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Directions for gravitational wave propulsion

Abstract

This paper summarizes results of past analyses, including proposed examples, in order to build a modern theoretical framework for Gravitational Wave Propulsion. The framework consists of families of generators of gravitational waves, which have been theorized but still require experimentation, and models of thrust generation. High efficiency generators are based on coherent sources, for instance synchronized MEMS oscillators, the HTSC Gaser, based on coherent spin-2 transitions in s-wave/d-wave superconductors, and the nuclear electromagnetic wave to gravitational wave up-converting transducer, based on dineutrons.
After gravitational wave generation is successfully proven in the laboratory, it will be possible to apply a concept developed in the field of cosmology. It was found that the background energy density may give mass to the graviton, which in turn may allow gravitons to produce thrust. Local background energy density can be increased by charging materials with high dielectric constant in close proximity to the wave generating elements. Focused Gravitational Waves may also produce singularities, where the radiation is converted into a coulomb-like gravitational field. Gravitational singularities will set an n-body gravitating system among themselves, the spacecraft, and the remaining bodies of the universe, with obvious propulsive effects. Applications of the present analysis will lead to a unique propulsion system capable of enabling the fast exploration of the solar system, the local star system, and possibly the whole galaxy.

Keywords

Space; Propulsion; Gravitational wave; Gaser; Dineutron; HFGW; HTSC; MEMS.

INTRODUCTION

On a general basis, a vehicle traveling in space requires energy and a reaction mass to accelerate and reach useful speeds. Usually the reaction mass is the mass of the propellant, which in most circumstances has also the role of energy source. Vehicles that are not required to carry reaction masses are more efficient and lightweight, but conventional ones are limited in scope. It is a fact that, after extraordinary developments, space travel by rocket technology has reached its limits and a new paradigm is required to make a big step forward in space propulsion; a step that should enable the exploration of nearby star systems and possibly the whole galaxy. These goals may seem unreachable with the current understanding of physics. Anyway with an open mind and a pragmatic approach, it is well known that we are dealing with opinions that are often suggested by the lack of interdisciplinary approaches to complex problems. It often happened that when so called theoretical limits were found wrong, accidental discoveries have shown why the good theory was erroneously applied the first time. An alternative to accidental discoveries are pieces of knowledge gathered from hundreds of research papers from different disciplines combined in an unusual way to create new concepts. They are normally rejected by experts of their single research field, thus painstaking efforts are required to simply communicate the new concept and let it grow in the laboratories.
At the and of the last century numerous theoretical efforts have started to show that Gravitational Waves (GWs) have not only astronomical and astrophysical relevance, but they also have technological applications[1,2]. Among them, several theories have approaches identified for telecommunication, imaging, material processing, and space propulsion. All of them elaborate on the fact that gravitational waves do exist and are emitted according to a theoretical

framework, namely General Relativity, which looks correct to a high accuracy[3]. Unfortunately successful experiments are yet to occur. However, the emission of GWs by star systems has been observed, and celebrated by a Nobel Prize[4,5].

For developing gravitational wave propulsion, multiple results of this framework have been adopted, combined, and applied to technological devices and methods. This same framework is also currently adopted for developing detectors of GWs from astronomical studies[6]. The detection difficulties suffer by today's detectors' accuracy although they have motivations that will be certainly discovered in the near future and will possibly reveal new information and a new paradigm about the universe and regarding specific approaches to propulsion.

Conceptually, gravitational wave propulsion is based on a generator of gravitational waves, and on one or more methods, that can theoretically produce motion. No physical reaction mass is used. Almost all generators are based on the Nobel Prize tested quadrupole formula[3,5] applied to various GW generating elements; among them there are MEMS oscillators, couples of non-electromagnetically radiating electrons and couples of neutrons.

DISCUSSION

Generators of gravitational waves for propulsion

This section introduces various generators of GWs that appear suitable for propulsion applications. According to the following elementary analysis, it is possible to prove that starting with given mass, volume and mechanical properties for the emitting solid body, the process of splitting the body into smaller parts will permit to increase the frequency and the power emitted.

By considering two equal revolving point masses each with mass m, distance between the masses r, and Universal constant of Gravity G, the power emitted in GWs can be computed by Eq. (10.5.25) at page 272 of Ref.[3], by considering two masses at half distance from the center of rotation, the two equal masses revolving about one another:

$$\mathbf{P} = \frac{8G}{5c^5} m^2 r^4 \omega^6 \qquad (1)$$

Equation (1) indicates that the power emitted is proportional to the 6th power of the frequency ω; obviously, the higher the frequency, the higher the power. Note that the denominator involving the fifth power of the speed of light, c, implies that the gravitational waves will be very weak. For real world materials a different analysis is required. In fact the actual limit is the ability to keep the emitting object in rotation (and/or vibration) at the highest possible frequency and avoiding that it breaks apart because of excessive internal stresses. The analysis is the following.

