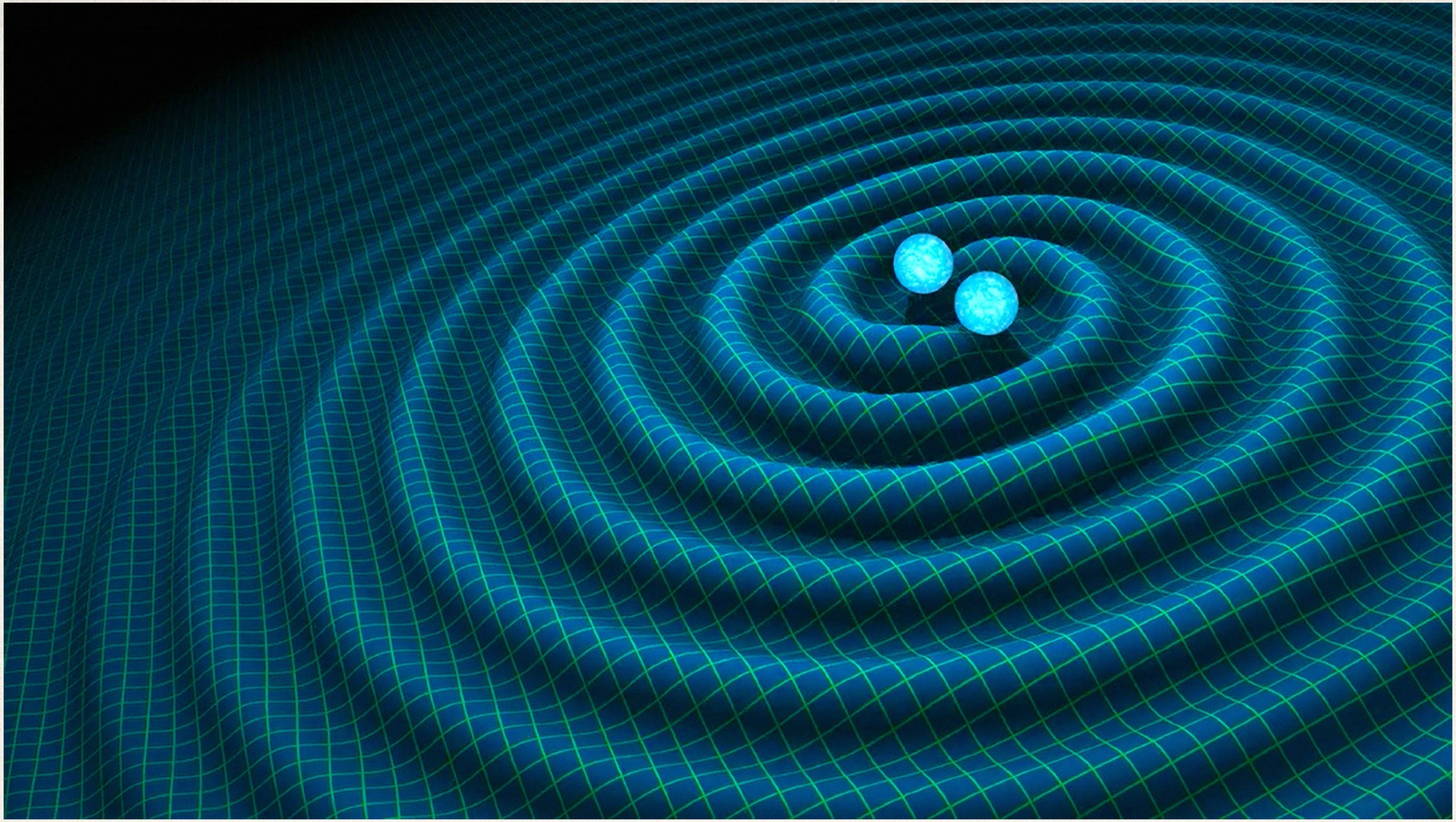


[credit: R. Hurt/Caltech-JPL]

