# ‘Like classical Thermodynamics before Boltzmann’. Why did Einstein Compare Relativity Theory with Thermodynamics ?

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Towards the end of 1919, in a brief article for the *Times* of London, Einstein (1919b) famously declared relativity theory to be a ‘principle theory,’ like thermodynamics, rather than a ‘constructive theory,’ like the kinetic theory of gases. Over the last decade, this distinction has attracted considerable interest in the literature, originating a vast and still living philosophical debate on the foundation of spacetime theories (Brown, 2005; Janssen, 2009; Norton, 2008), and, to a lesser extent, on the foundation of quantum mechanics (Bub, 2000). Historically oriented scholarship has attempted to clarify Einstein’s principle/constructive theories opposition (Howard, 2005), showing how it was deeply rooted in the 19th-century physics emphasis on the role of general principles in physics (Howard, 2007; cf. also Stachel, 2000). At the turn of the century, H. A. Lorentz (Frisch, 2005) and H .Poincaré presented the opposition between the ‘physics of principles’ and the ‘physics of models’ as commonplace (Darrigol, 1995). In a similar vein, in the early 20th-century, A. Sommerfeld opposed a ‘physics of problems,’ a style of doing physics based on concrete puzzle solving, to the ‘practice of principles’ defended by M. Planck (Seth, 2010).

In spite of the recent spike of interest, a systematic account of Einstein’s principle/constructive theory distinction is missing. Most of all, the rationale behind Einstein’s compare relativity theory with thermodynamics has been, in my opinion, misunderstood. In particular, it is argued, the comparison not have much to do with the question of the ontological status of space-time, as it is usually claimed in recent literature (Brown, 2005; Janssen, 2009). This paper, by reconstructing in some details both the prehistory and the aftermath of the Einstein’s 1919 article, aims to show that both conclusions are, to a certain extent, misleading.

Einstein started to compare relativity theory to ‘thermodynamics before Boltzmann,’ rather in passing, on two occasions, between 1907 (Einstein, 1907) and the beginning of 1908 (Einstein to Sommerfeld, 14-01-1908), to answer to a rather specific objection. The comparison was meant to defend the derivation of the velocity dependence of the mass the electron presented in the last section of Einstein’s 1905 paper. Even physicists who would soon give fundamental contributions to relativity theory were puzzled. A. Sommerfeld, P. Ehrenfest (1907), and M. Born (1909a,b,c) insisted for several years, in private correspondence and published writings, that Einstein could not get away without making some assumptions about the shape, the charge distribution and the nature of the mass of the electron. By contrast, M. Planck (1906), H. Minkowski (1907a,b), and Laue (1911a,b) embraced Einstein’s strategy of setting up a relativistic mechanics of structureless point particles, by imposing the requirement of Lorentz invariance on an existing law valid for slow velocity.

When the dispute was long over, Einstein started to systematize (Einstein, 1914) his occasional methodological reflections (Einstein, 1919a). Einstein distinguished between: (a) *constructive theories*, which synthetically construct hypothetical models (*Bilder*) compatible with the current laws of nature (mechanical model of a gas, an electromagnetic model of the electron) (b) ‘principle theories,’ which search analytically for empirically motivated and mathematically formulated requirements that such laws (of mechanics, electrodynamics, etc.) have to satisfy. Relativity theory, like thermodynamics, belongs to the latter category. The constructive/principle theory distinction has become somehow iconic, but, as the paper attempts to show, somehow obscures the fundamental point.

Only towards the end of his life, getting back with his memories to the early years of relativity, Einstein revealed more explicitly the rationale for building special relativity following the analogy with thermodynamics. As Einstein explained to W.F.G. Swann, when he was setting up the theory, he attempted to ground it on a foundation that "from the standpoint of our experience," was "*better justified than any particular structural laws*, e.g. Maxwell's equations" or any other constructive theory that would take its place (Einstein to Swann, 24-01-1942). For this reason in special relativity, "nothing is stated about the structural laws of nature other than the fact that they *should* be Lorentz-invariant" (Einstein to Swann, 24-01-1942). As a consequence of Planck's radiation law, Einstein suspected that the structural or fundamental laws of nature that where taken for granted at that time, not only Newtonian mechanics, but also vacuum Maxwell's electrodynamics, could not be exactly valid (Einstein, 1946). Einstein might have attempted to account for the failure of the ether-drift experiments by modifying classical electrodynamics directly, in particular by embracing an emission theory of light. When these "constructive attempts" (Einstein, 1946) failed, he considered preferable to follow the "logical equivalent" of the strategy used in thermodynamics. (Einstein to Amiet, 17-12-1947). Thermodynamics could justify its two principles without referring to Newtonian mechanics, but by relying on the universally accepted empirical fact that the construction *perpetuum mobile* of first or second kind. Similarly, in Einstein's approach, the Lorentz transformations are "*defined independently* of Maxwell equations" (Einstein, 1950, 14), they are derived from empirical generalizations summarized in the two famous postulates. For this reason they can be used as an "*heuristic principle* valid far *beyond the range of the applicability or even validity of the equations themselves*" (Einstein, 1950, 14).

As Einstein explained in an often-quoted letter to von Laue, special relativity was "based essentially only on the constant $c$, and *not on the presupposition of the reality of the Maxwell field*" (Einstein to Laue, 17-01-1952). In 1905—Einstein conceded to his biographer C. Seelig a few months—special relativity was, so to say, in the air. "Lorentz had already recognized that the transformations named after him are *essential for the analysis of Maxwell equations*, and Poincaré deepened this insight still further". The peculiarity of his approach, Einstein explained, consisted in the "the realization that the Lorentz transformation *transcends its connection with Maxwell's equations*" and are elevated to "a general condition *for any physical theory*" (Einstein to Seelig, 19-02-1955).

The importance of this letter was first emphasized by Born, just after Einstein's death (Born, 1956). The letter, according to Born reveals that in Einstein's view, "the principle of relativity was more general and should be founded on considerations *which would be still valid when Maxwell equations had to be discarded*", that is replaced by a theory that would account for the discrete structure of radiation (Born, 1956, 104). The difference between Einstein's approach and Lorentz-Poincaré approach lies precisely here, as Wolfgang Pauli pointed by commenting on the very same letter. Einstein sensed that Maxwell's electrodynamics could not be generally correct. "He, therefore, formulated the invariance of the laws of nature with respect to Lorentz transformations as *a general postulate which is more reliable than Maxwell equations*" (Pauli, 1959, 241; tr. 1994, 119). The paper will conclude that these few remarks unwittingly express the rationale behind Einstein's comparison between special relativity and thermodynamics. Differently to what it is usually claimed, Einstein's thermodynamics/relativity theory analogy was not meant to emphasize that relativity theory is ultimately a *byproduct* of some deeper level theory constructive analogous to the kinetic theory of gases. On the contrary, it was meant to show that the relativity principle, like the two principles of thermodynamics, is a *constraint* that we impose on such theories, but whose validity does not depend on any of them (Lange, 2001, 2007, 2009).

## Abbreviations

CPAE Albert Einstein (1987–). *The Collected Papers of Albert Einstein.* Ed. by John Stachel et al. 15 vols. Princeton: Princeton University Press, 1987–.

EA *The Albert Einstein Archives at the Hebrew University of Jerusalem* (n.d.).

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Harvey Brown's celebrated *Physical Relativity* (2005) introduced a dynamical-constructive interpretation of relativity theory. A main claim in this interpretation is that Lorentz invariance has a more fundamental place in special relativity than Minkowski spacetime structure. Actually, Brown claims, the former explains the latter.

Brown finds historical and conceptual support in the approach in electrodynamics undertaken by late 19th century physicists such as Larmor, Fitzgerald and Lorentz. They allegedly provided a dynamical foundation—crowned in Lorentz's model of the electron in his ether theory—for physical effects which today we characterize as paradigmatically relativistic, e.g., clock-retardation and length-contraction. The 19th century explanation of these effects is supposed to be given by the (Lorentz invariant) laws governing the interaction between matter and the ether. In simple terms, the "relativistic" behavior of physical bodies results from the way they are made, not from the structure of an embedding spacetime. Brown does not propose a return to ether physics, of course, but he argues for an interpretation of relativity theory along these lines—where the ultimate dynamical foundation and explanation of Minkowski spacetime structure is provided by a (Lorentz invariant) quantum theory of matter.

I will contest Brown's interpretation and propose a more nuanced view concerning the relation between dynamics and spacetime structure. I will look back to the 19th century too, but this time to arguments concerning the epistemology of geometry introduced by Helmholtz (1977) and Poincaré (2001).

Helmholtz's main insight was that for the question of the geometric structure of physical space to make sense at all, dynamical considerations must be involved from the outset. He stated that if the notions of congruence and rigidity are not previously defined and operationalized—an issue that involves dynamical laws governing physical bodies—the measurements that can tell about the geometric structure of physical space are neither defined nor possible. In other words, a geometric structure cannot even refer to the physical world unless dynamical principles define notions like congruence and rigidity. Only once this is accomplished, measurements of spatial structure are meaningful and possible.

Now, a crucial point is that the converse is also true, i.e., dynamics makes physical sense only on a geometric structure background. This important insight is implicit in Helmholtz's work: that is why measurements performed with rigid bodies can be taken as empirical evidence for a certain geometric structure in the first place. If dynamics—and hence the corresponding definition and operationalization of rigidity and congruence—were geometrically neutral, those measurements would be idle with respect to the geometric structure of physical space.

This point can be clearly seen if we consider Poincaré's argument for the conventionality of geometry, in the context of the predictive equivalence and rivalry between Lorentz's ether theory and special relativity. We can take this historical episode in physics as an instance of Poincaré's parable of a single world that can be correctly described by two incompatible (chrono)geometric structures. The mathematical form of the dynamical laws in both theories is exactly the same, but they have a different meaning. For example, in the ether theory, $\Delta x' = \Delta x/\gamma$, where $\gamma = 1/\sqrt{1 - v^2/c^2}$, refers to the longitudinal contraction of an object that moves with respect to the ether with velocity $v$; whereas in special relativity the same formula refers to the different measurements of the length of the same object in two frames that move with respect to each other with velocity $\pm v$. For this difference in meaning to be possible at all, $\Delta x' = \Delta x/\gamma$ must be setup on different chronogeometric structures. For the ether theory to be able to pick a privileged ether-rest frame, Newtonian spacetime must be the chronogeometric background for the law. In turn, in special relativity the formula is about kinematics in different frames since the chronogeometric structure on which it is defined is Minkowski spacetime. On the other hand, if the law were chronogeometrically neutral we could not assign it any of the two meanings—or any physical meaning at all.

We can thus draw a Helmholtzian conclusion. If the chronogeometric structures we call spacetimes are to have a physical meaning at all, dynamical principles that operationalize them in terms of the behavior of physical objects are necessary[1]. On the other hand, if the mathematical equations we call dynamical laws are to have a physical meaning at all, they must be setup on a chronogeometric structure background. Borrowing a Kantian expression, spacetime structure without dynamics is empty, and dynamics without spacetime structure is blind. Hence, Brown's thesis that Lorentz invariance explains and is more fundamental than Minkowski spacetime structure cannot be right. The thesis here presented is a generalization of the argument in (Acuña 2016): there it is argued that in special relativity Minkowski spacetime and Lorentz invariance are like the two sides of a single coin, here I argue that the same relation holds between spacetime structure and dynamics in all spacetime theories. Actually, the approach of 19th century physicists is not substantially different from Einstein's in this respect: the dynamical "ether laws" that explain length-contraction and clock-retardation are as chronogeometrically laden as special relativistic laws.

