Status of MHFT-PO activities and Phase A2

LiteBIRD Italy workshop, Frascati, May 22-23, 2023

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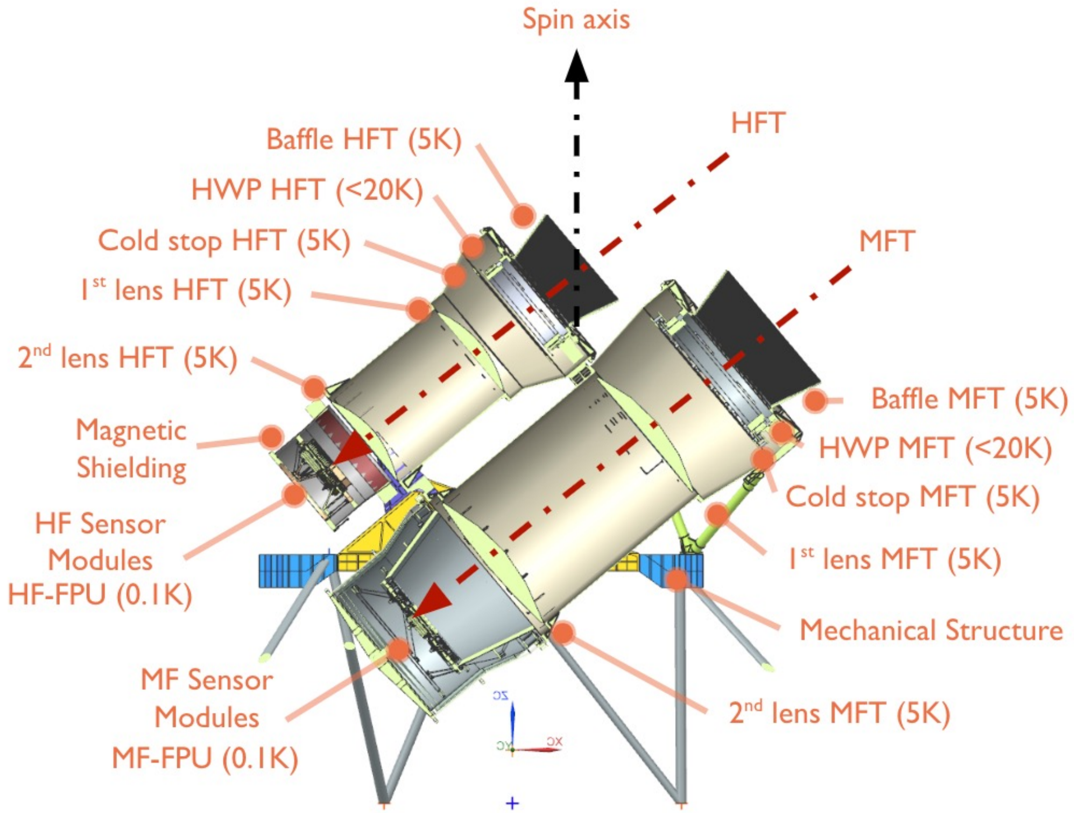
MHFT overview and Task-Sharing



Italy:
- HWP Mechanism
- HWP
- Cold Aperture Stop / Absorbers
- FPGA Warm Readout Electronics
- Sub-Systems Calibration

UK:
- Front Baffles
- Lenses / Filters

Japan / USA:
- Sensor Modules
- Delivered by QUP Japanese Collaboration with US teams

Germany:
- Magnetic Shielding

Spain:
- Thermometers readout electronics

Canada:
- Warm Readout Electronics

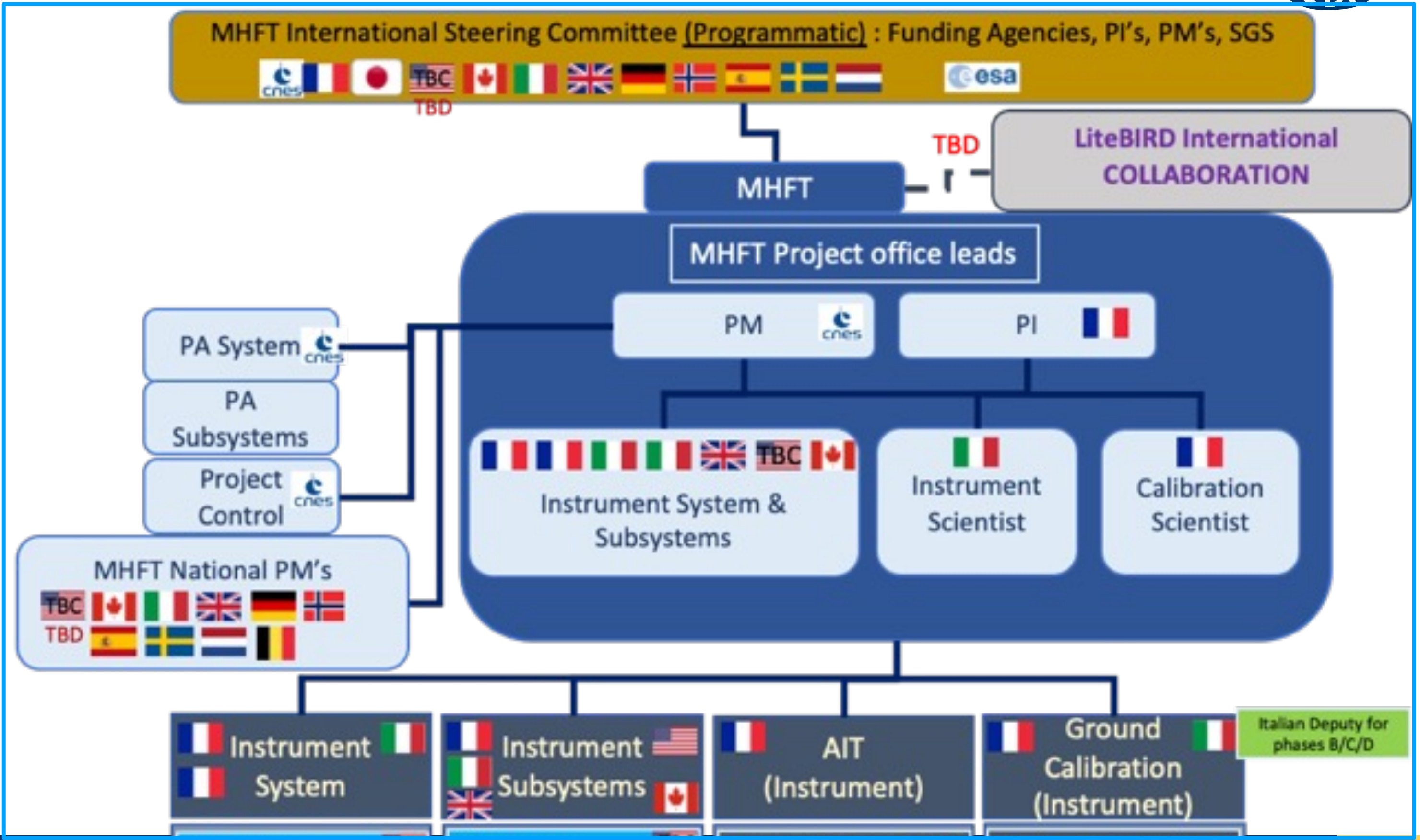
France:
- System Responsibility
- Mechanical Structure 5K
- Focal-Plane Structure + FPU Integration
- DPU
- AIV + Calibration

