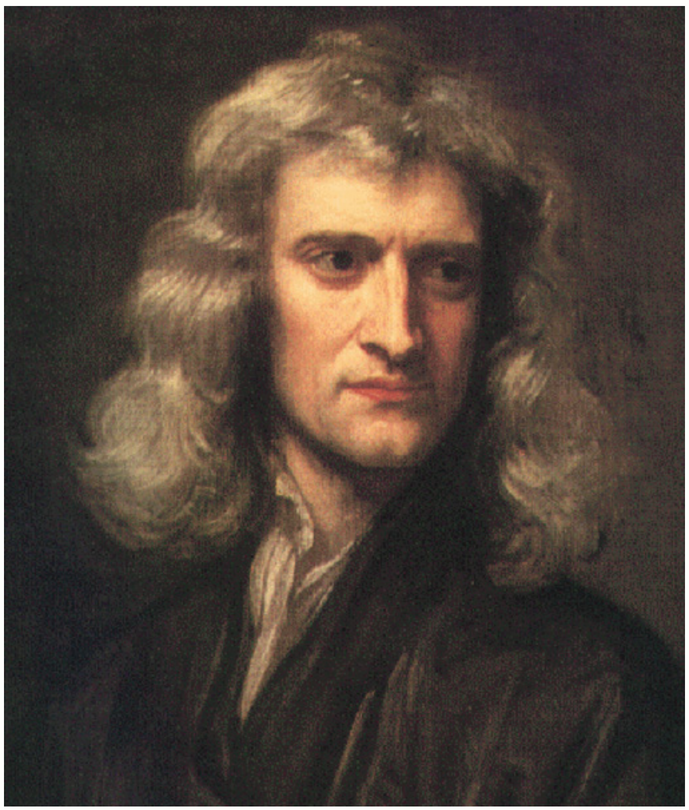
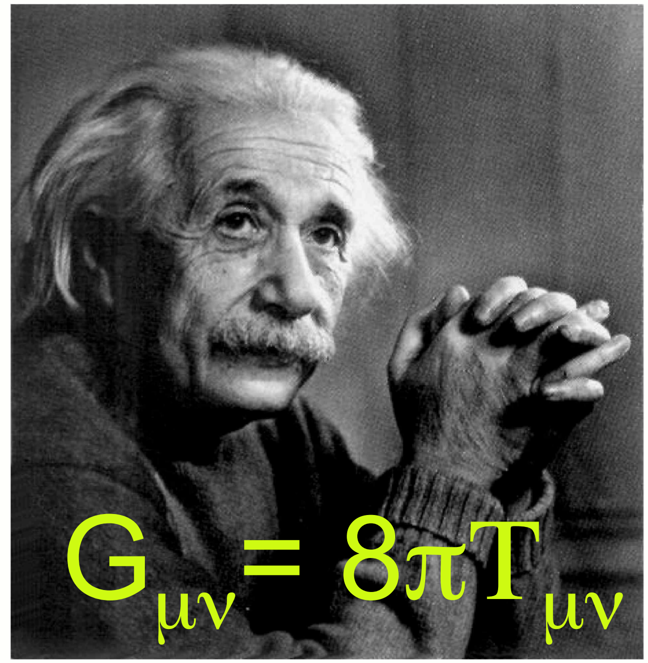
Why must there be gravitational waves?

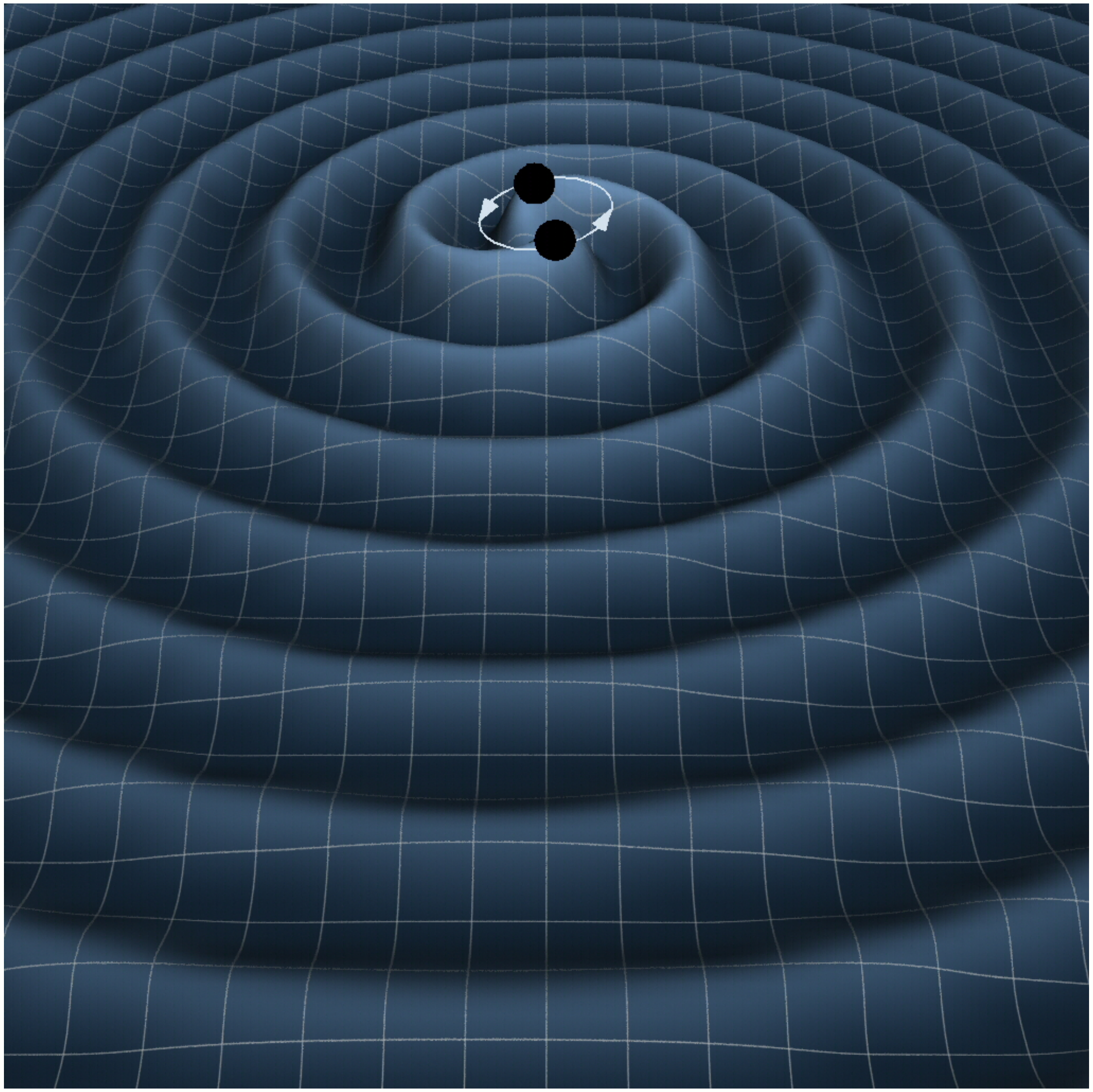
Newton's puzzle:
"instantaneous action at a distance"





