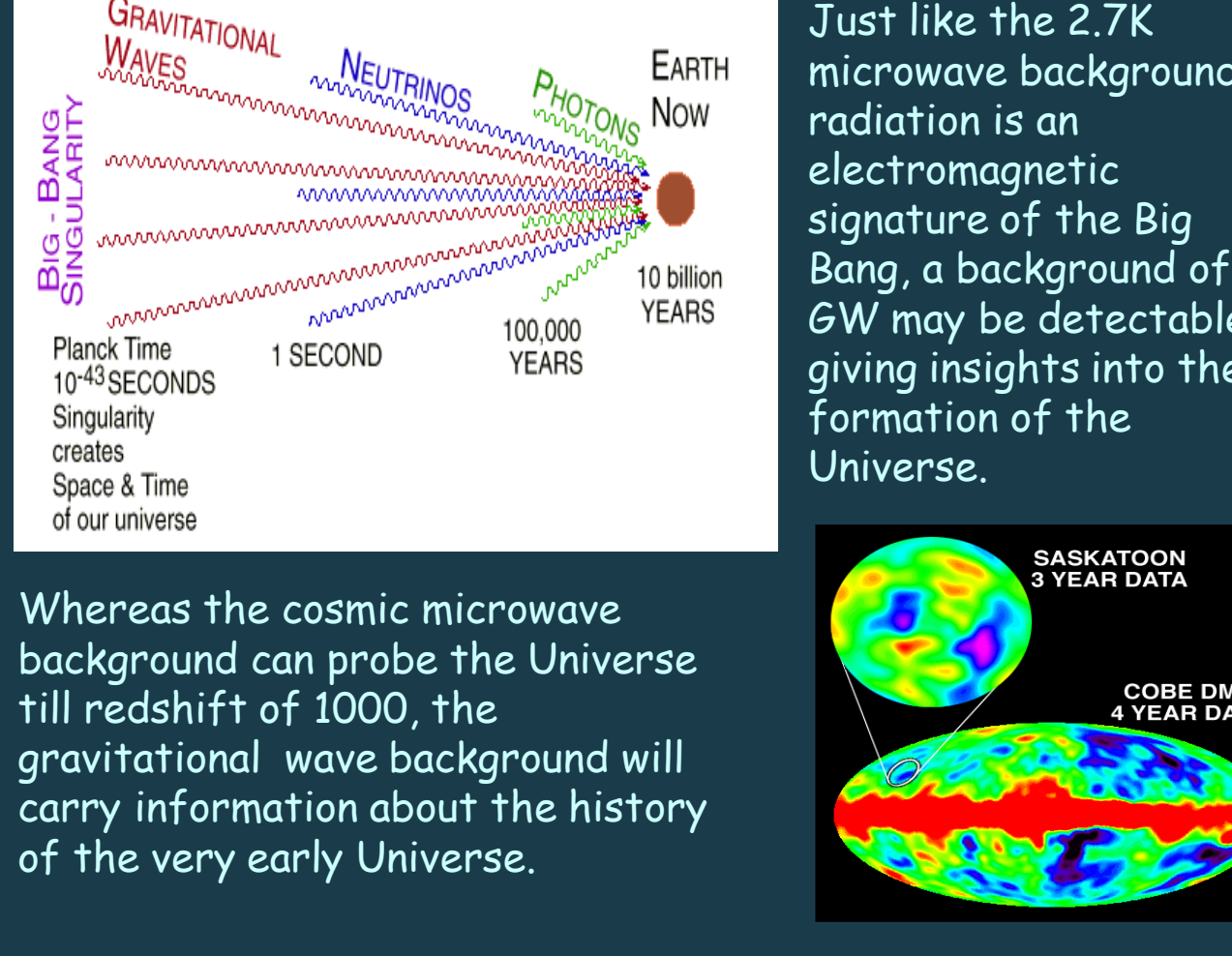
