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Layperson's Description of High-Frequency Gravitational Waves or "HFGWs"

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What are high-frequency gravitational waves or HFGWs? Visualize the luffing of a sail as a sailboat comes about or tacks. The waves in the sail's fabric are similar in many ways to gravitational waves, but instead of sailcloth fabric, gravitational waves move through a "fabric" of space. Einstein called this fabric the "space-time continuum" in his 1915 theoretical work known as General Relativity (or GR). Although his theory is very sophisticated, the concept is relatively simple. This fabric is four-dimensional: it has the three usual dimensions of space: (1) east-west, (2) north-south, (3) up-down, plus the dimension of (4) time. Here is an example: we define a location on this "fabric" as 5th Street and Third Avenue on the forth floor at 9 AM. We can't see this "fabric" just as we can't see the wind, sound, or gravity for that matter. Nevertheless, those elements are real, and so is this "fabric." If we could generate ripples in this space-time fabric, then many applications become available to us. Much like radio waves can be used to transmit information through space, we could use gravitational waves to perform analogous functions. Still the question arises … how can we generate and detect these gravitational waves in the space-time fabric?

One way we can generate wind waves is by the motion of fan blades. Likewise, gravitational waves (GWs) can theoretically be generated by the motion of masses. We can detect wind waves by the motion of a weather vane. Similarly, we could detect gravitational waves by a transient change in a dimension, such as the distance between two points at the ends of a ruler. Gravitational waves will make the ruler seem to behave, to an outsider observer, as if it was made of rubber, stretching and contracting. However, the change in length would be extremely small, smaller than the diameter of a proton! Ordinarily we would not be able to observe it, but scientists are now testing techniques to detect gravitational waves by very accurately measuring the distance between two points (technically it is called the Laser Interferometer Gravitational Observatory or LIGO), which went into operation about two years ago.

So, Gravitational Waves are like other waves, but they exist in a rather strange fabric of space-time. Now comes the tough part: how are gravitational waves generated in nature? One possible generation mechanism is a double-star orbit, two stars that circle around or orbit each other. If these stars are very heavy, perhaps black holes, then there exists an incredibly large **change** in force, called centrifugal force, as they orbit one another. According to Einstein's publication in 1916 (a year after his GR) such a rapid change in force over a brief time generates gravitational waves and he developed an equation – the "quadrupole" – to estimate the gravitational-wave power from a source, such as orbiting stars in 1918. At the time it was believed by the scientific community that these "gravitational waves" were just artifacts of Einstein's theory and probably didn't exist in a meaningful form. Then two astronomers – Hulse (a student) and his professor Taylor were studying a radio star pair at the huge Arecibo radio observatory in Puerto Rico (it's 305 meters across). The star pair they observed was coalescing and the energy it was loosing during this coalescence was **exactly** as predicted by Einstein. They received the Nobel Prize in 1993 and from then on the skepticism evaporated and all scientists believed that, due to this indirect evidence, gravitational waves did indeed exist.

However, the gravitational waves generated by these star pairs are of very low frequency, only a few cycles to a fraction of a cycle per second. So if the stars orbit very tightly around each other with a period of, say, one second (for comparison, the period of our motion around the

Sun is one year), then the gravitational-wave frequency is two cycles per second or two “Hertz,” (2 Hz for short – gravitational waves have twice the orbital frequency according to Einstein’s theory). If black holes spun around each other during the final phase of their coalescence (or “death spiral”) in say one fortieth of a second, then their frequency would be 80 Hz. For a reference, US house current has a frequency of 60 cycles per second (60 Hz) whereas radio waves have frequencies of thousands or millions of Hz.

