Advanced LIGO and Beyond: The next generations of gravitational wave detection

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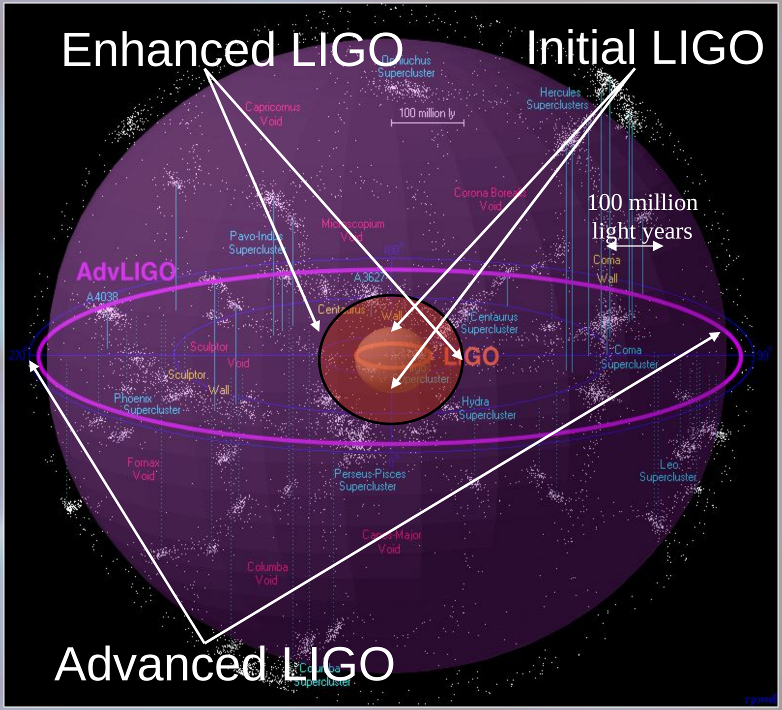
Advanced LIGO Overview

- Designed to have ~10X sensitivity of initial LIGO
  - ~1000X in sensitive volume
- Higher bandwidth
  - Sensitive down to 10 Hz
- Install at existing sites



Advanced LIGO Astronomical Reach

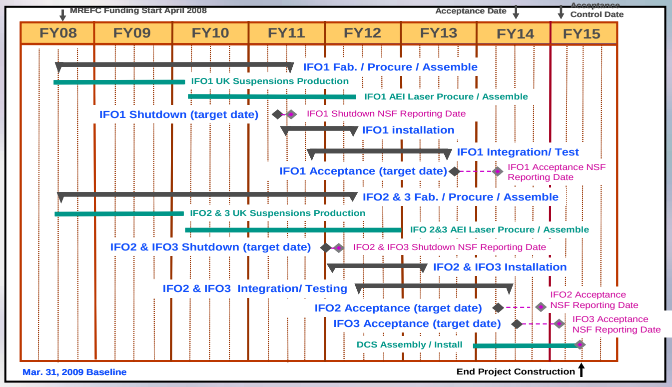
LIGO Sites

- Binary neutron star inspiral range ~200 Mpc
- Beyond detection, do gravitational astronomy

Advanced LIGO Scope and Schedule

- Reuse vacuum system and buildings
- Replace nearly all of the initial LIGO detectors
- 3 interferometers
  - All 4 km long
  - Lengthen current 2 km at Hanford
  - Likely identical, possibly one narrowband

