General Relativity Gravitational Radiation & LIGO at *more than* full sensitivity

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Maxwell: EM waves with velocity c= 299792458m/sec

- Einstein: c with respect to what?
  - Every observer measures the same speed!
- All observers see the same laws of physics!

Lorentz Transformations

$$x' = \gamma[x-(v/c)ct]$$

$$y' = y$$

$$z' = z$$

$$ct' = \gamma[ct-(v/c)x]$$

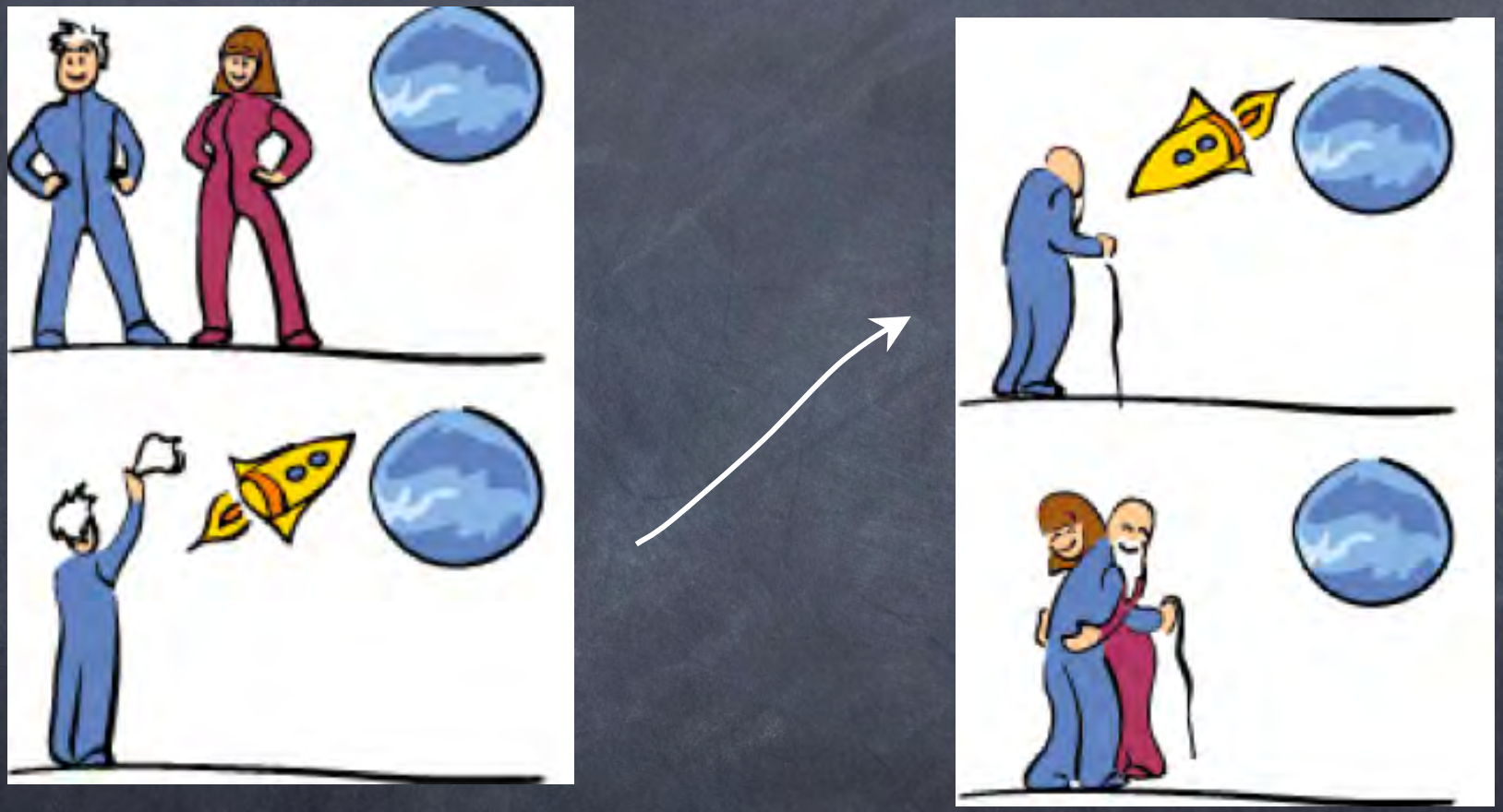
where

$$\gamma = 1/\sqrt{[1-(v/c)^2]}$$

(Lorentz had discovered these transformations in a physical model of the electron in an EM field.)

Lorentz transformations imply time dilation and length contraction, but have dramatic new implications for causality and "spacetime" (rather than "space" and "time").

Simultaneity is Relative!



Twin Paradox-- moving twin "ages slower"

Observational status: twin paradox

Science 14 July 1972:
Vol. 177. no. 4044, pp. 168 – 170
DOI: 10.1126/science.177.4044.168

ARTICLES

Around-the-World Atomic Clocks: Observed Relativistic Time Gains

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"These results provide an unambiguous empirical resolution of the famous clock "paradox" with macroscopic clocks."

