LIGO

Advanced LIGO
The Next Generation

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Gravitational Waves and Experimental Gravity

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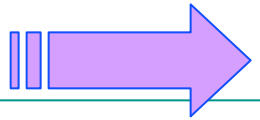
The LIGO Mission

To develop the field

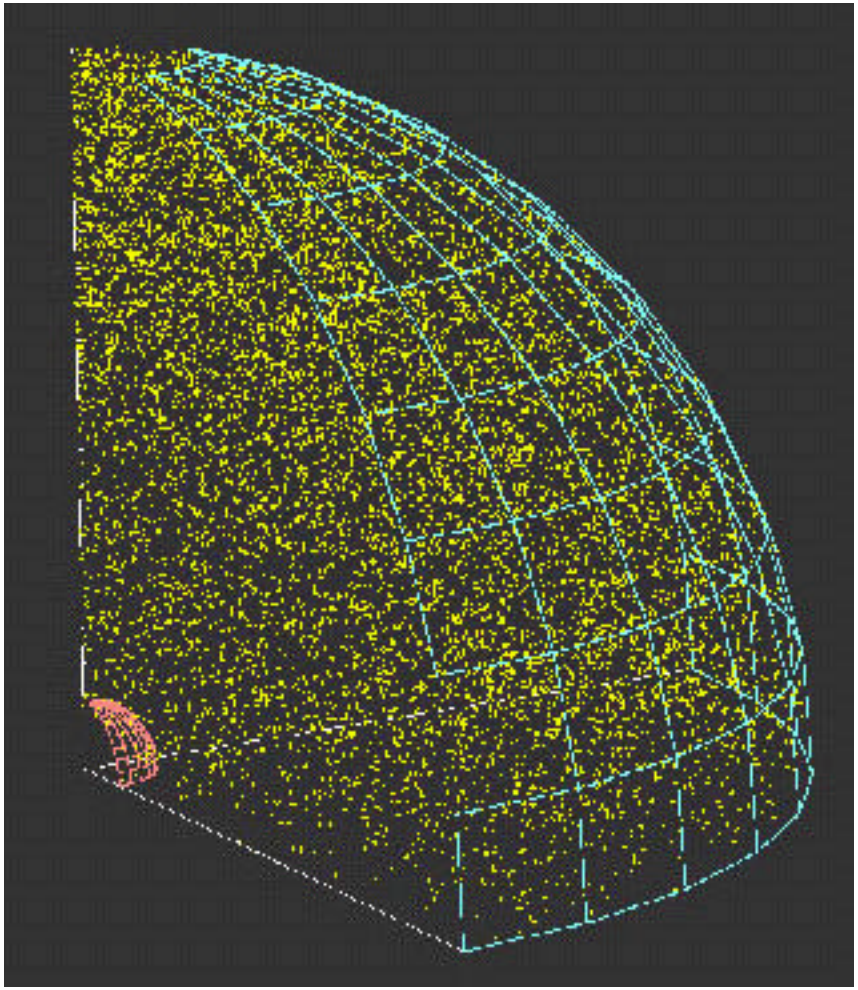
- LIGO infrastructure is in place
  - » Designed to support the evolving field of gravitational wave science
- Initial LIGO is in operation
  - » Sensitivity is improving steadily, approaching goal
  - » Observations are yielding first astrophysical results
- One year of integrated observation time is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