These Low-Frequency Gravitational Waves (LFGWs), generated by changes in force (for example, during the orbiting of two black holes), could be detected by LIGO if they exhibited frequencies from 40Hz to 2000 Hz. And there are high-frequency gravitational waves (HFGWs) still reverberating around the universe generated by the Big Bang and our Earth is bathed in the sea of these relic GWs. But what use are these gravitational waves if we can’t harness their potential? To be useful we not only need to detect them… we need to generate them. So, could gravitational waves be generated in the laboratory? It’s obvious we cannot have two black holes orbiting in a laboratory, but it turns out we really don’t need to. The trick is that we **don’t require gravitational force** to generate gravitational waves! It’s really the motion of the mass that counts, not the kind of force that produces that motion. How do we obtain a large force change? To make it practical we need a force that is much larger than the force of gravitational attraction. Let's do a thought experiment and think of two horseshoe magnets facing each other (North poles facing South poles). They will attract each other strongly. If we reverse the magnets, put them down back-to-back with their poles facing outwards, then primarily their gravitational force acts due to their masses and we sense little or no attractive pull. As a matter-of-fact, magnetic, electrical, nuclear and other non-gravitational forces are about 1,000,000,000,000,000,000,000,000,000,000,000,000 times larger than the gravitational force! So, if we have our choice, we want to use "electromagnetic force" as our force, not weak little gravity.

How could we make use of this analysis and generate GWs in the laboratory? Instead of the change in "centrifugal force" of the two orbiting black holes, let us replace that force change with a change of non-gravitational force, the much more powerful one of electromagnetism. One way to do this is to strike two laser targets with two oppositely directed laser pulses (a laser pulse <u>is</u> an electromagnetic wave). The two targets could be a small masses, possibly highly polished tungsten. Each laser-pulse strike imparts a force on the target mass acting over a very brief time, commonly defined as a "jerk" or a shake or an impulse. Einstein says, according to his broad concept of "quadrupole formalism," that each time a mass undergoes a change or buildup in force over a very brief time; gravitational waves are generated – **in the laboratory!** The duration of these pulses is very short—a very small fraction, perhaps only one thousand billionth of a second, but that short duration leads to an extremely high frequency, on the order of billions cycles per second (say, 1,000,000,000,000 Hz or a Terahertz or THz) for this pulse duration. And such high GW frequencies of over 100,000 Hz have been defined by Stephen Hawking as HFGWs. The combination of two masses in the form of laser targets acted upon (jerked) by two lasers is one embodiment of a laboratory HFGW generator.

Another embodiment of the concept is to replace the laser targets by two clusters of millions of very inexpensive little piezoelectric crystals found in cell phones and energized by thousands of inexpensive Magnetrons found in microwave ovens. The little crystals each produce a small force change, but millions or billions of them operating in concert produce a huge force change and generate HFGWs. Other ideas could involve molecular-size resonators or even off-axis spinning atomic nuclei.

These HFGWs that will soon be generated in the laboratory have wonderful and revolutionary applications that low frequency gravitational waves simply do not have!

But what are those wonderful applications of HFGWs? The successful completion of the experiment in China, Russia, the US, or anywhere else, to prove that HFGWs can be generated and detected in the laboratory would be even more important than Marconi's development of the Radio Telegraph. Besides almost assuring a Nobel Prize for whoever successfully accomplishes the HFGW generation/detection experiment, there would be tremendously lucrative commercial and military applications. Some examples:

(1) Multi-channel communications (both point to point, for example to deeply submerged submarines, and point to multipoint – like cell phones-- through all ordinary material things – the ultimate wireless system). One could communicate directly through the Earth from New York in the United States to Beijing in China, without the need for fiber optic cables, microwave relays, or satellite transponders – antennas, cables, and phone lines would be things of the past! Even the timing afforded by HFGW stations around the globe could result in at least a **50 Billion dollar** savings in conventional telecom systems over ten years according to a recent analysis of Harper and Stephenson. Essentially it would allow for greater telecommunications bandwidth usage efficiencies by synchronizing, through the use of HFGWs (which, unlike

electromagnetic waves, move at constant speed through the Earth and atmosphere) all telecom transmitters and receivers. Thus no communication time would be needed for "waiting" for messages to appear – one message could follow right after another since you know precisely (to nanoseconds or better) when they will come in. Specifically, Harper and Stephenson find cost savings in communications message search-space and frequency-reference improvement and phase-noise reduction. Each savings is small, but their analyses show that Billions of dollars in telecommunications costs could be saved.

