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Paper 008

High-Frequency Gravitational Wave (HFGW) Generation by Means of X-ray Lasers and Detection by Coupling Linearized GW to EM Fields

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Abstract. An experiment is described for the generation and detection of High-Frequency Gravitational Waves (HFGWs) in the laboratory utilizing a pair of tabletop X-ray lasers for generation and a coupling system of semi-transparent, beam-splitting membranes with a pulsed Gaussian beam passing through a static magnetic field for detection. The laser axes are coplanar, their pulses are synchronized, and they are aligned in exactly opposite directions. They produce equal and opposite impulsive forces at the laser targets. Essentially, the X-ray lasers emulate a double-star orbit. Photons striking a target will produce a jerk (time rate of change of acceleration) and together with a computer controlled logic system will generate a HFGW spike each time the laser pulses are repeated. Specifications are tabulated for several different X-ray lasers. The focus or concentration point of the gravitational radiation generated by the X-ray laser pairs is located at the midpoint between the laser targets. The HFGW detecting system, proposed by *Chongqing University*, is situated at the HFGW focus. A High-Temperature Superconductor (HTSC) could might possibly concentrate the peak HFGW flux, potentially up to 4.93×10^{24} Wm^{-2} (over a very small detection area). Such large HFGW fluxes may be suitable for future aerospace applications.

INTRODUCTION

Einstein (1915) theorized a revolutionary *spacetim*e fabric or continuum in his general theory of relativity. He called the undulations or waves propagated in this fabric *"gravitational waves"* (Einstein, 1916). He theorized that they propagate at the speed of light and could be generated, for example, by orbiting stars, spinning rods or dumbbells. Gravitational waves (GWs) can be sensed by, for example, the change in lengths measured by extremely sensitive interferometers, piezoelectric crystals, superconductors, resonance chambers, GW to electromagnetic (EM) wave conversion (Gertsenshtein effect, Stephenson (2005)), etc. They have never been directly sensed, however, and some scientists believed that these waves were unobservable artifacts of Einstein's theory. The indirect evidence obtained by J. H. Taylor (1994) and R. A. Hulse concerning their observations of a contracting binary star pair or pulsar PSR 1913+16, which perfectly matched Einstein's GW theory, garnered them the 1993 *Nobel Prize* and the skepticism concerning GW evaporated. According to a set of definitions provided in Chapter 3 of the basic text by Hawking and Israel (1979), High-Frequency Gravitational Waves (HFGWs) have frequencies in excess of 100 kHz and have the most promise for terrestrial generation and practical, scientific, and commercial application. As discussed in Baker (2001), p. 43, the effectiveness of a GW communications system is proportional to the forth to sixth power of the GW frequency. Thus 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 technology. Thus LFGW detectors such as LIGO, VIRGO, LISA, GEO600, DECIGO (Japan), CEGO (China), *et al.,* are totally irrelevant and *useless* for HFGW detection.

The objective of the current effort is to generate and detect HFGW in the laboratory. This paper analyzes the feasibility of reaching this objective. We emulate the scientifically accepted GW generation process by means of a pair of orbiting masses (neutron stars to black holes) by a pair of jerked masses (time rate of change of acceleration conventionally referred to as a "jerk"). These masses or "targets" are jerked in equal and opposite directions by the impact of equal and opposite X-ray laser pulses. In effect the change in centrifugal force, Δf_{cf}, as the orbiting masses move (the orbital jerk) is emulated by the impulsive, Δf_t, acting on the laser targets. We visualize a circle whose diameter is the distance between the laser targets in a plane that is defined by the two coplanar laser beams acting on the laser targets. The Δf_t's act tangential to this circle just as the Δf_c's act tangential to a pair of masses moving on a circular orbit. Figure 1 is a schematic of the situations. The GW radiation pattern is shown in red and, as discussed in Baker, Davis, and Woods (2005), in three dimensions resembles a dumbbell. In the present case there is a single pair of targets (rather than a sequentially energized, asymmetrically distributed set of targets around a ring) and the pattern is a dumbbell cross section or slice having a diffraction-limited thickness. The axis of the radiation pattern is normal to the plane of the circle through the center. At each target site there are two lasers, one on each side of the target, that alternate their pulses since if continually jerked in one direction, then acceleration (and attendant velocity and displacement) would build up. In the case of the jerking, but overall stationary X-ray laser targets, the circle radius is much larger than the HFGW wavelength, but as discussed in Baker, Davis, and Woods (2005) and by Grishchuk (2003) the quadrupole approximation to the generated GW power still holds. Hopefully, the laser targets will withstand more than one pulse (or, if a gas, then cool sufficiently between pulses to allow repetition), but the experiment might successfully detect a single pulse, analogous to the astrophysical LFGW-detection case of a binary black hole coalescence and ring-down or the collision of a black hole and a star on a rectilinear hyperbolic trajectory single event. Essentially, each X-ray laser pulse striking a target produces a build up of force, Δf, over a brief time period, Δt. This is commonly referred to as a "jerk" and results in the generation of a single gravitational wave (GW) pulse. As just indicated, if a target does not survive the strike, then only this single pulse will be generated. If the target does survive the strike, then a GW pulse will be generated at each successive strike. The shape of these GW pulses will, of course, depend upon the characteristics of X-ray laser pulse, but it will mainly be contained in the Δt time duration of the laser pulse. The GW wavelength, $\lambda_{GW,}$ is essentially the GW pulse duration, Δt, multiplied by the speed of light, c. This is analogous to the conventional calculation of the GW wavelength generated each half cycle (half orbital period) of an orbiting star pair or the half period of a rotating rod (Weber, 1964). If there were a multitude of laser target pairs, sufficient to generate one GW pulse after another (similar to GWs generated by a rotating rod), then one would have continuous GW rather than a train of discrete GWs or, in other words, rather than pulsed GW.

