Gravitational waves

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Einstein's general relativity (GR), although more than 100 years old, is so far the most accurate theory describing gravitation. Many of its predictions have been successfully tested up to day, for instance the perihelion precession of Mercury, light deflection, gravitational redshift, gravitational lensing, time-delay or frame-dragging, to name only a few.

GR also predicts the existence of gravitational waves (GW), ripples of space-time caused by accelerated masses. The detection of such signals as well as their analysis can tell us more about the physics of the sources, the early universe or its evolution, and can at the same time provide additional tests for GR.

Linearization

Einstein field equations are a set of 10 highly non-linear equations describing the relation between space-time geometry (on the left-hand side, through the metric tensor $g_{\mu\nu}$) and its matter or energy content (via the stress-energy tensor $T_{\mu\nu}$ on the right-hand side):

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

One can linearize the metric by assuming small perturbations,

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \qquad |h_{\mu\nu}| \ll 1$$

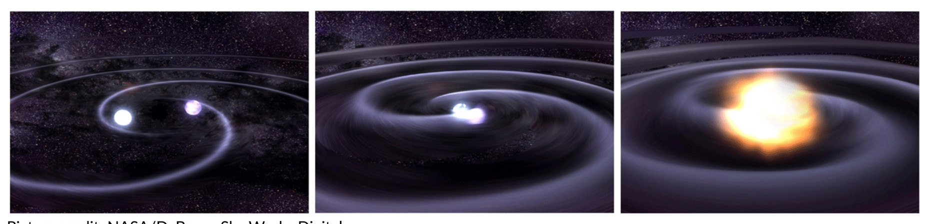
and after an appropriate choice of gauge, obtain the following wave equation describing gravitational waves:

$$\Box \bar{h}_{\mu\nu} = -\frac{16\pi G}{c^4} T_{\mu\nu}$$

Gravitational waves are thus nothing else than ripples of space-time caused by accelerated systems and propagating at the speed of light.

