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What are the wild waves saying?*
Yet another meditation on the predictions, searches
for, and detections of gravitational waves

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A large majority of the physics and astronomy communities are now sure that gravitational waves exist, can be looked for, and can be studied via their effects on laboratory apparatus as well as on astronomical objects. So far, everything found out has agreed with the predictions of general relativity, but hopes are high for new information about the universe and its contents and perhaps for hints of a better theory of gravity than general relativity (which even Einstein expected to come eventually). This is one version of the story, from 1905 to the present, told from an unusual point of view, because the author was, for 28.5 years, married to Joseph Weber, who built the first detectors starting in the early 1960s and operated one or more until his death on 30 September 2000.

Keywords: General relativity; gravitational waves; black holes; binary stars; Weber bars; laser interferometers.

1. Introduction and the Universe of Discourse

Can there possibly be anything new to be said about gravitational waves (GWs) after the blast of papers, books, and lectures occasioned by the events detected by LIGO and Virgo over the past three years? Possibly not, but, like a Rubik's Cube in the hands of an eager child, the pieces can perhaps be put together differently. One piece that has become available only recently is the Naval service record of Joseph Weber, which may have something to say about why he picked out such a difficult problem to work on and stuck to his guns till the end.

*Title of a poem by Joseph Edwards Carpenter (1813–1885).

Gravitational waves are the same as gravitational radiation, though the latter phrase is perhaps more aggressive in saying they carry energy. The two were used interchangeably for many years, but the LIGO/Virgo folks opted for “wave,” perhaps because “radiation” sounds dangerous, and perhaps because Einstein wrote “welle” rather than “strahlung.” Gravity waves are different, propagating through the Earth’s atmosphere (etc.) with gravity as the restoring force, much like sound waves having pressure as the restoring force.

This discussion will be confined to gravitational waves of wavelengths and frequencies likely to be emitted by, or to affect, entities the sizes of stars and smaller. This leaves out, at least, (1) longer but conceptually similar GWs expected from black hole mergers when entire galaxies come together (for which space experiments are planned), (2) a purely hypothetical background with wavelengths like the separations of galaxies in clusters, which could shake those galaxies around and so mimic dark matter,¹ and (3) a remnant of inflation preceding the hot big bang that could perhaps have imprinted particular patterns of polarization on the cosmic microwave background, and which were reported but retracted in 2014.²

The next section is a timeline of events more or less familiar to anyone a bit interested in gravitation physics and its history, spotted with reminders that there were always more people and more ideas involved than make it into standard textbooks. Other sections fit into this timeline, providing more details for a subset of events and people, especially Weber. The last section, of course, looks to the future.

2. A Timeline for Relativity and Gravitational Waves

- 17th Century Newtonian mechanics incorporates a principle of relativity, that you cannot tell if you are in a system moving at constant velocity relative to another (if you can sleep on planes, you probably know this).
- 19th Century Maxwell’s equations summarize behavior of electricity and magnetism, requiring the speed of light to be the same as measured by any observer.
- 1905 Poincaré writes that gravitational information must travel at the speed of light. Einstein’s two papers outlining what we now call special relativity (though it had to be put into appropriate mathematical formulation by Poincaré, Minkowski, and Sommerfeld.³ Contents include simultaneity, relativity of lengths and times, coordinate transformations and their meaning, addition of velocities, transformation of Maxwell–Hertz equations, Doppler effect, aberration, radiation pressure, a slowly-accelerated electron, and, in the final paper, dependence of inertial mass on energy content.
- 1907–1916 Einstein gradually works through what we now call the general theory of relativity (GR). Essential collaboration with Marcel Grossmann⁴ and mathematics developed by Ricci–Curbastro and Levi-Civita, with post-GR elaboration from Levi-Civita and Weyl.

- 1916 The four papers presented to the Berlin Academy of Sciences on successive Thursdays that are now always cited as the genesis of the general theory.⁵ Something in excess of 100 scientists and mathematicians (two of them women) are interacting with Einstein or propounding competing theories before, during, and just after GR appears.⁶⁻⁹
- 1917 Einstein's paper always cited as the first prediction of gravitation waves, though he had written to Karl Schwarzschild the previous year that there would be no waves analogous to those of electromagnetism [perfectly true; electromagnetic (EM) waves are dipole and higher order, GR waves quadrupole and higher order]. A letter from Friedrich Adler to AE (document 316 in Ref. 10) calls his attention to an 1898 paper by Paul Gerber which calculates the speed of the gravitational potential from Mercury's perihelion motion and finds it equal to the speed of light (presumably within some errors).
- 1918 November 11, World War I (WWI) Armistice.
- 1919 May 17, Joseph (Yonah ben Yakov) Weber born, Paterson, New Jersey.
May 29, the solar eclipse at which light bending measured by Eddington, Dyson, Crommelin, and Davidson.¹¹
June 28, Treaty of Versailles signed in Paris.
July 28, International Astronomical Union established in Brussels, under the International Research Council, Committee 1 = Relativity, with Eddington as President.
November, results of eclipse expedition announced. Widespread newspaper headlines and Einstein became a celebrity.
- 1920 Numerous books on relativity in German and English begin to flood the market through about 1925. Some mention waves or radiation; others do not. A period of general neglect of GR follows.
- 1925–1955 “Low water mark” of general relativity.¹² Notice that the chaotic events of Sec. 3 come in the middle of this period.
- 1932 Rainer Weiss born in Berlin.^{13,a}
- 1937 Einstein and Nathan Rosen write on gravitational waves in English eventually, coming down on the side of existence and energy transport under some circumstances.
- 1943 Virginia Louise Trimble (VT) born 15 November in Hollywood, CA. Graduates from Hollywood High School January 1961, UCLA (BA in Astronomy and Physics) June 1964, Caltech (MS Astronomy and Physics) 1965, Ph.D. (Astronomy) 1968.
- 1957 The Chapel Hill Conference (GR1) with much discussion about reality and detectability of gravitational radiation.¹⁴

