CMB research at IAC: technological challenges and future needs

J.A. Rubiño-Martín on behalf of the CMB team @ IAC
(inputs from R. Hoyland, R. Génova, J. J. Diaz, A. Perez)

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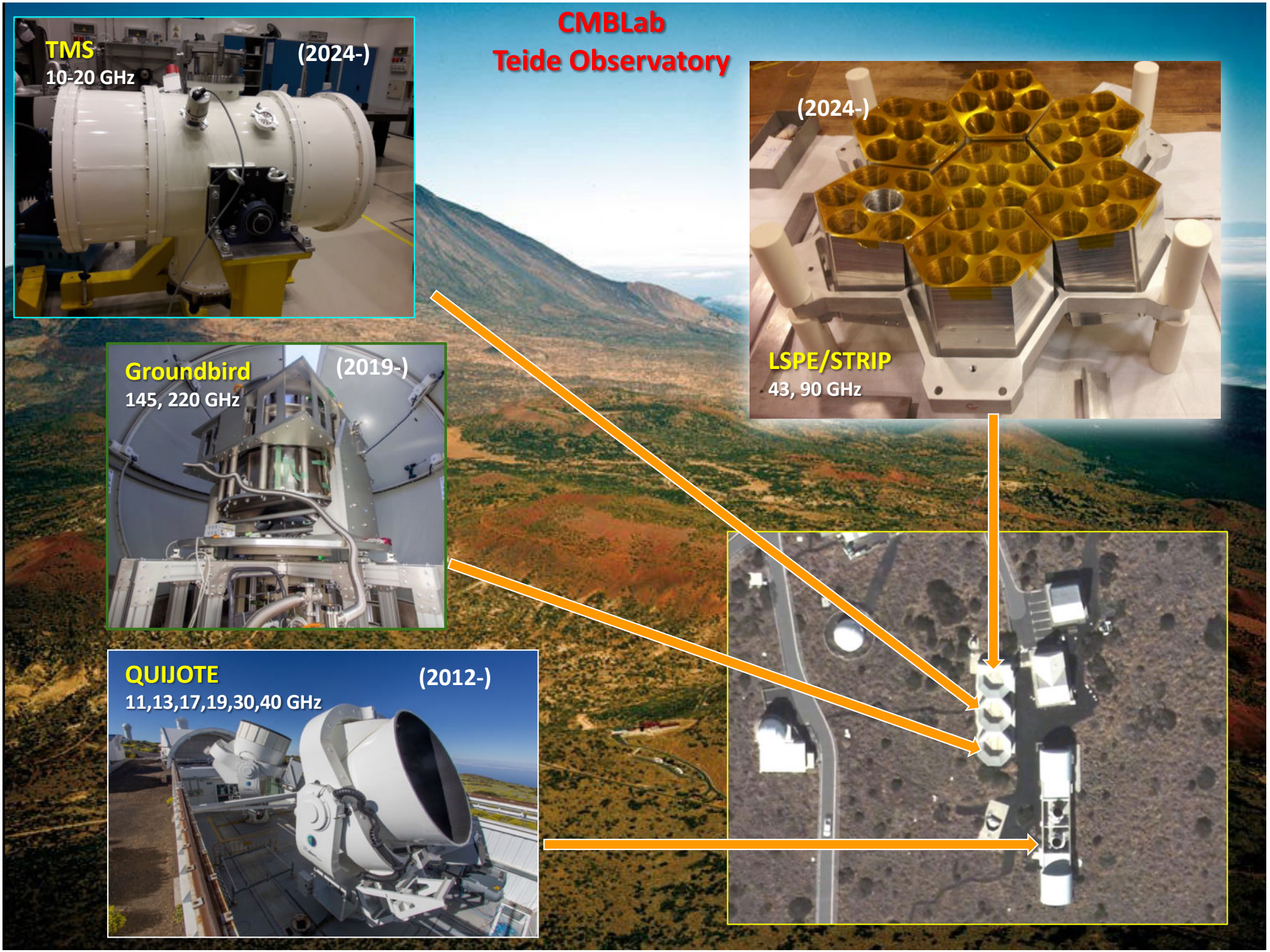
Ref. de la ayuda: ICTS-2019-03-IAC-12

@QuijoteCMB

September 28th 2023


CMBLab
Teide Observatory
TMS
10-20 GHz
(2024-)
(2024-)
LSPE/STRIP
43, 90 GHz
Groundbird
145, 220 GHz
(2019-)
QUIJOTE
11,13,17,19,30,40 GHz
(2012-)