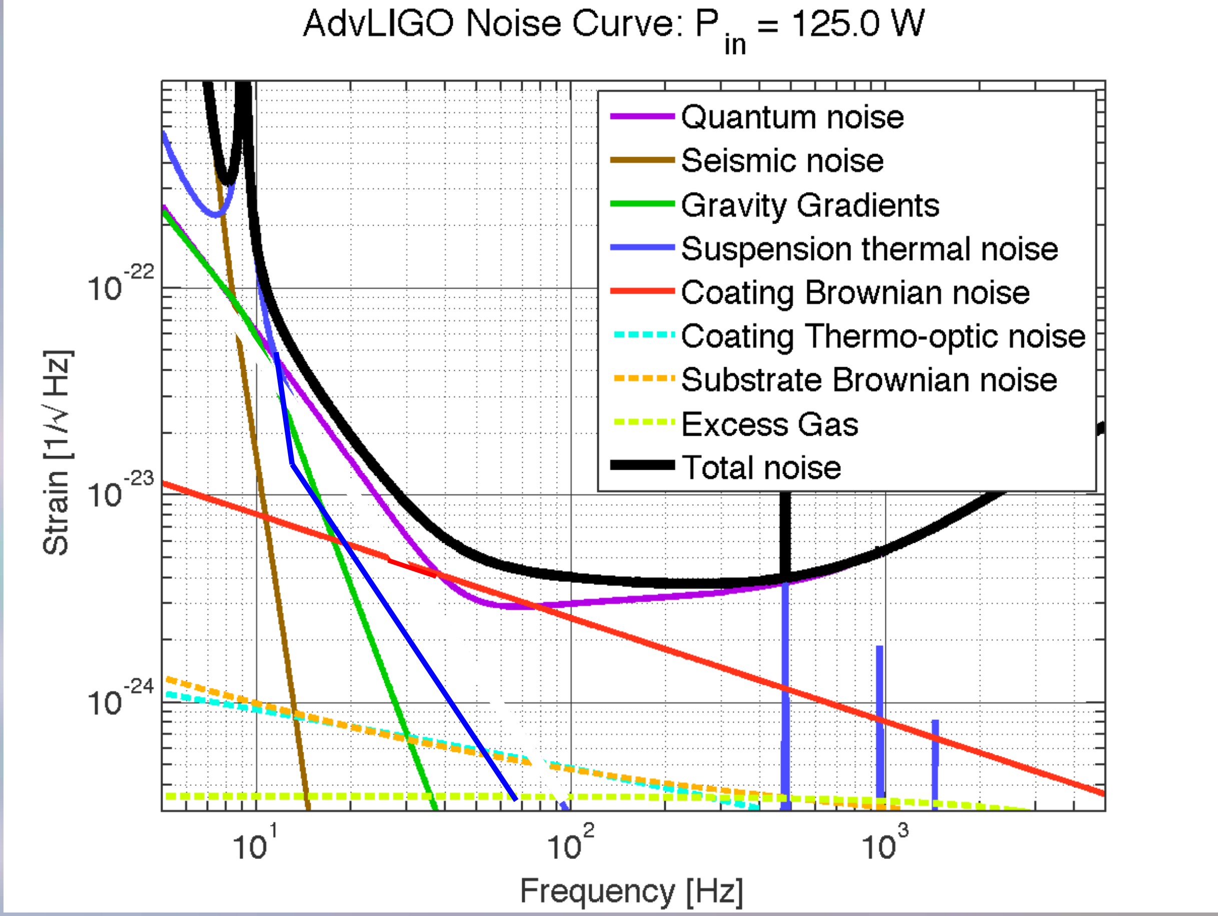
- Funded in April 2008
- All subsystems in procurement/ fabrication end of 2009
- Begin installation at Livingston Feb 2011, Hanford Oct 2011
  - Right after enhanced LIGO
- Finish installation 2013-2014



