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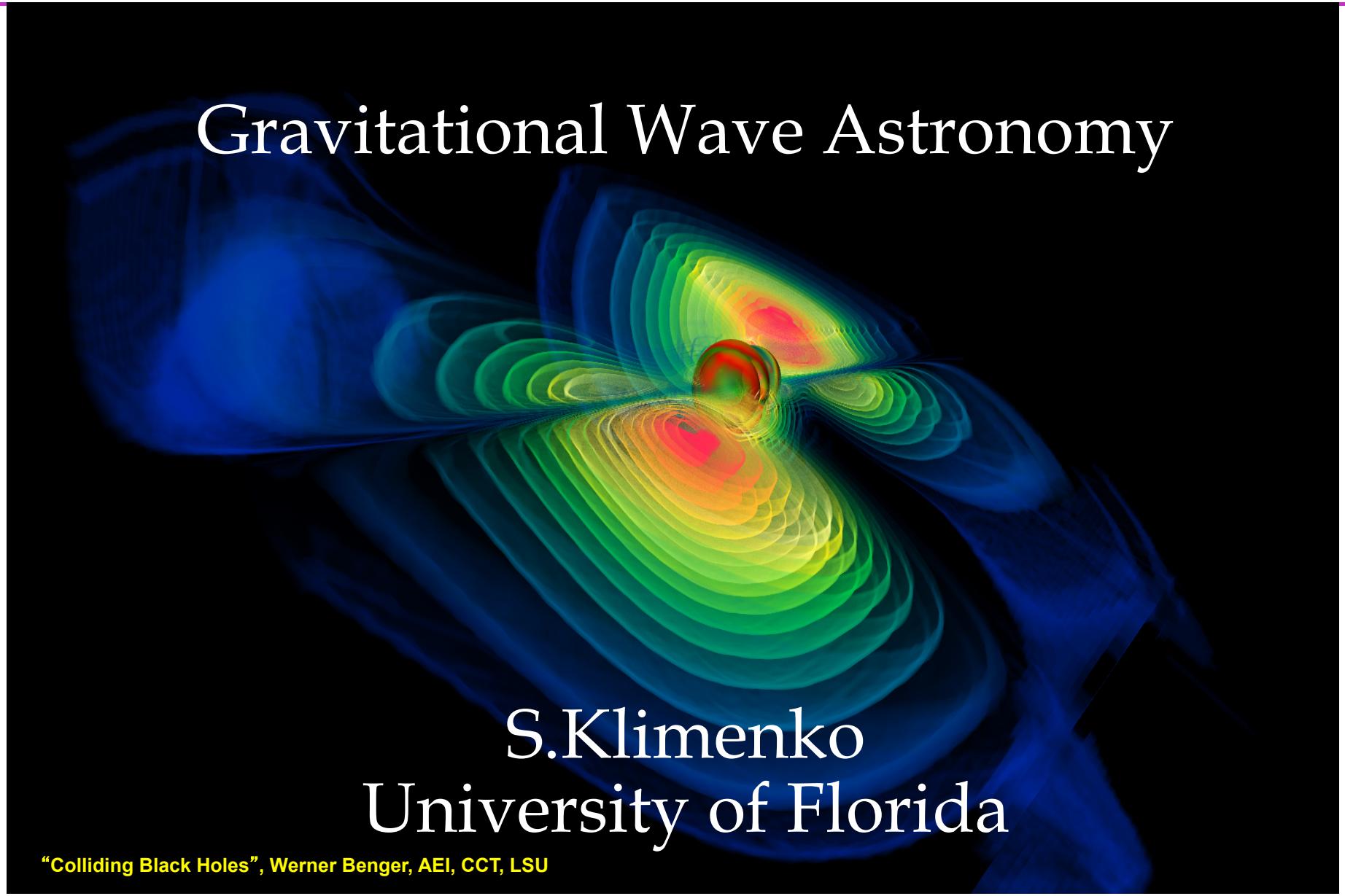
Gravitational Wave Astronomy



S.Klimenko
University of Florida

"Colliding Black Holes", Werner Benger, AEI, CCT, LSU

The nature of Gravity

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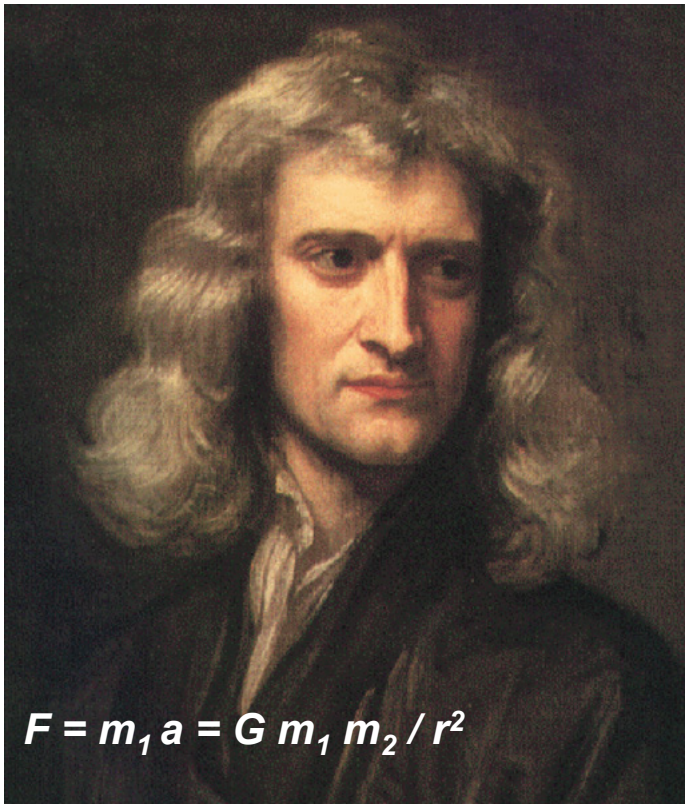
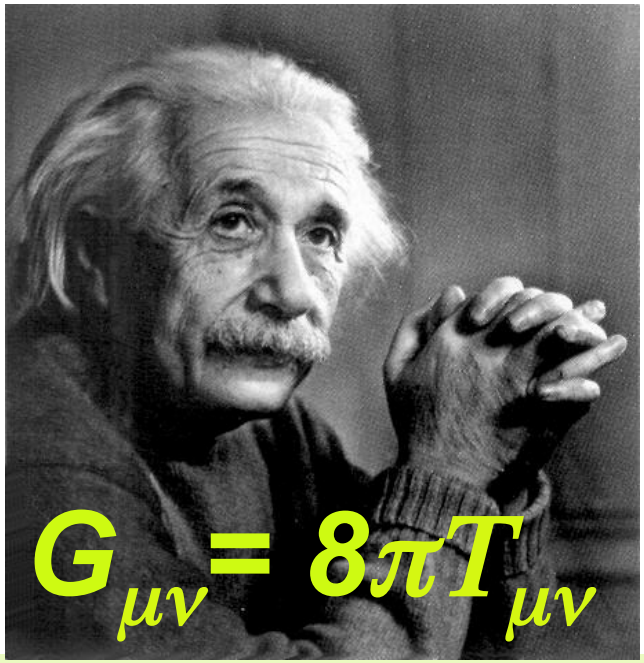
Newton's Theory
"instantaneous action at a distance"