This thesis can provide further insight regarding the discussion about the ontology of spacetime. If chronogeometric structure has no physical meaning when disentangled from dynamics, and if it plays the role of making dynamical laws intelligible, the view that spacetime represents an entity—whatever its mode of existence may be—becomes unmotivated. On the other hand, if dynamical laws are not (kinematically) intelligible unless they are setup on a chronogeometric background, it is not possible to conceive spatiotemporal relations between bodies prior to the introduction of chronogeometric structure—so that the relationist thesis gets challenged as well. I will then suggest that the thesis I am introducing promises a dissolution of the substantivalism/relationism debate.

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[1] Helmholtz was wrong in that rigidity is a necessary concept to operationalize geometric structure. In special relativity there are no rigid bodies. His main point stands, though. How the operationalization is achieved is a different issue.

Extended Abstract

# Kant, Einstein, Reichenbach

*Fedde Benedictus*

My aim in this talk is to analyse the relation between Einstein's postulate of relativity and Kant's view on *a priori* knowledge, in the light of Reichenbach's take on this relation. It is well known that Einstein was inspired by Kant. Although the precise role of Kant's philosophy in Einstein's thought is an issue of an ongoing debate, within the first generation of philosophers who tried to gauge the consequences of Einstein's theories for the philosophy of science – Reichenbach, Cassirer and Carnap, among others - there were already opposing views as to the relation between Kant's philosophy and Einstein's physics. In this talk I will focus on Reichenbach's interpretation of that relation.

Reichenbach famously distinguished between two different aspects of Kant's concept of the *a priori* – the *apodictic* and the *constitutive* a priori. According to Reichenbach we should do away with the apodictic aspect, because it goes against the foundations of empirical science. In his habilitation thesis "The Theory of Relativity and A Priori Knowledge" (1920) Reichenbach sees it as his task to discover what remains of the Kantian a priori in the face of Einstein's theories. In the work Reichenbach formulates his idea of the *relativised a priori* – making it precise how an element of knowledge can be constitutive without being apodictic. In my talk I will show that Reichenbach's idea about the relativised a priori is closely related to the idea of the *functional* a priori of Arthur Pap. Pap's a priori does not refer to propositions that are a priori in the sense of being independent of observation, but rather a priori in the sense of being a *pre*condition for a specific theoretical context. (for example, in the context of Newton's physics it is a priori assumed that forces behave as vectors. This assumption, although a priori, has proven useful in aeons of physics – it is very *a posteriori* indeed)

After characterising the different kinds of a priori of Kant, Reichenbach and Pap, we revisit the relation that we began with: that between Einstein's physics and Kant's a priorism. In what sense should we regard Einstein's relativity postulate as a priori? Certainly not in Kant's sense, of the *synthetic a priori*. Is there a sense of the a priori which we should apply to Einstein's postulate? This and related questions I will attempt to answer in in my talk.

For a draft version of a paper on the relation between Einstein's relativity and Kant's a priorism, please see the following:
https://feddebenedictus.com/2018/03/20/einstein-kant-synthetic-relativity/

Diff constitutive/conditional
Diff factual/synthetic

**Too distant worlds. Spacetime Structural Realism and Physicality. [Extended abstract]**

*Damian Luty*[1]

The goal of my presentation is to evaluate spacetime structural realism (SSR)) in the context of problems about classifying certain spacetime models as physical or unphysical. I claim that those problems lead to serious doubts about „realism" in spacetime structural realism.

SSR, if modelled after ontic structural realism (OSR) or moderate ontic structural realism (MOSR) should be considered, I think, as a strong realistic position towards spacetime. By „strong realistic position" I mean such a position in which one holds metaphysical, epistemological and semantic beliefs towards entities posited in the domain of discourse of a given scientific theory. Ontologically oriented structuralists seem to take the thesis of epistemological realism for granted; they sometimes try to ground their position in certain semantics (e.g. partial isomorphisms approach). The fuss is, of course, about the thesis of metaphysical realism - how to cash it out in structural terms, especially when one has in mind interpretative applications to certain theories, like general theory of relativity (GTR)? I claim that even if all three thesis are non-standard or somehow revisionistic, when all of them are hold jointly in one way or another, then we are dealing with strong realism. For some, surely, metaphysical realism alone is far too strong; but I bracket naive realism here.

What is the metaphysical thesis of SSR, what is the nature of spacetime according to SSR-ist? Surely, spacetime is treated here as a real existent. If SSR is modelled strictly after OSR then spacetime, metaphysically, has no parts, for only spacetime relations invariant under relevant transformations are considered ontologically real. Individuals – spacetime points – are banned from SSR-ists ontology. Structure is taken to be a set of relations. This version of SSR seems not to be promising.

SSR modelled after MOSR treats spacetime points and spacetime structure encoded in the metric tensor field as ontologically on a par, with the addition that spacetime points have no primitive individuality; they gain individuality via the metric tensor. However, this leads to the concept of discernibility only *via* spacetime relations. Admitting individuals in SSR while formulating criteria of identity in relational terms means that in case of spacetime in GTR the role of identification can only be played by spacetime curvature. This criterion is valid only in generally non-symmetric spacetimes. The argument called „the abysmal embarassment for spacetime structuralism" points out that in highly symmetric, cosmic spacetimes (with Robertson-Walker metric) there is no way to discern spacetime points and SSR-ist is forced into accepting that there is only one point in the universe. This is a very

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[1] Damian Luty is Adam Mickiewicz University Foundation scholar in 2017/2018 academic year.
This presentation is a part of a project funded by National Science Centre in Poland, grant registration number: 2016/23/N/HS1/00531.

uncomfortable result: to avoid this conclusion one must resort to arbitral admittment of numerical distinctivess or toy with the notion of discernibility.

Now, the usual response to problems generated by symmetries in spacetime is to discard such examples with highly symmetrical spacetimes, deeming them unphysical. But this price seems too high. Should we discard Minkowski spacetime or the Schwarschild solution, and claim that those are unphysical? This would seem to be an instrumentalist ploy or a sort of selectivism. I think that this doesn't suit any realist well.

Given that in some forms of SSR one must reduce the number of physically sound spacetime models, it is reasonable to say that this lack of trust towards GTR makes SSR not that realistic at all. If we accept the strong realist reading of SSR, then in SSR there is an inconsistency regarding how to formulate (approximatly) true statements about physical facts dealed with in certain models generated from GTR. If we accept that SSR is only a metaphysical thesis then solutions to problems concerning symmetric spacetimes are poorly motivated.

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# ALGORITHMS, THEORIES AND ONTOLOGY; SPACETIME FROM THE PERSPECTIVE OF STATISTICAL MECHANICS

G. N. ORD

Abstract. Relativity and quantum mechanics both claim impressive empirical accuracy and are both considered to be *fundamental* theories, despite being based on very different paradigms. From the perspective of classical statistical mechanics, there are good reasons to suggest that quantum mechanics is more *algorithm* than theory. The addition of a discrete signal to worldlines in special relativity reveals the task that the quantum algorithm accomplishes. It also displays the reason that a linear superposition principle applies to a 'square root' of probability density functions. In this view the quantum algorithm is directly linked to spacetime and would *not occur* in a Newtonian world where space and time are independent. It arises as a consequence of Minkowski's merger of space and time under the additional condition that worldlines have an intrinsic scale at the Compton length.

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# Abstract for 5th International Conference on the Nature and Ontology of Spacetime 2018

Uri Ben-Ya'acov

Title : **Proper-time measurement in accelerated relativistic systems**

Abstract :

The proposed lecture emerged from a work which addresses the question of *Whether it is possible to assign the concept of common proper-time to complex, spatially extended, relativistic systems as a whole*; in particular, with the wish to use this common proper-time for the *age* of the system.

The process of time measurement uses ideal clocks – inertial point-like clocks – and requires simultaneity between events in the clock system and the measured system. Therefore, in a basic time measurement the clock must be at rest relative to the system in which the measured process occurs.

For a point-like body, the proper-time measurement is identical with the reading of a clock momentarily at rest with the body : An un-accelerated point particle may always be found at rest relative to some inertial frame, so the proper-time measurement for it is identical to the clock reading in that frame. Otherwise, if accelerated, at each and every point along the body's journey in space-time a different ideal clock must be used, relative to which the body is momentarily at rest. Then the proper-time lapse of the particle moving on the world-line $\left(t,\vec{r}\left(t\right)\right)$ relative to some inertial reference frame is the integral $\Delta\tau=\int\sqrt{dt^2-d\vec{r}^{\,2}}=\int\sqrt{1-\vec{v}^{\,2}}dt$ along the world-line. Since this is the only time measurement available for that particle, it must necessarily serve as the measure for its age.

Real physical systems are not point-like but composite, spatially extended. Even if their constituents may be regarded point-like, these move on different world-lines, each with its own proper-time lapse.

Comparing the proper-time lapses at two different points of the system, say A and B, between any two states of motion, requires using some kind of simultaneity at any of the two states. Since simultaneity is frame dependent and not preserved by Lorentz transformations, much care has to be taken at this point. If the system is inertial there is just one (inertial) rest frame that accompanies the system through its space-time journey, and the correct measurement of proper-time is relative to this rest frame. But if the system accelerates then we must identify a momentary inertial rest frame common to A and B in the initial state, and similarly for the final state, so as to mimic the proper-time measurement for an inertial system.

Therefore, if we want to be able to compare the proper-time lapses at A and B at any stage of the system's journey, then it is required that a momentary inertial rest frame common to A and B must be found at each stage. If A and B are arbitrary points within the system then it implies that the whole system must be moving rigidly. Rectilinear rigid motion is possible for arbitrary (also time-dependent) accelerations (taking into account necessary differential accelerations between different points), thus making it possible to use rigidly accelerated extended systems to model comparative proper-time measurement.

Since proper-times are Lorentz invariant quantities they should be treated in a Lorentz covariant manner. Linear relativistic rigid motion with general (not-necessarily constant) accelerations is discussed Lorentz-covariantly, allowing to relate accelerations, velocities and proper-times of arbitrarily different points along the moving body. Differential ageing is computed, found to be proportional to the proper spatial distance between the two points and to the rapidity difference between initial to final states.

Once instantaneous simultaneity is determined, the clocks at A and B must be synchronized in some way. This is done using light signals transmitted between the clocks, and the effect of the acceleration on the synchronization is discussed.

Proper comparison of the proper-time lapses at two points of an accelerating system is thus uniquely determined, Lorentz-covariantly, for rectilinear relativistic rigid motion, which may then serve to model comparative proper-time measurement in accelerated relativistic systems.

In particular, this model may be used to consider ideal vs. physical clocks:

The idea of a point-like clock is fundamental for the concept of space-time continuum. It is necessary in order to define a time-like axis. An inertial reference frame in Minkowski space-time consists of point-like clocks moving on parallel time-like geodesics. But point-like clocks are idealizations. Real clocks are composite systems, consisting of many points. If the clock is inertial then all its constituents measure the time equally, which is also the rate that time is measured by the clock. But if the clock accelerates then different constituents of it, moving on different world-lines, may have different proper-time rates. Thus the question arises, *How does this fit with the clock being itself a timekeeping device?* Or, in other words, *What is the relation between the intrinsic time-unit of the clock and external proper-time measurement ?* A discussion of these issues will also be included, as time allows.

