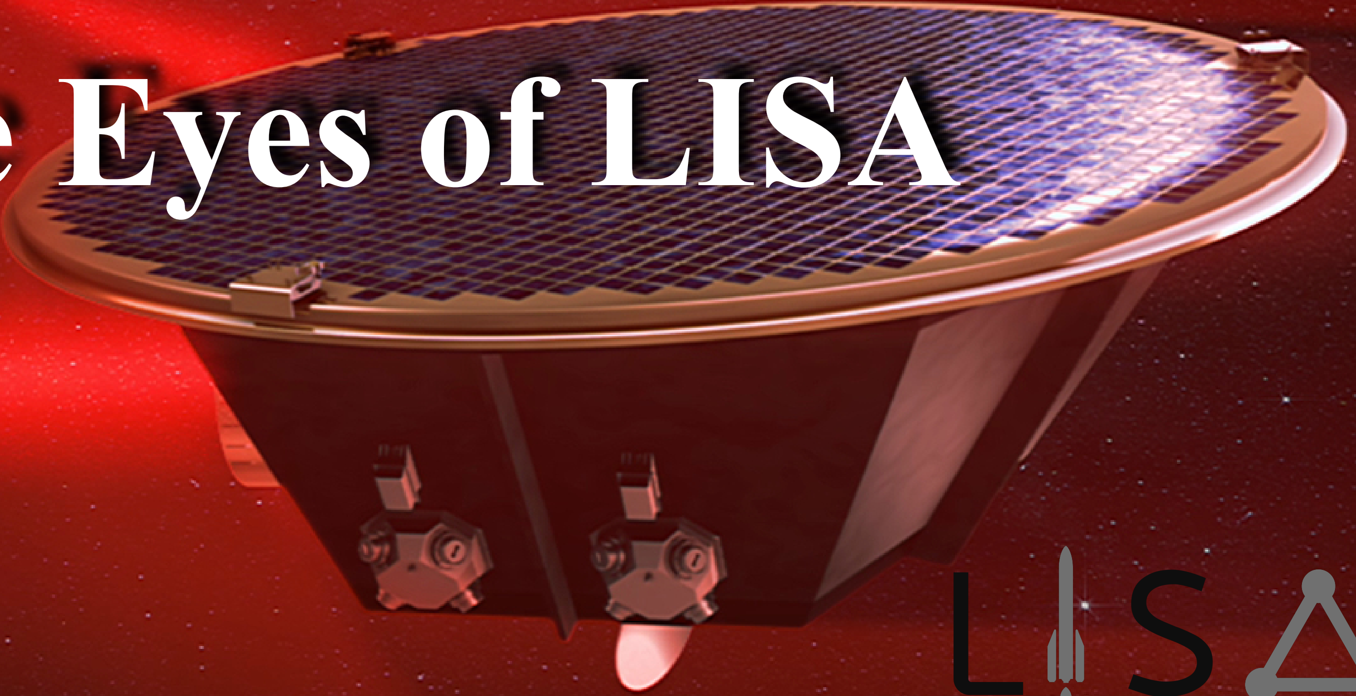
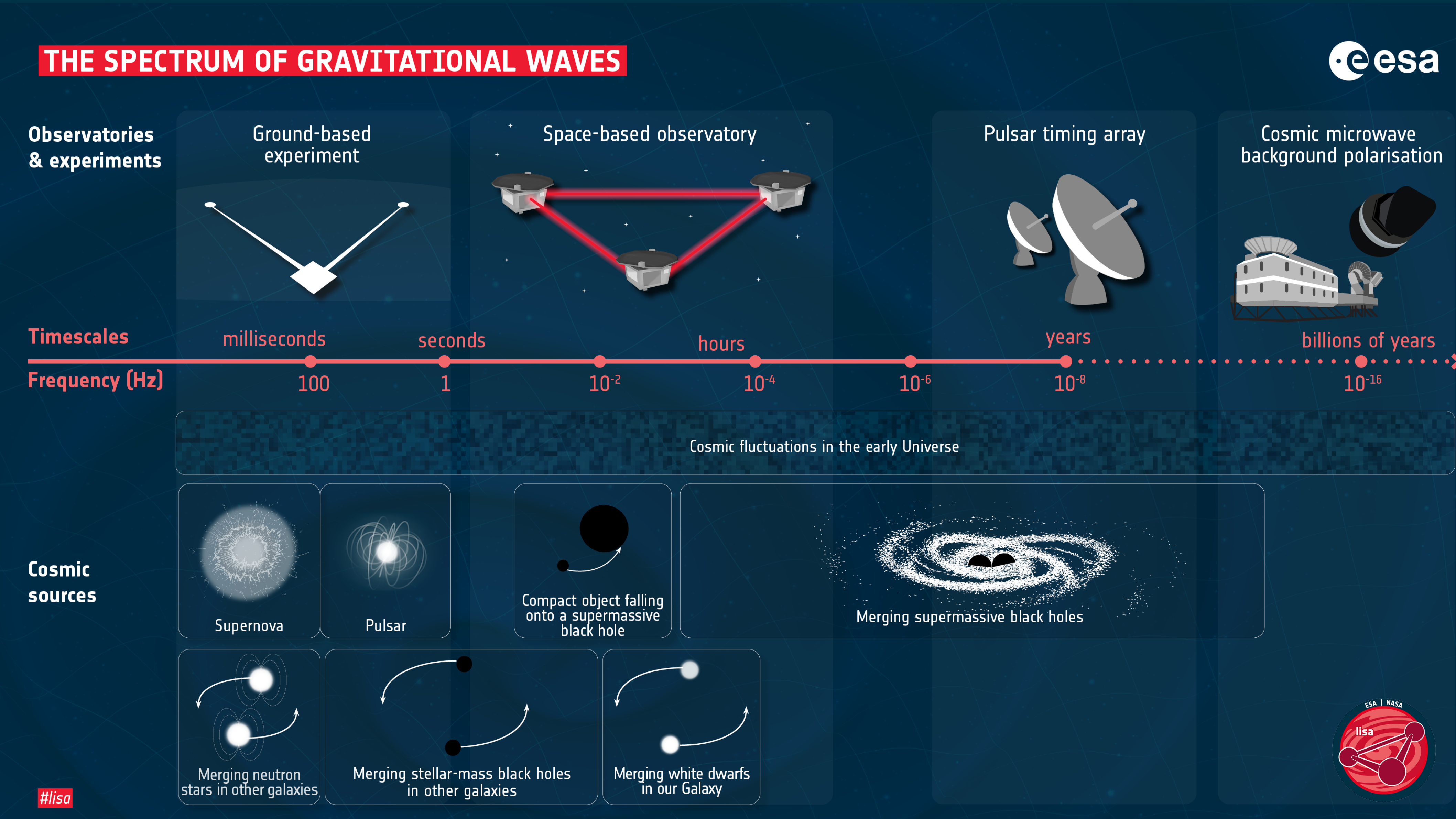
The Eyes of LISA

