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Given 1960's waveform and data analysis (but 2015 detector technology) could GW150914 have been found in the data?

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5 Aug 2020

Why the topic?

Popular among students

Multi disciplinary

Excellent Introductory Analysis- Authentic Hands on Experience of Real time data

Interest in Astronomy

Timeline

Rainer Weiss, Barry Barish, Kip Thorne

Einstein's Theory of General Relativity

Interferometry was suggested
Experiments: Weber Resonant antenna
Peter and Mathews use 0 PN waveforms

Nobel Prize
LIGO construction
Solved 2 body problem in GR
Numerical relativity simulations

1910s — 1930s — 1960s — 1970s — 1990s — 2015

Einstein, Infeld, Hoffman investigates relativistic equation to determine motion of bodies

First GW evidence
Hulse-Taylor binary pulsar
LIGO idea sketched

GW150914

New era in Astronomy

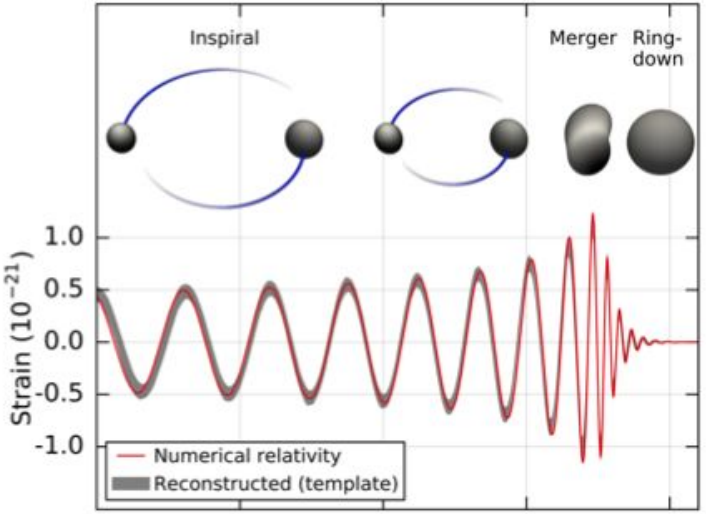
Theorists

Theorists, Experimentalists, Data analysts

1960s	Present
0 PN waveform Newtonian order is the first approximation for the GW signal (Newtonian dynamics with Einstein's quadrupole formula)	**Next to...Next to.... Next to.... Leading order waveform**
Dependent largely on mass	**Parameterised by masses, spins, distance, etc**
Match filtering Noisy signal is convoluted with a theoretically constructed template (gives SNR)	**Match filtering technique, Signal Vetoes, Numerous algorithms for full detection pipelines**
No idea how to detect	**LIGO Detectors**

Compact binary coalescence waveform:

Inspiral, **Merger, Ringdown** explained using Post Newtonian expansions and Numerical Relativity



0 PN Waveform

- Inspiral Only, no merger and ringdown
- No relativistic corrections
- Very Simple

Inspiral of compact binaries in Newtonian approximation

The data output of the detectors is the measure of strain of GW.

GW strain in time domain:

$$h^{+}(t) = A(t)\cos(\Phi_{GW}(t))$$

$$h^{\times}(t) = A(t)\sin(\Phi_{GW}(t))$$

Amplitude:

$$A(t) = -(2G\mu/c^4)(\pi G\mu f_{GW}(t))^{2/3}$$

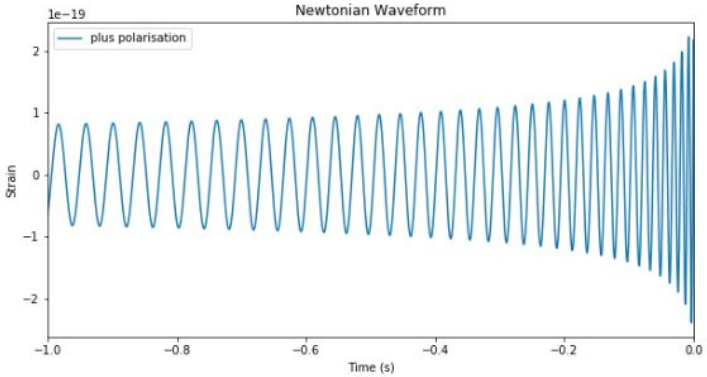
Phase:

