Prepared for: Moscow State University (Valentine Rudenko), National Astronomical Observatory of the Ukrainian Academy of Sciences (Yaroslav Yatskiv) & Prague Institute of Theoretical Physics (Jiri Bicak)

EXOPLANET APPLICATIONS OF HIGH-FREQUENCY GRAVITATIONAL WAVES

by

Robert M L Baker, Jr.
Fellow American Association for Advancement of Science
and Bonnie Sue Baker

March 15, 2017

.

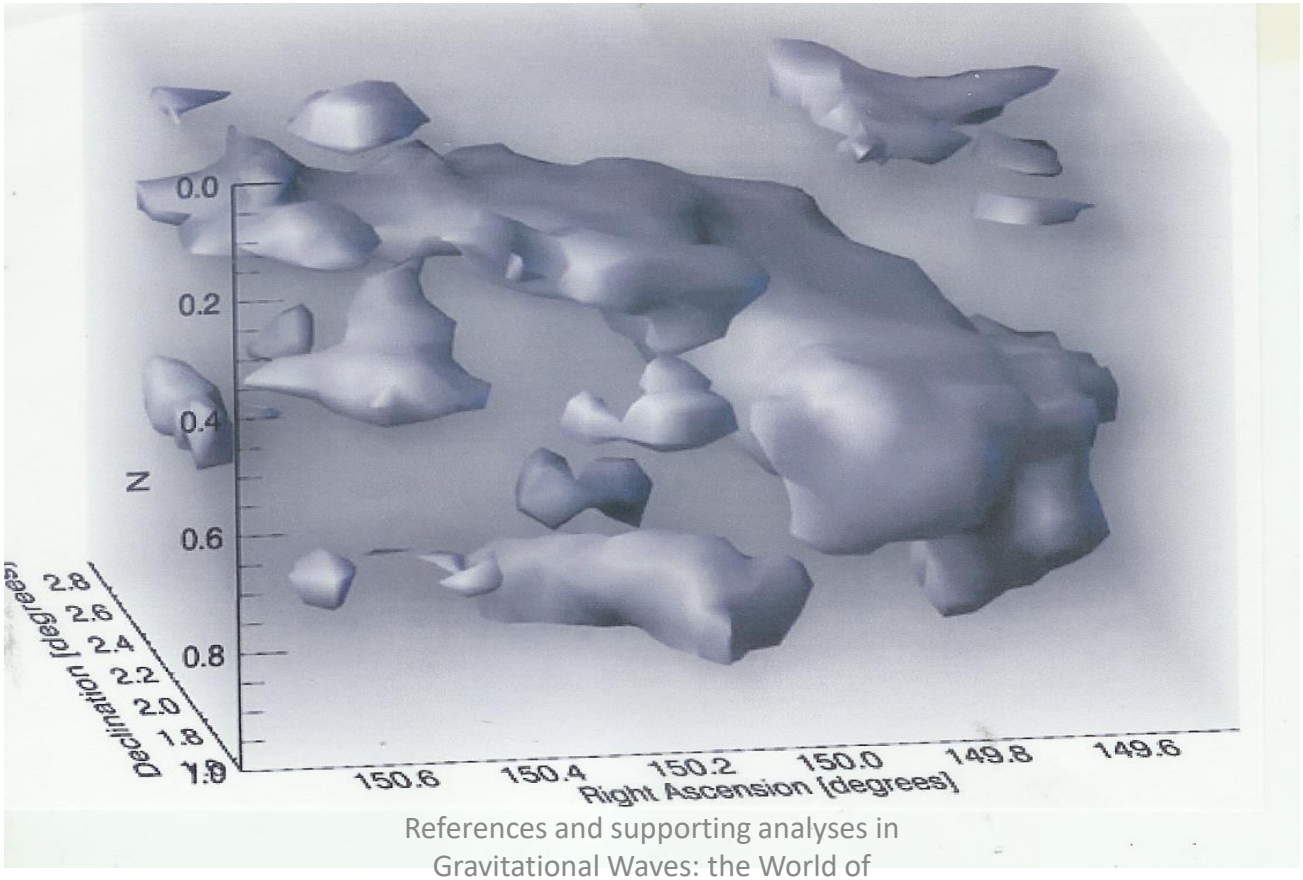
Kepler Spacecraft

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

Our Galaxy (and there are 100 to 200 billion galaxies in our Universe) contains at least as many planets as stars and there are 200 to 500 billion stars per galaxy! Thus there may be as many as about 200,000,000,000X500,000,000,000 = 100,000,000,000,000,000,000,000 (= 10^{23} or one followed by 23 zeros or one hundred sextillion) Exoplanets out there! That does not mean that every star has a planet, but one may have 8 or 9 like our Sun, some may have none, some may have 12 or more, but on average assume one exoplanet per star.

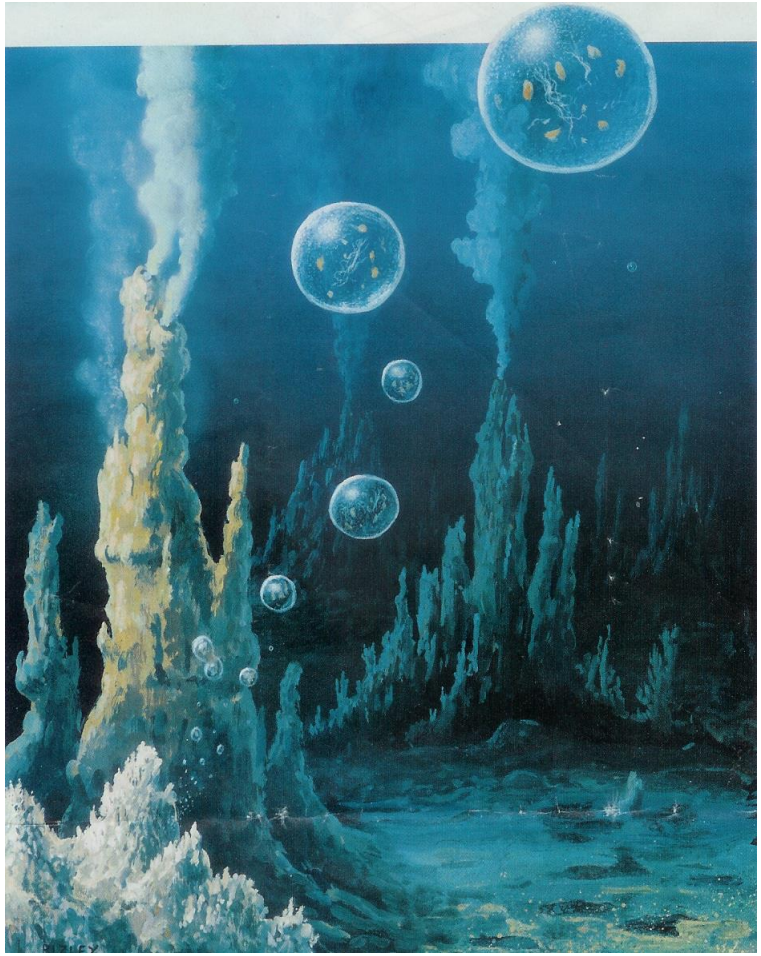
References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

We should not rule out non-carbon based entities (e.g., Silicon based). In fact consciousness or intelligence might exist within stars or within any structure, <u>even dark</u> matter in the Universe; but for such "intelligence" to matter the ability to communicate is essential.