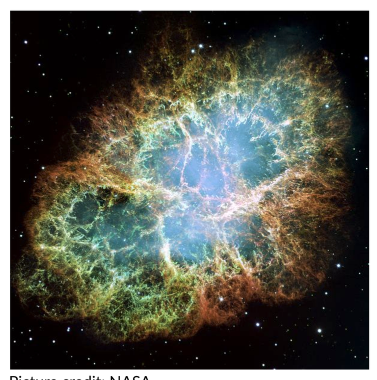
Sources: some examples

Binary white dwarf



Picture credit: NASA/D. Berry, Sky Works Digital

Supernova

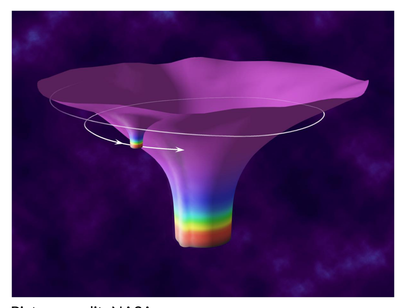


Picture credit: NASA

Binary neutron star

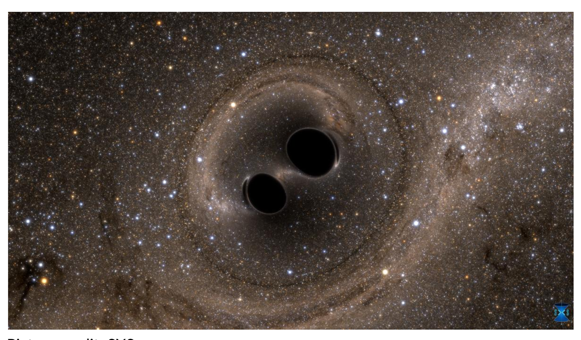
Picture credit: LISA

EMRI



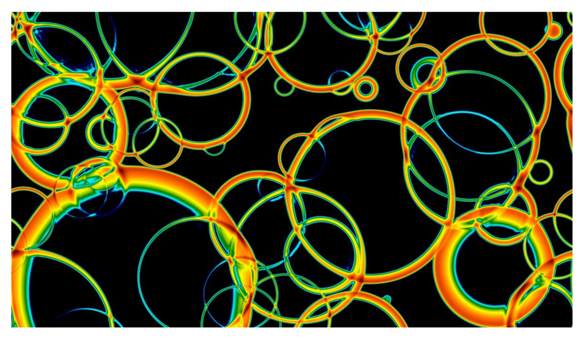
Picture credit: NASA

Binary black hole



Picture credit: SXS

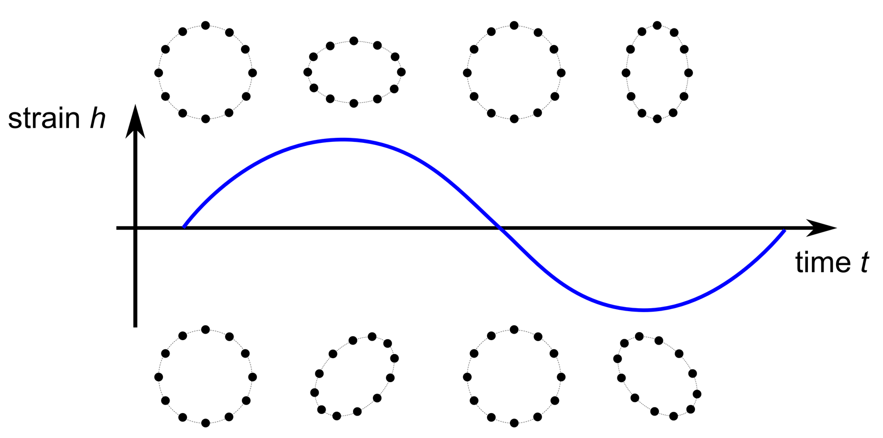
1st order phase transitions in the early universe



Picture credit: D. Weir

Detection

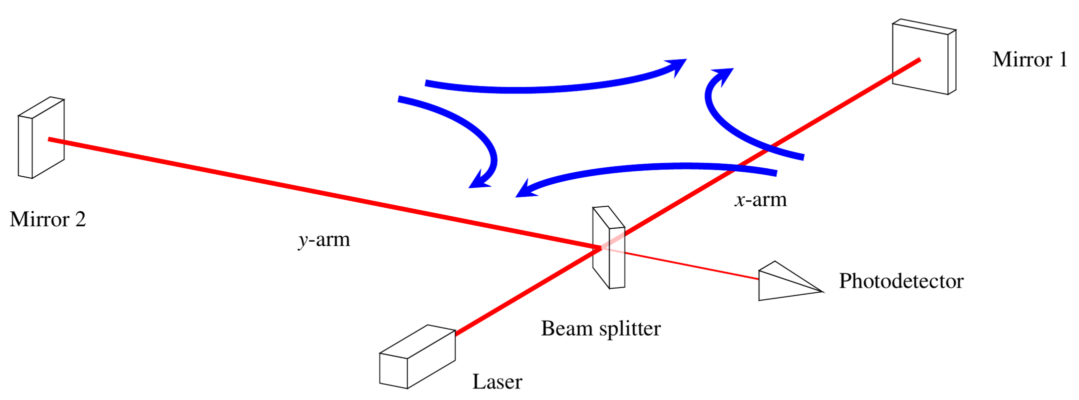
GW induce deformations in the plane transverse to the direction of propagation. This strain is characterized by two polarization: + and x.



