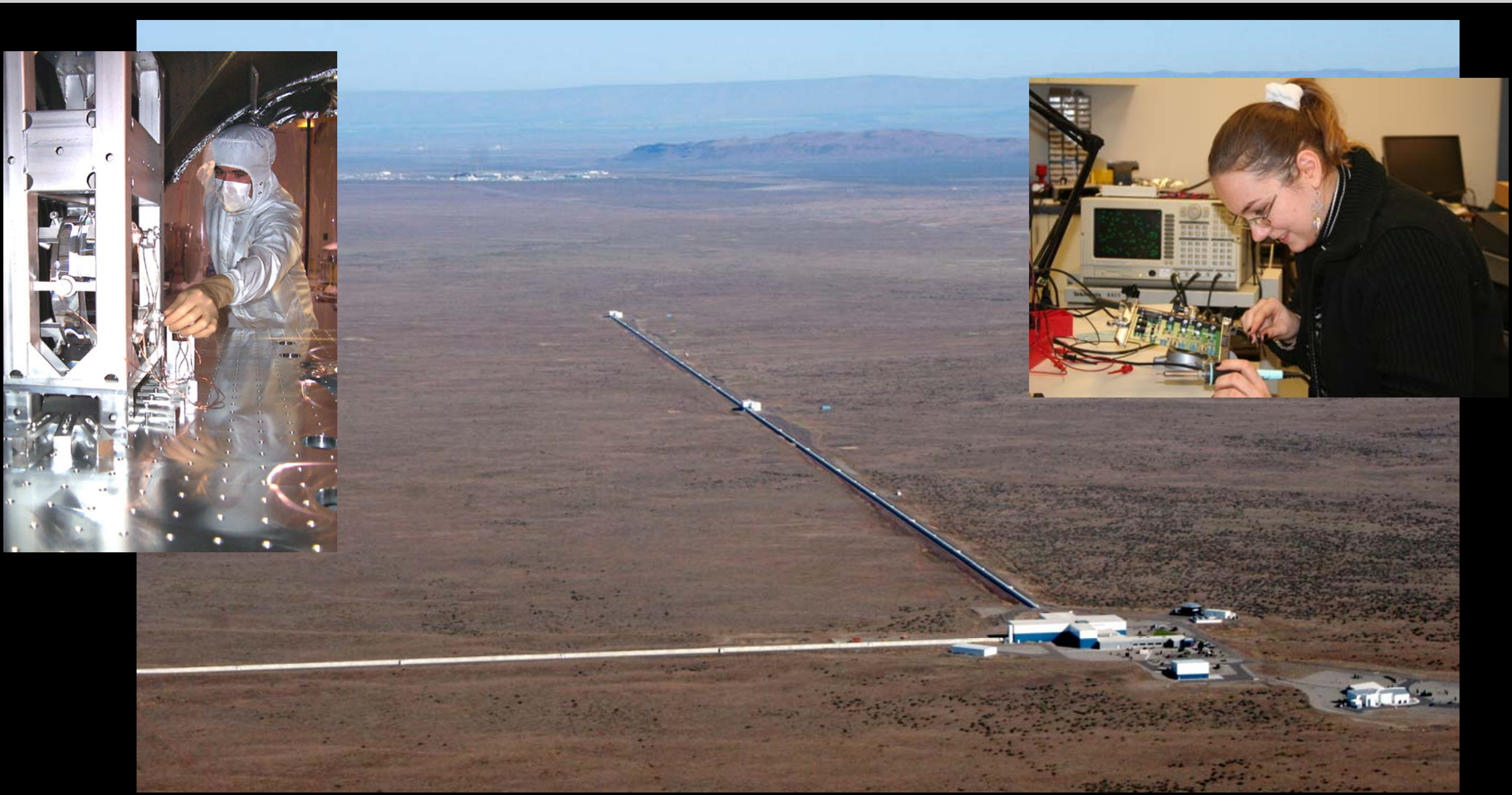
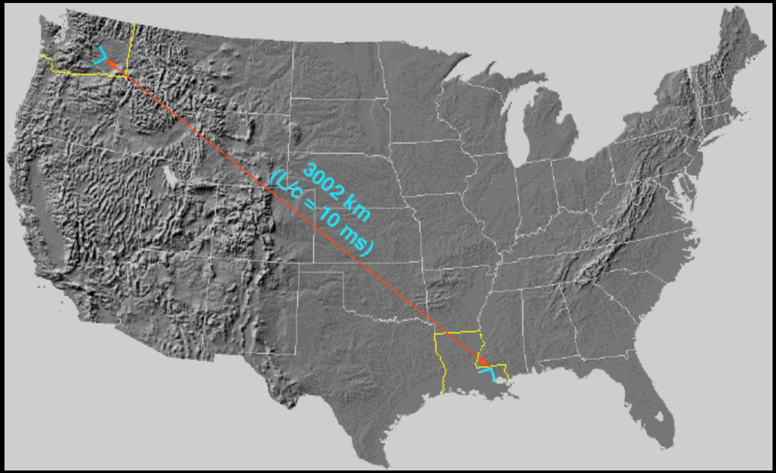
Preparations for Gravitational Wave Searches with the Enhanced LIGO Detectors



Today's Talk

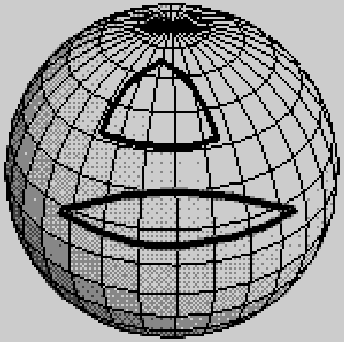
- General relativity framework
- Some potential gravitational wave sources
- Overview of interferometer operations
- Enhanced LIGO improvements

Dale Ingram
LIGO Hanford Observatory
ingram_d@ligo-wa.caltech.edu

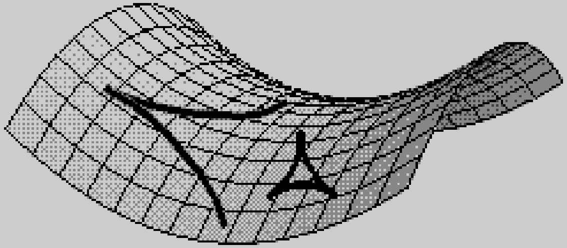


With thanks to
Michael Landry,
Fred Raab,
Vern Sandberg,
Kate Dooley

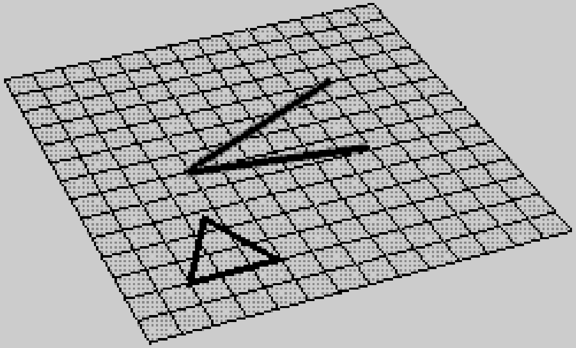
Geometry lies at the heart of general relativity



Universe with *positive* curvature. Diverging line converge at great distances. Triangle angles add to more than 180°.

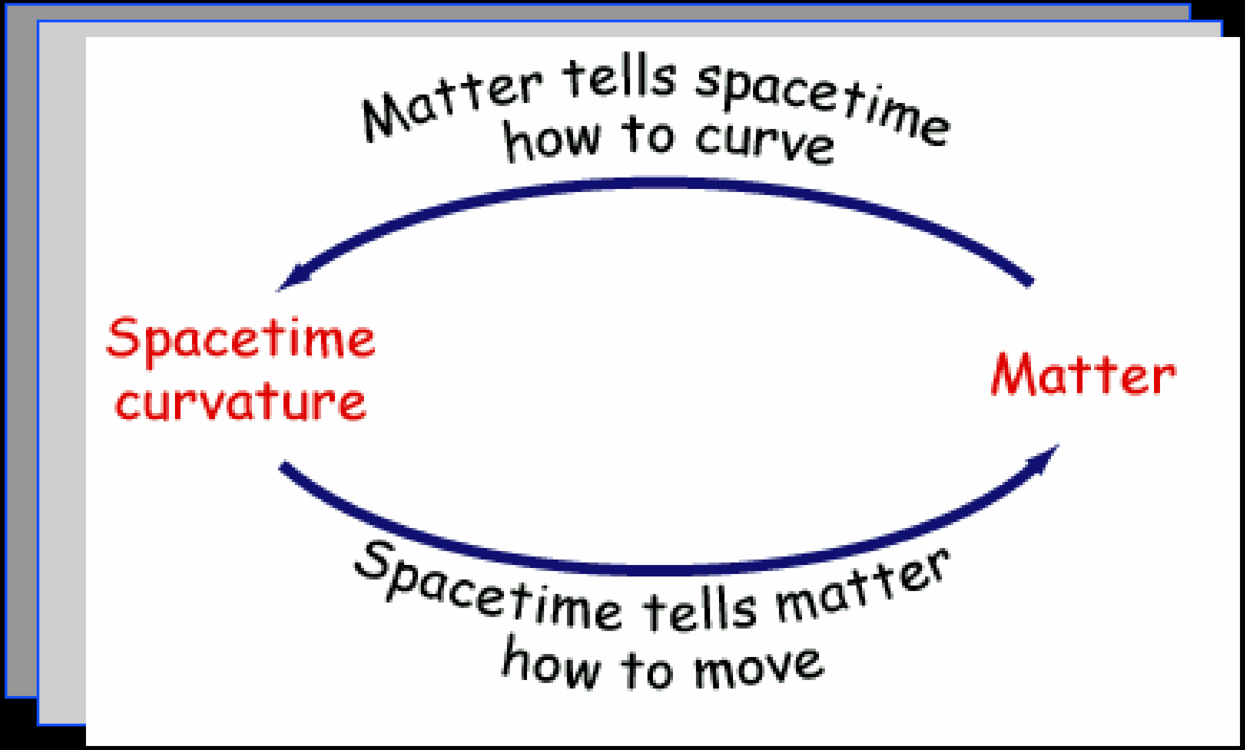


Universe with *negative* curvature. Lines diverge at ever increasing angles. Triangle angles add to less than 180°.