General Relativity
Spacetime itself is a medium
Geometry carries information

Gravitational Waves



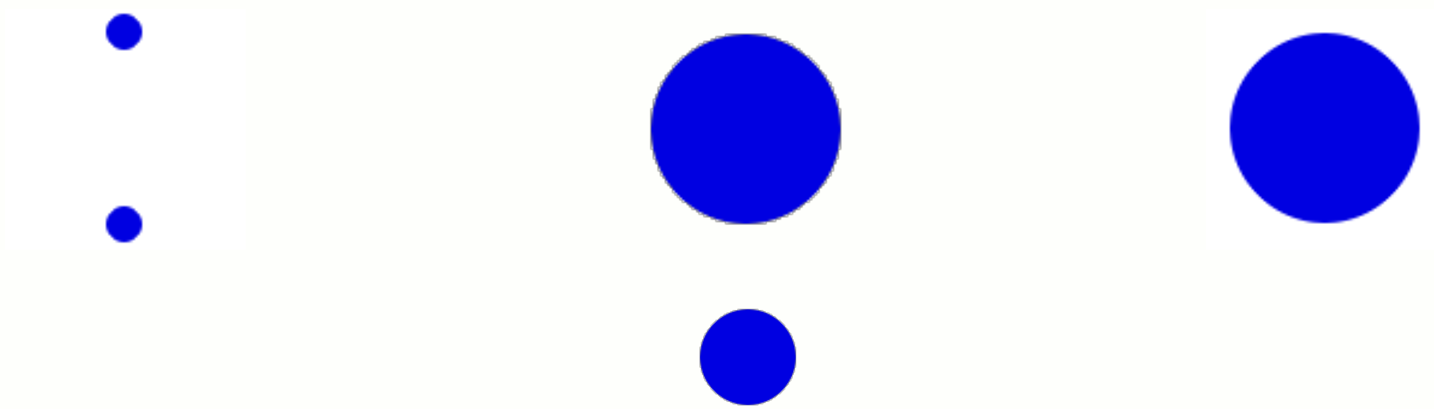
Changes of matter in one part of space affect geometry elsewhere