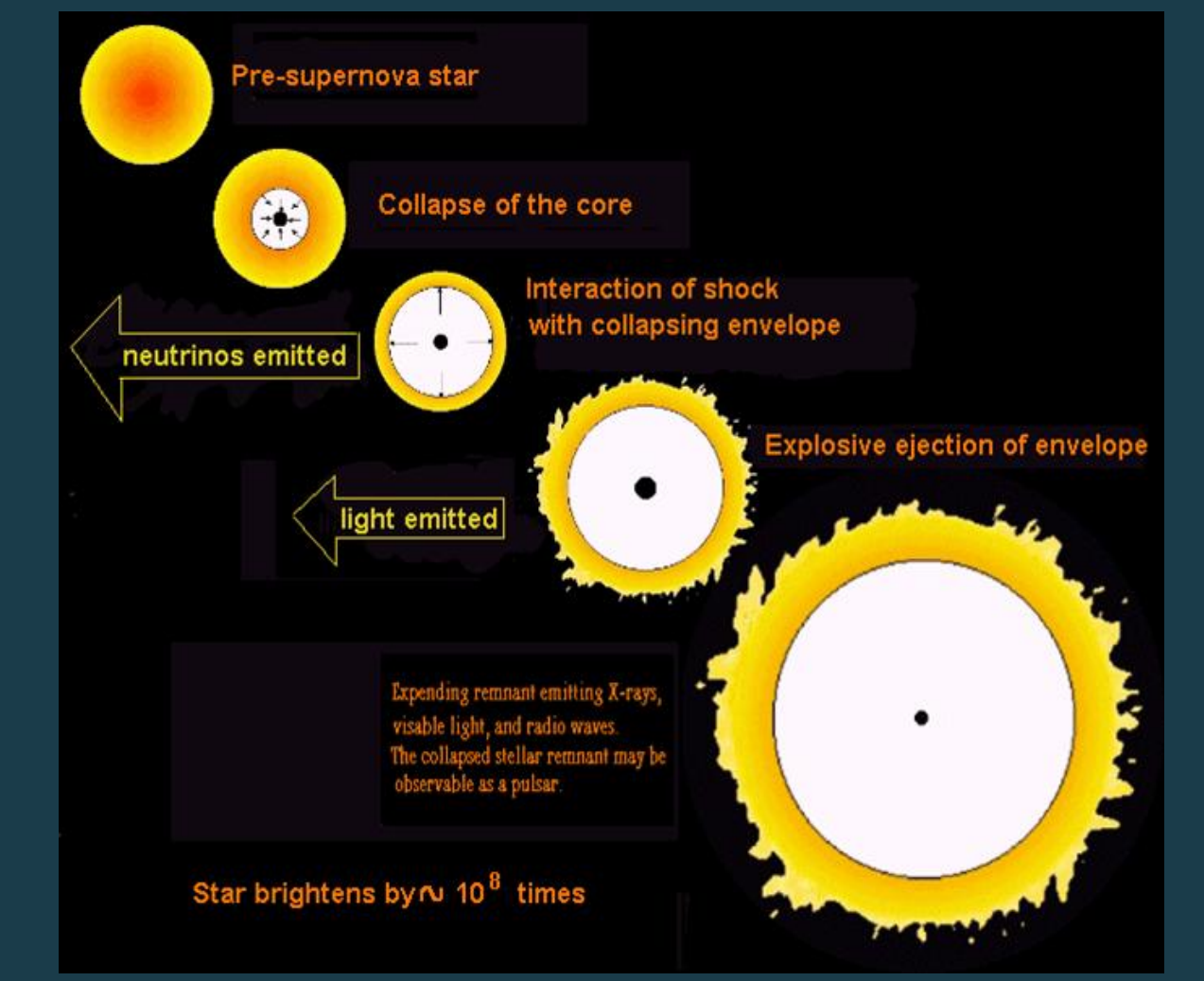
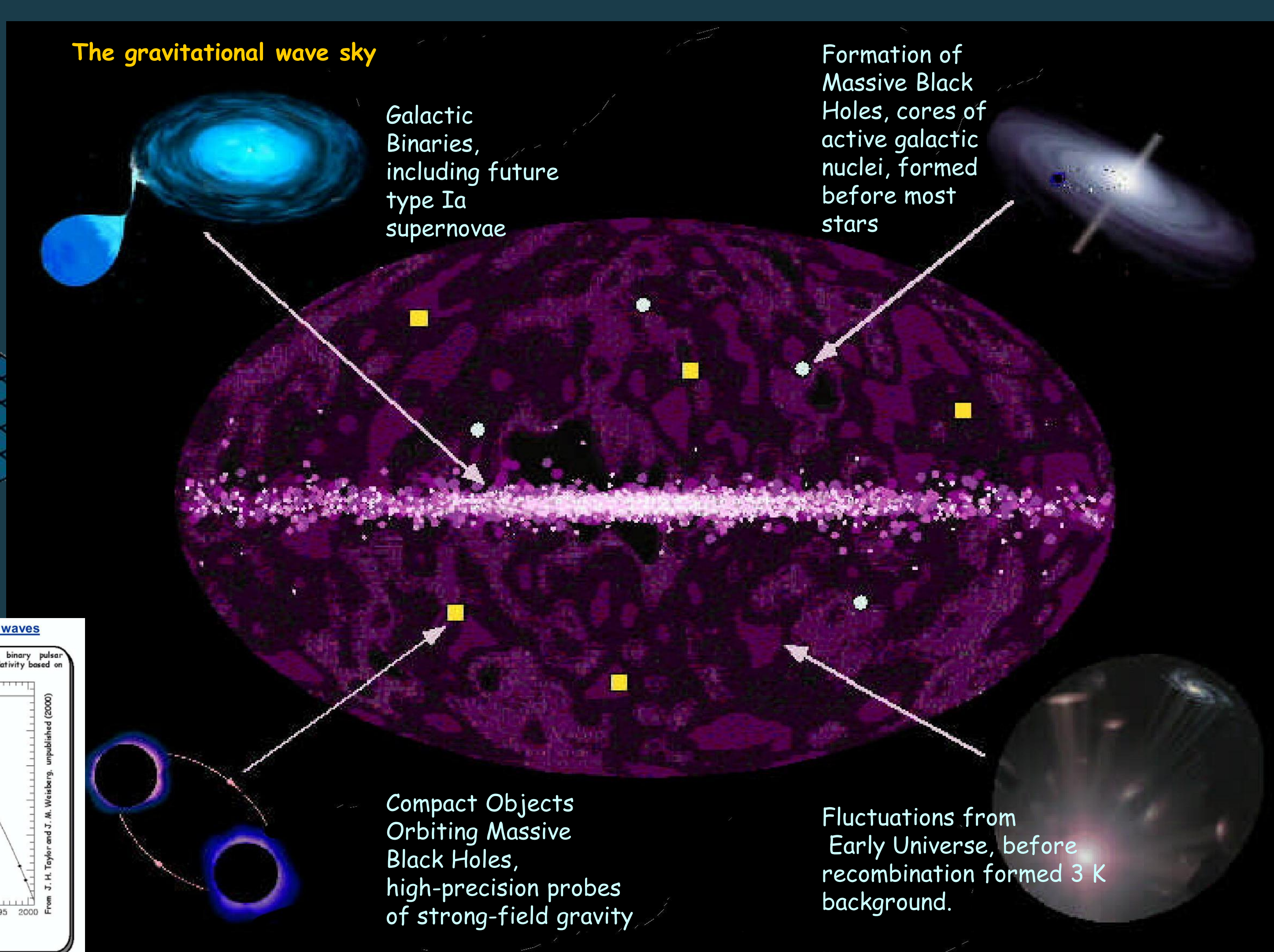