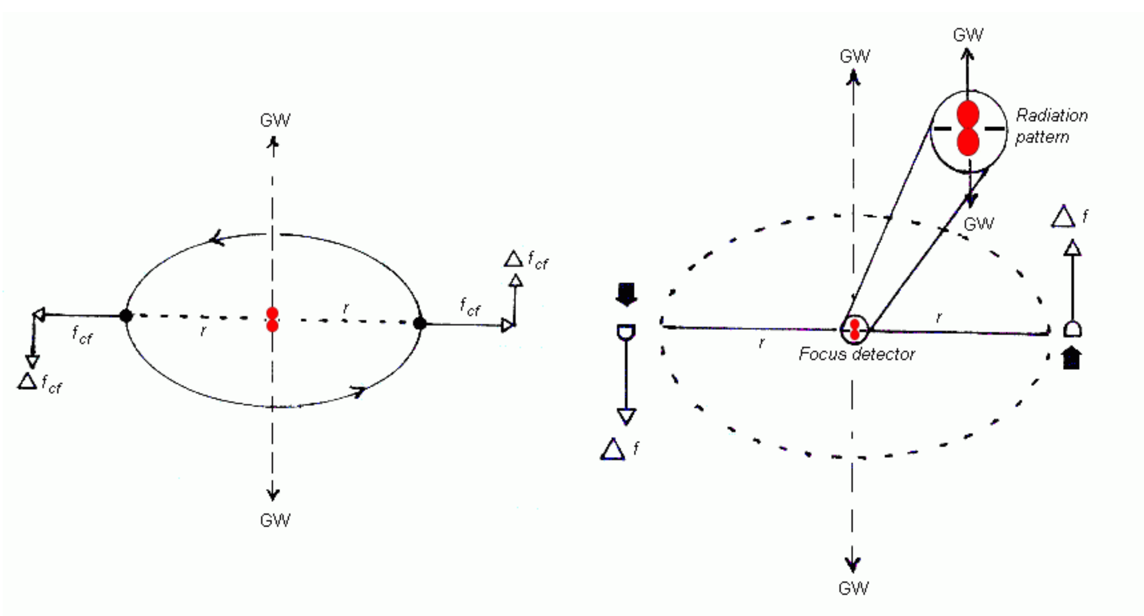

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FIGURE 1. Emulation of Two Massive Orbiting Bodies by Two Opposed X-Ray Lasers.

Once the epoch-making experiment to generate and detect HFGW is completed successfully, ultra small accelerometers (such as one utilizing MEMS and sensitive to less than a μg, according to Waters and Jones (2004)) will be introduced at the very small focal spot of the HFGW generator to sense the gravitational-field modification as a function of HFGW frequency, amplitude, polarization, and duration. A computer-controlled logic system will be introduced to modulate the generated HFGW by changing the X-ray laser's repetition rate and a communications system will be experimentally studied with various distances between generator and detector and various HFGW pulse durations, amplitudes, and polarizations.

X-RAY LASER HFGW GENERATOR FOR EXPERIMENT

The details of the derivation of the HFGW generation equations are to be found in Baker (2000; 2001; 2003; 2005) and a description of the tabletop X-ray generator approach to be studied is to be found in the Appendix of Baker, 2004. There is no new Physics here, simply a different approach or formulation to render engineering applications more apparent. From an extension of Einstein's General Theory of Relativity (Einstein, 1916) the power of a GW generator is given by his quadrupole equation -- an *approximation* to the *power* of GWs that are ***generated by a rapid change in acceleration***. The quadrupole is *not* the GW generation process itself (Einstein, 1916; Einstein and Rosen, 1937), it is the lowest-order solution to the GW propagation problem and mass motions that have quadrupole moments are the most effective GW generators. There are, of course, other means to generate GWs besides mass motion, for example the Gertsenshtein (1962) EM to GW effect. The quadrupole approximation to GW power can be phrased as

