# Gravitational Waves

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Scan Me!

### What are gravitational waves?

Gravitational waves are ripples in spacetime, travelling at the speed of light. They will disturb the spacetime thus any object in the path will get squeezed and stretched as the waves pass by.

### How to detect them?

When gravitational waves reach us from distant events that caused them, they distort spacetime by an almost negligible amount. This distortion is many times smaller than the size of a proton nucleus. However, with Michelson interferometers with arms of 4 km length, they can still be measured.

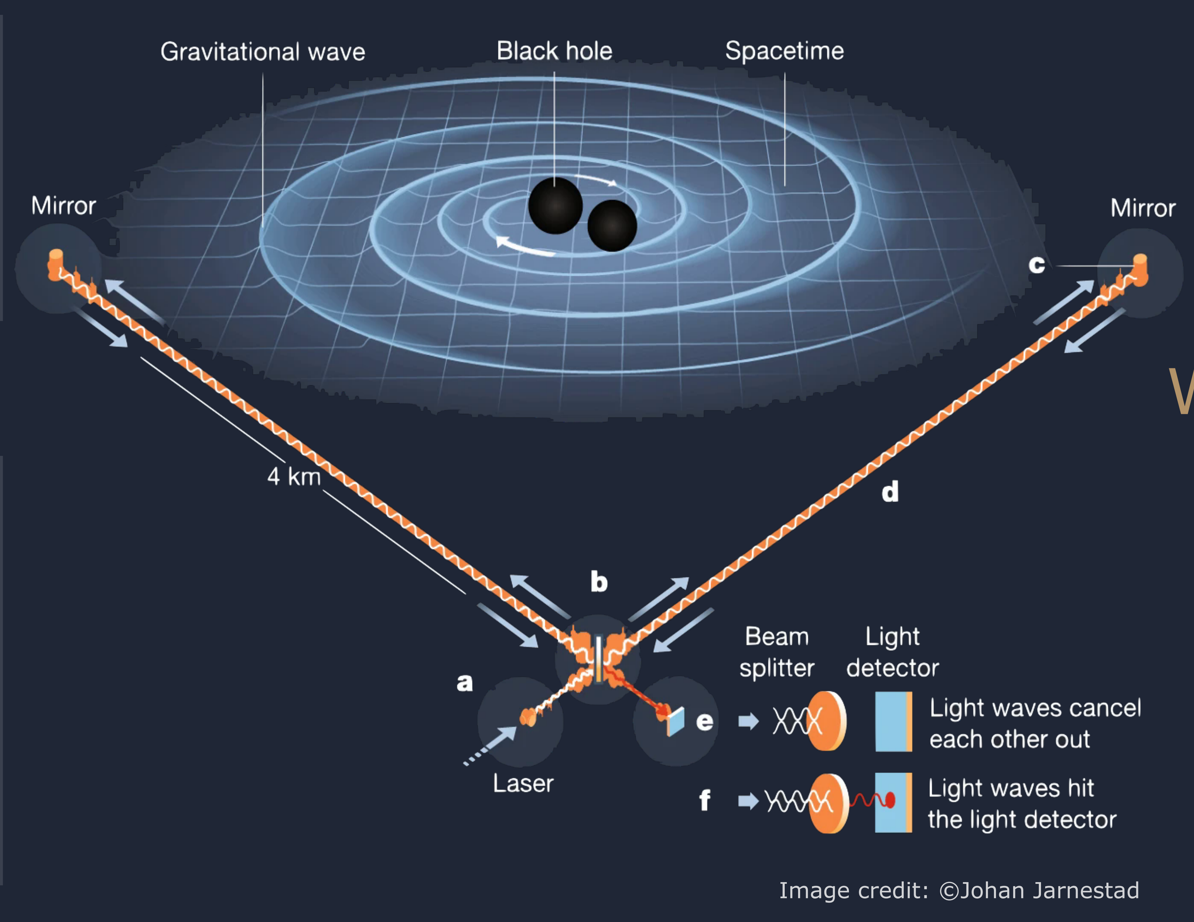



Image credit: ©Johan Jarnestad

### Where do they come from?

Strong gravitational waves can be produced by catastrophic events, such as colliding black holes and neutron stars, supernovae, or gravitational radiation left over from the Big Bang.

