Foundations of Localized Symmetry Mathematics

(Transcript with slides – Edited with many corrections, additions, and links)

Terry Bollinger

Presented at: Washington Quantum Computing Meetup (on OrionX YouTube)
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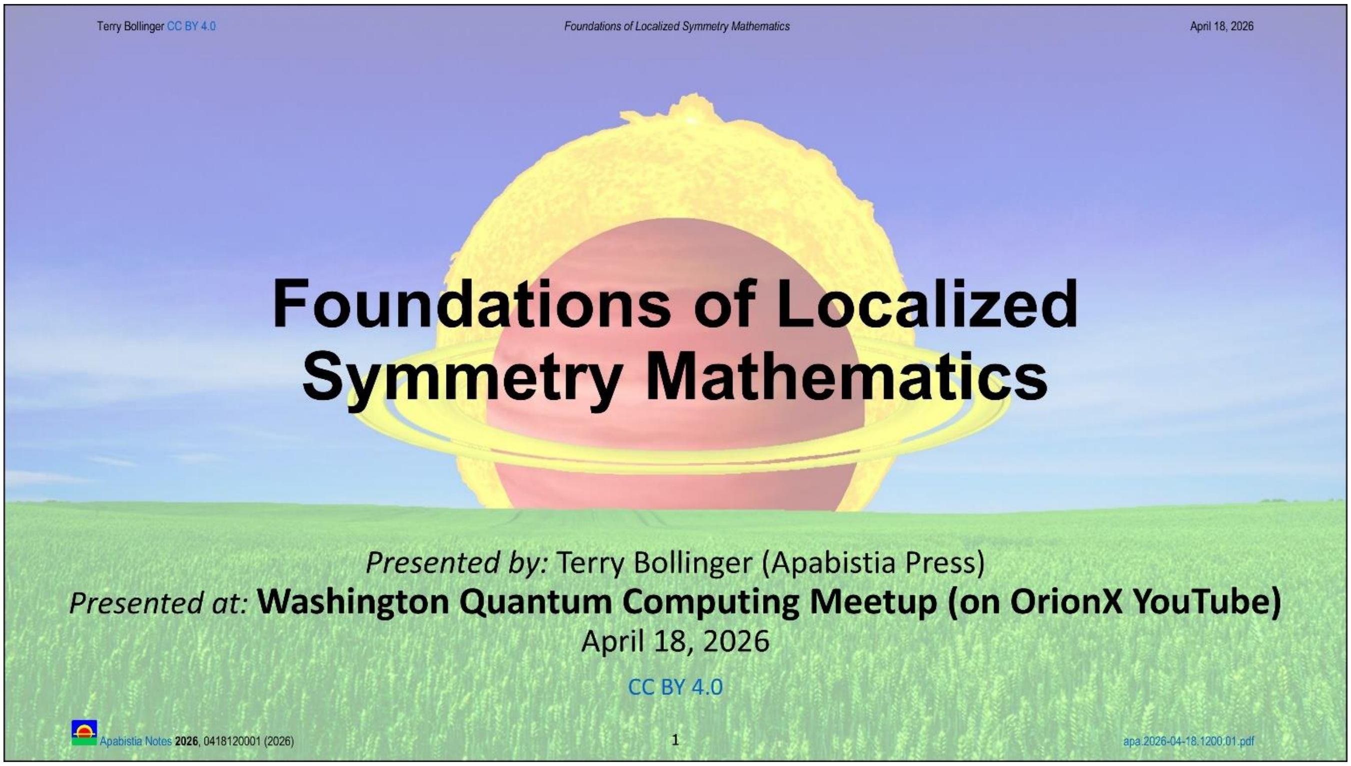
This is an edited transcript with additions and links. You can view the full video at https://youtu.be/8i05Q7IT_T4



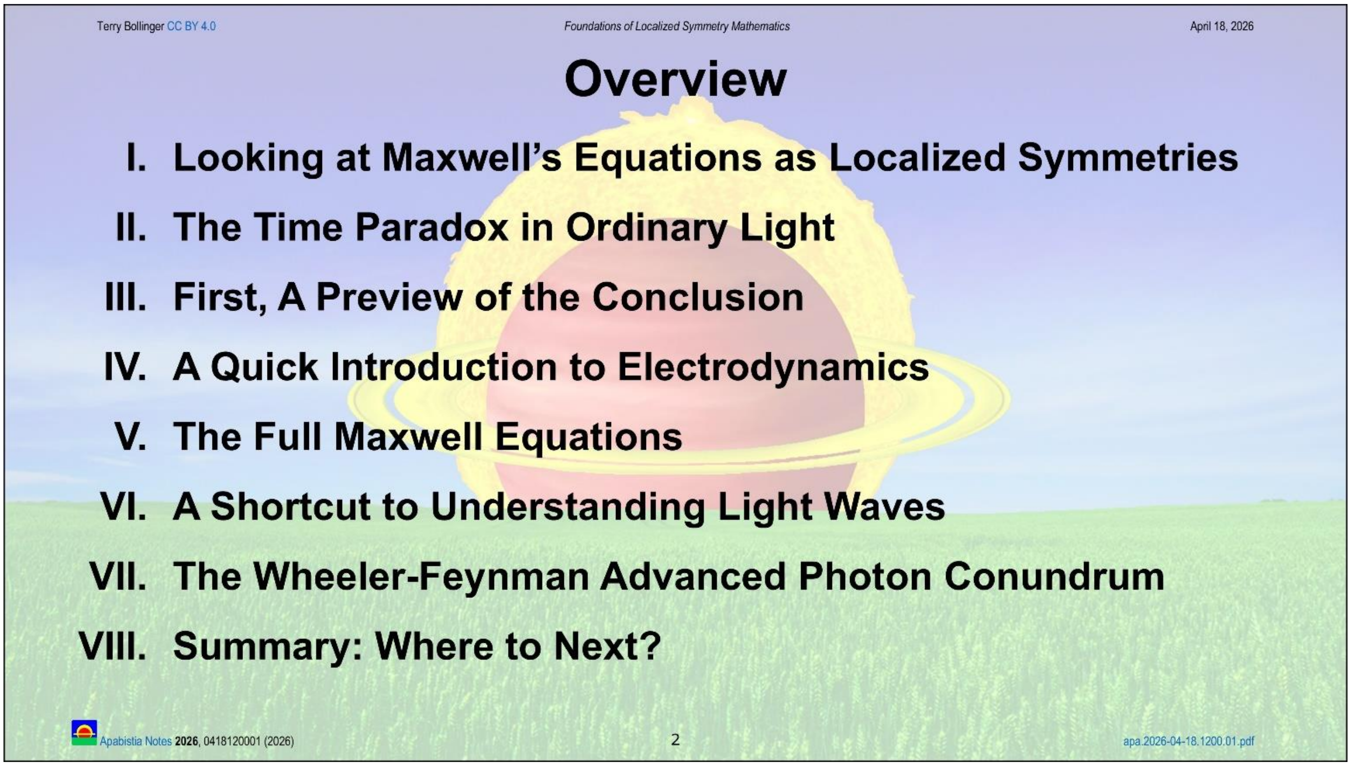
0:00 **Terry Bollinger** (TB): The title of today's topic is Foundations of Localized Symmetry Mathematics. Originally, my intent had been to give a kind of a re-summary of the idea of sparse information physics and bottom-up spacetime, which are themes that I've covered fairly extensively in previous presentations.

Those two concepts, when you take them seriously, give you opportunities to expand mathematics in ways that are quite different from the current focus on smoothness and differentiability. Smoothness and differentiability are *assumptions*. The actual physical universe, though, *definitely* has some constraints where you have to be a little careful about whether you're overgeneralizing your mathematics.

So, that was the original intent. What I actually wound up doing, though, is giving more of a specific example from a very interesting paper written all the way back in 1949 by Wheeler and Feynman. That particular paper has some features to it that work very well with the concept of bottom-up spacetime with finite amounts of information. And again, that's a theme you'll see on every talk I give, is the idea that spacetime has infinite information is for me a very non-productive assumption. Because, yes, you can define the mathematics [that way]; there's nothing wrong with defining the mathematics that way. But the question you always must ask is, "Am I generalizing the mathematics in a way that reflects *reality*, or am I generalizing it in a fashion that I simply find *appealing*?"

Infinite smoothness, differentiability, the idea that there's an infinite number of numbers in a small space… these are very appealing concepts. They're *interesting*, they're *fascinating*. But when we look at the *physical* universe, we *always* see limits, *especially* on information.

Quantum mechanics is, *by definition*, the idea that [until] you get to a certain point, everything looks very smooth. But after a certain point, it *stops* [looking] smooth. We probably should be listening to that a *little more carefully* [to that] in the *deep details* of how we do the mathematical approaches. We've got excellent maths, and they are extremely powerful, but we also want to look for opportunities to go in new directions.

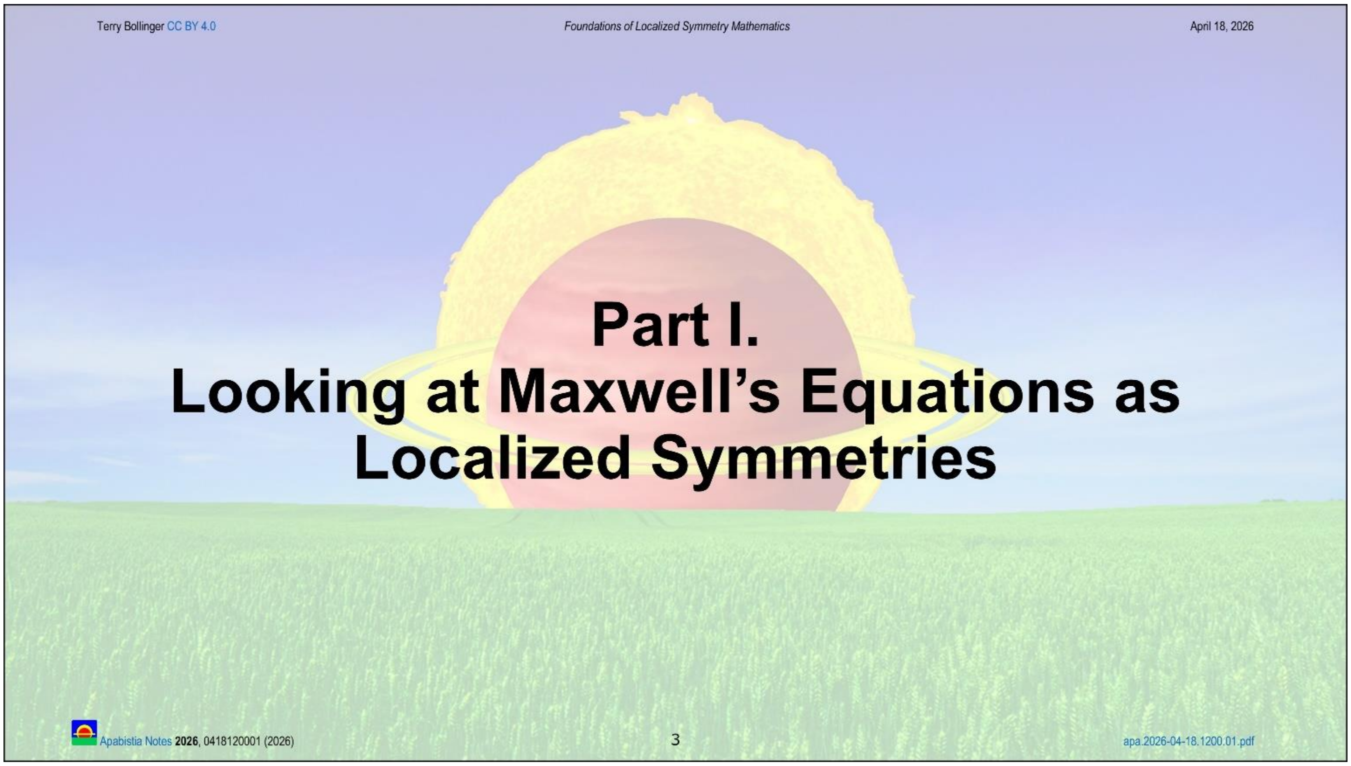


2:30 TB: I've got,
You see a quick overview of some of the things I'll be addressing here. It's mostly electrodynamics. And I'm going to try to keep this. I'm doing kind of an odd combination. I'm looking at a paper that really gets down into the details about some of the space-time issues, and to bring out some of what was made in that paper.

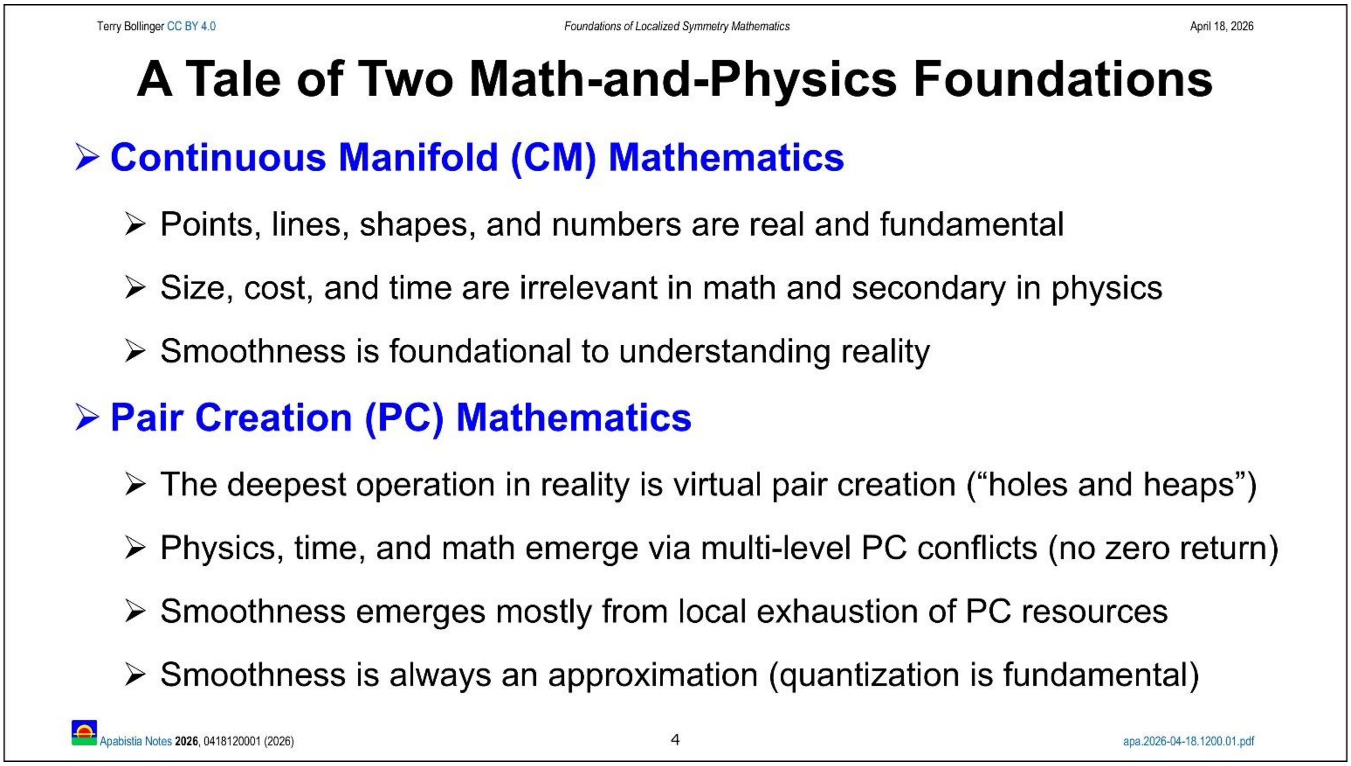
Sometimes physicists say just absolutely remarkable things in terms of the implication for how reality works. And it just becomes a standard term in the papers. Some of the Wheeler and Feynman papers definitely fall in that category! They make remarkable assertions about how reality works, and yet, you know, in many ways, they don't make a big deal about it. They say, "Well, this is what the math tells us. How do we work with it?" But then you go back and you think about some of the implications of that. You say, "What in the *world?* Does the universe *really* work like *that?"* And yet, from that same work you get Feynman's QED work, for which he got a Nobel Prize.

So, interesting issues. I wanted to get into some of the details, pick up a paper that was difficult to read. I kept laughing when I was going over the figure, because I was going, "Like… *what?"* This figure was so confusing, the way it was done! And yet, the point that Wheeler was trying [to make is important.] It was definitely a Wheeler figure. You can tell the difference. Feynman does simple diagrams, they're easy to understand. Wheeler does [figures] differently. He has a different style entirely on how he goes about doing these things. But he was a very deep thinking! So I wanted to, essentially, in this presentation, emphasize the work and thinking that Wheeler and Feynman did prior to QED by giving a specific example.

I also [wanted to] show how this idea of a bottom-up approach to the mathematics of that has some promise, so I wanted to give a specific example. And in doing so, I'm going to give a quick intro to electrodynamics. I'm just going to give an idea in terms that intentionally avoid the details that you need in order to do actual calculations. If you want to do the calculations, you've got to learn the math. But if you want to understand the concepts, and how those concepts affect our interpretation of reality, and some of the relationships [implied by those concepts]… Well, that often is a different matter — and goes back to this idea that there's little simple things that then bubble up and create the complexity that we see.



4:57 TB: [Silence]



5:03 TB: The theme that I've just been talking about is this idea that you have mathematics that come from inspiration in the physics world itself. Not from how we *want* the math to work, but from what we actually *see* it work in reality. Our math certainly reflects that [when used] in physics.

You see the second item: Pair-creation mathematics. That's the creation and annihilation operators, which are some of the most common events that you do in field theory. This is this idea of creating, [for example,] an electron and positron pair — the classic example. There are many other examples where you're creating pairs of particles that have opposite properties with that [same creation-annihilation idea]. So, one of the themes that I'm following — I'll be giving a little bit of an example of here — is that idea that we need to get *underneath* the continuum.

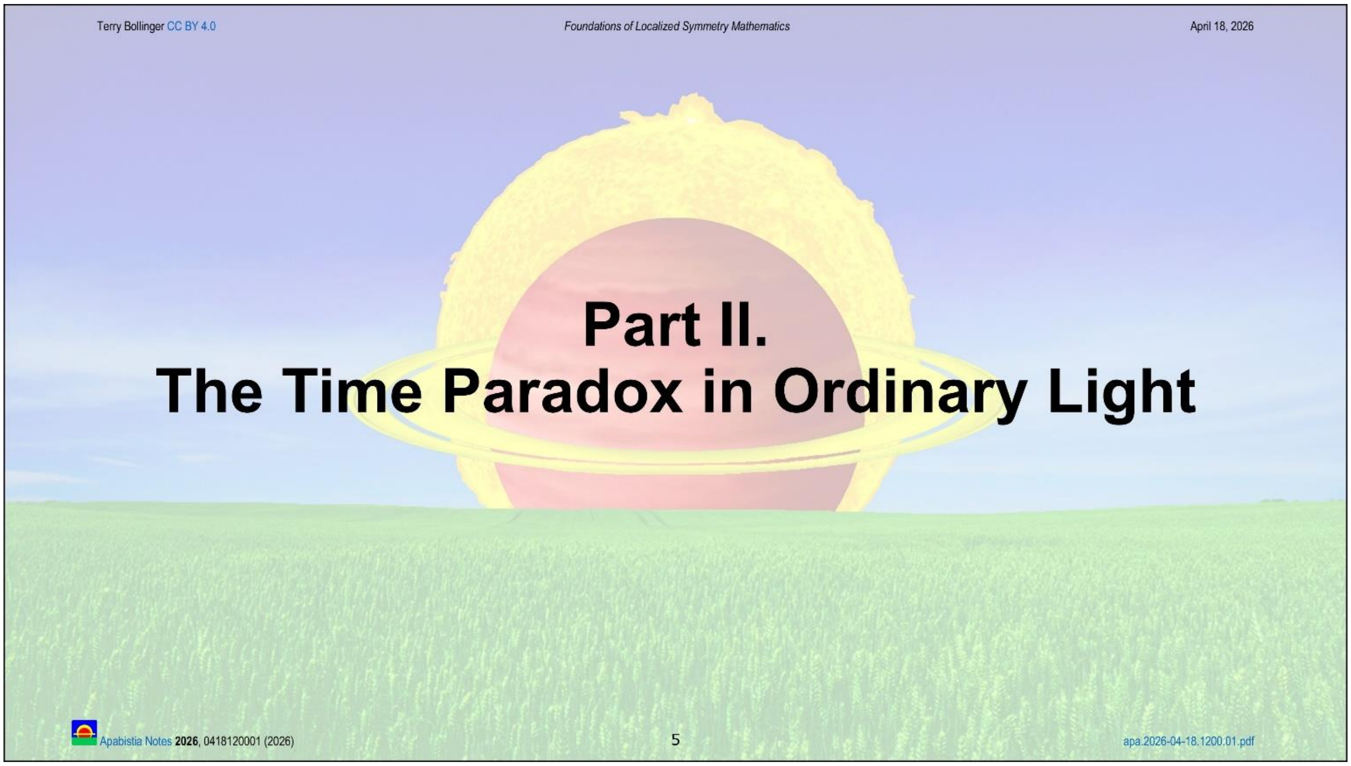
You can especially see the continuum in gravitational mathematics, where everything is a smooth manifold, infinitely precise. [The idea is to] get a little bit *below* that, and use the inspiration of what we actually *see* in physics. And what the simplest operations that we see there are — and the one I really want to emphasize — is this simple idea of pair creation.

