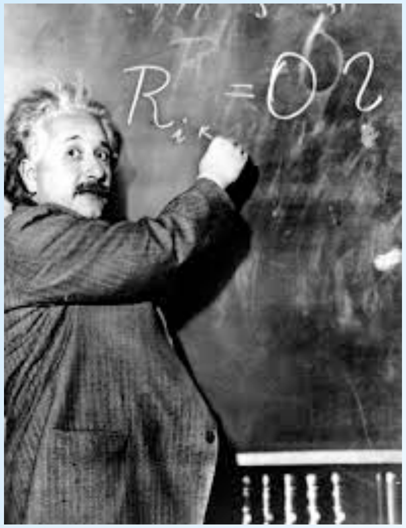
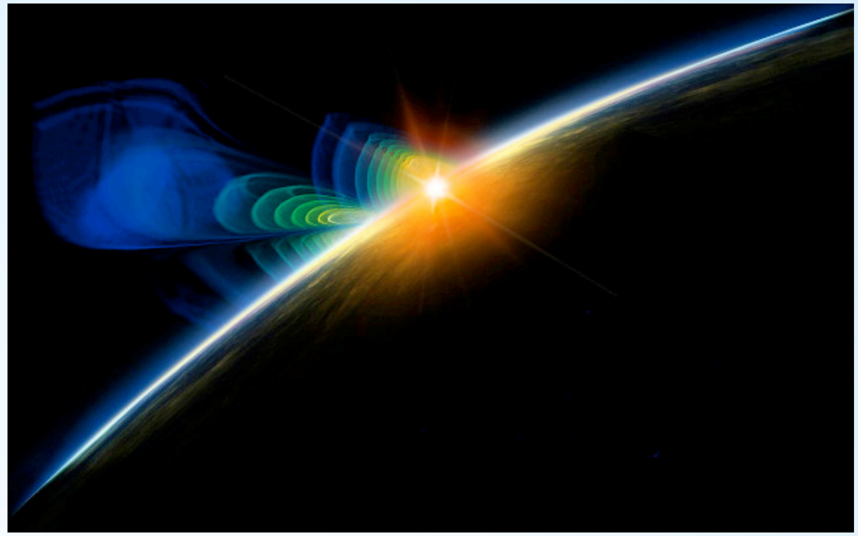
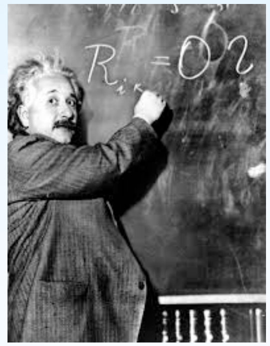




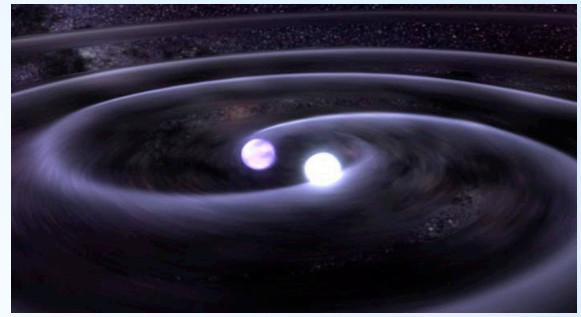
Gravitational Waves
Einstein's Astrophysical Messengers

Gabriela González
Louisiana State University

Lecture plan

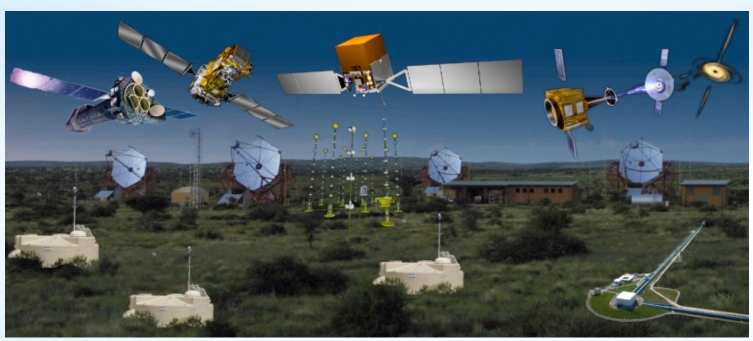


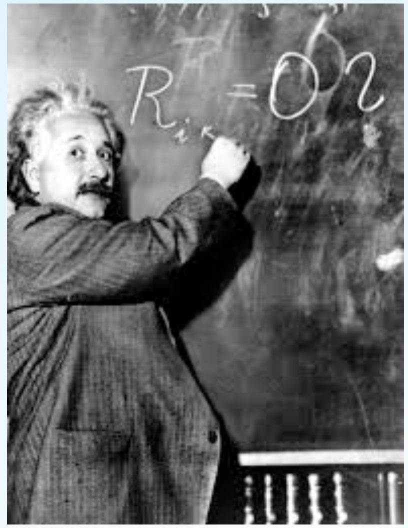
* Einstein's gravity



* Sources of gravitational waves

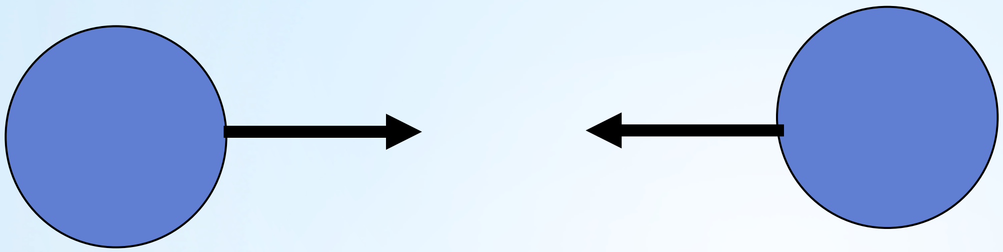
* Detecting gravitational waves
* Multi-messenger astronomy





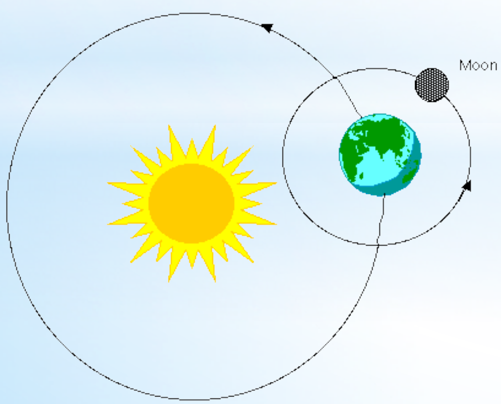
Einstein's gravity

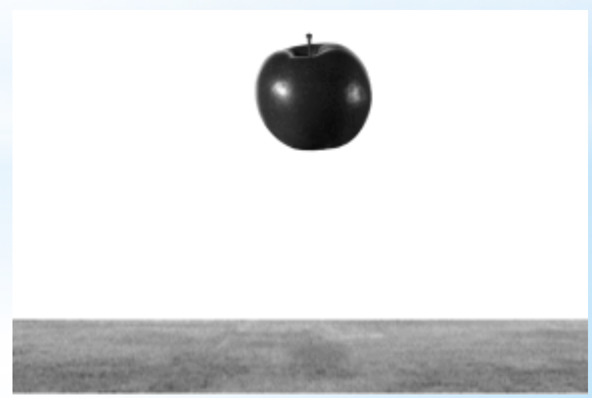
Newton's gravity



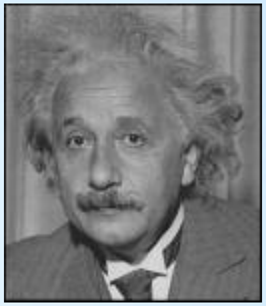
"Newton's law": $F = Gm_1m_2/r^2$

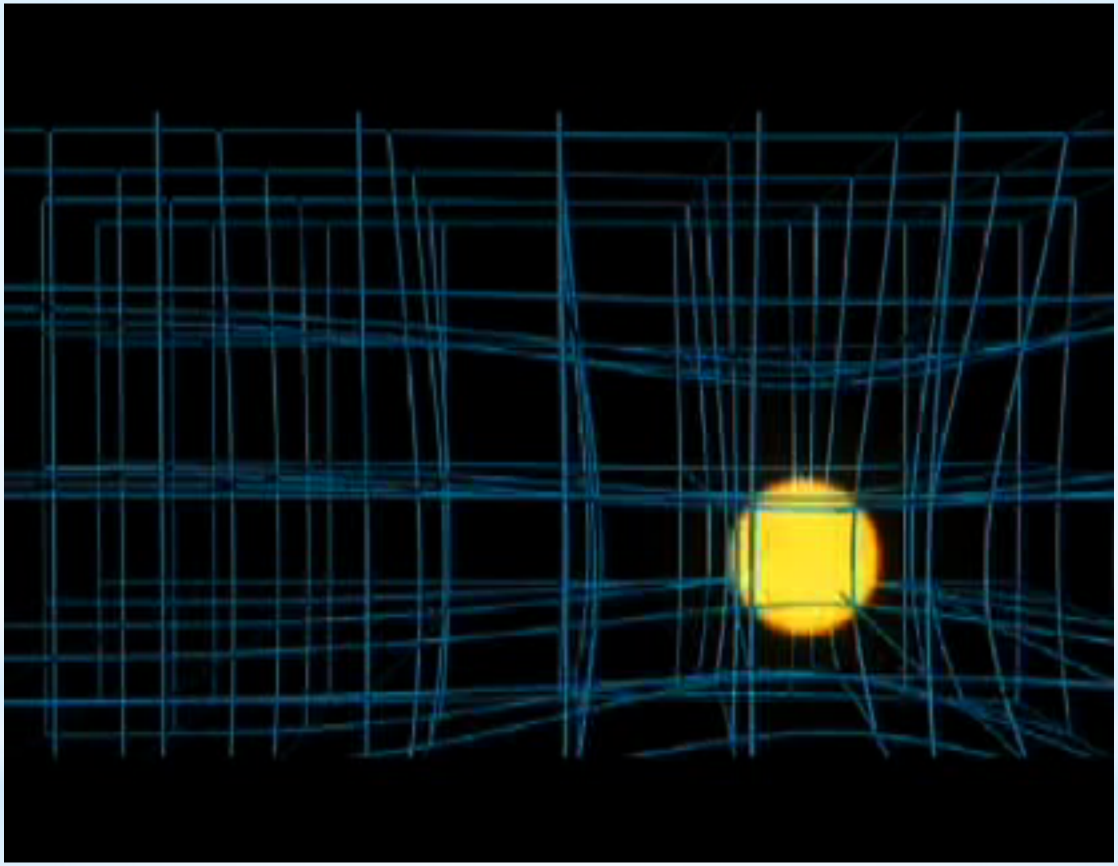
Explains why apples fall, why the planets move around the Sun,…





Einstein's gravity

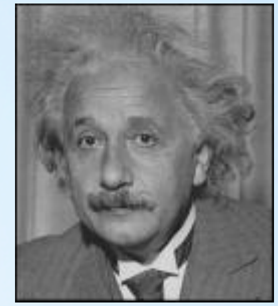


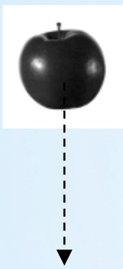


sciencebulletins.amnh.org
And in YouTube!

