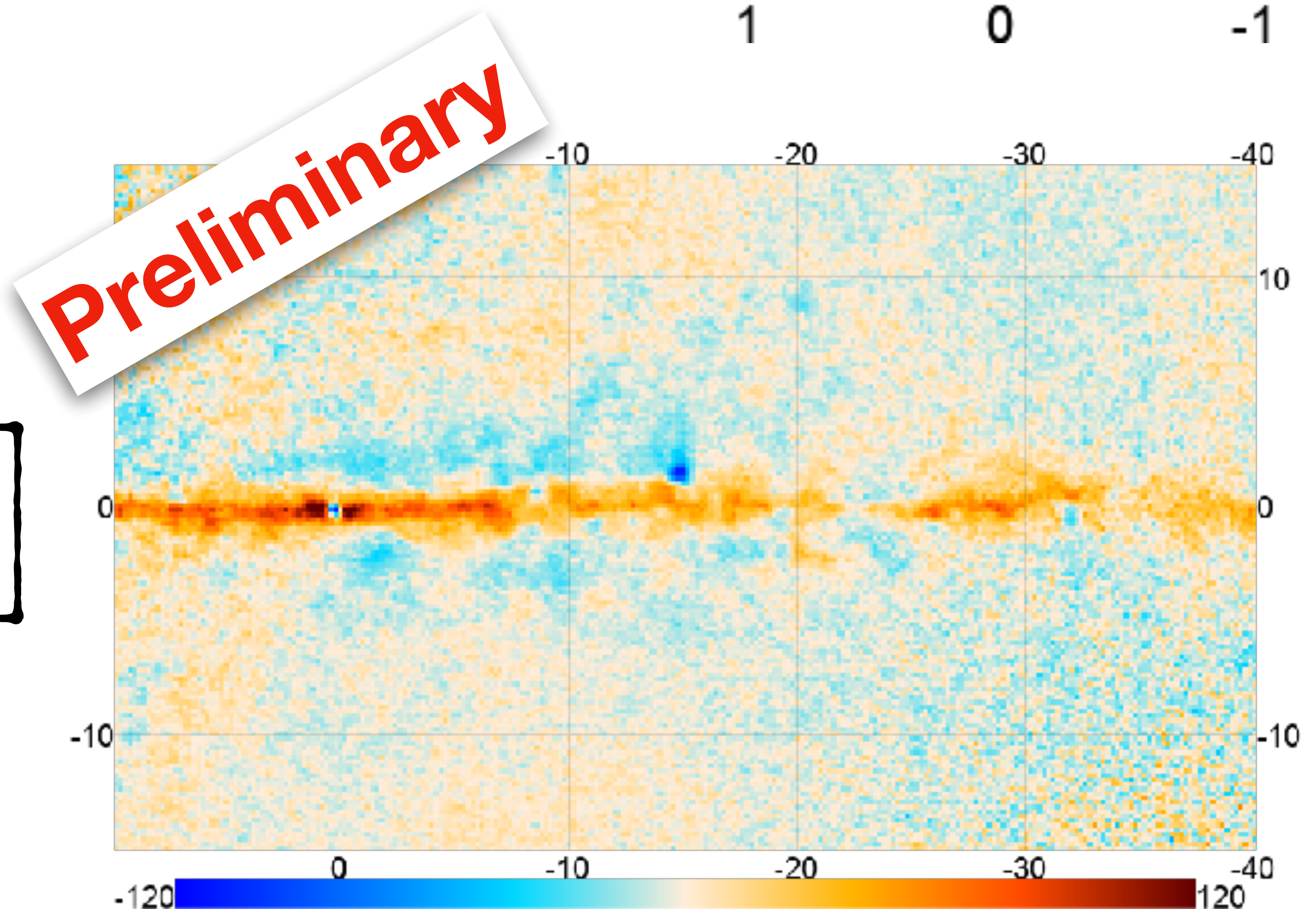
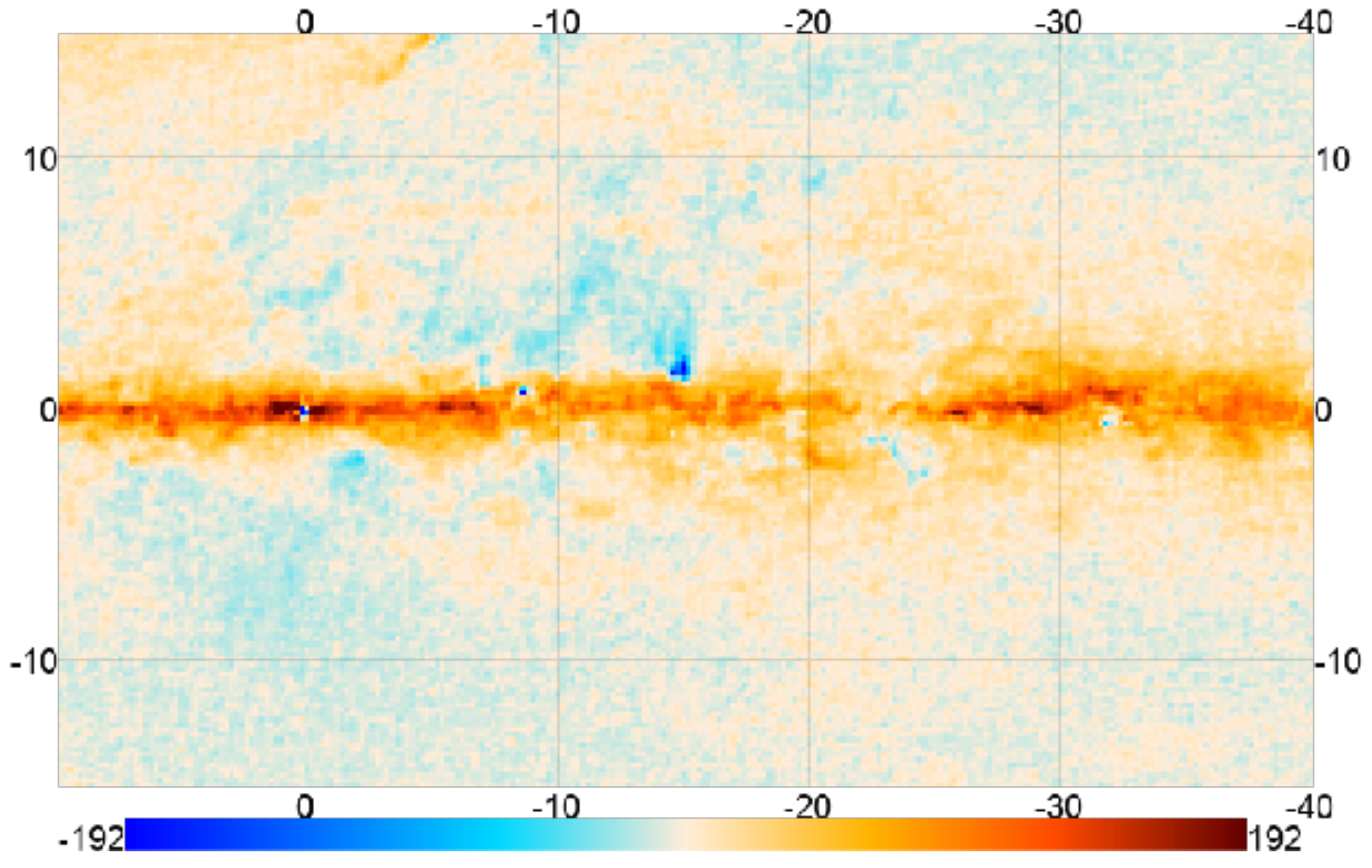
Simons Observatory

First light of Jupiter



SO Q-map of galactic plane





***Planck* Q-map of galactic plane**

Simons Observatory - Science

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

[arxiv:1808.07445]