For rotating objects, the centripetal force is:

$$\mathbf{F = mr\omega^2} \qquad (2)$$

If we choose to keep our system at the limit for the structural integrity of the selected material, F will be bounded by a limiting constant; let's choose force units, or just normalize the expression, according to the properties of the selected material in order to have for this limiting constant $F_{lim}=1$ so that $mr\omega^2 = 1$. Therefore splitting our system in two identical smaller systems each defined by:

$$\mathbf{m_{split} = m/2 \text{ and } r_{split} = r/2} \qquad (3)$$

substituting into Eq. (2), we have from the centripetal force limiting formula:

$$\omega_{split} = 2\omega \qquad (4)$$

Using these changes in the quadrupole formula for equal masses in Eq. (1) and considering that we obtain two systems, for each of them we obtain:

$$\mathbf{Psplit} = \frac{8G}{5c^5}(m/2)^2(r/2)^4(2\omega)^6 \qquad (5)$$

explicitly it becomes:

$$\mathbf{Psplit} = \frac{\frac{8G}{5c^5}(m)^2(r)^4(\omega)^6}{4\cdot 16/64} = \mathbf{P} \qquad (6)$$

Therefore starting with a given mass (and volume) of a preferred emitting material at the limit of structural integrity and cleverly rearranging the mass distribution in order to keep it always at the limit structural integrity by increasing the frequency, the power emitted by each "small piece" is equal to the power emitted by the "originating" element. If the "small pieces" do not interact with each other, and considering N elementary generators, incoherent summation gives $P_{splitN}=N\cdot P$. If the system of N elementary generators is coherent[7], amplitudes will add up instead of the powers and the power summation will give $P_{splitN}=N^2\cdot P$, the quadratic growth will proceed till the conversion efficiency of the generator will be near 100%, after that it will saturate. The analysis clearly indicates that it is necessary to arrange the given mass into the largest number of discrete sources that technology allows; this approach leads to High Frequency Gravitational Waves – HFGWs[1]. Moving at high frequency coherently will increase the conversion efficiency of the generator. Equation (6) is the first direction to follow for increasing the power emitted by a GW generator with given mass and/or volume. It follows that the first technical and scientific development for achieving high power and high frequency is the MEMS generator[8]. The MEMS generator is a composite ensemble of micromechanical devices; it can be produced using available technology.

Further developments capable of increasing the frequency and the emitted power in GWs as a function of generator mass may come from particle based and nuclear-based generators. Specifically, in this paper we consider electromagnetically shielded electrons and neutral nucleons. Theoretical models have been developed even for those more advanced systems therefore programs for advanced developments are possible.

The MEMS generator

The MEMS generator represents the first significant improvement above the fundamental rotating bar emitter of GW. It is proposed by Dr. Robert M. L. Baker Jr.[9] Because of its very reasonable complexity it will probably be the first one to be tested.

Dr. Baker and collaborators[10], suggested in a number of very detailed papers that commercially available film-bulk acoustic resonators (FBAR), can be arranged in phased arrays and excited by 2.5 GHz electromagnetic microwave generated by magnetrons like those employed in microwave ovens. The phased array will convert EM radiation at 2.5 GHz to 5 GHz High Frequency Gravitational waves (HFGWs).

In Figure 1, a simple MEMS generator is schematized by an array of microscopic GW sources excited in parallel by an electromagnetic field at microwave frequencies that couples to the resonators.

Two electrodes are used to confine the field in a small volume to achieve very high energy densities. In the schematization of Figure 1, the electromagnetic energy in

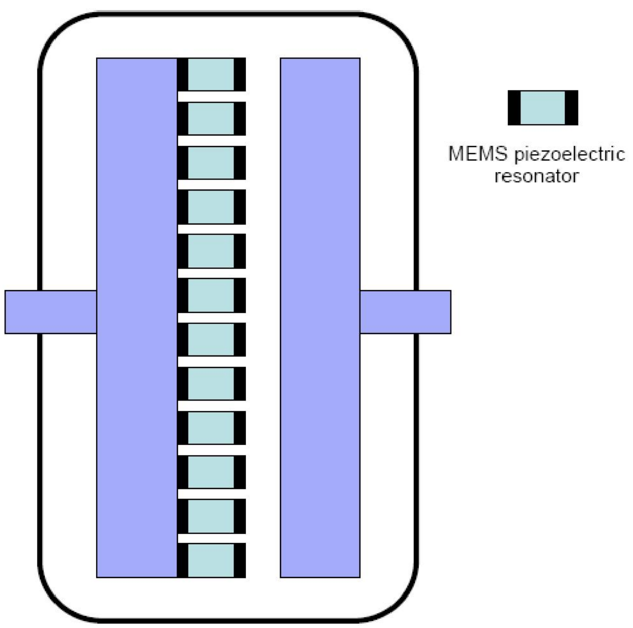

Figure 1 : Schematization of a MEMS generator of HFGWs.

the space surrounding the MEMS has a secondary purpose that will be discussed later.