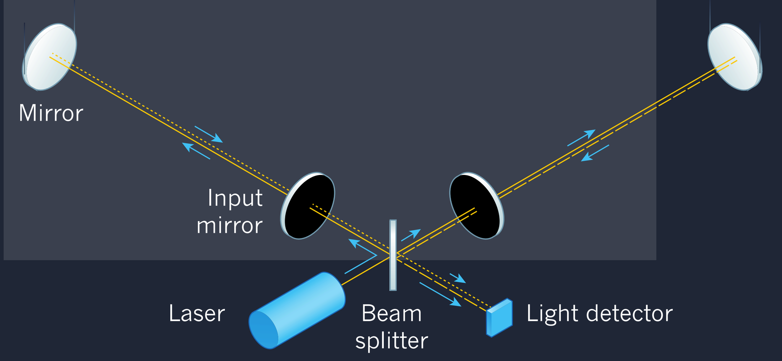
### Why are they important?

Gravitational waves will help us understand processes that occur in outer space, such as the collisions of pairs of black holes. The knowledge gain from that could also improve our understanding of space, time, matter, energy, and their interactions. We could revolutionize humanity's understanding of the nature of existence itself.

## Detectors

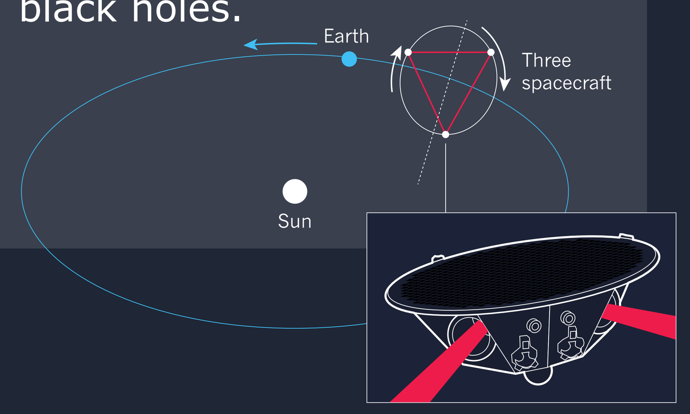
### 1000 Hz - 10 Hz
### Ground Based Detector

Current and future ground based observatories such as LIGO and Einstein Telescope can detect longer wave-lengths than the detectors' lengths (a few kilometres), corresponding to periods of a few hundredths to a few thousandths of a second.



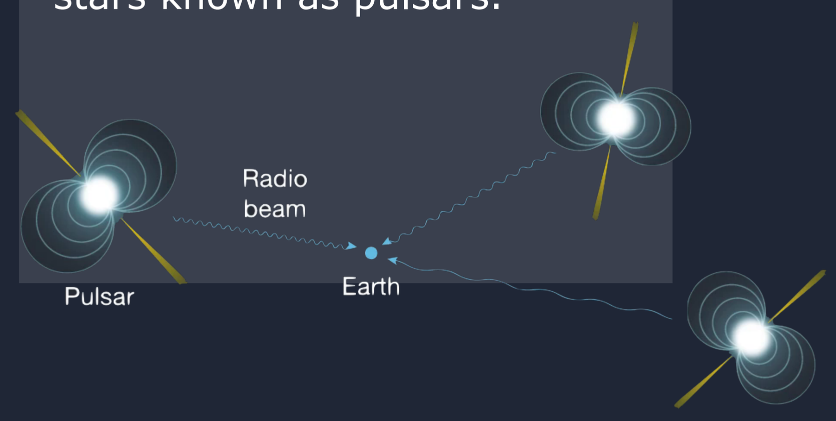

### 100 mHz - 0.1 mHz
### Space Detector

LISA, the trio of probes scheduled to launch in 2034, will have virtual arms millions of kilometres long, making it sensitive to waves with periods of a few seconds up to several hours. That will allow us to detect gravitational waves from supermassive black holes.



