LIGO-India Project

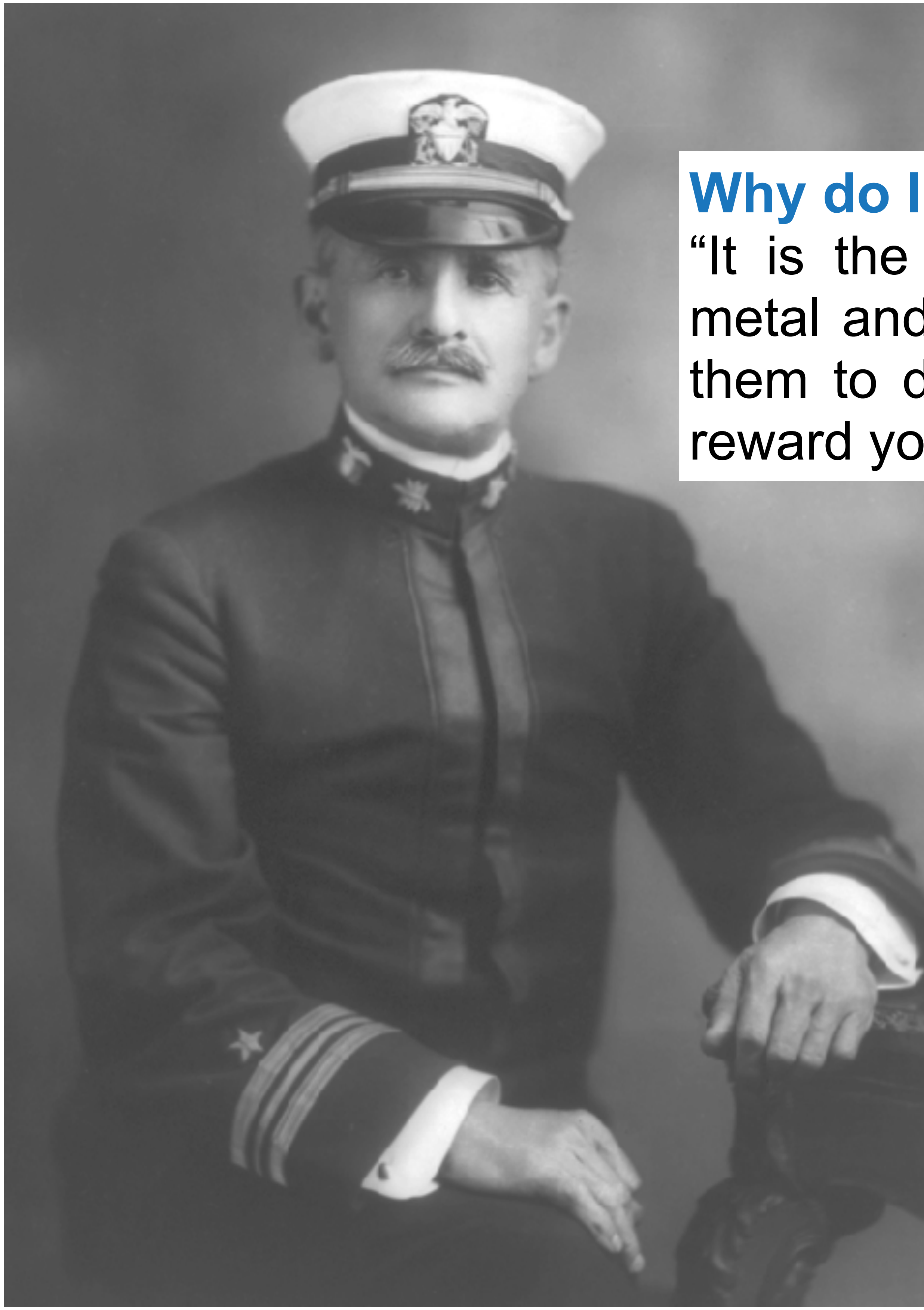
Optical instrumentation at its limits!

IUCAA, DCSEM, IPR & RRCAT
+ “Other Institutions..” & LISC

May 9, 2019

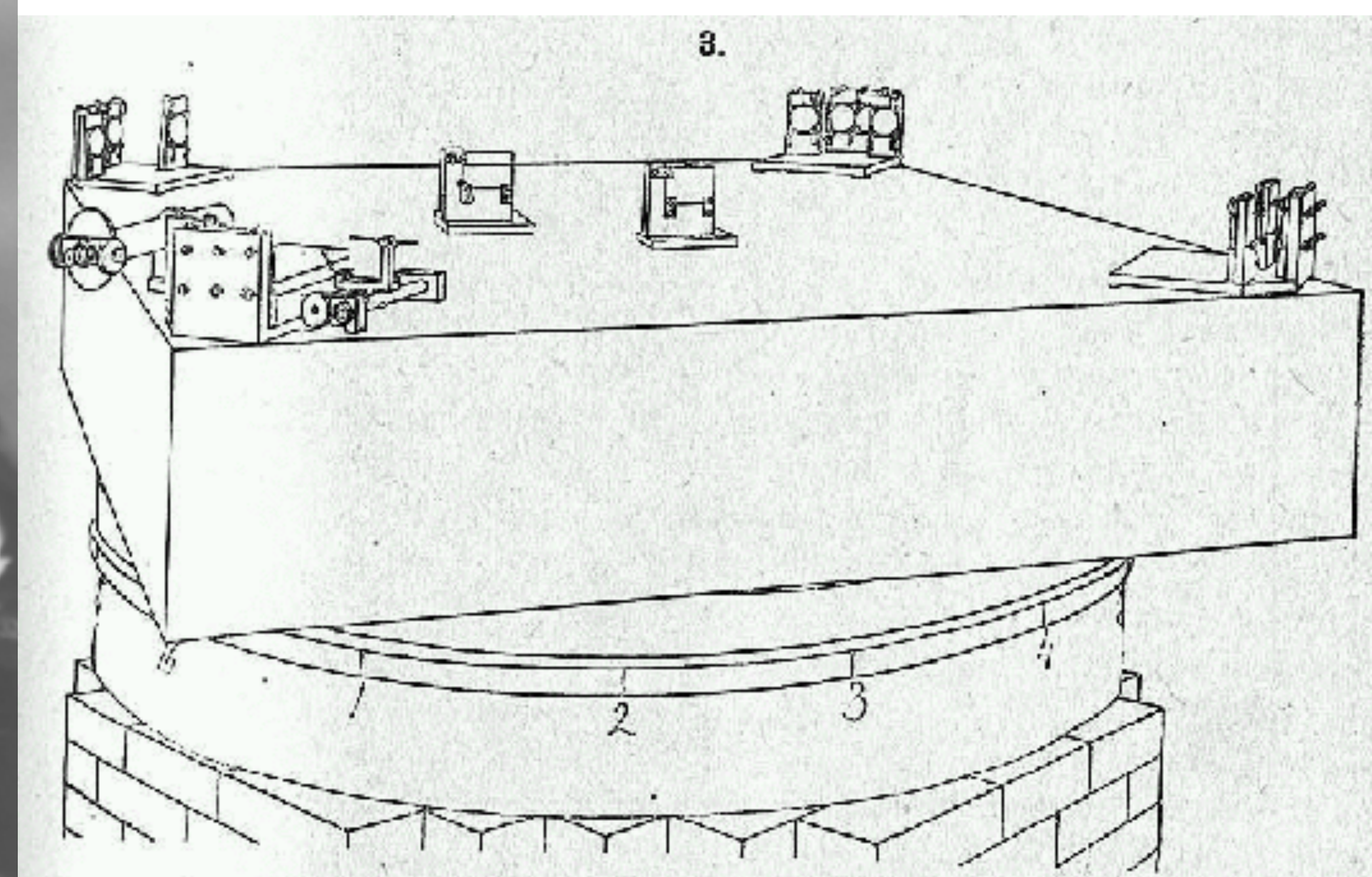
Vigyan Samagam

Optical Instrumentation

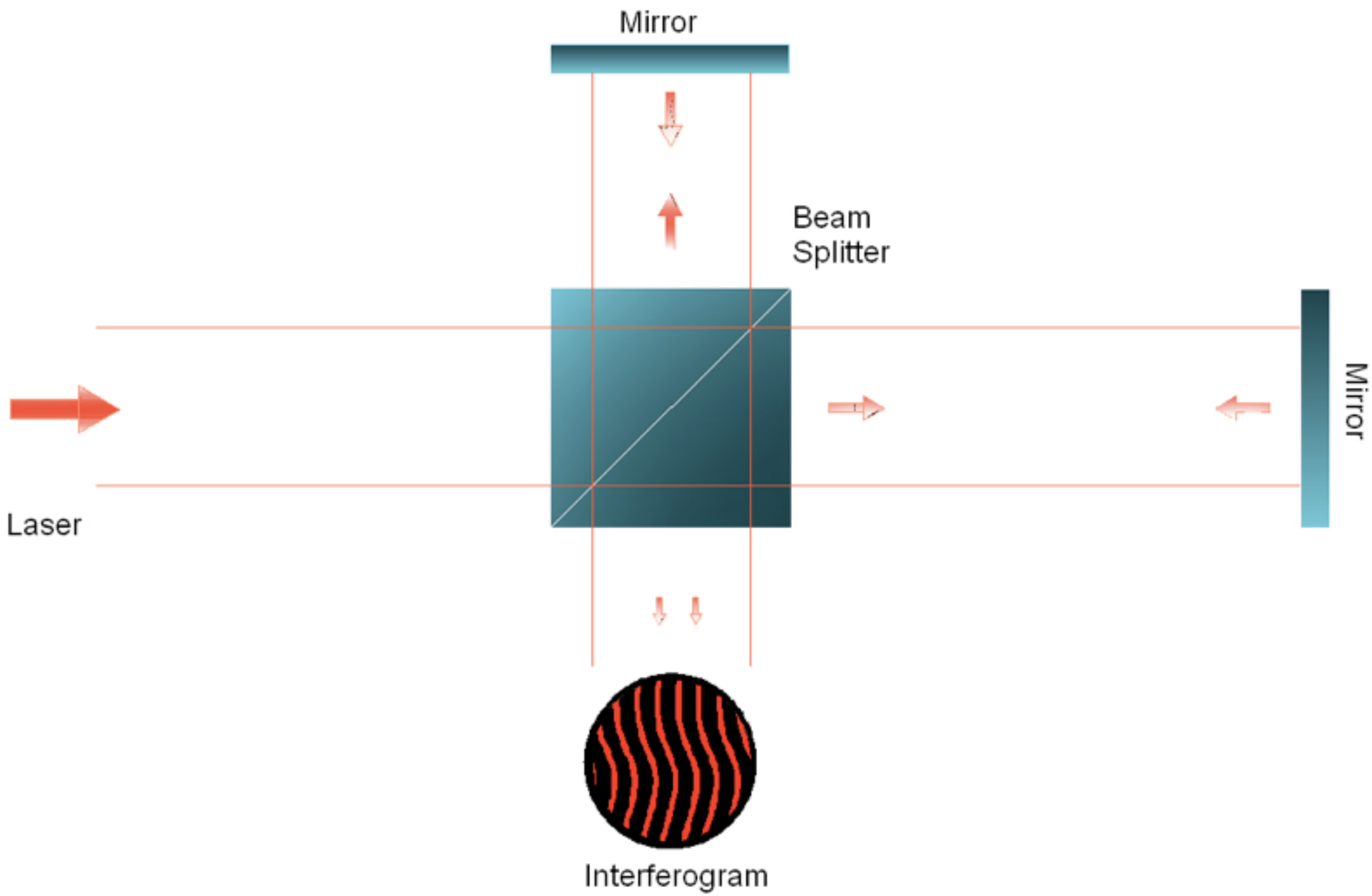


Why do I like to design Machines (Instruments)?

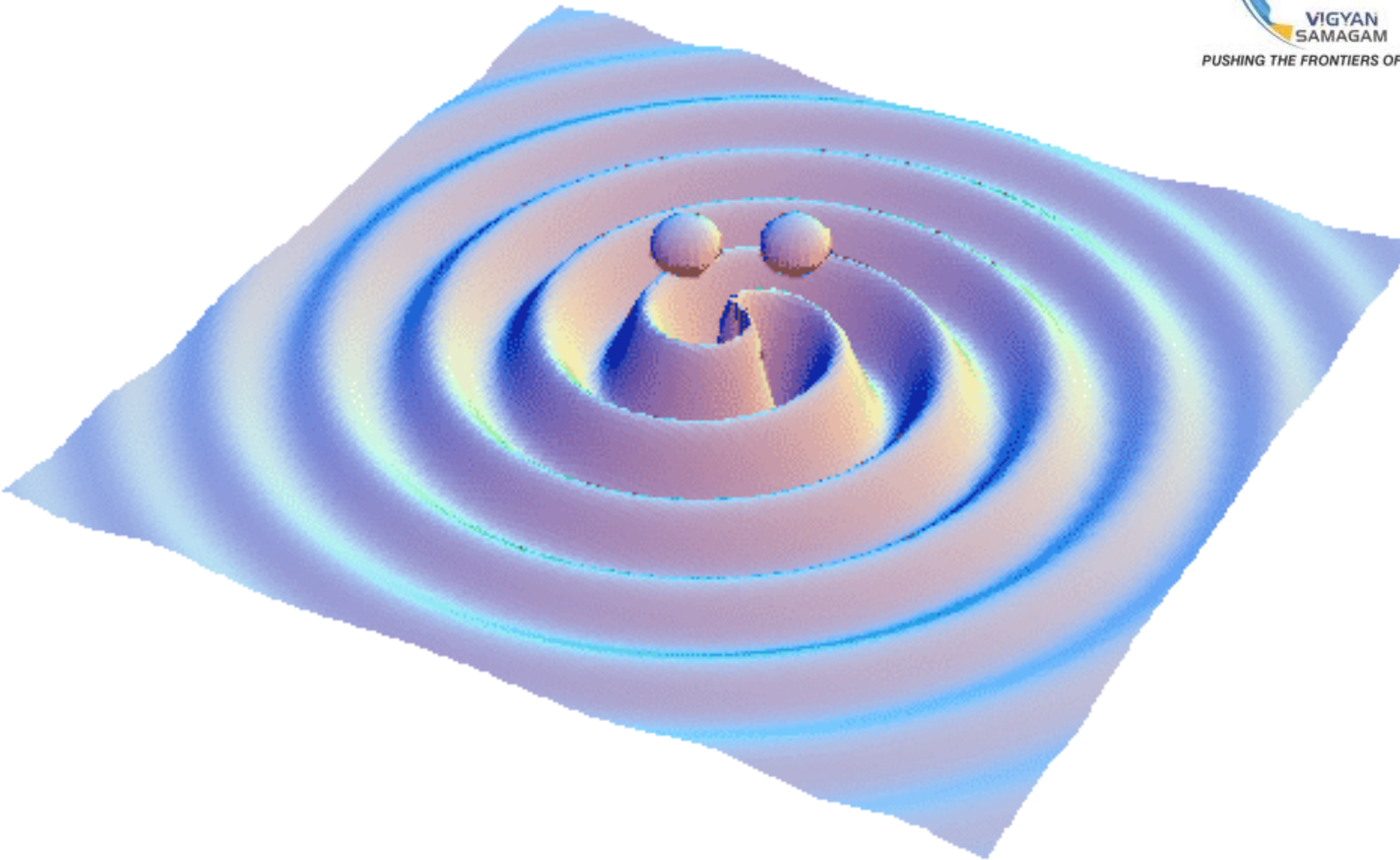
“It is the pitting of one’s brain against bits of iron, metal and glass and making them do what you want them to do. When you are successful that is all the reward you want”. - *Albert A. Michelson*



