



# HIGH PRECISION HETERODYNE INTERFEROMETRY

## MIFO/ZIFO DEMONSTRATORS

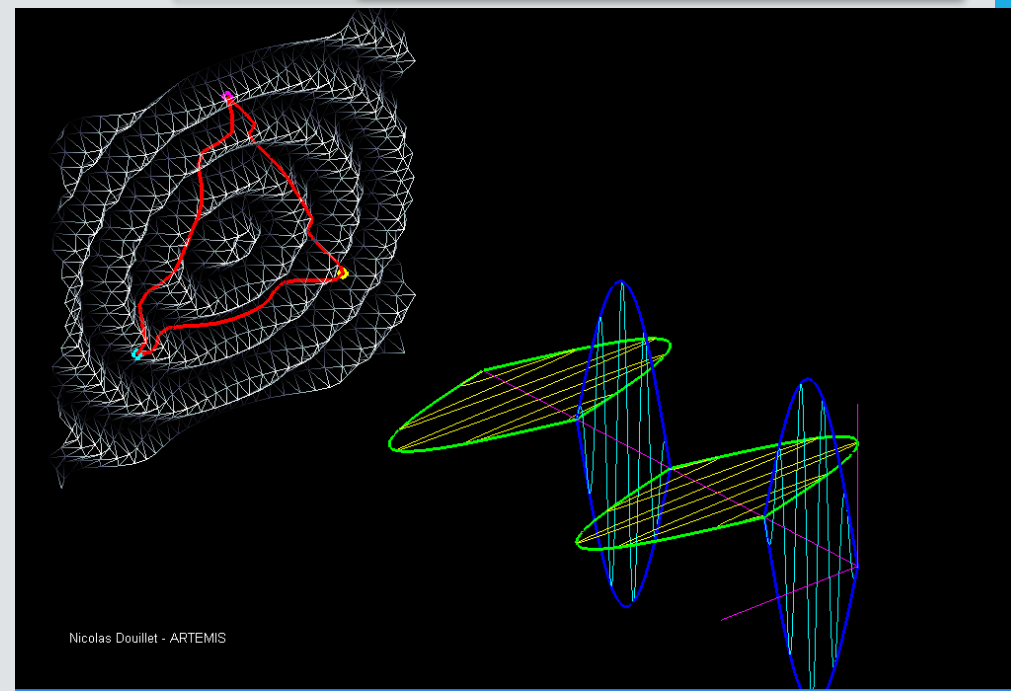
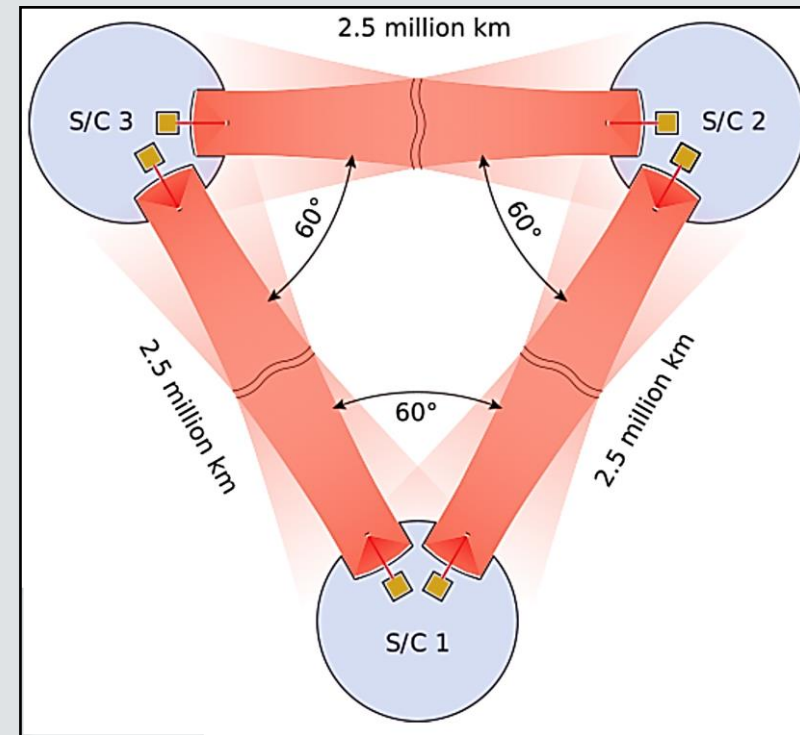
LABORATOIRE ASTROPARTICULE ET COSMOLOGIE  
MAXIME VINCENT