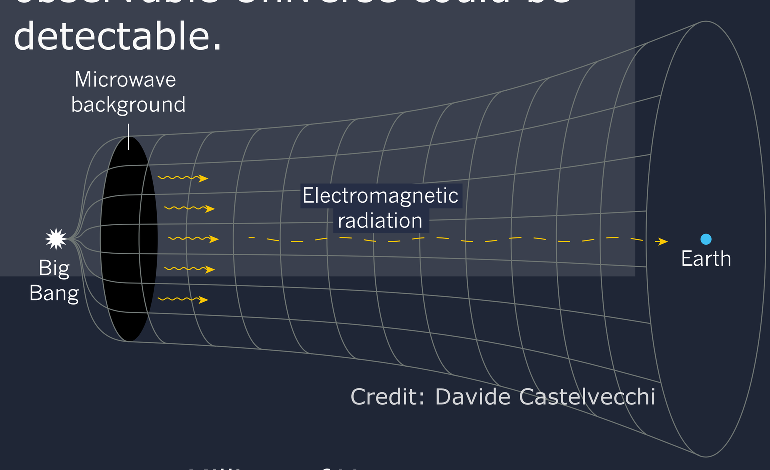

### 320 nanoHz - 1 nanoHz
### Pulsar Timing Array

Gravitational waves from distant galaxies perturb the distance between Earth and stars in the Milky Way. The goal is to detect waves of periods lasting years by examining delays in the radio signals from spinning neutron stars known as pulsars.

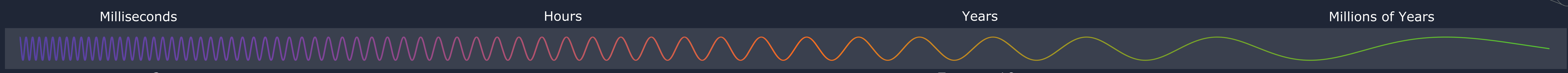



### $10^{-13}$ Hz - $10^{-16}$ Hz
### Microwave Background

The Universe's oldest measur-able radiation could carry evidence of gravitational waves from the Big Bang. Those waves would not be detectable directly. However, their stretch across a significant fraction of the observable Universe could be detectable.



