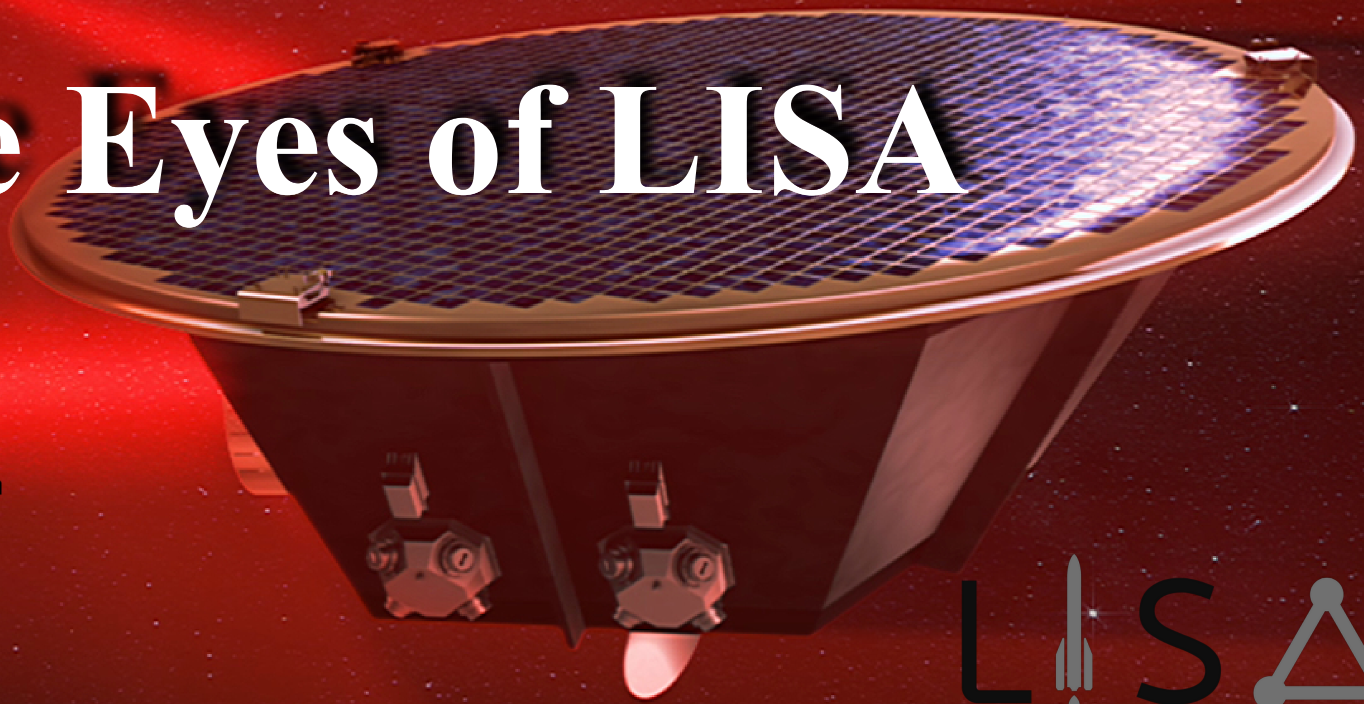
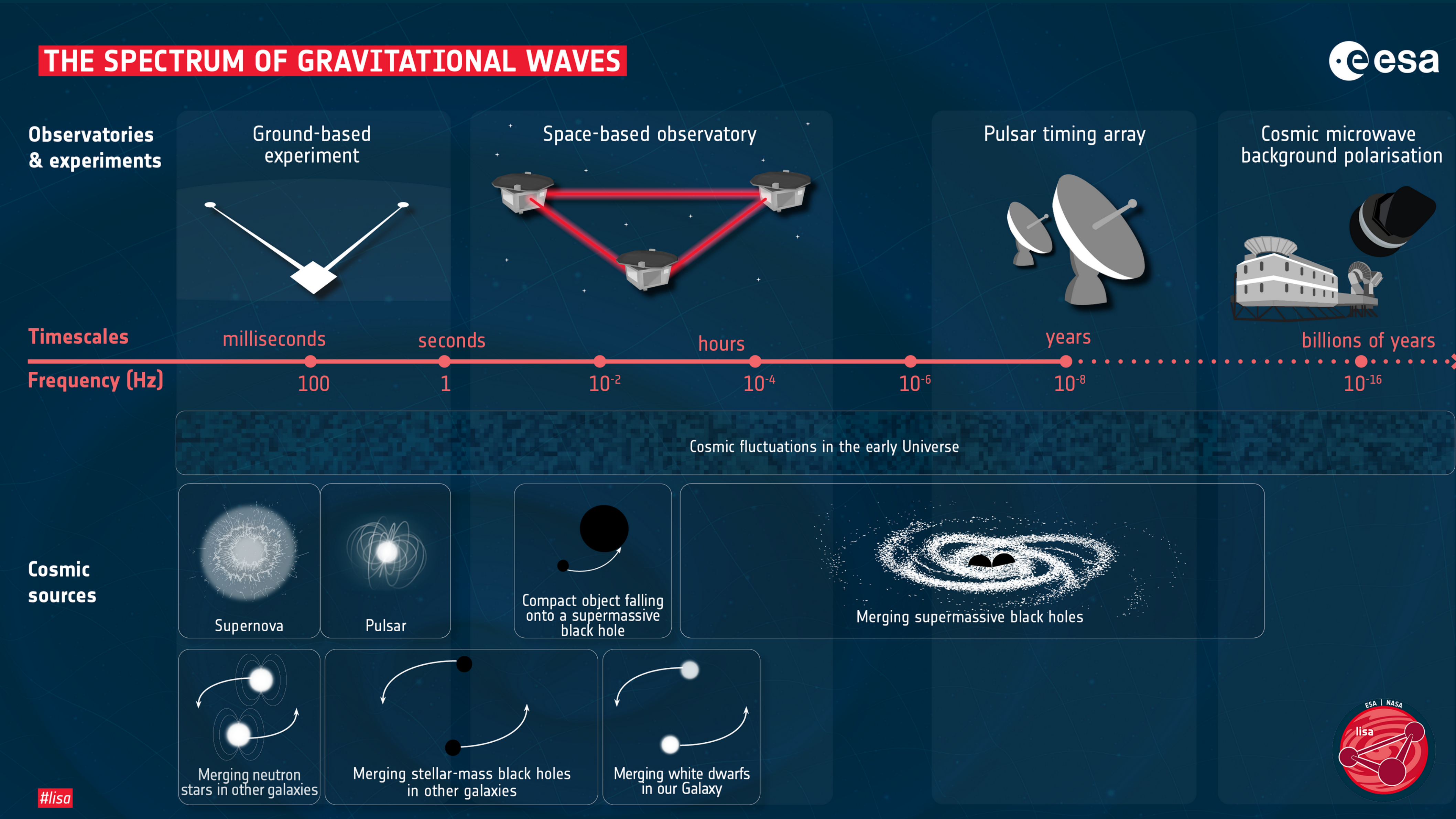
# The Eyes of LISA



Netherlands Institute for Space Research

Timesh Mistry (on behalf of the Nikhef LISA team)

LISA CONSORTIUM


THE SPECTRUM OF GRAVITATIONAL WAVES
esa
Observatories & experiments
Ground-based experiment
Space-based observatory
Pulsar timing array
Cosmic microwave background polarisation
Timescales
milliseconds
seconds
hours
years
billions of years
Frequency (Hz)
100
1
$10^{-2}$
$10^{-4}$
$10^{-6}$
$10^{-8}$
$10^{-16}$
Cosmic fluctuations in the early Universe
Cosmic sources
Supernova
Pulsar
Compact object falling onto a supermassive black hole
Merging supermassive black holes
Merging neutron stars in other galaxies
Merging stellar-mass black holes in other galaxies
Merging white dwarfs in our Galaxy
#lisa
ESA | NASA
lisa

# A Brief History of LISA

- 1993 – M3 proposal for 4 spacecraft ESA/NASA collaborative mission
- 1995 – LISA selected as ESA Cornerstone
- 1997 – 3 spacecraft ESA/NASA LISA proposal
- 2005 to 2011 – Mission directive changes to ESA –led mission called eLISA (evolving LISA)
- **2013 – LISA becomes a flagship mission for ESA.**
- 2015 – Launch of LISA pathfinder.
- 2016 – LISA pathfinder reaches orbit and mission
  **Nikhef + SRON join the party!**
- 2017 – LISA pathfinder mission end. LISA proposal

