

Howard Astronomical League



February 18th, 2016

Introductions

Alice Bowman

Mission Operations Manager (MOM)

New Horizons

Upcoming outreach events

- Members only star party, Saturday, March 5th, Alpha Ridge Park. Chris Todd hosts a Messier Marathon.
- Public star party, Saturday, March 19th, Alpha Ridge Park.



**Member's
astrophotos and
sketches**

Brad Sheard

*M33 - Pinwheel Galaxy
modified Canon 5T1 / Stellarvue SVR102T
Alpha Ridge & Ellicott City
Brad Sheard*

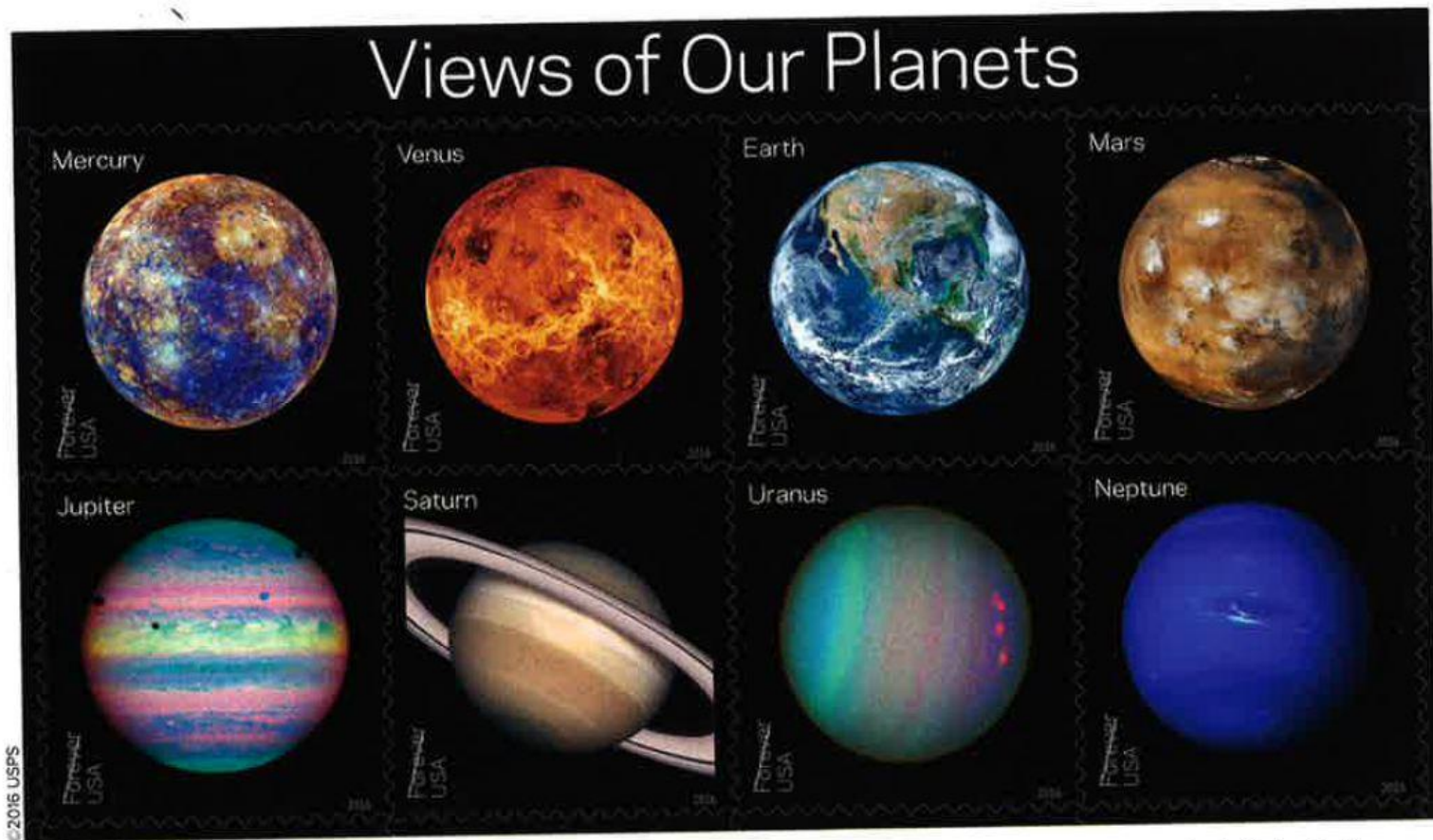


Robert Hambleton



USPS, submitted by H. Heyn

Special Delivery: Post Office to Issue Space-Themed Stamps



The "Views of Our Planets" sheet of 16 Forever stamps (upper half shown here) depicts full-disk images of our solar system's eight planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

Joel Goodman (by proxy)



LIGO Gravitational Wave
Announcement: a Quick Peek
Behind the Curtain

LIGO Press Release:

For Immediate Release

February 11, 2016

GRAVITATIONAL WAVES DETECTED 100 YEARS AFTER EINSTEIN'S PREDICTION

LIGO Opens New Window on the Universe with Observation of Gravitational Waves from Colliding Black Holes

WASHINGTON, DC/Cascina, Italy

For the first time, scientists have observed ripples in the fabric of spacetime called gravitational waves, arriving at the earth from a cataclysmic event in the distant universe. This confirms a major prediction of Albert Einstein's 1915 general theory of relativity and opens an unprecedented new window onto the cosmos.

Gravitational waves carry information about their dramatic origins and about the nature of gravity that cannot otherwise be obtained. Physicists have concluded that the detected gravitational waves were produced during the final fraction of a second of the merger of two black holes to produce a single, more massive spinning black hole. This collision of two black holes had been predicted but never observed.

The gravitational waves were detected on September 14, 2015 at 5:51 a.m. Eastern Daylight Time (09:51 UTC) by both of the twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors, located in Livingston, Louisiana, and Hanford, Washington, USA. The LIGO Observatories are funded by the National Science Foundation (NSF), and were conceived, built, and are operated by Caltech and MIT. The discovery, accepted for publication in the journal *Physical Review Letters*, was made by the LIGO Scientific Collaboration (which includes the GEO Collaboration and the Australian Consortium for Interferometric Gravitational Astronomy) and the Virgo Collaboration using data from the two LIGO detectors.