^aSome additional LIGO dates come from this and later books by Collins on search for and detection of gravitational waves.

- 1959 Weber's prize-winning essay for the Gravity Research Foundation on detection techniques for gravitational radiation.
- 1961 Weber publishes *General Relativity and Gravitational Waves*. It was, even then, the thinnest GR text around and shows drawing of three sorts of gravitational wave detectors: two masses connected by a spring, a large piezoelectric crystal connected to a radio receiver and a recorder, and two large piezoelectric crystals connected to separate radio receivers and then to a cross correlator. American industry did not provide crystals of the required size, and the detectors built glued much smaller ones to giant aluminum bars. A footnote credits two papers by Pirani for analysis of measurement of the Riemann tensor by comparing accelerations of free test particles, but the analysis in Weber's Chapter 8 shows that interacting test particles must be used. The bar detectors are connected test particles; the LIGO, etc. design free particles.
- 1965 Weber begins building massive aluminum bar detectors; he operates one or more of these until his death on 30 September 2000.
- 1969 Weiss begins thinking about interferometric detectors (possibly earlier).
- 1969–1971 Robert Forward builds and operates a small interferometric detector at Hughes Malibu Labs, crediting the basic design to Weber. VT visits there late December 1969 and, at Forward's request, estimates the luminosity of gravitational radiation to be expected from a pulsar if pulsar glitches are caused by starquakes. The expected flux is soberingly weak.
- 1969 Weber publishes "Evidence for discovery of gravitational radiation."¹⁵
- 1970 and beyond Very many groups build assorted bar-type detectors; none are exact copies of the Maryland ones. The most similar (Rome and Japan) report tentative detections. Others claim upper limits inconsistent with Weber's reports.
- 1972 Early February, Weber and Trimble meet and begin transcontinental "relationship," marrying on 16 March 1972. Weiss submits first NSF proposal for a interferometric detector; not funded December, launch of Lunar Surface Gravimeter on Apollo 17 (funding for which supported the ground-based effort and theoretical efforts for some time). December 18–22, Sixth Texas Symposium on Relativistic Astrophysics in New York. Trimble speaks for the Maryland group. Hostility is already fairly blatant, and the LSG largely fails because builders (not

at University of Maryland) forgot that gravity on the Moon is only one-sixth that on Earth.

- 1985 Major funding from NSF for LIGO; Weber cut off. Meanwhile, ongoing analysis of the in-spiral of the binary pulsar PSR1913+16 has persuaded nearly everybody that gravitational waves exist and carry energy at exactly the rate predicted by general relativity.^{16,b}
- 2000 September 30, Joe Weber dies in Pittsburgh, PA.
- 2015 September 14, first glimpse of the first LIGO event, strong enough that very little data processing is required for recognition (but much to determine properties as accurately as possible). Some information leaks out. The arrival date happens to be Weber's *Yahrzeit* (anniversary of death) on the Hebrew calendar.
- 2016 February 11, press conference and simultaneous publication of the first event: Abbott *et al.*, "Observation of gravitational waves from a binary black hole merger."¹⁸ The *et al.* used above is a cast of more than a thousand.
- 2016 January 31, deadline for nominations for Physics Nobel Prize, but the LIGO team, by then fixed as Ronald Drever, Kip S. Thorne, and Rainer Weiss win at least four major prizes over the next few months (Breakthrough, Gruber, Kavli, and Shaw).
- 2017 August 17, arrival of the GW170817 signal and near-simultaneous gamma rays and other electromagnetic radiation, representing the merger of two neutron stars into a black hole with the expulsion of a significant amount of material that has been processed by rapid capture of neutrons to elements above iron in the periodic table. The Virgo detector is also involved, and the cast has grown to more than 3000.
- October, the award of the 2017 Nobel Prize in Physics to Rainer Weiss, Kip S. Thorne, and Barry Barish is announced. Barish was the manager of the project during the critical construction and commissioning phases, and Drever had died in March 2017.
- 2018 August, as this is being written, the LIGO installation is down for further improvement, but the astronomical community is sure that "multimessenger astronomy" is with us.

3. The Messiest Story Ever Told?

Probably it is not, since stiff competition comes from events where conspiracy theories have been invoked — the Kennedy assassination; faking of Moon landings; causes of the World Wars (or one World War, 1914–1939); who killed Cock Robin? But there have been many versions of whether gravitational radiation exists, what

^bNotice that the enforcement of "waves" rather than "radiation" has not yet taken place, and it should perhaps be mentioned that as early as 1967, Paczyński¹⁷ had suggested that the orbital evolution of a few short-period binary stars with white dwarf components, like WZ Sge and HZ29, is driven primarily by loss of energy and angular momentum in gravitational radiation.

