LIGO CONCEPT

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LIGO CONCEPT

LIGO GOALS

Long Term:	**Gravitational Wave Observatory Operation**
Initial:	**Autonomous facility for detection of gravitational waves and Source Survey**

LIGO SENSORS

Free mass, broad band, laser interferometric

$$h = \frac{\triangle L}{L}$$

h = gravitational wave strain

$\triangle L$ = net displacement of test masses

L = separation of test masses (interferometer arm length)

- **Ultimate operation as part of global observatory**
- **Initial objectives can be achieved by LIGO alone**

LIGO CONCEPT

LIGO: PRINCIPAL FEATURES

1) **Two Sites**

$$\underline{\triangle L} = h \cdot L$$

Signal Rate ≥ 3 events per year

Noise Rate < 0.1 events per year

- Operate several interferometers in coincidence mode

2) **4-km Arm Length**

For random-force noise (seismic, thermal, acoustic .....)

Displacement Sensitivity:

$$\triangle L_{\text{SIGNAL}} = h \cdot L > \triangle L_{\text{NOISE}}$$

$$h_T > \frac{\triangle L_{\text{NOISE}}}{L}$$

Event Rate: Signal Rate $\propto \frac{1}{h_T^3} \propto L^3$

- Economy dictates no tunneling, no large earth movement
- Scarcity of level, flat sites determines 4-km arm length choice

3) **2-km Length Interferometers at One Site**

$$\underline{\triangle L} = h \cdot \underline{L}$$

amplitude discrimination for diagnostics and event verification

- LIGO detector: Site 1: 4-km IF
  2-km IF
  Site 2: 4-km IF
  } Triple coincidence
- LIGO facilities designed to ultimately accommodate 3 detectors

LIGO CONCEPT

LIGO PRINCIPAL FEATURES: Cont'd

4) **Beam Tube Clear Aperture:** $d = 1m$

6 Fabry-Perot IFs $(0.5\mu m)$

1 Delay Line IF $(1.0\mu m)$

5) **Vacuum**

$$H_2 < 10^{-9} \text{ torr}$$
$$N_2, H_2O < 10^{-10} \text{ torr}$$

Requirement need be achieved only gradually, allowing engineering trade-offs.

6) **Lasers**

present: Argon-ion
$\lambda = 0.5\mu m$
5W
CW
Single mode
High beam quality
$\epsilon \sim 10^{-4}$

future: Nd-YAG $(1\mu m)$
Frequency doubled
100W
$\epsilon \sim 10^{-2}$ to 10^{-1}

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LIGO PRINCIPAL FEATURES: Cont'd

7) Site Strategy

- **Consideration of noise and directional sensitivity**

a) Global

i) Separation of sites

- **l > 300 km (noise correlation)**
- **l < 4500 km (beam pattern overlap)**
- **l = large (triangulation baseline)**

ii) Orientation of connecting axis:

- **arbitrary for 2 sites**
- **maximize area (volume) defined by 3 (4) sites**

iii) Relative IF alignment:

- **co-aligned for maximum detection sensitivity (arm alignment coincides when projected on bisecting plane)**

b) Local

- **level geometry (< m rad) (Earth's gravity vector: $\Delta \sim$ 0.6 m rad @ 4 km)**

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LIGO PRINCIPAL FEATURES: Cont'd

8) **Single-Detector Start-Up to Three-Detector User Facility**

- **Building Capacity: 6 (3) IFs**
- **Vacuum System Capacity**
  initial: 2 (1) IFs
  expandable to:
  final: 6 (3) IFs

9) **Continuous, Round-the-Clock Operation**

10) **Life Expectancy: > 20 years**

11) **Ancillary Instrumentation**

Monitor noise: acoustic noise
seismic
electromagnetic
cosmic ray
.
.
.
.
.

