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Gravitational waves discovery, intellectual property and technology transfer

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A B S T R A C T

Gravitational waves were discovered in the USA on the 14th September 2015. The worldwide media have presented this as a significant achievement of scientific discovery. Detection of the waves was due to the development of accurate and sensitive scientific measurement instrumentation by an international collaboration of scientists. However, patents on the detection of gravitational waves are few. Technology transfer of intellectual property by science groups associated with gravitational waves research has been identified and has the potential of yielding important spinoffs now and in future years.

1. Introduction

1.1. Discovery of gravitational waves

Albert Einstein was involved in original theoretical work in physics in 1915 and published his significant Theory of General Relativity [1]. As a consequence of this work on gravitational forces, in 1916 he predicted the existence of gravitational waves. Now 100 years later we see the verification of this work that had a worldwide impact on the physics and astronomy community [2].

Gravitational waves (GW) were discovered almost simultaneously on the14th September 2015 at the identical Laser Interferometer Gravitational Wave Observatories (LIGO) located in Livingston and Hanford, USA. In February 2016, the scientific discovery categorized as GW150914 (Gravitational Waves and date of discovery) was revealed to the world and results were published in the journal *Physics Review Letters* [3], and this is listed by the European Patent Office as Non Patent Literature (NPL) reference number XP055253115 (Observation of Gravitational Waves from a Binary Black Hole Merger). Confirmation of the discovery occurred on 26th December 2015 by the observation of second signals (GW151226) at LIGO observatories and in June 2016 these supportive observational results were published in a second paper also in *Physics Review Letters* [4]. The event GW150914 conveyed a wealth of information concerning the structure of the astronomical bodies involved in the production of gravitational waves, including their distance from Earth and their mass. None of this was visible to any astronomical telescope (visual or radio) on Earth or orbiting in space. Significantly, a third detection of gravitational waves (GW170104) made on 4th January 2017, was described in the journal *Physical Review Letters* [5].

The advanced LIGO large-scale observatories utilised sensitive measurement instrumentation to detect gravitational waves [6] and are funded by the National Science Foundation (NSF) of USA. They were designed, constructed and are operated by the California Institute of Technology (Caltech) and the Massachusetts Institute of Technology (MIT). However, the LIGO Scientific Collaboration (LSC) is composed of over 1000 scientists with many universities and research institutions throughout the world actively participating (see Fig. 1). Other major observatory facilities for detection of gravitational waves are GEO600 in Hannover Germany, VIRGO in Pisa Italy and KAGRA in Japan.

In addition, on 3rd December 2015 a rocket containing a spacecraft LISA (Laser Interferometer Space Antenna) Pathfinder was launched from French Guiana in Africa. The spacecraft was launched into space and the experimental equipment successfully put into operation remotely from the ground-based control centre. This was described as an exploratory mission initiating the '*first step in observing gravitational waves from space*' [7]. The mission

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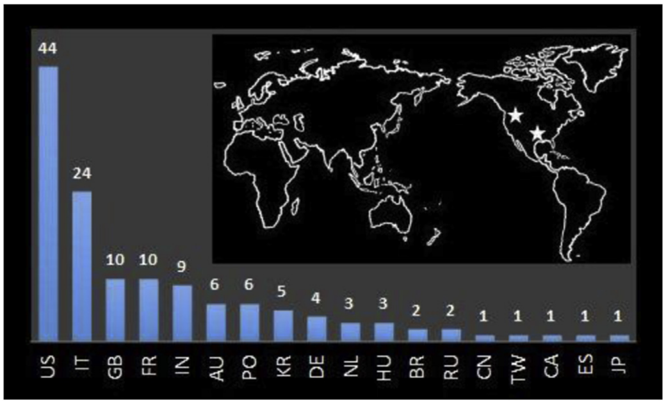

Fig. 1. Number of groups per country participating in LIGO Scientific Collaboration [3]. The stars indicate the location of the LIGO observatories at Hanford and Livingston, USA. (Country codes in Appendix).

involved a collaboration of scientists led and funded by the European Space Agency (ESA). Due to the successful outcome of this mission, scientists are confident this will pave the way for the proposed space-based gravitational wave detector named eLISA (evolved Laser Interferometer Space Antenna), consisting of three spacecraft millions of kilometres apart, linked by laser beams, to be launched 2034.