Einstein thought, who first thought of looking for energy transported that way, and so forth. Most of this paper is my view of the history or story (the words coming from the same Latin and Greek roots, meaning knowledge), and parts have been published elsewhere.¹⁹ But there are others, wildly different.

Most recently, Dennis Lehmkuhl, now Scientific Editor of the ongoing volumes of the Collected Papers of Albert Einstein, has provided abstracts for two presentations.^{20,21} In these he starts with Einstein 1916–1918, goes on to Einstein’s work “with Nathan Rosen in the 1940s” (remember the famous paper is in 1937), “their influence on Hermann Bondi, Richard Feynman, and Felix Pirani in the 1950s”, which “in turn influenced Rainer Weiss in his original design of what would become LIGO.” Presumably his take on the history will appear in print in due course.

Meanwhile, Harry Collins^{13,22,23} has gradually modified his views from “Weber never did anything right” to “the field of searching for gravitational waves probably wouldn’t exist if Weber hadn’t pioneered it.” Apart from his partial change of heart, the most surprising aspect of the third of these volumes is that Collins is disappointed that the first LIGO event was so strong and clear. He had hoped for something rather marginal, so that he could study how the enormous, thousand-plus community came to decide what to claim. As it was, the sorting out pertained more to how to present the data, whether to call it a “first direct detection” in comparison with results from monitoring binary pulsars, and whether to include a second, less clarion burst in the first paper. There are other substantive problems with this volume.²⁴

Long before the first LIGO event, Daniel Kennefick had delved deep into the saga of the Einstein–Rosen paper, submitted to Physical Review but withdrawn when Editor Tate had it reviewed.²⁵ Einstein never sent them another paper, and who is to say which was the greater loser. This volume is still our best guide to that period, and the title is a quote from Eddington.

Since the February 2016 announcement of the first LIGO event, at least four other books meant for general readers and focused on gravitational waves have appeared. In rough order of publication, and with one comment each, these are by:

- Janna Levin.²⁶ Since she gets wrong things I know about, for instance writing *Kaddish* (a prayer said at funerals and gravesites) where *Kiddush* is meant (a cheerful blessing, often sung, over wine at Sabbath and other festive meals), I wonder about the rest.
- Govert Schilling.²⁷ A reasonable, fair treatment.
- Marcia Bartusiak.²⁸ A second edition of an earlier volume predating the event, and I think the best of the lot.
- Pierre Binetruy.²⁹ The first chapter is called “Transfigured Night,” and I prefer the version by Schoenberg.

And if you think this is rather a lot, you would be horrified by the dozen or more texts explaining, supporting, and opposing general relativity itself that appeared between 1918 and 1925 (listed in Ref. 13).

It has been claimed that the LIGO team deliberately scheduled their first public announcement for shortly after the 31 January deadline for Nobel Prize nominations. This may well be so, and the year's delay yielded a team of Thorne, Weiss, and Barish, while a great many 2016 prizes went to Thorne, Weiss, and Drever (including the Gruber, for which I did a nomination, a Breakthrough, a Shaw, and a Kavli, the Gruber being decided first, but the Breakthrough announced first, and the language of the later ones suggested some "leakage" from the Gruber nomination). Ron Drever died in March 2016, opening the gap filled by Barish. In any case, the fact that LIGO would announce *something* in February 2016 was widely known from early January, when France Cordova, at a meeting of the American Astronomical Society, graciously invited me to what she called, using her fingers to make quote marks, "the secret event." Some astrophysicists not on the team also leaked approximate data early, claiming that theorists needed the lead time to be able to respond to the actual announcement. If you have theoretical astrophysicists among your colleagues, you can be forgiven for doubting this claim.

The bottom line is that a brave soul could have nominated the LIGO folks for the 2016 Physics Nobel, though it would have been a bit tricky to describe honorably what it was going to be for. Apparently no one did.

Since we are focused on "mess" here, three more items come to mind. First, a few years ago NASA decided it would like to take another look at the data that had come from the Apollo Lunar Scientific Experiment Package (ALSEP) instruments and asked both me and Russell Tobias (the student who had originally processed the Lunar Surface Gravimeter data for his Ph.D. dissertation) if we knew what had become of the data tapes that were handed over to Joe as the LSG Principal Investigator. The answer was no.

Second, at least a couple of Italian scientists are still not persuaded that gravitational waves as now generally understood exist and can carry information and energy.³⁰ The version they sent me is not quite in English, nor apparently Italian, for instance: "We recall now the essential part come sostiof our results." They conclude that the signal ascribed to the merger of the two neutron stars... is really "generated by the gravitational field of the electromagnetic radiation created by the gamma-ray burst GRB170817A and the following kilonova." And "The signals ascribed to fictive BBHs are spurious."

Third, retired engineer Darrell Gretz has published his reminiscences of working with Weber, mostly on bar detectors for gravitational waves,³¹ saying that he thinks the bars were recording real, physical signals, but he is not sure from what.

