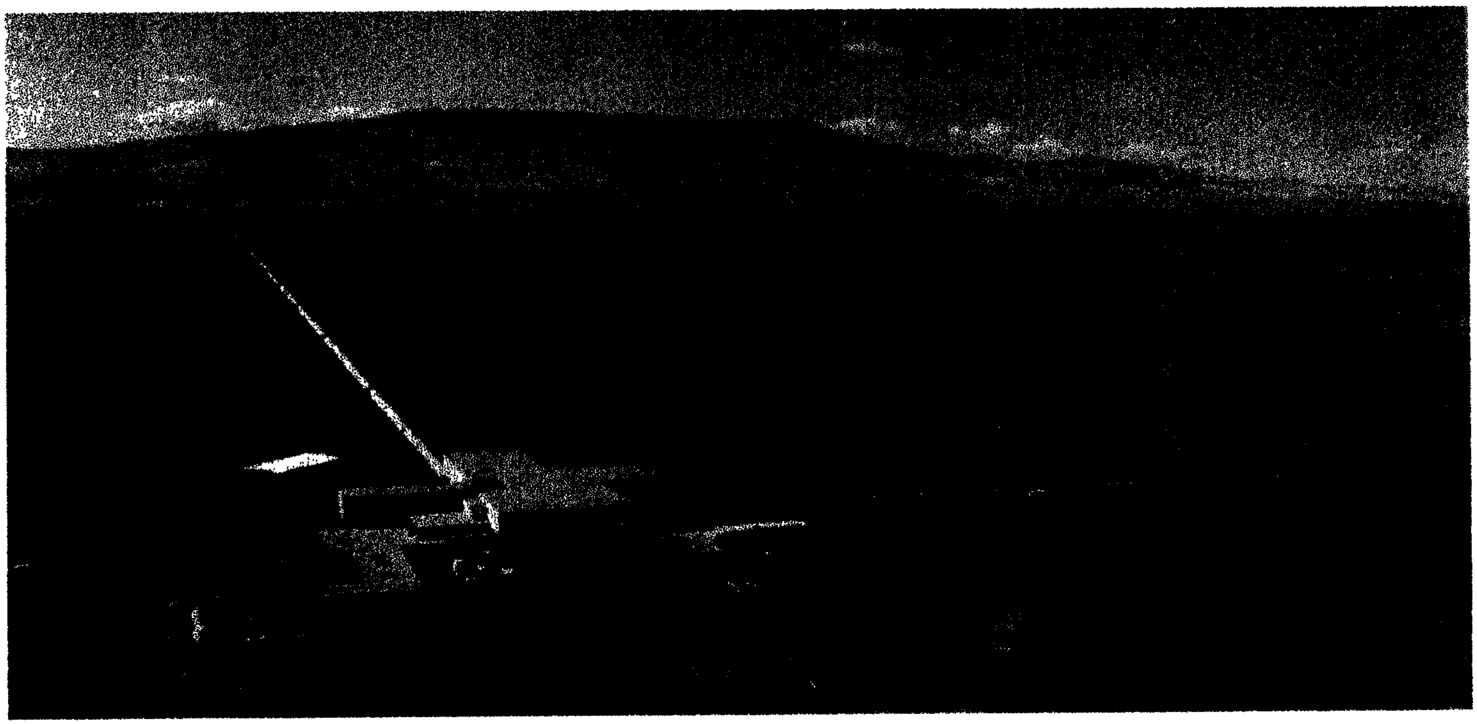
The Laser Interferometer Gravitational-Wave Observatory: Coming of Age in the Northwest

Fred Raab; March 26, 1998



LIGO-G980038-00-W

LIGO

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 Mission

- Open field of Gravitational-Wave Astronomy

  ››LIGO 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 to 10^{10} times larger than has been accessible in the past

  ››Upgrades to LIGO-1 currently in R&D phases should extend the space time volume accessible by another factor of 10^3

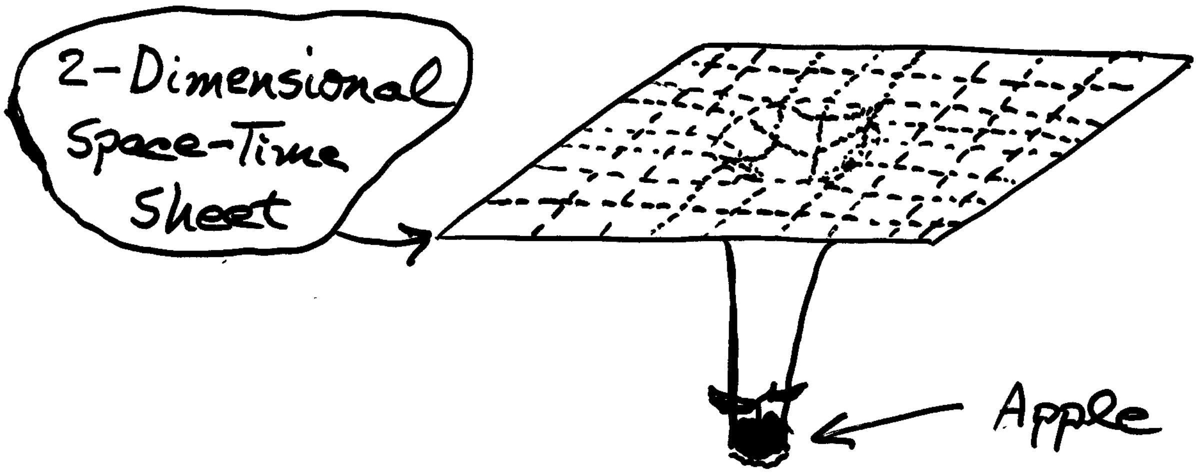
  ››LIGO is part of an international community of GW detector efforts (GEO, VIRGO, TAMA, ACIGA, various bar detectors)

