The Large Scale Polarization Explorer

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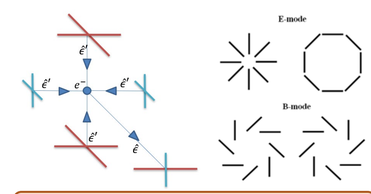
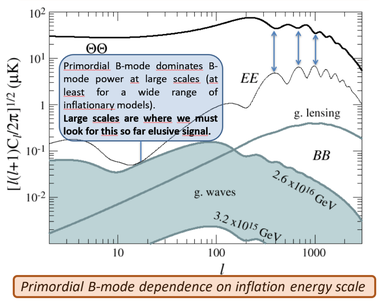
Context and Science Case

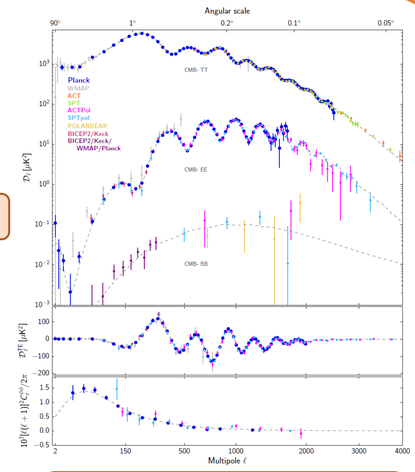
Measurements of the Cosmic Microwave Background (CMB) polarization anisotropies offer strong probes of the standard cosmological model. **Linear polarization of the CMB** is known to emerge from Thomson scattering off electrons at the last scattering surface in the presence of local quadrupole anisotropies in the scattered radiation field.
The polarization pattern observed in the sky is commonly decomposed in a **curl-free "E-mode"** and a **divergence-free "B-mode"**. E-modes alone emerge in the presence of the velocity fields around peaks in the baryon-photon fluid at last scattering, and thus exhibit a tight correlation with the temperature anisotropies of the CMB. As such, the TE angular cross-power spectrum and the EE power spectrum can be usefully combined with the TT power spectrum to break degeneracies among cosmological parameters, and to constrain specific parameters (e.g. the reionization optical depth) otherwise intrinsically degenerate with respect to temperature anisotropies. On the other hand, B-modes at small angular scales are observed as a result of E-to-B leakage due to gravitational lensing, and as such observed in correlation to the line-of-sight integrated lensing potential due to the presence of large scale structure across the light path to last scattering surface.
In addition, **a large (degree and above) scale contribution to the B-mode angular power spectrum** is predicted to emerge from a stochastic background of tensor (metric) perturbations, i.e. **gravitational waves, generated during the inflationary expansion history of the early universe**. The amplitude of the gravitational wave background can be effectively used to constrain the inflationary paradigm: the B-mode power yields a direct measurement of the so-called **tensor-to-scalar ratio r**, i.e. the power ratio between the tensor and scalar perturbations at the end of the inflation. **A detection of large scale B-modes, if any at all, would thus represent the ultimate constraining probe for the physics of inflation. The best current upper limits on r from the joint BICEP2 and Planck analysis, yields r<0.07 at 95% c.l** (Phys. Rev. Lett., 114, 101301, 2015).
Observationally, not only the **inflationary signal is tiny** (at most a fraction of percent of the total polarized CMB power), but **no region of the microwave sky can be safely considered free from foreground contamination** to allow a direct measurement down to the level required for primordial B-mode detection.
A large scale B-mode measurement demands very clever and careful strategies, both in instrument design and signal conditioning to mitigate the hardware systematics but also accurate modeling and treatment of the foregrounds through component separation techniques, with systematics understood and traced across the analysis pipeline down to a fraction of the sensitivity level allowed by observations.
The CMB community is currently devoting a huge effort towards large scale polarization measurements. A number of ongoing and upcoming projects, including the recently JAXA-approved LiteBIRD satellite, have been designed to shed light on the so-far elusive B-mode signal from inflationary gravitational waves.



