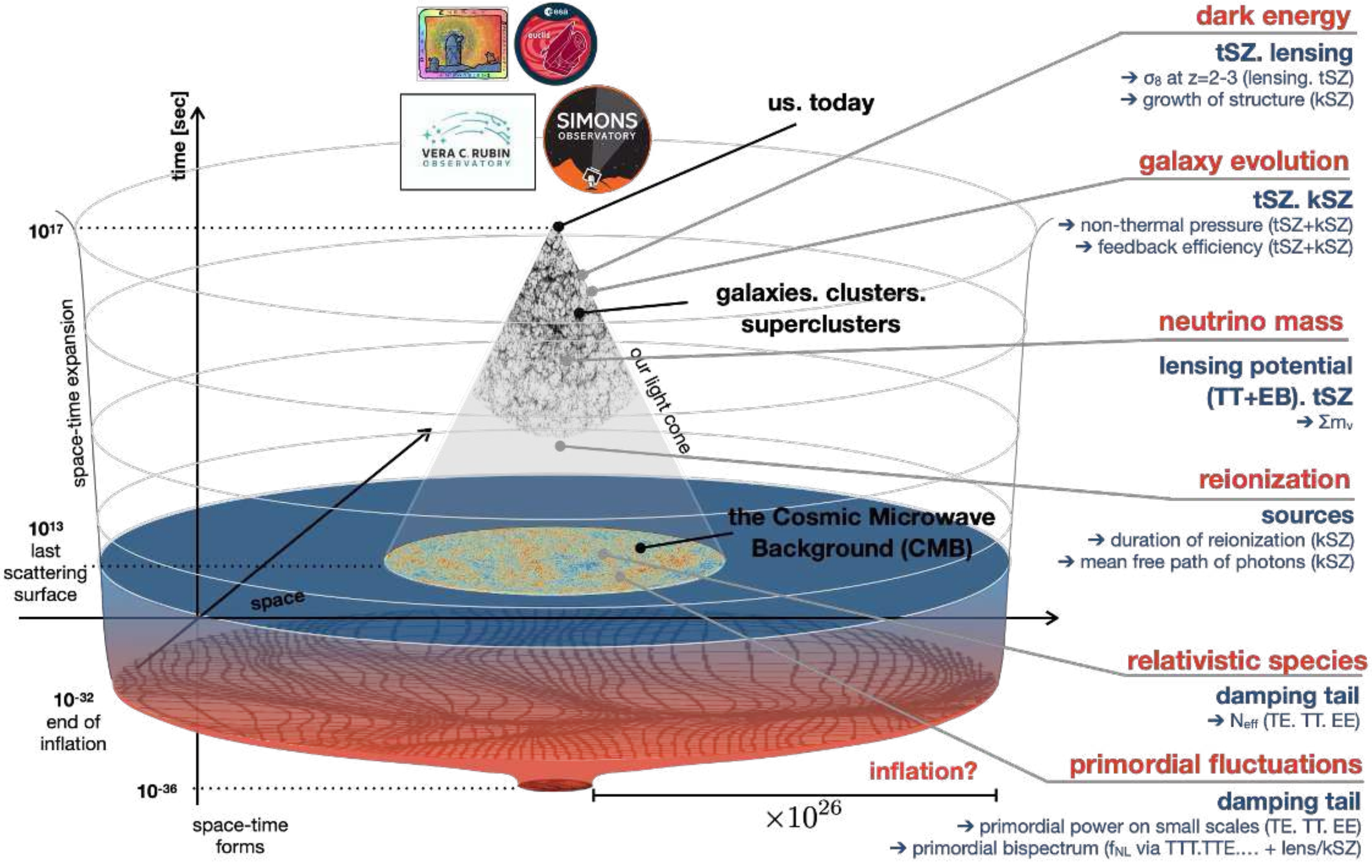
Cosmology Pillar

Josquin ERRARD (APC - IN2P3)
Raphaël Gavazzi (LAM - INSU)

Atlast

J-PAS



- ☞ **Explain the origin, composition, and evolution of the Universe**
- ☞ **Test ΛCDM at percent-level precision (or better)**
- ☞ **Find signs of new physics beyond it**

The Simons Observatory

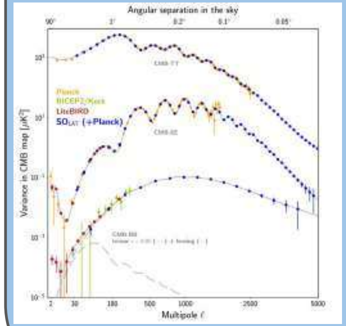
Simons Observatory collaboration: 450+ researchers across 60+ institutions

Simons Observatory Site

Cerro Toco,
Atacama Desert,
Chile
(Elevation 5190 meters)

Simons Observatory Science

Cosmology

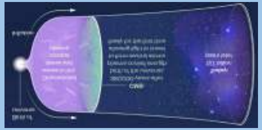


Dark energy

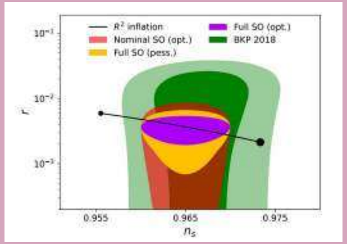
Dark matter

Reionization

Growth of structure



Primordial Perturbations

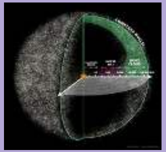


Tensor-to-scalar ratio

Scalar spectral index

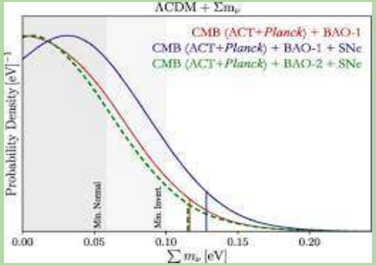
Non-Gaussianity

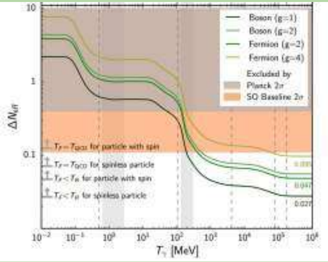
Stellar System Science



Star formation, asteroid regoliths, exo-Oort clouds, Planet 9

Neutrinos and Light Relics

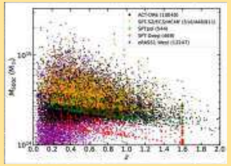


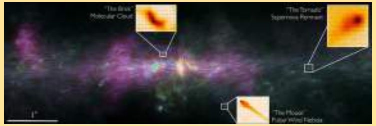


Sum of neutrino masses
Number of relativistic species

Galaxy Formation and Evolution

Interstellar dust, molecular clouds, cluster catalogs, AGN





Time-domain astrophysics

Gamma ray bursts, tidal disruption events,
Interacting supernovae, stellar flares

