HIGH-FREQUENCY GRAVITATIONAL WAVES

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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 three 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 (*UCLA* termed it an "Aerospace" degree) 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 from a Hughes Research Laboratory in Malibu, California 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 in 1961 and was intrigued with the possibility of sensing low-frequency (LF) gravitational waves (GWs) 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 (HF) gravitational waves (GW) exhibiting frequencies of 100kHz or more (such a frequency was suggested by Hawking and Israel in 1979). At the time, however, I saw no practical means to generate the HFGWs. Recently, my interest in HFGW has been rekindled and I presented a paper on the subject in 2000 to the *American Institute of Aeronautics and Astronautics* or *AIAA* (included as Attachment 3 to this lecture). I will commence my lecture with a literature survey.

2. Literature Survey:

I preface my remarks by noting that in the 1920s to 1980s there was considerable skepticism concerning even the existence of gravitational waves and consequently little attention was paid to the literature concerning the laboratory generation of GWs. In what follows, I list the various publications by date and include several in the Attachments – it should be recognized, however, that there far more publications than those that I have listed (as can be found on the Internet at www.gravwave.com) – the list is just a sample. There is ample evidence, as seen below, that the laboratory generation and detection of high-frequency gravitational waves has been thoroughly studied by dozens of scientists and many of the devices suggested are both feasible and practical if we take advantage of recently developed technology.

1961: 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 or EM radiation in general into HFGWs-- "Gertsenshtein Waves." The inverse of this process, EM produced by GWs, and the directional properties were later utilized by Fangyu Li in his HFGW detector.

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 GWs (**only non-gravitational forces** may generate GWs 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." Attachment 4 to these lecture notes.

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 HFGWs; but deemed too weak (using 1973 technology). Attachment 5.

1975: Belokon, "Compression of a perfect gas by multiply reflected shock waves," His work, as described by Braginsky and Rudenko, could lead to the result that a 10^7 Joule laser pulse (possibly generated by thermonuclear fusion) accelerating (jerking) foil layers resulting in a compression and repeated reflection of shock waves in the layers of 2GHz to 20PHz frequency. The peak power of the resultant HFGWs is about one watt according to Braginsky and Rudenko.

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.

1976: Sokolov and Galtsov, They propose a plasma HFGW generator in which vibrations (jerks) of electrons are excited by transverse EM waves polarized circularly and propagated along the plasma beam.

1978: Braginsky and Rudenko (1978), "Gravitational waves and the detection of gravitational radiation." Section 7: "Generation of gravitational waves in the laboratory." Suggested a possible GW laboratory experiment with 10 MHz HFGWs. 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! Attachment 6 to these lecture notes.

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 the laboratory generation of HFGWs "... 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 GWs from rotors is not possible since for any significant GW flux the rotor would break due to centrifugal force. This fact lead many researchers to conclude erroneously that the laboratory generation of GWs was not feasible.

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 HFGWs, 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 (HTSCs). Attachment 7 to these lecture notes.

2000: Baker, *AIAA* paper ... jerk formulation and many alternative means and devices for generating HFGW are described. This paper is Attachment 3 to these lecture notes. 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 (Li's detector below), 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.

*2000:*Fang-Yu Li, 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. Use of a Gaussian beam and filters to detect high-frequency gravitational waves or HFGWs using GW –to-EM conversion (inverse Gertsenshtein effect).

2000: A. M. Cruise, "An electromagnetic detector for very-high-frequency gravitational waves," *Class. Quantum Gravity,* Volume 17, pp. 2525-2530. Ring-shaped, microwave-guide HFGW sensor

2001: R. M. J. Ingley and A. M. Cruise, "An electromagnetic detector for high frequency gravitational waves," *4th Edoardo Amaldi Conference on Gravitational Waves*, Perth, Australia, July. Description of working model of the above device.

2001: Philippe Bernard, Gianluca Gemme, R. Parodi, and E. Picasso, "A detector of small harmonic displacements based on two coupled microwave cavities," *Review of Scientific Instruments,* Volume 72, Number 5, May, pp. 2428-2437. Coupled resonance chamber HFGW detector.

† Please note hat a mass dipole generates **no** gravitational waves (please see, for example, Weber {1964}), but **does** generate oscillations in its gravitational field or "waves of gravity," which perturb other masses and have tidal influence (please see, for example my 1957 paper on "Satellite Librations"). Tidal influences have amplitudes on the order of meters at the Earth, whereas gravitational-wave disturbances are but fractions of a proton diameter in amplitude over hundreds of meters.

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. Also herein I will draw a distinction between the "quadrupole formalism," which implies that a GW is generated by the **change** in acceleration of a mass, and the "quadrupole-approximation equation," which is an approximate means for estimating the power of the GW source.