K. Thorne (Caltech) , T. Carnahan (NASA GSFC)

Gravitational Waves in Action

Two massive, compact objects in orbit

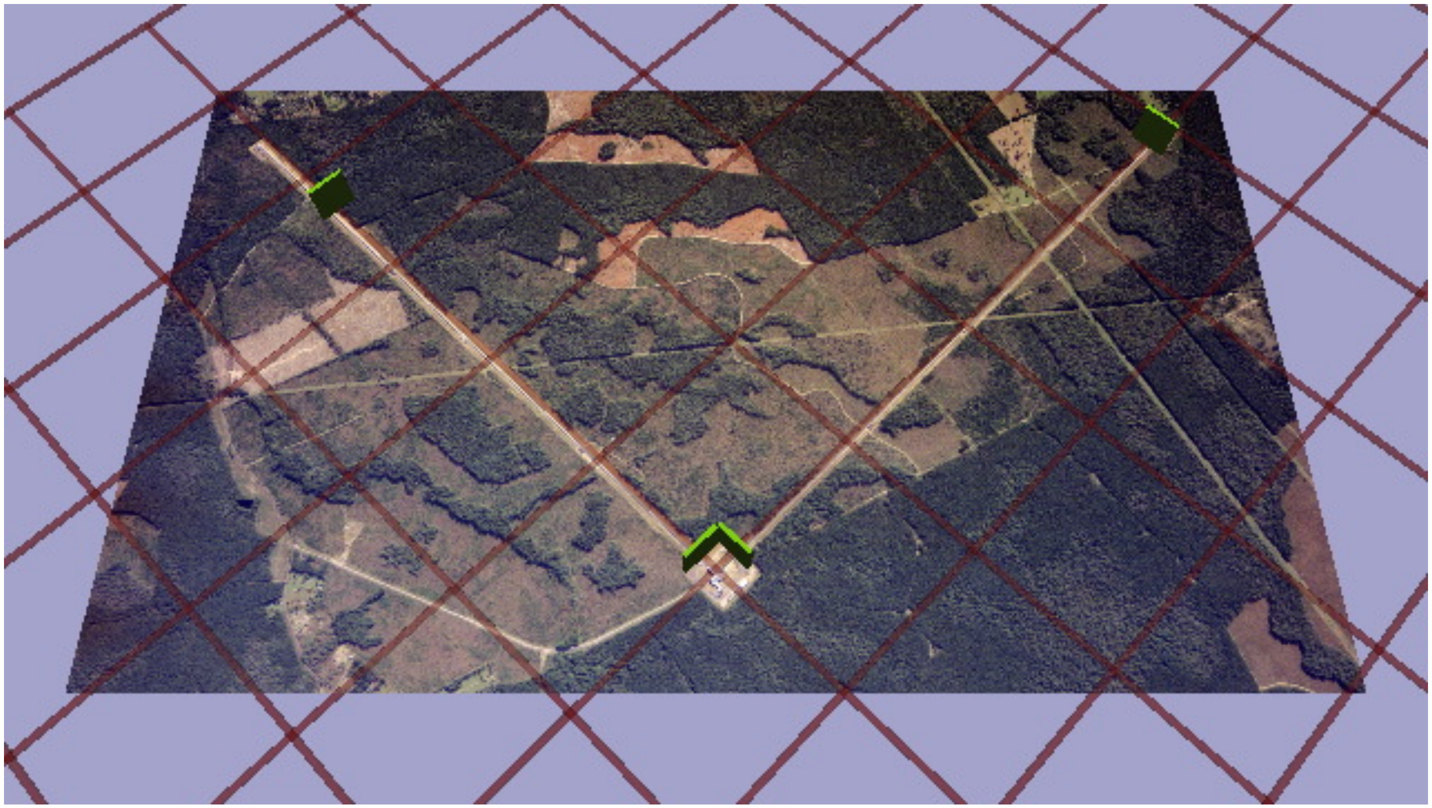
deform space (and any object in it) with a frequency which is twice the orbital frequency



The stretching is described by a dimensionless strain, $h = \Delta L / L$

h is inversely proportional to the distance from the source

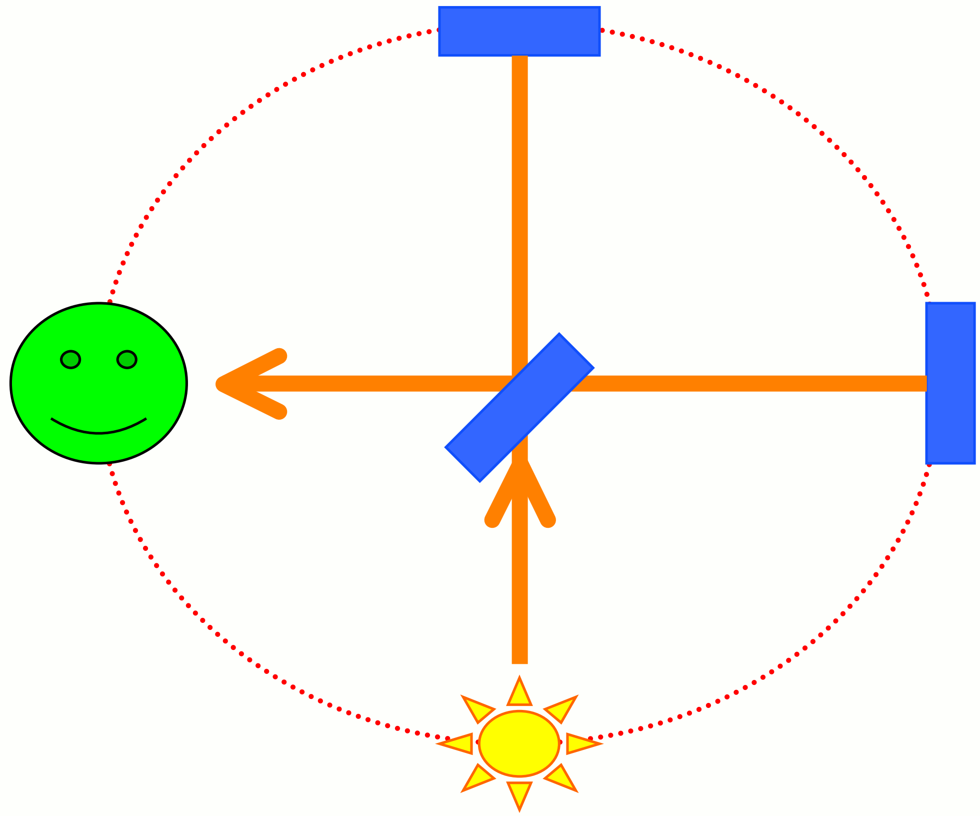
On a small planet in a spiral galaxy far far away…



How can we measure these waves?

Use a Michelson interferometer

Automatically compares orthogonal geodesics using light beams



So what's the catch?

