HIGH-FREQUENCY GRAVITATIONAL WAVES

Notes of Lecture Delivered to

The Max Planck Institute for Astrophysics (MPA)
Gauching, Germany, May 9, 2002, 1530-1700

and

The National Institute for Nuclear Physics (INFN)
Genoa, Italy, May 28, 2002, 1000-1130

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1. Introduction:

Good Day. I'm Robert Baker and today I am going to deliver a lecture to you concerning an exciting new concept: the generation, detection and utilization of *high-frequency gravitational waves* (HFGWs). **This is the *clarion* call**:

● *today*, we have the unique **opportunity** to study and utilize the gravitational-wave phenomenon predicted by Poincaré and Einstein decades ago because of recent advances in technology;

● *today*, we have the **means** to generate HFGWs and to detect HFGWs in the laboratory because of the availability of two new HFGW detectors. And we now,

● *today*, have the **motivation** to apply HFGWs to communication, space propulsion, imaging and, in general, the motivation for the laboratory study of HFGWs!

But first, allow me to tell you a bit about myself and how my interest in HFGWs developed:

In the 1950s, I co-authored a paper on gravitational dynamics entitled "Satellite Librations." I had just received my Ph.D. at *UCLA* in Engineering with specialization in Astronomy and I was appointed to the faculty of the Astronomy Department and later the Engineering Department as Lecturer and Assistant Professor. In the 1960s, I became the Head of a Lockheed laboratory and a Dr. Robert Forward contacted me regarding my Satellite Librations paper. He was interested in something called "gravitational waves" and his Ph.D. thesis was the design of a resonance device developed by a Joseph Weber called the "Weber Bar." I invited Dr. Forward to deliver a lecture to my staff and was intrigued with the possibility of sensing Low-Frequency Gravitational Waves (LFGW) with frequencies on the order of a kHz or less using the Weber Bar. I was also intrigued by the possibility of generating **High-Frequency Gravitational Waves (HFGWs)** exhibiting frequencies of one tenth of a megahertz or more. At the time, however, I saw no practical means to generate the HFGWs. Joseph Weber originally calculated in 1964 that for a rod about a meter long, spun at such a speed that it is on the verge of breaking, it would radiate about 10^{-37} watts. Such a miniscule power output led many to conclude that the laboratory generation of GW was impossible. This conclusion was reinforced by astrophysical modeling of GW generation from super-dense and rapidly moving celestial objects such as neutron stars and black holes whose gravitational fields were enormous. Obviously, nothing like that could be replicated in the laboratory. Because of these analyses no serious attention was paid to laboratory GW generation. Recently, my interest in HFGW technology has been rekindled and I presented a paper on the subject in 2000 to the *American Institute of Aeronautics and Astronautics* or *AIAA*.

At the outset it is important to establish the reasons for concentrating on **High-Frequency** Gravitational Waves. According to Hawking and Israel HFGWs exhibit frequencies above 10^5 Hz. As will soon be demonstrated the power of gravitational-wave generation increases with the square of the HFGW frequency. Let us consider a GW communications link. If collimated in a diffraction-limited beam, then the GW flux (watts per square meter) increases inversely with the square of the GW wavelength (that is, produces a more intense, narrower beam) and if the GW beam is intercepted by a diffraction-limited focusing device (in order to focus an intense spot on a detector), then the flux is increased by another inverse square of the wavelength. The frequency is inversely proportional to the wavelength so we have a square times a square times a square for the efficiency of a GW link. The resulting sixth-power relationship is slightly reduced because the sensitivity of many GW detectors decreases with the square root of the GW frequency. Nevertheless, the value of High Frequency is manifest. In this same regard it should be recognized that Low-Frequency Gravitational Waves (LFGW) generated by most astrophysical sources are expected to be detected by interferometric and resonance devices whose technology is **TOTALLY** different from the technology of high-frequency detector devices -- as different as AC-motor technology is from microwave-transmitter technology. Thus LFGW detectors such as LIGO, VIRGO, GEOS6000, LISA, *et al,* are totally irrelevant and **useless** for HFGW detection.

