# Advanced LIGO and the Second Generation of Gravitational Wave Detection

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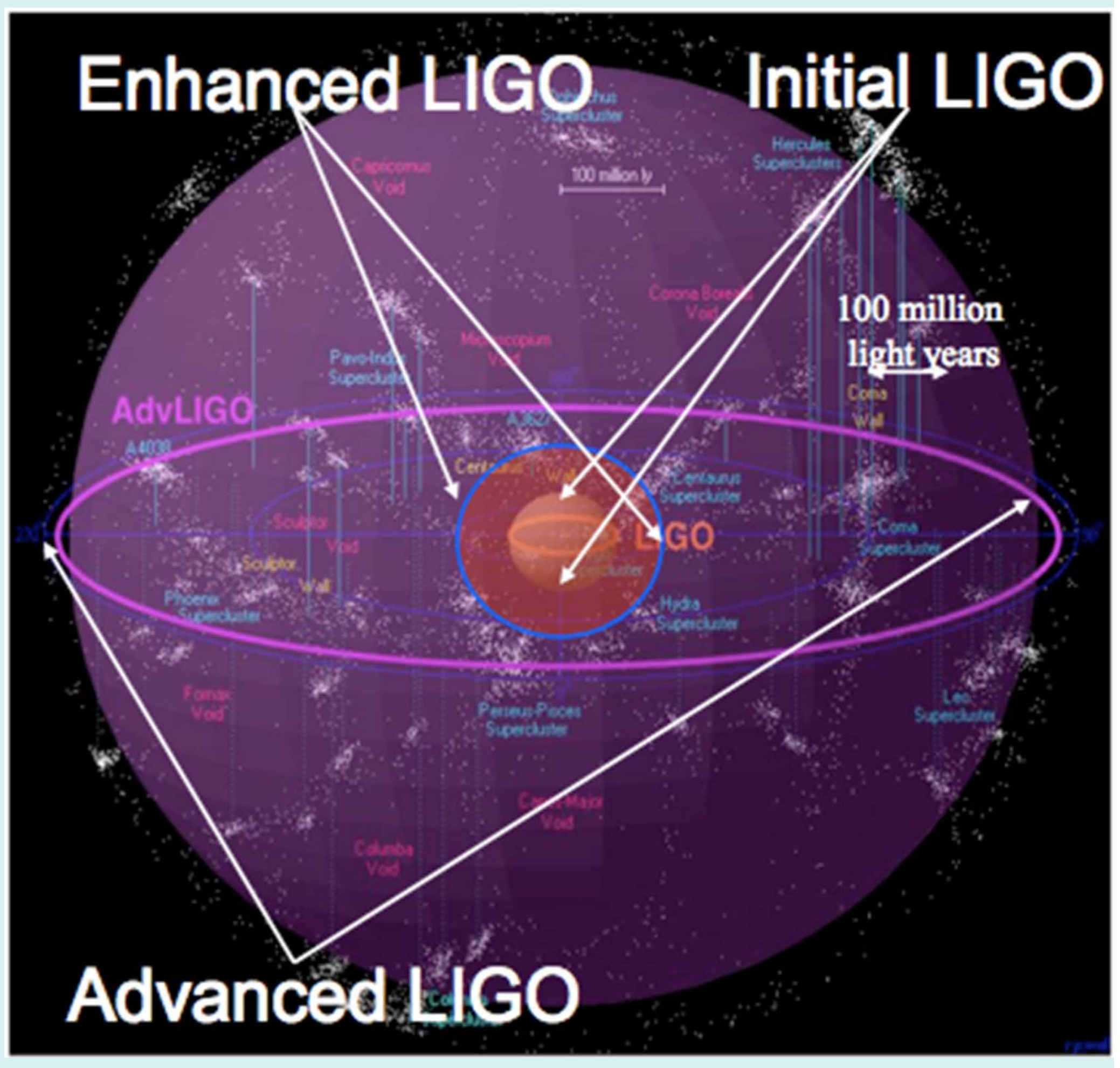
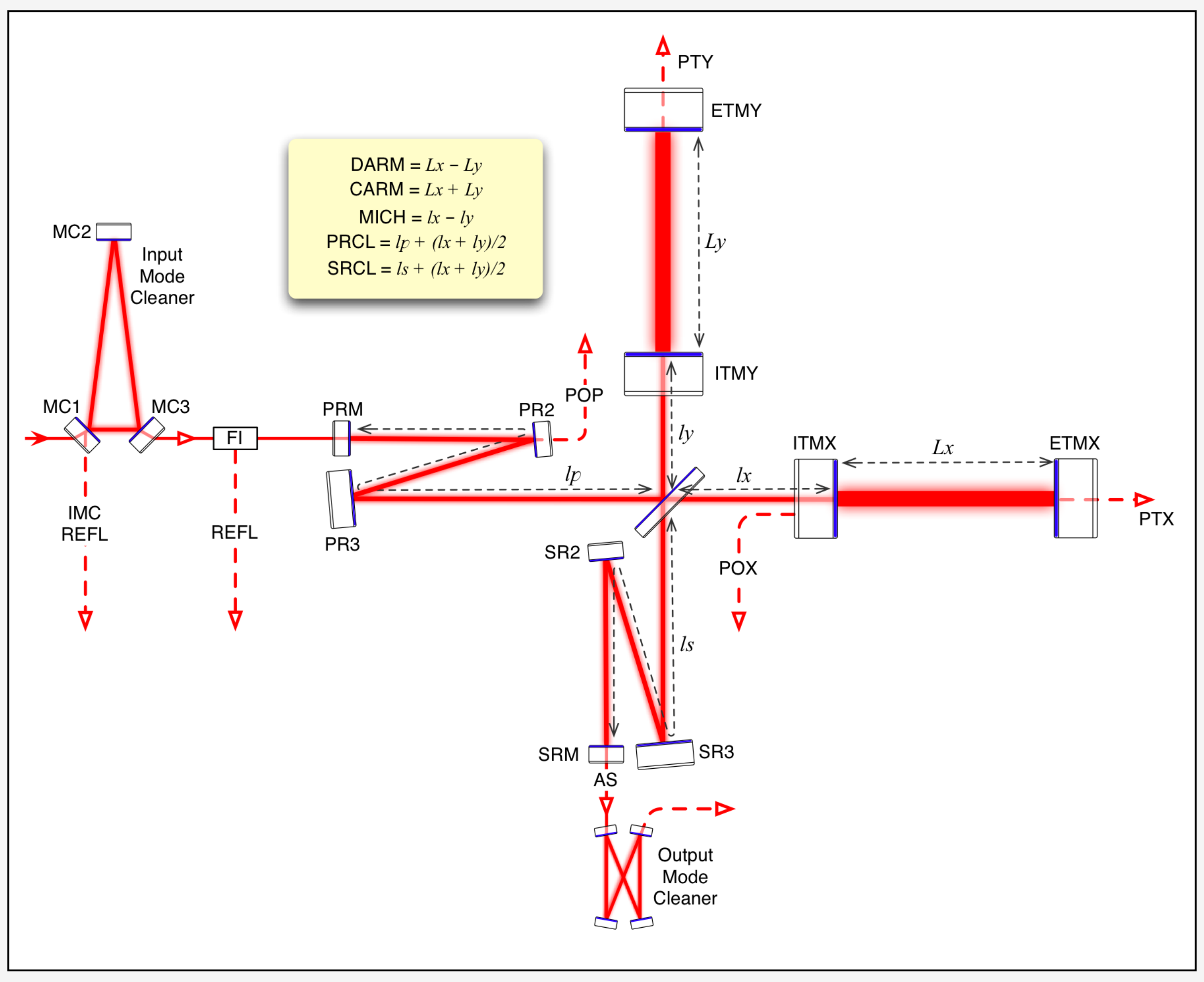
## Gravitational Wave Astronomy