The QUIJOTE experiment

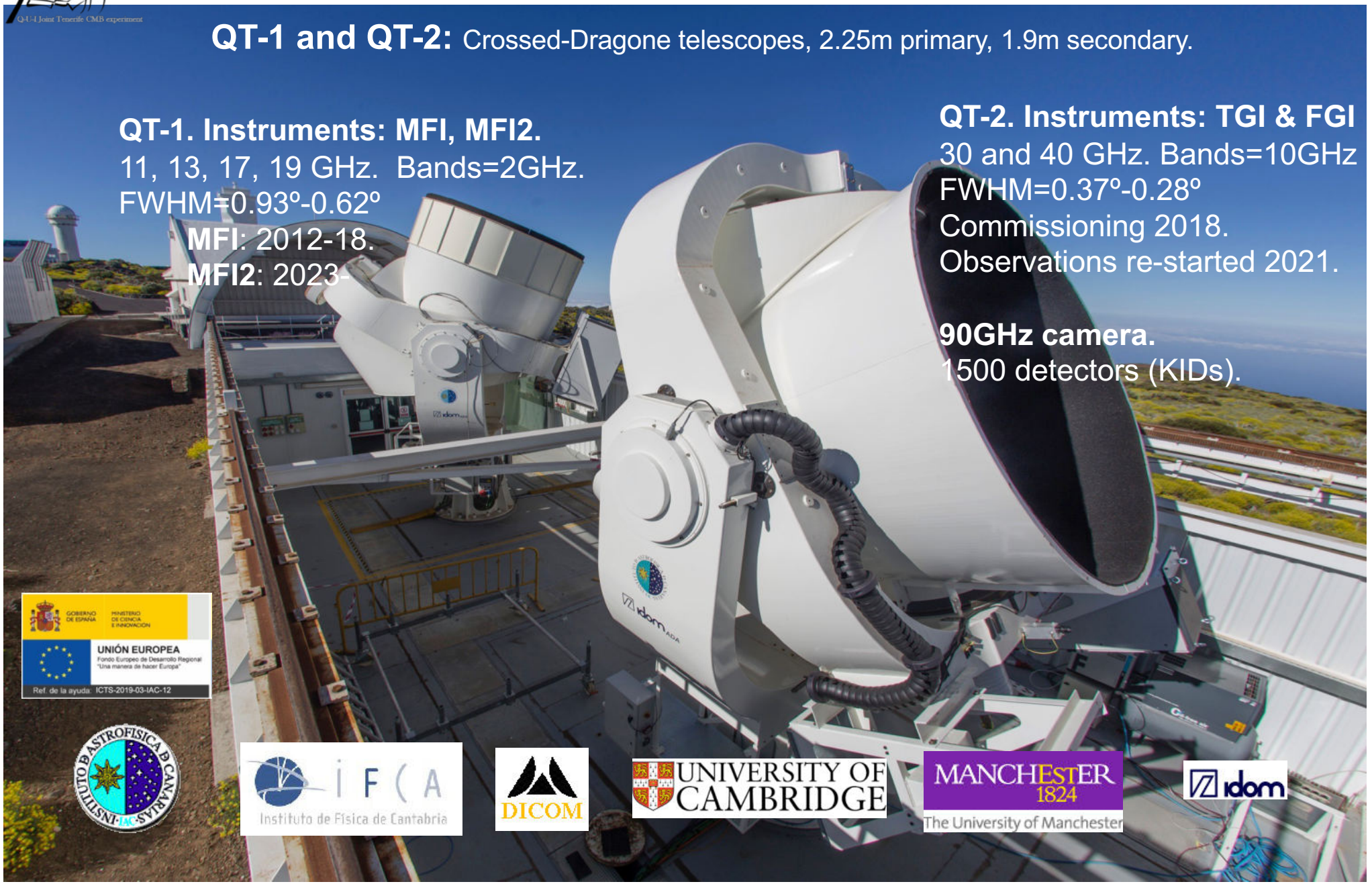
(Q-U-I JOint Tenerife Experiment, http://research.iac.es/project/quijote)

QT-1 and QT-2: Crossed-Dragone telescopes, 2.25m primary, 1.9m secondary.

QT-1. Instruments: MFI, MFI2.
11, 13, 17, 19 GHz. Bands=2GHz.
FWHM=0.93º-0.62º
MFI: 2012-18.
MFI2: 2023-

QT-2. Instruments: TGI & FGI
30 and 40 GHz. Bands=10GHz
FWHM=0.37º-0.28º
Commissioning 2018.
Observations re-started 2021.

90GHz camera.
1500 detectors (KIDs).



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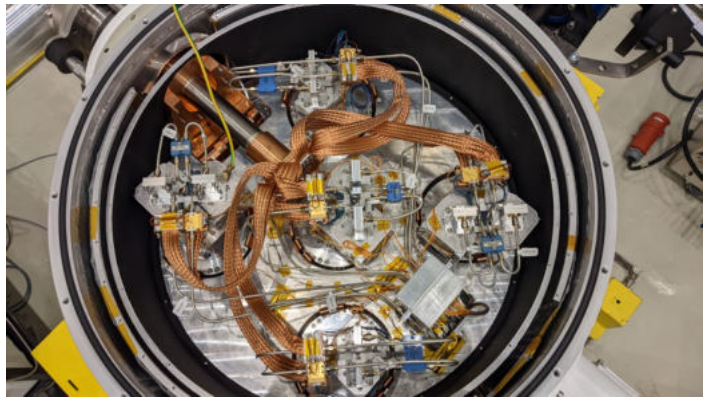
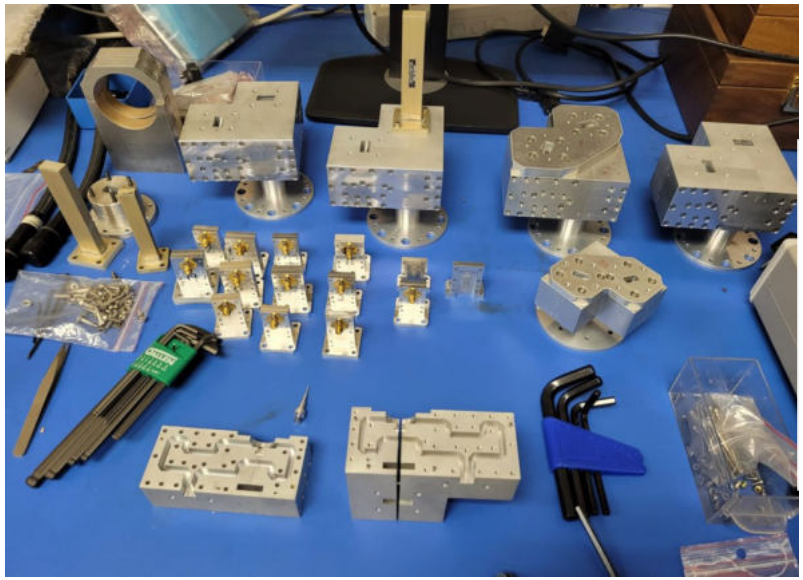
MFI2 Instrument (10-20 GHz)

