Are Gravitational Waves Directly Observable?

Explanatory Note

http://www.God-does-not-play-dice.net/gw.pdf

Let's look at the **facts** about GWs. What we know for sure is that an astronomical object called PSR 1913+16 has been losing energy in a very peculiar fashion, and Russell Hulse and Joseph Taylor have decided to explain it by applying the old Tanzanian saying: "How do we know that Father Christmas has a beard? We know it, because snow falls when he shakes his beard."

Then Hulse and Taylor were awarded a Nobel Prize for explaining exactly how we get snow from Father Christmas' beard.

Fair enough. But can we **directly** observe Father Christmas' beard? That's the whole question. Let's zoom on the facts, as presented by Clifford Will [Ref. 1, p. 5]:

"The binary pulsar

"In 1974 Russell Hulse and Joseph Taylor, then at the University of Massachusetts, discovered a binary pulsar called PSR 1913+16 that was to play a crucial role in tests of general relativity. Pulsars emit pulses of radio waves at very regular intervals and are thought to be rotating neutron stars. PSR 1913+16 was special because it was a pulsar that was in orbit around another compact object.

"By carefully measuring small changes in the rate of the pulsar "clock", Hulse and Taylor were able to determine both non-relativistic and relativistic orbital parameters with extraordinary precision. In particular they were able to measure three relativistic effects: the rate of advance of the periastron (the analogue of the perihelion in a binary system); the combined effects of time-dilation and gravitational redshift on the observed rate of the pulsar; and the rate of decrease of the orbital period.

"If we assume that general relativity is correct and make the reasonable assumption that both objects are neutron stars, then all three relativistic effects depend on the two unknown stellar masses. Since we have, in effect, three simultaneous equations and just two unknowns, we can determine the mass of both objects with an uncertainty of less than 0.05%, and *also* test the predictions of general relativity. If we assume that the orbital period of the system is decreasing due to the emission of gravitational waves, then theory and experiment agree to within 0.2%."

1. If we **assume** that GR is correct, and **assume** that we know the physics of neutron stars, and finally **assume** that the orbital period of the system is decreasing due to the emission of gravitational waves, we would have, in effect, **three** assumptions. That's a fact.

2. The second fact is that these three assumptions taken *en bloc* and experiment agree to within 0.2%.

3. It is now 45 years since Joseph Weber initiated his development of gravitational-wave detectors [Ref. 2], and 34 years since Robert Forward [Ref. 3] and Rainer Weiss [Ref. 4] initiated work on interferometric detectors. Yet there is no consensus among theoretical physicists on whether GWs can be **directly** observed: there are still daunting ambiguities in the quadrupole formula of gravitational "radiation", despite all the efforts of the proponents of GW astronomy to fix them. As acknowledged (emphasis added) by Clifford Will [Ref. 5, Sec. 4.2]:

"These questions were answered in part by theoretical work designed to shore up the foundations of the quadrupole **approximation**, and in part (**perhaps mostly**) by the agreement between the predictions of the quadrupole formula and the observed rate of damping of the pulsar's orbit (see Section 5.1)."

4. Back in 1970s, the opponents to the quadrupole approximation were not able to provide an alternative explanation of how the three assumptions taken *en bloc* and experiment would agree to within 0.2% (cf. above). They just had to **shut up**. This too is a fact.

5. As of today, the ambiguities in the quadrupole approximation of GW radiation and the resulting "sensitivity limit" are still **not** resolved [Ref. 6]. All the failures of LIGO Scientific Collaboration (LSC) to detect GWs have been interpreted as helpful hints toward the "desired" level of sensitivity of GW interferometric detectors. Subsequently, all papers (currently 42) and monographs by Prof. Angelo Loinger were totally ignored, and my paper was deleted by ArXiv "moderators".

I believe these are the facts. The crux of the matter, in my view, is in the following.

The proponents of GW astronomy have made an **incredible error** in treating the "waves" of spacetime metric as 'waves propagating **through** spacetime', thus ignoring their own warnings [Ref. 7].

And here begins the whole mess of GW astronomy: see again Clifford Will [Ref. 5, Sec. 4.5], and notice that the waveforms h_+(**t**) and h_x(**t**) refer to some time variable, **t** , pertaining to the amplitude of GWs, denoted with **h** . However, **h** is not a parameter but some mysterious "dimensionless number". But it is not a constant. It certainly *evolves*, but somehow remains a "dimensionless number" as well. We know from Kip Thorne that GWs (supposedly) travel along null geodesics with "slowly evolving amplitudes and polarizations" [Ref. 8]. Exactly how "slow" the amplitudes and polarizations would evolve "during" their travel along null geodesics is a huge mystery, since the GW clock that would travel along null geodesics will be dead frozen. In what **time** would the amplitudes and polarizations *evolve*?

