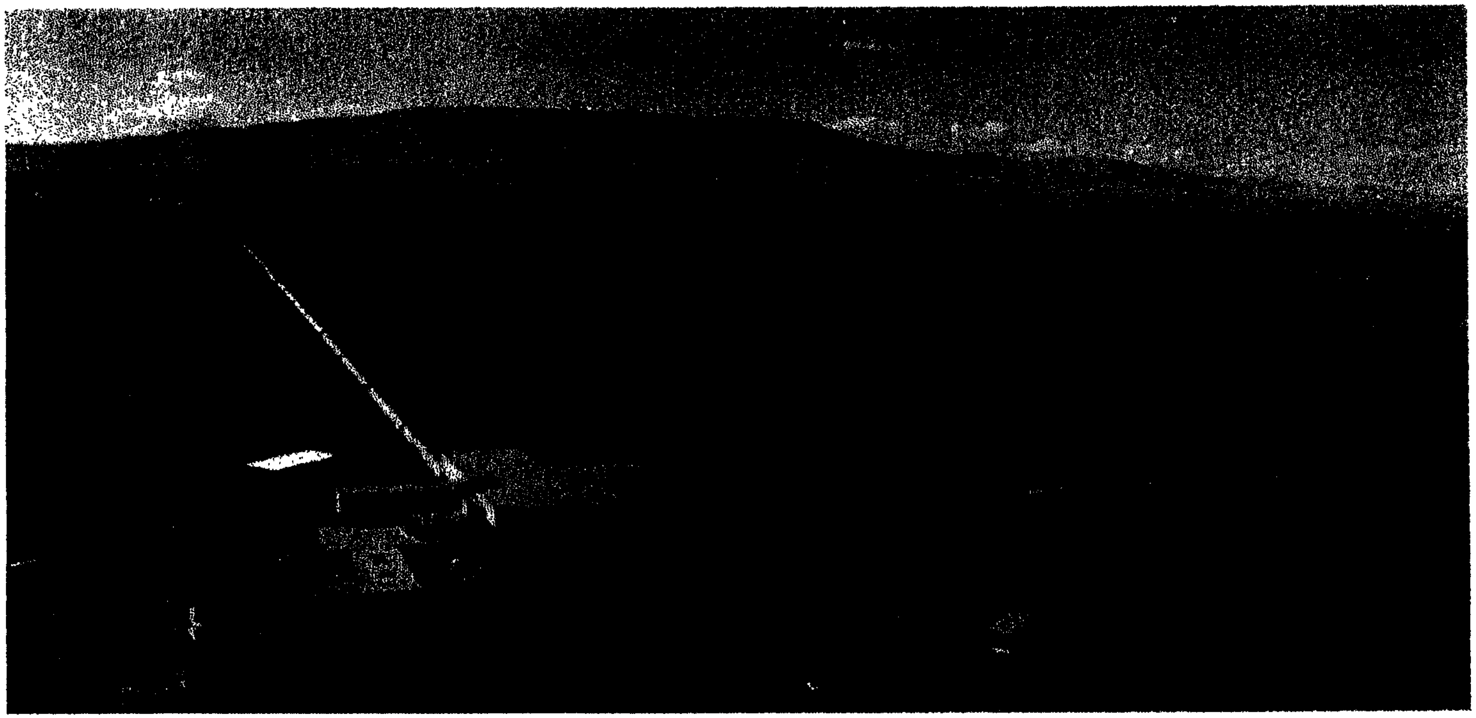
The Laser Interferometer Gravitational-Wave Observatory: Coming of Age in the Northwest

Fred Raab April 14, 1998



LIGO-G980041-00-W

LIGO Hanford Observatory: A National Facility for a New Field of Science

››LIGO is being built and operated by the California Institute of Technology (Caltech) and the Massachusetts Institute of Technology (MIT) with sponsorship by the National Science Foundation (NSF) to establish and pursue the new science of gravitational-wave astronomy.

››LIGO will operate as a national facility for scientific research, known as the LIGO Laboratory, with four key research facilities shown at left.

››An international group of scientists, known as the LIGO Collaboration, will use the LIGO Laboratory facilities to conduct their scientific research.

››LIGO will become part of an international network of gravitational-wave observatories and a foremost testing ground for high-technology development.

LIGO Will Give Us an Entirely New Way to Experience the Universe

- For most of history, astronomy has “looked” at various kinds of “light”, made up of electric and magnetic forces
- We now know that only about 1/10 of the matter in the universe can be seen this way
- LIGO will “hear” the underlying disturbances created by violent motions of matter, using the force of gravity
- LIGO will provide a new “sense” to look for:
  - ››vibrations of black holes
  - ››colliding or collapsing stars
  - ››motions of burnt-out cores of stars
  - ››echoes from the birth of the universe

LIGO Mission

- Open Field of Gravitational-Wave Astronomy

  ››LIGO observatory facilities designed to house detectors of ever-increasing sophistication - analogous to Palomar Observatory

  ››LIGO-1 will probe a region of space-time for GW sources that is 10^9 - 10^{10} times larger than has been accessible in the past