I will commence my further remarks with a literature survey.

2. Literature Survey:

I preface my remarks by noting that in the 1960s to 1980s there was considerable skepticism concerning the existence of gravitational waves – low frequency and high frequency -- and consequently little attention was paid to the literature concerning the laboratory generation of GW. Some scientists believed that these waves in Einstein's revolutionary spacetime continuum were unobservable artifacts of his theory. The indirect evidence obtained by R.A. Hulse and J. H. Taylor concerning their observations of a contracting binary star pair, which perfectly matched Einstein's GW theory, garnered them the 1993 *Nobel Prize* and the skepticism concerning GW evaporated.

In what follows, I list the various publications by date (the list is illustrative and **not meant to be comprehensive**), provide a very brief description, and include several in the handouts to this lecture – it should be recognized that there may well be more publications than those that I have uncovered. However, there is ample evidence, as seen below, that the laboratory generation of gravitational waves has been and is being thoroughly studied by dozens of scientists worldwide and many of the devices suggested are both feasible and practical if we take advantage of recently developed technology.

1960: Weber, "Detection and generation of gravitational waves." Suggests the use of piezoelectric crystals to generate 10^{39} more GW power than could be generated by a rapidly spinning rod.

1962: Gertsenshtein, "Wave resonance of light and gravitational waves." This one-and-one half page note suggests the conversion of light into HFGW-- "Gertsenshtein Waves".

1964: Halpren and Laurent, "On the gravitational radiation of microscopic systems." The possibility of increasing HFGW flux by stimulated emission ("gaser") is discussed and "... the maximum of the gravitational radiation occurs in a direction from which the corresponding electromagnetic (EM) radiation is excluded."

1966: Forward and Miller, "Generation and detection of dynamic gravitational-gradient fields." Concerned with oscillating[†] gravitational gradients such as those that were the subject of Dr. Klemperer and my earlier paper on satellite librations.

1968: Halpern and Jouvet, "On the stimulated photon-graviton conversion by an electromagnetic field." They questioned whether gravitational forces can produce GW (only *non-gravitational forces* may generate GW they thought), "... electromagnetic (EM) field enhances the emission of gravitational bremsstrahlung photons ... such effects are however below the threshold observability in all (using 1968 technology) empirically known cases."

1969: Weber, U.S. Patent 3,722,288 alluded to a piezoelectric-crystal HFGW generation without significant attendant EM radiation.

1974: Grishchuk and Sazhin, "Emission of gravitational waves by an electromagnetic cavity." according to Weiss was "... only a factor of 100,000 from being feasible." Thousands of "... such cavities" were ganged together to produce GHz HFGW; but deemed too weak (using 1973 technology).

1975: Sekie, et al, "GW generation from an array of Cds plates." This paper was computationally flawed and the calculation and design were significantly in error.

1978: Rudenko and Braginsky, "Hertz-type gravitational wave generator." Suggested a possible GW laboratory experiment with 10 MHz HFGW. Calculated it could generate 10^{-18} [watts].

1981: Romero and Dehnen, "Generation of gravitational radiation in the laboratory." A long row of piezoelectric crystal oscillators (10,000) is utilized to produce coherent HFGW (up to GHz frequencies) in a 20 degree ".... needle radiation" forward beam without significant associated EM emissions; but "... may be under the observational limit." On the other hand, from their equation (A.11) if utilized more and closer spaced crystals and THz frequencies, then the radiated energy climbs to much more than 10^{-9} [watts] and is probably observable!

1988: Pinto and Rotoli, "Laboratory generation of gravitational waves?" They suggested three classes of HFGW generators: (1) EM stress-energy field, (2) HF electrical oscillations for acoustical stress or mechanical stress energy, and (3) array (linear) of such sources. 500 MHz and Germanium crystals are utilized. They conclude that HFGW "... seems to be conceivable... but very difficult to concretize...." They predict little or no excessive EM to be generated.