7<sup>ÈME</sup> ASSEMBLÉE GÉNÉRALE DU GDR ONDES GRAVITATIONNELLES



# THE LISA MISSION

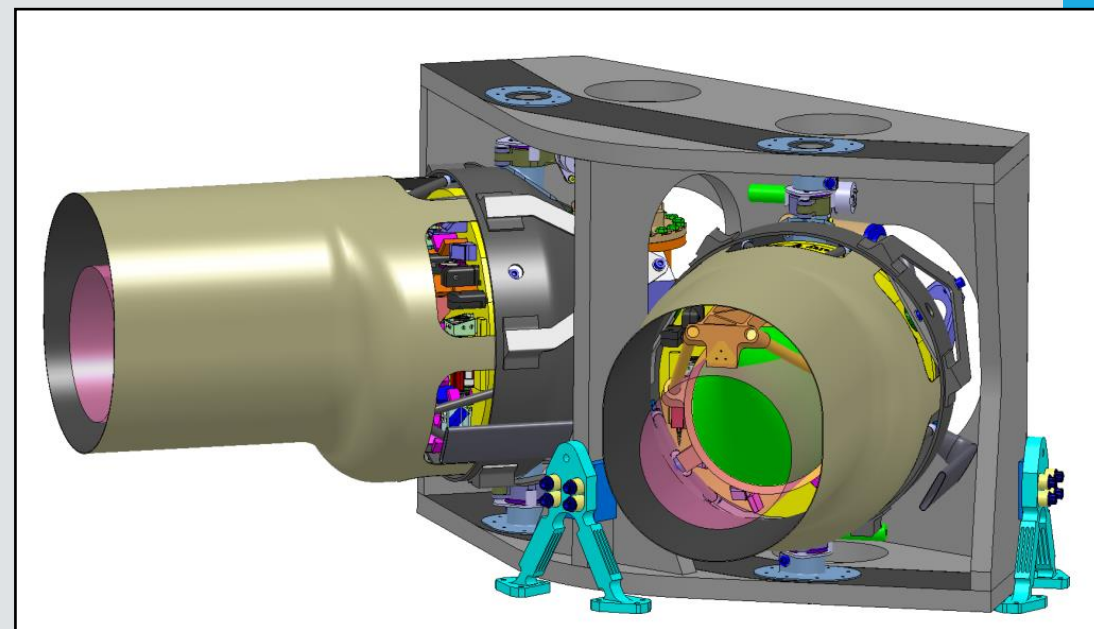
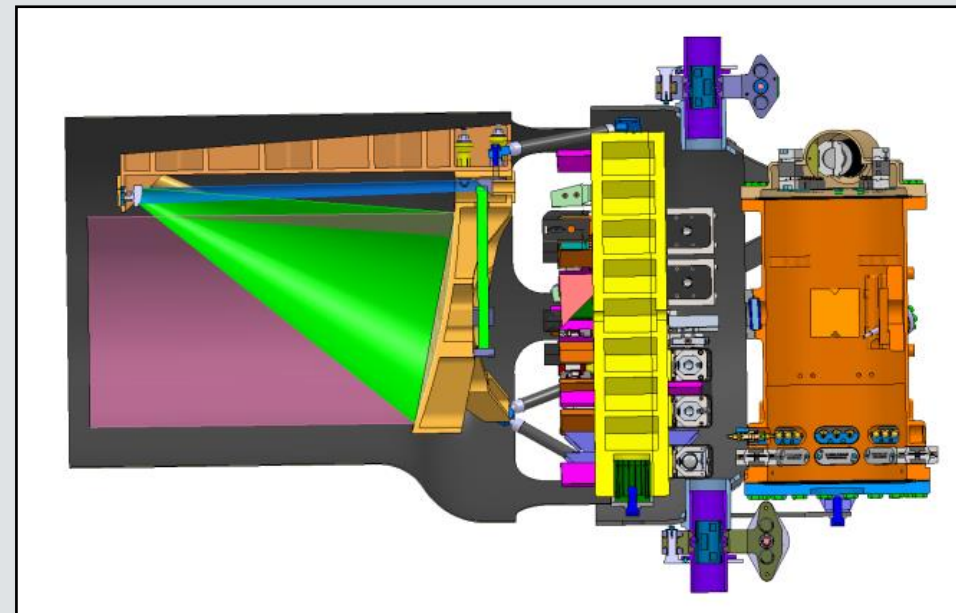
- Three satellites constellation in a triangular formation, forming 3 interferometers with 2.5 MKm arms
- Detection in the 0,1 mHz to 1 Hz frequency band
  - Richest frequency band for GW astronomy
  - Frequency band not accessible on earth due to seismic noise at low frequency
- Utilisation of **heterodyne interferometry** : the frequency of the two interfering laser beams are slightly shifted (  $\sim 15$  MHz )
  - Results in a sine optical signal (**beatnote**) oscillating at the frequency of the off-set between both lasers
  - Variation of the optical pathlength will induce a variation in the phase of the beatnote signal





# TESTING THE INSTRUMENTS

- The optical section of the LISA instrument is called the **MOSA** (Movable Optical Sub Assembly)
- France is tasked with the **testing** and **characterization** of the **interferometric detection system** at the heart of the MOSA and insure that **picometer stability** is reached on the interferometers of the optical bench
- The french laboratories are organized as a consortium called the **LISA France consortium** working together for the development of on-ground testing equipment
- Demonstrator campaign to develop expertise and prove our capability fullfil our commitment to ESA