Advanced LIGO Schedule

Advanced LIGO Sensitivity

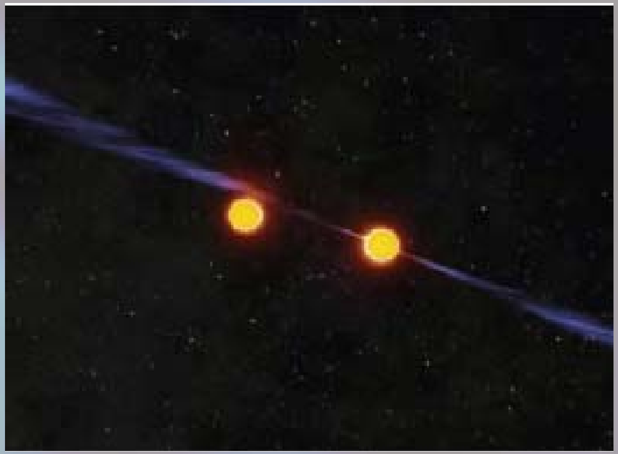
- RMS Strain (100 Hz BW)
  - Requirement: 10^{-22}
  - Goal: $3\ 10^{-23}$
- Duty Cycle
  - 75% triple coincidence
- Sensitivity Limitations
  - 10-40 Hz: Radiation pressure/Suspension thermal noise/Gravity gradient
  - 40-200 Hz: Coating thermal noise/ Quantum noise
  - > 200 Hz: Shot noise



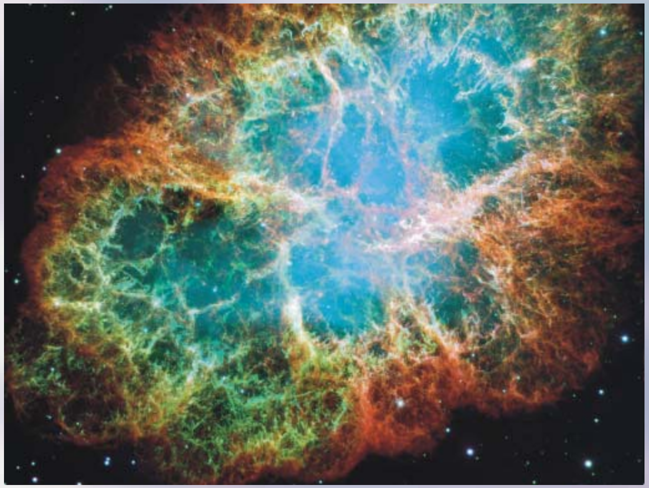
Astrophysics

- Inspirals:
  - Neutron Stars ~ 40/yr
  - 10 $M_\odot$ Black Holes ~30/yr
  - Neutron Star-Black Hole ~10/yr
- Stochastic Background:
  - $\Omega \sim 10^{-9}$ in 3 months
  - Cosmic strings, defects, etc

Inspiralling Neutron Stars



- Low Mass X-ray Binaries
  - ~500 Hz
  - Several possible in 2 years
  - Sco X-1 in narrowband
- Multimessenger astronomy
  - Gamma ray bursts
  - Neutrinos from supernova