More publicity leads to more mess, and one cannot possibly clean it all up, but something with a heading "Reliable news for an expanding universe"³² ends by saying "(Kip) Thorne studied under (Joe) Weber." Nope. Thorne earned a Princeton Ph.D. with John A. Wheeler as his advisor, and returned to Caltech (where he had been an undergraduate) without an intervening postdoctoral term.

4. A Gravitational Wave Do-It-Yourself Project

Well, neither you nor I is likely to deploy our own detector, though Weber occasionally jokingly held a spoon up to his ear, claimed not to hear anything and thereby to have established an upper limit to the flux of gravity waves with frequencies between about 30 Hz and 15,000 Hz. But we can do some of the calculations ourselves. An interesting one pertains to the speed at which gravitational waves or gravitational information travels.

Announcements of the 17 August 2017 binary neutron star merger event^{33–35} included the fact that the first gamma-ray photons arrived about 1.7 s after the gravitational wave burst and that the source was about 40 Mpc away. If photons and “gravitons” left at the same time, then you can say something about relative speeds. The observing (etc.) team allowed for some error in the distance and for the two messages having left at slightly different times, and concluded that the speed of gravitational information differs from the speed of light by at most about one part in 10^{15} . Add in $E = h\nu$, that the detected frequencies were about 50–400 Hz, and the special relativistic formula for the energy of a particle with rest mass m and speed v ,

$$E = \frac{mc^2}{\left(1 - \frac{v^2}{c^2}\right)^{1/2}}, \quad (1)$$

to discover that the rest mass of the graviton is at most of order 10^{-22} eV/ c^2 or something times 10^{-54} g.

Now we can join Hideki Yukawa (Physics Nobel Prize 1949), who predicted a mass for the carrier of the strong (nuclear) force given that its range is only 10^{-13} cm (1 fm). This works in reverse, so that we can say that a graviton of 10^{-54} g would give gravity a range of only about 4000 astronomical units (1 au = semimajor axis of the Earth’s orbit around the Sun). What is that range? The remarkable astrophysicist Fritz Zwicky (supernovae, gravitational lenses, and much else) said 10 Mpc, the size of a large cluster of galaxies,^{36,37} corresponding to a mass of 10^{-63} g and a speed that, for waves in the LIGO frequency range, should differ from that of light by about a part in 10^{24} . The gravity waves will lag the electromagnetic waves by less than a microsecond after crossing the observable universe.

Thus if we say with Poincaré³⁸ and Einstein^{5,c} that gravitational information travels at precisely the speed of light, and we are wrong, the computational errors will not matter very much, though perhaps there are philosophical arguments that will.

A good many commentators seem to have thought that the GW170817 event was the first observation that said anything directly about the speed of gravitational

^cThis is the third of the four Berlin Academy papers that Einstein submitted on successive Thursdays in November 1915, and the only one he read to the members attending in person. “Über Gravitationswellen” is in the 1918 volume, pp. 154–167.

information. Not so. When Einstein⁵ and others calculated the general relativistic prediction for the advance of the perihelion of Mercury, they assumed $v_g = c$, and they got the right answer to within observational errors both then and now. I have guided a hypothetical reader through that calculation elsewhere,⁸ concluding that when my late husband told me the two speeds were the same to within about 5%, this was correct for the early 1970s. With modern observations of orbits of the four inner planets, the room for disagreement shrinks to something like 0.05%, admittedly not competitive with LIGO, and not even infinitely cheaper, though the satellites that have given us better masses for Mercury and Venus and so forth were primarily launched for other purposes than to test GR.

5. Fair Winds and Following Seas: Joseph Weber and the United States Navy

Weber knew, from at least his last year of high school (Eastside High, Paterson, NJ) that he wanted to be a physicist and to marry classmate Anita Meinhardt Strauss. Both took some time. They had taken physics classes from Hallie Turner (who in turn had an M.S. in physics from the University of Chicago, where she had worked with Albert Abraham Michelson, both the first Jew admitted to the US Naval Academy (USNA) and the first American to win a Nobel Prize). At graduation, Anita went on to Smith College, graduating with the class of 1940 and a major in physics. She taught high school physics for some years afterwards.

Joe graduated from Eastside High a year earlier, in 1935, although he was a bit more than a year younger than Anita. He looks believably at most 16 in his high school annual. Weber took a civil service exam in order to be considered for admission to the US Naval Academy, where he could receive a very good education at no expense to his family. The congressman who appointed him came to the family house (172 Fulton Place), which enormously impressed his mother. He had scored only third on the exam, but the first two place-winners chose other colleges. Because he was too young for the Academy, Joe spent a year at Cooper Union College before joining the class of 1940 in fall, 1936. He borrowed \$100 from his older brother Jules for dental work and clothing required by the USNA.

Weber stood number 52 in his class of 456 USNA graduates, having, he said, ranked very high in thermodynamics and differential calculus and other subjects of very little interest to the Navy, but much lower in “fitness for the service” (roughly social graces expected of officers and gentlemen as the graduates of those days were declared). Other parts of this story and the following ones are told in Ref. 19.