More complex distributions are under development to improve the density of the microscopic emitters and the ability to drive them synchronously with microwaves and with the best possible use of the quantities appearing in Eq. (1) for each couple of associated masses of the elementary emitter. Among them there is a remarkable three-dimensional FBAR configuration recently proposed by Baker and Baker[9] shown in Figure 2.

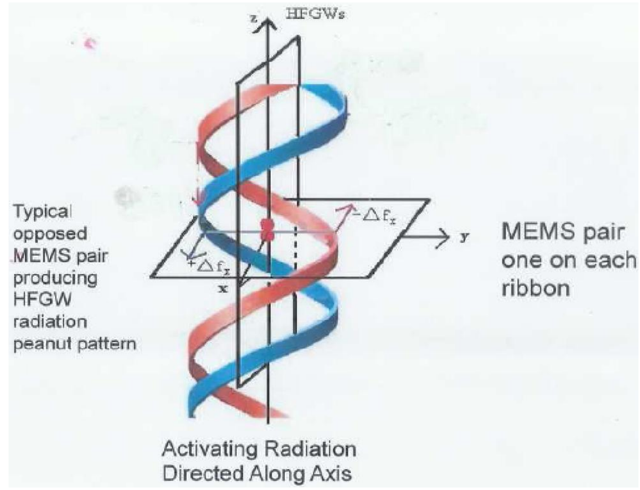

Figure 2 : The double helix MEMS generator of HFGWs.

The FBAR distribution is arranged on a double helix allowing dense packing, and efficient coupling to electromagnetic wave excitation. The configuration takes advantage of coherence and superradiance[9], by which the power emitted is proportional to N^2, where N is the number of elementary sources.

The HTSC gaser

The HTSC Gaser is a quantum source of GW in the THz range. First proposed by the author[11] in 1998, it was theoretically studied for more than a decade[12-15]. The HTSC Gaser promises to offer very high efficiency with directional and focusable GW beams.

The HTSC Gaser adopts electron couples for emitting HFGWs. Because electrons are charged, the whole HTSC Gaser technology is a method to make electron couples to start spinning coherently without emitting electromagnetic waves. The technology is based on early studies of L. Halpern and B. Laurent[16] on the emission of gravitational radiation from microscopic sources. The theory has to wait for the discovery of orthorombic cuprate high Tc superconductors, in which s-wave and d-wave cooper pairs were experimentally observed[17,18]. Transitions between s-wave and d-wave are gravitational *spin-2* transitions and may produce gravitational waves at THz frequencies. The HTSC Gaser depicted in Figure 3 operates by the injection of s-wave Cooper pairs generated in a low-Tc superconductor into the high-Tc superconductor. The injection process is well known and described in the literature with great detail[18]. The relatively new and relevant process is that transitions are linked to a gravitational phenomenon. The HTSC Gaser properly exploits the coherence of the order parameter of the superconductors and superrandiant effects in the very large number of Cooper pairs in the bulk superconductor.

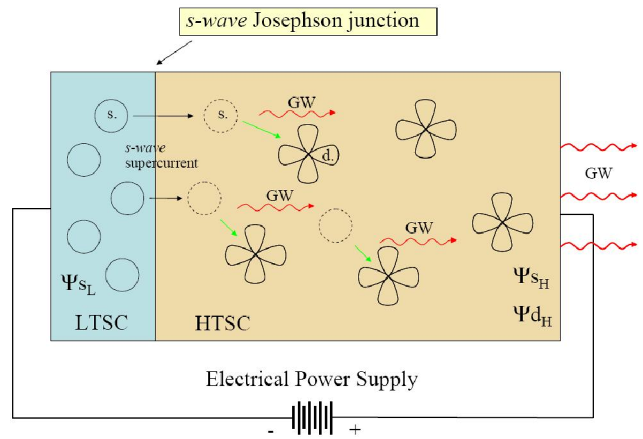

Figure 3 : Spin-2 transitions and HFGW emission in the HTSC gaser.

There are multiple advantages in the use of the HTSC Gaser. It converts DC current directly to HFGWs, it operates at submillimeter wavelengths, allowing easy productions of HFGWs beams. It is an efficient quantum device and allows the production of focused radiation because the junction can be constructed on a spherical dome with HFGWs focused at the center of the sphere. On the other hand it is a cryogenic device and requires special care and the use of very low temperature techniques.

