Latest news from LISA

Report to the IN2P3
Scientific Council
03.07.2023

Hubert Halloin, on behalf of the
LISA@IN2P3 collaboration

Outline

- LISA In brief
- Organisation & Contributions
- Achievements & Prospects
- Conclusion

LISA CONSORTIUM

LISA

LISA in brief

LISA in brief

APC

CCIN2P3
Centre de Calcul
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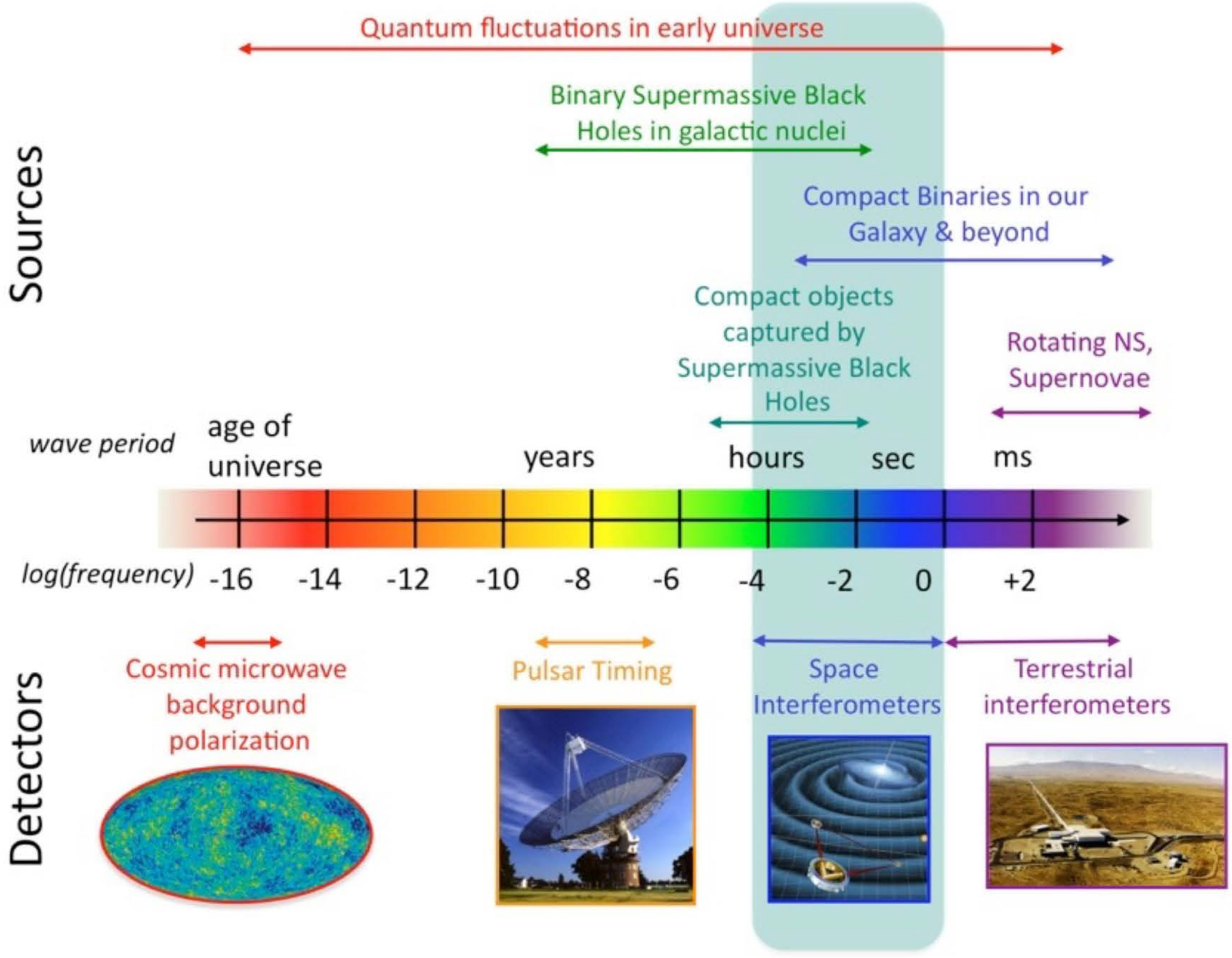
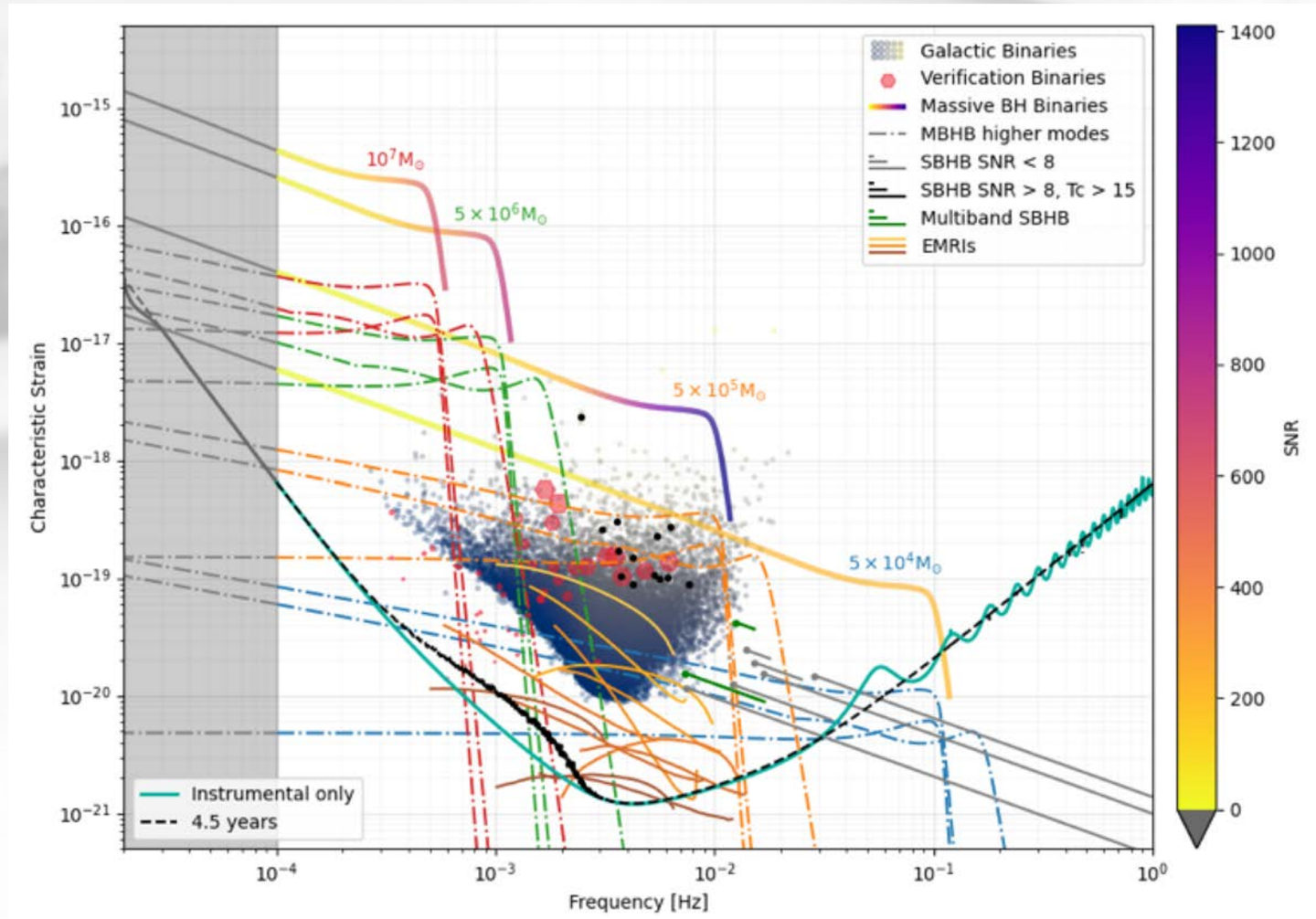
The GW spectrum



Science of the GW from Space

- LISA will observe GWs from 0.1 mHz to 1 Hz
- Main GW sources in the LISA bandwidth :



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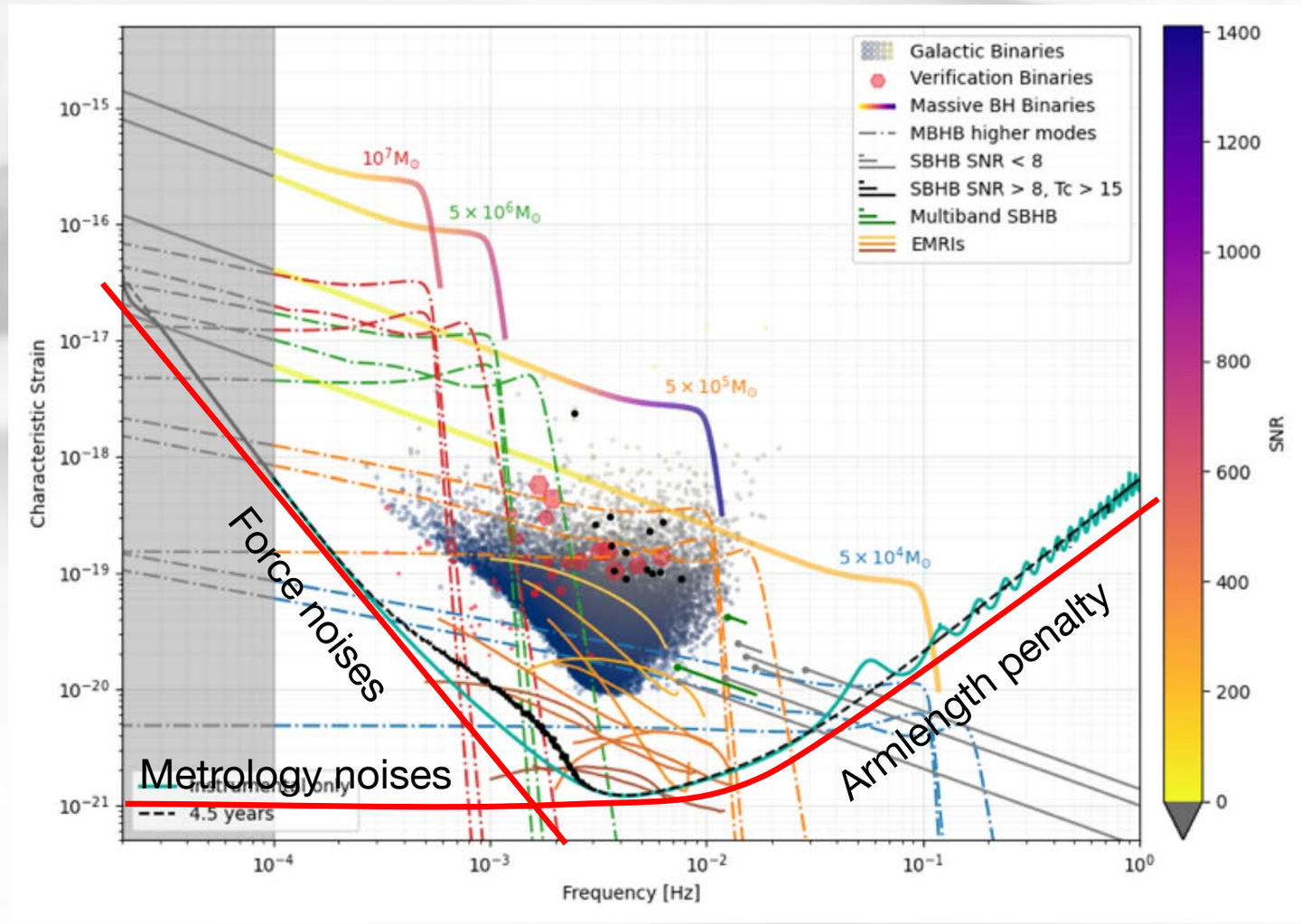
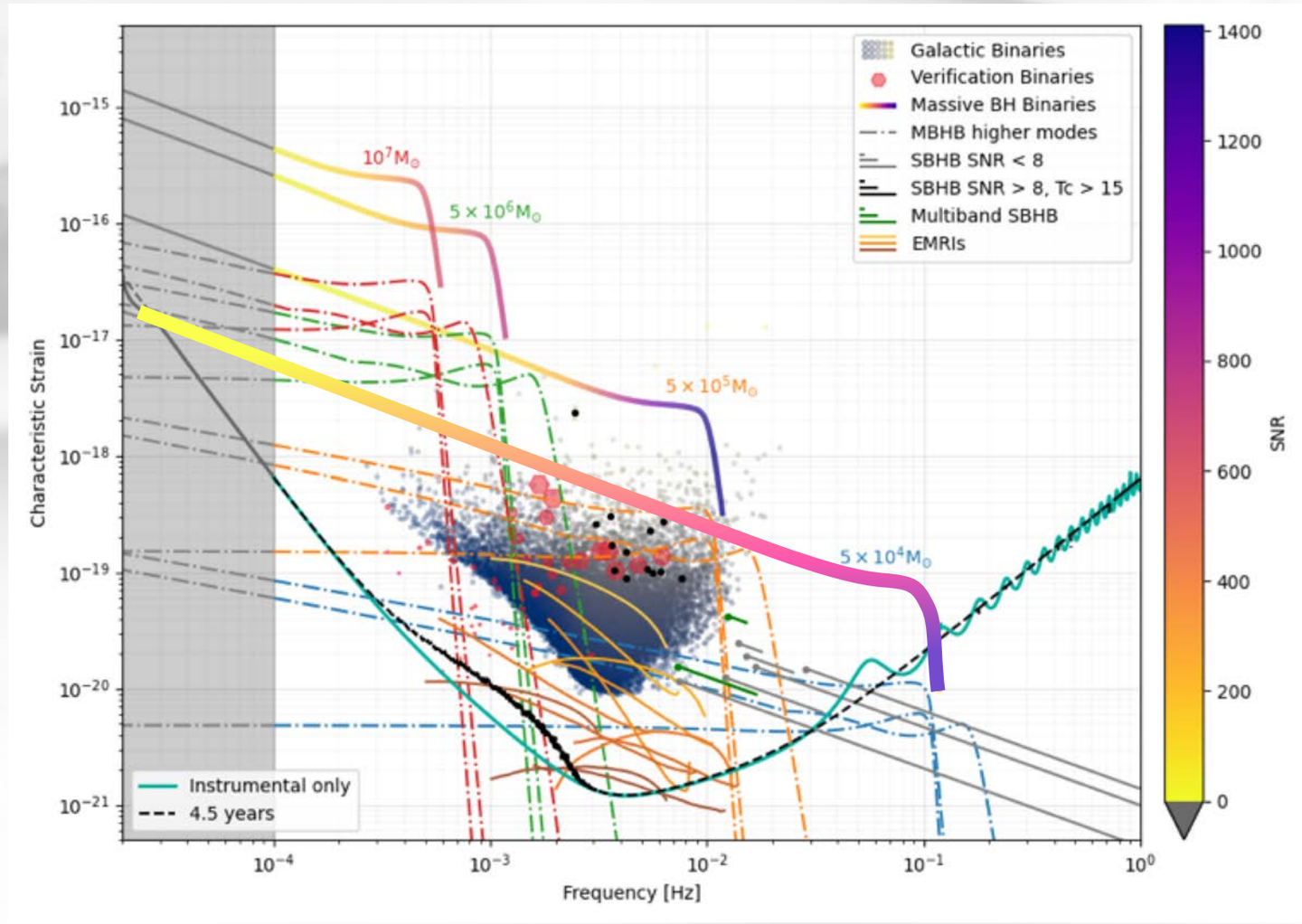