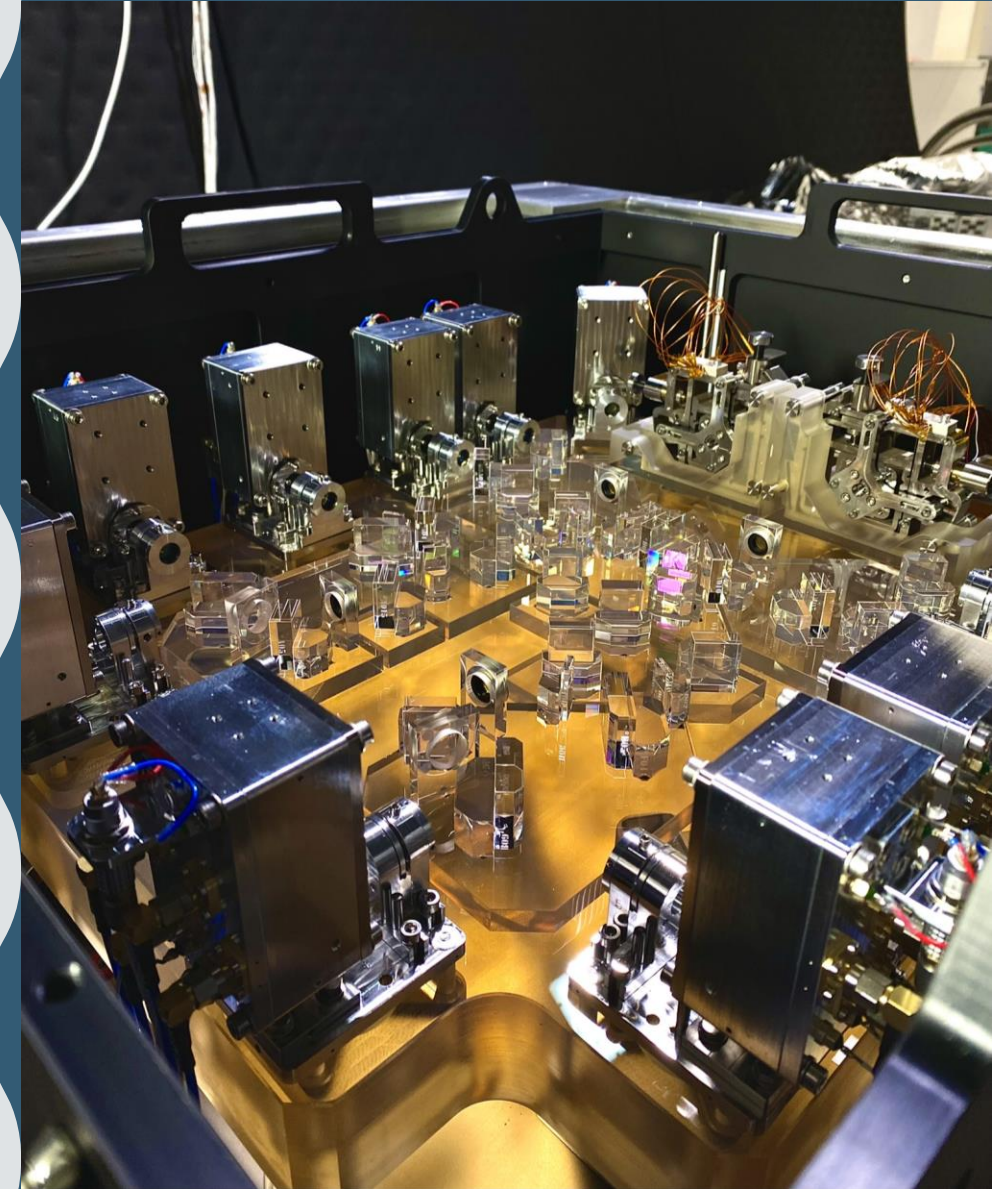






# HETERODYNE INTERFEROMETRY DEMONSTRATORS

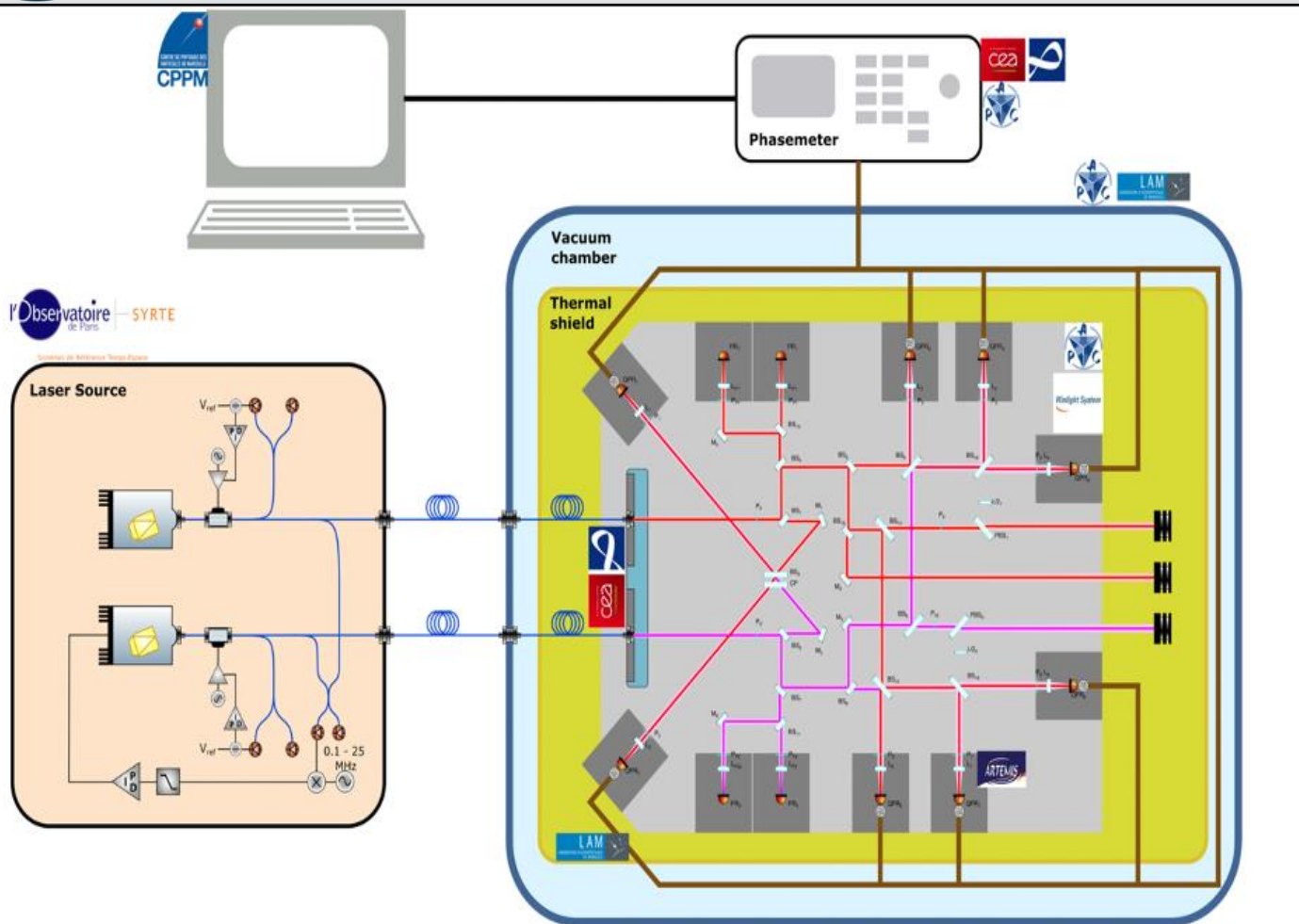
- Two heterodyne interferometry demonstrator :
  - MIFO : Metallic InterFerOmeter Optical Bench
  - ZIFO : Zerodur InterFerOmeter Optical Bench
- Objectives :
  - Optical pathlength measurement with a stability of 10 pm/VHz in the 0,1 mHz to 1 Hz frequency band
  - Organisation of the french community to prepare for future and more complex optical benches
  - Identification of noise sources, environmental parameters and associated performances
  - Development of the data analysis procedures
- MIFO test campaign to prepare the ZIFO campaign
- Laser system stability for MIFO :  $\sim 10\,000$  Hz/VHz
- Laser system stability for ZIFO :  $< 30$  Hz/VHz



