After Peer Review, Accepted for Publication in the ***Proceedings of the Space, Propulsion and Energy Sciences International Forum (SPESIF),*** 24-27 February, 2009, Edited by Glen Robertson.

The Peoples Republic of China High-Frequency Gravitational Wave Research Program

Robert M L Baker, Jr.

GravWave® LLC and Transportation Sciences Corporation, 8123 Tuscany Avenue, Playa del Rey, CA 90293, USA
Phone: 310-823-4143, Fax: 310-821-1694, DrRobertBaker@GravWave.com

Abstract. For the past decade the Peoples Republic of China has been increasingly active in the pursuit of High-Frequency Gravitational Wave (HFGW) research. Much of their progress has been during 2008. An epochal achievement was the publication of the theoretical analysis of the Li-Baker HFGW detector in the *European Physical Journal C* (Fangyu L, Robert M L Baker, Jr., Zhenyun Fang, Gary V. Stephenson and Zhenya Chen (2008), "Perturbative Photon Fluxes Generated by High-Frequency Gravitational Waves and Their Physical Effects"). Many Chinese scientists and graduate students have participated in these HFGW studies and their contributions are briefly discussed. Some of the key scientists and their institutions are as follows: first from *Chongqing University*: Zhenyun Fang, Director of the Institute of Theoretical Physics, Xing gang Wu, The Institute of Theoretical Physics, Nan Yang, The Institute of Gravitational Physics; Jun Luo, *Huazhong University of Science and Technology* (HUST), Wuhan, China, the Head of Gravitational Laboratory, Yang Zhang, *University of Science and Technology of China,* Associate Dean of the College of Sciences, Biao Li, *Institute of Electronic Engineering of China* Academy of Engineering Physics (CAEP), Chief of Microwave Antenna Division, Chuan-Ming Zhou, *Technology Committee of Institute of Electronic Engineering of the CAEP*, Jie Zhou, *Institute of Electronic Engineering of the CAEP*, Chief of the Signal Processing Division; Weijia Wen, Department of Physics, *The Hong Kong University of Science and Technology*. This Chinese HFGW team includes two parts: (1) Theoretical study and (2) Experimental investigation. These two parts have closed relations, and many cross projects, including cooperation between the American GravWave and Chinese HFGW teams. Referring to financial support, *The Institute of Electronic Engineering (i.e., Microwave Laboratory) has already* (June 2008) provided support more than three million Yuan for the HFGW detection project and this activity is discussed.

Keywords: China, Li-Baker Detector, High-Frequency Gravitational Waves, HFGW, Chinese Science& Technology.
PACS: 95.55.Ym, 04.80.Nn, 98.80.Qc, 01.30.Rr.

INTRODUCTION

The Peoples Republic of China's High-Frequency Gravitational Wave or HFGW research program was initiated by Professor Fangyu Li at *Chongqing University*, China in 1990. His first paper on the subject was published in *ACTA Physsica Sisica* in 1992 entitled "Interaction between Narrow Wave Beam-type High Frequency Gravitational Radiation and Electromagnetic Fields." In essence Professor Li recognized the value of the inverse of the Gertsenshtein effect, first published in 1962, to detect HFGWs. In this case gravitational waves in a strong static magnetic field interact with a beam of electromagnetic waves, having the same frequency as the HFGWs (synchro-resonance), to generate photons that result from the passage of the HFGWs. (The usual Gertsenshtein effect involves the generation of gravitational waves by the passage of electromagnetic waves through a static magnetic field.) Different approaches to HFGW detection had also interested A. Michael Cruise of *Birmingham University*, England, who in 2000 published "An electromagnetic detector for high-frequency gravitational waves," in *Class. Quantum Gravity*, Philippe Bernard, Gianluca Gemme, R. Parodi, and E. Picasso of *INFN*, Genoa, Italy who in 2001 published "A detector of small harmonic displacements based on two coupled microwave cavities," in the *Review of Scientific Instruments* and the development of a 100 MHz detector by the *National University of Japan* . Thus among the burgeoning scientific interest and activity in detecting and studying

HFGWs, Fangyu Li in China was first to establish a program of HFGW research and develop the most sensitive HFGW detectors. He formed a "Gravitational Research Group" at *Chongqing University* in the 1990s whose major research direction was HFGWs, especially their detection and possible generation in the laboratory.