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

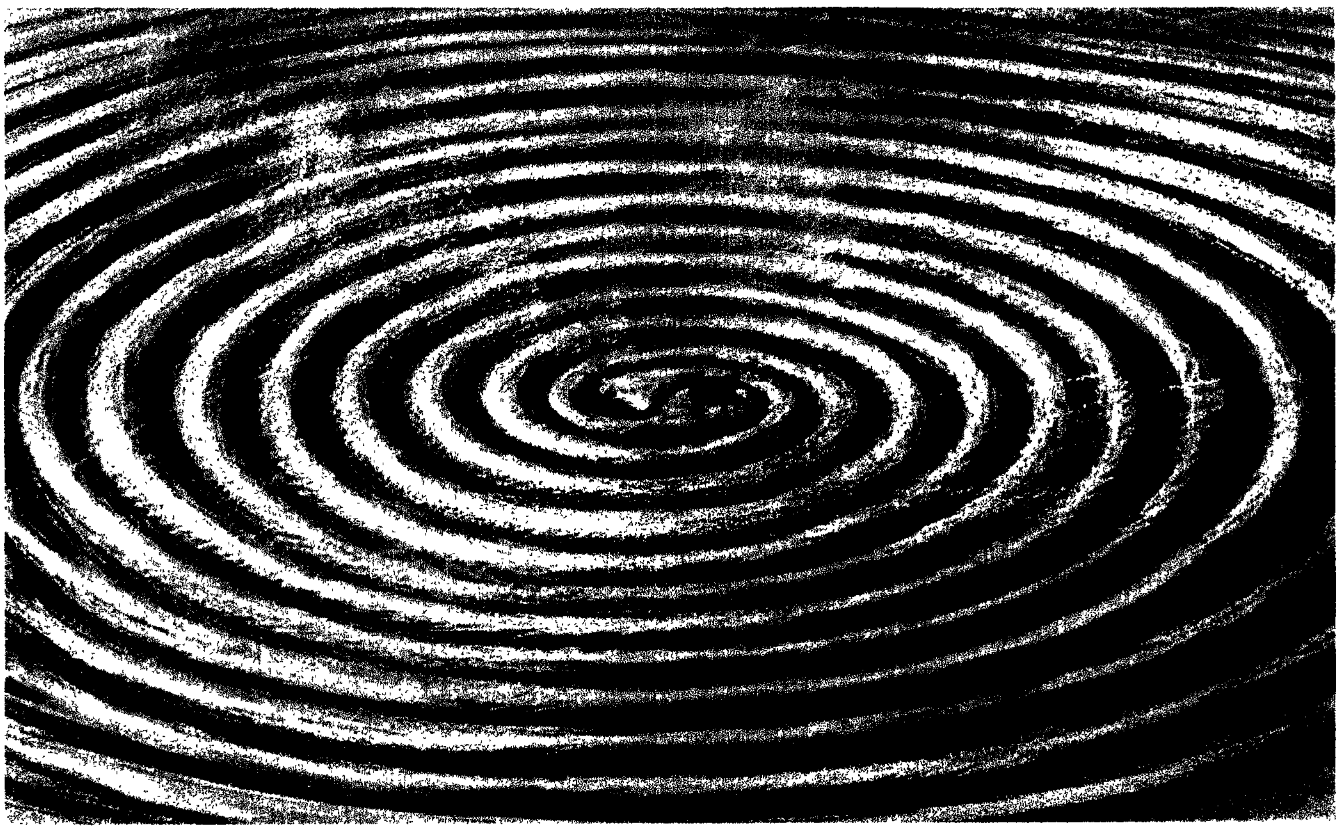
LIGO

Einstein Described Gravity as Resulting From the Curvature of Space-Time By Concentrations of Mass



A Cartesian set of spacetime points is distorted by the presence of mass. This warpage affects trajectories of massive & non-massive objects and affects any distance or time measurements.

Inspiral of Two Black Holes



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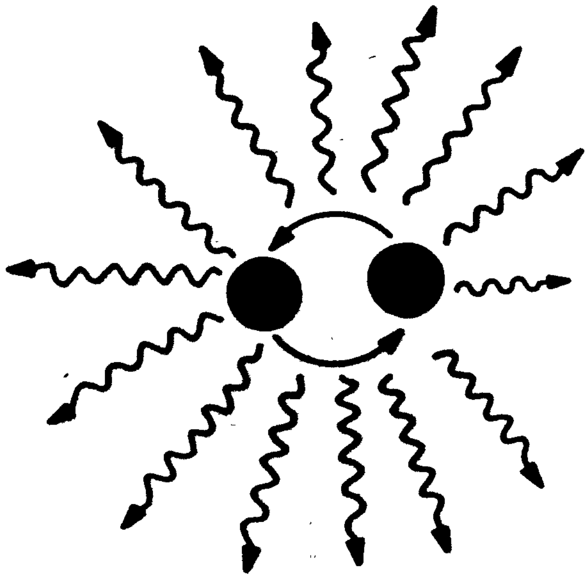
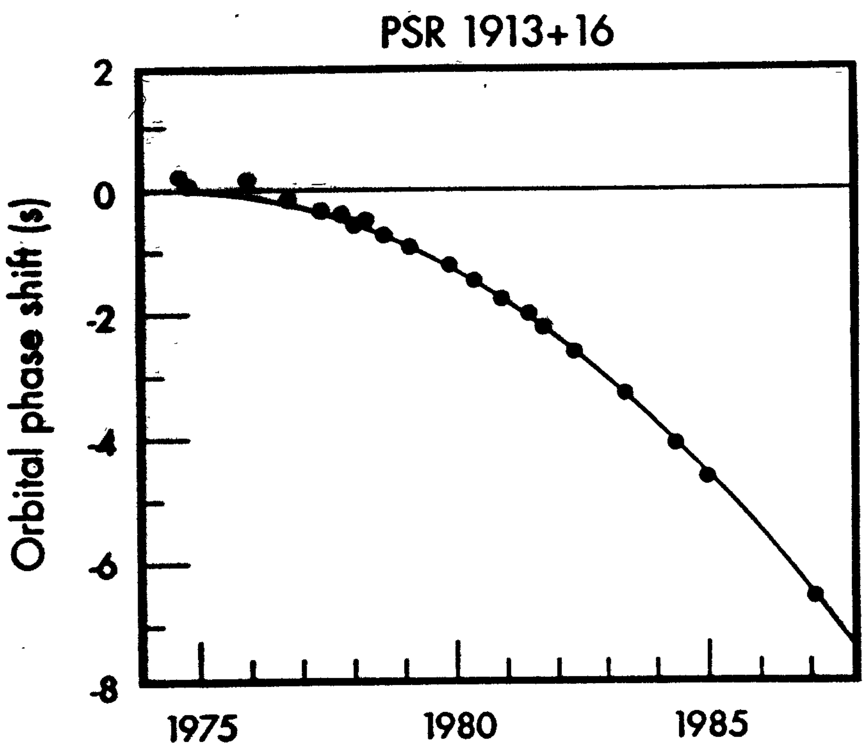
DO GRAVITATIONAL WAVES EXIST?