12) **Signal/Science Capability**

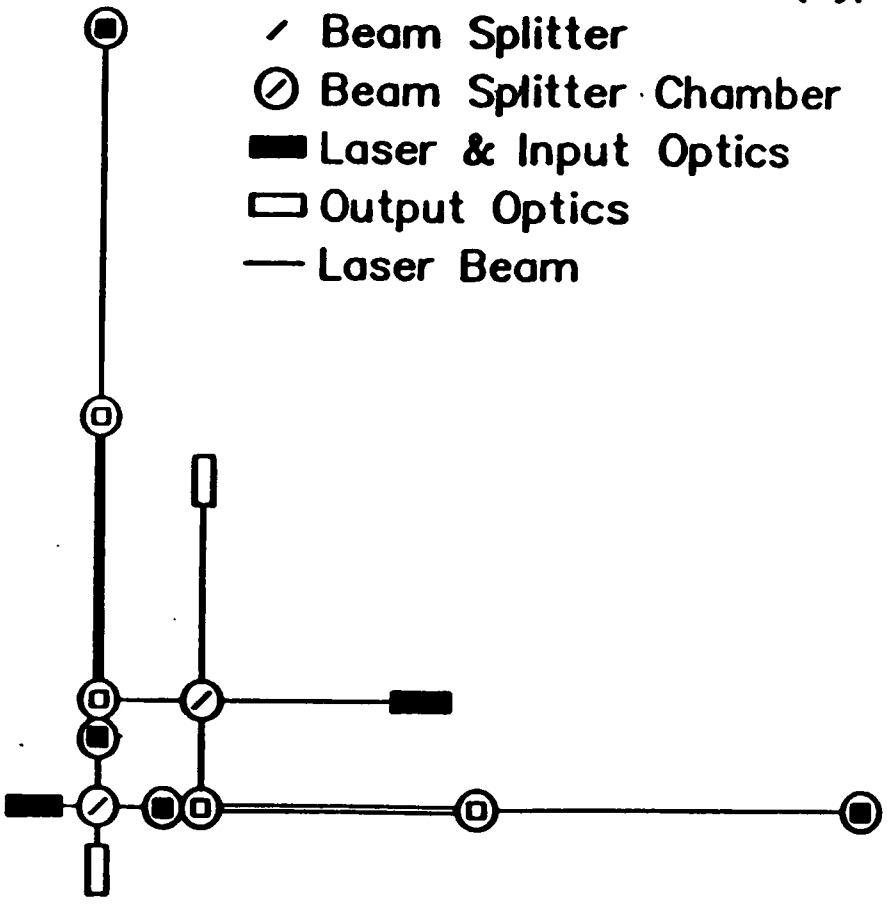
10 Hz - 10 kHz
polarization
source direction