Belgium:
- Calibration

Objectives of Phase A2 – started in early 2020

- To demonstrate **MHFT technical feasibility**:
  - MHFT architecture baseline and technical justification
  - MHFT science and technical requirements flowdown from JAXA LiteBIRD requirements
  - MHFT science and technical requirement compliance status, including ground and flight calibration feasibility
  - MHFT budgets (mass, volume, thermal, electrical, data) with JAXA agreement
  - MHFT interfaces definition with JAXA agreement
  - MHFT AIV and ground calibration plan
  - MHFT development plan and schedule with JAXA agreement
  - MHFT subsystems technical feasibility:
    - Subsystems architecture baseline and technical justification (when critical)
    - Subsystems budgets (power, mass, thermal, ...)
    - Subsystem requirements
    - Subsystem development plan and schedule
  - MHFT ORFDM (Optical/RF Demonstration Model) design & realization for warm RF tests (test 2022)
- MFHT contribution to LiteBIRD SGS (organization, work packages)
- MHFT organization and management plan for phase B/C/D/E (organization, WP) agreed by all
- MHFT consolidated cost (hardware and manpower) to give input to agencies; not shared
- End of CNES MHFT Phase A2 review: **End 2021** with participation of JAXA and all MHFT funding agencies

MHFT Project Office structure



MHFT Project Office

- MHFT-PO progress meetings every ~3 months to follow the
- Next meeting: later this week in MPE – Garching

MHFT PO – leads members

Name		Partner	Institute	Function
Maciaszek	Thierry	F	CNES	Project Manager
Montier	Ludovic	F	IRAP	Principal Investigator
Piacentini	Francesco	I	La Sapienza	Instrument Scientist
Mot	Baptiste	F	IRAP	System Lead / Sub-System co-lead France
Henrot-Versillé	Sophie	F	IJCLab	Calibration Scientist
Maffei	Bruno	F	IAS	Advisory System Scientist
Pisano	Giampaolo	I	La Sapienza	Advisory System Scientist
de Bernardis	Paolo	I	La Sapienza	Sub-System co-lead Italy
Hargrave	Pete	UK	Cardiff University	Sub-System co-lead UK
Hubmayr	Johannes	US	NIST	Sub-System co-lead US
Montgomery	Joshua	CA	Mc Gill	Sub-System co-lead Canada

Italian responsibilities in MHFT-PO

MHFT-PO (leads)

1. Instrument scientist: F. Piacentini
2. System advisory scientist: G. Pisano
3. Sub-system co-lead: P. de Bernardis

MHFT-PO (system level)

4. Sys-lev SQUID electronics: G. Signorelli
5. Sys-lev HWP mechanism unit: P. de Bernardis
6. Sys-lev HWP optics: G. Pisano
7. Sys-lev Optics: L. Lamagna

MHFT-PO (sub-system level)

8. Sub-sys SQUID Electronics: M. Zannoni
9. Sub-sys Absorbers: L. Lamagna
10. Sub-sys Cold Aperture Stop: A. Paiella
11. Sub-sys HWP electronics: P de Bernardis
12. Sub-sys HWP mechanism: F. Columbro
13. Sub-sys HWP Optics: G. Pisano
14. Sub-sys HWP Testing: S. Masi

MHFT-PO (ground calibration)

15. Cosmic rays testing: A. Tartari
16. Warm test BBM: C. Franceschet
17. Warm Test prototype: C. Franceschet
18. 4K test prototype: G. Morgante
19. Ground test Spectro-polarimetry: S. Masi

(12 members in total)

Key Point review, April 2023

- Main goals of this KP:
  - to get an MHFT progress status, to determine when the MHFT PO could be ready to have the MHFT phase A2 final review and to propose recommendations.
  - It is expected to have presented and discussed the work plan and organization implemented towards reaching end- of-phase A maturity level.
  - This KP will then propose recommendations to the board with the aim to consolidate the remaining of phase A2 work.

