IDEAS OF RELATIVITY:
INTERPRETATIONS IN CONFLICT

The PIRT-Conferences 1988-1998
PIRT-Proc. 1998, Imperial College London

Mogens True Wegener
emeritus professor of philosophy
Aarhus University, Danmark

As one of the rather few philosophers attending the biennial conferences on the *Physical Interpretations of Relativity Theory* from their start in 1988 until 1998, ten years later, I would like to take this opportunity to assess the import of the various contributions offered by these conferences from a philosophical point of view, in order to give some clues as regards the perspectives of future progress in this field of physics. Throughout the past decade all our conferences have been sponsored by the *British Society for the Philosophy of Science*. For that reason it may not seem imposterous for a philosopher to assume this task.

Dr Duffy, the glorious initiator and excellent secretary of these conferences, has also chosen their title and written the text of their programme, from which I quote: "Contributors should note that the starting point of the conference programme is the acceptance of the accuracy and excellence of Relativity Theory which provides the framework for the discussion. The questions raised are directed towards examining the philosophical, historical and methodological aspects of the various interpretations of the formal structure, and the implications which these several interpretations have for physical theories". No one, however, could rightly accuse Dr Duffy for having exerted the harsh strictures of blind orthodoxy and I, for one, am gratified that the actual course of these conferences has not shown any resemblance to what one might have feared from a very rigorous implementation of the passage just quoted. In fact, our little society has rather witnessed "the flowering of a thousand flowers", in contrast to those much larger societies which have been marred by the crippling influence of dogmatism.

But not everything is well in our little garden, part of the great field of natural science. Relativity is a topic in mathematical physics. I remember from a conversation with a collegue from the mathematics department at our university, how one of his casual remarks struck me with surprise. Mathematical physics, he told me, is an altogether different subject depending on whether it is practised by a mathematician or by a physicist. Indeed, mathematicians and physicists constitute two different camps within the field of mathematical physics; each camp having developed its own scientific journals and organizations, their mutual communication and intercourse is next to nill. Metaphorically, the two camps are separated by a huge distance covering a vast desert of wasteland too hostile to the passage of visitors. This division into two camps has its counterpart in a cleavage that threatens to split our own society into sections that do not communicate. So their adherents sometimes behave like sectarians.

One could say that such conflict of interpretations is the price we have to pay for our freedom of thought. In a way I believe that this is right - but it is a philosopher's task to work for unification wherever unity is possible, and I do not see any reason for giving up in advance.

The division, alluded to by my collegue, between mathematicians and physicists, I see repeated in our own forum as the cleavage between two divergent attitudes to issues of relativity theory. These attitudes, exposed as *ideal types*, I shall henceforth characterize as ***naïve formalism*** and ***naïve realism***, respectively. So I put up two ideal types as virtual targets in order to shoot them down by intellectual criticism. By treating the two attitudes as radical extremes, I hope that I can attack them freely without running the risk of hurting anybody personally. Fortunately, the two ideal types rarely manifest themselves historically in a pure form; but the divergency of trends is clear, although their statistics is a far cry from equilibrium. Correspondingly we find a marked tendency towards the preponderance of realists among the participants in our meetings which may be due to the presence of the predicate 'physical' in the title given to them.

