The future of the Earth-based gravitational-wave astronomy

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From theory to strategy of discovery
14 September 2015
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)
Virgo enters in the network: August 2017
Triple detection – 14 August 2017

Credit: LIGO
GW170814: A Three-Detector Observation of Gravitational Waves from a Binary Black Hole Coalescence

B. P. Abbott et al.*
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 23 September 2017; published 6 October 2017)

On August 14, 2017 at 10:30:43 UTC, the Advanced Virgo detector and the two Advanced LIGO detectors coherently observed a transient gravitational-wave signal produced by the coalescence of two stellar mass black holes, with a false-alarm rate of \( \leq 1 \) in 27 000 years. The signal was observed with a
Binary neutron star merger

The discovery of the kilonova

SSS17a

August 17, 2017

August 21, 2017

Swope & Magellan Telescopes
Multi-messenger Observations of a Binary Neutron Star Merger

2015-2017: the results

- First detection of gravitational-waves
- Gravitational waves travel at the speed of light
- First test that the GW polarisations are in agreement with GR

- First observation of a NS-NS merger
- First observations of BH-BH mergers
- A new population of stellar mass black-holes
- First measurements on NS tidal deformability
- Link between sGRB and binary neutron star mergers
- Kilonova powered by binary NS merger
- Alternative measurement of Hubble constant
Open data

The LIGO Open Science Center provides data from gravitational-wave observatories, along with access to tutorials and software tools.

Download O1 data release
Get started!
See LIGO and Virgo discoveries
Join the email list
Attend Open Data Workshop
Light detectors
The challenges

Sensitivity needed $h \sim 10^{-21}$ ($\sim 10^{-18}$ m for 3 km arms)

Challenges:

- Seismic noise $10^{-6}$ m (factor $\sim 10^{12}$ to gain)
- Wavelength of the light $10^{-6}$ m (factor $\sim 10^{12}$ to gain)
- Brownian motion of the atoms of the mirrors
- Other environmental and technical noises
GW detector progress since J. Weber

Mirrors used in the LIGO interferometers for first detection of gravitational waves

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Virgo performances in August 2017
The path to the detection

Theoretical developments (waveforms, estimation of the amplitudes)  Technology (lasers, control systems)

Discovery of black-holes and neutron stars  Hulse and Taylor binary pulsar (GW exist)

Motivated People and collaborative work  To detect $h=10^{-21}$
(some) questions for the future

- Which are the formation scenarios for BBH?
- Which is the value of the Hubble constant?
- Is GR the only theory compatible with GW observations?
- Why the GRB observed was so dim? Is there a new class of GRB discovered?
- Which is the EOS of neutron stars?
- Which is the physics of the supernovae?

GW detections are a trigger for EM observations
• Which is the nature of the gravity near the horizon of black-holes?

• Can we probe the early Universe with a stochastic background of gravitational-waves?
What GWs can tell us about extreme matter?

Tidal interactions between neutron-stars give their imprint in the gravitational-wave signal

This give access to the equation of state

GW for different equations of state

\[ S_n(f) \text{ and } 2(f |\tilde{h}(f)|)^{1/2} \]

credit: J. Read
GW for different equations of state

\[ S_n(f) \text{ and } 2(\tilde{f} | h(f) |)^{1/2} \]

- Effectively point-particle
- Initial LIGO
- Tidal effects
- NS–NS EOS 2H
- Advanced LIGO
- NS–NS merger
- Post-merger
- BBH

Credit: J. Read
A new approach to constrain the EOS


Credit: L. Rezzolla
Dark energy and GW speed


A new measurement of $H_0$


With a few tens of sources $H_0$ at $\sim 5\sigma$
Bigger instruments
Better places
Different wavelengths
Observational scenarios

Prospects for observing and localizing gravitational-wave transients with Advanced LIGO, Advanced Virgo and KAGRA

Abbott, B. P. et al. (KAGRA Collaboration, LIGO Scientific Collaboration and Virgo Collaboration)*

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Observing runs and sensitivities
Seismic and gravity gradient noise
Geophysics

Quantum noise
Quantum mechanics

AdV Noise Curve: $F_{in} = 125.0 \text{ W}$

Thermal noise
Thermodynamics
The big picture

Credit: Virgo roadmap document
Einstein Telescope

Credit: Einstein Telescope
**ET - implementation**

**Einstein Telescope Xylophone option (ET-C)**

Each detector (red, green and blue) consists of two Michelson interferometers. The HF detectors need one filter cavity each, while the LF detectors require 2 filter cavities each due to the use of detuned signal recycling.

Number of 'long' suspensions = 21
(ITT, ETM, SRM, BS, PRM of LF-IFOs)
of which 12 are cryogenic.

Number of 'normal' suspensions
(PRIM, BS, BS and FC) = 45 for
linear filter cavities and 54 for
triangular filter cavities.

Beams per tunnel = 7

From: Einstein Telescope conceptual design study, www.et-gw.eu
56 teams and collaborations, 3600 authors, 900 institutes...