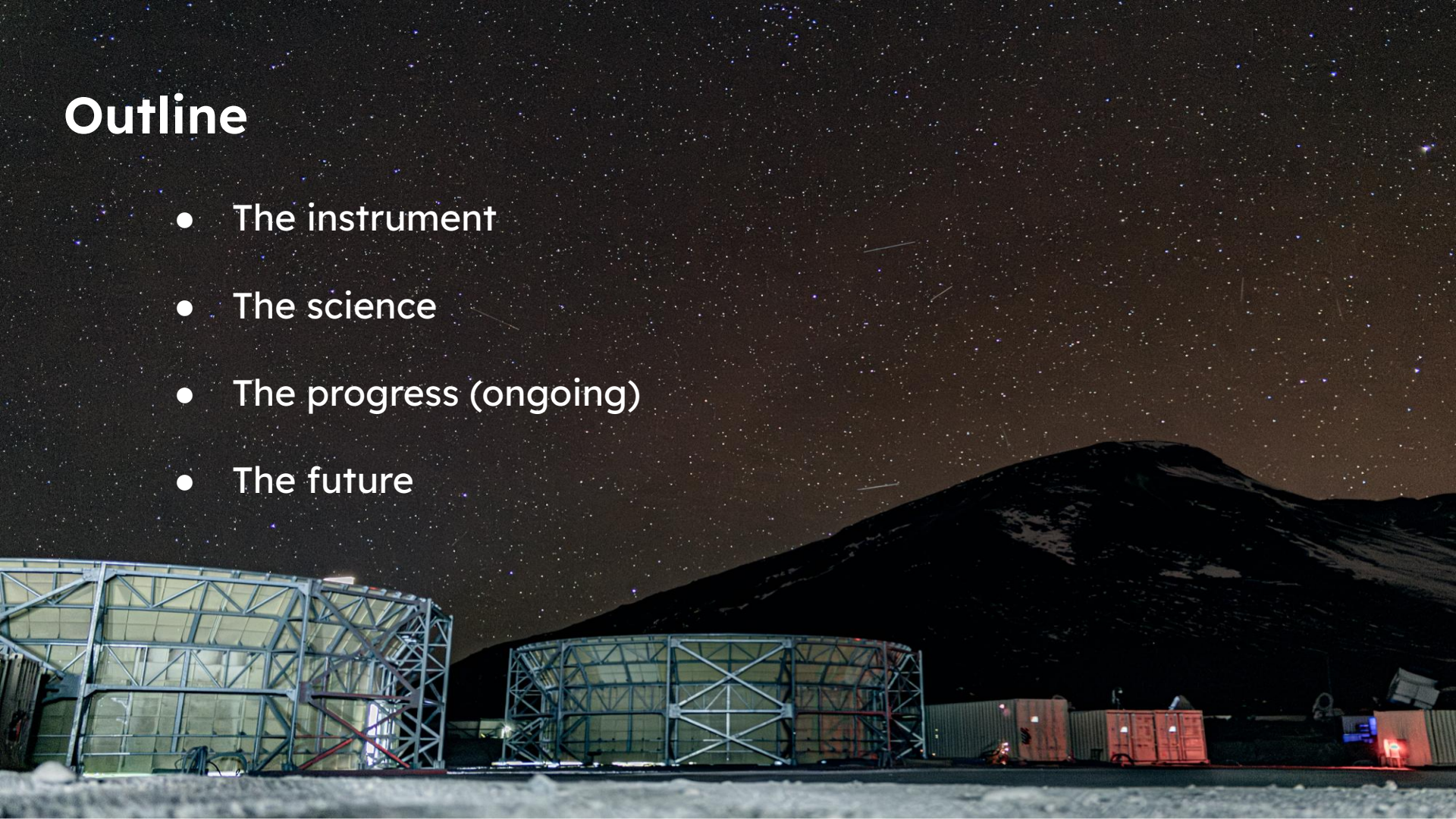
Simons Observatory

21st Rencontres du Vietnam Cosmology

Sherry Song, Kavli IPMU, 20250815

Outline

- The instrument
- The science
- The progress (ongoing)
- The future

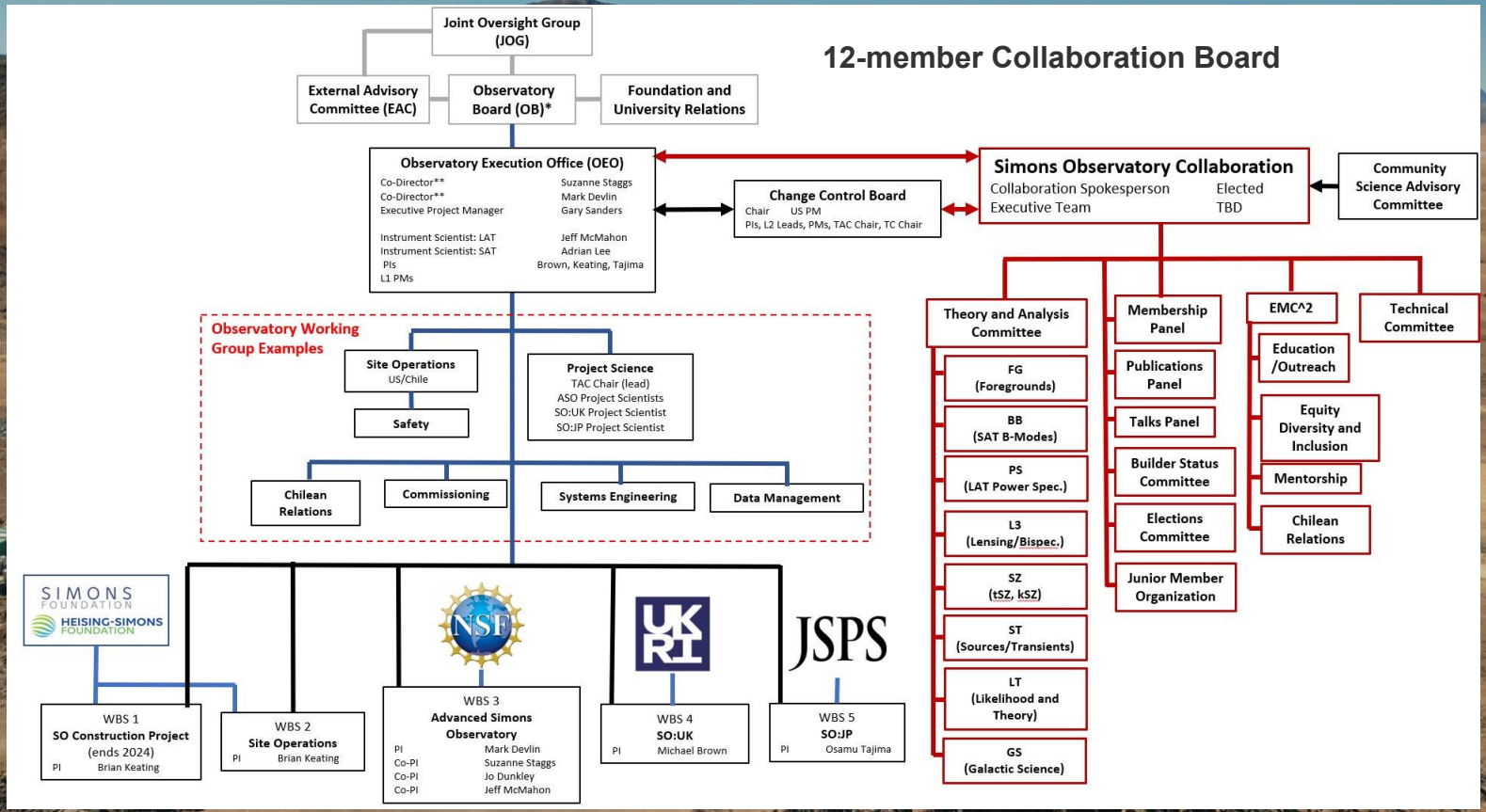


The collaboration

400+ people

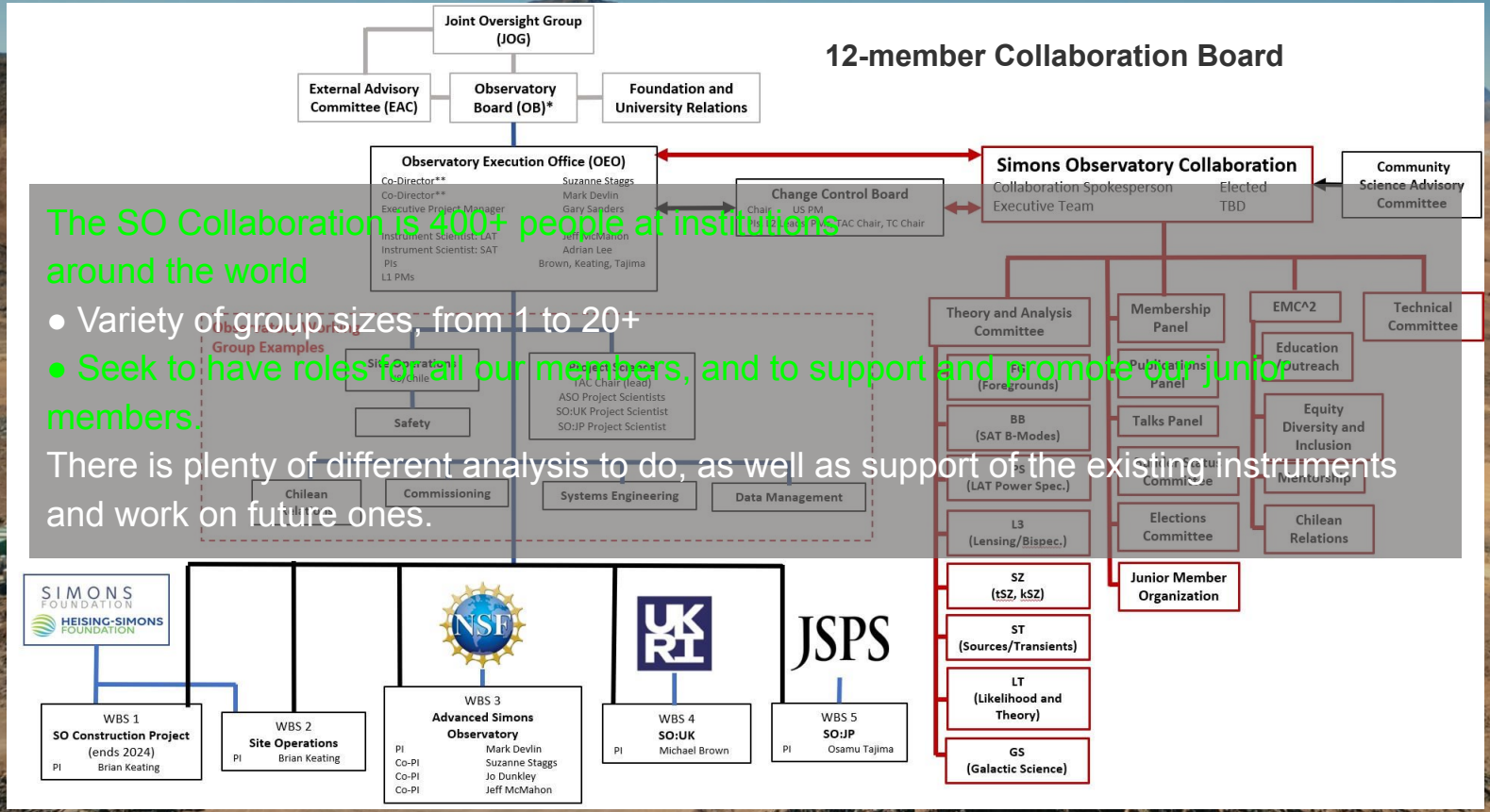
The collaboration

400+ people



The collaboration

400+ people



