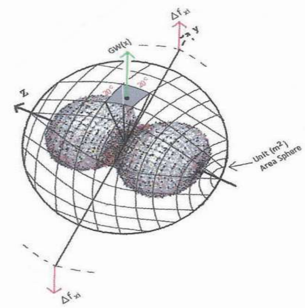
Gravitational Waves

The World Of Tomorrow, a Primer



Robert M L Baker, Jr.

This Book is dedicated to my Wife

Bonnie Sue Baker, MBG

(June, 2016)

Who in the 1960s suggested to me "Why don't you work on gravitational waves? I have a feeling they may be important in the future!"

Gravitational Waves: The World of Tomorrow

a Primer

FOREWORD

I have been a member of Dr. Robert Baker's Gravitational-Wave Team since 1999. However, our relationship goes back further to when I was preparing for my doctorate at the Massachusetts Institute of Technology. Many of us utilized Dr. Baker's textbooks in Astrodynamics. Many of his orbit-determination concepts progressively led to my selection as Eagle Pilot of Apollo XI and to the successful first Moon landing. Those were exciting times and somewhat similar to today. With the launch of Sputnik and my journey to the Moon a new era in the world of tomorrow arrived: The Space Age!

Now, having actually detected gravitational waves, another new world of tomorrow has arrived: The Gravitational Wave Era! We are now on edge of learning more about the merger of black holes from low-frequency gravitational waves detected recently by LIGO. We can learn even more at the higher end of the gravitational–wave frequency spectrum, possibly about higher-order dimensions, multiple universes, how the universe started … the Big Bang!

But now of even greater practical importance is the potential use of high-frequency gravitational waves for communication. Since, like gravity itself, these waves go through all matter unattenuated, not absorbed like microwaves. They propagate almost without absorption though interstellar space – and, for example, could convey messages from the star Antares to Earth or from Mars cyclers back to Earth. The high-frequency gravitational wave advantage would be that direct communication can be maintained without relays even if Mars or the Moon is between the cyclers and Earth. Here on Earth, there would be no need for microwave or cell phone stations, cables or even relay satellites – the ultimate wireless system! However, that is not the main reason I recommend your reading this book. I believe what the world needs are not many more highly trained scientists and engineers, but a greater knowledge of those of you without advanced scientific university background, business people and others with only high school training in science and mathematics. All of us should achieve some fundamental understanding of the basics of science and engineering, now that understanding should include gravitational waves. That is the purpose of this very instructive book and I strongly urge you to read it.

Dr. Buzz Aldrin

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PREFACE

This volume is a *primer* that presents the most basic elements of gravitational waves (GWs). It is meant to fill the gap between general news articles and technical treatments in order for the layperson as well as for those readers with considerable scientific background to understand better gravitational waves as well as the potential of gravitational waves in the *world of tomorrow*.

There is always difficulty in writing a book that is valuable reading for persons having different educational backgrounds. Freshly minted PhDs in the physical sciences may find this book too elementary or glossing over important science. Those who measure their last exposure to introductory science courses in decades, may find the book too challenging. In order to bridge this educational gap, five of the more technical sections of the book are optional reading. The reader who chooses to bypass these sections will also find that careful reading of chapters 1 through 4,7,10 and 12 and simply skimming the other chapters, will provide them valuable insights concerning gravitational waves. Equations and arithmetic involved in utilizing such equations are included in the book as being essential to the understanding of gravitational waves. In this regard, an extensive nomenclature of symbols and list of important equations provides a self-contained key to all of the physics and astronomical nomenclature utilized in the book and each equation definition includes a reference to the chapter in which the term or equation is used. A sufficient prerequisite for the book would be a high school course in astronomy, physics and/or engineering. The prerequisite mathematic background would be algebra, solid geometry and trigonometry. Course or courses in calculus would be valuable, but not essential for the reader.

In general, this book presents compelling routes for individuals in order for them and their organizations to take advantage of the new technology of gravitational waves. Those gravitational waves at the high-end of the gravitational-wave frequency scale may have practical applications. Such high-frequency gravitational waves or HFGWs seem to be of little interest to much of the current research and news media. This neglect is unfortunate since HFGW research, like low-frequency gravitational wave research, is **not** speculative and should be brought to the attention of all parties interested in gravitational waves.