Gravitational waves: Ripples in spacetime

Eric Poisson, University of Guelph

Summer Lectures Club, Guelph, 20 April 2017

11 February 2016: GW150914

Selected for a Viewpoint in *Physics*

PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.**

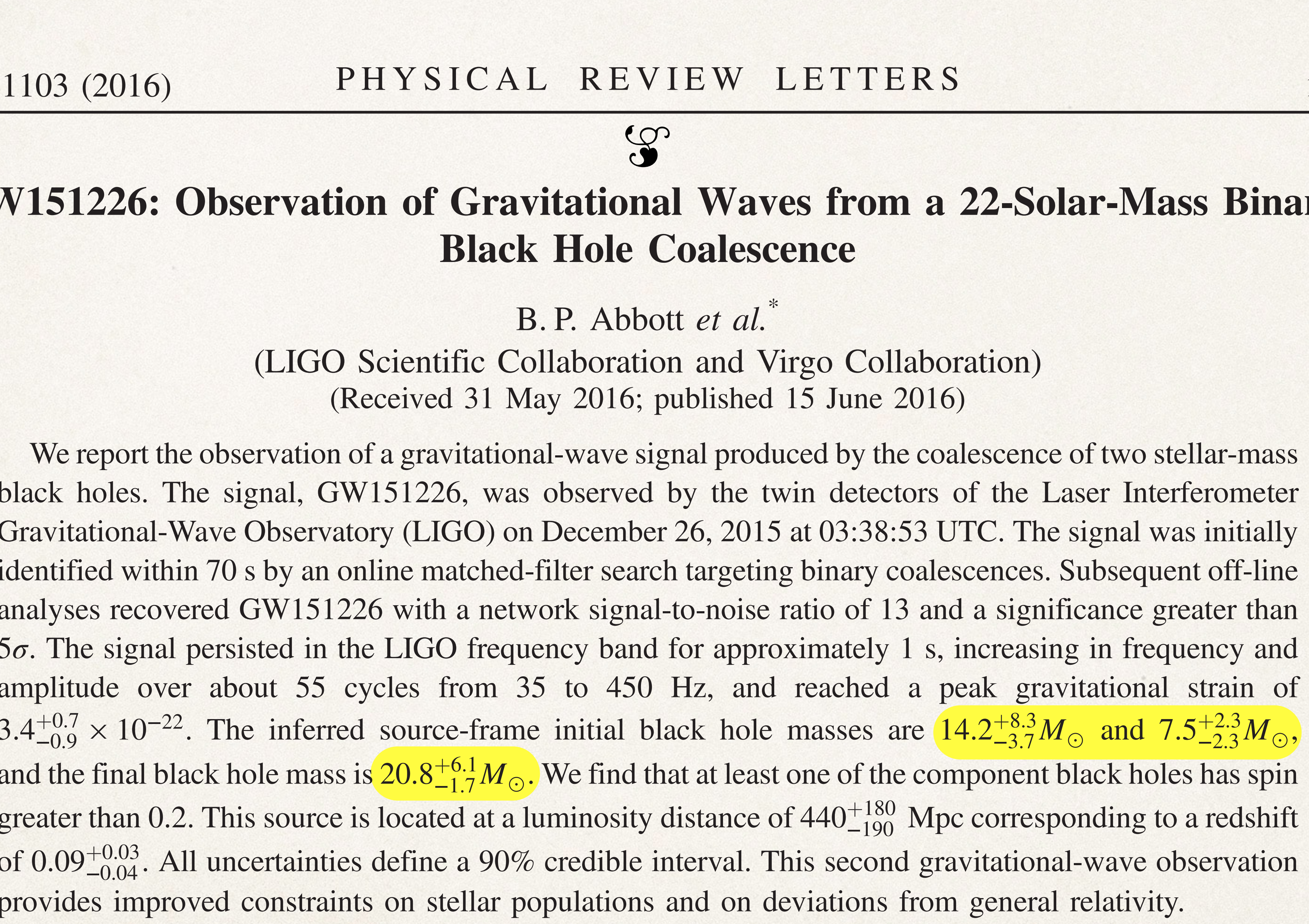
(LIGO Scientific Collaboration and Virgo Collaboration)

(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^{+160}_{-180} Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4} M_\odot$ 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.

First direct detection of gravitational waves
First detection of a binary system of black holes
First detection of a black-hole merger

15 June 2016: GW151226



PRL **116,** 241103 (2016) PHYSICAL REVIEW LETTERS week ending 17 JUNE 2016

GW151226: Observation of Gravitational Waves from a 22-Solar-Mass Binary Black Hole Coalescence

B. P. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)

(Received 31 May 2016; published 15 June 2016)