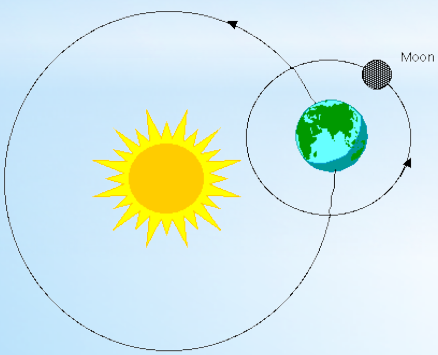
Einstein's gravity

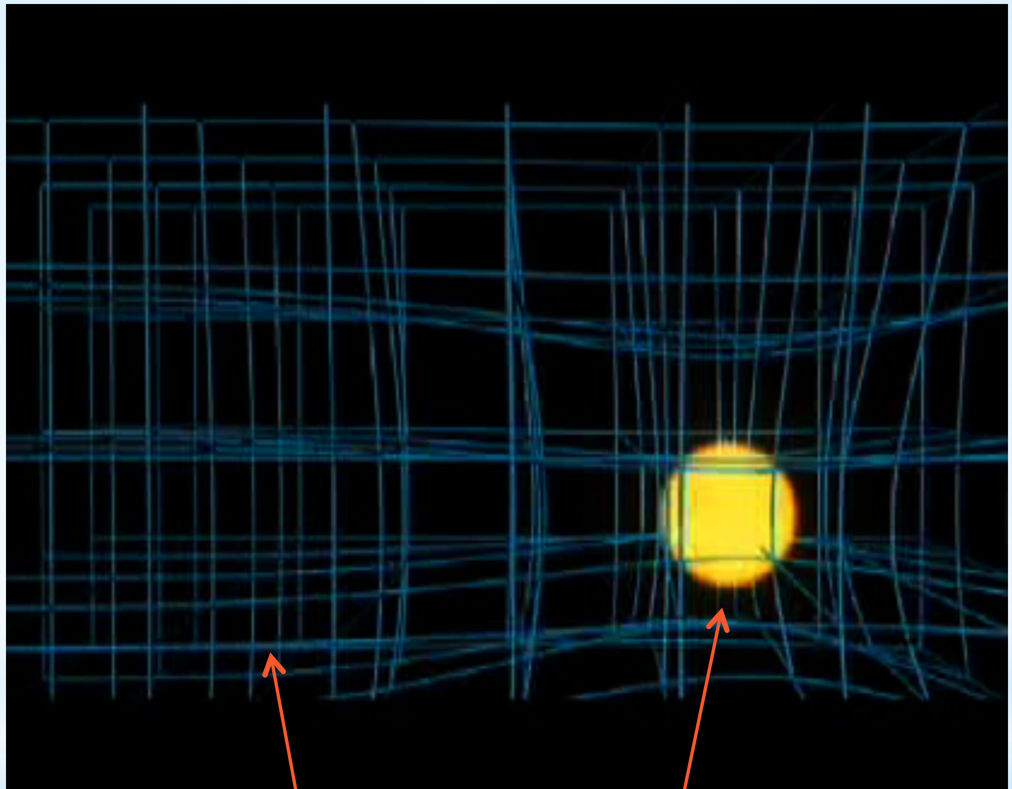
When masses move, they wrinkle the space time fabric, making other masses move.





Explains just as well as Newtons' why things fall and planetary motion.

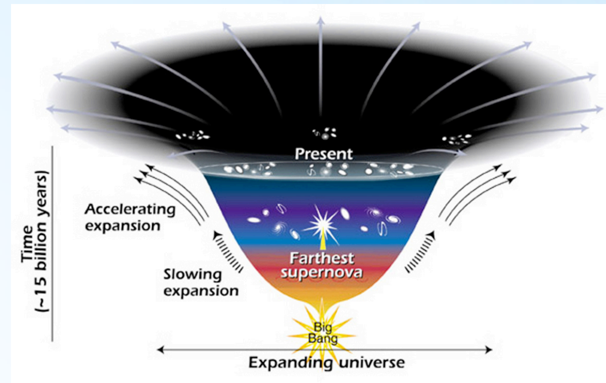




$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

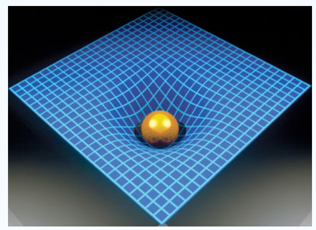
(Some of) Einstein’s predictions

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

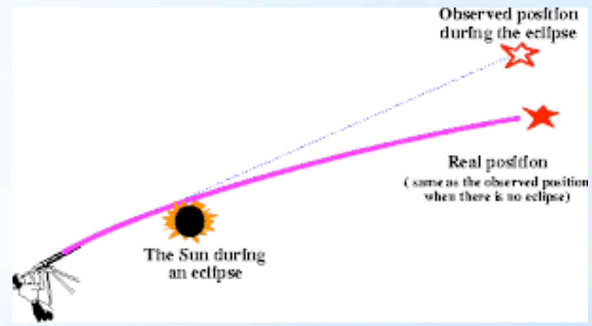


* The Universe expands.

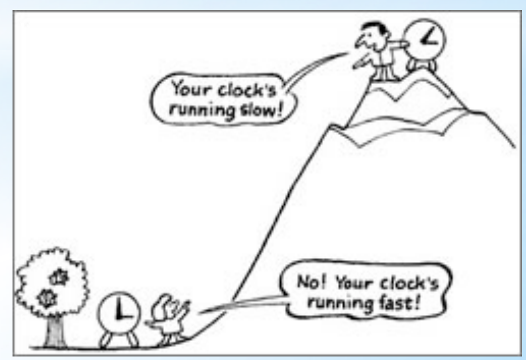
* There are “black holes”.



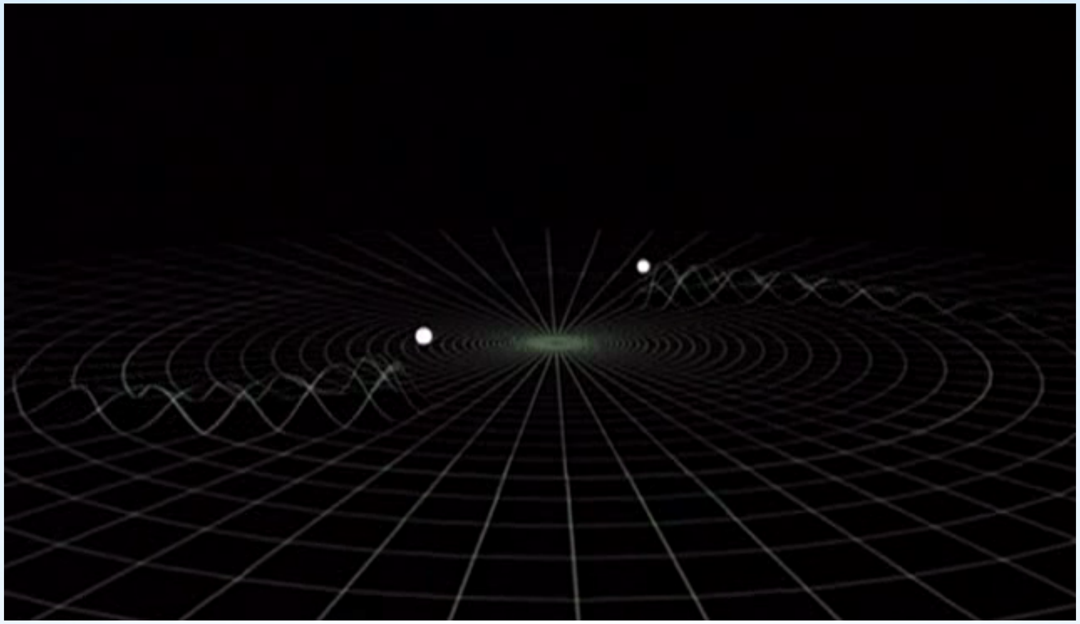
* Light bends its path around matter (following with space-time).

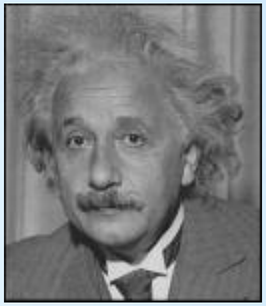


* Clocks run at different rates at different heights from Earth.



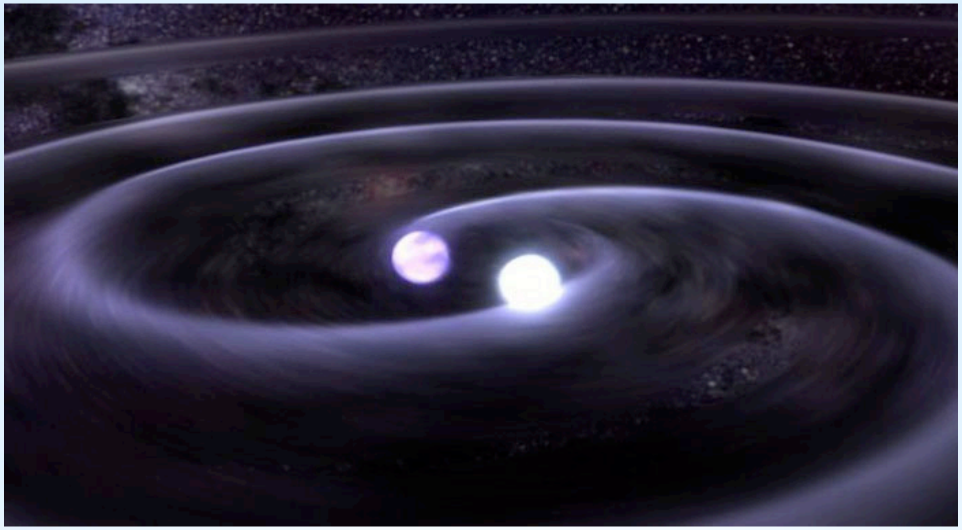
Einstein's gravity





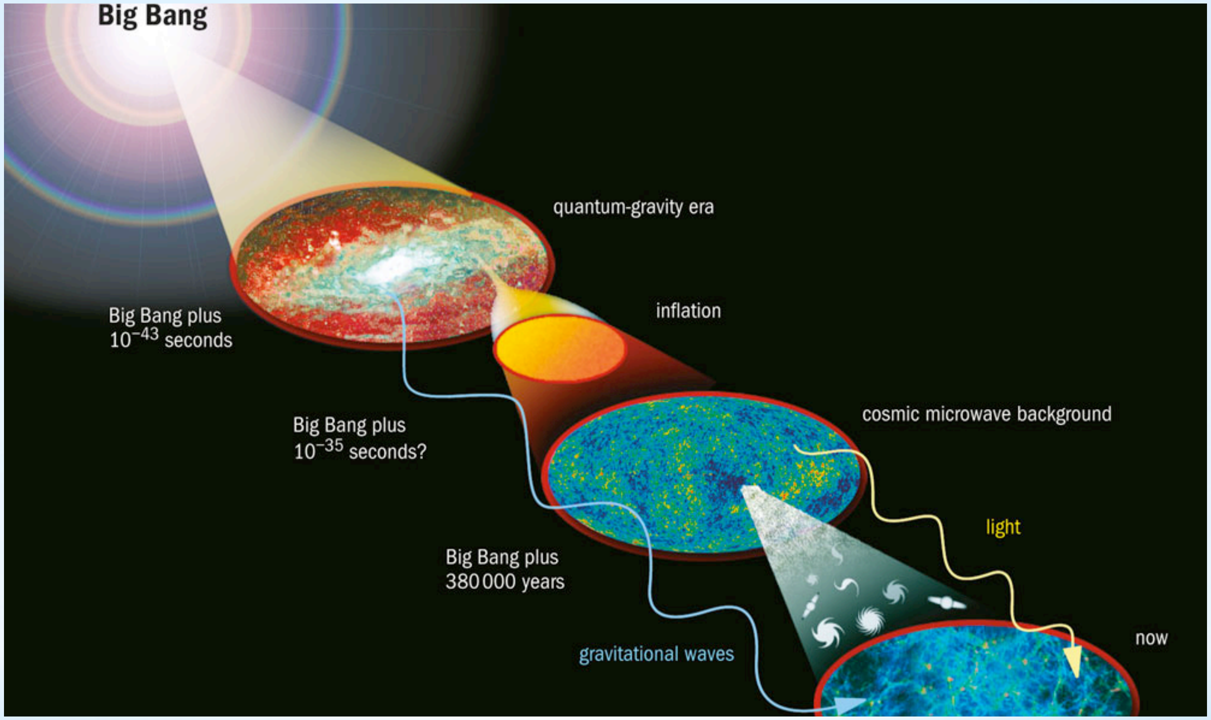
Einstein's messengers,
National Science Foundation video
www.einsteinsmessengers.org