I've had previous slides [in previous presentations] where I talked about how if you want to understand the idea of a pair creation, think of digging a hole. You create a pile on one side; you create a hole in the other side. So, you have [these] holes and these heaps. And that is the essence of the kind of activity we see in physics all the time. You get a positive charge, you get a negative charge: one's piled up, the other one's shrunk down.

They always cancel out, and that's the critical constraint on mathematics. That is, instead of saying that conservation is a *derived* property of *infinite smoothness*, you really flip it around the other way completely. You say that, "*No*, the *absolute conservation* is what's driving the emergence of these [smoothness] symmetries. It's what is forcing those symmetries to come into existence, because the symmetries — the complicated math — always has to go back to that concept of absolute conversation. You can create piles and create holes, but you can't do one by itself. You have to do *pairs*. You have one that goes up, but the other goes down.

There are so many quantum numbers where you can do that, and you wind up getting a very interesting kind of an infrastructure that then algorithmically can produce all sorts of smoothness at large scales, but also more complicated things when you get down to the particle level. And you want that! You want to have simple concept of smoothness to start breaking down, because somewhere, this all has to be emerging from some simpler set of rules. The universe persistently tells us that it has simple rules underneath. You just can't get away from that message.

So we should look for those simplicities and see if we can find them, including in some of the mathematics.



8:03 TB: The Time Paradox in Ordinary Light!

I'm willing to guess that most folks have not heard this message. [For example,] if you've taken a course in electrodynamics, you probably have not heard the message that there's a time paradox in ordinary light. And I find that delightful, because it's *there!* It goes all the way back to Maxwell's equations from the 1800s.

Physicists have spent decades — actually over a century — exploring some of these little paradoxes that are in those Maxwell equations. Maxwell's equations are really insightful! Einstein loved Maxwell. Einstein was very fond of Maxwell's work because Maxwell had pulled together and collected some ideas that no one else had really [looked at with his] level of insight. He built on the work of others, but it was Maxwell who really kind of [pulled everything] together on this stuff.

Terry Bollinger CC BY 4.0 Foundations of Localized Symmetry Mathematics April 18, 2026

Wheeler, Feynman, and the Problem of Time

- Before developing his Nobel-Prize-Winning Quantum Electrodynamics (QED) method, Richard Feynman worked on a series of papers with his adviser, John Wheeler, in which they took decades-old time paradoxes in Maxwell's Equations seriously
- The result was a remarkable series of papers that questioned the nature of causality and inspired Feynman to develop his QED methodology. Here are two notable examples:
  - J. A. Wheeler and R. Feynman, *Interaction with the Absorber as the Mechanism of Radiation*. Reviews of Modern Physics, vol. **17** (2-3), 157 (1945) https://authors.library.caltech.edu/11095/1/WHErmp45.pdf
  - J. A. Wheeler and R. Feynman, *Classical Electrodynamics in Terms of Direct Interparticle Action*, Reviews of Modern Physics **21** (3), 425 (1949). https://journals.aps.org/rmp/abstract/10.1103/RevModPhys.21.425

9:02 TB: So, back in the late 1940s, a fellow named Richard Feynman — an unknown student at that time — worked for his thesis advisor, John Wheeler.

I occasionally refer to them as being, together, the greatest physicist of the mid to late 1900s. Why do I say "together"? Because individually, neither one of them was as creative or powerful as they were as a team. These two made a *fantastic* team. And the reason they did was that John Wheeler could just go *wild!* [Chuckle]. He would just go *anywhere!* That was the way he *worked!* His mind was always looking to say, "How can I generalize this? How can I *break* the concept of time? How can I *break* the concept of space?" And he loved that stuff, he just loved getting into that [kind of breaking the rules].

Richard Feynman, in contrast, wanted to *understand* everything. That was *his* goal. He would always say, "I want to *understand* how that works. And he couldn't do that with [as] broad of a view [as Wheeler's ideas]. But he could *take* those ideas… and then he could *pull them in* and say, "Whoa! How about if we control it a little better? How about if we force it into equation? How about if we do…" …some kind of approach where it winds up producing a testable result.

So, you put these two in a room together, and they spent a lot of time with each other. They respected each other highly and they really got along well. And then, they would come up with these *ideas*.

Especially because of Wheeler's influence, they did not mind exploring wild things. It's interesting that after they separated, there was a noticeable drop-off in the creativity of Feynman's work, because Wheeler was the one who was poking him. And by the way, for Feynman, when I say "a drop-off in creativity," wow, that's only *relative*. I mean, Richard Feynman still just casually did things like invent quantum vortices and superfluids, almost without even thinking about it. So [Feynman] dropping off in creativity is a very relative scale, but he certainly didn't have the same kind of [new] creative directions — you know, looking at different directions. [For example] you see that his [work in] quantum chromodynamics is, in many ways, just an extension of [his earlier work in] quantum electrodynamics. And Wheeler kind of kept him away from that [kind of a slog]. Wheeler got him into *interesting* "sets" of thinking.

One of the most interesting "sets," I'd say, was this whole idea of the photon paradox and how this worked. And the problem goes back to the equations — and to the idea of, oddly enough, of "Where do you get this little *kick* that you get from [emitting] a photon?"

What an innocent-sounding thing! When you turn on a bright light, [you get a little kick]. You see this concept in photon rockets. If you've looked at [this idea,] it's not just science fiction. It is an actual [propulsion] concept that's been presented [and studied]. If you put a very bright laser out the back of a spacecraft, it becomes a propulsion system. It has some very nice properties, and it has some difficult properties — and you certainly don't want to be on the receiving end of that laser! That is one of the problems with a photon rocket. But nonetheless, it's very efficient for certain types of applications, [certain] method of propulsion, because you get a little kick from those photons. They push against your spacecraft.

Now, here's the weird thing in what seems so straightforward [about photon propulsion]: You run into it, and you just say, "Yeah, you know… I've got photons shooting out [the back]. It's just a rocket!"

[The trouble is that] Maxwell's equations don't *say* that. They don't *give* you that. At least not in the first iteration of [using] them. And this baffled physicists for a long time. They're going like, "Wait a minute… if I give off a photon, if I "accelerate" a photon, there's this recoil effect that gives me this kind of bump. But where's it coming from?" Because it's not actually in the equation. It's an idea [similar to] that, you know, [after] you accelerate your car and you keep on coasting, you don't suddenly get a kickback that slows you down. So that's the general idea, is you're accelerating your car, and if your car is a photon, then you suddenly get a little bump back, saying, "Wait a minute… you just gave me some energy, so I'm gonna slow you down. I'm gonna go off and give that momentum to somebody else." And this was baffling, because the photon, according to Maxwell's equations, wasn't doing *quite* what they thought it should do.

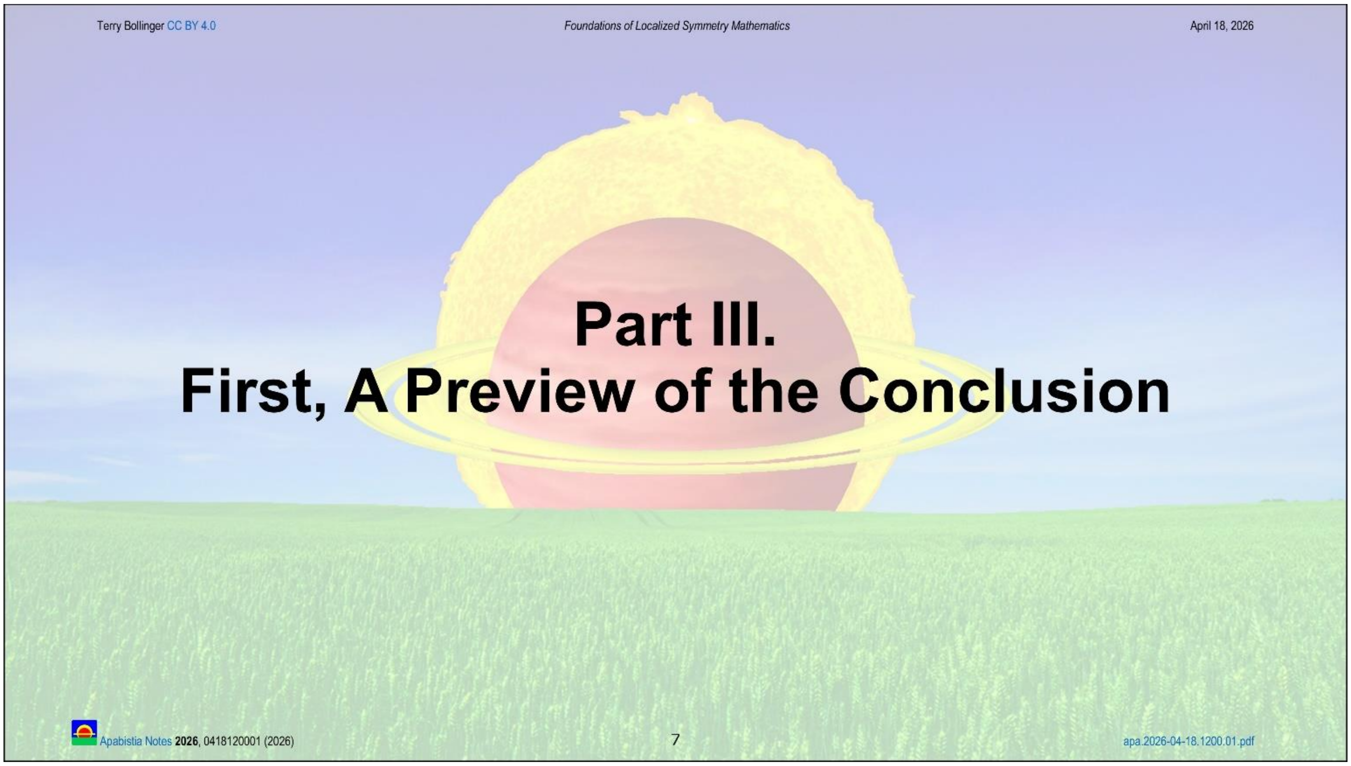
So people looked at this for decades. There's a whole list of names of people who examined this problem, and Wheeler and Feynman decided to get into it. And Feynman, he even tells stories on himself about how he completely misinterpreted the problem at first. He didn't understand what Wheeler was saying. [Feynman proposed] some actually silly ideas. (It's an interesting thing about Feynman: He didn't mind telling stories on his own stupidity. And since he's not a very stupid guy, he didn't have many such episodes. But when he did, he would tell them on himself. That was one of the examples.) So, Feynman had trouble even understanding what Wheeler was talking about. In some cases, it took them time [for Feynman to] get into [Wheeler's ideas].

If you look at the titles, [you see a hint of how radical Wheeler was]. I've got two [of the resulting] papers [listed here]. [The first is, "Interaction with the Absorber as the Mechanism of Radiation." Now, isn't that an innocent-sounding title? I mean, it just sounds like a techie title, you know, it's not [obvious that] what it's actually saying is that something weird is going on in time. [Why?] Because the absorber may be a billion years in the future!

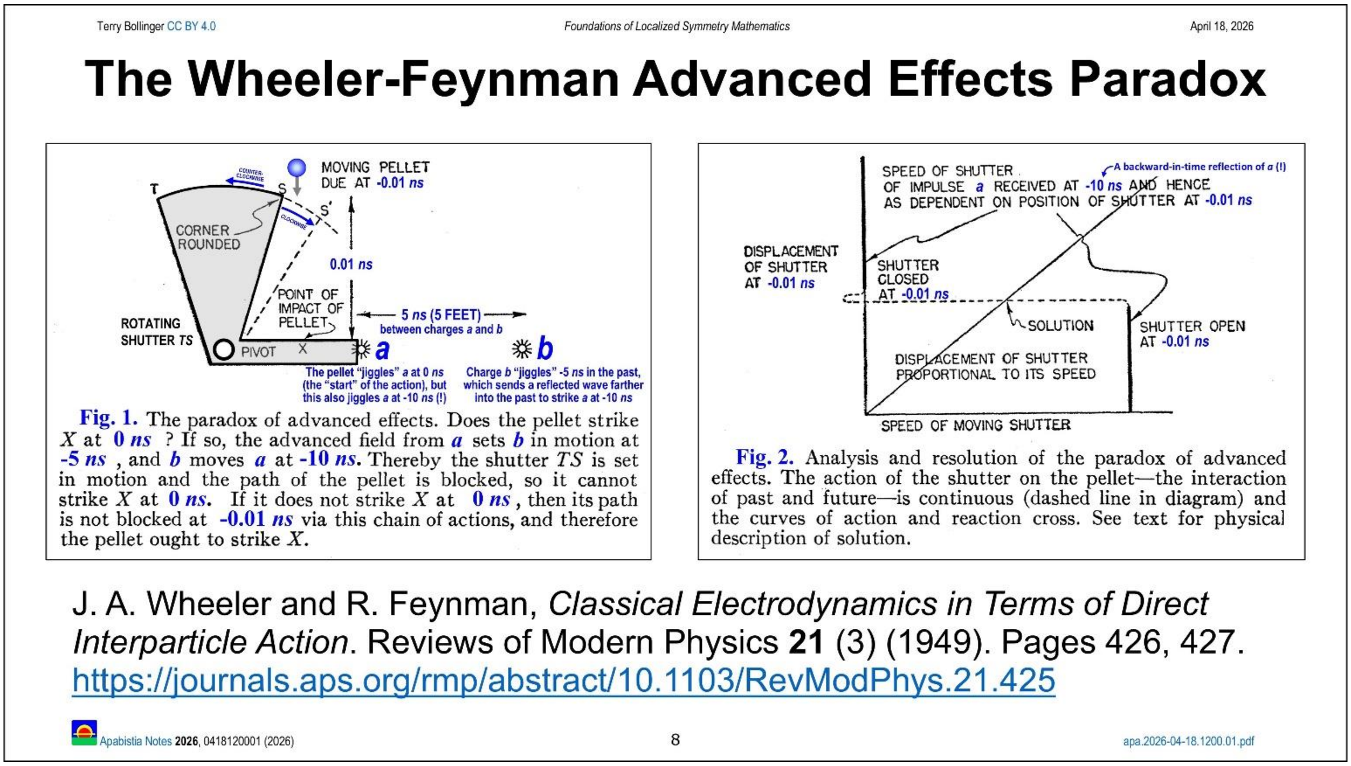
So, even the title is saying something very unusual that comes out of this question [about how to interpret Maxwell's equations], because it says, "Well, [because] the absorber of the photon may be *way* off in the future [when you] shine a laser out in space, those photons are gonna travel for a long time." And yet, even in the title, Wheeler and Feynman are invoking that [absorber as] part of the radiation mechanism itself. It's part of the *recoil*, in fact, some of the kickback.

Another paper kind of summarized [this issue] in 1949, and that's the one [here, "Classical Electrodynamics in terms of Direct Interparticle Action."] I'll be addressing mostly in this [presentation], explaining Wheeler's diagram: Explaining his figure a little bit, about why it's such an unusual figure and unusual message.

This [exploration] didn't end with these papers. After this, Feynman went on to do Quantum Electrodynamics. Quantum Electrodynamics was very much inspired by this work, but also takes it to a whole new level. So there's a connection. These aren't just, events that happened, and nothing came from it. Some *extremely* good work came from this.



15:53 TB: [Silence]



15:54 TB: I want to show the figure first, because I'm going to be getting into actually much easier stuff — just talking about electrodynamics, and kind of a quick intro to Maxwell's equations, because that's where it comes from, so you need to have some basic understanding of Maxwell's equations to see why there's a problem here.

But here are the two figures that he had. The first figure, the one on the left, he doesn't introduce it until he's started talking about the second figure — and then he starts talking with terminology that he hasn't introduced anywhere. So, it's just [a good example of how not] to write a clear example of a figure. This is not a stellar case!

You can tell that Wheeler's mind was zooming around in this. He [thought], "Oh, this is really *interesting!"* He has the idea, but he has some difficulty trying to present that idea and [convey] that idea over [to readers]. And again, I keep blaming Wheeler just because Feynman's diagrams are so different. This has had to be heavily a Wheeler type of diagram.

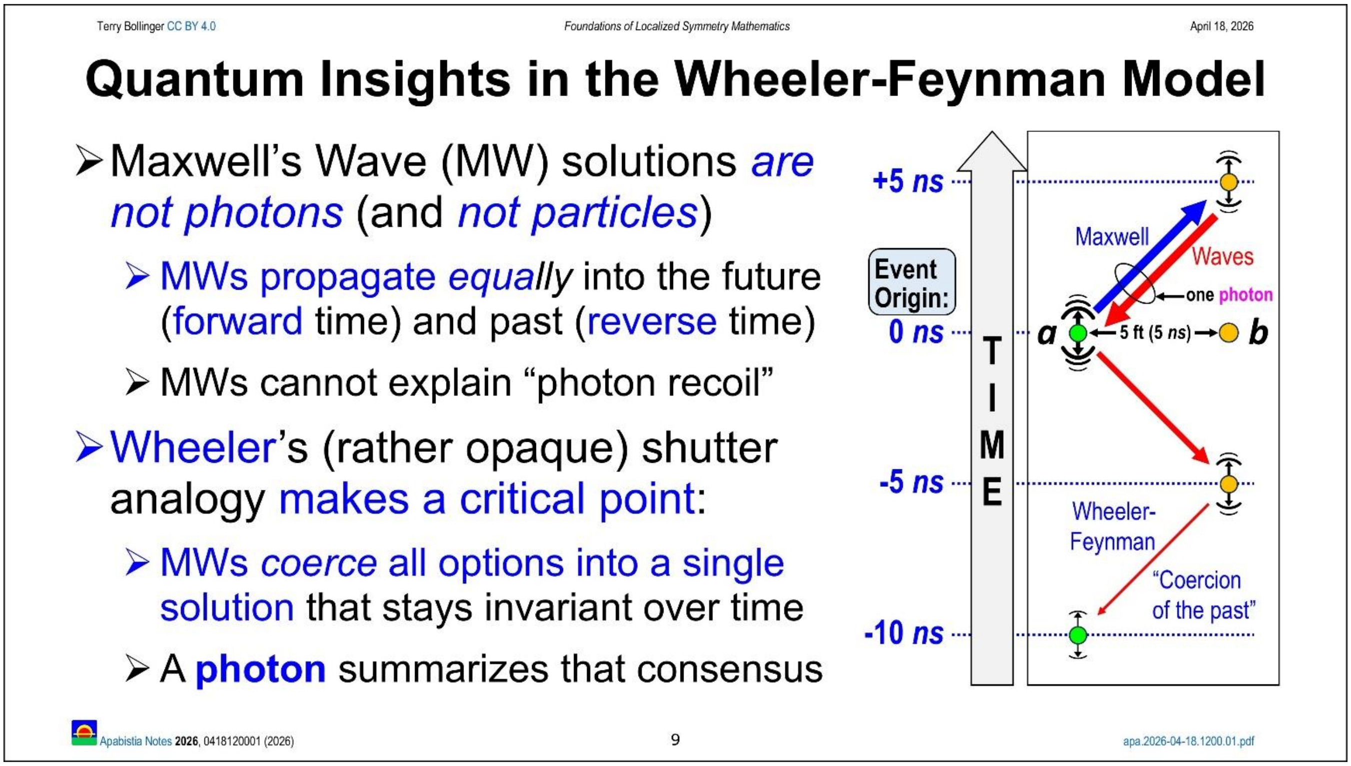
So, in his diagram, the first thing I did is he talked about times in a day, AM, PM, and gaps of 5 hours. So, just for simplicity, let's bring that down a little bit [to] nanoseconds [instead of hours].

One nanosecond is the [time it takes light to travel a] distance [of one foot]. [So,] light travels one foot in one nanosecond, to a very close approximation. [Using nanoseconds thus] makes this a little more lab-sized, and that's what these figures are doing.

And then he has this interesting puzzle that he comes up with: The one where he says that, "It seems to be that there is a future connection in the absorber that then somehow comes back and impacts [the past]. Could we make a device that would actually detect that? And if we can do that, can we create a paradox?"

That's when you have to say, "Oh, time's gonna have to diverge in two different directions for this to happen!" You literally are seeing into the future, into what you're doing [then]. And this is what Wheeler came up with. It is a fascinating and deep paradox. But unfortunately, I think it's not gotten as much attention. That's partly because it's, like I said, kind of confusing when you go through the paper. You're just saying, "What is he really saying with this?"

And so bringing it out is worthwhile, because [Wheeler's] thinking is very deep. It's just that the presentation is a little hard to get into. So, I'll be getting back to this. I just want to give a quick advance to show that even though I'm going to be going through some very simple stuff, the goal is to get at this very intriguing representation that Wheeler came up with.



18:45 TB: The second part of this that shows what I'm talking about. I'll just give you a quick intro to the actual paradox itself. When you send out a photon, it goes in *two* directions. At the quantum level, space is *four*-dimensional; it's not [only] three-dimensional. You have *time*.

