On the gravitational field of a moving body: redesigning general relativity

Eric Baird *(26 October 2015)*

Einstein wrote in 1950 that he no longer believed that general relativity should include an enforced reduction to flat-spacetime physics. The behaviour of velocity-dependent distortions around a "moving" gravitational source is explored using the principle of relativity, with the resulting descriptions and principles suggesting a more general agreement between the general principle of relativity and the behaviour of particulate-matter physics and quantum mechanics than is normally assumed, evoking W.K. Clifford's concept of "all physics as curvature". The removal of special relativity from general relativity and the substitution of its Minkowski metric with a relativistic acoustic metric replaces the current layered approach – SR, GR1916, quantum gravity – with a single set of more powerful principles, giving enhanced compatibility (and perhaps even duality) between a suitably revised general theory and quantum mechanics.

Table of Contents

1. Introduction

Modern relativity theory traditionally uses two different approaches to analyse and model relative motion – simple inertial physics is dealt with by assuming flat spacetime throughout and applying special relativity (SR) [1], while problems that involve explicit gravitation, or acceleration or rotational effects are "relativised" with the help of Einstein's 1916 general theory of relativity (GR1916) [2]. Both systems are in turn assumed to give Newtonian mechanics as an approximation.

For convenience, the 1916 general theory was designed to reduce to the physics of special relativity over smallish regions of spacetime [3]. This combination of two sets of rules and principles introduces potential logical conflicts into the final theory, as the Mach-Einstein arguments insist that inertial and gravitational explanations should be interchangeable, while special relativity models inertial physics with gravity "switched off". Einstein later wrote (Scientific American, April 1950 [4]) that he thought that his incorporation of special relativity into the 1916 theory had been a "historically understandable" flaw in its construction:

> *"... all attempts to obtain a deeper knowledge of the foundations of physics seem doomed to me unless the basic concepts are in accordance with general relativity from the beginning. … I do not see any reason to assume that the heuristic significance of the principle of general relativity is restricted to gravitation and that the rest of physics can be dealt with separately on the basis of special relativity, with the hope that later on the whole may be fitted consistently into a general relativistic scheme. I do not think that such an attitude, although historically understandable, can be objectively justified. … In other words, I do not believe that it is justifiable to ask: What would physics look like without gravitation? "*

Einstein's 1950 position seems to resurrect the idea promoted by W.K. Clifford in the Nineteenth Century, that "all physics is curvature" [5] – in a "Cliffordian" universe, general relativity would not reduce to "flat-spacetime physics", as truly flat spacetime would represent a state in which no meaningful physics was taking place. [*]

The starting point for this paper is an attempted exploration of the case of a moving gravitational source coasting at constant speed in a straight line, a situation that is difficult to analyse satisfactorily under existing theory as it involves curvature (normally dealt with by general relativity), but also simple inertial motion (normally dealt with by SR in the assumed absence of curvature).

Starting with this simple case of a moving gravity-source, we argue for the existence of velocity-dependent curvature effects between bodies with significant gravitation (velocity-dependent "gravitoelectromagnetism"), the existence of analogous effects in other moving-body problems, and – as a consequence – an invalidation of the argument that a general relativistic theory has to reduce exactly to the physics of special relativity. This alternative approach leads instead to a Cliffordian universe, a relativistic acoustic metric, some new and powerful equivalence principles, and a revised form of general theory that is in greater agreement with quantum mechanics.

---

* If a general theory turned out to *incidentally* generate the relationships of special relativity then this might be acceptable: but we could not *impose* on the theory a reduction to special relativity based on an assumed geometry that was not derived from within the general theory, or derived from external arguments that were not provably compatible with the general principle of relativity.

2. Gravitoelectromagnetism

2.1. In brief

The subject of the field effects associated with moving matter has been referred to as *gravitoelectromagnetism* (GEM), by analogy with electromagnetism (EM), the study of field-effects associated with a stationary or moving electric charge. GEM differs from EM in that the "charge" is inertial/gravitational rather than electric, and is always positive. GEM effects should be measurable as an apparent deflection of nearby test masses, or by strains felt by tethered nearby test masses, and by the deflection and/or change in energy of light passing through a region.

Since we use the behaviour of light to map and define a region's geometry, a GEM field is also a *geometrical* field, and can be considered as a special class of nontraditional gravitational field effect associated with moving masses that acts in addition to a body's conventional "static" gravitational influence.

While electromagnetic signals are typically assumed to be superimposed on an existing predefined metric with little or no interaction (except at extreme energy-densities), GEM signals represent modifications of the metric itself, leading to extreme nonlinear behaviour that can be dealt with by acoustic metrics (section 10).

2.2. Categories:

For the purposes of a general review it can be useful to divide GEM effects into three main categories (ignoring the additional higher-order effects):

1. **Velocity-based effects**, (GEM_{VEL})
2. **Acceleration-based effects**, (GEM_{ACC}), and
3. **Rotation-based effects**, (GEM_{ROT})

Einstein argued in 1921 that the latter two effects (GEM_{ACC}, and GEM_{ROT}) were the result of Machian logic, and were consequences of the principles of relativity of rotation and acceleration. [6] The best-known of the three is the rotational dragging effect, which causes a rotating star's field to pull nearby matter around with the star's rotation, and also causes the precession of orbiting gyroscopes ("frame-dragging", the Einstein-Lense-Thirring effect [7]), a result that can also be calculated "generically" using Wheeler's "democratic principle". [8]

While the second and third effects seem to be well accepted as standard physics, establishing the status of the first (velocity-based) effect is more difficult, since derivations of special relativity traditionally presume an entirely flat spacetime free from any complicating dragging effects caused by the motion of matter (Einstein, 1905: *"... the view here to be developed will not ... assign a velocity-vector to a point of the empty space in which electromagnetic processes take place."* [1]). Derivations of special relativity typically take this assumed absence (or assumed *effective* absence) of velocity-dependent curvature as a starting-point, without asking whether velocity-dependent curvature may allow for other forms of relativistic theory, or how such theories might diverge from the equations of the 1905 theory.

2.3. Special relativity vs. GEM$_{VEL}$

Definitionally, the special theory is commonly described as having only two postulates [1],

(1). The principle of relativity, and,

(2). The principle of the constancy of the speed of light [9].

However, when comparing different theories it is perhaps more correct (and more useful) to describe the special theory as having *three* postulates:

(I). The principle of relativity,

(II). The principle of the local constancy of lightspeed, and,

(III). The principle that spacetime is entirely flat.

Postulate **II** (local *c*-constancy) is required for various logical and philosophical reasons [*], and postulate **III** then allows this purely local c-constancy to be extrapolated and extended over a wider region containing multiple differently-moving bodies, giving *global c-*constancy. The apparent paradox that all inertial observers then need to be able to agree that any specified lightsignal propagates at *c* with respect to *themselves*, regardless of any velocity offsets between observers, is then resolved using special relativity. [10]

If we choose to accept only **I** and **II** – the principle of relativity and the principle of (local) lightspeed constancy – we are still free to decide between at least two different systems of relativistic physics. Assuming that inertial physics is an inherently “flat spacetime” problem inevitably gives us Minkowski spacetime and special relativity, but if we assume the opposite, assume that only local c-constancy matters [11], and suppose that relative motion of masses is always associated with curvature (Clifford's “all physics as curvature” idea), we obtain a different form of relativistic model based on curved-spacetime principles, and a relativistic acoustic metric.

Since GEM$_{VEL}$ is associated with distortional effects around moving masses that contradict the assumption of flat spacetime, SR's implicit third postulate and GEM$_{VEL}$ effects appear to be mutually exclusive – if local velocity-dependent dragging or curvature effects exist then even though the *local* speed of light may still be constant, postulate (III) is wrong, invalidating the concept of Minkowski spacetime … conversely, if special relativity's implicit postulate of flat spacetime is physically *correct*, then GEM$_{VEL}$ effects do not occur.

Velocity-based GEM effects are closely related to rotational GEM behaviour (GEM$_{ROT}$), and can also be thought of as lower-order effects underlying accelerational GEM effects (GEM$_{ACC}$). The next sections suggest that the appearance of GEM$_{VEL}$ effects may be unavoidable in a structurally-consistent “completely general” theory of relativity.

---

* For instance: if an atom moved at more than *its own* local speed of light, the forward part of the moving atom would be able to communicate with the rear using electric and magnetic fields, but the atom's rear would not obviously be able to communicate electromagnetically with the atom's forward regions. It would then be difficult to imagine how the atom's internal electromagnetic structure could self-regulate and remain in a stable equilibrium. However, to be nominally moving at more than *someone else's* local speed of light is less problematic.

3. Rotating stars, frame-dragging, and simply-moving bodies

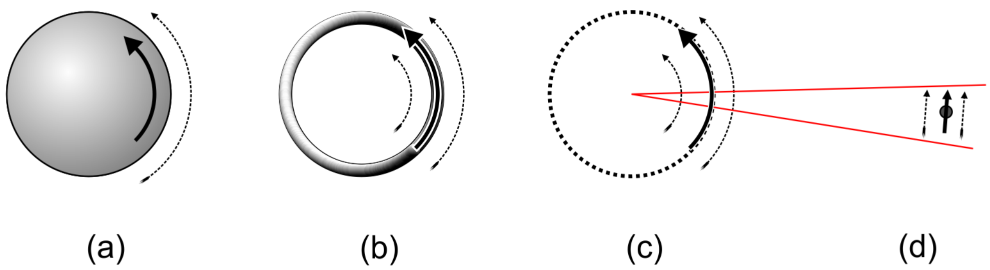
A limited form of velocity-dependent gravitational effect already appears in current mainstream theory, associated with rotating gravitational masses.

For a test body near the equator of a rotating star, the star's rotational dragging effect appears as a stronger pull towards the receding, redshifted side of the star than to the approaching, blueshifted side. The star also shows an increased overall attraction (due to the gravitational effect of the star's rotational kinetic energy), but shows an observer-dependent offset of the star's apparent centre of gravity. *

3.1. Rotation and velocity

We can extrapolate from this rotational dragging effect to the case of a non-rotating moving mass by replacing the spherical body of the original star (**Figure 1 (a)**) with a thin ring of material, and noting that the dragging effect should still be present **(b)**. The “twist in spacetime” caused by the rotating ring should drag nearby material around with it regardless of whether this material is nearest to the ring's outer equator or inner equator, or is above or below the equatorial plane. The “twist” and dragging effects should also still exist if the ring is broken into small segments orbiting their common gravitational centre **(c)**.

If the radius of the “broken” ring is sufficiently large or the pieces are sufficiently small, we can “zoom in” far enough for a section of its path to approximate a straight line, and the local dragging effect should still be measurable even though there is now nothing for local instrumentation to associate with the effect other than mass, proximity, and relative velocity. In terms of the local physics around one of these small segments, a local observer would be entitled to relate the detected dragging effect to the apparent constant-velocity straight-line motion of the segment, regardless of any additional “circling” motion detectable at larger scales.



If this local observer is then presented with a second body with the same mass, density and velocity as the segment except that the new body is “really” moving in a straight line, then, if they cannot otherwise distinguish locally between the motions of the two similar bodies, Occam's Razor should lead them to declare that if equivalent local situations lead to equivalent local outcomes, the second moving body should have a gravitational dragging field component associated with its velocity, too **(d)** – giving the GEM_{VEL} effect mentioned in section 2.1.

* If a number of observers distributed around a rotating black hole's equator were each asked to try to point out the apparent centre of gravity of the hole, and were all on the equatorial plane at identical distances from the hole, the resulting side-offset locations would lie on a circle.

4. Velocity-dragging effects considered as real

4.1. Collision by proxy

The effects in the last section correspond to a physics in which not only is a body's rest mass "smeared out" into the surrounding region as a gravitational field (Einstein: *"... objects are spatially extended"* [12]), but the influence of the body's momentum is also spread out in space, and appears as a velocity-dependent distortion of that field.

