Simons Observatory

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We describe the Simons Observatory project, its science goals and design, and emphasize the involvement of IN2P3 teams within the international collaboration.

The Simons Observatory in a nutshell

- A new-generation CMB polarization observatory located on the Chajnantor plateau in Chile, 5200m above sea level;
- Two types of telescopes: 6 small aperture telescopes (SAT) targeting large angular scales and 1 large aperture telescope (LAT) targeting small scales;
- $60,000$ polarization-sensitive, transition-edge sensors will be deployed by 2024, observing in six frequency bands. A total of $120,000$ detectors will be deployed by 2027;
- First light is expected to be achieved by Spring 2024 for the LAT and by the end of 2023 for the three first SATs (the three other SATs to be deployed by 2027). Observations will last $\sim$10 years until 2032, close to the expected first lights of CMB-S4 and LiteBIRD observations.
- Unprecedented constraints on broad science goals: cosmic inflation, cluster physics, neutrino masses and the number of relativistic species, dark energy properties, transients and search for Planet 9;
- 20,000 square degrees of overlapping sky coverage with Rubin observatory, allowing a wealth of cross-science;
- $\sim$ 200M$ budget mainly from the US National Science Foundation, the Simons Foundation, the UK, US Universities and Japan;
- A collaboration gathering more than 300 researchers from more than 50 international institutions;
- At IN2P3:
  - IJClab and APC are strongly involved and coordinating two major analysis working groups: the SAT B-modes and the LAT power spectrum and likelihood teams;
  - One ERC consolidator (SciPol) coordinated by J. Errard started on January 2023;
  - 6 FTE on the project from IN2P3 averaged over the 2022-2024 period. We expect to reach 11 FTE within the coming 5 years.
  - We have a quite unique involvement in CMB-S4, LiteBIRD and Rubin observatory that puts France in a rare position to exploit the combination of these probes.

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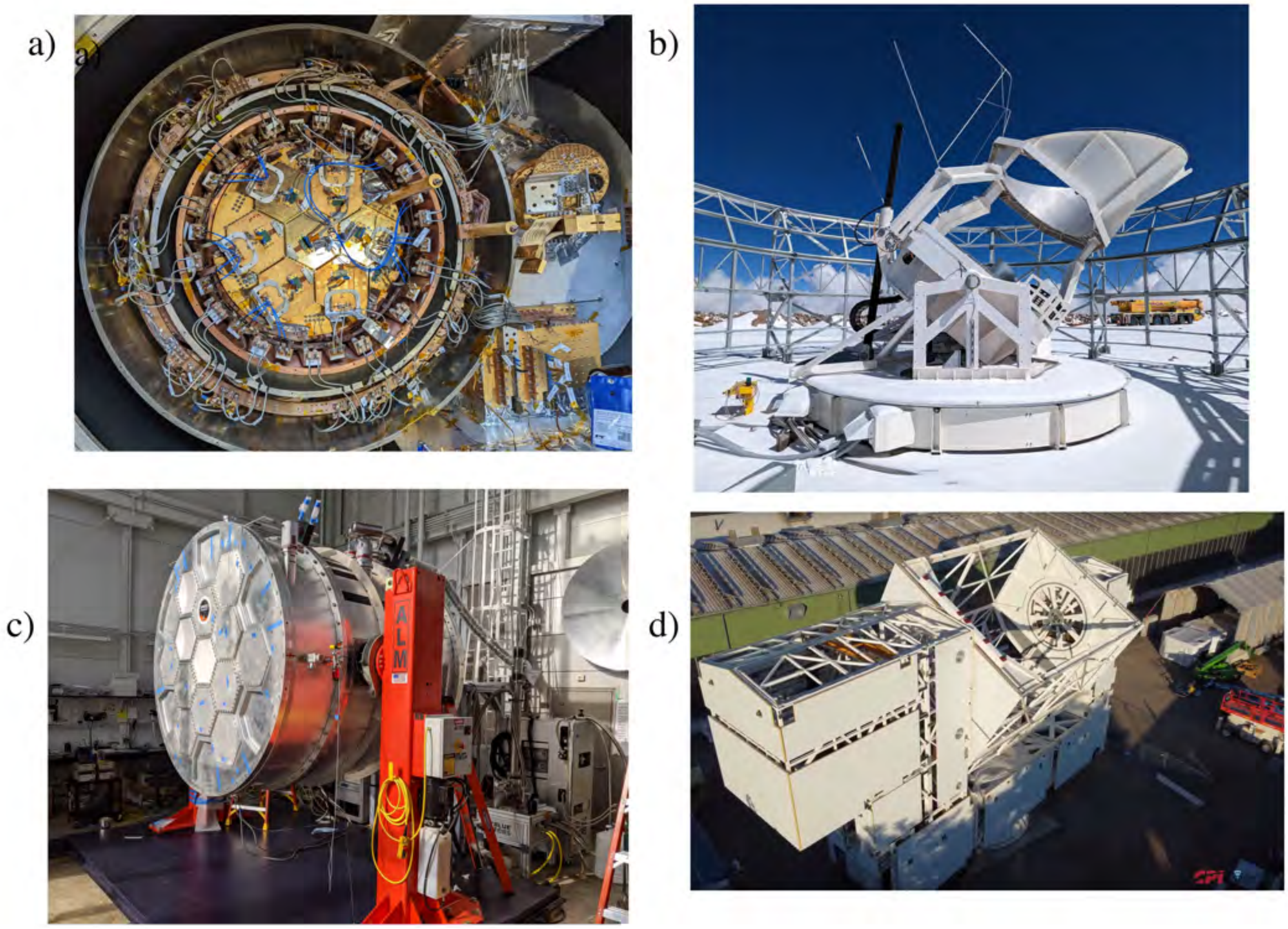