In the Literature Survey Appendix of this book *are in excess of 600 references*. The majority of these references are directly related to HFGW research. Many of them are peer-reviewed and published in recognized journals and conference proceedings dating back to the 1960s. The important points of this considerable HFGW research are spotlighted in this volume although gravitational waves of all frequencies are discussed.

The Literature Survey references also serve as a key to the literature for the purposes of self-study or research. They are in chronological order and are annotated and divided into categories of:

Gravitational Waves Basic References

Low Frequency (LF) GWs from Orbiting Objects and Black Hole coalescence (mHz – kHz)

Interaction of Electromagnetic and Gravitational Waves (100 kHz – GHz)

Terrestrial or Laboratory Generation of High-Frequency Gravitational Waves (HFGWs 100 kHz – PHz)

High-Frequency Gravitational Wave (HFGW) Detectors

HFGW Applications

HFGW Propulsion and Gravity Modification

Cosmology: Relic and Primordial Background (HFGW: kHz –THz)

Gravitational Collapse

(Some References are in more than one category.)

The medium through which gravitational waves move, spacetime, is described in Chapter 1. Spacetime's most difficult to understand dimension, *time*, is analyzed by means of light cones in Chapter 2. Gravitational waves are destined to unlock the secrets of the beginning of our Universe, cosmology. In order to grasp cosmological concepts an understanding of entropy is essential and a simplified description of entropy is provided in Chapter 3. Chapter 4 involves the actual definition of gravitational waves and comparison with other waves. Chapter 5 provides a history of gravitational waves and introduces the basic quadrupole equation from general relativity. Chapter 6 discusses natural sources of low-frequency gravitational waves, or LFGWs, such as the merger of binary black holes, supermassive black holes and neutron stars. Such mergers will enhance our understanding of dark energy and the history and composition of the universe as a whole. The use of interferometers, such as the Laser Interferometer Gravitational Wave Observatory or LIGO and the proposed Laser Interferometer Space Antenna (LISA) as well as its pre-deployment LISA-Pathfinder mission are discussed in this Chapter.

The reader is introduced to high-frequency gravitational waves, or HFGWs, in Chapter 7. The concepts of diffraction as well as a detailed analysis of the gravitational-wave generation radiation pattern are also presented in this chapter. In Chapter 8 cosmological natural sources of high-frequency gravitational waves from the early Universe are described. In Chapter 9 several possible laboratory sources of HFGWs are discussed.

These laboratory HFGW generators are still in the early development phase. Their possible practical application to communications awaits that development. The same could be said about radio waves before Marconi generated them in the laboratory 25 years after Maxwell published "A Treatise on Electricity and Magnetism" in 1873. Even though there was no successful radio-wave generator or crystal radio detector at that time, the Treatise stimulated many people to experiment with the concept of radio communication. In the literature survey, Appendix of this book can be found a rich collection of hundreds of HFGW references that may also serve to stimulate the development of HFGW communication as did Maxwell's Treatise for radio communication. Eight designed or actually built high-frequency gravitational wave detectors or receivers are introduced in Chapter 10. Specifically, the Cruise-Ingley Birmingham University and the Li-Baker Chongqing University high-frequency gravitational wave detectors are described in more detail. Such high-frequency gravitational wave detectors may allow for the reception and analyses of primordial high-frequency waves from the early Universe. These waves could have been produced in the period of inflation or "The Big Bang". Unlike light photons, high-frequency gravitational waves would have traveled without attenuation through the newborn Universe. If primordial high-frequency gravitational waves and those from the so-called "brane world" were detected, then extra dimensions of space discussed in Chapters 1 and 11 might be sensed.

Although considerable theoretical work has been published since the 1960s, so far none of the HFGW astrophysical sources from the early Universe have produced signals that have been detectable by these eight different HFGW detector systems. There is a similar situation for the single interferometer detector system (including LIGO and the European Virgo) developed for the detection of LFGWs, whose future development was suggested in 1972 by Rainer Weise of MIT, but formally announced in 1992. That system's detection of the theoretically predicted black-hole merger LFGWs emissions was finally announced after 24 years of research and development and a total expenditure of over a half billion dollars of research funds. Eventually, following LIGO's example, detection of early Universe HFGWs emissions may also be expected.