The Laser Interferometer Gravitational Wave Observatory (LIGO) operates three km-scale interferometric gravitational wave detectors at two locations (two in Hanford, WA and one in Livingston, LA), and recently completed a year-long observation run. The detectors are currently undergoing a modest upgrade known as Enhanced LIGO (see poster by S. Ballmer), but work has also begun on a more substantial upgrade (due to be complete in 2014) known as Advanced LIGO. This upgrade will improve the sensitivity by approximately an order of magnitude. Advanced LIGO will be able to detect inspiraling binaries made up of two 1.4 M neutron stars to a distance of 300 Mpc; Neutron star - black hole (BH) binaries will be visible to 650 Mpc; and coalescing BH+BH systems will be visible to cosmological distance, to z=0.4. It is expected that this level of sensitivity in Advanced LIGO and other second generation detectors (such as Advanced VIRGO and LCGT) will enable regular detections, and thus open the field of gravitational wave astronomy.



## Interferometric GW Detection

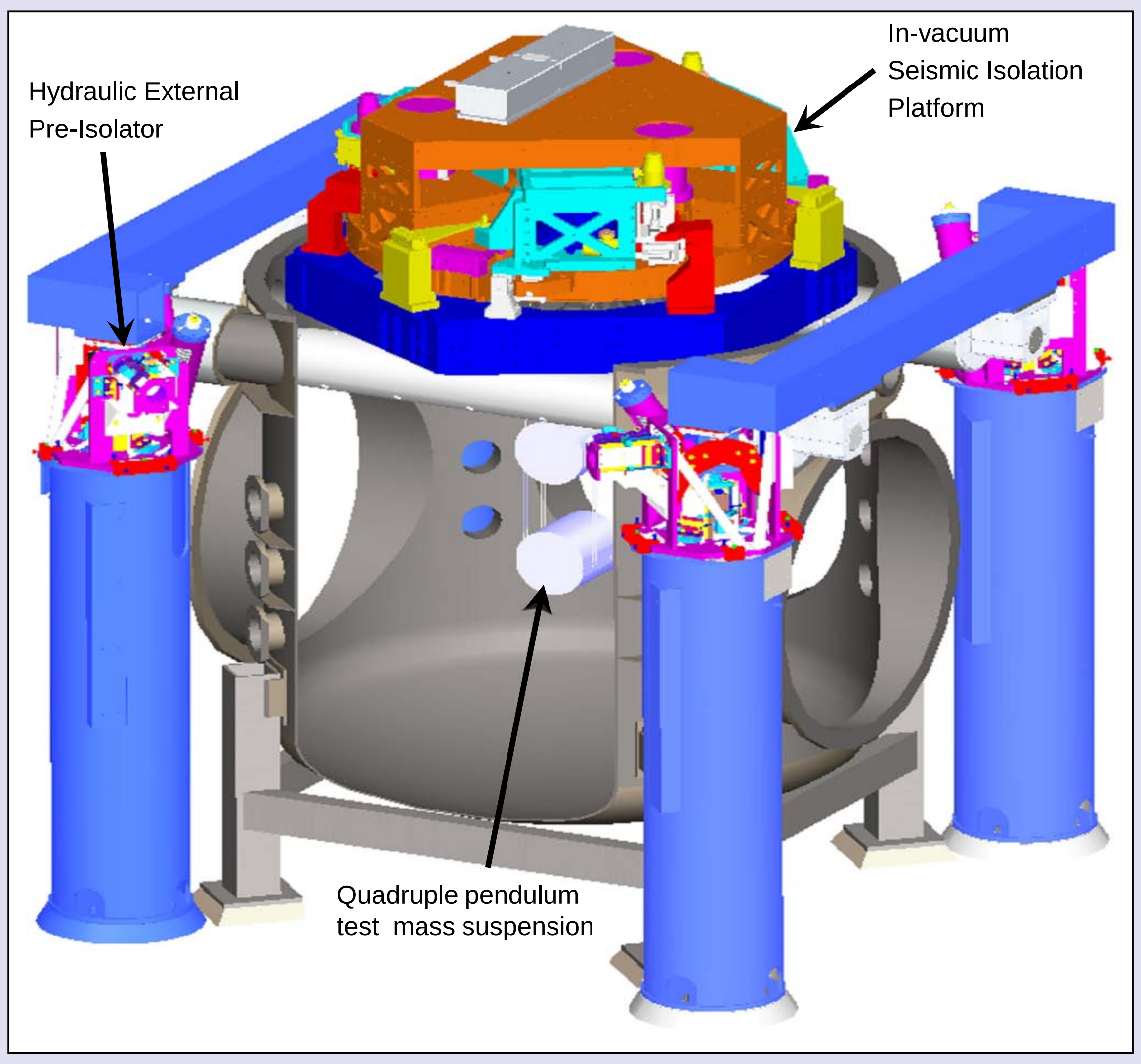
The transverse quadrupolar nature of gravitational waves makes a Michelson interferometer a natural choice for a gravitational wave detector. The extreme sensitivity required for detection, however, necessitates several enhancements to the basic topology.



