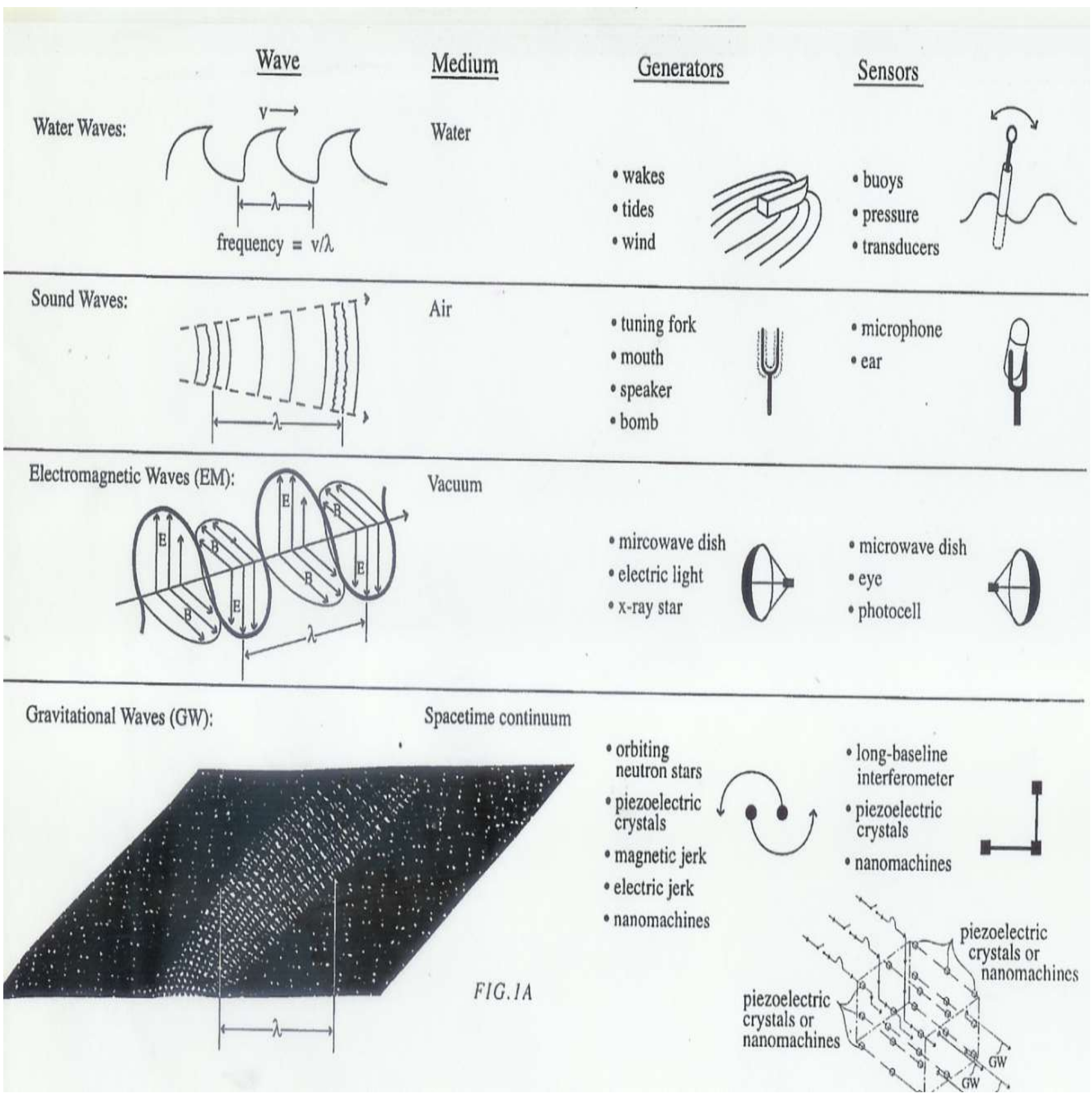
The 3rd High Frequency Gravitational Wave Workshop, 7-9th, April 2017 at Southwest Jiaotong University, Chengdu, China.

SEARCH FOR THE INVISIBLE WAVES: BRIEF HISTORY OF HIGH-FREQUENCY GRAVITATIONAL WAVE RESEARCH

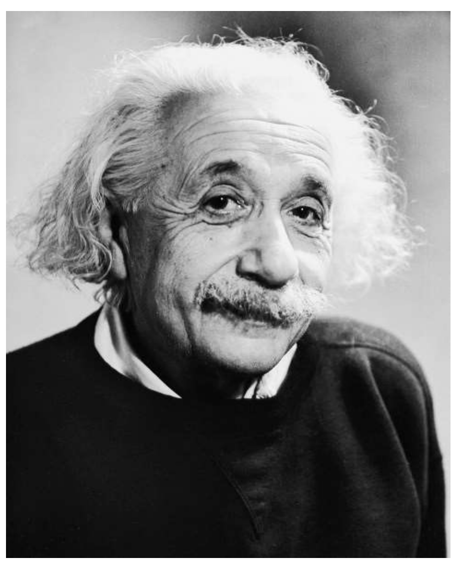
By Robert M L Baker, Jr.

If we swim in the ocean we feel the water waves. When we listen to a song we hear acoustical waves. When we look at each other we see the light or electromagnetic waves. But are there other possibly ***invisible waves*** not so easily sensed?



It was in 1905, several weeks before Einstein presented his Special Theory of Relativity that Henri Poincaré, the famous French mathematician and Celestial Mechanic, suggested that Newton's theories needed to be modified by including "Gravitational Waves." However, Poincaré, presented little or no specific analyses.

Henri Poincaré 1905



Albert Einstein 1916, 1918, 1937

Such Gravitational Waves were first mathematically analyzed in a 1916 paper authored by Albert Einstein where he discussed Gravitational Waves in his theory of General Relativity. Specifically, in 1918 Einstein derived the quadrupole formula or equation according to which Gravitational Waves are produced in his newly studied ***spacetime continuum*** by a time-dependent mass quadrupole moment (literally a four-pole moment, actually a 4×4 tensor [Steven A. Balbus (2016),"Simplified derivation of the gravitational wave stress tensor from the linearized Einstein field equations" arXiv.org > astro-ph > arXiv:1604.05974v2, https://arxiv.org/pdf/1604.05974.pdf]. As pointed out in an overview of gravitational radiation by the University of Maryland's Astronomy Department, there cannot be monopolar gravitational radiation, there is no dipolar gravitational radiation either, but there can be quadrupolar gravitational radiation. The quadrupole wave is the simplest solution that maintains conservation of momentum during the propagation of the wave. [Jules Henri Poincaré (1905), C.R. Ac. Sci. Paris, 140, 1504 and also appears in *Oeuvres*, Volume 9, p. 489,Gauthier-Villars, Paris, 1954. (First mention of Gravitational Waves). Albert Einstein, (1916), **"**Die Grundlage der allgemeinen Relativitätstheorie**",** *Annalen der Physik* 49, (Gravitational Waves). Einstein, Albert (1918), Über Gravitationswellen. In: Sitzungsberichte der Königlich Preussischen Akadee der Wissenschaften, Berlin (1918), 154–167. (Quadrupole equation and formalism). Albert Einstein and Nathan Rosen (1937), "On Gravitational Waves," *Journal of the Franklin Institute* **223**,43-54.]

The quadrupole moment showed that Gravitational Waves can and do carry energy. In 1936 Einstein submitted, together with Nathan Rosen, a manuscript to the *Physical Review* in **which they claim that gravitational waves do not exist**. In 1937, after receiving a critical referee report, Einstein was upset and withdraws the manuscript (**with the erroneous claim**) and published, again together with Rosen, a strongly revised manuscript **confirming Gravitational-Wave solutions** in the *Journal of the Franklin Institute.* (Rosen actually departed just before the actual publication.)[Galine Weinstein (2016), "Einstein and Gravitational Waves 1936-1938," https://arxiv.org/ftp/arxiv/papers/1602/1602.04674.pdf].

After reviewing the early work of Einstein, Joseph Weber suggested the detection of Gravitational Waves utilizing a large 2,400 pound Aluminum cylinder that, when isolated from all external vibrations, would resonate like a "bell" excited by incoming Gravitational waves – his so-called "Weber Bar." His results were inconclusive and resulted in some reports that are still debatable.