Science of the GW from Space

- LISA will observe GWs from 0.1 mHz to 1 Hz
- Main GW sources in the LISA bandwidth :

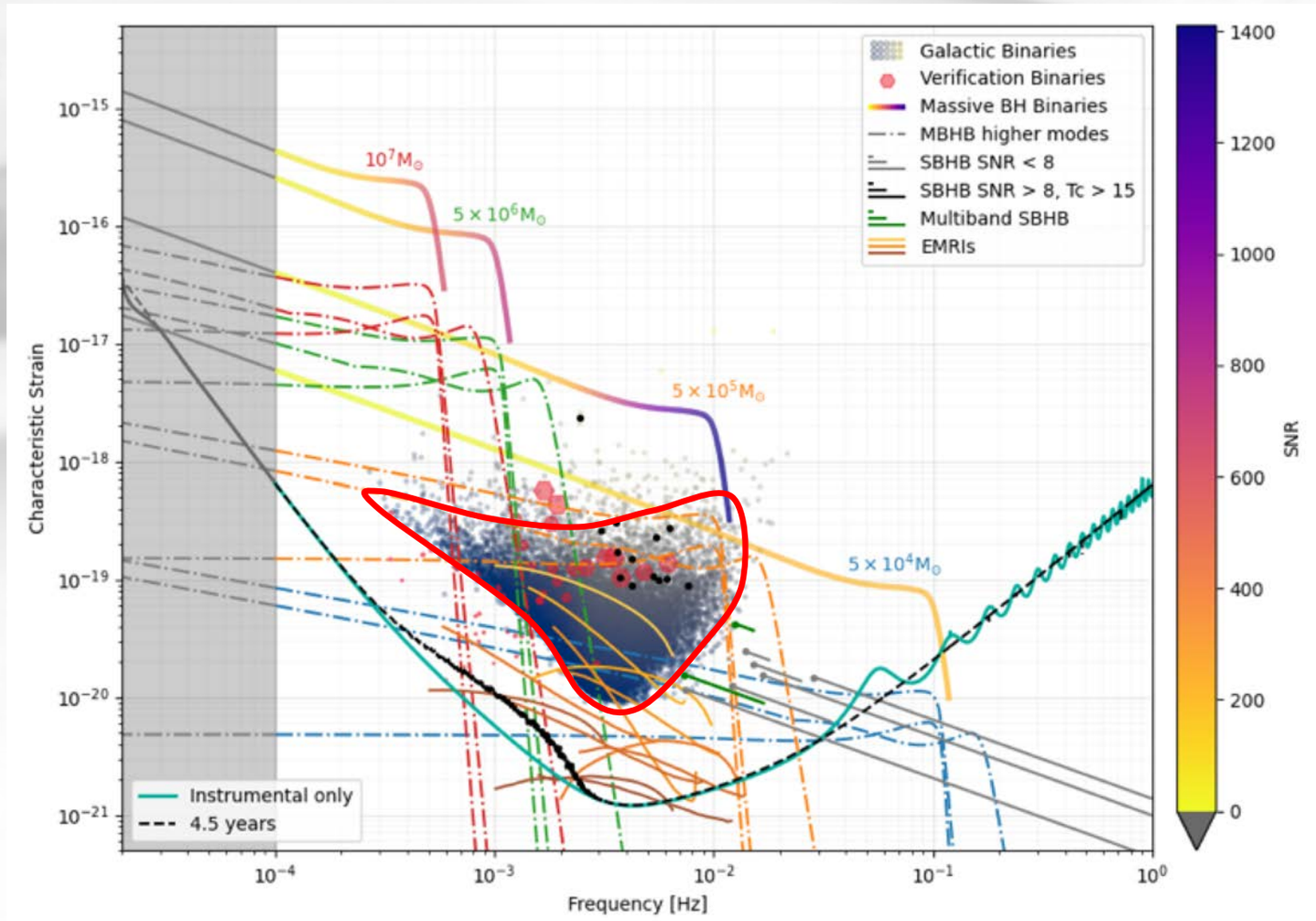
- Super massive black holes binaries (10^4 - 10^7 M_{sun}) – MBHB ~ few to few hundreds / year
  - Up to z~20 → origin and evolution
  - Post merger ringdown to test GR
  - Cosmology with standard sirens



Science of the GW from Space

- LISA will observe GWs from 0.1 mHz to 1 Hz
- Main GW sources in the LISA bandwidth :

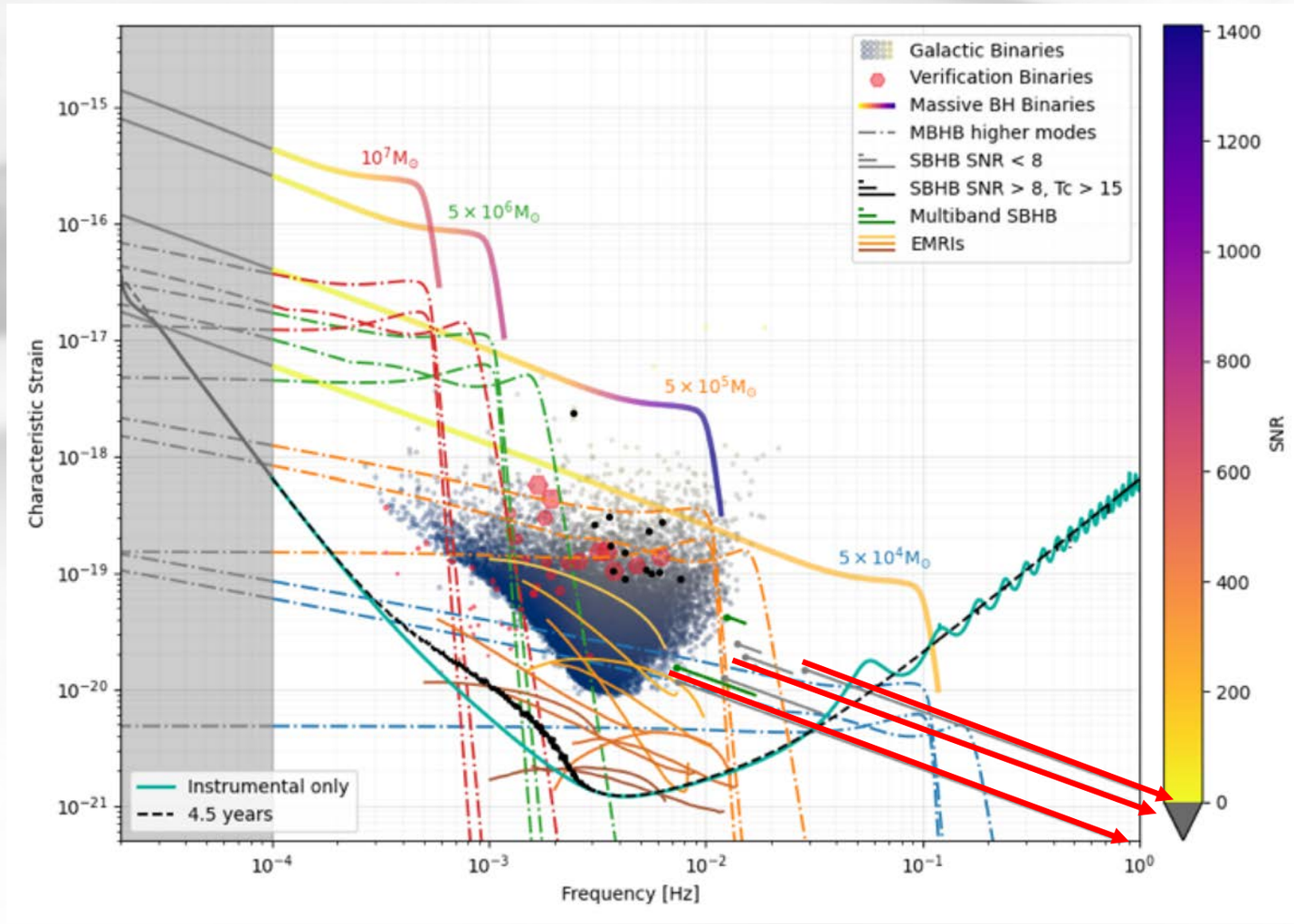
- Galactic white dwarf binaries (~ 10 000 resolved) – GB
  - Binary populations, evolution, merger rate
  - Milky way mass distribution



Science of the GW from Space

- LISA will observe GWs from 0.1 mHz to 1 Hz
- Main GW sources in the LISA bandwidth :

