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Space-Time Diagrams Lead to False Paradoxes

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Abstract

This paper provides a clear analysis of how hypothetical concepts not allowed in Special Relativity should be treated and exposes hidden assumptions in space-time diagrams used on YouTube, where some prominent physicists have taken to publishing on popular topics that may not survive peer review. Such casual graphical treatment conceals the fact that space-time diagrams provide only for the Einstein synchronization convention for all observers, not the many other valid synchronization protocols, and also obscure that relativity's equality of reference frames is rebutted if concepts outside relativity, such as instant communication, are introduced. These omissions of unconscious assumptions have been used to "prove" the existence of block time and time travel or time paradoxes. We will show the contradictory assumptions amount to assuming time travel, rather than the more mundane need to adjust synchronization conventions. We further show a new result that the use of the space-time diagrams as proposed by these "explainers" leads to discontinuities in which a differential change in communication speed leads to a sudden jump from present to long-past arrival time, strongly suggesting invalidity of the method.

Keywords

Space-Time, Block Time, Block Universe, Special Relativity, Faster Than Light, FTL, Causality Violation, Time Paradox, Simultaneity

1. Introduction

Analysis done two decades ago showed that Faster-Than-Light (FTL) signals do not necessarily lead to causality violations [1]. It is well-known that no philosophical issues with simultaneity exist in the Global Positioning System (GPS) and a firm mathematical foundation exists for analyzing the combination of velocity and gravity [2]. One can even find theoretical work which reconciles apparently remote instantaneous but statistical effects in quantum mechanics for which the order of apparent "causality" varies by reference frame [3].

Yet recently three respected physicists have published social media "explainers" claiming FTL signals would definitely lead to causality violations, overlooking that they might merely lead to identification of a preferred frame or to statistical ambiguity as in quantum mechanics. Each has their own reasons, from arguing against FTL (a reasonable objective, but not from this argument) in one case, and superdeterminism in two more (which is less well accepted, in fact not well at all).

David Kipping published an explicit argument that FTL signals must lead to causality violations, and that therefore FTL is unlikely. See https://www.youtube.com/watch?v=an0M-wcHw5A "Why Going Faster-Than-Light Leads to Time Paradoxes". By using social media, any professional critique is avoided (no peer review) or minimized (perhaps one of 11,792 comments?). While one may argue that the conclusion is correct, the correctness of the argument still matters. A review of Kipping's research profile reveals no papers published on this subject, so there has been no critical review of it. One of the most frequent contributions of peer reviewers is to call attention to references an author may have missed, such as the decades old treatment that FTL signaling does not violate causality. So a peer review, even at a superficial level, might have saved Kipping.

Sabine Hossenfelder uses an argument, which we will show is essentially similar to Kipping's, to argue definitely for the existence of the block universe. See https://www.youtube.com/watch?v=GwzN5YwMzv0 "Does The Past Still Exist?" The trouble here is that while many physicists might be comfortable with the idea of the block universe, Hossenfelder builds on the argument in a following post https://www.youtube.com/watch?v=ytyjgIyegDI "Does Superdeterminism save Quantum Mechanics?" to argue for superdeterminism. Most physicists do not currently agree with superdeterminism [4]. A review of Hossenfelder's profile reveals that while she has published on superdeterminism [5] [6] [7] [8], she has not published in any peer-reviewed venue the key predecessor argument. We will show this argument is based on a misuse of space-time diagrams.

Two years before Hossenfelder, Matt O'Dowd under the auspices of PBS published "Do the Past and Future Exist?" https://www.youtube.com/watch?v=EagNUvNfsUI with essentially the same argument. He left more of an "out" but it was a complex one involving quantum mechanics. O'Dowd's argument will be assumed to be deconstructed when we rebut Hossenfelder.

However, we will start with Kipping, because the FTL argument is not subtle and makes things clearer. First, we must understand exactly how we are using space-time diagrams and how a particular one of many possible clock synchronization conventions is embedded in them. We also ask the question, exactly how should we draw an FTL transport or communication on a space-time diagram? The answer, ultimately, is that it is empirical, and lacking any effective experiment we can't say. But it does seem we can rank likely and unlikely methods.