Doing the math…

A wave's strength is characterized by its *strain*

$$h = \Delta L / L$$

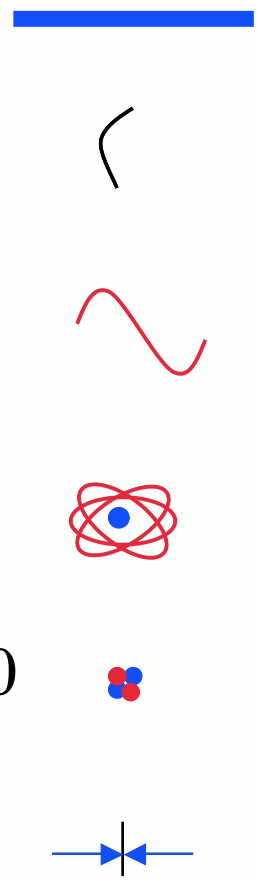
We can calculate the expected strain at Earth for, say, an orbiting binary system;

$$|h| \approx 4\pi^2 GMR^2 f_{orbit}^2 / c^4 r \approx 10^{-21} \left(\frac{R}{20\text{km}}\right)^2 \left(\frac{M}{M_\Theta}\right) \left(\frac{f_{orbit}}{400\,\text{Hz}}\right)^2 \left(\frac{10\text{Mpc}}{r}\right)$$

If we make our interferometer very big, say 4,000 meters long, then

$$\Delta L = h \times L \approx 10^{-21} \times 4{,}000\, m \approx 10^{-18}\, m$$

How Small is 10^{-18} Meter?



One meter, about 40 inches

÷10,000 — Human hair, about 100 microns

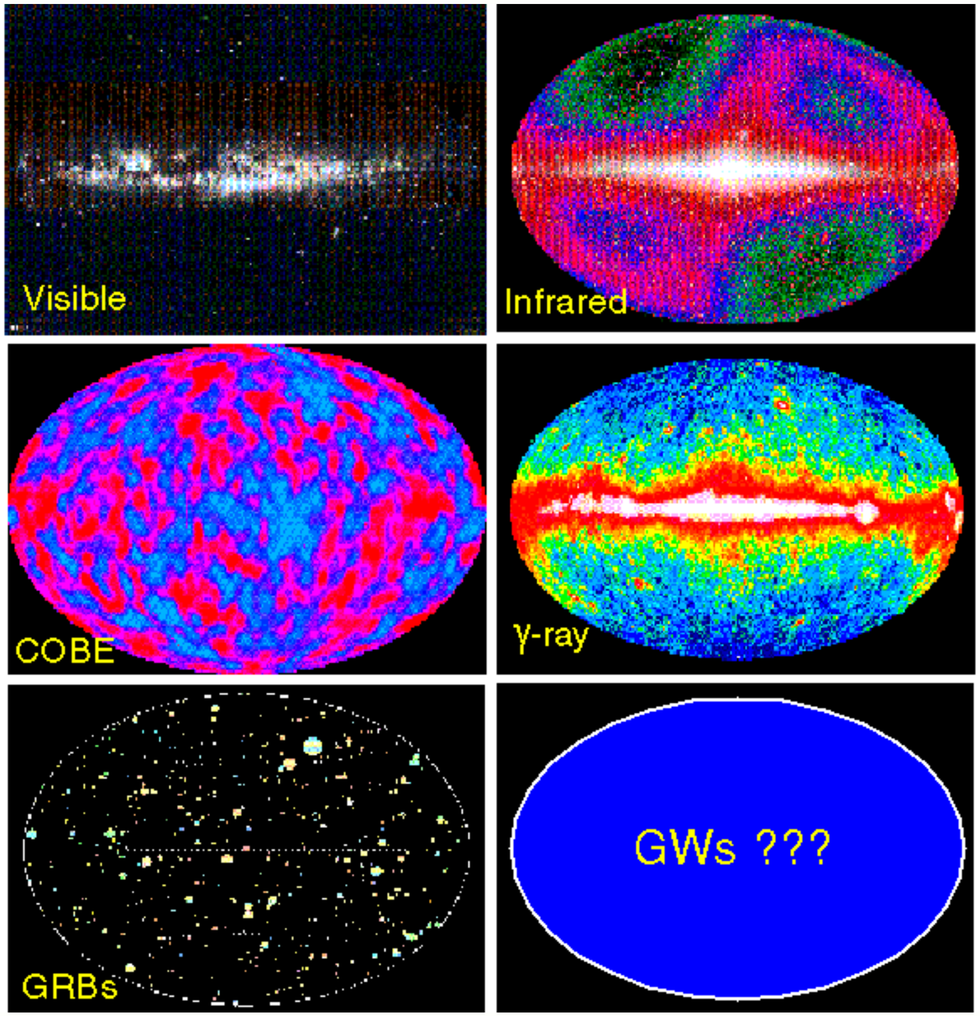
÷100 — Wavelength of light, about 1 micron

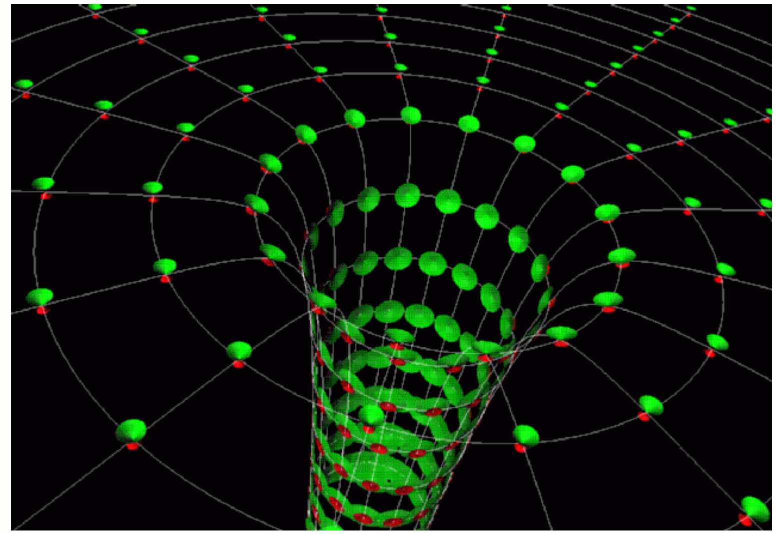
÷10,000 — Atomic diameter, 10^{-10} meter