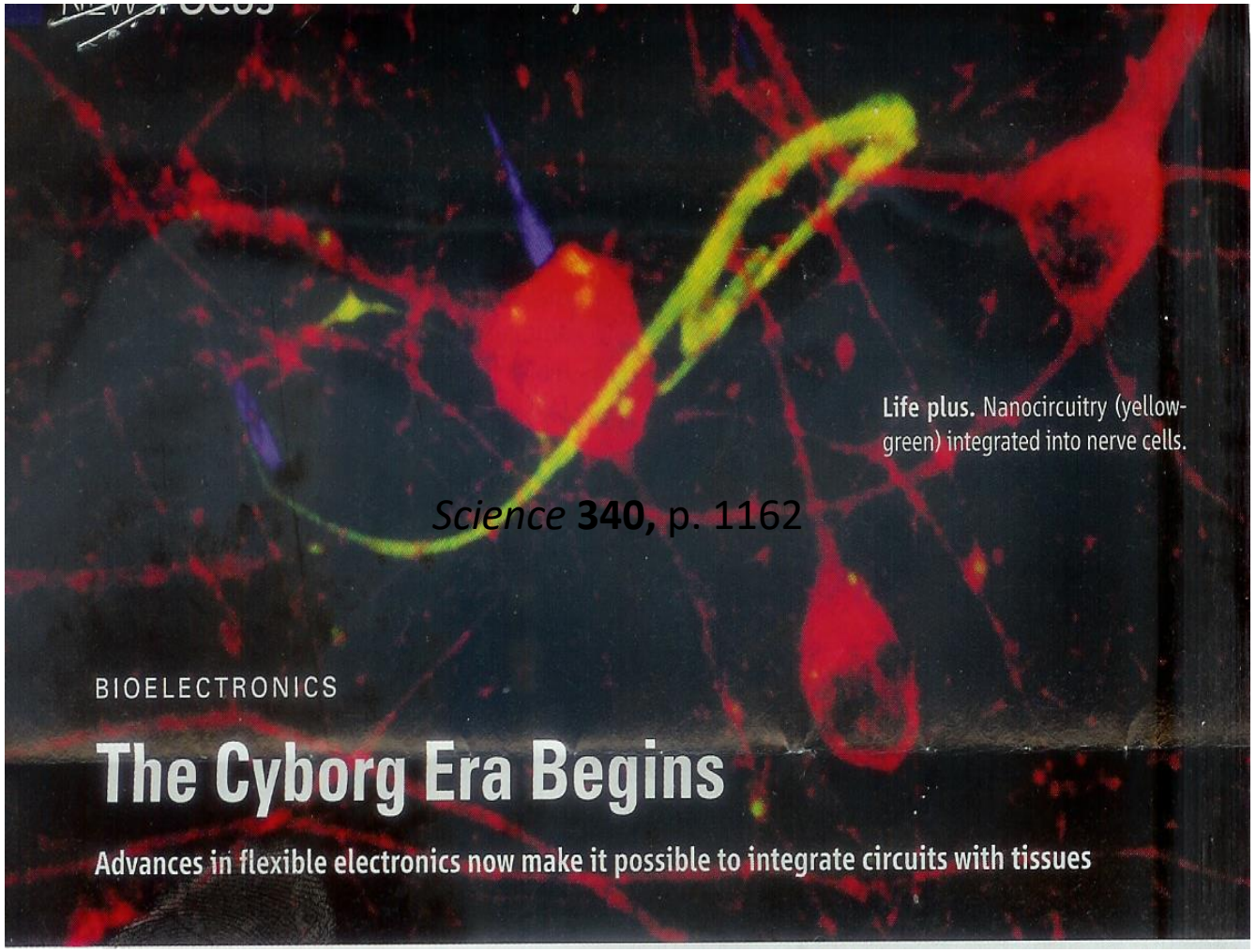


References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

Deep-sea hydrothermal vents may have created the first spark of life
Nature **514**, p. 302.



References and supporting analyses in
Gravitational Waves: the World of
Tomorrow, with Exercises - by Robert Baker,
December 2016



Science **340,** p. 1162

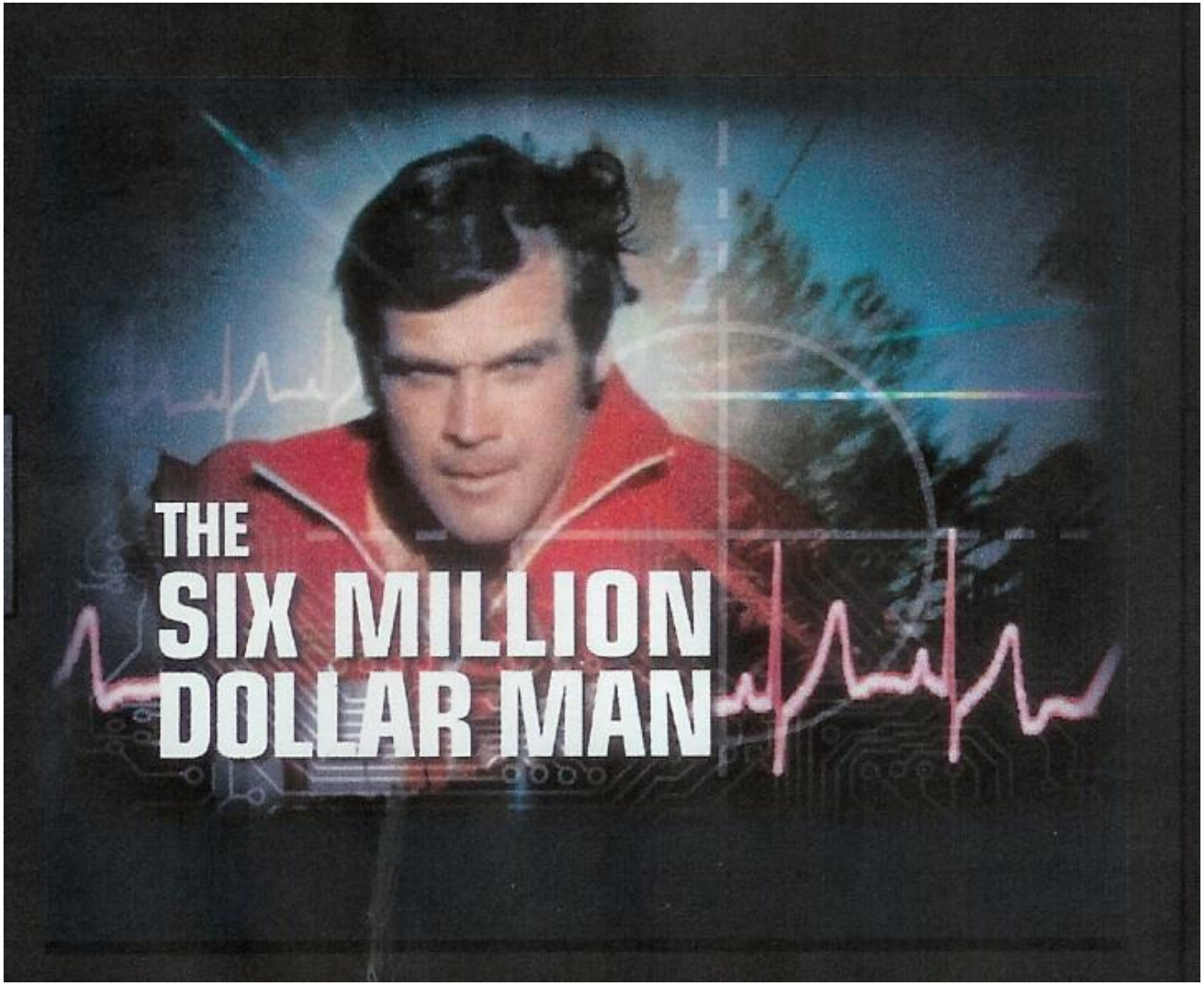
References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

