Research on the Distinctive Construction and Operational Model of Laser Interferometer Gravitational-Wave Detectors

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Abstract

In 2015, the Laser Interferometer Gravitational-wave Observatory (LIGO) directly detected gravitational wave signals, which not only brought hope to new physics and astrophysics but also sparked a new wave of development in laser interferometer gravitational wave detectors. Against the backdrop of vigorous development of laser interferometer gravitational wave detectors from ground-based to space-based platforms, this paper conducts comparative research on various detectors from the perspectives of construction history, technical characteristics and development positioning, operational models, etc., and summarizes the experiential insights from the construction and operation of laser interferometer gravitational wave detectors, namely: the construction of laser interferometer gravitational wave detectors is a long-term endeavor, which helps promote the improvement and development of scientific research fault-tolerance mechanisms and scientific evaluation mechanisms; the construction of laser interferometer gravitational wave detectors is a high-tech endeavor, which helps promote the collaborative development of multidisciplinary technologies; and the construction of laser interferometer gravitational wave detectors is an international endeavor, which helps promote the healthy development of scientific research collaboration.

Full Text

Research on the Characteristic Construction and Operation Models of Laser Interferometer Gravitational Wave Detectors

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Abstract

The direct detection of gravitational wave signals by the Laser Interferometer Gravitational-wave Observatory (LIGO) in 2015 brought new hope to physics and astrophysics while simultaneously triggering a new wave of development in laser interferometer gravitational wave detectors. Against the backdrop of vigorous development of interferometer gravitational wave detectors from ground-based to space-based platforms, this paper conducts a comparative study of various detectors from the perspectives of construction history, technical characteristics, development positioning, and operation models. We summarize the key experiences and insights from the construction and operation of laser interferometer gravitational wave detectors: first, these projects are long-term endeavors that help promote the improvement of scientific research fault-tolerance mechanisms and evaluation systems; second, they are high-tech engineering projects that drive coordinated development across multiple disciplines; and third, they are international collaborations that foster healthy development of scientific research cooperation.

Keywords: Gravitational Wave Detector; Laser Interferometer; Long-term Project; High-tech; International Cooperation

Introduction

In 1915, Einstein predicted the existence of gravitational waves in the universe based on general relativity [1]. In 1962, American physicist Joseph Weber led the construction of the first gravitational wave detector—a resonant bar—while Soviet physicists Mikhail Gertsenshtein and Vladislav Pustovoit proposed building an interferometer to search for gravitational waves [2]. Entering the 21st century, resonant bar detectors gradually exited the historical stage due to issues such as low sensitivity and limited detection frequency, while interferometer gravitational wave detectors entered a golden age of development. In particular, on September 14, 2015, LIGO detected gravitational waves from the merger of two stellar-mass black holes for the first time [3], and subsequently LIGO and Virgo announced detections of several additional black hole systems and a neutron star merger [4, 5], ushering in a new era of gravitational wave detection.

The rapid international development of laser interferometer gravitational wave detectors has attracted significant attention from Chinese scholars. Luo Ziren et al. [6] provided a detailed analysis of the two major space-based laser interferometry technologies: space laser ranging systems and drag-free spacecraft technology. Wang Yunyong et al. [7] discussed the differences between third-generation laser interferometer gravitational wave detectors and their first- and second-generation predecessors, while introducing the pre-research status of key components and technologies for third-generation detectors. Feng Yan [8] detailed LIGO’ s optical and laser technologies. Li Yonggui et al. [9] introduced the principles, methods, and key technologies of gravitational wave detection using laser interferometers. Hu Wenrui [10] analyzed two different space-based gravitational wave detection schemes based on solar orbit and Earth orbit. Tang Chuan et al. [11] pointed out that China should pay attention to learning from LIGO’ s experience in building and using information technology infrastructure when developing gravitational wave detection work. Wei Ren et al. [12] used bibliometric methods to analyze international development in the gravitational wave field. Overall, domestic scholars tend to focus on the development of gravitational wave detection-related technologies, while systematic and comparative studies of existing laser interferometer gravitational wave detectors remain relatively scarce [13-15]. Considering that China’ s development of laser interferometer gravitational wave detectors lags behind by many years and that the construction of such detectors represents a massive scientific undertaking, a systematic comparative study of the construction history, characteristic positioning, and operation models of major domestic and international laser interferometer gravitational wave detectors at this juncture will help promote the healthy and scientific development of China’ s gravitational wave astronomy endeavors.