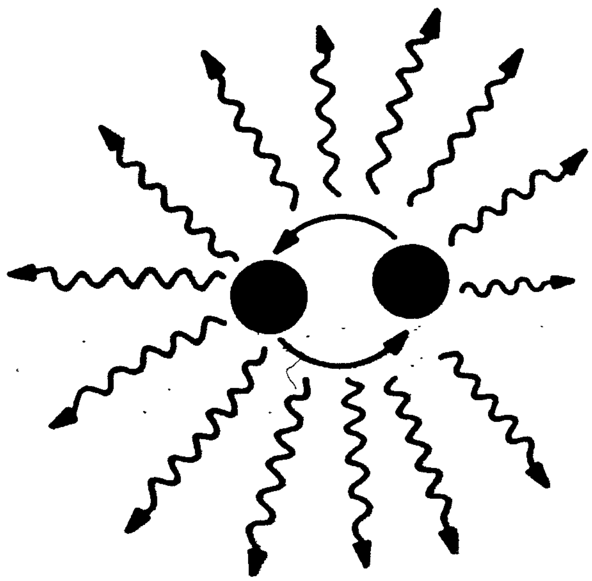
  ››LIGO Science Collaboration is currently developing upgrades to LIGO-1 that should extend the searchable space-time volume by another factor of 10^3

  ››LIGO has joined with VIRGO to establish common data formats & libraries for the international GW-detector community

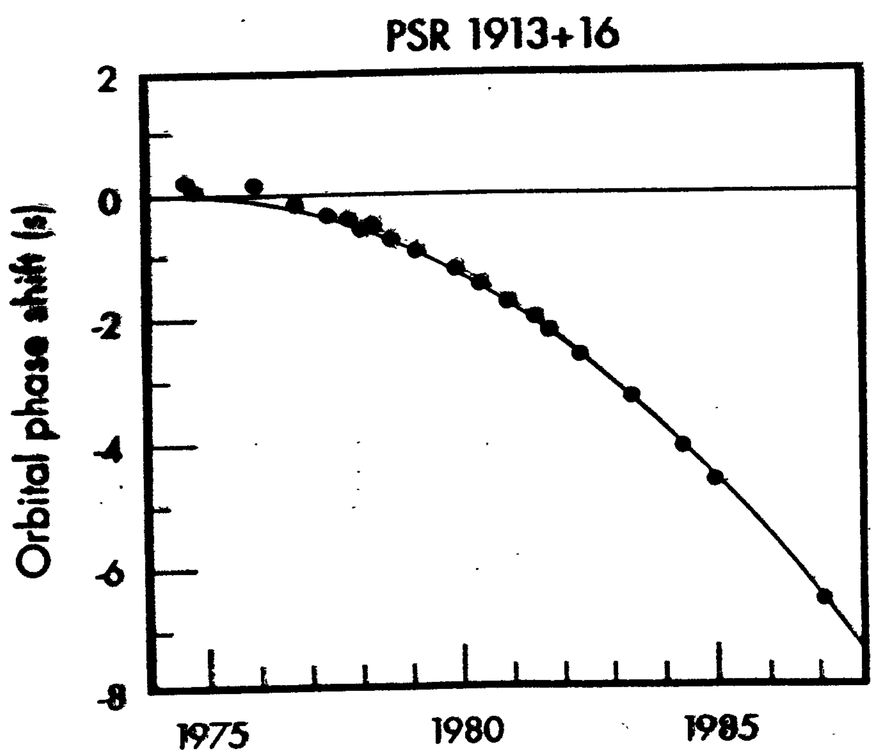
  ››VIRGO, GEO, and TAMA will have interferometers coming on line on a similar time scale to LIGO-1

LIGO

DO GRAVITATIONAL WAVES EXIST?

