Introduction to Gravitational Waves

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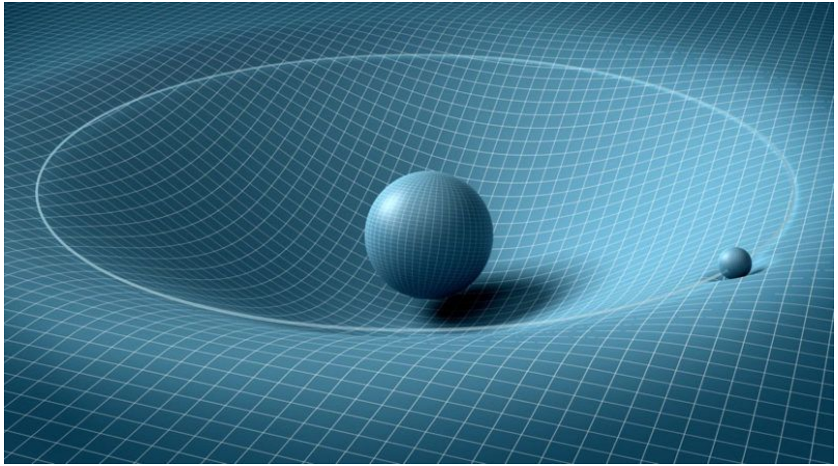
General Relativity

1. An update to Newton's notion of gravitational force.

2. Proposes the notion of spacetime 'fabric' to realise gravity as an effect of the curvature in spacetime.

3. Introduces notions of gravitational time dilation, existence of black holes, gravitational waves, etc.



Credits: POSTERIORI/SHUTTERSTOCK

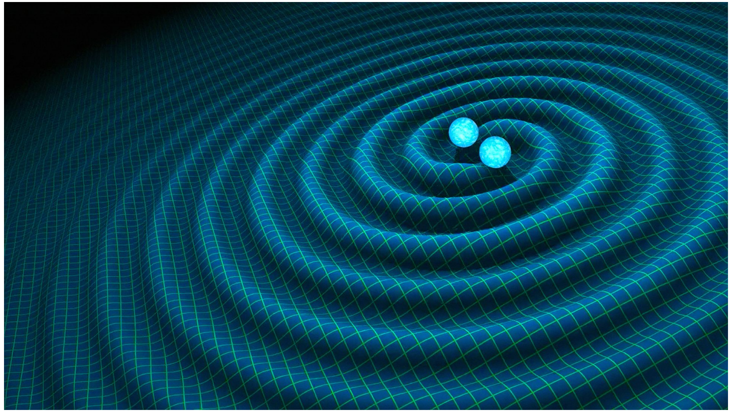
$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Gravitational Waves (GWs)

1. Perturbations in spacetime fabric.

2. Propagate at the speed of light.

3. Proportional to the second time derivative of the mass quadrupole moment.



Credits: R. Hurt (Caltech-JPL)