In a GEM_{VEL}-compatible model, we would expect a passing body to "tug" on nearby matter as it passes, and this might *seem* to allow a way of distinguishing between current and GEM_{VEL} models. However, current physics accepts the existence of a higher-order version of the effect, even if not GEM_{VEL} effects are in play. When a compact gravitational source such as a mini-black hole skims our position, we'd expect to feel an impact as we are hit by the exterior geometry of the object's field. This impact allows momentum to be exchanged between us and the object via the field-mediated interaction of our masses, which can be considered as a form of indirect partial collision. In a GEM_{VEL} model, momentum-exchange also takes place while the field of the passing mass at our location is reasonably constant over time, but distinguishing between two similar effects during a brief encounter with a gravity-source, in a convincing way, might not be easy.

In theory, we could study the effect of gravitational field due to "passing" matter whose properties do *not* vary significantly with time for an extended period, by looking at the case of a test particle suspended above the surface of a rotating star, with GEM_{VEL}-compatible theory predicting a dragging effect in the direction of the star's moving surface. Unfortunately, current theory already predicts this type of effect as a special-case behaviour of rotating bodies (section 3.1, previous page), so we can't obviously use this situation to distinguish between the standard and non-standard models.

4.2. Gravitational slingshotting

Another feature of GEM_{VEL} models would be that if we throw a test mass at a moving gravitational body so that it undergoes a "near miss", the mass should generally emerge from the encounter with a deflection in the direction of motion of the moving body.

This behaviour has been a known feature of Newtonian gravity since at least the 1960s (Minovitch, 1961), and is currently used by NASA to slingshot space probes across the solar system.

4.3. The dropped brick

If our velocity-based field component is real, we should be able to detect it by measuring the change in velocity of a test object (such as a domestic housebrick) dropped from an agreed initial nominal height onto a planet that is either receding or approaching – if there is a velocity-dependent field component, the effective terminal velocity of the gravitational gradient, expressed as the corresponding change in velocity due to gravity (Δv) of the brick by the time it hits the planet surface, should be affected by the relative speed and direction of the planet's motion – the final change in velocity Δv should be greater if the planet recedes (stronger total field) and smaller if it approaches (weaker total field).

If we model the problem in its simplest form by tracking position against time and assuming Newtonian gravity, we find that GEM_{VEL}'s broad characterisation of the physics is trivially correct – the brick *obviously* has a greater or smaller Δv when the planet recedes or approaches, simply because in the recessional case, the brick has to fall further in order to catch up with the receding planet, and is therefore acted on by the gravitational field for longer, giving a larger Δv – in the approaching case, the field has less time to act on the brick and accelerate it before the approaching planet intercepts it, so Δv is smaller.

Although these basic time-domain results might not seem obviously connected to the issue of the existence of gravitoelectromagnetic fields, this distinction is not so obviously valid in an "observerspace" description, especially if the time dimension is suppressed and we confine ourselves to examining Δt=0 "snapshots" of the situation. Changes in signal wavelengths due to the planet's relative velocity still exist In these "frozen" views, even though the planet's relative velocity does not … however, in these "momentary" Δt=0 descriptions, the planet's motion appears as an apparent "smearing" of the moving body's position, which is expressed as an apparent geometrical distortion – the "effective distances" to the planet's surface for surrounding observers seem shortened on one side and lengthened on the other and this apparent decrease and increase in the amount of "space-per-unit-volume" can be expressed in terms of the effective length-changes seen when we look across a region containing a gravitational gradient. * In the Δt=0 snapshots, motion shifts due to the planet's relative velocity can instead be blamed on the gravitoelectromagnetic distortions that appear to be frozen into the snapshot view.

We then have an (admittedly limited) situation in which the effect of velocity and the effect of a gravitoelectromagnetic field are equivalent and interchangeable. We can go on to explore this new principle of equivalence, and look at its implications for other more complex situations, provided that we remember that the associated geometry is not necessarily flat, and the relationships are therefore not necessarily those of Minkowski spacetime. ** ***

---

* It seems significant that, under a range of propagation models and theories (including SR), differential time-delay effects make a receding (Doppler redshifted) body appear in a photograph to be contracted, and an approaching (blueshifted) body to appear stretched, with the degree of apparent length-change being exactly inversely proportional to the Doppler wavelength-change. To an observer who knew no better, the apparent photographed changes in dimensions might be explained as evidence of gravitational differentials across the viewing path.
The subject of the photographable (as opposed to interpreted) appearance of a moving bodies did not appear in the SR literature until around 1958, when the Terrell and Penrose papers prompted a flurry of followup research. Our appreciation of the photographable effects of motion on the apparent shape of moving bodies masses came too late to play a part in the development of the 1905 theory (which focussed mostly on the properties of round-trip signals rather than on "photographable" effects) or general relativity (which assumed a reduction to SR). Note that "popular" explanations written before 1958 of what an observer "sees" according to SR are typically wrong (the usual cited example being Gamow's 1940 book "Mr. Tompkins in Wonderland".
If we had tried basing a theory of relativity on the visual, "photographable" distortions of moving bodies, we would have obtained a curved-spacetime theory that included GEM_{VEL} effects, but by 1958, we were already strongly committed to using special relativity.

** For this correspondence to be exact and universal seems to require a generalisation in which all gravitational (and also non-gravitational!) bodies are somehow assigned the same surface gravitation – this implies that bodies other than black holes need to be composed of smaller particles whose emission and absorption of light occurs at standardised horizon-like particle boundaries. This generalisation is touched on in later sections.

*** Although it may seem odd to use distortions to re-explain effects that can already be easily understood using much simpler arguments, the approach does seem qualitatively consistent with real-world physics. We can also argue that this distortional effect is responsible for the persistence of motion – if we take an instantaneous snapshot of the entire universe and all objects and distortion-fields within it, the motions of those objects will be frozen into the snapshot as geometrical distortions, allowing us to predict "what happens next" in subsequent snapshots by extrapolating the metric's subsequent evolution from its current shape, without having to include additional velocity information – the distortions are how the universe "remembers" how things are moving from moment to moment, and also act as a storage medium for a system's recoverable energy due to relative motion. Associating the velocity of a physical body with a distortion means that physical velocity information is embedded in the metric itself, which then holds details of all matter in a region along with associated energy and momentum information.

5. Impossibility

5.1. Newton's First Law

So far, the phenomenology associated with our GEM_{VEL} effect has appeared not to be in obvious conflict with experience, but we now encounter our first real problem – **Newton's First Law** ("**N1L**"). This law states that a simply-moving body should continue moving in a straight line at constant speed indefinitely unless some external force intervenes. Despite the fact that our previous arguments seem to insist that the GEM_{VEL} effect logically *must* exist, and that the phenomenology looked at so far seems to agree that it *does* exist, a proponent of GR1916 could argue that it is known for a fact that this effect *cannot* exist in a general theory, if that theory is to agree with experience – "*logic insists but reality denies*":

5.2. Gravitational braking

The simplest counter-argument to the existence of GEM_{VEL} effects is this: if a test body moves at high speed with respect to its background starfield, and each and every one of these stars exerts a GEM_{VEL} gravitational drag in their apparent direction of motion, then the test body should feel a stronger net pull rearwards towards the redshifted stars behind it than towards the blueshifted stars ahead. The body would then be expected to slow until it was effectively stationary with respect to the average velocity of the background starfield.

This behaviour would break N1L and doesn't correspond to observed reality, suggesting that all of our previous arguments have (somehow) to be wrong.

However, if we look more closely at the problem, we find that there is a second "impossible" effect – gravitational aberration – that also needs to be taken into account.

5.3. Gravitational aberration

Relativistic arguments tell us that, as a consequence of the finite speed of light, a "moving" camera surrounded by a nominally-uniform distribution of stars should record a distortion of the background starfield, in such a way that stars appear more densely packed in the forward direction and less densely packed to the rear [13]. Useful diagrams of this starfield distortion effect have been published by Scott and van Driel [14].

If the speeds of gravitational and optical signals are the same, we might expect analogous distortion effects to make the *gravitationally*-sensed positions of the background stars distort in the same way, so that the optically- and gravitationally-sensed positions of the stars correspond. [*]

The problem with this argument is that if gravitational aberration exists, unchecked, then a moving body will be expected to feel the effect of a larger number of stars ahead of it than behind it, and will then be expected to undergo a forward freefall acceleration towards the region of greatest apparent mass-density. This will further increase its relative velocity with respect to the starfield and cause the apparent background distribution of stars to distort even more. This positive-feedback behaviour would then mean that any significant motion of a body with respect to background matter would be expected to cause a runaway forward acceleration.

---

* If the optical and gravitationally-observed positions of bodies do *not* correspond, then we lose the concept of "the apparent position of a moving body".

5.4. Apparent cancellation

While the GEM_{VEL} dragging effect is associated with a predicted *deceleration* of a moving body, the gravitational aberration effect is associated with a predicted *acceleration*, suggesting at least a partial cancellation. If cancellation is *complete* then the status of Newton's First Law changes from a behaviour that has to be imposed on a theory from outside on purely empirical grounds, to something that emerges spontaneously from curved-spacetime arguments.

5.5. The "No gravitational aberration" argument

The exact relationship between gravitational aberration and general relativity is not obvious in much of the C20th literature, perhaps out of respect for special relativity's requirement that there be no complicating curvature effects associated with relative velocity between masses.

The subject does seem to have been addressed in peer-reviewed papers comparatively recently (Carlip, 2000 [15]), with the conclusion that in general there is there should be no *measurable* first-order gravitational aberration effect in gravitational physics, because of cancellation with additional GEM_{VEL}-like effects (*"aberration in general relativity is almost exactly canceled by velocity-dependent interactions."*). Carlip argues that the absence of the effect is not arbitrary but is a result of solid calculations, best explained by making an analogy to a similar effect that appears under electromagnetism – we then find ourselves discussing velocity-dependent gravitoelectromagnetic effects whose magnitude is not insignificant, whose presence has detectable consequences, which play an integral part in gravitational physics, and whose presence appears to be essential and unavoidable. *

5.6. GEM_{VEL} effects are real?

Our "basic" colinear argument in section Error: Reference source not found5.4 and Carlip's more advanced transverse/orbital arguments appear to be in broad agreement: once we assume a finite speed of gravity and consider the effect of gravitational aberration, we need to invoke the existence of GEM_{VEL} effects (or something functionally equivalent) in order to make the system work. **

It is tempting to assume that if these velocity-dependent effects really *are* necessary to a consistent gravitational theory, then they must *of course* already be fully-integrated components of GR1916, and therefore cannot be in conflict with other parts of the 1916 theory. However, we will see in section 6 that these effects, though apparently unavoidable (Carlip: *"This cancellation is dictated by conservation laws and the quadrupole nature of gravitational radiation"*, *"any Lorentz-invariant model of gravitation necessarily requires additional velocity-dependent interactions, which can provide "a more or less perfect compensation" for the effects of aberration"*), do not appear to have been taken into account in the 1916 theory's design, and might be fundamentally incompatible with SR-based physics.

* Putting this argument in reverse, we can also suggest that perhaps any theory that includes GEM_{VEL} effects may have to invoke gravitational aberration as a mechanism for restoring Newton's First Law, so that any relativistic light-dragging model (e.g. Fresnel, ~1818) is likely to be inconsistent or incomplete unless it is also a theory of gravity.

** Cancellation requires an effect that compensates for the apparent positional displacement of a gravitational source (so it depends on velocity), and that makes the combined centre of gravity appear to be somewhat forward of the object's viewed position. To cancel the gravitational effect of the offset for large and small masses, it also needs to be a function of the moving body's rest gravitational field strength at any given point in space. If we have an effect associated with a moving gravitational source that deflects in the source's direction of motion, is a function of the strength of the gravitational field, and also has an effect on observers that depends on their distance (because the effect that needs to be cancelled also depends on distance), then it would seem by definition to be a velocity-dependent gravitoelectromagnetic effect (GEM_{VEL}), or a velocity-dependent dragging effect.

6. Difficulties with special relativity

The appearance of GEM_{VEL} effects in situations involving explicit moving gravitational fields also has implications for "nongravitational" physics.

