The Future - How to make a next generation LIGO

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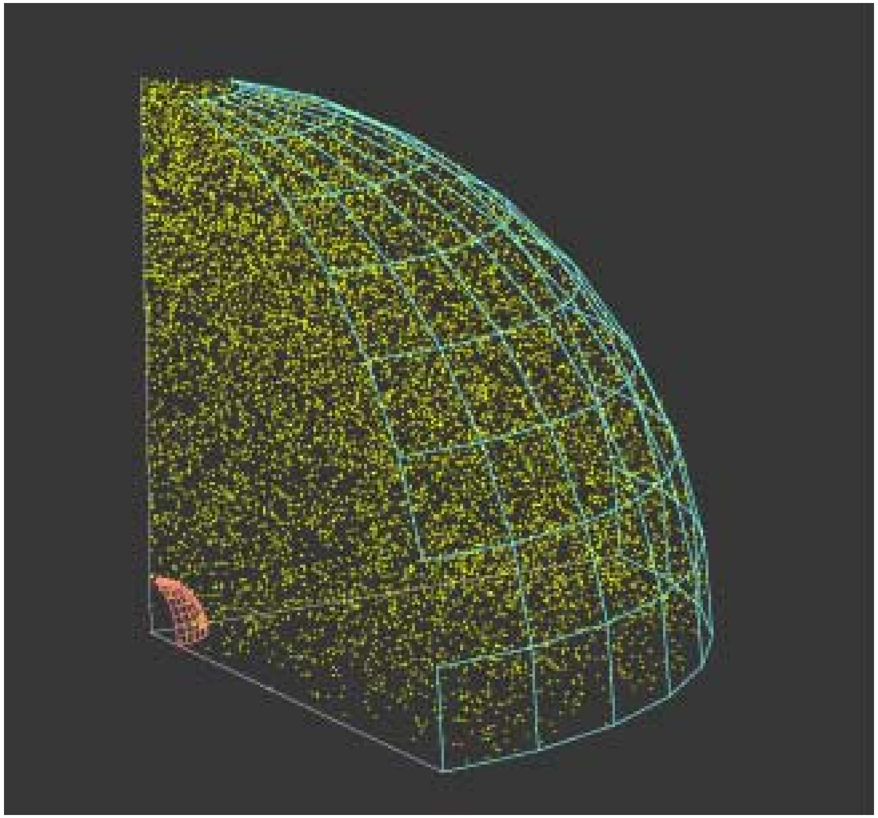
The LIGO Mission: Develop the Field

- LIGO Observatory infrastructure in place
  - » Designed to support the evolving field of gravitational wave science
- Initial LIGO in operation
  - » Sensitivity improving steadily, approaching goal
  - » Observations yielding first astrophysical results
- One year of integrated observation time planned
- Detections plausible with initial LIGO
- With or without detections, astrophysical community will demand more sensitive detectors:

Advanced LIGO

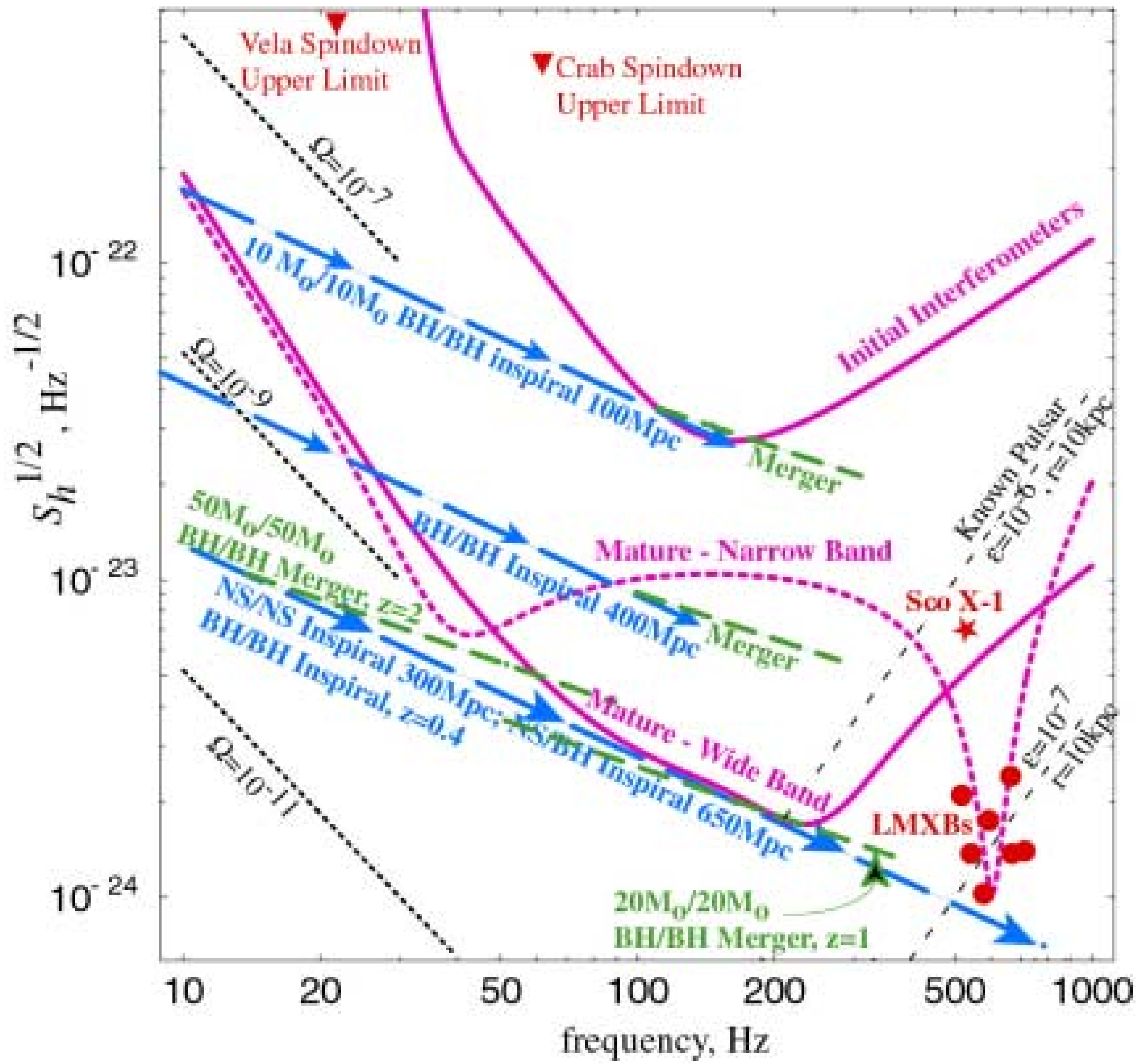
Advanced LIGO

- Next detector
  - » Must be of significance for astrophysics
  - » Should be at the limits of reasonable extrapolations of detector physics and technologies
  - » Should lead to a realizable, practical, reliable instrument
  - » Should come into existence neither too early nor too late
- Advanced LIGO:
  ~2.5 hours = 1 year of Initial LIGO
  - » Volume of sources grows with cube of sensitivity
  - » >10x in sensitivity; ~ 3000 in rate