Joseph Weber and his "Weber Bar" 1960s

The first mention of High-Frequency Gravitational Waves or HFGWs that I could determine was in a Lecture in 1961 that I had given with Dr. Robert Lull Forward at my Lockheed Astrodynamics Research Center in Bel Air, California. [Lecture given at the *Lockheed Astrodynamics Research Center (LARC),* 650 N. Sepulveda, Bel Air, California, USA, a few blocks from UCLA, November 16th. *Lockheed Research Report RL 15210,* based upon notes taken by Samuel Herrick a *Lockheed* Consultant and UCLA Professor. Attendees included LARC members Robert Rector, Professors Geza Gedeon, Kurt Forester, my secretary Joan Boyle who typed up Herrick's notes in the *Lockheed Research Report* of the Lecture, plus UCLA students.] I had invited Dr. Forward over from the Hughes Research Laboratory in Malibu, California to deliver a lecture on the "Weber Bar" that he and Dr. Joseph Weber were constructing at the Hughes Lab to detect Low-Frequency Gravitational Waves (1660 Hz). During the Question and Answer part of our Lecture, Bob Forward and I talked about building a Laboratory generator and detector for "High-Frequency Gravitational Waves," having frequencies over 100 kHz. As far as I know this was the first time the subject had been broached. I recall that we concluded that it could not be accomplished with the technology then available; but I suggested that such high-frequency gravitational waves, or HFGWs, would have practical applications, for example communication (the ultimate wireless system). They would be useful for the interception of interstellar communications by extraterrestrial advanced civilizations, whose communications means of choice would be high-frequency gravitational waves since, unlike electromagnetic radiation, HFGWs pass unattenuated through all matter including interstellar matter. [Joseph Weber (1960), "Detection and generation of gravitational waves," *Physics Review*, Volume 117, Number 1, pp.306-313. Joseph Weber (1964), "Gravitational Waves" in *Gravitation and Relativity*, Chapter 5, pp. 90-105, W. A.Benjamin, Inc., New York.]

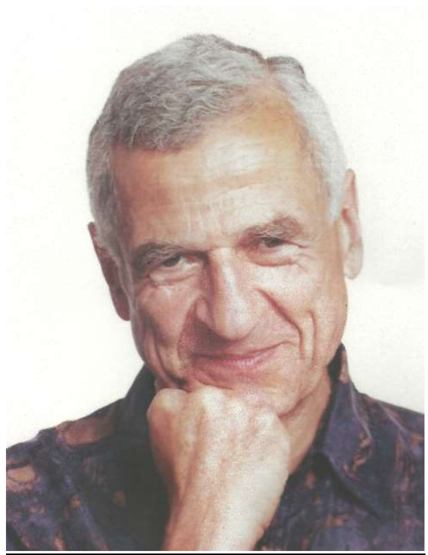
Robert Lull Forward 1961

There were no actual scientific or technical publications concerning High-Frequency Gravitational Waves (HFGWs) that I could find until mid-1962 when Mikhail Evgen'evich Gertsenshtein authored the pioneering paper entitled "Wave resonance of light and gravitational waves," [*Soviet Physics JETP* **14**, Number 1, pp. 84-85]. The Gravitational-Wave frequencies being about those of light (4×10^{14} Hz is red light, 8×10^{14} Hz is violet light) would be considered HFGWs. Unfortunately, the Gertsenshtein effect is so weak that it has no value for the detection, generation or applications of HFGWs. By the way, the idea that laid the theoretical basis for, or a precursor of, future big Gravitational-Wave interferometers, such as the Laser Interferometer Gravitational Observatory (for the detection of Low-Frequency Gravitational Waves or LFGWs), was put forward by Gertsenshtein and another Russian scientist Vladislav Pustovoit in 1962 and reported on in 1963. [Mikhail E. Gertsenshtein and Vladislav I Pustovoit, (1963) "On the detection of low frequency gravitational waves," *Soviet Physics JTEP* **16**, pp. 433-435.]

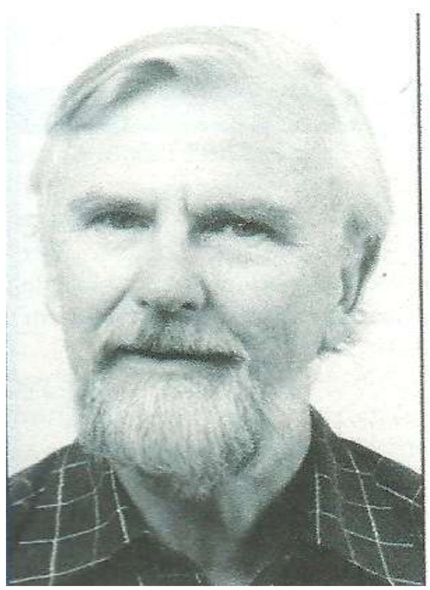
Mikhail Evgen'evich Gertsenshtein 1962, 1963

In 1967 Rainer Weiss of MIT published another analysis of interferometer use for LFGW detection and initiated the construction of a prototype with US military funding. Unfortunately, the construction was terminated before the laser LFGW detector could become operational. The concept eventually was utilized in the Laser Interferometer Gravitational-wave Observatory or LIGO. [Alex Abramovici, William E. Althouse, Ronald W. P. Drever, Yekta Gursel, Seiji Kawamura, Frederick J. Raab, David Shoemaker, Lisa Sievers, Robert E. Spero, Kip S. Thorne, Rochus E. Vogt, Rainer Weiss, Stanley E. Whitcomb and Michael E. Zucker (1992), "LIGO: The Laser Interferometer Gravitational-Wave Observatory.," *Science* 256,pp. 325-333.]

The next publication concerning HFGWs was in August of 1964 when Leopold Ernst Halpern and Bertel Laurent wrote a paper in *Il Nuovo Cimento* [Volume XXXIII, Number 3, pp. 728-751]. They suggested that "… at some earlier stage of development of the universe (the Big Bang) was suitable to produce strong (relic) gravitational radiation." (p.729). They then discuss "short wavelength" or High-Frequency Gravitational Waves or HFGWs (p.743) and even suggest a "gaser" generator of HFGWs on p. 747, analogous to a laser for EM (electromagnetic) wave generation.



Leopold Ernst Halpern 1964



Bertel Laurent 1964

Leonid Petrovich Grishchuk_and Mikhail Vasilievich Sazhin in early 1974 authored a paper on "Emission of gravitational waves by an electromagnetic cavity" (*Soviet Physics JETP*, Volume 38, Number 2, pp. 215221), which involved HFGWs. In August of 1974 G. F. Chapline, J. Nuckolls, and L. L. Woods suggested the generation of HFGWs by nuclear explosions (*Physical Review* D, Volume 10, Number 4, pp. 1064-1065) and in 1978 Vladimir Borisovich Braginsky and Valentin N. Rudenko wrote about "Gravitational waves and the detection of gravitational radiation," [Section 7: "Generation of gravitational waves in the laboratory," Physics Report (Review section of *Physics Letters*), Volume 46, Number 5, p. 165-200]. In that regard, a more recent paper by Rudenko (with N. Kolosnitsyn) in *Physica Scripta* suggests it is possible to couple a HFGW Generator and Detector (theoretically, a possible communications link) with a HFGW amplitude sensitivity of $h \sim 10^{-31}$ at frequencies in excess of 10^{10} Hz.

Leonid Petrovich Grishchuk, 1974

Valentin N. Rudenko 1978

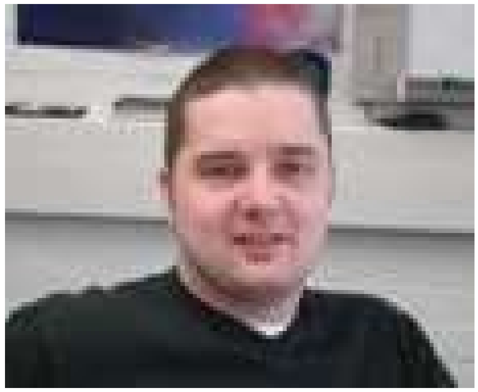
The Russians were most interested in HFGWs during the "Cold War" especially in the 1970's. Then in 1979 Steven W. Hawking and W. Israel presented an actual definition for HFGWs in a book. They suggested HFGWs have frequencies in excess of 100 kHz ["General Relativity – An Einstein centenary survey," Cambridge University Press, page 98].

In Germany Professor Dr. Heinz Dehnen was developing another HFGW generator, which made use of an array of crystal oscillators. Dehnen concluded that utilizing the relatively large crystal oscillators then available in the 1980s, the generated HFGWs would be too weak to be of value. [Heinz Dehnen and Fernando Romero-Borja (2003), "Generation of GHz – THz High-Frequency Gravitational Waves in the laboratory," paper HFGW-03-102, *Gravitational-Wave Conference,* The MITRE Corporation, May 6-9. pp. 22 ff of http://www.gravwave.com/docs/Analysis%20of%20Lab%20HFGWs.pdf . F. Romero B and H. Dehnen (1981), "Generation of gravitational radiation in the laboratory," *Z. Naturforsch*, 36a, pp. 948-955. http://dx.doi.org/10.1515/zna-1981-0905.]