Engineering a Functional Ear (*Science* **340,** p. 1165)

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

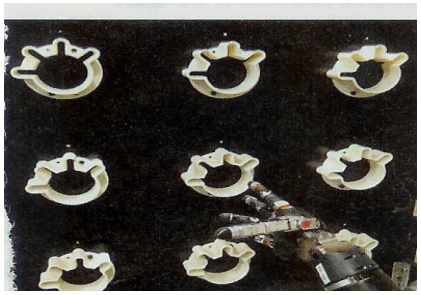
Science Fiction Can Often Best Portray the Future

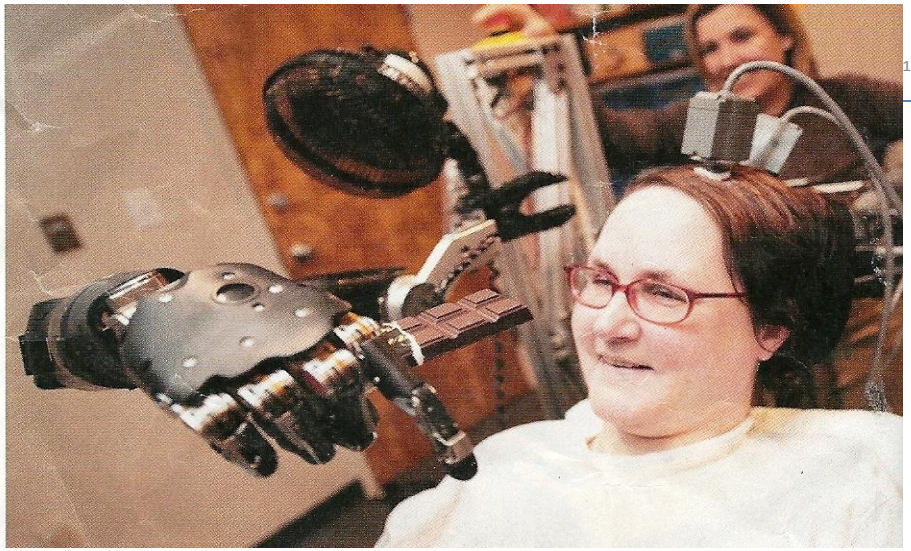
- “Imagination is more important than knowledge. For knowledge is limited to all we now know and understand, while imagination embraces the entire world, and all there ever will be to know and understand.”
- — Albert Einstein



References and supporting analyses in
Gravitational Waves: the World of
Tomorrow, with Exercises - by Robert Baker,
December 2016