Finally, it is important to emphasize that incorrect application of simultaneity to comparative time measurement in accelerated systems (partly due to lack of using Lorentz covariance) leads to wrong conclusions and appearance of so-called `paradoxes'. This will be illustrated with two examples, Bell's spaceships `paradox' and Boughn's `identically accelerated twins'.

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**Tenses modally introduced:  a reductio argument?**

There is a conflict between manifest time and time of physics, as structures needed for manifest time cannot exist in space-times of physics. The main elements of the manifest time are (1) a tripartite division of the world into the past,  the present (now), and the future, (2) a continuous succession  of the nows, and (3) an ontological difference between the fixed (settled) past and present,  and the open future.

A little explored road to introduce relativistic-friendly tenses takes the settledness vs. openness for their essential feature, while reading this distinction as modal, i.e.,  concerning alethic necessity and contingency. On this view, tenses and what their loci are, depend on patterns of chancy local events. Suggestions  to link tenses to indeterminism can be found in Whitrow (1961, pp. 295–296), or more recently in Ellis (2006, pp. 1812–13), yet, since the project requires a framework combining time and modality, it has not been rigorously investigated until recently.

Our aim is to first define, in the context of special relativity, the future of a given point-like event, and then use it to intrude the remaining tenses. Having said that the future has an aspect of contingency, there are many ways how to precisify this intuition. Motivated by examples like the Summer solstice 2018 (i.e., an apparently deterministic yet future event), I opt for the following weak reading:

*(*)  f* is in the future of *e* because there is some event *e'* before (or identical to)  *f* and a subject matter *A* such that at *e* it is contingent that *A* obtains at the location of *e'*.

To turn this idea into a  rigorous definition, we construct a semantic model based on the so-called Minkowskian Branching Structures (MBS) of  Placek & Belnap (2012). An MBS represent alternative possible scenarios, all developing on a stage of Minkowski space-time from some common past (initial conditions). A possible scenario is thought of as Minkowski space-time plus a physical content, the latter being represented by an attribution of "point properties" to quadruples of real numbers.

The construction of an MBS is governed by two rules: (1) An anti-haecceity thesis requires that any two scenarios must be qualitatively different somewhere. (1) A strong anti-haecceity thesis further postulates that if a quadruple *x* has different properties assigned in two scenarios, then there is a special point (quadruple) *c* below *x* such that the two scenarios agree qualitatively in the past of *c* but disagree somewhere closely above *c*.

An MBS is a semantic model for languages with modal and temporal operators. Hence given an event *e* in an MBS, the definition (*) picks its future, past, and present. Tenses so defined have the following features:

1. the concept of "the present of *e*" is (special) relativistically invariant;
2. tenses and causal relations (light cones) are different, e.g., the past of *e* is typically *not* the backward cone of *e*;
3. what the present of *e* is is contingent: it depends on the localization of chancy events, which in turn depend on localization of qualitative differences (on what might have beens);
4. there are two extreme cases for the now: the whole world and an achronal 3-dim space-like surface.

I will leave it to the audience's evaluation whether such contingent tenses with somewhat weird features are satisfactory for friends of tenses.

# Conventionality and Reality

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Two debates have been central in the philosophy of special relativity. The debate on the *conventionality of simultaneity* was sparked by Einstein in 1905, and the debate on the *dimensionality of the world* was initiated by Minkowski in 1908. Both debates have raged ever since. Yet, interestingly, the link between them has rarely been explored.

Important exceptions are Weingard, Petkov, Ben-Yami, Cohen and Sklar. Radically different conclusions were reached however about the way the former debate impacts the latter. According to Weingard [1] and Petkov [2–3], the conventionality thesis lends further support to the claim that the world is four-dimensional. Ben-Yami [4] and Cohen [5] disagree and argue for the opposite thesis, whereas Sklar [6] remains largely uncommitted.

The purpose of this talk is to clarify the current situation by further exploring what implications (if any) the conventionality of simultaneity has for the debate on the reality of spacetime.

In the first part of my talk, I focus on the (in)famous *Rietdijk–Putnam argument* for the four-dimensionality of the world [7, 8]. Drawing on the work of Peterson and Silberstein [9], I reformulate the Rietdijk–Putnam argument in order to make its structure more explicit, and thereby expose the different assumptions that go into the argument.

I then turn to the various objections that have been raised against it. After briefly reviewing the *transitivity objection*, I focus on the *conventionality objection* which is based on the conventionality thesis of simultaneity and which was first put forward by Weingard [1] in 1972 and by Sklar [6] in 1981. Since then, it has also been voiced by Cohen [5] and (apparently without knowledge of the earlier authors) by Ben-Yami [4].

According to the conventionality objection, since simultaneity is a conventional notion, reality becomes conventional too. Sklar [6] for instance argues that since "what counts as the present is only a matter of arbitrary choice, so then is what is taken as real." As a result, the Rietdijk–Putnam argument does not even get off the ground.

I show the situation to be more subtle than that, and argue that the way in which the conventionality thesis impacts the Rietdijk–Putnam argument depends on whether the conventionality of simultaneity is an ontic or epistemic thesis. If it is an ontic thesis, the conventionality objection goes through as intended.

With regard to the epistemic position, I make a further distinction between the *agnostic* and the *ε-epistemicist*. I argue that on most epistemicist positions regarding distant simultaneity, the Rietdijk–Putnam argument remains unaffected by the conventionality objection. Only on a neo-Lorentzian reading of special relativity with a notion of absolute simultaneity, or in certain interpretations of quantum mechanics which introduce a preferred foliation of spacetime, does the Rietdijk–Putnam argument fail.

In the second part of my talk, I turn to the *Weingard–Petkov argument* for the four-dimensionality of the world [1–3]. Whereas the Rietdijk–Putnam argument relies on the relativity of simultaneity, the Weingard–Petkov argument relies directly on the conventionality of simultaneity. It therefore does not face the threat of the conventionality objection. However, I show that the Weingard–Petkov argument still suffers from the same transitivity objection as the Rietdijk–Putnam argument, and also raise a number of further objections.

I conclude that the soundness of the Rietdijk–Putnam and Weingard–Petkov arguments hinges on our interpretation of reality, and in particular on whether 'being real' is a monadic, dyadic or triadic relation. Whatever the case, since the reality relation does not belong to the formalism of special relativity, I concur that special relativity is unable to resolve the debate on the dimensionality of the world. Special relativity leaves the dispute underdetermined.

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Anguel S. Stefanov

# THE GROWING BLOCK CAN HARDLY EXPLAIN THE EXPERIENCE OF TIME FLOW

Every physical theory works with a concept of time that is perfectly, but formally inscribed within its mathematical apparatus. The fundamental problem what is the nature of time, and of space-time, is left for a more abstract theoretical reasoning, and chiefly for philosophy (metaphysics).

From a metaphysical point of view there are two different conceptions about the nature of time. The first is a *dynamic one*, and is elaborated by different, so called A-theories of time. Usually, they seriously speak about time as flowing. This conception stays in harmony with the classical view that the physical world is three dimensional and evolves through time. However, this classical view is taken to be obsolescent against the background of the ontologies of the special and of the general theory of relativity.

The second conception of time, *the static one*, is elaborated by different, so called B-theories of time. It postulates time to be a universal dimension of a basic physical reality – the space-time. So, time ceases to be accepted as flowing. The static conception stays in harmony with the ontologies of the special and of the general theory of relativity. However, it implies the view of the *block-universe*, which is somehow reluctantly accepted by scientists and philosophers, and raises a problem of its own – why then time *is experienced* as flowing?

Against the background of the embarrassments just mentioned, a third conception about the nature of space-time has emerged – the so called *growing block theory*. It shares parts of the ontology both of the static and of the dynamic conception of time. To this effect it is expected that this theory can provide a better understanding of the nature of time. And if so, one could also expect that the growing block is in a position to explain why time is perceived by us to be flowing.

I'll try to show that unfortunately this expectation does not hold water.

According to the growing block theory, the spatio-temporal aspect of the physical world is but a growing "block" of space-time filled with material events. This means that the universe remains static regarding all its states belonging to the past, while it is intrinsically dynamic regarding all its future states.

If the physical world is accepted to be a growing block, then a natural assumption is the experience of the flowing time to be referred to the effect of the growth of the spatio-temporal block itself. *Time flow is explained by the process of addition of new slices of reality onto the block*. The curious question then can be posed "How fast does the block grow?" I am not sure that this question has obtained a definite answer.

Let us suppose, however, that the universal block grows at some definite rate. Then this rate could be taken to be at the base of our sense of time passage. But this contention can hardly be taken to be true, neither from a psychological, nor from a physical point of view.

For one reason, human experience of time flow does not seem to be fixed. It depends on our emotional states initiated by different life conditions.

And for another reason, because of the fact that for two observers, being in relative motion to one another, an event lying into the future of the first observer can be a present event for the other one. According to the growing block theory such an event must not have a real existence for the first observer. However, the same event is taken to be quite real for the other one.

Along the line of this consideration the conclusion comes to the fore that *the concept of real existence becomes relative*. And if this conclusion is unacceptable, then one has to assume one of the horns of the following *dilemma*: either there is something wrong with the theory of the growing block, or the universal block is really growing, but its enlargement cannot explain the human sensation of time flow.

The proponents of the growing block could wish to cope with the first horn of the dilemma, and to evade the conclusion about the relativization of reality. This could solely be done through the claim that the accreting slices of reality have some well-defined thickness, allowing one and the same event to be both present for one observer, and a future one for another observer. However, this supposed thickness of the block slices would be a *purely arbitrary assumption*, in so far as it is not an empirical consequence from any affirmed theoretical principle. This is an ontological difficulty.

But even more, if one would like to relate the growing block theory with what we know about the real expansion of the universe, then one would meet two other embarrassments. The first one is the alleged non uniform way of the universal expansion, and the other is concerned with putative local variations of the expansion, dependent on the matter and energy distribution along the boundaries of the universe (while the so called "dark energy" has a constant value).

Does this mean that the experienced passage of time will undergo a parallel change as well? An objection could here be raised that this question does not presuppose a reasonable answer, since if our subjective feeling of time passage is induced directly by the universal expansion, any observation of a change of our human subjective feeling would be impossible. But even if this were true, the very posing of the question is not meaningless. It comes out then that the changing rate of the universal expansion is somehow ontologically connected with the variable speed with which the time of our experience is contended to pass. Thus one becomes bound by another unsolved (and as it seems, unsolvable) problem about the speed of time passage.

In the face of the difficulties of the growing block to explain the reason why time is perceived to be flowing, it seems reasonable the second horn of the dilemma to be embraced. So, it comes out that the growing block theory, even if taken to be an adequate account of spatio-temporal reality, is not in a position to explain the human sensation of time passage.

# Can a worldview contradict experiment: can experiment decide whether spacetime represents an evolving present, a block universe or a growing block universe?

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*Note that there is no dynamics in space-time:*
*nothing ever happens there. Space-time is an unchanging,*
*once-and-for-all picture encompassing past, present, and future.*
Robert Geroch [1]

The issue of whether experiment can prove or disprove a worldview is controversial. On the one hand, a worldview is supposed to reflect adequately what exists which means that a worldview must be based on observations or experiments. On the other hand, both observations and experiments may have more than one interpretation which implies more than one view of the world. What further complicates this issue is that some philosophers still seem to believe that philosophical views about the world are exempted from the scrutiny of experiment, which leaves open the obvious question – how can it be determined whether such views have anything to do with the external world?

