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# Chinese High-Frequency Gravitational Wave Research Program

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**Abstract.** The objective of this paper is to present the history and progress to date of the Peoples Republic of China's research program in the area of High-Frequency Gravitational Waves (HFGWs). The Chinese research is compared with HFGW research programs of the Italians, Russians and the British. The initial pioneering activities of Professor Fangyu Li at *Chongqing University* will be chronicled. Their current research activities involving the Chengdu Microwave Laboratory (CML) and the *Hong Kong University of Science and Technology*, especially the fractal-membrane research (of great value in detecting relic HFGW) being accomplished by Weijia Wen, will be discussed. Most of the future research plans of the Chinese are found at the www.GravWave.com web site and will be presented in more detail and the current status of their HFGW Research Program, some of which is being accomplished in cooperation with the privately funded GRAVWAVE®LLC in the United States, will be identified. The importance of basic and applied HFGW research to the Chinese, especially its commercial and military applications, is discussed. It is concluded that the US would be well advised to enter into the HFGW research arena.

## 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*, and 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*. 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* 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. 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, 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 polarization angle. This not to say that there is not interest and research connected with 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.

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 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. In the ATTACHMENT 1 is to be found an outline of a Chinese & GRAVWAVE® Joint HFGW Project that exhibits the Chinese approach to HFGW research and development (both basic and applied). It will be accomplished in partnership with the US team of HFGW scientists involved with the US Company GRAVWAVE®LLC (please see ATTACHMENT 2).

## FRUITS OF THE CHINESE HFGW RESEARCH PROGRAM TO DATE

Thus far the published fruits of the basic and applied Chinese & GRAVEWAVE®LLC Joint HFGW research program outlined in ATTACHMENT 1 are:

December, 2004: Peer-reviewed technical paper published as result of the Chinese & GRAVWAVE®LLC Joint HFGW Project; with Fang-Yu Li 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.

February, 2005: Peer-reviewed technical paper published as result of the Chinese & GRAVWAVE®LLC Joint HFGW Project; with Fangyu 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**, pp. 1271-1281.

February, 2006: Peer-reviewed technical paper published as result of the Chinese & GRAVWAVE®LLC Joint HFGW Project; with Fangyu Li and Ruxin Li, "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.

February, 2006: Peer-reviewed technical paper published as result of the Chinese & GRAVWAVE®LLC Joint HFGW Project; with 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. 1280-1358.

July, 2006: Peer-reviewed technical paper published as result of the Chinese & GRAVWAVE®LLC Joint HFGW Project; "Gravitational Power Estimation Utilizing a Novel Formation of the Quadrupole Equation," *Astronomische Nachrichten / Astronomical Notes* **327,** No. 7, pp. 710-713.

December, 2006: Peer-reviewed technical paper published as result of the Chinese & GRAVWAVE®LLC Joint HFGW Project; with Fangyu Li 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** .

To be published Peer-reviewed technical paper that is a result of the Chinese & GRAVWAVE®LLC Joint HFGW Project with Fangyu Li and Zenyun 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.

To be published Peer-reviewed technical paper that is a result of the Chinese & GRAVWAVE®LLC Joint HFGW Project, "Surveillance Applications of 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.

## CONCLUSIONS

The Chinese have the most vigorous and well-planned research program on HFGWs throughout the world. They have designed two HFGW detectors based upon the inverse Gertsenshtein effect that are expected to have the unprecedented sensitivity to HFGW amplitudes on the order of $10^{-32}$ m/m. The Italians are very active in the theory of relic HFGWs (especially Maurizio Gasperini's pre-Big-Bang string cosmology) and have constructed a coupled microwave resonance-chamber HFGW detector at *INFN* Genoa. The English have built a HFGW detector sensitive to 100 GHz HFGWs (equipment uses microwave techniques to search for the polarization rotations expected when a beam of electromagnetic radiation travels in the presence of a gravitational wave produced during the Big Bang), the Czech's have recently entered into HFGW research and Russia has been theoretically studying HFGWs, but to a lesser degree than during the Cold War. The Chinese especially recognize the potential practical commercial and military applications of HFGWs. The US scientific community, although very active in LFGW research, has not chosen to become involved in HFGW research. In order that the US not be left behind (or not be able to participate in or respond to the practical applications of HFGWs), it is concluded that the US sponsors two study groups to analyse an appropriate program of basic and applied HFGW research. The two groups should be funded at the level of about $300,000 each. The first would be the existing GRAVWAVE®LLC Team (please see ATTACHMJENT 2; by the way, GRAVWAVE®LLC holds twenty current and pending patents on HFGW apparatus and devices both in the US and in China). This group's charter would be to determine how best for the US to enter the HFGW research arena. The second team would be chosen from the US LIGO Groups and determine the technology that can be transferred from the LFGW programs to HFGW research.

## UPDATE (May, 2008)

In April, 2008 the P.R. China sponsored Dr. Baker's second HFGW lecture tour of China. On April 28 and 29 Dr. Fangyu Li and Dr. 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. Dr. 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 Chendu Microwave Laboratory (CML). Thus, Dr. Fang and I will go to USTC and CML to further study relative issues for our HFGW project." In October, 2008 Dr. Baker is again be invited to China to assist with their HFGW research program.

## ADDITIONAL FRUITS OF THE CHINESE HFGW RESEARCH PROGRAM

Lei Zhou, Weijia Wen, C. T. Chan, and Ping Sheng, Fractal Membrane Component of Li-Baker Chinese HFGW Detector. http://www.gravwave.com/presentations/Fractal%20Membranes.ppt.