Einstein's General Theory of Relativity
Gravity is a local property of the space occupied by mass m_1 , curved by the source mass m_2 .
Information about changing gravitational field is carried by gravitational radiation at the speed of light

Gravitational Waves

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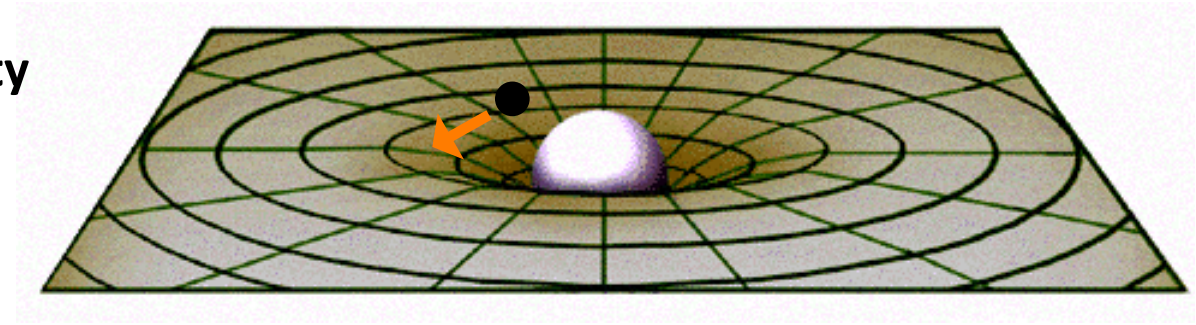
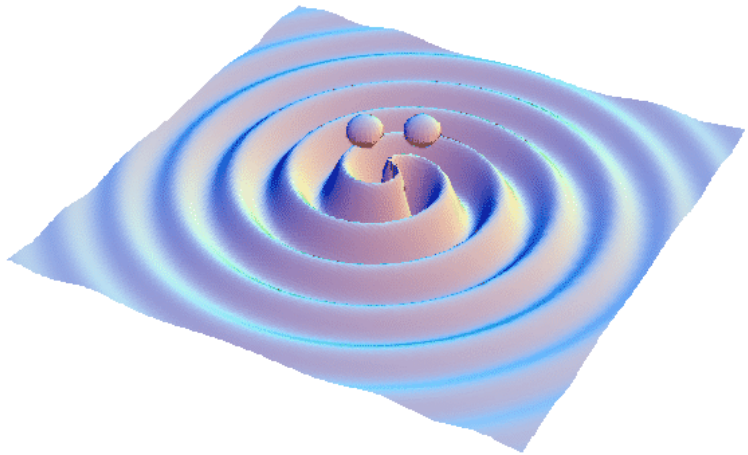
Static gravitational fields are described in General Relativity as a curvature or warpage of space-time, changing the distance between space-time events.



Shortest straight-line path of a nearby test-mass is a ~Keplerian orbit.

If the source is moving (at speeds close to c), eg, because it's orbiting a companion, the "news" of the changing gravitational field propagates outward as gravitational radiation – a wave of space-time curvature



Einstein's Theory of Gravitation
experimental tests

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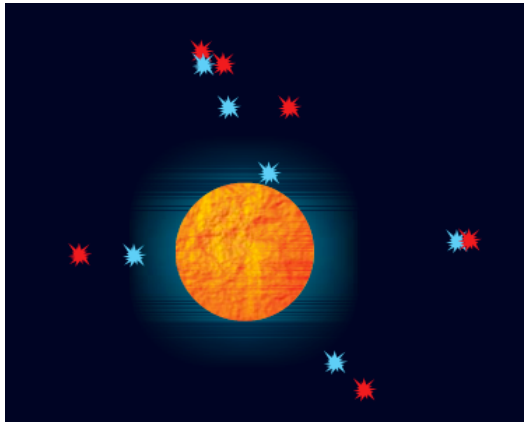

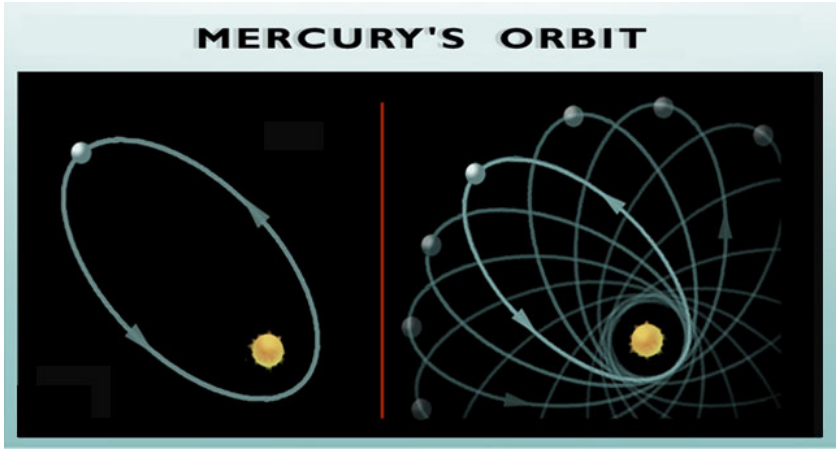

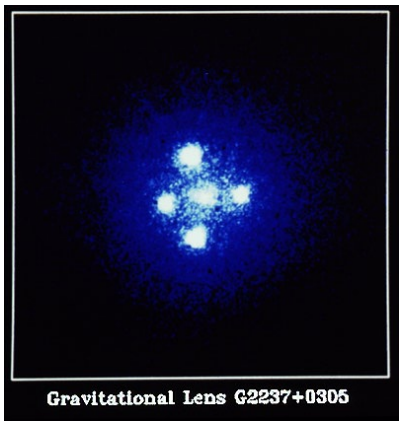

bending of light
As it passes in the vicinity of massive objects

First observed during the solar eclipse of 1919 by Sir Arthur Eddington, when the Sun was silhouetted against the Hyades star cluster

Mercury's orbit
perihelion shifts forward twice Post-Newton theory

Mercury's elliptical path around the Sun shifts slightly with each orbit such that its closest point to the Sun (or "perihelion") shifts forward with each pass.

