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*Article*

# Does Our Universe Have More Than One Dimension of Time?

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**Abstract:** Yes, this is possible. Provided that the extra temporal dimensions are compact and have a time-radius less than the current measured time limit of about $10^{-19}$s. We show, as a consequence of the holographic principle, that in today's universe, there is a fundamental lower limit to time at about $10^{-26}$s. Having additional dimensions of time yields a simple resolution of the EPR paradox, without having to modify the rules of either quantum mechanics or special relativity. It also helps understand the origin of supra-quantum non-local correlations stronger than the Tsirelson bound. The extra time dimensions arise from a unification of gravitation and the weak force on a six dimensional space-time with signature $(3,3)$. Spontaneous symmetry breaking bifurcates the 6D universe into two overlapping 4D space-times.

**Keywords:** quantum foundations; time-like extra dimensions; Connes time; non-commutative geometry; Einstein-Podolsky-Rosen paradox; quantum non-locality; Tsirelson bound; Popescu-Rohrlich bound; supra-quantum non-local correlations; gravi-weak unification; 6D spacetime

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Does our universe possess more than one dimension of time? Say, two additional time dimensions? So that spacetime has three temporal dimensions - same as the number of spatial dimensions. This would be a maximal fulfilment of the spirit of relativity: time treated on precisely the same footing as space.

One would be strongly inclined to answer this question in the negative, because we experience only one dimension of time. But the history of physics tells us that often the underlying microscopic truth is different from our immediate experience. For instance, we do not directly experience the quantum uncertainty principle, nor do we experience the unification of space and time into a Lorentz invariant 4D spacetime. Thus it could well be that there are two additional time dimensions which are periodic and compactified to a tiny time scale beyond direct experience, and beyond detection by current technologies. In fact, this tiny time scale need not be as small as the Planck scale $\sim 10^{-43}$ s; it could be say $10^{-26}$s, which is still a few orders below the current measurable limit of about $10^{-19}$s. We should ask if such additional time dimensions are predicted by some falsifiable theories, and if such multiple times solve one or more currently unsolved problems in fundamental physics, and if technologies in the foreseeable future can detect such additional time dimensions.

We must also distinguish dimension(s) of time from absolute time. Absolute time is time that flows: it keeps track of past, present, and future. In contrast to absolute time, the dimensions of time (or we could say time coordinates) do not flow. Just as spatial dimensions / coordinates do not 'flow'. They are mechanical and reversible. We must treat dimensions of time precisely on the same footing as dimensions of space - absolute time is separate from these, and is outside of the spacetime manifold. Newton was acutely aware of the need to discriminate 'common' time [which is what clocks measure] from absolute time. Without such discrimination, one runs into a circular argument, a paradox: to measure time one requires motion, and to define motion one needs time! Newton says instead: motion takes place in absolute time $T$; to measure common time $t$ we need motion. But motion is not required to define absolute time, which flows in and of itself. Motion is required only to measure common time. And then with a grand gesture Newton proposes $T = t$.

In going over from Galilean relativity to special relativity, Einstein and Minkowski unified common time $t$ with space $\mathbf{x}$ into 4D spacetime. And Einstein abandoned absolute time $T$, deeming it

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as superfluous and unnecessary! But was such abandoning the right thing to do, was it compelled upon us? Lorentz disagreed, and chose to retain the absolute time of Newton, in his 'Lorentz ether theory' version of special relativity. And he clarified that his formulation was equivalent to that of Einstein and Minkowski, and the choice between the two formulations was a matter of taste [1].

In hindsight, it may have been a matter not just of taste, but of necessity, in Lorentz's favour. Does the isotropic nature of the cosmic microwave background (CMB) not point towards an absolute time? One that is kept by the temperature of the CMB? Furthermore, in quantum theory, when position is raised to the status of an operator, but time is not, is the spirit of relativity not violated? In fact, in the Stueckelberg-Horowitz formulation of relativistic quantum mechanics [2], coordinate time is also raised to the status of an operator, and an auxiliary parameter time is introduced so as to play the role of absolute time. This truly relativistic formulation reproduces the results of conventional relativistic quantum field theory, and is also amenable to experimental validation, because it predicts the phenomenon of 'quantum interference in time'. [Pauli's no-go theorem against operator time continues to be respected, because a non-operator parameter time (the auxiliary time) is still on the scene].