(2) As discussed in the authoritative text by Landau and Lifshitz, HFGWs provide a remote means for causing perturbations to the motion of objects such as missiles (anything from bullets to ICBMs), spacecraft, rogue comets or minor planets that are destined to impact Earth, land or water vehicles or craft – **a totally new propulsion system!**

(3) Remote coalescing of clouds of hazardous vapors, radioactive dust, etc. by changing the gravitational field in their vicinity.

(4) The potential for through-earth, or through-water "X-rays" utilizing the extreme sensitivity of HFGW generation-detection systems to polarization angle changes (possibly less than 10^{-40} radians or one

Billion, Billion, Billion, Billionth of a degree) in order to observe subterranean structures, geological formations (such as oil deposits), create a transparent ocean, view three-dimensional building interiors, buried devices, hidden missiles, weapons of mass destruction, achieve remote acoustical surveillance or eavesdropping, etc. – a full-body scan without radiation danger.

(5) the potential for remotely disrupting the gravitational field in a specific region of space (using a HFGW "beam") and even producing nuclear reactions there – possibly without any radioactive waste!

(6) Possible dermatological applications since Dr. Lawrence Moy has determined that HFGWs might tighten facial muscles and **reverse the aging process!**

If Einstein's quadrupole formalism holds, and we expect it does as I wrote in a recent Journal ***Astronomische Nachrichten / Astronomical Notes*** peer-reviewed scientific paper, then GW radiators (e.g., laser targets, clusters of piezoelectric crystals, off-axis spinning nuclei, etc.) could be placed at lunar distance. By adjusting them a remote GW focus, which would itself be a powerful, movable, remote HFGW emitter could be moved to any point above, on, or under the Earth's surface – certainly a fantastic possibility!

There are no commercial or military secrets here since all of the technology is openly disclosed in the four patents now issued (2006) in the United States and China (6160336, 6417597, 6784591 and 100055882.2) and the 16 pending in the U.S., Europe, Russia, and China. By the way, low-frequency gravitational waves do not have any of the foregoing applications.

The next question that arises is what steps would need to take place, once minute amounts of HFGWs are generated and detected in the laboratory, in order to eventually realize the fantastic possibilities of HFGWs? The first experimental laboratory model could be enlarged many fold and still remain within practical funding limits. For example, 200 lasers (rather than two utilized for one possible HFGW generation experimental apparatus) could be positioned at a distance apart some one-hundred-times larger than the experimental version (say, tens or hundreds of kilometers apart). Hundreds of billions of piezoelectric crystals and hundreds of millions of microwave-oven Magnetrons could be positioned in clusters many kilometers apart – even extending to the Moon’s distance. According to published theory, and assuming that the quadrupole formalism holds at least approximately at these distances, this would increase HFGW power some 100,000,000 fold!

(1) Using such an enhanced HFGW generator, HFGW receivers (detectors) could be positioned on the opposite side of the globe to test through-earth communications.

(2) First sensitive accelerometers, then massive objects, say 50 kilograms, could be tested for gravitational-field change and movement at the HFGW generator's focus.

(3) Various aerosols could be tested for coalescence at the focus.

(4) The HFGW detectors on the opposite side of the Earth from the generator could be moved around over known geological formations to determine if the characteristics of the GWs change (especially an extremely small polarization angle change) depending upon intervening material. In fact, detectors local to the HFGW generator could be utilized to determine the effect of particular objects and materials placed between the detector and the more powerful HFGW generator.

(5) Even with the less powerful experimental HFGW generator the gravitational-wave intensities could be many times larger than the intensity of sunlight at the Earth's surface! Strong disruptive events (including nuclear) could result in very small regions of space at the focus and generation of energy is a possibility without hazardous nuclear waste.

Actually though, such a question of technology transfer is difficult to answer. The same question put to Marconi, after his successful test of miniscule radio-telephone power, would not have revealed the revolutionary applications of his experiment to microwave ovens, cell phones, radar, television, etc. The same will no doubt be true of the applications of a successful HFGW-generator test.