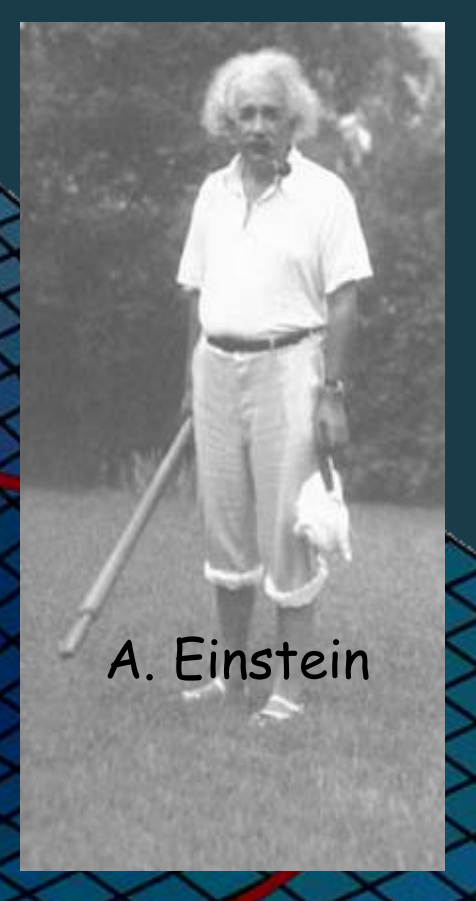