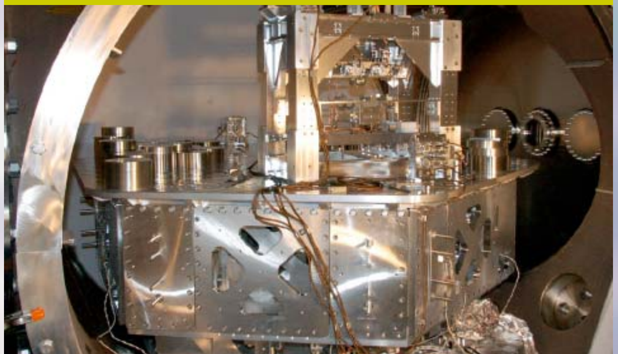


Crab Pulsar Nebula

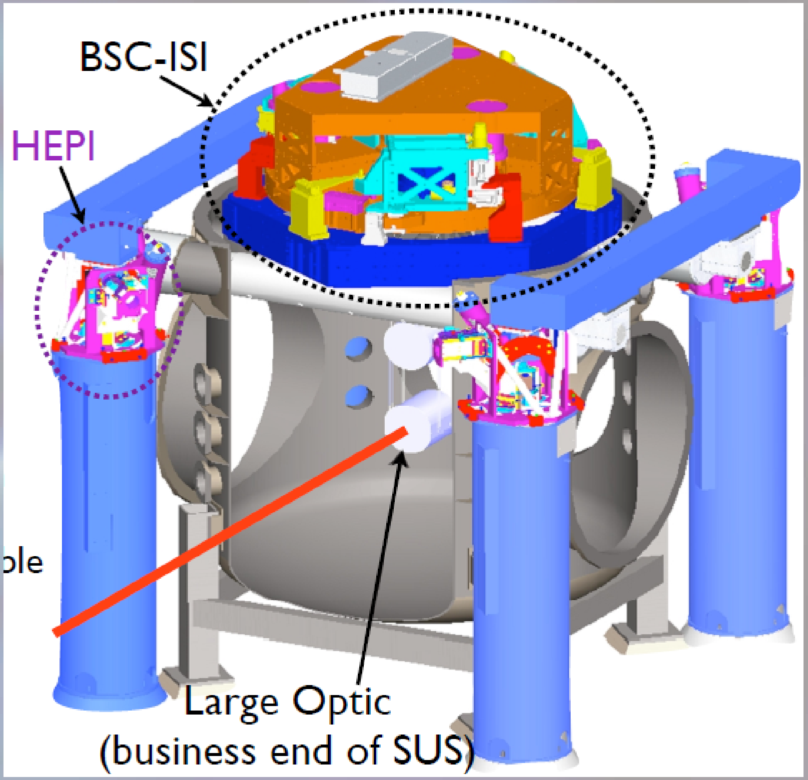
Seismic Isolation

- Two related designs
  - BSC for tests masses and beamsplitters
  - HAM for supporting optics
- 3 stages of 6 degrees of freedom
  - 2 active stages
- Hydraulic external stage
- Prototyping
  - BSC in LASTI at MIT
  - HAM in enhanced LIGO