1.2. The fundamental components of gravitational wave research

The basic technological component parts of the gravitational wave detector are the interferometer, lasers, mirrors and mirror suspensions, signal detectors and IT hardware and software. The interferometer was invented by Albert Abraham Michelson in the 1880s for which he received the 1907 Nobel Prize in Physics. A basic laboratory laser interferometer with its component parts is shown in Fig. 2. However, a significant difference is that gravitational wave observatories use very large interferometer structures. For example, LIGO consists of a basic Michelson interferometer with 4 km length arms constructed of 3 mm thickness stainless steel vacuum tubes of 1.2 m diameter, along which the laser beam can propagate without hindrance. The steel tubes are encased in concrete along the complete length. The vacuum is maintained indefinitely. The LIGO instrumentation has the capability to measure distances as small as 10^{-19} m.

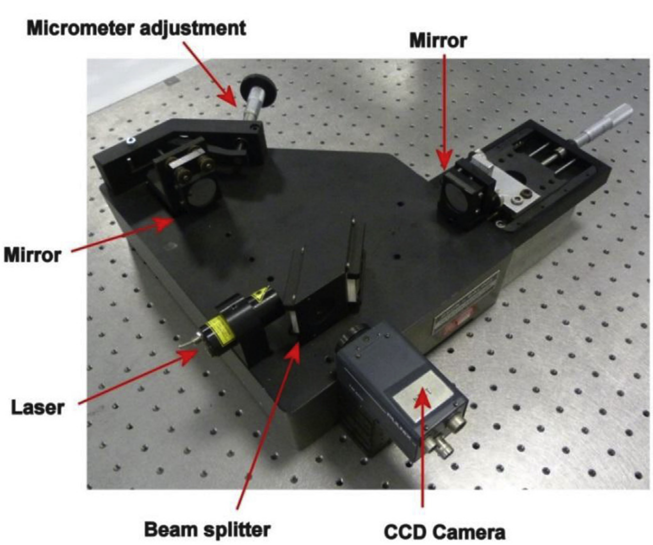

Fig. 2. Basic laboratory laser interferometer (Glasgow University).

The infrared laser used by LIGO consists of a serious of Nd:YAG (synthetic Yttrium Aluminium Garnet) crystals pumped up by laser diode light to an output power of ~220 Watts. A complex feedback system produces a laser beam of remarkable stability of power and frequency, essential for gravitational wave laser interferometers. The qualities of these Nd:YAG lasers are such that they provide the main laser beam for the gravitational wave interferometers in VIRGO, GEO600, KAGRA, and LIGO. The first Nd:YAG laser (Geusic et al. US3252103, 1966) was first demonstrated in the Bell Laboratories USA in 1964.

Mirrors and suspensions are an important part of the laser interferometer used in gravitational wave research. Fig. 3 shows an Institute of Gravitational Research (IGR), Glasgow University exhibit of the type of mirrors used in the detectors. They appear transparent because the mirror reflecting films are for reflection of infrared laser light rather than visible light. In LIGO, robust fused silica fibre suspensions support large interferometer fused silica mirrors, weighing 40 kg. The purpose of the silicon fibre suspensions is to reduce noise sources due to ground motion, nearby railway activity, automobile traffic and earthquakes [8]. Also mechanical movement of apparatus and surrounding environmental thermal fluctuations must be considered. The noise must be isolated from the signals otherwise the extremely weak gravitational waves would not be detectable.

2. Research methodology

Patent data was generated from searches using the European

Fig. 3. Fused silica mirrors for laser interferometer gravitational wave detector (Institute of Gravitational Research, Glasgow University).