Chapter 11 discusses miscellaneous opportunities and concepts; a new approach to theoretical cosmology, entropy, parallel universes, or "realities," and even presents a theory on time travel between universes that could be tested by the detection and analyses of gravitational waves. Chapter 12 considers the very practical applications of high-frequency gravitational waves, especially to global communications, *which is expected to change the world of tomorrow*.

Applications of high-frequency gravitational waves to the Search for Extraterrestrial Intelligence or SETI and to interstellar travel, "starshot," are also presented in this final chapter.

The proofreading by Penee Conlee Hull, Robin Baker Fell and Diana Dunn Walker is very much appreciated. Ames Reed did an excellent job with many of the scientific drawings. Professor Fangyu Li was instrumental in developing the cosmology sections of Chapter 8. Professor R. Clive Woods provided me with important quotations and information, especially on gravitational-wave optics. Gary Stephenson and Thomas Lane contributed many scientific insights. Dr. Eric Davis provided much of the most up-to-date reference material for this Book and especially for the propulsion section of Chapter 12. Fred Noble, of Wintec Corporation in Palm Springs, California, backed all of the several gravitational-wave patents -- without his assistance, no such patents would have been granted. Transportation Sciences Corporation provided the financial support for the preparation of this Book. And, finally, thanks to my Economic Round Table of The California Club fellow Executives for putting up with yet another presentation of parts of this book on gravitational waves.

Robert M L Baker, Jr., PhD, November 15, 2016

Postscript

On June 17, 2008, a research group called the JASONs, composed of very influential and respected university scientists, was given a briefing on the generation, detection and applications of high-frequency gravitational waves (HFGWs). The JASON Report (JSR-08-506) on that briefing was published in October 2008. The Report was widely distributed to the US scientific community and various press organizations reported it. The JASON Report stated that "Our main conclusions are that the proposed applications of the science of HFGW are fundamentally wrong; that there can be no security threat; and that independent scientific and technical vetting of such hypothetical threats is generally necessary. We conclude that previous analysis of the Li-Baker detector concept is incorrect by many orders of magnitude …" The author of the JASON Report's basic premise for generating HFGWs was: "*A basic mechanism* for generating a HFGW is the direct conversion of an electromagnetic wave into a gravitational one of the same frequency by a strong static magnetic field. This ***Gertsenshtein process*** is idealized in Figure 3." In addition the Report states: "Proposed HFGW detectors *have generally been based upon versions of the inverse* ***Gertsenshtein process***." These statements are both incorrect. The ***Gertsenshtein process*** or effect was published in 1962: M. E. Gertsenshtein, "Wave resonance of light and gravitational waves," *Soviet Physics JETP*, **14**, Number 1, pp. 84-85. The effect is extremely weak and is **not** utilized in most of the modern HFGW generation, detection or applications. ***Specifically, the Gertsenshtein process is not involved in any of the analyses in this Book and the JASON Report does NOT apply to this text.***

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EXERCISE SOLUTIONS

1.1 The sports car will back down a spiral below the origin to -1 minute, -2 minute, -3 minute, etc. points.

1.2 The pendulum period will be increased, so at (a) it will be further up the time axis (greater time) and more to the right.

2.1 The trajectory would start out at the coordinate of -1 hour down (the time axis of the cones) and 100 miles out from the polling place or origin of both time cones. It would be a straight line ending at the 0 hour (pole closes) point and 50 miles out from the polling place at the cone's axis. The voting was missed and not cast!

2.2 The starship Enterprise trajectory would start out at the origin of the upper cone (polling place at the time 0). After one hour it would have traveled' and spread the election results, to the 200-mile point out from the upper cone's axis. Its own light cone would be 100 miles broader at the one-hour point than the one hour point of those who obeyed the speed limit and the Enterprise would have informed more people of the election results.

3.1 There are 5,000 chips (locations) plus 5 individual ski locations multiplied by 2 skies plus a single trash can = 5,011 microstates. The skies stored in their specified locations is one microstate and the chips in the trash can is the second microstate. It should be recognized, however, that there may be several alternative answers! Just explain them.