HAM in enhanced LIGO



BSC Isolation Design

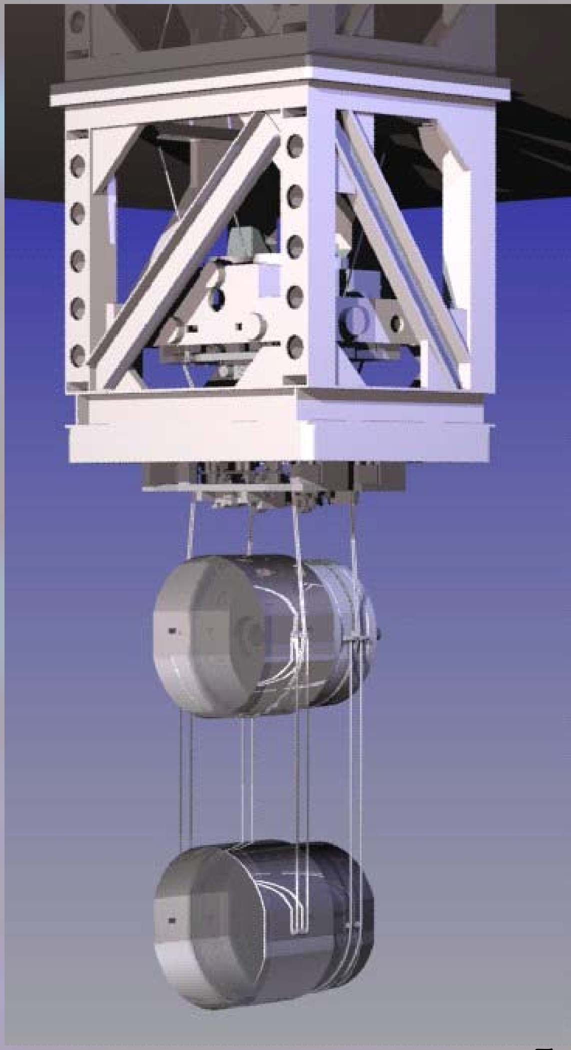


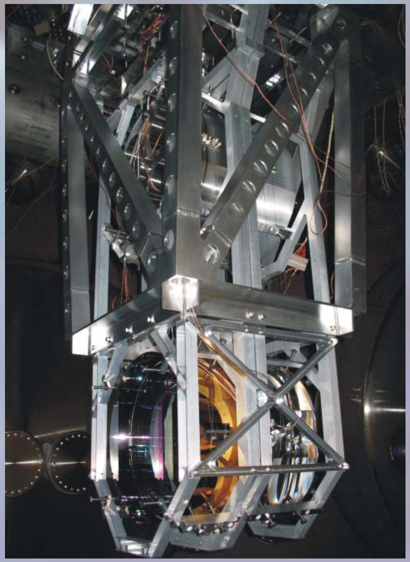
- Fabrication
  - HAM: October 2009
  - BSC: July 2010

Suspensions

- Based on GEO 600 design
  - British groups lead for Advanced LIGO
- Quadruple pendulums for test masses and beamsplitters; triples for others
- Two chains: test mass and reaction mass
- Maraging steel blades for vertical isolation
- Monolithic silica last stage
  - Dumbbell fibers (not ribbons)
  - Ears silicate bonded to optic
  - Fibers welded to ears
- Full testing in LASTI at MIT

Quadruple Pendulum





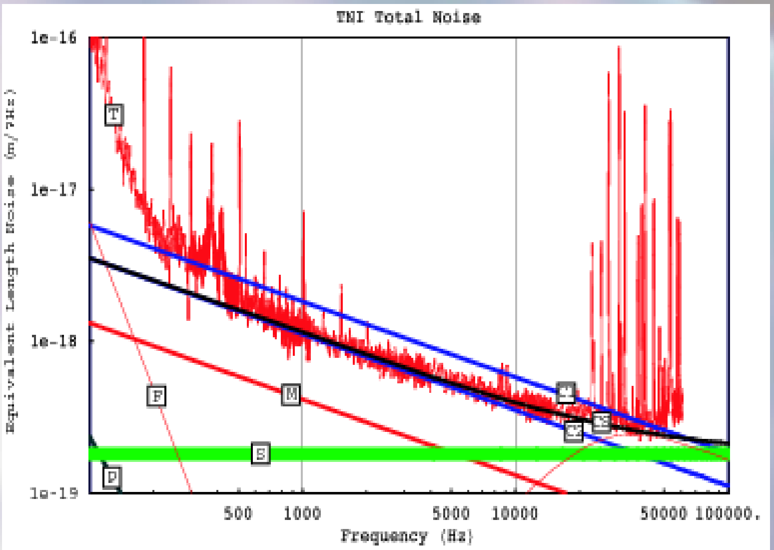
Suspension Test at LASTI

Welded Fiber-Ear

Optics

- 40 kg silica substrates for test masses
- Titania doped tantala/silica coatings
  - Improved absorption and thermal noise
  - Design optimized, lower thermal noise
  - Prototyped at Caltech
  - Dichroic at 1064 and 532 nm