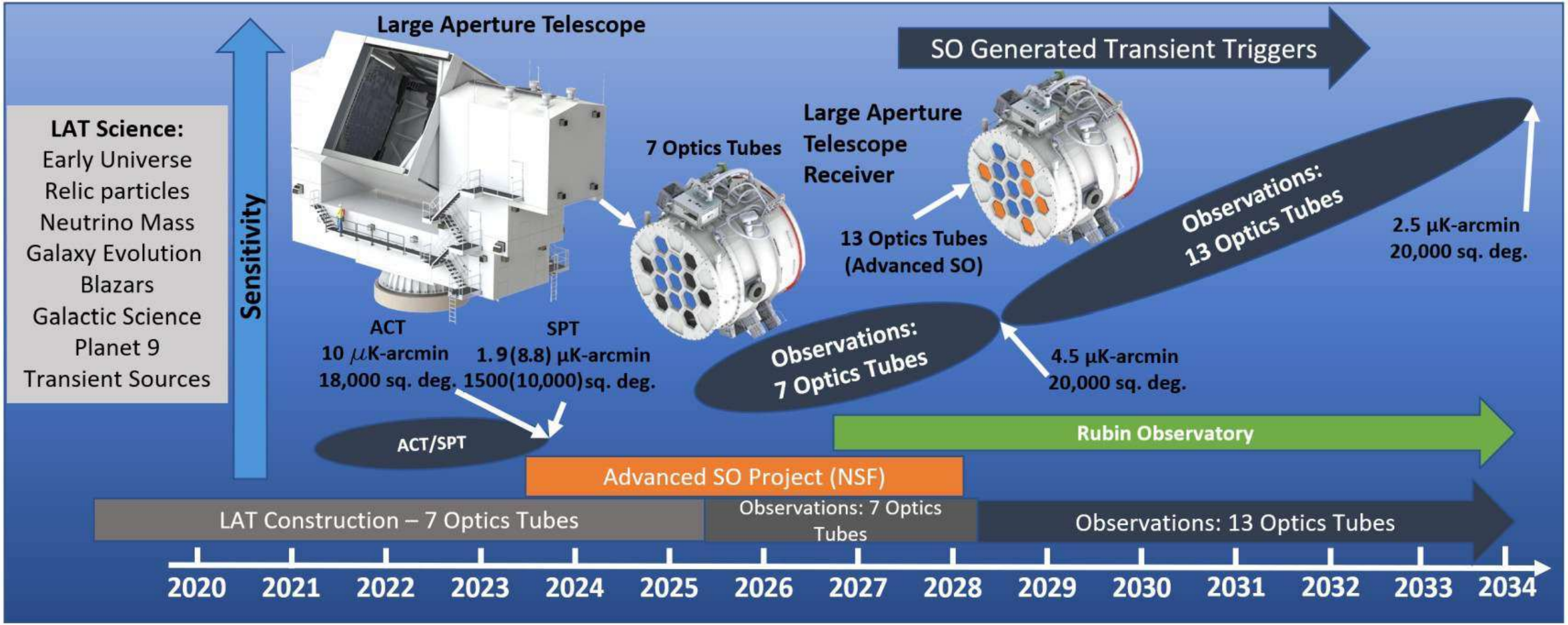
SO is taking data!

- SATp1 (90/150) first light: October 2023
  - Conducting **Initial Science Observations**
- SATp3 (90/150) first light: December 2023
  - Conducting **Initial Science Observations**
- SATp2 (220/280) first light: September 2024
  - Undergoing commissioning
- LAT (four 90/150 OT and two 220/280 OT)
  - Six optics tubes installed: February 2024
  - Mirrors and first light: February 2025
  - Conducting **Initial Science Observations**

Preliminary results from ISO on the following slides

Time lapse: one week of observing

SO LAT Science Timeline



Observatory Upgrades: SATs

Coming 2027!

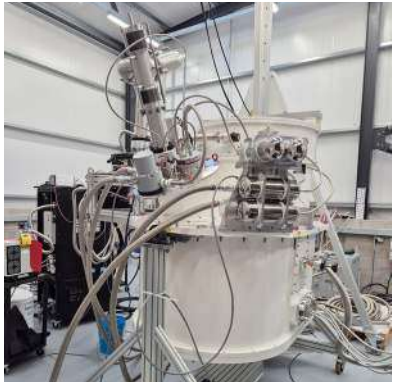
- **Three more SATs**: 1 LF (SO:JP, TESs) and 2 MF (SO:UK, KIDs)
  - Will double deployed MF detectors in SATs: 24,000 ⇒ 48,000

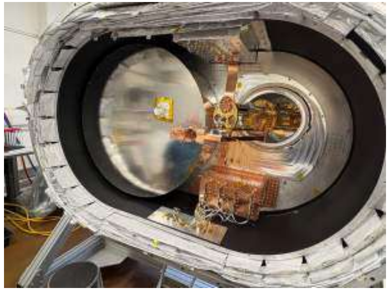
SATp4 (SO:JP)

SATp5 (SO:UK North)

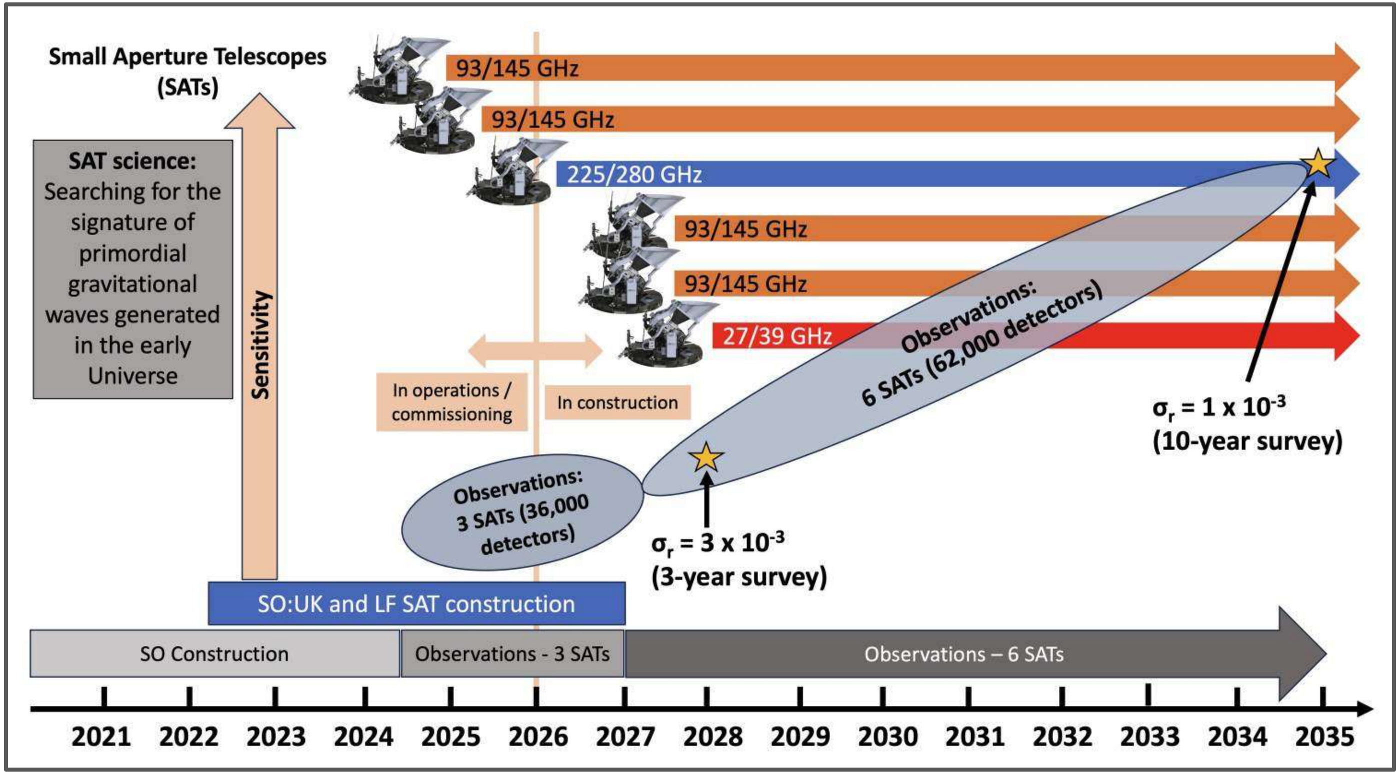
UKRI Science and Technology Facilities Council JSPS

SATp6 (SO:UK South)

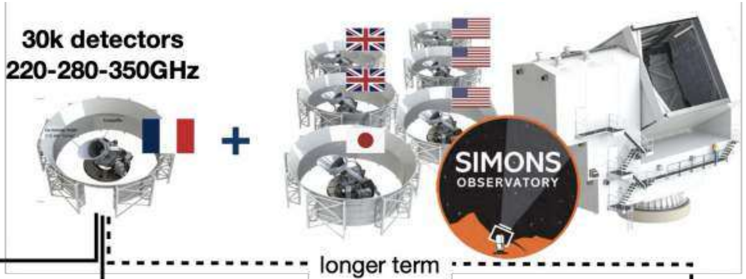




SO SAT Science Timeline



SO:France? → KAIROS: KID Array Instrument to Reveal the Origin of Structures



Potential Funding

- Participation to the CNRS (RI2) program to design, install and commissioning the KID French SAT. Support of the three CNRS institutes (IN2P3,INSU and INP).
- ERC Synergy was submitted (4 PIs: Catalano, Ponthieu, Calvo, Ganga)
- Started discussions with DOE / LBNL / UCB