Based on the observed signals, LIGO scientists estimate that the black holes for this event were about 29 and 36 times the mass of the sun, and the event took place 1.3 billion years ago. About 3 times the mass of the sun was converted into gravitational waves in a fraction of a second—with a peak power output about 50 times that of the whole visible universe. By looking at the time of arrival of the signals—the detector in Livingston recorded the event 7 milliseconds before the detector in Hanford—scientists can say that the source was located in the Southern Hemisphere.

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LIGO Science Publication:

PRL 116, 061102 (2016)

Selected for a Viewpoint in *Physics*
PHYSICAL REVIEW LETTERS

week ending
12 FEBRUARY 2016



Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.**

(LIGO Scientific Collaboration and Virgo Collaboration)

(Received 21 January 2016; published 11 February 2016)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of 1.0×10^{-21} . It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than 5.1σ . The source lies at a luminosity distance of 410_{-180}^{+160} Mpc corresponding to a redshift $z = 0.09_{-0.04}^{+0.03}$. In the source frame, the initial black hole masses are $36_{-4}^{+5} M_{\odot}$ and $29_{-4}^{+4} M_{\odot}$, and the final black hole mass is $62_{-4}^{+4} M_{\odot}$, with $3.0_{-0.5}^{+0.5} M_{\odot} c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

DOI: 10.1103/PhysRevLett.116.061102

I. INTRODUCTION

In 1916, the year after the final formulation of the field equations of general relativity, Albert Einstein predicted the existence of gravitational waves. He found that the linearized weak-field equations had wave solutions: transverse waves of spatial strain that travel at the speed of light, generated by time variations of the mass quadrupole moment of the source [1,2]. Einstein understood that gravitational-wave amplitudes would be remarkably small; moreover, until the Chapel Hill conference in 1957 there was significant debate about the physical reality of gravitational waves [3].