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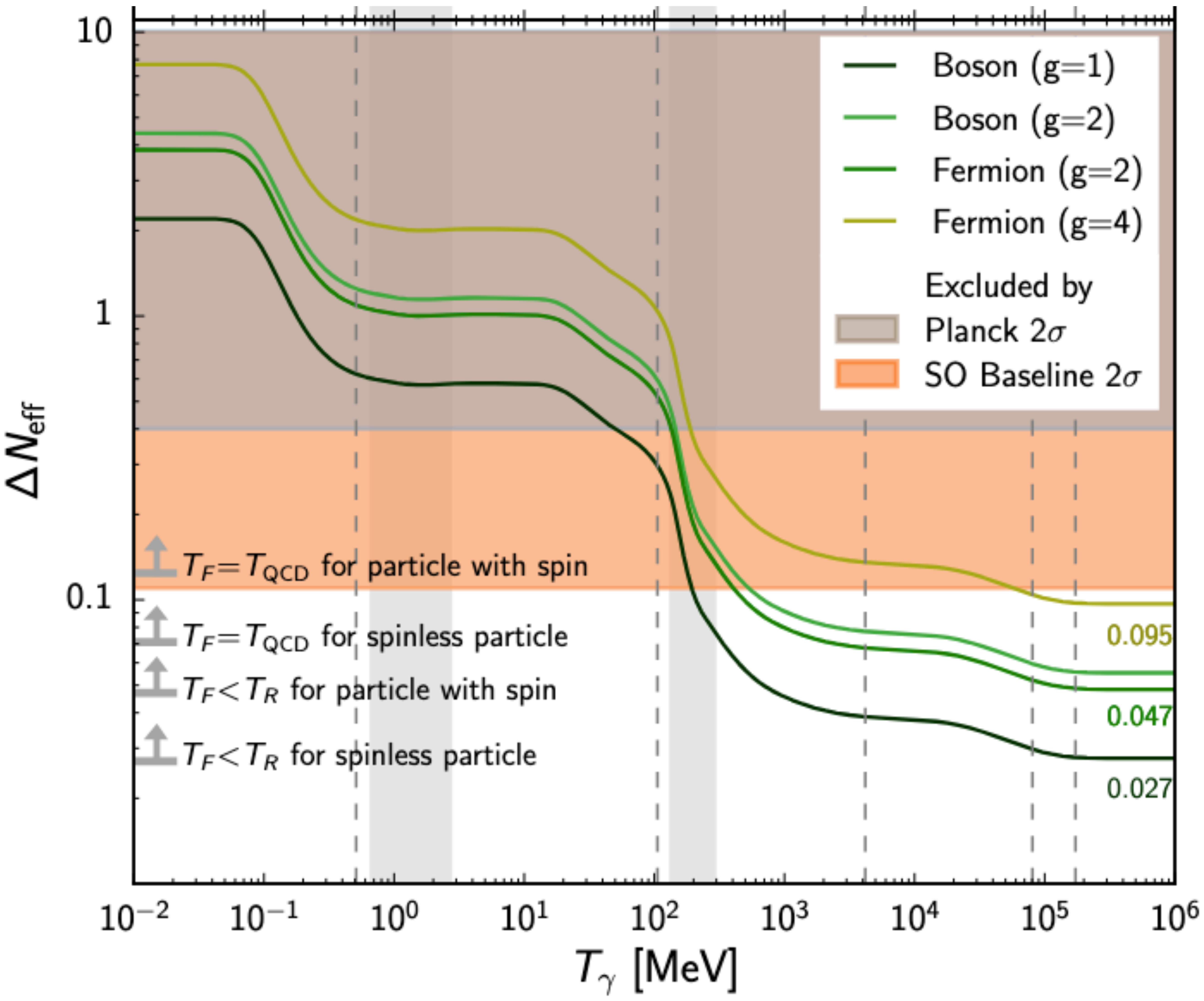
Simons Observatory - Science



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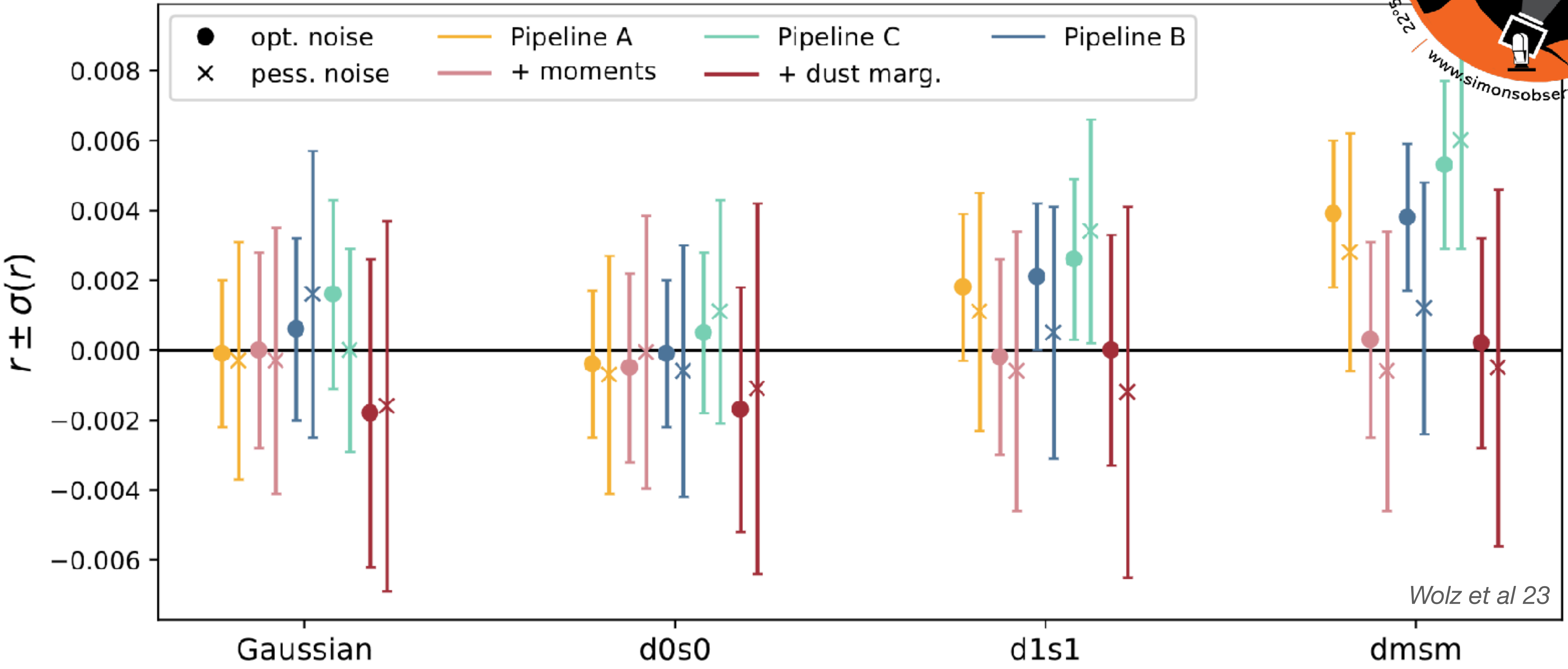
Simons Observatory - Science



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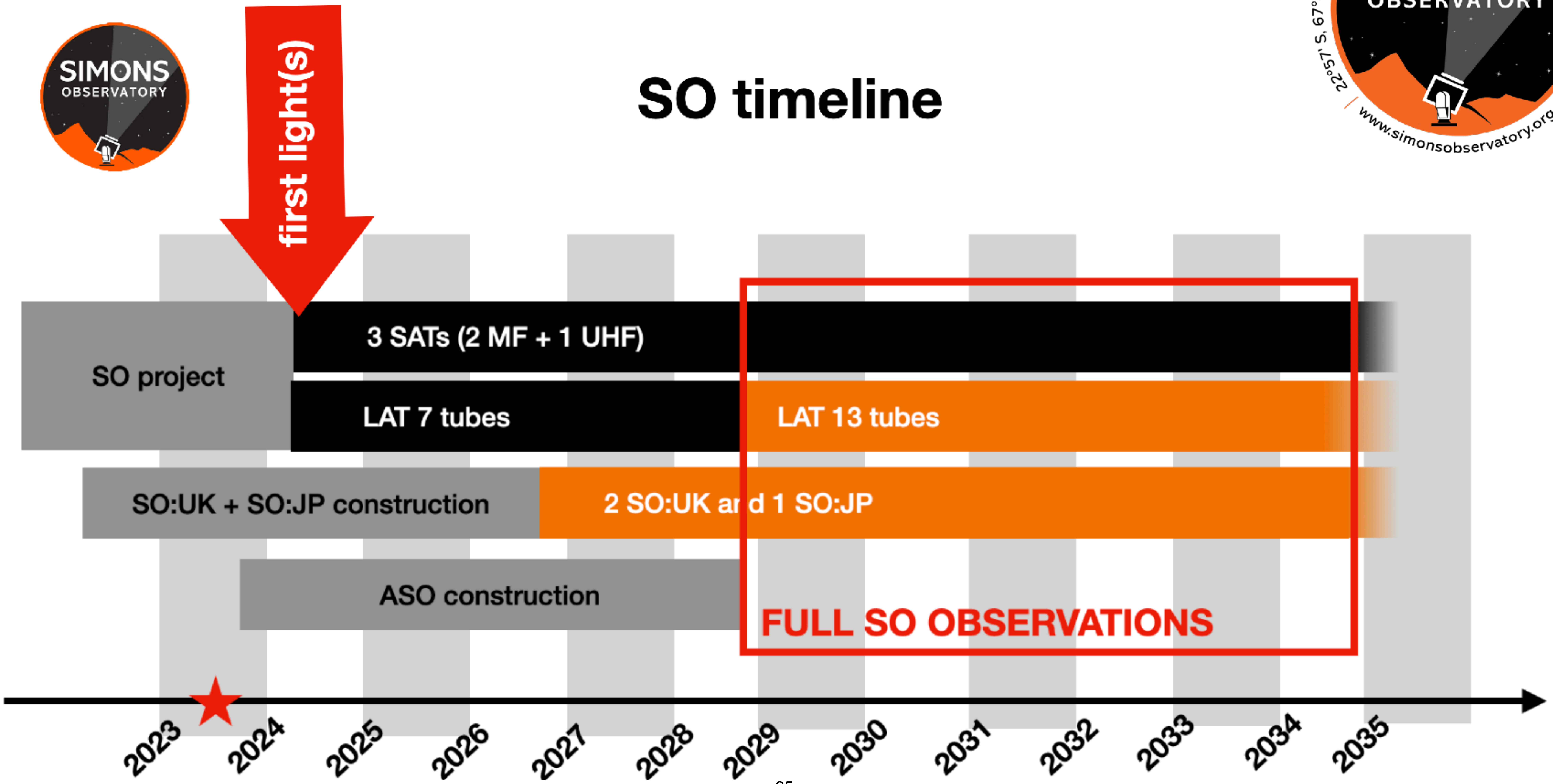
Simons Observatory - Science



