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Ultra-High-Intensity Lasers for Gravitational Wave Generation and Detection

R.M.L. Baker, Jr.[1], Fangyu Li[2] and Ruxin Li[3]

[1]GRAVWAVE® LLC, 8123 Tuscany Avenue, Playa del Rey, California 90293, USA,
[2]Department of Physics, Chongqing University, Chongqing 400044, P.R. China
[3]Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, P.R. China
[1] (310) 823-4143, robert.baker.jr@comcast.net

Abstract. Ultra-high-intensity lasers are used to generate and detect short-pulse or high-frequency-gravitational-waves (HFGWs) in the laboratory. According to accepted definitions HFGWs have frequencies in excess of 100kHz (pulses less than 10μs duration) and may have the most promise for terrestrial generation and practical, scientific, and commercial application. Shanghai-Institute-of-Optics-and-Fine-Mechanics' (SIOM) lasers are described whose action against targets emulates a double-star system and generates a GW flux at a focus midway between two such GW-generation lasers. The detector is a coupling-system of semitransparent beam-splitters and a narrow, 2.5-millimeter-radius, pulsed-Gaussian-laser-detection beam passing through a static 15T magnetic field. It is sensitive to GW amplitudes of $\sim 10^{-32}$ and detects the 10^{-17} to $\sim 10^{-32}$-amplitude GWs to be generated, with signal-to-noise ratios greater than one The experimental approach, which involves new mechanisms (e.g., high-intensity lasers causing $\geq 1.5\times10^5$N-impulsive force on laser targets), is quite different from previous work involving older technology. It is concluded that the GW-generation and detection apparatus is now feasible and will result in a successful laboratory experiment to test theory and this paper will serve to attract ideas from various disciplines to improve the prospects for a successful experiment. As a space technology application, if the Ultra-high-intensity lasers were space borne and at lunar distance (e.g., at the Moon and the lunar L_3 libration point) and the quadrupole formalism approximately holds for GW radiators (laser targets) many GW wavelengths apart, then the HFGW power would be about 2×10^3 W and the flux would be about 10^{13} to 10^{14} Wm^{-2} during each pulse at an infinitesimal focal spot between the laser targets. The focal spot could be located at any point on or below the surface of the Earth by adjusting the laser timing and laser target orientations.

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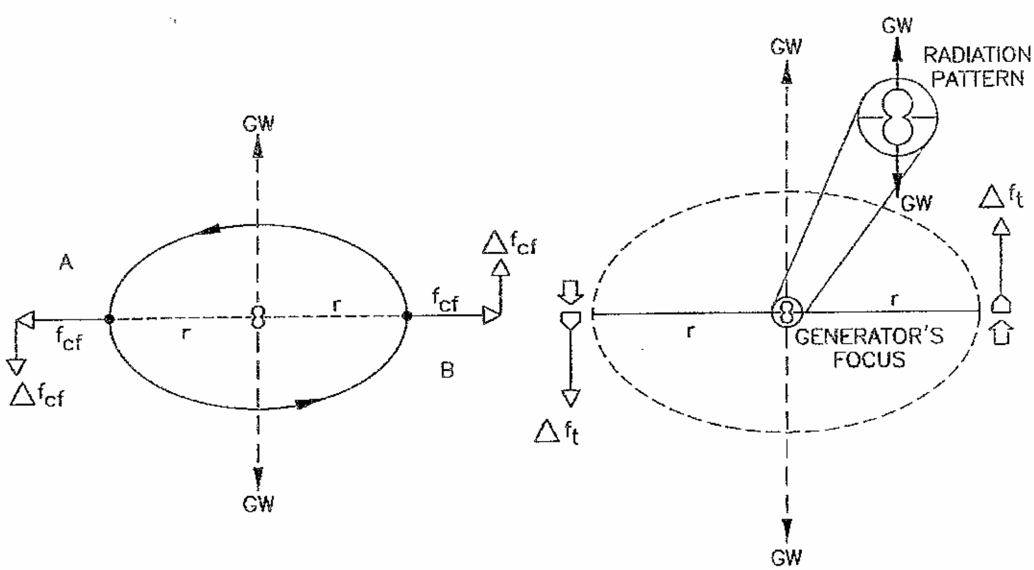
INTRODUCTION

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. The roots of HFGW research are similar to the roots of low-frequency-gravitational-wave (LFGW) research, which has spawned the LIGO, Virgo, GEO600, and other such projects as well as the proposed LISA experiments – all essentially proposals to detect gravitational waves (GWs). Einstein's paper (1916) , which first suggested the existence of GWs, and the research of Joseph Weber (1964), Robert Forward and R. L. Miller (1966), M. E. Gertsenshtein (1962), L Halpren and B. Laurent (1964), Heinz Dehnen and F. B. Romero. (1981), and others commencing in the 1950s, examined the astrophysical generation of LFGW and, especially, the laboratory generation and/or detection of HFGW. Just as the extensive LIGO project has so far not detected LFGWs, there has not yet been an unequivocal demonstration of generating and detecting HFGWs. The present paper is prompted by the increasing likelihood of laboratory-scale generation and detection of HFGW in the near future due to the advent of new laser technology. In Baker and Li (2005) the use of X-ray lasers was suggested for the generation of HFGWs. Here we utilize ultra-high-intensity lasers for that purpose. The *Shanghai Institute of Optics and Fine Mechanics'* (SIOM) ultra-high-intensity lasers are described (Aoyama, et al.(2003) and Yang, (2002)) whose action against a target emulates a double-star system and generates a GW flux at a focus midway between two such GW-generation lasers according to