IMPORTANCE OF HFGWs

The Chinese consider that their research into HFGWs is extremely important. They believe that experimental tests can be accomplished in the detection of both relic HFGWs (from the Big Bang) and those generated in the laboratory addition They believe that the development and validation of the detector will lead to practical applications especially in communications and remote initiation of nuclear events Along with Fangyu Li, Professors Zhenyun Fang and Dongping Shi lead a group of faculty and graduate students in HFGW research at *Chongqing University*. Meng-Xi Tang, Yi-Chuan Li, Jin Li, Nan Yang, and Zhenya Chen are also members of the HFGW team at *Chongqing University*. While most of the other gravitational-wave researchers around the world are interested only in low-frequency gravitational waves (LFGWs), for example as generated by the in-spiral death of orbiting Black holes and possibly to be detected by LIGO, GEO600, Virgo, TAMA et al., the Chinese are concentrating on HFGWs. Besides the research at *Chongqing University*, other Chinese institutions are involved in HFGW research-related activities. Ruxin Li, Vice Director of the *Shanghai Institute of Optics and Fine Mechanics* (SIOM), has conducted and published research on the generation of HFGWs utilizing ultra high intensity lasers. Jun Luo accomplished HFGW research with Fangyu Li and is the Head of the Gravitational Laboratory of *Huazhong University of Science and Technology*. Dr Zhou is involved in the development of the microwave Gaussian-wave generation and microwave receiver devices for HFGW detection that will be built at the *Chengdu Microwave Laboratory* (CML). Weijia Wen of the *Hong Kong University of Science and Technology* will be fabricating the fractal membranes that are at the heart of the Chinese HFGW detection apparatus. These membranes selectively reflect microwaves and are extremely sensitive to their frequency and polarization angle. This not to say that there is not interest and research connected with Low-Frequency Gravitational Waves or LFGWs by the Chinese, only that the Chinese are almost unique in their concentrated study of HFGWs.

HFGW RESEARCH WORLDWIDE

Although less concentrated on HFGW research than the Chinese, the Italians have research activity especially in relic HFGWs. Maurizio Gasperini, M. Giovannini, and G. Veneziano since 1995 have accomplished significant research in the theoretical generation of relic gravitational waves from string cosmology. Giorgio Fontana at *University of Trento* has studied the production and influence of HFGWs involved in nuclear events such as inducing nuclear fusion and mass disruption remotely. Philippe Bernard, Gianluca Gemme, R. Parodi, E. Picasso and Andrea Chincarini proposed a microwave based high-frequency gravitational wave detector at *INFN* Genoa. In Russia G. S. Bisnovatyi-Kogan and Valentin N. Rudenko recently published research concerning the very high frequency gravitational wave background in the universe. As noted earlier, A. Michael Cruise of *Birmingham University a*nd his student Richard Ingley have fabricated a HFGW detector, which like the *INFN Genoa* detector, has insufficient sensitivity to detect most HFGWs of interest. In Japan Seiji Kawamura and the *National Astronomical Observatory of Japan* have developed a 100 MHz interferometric HFGW detector,

After the indirect proof of the existence of gravitational waves by Hulse and Taylor and especially after their winning the 1993 Nobel Prize for it, there was much interest in gravitational-wave research. The research, however, was primarily focused on LFGWs and, with the development of LIGO and other such LFGW detectors, various gravitational-wave research groups became associated with most US university departments of Physics or Astronomy as they did with other such institutions internationally. Except for the few examples already cited little basic research activities have been focused on HFGW research. The Chinese and to a lesser degree the Italians and English are an exception. And in the case of the Chinese there is not only an interest in basic HFGW research but also in applied HFGW research. There exist few if any applied science or practical applications of LFGWs so the Chinese have determined to give special attention to the new technology advances associated with the development of HFGW applications. The very speculative, but potentially most important practical HFGW applications include communications, ultra accurate global positioning, surveillance (especially of underground and underwater sites), induced nuclear fusion and mass disruptor beams, remote propulsion, etc.

