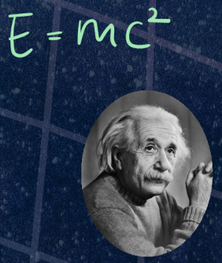
The evolution of Gravitational-Wave (GW) science

1910s

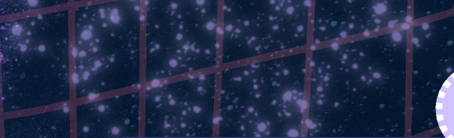
START

In 1905, Henri Poincaré proposed the existence of GWs propagating at the speed of light, analogous to electro-magnetic waves. A decade later, Albert Einstein predicted the existence of GWs as a direct consequence of his theory of general relativity.



1950s

Andrzej Trautman, Ivor Robinson, Felix Pirani, Hermann Bondi, and Richard Feynman developed frameworks showing that GWs are not artifacts of the coordinate system, but instead carry energy and produce measurable physical effects, such as the relative motion of particles.



1978

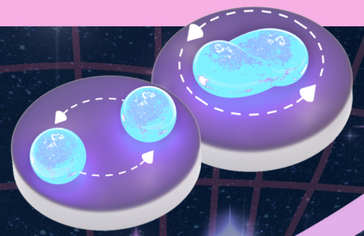
Russell Hulse and Joseph Taylor discovered a binary pulsar exhibiting orbital decay due to energy loss through GW emission. This observation confirmed the predictions of general relativity and provided the first indirect evidence for the existence of GWs.

Initial detectors

The search for GWs began with resonant-bar detectors before advancing to laser interferometry, which then led to the founding of LIGO in the 1980s. The initial LIGO detectors in Hanford and Livingston, USA, were inaugurated in 1999. Independently, the Virgo project was developed by a European collaboration and inaugurated in 2003. The two observatories began joint observations in 2007.

First detections

On September 14 2015, LIGO detected GW150914, a GW signal from a pair of merging black holes 1.3 billion light-years away, marking the first direct observation of GW. Two years later, the joint LIGO-Virgo network detected GW170817, the first GW signal from a pair of merging neutron stars, accompanied by multiple electromagnetic counterparts.

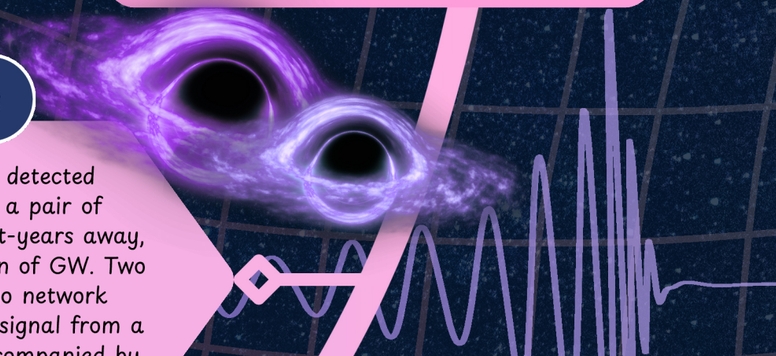


Advanced detectors

In the 2010s, LIGO and Virgo underwent major upgrades. With increased laser power and noise isolation, sensitivities of Advanced LIGO and Virgo were enhanced tenfold, enabling detection of GWs from more distant sources. In parallel, the cryogenic KAGRA detector was being commissioned in Japan.

10 years of GWs

GWs have enabled the study of obscured astrophysical sources and interiors previously inaccessible to electromagnetic observations. So far, the LIGO-Virgo-KAGRA collaboration has detected over 300 GW events, confirming key predictions of general relativity, revealing intermediate-mass black holes, and offering new insights into black hole formation and populations.



FUTURE

GW astronomy is entering an exciting and transformative era. With LIGO-India underway, next-generation ground-based detectors like Cosmic Explorer and the Einstein Telescope in development, and the space-based Laser Interferometer Space Antenna (LISA) on the horizon, the network of GW observatories is rapidly expanding. These advancements will significantly boost detector sensitivity, enabling us to probe deeper into the cosmos. Progress in GW astronomy, together with electromagnetic and neutrino observations, can help answer long-standing astrophysical questions, from the violent births of heavy elements to the nature of dark matter.

credit: Yi Shuen Christine Lee / Carl Knox / OzGrav