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 (of Einstein's quadrupole-approximation equation) can be related to a principal moment of inertia, I, of a three-dimensional tensor of the system and … can be approximated by

$$-dE/dt \approx -G/5c^5 (d^3I/dt^3)^2 = -5.5\text{x}10^{-54} (d^3I/dt^3)^2.\text{"} \quad (1)$$

In which -dE/dt is the generated power output of the GW source, P, in watts, c is the speed of light, k in Burdge's notation is G (not, however, the Einstein tensor) the universal constant of gravitation and the units are in the MKS system not the cgs . The two sides of the equation are essentially the same. In this case, for a collection of masses like a dumbbell or a pair of orbiting masses,

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

where

δm = mass of an individual mass [kg] and

r = the radius of gyration of the system of masses [m].

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

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

where f = the force on δm . 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 the masses δm, caused by some electromagnetic or nuclear energizing means, developed in time Δt. The $\Delta f_r/\Delta t$ is conventionally defined as a "jerk" but can also be thought of as a shake or an impulse. In order not to build up acceleration the jerks could be reciprocating; but (arguably) due to the square in the kernel of the quadrupole equation, the GW radiates in both directions perpendicular to the plane of the jerk no matter which direction the masses are jerked. In fact, if the jerks are along the long axis of a bar, then the GWs spread out in a plane perpendicular to the bar's long axis. In summary, the quadrupole formalism of Einstein, which results in the quadrupole-equation approximation for GW power, P, approximately holds for all values of the ratio of the GW wavelength and r, and can be phrased in terms of a jerk as

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

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

$$P = 1.76\text{x}10^{-52}(I\omega^3)^2 = 1.76\text{x}10^{-52}(r[rm\omega^2]\omega)^2 \qquad [\text{watts}] \tag{8}$$

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 the GW 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-ends moves through. Equation (6), like Eqs. (7) and (8), are approximations and might only hold accurately for $r << \lambda_{GW}$ and for speeds of the GW generator components far less than c; but as Kip Thorne suggests, the quadrupole formalism my hold approximately **for almost all values of λ_{GW} and r.**

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

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

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

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 (Attachment 3) 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 $\Delta t = (1/2)(7.75hrx60minx60sec) = 1.395x10^4$ [s]. Thus using the jerk approach:

$$P = 1.76x10^{-52}\{(2r\Delta f_{cfx}/\Delta t)^2 + (2r\Delta f_{cfy}/\Delta t)^2\} = 1.76x10^{-52}(2x2.05x10^9x5.77x10^{32}/1.395x10^4)^2x2$$

$$= \mathbf{10.1x10^{24}} \text{ [watts]} \qquad (11)$$

versus the result of $\mathbf{9.296x10^{24}}$ [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 variations 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!** As an aside, the acceleration at periapsis is over 100 g's for PSR1913+16, so the requirement for weak gravitational fields is not too stringent.

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 (Attachment 6 to these lecture notes) 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 *quadrupole formalism*: the basic physical process for generating a gravitational wave is the third time derivative of the motion of a mass or system of masses (which could be *far apart,* but "connected" physically as in the case of a dumbbell or by gravity as in the case of attractive masses in space) exhibiting a radius of gyration, which we have 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 noted in Attachment 3, that physical process produces a gravitational wave with a power given by, for example, the *quadrupole-equation approximation* (as originally derived by Einstein in 1918) 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 I have already cited. That is, the quadrupole itself is not the physical process at all, but only one means of establishing the power of the gravitational wave. Other algorithms, often most complicated, can define other GW properties such as direction, polarization, constructive/destructive interference, etc. 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, in which a nuclear particle is ejected from a nucleus it is like a small rocket or in the case of electrons shaken in a resonance cavity, plasma beam, superconductor, or a jerk or impulse given to a laser target, the rapid motion of a piezoelectric crystal, etc., there is a third time derivative of the motion of the nucleus or electron mass, target, crystal-lattice molecule or a jerk, which produces a gravitational wave, the "quadrupole formalism," whose power can be estimated, for example, by "quadrupole-equation approximation." Thus when I mention a "quadrupole formalism" 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 or a bar is concerned (harmonic oscillator), gravitational waves are generated as shown by Einstein and Rosen in 1937. 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 (the quadrupole formalism), which can be estimated using a quadrupole-equation approximation, or a series with the quadrupole as the leading term, or computed exactly by means of a rather complicated solution of the equations of special and general relativity.

Applications

4.1 *Propulsion:*

Landau and Lifshitz (1975), in their classical treatise: *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 inanimate object by means of HFGWs and move it.