ZIFO Optical Bench



# ZIFO EXPERIMENTAL SET UP



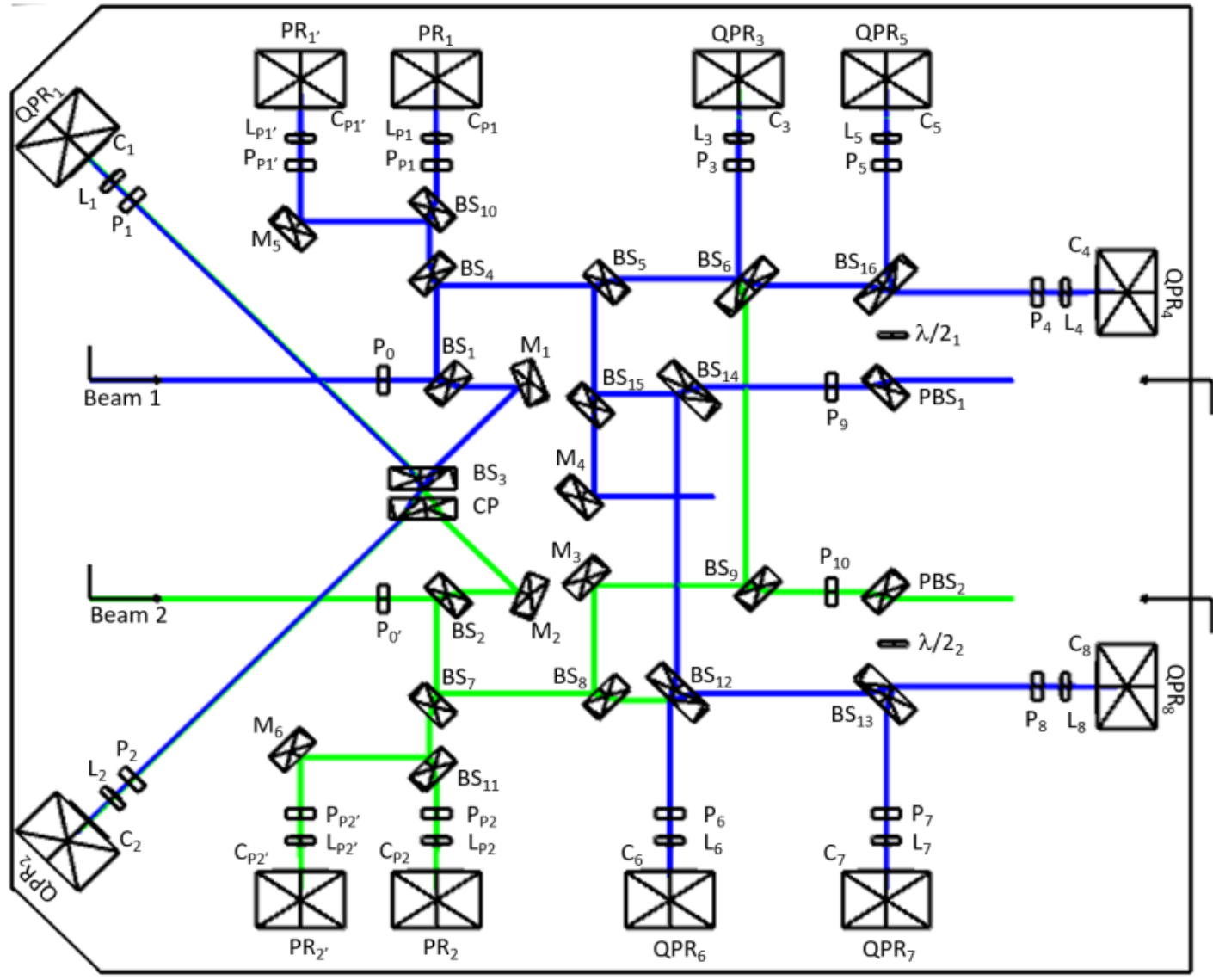
**MIFO Laser** : two laser beam (1064 nm) are phase locked to one another and have a  $\sim 15$  MHz frequency offset

**ZIFO Laser**: provides a frequency reference to stabilize the MIFO laser system

**Zerodur baseplate** : thermally ultra stable material

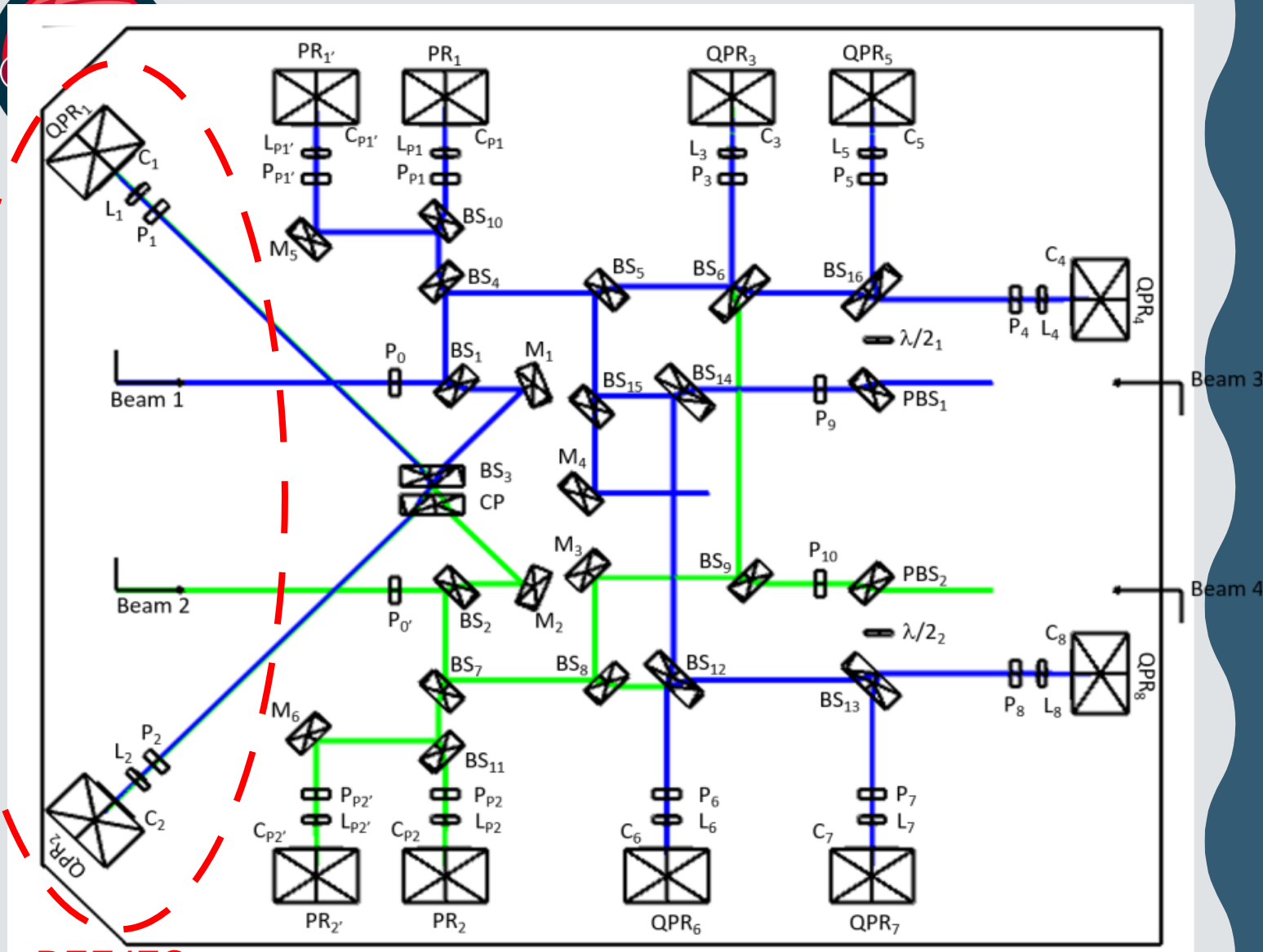
**Molecular adhesion**: increase the thermal stability of the components on the OPL