$$\Phi_{gw}(t) = -\frac{16\pi}{5} f_{gw}(t_c - t)$$

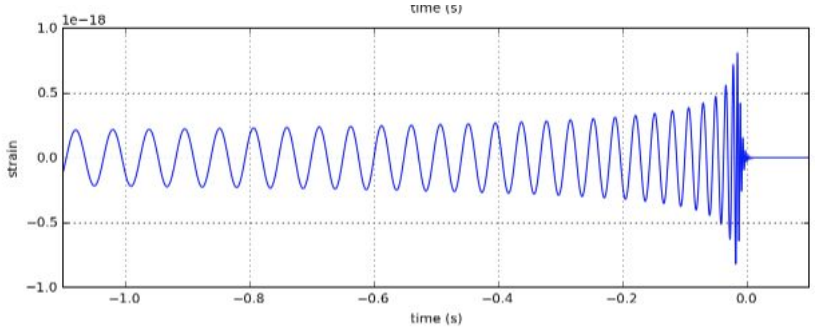
Time of coalescence:

$$t_c = \frac{5}{256\eta}\frac{G\mu}{c^3}\left(\frac{\pi G\mu f_0}{c^3}\right)^{-8/3}$$

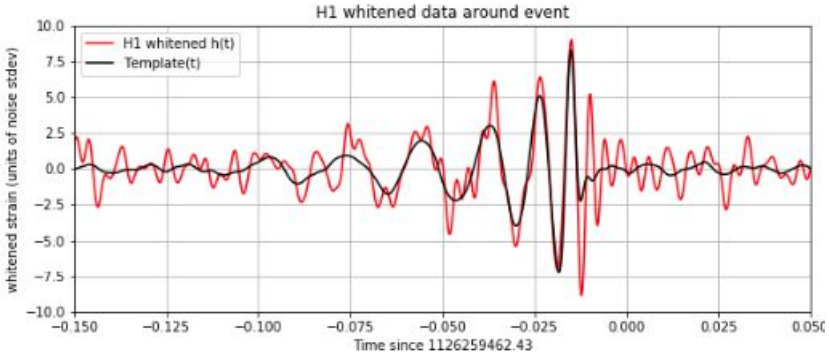
Uses
Kepler's law,
Newton's laws of motion,
Newton's universal law of gravitation, and
Einstein's quadrupole formula



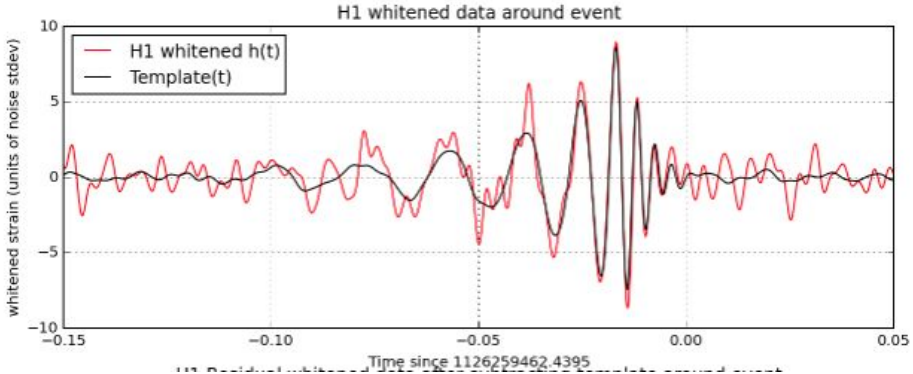
0 PN Waveform



LIGO Waveform



0 PN Waveform + Data



Data + LIGO Waveform

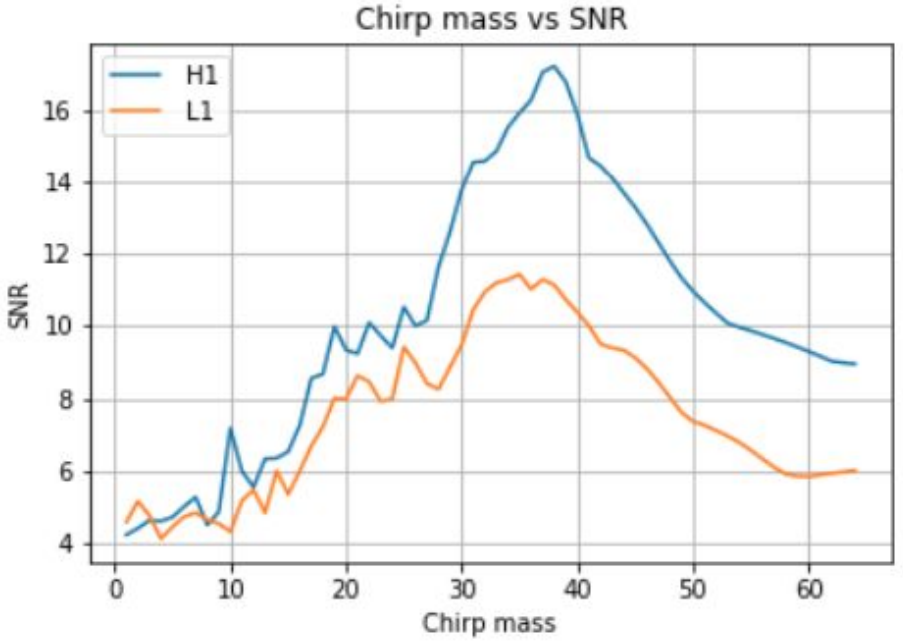
Chirp mass

The combination of the two component masses which sets how the binary inspirals together