If a moving star's gravitational field has a velocity or momentum component, the energy of light emitted or received by the star should appear to change as it crosses the associated field gradient. * The star's light should then show a gravitoelectromagnetic shift in energy associated with relative motion, with the star's light appearing redder if the star recedes from us and bluer if it approaches, as with conventional Doppler effects. The calculation of a rough magnitude for this effect using gravitational aberration arguments suggests that this is not a small and insignificant correction to the star's normal Doppler behaviour – the magnitude of the "gravitational" motion-shift effect, calculated under a range of possible propagation models, seems to be suspiciously similar to the shift associated with those models' conventional Doppler shifts.

This suggests one of two difficult options:

a) If the star's conventional motion-dependent shift *is in perfect agreement* with special relativity's "relativistic Doppler" relationship, then with the addition of a further velocity-dependent gravitational shift effect, the star's *total* velocity-shift must then disagree with special relativity. If the overall "composite" velocity-shift relationship does not match that of SR, then this would suggest that the corresponding equations of motion for our moving star should not be those of special relativity, either.

a) On the other hand, we could argue that perhaps the gravitational shift component due to the star's motion dues not act *in addition to* the conventional Doppler shift, but rather *is* the star's conventional motion shift, expressed within the gravitational domain. This idea meshes well with the idea in section 4.3 on a "dual" relationship between conventional time-domain effects and gravitoelectromagnetic curvature-domain effects, but these GEM-compatible curved-spacetime relationships would then not obviously be those of special relativity. **

With the first option, special relativity is considered *nominally* correct but is not exact for moving gravitational bodies, which require either a different theory or the retrofitting of some sort of additional gravitoelectromagnetic curvature correction factor, which needs to be calculated from a different relativistic principles.
Since the principle of relativity requires that a signal passed between a pair of "gravitational" and "non-gravitational" bodies should generate the same reading on a detector regardless of which body we consider to be "moving", a divergence from SR's velocity relationships for "gravitational" moving bodies implies a matching divergence for "non-gravitational" bodies. We would then have an odd situation in which SR would still be considered *nominally* correct for all moving bodies, but would not generate the correct relationships for any of them.

---

* Given a "gravitational" blueshift for approaching bodies and a "gravitational" redshift for receding bodies, there should also be one exact intermediate viewing angle for a body with a specified velocity where light will show no detectable GEM_{VEL} shift effect. However, this is a special case.

** It appears that nobody has yet been able to produce a derivation of special relativity that does not rely somewhere on the simplifying assumption of flat spacetime. It is quite conceivable that such a derivation might not be possible.

> **With the second option**, our Doppler equations and equations of motion don't require an additional GEM correction, as the GEM_{VEL} effect and the Doppler propagation shift effect are considered to be one and the same effect, calculated using two different approaches. However, the problem of deriving these Doppler equations and equations of motion then becomes a curved-spacetime problem, and since the relationships of special relativity are so uniquely identified with flat Minkowski spacetime, it is not obvious that the required curvature-compatible equations should still be those of special relativity. If special relativity is an expression of the geometry of Minkowski spacetime, then by changing the geometry, we should presumably be changing at least *part* of the mathematics.

With either of these two interpretations we would need to devise a new set of relativistic arguments and theory that could model simple motion as a curved-spacetime problem, either to supplement and correct special relativity (adding the gravitoelectromagnetic behaviours missing from special relativity [*]) or to replace the theory altogether. [**]

For the resulting equations to apply at *all* scales, geometrical analogues of the earlier "gravitational" arguments involving gravity-wells and GEM_{VEL} field components would then also need to apply to human-scale objects, and also at the smaller scales involved in particle physics.

---

* It might seem pragmatic to try to preserve special relativity and derive the missing gravitoelectromagnetic effect as a separate component (in which case the principle of relativity requires this component to have a separate Lorentzlike characteristic), but since we are dealing with nonlinear behaviour and inherently non-SR geometry, the idea of a simple superposition of a GEM component on an SR background is probably inadvisable.

** Although we might prefer to preserve special relativity within a larger system for its familiarity, it is not obvious that the amount of work necessary to correct the special theory is any less than the amount of work needed to replace it, or whether, if we *did* somehow nominally preserve special relativity within a larger multi-layered model, this might not introduce new problems that might require yet more layers of corrections at some future date. Although we might hope that the sequence of required cumulative corrections might eventually come to an end, this is not guaranteed.

7. Application to particle physics

The idea of applying GR-style arguments to particle physics has been a recurring theme in theoretical physics, encouraged by the similarity between the classical radius of an electron and its Schwarzchild radius. The best-known attempts along these lines were probably Einstein, Infeld and Hoffamn's 1938 modelling of particles as singularities, [16] and Wheeler's 1960s "geometrodynamics" project. [17] [18]

Although most of this earlier work has involved explicit departures from special relativity's flat spacetime geometry, authors have still tended to assume that the flat-spacetime *relationships* of special relativity should still emerge (somehow) from these models.

7.1. A Cliffordian universe as a counterexample to SR logic

As mentioned in the introduction, the idea of a curvature-based system of physics dates back at least as far as the mathematician W.K. Clifford, who suggested that all particles were associated with curvature, that the interaction of particles was a result of their interactions, and that, therefore, "all physics is curvature". [5]

It has been argued in support of special relativity that *all* curved-spacetime models must reduce to flat-spacetime physics over small regions as a simple matter of geometrical reduction – just as a smooth curve must reduce over a sufficiently small region to an arbitrarily-close approximation of a straight line, so a curved-spacetime general theory of relativity must reduce to an arbitrarily-close approximation of a flat-spacetime theory, which then, by geometrical necessity, has to be Einstein's special theory.

However, this "geometrical reduction to SR" argument does not apply in a "Cliffordian" universe, where the very concept of a "flat-spacetime physics" is considered to be a contradiction in terms. In a Cliffordian system we obtain flat spacetime as a limit only when the region being examined doesn't contain any moving or stationary particles – in other words, if the region is by definition devoid of objects to observe, and of any observers to do the observing. In such a universe, the condition of flatness as a limit to curved-spacetime physics does not represent the limit at which flat-spacetime physics applies, but rather the limit at which meaningful observerspace physics disappears altogether. It is not a limit at which relativistic curved-spacetime physics reduces to special relativity, but the "null physics" limit at which relativistic arguments, based on the requirement that physical observations must obey the principle of relativity, cease to have any real physical meaning. [*] [**]

Since Cliffordian universes are a counter-example to the argument that gravitational theory needs to reduce to SR physics (by reducing to a "curved" acoustic metric rather than a "flat" Minkowski metric), a proof that gravitational models really *must* reduce to SR physics would seem to require either a proof that Cliffordian universes cannot exist, or a demonstration that our own universe is not Cliffordian. To date, nobody seem to have managed either of these things.

---

* … The rules of observerspace physics become moot if our spacetime geometry says that the region contains nothing capable of acting as an observer, and also nothing capable of being observed. This is related to the famous philosophical poser touched on by George Berkeley in 1710, later stated as "*If a tree falls in the forest and nobody hears it, does it make a sound?*", except that in this case the "flat" geometry tells us that there is, by definition, not just no physical observer, but also no physical tree and no physical forest.

** Similarly, we might argue that while biology reduces to chemistry (which in turn reduces to atomic physics), chemistry is not a "limiting case" of biology in which organisms are at their simplest, it represents a scale at which no biological organisms are present – in other words, this limit represents the *absence* of biology.

8. Experimental evidence

8.1. Evidence for a Cliffordian model

We can now ask, by analogy with the earlier gravitational arguments, what physical consequences might be expected if our universe *was* "Cliffordian", with inertial physics corresponding to the rules of a relativistic acoustic metric rather than the Minkowski metric.

If moving particles were to show behaviour analogous to moving black holes with a strong GEM_{VEL} component, we would expect to find that:

a) **The speed of light would be lower in the immediate vicinity of a particle** (analogue of the Shapiro effect) [19], testable by measuring the bulk speed of light though a region containing many such particles.

b) **The velocity of light in a region would be anisotropic in the immediate vicinity of a moving particle** (due to GEM_{VEL}-analogous dragging), testable by examining bulk signal velocities in different directions through a moving medium containing many such particles.

c) **The mass and momentum of a particle would be smeared out into the immediately-surrounding region**, and modellable as a field, analogous to the gravitational field of a large body.

If we now look at standard physics, we find that:

1. **The speed of light *does appear* to be lower in the immediate vicinity of a particle**, as demonstrated by the reduced speed of light in a region inhabited by a group of particles (reduced speed of light in a particulate medium).

2. **The velocity of light *does appear* to be dragged along by a moving particles**, as demonstrated by the anisotropic lightspeeds measured in a region inhabited by a moving particulate medium such as flowing water (Fizeau [20]) or a spinning plastic disc (Jones [21]).

3. **The massenergy and momentum properties of a particle *do appear* to be smeared out into the surrounding region**, normally explained by invoking Heisenberg's uncertainty principle [22], with the smearing suggestive of the existence of an underlying classic mass-field with both "static" and "momentum" field components (Namsrai, [23] *see:* section 12.6).

These three predictions, obtained by assuming that our universe is Cliffordian rather than Minkowskian, seem to agree with the available evidence. *

---

* Special relativity's velocity-addition formula is sometimes used to model the progress of light through a particulate medium, with the success of the exercise presented as validating special relativity's approach (*e.g.* chapter 13 of the Einstein book). However, the exercise relies on our *overriding* the default behaviour assumed by special relativity – that light propagates at a speed unaffected by the presence or motion of observers – and saying that light passed between observer-atoms is for some reason exempt from the usual SR rules if those atoms are close enough to count as a particulate medium. This suggests a proximity-effect not dealt with by SR.
While it may be "common sense" not to treat light in a region containing a cloud of atoms as behaving like light in a vacuum, *the difference in behaviour is not predicted by special relativity*. If we are allowed to use the "external" knowledge that lightspeed is not isotropic in a moving particulate medium, we may as well use the approach used by Fresnel *circa* ~1818 and argue that lightspeed regulation is *generally* a result of the dragging effects of matter, making SR's explanation redundant.

8.2. Evidence for an SR-based model

Standard teaching tells us that special relativity has been proved "*Beyond a shadow of a doubt*" (Will [24]), with the theory being so well tested that we now insist on SR-compliance as a compulsory element of any credible gravitational model (*see:* Parameterised Post-Newtonian "PPN" formalism [25]). We're told that if it was not for special relativity, we wouldn't have $E=mc^2$, particle accelerators wouldn't work as they do, [24] and the Sun wouldn't shine. To question such an overwhelming weight of evidence supporting the special theory does not seem sensible.

However, the C20th literature often overstated (and in some cases badly misrepresented) the strength and significance of of evidential support for special relativity – while the effects being validated were often "relativistic" in the sense that they supported the *principle* of relativity, they were often not exclusive to the special theory's particular *implementation* of relativity theory, and it was often difficult (and in some cases impossible) to distinguish these outcomes even from the results of Newtonian relativity. To give a couple of examples:

- **Transverse redshifts**, often presented as novel to special relativity, [26] [27] appeared in a range of C19th theories, [28] with Newtonian optics predicting a stronger Lorentzlike (in this case Lorentz-squared) redshift [29].
- **Einstein's 1905 argument for $E=mc^2$ based on special relativity** [30] also works if we replace the SR relationships with those of Newtonian optics [31] ... so while Einstein was technically correct to write in 1905 that we obtained the $E=mc^2$ result if special relativity was correct, we could obtain the same result if SR was wrong.

With proper analysis, other "classic" SR outcomes such as the particle accelerator lightspeed limit [*] and SR muon decay tracklengths [**] also turn out not to be unique to SR, but shared across a range of potential relativistic theories within the range $0.5 =< x =< 1$, which includes both special relativity and Newtonian theory.