÷100,000 — Nuclear diameter, 10^{-15} meter

÷1,000 — LIGO sensitivity, 10^{-18} meter

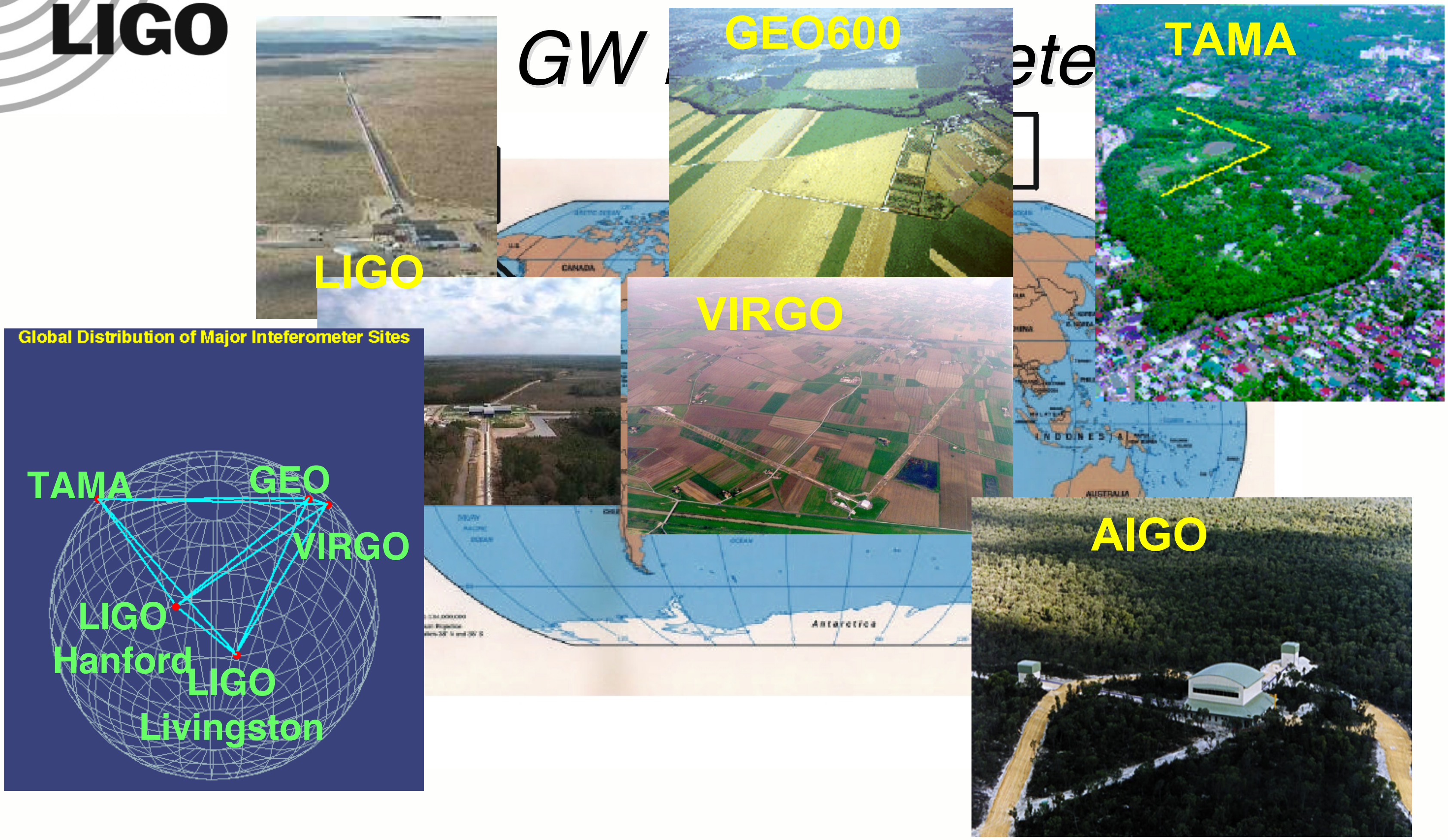
A New ‘Sense’- A New Universe





Gravitational Waves will provide complementary information, as different from what we know as sound is from sight.