Landau and Lifshitz (1975). (By utilizing the *SIOM*-laser procedure the intensity at laser focus was recently obtained up to 10^{20}W/cm^2 by using a beam-shaping method, Aoyama, et al. (2003). Even greater laser power P approaching 10^{15}W on a single shot basis from a compact-laser facility is possible.) In *SIOM* an output of 120TW or more (five to ten times larger than the laser power considered for the current experiment and 25 to 100 times more GW power), over 33.9fs to 36fs time interval Δt has recently been predicted. A scheme of parametric amplification of chirped pulse was proved to deliver 10^{13}W pulses (Yang, (2002)) and could be much more powerful. This might be used to generate intense-ultra-short laser pulses at other interesting wavelength beyond the limitation of current 800nm, 0.5μm or 1μm for use in the current experiment at pulse repetition rates (PRRs) of 10Hz. Good results for GW frequency $\nu_{GW} = 1/\Delta t$ (29.5THz), can also be obtained with PRR = 0.01Hz, distance between laser target 2r = 20km, detector exposure time factor of 20 (1000s observation time spans), 280TW power, the incident power on the target is 9.5 watts, with a pulse durations of Δt = 67.8 ps. Note that the total-laser-output energy in a $\Delta t = 33.9$fs pulse-duration is only $\Delta E \sim P\Delta t = 2.3\text{x}10^{13}\text{x}3.39\text{x}10^{-14} = 0.78$J, a small enough energy not to damage the laser target (the incident power on the target is only $\Delta E(1\text{-}R)\text{xPRR} = 0.4$W, where target reflectivity R = 0.95)). The Chinese-HFGW detector is a coupling-system of semitransparent beam-splitters and a narrow, 2.5-millimeter-radius, pulsed-Gaussian-laser-detection beam passing through a static 15T magnetic field. It is sensitive to GW amplitudes of $\sim 10^{-30}$ and detects the 10^{-17} to $\sim 10^{-24}$ amplitude GWs to be generated, with good signal-to-noise ratios (Li, Tang, and Shi (2003) and Li and Yang (2004)). We can, therefore, emulate the GW-generation process of a pair of orbiting masses (stars, black holes, etc.), with their attendant change in centrifugal force according to the quadrupole formalism, by a pair of jerked masses (time-rate-of-change of acceleration or third-time-derivative-of-motion conventionally referred to as a "jerk" or a shake or an impulse) as shown in Fig. 1a. These masses are jerked in equal-and-opposite directions by the impact of equal-and-opposite laser pulses with the lasers under the control of a computer-controlled-logic system.