The SO Collaboration is 400+ people at institutions around the world

- Variety of group sizes, from 1 to 20+
- Seek to have roles for all our members, and to support and promote our junior members.

There is plenty of different analysis to do, as well as support of the existing instruments and work on future ones.

The instrument

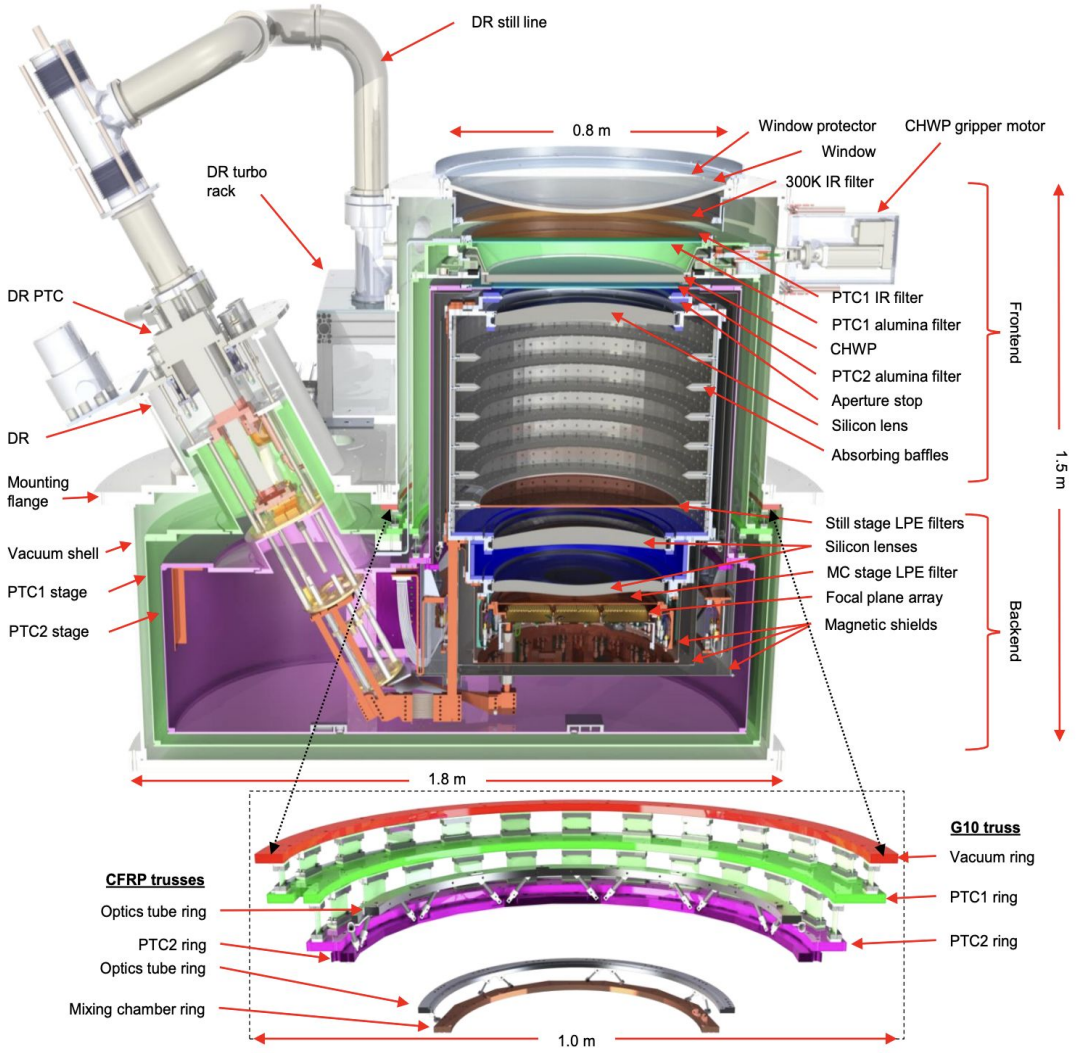
Why Chile ?
- PWV level 1.2mm
- Low latitude, more coverage