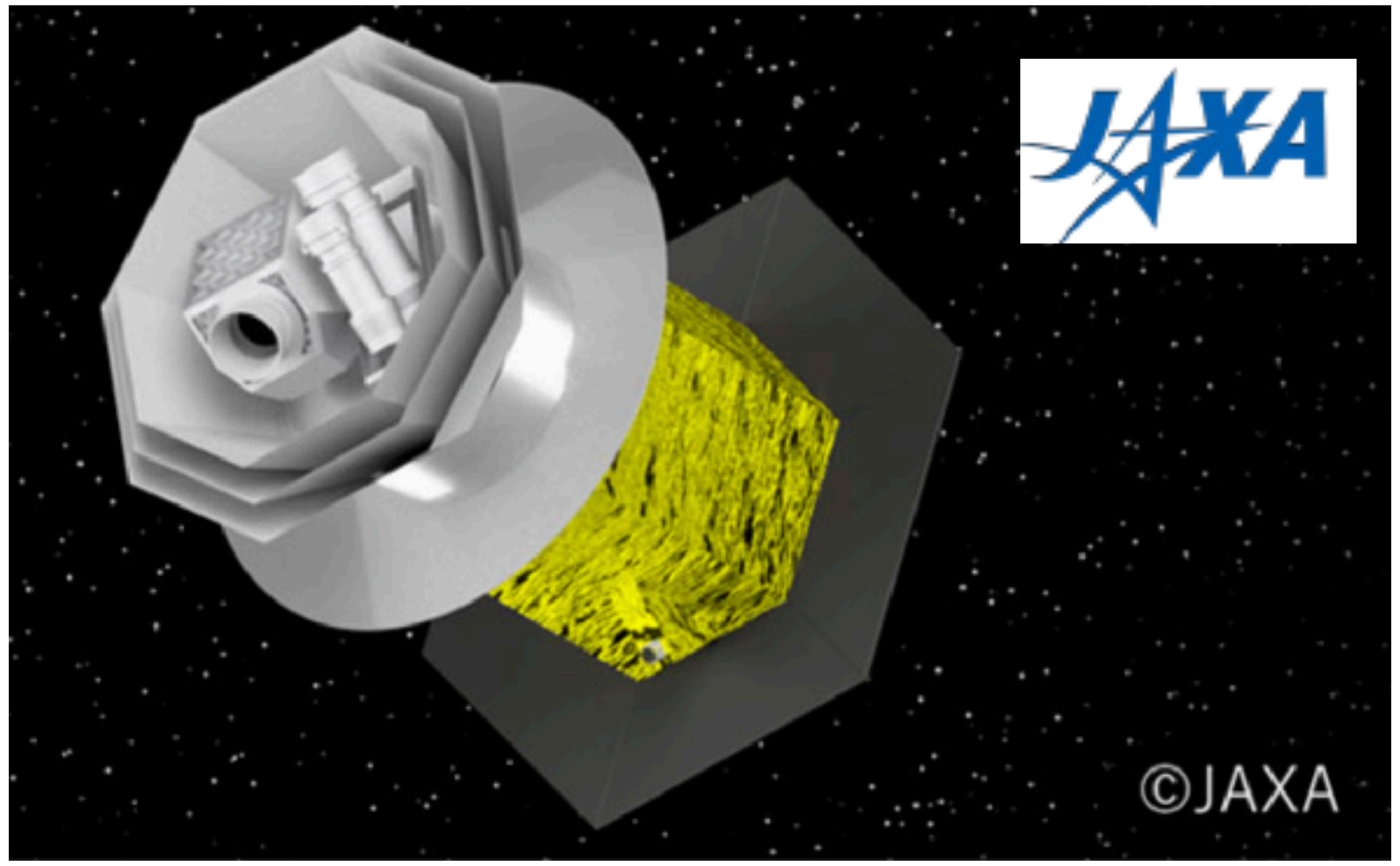
LiteBIRD

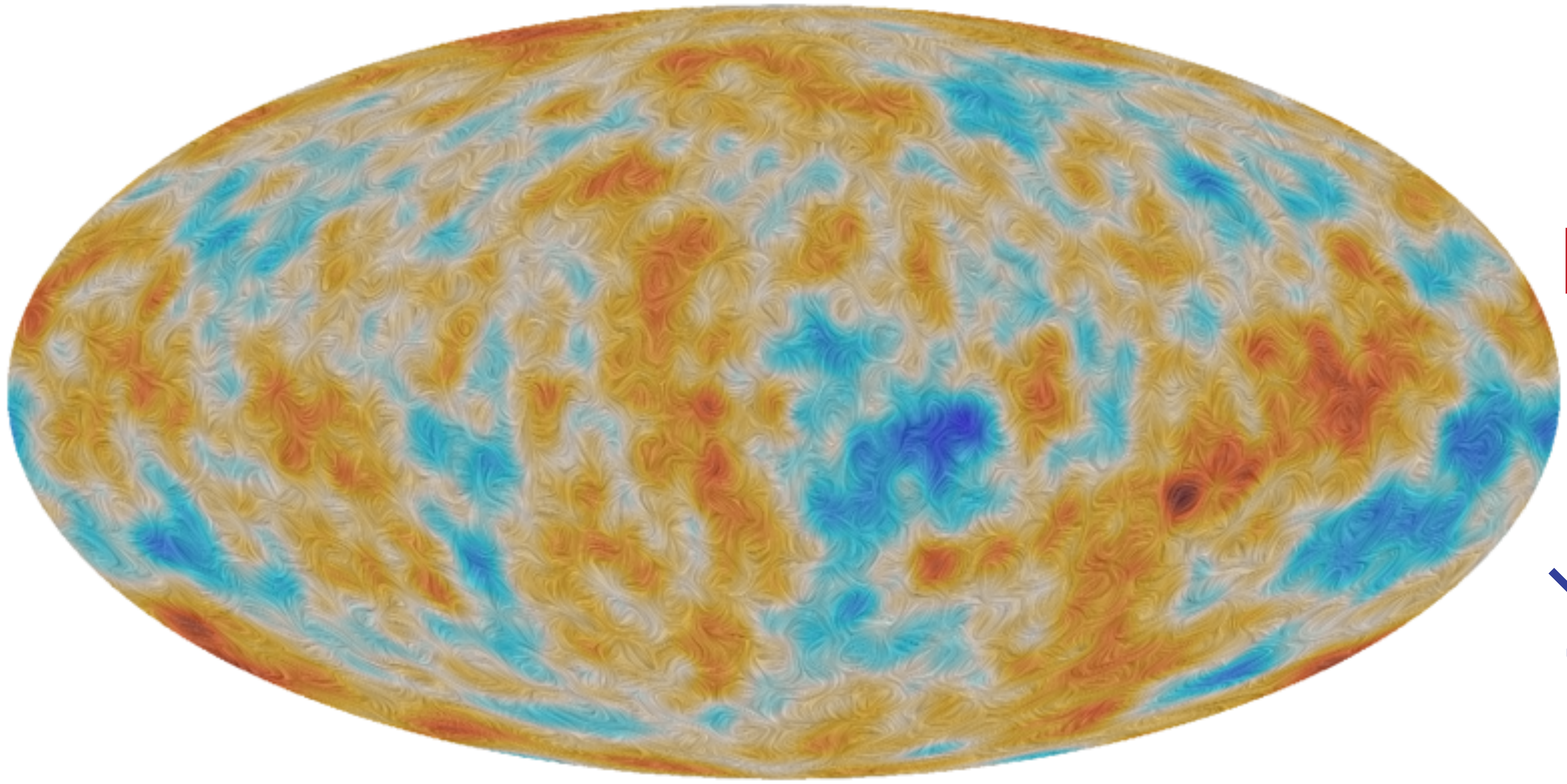
- APC
- ASI
- Berkeley University of California
- Berkeley Lab
- Università degli Studi di Milano Bicocca
- Cardiff University / Prifysgol Caerdydd
- cea
- Centre Pierre Binétruy CNRS • Berkeley
- cnes
- cnrs
- CSA ASC Canada
- CSIC Consejo Superior de Investigaciones Científicas
- CSL Centre Spatial de Liège
- ENS | PSL
- European Research Council
- Excelencia María de Maeztu
- Excelencia Severo Ochoa
- FAU Friedrich-Alexander Universität Erlangen-Nürnberg
- Forskningsrådet The Research Council of Norway
- NASA Goddard Space Flight Center
- GSSI Gran Sasso Science Institute
- Instituto de Astrofísica de Canarias IAC
- IAP
- IAS Orsay
- IFCA Instituto de Física de Cantabria
- ifpU
- IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis
- INFN
- INAF Istituto Nazionale di Astrofisica
- IPMU
- IPNS 素粒子原子核研究所 Institute of Particle and Nuclear Studies
- irap astrophysique & planétologie
- JAXA
- NASA Jet Propulsion Laboratory California Institute of Technology
- National Institute of Technology Kagawa College 香川高専
- KEK
- KIPAC
- KMI Kobayashi-Maskawa Institute Nagoya University
- LMU
- LPSC Grenoble | Modane
- Max-Planck-Institut für Astrophysik
- McGill
- Maynooth University National University of Ireland Maynooth
- 名古屋大学 Nagoya University
- Néel institut
- NIST
- Norwegian Directorate for Higher Education and Skills
- OAC
- 岡山大学 Okayama University
- QUP International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles
- Politécnica | idr
- RWTH Aachen University
- Sapienza Università di Roma
- SISSA
- Sorbonne Université
- SRON
- SSDC Space Science Data Center
- Leland Stanford Junior University
- Stockholm University
- 公立諏訪東京理科大学 Suwa University of Science
- Tor Vergata Università degli Studi di Roma
- UCL
- The University of British Columbia
- UC Universidad de Cantabria
- Università di Catania
- University of Colorado Boulder
- Science and Technology Facilities Council UKRI
- ULB Université Libre de Bruxelles
- Universidad de La Laguna
- Manchester 1824 The University of Manchester
- UiO University of Oslo
- University of Oxford
- Università di Pisa
- Università degli Studi di Ferrara
- Università degli Studi di Milano
- Università degli Studi di Padova
- The University of Tokyo
- University of Toronto