**Phasemeters** : receives the interferometric signal from the photoreceptors and measures the frequency of the signals



# OPTICAL LAYOUT

Three interferometers :



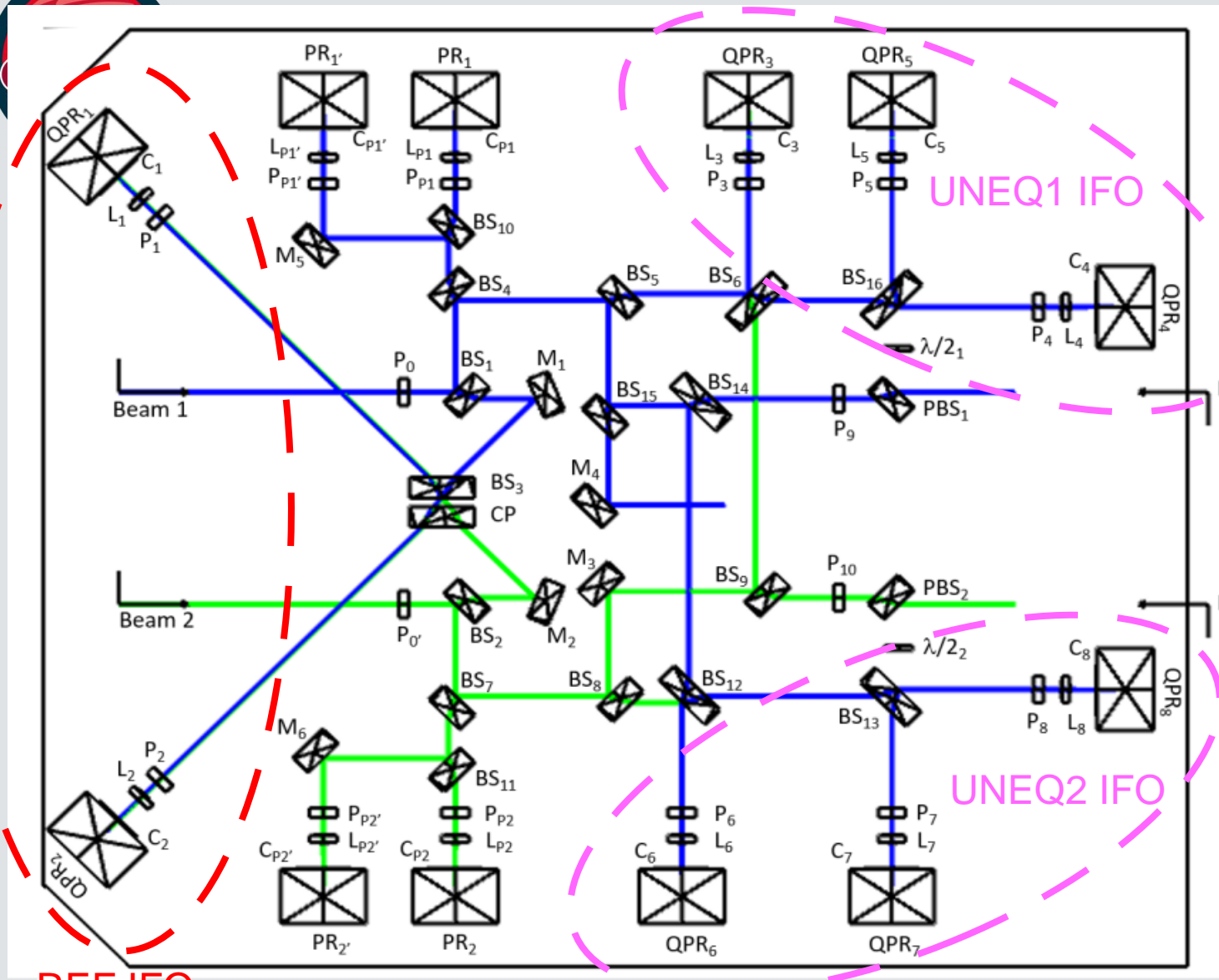
REF IFO

## REFERENCE INTERFEROMETER

Equal arm interferometer : same optical pathlength for both lasers

1. used as the reference IFO for phase measurements
2. used to remove thermoelastic noise caused by the optical fibers and other common correlated noises





# UNEQUAL ARM INTERFEROMETERS

Unequal arm IFO : optical path length difference of ~20 cm between laser 1 and 2

UNEQ 1 and 2 are used to **estimate the measurement noises**, like thermal noises and laser frequency noise