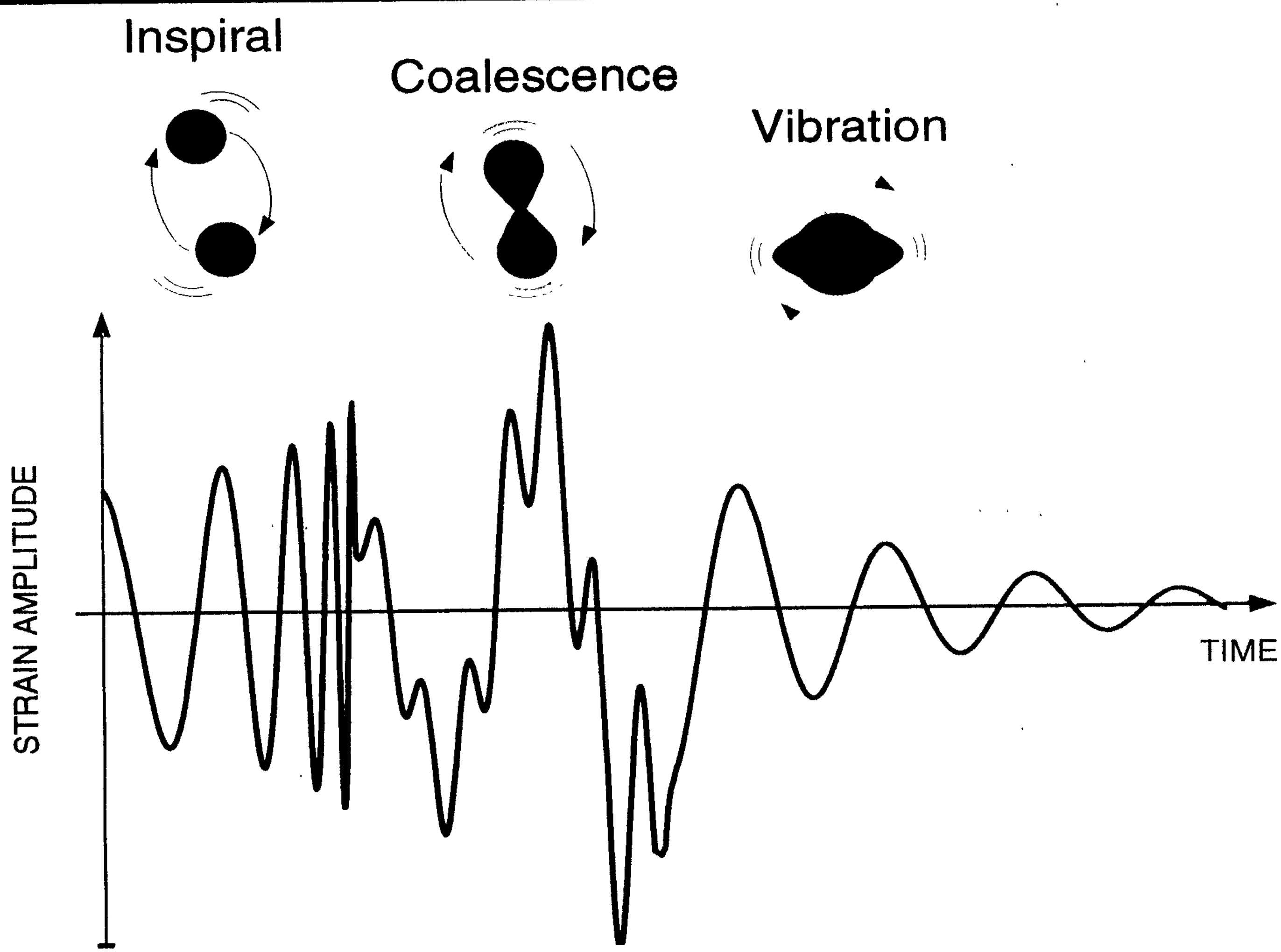


BINARY PULSAR

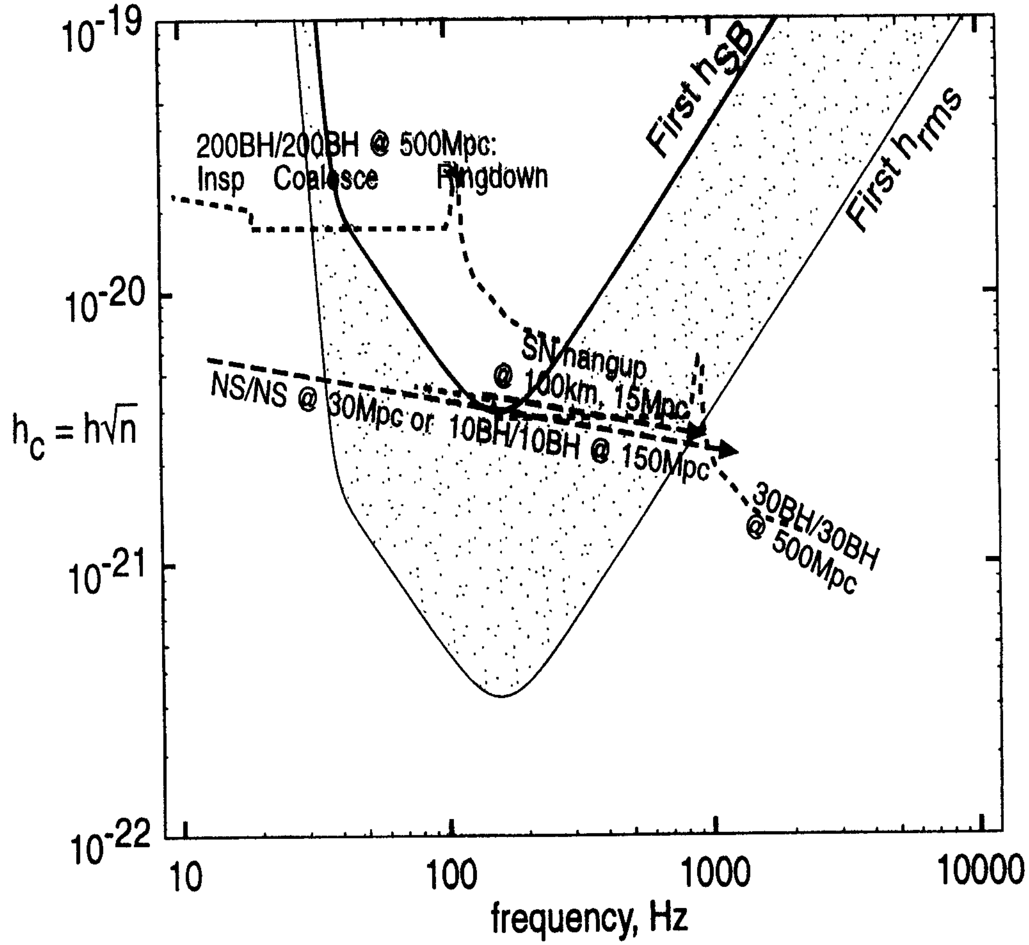


TAYLOR ET. AL: BINARY PULSAR SYSTEM'S ORBITAL DECAY (BY GRAVITATIONAL WAVES) AGREES WITH EINSTEIN PREDICTION

Capturing Black-Hole Waveforms



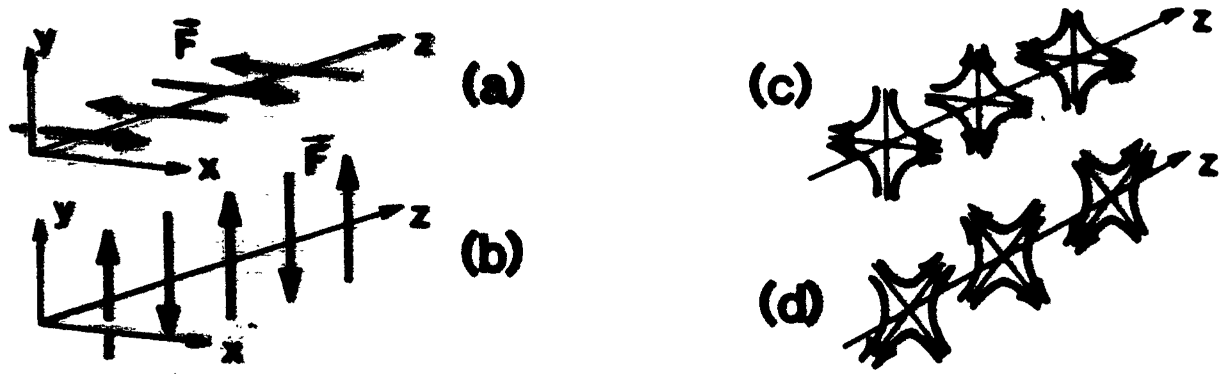
Expected Sensitivity of LIGO-1



LIGO

How Does Matter React to a Gravitational Wave?