And how about the *phase* of GWs? Bernard Schutz explains:

"You can prove that light is a transverse wave by using Polaroid, the semi-transparent material that is used in some sunglasses. If you take two pieces of Polaroid and place them over one another, then if they are oriented correctly they will pass about half the light through that falls on them. But if you rotate one piece by 90^o, then the two pieces together will completely block all the light. (...) A further rotation by 90^o restores transmission. The kind of geometrical object that is turned into itself by an 180^o rotation is a line." [Ref. 9, p. 311]

What geometrical object corresponds to the *cancellation* of the phase of GWs? Namely, what geometrical object is **turned into itself** by an 90^o rotation? Recall that the alleged "+" and "x" waveforms are shifted in 45^o [Ref. 9, Fig. 22.1, p. 312], not in 90^o, as in the example provided by Bernard Schutz above. Such a peculiar "phase" (if any) is nothing but an artefact from the quadrupole approximation. For if it were a genuine *phase*, then somebody from the LIGO Scientific Collaboration should be able to explain the conditions under which it can be **cancelled**, hence will (i) prove that GWs are indeed transverse waves, and (ii) demonstrate the "direction" of the mysterious dimensionless number **h** [Ref. 9, Fig. 22.1]. However, its "direction" should be **transverse to the 3-D space**, namely, to the x-y-z 3-D volume, and not to some preferred 2-D plane, as speculated by C. Will [Ref. 5].

One way to provide a **reversible** cancellation of the GW phase is to discover some geometrical object which can be **mapped into itself** by an 90^o rotation, in 3-D space and using Cartesian coordinates [Ref. 10]. Well, this might be tough. Perhaps LIGO Scientific Collaboration can try something else: rotate the whole "installation" in 3-D space into the longitudinal mode [Ref. 5, Fig. 9], in which no GWs can propagate, ever. This should be a perfectly legitimate diff-invariant state, correct? Try to discover it then. If you find it, try to figure it out how would GWs **avoid** the longitudinal quadrupole mode, and why.

This is the essence of the L-shaped laser interferometers. It is sheer parapsychology, because LIGO Scientific Collaboration does not offer a falsifiable hypothesis under which one could cancel the phase of GWs and/or switch to the longitudinal quadrupole mode. They simply cannot do that in the framework of the so-called linearized gravity [Ref. 10], and of course cannot define the dynamics of GWs on **the whole spacetime** [Ref. 5]. Just like in parapsychology, their “predictions” can be “derived” only in their “linearized gravity”, upon displaying Einstein’s equations in “relaxed form” [Ref. 5].

Not convinced?

Look at the center (horizontal) line of Fig. 22.1 [Ref. 9]. It gives the wave as a function of **time**, while the small segment from the vertical line displays the famous amplitude and **wave strain** of GWs, which come straight from Father Christmas' beard, as explained above.

How do you *time* the evolution of GWs? With respect to **what**? Recall that GWs are "oscillations of the "fabric" of spacetime itself" [Ref. 7]. There is no "extra" dimension to define the dynamics of GWs on **the whole spacetime** [Ref. 5] (as well as to define the dynamic dark energy, which was also the subject of my paper).

NB: How would you **separate** the "time parameter" of the propagation of GWs, depicted with the center (horizontal) line of Fig. 22.1 [Ref. 9], from the coordinate "time" in GR? B. Schutz argues that "the force of the Moon comes from the curvature of time" [Ref. 9, p. 310], and "the deformation produced by the Moon is partly directed towards the Moon (the longitudinal direction), whereas gravitational waves are transverse" [Ref. 9, p. 311]. Thus, you have to separate two crucially distinct cases: **curvature of time**, as in the example with the tidal effect on Earth caused by the Moon (no GWs in principle), from **curvature of space**, as in the case of time-dependent spatial curvature (lots of GWs waiting for the Advanced LIGO), depicted with the center (horizontal) line of Fig. 22.1 [Ref. 9]. To elucidate the situation, let me quote again from B. Schutz: "The fact that gravitational waves are transverse and do not act like the Moon does on Earth implies that they are **not** part of the curvature of time, since that is where the Newtonian forces originate. They are **purely** a part of the curvature of space (Sic! – D.C.). When gravitational waves move through a region they do not induce difference between the rates of nearby clocks. Instead, they deform proper distances according to the pattern in Fig. 22.1" [Ref. 9, p. 312]. Thus, all you have to do is to separate the curvature of time from the curvature of space.

Then you'll need an undisturbed reference object, or rather some "non-uniform" component of GWs, which "acts in such a way that one section of an apparatus is affected by gravity differently than another" [Ref. 9, p. 310]. How can you find something that is **not** being affected by GWs, hence can serve as the **reference object** with respect to which you can detect the distortion of spacetime metric caused by GWs? Moreover, can you record the **instant** at which such distortion enters your light cone?

Sorry, GWs cannot be **directly** observed [Ref. 11]. Read also the warning by Steven Weinberg: "The device measuring, say, the displacements of free mirrors in an interferometer would be "stretched and squeezed" as well." This is as it should be, since LIGO operates with **one** time parameter only. However, Steven Weinberg has explained his objections in a private email to Leonid Grishchuk (25 February 2003), and has not (yet) submitted a paper to ArXiv.org e-print archive. He still prefers to keep quiet.

This whole mess was made possible by introducing an illegitimate approximation to Einstein's GR, called 'linearized gravity' [Ref. 10]. It's an **oxymoron**, strictly speaking. It is utterly unclear how those "additional, non-radiative degrees of freedom" [Ref. 10] can be safely distilled from the genuine metric perturbations (if any) caused by GWs. The obvious "merit" of such linear approximation is that, for weak waves, "it is possible to define their energy with reference to the "background" or undisturbed geometry, which is there **before** the wave arrives and **after** it passes" [Ref. 9, p. 317].