FIG. 1. a) Pictures of the back of a SAT with all seven detectors wafers, b) a SAT platform at the site, the structure of the ground shield surrounding each SAT is also visible, c) the 2.5m-diameter LAT cryostat which will ultimately cool down 60,000 detectors. d) The $\sim$ 15m-high LAT structure, assembled by Vertex (Germany).

I. SCIENTIFIC CHALLENGES

We describe in this section the different science goals of the Simons Observatory. Part of this text originates from the Advanced SO proposal funded by the US National Science Foundation in 2023. Throughout this document we assume that SO corresponds to the advanced SO design, with e.g. a full LAT focal plane and observations lasting till 2032.

The goal of the Simons Observatory (SO) is to produce millimeter-wave maps of the sky with a regular cadence. One survey will cover half the sky at five times the angular resolution and ten times the map depth of the Planck satellite, while another will deeply cover 10% of the sky in search of primordial B-mode polarization, a tracer of gravitational waves induced by cosmic inflation. The analysis of these maps by the SO collaboration — and later, through regular public releases, by the whole community — will: (1) determine the physical conditions in the early universe and in particular look for the presence of primordial gravitational waves, as well as constrain the existence of new light particles; (2) measure the integrated distribution of mass, electron pressure, and electron momentum in the late-time universe, and, in combination with large-scale structure surveys, determine the neutrino mass and the effects of dark energy at redshifts $z \approx 1-2$; (3) measure the distribution of electron density and pressure around galaxy groups and clusters, and calibrate the effects of energy input from galaxy formation on the environment; (4) produce a sample of more than $30,000$ galaxy clusters, detected by the thermal Sunyaev-Zel'dovich effect (to be compared to the $\sim$ 4,000 tSZ cluster known today), and more than $100,000$ extragalactic millimeter sources. (5) measure the alignment of dust grains by magnetic fields in our Galaxy, providing clues to the role of magnetic fields in star formation and the cycle of matter; (6) search for trans-Neptunian objects and either detect or eliminate large portions of the phase space in the search for Planet 9; (7) provide a powerful new window into the transient universe on time scales of minutes to years concurrent with Rubin observations on the overlapping sky.

A. A search for gravitational waves from the Big Bang

How did the initial expansion of space take place? A highly compelling early-universe scenario is inflation, which generically produces gravitational waves. The SO polarized sky maps will open up a new search for their imprinted signal. The amplitude of the signal depends on the energy scale of inflation and is characterized by r, the tensor-to-scalar ratio, with a current upper limit $r < 0.032$ at 95% CL from the BICEP/Keck experiments at the South Pole in combination with Planck and WMAP. Targeting a robust detection by reducing the uncertainty on r by over an order of magnitude is the next major goal. At this level, a non-detection would put significant pressure on large-field models of inflation, in which the inflaton traverses a trans-Planckian distance in field space. SO enables such a transformative new measurement from Chile, complementing the South Pole program; SO is projected to achieve $\sigma(r) = 0.0012$, reaching below the projected errors expected in the mid-2020s from the BICEP Array. A robust detection of a signal at levels below $r = 0.01$ would be transformative, yielding new insights into the early universe, informing us about the energy scale of inflation, and providing direct evidence for the quantization of gravity. Achieving this requires undoing the distorting effects of gravitational lensing on the polarized sky maps; we project that at least 70% of the lensing contamination can be removed with the use of overlapping large-scale structure surveys including Rubin. By measuring primordial fluctuations in the CMB over twice the dynamic range of the Planck satellite, SO will also better characterize the scale-dependent, Gaussian, and adiabatic nature of the primordial density fluctuations that are the signature of the dynamics of the first moments of the universe. The survey will halve the current uncertainty on the scalar perturbation spectral index, testing the near-scale-invariant prediction of inflation over a wider range of scales than accessible to Planck. it will further test early-universe models by constraining the Gaussianity of the perturbations to $\sigma(f_{\mathrm{NL}}^{\mathrm{local}}) = 1$, improving current constraints by a factor of five, and also by constraining primordial isocurvature perturbations.