Origin of CMB polarization from inhomogeneous Thomson scattering and E-mode B-mode decomposition



Primordial B-mode dependence on inflation energy scale



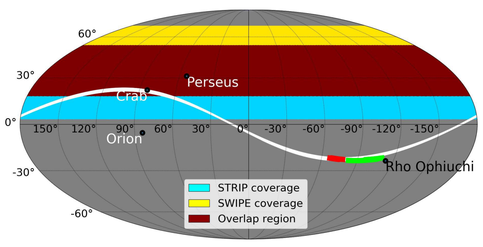
Status of CMB anisotropy measurements in 2018 (adapted from Planck 2018 paper I, https://arxiv.org/abs/1807.06205)

Project Description

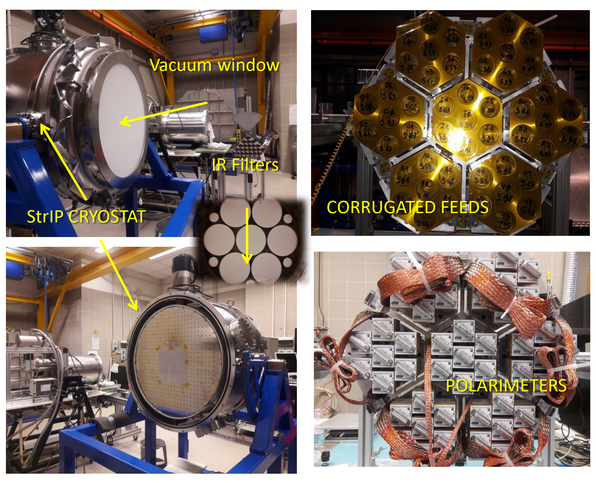
LSPE is a program funded by the Italian Space Agency and INFN with the threefold aim to:
– perform a large coverage survey of the microwave polarized sky in 5 spectral bands, with the scope to understand the galactic foregrounds at degree scales;
– test and validate hardware solutions, observing strategies, and data processing techniques for the observational challenge of the inflationary B-modes, in view of even more ambitious ground-based and space-borne programs devoted to CMB polarization in the next decade (including LiteBIRD);
– constrain r at the level of 0.01.

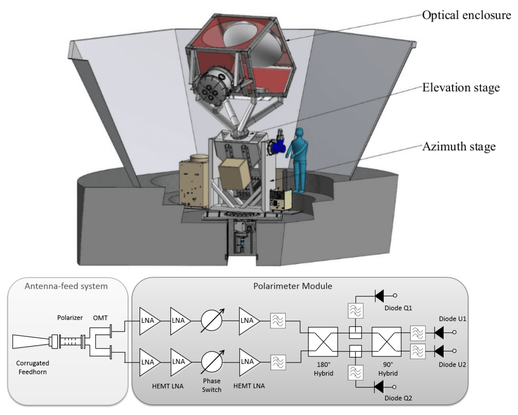
LSPE will observe a 25% fraction of the sky in the Northern hemisphere by means of two instruments, complementary for frequency coverage and technology.

Instrument	STRIP		SWIPE		
Site	Tenerife		balloon		
Freq (GHz)	43	90	145	210	240
Bandwidth	16%	8%	30%	20%	10%
Angular resolution FWHM (arcmin)	20	10	85		
Detectors technology	HEMT		TES multimoded		
Number of detectors N_{det}	49	6	110	108	108
Detector NET ($\mu K_{CMB}\sqrt{s}$)	460	1247	11	14	28
Mission duration	2 years		8 - 15 days		
Duty cycle	35%		90%		
Sky coverage f_{sky}	37%		38%		
Map sensitivity $\sigma_{Q,U}$ (μK_{CMB} · arcmin)	104	809	12	14	29
Noise power spectrum $(\mathcal{N}_\ell^{E,B})^{1/2}$ (μK_{CMB} · arcmin)	171	1330	19	24	47