Advanced LIGO

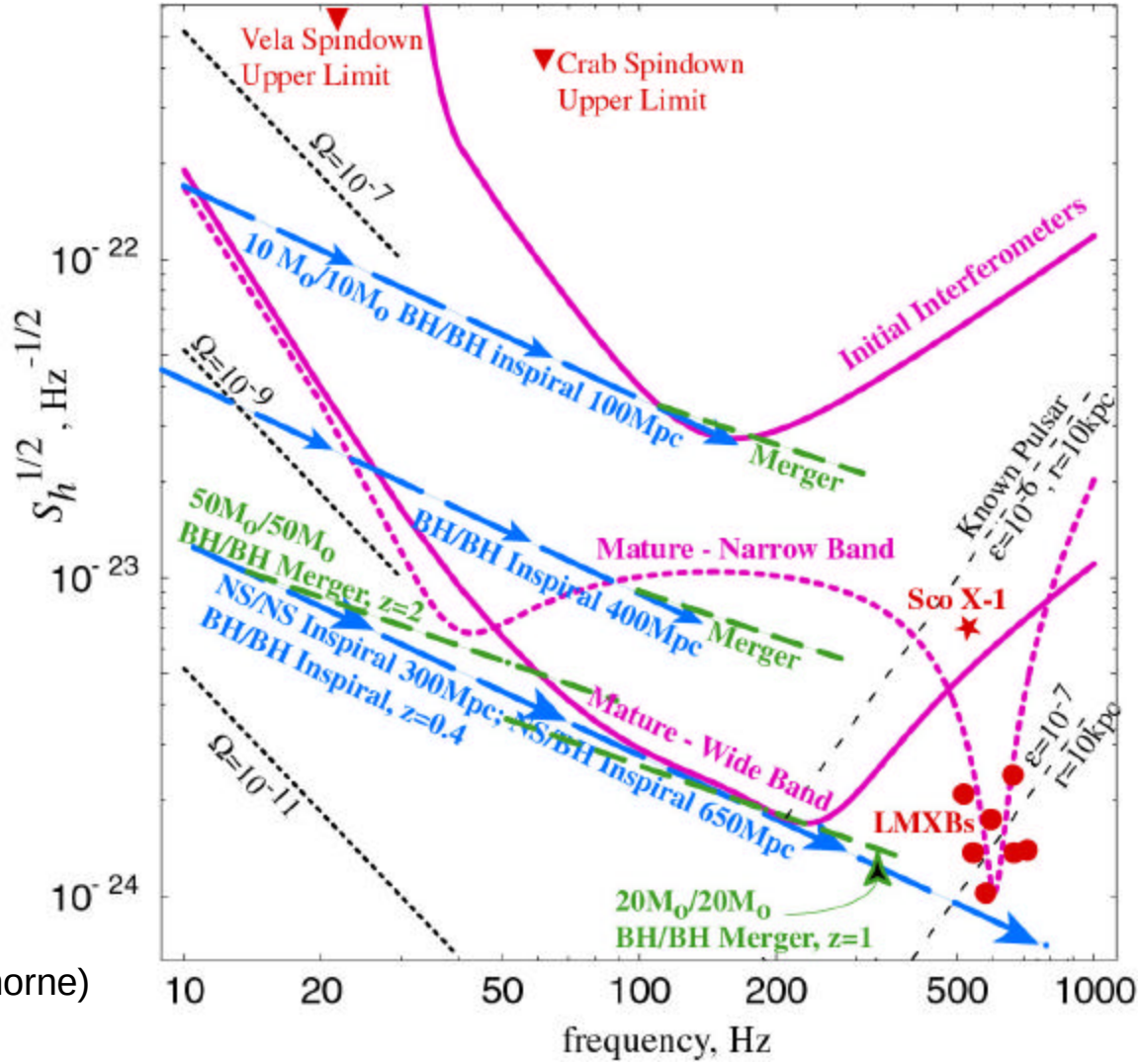
Advanced LIGO Reach

- Next Detector
  - » Must be relevant for astrophysics
  - » Should approach limits of reasonable extrapolations for detector physics and technologies
  - » Should lead to realizable, practical, reliable instrument
  - » Should exist neither too early nor too late
- Advanced LIGO
  - » >10 X sensitivity, ~ 3000 in rate (population density dependent)
  - » **~2.5 hours = 1 year of initial LIGO**



