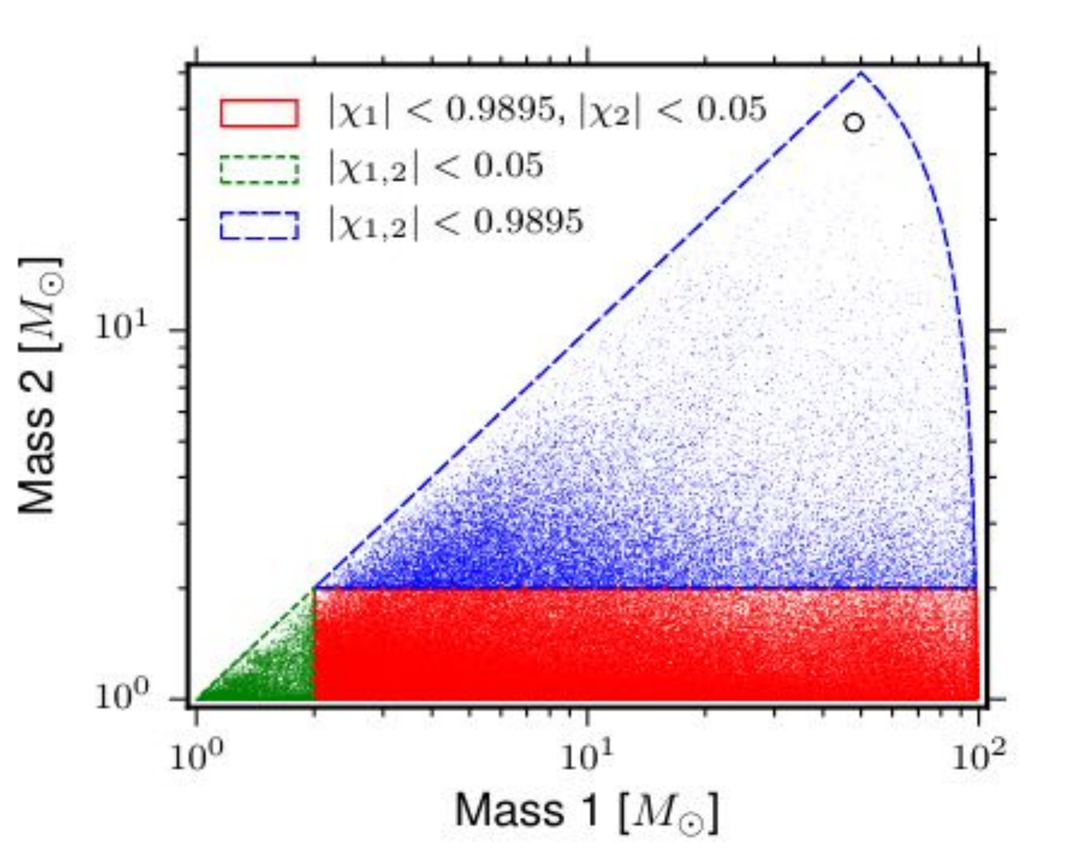
GW150914 ("The Event"): Results and Implications

Matched Filter for the Detection

We model the expected gravitational waves coming from black holes (BHs). These waves depend on BH masses and other parameters. So parameter space is discretely sampled to form template bank. Then we search through the very noisy data to see if we have that signal. This is like we are in the very noisy, crowded place. But when someone calls our name out, our brain picks it over the background noise. Our name works as a modelled signal for our brain. Thats is how we can extract particular GW signal even from very the noisy LIGO data .



GW150914:FACTSHEET

BACKGROUND IMAGES: TIME-FREQUENCY TRACE (TOP) AND TIME-SERIES (BOTTOM) IN THE TWO LIGO DETECTORS; SIMULATION OF BLACK HOLE HORIZONS (MIDDLE-TOP), BEST FIT WAVEFORM (MIDDLE-BOTTOM)

first direct detection of gravitational waves (GW) and first direct observation of a black hole binary

observed by	LIGO L1, H1
source type	black hole (BH) binary
date	14 Sept 2015
time	09:50:45 UTC
likely distance	0.75 to 1.9 Gly 190 to 590 Mpc
redshift	0.054 to 0.136
signal-to-noise ratio	24
false alarm prob.	< 1 in 5 million
false alarm rate	< 1 in 200,000 yr
Source Masses	M⊙
total mass	60 to 70
primary BH	32 to 41
secondary BH	25 to 33
remnant BH	58 to 67
mass ratio	0.6 to 1
primary BH spin	< 0.7
secondary BH spin	< 0.9
remnant BH spin	0.57 to 0.72
signal arrival time delay	arrived in L1 7 ms before H1
likely sky position	Southern Hemisphere
likely orientation	face-on/off
resolved to	~600 sq. deg.