In such a generalisation of relativistic quantum mechanics, the wave function $\psi(x^\mu, \tau)$ of a particle is a function of the space-time coordinate $x^\mu$ and evolves in absolute time $\tau$. The absolute square $|\psi(x^\mu, \tau)|^2$ of the wave function gives the probability for the particle to be on a spacetime path $x^\mu$ at a given absolute time $\tau$. At a given time $\tau$, a particle can be at more than one times $t$. Classical limit now also consists of being localised to a specific $t$, not just a specific $\mathbf{x}$. Motion is defined as evolution from one spacetime trajectory to another, and not just as evolution from one position to another. A particle at rest at $\mathbf{x}$ 'moves' in time $t$.

The Stueckelberg-Horowitz absolute time parameter is ad hoc, much as Newton's absolute time is ad hoc. However, subsequent developments in Connes' non-commutative geometry imply an absolute time parameter $\tau$ from first principles. The Tomita-Takesaki theory for von Neumann algebras implies the existence of a one parameter family of outer algebra automorphisms and these play the role of an absolute time parameter. Connes calls it 'God given time' and notes that non-commutative spaces evolve with time. We call it the Tomita-Takesaki-Connes time, or for brevity, TT time or Connes time [3–5]. Such a time is absent in Riemannian geometry, and it is over and above the spacetime manifold. An approach to unification that we are developing [6,7], builds on Connes' non-commutative geometry, with Riemannian geometry emerging as a classical approximation. Connes time is always present, and the spacetime manifold evolves in Connes time. It is not that spatial hypersurfaces evolve in coordinate time. We propose to identify Connes time $\tau$ with Newton's absolute time, and also with the Stueckelberg-Horowitz time. And now we can distinguish between the time that flows (this being Connes time) and common time. In fact we can have more than one common time, for none of them flow. And our experience of there being only one time dimension is because this experience refers to absolute time, and not to dimension(s) of time.

The greatest advantage of having multiple dimensions of time is that they offer a neat resolution of the EPR paradox and of the quantum non-locality puzzle [8]. We know from experiments that when measurements are made on a correlated pair of entangled quantum particles, measurement on one particle influences the other particle non-locally (i.e. outside the light cone). Even though no information is transmitted superluminally, one still needs to explain how the quantum influence of wave-function collapse is felt out outside the light cone? This, even though quantum field theory is microcausal, which means that two-point correlation functions vanish outside the light cone, as one would expect from the principles of special relativity.

In mathematical terms, the central problem is that the space-time interval $ds^2 = c^2dt^2 - d\mathbf{x}^2$ separating the two correlated measurements is space-like. On the other hand, if a causal influence has to travel from one particle to the other, then the interval has to be timelike or null, of course.

Consider now the possibility that our 4D description of spacetime is an approximate one, and in reality spacetime has additional timelike dimensions, say $t_2$ and $t_3$. Then the true spacetime interval is

$$ds_6^2 = c^2 dt_3^2 + c^2 dt_2^2 + c^2 dt^2 - d\mathbf{x}^2 \qquad (1)$$

It could well be that the influence travels locally through the true 6D spacetime, so that this interval is timelike / null. But by being unaware of the times $t_2$ and $t_3$, we perceive spacetime to be 4D, and we inadvertently drop the positive quantity $c^2 dt_3^2 + c^2 dt_2^2$ from $ds_6^2$, and consequently, the remnant $ds^2 = c^2 dt^2 - d\mathbf{x}^2$ could turn out to be negative and hence spacelike. In other words, the apparent quantum non-locality is a consequence of ignorance of additional timelike dimensions of a higher dimensional spacetime which obeys special relativity. In this manner we remove the tension between relativity and quantum mechanics, without having to modify the laws of either theory! Note that such a resolution of the EPR paradox will not work if the extra dimensions are spacelike.