1991: Pia Astone, et al., "Evaluation and preliminary measurement of the interaction of dynamical gravitational near field with a cryogenic gravitational-wave antenna." High-rpm (approximately 30,000) rotor about 1 kHz. They couldn't control the detector frequency and the results were inconclusive. Actually, they were not producing GW but rather an oscillatory gravitational field[†] – the generation of GW from rotors is not possible since for any significant GW flux the rotor would break due to centrifugal force.

1991: John D. Kraus, "Will gravity-wave communication be possible?" Describes a gravitational –wave generator in which an electromagnetic pulse is introduced into a toroidal cavity at its resonance frequency to produce a very small phase shift that distorts the medium in the toroid i.e., the pulse causes "physical motion of submicroscopic particles" or a jerk.

1997: Argyris and Ciubotariu, "A proposal of new gravitational experiments." Their experiments concern the simulation of accelerations produced by a wave of gravity, a source of HFGW, a direct-current gravitational machine, materials with high gravitomagnetic permeability (the "gravitational superconductor") and the possibility of attenuation of gravitational attraction..

1998: Fontana, "A possibility of the emission of high frequency gravitational radiation from junctions between d-wave and s-wave superconductors." Gigahertz frequencies would be expected. He extends Halpern and Laurent's work. His proposed device involves strong magnetic coupling and high temperature superconductors (HTSC).

2000: Baker, *AIAA* paper ... jerk formulation and many alternative means and devices for generating HFGWs are described. The more than one-watt-per- square-meter HFGW flux generated (page 29 of the paper) should be sensed by spacetime-curvature, piezoelectric-crystal-array, GW-to-EM conversion, and/or gravity-modification detectors. The devices discussed in the paper are protected under U. S. Patents 6,417,597 and 6,160,336 and patents pending.

2001: Portilla and Lapiedra, "Generation of high frequency gravitational waves." References Gertsenshtein's work and relies on an electric charge shaken (jerked) in a homogeneous stationary magnetic field -- suggested that it is promising.

† Please note that a librating-mass-produced oscillation (periodic, time-varying change) in a *classical* “gravitational field” (like tidal changes) is **not** a quadrupole-produced “gravitational wave” in the *spacetime* continuum. As an example, a rapidly rotating asymmetrical neutron star generates significant gravitational waves, but no appreciable oscillations in its gravitational field or tides. On the other hand, a mass dipole generates **no** gravitational waves, but **does** generate oscillations in its gravitational field or “waves of gravity”, which perturb other masses and have tidal influence. An electrically charged dipole will produce electromagnetic (EM) waves, however.

3. Jerk Formulation of the Quadrupole Equation (Sophomore Physics)

There is no new Physics here, simply a different approach or formulation to render engineering applications more apparent.

As is well known and noted specifically in a letter to me from Dr. Geoff Burdge, Deputy Director for Technology and Systems of the *National Security Agency,* "Because of symmetry, the quadrupole moment can be related to a principal moment of inertia, I, of a three-dimensional tensor of the system and "… can be approximated by

$$-dE/dt \approx -G/5c^5 (d^3I/dt^3)^2 = -5.5x10^{-54} (d^3I/dt^3)^2." \quad (1)$$

In which k in Burdge's notation is G and the units are in the MKS system [watts] not the cgs and the two sides of the equation are essentially the same. In this case, for a collection of masses like a rod or dumbbell rotating around a pivot, a pair of stars rotating around their orbital center, a sphere, disk or rim rotating around their axes or even masses attached to a fixed ring, the moment of inertia, I, is given by

$$I = \delta m\, r^2 \quad [kg\text{-}m^2], \quad (2)$$

where

δm = mass of an individual mass [kg], and

r = the distance from a pivot out to any single δm [m] (or more exactly, the radius of gyration of the collection of masses). Thus