Galactic science

- is there one or two dust populations?
- map of Bd ➔ impact on our understanding of dust life cycle
- what is the amplitude and properties of the EB correlation for the interstellar dust ➔ potentially a huge impact for the cosmic birefringence

Impact on component separation and inflation

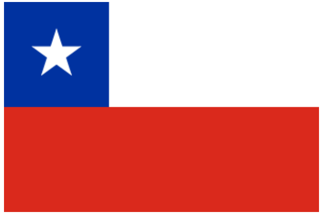
- improved quality and robustness of component separation ➔ better CMB map depth and stronger control of biases/systematics
- better and more robust constraints on inflation

Reionization

in its extended version, KAIROS would have potentially a unique access to low ell through

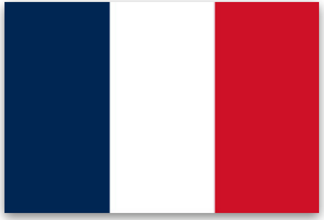
- improved calibration and treatment of environmental systematic effects (atmosphere)
- optimized scanning strategy for large sky area

South America - France



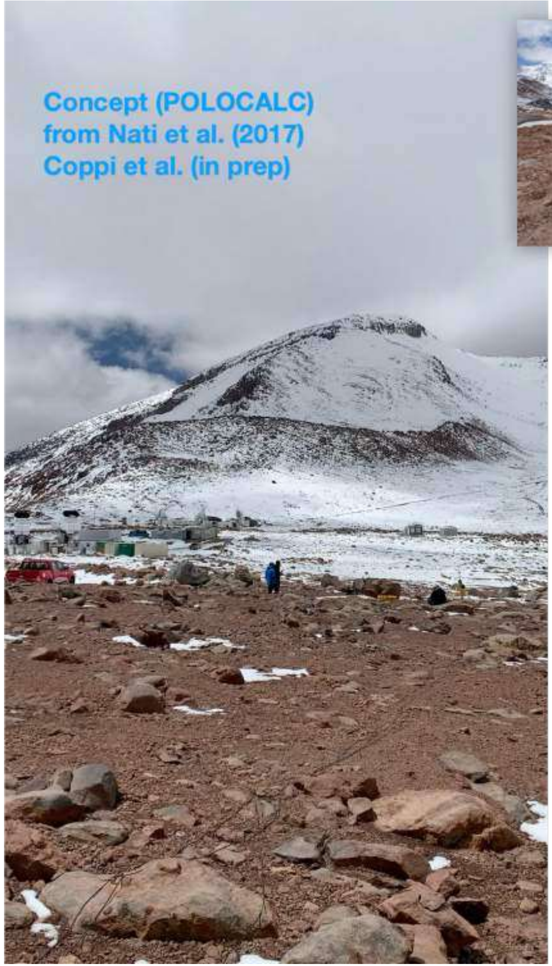
Pontificia Universidad Catolica de Chile: Rolando Dünner, Carlos Hervías-Caimapo, Roberto Puddu,

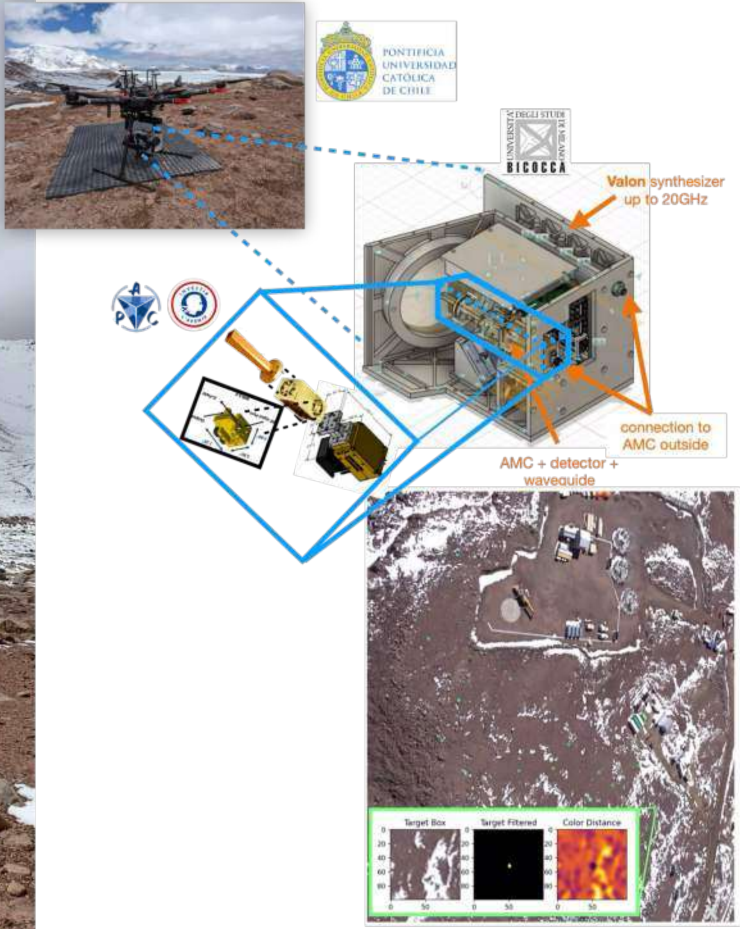
University of Chile: Claudia Scoccola

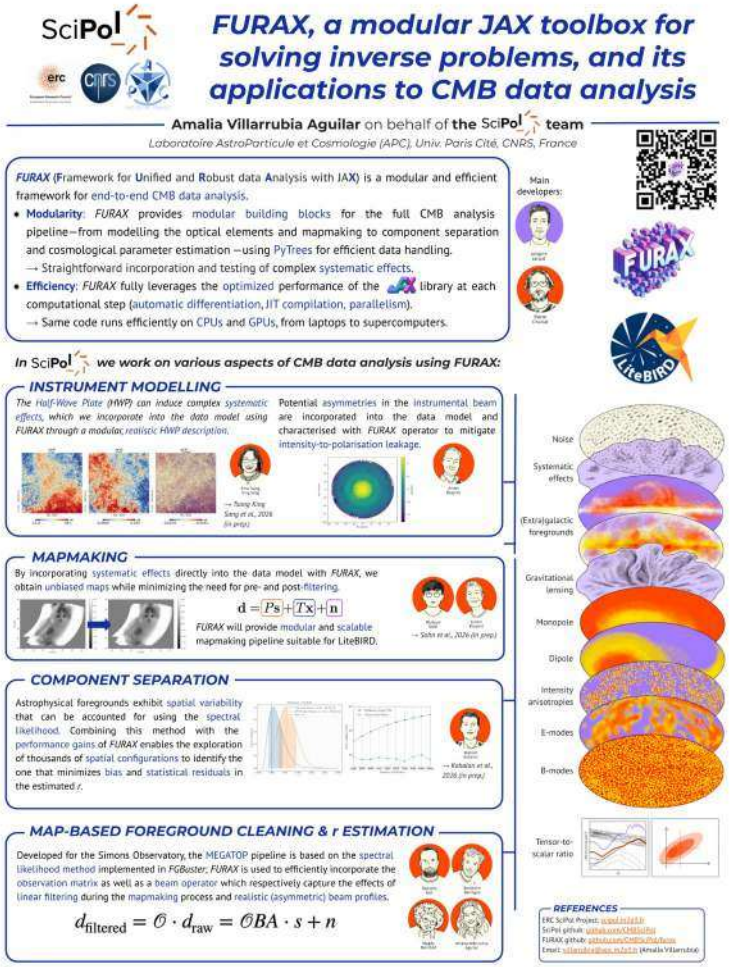


Université Paris Cité: James Bartlett, Artem Basyrov, Benjamin Beringue, Pierre Chanial, Josquin Errard, Ken Ganga, Wassim Kabalan, Andrea Landais, Pierre Masson, Jean-Baptiste Melin, Wuhyun Sohn, Radek Stompor, Halim Tannous, Ema Tsang King Sang, Amalia Villarrubia Aguilar

