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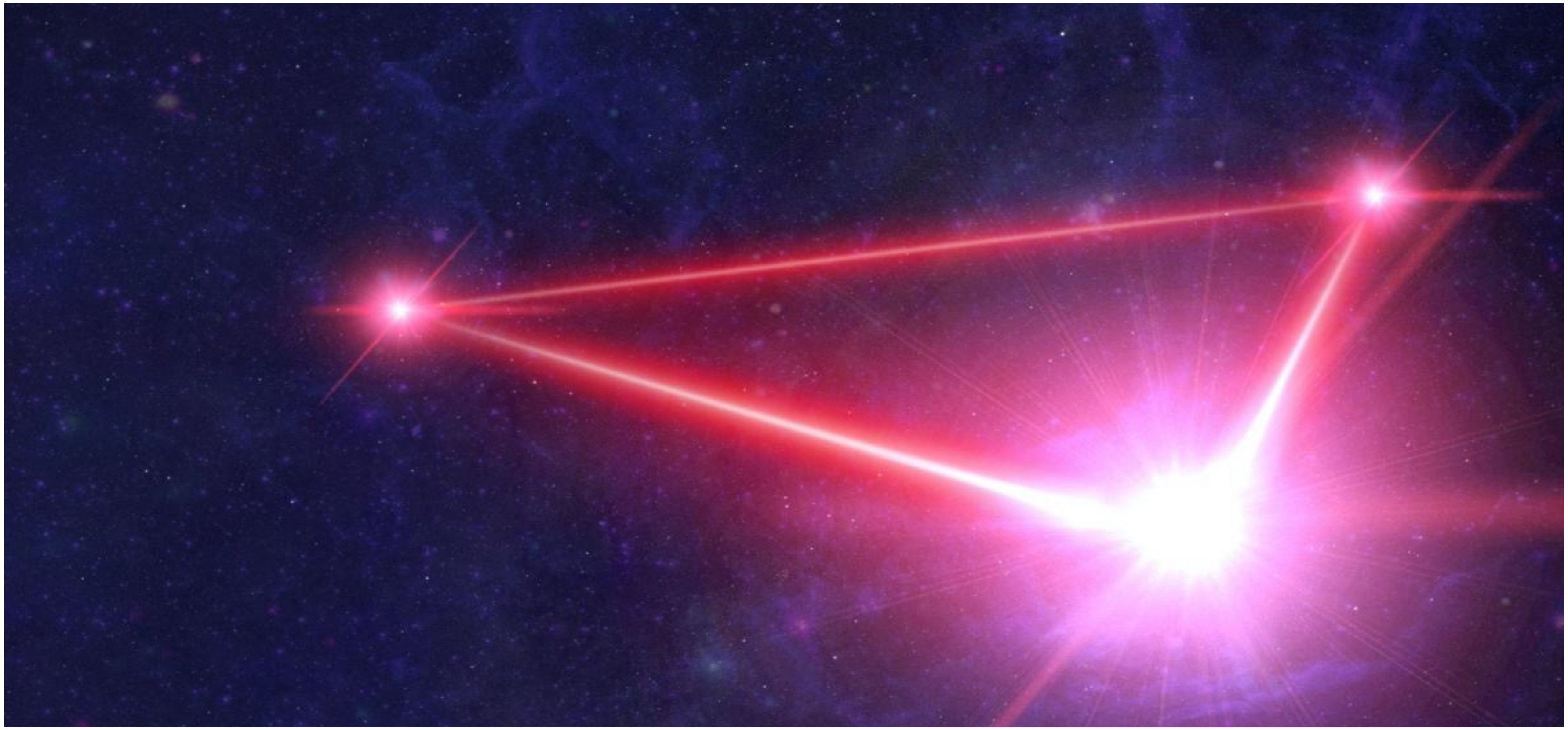


LISA progress and possible Canada hardware contribution

Domenico Giardini & Luigi Ferraioli, ETH Zurich

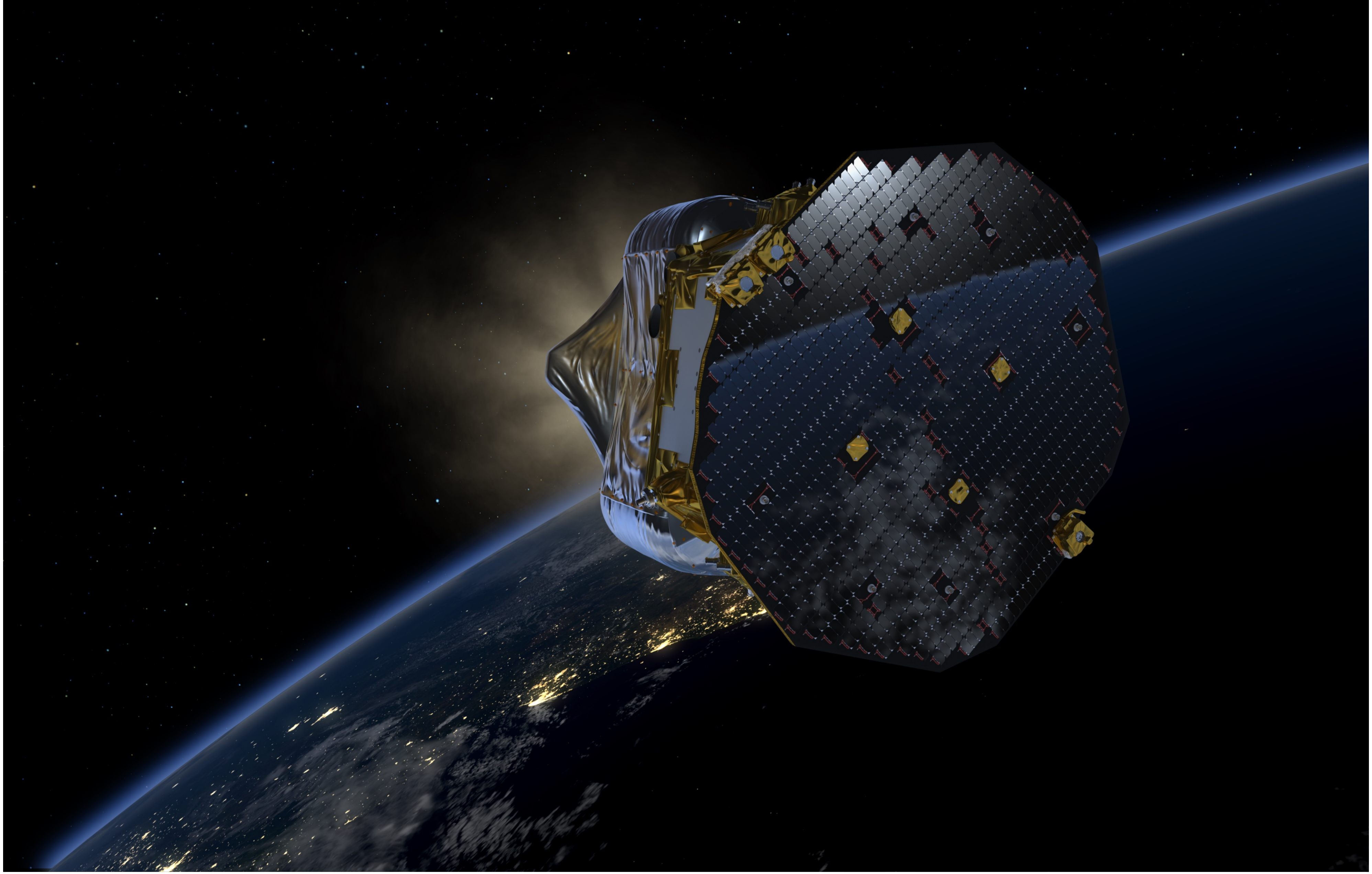
Contents

- Coming from Mars
- LISA PathFinder
- LISA overview
- GRS + FEE overview
- LISA schedule and milestones
- LISA Phase B1

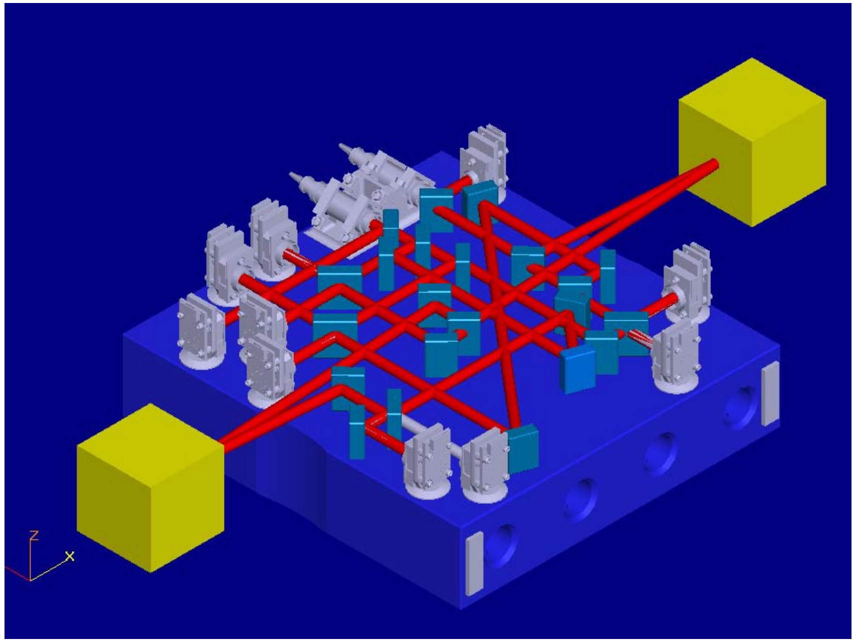
- Why should Canada contribute?
- What could Canada contribute?
- How could Canada contribute?
- When should Canada contribute?

