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Summary: On September 14, 2015, the newly upgraded Laser Interferometer Gravitational-wave Observatory (LIGO) recorded a loud gravitational-wave (GW) signal, emitted a billion light-years away by a coalescing binary of two stellar-mass black holes. The detection was announced in February 2016, in time for the hundredth anniversary of Einstein’s prediction of GWs within the theory of general relativity (GR). The signal represents the first direct detection of GWs, the first observation of a black-hole binary, and the first test of GR in its strong-field, high-velocity, nonlinear regime. In the remainder of its first observing run, LIGO observed two more signals from black-hole binaries, one moderately loud, another at the boundary of statistical significance. The detections mark the end of a decades-long quest and the beginning of GW astronomy: finally, we are able to probe the unseen, electromagnetically dark Universe by listening to it. In this article, we present a short historical overview of GW science: this young discipline combines GR, arguably the crowning achievement of classical physics, with record-setting, ultra-low-noise laser interferometry, and with some of the most powerful developments in the theory of differential geometry, partial differential equations, high-performance computation, numerical analysis, signal processing, statistical inference, and data science. Our emphasis is on the synergy between these disciplines and how mathematics, broadly understood, has historically played, and continues to play, a crucial role in the development of GW science. We focus on black holes, which are very pure mathematical solutions of Einstein’s gravitational-field equations that are nevertheless realized in Nature and that provided the first observed signals.

MSC:
83C35 Gravitational waves
83-02 Research exposition (monographs, survey articles) pertaining to relativity and gravitational theory
83-03 History of relativity and gravitational theory
85-02 Research exposition (monographs, survey articles) pertaining to astronomy and astrophysics
85-03 History of astronomy and astrophysics
01A60 History of mathematics in the 20th century
01A61 History of mathematics in the 21st century
62P35 Applications of statistics to physics
83F05 Relativistic cosmology
83C57 Black holes
35Q75 PDEs in connection with relativity and gravitational theory
53Z05 Applications of differential geometry to physics
65T60 Numerical methods for wavelets
68U10 Computing methodologies for image processing
83-08 Computational methods for problems pertaining to relativity and gravitational theory

Keywords:
gravitational wave; detectors; data analysis tools; Laser Interferometer Gravitational-wave Observatory (LIGO); stellar-mass black holes; Einstein’s prediction; general relativity; black-hole binary; statistical significance; dark Universe; differential geometry; numerical analysis; signal processing; statistical inference; data science; synergy

Software:
SG; FINDCHIRP

Full Text: DOI

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