+ polarization

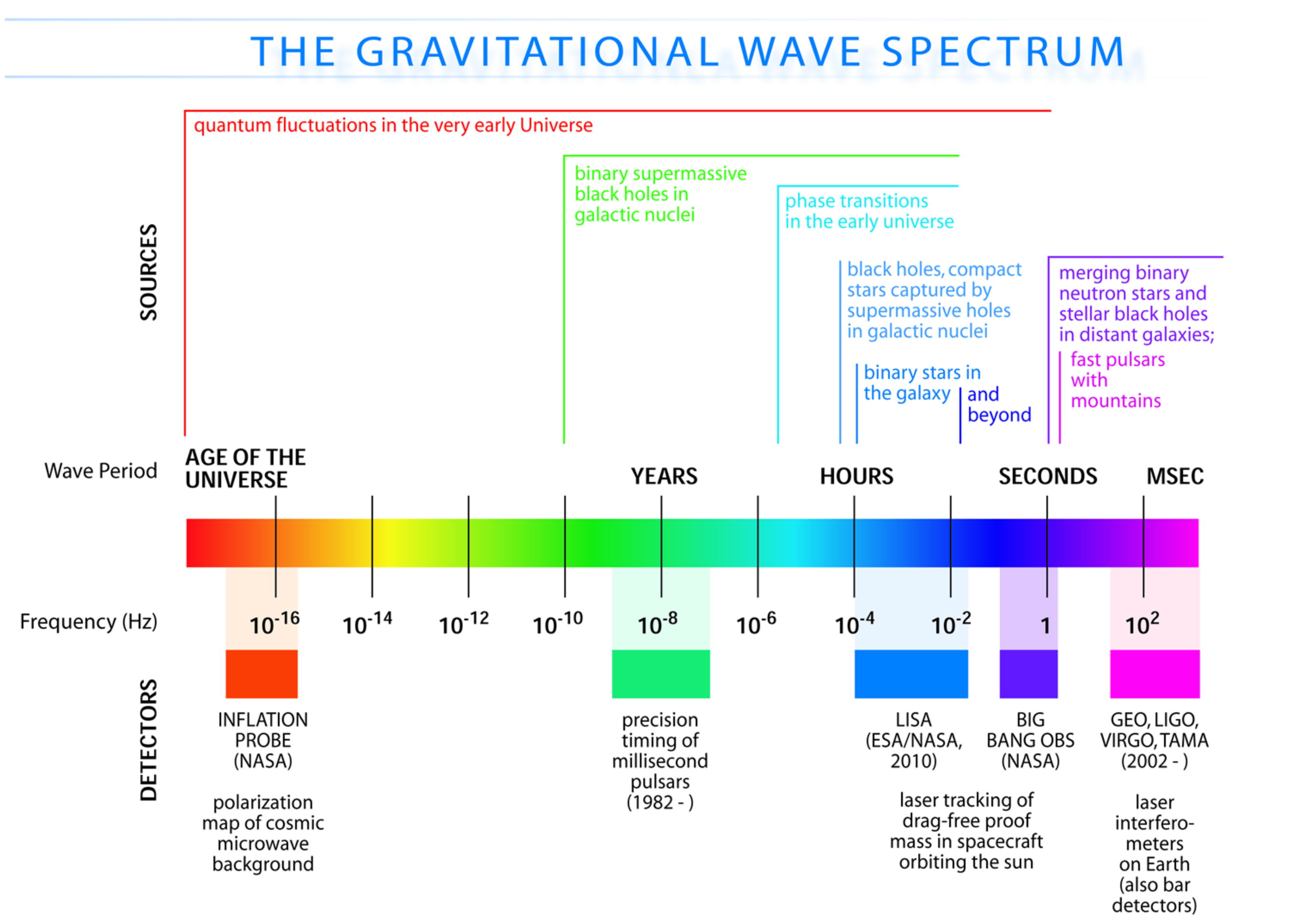
x polarization

This can be used to detect GW with an interferometer. Note that a typical expected relative strain is of the order $h \sim 10^{-21}$



GW spectrum

The GW frequency depends on the source, and complementary experiments are required to cover the whole spectrum, similarly to EM observations.



Picture credit: Institute for Gravitational Research/University of Glasgow