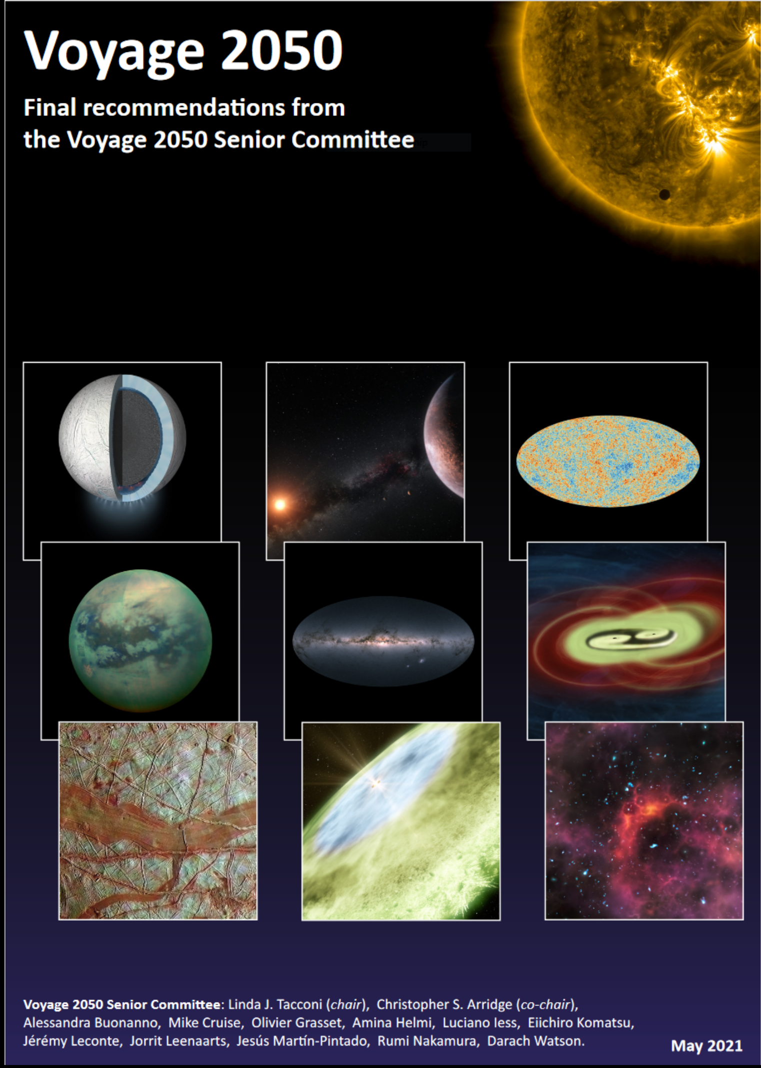
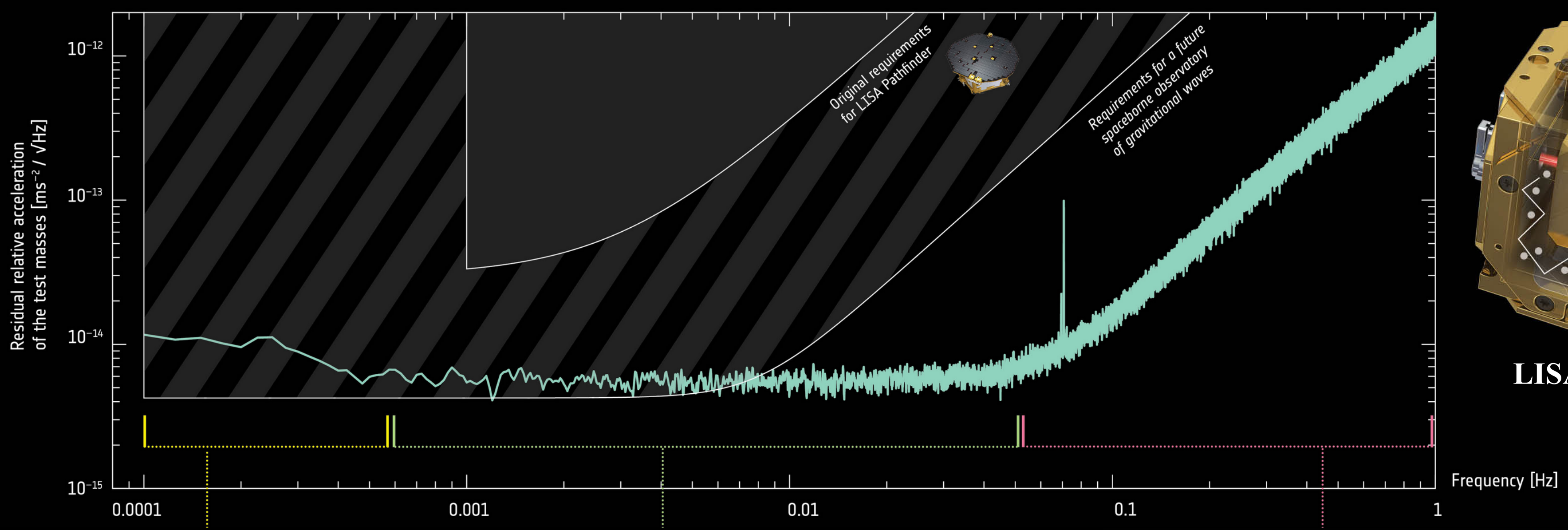
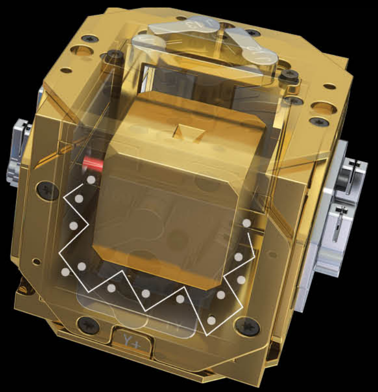


Image credit: ESA

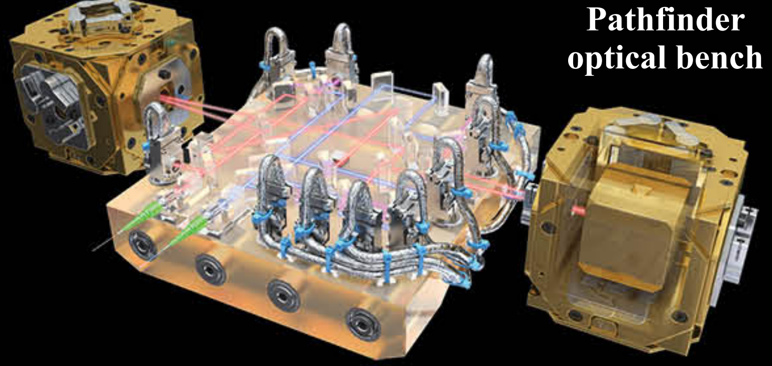


LISA Pathfinder test mass

# LISA Pathfinder 2015-2016

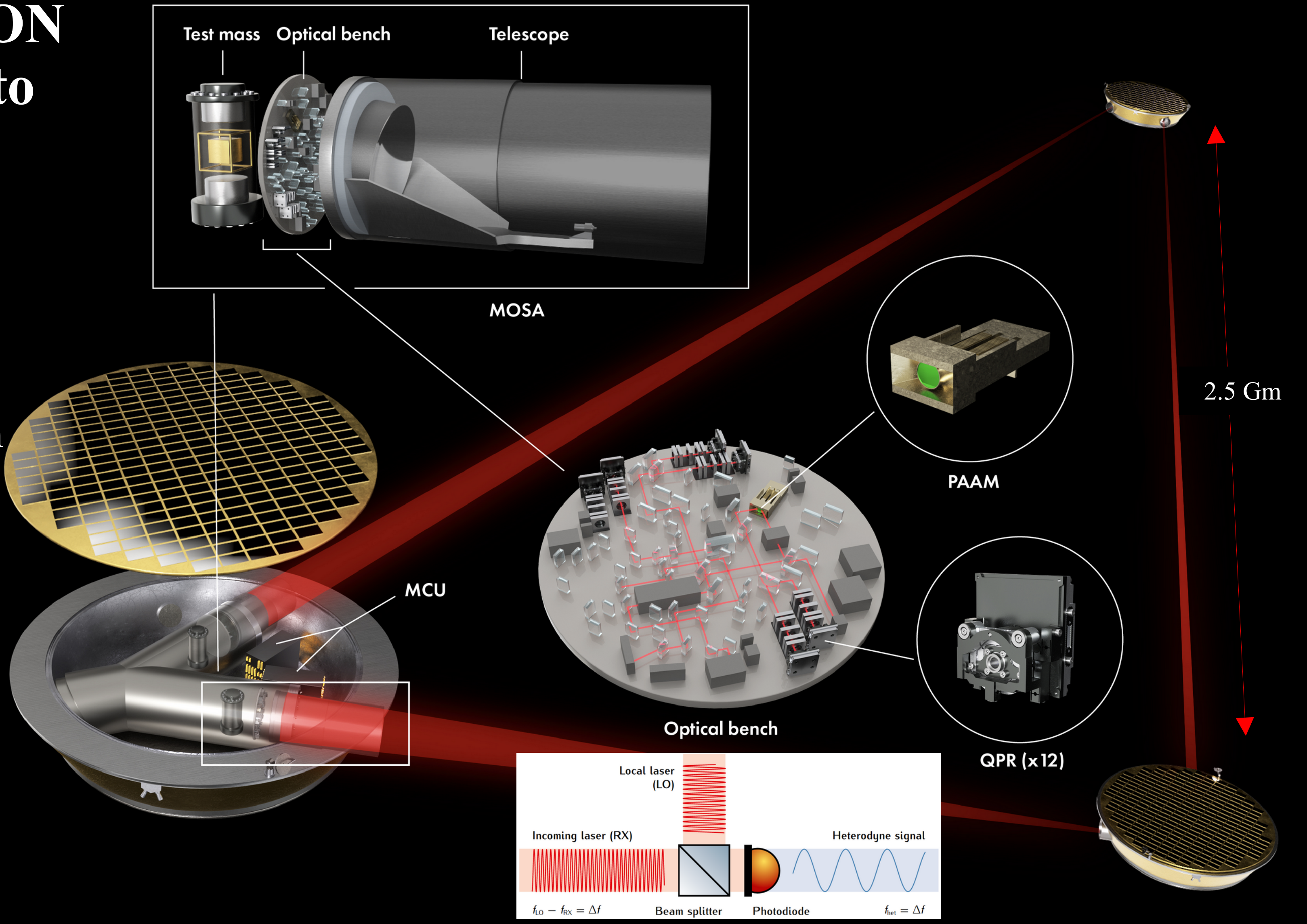
- Technology demonstration for test mass and reference interferometery.