Interestingly, even though the transmission in 6D is local, Bell inequalities continue to be violated. This is because the root cause of the violation is quantum indeterminism. In classical physics the outcome of a measurement is deterministic and pre-ordained. Hence Bell inequality is obeyed. On the other hand, in quantum physics the outcomes of a measurement are indeterminate and random. Consequently, stronger-than-classical correlations are produced, and the inequality is violated. In our proposal, we have local indeterminism, not nonlocal indeterminism. The random nature of quantum wave function collapse is what makes quantum theory different from classical physics. God does play dice, but only locally so. Of course Einstein might still be right about dice not being played. This could happen if quantum mechanics and its indeterminism are a consequence of coarse-graining a deterministic underlying theory [9]. Observing on a coarse-grained (absolute) time scale can give rise to apparent randomness [10], much as the apparent randomness in Brownian motion results from not observing the underlying deterministic motion of molecules.

How can we be certain that restriction from the 6D spacetime to 4D definitely converts timelike intervals to spacelike ones? To understand this, we must look into the dynamical relation between 6D and 4D spacetimes. How exactly does the latter arise from the former? It is a known mathematical fact that two overlapping 4D spacetimes with relatively flipped signatures can be embedded in a 6D spacetime of signature $(3,3)$ [11]. Thus if the 6D spacetime has coordinates $(t_3, t_2, t_1, x_1, x_2, x_3)$ and our 4D one has coordinates $(t_1, x_1, x_2, x_3)$, then the flipped 4D has coordinates $(t_3, t_2, t_1, x_1)$. The spatial direction $x_1$ and the temporal direction $t_1$ are common between the two 4D spacetimes.

The universe starts out as a 6D spacetime undergoing a deSitter like inflationary expansion, in which the acceleration gradually decreases. At a certain critical acceleration (which is the order parameter) the universe undergoes a quantum-to-classical transition, such that the 6D spacetime undergoes symmetry breaking to two overlapping 4D spacetimes. Classical systems become confined to our 4D spacetime, described by the laws of general relativity. The other 4D spacetime develops its distinct Riemannian geometry, and (as we justify below) spatial and temporal dimensions are approximately cube roots of dimensions in our 4D spacetime when expressed in Planck units. What this means is that the other 4D spacetime has its own metric, and in that metric, the cosmic horizon is at $(10^{28}\text{cm}/10^{-33}\text{cm})^{1/3} L_P \sim 10^{-13}$cm. This implies that whereas in our 4D subspace a signal takes $10^{28}\text{cm}/c \sim 10^{17}$ s to travel to the cosmic boundary, through the other spacetime the signal takes only about $10^{-23}$ s to do so. We can consider the 6D spacetime path as a superposition of two 4D spacetime paths, and the path through the other 4D spacetime is far shorter. We could call the other 4D spacetime a quantum wormhole! Quantum nonlocality is only an apparent feature, because we are unaware of the wormhole - this is highly reminiscent of the ER = EPR proposal [12]. In fact what we have is a concrete realisation of the ER=EPR idea.