Training of midshipmen included summer cruises under conditions like those experienced by enlisted men in the Navy. Weber particularly remembered one to Germany, where they sailed up the Kiel Canal, and spent some time on land, where his US uniform prevented any unpleasantness that might have been associated with his being Jewish. A University of Maryland Physics Department colleague

remembered many years later having been on a bridge over the canal and seeing the US ship pass underneath it when he was 14.

The summer 1939 cruise was confined to Canadian waters, because some danger in Europe was already foreseen (indeed Germany marched into Poland on 1 September 1939).

Joe told me many years later that sleeping in a hammock is doable but not very pleasant and that standard Navy watches of “four hours on, four hours off” with the dog-leg shift 4–6 and 6–8 in the afternoon and evening (so that everybody can get some dinner) had seemed to be the best available compromise between the need for continuous alertness and for rest. Modern research on human circadian rhythms suggests that almost anything else might be better. Weber, however, retained through later life the ability to eat and sleep whenever the opportunity arose. He jogged before an early breakfast in hot weather and responded to a 7:30 PM query from me with “Have you ever heard me say it was too early to go to bed?” He was prone to “ear-splitting” tension headaches, which normally yielded to a short nap, and like most terminal cancer patients can be described as having starved to death.

We turn now to information from documents recently accessed by Joe’s granddaughter Elizabeth Weber Handwerker. These materials become open access 62 years after a member of US military forces is separated from the service.

Ensign Weber’s first assignment after Annapolis graduation was on 7 June 1940, to the USS Lexington (Lex), though he probably reported on 1 July after crossing the country by train and stopping in Chicago to visit his by then divorced father, the last occasion on which they met.

This Lexington (two previous and one subsequent US ship carried that name) had been planned as a battleship with guns larger than those allowed by the Washington Naval Treaty of 1922 and so was completed as an aircraft carrier, typically carrying about 100 officers and more than 1840 enlisted men, under Captain Frederick C. Sherman, who can be Googled and for whom Weber maintained lifelong great respect. For what it is worth, Frederick C. Sherman stood 24th in his 1910 class of 156 graduates and 55 nongraduates. There were some, but few, WWI deaths, and by 1941 also fairly few of the class were still on active duty. The Lex was then based in San Diego, where early on Joe improperly showed up at a swank hotel for a tennis match already in tennis clothes, instead of wearing his uniform and changing at the hotel.

Captains were required to produce quarterly fitness reports (presumably only for their officers), and Weber’s first describes him as qualified for a “day’s work” in navigation, in accordance with his first assignment as assistant to the Navigator. He was not yet qualified for a deck watch at anchor or at sea, for engine room watch underway, as a signal officer, communications officer, or to command a gun division as of 30 September 1940. Grades included five levels each of Exceptional, Very Good, Fair, and Unsatisfactory. Officers were graded on 13 qualities: Intelligence, Judgment, Initiative, Force, Leadership, Moral Courage, Cooperation,

Loyalty, Perseverance, Reaction to Emergencies, Endurance, Industry, and Military Bearing and Neatness of person and dress. Joe's highest grade was a "middle excellent" in Cooperation and his lowest "top of very good" for Force, Endurance (he had, after all, been a member of the "weak squad" of rope climbers at the Academy), and Judgment (erased and moved one spot down).

Sherman described him as "keenly interested in his profession... exceptionally quick to learn... steady and reliable... more mature than average for his experiences... (and) qualified for promotion when due." Promotion came to Lieutenant, junior grade (Navy ranks are slightly different from Army ones) on 15 April 1942. A letter home to Anita Strauss (he wrote regularly when at sea, and she kept very many, perhaps all, of the letters) tells her not to get too excited about this, because all members of his class were so promoted.

Meanwhile, and onward for a month or so, Weber rotated among tasks as deck watch officer, gunnery officer, radar officer, battle lookout officer, and so forth. He requested both postgraduate instruction (in construction and engineering) and aviation training, for which a flight surgeon found him qualified. He was never formally trained for "duty involving aircraft" but did at least occasionally fly planes from the carrier (saying once that he had learned to steer a ship and fly a plane before he learned to drive, which was perhaps not quite true).

By the end of November 1941, the Lexington was one of three aircraft carriers nominally stationed in Pearl Harbor, but one was in drydock up in Bremerton, WA, one already in the Philippines. And the Lexington left Pearl Harbor on 5 December 1941, to transport new fighter planes to Midway Island.

I quote now from archival data prepared by "Joseph Weber USNA 1940":

I was the Officer of the Deck during the 8-12 watch Sunday, December 7, 1941. A message was given to me by the signalman. The message was: "Hostilities with Japan commenced with air raid on Pearl. This is no drill (signed) CINCPAC." (A transcription error actually made this read "This is no dripp.")

I gave the message to the Lexington Commanding officer, Captain Frederick C. Sherman. He sent for the Air Officer, Commander Duckworth. When Duckworth arrived, Captain Sherman showed the CINCPAC message to him, and said "Ducky, perhaps we should send up a fighter patrol."

The Lexington returned to Pearl Harbor on December 12, 1941. There were (smokeless) gunpowder grains from the Arizona explosion all over Ford Island, and also small pieces of red rising suns from wings of Japanese attack bombers, which had been shot down.