Astrophysical Reach

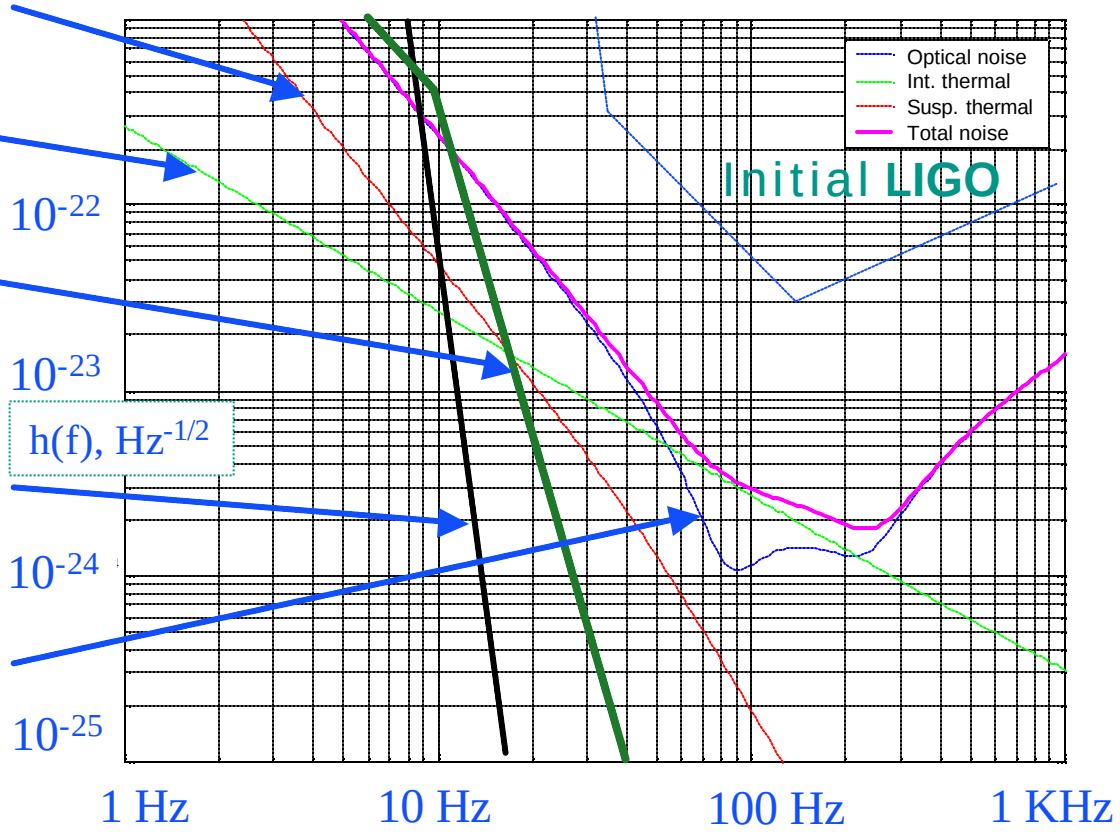
- Neutron Star and Black Hole Binaries
- Spinning Neutron Stars
- NS Birth (Super Novae, AIC)
- Stochastic Background



(Chart by Kip Thorne)