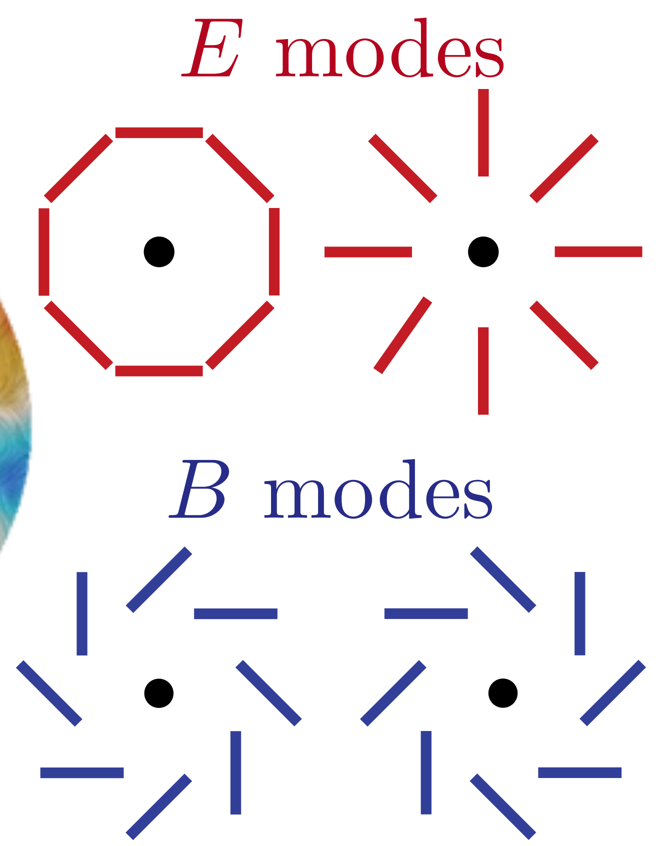
LiteBIRD overview

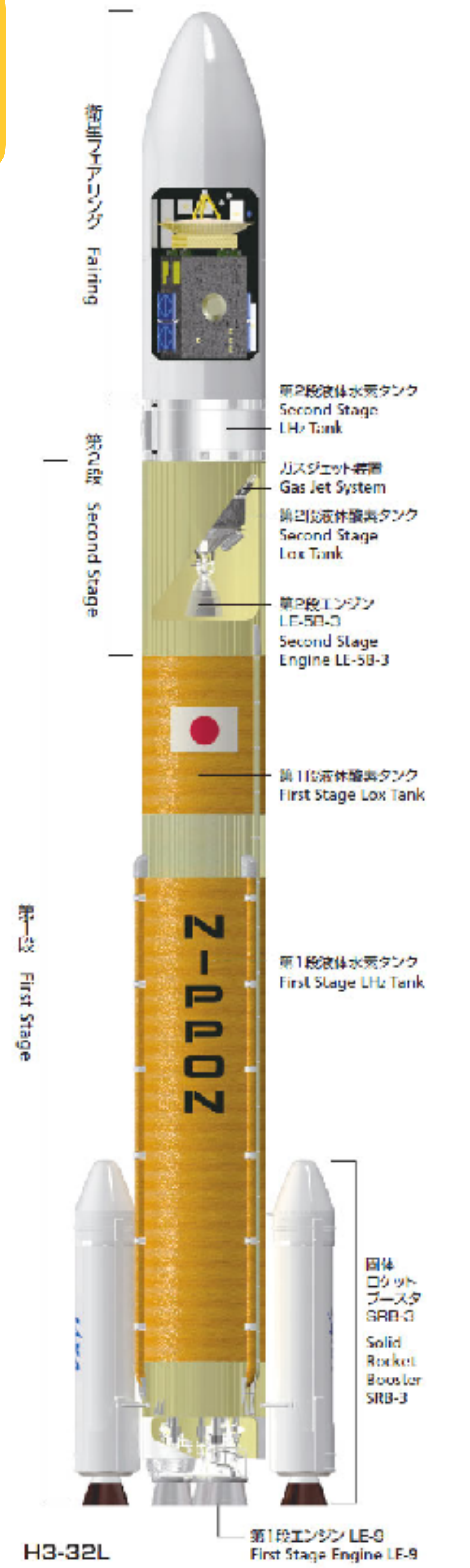
- Lite (Light) satellite for the study of *B*-mode polarization and Inflation from cosmic background Radiation Detection
- JAXA's L-class mission was selected in May 2019 to be launched by JAXA's H3 rocket.
- **All-sky 3-year survey**, from Sun-Earth Lagrangian point L2
- Large frequency coverage (**40–402 GHz**, 15 bands) at **70–18 arcmin** angular resolution for precision measurements of the **CMB *B*-modes**
- Final combined sensitivity: **2.2 μK·arcmin**