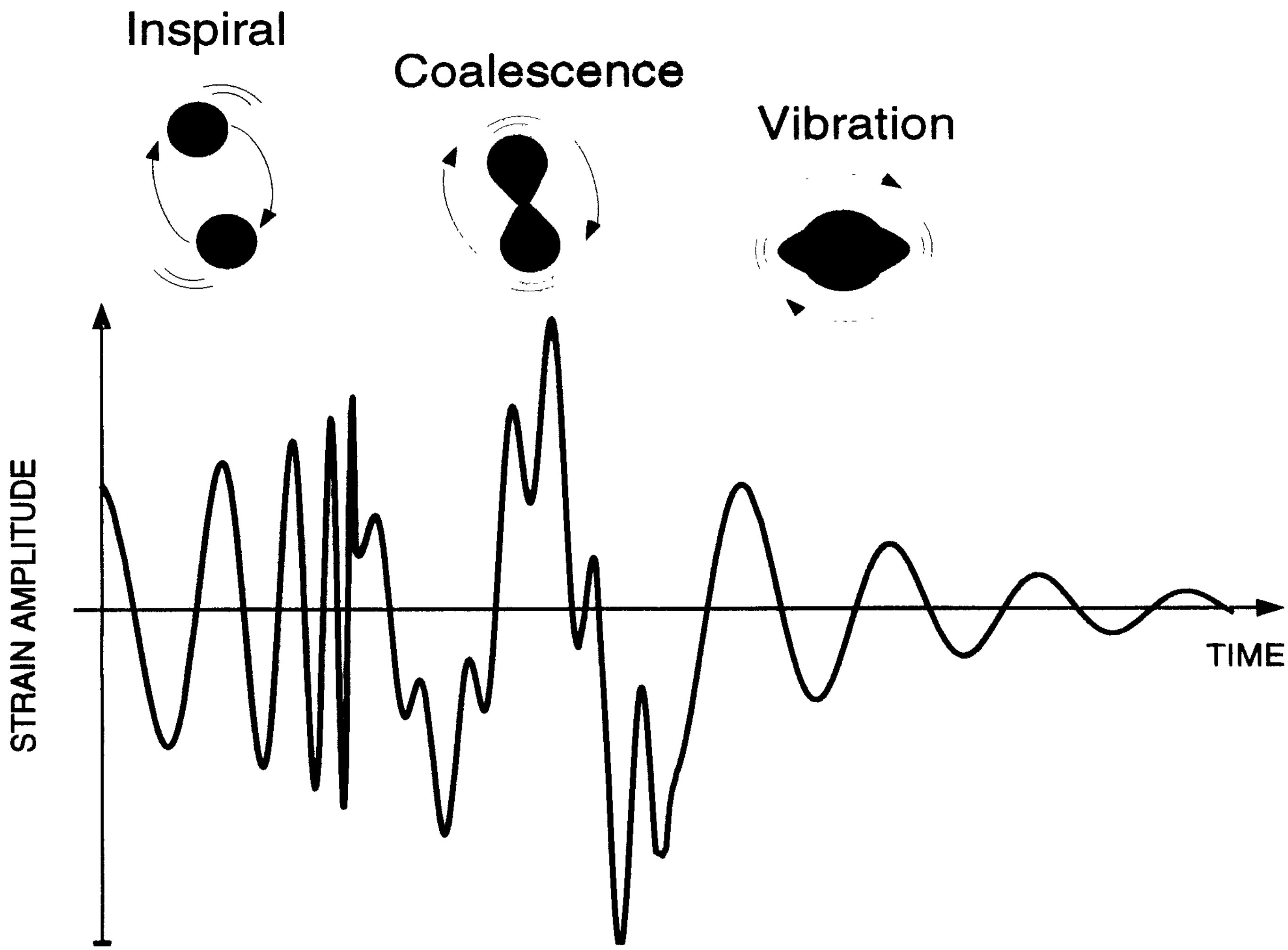


BINARY PULSAR



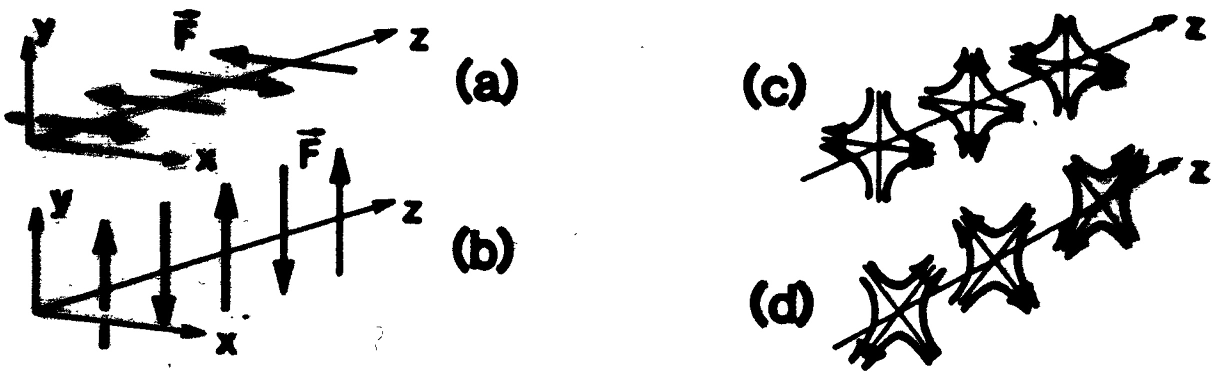
TAYLOR ET. AL: BINARY PULSAR SYSTEM'S ORBITAL DECAY (BY GRAVITATIONAL WAVES) AGREES WITH EINSTEIN PREDICTION

Capturing Black-Hole Waveforms



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

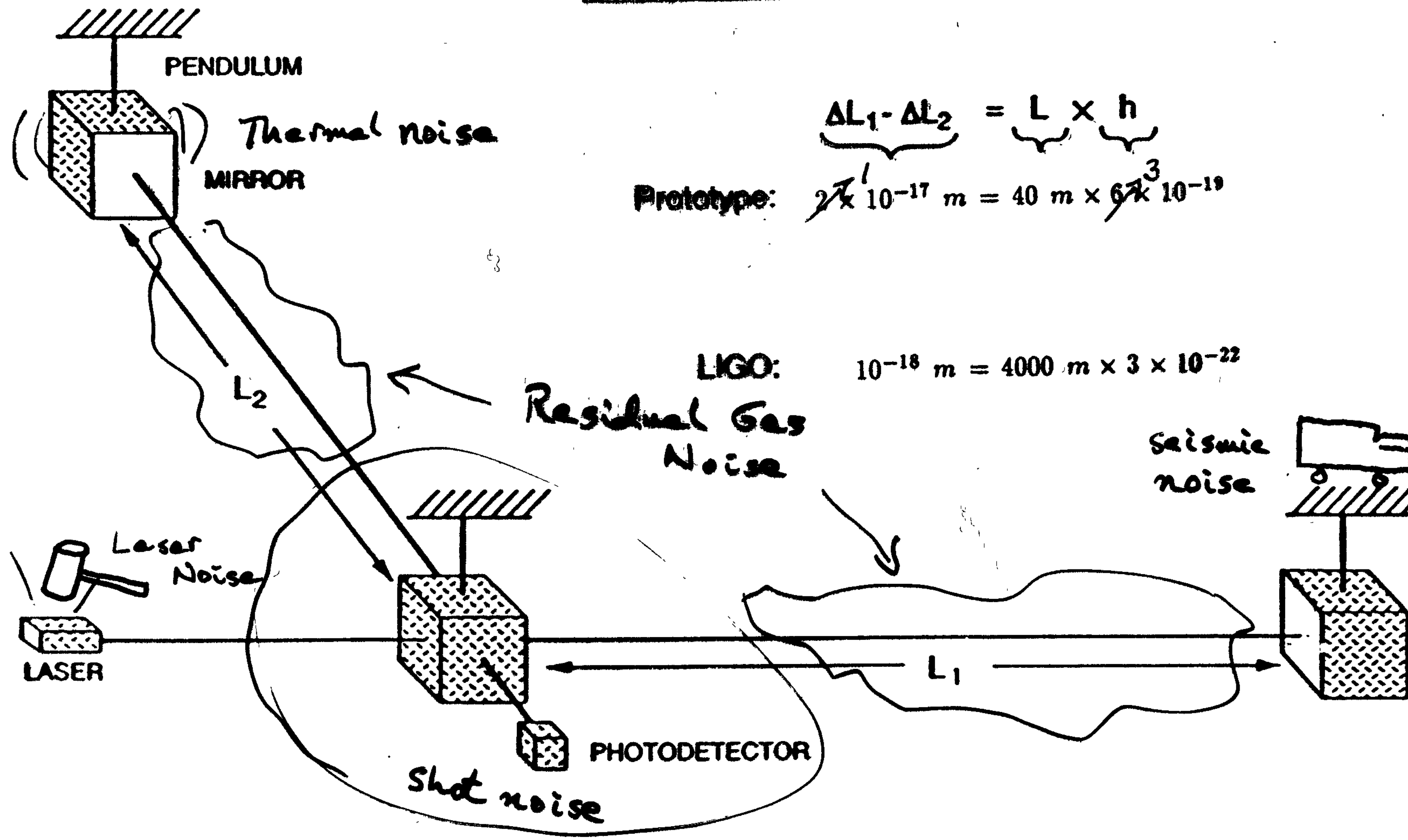
A Michelson Interferometer is a "Natural" Device for Gravitational Wave Detection