Brain Implants Using Fabric Flexible Circuits

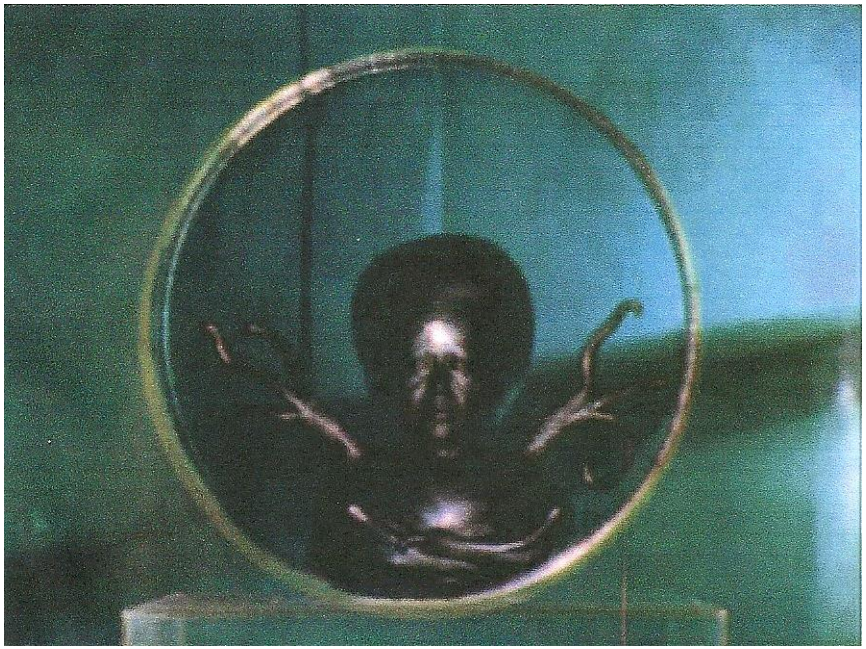




14

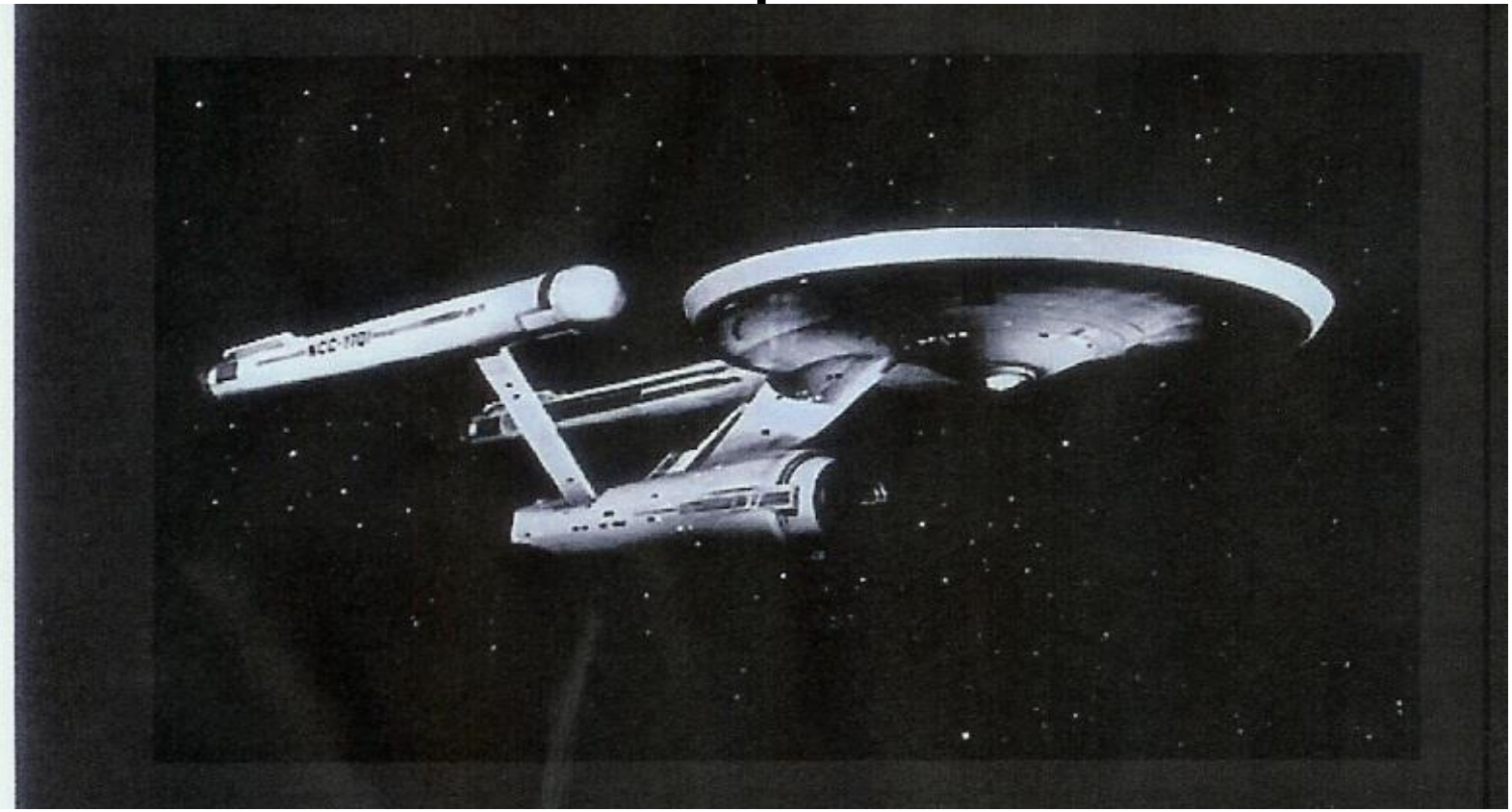
References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

What might an Advanced Exoplanetary Being look like?



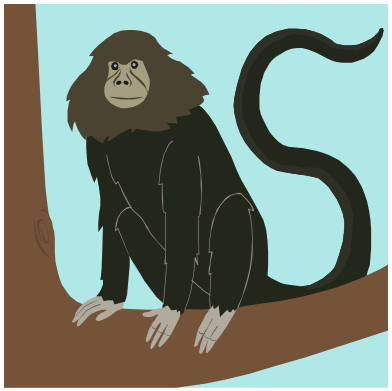
References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

Advanced Intelligent Civilizations May Include Communications with their Explorers

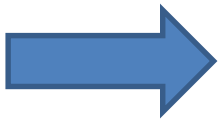


References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

Homo sapiens and advanced civilizations may have a mean time to failure built into their evolutionary processes (Fermi's Paradox)

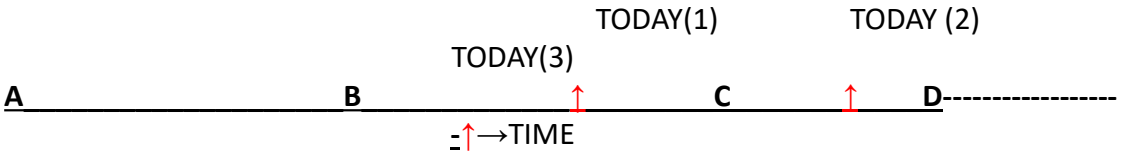


B



D

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016



Exoplanet Advanced Civilization Time Line or String

A Beginning of Universe
B Birth of a new Exoplanet civilization
C Interstellar communications capability achieved
D Demise of an Exoplanet civilization

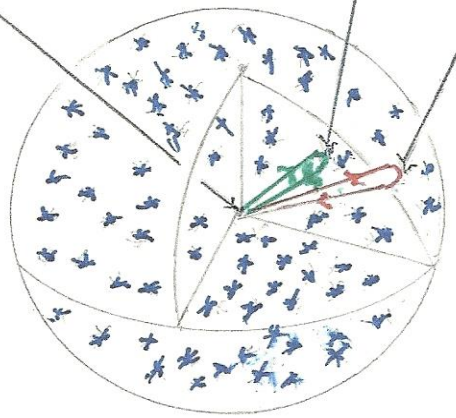
NOTE: All of following analyses are discussed in the foot-noted Book.

Message sent by an advance Exoplanet near our Solar System (to a 5000 light year distant Exoplanet) just at time when it reached stage C and reply received from that Exoplanet 5000 light years away just in time (10,000 years after sent) before it blinked off at D. Another Message sent by that advance Exoplanet near our Solar System to a 5005 light year distant Exoplanet just at time when reached stage C but Oh Oh! it had blinked off (at D) at time 10,000 or 10 years before reply was received at 10,010 years since transmission so that there was failed stellar intercommunication

Therefore only advanced Exoplanets 5,000 light years away or less can be communication partners with advanced Exoplanets all with 10,000 year lifetimes.

Advanced Exoplanet receiving message from another advanced Exoplanet system near our Solar System 5000 light years away that was sent 5000 years ago by this advanced Exoplanet and reply immediately sent back.

Advanced Exoplanet receiving message from another advanced Exoplanet system near our Solar System 5005 light years away that was sent 5005 years ago by this advanced Exoplanet and reply immediately sent back.