The instrument

Small Aperture Telescope (SAT) 0.42m

The instrument

Small Aperture Telescope (SAT) 0.42m



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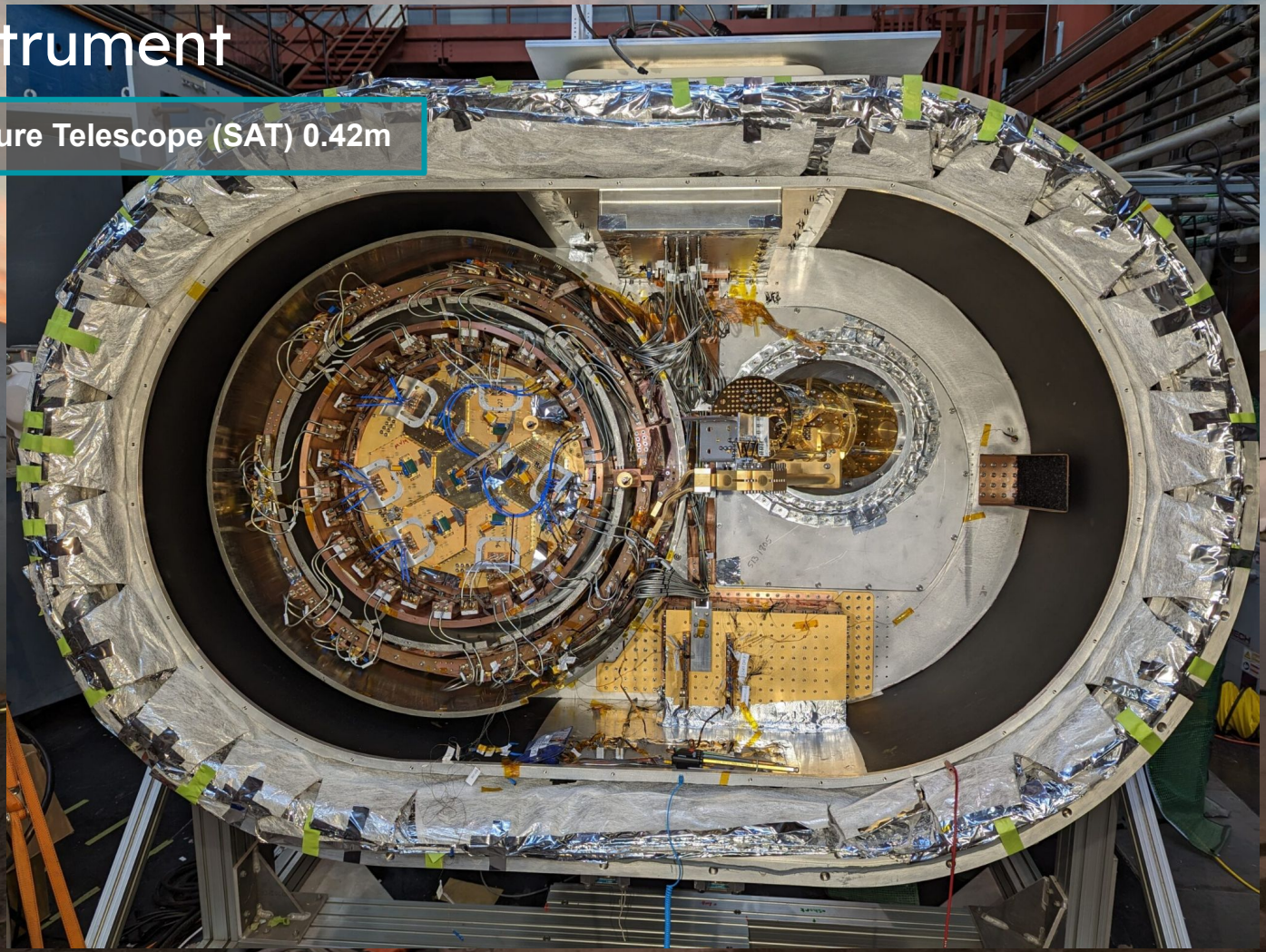
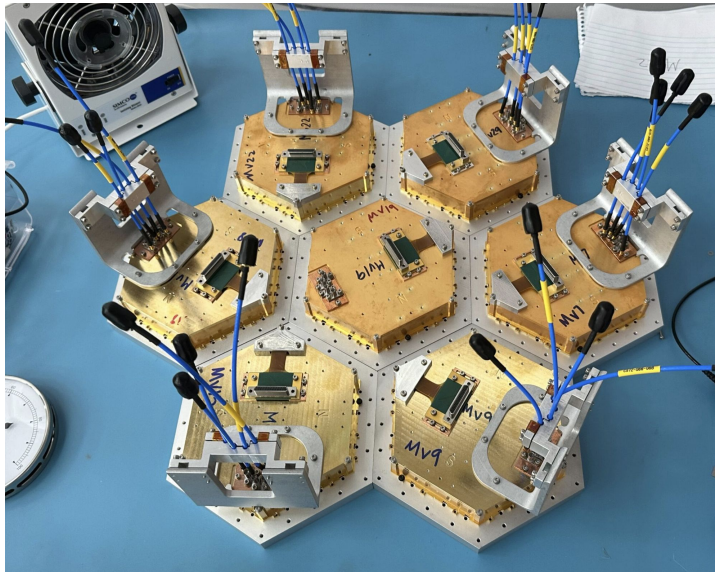
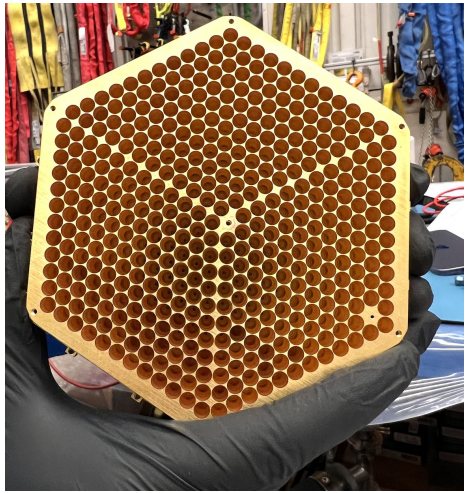
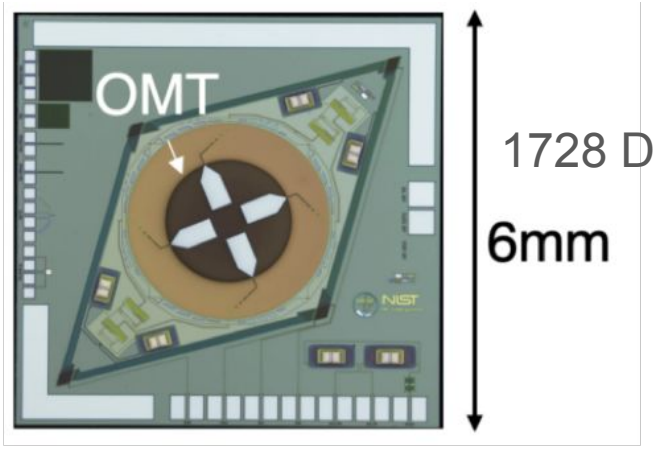






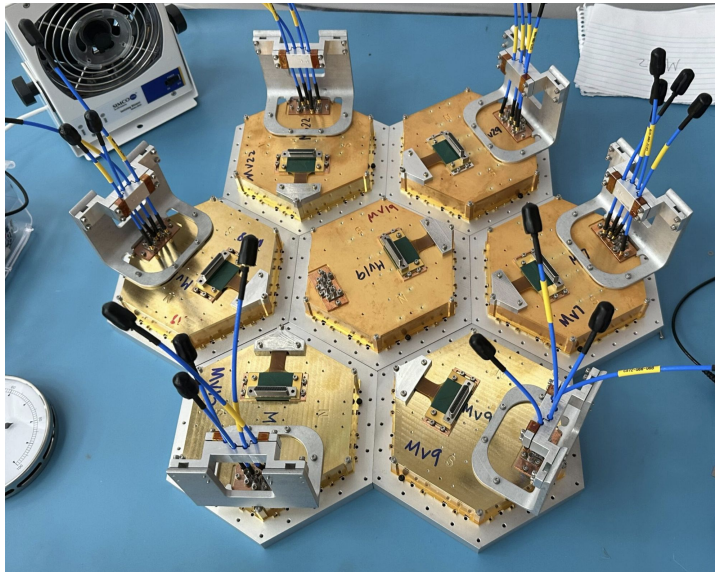
1728 DET
Per tile



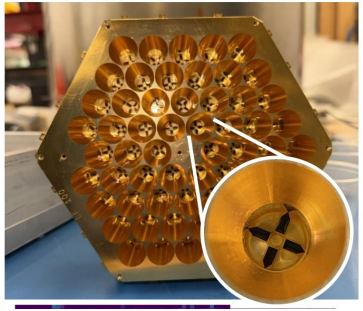
1728 DET Per tile

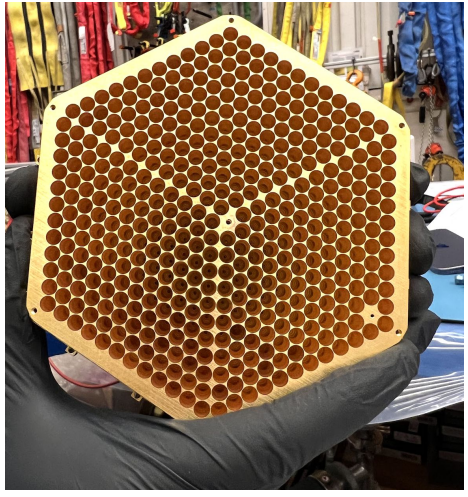
6mm

Superconducting Transition Edge Sensor (TES)



LF beams





1728 DET Per tile

The instrument

Small Aperture Telescope (SAT) 0.42m

Optical Design: Cryogenic Refracting Telescope
Field of view: 35 degrees
Sky coverage: 10%
Detector counts:
- 36,000 TES for 3 SATs
- 61,000 TES in total in the future
- Dichroic modules

Frequency bands:
- **MF** (90/150 GHz)
- **UHF** (220/280 GHz)
- **LF** (30/40 GHz) - future

Focal Plane Temperature:
- 100mK

Half-wave plate: 40K, rotate at 2Hz

ν (GHz)	27/39	90/150	220/270
# detectors	1036	24192	12096

Table 1. SO SAT Design Specifications

Frequency (GHz)	FWHM (arcmin)	Baseline (μK-arcmin)	Goal (μK-arcmin)	Frequency Bands	Detector Number	Number of SATs
27	91	35	25	LF	518	1
39	63	21	17		518	
93	30	2.6	1.9	MF	12,096	2
145	17	3.3	2.1		12,096	
225	11	6.3	4.2	UHF	6,048	1
280	9	16	10		6,048	

The instrument

Large Aperture Telescope (LAT) 6m

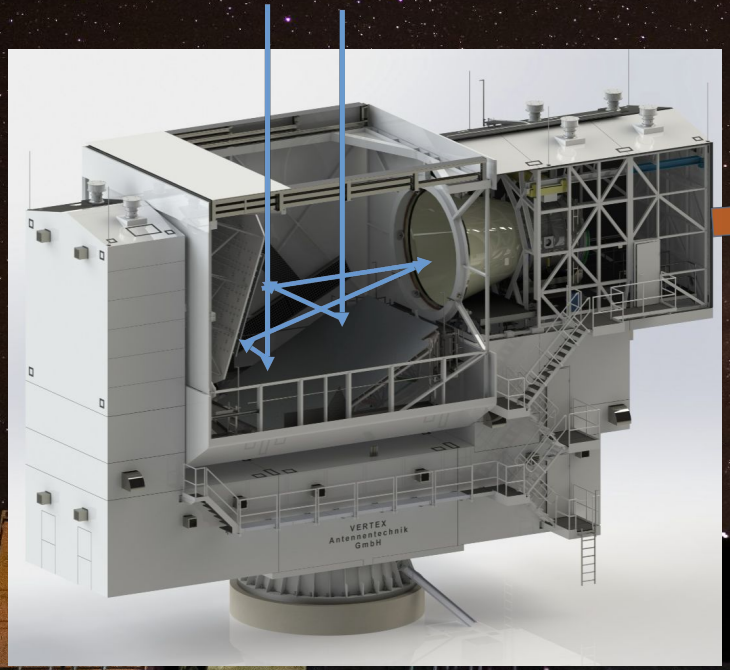
Optical Design: Crossed Dragone
Primary & Secondary Mirror: 6 meters