Other well known implications

$$E = mc^2$$

Energy and mass are interchangeable!

$$m = m_0/\sqrt{[1-(v/c)^2]}$$

Mass of a moving object increases

$$E = m_0c^2 + KE$$

Energy equivalent of mass increase is Kinetic Energy

General Relativity

Einstein's Description of Gravity

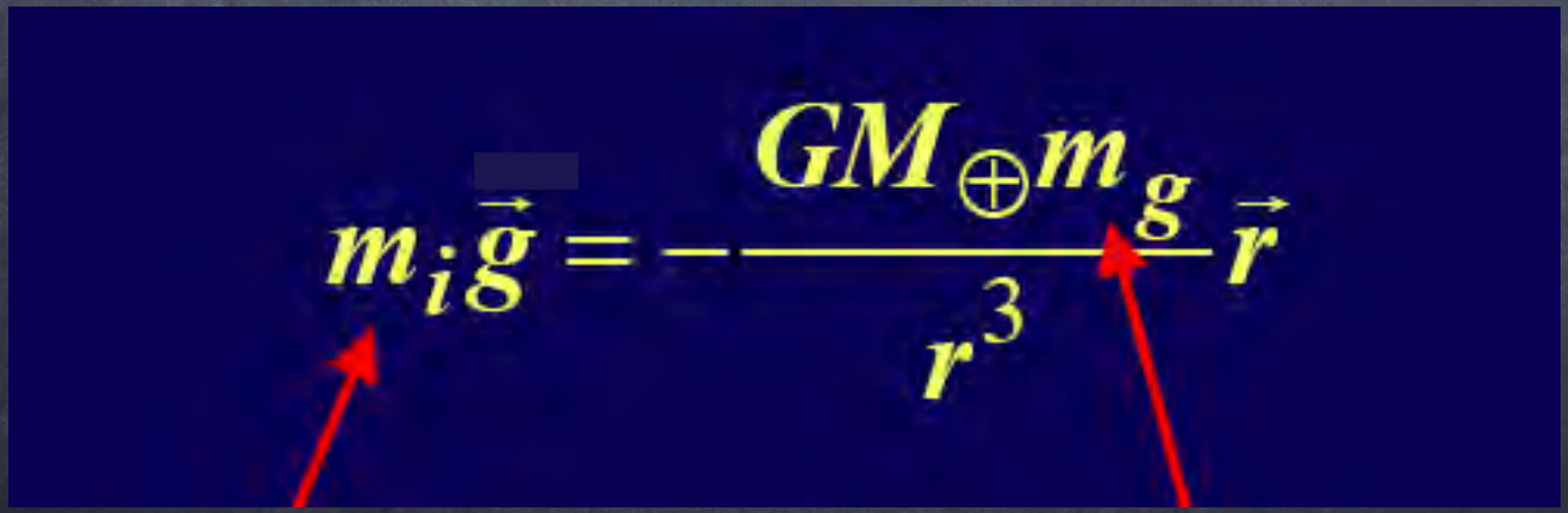
- fully **Geometric** formulation
- replaces Newton's gravitational **Force**

Basic motivation:

Equivalence Principle

Newtonian Equivalence Principle

Everything falls under gravity with the same acceleration!