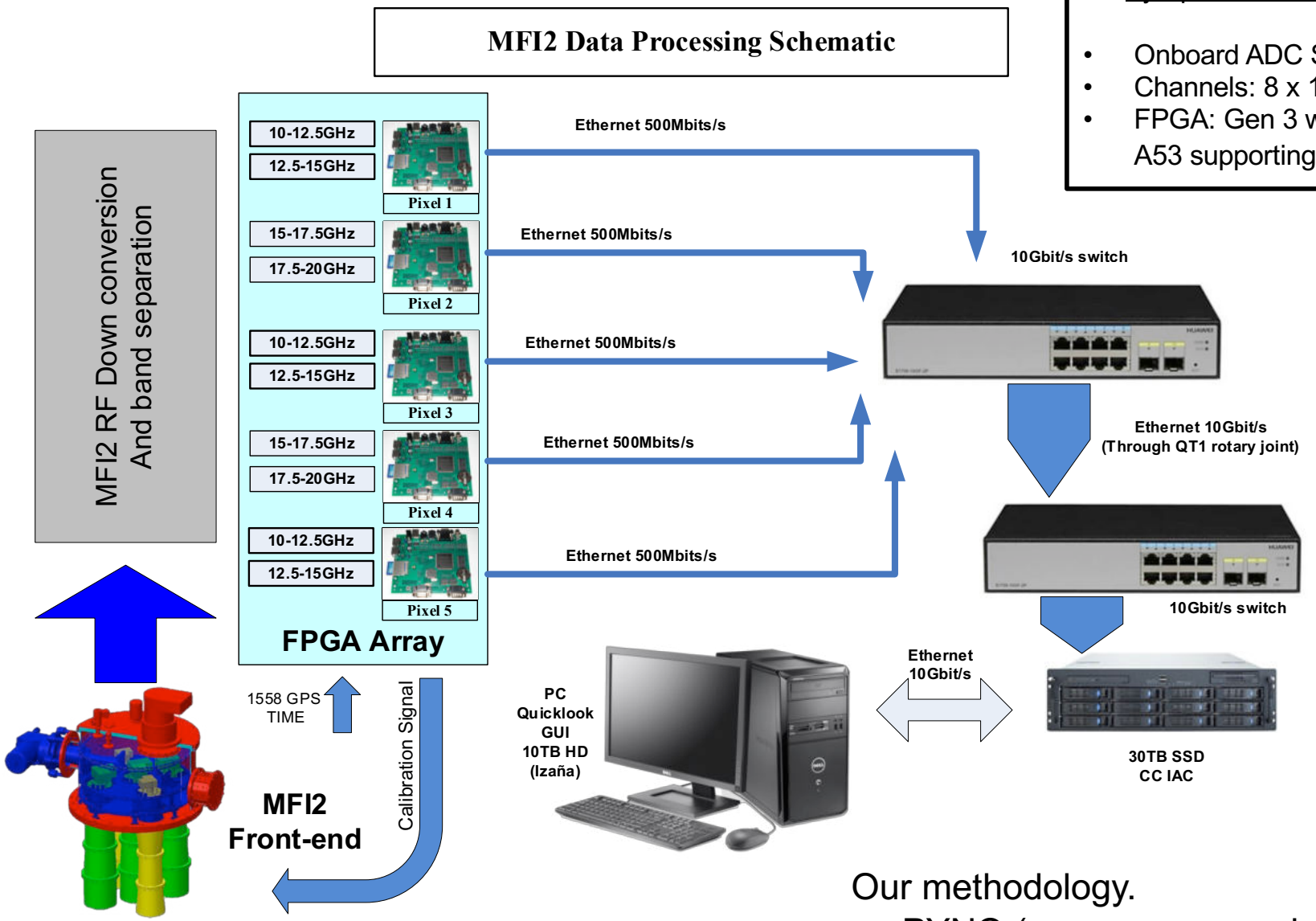


- **MFI upgrade (MFI2 @ QT-1)**. Aim: to increase the integration speed of the MFI by a factor 3.
- **5 horns**. Three covering the 10-14GHz band, and two coverning 16-20GHz.
- Full digital back-end (FPGAs) → RFI removal (TV sats, Megaconstellations Starlink, OneWeb, Kuiper).
- **Status**: Comissioning with old MFI DAS in the next few months. New DAS (FPGA based) for mid 2024.
- **Operations**: 3 effective years.