Also predicts gravitational waves traveling away from moving masses, and carrying energy away.
Two stars would orbit around each getting closer and closer together, as energy is emitted from the system through gravitational waves



Sources of Gravitational Waves

Early Universe



(Courtesy: NASA)

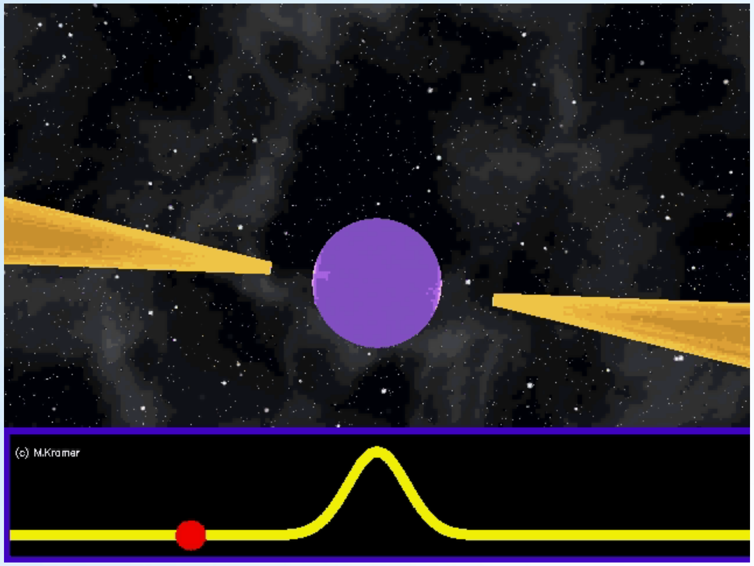
We have learned much about the early history of the Universe from observation of the “cosmic microwave background – there is also a “gravitational wave background” from even earlier times.

Supernova explosions

Credit: NASA

SN explosions generated by the collapse of a star under its own gravity give birth to neutron stars and black holes with masses close to the Sun's, but with the size of a city.
If the explosion is not perfectly symmetric, it produces gravitational waves that may be detected on Earth.

Rotating stars

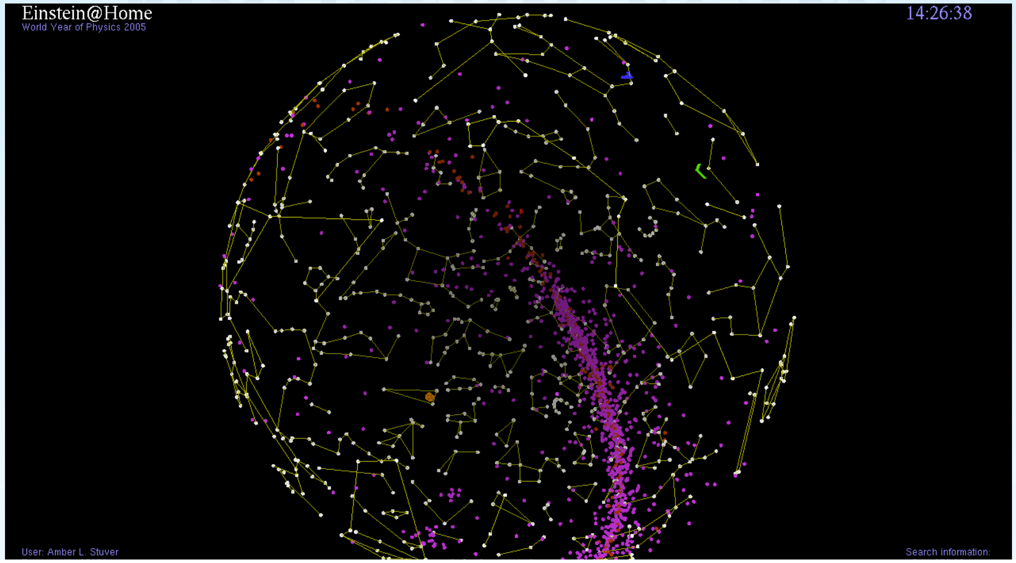


Credit: M. Kramer

Crab pulsar and nebula
Credit: NASA/CXC/ASU/J. Hester et al.

Neutron stars are born rapidly spinning, emitting electromagnetic beams: they are “pulsars”. Eventually, electromagnetic power is exhausted, and older, isolated, neutron stars do not emit beams. Pulsars are very precise clocks – rivaling atomic clocks.

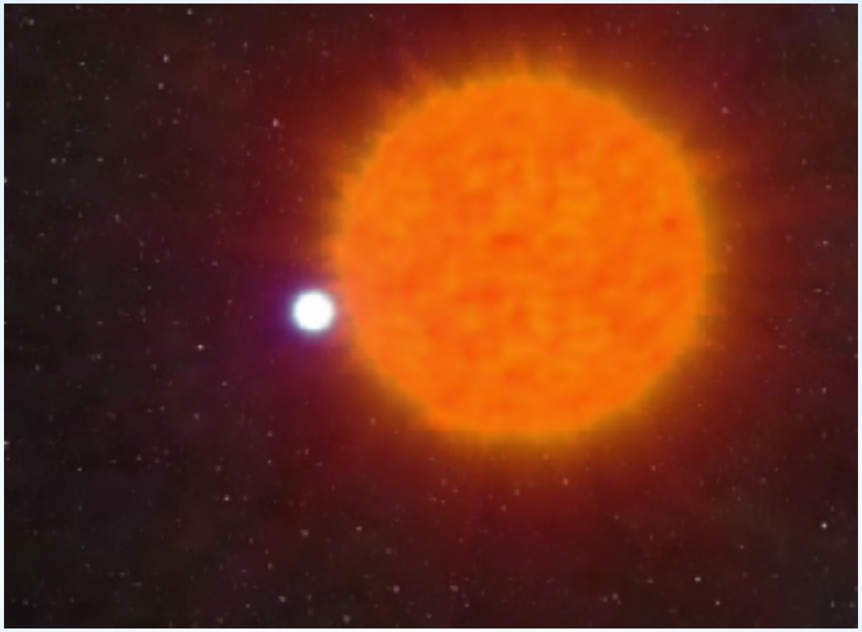
Neutron stars



Neutron stars emit gravitational waves themselves, with an amplitude proportional to their non-spherical shape and twice their rotation frequency – but neutron stars are *very* smooth!

There are about 2,000 pulsars observed in our galaxy, but there are about 100 million neutron stars in the Milky way.

Neutron stars in Binary systems

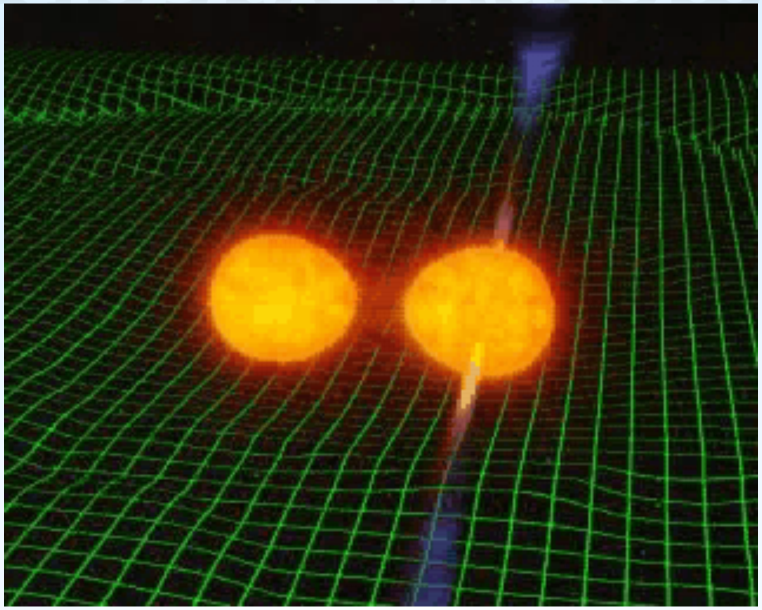


Credit: John Rowe animations

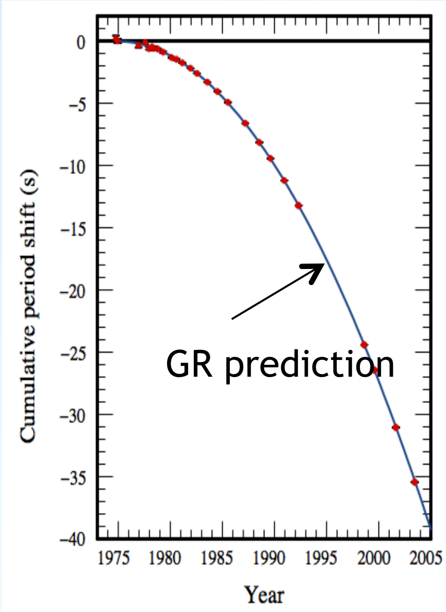
About 5% of neutron stars are part of a binary system, eventually forming a binary system with two neutron stars, or a neutron star and a black hole.