Key Point submitted Document Package

Document tree	Title	Purpose	Status
JAXA Requirements			
	LB_Integrated_System_Performances_Requirements_v1.0	L3 performances requirements prepared by the collboration for JAXA MDR and CNES KP. This doc is complementary to the L3 System Requirements prepared by JAXA for the MDR, which covers all L3 requirements.	KP version
	RPR-LB16003B_LiteBIRD_system_requirements_20230314	L3 system requirements prepared by JAXA prepared for JAXA MDR	Draft for MDR
	LiteBIRD_mission_requirements_for_MDR	L1 & L2 requirements prepared for JAXA MDR	Draft for MDR
	MHFT_IRD_v3_0	MHFT Interface Requirements Document	KP version
	MHFT_Comment_to_JAXA_MHFT_IRD.xlx	Comments to MHFT IRD v3.0	
	RPR-LB20002A_MHFT-SoW_v01a	LiteBIRD MHFT Statement of Work	Draft for MDR
MHFT-PO System-Calib			
/Management			
	2021_09_27_Organisation_V1_1	Note d'organisation du MHFT-PO	KP version
	2023_03_23_MHFT_PO_Organisation_	Organigram of the MHFT-PO	KP version
	2023_03_23_MHFT_PO_Risk	MHFT risk	KP version
/Requirements			
	MHFT_Mechanical_IRD	MHFT mechanical interface requirements	KP version
	L4-Requirements-for-MHFT-SubK-TLA	L4 Requirements for MHFT, SubK, TLA, warm electronics...	KP version
	L4-MHFT-SubK-TLA-Verification-and-Compliance-matrix	L4 MHFT requirement compliance matrix	KP version
	MHFT-MICD	MHFT Mechanical Interface Control Document	KP version
/Instrumental Design			
	ESA-CDF-Report	Report from the ESA CDF onLiteBIR Feasibility in 2018	Final
	Refractive vs Reflective design trade-off conclusion	Conclusion from the ESA CDF study to decide on the optical design	Final
	Sensitivity_Calculation_V28	Description of the sensitvity calculation code to derive instrumental performances	Final
	MHFT_performance_code_structure	Detailed description of the Performance Code	Final
	20221113_LiteBIRD_PTEP	LiteBIRD overview in the PTEP Journal	Final
	MHFT_Overview__SPIE_Proceeding_11443_250_	MHFT Overview in SPIE	Final
	PhaseA2-MHFT-Budget	Mass, Power, Thermal, Data budgets	KP version
/Architecture and Modeling			
	2023-03-23 KP Electrical Architecture v1.0	Electrical architecture	KP version
	MHFT thermal study report	Thermal study report	KP version
	MHFT Mechanical Study Report	Mechanical Study report	KP version
	liteBIRD-DSBT-KP_system cryo_model	<5K thermal study repport	KP version
	MHFT Global CAD	MHFT Global description and rules	KP version
	RF_Optics modeling_V2	MHFT RF Modeling (v2)	KP version
	MHFT_Optics__SPIE_Proceeding_11443_283	MHFT Optical design	Final
	MHFT_Optics__SPIE2022_paper_12190_117	MHFT Optical modeling	Final
	20230323_KP_Mar23_Magnetic_Shield_Simulation_01_001	Magnetic modeling	KP version
/AIV- Schedule			
	2023_03_23_MHFT_Dev_Plan	MHFT Devlepment Plan	KP version
	2023_03_23_MHFT_Schedule	MHFT Schedule	KP version
/Calibrations			
/SpectroPoar E2E			
	Spectro_Polar_GSE	Spec of spectrosopic measurements	KP version
	GS_PolAngle_prelim_accuracy_Note-1	Spec of Polarisation Angle Tests (preliminary study)	KP version
	GS_spectroscopy_testing	Spec of spectroscopic calibration tests	KP version
	GS_PolAngle_andRelated_testing_v2	Spec of Polarisation Angle calibration tests	KP version
/CalibrationsOperations			
	CalibOperationsPlans	Calibration plan	KP version
/Facilities			
	Cold Facility Spec for E2E calibration	Requirements on E2E calibrations	KP version
	LessonsFromPlanck_ForE2ELiteBIRD	Lessons lerned from Planck on Calibrations	Final
	LB-MHFT-CAL-001-V1	Absorber requirements for RF calibrations	KP version
	LiteBIRD_CSL contribution	Combining thermal and RF absorbance on panels	Final
	LiteBird_CSL_Temperature operationelle du SKYLOAD	Slides on the temperature of the skyload	Final
	LiteBIRD_WP1000_final report	Development of modelling for attenuation analyses	Final
/BBM			
	SPIE2022_12190-127_Franceschet_MHFT-BBM	Paper on first results obtained on BBM	Final
	MHFT-BBMs-F2F_okayama22	Presentation at the last F2F meeting	Final
/ORFPM			
	Nearfield-Straylight-identication-Takakura_et_al_SPIE2022	SPIE paper / poster summarising NearField + Holographic method	Final
	Nearfield-Straylight-identication-Takakura_et_al_SPIE2022_Poster	SPIE paper / poster summarising NearField + Holographic method	Final
	Holographic-nearfield-measurement-Nakano_phase_retrieval_JATIS_20221117	SPIE paper / poster summarising NearField + Holographic method	Final
	holographic-nearfield-measurement-2022_0704_phase_retirval_SPIE-Poster	SPIE paper / poster summarising NearField + Holographic method	Final
	ORFPM_Test_Plan_v0_20221005	Test plan of tests with ORFPM at CNES CATR	KP version
	ORFPM description	Description of the ORFPM	Final

Document tree	Title	Purpose	Status
MHFT-PO Sub-Systems			
/Sensor Modules			
	TF of Focal Plane wafers	Technical Feasibility of the Sensor Modules	KP version
	Proposals for HFT focal plane designs with increased pixel counts	Details on design and tradeoff	
	QUP-LB-B006_MHFT Detector Sub-system	QUP description of MHFT Sensor Modules for JAXA MDR	MDR version
/Integrated Focal Planes			
	TF of Integrated Focal Planes	Technical Feasibility of the Focal Plane Structure	KP version
	Focal_Plane_Mechanical_Design_slides	Focal plane mechanical structure description	KP version
/Warm Readout Electronics			
	LBRD-DD-001-LiteBIRD-Warm-Readout-Design-Description v1.0	Mc Gill WRE Design	Final
	LBRD-RPT-002-Warm-Electronics-Development-Plan	Mc Gill WRE Dev Plan	Final
	LBRD-IRD-001-LiteBIRD-Warm-Readout-IRD v2.4	Mc Gill WRE IRD	Final
	LBRDSTDP RPT10 Honeywell Vibration and Thermal Cycling Tests (2021)	Mc Gill SPU TRL5 Verification: Vibration and Thermal cycling tests	Final
	LBRDSTDP RPT06 McGill TRL5 Verification Summary (2021)	Mc Gill SPU TRL5 Verification Summary	Final
	TF of SQUID Control Unit_V1_for_CNES_KP	Technical Feasibility for SQUID Control Unit	KP version
	RPR-LB20005_WRE_IRD_rev2.0_INFN-commented	WRE JAXA IRD	KP version
	List_of_JAXA-INFN-comments_to_RPR-LB20005_WRE_IRD_rev2.0_20230128	Comments to WRE JAXA IRD	KP version
/Instrument Control Unit			
	LiteBird_Science_ICU_ICD_0v01	ICU ICD	KP version
	LiteBird_ICU_Declared_Components_List-V0-5	ICU Components List	KP version
	ICU-HW_Key_Point_2023_03	Description of ICU functionalities	KP version
	TF of ICU-HW	Technical Feasibility Doc of ICU	KP version
/PMU-rotator			
	DEL01_PMU Requirement Specification_is2	PMU specifications	Final
	DEL02_PMU Dev&AIV Plan with Deliverables&Shedule_is1	PMU Dev Plan	Final
	DEL03 and DEL 08_PMU_DD and JF with budgets_is1	PMU Design and Justification	Final
	DEL04_and_DEL05_PMU Mechanical and Thermal Preliminary Analyses	PMU Mechanical & Thermal Analysis	Final
	DEL06_and_DEL07_M_HFT_PMUs_Electrical_and_Mechanical ICD_is1	PMU ICD	Final
	Annex to DEL06_SuMBA_ICD_i1_1.pdf	Annex	Final
/HWPs optics			
	TF of HWP_PhaseA2_v1.0	Technical Feasibility of the HWPs optics	KP version
/ADR			
	TF of ADR 100mK	Technical Feasibility of the ADR 100mK	KP version
	LiteBIRD-DSBT-LASC-SP-003-0-1 (SPEC)	SubKelvin Cooler specification	KP version
	LiteBIRD-DSBT-LASC-PL-006-0-0 (AIV PLAN)	SubKelvin Cooler AIV plan	KP version
	LiteBIRD-DSBT-LASC-TN-007-0-0 (Design justification)	SubKelvin Cooler design justification	KP version
	LiteBIRD-DSBT-LASC-PL-002-0-4 (DEV PLAN)	SubKelvin Cooler devlopment plan	KP version
	TF of ADR 100mK Electronics	Technical Feasibility of the ADR 100mK Electronics	KP version
/Thermal Links			
	TF of Thermal Links	Technical Feasibility of the Thermal Links	KP version
/Baffles			
	Ø	Technical Feasibility of the fore baffle	
/Lenses			
	Ø	Technical Feasibility of the lenses and ARC	
/Filters			
	Ø	Technical Feasibility of the filters	
/Absorbers			
	Extended KP presentation - MHFT Absorbers	Extended slides	KP version
/Mechanical Structure			
	TF of MHFT Mechanical Structure	Technical Feasibility of the mechanical structure	KP version
/Temperature Monitor and Control System			
	DE-VS-LBI_0013v1.0 - Technical Feasibility of the Temperature Monitoring and Control System	Technical Feasibility of the Temperature Monitoring and Control System	KP version
	(READ ME FIRST) DE-RF-LBI_0017v1.0 - List of Documents on data-pack delivered for PO KeyPoint(...)	List of Documents on data-pack delivered for PO KeyPoint	KP version
	DE-PR-LBI_0016v1.0 - Temperature Sensors Validation. Test Bench Verification(...)	Temperature Sensors Validation	KP version
	EX-CD-LBI_0008v1.0 - Design Report	Design Report	KP version
	EX-SR-LBI_0007v1.2 - L4&L5 Preliminary Requirements for the TMCS (...).	L4&L5 Preliminary Requirements for the TMCS	KP version
	EX-IV-LBI_0009v1.0 - Design, Development & Verification Plan	Design, Development & Verification Plan	KP version
/Magnetic Shielding			
	20230323_KP_Mar23_Magnetic_Shield_Subsystem_01_001	Technical Feasibility of the magnetic shielding	KP version