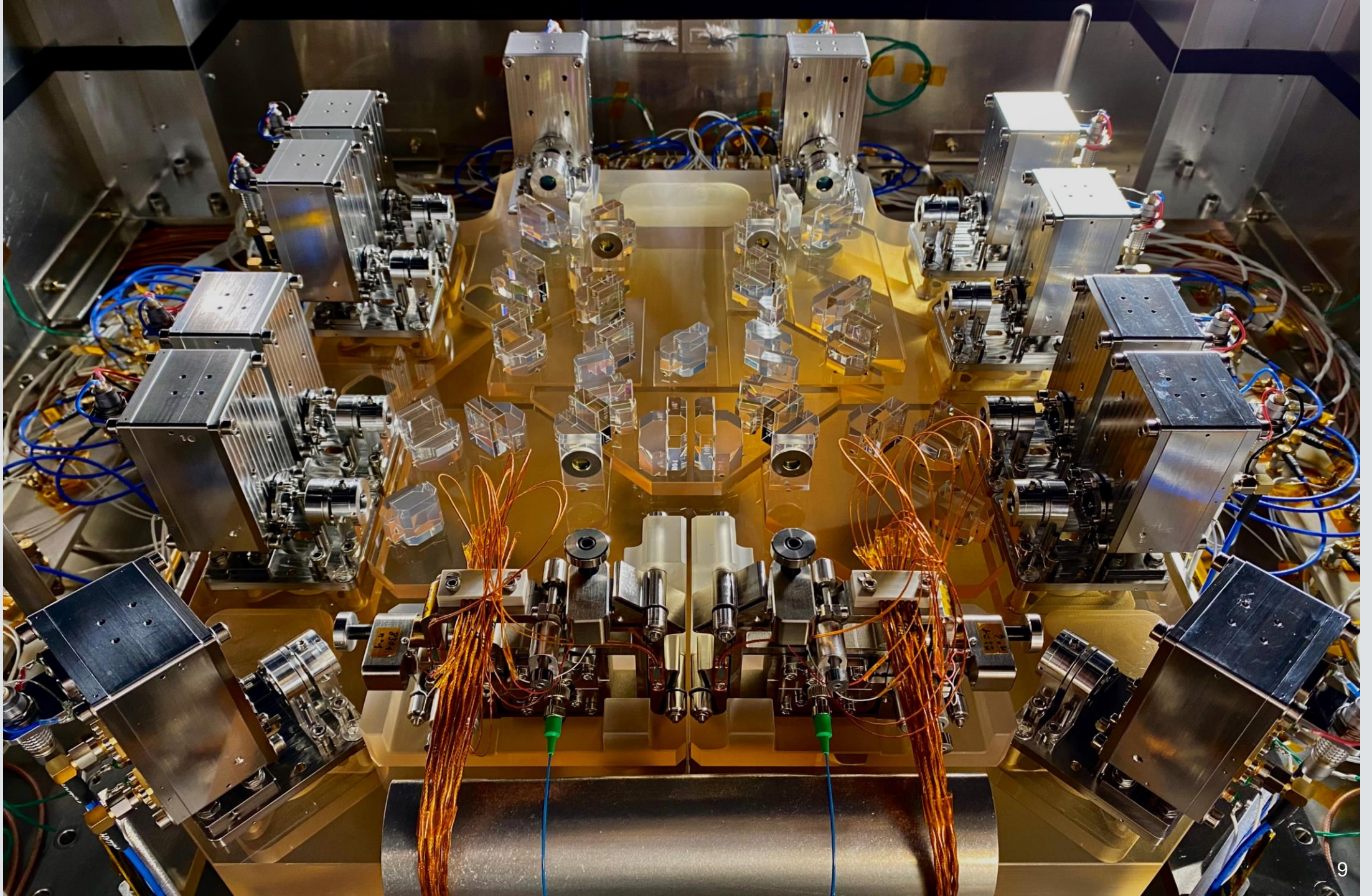
The combination of the IFO's allows to retrieve the **optical path length stability**

REF IFO

UNEQ1 IFO

UNEQ2 IFO







ZIFO Laser

MIFO Laser

Monitoring

Phasemeter



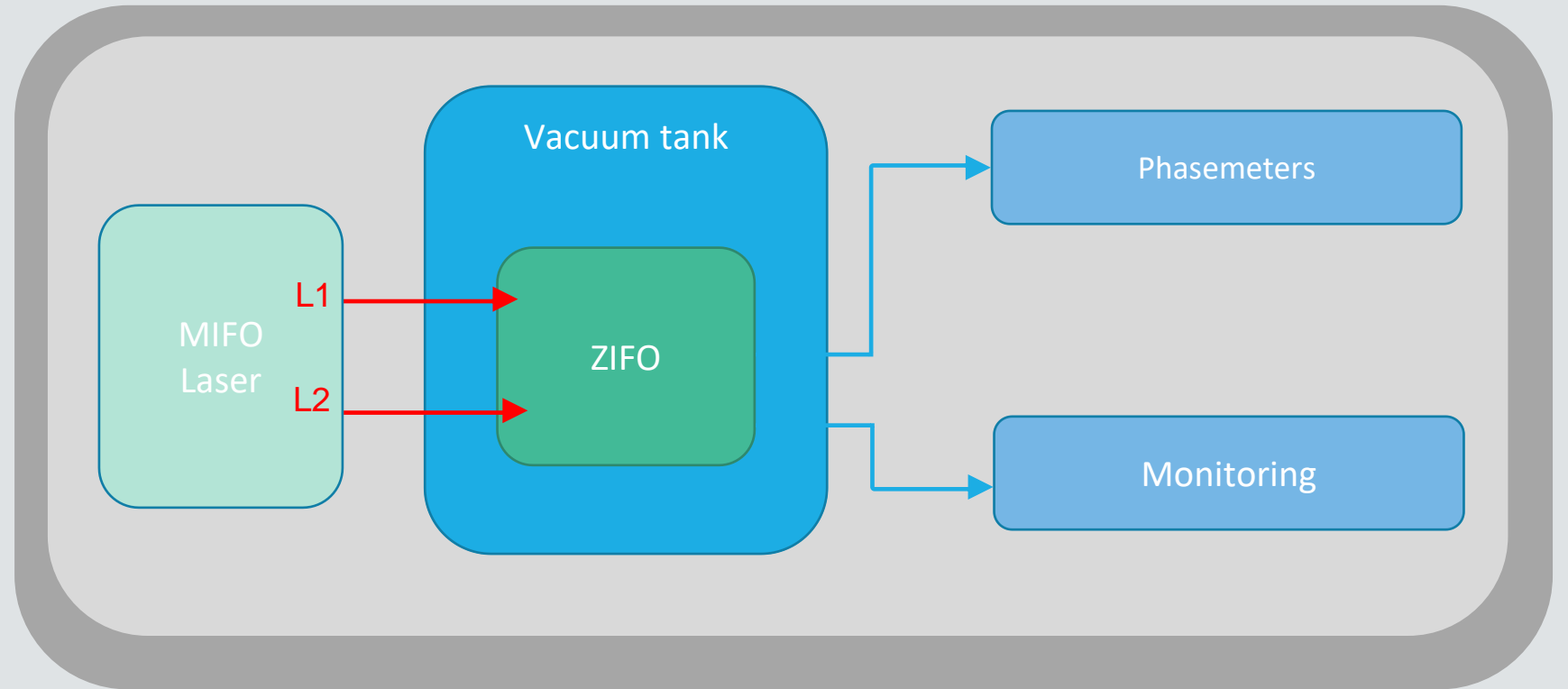
Laboratoire d'Astrophysique de Marseille



## ZIFO TESTS RESULTS : OPTICAL PATHLENGHT STABILITY MIFO LASER ONLY

Configuration 1 :