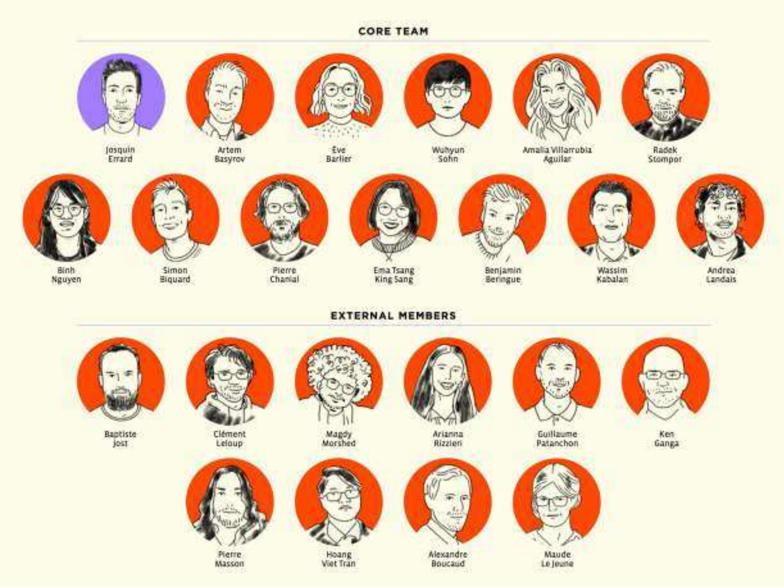
Universite Paris Saclay: Merry Duparc, Giulio Fabbian, Xavier Garrido, Clément Leloup, Thibaut Louis, Léo Vacher


Concept (POLOCALC)
from Nati et al. (2017)
Coppi et al. (in prep)


PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE
BICOCCA
Valon synthesizer
up to 20GHz
connection to
AMC outside
AMC + detector +
waveguide
Target Box
Target Filtered
Color Distance



More info here: scipol.in2p3.fr



https://www.lsst.org/

LSST DESC
Dark Energy Science Collaboration

IN2P3 (IJCLab, APC, LPSC, LPC, LPNHE, LAPTh, CPPM, CC, …) + CEA
R. Canameras, R. Gavazzi, O Ilbert, S Arnouts (LAM) + IAP + many others

CBPF: M. Makler, C.R. De Bom, J.P. Correia de França, B. Fraga, P. A. Darc de Matos, J.C. Rodríguez Ramírez, A. Santos, G.S.M. Teixeira,
Univ. Federal do Rio Grande do Sul: P. Floriano, B. Lorrany de Castro Araujo, V. Güez, P. S. Lopes, A. Chies Santos, G. Scheffel
+ many others

T. Anguita (U. Andrés Bello), V. Motta (U. Valparaiso), S. Panda (Int. Gemini Obs)

A. Carignano (Cordoba Univ.), M. Makler (San Martin Univ), G. J. M. Luna (UNAHUR/CONICET), K. Nowogrodzki (UNSAM)

- Calibration, filter changer on the LSST
- Data analysis and scientific exploitation
- Static sky : Cross-correlations with other surveys (Euclid, DESI, CMB)
- Transient events : brokers (Fink)

+ more names here: **https://fink-broker.org/members/**

- **Survey is about to start !**
- At least 100 pre-LSST visits were acquired on each night of the past week, and more than 3000 total pre-LSST visits have been acquired since resuming intermittent pre-LSST observations on 3 April following a period of intensive on-sky engineering in March.
- The pre-LSST observations of the past week included observations of the COSMOS LSST Deep Drilling Field that produced alerts on 6 distinct nights, with >30 total visits acquired across the griz bands

J-PAS: Javalambre Physics of the Accelerating Universe Astrophysical Survey

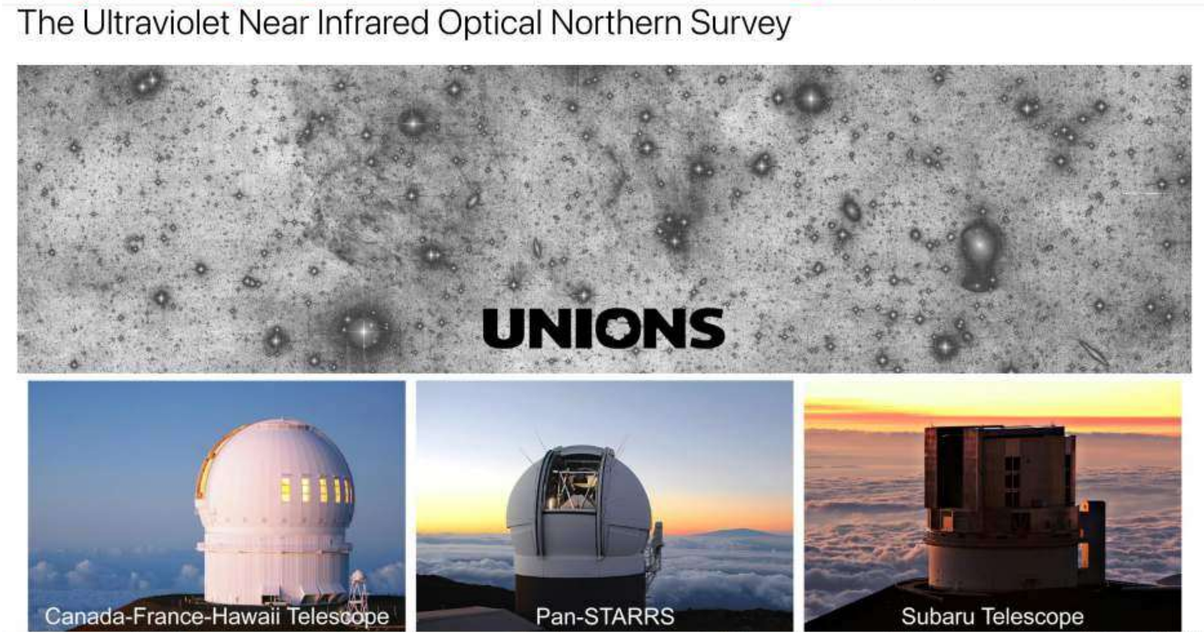
Javalambre Physics of the Accelerating Universe Astrophysical Survey, J-PAS, is an unprecedented **photometric sky survey of 8500 deg2 (20%) visible from Javalambre in 59 colors**, using a set of broad, intermediate and narrow band filters. J-PAS will discover an unprecedented number of **stars, galaxies, supernovas, quasars and solar system objects**, which will be mapped with exquisite accuracy. The innovative designs of the J-PAS camera and filter system will allow, for the first time, to map not only the positions of hundreds of millions of galaxies in the sky, but their individual distances to us as well, providing the first complete 3D map of the Universe.

R. Dupke (Observatorio Nacional do Río de Janeiro)
R. Abramo (Universidade de São Paulo)

M. Pieri (LAM)

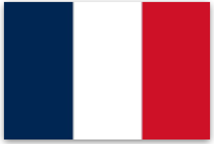
↔ **WEAVE-QSO**

https://www.j-pas.org/



https://www.skysurvey.cc/

J.-C. Cuillandre (CEA)
M. Kilbinger (CEA)
R. Gavazzi (LAM)



L. Ferreira
(Universidade Federal
do Rio Grande)

UNIONS brings together more than 200 astronomers from the international community and is a close collaboration of three major Hawaii-based facilities – the Subaru Telescope, Pan-STARRS, and the Canada-France-Hawaii Telescope (CFHT) – to enable a tremendous breadth of new science in the era of survey astronomy.

The UNIONS collaboration operates through a **memorandum of understanding** between: **CFIS** (Canada-France Imaging Survey), **Pan-STARRS** (Panoramic Survey Telescope And Rapid Response System), **WISHES** (Wide Imaging with Subaru HSC of the Euclid Sky)
New science is enabled by combining the CFIS u & r from CFHT-MegaCam imaging with i imaging from Pan-STARRS, z imaging from WISHES using Subaru Hyper Suprime-Cam (HSC), and g band imaging using Canadian and University of Hawaii access by UNIONS co-leads to Subaru HSC through the Waterloo Hawaii IfA G-band Survey (WHIGS). The Canadian Astronomy Data Centre (CADC) provides logistic support for processing and distributing the UNIONS products, from raw images to advanced catalogs.

→ **Weak gravitational lensing, Galaxy clustering and large-scale structure, Cross-correlations (multi-probe cosmology), Galaxy evolution and astrophysics, Milky Way and nearby Universe science, Strong lensing and clusters**

https://www.atlast.uio.no/

AtLAST is a concept for a next generation 50-meter class single-dish astronomical observatory operating at sub-millimeter and millimeter wavelengths, run as a facility telescope by an international partnership and powered by renewable energy.

