# SYNCHRONY, SCIENCE AND THE 'RELATIVITY OF FACTS'

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ABSTRACT: This is an analysis of the validity, and assertion of scientific value, of Einstein's 1905 claimed discovery denoted "the relativity of simultaneity".

KEYWORDS: Simultaneity; Einstein; Information Theory; Relativity of Simultaneity

An analysis of the validity, and assertion of scientific value, concerning Einstein's 1905 claimed discovery denoted "the relativity of simultaneity":

> After seven and more years of toil, Einstein made the breakthrough that brought him his special theory of relativity. Some five to six weeks were then needed to complete his famous 1905 paper, "On the Electrodynamics of Moving Bodies." The breakthrough was his recognition of the relativity of simultaneity: **judgments of the simultaneity of events will vary according to the state of motion of the observer**. As a reflection of its importance, Einstein later simply talked of the discovery as "The Step."
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> This recognition proved to be key to the new theory. It enabled him to dissolve the paradoxes that the theory might otherwise bring. How is it possible that an observer chasing rapidly after a propagating light wave judges no slowing down of the wave? The rapidly moving observer has judgments of simultaneity reconfigured in exactly the way needed to undo any effect of the observer's motion on the measured speed of light.
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> Einstein's analysis of simultaneity is provided in the first section of the 1905 special

> relativity paper. It establishes the relativity of simultaneity by investigating the behavior of clocks synchronized by light signals using natural rules. **The analysis is the most celebrated conceptual analysis of 20th century science and has become a model for theorizing both inside and outside physics**. (Norton, 2008, p. 2emph. added.)

Writing later in December 1916, in his "Relativity: The Special and General Theory" (Einstein, 1920c), Einstein fielded a scenario involving a railway embankment, a rapidly moving train and two strategically placed observers: one in the time-coordinated reference frame of the railway embankment and equidistant from two simultaneous lightning strikes, and another seated in the moving train (and also equidistant from the lightning strikes at the moment of the simultaneous events). The ensuing discussion purported to provide an account of the theoretical implications of the relativity of simultaneity and to establish its logical construct and veracity in a form accessible to a wider readership. In that account Einstein required that:

> Lightning has struck the rails on our railway embankment at two places A and B [one in front and one behind the rapidly moving train,] far distant from each other. I make the additional assertion that these two lightning flashes occurred simultaneously. (Einstein, 1920a, pp. 16-7)
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> Are two events (*e.g.* the two strokes of lightning A and B) which are simultaneous *with reference to the railway embankment* also simultaneous *relatively to the train?* We shall show directly that the answer must be in the negative.
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> … in reality (considered with reference to the railway embankment) [the observer on the moving train] is hastening towards the beam of light coming from B, whilst he is riding on ahead of the beam of light coming from A. Hence the observer will **see the beam of light** emitted from B earlier than he will see that emitted from A. Observers who take the railway train as their reference body **must therefore come to the conclusion** that the lightning flash B took place earlier than the lightning flash A. We thus arrive at the **important result**:
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> **Events which are simultaneous with reference to the embankment are not simultaneous with respect to the train**, **and *vice versa* (relativity of simultaneity)**. Every reference body (coordinate system) **has its own particular time;** unless we are told the reference body to which the statement of time refers, there is no meaning in a statement of the time of an event. (Einstein, 1920b, pp. 18-9)

In view of the claim that insights from the 'relativity of simultaneity' originally gave crucial developmental guidance to what is now accepted as a foundational theory of physics, we are entitled to ask: What factual, or physically significant, or previously unrecognized information about the world, did this discussion by Einstein actually provide?

Within the vast arena of that grand human/inquisitorial adventure summarily called science, enquiry into those phenomena usually gathered under the term 'objective reality,' is assigned to physics.

Physics, as an 'exact science' is promoted as that specific scientific endeavour charged with attempting to reveal facts about phenomena of the objective world primarily by a logically secured methodology of measurement.