Robert M L Baker, Jr., Gary V. Stephenson and Fangyu Li (2007), "Analyses of the Frequency and Intensity of Laboratory Generated HFGWs," in the proceedings of the *HFGW2 Workshop*, Institute of Advanced Studies at Austin (IASA), Texas, September 19-21, including comparative analysis of Dehnen and Romero-Borja (2003); http://earthtech.org/hfgw2/.

Robert M L Baker, Jr. (2008), "Proposed Laboratory Generation of HFGWs," *Chongqing University*, P. R. China, Lecture #2 ,April. Slides 48-72 of http://www.gravwave.com/presentations/ChineseLectures2008/index.html

Fangyu Li and Robert M. L. Baker, Jr. (2007), "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.

R. M L Baker, Jr., G. V. Stephenson and F. Li (2007), "Proposed Ultra-High Sensitivity High-Frequency Gravitational Wave Detector," Discussion-Focus Paper 1.2, *2nd HFGW International Workshop*, Institute for Advanced Studies at Austin (IASA), Texas, September 19-21; http://earthtech.org/hfgw2/.

R. M L Baker, Jr., G. V. Stephenson and F. Li (2007), "Analyses of the Frequency and Intensity of Laboratory Generated HFGWs," Discussion-Focus Paper 2.3, *2nd HFGW International Workshop*, Institute for Advanced Studies at Austin (IASA), Texas, September 19-21 and comparison with Dehnen and Romero-Borja, 2003; http://earthtech.org/hfgw2/.

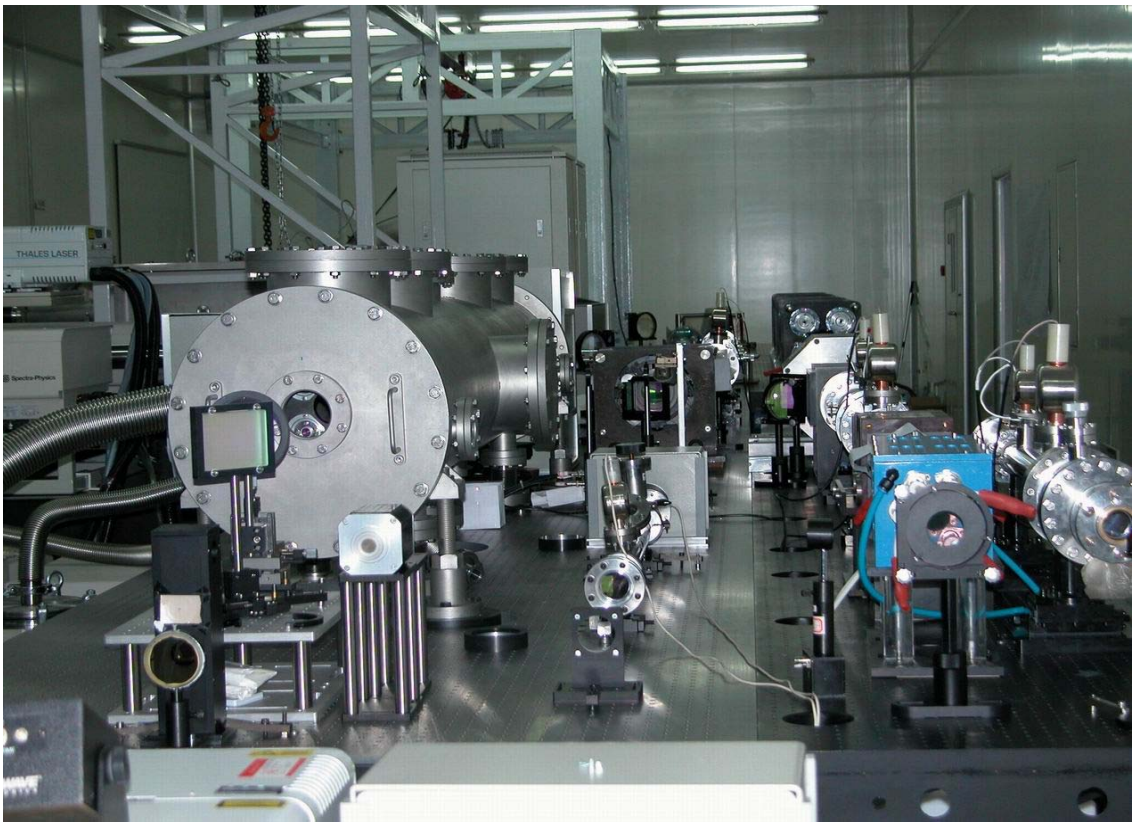
R. M L Baker, Jr., R. Clive Woods and Fangyu Li (2007), "Piezoelectric-Crystal-Resonator High-Frequency Gravitational Wave Generation and Synchro-Resonance Detection," Discussion-Focus Paper 2.4, *2nd HFGW International Workshop*, Institute for Advanced Studies at Austin (IASA), Texas, September 19-21;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

Fangyu Li , Robert M.L. Baker, Jr.. and Zhenyun Fang, (2007), "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.

R. M L Baker, Jr., G. V. Stephenson and F. Li (2008), "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. http://www.gravwave.com/docs/Proposed%20%20Ultra-High%20Sensitivity%20HFGW%20Detector%20Revision%209-11-07.pdf.

Typical HFGW Equipment Layout, 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)



# CHINESE DETECTOR SCHEMATIC