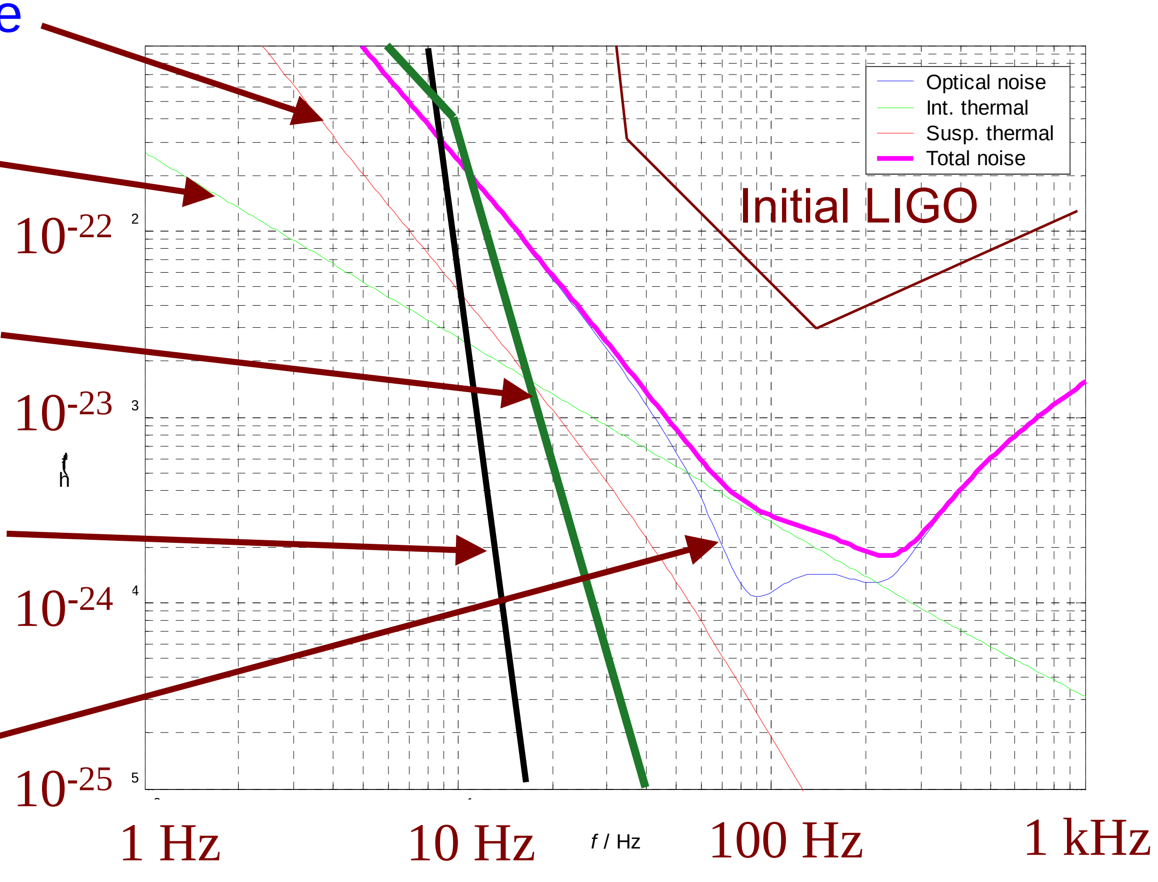
Astrophysical Reach
(Kip Thorne)

- Neutron Star & Black Hole Binaries
  - » inspiral
  - » merger
- Spinning NS's
  - » LMXBs
  - » known pulsars
  - » previously unknown
- NS Birth (SN, AIC)
  - » tumbling
  - » convection
- Stochastic background
  - » big bang
  - » early universe



