CHAPTER 1

RELATIVITIES AT VARIANCE

CONFLICTING IDEAS OF RELATIVITY THEORY

A Philosopher's report from
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As one of the rather few philosophers attending the biennial conferences on the *Physical Interpretations of Relativity Theory* right from the beginning 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 kindly 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, methodological and historical 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. In fact, 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 nil. 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 true; 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. Luckily, these ideal types rarely manifest themselves historically in a pure form; but the divergence of trends is clear, although their statistics is a far cry from equilibrium. In fact 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.

Attitudes towards science are not themselves scientific. Neither can arguments advanced in support of such attitudes be called scientific, although their proponents 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 which has its foundation in "the hidden depths" of *Nature*. Therefore they remain on a par as regards their philosophical urge towards ***ontology***, or ***metaphysics***.

What differentiates them is merely the sort of explanation they suggest. *a*) In the case of *naïve formalism* the explanation consists of a reference to the immanence in *Nature* of eternal forms, mathematical or geometrical. So naïve formalism is just *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 reality, consists of matter-in-motion, of non-sensible fields, or of a substance, or substratum, termed the aether. Thus understood, naïve realism may stem 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 a principle of origin, we may describe naïve realism as *archaic*. Since formalists often take over the *jargon* of realism, by their speaking of "curved spacetime" or "the structure of pure vacuum" as ultimate realities, the issues sometimes get somewhat blurred. Hence, 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 most certainly naïve. However, 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 "hidden substance", of Nature

How do these different 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 Simon Prokhovnik. In his monograph professor Prokhovnik discussed three seemingly very different interpretations of ***SR***, based on: 1) *the logic of spacetime* (standard), 2) *the logic of relative motion* (kinematic relativity), 3) *the logic of absolute motion* (substratum theories). For my part, I regard the kinematic (constructive) approach as a proper mean of the other two:

a) ***The SpaceTime Approach - seeks the inherent structure of space***
b) ***The Substratum Approach - hunts the ultimate substance, or frame***
c) ***The Constructive Approach - invents world-models from first principles***

It is characteristic for the presentations and discussions delivered 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 rather important reasons.

First, a dogmatic accentuation of one of the opposite views to the exclusion of the other would immediately transpose us to that philosophical brand of naïveté which I rightly denounce. I fully acknowledge the value of the formalistic approach of *spacetime geometry as a technical instrument of relativistic physics*. Only I side with my mentor André Mercier who in his 1994 *PIRT*-lecture on "The Reconstruction of Spacetime as Timespace" insisted that time should be considered more important than space, so that 'spacetime' should be reconstructed as 'timespace' and that it is illegitimate to hypostasize geometry into a *structure* which is immanent in Nature. Likewise, I fully recognize the value of the realistic approach of *aether-theory as a heuristic device to be utilized* 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.

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. However, viewed as extremes, these positions are glaring transgressions of the limits of science. *As argued convincingly by Kant, all sober science should abstain from statements of ontology.* Thus, if one of the approaches is considered 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 our refuge in scientific dogma.

Second, I suspect that the two 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 program was to reduce everything in physics to space-like 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 reknown 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 consider time to be a mere illusion, both parties want to exclude it from serious consideration and analysis.

Am I exaggerating? I very much 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 incorporation in a changing world where he could think and reason and thus partake in temporal processes. His contemporary, Herakleitos, 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, Anaximandros (*floruit* 560 BC) took interest in time when describing the principle (*arché*) and element (*stoicheion*) of things as the infinite, or indefinite (*tò ápeiron*) "that 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 further added: "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 form* is the object of *reason*, 2) *Pure Becoming*, which as *temporal events* is the object of *sensation*, and 3) *Pure Void*, which as the *receptacle* of becoming-simulating-being is *dreamlike*, neither an object of pure reason, nor one of pure sensation, hardly one of belief. Has our enigma ever found a finer expression?

