European Commission

A Career to Manage: Research Skills & Evolving Needs of the Job Market

OR

When Marie Skłodowska -Curie met Albert Einstein

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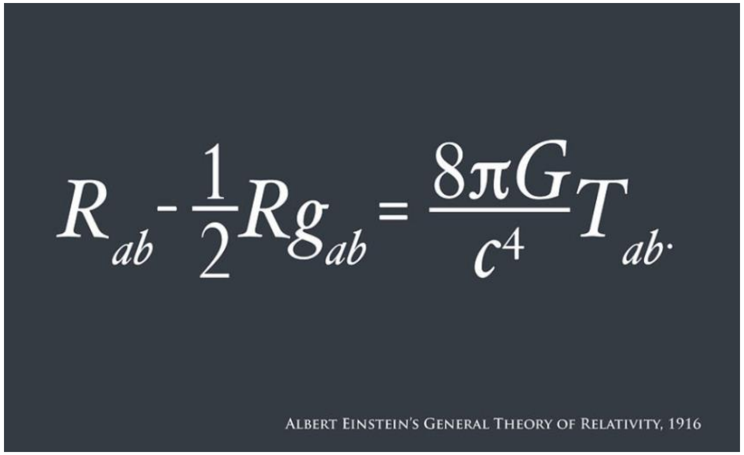

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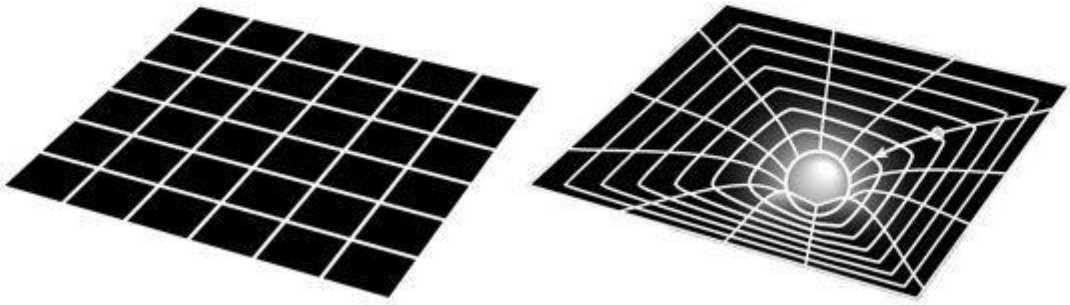


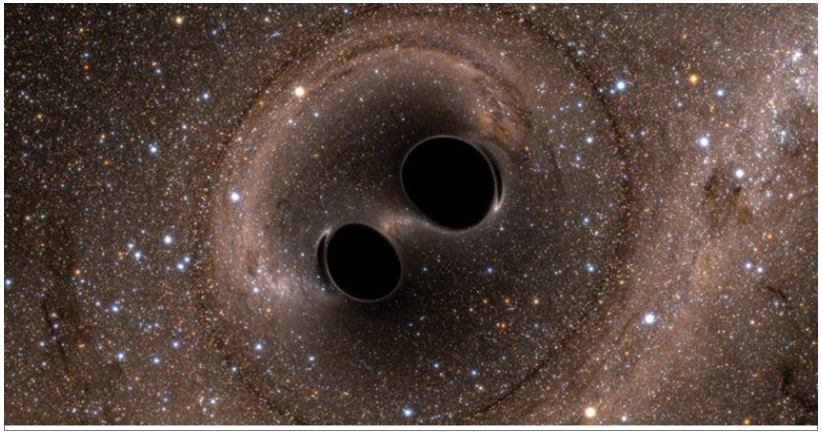
Without matter, space-time is flat (left), but it curves when matter is present (right).
Source of image ***Einstein's General Relativity Theory: Gravity as Geometry*** *(http://www.dummies.com/how-to/content/einsteins-general-relativity-theory-gravity-as-geo.html)*

General relativity *was Einstein's theory of gravity, published in 1915. With this theory, he was able to describe gravity as the bending of space-time geometry (not as force as Newton had done).*

In 1916 Einstein also predicted that ***gravitational waves exist*** *as a consequence of the theory of general relativity.*

Gravitational waves are not easily detectable. When they reach the Earth, they have a small amplitude with strain approximates 10^{-21}, meaning that an ***extremely sensitive detector*** *is needed, and that* ***other sources of noise can overwhelm*** *the signal.*