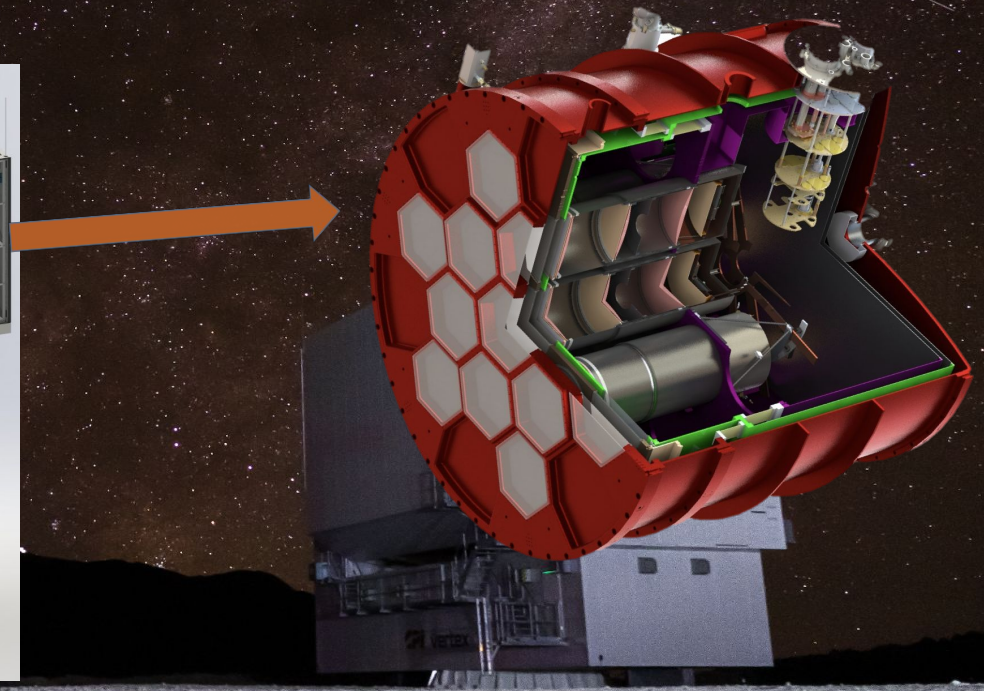
The instrument

Large Aperture Telescope (LAT) 6m

Optical Design: Crossed Dragone
Primary & Secondary Mirror: 6 meters

The Simons Observatory Camera contains 13 “Optics Tubes”. The light from the telescope enters an Optics Tube through one of 13 windows. Light coming from different parts of the sky will enter into different windows.





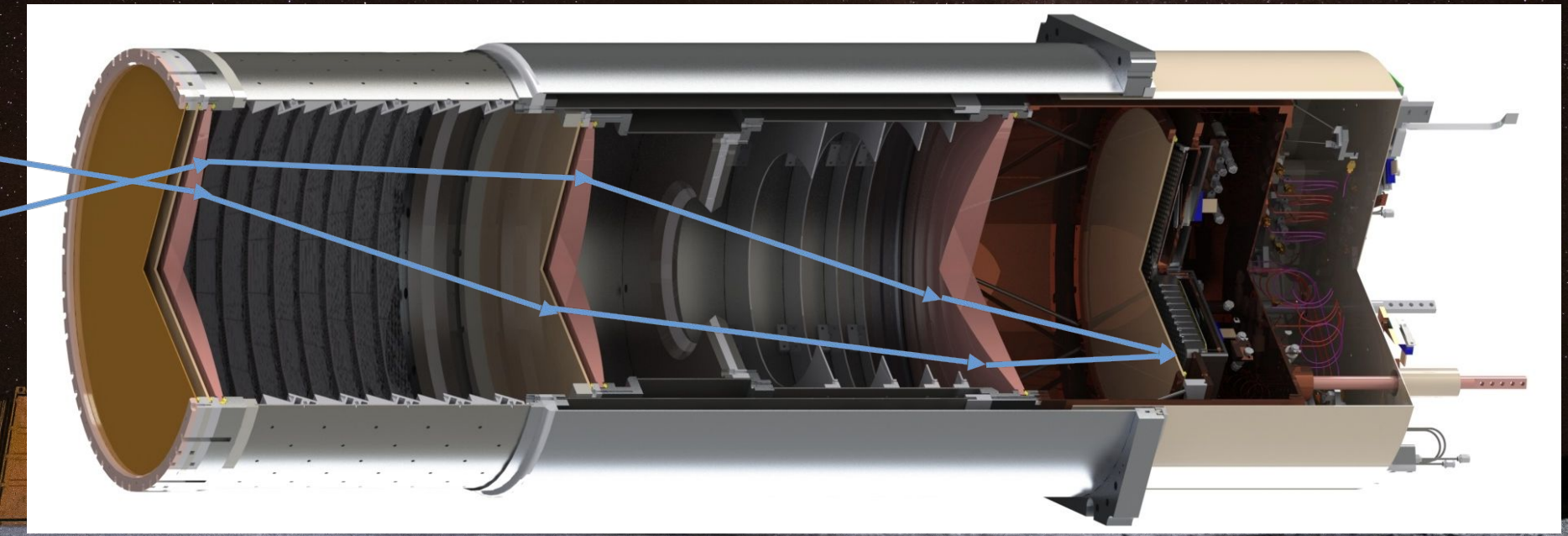
The instrument

Large Aperture Telescope (LAT) 6m

Optical Design: Crossed Dragone
Primary & Secondary Mirror: 6 meters

The Light Enters an Optics Tube

A series of lenses and filters are used to focus the light on to the detectors.

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Penn
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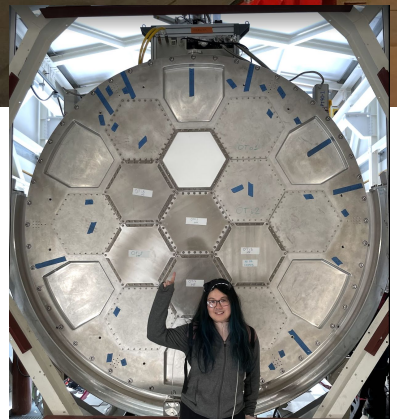


The instrument

Large Aperture Telescope (LAT) 6m

Optical Design: Crossed Dragone
Field of view: 7 degrees
Sky coverage: 60%
Primary & Secondary Mirror: 6 meters
Detector counts:
- 31,000 TES
- 62,000 TES (Advanced SO)
- Dichroic modules

Frequency bands:
- **MF** (90/150 GHz)
- **UHF** (220/280 GHz)
- **LF** (30/40 GHz)

Focal Plane Temperature:
- 100mK

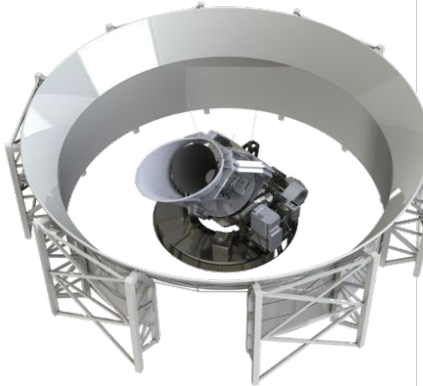
ν (GHz)	27/39	90/150	220/270
# detectors	708	41280	20640

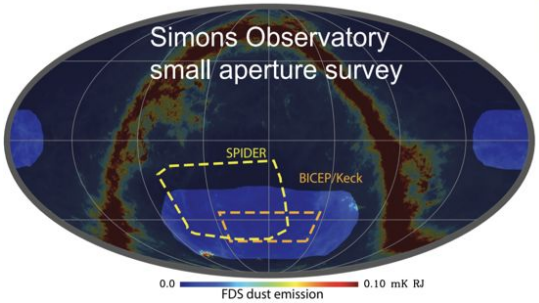
Table 1. SO Large Aperture Telescope Survey Specifications

Frequency [GHz]	FWHM [arcmin]	Baseline Depth [μK · arcmin]	Goal Depth [μK · arcmin]	Frequency Bands	Detector Count	Optics Tubes
27 (22 – 30)	7.4	61	44	LF	354	1
39 (30 – 47)	5.1	30	23		354	
93 (77 – 104)	2.2	5.3	3.8	MF	20,640	8
145 (128 – 169)	1.4	6.6	4.1		20,640	
225 (198 – 256)	1.0	15	10	UHF	10,320	4
280 (256 – 313)	0.9	35	25		10,320	

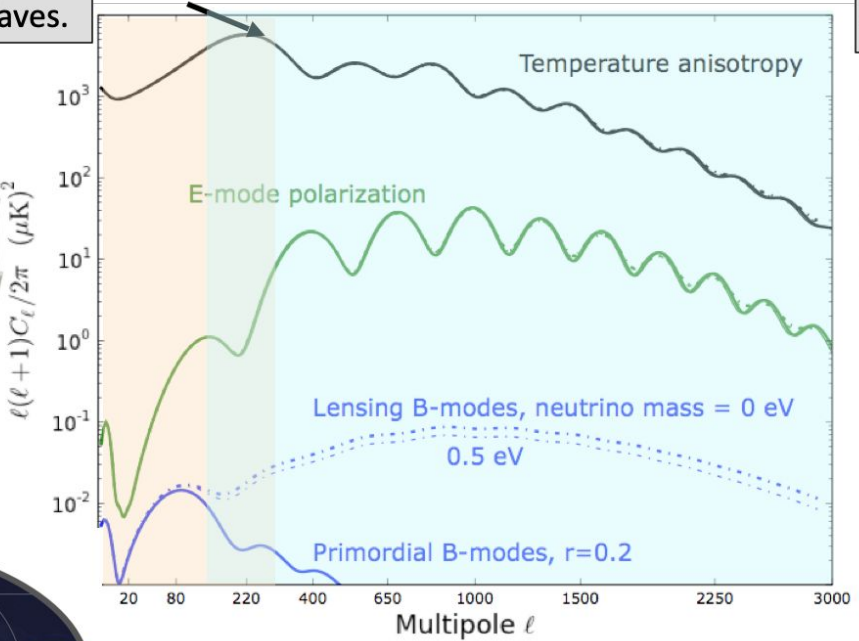
The science

Small Aperture Telescopes (SAT)
- 0.5-meter aperture x 6 SATs.
- Survey 15% of the sky.
- Primordial Gravitational Waves.