I will first provide arguments which I believe show that any knowledge about the world (not just science) must be based on the existing experimental evidence and be amenable to test by experiment. Then I will consider the main theme of the conference – the nature of spacetime – as a case study and will examine whether the existing experimental evidence is sufficient to rule decisively on whether spacetime should be regarded merely as an abstract mathematical notion which models an evolving present, or spacetime represents a block universe or a growing block universe.

In other words, as the dimensionally of the world is an integral feature of reality, the examination of the experimental evidence will determine whether the crucial question of what the dimensionality of the world is can be unambiguously answered.

I will begin the case study by rigorously examining Minkowski's insistence, made in his 1908 lecture "Space and Time," that the spacetime view of the world (introduced by him and often called block universe) "arose from the domain of experimental physics" [2] and will show why his assertion is correct which means that a worldview can indeed be tested by experiment. Then I will discuss whether there is any support from experimental physics for the other two main worldviews – the evolving present and the growing block universe.

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# THE POST-DETERMINED BLOCK UNIVERSE

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By starting from the assumption that the time evolution of a quantum system is always unitary, I arrive at a type of block universe which is different from both the standard one, and from the evolving one.

In fact, the unitary time evolution of quantum systems is not an additional assumption, it follows from the Schrödinger equation and its relativistic versions. What I do is not to add a new assumption, but to argue that the assumption that unitary evolution is suspended during measurements and replaced by a discontinuous collapse of the wavefunction is not actually proven by experiments, and its acceptance was done too quickly. If we can show that the discontinuous collapse is unnecessary, new possibilities open, including for combining Quantum Theory with General Relativity without sacrificing any of them.

The solutions of Schrödinger's equation are unitary, but when we think about "unitary evolution", we think at two different things. On the one hand, as long as no measurement is made on a quantum system, we can regard the wavefunctions as physical fields. Not fields on spacetime, but fields on the phase space. On the other hand, Born's rule gives a statistical interpretation of the wavefunction, which is consistent with the experiments too. Let us call the first interpretation "ontic", and the second "epistemic" (these notions may be used differently by different authors, but I will stick with the definition that "ontic" means that the wavefunction is a physical field on the phase space, and "epistemic" is the knowledge of probabilities or information). Both positions are correct and mutually consistent, once we realize that they refer to different wavefunctions, as I will explain.

The second view was introduced because quantum measurements don't give the wavefunction, but an eigenvalue of a Hermitian operator which is associated to the quantities that we measure. Consequently, we find the wavefunction in an eigenstate, with a probability given by the Born rule. If there was no such problem of measurement, we could interpret very well the wavefunction as being a field in the phase space, and we would have no measurement problem at all. But when we successively perform two incompatible measurements, it seems that the only way to get both times an eigenstate is if we admit a projection happened between the two measurements, which is taken as a collapse and as forcing on us the idea that the wavefunction is probabilistic.

A quantum measurement requires a measurement device, which is a very large quantum system assumed to behave almost classically. This means that we ignore its true quantum state. We also assume that quantum measurements are sharp, which was proven by Wigner to hold only approximately [13, 3]. However, can we make such a strong statement, which amounts to suspending one of the most successful equations, given that the true quantum state of the measurement apparatus is ignored, and that in fact no truly sharp measurement can be made? Why would the evolution be always unitary, no matter for what systems, only to be violated during quantum measurements?

A discontinuous collapse leads to several problems. The conservation laws are due to the commutativity of the operators with the Hamiltonian, but they don't commute with the projectors invoked during measurement. In fact, simple thought experiments show that conservation laws are broken, no matter how we interpret the wavefunction, and this happens even in the Many Worlds Interpretation, for each single world [12]. Moreover, a discontinuous collapse introduces problems with General Relativity, since it implies that also the stress-energy tensor associated to the field collapses, hence, by Einstein's equation, the geometry of spacetime becomes discontinuous, and the covariant derivatives infinite, which is more than unpredictable.

Fortunately there is a way by which unitary evolution is preserved also during measurements, such that the recordings are still consistent with the experiments [7, 11, 12] [1]. This of course should take into account the low-level interaction between the observed system and the measurement device.

However, unitary evolution implies the necessity that the initial state of the observed system and that of the apparatus are in a special relation, even before they interact [9]. The initial conditions for which this works form a zero-measure subset of the Hilbert space! Now this can be seen as "retrocausality" or "superdeterminism". But we know from Bell's theorem that we have to choose between nonlocality and statistical independence (the second option

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[1] Schulman proposed that this may be ensured by imposing that the initial and final states of the universe are separable [4, 5], which is not the position taken here.

was coined by Bell "superdeterminism"). For someone who prefers that the state of the universe is determined (even though unknown) at each instant, in particular for a *presentist*, nonlocality may seem acceptable. But for a relativist nonlocality may be unacceptable. All dynamical equations, including Schrödinger's and its relativistic versions, are local, since the interactions involved are local (although the states can be entangled). Nonlocality will seem at odds with relativity, but assuming that the initial conditions are very special somehow is still consistent with locality and with special and general relativity. The block universe comes to rescue.

We tend to see the dynamics as determined by the initial conditions and the evolution equation. However, in some cases there are obstructions to the existence of global solutions for most initial conditions. When topology is involved, these obstructions imply that not all initial conditions lead to global solutions. A simple example comes from finding all holomorphic functions on a sphere, where the mere topology of the sphere combined with the Cauchy-Riemann equations lead to a drastic reduction of the possible global solutions, allowing only the constant ones.

The study of these obstructions on the existence of global solutions is done in *sheaf theory*, in particular in *sheaf cohomology* [2]. We don't know at a fundamental level what quantization is, we only know recipes to get quantum theories out of classical theories. We don't fully know the topological implications of the various bundles involved in gauge theory, neither the topological properties of particles, but there are indications that they may be relevant. When we will have such a theory, we will have to take into account the topological obstructions, and see what are the implications on the initial conditions. Then, in such a theory it may be the most natural thing to assume what for a presentist looks like "superdeterminism" or "retrocausality". This possibility was proposed in [8, 10].

This kind of block universe is deterministic, but it is not predetermined in the usual sense. The initial conditions are determined with a delay, by each new measurement and each choice of what to measure. The requirement of global consistency implies a severe restriction of the solutions of the Schrödinger equation, but since the observers can choose what to measure, it looks like they determine the past initial conditions more, with each new choice. The solution is still deterministic, but it is determined by future choices. We can still think at this as superdeterminism or retrocausality, if we assume that the initial conditions are fixed from the beginning. But we can also take the stance that the quasi-classical limit, which is a coarse graining of the low-level quantum state, evolves by usual causality in an indeterministic way. As observers, we start with the full set of quantum states consistent with the macroscopic observation, and then reduce them as new measurements provide more information. And since we never know the true quantum state, but only outcomes of our observations made on subsystems, these observations allow us to predict only probabilities, or an epistemic wavefunction which is an approximation of the ontic wavefunction. Moreover, this combination between choice and determinism has implications about free will [6, 10, 1].

By eliminating the discontinuous collapse, we remove an important obstruction which seemed to put quantum theory and general relativity at odds with each other. The so-called *semi-classical gravity* can now be more than an approximation of a future theory of quantum gravity. With an ontic wavefunction, the "expectation value" of the stress-energy operator is not a probability, but a field, and we can plug in into Einstein's equation and get a well-defined classical geometry.

This type of block universe is as deterministic and fixed as the standard one from the bird's eye view of someone who knows completely the ontic wavefunction of the universe. From the point of view of someone who is part of the universe itself, like us, it may look as a growing block universe, with the amendment that the growth is not only towards the future, but at quantum scale it is also towards the past, giving the impression of retrocausality. But this retrocausality is not accessible to us to send messages into the past or at a distance, being forbidden by the fact that we only have clearance to approximate eigenstates, and not to the full quantum state of the observed systems.

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## Abstract for 5th International Conference on the Nature and Ontology of Spacetime 2018

Uri Ben-Ya'acov

Title : **<u>The implication of Gödel's incompleteness theorem on our apprehension of the nature of space-time</u>**

Abstract :

The central theme of this conference is the nature of space-time, and my question is : To what extent can such questions be answered ? Is it possible to arrive at a final statement regarding the nature of space-time ? Is it possible to encompass with a finite number of first principles and inference rules the full extent of the Universe ?

Gödel's incompleteness theorem implies that *in any consistent and rich enough formal structure, based on a finite number of first principles and inference rules, there will always be claims that may be formulated within this formal system but are undecidable* – questions that are not answerable, claims that cannot be either proved or refuted.

A close inspection of Gödel's theorem demonstrates that this impossibility arises when the claims are self-referential, or, more precisely, when the system asks to define itself in its own terms. This is very relevant to our case, since questions regarding the nature of space-time, the basic structure of the Universe, are asked from within it.

The way to remedy, in a sense, the non-answerability, is to add new first principles that allow an answer. Such first principles necessarily rely on new observations. But their addition creates a new theory, which in its turn produces new non-answerable questions.

In this way new insights, new knowledge, new information that are not derivable from old ones will be accumulated. The scientific research will produce, in a never-ending process, more and more insights, understandings and knowledge, within larger and larger theories.

This situation is certainly very familiar from the history of science, and I don't pretend to present in this sense any novelty. However, the fact that it is organically inherent in the nature of the scientific process, as is asserted by Gödel's theorem, is not realized by many, and if it is it seems to bring disappointment: Many people wish to arrive, hopefully in their life-time, to a theory that fully describes, with few and simple first principles, the whole of the physical world. This was certainly

the vision of Newton and Einstein. The realization of impossibility of such aspiration causes them much disappointment.

My view is different :

> The more we know then there is, and will be, even more to be known and reveal. The prospects to discover become larger, not smaller.
>
> The "cake of knowledge and understanding" is not fixed, unchanging, but rather ever-growing. Thus there will always be more to be known, to be revealed, to discover, not less.
>
> And indeed, if this were really the case (*i.e.*, that a theory that fully describes, with few and simple first principles, the whole of the physical world, is possible), then what new first principles will be left for the coming generations to reveal and discover ? What prospects would they have then ?

Not every question that lacks answers is Gödelean (*i.e.*, self-referential and non-answerable in the absence of appropriate first principles), but it is very reasonable that questions regarding the nature of space-time, like the theme of the conference, are Gödelean. I will attempt also to discuss, as much as possible, also the nature of such Gödelean questions, which is currently an evolving research.

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## Dark Matter = Modified Gravity?

*Scrutinising the spacetime-matter distinction through the modified gravity/ dark matter lens*

*Niels Martens & Dennis Lehmkuhl*

When applying the laws of gravity to the luminous matter that we observe around us in the universe, one obtains an evolution of that matter which is not empirically adequate---at the scale of galaxies and galaxy clusters as well as at the cosmological scale. We face a dilemma between two options that seem to be obviously distinct: either the matter sector needs to be complemented with non-luminous (i.e. dark) matter (DM), or the gravity sector needs to be modified (MG) (or perhaps a bit of both).