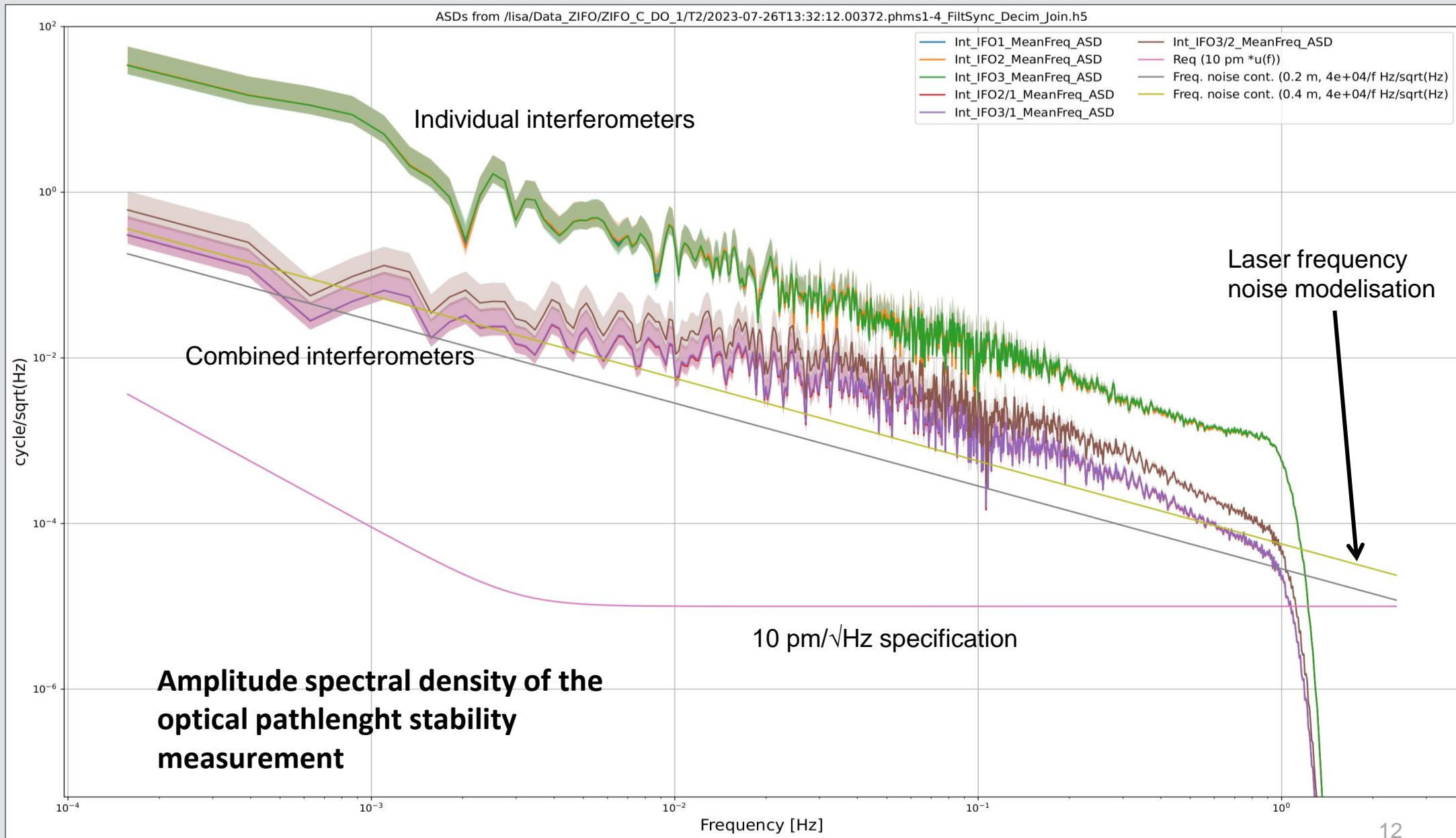
- In air
- MIFO Laser
- Laser frequency noise limited
- 15 hour acquisition with a heterodyne frequency of 16 MHz
- In the ERIOS vacuum tank at Laboratoire d'astrophysique de Marseille







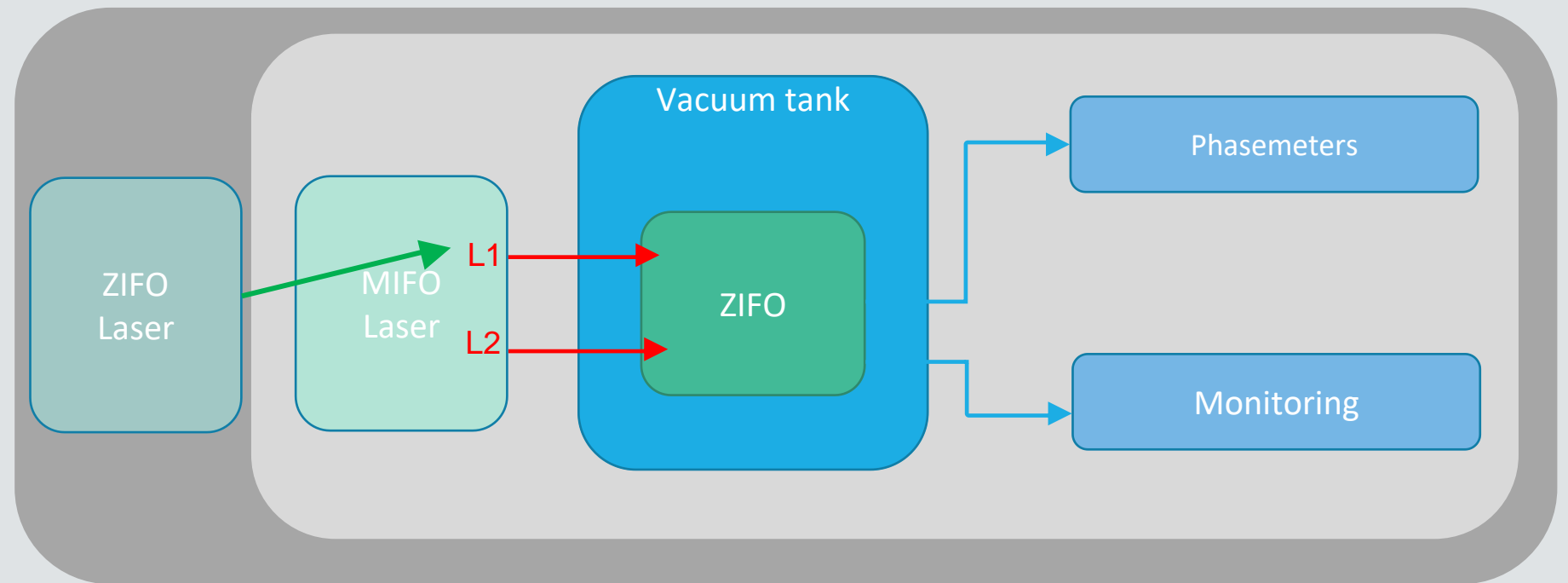
# ZIFO TESTS RESULTS : OPTICAL PATHLENGTH STABILITY WITH MIFO LASER







