After peer reviews, to be published in the *Proceedings of the Space Technology and Applications International Forum (STAIF-2007)*, edited by M. S. El-Genk, American Institute of Physics, Melville, New York, Feb. 12-15, 2007, Paper 052

Reviewer's Comments

Your paper was submitted for peer review. Below are the reviewer's comments, provided for your information. Reviewer's names have been omitted:

Reviewer's Comments on Log No. 052

Reviewer #1:

This paper has explored the possibility that an intense beam of HFGWs might be used to change the relativistic mass of elementary particles and clusters of elementary particles in combination with space-time compression. The focused is on the application of the predicted phenomenon for nuclear fusion and energy production. The auhers indicate that HFGWs could temporarily change the physical electronic properties of materials, from solid to liquid for instance, from conductor to insulator, depending on the amplitude and frequency of the oscillation. This possibility may have extraordinary applications to micro-manufacturing, micromechanics, microelectronics, chemistry and even biology.

The paper is very well written, subject to a clerical review by STAIF.
I recommend acceptance.

Reviewer #2:

* The "principles" section would benefit from a sentence or two providing a unit analysis or background description of the physical meaning of Δh.
* Third bullet under advantages, I do not understand why the electrons are at issue when we are discussing nuclear fusion. Because they are often present in a confined plasma? For instance, in electro-statically confined schemes, the electrons are driven out of the ionized plasma to the confinement grid.
* "radial velocity" versus "velocity" for the line above equation (5)
* Figure 1 shows the generation of a pair of HFGW wave fronts but does not show them coming back together for GIF confinement purposes, which is the point of the current paper. Please update the figure to show confinement.

<u>Summary</u>
This paper may very well prove to be a seminal work in the area of gravitationally induced nuclear fusion.
I recommend acceptance.

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High-Frequency Gravitational Wave Induced Nuclear Fusion

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Abstract. Nuclear fusion is a process in which nuclei, having a total initial mass, combine to produce a single nucleus, having a final mass less than the total initial mass. Below a given atomic number the process is exothermic; that is, since the final mass is less than the combined initial mass and the mass deficit is converted into energy by the nuclear fusion. On Earth nuclear fusion does not happen spontaneously because electrostatic barriers prevent the phenomenon. To induce controlled, industrial scale, nuclear fusion, only a few methods have been discovered that look promising, but net positive energy production is not yet possible because of low overall efficiency of the systems. In this paper we propose that an intense burst of High Frequency Gravitational Waves (HFGWs) could be focused or beamed to a target mass composed of appropriate fuel or target material to efficiently rearrange the atomic or nuclear structure of the target material with consequent nuclear fusion. Provided that efficient generation of HFGW can be technically achieved, the proposed fusion reactor could become a viable solution for the energy needs of mankind and alternatively a process for beaming energy to produce a source of fusion energy remotely -- even inside solid materials.

Keywords: high frequency, gravitational wave, HFGW, nuclear fission, nuclear fusion, nuclear reactor, isomer, particle accelerator.
PACS: 04.30.-w, 28.41.–i, 28.50.–k, 33.15.Hp.

INTRODUCTION

Fusion reactions are so common in the Universe that it seems surprising that our technical efforts have not yet produced a working generator based on nuclear fusion. Combining theoretical results from different fields to build a new technical process is the main difficulty. The engineering design of an appropriate apparatus requires great investments in money and time. Sometimes it happens that the development of new technologies is delayed for years, sometimes forever, by unforeseeable effects, discovered during the development of a prototype apparatus.

For light elements nuclear fusion is exothermic and could theoretically happen spontaneously. Fortunately, this is not actually the case; since for most fuel materials, some threshold of ignition temperature must be reached. The barrier for nuclear fusion is electrostatic and is related to the fact that the electrostatic force has a longer range respect to the strong force that drives nuclear processes. In principle the engineering of practical fusion reactors deals with methods to overcome the electrostatic repulsion barrier with, for example, high temperature. Once the electrostatic barrier is overcome, the fusion is spontaneous and energy is released for practical applications.