The idea that these effects and others are unique to special relativity and would not appear unless the theory was correct does not survive mathematical analysis. While it was understandable for Einstein to be selective in his comparisons in order to "make a case" for his special theory, to construct a narrative and chain of arguments that led inevitably to it, and to select his starting assumptions and "knowns" with this end result in mind, the resulting "expositional" characterisation of "SR *vs*. pre-SR physics" should not have been taken as an accurate representation of science history, or used as a basis for experimental testing. [***]

---

* The particle accelerator lightspeed limit: The Doppler predictions of Newtonian optics are even redder than those of SR for a given nominal velocity, for both transverse and radial motion. This means that the coupling efficiency between the accelerator coils and a particle drops to zero as $v \to c$, making the "SR particle accelerator lightspeed limit" also a feature of Newtonian theory.

** Muons: Under NM, a muon with an agreed rest-frame decay time and an agreed energy and momentum will decay at a known position. Because of SR's modified relationships, the nominal velocity of the muon under SR (v_{SR}), is lower than the nominal velocity under NM (v_{NM}), by the Lorentz factor (calculated using $v_{LORENTZ}=v_{SR}$). This reduced nominal velocity shortens the calculated pathlength of the muon before decay compared to NM. However, SR's time-dilation effect then extends the distance that the muon travels before decay by the same Lorentz ratio. Although the excellent agreement between SR and experiment for muon pathlengths is presented as significant evidence for special relativity (Will: "Evolution of the species … The muon … would decay long before reaching sea level … if it weren't for the time dilation of special relativity"), in reality, SR's predictions for these muon decay positions, when analysed properly, are **exactly identical** to those of Newtonian mechanics, and probably identical to the predictions of a range of other possible relativistic models based on other Lorentzlike relationships.

*** The practical difficulty of distinguishing between the optical predictions of predictions of special relativity and Newtonian theory may help to explain why so many C20th experimenters chose to use a somewhat incomplete test theory that did not include Newtonian optics in its comparative analysis.

8.3. Problems with existing SR test procedures

It would be very useful to be able to compare special relativity's shift predictions against those of an acoustic metric using existing data, but in many cases the differences between models with diverging Lorentzlike factors are nominal and interpretative, and do not generate testable differences … in others, effects present in an acoustic metric but missing from SR are already dealt with as separate "particulate-matter" or "GR", or "quantum" effects … and in the comparatively few cases where there should be an unambiguous "purely classical" difference between the two types of theory that cannot be "patched" with quantum theory, an oversight in common C20th testing protocols meant that any data favouring an acoustic metric would have been prone to rejection or adjustment.

Historical limitations of SR test theory

When testing special relativity, it was traditional to assume that the speed of light was known to be globally fixed with respect to the observer, generating the same propagation-based predictions as a fixed flat aether stationary in the lab frame. These "Classical Theory" (CT) predictions were then modified with a Lorentz redshift, and SR tested by confirming the expected divergence from CT. * With CT and SR taken as extremal possibilities, we could write $\mathbf{CT \times [1 - v^2/c^2]^x}$, and test which value of the exponent "*x*" gave the best match to experimental data, with "*x*=0" corresponding to "classical theory" and "*x*=0.5" special relativity. ** Our range for testing was therefore $\mathbf{0 <= x <= 0.5}$, with values smaller than 0 or larger than 0.5 considered to be the result of experimental error, as they were outside the defined range. Experiment then demonstrated that *x* was emphatically at the "SR" end of the CT-SR scale, and it seemed that we had shown beyond reasonable doubt that the special theory was correct.

These SR-testing protocols tended not to consider the possibility that the real value of *x* might be *higher* than 0.5 (a divergence from CT *stronger* than SR's), as there were no known flat-spacetime models in this range. Unfortunately, a preliminary study suggests that relativistic acoustic metrics generate values in the range $\mathbf{0.5 < x <= 1}$ [32], outside the "window" that testing protocols would have tended to consider legitimate. If *x* actually lay in the range 0.5-1, supporting data would have been liable to being discarded as faulty, or "clipped" to fit the expected range, and then misinterpreted as "*x*=0.5" data validating special relativity.

SR testing in practice

We can see this "clipping" process in action in the 1979 transverse redshift test [33], in which the experimental hardware reported a redshift of around *x*=~1, roughly double the SR prediction. The experimenters reasoned that since this result was twice what could be explained by either reference theory, it was fair to dismiss at least half of the effect as experimental error, due to an unexpectedly bad detector misalignment. They then used statistics to argue that the remainder of the effect *was* genuine, and concluded that the experiment's (halved) figures then successfully confirmed special relativity's predictions, to within a few percent.

Since testing protocols allowed experimenters to eliminate "inexplicable" excess redshifts at the hardware level through recalibration or correction (without the transparency of the 1979 paper) it is difficult to know which relativistic theory was really being validated in these tests.

---

* Einstein's "Classical Theory" reference model generates inconsistent Doppler predictions: A fixed stationary aether gives a simple recessional Doppler effect of freq'/freq = $c/(c+v)$, while the Newtonian relationships for energy and momentum require freq'/freq = $(c-v)/c$. SR resolves this conflict by replacing both conflicting equations with their geometric mean, giving freq'/freq = SQRT[(c-v)/(c+v)], flat spacetime, and special relativity.

** Or, more crudely, using the approximation CT × $\alpha[1 - v^2/c^2]^{1/2}$, where α=1 represents special relativity.

9. GR1916 vs. the equivalence principle (1960)

The idea that special relativity is incapable of being wrong seems to date back to 1960, when the community faced a crisis over the apparent invalidation of the 1916 general theory.

The Harwell group in England was one of several groups trying to use the Mössbauer effect [34] to measure small frequency-shifts. [35] [36] Hoping to verify the existence of gravitational redshifts, the group decided that since gravitational differentials available at the Earth's surface were so small, it was better to invoke the principle of equivalence of inertial and gravitational effects and measure the shift on a centrifuged clock. [37] When viewed from an inertial frame, the clock-slowing could be explained by the clock's speed and special relativity, and when viewed from the centrifuge frame (in which the centrifuge and clock did not move), the same effect could be blamed on gravitational time dilation due to the centrifugal field.

The paper's publication seems to have caused a small crisis in the theoretical physics community as it was realised that these two explanations were geometrically incompatible. If the clock-slowing seen in the centrifuge frame was the result of physical spacetime curvature, then since this was *intrinsic* curvature, the same geometrical curvature (and the same gravitational explanation) would apply for an inertial onlooker. Since curvature explained the full effect, special relativity's alternative explanation was redundant. If the equivalence principle was correct, then special relativity represented a simplified flat-spacetime method for calculating an inherently curved-spacetime effect – the theory was not supplying a geometrically-valid description and could not be used as a foundation for a general theory.

Schild's 1960 response [38] mentions a certain “lack of unanimity” amongst community members over the situation and declared the problem resolved: since *“... special relativity and the equivalence principle do not form a consistent theoretical system. ... ”*, and since the failure of special relativity would mean the unacceptable loss of both SR *and* GR1916, this had to be avoided by always giving special relativity priority over the principle of equivalence. [*]

In subsequent texts, the original PoE was downgraded from a principle [39] to a guide, and the 1916 theory changed from being a “principle” theory as originally designed, [40] to a “constructive” one. MTW (1973) told us that “the equivalence principle” was now the principle that physics over small regions must obey special relativity, [41] and that metric theories were *defined* as reducing to SR. [42] Not only were non-SR theories now declared to be theoretically “bad” by default [43], we were also told that (*“... any new theory has to be compatible with special relativity if it is to be observationally viable.”* [44]), which ruled out the idea that any alternative theory could be a good physical match to reality. Non-SR theories could now be automatically rejected on the grounds that they disagreed with experience without the tedious business of finding actual examples, or conducting actual experiments.

This “defensive” position regarding SR prevented mainstream research into alternative classical relativistic models, and until the 1998 Visser paper [45] and the subsequent involvement of the quantum gravity community, almost nothing was widely known in the classical relativity community about the properties of competing acoustic metrics. [**]

---

* Schild's rejection of the “total rewrite” option seems to have been due to expediency rather than logical or scientific argument (“SR *can't* be wrong, because if it is, we have to start over, which is unacceptable”). The community had no replacement theory to hand, no timescale for how long it might take to develop one, no obvious ideas as to how to proceed, and the main expert who might have had some ideas about how to proceed (Einstein) had died in 1955.

** Another post-1960 defence of SR was the “clock hypothesis”, which said that since special relativity could describe the full redshift in the circling-clock experiment, we knew that there were no significant additional effects due to acceleration (despite Einstein's work to the contrary). We could of course run the same argument backwards and say that since the full effect is explicable using the PoE, we “know” that there's no significant contribution due to SR.

10. Acoustic metrics

10.1. Basic behaviour of acoustic metrics

A metric-compatible system of physics that includes GEM_{VEL} effects tends to generate an **acoustic metric**. The term "acoustic" in this context does not refer just to the behaviour of sound in a particulate medium, but to a wider class of nonlinear behaviour in which a signal's speed is nominally defined by the properties of a metric, but where those properties are is in turn modified by the presence of the signal – the region's nominal signal speed is not necessarily the same as it would have been if the signal was not present. [45] We might expect to find acoustic behaviour in gravitational waves [*] – if a gravity-wave travels at the nominal speed "*c*", but its signal also represents a *modification* of *c*, it gives rise to complex behaviours and definitional complexities that can confound some traditional classical approaches, and which suggest parallels with parts of quantum mechanics. In an acoustic-metric-based theory of gravity, the "acoustic" behaviour of a gravitational wave can then be generalised for other gravitational "signals", including the gravitational fields associated with moving masses.

In a relativistic theory of physics that incorporates GEM_{VEL} effects (and uses an acoustic metric), the speed of a particle can be taken as a function of the particle's mass, momentum and energy and the local speed of light, but the local properties of light are in turn modified by the effect of the moving particle. The propagation of light in the region is then affected by the motion of the bodies within it, *contra* special relativity, giving us a system of mechanics whose relationships require curved spacetime. [**]

10.2. Comparisons with current theory

One of Einstein's criticisms of special relativity was the "absolute" nature of its spacetime geometry –the Minkowski metric was an entity that acted (dictating inertial physics) without itself being acted upon [46]. This problem was supposed to be solved by general relativity [47], which used a new, more interactive concept of spacetime (Einstein, [11] Wheeler: *"Space tells matter how to move, matter tells space how to bend"*) ... but since the 1916 general theory also incorporated special relativity, the "new, improved" spacetime behaviour only applied to situations that were not already being dealt with by special relativity, so the original behaviour remained in the 1916 theory as a limiting case.

Acoustic metrics take the "dynamic" aspect of a GR-style metric and extend it to cases involving simple relative motion. The cost of this greater interactivity is additional geometrical complexity and a reduced reliability for "test particle" calculations. Even though a small moving particle's influence on the surrounding geometry might be thought to only be significant over a vanishingly small region of spacetime, this is a region that all of the particle's incoming and outgoing signals pass have to pass directly through. The distortion potentially affects what a particle sees and how the particle itself is seen, so transformations derived by comparing exchanged signals and assuming *flat* spacetime, although easier to derive, will not necessarily generate all of the same relationships.

---

* Gravitational waves count as a good example of "acoustic" nonlinear behaviour without the assumption of a particulate medium.

** In special relativity, we say "*the speed of a body is always less than the speed of light*", while in emission theory, we say "*the speed of light is always more than the speed of the emitting body*". In a relativistic acoustic metric the situation is more nuanced.

10.3. Acoustic metrics and the measurement problem

For acoustic-metric-based calculations and transformations to be valid, the metric's shape already has to include the positions and states of motion of every particle in the system capable of making an observation, whose experiences we intend to use as a reference – we cannot start with an initial shape and populate it with physical observers with new states of motion without changing the geometry. Acoustic metrics overlap with quantum mechanics in including an element of observer-dependence, although the philosophical basis of the dependency differs from traditional quantum theory. Under conventional QM, the act of observation can affect the physics, suggesting non-classical behaviour … but in an acoustic system, the earlier act of *preparing to make the observation* – physically placing an observer at a given location with a state of motion not shared by other matter in the region – will also alter the geometry at that location and the data that can be gathered there, even before any readings are taken.