Test Mass Blank

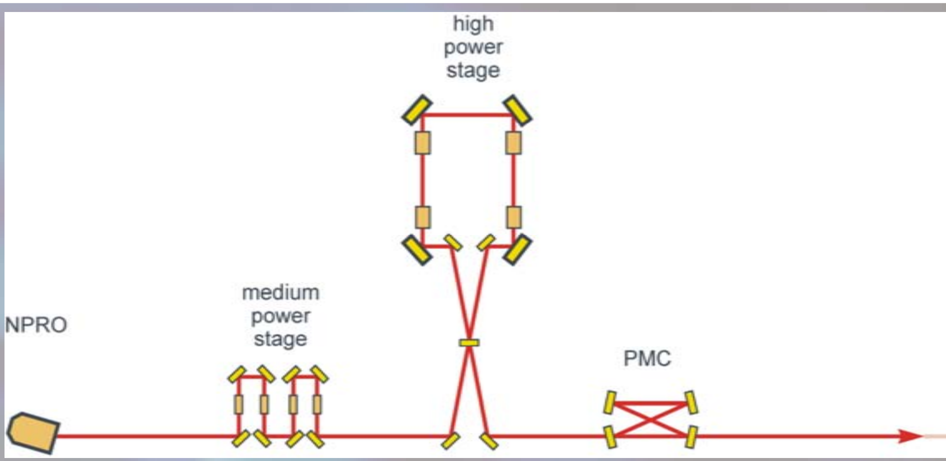


Coating Thermal Noise Data

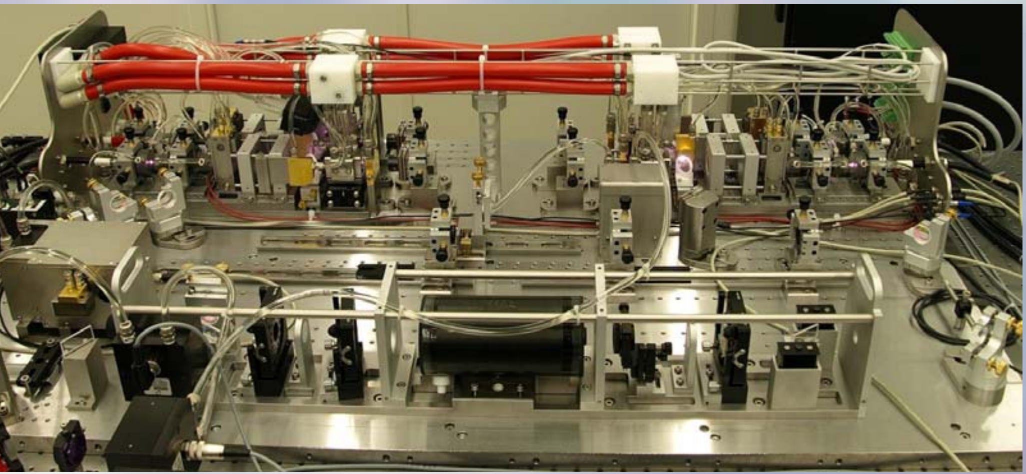
- Thermal compensation
  - Ring heaters
  - Projected 10 μm laser
  - Prototyping in enhanced LIGO
- >90% of substrate blanks received at Caltech

Lasers

- German Albert Einstein Institute lead
- Non-planer ring oscillator (NPRO)
- Nd:YAG 1064 nm
- 180 W after 3 gain stages



Amplification Stages



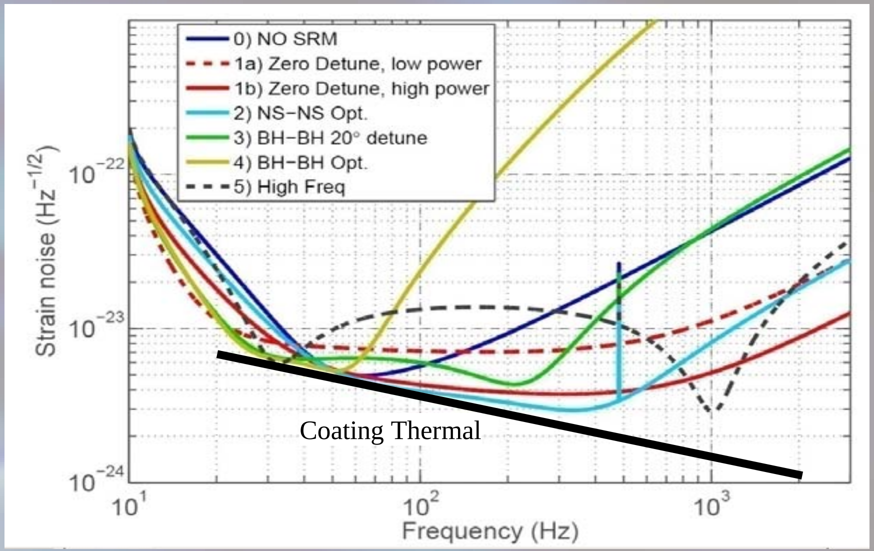
Engineering Prototype

- First two stages (30 W) prototyping in enhanced LIGO
- Full power engineering prototype at AEI
- Squeezed light possible as enhancement to Advanced LIGO