(Hoyland et al. 2022, SPIE)

FPGA based Data Acquisition Systems (MFI2)



Zynq UltraScale+ RFSoCZCU208

- Onboard ADC Sample rate: 5GSPS
- Channels: 8 x 14 bits ADC
- FPGA: Gen 3 with Arm® Cortex®-A53 supporting ZYNC interface

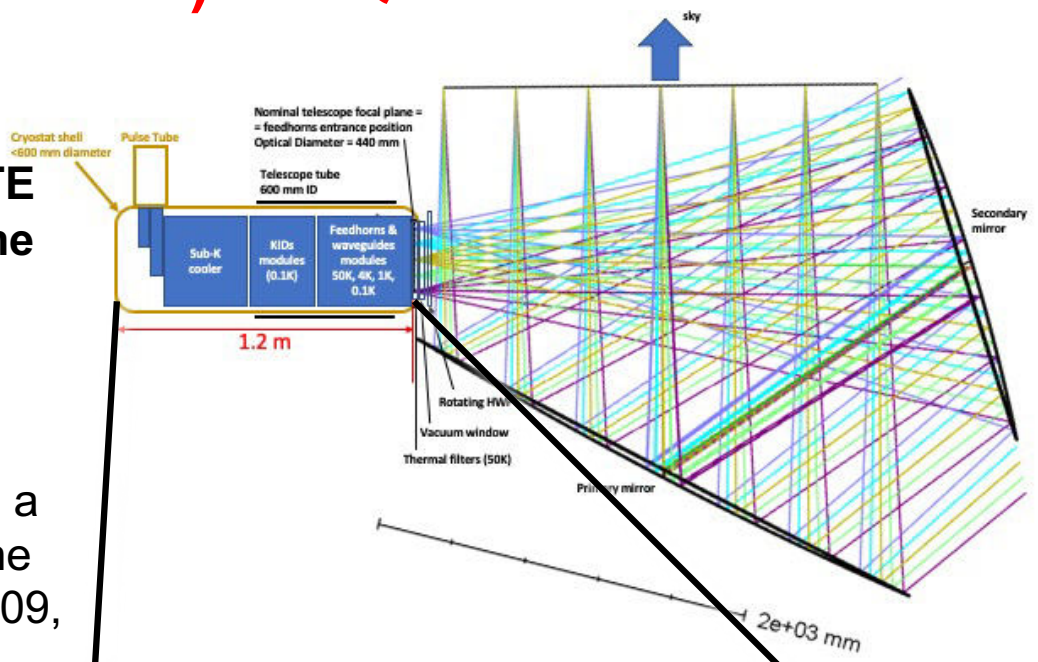
Our methodology.

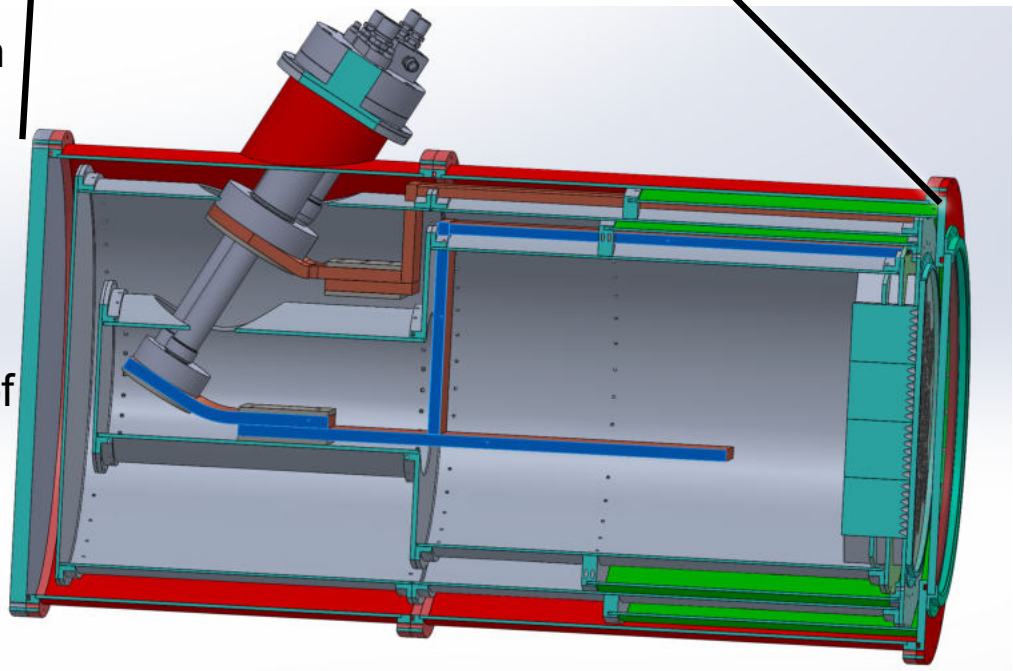
- PYNQ (open-source project from AMD).
- Python language and libraries.

W-band camera (85-110 GHz) for QUIJOTE

- **Scientific collaboration between QUIJOTE nodes (IAC, IFCA) and University of Rome La Sapienza: 90GHz camera.**
- **To be used in QUIJOTE QT-2, or larger telescope.**
- The Sapienza team has recently developed a 400 KIDs W-band camera (MISTRAL) for the Sardinia Radio Telescope (Paiella & JLTP 209, 889 (2022).
- **Aim**: to reach a survey depth of 4 uK.arcmin in 2000 sq.deg after 2 years of integration.
- **KIDs**. 1400 detectors (dual polarization).