$$d^3I/dt^3 = \delta m\, d^3r^2/dt^3 = 2r\delta m d^3r/dt^3 + \ldots \quad (3)$$

and d^3r/dt^3 is computed by noting that by Newton's second law of motion

$$2r\delta m\, d^2r/dt^2 = 2rf \quad [N\text{-}m] \quad (4)$$

where f = force on δm. (For example, a radial centrifugal force acting on two massive stars moving on a circular orbit or two masses undergoing a force change directed tangential to a circle that passes through them.) The derivative is approximated by

$$d^3I/dt^3 \cong 2r\,\Delta f/\Delta t\ , \tag{5}$$

in which Δf is the nearly instantaneous **increase** in the force on energizable-element sites, δm, caused by a pulsed magnetic fields acting on magnets, or piezoelectric resonator elements, or X-ray laser targets, etc. that is, a "jerk" (time rate of change of acceleration of a mass). In order not to build up acceleration the jerks are reciprocating. In summary

$$P = 1.76\text{x}10^{-52}\,(2r\Delta f/\Delta t)^2 \quad [\text{watts}], \tag{6a}$$

which is the **jerk formulation of the quadrupole equation** and for a constant mass, δm, Δf/Δt = δm Δa/Δt, so that the equation states that a third time derivative is imparted to the motion of the mass such as a magnet, piezoelectric vibrator element, laser target, etc.**.** For a continuous train of jerks the frequency, ν, is ν = 1/Δt, and Eq. (6a) can be phrased as a function of HFGW frequency as

$$P(r, \Delta f, \nu) = 1.76\text{x}10^{-52}\,(2r\nu\Delta f)^2 \ \text{watts}. \tag{6b}$$

Or as a function of the third time derivative imparted to a mass, δm,

$$P(r, \delta m, \Delta a/\Delta t) = 1.76\text{x}10^{-52}\,(2r\delta m\,\Delta a/\Delta t)^2 \ \text{watts}. \tag{6c}$$

Alternately, from Eq. (1), p. 90 of Joseph Weber, one has for Einstein's formulation of the gravitational-wave (GW) radiated power of a rod spinning about an axis through its midpoint having a moment of inertia, I [kg-m^2], and an angular rate, ω [radians/s] (please also see, for example, pp. 979 and

980 of Misner, Thorne, and Wheeler, in which I in the kernel of the quadrupole equation also takes on its classical-physics meaning of an ordinary moment of inertia):

$$P = 32GI^2 \omega^6 /5c^5 \quad = G(I\omega^3)^2/5(c/2)^5 \text{ [watts]} \tag{7}$$

or

$$P = 1.76x10^{-52}(I\omega^3)^2 = 1.76x10^{-52}(r[rm\omega^2]\omega)^2 \quad \text{[watts]} \tag{8}$$

where $[rm\omega^2]^2$ can be associated with the square of the magnitude of the rod's centrifugal-force vector, $\mathbf{f_{cf}}$, for a rod of mass, *m*, and radius of gyration, r. This vector reverses every half period at twice the angular rate of the rod (and a component's magnitude squared completes one complete period in half the rod's period). Thus the GW frequency is 2ω and the time-rate-of-change of the magnitude of, say, the x-component of the centrifugal force, f_{cfx} is

$$\Delta f_{cfx}/\Delta t \propto 2f_{cfx}\omega. \tag{9}$$

(Note that frequency, $\upsilon = \omega/2\pi$.) The change in the centrifugal-force vector itself (which we call a "jerk" when divided by a time interval) is a differential vector at right angles to $\mathbf{f_{cf}}$ and directed tangentially along the arc that the dumbbell or rod moves through.* Equations (6), like Eqs. (7) and (8), are approximations and **only hold accurately** for $r << \lambda_{GW}$ and for speeds of the GW generator components far less than c. (On the other hand, Leonid P. Grishchuk suggested that the requirement that $r << \lambda_{GW}$ may not be a stringent one and in the case of a laser-target energizable element, "r" may actually simply be the displacement of the target, which is much smaller than λ_{GW}.) Please see, for example, Pais, p. 280.