10.4. Paths not taken

A range of different categories of Nineteenth Century physics seem to converge on the same solution – a relativistic acoustic metric – when their main shortcomings are identified and resolved. This suggests that the C20th standardisation on SR/GR1916 may not have been inevitable, and might rather have been the result of a series of historical accidents.

1. **Aether theory** can be geometrised to create a field theory that does not necessarily require a physical particulate medium. While Einstein on at least one occasion described general relativity as a non-particulate form of aether theory in which the "medium" was spacetime [48], "relativising" aether theory *without* involving Lorentz ether theory (LET) or SR tends to lead to a relativistic acoustic metric.

2. **Ballistic emission theory** fails because it leads to signals passing along the same path at the same time in the same direction with different velocities, which confounds wave-theory and field-theory descriptions (Einstein [49]). This is also at odds with Newton's own approach, which used particle or wave arguments according to convenience. Forcing emission theory to be metric-compatible by making its lightspeed-dependencies strictly the result of proximity gives a relativistic acoustic metric.

3. **Fresnel's Nineteenth Century light-dragging concept,** if modernised and recast as a geometrical theory, would seem to give rise to a relativistic acoustic metric.

4. **The shift relationships of Newtonian optics** can be derived from Newtonian mechanics without committing to a geometry or a propagation model. The wavelengths of standing waves of light trapped inside a reflecting cavity are longer when the cavity is "moving" with NO than they are under special relativity – the NO-predicted wavelengths cannot be fitted into the available space with a simple Lorentz contraction, and require distances to be modified more strongly around a moving mass. The extension of Newtonian mechanics to optics therefore requires a curved-spacetime theory of relativity, with a velocity-dependent deviation from flat spacetime, GEM_{VEL} effects, and a relativistic acoustic metric.

5. **Attempts in the Nineteenth Century to create a geometrical theory of gravity** failed because Gauss and others did not realise that curvature needed to be applied to temporal as well as spatial coordinates. Rindler [50] outlines a credible "alternative history" in which C19th researchers try warping space *and* time, and construct a

general theory of relativity with no knowledge of special relativity. In Rindler's tale, SR emerges at the end as the "flat" limit of the theory, but given C19th physicists' familiarity with aether models, an acoustic metric may have seemed a more natural result.

Given these convergences, it may seem surprising that we *didn't* end up with an acoustic metric as our default model. Contributing factors for this seem to have been:

1. The recognition in around ~1800 of Newton's mistake regarding the relationship between energy and wavelength (the Newtonian catastophe [51]) led to a restructuring of Newtonian physics and the "benign neglect" of material relating to Newton's mistake. John Michell's exploration of the effect of gravity on light in 1783 [52] had referenced Newton's faulty argument, and Michell's piece duly disappeared from the citation chain until its rediscovery in the mid-C20th. [53] [54] Michell's derivation of the existence of gravitational shifts in starlight *should* have led directly to Einstein's 1911 gravitational time dilation argument during the C19th, leading to Rindler's "GR before SR" scenario.

2. Einstein's publication of the general argument for gravitational time dilation circa 1908-1911 [11] made a general theory possible, but didn't happen until *after* he had already committed to special relativity. If the order of these two events had been reversed, we might again have had the Rindler-like scenario of an "early" general theory (perhaps authored by someone other than Einstein) built without special relativity.

3. An apparent failure in 1960 of both SR *and* the 1916 theory (section 9) led to a defensive position that special relativity *could not* be wrong, meaning that alternative solutions were automatically classified as "bad" without further investigation. [*]

Of these three factors, two are due to human error, and one was due to the sequence of events in a single physicist's career. With SR-compliance defined as an essential property for any metric theory, acoustic metrics (which fail this condition), weren't included in mainstream reviews of gravitational theory.

10.5. Mainstream research

Acoustic horizons are "noisy" and leak information, and lead to effects analogous to Hawking radiation. These behaviours seem definitionally impossible under GR1916, and acoustic metrics are sometimes used as "toy models" to explore the phenomenology of these non-GR1916 effects, intuitively, using classical arguments. Unruh's 1981 result that sonic black holes emitted classical Hawking radiation was soon followed by other papers on the subject, with Visser's 1998 paper [45] identifying acoustic metrics as a serious subject in their own right. An excellent review paper ("Analogue Gravity") is maintained (and updated) by Barceló, Liberati and Visser on the LANL server [55]. Much of the research on acoustic metrics has been done this century, in context of work toward a theory of quantum gravity.

Although the review's conclusion tentatively includes, as an idea *" ... the rather speculative suggestion that there may be more going on than just analogy ..."* – acoustic metric descriptions might actually be "real physics" rather than just "toy models" – acoustic metrics tend not to be taken seriously (or literally) as "real" classical gravitational theory due to their incompatibility with special relativity.

* Additionally, in the case of "redder" relativistic solutions than SR, it seems that the experimental community didn't allow for reporting these results as significant because they thought that the range had already been ruled out by the theorists, while the theoretical community ignored the range because of the apparent strength of experimental evidence for special relativity. Both groups apparently thought the other had done the work.

11. Notes on indirect radiation effects

Before we start comparing the types of physics that are affected by the introduction of an acoustic metric, it may be useful to compare the "horizon" physics of a few different models.

… "C19th" horizon radiation

John Michell's 1783 exploration of the gravitational physics of large dense bodies [52] described a horizon-bounded object with the same horizon radius as general relativity (r=2GM/c^2, abbreviated "r=2M"). The leaky horizons of these "dark stars" would have emitted radiated indirectly, leading to classical analogues of Hawking radiation and Unruh radiation. [*]

… the 1916 theory

GR1916 does not support indirect radiation. Under GR1916, an event "happens" (for us) either when its directly-observed light is received, or at an earlier time back-calculated from the moment of observation, taking into account the assumed signal flight time. Since signals from events within r=2M can *never* reach a distant observer along an unaccelerated path, these events are assigned dates in the observer's more-than-infinitely-distant future. It is then reasoned that their effects can't influence the outside universe without reverse causality. This makes GR1916's horizon-bounded bodies not just *dark*, but totally *black*, non-radiating, one-way surfaces with a surface temperature of absolute zero, inspiring the term "black hole".

… Quantum mechanics

In the 1970s, Bekenstein and Hawking introduced the idea of Hawking radiation under QM, [56,57] the mechanism typically being described in terms of pair-production operating outside the horizon. The information encoded in this radiation was initially thought to be "random", but is now generally believed to be causally related to information that previously fell into the hole.

This produces the "black hole information paradox" [58], a disagreement between GR1916 (which insists that black holes can't radiate and that infallen information is permanently lost to the outside world), and quantum mechanics (which insists that they *must* radiate and that swallowed information must reappear).

… Cosmological horizons

The cosmological horizon is an "effective" or "apparent" horizon, and its causal behaviour is not that of gravitational horizons under GR1916. It corresponds instead to the behaviour of an "acoustic" horizon, and, statistically, to the description of a fluctuating, radiating horizon that we get from quantum mechanics.

… and acoustic metrics

Acoustic metrics include a counterpart of the old "dark star" indirect radiation effect.

While the limit to observability for a horizon-bounded object can be mapped as a spatially-smooth surface, this surface can fluctuate discontinuously in response to nearby events. [59] As with a cosmological horizon, the local physics is entirely causal, but *apparent* acausalities can appear in distant observers' projected maps of the region.

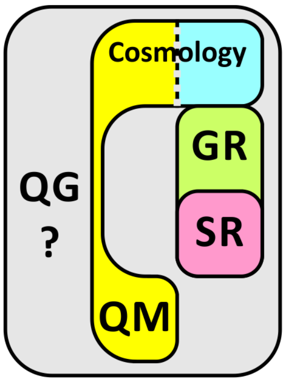
---

* The "dark star" and acoustic metric indirect escape mechanisms can't be modelled with a single test particle, or with purely inertial physics, as they are the statistical result of multiple interacting particles undergoing physical interactions and accelerations.

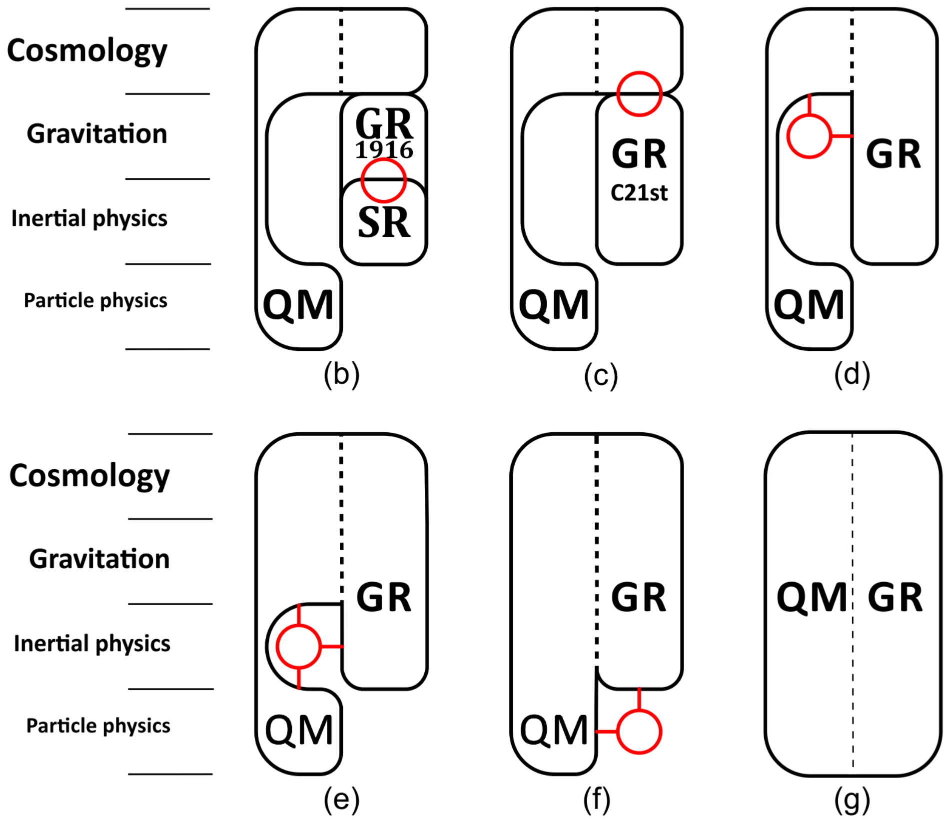
12. Unification overview

12.1. The stratification problem

The current system of physics is strongly stratified – **quantum mechanics** is applied to particle physics, **special relativity** to smallish-scale inertial physics, **general relativity** to gravitation and rotational and accelerational curvature, **cosmological** arguments are then layered on top of general relativity, and at some point we also expect to see a theory of **quantum gravity** which will (somehow) to be a full superset of both GR1916 and quantum mechanics **(a)**.



(a)



In **(b)** we have a stack of four sets of scale-specific physical laws: **Quantum mechanics** (left hand side) has a supposedly non-classical fluctuating geometry, special relativity uses flat Minkowski spacetime, general relativity adds curvature effects, and cosmology introduces the concept of a cosmological horizon whose observerspace causal structure is not the same as that of GR1916's gravitational horizons. Since the cosmological horizon fluctuates, radiates and has a non-zero temperature, it seems to show behaviour normally associated with QM.

12.2. Merging "gravitational" and "non-gravitational" physics

In **(b→c)** we eliminate special relativity from the stack and replace the 1916 general theory with a revised general theory based on an acoustic metric. This removes the distinction between "gravitational" and "nongravitational" physics, reducing the number of vertical layers from four to three.

12.3. Large scales

In **(c→d)** an acoustic metric then produces a single classical description for both cosmological and gravitational horizons:

In a single observer's view of an expanding universe, a large-scale map of the universe's contents shows an apparent gravitational field intensity that increases with distance, with more distant regions seen as they were in a younger and smaller (and denser) universe. If we turn this map inside out, it appears to show the gravitational field surrounding an unseen source that corresponds to the nominal Big Bang singularity, which is then cloaked from us by the cosmological horizon, which plays the part of a gravitational horizon ("farside black hole" argument [60]).