Although this dichotomy indeed seems to hold up when merely applying Newtonian Gravity, as is often sufficient at the level of galaxies, this distinction becomes much less clear when moving to relativistic and quantum theories. Features that are historically taken to be paradigmatic hallmarks of matter suddenly feature in theories labeled as modified gravity theories, and vice versa. Instances of self-identified modified gravity theories feature novel degrees of freedom, which are dynamical, often contain mass terms in the Lagrangian, sometimes even have an associated stress-energy-momentum tensor, and/or exhibit violations of versions of the equivalence principle. Instances of self-identified dark matter theories contain fractional powers of the dark matter field in the Lagrangian, rendering a standard field theoretic treatment in terms of Feynman diagrams implausible. Sometimes the coupling of the DM to the Standard Model fermions obtains only indirectly, via the Higgs boson, which is associated with mass (even if not gravitational mass). Moreover, one can obtain certain DM theories from MG theories via a simple conformal transformation, and vice versa. And taking back a step: were we ever clear on why the metric tensor should be considered more geometrical than, say, the electromagnetic vector potential? Einstein doubted it.

In this paper we investigate what criterion, if any, distinguishes DM theories from MG theories. In doing so, we not only draw upon literature on the broader distinction between matter on the one hand and spacetime/gravity/geometry on the other, we also move in the other direction by pointing out the implications of the ambiguities inherent in the DM/MG dichotomy for this broader distinction. More specifically, we compare Khoury and Berezhiani's Superfluid Dark Matter with Hossenfelder's Lagrangian formulation of Verlinde's emergent gravity. We extract from the literatures on spacetime functionalism and on the substantivalism-relationalism debate---in particular responses to the hole argument---a family of candidates for being necessary and/or sufficient criteria for an object being (dark) matter, as well as a similar family of criteria that determine whether an object is a (modified) spacetime. Both of the above theories score maximally with respect to both families of criteria: both theories are as much of a dark matter theory as possible, as well as being as much of a modified spacetime/gravity theory as possible.

This case study is a first sign that the distinction between modified gravity and dark matter theories is much less clear than usually assumed, in a variety of respects---and by extension the spacetime-matter distinction. Or, at the very least, if one insists in holding on to a strict criterion, several candidate theories have been incorrectly labeled as DM or MG theories. This blurring severely undermines the current animosity between dark matter advocates and modified gravity advocates, as well as the substantivalism-relationalism debate (where both camps agree that spacetime and matter are clearly conceptually distinct).

**Space-Time in Upheaval: Relativistic Cosmology and the End of a Static Universe.**

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History of science demonstrates that throughout the centuries, metaphysical ideas and philosophical preferences played a very significant role in the development of cosmological thought. This is probably unavoidable, given the fundamental incompleteness of empirical data when the object of investigation is defined as the entire Universe as a whole. This paper investigates the major transformation in the conception of the cosmological space-time that occurred during the first half of the twentieth century, namely, the abandonment of the traditional preference for a stable, static Universe and the gradual acceptance of the uncomfortable view that our Universe was born out of a singularity, in a violent, explosive way billions of years ago, then expanded dramatically, eventually can possibly collapse back into a point, and maybe even be born again. The first proposal of such a Universe appeared shortly after the formulation of the general theory of relativity, even before the discovery of any empirical astronomical evidence that could support it. The analysis of the 1922 mathematical paper by Alexander Friedman reveals its three fundamental conceptual assumptions that contradicted the then generally shared expectations of what a satisfactory cosmological model should entail: non-stability of the cosmological space-time, singularity of the creation of the Universe that decades later would be called the “Big Bang,” and potential periodicity of cosmological lifecycles. No surprisingly, the non-static model was initially rejected or, more typically, ignored. Further analysis of its gradual reception, development and confirmation during the subsequent four decades in the works by Weyl, Eddington, Lemaitre, Hubble, Einstein, De Sitter, Tolman, Gamow, and others, resulted in the acceptance of most, though not all, of its initial hypothetical assumptions. Historical debates and arguments pro and contra also allow a discussion of what was the possible philosophical/metaphysical/existential basis behind the initial proposal of the “Big Bang” model.

# Renormalizing Spacetime

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(April 24, 2018)

**Abstract**

Three of the four fundamental forces have been successfully renormalized, yielding theoretical predictions that agree with experiment to an unprecedented level of accuracy. However, gravity is not renormalizable [1]. Why does renormalization work so well for the other three forces, but not for gravity? Firstly, consider how renormalization is applied in the case of quantum electrodynamics (QED). The QED Lagrangian is a function of bare charge and mass, as well as bare fields. Renormalizing only the bare parameters of charge and mass will not yield a finite theory. It is crucial that the bare fields are also renormalized. The same is true in perturbative quantum chromodynamics (QCD), where one must renormalize the quark and gluon fields, in addition to the coupling constant and quark mass, in order to obtain a finite theory. In fact, in all quantum field theories, field fluctuations modify bare fields such that they become a function of scale. A bare field $\phi$, for example, is converted into a renormalized field $\tilde{\phi}$ via so-called wavefunction renormalization $\tilde{\phi} = \phi Z^{-1/2}(p)$, where $Z(p)$ is a renormalization factor encoding how $\phi$ depends on the momentum scale $p$. However, up until now the renormalization of the gravitational field (the spacetime metric tensor $g_{\mu\nu}$) has been largely neglected [2]. The aim of this talk is to determine a unique expression for the wavefunction renormalization of gravity, and to explore how this procedure may help to make quantum gravity renormalizable.

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# Extended Space-Propertime Diagrams

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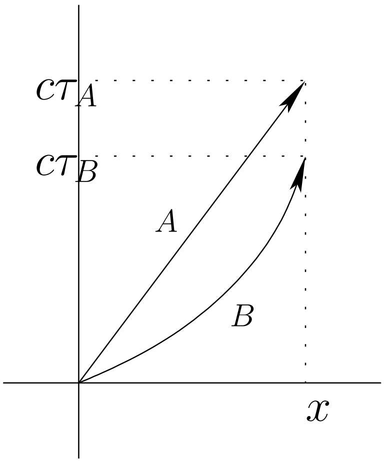
January 31, 2018

Benefits of using space-propertime diagrams are demonstrated by giving a new visual and geometrical derivation of the Lorentz transformations. With a space-propertime diagram we mean a diagram with the usual three spatial dimensions $x$,$y$ and $z$ and the proper time times $c$ ($c\tau$) as the fourth dimension. By extended we mean that we also use the negative proper time direction to represent anti-particles. Note that this is not possible in Minkowski spacetime diagrams, so these diagrams can represent more. Now we introduce the following axiom:

**1) In at least one frame everything moves with the velocity of light ($c$) through space-propertime.**

Mathematically this can be expressed as $c^2dT^2 = c^2d\tau^2 + dx^2 + dy^2 + dz^2$ with $T$ representing the time of a stationary clock in that frame. Note that if we rewrite this we see it is equivalent to the line-element of special relativity: $c^2d\tau^2 = c^2dT^2 - dx^2 - dy^2 - dz^2$. In a space-propertime diagram $T$ is the length of the worldline of any particle, and the propertime can be directly seen on the new axis. So if twins $A$ and $B$, of which only $B$ accelerated, meet again after a time $T$ (so the lengths of their worldlines must be equal) at location $x$, it is easy to see that the proper time of the accelerated person must be less, so $B$ is younger. This visually solves the twin-paradox.




It is also easy to derive the time-dilatation factor $\gamma$ by using purely geometrical arguments. The angle depends on the velocity. To visualize and geometrically derive length contraction we use can use the following axiom:

**2) The three dimensional space (x,y,z) corresponding to each individual reference frame is orthogonal to the direction of motion of that frame through the four-dimensional space-propertime.**

By using the same angle to compare rulers, the scaled spatial transformation becomes $x' = \gamma\,(x - VT)$.

If an observer in any other inertial frame uses slow clock transport in its frame to synchronize clocks and to define simultaneity, we can then see that the transported clock (dotted wordline) will have a different proper time, even when the clock is moved infinitely slow. In that limit the worldlines can be seen as parallel and by using geometry that time difference can be derived.

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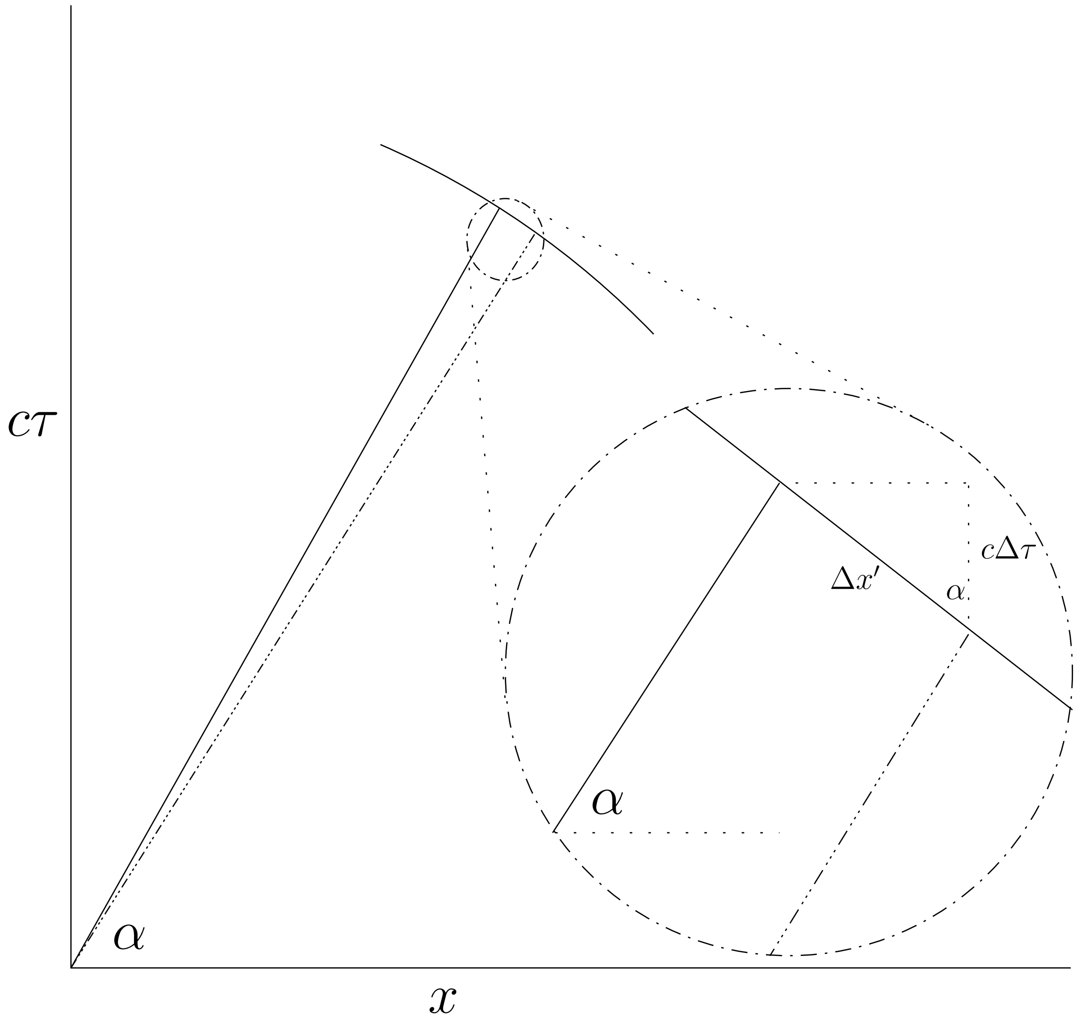


This leads to $t' = \frac{T}{\gamma} - \frac{V}{c^2}x' = \frac{T}{\gamma} - \frac{V}{c^2}\gamma\,(x - VT) = \gamma\left(T - \frac{V}{c^2}x\right)$. So here it is shown that using slow clock transport to define simultaneity leads to the Lorentz transformations and all its consequences. These geometric derivations and these axioms, that do not postulate relativity, are new according to the author. The author previously also proposed the following: The energy-momentum four-vector can be visualized in a similar diagram, by using the mass $m$ as the extra dimension, and the energy as the length of the new vector. In the theory of the author and in these diagrams it is possible to move in a negative proper time direction and to have negative mass. The author interprets these as antiparticles. Usually the minus signs of the mass and proper time cancel, but not for the gravitational source tensor. So the author predicts that antimatter produces anti-gravitational fields and gravitationally repels one another and could cause effects such as dark energy and could be present at the Dipole Repeller, a region in the universe which seems to gravitationally repel everything. This could also help locating the missing antimatter in the universe. In this theory antimatter can't form stars, so it will be dark and distributed. It can also solve the vacuum energy problem, because the gravitational effects of the virtual particles and virtual antiparticles in the quantum vacuum would cancel each other in this theory. See [1, 2] for more details and references.