Research should be directed towards the above mentioned potential discoveries because, in spite of the extremely large amount of data collected in more than twenty years, the real nature of high Tc superconductivity remains elusive; gravitational phenomena may be a key factor for a better understanding of the complete phenomenology.

To reach the ultimate goal of producing high intensity HFGWs and further increase the power, the frequency has to be increased as well as the mass of the emitting particles. Neutron mass is thousands of times higher than electron mass and they are electrically neutral. The clever point is how to induce controlled coherent motion to couples of neutrons and, most important, do stable couples of neutrons exist in nature?

It is possible to say yes to both questions.

The dineutron upconverting transducer

The Dineutron Upconverting Transducer (DUT) is the most complex and speculative device. First proposed by the author and Bernd Binder[19], it can convert nuclear excitations both from conventional X-ray sources and NMR signals to HFGWs at a much higher frequency respect to the excitation frequency. It is based on a nuclear model proposed by the late, two times Nobel laureate, Prof. Linus Pauling.

Pauling's nuclear model suggests a nuclear makeup of "spherons" that are protons, neutrons, alpha particles, and the more exotic dineutron[20-23]. Dineutrons are of great interest for this application. In fact dineutrons are ideal emitters of HFGWs. Dineutrons have nuclear densities, they are electrically neutral and the couple has a very small residual magnetic moment. According to Pauling, some nuclei, like for instance some stable isotopes of Gadolinium[21], may have one or two dineutrons floating almost in contact with the "surface" of the core nucleus as shown in Figure 4, under these conditions dineutrons are stable. According to detailed solutions of nuclear equations dineutrons do exist[24], and there are claims of their direct observation[25]. Dineutrons are dynamically coupled to the core of the nucleus by the highly "non linear" strong force. It is not necessary to know much about this dynamical system of nonlinearly coupled oscillators. Every system of nonlinearly coupled oscillators can be forced into a dynamic in which energy fully moves periodically from one oscillator to the other. Each oscillator oscillates at its own characteristic frequency. A well know example is the toy model "swinging spring"[26], which is indeed a simplified model of earth atmosphere. Another example is the multi pendulum marionette, a toy consisting of small pendulums appended to a bigger pendulum.

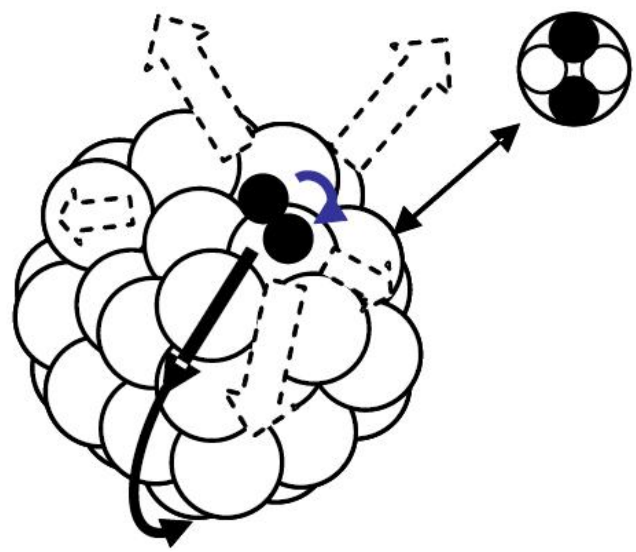

Figure 4 : The dineutron spins and orbits on the surface of the core nucleus, composed of alpha particles in this representation.

In our approach the system of coupled oscillators is composed by two or more spherons, one is the nucleus core, which being electrically charged can absorb electromagnetic waves. The others are the dineutrons that cannot absorb or emit electromagnetic waves; instead they can absorb and emit HFGWs. In Ref.[19], it is shown that according to the quadrupole formula the system can convert electromagnetic waves to HFGWs with high efficiency and at the same time coherently increase the frequency of HFGWs to high harmonics of the exciting electromagnetic radiation. It is the upconversion capability, mediated by the nonlinear "strong force" coupling that makes the efficient emission of HFGWs possible. The converter is estimated to absorb electromagnetic radiation at X-ray frequencies and emit HFGWs at gamma-ray frequencies.

In addition, according to a theory developed by Bernd Binder[27], dynamical instabilities may exist in some heavy nuclei capable of permitting the generation of energy by extracting it from the electromagnetic vacuum fluctuations. We observe that electromagnetic vacuum fluctuations will be converted to HFGWs of much higher frequency. The emitted HFGWs "should" be at the thermodynamic equilibrium with the gravitational quantum fluctuations, being this device an efficient transducer between the two radiation quantum fields. On the other hand, because our knowledge of gravitational quantum fluctuations is marginal at this time, electromagnetic quantum fluctuations might be converted by this device to HFGWs and allowed to propagate into an "almost empty and ultracold" gravitational radiation space, which is pure speculation but still remains a viable theoretical and experimental possibility and, certainly, create a direction to follow for future research. If this hypothesis is experimentally proved correct, a thermodynamic machine could extract useful work from the DUT, which could be therefore used as combined propulsor and useful energy generator.