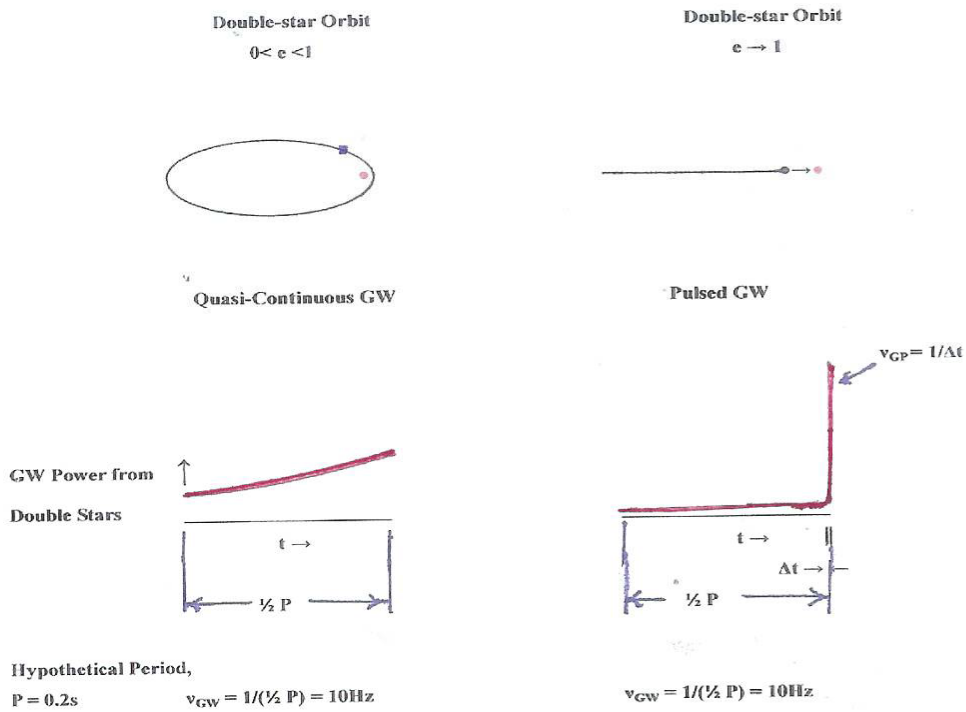
GENERATOR

The process underlying the experiment can be clarified by the following: Imagine a circle of light bulbs with the bulbs arbitrarily close to each other. Energize a pair of lights that are exactly opposite each other on the circle in sequence so that an observer perceives the two lights moving in a circle about each other. If the lights are very close together, then even though the lights are fixed, the observer has the illusion of orbiting lights whose emulated "angular-frequency," ω, radians/second, is determined by the rate of sequentially energizing the lights – similar to a string of "chasing" Christmas-tree lights. Next imagine that you have replaced the light bulbs by energizable, jerked masses, e.g., laser-targets, piezoelectric-crystals, etc. Again the perception is of orbiting masses even though the masses are overall fixed (except for very brief jerks). Since the masses are sequentially energized, an orbiting pair of masses is emulated. As each pair of masses is energized or jerked the GW-radiation pattern (Landau and Lifshitz (1975) and Baker, Davis, and Woods (2005)) is approximately in the form of a figure "8" at the circle's center midway between the laser targets, directed both ways along the circle's center-line or axis. As depicted in Fig. 3 of Puthoff and Ibison (2003), the radiation-pattern equations of Landau and Lifshitz (1975) give rise to two symmetrical lobes of radiation directed in both directions (thus a figure "8") normal to the plane of the masses motion. As the pairs of masses are jerked in sequence around the circle the figure "8" sweeps out a radiation pattern that is a dumbbell-shaped or peanut-shaped figure-of-revolution involving the integrated sum of two polarizations (Landau and Lifshitz, 1975) Thus the surface of a dumbbell-shaped-radiation pattern is swept over each half revolution and the GW-polarization exhibits a frequency that is exactly twice that of the orbiting mass pair. Next choose any pair of opposite laser-energizable or jerked masses. When energized, a GW pulse is generated exhibiting a polarization defined by the orientation of the two fixed masses and the directions of the jerks (i.e., the directions of the energizing-laser beams). Unlike the orbiting stars the polarization is fixed. A short-duration GW pulse, having a length $c\Delta t$ (about 10μm for a 33.9fs pulse and $c = 3\text{x}10^8\text{ms}^{-1}$), is generated each time that the two targets, 2r apart, are struck by the energizing-laser pulses. These strikes create an impulsive-force-vector, $\Delta\mathbf{f_t}$, acting tangential to the imaginary circle. Impulsive forces, applied over a laser-pulse-duration, Δt, emulate the $\Delta\mathbf{f_{cf}}$ caused by the change in centrifugal force as two massive objects orbit a central axis and generate GW having a focus midway between them as in Fig. 1a The situation with regard to the analogous star pair would be that star "A" is on the left side of their orbit and star "B" is on the right side of their orbit and then they trade positions at every laser repetition, which represents one GW period or half a circular-orbit period. From another perspective, the shape of the GW would be similar to a nearly-rectilinear (eccentricity, $e \rightarrow 1$) elliptical orbit, as shown in Fig. 1b with a GW- pulse each periastron passage. The orbital analogy is that even though the GW-pulse duration is relatively short, the half-orbital period or GW-wavelength is relatively long (a "synthetic wavelength"), and the fundamental GW frequency, ν_{GW}, is the pulse-repetition-rate (PRR) of the GW-generation lasers. There are two different ways to define the GW wavelength. The first is the one just discussed and described in Fig. 1b. In this case the wavelength, λ_{GW}, would be between c/PPR = $3x10^7$m (for PPR = 10Hz) and $3x10^{10}$ m (for PPR = 0,01Hz). These λ_{GW}'s are certainly greater than the dimensions of the system, 2r, except perhaps for situating the targets on the Moon and at the L_3 lunar libration point. The second wavelength definition is $c\Delta t = 10^{-5}$m. GW is still generated, but λ_{GW} is much less than 2r, and may lead to a poor power estimation using the quadrupole approximation as, for example, A. Pais (1982) and K. S. Thorne (1987) indicate. On the other hand, L.P. Grishchuk (2003) suggested that the requirement that $2r << \lambda_{GW}$ may *not* be a stringent or even a necessary one for the quadrupole approximation to GW power to hold. As K. S. Thorne (1987) states "… the quadrupole formalism typically is accurate to within factors of order 2 even for sources with sizes of (the) order (of) a reduced (GW) wavelength …" Whether the quadrupole approximation to the power of gravitational wave generation holds or not does not necessarily imply that no GWs are generated by an impulsive force acting on a pair of masses or laser targets or that the power does not increase with the distance, 2r, between them. The quadrupole formalism may still provide order-of-magnitude estimates perhaps augmented by higher-order octupole, hexadecapole, etc. modes of pulsation and possibly reduced at the GW focus by diffraction. It is a problem deserving study in future. In any event considerable GW should be generated, but the approximations to GW power *P* (from the quadrupole formalism) and amplitude A (Eqs. (1) and (2)) may not accurately hold especially when the two GW radiators, the laser targets, are many GW wavelengths apart.