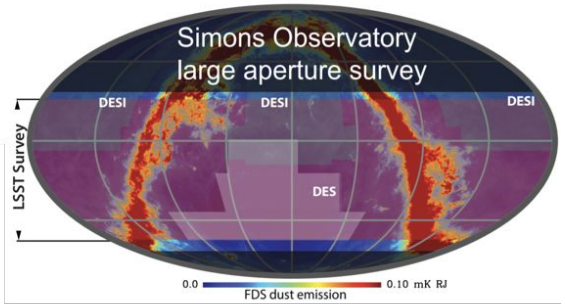




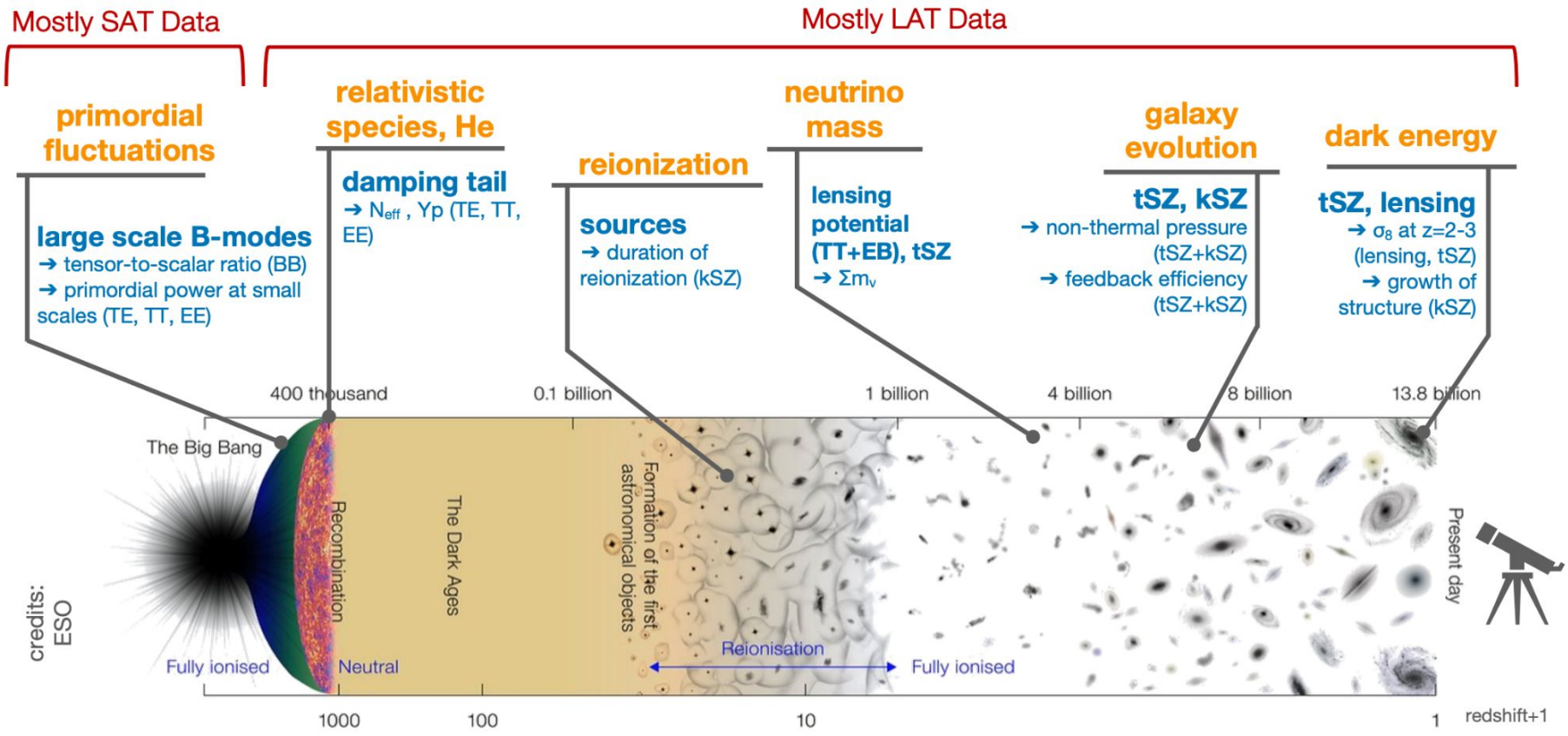
1 degree



Large Aperture Telescope (LAT)
- 6-meter aperture.
- Survey 40% of the sky.
- N_{eff} , Σm_ν , w(z), cluster science…



The science


Mostly SAT Data
Mostly LAT Data
primordial fluctuations
large scale B-modes
➔ tensor-to-scalar ratio (BB)
➔ primordial power at small scales (TE, TT, EE)
relativistic species, He
damping tail
➔ N_{eff} , Yp (TE, TT, EE)
reionization
sources
➔ duration of reionization (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)
400 thousand
0.1 billion
1 billion
4 billion
8 billion
13.8 billion
The Big Bang
Recombination
The Dark Ages
Formation of the first astronomical objects
Reionisation
Present day
Fully ionised
Neutral
Fully ionised
credits: ESO
1000
100
10
1
redshift+1

The science

Time Domain Astrophysics

Tidal Disruption Events

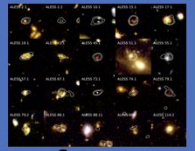
Stellar Flares

Variable AGN

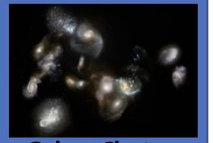
Training the Next Generation

Extragalactic Astronomy

Missing Baryons



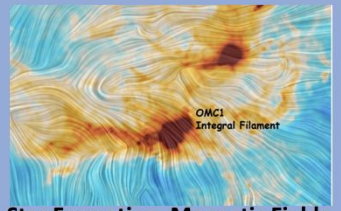
Sources



Galaxy Clusters

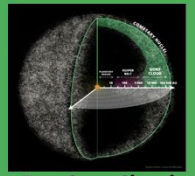
Galactic Astronomy

Interstellar Dust

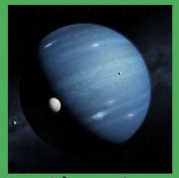


Star Formation, Magnetic Fields and Dust Turbulence

Planetary Science

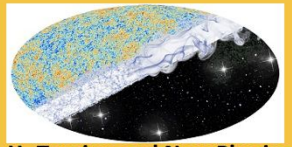


Exo-Oort Clouds

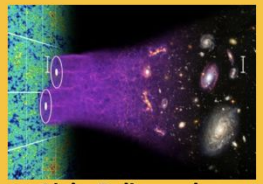


Planet 9

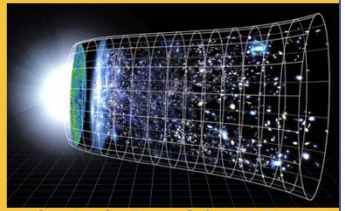
Cosmology and Particle Physics



H_0 Tension and New Physics



Light Relics and Neutrinos



The Evolution of the Universe Over Cosmic Time

The science

SO Nominal Forecasting

Title	Parameter	Baseline	Goal	Current	Method
Primordial Perturbations	r	0.003	0.002	0.03	BB
Relativistic Species	N_{eff}	0.07	0.05	0.2	TT/TE/EE + κκ
Neutrino Mass	Σm_ν	0.04	0.03	0.1	κκ+DESI
Deviations from Λ	H_0(ΛCDM)	0.4	0.3	0.5	TT/TE/EE + κκ
Galaxy Evolution	Feedback efficiency in massive halos	3%	2%	50-100%	kSZ+tSZ+DESI
Reionization	Δz	0.6	0.3	1.4	TT (kSZ)

☐ SAT focus

SO Collaboration 2019,
adapted from a table by N. Galitzki

Note: SO = SO Nominal (current) + SO:UK + SO:Japan + Advanced SO

The progress hardware, Data Managing infrastructure, and analysis

HARDWARE

Two Middle Frequency ***(MF)*** 90/150GHz SATs are deployed and have been operating for nearly a year.

3rd SAT, Ultra-High-Frequency ***(UHF)*** is on site and commissioning to be completed.

LAT commissioning (nearly) completed.
expect 10x the mapping speed of AdvACT starting next year, already have 5x

More upgrades on the way.

INFRA

Observatory control system ***(OCS)*** and supporting software enable remote observations

- 50+ unique agents
- 300+ agent instances deployed on site
- 5000+ hk feed

Last year: ***210TB*** transferred to data centers

SO Nominal ***site*** complete, working on more stable power (PVA deployments)

ANALYSIS

Exciting preliminary results and progresses including:

Beam characterization;
Calibration and pointing;
Optical efficiency;
Focalplane testing;
Sensitivity measurements;

Mapmaker;
Preliminary power spectrum and covariance;
Preliminary lensing;

Higher level analysis;
Simulations;
Pipeline ready…

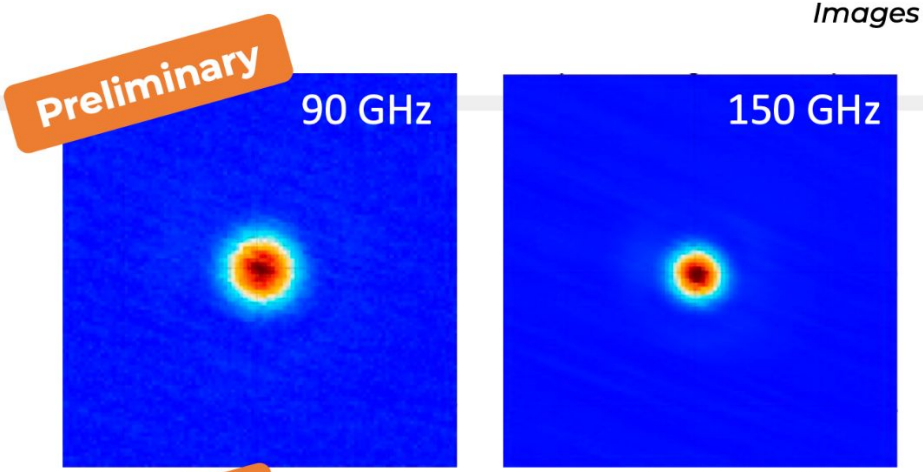
The progress Things I can show...