Projected Advanced LIGO 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**



Advanced LIGO Basic Configuration

Current LIGO

Power recycled

Fabry-Perot to increase storage time

Advanced LIGO

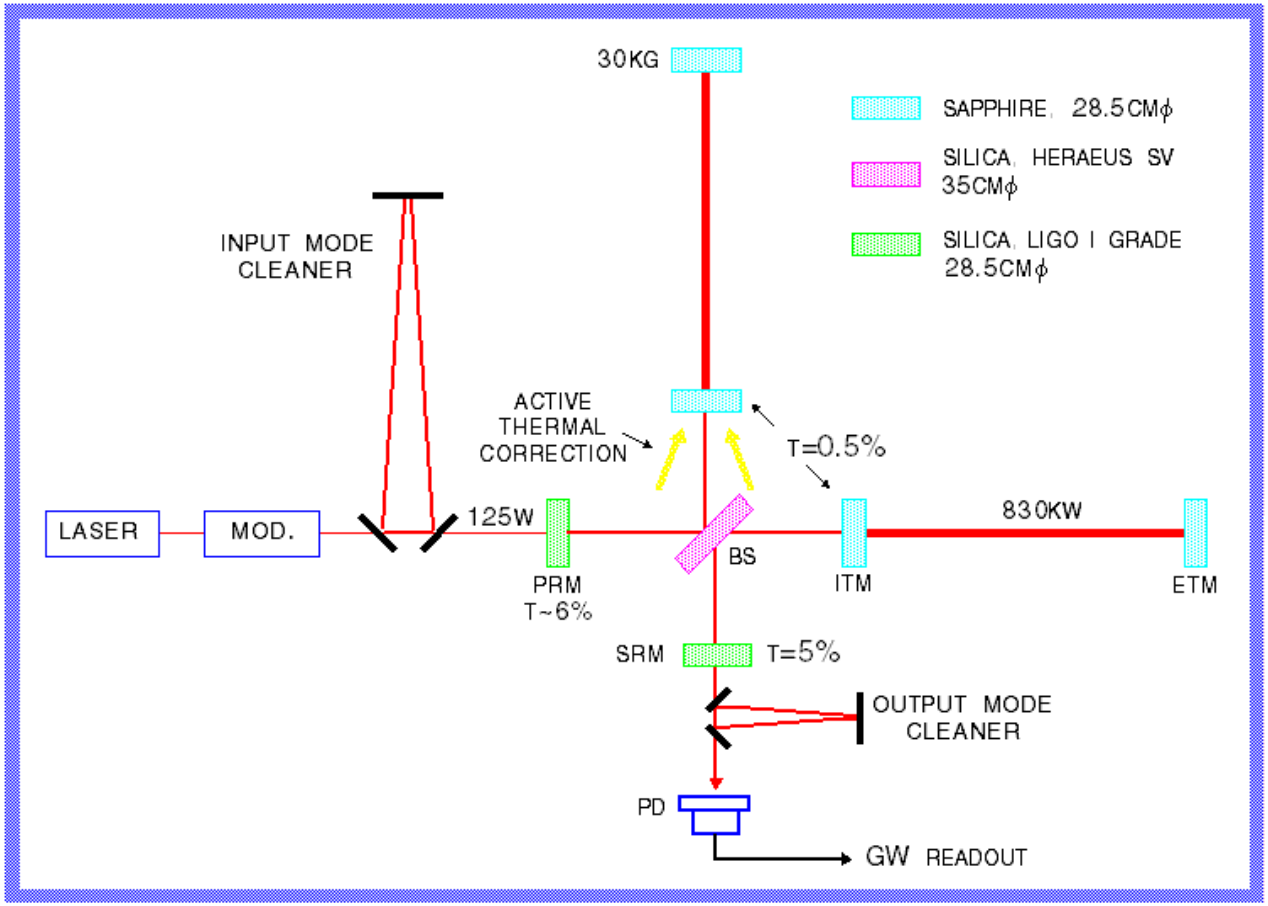
Increased Power

Heavier Test Masses

Quad Suspensions

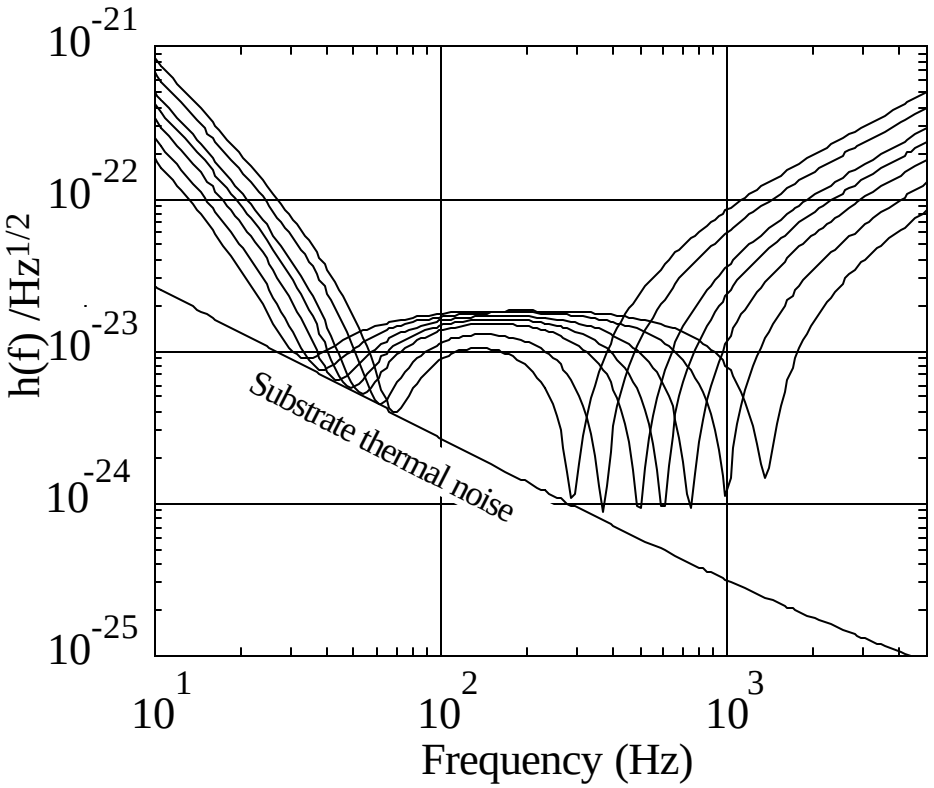
Improved Isolation

Signal Recycling



Signal Recycling

- Can focus sensitivity where needed
  - » Sub-wavelength adjustments of resonance in signal recycling cavity
- Allows optimization
  - » Technical constraints
  - » Astrophysical signatures