Pure Being *(tò ón)* = ***eternal forms:*** *ideas, geometry - objects of reason*
Pure Change *(génesis)* = ***temporal events:*** *phenomena - objects of sensation*
Pure Void *(chóra)* = ***the uterus of creation:*** *in between - 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 (*demiourge*) right from the dawn of creation. In the same passage he wrote of the Void (*chóra*): "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, Treder & Yourgrau (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: "(A) 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"* (my italics, MTW), This stance, which I entirely share, supports the view of Poincaré: *space in itself is devoid of structure*. But is space an illusion?

Not quite! Rather it is "pure possibility" as proposed by Aristotle, or "well-founded appearance" as suggested by Leibniz, a late pupil of Plato. So, in what do we find its foundation?

In my view: *physical space is timespace, i.e., a modification of time*. We may have time without space: that would be something like a particular relativistic *world-line*, the symbol of existence of a material particle, or of a human observer. But we cannot have space without time; that would, quite literally, be sheer nonsense. Space is *multiplicity unfolded across time* or, in logical terms, spatial extension can be defined as: local exclusion of simultaneous events. Such simultaneity is 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, moreover, 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 without explicitly or implicitly referring to a prior order, or "arrow", of time. The causal theory of time involves a vicious circle, and to explain it by Reichenbach's method of marks is unconvincing; cf. p.112.

Our definition of simultaneity, and that of spatial extension across time, hinges on signal communication. The only relevant signals consist of electromagnetic radiation; whether they be visible or invisible to a human eye, let's for simplicity's sake agree to speak of "light signals". There is, then, an indisputable interdependence between the speed of light and the definability of simultaneity and that of spatial extension. But how speak of a "speed of light", how suppose light to be "something travelling" in space, even before having defined space? In this forum it is 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 made synchronous to 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 ("radar") light-signal, or of series of such signals.

Hence, as stressed by an impressive number of papers during the past decade including e.g., those of Kroes, Selleri, Sjödin, Sklar, Øhrstrøm, and myself, two of 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; and: 2) that an indefinite number of non-standard definitions of simultaneity, all involving variable one-way light-speeds, and thus at variance with Einstein's own convention, are indeed possible. Thus the issue of simultaneity remains a stumbling block to any "realistic" view of space.

For that reason I accept the suggestion of Viv Pope [1996] that we consider the phrases "light-speed" and "velocity of light" to be 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 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, since light, albeit *retarded relative to frame time*, may yet be *instantaneous relative to proper time*. However, when Pope rejects what he calls a "God's Eye View" of cosmic symmetry, accusing it of having mislead him to think that there was a clock paradox, I simply don't understand him. According to Pope, it is not merely logically impossible to think of three observers in relative motion as being in a situation of perfect symmetry, it is also (it seems) a kind of blasphemy ...

I quote from his [1994]: "What (standard, MTW) 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." This amounts to a complete denunciation of the cosmological approach of kinematic relativity. But, surely, what has mislead Pope is the approach of spacetime geometry.

Since 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 the urge for ontology. But the world as ultimate reality is and remains inscrutable. Never, never shall we know! 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 attacked by Giambattista Vico. According to Vico, *verum et factum convertuntur*, what we can know is what we can do, nothing more and nothing less. Now, to create the universe was the feat of God, our Creator. His act was unique and therefore cannot be repeated. What we can hope to understand, as human beings, is therefore history, said Vico, not physics. So the arts, humanities, and culture, are more important than science.

In a way 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 Nicolaus Cusanus (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. [MTW, 1994 & 2000].

Let us start again 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 all right, while that of *frame* is not.

This is reflected in the difference between Einstein and Poincaré regarding their various formulation of ***the relativity principle***: whereas Poincaré spoke of the ***invariance*** of the laws of nature with regard 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 are artificial constructs which are do not pre-exist in nature*.

