Minkowski Space-time and Einstein's Now Conundrum

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ABSTRACT

The Minkowski formula X4=ict indicates that time *t* does not express the 4th dimension of space-time, i.e., X4 is not *t*. Therefore, Minkowski space-time is not a 3D+T manifold, it is 4D. The 4D manifold has 4 spatial dimensions and is timeless, in the sense that it does not contain some physical time in which material changes run. In physics we experience the timelessness of 4D space as "Einstein's Now." From this perspective, the time that we measure with clocks is just the sequential numerical order of changes, i.e. motions that run in the timeless space of Now. On the other hand, past and future are nothing more than psychological or conceptual realities that derive from the neuronal activity of the brain. Therefore, "time flow" and "arrow of time" have only a mathematical existence.

Key Words: Now, Time, Space, Space-Time, GPS, Closed Timeline Curve, Arrow of Time

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Introduction

Today, 130 years after the pioneering work of Ernst Mach regarding the interpretation of time as a measure of the changes of things, the related ideas that time cannot be considered as a primary physical reality that flows on its own in the universe, and thus that universal space is timeless, are receiving more and more attention. For example, Girelli, Liberati and Sindoni, by following the philosophy of analog models of gravity, suggest that time and gravity might not be fundamental per se, but only emergent features, in the context of a toy-model where the Lorentzian signature and Nordström gravity (a diffeomorphisms invariant scalar gravity theory) emerge from a timeless non-dynamical space (Girelli *et al*., 2011). Moreover, as regards the meaning of time in a timeless background, interesting results have been obtained recently by Gózdz and Stefanska (Gózdz, Stefanska, 2008), Elze (Elze, 2002), Caticha (Caticha, 2011), Prati (Prati, 2011) and Anderson (Anderson, 2013). In particular, Prati showed that a physical system S, if complex enough, can be separated into a subsystem S2 whose dynamics is described, and another cyclic subsystem S1 which behaves as a clock and that, as a consequence of the gauge invariance, this separation may be made in many ways. Prati's model thus suggests, from the physical point of view, that the time provided by each subsystem that acts as a clock cannot be considered as an absolute quantity, indicating that the meaning of time in a timeless picture is as follows: the ticking of each subsystem acts as a clock that provides a different reference system describing the dynamics of that subsystem, and therefore that time, as an idealized quantity that flows on its own, does not exist.

An analysis of the Minkowski manifold confirms that space-time is timeless. In this way, "Einstein's Now" fully enters the realm of physics, in the sense that, in physics, we experience the timelessness of space as Now. In the Minkowski manifold the formula for the 4th dimension of space-time is as follows:

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$$X4 = ict \quad (1),$$

Namely the fourth dimension is the product of the imaginary number i, light speed c, and time t. This formula has an internal structure that is similar to the formula for distance d, in which the imaginary number i is missing:

$$d = vt \quad (2),$$

Where d is distance, v is speed, and t is time. The formula (1) confirms that the 4th dimension of space-time is not temporal, but is also spatial, as are the other three dimensions: X_1, X_2, X_3. Thus, the space-time manifold of Minkowski is not 3D + T. Therefore, the generalization that time is the 4th dimension of space is not appropriate. Rather, the space-time manifold of Minkowski is 4D. Minkowski's vision was to fully integrate space and time as an inseparable entity. On September 21, 1908, Hermann Minkowski began his talk at the 80th Assembly of German Natural Scientists and Physicians with the now famous introduction: "The views of space and time which I wish to lay before you have sprung from the soil of experimental physics, and therein lies their strength. They are radical. Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality" (Minkowski, 1952). Minkowski was right. The mathematical formalism X4=ict confirms that, in his model, time is fully integrated within a timeless 4D space.