Key point recommendations

- **Recommendation #1:**

The panel recommends that a group of senior project experts make an inventory and analysis of the management of the MHFT and suggest ways to improve the governance of the MHFT instrument. This group should be co-piloted by CNES and JAXA with a representative from each agency involved in the MHFT instrument.

- **Recommendation #2:**

The panel recommends MHFT PO to closely collaborate with the JAXA team to revisit and to clarify L3 integrated system document in order to make a clear connection between L3 level + IRD and L4 MHFT requirements. Clear correspondence between L3 and L4 items has to be ensured to make sure the compliance can be checked.

The management plan shall describe how will be managed the requirements of the units in common between LFT and MHFT.

- **Recommendation #3:**

The panel recommends revisiting the model philosophy and the schedule, include in the schedule the delay between end of Phase A2 and beginning of Phase B for agencies decision process, plan contracting times, the procurement delays, considered the humans resources availability to perform all the parallel activities proposed in the development plans, include some margins for NC management and uncertainties. MHFT PO should work with the JAXA team to solve the schedule inconsistency.

Key point recommendations

- **Recommendation #4**
- The panel recommends MHFT PO to involve the JAXA team for the discussion of the mitigation plan with KEK QUP.
- **Recommendation #5:**
- In order to limit the schedule delay, we recommend to plan the end-of-phase A2 review beginning of December.
- CONCLUSION
- LiteBIRD is a CMB mission succeeding to COBE (NASA, 1989), WMAP (NASA, 2001) et Planck (ESA, 2009). This mission is a high priority for the French Scientific Programs Committee. This is a challenging project and the MHFT is a very complex instrument develop by a huge consortium.
- The KP panel thanks the project team for the clarity of the presentations, the quality of the exchanges during the meeting of the responses to the RIDs. The panel recognizes good preparation in the organization of this Key Point. This clear vision allows us to propose actions and recommendations to optimize the chances of obtaining a successful end-of-phase A2 review.
A lot of work remains to be done but the proposed way forward should help the team.

Project Manager: readiness status

Color code :
Green : Ready for phase A2 review
Yellow : Not fully ready for review but should be OK for phase A2 review; but the question is for **WHEN**
Orange : Not ready for the review and could be problematic for the phase A2 review
Red: Not ready and could be a major feasibility point for MHFT

System

- ✓Litebird JAXA system Specification L3 :
  - Not yet fully established (mainly for the IRD spec)
- ✓MHFT specifications L4 :
  - Not yet fully established, not correctly flowdown from L3 (except for the performances) and justified
- ✓MHFT subsystem Main specifications L5 :
  - Not yet fully established, correctly flowdown from L4 and justified
- ✓MHFT performances
  - Not yet fully established and justified for the current MHFT design
- ✓MHFT optical and RF model :
  - No HWP, no 2K filters yet considered; straylight / ghost study and V-groove impact not finalized
- ✓MHFT mechanical architecture and model :
  - Interfaces to be discussed and agreed soon with JAXA (come back to 5K interface instead of 30K is probable)
- ✓MHFT Thermal model :
  - Sensitivity study to all parameters be done
  - Transient analysis considering realistic ADR, 2K, 5K thermal fluctuation, sky fluctuation and PI 100mK thermal control

Project Manager: readiness status

Sub-System

- ✓Detectors & cold electronic (QUP / US) :
  - Very huge work to demonstrate the performances, BUT no real consideration yet about space environment (except Cosmic Rays)
  - Lack of detector / cold electronic interfaces with the FPA (SQUID at 300mK linked to the 100mK TES could be a significant issue)
- ✓Warm readout electronic (Canada / INFN)
  - Some update could be needed in case the redundancy scheme is modified (JAXA decision)
  - Very good level
- ✓Structure with PLM Interface at 30K (IRAP)
  - OK (NOT OK with interface at 38K)
- ✓Structure with PLM interface at 5K (IRAP)
  - To be done if JAXA decide to ask for a 5K PLM interface
- ✓Focal plane (IAS)
  - Lack of detector / cold interfaces to go ahead
  - RF shield, Faraday cage not yet considered
- ✓Lenses (UK, Cardiff)
  - TRP ESA on going but not finalized
  - Ageing degradation and radiation dose effect on the index (no spec but the index is critical for the beam shape)
- ✓Filters (UK, Cardiff)
  - No Cardiff activity (large filter made with 1mm plastic ➔ frequency << 100Hz)

Project Manager: readiness status

- ✓Half Wave Plate mechanism (Univ Rome & Cardiff)
  - TAS-I study very well ongoing including electronic (end 2022)
  - HWP complete design including mechanical mount (Cardiff / Rome)
  - Expected cold performances tests soon on a representative breadboard to be done
- ✓Magnetic shield (MPE)
  - Missing spec for periodic magnetic field sensitivity at detector level is missing; impact on the design ?
  - Mass much to high
- ✓Absorbers (Univ Rome)
  - material well studied; mounting of the absorbers on the tubes TBD
- ✓ADR 100mK (CEA)
  - OK for ADR; Elegant Breadboard continuous ADR 350mK (the most critical); new test expected in 2023 with a more MHFT representative breadboard
  - ADR electronic design proposed (similar XIFU)
- ✓Thermal links (CEA)
- ✓DPU-ICU (IRAP)
  - Representative tests expected Mid 23
- ✓Harness between WRE and cold focal plane (length, characteristic, EMI); (JAXA)
- ✓MHFT ORFPM
  - Definition and realization on going. Test in CATR CNES not yet done (expected mid 2023)
- ✓**MHFT RF cold calibration**
  - Feasibility of the beam measurement (including polarization) on ground with the present required accuracy (-80dB) is not demonstrated; V-grooves impact ?
- ✓**Schedule**
  - NOT in line with JAXA need; MHFT schedule credibility is TBD (when the phase B could start, …)
- ✓MHFT governance and organization if stays as presently