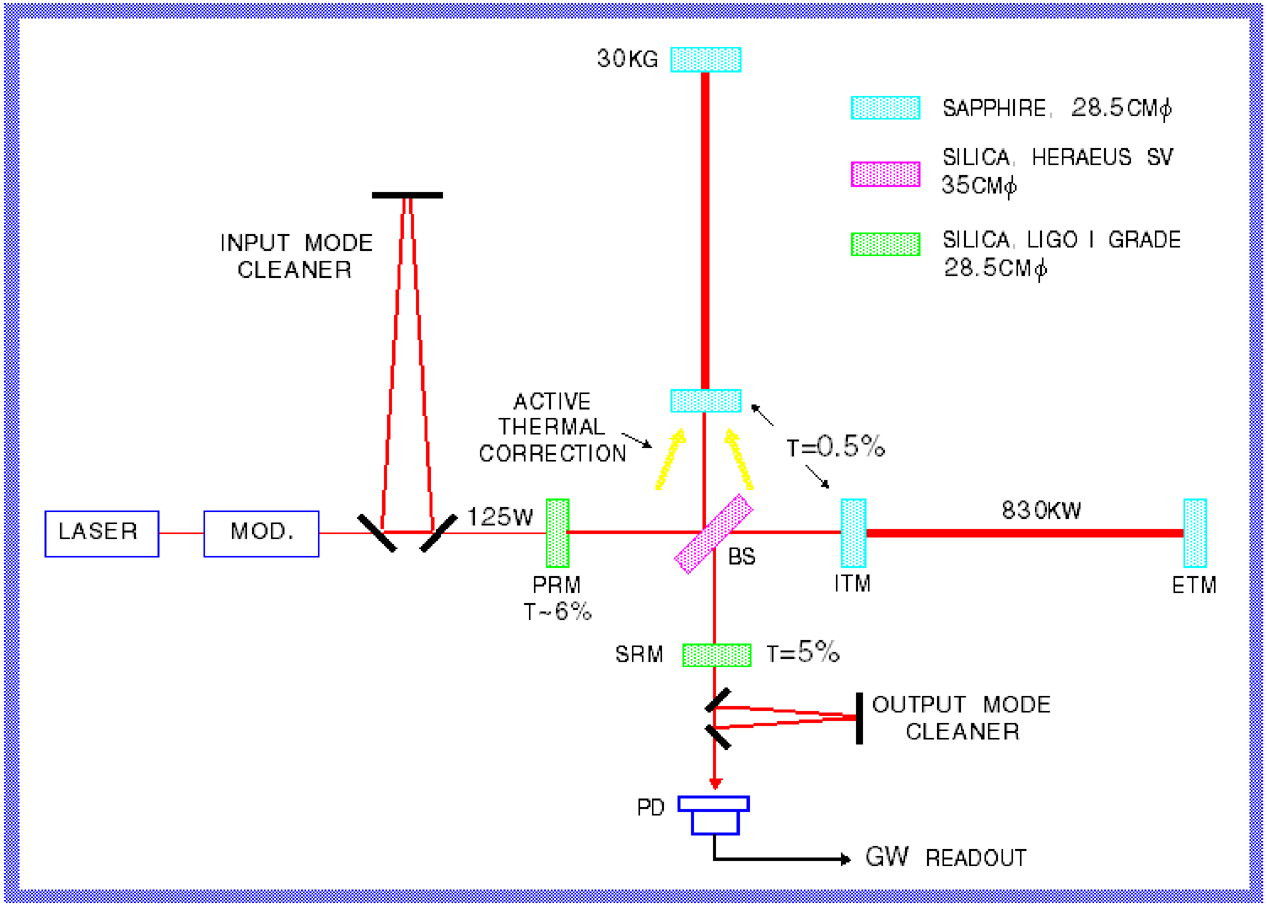
Anatomy of the Projected Adv LIGO Detector Performance

- Suspension thermal noise
- Internal thermal noise
- Newtonian background, estimate for LIGO sites
- Seismic 'cutoff' at 10 Hz
- Unified quantum noise dominates at most frequencies for full power, broadband tuning