The solution to Einstein's now conundrum

The research of Catalin V. Buhusi and Warren H. Meck confirms that the human experience of duration (time interval) is based on the neuronal activity of the brain (Catalin at al., 2005). Therefore, the linear time of "past-present-future" exists only as a function of the neuronal activity of the brain. We experience the run of changes in timeless space within the frame of the conceptual linear time of "past-present-future." Einstein himself was aware that the linear time of "past-present-future" was only a psychological reality. He used to say: "People like us, who believe in physics, know that the distinction between past, present and future is only a stubbornly persistent illusion" (Einstein 1915). The Minkowski manifold X4=ict, in which time t is just an internal element of the formula for the 4th imaginary dimension, is a mathematical model that is completely consistent with Einstein's view of time. In his book "Now: The Physics of Time" Richard Muller presents very directly Einstein's trouble with Now: "Albert Einstein was troubled with the concept of now." Further, philosopher Rudolf Carnap writes in his Intellectual Autobiography that Einstein said that the problem of the Now worried him seriously. Einstein explained that the experience of the Now means something special for man, something essentially different from the past and the future, but that this important difference does not and cannot occur within physics. That this experience cannot be grasped by science seemed to him a matter of painful but inevitable resignation. So Einstein concluded "that there is something essential about the NOW which is just outside the realm of science" (Muller, 2016).

The solution with regard to bringing the NOW into physics is through an understanding that material changes actually run in the physical reality of 4D timeless space, which we experience as "NOW," and not in the psychological or conceptual reality of "past-present-future." In order to illustrate this, let us take an everyday example: walking from point A to point B we experience that our walking occurs in space, and always takes place NOW. We do not perceive with our senses that we walk in time. We have a sensation of moving in time, because we experience our motion in the frame of the linear conceptual time of "past-present-future," which as previously stated, has only a psychological existence.

Another example of material changes actually running in the physical reality of 4D timeless space can be found by examining the motion of a photon in space. On the basis of a granular structure of space and time, this emerges from the results of loop quantum gravity, as well as other significant models, such as reticular space-time dynamics (Rovelli, 1998; Rovelli 2011; Licata 1991). One can assume that quanta of space having the size of Planck length $l_P = \sqrt{\frac{\hbar G}{c^3}}$ are the fundamental constituents of space, and that Planck time $t_P = \sqrt{\frac{\hbar G}{c^5}}$ is the least unit of motion, and so represents the fundamental unit of numerical order of material changes (Fiscaletti, Sorli, 2015). For example, let us examine the motion of a photon in space. The photon passes Planck distance in Planck time, which is just the numerical order of the photon's motion. The photon is not moving in some physical time, as elementary perception and experimental data both confirm that the photon moves only in space. When we calculate the sum of the Planck times of the photon's motion from point A to point B we get time t as the duration:

$$t = t_{P1} + t_{P2} + \ldots + t_{PN} = \sum_{i=1}^{N} t_{Pi} \qquad (3)$$

What this demonstrates is that changes run in timeless space, and that the existence of duration requires a measurement from the side of the observer. Equation (3) expresses the duration of the photon's motion from point A to point B, which is generated (and thus enters existence) as a consequence of the measurement of an observer. For this reason, we can call the time t that expresses duration the emergent time. Without a measurement there is no duration. Moreover, by taking into account that the existence of duration of physical events requires that the observer make a measurement, one can speculate that there are two ways to understand time:

– Time measured with clocks is a numerical order of change that has only a mathematical existence;
– Duration of a given material change requires that the observer makes a measurement.

These two ways to understand time indicate that in physics we have two kinds of time:

1. *Fundamental time*, which is the numerical order of change and exists independent of the observer.
2. *Emergent time*, which is the duration of material change and originates from the observer's measurement (Fiscaletti, Sorli, 2015).

An interesting possible mathematical characterization of fundamental time, namely of the numerical order of material changes, is represented by Prati's number k_{AB}, which provides a counter function of the number of states of the Hilbert space of the system of interest whose dynamics are being analysed, and that satisfies an appropriate initial condition (namely the origin of measurement) $\overline{\Psi}_1$ of the subsystem acting as a clock. By considering fundamental time as the numerical order of material changes defined by Prati's counter function of the states of a system k_{AB}, one obtains a suggestive unifying re-reading of the two fundamental theories of time existing in literature, namely the ephemeris time of the Jacobi-Barbour-Bertotti theory, and Rovelli's thermal time hypothesis. In our approach, Barbour's ephemeris time, the unphysical evolution parameter λ which provides a metric-trans-temporal notion of identity between two subsequent configurations, and thus a duration corresponding to the relative change in the positions of the particles in the system, can be considered as an emergent time that derives from the dynamics of the system, in the sense that it derives from the numerical order associated with the number k_{AB} of states of the Hilbert space of the system of interest whose dynamics are being described, on the basis of equation:

$$\int_{\lambda_0}^{\lambda_f} \frac{\sqrt{T}}{\sqrt{E-V}} d\lambda = k_{AB} \qquad (4)$$

Where V represents the potential energy of the system, and E the total energy of the system.