AtLAST science themes

Where are all the baryons?

Measuring the total gas and dust content of the Milky Way and other galaxies, in the interstellar, circumgalactic, and intergalactic media, reaching down to the sensitivities required to probe the typical populations of submm sources.

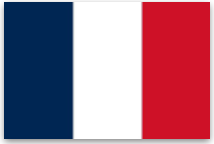
How do structures interact with their environments?

Understanding the lifecycle of gas and dust near and far; mapping the baryon cycle on multiple- scales; observing the interplay between gravity, radiation, turbulence, magnetic fields, and chemistry and their mutual feedback.

What does the time-varying (sub-)mm sky look like?

Identifying the mechanisms responsible for time variability across astrophysical sources: from the Solar corona and other objects in our solar system to luminosity bursts in everything from protostars to active galactic nuclei.


Prof. Felipe Diaz-Alvarado (U. Chile)

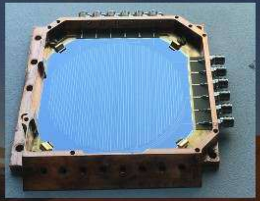
Benjamin Magnelli (CEA)

Alessandro Monfardini (CNRS/Néel)

G. Lagache (LAM)

Observations with Concerto

2 KID Arrays (4304 pixels)



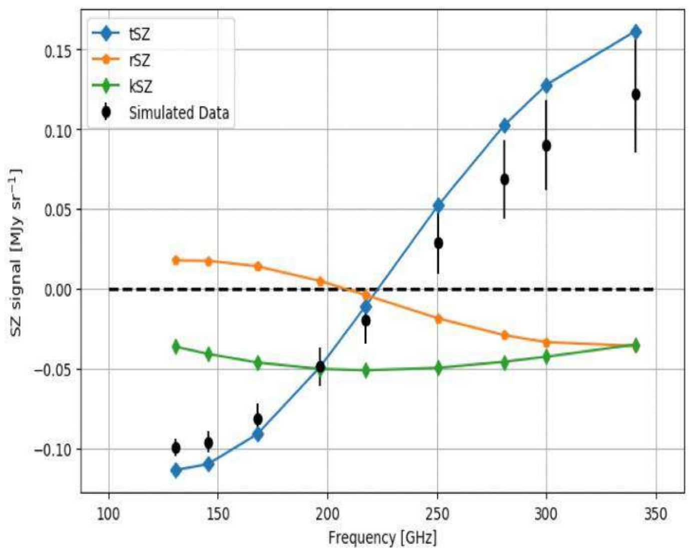
12 readout boards NIKEL

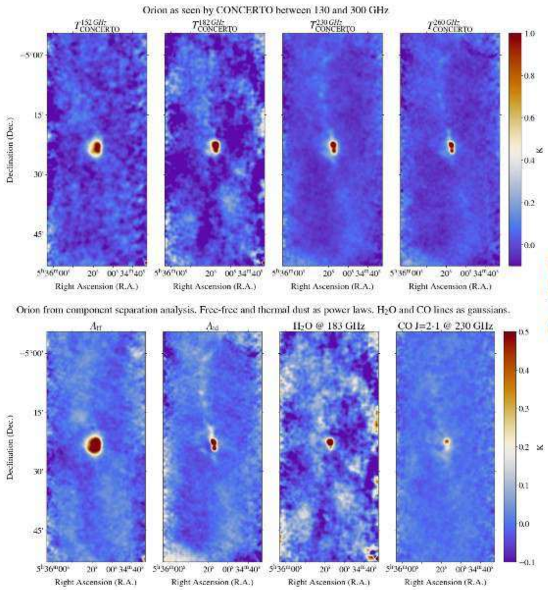
- Spectro-Interferometer (spectral resolution R > 100)
- Observing from 120 GHz to 350 GHz at 12 m APEX Tel.
- Large Field of View (20 arcmin)
- LEKID Technology
- Collaboration LAM - Inst. Néel - LPSC - IPAG

Scientific case:

- Observations of [C II] line emission at z>5
- Sunyaev–Zel'dovich effect in galaxy clusters
- Galactic emission, others

https://www.apex-telescope.org/ns/observing/the-telescope/instruments/concerto/



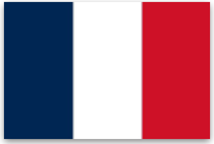


Preliminary results
Mateo Fernandez Torreiro et al., (in prep)

+ see Désert et al. 2504.20487

Andrea Catalano (LPSC)

C. Duran (ESO)



G. Lagache (LAM) + LPSC + IPAG + Néel

https://www.ccatobservatory.org/

FYST

CCAT

R. Reeves, A. Stutz (Universidad de Concepción, Chile)
M. Aravena (Univ. Diego Portales)

B. Beringue (APC, IN2P3, France)
B. Magnelli (CEA, France)

Science Projects

1. **Tracing the epoch of reionization with CII intensity mapping**
   Lead: Dominik Riechers (UKöln)
   Deputy Lead: Gordon Stacey (Cornell)

2. **Understanding galaxies and galaxy cluster formation via millimeter and submillimeter observations**
   Lead: Nick Battaglia (Cornell)
   Deputy Lead: Kaustuv Basu (UBonn)

3. **Enhancing constraints on new particle species and cosmology with Rayleigh Scattering**
   Lead: Daan Meerburg (UToronto)
   Deputy Lead: Joel Meyers (SMU)

4. **Measuring CMB foreground to aid the search for primordial gravitational waves**
   Lead: Mike Niemack (Cornell)
   Deputy Lead: Steve Choi (UC Riverside)

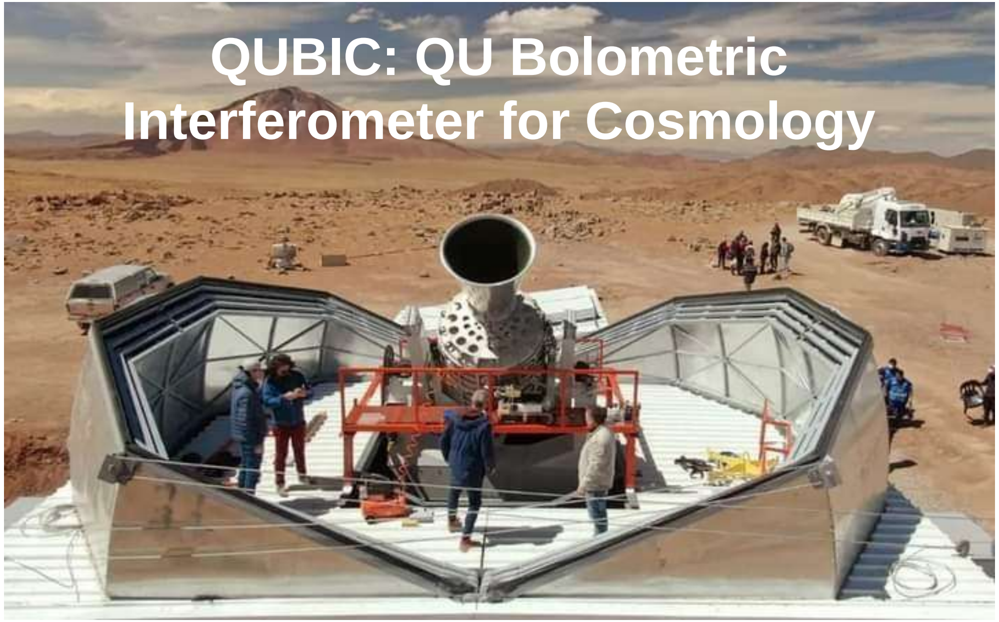
5. **Tracing galaxy evolution from the first billion years to Cosmic Noon with the cosmic infrared background**
   Co- Lead: Scott Chapman (UBritish Columbia)
   Co-Lead: Manuel Aravena (UDiego Portales)
   Deputy Lead: Thomas Nikola (Cornell)