LISA Pathfinder optical bench

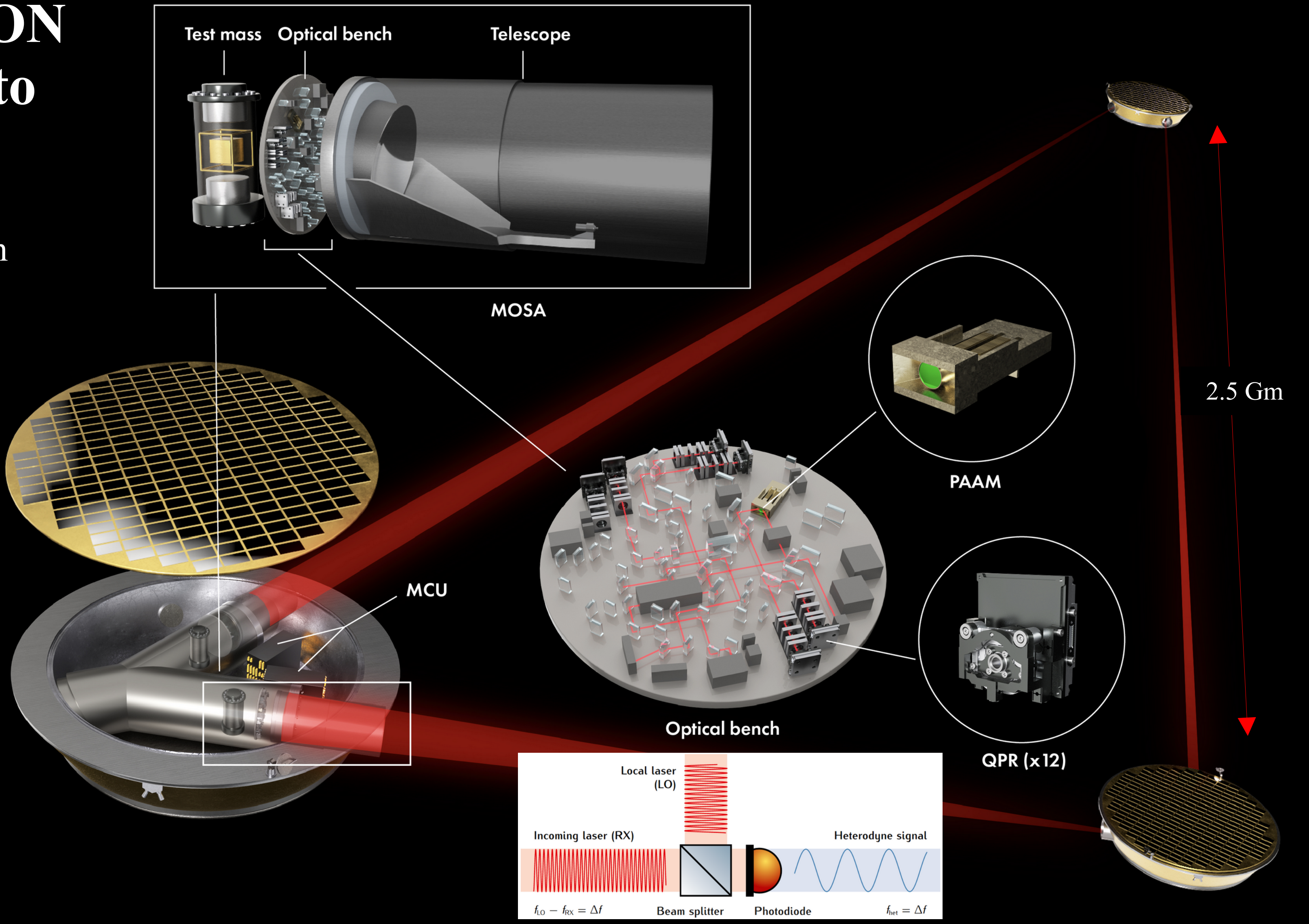
# Nikhef and SRON Contribution to LISA

- First time developing long arm (science) interferometer.
- Three inteferometers on each optical bench
  - Science
  - Test mass
  - Reference
- Quadrant Photo-Receiver (QPR) will measure the phase of the beatnote frequency.