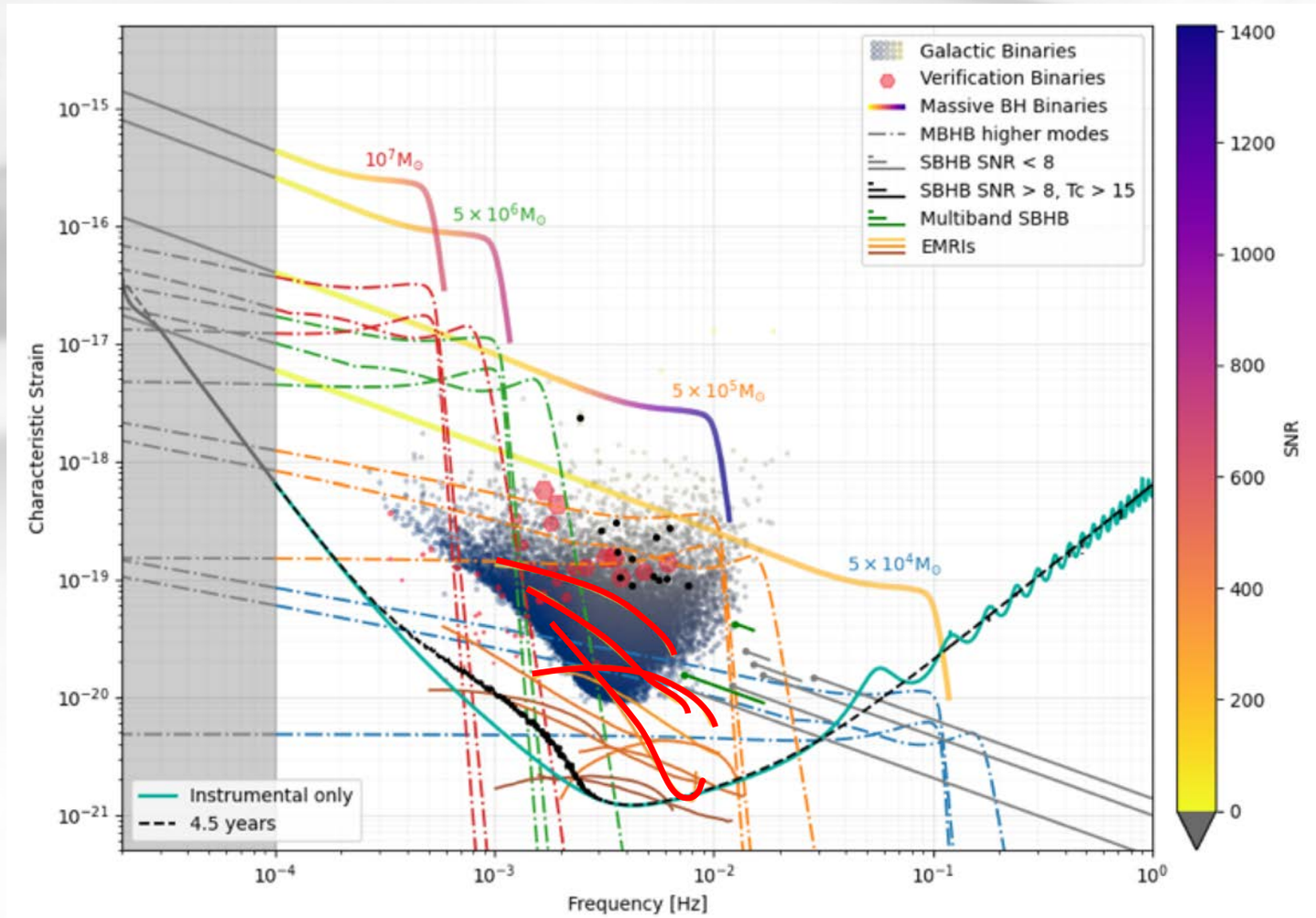
- Stellar mass black holes binaries – SBBH ~ a few and a couple multibands
  - Inspiral phase of LVK like events → formation channel and environmental effects, EM counterpart



Science of the GW from Space

- LISA will observe GWs from 0.1 mHz to 1 Hz
- Main GW sources in the LISA bandwidth :

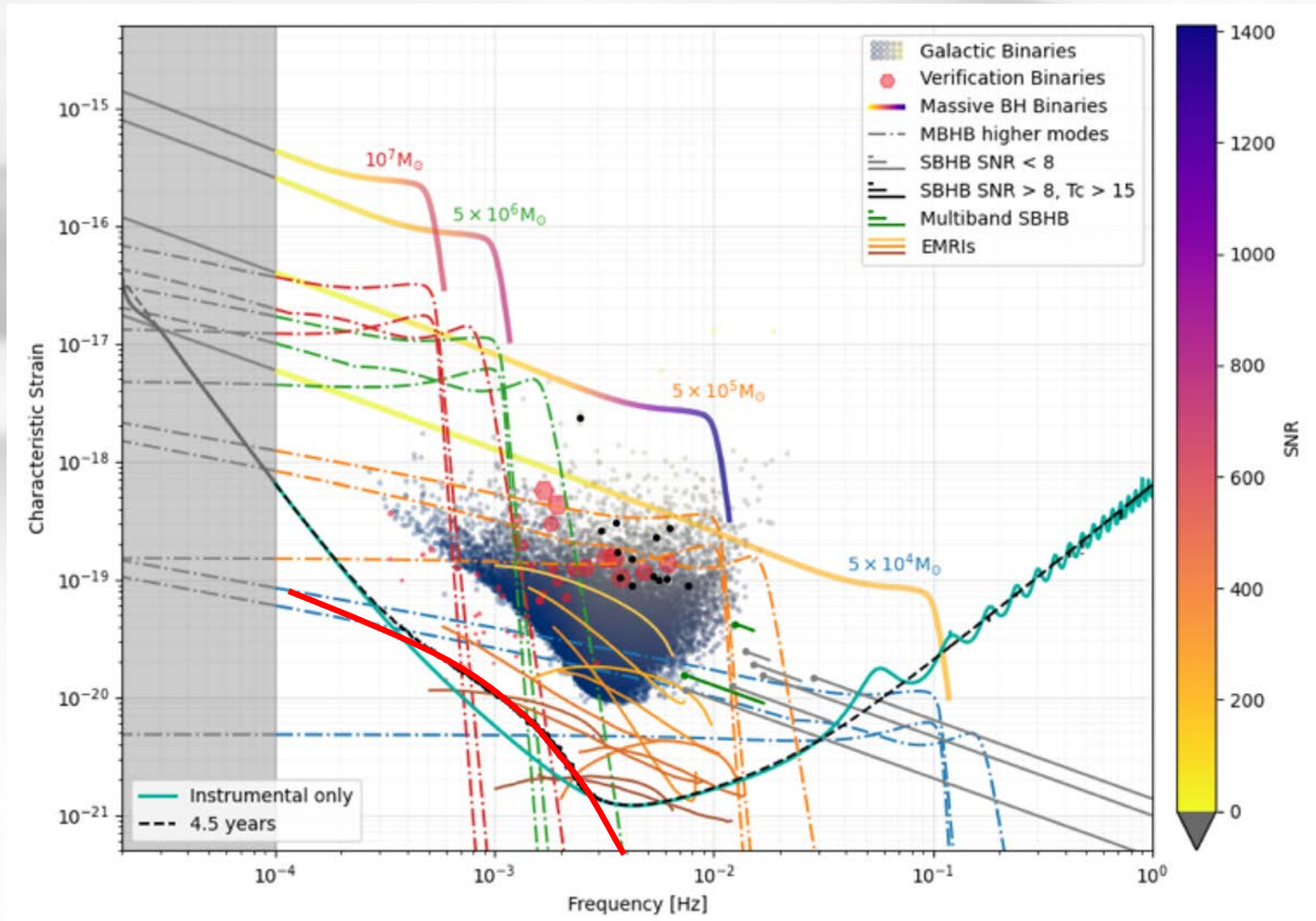
- Extrem Mass Ratio Inspirals (EMRI) ~ 1 to 1000 / year
  - Origin and local environement of MBH
  - GR in the strong field regime



Science of the GW from Space

- LISA will observe GWs from 0.1 mHz to 1 Hz
- Main GW sources in the LISA bandwidth :

- GW stochastic backgrounds (unresolved sources of all types, cosmological origin)
  - Population studies
  - High energy physics at the TeV scale



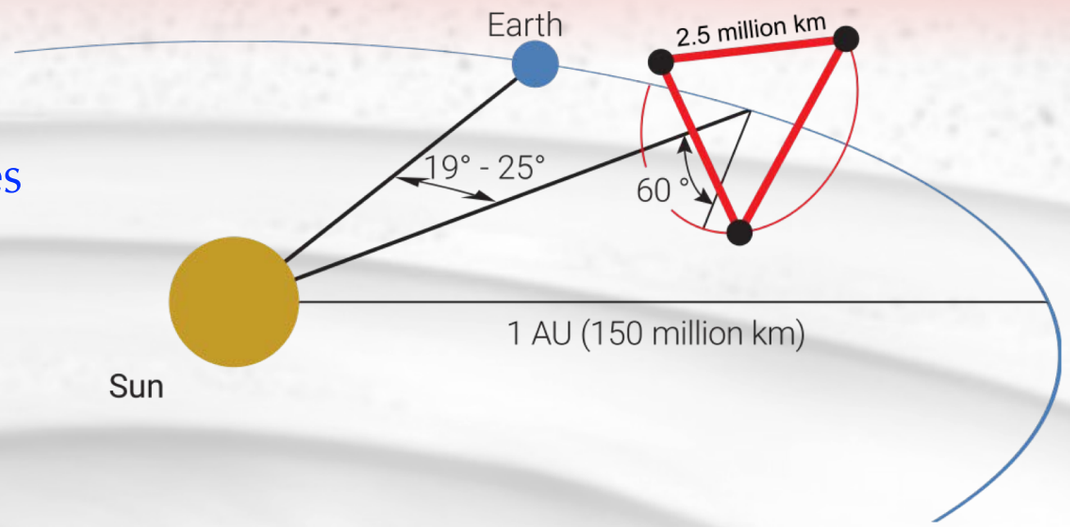
LISA mission profile

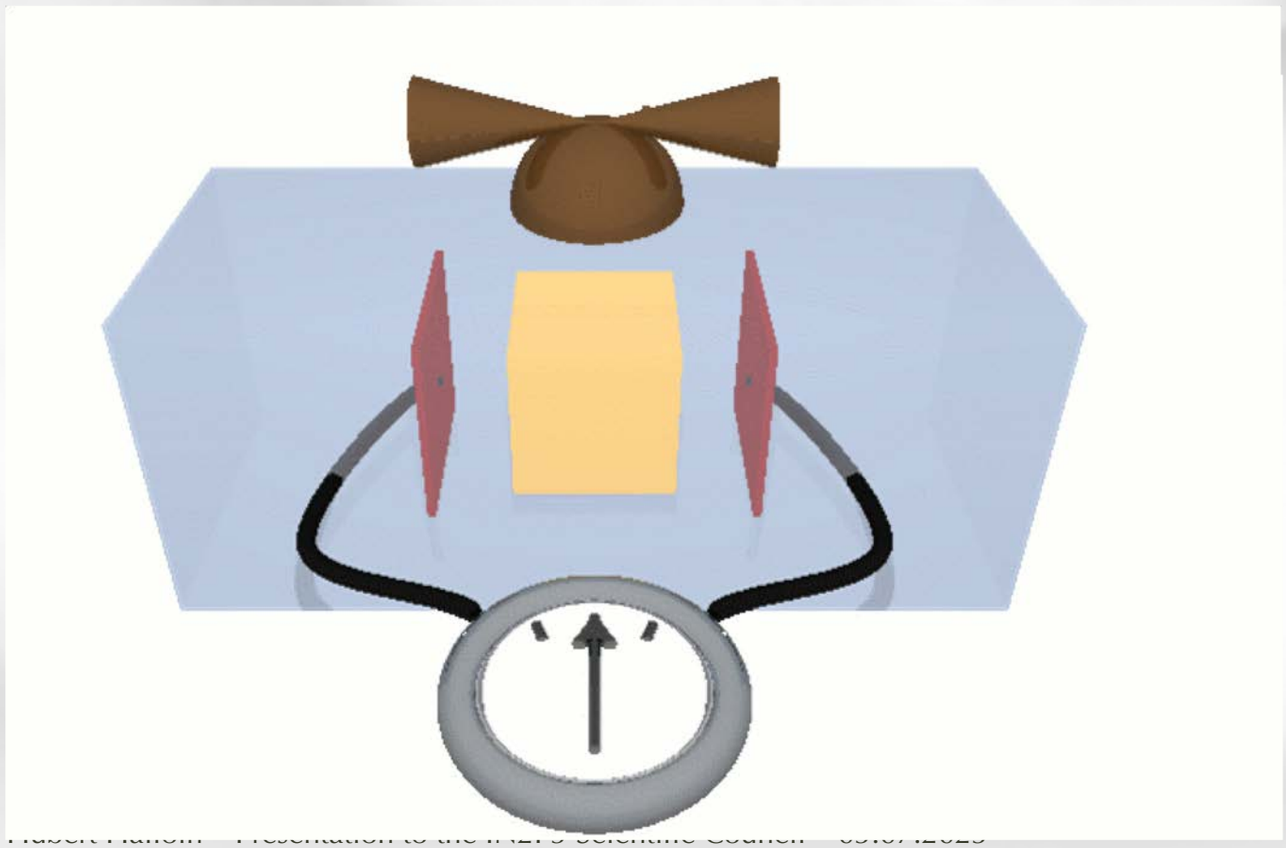
- Giant Space interferometer
  - 2.5 Mkm armlength
  - Length measurement between ‘free-floating’ test masses
  - Required performance between 0.1 mHz and 1 Hz :
    - Inertial test masses