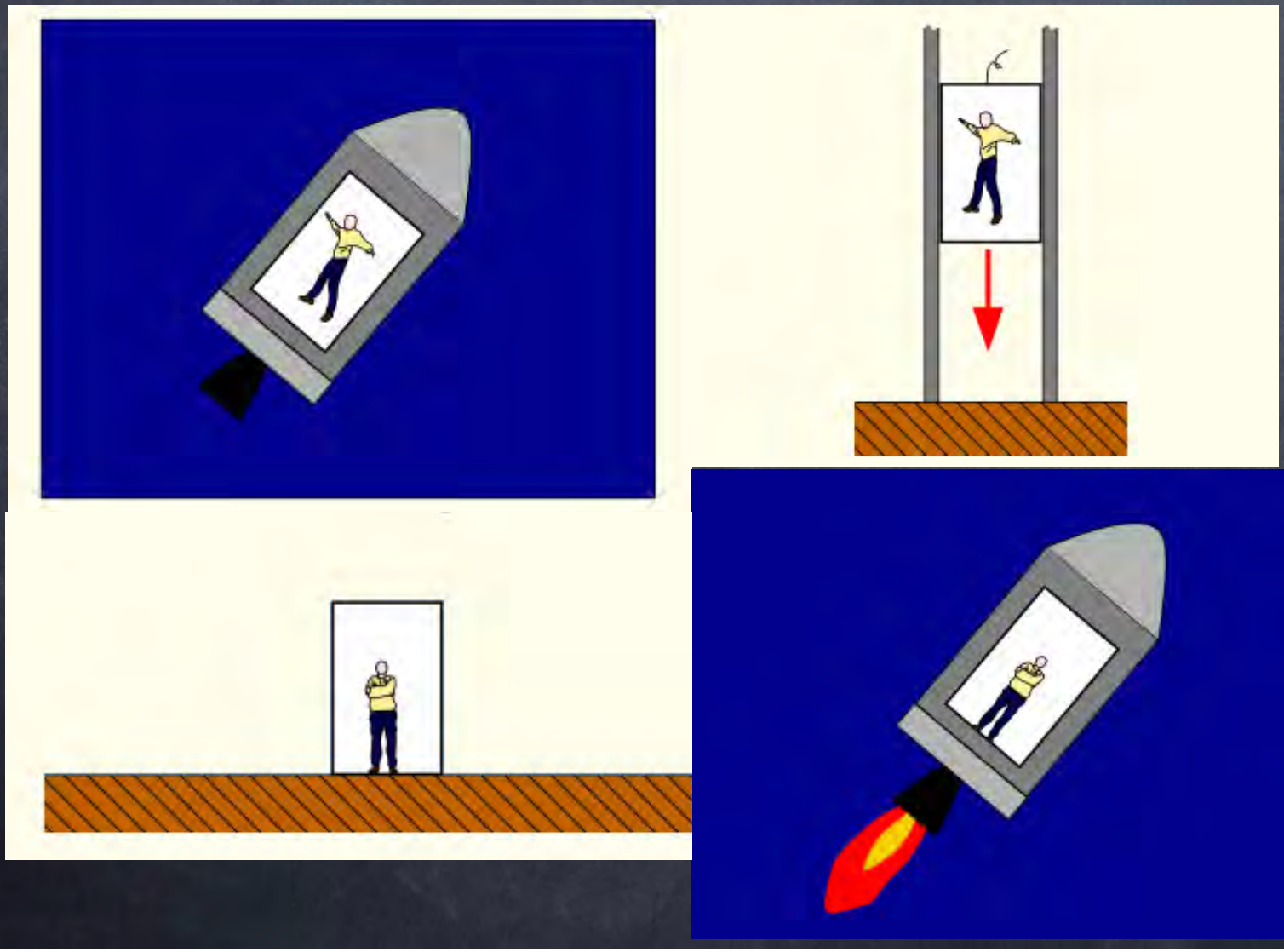


inertial mass gravitational mass

inertial mass = gravitational mass

Different from E&M

Practical effect: Einstein Elevator



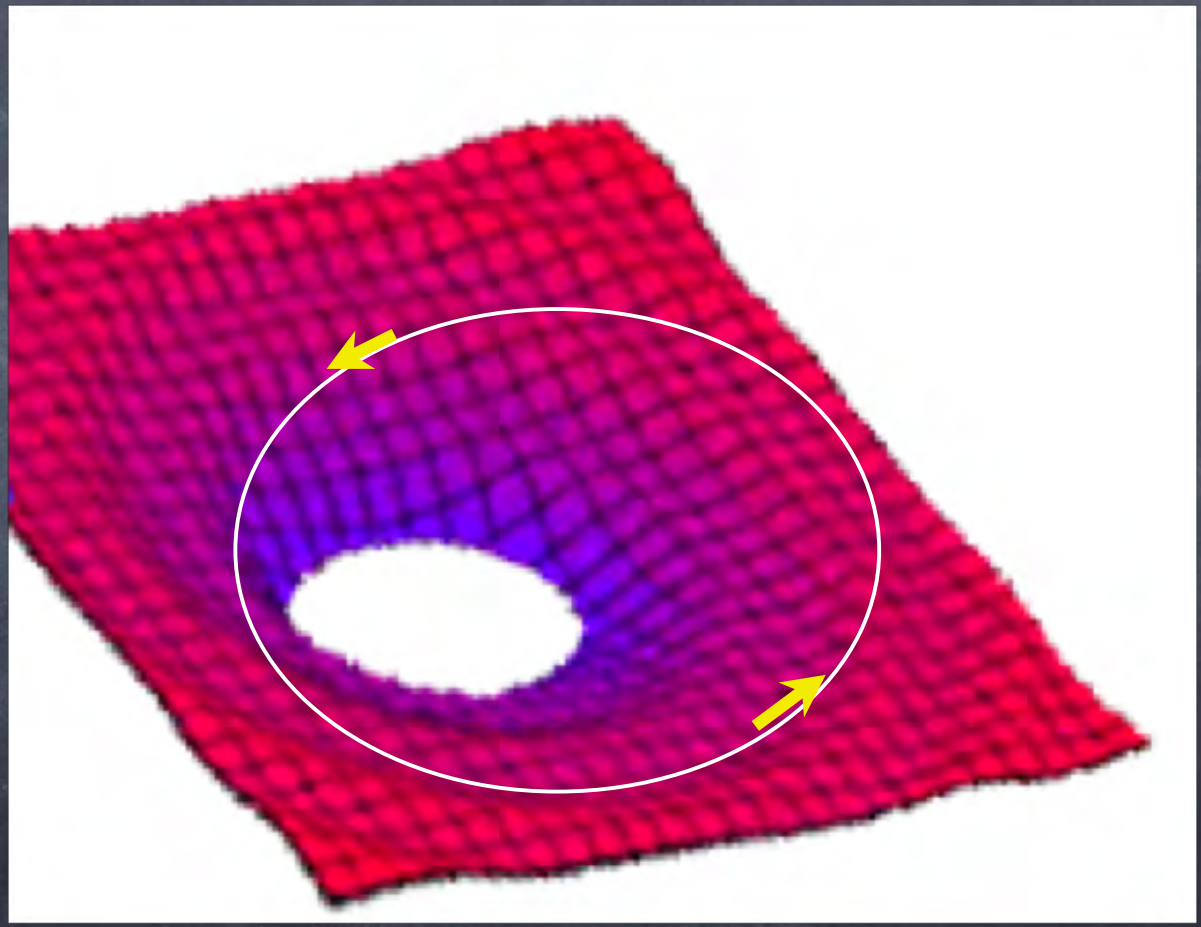
Why is this true? (Theoretical Question)