Binary systems

Hulse, Taylor Nobel Prize 1993

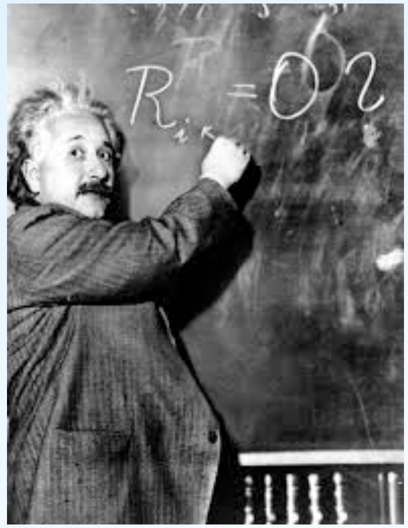


Credit: John Rowe animations



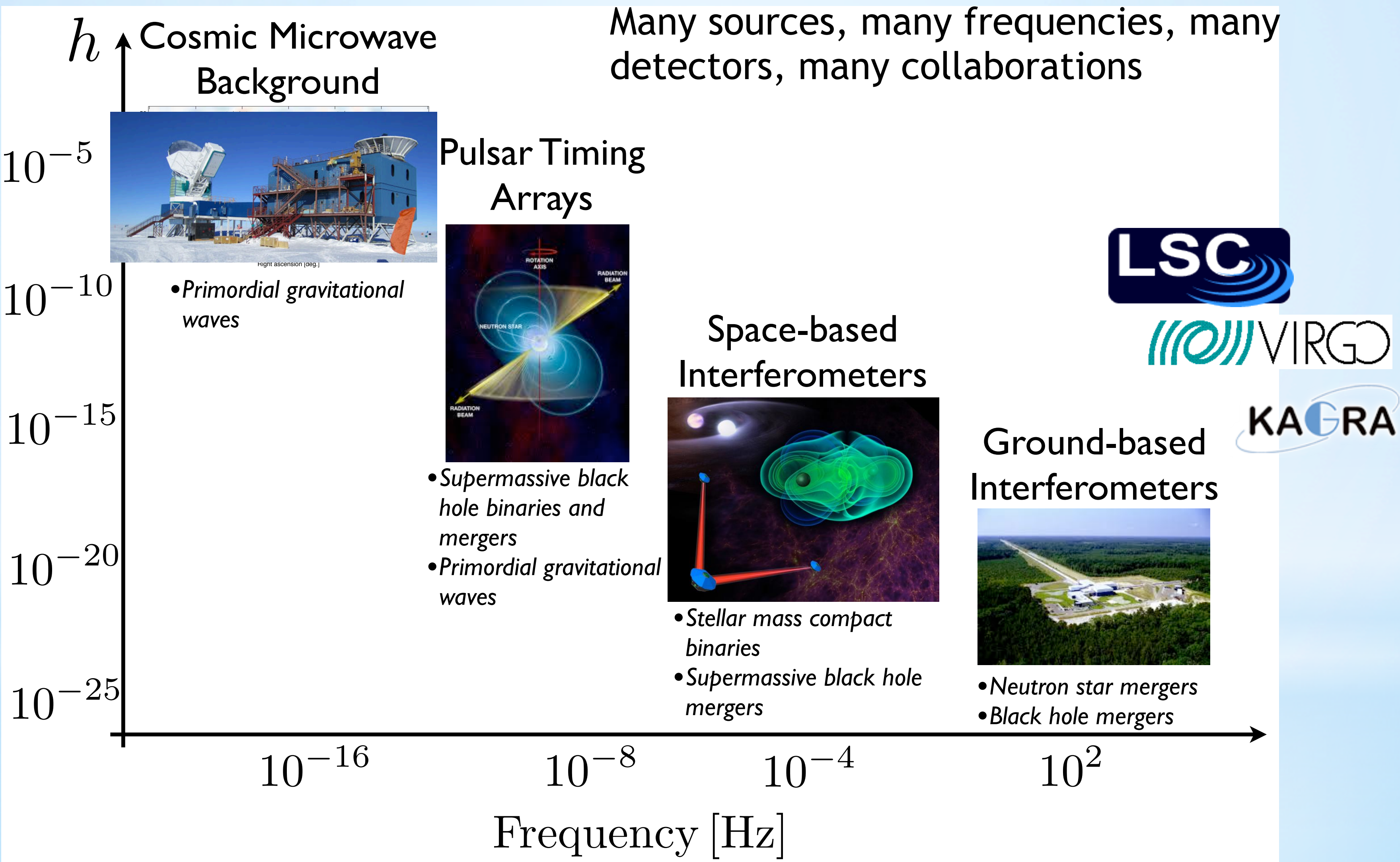
Weisberg, Nice & Taylor, 2010
(Courtesy Joel Weisberg)

Binary systems of compact objects as neutron stars and black holes lose energy to gravitational waves, orbiting closer and closer until merging into a larger black hole. The amplitude and frequency of the gravitational wave before the merger is "easy" to calculate using Einstein's theory – this is likely to be the bread-and-butter of Advanced LIGO when it begins detecting astrophysical signals.



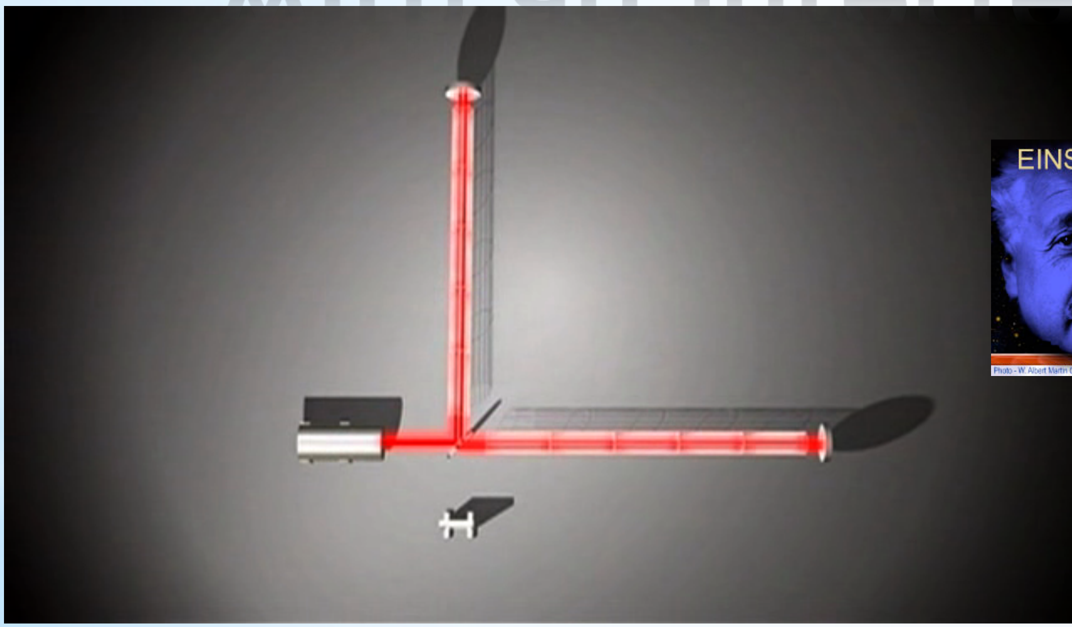
Detecting gravitational waves

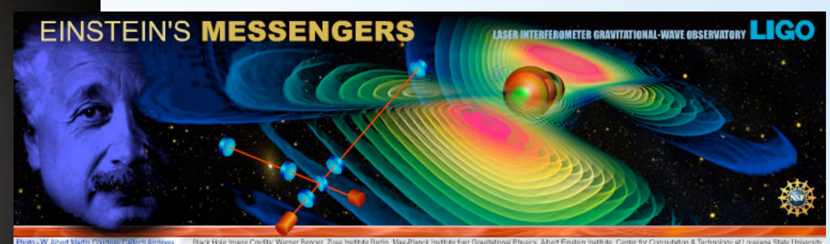
GW landscape



Credit: Nanograv/Bicep2

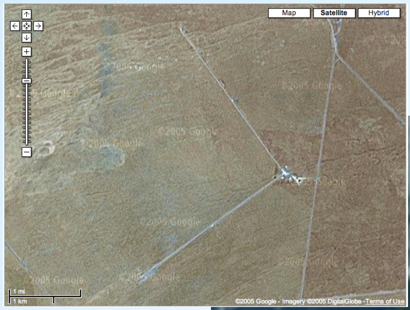
How to detect gravitational waves with an interferometer

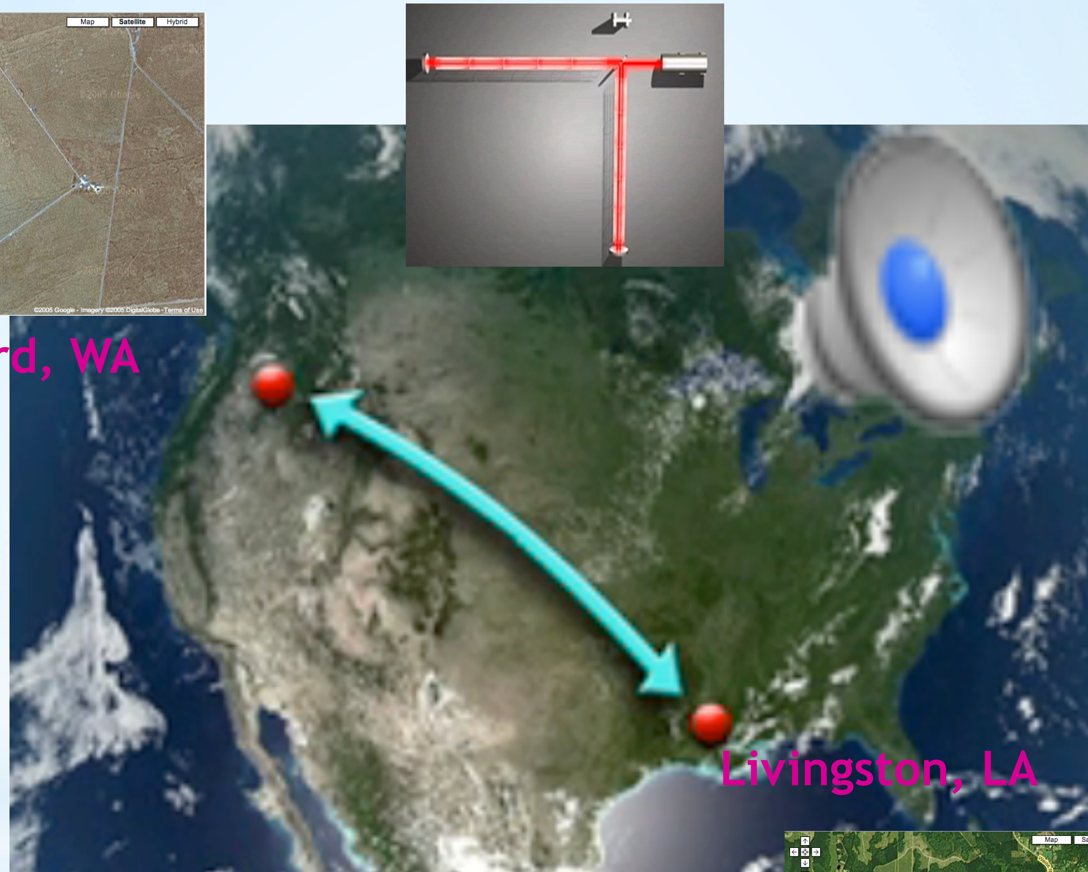


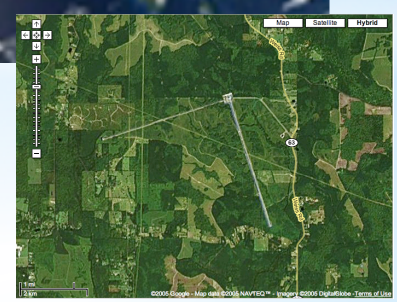


Einstein’s messengers,
National Science Foundation video
http://www.einsteinsmessengers.org/