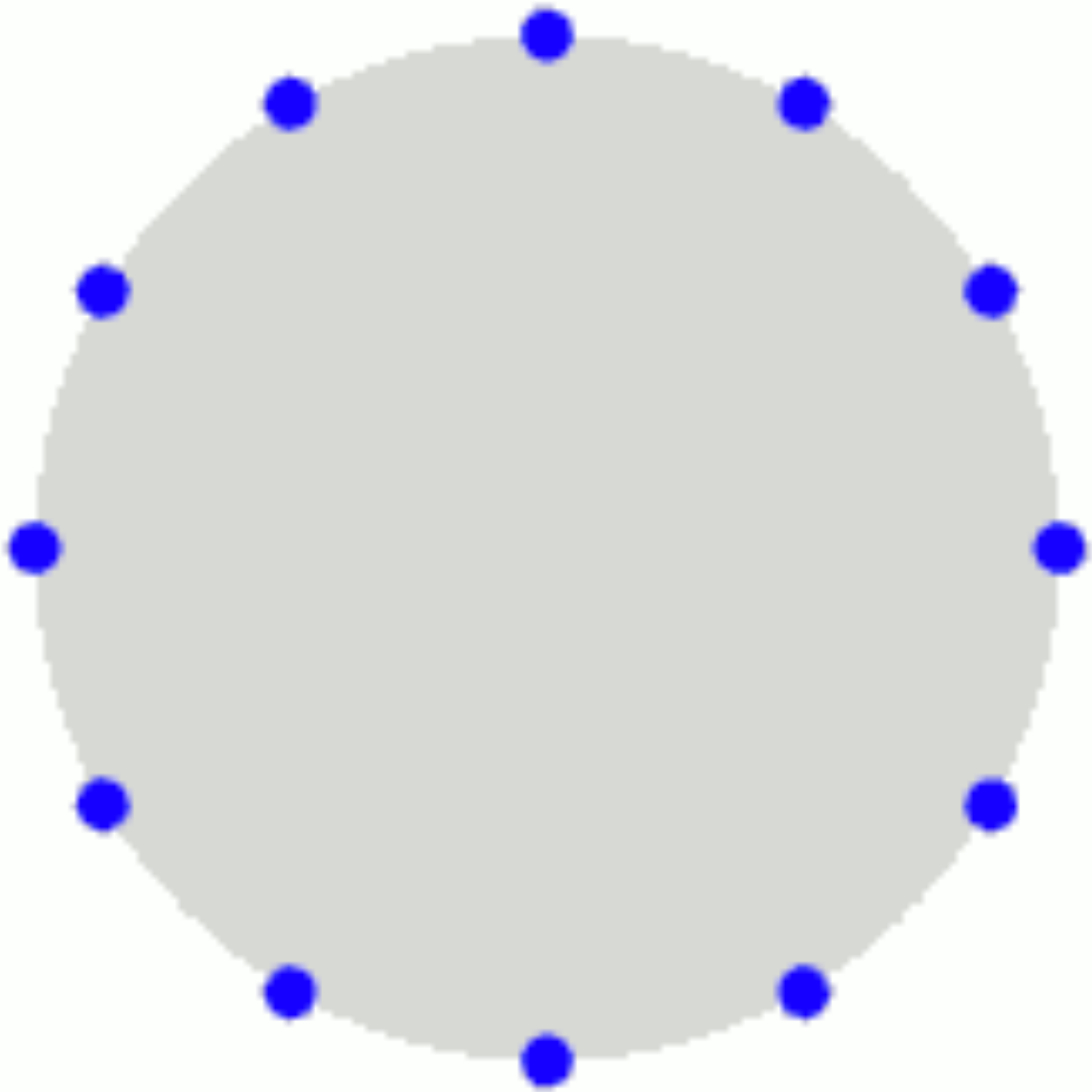
Laser Interferometer



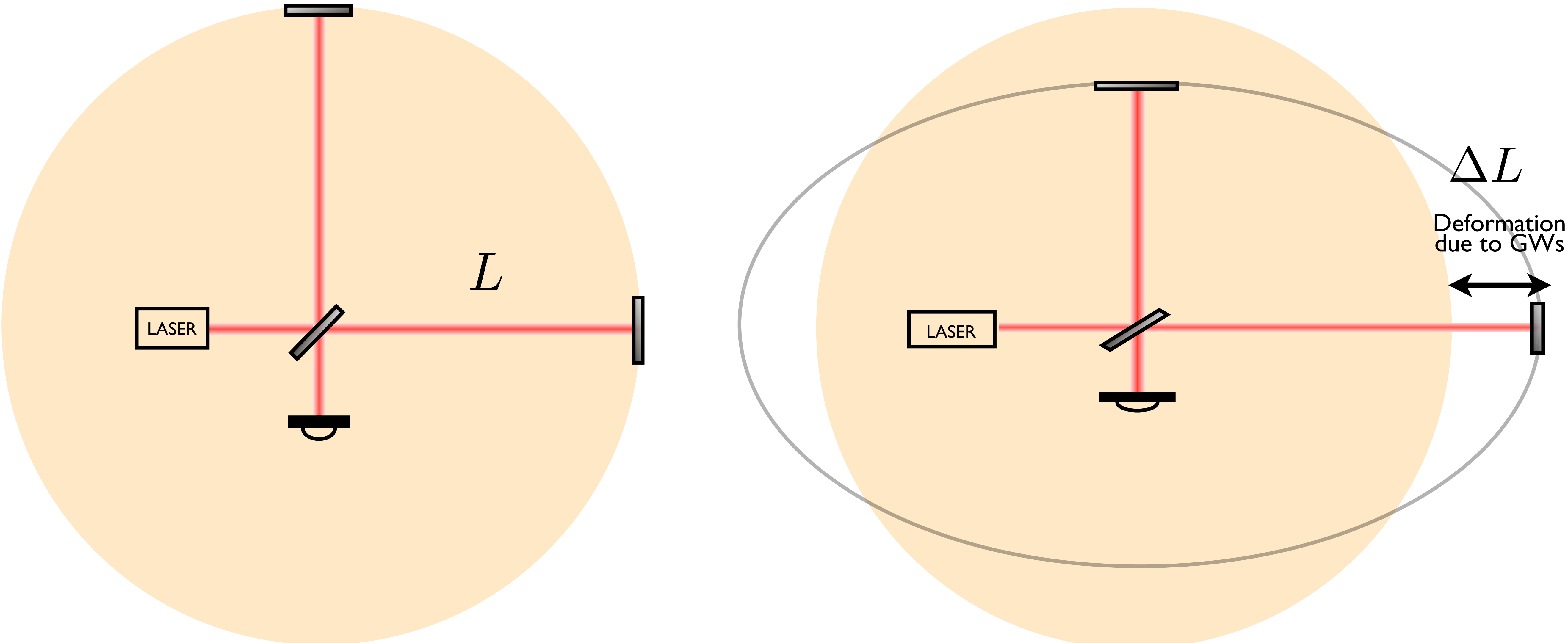
Gravitational Wave Detection



Gravitational Waves & Detectors



Gravitational Waves & Detectors

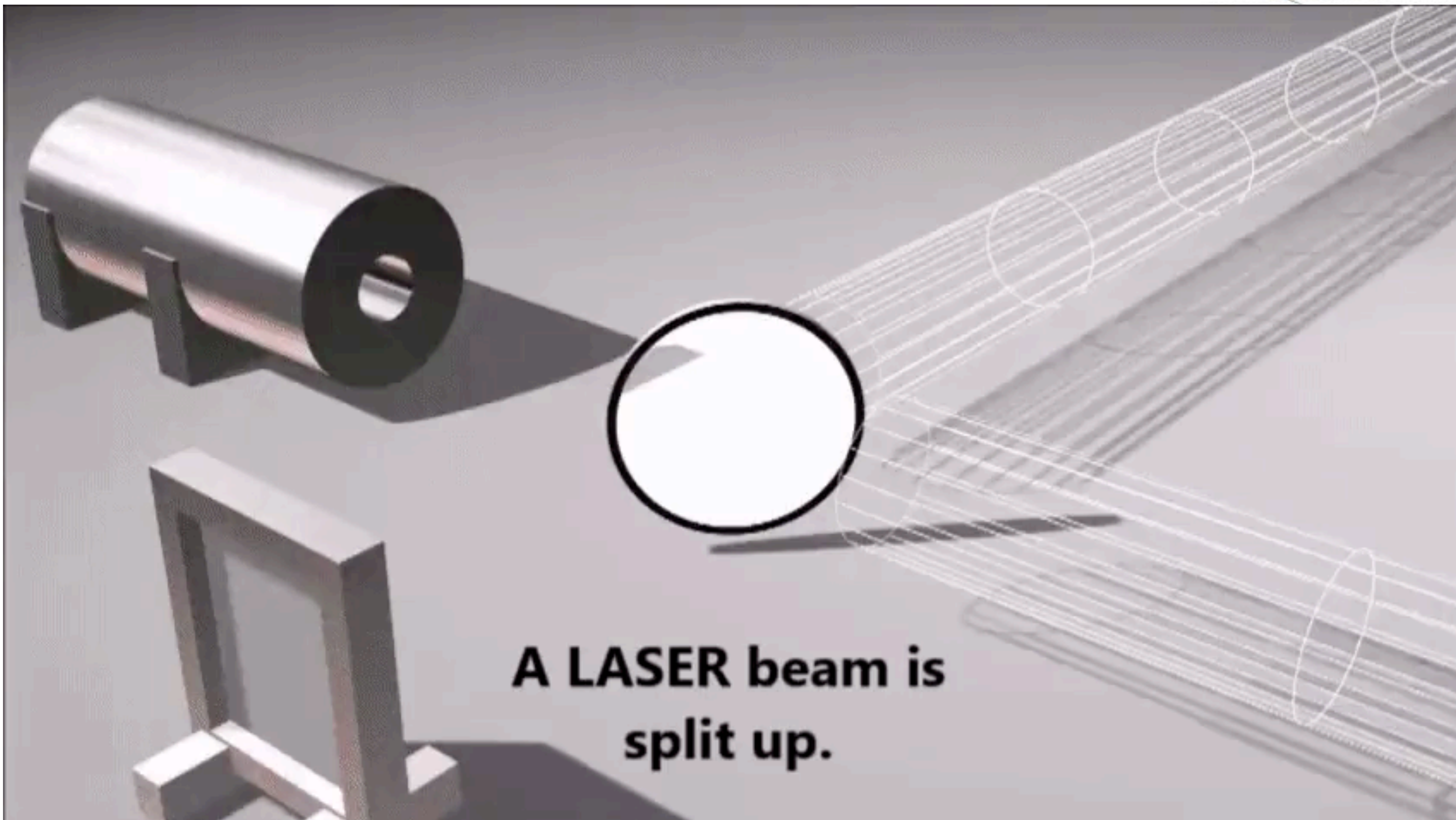


GW strain

Expected distortions: $h = \dfrac{\Delta L}{L} \sim 10^{-21}$ (BNS inspiral at 20 Mpc)

Laser Interferometer

as a Gravitational Wave Detector



GW sources & detector sensitivity

- Source of gravitational waves such as such as binary neutron stars (BNS) and binary black holes, etc., though the strongest sources of gravitation waves (GWs) are also at astrophysical distances
- The strain ($\Delta L/L$) they produce on earth are of the oder of 10^{-22} to 10^{-23}

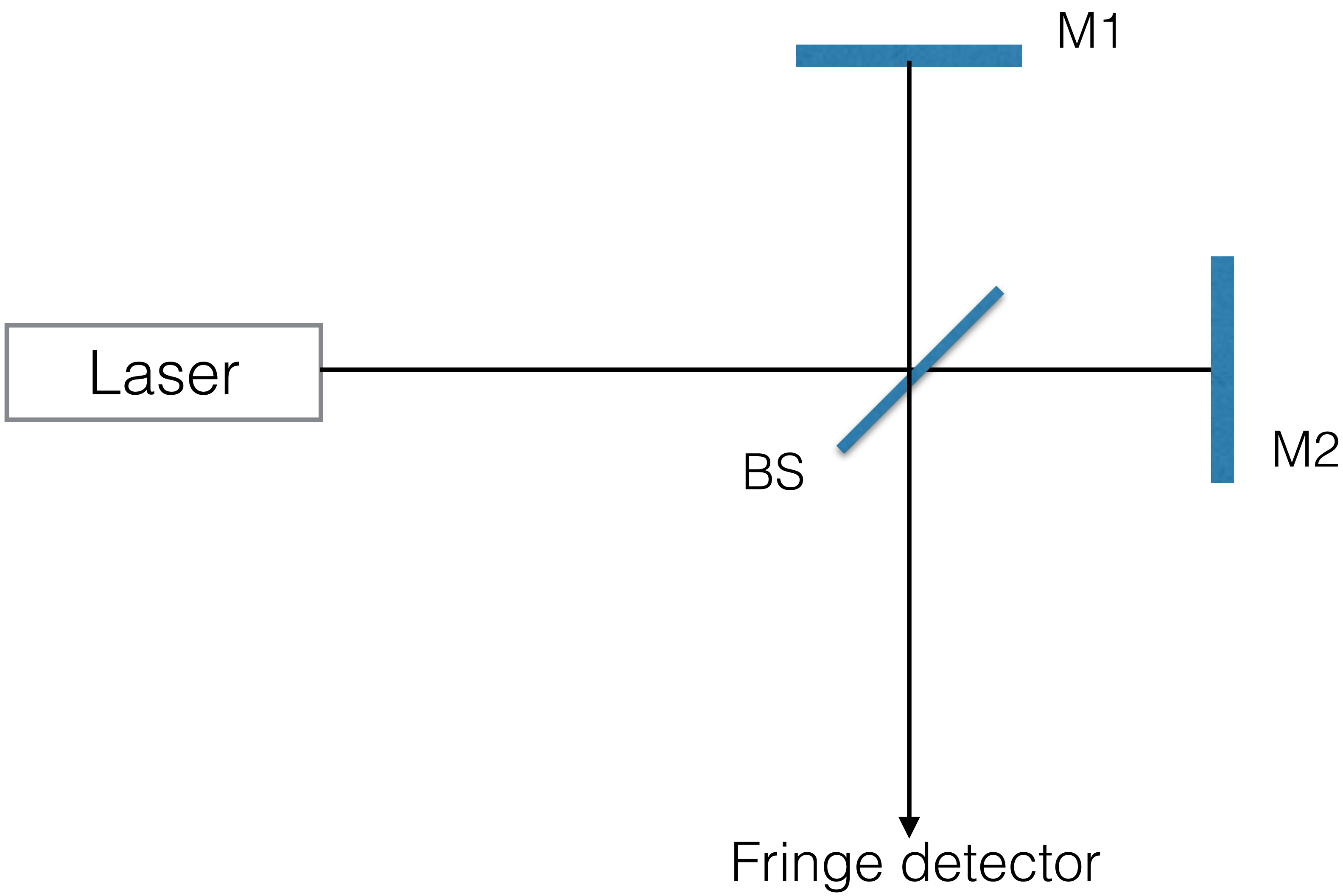
The LIGO Project funded by NSF was in two phases; LIGO and Advanced LIGO with strain sensitivities of about 10^{-22} and 10^{-23} respectively

The LIGO-India Detector will be the Advanced LIGO detector

- Detection of gravitational waves require strain sensitivity

$$\Delta L/L \approx 3 \times 10^{-24}$$

- For $L = 4$ km, $\Delta L \approx 10^{-20}$ m



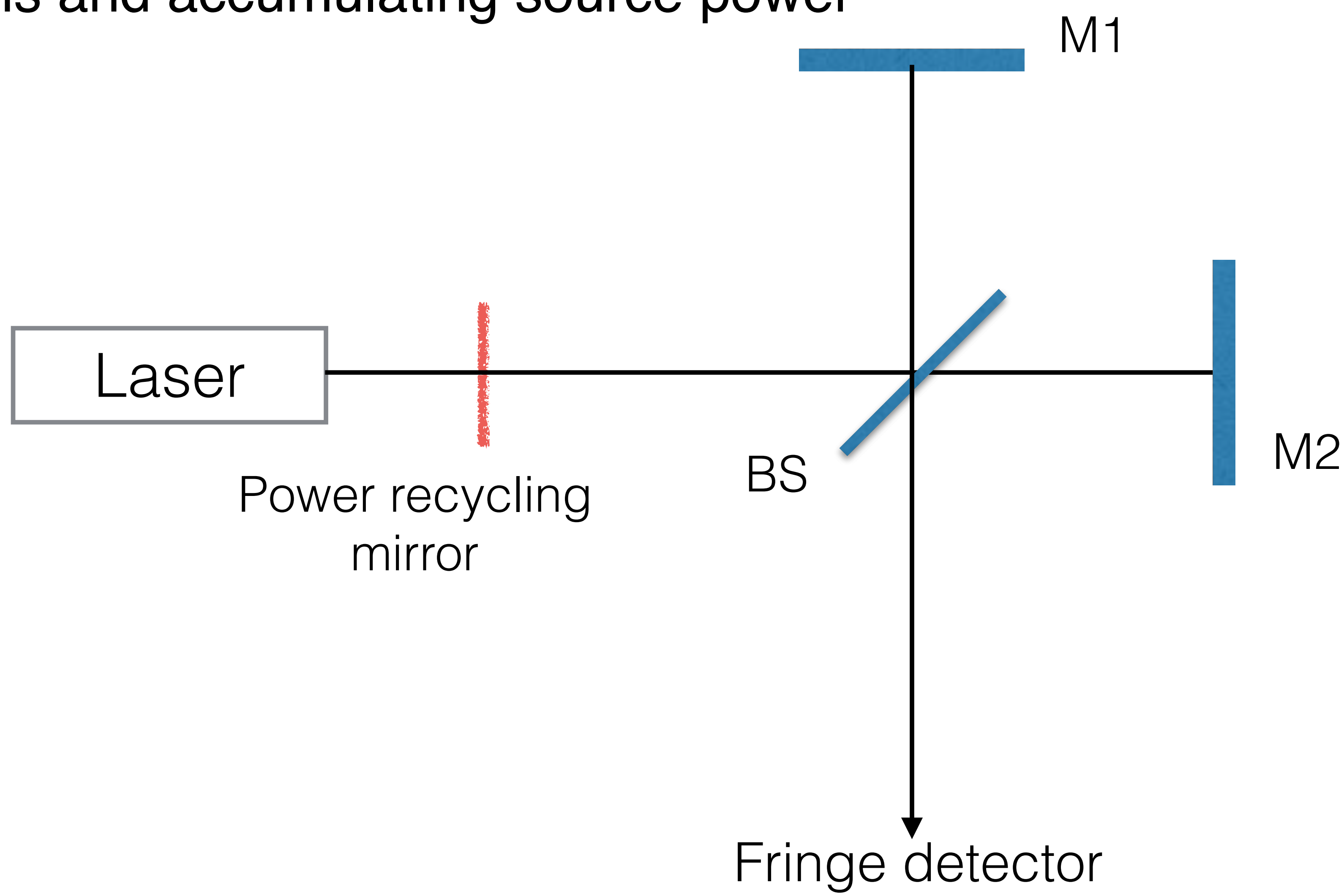
Typical minimum ΔL measurable in laboratory interferometer $\approx 10^{-9}$ m

Steps involved to reach 10^{-20} m sensitivity

- A highly stabilised, coherent, and high power laser needs to be used.
  LIGO-laser power : 200 W (c/f a lab interferometer ≈ 1 mW)