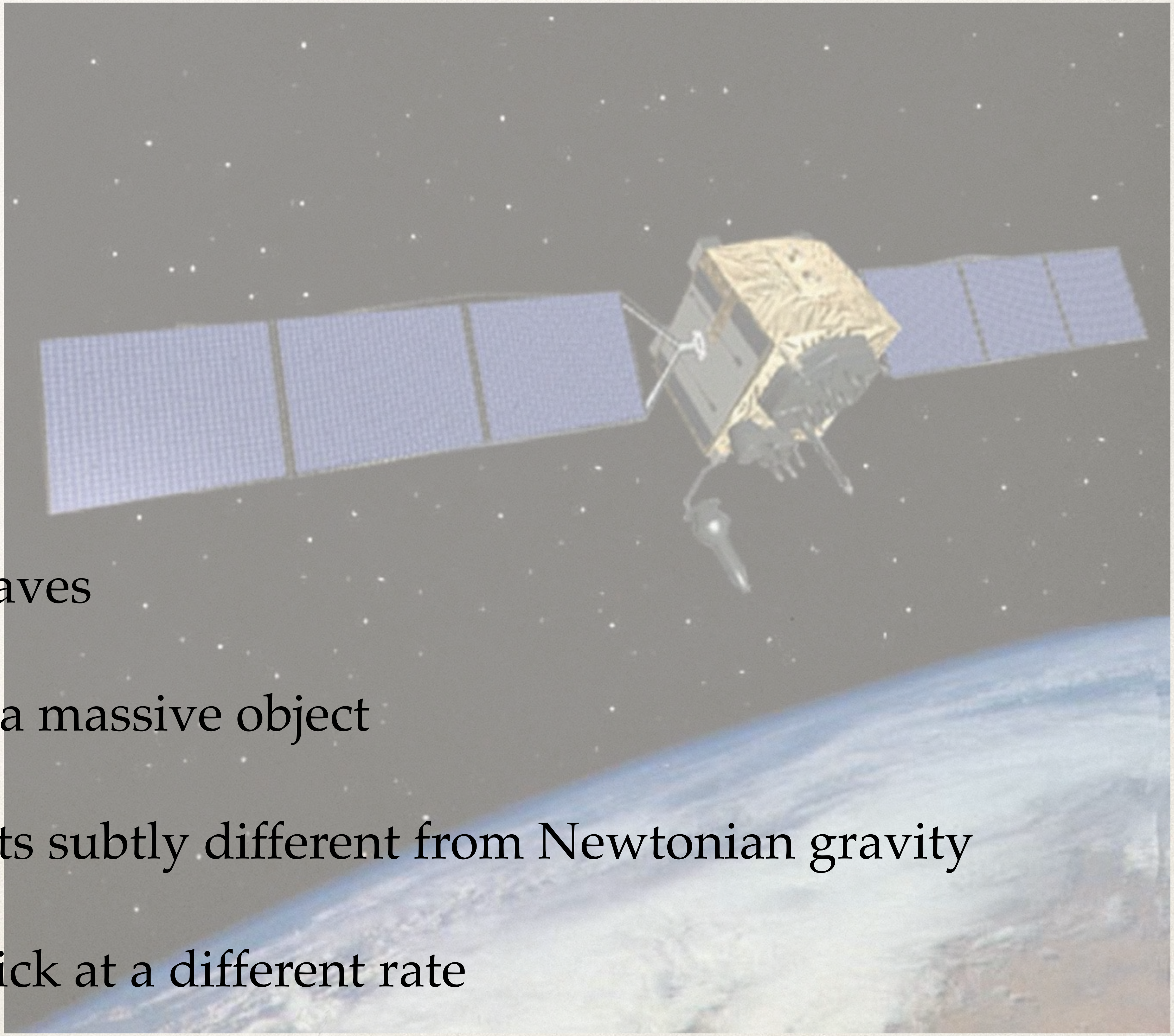
We report the observation of a gravitational-wave signal produced by the coalescence of two stellar-mass black holes. The signal, GW151226, was observed by the twin detectors of the Laser Interferometer Gravitational-Wave Observatory (LIGO) on December 26, 2015 at 03:38:53 UTC. The signal was initially identified within 70 s by an online matched-filter search targeting binary coalescences. Subsequent off-line analyses recovered GW151226 with a network signal-to-noise ratio of 13 and a significance greater than 5σ. The signal persisted in the LIGO frequency band for approximately 1 s, increasing in frequency and amplitude over about 55 cycles from 35 to 450 Hz, and reached a peak gravitational strain of $3.4^{+0.7}_{-0.9} \times 10^{-22}$. The inferred source-frame initial black hole masses are $14.2^{+8.3}_{-3.7} M_\odot$ and $7.5^{+2.3}_{-2.3} M_\odot$, and the final black hole mass is $20.8^{+6.1}_{-1.7} M_\odot$. We find that at least one of the component black holes has spin greater than 0.2. This source is located at a luminosity distance of 440^{+180}_{-190} Mpc corresponding to a redshift of $0.09^{+0.03}_{-0.04}$. All uncertainties define a 90% credible interval. This second gravitational-wave observation provides improved constraints on stellar populations and on deviations from general relativity.