Professor Dr. Heinz Dehnen 1981

One of the first practical HFGW detectors was developed at *Birmingham University*, England by Professor Mike Cruise and his graduate student Richard Ingley. Professor Cruise published his years of research in 1983 and during the 1990s on an electromagnetic detector for very-high-frequency gravitational waves, in *Class. Quantum Gravity* in 2000. Professor Cruise has published over 100 research papers and a textbook on *The Principles of Space Instrument Design*. He is a member of the European Space Agency and a member of international teams searching for gravitational waves using ground based and space based facilities such as LIGO and the proposed Laser Interferometer Space Antenna or LISA.

Mike Cruise, Professor of Astrophysics and Space Research 1983.



Richard Ingley, 1999

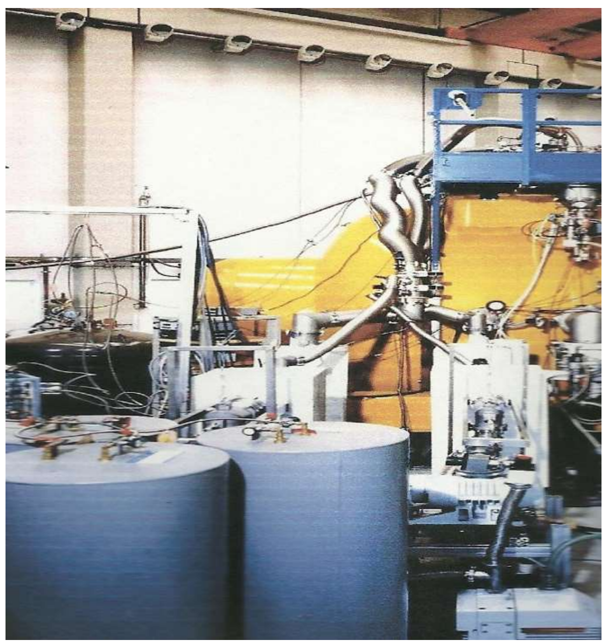
An interaction between a gravitational wave and the polarization vector of an electromagnetic (EM) wave is the basis for the *Cruise-Ingley Birmingham HFGW detector*. The polarization vector of the EM wave rotates about the direction of its propagation. If a resonant condition can be established with the EM wave always experiencing the same phase as the gravitational wave, then the effect is cumulative and can be enhanced linearly by repeated circuits of a closed loop. The detector measures changes in the polarization, using a short filament or probe, of the EM microwave beam (indicating the presence of a HFGW) propagating within a waveguide loop about one meter in diameter. This is about the wavelength of 300 MHz HFGWs. A pair of the Cruise-Ingley HFGW detector loops is shown in the slide. [A. Michael Cruise (1983), "An Interaction between gravitational and electromagnetic waves", *Monthly Notices of the Royal Astronomical Society,* Volume 204, pp. 485-482. A. M. Cruise (2000), "An electromagnetic detector for very-high-frequency gravitational waves," *Class. Quantum Gravity,* 17, pp. 2525-2530. http://dx.doi.org/10.4236/jmp.2011.26060 R. M. J. Ingley and A. M. Cruise (2001), "An electromagnetic detector for high frequency gravitational waves," *4th Edoardo Amaldi Conference on Gravitational A. M. Cruise and Richard M. J. Ingley (2005), "A correlation detector for very high frequency gravitational waves," Class. Quantum Grav.* ***22****, 5479-5481. M. Cruise (2007), "Operational Performance of the Birmingham 100 MHz Detector and Upper Limits on the*

Stochastic Background," Amaldi 7 Gravitational Wave Conference, July 9, 2007, Sydney, Australia. Mike Cruise (2008), "Very High Frequency Gravitational Waves," [*Gravitational Wave Advanced Detector Workshop (GWADW)*](), *Elba Conference, 17 May, slide presentation 132.* *https://indico.pi.infn.it/contributionDisplay.py?contribId=132&sessionId=13&confId=225]*

The *Cruise-Ingley Birmingham University HFGW Detector* Photo by author during visit, 2003

Another of the early HFGW detectors was also developed 1990s on the other side of our planet in Australia, by the gravitational wave pioneer Professor David G. Blair [M. E. Tobar and D. G. Blair (1993),"Parametric transducers for resonant bar gravitational wave antenna, *J. Phys. D: Appl. Phys.* ***26****, 2276-2291.*D. G. Blair, et al. (1995), "High Sensitivity Gravitational-Wave Antenna with Parametric Transducer Readout," *Phys. Rev. Lett.* ***74****, No. 1*]. It is a Parametric Transducer device that is essentially gravitational-wave antenna and in many ways similar to the Weber Bar detector. It is expected to be sensitive to HFGWs having spacetime maximum fractional deformations or spacetime strain of $A \sim 1 \times 10^{-20}/\sqrt{\text{Hz}}$ meters per meter.

Professor David G. Blair, Director of the Australian International Gravitational Research Centre (AIGRC), 1993

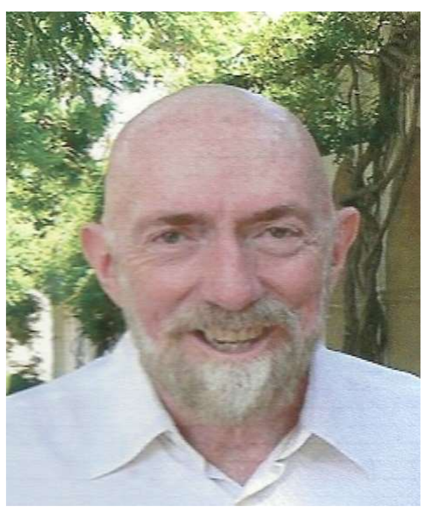


The Blair Parametric Transducer Gravitational Wave Detector Component photo by Blair, 1990s

Different from the LFGW research funding, all of this pre-2000 HFGW research was accomplished without significant funding by major foundations or agencies.

There was, however, no real acceptance of gravitational waves, or GWs, in the scientific community until some observations were made from the Arecibo Radio-Astronomy telescope in Puerto Rico in the 1970s of binary pulsar 1913+16. They were made by Joseph H. Taylor and his graduate student, Russell H. Hulse and led to the *indirect* verification of gravitational waves and their being awarded the 1993 Nobel Prize. Now GW research began to flourish

The Nobel Prize legitimized the existence of gravitational waves. This acceptance led Kip Thorne and others, especially Ronald W. P. Drever, both from Caltech, to promote the Laser Interferometer Gravitational Observatory or LIGO low-frequency gravitational-wave detector with the US National Science Foundation. LIGO was developed to detect the intense gravitational waves theoretically generated by the merger of a binary pair of black holes. [R. A. Hulse and J. H. Taylor and (1975)," Discovery of a pulsar in a binary system," *Astrophysical J* .195, L51. L. W. Esposito and E. R. Harrison (1975), "Properties of the Hulse-Taylor binary pulsar system," *Astrophys. J.* **196,** L1-L2. . J. H. Taylor and J. M. Weisberg (1982), "A new test of general relativity – gravitational radiation and the binary pulsar PSR 1913-16," *Astrophys. J.* **253,** 908-920. Alex Abramovici, William E. Althouse, Ronald W. P. Drever, Yekta Gursel, Seiji Kawamura, Frederick J. Raab, David Shoemaker, Lisa Sievers, Robert E. Spero, Kip S. Thorne, Rochus E. Vogt, Rainer Weiss, Stanley E. Whitcomb and Michael E. Zucker (1992), "LIGO: The Laser Interferometer Gravitational-Wave Observatory.," *Science* 256,pp. 325-333.]



Kip S. Thorne. Internationally known cosmologist and a Designer of LIGO, 1992.