$$P(r, \Delta f, \Delta t) = 1.76\text{x}10^{-52}\,(2r\Delta f/\Delta t)^2 \quad \text{W}, \tag{1}$$

which is the *jerk formulation of the quadrupole equation* and for a constant mass, δm, $\Delta f/\Delta t = \delta m\, \Delta(\text{acceleration})/\Delta t$, so that the equation states that a third time derivative is imparted to the motion of the mass such as a laser target (this is conventionally referred to as a "jerk" or time rate of change of acceleration). In Eq. (1) r is the radius of gyration of the pair of masses (two laser targets – half of their distance apart) in meters (about 10 m for the proposed experiment), Δf is an incremental increase in force on a mass in Newtons during an incremental time period, Δt, in seconds. The basic concept is to utilize a tabletop X-ray laser to impart a Δf to a target by means of a very brief duration laser pulse, Δt. As has been noted, the centrifugal-force jerk tangential to the orbit of two orbiting masses is analogous to two fixed masses jerked in opposite directions perpendicular to the line joining them. In the first, orbital case, the jerk is occasioned by a gravitational force and in the second, laser-target-jerked case, by an electromagnetic force that is 10^{35} times larger than the gravitational force. In this regard, it is important to recognize that Δf need *not* be gravitational force (Einstein, 1916; Infeld, quoted by Weber, 1964, p. 97). The concept is to focus the generated HFGW in as small an area as possible at the focal spot midway between the two juxtaposed laser pairs (whose targets are the jerked masses) in order to achieve a large HFGW flux (as measured in Wm^{-2}) for detection. For convenience we shall utilize two tabletop X-ray lasers some 20 m apart (r =10 m). The laser pulse (essentially an energizing element) will strike a small target (energizable element) and produce a force given by Δf = photon flux (photons per unit time) times momentum transferred to the target per photon. The momentum of a given photon is $h/\lambda_{EM} = h\nu/c$, where h is Planck's constant = $6.62\text{x}10^{-34}$ Js, λ_{EM} is the wavelength of the light or X-ray in meters, ν is the frequency of the light 1/s,and c is the speed of light m/s. As an explicit example let us consider a one-thousand watt (estimated), 760 nm pulse/wavelength, 20 fs pulse duration (one fs = 10^{-15} s), and 100 MHz repetition rate X-ray laser (Shelton, *et al.*, 2001). The energy of a photon is hc/λ_{EM} so that one photon of 760 nm wavelength has an energy of $(6.62\text{x}10^{-34}\text{ Js})(2.998\text{x}10^{8}\text{ m/s})/760\text{x}10^{-9}\text{ m}) = 2.61\text{x}10^{-19}$ J. Since one watt is one J/s, the number of photons per second is $10^3/2.61\text{x}10^{-19} = 3.83\text{x}10^{21}$. At a repetition rate of 100MHz they are divided up into $100\text{x}10^6 = 10^8$ pulse packets in each second. Thus there are $3.83\text{x}10^{21}/10^8 = 3.83\text{x}10^{13}$ photons per pulse packet. Each transform-limited pulse lasts approximately $20\text{x}10^{-15}$ s so there are $(3.83\text{x}10^{13}/20\text{x}10^{-15}) = 1.91\text{x}10^{27}$ X-ray photons per second, and if there is no reflection at the target (total absorption), then

$$\Delta f = (h/\lambda_{EM})(\text{photons per second}) = (6.62\text{x}10^{-34}/760\text{x}10^{-9})(1.91\text{x}10^{27}) = 1.\ 67\text{ N}. \tag{2}$$

This X-ray photon flux and attendant Δf will be delivered over the pulse time, Δt, of approximately twenty femtoseconds. Thus the peak HFGW power from Eq. (1) with 2 targets is

$$P = 1.76\text{x}10^{-52}\,(2\text{x}10\text{x}2\{\text{targets}\}\ \text{x}1.67/20\text{x}10^{-15})^2 = 1.96\text{x}10^{-21}\ \text{W}. \qquad (3)$$

