Advanced LIGO: The Rubber Hits the Road!

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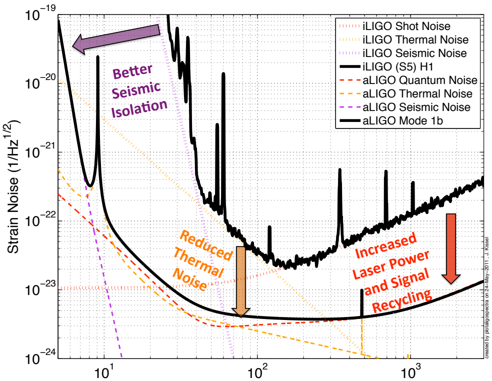
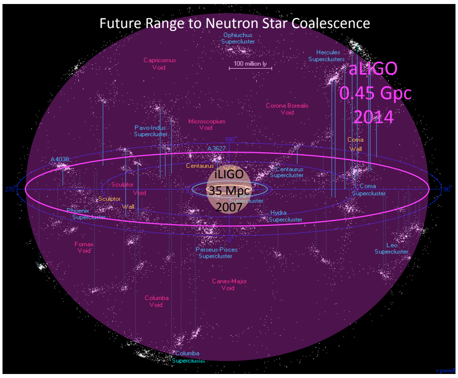
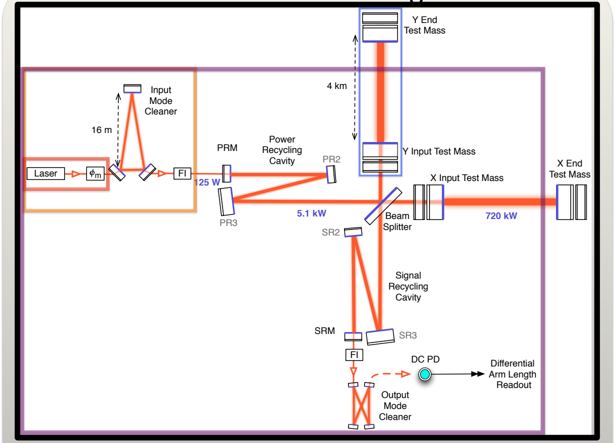


Between 2005 and 2010, the LIGO gravitational wave detectorrs collected two and a half years of data at the strain sensitivity predicted by their original design. In October of 2010, the three detectors were decommissioned and are now offline undergoing a major upgrade; the first interferometer to see "first light" in 2013, and all three by the end of 2014. The advanced detectors, collectively dubbed Advanced LIGO, will implement improvements on many opto-mechanical fronts in order to achieve the designed strain sensitivity; a factor of 10 improvement in the most sensitive frequency band and above, and by many orders of magnitude in the lower third of the detectors' bandwidth. When the designed sensitivity is achieved, the astrophysical range out to which each detector would see and optimally oriented, binary neutron star system will increase from 35 Mpc to 0.45 Gpc, increasing the expected obervation rate from 0.02 to 40 per year.

(Left) A comparison of the measured strain sensitivity of the Initial LIGO detectors, compared against the design sensitivity of the Advanced LIGO detectors.
(Right) An illustration comparing the approximate volume of the local universe covered by the initial and advanced LIGO detectors.



Interferometer Design

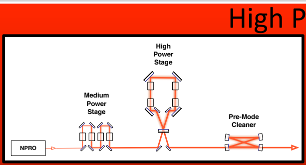


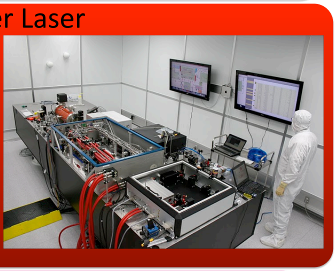
(Above) The optical layout of an Advanced LIGO Interferometer. In principle, the detectors are Power- and Signal- Recycled Michelson Interferometers with Fabry-Perot Cavities for arms. The differential change in length of the 4 km arms is the degree of freedom most sensitive to gravitational waves.

(Below) A comparison the design parameters of the initial LIGO detectors with the Advanced Detectors, explaining how each change improves the design.