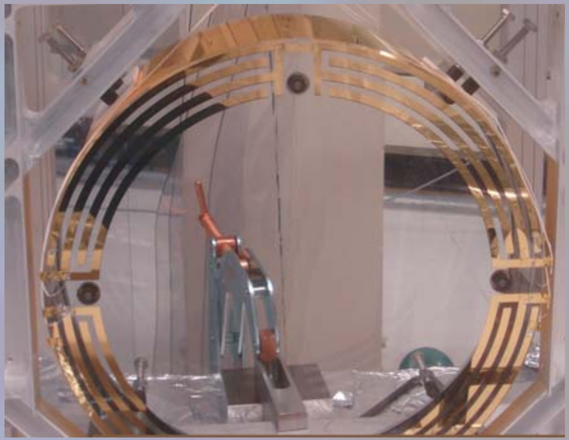
Systems

- Homodyne (DC) readout
  - Prototyping in enhanced LIGO
  - Requires output mode cleaner
- Secondary, green interferometer
  - Lock acquisition
  - Arm length stabilization
- Electrostatic drive to control test mass
- High optical power
  - Finesse of 450
  - Concerns about parametric instabilities
- Signal recycling cavity
  - Allows for tuning of quantum noise
  - Baseline is broadband

Different Tunings



Enhanced LIGO Output Mode Cleaner

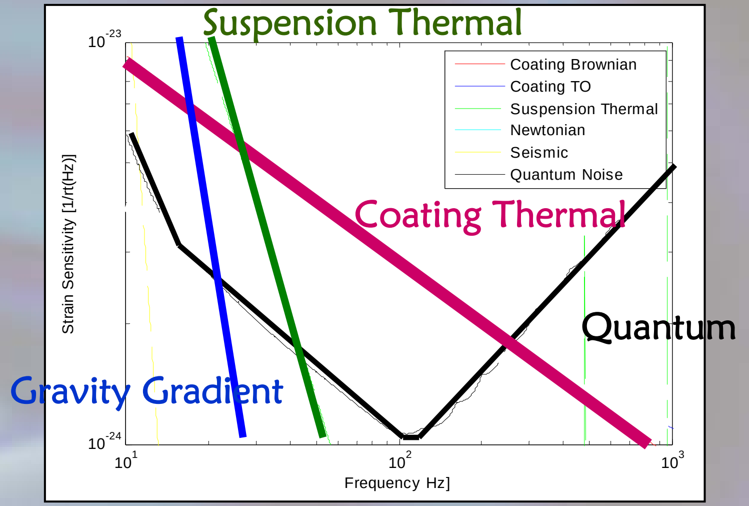


Electrostatic Drive

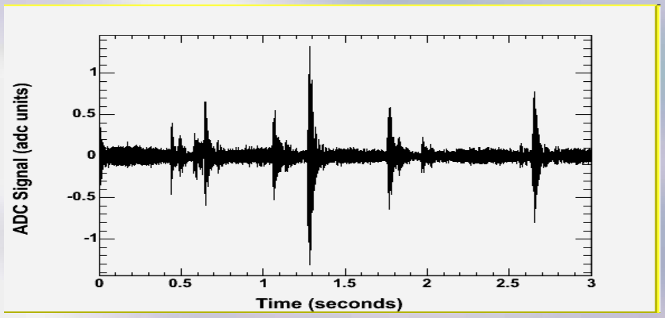
Sensitivity Limitations

- Gravity gradients
- Suspension thermal noise
- Mirror thermal noise
  - Coating: Brownian and Thermo-optic
  - Substrate: Silica