And finally, we develop and present a new argument that time travel as a result of FTL communication leads to a discontinuity, a situation in which changing the speed of a signal by an incrementally small amount leads to an anomalously large arrival time difference, suddenly years in the past. This strongly suggests the formulation that produces it is invalid.

2. Analysis

Space-time diagrams, also called Minkowski diagrams, have long been used in teaching Special Relativity for their presentation of the competing views of different reference frames on the same chart. A description of how they are drawn and used which provides insight we will need into synchronization conventions is provided by Alexander Fufaev at https://en.universaldenker.org/lessons/230particularlyinIllustration12. To explain our issues we make a custom version in our **Figure 1**.

The primary observer's axes are x and ct. Space ship S travels with two co-moving mirrors L and R at equal distance from ship S on axis x_S and parallel to axis ct_S, and sends a light pulse toward each. Synchronized clocks at each mirror record the time of reflection $T_{LRS} = T_{RRS}$. The x_S axis defines simultaneity of the reflections in the ship frame.

All light paths are shown at 45 degrees (double yellow lines). In the primary observer frame, it seems the light takes a short time to reach L and longer to return to ship S, and vice versa for the other light path. The one-way speed of light is, however, not determinable in Special Relativity. The Einstein synchronization convention is to set distant clocks based on half the round-trip light travel time. In a space-time diagram, drawing light paths at 45 degrees implements this convention. However, setting the clocks based on ANY fraction of the round-trip time between 0 and 1 works equally well [1]. Reichenbach suggests using $t_2 = t_1 + \varepsilon(t_3 - t_1)$ where the t's are recorded times of signal transmit initially, receive and retransmit, and receive back at the origin, and $0 < \varepsilon < 1$. The Einstein convention is $\varepsilon = 1/2$ [9].

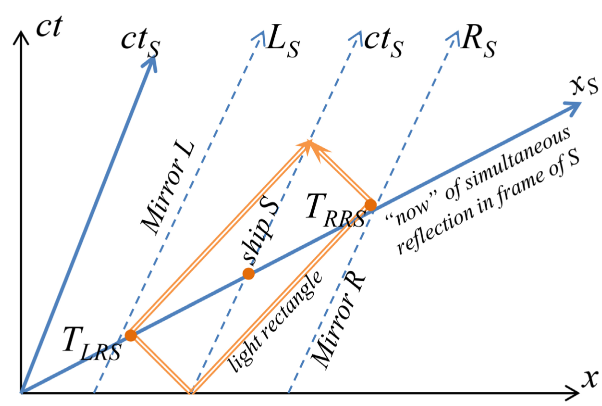

Figure 1. Space-time diagram with a space ship, two mirrors and light rectangle.

If clock synchronization is a convention, not an empirical measurement, then it is misleading to draw conclusions about an existential "now" based on clock synchronization. But if one speaks with reference to a space-time diagram, that is exactly what one is doing.

Now we ask, how would we draw an FTL path on a space-time diagram? We've already held that such a property must be empirical and we don't know, yet pundits draw them anyway. It is easiest to see if we ask how we would draw an instantaneous path on a space-time diagram.

Would we draw it parallel to the base axis? That would establish the primary observer as being in a preferred reference frame, the one in which instantaneous communication does not conflict with Einstein clock synchronization. It seems extremely unlikely we'd find ourselves in such a frame. Most likely we'd find our clock synchronization was in error.

By drawing any other, or an arbitrary, FTL path, one has inadvertently incorporated "time travel" into the problem as an assumption. So it is natural one would get time travel paradoxes out of it.

Lest the reader jump to conclusions about what the author is saying, we are not advocating for any violation of Special Relativity, or the existence of FTL or instantaneous communication. We are responding only regarding the correctness, or not, of arguments made by others which have not received critical review, and may be, we think, misleading.