The sphere of radius 5,000 light years containing stars in the neighborhood of our Solar System containing about 4.2 Billion stars of which about 420,000 Exoplanets, having advanced intelligence and interstellar communications capability will simultaneously exist -- each having a mean time to failure of 10,000 years.

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

Table 1. The Length of Time in Years between a Civilizations' Emergence of Cyborgs and/or Interstellar Communication Capability and their Demise, **C** to **D** or *d*

No. of Generations→ Generation length, years ↓	1	4	40	400	4,000	40,000
25	25	100	1,000	10,000*	100,000	1,000,000
100	100	400	4,000	40,000	400,000	4,000,000
1,000	1,000	4,000	40,000	**400,000**	4,000,000	40,000,000
10,000	10,000	40,000	400,000	4,000,000	40,000,000	$4x10^8$
100,000	100,000	400,000	4,000,000	40,000,000	400,000,000	$4x10^9$
1,000,000	1,000,000	4,000,000	40,000,000	400,000,000	4,000,000,000	$4x10^{10}$

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

Intercommunication Time

Thus up to **C** our civilization would have survived about 2000 to 4000 generations. Assuming our civilization is about to evolve rapidly into advanced biological/electronic beings i.e., cyborgs at **C** it is estimated (or "conjectured") the longevity of our and other civilizations near us in our Galaxy **to average about 400,000 years C** to **D.** Various other alternatives are exhibited in **Table 1**. However, the demise of the advanced civilization might occur almost any time during the time interval between **B** and **D**. That is, during that time interval between **B** and **D** advanced civilizations could "blink" on at **B** and then off, that is reach its **D.** There are numerous values that could be chosen for these dates. Let us speculate that civilizations reach its **D** in a serial fashion. Of course, there could be overlap and the time spans would be quite randomly distributed. In order, however, to get some approximate numerical results simply assume that when one advanced civilization reaches its **D** ("blinks off") another civilization reaches its **C** ("blinks on"). In the numerical example, the number of such intervals would be 3.6 billion years divided by 400,000 years or 9,000. By the way, only if TODAY were at TODAY (2) would a particular one of the 9,000 advanced civilizations have the opportunity for interstellar communication that could be intercepted by us. But only those Worlds that are clustered together close enough to communicate with each other in a time span less than 400,000 light years apart in the numerical example could communicate in time before their demise **D**. Let us suppose that the average distance apart of stars in our Galaxy is about five light years, so that minimum intercommunication time would average some 2 × 5 = 10 years for this pair of close-by stellar exoplanetary systems.

Potential Intercommunicating Civilizations

- In general, if we define ***d*** as the time interval **C** to **D** in years as found, for example, in the entries of **Table 1**, then given a 5 light year average distance apart of the stars and their advanced exoplanet civilizations in our neighborhood of the Universe, they could be ***S***=(***d***/5)/2= ***d***/10 stars away. In the numerical example ***S*** = 400,000/10 = 40,000. Thus the number, *n*, of such potentially intercommunicating civilizations in the spherical volume of interstellar communicating exoplanet civilizations would be

- $$n = (4\pi/3)\, \boldsymbol{S}^3 \quad ,$$

- which is somewhat similar to the factor $R_* \times f_p$ in the Drake equation.
- For derivation of the equations that follow, see pp. 143-153 of the foot-noted Book

Number N of potential interstellar-communicating Exoplanets

- In the example, $n = 2.68 \times 10^{14}$. Of course, this number must be greatly reduced, which also will reduce the estimated number of the true potential intercommunicating advanced civilizations around Earth. Let us assume that on average only one out of ten exoplanets would be in the habitable zone between the freezing and boiling point of water (probably conservative because not all intelligent extraterrestrial life may need to be in this temperature range). Next, let us assume that only one out of ten of these habitable exoplanets will reach the advanced stage **C**. Finally, cut their number in half to account for very old and dead exoplanetary civilizations and then by dividing by the number of stars that have reached **C** but have not reached **D** or, in the numerical example, divided by 2×9000. So, under these arbitrarily parameters, the actual number N of potential interstellar-communicating Exoplanets is estimated to be

- $N = 2.68 \times 10^{14} / 10 \times 10 \times 9000 = 1.485 \times 10^{8}$

Independent Intercommunicators

Each intercommunicating advanced civilization may be comprised of thousands, if not millions, of independent interstellar transmitting/ receiving individuals or cyborg entities. There are about three million independent radio operators or “hams” worldwide on our planet. Thus we are considering a minimum of intercommunications.

Number, N, of potential intercommunicating advanced civilizations as a function of the years between **C** to **D** or ***d***

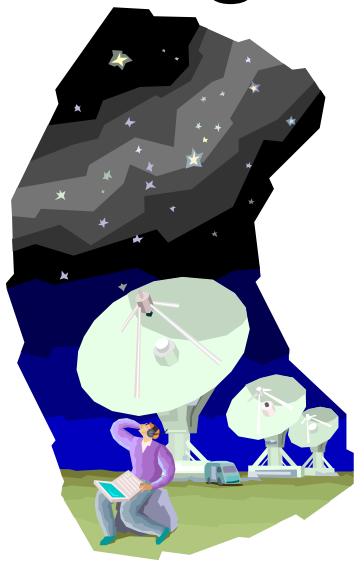
d years between **C** to **D**	N
4000	1.48
40,000	14,800
400,000	**1.48×10^{8}**
4,000,000	1.48×10^{12}
40,000,000	1.48×10^{16}

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

Potential Frequency of Intercepts

- In the numerical example for the 0.1 ***d*** case there might be 550,000 possible messages to intercept each year or about **1500 per day**. It is also interesting to note the distance of the stars/exoplanets in light years for 0.1***d*** and 0.001***d***. These distances are, for the most part, in our Galaxy.

Search for Extraterrestrial Intelligence



SETI. But Electromagnetic (EM) not High-Frequency Gravitational Waves (HFGWs) are being listened for. Since HFGWs are not absorbed by interstellar material as are EM waves, an advanced civilization would choose HFGWs for interstellar and other communications purposes.

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

What are Gravitational Waves?