The LIGO Observatories







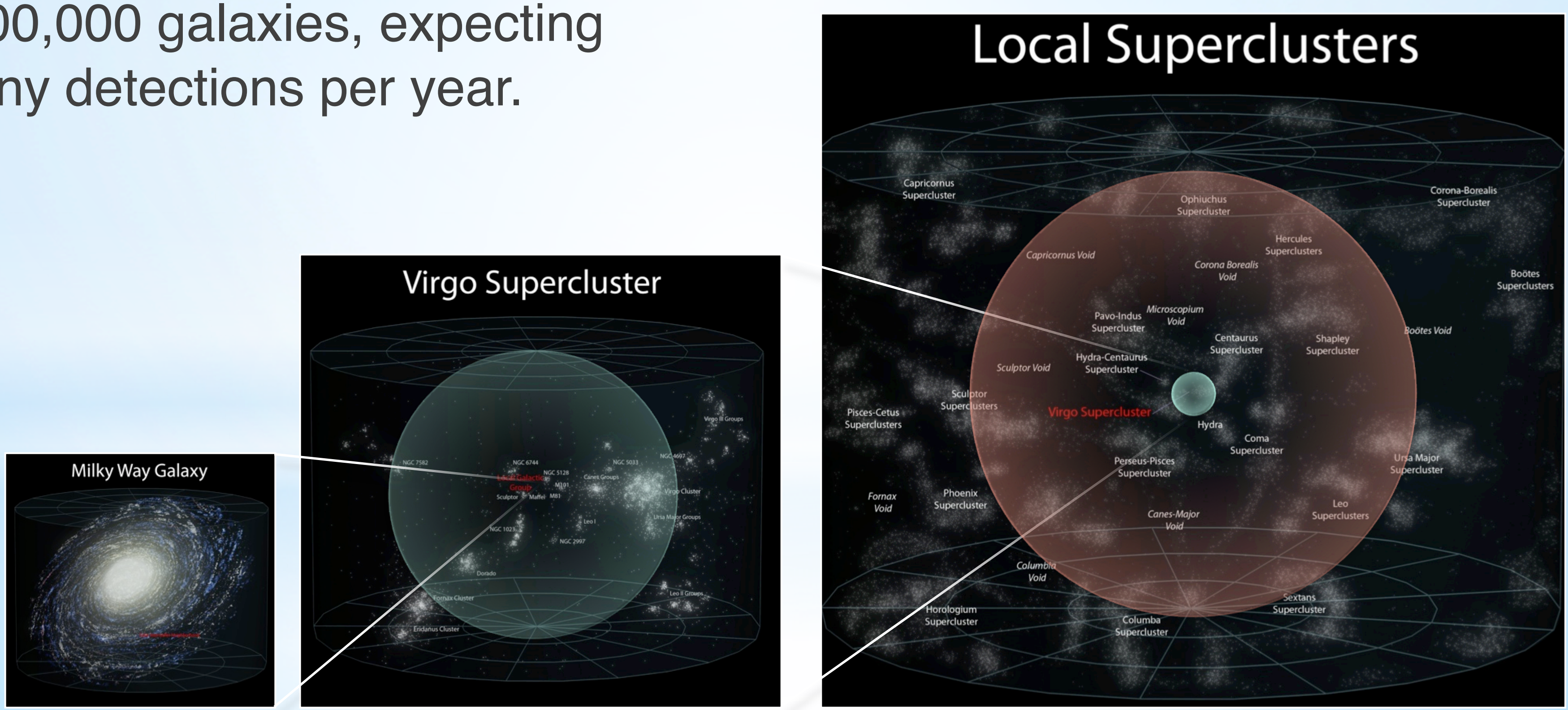
Hundreds of people in 16 countries working on the experiment and looking at the data:

LIGO Scientific Collaboration

www.ligo.org

Initial and Advanced LIGO

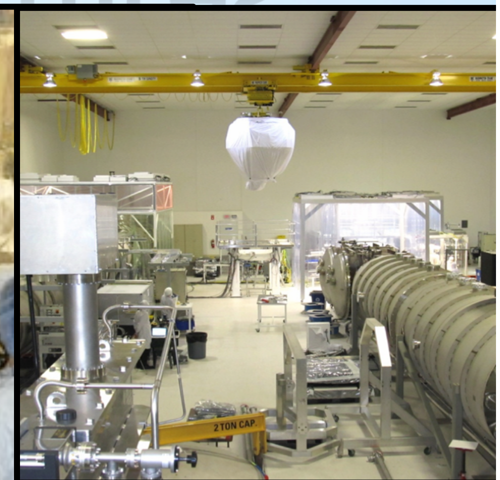
Advanced LIGO will be ~10x more sensitive than initial LIGO (2005-2010), sensitive to colliding neutron stars in ~100,000 galaxies, expecting many detections per year.