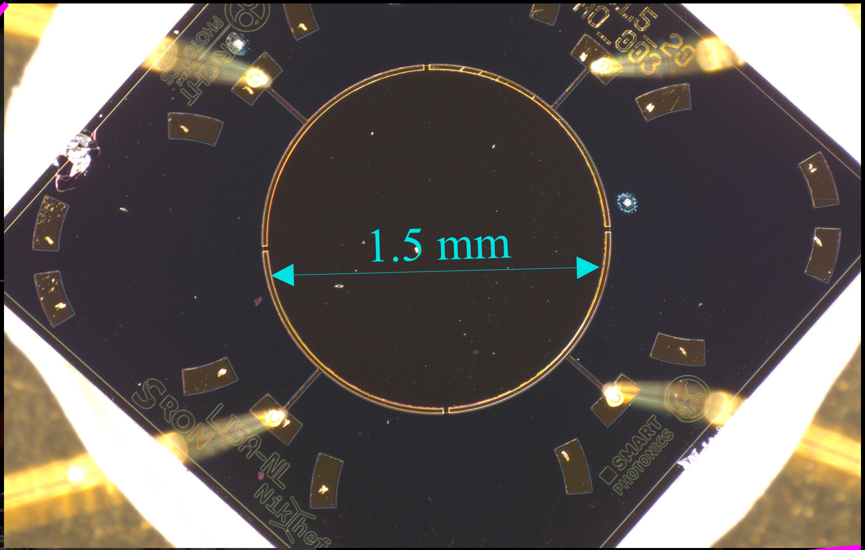
# Nikhef and SRON Contribution to LISA

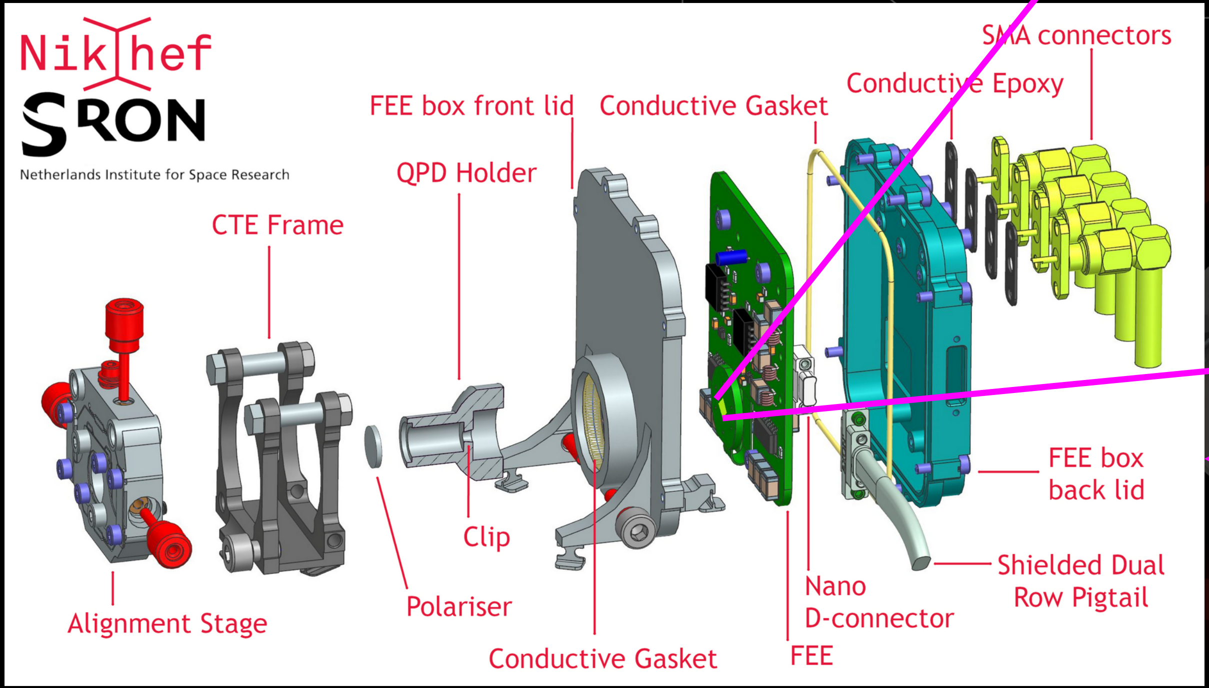
- Heterodyne signals from science interferometer.
  - 1-30 MHz beatnote frequency
  - Beatnote frequency changes due to satellite breathing
  - QPR will measure the phase change of the beatnote
  - GW signals in mHz frequency range
- **120 flight ready QPR systems!**

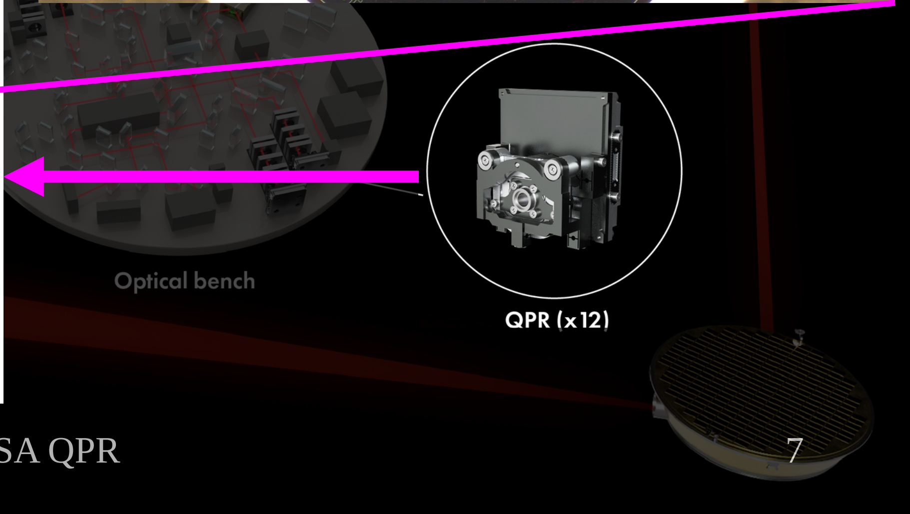


# What is the Quadrant Photo-Receiver (QPR)?

## Quadrant Photo-Diode



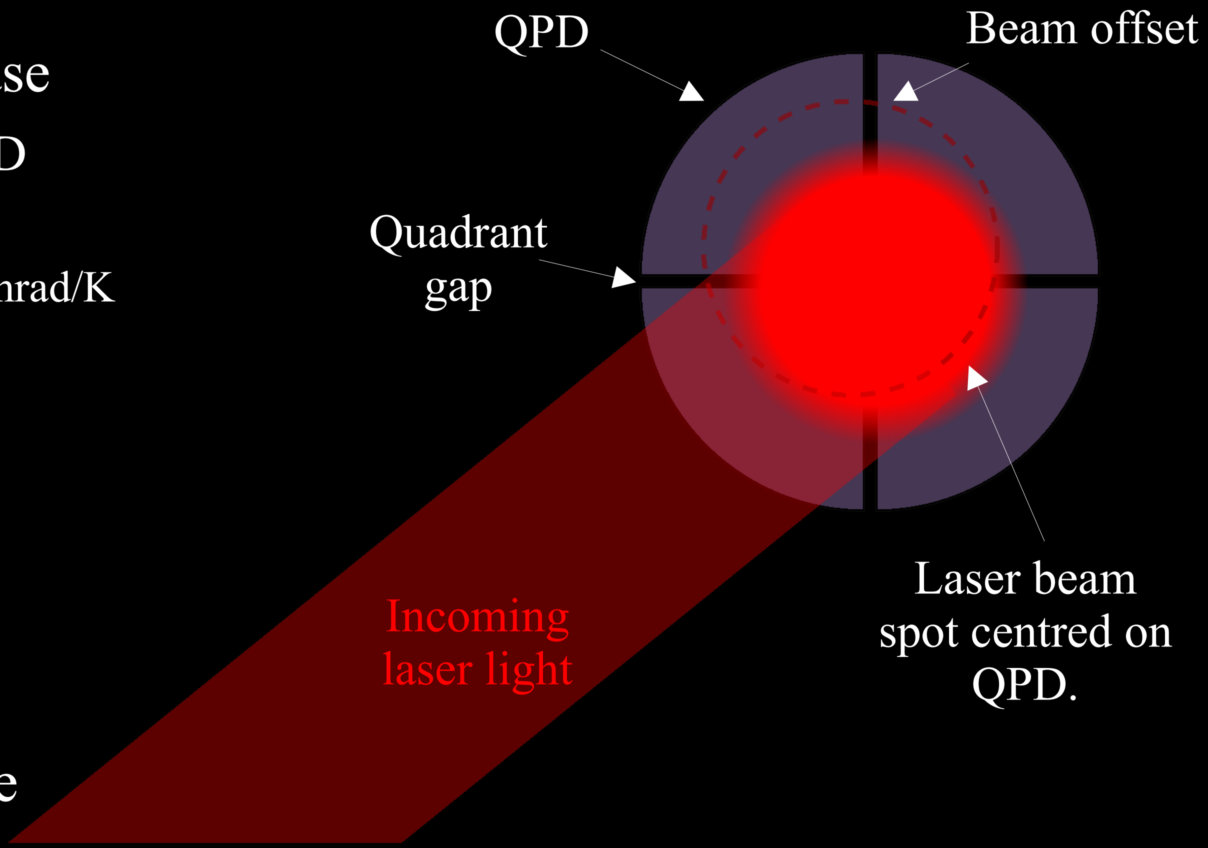




## Housing

# The Eyes of LISA - Why use QPDs?

- Science signal – Common Phase
  - Sets the specification of the QPD
    - Phase sensitivity of 6 µrad/√(Hz)
    - Phase temperature stability of 5 mrad/K
  - Hence low noise
    - Low capacitance.
  - Custom diode with a thickness uncommon in commercial photodiodes.