The well known methods for overcoming the electrostatic repulsion are the following:

- High reactant speed in relatively low density plasmas, which is the kinetic-fusion principal employed in the design of *tokomaks.*
- High reactant density in high density plasmas driven by radiation pressure, which is the principal employed in laser and particle beam inertial confinement fusion devices.
- Electrostatic shielding down to the strong force range with mesonic particles, which is the principal employed in theoretically proposed muon catalyzed fusion reactors.

All those methods might be viable paths to an economically profitable reactor. On the other hand, new technology theories such as those involved in this paper, may indeed provide new concepts capable of initiating different paths to useful fusion energy. If successful, they might be employed for applications not requiring big generation plants. Small nuclear-fusion generators, which could be utilized as land and marine vehicle power sources, in spacecrafts, or simply to provide electrical power to small communities are contemplated herein.

The objective of this paper is to initiate the development of a technology capable of replicating the mechanisms of the "fusion reactors" that we observe in nature. The fusion reactions active on stars are driven by gravity, therefore why not consider a similar process built at a much smaller scale? A heritage of thousands of theoretical results from the field of General Relativity (GR) are waiting for clever engineering applications, and among them some can be selected for demonstrating that fusion reactors can be constructed according to new principles. For instance non linear effects related to High-Frequency Gravitational Waves or HFGWs can be applied to "Gravity Induced Fusion" (GIF). Metric changes at the atomic scale can emulate the muonic fusion process without the need for muons, therefore the process can be described with known theories and supporting experiments. All the difficulty is then transferred to the technical difficulty of building a suitable generator of HFGWs, like one of those already described by the authors (Fontana and Baker, 2003; Baker, 2003; Baker, 2004a; Fontana, 2004; Fontana and Baker, 2006) based upon the generation concept derived in Baker (2006) and referenced in part in patents granted to Baker (2004b; 2005).

PRINCIPLES OF HFGW INDUCED FUSION

The goal of the proposed technology is simple: to reduce the distance between the nucleus and the associated electron of a suitable hydrogen isotope (typically deuterium) by a factor of 200. With such a squeezed hydrogen nucleus, experiments with muonic hydrogen molecules show that fusion can take place on a picosecond time scale (Cohen, 1989). The associated HFGW metric distortion is simply Δh=199/200= 0.995, which is extremely high if compared to typical numbers related to astrophysical events as detectable here on Earth. It is indeed slightly less than 1, which is a value that represents a black hole collapse, a supposedly common event in the Universe.

HFGWs transport energy and momentum and therefore they exhibit their own gravitational field (Landau and Lifshitz, 1975). The relation between gravitational wave amplitude and the metric distortion that applies to a couple of test particles is positive and unitary according to the pioneering work of Braginsky and Thorne (1987), Christodoulou (1991), and Thorne (1992). HFGWs must be focused to a small spot, possibly utilizing the variable-focus HFGW lenses described by Woods (2007), in order to reach the required amplitude Δh = 0.995. The problem can be approximated by geometric optics, provided that the frequency of HFGW is high enough to provide the required amplitude at a diffraction limited spot. At high amplitudes GR is non linear, thus we might expect a departure from geometric optics. Fortunately, the problem has been already theoretically examined and the resulting effects are found to be advantageous. Non linearity improves the focusing process and h goes to one in finite time producing a singularity "regardless" of the starting, non-focused, amplitude of the impinging gravitational wave (Corkill and Stewart, 1983; Ferrari, 1988a; Ferrari 1988b; Ferrari, Pendenza and Veneziano, 1988; Veneziano, 1987; Szekeres, 1992). The effect of a Δh = 0.995 pulse of HFGWs on the couple formed by a deuterium nucleus and its electron is the reduction of their relative distance by a factor of 200. If this distance reduction is effective for few picoseconds, then the two nuclei of a deuterium molecule can fuse and give a He atom plus energy, which is the usual nuclear-fusion process in a star. In the GIF scheme the lesson learned with the muonic hydrogen fusion takes an important role. Muonic hydrogen fusion has been experimentally observed in nature and is therefore a fact. In addition the electrostatic shielding properties of electrons makes the compression possible with low energy input and low ignition temperature, the reactor will be capable of operating in pulsed condition, which is also a prerequisite for the HFGW generator.

The approach suggested has advantages over three competing techniques:

- It is not necessary to accelerate the reactant to high speed, this will save energy.
- It is not necessary to employ electromagnetic (EM) radiation pressure which is not very efficient for transferring energy to target ions that exhibit full electrostatic repulsion.