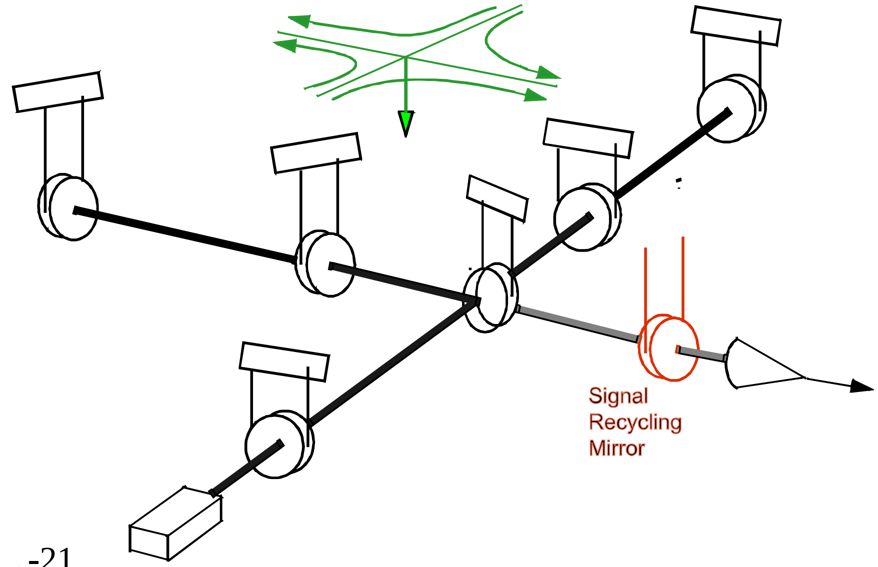


Limits to Sensitivity: Sensing the Test Mass Position

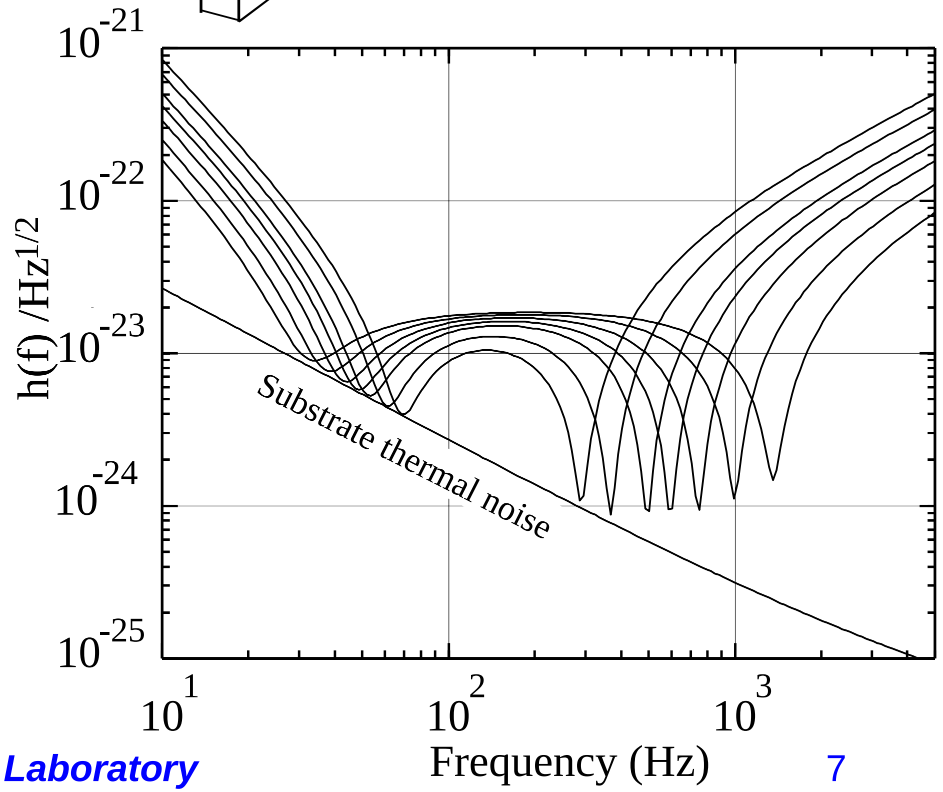
- One limit is the shot noise – counting statistics of photons
  - » Improves with $\sqrt{P_{laser}}$
- Second limit is the radiation pressure noise – momentum transfer of photons to test masses
  - » Becomes WORSE with $\sqrt{P_{laser}}$, frequency dependence
- The two are coupled in a signal-recycled interferometer