Several things might be noted. The timely departure of the Lex from Pearl almost suggests foreknowledge somewhere. Since the carriers had been the primary target, the attack was not a complete success. Many battleships were damaged; some refloated, some not, one or two scuttled *in situ* to prevent their being sunk where they might block harbor access. The most meaningful loss was the hundreds

of people killed. This included significant representation of the class of 1940, with an odd selection effect: men on duty were supposed to sleep on their ships, but some officers had girlfriends in town, with whom they spent the night of 6–7 December and so were spared. CINCPAC is Commander in Chief, Pacific.

This brings us to 8 May 1942, the Battle of the Coral Sea, generally described as having stopped the Japanese southward penetration and so saving Australia from invasion. At any rate, for many years, US Naval personnel who had fought in that battle were entitled to a free drink on 8 May, at the Australian embassy in Washington, DC, and we took advantage of this once or twice. Again I quote:

The Lexington was attacked by about 125 Japanese aircraft [off their carriers, and the first approaching planes were briefly thought to be American, so that flagmen started to wave them in] on May 8, 1942, in the Coral Sea. Torpedo hits ruptured the ship gasoline and oil tanks; fires started. The Lexington was abandoned when it became impossible to control the fires. When last seen by me, she was incandescent. United States destroyers fired torpedoes to guarantee that the burning ship would sink.

Very roughly, 20% of the crew were below decks, trapped in engine rooms, etc. and went down with the ship. Thus (as with the case of the recently relocated USS Indianapolis) there is no intent to raise the wreckage recently found well off the NE coast of Australia. The Arizona in Pearl Harbor is also regarded as a Navy gravesite. Weber was fortunately above decks and was among those rescued by other US ships in the area and taken to Tonga Tabu, returning to the US before 18 June, when he was in Newark, NJ.

The last “Report on the Fitness of Officers” from Captain Sherman is dated 19 June 1942, and covers the period from 1 April to 12 June 1942 (how to write dates has always been a bit of a mess in the US, with military, scientific, and civilian customs differing). Weber is listed as having served as Watch Officer (Deck), Radar Officer, Battle Lookout Officer, and Jr. Division Officer, and showing proficiency in French at level 3.2. Yiddish, which had been his first language, was probably not regarded by the Navy. He is ranked 4.0 on a scale of 1–4 as a deck watch officer, and Sherman says he would particularly desire to have him under his command in the future. But Weber expressed his preferences for post-Lexington duty as “New Construction — Atlantic” or “Postgraduate Work.”

Other bits of the form are marked “Outstanding” in comparison with other officers of his rank and approximate length of service, and professionally qualified to perform *all* the duties of his grade. The remarks section says “He did outstanding work in preparing rangefinder equipment for service” and is heartily recommended for promotion. There is a paraphrase of a CincPac Despatch, commending conduct during the battle of the Coral Sea: “By his calm bearing under stress and personal courage in battle he contributed materially to the successes obtained.”

As for the “report card”, Weber now ranks in the highest range of “Exceptional” for Intelligence, Moral Courage, Loyalty, Endurance, and Industry; in the

middle of exceptional for Force, Leadership, and Military Bearing; and second-to-top of exceptional for the other traits listed above. The Military Bearing score perhaps reflects the time when Captain Sherman asked, “did someone die, Mr. Weber?” meaning that the knot of his tie had not quite been tublocked, like a flag at half-mast.

Next came six weeks at the Submarine Chaser Training Center. Subchasers (SCs), of which the World War II (WWII) US Navy had more than 1000, were “The Splinter Fleet,” wooden ships 110’ in length with a draft of only 6’6”, and normally carrying 2–3 officers and 20 enlisted men. With a cruising speed of about 12 knots, they could reach 20 knots if needed. This was, say online documents, faster than a submarine under water and dependent on batteries for oxygen. But, Joe said, the submarines if they surfaced could go faster than the subchasers “but the submarines didn’t know that.” The professorial equivalent is being only one chapter of textbook ahead of the students in your class (but the students do not know that).

Weber traveled from the east coast to San Pedro Terminal Island, where he spent the last two weeks of August 1942 with the SC 723. But then back again on 11 September, with the “Supervisor of Shipbuilding at Annapolis”, where he oversaw the SC 690 being fitted out as prospective commanding officer. Promotion to Lieutenant came on 1 October 1942. His tasks there on included Commanding Officer, Navigator, Engineering Officer, Watch Officer, Medical Officer, Morale Officer, and a few other things. The SCs were notoriously unstable, rolling even in peaceful seas and pitching vigorously in heavy weather. Many serving on them experienced extreme seasickness, especially the first day or two out after some time on shore. Joe was among them and never, at any time in later life, expressed any desire for cruises, even with full expenses paid. Again I quote:

My next assignment was as Commanding Officer of the Submarine Chaser USS SC 690. Our first duty was convoying merchant ships in the Caribbean and to and from South America. Later we joined a force proceeding to the Mediterranean.

(The convoy system, incidentally, was at least partly invented by Lord Patrick Blackett, Physics Nobel Prize 1948, and proved safer than sending ships out individually and at random.)