Other nuclear generators

The DUT is the most complex, speculative, and potentially safe nuclear generator of HFGWs. Different generators were studied in past years and reported here for completeness, they may require nuclear reactions and may produce harmful radiation.

GW pulses could be emitted by the pulse of neutrons from a fission device[28], this is a one-shot concept that cannot be applied to GW propulsion. More recently Fontana and Baker[29] have proposed a HFGWs generating variant of the nuclear propulsion system in which neutrons or antiprotons may induce fission in a blanket of fissionable material. Layer by layer, in Rubbia's design[30], fission fragment may produce thrust.

We proposed an alternative approach in which the fissioning nucleus is prepared in a high rotational state (isomer), as shown in Figure 5; the rotational dynamics before the exact fission instant produces highly deformed nuclei that can emit HFGWs at X-ray and gamma-ray frequencies. By changing the angle between the wavefront of neutrons and the rotational axis of the isomers it is possible to match the speed of neutrons and the speed of HFGWs in order to produce high power pulses. This method is supported by theoretical papers on fission dynamics, on the other hand most energy is released as kinetic energy of fission products. Estimation of the power emitted in HFGWs is reported in Fontana and Baker[29].

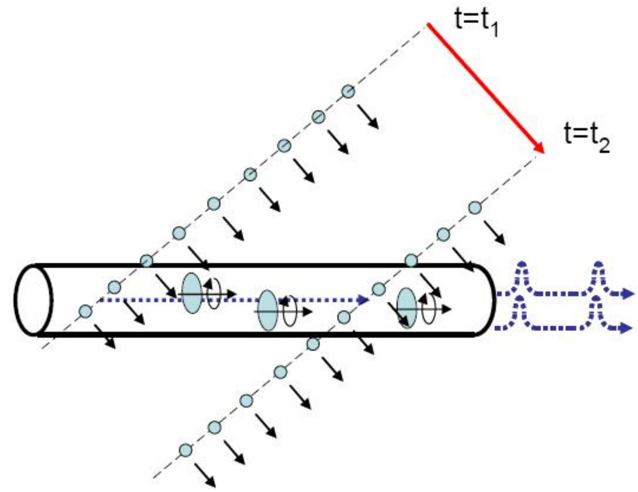

Figure 5 : Conceptual design of a traveling wave HFGW nuclear generator. Fissionable isomers are hit by wevefronts of neutrons. Pulses of HFGW are emitted.

ANALYSIS

Production of gravitons with mass

In the linearized approximation in flat space-time, GWs are purely transverse; therefore the interaction of GWs with matter is not useful for inducing longitudinal motion. In spite of this supposed inapplicability, the production of gravitons with mass is possible and it is the method that may permit propulsion by GWs[15,31]. If gravitons have mass while exiting the generator, propulsion by conservation of linear momentum is a straightforward possibility.

The existence of massive gravitons is predicted by General Relativity, which also gives some information on how to create the conditions required for giving mass to the graviton. The theory has been formulated by studying the propagation of *spin-2* fields in space-times with a background energy density.

While studying the propagation of GWs, it is normally assumed that space-time is flat and gravitational waves propagate as *spin-2* perturbation of flat space-time. Under these conditions gravitons are mass-less and travel at the speed of light. If there is a background energy density, like a cosmological constant, the background curvature and the graviton wave-packet curvature add non-linearly and the unbalance gives mass to the graviton (i.e. the positive perturbation "weights" more than the negative perturbation). Detailed analysis has provided a relationship between the mass of the graviton and the value of the background cosmological constant Λ in order to make propagation formally possible.

The relationship between the mass of the graviton m_g and background Λ, is, expressed in Planck units[32]:

$$mg^2 = \frac{2}{3}\Lambda \quad (7)$$

If the above relationship is not satisfied, the field is no longer a propagating radiation field. The theory was developed for large scale energy fields, like the cosmological constant, but it keeps validity at any scale above some wavelength of the selected GW. We promptly ask what happens if localized static high energy densities, for instance high electric energy densities in vacuum or in dielectrics, surround the GWs generator.

We expect that massive gravitons will be emitted, producing a back reaction on the generator, a thrust, and massive gravitons may possibly interact with distant matter, or maybe not very distant matter, because gravitons will leave the high energy density region where they are produced and will then propagate in "nearly" flat spacetime in which different propagation conditions apply[33].