Universe with no curvature. Lines diverge at constant angle. Triangle angles add to 180°.

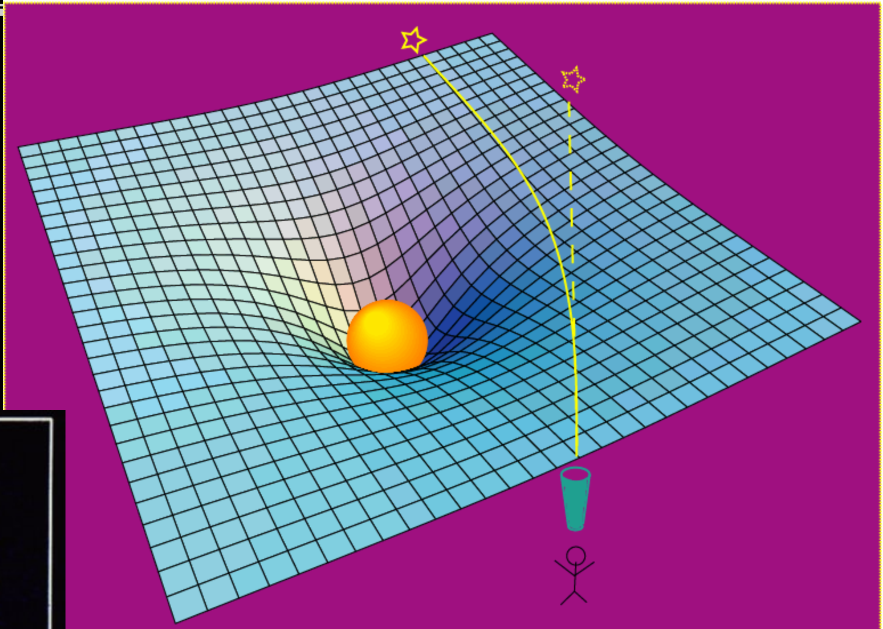
General relativity tells us that spacetime has measurable properties such as curvature and stiffness



John Wheeler's view of Einstein's description of space, time and gravity

Curvature is real!

Not only the path of matter, but even the path of light is affected by gravity from massive objects

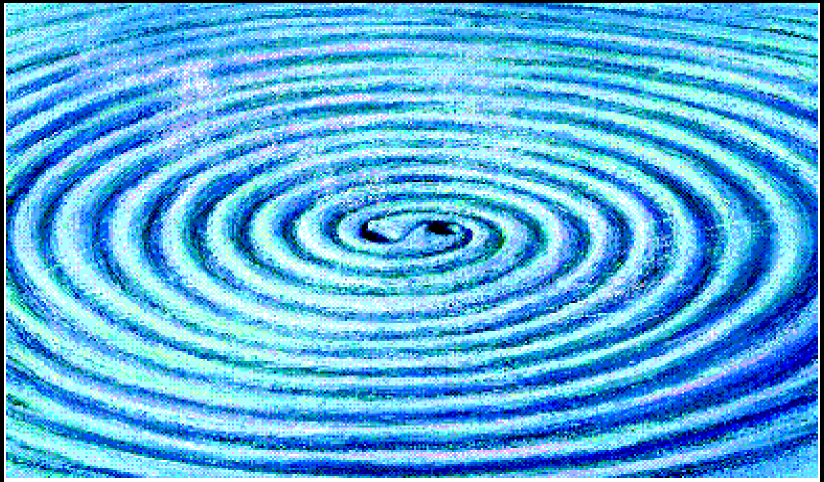


A massive object shifts apparent position of a star

Einstein Cross
Photo credit: NASA and ESA

Gravitational waves -- ripples in the curvature of spacetime

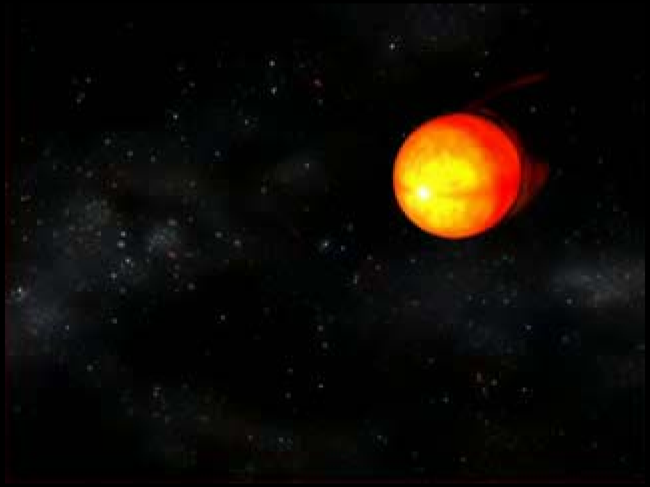
Rendering of space stirred by two orbiting black holes:



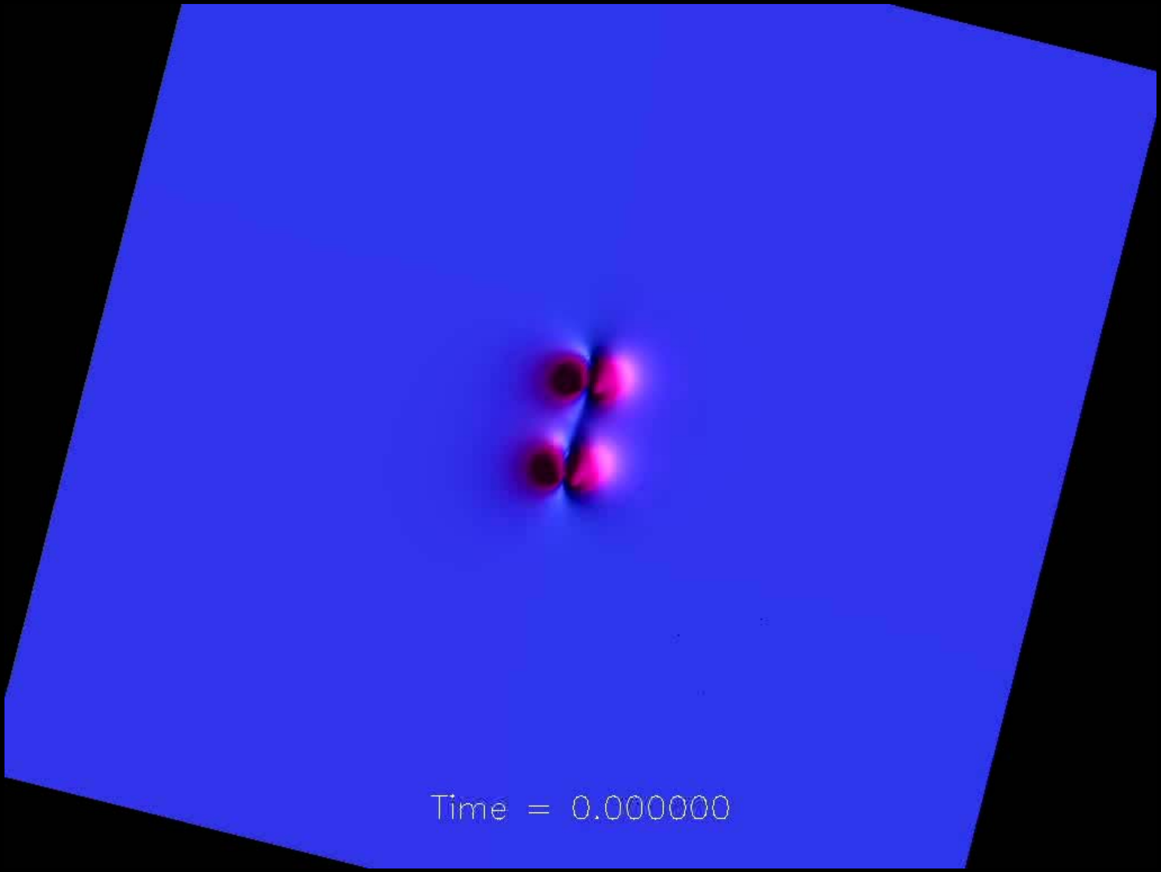
Fluctuations in the quadrupole moment of a system of masses will produce ‘kinks’ in the spacetime fabric. The kinks will propogate as transverse waves.

Sources: Bursts such as supernovae could yield GW signals depending on the asymmetry of the explosion

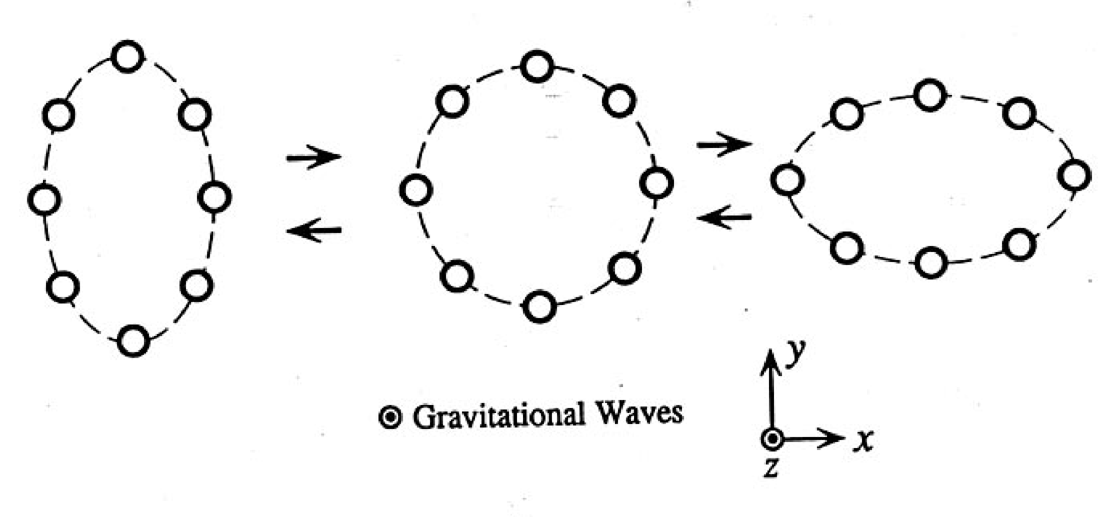
Pulsars require an asymmetric mass distribution (bumps)