"Einstein Cross"
The bending of light rays gravitational lensing

Quasar image appears around the central glow formed by nearby galaxy. Such gravitational lensing images are used to detect a 'dark matter' body as the central object

Gravitational Waves: *the evidence*

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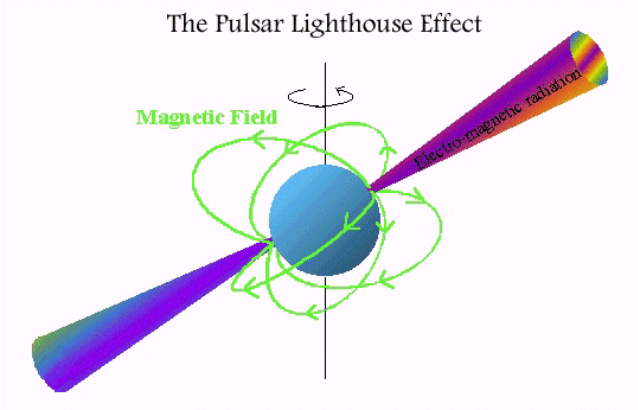
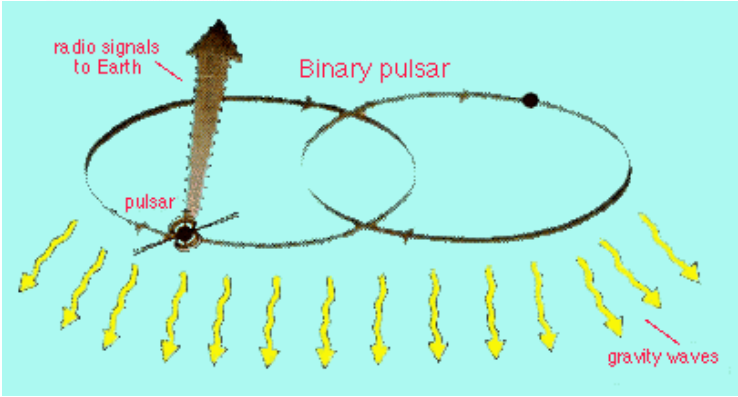
PSR 1913 + 16 Neutron Binary System

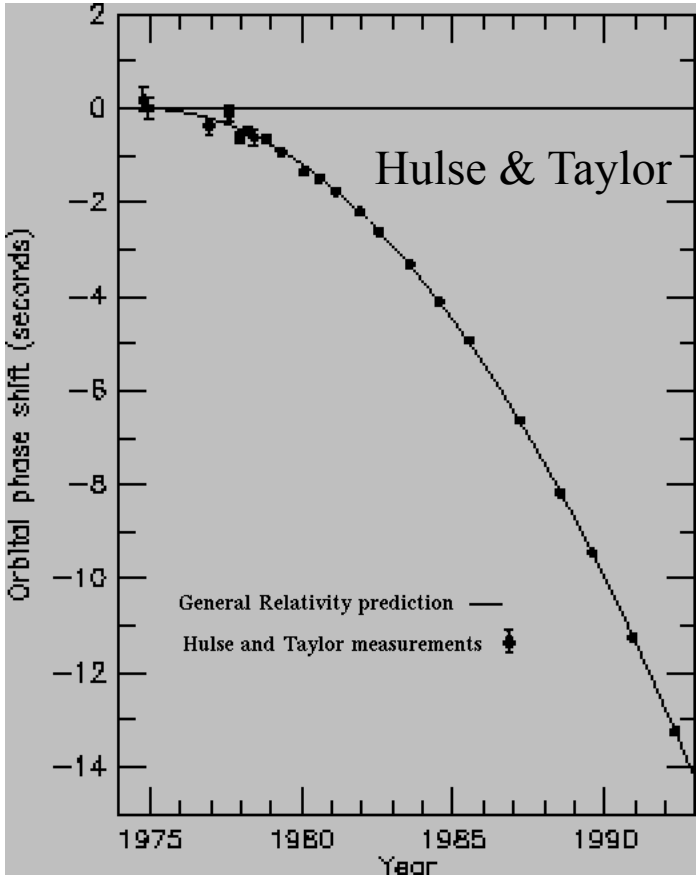
Separated by 10^6miles,

$m_1 = 1.4m_\odot$; $m_2 = 1.36m_\odot$;





Emission of gravitational waves



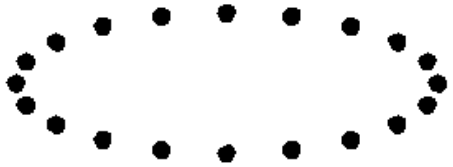
Prediction from general relativity

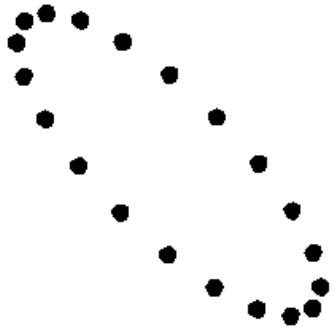
- **spiral in by 3 mm/orbit**
- **merge in 300 million years**

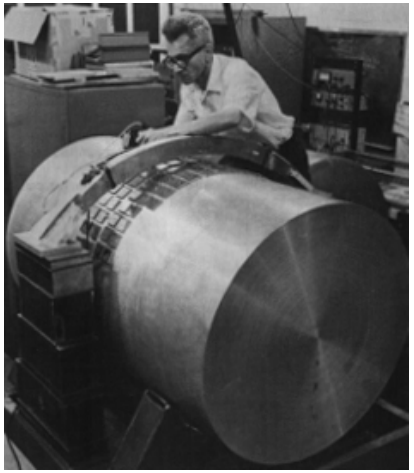
time of periastron relative to that expected if the orbital separation remained constant.