Now attitudes towards science are not in themselves scientific. Neither can arguments advanced in support of such attitudes justly be called scientific, although their proponents, of course, attempt to underpin them by reference to what they believe is well established science. What unifies the two attitudes just mentioned as opposite poles within a single field of tension is *their common quest for an ultimate explanation*, meaning an explanation of our sensible experiences that has its foundation in "the hidden depths" of *Nature*. So they remain on a par as regards their philosophical urge towards ***ontology***, or ***metaphysics***. What differentiates them is the sort of explanation suggested: *A)* In the case of *naïve formalism* the explanation consists of a reference to the immanence in *Nature* of eternal forms, mathematical or geometrical. Thus naïve formalism is pure *idealism*, the most vulgar kind of Platonism, or Pythagoreanism. *B)* In the case of *naïve realism* the explanation involves the claim that *Nature* in itself consists of matter-in-motion, of non-sensible fields, or of a substance, or substratum, termed the aether. Thus understood, naïve realism may derive from the Ionic search for a material principle, from the atomism of Democritus, from the aether-theory of Descartes, or from some other source. *Arché* being the Greek word for principle of origin, we may describe naïve realism as *archaic*. As the formalists often take over the *jargon* of realism, speaking of "curved spacetime", or the "structure of pure emptiness", as ultimate realities, the issues sometimes get somewhat blurred. So instead of speaking of realism in contrast to formalism I might have spoken of *materialism*, or *substantialism*. In that case I would not have needed the predicate 'naïve' since, today, all traditional kinds of materialism, or substantialism, are certainly naïve. But what I here brand as *naïveté* is purely philosophical, viz. a peculiar kind of intellectual immaturity that, nevertheless, remains compatible with the highest degree of scientific sophistication and ingenuity.

The Urge for Metaphysics as Ontology

Naïve Formalism *(vulgar Platonism/Pythagoreanism)*
seeks to unveil the "natural geometry immanent" in the depths of Nature
Naïve Realism/Materialism *(the Ionians, Democritus, or Descartes)*
seeks to disclose the "underlying reality", the "secret substance", of Nature

How do these two positions manifest themselves in the context of our conferences? This can best be illustrated by reference to a now famous little book entitled *The Logic of Special Relativity* (Cambridge 1967), due to one of our most prominent collegues and friends, the late Professor Simon Prokhovnik. In this classical monograph Professor Prokhovnik discussed three apparently *very different interpretations of* ***SR*** *- the spacetime geometrical approach, the approach of kinematic relativity*, and *the aether-theoretical approach*, which he prefers. Now, for my part, I prefer to view *the kinematic approach* as a *proper mean* of the other two:

1) ***The SpaceTime Approach*** *(orthodox)* ***- seeks the inherent structure of space***
2) ***The Substratum Approach*** *(heterodox)* ***- seeks an ultimate substance, or frame***
3) ***The Constructive Approach*** *(kinematic)* ***- invents world-models from first principles***

However, it is characteristic of the presentations and discussions given at these conferences that a majority of the participants are adherents of *realism* and the *aether-theoretical* approach and that a considerable part subscribe to *formalism* and the *spacetime geometrical* approach, while almost nobody, except myself, pays any interest to the approach of kinematic relativity. This I find regrettable for at least two, in my own view very important, reasons.

First, a dogmatic accentuation of one of these opposites to the exclusion of the other would at once take us into that philosophical kind of naïveté which I have rightly denounced. I fully recognize the value of the formalistic approach of *spacetime geometry as a technical instrument of relativistic physics*. Only I would follow Professor André Mercier who in his 1994 lecture on "The Reconstruction of Spacetime as Timespace" claimed that time should be considered more important than space, whence 'spacetime' should be re-baptized 'timespace'. But it is illegitimate to hypostasize geometry into a *structure* that is immanent in Nature itself. Likewise, I fully approve the value of the realistic approach of *aether-theory as a heuristic device to be exploited* in order to further the fruitful development of relativity theory; but it is also illegitimate to hypostasize the aether into a *substance* underlying the existence of Nature. However, since the relevant questions of modern science are questions of structure rather than questions of substance, it is easier to unmask the mistake of realism than the fault of formalism. But, viewed as extremes, the two positions are glaring transgressions of the limits of science. As shown convincingly by Kant, all sober science should abstain from statements of ontology. Hence, if one of these approaches is viewed in spendid isolation from the other, and its content is elevated to the exclusive status of *Ultimate Reality*, or *Essence of Nature*, then I must object. Philosophically, this inborn ontological urge, this drift towards a deep metaphysics - in short, this *deep naïveté* - is not only misleading in the sense that it takes us out in a swamp in order to leave us there with a mess of inconsistencies and unsolved problems: it is also dangerous in the more serious sense that it tempts us to seek a refuge in scientific dogma.