Inspirals are expected to be the loudest sources



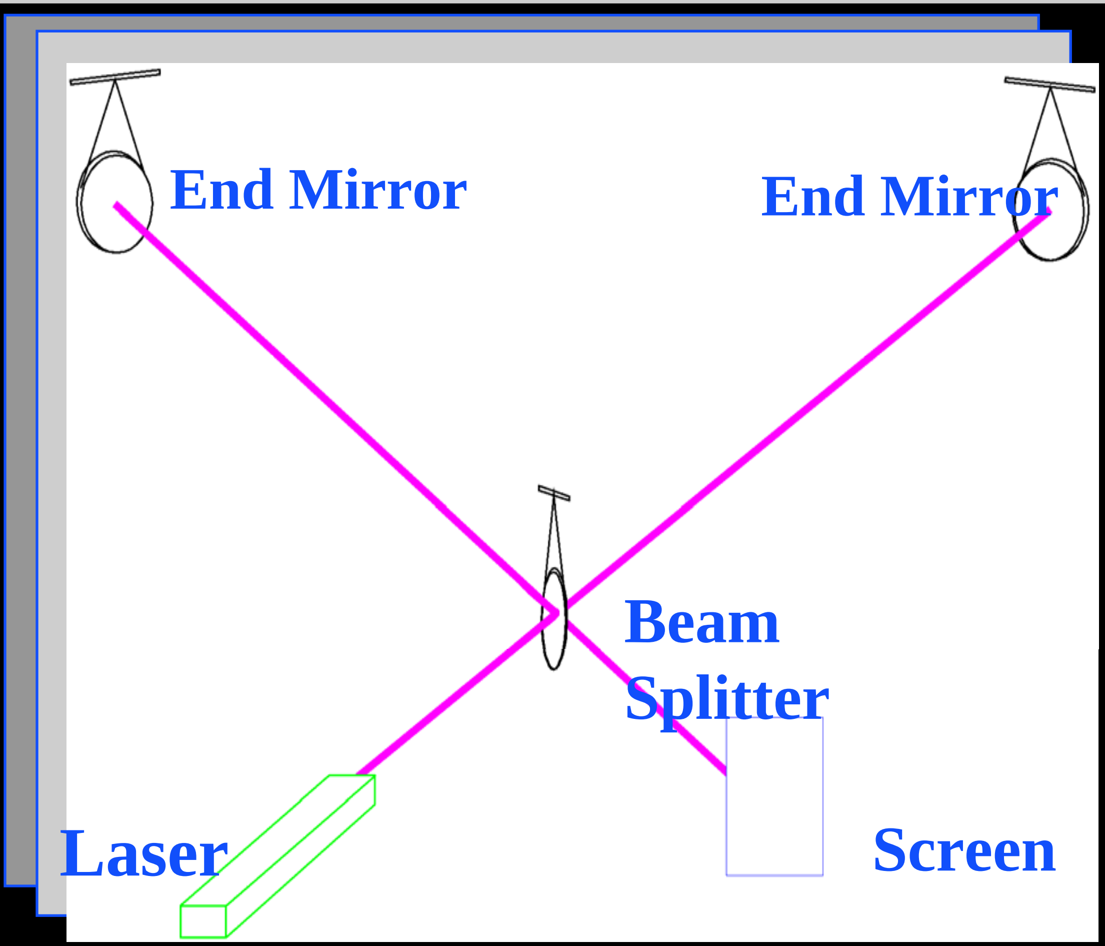
Why use interferometers as gravitational wave detectors?



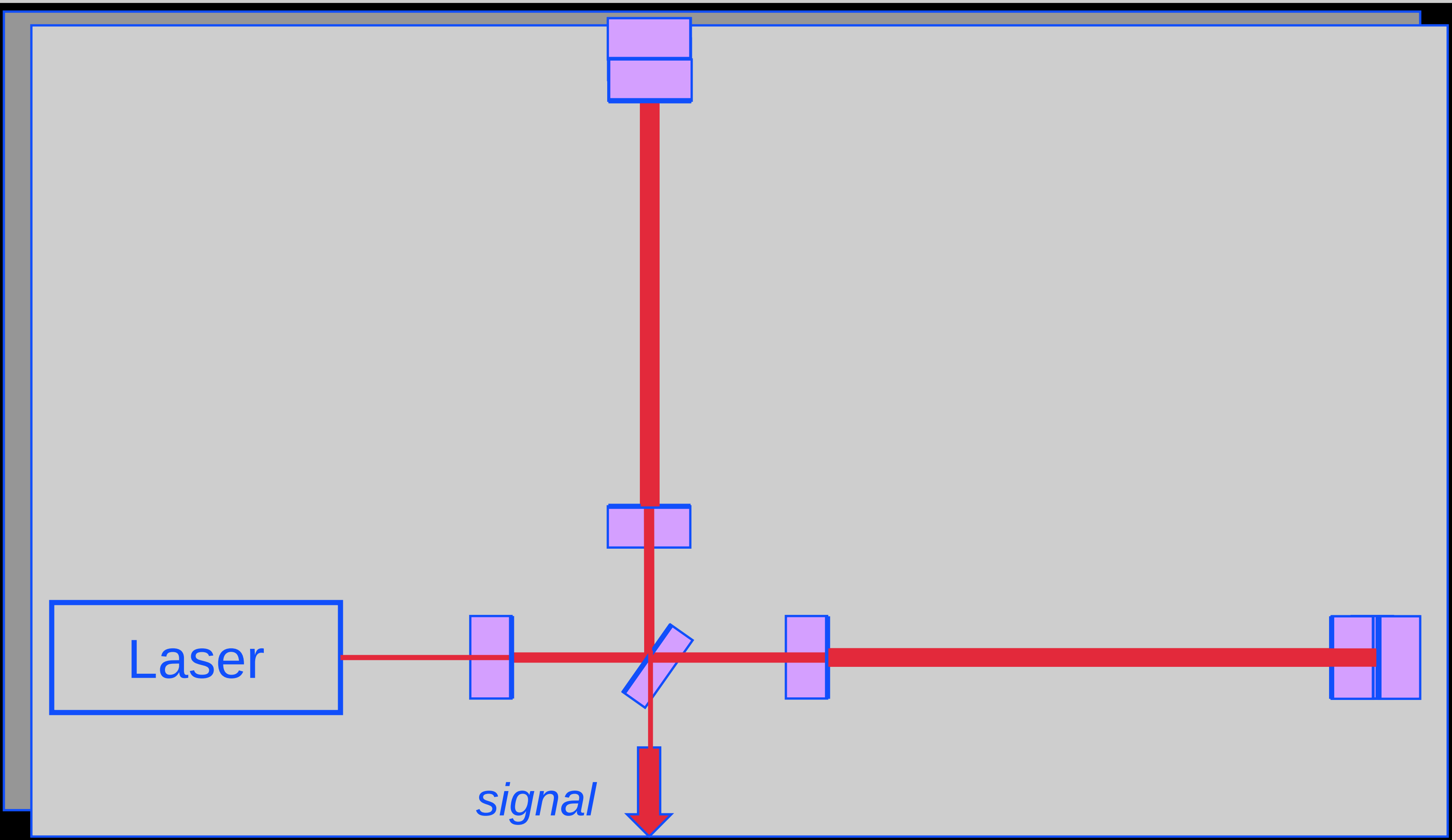
Gravitational waves shrink space along one axis as they stretch space along a perpendicular axis. Both axes are perpendicular to the direction of propagation.

Mark the space at (x) and (y); look for the lengths of the ellipse axes to fluctuate

The basic Michelson design provides the ability to monitor a circle of space

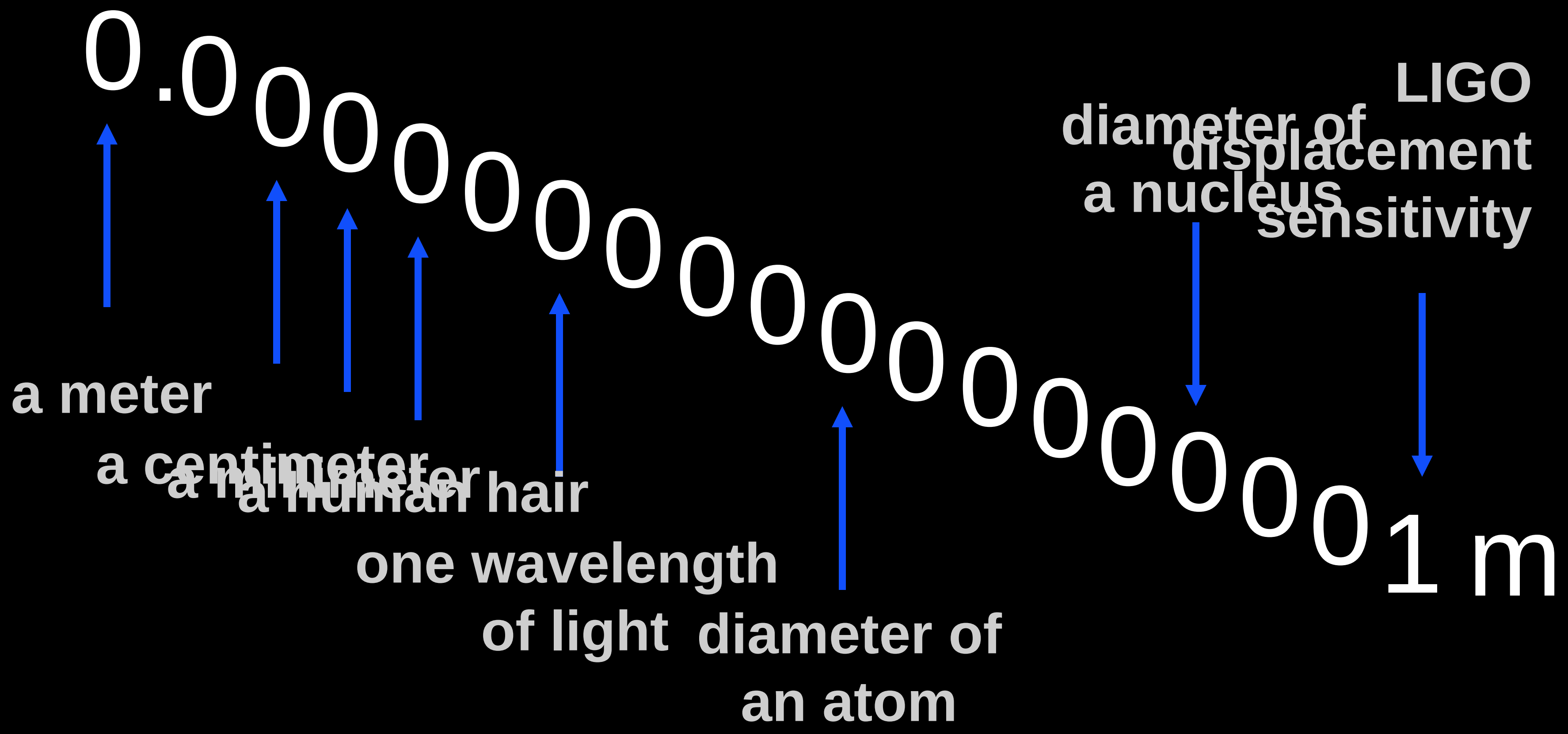


Fabry Perot cavities and power recycling provide additional sensitivity



“Sensitivity” means displacement sensitivity – the ability of the detector to sense differential motions of the mirrors

How sensitive?