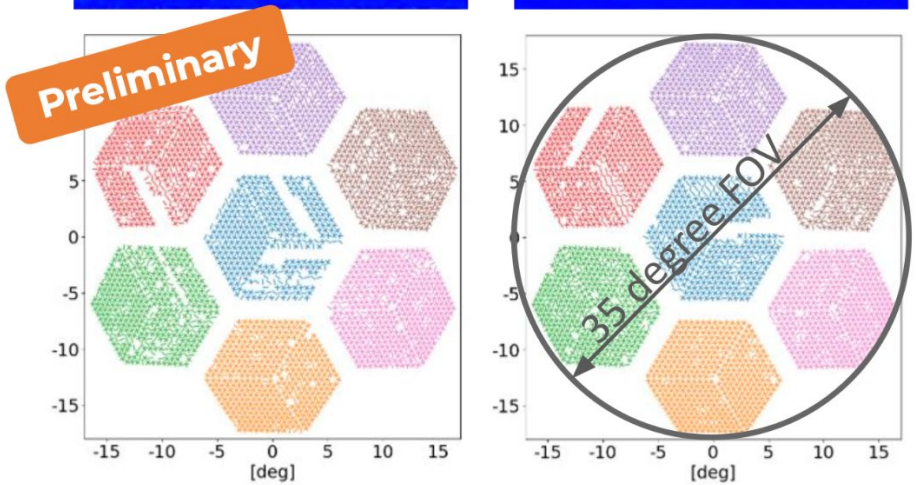
Images credit: SO

Preliminary results

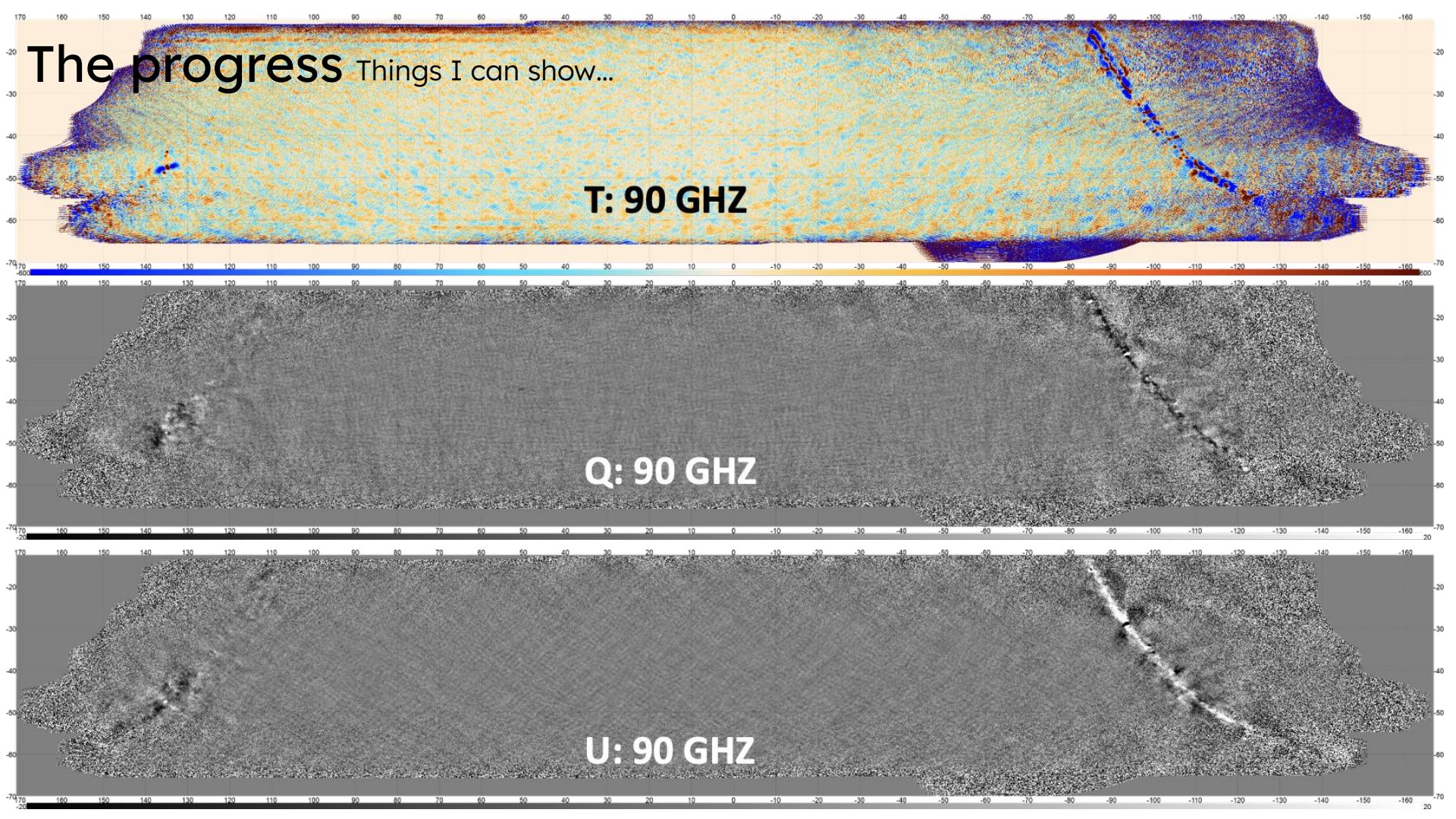
First Light of **Jupiter**.
Observations show expected beam shapes

Per-detector **pointing** developed from Moon and Jupiter observations.



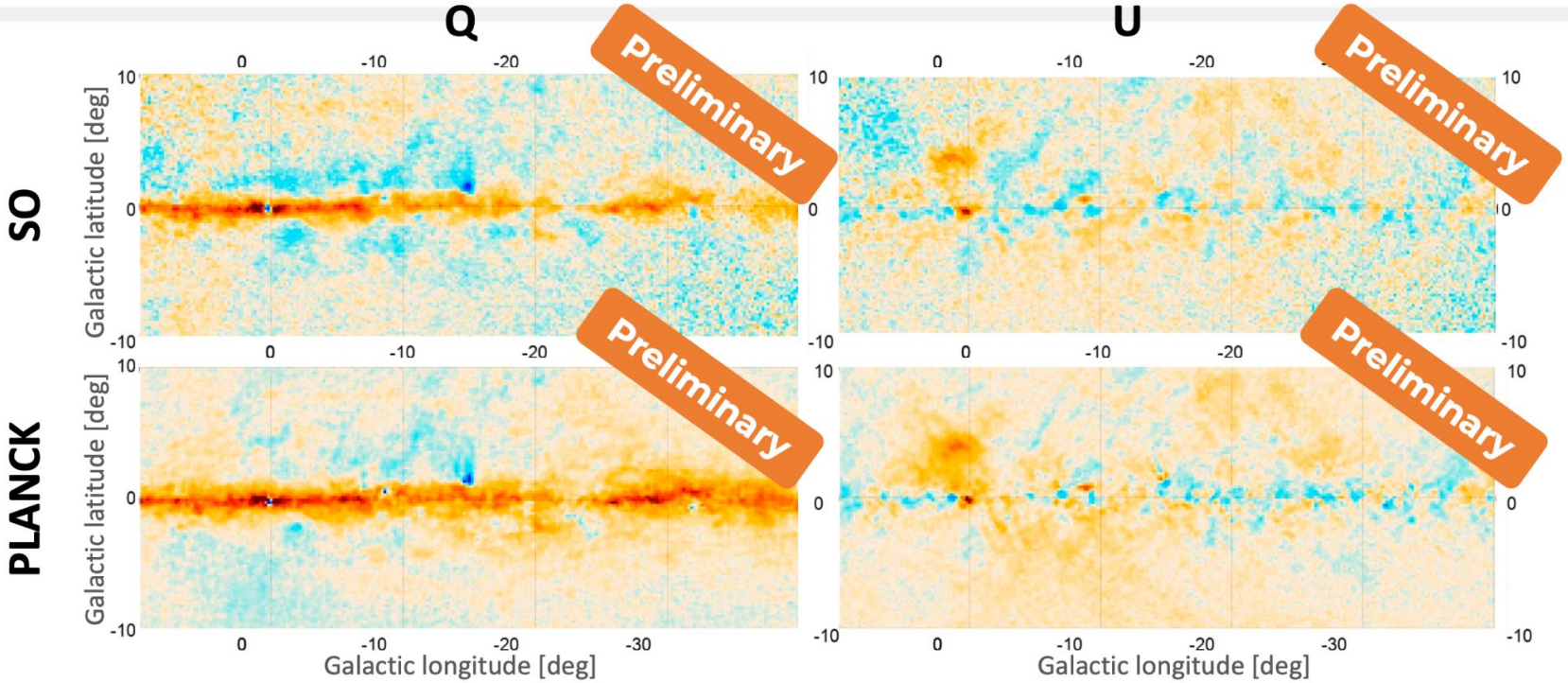


The progress Things I can show...