Effect of GW

- Einstein doubted GW physical reality until the end of his life. He proposed many experiments, including really hard ones, but never a search for gravitational waves.
- Felix Pirani's breakthrough was to analyze the reception of gravitational waves: in the presence of a gravitational wave, a set of freely-falling particles would experience genuine motions with respect to one another.
- J.Weber: "When I decided to search for gravitational waves some 14 years ago, most physicists applauded our courage@, but felt that success – detection of gravitational radiation – would require a century of experimental work." (Popular Science May 1972)







Gravitational Waves

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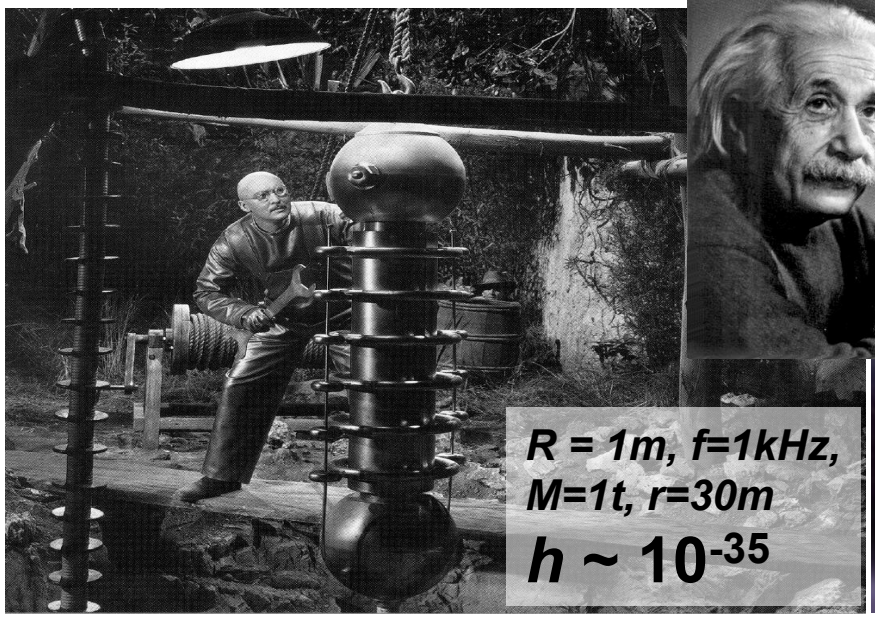
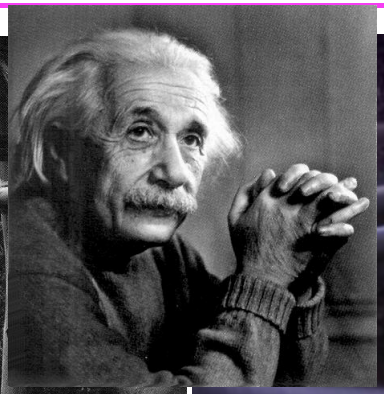
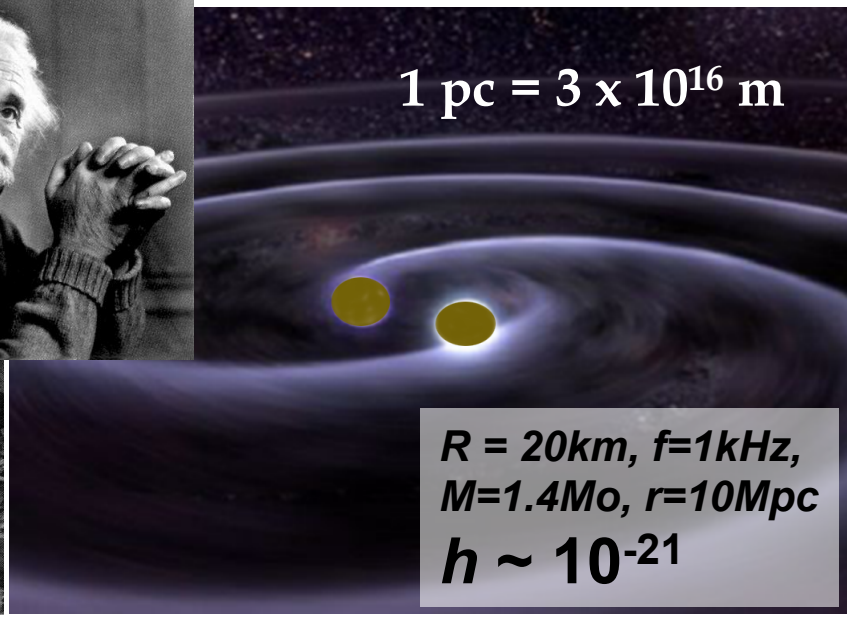




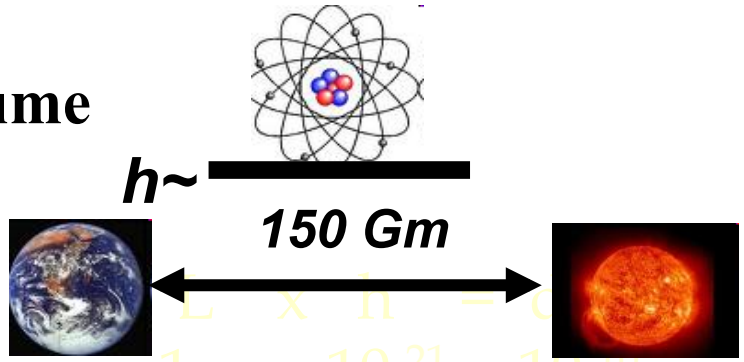


- **Predicted by Einstein's theory of GR**
- **Not feasible in the lab**
- **astrophysical sources are the only hope: need to search a vast space volume**