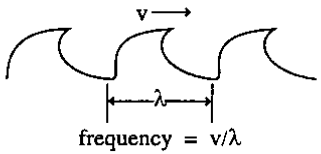
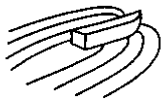
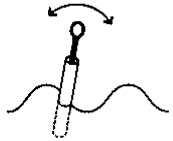
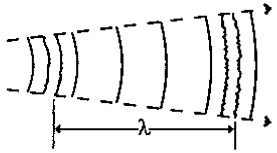
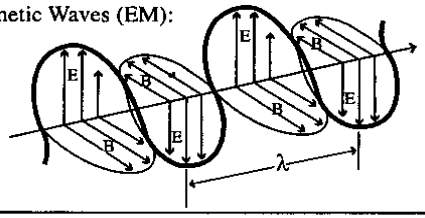
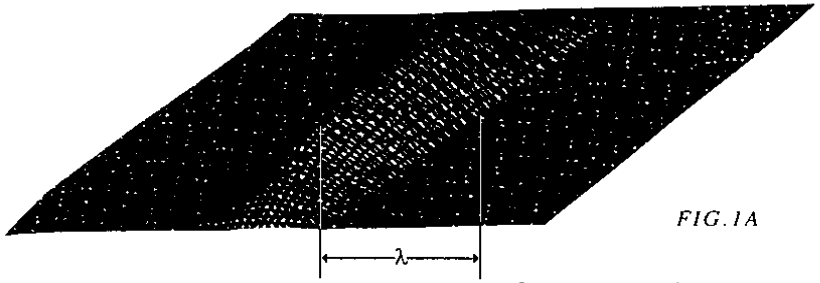
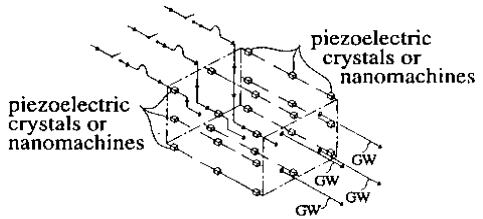
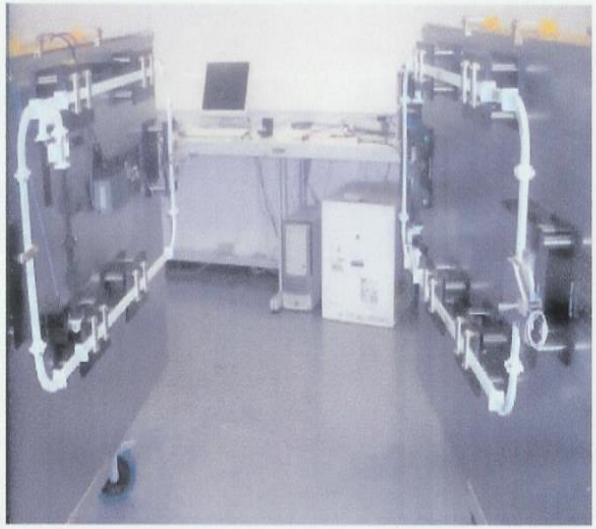
	Wave	Medium	Generators	Sensors
Water Waves:		Water	• wakes • tides • wind 	• buoys • pressure • transducers 
Sound Waves:		Air	• tuning fork • mouth • speaker • bomb 	• microphone • ear 
Electromagnetic Waves (EM):		Vacuum	• mircowave dish • electric light • x-ray star 	• microwave dish • eye • photocell 
Gravitational Waves (GW):		Spacetime continuum	• orbiting neutron stars • piezoelectric crystals • magnetic jerk • electric jerk • nanomachines 	• long-baseline interferometer • piezoelectric crystals • nanomachines 

FIG. 1A



References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

Birmingham University HFGW Detector



15

Sensitivity to HFGWs: h_{det} is the metric (strain) detection limit in m/m = 10^{-17} to 10^{-20}.

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

INFN Genoa HFGW Detector.

16

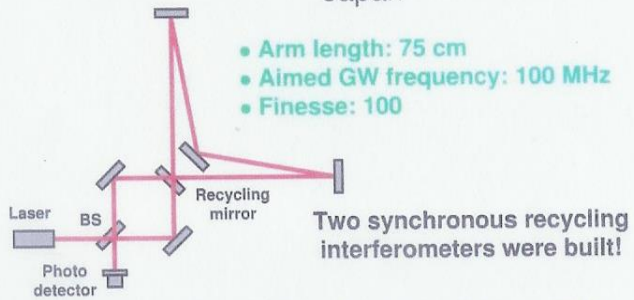
Sensitivity to HFGWs: h_{det} is the metric (strain) detection limit in m/m = 10^{-17} to 10^{-20}.

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

The National Astronomical Observatory of Japan 100MHz HFGW Detector.

UNIVERSITY OF BIRMINGHAM

Development of 100MHz GW detectors at National Astronomical Observatory of Japan



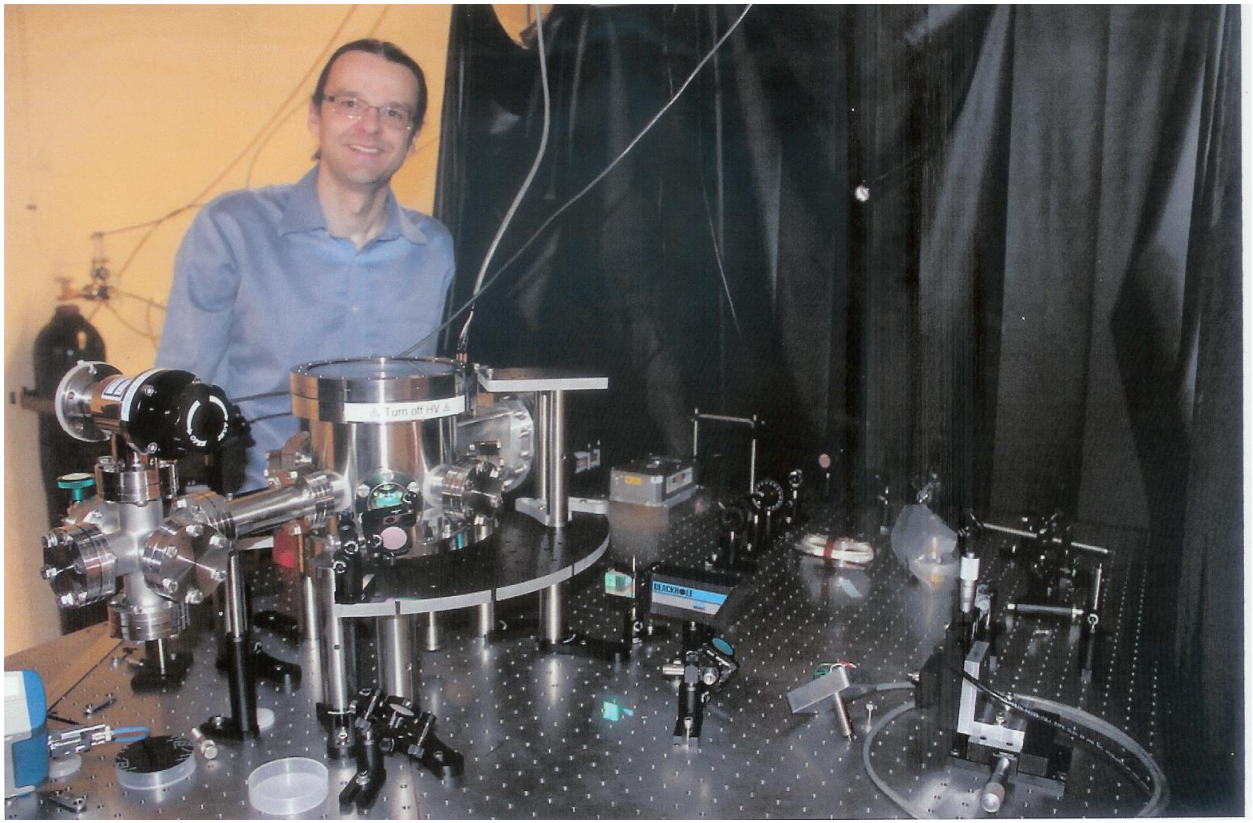
Synchronous recycling Interferometer (Concept: Drever 1983)

17

Sensitivity to HFGWs: h_{det} is the metric (strain) detection limit in m/m = 10^{-17} to 10^{-20}.