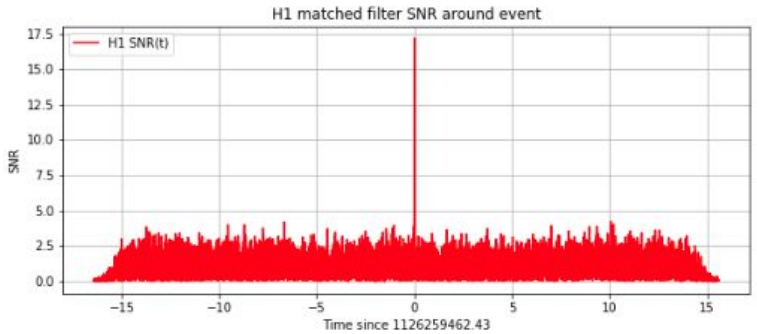
$$\mu = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

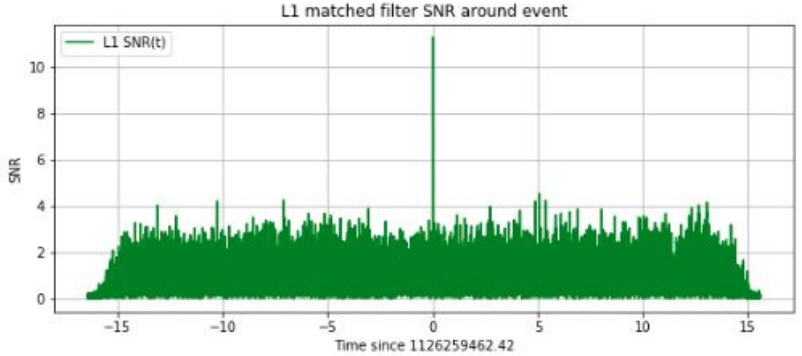
SNR (Signal to noise ratio)

A value which measures strength of the **signal** compared with the sources of **noise** that could potentially contaminate it