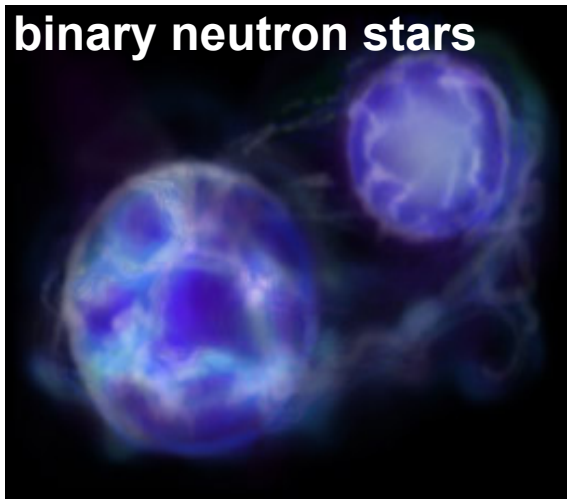
$$h \approx \frac{4\pi^2 G M R^2 f^2}{r c^4}$$

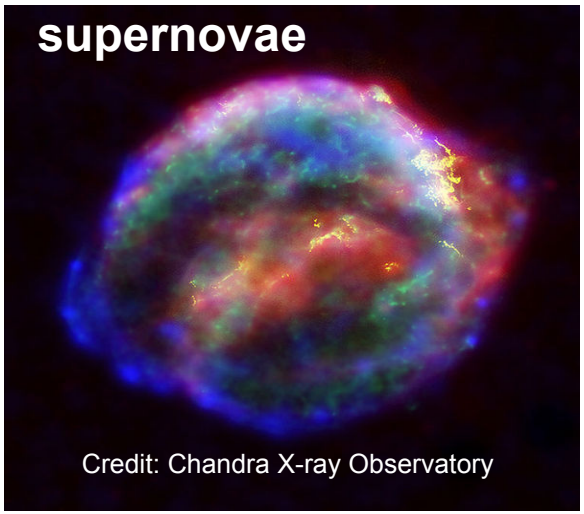
need detectors with sensitivity better than

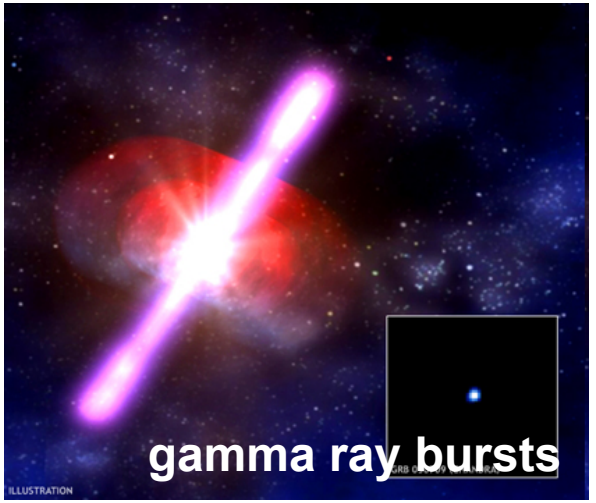
$$h = \frac{\Delta L}{L} \sim 10^{-23}$$

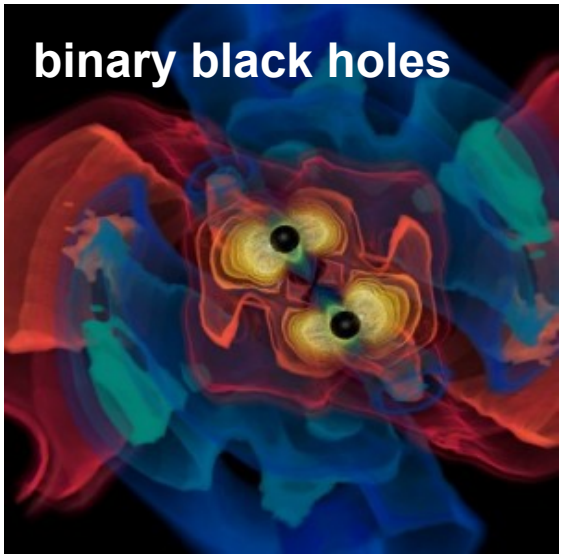


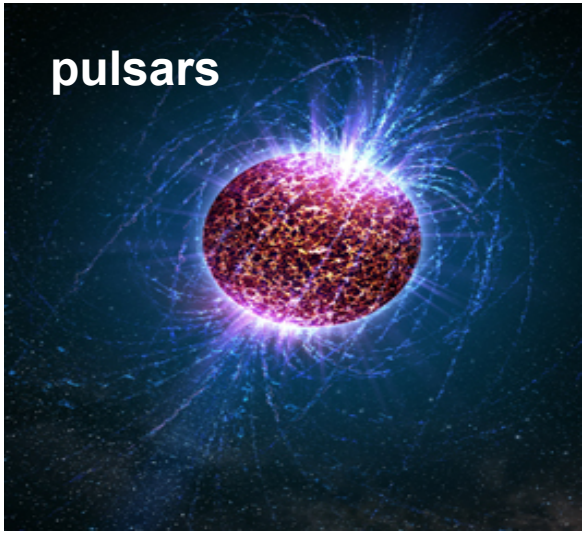
Sources

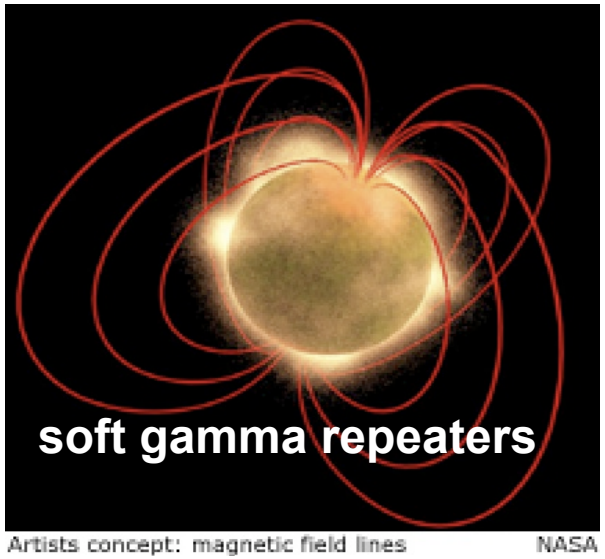












and other violent astrophysical sources..