duration from 30 Hz	~ 200 ms
# cycles from 30 Hz	~10
peak GW strain	1×10^{-21}
peak displacement of interferometers arms	±0.002 fm
frequency/wavelength at peak GW strain	150 Hz, 2000 km
peak speed of BHs	~ 0.6 c
peak GW luminosity	3.6×10^{56} erg s^{-1}
radiated GW energy	2.5-3.5 M⊙
remnant ringdown freq.	~ 250 Hz
remnant damping time	~ 4 ms
remnant size, area	180 km, 3.5×10^5 km^2
consistent with general relativity?	passes all tests performed
graviton mass bound	$< 1.2 \times 10^{-22}$ eV
coalescence rate of binary black holes	2 to 400 Gpc^{-3} yr^{-1}
online trigger latency	~ 3 min
# offline analysis pipelines	5
CPU hours consumed	~ 50 million (=20,000 PCs run for 100 days)
papers on Feb 11, 2016	13
# researchers	~1000, 80 institutions in 15 countries

Detector noise introduces errors in measurement. Parameter ranges correspond to 90% credible bounds.
Acronyms: L1=LIGO Livingston, H1=LIGO Hanford; Gly=giga lightyear=9.46×10^{12} km; Mpc=mega parsec=3.2 million lightyear, Gpc=10^3 Mpc, fm=femtometer=10^{-15} m, M⊙=1 solar mass=2×10^{30} kg

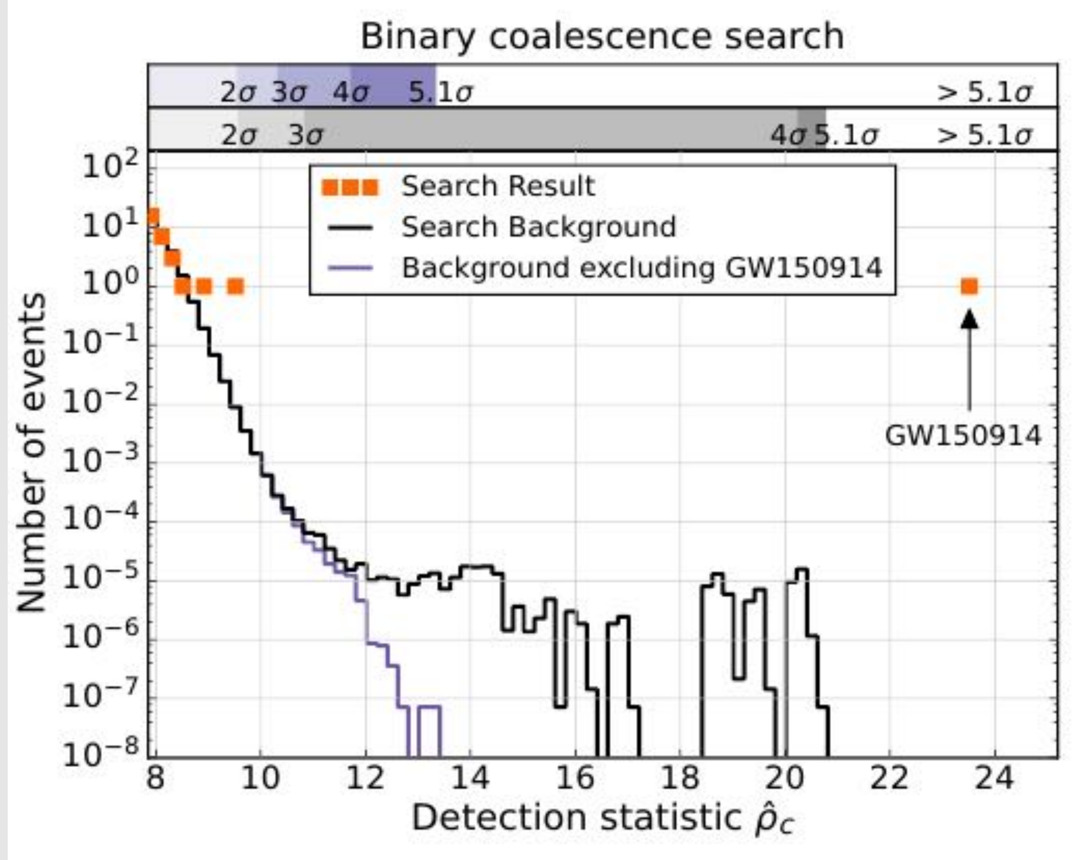
Significance of the Detection

Histogram plot of all the triggers: Real and time slides (noise only).