However, as Margenau has pointed out:

> The trouble with the idea of measurement is its seeming clarity, its obviousness, its implicit claim to finality in any inquisitory discourse. Its status in philosophy of science is taken to be utterly primitive; hence the difficulties it embodies … tend to escape detection and scrutiny. Yet it cannot be primitive in the sense of being exempt from analysis; for if it were every measurement would require to be simply accepted as a protocol of truth, and one should never ask which of two conflicting measurements is correct, or preferable. Such questions are continually being asked, and their propriety in science indicates that even measurement, with its implication of simplicity and adroitness, points beyond itself to other matters of importance on which it relies for validation.
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> Measurement stands, in fact, at the critical junction between theory and the kind of experience often called sensory, immediate or datal. The coverall term for this latter type of experience is, most unfortunately and misleadingly, "observation".
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> This word is vague enough to hide a variety of problems; **its penumbra of meaning overlaps that of measurement and the two are often confused** ... What should be clear upon very little critical inspection is the following: If observation denotes what is coercively given in sensation, that which forms the last instance of appeal in every scientific explanation or prediction, and if theory is the constructive rationale serving to understand and regularize observations, then measurement is the process that mediates between the two, the conversion of the immediate into constructs via number or, viewed the other way, the contact of reason with Nature. (Margenau, 1958, p. 23 (emphasis added))

More recently Eran Tal has warned us in similar vein that:

> As measurement and computational methods have become more sophisticated, it is increasingly difficult to specify what sort of connection with observation is

> sufficient to grant a procedure the privileged epistemic status normally called 'measurement'. The problem is not merely terminological. The designation 'measurement procedure' supposedly implies suitability for producing scientific evidence, a distinction that is not shared by scientific procedures in general. This difference ... is complicated further by the fact that the notion of observation is itself highly ambiguous and technology-laden. (Eran Tal, 2013, p. 1168)

## WHAT, THEN, CONSTITUTES A SCIENTIFIC MEASUREMENT AS DISTINCT FROM OBSERVATION?

*History and philosophy of measurement:*

> During the late nineteenth and early twentieth centuries several attempts were made to provide a universal definition of measurement. Although accounts of measurement varied, the consensus was that measurement is a method of *assigning numbers to magnitudes*. For example, Helmholtz defined measurement as the procedure by which one finds the denominate number that expresses the value of a magnitude, where a "denominate number" is a number together with a unit, e.g., 5 meters, and a magnitude is a quality of objects that is amenable to ordering from smaller to greater, e.g., length. Bertrand Russell similarly stated that measurement is any method by which a unique and reciprocal correspondence is established between all or some of the magnitudes of a kind and all or some of the numbers, integral, rational or real. Norman Campbell defined measurement simply as "the process of assigning numbers to represent qualities", where a quality is a property that admits of nonarbitrary ordering. (Eran Tal, 2015, pp. 4-5)
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> Modern philosophical discussions about measurement—spanning from the late nineteenth century to the present day—may be divided into several strands of scholarship. These strands reflect different perspectives on the nature of measurement and the conditions that make measurement possible and reliable. The main strands are mathematical theories of measurement, operationalism, conventionalism, realism, information-theoretic accounts and model-based accounts. These strands of scholarship do not, for the most part, constitute directly competing views. Instead, they are best understood as highlighting different and complementary aspects of measurement. (Eran Tal, 2017, Sec."Overview")

## MEASUREMENT THEORY:

For a measurement outcome to count as a valid knowledge claim and thus to be the lawful harbinger of physical fact, it must conform to tenets of procedure and analysis dictated by the rationality and logical edicts of a sound philosophy of physical measurement.

> Broadly speaking, measurement theory sets out to (i) identify the assumptions underlying the use of various mathematical structures for describing aspects of the empirical world, and (ii) draw lessons about the adequacy and limits of using these mathematical structures for describing aspects of the empirical world… A key insight of measurement theory is that the empirically significant aspects of a given mathematical structure are those that *mirror relevant relations* among the objects being measured. For example, the relation "bigger than" among numbers is empirically significant for measuring length insofar as it mirrors the relation "longer than" among objects. This mirroring, or mapping, of relations between objects and mathematical entities constitutes a measurement scale….usually thought of as isomorphisms or homomorphisms between objects and mathematical entities. (Eran Tal, 2017. Mathematical Theories of Measurement ("Measurement Theory"))

THEORY DEPENDENCE AND EMPIRICAL GROUNDING:

> A scientific theory offers models for the phenomena in its domain; these models [or empirically realizable representations based on theoretical veracities] involve theoretical quantities, and a model's structure is the set of relations it imposes on these quantities. A fundamental demand in scientific practice is for those quantities to be **clearly and feasibly related to measurement.** This demand for empirical grounding can be articulated **by displaying the theory-dependent criteria for a procedure to count as a measurement and for identifying the quantity it measures.** (van Fraassen, 2012, p. 773)

In this context, models are specific representations and implementations of intrinsic theoretical considerations employed in the cause of deploying measurement theory at an empirical level.