Tunability of the Instrument

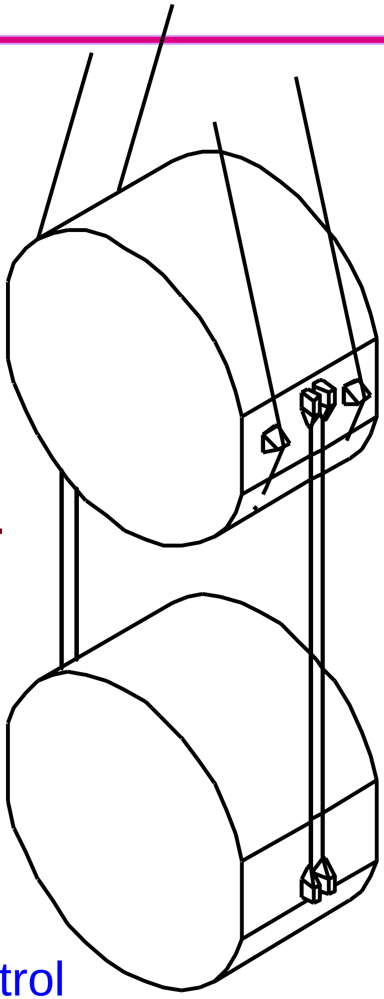


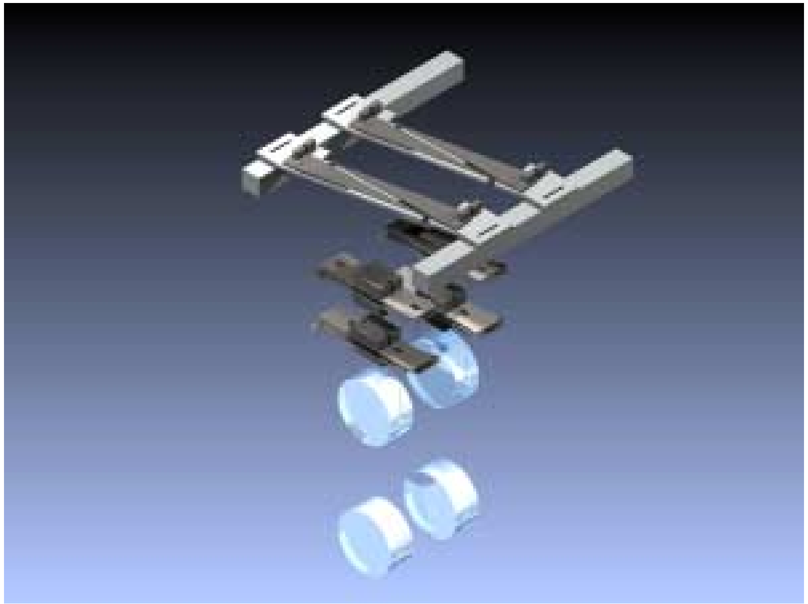
- Signal recycling can focus the sensitivity where it is needed
  - » Sub-wavelength adjustments of resonance in signal recycling cavity
- Allows optimization against technical constraints, or for astrophysical signatures
- E.g., Tracking of a sweeping inspiral signal ‘chirp’ possible



Limits to Sensitivity: Thermal Noise

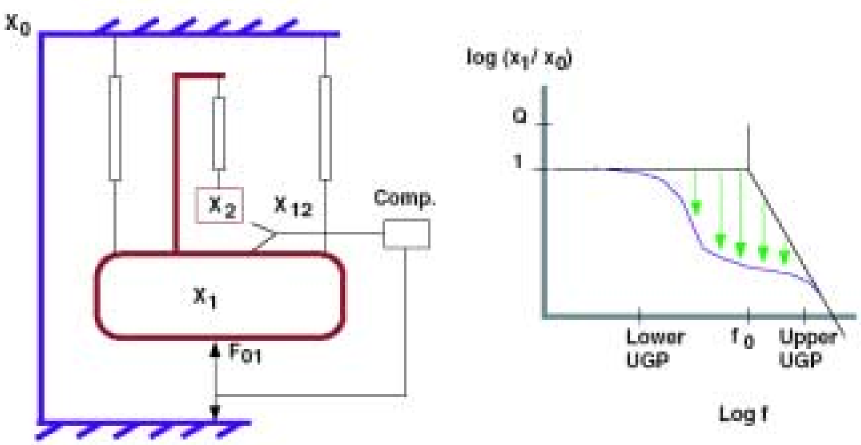
- Thermal motion is proportional to $L^{1/2}_{\text{mechanical}}$
- Low-loss materials and techniques are the basic tools
- Test masses: crystalline Sapphire, 40 kg, 32 cm dia.
  - » $Q \geq 6\text{x}10^7$
  - » good optical properties
- Suspensions: fused silica
- Joined to form monolithic final stages
- Multiple-pendulums for control flexibility, seismic attenuation