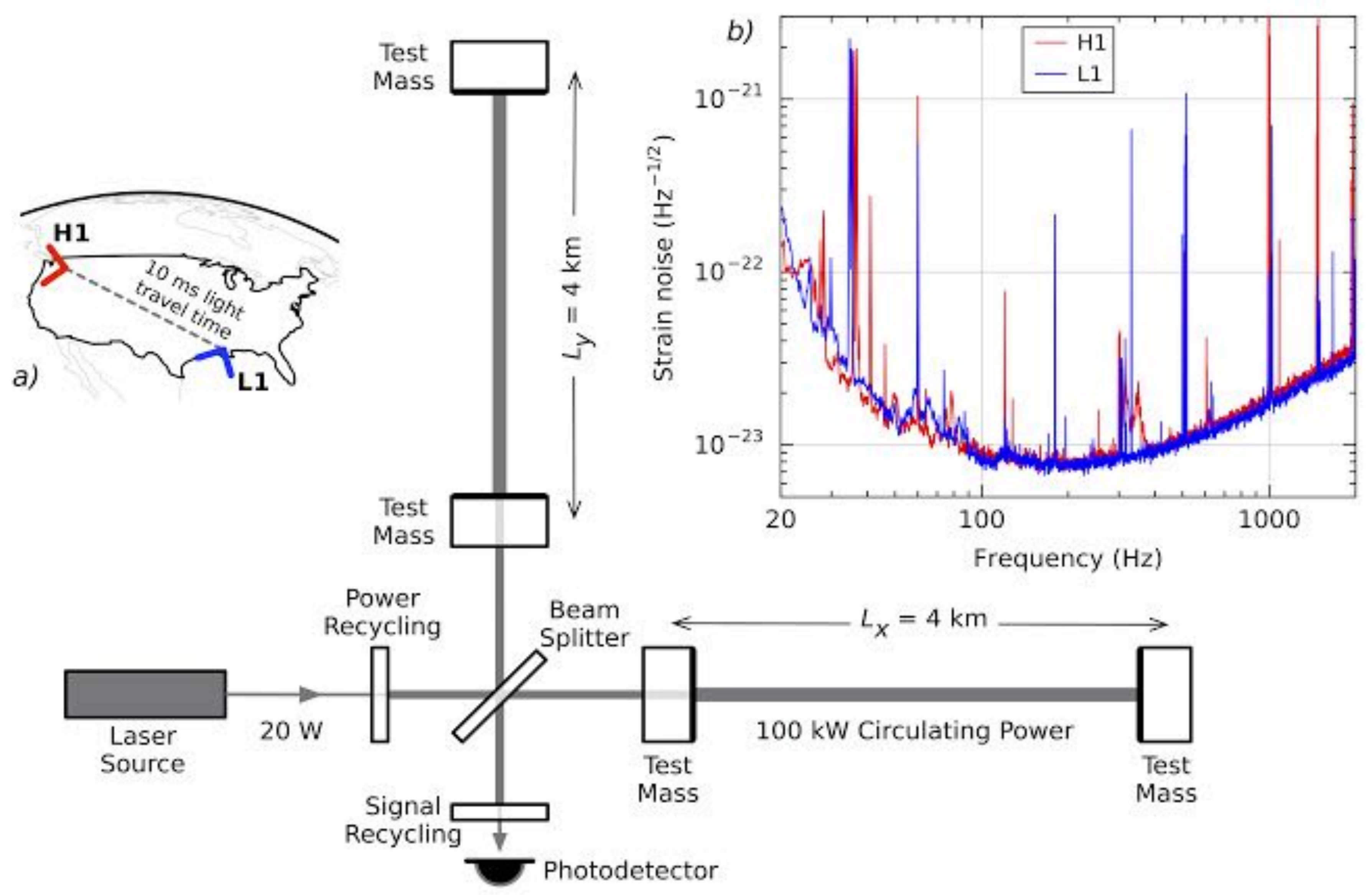
Black-gray histograms are all coincident triggers including time slides.