List of MHFT models

- HFT **ORFPM** (Optical / RF Prototype Model of HFT) -> internal
  - HFT RF prototype to do RF test at ambient in CATR
- HFT **ORFEM** (Optical / RF Engineering Model of HFT) -> internal
  - HFT RF prototype to do RF tests at COLD in adapted TV chamber
- MHFT **AVM** (Avionic Model) -> internal
  - On table Electrical model
- MHFT **STM** 30K-5K -> delivered to JAXA
  - MHFT Structural and Thermal Model limited at 5K
- MHFT **EM** -> delivered to JAXA
  - A full MHFT engineering Model requested by JAXA
  - A quasi flight model
- MHFT **FM** -> delivered to JAXA
  - Flight Model
- Flight **Spare**

JAXA needs

- MHFT models to be delivered to JAXA: STM, EM, FM; AVM TBD

JAXA need dates

- MHFT STM 30K/5K : April 2025
- MHFT EM & 100mK ADR : January 2027
- MHFT FM & 100mK ADR : January 2029

MHFT "realistic" schedule

JAXA need dates

- MHFT STM 30K/5K : April 2025
- MHFT EM & 100mK ADR : January 2027
- MHFT FM & 100mK ADR : January 2029

MHFT reviews

- MHFT IPDR : December 2025
- MHFT ICDR : March 2029

Note : MHFT ICDR is linked to the end of MHFT EM Cold E2E test

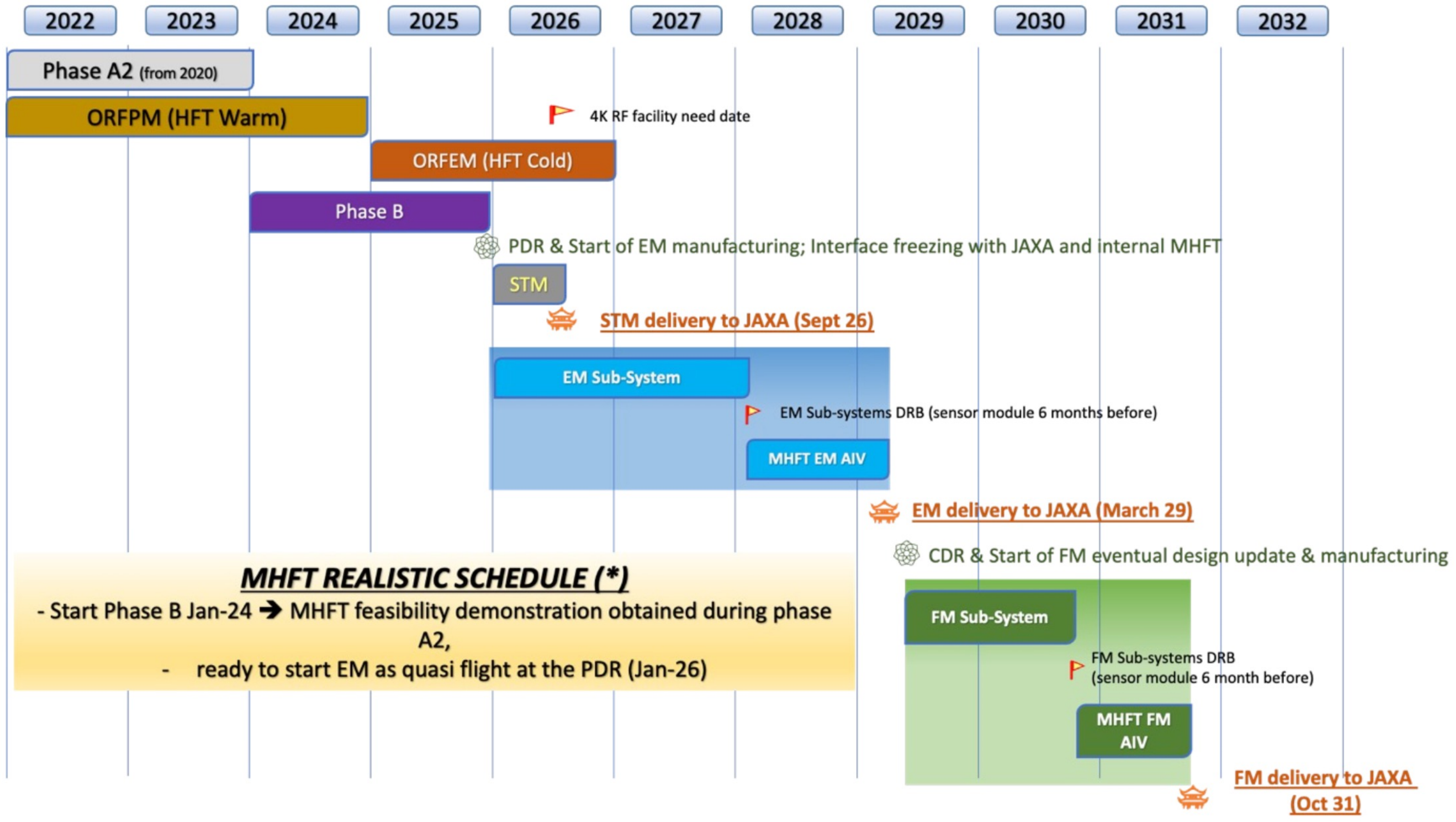
MHFT delivery dates

- MHFT STM 30K/5K : Sept 2026
- MHFT & 100mK ADR EM : March 2029
- MHFT & 100mK ADR FM : Oct 2031

MHFT Schedule (from PM Thierry Maciaszek)

Schedule main hypothesis

- MHFT technical, organization and programmatic feasibility demonstration obtained end 2023
- Ready to start EM manufacturing as quasi flight just after the PDR (Jan-26)
- 2 weeks of vacation is considered during summer and 1 week during the Christmas break
- Normal shift activity during all the project, except during the cold TV for which 3 real shift activities are considered
- “Realistic planning” considering a slight margin to treat “normal” issues at subsystem and system level
- Short duration (2 months) for subsystem FM update design following MHFT system EM test
- **The MHFT shall work as a space project; a single technical authority of conception must be established; decision shall be taken quickly (all of that are not the case presently)**



2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
Phase A2 (from 2020)
ORFPM (HFT Warm)
4K RF facility need date
ORFEM (HFT Cold)
Phase B
PDR & Start of EM manufacturing; Interface freezing with JAXA and internal MHFT
STM
STM delivery to JAXA (Sept 26)
EM Sub-System
EM Sub-systems DRB (sensor module 6 months before)
MHFT EM AIV
EM delivery to JAXA (March 29)
CDR & Start of FM eventual design update & manufacturing
MHFT REALISTIC SCHEDULE (*)
- Start Phase B Jan-24 ➔ MHFT feasibility demonstration obtained during phase A2,
- ready to start EM as quasi flight at the PDR (Jan-26)
FM Sub-System
FM Sub-systems DRB
(sensor module 6 month before)
MHFT FM AIV
FM delivery to JAXA (Oct 31)