Equation (7) can be rewritten in terms of energy density with the Einstein field equations:

$$mg^2 = \frac{2}{3}8\pi\rho \quad (8)$$

For engineering applications, the equation is converted to SI units by dividing the mass by the Planck mass. The energy density will be divided by the Planck energy and multiplied by the Planck volume:

$$\frac{m_g^{\,2}}{m_P^{\,2}} = \frac{16\pi}{3}\frac{\rho}{m_P c^2}\left(\frac{\hbar G}{c^3}\right)^{3/2} \Rightarrow m_g = \sqrt{\frac{16\pi m_P}{3}\frac{\rho}{c^2}\left(\frac{\hbar G}{c^3}\right)^{3/2}} \quad (9)$$

Substituting the SI values of the constants involved we have:

$$m_g = \sqrt{\frac{16\pi \cdot 2.17 \cdot 10^{-8}}{3}\frac{\rho}{9 \cdot 10^{16}} 4.22 \cdot 10^{-105}} = 1.3 \cdot 10^{-48}\sqrt{\rho} \quad (10)$$

Focusing our attention only on the emission process, it is possible to adopt Eq. (10) to predict the amount of thrust that can be obtained from a GWs generator and the associated localized energy density. It is necessary to know the number of gravitons produced per second and the relationship between the energy density and the mass of the gravitons. According to Eq. (10) it is not necessary to know the frequency of the GW to define the mass of the graviton, the frequency must be sufficiently high for the gravitons to be generated in a beam that can resemble a rocket thrust, and therefore this section is developed following this specific approach.

To maximize the mass of the gravitons, it is necessary to employ dielectrics that may support high energy densities. Dielectrics are characterized by the dielectric constant å higher than that of vacuum. Considering a plane capacitor with area A and armature distance d, the energy E of the electric field in the capacitor as a function of voltage V is:

$$E = 0.5CV^2 = 0.5\,\varepsilon\,V^2 A/d \quad (11)$$

Dielectrics may suffer voltage induced breakdown if overstressed, and measurements can provide indications about the preferred materials and predicted performances. Table 1 of[34], suggests that $E_b = 10^6$ J/m^3 can be considered a standard high range value. Dielectrics are important for intra atmospheric travel, where air ionization must be reduced without reducing the background energy density. With $E_b = 10^6$ J/m^3, using SI units in the above formula we have:

$$m_g = 1.3 \cdot 10^{-48}\sqrt{10^6} = 1.3 \cdot 10^{-45}\,\text{kg} \quad (12)$$

It could be considered as a rest mass. To calculate the speed of the gravitons from an engineering point of view, it is possible to consider the Planck relationship applied, for instance, to high frequency gravitons. Let us choose $f = 5$ Ghz. The graviton energy is of the order of $hf = 3.3 \cdot 10^{-24}$ J. The mass of the graviton is induced (produced) by the background energy density, being the particle massive and subluminal. It is possible to assume that its energy (most of it) is relativistic kinetic energy. With graviton mass of $1.3 \cdot 10^{-45}$ kg, by using the relativistic kinetic energy E_k formula for massive objects, the graviton speed is 0.2 m/s less than the speed of light and the relativistic mass m_{gr} becomes of the order of $3.6 \cdot 10^{-41}$ kg. If 10^6 W of GWs are produced by a generator, with $f = 5$ GHz, the number of gravitons per second is $3 \cdot 10^{29}$. The amount of mass turns out to be about $1.1 \cdot 10^{-11}$ kg/s expelled at nearly the speed of light. The momentum flow rate is $3 \cdot 10^8$ m/s $\cdot 1.1 \cdot 10^{-11}$ kg/s = 3.3 $\cdot 10^{-3}$ kg·m·s^{-2}, that is a measurable force.

With invariant GW power and invariant background energy density, reducing the frequency by adopting the generators discussed above, will increase the number of gravitons and reduce their relativistic kinetic energy. Relativistic effects combined with the background energy density that gives a "guaranteed rest mass to each graviton" turns out to be advantageous and with a frequency of 1 μHz, the thrust is 2000 kg·m·s^{-2}; 10^{-10} Hz will produce 2 $\cdot 10^5$ kg·m·s^{-2} thrust.

Gravitons with low frequency f_L can be produced by mixing two HFGW beams, with frequencies differing by f_L, within the the background energy density field. The method might be called gravitational wave mixing, and certainly will become a new research direction.

Gravitational wave focusing

The non-linearities of Einstein equations have also inspired a large number of theoretical papers on "colliding gravitational waves". Figure 6 shows a numerical solution of the collision of two impulsive gravitational waves[35].