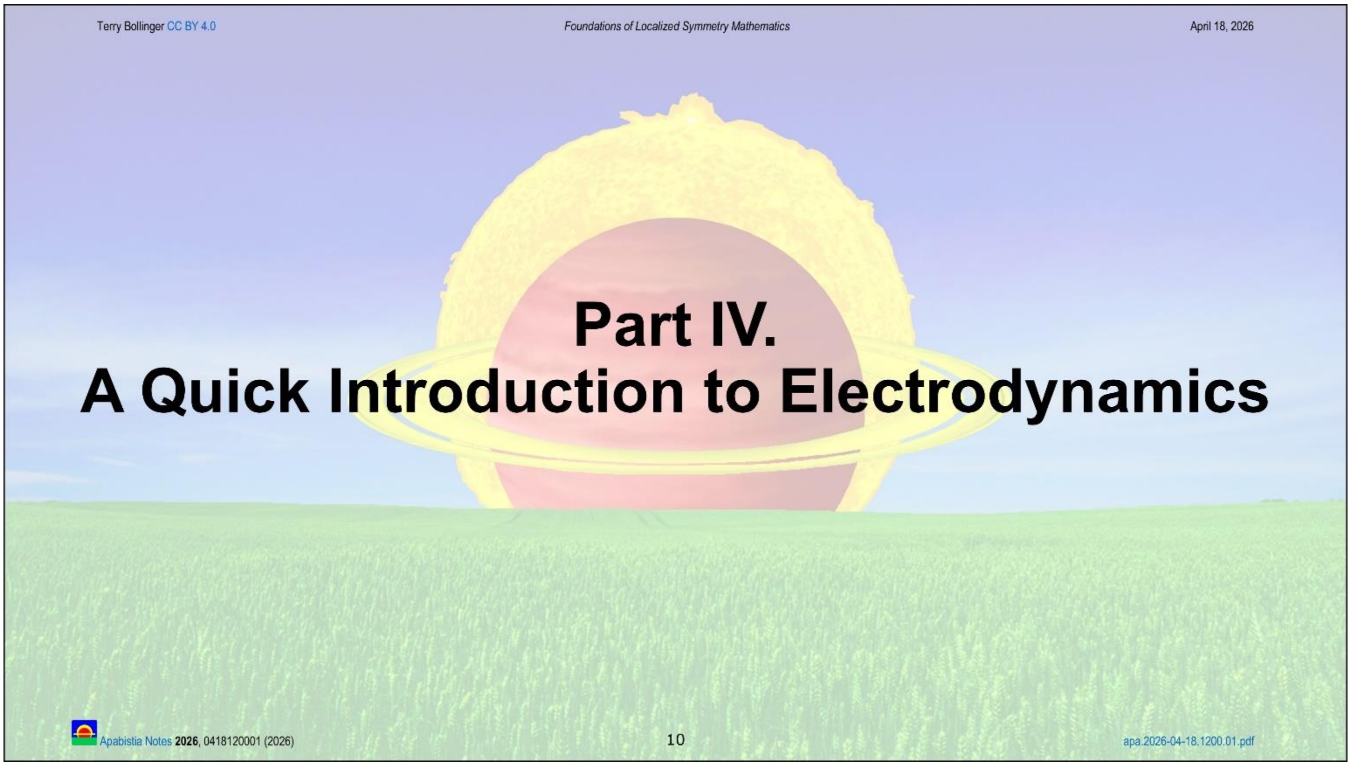
You hear this statement that the laws of physics work the same in both directions in time. That's true, but when you work at electromagnetic radiation, it becomes especially unusual because it means that your waves can go in *either direction* [in time]. It's just a simple sign change; the waves work the same way. So, in a nutshell, what Wheeler was saying was that if I *jiggle* a charge, that creates an electromagnetic wave that goes into the future — no problem — [but] it also goes into the *past*.

And this is the problem that so many physicists have struggled with since the 1800s. [They] say, "Wait a minute… that doesn't make any sense!" So the reflex reactions says, "Well… we'll just *discard* the past solutions. Those can't be valid!" But as soon as you do that, you lose the recoil: You lose this effect, the fact that you have a slowdown [of the charge that says] that, somehow, you're transferring momentum to that *future* particle.

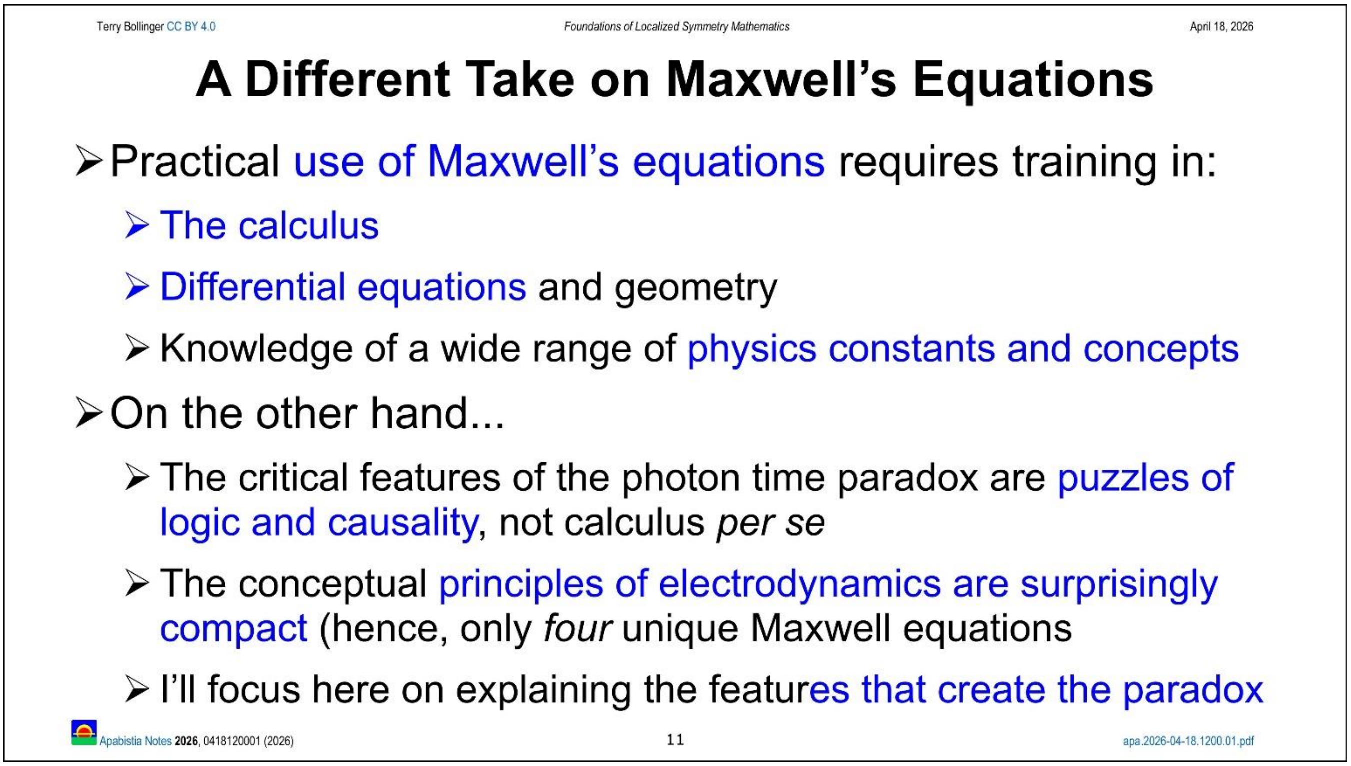
This is a conundrum that Wheeler and Feynman put together into an actual example, one where you get a wave going in the past, bounces off of another charge — easy to do, it's not a complicated process. And that [reflected wave] in turn creates another backward wave that goes *this* way.

So you're getting this interesting combination of radiation events. This one's also producing a *forward* wave, but it's also producing a *backward* wave.

And the bottom line is, here you are: You *shake a charge*, and then you look at your lab records, and you say, “Oh yeah… I see that I did that *10 nanoseconds ago*… *oh*, I should have noticed that *then*. Well… you know… I didn’t *notice* that I jiggled it 10 nanoseconds ago!” And then Wheeler and Feynman, with their little device, come up with a way and say, well, “Can I make that into a time paradox? And if so, what’s the resolution?”



21:10 TB: So, that’s where I’m heading. Now, I want to just get into this a little bit — like a quick, quick course in Maxwell’s equations, intentionally avoiding all the detail that you must know if you actually want to actually use these things. But the geometric [part] — when you go down the level of the algebraic constructs, the relationships — a lot of this is surprisingly simple. You have all these constants [that make the equation look more complicated], but you don’t really need to get into [either those or] the details of the differential part.



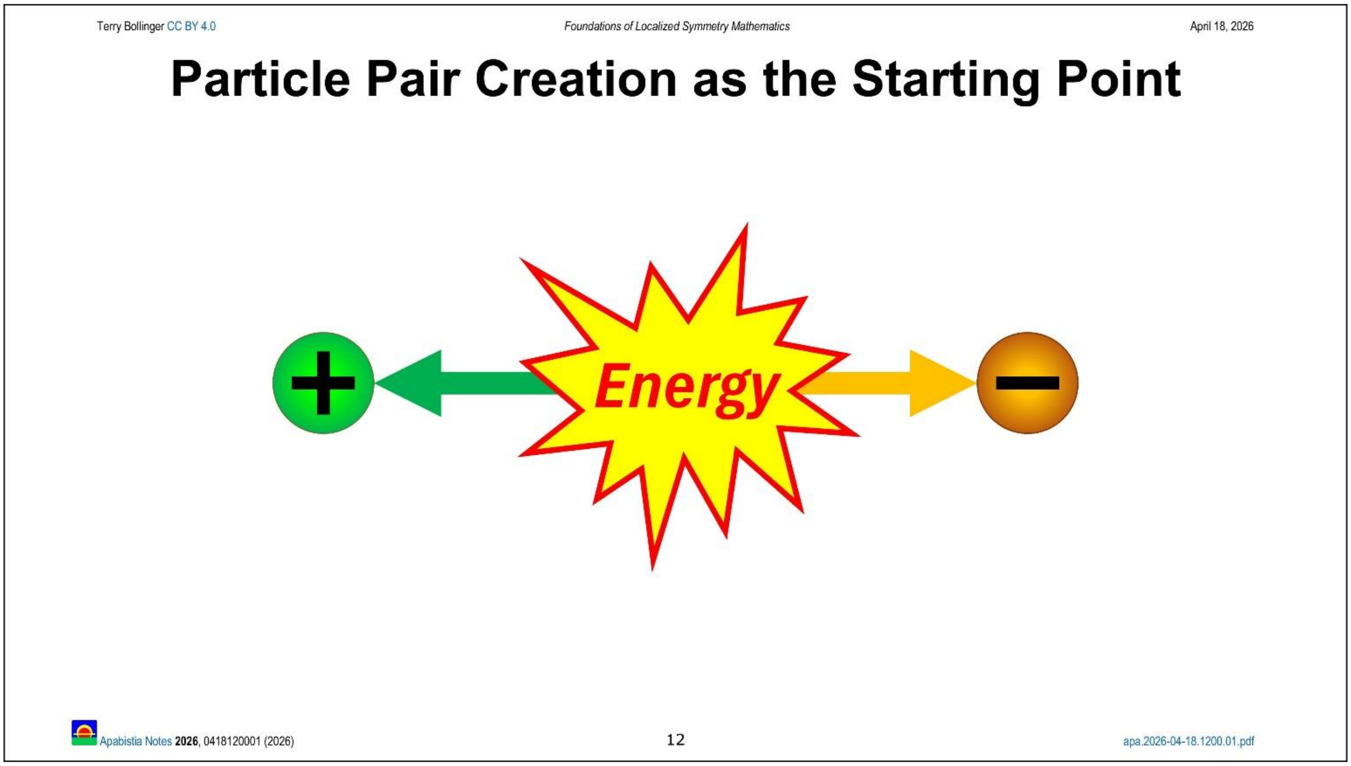
21:41 TB: And also, again, some of these equations — because they're differential equations — kind of ignore the fact that it all *starts* with just simple pairs with very discrete charges.

No one ever sees free charges of less than one electron unit. And that's a constraint on the *mathematics*. We can say that, "Well, *I* [want to] generalize and think [the level of charge] could be *anything*."

But that's not what we actually see! (And there are quarks. Quarks are a very interesting case, but that was something for some other time.)

So, you want to, if you want to use Maxwell's equations [for large-scale situations where the number of electrons involved makes the variable representing total electric charge to be continuous, you need to learn the *full* set [of Maxwell's equations in both their differential and integral forms]. There are many excellent representations of it for different applications.

But [for this case, we] want to look at [the simpler, more geometric] issues that are producing these time problems



22:26 TB: Pair creation!

This is *not* where you normally start electrodynamics! But this is where — because I'm taking the viewpoint of *bottom-up*, and that we should take a *stronger clue* from physics than we do — [we need to pay closer attention to quantization].

In the *full* Maxwell equations, you just have the *concept* of charge. It's not quantized. It's just an entity that you have that could be infinitely small — which is reasonable at Maxwell's time, because they didn't know about the electrons, they didn't know about quantization of these issues. They could only see lumps of charge that seemed to be quite smooth and quite continuous.

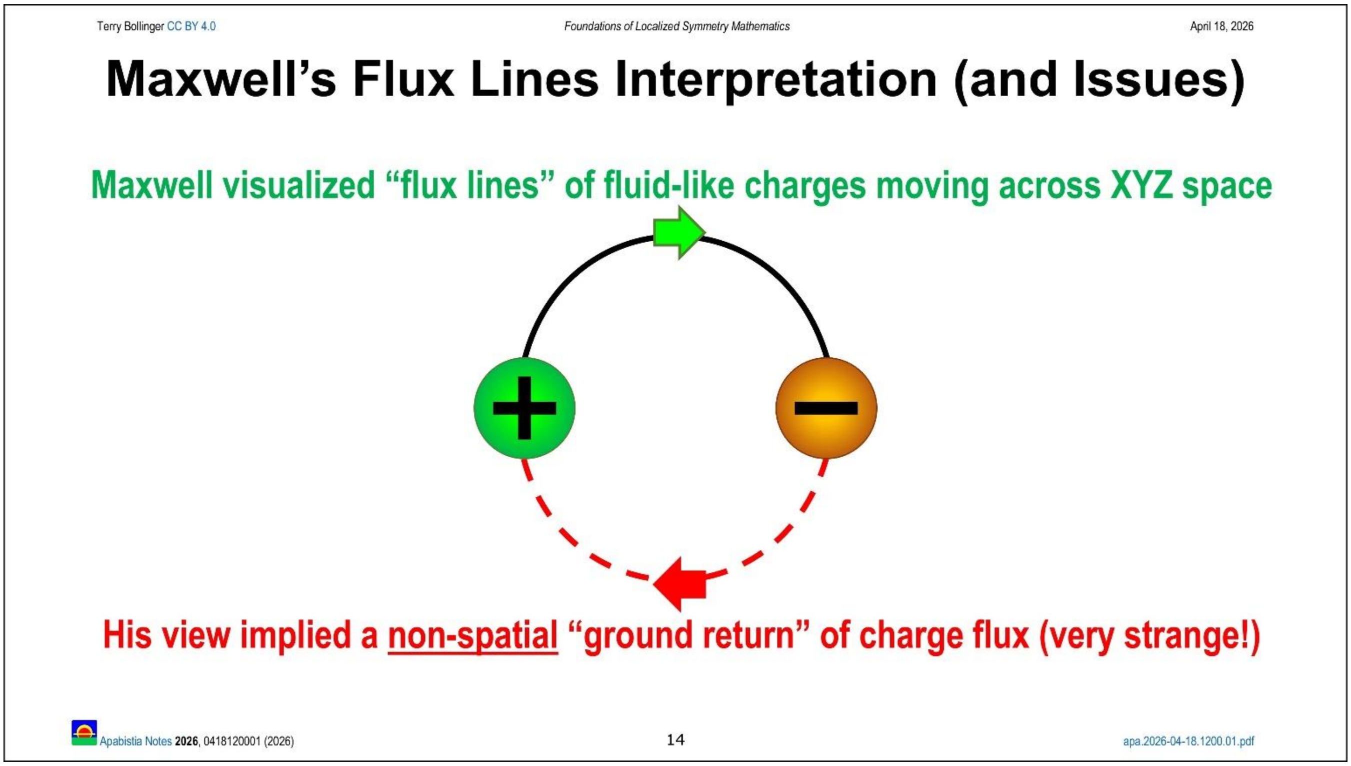
But that's also the danger, because if you see everything, it looks continuous, and it looks smooth, and it looks like that, it is so tempting to make the *mathematics* equally smooth and differentiable to an infinite limit. So the reason I start off talking about Maxwell's equations with pair creation is because that is not what we see in physical reality. The universe that we're trying to model with our mathematics does not begin with infinite differentiability of charge. It begins with lumps of charge, and it's an extremely specific process. It's a hole-and-heap process… you know, you have a *hole* in one side, and you have a *heap* in the other.

[In terms of electrical charge,] we label the minus sign, the electron, as the hole. We label the positron [and] the proton very arbitrarily as the heap — although, if you go on deeper levels, at some point I think we may get to a point where there actually is a relationship between these charges and the direction of time. So it may not be entirely arbitrary in that, but it's certainly the starting point where we see actual charge.
Begins at this, this energy event.

That energy event, incidentally, in a very real sense, [exists]. You can take two photons… take an extremely high-energy gamma photon, collide it head-on into [the photons of] a green laser (I think that was the first version I saw that actually did this), and it produces a positron-electron pair. So, you go, "Like, wow, okay… I can use pure energy in the form of photons to create a pair of charges!

And this is just a beautiful little micro-symmetry, one that causes all sorts of interesting things to come from that. If it was only positrons and electrons, we'd be in trouble, because the whole universe would lapse back [into pure photon energy]. [That does not happen because of existence of baryon charges like protons, but then the] problem [becomes], "Where does all the baryonic matter come from?"

Okay, so you've got two things called positive and negative charge. What in the heck *are* charges? Well…



25:05 TB: There's many ways you can represent this, but one of the ways that I think for understanding intuitively what these things do is just a good old field lines representation.

We've all seen this with magnets, you know, which are very closely related phenomena. And you can do it with electric charges also. So you get these lines where it looks like there's a connection, a little pathway. And in a case of, like, iron filings, it's a literal pathway that connects this magnetic force, kind of concentrates it a little bit.

And [each field line] has a direction to it! So, in the case of electrons, we arbitrarily say that it's coming from the positive and going out to the negative.

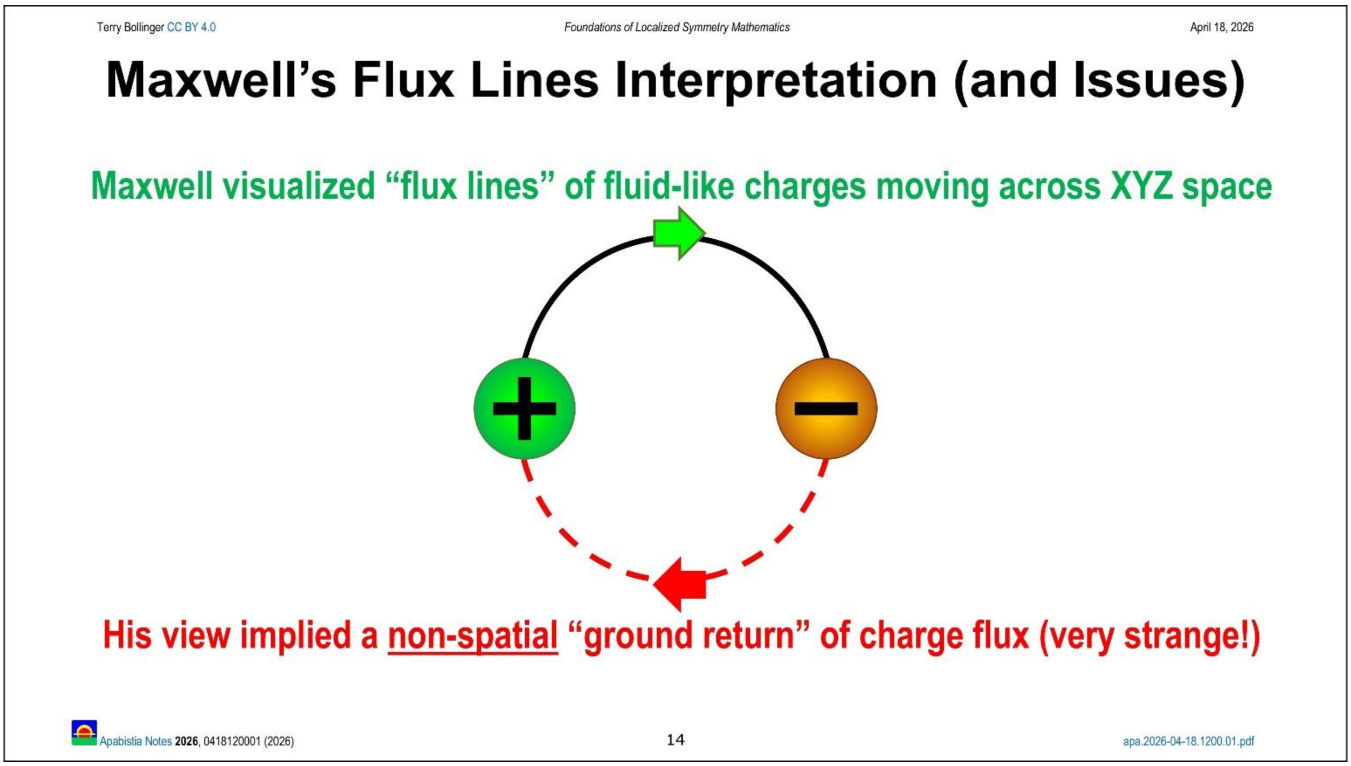
[Field lines also] like to [expand sideways to their direction to] fill space. And that's important. It doesn't just go in a straight line, just go from, you know, from the positive to the negative. [Instead,] these guys [also] don't like each other [as they expand sideways]. Maxwell called them *molecular vortices*. He had this whole delightful model in which they were like little tornadoes. They would whiz around, they would expand, and they would push against each other and try to go out in [sideways] different distances.

[Later on, Maxwell] replaced [his vortices] with differential equations. But before you dismiss his molecular vortex model too much, [it's worth noting that he used them] to figure out that light was electromagnetic radiation. So, [despite being very mechanical by modern mathematical standards that de-emphasize the physical world as much as possible,] it was a powerful model. [Maxwell made very effective use of] concepts like this — the idea that these, for instance, these lines would literally be little vortices that are going out and rotating, pushing against each other, doing these things.