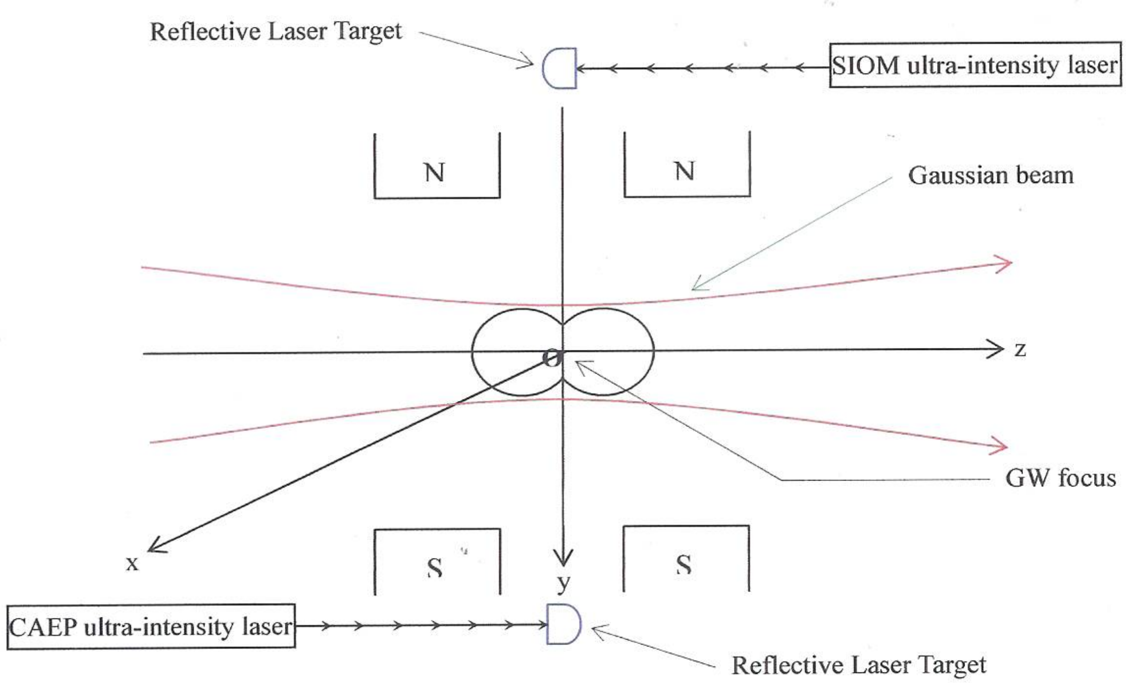
(a)

Stars "A" and "B" move on a circular orbit emulated by laser targets on an imaginary circle of the generator. The circle radius can be much larger than the GW-pulse length for the initial experiments, but the quadrupole formalism is still a good approximation to the GW power (U.S. Patent, 2000 and Baker, 2005).



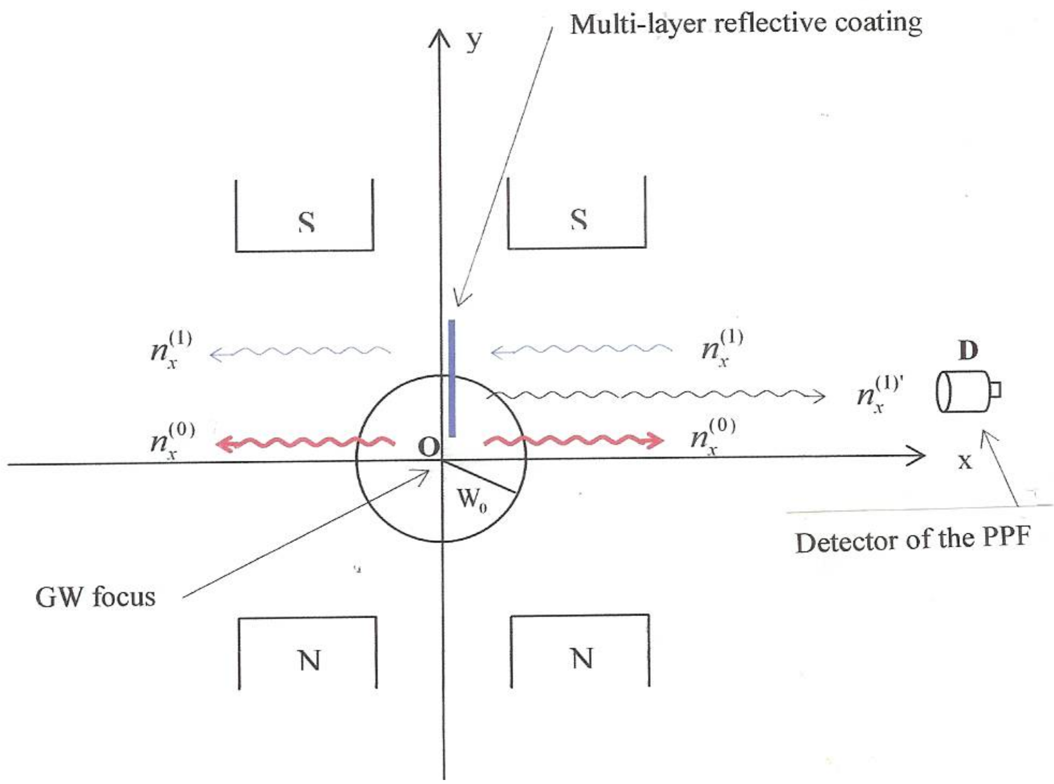
(b)

The analogy to a nearly rectilinear (e → 1) double-star orbit to the 10Hz-pulsed-GW-frequency, $\nu_{GW} = 1/(½\text{orbital-period})$ fundamental GW frequency, is illustrated.