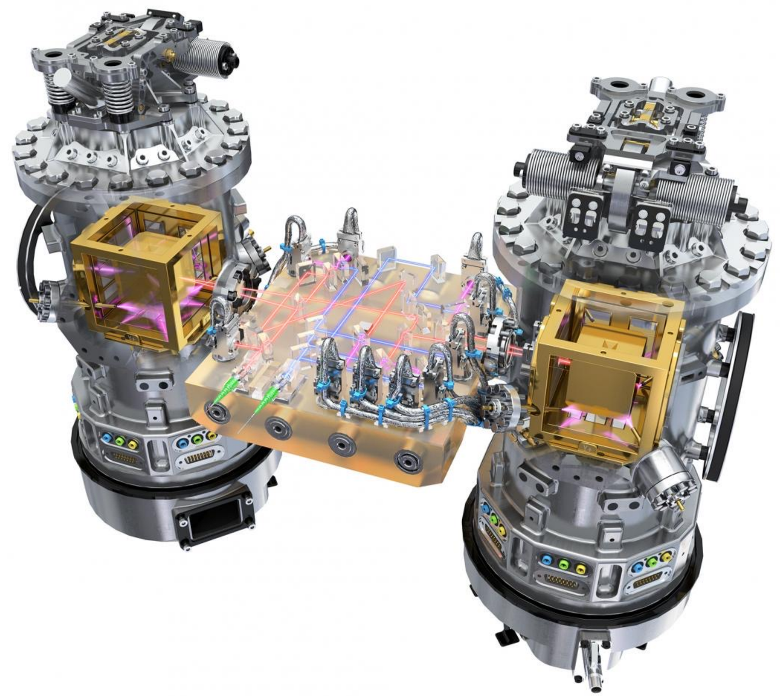
NASA InSight: Interior Exploration using Seismic Investigations, Geodesy and Heat Transport