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

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

Prototype: $\cancel{2}\,1 \times 10^{-17}\ m = 40\ m \times \cancel{6}\,3 \times 10^{-19}$

LIGO: $10^{-18}\ m = 4000\ m \times 3 \times 10^{-22}$



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

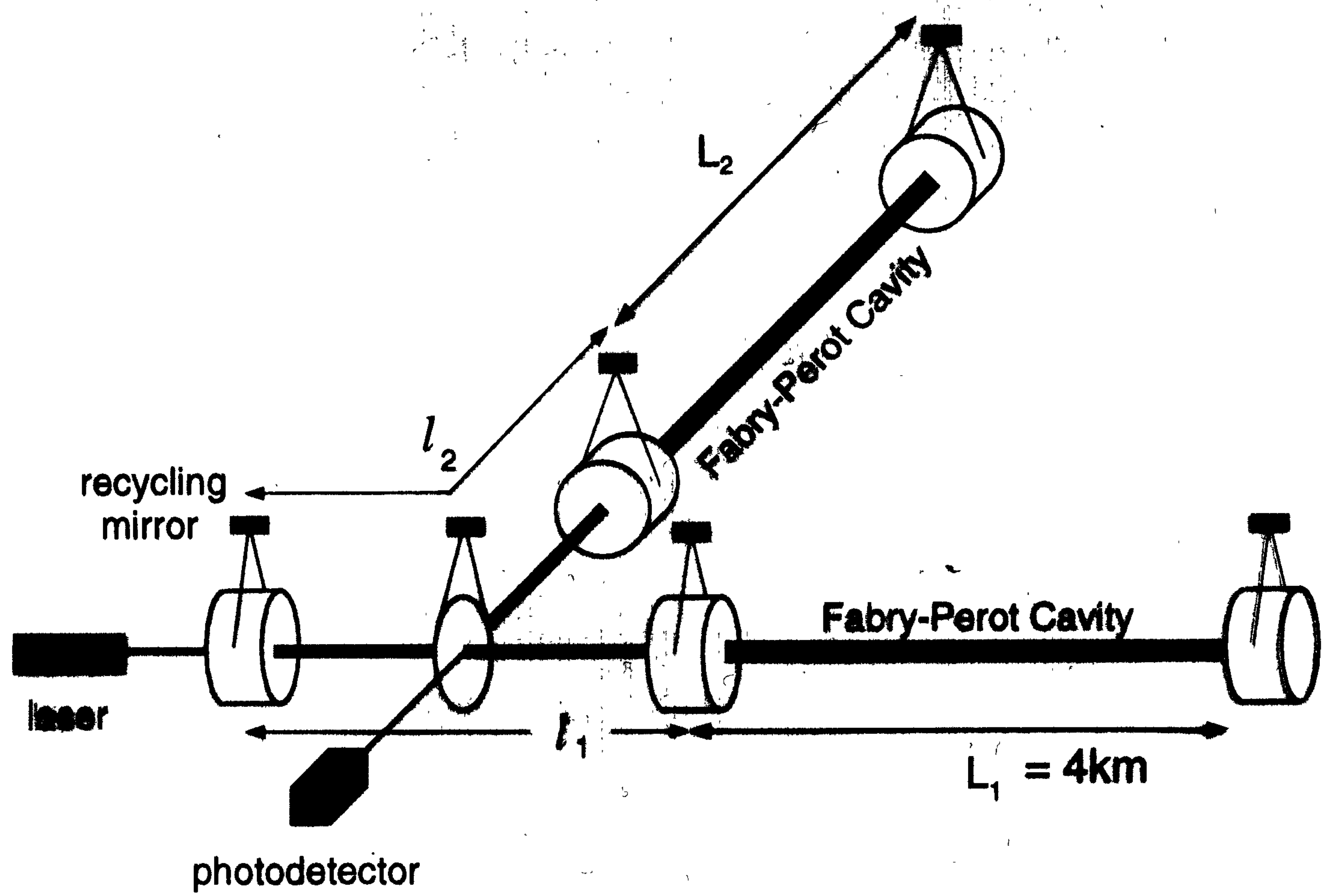
  --->use cavity to narrow fringe by ~ 100