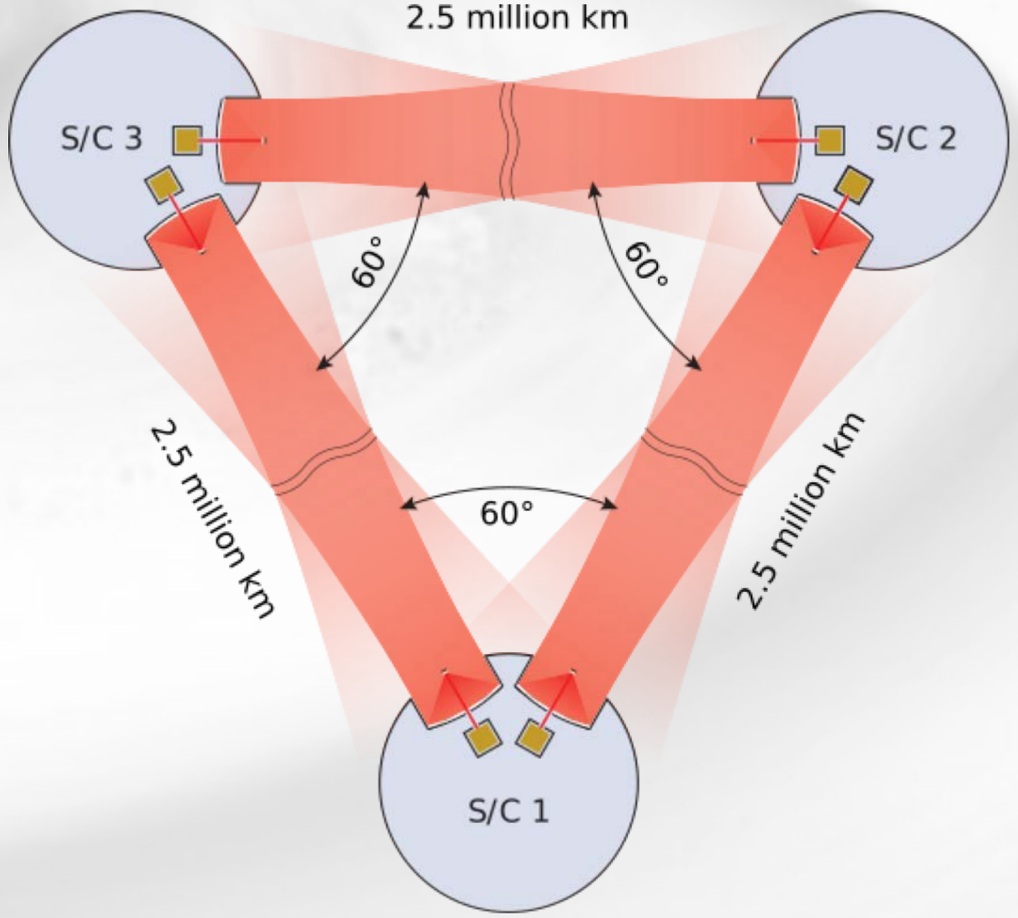
$$\approx 3 \times 10^{-15} \cdot \frac{0.2\ \mathrm{mHz}}{\mathrm{f}} \quad \mathrm{g}/\sqrt{\mathrm{Hz}}$$

      - Demonstrated with LISA Pathfinder
    - Metrology noise

$$\approx 10 \times 10^{-12} \quad \mathrm{m}/\sqrt{\mathrm{Hz}}$$

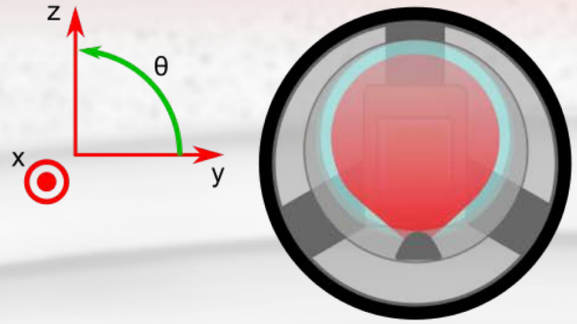


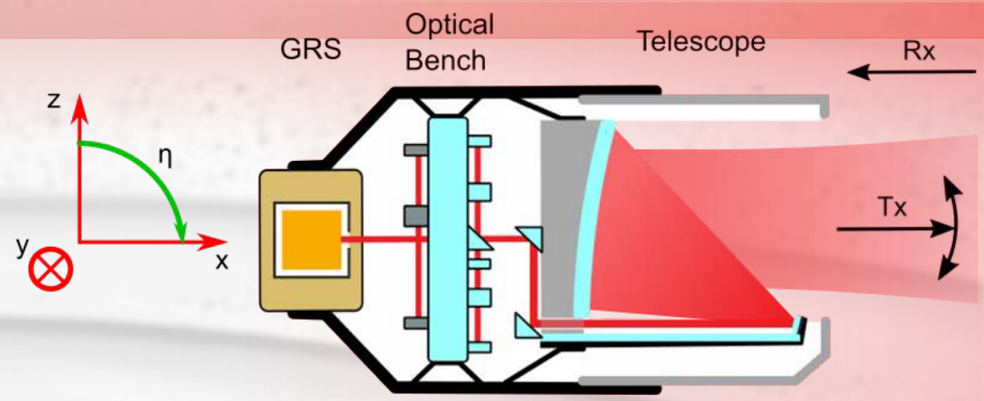


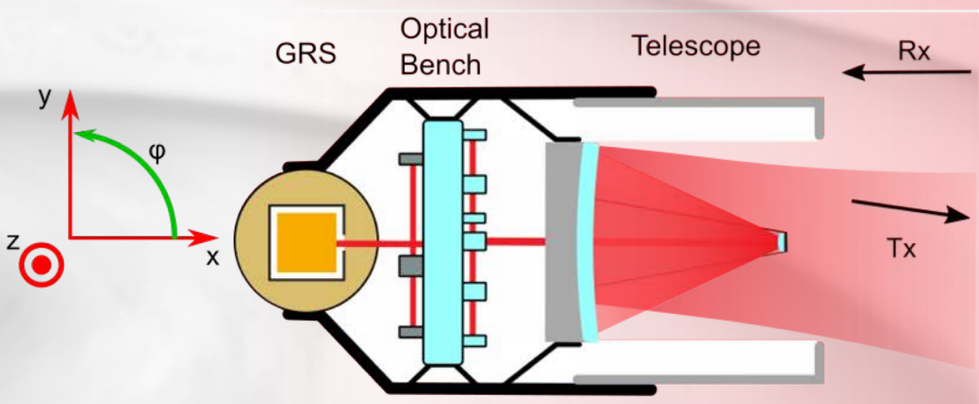


LISA Payload

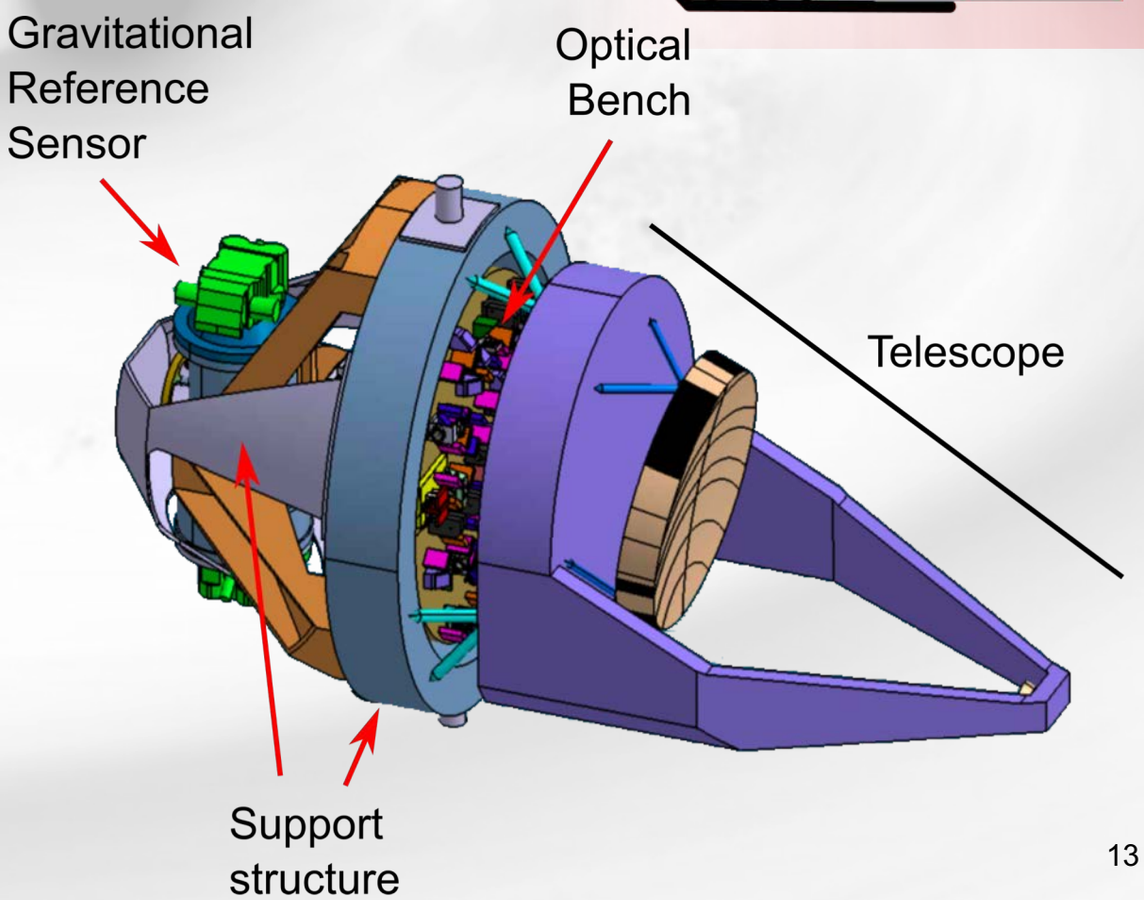
- Instrument units
  - Telescope [USA]
  - Optical Bench [UK]
  - GRS [IT]
  - Movable structure [ESA]
  - Phasemeter [DE]
  - Laser [USA]
  - Diagnostics [ESP]