In an analogous way, Rovelli's "thermal time hypothesis" – according to which time is a reflex of our incomplete knowledge of the state of the world, i.e. a statement about the statistical state in which the world happens to be, when described in terms of the macroscopic parameters we have chosen – can be seen as a consequence of the fact that clocks measure merely the numerical order of material changes corresponding to Prati's number k_{AB} of states of the Hilbert space of the system of interest whose dynamics are being described. In other words, Rovelli's thermal time t_P (provided by the thermal clock whose ticking grows linearly with the Hamiltonian flow $s(t_P)$ of the nonrelativistic Hamiltonian of the system) can be considered as a statistical characterization of an emergent time which derives from the fundamental time represented by the numerical order of material changes defined by the counter function k_{AB} of states of the Hilbert space of the system of interest whose dynamics are being described, on the basis of equation:

$t_P = k_{AB}$ (5) (Fiscaletti, Sorli, 2015).

Einstein's famous quote confirms this view of time: "Time has no independent existence apart from the order of events by which we measure it" (Gomel, 2010). The view presented above solves the Now conundrum in some detail, as follows: Fundamental time is the sequential numerical order of changes that run in the Now, whereas emergent time is the duration of changes that run in the Now, and only comes into existence when measured by an observer.

Girelli, Liberati and Sindoni have shown in their article that time may not be fundamental, but may instead be an emerging feature: "We have showed, in a toy model, how the Lorentzian signature and a dynamical space-time can emerge from a flat non-dynamical Euclidean space, with no diffeomorphisms invariance built in. In this sense the toy-model provides an example where time (from the geometric perspective) is not fundamental, but simply an emerging feature" (Girelli *et al.,* 2011). Our research confirms their results: time as duration is an emerging feature that only comes into existence when fundamental time is measured by an observer. Further, this way of conceiving of time provides a unifying re-reading of Barbour's ephemeris time and of Rovelli's thermal time, by including both of these ways of looking at time in a model where the concept of duration measured by an observer emerges from a more fundamental numerical order of material changes that exist independent of the observer.

Discussion

Andrew Jaffe is convinced that the Now is not a problem: "I'm convinced that 'now' is a non-problem. Once quantum mechanics and thermodynamics have given time a direction, 'now' isn't physics, but a combination of time's arrow with psychology and physiology. The past is what is encoded in our memories. To a rock, an electron or a galaxy, there is no now. But occasionally I wonder whether this is sufficient" (Jaffe, 2016). In physics we do not have any tangible experimental data that time has a physical direction, nor do we have any tangible experimental data that the physical arrow of time exists. Now is not a problem once one understands that time is the sequential numerical order of changes running in the timeless space of Now.

Shapiro has observed through measurement that in a relatively strong gravitational field light has a diminished speed. In an article entitled "Fourth Test of General Relativity" Shapiro wrote: "Because, according to the general theory, the speed of a light wave depends on the strength of the gravitational potential along its path, these time delays should thereby be increased by almost $2x10^{-4}$ sec when the radar pulses pass near the sun. Such a change, equivalent to 60 km in distance, could now be measured over the required path length to within about 5 to 10% with presently obtainable equipment" (Shapiro, 1964).

The solution to Einstein's Now conundrum presents us with a new physical model in which light moves in space, which is always Now, and time is its duration. In this new physical model, time does not exist as a physical reality (time as duration is only an emergent quantity which originates from observer's measurements) and as such, cannot shrink or dilate. The results of Shapiro confirm that in a relatively strong gravitational field the speed of light is diminished only minimally, because in a relatively strong gravitational field what actually changes are the permeability and permittivity of space, which changes only minimally influence light speed. In a relatively strong gravitational field light is moving a bit slower and so needs more duration to move from point A to point B than it does in space with weaker gravity. Understood in this way, it is more appropriate to refer to this effect as a "gravitational velocity decrease," rather than as a "gravitational time delay." Several pieces of research already confirm that gravity changes the permittivity and permeability of space, and that these changes diminish light speed (Sato, 2007; Ellis *et al*., 2007).