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

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

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

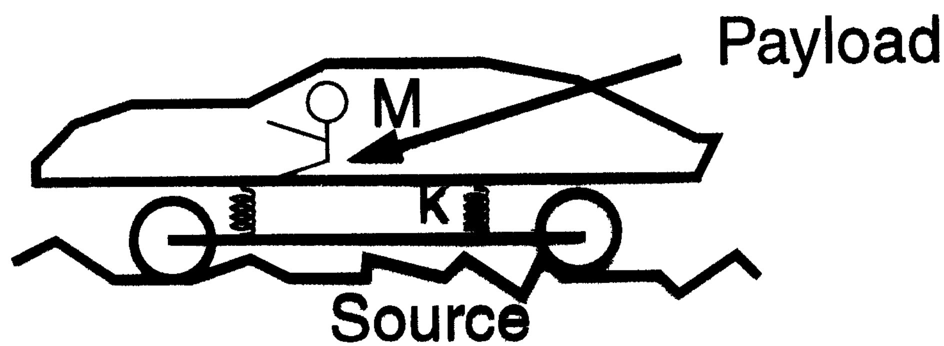
LIGO Laser Interferometer

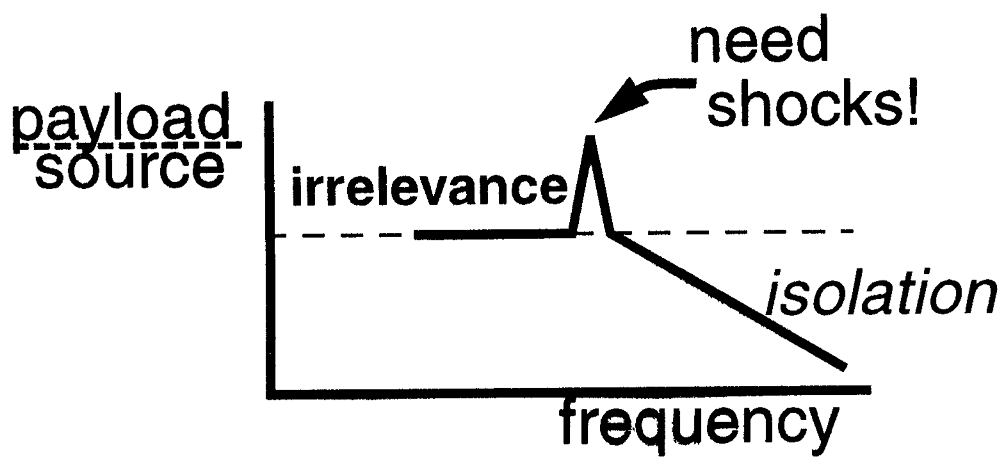


40-m Lab

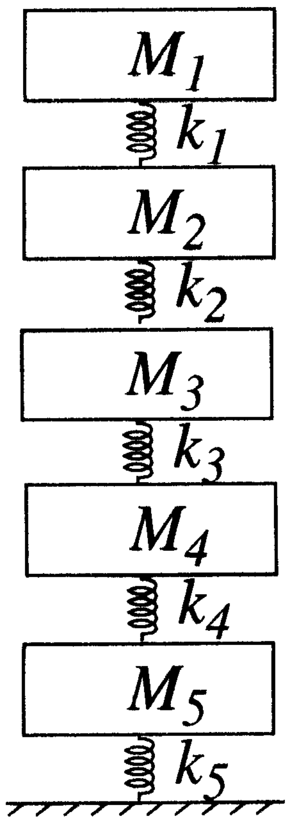
Photo

Everything to Know about Seismic Isolation Can Be Learned from Your Car





Generalized Cascaded Seismic Filter



Negligible Seismic Noise

↑

Smaller Seismic Noise

↑

Large Seismic Noise

Thermal Noise Crucial

↑

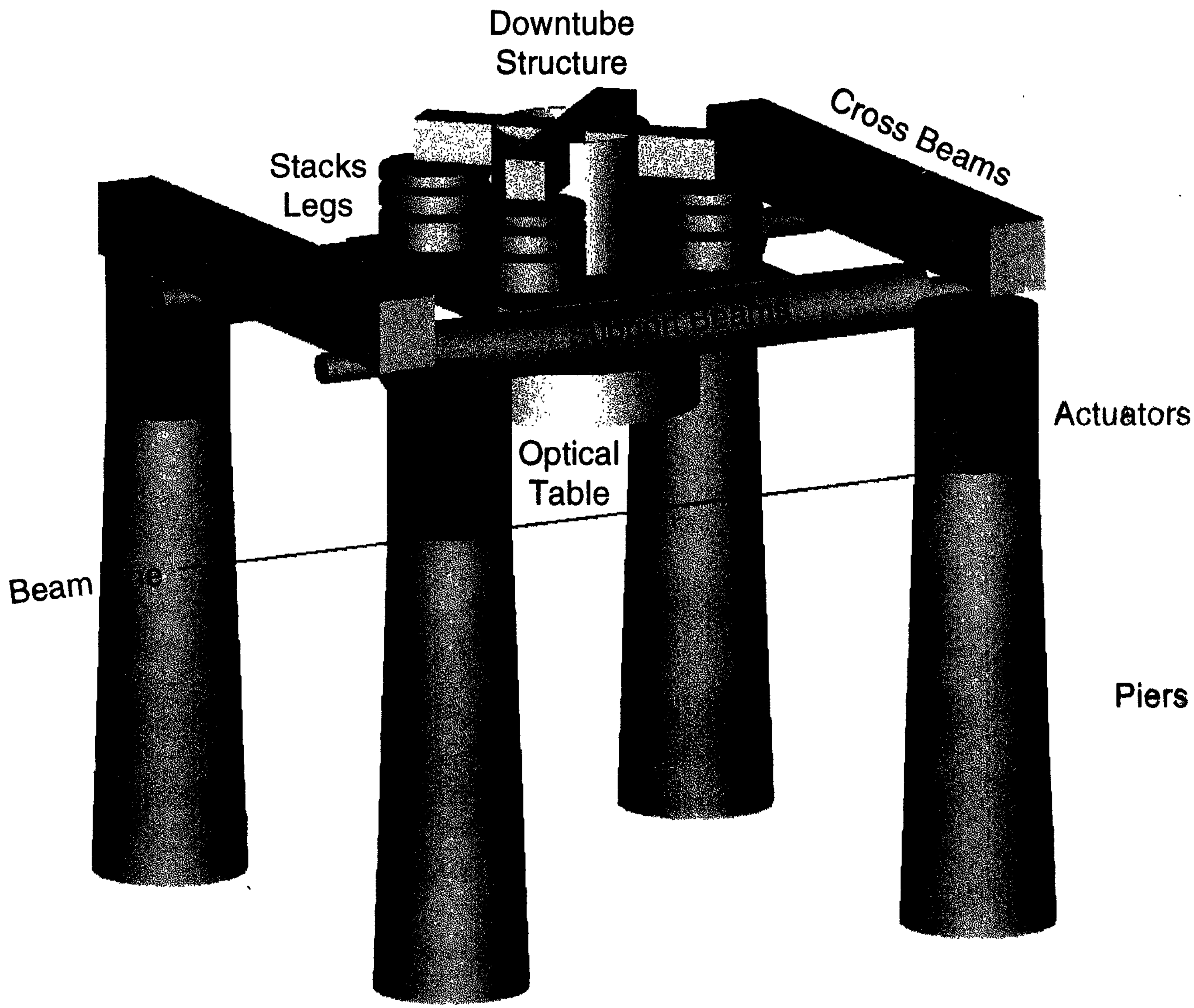
Thermal Noise a Possible Concern

↑

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.