That's how LIGO Scientific Collaboration (395 distinguished scholars) are trying to catch Father Christmas' beard. And they have a lot of cash to spend. Taxpayers' money, of course.

On February 2, 2005, the James S. McDonnell Professor and Nobel Prize Laureate Joseph Hooten Taylor Jr. made the following statement before the Committee on Science at The U.S. House of Representatives:

"Our nation's science enterprise has been well served by having open, broadly based mechanisms for setting priorities in astronomy, and by closely following the wise decisions made in that way."

I just wonder who made those "wise decisions" to pursue GW astronomy. If they really want to have "open, broadly based mechanisms for setting priorities in astronomy", here's the first off puzzle: GWs exist, but cannot be directly observed, just as the so-called dark energy cannot be directly observed.

Do we treat spacetime as *one* entity, after Hermann Minkowski? Look again at the "direction" of **h** [Ref. 9, Fig. 22.1]. It should be **transverse to the 3-D space**, not just to **the x - y plane** [Ref. 5; see also Fig. 9], because "gravitational waves are oscillations of the "fabric" of spacetime itself" [Ref. 7]. Since EM waves propagate **through** spacetime, there is always a spacetime domain 'ahead of them', in which they are 'not yet', while GWs are spacetime themselves -- there is no "place" ahead of them, in which they are 'not yet', simply because the spacetime itself does not "move" [Ref. 12]. If we picture the 3-D space as some 2-D lake with axes **x** and **y** [Ref. 5], there would be a **preferred transverse** direction, **z** , to the whole lake. Then it would be possible for some preferred observer to define GW dynamics "with reference to the "background" or undisturbed geometry, which is there **before** the wave arrives and **after** it passes" [Ref. 9, p. 317], because this preferred observer placed "across" the 2-D lake would have an absolute clock to time the dynamics of GWs on the whole spacetime *en bloc*, namely, **over all spacetime** [Ref. 5]. She would then be able to **notice** some GW "push" on a fishing rod float on the 2-D lake [as in cases (a), (b), and (c) in Fig. 9, Ref. 5], and perhaps will be terribly happy as well, because she will vindicate the so-called linearized gravity and the whole GW astronomy.

We cannot, of course, extend this 2-D lake metaphor to 3-D space. Measurements **across 3-D space** are unphysical [Ref. 9, Fig. 24.3, p. 349], which is why we have "dark" energy along the "dark" preferred axis. And it isn't a matter of "improving sensitivity" to (i) detect the elementary step/increment of time along the cosmological time arrow driven by the "dark" energy, as well as (ii) detect some GW "push" on a fishing rod float (LIGO's or LISA's arms) inside the 3-D "lake". Put it differently, if GW energy does spring from the "dark" one, then the value of the **observable** physical energy of GWs should *not* exceed the cosmological constant. Perhaps Mother Nature has imposed a strict ban on **direct** measurements on its "dark" energy, or else it will be converted into a physical energy which will be instantaneously poured into spacetime.

If this is the case chosen by Mother Nature, what can we make from these long, air-conditioned, L-shaped tunnels of LIGO? I suggest we convert them into wine cellars.

Well, the ArXiv "moderators" didn't like the idea, and my paper was deleted. In the past two and a half years, the sole feedback from LIGO Scientific Collaboration was an email from Dick Gustafson from Tue, 07 Jun 2005 00:13:17 -0400: "I don't know you and wish you out of my face, my computer." Perhaps such kind of reaction can be classified as 'ostrich behavior', only Dick Gustafson cannot hide his head in the sand, because the underlying problem is the nature of the cosmological time arrow driven by the so-called dark energy, and nobody can escape from it. Stated differently, "preposterous universe will require preposterous explanations and one needs to get bolder" [Ref. 13].

Let's get bolder then. Where does the "dark" energy come from? Once it starts dominating over the normal matter, we may speculate that it will possess negative pressure enough to **accelerate** the expansion of the universe, hence all we have to do is to solve the coincidence problem and explain the expansion rate of the universe in the past [Ref. 13]. This would be the solution to the intrinsic dynamics of the source of "dark" energy.

Trouble is, we currently cannot explain the **source** of "dark" energy, since it does not, and cannot fit into the universe it accelerates. It has its own dynamics, such that it can grow larger as it accelerates the universe, but can (and must) almost disappear in the first "moments" after The Beginning[φ]. If we imagine the whole universe as a car being accelerated by some "dark" elephant behind it, the moral of the whole story is that we cannot **in principle** embed the dark elephant into the car. It resides somehow "outside" the car/universe, and requires a new (to present-day theoretical physics) ontological status.

We simply have to recall the First Cause of Aristotle, and seek its intrinsic dynamics. We cannot resort to some "anthropic considerations", which are sheer parapsychology, too. We need to understand the contribution of quantum fluctuations to gravity [Ref. 14], because all efforts to 'play ostrich' with the cosmological constant problems (say, by introducing some *ad hoc* scalar field) simply do not work [Ref. 13].