As far as travel *through* space, there are a multitude of reasons to doubt FTL. One seldom mentioned is that our molecules are bound by electromagnetic fields, and reaching or exceeding light speed would leave those fields behind.

Kipping's presentation is primarily addressed at wormhole or warp bubble travel. Hossenfelder's and O'Dowd's arguments depend on the existential "now" which we've argued is a convention and not physical. The two are related in that if FTL communication were possible, we might determine empirical clock synchronization for a meaningful existential "now", whereas the current situation is that we cannot.

3. Rebuttals

3.1. Kipping's FTL Argument

Kipping hypothesizes that Earth sends an FTL message to a fast but sub-light ship. The ship sends back a message "turn off your transmitter". He then draws the first FTL message at an angle greater than 45 degrees to the vertical to represent FTL in Earth's frame of reference (in which the space-time diagram is drawn). The reply he draws at a corresponding angle transformed into the ship's frame of reference, so it is an even greater angle (to the vertical), and arrives before the message is sent, causing it never to be sent, a paradox.

Kipping just says "Our entire diagram is cast in Earth's frame of reference, and in this frame the message appears to be traveling backward through time". But he has not drawn the return message at the same angle as the outgoing message. It is drawn at a steeper angle, one which looks about right for the ship's frame of reference, without mentioning his rationale for how to draw it.

Later Kipping draws an instantaneous communication line (horizontal), and clearly draws the return path as between simultaneous synchronized clocks in the ship's frame, so it returns parallel to the ship's space axis. There are two red lines on the lower left of **Figure 2** below, labeled "*Kipping's instant comm.*" which illustrate his path choices.

What we might most easily expect from two way "instantaneous communication" is real-time conversation. Suppose we are communicating round-trip with Alpha Centauri. As communication approaches the speed of light, the time of a return message approaches 8 years in the future. Marginally exceeding the speed of light should remain on this continuum and return messages should come slightly less than 8 years in the future, not suddenly in the past giving an 8-year discontinuity in the velocity and time relationship.

The reply to an instantaneous communication round trip from Earth to the ship and back would reach Earth moments after the transmission, That is, the slope of incoming and outgoing messages would not depend on the transmitter, and would be the same. This might or might not be near to the space axis of any of the participants. That is a piece of empirical information that physicists were unable to obtain in the late 1800s and which led to accepting relativity theory and proceeding without.

The most reasonable assumed result of instant communication is that all clocks could by synchronized, identifying a universal reference frame. Could we empirically find time travel instead? Well, the universe can be strange and we should not predispose ourselves entirely, but it seems a good deal less likely. So Kipping made an illogical and inconsistent portrayal of FTL and instantaneous communication on the space-time diagram, relying on the reference frame of the sender, separately in each case, and his argument is void.

3.2. Physical Meaning of Kipping's Assumptions

There is physical evidence that quantum systems prefer the Einstein clock synchronization convention. This takes the form of the phase of de Broglie waves.

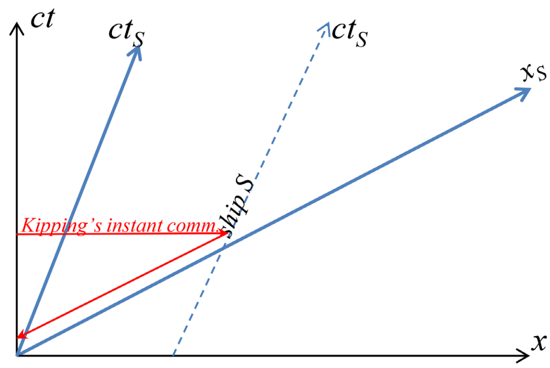

Figure 2. Kipping's different choices of instantaneous FTL communication "angles".

In the reference frame of a particle where it has zero velocity, the de Broglie wave is in phase everywhere, when checked by the Einstein clock convention. The matter may be explored by switching roles in the classic double slit apparatus and using a moving double slit [10].