LISA PathFinder, 2015-2016

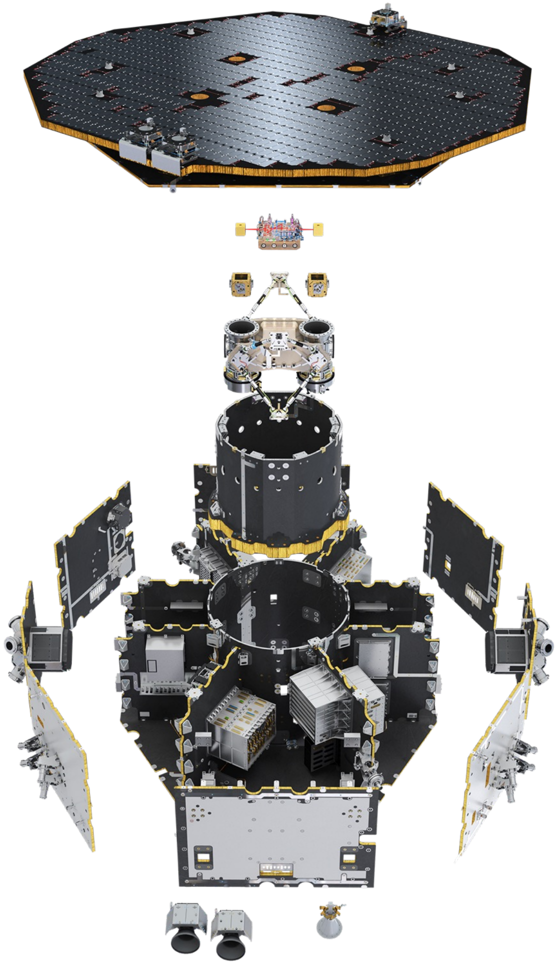


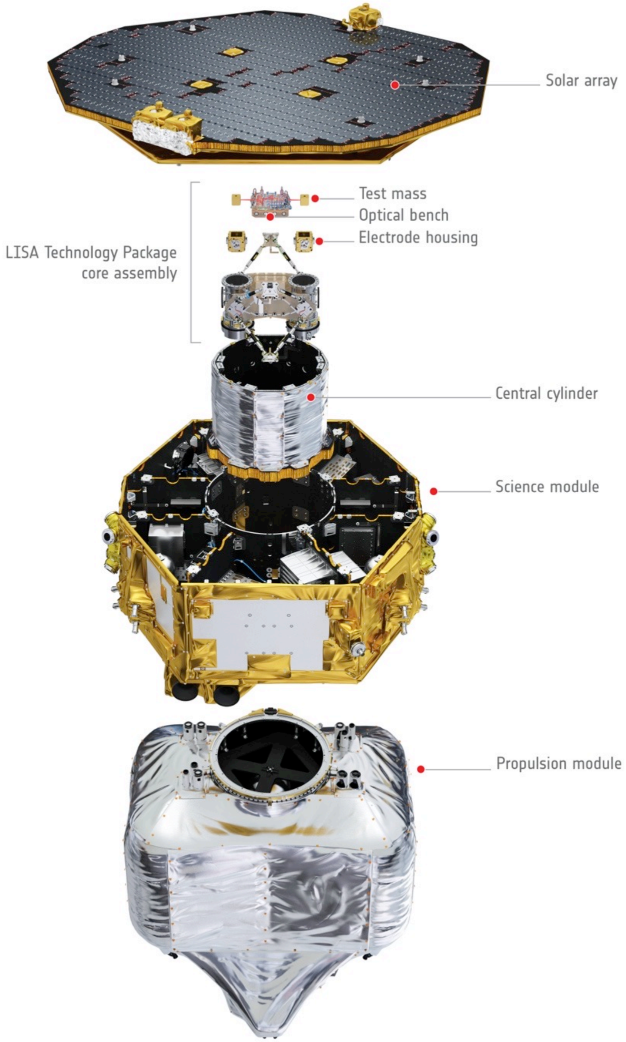
LISA PathFinder



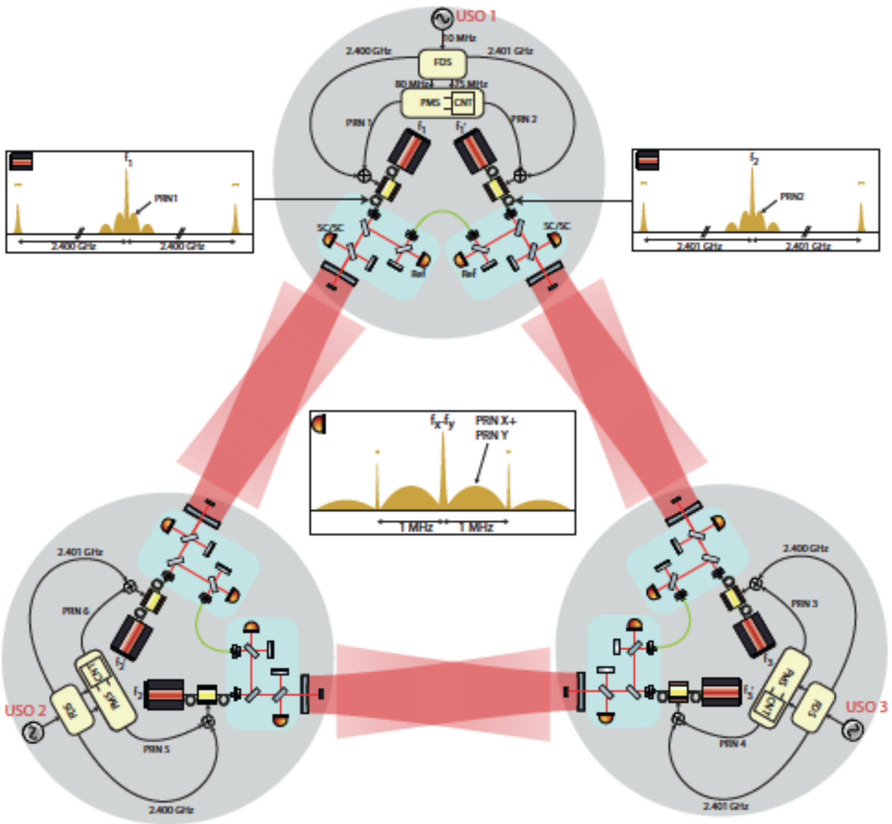


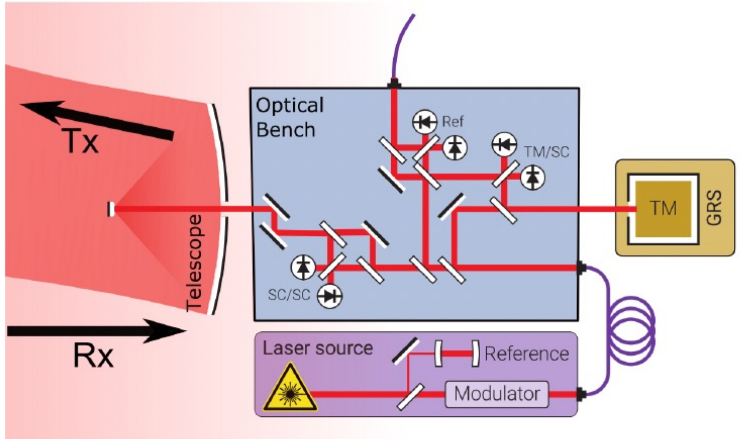
LISA PathFinder





LISA Overview

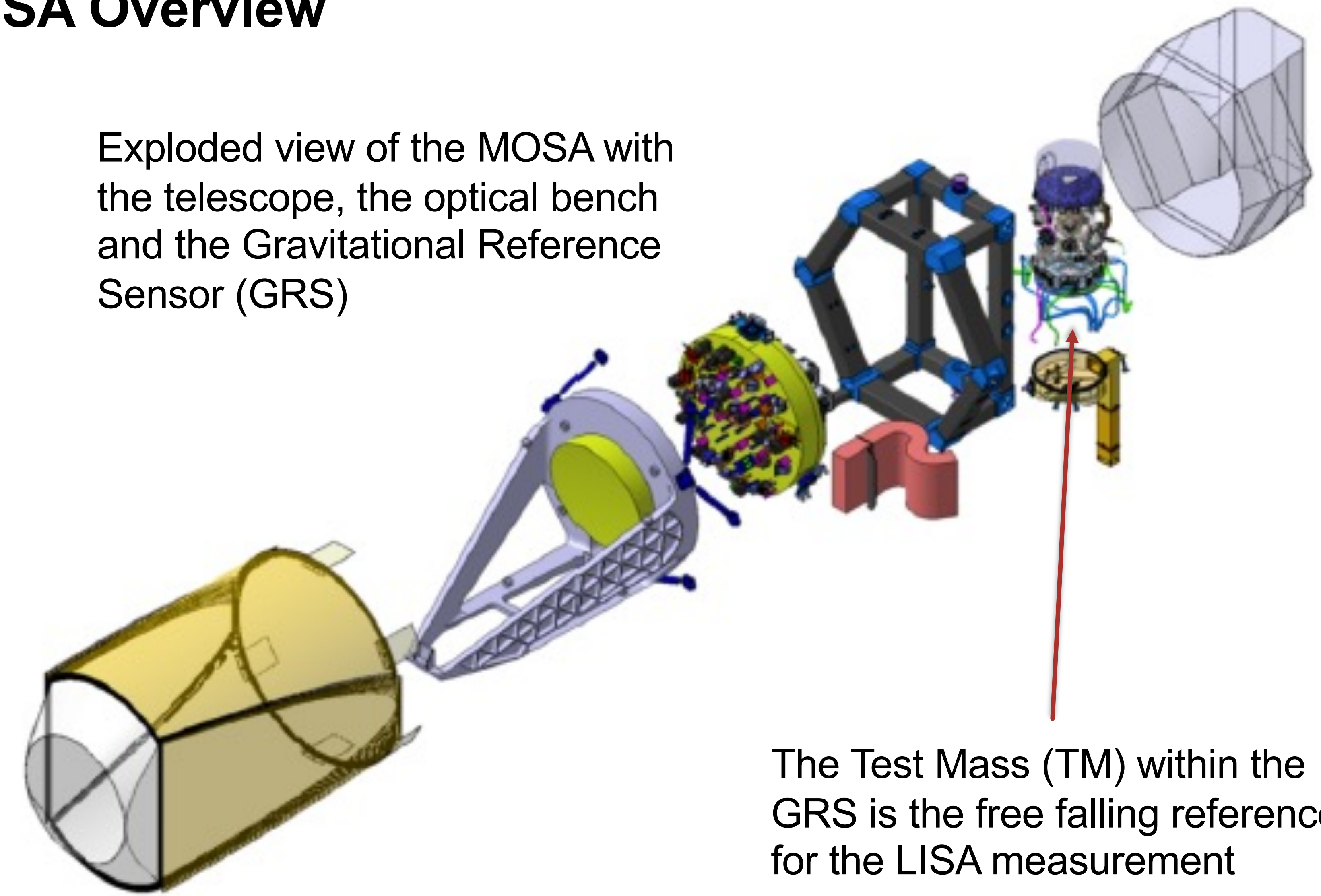




TM-to-TM measurement principle over a LISA link and scheme of the interferometric measurements within a MOSA (Moving Optical Sub-Assembly)

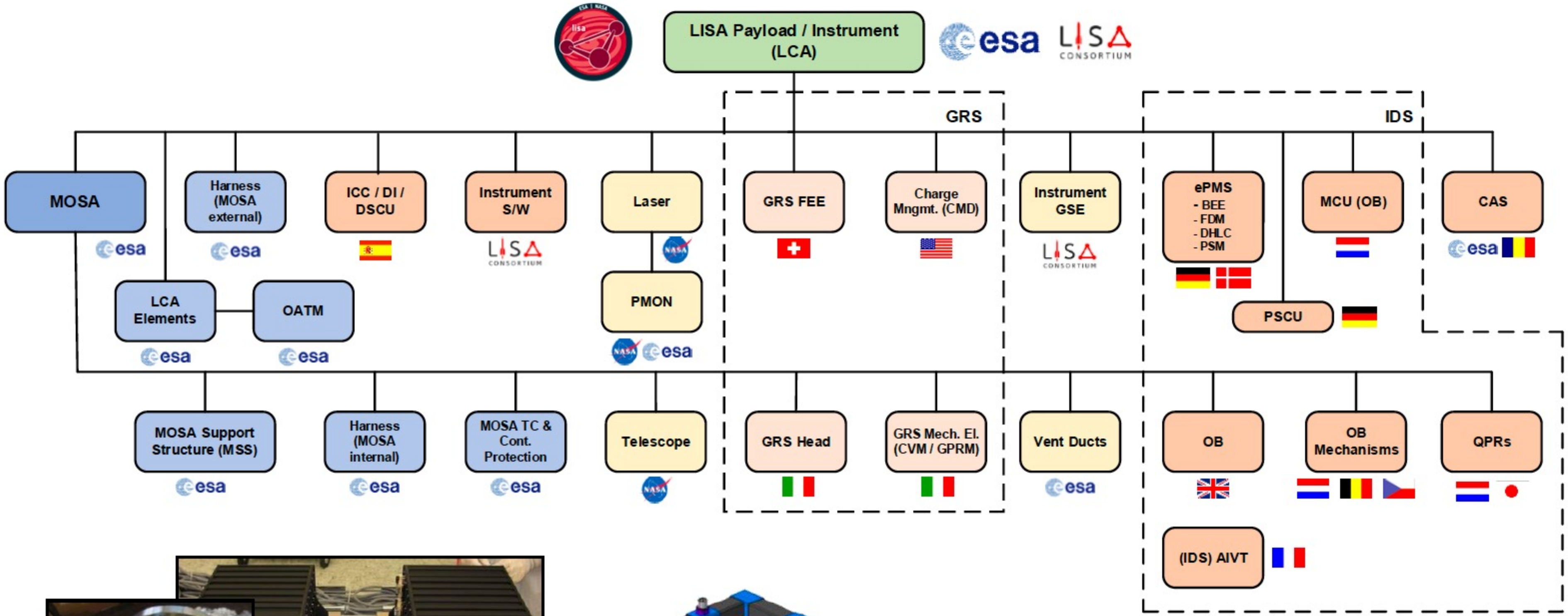
LISA Overview

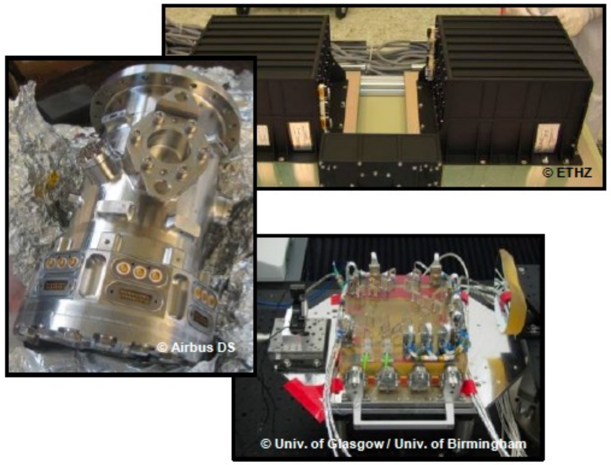
Exploded view of the MOSA with the telescope, the optical bench and the Gravitational Reference Sensor (GRS)