Let's begin by recalling that Einstein's Cosmological Constant is totally alien to GR, since it springs from 'empty space'. We shall give this 'empty space' a new ontological status, called 'potential reality', and will introduce **two modes** of spacetime, local and global, for modelling the elementary step/increment of the cosmological time. We will place the First Cause of Aristotle and the newly introduced 'potential reality' in the global mode of spacetime, because we need some genuine **gaps** for the phenomenon of transience, as we know from St. Augustine. Think of these "dark" gaps in the global mode of spacetime as unobservable strips from film reel. We need these "dark" gaps also to solve another puzzle: the self-determination or self-measurement of the whole universe [Ref. 15].

Imagine a reel of snapshots, in which you see an object, X , moving from the left to the right. These snapshots are separated by a dark strip, [---]. Let's label the snapshots with t_1, t_2, t_3, and think of the commas as dark strips, [---]. The story will look like a ladder:

[---]
[X] is t_3
[---]
[X] is t_2
[---]
[X] is t_1

What can be seen in the **local mode** of spacetime? Nothing but a perfect continuum of the states of X moving from the left to the right. What I mean by 'perfect continuum' is the following: in this local mode of spacetime, the size of the dark strips is zero to you, because of the so-called speed of light. You can see things only in their **past** state, and in this chain of past states the dark strips are **strictly zero**. Thus, you have a **perfect** (not FAPP) continuum in the local mode of spacetime, and subsequently a stand-still 'block universe' [Ref. 12]. You will find there only the 'end result' from a process termed Renormalization [Ref. 16], and the 'end result' from the bi-directional talk of matter and space [Ref. 17], as well as all sorts of catastrophes, which have never happened: Closed Time Curves (CTCs), Cauchy problems and geodesic incompleteness, and spacetime singularities, either shielded by some mythical Cosmic Censorship Conjecture (black holes) or not (naked singularities).

You will also see there the 'end result' from some gravitational waves, but these "waves" can live in the local mode for just **one instant** from the cosmological time arrow. Surely their effects can be *inferred* from the history of the universe, but if you want to detect them "online", as they evolve along the ladder, you need access to the global mode of spacetime: the dark step/strip of the ladder. Briefly, we introduce a pocket of 'propensity states' in the global mode of spacetime, and suggest that its "volume" is vanishing small only at the scale of tables and chairs. Its "dark" effects show up as 'quantum effects' in the Small, and 'dark matter & dark energy effects' in the Large (more in the full paper).

In summary, we still do not know what caused the anomalous behavior of the binary pulsar PSR 1913+16 [Ref. 1], hence it's all in the basket of Father Christmas' beard. However, if somebody from LIGO Scientific Collaboration is genuinely interested in detecting GWs, the first off task is to design an experimental setup which would account for the **quasi-local** nature of gravitational field: the gravitational energy-momentum and angular momentum, which are the gravitational analogs of the classical conserved quantities and observables, are quasi-local in the sense that they should be associated to **extended** domains rather than to points (Laszlo Szabados, private communication). At least two 'ideal observers' are needed to detect gravitation [Ref. 18], which is a highly non-trivial task, because these two (or more) 'ideal observers' should be entangled, EPR-like correlated in order to detect **simultaneously** the GW "push" from the spatial curvature. The latter is a quasi-local effect, in the sense that the GW energy is **not** localisable in "points". The action of geometry on matter is **not** a local phenomenon. We may enjoy exact conservation laws and local physics only in Newtonian gravity, due to the absolute time in it, while in Einstein's GR we have quasi-local conversion of GW energy into physical energy. This conversion may be considered "local" only within an extended spacetime domain, and with a lot of wishful thinking [Ref. 19]

Imagine a shoal of fish swimming along a coral reef: each fish follows its strictly **local** geodesic path, such that at each point it has **already**-fixed contribution to its stress-energy from the Christoffel symbols in the covariant derivatives, from the whole shoal of fish. At each **next** point from its geodesic, the state of the fish will be again **already**-negotiated in the global mode of spacetime with 'the rest of fish'. We can see, in the local mode of spacetime, only the 'end result' from this "dark talk" in the shoal (footprints of H-space on asymptotically flat spacetime[▽]). We cannot see its quantum-gravitational wave which bootstraps the whole shoal of fish "from inside" the **infinitesimal displacement** along the geodesic line. Mother Nature can, but not LIGO. Forget it. Think of wine cellars instead.

To be completely honest, I have to stress that there could be light in the tunnel for LIGO Scientific Collaboration. Namely, I could be **all wrong**. Three years ago, on Wed, 23 Oct 2002 19:24:15 +0100, Chris Isham delivered his opinion on my work with the following statement: "You do not know enough theoretical physics to help with any research in that area."

The opinion of the leading expert in quantum gravity is a double-edged sword, however. He hasn't yet refuted any of the ideas outlined above. In fact, none of his colleagues has so far responded to my numerous requests for opinion.

Do you, my dear reader, understand GR [Ref. 20] and the gravitational waves [Ref. 21]? Do you know enough theoretical physics to help with any research in that area? If you do, perhaps you may wish to contact Chris Isham, and then you all, like a shoal of fish, could sort out this whole mess called 'gravitational astronomy'. A humungous amount of time and money has already been wasted, and even more are scheduled to be wasted.