Next, we must justify the assertion that the scale of distances in the other 4D spacetime is a cube root of the scale in ours. The answer lies in the holographic principle, namely that the amount of information in a spatial volume is determined by the area of its boundary. Consider a 3D volume $L^3$ which supposedly has a minimum of length $l$ and hence a volume unit of information $l^3$. The number of bits of information, $L^3/l^3$, is of the order of the area of the boundary, $L^2/L_P^2$, expressed in Planck units. Thus we have $L^3/l^3 \sim L^2/L_P^2 \implies l \sim (L_P^2 L)^{1/3}$. This is the well-known holographic length uncertainty relation, also known as the Karolyhazy length relation [13]. Note that the minimum of length $l$ depends on the size of the system, and this minimum is larger than Planck length. The absolute minimum is $L_P$, obtained when $L = L_P$. Also, we can obtain a corresponding relation $\delta t \sim (t_P^2\, t)^{1/3}$ for time intervals. In our case, we have the novel situation that the boundary of the 3D spatial region of our 4D spacetime is constituted by the two timelike dimensions $t_2$ and $t_3$ of the other 4D spacetime. Consequently, the length and time scales in the other spacetime are of the order $l \sim L^{1/3}$ and $\delta t \sim t^{1/3}$ justifying the claim made in the previous paragraph. This also explains why the signal is transmitted so quickly through the other 4D spacetime.

What is the physical motivation for having a 6D spacetime, and what is the mediating field which transmits the signal through the other 4D spacetime? To answer these important questions, we must turn to the weak force. As is well known, the weak force has remarkable similarities with the gravitational force. The weak interaction, like gravity, is universal; but it is parity violating; only fermions with left-handed chirality take part in it. Parity is a spacetime symmetry; so it seems that the weak interaction knows about spacetime (despite being an internal symmetry); just as gravitation (= curvature) knows about spacetime. Both gravity and the weak force have dimensionful coupling constants (unlike QED and QCD) and in natural units ($\hbar = c = 1$) they both have the same dimensions, i.e. inverse square of mass. The weak force, described by the four-point Fermi theory, is perturbatively non-renormalizable. So is general relativity. The weak force, when unified with electromagnetism into the unbroken electroweak $SU(2)_L \otimes U(1)_Y$ Yang-Mills theory, becomes renormalizable. Electroweak symmetry breaking gives rise to the short range weak force and to the unbroken symmetry $U(1)_{em}$ which is electromagnetism.

Do all these observations suggest that the weak interaction, like gravitation, is spacetime geometry? But geometry of which spacetime?! Our spacetime is already taken up by gravitation. Furthermore, could it be that (non-renormalisable) general relativity is also the result of a broken symmetry, perhaps resulting from the breaking of an $SU(2)_R \otimes U(1)_{Y'}$ symmetry, which leaves behind some unbroken $U(1)_{YDEM}$? The answer to all these questions is in the affirmative, and lies in the 6D spacetime. But, right away one could point out the stark differences between gravity and the weak force. The former is long range, and the latter is short range. The latter is chiral. The former? Actually we do not know that gravitation is not chiral. Perhaps it is - this is currently an active area of research. Also, when we say weak interaction is short range, we mean it is short range compared to the scale of human experience. Compared to Planck length scale, the weak interaction is hugely long range, by some seventeen orders of magnitude. This so-called short range will be justified by the holographic argument given above.

In our approach to fundamental interactions, there is gravi-weak unification in 6D spacetime, prior to the electroweak (EW) symmetry breaking [7,14]. This unification is described by an $SU(3) \otimes SU(3)$ Yang-Mills gauge symmetry on 6D spacetime with signature $(3,3)$. Upon EW symmetry breaking, which is also a quantum-to-classical transition, and which takes place at the end of the deSitter like expansion below a critical acceleration, the two $SU(3)$s branch as follows. The first $SU(3) \to SU(2)_L \otimes U(1)_Y \to U(1)_{em}$ and the second $SU(3) \to SU(2)_R \otimes U(1)_{Y'} \to U(1)_{DEM}$. Concurrently, the 6D spacetime bifurcates into two overlapping 4D spacetimes - same as the ones discussed above. The broken $SU(2)_R$ symmetry gives rise to general relativity, this being the curvature of our 4D spacetime. GR is predicted to be chiral, and this is consistent with the fact that an action built from the self-dual part of the connection and of the curvature is adequate to derive Einstein equations. The broken $SU(2)_L$ symmetry gives rise to the weak force, and this can be cast as the Riemannian geometry of the other 4D spacetime. From the vantage point of our spacetime, the two additional time dimensions $t_2, t_3$ can be thought of as internal gauge symmetry directions. This is consistent with the well-known fact that two additional dimensions are needed, beyond the four of our spacetime, if the weak interaction is to be described via a Kaluza-Klein unification. This makes the 6D spacetime a natural candidate for gravi-weak unification, and in this manner our proposed resolution of the EPR