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* In more detail we have: The change in the centrifugal-force vector itself (*which is called a "jerk" when divided by a time interval*) is a differential vector at right angles to the $\mathbf{f_{cf}}$ vector and directed tangentially along the arc that the dumbbell or rod or orbiting mass moves through. The differential change in, for example, the x-component of the change in centrifugal force, Δf_{cfx}, is $f_{cfx}\ \Delta\theta$ and the change in the y-component is Δf_{cfy} is $f_{cfy}\ \Delta\theta$, where θ is the central angle of the rotating rod (or the true anomaly of an orbiting pair of masses) in radians. By delta differentiation of $f_{cf}^2 = f_{cfx}^2 + f_{cfy}^2$,

$$f_{cf}\, \Delta\, f_{cf} = f_{cfx}\Delta\, f_{cfx} + f_{cfy}\Delta\, f_{cfy} \tag{A1}$$

and when one associates the components $\Delta f_{cfx,y}$ with $f_{cfx,y}\ \Delta\theta$ and, after dividing by Δt\` (t\` being spinning-rod time), and noting that $\Delta\theta/\Delta t` = \omega$, Equation (8) is the *same equation as that given for two bodies on a circular orbit* on p. 356 of Landau and Lifshitz ($I=\mu r^2$ in their notation) where $\omega = n$, the orbital mean motion.

Equation (9) substituted into Eq. (8) with $rm\omega^2$ associated with Δf_{cf} yields

$$P = 1.76x10^{-52} (2r\Delta f_{cf} /\Delta t)^2, \quad (10)$$

where $(2r\Delta f_{cf} /\Delta t)^2$ is the kernel of the quadrupole approximation equation.

The essential concept here is that one can emulate an asymmetrical collection of rotating masses, with their attendant centrifugal-force jerks, by a series of fixed masses that are jerked by electromagnetic forces – energizable elements (magnets, piezoelectric elements, laser targets, etc.) acted upon by energizing elements (current-carrying coils, piezoelectric mechanisms, lasers, etc.). Three important points should now be made:

- **Energizing/Energizable element's Action/Reaction does not cancel out in GW generation: Einstein & Rosen (1937).**
- **Weak field can be well over 100 g's: e.g., PSR 1913 + 16, 112 g's at periastron.**
- **Δf need NOT be gravitational force (please see Einstein (1916), Infeld and Weber (1964, p. 97)). EM forces are 10^{35} larger than gravitational and should be employed in laboratory GW generation.**

As a validation of Eq. (10), that is a validation of the use of a jerk to estimate gravitational-wave power, let us utilize the approach for computing the gravitational-radiation power of PSR1913+16. From section 3, Eq. (2) of my *AIAA* paper we computed that each of the components of force change, $\Delta f_{cfx,y}$ = $5.77x10^{32}$ [N] (multiplied by two since the centrifugal force reverses its direction each half period) and Δt =

$$f_{cf}\, \Delta f_{cf} / \Delta t` = (f_{cfx}^2 + f_{cfy}^2)\omega \ . \quad (A2)$$

Thus $\Delta f_{cf} / \Delta t` = f_{cf}\omega$ ; but $\Delta t` = ½\Delta t$ since the period of the GW is half the period of the rod, so that

$$2\, \Delta f_{cf} / \Delta t = f_{cf}\omega, \quad (A3)$$

but $f_{cf}= \{rm\omega^2\}$ so

$$2\, \Delta f_{cf}/\Delta t = \{rm\omega^2\}\omega \quad (A4)$$

and substituting Eq. (A4) into Eq. (8) yields the jerk formulation of the quadrupole equation:

$$P = 1.76x10^{-52} (2r\Delta f_{cf} /\Delta t)^2 \quad \text{watts.} \quad (A5)$$