- **Decode information carried in waveforms.**

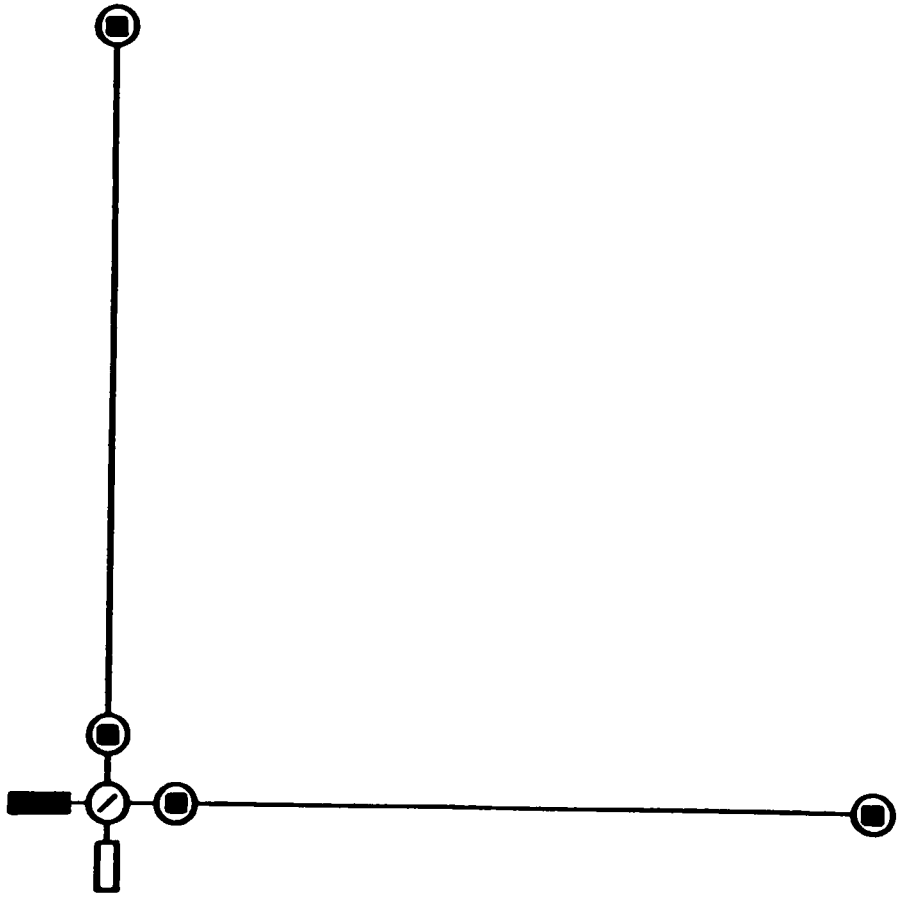
	Measurement Capability	Science Capability
I. 2 U.S. Sites	$(ah_+ + bh_\times)$, arrival angle (w/r to line joining 2 sites)	1. *Physics* • Confirmation of existence of gravitational waves • Propagation speed of gravitational waves (from periodic sources, or from burst sources if event also observed in electromagnetic band) • Graviton spin (from periodic sources) • Existence of Black Holes (if sufficient number of events) 2. *Astrophysics:* • Classification of signals • Statistics on types of sources (burst, periodic, semi-periodic...) • Distances and mass information for spiralling binaries • Source location on cone (from "time of flight") • Search for stochastic background
II. 2 U.S. Sites + 1 abroad	h_+, $h_\times$, θ, ϕ	All of I, with higher precision and greater detail, plus 1. *Physics:* • Graviton spin (from polarization of waves) • Test of general relativity in strong-gravity, high-speed regime (via waveforms of strong field sources) • Measure geometry of spacetime around spinning black holes • Study of non-linear gravity in black-hole collisions 2. *Astrophysics:* • Source location (θ, ϕ) • Waveforms give information on sources: e.g., core dynamics of supernovae, pulsar deformations, starquakes • Sky survey of sources
III. >3 Sites	h_+, $h_\times$, θ, ϕ	All of II, but with higher precision and greater detail; more accurate source locations

SYMBOLS

- Test Mass
- Test Mass Chamber (Type1)
- Test Mass Chamber (Type2)
- Beam Splitter
- Beam Splitter Chamber
- Laser & Input Optics
- Output Optics
- Laser Beam