What is actually going on now (2006)? Let's examine and discuss the current Chinese initiatives in the area of HFGW generation, detection and applications. In October 2004 the Chinese invited me to carry out a month-long lecture tour of Chinese universities and institutes. They had an active program in HFGW research – as opposed to the US where I was unable to obtain either interest by the US scientific establishment or funding for HFGW research. The Chinese have an HFGW project funded by various Chinese Foundations. I had formed a team of US scientists interested in HFGW (GRAVWAVE® LLC) and accomplishing some unfunded research (the team includes Professor Clive Woods, the Department Chairman of Electrical and Computer Engineering at Louisiana State University, Dr. Buzz Aldrin, the Astronaut, Dr. Eric Davis, a Senior Scientist at ***The Institute for Advanced Studies at Austin***., and a few others). Next year we may participate in the Chinese HFGW Project and be funded by them. But why is there no US interest?

` For the answer let me go back to when Hulse and Taylor received the Nobel Prize in 1993 for their indirect confirmation of the existence of gravitational waves. Prior to that time there had been some effort to detect gravitational waves – specifically, by Dr. Joseph Webber who, along with his protégé in the project, Dr. Robert Forward, fabricated a meter-sized Aluminum bar at the Hughes Research Facility in Malibu, California called the “Weber Bar.” The idea was that the bar would resonate or “ring” when gravitational waves passed by. After a year or so of operation the device did not detect any gravitational waves; but Dr. Forward believed that it eventually would. In 1960 I invited Dr. Forward to present a lecture on gravitational waves to my staff at the Lockheed Astrodynamic Research Center in Bel Air, California and that was when I first became interested in gravitational waves. Weber’s device never made a detection, but after the 1993 Noble Prize the skepticism over gravitational waves evaporated. Scientists from Caltech (including Professor Kip Thorne) and MIT sought funds from the National Science Foundation to construct the Laser Interferometer Gravitational Observatory (LIGO). They initially asked for about 390 million and by the time it went operational its price tag rose to over half a billion dollars. Like the Weber Bar there has not yet to been a detection, but it could come at any time. Now the group is soliciting in excess of 200 million for an “Advanced LIGO” and then a space-based Laser Interferometer Space Antenna or LISA, which may cost as much or more than the current LIGO. This is a long way around to explain why the US scientific establishment does not want to fund High-Frequency Gravitational Wave research – it would be an unwanted diversion from its Low-Frequency Gravitational Wave detector aspirations and hundreds of scientists worldwide are on the “LIGO payroll.” Unfortunately, at the lower frequencies and longer wave lengths (thousands to millions of meters in wavelength) there do not exist any of the potential practical applications already discussed. Then there is the inherent reluctance of top scientists to look into something new especially if they, or their immediate colleagues, have not themselves discovered the novel concept. The old “Not invented here” complex. The famous scientist Dr. George Chaplain put it best in an E-mail he sent to me when he heard of the Chinese interest in my work:

Re: Gravitational-Wave Research Page 1 of 2

Robert M. L. Baker, Jr. Ph. D.

From: George Chapline [chapline1@llnl.gov]
Sent: Tuesday, August 17, 2004 12:48 PM
To: robert.baker.jr@comcast.net
Subject: Re: Gravitational-Wave Research

Dear Bob,

I'm very pleased to hear that someone is interested in funding your research on HFGW; I've always thought this was worth pursuing. As you probably well know both DARPA and NSF are part of "old boys" networks. Unless you personally are a close friend with someone there - forget it. Just be thankful that the Chinese are not as close minded on the subject of HFGW as the U S funding establishment.

george chapline

(DARPA = Defense Advanced Research Projects Agency (the research and development agency for the US Department of Defense)

NSF = National Science Foundation

Dr. Chapline is the senior physicist at the Lawrence Livermore National Laboratory, USA. He was Edward Teller's Principal Assistant. Teller developed the Hydrogen Bomb.)

We are, nevertheless, driven by both scientific curiosity and the prospect of manifest potential practical applications to accomplish the HFGW test. Several technical papers found at www.Gravwave.com provide the interested scientist or technical person a more complete and technically detailed analysis of HFGWs, their generation and detection in the laboratory experiment. As I said in a lecture I delivered in Europe in 2002 at the *Max Planck Institute* in Munich: **The time is right, *carpe diem*... seize the moment! And on with the experiment!**