W. P. Drever, Professor Emeritus, California Institute of Technology and a

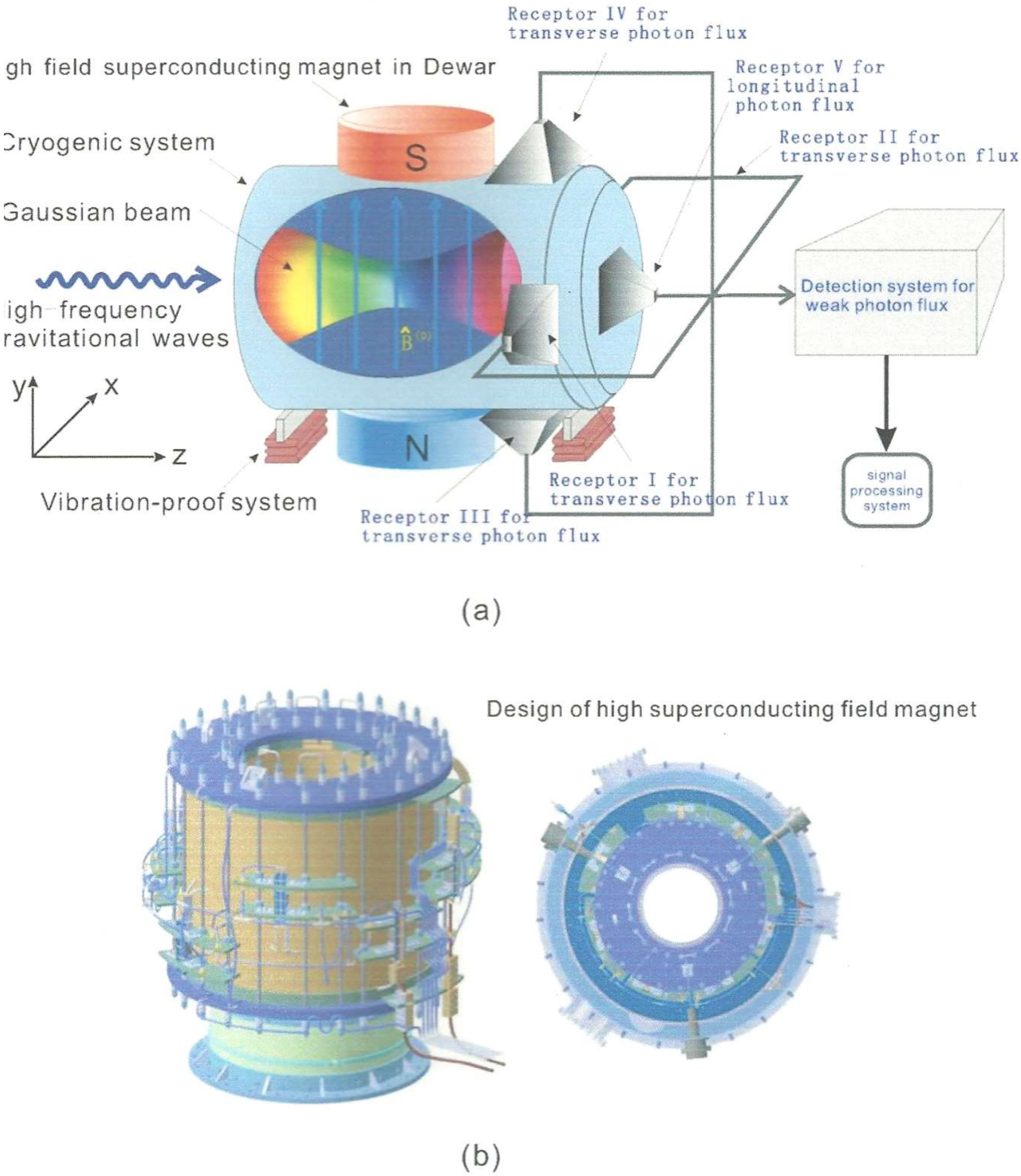
Designer of LIGO, 1993

Artist conception of the merger of two Black Holes

Giorgio Fontana in Italy had been studying another possible HFGW laboratory generator also similar to a Laser that he termed a "HTSC Gazer." His high-temperature superconductor or HTSC generator is based upon the previously mentioned Halpern and Laurent studies and "... the properties of cooper-pair pairing states …" [Giorgio Fontana (1998), "A possibility of emission of high frequency gravitational radiation from junctions between d-wave and s-wave superconductors," *Preprint, Faculty of Science, University of Trento*, 38050 Povo (TN), Italy, pp. 1-8. http://xxx.lanl.gov/html/cond-mat/9812070. Giorgio Fontana and Robert M. L. Baker, Jr. (2003), "The high-temperature superconductor (HTSC) gravitational laser (GASER)," paper HFGW-03-107, *Gravitational-Wave Conference,* The MITRE Corporation, May 6-9.]

Giorgio Fontana 1998

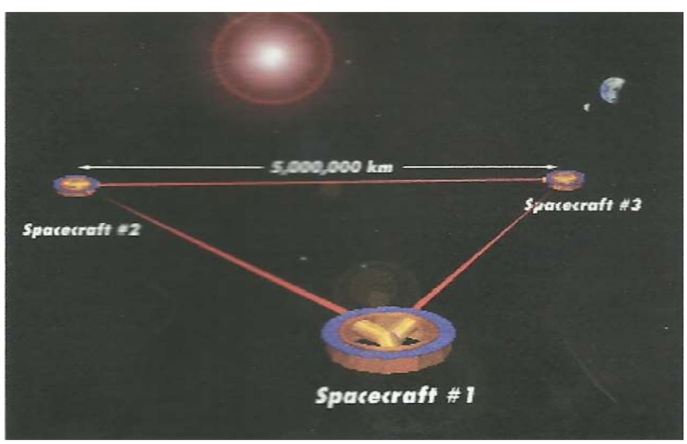
At this point in history let us pause and consider the state of Gravitational-Wave science at the turn of the Century, 2000. In the United States, as funded by the US National Science Foundation, the *California Institute of Technology* and other top institutions such as the *Massachusetts Institute of Technology* were actively pursuing the design and construction of the LFGW detector, LIGO. In England the first practical HFGW detector was under development by Professor Mike Cruise and his graduate student Richard Ingley. And in Australia Professor David G. Blair was actively involved in gravitational-wave research. I contacted the US National Security Agency [Hendge, G. (2000). Written communication from the United States National Security Agency (NSA) to Robert M L Baker, Jr., dated January 19]. In Russia top scientists had accomplished considerable HFGW research, especially concerning the "Gravitational-wave Hertz" experiment, the concept of the laboratory generation and detection of HFGWs. In Germany, Heinz Dehnen was analyzing a crystal-oscillator laboratory HFGW generator or transmitter. In Italy, Giorgio Fontana was analyzing a "HTSC Gazer," initially suggested by Halpern and Laurent, to generate HFGWs in the laboratory. Massimo Giovannini and others were continuing their research into the early universe generation of HFGWs. Fangyu Li had completed studies with Valentin Rudenko at the Sternberg Institute of *Moscow State University*. In China Dr. Li had accomplished research into the Li effect in which HFGWs in a Gaussian electromagnetic field and an intense magnetic field could allow for the detection of HFGWs. This detector, termed the *Li-Baker HFGW Detector,* was under initial development in China at *Chongqing University*.



Li-Baker HFGW Detector, 1990s -2000s

The *Astronomical Observatory of Japan* 100 MHz HFGW detector had been built and reported on later in an article in the *Phys. Rev. D* [Atsushi Nishizawa, Seiji Kawamura, Tomotada Akutsu, Koji Arai, Kazuhiro Yamamoto, Daisuke Tatsumi, Erina Nishida, Masa-aki Sakagami, Takeshi Chiba, Ryuichi Takahashi, and Naoshi Sugiyama (2008), "Laser-interferometric detectors for gravitational wave backgrounds at 100 MHz: Detector design and sensitivity," *Phys. Rev. D* 77, Issue 2, 022002. http://dx.doi.org/PhysRevD.77.022002] It consists of two synchronous interferometers with arm lengths of 75 cm. Its maximum amplitude sensitivity was about $10^{-16}/\sqrt{\text{Hz}}$ meters per meter.

- By the way, high-frequency gravitational waves cannot be detected by large-scale interferometer devices such as LIGO, Virgo or the proposed Laser Interferometer Space Antenna or LISA. "At higher frequencies (above a kilohertz) the quantum nature of the laser beam (made up of discrete photons, albeit a large number of them) limits the precision of the measurements. Increased laser power would reduce the problem of quantum noise, but ultimately, the LIGO (-like) interferometers are not suited to measuring gravitational waves that stretch or shrink the arms much more rapidly than the time a photon typically remains in the optical cavity (laser arm), which is roughly a millisecond for these (long) interferometers (or approximately a one-kilocycle frequency limit) …" [P. S. Shawhan (2004), "Gravitational Waves and the Effort to Detect them," *American Scientist* **92**, 4, pp. 350- 356]**.** LISA would be even less sensitivity to HFGWs, due to very much longer Laser arms.