1. Construction History of Gravitational Wave Detectors

LIGO: In the 1970s, MIT conducted research on kilometer-scale laser interferometers and evaluated their noise sources [16]. In 1979, the U.S. National Science Foundation funded Caltech and MIT to develop laser interferometers, and the Caltech/MIT joint project LIGO was established in 1984. In 1990, the U.S. National Science Board approved the LIGO construction proposal, deciding to first build Initial LIGO to achieve large-scale laser interferometry, then construct Advanced LIGO to dramatically improve interferometer sensitivity and performance. Construction of the two LIGO observatories—LIGO Hanford in Washington State and LIGO Livingston in Louisiana—began in 1994-1995. Initial LIGO construction was completed in 1999, and first operations began in 2002. During 2002-2010, Initial LIGO never detected gravitational waves, but the experience and lessons learned regarding how to operate, maintain, and improve one of the world’ s most technologically sophisticated measuring devices were invaluable. Based on these operational lessons, the interferometers were completely redesigned and upgraded to Advanced LIGO between 2010-2014. Advanced LIGO’ s sensitivity improved by 10× compared to Initial LIGO, its detection range extended 10× farther, and its sampling volume increased by 1000×.

Virgo: In the early 1980s, the French National Center for Scientific Research and the Italian National Institute for Astrophysics decided to collaborate on developing a large-scale gravitational wave detection instrument based on laser interferometry. The Virgo proposal was formally presented in 1989, approved in 1994, and design was completed in 1997. Initial Virgo was completed in 2003 at the European Gravitational Observatory near Pisa, Italy, and began operations in 2007, but detected no gravitational wave signals. Considering that even if first detection were achieved, Initial Virgo’ s sensitivity would be insufficient to detect more than 0.1 events per year, Virgo began upgrade and renovation in 2012 with the primary goal of improving sensitivity to 10× that of Initial Virgo and increasing the detectable event rate by 1000×. Advanced Virgo construction was completed in 2017.

GEO600: In 1994, the UK and Germany proposed jointly building GEO600, a 600 m arm-length laser interferometer gravitational wave detector. Construction began near Hannover, Germany in 1995. GEO600 began commissioning runs in 2002 and achieved design sensitivity in 2006, though it has not detected gravitational wave signals. To improve high-frequency signal detection sensitivity and conduct advanced technology development, GEO600 began upgrade and renovation in 2009 in a process known as GEO-HF, with upgrades completed in 2014.

KAGRA: In 1995, the University of Tokyo began constructing TAMA300, a 300 m arm-length laser interferometer prototype at the Mitaka campus of the National Astronomical Observatory of Japan [17]. TAMA300 began operations in 1998 as the largest and most sensitive gravitational wave detector at the time. Entering the 21st century, Japan developed CLIO (Cryogenic Laser Interferometer Observatory), a 100 m arm-length cryogenically cooled mirror prototype to verify the feasibility of cryogenic operation [18]. In 2010, the Japanese Diet approved the KAGRA (Kamioka Gravitational Wave Detector) Large-scale Cryogenic Gravitational Wave Telescope project. On October 4, 2019, KAGRA was completed in the Kamioka mine tunnel in Japan, and began commissioning runs at the end of 2019.

ALGO: The Australian Consortium for Interferometric Gravitational Astronomy advocates building a Southern Hemisphere gravitational wave detector in Australia. Currently, the Australian National University and the University of Western Australia have launched the Australian International Gravitational Observatory (ALGO) project in Perth. According to plans [19], ALGO will be built on the Wallingup Plain where the Gingin research facility is located.

ET: In 2008, France, Germany, Italy, the Netherlands, Poland, the UK, the USA, and the European Gravitational Observatory proposed building the Einstein Telescope (ET), a third-generation gravitational wave detector with sensitivity of 10^{-24}. The project team has already held 10 consecutive workshops. According to plans, ET will be constructed in tunnels more than 100 m underground and employ cryogenic technology, featuring three 10 km-long interferometer arms forming an equilateral triangle. Each pair of arms forms one detector, and the three detectors will expand the detection window below 10 Hz, covering all frequencies detectable from Earth—1 Hz to 10 kHz. One detector will monitor low-frequency components from 2 Hz to 40 Hz, while the other two will monitor high-frequency components.