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paradox involving two additional timelike dimensions has its roots in fundamental physics. The two additional time dimensions are compact and of the order of the weak interaction time scale, $10^{-26}$ s. The smallness of this number keeps these two times outside the range of human experience, giving the impression that our universe is 4D, when in reality it is 6D. The gauge symmetry $U(1)_{DEM}$, dubbed dark electromagnetism (dark photon) is a newly predicted fifth force which couples to square root of mass, and is a promising alternative to dark matter [15].

As for the mediating force field which transmits the EPR signal in the other 4D spacetime, there are two candidates. One is the massless dark photon, which couples to square root of mass, and which is the gauge boson corresponding to dark electromagnetism, the $U(1)_{DEM}$. This is equivalent to saying there are dark electromagnetic waves in nature, and these should be sought in experiments. The other (falsifiable) candidate is what we call 'weak waves'. Since the weak interaction is Riemannian geometry of the other 4D spacetime, it will admit weak waves, analogous to gravitational waves, on length scales much smaller than the weak scale of $\sim 10^{-16}$ cm [8].

There is yet another serious quantum non-locality puzzle, even though it is nowhere near as well known as the EPR paradox. This is the mystery of supra-quantum nonlocal correlations. As we well know, experiments have confirmed that quantum mechanics admits non-local correlations stronger than those allowed for classically correlated systems. But quantum mechanics is, in principle, only one of a class of non-local dynamical theories which all violate Bell's inequalities. The maximum extent to which the inequalities are violated is decided by the principle of relativistic causality, which of course is what special relativity dictates. There is no a priori reason that this maximum extent should coincide with the maximal Bell inequality violation permitted for quantum mechanics. Very surprisingly, it does turn out that the two maxima do not coincide!

This is seen in a straightforward way in the CHSH version of Bell's inequalities, for a system of two detectors each of which has two possible settings. The CHSH correlation satisfies $|S| \leq 2$ for a classical system, whereas for a pair of quantum entangled states this inequality is violated; yet there is a maximum bound on the violation, this being the Tsirelson bound $|S| \leq 2\sqrt{2}$ [16]. On the other hand, if only the condition of relativistic causality is imposed, and quantum mechanics is not invoked, the maximum allowed non-local correlation obeys $|S| \leq 4$ (the Popescu-Rorlich bound) [17]. This blatant discord between the Tsirelson bound of $2\sqrt{2}$ and the Popescu-Rohrlich [PR] bound of 4 is the puzzle of supra-quantum non-local correlations; it is as much of a conflict between quantum mechanics and relativity as the EPR paradox is. Even though it is mostly shrugged off as not having any deep significance.

Remarkably enough, here too the 6D spacetime comes to our rescue, just as having extra timelike dimensions resolves the EPR paradox. We return to noting that the 6D spacetime can be regarded, in our low-energy symmetry broken universe, as a superposition of two overlapping 4D spacetimes. Detectors, such as those employed in the CHSH test, are classical objects and these are confined to our 4D spacetime. However, the causal signal which correlates wave function collapse at the two detectors is a superposition of two paths, one through each of the two 4D spacetimes. If, while evaluating the CHSH correlation for a pair of quantum entangled states, we assume no interaction between the two 4D spacetimes, we still get the Tsirelson upper bound of $2\sqrt{2}$. However, in principle there can be an interference between the two 4D spacetimes, and we found that such interference terms contribute additionally to the CHSH correlation, allowing the Tsirelson bound to be violated in principle [8]. In fact, in principle the PR bound of 4 now becomes attainable, while staying within the rules of quantum mechanics. The resolution is still the same as for the EPR puzzle - we were not aware of the quantum wormhole.