LIGO Observatory

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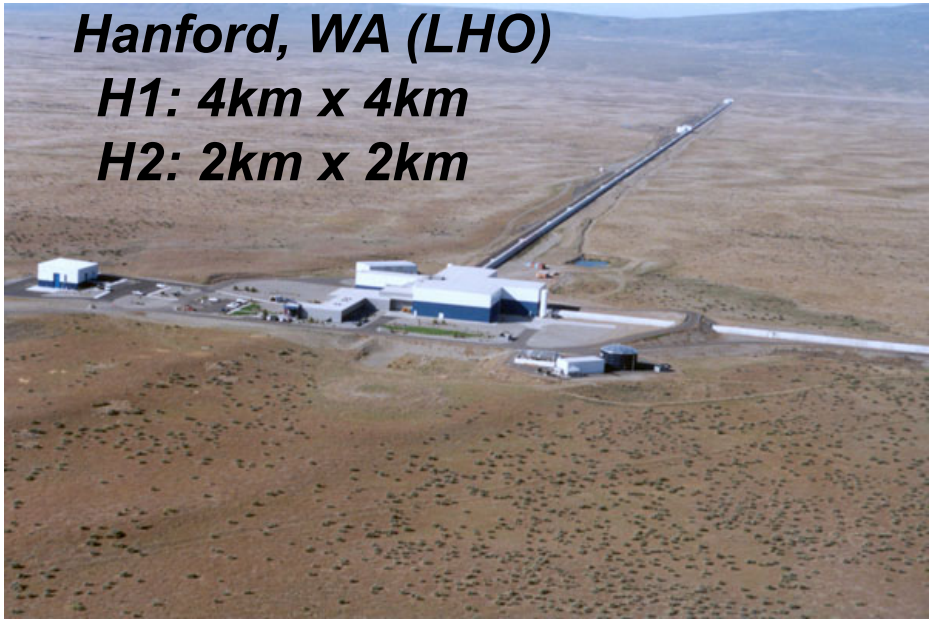

- **Largest (~$1B) project funded by NSF**
- **Several data taking runs between 2001-2009**
  - ✓ most sensitive instrument to date→ capable to see NS-NS mergers out to ~20Mpc
  - ✓ started upgrade in 2010

LIGO Scientific Collaboration

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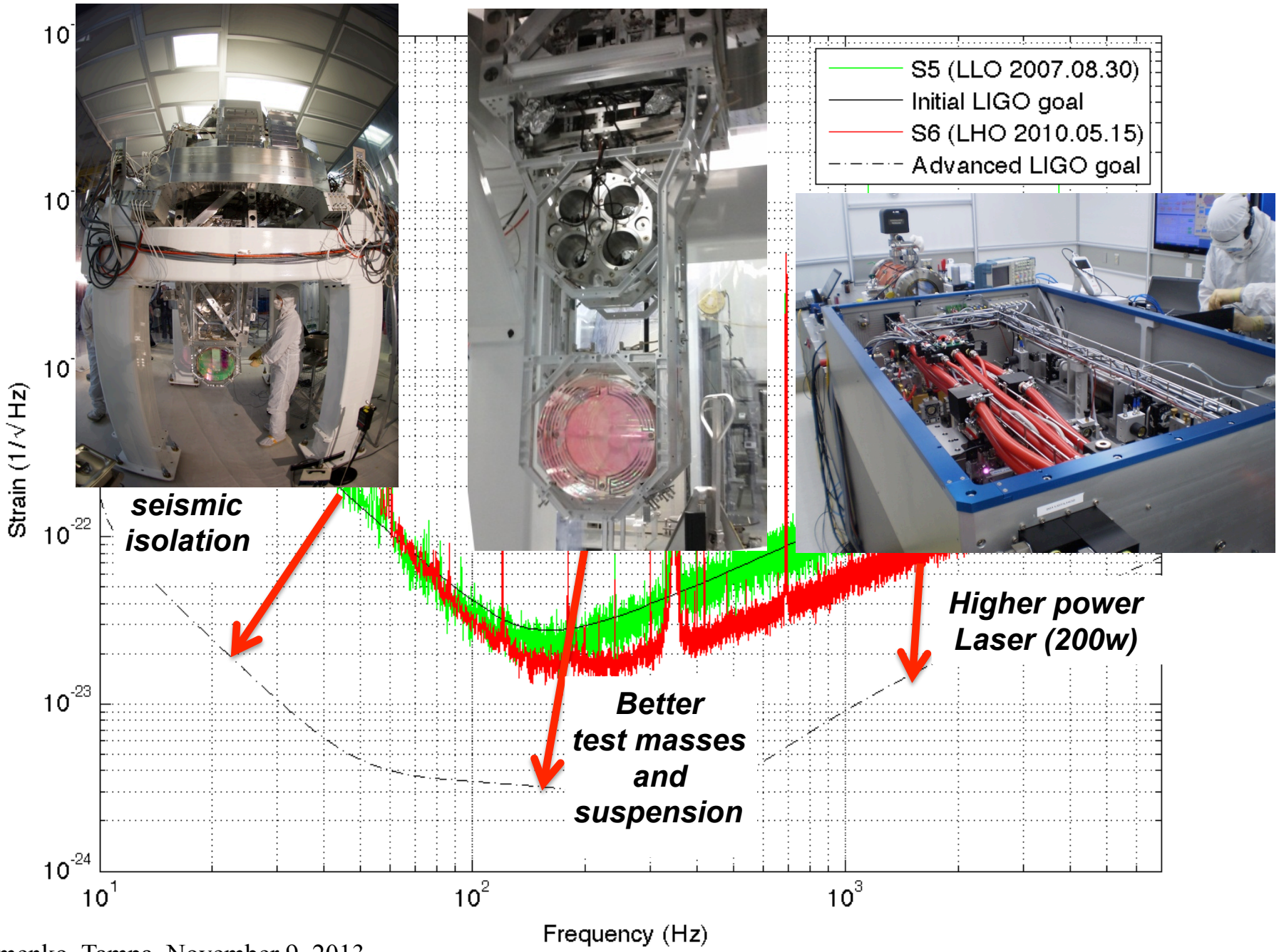
- 900+ members, 86+ institutions, 17 countries


S5 (LLO 2007.08.30)
Initial LIGO goal
S6 (LHO 2010.05.15)
Advanced LIGO goal
seismic isolation
Better test masses and suspension
Higher power Laser (200w)
Strain (1/√Hz)
Frequency (Hz)