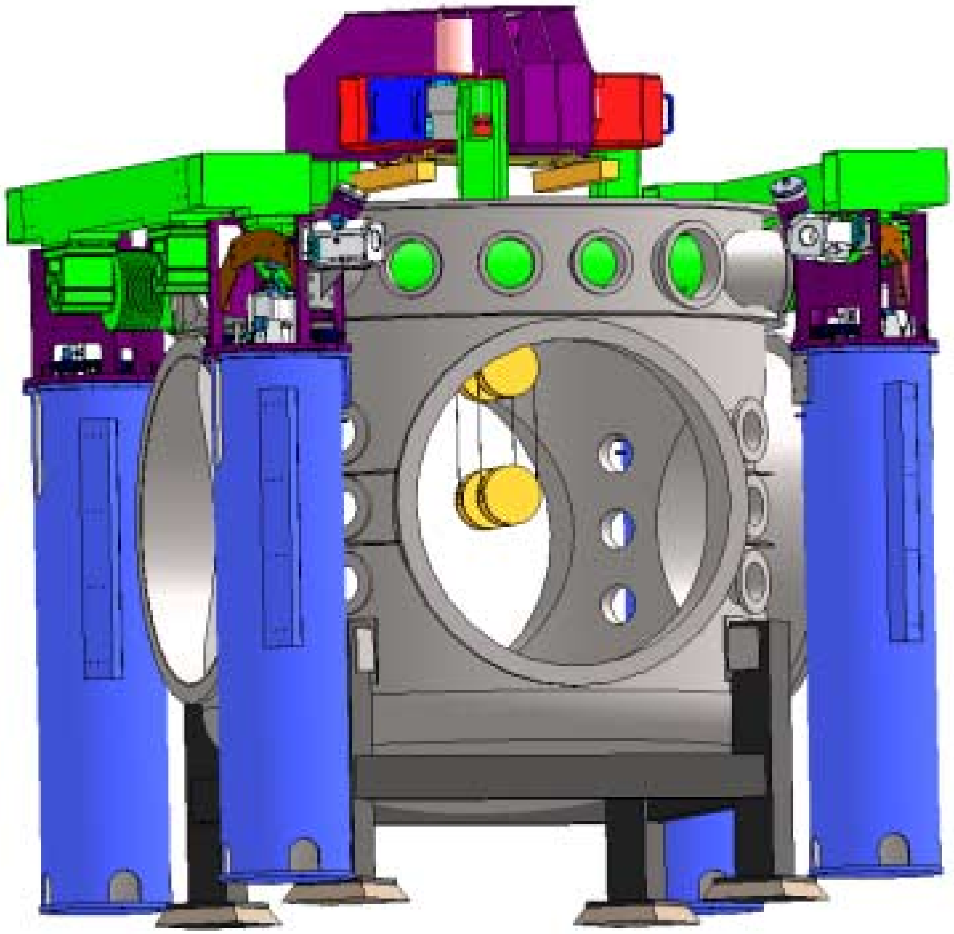


- Optical coating is also a source of *mechanical* loss
- Development underway of suitable coating with optical and mechanical properties