A little side note: If you get into standard model of particle physics, when you talk about the *color* charges, they don't do this. They attach more or less in a straight line, much more like a rubber band. So they don't resist [being close to] each other. [The field lines of color charge pairs] don't push out against each other [sideways] like electric charge [lines] do. They just kind of *lock on*. And the farther you stretch them, the more upset they get!

So, there's more than one way this can happen. It's important to notice that there are different configurations, different micro-configurations, of this concept of field lines.

Can you represent electromagnetics in other ways [than field lines]? Of course you can! There are all sorts of equivalent representations. But field lines, as Maxwell noted, provide a particularly interesting way of understanding the relationship between these charges.



27:28 TB: Now, [another thing that] Maxwell did was [use the term *flux*]. I don't think he introduced the term, but he liked to use the term flux.

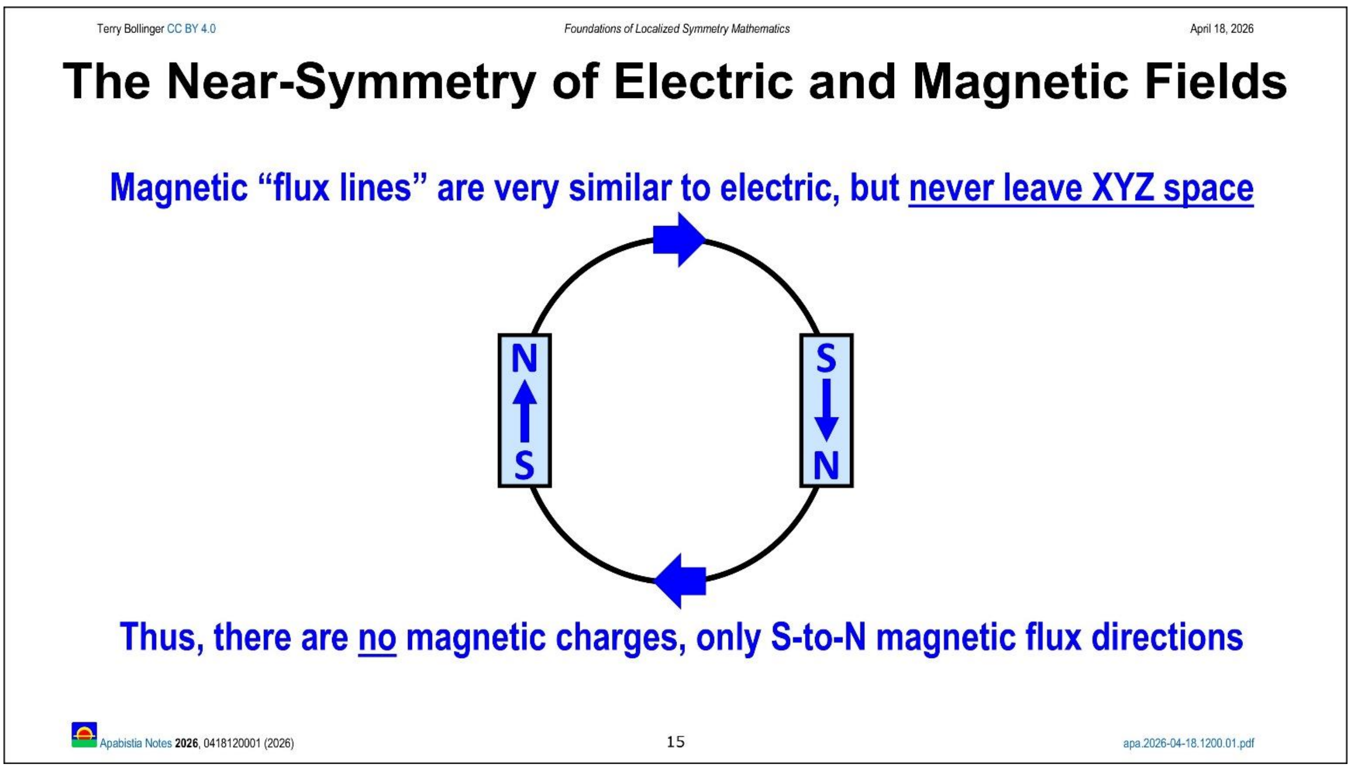
Now, if you recall your linguistics, your etymologies, flux just means *flow*. It's a it's a flow of something. Maxwell literally viewed these lines as a flow of something like a fluid going across these two locations. Now, when you're talking about batteries, it's a literal flow: You have actual electrons flowing from one side to the other, [in] reverse polarity, unfortunately, [from minus to plus. We can blame Ben Franklin, who just guessed, for that boo-boo!]

But [when he used the term "flux" for electric and magnetic field lines, Maxwell] was something talking about something a little more subtle. He was saying that we see that same [flow-like] effect even between these *static* charges — that it looks like [the field lines are] pathways where you could think of it as something was *flowing* there, even though [the situation is] static [and no energy is being consumed]. Nothing's moving, it's not giving off energy, it's not radiating. Nonetheless, it seems as though there's a path. And the odd thing about that path is that you have a source — you have the positive side — and you have a drain, [in which the flow] just sort of disappears.

And one of the obvious questions is, if you look at Maxwell's model, [is, "Where does the flux go?"] I remember the first time going through some of these models, and [that was always my first thought: "Where does the flux *go* after [it arrives at the drain]? And that sounds, in some ways, like a silly question. But I don't think it is. I think there's something that nature's trying to tell us about the relationship of charges that we still haven't quite figured out, because there is some kind of a connection, there is some kind of a loop.

But we only see *half* of that loop when we're talking about a positive and negative electric charges. That's interesting, because if that wasn't true, we would *not* have a physical universe as we know it! The fact that we can only see *half* of this flow cycle is incredibly important for the existence of things like electrons [and] for the existence of things like protons.

So there's some little bit of trickery going on in the deeper physics that we don't really understand. Nor do people really worry about it very much! But I would suggest that that's actually a *very* interesting thing to worry about, and one reason why you could argue that is that…



29:41 TB: … that in the case of magnetic lines of force, you don't have this problem! That is the single biggest distinction between electric and magnetic lines of force. When you have magnetic lines of force, they're also flux lines. They also seem to come from one direction, go into the other, but they're always, always, *always* eventually looped. They never go to a point, they never go to what would be called a "magnetic monopole," at least not that we've ever seen, the [never-reproduced 1982] Valentine's Day event excepted.

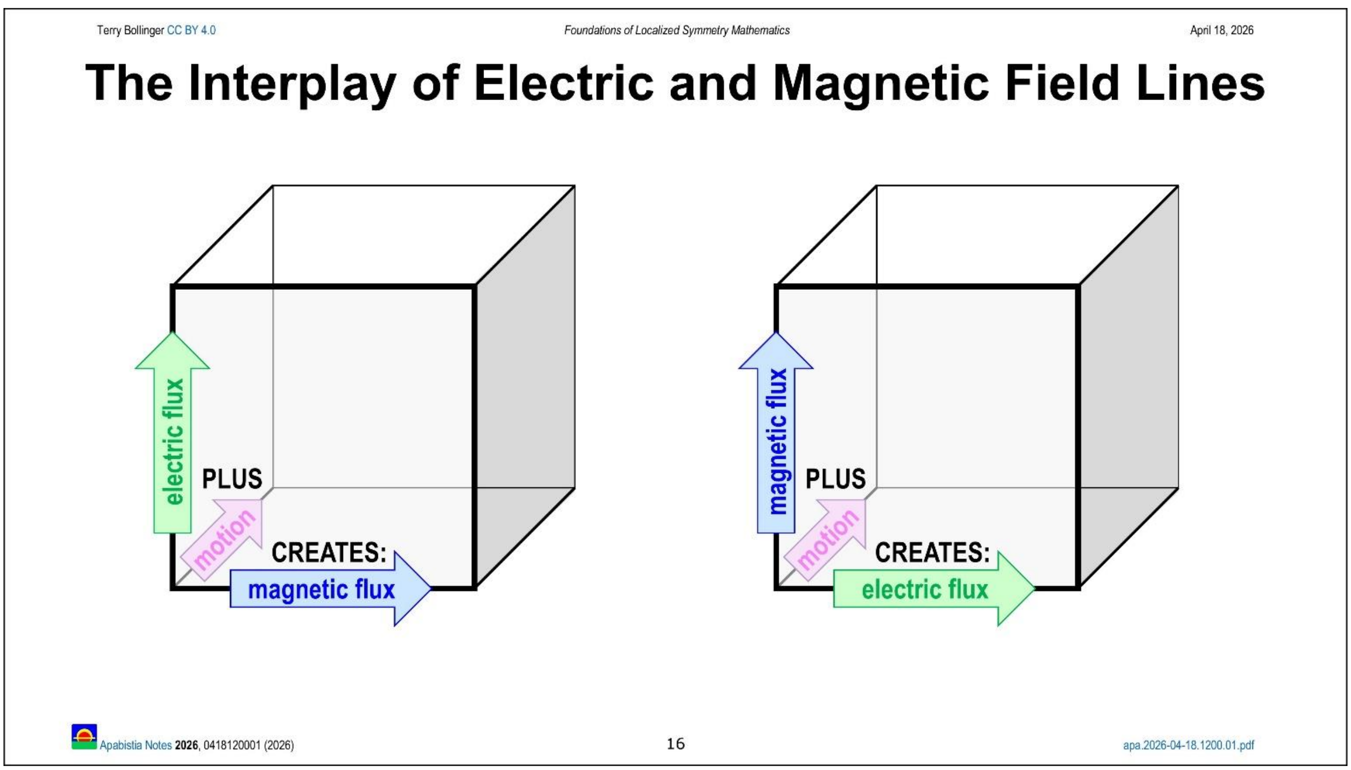
(Good luck on that one! That's always an amazing story about [Blas Cabrera] finding a monopole on Valentine's Day in a lab that was not attended. No one was ever able to reproduce it, but it was a fascinating result.)

So, observationally, we see these two kinds of flows like this, these two flux concepts in electrodynamics. But only one of them is able to terminate at a source and a sink, and that's the electric force. The magnetic force is remarkably similar. There are some scaling differences, but just like the electric, the magnetic field lines [like to expand sideways and] don't like each other — they try to get away from each other.

You have all sorts of interesting effects with magnets because of that. They pull in one direction, and they expand in all the others. Which, again, goes back to Maxwell's beautiful little vortex models, where you have these little tornado-like behaviors where they're sucking in one direction and trying to expand in the other. So, it's a delightfully physical model that Maxwell used, to great effect, to understand what's going on with [magnetic field lines]. The end result is that you get these loops, but you don't get the charges.

Now, electric can do this also! However, electric can do *both*: You can have these *loops* with electric, or you can have these *loops* with magnetic. But you *can't* have the termination points with the magnetic [field lines].

So, it's an interesting broken symmetry. I remember one of the earliest ideas I ever got into in physics was a very long time ago. I got fascinated by this [in middle school] and wondered if there was some kind of magnetic equivalent of the electric and positron particles. [That was in a] small [Missouri] town with a small-town library, [decades before the Internet], so I didn't have very good resources. I finally ran across some guy named "Dirac" who had come up with [the word "monopoles,"], and I [immediately] thought, "Oh, *shoot*, it's been known for a long time!" But it's a fascinating little symmetry.



32:16 TB: Now, the most complicated equations in electrodynamics deal with the issue that you see in these two cubes. Now, the more you get into it, you really have to get into your differential equations, you have to get into the relationships, but the idea is not complicated. In fact, the name of this is even reflects what's going on here. It's called a cross product.

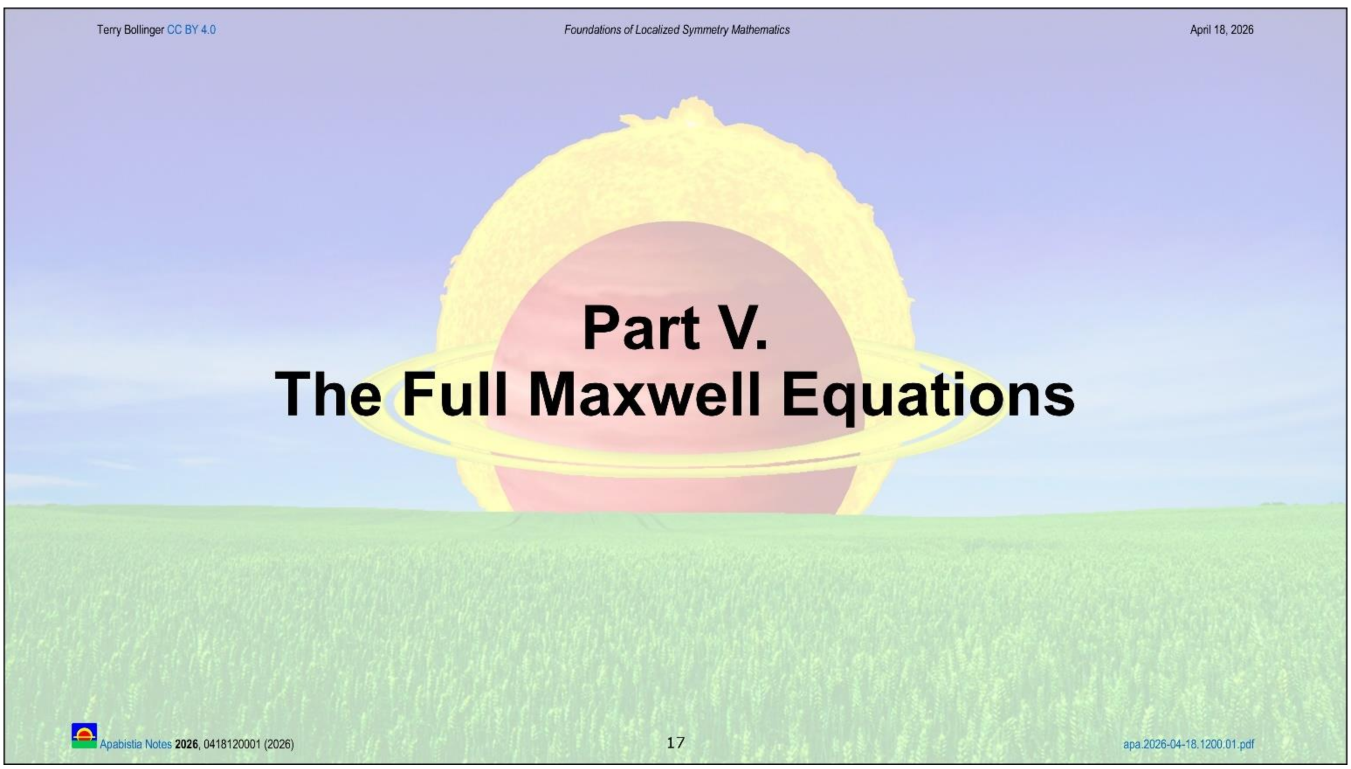
If you look over in the left-hand figure, you've got an electric line of flux, just like I showed before. But let's say you move that thing, so relative to you, you're pushing against it, you move it this way, move it out towards the back of the cube. What does that do? What that does is create a magnetic line of flux, and it's perpendicular to the other two. This is why it's a cross. It literally forms a little right angle cross here, and then the product of that right angle cross is the third dimension, is this dimension magnetic flux.

Maxwell got this from something called quaternions, which are the four-dimensional equivalent of complex numbers. There's a little thing that, in the math of quaternions, that has this cross-product capability. And boy, did it prove useful for a lot of physics, because when you're working in three-dimensional space, there are all sorts of things where this idea of you have some kind of a force line here with a direction, you have some kind of a motion, and when they're exactly right angles, you get the maximum product going in the other direction.

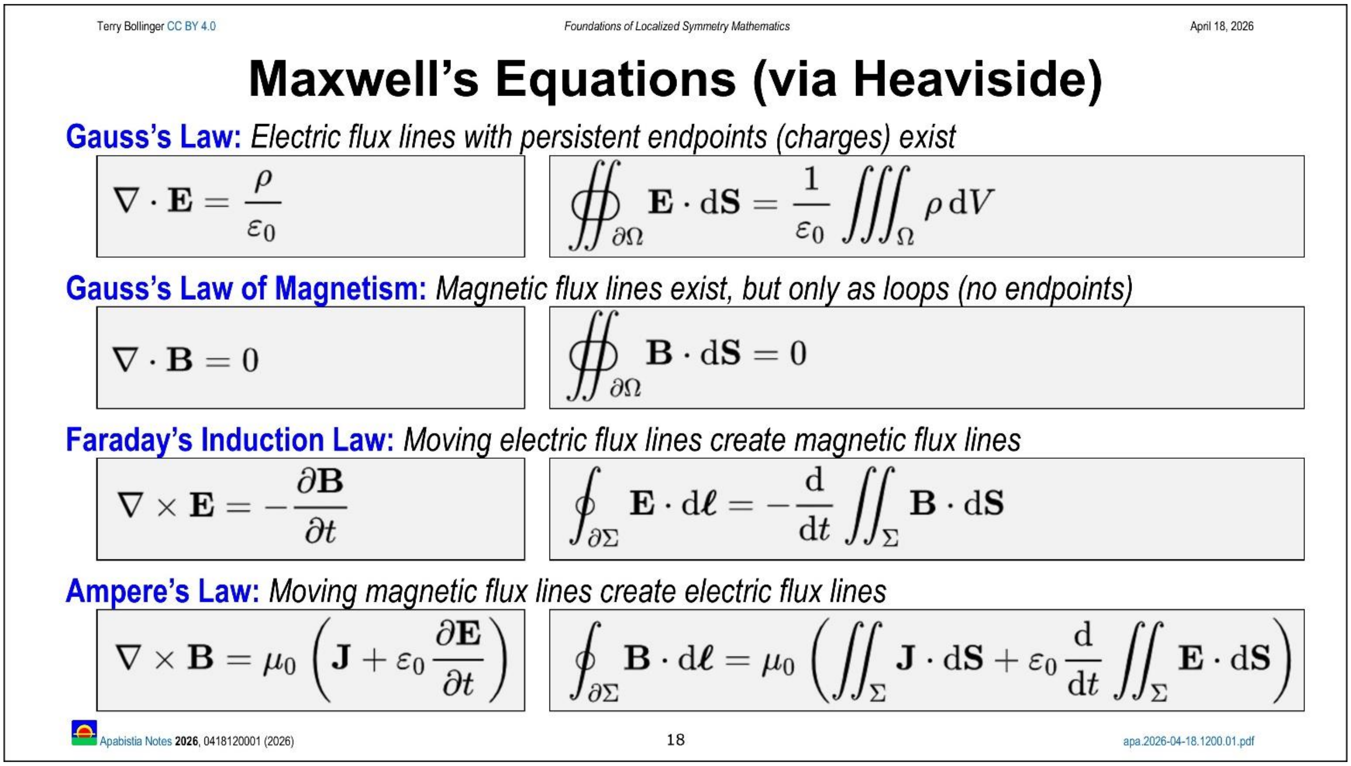
And then you have another thing called a dot product that tells you what happens if it's not at a right angle, which is just basically a shadowing effect. You take the part that is at right angles, and that gives you the cross product. The dot product tells you, says, well, if they're not at right angles, what happens? And the answer is that if they're completely parallel, nothing happens [with the cross-product, but those same parts multiply like numbers with the dot product].

So you have these sets of relationships, and all of this comes out of quaternion math. But it was just broken apart into these two concepts.

And the symmetry is that magnetic flux and motion do the same thing, except they produce electric flux. So, not too surprisingly, put these together, and you have the basis of electromagnetic radiation. You have radio waves, which have both of these components. They flip, they tradeoff between each other, and produce different ways of looking at the same packet of energy.