LSPE instruments key parameters and sky coverage

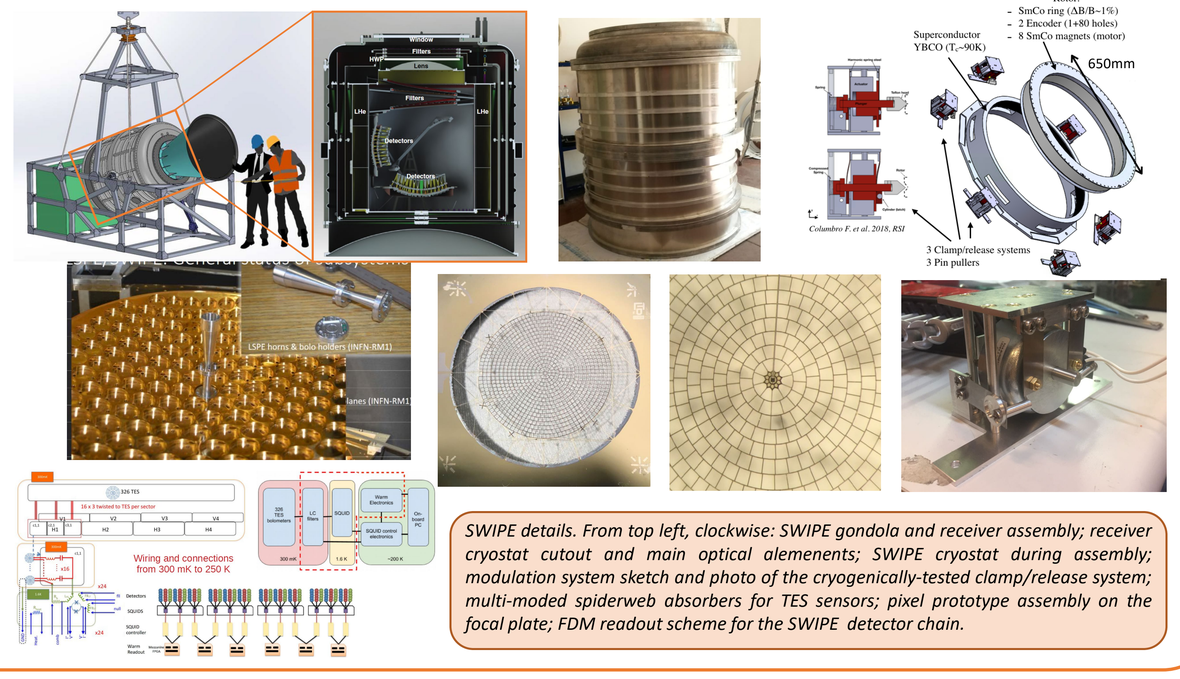




Top: STRIP telescope sketch and polarimeter principle of operation. Left: receiver and focal plane assembly.

STRIP (Survey TeneRife Italian Polarimeter) is a **coherent polarimeter array** that will observe the microwave sky from Tenerife in two frequency bands centered at 43 GHz (Q band, 49 receivers) and 95 GHz (W band, 6 receivers) through a dual-reflector crossed-Dragone telescope of 1.5 m projected aperture.
STRIP will start operations by Spring 2021 at the **Teide Observatory in Tenerife**. The STRIP main scientific requirements for the two channels in the Q and W bands are summarized in table. The Q-band goal sensitivity corresponds to an improvement of a factor 5 over the Planck-LFI 44 GHz sensitivity on the same pixel size at the end of the 30 months mission. STRIP will scan the sky with a continuous azimuthal spin at 1 rpm, while maintaining telescope boresight at a fixed elevation angle (approximately 20 degrees from the Zenith at Tenerife latitude). By combining the telescope spinning with the daily rotation of the Earth around its axis, **STRIP will cover a region of the Northern Sky that overlaps at least 80% of the SWIPE survey**.
The design of the STRIP polarimeters is based on InP cryogenic High Electron Mobility Transistor (HEMT) low noise amplifiers integrated in Monolithic Microwave Integrated Circuits (MMIC) and on high-performance waveguide components cooled to 20 K.
A schematic of the detection chain of STRIP is shown in figure. The benefit of this design is that the Q and U Stokes parameters are directly extracted from each pair of diodes at the output.