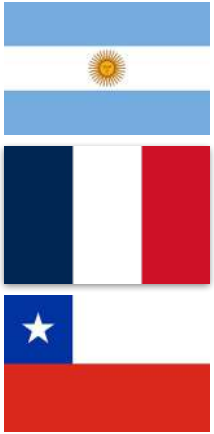
6. **The star formation-ISM cycle in local galaxies with high spectral resolution submillimeter observations**
   Lead: Robert Simon (U.Köln)
   Co-Deputy Lead: Frank Bigiel (UBonn)
   Co-Deputy Lead: Amelia Stutz (UConcepción)

7. **A new submillimeter window into time domain astrophysics**
   Co-Lead: Doug Johnstone (NRC-CNRC)
   Co-Lead: Anna Ho (Cornell)
   Deputy Lead: Greg Sivakoff (UAlberta)

8. **Magnetic fields and broadband galactic polarization science**
   Lead: Laura Fissell (Queens U)
   Clark: Susan Clark (Stanford)

QUBIC: QU Bolometric Interferometer for Cosmology





\+ Many others

https://apc.u-paris.fr/fr/qubic

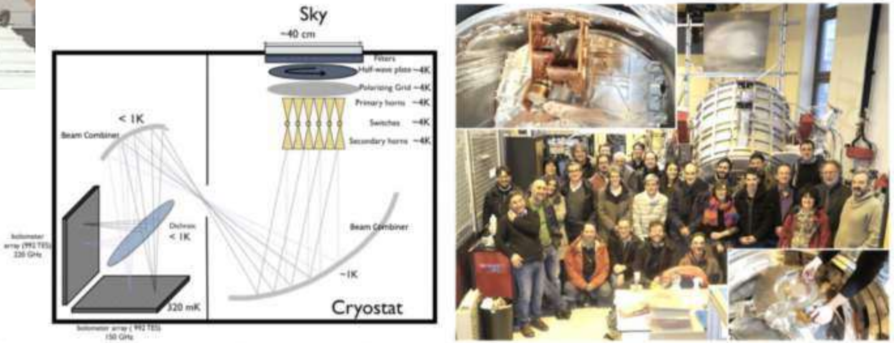
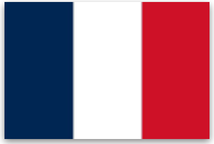


Figure 2. Left: Conceptual design of QUBIC. Right: Picture of the instrument and a part of the Collaboration

Aiming at cosmic inflation: tensor-to-scalar ratio
$r < 0.03$ at 95% C.L. (3 years)

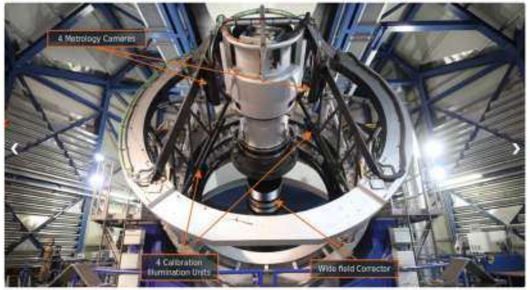
https://www.4most.eu/cms/home

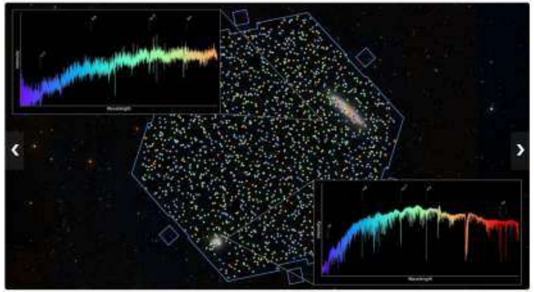


J.-K. Krogager (CRAL)
J. Richard (CRAL)

F. E. Bauer (Pontificia)
C. Haines (U. de Atacama)

Science





VISTA telescope (Cerro Paranal). Currently under commissioning!

FYST CCAT

Concerto

4MOST

UNIONS

Atlast

SIMONS OBSERVATORY

J-PAS

VERA C. RUBIN OBSERVATORY

QUBIC

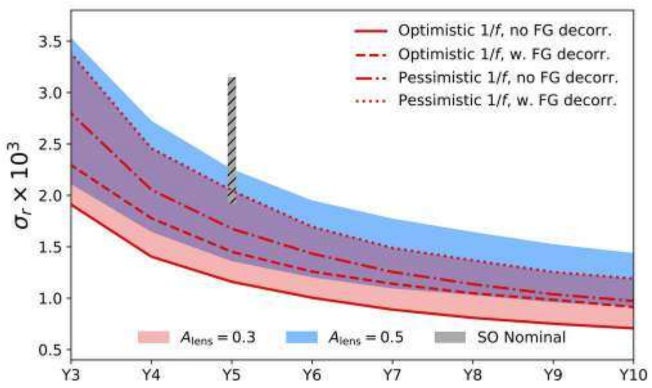
Backup slides

SO Forecasts: Science Goals

LAT forecast paper:
arXiv: 2503.00636

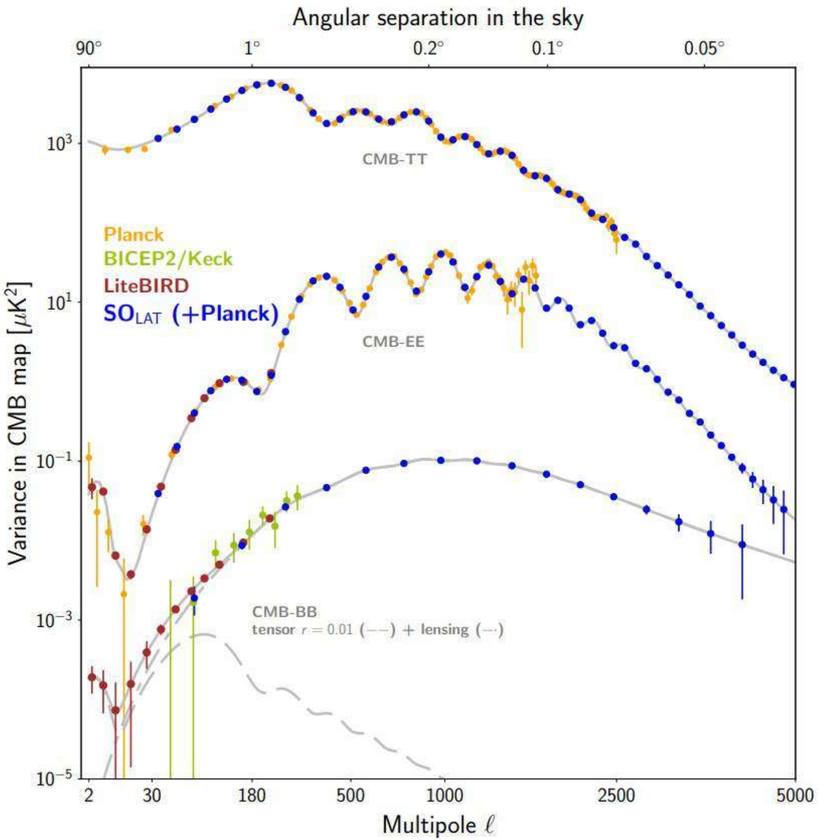
SAT forecast paper:
arXiv: 2512.15833

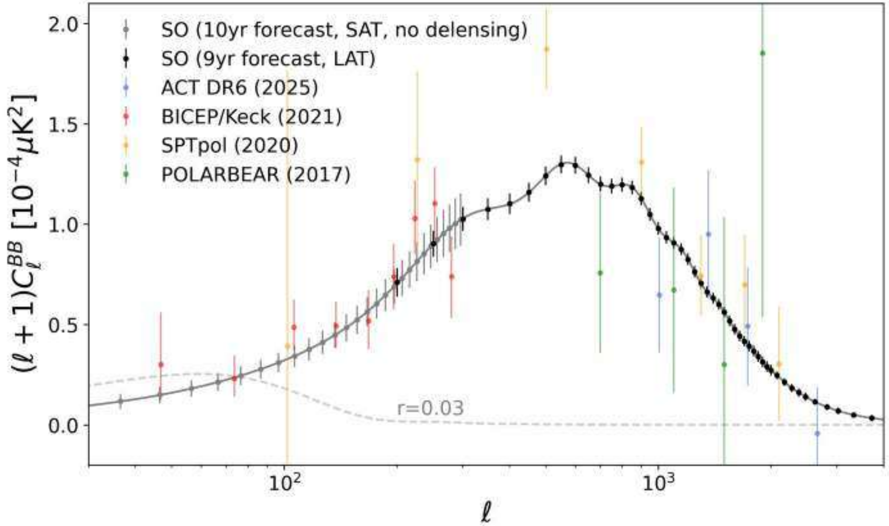
- SO will tighten constraints on primordial gravitational waves by an order of magnitude
- Halve the uncertainty on sum of neutrino masses
- Halve the uncertainty on optical depth to reionization, via kSZ 2- and 4-point functions, independent of large scale *E*-modes.
- Detector over 33,000 galaxy clusters
- Daily maps for transient event detection with 7 mJy sensitivity