- Alignment – Differential Phase



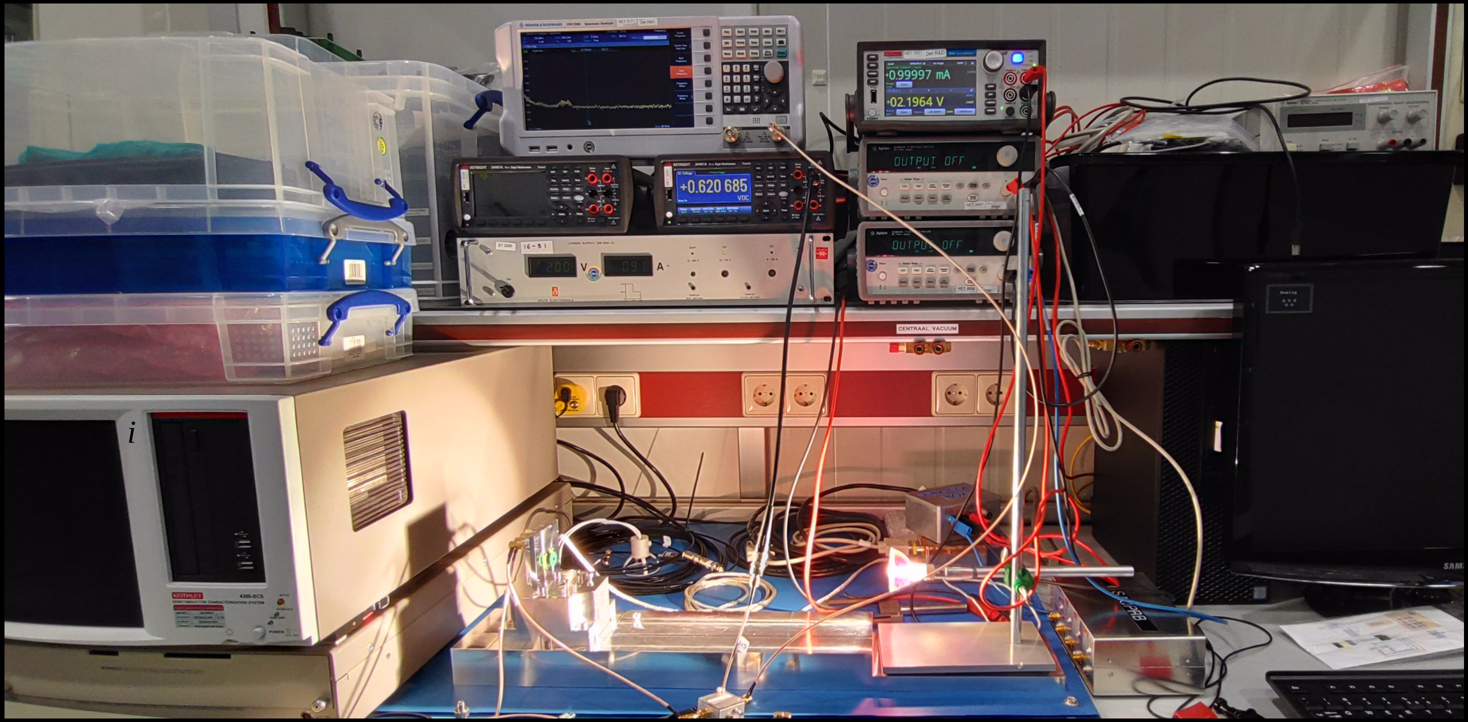
# Noise Measurements

- Equivalent input current noise.

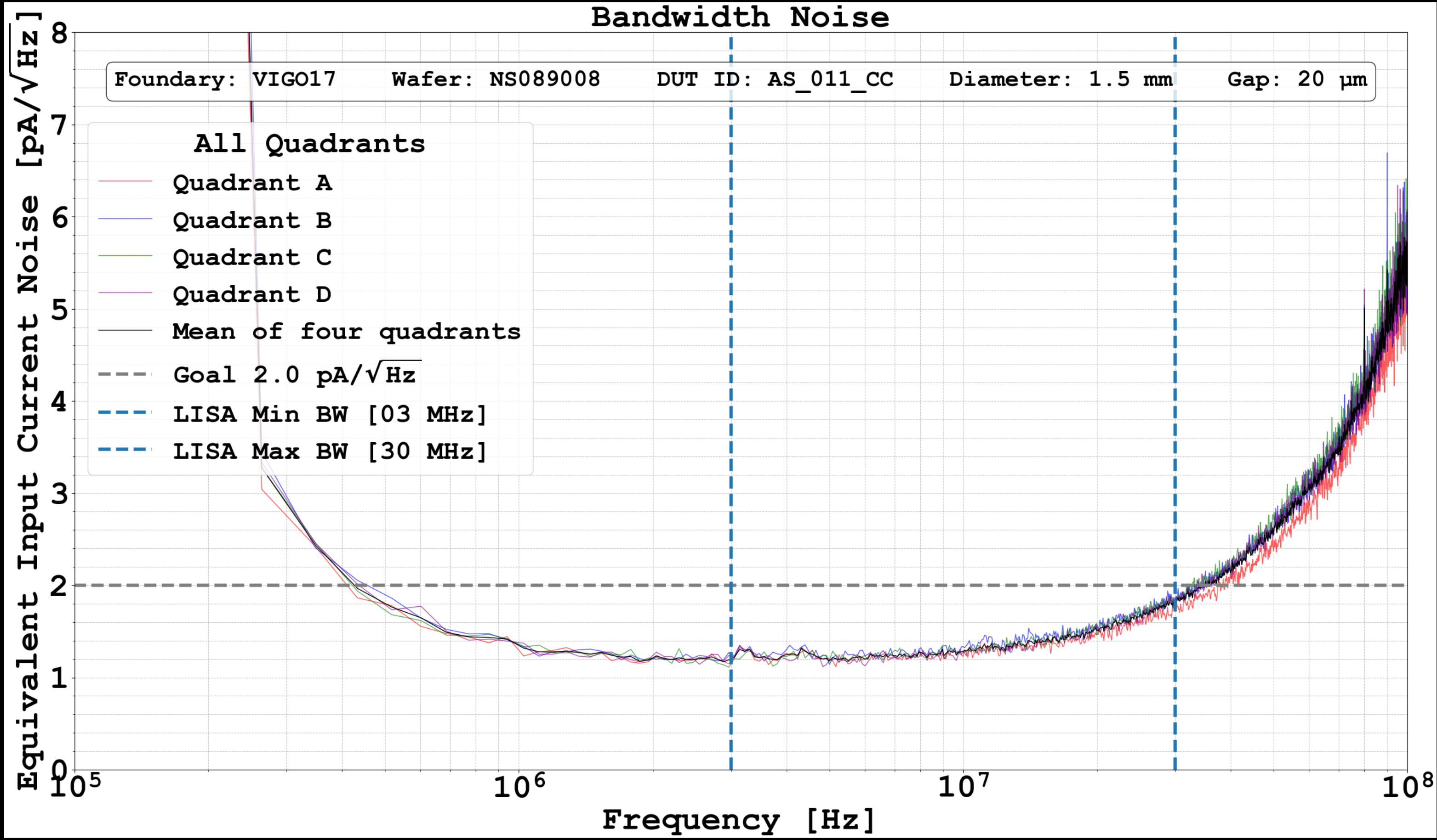
$$i_{EN} = \sqrt{\frac{i_{shot}^2}{\left(\frac{V_N}{V_{EN}}\right)^2 - 1}}$$

Measured voltage when the light is on ($V_N$)

Measured voltage when the light is off ($V_{EN}$)