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## Enforcing the Unity of Space and Time using Quaternions

Gentlemen! And women! The radical change where "space by itself and time by itself will receded completely to become mere shadows" has yet to occur. Well-respected physicist continue to debate the problem of the arrow of time, when the discussion should be about the arrow of space-time.

Why are we still waiting?

The tools of tensor calculus are flexible in regards to dimensions. The Universe is not. If I were so radical as to erase all the Greek subscripts and superscripts from technical books and papers on physics, then I might be able to replace them all with a kind of four dimensional number known as a quaternion. A quaternion forces one to write time or time-related terms in the scalar part, and space or space-related terms in the 3-vector part of a quaternion. There is never a choice to omit. There are a number of immediate benefits to this Minkowski-friendly change of accounting systems. When Newton's second law is written out, there are two time derivatives that have no corresponding spatial derivative. The appearance of zeros or constants where operators could go shows an expression is classical. To generate the second law requires three zeros, so the law is as classical as can be. A relativistic expression on the other hand will have no space-time terms that are zero or constant. Take for example the difference between two arbitrarily close events in space-time and square it:

$$(dt,\ dx/c,\ dy/c,\ dt/c)^{2} = (dt^{2} - (dx^{2} + dy^{2} + dz^{2})/c^{2},\ 2\ dt\ dx/c,\ 2\ dt\ dy/c,\ 2dt\ dz/c)$$

Notice that the first term is identical to the Lorentz invariant interval for inertial observers, the symmetry at the heart of special relativity. There is now an opportunity for new physics by considering the a symmetry for the other three terms which I call space-times-time. The Schwarzschild solution of Einstein's general relativity theory for gravity almost leaves the space-times-time terms unchanged. I propose that the accidentally unchanged space-times-time is an an exact symmetry, the symmetry that gravity is about. Currently, gravity is the solution of ten nonlinear differential field equations. This proposal argues that gravity is a symmetry about all space-time algebra. In special relativity, one uses observers velocities to figure out how to conserve the interval. In this proposal, gravitational escape velocities do the same task to conserve space-times-time.

Radical ideas require much work. Such is the case for quantum mechanics which is usually written using a Hilbert vector space over a complex number field. I have made technical progress on this subject using series of quaternions to define precisely the inner product of two states: $< A|B > \equiv A^{*}B = \sum_{n}^{m} a_{n}^{*} b_{n}$. I have an iPython notebook which demonstrates different ways the quaternion representation is equivalent to the standard Hilbert space approach. Here again, when one writes out central equations in quantum mechanics such as the Schrödinger equation or the Klein-Gordon equation, one gets four equations instead of just one. We should expand Minkowski's vision of the profound union of time-like and space-like expressions into the quantum domain for fresh insights.

# Slicing the Schwarzschild spacetime block

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Nature and Ontology of Spacetime, 2018

In the spacetime of a non-rotating black hole, simultaneity is typically defined using the Schwarzschild-Droste $t$-coordinate, interpreted as the time at spatial infinity. Under such a choice, 4-dimensional spacetime is sliced into 3-dimensional hypersurfaces, each representing a present moment of constant "time". This coordinate slicing is the same as that determined by static observers, who are situated at a fixed location outside the event horizon. I present a different choice of simultaneity, based on families of observers freely-falling in the radial direction. (Because the observers have zero vorticity such a global time is well-defined by Frobenius' theorem, see Ellis.) This choice yields a different convention of the "present" time in the Schwarzschild block universe.

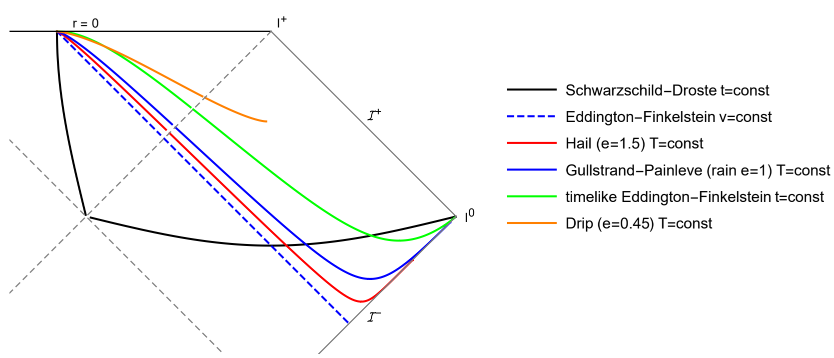


Figure 1: Simultaneity choices under various coordinates and observers, shown in a Penrose diagram. Hail, rain and drips are metaphors for radial motion at various different velocities. The plotted lines are not worldlines (mostly), but rather spatial surfaces (mostly) of constant time. Only one spatial slice is shown for each simultaneity convention, and while they particular slices coincide at the singularity they diverge dramatically near infinity.

Many familiar textbook properties of black holes are implicitly based on the static slicing. For instance 3-dimensional space has a funnel-shaped embedding geometry (Flamm's paraboloid) under the static slicing, but the geometry of a cone under our slicing because the 3-spaces are different. The usual radial proper distance is measured along a static slice, but the alternate slicing gives a simple formula based on the observer's energy. The way "time at infinity" extends to finite locations is different under the alternate convention, which is conceptually important because of the rough analogy with human observers in the Solar System far from any black hole. Hence an object freely-falling through the horizon takes infinite time at infinity under the static slicing, but only finite time at infinity under the alternative.

I will present new coordinates to describe the falling observers, extending a generalisation of Gullstrand-Painlevé coordinates made by Gautreau & Hoffmann and others. However both the static and falling observers are mathematically well motivated from the intrinsic geometry, being determined from Killing vector fields and asymptotic flatness. If possible I will relate the implications for this simultaneity convention to the various positions on the block universe as presented at the conference.

# Minkowski Conference 2018

## Albena, Bulgaria

**Peter Bongaarts. Leiden, Rotterdam**

***Is Special Relativity in Contradiction with Quantum Mechanic?***

# Abstract

*Is special relativity in contradiction with quantum mechanics?*

The average theoretical physicist will spontaneously answer this question with a definite “No!”. However, in the very large community of theoreticians who work in the area of the foundations of quantum theory, an overwhelming majority will answer with “Yes!”.

In this talk I shall show that in this case the average theoretician is right, and mosts experts in foundational matters wrong, even though they will come up with complicated and sophisticated looking arguments to prove their point.

For this I have developed a mathematical formalism in which one can simultaneously consider classical and quantum systems, a formalism that is completely equivalent to the standard description, but that allows a much better comparison between the two types of systems. It is like looking at the situation from another angle. I have called this formalism an ”an algebraic dynamical system”. It turns out to be particularly useful for a rigorous study of the foundations of quantum theory. Using it I have found surprising but also very provocative results, which amount to the fact that most of the literature on this subject is wrong, or irrelevant, at best.

For example, the much discussed notion of ’collapse of the wave function’ does not exist or is trivial; the well-known thought experiment of ’Schrödinger’s Cat’ is just a simple classical stochastic process, which has nothing to do with quantum mechanics. There does not exist a ’measurement problem’, etc., etc.

I shall not discuss here the general situation the properties of algebraic dynamical systems.

The problem (or so-called problem) of the incompatibility of special relativity and quantum mechanics is a relatively minor one, but it fits nicely in the general theme of these conferences, and is sufficiently representative of the general problem. In this problem *entanglement* is an important notion.

I shall make use of slides. They will be simple; each with just a gew lines of text, and with very few formulas, all this just enough to serve as support for my oral presentation.

# The ontology of spacetime and the ontology of the wave function!

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In 2007 Three Wave Hypothesis (TWH) [1,2] has been considered in angular form, and combine its two dispersion relations in only one relation, this system of the three waves is transferred to a system of two perpendicular rolling circles [3,4]. The position vector of a point in a system of two rolling circles may be transformed to a complex vector under an assumption of partial observation effect [5]. Based on that model an analogy has been presented, with extended consideration for the partial observation in the Hermann Minkowski Meeting in 2017[6].

We can say that the concept of the partial observation and the lab observer shows that there are two types of regions (Fig.1), the mathematical space & time, and the observable spacetime. The classical space & time in macroscopic world is no more than an approximation due to the slow speed in comparison with light speed $v \ll c$.
The mathematical space & time is an absolute case and has no relation with the observer's frame of reference. The observable spacetime is an approximation case due to the partial observation.

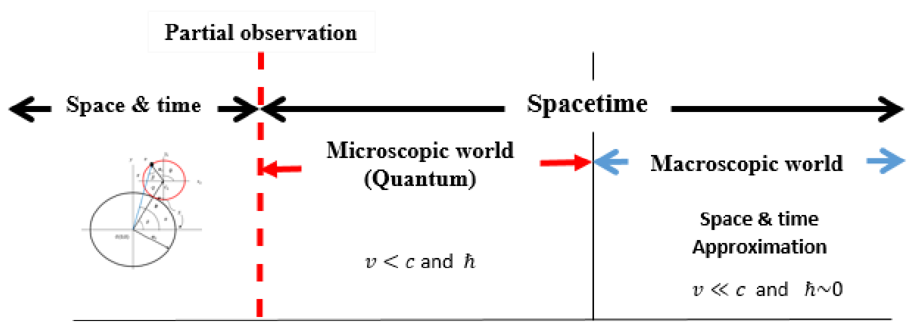


Fig.1 The two regions.

The partial observation works as a filter. This filter separates two different worlds, the real full deterministic world (mathematical) and the physical world (observable) of the complex vector (analogy of wave function). The lab observer and owing to the partial observation cannot recognize the system of two rolling circled and deals with an abstract form. In such a case, the lab observer may use some of the quantum mechanics axioms as a technique.

The observable world (of the lab observer) is defined by a complex vector function and the flat spacetime. Then the both of the quantum world and its spacetime are related to a partially observable system. The approximation of partial observation is not related to the Planck length (minimal physical length).
The combination of space and time that form the interval is related to the system of the two circles combination. The speed of the touch point of the two circles is found to be an analogue for the speed of light.

That analogy [6] may sagest that both of the relativistic quantum mechanics and the special relativity are emergent, and are of the same origin.