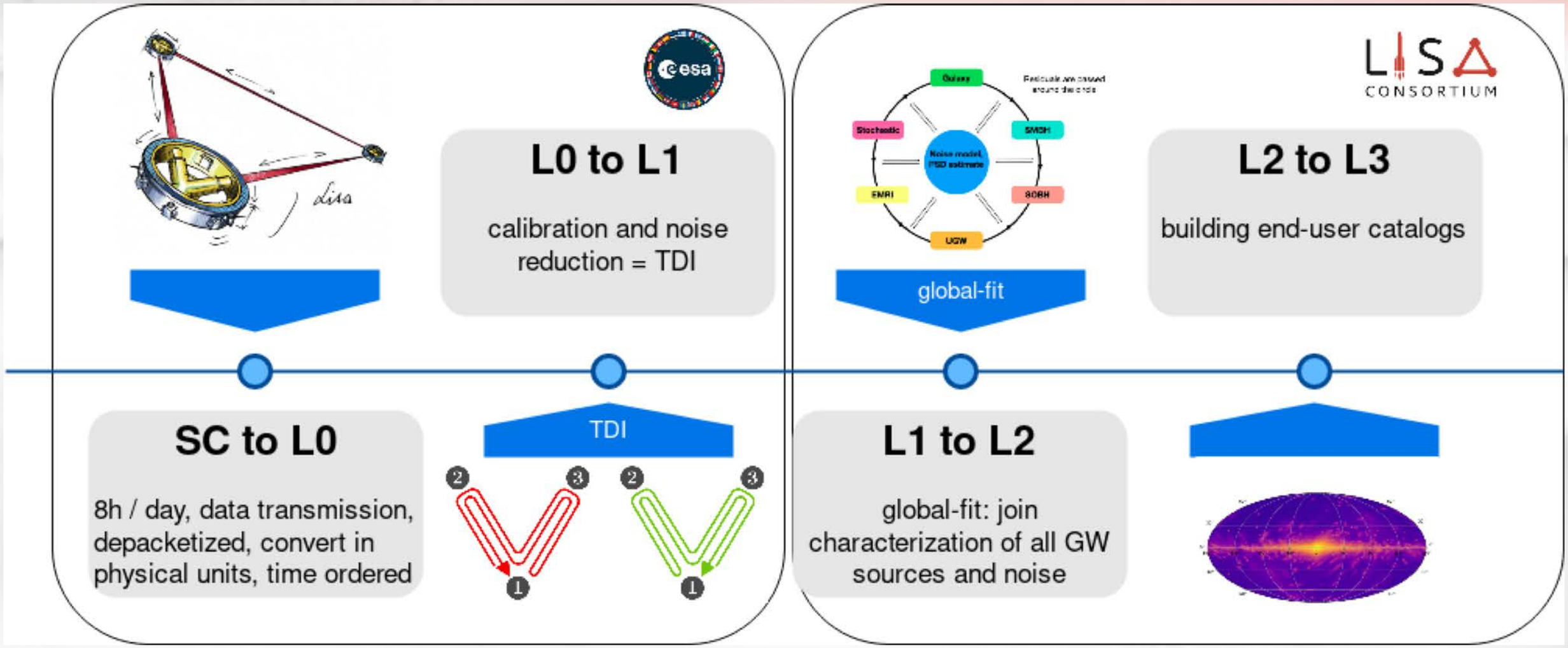




- Two levels of integration and tests
  - **IDS** (Interferometric Detection System)
    - ‘Core’ of the metrology system
    - Optical Bench + phasemeter + laser Tested at EM + FM1 levels
  - **MOSA** (Movable SubAssembly)
    - Integrated optical system
    - Telescope + Optical Bench + GRS + Structure
    - Tested at QM + FMs models



LISA ground segment



- SC → L0 → L1
  - Mission Operation Center + Science Operation Center
  - Under ESA reponsibility
- L1 → L2 → L3
  - Under responsibility of the Distributed Data Processing Center (DDPC)
  - LISA consortium through national agencies
- Public data release by ESA
  - Alerts, catalogs

Main LISA development milestones

Event	From	To	Comment
Phase 0 (Concept study)	Jul 2017	Nov 2017	Completed
Mission Definition review (MDR)	27 Nov 2017		Successful
Phase A (Feasibility study)	June 2018	Oct 2020	Completed
Mission Consolidation review (MCR)	22 Oct. 2019		Successful
Extended Phase A	Oct 2020	Dec 2021	Completed
Mission Formulation review (MFR)	End 2021		Successful
Phase B1 (Preliminary Definition with concurrent Prime Contractors)	*Jan 2022*	*Dec 2023*	*On-going*
Mission adoption review (MAR)	Nov. 2023		
Mission adoption (by ESA SPC)	**Janv. 2024**		
Phase B2 (Preliminary Definition with a single Prime Contractor)	Q1 2024	April 2027	
Mission Preliminary Design review	April 2027		
Phase C (Detailed Definition)	Q3 2027	Q4 2030	
Mission Critical Design review (CDR)	Jan. 2031		
Phase D (production and Verification)	Q1 2031	2034/2035	
Flight Acceptance Review (FAR) and Launch	**2034/2035**		
Transfer & commissioning	1.5/0.5 years		
Operations	4.5 years		7.5 years of science mission
Extended mission	Up to 3 more years		

Organisation & Contributions

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Organisation et contributions

Mission Operation Center

LISA Science team
Project Scientist

Observational Science Group
Waveforms WG
Massive BH WG
EMRI WG
...

Prime Contractor
AIRBUS ThalesAlenia Space

LISA Project team
Project Manager

Science Community

P&O team

Science Operation Center

NASA SGS

DDPC

Science Ground Segment

OTS

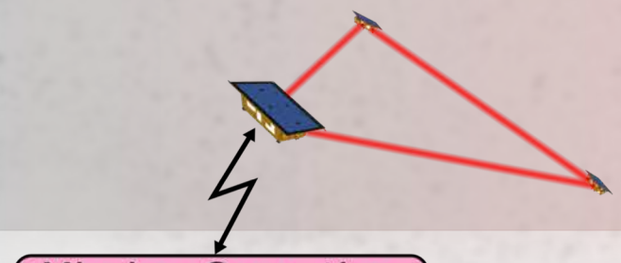
SDS

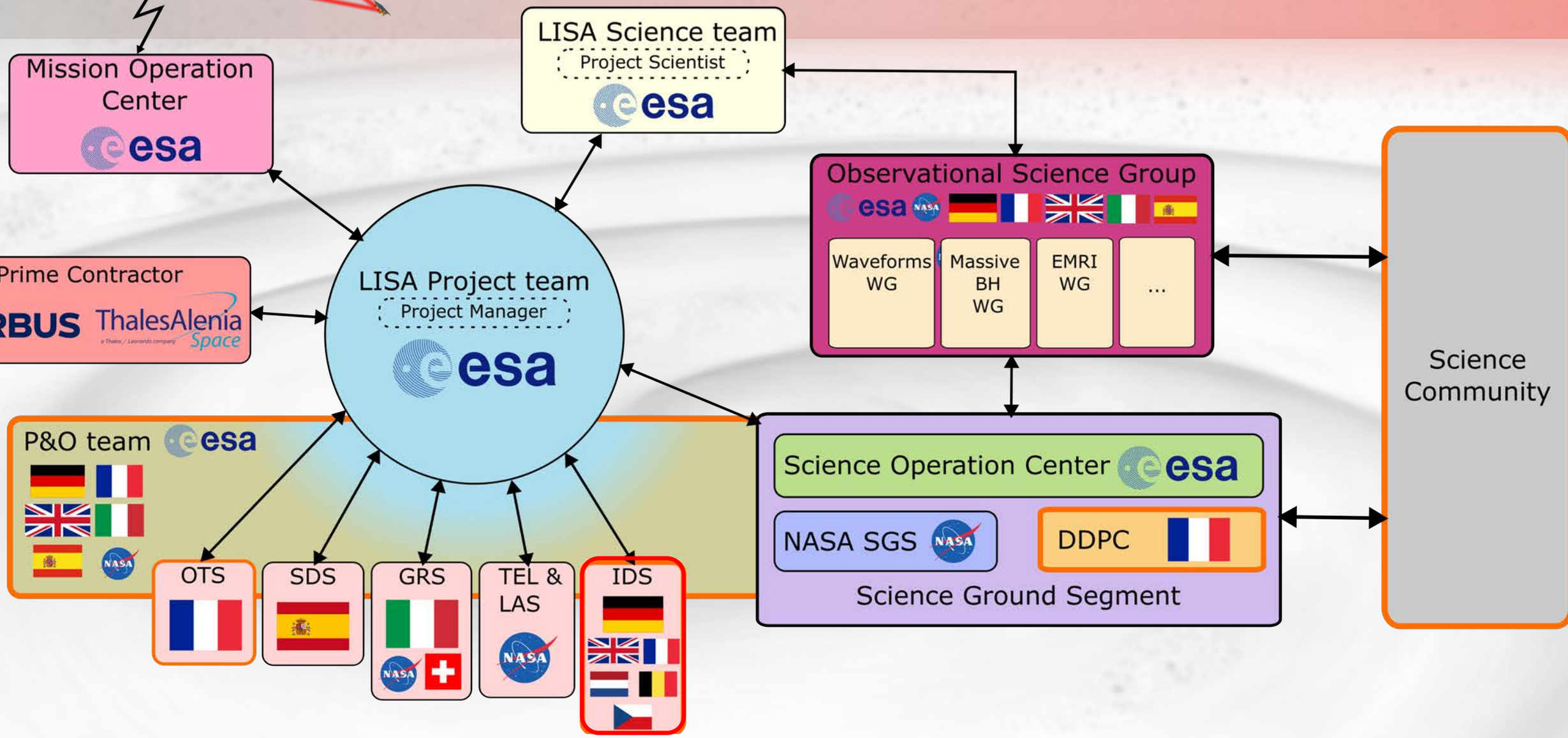
GRS

TEL & LAS

IDS

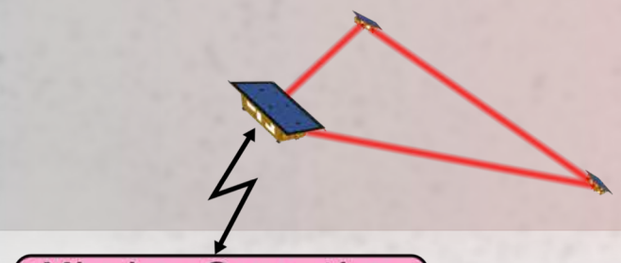
Organisation et contributions

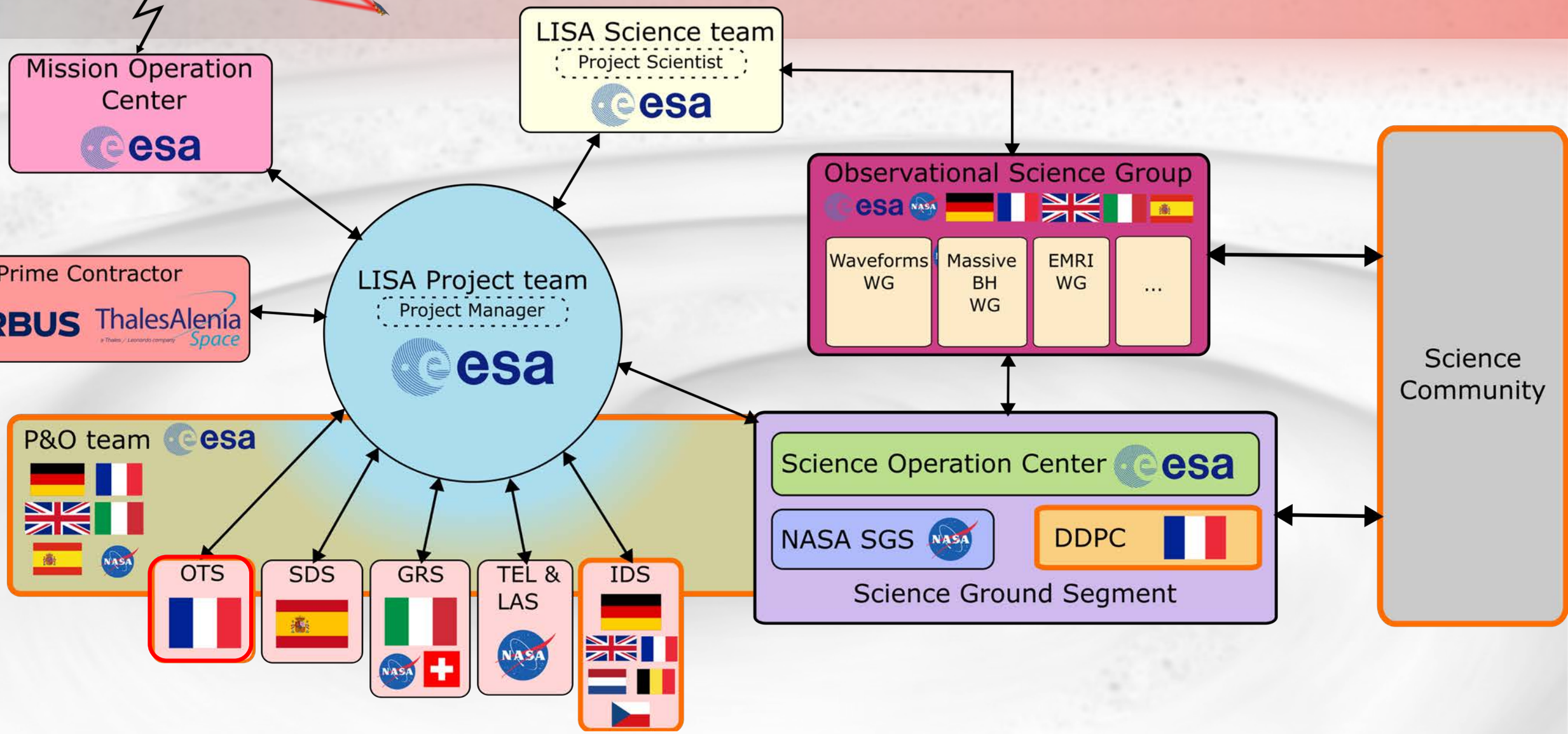




- IDS (Interferometric Detection System)
  - French contribution : Tests infrastructures and benches
    - Tests campaigns on EM and FM1
  - @IN2P3 :
    - Contributions to tests and benches specifications *[**APC**, L2IT, LMA]*
    - Delivery of the Beams Simulator bench *[**APC**, LPCCaen, CPPM, LMA]*
    - Delivery of the GSE phasemeter *[**APC**]*