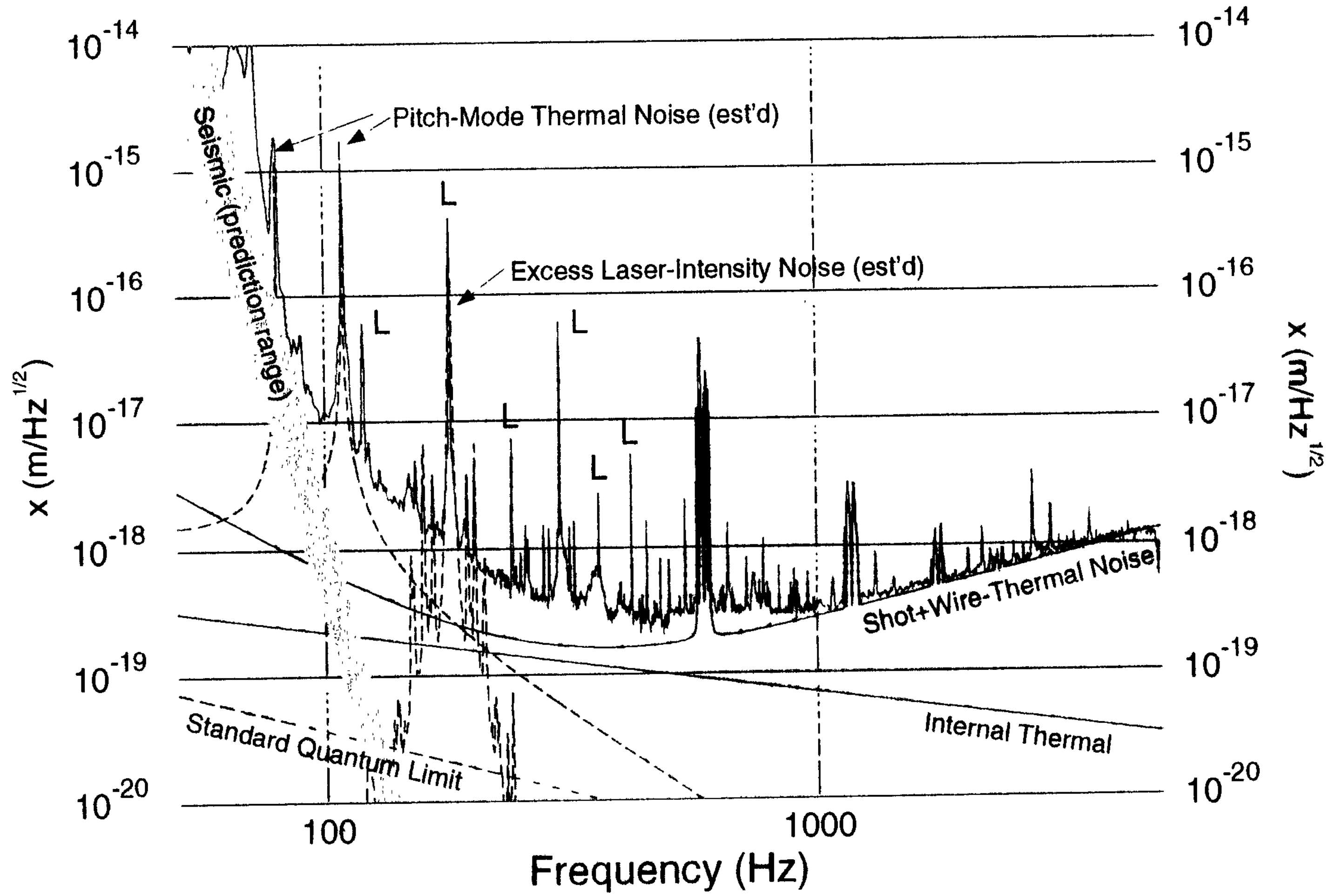
BSC Stack Layout



PNI Photo

Suspended 40-m
Test Mass
Photo

Comparison of Noise Models to Experience in 40-Meter Interferometer



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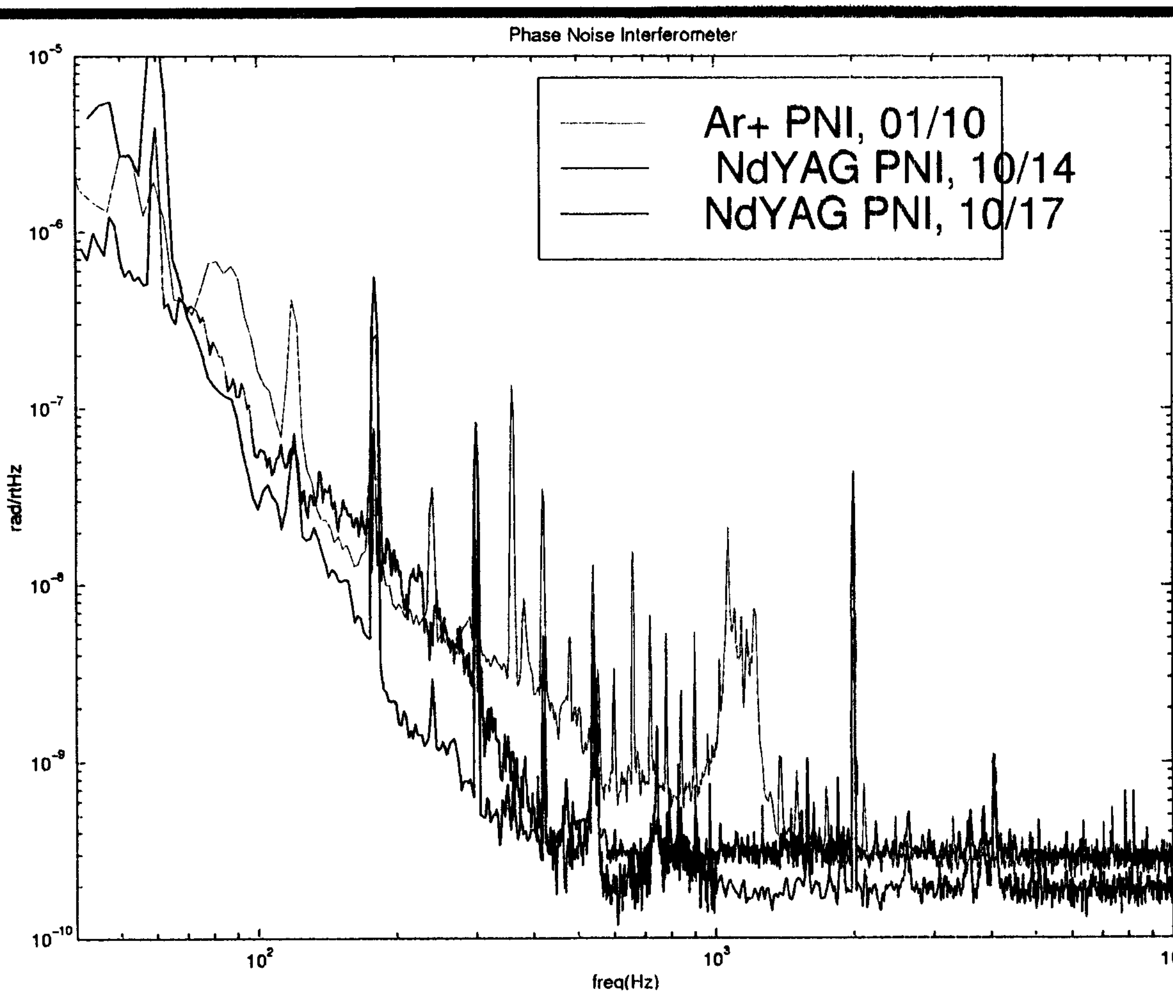
Phase Noise Interferometer