(c)

The EM detector is a pulsed Gaussian beam passing through a static magnetic field pointing along the y-axis. The GW focus region is localized inside the spot radius W_0 of the Gaussian beam, and the z-axis is the beam's symmetrical axis, which is also the optimal radiation direction of the GW.



(d)

A lateral view of Fig.1c where $n_x^{(1)}$ is the x-component of the perturbative photon flux (PPF); $n_x^{(0)}$, the x- component of the background photon flux (BPF); $n_x^{(1)'}$, the PPF reflected by Multi-layer reflective coating (Monical et al. 1998); W_0, the spot radius of Gaussian beam; and **D**, the terminal detector for the PPF.

FIGURE 1. The GW Generator-Detector System**.**

At the focus the GWs are concentrated at a diffraction-limited focal-spot (Saleh and Teish, 1991) of area $(c\Delta t)^2/\pi = 3.3\text{x}10^{-11}$ m^2 and fans out into a slice of the dumbbell-shaped radiation pattern (Landau and Lifshitz, 1975 and Baker, Davis, and Woods, 2005). Predicted misalignment of the laser beams such that they are not exactly coplanar and anti-parallel will be on-the-order of 7.5micro-radians resulting in a shift of the focal spot. At a 100-meter distance a focal-spot shift of $100\text{x}7.5\text{x}10^{-6} = 0.75$mm is predicted, well within the 5mm-diameter pulsed Gaussian-detection-laser-beam of the detector. A 2.5ps difference in laser synchronization or laser-target-strike time also results in a $3\text{x}10^8\text{x}2.5\text{x}10^{-12} = 0.75$mm shift. The focal-spot shift is analogous to the shift in double-star distance from a fixed focus for their motion on an elliptical orbit. It is emphasized that gravitational forces are <u>not</u> required to generate gravitational waves. As noted by Weber (1964): “The nongravitational forces play a decisive role in methods for detection and generation of gravitational waves..." The quadrupole equation is an approximation to the power of GWs in weak fields that are generated by a *rapid change* in acceleration of a mass. The weak field can be well over 100g's e.g., the weak-field acceleration of PSR1913+16 is 112g's at periastron (U. S. Patent, 2000 and Baker, 2005). Analyses of a double-pulsar-star system (Lyne, 2004) may show that much larger g-forces would not greatly reduce the quadrupole's accuracy (In fact, the quadrupole formalism appears to be a reasonable estimate of GW power even in the interior of the radiating system (Landau and Lifshitz, 1975). In any event, the GW flux at the focus and axially distant from it will be established experimentally in order to validate the theory (that is, Eq. (1)), that the GW power is proportional to the square of r, and independent of its size relative to GW-pulse length , and whether or not the GW flux is measured interior or exterior to the system of masses (laser targets)). The quadrupole itself is *not* the physical process (the motion of the mass or masses is that process), but only one means of establishing the power of the gravitational wave -- the lowest-order-solution. For a harmonic oscillator there is another approximation to GW power (Einstein and Rosen, 1937) Previous work published in mainstream, albeit specialized, scientific literature involves other proposed GW generators (Weber, 1964; Halpren and Laurent, 1964; Dehnen and Romero, 1981; Woods and Baker, 2005; Chapline, Nuckolls, and Woods, 1974; Davis, 2003; Fontana, 2004; Rudenko, 2003; and Stephenson, 2005). There also exist other means to generate GWs besides mass motion, for example the Gertsenshtein-EM-to-GW effect (Gertsenshtein, 1962 and Stephenson, 2005) and there are other ways to establish GW power, which are more complicated such as numerical relayivity (Ashby and Will, 2000), but the approach proposed here is novel in that it takes advantage of new laser technology. The quadrupole approximation to GW power for a spinning rod or dumbbell or baton consisting of two masses, δm, can be phrased as:

$$P = 2G(2\delta m)^2 r^4 \omega^6/45c^5 = 1.76\times10^{-52}\,(2r\Delta f/\Delta t)^2\ \mathrm{W}, \tag{1}$$