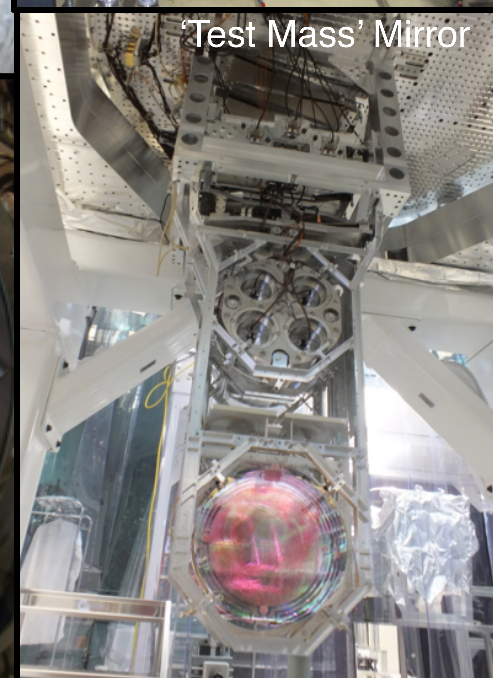


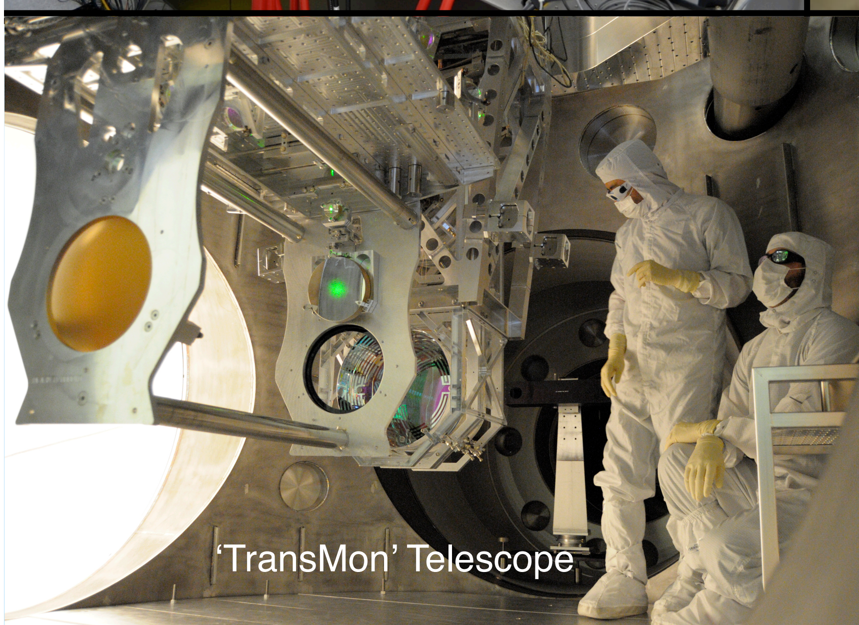
Initial Reach

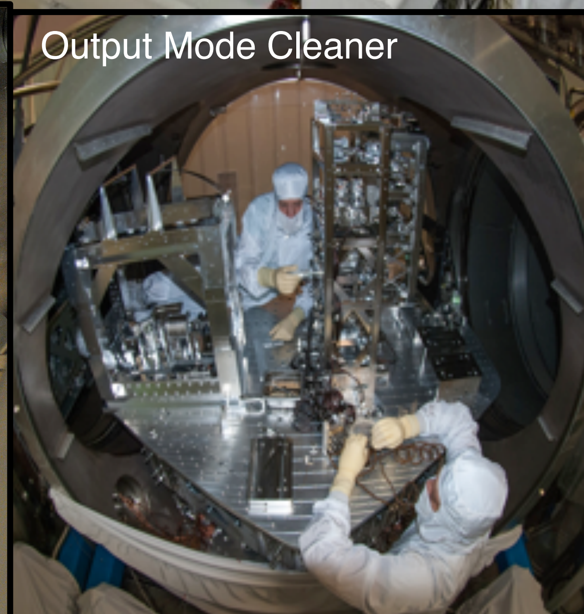
Advanced Reach

Advanced LIGO in Pictures

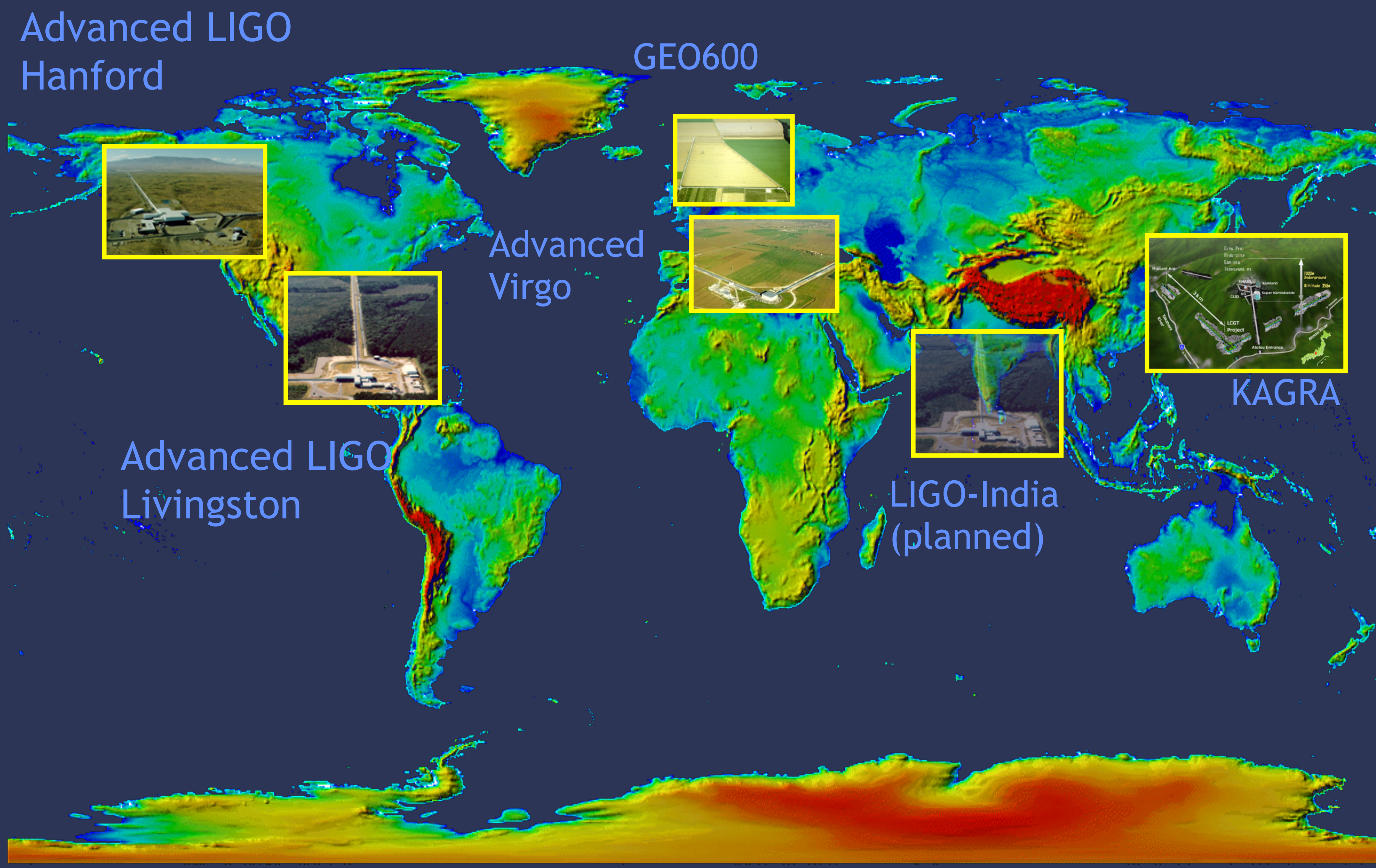


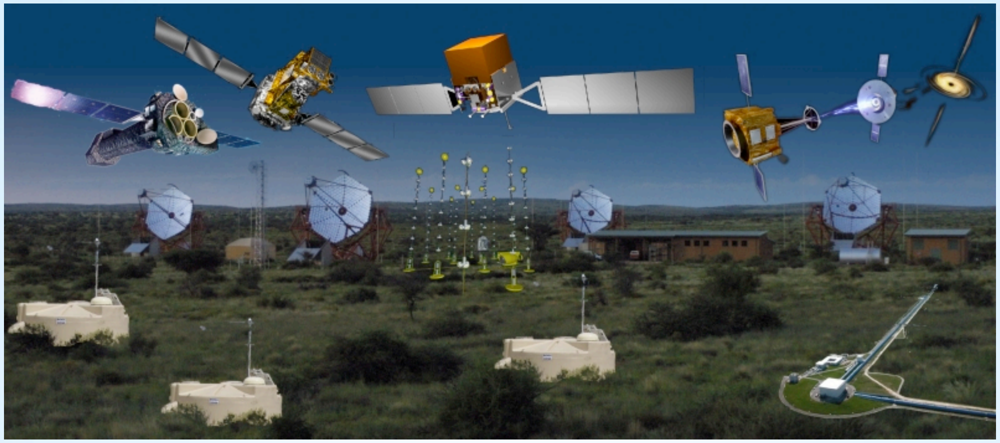






The GW Detector Network~2022

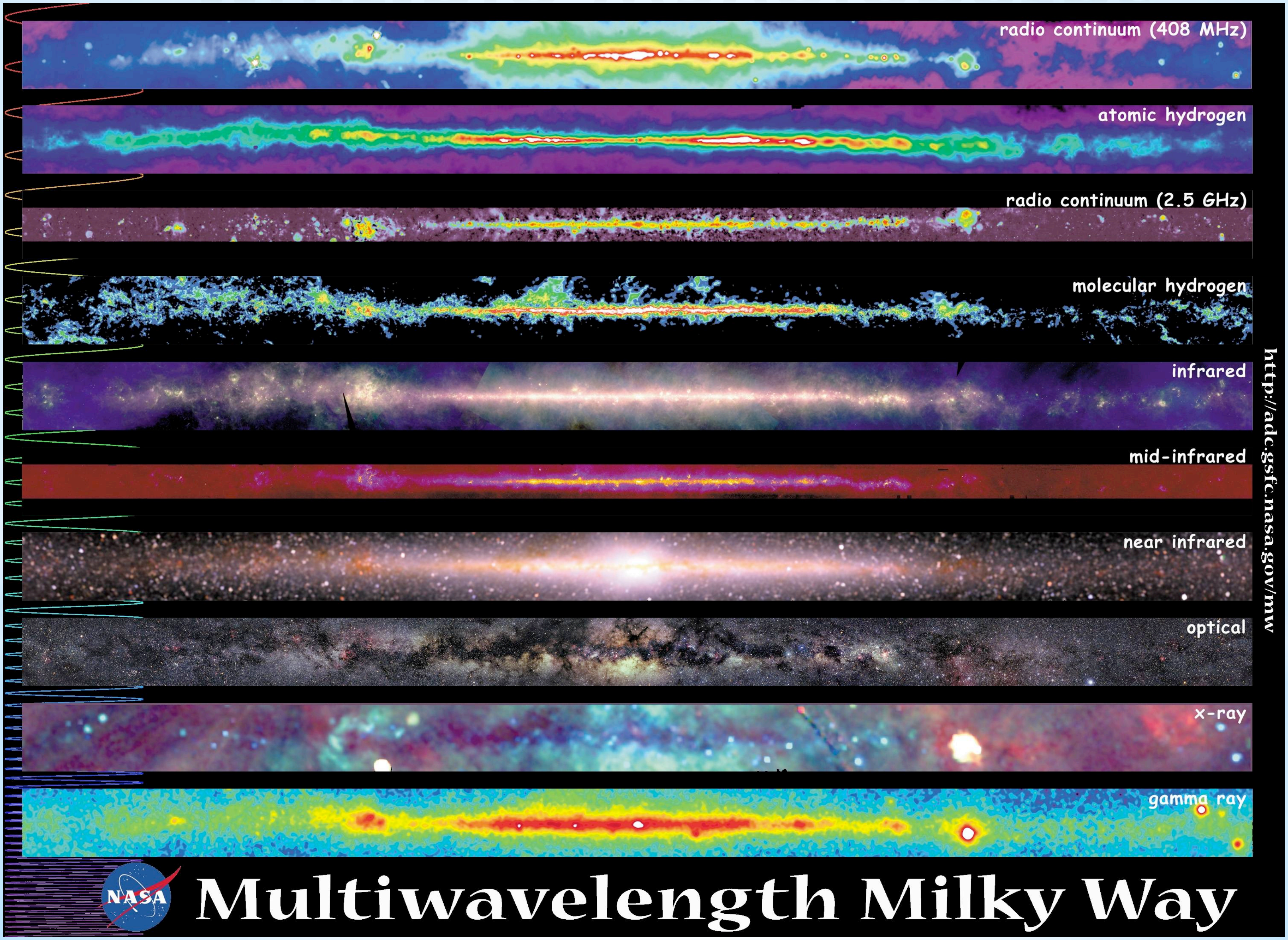




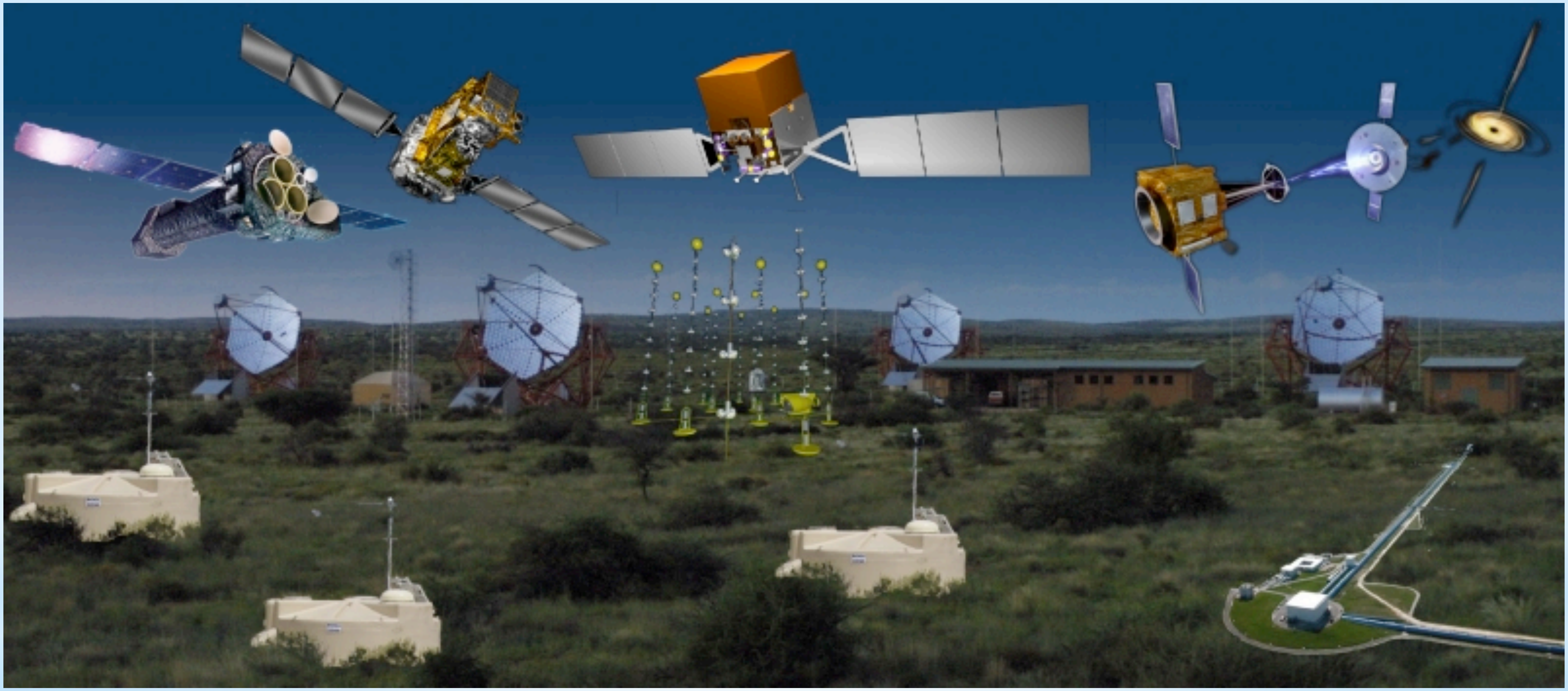
Credit: Heidi Sagerud