Indigo-voilet histograms are coincident triggers after excluding "the Event: GW150914".

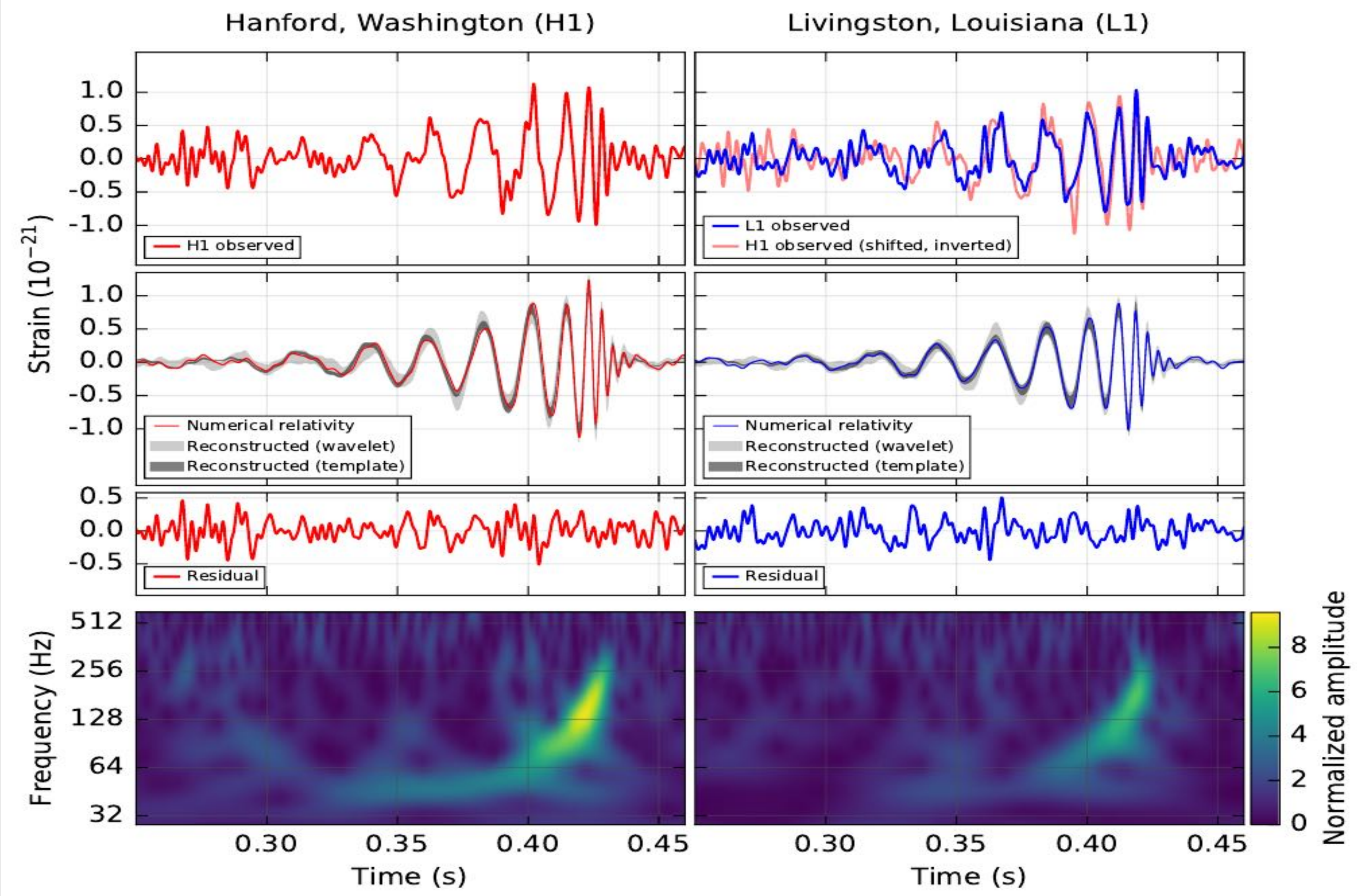
Real detection is much more than 5.1 sigma, but we lack the enough data to get there numerically.