  → Enhancement of sensitivity by a factor of ≈ 10^5

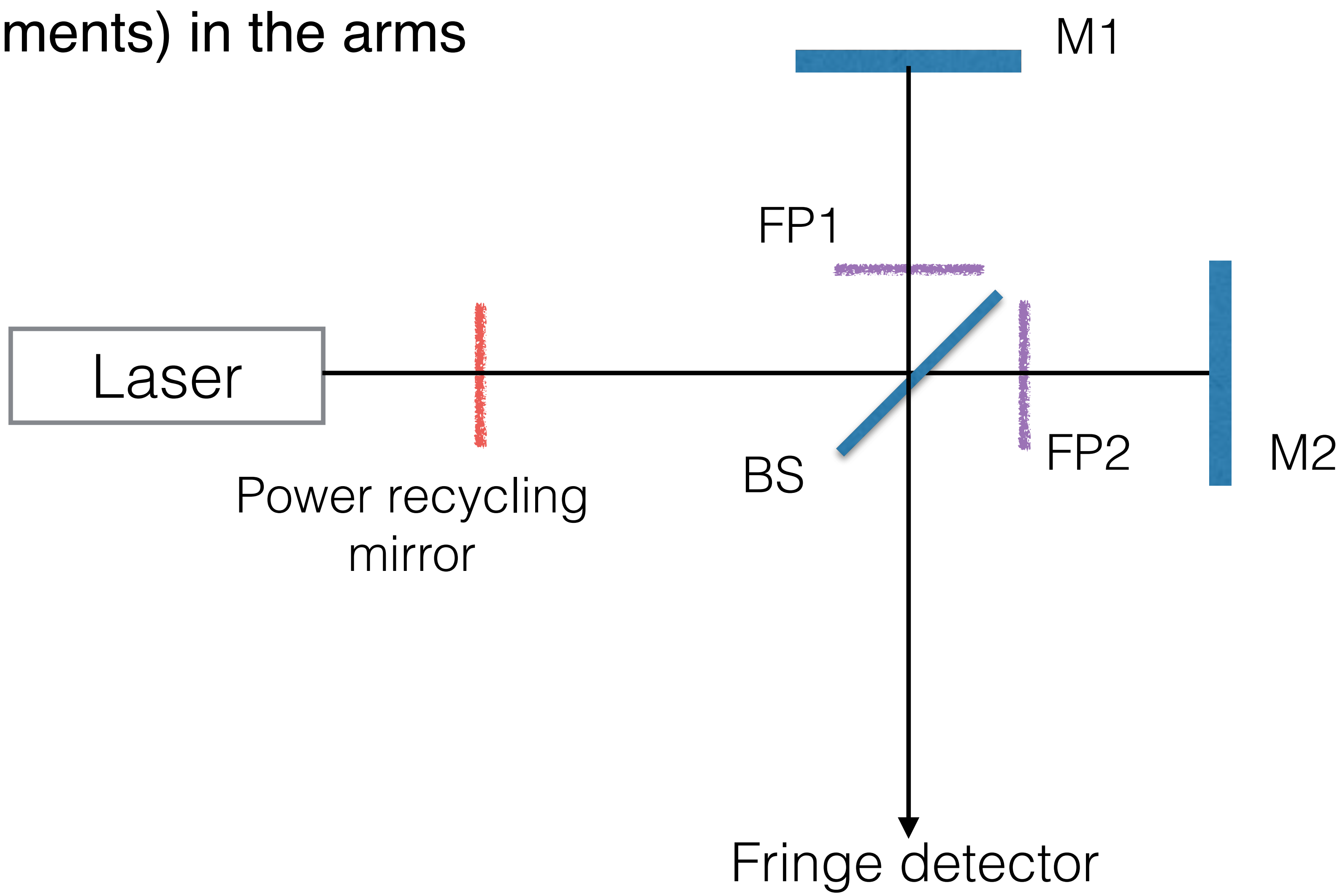
- Laser Power circulating in the interferometer arms can be increased by multiple reflections and accumulating source power



→ Enhancement of sensitivity by a factor of ≈ 10^2

Steps involved to reach 10^{-20} m sensitivity (cont.)

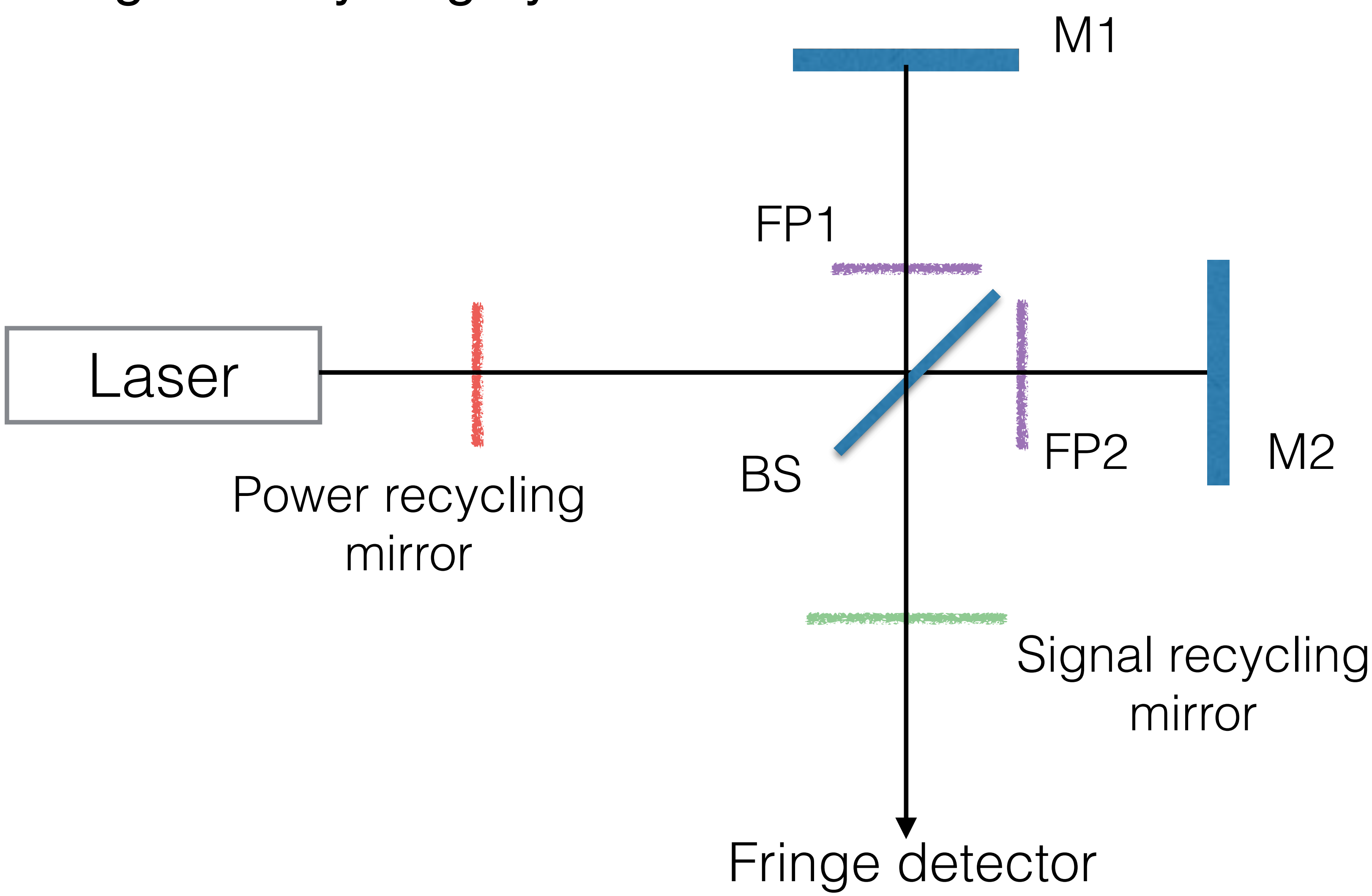
- Length of interferometer arms (4 km) can be effectively increased by multiple passes of laser light by placing additional mirrors (called Fabry-Perot enhancements) in the arms



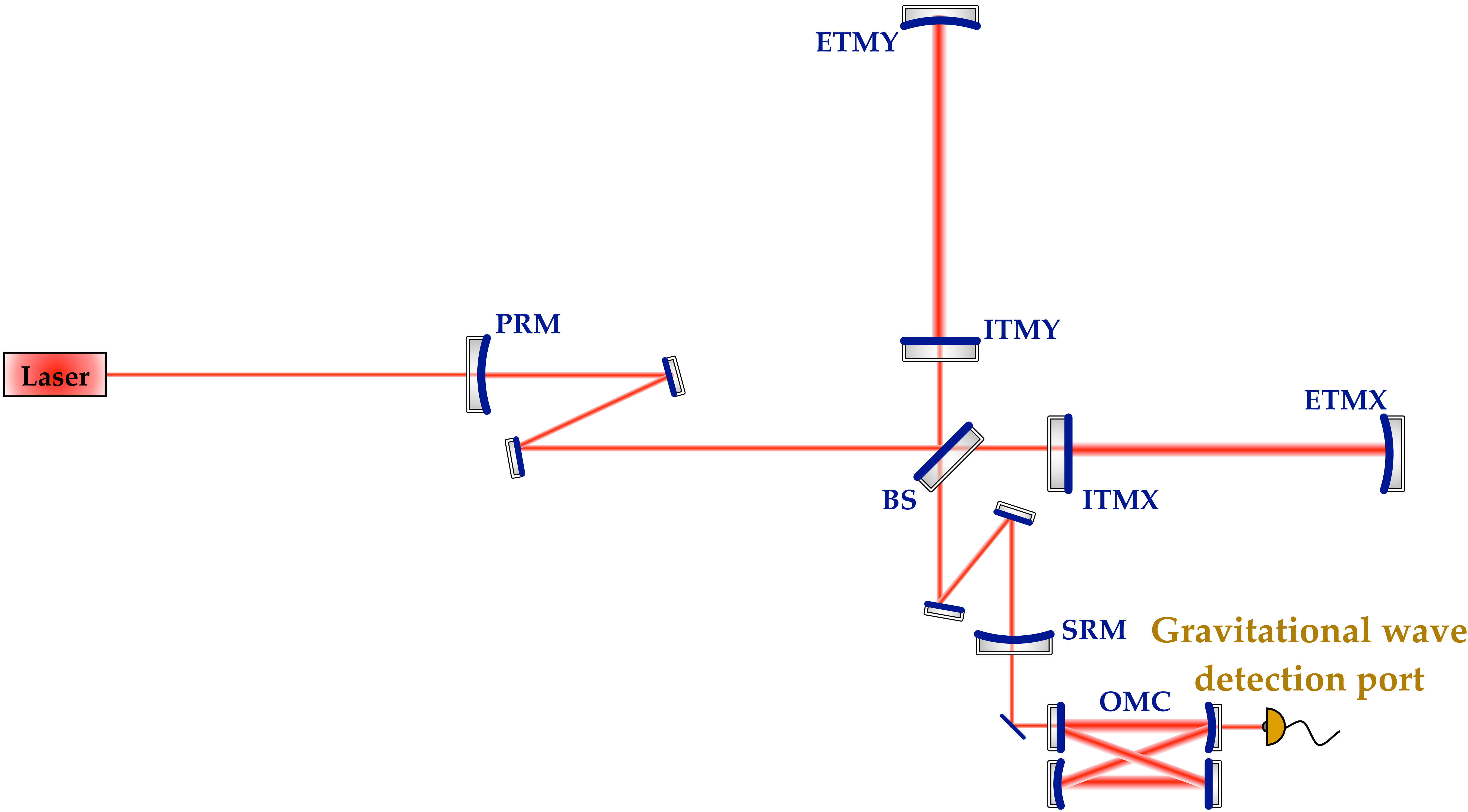
⟶ This gives an enhancement of sensitivity by a factor between 10^2 to 10^3

Enhancement of sensitivity by signal recycling

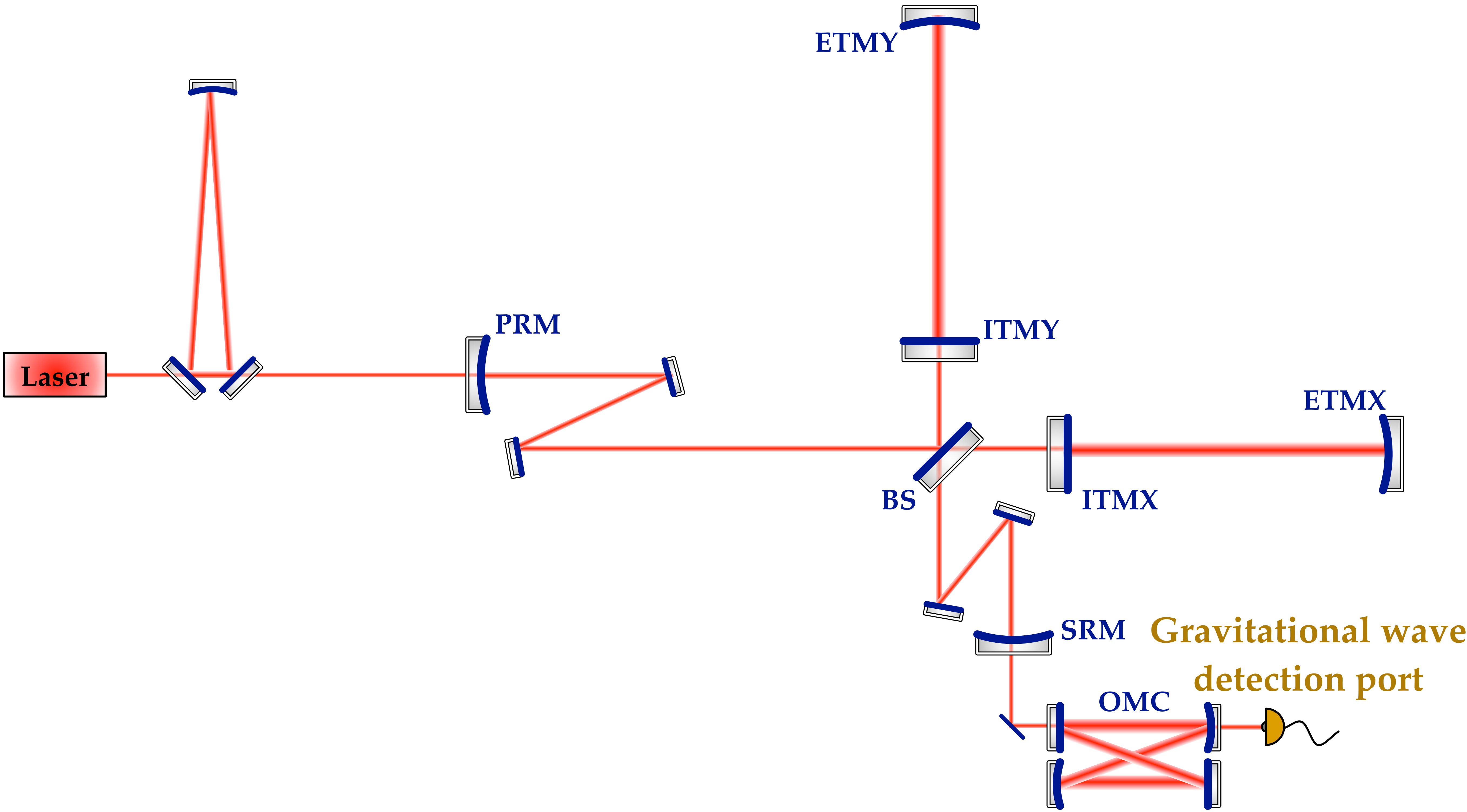
- The length of interferometer arms = 4 km
- Effective arm length ≈ 400 km
- Typical wavelength of gravitational waves ($\lambda_{\rm GW} \approx$ tens of thousand km) is much larger the the effective arm length
- This allows signal re-cycling by a factor of 100