Since the cosmological horizon unavoidably fluctuates and radiates in response to events taking place behind it and has a non-zero temperature, it doesn't behave like a gravitational horizon under GR1916. It *does*, however, behave like the acoustic gravitational horizon of our revised general theory, removing the separation between classical cosmology and classical gravitation on the original diagram, (a). [*]

In the revised system, the same cosmological redshift can be described *either* as a cosmological expansion shift, *or* as an apparent gravitational shift, *or* as a recession shift. [**] [***]

12.4. Gravitational behaviour

The black hole information paradox

According to quantum theory, gravitational horizons need to emit Hawking radiation. This results in the hole losing mass (and according to information theory), losing information-content, while a corresponding quantity of information is encoded in the radiation. Since the radiated information cannot be *truly* random without breaking QM's underlying causality, it is

---

* If we knew nothing about the 1916 theory, we could have run the exercise backwards ... started with cosmology, proved that an expanding universe leads to a fluctuating horizon, applied a topological inversion, argued that this meant that gravitational horizons *also* fluctuate, argued that quantum mechanics needed to be able to model that result statistically, and predicted the existence of gravitational Hawking radiation under QM, from cosmological principles.

** These cosmological arguments were not available to Einstein when he constructed the 1916 theory, as he had initially assumed that general relativity would need to operate within a static universe.

*** We could also argue that since a cosmological horizon appears (functionally) to be an acoustic horizon, that the physics of the region that it intersects ought to be using "acoustic metric" physics. Since *every* visible region of the universe can be considered as being intersected by some future distant observer's cosmological horizon, this would lead to the conclusion that our entire visible universe operates according to acoustic metric principles.

natural to assume by default that the information that escapes originates inside the black hole. This corresponds to Unruh's observation that the escaping radiation appears to a nearby hovering observer to be coming directly out of the horizon region.

If the radiated particles have the identities of previously-infallen particles, it would then seem that the physics is conspiring to make it look as if particles are being emitted outwards *through* the horizon, *contra* GR1916. *

In **(d→e)** the new “acoustic” behaviour of black holes gives “leaky” horizons that allow particles to escape along accelerated paths, removing the main known “conflict between classical and quantum theory with regard to gravitational physics.

With dual “classical” and “quantum” descriptions of cosmology and gravitational physics, and also vertical integration for both bands, the top “2×2” part of our diagram becomes a single logical block. We can now fill in the remaining holes.

12.5. Applying QM to other lightspeed limits

In **(e→f)** we introduce integration between quantum mechanics and classical theory for physics that would normally be considered “non-gravitational”.

Trans-horizon physics

Although special relativity and the acoustic metric solution(s) give a direct-acceleration upper limit of “background lightspeed” for the speed achievable in a particle accelerator using force applied by the accelerator's “stationary” coils, a relativistic acoustic metric allows travel at more than $c_{\text{BACKGROUND}}$, for at least a small amount of time and a small distance, provided that the accelerating force is applied *indirectly*. The modified theory allows a high-speed particle to throw off daughter particles that initially travel at more than background lightspeed (without exceeding local c), while under the influence of their parent. **

This non-SR behaviour can be modelled using quantum mechanics – the SR lightspeed barrier can be treated as a classical barrier, with information about the parent-particle able to propagate forwards at more than $c_{\text{BACKGROUND}}$, either as the result of Hawking radiation emitted ahead of the horizon or as the result of information quantum-tunnelling forwards. *** In the acoustic metric description, the outcome results from purely classical (but non-SR) behaviour, and the forward-moving information can be compared to indirect radiation migrating outwards through an “acoustic” gravitational horizon.

---

* We can also argue that in the “particle-pair” description of Hawking radiation, the emitted particle has a “twin” with a mirrored copy of the same information, which is captured by the hole. If the absorption of this antiparticle reduces rather than increases the hole's information-content, then the swallowed antiparticle would seem to be cancelling with *another* exact twin inside the hole, meaning that the particle that is seen escaping shares an identity with a twin that “disappears” inside the hole. The overall effect is that of a single particle's position changing from inside to outside the horizon.

** At the time of writing (2015) it has not yet been established whether N1L continues to operate in an acoustic metric for object velocities greater than $c_{\text{BACKGROUND}}$, or whether initially super-fast particles are then braked to background subluminality by Cerenkhov radiation and/or other analogous field-effects.

*** In this context the apparent discontinuous nature of the forward transfer of information under QM is an artefact of applying an oversimplified classical reference model.

Acceleration effects and acceleration radiation

Under current theory, the question of when we are supposed to apply special relativity to acceleration problems and when we are supposed to apply full-blown GR does not have an obvious answer – or rather, it has multiple answers depending on which set of arguments from which theory we choose to use as a starting point. MTW address the question of whether SR can be applied to accelerating objects by cheerfully declaring that SR can be used for bodies with *any state of motion whatsoever, "when spacetime is flat"*, [61] – a slightly unhelpful statement given that according to Einstein, this condition can't be met when bodies move on physically accelerated paths. [*]

The advice seems to be that we "know" that acceleration has no effect on geometry (SR clock hypothesis), because otherwise the 1960 arguments would disprove special relativity, so we must *always* be able to model accelerated bodies using SR in the absence of explicit gravity … unless we get the wrong answers, or the description becomes geometrically inconsistent, in which case we have to use GR. This also gets us into the territory of GR clock paradoxes, which do not appear to have been resolved. The overall picture seems to be of a range of different conflicting arguments which we are supposed to choose between, pragmatically, with the job of establishing which set of rules applies to any given situation apparently left as an exercise for the student.

With an "acoustic" version of general relativity, we unambiguously restore the general theory's original principle of equivalence, and associate physical gee-forces with curvature in the region(s) between relatively-accelerated masses. Since this curvature is (in an acoustic model) associated with a modification of an accelerated observer's effective velocity-horizon, it suggests that a physically-accelerated observer should be able to see radiation that would not be visible if they were moving inertially. This in turn suggests a counterpart of the Unruh radiation effect Kip [62] that appears under quantum mechanics, giving us another connection between quantum and classical effects.

12.6. Small scales

In section **(f)** of Figure 2 we now have one last empty position to fill, at the bottom right. This requires the extension of general relativity downwards into the scale-range occupied by particle physics, and also the extension of small-scale quantum mechanics across into the "classical" region on the diagram's bottom-right.

Extending general relativity downwards

The case for extending a modified general theory of relativity down into the particle physics range has been made in section 8.1 – the main "new" physical behaviours introduced by replacing special relativity with an acoustic metric – the existence of medium-dependent lightspeeds and dragging effects – correspond to well-known and long-accepted physics. [**]

---

* MTW's reassurance is a little like a proud dog-owner being asked by a passer-by whether it's safe to approach their dog, and answering, "Oh, yes, my dog's always *absolutely* safe … when he's not biting". The qualification rather undermines the reassuring tone of the answer, especially when one finds that the dog has a *reputation* for biting.

** In an acoustic model, the reduced speed of light in glass is due to cumulative short-range curvature effects, and is analogous to the Shapiro effect, with a wavelength-dependency due to the distances seen by different wavelengths of light. Under current textbook theory, the region is considered flat, but the light is described as being absorbed and re-emitted by atoms with a time-delay that depends on wavelength, producing the same basic end-result.

Extending quantum mechanics sideways – Namsrai's stochastic QM arguments

Namsrai's work on stochastic QM argues that although the uncertainty principle can create a spread of different measurements of a particle's apparent position, the sum of the possible measurements, when overlaid, describes a smooth underlying probability-field. [23]

Since this derived classical field smears the particle's mass and momentum over the region, it is functionally a "mass field" (or inertial/gravitational field) with its stationary mass component considered analogous to a stationary gravity-well, and its momentum component effectively an additional velocity-dependent gravitoelectromagnetic field component. In Namsrai's description and sketch, the underlying mass-field has a "tilted hat" shape, with the "hat" representing the static field and the "tilt "of its throat being a gravitoelectromagnetic distortion representing the relative velocity.

The presence of these two features means that we are then dealing with an acoustic metric.

Namsrai, 1984:

> " ... Physically this relationship means that by knowing the space-time structure near the particle we can calculate its velocity (generalized) and, on the contrary, by the value of the particle velocity one can try to build the space-time structure near the moving particle. Thus, it seems, there exists a profound connection between these two concepts and they enter as a single inseparable entity into our scheme. "

This is essentially the same "duality between velocity effects and curvature" concept used in our earlier sections for describing moving stars (section 4.3), with the velocity expressed as an asymmetrical "tilt" in the geometry of a moving body's gravitational field, giving different effective distances and curvatures around the front and rear of a moving gravitational-well. A body's velocity and its associated velocity-dependent distortion again allow different ways of describing the physics, with the velocity calculable from the distortion and *vice versa*, but (with Namsrai's scheme) using the uncertainty principle as a starting point, rather than gravitational physics.

If we accept Namsrai's arguments, it would seem that we can derive GEM_{VEL} effects and a relativistic acoustic metric directly from quantum mechanics, by asking what the properties of classical physics would need to be for it to be capable of yielding the statistical behaviour of quantum mechanics by quantisation.

The revised general theory therefore seems to be a good match to quantum mechanics at the smallest scales as well as at the largest.

12.7. Overall

(g) It would seem that the use of an acoustic metric in general relativity collapses at least three different systems of classical physics down to one, and also extends the system into a fourth range, particle physics, so that a single set of rules applies at all scales, from that of a single particle to the scale of the entire observable universe.

Adopting an "acoustic" general theory of relativity also seem to remove the fundamental distinction between "quantum" and "classical" physics across the full range, with "dual" QM and classical descriptions available across all four zones.

13. Conclusions

The exercises in this paper, if taken at face value, appear to support Einstein's 1950 position that a general theory of relativity need not (and should not) include an enforced reduction to special relativity. They instead suggest that our universe is Cliffordian and that the appropriate geometry for describing mechanics is therefore a relativistic acoustic metric rather than a Minkowski metric.

Although moving to a different set of Lorentzlike relationships leaves much of existing classical physics unchanged, eliminating the Minkowski metric results in the compaction of multiple layers of scale-specific classical physics into a single set of laws and behaviours that apply at all scales, unifying situations that would otherwise be considered distinctly different under the current system. By making more situations “dual”, removing scale-specific “special” limits and arbitrary suspensions of logic, and reinstating the original Mach-Einstein principles underlying general relativity, the revised general theory is held to a much more ambitious and rigorous set of standards than the current multi-layered (and more forgiving) system.

The result is a *more general* general theory of relativity than the 1916 theory, with a greater degree of scientific falsifiability than its predecessor. Not only is it required to obey the principle of full equivalence between inertial and gravitational effects (which GR1916 was allowed to “opt out of” in 1960) and required to agree with quantum theory (which the current theory doesn't), it *also* has to apply a single set of equations to velocity shifts, gravitational shifts *and* cosmological shifts. While current theory allows these to be derived independently, on the grounds that we believe them to be inherently distinct sets of effects, the suggested replacement system requires all three effects to obey a single shift relationship – it requires not just duality but *triality*, merging *three* classical descriptions, and also requires these results to be dual with quantum mechanics at every level.

It is good scientific practice to “sanity-test” theories by asking to what degree the shape of a theory depends on the shortcuts and idealisations used to construct it. In the case of Einstein's 1916 general theory, this means asking what a general theory would look like without SR as a convenient limiting case, and in the case of the 1905 “special” theory it means asking what relativity theory would look like if mechanics was *not* a totally flat-spacetime problem. The answer to both questions would seem to be: “a relativistic acoustic metric”.

These questions appear not to have been asked. Given that acoustic metrics appear to have the highly desirable property of being dual with quantum theory, and share a causal structure with QM that SR-based theories seem to find impossible to reproduce, this oversight may be responsible for our inability to construct a working theory of quantum gravity.