Please act promptly. The sooner, the better.

Dimi Chakalov dimi@chakalov.net
Wednesday, 26 October 2005, 23:00:00 GMT

References

[Ref. 1] Clifford M Will, Relativity at the centenary, *Physics World*, January 2005, pp. 1-6.
http://physicsweb.org/articles/world/18/1/5/1

[Ref. 2] J. Weber, *Phys. Rev*., 117, 306 (1960).

[Ref. 3] G.E. Moss, L.R. Miller, and R.L. Forward, *Applied Optics*, 10, 2495, 1971.

[Ref. 4] R. Weiss, Quarterly Progress Report of RLE, MIT, 105, 54, 1972.

[Ref. 5] Clifford Will, The Confrontation between General Relativity and Experiment, *Living Rev. Relativity* 4, (2001), 4. URL (cited on 11 May 2001):
http://www.livingreviews.org/lrr-2001-4
Updated (16 October 2005) with gr-qc/0510072 v1.

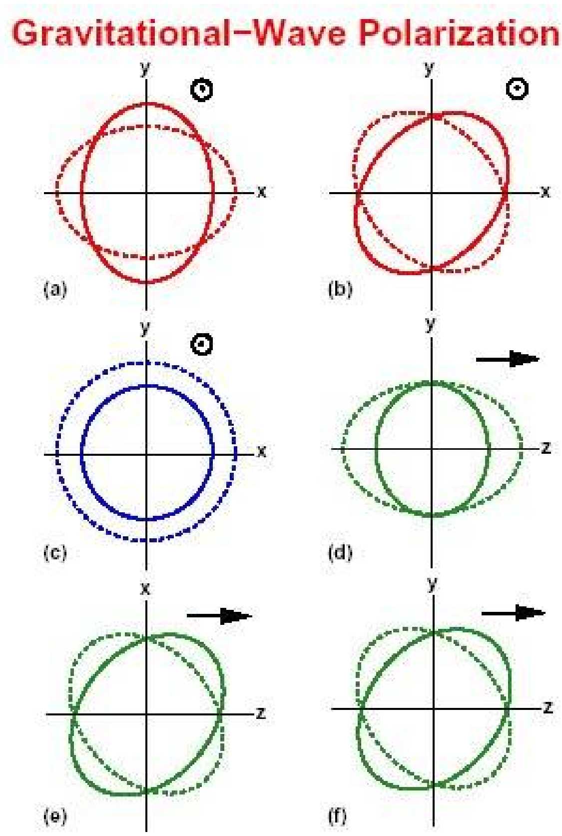
"4.3 Einstein's equations in "relaxed" form

"In general relativity, the gravitational field itself generates gravity, a reflection of the nonlinearity of Einstein's equations, and in contrast to the linearity of Maxwell's equations.
...
"However, because the source [tau_ab] contains [h_ab] itself, it is not confined to a compact region, but **extends over all spacetime**. As a result, there is a danger that the integrals involved in the various expansions will diverge or be ill-defined. This consequence of the non-linearity of Einstein's equations has bedevilled the subject of gravitational radiation for decades. Numerous approaches have been developed to try to handle this difficulty.
...
"4.5 Gravitational wave detection

"From the equation of geodesic deviation, the **infinitesimal displacement** E of the mass along the line of separation from its equilibrium position satisfies the equation of motion [Eq. 56]

"In a source coordinate system in which **the x - y plane is the plane of the sky and the z -direction points toward the detector**, these two modes are given by [Eq. 57]
...
"For a laser interferometer with one arm along the laboratory x -axis, the other along the y -axis, and with E defined as the *differential* displacement along the two arms, the beam pattern functions are [XXX] and [XXX] .

"The waveforms h_+(**t**) and h_x(**t**) depend on the nature and evolution of the source. …



“Figure 9: The six polarization modes for gravitational waves permitted in any metric theory of gravity. Shown is the displacement that each mode induces on a ring of test particles. The wave propagates in the +z direction. There is no displacement out of the plane of the picture. In (a), (b) and (c), the wave propagates out of the plane; in (d), (e), and (f), the wave propagates in the plane. In GR, only (a) and (b) are present; in scalar-tensor gravity, (c) may also be present.”

[Ref. 6] Linqing Wen, Bernard F Schutz, Coherent Network Detection of Gravitational Waves: The Redundancy Veto, gr-qc/0508042 v1.

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"By the end of 2005, LIGO and GEO are expected to have embarked on full-time observing. Within a year or two we should know whether or not the first-stage sensitivity of these detectors is sufficient to make the first detections of gravitational waves, or whether the field will have to wait for the sensitivity upgrades that are planned over the subsequent five years."

[Ref. 7] K. S. Thorne, Gravitational waves, gr-qc/9506086 v1.