Table 1 presents some representative values of current X-ray laser technology listed in chronological order; but it is not meant to be comprehensive. The theoretical extrapolations of current technology, found in the last two rows, are extrapolations that may be achieved with an advance in the current state of the art. For example, if one were able to achieve a one-femtosecond pulse duration (as suggested in Drescher, *et al.*, 2001) extrapolated to a MHz repetition rate, one kilowatt power, and a 760 nm wavelength, then there would be $3.83\text{x}10^{15}$ photons per pulse or packet (the 100MHz repetition rate reduced to 1 MHz). Note that (photons/pulse)(J/photon) = $(3.83\text{x}10^{15})(2.61\text{x}10^{-19}) = 10^{-3}$ J laser. In the one femtosecond pulse there are $3.83\text{x}10^{15}/1\text{x}10^{-15} = 3.83\text{x}10^{30}$ photons-per-second pulse-photon rate. Thus $\Delta f = \{(6.62\text{x}10^{-34})/(760\text{x}10^{-9})\}\text{x}4.05\text{x}10^{30} = 3.34\text{x}10^{3}$ N, which is an extremely forceful strike on the target. Such one-femtosecond ultra-short pulses are not monochromatic; they involve a wide range of wavelengths and energies and contain only a fraction of a cycle, e.g., $1\text{x}10^{-15}c/760\text{x}10^{-9} = 0.395$, so smaller wavelength X-rays, such as suggested in the theoretical X-ray laser of Table 1, might be required (however, for a given Δt, repetition rate, and laser power, the Δf is independent of the wavelength of the electromagnetic laser, λ_{EM}). Two of these lasers oppositely directed and accurately positioned 20 meters apart could generate 54.7 Wm^{-2} peak power flux at a detector at the focus. The detector averages this input flux over an area that is the focal-spot size. Such a flux might be detectable by the *Chongqing* instrument. For the theoretical X-ray laser, at a diffraction-limited focus spot of area $\lambda_{GW}^2/\pi = 2.86\text{x}10^{-16}\ \text{m}^2$ (Saleh and Teich, 1991), the flux would be huge, some $5.48\text{x}10^{19}\ \text{Wm}^{-2}$, and probably more detectable; but there is the question of how to obtain that small of a detector Gaussian-beam cross-sectional area.

Refractive properties, which lead to the concept of HFGW optical systems, were first published by Ning Li and David G. Torr, in 1992 in which on p. 5491 they demonstrated that the phase velocity of a GW, v_p, was reduced by a factor of about 300 in a superconductor (actually, about a factor, termed the index of refraction, N, of 400±200). This paper was peer reviewed and examined by C. A. Lundqist and Jeeva Anandan, but their results are disputed by Kowitt (1994. Fontana (2004), however, suggests that there is some change in the phase velocity in a SC and an attendant increase in the index of refraction, N. Thus we will keep the question open. This process could serve to concentrate the HFGW and reduce the diffraction-limited spot size. *Specifically, if a High Temperature Superconductor or HTSC wafer encloses the focus, then the focal-spot area is reduced by the index of refraction of the HTSC, N (theoretically 300 for HFGW) squared to ~ $3.17\text{x}10^{-21}\ m^2$ (about one third of the "area" of a hydrogen atom). Thus the HFGW flux is increased to $4.93\text{x}10^{24}\ Wm^{-2}$ and there may be some fundamental physics problems that such a HFGW generator could address.* (Please see section 6 of Baker, 2003.) There is also the possibility that there exists Fresnel reflection at the air-HTSC interface surrounding the target as noted in Baker, Davis, and Woods (2005). Although HFGW Fresnel reflection may be speculative, especially for GW pulses, such a possibility is deserving of theoretical study as is the study of the possible anti-reflection quarter-wave $\sqrt{N}$ coating at the air-HTSC interface. Also one might utilize a HTSC wafer constructed by nano-fabrication or assembly of a well-defined set of discrete molecular layers (the nanostructure in a plane perpendicular to the line between the laser targets), integers of half λ_{GW}s thick (in order to cancel reflection), of the MgB_2 or other HTSC enclosing the submicroscopic, high-flux, focal-spot location.

Several alternative existing tabletop X-ray generators and their relative powers and fluxes are given in Table 1. The most recent published results are listed first. Also the extrapolated and theoretical lasers are included at the end of the Table. Please note that the theoretical X-ray laser is the most energetic and exhibits the highest flux. The microwave laser exhibits the largest diffraction-limited spot (diameter of 2.5 cm) at the focus, but the smallest HFGW average power and flux.

TABLE 1. Tabletop X-ray HFGW Generator Specifications.