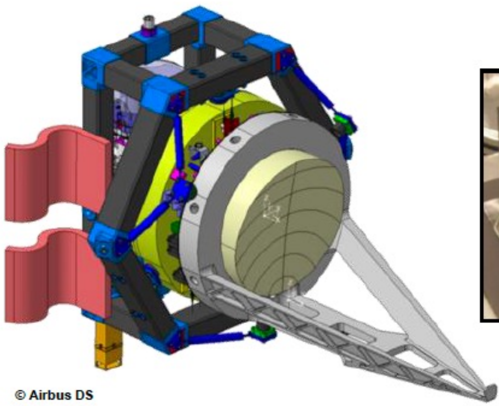


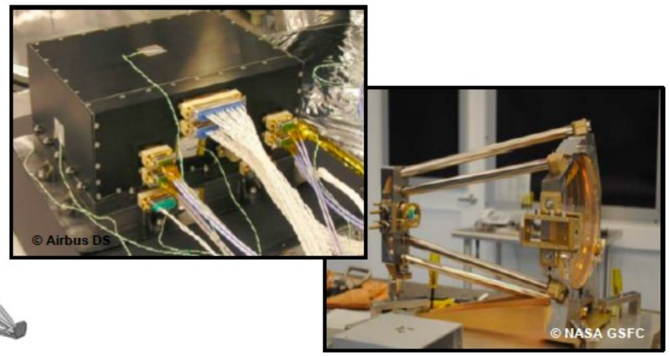
The Test Mass (TM) within the GRS is the free falling reference for the LISA measurement

LISA Payload / Instrument (LCA) – Product Tree

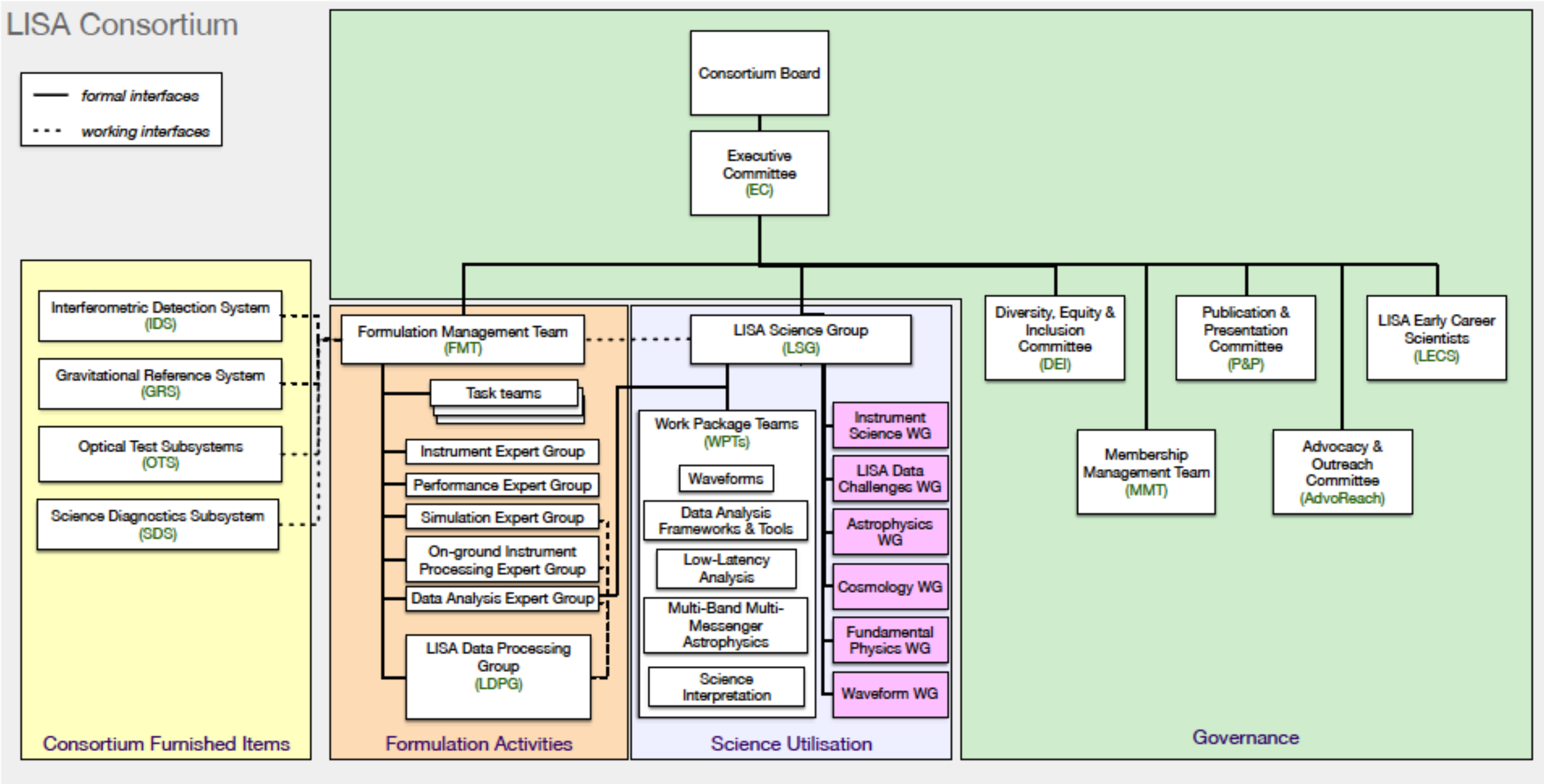








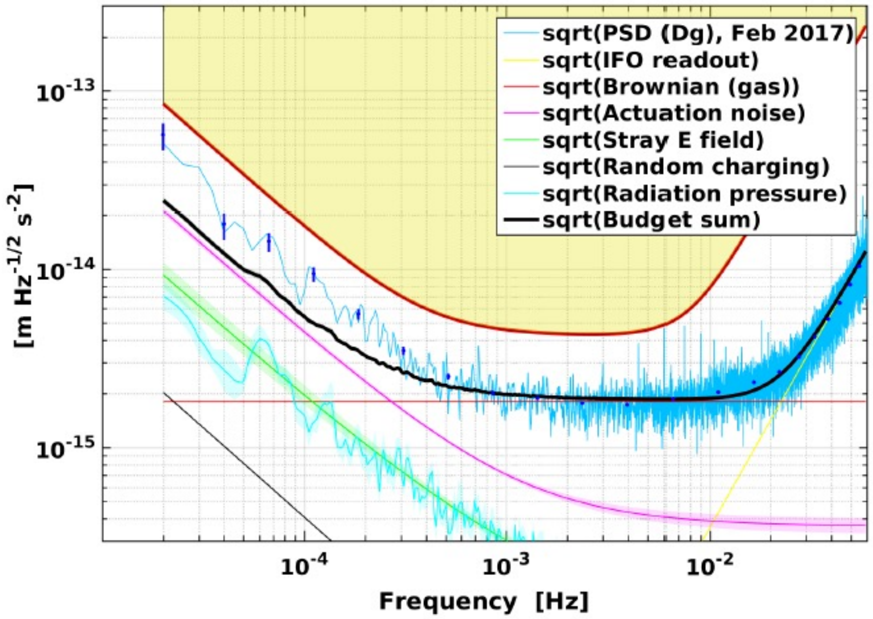
LISA Consortium in Phase B1



GRS - SS

Top science requirements

- geodesic reference TM to trace GW tidal acceleration *[SSRD 2.4 fm/s^2/Hz$^{1/2}$]*
- optical reference for IFO readout of GW *[SSRD 12 pm/Hz$^{1/2}$]*



Science mode DFACS:

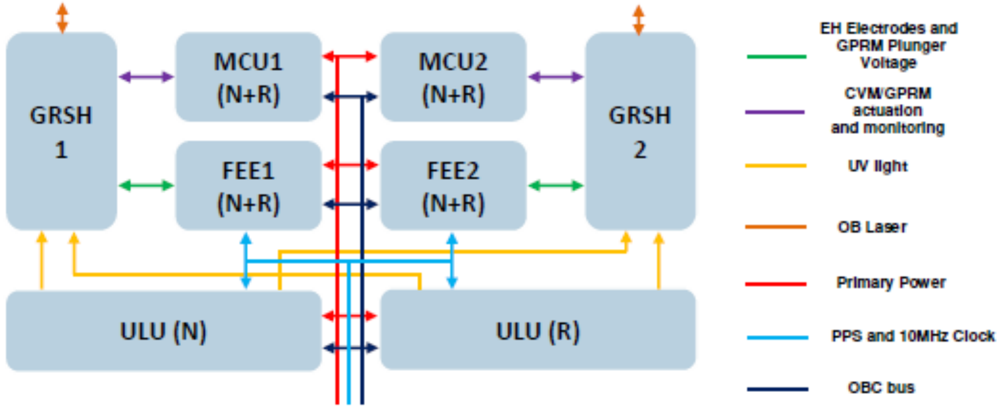
- capacitive position sensing *[nm/Hz$^{1/2}$ level]*
- electrostatic force actuator *[nm/s^2 force level]*

Preparing science mode:

- Survive launch/release into free-fall [caging + TM release mechanism + μm/s^2 forces]
- TM discharge with UV photoelectric illumination