Effects of passing of GWs

1. Stretching and contracting of spacetime.

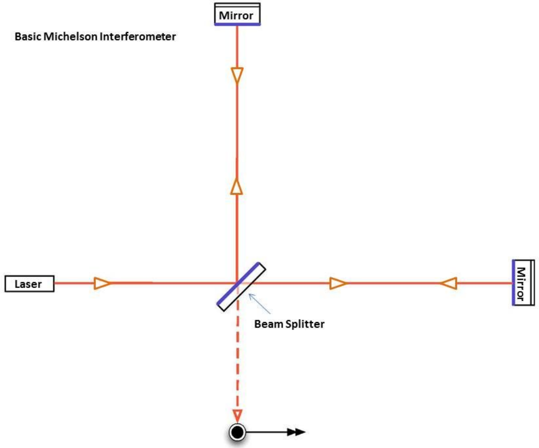
2. Two polarizations: h_+ and h_x

3. Use of laser interferometry for detection.

4. GW150914 changed the length of a 4 km long ligo arm by a thousandth of the width of the proton.

Plus Polarization

Cross Polarization

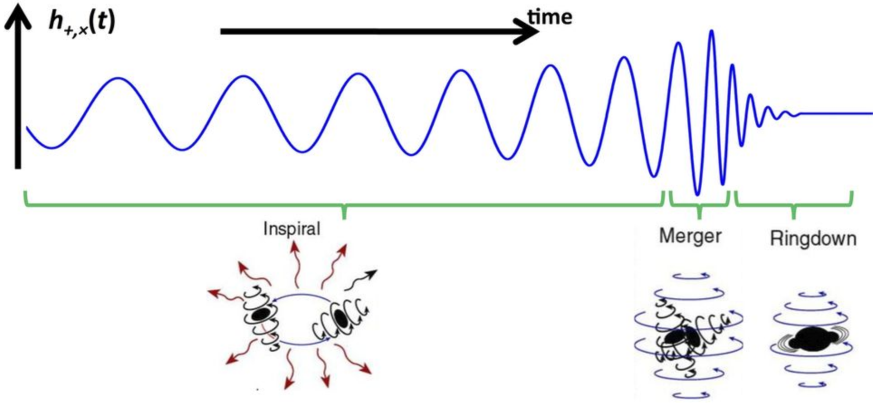


Sources of GWs

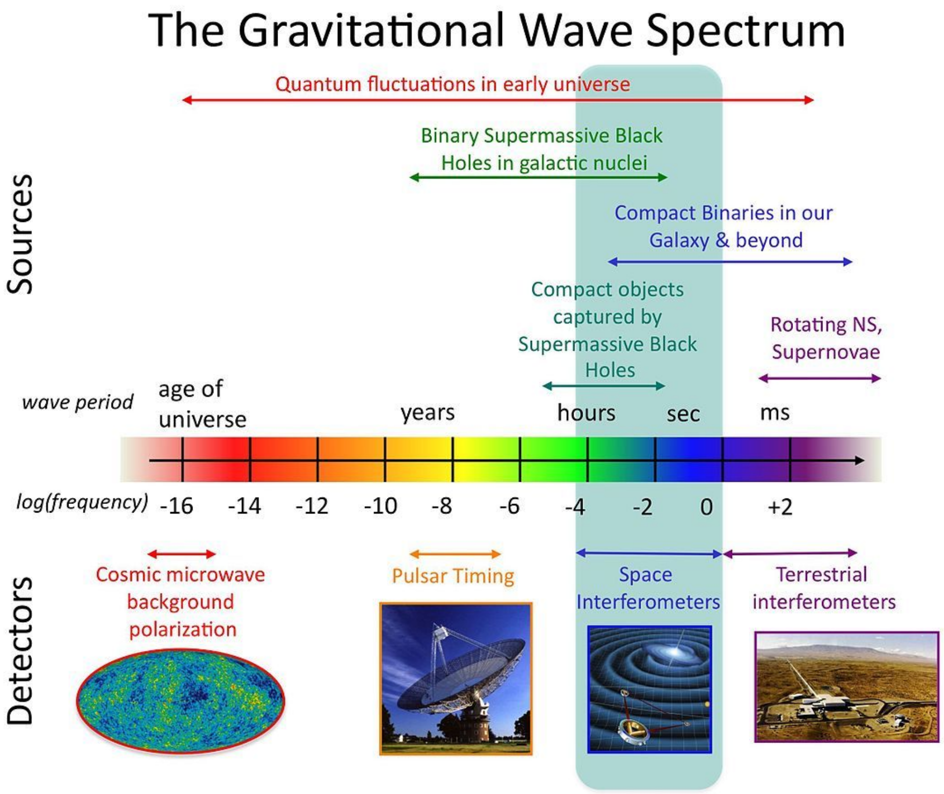
1. Continuous gravitational waves

2. Compact binary gravitational waves
   a. BH-BH (BBH)
   b. NS-BH (NSBH)
   c. NS-NS (BNS)

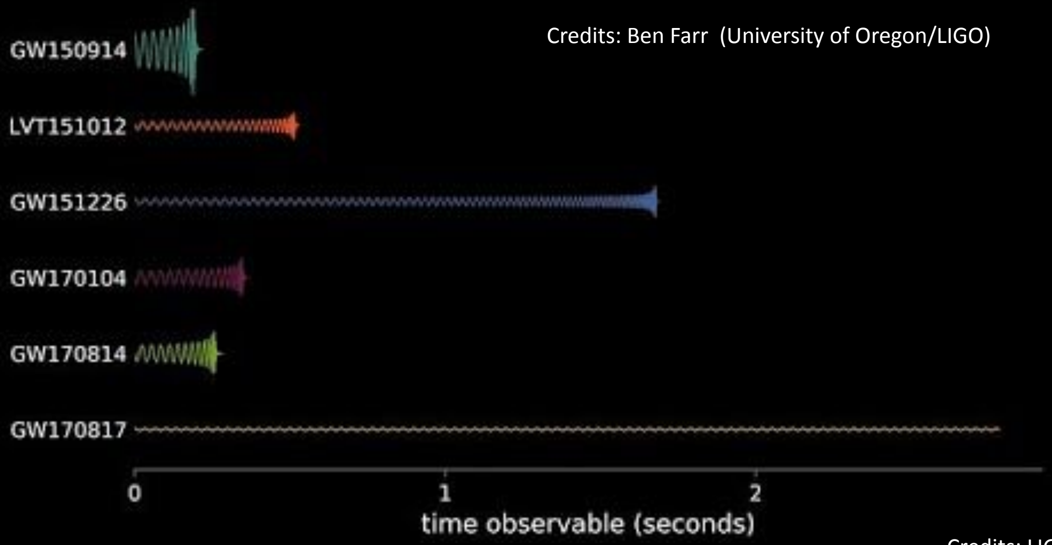
3. Stochastic gravitational waves



Credits: M. Favata/SXS/K. Thorne

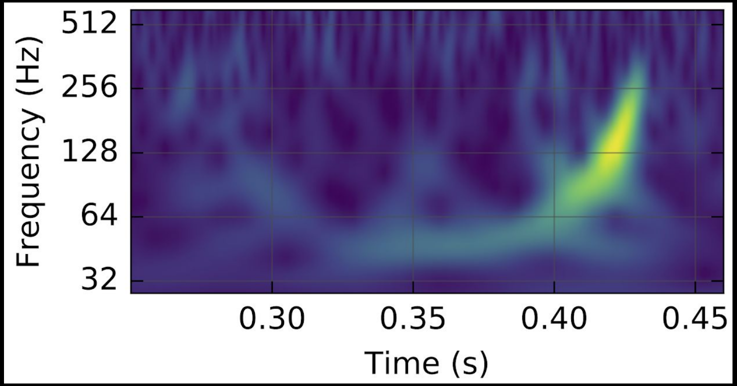


Credits: NASA Goddard Space Center

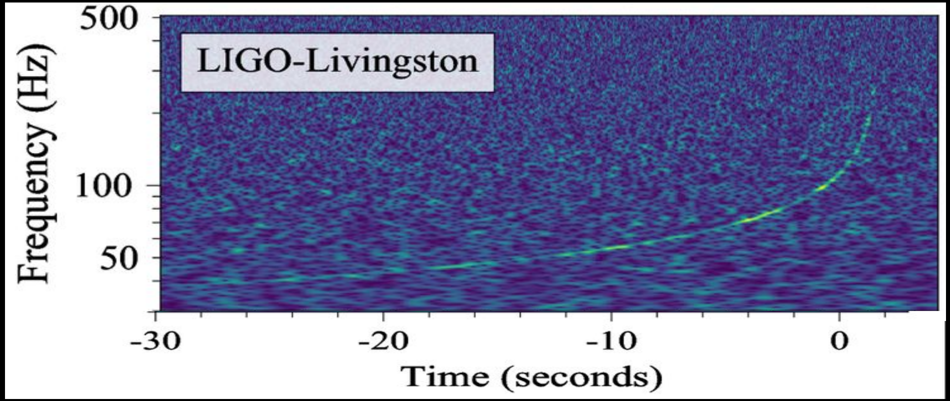


Credits: Ben Farr (University of Oregon/LIGO)

Credits: LIGO Discovery papers for GW150914 and GW170817



GW150914



GW170817

What can be measured?

1. GW detection leads to measurements of many properties related to the compact binaries with varying amounts of accuracies.

2. Intrinsic parameters:
    a. Masses (chirpmass and mass ratio)
    b. Spin and precession
    c. Tidal deformity

3. Extrinsic parameters:
    a. Right ascension, declination and inclination angle
    b. Luminosity distance
    c. Polarisation angle and phase

How do we measure the properties?

1. Parameter estimation: matching waveforms with data to obtain distributions for parameter values.

2. Since the data has noise, we do not predict the exact values for the parameters. Instead, we obtain distributions.

3. Base of the techniques used is the Bayes!

Bayesian Analysis

$$P(\mathcal{E} \mid d, H) = \frac{P(\mathcal{E} \mid H)P(d \mid \mathcal{E}, H)}{P(d \mid H)}$$

- $P(\mathcal{E} \mid H)$ is called the *prior*. It is the probability distribution of the parameters based on our hypothesis.
- $P(d \mid \mathcal{E}, H)$ is called the *likelihood*. It is the probability that the data contains the signal described by the parameters and our hypothesis.
- $P(d \mid H)$ is the normalization constant and is also referred to as the *evidence*.
- $P(\mathcal{E} \mid d, H)$ is called the *posterior*. It gives the probability distribution of parameters given the data and the hypothesis.