Second detection of gravitational waves from the merger of two black holes

25 November 1915

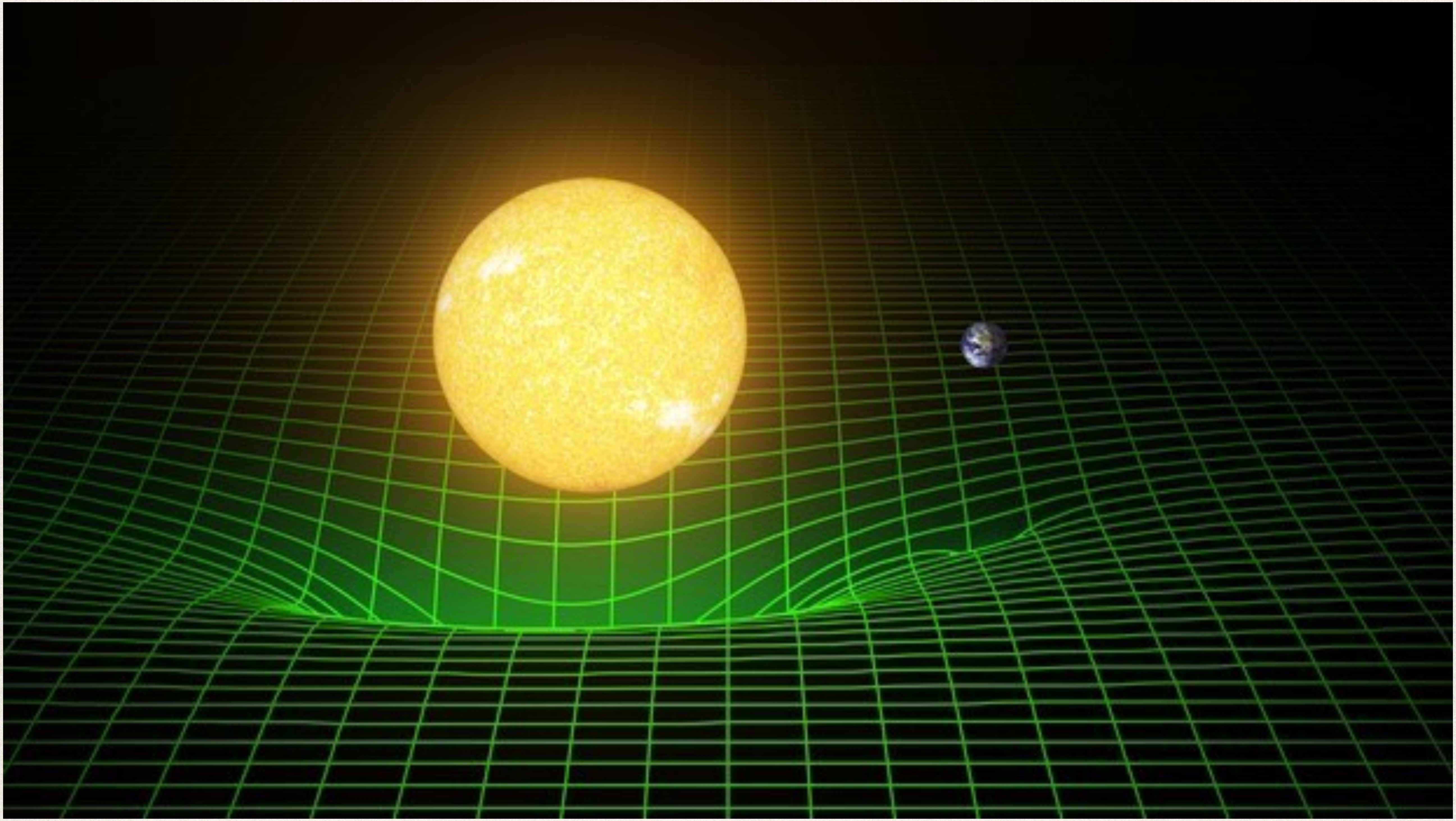
- Einstein completes his scientific masterpiece, the general theory of relativity.
- This description of gravitation, in terms of a **curved spacetime**, has so far withstood all observational tests.

Predictions of general relativity



- Black holes
- Gravitational waves
- Light is bent by a massive object
- Motion of planets subtly different from Newtonian gravity
- Clocks in orbit tick at a different rate