Gravitational Waves

ripples in spacetime

- Gravitational waves are propagating gravitational fields, ripples in the curvature of space-time
- Gravitational waves are analogous to light waves.
- Light consists of propagating electromagnetic fields, generated by the motion of electrically charged particles.
- According to Einstein's theory of General Relativity, compact concentrations of energy (e.g. neutron stars and black holes) should warp space-time strongly, and whenever such an energy concentration changes shape, it should create a dynamically changing space-time warpage that propagates out through the Universe at the speed of light.
- Gravitational waves result in changes in the distance between points, with the size of the changes proportional to the distance between the points.



Neutron Binary System - Hulse & Taylor
PSR 1913 + 16 - Timing of pulsars

- separated by 10⁶ miles
- $m_1 = 1.4m_{\odot}$; $m_2 = 1.36m_{\odot}$; $e = 0.617$
- Prediction from general relativity: spiral in by 3 mm/orbit
- rate of change orbital period: 17 / sec

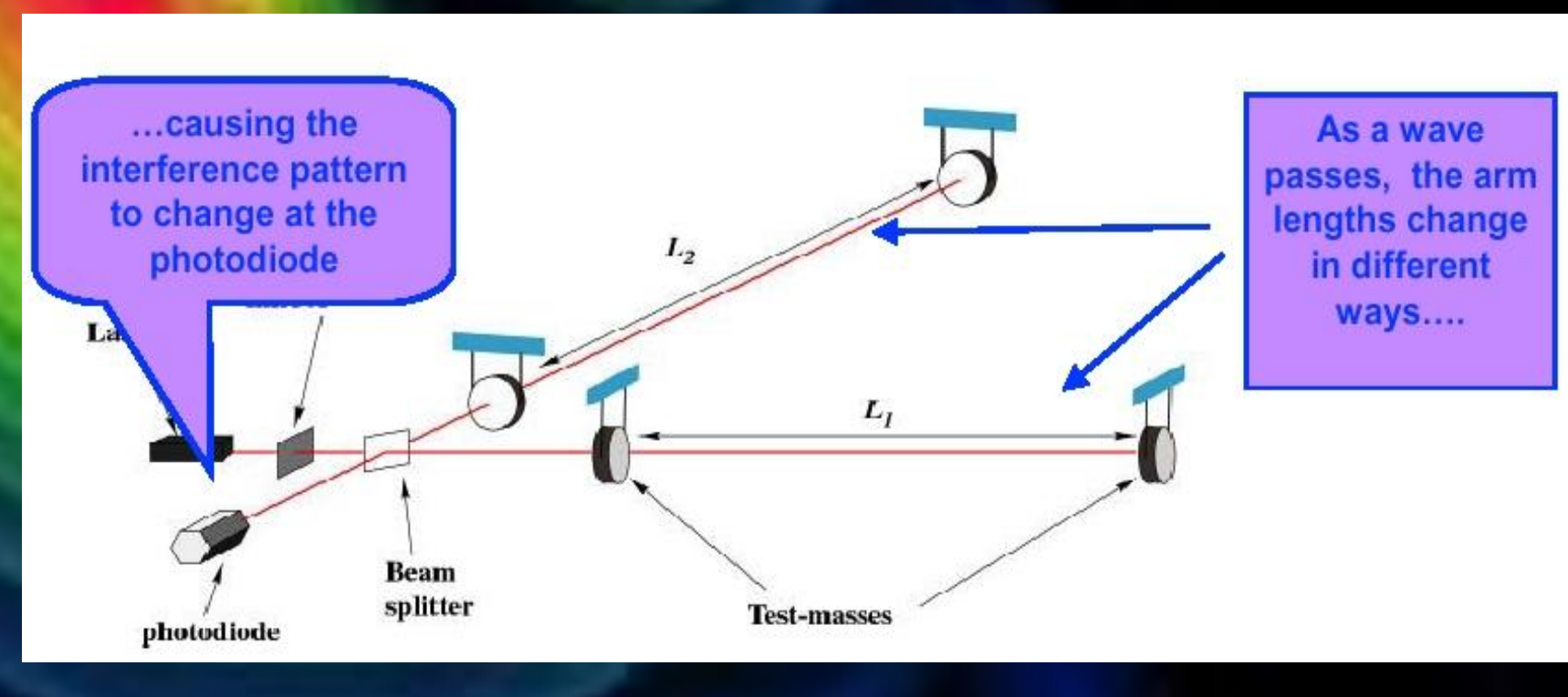
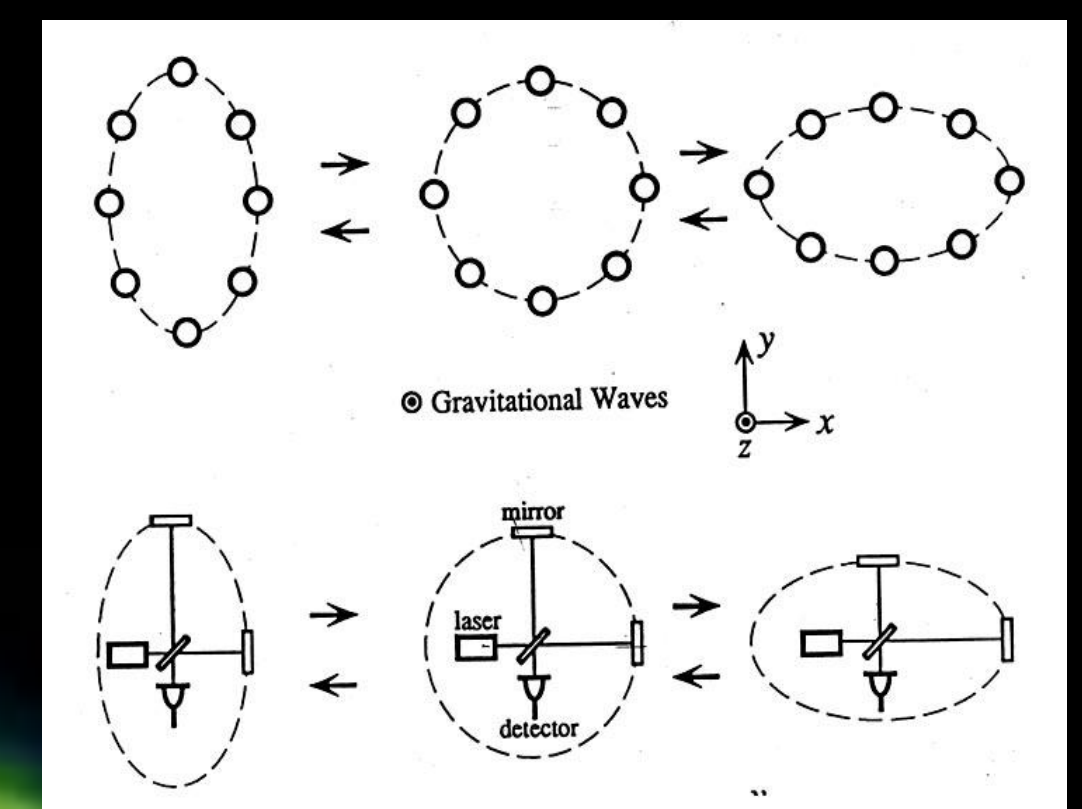
Emission of gravitational waves