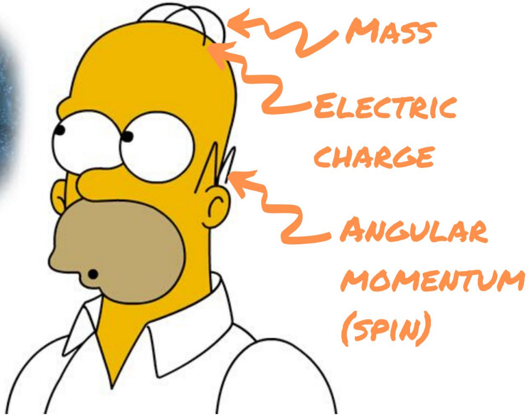
My Research

Testing the no-hair theorem

Black hole no-hair theorem

1. General relativity predicts that a black hole can be completely characterised by their mass, charge and spin.

2. So, binary black holes can also be completely characterised by a set of intrinsic parameters (like chirpmass, mass ratio and spins).



Credits: Matt Groening and Fox Broadcasting

The test we implement

Allow inconsistencies in higher order modes (H.O.M) by introducing deviation parameters

$$h(t;\mathbf{n},\lambda,\Delta\lambda) = \underbrace{\sum_{m=\pm 2} Y_{2m}^{-2}(\mathbf{n})\, h_{2m}(t,\lambda)}_{\text{Dominant mode}} + \underbrace{\sum_{\text{H.O.M}} Y_{\ell m}^{-2}(\mathbf{n})\, h_{\ell m}(t,\lambda+\Delta\lambda)}_{\text{Subdominant modes}}$$

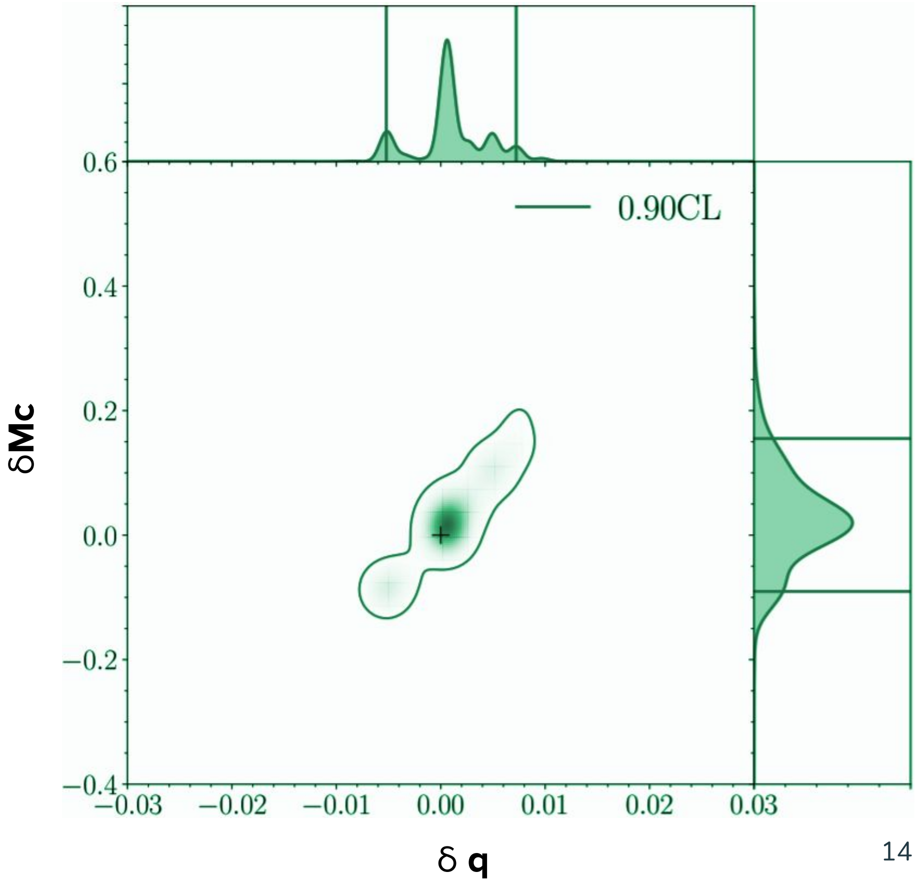
We introduce deviations in chirpmass and mass ratio. If the deviation is obtained to be 0, this will verify the claims of general relativity.

PARAMETER ESTIMATION

System Configuration

- For injection:
  - Mc = 9.43
  - q = 1/9 = 0.11
- Waveform: IMRPhenomHM (including Mc_{HM} and q_{HM})

We inject a GR waveform and retrieve using modified GR version of our model, i.e. allowing Mc_{HM} and q_{HM} to deviate from Mc_{22} and q_{22}.



Questions?