Motions of test particles in response to passage of a wave.



Test charge | Test mass

responding to

Electromagnetic Wave | Gravitational Wave

E | h

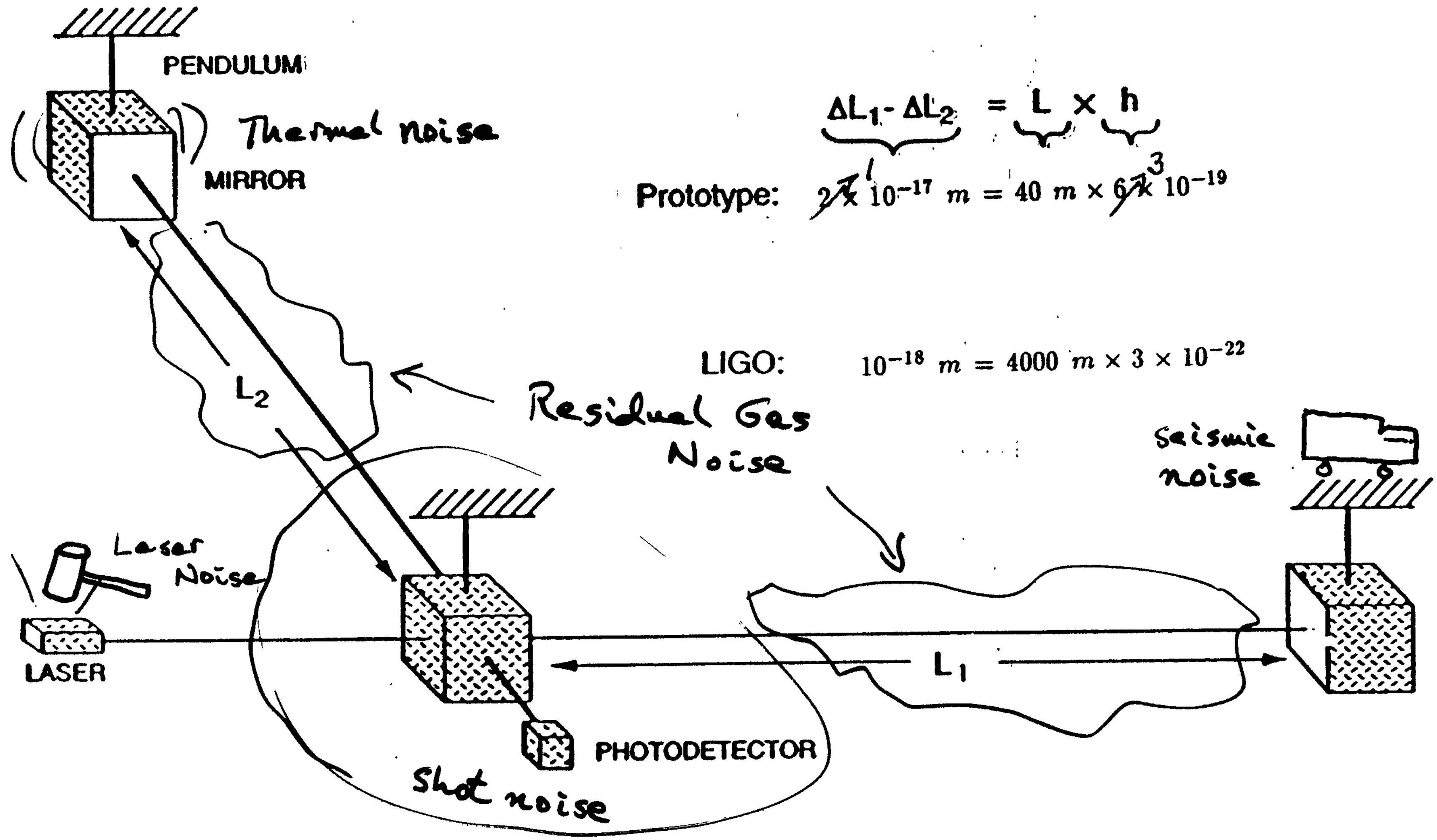
A Michelson Interferometer is a "Natural" Device for Gravitational Wave Detection

$$\boxed{\Delta L / L = h}$$

$\underbrace{\Delta L_1 - \Delta L_2}$ = $\underbrace{L}$ × $\underbrace{h}$

Prototype: ~~2~~ 1 × 10^{-17} m = 40 m × ~~6~~ 3 × 10^{-19}

LIGO: 10^{-18} m = 4000 m × 3 × 10^{-22}



The Experimental Challenge

- expected strains ~ milli-fermis (10^{-18} m) over kilometers
- sensing with wavelength of light ~ 10^{-6} meters