Comparison between observation of the binary pulsar PSR1913+16, and the prediction of general relativity based on loss of orbital energy via gravitational waves

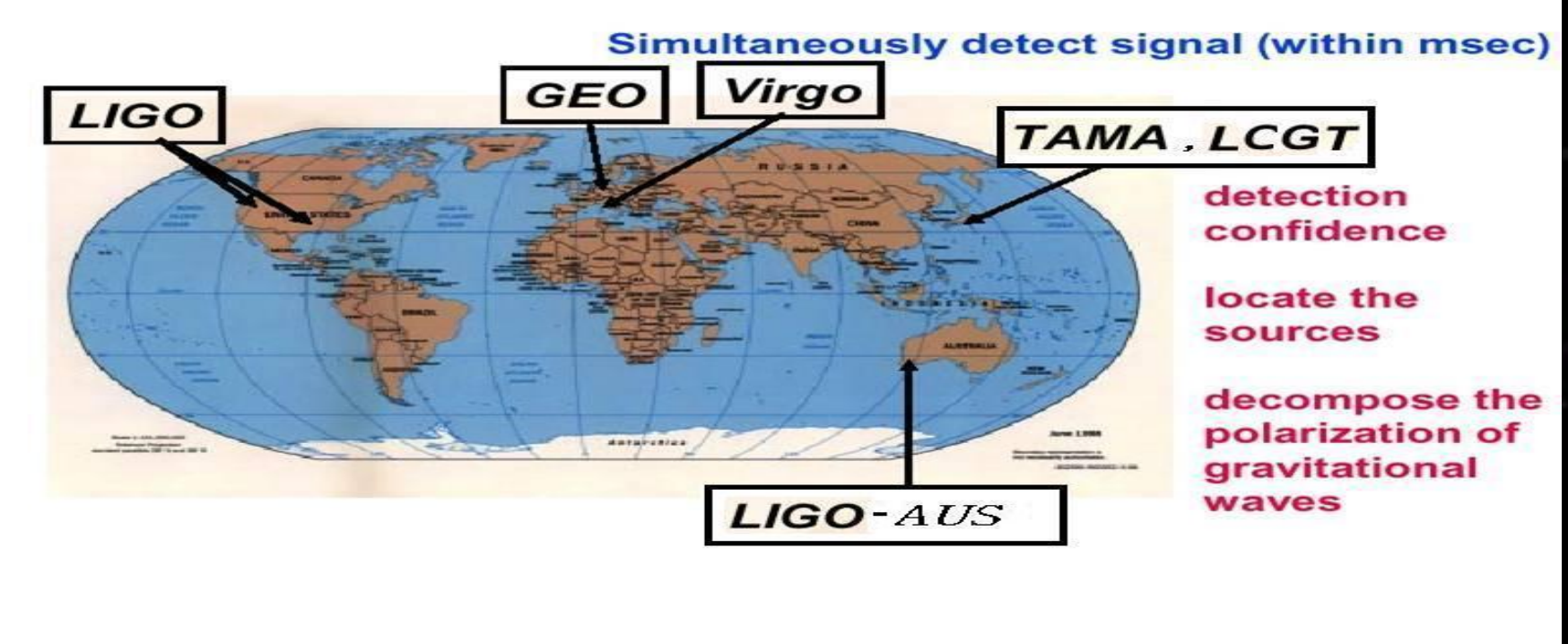
- Indirect observation of GWs**
- Existence of gravitational waves has been proved indirectly by R.A. Hulse and J.H. Taylor.
 - In binary pulsar system like PSR 1913+16, due to loss of orbital energy the period decreases. The measured decrease is 14 sec from 1975-94 and has been measured to ~50 msec accuracy.
 - They were awarded the Nobel prize in 1993