Josquin Errard (APC) is co-leading the SAT analysis working group developing the pipeline for CMB B-modes search. These B-modes are the main signature of primordial gravitational waves. With the recently awarded ERC-project SciPol, his team at APC is developing new time-domain analysis frameworks which will propose new statistically-sound and numerically-efficient approaches to deal with instrumental, astrophysical and environmental systematic effects.

B. Are there new light particle species?

Wide classes of beyond-standard-model (BSM) particle physics scenarios, constructed to solve known theoretical issues including the hierarchy problem, predict the existence of new light species that were in thermal equilibrium at some early time with the primordial plasma. Such scenarios leave distinct imprints in the small-scale damping tail of the CMB temperature and polarization anisotropies, thus yielding tight CMB-derived constraints on many BSM scenarios, including axions, sterile neutrinos, gravitinos, high-frequency gravitational waves, and other forms of relativistic energy density in the early universe. SO will either detect new particles via this signature or constrain BSM theories by improving current limits on the number of relativistic species by a factor of four, with $\sigma(N_{\mathrm{eff}}) = 0.045$. For example, SO can rule out at $>$ 95% CL any light spin-3/2 particle that was in thermal equilibrium at any time back to reheating. A robust detection would be a landmark evidence of new physics, yielding the first direct cosmic signature from the epoch between post-inflationary reheating and neutrino decoupling one second later.

Thibaut Louis (IJCLab) is the co-lead of the pipeline development of the LAT power spectrum and likelihood code. Part of his and his team's work is to develop tools to distinguish between the effect from new light particles and astrophysical and instrumental systematic effects.

C. What is the sum of the neutrino masses?

Oscillation experiments show the three neutrino species have a total mass of at least 0.06 eV, and 0.1 eV if the hierarchy of particle masses is inverted. In combination with DESI data, the gravitational lensing maps enabled by the SO infrastructure will lead to $\sigma(\sum m_\nu) = 0.03$ eV. If combined with future constraints on the reionization optical depth τ, from e.g. LiteBIRD, SO+DESI measurement will improve to $\sigma(\sum m_\nu) = 0.015$ eV. Evidence for non-zero neutrino mass from cosmological data, and constraints on the hierarchy, will be of enormous interest to the particle physics community.

D. Cosmic Census

The French community is deeply engaged in the next generation of large scale structure surveys, such as the Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST) and the Euclid space mission. Cross-correlation of CMB lensing, kinetic, and thermal Sunyaev-Zeldovich effects (kSZ, tSZ respectively) with galaxy surveys enables, for the first time, a comprehensive census of all components of the cosmic web: dark matter, stellar matter, and diffuse gas. Lensing maps the total matter distribution, dominated by dark matter, while the kSZ probes the amount of diffuse ionized gas and the tSZ its thermal energy content.

Combining SO LAT observations with Rubin/LSST and Euclid, as well as other galaxy surveys and multiband sky surveys across the electromagnetic spectrum, will trace the interactions between these components as the cosmic web emerges. It will inform us in particular about the role of feedback in structure formation, answering the question of why only $\sim 10\%$ of baryons have been able to cool and form stars by today. This is a key question at the heart of galaxy formation theory. In addition, feedback alters the matter distribution, potentially biasing attempts to use the matter power spectrum to constrain dark energy (e.g., cosmic shear); better understanding of feedback would help mitigate this systematic for Stage IV dark energy surveys, like Rubin/LSST and Euclid.

Thibaut Louis is co-organizer of the cross-correlation Transverse Task Force of the CoPhy GDR. James Bartlett, Ken Ganga, and Jean-Baptiste Melin have worked on cross-correlations between Planck CMB observations and the Sloan Digital Sky Survey. A detailed study was published recently by Bartlett and the Ph.D. student Raphael Kou [1].

II. THE PROJECT

In this section, we briefly describe the project, with parts of the text originating from our publication *The Simons Observatory: Science goals and forecasts* [2].

The observatory will eventually consist of seven telescopes, for a total of $120,000$ detectors observing in six frequencies bands. Equipped with 10 times more detectors than the ACT and Polarbear-2 experiments, the Simons Observatory is designed (Fig. 2) to set unprecedented constraints on a large variety of cosmological parameters, thanks to its hybrid design with small and large aperture telescopes. The project is moreover optimized to mitigate instrumental, environmental and astrophysical systematic effects. It offers a great milestone and a unique data set to prepare the community towards the exploitation of CMB-S4 and LiteBIRD.