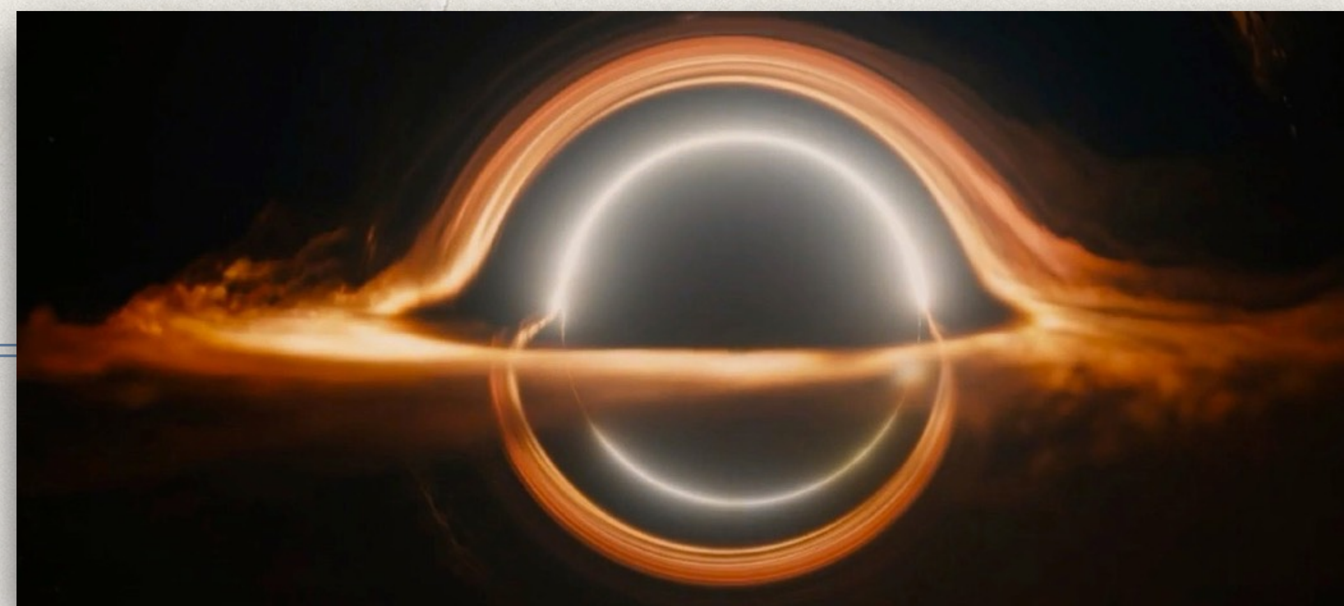
Gravity is curved spacetime



[credit: T. Pyle/Caltech/MIT/LIGO Lab]