Second, I suspect that the conflicting attitudes, that of formalism and that of realism, secretly uphold a sort of unholy alliance in the sense that they conspire to ascribe a conceptual primacy to space rather than to time. In this they just follow the lead of Einstein who explicitly stated that his scientific programme was to reduce everything in physics to spacelike concepts; but in that respect, at least, the tradition from Einstein is obsolete. As a historian of ideas I can affirm with confidence that, just as it was the unique feat of the renaissance to discover space - mind the introduction of perspective in the arts - so it is up to our own century to discover time (cf. the telling title: *From Being to Becoming*, given by Prigogine to a well-known book of his). The great minds behind the classical revolution of natural science, Galileo and Kepler, were unanimous in their assent to these words: *ubi extensio, ibi materia, ibi geometria*, where there is extension there is also matter and geometry. The same stand was taken by Descartes who was unable to make his analytic geometry relevant to physics without calling upon an aether-theory. This is also the reason why I can imagine a secret conspiracy between realists and formalists, between aether theorists and spacetime geometricians: both parties view time as mere illusion, and both parties wants to exclude it from serious consideration and analysis.

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Am I exaggerating? Indeed, I hope so! For *time*, which is the inmost gist of creation, freedom, life, can't be excluded! To exclude *time* would be to divest the world of its dynamics. Can we imagine a timeless world, a world without change? Such a universe couldn't be real! The Greek philosopher Parmenides (*floruit* 500 BC) seduced himself into believing that he was able to imagine a block-universe wholly devoid of time and motion, but I am convinced that it was an illusion made possible by his membership in a changing world where he could think and reason and thus partake in temporal processes. His contemporary, Heraclitus, had a much more realistic picture of the world, imagining it to consist of a steady flow of fire, sometimes bursting up and sometimes fading away, but always ruled by divine decree, or law (*lógos*). Before him, already Anaximander (*floruit* 560 BC) showed interest in time when he described the principle (*arché*) and element (*stoicheion*) of things as the infinite/indefinite (*tò ápeiron*) "which gave origin to the heavens and the worlds within them" and which is still "the source of becoming as well as destruction"; and, as he said: "all things change with necessity" for they "pay penalty and reprisal to each other for their crimes according to the judgment of Time".

But what of space? Cannot the void be "real"? In the '*Timaeus*', his cosmology, Plato spoke of three "things" (*ónta*): (1) *Pure Being* which, as *timeless forms*, is the object of *reason*, (2) *Pure Becoming* which, as *temporal things*, is the object of *sensation*, and (3) *Pure Void* which, as a *receptacle* of becoming-simulating-being, is *dreamlike* - neither an object of reason, nor an object of sensation, hardly one of belief. Has our enigma ever found a finer expression?

Pure Being *(tò ón)* = ***eternal forms*** *(geometry) - objects of reason*
Pure Change *(génesis)* = ***temporal events*** *(phenomena) - objects of sensation*
Pure Void *(chóra)* = ***the uterus of creation*** *- dreamlike, object of neither*

According to Plato these are timeless conditions for the temporal existence of World (*kósmos*) which was unified with Time (*chrónos*) by decree of the Divine Master Craftsman (*demiúrgos*) right from the dawn of creation. In the same passage he wrote of the Void (*chóra*) as follows: "Third is Space, which is everlasting, not admitting destruction, providing a situation for all things that come into being, but itself apprehended without the senses by a sort of bastard reasoning (*sic*) and hardly an object of belief. This .. we look upon as in a dream, saying that anything that is must needs be in some place and occupy some room." (Cornford's translation) Now what is the verdict of modern relativistic physics? Let us, for instance, consult the book *On General Relativity*, by Mercier, Yourgrau & Treder (Berlin 1979). Herein the concept of space is discussed, and the authors argue from a plurality of possible spaces to the conclusion that space is not real. I quote: "(Any) space must be constructed from a suitable axiomatics. Axioms are not evident truths, they are implicit definitions. Therefore, none of these spaces is "real space". *There is no such thing as real space* (cf. app.). " This statement, to which I wholly consent, supports the view of Poincaré: *Space in itself is devoid of structure*.