  --->fringe separation ~ 10^{-6} meters

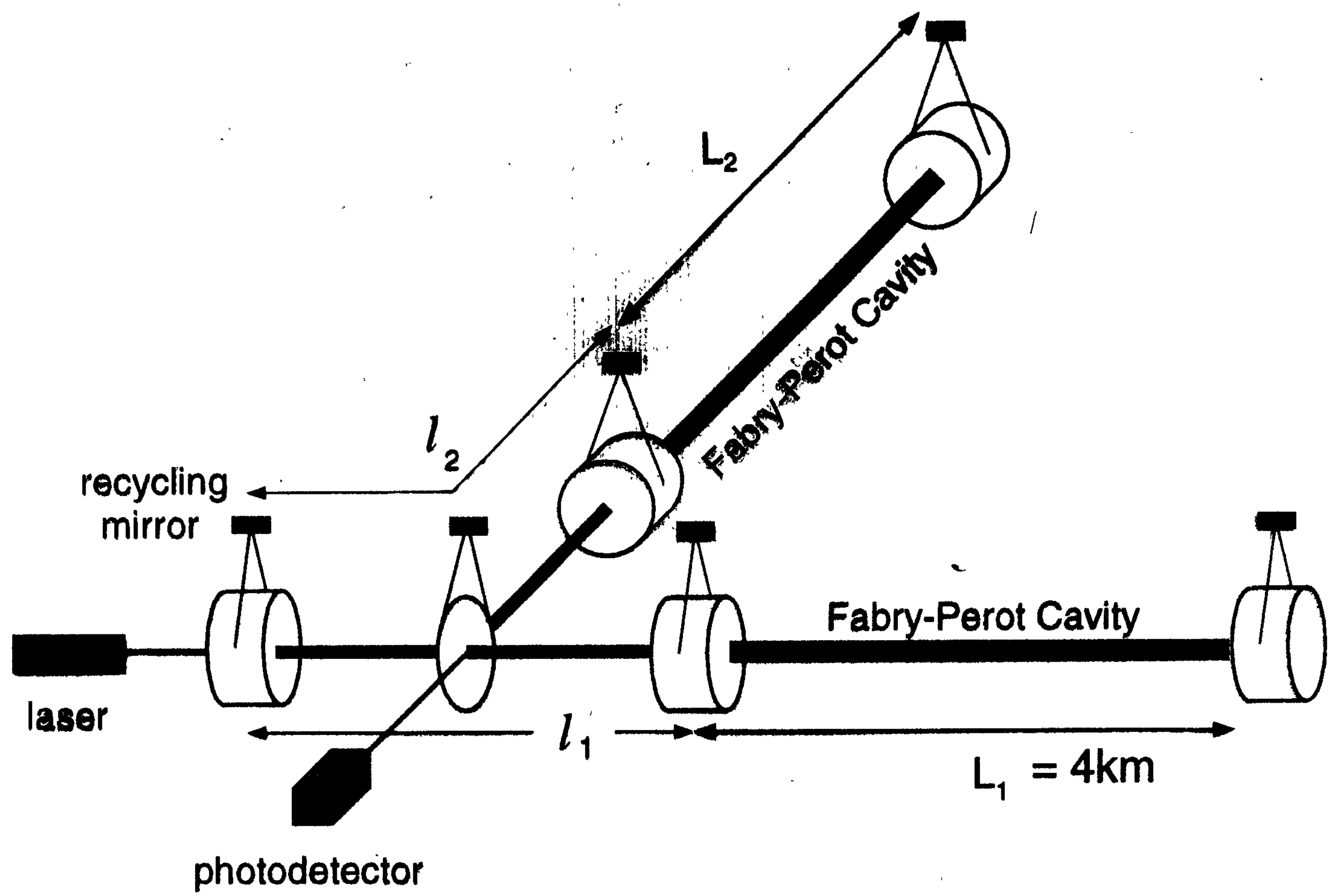
  --->use cavity to narrow fringe by ~ 100

  --->split resultant fringe by ~ 10^{10}

  --->high signal/noise on fringe, so high optical power
- background disturbances must be kept extremely low

  --->broadband seismic isolation must be good enough so that thermal motions of atoms dominate background