0.000000000000000001 m

a meter

a centimeter

a millimeter

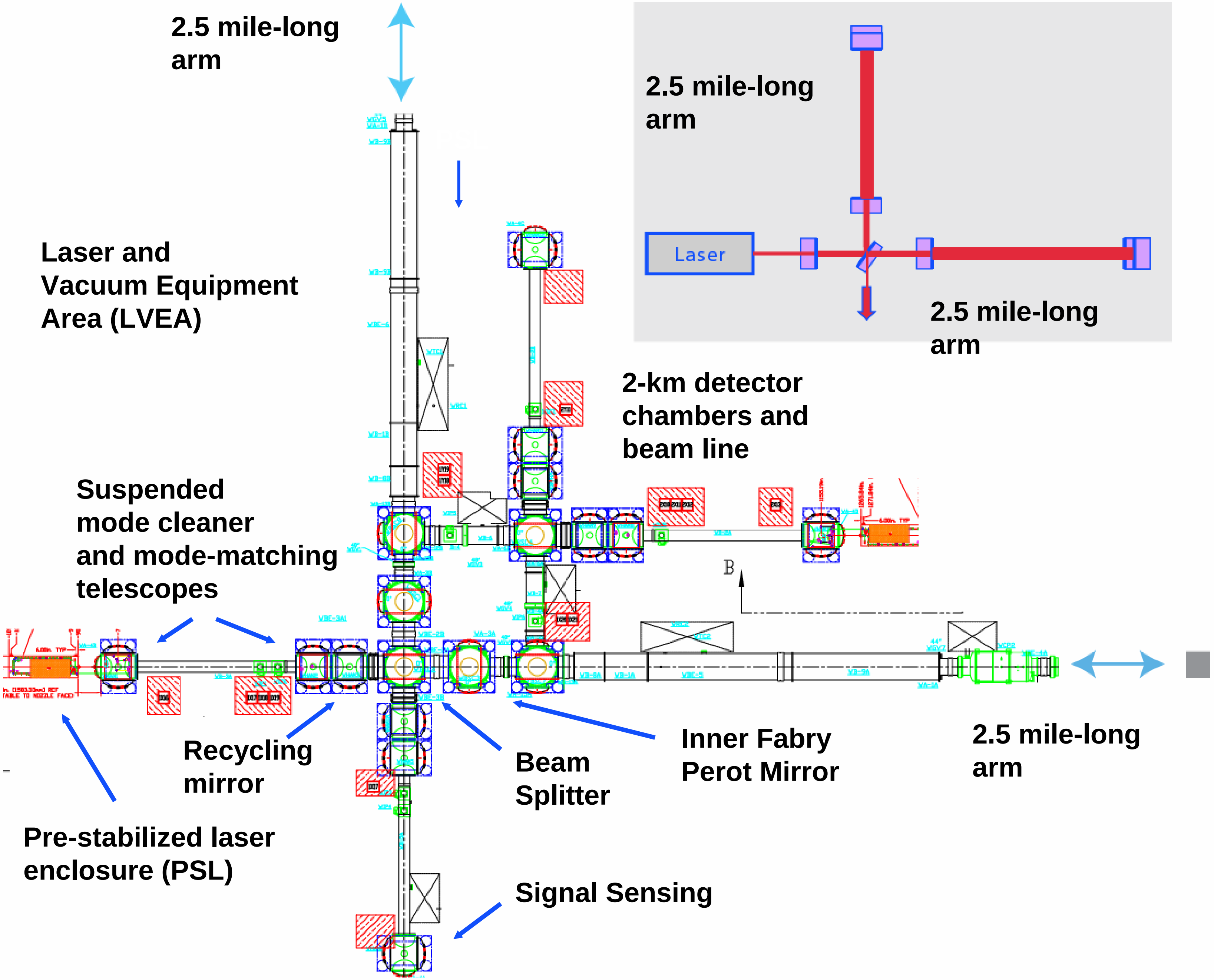
a human hair

one wavelength of light

diameter of an atom

diameter of a nucleus

LIGO displacement sensitivity



2.5 mile-long
arm

2.5 mile-long
arm

Laser and
Vacuum Equipment
Area (LVEA)

2.5 mile-long
arm

2-km detector
chambers and
beam line

Suspended
mode cleaner
and mode-matching
telescopes

Recycling
mirror

Beam
Splitter

Inner Fabry
Perot Mirror

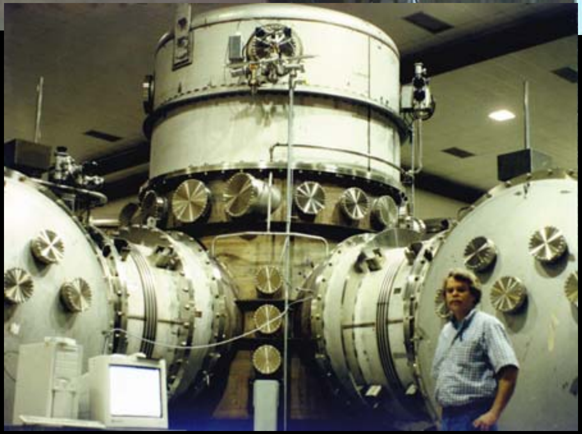
2.5 mile-long
arm

Pre-stabilized laser
enclosure (PSL)

Signal Sensing

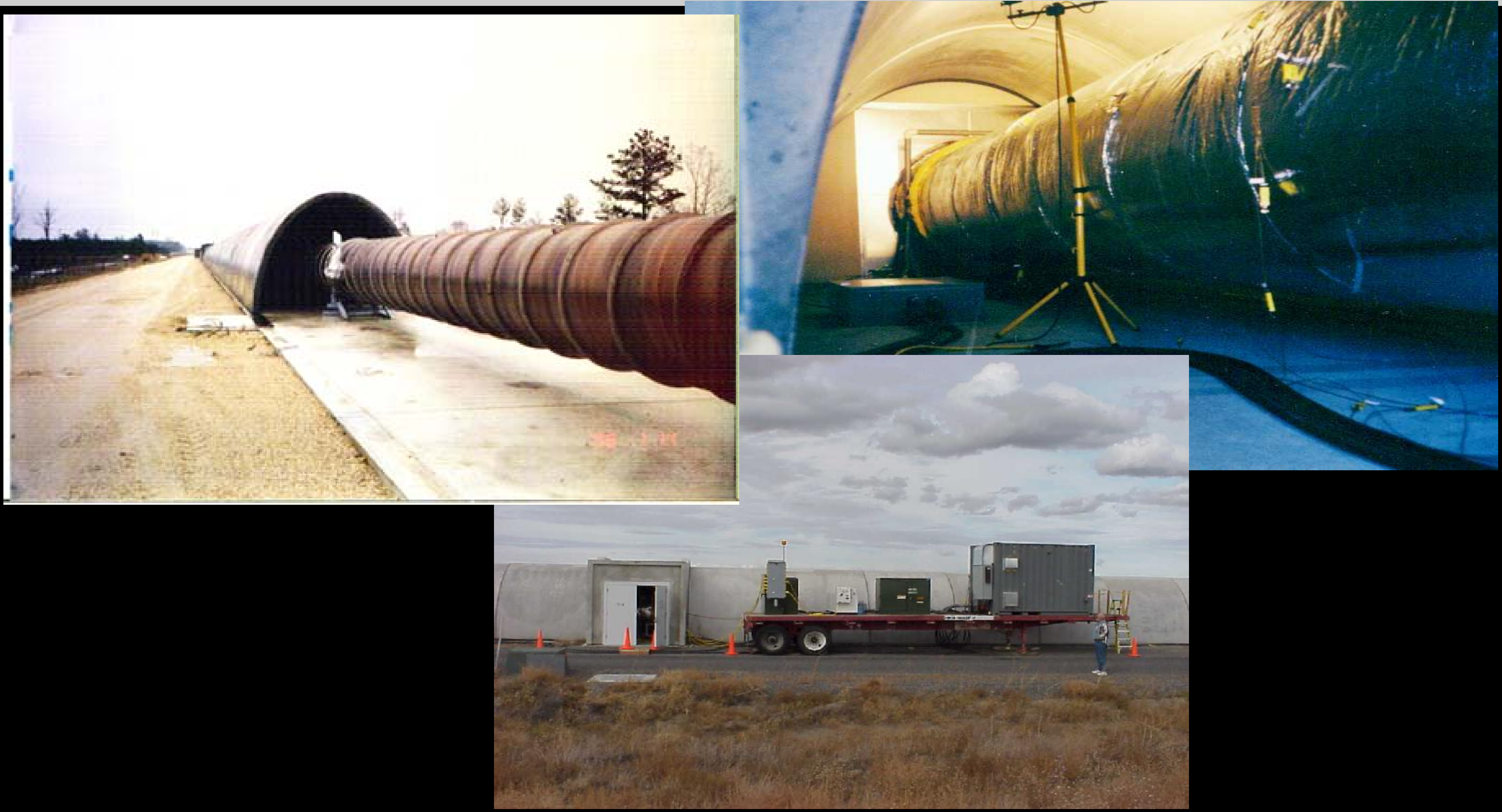
Vacuum chambers provide quiet homes for the mirrors