System works well, looking at noise sources carefully

››High frequencies: shot noise limited at ~150 W circulating,

$2\times10^{-10}\ \mathrm{rad}/\sqrt{\mathrm{Hz}}$, limited by thermal lensing

››Low frequencies: variable, related to seismic noise, probably accidental backscatter from injection optics

LIGO

BSC System Layout

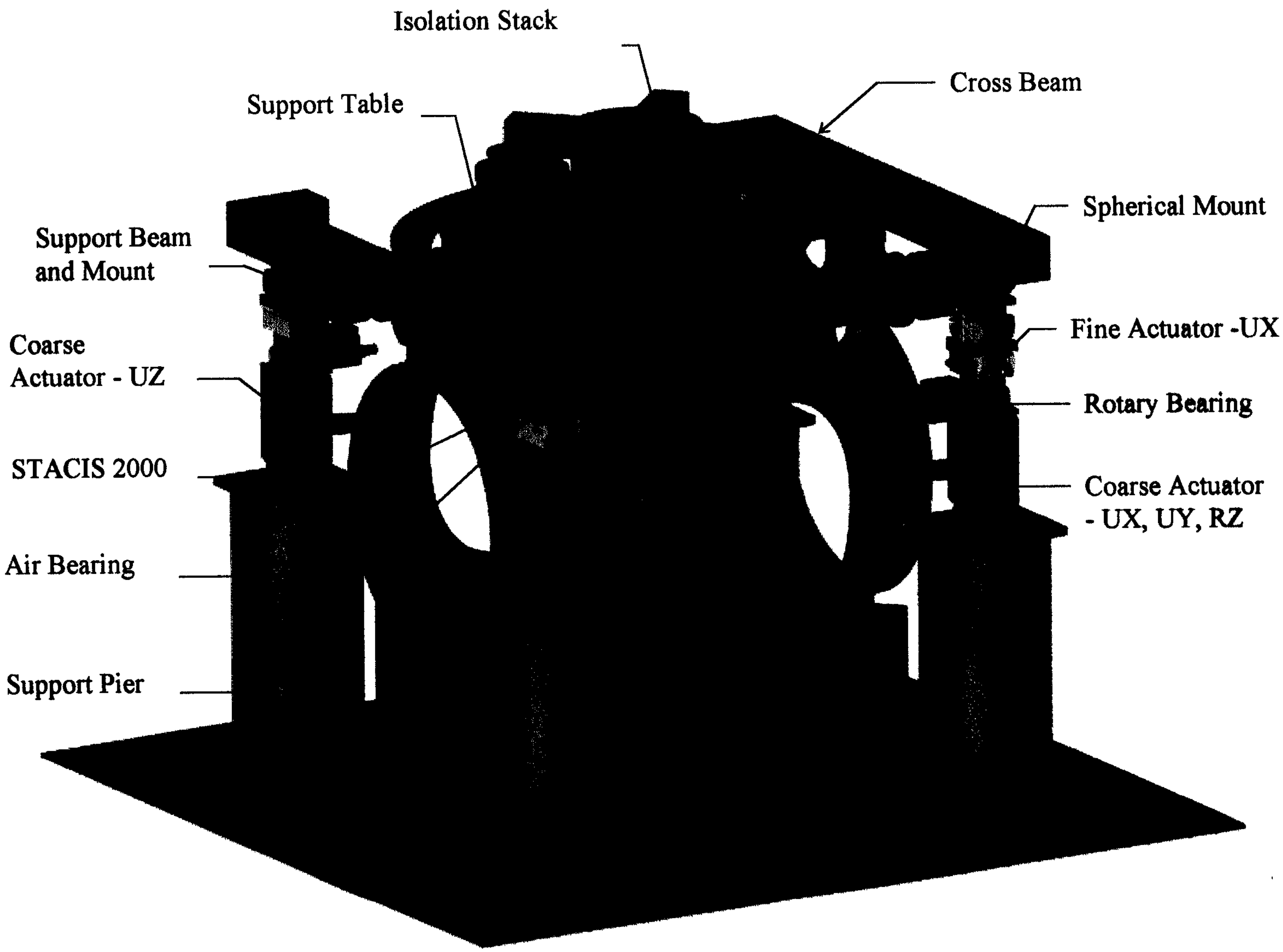
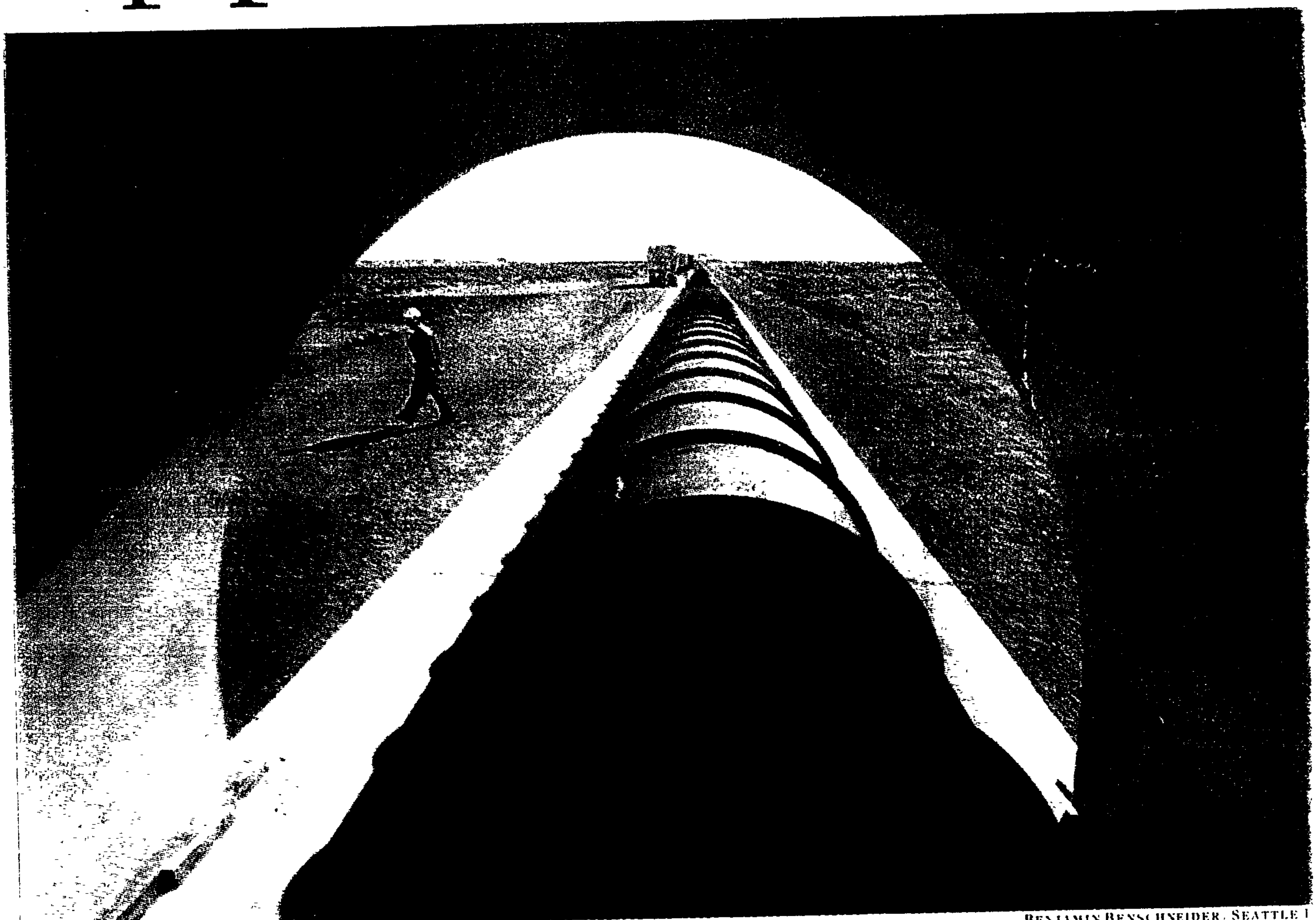