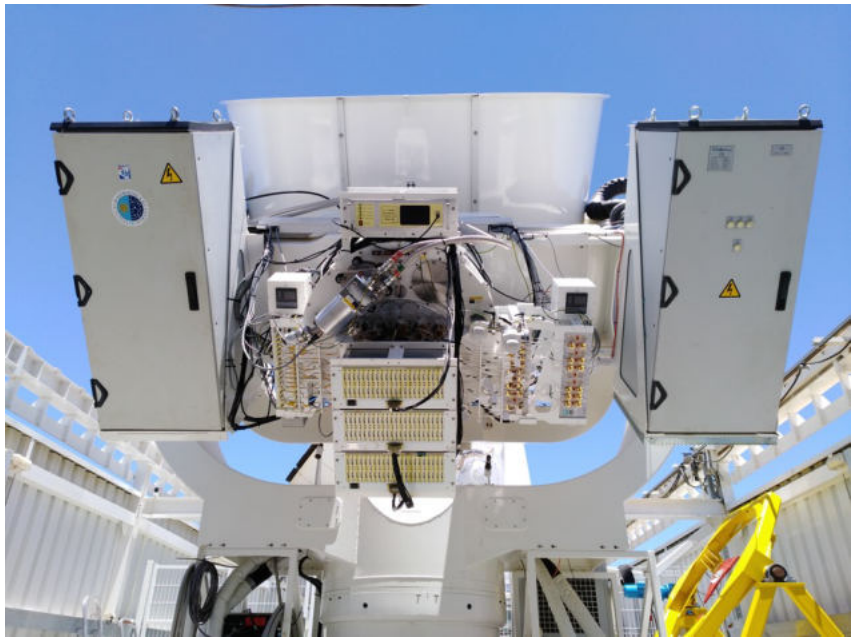
- **Status**: Conceptual design finished. Call for tender for the detailed design and fabrication of the cryostat and cold structure (50K, 4K, 1K and 0.1 K layers) to be announced in the coming months.



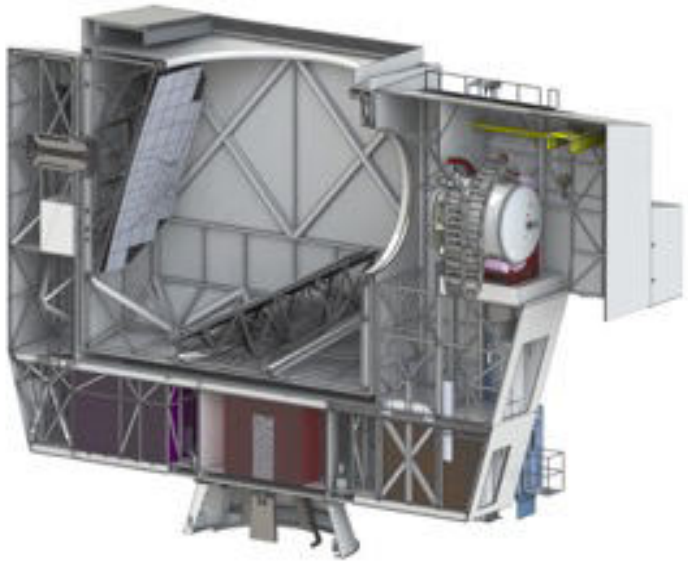


ELFS-north. A 6-8m class QUIJOTE telescope.

- **European Low Frequency Survey (ELFS).** MoU between IAC, CSIC, UniMi (Milan), Oxford, SISSA, Toulouse University.
- **North:** Exploring the preliminary design of a 6-8m class telescope, which should be a scaled version of QUIJOTE (optimised for polarization measurements).
- **South**: ELFS-S (next slide).



- Current QUIJOTE design: 2.25m primary. New concept.



- Funding for conceptual design available.

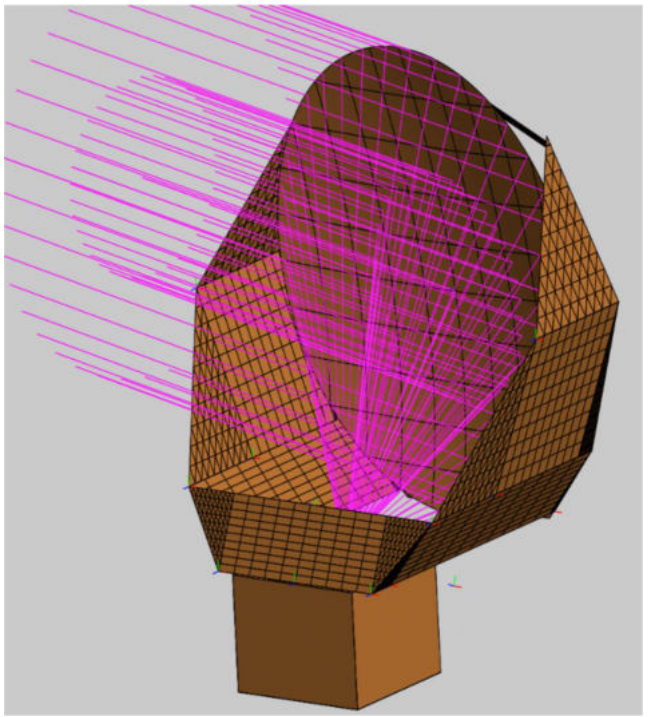
CCAT-Prime and Simons Observatory use similar designs (Large Aperture Telescope, 6m) (https://simonsobservatory.org/large-aperture-telescope-gallery/)

ELFS-Simons Array

- New project: Install European coherent receivers on one 3.5m Simons Array telescope in Chile.
- Initially single-pixel ~6-12 GHz (TBC) based on CBASS-North cryostat, later multi-pixel 10-20 GHz (MFI2 from QUIJOTE)
- New receivers give improved synchrotron foreground guard for Simons Array and Simons Observatory – important given new 6-SAT configuration.
- Spectral backend gives protection from satellite RFI.