"There is an enormous difference between gravitational waves, and the electromagnetic waves on which our present knowledge of the Universe is based:

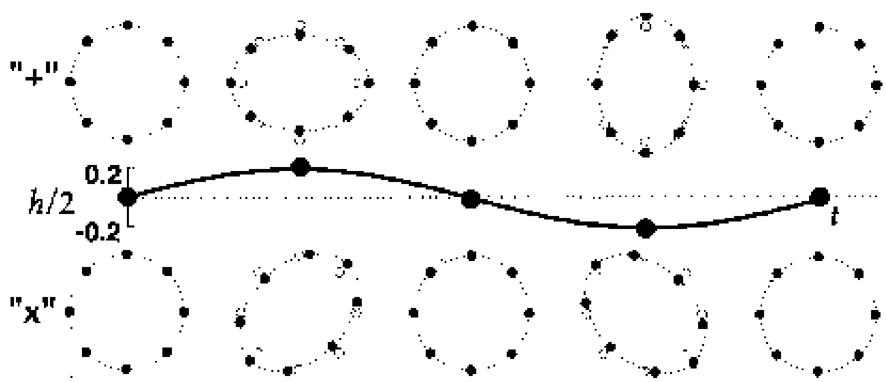
"Electromagnetic waves are oscillations of the electromagnetic field that propagate through spacetime; gravitational waves are oscillations of the "fabric" of spacetime itself.

...

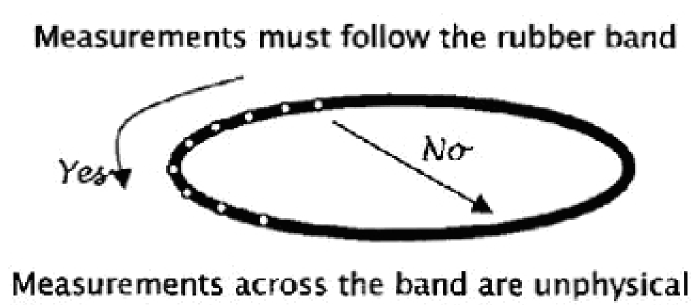
"If the source estimates described in this review article are approximately correct, then the planned interferometers should detect the first waves in 2001 or several years thereafter, thereby opening up this rich new window onto the Universe."

[Ref. 8] Kip S. Thorne, The Theory of Gravitational Radiation: An Introductory Review, in *Gravitational Radiation*, eds. N. Dereulle and T. Piran, North Holland, Amsterdam, 1983, pp. 1-57.

[Ref. 9] Bernard Schutz, *GRAVITY from the Ground Up: An Introductory Guide to Gravity and General Relativity*, Cambridge University Press, Cambridge, 2003.



(Fig. 22.1, p. 312)



(Fig. 24.3, p. 349)

[Ref. 10] Eanna Flanagan and Scott Hughes, The basics of gravitational wave theory, gr-qc/0501041 v3.

> 2. The basic basics: Gravitational waves in linearized gravity
>
> The most natural starting point for any discussion of GWs is *linearized gravity*. Linearized gravity is an adequate approximation to general relativity when the spacetime metric, g_{ab}, may be treated as deviating **only slightly** from a flat metric, h_{ab} :
>
> $g_{ab} = h_{ab} + h_{ab}, \quad ||h_{ab}|| << 1. \quad (2.1)$
>
> Here h_{ab} is defined to be diag(-1, 1, 1, 1) and $||h_{ab}||$ means “the magnitude of a typical non-zero component of h_{ab}”.
>
> Note that the condition $||h_{ab}|| << 1$ requires both the gravitational field to be weak, and in addition constrains the coordinate system to be approximately Cartesian. We will refer to h_{ab} as the metric perturbation; as we will see, it encapsulates GWs, but contains additional, **non-radiative** degrees of freedom as well.

In linearized gravity, the smallness of the perturbation means that we only keep terms which are linear in h_{ab} – higher order terms are discarded. As a consequence, indices are raised and lowered using the flat metric h_{ab}. The metric perturbation h_{ab} transforms as a tensor under Lorentz transformations, but not under general coordinate transformations.

[Ref. 11] Angelo Loinger, On the displacements of Einsteinian fields *et cetera*, physics/0506024 v2.

"In other terms, if we displace a mass, its gravitational field and the related curvature of the interested manifold displace themselves **along with the mass**."

See also A. Loinger, *On Black Holes and Gravitational Waves*, La Goliardica Pavese, Pavia, 2002, ISBN: 88-7830-371-2; *Idem*, *On BH’s and GW’s*, Vol. II, La Goliardica Pavese, Pavia, 2005, ISBN: 88-7830-427-1.

[Ref. 12] Robert Geroch, *General Relativity from A to B*, University of Chicago Press, Chicago, 1978.

“There is no dynamics within space-time itself: nothing ever moves therein; nothing happens; nothing changes.”

[Ref. 13] T. Padmanabhan, Darker Side of the Universe, astro-ph/0510492 v1.

[Ref. 14] Roland Triay, A Solution to the Cosmological Constant Problem, gr-qc/0510088 v1.

"Unfortunately, the state of the art does not allow yet to provide us with a definite answer for defining the right hand term of Eq. (15) ... ."

[Ref. 15] Thomas Breuer, The Impossibility of Accurate State Self-Measurements, *Philosophy of Science*, 62 (1995) 197-214.

[Ref. 16] A. N. Mitra, Einstein And The Evolving Universe, gr-qc/0510090 v1.