The Advanced LIGO optical topology is based on a Michelson interferometer with km-scale Fabry-Perot arm cavities and relatively short power (PRCL) and signal (SRCL) recycling cavities. The differential arm length (DARM) is sensitive to gravitational waves. Mode-cleaning ring cavities are also included at the input and output ports of the interferometer.

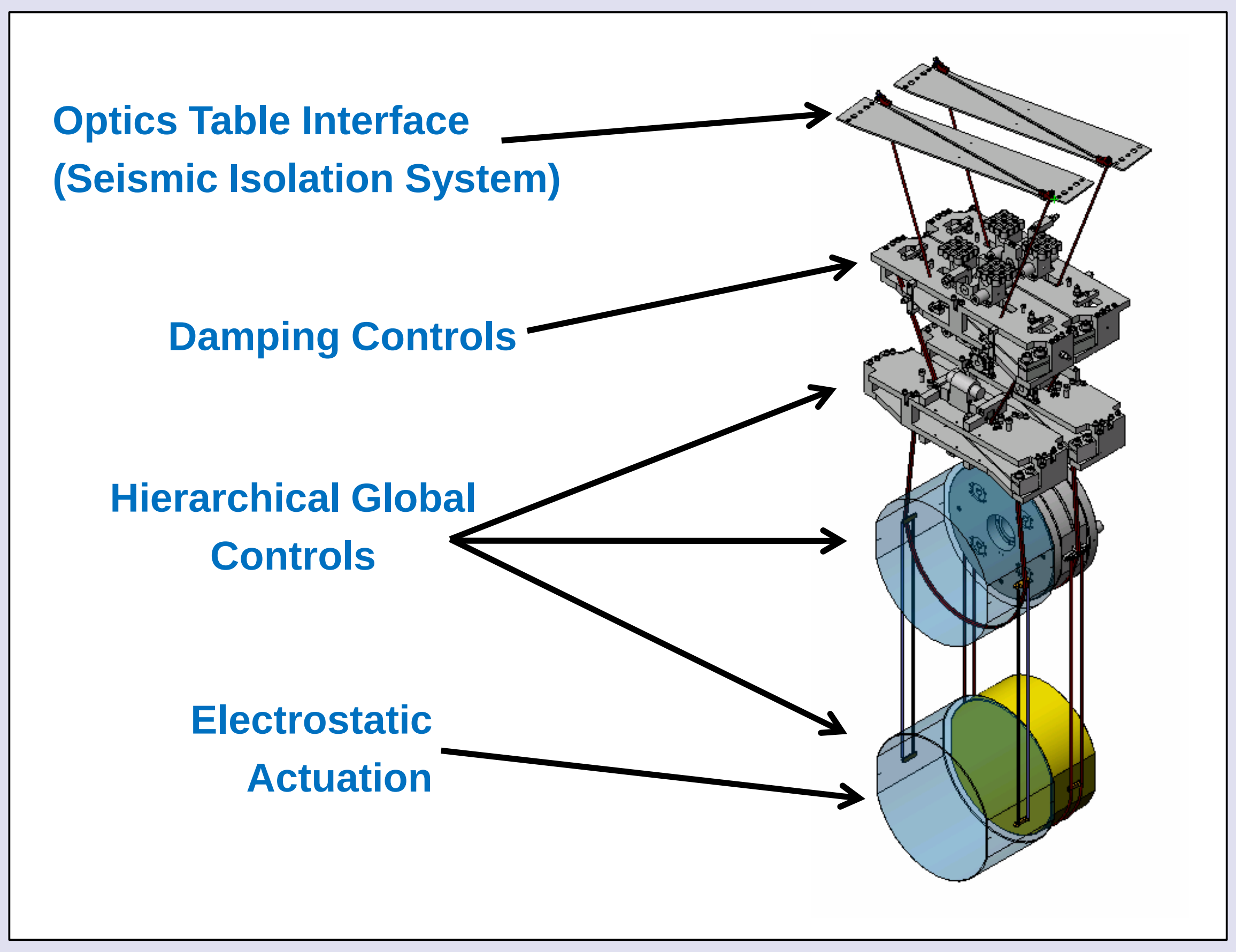
## High Power Laser

Advanced LIGO will require a very high power, low noise, continuous wave laser. The designed laser will provide 180 Watts of CW 1064 nm light. It must meet strict requirements for mode quality, frequency stability, and intensity stability. The most demanding requirement is that the laser have an intensity stability of $2\times10^{-9}$ /√Hz at 10Hz [1], to mitigate noise due to radiation pressure. High operational power and low noise requirements have also necessitated the design and fabrication of new optical components such as Faraday-Isolators and Electro-optic modulators, as well as a system of auxiliary 10 μm lasers to compensate for thermal distortions resulting from optical absorption.



## Seismic Isolation

Advanced LIGO will employ three stages of active seismic isolation to mitigate the deleterious effects of ground motion: a Hydraulic External Pre-Isolator (HEPI), an in-vacuum Internal Seismic Isolator (ISI), and a multistage pendulum. Together these systems will isolate the test masses sufficiently to reduce motion to ~$10^{-19}$ m/√Hz at 10Hz [2].