34:40 TB: [Silence]



Maxwell's Equations (via Heaviside)

Gauss's Law: *Electric flux lines with persistent endpoints (charges) exist*

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0} \qquad \oiint_{\partial\Omega} \mathbf{E} \cdot \mathrm{d}\mathbf{S} = \frac{1}{\varepsilon_0} \iiint_{\Omega} \rho \, \mathrm{d}V$$

Gauss's Law of Magnetism: *Magnetic flux lines exist, but only as loops (no endpoints)*

$$\nabla \cdot \mathbf{B} = 0 \qquad \oiint_{\partial\Omega} \mathbf{B} \cdot \mathrm{d}\mathbf{S} = 0$$

Faraday's Induction Law: *Moving electric flux lines create magnetic flux lines*

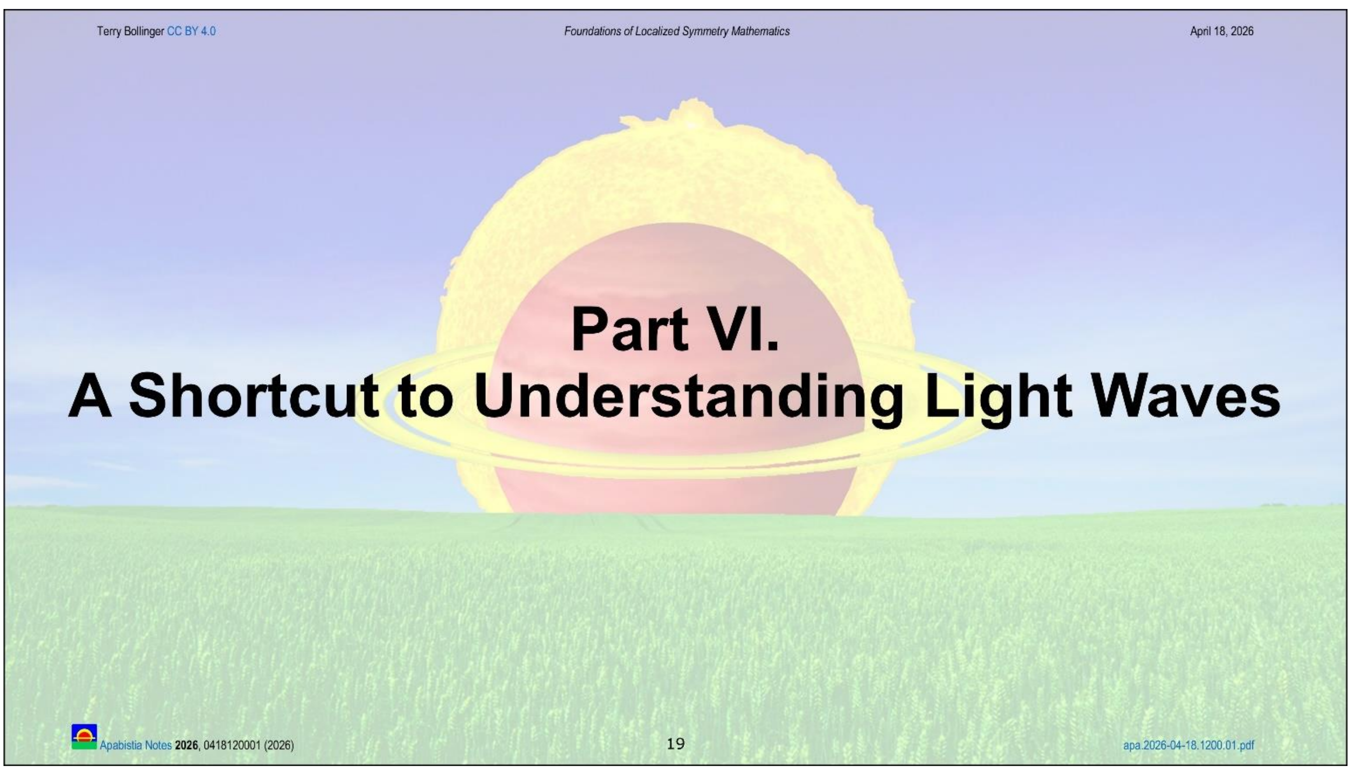
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \qquad \oint_{\partial\Sigma} \mathbf{E} \cdot \mathrm{d}\boldsymbol{\ell} = -\frac{\mathrm{d}}{\mathrm{d}t} \iint_{\Sigma} \mathbf{B} \cdot \mathrm{d}\mathbf{S}$$

Ampere's Law: *Moving magnetic flux lines create electric flux lines*

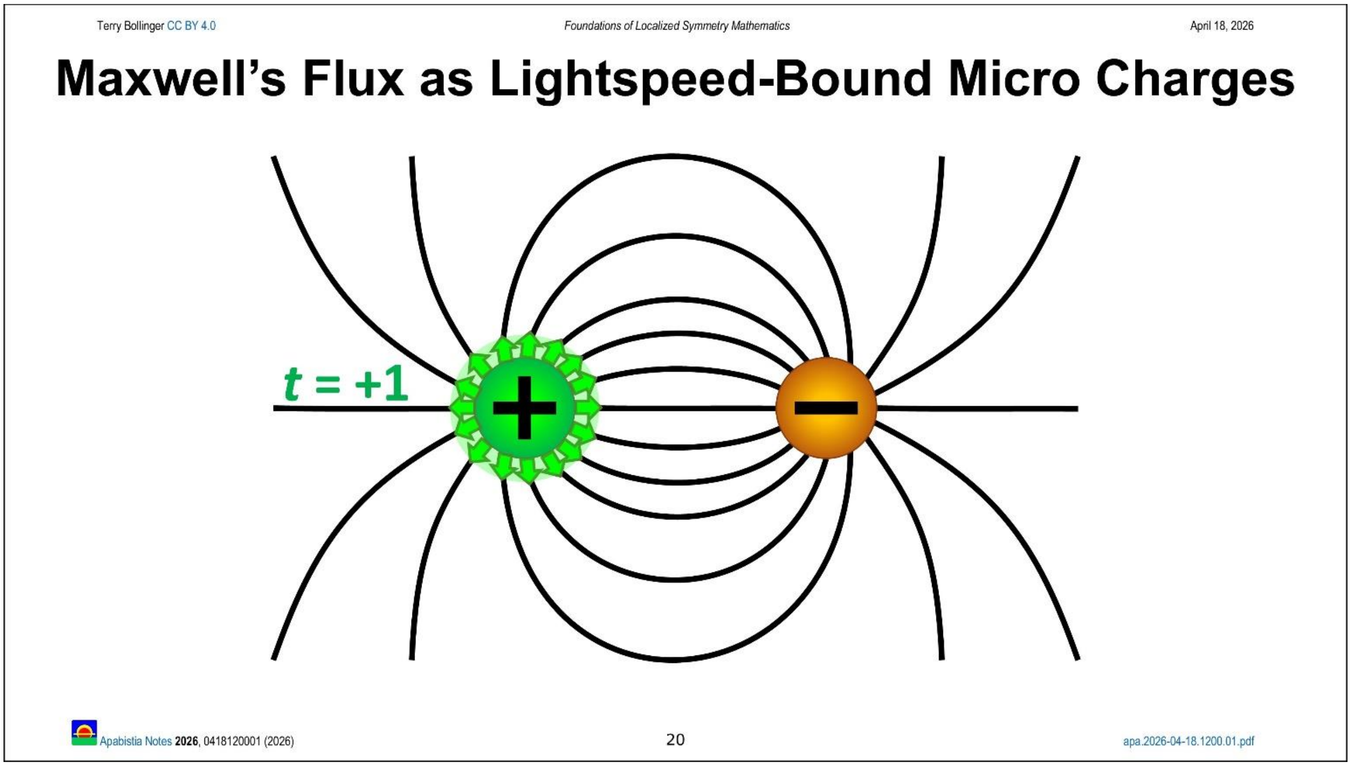
$$\nabla \times \mathbf{B} = \mu_0 \left(\mathbf{J} + \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right) \qquad \oint_{\partial\Sigma} \mathbf{B} \cdot \mathrm{d}\boldsymbol{\ell} = \mu_0 \left(\iint_{\Sigma} \mathbf{J} \cdot \mathrm{d}\mathbf{S} + \varepsilon_0 \frac{\mathrm{d}}{\mathrm{d}t} \iint_{\Sigma} \mathbf{E} \cdot \mathrm{d}\mathbf{S} \right)$$

34:43 TB: Now, if you go back to what I just covered, I just said pair creation.
Force lines, magnetic force lines, That you cannot have terminus points for magnetic, you can have them for electric.
And then you have this interesting thing where you have these cross products.
everything I just said is in these four equations, which, again, Maxwell pulled them together.
And, but they were already, for the most part, known in other areas.
So, he pulls them together, but if you take a look at this first one, there's two different ways to represent it. You have the form on the left is a differential form, the one on the right is an integral.
In many ways, this is… this is almost, like, in the top right line, it's almost like a pictographic representation of what you're doing. This little oval that they show with the integral lines. This is where you're just circling around. You're saying, I want to have a complete surface, and I want to make sure that everything is covered.
And the message from this is.
It really is just that charges exist. Something called charges exist.
That within an array, you can have a certain amount of charges, which actually turned out to be electrons or protons.
And then, once you have that, you're going to have a fixed number, proportionally, of these field lines coming out of that.
So you can… you can measure the amount of charge by giving a standardized, you know, definition of these field lines, which, again, they're always trying to spread, so they become more diffuse. But nonetheless, you've got a total amount of electric charge-ishness coming out of that volume.
And that's really all these first two are saying. They're saying it in a form that looks a little intimidating, but they're saying that if I have a closed space, I either have electrons in it or I don't.
And if I do, then I have this integral. I have this non-zero sum.
that rho over epsilon sub 0. I have this non-zero sum that tells me, essentially, how many electrons, or how many protons do I have in that space.
So, complicated ways of doing it, they give a lot of precision, but the concept is very simple. By the way, it does not say that electrons are points. In fact, it actually avoids that. It says that in a volume.
you will have a certain amount of charge. And that's an important distinction, because if you go into the quantum side of things, the smaller you make that volume.
The weirder it gets, and the higher the energy gets, until it gets to a point where it just starts breaking things.

So the idea of reducing these charges to a point is something… this frustrated Feynman his entire life. He was never satisfied with his own understanding of what happens when you shrink that envelope all the way down to a point like size.
The second law is just saying…
You don't have monopoles. That's all.
I once had an opportunity in high school to explain to a physicist
Who was there for promoting her college.
And she was kind enough to let me, to explain to me
these first two laws, because I was proposing to her, I said, well, isn't it possible you could have magnetically charged particles, was what I was asking. Again, small town, I didn't have money to talk to.
And at the very end of the conversation, she had gone through the second… the second law here.
And I made the mistake of saying, well, this is very interesting, thank you very much, but didn't you just say that there are no monopoles because there are no monopoles? Which was exactly what she had just said. She had quoted exactly the second law.
So, so much for my political skills. This did not go over well. She got quite upset at me, but it was not because I was wrong, because that's exactly what she was saying. She was quoting the second law.
But she was kind enough to go through the discussion for me.
And the second two groups, these are talking about the somewhat complicated relationships of those cross products, dot products, and how this all gets together, and of course, you have that charge issue, which further complicates that.
But keep in mind, again, equations look complicated, but the concepts going on here are not that complicated. They're straightforward things with a very strong geometric interpretation.
And that geometric interpretation can help you understand how these things will interact in a given situation.
And I am having trouble getting my varicose.
For some reason, my… Slide wasn't moving.

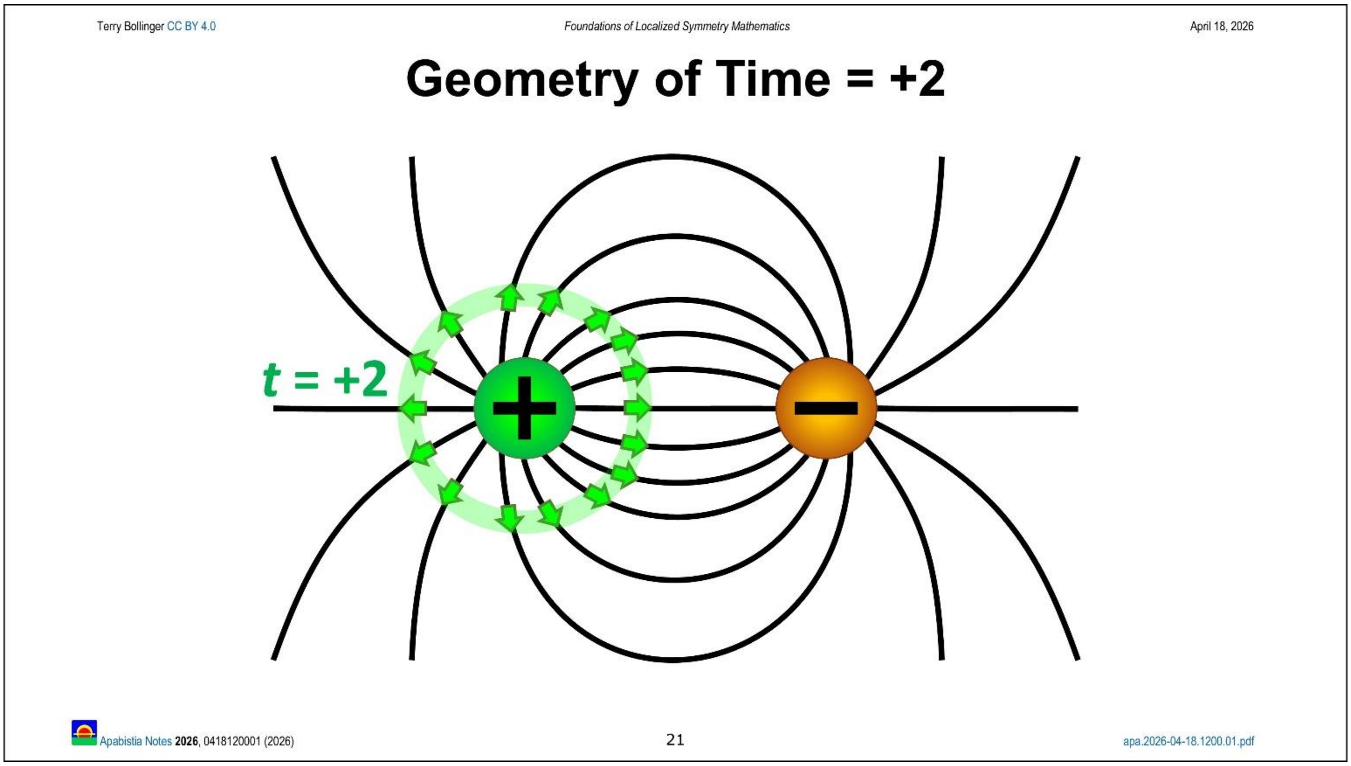


39:21 TB: Okay, now, given all that, I want to give a little shortcut on understanding the concept of waves, which is this…

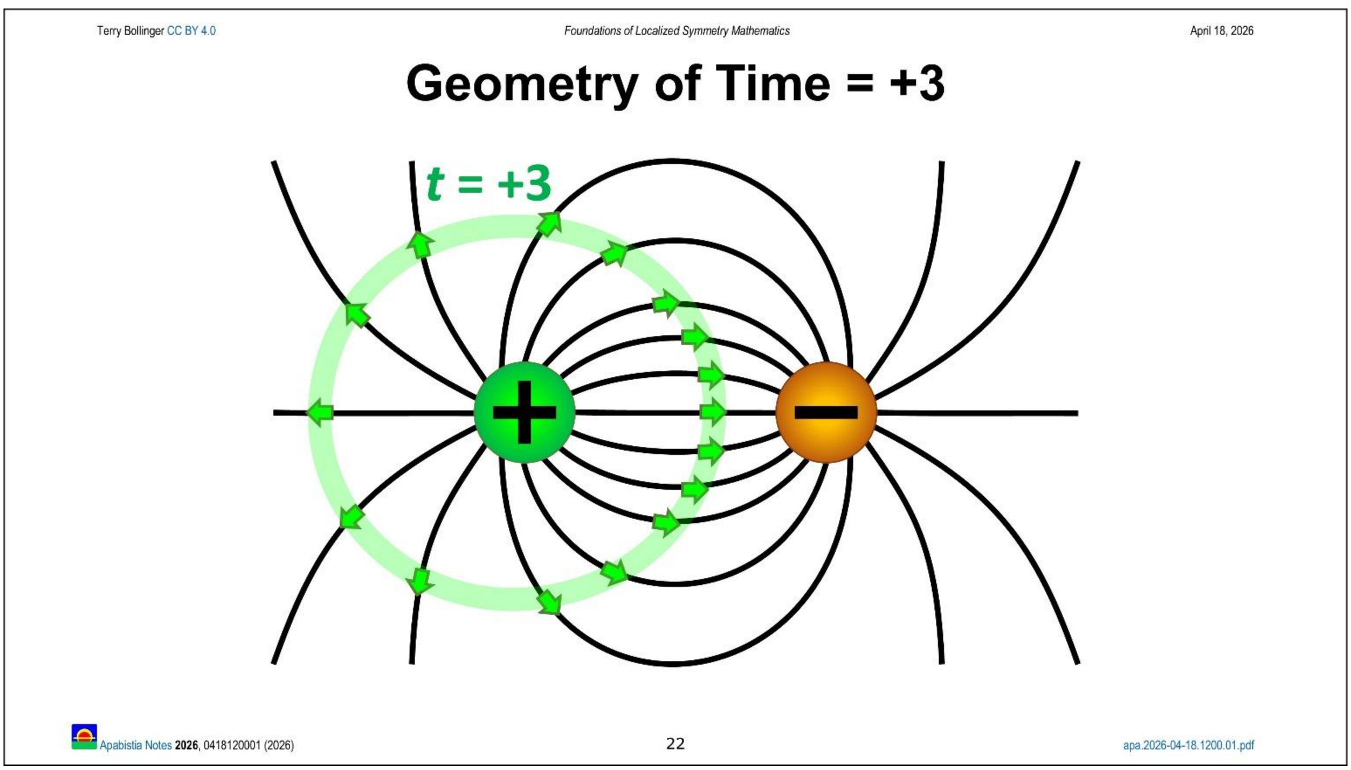


39:27 TB: Remember how I mentioned that Maxwell really viewed these [lines of force] as flows? He viewed them as some kind of flow, a strange flow. It was a flow that had a hidden dimension, essentially a little subspace where everything just suddenly magically went from one spot to the other spot, and started a cycle all over again. And none of this gave off energy; it was all static and still.

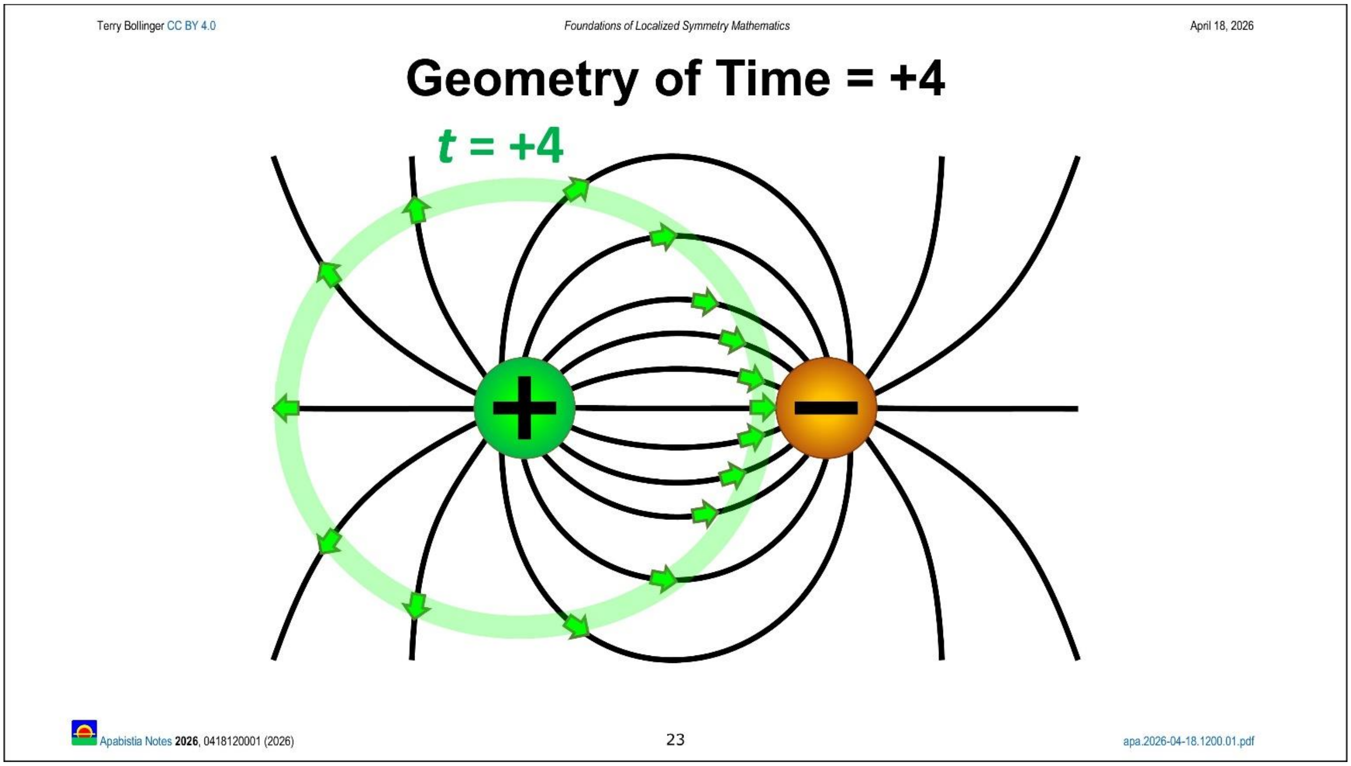
He had that model. He liked that model, and there are reasons why he liked the model. [It allowed him to] interpret [the flows within those] lines as [consisting] essentially of very tiny little chunks of charges of some unitary size. Not a real size; you can't [create chunks of charge that small] in the physical universe. But [in Maxwell's flux model], it does seem like they have little charges, and then they start out on one side [that acts as the source].



40:12 TB: And then they go out a little bit at time equals 2. Again, this is arbitrary, you're just saying this is how it works.