which is the *jerk-formulation of the quadrupole equation* (in summary (Appendix of Baker, 2005), we start with the basic quadrupole approximation for GW power (Burdge, 2000) $P = (G/45c^5)(d^3I/dt^3)^2$ W, where c is the speed of light and G the universal gravitational constant. We then take the third-time-derivative of the moment-of-inertia, $I = 2\delta m\, r^2$, apply Newton's-second-law, so that Eq. (1) is obtained). In Eq. (1) r is the radius-of-gyration and Δf is the change in force at δm over the incremental time interval Δt (that is, a "jerk"). For masses δm, Δf/Δt = δmΔ (acceleration)/Δt, so that the equation states that a third-time-derivative is imparted to the motion of the masses, or energizable elements, such as a piezoelectric-membrane resonators (Weber, 1964, Dehnen and Romero, 1981 and Woods and Baker, 2005), laser targets, etc. Two laser-targets with oppositely directed laser strikes and accurately positioned 20 meters apart (10m radius-of-gyration, r) will, according to the quadrupole formalism of Eq. (1), generate a peak-GW-power of approximately 1.76×10^{-52} (2targetsx2rxΔf/Δt)^2 = 5.5×10^{-12}W. The GW-radiation pattern (Baker, Davis, and Woods, 2005) of Fig. 1c covers the cross-section of the Gaussian-detection-laser beam of radius 2.5mm and cross-section area of δs =1.96×10^{-5}m^2.

DETECTOR

The Chinese detector, developed at *Chongqing University*, is a coupling system of semitransparent beam-splitters (multilayer-reflective coatings) and the pulsed-Gaussian-detection-laser beam passes through a static-magnetic field (Li, Tang, and Shi, 2003 and Li and Yang, 2004) The detector is to be situated within a Faraday cage or enclosed in shielding covers made from fractal membranes. Using the well-studied technology of Gaussian beams, for example described by Yariv in 1975 (to create a background-photon-flux (BPF) -- a Gaussian beam is a laser beam exhibiting a Gaussian-type or quasi-Gaussian-type distribution in space) and the propagating characteristic of the perturbative-photon-flux (PPF) produced by the GWs, it is found (Li, Tang, Luo, and Li, 2000) that under the synchro-resonance condition (when the frequency ν_{GW} of the Gaussian beam is tuned to the effective GW-pulse-frequency ν_{GP}, i.e., $\nu_{GB} = \nu_{GP}$ = 1/(pulse-duration) = 2.9×10^{13}Hz), the interaction between of the GW with such EM fields will generate the first-order PPF, and the PPF and BPF that would propagate along mutually orthogonal directions, or propagate in opposite directions in some regions. This is known as the Gertsenshtein effect (or "reverse" Gertsenshtein effect, 1962, p. 85). The amplitude of the GW with emulated "angular-frequency," ω , is approximately (Landau and Lifshitz, 1975, Eqs. (107.11) and (107.12) and Appendix A of Baker, Woods, and Li (2006)):

$$A = (8\pi G\, F_{GW}/c^3\omega^2)^{1/2} = 1.28\times10^{-18}\, F_{GW}^{1/2}/\nu_{GW}. \tag{2}$$

Equation (2) is strictly valid for monochromatic or quasi-monochromatic GW; but the GWs may cover a wide range of frequencies, the fundamental one being the PRR or, analogously to the orbital-motion shown in Fig. 1 b, twice the orbital frequency. Of course, we are only looking at a very brief snapshot of the emulated orbit or a very short segment of a relatively long GW. An objective of the experiment will be to validate this expectation. For a peak-GW-flux, F_{GW} = P(2.57)(0.282/D)^2 = 1.23x10^{-7} Wm^{-2} (from Eq. (10) of Baker, Davis, and Woods, 2005, with D = 3mm) and fundamental GW frequency, ν_{GW} = 10Hz we have predicted a GW amplitude of A = 4.5x10^{-23} at a 0.003m distance from the focus. There is a question as to estimating the GW power between the laser targets, i.e., interior to the radiating system where D<< 2r. This is a subject that will require additional theoretical study, but this restriction does not imply that no GW exists and A may be larger than 10^{-23}. By computer-numerical-integration, given an electromagnetic power of 10^{14} W, the amplitude of electrical field of the Gaussian-detection-laser beam will be ψ_0 = 1.8x10^{12} Vm^{-1}. Using such values and the approximate form (Li and Yang, 2004) for the PPF-density propagating along the x-axis we obtain for the total perturbative-power-flux detection-signal, *u*, passing through the effective receiving surface (the surface area is approximately the area of the Gaussian beam's cross-section, δs) :

$$u \approx \frac{1}{\mu_0} AB\psi_0 \delta s = 1.94 \times 10^{-8}\,\mathrm{W}\,, \tag{3}$$