LIGO Laser Interferometer



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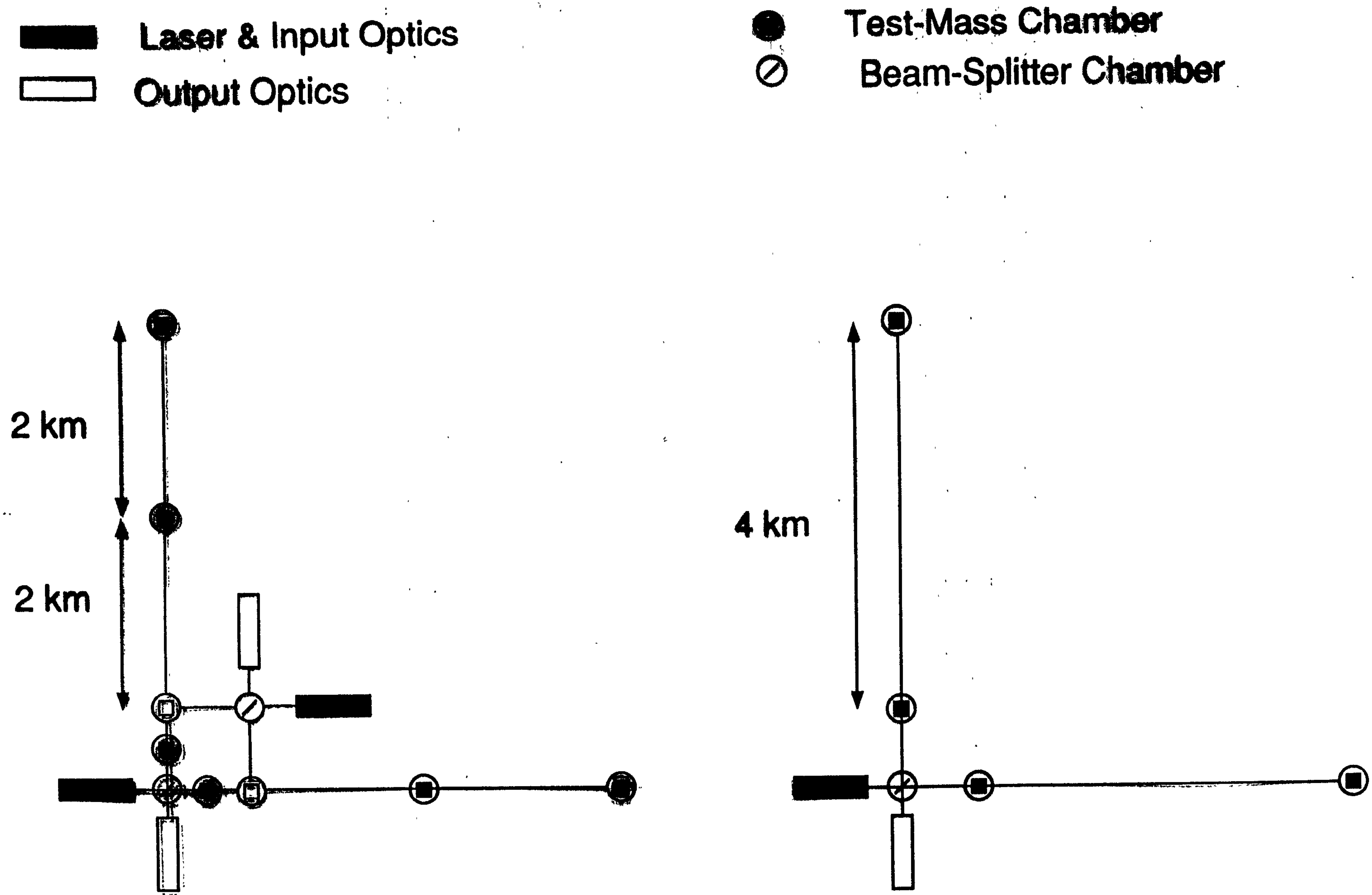


Hanford, WA Facility

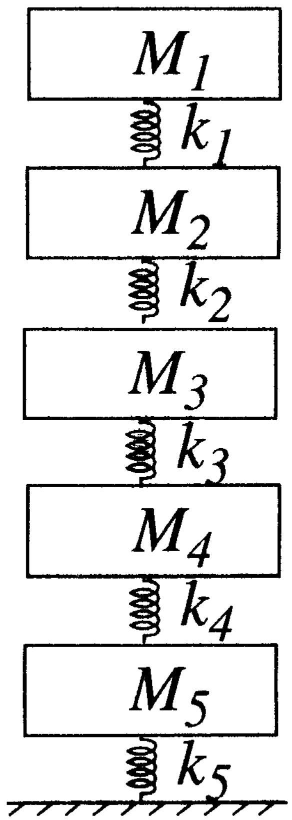
Livingston, LA Facility

Photo of Regehr's
IFO

Photo of 40-m

Lab

Generalized Cascaded Seismic Filter



Negligible Seismic Noise

↑

Smaller Seismic Noise

↑

Large Seismic Noise

Thermal Noise Crucial

↑

Thermal Noise a Possible Concern

↑

Thermal Noise Irrelevant

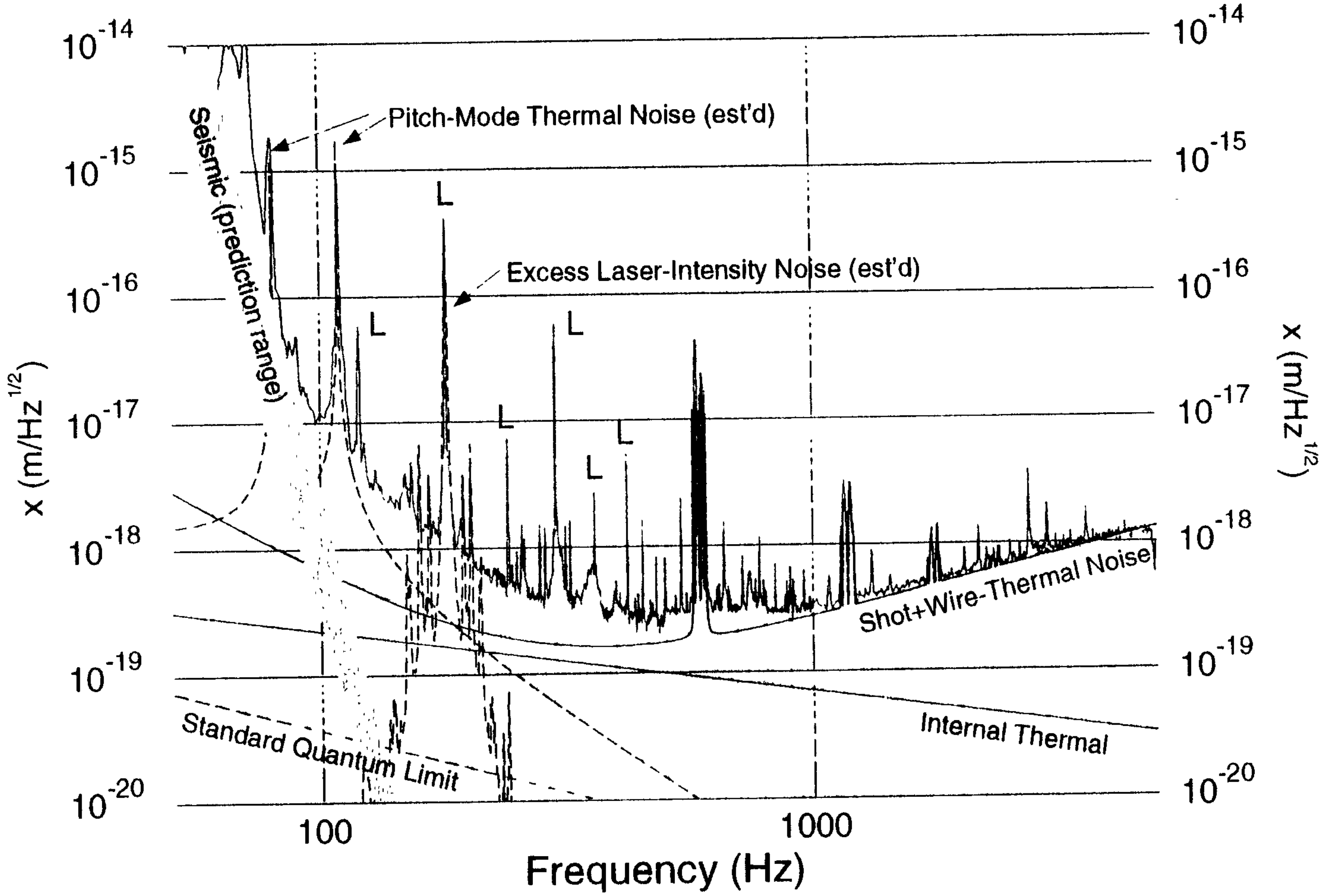
Passive damping will give good all-around performance on the coarser stages, but thermal noise will require high-Q final stage(s). Electronic damping servo allows resonance suppression with virtually no damping at higher frequencies.