CURRENT ACTIVITY OF THE CHINESE HFGW RESEARCH PROGRAM

At the present time (2008) there exists a large network of Chinese scientists and engineers working on HFGW and led by Prof. Fangyu Li at *Chongqing University*. This network includes the *Shanghai Institute of Optics and Mechanics, Chengdu Microwave Laboratory, China Academy of Engineering Physics, Southwest Institute of Electronic Engineering,* and the *Hong Kong University of Technology*, which will enable comprehensive international research discussions to take place regarding the design and development effort. The Chinese effort on HFGWs is funded by the *National Basic Research Program of China* under grant number 2003CB716300, the *National Natural Science Foundation of China* under grant number 10575140, the *Foundation of China Academy of Engineering Physics* under grant numbers 2008T0401 and 2008T0402, and the *Nature Science Foundation of Chongqing* under grant 8562.)

The Chinese HFGW effort is concentrated on research, development and fabrication of the Li-Baker HFGW detector. Please see Figs. 1 and 2. Based upon the theory of Li, Tang and Zhao (1992). The detector was proposed by Baker during the period 1999-2000, a patent for it was filed in 2001, subsequently granted (Baker, 2001), and preliminary details were published by Baker, Stephenson and Li (2008). This detector was conceived to be sensitive to High-Frequency Relic Gravitational Waves (HFRGWs) exhibiting amplitudes as small as $\mathbf{10^{-32}}$. In the past HFGW research has been controversial because of the current lack of direct unambiguous detection of HFGW. That is the focus of the present Chinese effort. The Fangyu Li theory, upon which the Li-Baker HFGW Detector is based, is not new. There have been some twelve peer-reviewed journal publications concerning the theory since 1992. Some of them are: Li, Tang and Zhao (1992), Li and Tang (1997), Li, Tang, Luo and Li (2000), Li and Yang (2004), Baker and Li (2005), Li, Baker and Chen (2006), Baker, Woods and Li (2006), Li and Baker (2007), Baker, Stephenson and Li (2008) and Li, Baker, Fang, Stephenson and Chen (2008).

FIGURE 1 Equipment Layout Representative of an HFGW Detection System, Notional Picture of Stainless Steel and Titanium Vacuum/Cryogenic Containment Vessel and Faraday Cage for HFGW Detection on left; Shanghai Institute of Optics and Fine Mechanics (SIOM).