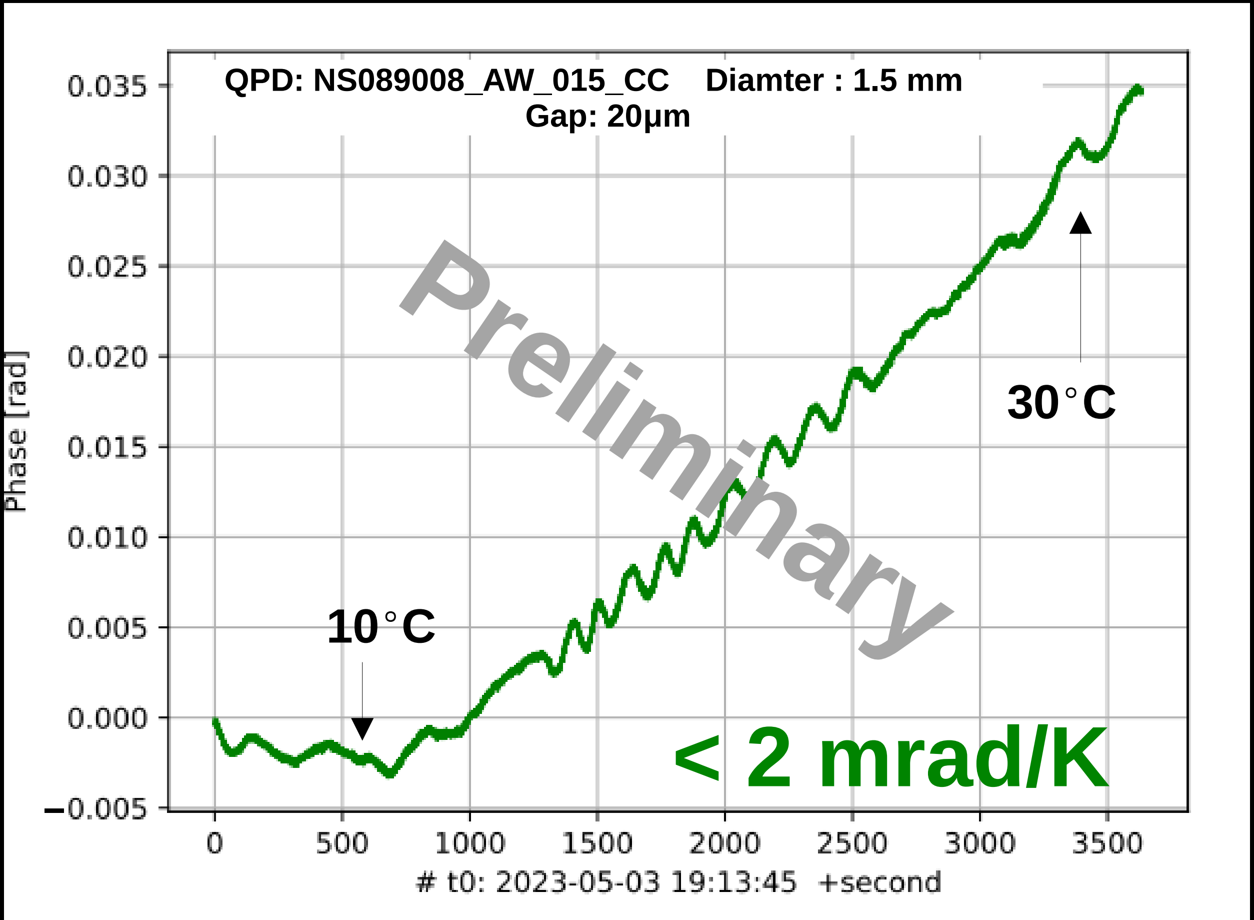


# Noise Measurements



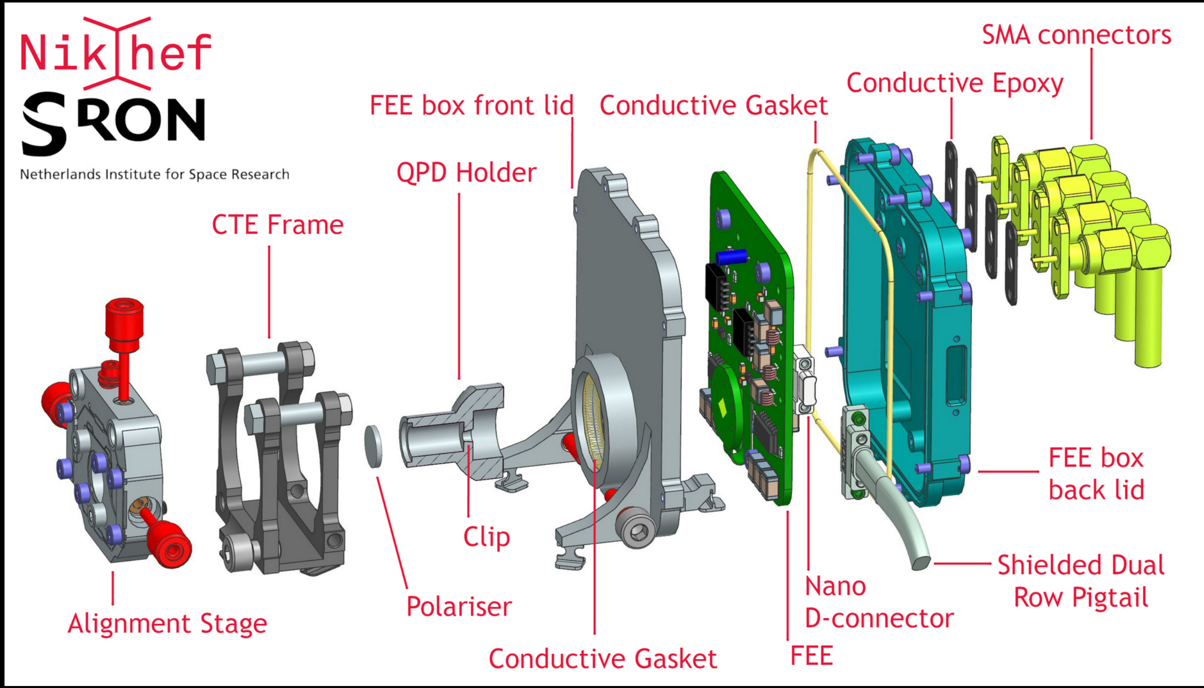
# Phase Stability over Temperature

# Phase Stability over Temperature



# Housing Design Challenges

- Alignment of QPD into housing
- Electromagnetic compatibility
  - Large isolation required from the power radiated by communication antenna of spacecraft.
- Thermal and vibrational stability

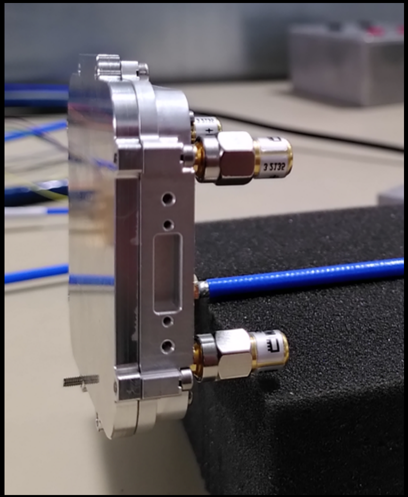


# EMC Tests

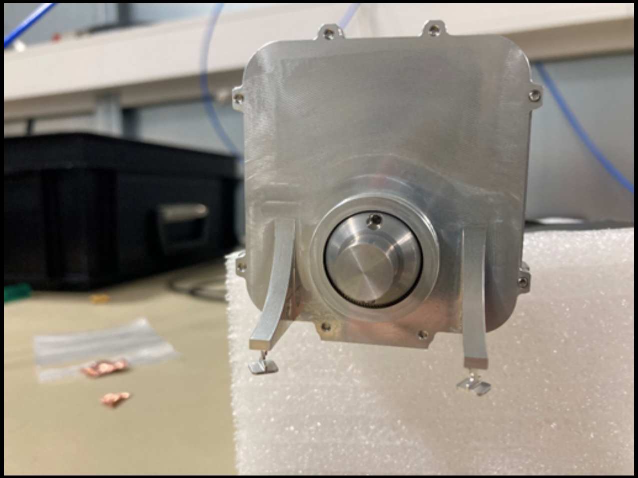
- Testing at ESTEC showed housing has lots of leaks.
- Time at ESTEC is expensive.
  - Build our own set-ups

# EMC Tests

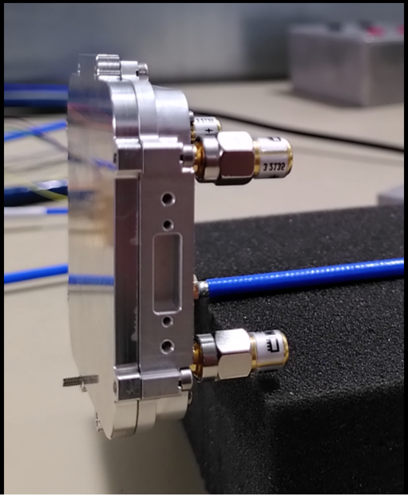
- To find the source(s) of the leak, incrementally build the full housing, testing at each stage.
- Use many different kinds of space qualified seals.
- Need 60 dB of isolation



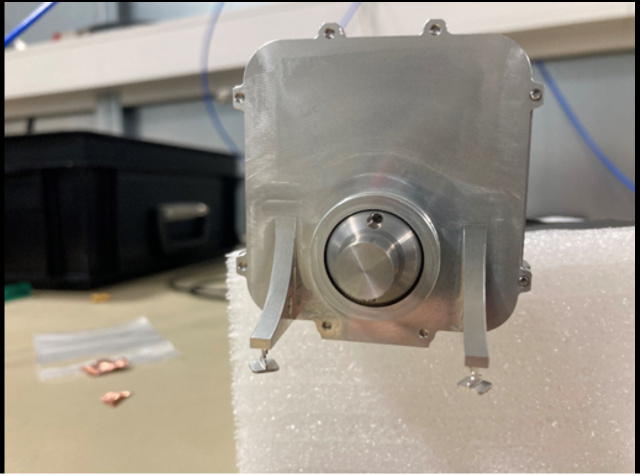
Housing with the lid only



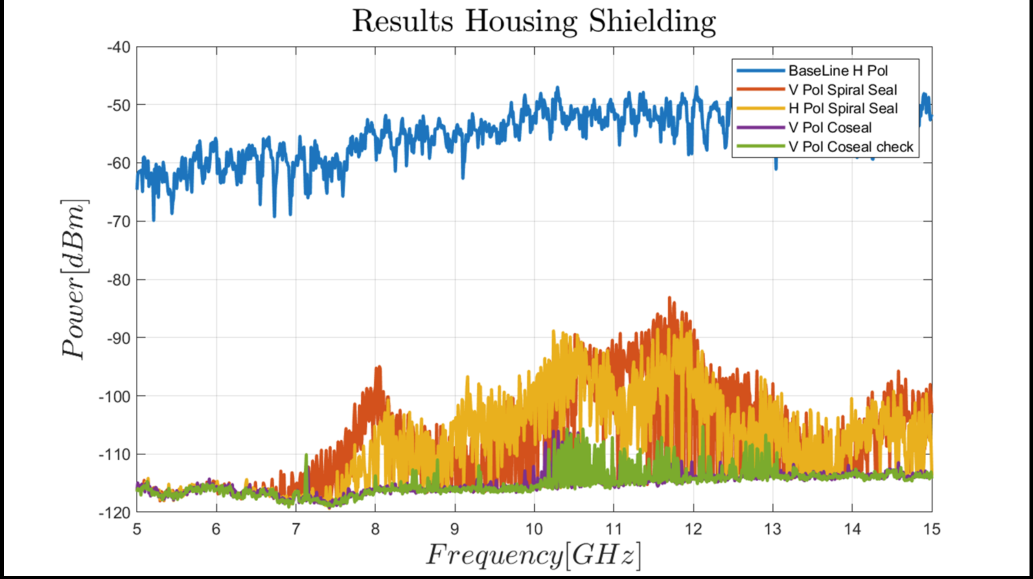
Housing with the lid QPD holder.