Bonner and Piper (1997), in their paper entitled "The gravitational wave a rocket" state: "Loss of mass and gain in momentum arises ... because of the emission of quadrupole or octupole GWs." Thus, according to them, one has the potential of propelling a craft by means of GWs.

Fontana (2000), in his paper entitled "Gravitational radiation and its application to space travel" quotes theories that predict GWs can be employed for propulsion, that is, the generation of space-time singularities (see also Ferrari, et al, 1988) with 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" that the spacecraft or other vehicle is repelled by, or "falls into," or "falls toward." Again, HFGWs are proposed as a propulsion means!

4.2 *Communication:*

At least three HFGW detectors or "receivers" are now functional {Cruise and Ingley (2001) Attachment 2 and Gemme, Parodi, and Chincarini (2001-2002) Attachment 3} and *2000:*Fang-Yu Li, 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. Use of a Gaussian beam and filters to detect high-frequency gravitational waves or HFGWs using GW –to-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 – *the higher the frequency the more efficient is the HFGW generation).* And, like the gravitational field itself, GWs 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:*

The possibility of diffraction of HFGWs allows for imaging using the predicted properties of HTSCs for use in communications and propulsion. (Such refractive properties are very controversial, but originally were found by Ning Li and David G. Torr in1992.)

Refractive properties of HTSC, if indeed they exist, also open up the possibility of a **HFGW Telescope**. It may be possible to intensify any anisotropic relic cosmic background features that may exist (MHz to THz) and possibly image HFGW celestial point sources such as: rapid stellar compression shock waves (jerks) and even very speculative, nearer, relic mini black holes – a candidate for *Dark Matter*. Dr. John Miller, who is a professor both at the *University of Oxford* and the *International School for Advanced Studies* (ISAS), Trieste, Italy and a well-known astrophysicist who was a classmate and shared the same mentor with Stephen Hawking, made the following observations: Before reading my paper he was quite skeptical, but now he realized that there might be a possibility of generating HFGWs in the laboratory ... now he felt that this may be quite feasible. With regard to the HFGW Telescope he suggested on May 4, 2002: **"It has been the fashion to look for celestial sources of rather low-frequency GWs... now my**

eyes are opening to the possibility of celestial sources of your high-frequency GWs." He went on to say that "… the possibility that primordial black holes could be interesting sources for frequencies in your range, the point being that characteristic frequencies go like 1/M where M is the mass of the black hole, with frequencies being around 10^3 Hz for a typical stellar mass black hole. You would then need to come down in mass by a factor of 10^6 to reach the GHz range and black holes with those masses could only be produced primordially. However, it is not inconceivable that this might have happened and that some of them might be around *close-by but currently undetected*. This idea is very speculative but not out of the question!   GWs from rather higher mass primordial black holes were discussed by Nakamura et al (*Ap. J. Lett.*, **487**, 139 - 1997) and one might make some similar arguments for lower mass ones. A useful review of primordial black holes will be Carr (*Lect. Notes .Physics*, **631** –in press)."

If intervening matter between the HFGW generator and detector causes a change (even a very slight one) in HFGW polarization, direction (refraction), 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 or building interiors (since HFGWs are far more penetrating than X-rays ever could be) , to a sub-millimeter resolution for THz HFGWs.

5. Recommendations:

5.1 Organize and schedule an *International HFGW Working Group* meeting early next year (2003) in order to trade ideas, stimulate thinking and define experimental parameters.

5.2 Promote an experiment utilizing one or more of the GHz HFGW (or higher frequency) generators from the list presented in the Literature Survey Section, for example a linear array of the piezoelectric crystals under computer control, one of the devices discussed in my *AIAA* paper (Attachment 4), such as the oscillatory spindle, or an opposed pair of laser targets, clusters of piezoelectric crystals, etc. The generator should be appropriately shielded in order to prevent the emission of EM radiation from the energizing elements of the generator, which might trigger a false detection result. In order to assure reliable and non-controversial results, one or preferably more detectors, utilizing different techniques, could be utilized: first, the Chinese detector developed by Fangyu Li, *et al.* at *Chongqing University* (probably the best; Attachment 1); second, the *University of Birmingham's* HFGW detector (Attachment 2); and the third being the *INFN, Genoa*'s HFGW detector (Attachment 3) – the last two detectors could be tuned to 4.9 GHz (a frequency selected for a practical-sized HFGW detector and a piezoelectric-crystal HFGW generator energized by Microwave-oven Magnetrons). The Chinese detector currently exhibits the greatest sensitivity and can be tuned to HFGWs having frequencies from GHz to PHz. Thus laboratory versions of HFGW generators and detectors are ready to be designed and fabricated.

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