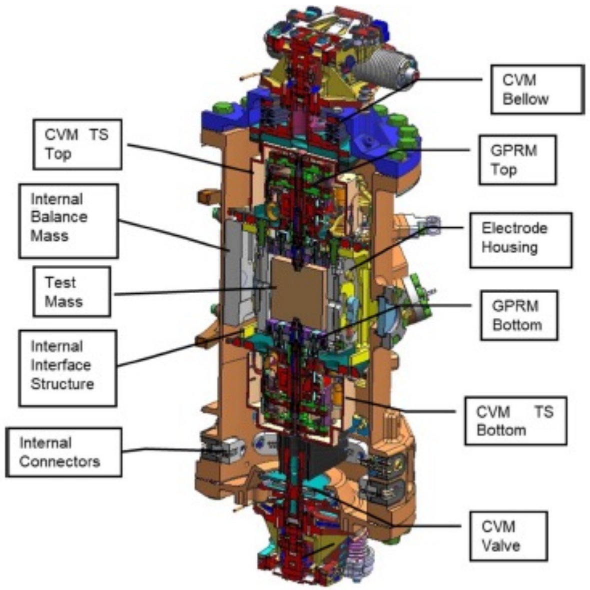
→ LISA Pathfinder demonstrated all of this, but the LF noise is still partly unexplained
→ Phase A-B1 for LISA provides
- δ-design for LISA for longer life and robustness
- full exploration of LISA noise sources
- performance analysis and testing updated for LISA

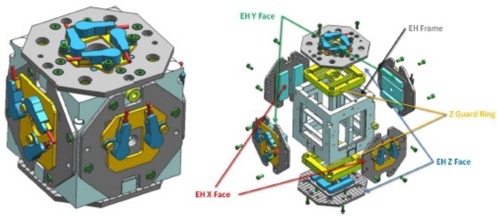
GRS - SS

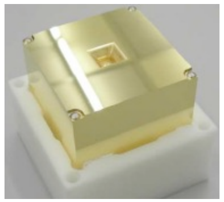


GRS head (Italy)

- TM and electrode housing
- vacuum chamber with balance masses
- caging and GPRM mechanisms
- LPF heritage, with new provider for mechanisms







GRS MCU (Italy)

- LPF heritage, design optimization

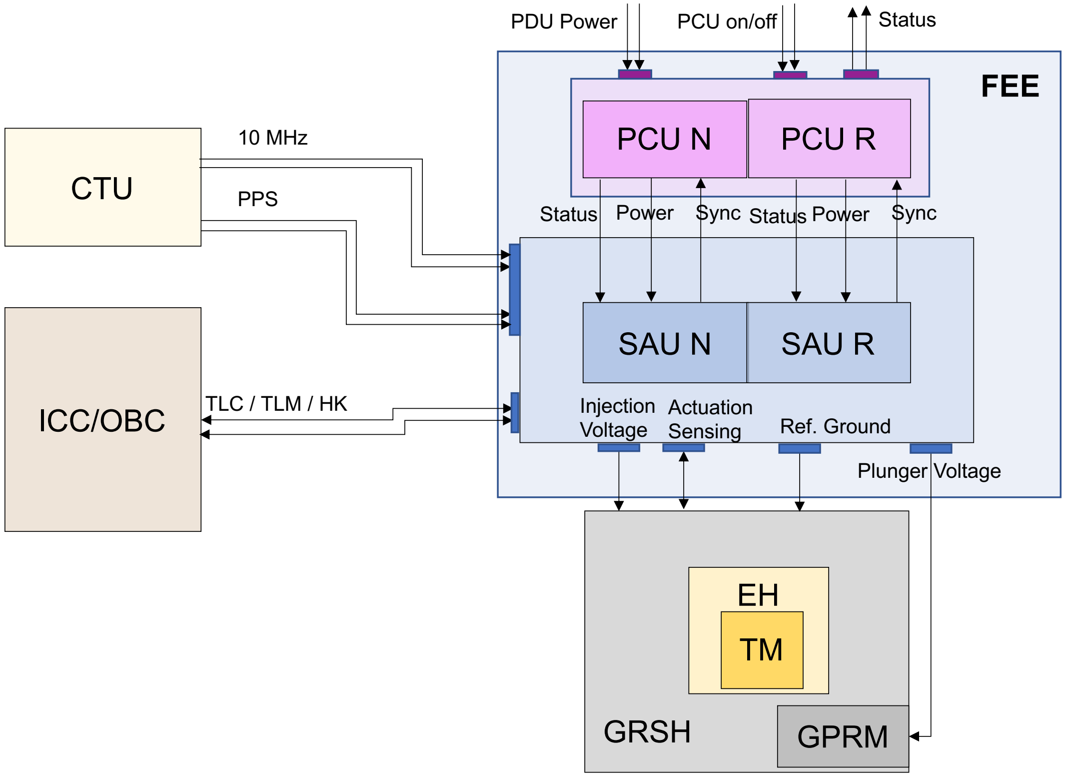
GRS FEE (Switzerland)

- LPF heritage, δ-design

GRS CMD (NASA)

- LPF heritage (technique + team)
- new pulsed UV LED illumination
- system level demonstration

GRS FEE Overview - Interfaces



Legend

FEE:	Front-end electronics
SAU:	Sensing and actuation unit
PCU:	Power conditioning unit
GRSH:	GRS Head
EH:	Electrode Housing
TM:	Test Mass
GPRM:	Grabbing, positioning and release mechanism
OBC:	On-Board Computer
CTU:	Central Timing Unit
PDU:	Power Distribution Unit

GRS FEE Overview - Functions

SAU – Sensing and Actuation Units

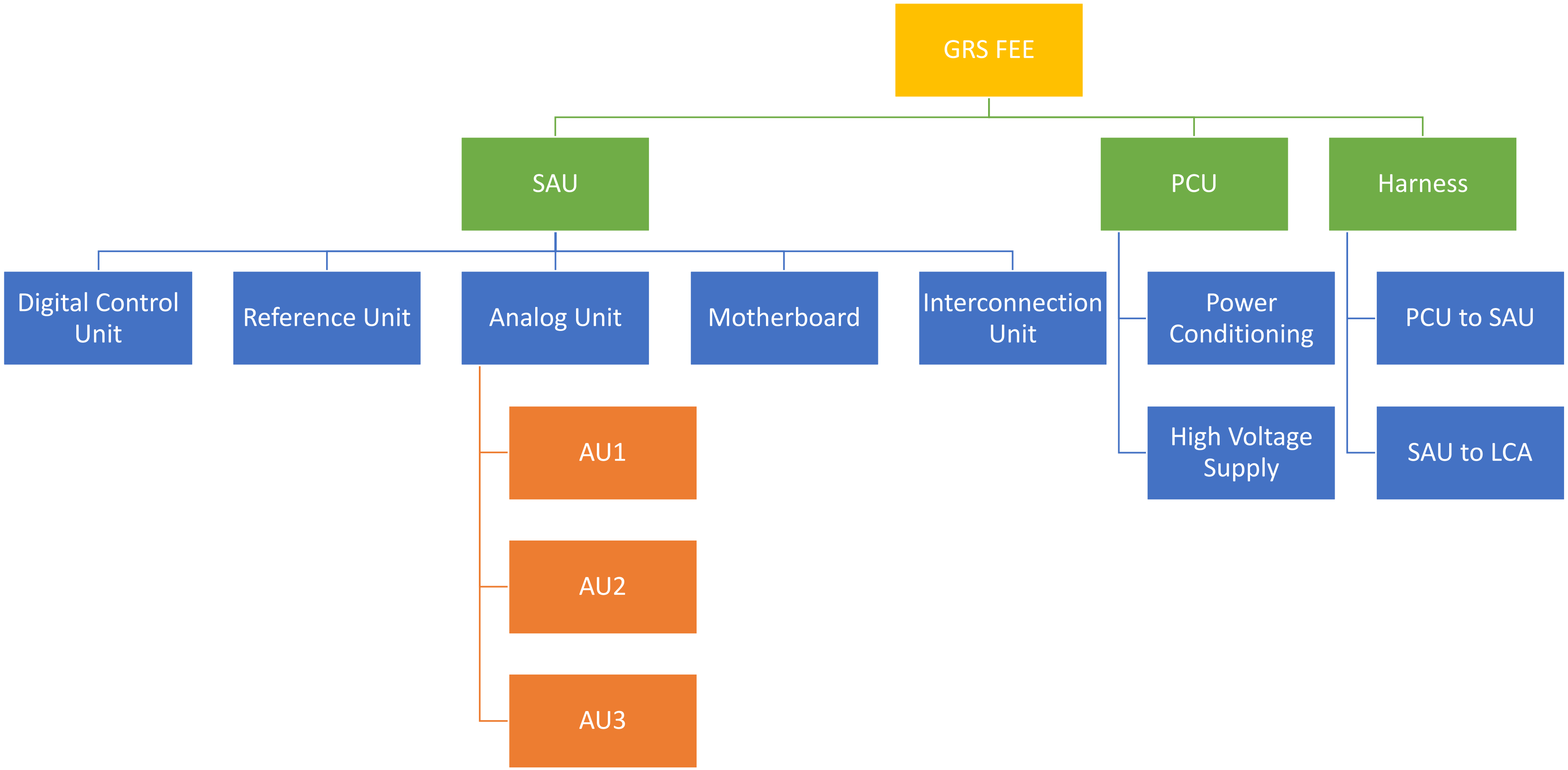
- Position sensing of TM, up to 200 µm in High Resolution (HR) mode and up to 2.5 mm in Wide Range (WR) mode
- Audio frequency actuation voltages to control TM with effective DC actuation forces of several nN in HR mode and ~µN in WR mode
- Bias TM with ~100 kHz to enable amplitude modulated capacitive sensing