The problem is usually described in *u, v* null coordinates (representing light propagation), expressed as: $v=t+r^*$; $u=t-r^*$; $r^*=r+2m\log((r-2m)/2m)$. The coordinate transformation is employed to represent space and time in a convenient

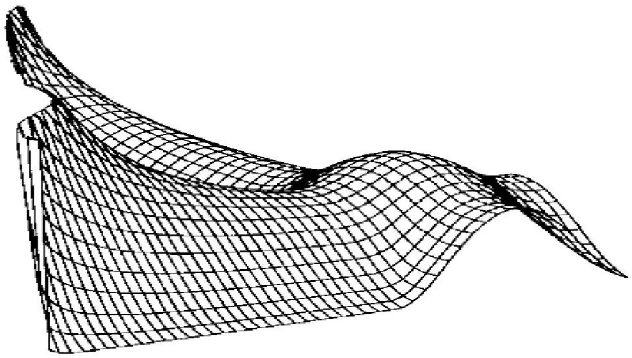

Figure 6 : Representation of the collision of two impulsive gravitational waves.

way, taking advantage of the symmetries of plane waves and "compressing" the space coordinates. The "bump" on the right of the picture represents the superimposing waves. The steep rise on the left of the picture is the effect of the non-linearity of Einstein equations and tends towards the singularity. The singularity does not appear by applying the linear approximation of Einstein equations.

Therefore, it has been shown theoretically and by numerical simulations, that, within the full theory of General Relativity, the singularity appears, accompanied by the diverging amplitude of the gravitational field.

The time (in Planck units) required for the creation of the singularity is a function of the amplitude of the waves A and the relative polarization α of the two waves[36,37].

$$\Delta t = \frac{1}{A^2}\sqrt{1+\sin\alpha} \tag{13}$$

According to Eq. 13 focused HFGWs with amplitude $A=\Delta l/l=10^{-22}$ at the source may collapse to a singularity in about a second (SI units). This amplitude is relatively large but could even be generated by MEMS in double-helix configuration[9]. The result is equally valid with the more realistic beam-like gravitational waves[38], and the interaction of two graviton beams[39]. Colliding plane gravitational waves will produce a curvature singularity or a coordinate singularity, and the radiation is completely converted into a coulomb-like gravitational field[37].

The calculation of the gravitational potential of the resulting coulomb-like field as a function of the amplitude of the impinging waves would require an evaluation of the energy of the wave during the focusing process, the study of the accumulation process and the lifetime of the resulting singularity. Because of the curved space-time model, energy is not well defined in General Relativity and the lifetime of singularities is the very complex subject of quantum gravitational theories and Hawking radiation. Assuming that the energy of the wave is completely converted into a coulomb-like gravitational field and that no matter is created, all the energy will be converted into additional kinetic and potential energy of the n-body system composed by the spacecraft, the gravitational wave singularity and the remaining bodies of the universe[40]. Because n-body simulations[41] show that most energy exchange involves nearest bodies, if the gravitational singularity is produced near a spacecraft, the associated gravitational potential will mostly affect the kinetic energy of the spacecraft. This phenomenology can be intuitively described as a pulling effect, because the singularity co-moving with the spacecraft continuously pulls the spacecraft toward itself.

A large number of exact and numerical solutions are available for the n-body problem; therefore many solutions are possible, including librations, gravitational slingshots, complex orbital motions and chaotic motion.

It has been shown that a singularity appears also at the focus of a single, focused beam of gravitational radiation. The perfectly focused beam can be represented by a spherical gravitational wave, which has a singularity at the focus[42]. The focus may be the source of the wave or the absorber of the back-scattered wave, the second interpretation is the one of our interest. It is believed that the wave creates the singularity, which moves away at the speed of light. With the spherical gravitational wave, produced for instance, by a hemispherical array of synchronized microscopic sources or by a curved HTSC Gaser, the optical imperfections of the beam near the focus region could be spontaneously reduced by the intrinsic focusing behavior of the collision process. With focused gravitational waves the phenomena described by Eq. 13 will take place at the final stage of the process.

Gravitational wave generators may be external or onboard the spacecraft. Massless gravitons should be preferred in this case, because the direction of motion is reversed respect to the propulsion method described in the preceding two sections.

EXPERIMENTS

Various experiments were already made and patents already filed describing apparatuses and results that may fit the above framework. All of them are considered controversial, some of them were partially replicated, and some of them went completely ignored by physicists and rocket scientists. All of them report effects that are more intense than what can be theoretically predicted by the common elementary use of the theory. It is not the scope of this paper to evaluate the work of other scientists; on the other hand some of their results may fit to a high degree the present analysis. This is a good reason to reconsider them and plan for future replications with the present analysis at hand.

Podkletnov[43] described an apparatus with a weak capacity of gravity modification. The apparatus was a kind of asynchronous electric motor with a dual layered HTSC disc rotor. The operating disc allegedly shielded from earth gravity objects put over it and located inside a cylindrical volume extending upwards for tens of meters. As an alternative interpretation it is possible to suggest that a repulsive force could have been applied to the target mass by an unidentified collimated radiation produced by the disc.