(1/2)(7.75hrx60minx60sec) = 1.395×10^4 [s]. Thus using the jerk approach:

$$P = 1.76\times10^{-52}\{(2r\Delta f_{cfx}/\Delta t)^2 + (2r\Delta f_{cfy}/\Delta t)^2\} = 1.76\times10^{-52}(2\times2.05\times10^9\times5.77\times10^{32}/1.395\times10^4)^2\times2$$

$$= \mathbf{10.1\times10^{24}}\ [\text{watts}] \quad (11)$$

versus the result of $\mathbf{9.296\times10^{24}}$ [watts] using Landau and Lifshitz's more exact two-body-orbit formulation given by Eqs. (1.1) and (1.2) of my *AIAA* paper integrated using the mean anomaly not the true anomaly. The most stunning closeness of the agreement is, of course, fortuitous since due to orbital eccentricity there is no symmetry among the $\Delta f_{cfx,y}$ components around the orbit and, as will be shown, there are errors inherent in the approximations of Eqs. (18) and (20) of my *AIAA* paper leading to Eq. (10). Nevertheless, since the results for GW power are so close, orbital-mechanic formulation compared to the utilization of a jerk, **the correctness of the jerk formulation is well demonstrated!**

There are some very sophisticated and exact computer simulations of the generation of gravitational waves (please see, for example, S. F. Ashby, Ian Foster, James M. Lattimer, Norman, Manish Parashar, Paul Saylor, Schutz, Edward Seidel, Wai-Mo Suen, F. D. Swesty, and Clifford M. Will (2000), "A Multipurpose Code for 3-D Relativistic Astrophysics and Gravitational Wave Astronomy: Application to Coalescing Neutron Star Binaries," *Final Report for NASA CAN NCCS5-153,* October 15, 30 pages). The quadrupole approximation utilized herein by me (Attachment 3 to these lecture notes) and, for example, by Romero and Dehnen are probably less exact. On the other hand, the computer simulations are less relevant to the devices involved in the generation and detection of HFGW. These computer simulations describe GW generation by strong-field astrophysical phenomena (e.g., neutron stars, black holes, etc.), coupled spacetime and general relativistic hydrodynamic equations, and are usually restricted to gravitational forces ; not non-gravitational forces involved in laboratory HFGW generation.

A word about the word *quadrupole*: the basic physical process for generating a gravitational wave is the third time derivative of the motion of a mass, termed a "jerk" or $\Delta f/\Delta t$, where Δf is an increase in force, f, on the mass carried out over a small time interval, Δt. As has been noted, that physical process produces a gravitational wave with a **power** given by, for example, the quadrupole approximation (as originally derived by Einstein) or it could be determined directly from the special and general relativity equations (using a computer- implemented numerical integration as, for example, discussed in. Ashby, et al (2000)). That is, the quadrupole itself is **not** the physical process at all, but only one means of establishing the power of the gravitational wave. This situation is similar to Newton's Laws, which govern the physical process of planetary motion. The effect of that motion can be computed using, for example, the two-body approximation, or it could be determined directly from the equations of motion described by Newton's Laws, using a computer- implemented numerical integration. The two-body approximation itself is **not** the physical law at all, but only one means of describing the resultant motion. In the case of a nuclear-reaction-generated gravitational wave, when a nuclear particle is ejected from a nucleus it is like a small rocket and there is a third time derivative of the motion of the nucleus, or a jerk, which produces a gravitational wave whose power can be estimated, for example, by quadrupole approximation. Thus when I mention a "quadrupole-produced gravitational wave" I'm really implying the fundamental physical concept of the jerk and not the computational means for establishing the power of the gravitational wave. As far as a harmonic motion of a mass or a pair of masses is concerned (harmonic oscillator), gravitational waves are generated. Just as in the case of a pendulum, the usual descriptor of harmonic motion, there exists a third time derivative of the pendulum bob. It is the jerk of that bob that produces the gravitational wave, which can be estimated using a quadrupole approximation or computed exactly by means of a rather complicated solution of the equations of special and general relativity. Finally, there are certain circumstances when symmetrical outwardly directed jerks occur, as in the case of an exploding star, the GW cancels out and there is no net GW generated.