LISA: In 1993, the European Space Agency proposed the Laser Interferometer Space Antenna (LISA). NASA joined the LISA program in 1997, withdrew in 2011, and rejoined in 2017. The smooth progress of the LISA program is based on the successful operation of LISA Pathfinder. Launched on December 3, 2015, LISA Pathfinder served as a proof-of-concept for LISA, aiming to test whether the noise characteristics of free-floating masses in spacecraft would be sufficiently small compared to expected gravitational wave signals. LISA Pathfinder completed its mission in 2017, with test results showing that the low noise level exceeded design requirements, indicating that key technology development for LISA was proceeding smoothly. According to plans, LISA will launch in 2034.

Other Projects: Using space-based laser interferometers to detect low- and medium-frequency gravitational waves is a major focus for astrophysicists today. In addition to LISA, other space-based laser interferometer detection schemes have been proposed. For example, the Chinese Academy of Sciences proposed the "Taiji Program" [20]. According to plans, the Chinese Academy will participate in bilateral cooperation with LISA, independently launching a satellite group that will complement and cross-validate the LISA satellite group launched in 2035. Additionally, Sun Yat-sen University proposed the "TianQin Program" [21], Japan proposed the DECi-hertz Interferometer Gravitational wave Observatory (DECIGO) [22], and the USA proposed the "Big Bang Observer" (BBO) mission within its "Beyond Einstein" program [23].

2. Characteristic Positioning of Gravitational Wave Detectors

LIGO: According to the LIGO Laboratory Charter, LIGO' s mission is to open the field of gravitational wave astrophysics through direct detection of gravitational waves. LIGO [24] operates at frequencies from 10 Hz to 1000 Hz and employs two nearly identical detectors—LIGO Hanford and LIGO Livingston—separated by 3002 km to reduce false signals. Each detector's core is a Michelson interferometer with two L-shaped long arms. The mirror structure inside the arms causes each laser beam to reflect approximately 400 times along the full 4 km arm length before merging with the other beam. After multiple reflections, the travel distance of each beam increases from 4 km to 1600 km, enabling measurement of distances as small as 10^{-19} m. Such precise measurement of minute distances relies on LIGO's advanced and highly characteristic vibration isolation systems, vacuum systems, optical components, and computing infrastructure to process the incredible volume of data LIGO collects.

LIGO' s vibration isolation system consists of active and passive components. The active isolation system first monitors various environmental vibrations through side-by-side sensors, then performs precise calculations based on sensor information to generate counter-motion that eliminates vibrations. The passive isolation system uses a 4-stage pendulum configuration to further absorb any motion not completely canceled by the active system, keeping all critical mirrors perfectly stationary. LIGO' s vacuum volume is second only to Switzerland' s

Large Hadron Collider. Using turbomolecular pumps, ion pumps, and other means, LIGO can achieve ultra-high vacuum of one trillionth of atmospheric pressure. LIGO also features the most stable lasers, with light sources maintaining excellent monochromaticity after continuous multi-stage amplification. Furthermore, LIGO' s mirrors employ the best materials and optimal shapes. Made from extremely pure fused quartz glass, the mirrors ensure high reflectivity, low thermal noise, and minimal deformation; differences between polished mirror surfaces and theoretical designs are measured in atoms to ensure high collimation of laser beams. LIGO' s supercomputer network can store and archive terabytes of newly added data daily, while its massive computing infrastructure can provide service cycles at the MSU level.

Virgo: The Virgo project aims to directly detect gravitational waves. Its operating frequency of 10 Hz to 6000 Hz combined with extremely high sensitivity enables Virgo to detect gravitational waves from supernovae and from binary system mergers in the Milky Way and external galaxies (such as the Virgo cluster). Virgo [25], similar to LIGO, is essentially a Michelson laser interferometer with two 3 km-long arms. Laser beams are split into two equal components by a beam splitter and sent into the arms. In each arm, a dual-mirror Fabry-Perot resonant cavity extends the optical length from 3 km to 120 km. The greatly extended arms amplify the minute distance changes caused by gravitational waves. The Virgo project has developed state-of-the-art technologies in high-power ultra-stable lasers, high-reflectivity mirrors, seismic isolation, and position and alignment control. In optics, Virgo uses a new generation of ultra-stable lasers and the most stable oscillators ever built. To produce ultra-high-quality mirrors combining the highest reflectivity (over 99.999%) with nanometer-scale surface control, the Virgo team established a dedicated optical coating facility. To avoid spurious motion from seismic noise, each optical component is isolated by a 10 m-high, exceptionally complex compound pendulum system. To avoid slight disturbances from residual gas, the Virgo interferometer was built as Europe' s largest ultra-high vacuum container, with beams propagating in ultra-high vacuum in an environment quieter than spacecraft orbiting Earth.