But is space just an illusion, then? Not quite! Rather it is "well-founded appearance", as proposed by Leibniz who was deeply indebted to Plato. So, in what do we find its foundation? As I see it, all *space* is timespace, or *a modification of time*. We may have time without space: that would be something like a single relativistic "world-line", the symbol of mere existence (namely that of a material particle or a human observer). But we never have space without time; that would, literally, be sheer nonsense. Space is *multiplicity unfolded across time* or, in logical terms, spatial extension is definable as local incompatibility of simultaneous events. This simultaneity is operationally definable by the absence of causal connectivity, "true causes"

operating in time by the communication of information-carrying signals propagated at a certain speed, viz. that of light, which is supposed to be the universally invariant limit to all motion. But our concept of causality depends on, and is derived from, our concept of laws of nature; Further, the distinction between before and after in the relation of causal connectivity, between the cause and its effect, cannot, in my opinion, be introduced satisfactorily without explicitly or implicitly referring to a prior order, or "arrow", of time. As I see it, the causal theory of time involves a vicious circle, and to explain it by Reichenbach's method of marks is unconvincing.

Hence our definition of simultaneity, as that of spatial extension across time, hinges on the communication of signals. The only relevant signals consists of electromagnetic radiation. Whether they are visible or invisible to the human eye, let's for simplicity's sake agree to call them "light signals". There is, then, an indisputable interdependency between the speed of light and the definability of simultaneity and of spatial extension. But how speak of a speed of light, and how suppose light to be something travelling in space, even before having defined space? In this forum it should be unnecessary to elaborate on the well-known circularity inherent in the attempt to determine the one-way light-speed by timing the arrival of a signal at a distance by means of a clock which is made synchronous with the master-clock of the emitting observer by another exchange of light-signals. What is operationally feasible is solely the timing of the interval between the advanced and retarded times of a reflected light-signal, or of series of such signals. Hence, as stressed by an impressive number of papers during the past decade, including those of Sjödin, Kroes, Sklar, Øhrstrøm, Selleri, and myself, the main conclusions of this forum seems to be: 1) that the only interpretation of Einstein's light principle relevant to physics is the one asserting a universal constancy of the round-trip, or average, light-speed; 2) that an indefinite number of non-standard definitions of simultaneity, all involving variable one-way light-speeds, hence at variance with Einstein's own convention, are indeed possible. So the issue of simultaneity remains a stumbling block to any realistic view of space.

For this reason I wholly accept the suggestion of Viv Pope that we regard the phrases "velocity of light", and "light-speed", as dubious metaphors which, for philosophical purposes at least, should be replaced by a much more precise linguistic usage that simply refers to the universally invariant proportionality between temporal and spatial standard intervals, or units. Likewise I also accept his proposal that we regard photons as binary quantum relations which are not in themselves spatial, but which may be useful to the purpose of introducing space. However, when Pope discards what he calls the 'God's Eye View' of cosmic symmetry, accusing it of having mislead him to believe that there was a clock paradox, I don't understand him. According to Pope it is, as it seems, not only logically impossible to imagine three observers in relative motion as involved in a situation of perfect symmetry, it is also a kind of blasphemy: I quote from his (PIRT 1994): "What (standard! MW) relativity was telling me was that so long as we drop that presumptuous, socially conditioned belief that the way we see things in our mind's eye is the way we imagine 'God sees it', then there is no paradox whatever in time being different for different observers. All we have to do is to settle for the fact that in reality one can only describe what happens in the time by which one sees it happen. In that relative time, objects which are in motion relatively to oneself age at different rates ... I saw very clearly that if observational distance is observational time in the ratio of units c, then the times ticked by clocks that change their observational distance as they tick observational time must, logically, be stretched-out, or 'dilated' relatively to the observer, in the *geometrical* way (***SR***) describes."