View inside Corner Station

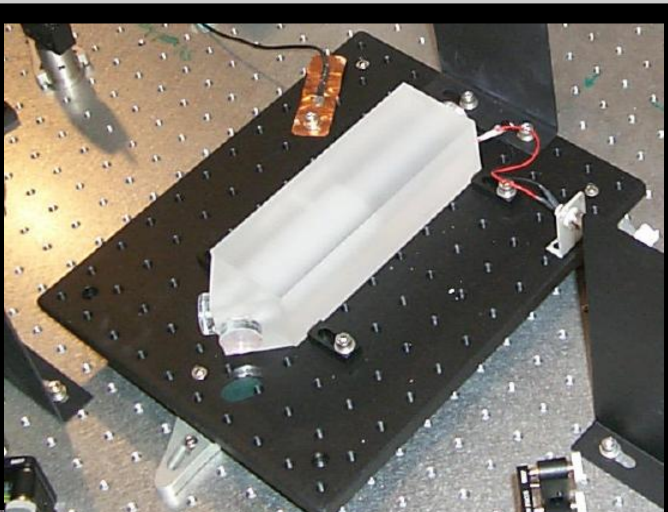


Standing at vertex beam splitter

Evacuated Beam Tubes Provide Clear Path for Light

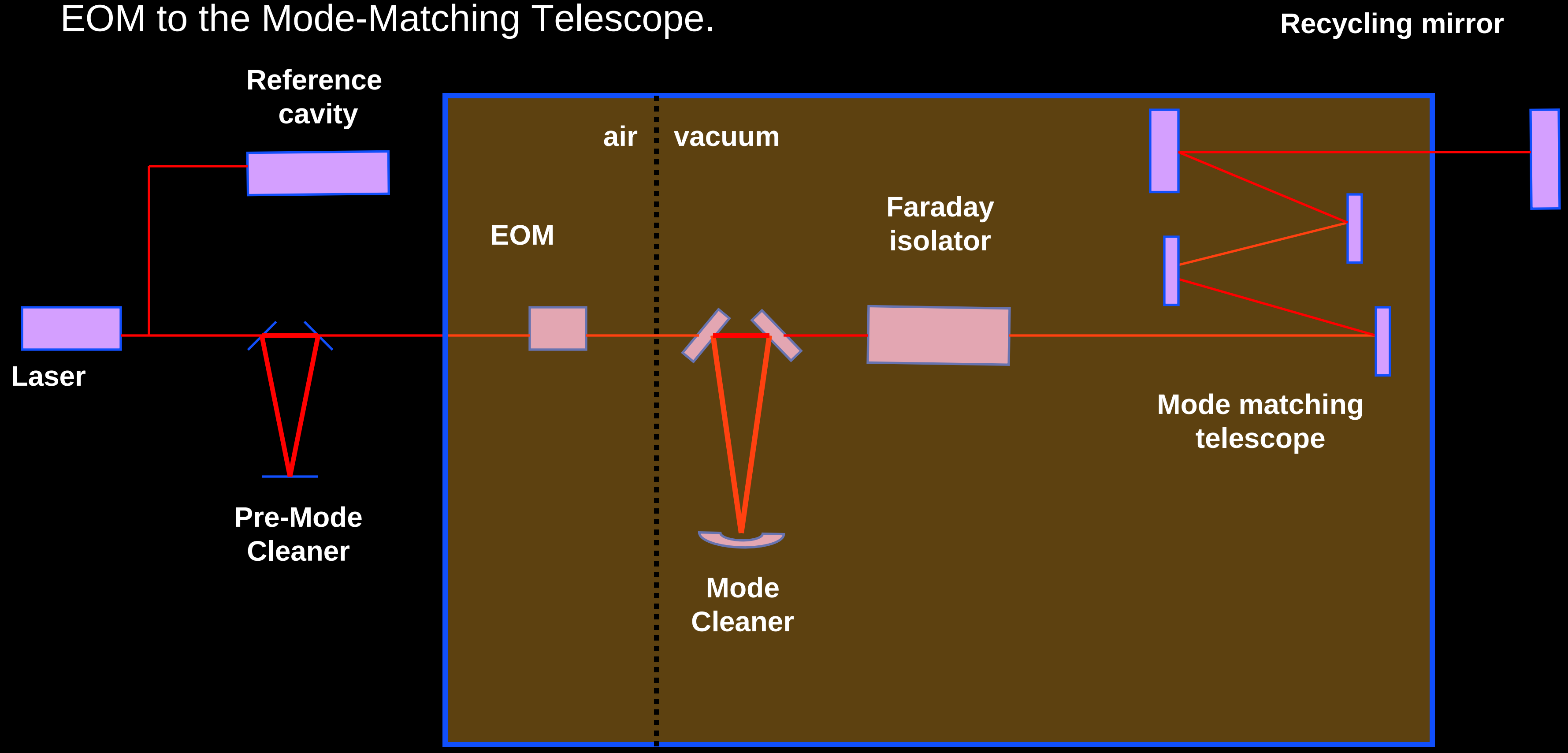


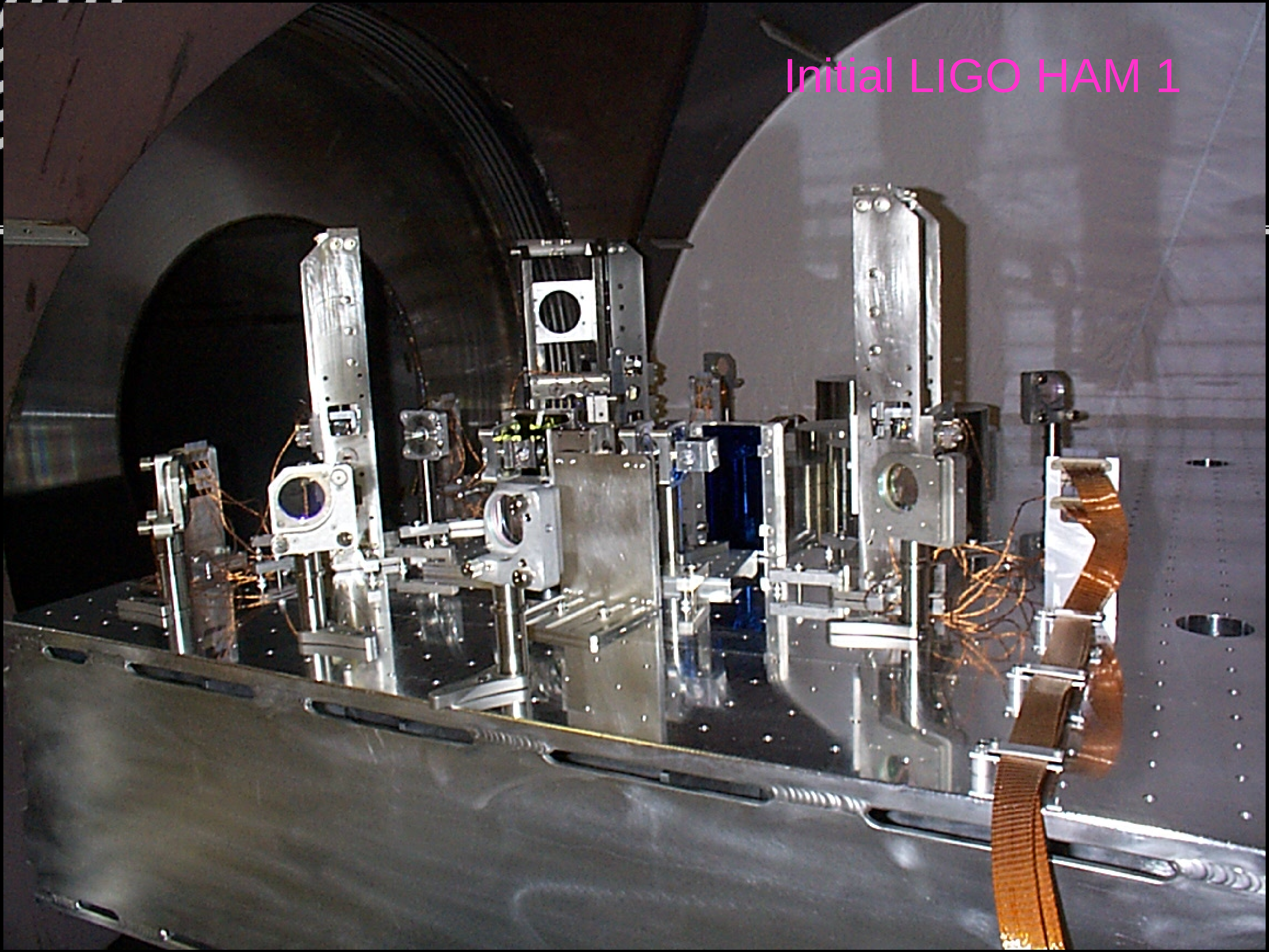
Initial LIGO PSL Components: All-Solid-State Nd:YAG Laser, Pre-mode Cleaner, Reference Cavity



Beam path from PSL through HAM1 and HAM2

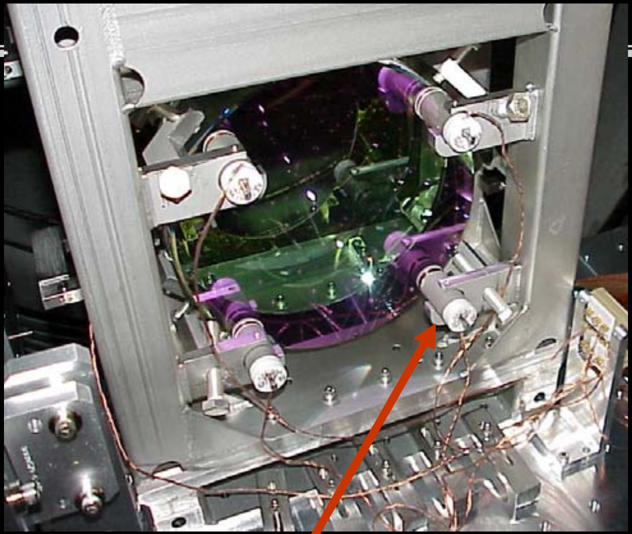
The Input Optics include all the elements from the EOM to the Mode-Matching Telescope.