The table below shows comparisons between the special relativity equations and those of the analogy.

| **Conventional definition** | **Equations of special relativity** | **Analogical model forms** | **Analogical definition** |
|---|---|---|---|
| **Light speed** | $c < v$<br>$c$ is constant | $v < v_p$<br>$v$ is constant | *Wave speed* |
| **Lorentz factor** | $\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ | $\frac{1}{\sqrt{1-\frac{{v_p}^2}{v^2}}}$ | *Lab transformation* |
| **Relativistic mass (angular frequency)** $\times \frac{\hbar}{c^2}$ | $\omega = \frac{\omega_\circ}{\sqrt{1-\frac{v^2}{c^2}}}$ | $\omega_{1m'} = \frac{\omega_{1m}}{\sqrt{1-\frac{{v_p}^2}{v^2}}}$ | *Lab transformation* |
| **Length contraction** | $\Delta L = \Delta L_\circ \sqrt{1-\frac{v^2}{c^2}}$ | $a_{2m'} = a_{2m}\sqrt{1-\frac{{v_p}^2}{v^2}}$ | *Lab transformation* |
| **Four-vector** $\times \left(\frac{\hbar}{c^2}\right)^2$ | $\omega^2 c^2 = \omega^2 v^2 + {\omega_\circ}^2 c^2$ | ${\omega_{1m'}}^2 v^2 = {\omega_{1m'}}^2 {v_p}^2 + {\omega_{1m}}^2 v^2$ | *Lab space* |

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**Physics theories in the context of multiverse**

The notion of physical law usually presupposes the existence of some exceptional conditions, of some mostly standing rules for nature. To this extent, the scientist`s intent often comes down to searching for a certain law and formalizing it in the equation – expressing it mathematically. Another kind of intent – the explanation of the laws nature – is more complicated and unacknowledged by some scientists. There are loads of questions for this way of research, such as why the entropy was so low at the start of the lifetime of the Universe, why the amount of dark energy is precisely fixed, why the particles masses have the observed values, but not any different ones, etc.

All these questions themselves presuppose that our Universe is unique and there is its only one possible implementation – the one we observe. Within such an approach the mentioned issues and their ilk are actually very important: answers mean unraveling of the enigma of origin. At the same time, these questions provoke one more: might the other laws of physics exist (other values of the constants)?

The anthropic principle is one of the attempts to answer the question of whether the values in our Universe are exactly as we observe them and not something different. The answer is: because we would not exist in the case of other values. However, this is not the solution for the core of the problem, because another question arises here once again: if the other values (at least, theoretically) might exist (in other possible worlds).

The question is to be declared meaningless by the significant part of the scientific community. We do not have and will not have an opportunity to observe any other worlds even indirectly in the foreseeable future and also to carry out experiments that would reveal them. The scientist`s intent is to predict the results of the experiments and to describe them, but not to frame theories according to the nonobservable.

This rational point of view, however, has seriously dented its confidence at the second half of the XX century. The modern cosmology (and other branches of physics) is forced to take into account the ideas that seem considerably conceptual from a practical perspective.

The ideas of the inflation by Alan Guth and the radiation of black holes by Stephen Hawking are the good examples here. The idea of inflation has become very convenient for the needs of cosmology - it allows explaining some very important up-to-date phenomena that the classical Big Bang theory had failed to explain. Although, there are no strictly scientific grounds to claim its validity. The same applies to the most important Hawking`s insight for no other reason than that we will never probably observe the radiation of black holes.

Despite these strong objections, physicists, however, have successfully used the ideas and got certain results following such theories. The superstring theory is another typical example, which is a long way off from the possibility of correlation with the observed reality, regardless of decades of development.

Therefore, the question arises as to whether a mathematical argument, which corresponds to the key standards of our intellectual intuition, such as consistency and completeness, is enough to be considered the theory validity criterion. This question will further show its close connection to the nature of physical laws.

The presentation deals with an attempt to define (or, at least, to formulate it properly) the nature of scientific theory, its validity criteria, the law in modern physics and to specify the tasks of scientific studies.

Almost all the constants, which appear in equations, can be questioned as if they could be different. At least, in theory. This question is purely theoretical. It is meaningless thus far from the point of view of classical physics - the mechanics of Isaac Newton, Albert Einstein's relativity theory, and from the point of view of non-classical one - quantum mechanics. These theories themselves have become the result of the certain laws discovery, their mathematical formulation and experimental verification. They predict the particular behavior of described systems - the results of future experiments. Thus, the law of physics is a certain mechanism, which underlies the processes in our reality, the one that we are able to observe. Accordingly, the search for alternative laws seems rather strange only because they are not related to our reality, and therefore no supervision or experience can formalize them. Moreover, it would be correct to say that the concept of “experience” and its inseparably associated “observation” have themselves been caused by the same physical laws that govern our universe and are possible themselves only because we are the part of our universe. This is true because the other laws of physics (e.g., in hypothetical worlds with the additional spatial dimensions, the other properties of elementary particles, the vacuum energy values, etc.) tend to exclude the possibility of human existence. Here we see, of course, the anthropic principle in such a formulation - these are the laws of physics because there is no point in referring to some others.

This is right. But, as it turns out, there are situations, when it is reasonable to talk about the other laws or their alterations (at least, these alterations occur themselves, even if we refuse to talk about them). In such cases, the consequences of the assumption of the fundamentally different physical conditions need close analysis. These consequences appear to be extremely important not only for understanding the organization of the universe but for the interpretation of the scientific theories and scientific process`s natures.

The presentation analyzes the consequences of the principles of inflationary cosmology and some of the results of the string theory.

How Einstein and Minkowski missed real valued Lorentz transformations for v>c which are possible in 2D and in extended special relativity to 6D spacetime (three space three time) and its possible relation to the nature of spacetime and consciousness

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**Abstract**

Before Einstein's 1905 paper [1] physicists could, as e.g. Sommerfeld [2], discuss superluminal velocities. Nowadays almost everyone knows that Einstein's theory of special relativity (SR), seemingly, excludes superluminal velocities, i.e.$|v| > c$, as Einstein from energy velocity relation argued that it will take an infinite amount of energy to accelerate a body to v=c [1, p 63-64]. And even more impossible to $|v| > c$. Yet already in 1962 it was clarified [3] that acceleration is not the only means to get a velocity, as light has the velocity c and is not accelerated but "born" with v=c. So Einstein's SR does not exclude phenomena, as e.g. particles, "tachyons", with $|v| > c$. Feinberg and others describe possible features of tachyons [4] and possible ways to avoid seemingly causality violation [5]. There has also been experimental search for tachyons, the first in 1960-ties [6]. Yet no direct detection has succeeded even if some argues for indirect traces [7]. Often is used the old energy-velocity relation even for $|v| > c$ but assuming "tachyons " having imaginary rest mass gives measurable real valued energy [3,4,6]. Possible but perhaps a little ad hoc.

Another approach that seems more in the spirit of principle of relativity and more concerns the nature of spacetime is to examine the possibility of faster-than-light inertial frames and possible generalisation of the Lorentz transformation: if tachyons exists it is conceivable that a group of them with same constant velocity $|\overline{\boldsymbol{v}}| > c$ relative to an ordinary IS could be thought of as an inertial frame where these tachyons are at rest and have real coordinates. And if they shall exist also in our physical world they must have real coordinates in ordinary IS [8]. Parker [9] showed that this is possible for (x, t) but explicitly stated that his approach was not possible for (x, y, z, t).

Yet this has been done. Some allow imaginary numbers in the LT [10]. Another way is to add extra dimensions [8]. Cole [11] has shown how for four complex variables or six real variables the extra parameters are uncoupled for $|v| < c$ but coupled for $|v| > c$. Pavsic [17] also show how contraction from 6D to 4D involves imaginary numbers, see below.

Rindler's derivation of LT [12] gives $ds^2 = \pm\, ds'^2$ for 4D. As a heuristic argument the same derivation in 2D gives (as also stated in [9])

$$x^2 - c^2t^2 = \pm(x'^2 - c^2t'^2)\ (I)$$

The argument to just choose +, that (I) must remain valid as $v \to 0$, is not valid if looking for transformations for $|v| > c$.

+ sign in (*I*) gives ordinary LT for standard configuration

$$x' = \gamma(v)(x - vt) \qquad t' = \gamma(v)\left(t - \frac{vx}{c^2}\right) \qquad \gamma(v) = (1 - \frac{v^2}{c^2})^{-1/2} \qquad |v\,| < c$$

but − sign in (*I*) gives "Generalised LT" (GLT)

$$x' = \gamma_G(v)(x - vt)\ \ t' = \gamma_G(v)\left(t - \frac{vx}{c^2}\right)\ but\ where\ \gamma_G(v) = (\frac{v^2}{c^2} - 1)^{-1/2} \quad |v| > c\ (II)$$

For 4D

$$x^2 + y^2 + z^2 - c^2t^2 = \pm\left(x'^2 + y'^2 + z'^2 - c^2t'^2\right) \quad (III)$$

the choice of − sign is not valid if only real valued transformations are allowed according to the law of inertia for quadratic forms [13] which states that the signature, the number of positive and negative terms must be the same on both sides i.e. +++ −. If allow imaginary number as [10] − sign can be used in (*III*). Or if we add two parameters or dimensions with negative signs [8]. This seems also near the spirit of Minkowski ".. along a purely mathematical line of thought, to arrive at changed ideas of space and time" [14].

$$x^2 + y^2 + z^2 - c^2t^2 - c^2t_2^2 - c^2t_3^2 = \pm\left(x'^2 + y'^2 + z'^2 - c^2t'^2 - c^2t_2'^2 - c^2t_3'^2\right) \quad (IV)$$

Signature in VL is +++ −−− and using – sign in HL gives signature −−− +++, which yet is same signature as only the number of positive and negative terms counts.

+ sign in (*IV*) gives a possible GLT which are uncoupled i.e.

$$x' = \gamma(v)(x - vt) \quad t' = \gamma(v)\left(t - \frac{vx}{c^2}\right) \quad y' = y \quad z' = z \quad t_2' = t_2 \quad t_3' = t_3 \quad \gamma(v) = (1 - \frac{v^2}{c^2})^{-1/2}$$

**-** sign in (*IV*) gives a possible GLT , which are necessarily coupled due to the – sign,

$$x' = \gamma_G(v)(x - vt) \quad t' = \gamma_G(v)\left(t - \frac{vx}{c^2}\right) \quad y' = ct_2 \quad z' = ct_3 \quad t_2' = \frac{y}{c} \quad t_3' = \frac{z}{c} \quad \gamma_G(v) = (\frac{v^2}{c^2} - 1)^{-1/2}$$

As the coupled GLT clearly shows we can not think of superluminal IS just as ordinary IS going faster and faster, which is due to the singularity for v=c. Therefore the concept of standard configuration is not clear which is also seen in Cole's more detailed transformations involving ambiguity in signs [11].

As it is shown that with Rindler's derivation $ds^2 = \pm\, ds'^2$ and thus there is a choice but many derivations of LT does not give this choice it is interesting to examine why and especially for Einstein's original derivation 1905 [1] and Minkowski' s Address 1908 [14].

It will be shown how Einstein and Minkowski use arguments and a diagram which are seemingly self-evident but are valid only for $|v| < c$ and thus implicitly rule out $|v| > c$.

The problem about dimensionality of the world is still under debate [15]. Petkov has strong arguments for that the experimentally verified kinematic effects in relativity is possible only in a 4D block universe [16] or actually is possible only in a world of at least four-dimensions. Pavsic [17] show that when six-dimensional real spacetime is contracted to 4D transformations must be complex and interpret imaginary coordinates as that events observable to one observer is not observable to another observer, which is difficult to understand if the world is only 4D.