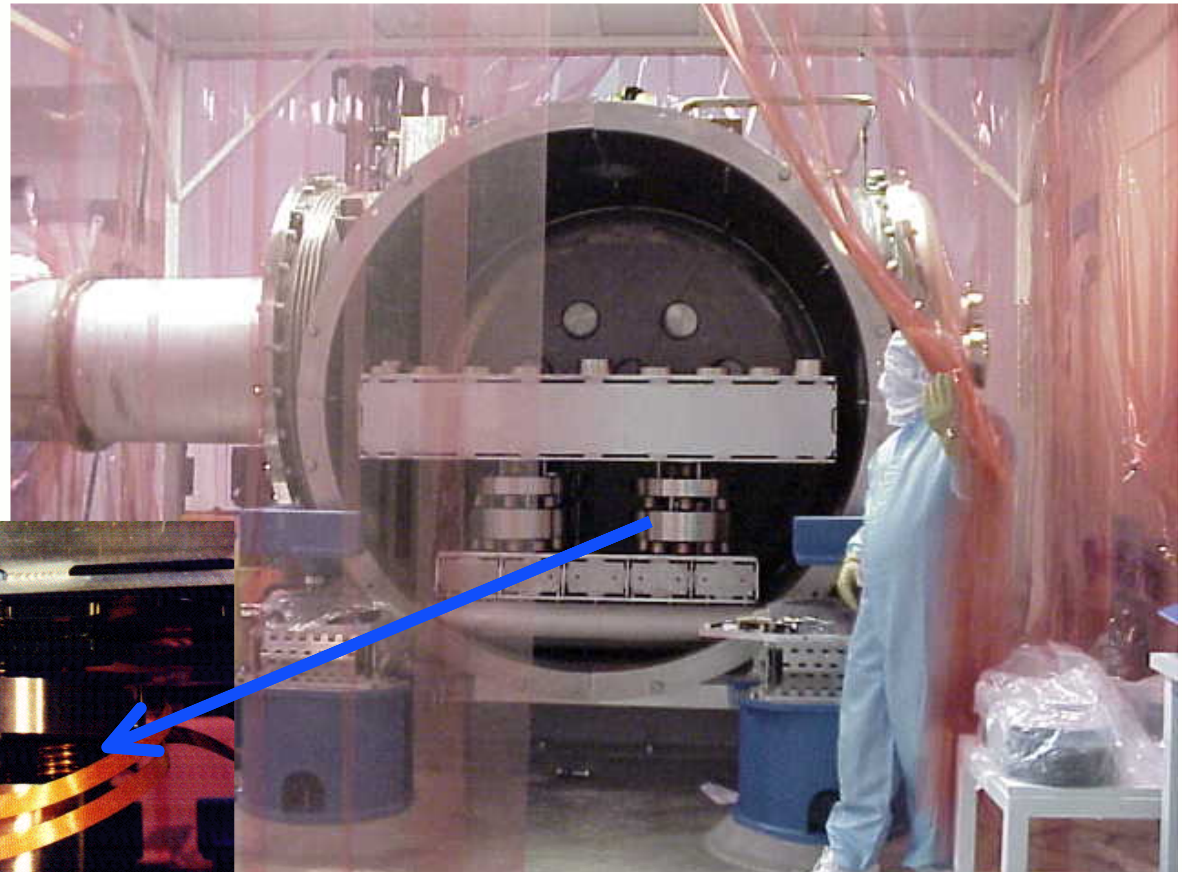
- Coincidence
  - local environments uncorrelated
- Amplitude discrimination
  - half- and full-length IFO's share Hanford site
  - 1:2 ratio required for true signals
- Source triangulation
  - ± 10 ms time of flight
  - ~ arcminute directionality
- Source polarization

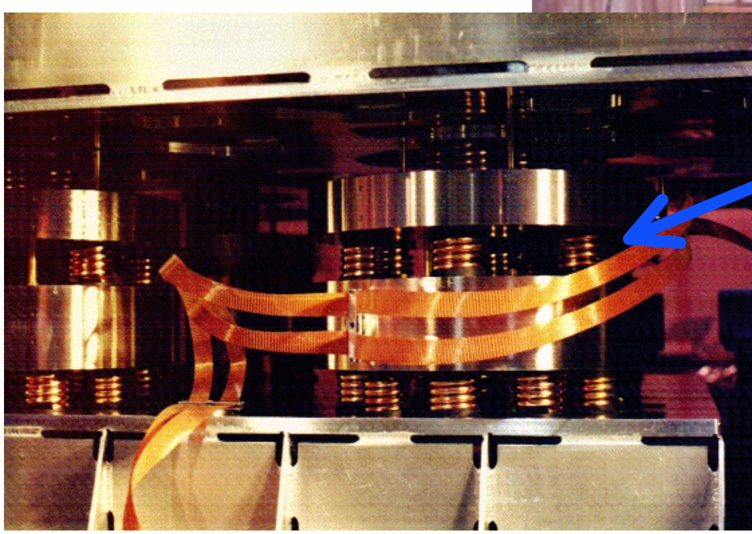


- Worldwide Network:
  - We coordinate observations and share data with TAMA and GEO
  - We are just finalizing similar agreements with VIRGO
  - AIGO is still in planning stage; AIGO personnel currently share in LIGO operation

Seismic Isolation System

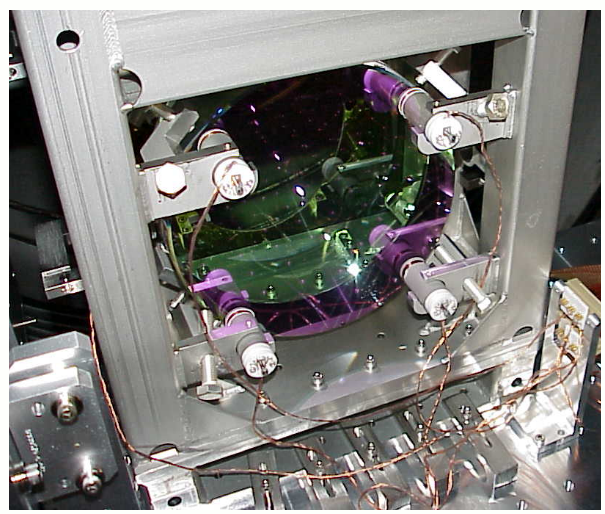
Tubular coil springs with internal constrained-layer damping, layered with reaction masses