GRAVITATIONAL WAVES DETECTED 100 YEARS AFTER EINSTEIN'S PREDICTION

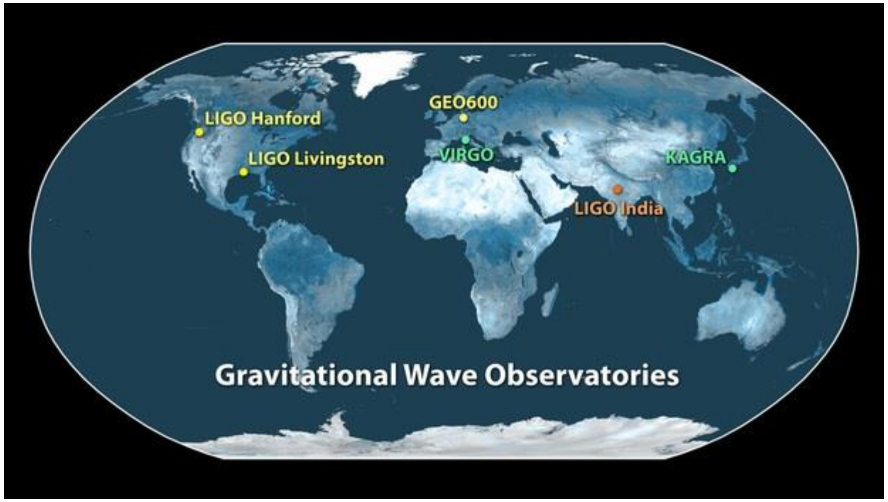


Gravitational waves produced by the merger of two black holes have been confirmed at the Laser Interferometer Gravitational-Wave Observatory (LIGO). Image credit: Caltech/MIT/LIGO Laboratory

For the first time, on 14th September 2015, scientists have observed ripples in the fabric of space-time called gravitational waves, arriving at the earth from a cataclysmic event in the distant universe. This confirms Albert Einstein's general theory of relativity and opens an unprecedented new window onto the cosmos.

The discovery was made by the **LIGO** Scientific Collaboration (which includes the **GEO Collaboration (UK-DE-ES)** and the **Australian Consortium for Interferometric Gravitational Astronomy**) and the **VIRGO (FR-IT-NL-PL-HU)** Collaboration, using data from the two LIGO detectors.

The LSC works closely with the VIRGO Collaboration, and the data from the LIGO detectors is combined with that of the VIRGO detector (located near Pisa, Italy) with ***researchers from both collaborations sharing the analysis effort****.*



Map of current and future gravity wave observatories.
Source of image: https://www.ligo.caltech.edu/news/ligo20160217

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VIRGO is a 3km long interferometer built in the framework of a French-Italian collaboration and located at the European Gravitational Observatory (EGO) in the countryside near Pisa (Italy).

Today, this collaboration involves 19 laboratories with more than 250 scientists in France, Italy and also in the Netherlands, Poland and Hungary as well.

Source of Image: https://www.ego-gw.it/public/about/whatIs.aspx

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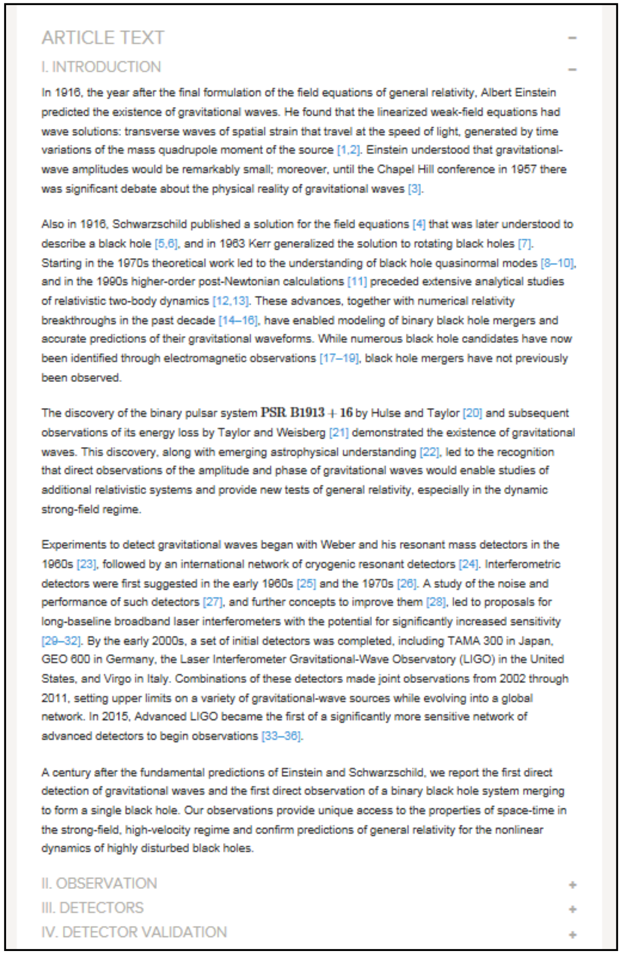

ARTICLE TEXT

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 studies of relativistic two-body dynamics [12,13]. These advances, together with numerical relativity breakthroughs in the past decade [14–16], have enabled modeling of binary black hole mergers and accurate predictions of their gravitational waveforms. While numerous black hole candidates have now been identified through electromagnetic observations [17–19], black hole mergers have not previously been observed.