Reference	**Laser Wave-length, nm λ_{EM}**	**Laser Rep Rate, MHz & Pulses Per s**	**Laser Average Power, W**	**Laser Pulse Duration, Δt, fs, & λ_{EM}'s in a pulse width**	**Peak & Average HFGW Power, watts, for r =10m**	**Peak Flux Diffraction -Limited Focus Free Air, Wm^{-2} & Δs m^2 N = 1**	**Peak Flux HTSC-Enclosed Focus, Wm^{-2} & Δs m^2 N = 300**
Kuroda (2003)	18.9	10^{-5} & 10	204	475 & 7535	2.56×10^{-14} & 1.27×10^{-25}	1.98×10^{-6} & 6.45×10^{-9}	0.179 & 7.17×10^{-14}
Constant (2003)	800	10^{-3} (Est.) & 1000	10 (Est.)	11 & 4.12	2.14×10^{-14} & 2.35×10^{-25}	3.09×10^{-3} & 3.46×10^{-12}	278 & 3.85×10^{-17}
Korn (2002)	780	10^{-3} & 1000	1.8	50 & 19.2	1.62×10^{-18} & 8.12×10^{-29}	1.13×10^{-8} & 7.15×10^{-11}	1.02×10^{-3} & 7.95×10^{-16}
Lin (2001)	25.5	$\geq 10^{-3}$ & $\geq$1000	200	100 & 1176	1.25×10^{-15} & 1.25×10^{-25}	2.19×10^{-6} & 3.46×10^{-10}	0.197 & 3.18×10^{-15}
Drescher (2001)	770	10^{-3} & 1000	1 (Est.)	7 & 2.72	1.30×10^{-15} & 9.13×10^{-27}	4.65×10^{-4} & 1.40×10^{-12}	41.9 & 1.56×10^{-17}
Extrapolated	760	1 & 10^6	10^3	1 & 0.395	3.13×10^{-12} & 3.13×10^{-21}	54.7 & 2.86×10^{-14}	4.93×10^6 & 3.17×10^{-19}
Shelton (2001)	760 (810)	100 & 10^9	10^3 (Est.)	20 & 7.90	1.96×10^{-21} & 3.92×10^{-27}	8.56×10^{-11} & 1.44×10^{-11}	7.70×10^{-6} & 1.27×10^{-16}
Li, Yuelin (2000)	19	4×10^{-9} & 0.004	1 (Est.)	1000 & 1.58×10^4	1.96×10^{-13} & 7.83×10^{-28}	3.42×10^{-6} & 2.86×10^{-8}	0.308 & 3.17×10^{-13}
Rocca (2000)	800	10^{-3} (Est.) & 1000	1000 (Est.)	50 & 18.7	5.01×10^{-13} & 2.51×10^{-23}	3.50×10^{-3} & 7.15×10^{-11}	315 & 7.95×10^{-16}
Li, Ruxin (1999)	19	10^{-5} & 10	10	100 & 1578	3.13×10^{-14} & 3.13×10^{-26}	5.47×10^{-5} & 2.86×10^{-10}	4.93 & 3.17×10^{-15}
Theoretical Microwave	1.31×10^7 (1.31 cm)	10^{-7} & 0.1	100	1.31e5 & 3	1.06×10^{-20} & 1.39×10^{-31}	1.08×10^{-17} & 4.91×10^{-4}	9.75×10^{-13} & 5.45×10^{-9}
Theoretical X-ray	10 (100Å)	10^{-7} & 0.1	100	0.1 & 3	3.13×10^4 & 3.13×10^{-13}	5.48×10^{19} & 2.86×10^{-16}	4.93×10^{24} & 3.17×10^{-21}

Of the HFGW generators considered so far (discussed in Baker 2000 and 2004)); the X-ray laser device has the most promise, but also several developmental risks. An X-ray laser of the theoretical specification needed is just on the threshold of the state of the art. The promise of "tabletop" X-ray lasers was discussed on p.1357 of the November 15, 2002 issue of *Science.* Note that it may be important to have at least one EM wavelength in a GW pulse length. The number of wavelengths in a pulse is exhibited in Table 1. If this requirement is not met, as in the extrapolated Drescher laser, then the fractional wavelength is given in red; but this restriction should be theoretically studied. The endurance of the targets needs to be estimated for various target materials including gases such as Krypton. The ability to synchronize the laser bursts to a fraction of a pulse duration should also be assessed. The laser targets need to be roughly positioned abreast and the lines of action of the target jerks (and, therefore the X-ray laser beams) should be coplanar, parallel, and oppositely directed. Only the long-light-pulse laser axes need to be coplanar (to an accuracy of a fraction of a HFGW wavelength) not the complete target locations. The focus would be defined accurately after installation. The influence of the relative size of the dimensions of the energizable elements and r should be studied theoretically in order to validate that their size relative to λ_{GW} is not important. Also the speculative refraction and Fresnel-effect reflection of the HFGW waves by an HTSC (Baker, Davis, Woods, 2005) and possible techniques for fabricating quarter-wave anti-reflection coatings and/or thin half-wavelength wafer by nano-manufacturing techniques should be considered.