PCU – Power Conditioning Unit

- Deliver conditioned power to the SAU
- Provide High Voltage Supply for the generation of WR actuation waveforms

Note: SAU and PCU are two distinct boxes

GRS FEE Overview – Product Tree



New LISA schedule, tbc

- Athena to be redesigned and descoped, MA delayed
- Target LISA MA anticipated to Nov 2023, target launch 2035
- For MA, payload and platform hardware must be at TRL5/6 and system design must be mature, and Cost-at-Completion must fit within the Science Programme
- Agreements and documents needed before Mission Adoption:
  - ✓ Science Management Plan (SMP)
  - ✓ Multi-Lateral Agreement (MLA)
  - ✓ Memorandum of Understanding (MoU)
  - ✓ Design Definition Report (aka Red Book)

GRS FEE Baseline Model Philosophy

	Harness	SAU		PCU		Required Units	Project Phase
		Nominal	Redundant	Nominal	Redundant		
EM	X	X	X	X	X	1	B2
EM-Lite	X	X		X		1	B2
STM	X	X	X	X	X	2	C/D
QM	X	X	X	X	X	1	C/D
FM	X	X	X	X	X	6	C/D
FS	X	X	X	X	X	1 (TBC)	C/D
Repair Kit						1 (TBC)	C/D

- EM: Needed for demonstrating functions and performances of the new design. Will be produced in Phase B2, after Mission Adoption.
- EM-Lite: Needed for integrated GRS SS EM test with torsion pendulum at UTN (Italy).
- QM: Needed for unit qualification. Built with the same components and design as the FM, will be used for assembly and testing of GRS FM, to shorten schedule.
- FM: 6 Flight Models
- FS: Flight Spare

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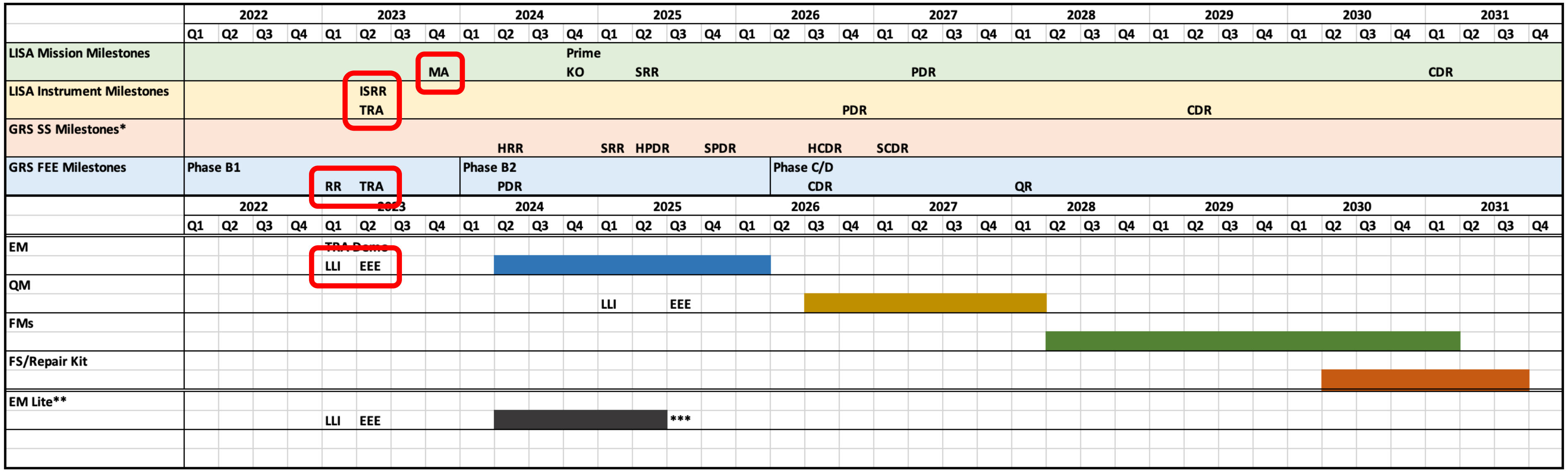
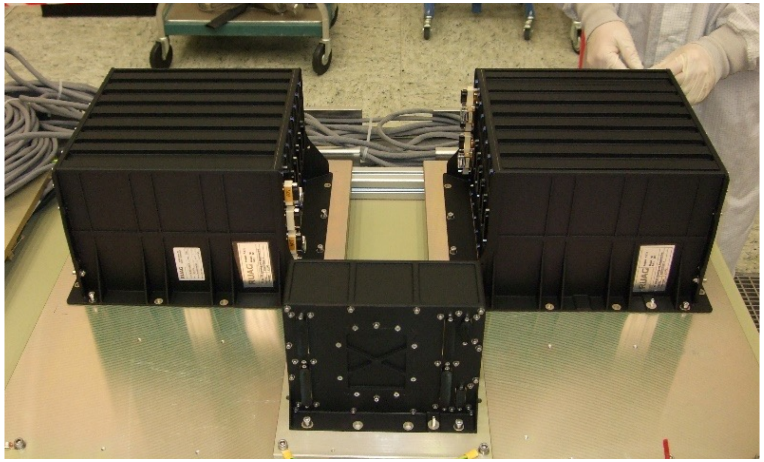
GRS FEE Schedule



LLI = Order of Long Lead Items
EEE = Order of all EEE components
TRA Demo = Demo Boars for TRA demonstration
*H = Head, S = System
** Non PRODEX activity
*** duration TBC by Industry

RR = Requirements Review
TRA = Technology Readiness Assessment
PDR = Preliminary Design Review
CDR = Critical Design Review
MAIT = Manufacture Integration and Testing
MA = Mission Adoption
ISRR = Instrument System Requirements Review
SRR = System Requirements Review

GRS FEE Phase B1

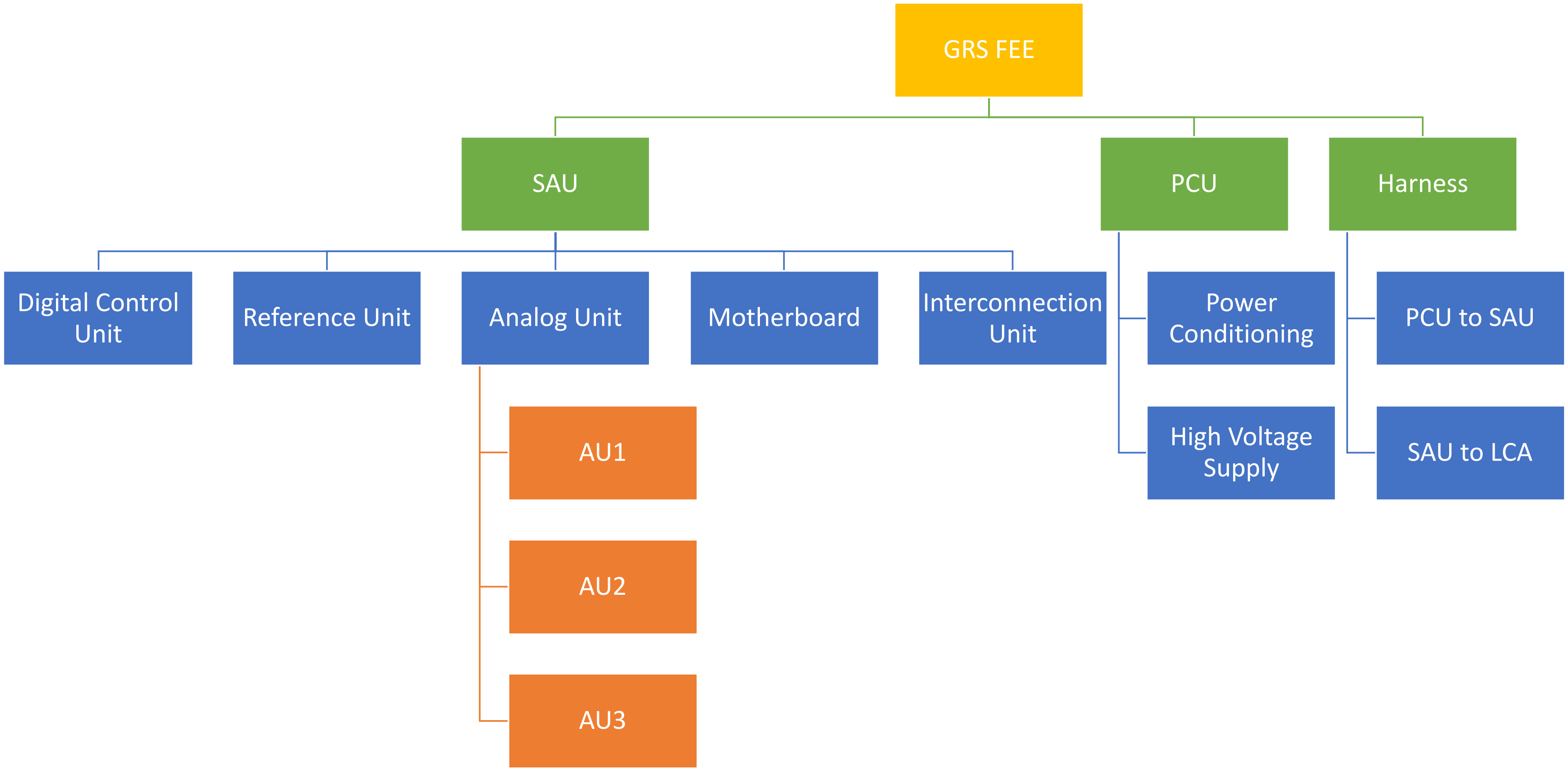


- Sensing full LPF heritage
- Key actuation science requirements met in LPF
- δ-design:
  - parts availability
  - one SAU per GRS head
  - LISA frequencies (FDS / DFACS / downlink), SC power
  - HV supply (avoid act/sense crosstalk, force increase), actuation implementation
  - Design and manufacture sensing transformers (explore design space, mitigate stray capacitance, reduce noise)
  - Reference voltage IC testing (finalize test campaign)
- BB Actuation (shadow engineering and test bench)
- Customer Requirements consolidation
- Test sensitivity of actuation, sensing and TM bias to harness bending
- Supporting documentation and project reviews