GEO600: The GEO600 project aims to directly detect gravitational waves in the 50 Hz to 1500 Hz frequency band through a 600 m arm-length laser interferometer, though its current sensitivity is insufficient to detect gravitational wave signals. In addition to conducting gravitational wave searches, GEO600 currently serves as a key technology development center for the international gravitational wave research community, with tested technologies being used in all major gravitational wave detectors worldwide. GEO600 scientists have pushed available technologies to their limits in laser stabilization, absorption-free optics, control engineering, vibration reduction, and data acquisition and processing. GEO600 [26] is characterized by amplification of laser power and signal intensity through "dual recycling." Using high-reflectivity mirrors, the laser used for interference is constructively superimposed with itself to achieve laser enhancement ("power recycling"); using additional mirrors, the detection signal is superimposed with itself to achieve signal amplification ("signal recycling").

These technologies also allow the detector to be tuned to specific frequencies. Additionally, using glass fibers to implement mirror suspension structures is one of GEO600' s many breakthrough technologies. GEO600 was also the first gravitational wave detector to use squeezed light to improve sensitivity. Moreover, GEO600 employs an output mode cleaner and compensates for thermal warping of optical components.

KAGRA: The KAGRA project aims to frequently detect gravitational waves from distant galaxies and obtain unique information about the universe. As a highly sensitive gravitational wave detector, KAGRA will work together with LIGO, Virgo, and others to form a more extensive global detection network. KAGRA [27] operates on the same principle as LIGO and Virgo, using four mirrors to repeatedly reflect infrared laser beams along two 3 km-long high-vacuum tubes as a long-baseline Michelson laser interferometer to detect gravitational waves. KAGRA' s unique features include: (1) being built more than 200 meters underground, making it the world' s first underground gravitational wave detector, where underground seismic noise is typically two orders of magnitude smaller than surface noise; (2) employing cryogenic technology to keep mirrors at 20 K to reduce noise from material thermal vibrations, making KAGRA particularly suitable for detecting gravitational wave signals below approximately 100 Hz; and (3) using sapphire as mirror material due to its excellent optical and thermal properties at cryogenic temperatures.

ALGO: With two LIGO sites, Virgo, and GEO600 all located in the Northern Hemisphere at similar latitudes, the existing gravitational wave detection network suffers from poor angular resolution perpendicular to the line connecting the US and Europe and poor polarization information. This missing information prevents resolution of many questions about gravitational wave sources. As a Southern Hemisphere detector, ALGO [19] can not only significantly improve the angular resolution of gravitational wave sources but also maximize the network baseline, enhancing sensitivity and sky coverage. Since ALGO is developed based on Advanced LIGO, its optical configuration is almost identical to Advanced LIGO, except for possibly using a fiber mode cleaner. Additionally, ALGO' s technical specifications are very close to Advanced LIGO' s, but it is especially suitable for detecting gravitational waves in the 4-20 Hz range.

ET: First-generation detectors (Initial LIGO, Initial Virgo, GEO600, and TAMA300, with sensitivity 10^{-22}) verified the feasibility of using laser interferometers for gravitational wave detection in principle. Second-generation detectors (Advanced LIGO, Advanced Virgo, GEO-HF, KAGRA, with sensitivity 10^{-23}) have successfully detected gravitational waves, opening the new field of gravitational wave astronomy. As a third-generation detector, ET [28] is positioned to conduct precision gravitational wave astronomy by further improving detection sensitivity. According to plans, ET will be located in tunnels more than 100 m underground and employ cryogenic technology, featuring three 10 km-long interferometer arms forming an equilateral triangle, with each pair of arms forming one detector. The three detectors will expand the detection window below 10 Hz, covering all frequencies detectable from Earth –1 Hz to 10 kHz. One detector will monitor low-frequency components from 2 Hz to 40 Hz, while the other two will monitor high-frequency components.