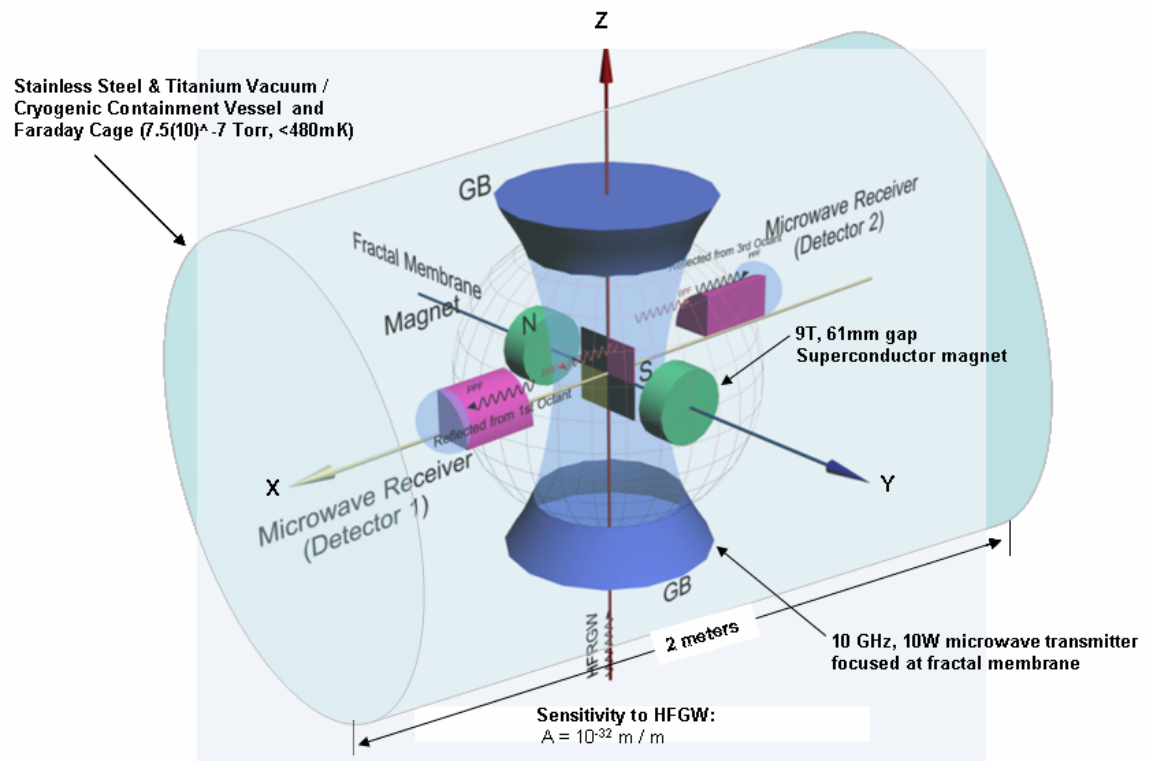

FIGURE 2. Li-Baker HFGW Detector Schematic

RECENT DEVELOPMENTS

In April, 2008 the P.R. China sponsored R. M L Baker's second HFGW lecture tour of China. On April 28 and 29 Fangyu Li and Zhenyun Fang (Dean of Graduate School, Director of the *Institute of Theoretical Physics, Chongqing University)*, visited the *National Natural Science Foundation of China in Beijing*. Fangyu Li reported that the "Next stage will be that how to combine works of three groups: Chongqing University, University of Science and Technology of China (USTC) and the Chengdu Microwave Laboratory (CML). Thus, Professor Fang and I will go to USTC and CML to further study relative issues for our HFGW project." In June 2008 the Institute of Electronic Engineering of the China Academy of Engineering Physics was awarded 3,020,000 Yuan (US$430,000) for research on HFGWs. In October, 2008 R. M L Baker, Jr. was again invited to China to provide lectures concerned with their HFGW research program. The Chinese HFGW detector-design effort is expected to commence in 2009, plans and specifications completed in 2010, fabrication completed of its mainly off-the-shelf components in 2012 and relic gravitational wave data collected subsequent to 2012.

CONCLUSIONS

The Chinese have the most vigorous and well-planned research program on HFGWs throughout the world. They have designed two HFGW detectors with Baker of GravWave® LLC, USA, based upon the theories of Fangyu Li that are expected to have the unprecedented sensitivity to HFGW amplitudes on the order of 10^{-32} m/m. This Li-

Baker detection system would detect faint relic HFGWs and be utilized in cosmology, space technology and Space Physics. Coupled with HFGW generators, HFGWs can carry broadband communications directly through the ground and oceans unimpeded (for example to deeply submerged submarines) without the need for fiber optic cable, microwave and satellite relays, etc.; Low-Frequency Gravitational Waves or LFGWs (such as detectable by LIGO, Virgo, GEO600 , Tama, et al.) cannot. HFGWs, according to Landau and Lifshitz, can affect the gravitational field (a new space propulsion means); LFGWs cannot. Although very speculative, HFGWs have the promise of X-ray-like imaging through all material things (directly through the oceans and the Earth); LFGWs do not. HFGWs might be concentrated in order to remotely affect matter at the nuclear level; LFGWs cannot. HFGWs are vastly superior in application as compared with LFGWs. China will be the first to take practical advantage of this emerging HFGW technology. In general, High-Frequency Gravitational Waves (HFGWs) have the promise of revolutionary practical applications to science, technology, and commerce. China can become the pioneer in this epoch-making event: no doubt the first to generate and detect Gravitational Waves on Earth!

REFERENCES

Baker, R. M L, "Gravitational Wave Detector," Peoples Republic of China Patent number ZL200510055882.2 filed (July 13, 2001), granted September 19, 2007; available at http://www.gravwave.com/docs/Chinese%20Detector%20Patent.pdf

Baker, R. M L Baker, Jr. (2003), "What Poincaré and Einstein have wrought: a modern, practical application of the general theory of relativity (The story of High-Frequency Gravitational Waves)," paper HFGW-03-101, *Gravitational-Wave Conference*, The MITRE Corporation, May 6-9. (2003)

Baker, R. M L , Jr. and Fang-Yu Li, "High-Frequency Gravitational Wave (HFGW) Generation by Means of a Pair of Opposed X-ray Lasers and Detection by Means of Coupling Linearized GW to EM Fields," 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**, 1271-1281, (2005)

Baker, R. M. L.,, Jr., Fangyu Li and Ruxin Li (2006), "Ultra-High-Intensity Lasers for Gravitational Wave Generation and Detection" in the proceedings of *Space Technology and Applications International Forum (STAIF-2006)*, edited by M.S. El-Genk, American Institute of Physics Conference Proceedings, Melville NY **813**, pp.1249-1258.(2006).http://www.drrobertbaker.com/docs/AIP;%20HFGW%20Laser%20Generator.pdf