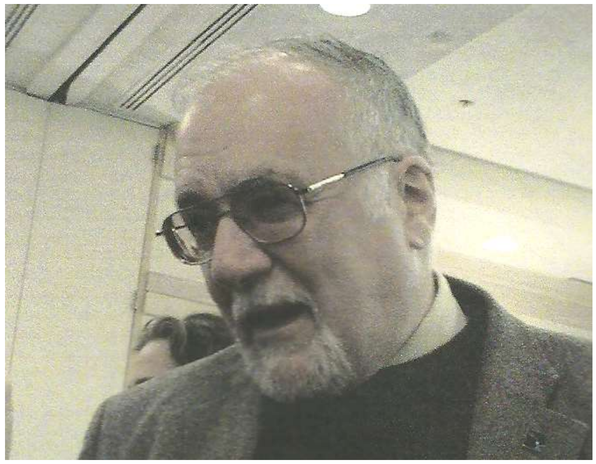


Laser Interferometer Space Antenna (LISA) Libration Point Locations in Solar System

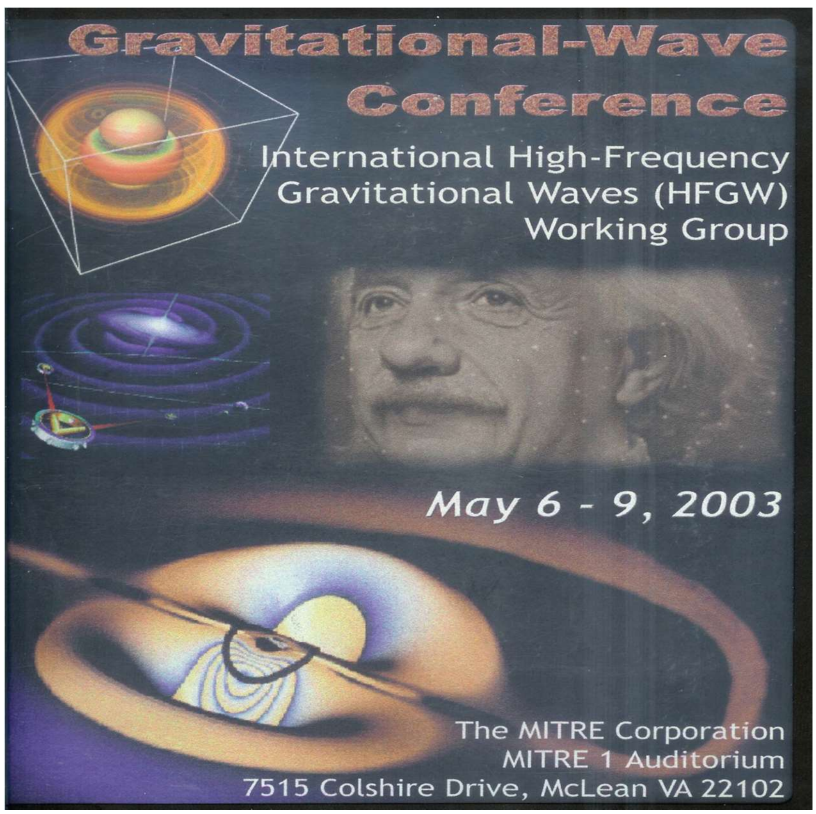
By 2000, research was picking up concerning detection of the LFGWs (funded by almost half a Billion dollars from the U S National Science Foundation), most probably produced by the merger of Black Holes. To a far lesser, to an almost negligible degree, research on the HFGWs, most probably produced by the early universe or Big Bang, was continuing especially in China. As a portent of things to come, the very first patent specifically concerning HFGWs was filed in 1999, United States Patent Number 6,160,336, "Peak Power Energy Storage Device and Gravitational Wave Generator," including its continuation in part, "Gravitational Wave Generator," United States Patent Number 6,417,5971 B1 and "Gravitational Wave Generator Utilizing Submicroscopic Energizable Elements," United States Patent Number 6784591 B2. (Another related patent was Peoples Republic of China Patent Number 01814223.0, "Gravitational Wave Detector," filed July 13, 2001.) Although HFGW research was encouraged by such important people such as Buzz Aldrin, at the turn of the Century there had been no actual detection of gravitational waves of any frequency to inspire the scientific community.

Buzz Aldrin, 1999

Although no significant funding was available for HFGW research, Paul Murad was able to organize the first HFGW Conference or Workshop at *The MITRE Corporation* in McLean, Virginia, USA, May 6th through the 9th, 2003.



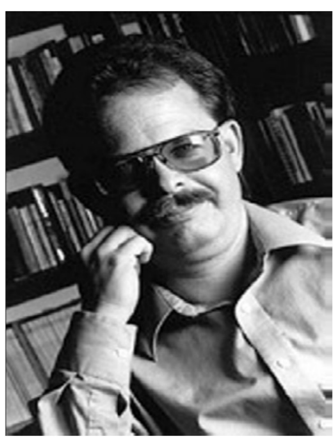
Paul Murad, 2003



The second HFGW International Workshop was organized by Eric Davis at the *Institute of Advanced Studies at Austin* (IASA), Texas, USA during September 17-20, 2007. Papers were presented by most of the attendees including Fangyu Li, Valentin Rudenko, Leonid Grishchuk, Gary Stephenson, Giorgio Fontana and Clive Woods.

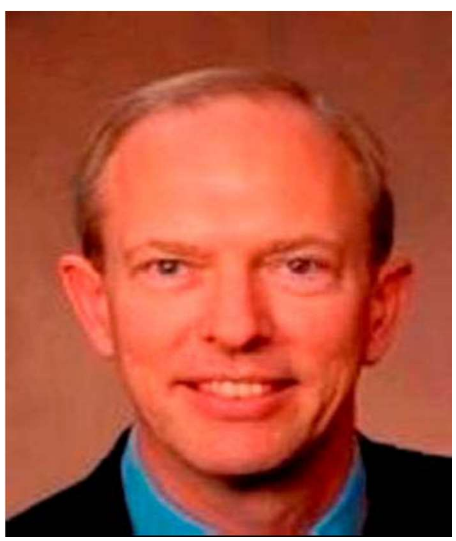
[Eric W. Davis (2003), "Laboratory generation of high-frequency gravitons via quantization of the coupled Maxwell-Einstein fields," paper HFGW-03-125, *Gravitational-Wave Conference,* The MITRE Corporation, May 6-9. Marc G. Millis and Eric W. Davis (2009), *Frontiers of Propulsion Science, Progress in Astronautics and Aeronautics Series*, 227, Published by AIAA, 739 pages, ISBN-10: 1-56347-956-7 and ISBN-13: 978-1-56347-956-4].

[Gary V. Stephenson (2003), "The application of High-Frequency Gravitational Waves (HFGW) to communications," paper HFGW-03-104, *Gravitational-Wave Conference,* The MITRE Corporation, May 6-9. Gary V. Stephenson (2009), "Lessons for Energy Resonance HFGW Detector Designs Learned from Mass Resonance and Interferometric LFGW Detection Schemes," after Peer Review, accepted for Publication in the *Proceedings of the Space, Propulsion and Energy Gary V. Stephenson (2009), "The Standard Quantum Limit for the Li-Baker HFGW Detector*, *" after Peer Review, accepted for Publication in the Proceedings of the Space, Propulsion and Energy Sciences International Forum (SPESIF)*, *24-27 February, Edited by Glen Robertson. (Paper 023), American Institute of Physics Conference Proceedings, Melville, NY* ***1103,*** *542-547***.** Edited by Glen Robertson. (Paper 016), American Institute of Physics Conference Proceedings, Melville, NY **1103**, pp. 532-541**.** http://www.gravwave.com/docs/Detector%20Development.pdf]



Eric Davis, 2007

Left to Right: Leonid Grishchuk, Valentin Rudenko, Hal Puthoff, Giorgio Fontana, Gary Stephenson, Bob Baker and Eric Davis. Fangyu Li, et al. not shown-2nd International HFGW Workshop, *Institute for Advanced Studies at Austin*, Texas, September 17-20, 2007.