Photo of PNI

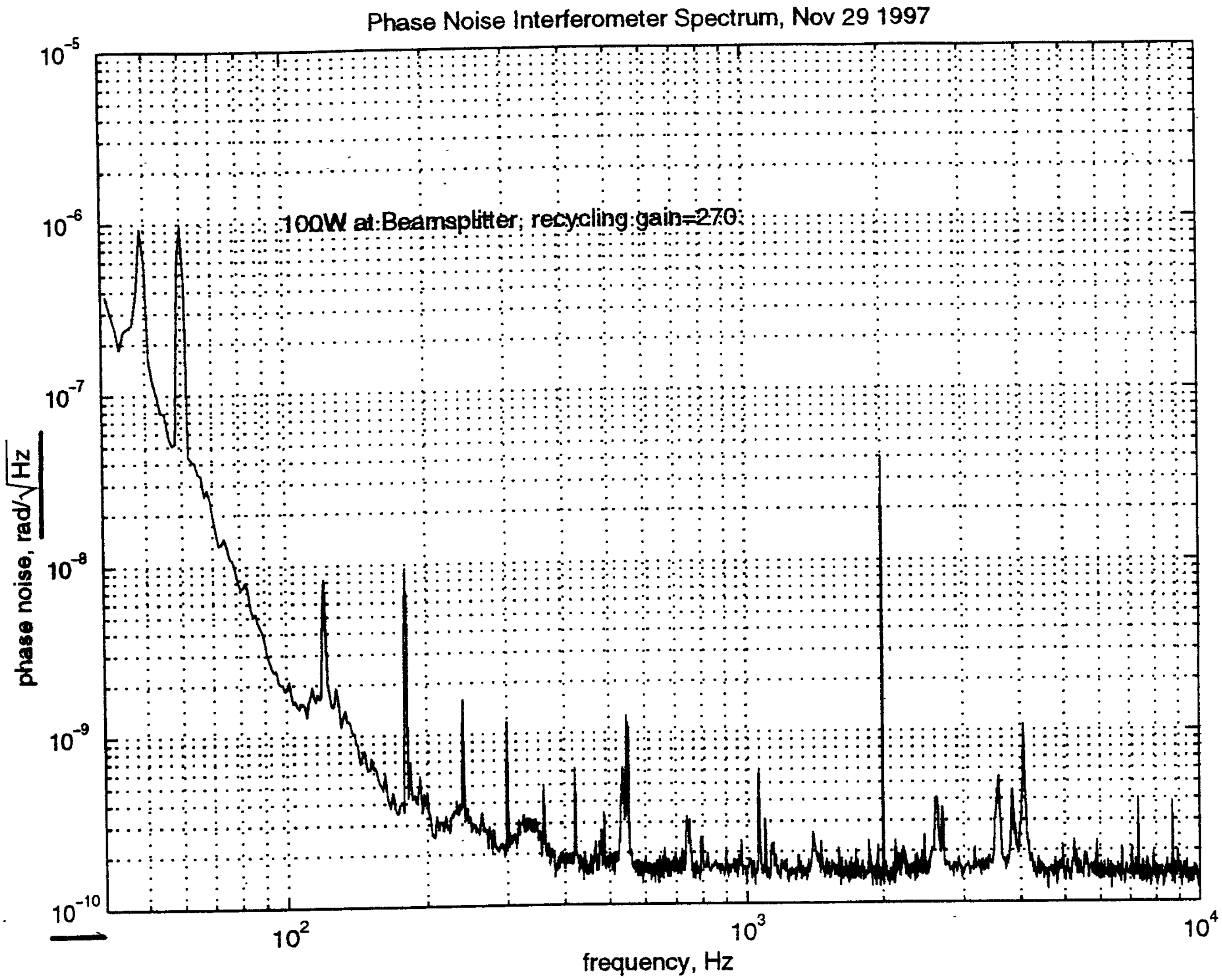
Photo of Suspended

40-m Monolithic Mass

Comparison of Noise Models to Experience in 40-Meter Interferometer



Sensitivity of the Phase Noise Interferometer at MIT - 11/29/97



$h \sim 2.5 \cdot 10^{-23}\ 1/\sqrt{Hz} \longleftrightarrow 1 \cdot 10^{-19}\ m/\sqrt{Hz} \longleftrightarrow 1 \cdot 10^{-10}\ rad/\sqrt{Hz}$