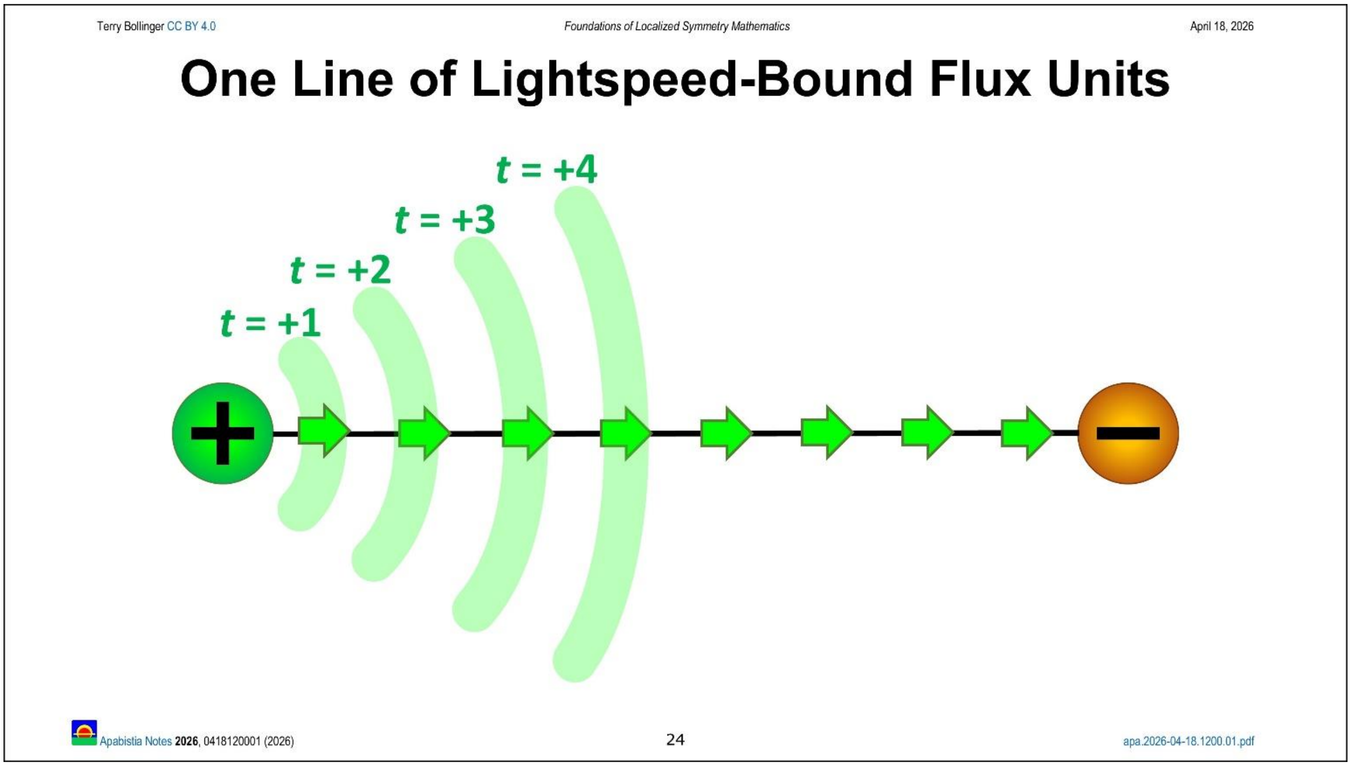


40:18 TB: Time equals 3…

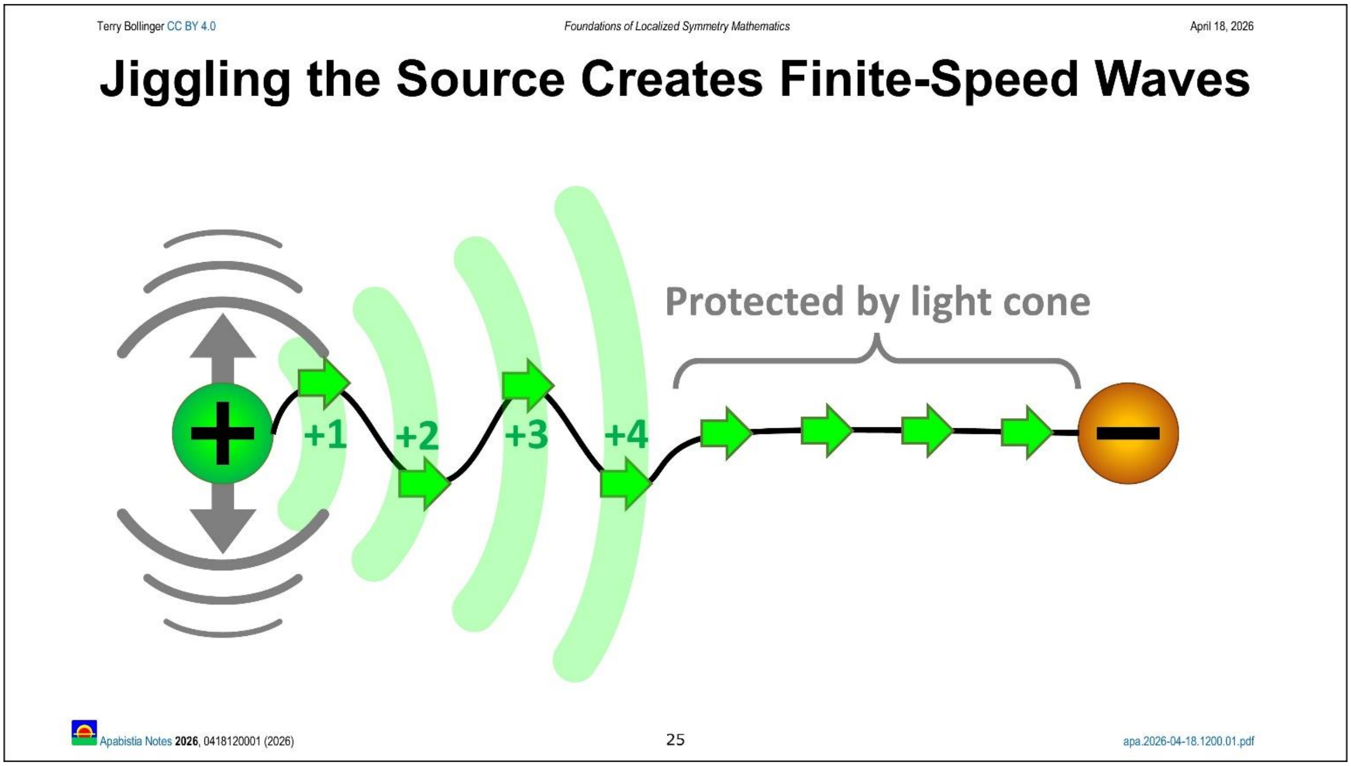


40:23 TB: So you keep going out [at each time interval], until finally [some, but by no means all, of the tiny packets] get to the other side.

So what's the importance of all that? What's the big deal? Well, the deal is this: All of that motion — in terms of understanding how light waves work, how radio waves work — depends on understanding that [the motion of these imaginary packets moving along] field lines are just as bound by the speed of light as anything else in the universe. The speed of light is a really, *really* hard limit, … and it applies to all of these concepts. So you don't just have a symmetric bunch of lines here. If you want to disturb something, if you want to make a change to it, you're suddenly going to hit this influence of the speed of light, [and there result is not at all as symmetric as the lines imply].

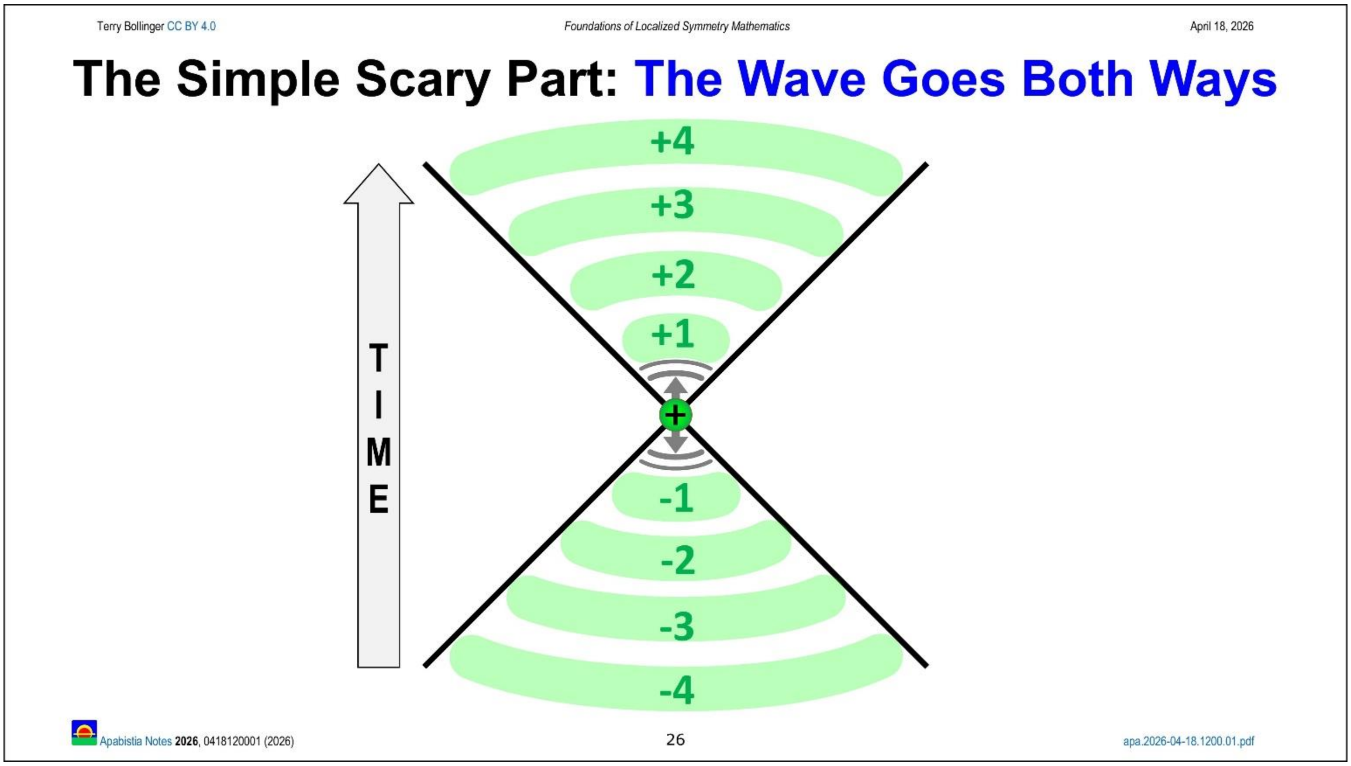


41:12 TB: And what that does is, if you look at one line, say this is one field line going from the positive all the way over to the negative…



41:19 TB: … And you say, well, I'm gonna start *jiggling* that [source]. What happens is you have to respect the speed of light. If you view that field line as a stream of little particles, that are, you know, tooling along, heading towards the drain on the other side, then as you jiggle [the source], you've changed the position at which each of the particles is emitted. So, you plot that out, and what you wind up with is, from a particle viewpoint of interpreting these little lines, you start getting this wavy thing. It's what we think of as a radio wave or a light wave, and it is strictly protected by the speed of light. So, very simple.

Now, are the actual dynamics more complicated? Oh, yeah, because you've got this whole thing I was saying about the cross products, electric field, and magnetic field. So, it's a lot more complicated than just this. But in terms of why you get a wave, this is kind of like the simplest possible case. You say that, "If I start jiggling things that have charge, I will get a wave. One way or the other, I'm going to get a wave." The variety of waves you can get, the kinds of waves you can get, is enormous, but you will get a wave.



42:28 TB: And here's where the problem is! I kept looking and saying, there's got to be some complicated way of [explaining the problem]. People worked [on this problem] for decades, and they figured out that [some fairly complicated math for describing the waves, so the problem must be complicated, right?]

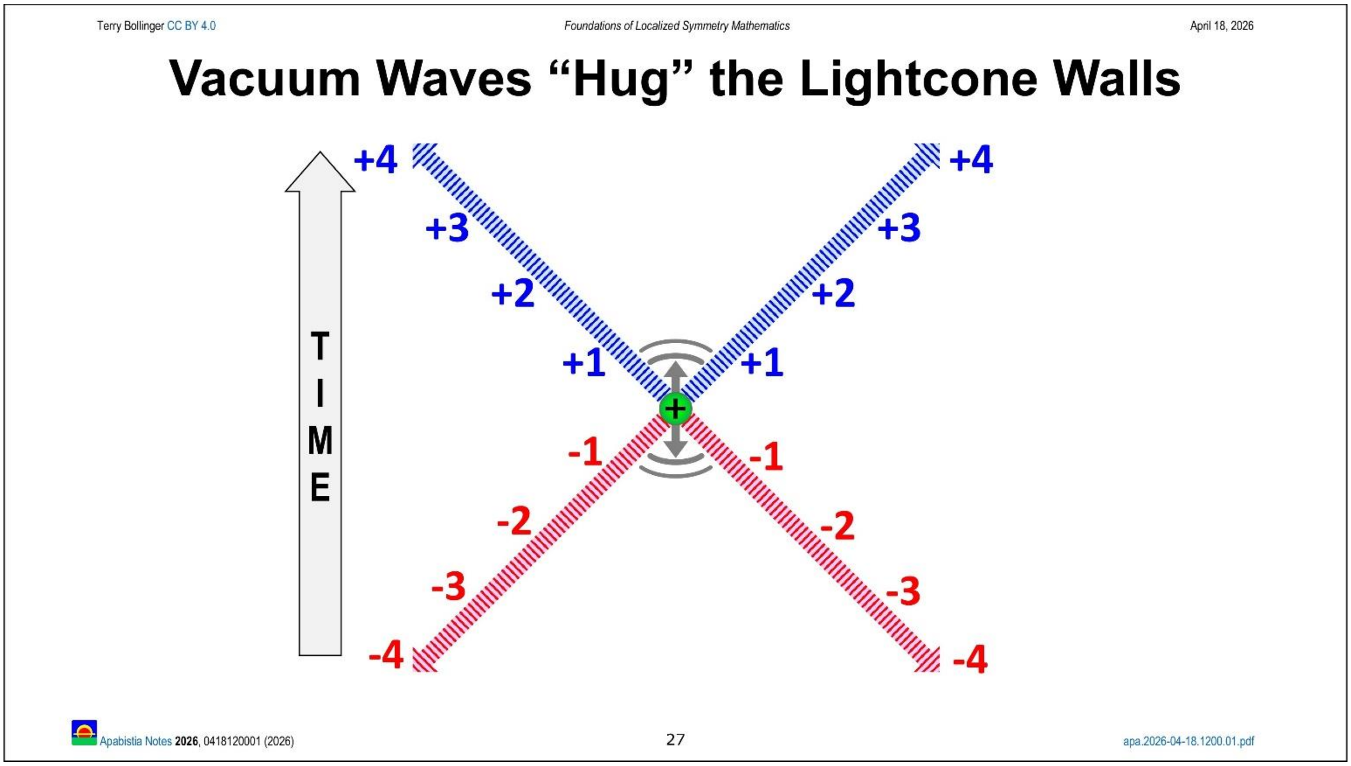
[But] no, it's none of that. [The problem is] that if you put a negative sign [on time] in Maxwell's equation, you still get a wave. So, if you put negative time, you [still] get a wave. It's as simple as that. The equations are not that complicated, so the problem is that if you use Maxwell's equations as they're written — and they seem to be very, very good, so nobody can think of a good reason not to — then you wind up waves going in *both* directions [in time]. They go forward in time, and they go backward in time.

The reflex response, for most people, for a number of people — I think Tetrode was one of them, I love that name, Tetrode — [was for] a number of people, to just say, "Well… fields don't *work* that way." They just arbitrarily say, "Fields don't work that way, they can't go backwards in time." And that was kind of the default position, for many people for many decades.

But again, it's not what the equations actually *say*. And what they say has a simplicity. Whenever an equation gets very, very simple, you want to be careful about ignoring the implications, because when the simpler it gets, the more likely it is it's trying to tell you something, and you may not be listening because it's a bit counterintuitive.

This is a good example of that. This is the part they probably didn't teach you in your electrodynamics course, which is that, "Oh, by the way, this all goes *backward* in time, also!" [They don't teach that] because you'd go, "No, it *doesn't*. I'm making a radio, and I'm *not* worried about my radio wave going backwards in time!" That's a very pragmatic way of interpreting it: Sayin, "Well, that *can't* be right, because time doesn't *work* that way, and electromagnetics don't *work* that way. But if you start looking at a level of particle physics, wow, you have to start being a *lot* more careful, because we can say that at the universal level [of shared causal time], we don't see this… or we *think* we don't see it.

That's a good point: We think we *don't* see [electromagnetic waves traveling backward in time at the level of shared causal time]. But in fact, if you go in the deeper level [of quantum physics], you start seeing stuff like this.



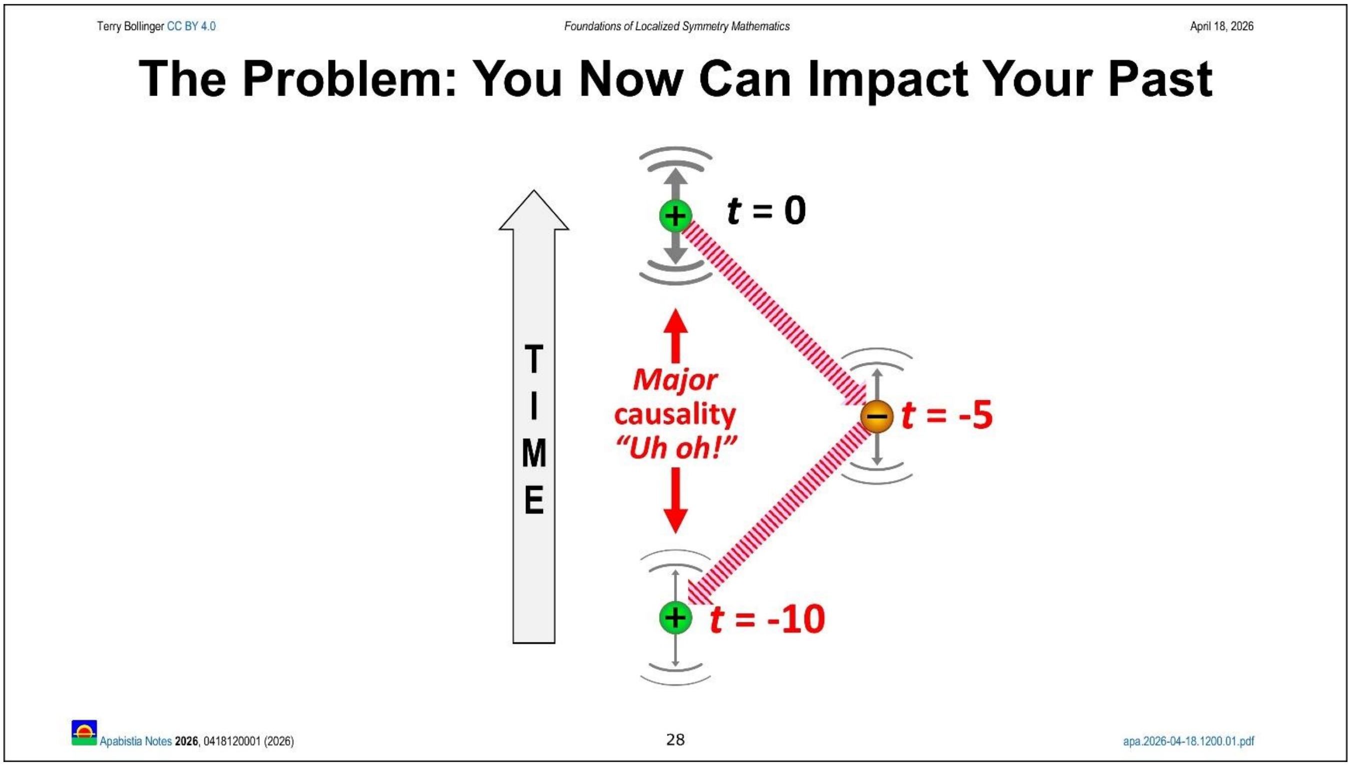
44:50 TB: While we're talking about electromagnetic waves, [I should note that] they're wall huggers. Not *face*-huggers, *wall*-huggers! They hug the wall of the light cone.

So, the blue there is the *forward* light cone. This is where you're going *forward* in time. And if you're electromagnetic and you're in a vacuum, you're going to go either this way or that way. In fact, you just go in a sphere that radiates outwards. [This diagram is] obviously just a very small subset of that [expansion over time].

So, if you do this wigging here, up and down, you're gonna get waves going out this [forward direction] in time, and [also] that way [backward] in time.

By the way, … if you're not in a vacuum, this this line [of light wave propagation] can get much more vertical. Optically dense material will slow it down, so you'll be more inside the light cone. Some of the fascinating work in actually stopping light will put it in this central part here. That [work on stopping light is,] to me, [some of] the most interesting [laboratory physics] work of the past 20 years. It's where folks have actually stopped the speed of light completely, and essentially frozen it in a medium, and then let it start moving again.

In a vacuum, though, these waves will radiate out from your location at the speed of light. And *also*, according to Maxwell's equations, they go *backward* [in time]. And, [seriously,] what do you do with *that?*



46:13 TB: Now, this [figure] is getting closer to actually representing what Wheeler was pointing out. Wheeler … said, "Well, you know… if I go backwards in time with one of these waves, and I hit another charge, then *that* charge is going to start wiggling. Not as strongly, granted, but it's going to start wiggling. And then, when it does that, it is *also* going to emit waves. And guess what? [While these new] waves also go forward in time — which I have not shown, because that's not the point of this [slide] — [the new wiggle] also [sends waves] backward in time, in the opposite direction [back toward the original emitter].

So, what happens is you find this thing that I mentioned earlier. If you take what's called the advanced solutions to Maxwell's equation, which just means backwards in time, … you wind up saying that, one way or the other, [I'm going to have an impact back at the original sender, only *earlier* in time!] It may not be a big effect, but I am going to bounce off of [that charge] mirror [in the past], and I'm going to wind up here, [even farther in the past, back at the origination point of the wave].

And by the way, this [reflecting] charge [in the past] could be a literal mirror, not just a figurative mirror. A literal mirror is, in fact, a bunch of X-ray-level-energy electrons in Fermi space. They jiggle, and when they jiggle, they send [new waves both] back [and forward in time]. So this is not just necessarily a figurative mirror, this could be a literal mirror.