A. The Small Aperture Telescopes

The Small Aperture Telescopes (SATs) are optimized for measuring degree-scale B-modes produced by primordial gravitational waves. Each of the SATs will have a single optics tube, and will all together contain $60,000$ detectors ($30,000$ in 2023, $30,000$ in 2027). The SAT optics tubes will each house seven detector arrays as well as a continuously rotating half-wave plate to modulate the incoming polarization signal — with the goal of reducing the large-scale atmospheric signal and mitigate many instrumental systematic effects. Two SATs will observe at 93 and 145 GHz (MF) and one will measure at 225 and 280 GHz (HF); Additional SATs (one low frequency, at 27 and 39GHz, one MF and one HF) will start oberving in 2027. The refractive optics of the SATs will have a $0.5°$ angular resolution at 93 GHz. The wide frequency coverage will allow us to distinguish between primordial CMB and galactic foreground emissions.

B. The Large Aperture Telescope

The LAT receiver will eventually have 60,000 TES bolometric detectors distributed among thirteen optics tubes that span six frequency bands from 27 to 280 GHz. Each LAT tube will contain three detectors arrays, each on a 150 mm detector wafer, and each measuring two frequency bands and in two linear polarizations. One "low-frequency" (LF) tube will make measurements in two bands centered at 27 and 39 GHz, four "mid-frequency" (MF) tubes will have bands centered at 93 and 145 GHz, and two "high-frequency" (HF) tubes will have bands at 225 and 280 GHz. These seven tubes will fill half of the LAT receiver's focal plane in 2024. With the recently awarded ASO program, the rest of the tube slots will be filled, increasing the detector count to 60,000. The LAT will attain arcminute angular resolution [2]. The field of view of each LAT optics tube will be approximately $1.3°$ in diameter, and the total field of view will be approximately $7.8°$ in diameter.

C. Organisation of the project

The project is organised as follows

- The design, development, deployment, integration and testing of the SO telescopes, site infrastructure and relevant software are managed via the SO Work Breakdown Structure (WBS). The WBS is overseen by the Project Manager Andrew Bazarko.
- The Data Manager (DM) oversees the development of the data software pipelines required to acquire, transport, condition, and simulate the SO data, up to providing science-quality products for science analyses. The DM oversees the Pipeline Working Groups (PWG).

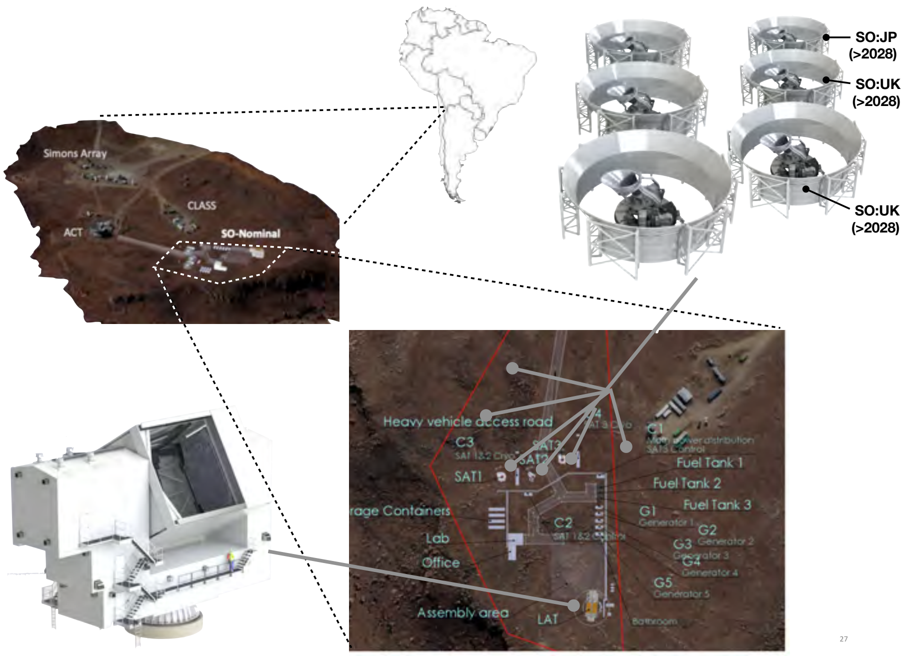

FIG. 2. Map of the SO site on the Chajnantor plateau, 5,200m above sea-level in Chile. This plateau is already the site of the Atacama Cosmology Telescope (ACT), Polarbear/Simons Array and CLASS.

- The Theory and Analysis Committee (TAC) oversees the design of the SO surveys and their data analyses. The work is divided in different Analysis Working Groups (AWG), among which two are led by IN2P3 researchers: Small Aperture Telescope B-modes (co-lead Josquin Errard (APC)) and Large Aperture Telescope Power Spectrum (colead Thibaut Louis (IJCLab).

D. A unique expertise at IN2P3, data analysis and software development

IN2P3, through the involvement of IJClab and APC, has played an important role in the SO project design, and will have a key position during upcoming operations and analysis.