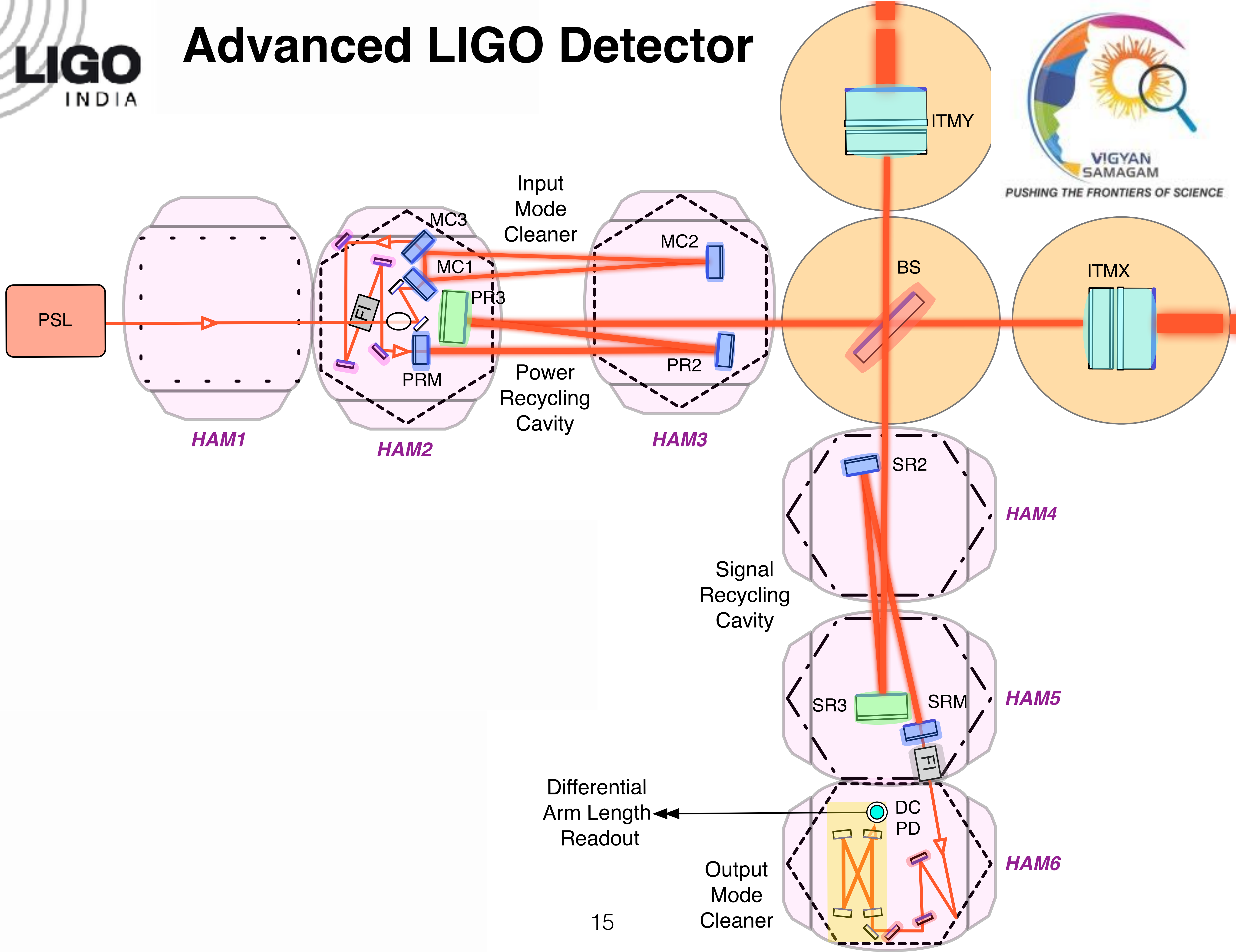
Detector overview



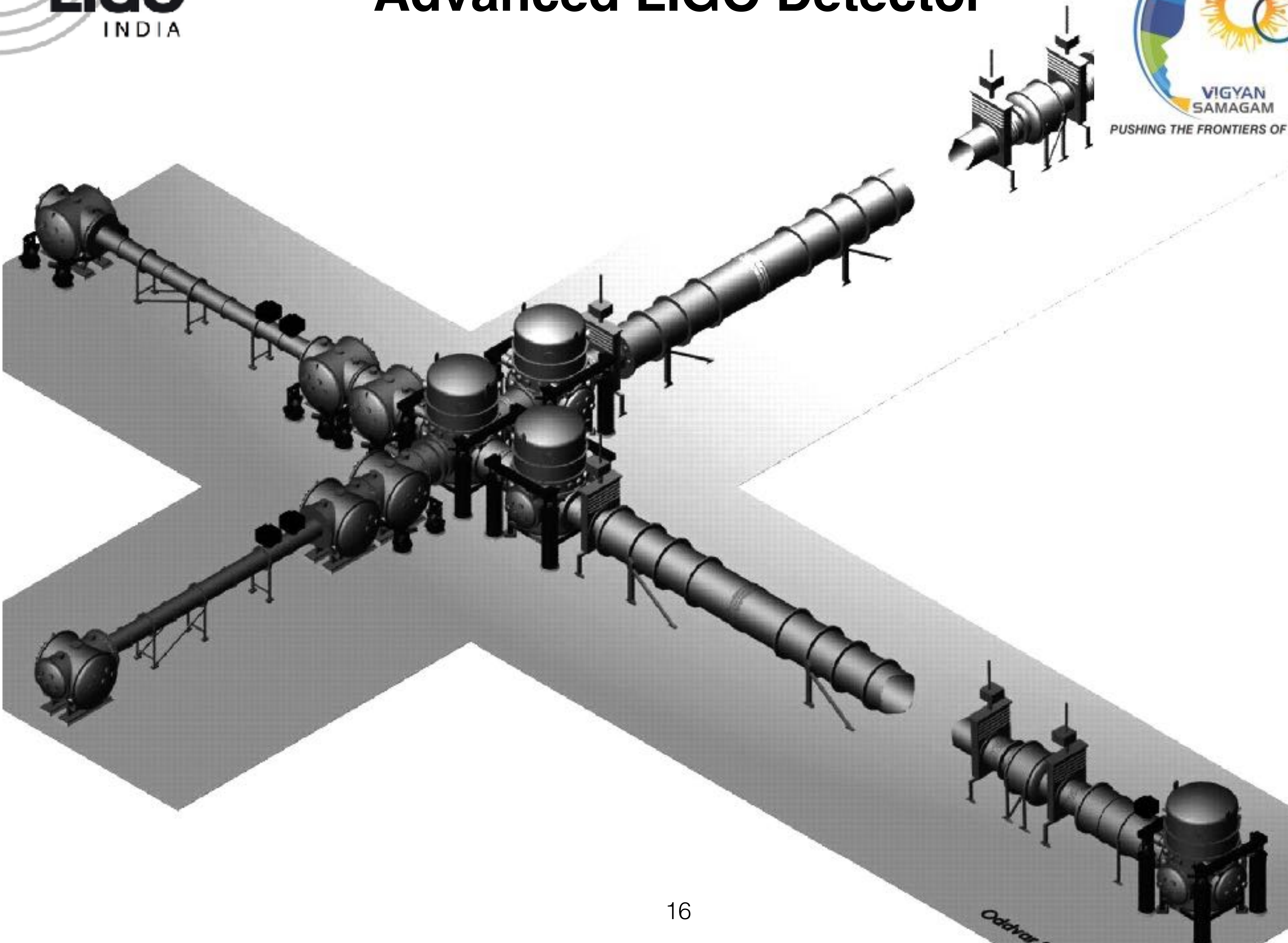
Detector overview



Advanced LIGO Detector



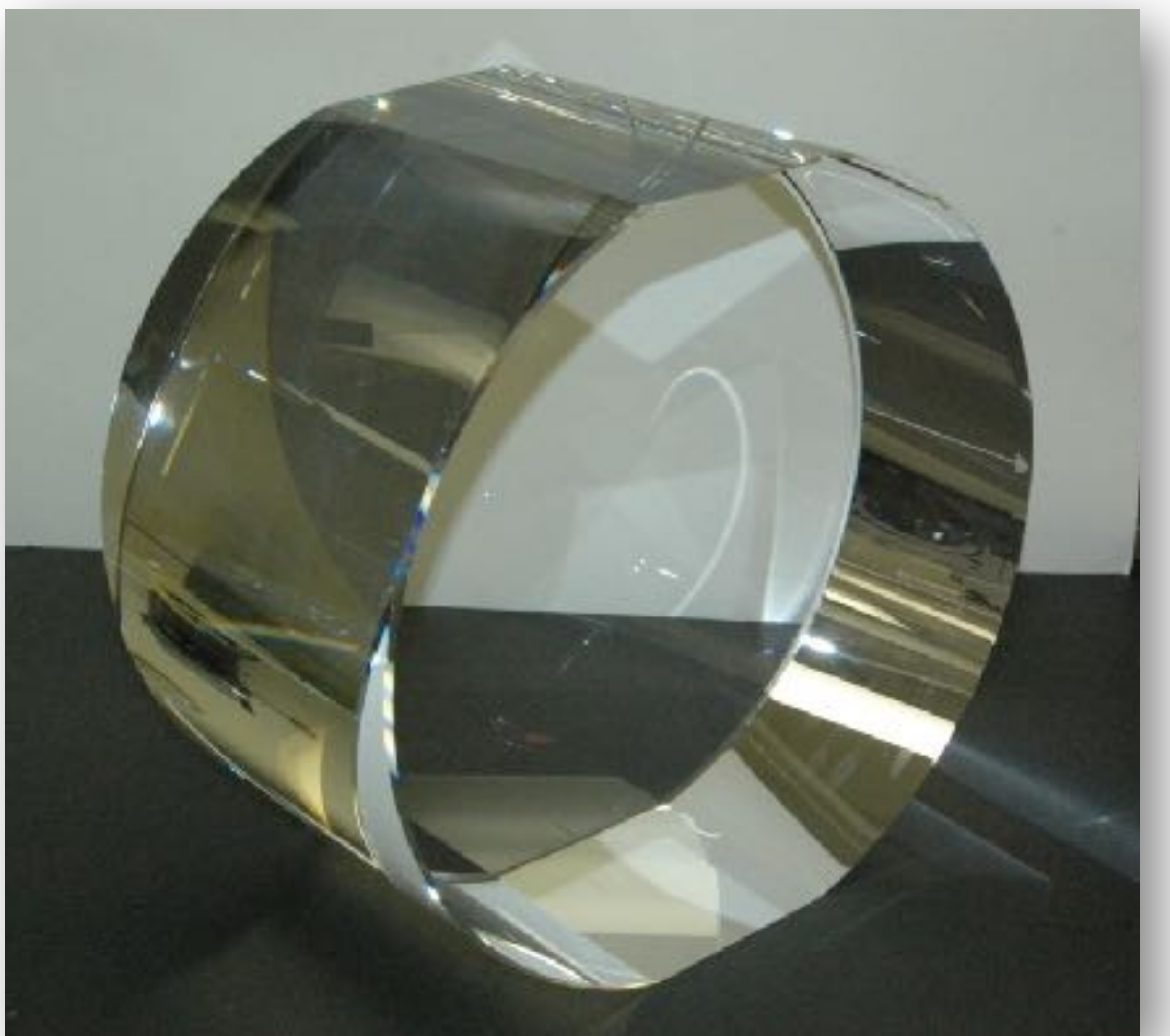
Advanced LIGO Detector



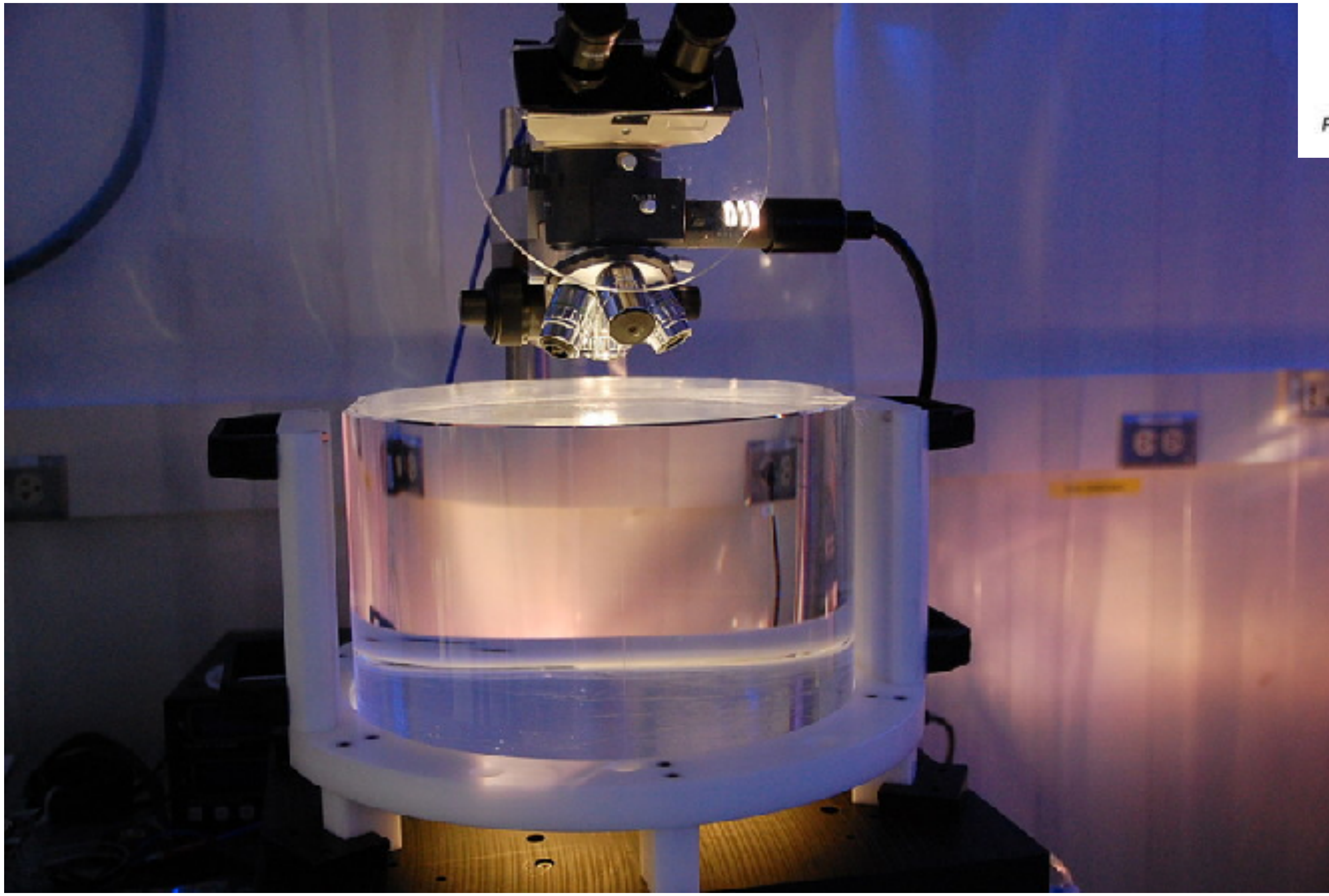
Advanced LIGO Detector

Test Masses:

- 40 kg
- 38 cm in diameter
- Polishing: 0.15 nm rms
- Coating absorption: 0.5 ppm



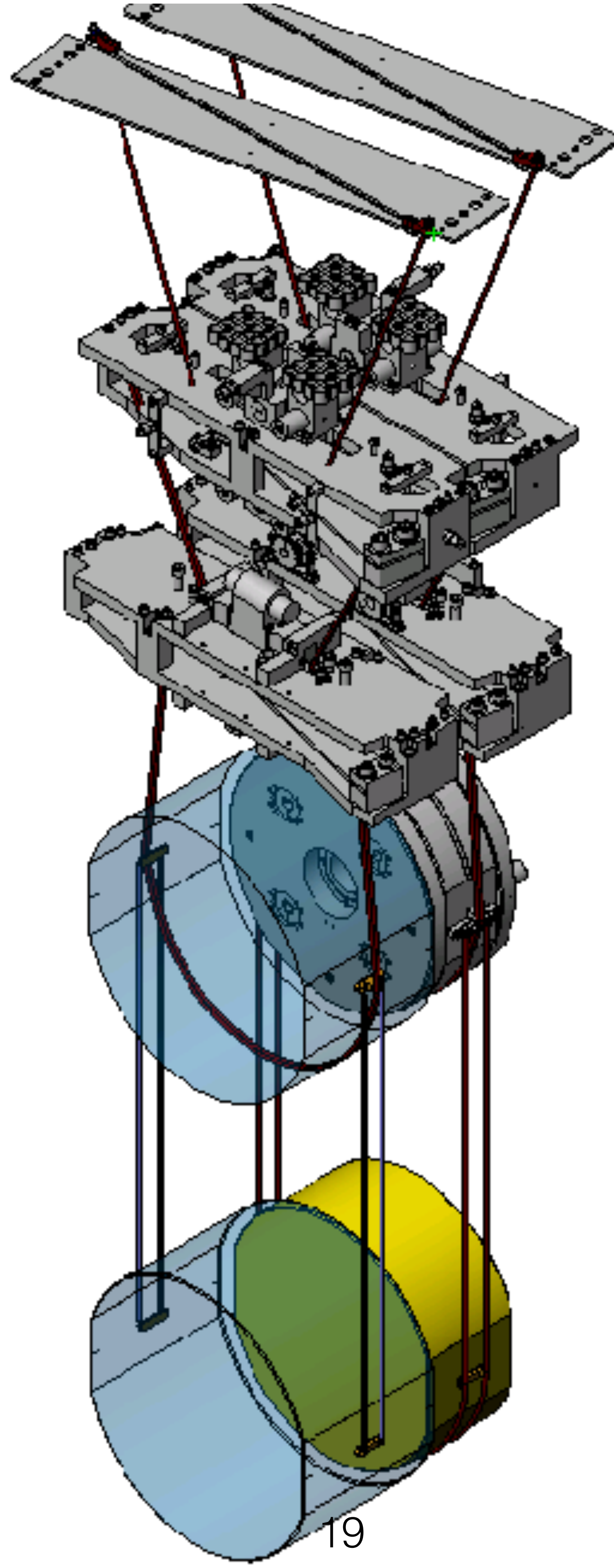
Advanced LIGO Detector



Surface 1, Frequency Band: $< 1\ \mathrm{mm}^{-1}$

- Central 300 mm diameter aperture: $\sigma_{rms} < 2.5$ nm
- Central 160 mm diameter aperture: $\sigma_{rms} < 0.3$ nm
- RMS_{Total} , *total area plus defect* < 0.125 nm