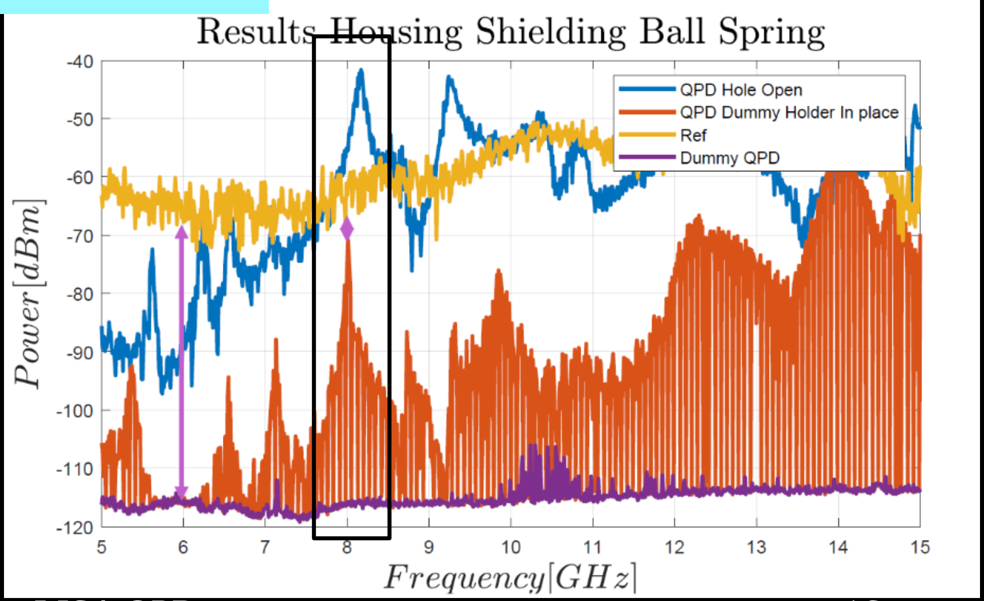


# EMC Tests

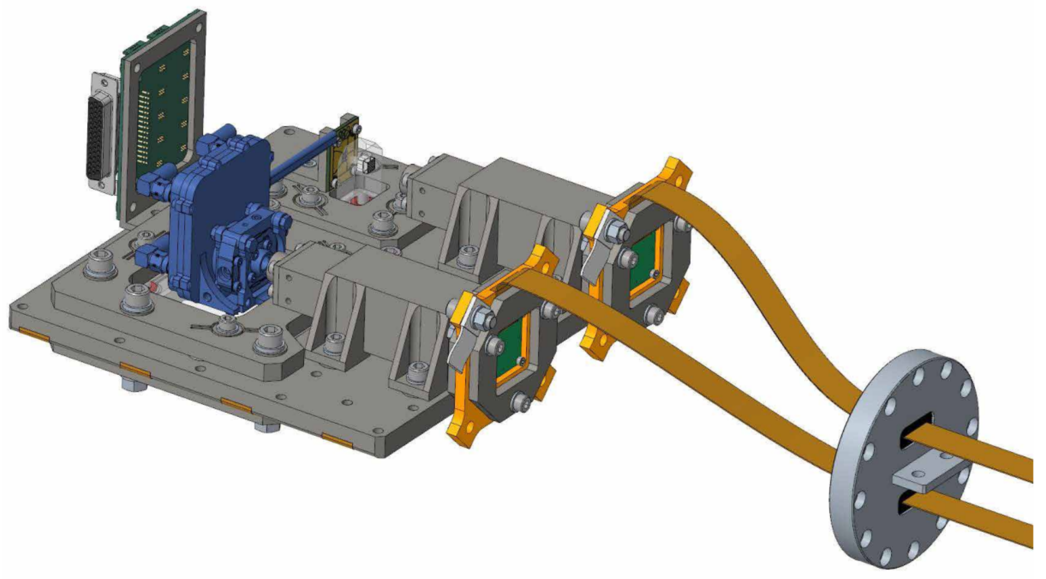


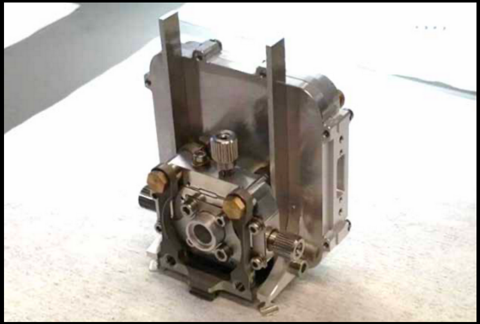
| Trace Color | Configuration |
|---|---|
| Yellow | Refenence housing open |
| Purple | Housing closed Co-seal |
| Blue | Housing closed QPD hole open & Co seal |
| Red | Housing closed QPD with bal canted spring & Co-Seal |



# Thermal Vacuum and Vibration Tests



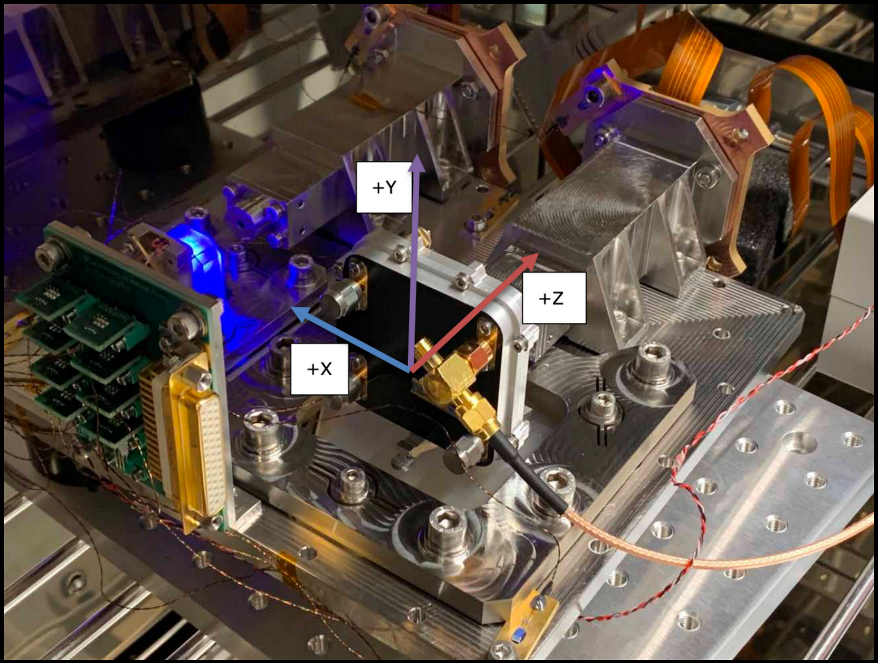


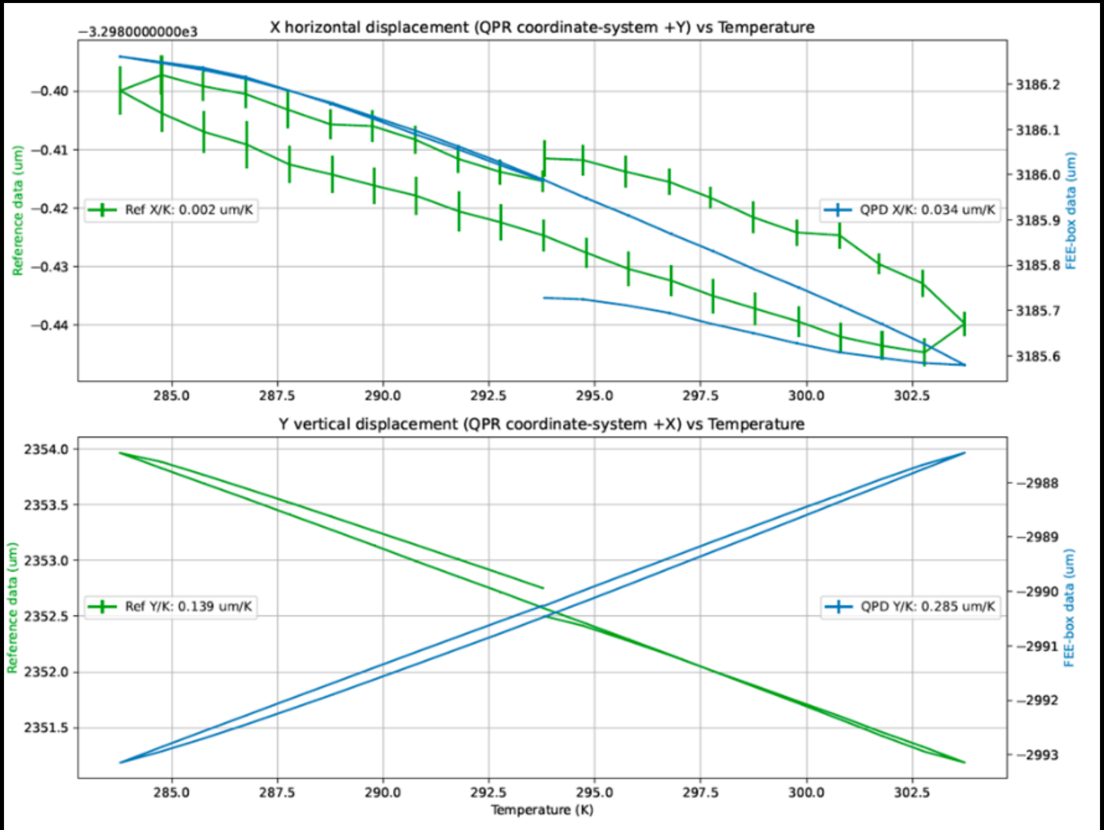
Top: CAD render of thermal vacuum set-up.