- The chosen combination of SAT and LAT had been shown to maximize science output [3] and is also the chosen option for CMB-S4. IN2P3 specifically participated to the optimization of the SATs resolution, frequency bands and scanning strategy.

- The IN2P3 teams studied the performance of multifrequency data sets in the context of astrophysical foregrounds rejection. We also built mitigation techniques for instrumental systematic effects, in particular related to the continuously rotation half-wave plate [4, 5] and in light of an enhanced calibration campaign (e.g. via a flying drone).

- Regarding the expected scientific production: the collaboration plans on regular collaboration-wide publications, but also AWG-led papers, as well as methodological papers. As detailed in the next sections, regular PhD thesis will also be published through the lifetime of the project.

- The data analysis pipeline will be made public using the web-based version control and collaboration platform for software developers Github. The collaboration is also planning on regular data releases.

- Through significant funding such as the recently awarded ERC SciPol, the IN2P3 teams will strengthen their visibility within the international collaboration and the scientific community. The arrival of seven new French collaborators between 2023 and 2028 will undoubtedly have a strong impact on the analysis developments and scientific exploitation.

The IN2P3 laboratories have also a unique position given their strong involvement in CMB-S4 and LiteBIRD. The participation to Simons Observatory will allow to maintain and develop the precious scientific expertise acquired in (among others) Planck, Polarbear and ACT. It will strengthen our expertise to (1) get prepared for these upcoming data sets and to (2) exploit the highly relevant combination of probes. IN2P3 can play an important card in the exploitation of such joined analysis that will combine the advantages of space and ground observations.

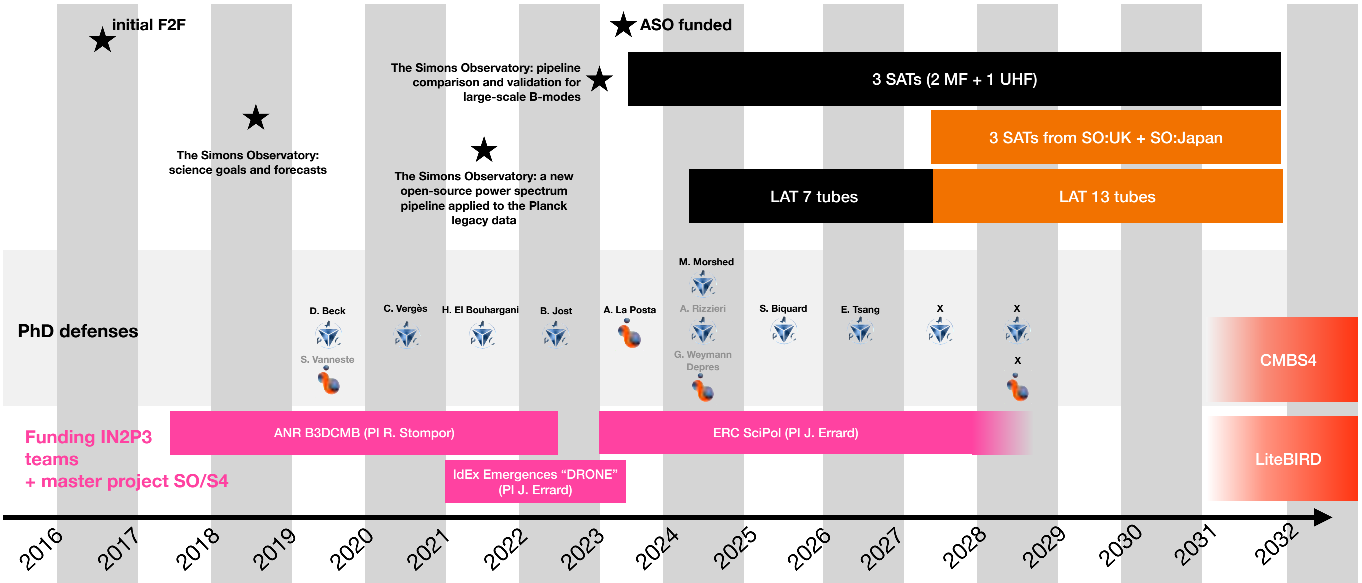

FIG. 3. Schematic Gantt chart of the Simons Observatory project. First lights for the initial SATs and LAT will happen by the mid-2024. The extension of SO (3 more SATs and full LAT focal plane) will start in 2027.

III. ORIGIN AND CALENDAR

The Simons Observatory was created in 2015 from the fusion of the Atacama Cosmology Telescope and PolarBear collaborations, thanks to a momentum and significant initial funding provided by the Simons Foundation.