Newton: because $m_i = m_g$

Einstein: Because objects are following the same path in curved spacetime

Gravity is Curvature!

Curvature determines orbits



Subtle GR Effects in Solar System

Solar gravitational field: 10^{-6}

- Small precession of perihelion of planets ≈ 42″ per century
- Small deflection of light ≈ 10^{-6} radians ≈ 1″.75

Strong Fields Produce Big Effects

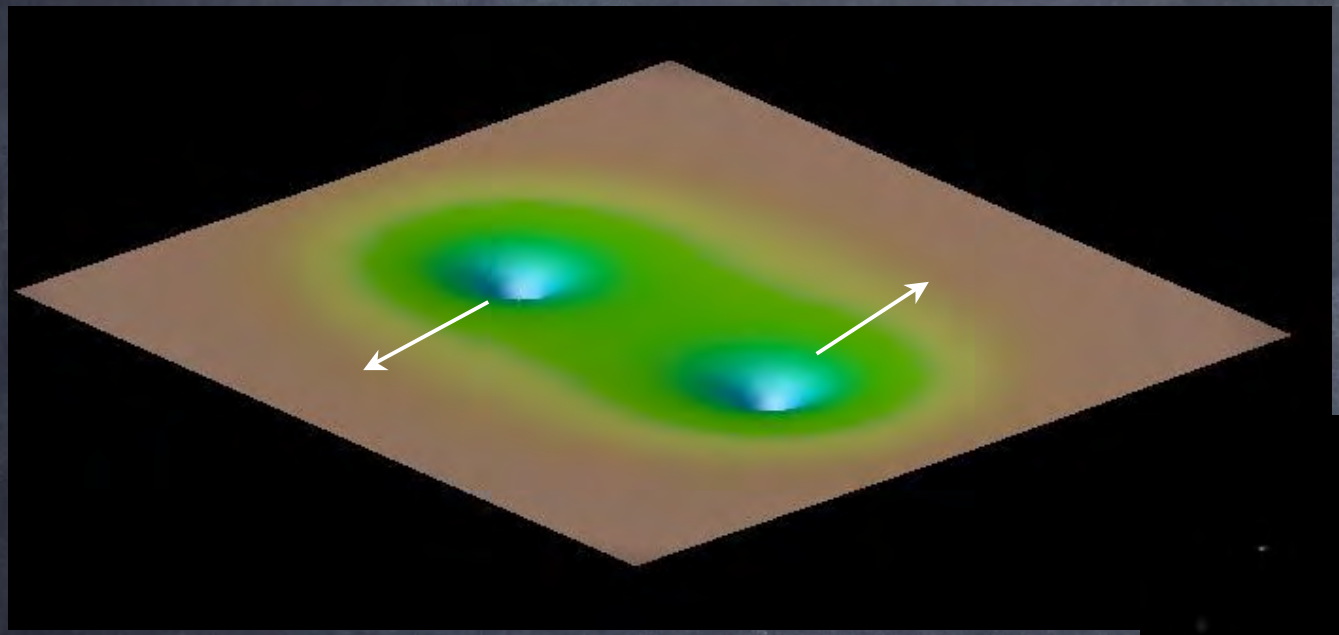
Galaxy Cluster Abell 2218 **HST** • WFPC2