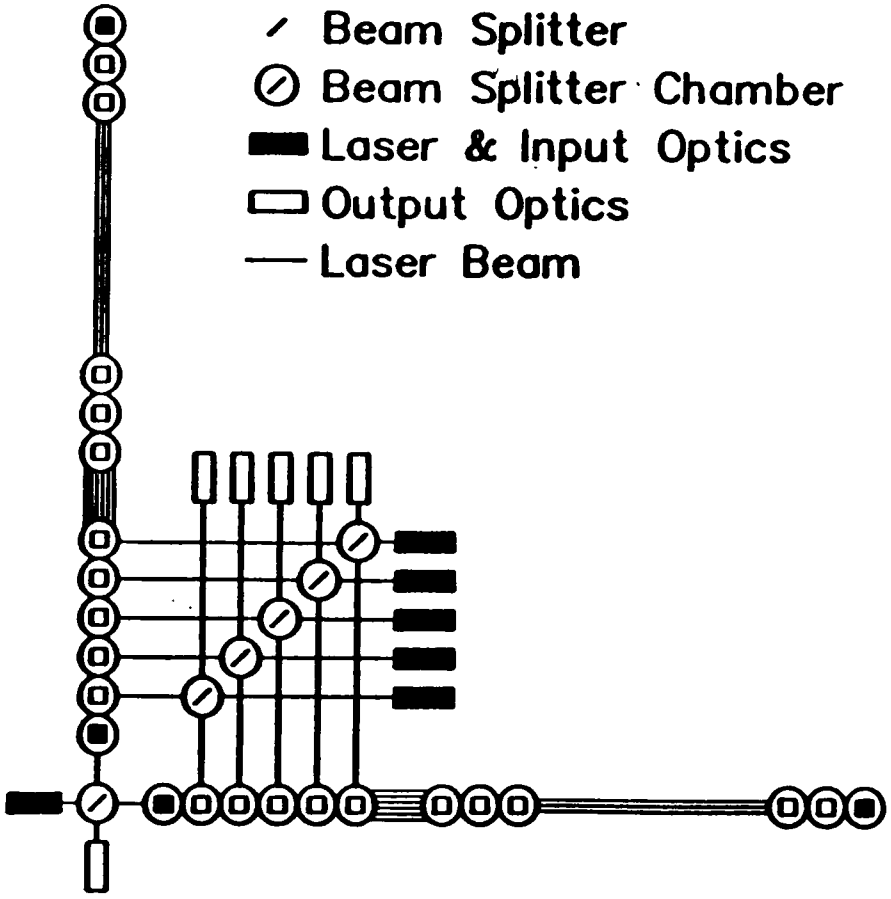
Site 1
Phase A



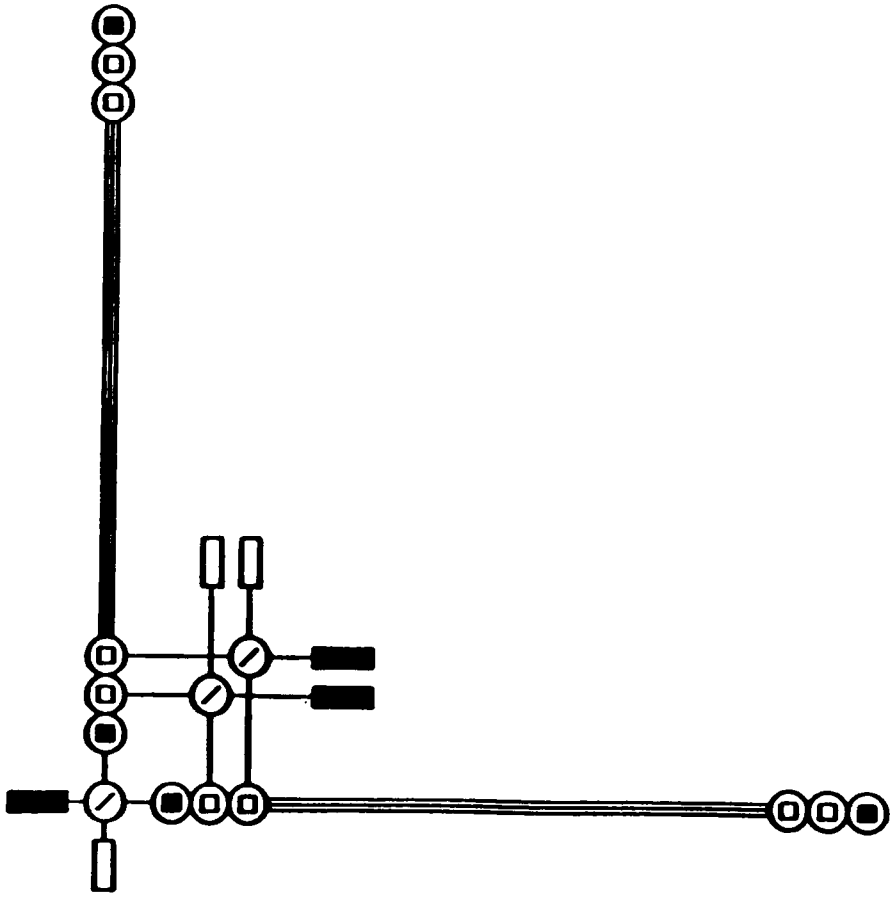
Site 2
Phase A

SYMBOLS

- Test Mass
- Test Mass Chamber (Type1)
- Test Mass Chamber (Type2)
- Beam Splitter
- Beam Splitter Chamber
- Laser & Input Optics
- Output Optics
- Laser Beam

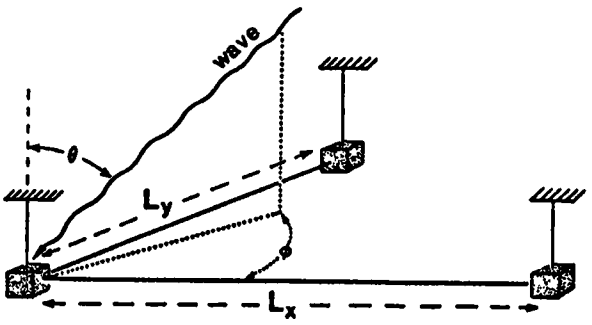


Site 1
Phase C



Site 2
Phase C

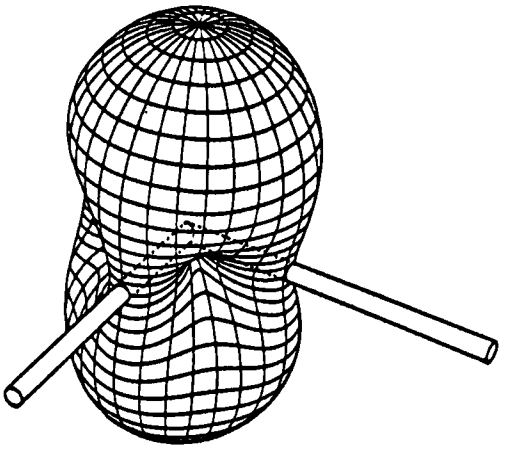