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This amounts to a total denounciation of the cosmological approach of kinematic relativity. But, surely, what has mislead Pope is the approach of spacetime geometry.

As my intention is to invite you to adopt precisely that 'God's Eye View' which Pope rejects, I shall make my stance clear: What I invite you to do is not blasphemy, but cosmology! The limitation of the spacetime geometrical approach is precisely that it is local, not universal. As I have just demonstrated, what the spacetime approach and the substratum approach have in common is an urge for ontology. But the world as ultimate reality is and remains inscrutable Never, never shall we know! I think Viv Pope agrees to this. Alexei Nesteruk does, I'm sure. When the modern picture of the universe as an aetherial machine was developed by Descartes, his scientific imperialism - which left nothing for the humanities to do - was severely attacked by Giambattista Vico. According to Vico, *verum et factum convertuntur*. What we can know is what we can do, nothing more, nothing less. Now, to create the universe was the feat of God. His act was unique and cannot be repeated. What we can hope to understand, as human beings, is not physics, but history. So the arts, humanities, and culture, are more important than science. In a deep sense Vico was right, I believe; but I don't share his pessimism with regard to science. In fact, I think that Vico - unintentionally - has presented us with the very key to good science! What we know is what we have done. Hence, to use a metaphor, the task of good science is to retrace the footsteps of God! This was also the clear conviction of Nicholas of Cusa (1401-64). Following him, I shall insist that *physics* can only realize its deepest aspirations as *cosmology*. The very aim of natural science is to reconstruct the universe, and in order to fulfil its purpose it must be based on simple principles and clear definitions (MW, 1994 & 2000).

But let us start from scratch. Exact science attempts to discover "the laws of nature". When found, such laws are represented as *invariant relationships in the stream of experience*. Only relationships *confirmed by repeated observation and experiment* can pass as natural laws. Science is a human business which refers to observers: the laws of nature must be valid to all possible observers - hence the importance of invariance, and hence that of the human observer. But couldn't we abstract from observers? Isn't it sufficient to refer to events and to "frames"? One of my main points is that the concept of event is OK while that of frame is certainly not. This is reflected in the difference between Einstein and Poincaré as regards their respective formulation of ***the relativity principle***: whereas Poincaré spoke of the ***invariance*** of the laws of nature with respect to the transformation of coordinates, *i.e.* the communication of observed data, between ***observers***, Einstein instead spoke of the invariance (meaning the ***covariance***, cf. Tom Phipps) of natural laws with respect to the transformation of coordinates between ***frames***. For my part, I clearly side with Poincaré and his observers as against Einstein and his frames. My point is that *frames should be constructed* instead of being assumed to pre-exist *á priori*. To accomplish this we must resort to a remarkable British tradition within relativity theory that is represented by the names of E.A. Milne, A.G. Walker, and G.J. Whitrow.

While Milne was the intuitive genius of ideas, Walker and Whitrow were gifted with the analytical talent needed to exploit his exceptional ideas and bring them into full blossom. According to Milne the first condition of describing the universe by a rational world-model is that the structure of the model is determined by the existence of a universal class of equivalent particles, or observers, called: the "substratum". In his '*Cosmologie du XXme siècle*' (1965), J. Merleau-Ponty very strikingly compares such "particle-observers", or "observer-particles", to Leibnizian monads, describing the kinematic relativity theory of Milne as a true monadology

translated into mathematics. The kinematic substratum should not be confused with an aether. Indeed, the difference between the kinematic approach and that of the aether-theory seems to be abysmal - at least to begin with. Later, when we have derived the geometrical structure of the kinematic substratum and deduced its consequences for the timing of light-signals, it may appear natural to speak of the "propagation" of some quasi-entities called "photons" and to ascribe them speed, or velocity, both one-way and two-way, at an instant, and on the average. However, we should be wise enough to remind ourselves that such phrases are just metaphors. Whether, at that stage, we find it appropriate to describe the kinematic substratum as a specific type of aether, or we prefer to abstain from such language, is merely a matter of taste.