Advanced LIGO

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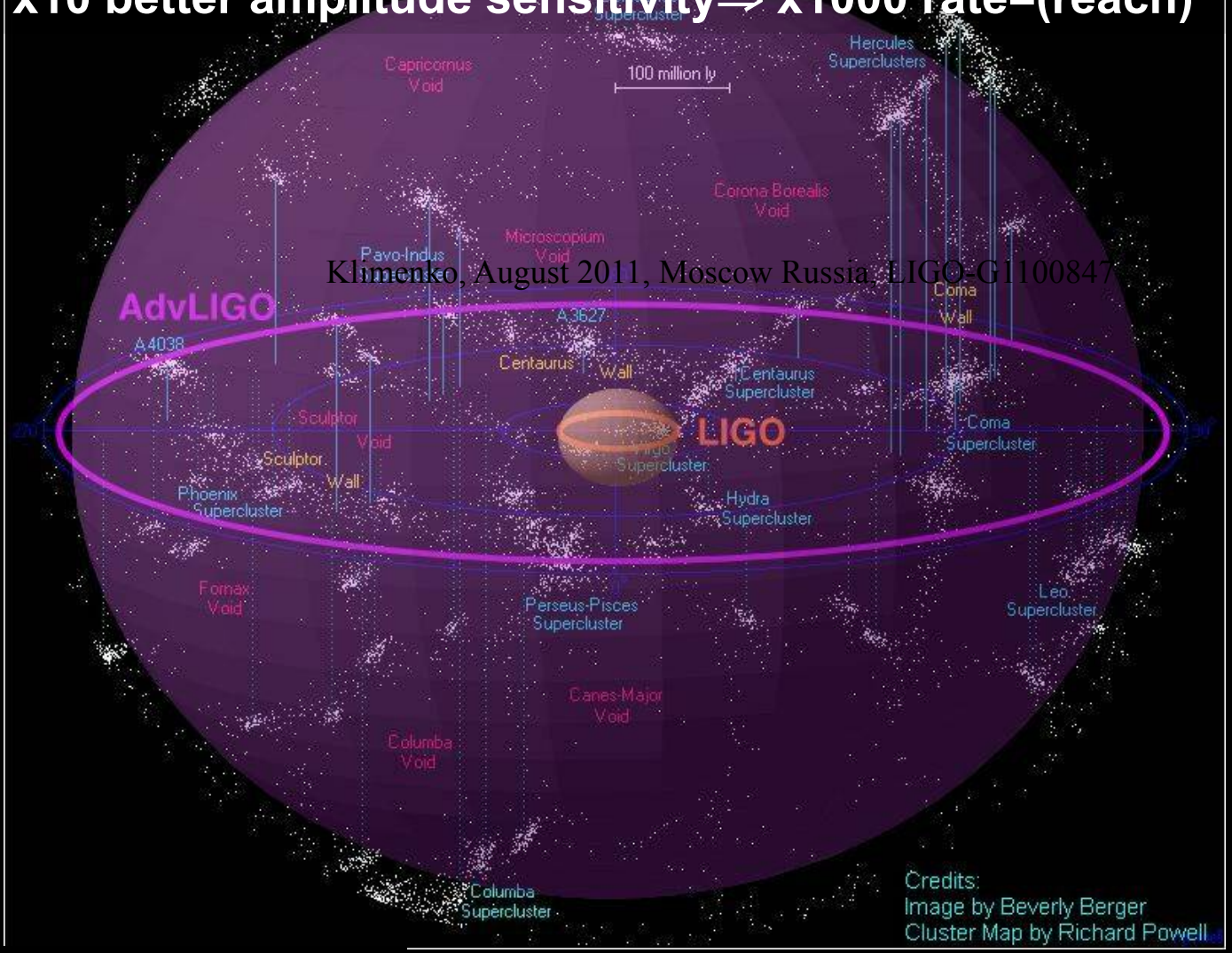
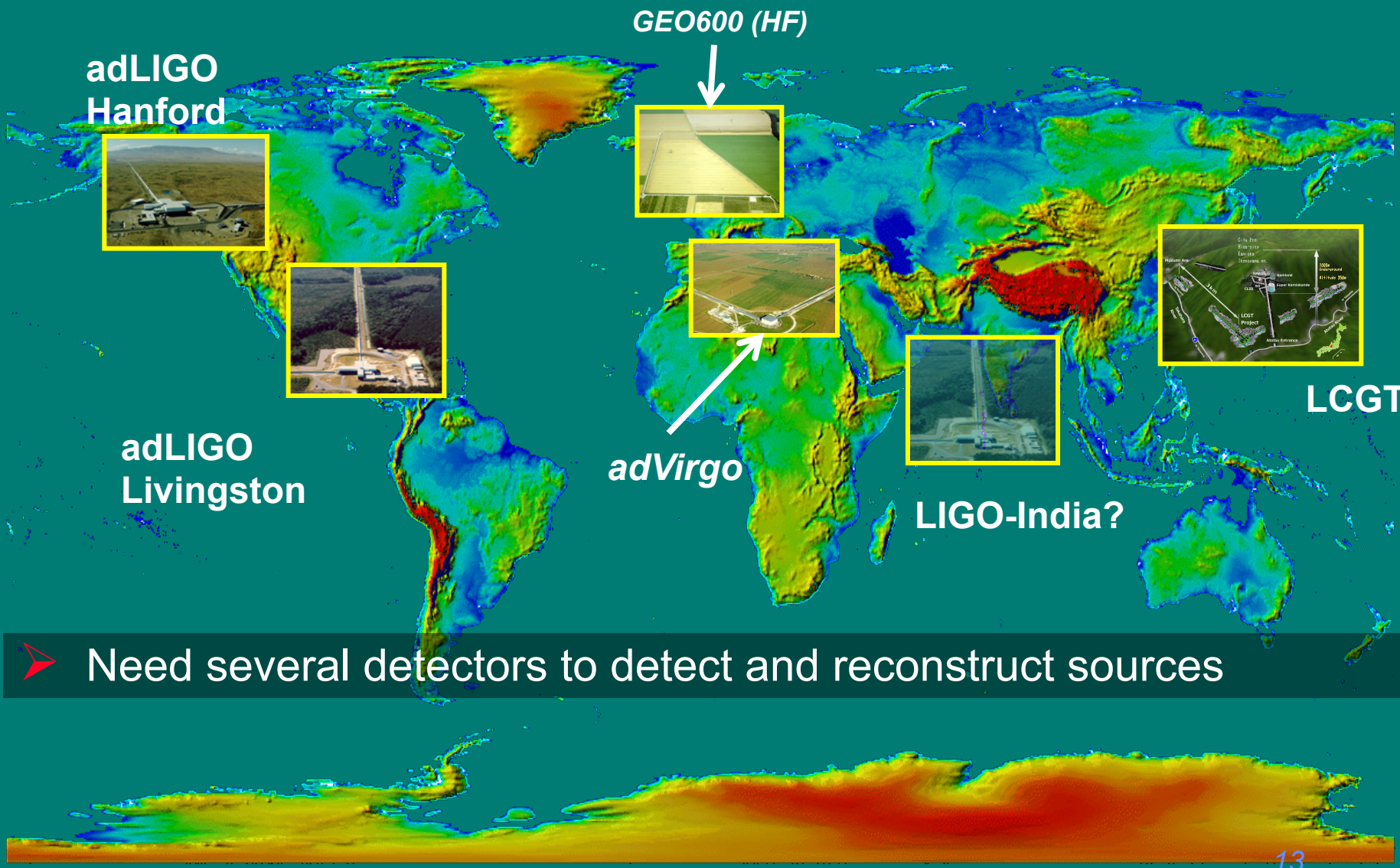
Under construction, target first detections after 2015