In the collapse of wave functions of entangled particles, the perceived order of causation can vary by reference frame. Observers widely separated can in fact perform measurements on each of a pair of separated entangled particles in any order they please, and the results are exactly the same. In speaking about this, there is a tendency to say that one or the other has collapsed the state function of both particles by a measurement, as if the state of the remote and as-yet-unmeasured particle has been "instantaneously" affected.

A rapidly moving space ship passing by may perceive the order of measurement to be different. But the results are exactly the same. Moreover, by the no communication theorem, no information may be communicated between the observers by their actions. They must wait for measurement results of the random results to be communicated in ordinary fashion to understand what they have done.

Therefore, despite the apparent preference by coupled quantum systems for the Einstein clock synchronization, there is no reason to suppose that either time travel or FTL communication is accessible. And there is no reason to suppose that if some unrelated means of FTL communication were available, it would involve coupled systems. The space ship and the observer in **Figure 1** and **Figure 2** might be carrying entangled particles, but are not themselves entangled with each other and cannot use entangled particles to communicate, so the clock synchronization of entangled particles does not enforce itself on the situation.

3.3. A Discontinuity in Kipping's Path Choices

Figure 3 shows two way light speed signaling between the observer and ship S. The light speed paths are drawn at 45 degree angles for all signals, regardless of who originated or received them, as the rules require for things moving at light speed in space-time diagrams. If the observer and ship are 8 light years apart (at the moment the signal is received on the ship) then the observer will get the ship's answer 16 years in the future.

Now consider the use of FTL communication only differentially faster than the speed of light. One would expect only a differential reduction in the round-trip transit time of the signal. But not according to Kipping. The reply would suddenly appear 16 years earlier, before it was sent.

This discontinuity is owing to Kipping's switching of reference frames for FTL signals, in an ad hoc manner not covered by the Lorentz transform or any physical meaning. It seems to be the strongest rebuttal of his method, and generally of using Special Relativity to argue that violations of Special Relativity must inevitably cause time travel. If such violations are found, it will be a new world of empirical physics and no prediction may be made based on Special Relativity.

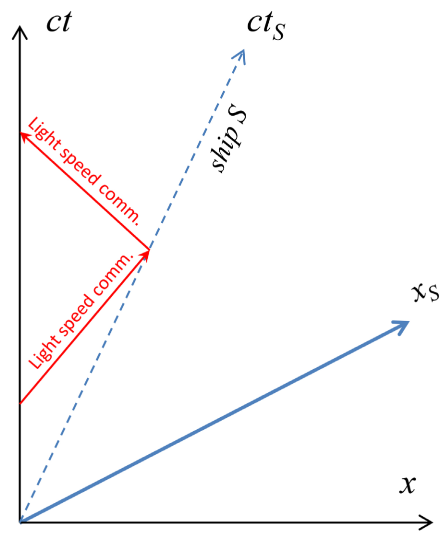

Figure 3. Light speed communication in Kipping's setup.

3.4. Hossenfelder's "Now" Argument and the Block Universe

This rebuttal is intended to apply to O'Dowd as well, but Hossenfelder distills the purest argument and we'll phrase it in her terms. She asks the viewer if they believe something exists "now" at remote places? She spends time asking if the screen of your cell phone still exists as you are viewing it. After all, it takes a finite amount of time for light to travel from the screen to your eyes. Your present sight of it is therefore not ironclad proof. This anecdote is irrelevant to her argument, and meant only to condition the viewer, one suspects. She asks the viewer to choose if they believe things exist "now" at remote distances.

Abandoning this line of thought, she asks if we can agree on what's meant by "now" and proposes adjusting mirrors in a space-time diagram (like Figure 1) so that a pair of photons simultaneously transmitted will arrive from two directions back at the transmitter at the same time. In other words, she derives light rectangles. The line between the reflection points defines "now" in that reference frame. This corresponds to line x_S in our figure for the ship, or any line parallel to it, and for the primary reference frame it corresponds to any line parallel to the space axis x.

She then proposes that by choosing different reference frames at different velocities, "now" in any particular reference frame, can by an intermediate reference frame, be connected to any point at all in space-time. This is true. But what does it mean?