## ZIFO TESTS RESULTS : OPTICAL PATHLENGTH STABILITY WITH MIFO AND ZIFO LASER

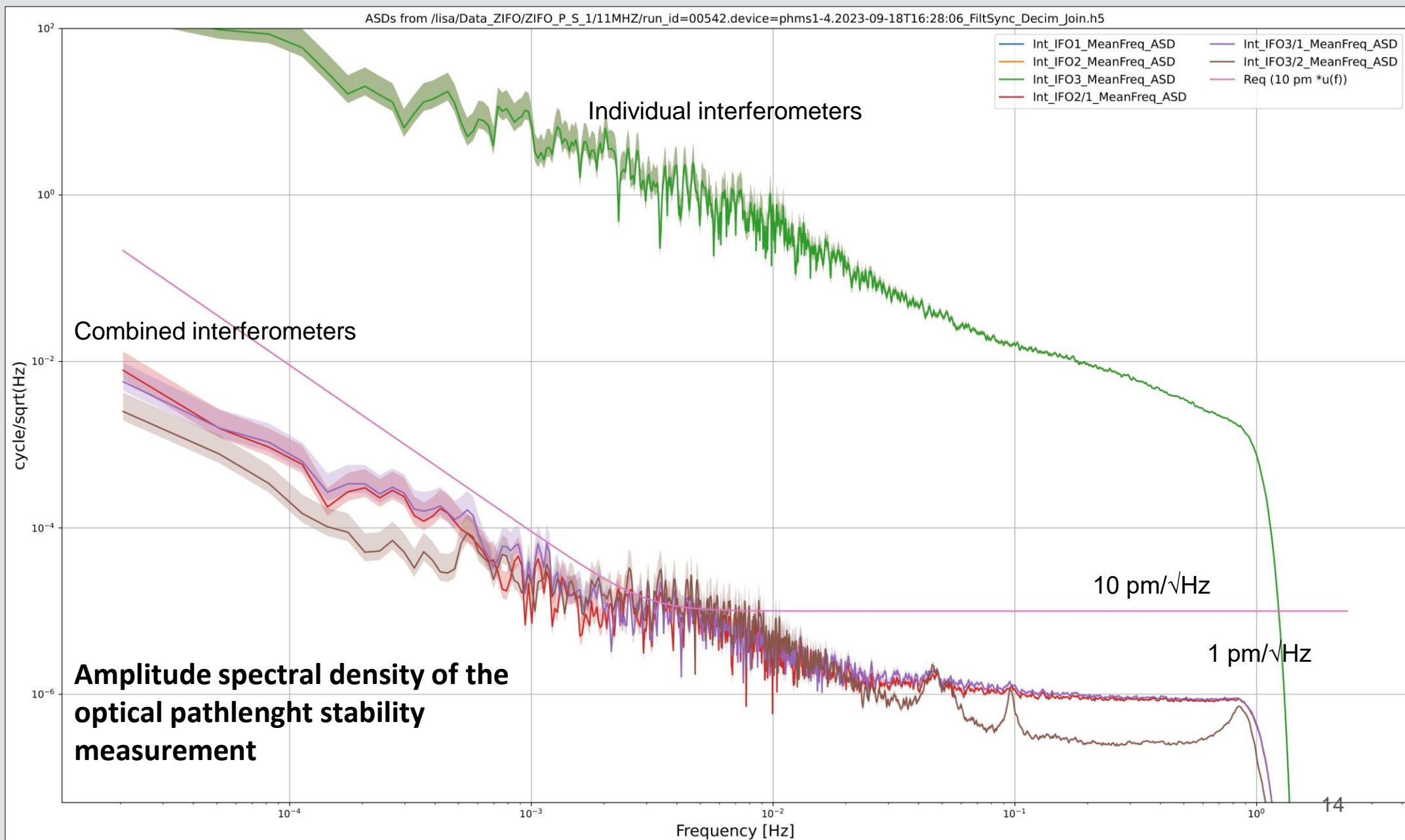


Configuration 2 :

- In secondary vacuum ( $10^{-6}$  mbar) in the ERIOS tank at Laboratoire d'astrophysique de Marseille
- **Additional stable frequency reference for the laser system**
- Heterodyne frequency of 11 MHz



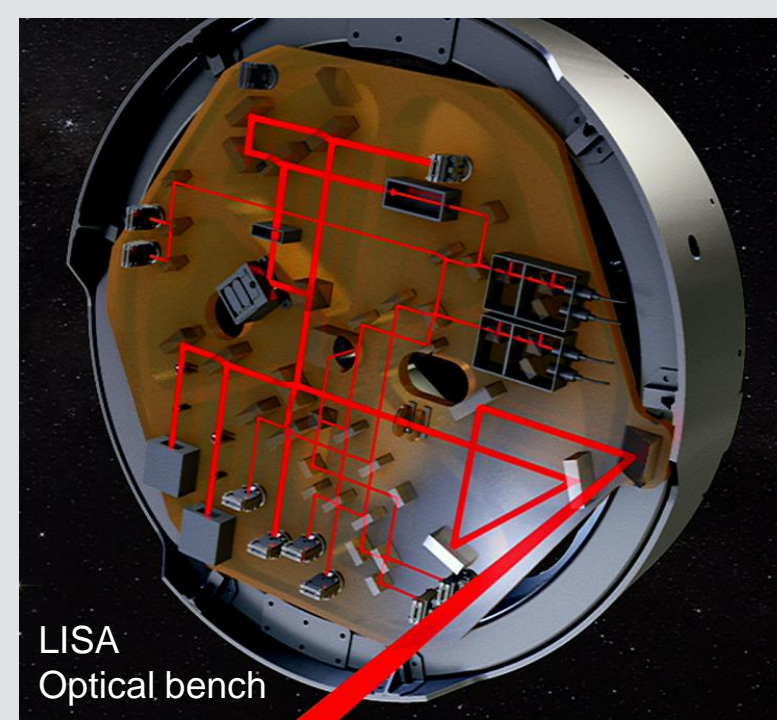
# ZIFO TESTS RESULTS : OPTICAL PATHLENGTH STABILITY WITH MIFO AND ZIFO LASER





# PAVING THE WAY FOR THE IDS TEST CAMPAIGN

- A lot of expertise has been gained in low frequency untrastabe interferometry amongst the french collaboration
- The technical specifrication for the 2026 IDS test campaign has already been reached for the ZIFO test campaign
- Development of the Beam Simulator optical test bench and IDS test set up are ungoing by the LISA France community for the futur picometric characterisation of the LISA interferometers



LISA  
Optical bench

Beam simulator bench