The SC 690 served as a control vessel in the Gela Beach, Sicilian landing of July 1943. The Commander Naval Forces North African Waters asked me to find the right beach for landing Brigadier General Theodore Roosevelt junior, and 1800 rangers. We employed our microwave (10 centimeter wavelength) radar [not standard equipment for a sub chaser but the product of Weberian ingenuity] to accurately locate the center of General Roosevelt’s assigned area. After he and the rangers landed, we gave them fire support until 7:00 AM.

In between as it were, on 18 October 1942, Joe and Anita married in a reform synagogue in NJ, with Anita and her mother (Elsie Sternberg Strauss; her mother's maiden name was Meinhardt) having made all the arrangements, Joe was back on duty no later than 27 October 1942, when a flight surgeon again found him "qualified for duty involving aircraft" and what is more a full lieutenant, as of 1 October.

Annapolis graduates of that generation were not supposed to marry for two years after completing their degrees, though apparently some of Joe's classmates bent this rule. Weber predictably did not, though he had been busy elsewhere shortly before the two years expired.

The engagement ring was purchased with part of the \$200 Weber received for "articles lost in a marine disaster." What were those articles? Again I quote from materials located by Elizabeth Weber Handwerker: uniforms, civilian clothes, a sword, a radio, a phonograph player, two phonograph records (Schubert and Tchaikovsky, favorites for the rest of his life, especially Schubert's Great C Major symphony), a slide rule, a tennis racket (predictable), a set of golf clubs (odd; he really hated his time as a caddy in boyhood), and lots of books, a few new, but most dating from his years at the Academy. Some were service related (Knight's *Modern Seamanship*; Bowditch's *American Practical Navigator*, *Exterior Ballistics*, etc.), some mathematical (*Differential and Integral Calculus*, *Determination of Orbits of Comets and Asteroids*, etc.), and the largest number on electricity and magnetism and engineering (two volumes of Maxwell, Starling, two volumes of Dawes on electrical engineering, and so forth). I believe the *tallit* and *tefillin* he had received at his *Bar Mitsvah* also went down with the ship, but were not the sort of thing the Navy would have been likely to replace, though someone else eventually did. Replacement copies of some of the books rejoined his library, and I have them now, along with his copy of Alfred Thayer Mahan *Influence of Sea Power upon World History*.

Following the Sicilian landing, Weber returned under orders to the US on 20 July 1943, and began study at the Naval Postgraduate School in Annapolis in Radio Engineering (Navy records) or Electronics (Weber's recollection). Promotion to Lieutenant Commander came near the end of classroom study, 17 October 1944, followed by practical instruction during visits to NBC, RCA, Sperry Gyroscope, CBC, GE, Bell Telephone Labs, and other places I had not even heard of. He completed that curriculum in July 1945 with an excellent record and was then designated as an Engineering Duty Officer.

Between 1945 and 1948, he was head of Code 920 Electronics Countermeasures Design at the US Navy Bureau of Ships in Washington, DC. "Countermeasures" mean mostly blocking the other guys' radar, and the job once again involved visiting commercial organizations, research labs, being part of a Joint Army-Navy Countermeasures committees for research, development, and operations, membership on the Bureau of Ships advisory committee on scientific training, meeting with Army Ground and Air Forces on the fuse program, consultations with Andrew Alford

and other knowledgeable senior engineers, and much else. There was also formal teaching at the Naval Ordnance Lab and the engineering school of the University of Maryland as an Associate Professor. He also spent 10 days in October 1947 at the Naval Hospital in Bethesda, MD, with a lipoma of the left chest.

Weber joined the Institute of Radio Engineers as a student member in 1944 and became a regular member in 1946, soon thereafter becoming part of the organizing committee for an Electron Tubes conference. I counted at least 28 organizations visited, some many times, during his years “sailing a desk”, and a good many of these organizations, whose granting officer he had been, offered him jobs when he decided it was time to leave the Navy. But in fact he became a full professor of engineering at the University of Maryland, beginning in fall 1948, with instructions to get a Ph.D. in something, somewhere, quite soon.

A document date-stamped 8 June 1948,

From: Lt. Comdr. J. Weber USN (EDO) 85016
To: The Secretary of the Navy
Via: Chief of the Bureau of Ships
Subj: Resignation, tendering of.
Ref: (a) Signed agreement... to remain in the Navy until the end of July 1948
(b) Bupers Manual Article C-7001

has clearly been preceded by some negotiations and tenders his resignation effective about 1 September 1948. As required by the Manual, he gives as reasons:

- (a) inability to support his dependent mother, wife, and two children (one chronically ill and requiring special diet and care, which amounts to approximately \$500 annually), plus heavy life insurance obligations on his Navy salary; and
- (b) the assurance from prominent engineers and scientists that he has unusual abilities for work in science and engineering and so could best serve his country by engaging in that type of work rather than administration.

In addition, he has been advised that the switch should be made immediately, because his age (29) means that he should get into the type of work for which he is best fitted as soon as possible (a paraphrase).

The next document is from the Chief of the Bureau of Ships (E. W. Mills) to the Secretary of the Navy, via the Chief of Naval Personnel and dated 10 June 1948. It recommends acceptance of the resignation, although the Navy will lose “an officer of unusual scientific capabilities, an excellent officer, and an engineer of high quality.” On 28 June 1948, there is a Memorandum to the Secretary of the Navy, from the Chief of Naval Personnel, recommending approval of the resignation.