Multi-messenger astronomy

Multiple wavelengths

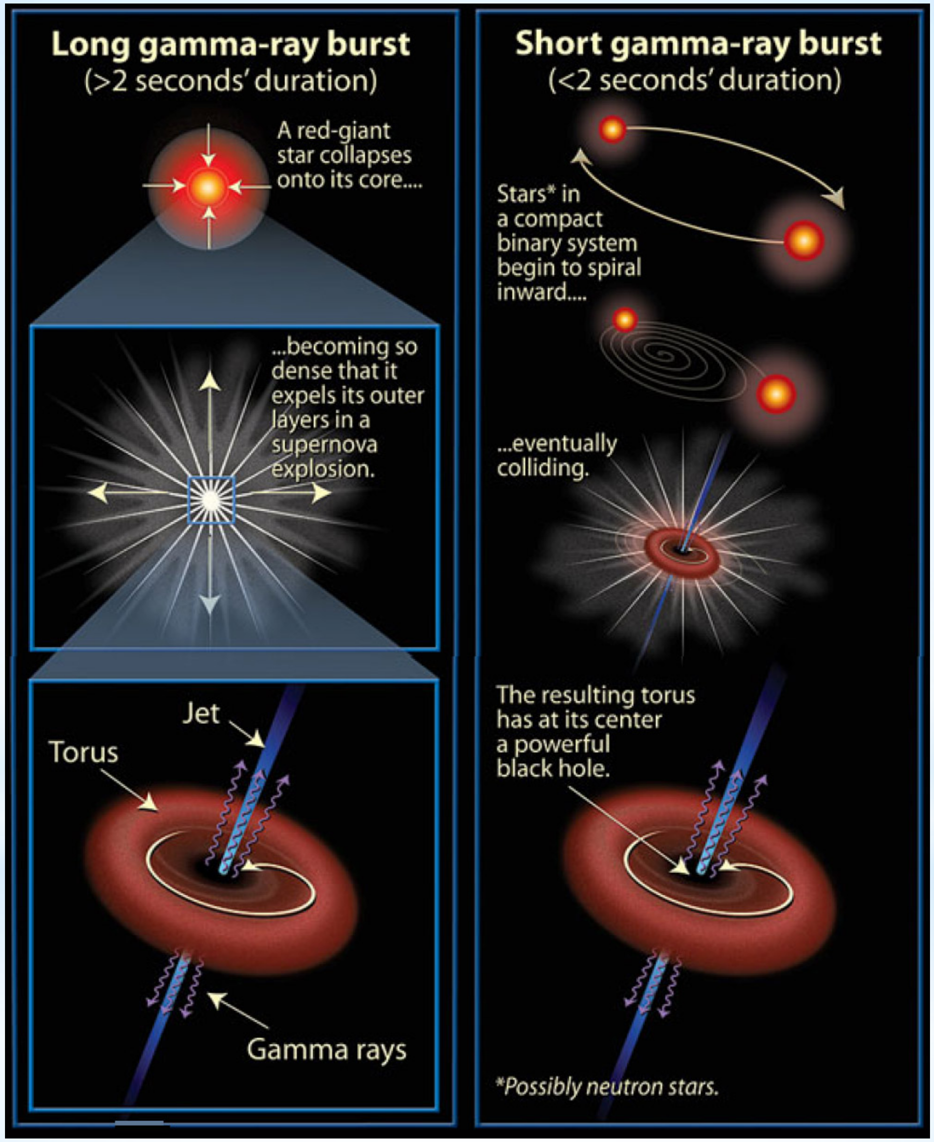


Multiple messengers

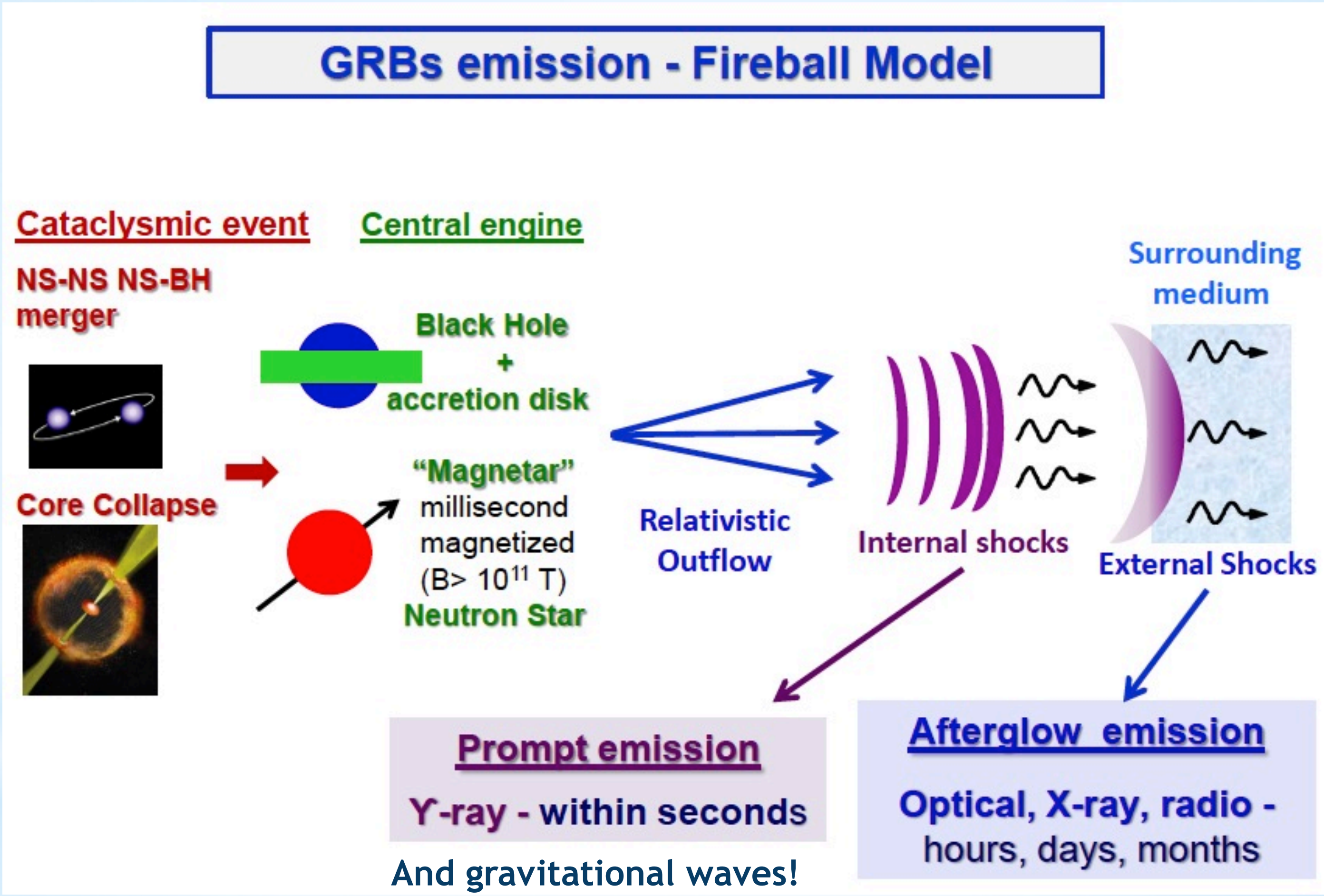


Credit: Heidi Sagerud

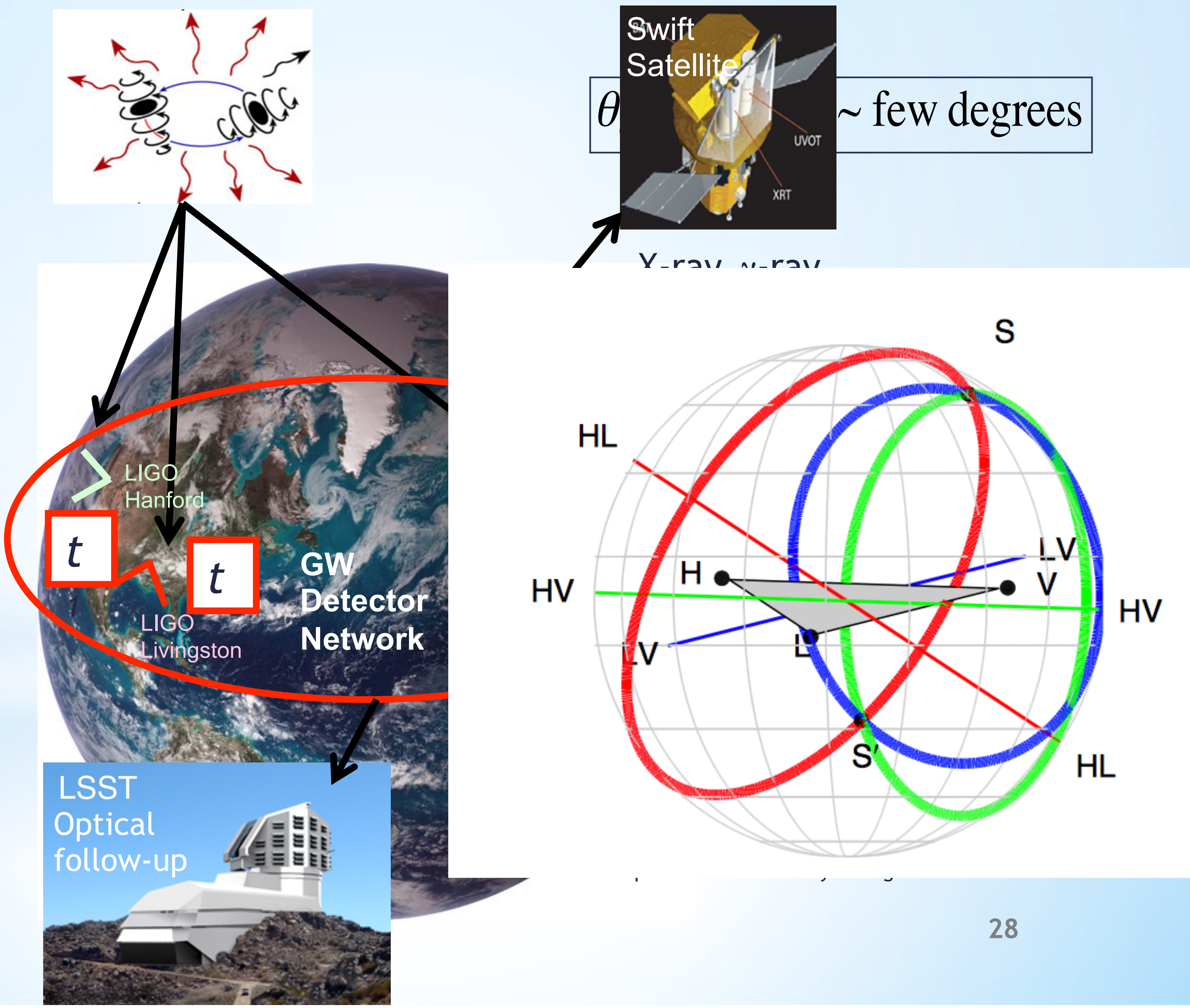
Gamma Ray Bursts



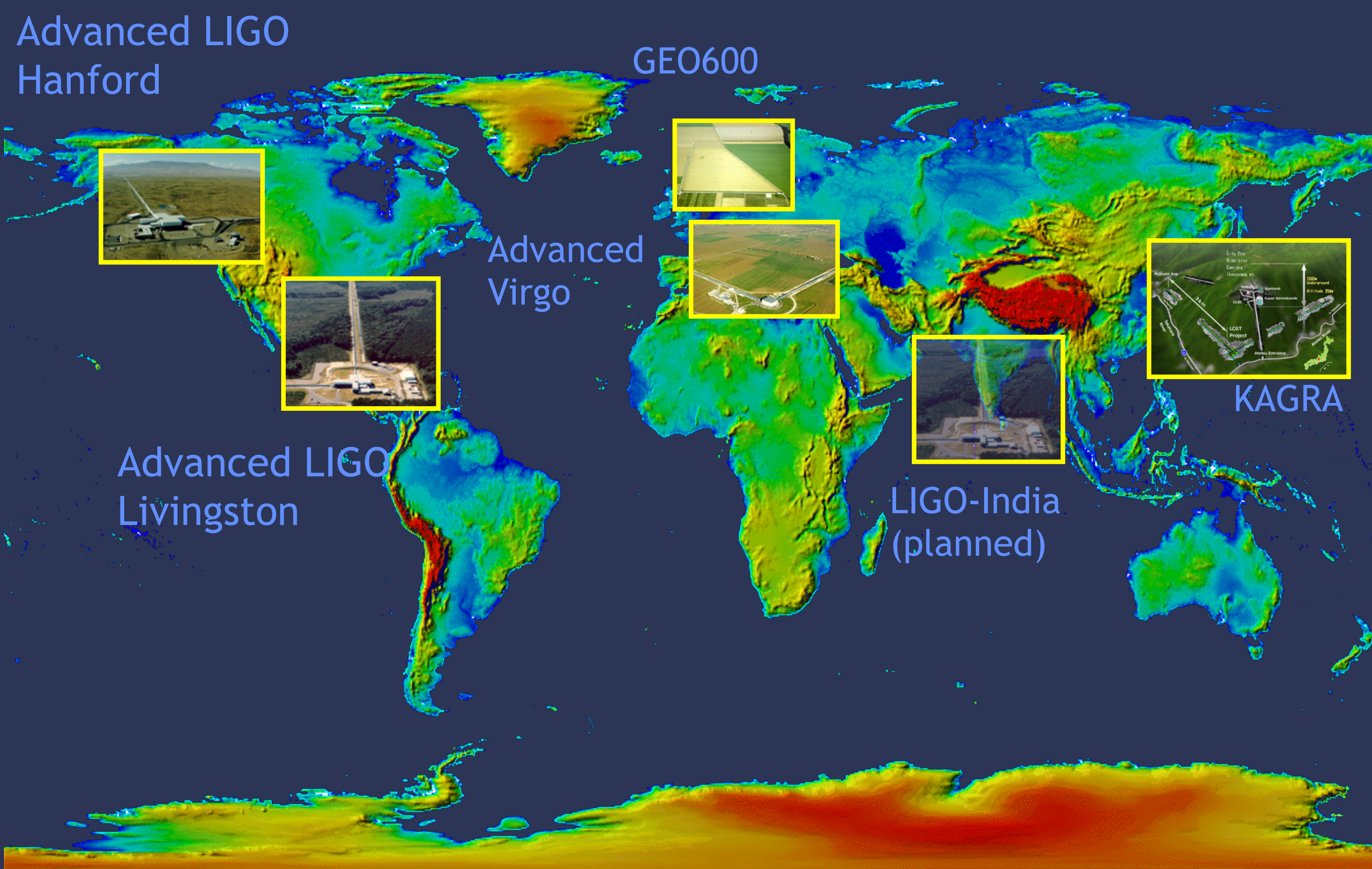
GRBs as multi-messengers



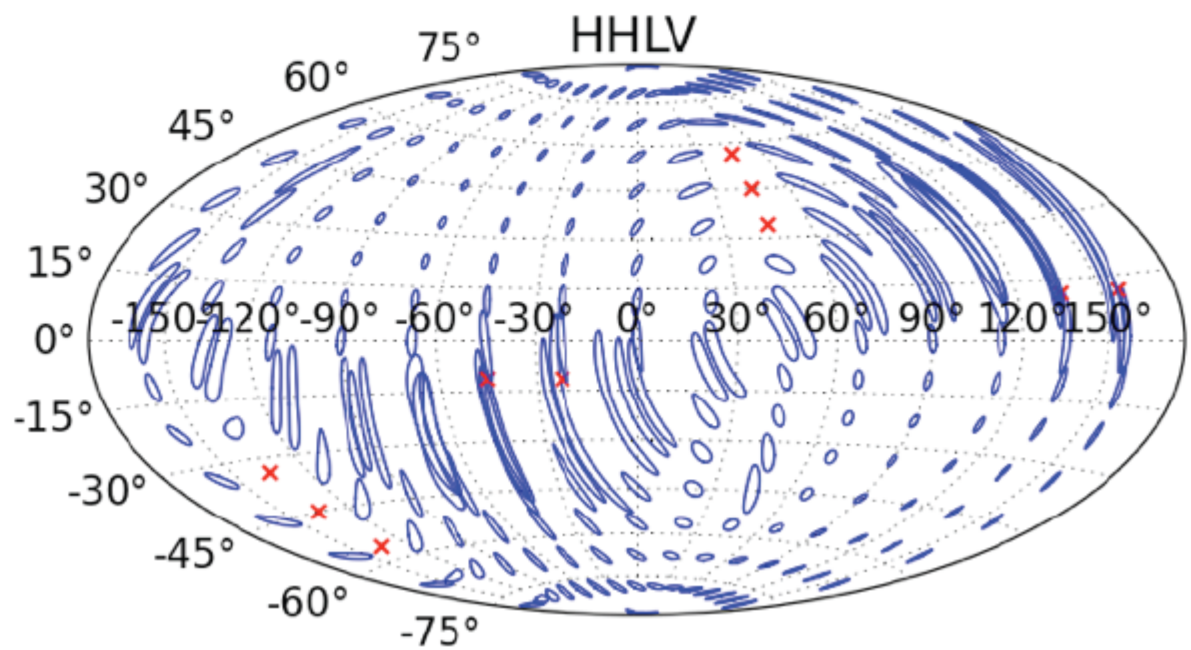
GW localization: networks



The GW Detector Network~2022