> Whether a procedure is a measurement and, if so, what it measures are questions that have, in general, answers **only relative to a theory**… those answers, provided by theory, are part of what allows a theory to meet the stringent requirement of empirical grounding. (van Fraassen, 2012, p. 774 emph. added.)

## WHAT, THEN, IS THE THEORY AND ITS PRACTICAL MODELLING UNDERLYING THE "RELATIVITY OF SIMULTANEITY" SCENARIO?

> [Einstein's] assumption[1], which defined what is usually called standard synchrony[2], can be described in terms of the following idealized thought experiment, where the spatial locations A and B are fixed locations in some particular, but arbitrary, inertial (i.e., unaccelerated) frame of reference: Let a light ray, traveling in vacuum, leave A at time t1 (as measured by a clock at rest there), and arrive at B coincident with the event E at B. Let the ray be instantaneously reflected back to A, arriving at time t2. Then standard synchrony is defined by saying that E is simultaneous with the event at A that occurred at time (t1 + t2)/2. (Janis, 2002)

A practical, or empirically realizable setting incorporating the theoretical underpinning of standard synchrony might then be proposed as:

If, either by chance or intention, an observation is made at a location

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[1] …If at the point A of space there is a clock, an observer at A can determine the time values of events in the immediate proximity of A by finding the positions of the hands which are simultaneous with these events. If there is at the point B of space another clock in all respects resembling the one at A, it is possible for an observer at B to determine the time values of events in the immediate neighbourhood of B. But it is not possible without further assumption to compare, in respect of time, an event at A with an event at B. We have so far defined only an "A time" and a "B time." We have not defined a common "time" for A and B, for the latter cannot be defined at all unless we establish by definition that the "time" required by light to travel from A to B equals the "time" it requires to travel from B to A. Let a ray of light start at the "A time" $t_A$ from A towards B, let it at the "B time" $t_B$ be reflected at B in the direction of A, and arrive again at A at the "A time" $t'_A$. In accordance with definition the two clocks synchronize if
$t_B - t_A = t'_A - t_B$.
We assume that this definition of synchronism is free from contradictions, and possible for any number of points, and that the following relations are universally valid:—
1. If the clock at B synchronizes with the clock at A, the clock at A synchronizes with the clock at B.
2. If the clock at A synchronizes with the clock at B and also with the clock at C, the clocks at B and C also synchronize with each other.
Thus with the help of certain imaginary physical experiments we have settled what is to be understood by synchronous stationary clocks located at different places, and have evidently obtained a definition of "simultaneous," or "synchronous," and of "time." The "time" of an event is that which is given simultaneously with the event by a stationary clock located at the place of the event, this clock being synchronous, and indeed synchronous for all time determinations, with a specified stationary clock.
Albert Einstein, 'On the Electrodynamics of Moving Bodies (*Annalen der Physik, 17, 1905, pp. 891-921*)', in John Stachel (ed.), *The Collected Papers of Albert Einstein*, trans. Anna Beck and Peter Havas, vol. 2, The Swiss Years: Writings, 1900-1909, (Doc. 23), Princeton, New Jersey, Princeton University Press, 1989, pp. 140-71, p. 3.

[2] The particular model of standard synchrony advanced by Einstein in his 1905 paper varies in notation and form from that of some other authors but is in essence the same theoretical construct and expresses the essentials of synchronization theory using light signals as earlier advanced by Henri Poincaré in 1900. A copy of Einstein's exposition is recorded for reference as Appendix 1.

**equidistant** from the locations of some factually simultaneous events, A and B, then an informative signal transmitted from them, if propagated at constant speed, and later encountered from each, would also be received simultaneously. If, however, an observer is at *any other location* within the originating event's time-coordinated frame of reference, information emanating from each event will eventually be encountered sequentially, separated by some interval of time. Both this perceived temporal disparity, and the fact of originating event simultaneity, are then both logically demonstrable and mathematically calculable from a data set of necessary and sufficient information. Pertinent information is to be found entailed in the frame-related coordinates of the events A and B and those of the observer together with the geometry of the shortest paths and the signal's constant propagation velocity between these events and the location of eventual information encounter.