The progress Things I can show...

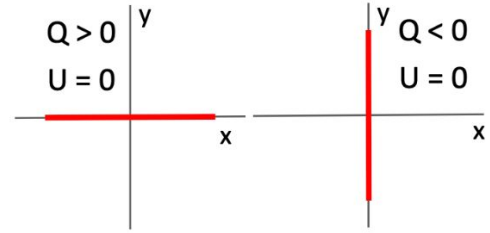
Galaxy maps

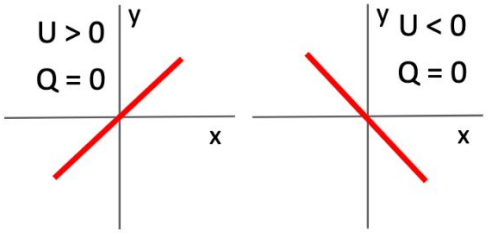


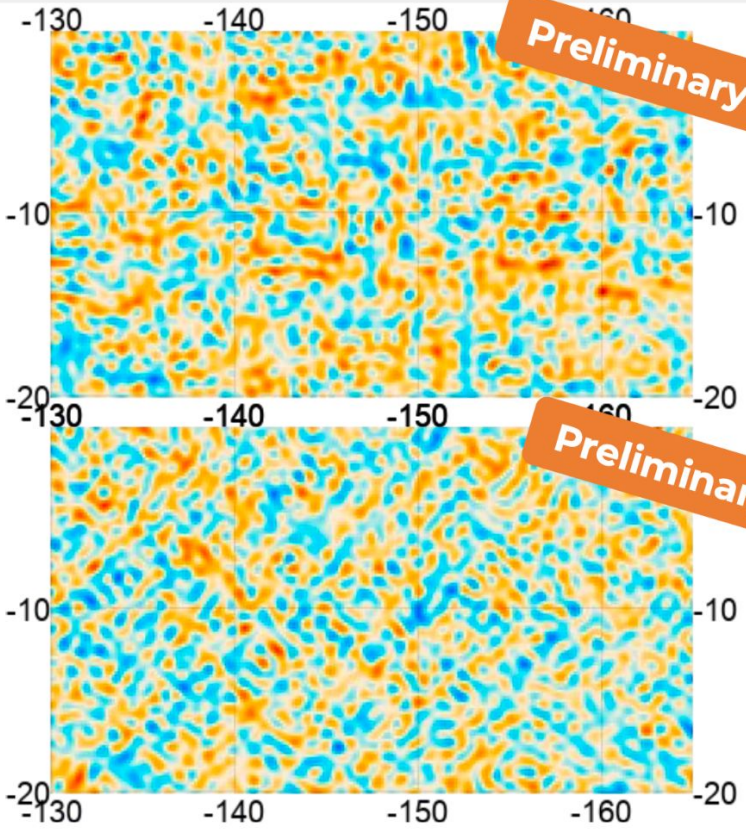
Galaxy center maps in comparison with Planck demonstrate instrument performance and larger scale recovery.

The progress Things I can show...

CMB maps







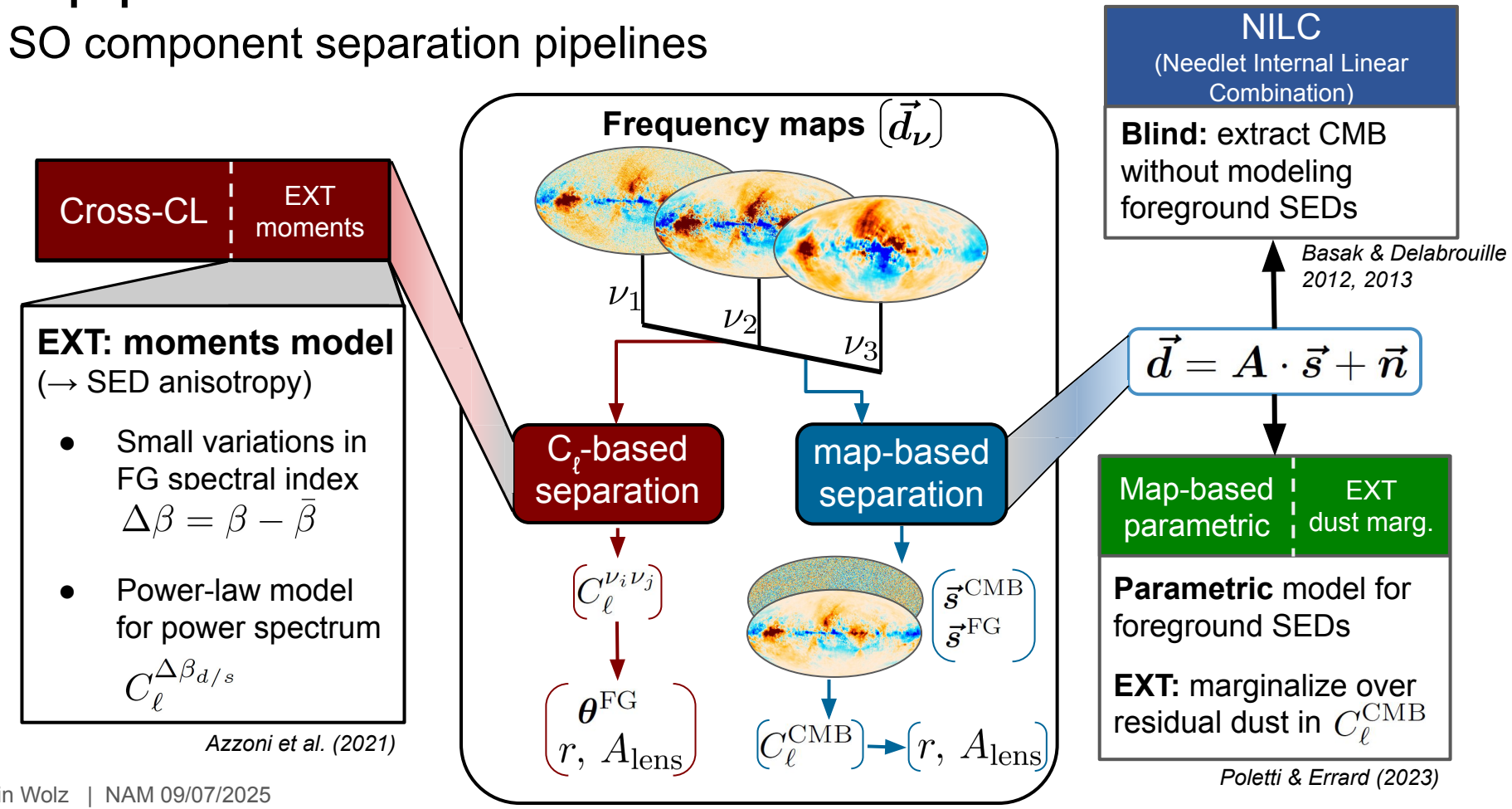
Started mapping the sky with two MF SATs.

Applied low-pass filter to maps. ⟶ **Zoom-in**

Q/U polarization patterns start being visible in the targeted SAT regions.