where μ_o = 4πx10^{-7} and the static-magnetic field B = 15T (such a magnetic field strength seems reasonable according to Boebinger, G. Passneyt, Aand Bevk, J., 1995). Of course, such process occurs in a very short-detection duration $\delta t = 100\Delta t = 3.39 \times 10^{-12}\,\mathrm{s}$ (the duration of the detection-observation is 100 times the period of GW, i.e., integrated over 100 GW pulses according to Montcal, Bajt, and Mirikarimi, 1998), thus the total output energy in the duration δt will be ΔE_r = *u*δt = 6.6x10^{-20} J. This corresponds to the energy of $\Delta E_r/h\nu_{GB}$ = 6.4x10^{-20}/1.95x10^{-20} = 3.4 detection photons (or 100 to 10,000 times that number for the more powerful advanced version of the SIOM laser). In Eq. (3) $AB\psi_0/\mu_o$ is the first-order-perturbative-EM-power-flux density or Poynting vector. The above results show that although ΔE is a very small value, the PPF in terms of integrated photon count, n_γ in the duration will be an observable value. Figure 1d is a schematic of the experiment. Utilizing the different physical behavior between the PPF and the BPF, in principle they can be split and distinguished. In other words, the PPF can be pumped out from the BPF. For example, the *x*-component of the PPF and the *x*-component of the BPF propagate along the negative and positive direction of the *x*-axis in the region of *x, y, z*>0 (see Fig. 1c and 1d), respectively. Using special multilayer-reflective coatings (Montcal, Bajt, and Mirikarimi, 1998) with the normal-direction parallel to the *x*-axis, it will reflect only $n_x^{(1)}$ and not $n_x^{(0)}$. Once $n_x^{(1)}$ is reflected (i.e., $n_x^{(1)'}$in Fig 1d), $n_x^{(1)'}$and $n_x^{(0)}$will have the same propagating direction. However, $n_x^{(1)'}$can keep its strength invariant within 5cm at least (such multilayer reflecting coatings can provide nearly total reflection for the photon fluxes in the THz to *x*-ray band, Momical et al., 1998) while $n_x^{(0)}$ decays as exp(-2x^2/ W-^{2}) [this is just a typical property (Li, Tang, and Shi, 2003, Li and Yang, 2004, and Yariv, 1975) of the background Gaussian photon flux, where *x* is the distance to the multiplayer-reflective coatings and *W* is the spot radius of the Gaussian beam]. Numerical calculation shows that although $n_x^{(0)}$ is much larger than $n_x^{(1)'}$ in the greater part of the focal region, however, the instantaneous PPF would be $n_x^{(1)'}$~10^{12}s^{-1} at x = 1.59 cm while the corresponding BPF $n_x^{(0)}$ will be reduced to 10^{-2} s^{-1} at the same position. Thus the terminal detector in the region of 1.59 cm < x < 5 cm would obtain an almost pure signal photon flux of 10^{12}s^{-1} in the duration δt = 3.39x10^{-12} s. The quantum picture of this process can be described as the interaction of the Gaussian-beam photons with the gravitons in a background of the strong-static-magnetic field (virtual photons) as a "catalyst," (Logi and Mickelson, 1977) which can greatly increase the interaction cross-section between the photons and gravitons. In other words, the interaction will effectively change the physical behavior of the photons in the local regions, even if the net increase of the photon number (the EM energy) in the entire detector approaches zero, such properties are useful to detect very weak signals of GW's. In order to suppress the thermal noise, the requirement of temperature must be kT < $h\nu_{GP}$ (*k* is Boltzmann's constant), which corresponds to T of 1.9x10^3 K for the PPF of $\nu_{GP} = \nu_{GB}$ = 2.9x10^{13}Hz. This means that the whole system can operate at room temperature. Therefore, we would expect to obtain a good signal-to-noise ratio (which would be larger than one) in the special local regions and in a room temperature environment.

EXPERIMENT

The experimental procedure is to utilize the *SIOM* and the *CAEP* lasers, assembled at a common site, to execute the experiments. As a numerical example, with a 33.9fs pulse duration, Δt , a ten-Hz repetition rate (ν_{GW}), a laser wavelength, λ_{EM}, of 800 nm (laser frequency of $\nu_{EM} = c/\lambda_{EM}$ = 3.75x10^{14}Hz), a laser-photon energy of hc/ λ_{EM} = 2.48x10^{-19}J, and 23TW of power, P, there would be PΔt/photon-energy = 23x10^{13}x3.39x10^{-14}/2.48x10^{-19} = 3.14x10^{18} photons-per-pulse or packet and the photons-per-second is

$3.14x10^{18}/33.9fs=9.27x10^{31}$. Thus the impulsive force is the photons-per-second times the momentum of each photon or $\Delta f = (1+R)\{(h/\lambda_{EM})\}$x(photons-per-second) = $(1+0.95)\{(6.62x10^{-34})/(800x10^{-9})\}x\ 9.27x10^{31}$ $=1.5x10^5N$ which is an extremely forceful strike on the target (factor of (1+R) since laser photons are reflected with reflectivity R at the mirrored target). The 33.9fs ultra-short pulses are not monochromatic; they involve a wide range of wavelengths, frequencies, and energies (however, for a given repetition rate, and laser power, the Δf is independent of the wavelength of the electromagnetic laser). It is noted that we are dealing with four different frequencies: electromagnetic-laser, Gaussian-beam-laser, GW-pulse, and GW where $\nu_{EM} > \nu_{GB} = \nu_{GP} >> \nu_{GW}$. As Giorgio Fontana has pointed out (2005), these intense ultra-short pulses of force, which occur every tenth of a second, produce very high-frequency GW (ν_{GP}) pulses or HFGW with, essentially, a fundamental 10Hz (ν_{GW}) modulation or "carrier wave" in radio parlance. Fontana also notes that with a GW frequency of "… 10 Hz the wavelength is 30,000km. At ranges shorter than that, the near-field effect … dominate(s) and no (theoretical) proof of GWs can be given." This situation is, of course, the astrophysical LFGW case. The distribution of GW energy and the resulting detection photons will be an interesting outcome of the experiment and will shed light on these concerns. Simulation results (please see the last two rows of Table 1) indicate that with the anticipated several-orders-of-magnitude increase in laser power (Bahk, 2004), there could be as many as 10^9 to 10^{13}detection photons available at ν_{GW} = 10Hz and at least one detection photon at $\nu_{GW} = \nu_{GP} = 2.9x10^{13}$Hz to study the GW amplitude predicted by Eq. (2) and to prove the actual presence of GWs. Note that at the frequency $\nu_{GW} = \nu_{GP} = 2.9x10^{13}$Hz the GW wavelength will be 10μm and no near-field effects will be present and the detector locations will be in the "wave zone" as discussed by Landau and Lifshitz (1975). In fact, on p. 348 they state "In the general case of arbitrary gravitational waves, simplification to a form like Eq. 107.8 (the ordinary wave equation) is not possible. This can, however, be done in the important case of waves of high frequency; when the wavelength λ_{GW} and the oscillation period λ_{GW}/c are small compared to characteristic distances …"