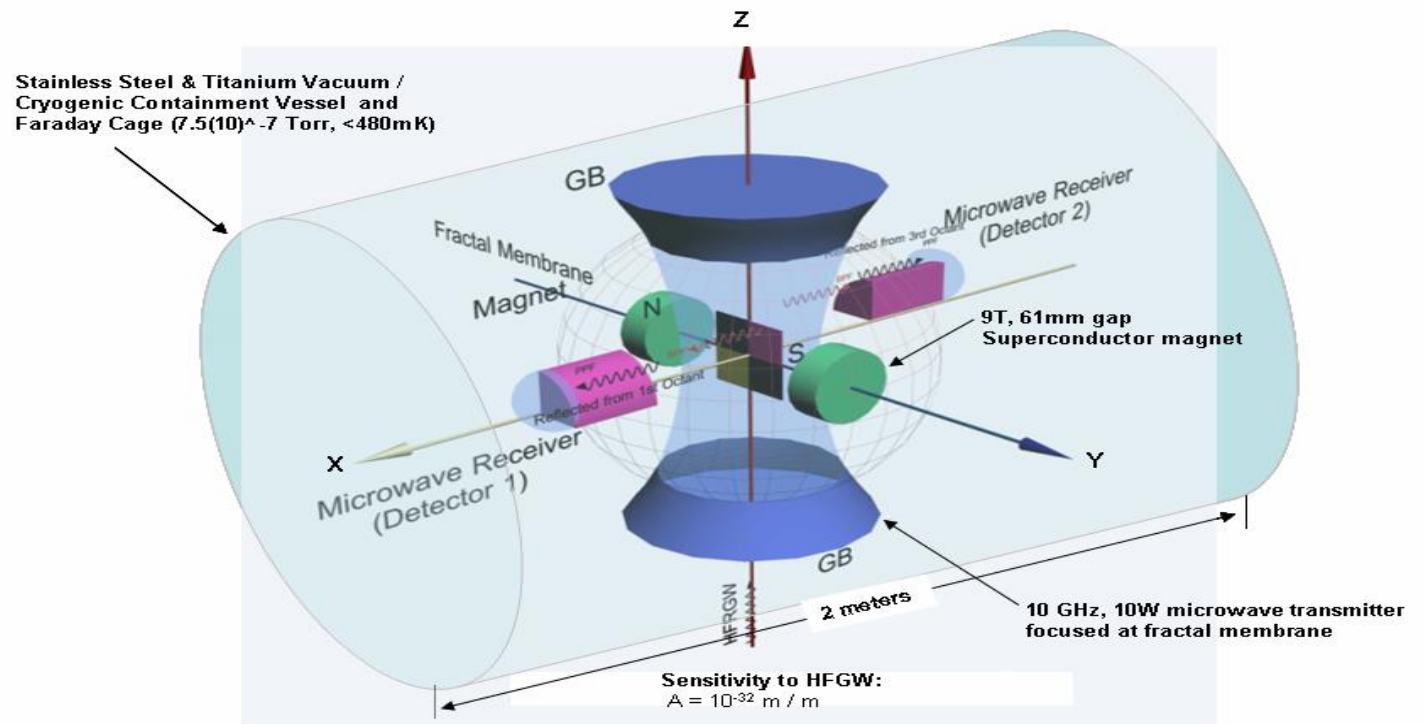
References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

Stanford/University of Nevada HFGW Detector
50 to 300 kHz



References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

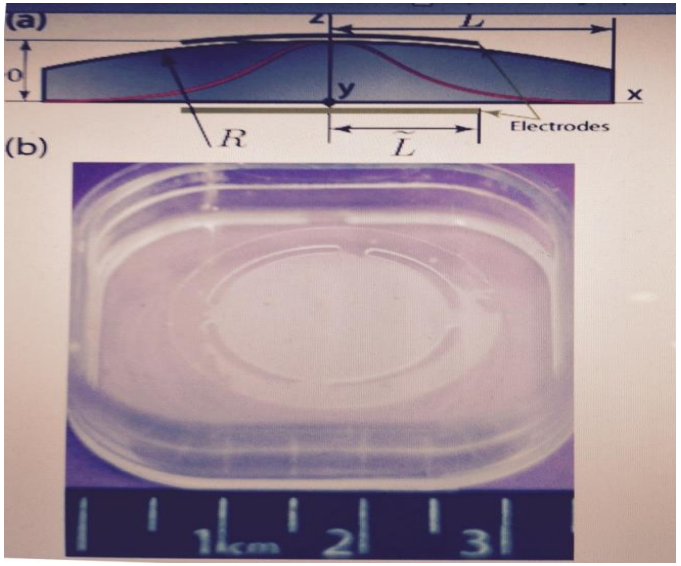
Notional Drawing of Li-Baker Detector effort of Chongqing University in China, High-magnetic-field Center of Chinese Academy of Science (construction of high magnetic background), Southwest Jiaotong University in China (so far the Li-Baker would be the most sensitive detector of weak signal high-frequency gravitational waves). Under Development October 2015



Li-Baker High-Frequency Gravitational Wave Detector
Journal of Modern Physics, 2011, 2, 498-518, http://www.gravwave.com/docs/Li-Baker%20%20EPJC%20%20Vol.%2056,%20pp.407-423.pdf
American Institute of Physics Proceedings 969, 1045-1054, http://www.gravwave.com/docs/Proposed%20Ultra-High%20Sensitivity%20HFGW%20Detector%2005-15-08.pdf

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

Gravitational Wave Detection with High Frequency Phonon Trapping Acoustic Cavities Maxim Goryachev and Michael E. Tobar, November 3, 2014, ARC Centre of Excellence for Engineered Quantum Systems, School of Physics, University of Western Australia



References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

What about LIGO, the first to actually detected gravitational waves, could those interferometer GW detectors be utilized for HFGW detection?