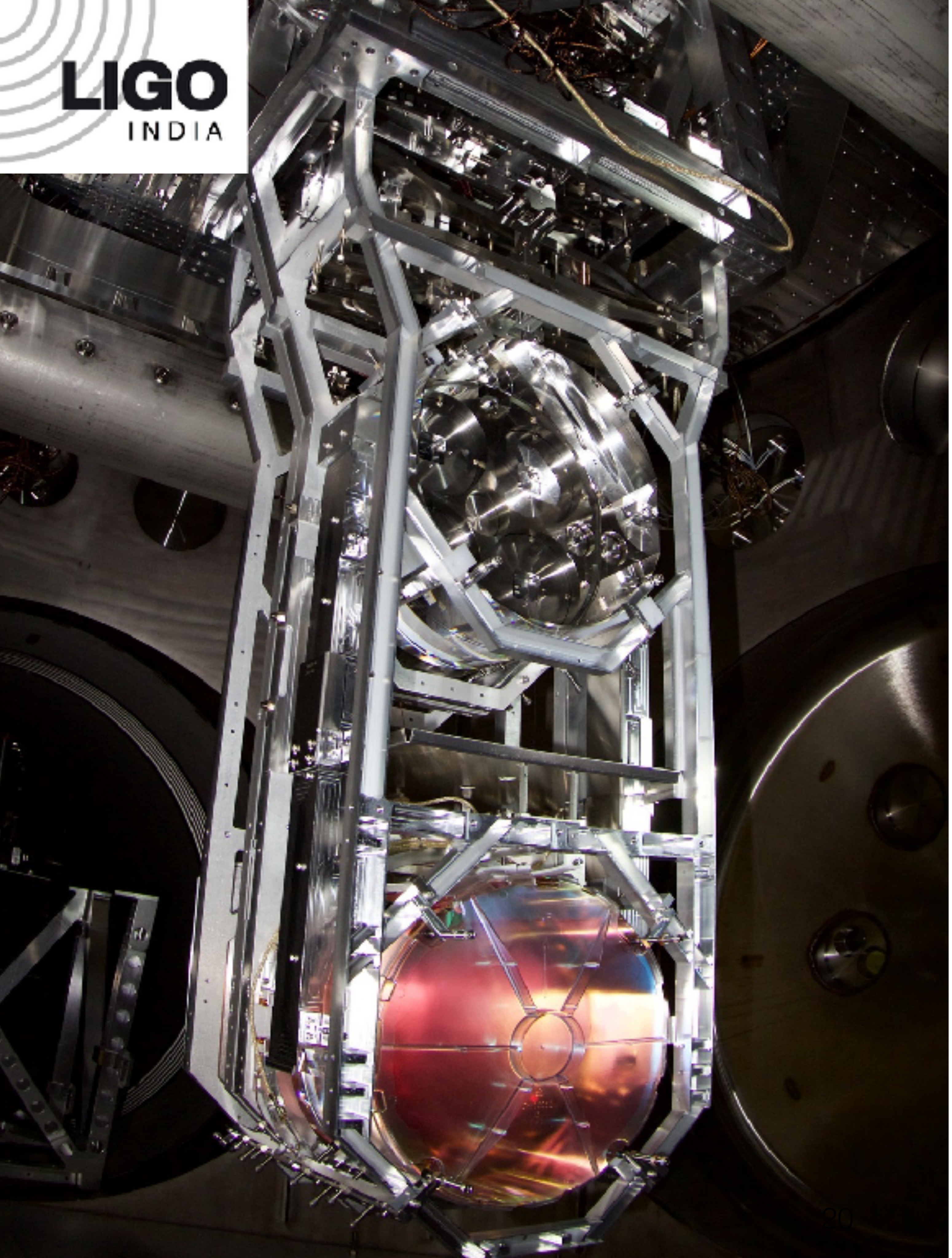
Advanced LIGO Detector



Quad Suspension

- Design : 4 stage pendulum
- Final stage: Monolithic
- Mechanical Q : 10^3
- Isolation: factor of 10^{12}
- Actuation: electro-magnetic
  electrostatic (4^{th} stage)

LIGO INDIA



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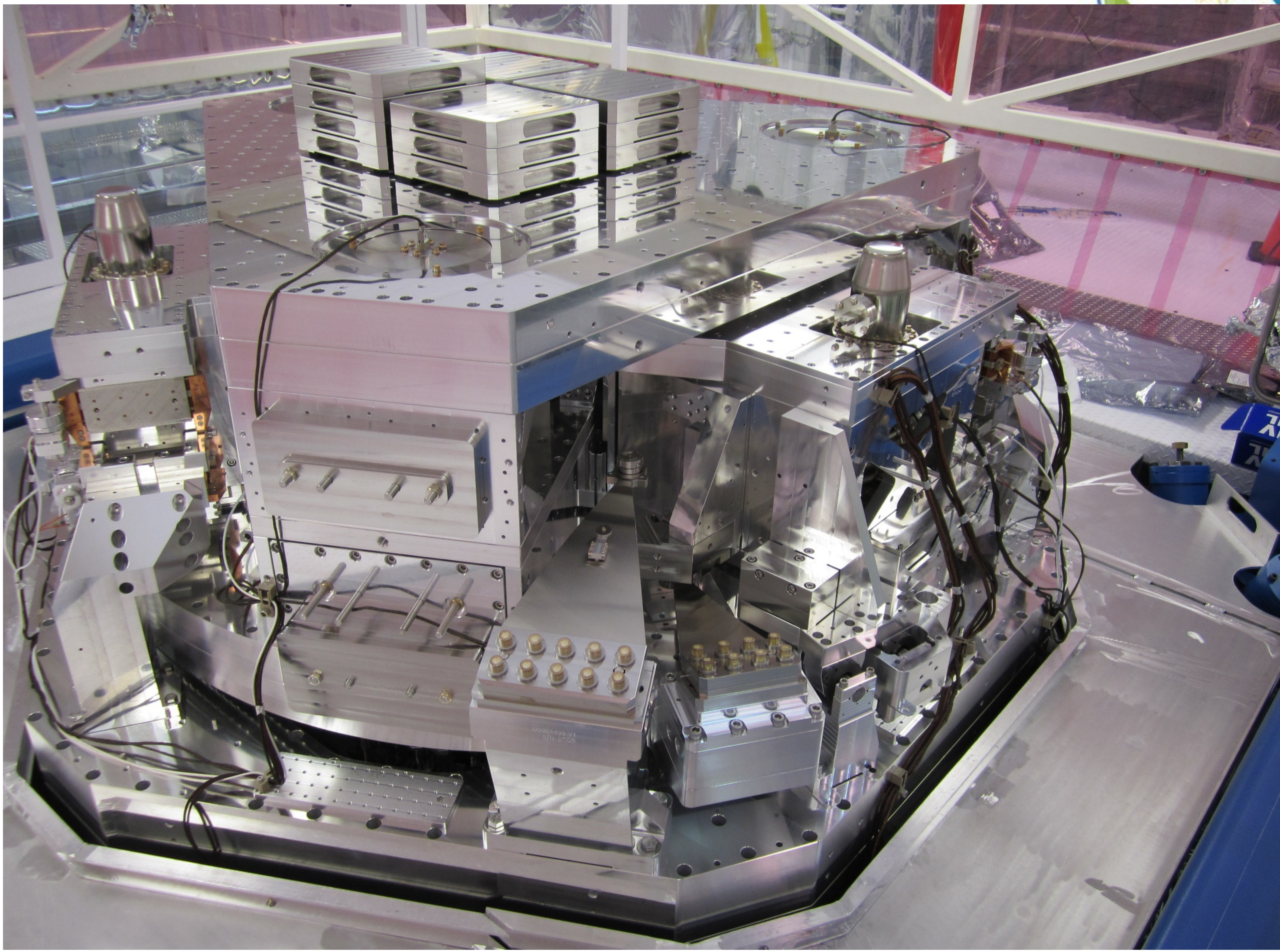
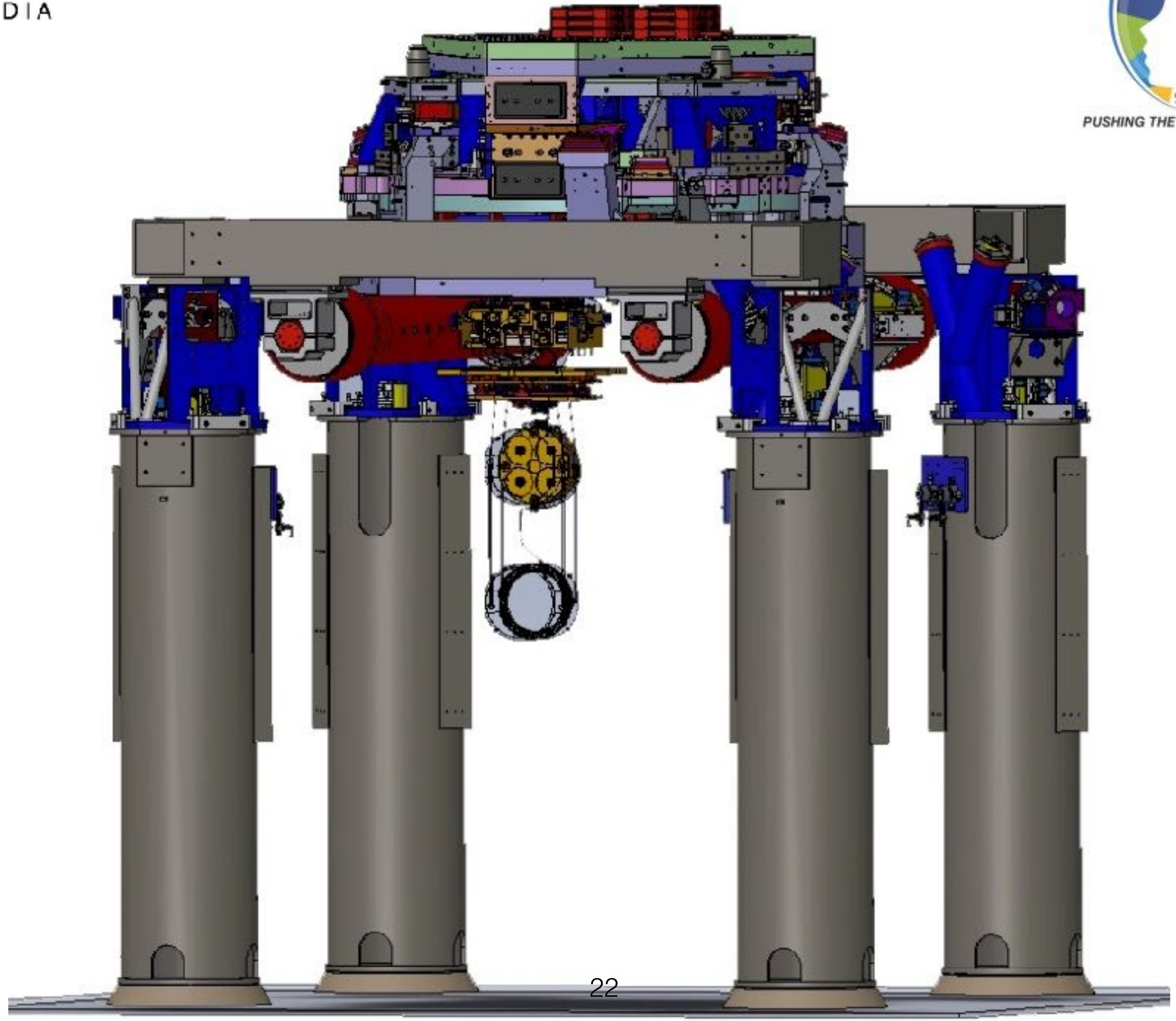
Quad Assembly

The assembly of the four-stage vibration isolation suspension of the core-optics of the detector needs to be developed in India