NASA, A. Fruchter and the ERO Team (STScI) • STScI-PRC00-08

Black Holes: the Strongest Gravitating Objects

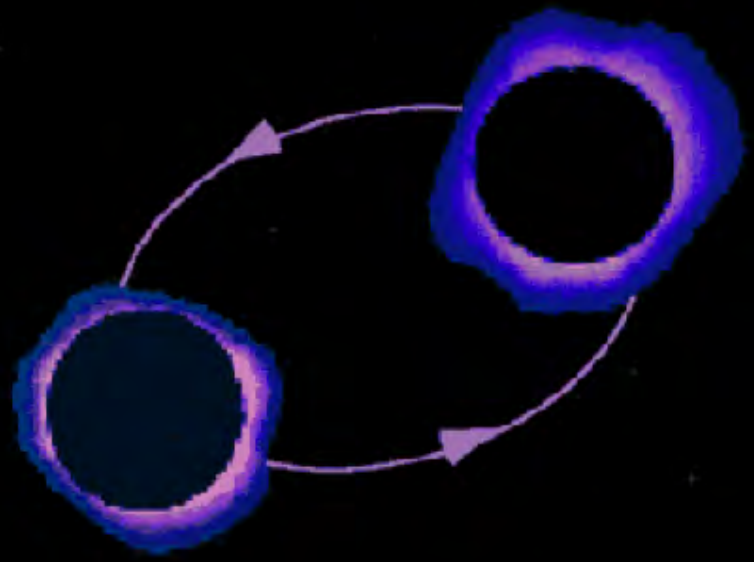
Brookhaven National Lab

Strongest Fields: Binary Black Holes in Orbit



Orbiting strong curvature

Strongest Astrophysical source of Gravitational waves



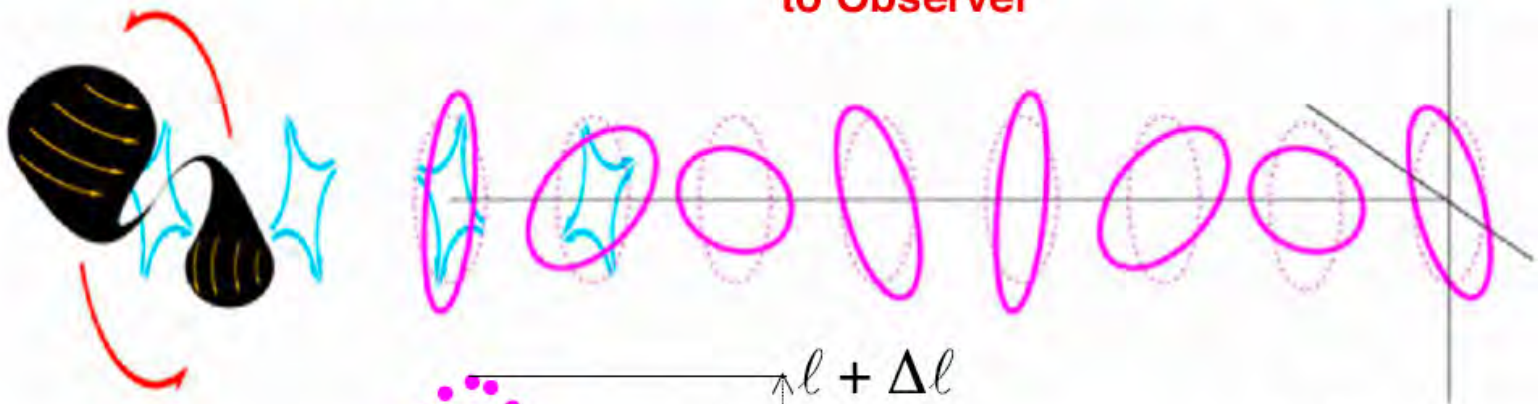
Strong Field Production of Gravitational Waves

Gravitational Radiation

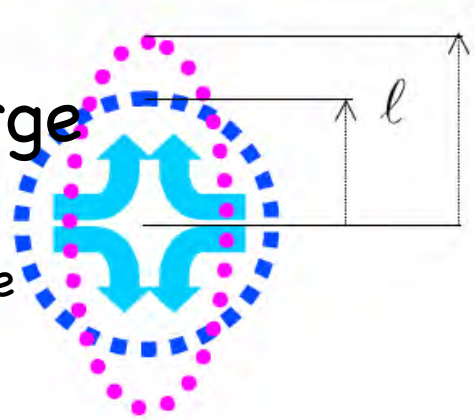
Source: Bulk Motion Produces Changing Tidal Field