- It is not necessary to replace the electron with the muon, which is short lived and requires energy to be produced. HFGWs might simply push the normally present electron to a much shorter distance from the nucleus so that fusion will be spontaneous.

When applied to our geometry, the order of magnitude of the Christodoulou effect is (Thorne, 1992; Christodoulou, 1991):

$$\Delta h \sim (0.1\,\text{to}\,1)E/r. \tag{1}$$

Δh = 0.995 is the required final memory effect (the term in parentheses is assumed to be one), E is the total energy of the burst at the focal spot near the nucleus of a Hydrogen atom, and r is the Bohr radius of Hydrogen. Using these values, the required energy in geometric units is $5\cdot10^{-11}$. To calculate the energy in Joules it is necessary to divide by G/c^4, obtaining E=$5\cdot10^{-11}/8.26\cdot10^{-45}$=$6.04\cdot10^{33}$J. The required power over a time-span of the order of the picoseconds is about $6\cdot10^{45}$W, which is fortunately about *100 times smaller* than the value of $5\cdot10^{47}$W computed in Fontana and Baker (2006), p. 1356 as possible output power of the therein described HFGW generator.

To find the amplitude h_{GW} of the burst of HFGW near the focus point we define the wavelength of the burst to be λ and r to be the distance between the source, which is the focal spot near the nucleus in our case, and the detector, which is the electron orbital in our case. We recall that for a burst of gravitational waves we have (Thorne, 1992):

$$E \sim (\pi h_{GW}/\lambda)^2 \lambda n r^2 \ , \tag{2}$$

where n is the number of cycles in the burst. Eq. (2) can be combined with Eq. (1), obtaining:

$$h_{GW} \sim \frac{1}{\pi}\sqrt{\frac{\lambda}{r}\frac{\Delta h}{n}}. \tag{3}$$

For a picosecond burst with frequency ω=$3\cdot10^{24}$ s^{-1}, n=$3\cdot10^{12}$, and λ=10^{-16} m. We find h_{GW} ~$2.6\cdot10^{-10}$.

The amplitude of the HFGW is quite small, and it is the integration of the large number of periods in the burst that induces the microscopic system to collapse because of the non-linearity memory effect. The smallness of h_{GW} is also due to the extremely high frequency of the burst we are considering.

The effect of HFGWs on matter is not limited to the memory effect. If HFGWs interact with a couple of test particles it induces a temporary increase of the mass of the two test particles because they are affected by vibrations. When test particles vibrate their energy increases, their mass increases and, if they are free, then their distance changes. If they are not free, then the dynamics of the system is affected in various ways depending on the frequency of the HFGWs. Again we stress that if the mass of the electron is increased by a factor of 200, then it is possible to mimic muon induced fusion, for which experimental knowledge has been already gained. The mass of the nuclei will also increase, and the slowdown of the relative motion between two nearby nuclei will be compensated in part by the compression due to the memory effect, at least for the fusion process.

For the analysis we propose to consider two clusters of fuel suitable for nuclear fusion that will react separately in their own location. The distance between the two clusters is r, which is a laboratory scale distance. The HFGWs considered here are of nuclear origin and their frequency is much higher than that generated by any electronic/atomic process. We suggest two HFGW beams be produced with exactly the *same* frequency and phase by synchronizing the two HFGW generators with the same laser beam, each HFGW beam is focused on its own cluster. Alternatively, it is also possible to develop a single HFGW generator with two outputs.

By referring to the change of the distance Δr induced on a pair of test particles, the two clusters, with distance r=10m, by a sine GW with amplitude h_{GW} and frequency $f=\omega/2\pi$, we have:

$$\Delta r = h_{GW}\, r \sin(\omega t). \tag{4}$$

The radial velocity is:

$$\frac{d}{dt}\Delta r = \frac{d}{dt}\left(h_{GW}\, r \sin(\omega t)\right) = \omega\, h_{GW}\, r \cos(\omega t). \qquad (5)$$