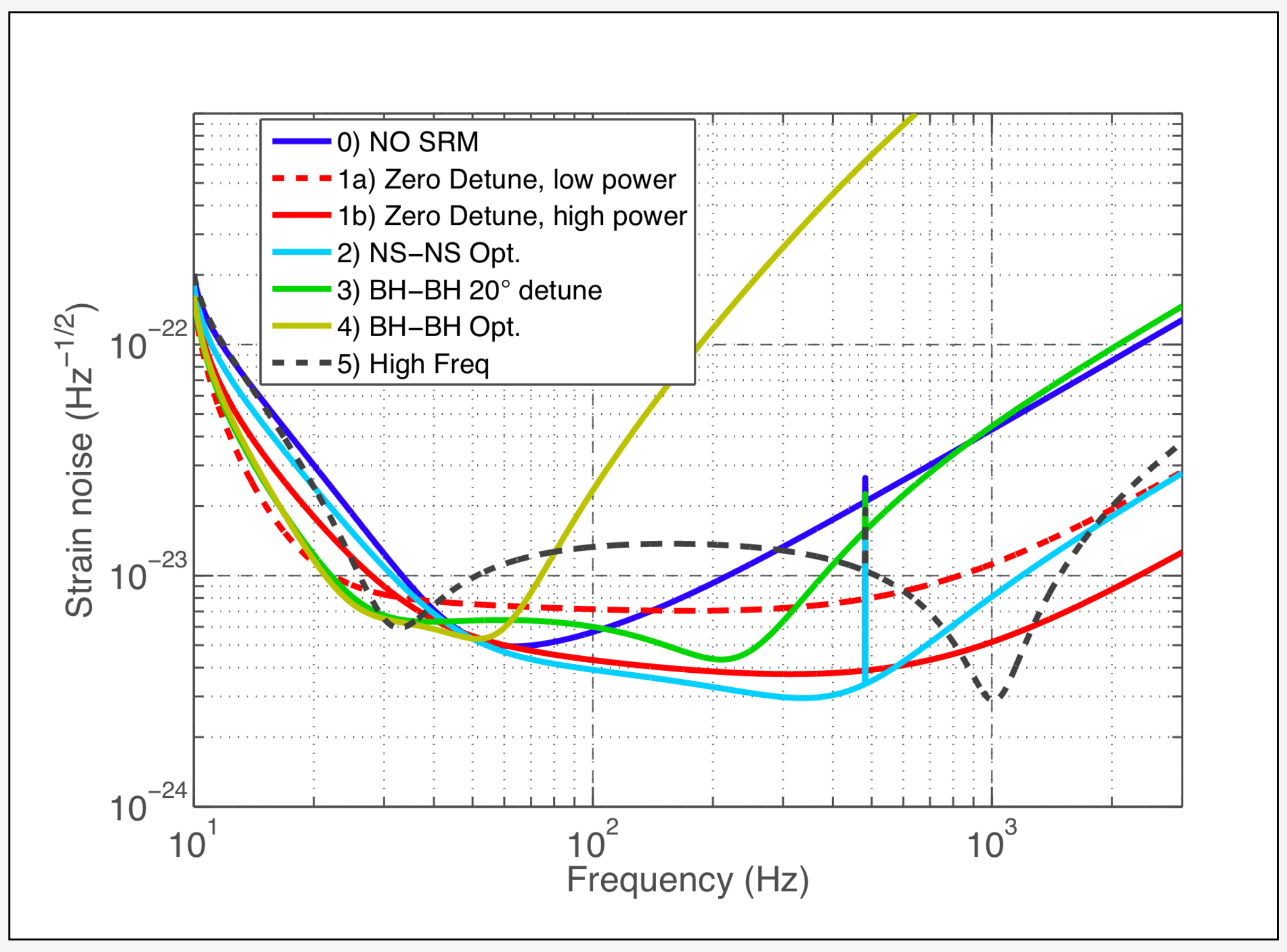


The test masses, which must be "freely falling" for the interferometer to detect gravitational waves, are suspended from a quadruple pendulum and controlled with a combination of coil/magnet pairs and electrostatic actuators. The 40kg test masses are made of low-loss fused silica and have high quality optical coatings.

**References**
[1] Advanced LIGO Pre-Stabilized Laser Preliminary Design, P. King *et al.*, LIGO-T080195-01-D
[2] Advanced LIGO, B. Lantz, LIGO-G080040
[3] B. Abbott et al. (LIGO Scientific Collaboration), Phys. Rev. D 77, 062002 (2008), arXiv:0704.3368 [gr-qc].

## Operating Modes

Advanced LIGO interferometers will be operable in several modes, with sensitivity tuned to better match certain types of sources.



By tuning the properties of the signal recycling cavity (which can be done via microscopic placement of a mirror) and by adjusting the input power, the frequency response of the instrument can be changed. The frequency response is adjusted to optimize sensitivity in the face of several limiting noise sources: seismic noise, thermal noise, and quantum noise of the laser light.