Oscillating Tidal Field Propagates (Unobstructed) to Observer

Observer Detects Distortion Strain



$\frac{\Delta \ell}{\ell}$ very large ≈1 at source



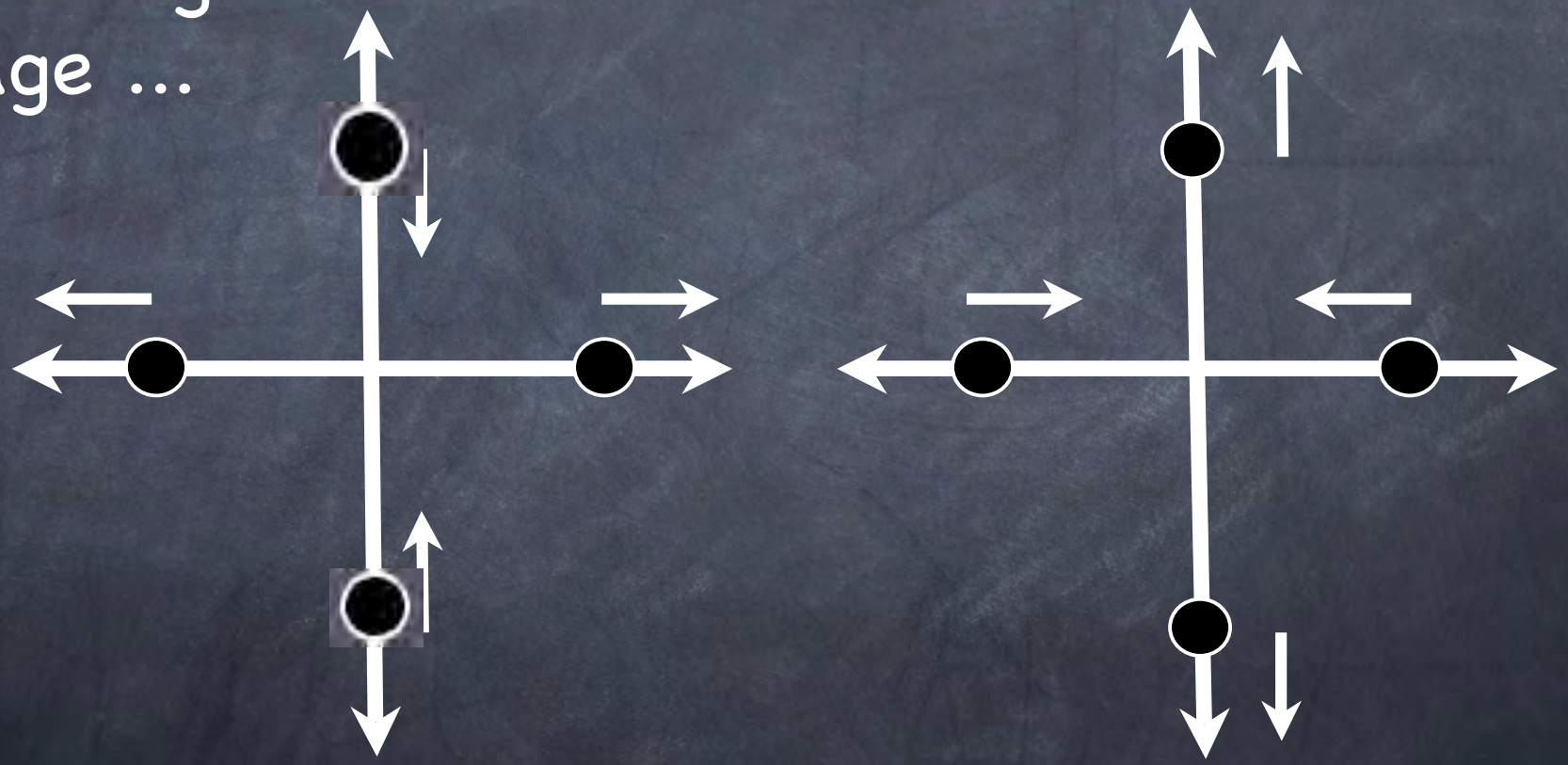
waves are transverse

$\frac{\Delta \ell}{\ell}$ very small ≈10^{-22} when detected

LIGO

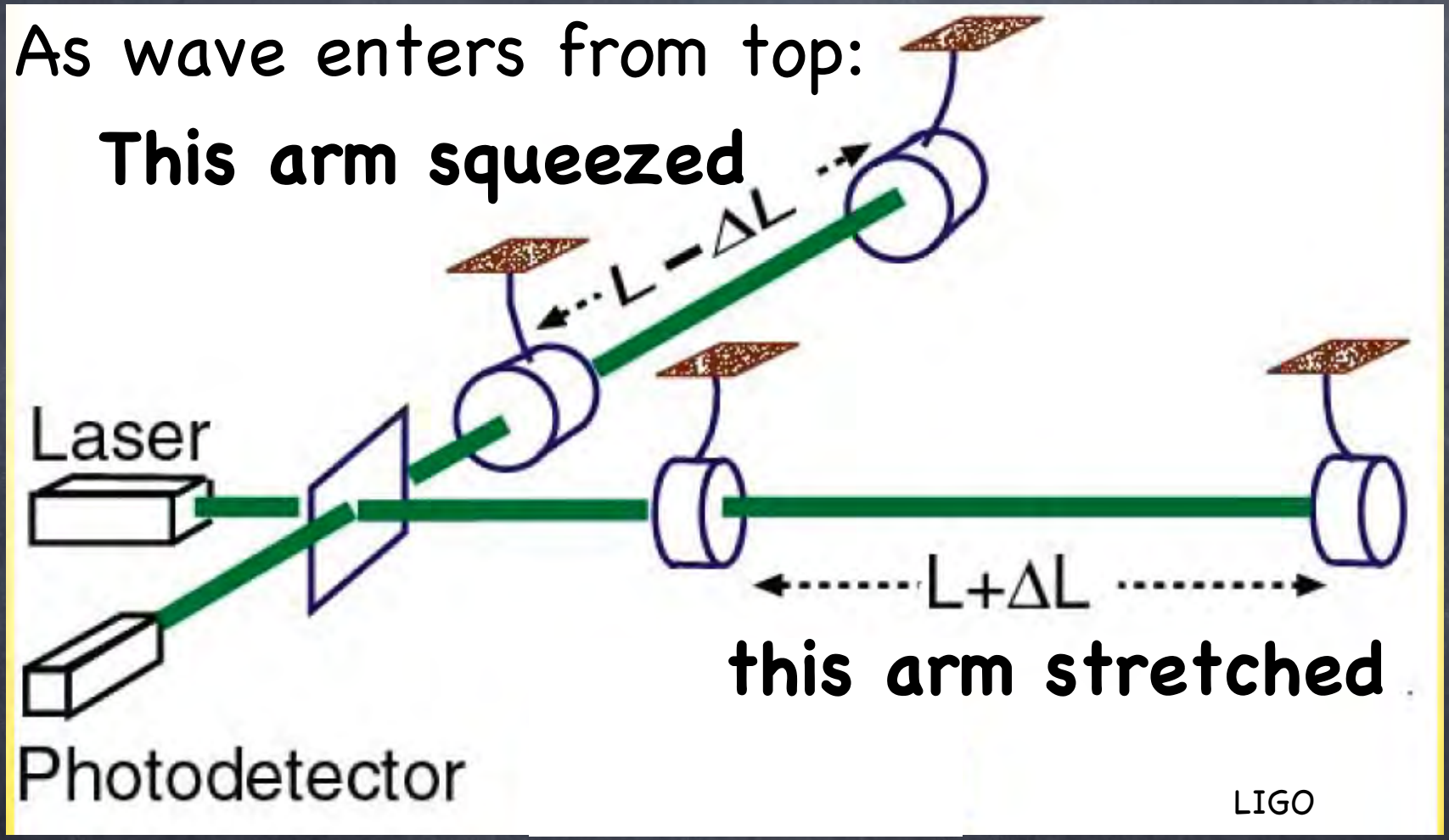
What Gravitational Radiation Does

Wave moving into page ...