The first collaboration meeting, in Princeton in 2016, corresponds to the establishment of the collaboration structure, in particular the pipeline working groups (PWGs, going from raw data to maps) and analysis working groups (AWGs, from maps to science). The IN2P3 teams, already members of ACT and PolarBear collaborations, were actively involved in this initial state of the project. For instance, optimization and scientific forecasts were heavily relying on xForecast [6]. These various steps are illustrated in Fig. 3.

Since the beginning of the project back in 2016, four PhD students – official members of the SO collaboration – have defended their thesis on subjects connected to the SO design and science.

Moreover, numerous articles have been published on the SO hardware, scientific performance and analysis, with strong IN2P3 contributions such as [2, 4, 5, 7–16]. As first light is approaching, a rather aggressive calendar is being set up for regular publications, with for instance a first constraint on inflationary tensor-to-scalar ratio r by 2026.

A last set of IN2P3 contributions but not the least concerns the publicly available analysis codes such as BBpipe [17], PSpipe [18] and pspy [19]. These algorithms are at the core of the SO data analysis for both small and large angular scale science.

IV. STATE OF THE ART

No other existing instrument matches the capabilities of the SO Large Aperture Telescope. It will have seven times the mapping speed of the Atacama Cosmology Telescope (ACT) and the South Pole Telescope (SPT). Millimeter observations of the sky require unique observing conditions available at only a few locations such as the South Pole and the high Atacama desert, both sites having excellent millimeterwave sky transparency. However, their locations provide very different access to the sky. Aside from the primordial B-mode science all of the science goals of the Simons Observatory require the largest sky coverage available from a mid-latitude location such as the SO site.

Expected constraints from SO on various cosmological parameters are summarized in Fig. 4. Current values and forecast ones for CMB-S4 are also provided.

Two important cosmological parameters that were used to optimize the CMB-S4 design are r and $N_{\rm eff}$. The SO is expected to reduce the error bars on both parameters by a factor 25 and 4.5 respectively. Further factors 3 and 1.5 will be brought by CMB-S4 on both quantities. These jumps in constraining powers are also visible in the left panel of Fig. 5 that shows the evolution of approximate experimental sensitivities as a function of time. The past and future corresponding constraints on r are shown in the right panel. The Simons Observatory, with a forecast $\sigma(r=0) \sim 0.0012$ by 2032, will have enough sensitivity to test Starobinsky-like inflationary models which are currently among the most favored theories.

With or without a detection of r, the SO will undoubtedly prepare the ground for CMB-S4 and LiteBIRD

Table 1. Summary of Key Science Goals from Advanced SO[a]

	Current[b]	**Advanced SO 2024-2032**	CMB-S4[c] 2028-2035	Using Rubin, DESI, or *Euclid*
Primordial perturbations				
r ($A_L = 0.3$)	0.03	0.0012 [d]	0.0005	✓
n_s	0.004	0.002	0.002	-
$e^{-2\tau}\mathcal{P}(k = 0.2/\text{Mpc})$	3%	0.4%		-
$f_{\rm NL}^{\rm local}$	5	1	0.6	✓
Relativistic species				
$N_{\rm eff.}$	0.2	0.045	0.03	-
Neutrino mass				
m_ν (eV, $\sigma(\tau) = 0.01$)	0.1	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				
$\eta_{\rm feedback}$	50-100%	2%		✓
$p_{\rm nt}$	50-100%	4%		✓
Reionization				
Δz	1.4	0.3	0.25	-
τ	0.007	0.0035	0.003	-
Cluster catalog	4000	33,000	70,000	✓
AGN catalog	2000	100,000	$> 100,000$	-
Galactic science				
Molecular cloud B-fields	10s	> 860		-
$\sigma(\beta_{dust})$	0.02	< 0.01		-
Planet 9				
Distance limit for 5 M_e		900 AU		✓
Transient Detection Distance				
Long GRBs, on-axis		420 Mpc		✓
Low-Luminosity GRBs		60-190 Mpc		✓
Normal SNe		$\gtrsim 4$ Mpc		✓
TDEs, on-axis		2100 Mpc		✓

FIG. 4. Projected 1-σ errors on SO's key Science goals. The r forecast uses SO-SAT data, while all others are based on the SO-LAT. The SO science goals paper [2] describes the methods to account for noise properties and foreground uncertainties. External data listed in the fifth column are those necessary to achieve the forecast precision on each individual science target; for the cluster catalog the external data are needed only for obtaining redshifts. b) Primarily from BICEP/Keck and Planck. We anticipate constraints from existing ground-based data to improve on the "current" limits by 2023. c) Forecast constraints for CMB-S4 for comparison.

which will eventually confirm or reject most of the inflationary models. The SO, thanks to the LAT observations, will in addition bring tight constraints on the scalar tilt, n_s, which will further help discriminating between inflationary models. Moreover, with publicly released maps, the international community and in particular the IN2P3 teams will be in a unique position to combine observations and exceed the scientific performance of each instrument taken separately.