But, to start with, following the lead of Milne and Walker (MW 1996a), our approach is much more in line with a *lógos-theory* than with a *physis-theory*, in the phrasing of Pope. For this reason, *the class of world-models encompassed by our approach* will display features making a comparison with *the general structure of information-processing research* natural. The central issue that will concern us is the nature and properties of the kinematic substratum. According to Milne, the structure of the universe is determined by the kinematic substratum, the members of which constitute a privileged class of equivalent observers, and laws of nature are by *the cosmological principle* (***CP***) taken to be invariant to all members of the substratum. In agreement with this we distinguish between *fundamental observers* which realize an almost perfect equivalence, and thus are members of the substratum, and *accidental observers* which are far from perfect equivalence, and thus do not belong to the substratum. This distinction puts the idea of cosmic symmetry to the fore. Without this idea it is impossible to develop a cosmology. The difference between fundamental and accidental is evidently not absolute, but rather a matter of degree, therefore the very idea of a class of perfectly equivalent observers is an idealization. Let us now reflect a little on the contents of *the principle of relativity* (***RP***). What does it state? In the formulation of Poincaré it states the invariance of all laws of nature to the transformation of coordinates, or the exchange of data, between equivalent observers. In a way this is a tautology, for if the laws are not invariant the observers are not equivalent. The formulation makes it *natural to regard the **CP** as a strong version of the **RP*** (MW 1994b). In agreement with this, no laws of nature can be excepted from the invariance assumed to hold between fundamental observers, especially not that law which governs the behaviour of clocks. So there is no clock paradox pertaining to the master-clocks of fundamental observers for the simple reason that all such clocks agree and, if they don't, these observers are not fundamental! I therefore conclude that ***a cosmic time is indispensable to rational cosmology***.

It is often stated that homogeneous and isotropic world-models possess a cosmic time. I now invite you to invert this order of reasoning. According to the strong ***RP***, *i.e.* the ***CP***, the structure of all rational world-models must be determined by the existence of a universal class of privileged observers that are distinguished by their common participation in a cosmic time. On what conditions can this claim be fulfilled? The only way to exclude all possible influence from external causes is to ensure the most perfect symmetry. Now this means cosmic isotropy. All directions in the universe must be equally "good". No spatial direction may be privileged. Only on that condition can the universal substratum function as a ***compass of inertia*** (Gödel). But this can only hold for the fundamental observers; for accidental ones it must be different. Hence, for accidental observers the cosmic symmetry must be broken, and anisotropy reigns. This anisotropy, or asymmetry, according to Milne, is the only reason which can be given for

the emergence of forces in the universe; all forces, including gravity, must be due to asymmetry. Now experience has shown clocks to be retarded, and light-rays bent, near gravitating bodies. This seems to indicate causal influence, but can't the relationship be seen the other way round? What if it is the retardation of clocks which - by the bending of light-rays, hence also of space - induces massive bodies in free motion to approach each other spatially? This view, at least, makes it more plausible to understand asymmetry as being the cause of gravity.

One last point. In his book as well as in several papers Prokhovnik has advocated the possibility of a "stretching" of light-in-motion (mind the metaphor) due to universal expansion. What Prokhovnik in this context calls "the hypothesis of McCrea" was anticipated with at least one year by Whitrow, who in his splendid book '*The Natural Philosophy of Time*' (1961/1980) assumes a variation of "the hesitation of light" (Rømer) over cosmic distances in connection with a discussion of the relativistic formula for clock-retardation from which he then, in a very simple way, "derives" the famous Robertson-Walker metric. What Whitrow obtained was:

$$v \equiv d\sigma/dt \;\Downarrow\; c_o \equiv unity \;\Downarrow\; c/c_o \equiv 1/R(t)$$
$$dT = dt\,\sqrt{1 - v^2/c^2} \;\Leftrightarrow\; dT^2 = dt^2 - c_o^{-2}\,R^2(t)\,d\sigma^2$$

This clearly shows the formula for clock-retardation to be relevant only for accidental clocks, as $v \neq 0$ for accidental observers only. So clock-retardation too is due to asymmetry!