Over the next few weeks he visited Cornell University, the Airborne Instruments Lab in Mineola, NY, the Naval Hospital (a lipoma check-up presumably), GE in Schenectady, NY, RCA Labs in Princeton, Raytheon Manufacturing Co., Waltham, MA, the office of Andrew Alford, and gave a speech at the Naval War College,

Newport, RI, on electronic countermeasures. He was discharged honorably on 10 August 1948, with a lump sum payment for 60 days of accrued leave.

And then onward to a Ph.D. from Catholic University of America, fellowship in IRE (1958), move to the University of Maryland Physics Department in 1959–1961, and so forth, but these are parts of different stories.

The evaluations from Captain Sherman in 1940–1942 and the quoted statements from almost-colleagues in 1948 very much describe the man I met and married in 1972 and the “officer and gentleman” he remained until his death. He also remained deeply attached to the Academy and class luncheons, Christmas dinner-dances, and so forth, and always willing to sing the Academy “loyalty song.” No, not Anchors Away, but Navy Blue and Gold.

6. The Aftermath

The 1969 announcement of “evidence for” the discovery of gravitational waves was quickly followed by several prizes, in 1970 the one from Sigma Xi (the Scientific Research Society) and the Babson Award from the Gravity Research Foundation, which came with a lovely silver bowl (which I still have), and in 1973 the Boris Pregel Award for Research in Physics and/or Astronomy. Weber was elected to the governing committee of the International Society on General Relativity and Gravitation during its contentious pre-establishment meeting in Copenhagen in 1971 (see Sec. 5.3 of Ref. 12). Part of the contention was over whether to hold the next triennial meeting, GR7, in Haifa, Israel (necessarily without the Russian scientists and probably without most of the Eastern Europeans). This happened under the SOC chairmanship of Nathan Rosen (who also got off the tour bus to help change a flat tire). Weber was still part of the program, but this was no longer true by the time of GR8, and the location was Tel Aviv, not Haifa.

The organizers of the Texas Symposia on Relativistic Astrophysics reacted even faster, and the subject of gravitational waves did not appear on any invited program from 1972 (when I spoke for the group in New York) to 9–13 December 2002, in Florence, Italy,³⁹ where there was an interferometer talk by Alain Brillet of the Virgo Collaboration and one on gravitational wave astronomy from space by Bernard Schutz of Germany, speaking for the LISA International Science Team. This was also the occasions of my first invited “Texas” talk since 1972 and the topic was “Supernovae: Ground Zero and the Aftermath.” The post-presentation discussions are not preserved in the proceedings, but a woman near the back of the room described something I had said about X-ray emission as “controversial.” I got a long laugh by saying “Believe me, you don’t know what controversial means, unless you have been married to Joe Weber for 28 years.” His accumulated frequent flyer miles (which I inherited, and he had mostly earned flying back and forth between CA and MD to keep experiments running) paid for my flight to that meeting.

Starting in the 1980s, Joe also tackled the problem of neutrino detection by methods different from the chemical ones pioneered by Ray Davis (Nobel Prize

2002). There was a brief burst of funding and interest, partly because the trial detectors were small enough to carry around and hunt for submarines via the emission from their nuclear reactors. The neutrino results were also initially published in mainstream journals.⁴⁰ Weber soon concluded that similar quantum mechanical considerations applied to the bar detectors and was soon again relegated to publication in conference proceedings.⁴¹

Some national differences appeared in physicists' reactions to Weber's work. He continued to receive invitations for major presentations at conferences in France, China, Japan, Pakistan, and especially India, where he was also declared an honorary member of the Indian Astronomical Society and the Indian Association for General Relativity and Gravitation.

A group of Italian physicists (initially fairly large but now only about two) continued to think that the Weber bars in Maryland and one of theirs in Rome had recorded a signal from Supernova 1987A, correlated with the neutrinos recorded at Mt. Blanc as well as the later events at other detectors.^{42,43}

In 2002, a couple of scientists from the Pirelli Tire Company came and took away many pounds of the neutrino detection equipment, intending to continue the experiments, perhaps in parallel with Rome bar detectors. A change in company structure brought that project to an almost instantaneous end.

Weber received some very laudatory obituaries, in the New York Times and elsewhere, though all agreed he had not found "evidence for gravitational waves." Once he was clearly no longer competing for funding (he had continued to submit unsuccessful proposals for both gravitational and neutrino experiments almost to the end), others working in the field gradually came to express the view that searches for gravitational waves would never had gotten started if Weber had not pioneered them. This view became more widespread after the first LIGO event was announced, and in the past few years, even I have been asked to give talks in Pasadena, MD, and elsewhere about Joe's work and to write my impression of "The story of the first searcher and searches for gravitational waves."

The University of Maryland has archived many of Weber's scientific papers, letters, proposals, and so forth, as well as his laboratory notebooks.⁴⁴ One of the early, small (meaning only a couple hundred pounds of aluminum) bar detectors is in the Smithsonian Museum. Several others are still at the University of Maryland and are planned for an art installation in a garden. One is at the Hanford LIGO site, again part of a small museum exhibit, and the disk, meant to test the Brans-Dicke theory of gravity in competition with general relativity, seems to have been sold for scrap.

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