LISA: Unlike ground-based detectors, the space-based gravitational wave detector LISA [29] can not only avoid noise from Earth but also detect lower frequency bands inaccessible from Earth through extremely long interferometer arms. Therefore, LISA searches for gravitational waves with longer wavelengths, corresponding to wider orbital motions and potentially much more massive objects than those LIGO seeks, pushing the detection field to a broader range of gravitational wave sources. Potential sources for LISA include ultra-compact binaries in the Milky Way, supermassive black hole mergers, extreme mass ratio inspirals, and other exotic possibilities. LISA employs a three-spacecraft laser ranging scheme in solar orbit, with three spacecraft forming an equilateral triangle in space, orbiting the Sun together with Earth. The paths between spacecraft (5$×10^{6}$ km) serve as interferometer arms, with onboard lasers measuring path variations to search for gravitational waves between 0.1 mHz and 1 Hz. The LISA team validated the fundamental technologies needed to develop a space-based gravitational wave detector through LISA Pathfinder. LISA Pathfinder included two gold-platinum cubes serving as test masses in vacuum suspension, capacitive sensors for monitoring relative position between test masses and spacecraft, laser interferometry for measuring relative position and attitude of the two test masses, and a drag-free control system using hybrid micronewton (cold gas) thrusters and capacitive actuators to adjust relative alignment between spacecraft and test masses.

Other Projects: Both the “Taiji Program” and “TianQin Program” have detection frequencies similar to LISA. The “Taiji Program” selects the same three-spacecraft solar orbit scheme as LISA but achieves higher sensitivity than LISA in the 0.01 Hz-1.0 Hz band, while the “TianQin Program” selects a three-spacecraft Earth orbit scheme more affected by Earth’ s gravitational field. DECIGO and BBO [30] both aim to detect the frequency band between ground-based interferometers and LISA to probe gravitational waves produced in the early universe. Both employ three-spacecraft solar orbit schemes with similar detection frequencies, differing only in sensitive bandwidth.

Overall, each detector has its own positioning and characteristics, but ground-based detectors primarily monitor medium-to-high frequencies between 1 Hz and 1000 Hz, while space-based detectors mainly monitor low-to-medium frequencies from 0.1 mHz to 1 Hz. The main detectors and their characteristics are summarized in Table 1 .

3. Operation Models of Gravitational Wave Detectors

LIGO: LIGO is primarily supported by the U.S. National Science Foundation, with Advanced LIGO also receiving funding from the German Max Planck Society, UK Science and Technology Facilities Council, German state of Lower

Saxony, and Australian Research Council. LIGO consists of the LIGO Laboratory and the LIGO Scientific Collaboration (LSC). The LIGO Laboratory, comprising Caltech, MIT, LIGO Hanford, and LIGO Livingston, is responsible for experimental operation of the detectors, research, development, and improvement of detector capabilities, and public education and outreach. The LSC is responsible for gravitational wave detection, using gravitational wave data to explore fundamental physics, and developing tools for gravitational wave detection. As an open scientific collaboration, the LSC currently comprises more than 1000 scientists from over 100 institutions in 18 countries. For example, the LSC provides computer resources for LIGO through partnerships with the LIGO Laboratory, the Atlas cluster, Syracuse University, and other institutions, while the GEO600 team has developed and tested multiple key technologies for Advanced LIGO. At the strategic level, the LSC's research goals cover all aspects of gravitational wave science, including design, development, and characterization of large gravitational wave detectors, development of data analysis techniques and algorithms for searching gravitational waves using detector data, exploring astrophysical implications of gravitational wave searches and conducting necessary fundamental and applied research, and developing future gravitational wave detectors that can probe deeper into the universe. Prospective members interested in joining the LSC must sign a memorandum of understanding with the LIGO Laboratory and LSC, present their proposed collaboration plan at an LSC meeting, and receive approval by a two-thirds majority vote of the LSC council.

The LIGO Laboratory and LSC are inseparable. The LIGO Laboratory, as the largest member of the LSC, plays a special role in the LSC, while LSC members also play special roles in the LIGO Laboratory. For example, the LSC spokesperson is a member of the LIGO Laboratory Council, which is responsible for the scientific development of the LSC. The LIGO Laboratory fully participates in the entire development process of the LSC, holds many leadership positions in the LSC, and follows LSC rules for publishing, presenting, and sharing LIGO data with the broader scientific community. In turn, the LIGO Scientific Collaboration makes significant contributions to the Laboratory' s mission, including developing gravitational wave detectors, operating observatories, and advancing related fields.