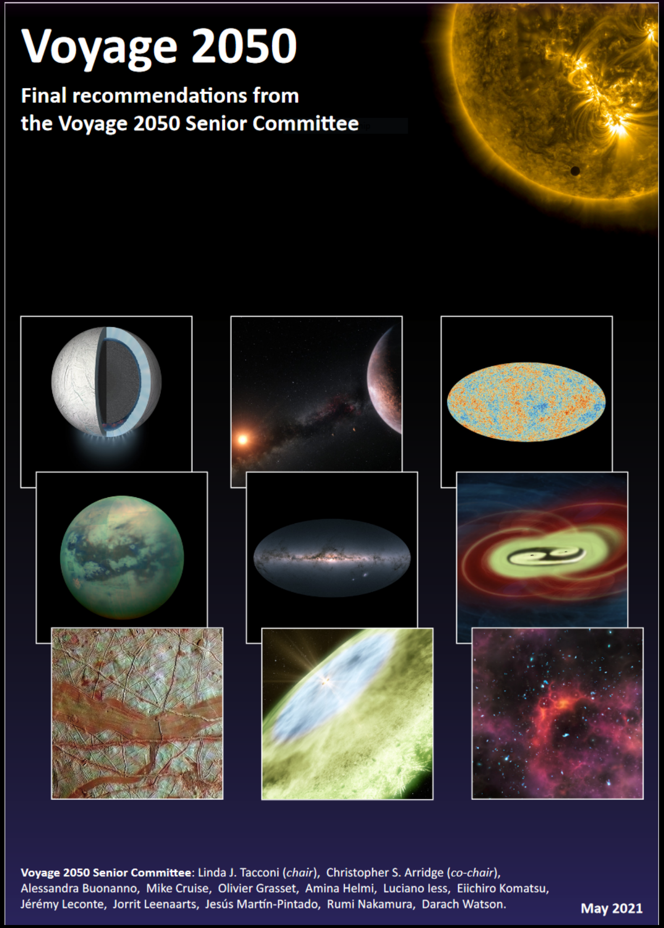


T. Mistry, M.v. Beuzekom, N.v. Bakel, R. Cornelissen, M. Adams, G. Vissier, J. Zand, P. Dieleman, M. Frericks, P. Laubert, R. Wanders, L. Dubbeldam, G. Aitink, M. Siegl


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 start
  Nikhef + SRON join the party!
- 2017 – LISA pathfinder mission end. LISA proposal
- **2024 – Mission adoption by ESA selected as ESA L3 mission.**



What GW will LISA Measure

- GW Signals expected to stay inband for ~ 30 days.
- Data is processed on Earth.
  - ‘Time Delay Interferometry (TDI)’ algorithm used to combine the data from the three satellites.
  - TDI will create interferometer like signal to suppress laser frequency noise (similar to mirrors in ground based interferometers).
- LISA requires ~ 10^{-12} m accuracy whereas current ground-based interferometers are at the ~ 10^{-15} m level.