It is also worth noting, that the signal is not restricted to light. In principle, information necessary and sufficient for the purposes may be propagated by a signal carried by many different carrier channels –visible or any other electromagnetic frequency; audible, as generated by a clap of thunder; or even seismic vibration. It is only necessary that the signal be perceivable and propagated at constant velocity.

## DOES THE EINSTEIN OBSERVER'S PROCEDURE COUNT AS A SCIENTIFIC MEASUREMENT - AND IF SO, WHAT DOES IT MEASURE?

> For a specific operation used to gather information or generate numbers, two questions are pertinent: does it count as a measurement, and if so, what quantity does it measure? (van Fraassen, 2012, p. 774)
>
> What Counts as Measurement, and What Is Measured? Undoubtedly theories are tested by confrontation of the empirical implications or numerical simulations of their models with data derived from measurement outcomes. …

When posing an answer to these fundamental questions, it is noteworthy that van Fraassen advances two basic, logical and unambiguous requirements:

> Determination of the value of a physical quantity, represented in a model of certain phenomena, must be by measurements performed **on those phenomena**—but with the outcomes related to the model **by calculations within the theory itself.** (van Fraassen, 2012, p. 783 emph. added)

With respect to the first proposition, Einstein's scenario is a *gedanken* or thought experiment - an attempt to provide a plausible example, or working model, of the theoretical framework of standard synchrony. To assist in analysis of this first requirement, - that evaluation must be performed **on those phenomena that are to be measured,** it would prove helpful to individually identify and label each of the events involved.

To this end, we might label the sensory event experienced when light emanating from the lightning strike at A enters the observer's eyes, as event X. Similarly, we might label the different sensory event experienced when light emanating from lightning strike B enters the observer's eyes, as event Y. We must first note that events X and Y are not ontologically A and B and are arbitrarily located EFFECTS not CAUSES. The train-traveller does **not** make an observation of events A and B since the observed timing relationship between sensory events X and Y is not a timing relationship between the lightning strikes A and B. So we must ask: 'does the scenario actually address or answer the question posed – this answer being the sole purpose of the current exercise?' Given that the lightning strikes were declared synchronous in their time-coordinated reference frame, the only conclusion the light-signal receiver can legally draw is that the subsequent arbitrarily located sensory events X and Y are located non-equidistant from the now earlier and remote causal events A and B. Period!

With respect to the second prerequisite, - that the outcomes must be made **by calculations made in accordance with the theory itself** - it must be insisted that without that additional information specifically demanded as necessary and sufficient by this representation of synchrony theory, as to the principal question concerning the timing relationship between the events A and B, no measurement has or can be made, no conclusion can be drawn, and no fact of synchrony or otherwise has, or can be established.

However, if both necessary and sufficient information were collected by the observer, its use to make a theory-conformal measurement of the timing relationship of events A and B, would logically, and of mathematical necessity, demonstrate that events A and B were factually simultaneous. And no other valid or contrary conclusions could be drawn, and no other could even be logically possible.

THE CLAIMED RELEVANCE OF AN OBSERVER'S RELATIVE MOTION.

Beyond an analysis of what now appears to be Einstein's conceptually flawed evaluation of his 'important result', the 'relativity of simultaneity' discourse claims most particularly as offering unique insights where the observer is in motion, i.e. that the observer's inertial frame of reference is in relative motion with respect to the originating event's inertial frame of reference. Let it first be established that, in this scenario, these later moments of sensory encounter with emanating information are, and by Einstein's own requirement, equally intended to be understood as **events**. As such, each encounter must take place at some particular spatial coordinates and at some specific moments in time, not only within the railway carriage, but also of necessity as definite event locations and times *within the originating event's time-coordinated reference frame*. Einstein made this clear when requiring that his moving observer was equidistant from events A and B at the moment of the lightning strikes. Had the train not been in motion, then this observer would have experienced his later encounters with information from both simultaneously.

Extending the Einstein scenario for the sake of exploring its ramifications, and more clearly exposing its essential features, we might place two additional but stationary observers, Cindy and Dave, standing along the railway embankment. Cindy just happens to be located equidistant from both events A and B. For her, information emanating from these remote events, when propagated to her location at constant speed, arrives simultaneously. However, for Dave, who is non-equidistant from these events, comparable information will be encountered, but sequentially.