Gary Stephenson, 2007

After the 2nd HFGW Workshop on June 17, 2008, a research group called the JASONs, composed of very influential and respected university scientists, were given a briefing on the generation, detection and applications of high-frequency gravitational waves (HFGWs). The JASON Report (JSR-08-506) on that briefing was published in October 2008. The Report was widely distributed to the US scientific community and various press organizations reported it. The JASON Report stated that "Our main conclusions are that the proposed applications of the science of HFGW are fundamentally wrong; that there can be no security threat; and that independent scientific and technical vetting of such hypothetical threats is generally necessary. We conclude that previous analysis of the Li-Baker detector concept is incorrect by many orders of magnitude …" The author of the JASON Report's basic premise for generating HFGWs was: "*A basic mechanism* for generating a HFGW is the direct conversion of an electromagnetic wave into a gravitational one of the same frequency by a strong static magnetic field. This ***Gertsenshtein process*** is idealized in Figure 3." In addition the Report states: "Proposed HFGW detectors *have generally been based upon versions of the inverse* ***Gertsenshtein process***." (Italics added by the author for emphasis**.)**

These statements are both **incorrect**. As already mentioned, the ***Gertsenshtein process*** or effect was published in 1962: M. E. Gertsenshtein, "Wave resonance of light and gravitational waves," *Soviet Physics JETP*, **14**, Number 1, pp. 84-85. The effect is **extremely weak and is not utilized in most of the modern HFGW generation, detection or applications.**

In spite of the flawed JASON Report, others continued with HFGW research such as Gloria Garcia-Cuadrado in Spain and Professor R. Clive Woods now at the University of South Alabama and Christine S. Black who studied the HFGW radiation pattern

[Gloria Garcia-Cuadrado (2009), "Towards a New Era in Gravitational Wave Detection: High Frequency Gravitational Wave Research," after peer review, accepted for publication in the *Proceedings of the Space, Propulsion and Energy Sciences International Forum (SPESIF)***,** 24-27 February, Edited by Glen Robertson. (Paper 038), American Institute of Physics Conference

Proceedings, Melville, NY **1103** pp. 553-563**.** . Please visit Internet site: http://www.gravwave.com/docs/Toward%20a%20New%20Era%20in%20Gravitational%20Wave%20Research.pdf. Christian Corda, Giorgio Fontana and Gloria Garcia Cuadrado (2009), "Gravitational Waves in the Hyperspace: a Critical Review," After Peer Review, Accepted for Publication in the *Proceedings of the Space, Propulsion and Energy Sciences International Forum (SPESIF2009)***,** 24-27 February, Edited by Glen Robertson. (Paper 027), American Institute of Physics Conference Proceedings, Melville, NY **1103.]**

[R. C. Woods (2002), “Comments on ‘A gravitational shielding based upon ZnS:Ag phosphor’ and ‘The gravitational mass at the superconducting state,” *Los Alamos National Laboratory Archive* physics/0204031. R. Clive Woods (2005), “Manipulation of gravitational waves for communications applications using superconductors,” *Physics C* 433, pp. 101–107. Clive Woods and Robert M. L. Baker, Jr. (2005), “Gravitational Wave Generation and Detection Using Acoustic Resonators and Coupled Resonance Chambers,” in the proceedings of *Space Technology and Applications International Forum (STAIF-2005)*, edited by M.S. El-Genk, American Institute of Physics Conference Proceedings, Melville, NY **746**, 1298. R. Clive Woods (2007), “Modified Design of Novel Variable-Focus Lens for VHFGW,” Discussion-Focus Paper 3.1, *2nd HFGW International Workshop,* Institute for Advanced Studies at Austin (IASA),Texas, September 19-21; http://www.gravwave.com/docs/AIP;%20HFGW%20Optics.pdf. R. Clive Woods, Robert M L Baker, Jr., Fangyu Li, Gary V. Stephenson, Eric W. Davis and Andrew W. Beckwith (2011), “A new theoretical technique for the measurement of high-frequency relic gravitational waves,” *Journal of Mod. Phys.* **2**, No. 6, pp. 498-518. The Abstract is available at: . http://vixra.org/abs/1010.0062 and the manuscript is available at: http://www.gravwave.com/docs/J.%20of%20Mod.%20Phys%202011.pdf. http://dx.doi.org/10.4236/jmp.2011.26060 . R. C. Woods and R. M L Baker, Jr. (2009), “Generalized Generators of Very-High-Frequency Gravitational Waves Including Ring/Cylinder Devices,” After Peer Review, Accepted for Publication in the *Proceedings of the Space, Propulsion and Energy Sciences International Forum (SPESIF)***,** 24-27 February, Edited by Glen Robertson. (Paper 001), American Institute of Physics Conference Proceedings, Melville, NY **1103.** pp. 515-523.

R. M L Baker, Jr. and C. S. Black (2009), "Radiation Pattern for a Multiple-Element HFGW Generator," After Peer Review, Accepted for Publication in the *Proceedings of the Space, Propulsion and Energy Sciences International Forum (SPESIF)*, 24-27 February, Edited by Glen Robertson. 3rd High-Frequency Gravitational Wave Workshop (Paper 035), American Institute of Physics Conference Proceedings, Melville, NY **1103.** pp. 582-590].

Gloria Garcia-Cuadrado, 2009

HFGW Research, *Celestia Aerospace*, Spain

Roger Clive Woods, M.A., D.Phil., D.Sc. (Oxford), HFGW Detection and possible HTSC Optics

Christine S. Black, 2009

Largely unaffected by the flawed JASON Report, research continued on relic HFGWs in Europe. The theme of the relic or Big-Bang generated HFGWs in the microwave band ($\sim 10^8$–10^{11} Hz) was predicted by the quintessential inflationary models (QIM) of the early universe by Massimo Giovannini.

Massimo Giovannini, CERN Switzerland, 2000s

[M. Giovannini, Phys. Rev. D 60, 123 511 (1999) , Class. Quantum Grav. 16, 2905 (1999). A. Riazuelo, J.P. Uzan, Phys. Rev. D 62, 083 506 (2000)], the pre-big bang scenario (PBBS) and some string cosmology scenarios [J.E. Lidsey et al., Phys. Rep. 337, 343 (2000). E.J. Copeland et al., gr-qc/9803070. M. Gasperini, G. Veneziano, Phys. Rep. 373, 1 (2003). G. Veneziano, Sci. Am. 290, 30 (2004)]. These publications suggested high-frequency gravitational wave random signals, and that the root-mean-square (rms) values of their dimensionless strain amplitudes of spacetime might reach up to ~ 10^{-33}–10^{-30}/ √ Hz. Because of their weakness and very high-frequency properties, such so-called "relic" HFGWs are quite different from low-frequency GWs for which the laser GW detectors, such as LIGO, were expected to detect. Although the relic GWs have not yet been detected, according to Massimo Giovannini, we can be reasonably sure that the Earth is bathed in a sea of these relic HFGWs. Since 1978 such relic and primordial background HFGWs have been of ever increasing scientific interest as many researchers have shown [L.P. Grishchuk, gr-gc/0002035. L.P. Grishchuk, gr-gc/0305051. L.P. Grishchuk, gr-gc/0504018. N.N. Gorkavyi, Paper HFGW-03-115, In: High-Frequency Gravitational Waves Conference, ed. by P. Murad, R.M.L. Baker Jr. (MITRE Corporation, Mclean, VA, USA, 2003). G. S .Bisnovatyi-Kogan and V. N. Rudenko (2004), "Very high frequencygravitational wave background in the universe," *Class. QuantumGrav.* **21**, 3344-3359. Y. Zhang, Y. Yuan, W. Zhao, Y.T. Chen, Class. Quantum Grav., 1383 (2005). L. Randall, R. Sundrum, Phys. Rev. Lett. 83, 3370 (1999). L. Randall, R. Sundrum, Phys. Rev. Lett. 83, 4690 (1999), J. Sokol, Science 355, p.120 (2017)]. In fact, the possible early universe conception of giant black holes by the direct collapse of primordial gas clouds, suggested recently by Sokol could be studied by the analyses of relic HFGWs.

Based on high-dimensional (termed "bulk") spacetime theories, it has also theoretically been shown by Giovannini and others, that all familiar matter fields are constrained to "live" on our three-dimensional, *space*-membrane or four-dimensional *spacetime* membrane (for short "brane") world, while gravity is free to propagate in the extra dimensions, and the HFGWs (i.e., high-energy gravitons) would be more capable of carrying energy from our brane world than lower-frequency LFGWs. It is noted that propagation of the HFGWs may be a unique and effective way for exchanging energy and information between two adjacent parallel brane worlds or between "parallel universes". Moreover, if the pre-Big Bang scenario is correct, then the relic HFGWs would be an almost unique window from which one can look back into the early universe before the Big Bang. Although these theories and scenarios may be controversial and whether or not they include a fatal flaw remains to be determined. The successful detection of the high-frequency relic gravitational waves (HFRGWs) will certainly shed light on many of these theories.