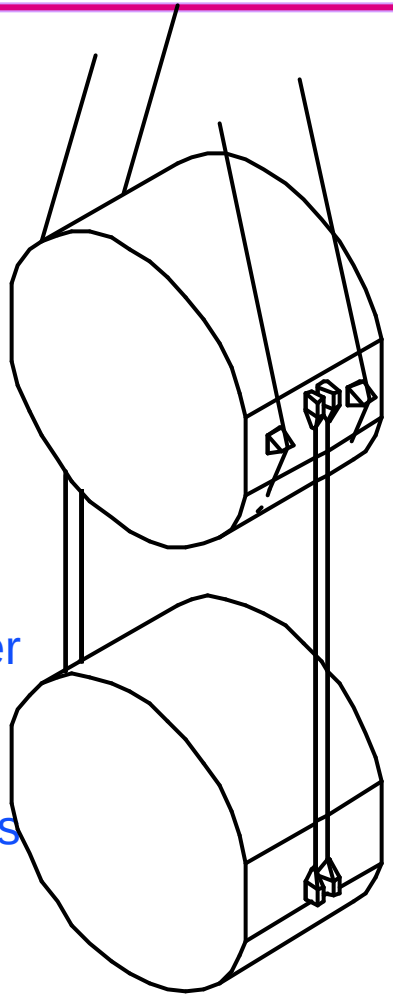


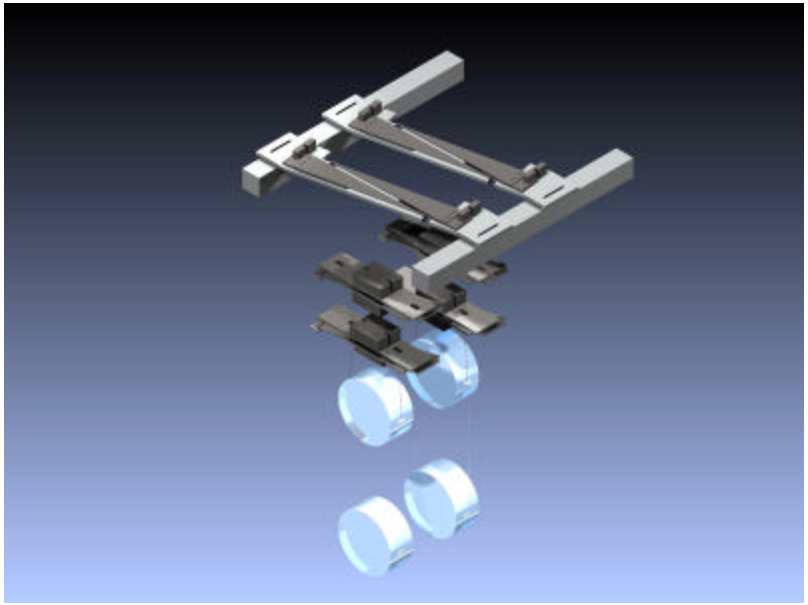
Limits to Sensitivity--Thermal Noise

- Thermal motion is proportional to $\sqrt{L_{mechanical}}$

Low-loss materials and techniques needed

  - » Test masses: crystalline sapphire, 40 kg, 32 cm diameter
  - » Suspensions: fused silica
  - » Monolithic final stages
  - » Multiple pendulums for control and seismic attenuation