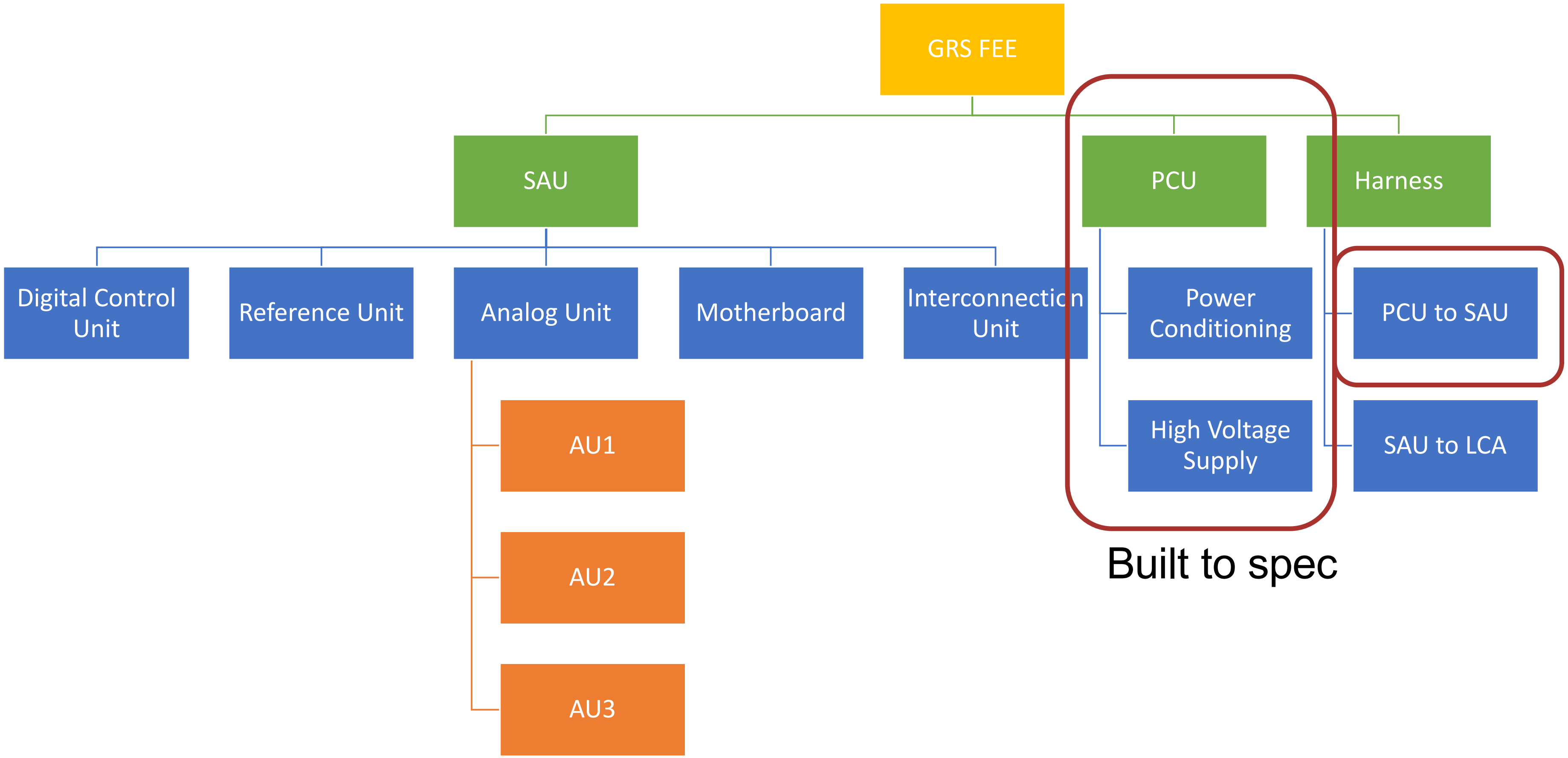
Contents

- Why should Canada contribute?
- What could Canada contribute?
- How could Canada contribute?
- When should Canada contribute?

GRS FEE Overview – Product Tree



GRS FEE Overview – Product Tree
Baseline Option 1 for Canadian contribution



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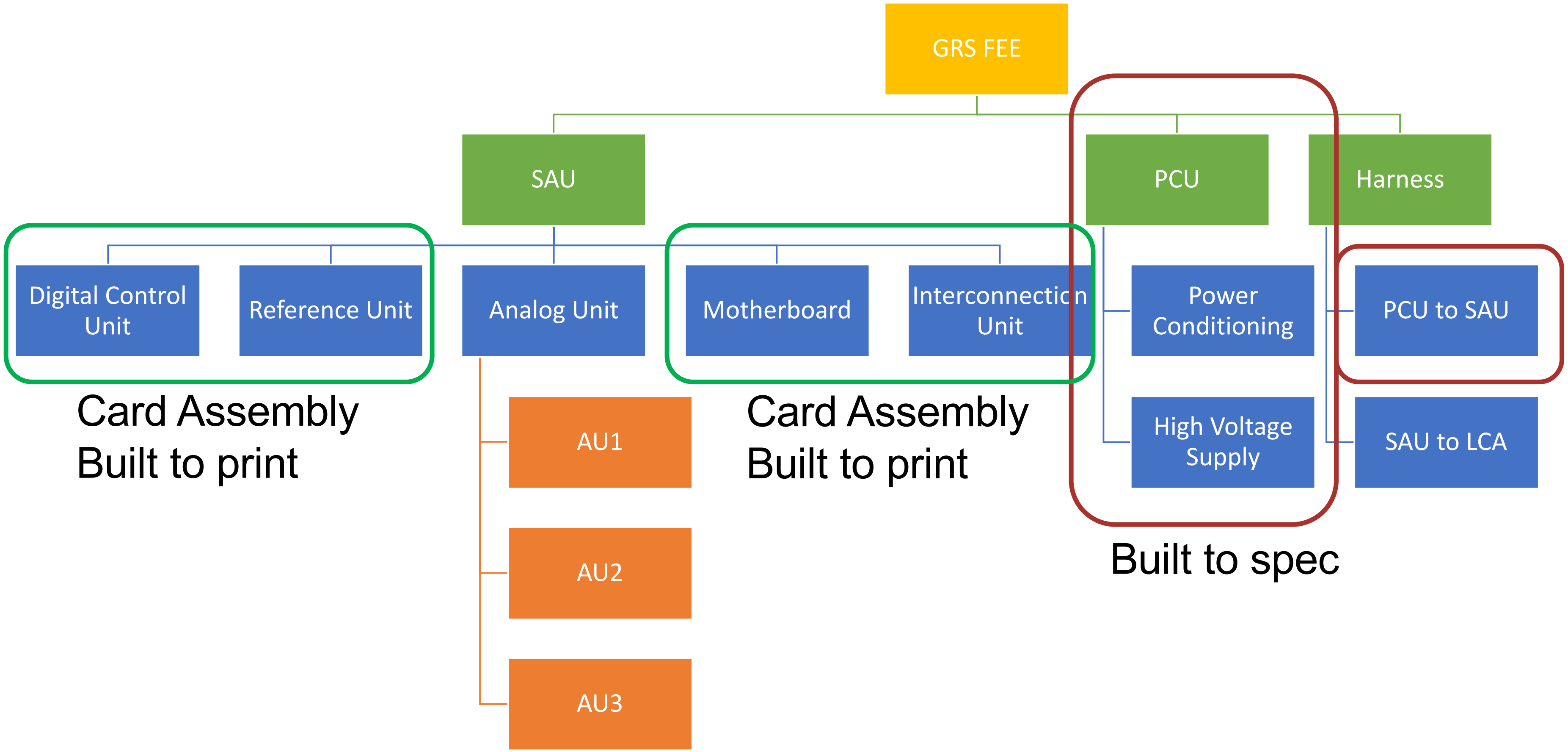
GRS FEE Overview – Product Tree
Baseline Option 2 for Canadian contribution