In respect of this, 'moving' observers could, in principle, be functionally replaced by stationary observers placed at appropriate locations and time coordinates, within the originating event's reference frame, yet nonetheless encountering functionally equivalent information, with no loss of analytical legitimacy. It then becomes apparent [necessarily follows] that any motion of an observer, before or after such events of information encounter, is completely irrelevant; i.e. examination of such motion provides no information required by this model of standard synchrony theory in its bid to measure the timing relationship between events A and B.

A rapidly moving train then proves to be surplus to theoretical requirements – its extraneous utility in the current scenario being no more than to place an observer at locations *non-equidistant* from the locations of events A and B, at the later events when he eventually encounters information emanating from them. In terms of the necessary and sufficient information required to make a physically significant measurement of the timing relationship between any two events in a synchronously coordinated reference frame, relative motion proves both superfluous and irrelevant. In relation to the simultaneity model invoked by the Einstein scenario, establishing synchrony at all locations throughout a frame of reference of notionally unlimited extent, both the existence and motion of such a train, and a record of its relative velocity, - i.e. technically the introduction of an additional reference frame - are simply and completely immaterial. Information deriving uniquely from observations related to such a reference frame are neither necessary nor even relevant to the particular model employed to facilitate a meaningful measurement. (In terms of fiscal responsibility, the cost of both the train and its driver could be trimmed from the exercise!)

## THE INTEGRITY OF SCIENCE AND CLAIMS MADE FOR "ALTERNATIVE FACTS": REFUTING AN INSINUATION OF "THE RELATIVITY OF FACTS".

Once again extending the Einstein scenario for the sake of exploring its ramifications, and more clearly exposing its essential features, we might imagine an additional passenger on the train – Alice.

In accordance with the original scenario, the original observer, Bob, happens to be seated exactly equidistant from events A and B at the moment that they occur, but, due to the distance travelled by the train before light-borne information reaches him, he is no longer at this providential location when this information is experienced by him. On the other hand, Alice, seated somewhere behind him, is also relocated by the train to now be exactly equidistant from the simultaneous events at the moment that information from both arrive at her location, and thus experiences the arrival of that information synchronously. Using an Einstein-styled version of the story, were Bob, for some perverse reason, disposed to use his carriage compartment as a suitable reference frame for the purpose of making a particular measurement in the process of imagining he was actually measuring a timing relationship of the two remote lightning events, he would 'conclude' that the events *were not* simultaneous. Alice, on the other hand, and by exactly the same methodology, would 'conclude' that the lightning events *were* simultaneous.

A conclusion or measurement outcome assumes a certain status of factual veracity as a knowledge claim, at least in part, as being a deduction that would be logically and *consistently* reached in accord with any valid methodology and conducted by any competent emotionally and ideologically detached enquirer. Working hypotheses and knowledge claims deriving from valid evidence-based enquiries can then be expected to find a high level of consensus with equivalent reports from other independent enquirers. It must be insisted that private observations as claimed by Einstein's mobile observer, leading to individual 'conclusions' that are intrinsically capable of being in irremediable conflict with equivalent observations and 'conclusions' of other equally competent observers, **are simply not science**.

Fundamental to a sound philosophy of science is its claim to distinguish between science and pseudo-science. Arbitration on this foundational distinction is conducted on the basis of granting certain tenets – including that a valid scientific enquiry into the nature and constitution of objective reality must be based on evidence – and further that the 'rules of evidence' are necessarily constrained by compliance to logical and rational rules of adequacy and admissibility. Without diminishing the need for a healthy scientific scepticism, a claim to the status of scientific 'fact' is proposed as one founded on evidence that is not just compelling with respect to all available data, both past and present, but *independently verifiable*. Facts are not established by a popularity poll or for convenience or by personal anecdote or 'point of view.' Scientific facts are, in some real sense, 'public' property.