So, [this figure is] saying that if you have a mirror, and I do an experiment here, and that mirror was still sitting there, you know, … 5 nanoseconds earlier, then this advanced wave is going to reflect off that mirror and head back to *me*… to *me!*... [at the source,] back at … minus 10 nanoseconds.

(Chuckle) How much do I have to *say* to emphasize that that could be a *problem* with causality?

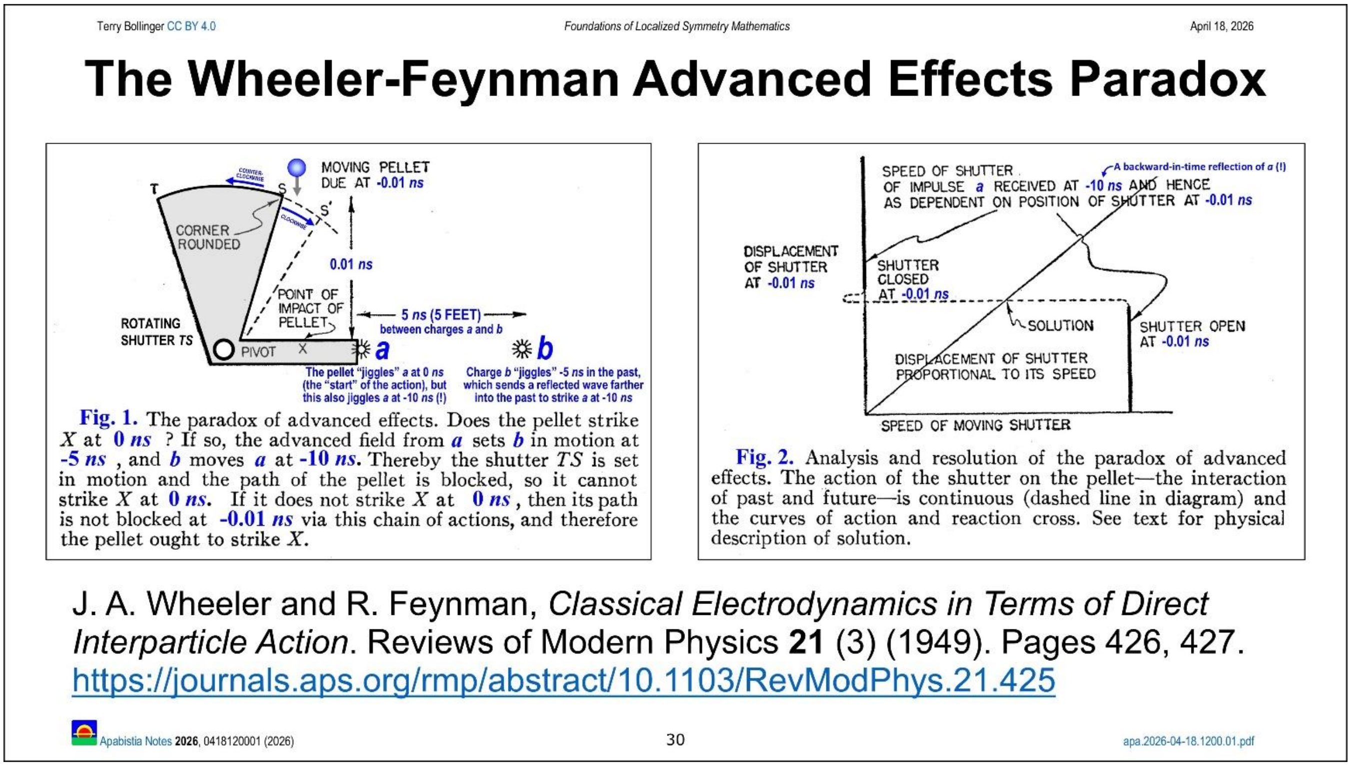
We see all these time … these time-traveling science fiction stories. And, maybe, this is a missed opportunity. Nobody ever talks about the time contradiction in *light* — in ordinary, everyday light, in electromagnetic radiation! And the fact that, when you [create] a radio wave, in some sense, it should go backwards in time.

Frequency, I think, was a movie maybe that did kind of explore that, because they use Aurora Borealis effects to kind of go backwards in time and let people talk to the past. So that's the nearest I can come to a movie that may have actually explored this issue.

But is it a real physics issue? Oh, *yeah*.

Yeah… and so much so that it has given field theory people fits for years… for *decades*… because, if they get rid of the advanced wave, you'll lose that *recoil* effect I mentioned earlier. You cannot reproduce what we actually see if you get rid of the ability to send momentum back to the earlier point in time.

49:13 TB: So, Wheeler looked at this and said, "Well… what can we *do* with this?"



49:18 TB: And now we get back to the figure I started out with. Wheeler came up with this clever [thought problem]. I would still like, at some point, to go over this [figure] even more carefully, and see if I could come up with a version of this figure that better captures the later work by Feynman about Lagrangians, because I think… I know… there's a [better] way to [show] this.

But at this point, [Wheeler] was just emphasizing the paradox. And the idea is that this is that *same* wave that I just showed [in the previous slide], going backwards in time. [The backward-in-time wave] hits here, [at *a* in Fig. 1].

So you've got 5 feet [separation], [and] 5 nanoseconds [separation]. You get this bouncing. So *a* sends off a wave, it goes over here to *b*, then the *b* sends it back to *a* — which does not show up well in this diagram at all — and it *jiggles* this lever! It jiggles this lever, so [the entire rotating device] pivots down a little bit…

And it blocks the falling of this pellet!

So you have this kind of clumsy, but still also clever, point that Wheeler is making, [which is this:] "You can make a physical — an actual device — in which the advanced wave, the wave that goes backwards in time and will have an actual physical effect on the system."

And then he goes into analysis. And again, this is one where I think there's a better [explanation of some sort for what is going on] here, but [Wheeler's] way of dealing this was essentially saying that there's a combination of attenuation — your [backward-in-time] effect is attenuated — and [that it is] a *continuous* issue. It's never *just* a fully discrete issue. It's something where you have this slow motion, and the motion has some finite level in the speed at which it progresses.

[Wheeler's] point was that what happens, instead [of a discrete pellet blocking event, what] you get is a negotiation. So you get a point where, for instance, the pellet nudges against the rounded corner, but it's not *completely* stopped. And the two kind of work together until they finally say, "Yeah, okay… you want it *this* way, I want it *that* way, so we're gonna *compromise*. I'm [the pellet and I'm] still gonna hit the pivot, we're still gonna [initiate the jiggle], but you did get to bump me a little bit. You did get to change [the details of what I did, in a detectable fashion.]"

Think about that!

What Wheeler was saying here is that, "Yeah… you can't *split* time into two parts. You can't [create a] time paradox with this. But you *can* affect the past… and you *will* affect the past… and you *have* to affect the past!"

So, [Wheeler's argument is] saying that not only are the advanced waves *real*, [but it is] actually part of the physics that we see with that *recoil*.

That is, when we have that recoil, we're actually [seeing the results of the wave that is] going back in time, taking something from the future, and applying it at this earlier point.

So, [Wheeler's point is] just an absolutely fascinating argument. Again, I wish this figure had been better publicized, but I think QED kind of took over later, and people kind of forgot this idea, and that these aren't just mathematical abstractions. These are actual physical effects [across time] that we can measure using [laboratory] devices, and they converge to a *single* solution.

So, one way to think of it personally is that it's like there's another dimension of time that we don't see. That is the *resolution* time. You can see this [idea in computer gaming], and gaming people can understand this concept quite easily, [since they live in a time flow that is independent of the one inside of the game].

[Looking back at the figure,] there's the point in which the pellet's falling, [and] the pellet's hitting [both the rounded edge and the plate at point X]. Everything is a negotiation. The advanced [backward-in-time] wave and the [forward-in-time] wave… negotiate with each other until they come out and say, "There's a single solution that will work for both of us!" And *then,* that becomes the actual, physical reality.

Now, I must put in a comment immediately. Notice how different that is from the [Everett] multi-world situation. The multi-world solution, which Feynman did *not* accept — Feynman, in fact, was the one who criticized [Everett's universal quantum wave, saying, "Well, you're going to *split the universe* into a gazillion pieces if you do that!"

So, Feynman did not go along with that. Feynman's idea [in] Feynman's later work is that one way or the other, you work all these different possibilities together, and you wind up with a *single* outcome — a singular definition of what's going on. So, that is a very different perspective from the many-worlds perspective.

However, I would also [point out] this: Which is *weirder*? Okay, you can have *multiple* universes. Fine, so you have universes all over the place. There's a little *mass and gravity* problem with that, by the way. But, is it any *less* weird, the idea that an event literally billions of years in the future could affect your measuring device in a lab *now*?

I think that's *pretty weird!* So, it doesn't mean that you're changing history. And again, this is a negotiation. It's saying, like, you know, some particle a billion years in the future is saying, like, "Oh, *all right*… you know, let's come to a *conclusion* here. Let's do it *this* way!"

This [Wheeler vision of how electromagnetics works] is just fascinating work, in a way that's very different from many-worlds. I'm not a many-worlds fan! In fact, … I've seen people propose that Everett meant it is a little bit of a joke. And I actually think he may have, because he *never* supported his own theory after he came out with it. He actually *hid* from it. So, something weird was going on with that.

But this [idea of the future impacting now] is a different and a much more experimentally verifiable version of what's going on [at the deeper levels of reality]. So, it has implications for other parts of physics.

Terry Bollinger CC BY 4.0 *Foundations of Localized Symmetry Mathematics* April 18, 2026

Wheeler's Intent

- Wheeler and Feynman's conclusions:
  - The impacts of advanced waves on the past **are real**
  - *However…*
  - Attenuation and continuity of action combine to keep these real impacts from splitting the outcome into multiple histories
  - The result is more like a "negotiation" of how much the wave from the future is permitted to impact the past
- These joint papers inspired Feynman's later work
  - Feynman's Lagrangian (variational) method — his "integral of all histories" — captured the negotiation process more precisely

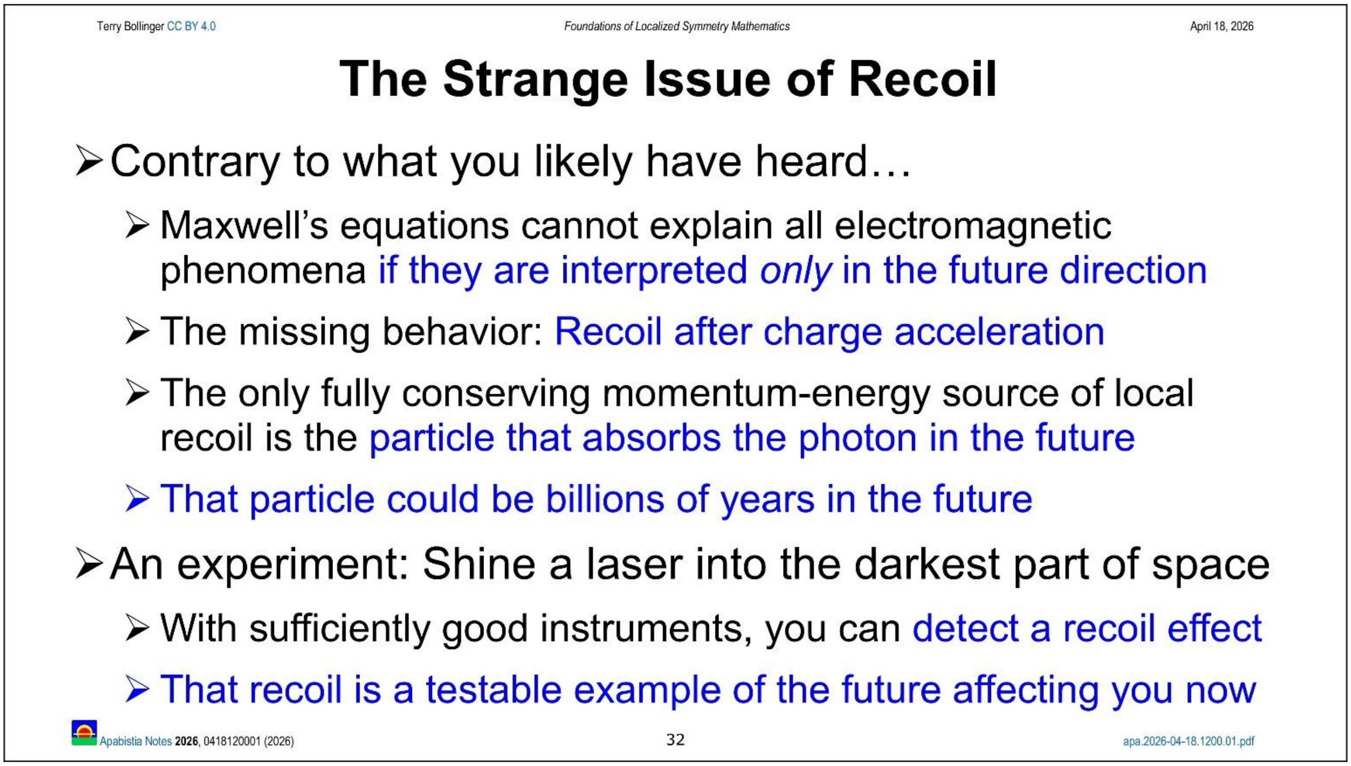
55:10 TB: So, [Wheeler and Feynman's] conclusions [were that] advanced ways are real. That you really do have [to acknowledge them.] This is where they went with this. [Waves from the future] affect what's going on [now].

But the combination of the continuity of the action — the fact that there's no such thing as a truly discrete event — and the fact that things always attenuate — [allows resolution down to a *single* reality.] Feynman got *very* specific on how this attenuation works, later on with his QED theory. It's his whole variational model. It's just *beautiful*, the integral of all [possible] histories, [which converts these time-spanning negotiations into specific, quantifiable contributions to a final probability wave function]. So, Feynman went on to get a much more mathematically precise version of how this negotiation works.

But it's still just fascinating, the idea that there's this connection between what could happen… what will happen… and what's going on right now. … If you take just take that at face value, [it means] our definition of "now" is a lot more nebulous than we think it is.

[That's] because what I do right *now*, especially if I'm measuring a quantum event, actually has pieces and fragments from some history that has not *happened* yet in my time frame.

This is not predestination, either. This is something a lot more complicated than predestination, because it's interactive. And it's not saying that the future determines what's going on now, it's saying that when I try to make a determination [of what will happen], I have to take the *future* into account. [When you wonder about the possible sources of quantum uncertainty, the idea that outcomes observed now may depend on events that have not yet become observable in your time frame is worth taking into account.]



56:46 TB: Now, recoil is the issue.

That's the one I want to point out. It's very simple, such a simple idea: That if you … turn on a laser, [and] you have [sufficiently] good equipment, you can measure a recoil after [turning it on, that recoil depends on the future].

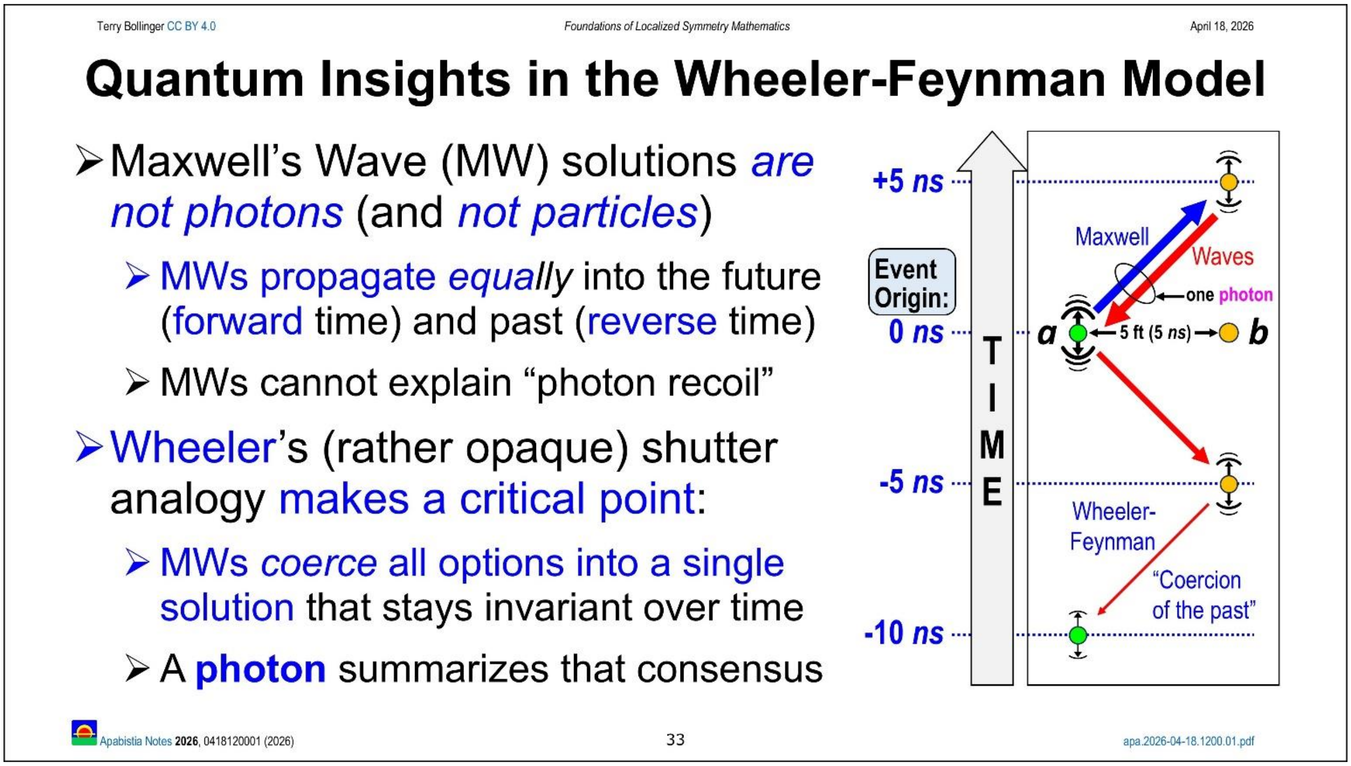
And incidentally, the models for [how that recoil works] are a little bit fuzzy, I think not accidentally. … I think part of the reason is because there is this connection to the future. It makes [modeling the recoil] a little tricky. … But [when] you turn on the laser, you get a little bit of recoil, and that recoil is coming from some very distant point of universe in both space and time.

And, yet, that's the only way you can explain it with Maxwell's equations.

So, strange… strange. I always [this thought] experiment: If I shine a laser [into outer space] — if I find the darkest spot, the darkest hole in the universe — and I shine a powerful laser out there, I would still get the exact same recoil effect that I [get by shining onto a target here on Earth]?

[For the case of shining the laser into the darkest spot in the universe], that recoil is coming from something that is so far in the future that we don't even have the mathematical models to understand what it looks like. We have no idea what matter [is like then], what organization matter [follow]. Will everything be black holes by then? If it's all black holes, how does this [recoil from the future idea] work? There are a lot of interesting philosophical questions, and actual physics questions, about how that works.

So, can you find a spot in space that is so dark that you actually don't get a recoil effect? Remember, there's a little bit of fussiness on this recoil. [There are] some *very* interesting issues involved with such a simple, *simple* concept.



58:38 TB: And Feynman and Wheeler *certainly* explored that [strangeness hidden in that simple concept of recoil]!

Now, the thing I want to point out — and now I'm getting back to [how all of this is], for me, an example of *sparse information physics* and of *bottom-up spacetime physics* — which, again, are two concepts that I have strongly [advocated in the past as providing a more experimentally compliant model of how reality works]. I've got plenty of past presentations [on those topics], so there's no point in rehashing some of that. But the idea is that the universe has a *finite amount of information*, and simply doesn't have enough *resolution* to go beyond the [level of] detail [seen in quantum mechanics]. You are limited by mass and energy, just like you are limited in how much storage you have in your computer. So, [in the sparse information view,] a lot of quantum mechanics comes *not* from *fuzzing* things, but from the fact that [*the detail*] *just is not there*. You have to *construct* it — you have to *construct* the details.

So, [getting back to] Maxwell's waves, [they] were never quantized [since] Maxwell was pre-quantum theory. But he had these waves going *backward* and *forward* [in time]. And what *quantum* theory gave us is a new insight that we didn't have before, [which is] that there is a way in which these waves can become *extremely tightly paired*. We call that pairing a *photon*.

The pairing is that you have a *forward wave* that's going, as we would normally think of it, [as forward through time], and you have the *backward wave* — the advanced wave — that's [going] backward [in time]. And the two, sometimes — and actually, it's very *rare* — *sometimes*, the two can kind of do a *collapse*. They just kind of go, *"shhhhluup!"*, and they just *lock together*. And *when* they lock together, you have a *photon*. The locking operation *ties* that photon — that two-way interaction between two *very* specific particle [potentials] out of a *universe* of possibilities — [into a single classical, experimentally measurable reality].

So, think about that! How *many* possibilities are there for a photon going out into deep space? The quantum probability you can calculate [for the number of possible photon paths] is absolutely *enormous*. That photon could go *anywhere* in the universe! *And yet*, at some point, it undergoes a collapse effect — and suddenly, the two possibilities *shrink together*, *wrap around each other*, and become a *specific* transfer of momentum [and] a *specific* transfer of energy that is *quantized*. You *don't* lose the energy. You *don't* lose [the momentum]. The *whole wave* becomes something where you have this [measurable and quantum-number-conserving] double [transfer] effect.

Now, what I would argue is — and again, this is a hypothesis, but one I would strongly [defend] — is that if we want to understand how quantum uncertainty works, we need to focus more on *just this problem* — this idea of how these wave structures — these combinations of Maxwell waves going *forward* [and] Maxwell waves going *backward* — [combine]. There are other variants of this [pairing-in-time idea] with other forces, but [the electromagnetic ones] are the *most* experimentally tractable.