李芳昱 Fangyu Li

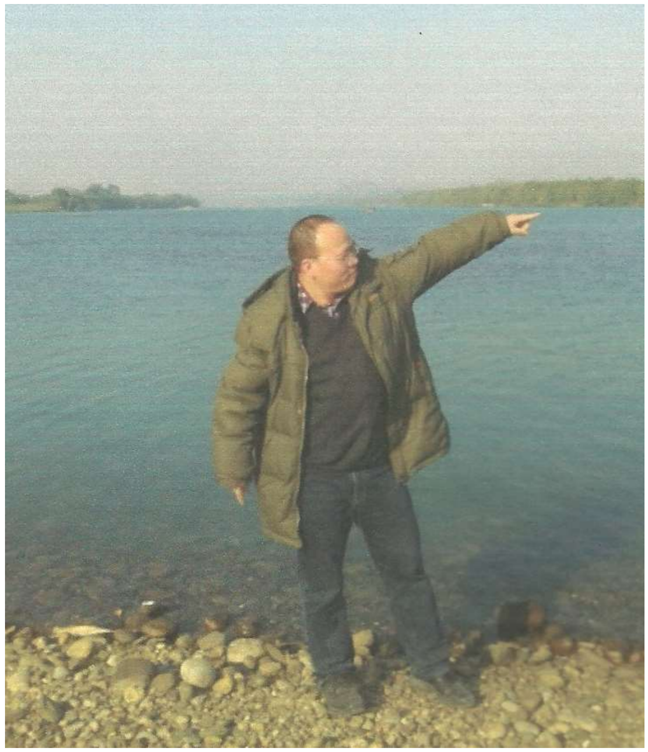
Fangyu Li is a professor in department of Physics of *Chongqing University*, China. Research projects of Prof. Fangyu Li includes General Relativity, gravitational wave and radiation theory, classical and quantum electrodynamics in curved spacetime, gravitational perturbation effects in topological phonon space, interaction between high-frequency gravitational waves (HFGWs) with electromagnetic fields, and related experimental issues. Currently, he is one of Principal Investigators of the aforementioned *Li-Baker HFGW Detector* construction project in China. He has published works in international journals such as Physical Review D, Nuclear Physics B, European Physical Journal C, Classical and Quantum Gravity, General Relativity and Gravitation, International Journal of Modern Physics B, Journal of Modern Physics, Science in China, etc. Mostly unaffected by the flawed JASON Report, Dr. Li and his colleagues in China, such as

Professors Zhenyun Fang Director of *Institute of Theoretical Physics* of *Chongqing University*, high frequency gravitational-wave research_and L. F. Wei, of the Quantum Optoelectronics Laboratory of the *Southwest Jiaotong University*, Chengdu, China (and a sponsor of this 3rd High Frequency Gravitational Wave Workshop, on 7-9th, April 2017 in Chengdu) continued development of the *Li-Baker HFGW Detector*, i.e., a synchro-resonance system, with sensitivity predicted to 10^{-23} meters per meter stain of spacetime and better, for HFGWs in GHz band. In the *Li-Baker HFGW Detector* distinguishing and observing of HFGWs from the multi-dimensional brane world could be accomplished. Although challenging, investigation of the early universe, by means of relic HFGW detected by the *Li-Baker HFGW Detector* should be possible.

Zhenyun Fang, Director of Institute of Theoretical Physics of Chongqing University, high frequency gravitational-wave research,

Zhenyun Fang, is the Director of *Institute of Theoretical Physics* of *Chongqing University*, high frequency gravitational-wave research. Prof. Fang studies in fields including quantum theory of fields, gauge fields theory, high-energy Physics, particle Physics, quantum gravity, interaction between high-frequency gravitational waves and electromagnetic fields, and related experimental issues. He has published work papers in international journals such as Physical Review D, Nuclear

Physics B, European Physical Journal C, Physics Letters B, etc. He currently focuses on corresponding quantum effects of high-frequency gravitational waves detection.



L. F. Wei, Quantum Optoelectronics Laboratory, Southwest Jiaotong University, Chengdu, China and a sponsor of the 3rd HFGW Workshop , 2017

Beginning before 2008 there were several HFGW students and faculty active at *Chongqing University.*

2008 *Chongqing University* High-Frequency Gravitational Wave Faculty and Staff

.[Li, F. Y., Tang M. and Zhao P. (1992), "Interaction Between Narrow Wave Beam-Type High Frequency Gravitational Radiation and Electromagnetic Fields," *Acta Physica Sinic*a **41,** pp. 1919-1928; Fangyu Li and Meng-Xi Tang (1997), "Positive Definite Problem of Energy Density and Radiative Energy Flux for Pulse Cylindrical Gravitational wave," *ACTA Physica Sinca* **6**, Number 5, 321-333; Fang-Yu Li, Meng-Xi Tang, Jun Luo, and Yi-Chuan Li (2000), "Electrodynamical response of a high energy photon flux to a gravitational wave," *Physical Review D,* Volume 62, July 21, pp. 044018-1 to 044018 -9; Fang-Yu Li, Meng-Xi Tang, and Dong-Ping Shi (2003), "Electromagnetic response for High-Frequency Gravitational Waves in the GHz to THz band," paper HFGW-03-108, *Gravitational-Wave Conference,* The MITRE Corporation, May 6-9; Fang-Yu Li and Nan Yang (2004), "Resonant interaction between a weak gravitational wave and a microwave beam in the double polarized states through a static magnetic field," *China Physics Letters* **21**, No. 11, p. 2113; et al, Fangyu Li, Hao Wen, Zhenyun Fang, European Physical Journal C, 2014,74:2998; Fangyu Li, R.M.L. Baker, European Physical Journal C, 2008, 56: 407. F. Y. Li, R. M. L. Baker, Jr., Z. Y. Fang, G. V. Stephenson, Z. Y. Chen. Physical Review D, (2003), 67: 104008. F. Y. Li, M. X. Tang, D. P. Shi. Physical Review D, (2009), 80(6): 064013; Fangyu Li, N. Yang, Z.Y. Fang, R.M.L. Baker, G. Stephenson, Hao Wen. International Journal of Modern Physics B, 21(2007):3274; Fangyu Li, Hao Wen, Zhenyun Fang, Lianfu Wei, Yiwen Wang, MiaoZhang, Quasi-B-mode generated by high-frequency gravitational waves and corresponding perturbative photon fluxes. Nuclear Physics B, 911(2016): 500–516; Hao Wen, Fangyu Li*, Zhenyun Fang, Electromagnetic response produced by interaction of high-frequency gravitational waves from braneworld with galactic-extragalactic magnetic fields, Physical Review D, (2014), 89: 104025.] I will rely primarily on Dr. Li's presentations for the remainder of this section. Li considers HFGWs having frequencies above one MHz and lists the following effects that may generate HFGWs naturally:

From Professor Fangyu Li:

For GW frequencies greater than 1 MHz:

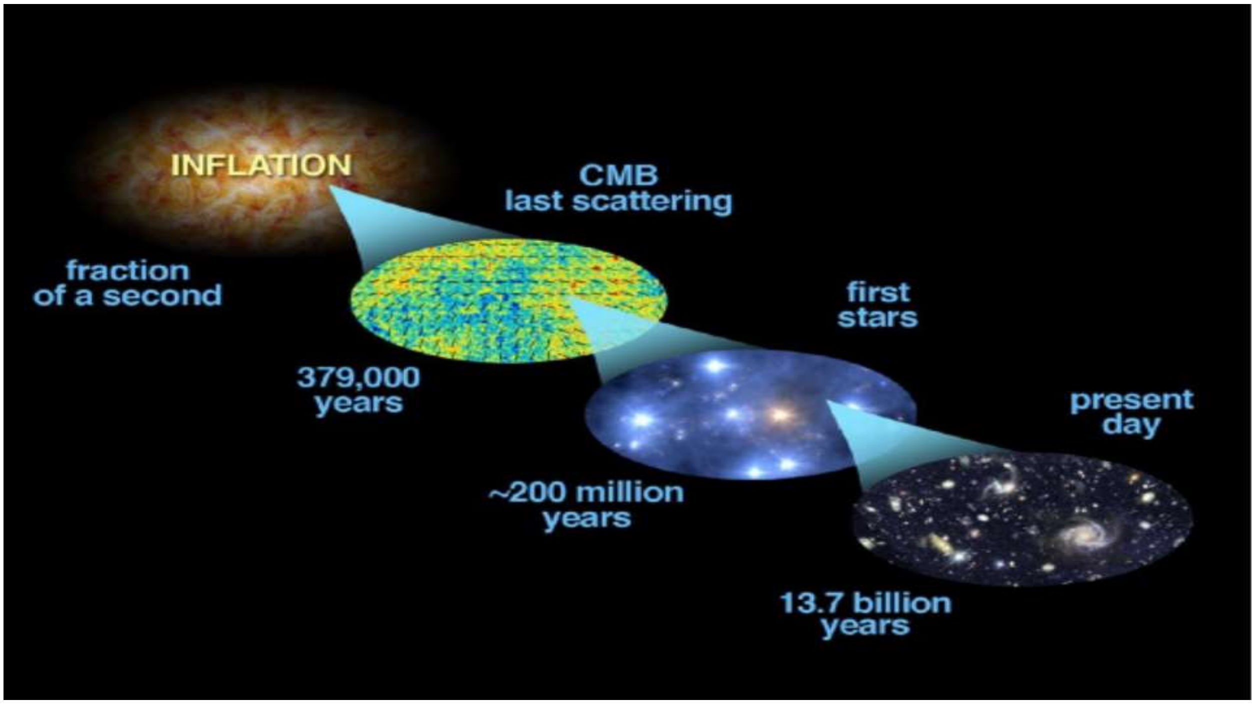
Cosmological signals from Planck era

K-K gravitons from brane oscillations in higher dimensions

Interaction of astrophysical plasma with EM waves

Gamma bursts of magnetars

In order to understand the importance of HFGWs to cosmology it is important to understand the development of our Universe. A graphical summary of this development and of the effects that have been just discussed should be carefully studied. It is important to realize how quickly the early Universe developed, in about 10^{-42} seconds for the early "construction" phases and, as previously mentioned, that HFGWs emerged before regular electromagnetic waves, such as light, was radiated.