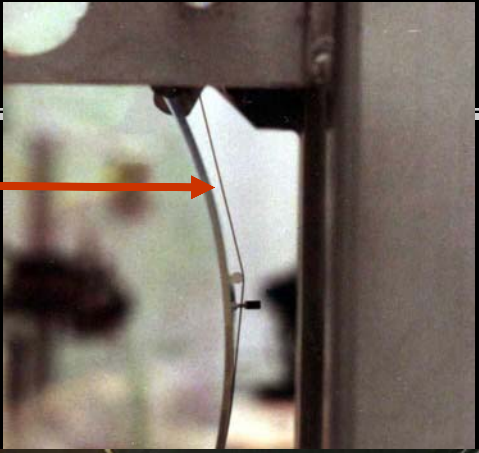


Initial LIGO HAM 1

Pendulum suspensions give mirrors freedom of movement in the LIGO frequency band



Optics suspended as simple pendulums

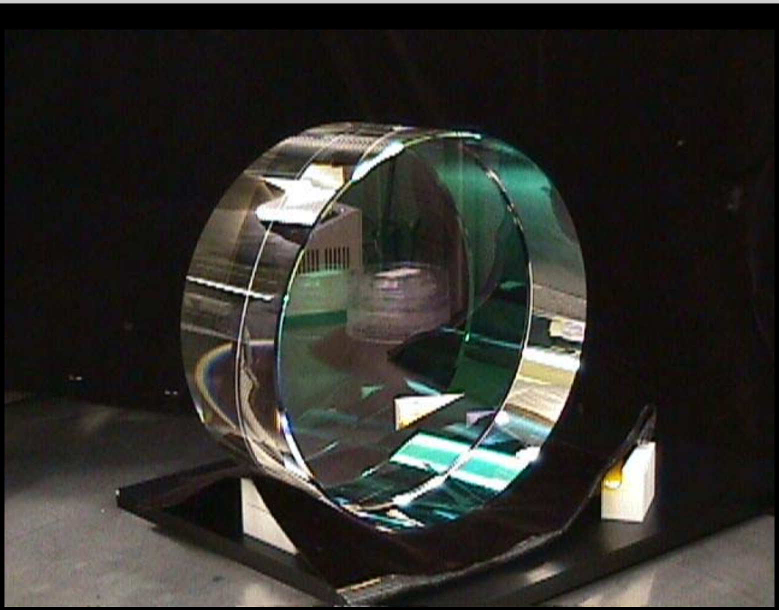


Local sensors/actuators provide damping and control forces

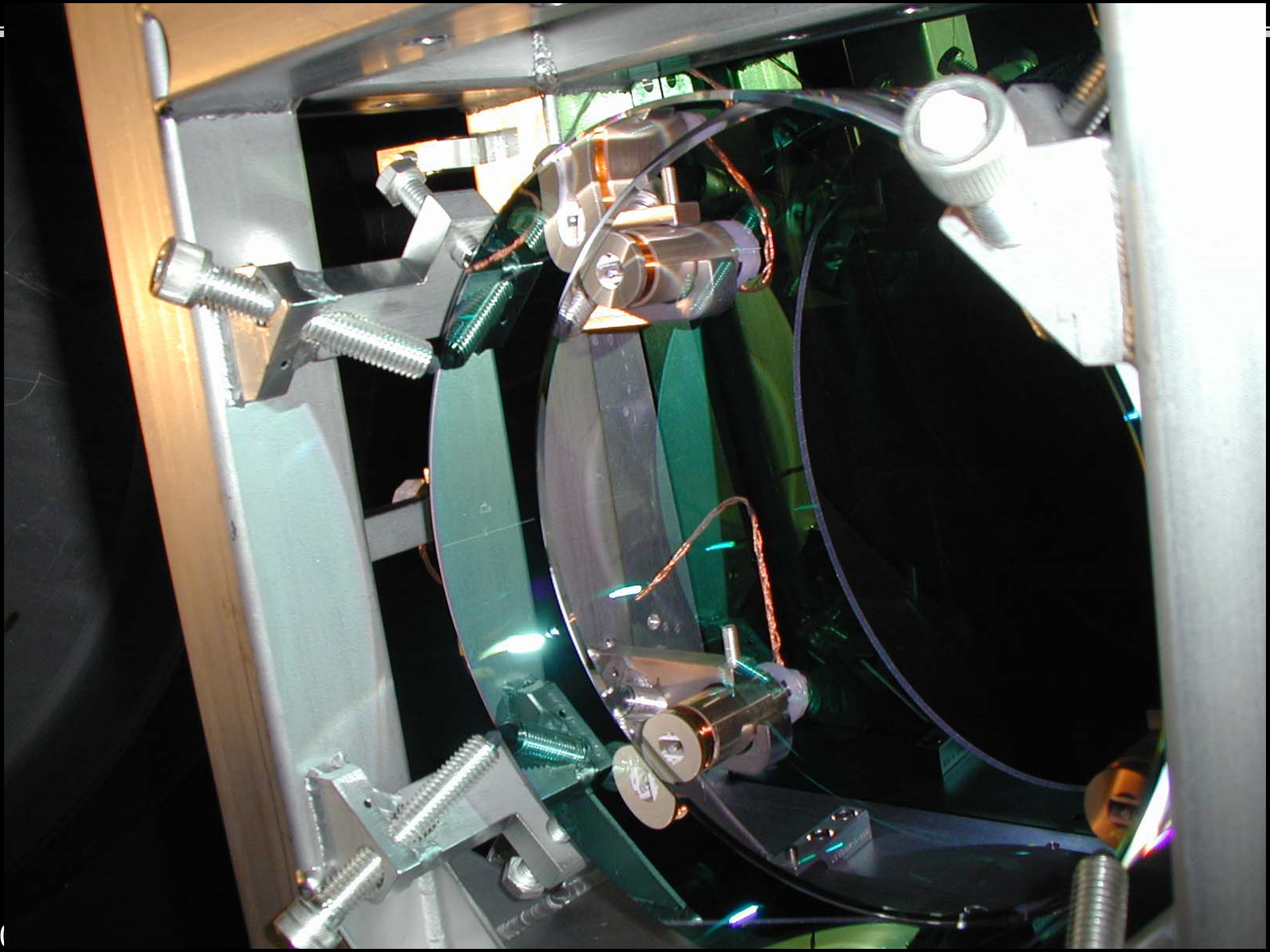
Mirror is balanced on 1/100th inch diameter wire to 1/100th degree of arc

Core Optics

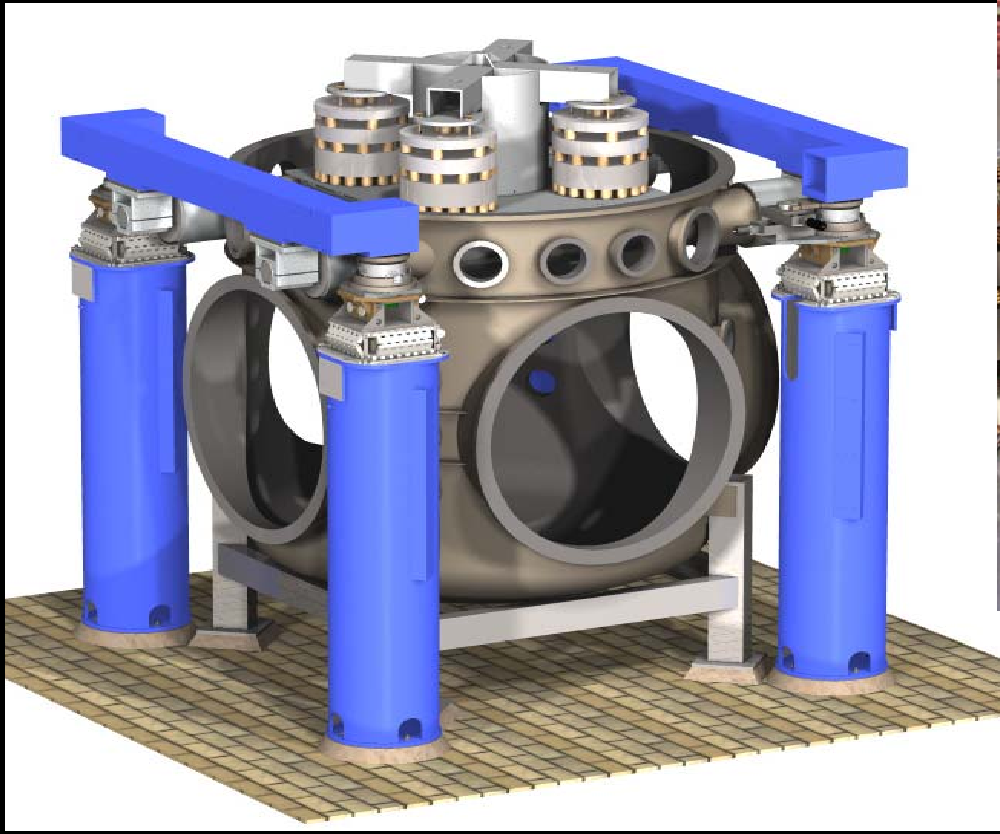
- Substrates: SiO2
  - » 25 cm Diameter, 10 cm thick
  - » Homogeneity < 5 x 10-7
  - » Internal mode Q’s > 2 x 106
- Polishing
  - » Surface uniformity < 1 nm rms
  - » Radii of curvature matched < 3%
- Coating
  - » Scatter < 50 ppm
  - » Absorption < 2 ppm
  - » Uniformity <10-3
- Production involved 6 companies, NIST, and LIGO