However, this effect applies not only to light speed, because the rate of all physical changes diminishes in a relatively stronger gravitational field. In GPS systems, clocks on the satellites are calculated to run 45 microseconds per day faster than clocks on the Earth's surface, because gravity is stronger on the Earth's surface. This is the so-called "General Relativity (GR) relativistic effect." However, in GPS systems, clocks on the satellites are also calculated to run 7 microseconds per day slower than on the Earth's surface, owing to "Special Relativity (SR) time dilation," which would be better named "SR velocity decrease." Owing to this combination of GR and SR effects, the rate of clocks on the satellites is faster than the rate of clocks on the Earth's surface by 38 microseconds per day (Ashby, 2003).

However, the rate of clocks on the Earth's surface do not get slower because they exist in a physical reality called time that can actually dilate. In SR and GR (and in physics in general) time is only the mathematical parameter of material changes, i.e. motion, and cannot be "relative." We see in GPS systems that what is actually "relative" is the velocity of material changes i.e. motion. All clocks are running in the same timeless space of Now. In a relatively stronger gravitational field the rate of clocks is slower, the speed of light diminishes, and the velocity of physical and biological changes diminishes as well.

As regards the famous special relativistic argument of the twins, once it is realized that the twins are both aging in space, and not in time, there is no longer a "twin paradox." A twin on the Earth's surface ages faster than his or her counterpart on a fast spaceship owing to the SR relativistic effect. A Twin on the Moon ages faster than his or her counterpart on the Earth owing to the GR relativistic effect. The rate of the aging process for each twin is therefore different, but is real for both twins, because both twins actually only ever age in the timeless space of Now.

In a universe where the fundamental arena is timeless space, travelling into either the past or the future is categorically excluded. The idea of time travel, as something that might actually be possible, was born with the prediction of "closed time lines," or the more frequently used term, "closed timelike curve (CTC)," which were predicted by Willem Jacob van Stockum (Stockum, 1937) and Kurt Gödel (Gödel, 1949). However, Gödel acknowledged that CTC allows for contradictive time travel, leading him to conclude that time cannot have a physical existence. He expressed this view in a famous statement: "In any universe described by the theory of relativity, time cannot exist." (Yourgrau, 2006). Stockum and Gödel simply used the wrong term to describe the "closed time lines" that they discovered, and this in turn then led them to the erroneous conclusion that one could travel in time. In the first chapter of this article it was shown that the fourth coordinate of space is not temporal, but is also spatial. Hypothetical movement in "closed time lines" means that we move only in space, and so we always end up at the same point from which we started, which is in space Now. Motion in time is categorically excluded, because time is merely the duration of motion in *space.* The result of Hawking's research is that the laws of physics do not allow for the physical appearance of closed timelike curves in which one could move in time (Hawking, 1992).

Moreover, the idea of time as the sequential numerical order of changes running in the timeless space of Now allows us to justify, in a clear way, in what sense in general relativity the idea of an idealized time *t* that flows on its own in the universe, without reference to anything that happens, must be abandoned and be replaced with different possible internal times associated with specific physical clocks. Taking this approach allows one to deal with the relative motion of the variables, with respect to each other, in a democratic fashion. In general relativity, there is not a preferred and observable quantity that plays the role of independent parameter of the evolution of a system, because clocks provide only a mathematical measure of the numerical order of physical events in the timeless space of Now. With clocks one measures frequency, speed, and numerical order of events in the timeless space of Now. Since clocks can be defined as those instruments which measure the speed of material changes and movements, the internal clocks/times of general relativity are only measuring systems, and what they measure is the numerical order of material changes in the timeless space of Now. The definition of time as a mathematical coordinate that indicates the sequential numerical order of material motion running in the timeless space of Now thus provides a clear and suggestive re-reading of the nature, significance, and meaning of the internal clocks/times of general relativity (Fiscaletti *et al*., 2012).