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HFGW DETECTOR FOR HFGW EXPERIMENT

As previously mentioned, LFGW detectors do not work for HFGW detection. For example LIGO's advertised GW frequency sensitivity is 40Hz to 2000Hz. As noted by Shawhan (2004) "At higher frequencies, the quantum nature of the laser beam (made of discrete photons, albeit a large number of them) limits the precision of the measurement. Increased laser power would reduce the problem of quantum noise, but ultimately the LIGO (and other) interferometers are not suited to measuring gravitational waves that stretch or shrink the arms much more rapidly than the time a photon typically remains in the optical cavity, which is roughly a millisecond for these interferometers." The *Chongqing University* HFGW detecting scheme is the most promising for this proposed experiment. In general terms this detector relies on the electromagnetic (EM) response to the HFGW. The detector is a coupling system of semitransparent beam splitters and a narrow pulsed Gaussian beam passing through a static magnetic field at the focal spot of the HFGW generator. Fang-Yu Li, *et al.,* (2003) at *Chongqing University* in China found that "…under the synchroresonance condition, the first-order perturbative EM power fluxes (photon fluxes) will contain a 'left circular wave' and a 'right circular wave' around the symmetrical axis of the Gaussian beam, and they and the background photon fluxes have a very different physical behavior (e.g., propagating direction, polarization, distribution and phase) in the local regions." This Chinese detector design is, thus far, the most desirable for this proposed experiment. Figure 2 is a schematic exhibiting the Gaussian EM beam and the static magnetic field encompassing the focal spot of the HFGW generator. In order to screen out any unwanted EM (that might give rise to false HFGW detection) the entire Chongqing detector apparatus could be enclosed in a Faraday cage. One would also look for correlations between the detector measurements and the known signal pattern of the X-ray laser HFGW generator in order to improve detection.

The entire apparatus would consist of two laser targets (including possibly gaseous targets). These targets would need to be designed to withstand very forceful strikes by energetic X-ray laser pulses. The targets would be separated by about 20 meters and would face in exactly the same direction. Imagine a 20-meter diameter circle with the laser targets positioned on the circle exactly across from each other; that is abreast. On each side of each target would be positioned two tabletop X-ray lasers, facing each other. Thus there would be four lasers, two on each side with their beams exactly parallel. Simultaneously two of the lasers on opposite sides of the circle would fire. Their laser beams exactly anti parallel or oppositely directed. Once the targets are struck by the laser pulses they are jerked in opposite directions, tangential to the 20-meter diameter circle. This process generates a GW. In order not to build up acceleration, speed, or displacement of the targets the other two lasers are simultaneously fired next, striking the other side of the targets and a second GW is generated. In advanced designs of the HFGW-generator apparatus many more laser/target sets could be positioned on the circle and the circle could be enlarged. The focus of the GW is at the center of the circle (or exactly between the two targets) according to the analyses of Baker, Davis, and Woods, 2005. This then is the location of the detector, which consists of a very narrow Gaussian beam (exhibiting a cross section about the size of the focal spot) and the cross-wise static magnetic field shown in Fig. 2. The HTSC optical concentrator would enclose the focal spot in order to greatly reduce its size and increase the HFGW flux if the speculative HTSC phase-velocity reduction exists.

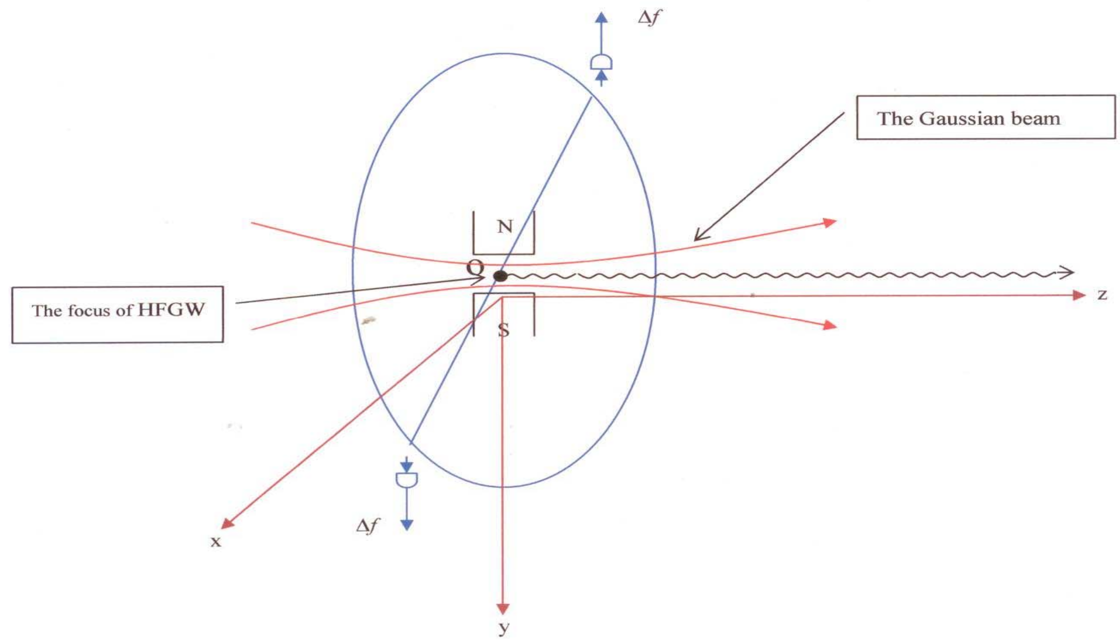

FIGURE 2. Schematic of the Chongqing University Detector.