Resonant Bar Detectors

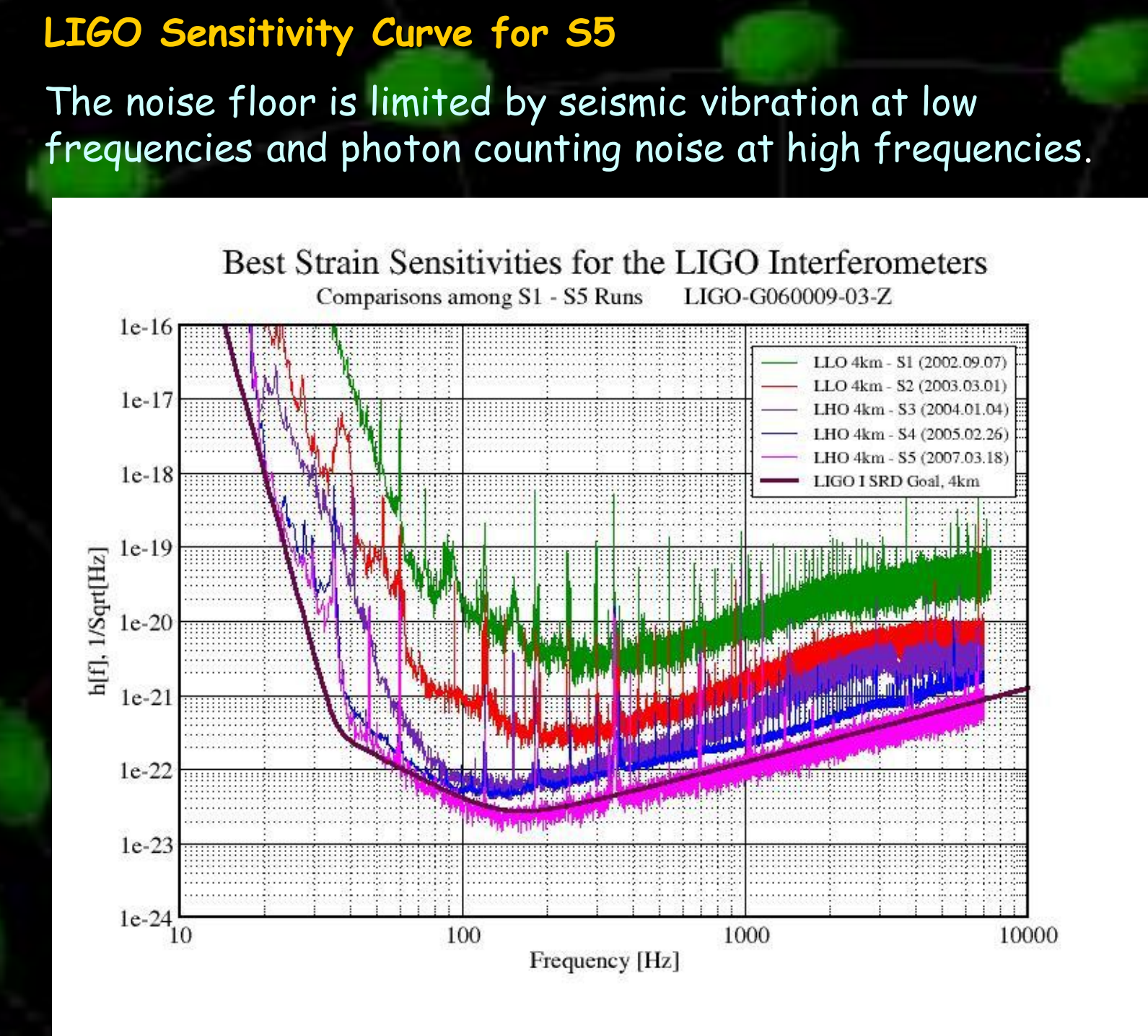
- Based on a very low loss ultra cryogenic mechanical oscillator.
- When a burst of gravitational waves hits and excites the oscillator, the bar will vibrate for a time span much longer than the duration of the burst (typically 1msec), thus allowing the extraction of the signal from the detector noise.
- These are narrow banded detectors and operate in a band around 1kHz.
- The typical strain sensitivities of these detectors are about $h \sim 10^{-20}$
- Cryogenic bar detectors are currently operational at several facilities in Italy and US.



