

A Brief History of High-Frequency Gravitational Waves

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After reviewing the early work of Einstein, Weber, *et al.* the first mention of High-Frequency Gravitational Waves or HFGWs that I could determine was in a meeting in 1961 that I had with Dr. Robert L. Forward at my *Lockheed Astrodynamics Research Center* in Bel Air, California. I had invited him 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. After the lecture Bob and I talked about building a Laboratory generator and detector of “**High-Frequency Gravitational Waves.**” 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.

The history of Gravitational Waves themselves predated Einstein’s 1916 paper where he discussed Gravitational Waves. Since 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.” There were no publications concerning HFGWs that I could find until mid 1962 when M. E. Gertsenshtein authored the pioneering paper entitled “Wave resonance of light and gravitational waves,” (*Soviet Physics JETP*, Volume 14, Number 1, pp. 84-85). The next publication was in August of 1964 when L. Halpern and B. 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) were suitable to produce strong (relic) gravitational radiation.” (p.729). They then discuss “short wavelength” or High-Frequency GW (p.743) and even suggest a “gaser” generator of HFGWs on p. 747, analogous to a laser for EM generation. In 1968 Richard A. Isaacson of the *University of Maryland* authored papers concerned with “Gravitational Radiation in the Limit of High Frequency” in the *Physical Review*, Volume 166.

L. P. Grishchuk and M. V. Sazhin in early 1974 authored a paper on “Emission of gravitational waves by an electromagnetic cavity” (*Soviet Physics JETP*, Volume 38, Number 2, pp. 215-221), 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 V. B. 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]. 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 having frequencies in excess of 100 kHz (*General Relativity – An Einstein centenary survey*, Cambridge University Press, page 98).

The theme of relic or Big-Bang generated HFGW (suggested frequencies of 10^6 to 10^9 Hz) and its relationship to “String Cosmology” (roughly related to the popular string theories of today) was picked up by G. Veneziano, at the First Conference on Particles, Strings and Cosmology, at *Northeastern University* in March of 1990 and later by M. Gasperini and M. Giovannini in 1992 (*Physical Review Letters B*, Volume 282, p. 36). This work continues on today and is the motivation for HFGW detectors

under development by *Birmingham University*, England, *INFN Genoa*, Italy, and *Chongqing University*, China.

After a rather long breather from my 1961 interest, a business associate of mine (not a scientist) Fred Noble and I filed the very first Patent Application for a GW generator in the world (now granted as *United States Patent 6,160,336*) on November 19, 1999. (Joseph Weber had a patent on an “Electromagnetic Coupled Detection of Dynamic Gravitational Force Gradients,” *United States Patent 3,722,288*, filed in 1969, but it was unrelated to GWs). And then, acting alone as the sole inventor, I was awarded *United States Patent Number 6,417,597*, for a “Gravitational Wave Generator,” filed July 14, 2000. After achieving patent protection, I presented a paper entitled “Preliminary Tests of Fundamental Concepts Associated with Gravitational-Wave Spacecraft Propulsion,” at the *American Institute of Aeronautics and Astronautics: Space 2000 Conference and Exposition* (Paper Number 2000-5250, September 20).

In 2002 I traveled to Europe to present my HFGW ideas to John Miller (a well-known Astrophysicist, who worked with Steven Hawking) at the *International School for Advanced Studies* in Trieste, Italy; Mike Cruise, Dean of Science at *Birmingham University*, England; Professor Giorgio Fontana of the *University of Trento*, Italy; Harald Dimmelmeier, of the *Max Planck Institute* in Munich, Germany; and several scientists at *INFN Genoa*, Italy. At the last two meetings I delivered a lecture on HFGWs and recommended that an *HFGW Working Group* meeting be held early next year (2003) “...in order to trade ideas, stimulate thinking and define experimental parameters.” After considerable work with Paul Murad, the *Gravitational Wave Conference* [International High-Frequency Wave (HFGW) Working Group] was organized for 2003 at the *MITRE Corporation* in Mclean, Virginia and Paul and I were co chairs with Ning Li as a honorary co chair. The Conference was dedicated to Robert Lull Forward who can be considered as the person who coined the term High-Frequency Gravitational Waves. The meeting attracted over 50 scientists from 14 countries and some 25 technical papers were presented. Several U S HFGW research pioneers were present including Eric W. Davis, Senior Scientist at *The Institute for Advanced Studies at Austin*; Gary V. Stephenson of *Boeing* and R. Clive Woods, Chairman of the Department of Electrical and Computer Engineering, Louisiana State University. One of the authors at that *Gravitational Wave Conference* was Professor Fangyu Li of *Chongqing University*, China. He is the leader of the Chinese HFGW research program and he and his Chinese colleagues have had a very active HFGW research program in operation for several years. I was given the opportunity to tour China in 2004 and present several lectures on HFGWs and confer with several other HFGW scientists there including Zhenyun Fang, Dean of Graduate School, Director of the Institute of Theoretical Physics, *Chongqing University*; Jun Luo, Head of the Gravitational Laboratory of *Huazhong University of Science and Technology* and Ruxin Li, Vice Director of the *Shanghai Institute of Optics and Fine Mechanics*.

That brings us up to date with many more HFGW papers being presented after the *MITRE Conference* at a *Space Technology Applications International Forum (STAIF)* sponsored by the *American Institute of Physics* (usually held in the spring at Albuquerque, New Mexico, USA). Special sessions at these forums allow for peer-reviewed HFGW scientific papers – specifically at STAIF2004, STAIF2005, STAIF2006, and, quite possibly, at the future STAIF meetings in 2007 and onward.