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

Can Interferometer GW Detectors like LIGO or LISA detect the HFGW Exoplanet Intercommunications?

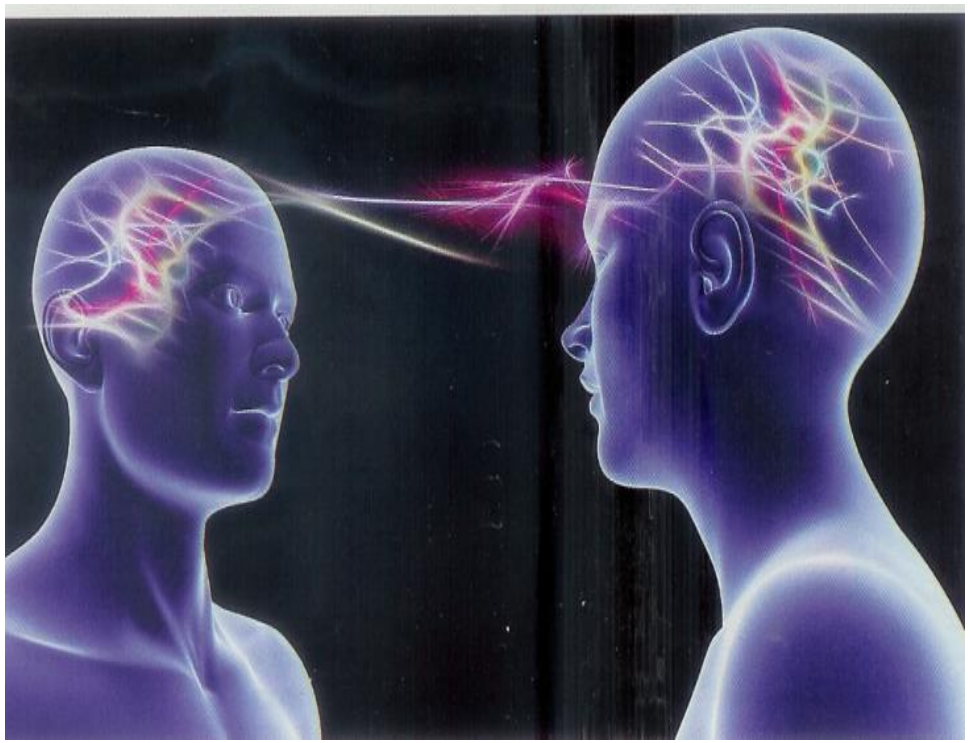
NO! Here's the problem with higher frequencies: One has to "observe" the interference pattern between the LIGO legs caused by the passage of a gravitational wave. As Peter Sven Shawhan, a key member of the team that assembled and tested the original LIGO stated, "At higher frequencies, the quantum nature of the laser beam (made of discrete photons, albeit a large number of them) limits the precision of the measurement. Increased laser power would reduce the problem of quantum noise, but ultimately the LIGO (and other) interferometers are not suited to measuring gravitational waves that stretch or shrink the arms much more rapidly than the time a photon typically remains in the optical cavity (the arms of the interferometers), which is roughly a millisecond for these (LIGO) interferometers." A millisecond is one thousandths of a second and equivalent to 1000 cycles per second or a kilohertz or 10^3 Hz.

What are we going to do with the intercepted signal between Exoplanets?

First, we must decode it. No doubt it will not be Morse Code. Probably not any kind of encryption that National Security Agency of the US can handle right away. As Richard Grey recently suggested: "… we may all one day speak telepathically so it may be brainwaves!"

Second, what will we learn from the intercepted messages? Here is where mankind may have great benefit from learning what the messages are about and "tell" us how to improve our way of life. But, this intercept will also be a **Cataclysmic Event** and may even lead to religious and other turmoil on our little planet!

Evolution will probably lead to the most efficient “Brain to Brain” communication means



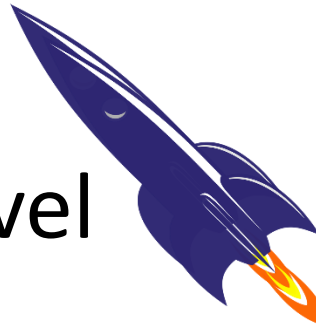
References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

How shall we prepare?

1. Conduct research and development of high-frequency gravitational wave (HFGW) detectors or receivers.

2. Conduct research in cryptography with special attention to the possible interception of “brain-wave” communications.

Application of High-Frequency Gravitational Waves to Interstellar Travel



- ***Starshot*** *Project suggested by Stephen Hawking to send a small Starship microchip to the nearest star.*
- *Instead of 100-gigawatt electromagnetic laser beams ("pushing" small microchip Starcraft) which are easily absorbed by interstellar material and Starcraft "solar sails" subject to ablation by such strong lasers, a few powerful HFGW beams, reflected by a possible Starcraft HFGW mirror, (hence a "pushing" force due to reflection) could be employed. The HFGW beams would* ***not*** *be intercepted by the Earth's rotation or orbital motion since the Earth is transparent to GWs. HFGW frequency would be quite high in order to reduce GW beam widening due to diffraction. Such a HFGW mirror could propel the little GW Starcraft. Upon reflection of the HFGW beam, when modulated by the HFGW Starcraft's mirror, the HFGWs could also serve as a return communications link.*

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

STARSHOT SPACECRAFT CONFIGURATION

- The GW Starcraft might have a spherical rather than a planer chip form. It might be more like a ping-pong ball. The ping-pong ball's equatorial cross section would be occupied by the Starcraft's High Temperature Super Conductor (HTSC) mirror and the rest of this volume occupied by small HTSC magnets, various nano-electronics and attitude control mechanisms. There could well be a flotilla of such GW Starcraft launched together.

Starcraft Flotilla

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

HFGW Reflection Propulsion

According to R. Clive Woods, the pressure on an ideal HFGW reflector (if experimentally demonstrated that GWs are slowed in a high-temperature semiconductor or HTSC) would be:

$$p(N/m^2) = 2\ \sigma_E\ (J/m^3\ ),$$

where σ_E is the energy per unit volume contained in the HFGW. Specifically,

$$\sigma_E\ (J/m^3\ ) = S(W/m^2\ )/c(m/s).$$

See Eqs. (12-1) and (12-2) of the foot-noted publication.

References and supporting analyses in Gravitational Waves: the World of Tomorrow, with Exercises - by Robert Baker, December 2016

RESEARCH AND DEVELOMENT GOAL

I believe that those interested in the research and development of High-Frequency Gravitational Waves should be guided by the LIGO approach for Low-Frequency Gravitational Waves (LFGWs). $625,000,000 and 21 years may not be necessary for HFGW Research and Development, but it is an interesting goal.