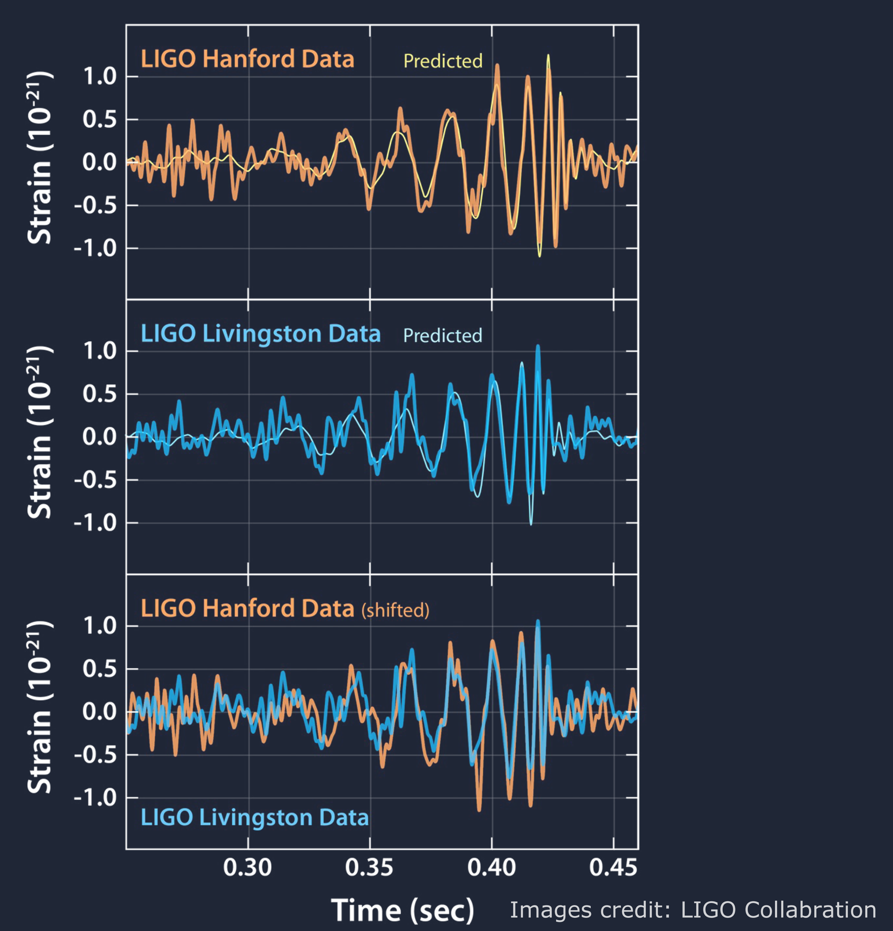

Credit: Davide Castelvecchi




$1\ M_\odot - 10^2\ M_\odot$ | $10^4 M_\odot - 10^7 M_\odot$ | $10^7 M_\odot - 10^{10} M_\odot$ | Primordial Gravitational Waves

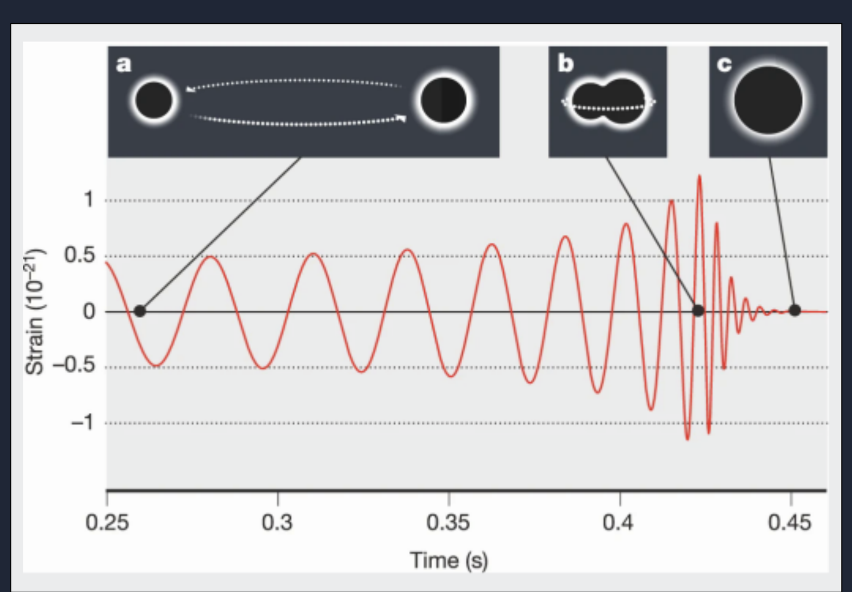
## "Sounds" from space

### First ever detection




Images credit: LIGO Collabration

### A binary black hole merger!

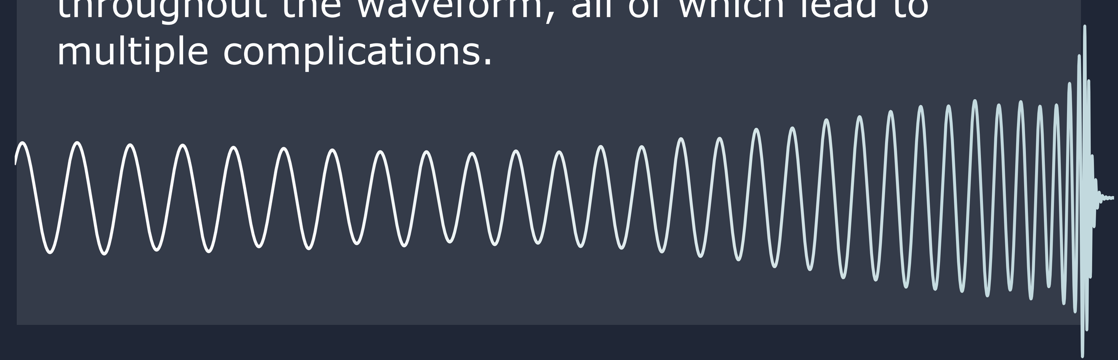



Images credit: M. Coleman Miller

### Complex factors that affect the waveform

#### Precession

When the black hole spins are not parallel to the orbital angular momentum, their orientation changes over time, causing the orbital plane to precess. The precession of the spins and the orbital plane introduce modulations in the GW amplitudes, oscillations in the GW frequency, and variations in the relative distribution of signal power throughout the waveform, all of which lead to multiple complications.