V. RESOURCES AND MEANS

The human resources involved in the project, estimated during the 2022-2024 period, are summarized in Table I. There are currently 7 permanent researchers (2.5 FTE) and 5 non-permanent researchers (3.5 FTE) combining to a total of 6 FTE. A significant contribution in terms of FTE will be coming from the ERC SciPol project (100% of 5 extra persons $\times$ 3 years until 2028 – PhDs, postdocs and software engineer, all at APC).

The SO-France team strongly believes that a long-term, durable solution for the youngest non-permanent researchers is critical for the success of this project but also the success of the upcoming ones: LiteBIRD and CMB-S4. **In particular, the creation of engineer and research positions would be crucial to keep the expertise and motivation of the students who have joined the project**.

In addition, we would like to ask our institute for **a permanent financial support to this project through a dedicated Simons Observatory IN2P3 master project** (currently, SO lives in a mixed SO/S4 project). Such funding will be primarily used to attend and participate to regular collaboration meetings (yearly face-to-face, regular workshops and hackathons). Expectations is to have on average 2 missions per person and per year, i.e. corresponding to a yearly $\sim 10 \times 2 \times 2000$€$\sim$ 40k€budget. Such continuous support is really important to make sure our contributions remain visible and to keep our responsibilities throughout the collaboration durable. Finally, in a context in which the access to computational resources becomes less obvious to the CMB community, France could certainly play an important role with plateforms such as the CCIN2P3 and Jean Zay. The SO-France team has already applied for run times on these machines, and a continuous support from the institute to make these solutions durable would be important. We note that preliminary simulations to optimize the SAT scanning strategy have already been run at CCIN2P3.

The project received 70M$ from the Simons Foundation, a similar amount from the US universities, and recently received 52.8M$ from the National Science Foundation (NSF) for ASO [20], i.e. completing the LAT focal plane, supporting analysis and developing a 2MW solar power plant next to the site (corresponding to 70% of the consumption of the observatory). The project got also significant contributions from the UK [21] (20M$ for the SO:UK i.e. the addition of 2 Small Aperture Telescopes equipped with KIDS, human resources, and computing facilities) and from Japan (3.5M$ for the building of an extra SAT).

Since the official start of the Simons Observatory project in 2016, we have participated to collaboration meetings, hackathons and attended conferences with other projects' funding (e.g. ANR) as well as support from the master project "S4/SO". Several students mentioned in Fig. 3, namely Bapiste Jost and Magdy Morshed, were and are funded by IN2P3 via international CNRS funds awarded to the Centre Pierre Binétruy (CPB at UC Berkeley).

VI. TECHNICAL REALIZATIONS

The main technical realization of the IN2P3 teams has been the development of data analysis pipelines, tested both on real data from Stage-3 experiment (such as ACT and Polarbear), and on Simons Observatory simulations. The next step is therefore the exploitation of these

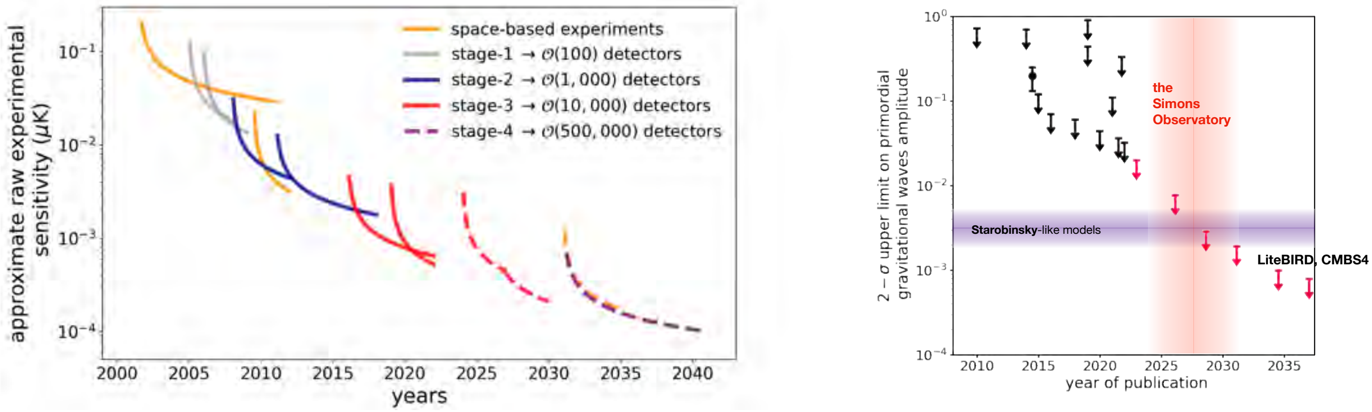

FIG. 5. Left panel: evolution of the approximate raw experimental sensitivity as a function of time. The Simons Observatory corresponds to the dash red-curve starting in 2024. Right: Evolution of the published (black) and expected (red) 2-σ upper limits on inflationary tensor-to-scalar ratio r.