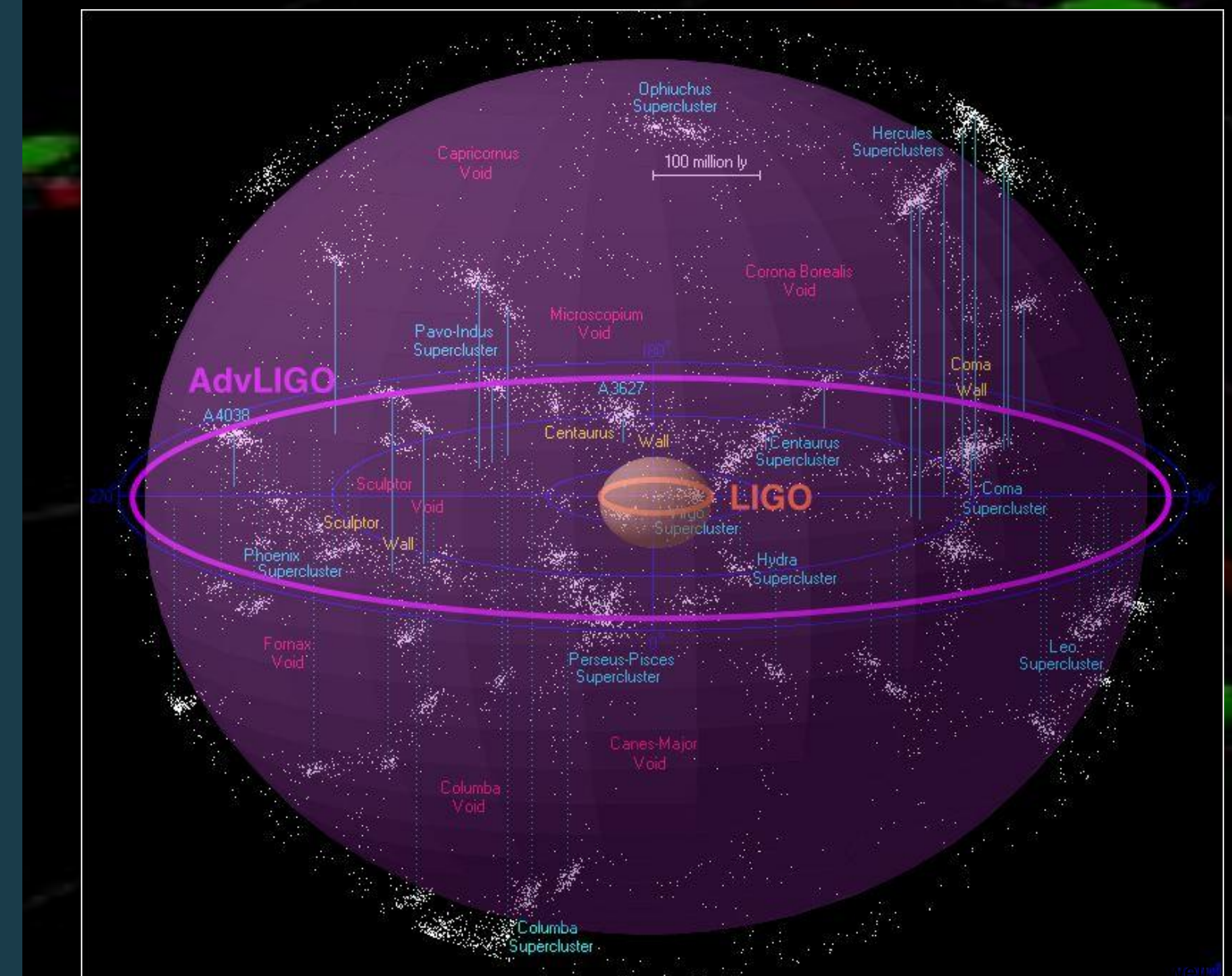
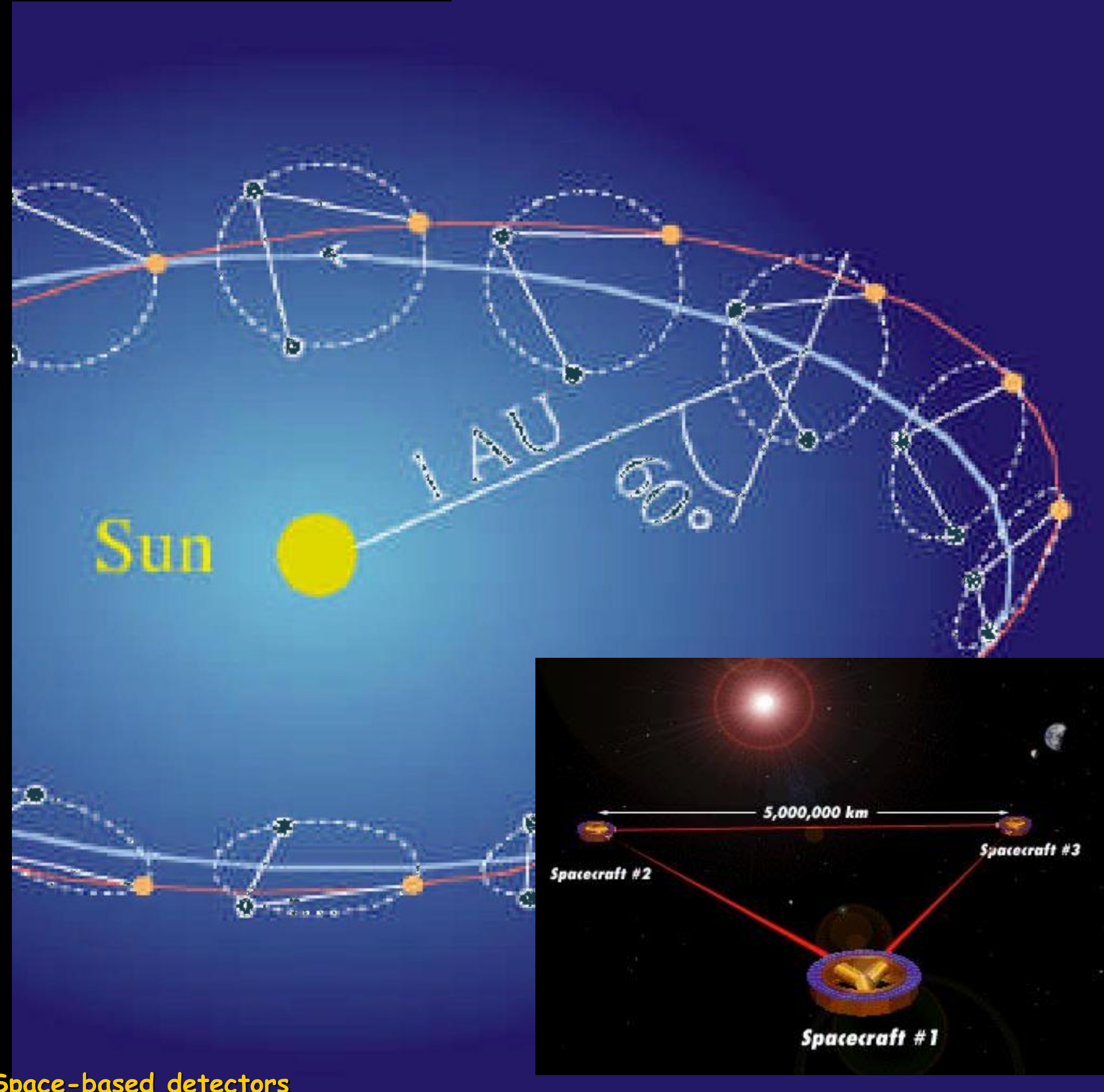
- Network of detectors**
- Due to the inherent weakness of gravitational wave signals, and the difficulty in distinguishing them from a myriad of noise sources, the direct detection of a GW burst will require coincident detection by multiple detectors with uncorrelated noise.
 - A network of interferometric and bar detectors spread around the globe will need to share data in order to discover the symphony of gravitational waves.



- Interferometric Detectors**
- A laser interferometer gravitational wave detector ("interferometer" for short) consists of four masses that hang from vibration-isolated supports, and optical system for monitoring the separations between the masses.
 - Two masses are near each other, at the corner of an "L", and one mass is at the end of each of the L's long arms. The arm lengths are nearly equal.
 - A gravitational wave, with frequencies high compared to the masses' 1 Hz pendulum frequency, will push the masses back and forth relative to each other as though they were free from their suspension wires, thereby changing the arm-length difference.
 - This arm length difference is converted to optical path length difference registered on a photo-detector.



- Current Status of LIGO**
- Massive improvement in instrumental sensitivity since commissioning. It has now reached design sensitivity above 50 Hz.
 - Commissioning strategy has helped to continuously improve the sensitivity of LIGO interferometers.
 - Astrophysically interesting sensitivity ON ALL 3 LIGO interferometers.
 - The first five science runs have put observational upper limits on event rates of astrophysical events giving rise to gravitational waves.
 - First six science runs have ended. Upgrading to Advanced LIGO has begun.**



"Seeing" Black Holes

Black holes are created when a massive star dies. It is not possible to observe them through telescopes as no light can escape their gravity. G-Wave signals from such black holes will allow us to directly observe them.