--==--

Additional notes

Note 1. The more mathematically-minded will notice that an exact mathematical form has not been given for the predictions of the proposed new theory. This is not an oversight – while the author is happy to propose ***x*=1** as a personal prediction (with supporting arguments given in the "Relativity in Curved Spacetime" book), the potential importance of acoustic metric models is such that it may be rash to commit the entire subject to a single solution until the wider community has had a chance to study the proposed structure and to identify whether other types of solution might exist.

Note 2. The author's previous piece identifies the value of **x** with the strength of a model's GEM_{VEL} effects, with ***x*<0.5** being unphysical, ***x*=0.5** being the "no-dragging" solution for flat spacetime and special relativity, and ***x*=1** being the maximally-dragged solution for the horizon of a moving black hole. No arguments are known to the author that would suggest a non-SR relativistic model with any value for the Lorentzlike exponent other than *x*=1, but this is a comparatively unexplored area of theory.

Note 3. For gravitational models that compete with GR1916, MTW list as essential *"... three criteria for viability: self-consistency, completeness, and agreement with past experiment."* We've seen that the 1916 theory in its pre-1960 incarnation failed the first test due to a conflict between its components, and MTW's definition of "completeness" says that a theory *"must … mesh with and incorporate a consistent set of laws for electromagnetism, quantum mechanics, and all other physics."* Since the original 1916 theory also does not "mesh" with quantum mechanics, it fails two out of MTW's three tests for viability.

Note 4. It might seem that we are faced with a choice between two systems, one describing a universe based on special relativity and the other a universe based on acoustic metrics. To a practitioner familiar with SR-based systems, it may seem that the greater simplicity of special relativity makes it the more efficient solution. However, we would still need "acoustic" physics (*e.g.* to describe a cosmological horizon), so our real choice would seem to be between a universe in which the laws of classical physics are represented by an acoustic metric *in conjunction* with special relativity and GR1916, or a universe in which an acoustic metric alone is sufficient.

Note 5. "Light-dragging" in a particulate medium is explained in an acoustic model by short-range GEM_{VEL} effects, while in textbooks it is modelled using the "extinction theorem", which says that the incoming wave is absorbed by atoms and replaced with a new wave moving at a physical speed of c_{MEDIUM} with respect to the secondary emitters – an apparent throwback to C19th emission theory. However, since the wavefront should not still be moving at an absolute speed of c_{MEDIUM} once it *leaves* the medium, it would seem that this explanation still doesn't remove *all* local proximity effects – the last plane of atoms encountered as the wave leaves the surface must either emit light differently to atoms in the interior of the medium (suggesting proximity sensing, and local fields that tell these atoms behave differently), or the light must change speed as it leaves the medium (suggesting a proximity field effect). Once we accept the existence of proximity field-effects that modify lightspeeds according to the presence and motion of particles, we may as well use this same mechanism to explain the change in lightspeed as the light enters the medium, and use a GEM_{VEL}-based theory.

Note 6. The new system requires surprisingly few changes. The "x=1" solution represents an additional Lorentz redshift and contraction compared to special relativity – since special relativity uses Lorentz relationships to amend nominal distances and times, substituting a Lorentz-*squared* factor often leaves final physical predictions unaffected. The practical differences between the two models will often be minimal or non-existent, allowing SR to still be used as a "quick and dirty" method for generating many correct results.
Since x=1 also generates the shift equations of Newtonian gravity, the suggested replacement for SR's relationships, when applied to gravitation, already appears in gravitational textbooks as the suggested Newtonian approximation of GR.

Note 7. It tends to be assumed that stable orbits require the speed of gravity under Newtonian gravity to be infinite. [63] Another interpretation would be that if the speed of gravity is not vastly in excess of *c*, Newtonian gravity must also include GEM_{VEL} effects, and Newtonian optics must then generate an acoustic metric rather than C19th ballistic emission theory, for the same reasons given in section 5. Once Newtonian theory and general relativity are both considered to be "curved" theories, it becomes easier to imagine GR reducing directly to NM without SR's intermediate layer of flat-spacetime physics.

Note 8. A common statement supporting SR/GR1916 is that both theories produce excellent results "within their domains of applicability" … where those domains are defined as "The regions in which the theories produce excellent results." This is somewhat circular, and makes it difficult to disprove a wrong theory (because whenever predictions do *not* agree well with the data, we can say that a theory is still correct but was, by definition, used outside its proper domain). The suggested replacement system is stricter in this regard.

References

[1] Albert Einstein, "*On the electrodynamics of moving bodies*" (1905) translated and reprinted in The P**rinciple of Relativity** (Dover Publications, 1952) ISBN 0486600815

[2] Albert Einstein, "The foundation of the general theory of relativity", translated and reprinted in **The Principle of Relativity** (Dover Publications, 1952) ISBN 0486600815

[3] Albert Einstein, "*What is the theory of relativity?*", The London Times (1919)

> " … I must observe that the theory of relativity resembles a building consisting of two separate stories, the special theory and the general theory. The special theory, on which the general theory rests, applies to all physical phenomena with the exception of gravitation; the general theory provides the law of gravitation and its relations to the other forces of nature. "

[4] Albert Einstein, "*On the Generalized Theory of Gravitation*", Scientific American, **182**, 4 (April 1950)

[5] W.K. Clifford, "*On the Space-Theory of Matter*", Proceedings of the Cambridge Philosophical Society (1876)

> " I hold in fact (1) That small portions of space *are* in fact of a nature analogous to little hills on a surface which is on the average flat; namely, that the ordinary laws of geometry are not valid in them. (2) That this property of being curved or distorted is continually being passed on from one portion of space to another after the manner of a wave. (3) That this variation of the curvature of space is what really happens in that phenomenon which we call the *motion of matter*, whether ponderable or etherial. (4) That in the physical world nothing else takes place but this variation, subject (possibly) to the law of continuity. "

[6] Albert Einstein, 1921 Princeton lectures, published in **The Meaning of Relativity** in 1922

> " What is to be expected along the lines of Mach's thought?
>
> 1. The inertia of a body must increase when ponderable masses are piled up in its neighbourhood.
>
> 2. A body must experience an accelerating force when neighbouring masses are accelerated, and, in fact, the force must be in the same direction as that acceleration.
>
> 3. A rotating body must generate inside itself a 'Coriolis field', which deflects moving bodies in the sense of the rotation, and a radial centrifugal field as well.
>
> We shall now show that these three effects … are actually present according to our theory … "

Note that while Einstein's effects (2) and (3) correspond to the (2) and (3) of section 2.2 (accelerational and rotational dragging) Einstein's listed effect (1) is the gravitational time dilation effect.

[7] Herbert Pfister, "*On the history of the so-called Lense-Thirring effect*" General Relativity and Gravitation **39**, 11, 1735-1748 (2007)

[8] John Archibald Wheeler**, A journey into gravity and spacetime** (Freeman, 1990) p232-233 ISBN 0716750163

[9] Albert Einstein, 1905 "*Electrodynamics*" paper, introduction:

> " In the following we make these assumptions (which we shall subsequently call the Principle of Relativity) and introduce the further assumption, —an assumption which is at the first sight quite irreconcilable with the former one— that light is propagated in vacant space, with a velocity c which is independent of the nature of motion of the emitting body. "

[10] Albert Einstein, **Relativity: The Special and the General Theory** "*Chapter 7: The apparent incompatibility of the law of propagation of light with the principle of relativity*"

[11] Albert Einstein, "*On the Influence of Gravitation on the Propagation of Light*", translated from "*Über den Einfluss der Schwercraft auf die Ausbreitung des Lichtes*", Annalen der Physik volume 35 (1911)

> " The principle of the constancy of the velocity of light holds good according to this theory in a different form from that which usually underlies the ordinary theory of relativity. "

[11 continued.]

Although Einstein had chosen to assume in 1905 that the principle of lightspeed constancy meant *global* lightspeed constancy, his subsequent work on gravity showed that "global *c*", while creating a convenient geometrical basis for the special theory, could not be a fundamental or universal principle or law of nature. Einstein was then faced with the choice of abandoning the 1905 theory and building a whole new theory of relativity from scratch, from first principles, or taking a more incremental approach and retaining the 1905 theory as a limited "special-case" solution of a larger structure.

[12] Albert Einstein, **Relativity, the Special and the General Theory**, Notes to the Fifteenth Edition

> " Physical objects are not ***in space***, but these objects are ***spatially extended***. In this way the concept "empty space" loses its meaning. "

[13] Eric Baird, **Relativity in Curved Spacetime** (2007), "*Chapter 8: Aberrtion of Angles*", pages 77-84

[14] G. D. Scott and H. J. van Driel, "*Geometrical Appearances at Relativistic Speeds*", American Journal of Physics **38** 971 (1970) http://dx.doi.org/10.1119/1.1976550

[15] S. Carlip, "*Aberration and the Speed of Gravity*" Phys. Lett. **A267** 81-87 (2000) arXiv:gr-qc/9909087v2

[16] A. Einstein, L. Infeld and B. Hoffmann, "*The Gravitational Equations and the Problem of Motion*", Annals of Mathematics Second Series, Vol. 39, No. 1 (Jan., 1938), pp. 65-100

[17] J.A. Wheeler, **Geometrodynamics** (1962)

[18] J.A. Wheeler (widely cited, original source attributions vary):

> " There is nothing in the World except empty curved space. Matter, charge, electromagnetism ... are only the manifestations of the bending of space. *Physics is Geometry.* "

[19] Irwin I. Shapiro, "*Fourth Test of General Relativity*" Physical Review Letters **13**, 789 (1964)

[20] H. Fizeau, "*Sur les hypothèses relatives à l'éther lumineux et sur une expérience qui parait démontrer que le mouvement des corps change la vitesse avec laquelle la lumière se propage dans leur intérieur*"
Ann. de Chim et de Phys. **57** 385-404 (1859)

[21] R V Jones "*Aberration of light in a moving medium*" Journal of Physics A: General Physics, **4** L1 (1971)

[22] Werner Heisenberg, **Encounters with Einstein: And Other Essays on People, Places, and Particles** (1989) pages 10 and 113-114

Heisenberg attributes the inspiration of his uncertainty principle to a meeting with Einstein:

> " To my astonishment, Einstein was not at all satisfied with this argument. He thought that every theory in fact contains unobservable quantities. The principle of applying only observable quantities simply cannot be carried out. And when I objected that in this I had merely been applying the type of philosophy that he, too, had made the basis of his special theory of relativity, he answered simply: "Perhaps I did use such philosophy earlier, and also wrote it, but it is nonsense all the same". …
> In [modern atomic physics], it is theory which first determines what can be observed."

Einstein's revised concept of causality is at odds with the causal structure assumed by SR/GR1916. The 1905 and 1916 theories assume that everything capable of influencing an observer's reality must itself be directly observable, which leads to the GR1916 concept of the interior of a black hole being causally disconnected from the outside universe with respect to outgoing signals.
However, with a cosmological horizon (or acoustic horizons in general), the "effective" horizon position for a distant observer is partly a consequence of the physics operating in the area, and can fluctuate discontinuously in response to changes in the local geometry either before or behind the surface – it is akin to the Earth's observational horizon over an area of ocean, where a line corresponding to the observational limit is discontinuously fluctuating due to small ocean waves, and can be influenced by the presence of a large oncoming ship that is over the horizon, and not yet visible. Quantum mechanics and acoustic metrics both support the concept of the indirect observation of a particle or event that cannot (currently) be observed directly – it is not

observability (alone) that defines the geometry and the physics, as the physics also affects the geometry, which can alter what is or is not observable (at a given moment, for a given observer).
One might draw a comparison between playing a game of cards in which either (scenario #1) each player can only see a fraction of the deck at any time (QM/acoustic models), or (scenario #2) all observers can always know each other's cards, and also see all the cards still undealt (SR/GR1916). If all the players within each game had identical skills and strategies then both games would play out deterministically, but even with the same set of cards in the same order, the two sets of gameplay would be different.