The average kinetic energy is:

$$E = 0.25\ \ h_{GW}^2\ r^2\ m_0\ \omega^2\ \ \mathrm{J}. \qquad (6)$$

For increasing the mass of the electron to that of the muon, the energy must become equal to:

$$E = 200\ \ m_0\ c^2\ \ \mathrm{J}. \qquad (7)$$

Therefore we have:

$$h_{GW} = \sqrt{[800\ c^2/(\ r^2\ \ \omega^2)]} = \sqrt{[800 \cdot 9 \cdot 10^{16}\ /\ (10^2\ 9 \cdot 10^{48})]} = 2.8 \cdot 10^{-16}\ , \qquad (8)$$

which compares favorably with the output of the generator presented by Fontana and Baker (2006) and with the laser-driven HFGW generator by Baker, Li and Li (2006).

For a sphere with the radius of the first Bohr radius of the Hydrogen atom ($4\pi\, r^2 = 3.14 \cdot 10^{-20}$ m^2) we therefore need a power flux of (Schutz, 2000):

$$F_{GW} = 1.6 \cdot 10^{-5}\left(\frac{f}{100}\right)^2\left(\frac{h_{GW}}{10^{-22}}\right)^2 W\, m^{-2}. \qquad (9)$$

Introducing the previously determined values into Eq. (6), we have:

$$F_{GW} = 1.6 \cdot 10^{-5}\left(\frac{0.47 \cdot 10^{24}}{100}\right)^2\left(\frac{2.8 \cdot 10^{-16}}{10^{-22}}\right)^2 W\, m^{-2} = 4.7 \cdot 10^{51} W\, m^{-2}. \qquad (10)$$

By computing the power flux at the Bohr radius, the required HFGW power impinging on the Hydrogen atom is:

$$4.7 \cdot 10^{51}\ \mathrm{W\ m^{-2}} \cdot 3.14 \cdot 10^{-20}\ \mathrm{m^2} = 1.47 \cdot 10^{32}\ \mathrm{W}. \qquad (11)$$

and finally we find that the HFGW energy impinging on the Hydrogen atom for 1ps is $1.47 \cdot 10^{20}$ J.

The resulting theoretically required energy is extremely high, but it is based on the one picosecond time scale of the experimentally observed tunneling times for the fusion of muonic hydrogen isotopes in flat space-time. As the experimental setup will require the focusing of HFGW along an axis, even the many hydrogen atoms aligned along that axis will be affected by increased gravitational force, increased mass and reduced inter-atomic distance, thus tunneling times (that is, how long to wait for the event to happen) will be reduced by many orders of magnitude, the exact value cannot be easily estimated because tunneling times are theoretically zero, and it is the physical system that do indeed define the tunneling probability. Therefore the energy we found is an upper limit and the energy required in practice will be less. Because the inter-atomic distance among atoms in a fluid depends on the size of each atom, it might be reasonable that the electronic orbital collapse along the beam of HFGWs will cause a drop in stiffness in that volume of fluid that is exposed to high intensity HFGWs. It is possible to conclude that HFGWs may also cause an implosion of already collapsed atoms, tunneling times could now be of the order of femtoseconds, thereby *reducing* the energy requirements to about 10^{17} J.

Taking into account that inter-atomic distances are of the order of 10^{-10} m, a well collimated beam of HFGWs, possibly utilizing the HFGW lenses described by Woods (2007), may affect a sufficient number of atoms and be capable of driving the system into effective production of energy at a laboratory scale. It is also possible to increase the distance between the two clusters to kilometers or use any suitable remote mass as "reaction" mass for balancing a single useful cluster, this will again reduce the required amplitude of the HFGWs.

APPLICATION EXAMPLE

To keep the application in agreement with the standard quadrupole formulation of gravitational waves, the application example is an implementation of the pulsed HFGW generator intended to jerk (Baker, 2000; 2006) a target mass. In the application example of Fig. 1, the Christodoulou effect, summarized in equations 1, 2, 3, is practically implemented by a cascade of effects.