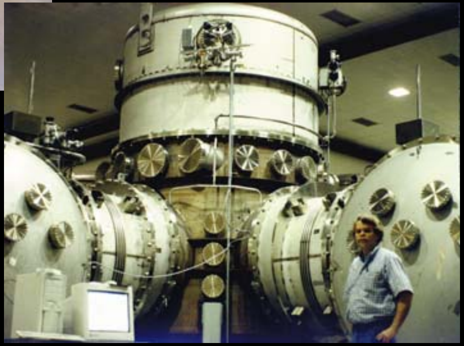


Suspended Core Optic

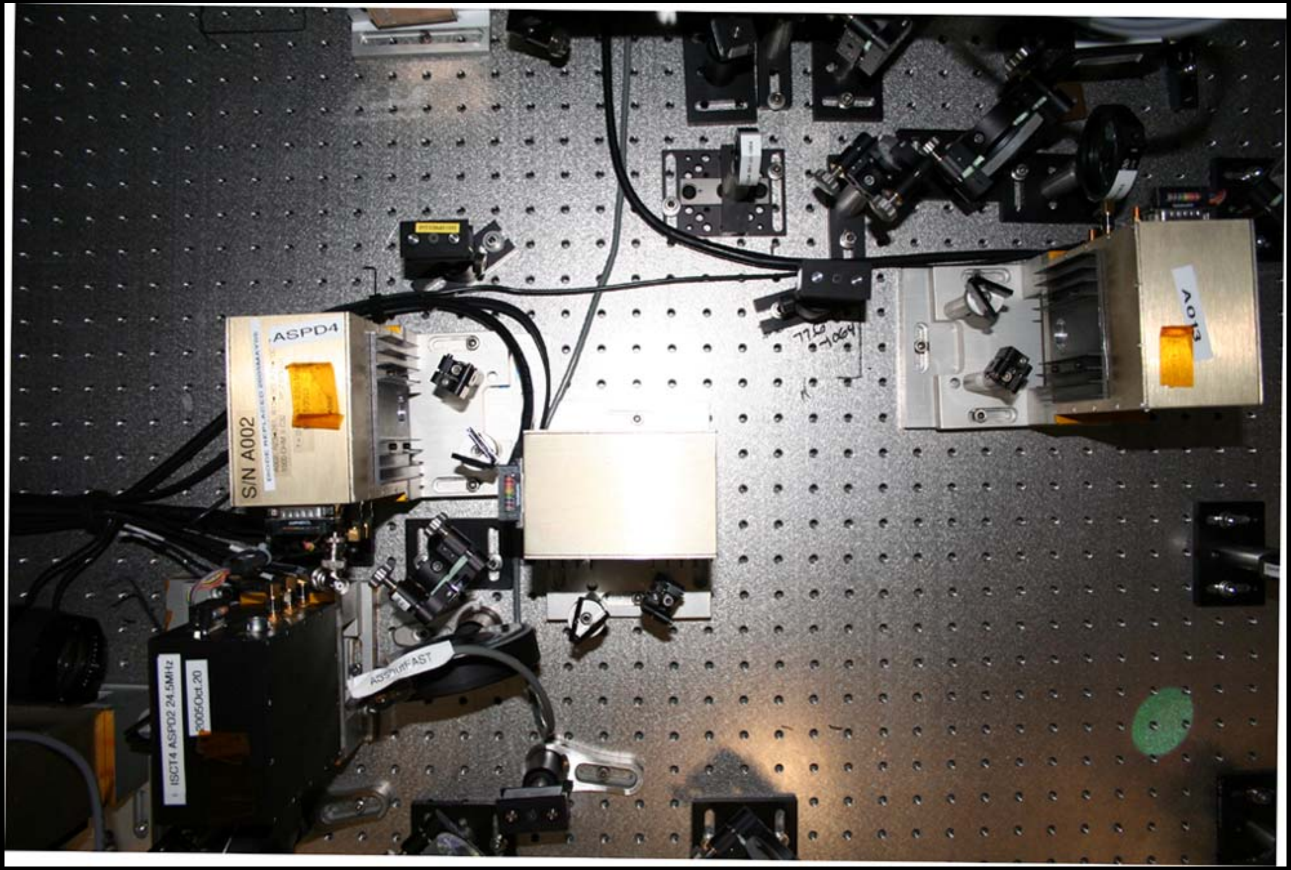


BSC Passive Vibration Isolation

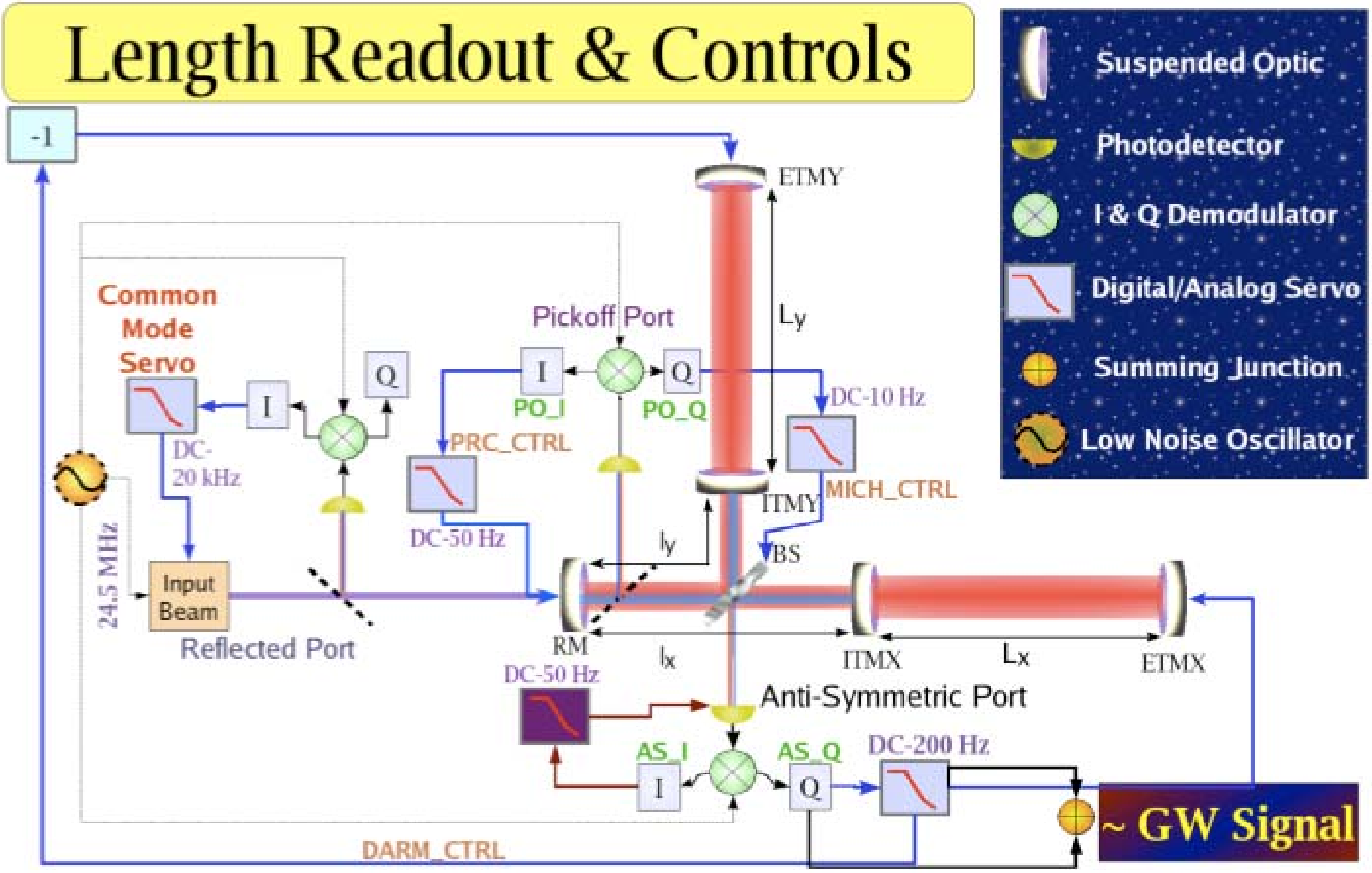




AS port signal sensing: Low noise configuration splits the light onto an array of photodiodes (looking down)