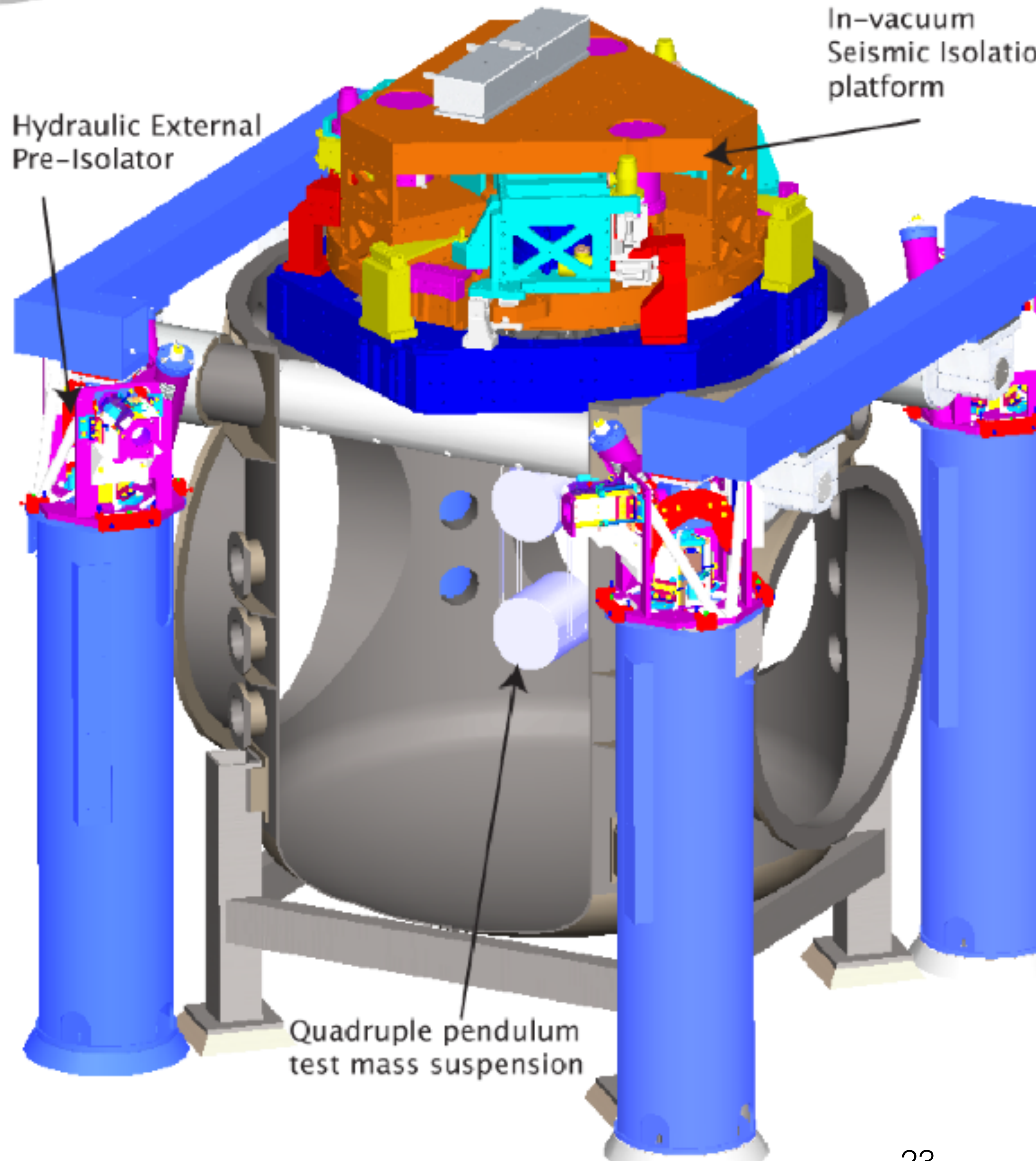
Advanced LIGO Detector

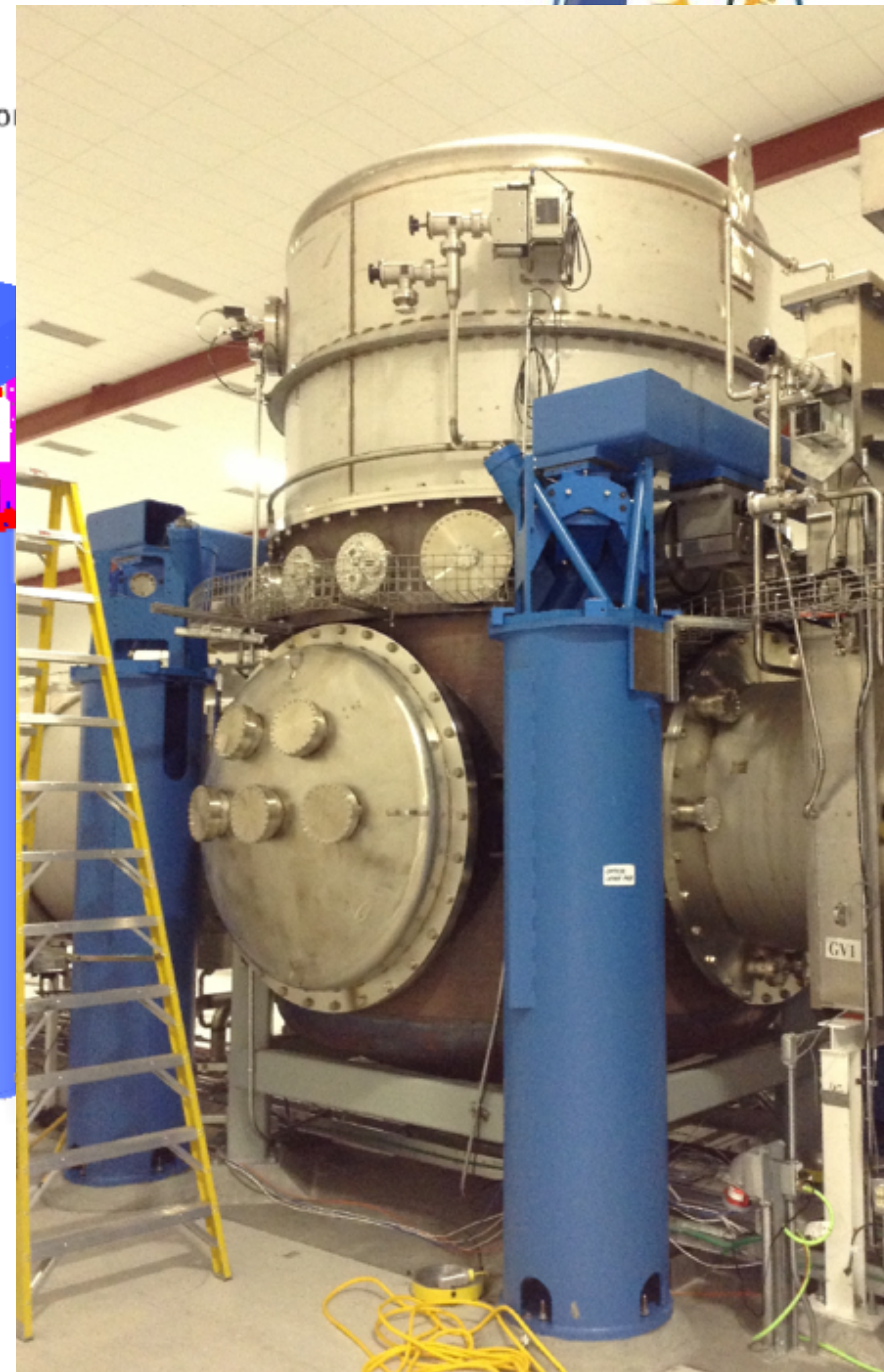


Advanced LIGO Detector

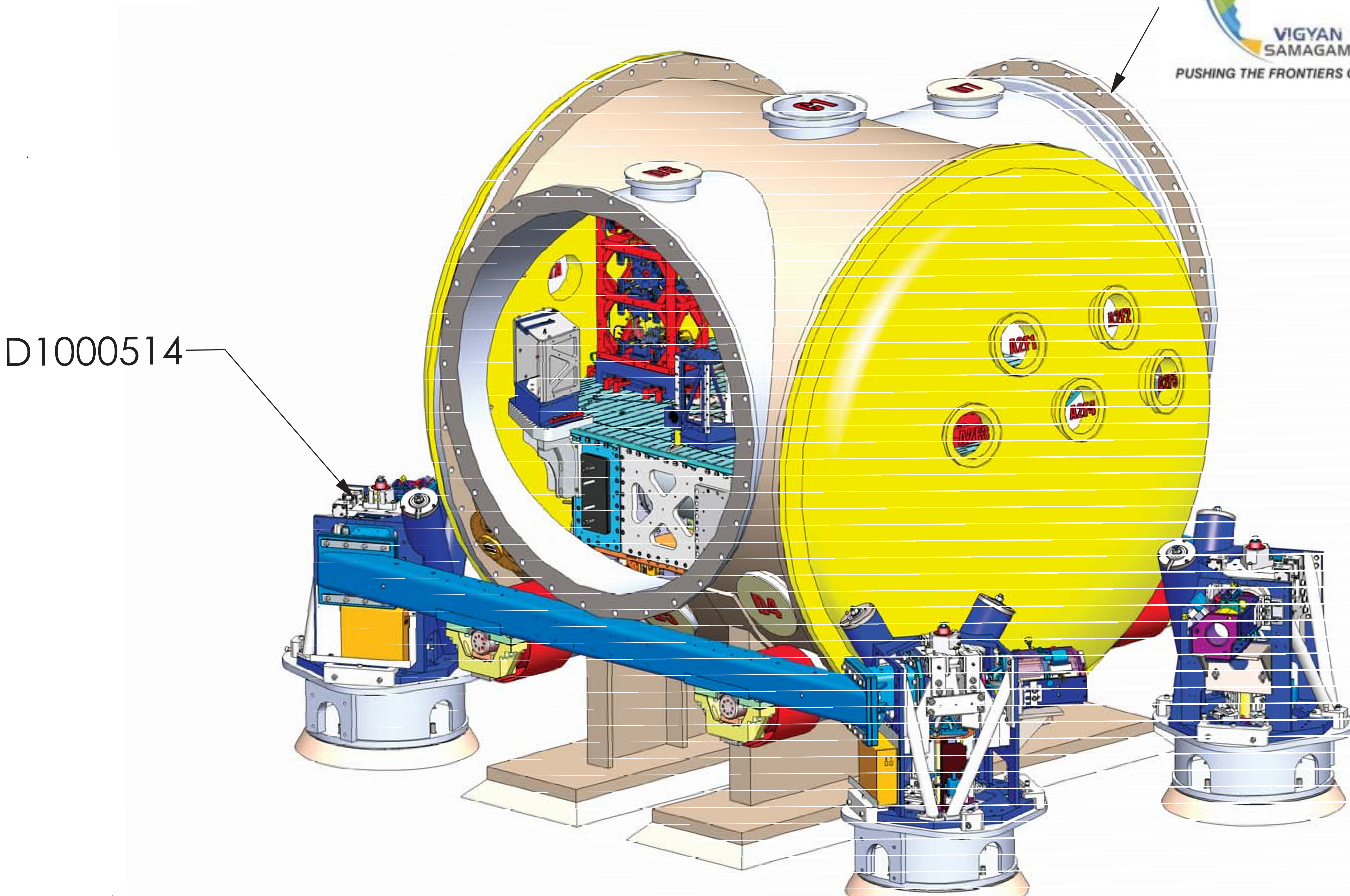


Advanced LIGO Detector

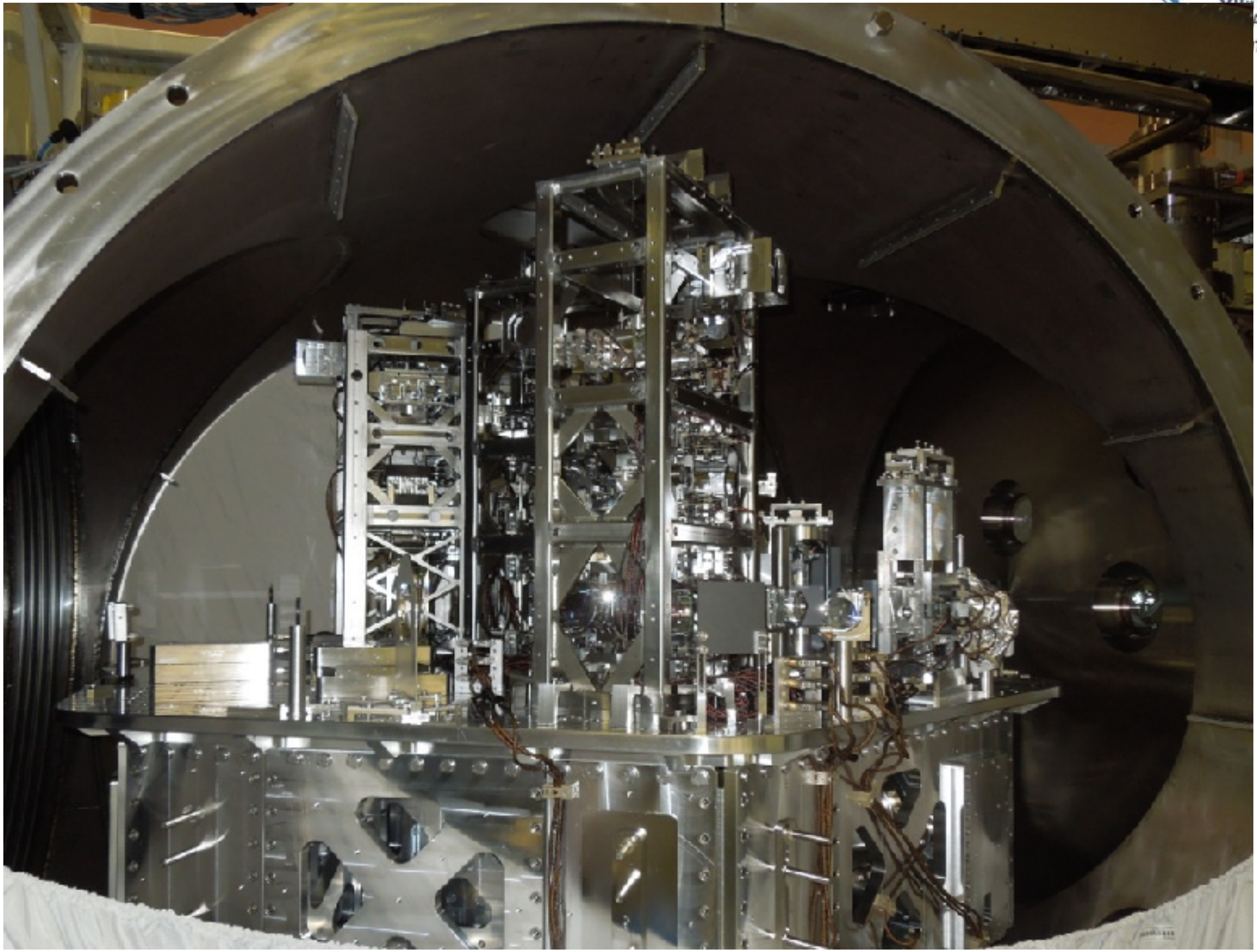




Advanced LIGO Detector



Advanced LIGO Detector



LIGO INDIA

Advanced LIGO Detector

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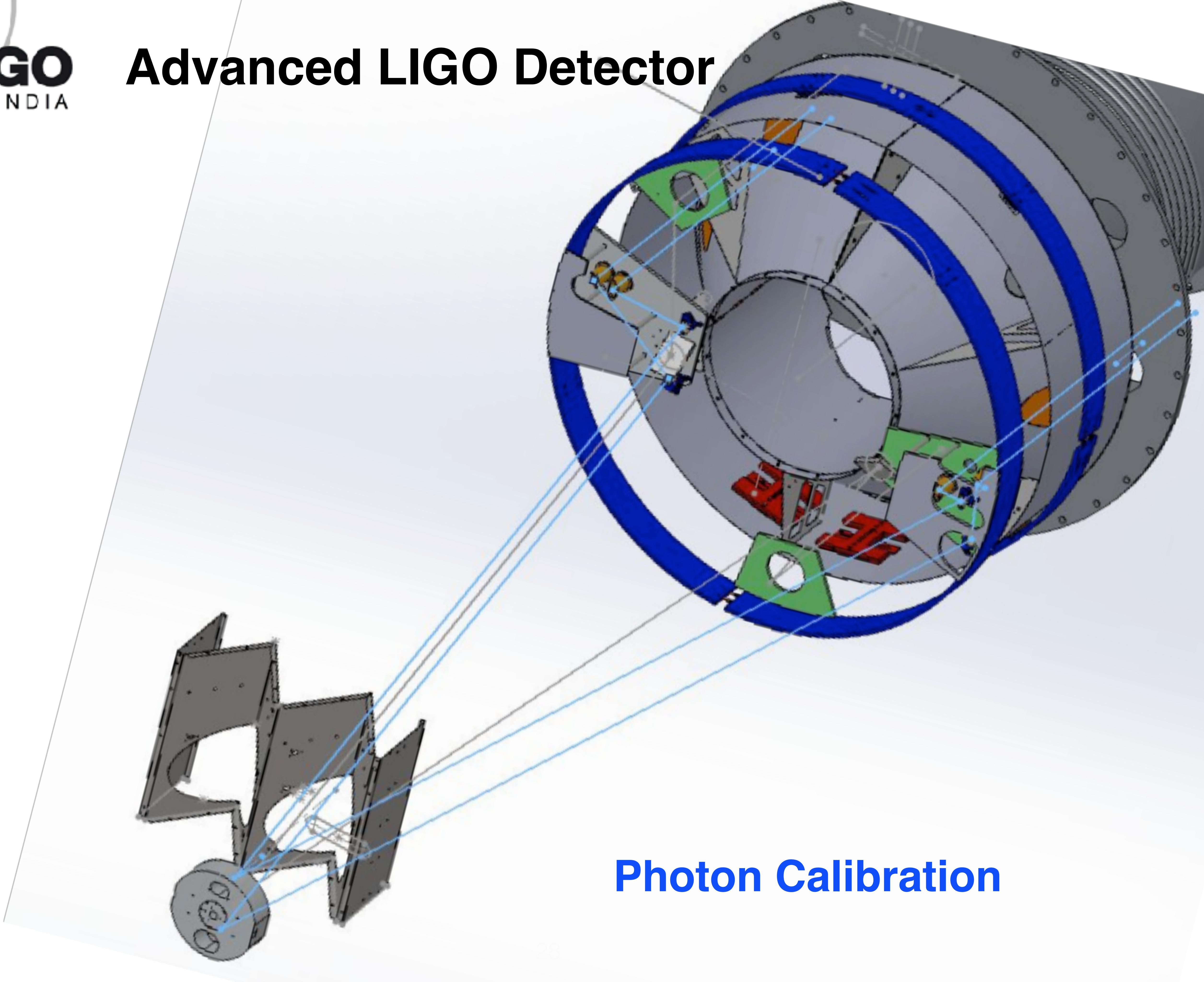
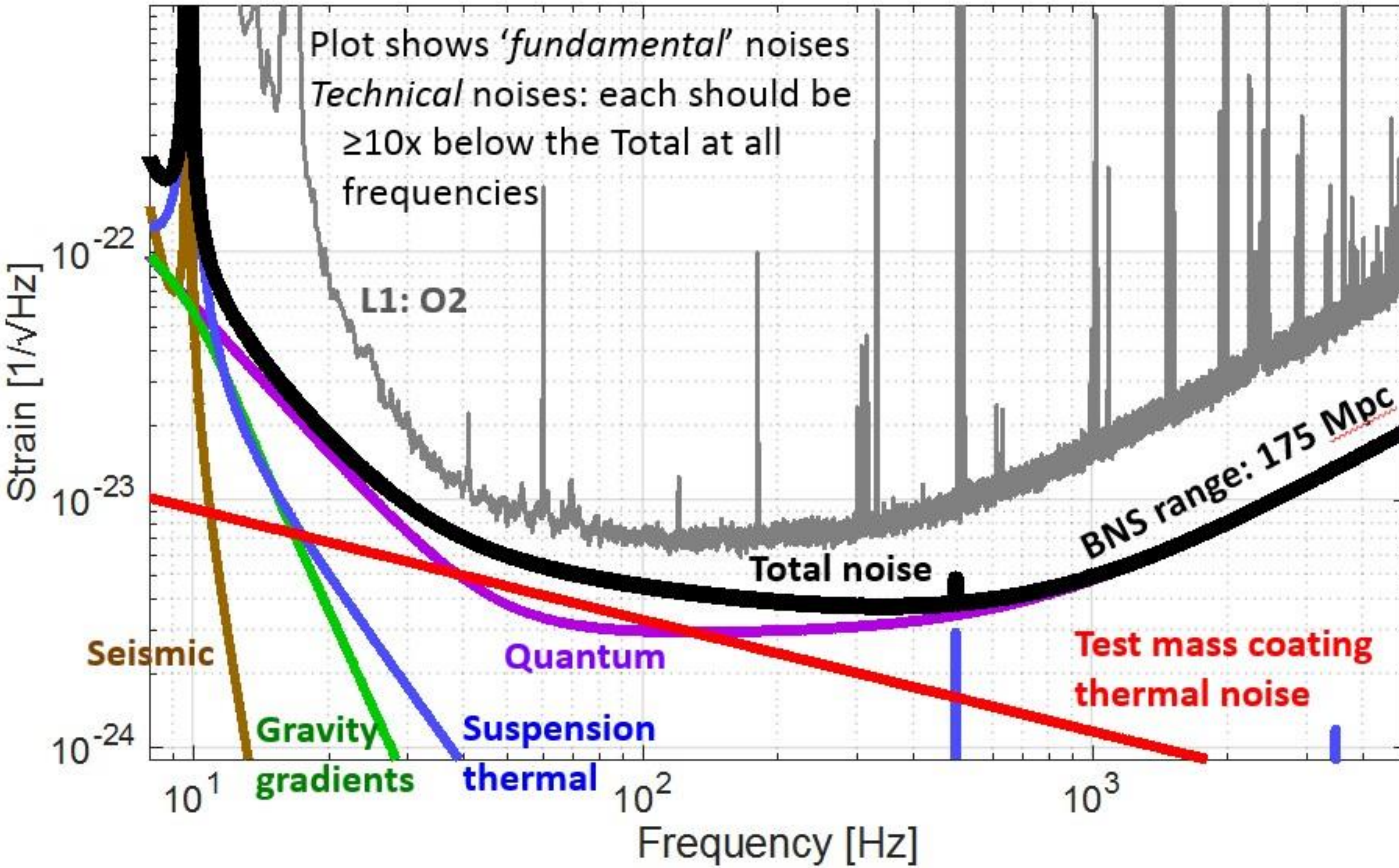
Advanced LIGO Detector

Advanced LIGO Detector



Photon Calibration

Detector Sensitivity



LIGO-India Project

The LIGO-India Project proposal is for the construction of an Advanced interferometric gravitational wave detector in India called LIGO-India under an international collaboration with Laser Interferometer Gravitational–wave Observatory (LIGO) Laboratory, USA.

The four lead institutes (IUCAA, DCSEM, IPR & RRCAT) and the LIGO Laboratory will work together in realising the Indian node (LIGO-India) of the international gravitational wave detector network in India.