The origin of these interference terms lies in a hitherto unforeseen interaction between the weak force and gravitation. Since this interaction is likely to be very feeble, that would be the reason why Bell experiments have not yet been able to detect supra-quantum nonlocal correlations. There is possibly a prospect that particle accelerator experiments testing Bell inequalities [18] might one day detect

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such correlations beating the Tsirelson bound, if we can carefully identify which particular particle interactions we should investigate.

It is possible that our idea of additional time dimensions could get confirmed or ruled out in the foreseeable future. Assuming that the two additional times are compact, then the weak interaction time scale, in conjunction with the holographic uncertainty relation, suggests a time minimum $\delta t \sim (t_P^2 T_U)^{1/3}$ where $T_U$ is the present age of the universe. This gives $\delta t \sim 10^{-23}$ s. This is not far off from the current time measurement sensitivity of about $10^{-19}$ s. The time minimum for the present universe is not Planck time, but somewhere between $10^{-23}$ s and the weak interaction time scale $10^{-26}$ s. Note that $\delta t$ starts out as Planck time when the universe was just one Planck time old, and then $\delta t$ grows larger with the increasing age of the universe. $\delta t$ grows as $T_U^{1/3}$.

Finally, we suggest that having two compact additional timelike dimensions could help arrive at a physical understanding of spin angular momentum. Understanding of quantized spin - originating from irreducible representations of the Lorentz group - is in perfect agreement with experiment. Nonetheless, it is not unreasonable to ask, in an extension of quantum mechanics, as to what is the space, rotation in which amounts to quantum spin. This enquiry becomes unavoidable in a matrix-valued Lagrangian dynamics such as trace dynamics, because all forms of angular momenta must now be defined canonically, as being conjugate to some angle. Obviously, when it comes to quantum spin, that angle cannot be in our spacetime, for that would simply yield orbital angular momentum. However, let us go back to the 6D spacetime, but instead of considering our 4D subspace $(\mathbf{x}, t_1)$, consider the two newly arising 4D subspaces $(\mathbf{x}, t_2)$ and $(\mathbf{x}, t_3)$. Namely, space is retained as such, but the time coordinate is replaced by one or the other of the two additional times $t_2$ and $t_3$. Next, given an angle $\phi$ in three space, consider the angular velocity $d\phi/dt_2$ or $d\phi/dt_3$, instead of the conventional angular velocity $d\phi/dt_1$ which arises in the definition of orbital angular momentum. What is the physical interpretation of the angular momenta associated with these novel angular velocities $d\phi/dt_2$ and $d\phi/dt_3$? Considering that these two extra time dimensions are compact, could it be that these two novel angular momenta are what we call quantised spin? One for each of the two observed chiralities, left-handed and right-handed? It would be interesting to investigate this further, to see if we can arrive at a spatio-temporal understanding of spin, which will be on the same physical footing as our understanding of orbital angular momentum.

Spacetimes with multiple time dimensions have been considered by other authors as well. Pettini [19] was probably the first to suggest that an additional time dimension can help resolve the EPR paradox. Our work differs from Pettini's in that we motivate the additional temporal dimensions through our programme on gravi-weak unification [7]. We have also argued thatn these additional time dimensions explain supra-quantum nonlocal correlations. In another work, physics with multiple time dimensions, including the initial value problem, has been investigated in detail by Weinstein [20]. Genovese [21] has studied how spatial extra dimensions might help resolve the EPR paradox. In an important study, Kauffman [22] considers a topological enhancement of 4D spacetime via a quantum tensor network to arrive at an Einstein-Rosen bridge-like structure and formalize the ER=EPR proposal. It is instructive to ask if, for a large tensor network, the extension could approximate a smooth manifold structure and an embedding of 4D spacetime in a higher spacetime of the type considered by us.