LIGO DIRECTIONAL SENSITIVITY

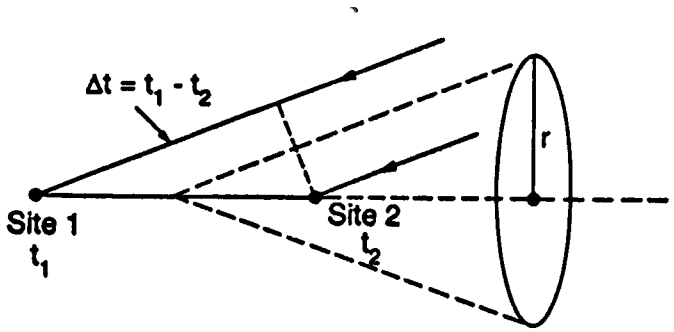


$$\frac{\Delta L}{L} = F_+(\theta,\phi)h_+(t) + F_\times(\theta,\phi)h_\times(t)$$

$$F_+ = \tfrac{1}{2}(1 + cos^2\theta)cos2\phi$$

$$F_\times = cos\theta sin2\phi$$





# SITES	ERROR BOX
2	Circle
3	$3' - 5'$ (U.S. - Europe) $\Delta\Omega = \frac{2c^2\Delta\tau_{12}\Delta\tau_{13}}{A cos\theta}$
4	$1' - 2'$ (U.S. - Europe - Australia)