Science Motivation

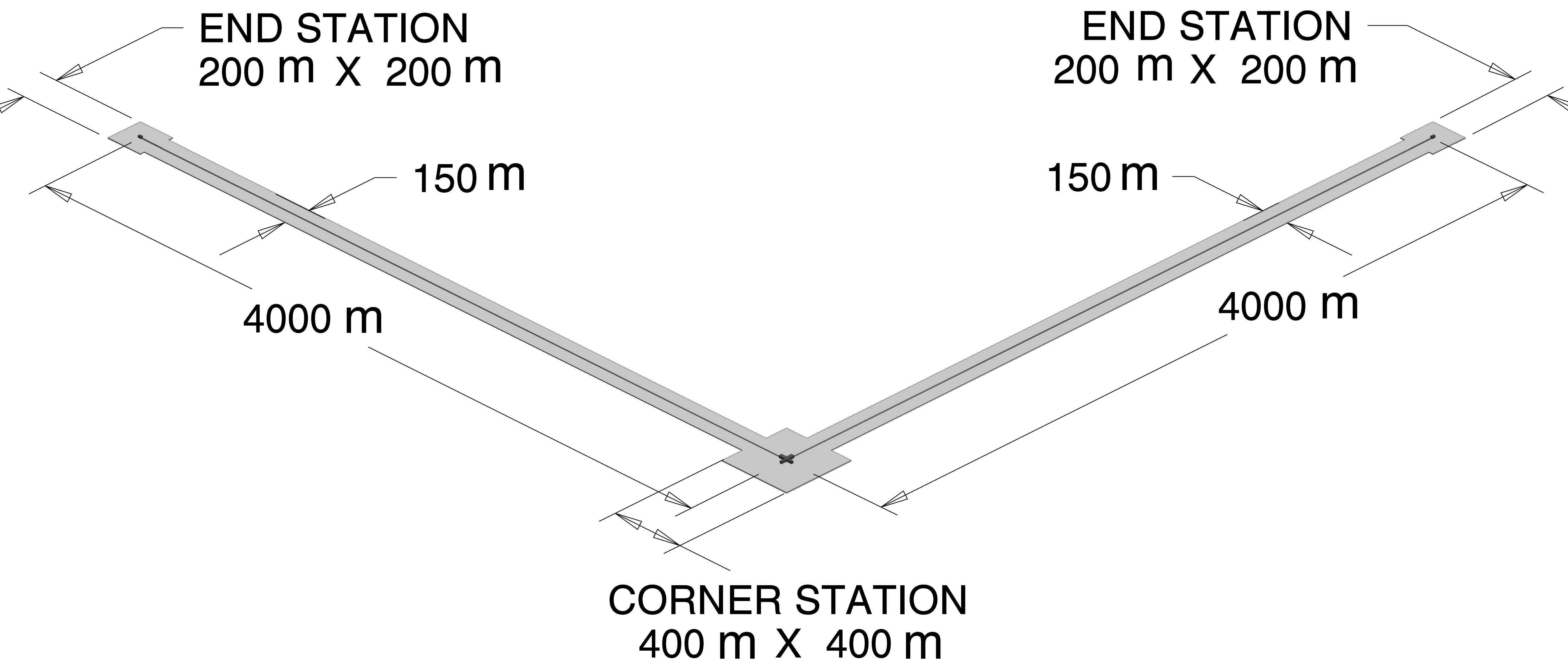
The primary motivation for LIGO-India is to enhance opportunities for multi-messenger astronomy using gravitational waves.

- Electromagnetic telescopes have fields of view a few times to 100 times smaller than the resolution of the LIGO-Virgo network.

- Addition of LIGO-India network improves angular resolution on average by 4X and in some directions by a factor of 10-20.
  – Made possible by longer baseline with respect to existing network

- LIGO-India also provides enhanced duty cycle for three-site networks: ~80% for HILV vs ~50% for HHLV

LIGO-India Site requirement



LIGO-India Site selection

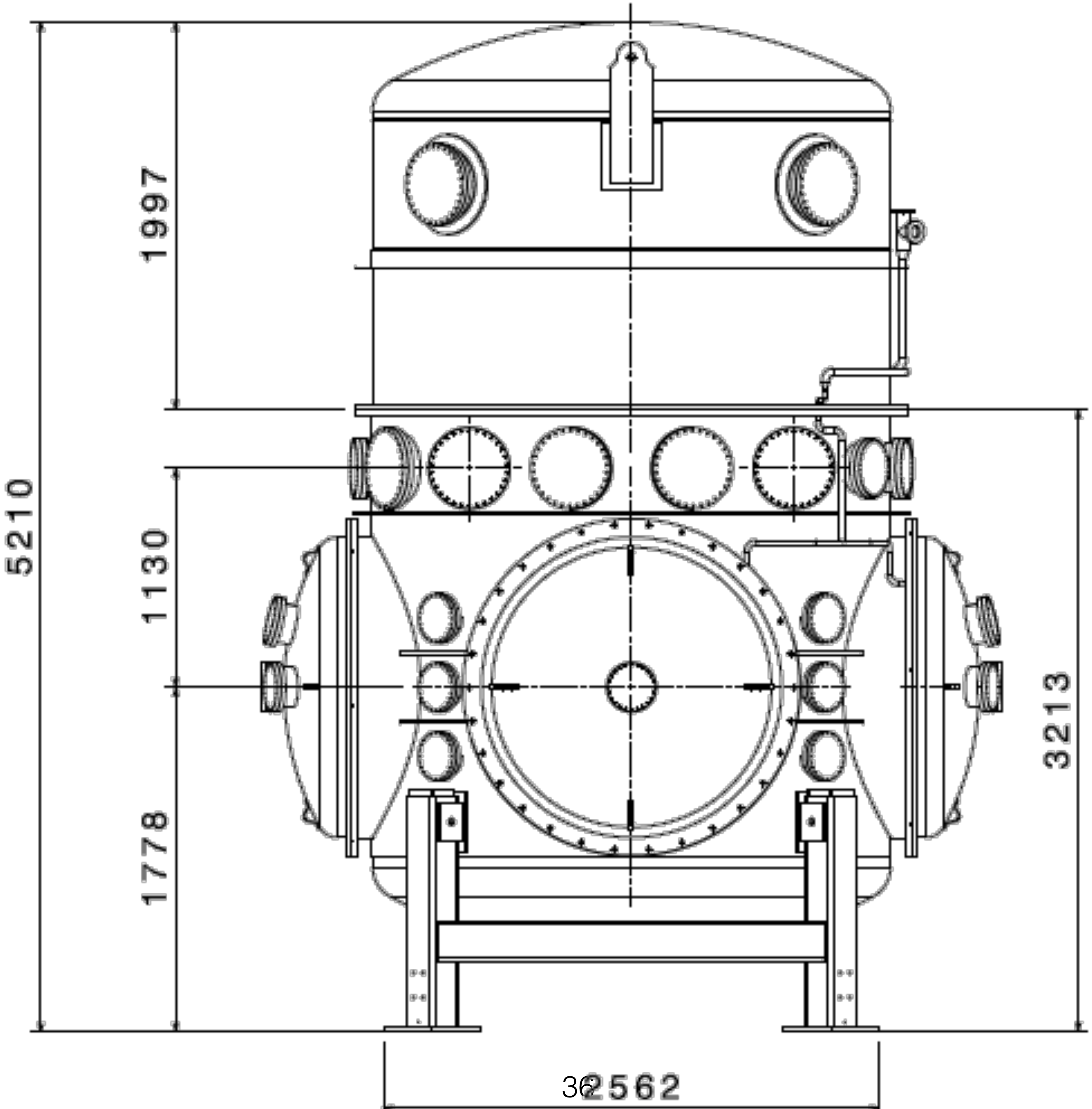
Aundha (Latitude 19° 36’ 50” N, Longitude 77° 01’ 54” E)

DGPS & Topographical Survey Work

LIGO INDIA - OBSERVATORY

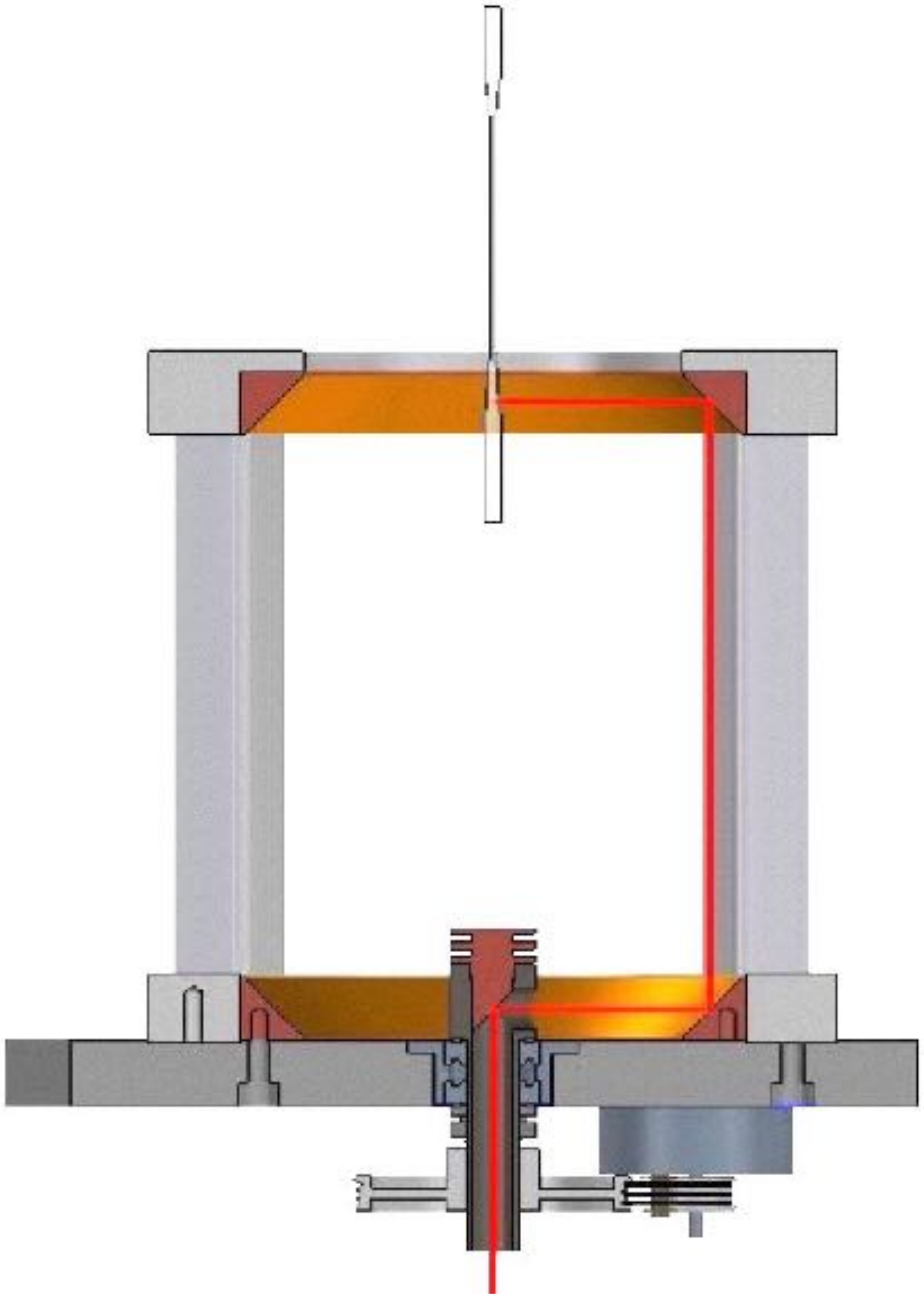
Conceptual ariel view

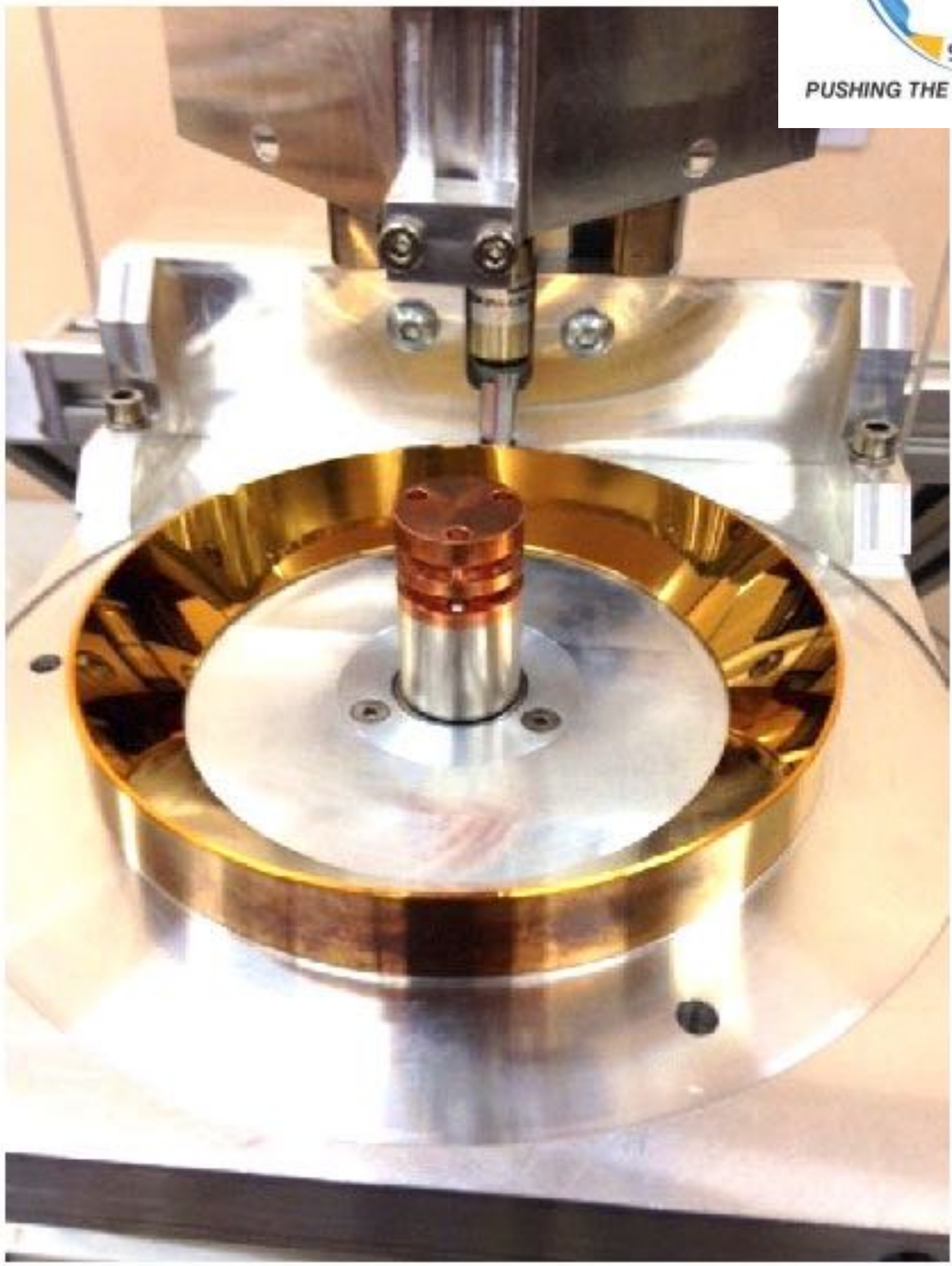
Vacuum Chamber Prototyping



Vacuum Chamber Prototyping

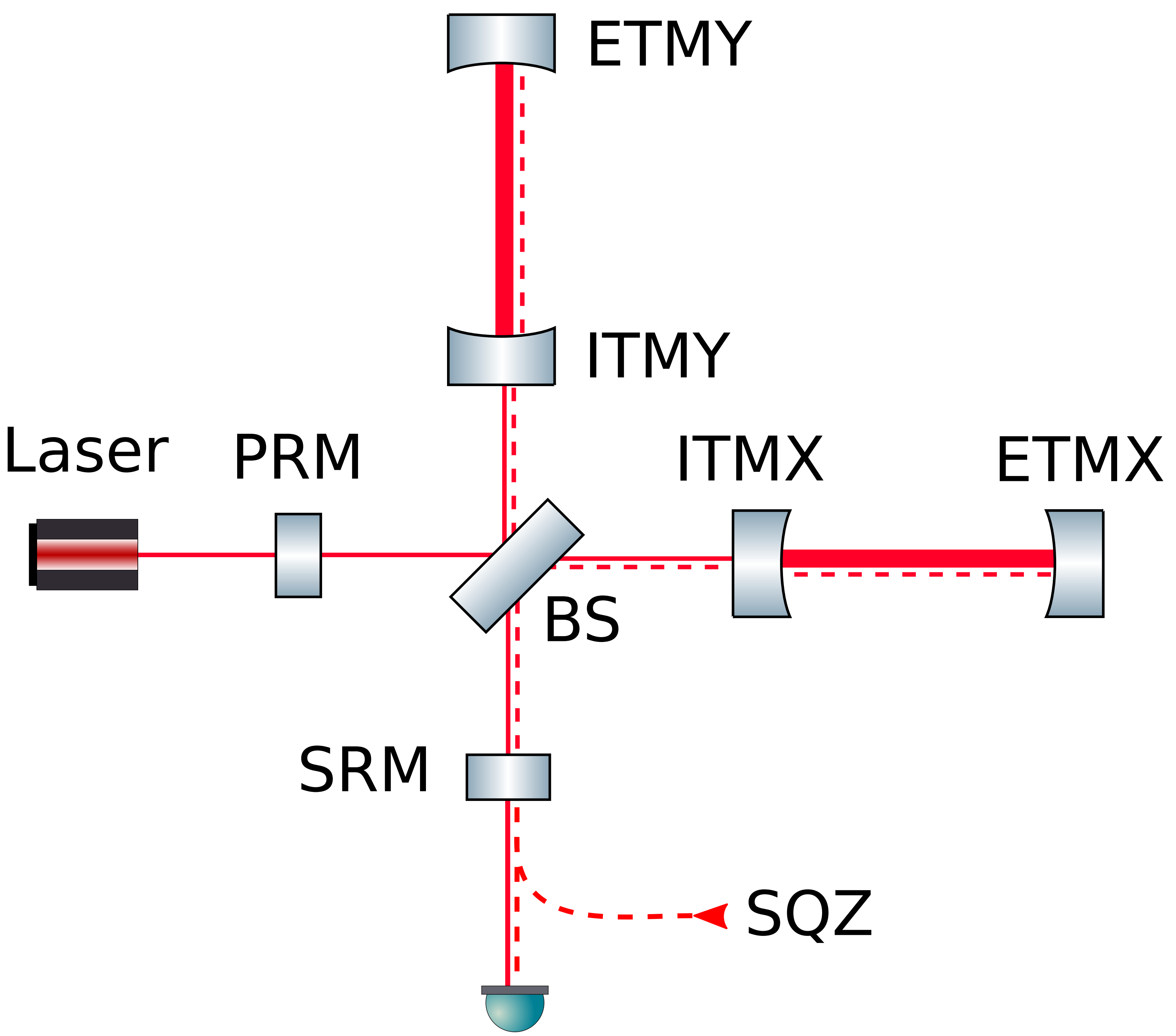
Fiber drawing for Quad suspension





A laser heated fiber drawing system required for fabrication of the silica suspension - fibers has been developed