The development of our universe (from PowerPoint presentation of Fangyu Li, in 2016 with permission). (Fraction of a second: Really small -- 0.000,000,000,000,000,000,000,000,000,000,000,000,000,000,1 seconds)

Other cosmological reserchers invoving the value of HFGW s to the study of thec early universe besides Massimo Giovannini and his associates, include Professor Andrew Beckwith, internationally well- known cosmologist*, Chongqing University* and Dr. Christian Corda; research on the "magnetic" component of gravitational waves and on the stochastic background of relic gravitational waves.[Andrew W. Beckwith, Stefan Antusch, Francesco Cefalà, and Stefano Orani (2017)," Gravitational Waves from Oscillons after Inflation,"*Phys. Rev. Lett*. **118**, 011303 – Published 6 January 2017. Andrew W. Beckwith (2016), "Geganderexperiment for Degree of Flatness, or Lack of, in Early Universe Conditions." *Journal of High Energy Physics, Gravitation and Cosmology*, **2**, 57-65. doi: 10.4236/jhepgc.2016.21006. Andrew W. Beckwith (2010), "HFGW and the search for relic gravitons / entropy increase from the early universe," *Proceedings of the Space, Propulsion and Energy Sciences International Forum (SPESIF 2010)***,** February 23-26, Johns Hopkins University Applied Physics Laboratory, Laurel, MD, U.S.A., Edited by Glen Robertson., American Institute of Physics Conference Proceedings, Melville**.** NY, USA **1208.** Andrew W. Beckwith (2009), "Relic High Frequency Gravitational Waves, Neutrino Physics, and

Icecube," After Peer Review, Accepted for Publication in the *Proceedings of the Space, Propulsion and Energy Sciences International Forum (SPESIF*), 24-27 February, Edited by Glen Robertson. (Paper 003), American Institute of Physics Conference Proceedings, Melville, NY 1103, pp. 564-570. A.W. Beckwith (2007), "Several routes for determining entropy generation in the early universe, links to CMBR spectra, and relic neutrino production," Presented at 6th International Conference on Gravitation and Cosmology (ICGC-2007), Ganeshkhind, Pune, India, 17-21 Dec 2007 and 43rd Rencontres de Moriond: Cosmology, La Thuile, Italy, 15-22 Mar 2008 and 23rd International Conference on Neutrino Physics and Astrophysics (Neutrino 2008), Christchurch, New Zealand, 26-31 May 2008. e-Print: arXiv:0712.0029. Andrew W. Beckwith (2008), "Implications for the Cosmological Landscape: Can Thermal Inputs from a Prior Universe Account for Relic Graviton Production?" in the proceedings of *Space Technology and Applications International Forum (STAIF-2008)*, edited by M.S. El-Genk, American Institute of Physics Conference Proceedings, Melville, NY **969**, p.1091.]

Andrew Beckwith

Christian Corda

[Christian Corda (2012), “Primordial Gravity’s Breath,” *Electronic Journal of Theoretical Physics* **9**, 26, pp.1-10. http://arxiv.org/abs/1110.1772 Christian Corda (2010),” Information on the inflation field from the spectrum of relic gravitational waves,” *General Relativity and Gravitation* **42,**5, pp 1323-1333Christian Corda (2007), “Tuning the Stochastic Background of Gravitational Waves Using the WMAP Data,” *Mod.Phys. Lett. A,* ***22,*** *No. 16 , pp. 11671173. Christan Corda, Giorgio Fontana and Gloria Garcia Cuadrado (2009), “*Gravitational Waves in Hyperspace*,” Mod. Phys. Ltrs. B* **24**, 8, pp. 575-582. Christian Corda (2007), “Tuning the Stochastic Background of Gravitational Waves Using the WMAP Data,” *Mod .Phys. Lett. A,* **22,** No. 16 , pp. 1167-1173.]

On the low-frequency end of the gravitational wave spectrum, LFGWs, an interesting source would be the merger of binary black holes. This was the motivation for the development of the Laser Interferometer Gravitational Observatory or LIGO. In 1994, twenty years after Rainer Weiss proposed the concept, with a budget of $395,000,000, LIGO stood as the largest overall funded U S National Science Foundation project in history. The project broke ground at two locations: in Hanford, Washington in late 1994 and in Livingston, Louisiana in 1995. As construction neared completion in 1997, two organizational institutions were formed, the LIGO Laboratory and the LIGO Scientific Collaboration (LSC). The LIGO laboratory consists of the facilities supported by the U S National Science Foundation under LIGO Operation and Advanced R&D; this includes administration of the LIGO detector and test facilities. The LIGO Scientific Collaboration, composed of over one thousand scientists and engineers, is a forum for organizing technical and scientific research in LIGO. It is a separate organization from the LIGO Laboratory with its own oversight. Initial LIGO operations between 2002 and 2010 did not detect any gravitational waves. In 2004 the funding and groundwork were laid for the next phase of LIGO development (called "Enhanced LIGO"). At this point the total funding for the LIGO Project reached in excess of one-half a Billion U S dollars. This was followed by a multi-year shut-down while the detectors were replaced by much improved "Advanced LIGO" versions. By February 2015, after over 21 years of R&D, the detectors were brought into engineering mode in both locations.

Four-kilometer long LIGO vacuum tunnel or Interferometer "Leg" by NASA.

By mid-September 2015 "the world's largest gravitational-wave facility" completed a 5-year U S $200-million overhaul at a total cost of $620 million. On September 18, 2015, Advanced LIGO began its first formal science observations at about four times the sensitivity of the initial LIGO interferometers. Its sensitivity will be further enhanced until it reaches design sensitivity around 2021.

On February 11, 2016, the LIGO Scientific Collaboration and Virgo Collaboration (a European version of LIGO) published a paper about the detection of gravitational waves by LIGO, from a signal detected at 09.51 Universal Time on 14 September 2015 of the merger of two ~29 and ~36 solar mass black holes merging about 1.3 billion light-years from Earth. [B. P. Abbott, et al. (2016), “Observation of Gravitational Waves from a Binary Black Hole Merger*,” Phys. Review Letters* 116, 061102-1 to -16. February 11. http://dx.doi.org10.1103/PhysRevLett.116061102.]

I believe that those interested in the research and development of High-Frequency Gravitational Waves should be guided by the LIGO approach for Low-Frequency Gravitational Waves (LFGWs). $625,000,000 and 21 years may not be necessary for HFGW Research and Development, but it is an interesting goal.

Postscript:

For the more technical reader, a good background for High-Frequency Gravitational Wave study can be found in my Book: “Gravitational Waves: the World of Tomorrow, a Primer, with Exercises.” December 2016, Infinity Press.

www.drrobertbaker.com

(Concerned about the relatively negligible funding of HFGW relative to LFGW funding?: “crowd wisdom”, “rolling snowball” and “Let’s all get on the Band Wagon” effects may be part of the answer.)

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"Now, having actually detected gravitational waves, another new world of tomorrow has arrived: The Gravitational Wave Era! We are now on edge of learning more about the merger of black holes from low-frequency gravitational waves detected recently by LIGO. We can learn even more at the higher end of the gravitational–wave frequency spectrum, possibly about higher-order dimensions, multiple universes, how the universe started … the Big Bang!... I recommend your reading this book. I believe what the world needs are not many more highly trained scientists and engineers, but a greater knowledge of those of you without advanced scientific university background, business people and others with only high school training in science and mathematics. All of us should achieve some fundamental understanding of the basics of science and engineering, now that understanding should include gravitational waves. That is the purpose of this very instructive book and I strongly urge you to read it."

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Palm Desert, California, USA

“Not familiar with the science of gravitational waves and yet we live in a world that is influenced by gravity, I thought to read this new book by Dr. Robert Baker. What a fascinating and well written read. Gravitational waves influence on time travel and communicating through the core of earth sans satellites was thoughtfully presented and fascinating to read. This book, unto its own, is a TIME TRAVELER for the curious inventor seeking create for the world of tomorrow.”

Robin Fell

Inventor

Santa Barbara, California, USA

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