Numbers show 1-σ unless catalog no. or distances	Current	**SO 2025-2034**	CMB-S4	Using Rubin, DESI, or *Euclid*
Primordial perturbations				
r ($A_L = 0.3$)	0.01	0.0012	0.0005	✓
n_s	0.003	0.002	0.002	-
$e^{-2\tau}\mathcal{P}(k=0.2/\mathrm{Mpc})$	1%	0.4%	✓	-
$f_{\mathrm{NL}}^{\mathrm{local}}$	5	1	~1	✓
Relativistic species				
N_{eff}	0.13	0.045	0.03	-
Neutrino mass				
m_ν (eV, $\sigma(\tau) = 0.01$)	0.06	0.03	0.03	✓
m_ν (eV, $\sigma(\tau) = 0.002$)		0.015	0.015	✓
Accelerated expansion				
$\sigma_8(z = 1-2)$	7%	1%	1%	✓
Galaxy evolution				
η_{feedback}	50-100%	2%	✓	✓
p_{nt}	50-100%	4%	✓	✓
Reionization				
Δz	~1.4	0.3	0.25	-
τ	0.007	0.0035	0.003	-
Cluster catalog	10000	33,000	$> 70,000$	✓
AGN catalog	20000	96,000	$> 100,000$	-
Galactic science				
Molecular cloud B-fields	10s	> 860	✓	-
$\sigma(\beta_{dust})$	0.02	0.005	✓	-
Solar System Science				
Distance limit for 5 $M_\oplus$ Planet 9	500 AU	900 AU	✓	✓
Asteroid detections		$\sim 10,000$	✓	
Transient detection distance				
Long GRBs, on-axis		1300 Mpc	✓	-
Low-luminosity GRBs		70–210 Mpc	✓	-
TDEs, on-axis		670 Mpc	✓	-

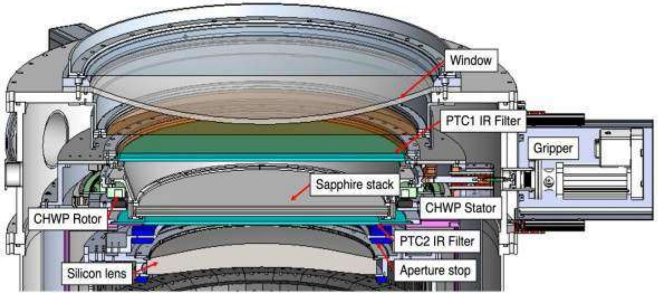
SO Forecasts: CMB Power Spectra





Overcoming Atmospheric 1/f in Chile

With more than a year of data, SO has demonstrated effective **polarization modulation** to achieve low noise at the large angular scales (low ell) where the primordial B-mode signal would peak, consistent with our requirements.

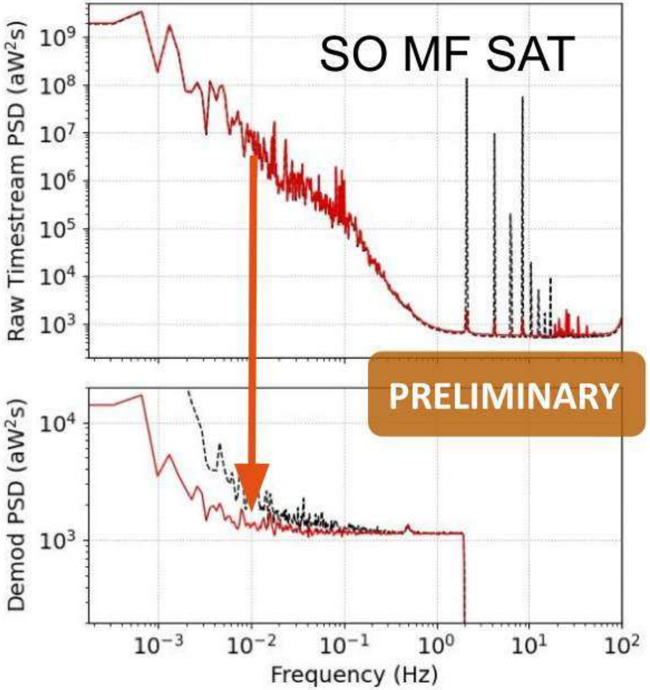


SO CHWP, Rev. Sci. Instr. 2024 [10.1063/5.0178066](https://doi.org/10.1063/5.0178066)

Key impacts:

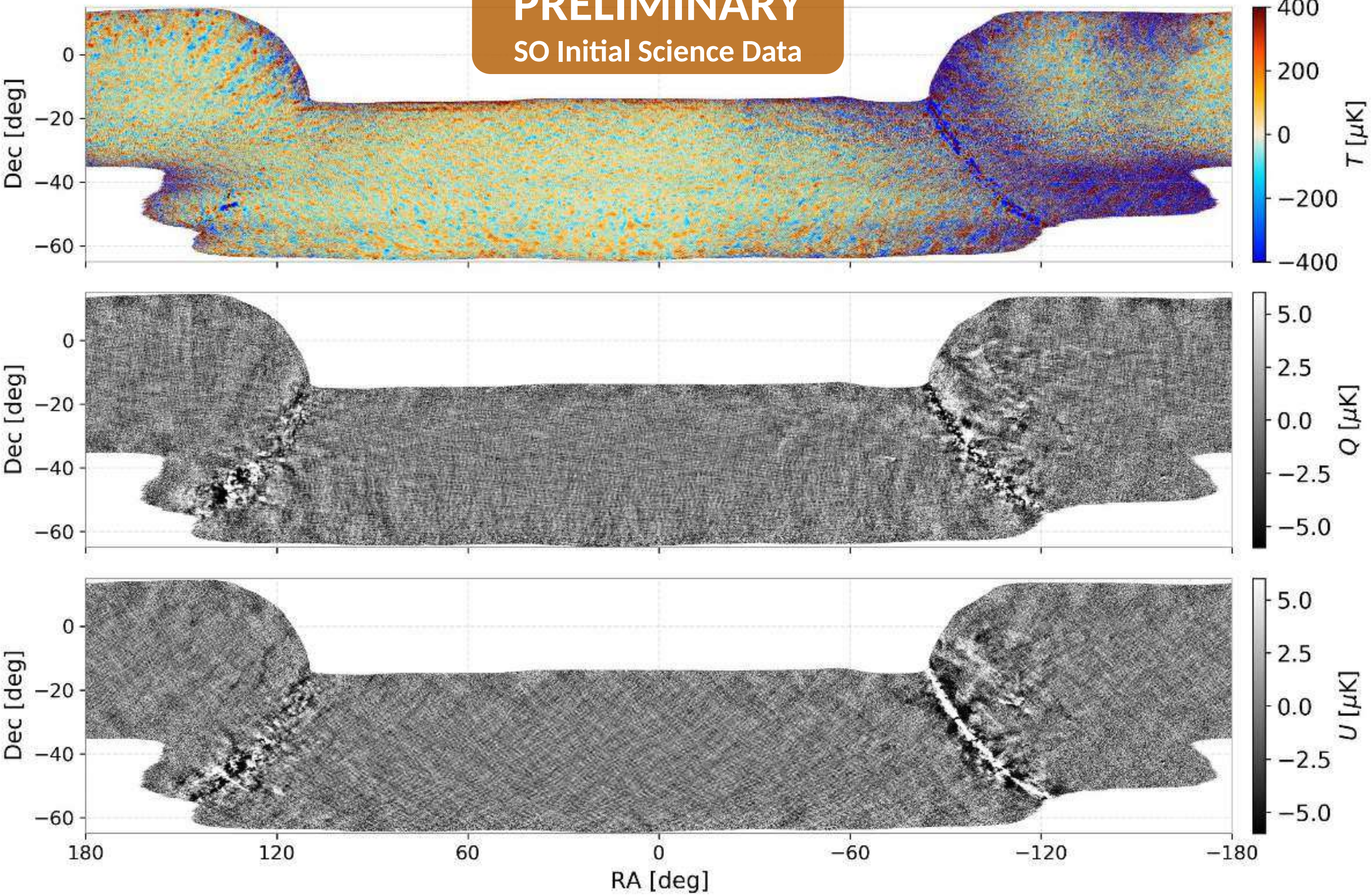
- Huge suppression of atmospheric 1/f noise
- Beam symmetrization reduces systematics including temperature to polarization leakage