[23] Khavtain Namsrai, "*Space-time structure near particles and its influence on particle behavior*" International Journal of Theoretical Physics **23** 1031-1041 (1984)

> "An interrelation between the properties of the space-time structure near moving particles and their dynamics is discussed. It is suggested that the space-time metric near particles becomes a curved one ... "

[24] Clifford M. Will, **Was Einstein Right: Putting general relativity to the test** (OUP, 1998) ISBN 019222039

> Appendix: Special Relativity: Beyond a Shadow of a Doubt:
>
> "... It is so much a part not only of physics but of everyday life that it is no longer appropriate to view it as the special "theory" of relativity. It is a fact, as basic to the world as the existence of atoms or the quantum theory of matter. ..."

[25] C.M. Will, **The Confrontation between General Relativity and Experiment**, Living Reviews **9** (2006) "*Section 3: Metric Theories of Gravity and the PPN Formalism*"

> " ... for the remainder of this review, we shall turn our attention exclusively to metric theories of gravity, which assume that
> 1. there exists a symmetric metric,
> 2. test bodies follow geodesics of the metric, and
> 3. in local Lorentz frames, the non-gravitational laws of physics are those of special relativity."

[26] Richard A. Mould, **Basic Relativity**, (Springer-Verlag, 1994) pp.80:

> " If a source is observed from a direction perpendicular to its motion, the resulting change in frequency is called a *transverse Doppler effect*. This is a relativistic effect, for classically one would not expect a frequency shift from a source that moves by right angles. "

– Classically, one *would* expect a frequency-shift from a source that moves at right angles wrt the experimenter's equipment, if one was using Newtonian theory (which generates a transverse aberration redshift).
Although it could be argued that SR time dilation and aberration redshift are conceptually different, SR has to generate the same final predictions regardless of the frame in which the lightspeed calculations are carried out, so the same final Lorentz redshift has to be interpretable under SR *either* as a propagation shift due to fixed-*c* in the observer's frame supplemented by time dilation due to the source's motion, *or* as the propagation shift due to fixed-*c* in the source's frame, giving the Lorentz-*squared* aberration redshift which is then partly cancelled by a Lorentz blueshift (caused by the observer's own supposed time-dilation due to motion), giving the same final result.
Since the SR outcome must not depend on our chosen reference frame, *we cannot in principle* distinguish qualitatively between SR's transverse effect and Newtonian aberration redshift – within SR we are not allowed to establish whether an SR transverse redshift is "really" due to SR time-dilation, or is "really" an aberration redshift partly cancelled by our own SR time dilation. Since the SR effect has to be qualitatively identical to aberration redshifts under other theories, the best we can do for cross-theory testing is to calculate whether two relativistic theories' predictions are *quantitatively* identical given SR's redefinitions of distances and times, and if they are not, to measure which Lorentzlike relationship best fits the recorded data.

[27] Ray d'Inverno, **Introducing Einstein's Relativity** (OUP, 1992) page 40:

> " ... **the transverse Doppler shift** ... This is a purely relativistic effect due to the time dilation of the moving source. Experiments with revolving apparatus using the so-called 'Mössbauer effect' have directly confirmed the transverse Doppler shift in full agreement with the relativistic formula, thus providing another striking verification of the phenomena of time-dilation. "

– For a circling source we can predict clock-slowing without SR either by extrapolating from the Newtonian aberration redshift effect (in a similar way to our extrapolation from the SR transverse effect), or by applying the principle of equivalence and calculating the effect as the result of gravitational time dilation (Harwell group, 1960). The SR **clock hypothesis,** which states that acceleration has *zero* effect on clockrate, seems to have been devised purely to eliminate competing explanations of these effects. The SR clock hypothesis seems to be at odds with the general principle of relativity.

[28] Oliver Lodge, **The Aether of Space** (Harper, 1909) "*Chapter X: General Theory of Aberration*", esp. page 135

[29] Eric Baird, **Relativity in Curved Spacetime** p352-353, "*Calculations 3: Aberration redshift*" (2007)

[30] Albert Einstein, "Does the Inertia of a Body Depend upon its Energy-Content?" (1905), translated and reprinted in **The Principle of Relativity.** Originally published as "Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?", Annalen der Physik

[31] **Relativity in Curved Spacetime**, pages 350-351, "*Calculations 2: $E=mc^2$ from Newtonian mechanics*" (2007)

[32] **Relativity in Curved Spacetime**, *Chapter 13,* pages 171-180 *(2007)*

[33] D. Hasselkamp, E. Mondry, and A. Scharmann, "*Direct observation of the transversal Doppler-shift*" Zeitschrift für Physik A, **289**, 151-155 (1979)

[34] A J F Boyle and H E Hall, "*The Mössbauer effect*", Reports on Progress in Physics, Volume 25 (1962)

[35] R. V. Pound and G. A. Rebka Jr., "*Gravitational Red-Shift in Nuclear Resonance*" Phys. Rev. Lett. **3**, 439 (1959)

[36] T. E. Cranshaw, J. P. Schiffer, and A. B. Whitehead, "*Measurement of the Gravitational Red Shift Using the Mössbauer Effect in Fe57*" Phys. Rev. Lett. 4, 163 (February 1960)

[37] H.J. Hay, J.P. Schiffer, T.E. Cranshaw and P.A. Egelstaff , "*Measurement of the red shift in an accelerated system using the Mössbauer effect in Fe57* " Phys.Rev.Lett. **4** 165-166 (1960)

[38] Alfred Schild, "*Equivalence Principle and red-shift measurements*" Am.J.Phys. **28** 778-780 (1960)

> Abstract: " Two questions are discussed. The first asks whether experiments on accelerated systems (e.g., red-shifts produced in rotating disks) can serve to verify the general theory of relativity. The answer is "no." The second asks to what extent the special theory of relativity and the principle of equivalence determine the well-known effects of the general theory of relativity. It is important to formulate this question very carefully because special relativity and the equivalence principle do not form a consistent theoretical system. ... "

[39] Albert Einstein, *The General Theory of Relativity*, 1921 Princeton lectures, published in **The Meaning of Relativity** in 1922:

> " [re: unaccelerated and accelerated frames] ... The assumption of the complete physical equivalence of the systems of co-ordinates *K* and *K'*, we call the 'principle of equivalence'; this principle is evidently intimately connected with the law of the equality between the inert and the gravitational mass, and signifies an extension of the principle of relativity to coordinate systems which are in non-uniform motion relatively to each other. "

[40] Albert Einstein, "*What is the theory of relativity?*", The London Times (1919)

> " The advantages of the constructive theory are completeness, adaptability, and clearness, those of the principle theory are logical perfection and security of the foundations.
>
> The theory of relativity belongs to the latter class. "

The 1960 redefinitions subseuently moved GR1916 from the "principle" class to the "constructive" class.

[41] Misner, Thorne and Wheeler (MTW), **Gravitation** (1973), page 1060:

> " Of all the principles at work in gravitation, none is more central than the equivalence principle. As enunciated in ss16.2, it states: In any and every Lorentz frame, anywhere and any time in the universe, all the nongravitational laws of physics must take on their familiar special-relativistic forms. "

[42] Misner, Thorne and Wheeler (MTW), **Gravitation** (1973), page 1060:

> " metric theory [defined] … (1) that spacetime possesses a metric; and (2) that metric satisfies the equivalence principle (the standard special relativistic laws are valid in each local Lorentz frame) . Theories of gravity that support these two principles are called metric theories. "

[43] Misner, Thorne and Wheeler (MTW), **Gravitation** (1973), **Chapter 39: Other Theories of Gravity and the Post-Newtonian approximation**, pages 1066-1095

– MTW present the PPN formalism for classifying credible theories, which requires them to be metric theories and to obey the principle of equivalence. MTW's definitions say that both of these both include the condition that a theory must reduce to special relativity.

[44] Abhay Ashtekar, Beverly Berger, James Isenberg, Malcolm MacCallum (eds) **General Relativity and Gravitation: A Centennial Perspective** "Beyond the Standard Model" page 222 (2015)

[45] Matt Visser "*Acoustic black holes: Horizons, ergospheres, and Hawking radiation*" Classical and Quantum Gravity **15** 1767–1791 (1998). gr-qc/9712010

[46] Albert Einstein, "*The General Theory of Relativity*" (1921 lectures)

> " … Just as it was consistent from the Newtonian standpoint to make both the statements, *tempus est absolutum*, *spatium est absolutum*, so from the standpoint of the special theory of relativity we must say, *continuum spatii et temporis est absolutum*. In this latter statement *absolutum* means not only 'physically real', but also 'independent in its physical properties, having a physical effect but not itself influenced by physical properties'. … It is contrary to the mode of thinking in science to conceive of a thing (the space-time continuum) which acts itself, but cannot be acted upon. … "

[47] Albert Einstein, **The Meaning of Relativity**, Appendix II (1950/1955)

> " It is the essential achievement of the general theory of relativity that it has freed physics from the necessity of introducing the "inertial system" (or inertial systems). This concept is unsatisfactory for the following reason: without deeper foundation it singles out certain coordinate systems among all conceivable ones. It is then assumed that the laws of physics hold *only* for such inertial systems (e.g. the law of inertia and the law of the constancy of the velocity of light). Thereby, space as such is assigned a role in the system of physics that distinguishes it from all other elements in the physical description. It plays a determining role in all processes, without in its turn being influenced by them. Though such a theory is logically possible, it is on the other hand rather unsatisfactory. "

[48] Albert Einstein, "*Ether and the Theory of Relativity*" (1920), An Address delivered on May 5th, 1920, in the University of Leyden, translated and published in **Sidelights on Relativity**, Dover Press 1983 (Dutton 1922) ISBN 048624511X

[49] R.S. Shankland, "*Conversations with Albert Einstein*" American Journal of Physics, Volume 31, pages 47-57 (1963)

> " … he told me that he had thought of, and abandoned the (Ritz) emission theory before 1905. He gave up this approach because he could think of no form of differential equation which could have solutions representing waves whose velocity depended on the motion of the source. In this case, the emission theory would lead to phase relations such that the propagated light would be all badly "mixed up" and might even "back up on itself." "

[50] Wolfgang Rindler, "*General relativity before special relativity: An unconventional overview of relativity theory*", American Journal of Physics, Volume 62, Issue 10, pp. 887-893 (1994)

[51] Eric Baird, **Relativity in Curved Spacetime** (2007), "*Chapter 5: The Newtonian Catastrophe*", pages 51-60 catastrophe

[52] John Michell, "*On the Means of discovering the Distance, Magnitude, &c., of the Fixed Stars …* " Proceedings of the Royal Society (1784)

[53] Simon Schaffer, "*John Michell and black holes*" Journal for the History of Astronomy, volume **10** pages 42-43 (1979)

[54] Gary Gibbons, "*The man who invented black holes [his work emerges out of the dark after two centuries]*", New Scientist, 28 June, page 1101 (1979)

[55] Carlos Barceló, Stefano Liberati, and Matt Visser, "*Analogue Gravity*" gr-qc/0505065 (2005-)

[56] S. W. Hawking, "*Black hole explosions?*" Nature 248, 30-31 (1 March 1974)

[57] S. W. Hawking, "*Particle creation by black holes*" Communications in Mathematical Physics vol. **43**, pages 199-220 (1975)

[58] Black Hole information paradox

[59] W.G. Unruh, "*Experimental Black-Hole Evaporation?*" Physical Review Letters, vol. **46**, pages 1351-1353 (1981)

[60] Eric Baird, **Relativity in Curved Spacetime** (2007), page 166, "*The universe considered as a (w)hole*"

[61] MTW, **Gravitation**, page 164:

> " … when spacetime is flat, move however one will, special relativity can handle the job. "

[62] Kip S. Thorne, **Black holes and time warps: Einstein's outrageous legacy** (1994), pages 442-445, including "*Box 12.5: Acceleration Radiation*"

[63] I.J. Good, "*Infinite speed of propagation of gravitation in Newtonian physics*" American Journal of Physics **43** (7). DOI: 10.1119/1.9766 (1975)

--=oOo=--

E.B. 26-10-2015