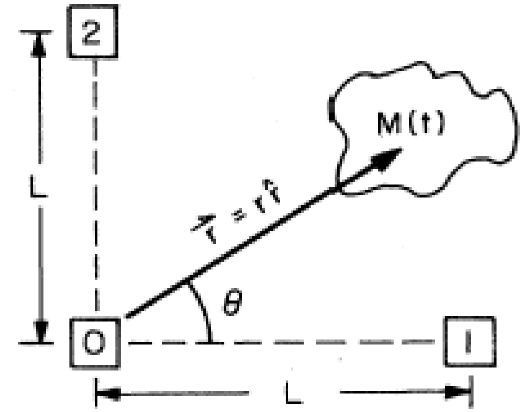
Limits to Sensitivity: External Forces



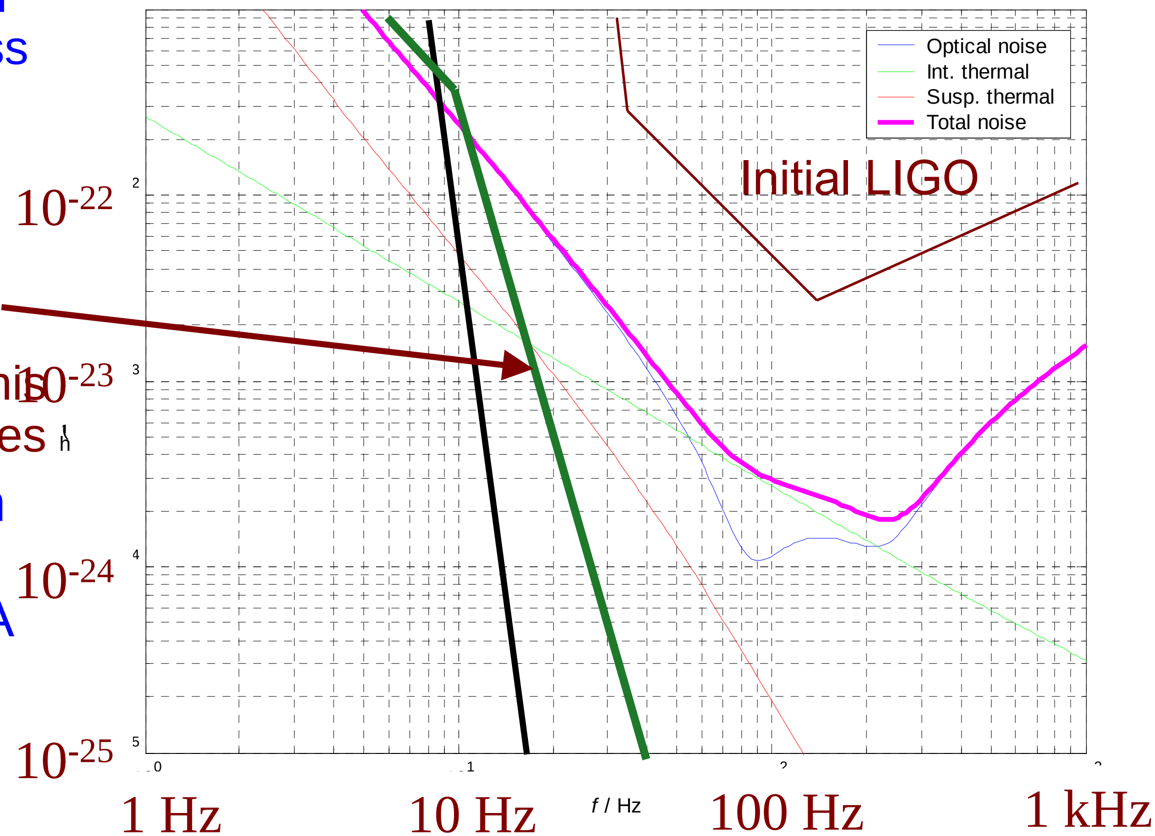
- Coupling of seismic noise through isolation system suppressed via active servocontrols followed by passive 'pendulum' isolation
  - » Two 6-deg-of-freedom platforms stabilized from 0.03 to 30 Hz
  - » Net suppression of motion in gravitational-wave band is 13 orders of magnitude or more
  - » Suppression of motion below the band also critical to hold sensing system in linear domain, avoid up-conversion



Low-frequency Limit



- Newtonian background is the limit for ground-based detectors: ~10 Hz
  - » Time-varying distribution of mass in vicinity of test mass changes net direction of gravitational 'pull'
  - » Seismic compression, rarefaction of earth dominates
  - » Advanced LIGO reaches this limit for our observatory sites
- For GW astrophysics much below 10 Hz, space-based instruments needed → LISA



The Advanced LIGO Community

- Scientific impetus, expertise, and development throughout the LIGO Scientific Collaboration (LSC)
  - » Remarkable synergy, critical mass
    (400+ persons, 100+ graduate students, 40+ institutions)
  - » International support and significant material participation
  - » Especially strong coupling with German-UK GEO group, capital partnership
- Advanced LIGO design, R&D, and fabrication spread among participants
  - » LIGO Laboratory leads, coordinates, takes responsibility for Observatories
- Continuing strong support from the NSF at all levels of effort – theory, R&D, operation of the Laboratory
- International network growing: VIRGO (Italy-France), GEO-600 (Germany-UK), TAMA (Japan), ACIGA (Australia)

Timeline

- Initial LIGO Observation 2002 – 2006
  - » 1+ year observation within LIGO Observatory
  - » Significant networked observation with GEO, LIGO, TAMA
- Structured R&D program to develop technologies 1998 - 2005
  - » Conceptual design developed by LSC in 1998
  - » Cooperative Agreement carries R&D to Final Design, 2005
- Proposal submitted in Feb 2003 for fabrication, installation
- Long-lead purchases planned for 2004
  - » Sapphire Test Mass material, seismic isolation fabrication
  - » Prepare a 'stock' of equipment for minimum downtime, rapid installation
- Start installation in 2007
  - » Baseline is a staged installation, Livingston and then Hanford Observatories
- Start coincident observations in 2009

LIGO

- Initial LIGO is in operation
  - Publications in preparation from first Science Run
  - Observing at this moment in the second Science run
  - Discoveries plausible
- Advanced LIGO is on the horizon
  - Groundbreaking R&D well underway
  - Detailed design and prototyping as well
  - Challenging astrophysics promised

Gravitational Waves:
A new tool in understanding the Universe,
complementary to other observational methods,
is becoming a reality