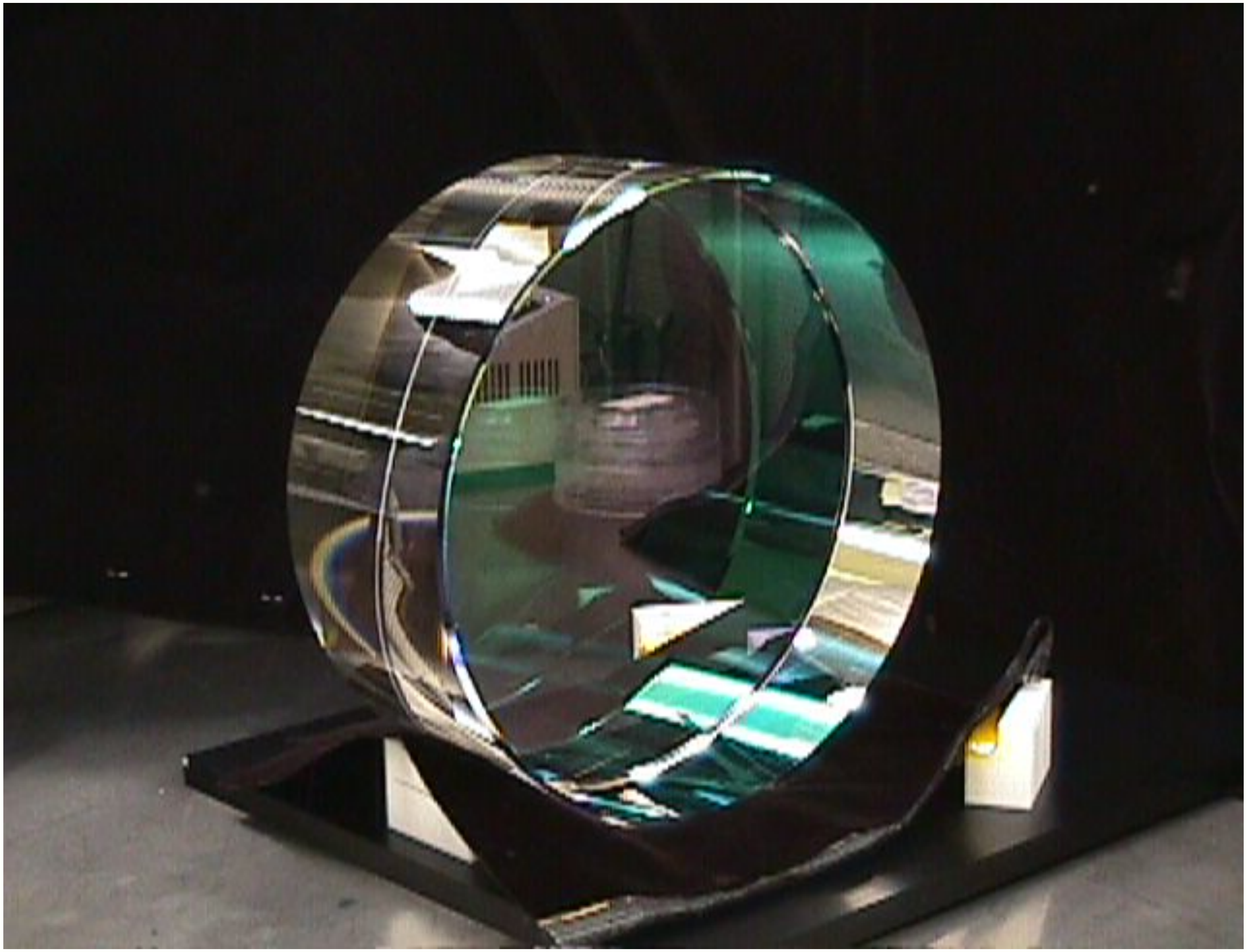


Isolation stack in chamber

Core Optic Suspensions

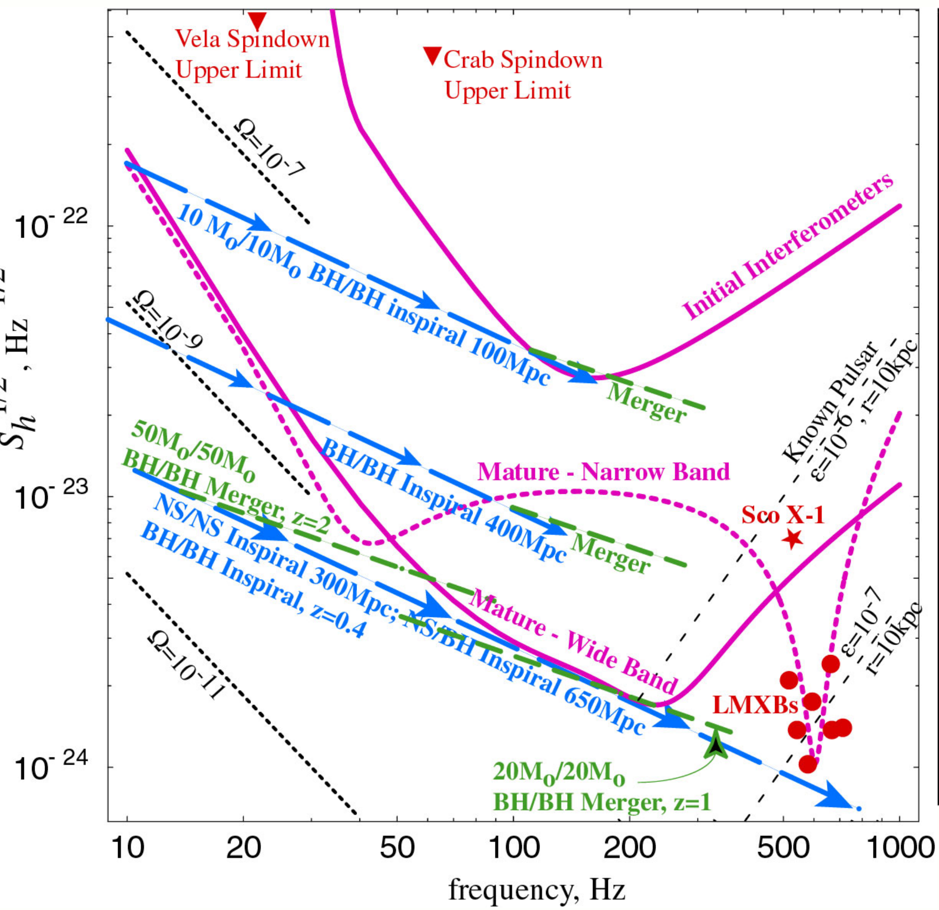


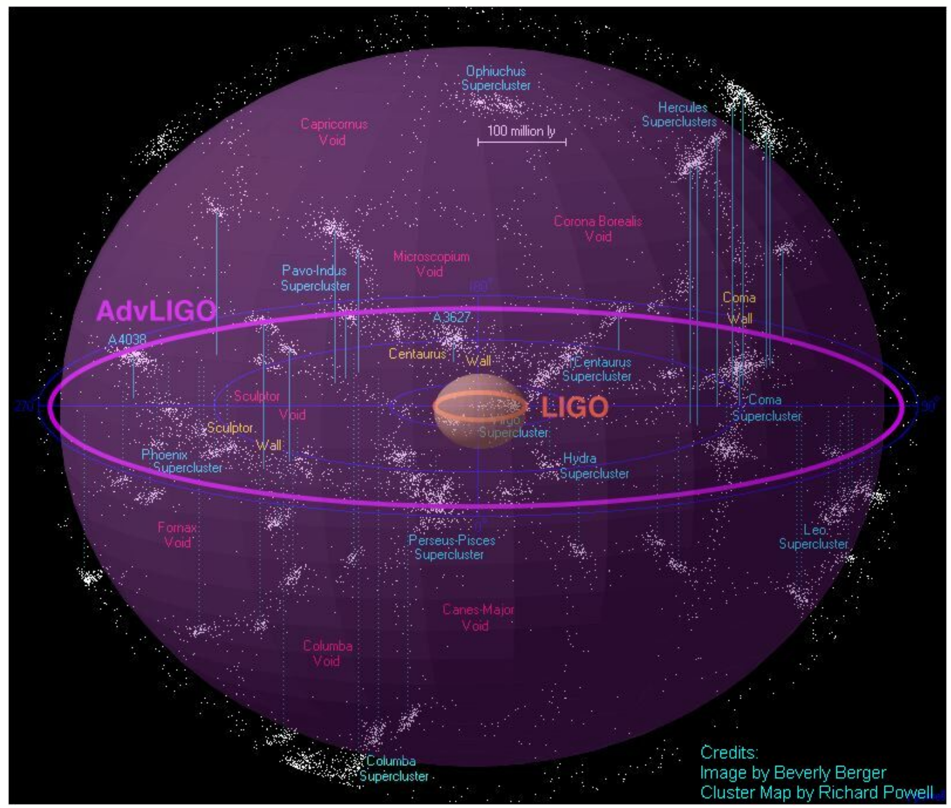
Core Optics



Advanced LIGO

10x increase in sensitivity; 1000x in volume!





Vacuum Equipment

Vacuum requirements: Particulates

- Particles absorb laser power, producing heat & optic distortion
- Particles also scatter power, producing phase noise (interference)
- A single 10 micron particle on a critical optic surface can limit Advanced LIGO performance
- Particles in the vacuum system MOVE AROUND

- HEPA- and ULPA-filtered environments critical to keeping cleaned surfaces clean
- Need to control not only airborne but shed particles from tools, clothing, etc.
- ISO-STD-14644 (formerly FED 209(E)) is referenced in requirements for clean ambient environments and processes
- Air environments are normally sampled with air particle counters
- IEST-1246D governs requirements for end item surface-resident particles
- Surface particulates may be sampled by liquid transfer, air suction/filter sampling, adhesive transfer, or other means

- LIGO will cooperate in finding the most effective *and* cost-effective means to insure compliance

Vacuum requirements: Hydrocarbons

- Laser beams in AdLIGO will be concentrated to ~ megawatt intensity
- Small absorption by contaminant film causes heating (& distortions)
- Invisible HC films can carbonize or break down, leading to thermal runaway

- Vacuum bake mitigates volatile residues, but…
- Won't succeed unless surfaces are as clean as possible to start with
- Emphasis is to insure removal of mill and fab residues

- NVR (Non Volatile Residue) requirements also reference IEST-1246D
- Parts can be tested, for example, by rinsing with solvent followed by evaporation & mass assay; or by FTIR analysis
- Alternatives (demonstrated equivalent) may be proposed

Cleanliness Certification

- Adopting good practices and training staff is the most important component of the program; you cannot “test-in” cleanliness
- LIGO has experience working with vendors to make *and* keep clean large and complex fabrications, efficiently and economically
- We would like to know *your* capabilities and experience