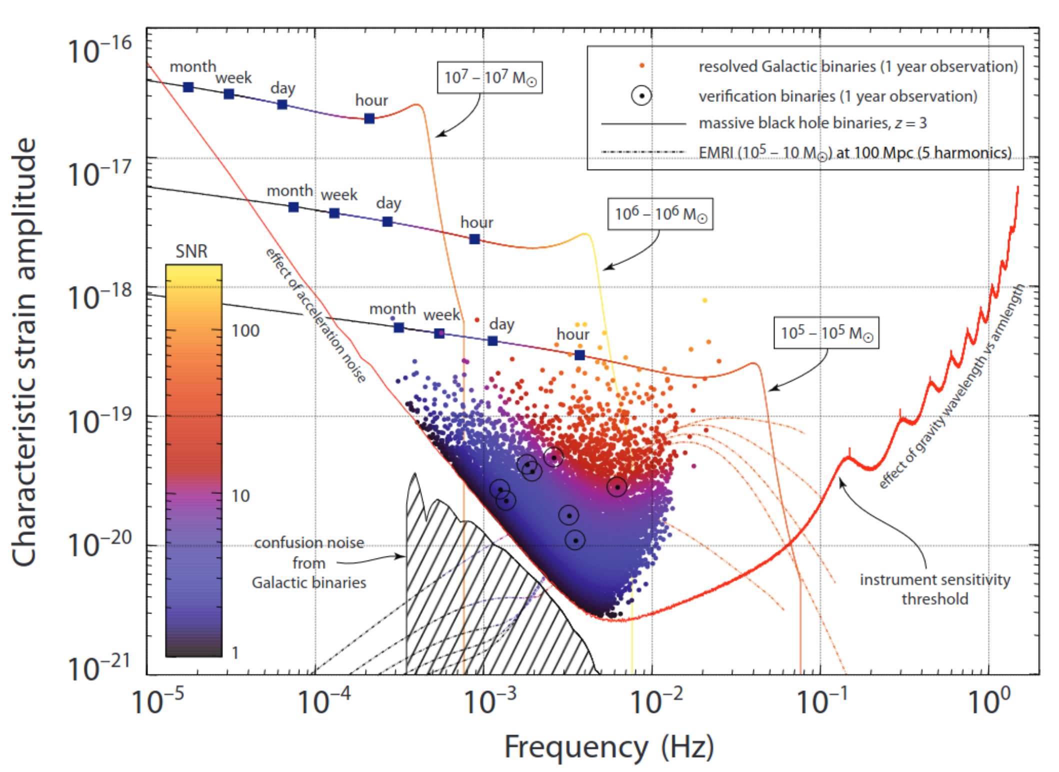
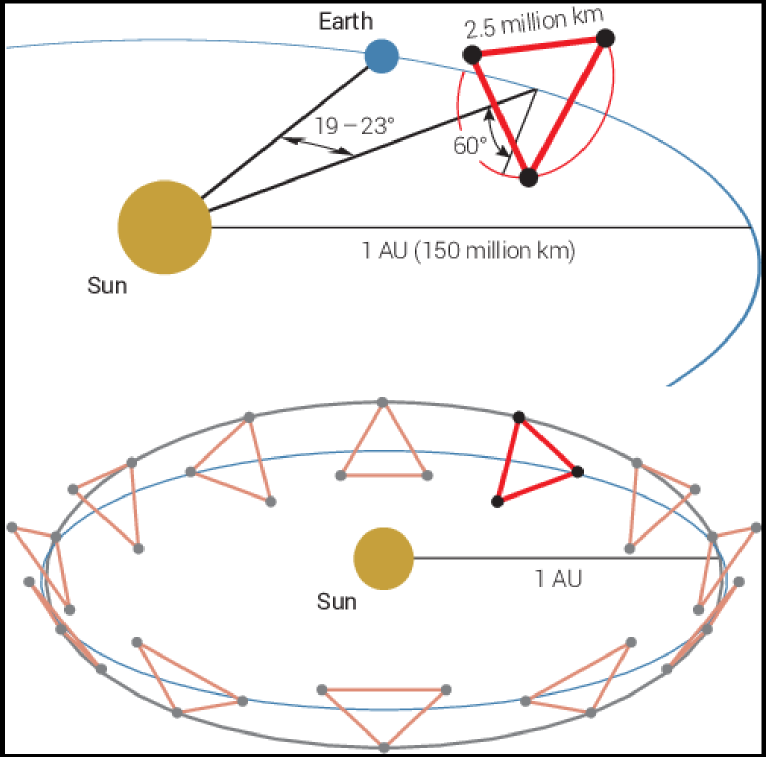


Image credit: LISA Mission Proposal for L3 submitted to ESA (LISA Consortium)

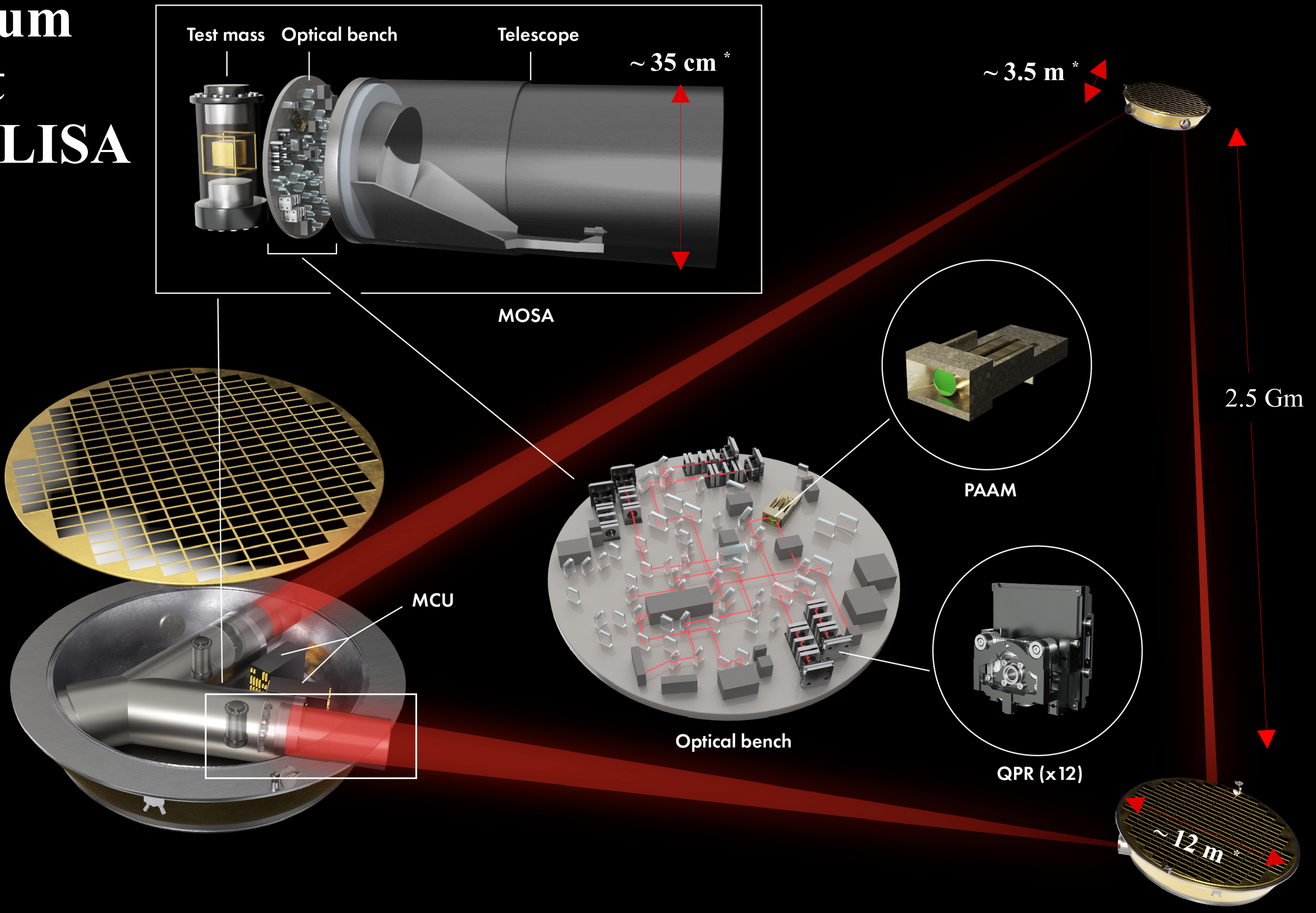
Where will LISA Measure GW?