Requirements flow-down

Mission Requirements

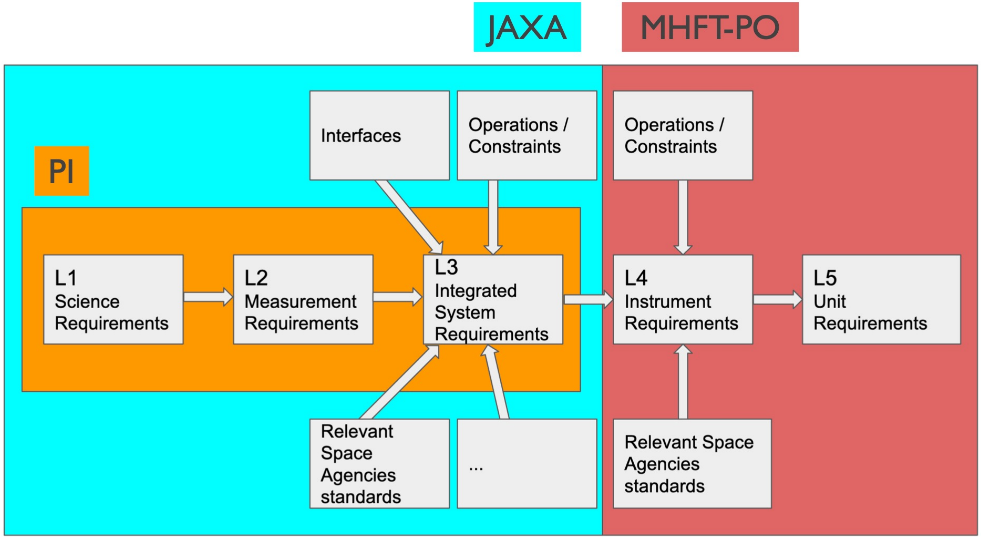
L1	Science Requirements	Top-level quantitative science requirements that are directly connected to the full success of the mission.
L2	Measurements Requirements	Measurement requirements to achieve Lv1. No assumption is made on an instrument.

Trade-off Studies

- Interfaces
- Operation contraints
- Agencies Standards

System Requirements

L3	Integrated system Requirements	Top-level implementation requirements for a chosen instrument to achieve Lv2. Between Lv2 and Lv3 are tradeoff studies for instrument selection.
L4	Instrument Requirements	Instrument requirements to achieve Lv3.
L5	Unit Requirements	Requirements on units composing each instrument to achieve Lv4.



Level 1 requirements

Table 1. The two basic science requirements for *LiteBIRD*, also called Level-1 (Lv1) mission requirements.

ID	Title	Requirement description
Lv1.01	Tensor-to-scalar ratio r measurement sensitivity	The mission shall measure r with a total uncertainty of $\delta r < 1 \times 10^{-3}$. This value shall include contributions from instrumental statistical noise fluctuations, instrumental systematics, residual foregrounds, lensing B-modes, and observer bias, and shall not rely on future external data sets.
Lv1.02	Polarization angular power spectrum measurement capability	The mission shall obtain full-sky CMB linear polarization maps for achieving $> 5\,\sigma$ significance using $2 \leq \ell \leq 10$ and $11 \leq \ell \leq 200$ separately, assuming $r = 0.01$. We adopt a fiducial optical depth of $\tau = 0.05$ for this calculation.

Level 2 requirements

Req. ID	Req. Title	Req. Alias	Requirement Description
L2.01	Statistical uncertainty	$\sigma_{sta} < 0.00065$	The statistical uncertainty, σ_{sta}, shall be less than 0.00065. This value shall include uncertainties due to lensing B-mode, and uncertainties due to residual foregrounds, which are obtained after foreground separation and bias correction.
L2.01.01	Measurements w/ sufficient sensitivity on CMB		For the combined band sensitivities for CMB linear polarization measurements (Q, U, E, B), total array sensitivity between 80GHz and 200GHz shall be better than 2.4uKarcmin.
L2.01.02	Measurements w/ sufficient sensitivity on dust		For the combined band sensitivities for dust measurements (Q, U, E, B), total array sensitivity between 200GHz and 448GHz shall be better than 8.0uKarcmin.
L2.01.03	Measurements w/ sufficient sensitivity on synchr.		For the combined band sensitivities for synchrotron measurements (Q, U, E, B), total array sensitivity between 34GHz and 80GHz shall be better than 8.6uKarcmin.
L2.01.06	Number of observing bands	Number of Observing Bands	The number of observing bands (or more generally the effective number of observing bands) shall be sufficient to provide sufficient foreground separation capabilities. Based on current results of foreground studies, it shall be 15. In case new findings are obtained from foreground studies, however, the number is subject to change.
L2.01.07	Observing frequency range	Obs. frequencies	The observing frequency range shall be sufficient to provide sufficient foreground separation capabilities. Based on current results of foreground studies, it shall be between 40 GHz and 402 GHz. In case new findings are obtained from foreground studies, however, the number is subject to change.
L2.02	Systematic uncertainty	$\sigma_{sys} < 0.00065$	The total systematic uncertainty, σ_{sys}, shall be less than 0.00065.
L2.02.01	Uncertainty in polarization responsivity	Responsivity	Uncertainty in linear-polarization responsivity shall be small enough to satisfy the requirement L2.02. This covers a broad class of uncertainties including those in polarization efficiency and also in absolute gain. Each registered item that belongs to this category should satisfy $\delta r < 0.65 \times 10^{-5}$.
L2.02.02	False polarization	False pol.	Effect of false polarization (polarization that appears in case input has no polarization such as I-to-P leakage) shall be small enough to satisfy the requirement L2.02. Each registered item that belongs to this category should satisfy $\delta r < 0.65 \times 10^{-5}$.
L2.02.03	Disturbance to instrument		Instrument disturbance, such as cosmic ray effects and 1/f noise due to fluctuations from the cooling system, shall be mitigated sufficiently. Each registered item that belongs to this category should satisfy $\delta r < 0.65 \times 10^{-5}$.
L2.02.04	Off-boresight pick up		Effects of off-boresight pick up, such as signals from the galactic plane picked up by the far sidelobe of the beam, shall be small enough to satisfy the requirement L2.02. Each registered item that belongs to this category shall satisfy $\delta r < 0.65 \times 10^{-5}$.
L2.02.05	Pol. pattern distortion		Polarization pattern distortion (including E-to-B leakage), such as those from pointing errors, angle calibration errors, absolute gain fluctuations, or cross polarization response, shall be small enough to satisfy the requirement L2.02. Each registered item that belongs to this category shall satisfy $\delta r < 0.65 \times 10^{-5}$.
L2.02.06	CO line separation	CO line	The observations shall avoid severe contamination from following CO lines: 115GHz(J10), 231GHz(J21), 346GHz(J32), 461GHz(J43). The observations shall avoid severe contamination from following HCN line: 88GHz(J10).
L2.03	Scan strategy for achieving full-sky surveys		Observations with a scan strategy for achieving full-sky surveys shall be performed. Detailed requirements of scan strategy shall be described in L3.
L2.04	Angular resolution		The angular resolution of each detector response shall be sufficient to cover the required ell range. It shall have a FWHM of 80' or better. Angular resolution shall be better than 30' FWHM at 150GHz for measuring the recombination bump and be better than 80' FWHM at 40GHz, for dealing with point sources.
L2.05	Calibration measurements	Calibration	The spacecraft sysmtem shall allow calibration measurements before and during flight using known polarized and unpolarized optical calibration sources. Calibration uncertainties shall be included as a component of systematic uncertainty. This operational requirement is satisfied if the entire suite of ground and inflight calibration measurements is completed with sufficient precision levels imposed on each of the measurements (which will be given in L3).
L2.06	Error budget allocation	Error budget	We shall decouple systematic uncertainty estimation studies and statistical uncertainty estimation studies (including foreground separation) as much as possible to avoid too-complex computation. We shalll assign an error budget of 6.5 x 10^-4 to each of sigma_sta and sigma_sys. Here sigma_sta is the total statistical uncertainty, and sigma_sys is the total systematic uncertainty in the error budget. We shall assign 4.0 x 10^-4 to sigma_mar which is the magin in the error budget.
L2.07	Systematic error budget allocation	Sys error budget	We shall decouple studies of each systematic error on r as much as possible. Each component of systematic error on r shall be less than 1% of the total budget. In case an outstanding component is identified, however, it is allowed to ask for a special budget for that item. If this happens, a careful investigation shall be done and a collaboration-wide agreement shall be made.
L2.08	Duration of normal observation phase	T_{obs} = 3 years	The duration of normal observation phase shall be 3 years. This is chosen with some margin and taking constraints on the total cost into account.
L2.09	Orbit	Orbit	Observations shall be performed in a L2 Lissajous orbit.
L2.10	Data management and analysis	Observer bias	Collaborative effort of massive and complicated data analysis is needed for achieving the science goal. Organized data management and analysis activities shall be formed. We raise a policy that data analysis shall be free from observer bias. Blind analysis methods shall be used whenever appropriate to this end.
L2.11	Noise covariance knowledge		Noise levels and correlations shall be sufficiently calibrated for foreground rejection and cosmological analysis.