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APPENDIX (quotations from Duffy & Wegener, 2000, vol.1)

B. Tonkinson: 'Clocks don't go slow, Rod's don't contract' (PIRT 1996)

"The notion that there will be different clock rates or changed lengths in different mertial frames is misleading, clocks do not "go slow" and measuring rods are not "contracted"." (Cf. Törnebohm below)

L. Sklar: 'The Conventionality of Simultaneity! Again?' (PIRT 1990)

"Only the denial that such a (reversal of the temporal order) of events that can causally influence one another can ever be tolerated in physical theory can back up the claim that distant simultaneity is a matter of convention in relativistic, but not in pre-relativistic, physics."

P. Kroes: 'The Status of Time Dilation within **SR**' (PIRT 1988)

"The only way that the notion of an ether can be made compatible with ***SR*** is to deny that the ether can be ascribed a definite state of motion .. (But) if the ether cannot be ascribed a state of motion then .. Lorentz's conception of length contraction and his dynamical explanation loose their objective meaning." - (See also L. Kostro (PIRT 1988)

P. Øhrstrøm: 'Tense Logic and **STR**' (PIRT 1990, §7)

"It is even possible to solve the problem without introducing a preferred reference frame, or a preferred direction, as it suffices to assume the existence of a set of fundamental particles, i.e. a so-called substratum. All fundamental particles are assumed to move inertially, and each fundamental observer is supposed to have his clock synchronized with that of any other fundamental observer by their original coincidence at $\tau = 0$. It is easy to show that this definition corresponds to a re-synchronization according to the convention: $\tau = \sqrt{t^2-x^2-y^2-z^2}$.

Prof. H. Törnebohm has discussed this interesting idea in several publications. It is evident that τ-time is invariant under ***LT***, and τ-simultaneity can therefore be considered absolute on the condition that the τ-scale can be ascribed an absolute zero. Törnebohm sees *The Big Bang* as a plausible description of the origin of time $(\tau = 0)$. In his opinion, it is tempting to identify the fundamental particles with (the centers of) galaxies. There are two problems associated with this solution.

The first problem is that (it) presupposes $x < ct$. (Hence) clocks can only be synchronized within a uniformly expanding universe ... (A consequence of Törnebohm's solution is that) the velocity of light varies over space as well as in time. (Thus) at $\tau = 0$ signals have infinite velocity. I (believe) that (Törnebohm's) alternative version of ***SR*** is empirically equivalent to the ordinary version. I think that this equivalence is very important from a philosophical point of view. In the first place it demonstrates the possibility of an absolute simultaneity that is consistent with all empirical consequences of ***SR***. Secondly, it shows that the 'light-age argument' needs not be valid, i.e. a light-signal that has travelled over a distance measured to be *n* 'light-years' was not necessarily emitted *n* years ago ...

Another problem related to the above solution is that the transformation of space-coordinates is non-linear: $\tau' = \tau$. $x' = \gamma(v)\,\{x - v\sqrt{\tau^2+x^2+y^2+z^2}\}$. $y' = y$. $z' = z$ ... (This) non-linearity leads to the result that 'force-free' particles will in general be accelerated ... The difference between the orthodox version of ***SR*** and (Törnebohm's) version can easily be explained. Suppose that a light signal is sent from a clock located at $(x, y, z) = (0, 0, 0)$, at the time t_1 to a clock located at (x, y, z), where it is immediately reflected at the clock reading τ_2 to be received at $(0, 0, 0)$ at the τ_3. If the two-way velocity of light is unity, then: $r = \sqrt{x^2+y^2+z^2} = (\tau_3-\tau_1)/2$. $t = (\tau_3+\tau_1)/2$. It follows that the non-standard time coordinate (is): $\tau = \sqrt{\tau_3\tau_1}$ .. whence: $t - \tau = t\{1 - \sqrt{1-r^2/t^2}\}$."