The pipeline

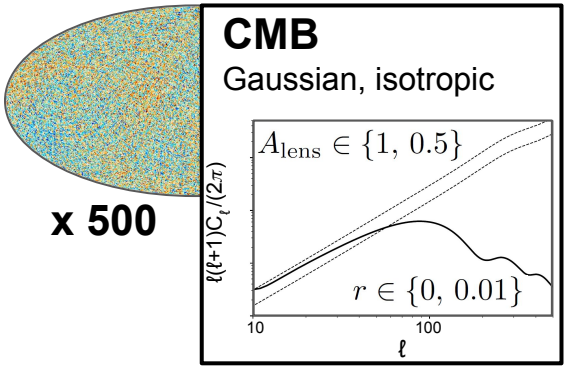
SO component separation pipelines

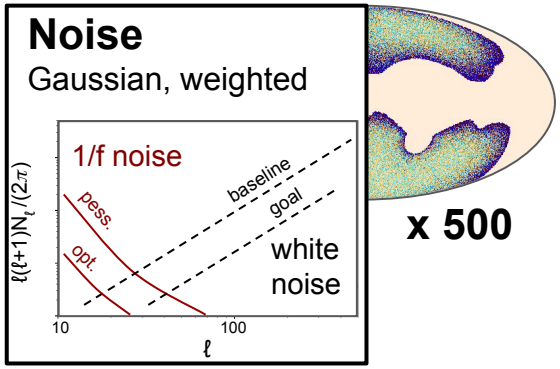


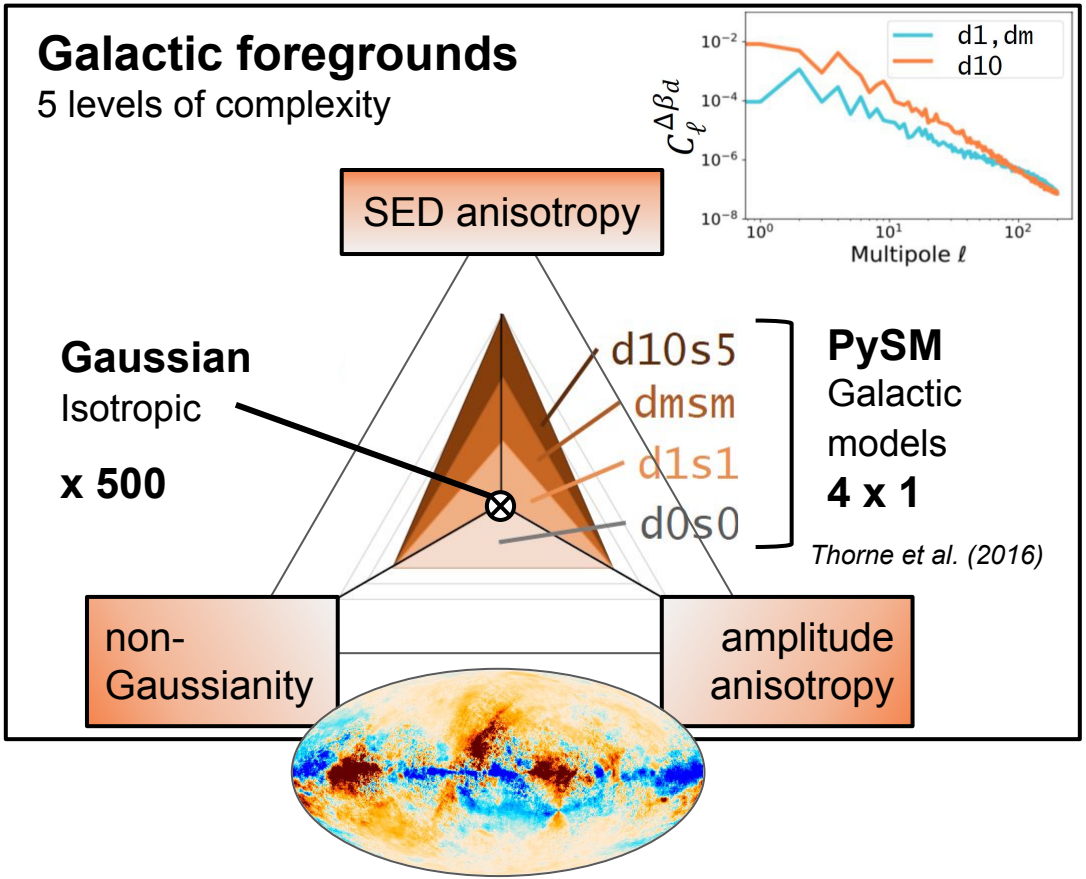
The pipeline

Wolz++ 2024, *2302.04276*

Sky simulations





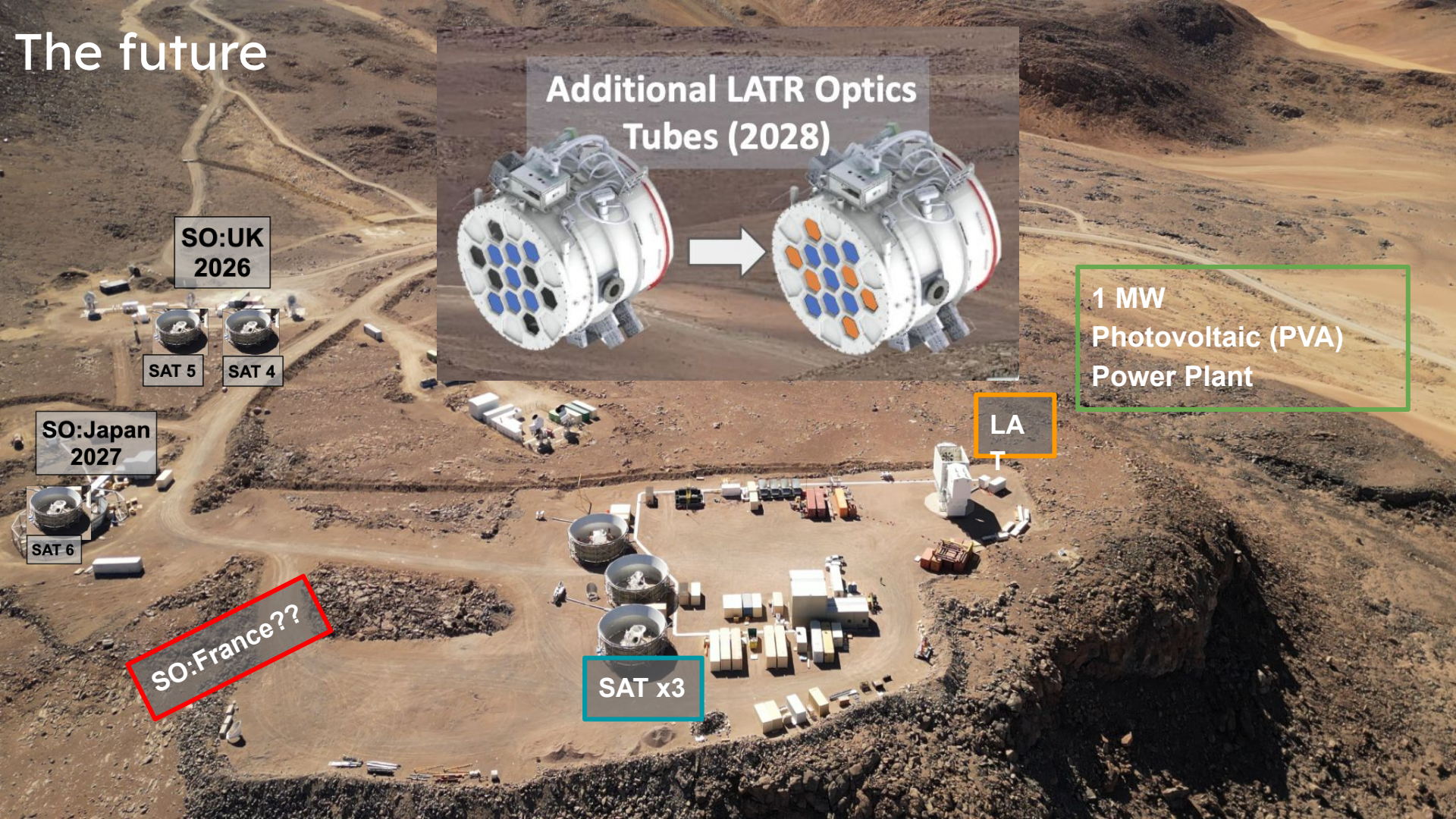


The conclusion

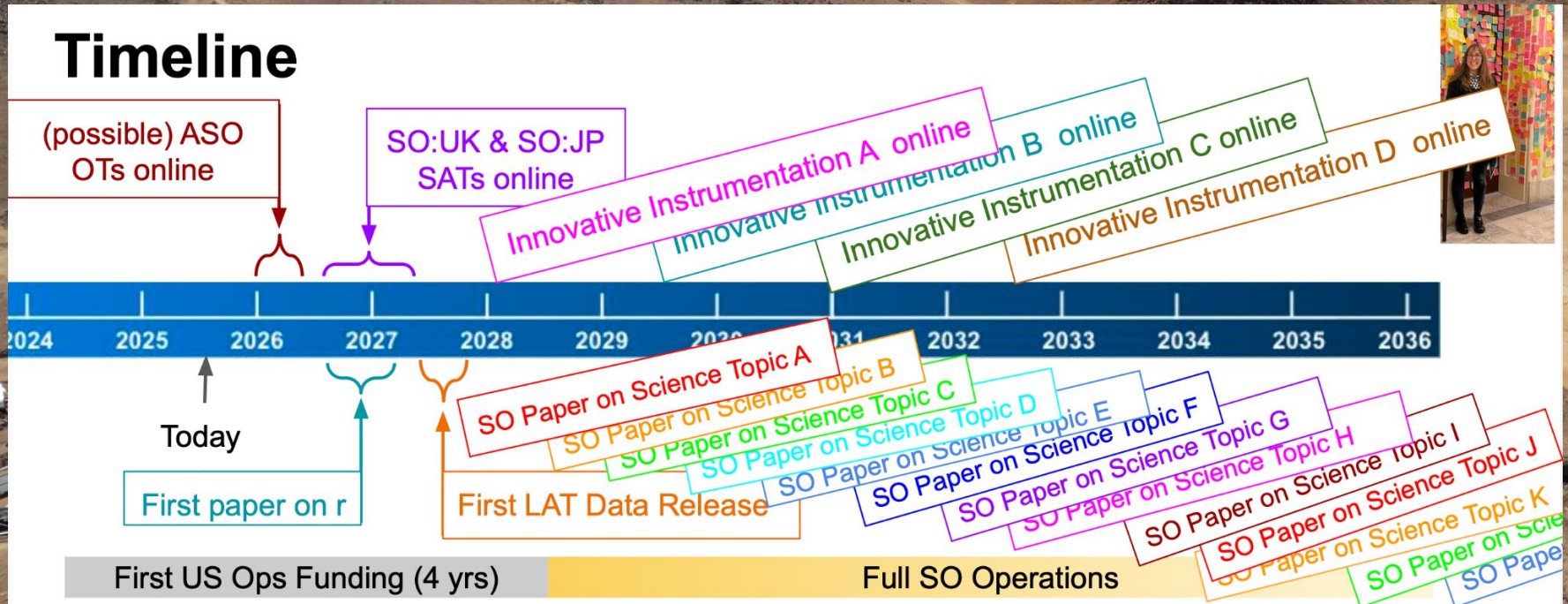
SO is deployed and 93% deployed with many upgrades coming.

The site/pipeline is almost ready and has been observing the sky.

The future


Additional LATR Optics Tubes (2028)
SO:UK 2026
SAT 5
SAT 4
SO:Japan 2027
SAT 6
SO:France??
SAT x3
LA T
1 MW Photovoltaic (PVA) Power Plant

The future



- SO & more SO: the stream of data is switched on & will be a firehose soon
- We are exquisitely positioned to take advantage of our data
  - We have expertise and real effort across a remarkable range of analysis areas
  - We have vibrant involvement from a wide range of participants – from theorists defining questions to creators of brand new analysis techniques to newcomers who will carry the field forward

Thank you for your attention.