📖 LiteBIRD collaboration PTEP 2023







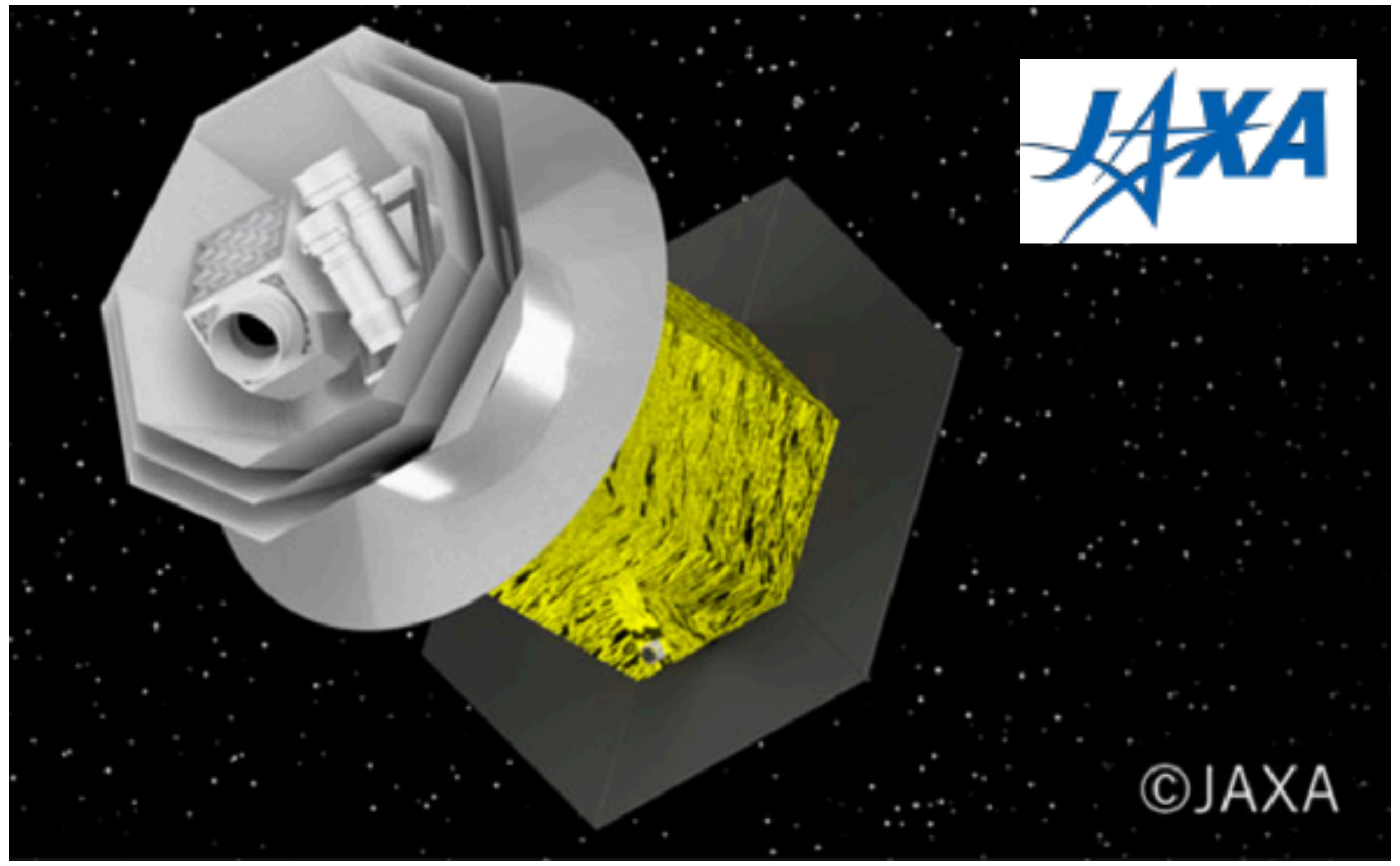


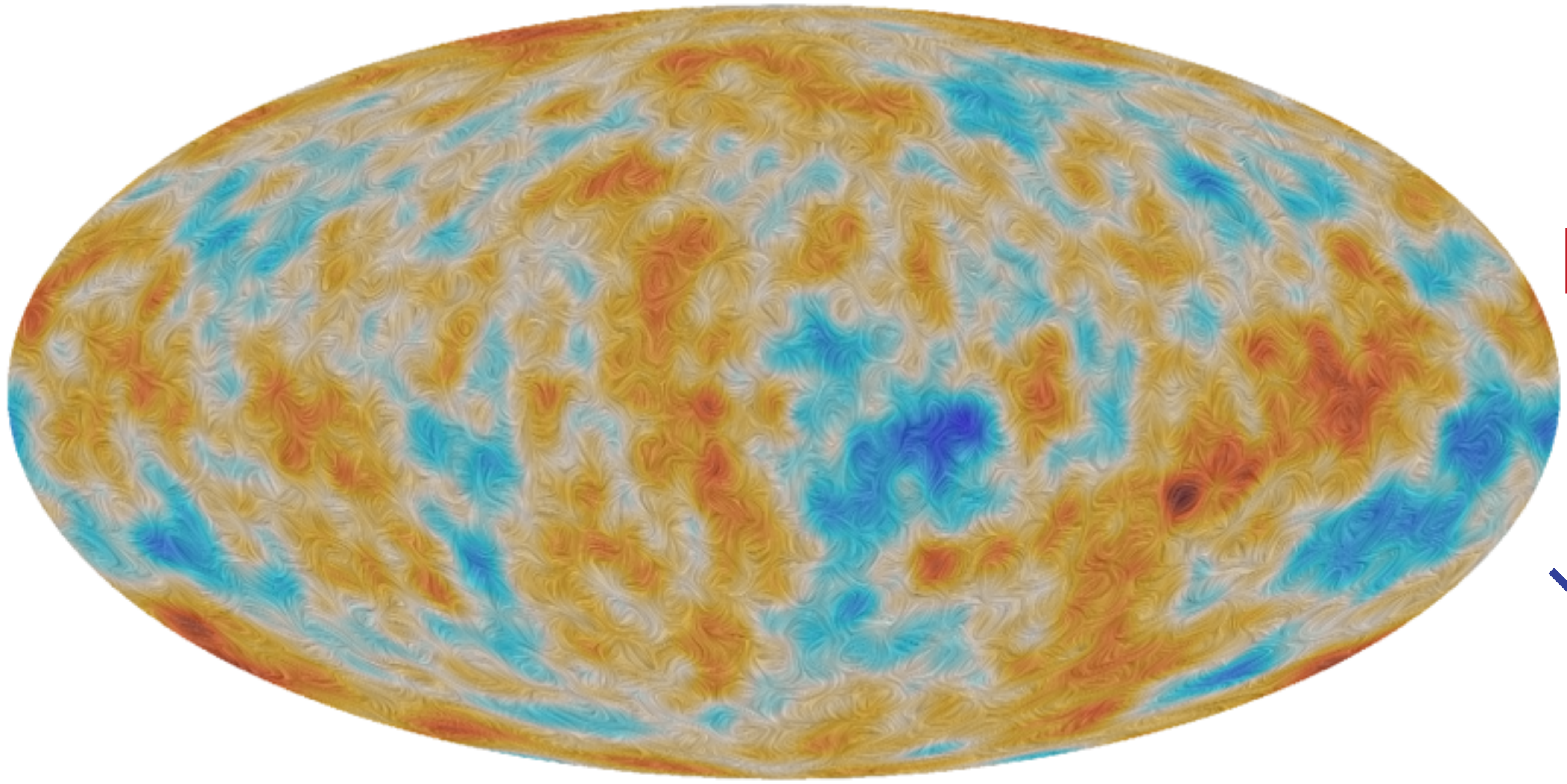
LiteBIRD overview

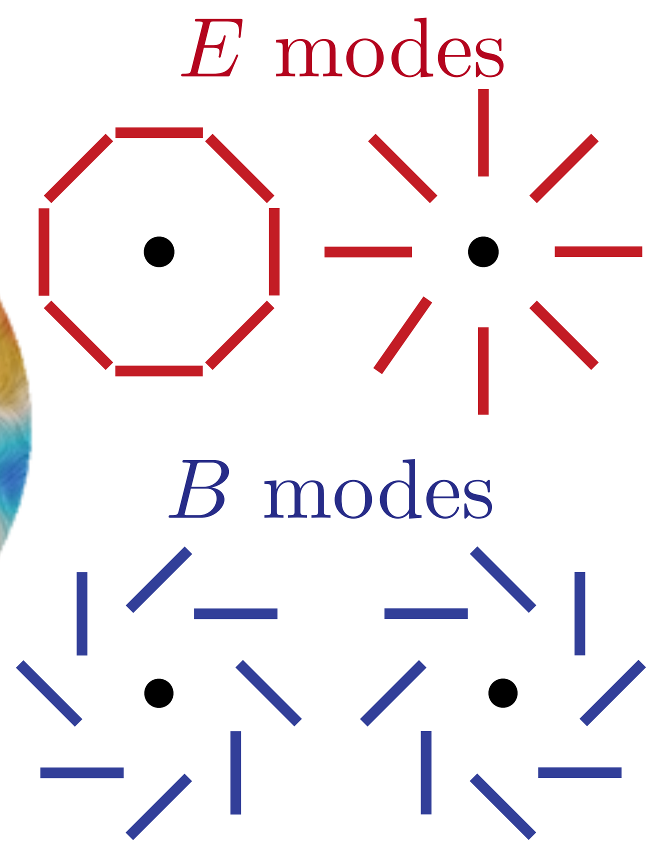
📖 LiteBIRD collaboration PTEP 2023

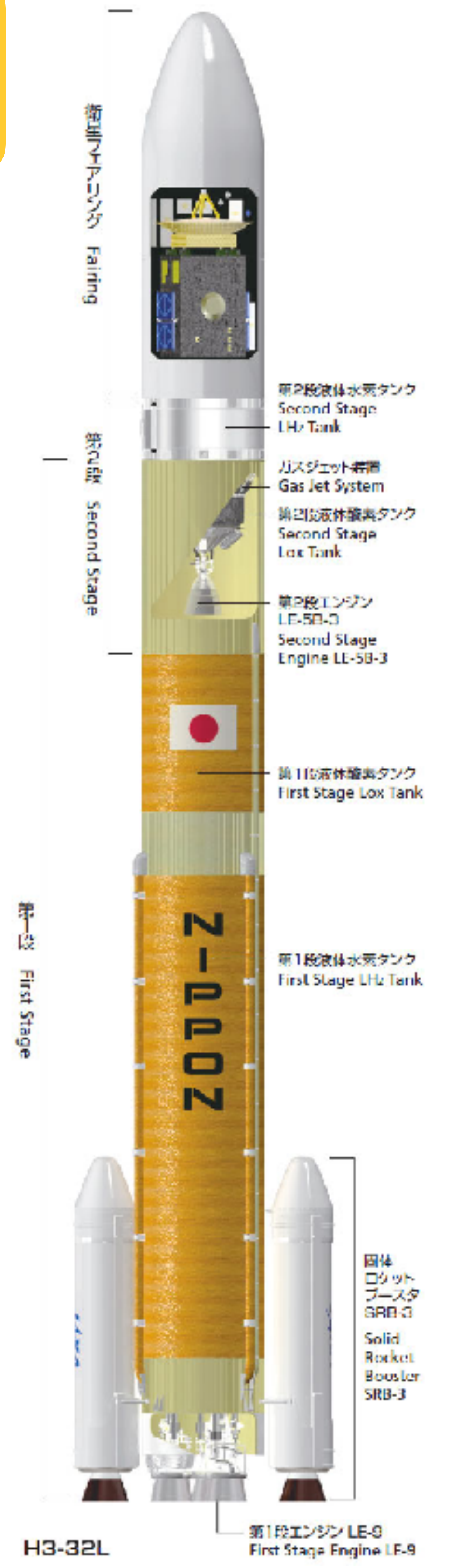
LiteBIRD reformation phase

- After the ISAS/JAXA mission definition review, LiteBIRD is under rescope studies to consolidate the mission's feasibility with the same scientific goals.
- The LiteBIRD collaboration will spend approximately one year (~ late 2025) on the studies of the reformation plan.