If one has accepted that clock synchronization is not just a convention, but an indication of an actual existing "now" at a remote location, then it means that a block universe literally exists, all points past and future existing, by a chain of someone's idea of remote things existing "now". This is the conclusion Hossenfelder seizes.

An interesting implication of this is that the Einstein clock synchronization convention is reality, and that other conventions are NOT. We are not able to run any experiment to prove this. It would require a violation of Special Relativity to prove this. So Hossenfelder's "now" violates Special Relativity just as thoroughly as Kipping's FTL or instantaneous communication. It amounts to the same thing. It's just disguised as a philosophical question at first, that's hard to disagree with, and then migrated to the realm of "physics". But one can't demonstrate that existence without instantaneous communication. Hossenfelder's earlier analysis of the cell phone screen essentially said that.

We are not saying it is meaningless to talk about existence "now" at remote locations, rather that the Einstein convention does not identify them necessarily. The Reichenbach ε for each differently moving frame of reference likely is different. So the "now" points cannot be connected together throughout reality by simply using differently moving frames as Hossenfelder suggests. That relativity prevents us from finding each ε should not lead us to assume we can choose one ε for every frame.

3.5. Is There a Better Way to Say Nothing Goes Faster than Light?

Above we mentioned the electromagnetic structure of matter as a simple explanation (not available when Special Relativity was developed in 1905) why we can't go faster than light *through* space. What about wormholes and warp drives, which Kipping was attempting to address? It is important the public be educated as to what can realistically be expected from physics, which was Kipping's goal, and which we approve. There is a way to address this, but the "language," while conventional, is not customarily used in this way by physicists.

The universe is thought to be flat at large scales (perhaps not at the largest scale but that doesn't affect our argument). However, this has a specific meaning that does not prevent it being folded or even rolled into a cylinder. The paths within would still be indistinguishable from those in a conventionally flat space. Most treatments on wormholes, already plagued by unreasonable requirements for opening and keeping open the wormhole, rely on accidental folding of the universe such that something interesting is nearby through a wormhole, while distant in ordinary space. But there is no reason to expect this. With accidental folds, most wormholes might exit in the intergalactic void. Unless we can create and measure paths through wormholes, we have no way to investigate this. But it is safe to call attention to the problem, to the low likelihood of wormholes providing useful paths.

Warp fields are poorly understood even by the theoreticians who envisioned them. "Turning on" the warp field, which is basically just an oddly configured gravitational field, dependent on negative energy to contract space in front of the spacecraft, requires propagating a gravitational wave ahead of the spacecraft to perform the compaction. Gravitational waves only propagate at the speed of light.

4. Conclusions

The author personally likes most of the social media presentations of the physicists mentioned, as well as the many enthusiast physics channels. These discrepancies were not noticed until viewing Kipping's presentation about whether the past and future exist, where the logic is most egregious, and only then were the subtle flaws in Hossenfelder and O'Dowd evident. While they are mostly free to say what they wish, they do have reputations built on many peer reviewed papers. It would be appreciated if they distinguish arguments they make which are not thoroughly accepted.

Of course, Kipping probably didn't even realize he was making a mistake. But professionals are held to higher standards. Some of the enthusiast physics channels are able to raise funds to experimentally validate, or not, their claims, or may investigate bizarre claims of others, like whether a wind powered car can go faster than the wind. Some invite rebuttals of their more esoteric conclusions. Social media can enhance the discussion of physics in the public view. Let's just be careful not to rest on our laurels.

We have reviewed the physical evidence for the Einstein clock synchronization on which both Kipping's argument and the "now" arguments of Hossenfelder and O'Dowd are based. This consists of interference patterns of de Broglie waves and there are no "now" and no communication and no time travel in this physical evidence. We have presented a discontinuity argument rebutting Kipping's argument strongly. Further effort is needed to find a practical convention to guide physicists presenting ideas in popular media, as well as ways to keep the public interested in long term projects valuable to the species like interstellar travel even if there is no magic bullet to make them like fictional space opera.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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