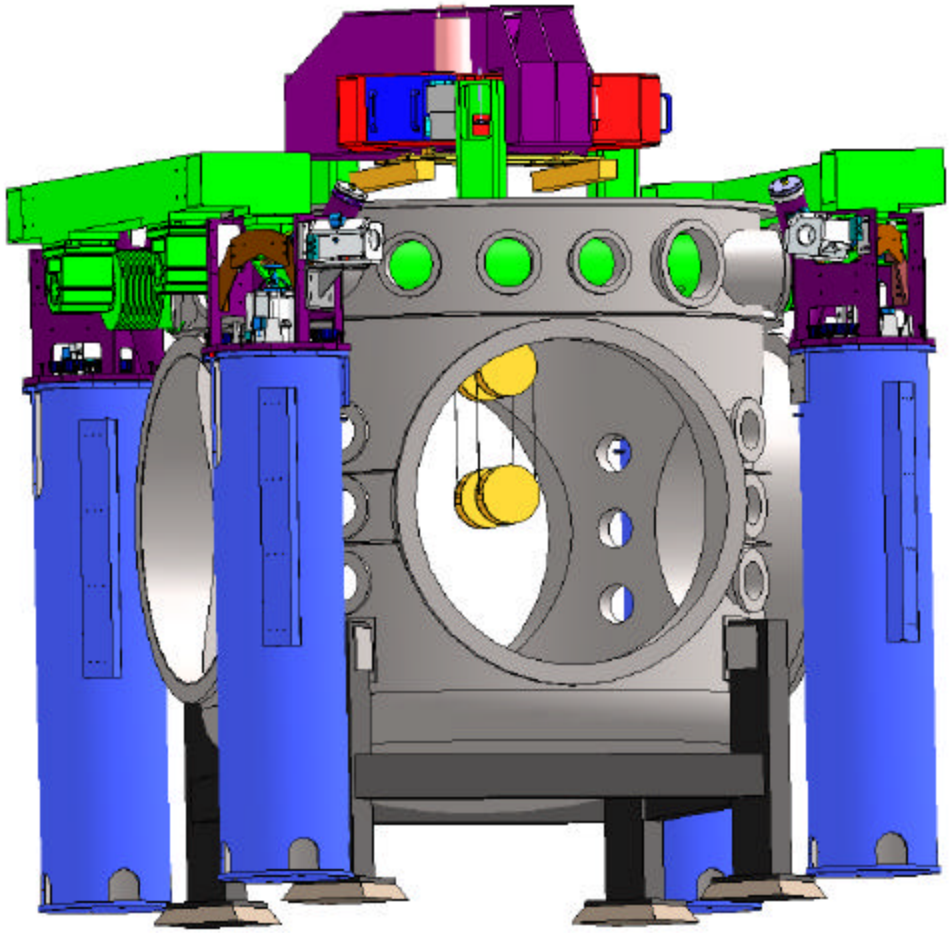




Optical coating also source of mechanical loss, development underway

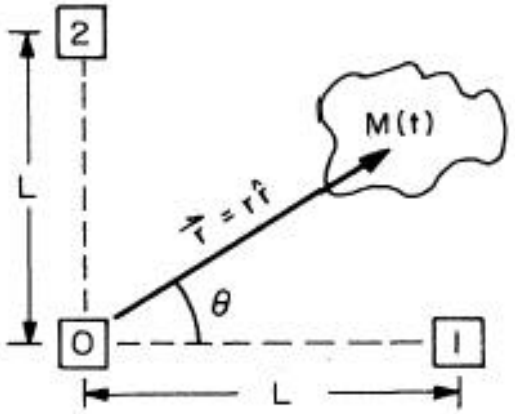
Limits to Sensitivity--External Forces

- **Coupling of seismic noise through isolation system suppressed using active servo controls, passive "pendulum" isolation**
  - » Two 6-degree-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 (control) in linear domain, avoid up-conversion



Low-Frequency Limit

- Newtonian background is limit for ground-based detectors (~10 Hz)
  - » Time-varying distribution of mass in vicinity of test mass
  - » Seismic compression, rarefaction or earth dominates
  - » Advanced LIGO targeted to reach this limit for our sites
- For GW astrophysics below 10 Hz, space-based instruments needed ® **LISA**



Advanced LIGO Proposal

Submitted February 2003 (NSF PHY-0328418)