GRS FEE Overview – PCU Functions and critical requirements drivers

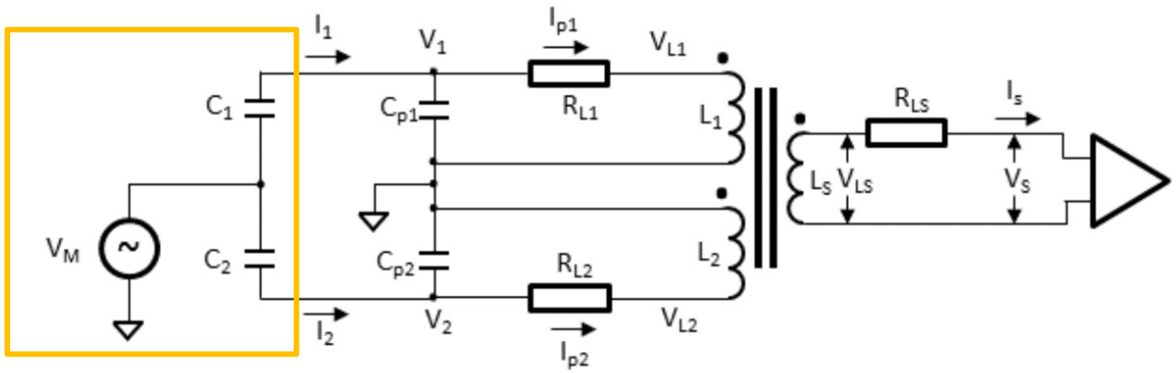
- Provide conditioned power to the SAU
  - Critical for SAU performances
  - 15V line powers directly the drive amplifier for the actuation voltages in High Resolution mode (science mode)
- Provide High Voltage Supply for Actuation waveforms in wide range
  - New element with respect to LISA Pathfinder
  - High voltages are critical for TM stabilization in free-fall after the release
  - High voltage line powers the drive amplifier for the actuation voltages in Wide Range mode

GRS FEE Overview – RU Functions

- Provide TM bias voltage to enable amplitude modulated capacitive sensing
  - Critical for sensing performances!
- Provide one stable voltage reference for all ADCs and DACs in the SAU
  - Critical for actuation and sensing performances!

GRS FEE Overview – RU Functions – Critical Requirements Drivers

- Provide TM bias voltage to enable amplitude modulated capacitive sensing
  - Direct impact on sensing performances, TM bias (V_{TM}) stability directly connected to sensing noise at low frequency.



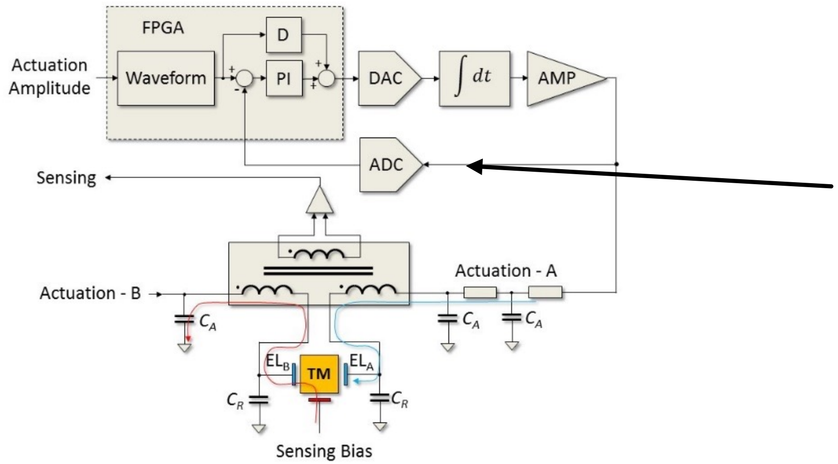
TM

$$V_S \propto \Delta C \, V_{TM}$$

TM bias voltage is a gain factor for the sensing measurement

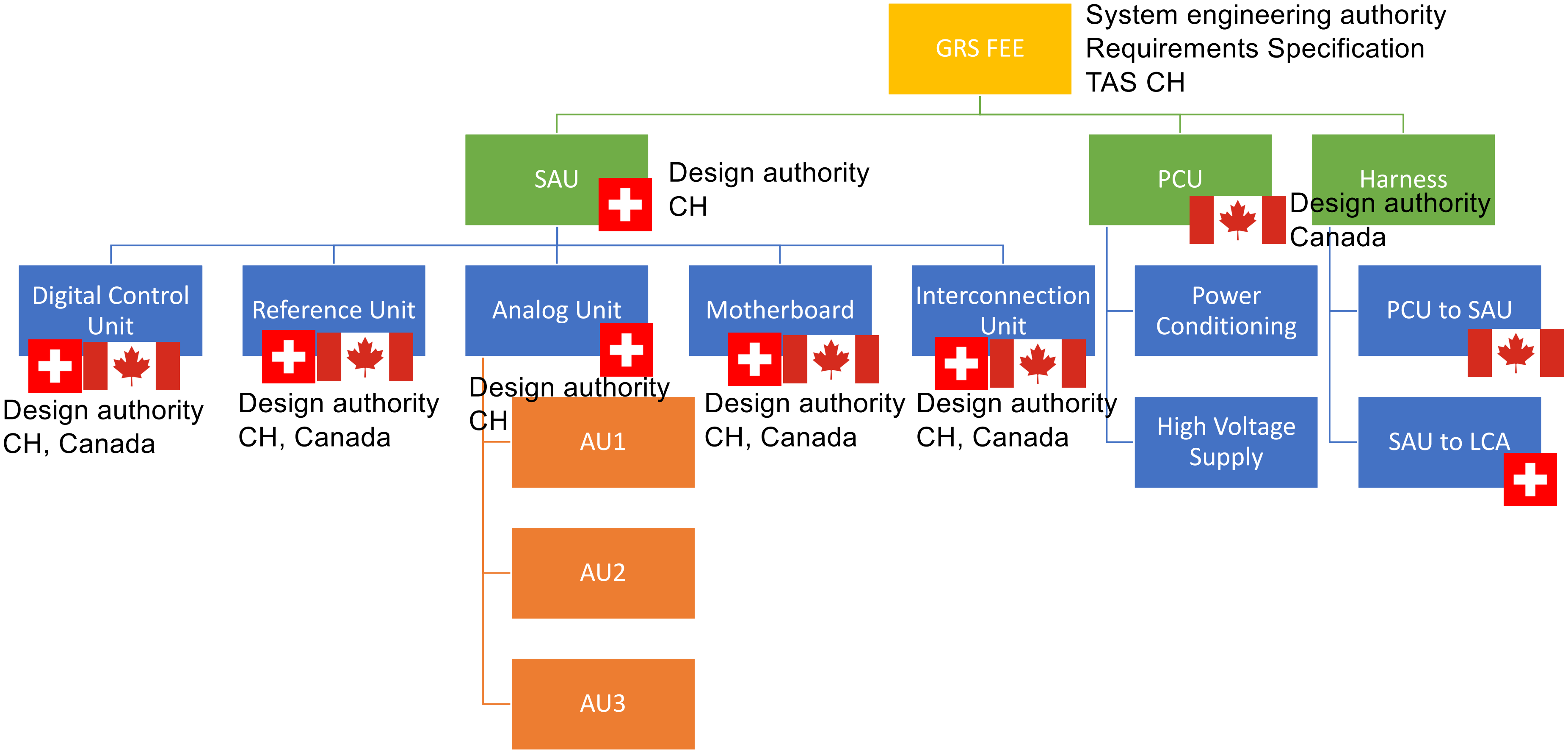
GRS FEE Overview – RU Functions – Critical Requirements Drivers

- Provide one stable voltage reference for all ADCs and DACs in the SAU
  - Actuation amplitude stability at low frequency directly affected by reference voltage stability (correlated amplitude fluctuations)
  - Also affects sensing performances (at sensing ADC)



ADC reference is critical for actuation performances

Project setup for the baseline option for Canadian contribution



Possible Canada Schedule

	2022				2023				2024				2025				
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
LISA Mission Milestones												Prime					
								MA				KO		SRR			
LISA Instrument Milestones						ISRR											
						TRA											
GRS SS Milestones*																	
										HRR			SRR	HPDR		SPDR	
GRS FEE Milestones	Phase B1								Phase B2								
					RR	TRA				PDR							
	2022				2023				2024				2025				
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
EM					TRA Demo												
					LLI	EEE											
QM																	
													LLI		EEE		
FMs																	
FS/Repair Kit																	
EM Lite**																	
					LLI	EEE									***		

- Commitment of Canada required by Mission Adoption (MLA)
- EM will be designed and commissioned by CH (LLI, EEE)
- Some participation of Canada in EM needed for cooperation in design
- Full participation latest by end 2024, for the QM commissioning

Why should Canada contribute LISA hardware?

- It would ensure a “true” participation in all phases of LISA and in the consortium activities and structure
- Canada can and should contribute to the top missions of ESA
- It would provide a much better understanding of LISA data and its limitations
- The planning for post-LISA instruments has already started and Canada would be better positioned to play a role
- It will help with terrestrial GW observatories
- The proposed development has important potential for industrial return: we started working in 1997 on successive proposals to bring a seismometer to Mars, which in the end resulted in the SEIS instrument on the NASA InSight installed on Elysium Planitia → The same class of electronics was needed for LPF and LISA → We now have EU projects with leading industry partners to develop high-precision electronics for space navigation