Personnel: main groups worldwide working at low frequency (SPASS, CBASS, QUIJOTE, STRIP)

Spanish team (IAC, IFCA): development of the FPGA digital back end, based on the MFI2 concept.



Tenerife Microwave Spectrometer (TMS), 10-20GHz

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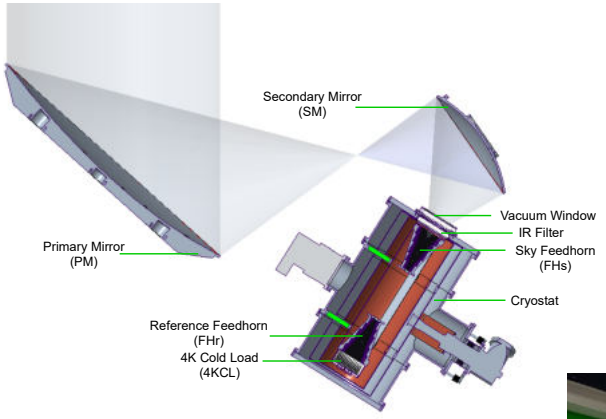
- **IAC project. Instrumental participation:**

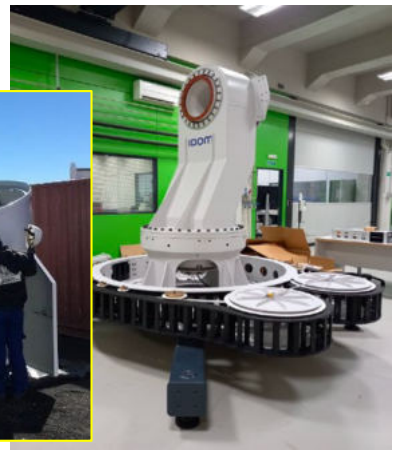
- **Science driver**: Ground-based low resolution spectroscopy observations in the 10-20GHz range to characterize foregrounds and CMB spectral distortions. Provides frequency intercalibration for QUIJOTE-MFI. (Rubino-Martin et al. 2020).
- **Location**: Teide Observatory (former VSA enclosure). Full sky dome.

- **Prototype for future instruments**. **Legacy value (radio synchrotron background).** Complementing future space missions (10-20GHz).

- **Proposed instrument concept**:
  - FEM cooled to 4-10K (HEMTs).
  - Reference 4K cold load.
  - DAS based on FPGAs (Xilinx ZCU208).
  - ~2deg beam, 0.25 GHz spectral resolution (40 bands).



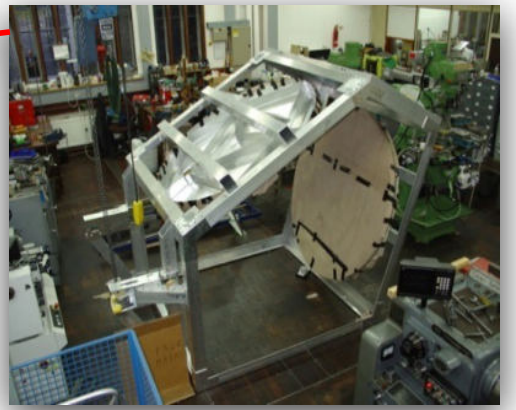
- **Project Status**:
  - Enclosure and dome at the Teide Observatory. ✓
  - Platform fabricated (IDOM). Installation Nov 2022. ✓
  - Cryostat at the IAC since July 2019. ✓
  - 4K load fabricated and tested (Nov 2021). ✓
  - Mirrors designed (Alonso-Arias et al 2022). To be fabricated .
  - Shielding and support structure to be designed and fabricated.
  - DAS based on FPGAs, similar to MFI2.
  - Optomechanics in final fabrication phase (OMTs, hybrids).
  - Commissioning in late 2024, early 2025.