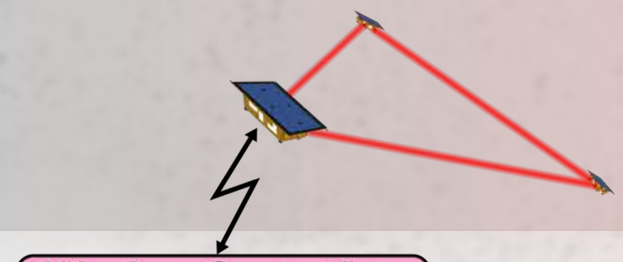
Organisation et contributions

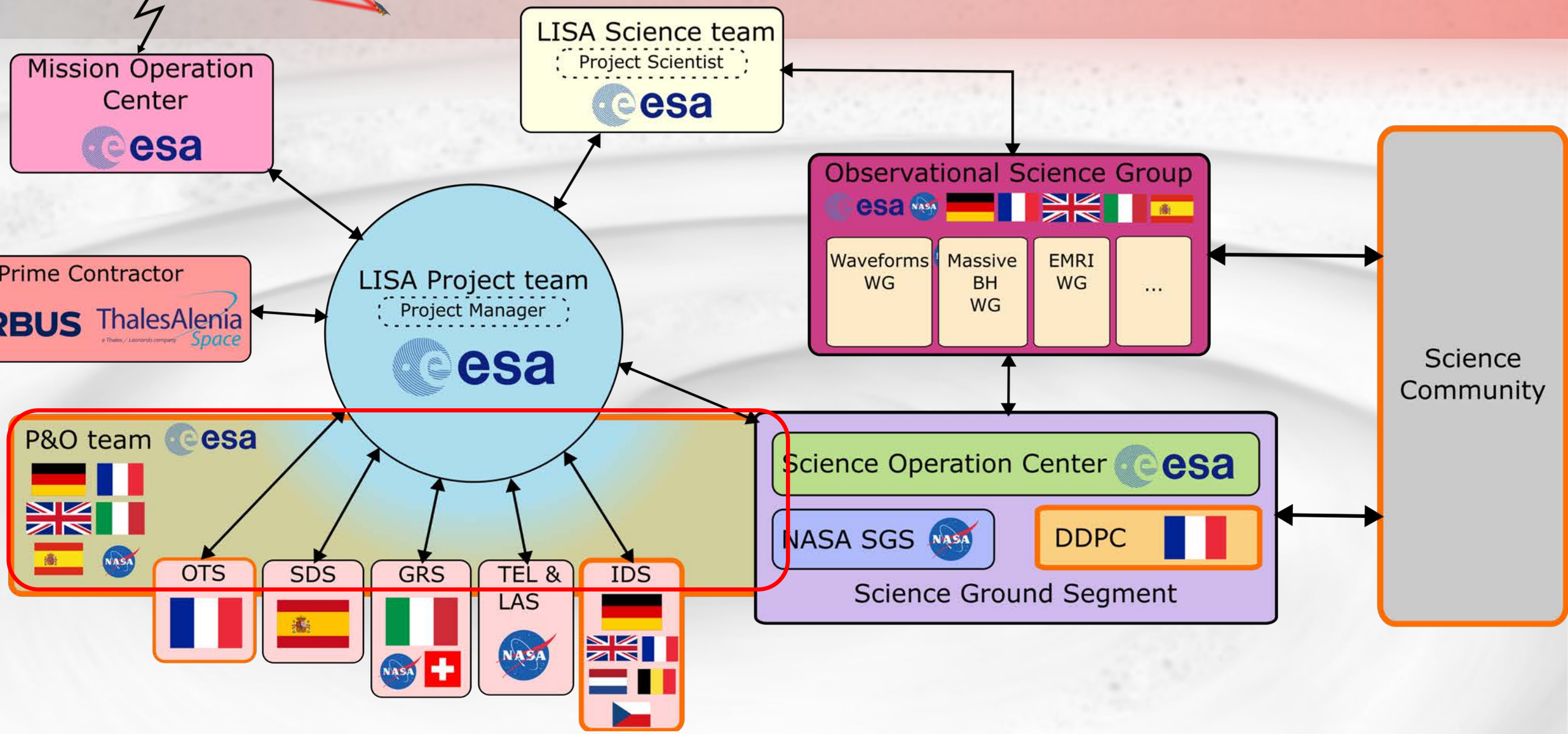




- OTS (Optical Tests System)
  - French contribution : Complex OGSEs for testing the MOSA
    - Tests campaigns on QM, FMs and Spares in Prime's premises
  - @IN2P3 :
    - Contributions to tests and benches specifications *[APC, L2IT]*

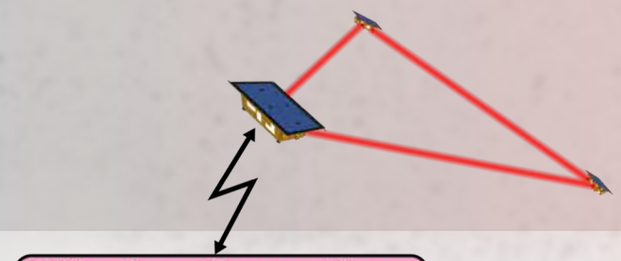
Organisation et contributions

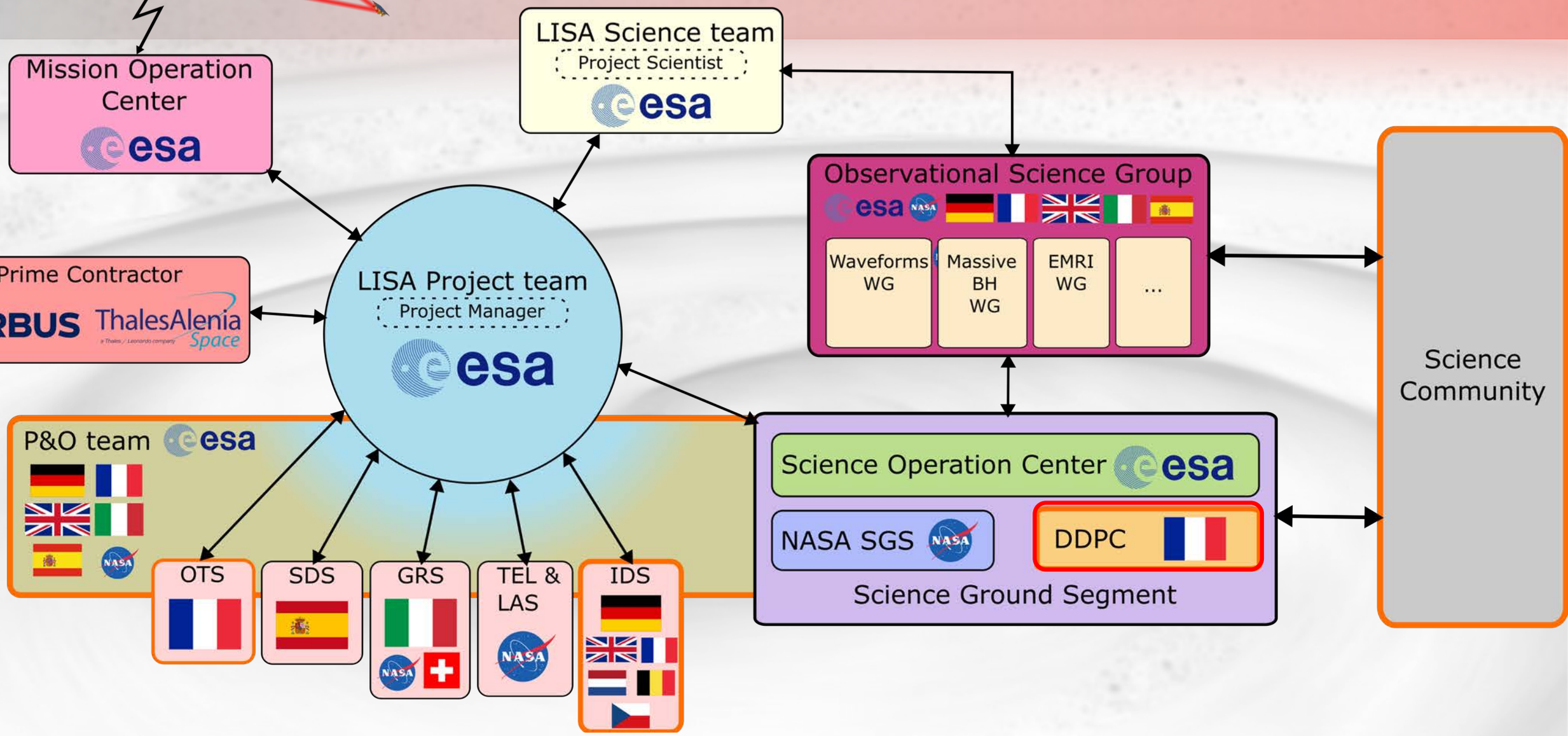




- P&O (Performance and Operations)
  - Role
    - Support ESA with the development of the performance model of LISA
    - Participate to the definition of in-flight commissioning plans, early science phase characterization experiments.
  - @IN2P3 :
    - Constellation performance model, Impact of TDI algorithm, Figures of Merit, … *[APC, L2IT, LPCCaen]*
    - Operational concept definition, in-flight commisioning and calibration, …. *[APC, L2IT, LPCCaen, …]*

Organisation et contributions



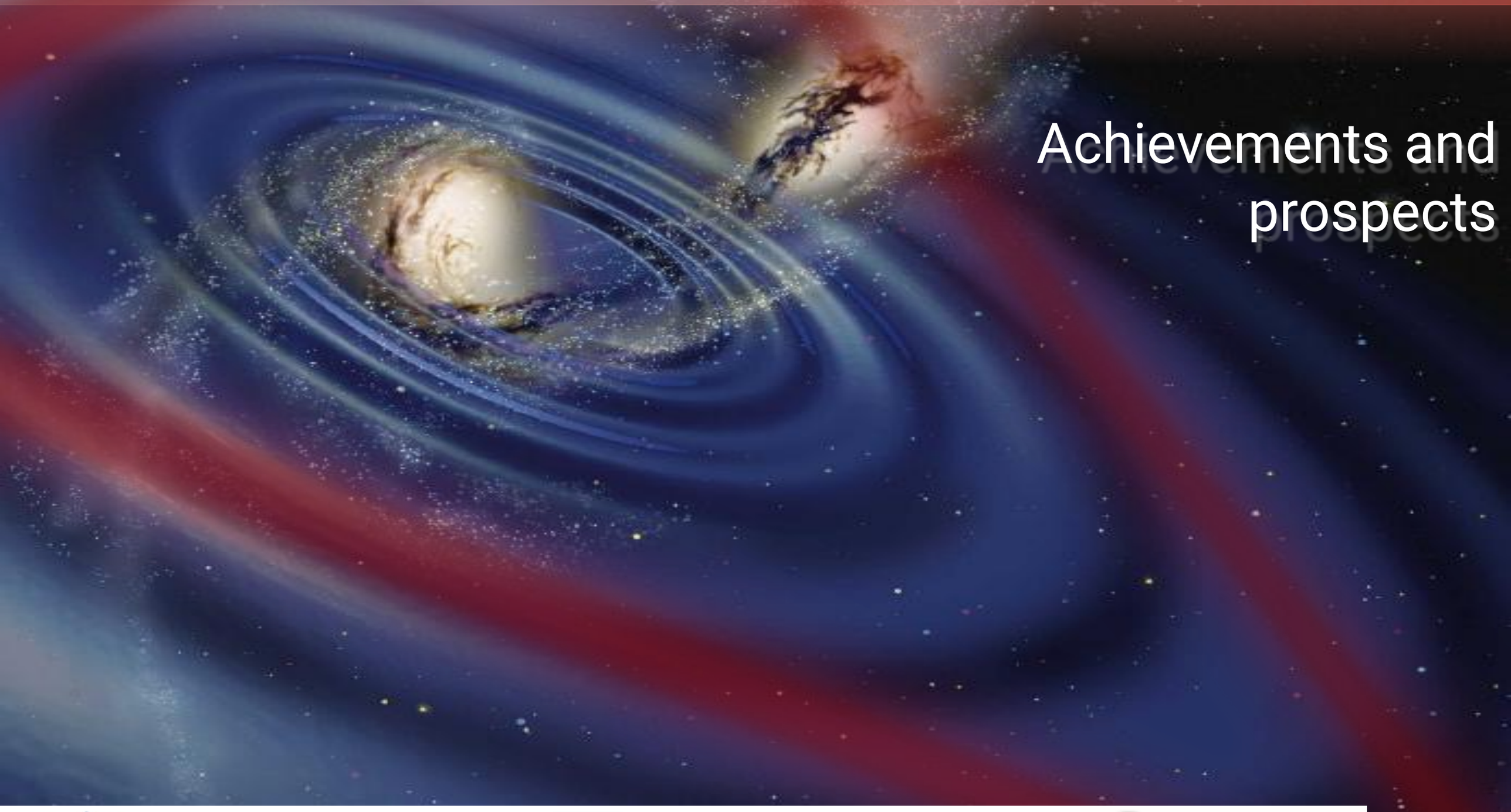


- DDPC (Distributed Data Processing Center)
  - Produce L3 (catalogs) data from L1
  - @IN2P3 :
    - Global fit (L2 to L3) *[**APC**, L2IT, LPCCaen]*
    - Connections with external data *[**L2IT**]*