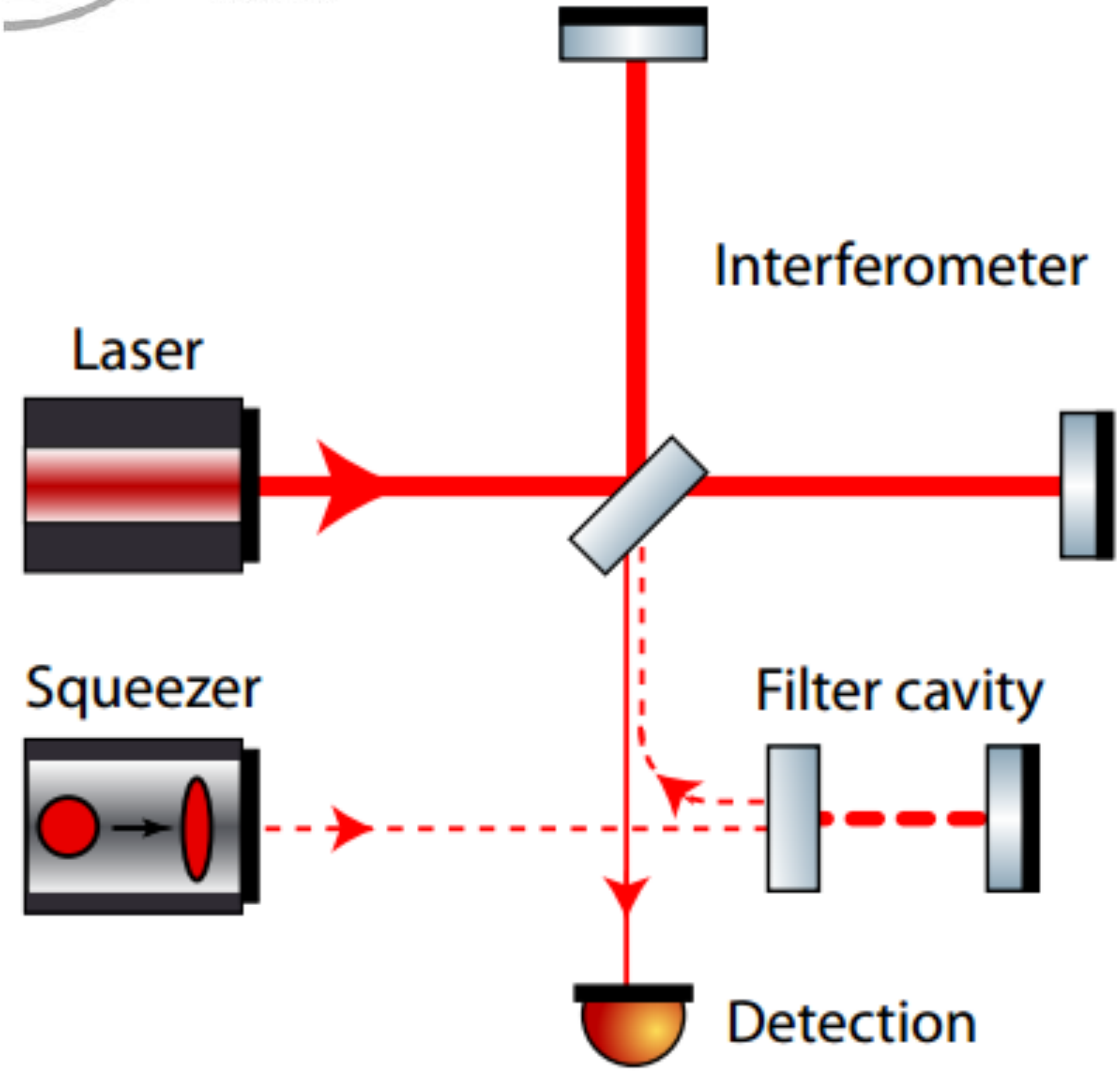
Squeezing



Schedule for the Project

Site acquisition and development	(Aug 2018 - Jun 2020)
Construction of the civil facility	(Jan 2020 - Dec 2022)
Fabrication of vacuum system	(Aug 2019 - Nov 2022)
Installation of vacuum system	(Jun 2022 - Mar 2023)
Installation of the interferometer	(Sep 2022 - Nov 2024)
Engineering runs + Commissioning	(Nov 2024 - Nov 2025)
Science runs as part of global network	(Nov 2025 - Mar 2026)

LIGO-India Detector upgrades

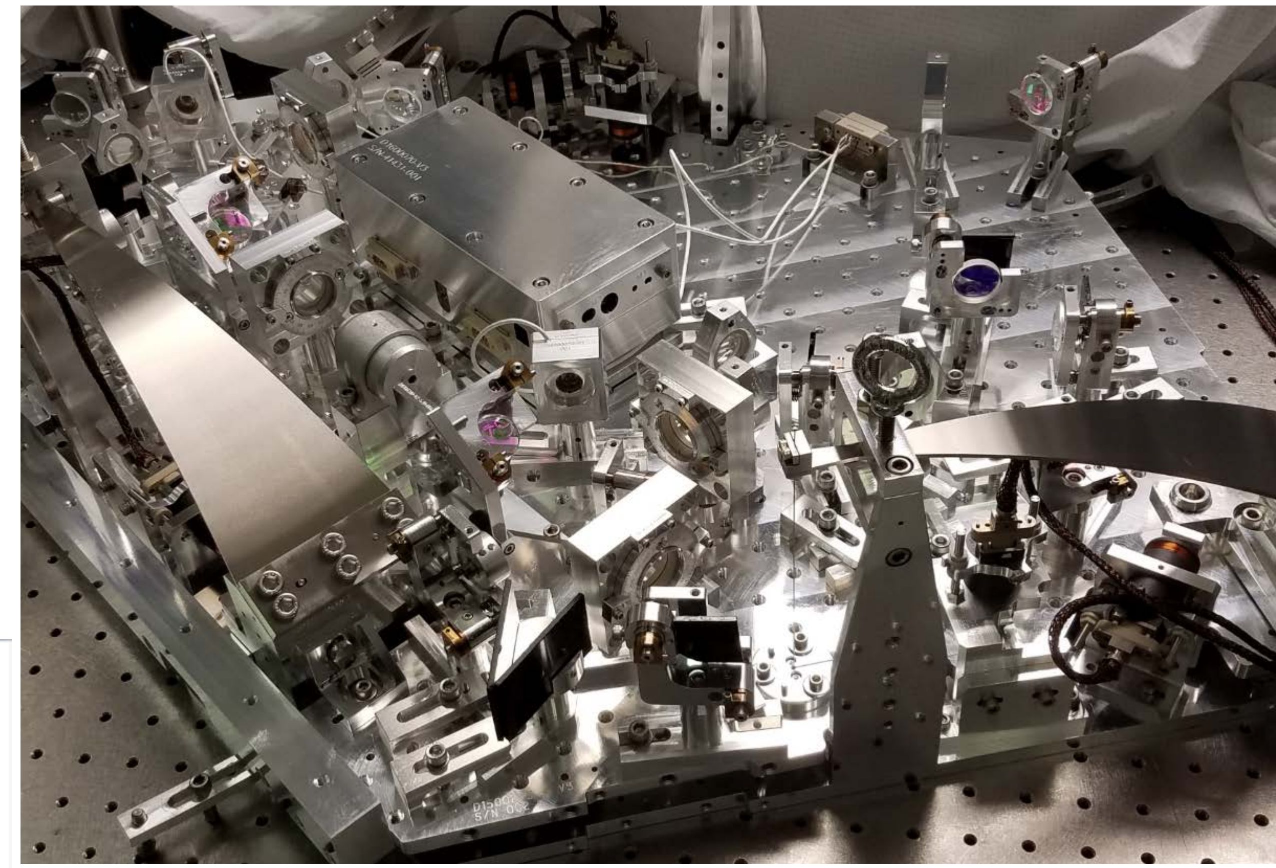


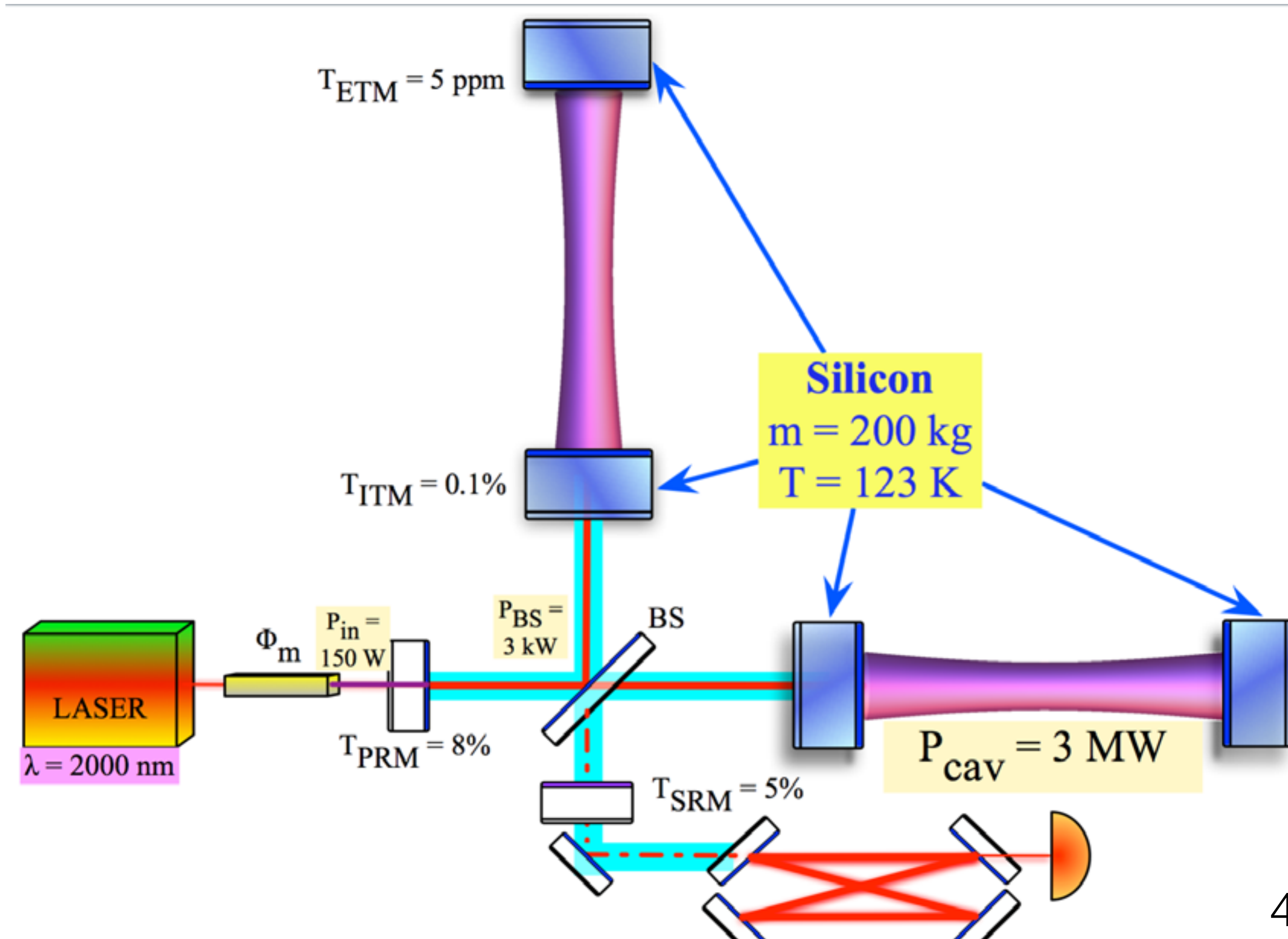
Squeezed light injection is one of the upgrades to the aLIGO detector

LIGO-India Upgrades

Advanced LIGO Plus (A+)

- An incremental upgrade to aLIGO that leverages existing technology and infrastructure, with minimal new investment and moderate risk
- Target: x1.7 increase in range over aLIGO x5 greater event rate



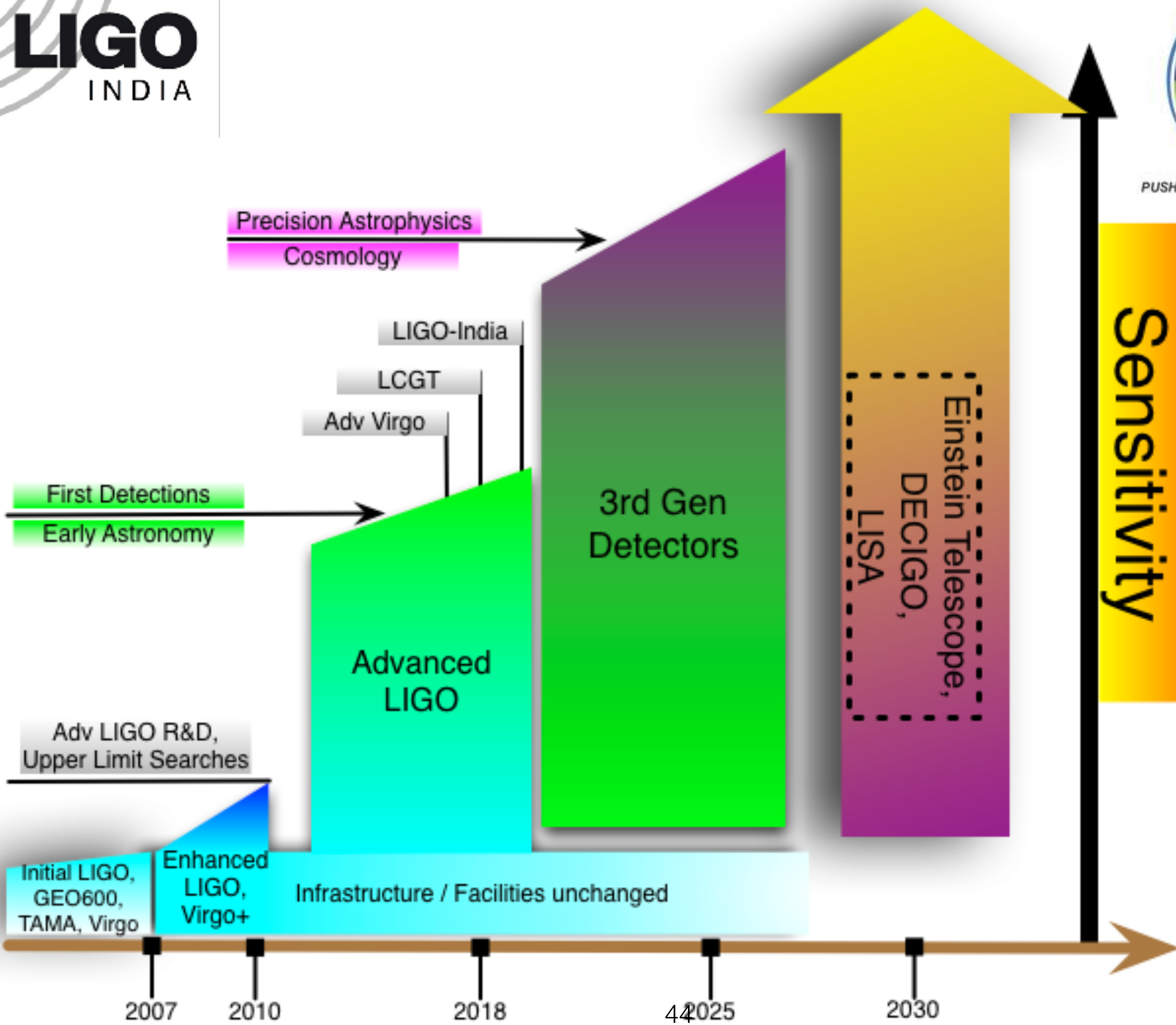


LIGO Voyager

- Additional x2 sensitivity broadband improvement,
  lower frequency 20Hz → 10Hz
- Larger Si masses, cryogenic operation, new laser wavelength

3rd Generation R&D

- 2 micron laser source development
- Silicon optics development
- Crystalline coating development at 2 micron
- Squeezed light source at 2 micron
- At wavelength metrology for Si Optics & coatings
- FPGA based digital filters for control loops


Precision Astrophysics
Cosmology
LIGO-India
LCGT
Adv Virgo
First Detections
Early Astronomy
3rd Gen Detectors
Einstein Telescope, DECIGO, LISA
Sensitivity
Advanced LIGO
Adv LIGO R&D, Upper Limit Searches
Initial LIGO, GEO600, TAMA, Virgo
Enhanced LIGO, Virgo+
Infrastructure / Facilities unchanged
2007
2010
2018
2025
2030

Thank You

Gravitational Wave Antenna

- The interferometric GW detectors can be viewed as a GW antenna.
- The Antenna pattern for the detector is symmetric about the interferometer plane.
- So with only one detector only the GW arrival time (phase) can be determined.
- Two detectors will be able to localize the source to a disc.
- Three detectors will be able to localize the source in the sky with degeneracy regarding the direction.
- Having a fourth detector breaks this degeneracy and also improves the accuracy of sky localization which is very important for GW Astronomy.