There is significant literature on physics in six-dimensional spacetimes with signature $(3,3)$. The motivations for such considerations are diverse, starting with desiring as many time dimensions as spatial ones. Quaternions also suggest a 6D spacetime, as Lambek argues in his paper 'Quaternions and three temporal dimensions' [23]. He writes in the abstract of his paper: "The application of quaternions to special relativity predicts a six-dimensional universe, which uncannily resembles ours, except that it admits three dimensions of time." In an insightful paper 'Germ of a synthesis: space-time is spinorial, extra dimensions are time-like' Sparling [24] justifies the relation of null twistor spaces with 6D spacetime. Also relevant for us is also the (1985) paper of Patty and Smalley [11] titled 'Dirac equation in a six-dimensional spacetime'. The authors show that a (3+3) spacetime can be divided into six copies of (3+1) subspaces. 6D spaces are also of interest from the viewpoint of a superluminal extension of (3+1) special relativity, and it has been shown that a 6D spacetime is the smallest one which can accommodate a superluminal as well as a subliminal branch of (3+1) spacetime [25]. Six dimensional (3+3) spacetimes were investigated extensively in a series of papers by Cole [26] and also by Teli [27]. An early work on 'quaternions and quantum mechanics' is Conway (1948) [28]. Dartora and Cabrera (2009) [29] have studied "The Dirac equation in six-dimensional SO(3,3) symmetry group and a non-chiral electroweak theory". An old (1950) paper by Podolanski [30] studies unified field theory in six dimensions, and in fact the abstract starts by saying 'The geometry of the Dirac equation is actually six-dimensional'. An elegant (2020) paper by Venancio and Batista [31] analyses 'Two-Component spinorial formalism using quaternions for six-dimensional spacetimes'. An insightful (1993) work by Boyling and Cole [32] studies the six-dimensional (3+3) Dirac equation and shows that particles have spatial spin-1/2 and temporal spin-1/2.

*At the end of the day, time only will tell how many times we live in!*

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## References

1. H. A. Lorentz, A. Einstein and H. Minkowski, *Das Relativitätsprinzip. Eine Sammlung von Abhandlungen*; Leipzig & Berlin: B.G. Teubner (1913).
2. L. P. Horowitz, *Relativistic quantum mechanics*, Springer Dordrecht, 2015.
3. A. Connes, *Noncommutative geometry: Year 2000*, [arXiv:math/0011193 [math.QA]].
4. A. Connes, *Time in noncommutative geometry*, https://noncommutativegeometry.blogspot.com/2007/03/time.html
5. A. Connes and C. Rovelli, Class. Quant. Grav. **11**, 2899-2918 (1994) [arXiv:gr-qc/9406019 [gr-qc]].
6. T. P. Singh, *Gravitation, and quantum theory, as emergent phenomena*, J. Phys. Conf. Ser. **2533**, 012013 (2023) [arXiv:2308.16216 [physics.gen-ph]].
7. T. P. Singh, *Trace dynamics, octonions, and unification: an $E_8 \otimes E_8$ theory of unification*, J. Phys. Conf. Series **2912**, 012009 (2024).
8. M. Furquan, T. P. Singh and P. Samuel Wesley, *Time-Like Extra Dimensions: Quantum Nonlocality, Spin, and Tsirelson Bound*, Universe **2025** 11, 137 https://doi.org/10.3390/universe11050137
9. Stephen L. Adler, *Quantum theory as an emergent phenomenon: the statistical mechanics of matrix models as the precursor of quantum field theory*, Cambridge University Press (2004).
10. K. Kakade, A. Singh and T. P. Singh, *Spontaneous localisation from a coarse-grained deterministic and non-unitary dynamics*, Phys. Lett. A **490**, 129191 (2023) [arXiv:2305.06706 [quant-ph]].
11. C. E. Patty, Jr. and L. L. Smalley, *Dirac equation in a six-dimensional spacetime: temporal polarisation for subluminal interactions*, Phys. Rev. D **32**, 891 (1985).
12. Maldacena, Juan and Susskind, Leonard (2013), *Cool horizons for entangled black holes*, Fortschritte der Physik. 61 (9): 781–811. arXiv:1306.0533
13. T. P. Singh, *Quantum gravity, minimum length and holography*, Pramana **95**, 40 (2021) [arXiv:1910.06350 [gr-qc]].
14. T. Asselmeyer-Maluga, F. Finster, N. Gresnigt, J. Isidro, A. Marciano, C. Paganini, T. P. Singh and P Samuel Wesley, *Gravi-weak unification in a six-dimensional spacetime with signature (3,3)*, in preparation (2025).
15. F. Finster, J. M. Isidro, C. F. Paganini and T. P. Singh, *Theoretically Motivated Dark Electromagnetism as the Origin of Relativistic Modified Newtonian Dynamics*, Universe **10**, 123 (2024) [arXiv:2312.08811 [gr-qc]].
16. B. S. Tsirelson, *Quantum generalization of Bell's inequalities* Lett. Math. Phys. 1980; 4:93-100
17. D. Rohrlich and S. Popescu, *Nonlocality as an axiom for quantum theory*, [arXiv:quant-ph/9508009 [quant-ph]].
18. A. J. Barr, M. Fabbrichesi, R. Floreanini, E. Gabrielli and L. Marzola, *Quantum entanglement and Bell inequality violation at colliders*, Prog. Part. Nucl. Phys. **139**, 104134 (2024) [arXiv:2402.07972 [hep-ph]].
19. M. Pettini, *Quantum Entanglement without nonlocal causation in (3,2)-dimensional spacetime*, arXiv:2311.17070v5, to be published in Physical Review Research (2025).
20. S. Weinstein, *Multiple time dimensions*, arXiv:0812.3869 (2008).