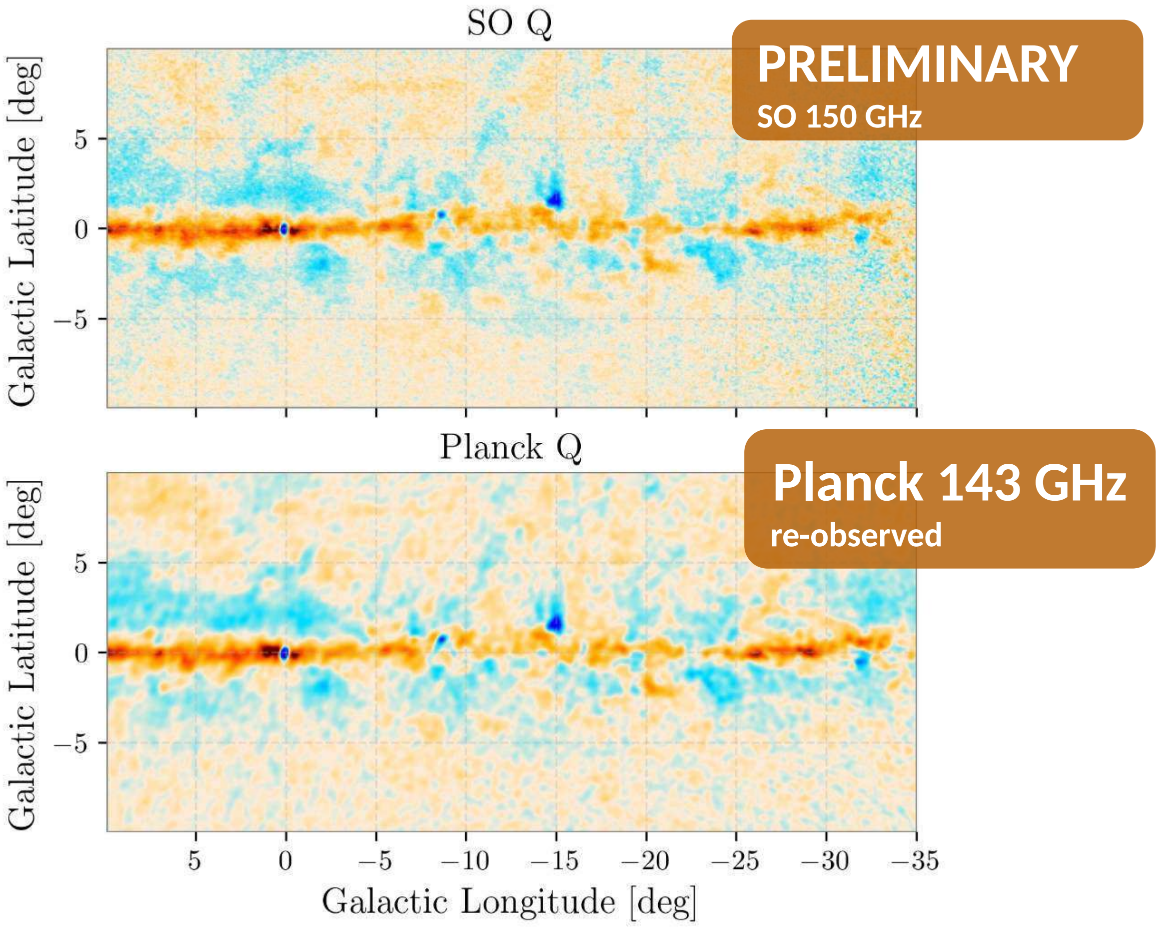
Polarization Modulation at 8 Hz



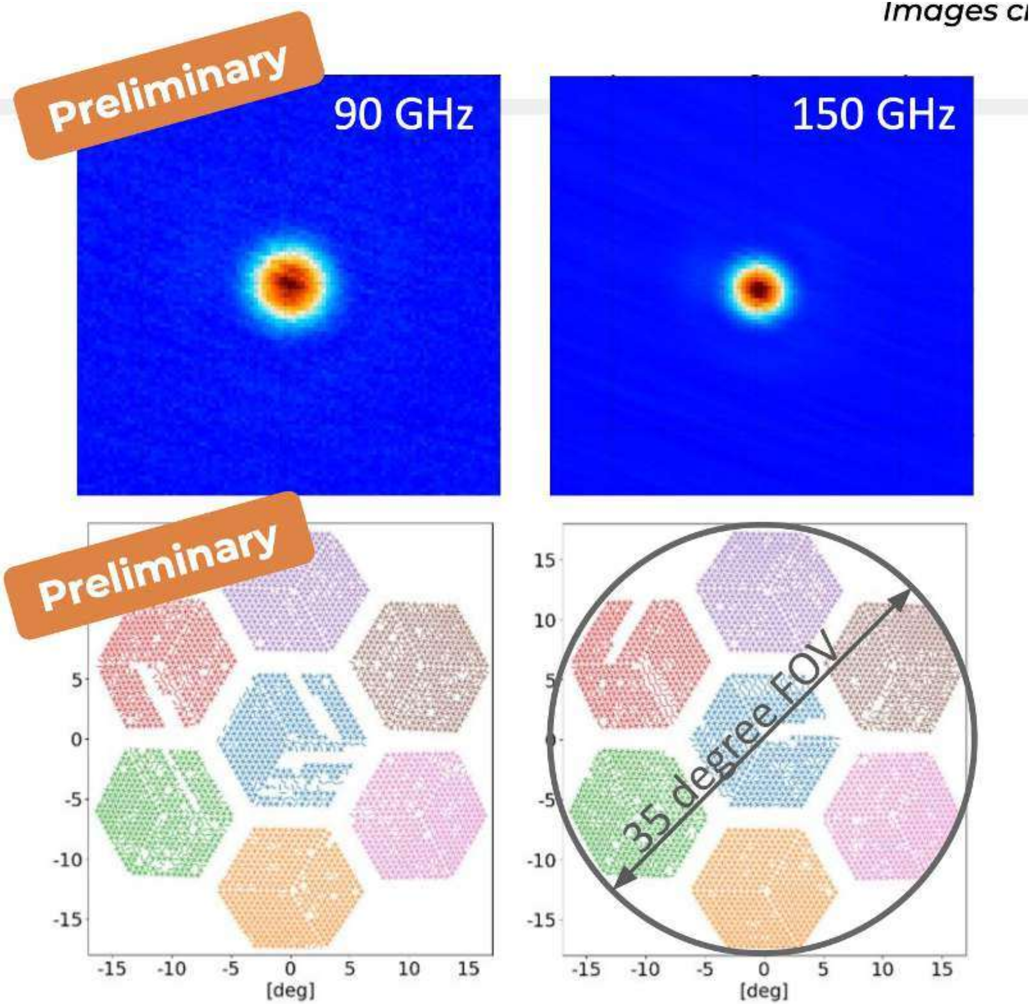
The atmospheric 1/f is suppressed by a factor of 1000 on 100 second time scales.

PRELIMINARY
SO Initial Science Data




SO Q
Planck Q
Galactic Latitude [deg]
5
0
−5
Galactic Latitude [deg]
5
0
−5
5
0
−5
−10
−15
−20
−25
−30
−35
Galactic Longitude [deg]
PRELIMINARY
SO 150 GHz
Planck 143 GHz
re-observed

Images c


Preliminary
90 GHz
150 GHz
Preliminary
35 degree FOV
15
10
5
0
-5
-10
-15
-15 -10 -5 0 5 10 15
[deg]
[deg]