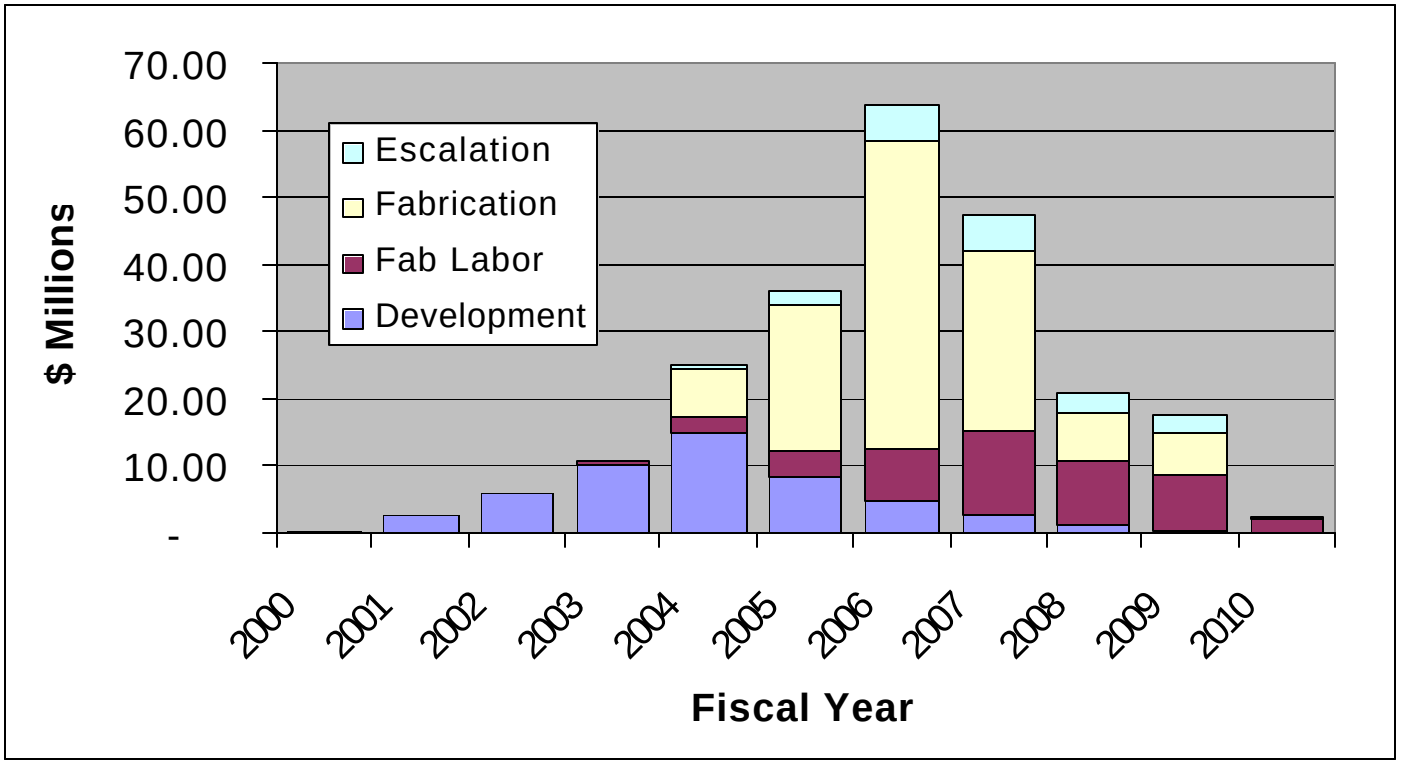
- **Prepared a "bottoms up" cost estimate (approximately 5000 detailed line items)**
- **Total Cost Estimate: $240,000,000**
- **Proposed LIGO Cost $122,000,000 (fabrication plus some salaries for installation, specialty engineering, added outreach)**
- **$25.5 million provided by collaborators**
  - » **GEO (Hanover, Birmingham, Rutherford, Glasgow)**
  - » **ACIGA**

Advanced LIGO 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
  - » Current 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 followed by Hanford Observatories
- Start coincident observations in 2009

Proposed Funding Profile

- Long lead procurements begin in 2004
- Procurements peak in 2006
- Installation begins in 2007



The Advanced LIGO Community

- Scientific impetus, expertise, and development provided by LIGO scientific collaboration (LSC)
  - » Synergy, critical mass (400+ individuals, 100+ graduate students, 40+ institutions)
  - » International support and significant material participation
  - » Especially strong collaboration with German-UK GEO group, capital partnership
- Advanced LIGO design, R&D, and fabrication shared with participants
  - » LIGO laboratory leads, coordinates, is responsible for observatories
- Continuing support from NSF at all levels
- International network growing: VIRGO, GEO-600, TAMA, ACIGA

Advanced LIGO Status

- **Initial LIGO is in operation**
  - » We are preparing publications from first science run
  - » Second science run underway
  - » Third science run at target sensitivity scheduled to begin next year
  - » Discovery plausible
- **Advanced LIGO on the horizon**
  - » Advanced R&D and baseline design proceeding
  - » Strong international partnership—GEO, ACIGA
  - » Plan supports start of installation in 2007

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

Acknowledgements

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