Space and time are affected by gravity

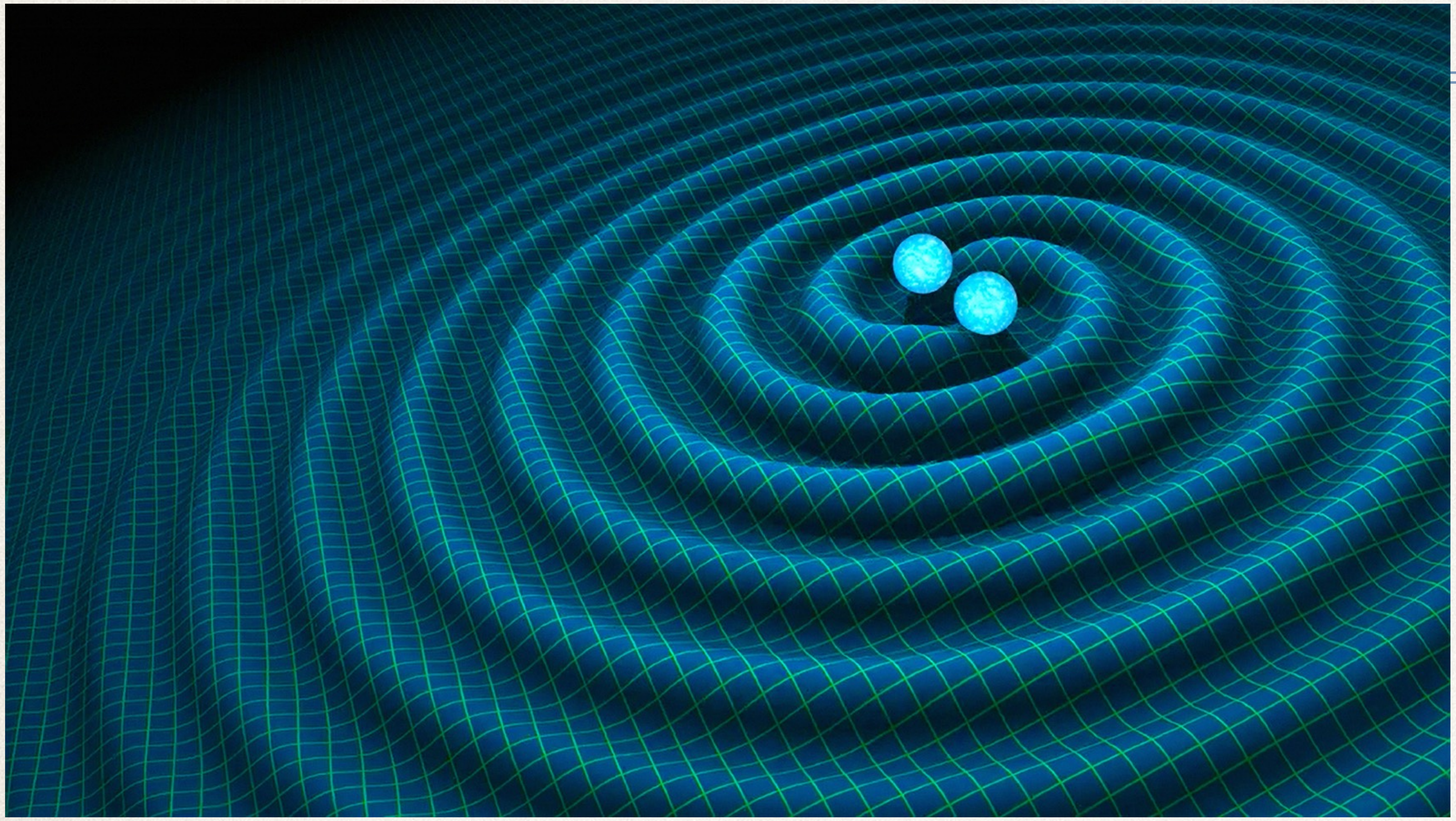
Black holes



[credit: Double Negative]

- A black hole is a **dead star**, the product of complete gravitational collapse after the star can no longer support its own weight.
- A black hole is so dense that even light cannot escape its intense gravitational pull.
- Black holes can merge, or they can swallow ambient matter, and become much larger.
- Black holes can be as massive as 10-100 Suns, or as massive as millions to billions of Suns (galactic black holes).
- A black hole resides in the centre of the Milky Way (4 million Suns).