We are to be further reminded that:

> Generally, measurements must form an aggregate to be of importance in science. … a measured number by itself signifies nothing that could safely be interpreted by means of rational constructs. If an aggregate is at hand, and only then, can the theoretical significance of the measurements be assessed. For in that case only do we have facilities for determining the error, [i.e. the 'uncertainty'] the measure of

> precision, of the results and can know what to do with them theoretically. (Margenau, 1958, p. 24)

In stating the initial conditions and preliminary assumptions upon whose foundation an argument could be presented, Einstein required that events A and B were ***factually*** simultaneous. This was a declared **fact** of the scenario. As an exact science, physics has no place for 'alternative facts'. Discussions and nefarious claims in the arena of politics aside, a factual proposition within the ambit of the exact sciences cannot, by definition, be both 'true' and 'false'. It must also be insisted that facts as pertaining to physical realities are not mutable by, or subservient to, the personal preferences or 'points of view' of individual commentators venturing distinctive assessment. Any such observer's 'conclusion' claiming a personally and uniquely different result as 'factual', **of necessity** demonstrates either **a flawed or invalid methodology and or insufficient or incorrect data.** As Margenau again reminds us:

> … it is the unconquerable mood of science that it will accept any "historically" valid fact of experience and see what it can do with it within its system of explanation, and if a contradiction arises, it is the theoretical system that is sacrificed. (Margenau, 1958, p. 27)

It thus follows that uniquely individual claims and personal points of view must be held strictly inadmissible as necessary and sufficient evidence for a valid scientific procedure. In this regard, it is a fundamental tenet of a useful philosophy of science, as it has long found approval by the greater scientific community, that an effective scientific methodology intentionally intends the elimination of anecdote, individual bias, and personal variabilities from the development of a lawful theorizing process. Unfortunately, the methodology and claimed 'conclusion' drawn by our travelling observer conspicuously fails in all these essential respects. Regrettably it must be asserted that these are **simply not science.**

## SUMMARY AND CRITIQUE:

So then, as specified by Einstein's claims for the 'relativity of simultaneity,' what does his observer's 'conclusion', now revealed as a factually bereft and theoretically worthless personal opinion of a supposed timing relationship between remote historical events, offer to our factual understandings in physics? Nothing. Absolutely nothing.

What specifically does this 'relativity of simultaneity' supposition have to offer as to the value of observations of events made by observers in relative motion over and above those by functionally equivalent observers stationary in the reference frame of originating events? Nothing. Absolutely nothing.

What do "conclusions" proffered in this 'relativity of simultaneity' speculation have in common with independently verifiable and reproducible physical measurements or those made on the basis of a diagnostic measurement protocol whose data is both sufficient and necessary? Nothing. Absolutely nothing.

What specific and new understanding about either 'light' or 'time' does the 'relativity of simultaneity' conjecture offer to, or as furthering, the previously attained body of classical physical knowledge? Nothing. Absolutely nothing.

## POSTSCRIPT: BUT, DOES IT REALLY MATTER?

Science, intended as a rationally ordered exhibition of innate human curiosity and the 'need to know', is an open-ended exploration of an unknown territory that may or may not have knowable boundaries. In ways reminiscent of finding a useful path through a maze, many avenues may appear of value in testing for the best way forward. As a matter of trial and error with notionally only one obscured route to success, it must be expected that many trials or investigations will end in failure. There is no shame or blame to be dispensed – in practice, all possibilities, conjectures and hypotheses are to be proposed, entertained, examined, debated and tested against a sometimes reluctant empirical arbitration and either provisionally accepted or rejected. In such a context, "failure" may misrepresent and mask a more complex actuality. Misadventures are in themselves fertile and instructive – they tell us something of importance in the cause of future intellectual navigation.

However, it greatly matters when an error goes unrecognized and is propagated throughout future science, being engaged as a verified pre-theoretic supposition. Viewed in accordance with a range of criteria advanced by a sound philosophy of science and measurement, the relativity of simultaneity has been shown to fail on multiple accounts.

Ptolemy's model was beautiful mathematically, and its success convinced astronomers and theologians for more than a millennium that its premises were correct. And how could they be wrong? After all, the model had been confirmed by observation.

There's a lesson here, which is that neither mathematical beauty nor agreement with experiment can guarantee that the ideas a theory is based on bear the slightest relation to reality. Sometimes a decoding of the patterns in nature take us in the wrong direction. Sometimes we fool ourselves badly, as individuals and as a society. Ptolemy and Aristotle were no less scientific than today's scientists. They were just unlucky in that several false hypotheses conspired to work well together.

**There is no antidote for our ability to fool ourselves except to keep the process of science moving so that errors are eventually forced into the light.** (Smolin, 2013, pp. 17-8)

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