TABLE 1. Perturbative Photons for Various r, ψ_0, Durations, and D.

Distance r (m) between Lasers and Focus	Pulsed Gaussian beam, ψ_0 TV(m^{-1})	Duration as factor of HFGW period	Distance, D, of Detector from Focus (m)	Graviton Per Pulse $\nu_{GW} = \nu_{GP}$	GW Amplitude, A	Perturbative Photons per Detection Span
10	1.8	100	0.003	$2.8x10^7$	$4.5x10^{-23}$	3.3
10	1.8	100	0.004	$2.8x10^7$	$3.4x10^{-23}$	2.5
10	1.8	100	0.005	$2.8x10^7$	$2.7x10^{-23}$	2.0
10	1.8	100	0.006	$2.8x10^7$	$2..2x10^{-23}$	1.6
50	18	1000	0.003	$7.0x10^8$	$2.2x10^{-22}$	1641.0
50	18	1000	0.01	$7.0x10^8$	$6.7x10^{-23}$	492.0
10	18	1000	0.003	$2.8x10^7$	$4.5x10^{-23}$	328.0
10	18	1000	0.01	$2.8x10^7$	$1.4x10^{-23}$	98.0
50	18	1000	0.01	$7.0x10^8$	$6.7x10^{-23}$	492.0
250	18	1000	0.003	$1.7x10^{10}$	$1.12x10^{-21}$	8205.0
250	18	1000	0.01	$1.7x10^{10}$	$3.4x10^{-22}$	2461.0
1000	18	1000	0.003	$2.8x10^{11}$	$4.5x10^{-21}$	$3.3x10^4$
1000	18	1000	0.01	$2.8x10^{11}$	$1.4x10^{-21}$	9846.0
10000	180	1000	0.003	$2.8x10^{11}$	$4.5x10^{-18}$	$3.3x10^8$
10000	18000	10000	0.003	$2.8x10^{11}$	$4.5x10^{-17}$	$3.3x10^{12}$

The GW amplitude and number of detection photons produced during an observation span will be analyzed experimentally and expected theoretical results are given in the Table. For the detector simulated in the Tables the wavelength of the energizing lasers is 800 nm, the repetition rate is 10Hz, the pulse duration is 33.9fs, the lasers' intensity is 23TW (except for the simulation in the last two rows where it is 2.3 and 23 Petawatt, respectively), and the static magnetic field is B = 15T. For the gravitons per pulse calculation, the fundamental frequency is also taken to be the Gaussian-beam frequency, ν_{GB}, or $1/\Delta t$ (29.5THz). For the highest-power case of the last row, the maximum GW flux at the focal spot is $5.48W/3.3x10^{-11}m^2 = 1.8x10^{11}Wm^{-2}$.

CONCLUSIONS

It is concluded that the GW-generation and detection apparatus is now feasible and will result in a successful laboratory experiment to test theory and this paper will serve to attract ideas from various disciplines to improve the prospects for a successful experiment. As a possible space-technology application, one could install the opposing table-top-size lasers on two satellites on coplanar geosynchronous orbits located on opposite sides of the Earth at a distance apart of ~ $8x10^7$ m or the radius of gyration, r ~ $4x10^7$ m. One would have a space antenna. Careful alignment of the laser beams and timing of the laser pulses could allow for the positioning of the HFGW focus at any location in the environs of the Earth – on or below the Earth's surface. From Eq. (1), with $\Delta f = 1.5x10^5$ N and $\Delta t = 33.9x10^{-15}$ s, P ~ 22 W. At the microscopic, diffraction-limited, $3.3x10^{-11}$ m^2 area focal spot (itself a remote source of HFGW), the HFGW flux would be F_{GW} = ~ $7x10^{11}$ Wm^{-2} during each pulse. If the ultra-high-intensity tabletop-size lasers were at lunar distance (e.g., at the Moon and at the stable lunar L_3 libration point, Baker (1967)) and r ~ $4x10^8$ m, then the HFGW power would be about $2x10^3$ W and the flux about 10^{13} to 10^{14} Wm^{-2} during each 33.9fs pulse. Again the HFGW focus or remote emitter could be located anywhere near the Earth's surface or within the Earth for that matter.

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