LSPE/STRIP

Deployment at Teide Observatory (Tenerife): Fall 2024

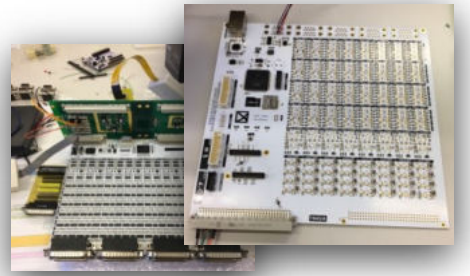
1.5m cross-Dragone telescope



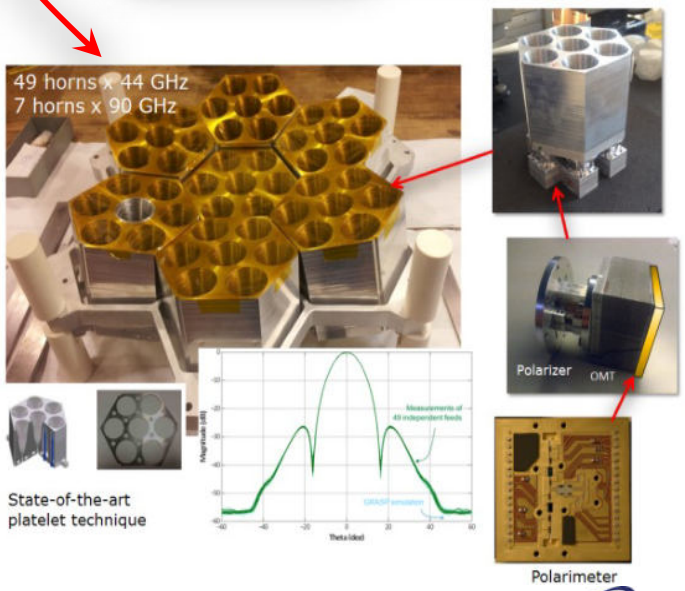
Direct measurement of Q & U, low systematics

Q band: 49-element array, resolution 20', sensitivity 1.5μK/deg

W-band: 6 elements, atmospheric monitor, calibration channel



- STRIP Electronics



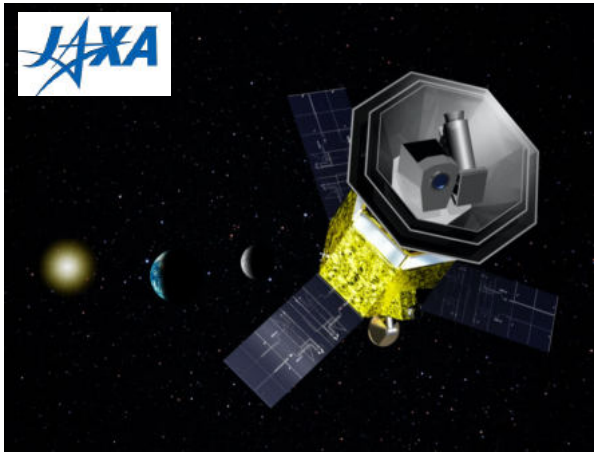
- STRIP focal plane

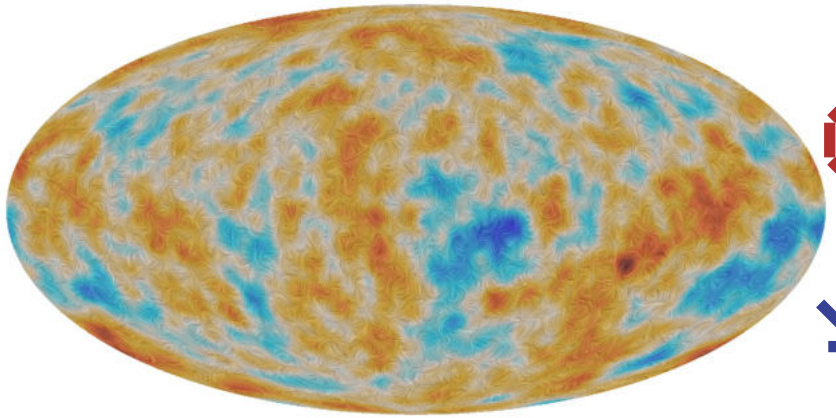
Call for tender for the fabrication of the cover and sliding roof to be announced in the coming months.

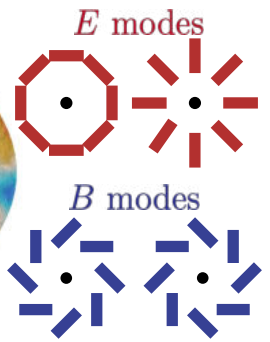
Misión espacial LiteBIRD

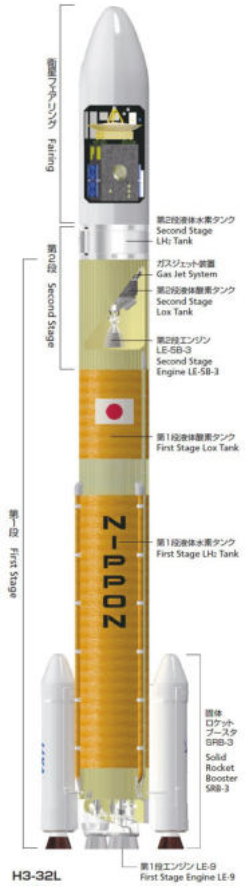
- Lite (Light) satellite for the study of *B*-mode polarization and Inflation from cosmic background Radiation Detection
- Misión de JAXA's clase L, seleccionada en mayo de 2019, en fase A2
- Lanzamiento previsto hacia el final de **2029** en un cohete JAXA H3
- Observaciones de todo el cielo durante 3 años desde L2
- Amplio rango espectral (**40–402 GHz**, 15 bandas), resolución espacial **70–18 arcmin** para la medida de los **modos B de la inflación**
- Sensibilidad final combinada: **2.2 μK·arcmin**