- Low Latency Pipeline *[LPCCaen]*
- Fast Waveforms *[L2IT]*
- L3 Production *[APC, L2IT]*
- Simulated data generation *[APC]*
- End-to-end validation *[APC, LPCCaen]*
- System Coordination *[APC]*
- Main DCC infrastructure *[**CCIN2P3** ou CNES]*

LISA CONSORTIUM

LISA



Achievements and prospects

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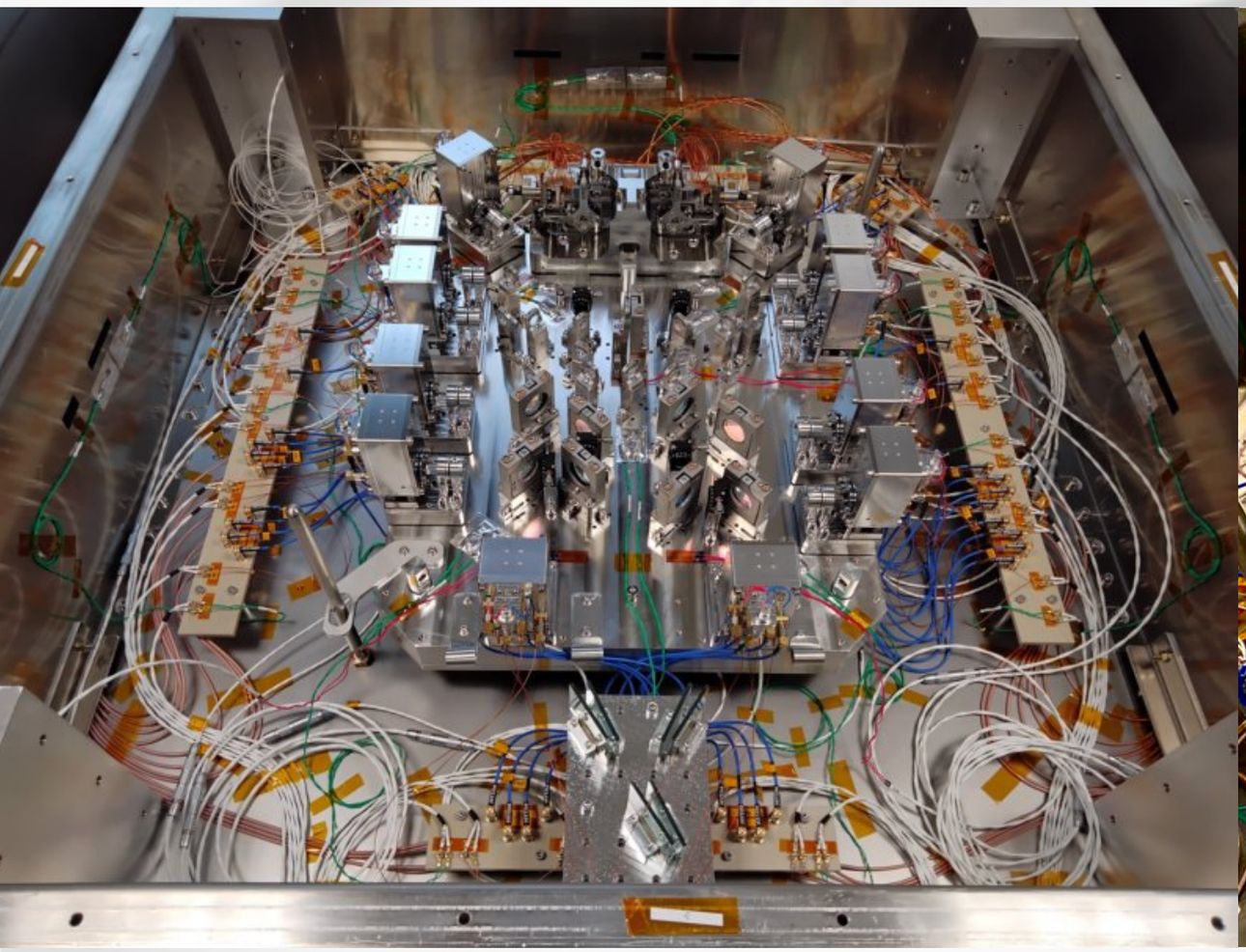
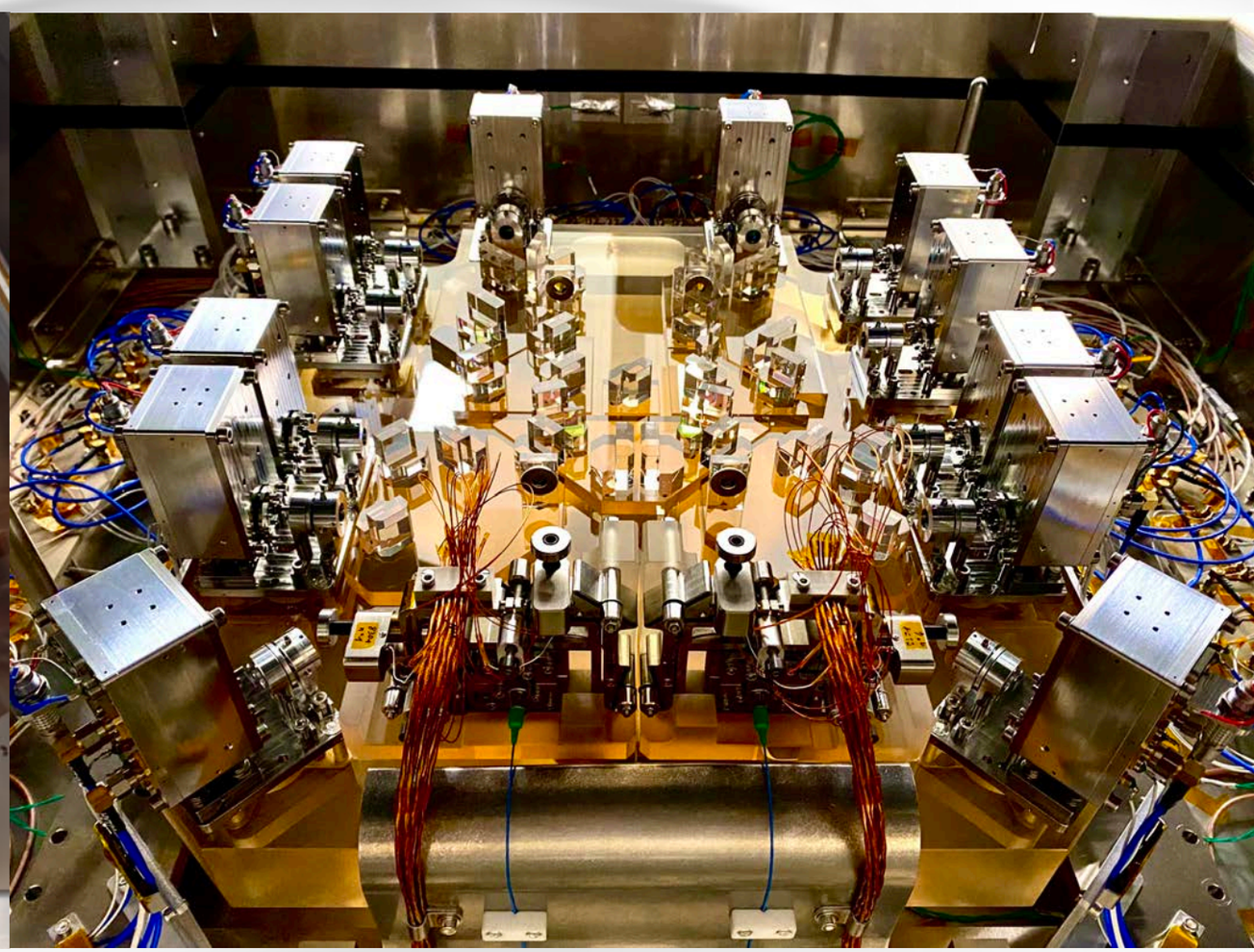
MIFO & ZIFO prototypes

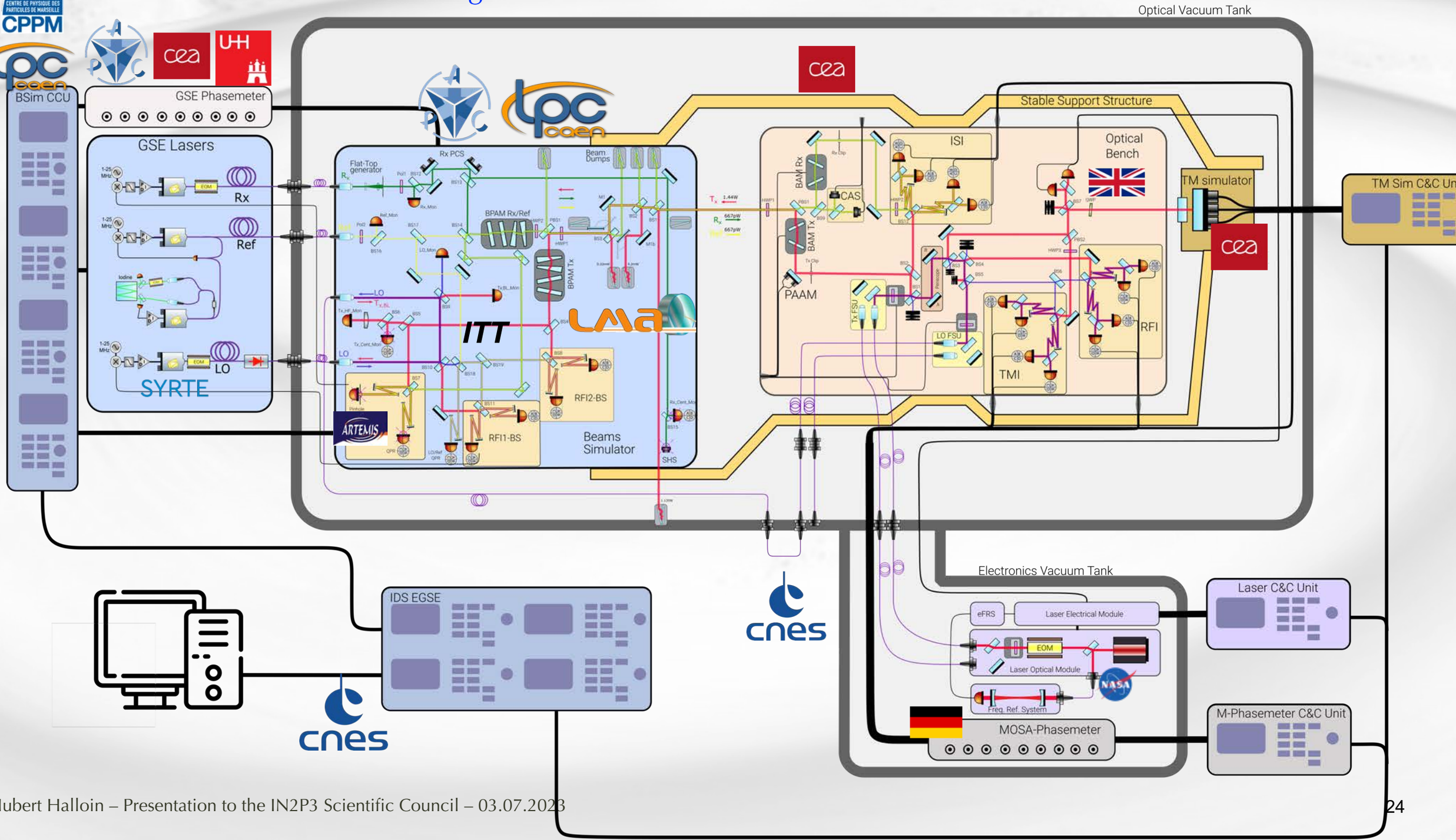
- Invar and Zerodur interferometric benches for evaluating the achievable metrology performance in representative conditions on ground
  - Return of experience for developing the IDS and OTS GSEs
- MIFO tests completed in 2022 at the APC
- ZIFO tests on going at the LAM (until sept. 2023)
  - Further ‘ad-hoc’ experiments at the APC afterwards