Photo of Pathfinder
& 40m Test Mass

A pipeline to space-time



BENJAMIN BENSCHNEIDER, SEATTLE T

One of LIGO's two *specially crafted stainless-steel pipes extends 2.5 miles into the Hanford desert on a perfectly flat plane of concrete.*

Mirrors and lasers and tunnels 2½ miles long in Hanford desert wait for the universe to twitch

BY BILL DIETRICH
Seattle Times science reporter

HANFORD SITE, Benton County — In the 12th century, people built cathedrals to express their wonder with creation.

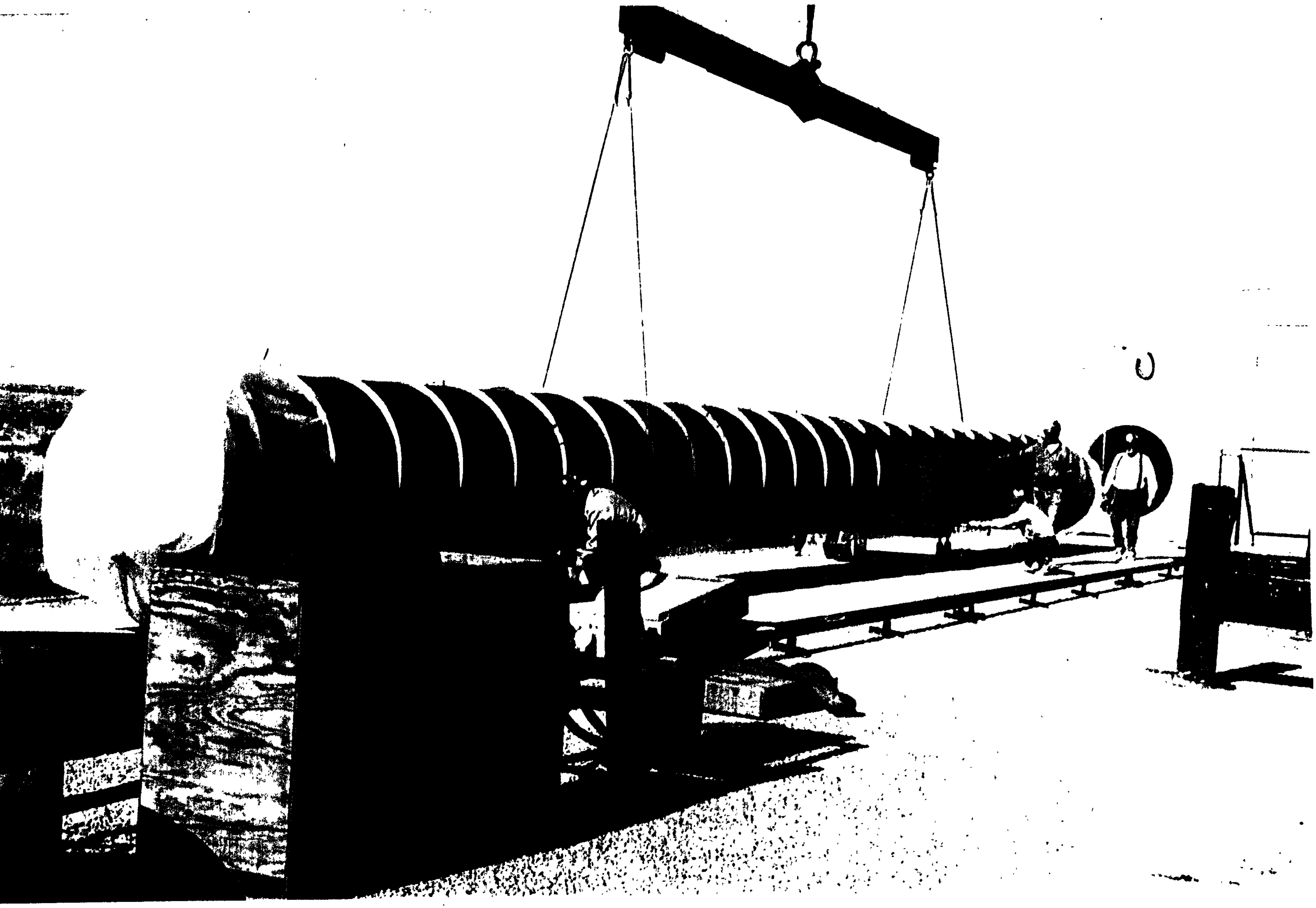
Here at the end of the 20th century, out in the sagebrush desert of a former nuclear weapons complex, Americans are nearing completion of a monument of a different sort: LIGO, or the $360 million Laser Interferometer Gravitational-wave Observatory.

LIGO has none of the beauty of Notre Dame. But the ingenuity, skill and dedication required to construct something that reaches so far beyond everyday life are reminiscent of the famed medieval churches.

Scientists from the California Institute of Technology yesterday showed off their half-completed observatory, its purpose based on a still unconfirmed prediction of Albert Einstein.

PLEASE SEE **Observatory** ON A 15

Worker Ray Fenn *had to pass through an air lock to re[...] dust particles before entering the LIGO pipe to check w[...]*

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Schedule

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

LIGO