Although the phase velocity of the GW may be reduced in superconductor by approximately a factor of 300 (Li and Torr, 1992), the GWs (gravitons) and EM waves (photons) have the same group velocity, thus the resonant condition in a superconductor may still be valid or be basically valid. For the pulse Gaussian beam (or a pulse quasi-Gaussian beam) with a duration of $10^{-13}s = 100\,fs$; if it keeps output energy at 10J, then the instantaneous power of the pulse Gaussian beam can reach up to 10^{14} W. If the focus of the HFGW is surround by the mosaic HFSC, then the power flux density of the HFGW of $\nu = 1.5\times10^{16}\,Hz$ at the focal spot might reach up to $F_{gw} = 2.5\times10^{9}\,Wm^{-2}$ at least (5.48x10^{19} Wm^{-2} for N = 1, from Table 1). Here we choose the static magnetic field of $\hat{B}^{(0)} = 3T$ and the pulse Gaussian beam of the spot radius $W_0 = 0.25cm = 2.5\times10^{-3}\,m$, so that the amplitude of electrical field of the Gaussian beam will be $\psi_0 \approx 4.38\times10^{11}\,V/m$. The amplitude or magnitude of the HFGW with angular frequency ω can be given by (Landau and Lifshitz, 1975, p.347)]

$$A = (\frac{8\pi G F_{gw}}{c^3\omega})^{\frac{1}{2}} \approx 7.88\times10^{-18}\frac{F_{gw}^{\frac{1}{2}}}{\omega}. \tag{4}$$

For the HFGW of $F_{gw} = 2.5\times10^{9}\,Wm^{-2}$, from Eq. (4) we have $A = 2.63\times10^{-29}$. Using such values, Eq. (4) and the approximate form for the perturbative power flux density (the perturbative photon flux density (PPF)) propagating along the x-axis (see Fang-Yu Li *et al.,* 2003), we obtain

$$F_x^{(1)} \approx \frac{1}{\mu_0}A\hat{B}_y^{(0)}\psi_0 = 2.75\times10^{-11}\,Wm^{-2}, \tag{5}$$

and

$$n_x^{(1)} \approx \frac{F_x^{(1)}}{h\nu} = 2.76\times10^6 s^{-1}m^{-2} . \qquad (6)$$

In this case even if considering the PPF passing the effective receiving area (the diffraction region) $\Delta s \approx (\Delta D)^2 (\Delta D = 1.22c\Delta t/2 = 1.83\times10^{-3} cm)$, or $\Delta s = \pi(c\Delta t/\pi)^2$ (please see Saleh and Teish, 1991) we still have

$$N_x \approx N_x^{(1)}\Delta s \approx 9.25 s^{-1} . \qquad (7)$$

If $\hat{B}^{(0)} = 10T$ (this is completely possible in such much small area), then we have $N_x \approx 30.43 s^{-1}$.

It is remarkable that because the PPF and the background photon fluxes have different propagating directions in the local regions, using the special semitransparent beam splitter (its reflectivity for the x-ray of $\nu = 1.5\times10^{16} Hz$ can reach up to 0.7, Montcalm *et al.,* 1998), the PPF can be pumped out from the background photon fluxes, and since the decay velocity of the background photon fluxes is much faster than that of the PPF (Fang-Yu Li, *et al.,*2003), so that we might obtain a good signal-to-noise ratio, which would be obviously larger than one at $x = 2cm$ (x is the distance to the beam splitter). In other words the terminal receiver would get an almost pure PPF (signal) of $30.43\times0.7 = 21.30 s^{-1}$ at $x = 2cm$. At a repetition rate of $10Hz$ the pulse Gaussian beam can be divided up into 10 pulse packets in each second, thus there are two photons per pulse packet or if a repetition rate of 0.1 Hz, then there would be 213 photons per pulse packet. Because the energy of single photon in the x-ray band is quite high, either case is very satisfactory! As Stephenson (2004) states "... even though the conversion efficiency (detection sensitivity) is falling off with frequency, it is more than made up by the fact that a higher frequency source can provide a more concentrated beam in cross-sectional area, giving a stronger power per unit area – essentially they have an inverse (GW to EM) Gertsenshtein effect." (Please also see, p. 85, of Gertsenshtein, (1962).) Stephenson (2004) also points out that "The topic (of GW to EM conversion and non-gravitational-force generation of GWs) appears to have continued in the main stream of Astrodynamics for some 30 or 40 years now... including the papers of Boccaletti (1970), Gerlach (1974), Zel'dovich (1974), Tatsuo Tokuoka (1975), Macedo and Nelson (1983), Brodin and Marklund (1999), Papadopoulos, *et al.* (2001), Moortgat (2003) and several others as found on the Internet site: www.gravewave.com." Of course, non-mainstream concepts realize many significant breakthroughs in natural science.