Tensor-to-scalar *r* error budget allocation (proposed)

L1

$\delta r < 10^{-3}$

This budget allocation is a top-level decision by JAXA

L2

$\delta r^2 = \delta r^2_{Stat} + \delta r^2_{Syst} + \delta r^2_{Margin}$

δr^2_{Stat}: Statistical budget for white noise + cosmic variance + component separation

$\delta r_{Stat} < 6.5 \times 10^{-4}$

Component Separation → (Bands Sensitivities)

δr^2_{Syst}: Systematic Effects from instrument and sky modelling

$\delta r_{Syst} < 6.5 \times 10^{-4}$

Budget Allocation →

$\delta r_{Syst} = \Sigma\, \Delta r_i$

Each systematics should be 1% of the Systematics budget

$\Delta r_i < 6.5 \times 10^{-6}$

δr^2_{Margin}: Margin to deal with unknown unknowns

$\delta r_{Margin} < 4.0 \times 10^{-4}$

Tensor-to-scalar r error budget allocation (proposed)

L1

$\delta r < 10^{-3}$

This budget allocation is a top-level decision by JAXA

L2

$\delta r^2 = \delta r^2_{Stat} + \delta r^2_{Syst} + \delta r^2_{Margin}$

δr^2_{Stat}

Statistical budget for white noise + cosmic variance + component separation

$\delta r_{Stat} < 6.5 \times 10^{-4}$

Component Separation

(Bands Sensitivities)

δr^2_{Syst}

Systematic Effects from instrument and sky modelling

$\delta r_{Syst} < 6.5 \times 10^{-4}$

Budget Allocation

$\delta r_{Syst} = \Sigma \, \Delta r_i$

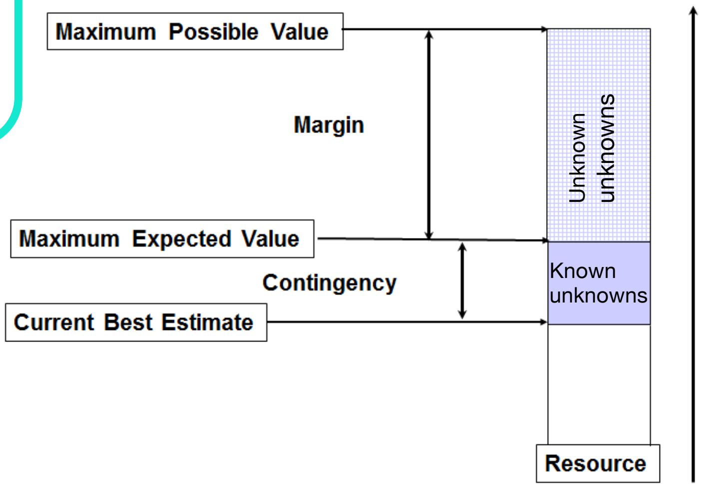
Each systematics should be 1% of the Systematics budget

$\Delta r_i < 6.5 \times 10^{-6}$

δr^2_{Margin}

Margin to deal with unknown unknowns

$\delta r_{Margin} < 4.0 \times 10^{-4}$



Tensor-to-scalar *r* error budget allocation (proposed)

- L2.01: Statistical uncertainty: The statistical uncertainty, $\boldsymbol{\sigma}_{stat}$, shall be less than 0.00065. This value shall include cosmic variance, uncertainty due to lensing B-mode, uncertainties due to statistical foregrounds residuals obtained after foreground cleaning assuming instrumental noise
- L2.02: Systematic uncertainty: The total systematic uncertainty, $\boldsymbol{\sigma}_{syst}$, shall be less than 0.00065, including instrumental systematics and systematics foregrounds residuals which are obtained after component separation and bias correction.
- L2.06: Error budget allocation: We shall decouple systematic uncertainty estimation studies and statistical uncertainty estimation studies (including foreground separation) as much as possible to avoid too-complex computation. We shall respect the following budgets: $\boldsymbol{\sigma}_{stat} = \boldsymbol{\sigma}_{syst} = 0.00065$ and $\boldsymbol{\sigma}_{margin} = 0.00040$. Here $\boldsymbol{\sigma}_{margin}$ is the margin taken in the error budget to deal with unknown unknowns.
- L2.07: Systematic error budget allocation: We shall decouple studies of each systematic error on r as much as possible. Each component of systematic error on r shall be less than 1% of the total budget (L2.02); i.e. $\boldsymbol{\sigma}_{syst}$ from each component be less than 0.65×10^{-5}. In case an outstanding component is identified, however, it is allowed to ask for a special budget for that item. If this happens, a careful investigation shall be done and a collaboration-wide agreement shall be made.