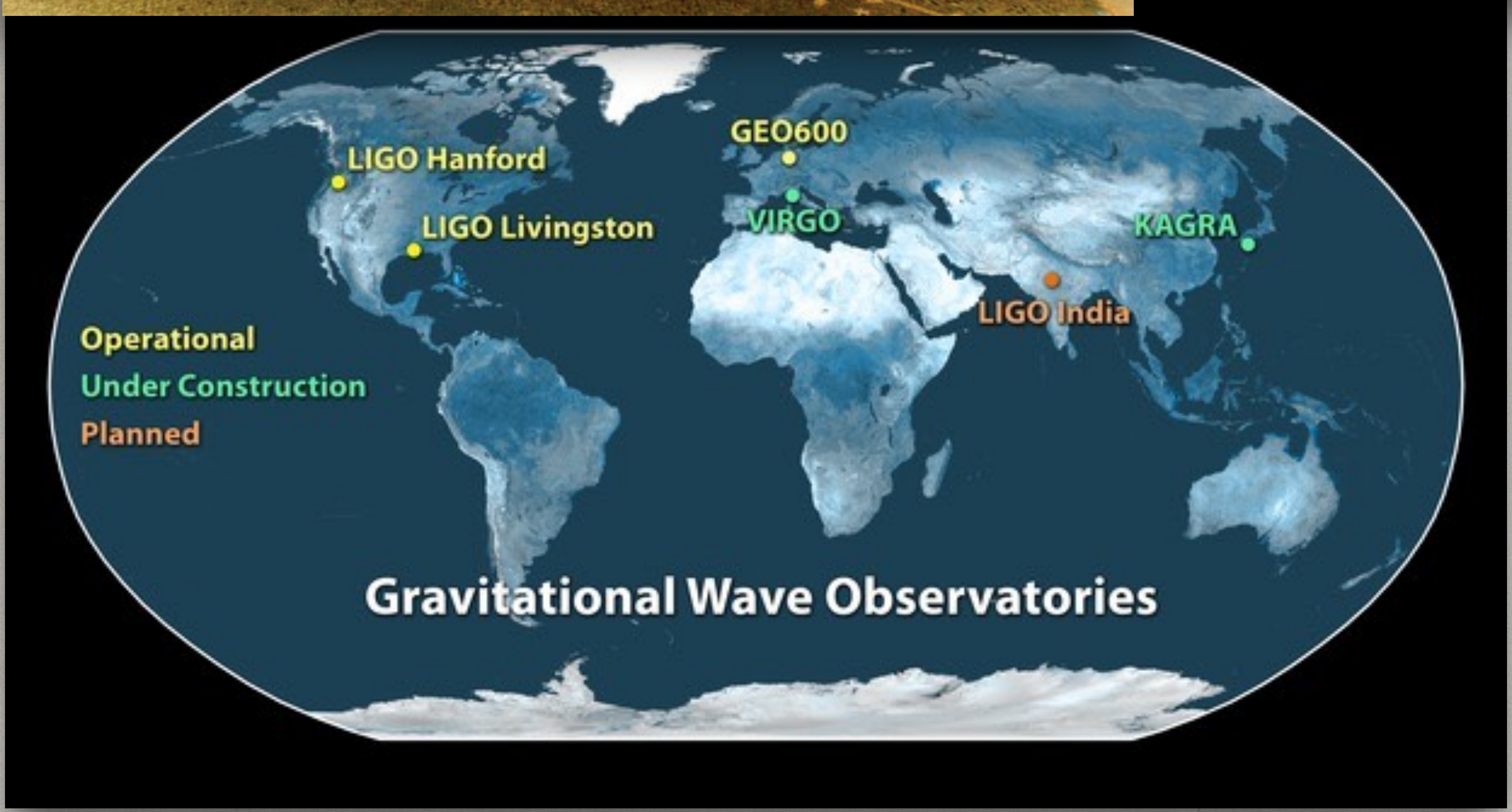
Gravitational waves



- Gravitational waves are ripples in spacetime. They stretch and squeeze the space between objects.
- They are produced when violent events occur in the Universe, such as the orbital motion and merger of two black holes.
- They are extremely tiny, and require huge facilities for their detection.

Detection of gravitational waves

[credit: LIGO Laboratory]



LIGO uses laser interferometry to measure gravitational waves.

It is part of a growing network of observatories.

[redacted]

What did Eric do?

PHYSICAL REVIEW D VOLUME 47, NUMBER 4 15 FEBRUARY 1993

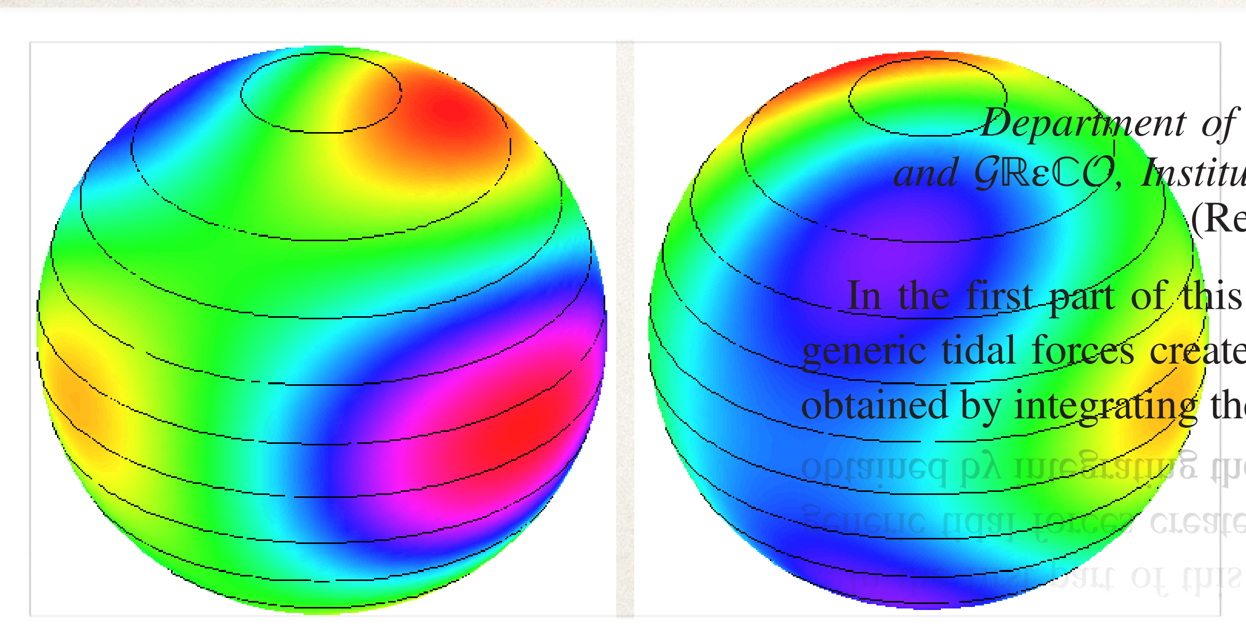
Gravitational radiation from a particle in circular orbit around a black hole. I. Analytical results for the nonrotating case

Eric Poisson
Theoretical Astrophysics, California Institute of Technology, Pasadena, California 91125
(Received 27 July 1992)

Among the most promising and interesting sources of gravitational waves for interferometric detectors, such as the ground-based Laser Interferometer Gravitational-wave Observatory (LIGO)/VIRGO system and the proposed space-based Laser Gravitational-Wave Observatory in Space (LAGOS), is the last several minutes of inspiral of a compact binary (one made of neutron stars and/or black holes). This paper is the first in a series that will carry out detailed calculations

PHYSICAL REVIEW D **91,** 044004 (2015)