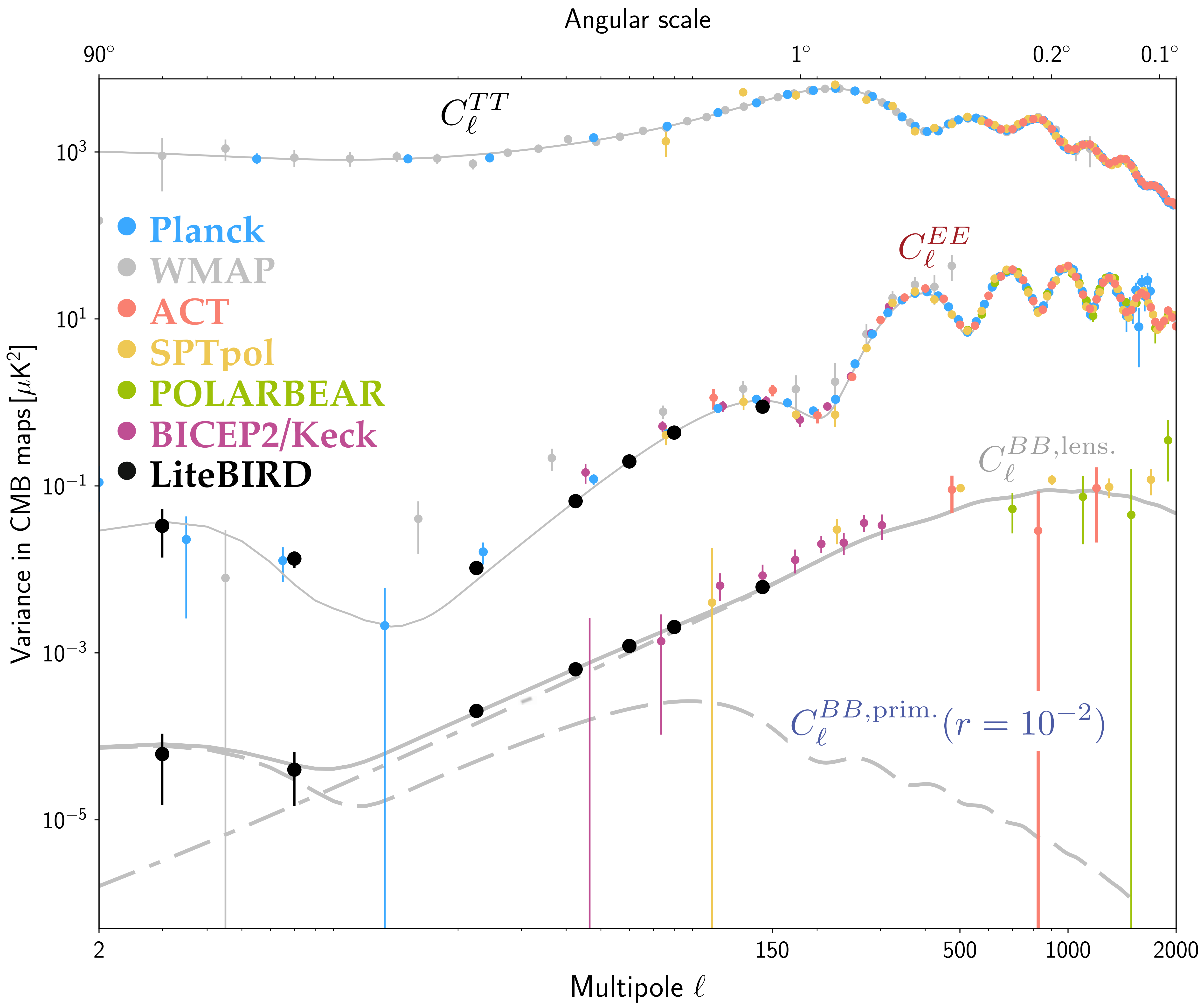




LiteBIRD main scientific objectives

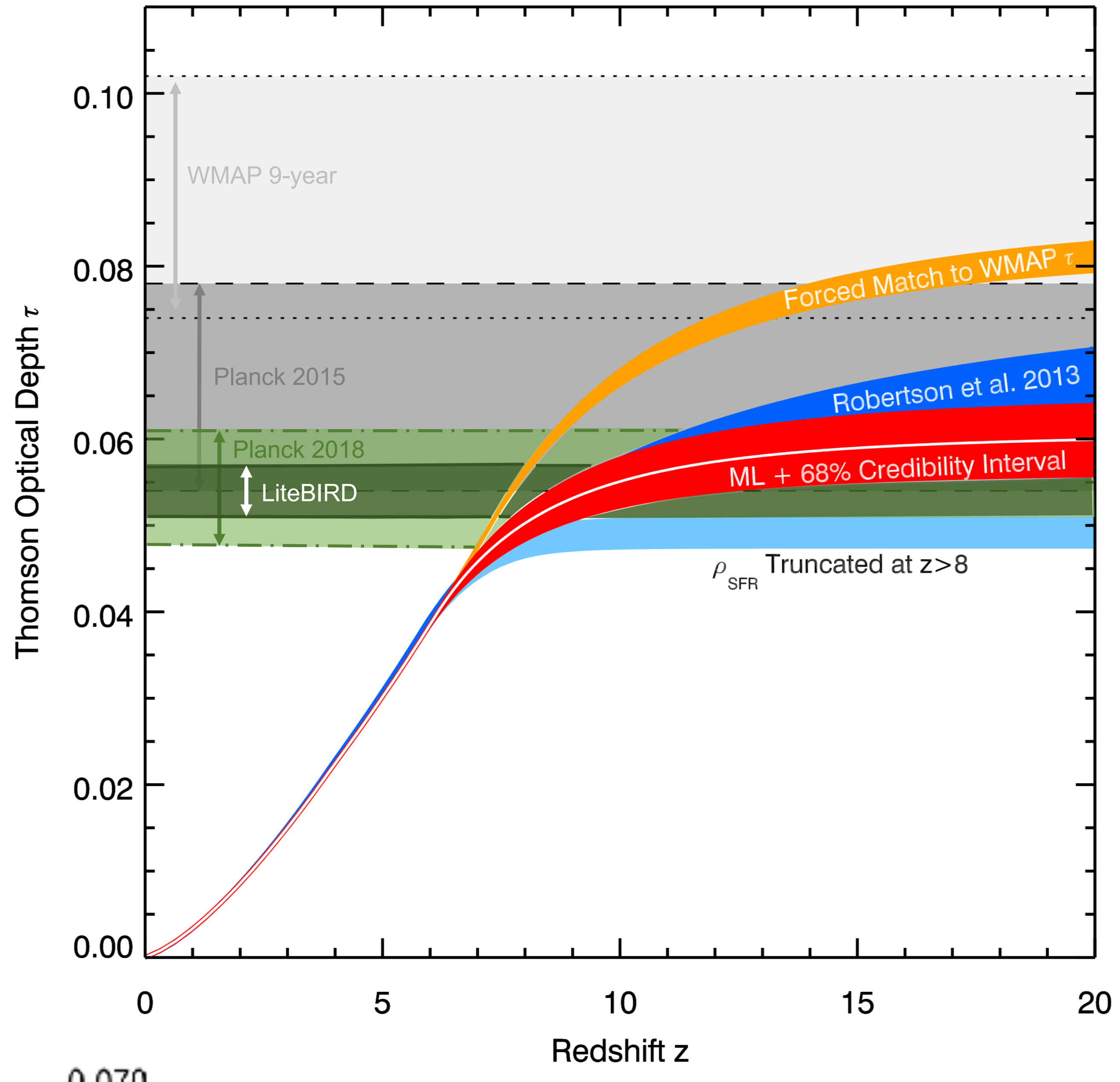
- Definitive search for the ***B*-mode signal** from **cosmic inflation** in the CMB polarization
  - Making a discovery or ruling out well-motivated inflationary models
  - Insight into the quantum nature of gravity
- The inflationary (i.e. primordial) *B*-mode power is proportional to the **tensor-to-scalar ratio, *r***
- Current best constraint: $r < 0.032$ (95% C.L.)
  (📖 Tristram et al. 2022, combining BK18 and Planck PR4)

- LiteBIRD will improve current sensitivity on *r* by a factor ~50
- L1-requirements (no external data):
  - For $r = 0$, **total uncertainty of $\delta r < 0.001$**
  - For $r = 0.01$, 5-σ detection of the reionization ($2 < \ell < 10$) and recombination ($11 < \ell < 200$) peaks independently
- L2-requirements:
  - $\sigma_{stat} < 6\times10^{-4}$ and $\sigma_{sys} < 6\times10^{-4}$
  - Additional security margin of $\sigma_{margin} < 6\times10^{-4}$