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 sensitivity [29–32]. By the early 2000s, a set of initial detectors was completed, including TAMA 300 in Japan, GEO 600 in Germany, the Laser Interferometer Gravitational-Wave Observatory (LIGO) in the United States, and Virgo in Italy. Combinations of these detectors made joint observations from 2002 through 2011, setting upper limits on a variety of gravitational-wave sources while evolving into a global network. In 2015, Advanced LIGO became the first of a significantly more sensitive network of advanced detectors to begin observations [33–36].

A century after the fundamental predictions of Einstein and Schwarzschild, we report the first direct detection of gravitational waves and the first direct observation of a binary black hole system merging to form a single black hole. Our observations provide unique access to the properties of space-time in the strong-field, high-velocity regime and confirm predictions of general relativity for the nonlinear dynamics of highly disturbed black holes.

II. OBSERVATION +

III. DETECTORS +

IV. DETECTOR VALIDATION +

Nine early-stage researchers, funded by the EU's Marie Skłodowska-Curie action **GraWIToN**, have co-signed the paper on the detection of gravitational waves.

These researchers were involved in the ***data analysis and the technological development*** *necessary for this scientific milestone.*

Photos courtesy of GraWIToN consortium

OBSERVATION OF GRAVITATIONAL WAVES FROM A BINARY BLACK HOLE MERGER, B. P. ABBOTT ET AL. (LIGO SCIENTIFIC COLLABORATION AND VIRGO COLLABORATION), PHYS. REV. LETT. 116, 061102 – PUBLISHED 11 FEBRUARY 2016

HTTP://JOURNALS.APS.ORG/PRL/ABSTRACT/10.1103/PHYSREVLETT.116.061102#FULLTEXT

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The **GraWIToN** Project is composed by 13 partners: 9 beneficiaries (full partners), recruiting the young researchers, and 4 associated partners, collaborating to the training of young researchers, coming from 4 EU MS.

The GraWIToN project began in 2014 and is designed to allow 14 early stage researchers to gain experience at gravitational science research institutes with a total budget of 3.670.303,56€ for a 4 years period.

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Challenges of the project

- Advanced **technological progress** required to reach the goal of the detection of the Gravitational Waves, linked to **industrial applications** and to sophisticated instruments
- Multidisciplinary approach involving combination of theoretical and applied domains

Skills 1

- New domain in which multidisciplinarity is important
  - **Researchers need to understand more than one subject in order to be able to contribute to the scientific goal: optics, simulation, high power lasers, data analysis**
  - **Data analysis is becoming more and more important in all domains**

Skills 2

- International collaboration
  - **The discovery happened not in one specific laboratory but at an international environment in which around 1300 scientists collaborated**
  - **The paper was co-signed by ~1000 scientists**

Skills 3

- Project management
  - **Working with so many teams, projects, laboratories, makes it necessary that project management principles are applied in order for the goal to be achieved within specific timeframes and budget**
  - **Sharing the lessons learned from the CERN's Large Hadron Collider project**
  - **This was recognised by the project and this training is included in the training programme**

Skills 4

- Communications skills
  - **It is important that you communicate the results of your research to**
    - the scientific community
    - the policy makers (national, EU, international)
    - the general public
  - **Learn how to do it and invest time in this: this is important for your future but also for the good of the science itself and the society in general.**

Outreach lectures

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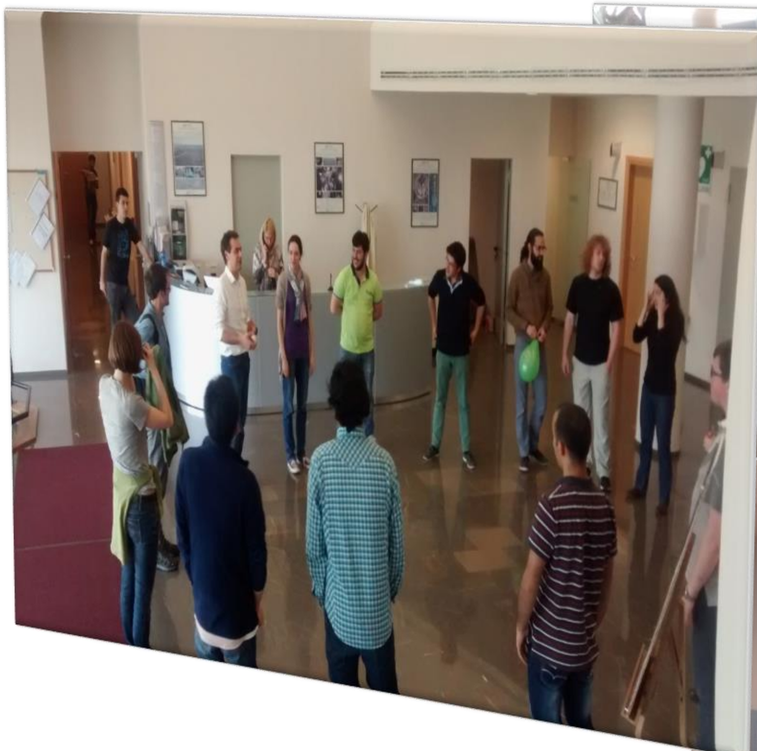