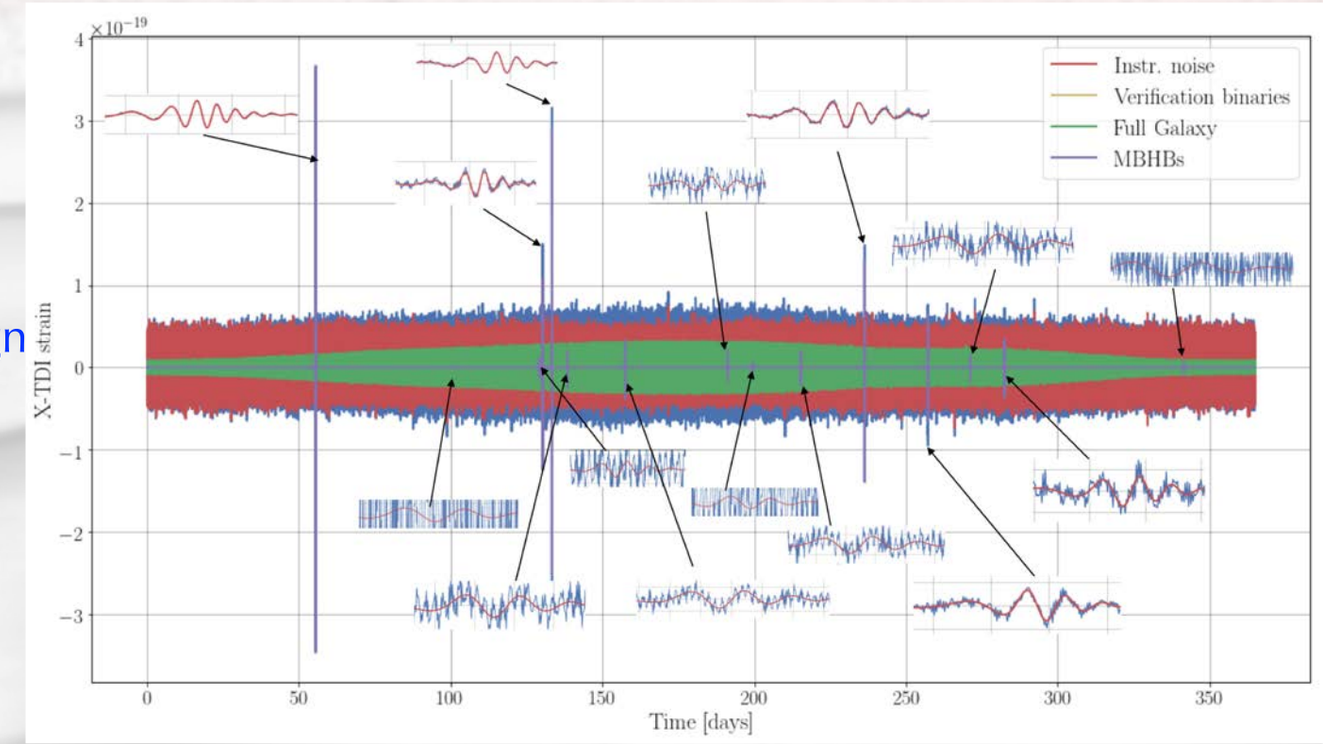
IDS Test Setup

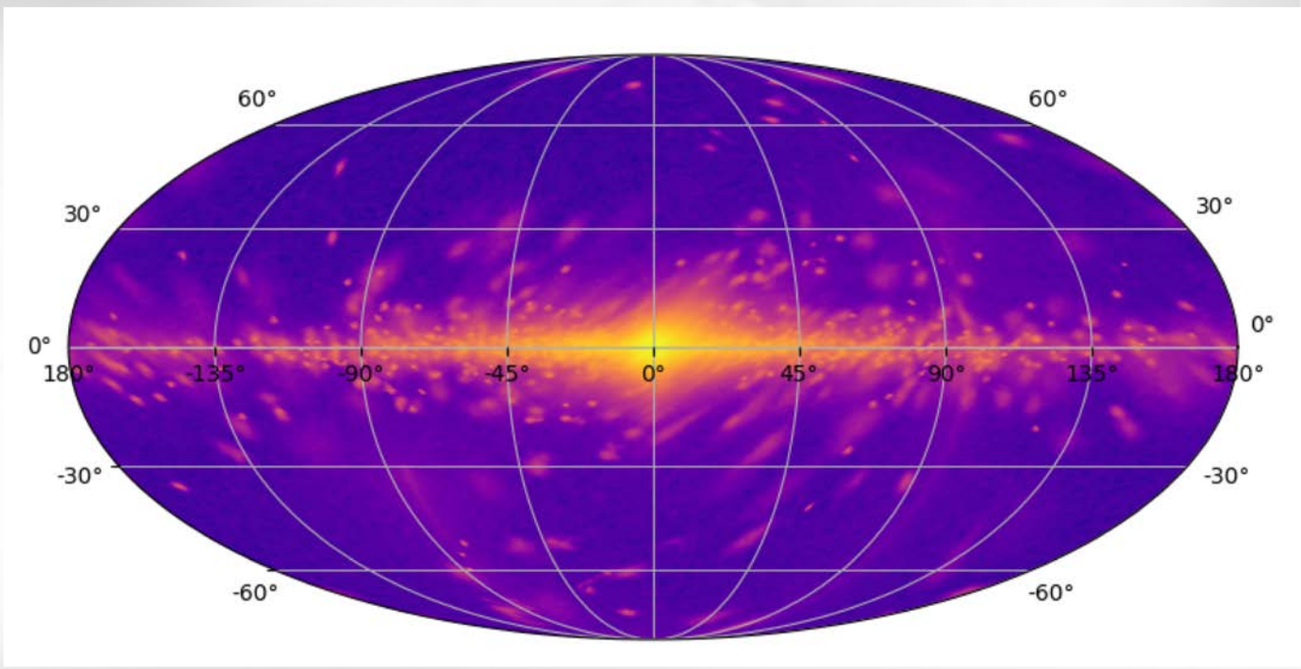
- Main objective : validate the metrological concept of LISA
  - Critical functionnalities
  - Optical path length stability
  - Wavefront errors and alignment accuracies



From LISA Data Challenges to DDPC deliverables

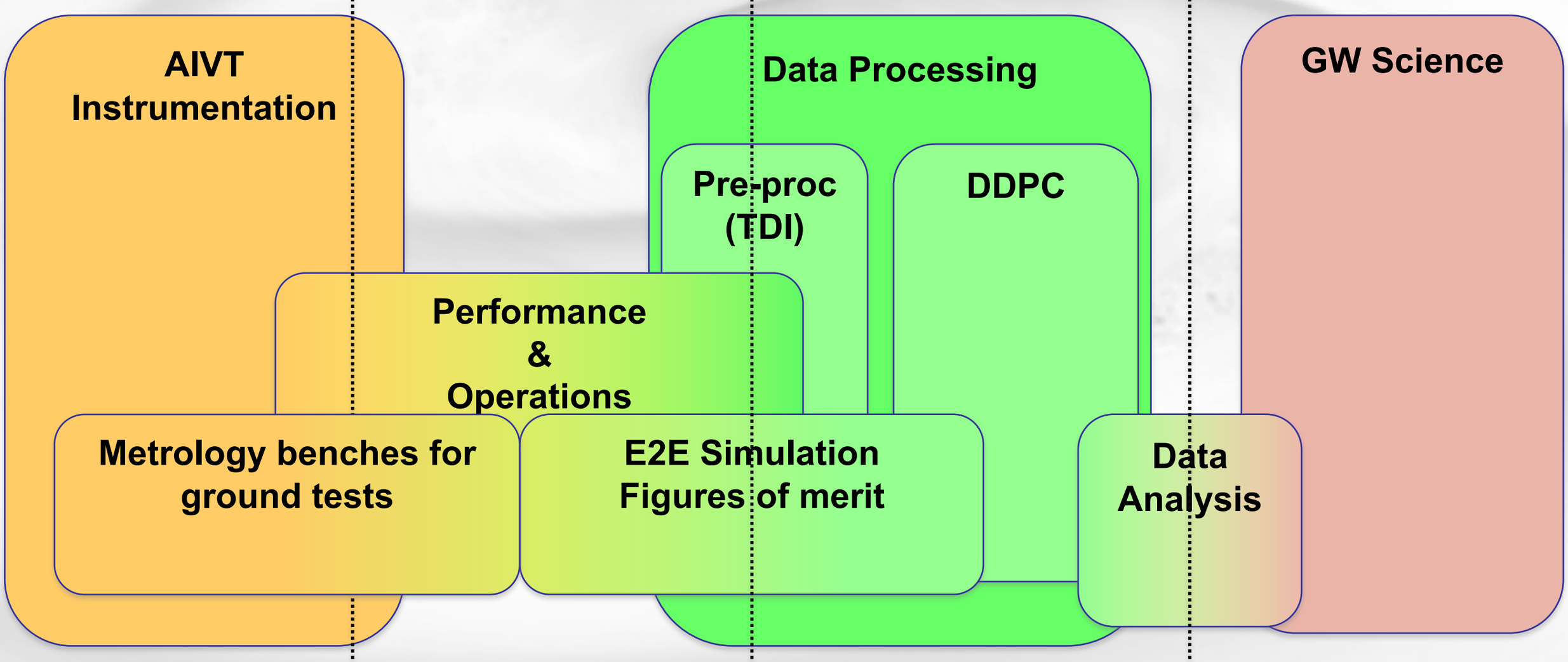
- Since 2018, LISA Data Challenges have been organized and fulfilled to :
  - Foster R&D on this challenging signal dominated analysis
  - Support phase A and B ESA reviews on that topic
  - Get preliminary cost estimate and DDPC design drivers
- Challenges
  - LDC 1a Radler
    - Various DA approaches for all GW source types
  - LDC 2a Sangria
    - 2/3 global-fit prototypes for first enchilada (GB+MBHB) challenge including one developed by APC+L2IT
  - LDC 2b Spritz
    - Dealing with gaps and glitches
- LDC have required :
  - development of a E2E simulation pipeline to produce realistic L1 TDI data
  - organization of weekly telecons to drive that effort
  - development of a web data portal to share data and results
  - development of evaluation and comparison tools
- This effort has mainly been supported by the French community





Overview of the French contributions

- Broad and continuous coverage from instrument development to GW science



Conclusion

Conclusions

- With the support of the institute and the CNES, the IN2P3 labs have acquired leading roles on LISA projects from instrumentation to science exploitation

- Optical Ground Test equipment
  - Challenging optical benches, based on previous R&D activities and prototypes
  - Tight schedules to manufacture, tune and verify the Beams Simulator in time
  - The design and production of the bench starts **now**, with important engineering activities until 2026.

- Performance & Operations
  - Important impact on science return achievable with limited HR investment
  - From 2030 on (after FM1 tests), some engineers and researchers participating to the OGSEs development will move to the preparation (and commissioning) of the instrument in flight

- Distributed Data Processing Center
  - Crucial to the scientific exploitation of LISA
  - Many interfaces and contributors to coordinate
  - The DDPC is important to maintain a strong link from instrument science to analysis pipelines

- **LISA is at the eve of adoption**
  - The next few years are crucial for demonstrating the ability of the laboratories to deliver complex and sophisticated hardware and software for LISA.
  - The continuing support of the IN2P3 is therefore very important, e.g. by securing the permanent positions with the expertise brought by young engineers and researchers.