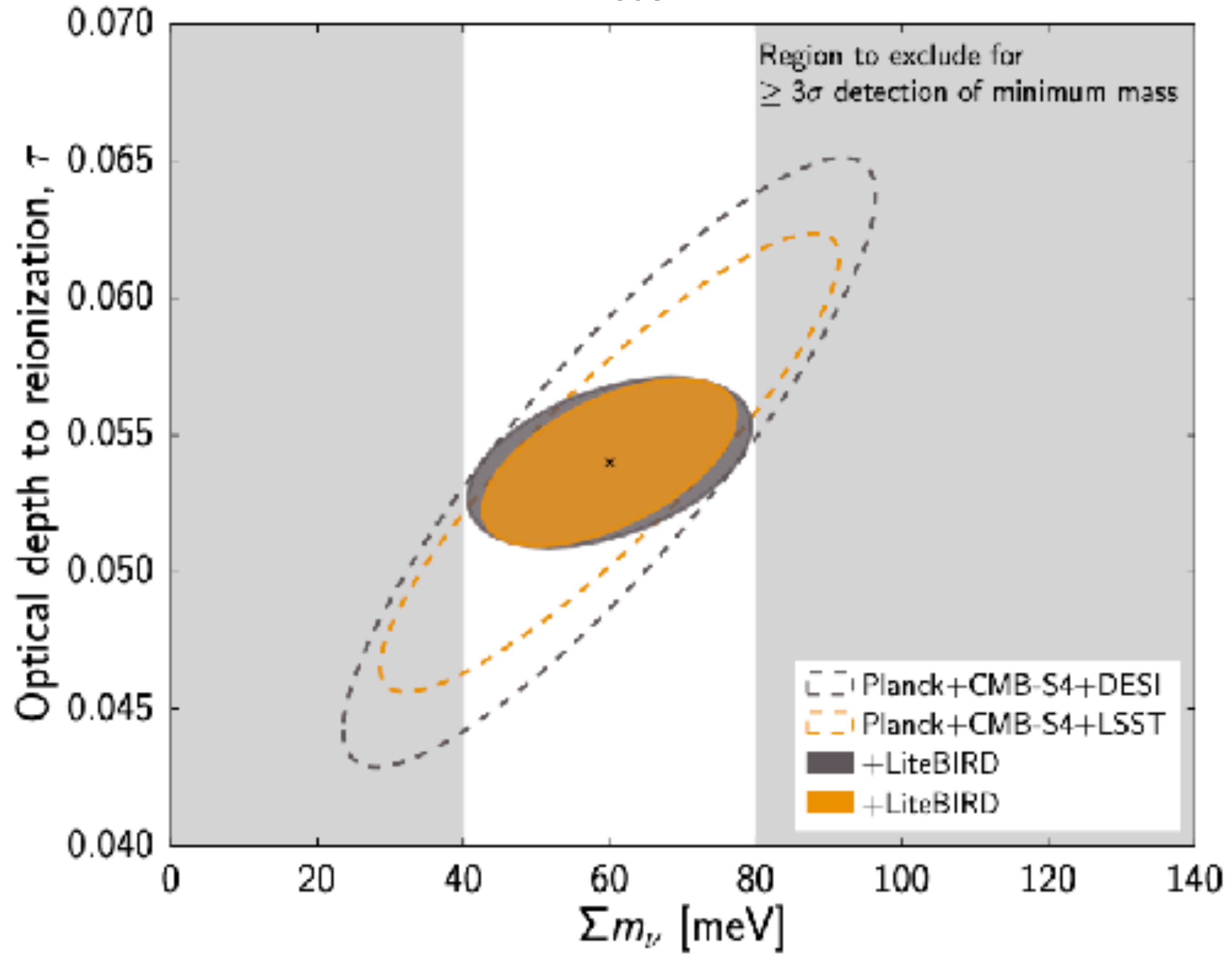


Optical depth, reionization and neutrino masses

- LiteBIRD will provide a cosmic-variance limited measurement of the ***E*-mode** power spectrum at large scales ($2 < \ell < 200$)
- This will lead to improved constraints on:
  - **Reionization**
    - Cosmic-variance measurement of the **optical depth** to reionization $\Rightarrow \sigma(\tau) \approx 0.002 \Rightarrow \times 2$ improvement with respect to Planck (📖 Planck Int.Res. LVII, 2020)
    - Improved constraints on reionization history models: 35% improvement on the uncertainty of $\Delta(z_{\mathrm{reion}})$
  - **Neutrino masses**
    - $\times 2$ improvement on $\sigma(\sum m_\nu)$
    - $\sigma(\sum m_\nu) = 12$ eV $\Rightarrow 5\sigma$ detection for a minimum value of $\sum m_\nu = 60$ meV (allowed by flavour-oscillation experiments) or larger
    - Potentially allow to distinguish between the inverted neutrino mass ordering and the normal ordering