Also in 1916, Schwarzschild published a solution for the field equations [4] that was later understood to describe a black hole [5,6], and in 1963 Kerr generalized the solution to rotating black holes [7]. Starting in the 1970s theoretical work led to the understanding of black hole quasinormal modes [8–10], and in the 1990s higher-order post-Newtonian calculations [11] preceded extensive analytical

The discovery of the binary pulsar system PSR B1913+16 by Hulse and Taylor [20] and subsequent observations of its energy loss by Taylor and Weisberg [21] demonstrated the existence of gravitational waves. This discovery, along with emerging astrophysical understanding [22], led to the recognition that direct observations of the amplitude and phase of gravitational waves would enable studies of additional relativistic systems and provide new tests of general relativity, especially in the dynamic strong-field regime.

Experiments to detect gravitational waves began with Weber and his resonant mass detectors in the 1960s [23], followed by an international network of cryogenic resonant detectors [24]. Interferometric detectors were first suggested in the early 1960s [25] and the 1970s [26]. A study of the noise and performance of such detectors [27], and further concepts to improve them [28], led to proposals for long-baseline broadband laser interferometers with the potential for significantly increased sensi-

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HUNDREDS of authors!

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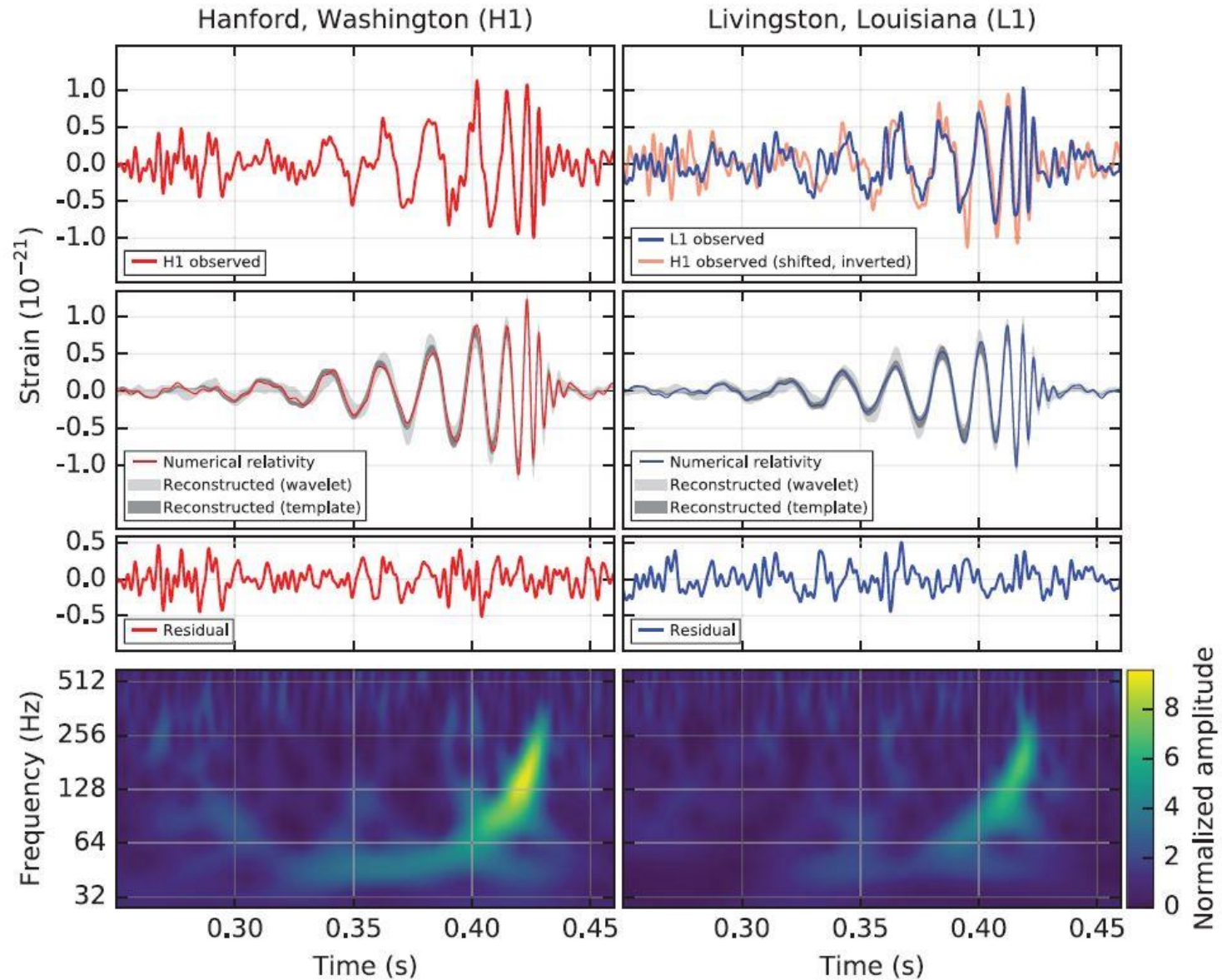
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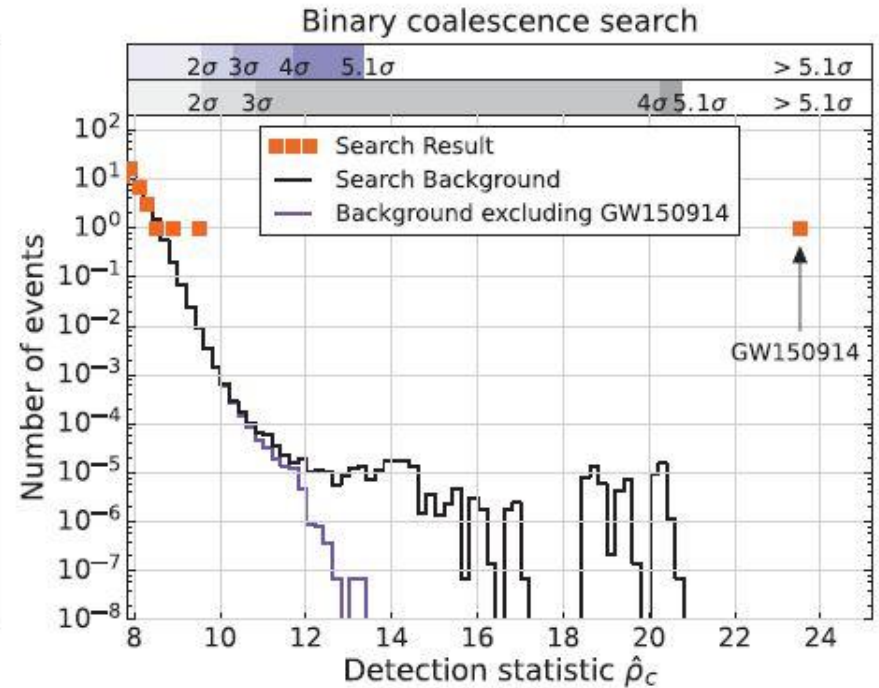
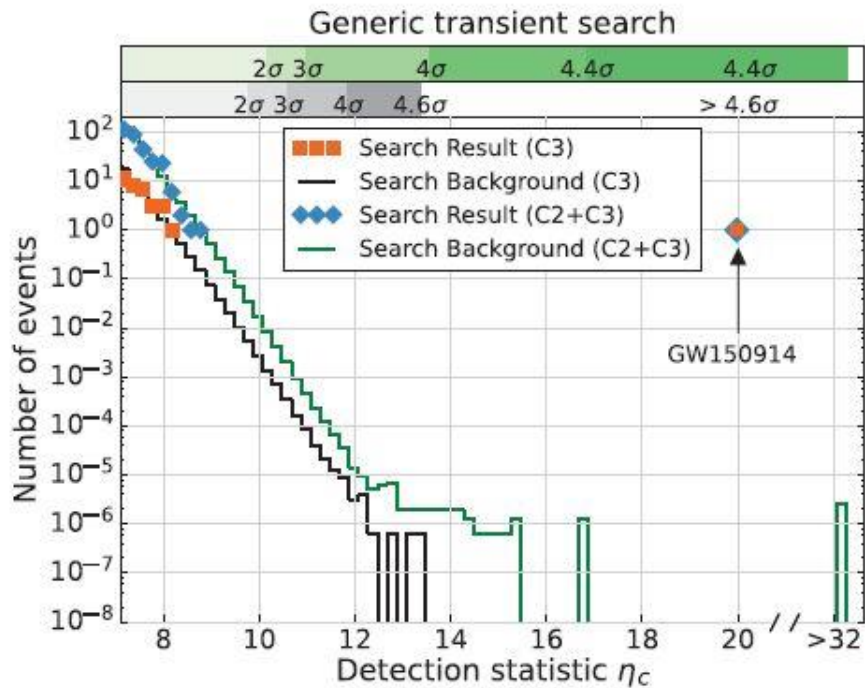
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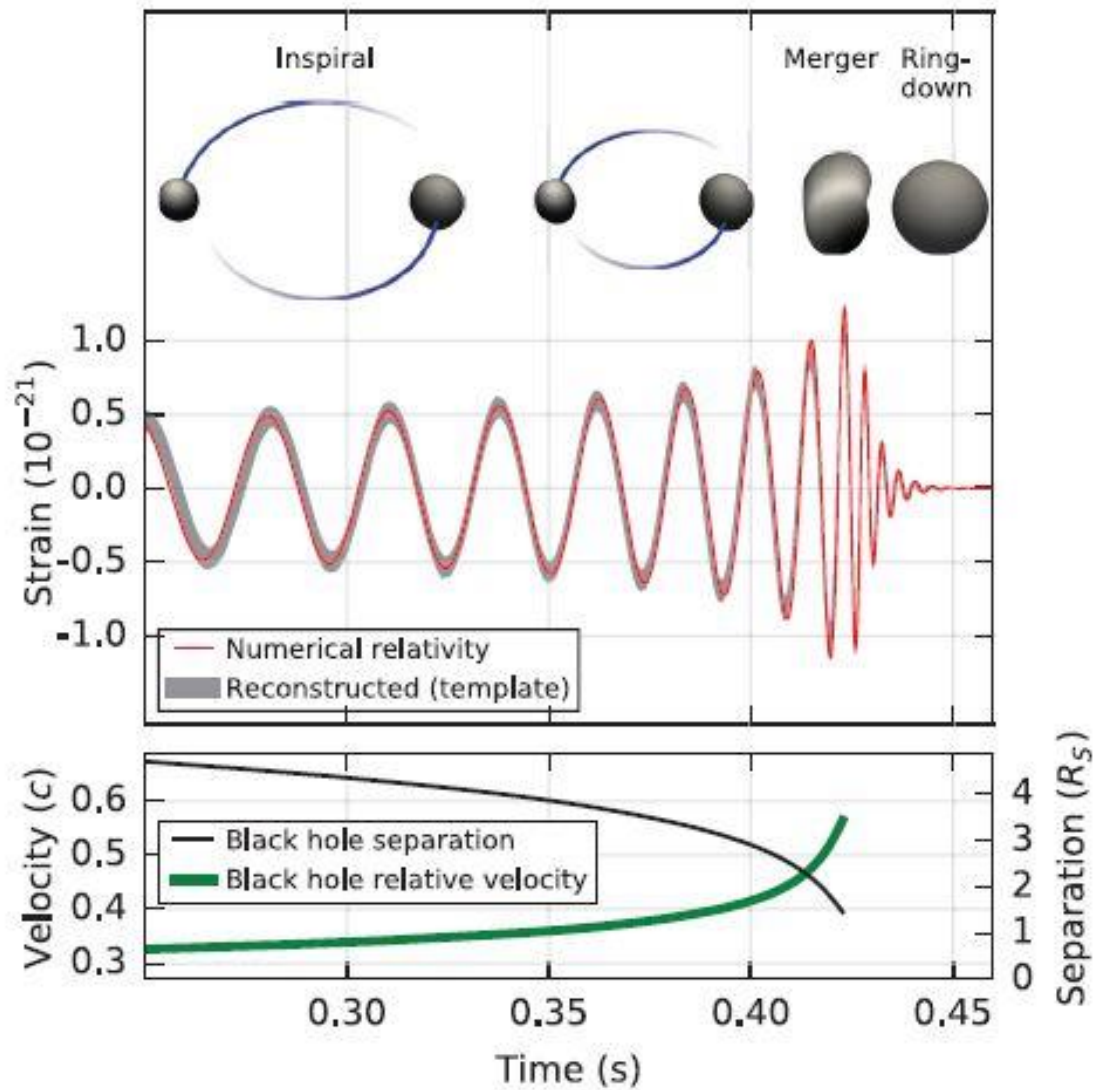
LIGO Observation:



Is It Real?



LIGO Hypothesis:



“Chirp” Mass:

The basic features of GW150914 point to it being produced by the coalescence of two black holes—i.e., their orbital inspiral and merger, and subsequent final black hole ringdown. Over 0.2 s, the signal increases in frequency and amplitude in about 8 cycles from 35 to 150 Hz, where the amplitude reaches a maximum. The most plausible explanation for this evolution is the inspiral of two orbiting masses, m_1 and m_2 , due to gravitational-wave emission. At the lower frequencies, such evolution is characterized by the chirp mass [11]

$$\mathcal{M} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}} = \frac{c^3}{G} \left[\frac{5}{96} \pi^{-8/3} f^{-11/3} \dot{f} \right]^{3/5},$$

where f and \dot{f} are the observed frequency and its time derivative and G and c are the gravitational constant and speed of light. Estimating f and \dot{f} from the data in Fig. 1, we obtain a chirp mass of $\mathcal{M} \approx 30M_\odot$, implying that the total mass $M = m_1 + m_2$ is $\gtrsim 70M_\odot$ in the detector frame. This bounds the sum of the Schwarzschild radii of the binary components to $2GM/c^2 \gtrsim 210$ km. To reach an

Putting It Together:

binary components to $2GM/c^2 \gtrsim 210$ km. To reach an orbital frequency of 75 Hz (half the gravitational-wave frequency) the objects must have been very close and very compact; equal Newtonian point masses orbiting at this frequency would be only ≈ 350 km apart. A pair of neutron stars, while compact, would not have the required mass, while a black hole neutron star binary with the deduced chirp mass would have a very large total mass, and would thus merge at much lower frequency. This leaves black holes as the only known objects compact enough to reach an orbital frequency of 75 Hz without contact. Furthermore, the decay of the waveform after it peaks is consistent with the damped oscillations of a black hole relaxing to a final stationary Kerr configuration.

What Size Black Holes?

Using the fits to numerical simulations of binary black hole mergers in [92,93], we provide estimates of the mass and spin of the final black hole, the total energy radiated in gravitational waves, and the peak gravitational-wave luminosity [39]. The estimated total energy radiated in gravitational waves is $3.0_{-0.5}^{+0.5} M_{\odot} c^2$. The system reached a peak gravitational-wave luminosity of $3.6_{-0.4}^{+0.5} \times 10^{56}$ erg/s, equivalent to $200_{-20}^{+30} M_{\odot} c^2 / \text{s}$.

LIGO Summary Results:

Primary black hole mass	$36^{+5}_{-4} M_{\odot}$
Secondary black hole mass	$29^{+4}_{-4} M_{\odot}$
Final black hole mass	$62^{+4}_{-4} M_{\odot}$
Final black hole spin	$0.67^{+0.05}_{-0.07}$
Luminosity distance	410^{+160}_{-180} Mpc
Source redshift z	$0.09^{+0.03}_{-0.04}$

Big Picture Conclusions:

1. Demonstrates the existence of stellar-mass black holes $> \sim 25 M_{\text{sun}}$
2. Binary black holes form in nature
3. Binary black holes can merge within a Hubble time

There is a LOT of work that goes behind seemingly simple statements in press releases!

Thank You!

Next month's meeting is on Thursday,
March 17th, 2016 7 PM

Guest Speaker:

Steve Conard, APL

Designing and building LORRI