LIGO

BSC System Layout

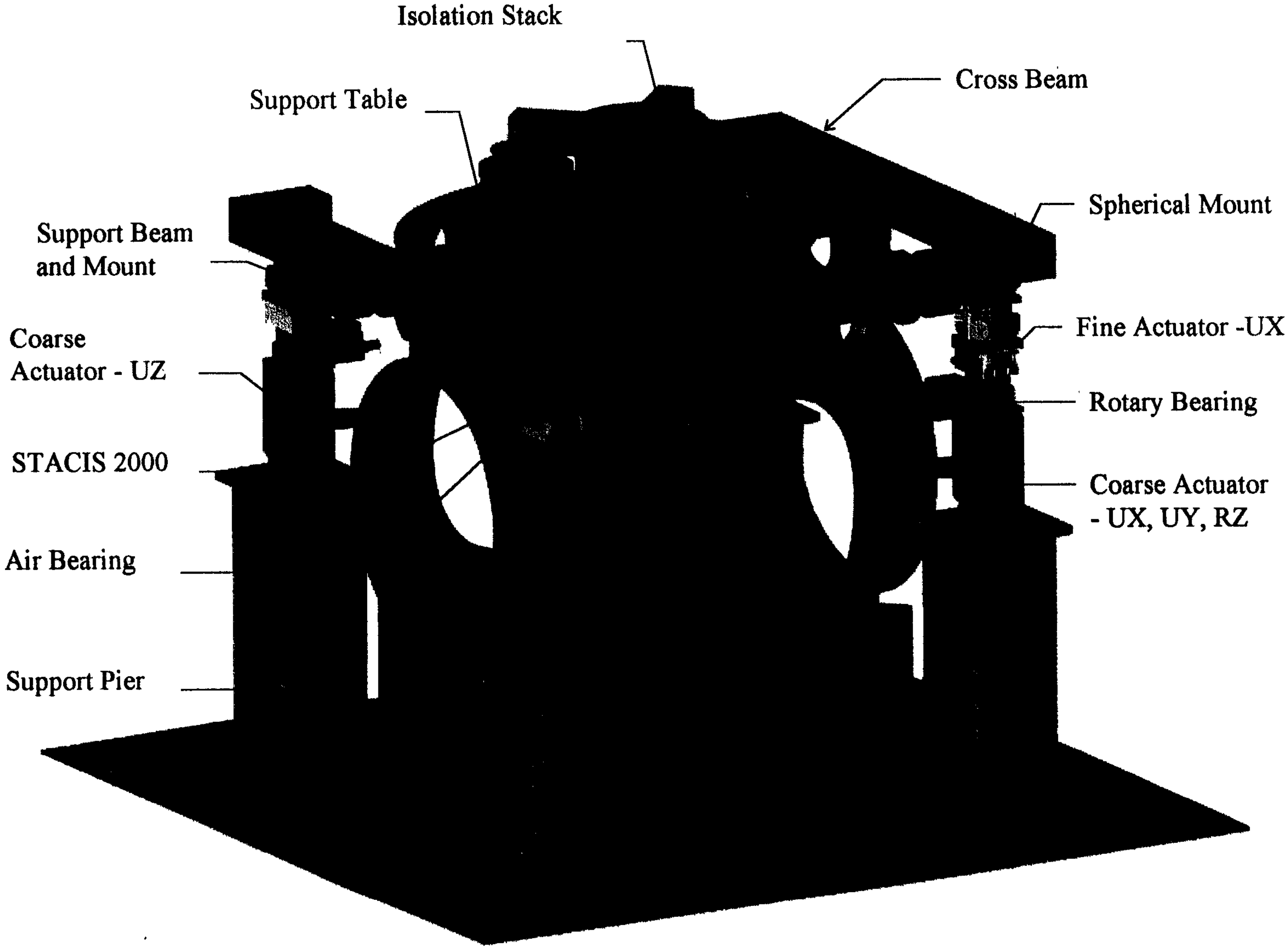


Photo of 40m Monolithic

Mass & Pathfinder Mass

Photo of Coated Pathfinder
w/ Technician

Location of LIGO at
Hanford WA

Aerial of Hanford

C6790235-02-0-V

Photo of Tube Segment
being Craned into Place

Photo of Beam Tube
Fab @ X-End Station
(showing clean room & shelters)

Photo of Tube Cover
Sections in Acme Yard

Photo of Tube Cover
being Craned into Place

Photo of John & Kyle
w/ Vacuum Equipment

Photo of Bolted Down
Vertex Chambers

Photo of Midstation

BSC wrapped for Bake

Status of LIGO Hanford Observatory

- Buildings are completed (total of 6 - corner station, x & y mid stations, x & y end stations, office/support structure)
- Beam-tube modules (4ea of 2-km weldments) have been built, evacuated and leak checked; preparing to bake out
- Vacuum chambers, gate valves, cryopumps, and other hardware are assembled; systems in 3 of 5 buidlings have been evacuated, leak checked and baked out
- Installation of support laboratories and computer networks is now under way
- First-article tests of seismic isolation systems underway
- Preparing for installation of first laser-system in July

Schedule

- 1997 Facility Construction
- 1998 Interferometer Construction
- 1999 Complete Interferometer Construction
- 2000 Commission Detectors
- 2001 Engineering Tests
- 2002 Initial LIGO Detector Run