To recognize this we must recur to a remarkable British Tradition within relativity theory, represented by the names of E.A. Milne, A.G. Walker, and G.J. Whitrow. While Milne was the intuitive genius of new 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 foremost condition of describing the universe by a rational world-model is that the structure of a world-model is determined by the existence of a universal class of equivalent particles, or observers, *the substratum*. This kinematic substratum *should not be confused with an aether*. In his work *Cosmologie du XXme siècle* [1965], J. Merleau-Ponty has strikingly compared such "particle-observers", or "observer-particles", with Leibnizian monads, describing the kinematic relativity theory of Milne as *a veritable monadology translated into mathematics*!

Indeed, the difference between the kinematic approach and that of aether-theory seems to be abyssmal, 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 begin with, following the lead of Milne and Walker [MTW 1996a], our approach is more in line with a *lógos-theory* than with a *physis-theory*, to use the phraseology of Pope. For this reason, the class of world-models encompassed by our approach will display features making a comparison with current research into the structure of information processes natural. The main 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; laws of nature are, according to his *cosmological principle* (***CP***), 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 a far cry from perfect equivalence and for that reason 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 not absolute, but a matter of degree, so the idea of a class of perfectly equivalent observers is an idealization. Let us reflect a little on the contents of *the principle of relativity* (***RP***). What does it state?

Following Poincaré, it states the invariance of all laws of nature to the exchange of data, or the transformation of coordinates, between equivalent observers. In a way this is a tautology, since. if the laws are not invariant, the observers are not equivalent. His formulation makes it natural to view the ***CP*** as a strong version of the ***RP*** [MTW 1994b]. In agreement with this, no law of nature can be excepted from the invariance assumed to hold between fundamental observers, especially not those laws that govern the behaviour of clocks. So there is no clock paradox pertaining to the master-clocks of fundamental observers for the very simple reason that all such clocks agree and, if they don't, these observers are just not fundamental.

Therefore I conclude that a cosmic time is indispensable to rational cosmology.

It is often said that homogeneous and isotropic world-models allow for a cosmic time. I now invite you to invert this order of reasoning. According to the strong ***RP***, *alias* 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 sustained? 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 can be privileged. Only on that condition can the universal substratum function as a *compass of inertia* (Weyl). But this can only hold for the fundamental observers. For accidental ones it must be different. Hence, for accidental observers, the cosmic symmetry is 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, also 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 that, 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 plausible to understand asymmetry as being the cause of gravity. In fact, my mentor André Mercier once made a remarkable statement in a paper, the reading of which encouraged me to make contact with him. What he wrote was: "*Gravitation* **is** *Time*" ...

One last point. In his book and in several papers, cf. e.g. the important quotation in the following appendix, Prokhovnik suggested the possibility of a stretching of "light-in-motion" (mind the metaphor!) due to universal expansion. What Prokhovnik here called "the hypothesis of McCrea" was anticipated with at least one year by Whitrow, who in his book *The Natural Philosophy of Time* [1961/1980] suggested a variation of light speed over cosmic distances. This Whitrow did in the context of a discussion of the relativistic formula for clock-retardation from which he claimed to be able to derive the standard Robertson-Walker metric ***(RWM)*** of modern cosmology. That issue will be treated more fully in Chapter 4, §3.

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APPENDIX:
Important Quotations from
Duffy & Wegener, 2000: *Recent Advances in Relativity Theory*, 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 inertial frames is misleading, clocks do not "go slow" and measuring rods are not "contracted"." - cf. Törnebohm below.

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."

P. Øhrstrøm: 'Tense Logic and **STR**' §7, cf. Duffy & Wegener, eds. [2000].

"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. (Hence), 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: $t - \tau = t\{1-\sqrt{1-r^2/t^2}\}$. "

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 cosmological 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* (my italics, MTW). In this context, the cosmological Doppler redshift effect can be considered as a direct and intelligible consequence of a light ray's maintenance of its substratum speed in the face of the expansion of the substratum; it is as if the ray is 'stretched' (and thus 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 - (notice that Prokhovnik, on p.75 of his book: *The Logic of Special Relativity* [1967], spoke of this as: *McCrea's light-hypothesis*, my insertion, MTW) - 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, Treder & Yourgrau** [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."