Page and Wootters criticise modelling time as a physical dimension (coordinate time), because time as a physical dimension is unobservable: "We shall argue that the temporal behavior we observe is actually a dependence on some internal clock time, not on an external coordinate time. It is perfectly consistent with our observations to assume that any closed system is in an eigenstate of energy and thus stationary with respect to coordinate time, since coordinate time translations are unobservable. Such a state can be decomposed into states of definite clock time. The dependence of these component states upon the clock time labeling them can then represent the observed temporal behavior of the system" (Page, Wootters,1983). In this article it has been shown that coordinate time (temporal dimension) is also spatial. Clocks run in a timeless 4D space. The relativistic rate of clocks depends on the strength of the gravitational field in a given region of 4D space, and is valid for all observers. GPS systems prove this point beyond any reasonable doubt.

And like the idea of time existing as a "temporal dimension," which therefore implies the existence of an unobservable "temporal coordinate," the idea of a hypothetical "internal observer" and "external observer" is also unobservable and so also has no direct experimental evidence, and so therefore should be carefully re-examined. Moreva's and others' prediction of a hypothetical observer external to the universe that has access to the abstract coordinate of time is questionable. In their 2014 Physical Review paper, Moreva and his co-authors wrote: "In super-observer mode (Fig. 2a, yellow box) the experimenter takes the place of a hypothetical observer external to the universe that has access to the abstract coordinate time and tests whether the global state of the universe has any dependence on it. Hence, he must perform a quantum interference experiment that tests the coherence between the different histories (wavefunction branches) corresponding to the different measurement outcomes of the internal observers, represented by the which-way information after the polarizing beam splitter PBS1" (Moreva *et al*., 2014). According to our opinion, the introduction of an observer that is external to the universe is questionable, because we do not have a single piece of data that confirms that such an observer could actually even exist. Models of space-time, i.e., models in which time is understood to be the fourth dimension of space, have no ability to describe entanglement without the introduction of hypothetical elements, e.g., an "observer which is external to the universe". Once it is understood that universal space is timeless, entanglement can be fully understood without the introduction of hypothetical elements, and therefore questionable elements, such as "coordinate time," "inner observer," or an "observer which is external to the universe". Recent research confirms that universal space, which has its origin in a fundamental three-dimensional quantum vacuum, is the direct information medium of EPR-type experiments (Fiscaletti, Sorli, 2017).

On the other hand, in Martinetti (Martinetti, 2013) suggested that the problem of time lies in explaining its emergence, both in quantum mechanics as an idealized abstract parameter in the background space of the observables of the system, as well as in relativity as a geometrical parameter of four-dimensional space-time. Our view of time as the sequential numerical order of material changes in the timeless space of Now allows a resolution of this problem in a clear and unifying way, as follows: both in relativity and in quantum mechanics time is a mathematical parameter measuring the numerical order of material changes in the timeless space of Now. And if in Borghi (Borghi 2016) claims that there is a fundamental inequivalence between thermal clocks and atomic clocks, in our approach it is not allowed – as it seems to be by Borghi – that there is a fundamental physical disagreement between the measurements obtained by relativistic clocks and those provided by thermal clocks in the same experimental situations. In our approach, physical time exhibits a different nature and different features depending on the level of observation of phenomena, which cannot be merged into an ultimate unifying theory, because, at a fundamental level, time existing as a primary physical reality of its own does not exist. Thus, in our opinion, Borghi's argument is poorly expressed. In our approach, the fundamental fact regarding the interpretation of the problem of atomic clocks and thermal clocks lies in nothing more than the existence of two kinds of time; namely, fundamental time, which is the numerical order of changes and exists independent of the observer, and emergent time, which is the duration of material changes and originates from the observer's measurement. One can say that Borghi's argument regarding the possible (eventual) disagreements between thermal clocks and atomic clocks in fact deals with the level of emergent time, but not the level of fundamental time. At the most fundamental level, both for atomic and thermal clocks, time is measured as the sequential numerical order of material changes in the timeless space of Now.