Hazumi+ SPIE 2020







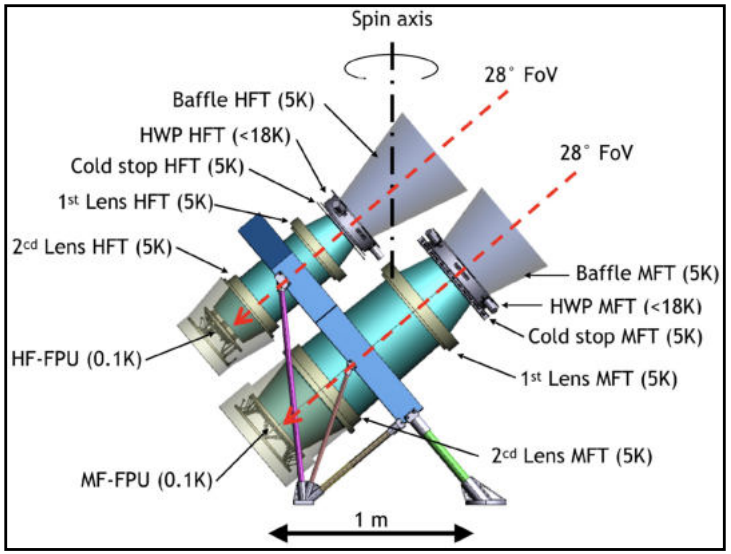


Misión espacial LiteBIRD

- Consorcio europeo encargado de la construcción de los telescopios de media y alta frecuencia (MHFT)
- Contribución española, formada por: IAC, IFCA CSIC-UC e IDR-UPM
- Participación en los grupos científicos, y en aspectos de desarrollo instrumental

- España tiene la responsabilidad y lidera el desarrollo de un sistema de medida y de control de la temperatura en las etapas criogénicas del MHFT
  - Los requerimientos son temperaturas mínimas de 100 mK, en el plano focal, y variaciones sub micro-Kelvin
- El diseño de fase A de este sistema comenzó con un proyecto liderado por el IAC y financiado con el programa ICTP de CDTI (377 k€, oct 2021 a jun 2023).
- 3 contratos menores:
  - IFCA (especificación de requerimientos)
  - SENER aeroespacial (soporte diseño electrónico)
  - IDR (soporte diseño térmico y mecánico)

Telescopios MHFT



Misión espacial LiteBIRD

- Organización temporal y previsión de costes para la continuación de estas tareas durante las fases B/C/D

- Fase B (1 año, 2024)
- Fase C (3 años, 2025-2027)
- Fase D (2 años, 2028-2029)
- Lanzamiento: 2029

Concepto	Periodo de ejecución	Coste estimado
Desarrollo de la electrónica de vuelo • Bancos de pruebas • Modelos de vuelo • Modelos de cualificación • Modelos de ingeniería	Fases B/C/D (2024-2029)	8M €
Desarrollo de un banco de pruebas en tierra (GSE) • Cámara de vacío • Equipamiento de vacío y enfriamiento • Equipamiento de medida y control de temperatura • Electrónica de control	Fases B/C/D (2024-2029)	1 M€
Pruebas de validación de componentes y modelos	Fases C/D (2026-2029)	0.8 M€
Caracterización y suministro de *sensores oscuros* • Caracterización de los detectores TES • Adquisición de sensores oscuros • Equipamiento para medida y caracterización	Fases B/C/D (2024-2029)	1.2 M€
TOTAL		11 M€

Summary slide

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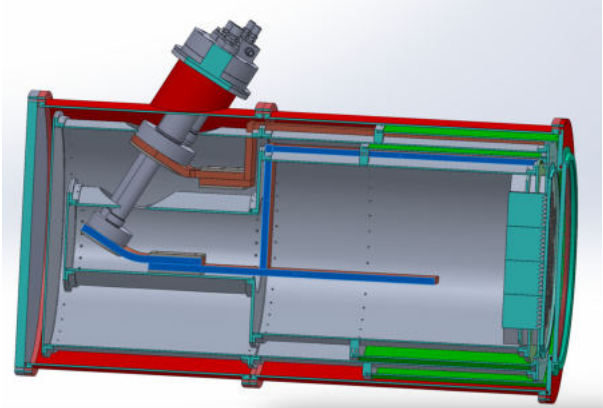
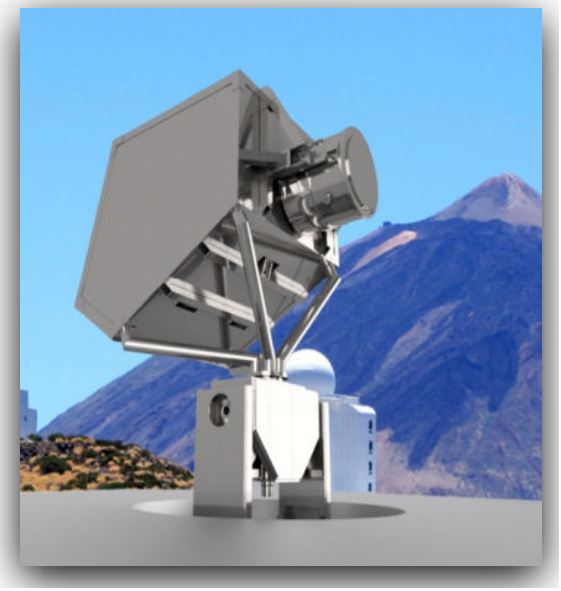
Technological challenges

- **FPGAs.** Technology.
- **KIDs based W-band camera:**
  - Cryostat operating down to 0.1K.
- **6-8m class telescopes:**
  - Conceptual design.
- **Litebird space mission.**



Other needs

- **Shielding, mirrors and optomechanical components for TMS.**
- **Cover and sliding roof for STRIP.**



CMB team @ IAC (http://research.iac.es/proyecto/cmb/)


Thank you!