SWIPE (Short Wavelength Instrument of the Polarization Explorer) **is a Stokes polarimeter based on a 50 cm refractive telescope** with a dual polarization focal plane hosting two arrays, one per polarization, **totaling 330 large throughput multimode 300 mK TES bolometers, with passbands cetered at 145, 210 and 240 GHz**.
SWIPE will survey the Northern Sky from a **spinning long duration stratospheric balloon, launched from Svalbard or from Kiruna during the Arctic Winter**. Its main features are summarized in table.
The key unique features of SWIPE are the use of a large aperture **Half-Wave Plate (HWP), acting as a broadband polarization modulator at the telescope input**, and the optimization of collection efficiency through t**he multi-moded coupling of the single detectors to the system optics**.
The HWP rotation mechanism is based on a superconducting magnetic suspension system allowing continuous rotation at 60 rpm, corresponding to 4 Hz modulation of the polarized signal.
The multi-moded detectors for SWIPE trade system resolution for optical efficiency, coupling few tens of modes per detector across the covered bands, so that the effective photon noise limited sensitivity equals that of a few thousands single-moded detectors in both polarizations.
The limited number of physical detectors and the comparatively small number of wires required for the implementation of the readout allow the SWIPE receiver to comply with the strong constraints on power supply applying to a stratospheric night flight, while still achieving a sensitivity scaling like the root of the total number of coupled modes.
The readout electronics is based on a **Frequency Domain Multiplexing (FDM)** scheme with a factor 16:1. The cold part of the electronics is based on LC filter boards (including the bias resistor) next to the focal planes, at 300 mK, while the SQUID is at 1.6 K, in a shielded box. The warm readout custom board is based on a Altera Cyclone V SoC, and it features mezzanine DAC and ADC boards.



SWIPE details. From top left, clockwise: SWIPE gondola and receiver assembly; receiver cryostat cutout and main optical alemenents; SWIPE cryostat during assembly; modulation system sketch and photo of the cryogenically-tested clamp/release system; multi-moded spiderweb absorbers for TES sensors; pixel prototype assembly on the focal plate; FDM readout scheme for the SWIPE detector chain.

STRIP Status

At present, most of the STRIP hardware has been developed and tested. Q-band and W-band sub-systems, including passive components (feedhorns, polarizers, OMT's) and HEMT-based coherent receivers, have been successfully characterized at unit-level. Integration and system-level testing of the focal plane arrays inside the instrument cryostat is planned to be performed within the next months.
Electronics and ancillary systems, such as the internal calibrator and the star tracker, are being finalized and verified as well. Verifications of the telescope parts are in progress. The preparation of the site and the construction of the sliding roof will be finalized between 2019 and 2020. STRIP is scheduled to be fully integrated at the observation site in Spring 2021.

SWIPE Status

Modulation system: The clamp/release system for the rotor, allowing to keep it in place before the superconducting transition of the support magnets, has been prototyped and successfully tested at cryogenic temperatures. The rest of the individual components (i.e. superconducting magnets, rotor permanent magnet, control coils and control electornics) have been built and individually tested in Rome. The full system will be assembled and cryogenically tested in the next months. Most of the issues involved with system design and the relevant systematics at 4-times the rotation frequency have been assessed. They need to be characterized and understood prior to system operation. These will be the target of the extensive calibration plan which will be performed at receiver level during the pre-integration campaign.
Multi-moded pixels: recent tests of the single-pixel prototypes for the SWIPE focal plane with a coherent source at 128 GHz prove a good consistency of the pixel response with the modeled multi-moded performance. Anyway, more extensive, broadband testing at the system-level is advised by the large size of the focal plane and by the frequency dependent positioning of the pixel units across the focal plane.
Readout: The first functional tests (e.g., tone generation) on the prototype flight model have been performed.

Gondola construction and flight cryostat assembly are underway.
The pre-integration campaign and subsystem compliance review for SWIPE is scheduled at the end of 2019.

SWIPE-related contributions at LTD18:
F. Columbro et al., "SWIPE multi-mode pixel assembly design and beam pattern measurements at cryogenic temperature", Orals LM003 (Tuesday, 12.00)
B. Siri et al., "Bismuth-Gold absorber for large area TES spiderweb bolometers", Poster no. 400 (poster session Jul 25th)
A. Tartari et al., "Development and testing of the FDM readout of the TES arrays aboard the LSPE/SWIPE balloon-borne experiment", Poster no. 267 (poster session Jul 25th)

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