In summary, in light of the arguments made in this paper, one can conclude that the fundamental arena of natural processes is a timeless background, and that material changes run in the timeless space of Now. This means that, when change X2 comes into existence, change X1 no longer exists; when change X3 comes into existence, change X2 no longer exists. Changes are irreversible, in the sense that a change that no longer exists is lost forever. Any increase in the entropy of a given system only happens in timeless space. In other words, "time flow" and "arrow of time" have only a mathematical existence. Time (as the sequential numerical order of changes) flows within the timeless space of Now, and has an arrow which points in the direction of numerical order increase: X1, X2,...,Xn.

In Newtonian physics, the fundamental arena of the universe is a space in which time runs uniformly, and so is a fundamental arena in which material changes run in time. Conversely, in Einstein's relativistic physics, time no longer runs in space, because in relativistic physics, time has become the fourth dimension of space in which material changes run. In this article we have shown that time is a mathematical parameter of changes that run in timeless space, bringing together into a unifying picture ideas that have already been proposed by Girelli, Liberati, and Sindoni, as well as by other authors, such as Prati, Caticha, Elze.

During the period of time in which Einstein came up with his Relativity theory, what we now know to be the linear psychological time of "past-present-future" was still considered to be an actual physical reality, and so the ability of this idea to influence physics remained strong. As a result, the idea of linear time as being the fourth dimension of space was incorporated into physics. In this way, time was sort of half-way integrated into space, somewhat like the way a round peg can be sort of half-way integrated into a square hole if one pounds on it hard enough.

In this article however, we are no longer trying to pound the round peg of time into the square hole of space, so to speak. To the contrary, in this article, rather than trying to merge space and time as some sort of composite physical reality, we have shown that time, at a fundamental level, is merely the sequential numerical order of material changes, i.e. motions that run in space. In this way, time is finally, fully, and accurately integrated into the timeless 4D space of Now: 3D space and time T (Newtonian physics) $\rightarrow$ 3D+T space-time (Relativity) $\rightarrow$ 4D timeless space (this article).

In Relativity it is accepted that motion from point A to point B in space happens in 3 spatial dimensions and one temporal dimension. In this article however, we have shown that, in relativity regime, motion happens in 4 spatial dimensions, and we have also shown that that motion happens exclusively in timeless space. In GPS systems clocks run simultaneously in timeless space. Their "relativistic rate" depends on SR and GR effects and is valid for all observers. As time is not an actual physical dimension, no clock can "tick" in some hypothetical physical past or future, since past and future, as has also been described in this article, are purely conceptual realities, and as such have no demonstrable physical correlate. All clocks in this universe run in the same timeless space, which means they all only ever run Now. GPS systems have proven that the relative rate of clocks is valid for all observers. This means that an observer on a train-station platform where there is a stationary clock, and an observer in a passing train where there is moving clock, will each observe the individual clocks to run at the same rate, i.e., they will be able to agree that the clock on the train, which is moving, is running at a somewhat slower rate than the clock on the platform. In this famous example of Special Relativity, it needs to be understood that the stationary observer and the stationary clock, as well as the moving observer and the moving clock, all exist, and so all run, in timeless Minkowski 4D space.

Applications of this model of time in cosmology are surprising: universal changes run in NOW. This present moment we experience is the only moment in which the universe exists (Sorli *et al.*, 2016; Sorli *et al.*, 2017; Sorli *et al.*, 2018).

Conclusions

In 20th-century physics, time is understood as a fundamental physical reality in which the universe exists. However, as of the beginning of the 21st-century, we still have not obtained a single piece of data that provides any evidence whatsoever confirming time to have an actual physical existence. Understanding time to have only a mathematical existence provides a plausible solution to Einstein's Now conundrum: time is the mathematical parameter of changes i.e. motions, which run in the timeless space of Now.

References

Albert Einstein Site Online http://www.alberteinsteinsite.com (1915)

Anderson E. Machian classical and semiclassical emergent time. Classical and Quantum Gravity 2013; 31(2):025006.

Ashby N. Relativity in the global positioning system. Living Reviews in Relativity 2003; 6(1):1.

Borghi C. Physical Time and Thermal Clocks. Foundations of Physics 2016; 46(10):1374-79.

Buhusi CV, Meck WH. What makes us tick? Functional and neural mechanisms of interval timing. Nature Reviews Neuroscience 2005; 6(10):755–65.