21. M. Genovese, *Can quantum nonlocality be connected to extra dimensions?*, Int. J. Quant. Inf. **21**, 2340003 (2023) [arXiv:2211.02884 [physics.gen-ph]].
22. L. H. Kauffman, *ER = EPR, entanglement topology and tensor networks*, Proc. SPIE Int. Soc. Opt. Eng. **12093**, 76 (2022) [arXiv:2203.09797 [quant-ph]].
23. J. Lambek, *Quaternions and three temporal dimensions*, https://www.math.mcgill.ca/barr/lambek/pdffiles/Quater2014.pdf (2014).
24. G. A. Sparling, *Germ of a synthesis: space-time is spinorial, extra dimensions are time-like*, Proc. R. Soc. A. **463**, 1665 (2007).
25. W. E. Hagston and I. D. Cox, *An extended theory of relativity in a six-dimensional manifold*, Foundations of Physics, **15**, 773 (1985).
26. E. A. B. Cole and S. A. Buchanan, *Space-time transformations in six-dimensional special relativity*, J. Phys. A: Math. Gen. **15**, L255 (1982).
27. M. T. Teli, *General Lorentz transformations in six-dimensional spacetime*, Phys. Lett. A **122**, 447 (1987) and references therein.
28. A.W. Conway, *Quaternions and quantum mechanics*, Pontificia Academia Scientiarum **12**, 204 (1948), Available at https://www.pas.va/content/dam/casinapioiv/pas/pdf-volumi/acta/acta12pas.pdf
29. C. A. Dartora and G. G. Cabrera, *The Dirac Equation in Six-dimensional SO(3,3) Symmetry Group and a Non-chiral "Electroweak" Theory*, Int. J. Theo. Phys. **49**, 51 (2010).
30. J. Podolanski, *Unified field theory in six dimensions*, Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences **201**, 234 (1950).
31. J. Venancio and C. Batista, *Two-Component spinorial formalism using quaternions for six-dimensional spacetimes*, Adv. Appl. Clifford Algebras **31**, 46 (2021).
32. J. B. Boyling and E. A. B. Cole, *Six-dimensional Dirac equation*, Int. J. Theo. Phys. **32**, 801 (1993).