Tidal deformation of a slowly rotating black hole

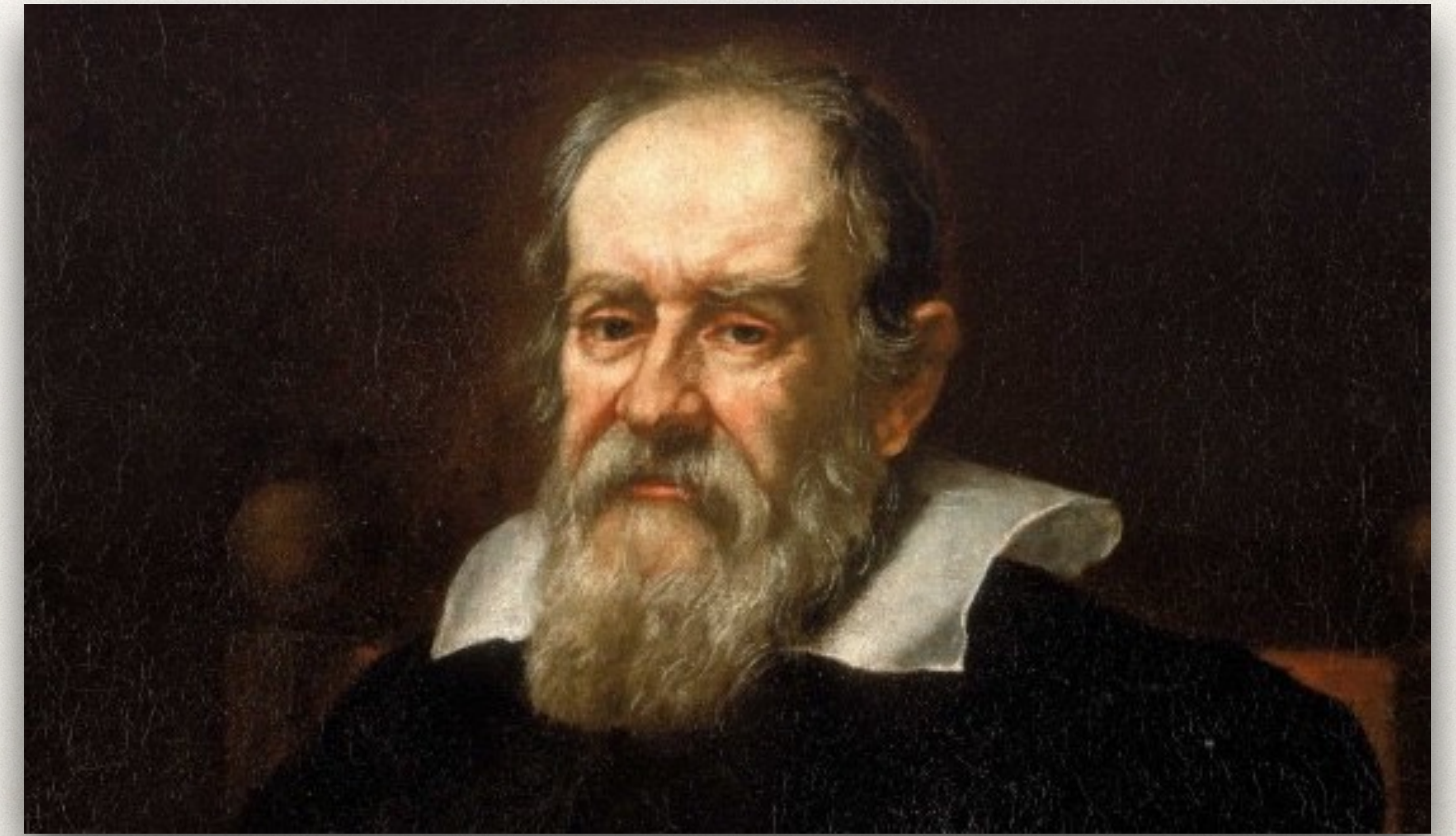


Eric Poisson
*Department of Physics, University of Guelph, Guelph, Ontario N1G 2W1, Canada
and $\mathcal{G}\mathbb{R}\varepsilon\mathbb{C}\mathcal{O}$, Institut d'Astrophysique de Paris, 98bis boulevard Arago, 75014 Paris, France*
(Received 17 November 2014; published 3 February 2015)

In the first part of this article I determine the geometry of a slowly rotating black hole deformed by generic tidal forces created by a remote distribution of matter. The metric of the deformed black hole is obtained by integrating the Einstein field equations in a vacuum region of spacetime bounded by $r < r_{\max}$,

What's next?

- LIGO is now observing, with improved sensitivity.
- Other detectors will soon follow suit.
- Many more detections are coming: black-hole binaries, neutron-star binaries, the unexpected.



- A new window onto the Universe is now open.

The future of gravitational-wave astronomy is bright!

Thank you!