Mogens True Wegener

S.J. Prokhovnik: 'The Nature and Implications of the Robertson-Walker Metric (***RWM***)' (PIRT 1990):

"Looking at the ***RWM***, we note that it defines a unique cosmological reference frame associated with the set of fundamental observers. The significance of the constant c in this context is unmistakable; it represents the speed of light considered in respect to this particular reference frame; hence, the formulation of the ***RWM*** clearly implies that the propagation of light takes place relative to the set of fundamental observers, which for this reason defines ***a cosmological substratum*** ... Both Bondi and Bergmann voice their concern that the existence of a preferred reference frame appears to be in conflict with ***SR***. Furthermore, the (idea of a cosmolgical substratum) implies that light will pass a succession of fundamental observers with the same speed c, irrespective of the expansion of their reference frame as described by the scale factor $R(t)$. This would mean that light could ultimately reach us from any fundamental particle no matter what its recession velocity, and that it will reach us, albeit redshifted, with the same speed as light emitted from any other origin. In this context, the cosmological Doppler redshift effect can be considered as a direct and intelligible consequence of a light rays maintenance of its substratum speed in the face of the expansion of the substratum; it is as if the ray is 'stretched' (and hence its energy diluted but not lost) by the expansion, depending on the scale factor $R(t)$. It is seen that this interpretation leaves open whether or not there exist galaxies with recession velocities greater than c, and hence it is also neutral on whether the universe is finite or not.

The idea that there exists a fundamental reference frame, a cosmological substratum, for light propagation is by no means inconsistent with physical observations. We know that light is affected by a gravitational field, so we might well expect that its cosmological behavior should be basically determined by the field associated with the overall distribution of matter in the universe. Such a non-arbitrary basis for its propagation would explain why its velocity is independent of its source, an amply-confirmed observation. That the velocity of a light ray should be the same with respect to every fundamental observer in its path is fully consistent with the equivalence of all fundamental observers as required by the Cosmological Principle, and it is also consistent with physical experience that light does not overtake light, signifying that light from a distant source must reach us with the same speed as light from terrestrial (or any other) sources, irrespective of the distance or relative velocity of the source. The light hypothesis enables one to calculate precisely the distance travelled by light relative to its source (treated as a fundamental particle) from the geodesic of the ***RWM*** for an assumed form of the scale factor, $R(t)$. Thus, accepting the ***RWM*** and its implications explicitly, we are able to interpret astronomical luminosity and redshift observations of distant galaxies more satisfactorily than by evading the notion of a fundamental frame and the associated light hypothesis."

The rest of the passage in **Mercier, Yourgrau & Treder** (1979) runs as follows:

"Yet many a relativist today might be tempted to say: Oh yes, Riemannian space is at least an approximation to real space. But why should not a quantum theorist then say: Hilbert space is such an approximation? The answer might be of course: each quantum system needs another Hilbert space, so this is a fiction, whereas the Universe (the totality of what is) needs something like a Riemannian space, it is even identifiable with it. Then we shall ask: with what Riemannian or other space exactly is it identifiable? Give me its metric g_{ik} and all its further properties as final datum, and then everything is determined, is even superdetermined, in it ... It is Spinoza's God, if you will, and we must be pantheists. .. Apart from the uneasiness produced by this eventuality, everyone may have guessed that the kind of revolution which, following the appearance of Einsteinian relativity, has taken place at the beginning of this century, may very well repeat itself .. making ***GRG*** obsolete and replacing it by some super-theory."