With / Without HWPs

Impact of removing HWP on MHFT

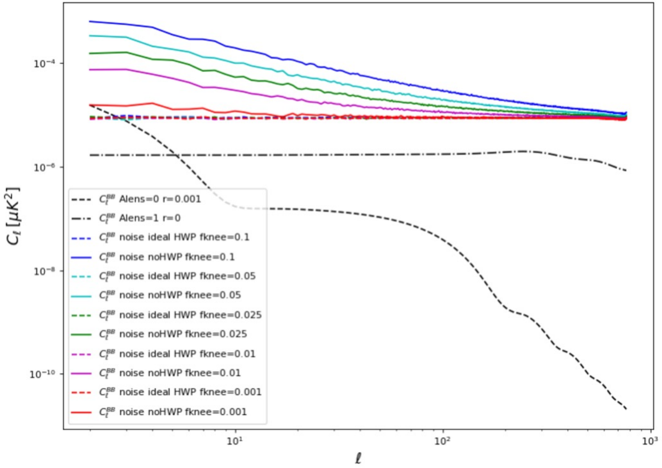
When removing the HWP we consider that:

- **Sensitivities are lower (one less optical element)**
- **1/f noise is not negligible**
- **1/f noise must be accounted for in the statistical residuals**

Methodology:

1. **Assume 1/f noise level**
2. **Propagate 1/f noise level into power spectrum**
3. **Not taking into account possible impact on systematics**
4. **Compute impact on statistical r uncertainty**

$$1 + \left(\frac{f_{knee}}{f}\right)^{\alpha} \Rightarrow N_\ell \left(1 + \left(\frac{\ell_{knee}}{\ell}\right)^{\alpha_{knee}}\right)$$

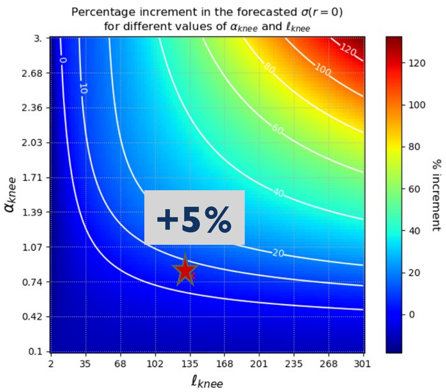


With / Without HWPs

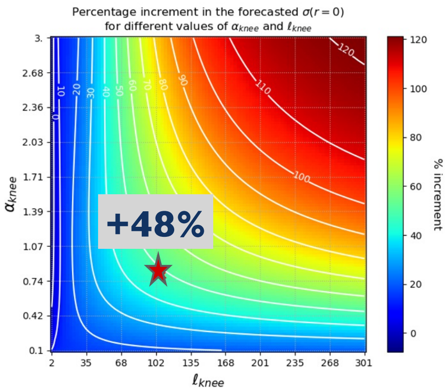
Impact of removing HWP

L1.01 $\delta r < 10^{-3}$

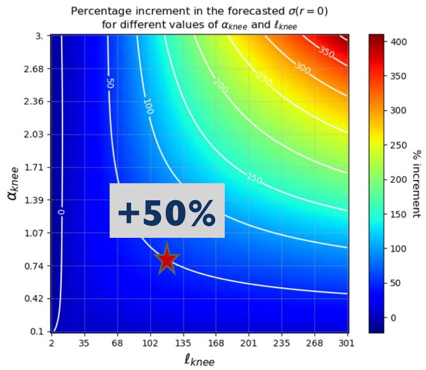
on HFT



on MFT



on MFT & HFT



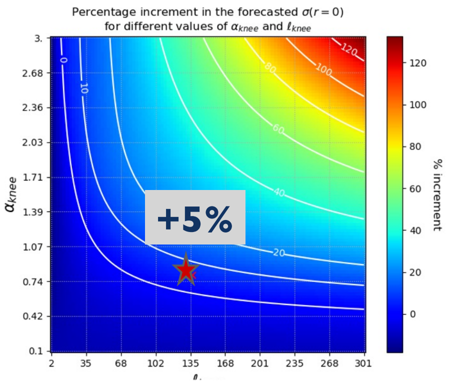
With / Without HWPs

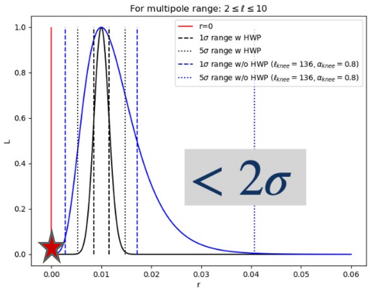
Impact of removing HWP

L1.01 $\delta r < 10^{-3}$

L1.02 Assuming $r = 10^{-2}$
Range $2 \le l \le 10$
Detection $> 5\sigma$

on HFT





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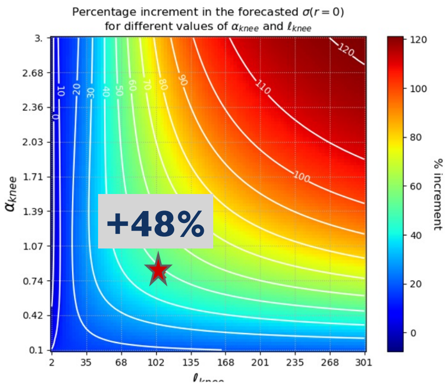
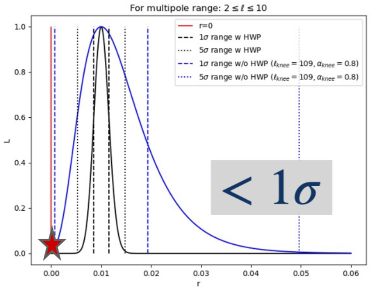
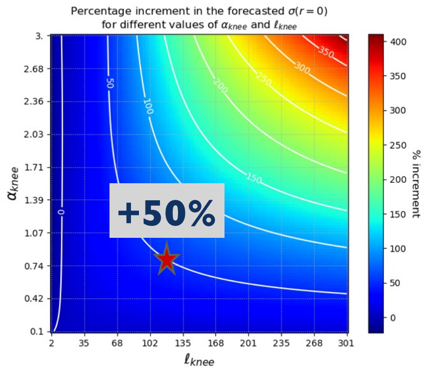
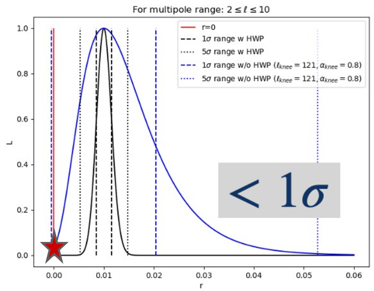




on MFT & HFT





Conclusion and message

- End of European phase A2 is next December
- Planning for switch to phase-B should be done in advance
- Big progress for KP event
- Momentum must be kept to complete needed documentation for sub-systems (and system level)
- Improve space-project attitude
  - Consolidate requirements and requirements flow down
  - Track changes
- Keep the researcher attitude on R&D and mitigation strategies
- Push to improve a clear mission governance definition (see KP recommendations)