The Gravitational Wave Open Science Center (GWOSC) is the network platform through which LIGO (together with GEO600 and Virgo) provides gravitational wave observation data. Through GWOSC, LIGO fulfills its commitment to release, archive, and provide LIGO data to the broader scientific community and the public, offering tutorials and software tools needed to research and use the data. GWOSC data are licensed under Creative Commons Attribution 4.0 International. If researchers use the data in their work, they must cite the data source in a specific format to protect LIGO' s rights.

Other Detectors: The Virgo project is funded by the French National Center for Scientific Research, Italian National Institute for Nuclear Physics, and

Dutch Institute for Subatomic Physics, with support from research institutions in Poland and Hungary, and is hosted by the European Gravitational Observatory. Its operation model is broadly similar to LIGO' s, with the difference that the Virgo Scientific Collaboration is responsible not only for research on detection data but also for detector design, construction, and operation. The Virgo team collaborates with the LSC in many areas, including data exchange. The GEO600 project is funded by the German Max Planck Society and UK Science and Technology Facilities Council, designed and operated by scientists from the Max Planck Institute for Gravitational Physics and Leibniz University Hannover together with UK partners, with an operation model similar to LIGO' s. The GEO600 project also has close cooperation with LIGO and together with LIGO forms the LSC detection network. KAGRA is funded by the National Astronomical Observatory of Japan and the High Energy Accelerator Research Organization, with support from Korea and Taiwan, jointly built by research groups from the University of Tokyo, National Astronomical Observatory, Kyoto University, and other institutions, and operated by the Institute for Cosmic Ray Research at the University of Tokyo. In October 2019, KAGRA signed a memorandum of understanding with LIGO and Virgo for research cooperation including joint detection and data sharing, and is currently widely calling for global researchers to join its collaboration organization to conduct joint research.

4. Experience and Insights from Gravitational Wave Detector Construction

(1) The construction of laser interferometer gravitational wave detectors is a long-term project that helps promote the improvement of scientific research fault-tolerance mechanisms and evaluation systems. As large-scale infrastructure, laser interferometer gravitational wave detectors often require decades for preparation and construction (LIGO took over 40 years from project establishment to signal detection; Virgo took over 40 years from preparation to detection; from TAMA construction to KAGRA completion took 25 years; from LISA proposal to LISA launch will also take about 40 years). Moreover, projects may undergo plan adjustments or equipment upgrades, and even after upgrades may still fail to effectively detect signals. Over such long time spans, the patience and wisdom of research project management will be severely tested, making the establishment of reasonable fault-tolerance mechanisms and scientific evaluation systems essential for the healthy development of large-scale infrastructure.

(2) The construction of laser interferometer gravitational wave detectors is a high-tech engineering project that helps promote coordinated development of multidisciplinary technologies. Laser interferometer gravitational wave detectors are systematic high-tech engineering projects whose construction and maintenance depend on highly developed laser technology, vibration isolation technology, vacuum technology, computer technology, crystal coating technology, ultra-precision automatic control technology, new materials technology, cryogenic technology, and more. Currently, China lags behind in laser technology, crystal coating technology, ultra-precision automatic control technology, and computer technology. During the construction of projects such as the "Taiji Program" and "TianQin Program," actively integrating domestic scientific and technological forces for collaborative innovation will effectively promote rapid development of multidisciplinary technologies including laser technology, crystal coating technology, ultra-precision automatic control technology, and computer technology.

(3) The construction of laser interferometer gravitational wave detectors is an international project that helps promote healthy development of scientific research cooperation. As large-scale infrastructure, laser interferometer gravitational wave detectors require substantial financial and intellectual support for construction and operation. In terms of funding sources, LIGO receives support from the USA, Australia, Germany, the UK, India, and other countries; Virgo is jointly built by France and Italy; GEO600 is jointly built by the UK and Germany; KAGRA receives support from Japan, Korea, and Taiwan; and eLISA receives support from Europe and the USA. In terms of operation models, LIGO, Virgo, GEO600, KAGRA, and others have all established scientific collaboration organizations that absorb global research institutions and personnel to participate in research cooperation and management. Currently, China is simultaneously carrying out the "Taiji Program" and "TianQin Program," facing considerable challenges in both funding and intellectual resources. Therefore, broadly uniting domestic and international financial and intellectual resources and conducting extensive and in-depth scientific research cooperation to further consolidate our financial and intellectual conditions represents an effective approach for developing China' s laser interferometer gravitational wave detector construction.

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