Property	Initial LIGO	Advanced LIGO	Improves
Num. 4 km Interferometers	2 (with 1 2km)	3	Network Sensitivity
Tunable Frequency Response?	No	Yes	Adaptabilty to Exected Sources
Test Mass Size	10 kg, Ø25x10cm	40 kg, Ø34x20cm	Susceptibility to Force Noises
Isolation Stages	6 (one active)	7 (three active)	Seismic Isolation
Laser Power	up to 10 W	up to 180W	Shot Noise
Stored Arm Cavity Power	~10 kW	~750 kW	Sensitivity
ETM Beam Spot Size (1/e^2 Radius)	4.5 cm	6.2 cm	Coating Thermal Noise
Differential Arm Readout Scheme	Heterodyne	Homodyne	Shot Noise

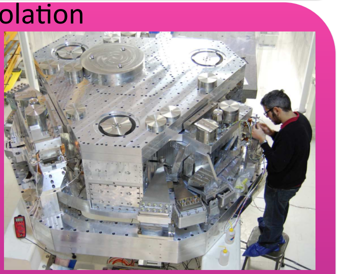
High Power Laser





(Above) The Advanced LIGO laser is a multi-stage, 180 W, 1064 nm wavelength laser. The light source is a 2W, Nd:Yag solid-state laser. This is fed into a medium power pump stage that increases the power to 35W. Finally, the light passes through a high-power ring oscillator stage to increase the output light to the full 180W.
(Left) A picture of the fully-installed laser in the first interferometer.

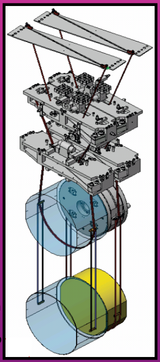
Seismic Isolation

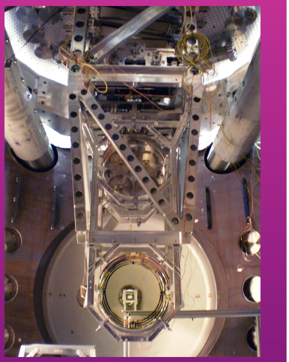


At each end of the Fabry-Perot arm cavities, the test masses need the most isolation from ground motion – a reduction in **9 orders of magnitude** at 10 Hz. To achieve this isolation, Advanced LIGO uses many successive stages of active and passive isolation.

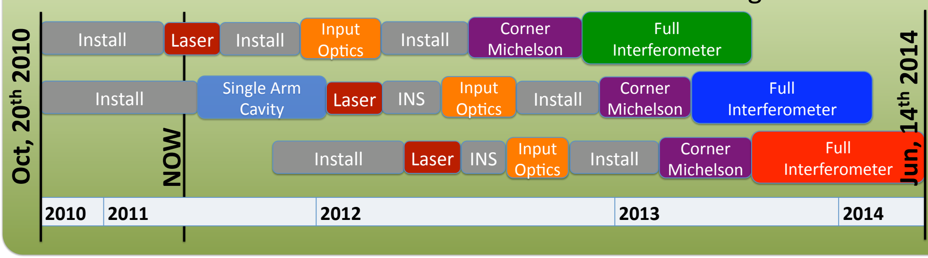
(Top) The two-stage, passive and active seismic isolation platform. Each stage is suspended from the next as pendula for passive isolation. In addition, these stages use information from on-board low-noise inertial sensors (seismometers) to sense the motion of the platform to feed-back to electro-magnetic actuators. (Left) SolidWorks model, (Right) Fully assembled first article.

(Right) The four-stage, passive quadruple pendulum. Each stage provides 1/f^2 isolation above its resoance frequency (~ 1 Hz). The final two stages are monolithic fused silica to further reduce thermal noise. (Left) SolidWorks Model, (Right) Fully assembled first article





Schedule and Progress



After spending the winter of 2010 decomissioning two of the three LIGO interferometers, installation has begun in early 2011. In order to mitigate risks and to commission critical subsystems as early as possible, the construction will follow two different paths. The detector in Livingston, LA will be the "path finder" -- its construction will follow a natural, from-the-laser-out installation and commissioing flow. The second detector in Hanford, WA will start by construct a full single arm cavity first, which will provide the first test a integrated test-mass seismic isolation systems over the long, 4 km baseline. Finally, the third interferometer in Hanford, WA will progress as the first, using the experience gained from building the first two.

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