- Heliocentric orbit lagging the Earth by ~ 20°
  - Location is a trade off between transfer vehicle ΔV, communication and mission lifetime.
- Not at a Lagrange Point!



Dutch + Belgium Instrument Contribution to LISA

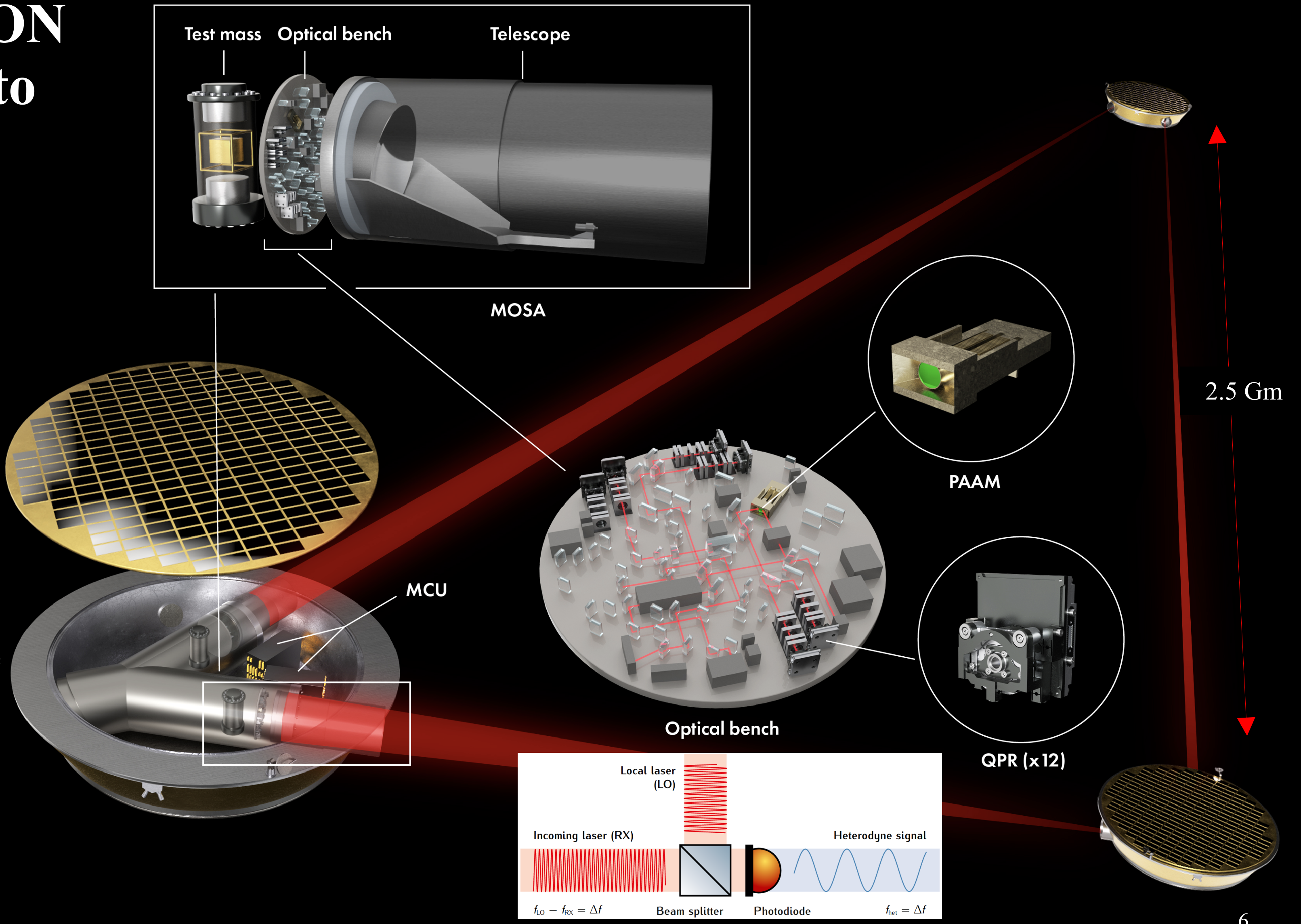
- First time developing long arm (science) interferometer.
- Three interferometers on each optical bench
  - Science
  - Test mass
  - Reference
- **72 quadrant photoreceiver (QPRs) systems will fly!**
  - **Plus 28 extra for ground testing.**
  - **120 total flight ready systems *.**