produces oscillatory transverse distortion. One transverse direction lengthens while the other shrinks. Then reverses.

Interferometer Detector (LIGO)



Oscillating difference in lengths causes phase difference in arms, interference changes light intensity at the photodetector

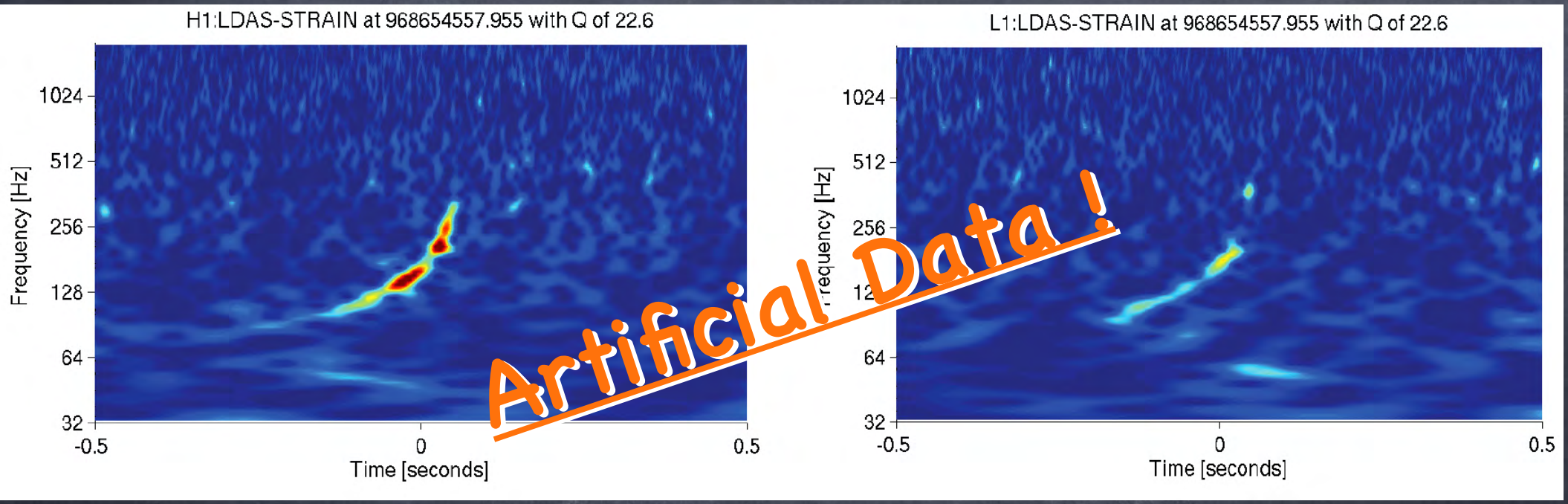
LIGO: Interferometer detector

LIGO has sites in Lousisiana (4km detector) and in Washington state (4km and 2km detectors)