Caticha A. Entropic dynamics, time and quantum theory. Journal of Physics A: Mathematical and Theoretical 2011; 44(22):225303.

Elze HT. Quantum mechanics and discrete time from "timeless" classical dynamics. Lecture Notes in Physics 2003; 633. 196 arXiv:gr-qc/0307014v1.

Ellis J, Mavromatos NE, Nanopoulos DV. Derivation of a vacuum refractive index in a stringy space–time foam model. Physics Letters B 2008; 665(5):412-17.

Fiscaletti D, Sorli A. Searching for an adequate relation between time and entanglement. Quantum Studies: Mathematics and Foundations 2017; 4(4):357-74.

Fiscaletti D, Sorli A. Perspectives of the numerical order of material changes in timeless approaches in physics. Foundations of Physics 2015; 45(2):105-33.

Fiscaletti D, Sorli AS, Klinar D. The symmetryzed quantum potential and space as a direct information medium. InAnnales de la Fondation Louis de Broglie 2012; 37: 41-71.

Gödel K. An Example of a New Type of Cosmological Solutions of Einstein's Field Equations of Gravitation. Review of Modern Physics 1949; 21: 447.

Girelli F, Liberati S, Sindoni L. Is the notion of time really fundamental?. Symmetry 2011;3(3):389-401.

Girelli F, Liberati S, Sindoni L. Is the notion of time really fundamental?. Symmetry 2011;3(3):389-401.

Góźdź A, Stefańska K. Projection evolution and delayed-choice experiments. Journal of Physics: Conference Series 2008; 104(1): 012007.

Gomel E. Postmodern Science Fiction and Temporal Imagination. London: Bloomsbury Publishing, 2010.

Hawking SW. Chronology protection conjecture. Physical Review D 1992; 46(2):603.

Jaffe A. Physics: Finding the time. Nature 2016; 537(7622):616.

Licata I. Minkowski space-time and Dirac vacuum as ultrareferential fundamental frame. Hadronic Journal 1991; 14: 225-50.

Moreva E, Brida G, Gramegna M, Giovannetti V, Maccone L, Genovese M. Time from quantum entanglement: an experimental illustration. Physical Review A 2014; 89(5):052122.

Minkowski H. Space and time. The Principle of Relativity. Dover Books on Physics, 1952: 75-91.

Martinetti P. Emergence of time in quantum gravity: is time necessarily flowing?. KronoScope 2013; 13(1):67-84.

Muller RA. Now: The Physics of Time. WW Norton & Company, 2016.

Prati E. The nature of time: from a timeless Hamiltonian framework to clock time of metrology. arXiv preprint arXiv:0907.1707. 2009.

Page DN, Wootters WK. Evolution without evolution: Dynamics described by stationary observables. Physical Review D 1983; 27(12):2885.

Rovelli C. Loop Quantum Gravity Living Reviews in relativity http://www. livingreviews. org/Articles. Volume1/1998-1rovelli.1998.

Rovelli C. A new look at loop quantum gravity. Classical and Quantum Gravity 2011; 28(11):114005.

Sato M. Gravitational effect on the refractive index: A hypothesis that the permittivity, ε0, and permeability, μ0 are dragged and modified by the gravity, https://arxiv.org/vc/arxiv/papers/0704/0704.1942v3.pdf (2007)

Shapiro II. Fourth test of general relativity. Physical Review Letters 1964; 13(26):789–91

Stockum WJ van. The gravitational field of a distribution of particles rotating around an axis of symmetry. Proceedings Royal Society of Edinburgh 1937: 57.

Sorli A, Fiscaletti D, Mageshwaran M. Advanced Relativity:
Unification of Space, Matter and Consciousness. NeuroQuantology 2016; 14(4):645-656.

Sorli A, Dobnikar U, Fiscalretti D, Kaufman S. Advanced Relativity for the Renaissance of Cosmology and Evolution of Life. NeuroQuantology 2017; 15(4):37-44.

Sorli A, Dobnikar U, Patro SK, Mageshwaran M, Fiscaletti D. Euclidean-Planck Metrics of Space, Particle Physics and Cosmology. NeuroQuantology 2018; 16(4):18-25.

Yourgrau P. A world without time: The forgotten legacy of Godel and Einstein. Basic Books, 2009.