* Subject to change

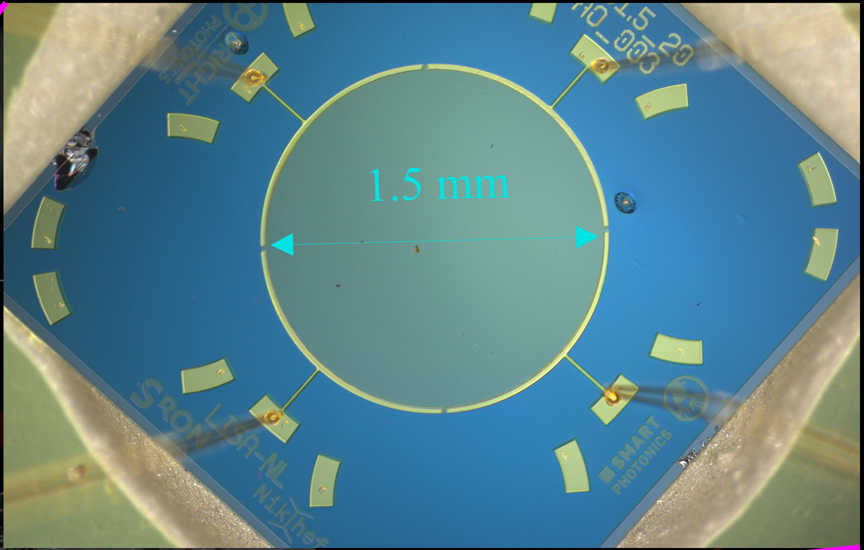
Nikhef and SRON Contribution to LISA

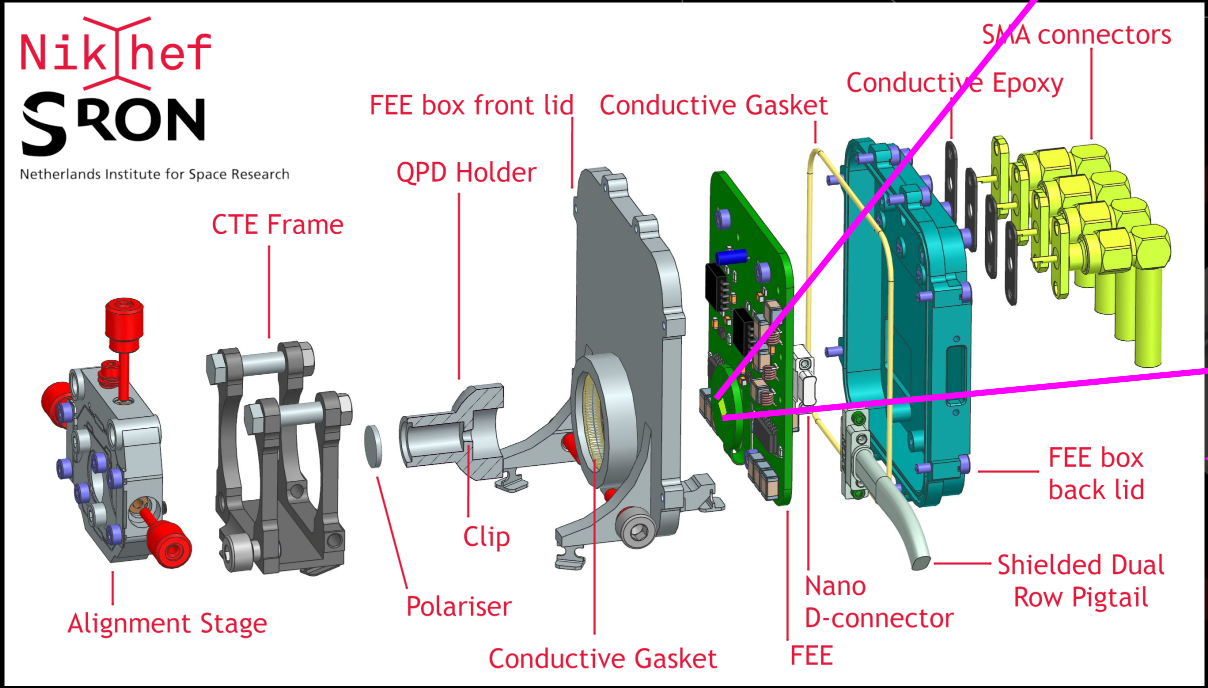
- Heterodyne signals from science interferometer.
  - 1-30 MHz beatnote frequency
  - Beatnote frequency changes due to satellite breathing.
  - QPR will measure the phase change of the beatnote.
  - ~300 pW light received from remote spacecraft.

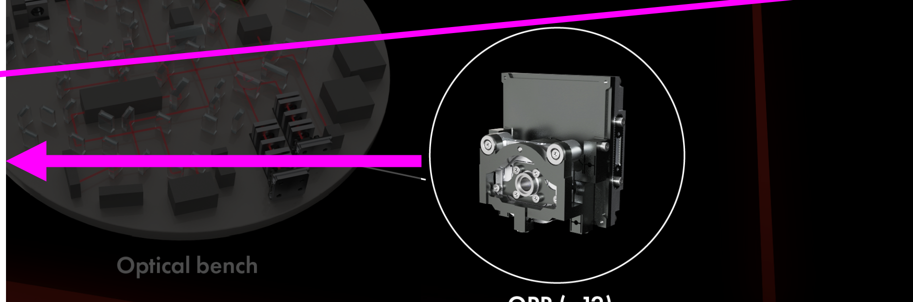


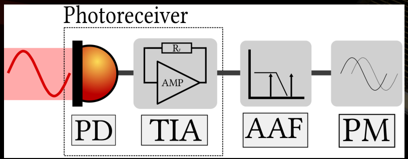
What is the Quadrant Photo-Receiver (QPR)?