Baker, R. M L, Jr., R. Clive Woods and Fangyu Li, "Piezoelectric-Crystal-Resonator High- Frequency Gravitational Wave Generation and Synchro-Resonance Detection," in the proceedings of *Space Technology and Applications International Forum (STAIF-2006)*, edited by M.S. El- Genk, American Institute of Physics Conference Proceedings, Melville NY **813**, pp. 1280-1289 (2006). http://www.drrobertbaker.com/docs/AIP;%20HFGW%20Piezoelectric%20Generator.pdf

Baker, R. M L, Jr., R. Clive Woods and Fangyu Li, "Piezoelectric-Crystal-Resonator High- Frequency Gravitational Wave Generation and Synchro-Resonance Detection," Discussion-Focus Paper 2.4, *2nd HFGW International Workshop*, Institute for Advanced Studies at Austin (IASA), Texas, September 19-21; 2007 http://earthtech.org/hfgw2/.

Baker, R. M L, Jr., G. V. Stephenson and F. Li, "Analyses of the Frequency and Intensity of Laboratory Generated HFGWs," 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**, pp. 1036-1044 (2008). http://www.gravwave.com/docs/Analysis%20of%20Lab%20HFGWs.pdf

Baker, R. M L, Jr., G. V. Stephenson and F. Li, "Proposed Ultra-High Sensitivity HFGW Detector," 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**, pp. 1045-1054. (2008) http://www.gravwave.com/docs/Proposed%20Ultra High%20Sensitivity%20HFGW%20Detector%2005-15-08.pdf.

Li, Fang-Yu, Mengxi Tang and Pengfel Zhao, , "Interaction between Narrow Wave Beam-type High Frequency Gravitational Radiation and Electromagnetic Fields." *ACTA Physsica Sisica*, Volume **41**, Number 12, pp. 1919-1928 (1992).

Li, Fang-Yu and Meng-Xi Tang, "Positive Definite Problem of Energy Density and Radiative Energy Flux for Pulse Cylindrical Gravitational wave," *ACTA Physica Sinca* **6**, Number 5, 321-333 (1997).

Li, Fang-Yu, Meng-Xi Tang, Jun Luo, and Yi-Chuan Li, "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 (2000).

Li, Fang-Yui, Meng-Xi Tang, and Dong-Ping Shi, "Electromagnetic response of a Gaussian beam to high frequency relic gravitational waves in quintessential inflationary models," *Chongqing University Report*, December 3, pp. 1-33 (2002).

Li, Fang-Yu , Meng-Xi Tang, and Dong-Ping Shi, "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 (2003).

Li, Fang-Yu and Nan Yang, "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 (2004).

Li, Fang-Yu, R.M L Baker, Jr. and Zhenya Chen, "Perturbative photon flux generated by high frequency relic gravitational waves and utilization of them for their detection," *International Journal of Modern Physics D* **15 ,** (2006)**.** http://www.drrobertbaker.com/docs/Li-Baker%206-22-08.pdf

Li, Fang-Yu and R. M. L Baker, Jr., "Detection of High-Frequency Gravitational Waves by Superconductors," *6th International Conference on New Theories, Discoveries and Applications of Superconductors and Related Materials*, Sydney, Australia, January 10; *International Journal of Modern Physics* **21**, Nos. 18-19, pp. 3274-3278 (2007).

Li, Fang-Yu , R.M.L. Baker, Jr.. and Zhenyun Fang, , "Coupling of an Open Cavity to Microwave Beam: A Possible New Scheme of Detecting High-Frequency Gravitational Waves**,"** in the proceedings of *Space Technology and Applications International Forum (STAIF-2007)*, edited by M.S. El-Genk, American Institute of Physics Conference Proceedings, Melville, NY **880**, pp. 1139-1148 (2007)

Li, Fang-Yu, R.M L Baker, Jr., Zhenyun Fang, Gary V. Stephenson and Zhenya Chen (Li-Baker Chinese HFGW Detector:) "Perturbative Photon Fluxes Generated by High-Frequency Gravitational Wave and Their Physical Effects," *The European Physical Journal C.(*2008) http://www.drrobertbaker.com/docs/Li-Baker%206-22-08.pdf