Estimated Noise in 3rd Generation Detectors



- Quantum noise
  - Radiation pressure
  - Shot noise
- Non-Gaussian noise
  - Important for Burst/Inspiral searches



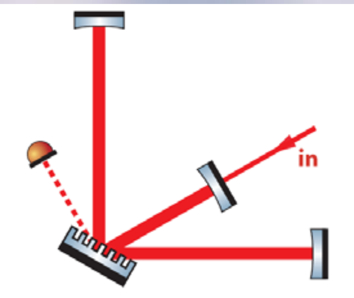
Initial LIGO Non-Gaussian Glitches

3rd Generation Solutions

Seismic and Gravity Gradient
- Underground
- Noise subtraction
- Testing at Homestake mine


Homestake Mine 1889

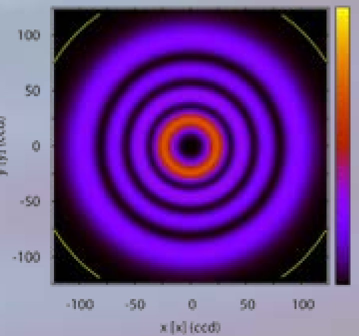
Quantum Noise
- High power
- Diffractive optics
- Squeezed light



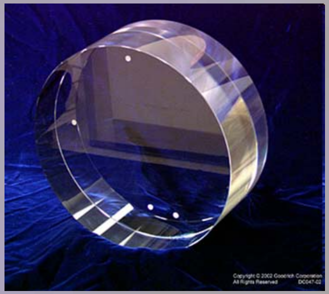
Diffractive Beamsplitter

Suspension and Mirror Thermal Noise
- Improved materials
  - Coating, substrate, suspension
  - Sapphire, silicon
- Cryogenics
- Displacement noise free interferometers

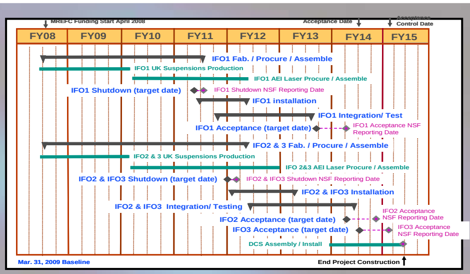
Coating Thermal Noise
- Beam shaping
- Change wavelength
  - Shorter or 1.55 micron
- Khalili cavities, corner reflectors



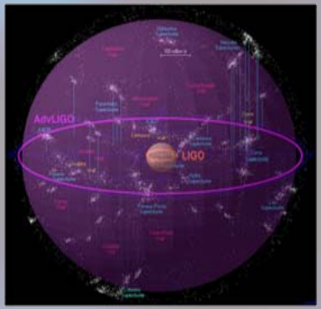
Laguerre-Gauss Mode 33


40 kg sapphire optic

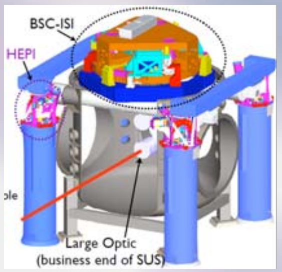
Conclusions

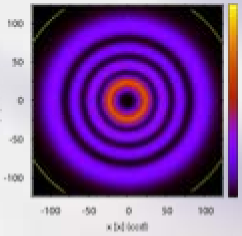


- Advanced LIGO in progress
  - Procuring and fabricating parts
  - Installation begins in 2011



- Significant increase in sensitivity
  - Likely detections of inspirals, bursts
  - Possibility of stochastic and pulsars





- Major subsystems designed, tested, and in production
- Sensitivity limited by laser power, materials, environment, etc
- Many directions for improved 3rd generation
  - Need active research now