Quadrant Photo-Diode



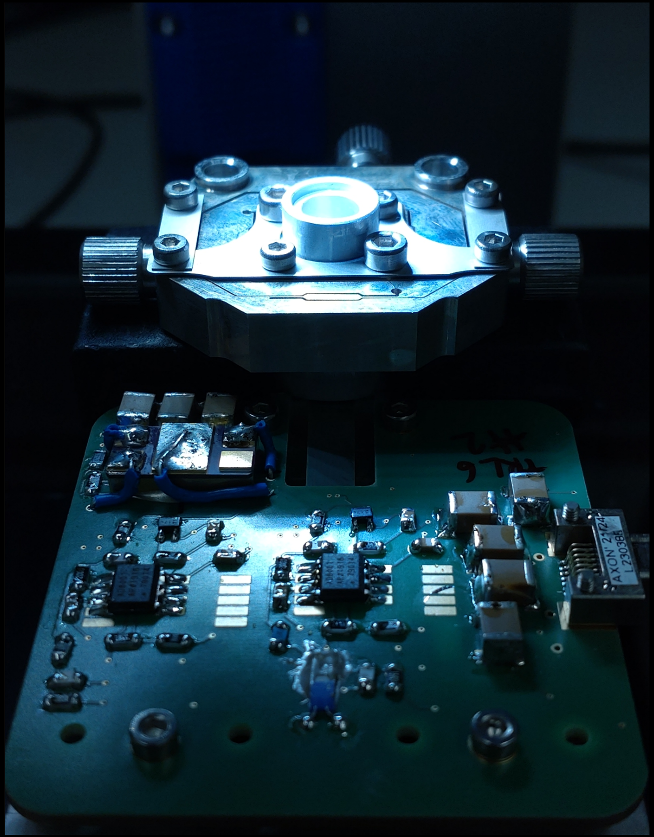


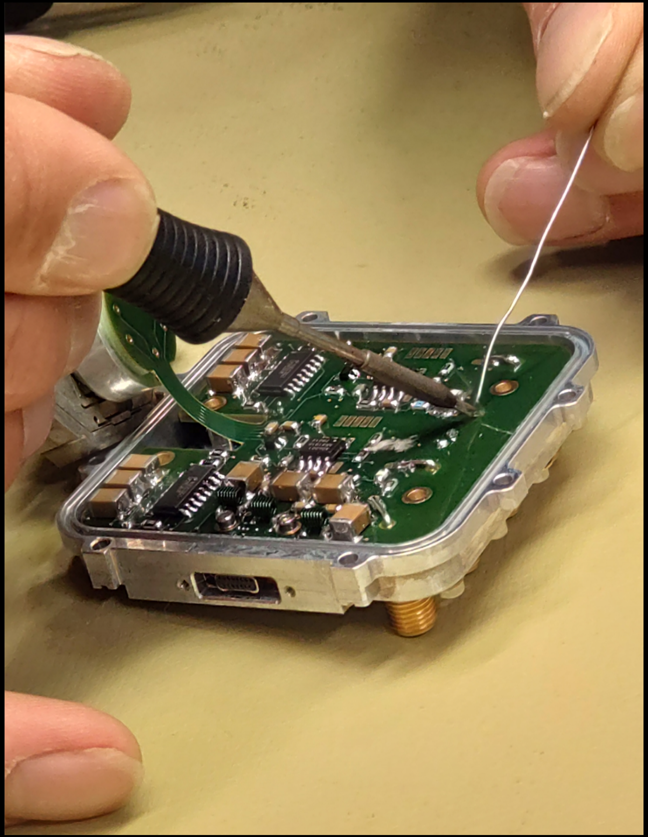


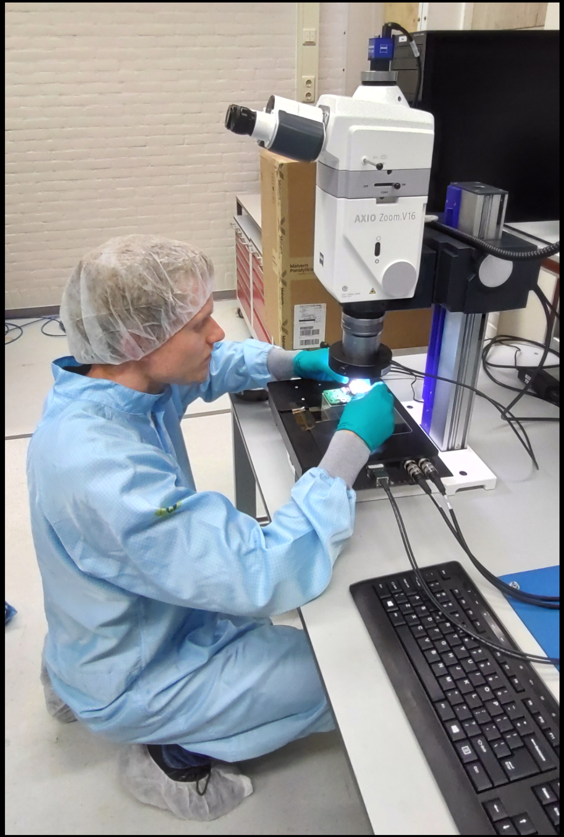


Housing

Building the (Housing 3) QPR

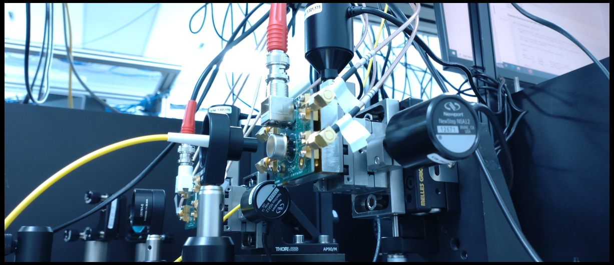




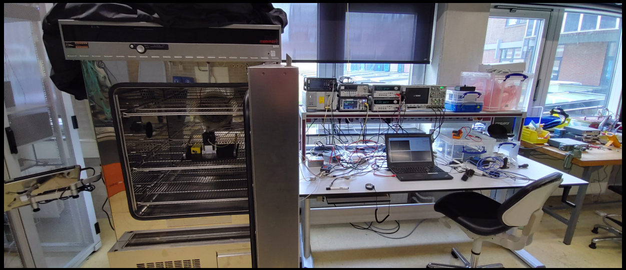


Qualifying a QPR for LISA

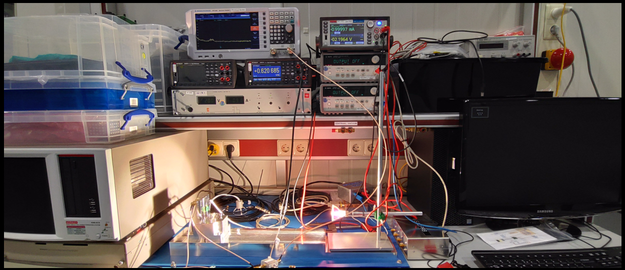