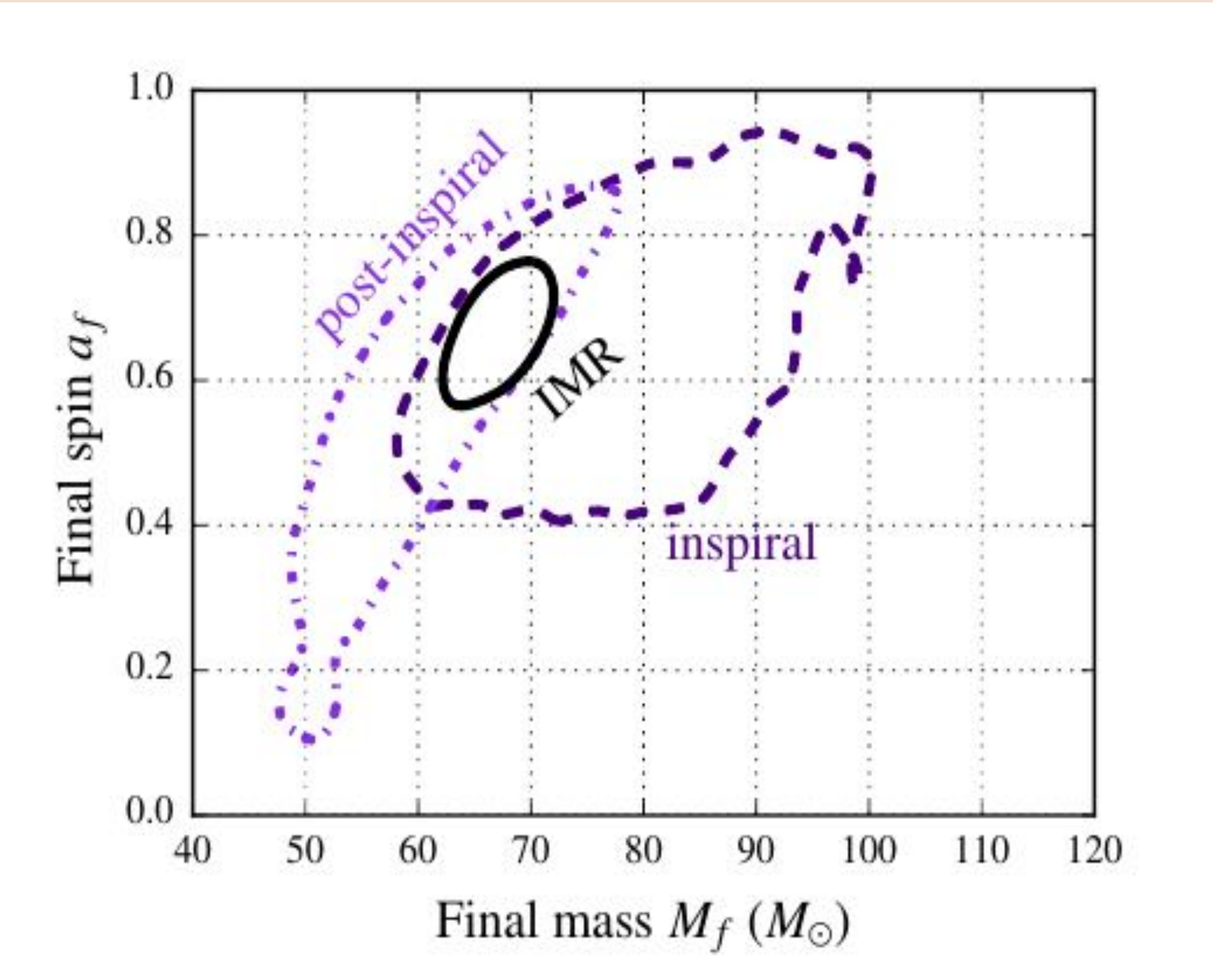
Schematic of LIGO Detector with there locations with correct orientation and PSDs of both H1 and L1 during "the Event"



"The Event" as recorded by H1 and L1 LIGO Detectors with the modelled signal and residual noise. Lower panel is time-frequency diagram of "the chirp Event".



Test of GR using I + MR consistency test-
Posteriors on the mass and spin of of the final BH formed during "the Event". All the the posteriors are consistent with GR (IMR) predictions.



Events similar to GW150914, if they are far away in the universe will not be resolved but they will result in a stochastic gravitational wave background (SGWB). The estimate of such SGWB based on parameters from GW150914 shows that the detection of this SGWB is possible with future observational runs of LIGO.