How disseminate their acquired knowledge, how writing about science. Set up of blogs, news letter and high-school related activities.

How to communicate science from the point of view of the scientist

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http://famelab.org

3 minutes to explain
a scientifc argument

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Skills 5

- Intellectual Property Rights (IPR)
  - **Learn about the IPR issues so that you can protect yourselves and the results of your research**
  - **This discovery depends on major technological developments in many domains. There are already advancements which will have commercial impact.**

Skills 6

- Technology transfer
  - **Will this discovery change the lives of the people?**
  - **The technological advancements necessary for this discovery to be made will have an important technological impact.**
  - **Learn more: public-private partnerships, vendors, patents, etc.**

And ... Open Access

- The paper was published in the Physical Review Letters, a high impact journal, that publishes short and excellent papers, with a wide "audience" not confined in the field of astrophysics.
- The paper is open access (which does not mean free).
- In some of the companion papers to be published in Astrophysical Journal, the journal exceptionally offered open access recognising the relevance of the companion papers.
- Open Access is an obligation in Horizon 2020 projects.

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Be curious
Be creative
Be confident

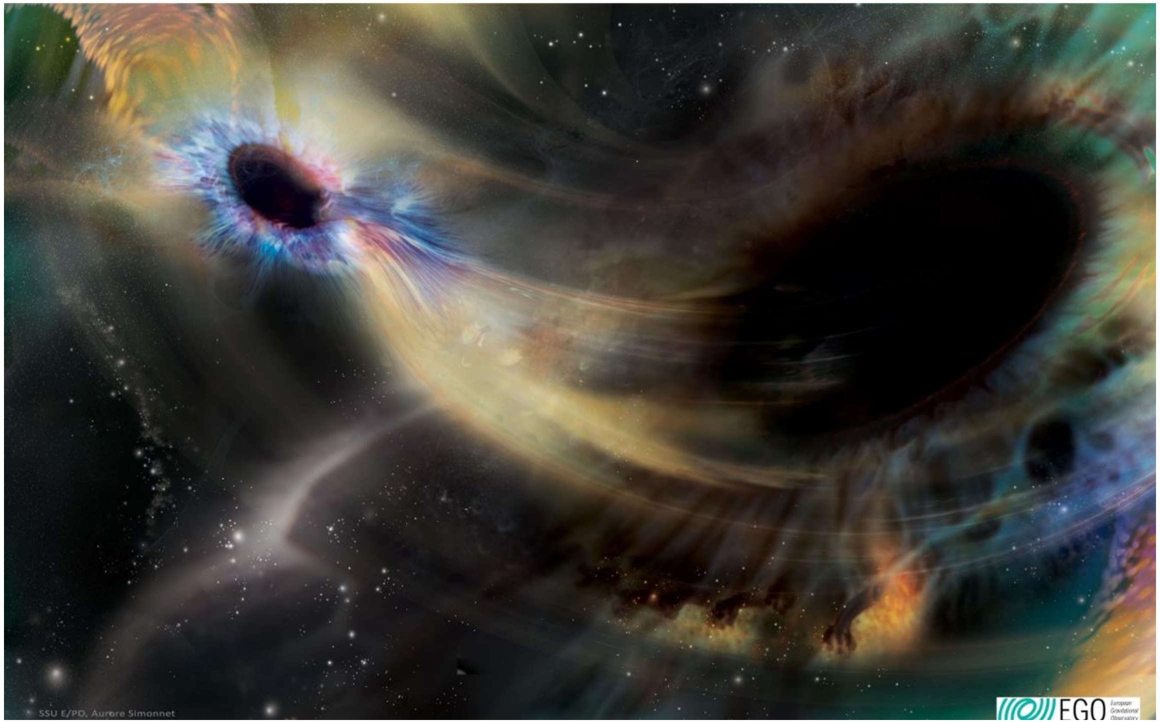

Image credit EGO/GraWIToN: http://ec.europa.eu/research/mariecurieactions/news-events/news/0211-breakthrough-gravitational-waves_en.htm

Thank you for your attention!

Athina Zampara

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