"Indeed quantum theory has even covered the problem of interaction of radiation with matter -- QED that is -- by addressing the problem virtual processes (the problem of emission and subsequent absorption of radiation) which was fraught with dangerous infinities that would not make sense for physical processes ! The solution lay in the absorption of infinities through a redefinition of physical entities like mass and charge (in terms of 'bare' charge and mass), a process termed Renormalization, so that physical process could be expressed entirely in terms of the 'renormalized' quantities only. A consistent treatment further required that the operation be independent of the inertial frame under consideration."

[Ref. 17] C. Misner, K.S. Thorne, and J.A. Wheeler, *Gravitation*, W. H. Freeman & Co., New York, 1973.

p. 5: "Space acts on matter, telling it how to move. In turn, matter acts back on space, telling it how to curve."

[Ref. 18] R. Aldrovandi, P.B. Barros, and J.G. Pereira, The Equivalence Principle Revisited, gr-qc/0212034 v1.

"An *ideal observer* immersed in a gravitational field can choose a *reference frame* in which gravitation goes *unnoticed*.

...

"An ideal observer in a gravitational field is locally equivalent to an ideal observer in the absence of gravitation, while an ideal observer in a gauge field will always feel its presence. At least two ideal observers are needed to detect gravitation, but only one is enough to detect an electromagnetic field. In this sense gauge fields are local, and gravitation is not."

[Ref. 19] Carl Hoefer, Energy Conservation in GTR, *Stud. Hist. Phil. Mod. Phys*. 31(2), 187 (2000).

p. 195: "... we could ask for a notion of energy conservation well-defined both locally and over regions, for GTR spacetimes in general and not just one unrealistic sub-class of them.

p. 194: "The pseudo-tensor nature of t^{ab} results in the integrals in (7) being ill-defined, coordinate-dependent in general. They do however yield unambiguous results, and constitute a conservation equation, when certain conditions are imposed. For a well-defined result,

(a) Integrals must be taken in limit $r \rightarrow \propto$.
(b) Asymptotic flatness of the spacetime is assumed ($g^{ab} \rightarrow n^{ab}$).
(c) The coordinate system must be Lorentzian asymptotically (but can vary arbitrarily in the interior)."

[Ref. 20] Hans Stephani, *General Relativity: An Introduction to the Theory of the Gravitational Field*, Cambridge University Press, Cambridge, 1990.

p. 142: "Before turning to [the problem of finding the field equations], we want to formulate clearly the alternatives confronting us. Either we wish to calculate only with tensors and allow only covariant statements, in which case we use [(1)] and can write down no balance equation for the energy transport by radiation. Or else we want such a balance equation [(6)], which can only be formulated in a noncovariant manner; as one can see from [(6)], t^{ab} is not a tensor ..."

[Ref. 21] Larissa Borissova, Gravitational Waves and Gravitational Inertial Waves in the General Theory of Relativity: A Theory and Experiments, *Progress in Physics*, 2, 30-62 (July 2005).

p. 35: "Generally speaking, in the General Theory of Relativity, there is a problem in describing gravitational waves in a mathematically correct way. This is a purely mathematical problem, not solved until now, because of numerous difficulties. In particular, the General Theory of Relativity does not contain a satisfactory general covariant definition for the energy of gravitational fields. This difficulty gives no possibility of describing gravitational waves as travelling energy of gravitational fields.

"The next difficulty is that when one attempts to solve the gravitational wave problem using the classical theory of differential equations, he sees that the gravitational field equations (the Einstein equations) are a system of 10 nonlinear equations of the 2nd order written with partial derivatives. No universal boundary conditions exist for such equations."

[Ref. 22] Norbert Straumann, Cosmological Phase Transitions, astro-ph/0409042 v2.

[Ref. 23] Carlos Kozameh, Ezra. T. Newman, and Gilberto Silva-Ortigoza, Twisting Null Geodesic Congruences, Scri, H-Space and Spin-Angular Momentum, June 8, 2005, gr-qc/0506046 v2.

"The purpose of this work is to return, with a new observation and rather unconventional point of view, to the study of asymptotically flat solutions of Einstein equations. The essential observation is that from a given asymptotically flat space-time with a given Bondi shear, one can find (by integrating a partial differential equation) a class of asymptotically shear-free (but, in general, twisting) null geodesic congruences. The class is uniquely given *up to the arbitrary choice of a complex analytic world-line in a four-parameter complex space*. Surprisingly this parameter space turns out to be the H-space that is associated with the real physical space-time under consideration. The main development in this work is the demonstration of how this complex world-line can be made both unique and also given a physical meaning. More specifically by forcing or requiring a certain term in the asymptotic Weyl tensor to vanish, the world-line is uniquely determined and becomes (by several arguments) identified as the 'complex center-of-mass'. Roughly, its imaginary part becomes identified with the intrinsic spin-angular momentum while the real part yields the orbital angular momentum.
...