Petkov also writes "..- that the flow time is mind-dependent – outlined by Weyl should have been examined more rigorously." and ".. this idea appears to be self contradictory since Weyl assumed that consciousness (leaving aside the question of what consciousness itself is) *moves* in Minkowski spacetime where no motion is possible" [16 p. 150]. My intuition is that in a six dimensional spacetime with time and two extra "timelike" dimensions both the merits of 4D block universe and the fundamental experience of change can co-exist and that 6D spacetime is possibly related also to possibilities in QM and to consciousness, which is located in spacetime and not in the brain. [18].

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    Posters, abstracts and a PowerPoint presentation from 2016 at http://www.drpilotti.info/eng/conscious-spacetime.html

# For Imaginary Dimensions and Causal Brane-Worlds

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21 January 2018

We address the nature of spacetime by looking squarely at the wave function. First we consider mounting evidence in support of the following assertions:

*a.* The wave function is ontic (an objectively present, holistic entity).
*b.* The wave function is non-local (holistic over space).
*c.* The wave function is time-symmetric (holistic over time).

Rather than endlessly debate these statements we ask the rhetorical question: What if these three assertions are true? What are the logical consequences?

We begin with time-symmetry, sometimes erroneously called time-reversal. On the basis of retro-causal effects demonstrated by delayed-choice experiments along with subsequent time-symmetric approaches to QM we deduce that the wave function is extended over time as well as over space. It follows that the wave function is a 4-dimensional object and hence cannot live in our 3-space. Being 4-dimensional it requires a 4-space, which necessarily must coincide with our 3-space, since the 4-dimensional wave function always corresponds to its cross-section in the 3-space. Whatever the philosophical implications of such an arrangement, it derives directly from the evidence and therefore is admitted for logical scrutiny.

It follows that our 3+1 spacetime, far from being a block universe, consists of a 3-space passing over the fourth dimension of a 4-space. This fourth spatial dimension is not time itself but the *spatial precursor* to time; it is the *relative spatial motion* that manifests as the phenomenon of time (all dimensions being orthogonal). While our 3-space exists only in the present moment ($t_{\text{now}}$), a wave function extending from an emission event at time $t_1$ to an absorption event at time $t_2$ continues to evolve holistically in the 4-space while $t_1 < t_{\text{now}} < t_2$. (Note that this notion of "spatial motion" might be more fundamentally understood as *propagation of energy*, but the term is retained here for logical continuity, since that is the observed effect – time does appear to "flow" after all.)

The wave function (as currently formulated) has complex phase while being extended in real 3-space, for a total of five dimensions to represent the wave function (conventionally considered). So, if the wave function is indeed ontic, we face directly the problem of imaginary dimensions. Our solution is to simply accept the evidence: the fourth dimension of the 4-space is imaginary. When the real part of the wave function's complex phase is understood as one of our regular spatial dimensions the wave function becomes 4-dimensional, with the fourth dimension being imaginary. It follows that the imaginary axis of the wave function correlates to time in our 3-space; thus does time enter QM as a dynamic variable.

Such a space having three real and one imaginary dimensions is familiar to physicists, being known as *Euclidean spacetime*, where the time dimension of Minkowski spacetime is rotated (Wick rotation) into "imaginary time" according to $\tau = \mathrm{i}t$ ($c = 1$). Hence the efficacy of imaginary time in quantum theory: so-called Euclidean spacetime is where the four-dimensional wave function finds its home, but with the fourth dimension interpreted here as spatial, according to $\boldsymbol{w} = \mathbf{i}t$ (note that imaginary terms are bolded for logical clarity). For present purposes we denote this 4-space *Minkowski 4-space*, where:

$$\mathrm{d}s^2 = \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 + \mathrm{d}\boldsymbol{w}^2 \qquad (1)$$

Since all four dimensions are spatial, the displacement $s$ must also be interpreted as spatial. This is crucial to what follows. We introduce the equation for the propagation of the wave function, $v_{\text{ph}}\, v_{\text{g}} = c^2$ (2), where $v_{\text{g}}$ is group velocity, interpreted as the velocity of the associated particle, and $v_{\text{ph}}$ is phase velocity, interpreted as the propagation of the wave function itself, with $c$ being the speed of light.

Since we know that photons adhere to a light cone in Minkowski spacetime, it follows from the propagation formula (2) that the wave function itself will adhere to a null cone in Minkowski 4-space. Technically, therefore, there is no spatial distance, $s$, between any parts of the photon wave function, no matter how unintuitive this may appear from our perspective in 3+1 spacetime. This accounts for the "quantum connection" being unattenuated (over any distance), discriminating (confined to specific null cones) and faster than light (instantaneous).

While this arrangement accounts for the holistic behaviour of the photon (massless) wave function over both space and time, it does not account for the wave function of a massive particle, which according to the propagation formula will travel at infinite speed for a particle at rest (which is definitely not on a null cone).

Since the wave function evolves in the 4-space, this dynamical process requires a time dimension in the 4-space, yielding a 4+1 spacetime. We call 4-space time $t_4$, while time in the 3-space we denote $t_3$. Consequently we have two reasons for requiring an additional dimension: as a spatial precursor for time in the 4-space, $t_4$; and to account for energy and mass. Hence we introduce a second imaginary dimension $\boldsymbol{v}$, such that:

$$ds^2 = dx^2 + dy^2 + dz^2 + d\boldsymbol{w}^2 + d\boldsymbol{v}^2 \quad (3)$$

This implies that a 5-space interpenetrates the 4-space and the 3-space, so in fact the complete wave function is 5-dimensional. We denote this space *Minkowski 5-space*, which includes two dynamic imaginary dimensions in addition to a real 3-space. We presume that the (massive particle) wave function will always adhere to a null geodesic in Minkowski 5-space ($s = 0$).

We consider a wave function extending from the origin of Minkowski 5-space over real distance $x$ ($y = z = 0$). We let $\boldsymbol{w} = \mathbf{i}ct$ and $\boldsymbol{v} = \mathbf{i}V$. For a particle at rest, from (2) we find $\boldsymbol{w} = 0$. To satisfy the null metric (3) it follows that $V_0 = x$. We also note that the wave function frequency relative to the $\boldsymbol{v}$ dimension, hence energy and mass, will be inversely proportional to $V$, such that $m/m_0 = V_0/V$. On this basis, beginning with (2) and (3), we trivially derive the mass transformation equation according to Special Relativity.

Using similar reasoning, accelerating a particle from its rest frame in 3+1 spacetime equates to some reduction in the $V$ coordinate in that frame, which requires energy, this being the mechanism of inertia.

We argue on both technical and philosophical grounds that the 5-space marks the end of the dynamical process; the $\boldsymbol{w}$ and $\boldsymbol{v}$ dimensions are in motion relative to a higher imaginary dimension $\boldsymbol{u}$ which is itself static, resulting in *real* time $t_5$ in the 5-space. Time in the 4-space therefore originates in the motion of the imaginary dimension $\boldsymbol{v}$ in real time $t_5$, so time in the 4-space is *imaginary* ($d\boldsymbol{t_4} = d\boldsymbol{v}/dt_5$). Time in our 3-space thus derives from the motion of the imaginary dimension $\boldsymbol{w}$ in imaginary time $\boldsymbol{t_4}$ ($dt_3 = d\boldsymbol{w}/d\boldsymbol{t_4}$) – hence physical time is *real*.

Here is unveiled a great mystery, the logical underpinnings of the Wick rotation, moving between 3+1 spacetime and the 4-space. How does motion of the imaginary dimension $\boldsymbol{w}$ become real time $t_3$? In a nutshell, physical time is real because time in the 4-space is imaginary. (It follows that time is equivalent to velocity over a higher dimension, which is precisely correct – hence the *apparent* dimensional inconsistencies).

To briefly review, we erect a spacetime framework supporting quantum non-locality and retro-causality. We derive a mechanism underpinning time and explain the Wick rotation. We derive the mass transformation equation according to Special Relativity *on the basis of both quantum and relativistic principles*. Hence do Special Relativity and the wave function meld in the 5-space, becoming aspects of an overarching framework, with General Relativity looming in the shadows. Furthermore, we propose a mechanism by which Kaluza's 4+1 Einstein-Maxwell theory becomes directly applicable to the 5-space. Thus we submit that the essential logical elements are in place supporting the formulation of a consistent quantum theory of gravity.

**A Ridiculous Theory of Dark Energy**

What does it mean to say that the entire universe is expanding? The whole universe can only be getting bigger, in any real sense, relative to some other reference frame. Expansion is not a meaningful concept without a reference frame relative to which the expansion occurs. It is common for nonscientists to immediately recognize this problem when they ask, "What is the universe expanding into?"[1]

At the most basic level, there are two theoretical models of the universe: infinite and finite.[2] Both models struggle, in their own way, to explain the universe's expansion.

In infinite models of the universe, the expansion we observe only applies to our portion of infinity. Within this infinite space, there might be an endless profusion of other universes, all of them expanding relative to an infinite reference frame.[3] The question, "What is the universe expanding into?" is therefore not answered so much as it is excused. The problem of the whole universe getting bigger is absolved of its problematical nature. Even though the universe is expanding, it is not getting bigger in any real sense, because the universe is infinite.

Finite models of universe, on the other hand, immediately face the problem of an inconceivable edge of the universe itself. Scientists typically address this problem by theorizing a fourth spatial dimension. The analogy of a sphere is often used. A sphere is a three-dimensional shape whose two-dimensional surface has no edge. Finite models of the universe propose that the entire known universe is like the surface of a sphere. The three-dimensional universe would have no edge if it formed another type of sphere in a fourth dimension. As the three-dimensional universe expands, its four-dimensional shape grows in volume in the fourth dimension.[4]

But consider what it means to say that the entire universe has shape. The whole universe can only have shape, in any real sense, relative to some other reference frame. Shape is not a meaningful concept without a reference frame relative to which the shape takes its form.[5] If the universe is shaped like a sphere relative to the fourth dimension, is the fourth dimension infinite, or does the fourth dimension itself have an edge? Ultimately, finite models of the universe can only extend the problem of an edge to another dimension. The question, "What is the universe expanding into?" is therefore only answered with a temporary stopgap. Finite models of the universe are perpetually undermined by an infinite regress in perspective.

At the most basic level, the fact that the universe is expanding destabilizes both infinite and finite models of the universe. It is difficult to overstate the crisis in our theoretical picture of reality. Infinite models can only excuse the universe's expansion as a provincial phenomenon, while finite models can only push away the inconceivable edge of the universe to another dimension. If a scientist chooses to interpret the expansion of the universe as a simple fact—in other words, if the whole universe is actually getting bigger—it becomes impossible to conceptualize how the universe could be either infinite *or* finite.

This crisis in the structure of our theories is occurring at the most basic level of analysis. The only way out, therefore, is to reconsider the basic logic of an expanding universe. The fact that the universe is expanding is actually only half of the fact in question. The other half of the fact—the reference frame relative to which the universe expands—must also be accounted for in order to arrive at any picture of reality that is logically coherent. In short, the fact that the universe is expanding compels us toward a concept of *that which is not the universe*; the fact that the universe is expanding implies the existence of an entirely different aspect of reality.

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[5] Moreover, to claim that the entire universe has a shape is to claim that shape is a higher category than reality itself. And to make the further claim that there is no reference frame relative to which the shape of the universe takes its form is to claim that the shape of the universe is an absolute reality, a mysterious end of all inquiry. It is to claim, in effect, that God is a shape—a tragicomical end to this system of thought.