Louisiana Site

LIGO

LIGO: Interferometer detector

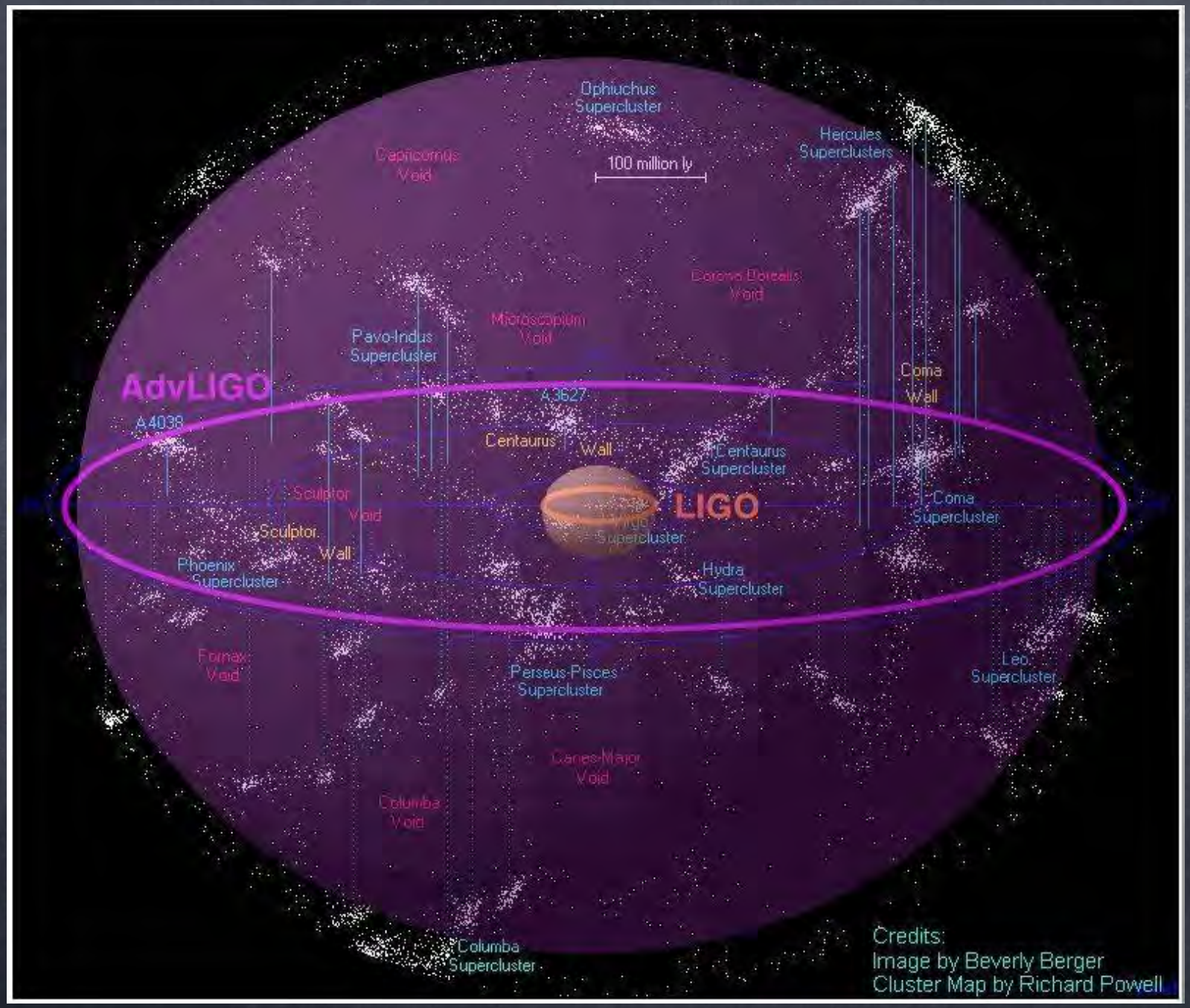


LIGO

- http://www.ligo.org/news/blind-injection.php

No detections so far,
but...

LIGO is being upgraded to examine 1000 x the volume!


Ophiuchus Supercluster
Capricornus Void
100 million ly
Hercules Superclusters
Corona Borealis Void
Microscopium Void
Pavo-Indus Supercluster
AdvLIGO
A3627
Coma Wall
A4038
Centaurus Wall
Centaurus Supercluster
LIGO
Sculptor Void
Coma Supercluster
Sculptor Wall
Phoenix Supercluster
Hydra Supercluster
Fornax Void
Perseus-Pisces Supercluster
Leo Supercluster
Canes Major Void
Columba Void
Columba Supercluster
Credits:
Image by Beverly Berger
Cluster Map by Richard Powell

Gravitational Waves and Spaceborne Detector