4. Applications

4.1 *Propulsion:*

Landau and Lifshitz (1975), in *The Classical Theory of Fields*, on page 349 state: **"Since it has definite energy, the gravitational wave is itself the source of some additional gravitational field... its field is a second-order effect ... But *in the case of high-frequency gravitational waves the effect is significantly strengthened ...*"** Thus it is possible to change the gravitational field near an object remotely by means of HFGWs and move it. Such objects could be missiles, spacecraft, dispersed particles or gases, etc.!

Fontana (2000), in his paper entitled "Gravitational Radiation and its Application to Space Travel" quotes theories that predict GW can be employed for propulsion, that is, the generation of space-time singularities (see also Ferrari, et al, 1988) with remotely generated colliding beams of HFGW and a form of "propellantless propulsion." The concept is that HFGW energy beamed from off board can create gravitational distortions, that is, "Hills" and "Valleys" in the fabric of *spacetime* that the spacecraft or other vehicle is repelled by, or "falls into," or falls toward. Again, HFGW is proposed as propulsion means!

4.2 *Communication:*

At least two HFGW detectors or "receivers" are now functional {Cruise and Ingley (2001) and Gemme, Parodi, and Chincarini (2001-2002) } together with HFGW generators or "transmitters" (many of them have been identified earlier in this lecture) can be linked in order to carry information at high frequencies/bandwidths (THz to PHz and above – as we have seen: *the higher the frequency the more efficient is the HFSC generation)*. And, like the gravitational field itself, GW passes unattenuated through *all* material things and can, for example, reach deeply submerged submarines. As Thomas Prince (Chief Scientist, *NASA/JPL* and Professor of Physics at *Caltech*) recently commented: "Of the applications (of HFGWs), communication would seem to be the most important. Gravitational waves have a very low cross section for absorption by normal matter and therefore high-frequency waves could, in principle, carry significant information content with effectively no absorption unlike any electromagnetic waves." Such a HFGW communication system would represent the **ultimate wireless system --** point-to-multipoint PHz communication without the need for expensive enabling infrastructure, that is, no need for fiber-optic cable, satellite transponders, microwave relays, etc. Antennas, cables, and phone lines would be a thing of the past!

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4.3 *Imaging*

If intervening matter between the HFGW generator and detector causes a change (even a very slight one) in HFGW polarization, diffraction, dispersion or results in extremely slight scattering or absorption, then it may be possible to develop a HFGW "X-ray" like system. It may, in fact, be possible to image directly through the Earth and view subterranean features, such as geological ones, building interiors, buried devices, underwater objects, etc., to a sub-millimeter resolution for THz HFGW!

5. Recommendations:

6.1 Organize and schedule an *International HFGW Working Group* meeting this year (2002) in order to trade ideas, stimulate thinking, and define experimental parameters.

6.2 Promote an experiment utilizing a HFGW generator for example from the list presented in the Literature Survey, for example a HTSC under a three GHz (or higher frequency) magnetic field, or an asymmetrical circular array of the piezoelectric crystal devices, laser-energized targets, etc., under computer control, one of the devices discussed in my *AIAA* paper, such as the oscillatory spindle, linear motor, etc. The generator should be appropriately shielded (placed in a Faraday cage) in order to prevent the emission of EM radiation from the energizing elements of the generator. In order to assure reliable and non-controversial results, two or more detectors, utilizing different techniques could be utilized: one being the University of Birmingham's HFGW detector another being the INFN, Genoa's HFGW detector, and the third being one proposed by Fang-Yu Li of Chongqing University, China – or any newly developed HFGW detector.

The time is right, *carpe diem...* seize the moment!