"In this work we have shown that for all asymptotically flat space-times there is a hidden structure that must be extracted dynamically from the known asymptotic Weyl tensor and its related characteristic data, the Bondi shear, [x]. This hidden structure is a specific field of asymptotically shear-free null directions - or an asymptotically shear-free null geodesic congruence. Within the information for the description of this direction field is a complex world-line that is defined in the H-space associated with the given asymptotically flat space-time. One can try to give meaning to this world-line by defining it to be the complex center of mass of the interior gravitating system. Though there is no proof or even overwhelming evidence that this assignment is completely reasonable, we can ask the question: what physical justification can be given for this assignment. On the surface it certainly is strange - where does a complex world-line in H-space enter in any direct physical observation.
...
"It is possible to ask the question: can one give, at least in principle, an observational means of "observing" this complex motion? The answer, we believe, is yes - though to really do so is impossible. It involves having a huge number of observers surrounding the gravitating source and looking at all the null rays reaching them, then picking out shear-free null direction fields and by angular integration finding the complex world-line. This type of argument must be tightened and made more precise."

[Ref. 24] Elizabeth A. Rauscher and Russell Targ, The Speed of Thought, *J. Sci. Exploration*, 15(3), 331 (2001), Sec. 5.

[Ref. 25] John and Marry Gribbin, *In Search of Schrödinger's Cat*, Black Swan, London, 1998, p. 209.

[φ] There is a vast literature on the cosmological constant problems; see the discussion of the gravitationally-effective vacuum energy density and the current matter energy density (asymptotically flat spacetime) in Sec. 4 of [Ref. 22]. As explained by Norbert Straumann, their joint evolution is a profound puzzle, since "the vacuum energy density is constant in time -- at least after the QCD phase transition --, while the matter energy density decreases as the Universe expands". If we employ only one time parameter – the "horizontal" displacement of X in the local mode of spacetime (cf. p. 6) – then we cannot solve the whole bundle of puzzles in the cosmological constant problems **in principle**. We need 'potential reality', in the global mode of spacetime depicted with the "vertical" displacement of X along the cosmological "ladder", to explain the meaning of 'the Universe starts **asymptotically** from time 0', as inferred from the local mode of spacetime. Hence I argue that the source of dark energy can (and must) almost disappear in the first "moments" after The Beginning (cf. p. 6), because I believe the values of explicated, physical quantities should run toward zero (not infinity), as they approach asymptotically The Beginning. In this asymptotic regime, the question of their ratio is meaningless, since they constitute an infinitesimal part from the pool of 'potential reality' [John 1:1].

[∇] Every "fish" follows its quasi-local geodesic in an asymptotically flat spacetime (cf. p. 8), and each quasi-local "point" in the local mode of spacetime corresponds to the 'end result' from its negotiation with the shoal. In the context of Ted Newman's H-space, see [Ref. 23] and [Ref. 24]. This type of argument must be tightened and made more precise. Let's try to explain how a wave *per se* is being created. Very briefly, because all fish are correlated -- in the sense that the instantaneous state of each fish depends on, and is the final result from, the negotiation with 'the rest of fish from the shoal' in the global mode of spacetime. However, in the local mode, the time span for this negotiation is strictly **zero** (by "looking at all the null rays" [Ref. 23]), hence each fish swims along a perfectly continuous geodesic. Thus, the **collective** movement of the shoal will inevitably display a (gravitational) wave pattern. We observe such wave pattern in the correlated movement of, say, the centipede's legs, but cannot "see" the wave pattern by looking at one leg/fish only. Yes, GWs exist, but – no, they cannot be observed with any **local** experimental setup (cf. Laszlo Szabados on p. 7). Moreover, the wave in question should be a *quantum-gravitational wave*. Recall the game of twenty questions played by John Wheeler [Ref. 25]: "There had been a plot not to agree on an object to be guessed, but that each person, when asked, must give a truthful answer concerning some real object that was in his mind, and which was consistent with all the answers that had gone before. With only one question left, John Wheeler guessed: Is it a cloud? The answer was Yes!" The answer 'cloud' did not exist before the first question asked by John Wheeler, nor until the last question. It was created *during the build-up* of the game context, which "takes place" in the global mode of spacetime. Its duration in the local mode is **exactly zero**. Hence a quasi-local observer will "see" a wave pattern being created in the local mode, due to the correlation of each instantaneous **next** state in the global mode. Another way to explain this wave effect is by the notion of 'relational reality'. Suppose you have to make a timetable for classes in a university, such that all students would begin their classes at some instant, t_1, and all rooms will be simultaneously occupied by all students. If you have a quantum-gravitational wave, you're done: each student "in the shoal" will proceed to its unique classroom in just one "quantum jump", from t_0 to t_1. Of course, such constellation of students/rooms will be valid for one instant only -- the collective movement of the shoal of fish/students will require a new negotiation for the next instant, t_2, etc. There are no jerky movements in the shoal, however. The so-called quantum jump is an artefact from observing quantum reality with inanimate measuring devices, which cannot have access to the global mode of spacetime: dead matter makes quantum jumps; the living-and-quantum matter is smarter. I do hope this could solace Albert Einstein: "I find the idea quite intolerable that an electron exposed to radiation should choose of its own free will, not only its moment to jump off, but also its direction. In that case I would rather be a cobbler, or even an employee in a gaming-house, than a physicist" (A. Einstein, Born-Einstein Letters, 29 April 1924). And also Erwin Schrödinger, who said in September 1926: "If all this damned quantum jumping (*verdammte Quantenspringerei*) were really to stay, I should be sorry I ever got involved with quantum theory." We need a new notion of relity, *potential reality*, to develop quantum gravity. It's a pity that nobody cares. Nobody, Chris Isham included.