Name	Function	FTE	Lab	Responsibility
Jim Bartlett	Prof	15%	APC	
Simon Biquard	1st year PhD	70%	APC	
Pierre Chanial	IR	60%	APC	
Josquin Errard	CR	60%	APC	BB AWG co-coordinator
Ken Ganga	DR	50%	APC	member of the talk panel
Xavier Garrido	MdC	30%	IJClab	
Adrien La Posta	3rd year PhD	75%	IJClab	
Thibaut Louis	CR	70%	IJClab	PS AWG co-coordinator
Magdy Morshed	2nd year PhD	70%	APC	
Jean-Baptiste Melin	Researcher	10%	CEA + APC associate	
Radek Stompor	DR	20%	CPB + APC associate	
Ema Tsang	1st year PhD	75%	APC	
total permanents		2.5 FTE		
total non-permanents		3.5 FTE		
total		6 FTE		

TABLE I. Distribution of FTEs per year, averaged over the 2022-2024 period on the project across IN2P3 labs. Light blue background corresponds to permanent researchers.

pipelines on the actual Simons Observatory data.

Given the size of the expected data volume and the scarcity of available computing resources, modern computational tools such as the use of Graphics Processing Units instead of CPUs or the development of machine learning algorithms to speed up part of the analysis should be considered. Having access to human resources, such as specialized engineers in such topics would be valuable.

We will also participate to the calibration campaign, following our initial participation to the DRONE project (IdEx funding, 2020-2023, 40k€, PI: J. Errard). This latter support allowed the team at APC to buy, integrate and test a millimeter wave source adapted to the high frequency band of the SO SATs (200-300GHz). The integration and lab-testing were done in Milan Bicocca, and the first flights of the source on the drone were successfully performed in February 2023 above the Chajnantor plateau, with observations performed by the CLASS instrument, see Fig. 6. Analysis of all the corresponding data sets are currently happening, in particular with the master 2 internship of Ema Tsang at APC.

The drone is one of the baseline solutions for calibrating the SO SATs optical response, in particular the polarization angle of the detectors — which is a critical quantity for measuring e.g. cosmic birefringence. Such calibration is also the opportunity of characterizing many instrumental parameters (bandpasses, beams, etc.) which are very important to the success of cleaning astrophysical contaminants and mitigating instrumental systematic effects. For all those reasons the SO-France team is actively engaged in the analysis of this technical solution, and we could imagine taking a larger role in the future.

With the acceptance of the Advanced SO proposal which effectively extends the duration of the observations, and the delays of the CMB-S4 project, a new window of opportunity is opening for proposing IN2P3 hardware contributions to SO. One of the investigated

FIG. 6. Flight campaign of the calibration drone at the high altitude site in February 2023. A preliminary analysis of the data is being performed at APC.

options is the full construction and operation of an extra SAT based on Kinetic Inductance Detectors (KIDs) technology from the GIS KIDS and lead by IN2P3. After a first positive contact with SO representatives, Andrea Catalano, Juan-Francisco Macias-Pérez in collaboration with the SO-France team intend to present the project to the SO steering committee and apply for funds. Instrumental design and science optimization forecasts are currently under development. Towards this possible significant hardware contribution, we are starting discussions to formalize a dedicated research consortium among the IN2P3 labs, namely the LPSC, IJClab and APC.

VII. SWOT SELF-ANALYSIS

- Strengths: position in the collaboration, unique upcoming data sets with imminent first light. Contrary to some other observatories, all the data will be public, in addition to the analysis codes. IN2P3 is also strongly involved in CMB-S4 and LiteBIRD, which is a rare position to benefit from the acquired SO expertise and later to optimize the scientific exploitation of their combination. Although their environments are obviously different, the SO SATs and LiteBIRD LMHFT instruments share a lot of commonalities in terms of optics, systematics and data analysis processes.

- Weaknesses: no current permanent support to our activities, difficulties to find permanent positions for young colleagues.

- Opportunities: we are transitioning towards the analysis and exploitation of real data sets: the timing is exciting! At IN2P3 the SO offers a unique opportunity for the researchers to perform analysis and get prepared to the upcoming CMB-S4 and LiteBIRD projects (starting early next decade). In addition the synchronicity with the Rubin Observatory offers opportunities for cross-correlation (e.g. study of transients).

- Threats: there is a direct competition with SPO (combination of BICEP and SPT) especially for the characterization of large scale B-modes. In the eventuality BICEP/Keck collaboration claims a first detection of r the SO will likely be second. Given the recent history of mistaking cosmological signatures with astrophysical foregrounds, a confirmation of the detection by another mean will be necessary.

Thanks to its new technology, unique sensitivity and sky coverage, the LAT is going to be quite advanced compared to the other currently running observatories.

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