x10 better amplitude sensitivity⇒ x1000 rate=(reach)^3



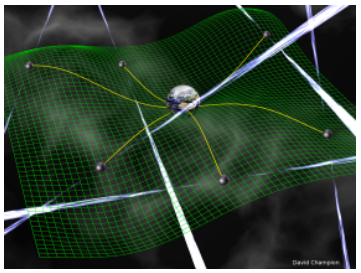
Klimenko, August 2011, Moscow Russia , LIGO-G1100847

The Largest Detector on Earth

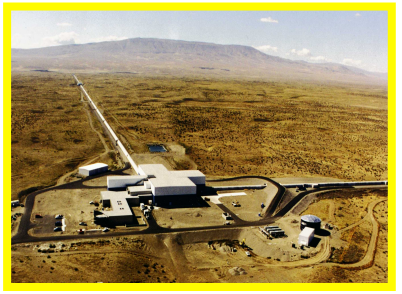


- Need several detectors to detect and reconstruct sources

Frequency range of GW Astronomy

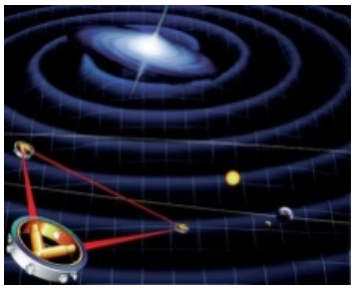


Pulsar timing



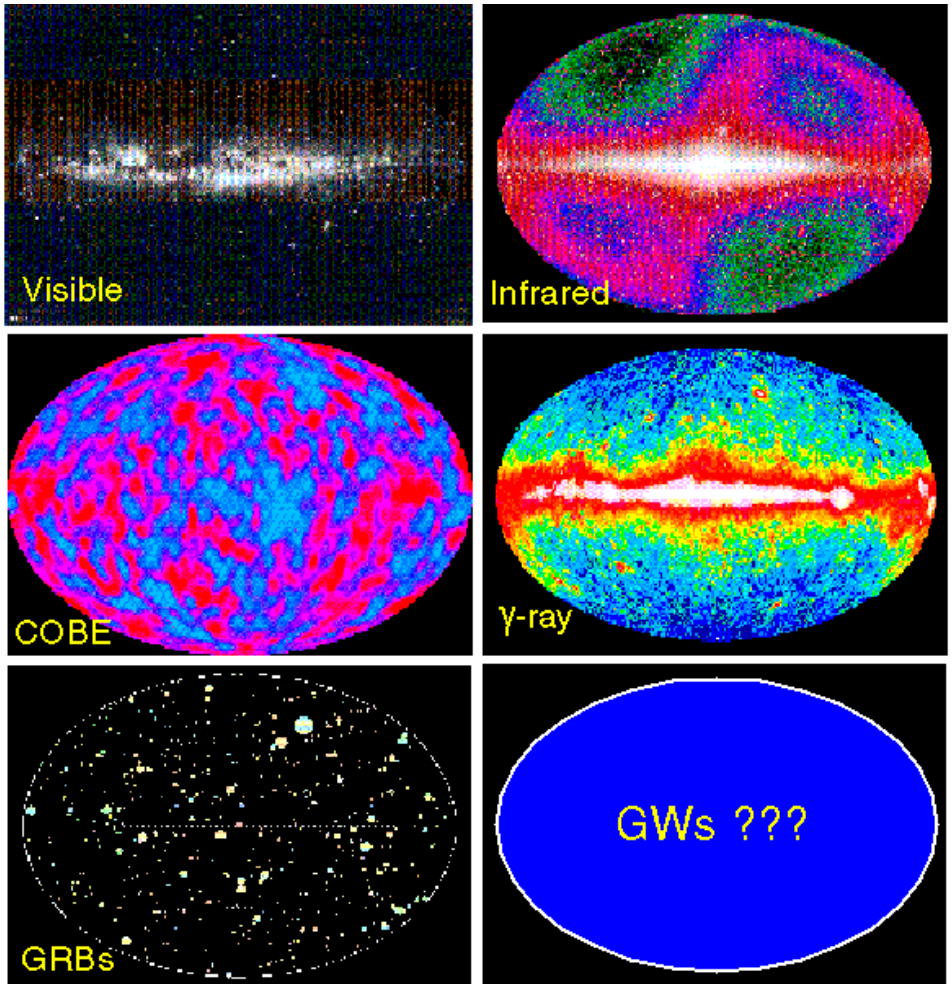
Terrestrial

space



http://www.tapir.caltech.edu/~teviet/Waves/gwave_spectrum.html

New Window on Universe



GRAVITATIONAL WAVES PROVIDE A NEW AND UNIQUE VIEW OF THE DYNAMICS OF THE UNIVERSE.