Crosstalk and Uniformity



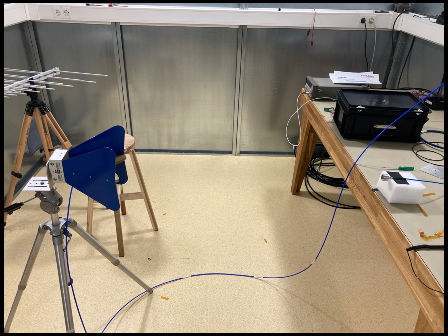
Phase versus Temperature



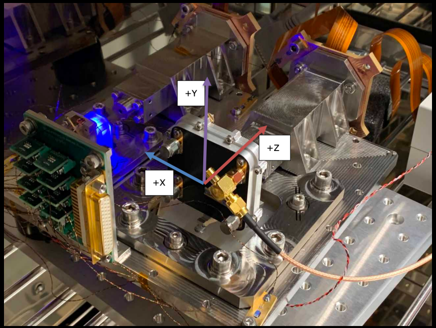
Bandwidth Noise and Gain



Electromagnetic Compatibility



Vibration, Vacuum and Temperature

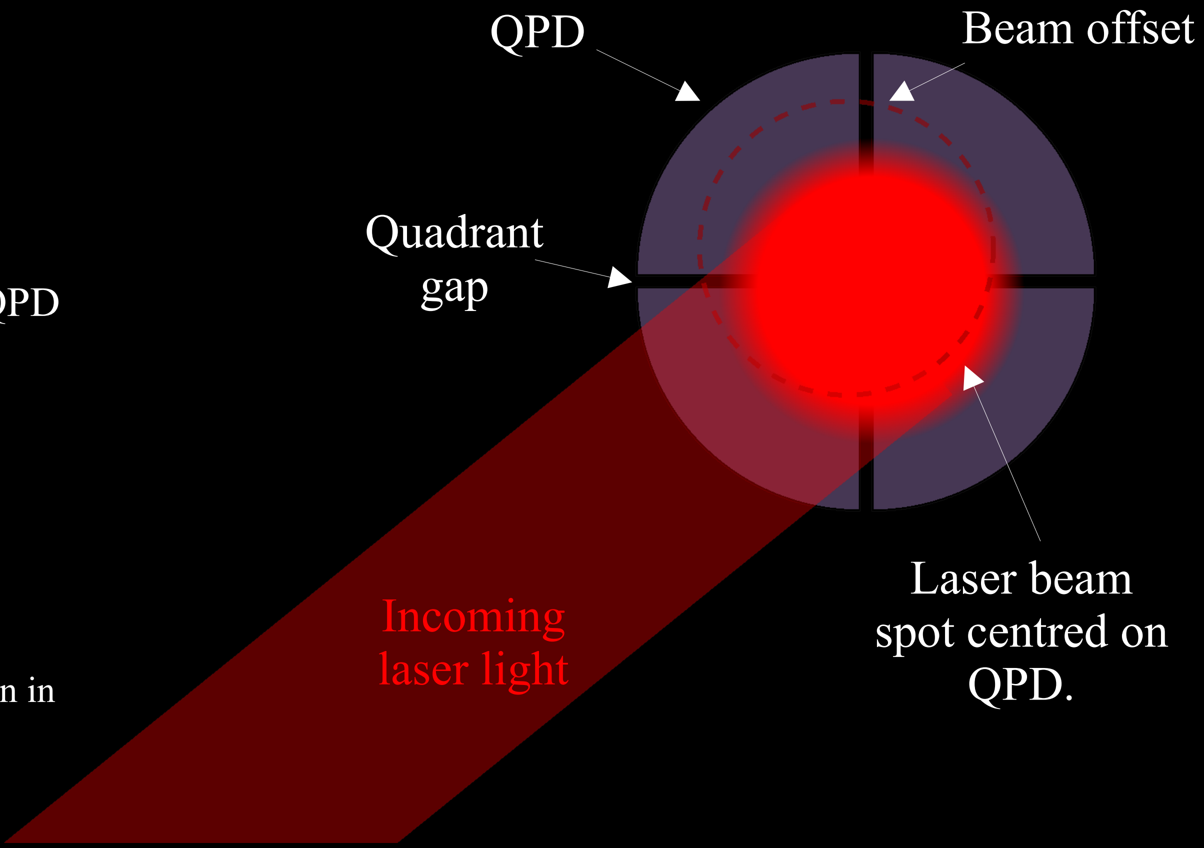


Quality Assurance

LISA QPR Nikhef Student Projects

The Eyes of LISA – Why use QPDs?