It is well known that the electric current in the rotor of asynchronous motors is higher than the current in the stator windings, and rotor current has maxima during acceleration and braking phases and under mechanical torque rotor load; this is a good reason to believe that the electric rotor current is what drives the phenomenon. In the second Podkletnov experiment[44], electric current with very high intensity was pulsed through the HTSC disc with a gas discharge apparatus. The current flowing through the disc produced similar effects, this time in a pulsed form and directed towards any desired direction, the intensity of the mechanical effects was more dramatic. This capability somehow confirms that the HTSC disc may emit a form of unusual radiation and the effects are very strong with higher voltages applied to the disc and the surrounding gas. According to the present analysis Podkletnov may have built and observed an HTSC Gaser, surrounded by electromagnetic fields capable of inducing the directional emission of massive gravitons. In the Podkletnov device the two layers, with different microscopic structures, but both made with YBCO, were probably characterized by different s-wave/d-wave Cooper pair densities. Because of the measured different critical temperatures, they were certainly characterized by different binding energies of cooper pairs, and transitions were possible. Unfortunately no direct measurement of the Cooper pair states was made on the Podkletnov devices.

The momentum back reaction on the source of massive gravitons was ignored in the Podkletnov apparatus, but it was possibly observed by Poher and described in Patent WO 200709369945. Poher experiment still adopts a dual layer HTSC both for propelling the disc itself and transferring linear momentum to nearby objects. Poher introduced a new hypothetical particle, the “Universon” to build a plausible theoretical framework for his experimental observations. Poher’s analysis could be complementary to the one described here.

The coordinated use of concepts like a source of gravitational waves and localized energy densities can be adopted for the analysis and design of these new space propulsion systems.

Less dramatic but still measurable effects have been observed since the beginning of the space era on rotating and highly charged objects, like charged rotating gyroscopes or rotating and electrically charged ballistic missiles. All those objects may have directionally emitted massive gravitons and be consequently affected by linear momentum change. Most observations are still disputed and controversial, waiting for a generally accepted classification and understanding.

CONCLUSIONS

The theoretical foundations of gravitational wave propulsion with massive gravitons were summarized and research directions given. The possibility of producing thrust and induce motion can be the result of the technical use of gravitational waves in combination with high intensity static electromagnetic fields.

Coulomb like gravitational fields produced by colliding gravitational waves may also enable an additional, truly gravitational, propulsion technique, a gravitational pull.

This paper was developed on established principles and results of the astrophysical, the material science and the nuclear science communities applied to space travel engineering. If efficient generators of HFGWs will be constructed and operated at the MW power level, measurable effects should be obtained and it will be possible to start improving the technology. Some known experimental results do fit the presented model as order of magnitude estimates, nature of the phenomena and physical-technical requirements to obtain the claimed result. Therefore, I recommend to replicate known related experiments and to proceed in designing gravitational wave engines for the spacecraft of the future.

NOMENCLATURE AND UNITS

m	=	mass in kg
f	=	frequency in Hz (cycles·s^{-1})
ω	=	$2\pi f$ = angular velocity in rad·s^{-1}
r	=	radial distance in m
v	=	speed in m·s^{-1}
E	=	energy in J
P=E·s^{-1}	=	power in W
ρ	=	energy density in J·m^{-3}
ε	=	dielectric constant in F·m^{-1}
$E_k = m_g c^2\left(\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}-1\right)$	=	relativistic kinetic energy of the massive graviton
$m_{gr} = \frac{m_g}{\sqrt{1-\frac{v^2}{c^2}}}$	=	relativistic mass of the massive graviton

$c = 2.997924 \cdot 10^{-8}$ m · s^{-1} = speed of light in vacuum

G = $6.7384 \cdot 10^{-11}$ m^{3}kg^{-1}s^{-2} = gravitational constant

$$\hbar = \frac{h}{2\pi} = 1.054571726 \cdot 10^{-34}\ \mathrm{J \cdot s}$$ = reduced Planck constant

$$m_P = \sqrt{\frac{\hbar c}{G}} = 2.17651 \cdot 10^{-8}\,\mathrm{kg}$$ = Planck mass

$$l_P^3 = \left(\frac{\hbar G}{c^3}\right)^{3/2} = 4.22419 \cdot 10^{-105}\,\mathrm{m}^3$$ = Planck volume

$$E_P = m_P c^2 = \sqrt{\frac{\hbar c^5}{G}} = 4.22419 \cdot 10^{9}\ \mathrm{J}$$ = Planck energy

$$t_P = \sqrt{\frac{\hbar G}{c^5}} = 5.39106 \cdot 10^{-44}\,\mathrm{s}$$ = Planck time

$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$ = Einstein field equations in Planck units

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