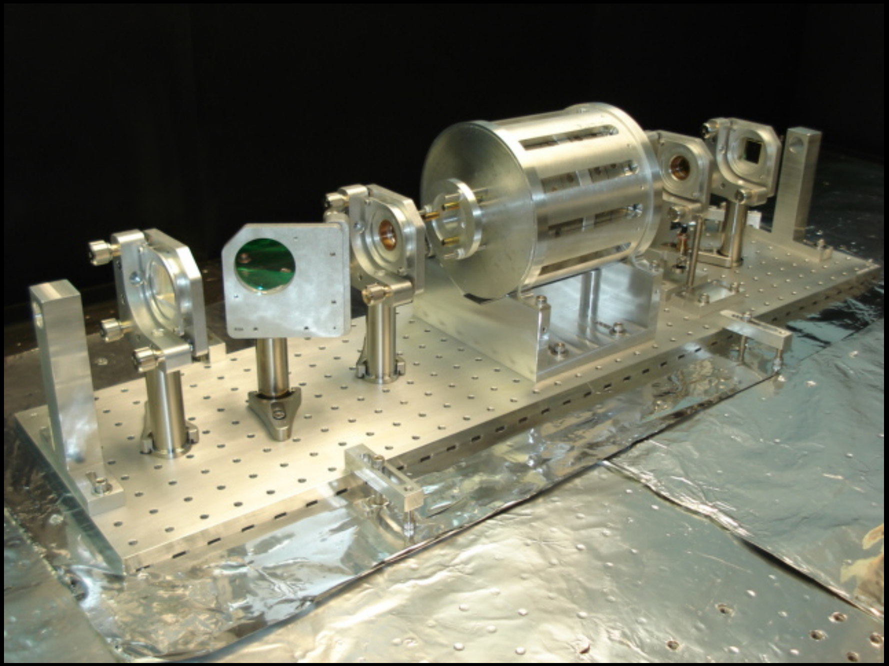
Length Readout & Controls



Enhanced LIGO – transition from 10W to 35W of laser power

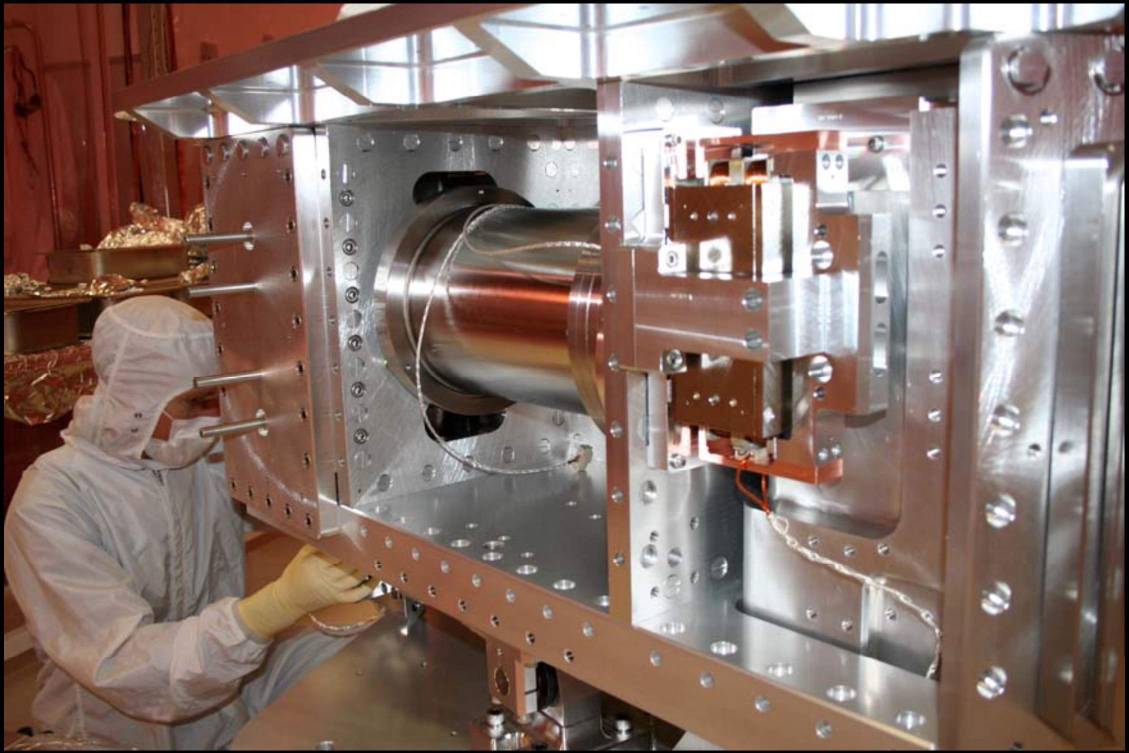
- Prepared by AEI/LZH (Germany)
- World-leading performance in frequency and amplitude stability
- Base unit for Advanced LIGO

More laser power requires enhanced input optics



- Faraday isolator re-polarizes and dumps returning light before it enters the laser enclosure
- IO R&D from University of Florida

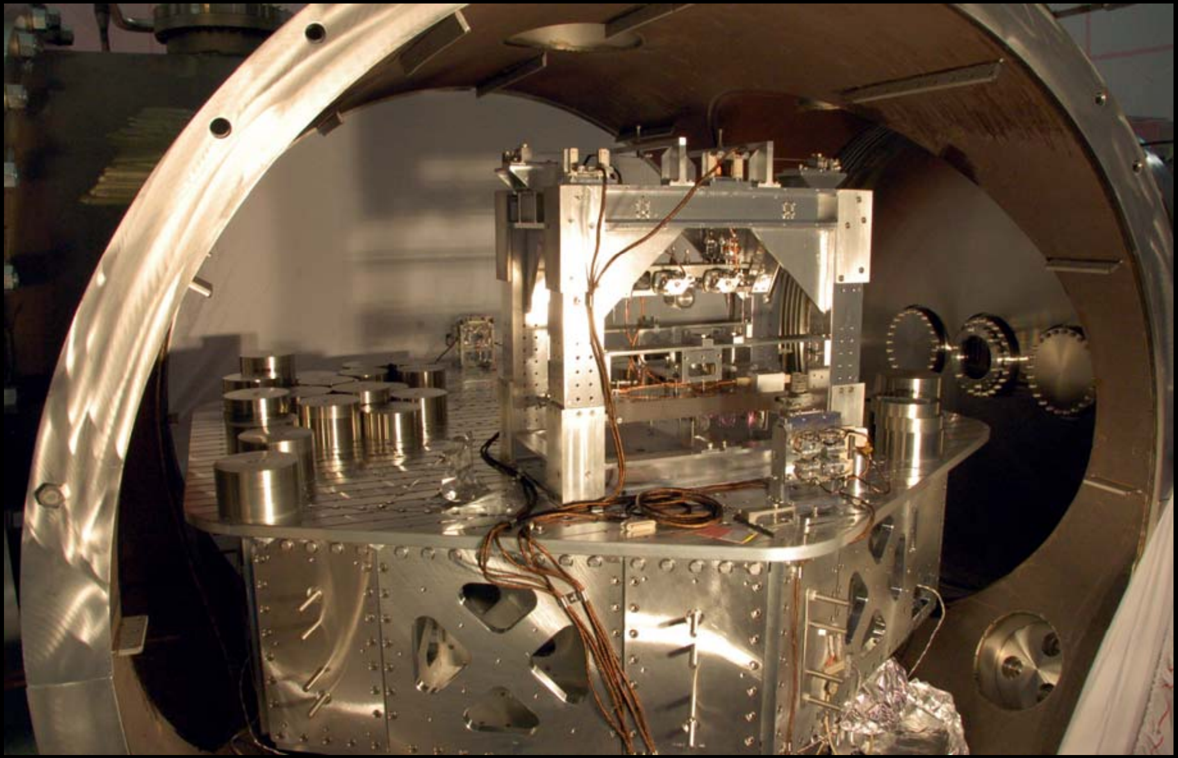
Active vibration isolation in HAM 6 (detection chamber)



- Signals from on-board sensors are used in the actuation scheme
- ISI will provide a quiet platform for GW photodiodes
- Stanford R&D

ISI Install

Isolated and suspended output mode cleaner

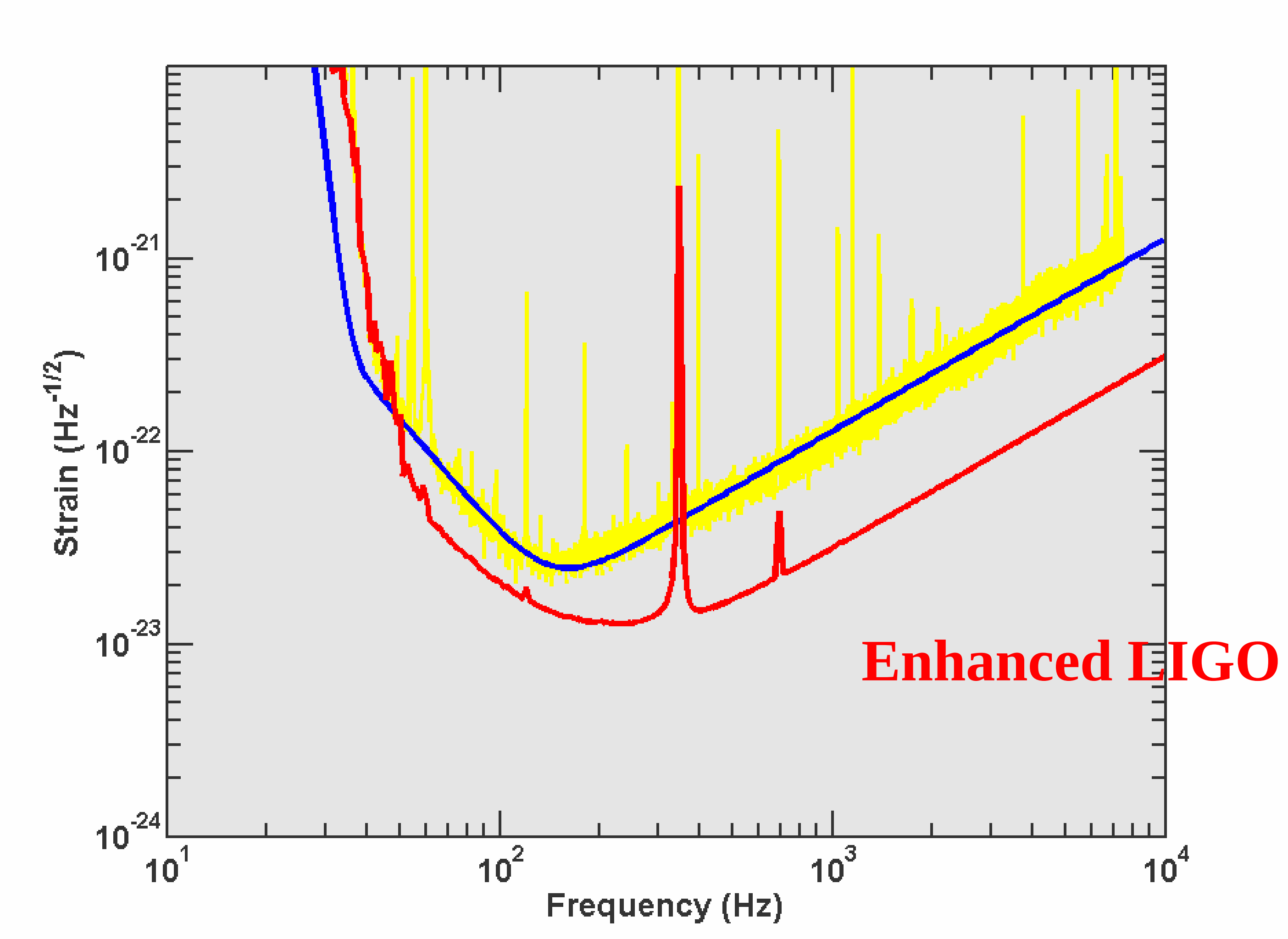


- OMC will remove ‘junk’ from detection port light
- In-vacuum (isolated) photodiodes tuned for DC readout scheme
- OMC – Caltech, GEO

Additional eLIGO changes

- Upgraded Thermal compensation on inner mirrors
- Replace viton stop tips with silica tips
- Replace selected control system magnets with lower-noise versions
- Mount baffles to reduce stray light
- Intense commissioning continues to precede the start of S6

Projected strain sensitivity for eLIGO



LIGO is operated by Caltech and MIT for the National Science Foundation

- NSF Cooperative Agreement # NSF-PHY-0757058
- LIGO’s research efforts are directed by the LIGO Scientific Collaboration, composed of roughly 600 researchers at more than 40 domestic and international institutions.
- Apply for a summer research internship!