## Event Rates

Estimates of astrophysical populations and event rates [3] along with knowledge of detector characteristics can provide insight into the rate at which detections may occur. The table below shows a mix of low, realistic, and plausible detection rates for several types of compact binary coalescences in Initial, Enhanced, and Advanced LIGO.

| Source | IFO | $N_{\rm min}$ yr$^{-1}$ | $N_{\rm low}$ yr$^{-1}$ | $N_{\rm re}$ yr$^{-1}$ | $N_{\rm pl}$ yr$^{-1}$ | $N_{\rm up}$ yr$^{-1}$ |
|---|---|---|---|---|---|---|
| NS-NS | Initial | $1.5\times10^{-5}$ | $1.5\times10^{-4}$ | 0.015 | 0.15 | 0.3 |
| | Enhanced | $1.5\times10^{-4}$ | 0.0015 | 0.15 | 1.5 | 3 |
| | Advanced | 0.02 | 0.2 | 20 | 200 | 400 |
| NS-BH | Initial | | $6\times10^{-5}$ | 0.004 | 0.13 | |
| | Enhanced | | $7\times10^{-4}$ | 0.04 | 1.4 | |
| | Advanced | | 0.1 | 5.7 | 190 | |
| BH-BH | Initial | | $7\times10^{-4}$ | 0.01 | 1.7 | |
| | Enhanced | | 0.007 | 0.11 | 18 | |
| | Advanced | | 1 | 16 | 2700 | |

## Acknowledgement

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