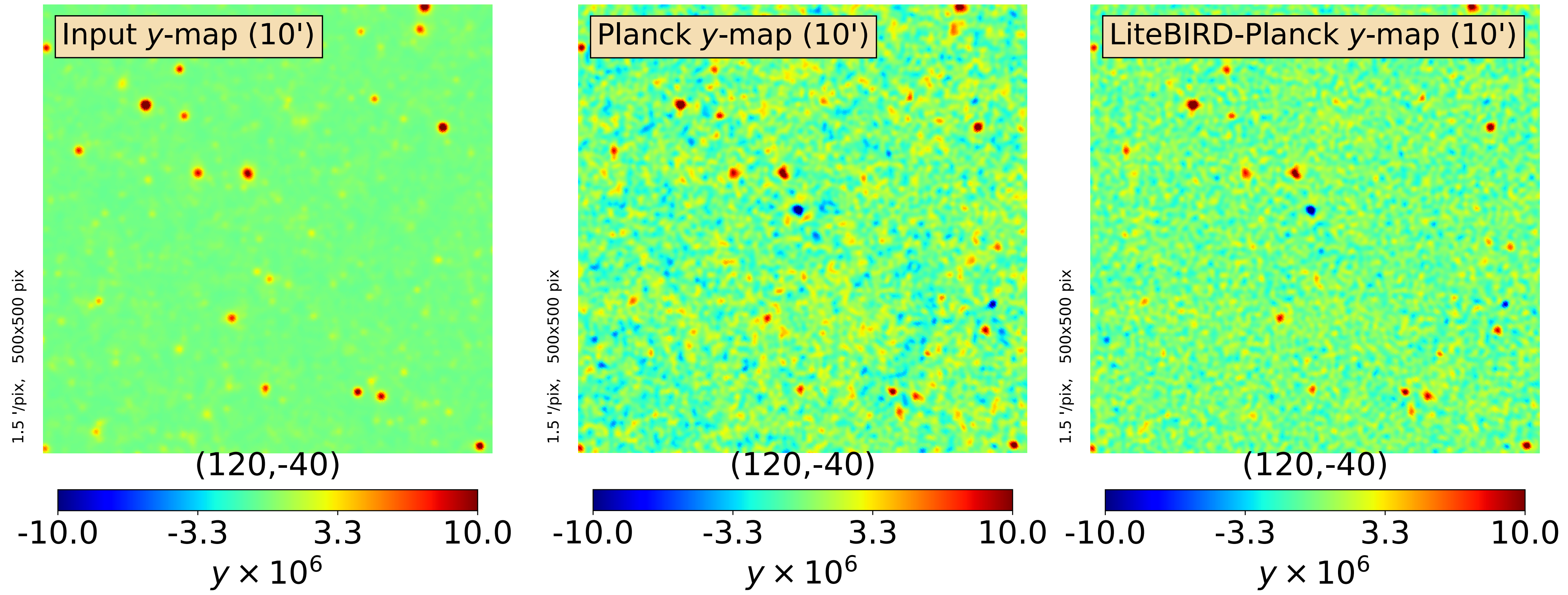
📖 adapted from Robertson+2015

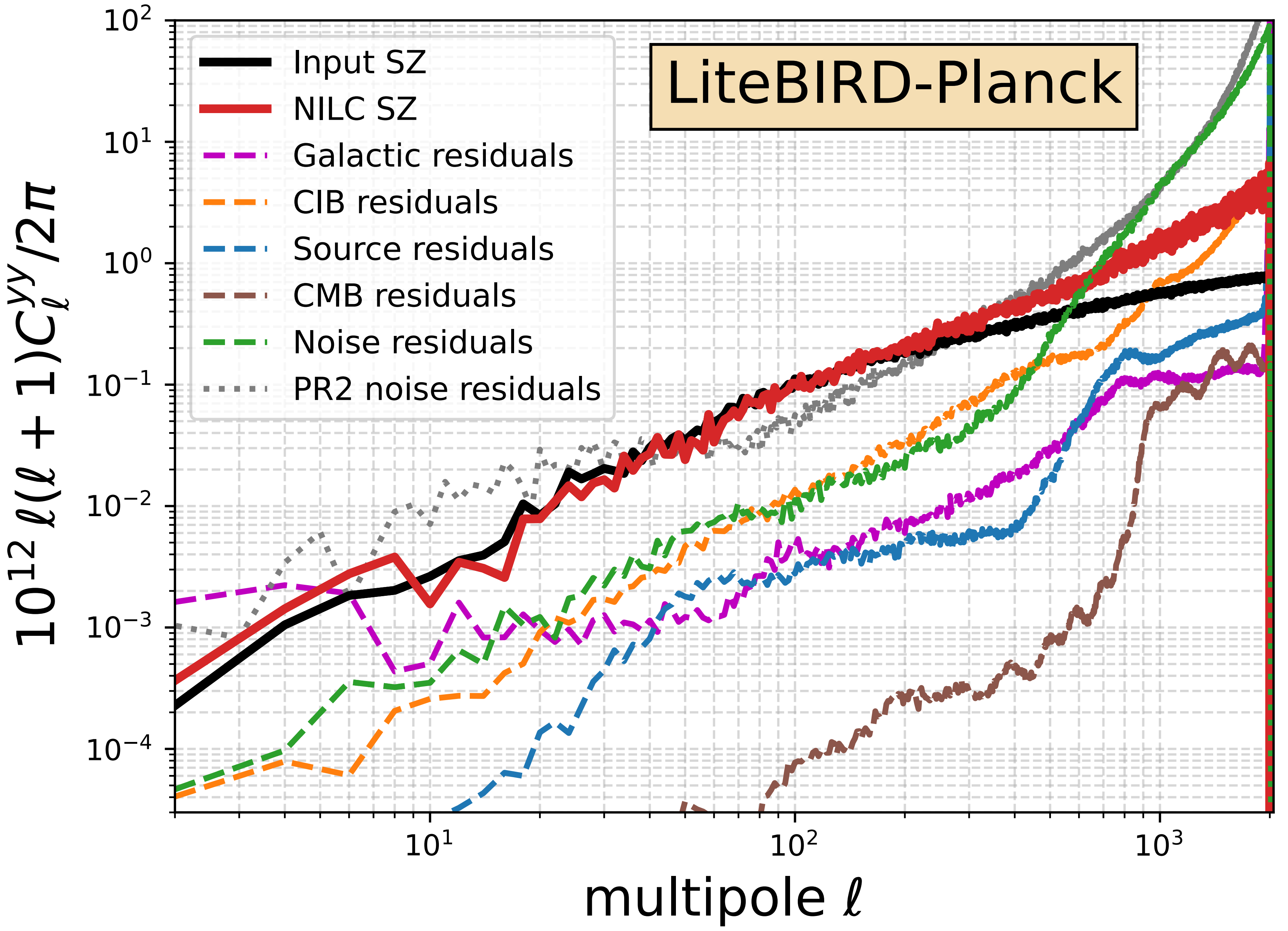


📖 adapted from Calabrese+2017

Mapping the hot gas in the Universe

- The **Sunyaev-Zel'dovich** effect provides a mean to map the distribution of hot electrons in the Universe
- Improved sensitivity and frequency coverage of LiteBIRD crucially contributes to improve these studies
- Combination with Planck adds the benefit of angular resolution
- LiteBIRD will **improve ×10 the noise in the SZ map** wrt Planck
- This will allow to:
  - Produce a high-fidelity SZ map over the full-sky essentially **free of contamination at $\ell < 200$**
  - Test theories of structure formation via **hot-gas tomography** from SZ × galaxy surveys correlations
  - Search form **WHIM** in filaments connecting clusters
  - Study an **inhomogeneous reionization** process via cross-correlations of SZ × CMB optical depth
  - Measure the mean gas T_e via the relativistic SZ
  - Improve constraints on $S_8 = \sigma_8(\Omega_m/0.3)^{0.5}$ by 15%



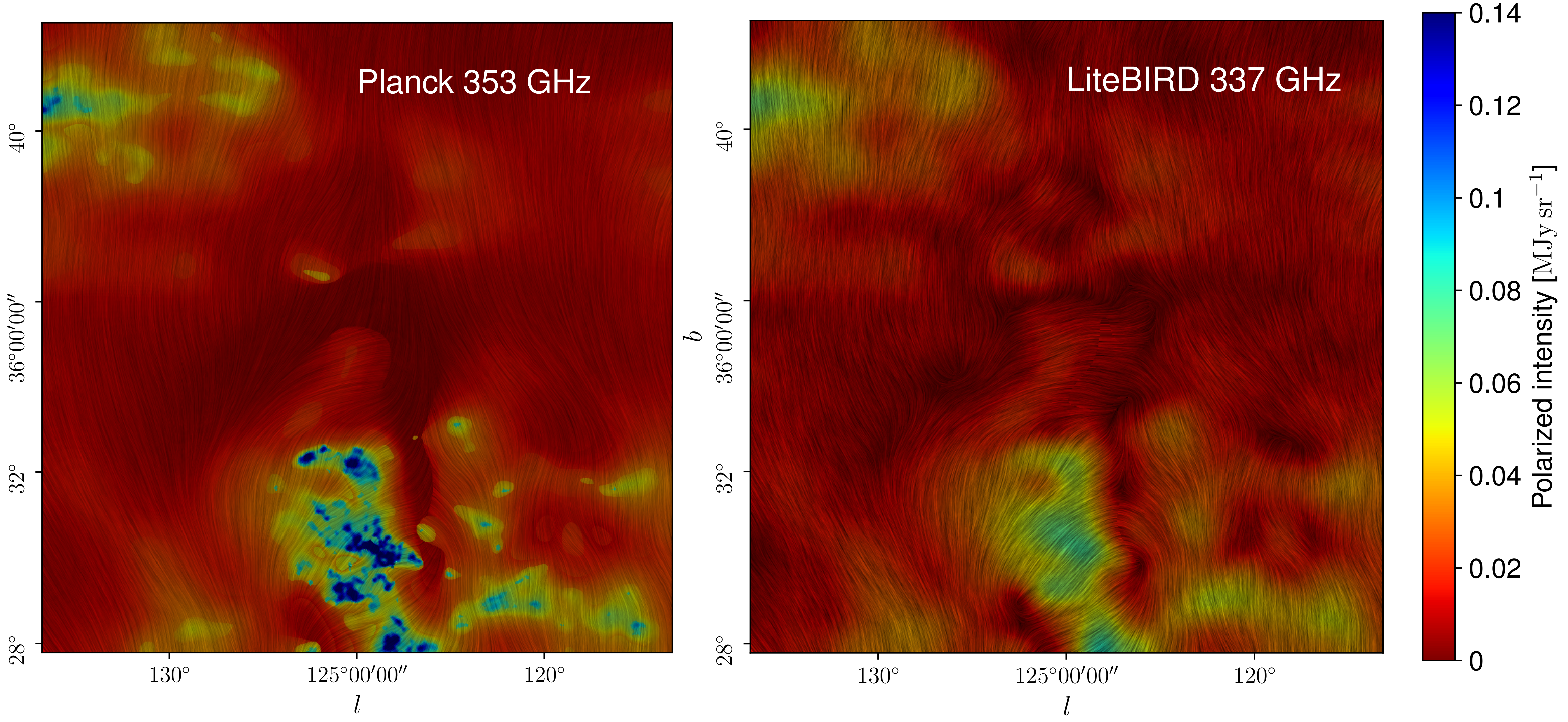


Remazeilles+ JCAP 2024

Galactic astrophysics

- LiteBIRD will provide 15 high-sensitivity polarization full-sky maps from 40 to 402 GHz
- Sensitivity improved by a factor of 5 at 40 GHz and 10 at 402, with respect to Planck
- Gain in spectral resolution

- **Wealth of Galactic science possible**:
  - Geometry of the Galactic magnetic field
  - Interstellar turbulence
  - Dust composition
  - Grain alignment
  - Cold clumps
  - Geometry of synchrotron-bright loops
  - SED of the synchrotron emission
  - Nature of AME and spectral variations...
  - … and many others!



Credit : ESA and the *Planck* Collaboration

Thanks a lot !

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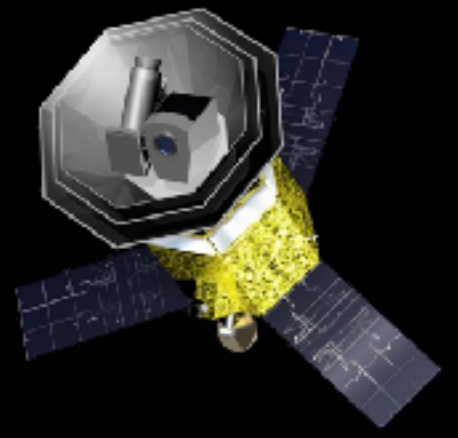

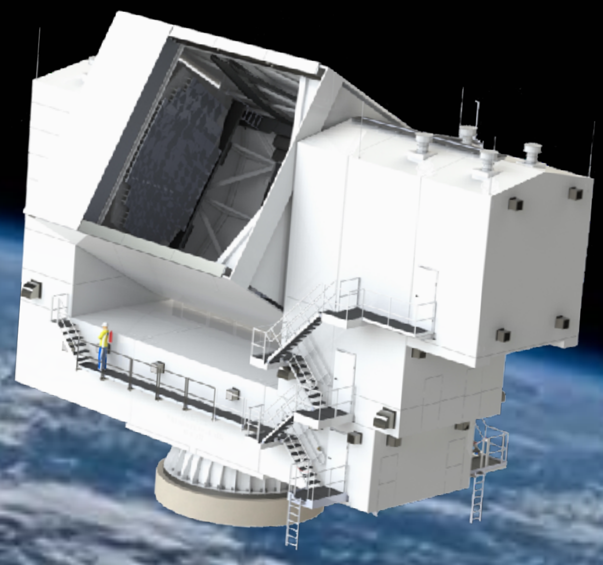

SciPol

Science from the large scale cosmic microwave background polarization structure