APPLICATIONS TO AEROSPACE

The objective is to accomplish an experiment to generate and detect HFGW in the laboratory. The benefits of such an experiment are in the context of future space missions. The utilization of remote HFGW generators to modify the gravitational field near an object or spacecraft results directly from the work of Landau and Lifshitz (1975). On page 349 of their fundamental (and internationally recognized authority on gravitational radiation) treatise, they 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 by means of HFGW and move or perturb it. And thus there exists a completely new means to propel a spacecraft – interplanetary and interstellar or perturb a rogue comet or minor planet to a safe orbit! Fontana (2004) has presented the specific analyses of this form of propulsion. With regard to the utilization of HFGW generators as a completely new means of space communication, Thomas A. Prince (2002), 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, especially with large HFGW fluxes, would represent the *ultimate wireless system:* point-to-multipoint PHz communication without 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. Thus future space missions would make use of the revolutionary new paradigm: *HFGW Communications!*

CONCLUSIONS

A description of the fabrication and test of a precursor HFGW generation/detection apparatus, utilizing tabletop X-ray lasers, has been broadly outlined. Its construction does not involve any insurmountable tasks; in fact, the project seems quite straight forward and within the current state of the art. There are, however, seven analytical tasks that remain. First, the need to characterize the actual sensitivity of the detectors to the short-pulse HFGW is warranted, especially with regard to spot size at the generator's focus and detector's Gaussian-beam cross section. Second, a more accurate analytical estimate of the possible change in HFGW phase velocity through a HTSC should be accomplished in order to more precisely define the HTSC index of refraction as well as any possible Fresnel-effect reflection of the HFGW pulses at the air-HTSC interface and the value and realization of a quarter-wave anti-reflection coating or half-wavelength-thick HTSC wafers surrounding the focal point if there exists any Fresnel reflection of the pulses. Third, the ability to accurately align the X-ray laser beams so that they are coplanar and synchronized must be studied. Forth, the pulsed Gaussian beam of the detector must be synchronized with the laser pulses and its focus coincident with the HFGW generator's focal spot and the approach to accomplishing this also needs investigating. Fifth, an analytical study should be mounted to establish the influence of the size of r relative to λ_{GW} on the generation of GW and the accuracy of the quadrupole equation. Sixth, the endurance of the X-ray laser target material (including a gas) under extremely forceful X-ray laser pulses should be studied and resolved. Seventh and finally, the requirement for multiple EM X-ray wavelengths in a GW pulse length and shape of the GW pulse should be analytically estimated.

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NOMENCLATURE

A = GW amplitude magnitude
$\hat{B}^{(0)}$ = background static magnetic field (T)
c = speed of light, $2.998\text{x}10^{8}$ (ms^{-1})
$F_x^{(1)}$ = Perturbative EM power flux density (Wm^{-2})
F_{gw} = HFGW power flux density (Wm^{-2})
h = Planck's constant, $6.26\text{x}10^{-34}$ (Js)
$n_x^{(1)}$ = perturbative photon flux density $(s^{-1}m^{-2})$
N = GW index of refraction in a superconductor
$N_x^{(1)}$ = perturbative photon flux (s^{-1})
P_0 = peak HFGW power (W)
P = instantaneous (peak) power of the Gaussian beam (W)
r = radius of gyration of the HFGW generator's energizable elements or the distance between the laser targets and their midpoint (m)
W_0 = spot radius of the Gaussian beam (m)
Δ = small increment
Δf = incremental force change over time Δt (N)
Δf_{cf} = incremental centrifugal-force change (N)

Δf_t = incremental laser-target force change (tangent to a circle defined by a diameter that is the distance between the targets in a plane defined by the coplanar laser beams) (N)
Δs =spot size or area of the diffraction-limited HFGW-generator's focus (m^2)
Δt = time increment for build up of Δf (s)
Ψ_0 = amplitude of the electrical field of the Gaussian beam (Vm^{-1})
λ_{EM} = wavelength of EM X-rays (m)

λ_{GW} = pulse or wavelength of the HFGWs (m)
μ_0 = permeability of free space, $4\pi x10^{-7}$ ν = frequency (s^{-1}) or phase velocity (ms^{-2})

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