How detection works





	LIGO	Me
SNR (H1)	18.6	17.2
SNR (L1)	13.2	11.3
Combined SNR	22.8	20.6

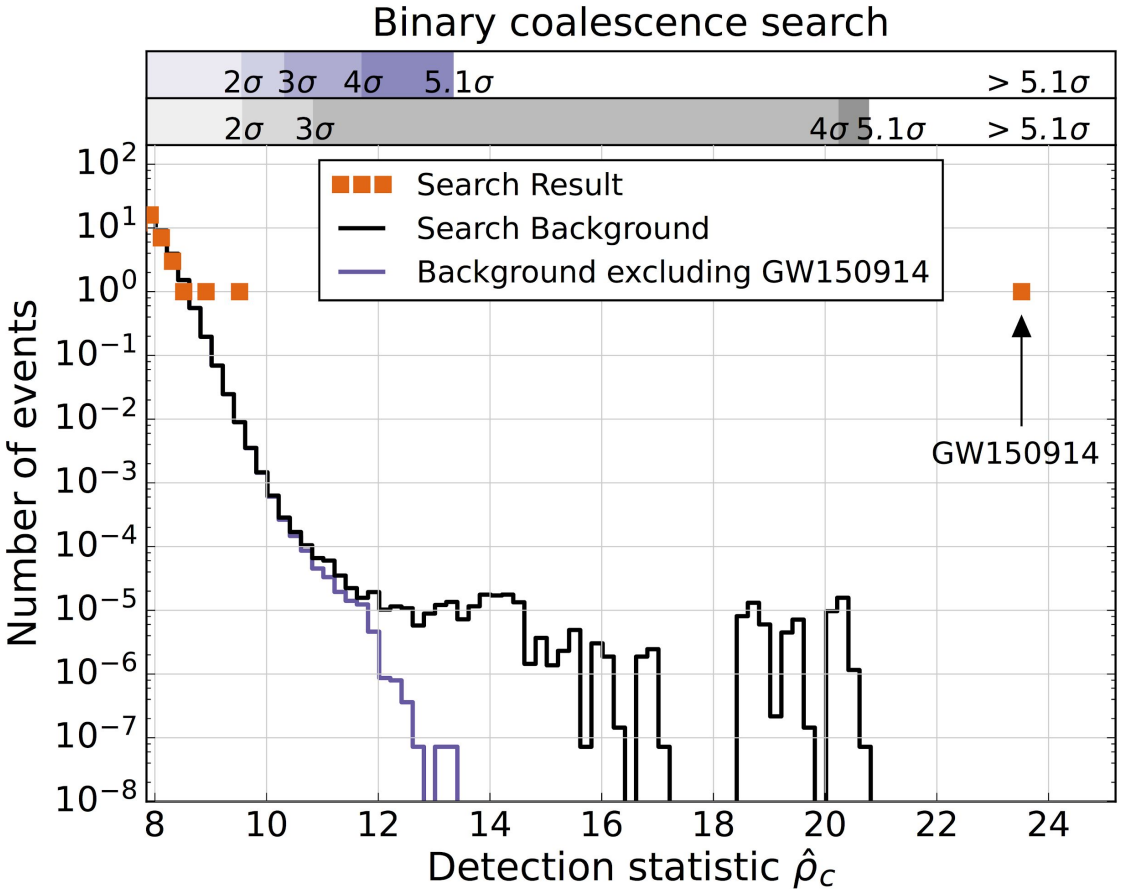
LIGO > Me

LIGO Result

Significance

P-value: 10^{-14}

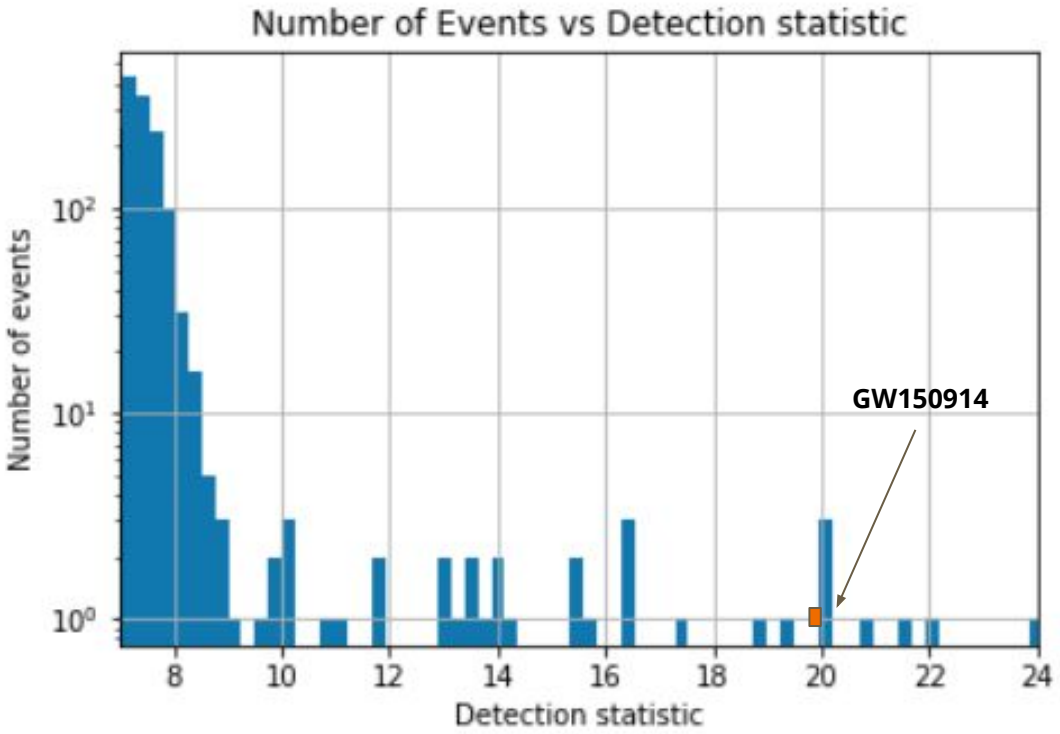
Probability that match would happen by chance due to a random noise fluctuation if the data was purely noise.



My 0 PN Result

Significance

P-value: 0.0104



Signal consistency test

We perform **Chi Squared** statistic to test how well the data actually fits the model

Chi Squared test 

Compare chirp mass

LIGO	Me
$30.4^{+2.1}_{-1.9}\ M_\odot$	$37.5^{+3.6}_{-3.6}\ M_\odot$

Conclusion

GW150914 is detectable with a Newtonian Waveform

Not suitable for parameter estimation

Time for Questions :)

Thank You !