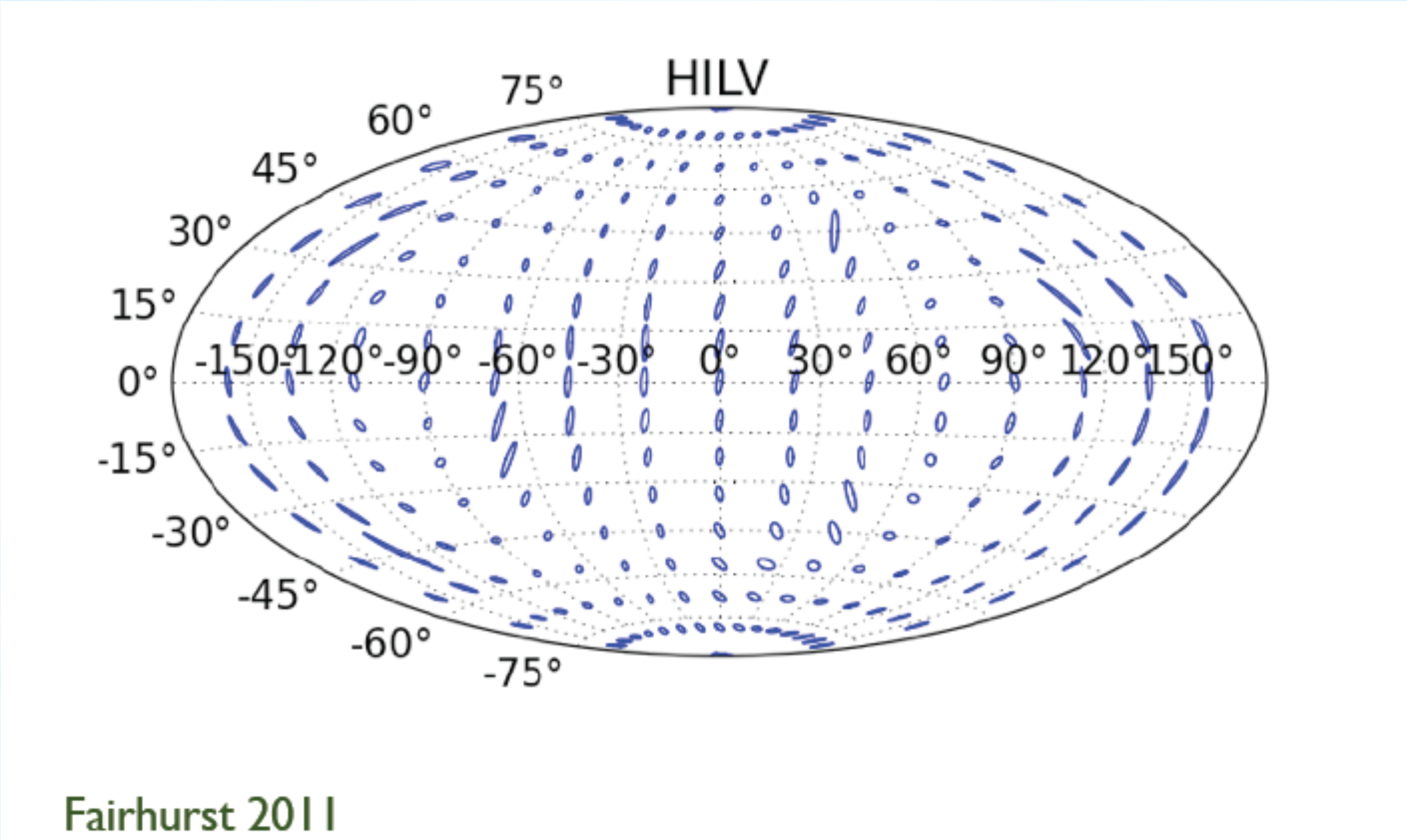
Localization with LIGO-Virgo only

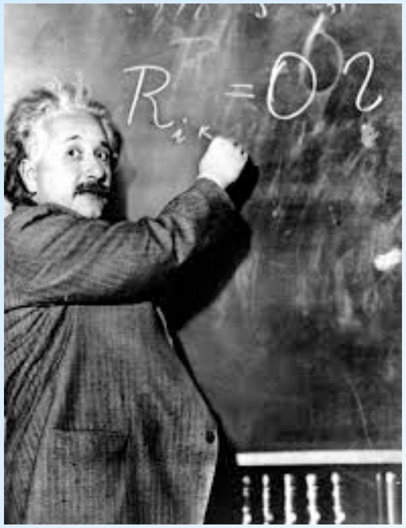


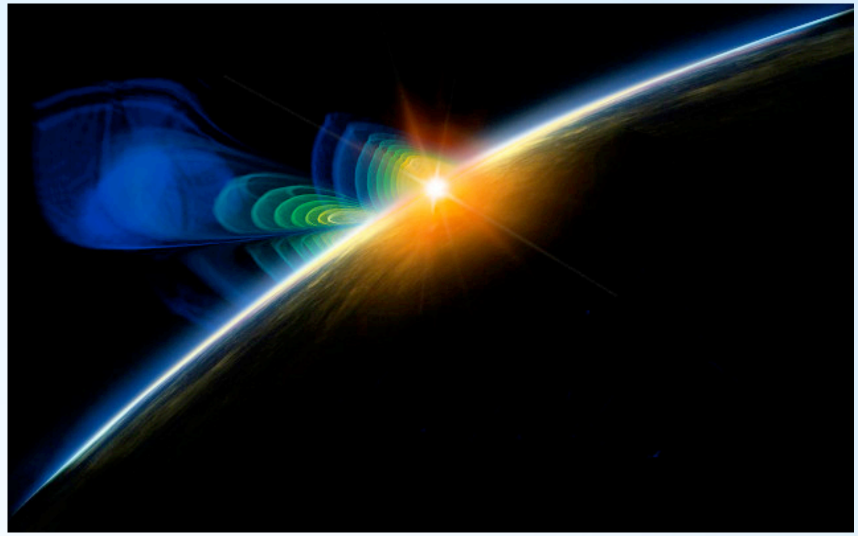
Fairhurst 2011

Red crosses denote regions where the network has blind spots

Localization: LIGO-Virgo plus LIGO-India







Gravitational Waves
Einstein’s Astrophysical Messengers

Questions? Email gonzalez@lsu.edu, or go to www.ligo.org