3.2 The simplified model associates the escape velocity (or speed) with the speed of light. The mass of the black hole remains the same. Therefore, a higher escape speed would be the result of a higher mass density. Essentially, more gravitational attraction to be overcome, so greater escape speed if closer to the mass center. Therefore, a denser black hole of the same mass would be smaller.

4.1 From Figure 4-1 for a water (and other) waves, the frequency, $\nu = v/\lambda$. In this equation v is the speed of the wave and λ its wavelength. Therefore, $\lambda = v/\nu$ and with v = 10 m/s and frequency equals one wave striking every ten seconds or 0.1 strikes per second or Hz, λ = 10/0.1 = 100 m long wavelength.

4.2 From Figure 4-1 for a gravitational wave the frequency, ν, is also, $\nu = v/\lambda$ and solving for the wavelength, λ, we again find $\lambda = v/\nu$. In this case $v = 3\times10^8$ m/s and frequency, $\nu = 10^8$ Hz, so that $\lambda = 3\times10^8/10^8$ = 3 meters.

5.1 From Chapter 4, the wavelength, $\lambda = v/\nu$. For GWs moving at light speed $v = 3 \times 10^8$ m/s, therefore, at the Weber Bar the wavelength = $3 \times 10^8 / 1.66 \times 10^3 = 1.81 \times 10^5$m or 181 kilometers.

5.2 From Figure 5-4 one can apply trigonometry, that is tan ($\Delta\theta$) = Opposite-Side (Δf)/Adjacent Side (200N). So that for $\Delta\theta = 1^0$, we have tan (1^0) = 0.01745 = $(\Delta f)_t$/200 N. So that solving for Δf one finds Δf = 3.49 N.

6.1 Since there are 9.46×10^{15} meters in a light year, at a distance of 4.4 light years for PSR1913 +16, its distance at the distance of the Alpha Centauri system, would be $R = 4.16 \times 10^{16}$ meters. We again assume that its power of 7.34×10^{24} watts, is spread evenly over a sphere of radius R since low-frequency gravitational waves (LFGWs) are completely diffracted away and have no preferred directivity (which makes LFGWs a very poor choice for GW applications). The sphere's area is about 2.18×10^{34} m^2 so that the GW's power flux at the Earth's distance would be about S = 3.37×10^{-10} watts per square meter. By the way, if we applied the key equation from Chapter 9,

$$A = 1.28 \times 10^{-18} \sqrt{S}/\nu_{GW} \text{ m/m}, \qquad (9\text{-}5)$$

with the GW frequency ν_{GW} = 1/period of PSR13 +16= $1/1.395 \times 10^4$ s = 7.17×10^{-5} per second or Hz, we find the maximum GW amplitude $A = 2.8 \times 10^{-21}$ m/m, which might be detected by LIGO.

6.2 As in Exercise 5.1, from Chapter 4, the wavelength, $\lambda = v/\nu$. For GWs moving at light speed $v = 3 \times 10^8$ m/s , therefore, at the low chirp frequency Hz of 35 Hz the wavelength = 3×10^8 /35 = 8,570 kilometers and at 250 Hz high chip frequency, when the black holes are near to coalescence, the wavelength is about 1,200 kilometers.

7.1 From Equation 7-1

$$\sin(\theta_{diff}) = \lambda/w = c/\nu$$

Therefore, with $= c = 3 \times 10^8$ m/s and $\nu_{EM} = 2.5 \times 10^9$ Hz (2.5 GHz), $\sin(\theta_{diff}) = 0.12$ and $\theta_{diff} = 6.9^0$. The HFGW frequency is twice the EM frequency, so for the GW $\sin\theta_{diff} = 0.06$ and $\theta_{diff} = 3.4^0$.

7.2 From Table 7-1 the fraction of radiation in the 10^0 segment is 0.3445 and contains about the 34 percent of the radiation.

8.1 Roughly ; an average or "root-mean-square" (rms) spacetime strain of $h_{rms} = 10^{-10}$ m/m.

8.2 The local speed of light during that 10^{-50} s time interval will be $c = \Delta l/\Delta t = (1 \text{ m}/3\times10^8)/(10^{50}/t) = 3.3\times10^{-60}$ Multiplied by today's speed of light, indicates a slowdown/speedup of the early universe clock of about 10^{-52}.