- Science signal – Common Phase
  - Single element.
- Alignment
  - Quadrant for alignment
- Science signal sets the specification of the QPD
  - Phase sensitivity of 6 μrad/√(Hz)
  - Received light ~ 300 pW
  - RF bandwidth 1 – 30 MHz
  - GW signal 0.1 mHz - 0.1 Hz
  - Long arm length accuracy ~ 10^{-12} m
  - Hence the need for low noise QPD.
    - Low capacitance via QPD thickness.
  - Custom diode made with a thickness uncommon in commercial photodiodes.
- Weight for SC!



Nikhef

SRON
Netherlands Institute for Space Research

Student Projects on Nikhef Website

Detector R&D: Laser Interferometer Space Antenna (LISA) - the first gravitational wave detector in space

The space-based gravitational wave antenna LISA is one of the most challenging space missions ever proposed. ESA plans to launch around 2035 three spacecraft separated by a few million kilometres. This constellation measures tiny variations in the distances between test-masses located in each satellite to detect gravitational waves from sources such as supermassive black holes. LISA is based on laser interferometry, and the three satellites form a giant Michelson interferometer. LISA measures a relative phase shift between one local laser and one distant laser by light interference. The phase shift measurement requires sensitive sensors. The Nikhef DR&D group fabricated prototype sensors in 2020 together with the Photonics industry and the Dutch institute for space research SRON. Nikhef & SRON are responsible for the Quadrant PhotoReceiver (QPR) system: the sensors, the housing including a complex mount to align the sensors with 10's of nanometer accuracy, various environmental tests at the European Space Research and Technology Centre (ESTEC), and the overall performance of the QPR in the LISA instrument. Currently we are fabricating improved sensors, optimizing the mechanics and preparing environmental tests. As a MSc student, you will work on various aspects of the wavefront sensor development: study the performance of the epitaxial stacks of Indium-Gallium-Arsenide, setting up test benches to characterize the sensors and QPR system, performing the actual tests and data analysis, in combination with performance studies and simulations of the LISA instrument. Possible projects but better to contact us as the exact content may change:

1. **Title**: Simulating LISA QPD performance for LISA mission sensitivity.
   Topic: Simulation and Data Analysis.
   Description: we must provide accurate information to the LISA collaboration about the expected and actual performance of the LISA QPRs. This project will focus on using data from measurements taken at Nikhef to integrate into the simulation packages used within the LISA collaboration. The student will have the option to collect their own data to verify the simulations. Performance parameters include spatial uniformity and phase response, crosstalk and thermal response across the LISA sensitivity.
   These simulations can then be used to investigate the full LISA performance and the impact on noise sources. This will involve simulating heterodyne signals expected on the LISA QPD and the impact on sensing techniques such as Differential Wavefront Sensing (DWS) and Tilt-to-Length (TTL) noise. Simulations tools include Finesse (Python), IFOCAD (C++) or FieldProp (MATLAB) depending on the student capabilities and preference. This work is important for understanding the stability and noise of LISA interferometry will perform during real operation in space.
2. **Title**: Investigate the Response of the Gap in the LISA QPD.
   Topic: Experimental.
   Description: At Nikhef we are developing the photodiodes that will be used in the upcoming ESA/NASA LISA mission. We currently have our first batch of Quadrant Photodiodes (QPDs) that vary in diameter, thickness and gaps width between the quadrants. The goal of this project is to develop a free-space laser test set-up to measure the response of the gap between the quadrants of the LISA Quadrant Photodiode (QPD). It is important to understand the behaviour of the gap between the photodiode quadrants since this can impact the overall performance of the photodiode and thus the sensitivity of LISA.
   The measurements will involve characterising the test laser beam, configuring test equipment, handling and installing optical components. Furthermore, as well as taking the data, the student will also be responsible for analysing the results using Python however other computer languages are acceptable (based on the student preference).
3. **Title**: Investigate the Response of LISA QPDs for Einstein Telescope Pathfinder.
   Topic: Experimental.
   Description: Current gravitational wave (GW) interferometers typically operate using 1064 nm wavelengths. However, future GW detectors will operate at higher wavelengths such as 1550 nm or 2000 nm. As a result of the wavelength change, much of the current technology is unsuitable thus, developments are underway for the next generation GW detectors. Europe's future GW detector, the Einstein Telescope, is currently in its' infancy. A smaller scale prototype, known as ET pathfinder, is currently being built and serves as a test bench for the full scale detector.
   At Nikhef's R&D group, we want to develop quadrant photodiodes (QPDs) that sense the light from the interferometer light for the Einstein Telescope (ET) and ET Pathfinder. These QPDs require very low noise performance as well as high sensitivity in order to measure the small interferometer signals. To that end, out first step is to use the current QPDs that have been developed for the ESA/NASA LISA mission.
   This project will focus on performance tests of the LISA QPDs using a 1550 nm. The student will be tasked with developing a test setup as well as taking the data and analysing the results. As part of this project, the student will learn about laser characterisation, gaussian optics and instrumentation techniques. These results will be important for designing the next generation QPDs and is of interest to the ET consortium, where the student can present their results.

Contact: Niels van Bakel or Timesh Mistry