A specific geometrical focusing and the orientation of the fissioning particles in the generator through optimally shaped magnetic flux lines and similarly shaped laser beam can produce focused HFGWs. The quality of the output HFGW is mainly determined by the optical quality of the laser beam, specifically spatial and temporal coherence of wavefronts and their focusing on the target. Calculation performed in the previous section and in (Fontana and Baker, 2006) show that it is possible to achieve the required energies to induce fusion in a suitable DD or DT mixture. In the figure the picosecond ultra high intensity laser is schematized for this specific implementation (Baker, Li and Li, 2006) as the source of fission inducing particles, alternatively relativistic antiprotons (Fontana and Baker, 2006) can be employed. From left to right, pulses of X-ray radiation, are focused on the target. The interposed fission generator of HFGW converts the impinging pulses of fission inducing particles to pulses of HFGW, the generator maintains the timing of wavefronts, thus maintaining focusing. The focusing is required to create the gravitational nonlinearity effect and high intensity vibrations that induce fusion. According to the principles here presented, it is not necessary to resort to uniform radiation pressure or symmetrical configurations around the target, confinement is gravitationally symmetric near the focus.

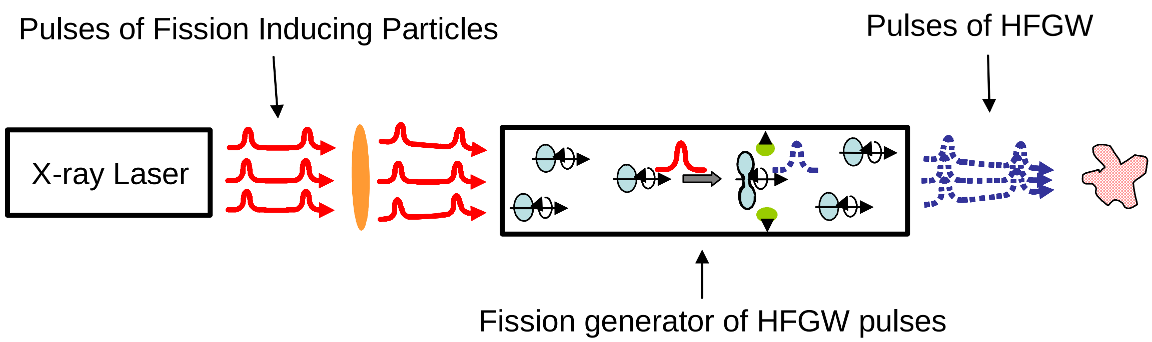

FIGURE 1. Possible Configuration for HFGWs Nuclear Fusion Experiment.

Besides applications to nuclear fusion, the described apparatus could find application to many other physical treatment of materials and manufacturing applications.

HFGWs could temporarily change the physical electronic properties of materials, from solid to liquid for instance, from conductor to insulator, depending on the amplitude and frequency of the oscillation. This possibility may have extraordinary applications to micro-manufacturing, micromechanics, microelectronics, chemistry and biology (Moy and Baker, 2006). Though if HFGW can find applications to space travel (Baker, 2000; Bonnor and Piper, 1997; Fontana, 2000; Fontana, 2003; Fontana, 2005), telecommunications (Baker, 2000; Stephenson, 2003), and surveillance (Baker, 2007). High intensity and focused HFGWs down to the microscale can be used for production of new materials and devices.

CONCLUSIONS

This paper has explored the possibility that an intense beam of HFGWs might be employed to change the relativistic mass of elementary particles and clusters of elementary particles in combination with space-time compression. We focused on the application of the predicted phenomenon for nuclear fusion and energy production. At lower intensity, high-frequency vibrations induced by HFGWs may also change the chemical and physical properties of materials and a wide spectrum of technical applications can be envisaged, including application to the physical treatment of materials and manufacturing applications. HFGWs could temporarily change the physical electronic properties of materials, from solid to liquid for instance, from conductor to insulator, depending on the amplitude and frequency of the oscillation. This possibility may have extraordinary applications to micro-manufacturing, micromechanics, microelectronics, chemistry and even biology. Finally, high intensity HFGWs, and the nuclear effects that they can cause can find applications to space travel, telecommunications, and surveillance.

NOMENCLATURE

Δh = dimensionless change of the distance of two test particles = $\Delta x/x$

h_{GW} = dimensionless amplitude of Gravitational Wave = peak change of the distance of two test particles ($\Delta x/x$) orthogonal to the direction of propagation.

F_{GW} = Power flux of Gravitational Wave ($W\ m^{-2}$)

E = Energy (J)

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