Left: Prototype QPR used for testing.

- We need to perform thermal under vacuum.
- The QPD thermomechanical stability shall be $<0.10\ \mu m/K$
- For the vibration tests the resonance frequencies need to be known and are simulated. Exact vibration load from ESA not known yet.
- The QPD positional hysteresis under standardized vibration loads shall be $<0.25\ \mu m$
- Testing performed at SRON

# Displacement vs Temperature Results.




- Results show good agreement in X but not in Y.
- Strange behavior between the reference system and the prototype.

Nikhef

SRON
Netherlands Institute for Space Research

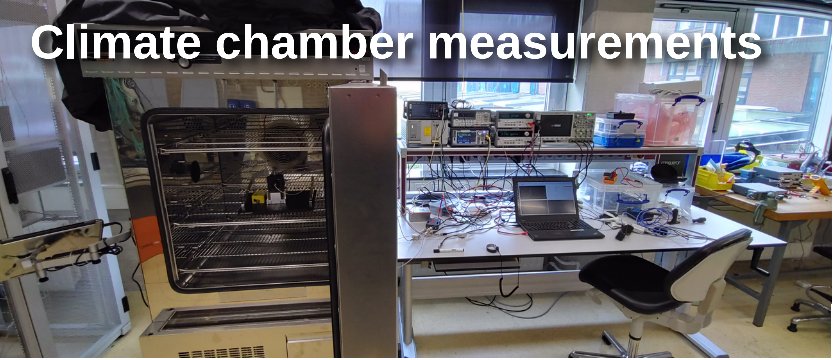
# Conclusion and Outlook

- Sucessfully demonstrated that current Nikhef QPD design meets LISA specification.
  - Room for further imporvements to reduce noise.
    - Could allow for the use of larger QPDs (better for alignment).
  - New ‘flight ready’ QPDs ready for manufacturing.

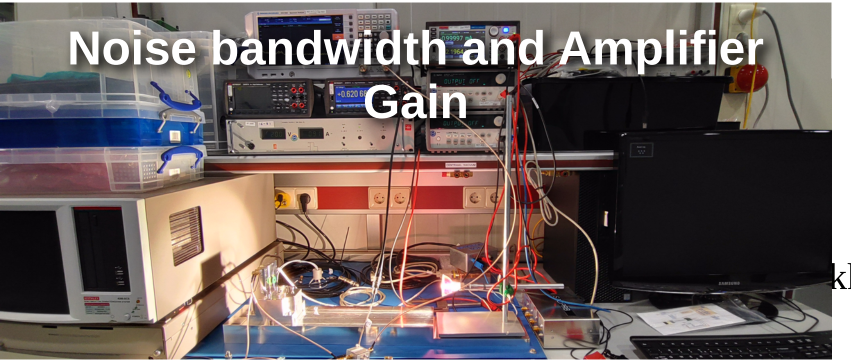
- Undergoing Technology Readiness Assessment with ESA.

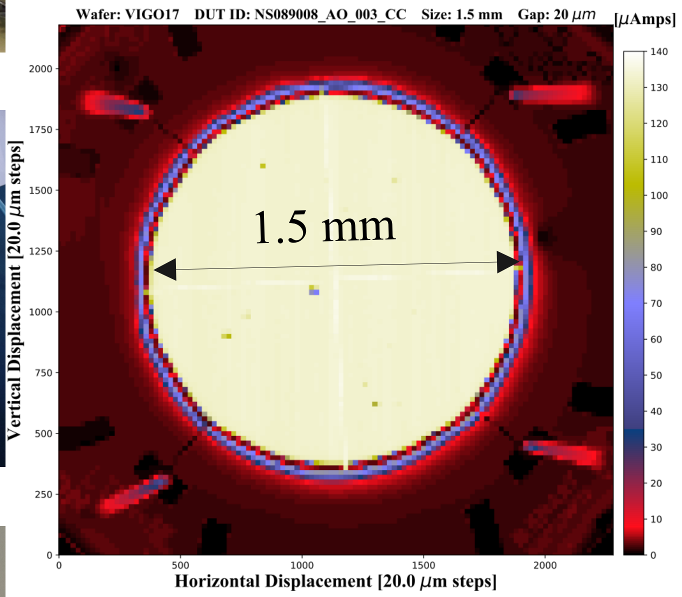
- Continue to improve housing to meet EMC requirements.

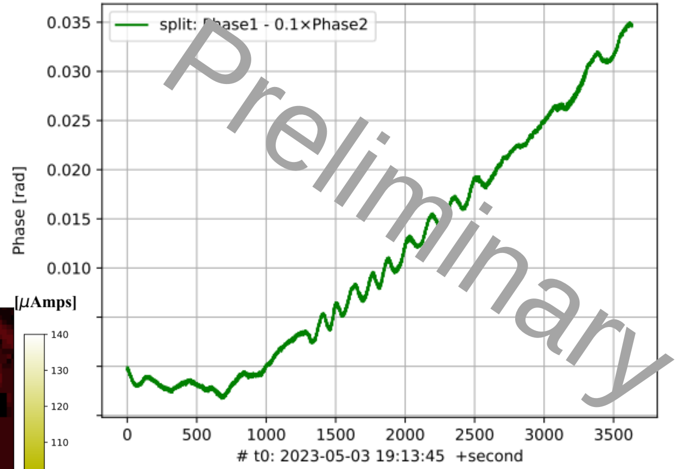
- Developing test procedures for LISA optical bench intergration.

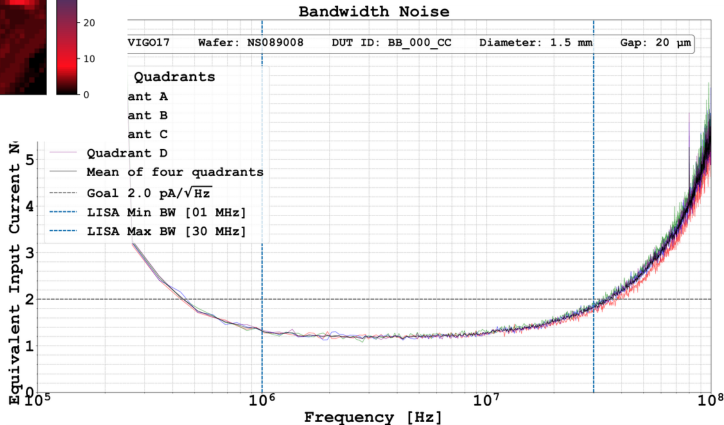

Climate chamber measurements


Crosstalk and Uniformity


Noise bandwidth and Amplifier Gain


Wafer: VIGO17 DUT ID: NS089008_AO_003_CC Size: 1.5 mm Gap: 20 µm
[µAmps]
1.5 mm
Vertical Displacement [20.0 µm steps]
Horizontal Displacement [20.0 µm steps]


split: Phase1 - 0.1×Phase2
Phase [rad]
# t0: 2023-05-03 19:13:45 +second
Preliminary


Bandwidth Noise
VIGO17 Wafer: NS089008 DUT ID: BB_000_CC Diameter: 1.5 mm Gap: 20 µm
Quadrants
Quadrant D
Mean of four quadrants
Goal 2.0 pA/√Hz
LISA Min BW [01 MHz]
LISA Max BW [30 MHz]
Frequency [Hz]

# Literature

- LISA Pathfinder final results publication.
  - M. Armano et al. Beyond the Required LISA Free-Fall Performance: New LISA Pathfinder Results down to 20 μHz, Physical Review Letters (2018). DOI: 10.1103/PhysRevLett.120.061101