9.1 Reducing the size of each dimension of the MEMS-HFGW generator elements, increases both *N* and (if energized on all individual planes) *N′* by a factor of 10^3. In addition the thickness of the elements' decreases by a factor of 10; thereby increasing the operating frequency by a factor of 10 and decreasing Δt in, for example, the power formulas, Equation 4-10 or 9-1. Therefore, we have for power

$P = 1.3\times10^{12} \times1000\times10^3\times1.76\times10^{-52}\times(0.5\times2/10^{-11})^2 = 2.3\times10^{-12}$ watts.

9.2 $S(1\text{ m}) = (P/4)/(1.71/N') = (2.3\times10^{-12}/4)/(1.71/1.3\times10^{18}) = 5.75\times10^{-13}/1.315\times10^{-18} = 4.37\times10^5$ watts per square meter. (One hundred times the solar flux at the Earth's surface.) At an Earth's diameter distance $S(1.3\times10^7\text{ m}) = 2.59\times10^{-9}$ watts per square meter. Both increases due to Superradiance.

10.1 The National Astronomical Observatory of Japan HFGW Detector utilizes two recycling interferometers with arms about 75 cm long whereas the LIGO Interferometers are about 4 kilometers in length. The National Astronomical Observatory of Japan HFGW Detector is sensitive to about 100 MHz (10^8 Hz) whereas LIGO's LFGW detectors are sensitive to less than 2 kHz to a small fraction of a Hz.

10.2 The Gertsenshtein Effect was published in 1962 and considered the interaction of gravitational waves and electromagnetic waves, specifically light, under the influence of a magnetic field. The Effect is extremely weak and of little value in GW, especially HFGW, detection or generation. The Li Effect was developed by Fangyu Li of Chongqing University in China during the 1990s. Far different from the Gertsenshtein Effect, it relies on an Electromagnetic (EM) beam having the same frequency and direction as the HFGW to be detected. Its only similarity is that it utilizes a magnetic field perpendicular to both EM GW radiation direction and is roughly 30 orders of magnitude more effective than the Gertsenshtein Effect.

11.1 From Equation 11-7, $L_2^2 = (1- v^2/c^2) \times L_1^2$ so their ratio of $(0.5)^2 = 0.25 = 1- v^2/c^2$. Therefore, $v^2/c^2 = 1 – 0.25 = 0.75$ and $v^2 = c^2 \times 0.75 = 9 \times 10^{16} \times 0.75 = 6.75 \times 10^{16}$ so the $v = 2.6 \times 10^8$ m/s.

11.2 Since the event occurred at one *instant* of time, ALL the horses would be transferred back and forth at the same time from one osculating universe (“point” in the STU). Thus there would be no change from their Gaussian distributional along the track. Of course, the location of the “starting gate” and “finish line” have no relevance except to set the imaginary scene. It is only the distribution of the vacillating sub-nano particles (“horses”) that counts.

12.1 The propulsion thrust would be like that of EM-propulsion thrust. That is, similar to a Flashlight since both forms of radiation travel at the speed of light and carry very little momentum. Furthermore, only HFGWs (not LFGWs) could be focused in the aft StarCraft direction and the HFGW generation process, discussed in Chapter 9, would require more energy for a given thrust value than thrust created by chemical reaction. Conventional propulsion means, for example, burning hydrogen and oxygen, is far more efficient than either the on-board generation of EM or GW would be.

12.2 From Table 12-1, the time is 40 million years of ability to practice interstellar communication. From Table 12-2 it is $N = 1.48 \times 10^{16}$ potential intercommunicating civilizations. From Table 12-3 $N_2^2 = 2.2$

$\times 10^{20}$ and the messages per year, f_2, 5.5 $\times 10^{15}$. Therefore, the messages per day is 5.5 $\times 10^{15}$/365 = 1.5×10^{13} and per hour is $6.3\times 10^{11.}$. Essentially, the longer the lifetime of advanced civilizations the more chance there is to intercept their interstellar messaging.