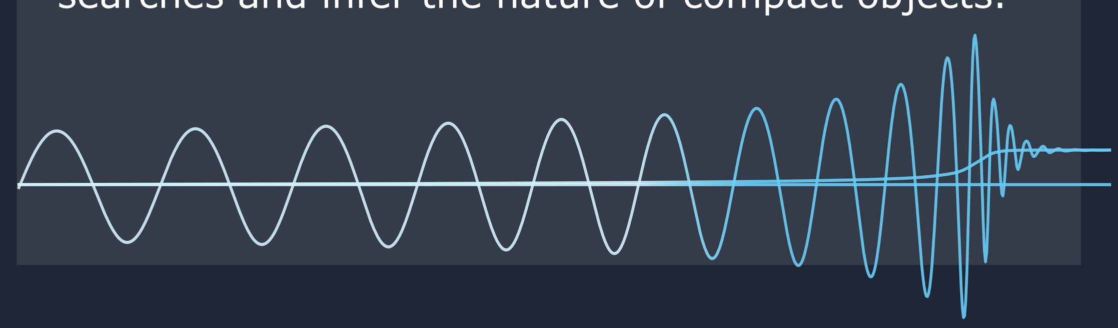


#### Eccentricity

In general, the orbit of a binary system can be eccentric. While it evolves for a long time in isolation, eccentricity is lost as the orbit shrinks due to the emission of gravitational radiation thereby becoming more and more circular. However, in dense stellar environments, the binary can form dynamically and merge in a short amount of time with residual eccentricity even close to the merger. Thus measuring eccentricity would provide hints about the formation scenario of binary black holes.

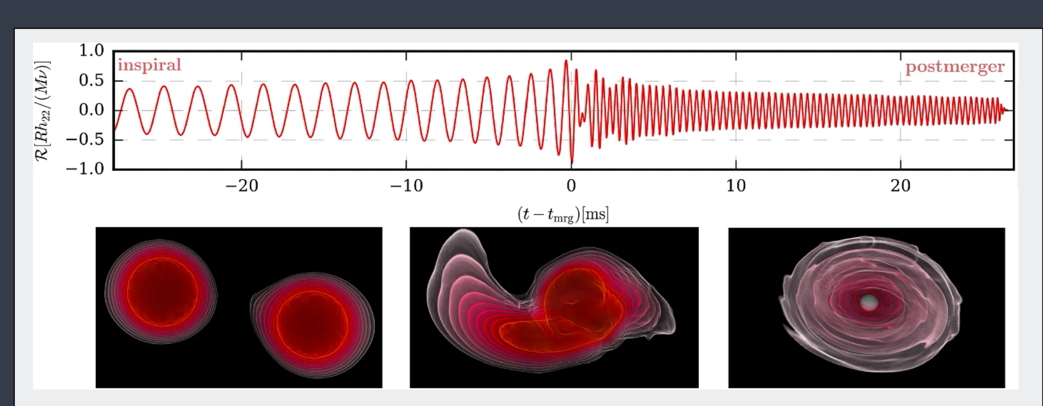
#### Memory

The gravitational-wave memory effect predicts a persistent change in the relative positions of two points in space due to the passing of a gravitational wave. This effect is a direct consequence of the non-linear nature of general relativity. The memory has not only been suggested to validate general relativity, but also to increase the parameter space of gravitational wave searches and infer the nature of compact objects.



#### Tidal Effects

Other than black holes, neutron stars experience tidal effects visible in the waveform. Measuring these can yield information about their extreme matter and still unknown equation of state.




Images credit: Tim Dietrich et al.