At some point, [the interaction of forward and backward waves] seems to create a *house of cards*. [Then] some kind of event — and we don't know *what*; everybody says that: "We don't *know* exactly *why* the photon goes *there*" — [causes the house of cards to collapse into a vastly more compact state].

But this at least gives a *framework* for talking about how [this collapse of a forward-and-backward house of cards] happens: You have these two-way frameworks, and then, *at some point*, *especially* when you push [the system into] a paradox, [it collapses]. I think, somehow, that's a *key idea* there. When Wheeler *pushes* the paradox and says, "I'm going to make it so that we'll *force* it to either go *one way* or the *other*, that sort of instability — if you think about it, it is almost a *necessity* — *has* to trigger a collapse event in which suddenly it becomes *specific*. It *no longer* has the option for [treating] one way or the other [as equal possibilities].

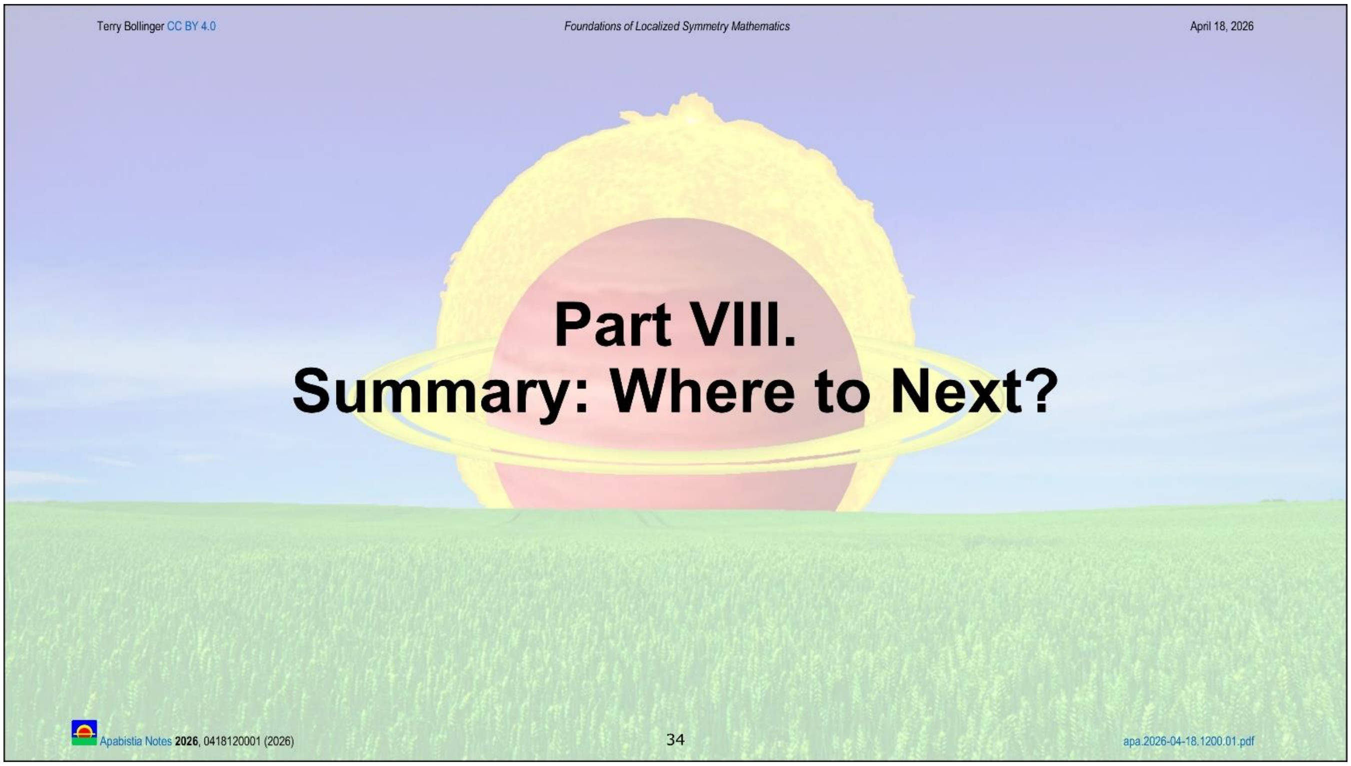
So, the idea of *creating a paradox* seems to be part of this issue about how the two waves — the forward and the backward waves from the Maxwell wave equations — suddenly turn into an actual [classical] event with *very specific* momentum and energy transfers. The creation of a paradox seems to be part of it. If you *force* it into a direction in which it *has* to make *one* decision or *another* — then at that point, it also causes this [volumetrically] *immense* collapse.

There's a concept here of a *different kind* of time. If you think of being in a [video game] — gamers know this — you can have your *own* time [in which] you're watching what's going on in the game. This would work in somewhat in that fashion. You have this idea that in that [in this] *broader*, [more encompassing] time, all of this can just suddenly go *whoosheet!* — and you wind up getting this photon.

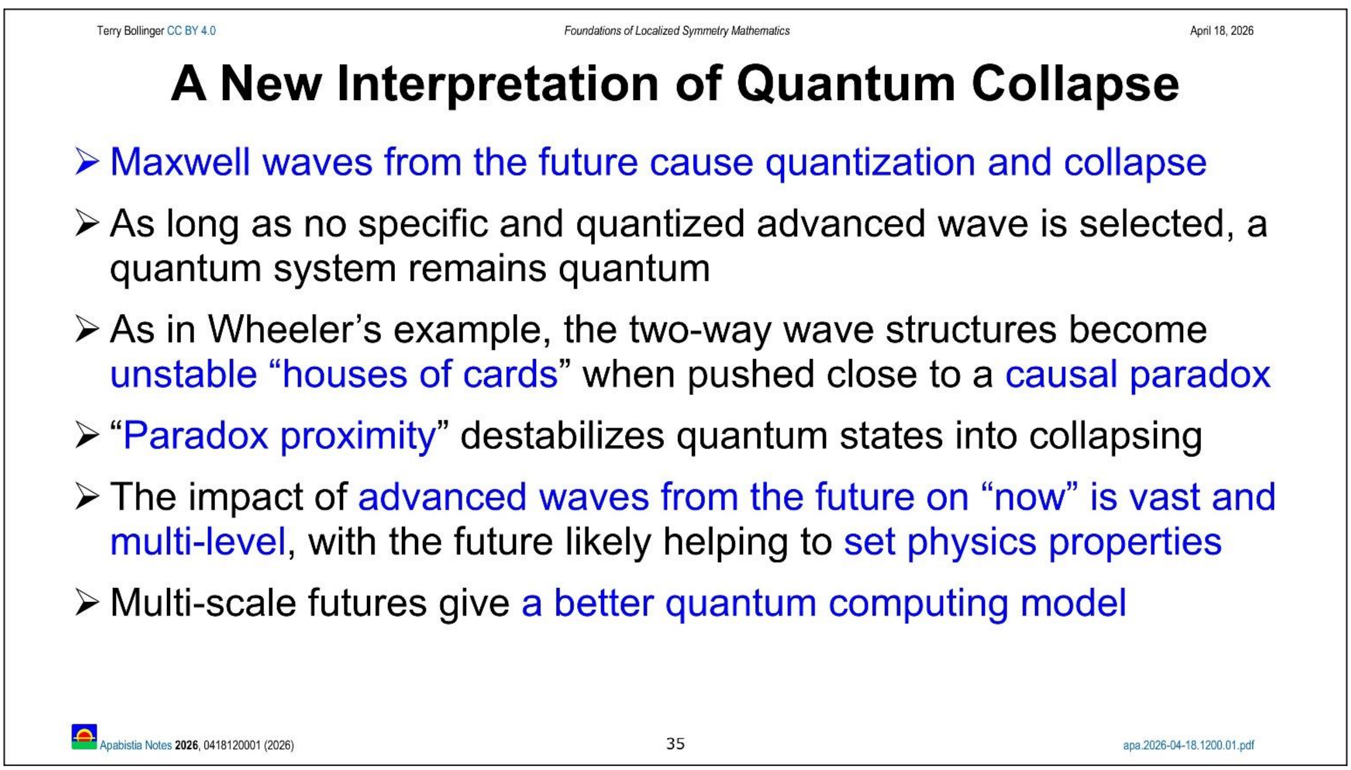
This means that a photon is *not* a particle! And, apologies to Einstein, [since] Einstein said that, "The fact that photons can be quantized on *emission* and quantized on *reception* means they *must* be a particle with a *specific* path in between." [But] that is just *not* what we *see*; it just *isn't*. We have *all sorts* of *complicated models* that *try* to say, "Well, there's a particle is *there*, and there's a wave *around* it." You [can] get *very* complicated. But *observationally*, what we see is kind of a *collapsing* event in which these different wave models suddenly *come together*.

And I think that is a *deeper* aspect of what it is to *be* a photon, because the path in between those two spots can be *unbelievably* complicated, large, time-consuming, whatever attribute you want to put to it. The *result* is tied down at two ends. But the in-between? You don't really *need*, necessarily, to make [the in-between states] all extremely precise and particle-like. You can [*try*], but the chances are [excellent] that you're going to wind up complicating the model instead of simplifying it.

So, I would suggest that photons are actually *extremely* interesting — and *rare*, statistically speaking — collapse events that happen with [the] combining of Maxwell waves for forward and advanced [(backward)].



1:04:56 TB: So, where to next? …



1:05:01 TB: Again, part of what I'm doing today is giving a little insight into some of the things that I've been working on. [What is important are the] same things I was just [talking about:] There's a *quantization* [of present-future interactions] — not a paradox, but a *quantization* effect — and [within that,] I think [lives the best hope for finding] the math that we need to understand *how* quantization happens… and, *possibly,* have some *better way of controlling* it, [at least] a little bit.

I *don't* think [controlling] quantum quantization is a completely "verboten" territory. I think there *is* some possibility of that [kind of control, even if only in limited cases]. The example I gave earlier, where you shine the laser into the *darkest part* of the universe, [is one example.] [The question to ask is whether that kind of experimental setup] affects the photon wave function going in both directions — the waves in both directions? It probably *does*. Is there a way that we could actually *do* that [in a more controlled fashion]? It's hard to say.

But if there is some kind of an effect, this at least gives a *framework* for modeling these [paired forward-and-backward Maxwell-wave] "houses of cards," and then talking about how they *resolve* when you try to force a paradox on them. And again, forcing the [experiment to generate what looks like a] paradox certainly seems to *impact* that [resolution process, possibly triggering it].

This [Wheeler-Feynman interaction across time] is a more *complicated* view of the universe. It just *is*. And I think it's coming directly out of a lot of the work that [Wheeler and Feynman did back in the 1940s.] I mean, the only thing I'm really adding here is just the assertion that the photon events are *rare*… and [even] that's kind of like stating the obvious: They *are* rare, [since each photon] could have gone in [almost *infinitely*] *many* different ways, but when [specific emission-and-absorption events] do [occur], they produce what Wheeler and Feynman were talking about in this paper: a *very specific* action. Suddenly, it quantizes, and… *Chunk!* You get this *resolution* that matches *all* the conservation properties that are required, [and] does *not* create new universes, [as Everett so casually and, frankly, naively assumed in his physics-obvious model of reality]. I don't know how a local event would do that *anyway*, because there are speed-of-light constraints [on such things]. But it *captures* all those [fundamental conservation constraints that Everett simply ignored, did not realize, or was secretly tongue-in-cheek about…]

("Speed of light," by the way, gets *very interesting* when you have speed-of-light *going backward!* [Chuckle.] When you have the "speed-of-light" *coming in from the future*, I think it's kind of amusing what you mean by "speed-of-light." "The speed-of-light is *very strict*, but it can go in *both directions!"* So, how's *that* for a strange concept?)

So, what we are now, and how things work, is *somehow related* to things that have not happened… yet! But it's not *predetermined* by things that have not happened, yet. So, this is an interplay; this is a calculation. And it's also why I would make a final comment that if we want a *better quantum computing model*, I think we need to pay *more attention* to these levels of interaction. And I would specifically say that the forward-and-advanced wave model of the Maxwell equations, *quantized* — and understanding *how* they quantize — could probably be something to help us get a better quantum computing model.

The [Everett-inspired] Deutsch model of multi-worlds is very *tempting* [and] very *attractive* [because] it phrases all the computation just in terms of just *multiple universes* [performing the computations in parallel]. I mean, back in that period, I just *loved* that model; I used to really *like* that model. I thought that was a great model *until it didn't work as well as it was supposed to*. Then, I started getting more skeptical about it, because…

…They even said *back then*, "Well, you know, we'll *find out soon* if this works!" — and that *didn't happen*. What happened *instead* was everybody started making *excuses*: "*Well*… the problem is… the *noise*!" It was *sad*, because, at first, people were *very emphatic* that [the Deutsch model] would either *prove to be true* or it *wouldn't be true* — that [just a few small experiments] would [either] prove [or disprove] the many-worlds model. [Since then, instead of reaching a decisive conclusion,] we've dangled along with that model for a long time.

So: Let's go to a *different*, radical, weird model! Let's go to the idea that quantum computing depends on *future events*, because we have some *actual experimental proof* of *that!* Even things as simple as [photon] recoil tell us that — and, [remarkably,] we *still* don't have [even] that fully tied down. There's probably a connection there. The more we understand that, the better we will be able to understand how [all of] this [works].

One other comment I'll make [has to do with the emergence of physics as we observe it].

When you look [at the Standard Model of particle physics, classical physics, quantum physics, special relativity, and general relativity, you see this fairly compact set of topologies, constants, and rules of interaction that all seem universally predetermined for all of the universe, no matter how far apart in space and time those particles, rules, or events may occur or apply.]

Call this a speculation, but it just is fascinating [to me] that one electron *here* is the same as one electron on the *other side* of the universe. That is [the kind of puzzle] that Wheeler loved. This is exactly the kind of turf that Wheeler would get into. So, [for example], he had his theory for one electron bouncing back-and-forth between the beginning and end of time, [thus becoming the image of every electron and positron in the universe as we see it].

But if the *future* is setting properties *now* and determining things *now*, *maybe* there's *some aspect* of this idea of "interaction with the future" that's also helping to set some of the *most fundamental* properties of our universe *now*. That is, [the physics of the universe *now* may] *may not be independent* of the future. There [may be] constraints in the future that help to say, "Hey, *all* your electrons back here are all going to look the *same*! *You've got no choice!"* [This would happen] because the future is helping to *set* [the physics of electrons] in a fashion that we can't directly see.

So, I think there's some interesting possibilities just on our understanding of how we get these *particular* definitions of [particle and physics-rule] commonalities across the physics.

And with that, I am done.

Questions and Answers from after the presentation:

HM = Helen Ma (Team OrionX)
TB = Terry Bollinger
GZ = George Zipperlen
RS = Rob Schreiner
CC = Carl Chalk
CP = Caetano Peng
JD = Jarek Duda

…

1:10:35 **Helen Ma** (HM): Thank you, Terry. I noticed George [Zipperlen] has a question: "Are the forward and backward motions a way to balance the books and maintain the conservation, laws, charge, mass?"

…

1:11:05 **Terry Bollinger** (TB): Yes. This is [where] Wheeler and Feynman, I think, really surprised themselves with that series of papers, because when they first went into it, said they were both going, "This can't work! We're playing games with causality!" They knew it; they knew it when they were going into it. And yet, the more they went into it, and 1949 paper kind of being the end of Wheeler's definitions of that. He kind of said, "Yeah, there's something *really interesting* going on that is this reconciliation thing." And, and of course, and Wheeler kind of ended that point in that, at least the papers that I've seen, the collaboration with Feynman. But Feynman went on.

And, if you want to look at the variational methods, they are a much less scary way of saying the same thing, but variational methods still say that I have a point here, and I have a point there, and they're way the heck far apart in time, maybe like a billion years apart in time, and they're one unit. So, even though the variational methods kind of hide this dependence on the future, not really. It's still there. And Feynman did it, and took it to the point where he could predict particle properties with exquisite precision.

So, again, this is not just a casual concept, this is something that has experimental backing to it as a method for explaining how things work.

Other questions?

1:12:38 HM: I think Ron [Schreiner] has a question.

1:12:43 **Ron Schreiner** (RS): Terry, this might sound naive, but this concept of a photon moving in a particular direction, as a wave, with that wave is traveling at the speed of light; but with this *other* wave also going in the *opposite* direction: Does that provide a basis for the wave going *forward* defining the speed of light as an absolute? And does the wave [going *backward*] define an "absolute zero" speed?

1:13:22 TB: The answer [for that excellent question lies somewhere] in [the] interplay between the backward speed of light — because it *is* the speed of light; it follows Maxwell's equation, so the advanced wave *is* a speed of light phenomenon, *but in the wrong direction* — and [the forward speed of light].

I'll be honest: I can't *wrap my mind* around exactly what the full set of implications of that are. But I think it's something that should be explored in some *new ways*, with more of an emphasis on its effect, for instance, on *quantization*. I put [forward in my slides today] the hypothesis that this [interplay of forward and backward Maxwell waves] is the basis for *quantization*. I think we need to look at that [idea] more carefully.

One reason why I think that's an intriguing area has to do with *why* the overall space is unstable. I think this is a *precarious* situation for these particles — [for] these waves in both directions — because, *one way or the other*, if they're *pushed*, they have to come to some *conclusion*.

I'll mention another idea that I've talked about many times in other [presentations, which is the nature of an "observer"]. People talk about "observation" as being a *cryptic* thing that requires — (chuckle) Wheeler was one of them — a *universal observer*, and stuff like that. And, if you have followed some of what I've said on this, I am as *opposite* of that [view] as you can imagine.

I would make the assertion, instead, that observation is *nothing more than momentum exchange*. Nothing more! It's *not* some mysterious force. When two particles *exchange momentum*, they [each] *know* where the other particle is. That's *observation*. It just *is*. When you [form] a hydrogen atom [by putting an electron] next to a proton, they have a force of attraction that *constantly* accelerates them around each other. And acceleration is *bumping*, is *momentum exchange* — and remember, in my book, that's *observation*.

So think about this: If you put an atom in the middle of deep space, does it quantum delocalize? Yes, it *does*: You [and the rest of the universe] don't know *where* it is. If you leave it out there long enough, it could be in a volume a light year wide, and it's a *quantum* state. It can *reflect*, as a wave, in that quantum state, over an enormous area. It could be *diffracted* through a gravitational lens over that enormous area.

Meanwhile… How are the electron and the proton doing? Are they delocalizing *away* from each other? *No*, they're *not*. Why do they *not* delocalize away from each other? Because they're *constantly observing each other* through momentum [exchanges].

This is *not* a complicated concept! It says that if you exchange momentum — [it says that] *every* time you exchange momentum, [whenever] you say, "I bumped *you*, you bumped *me*; I know where *you* are, you know where *I* am," [you are performing quantum observation.] There's no there's no *high-level entity*; there's no *magic* in this. It's just a *momentum exchange*.

The reason we don't *notice* [all of this quantum observation going on all around us at every level imaginable] is because classical physics is *built* out of this. This is what classical physics *is!* So, the irony is that [I am] essentially asserting that classical physics is the *most quantum* of all physics. [That's] because it is the physics of systems that are constantly *observing* each other at *incredible [levels of] detail*.

I think Boltzmann would have liked that idea, because Boltzmann, of course, thought thermodynamics was the essence of time. Well, *yeah!* Because if *thermodynamics* is observation — is [quantum observation] *constantly* going on at an *incredibly detailed level* to *give* the properties we think of as "ordinary physics" — then, *sure*, there's a *powerful* connection with [the nature of time].

1:17:14 RS: Thanks. I'm just thinking if something is moving away from you, but [it is also] emitting something back at you, it's almost like it's building a *standing wave* that *isn't* moving anymore…

1:17:32 TB: I *like* where you're going with that! Essentially, I'm saying, like, "*Yeah*, this has *got* to be part of this whole [question of how quantization works]."

1:17:40 RS: And, if that's true, it begs the question: Is the universe *full* of these *standing waves* that are *zero speed*? Do they just *decay* over time? Where do they *go*?

1:17:52 TB: I would agree with it, because that is what a photon *is*: A photon, by its own definition, has *zero time*. This is something you see in Feynman's [works]. If you read through Feynman's [works], he always is *adamant* about that point: A *photon interaction* between *this* point and *that* point, to the photon, takes *zero* time. You'll see this in QED, and you'll see it his Lectures. He doesn't *debate* it or anything. He just *accepts* that as a given.

The standing wave you're talking about, I would say, *is* the photon. It's the variational version of the photon. You are creating a *standing wave field*; I think you're on to something with that. It *becomes* what we think of as the "timeless" photon interaction between Part A and Part B, where they suddenly, *without* an elapse of time as far as the photon is concerned, *exchange momentum*. [They] "bump" each other [across time]; [they] "quantum collapse" each other [across time].

So, [as a result of this Lagrangian interaction,] we "become" real… But, *also,* the *future* becomes real! Some *part* of it! Some *tiny little piece* of it! *Not* the whole thing! (chuckle) Everything is *not* wrapped up! It's a *lot* more complicated than that! But it's still so… *interesting*. It's *neither* predestination *nor* free will, but [instead has] some beautiful options [than are not possible if one insists on the either-or distinction of predestination versus free will].

1:19:08 RS: Once again, very thought-provoking. Thank you, Terry.

1:19:12 TB: Thank you for the question! I like the way you phrased that; I hadn't thought of it that way. We have a defined phenomenon, which is known as a zero time [photon interaction]. And, essentially, from the variational [view] — from the Lagrangian viewpoint — it's a standing wave. So… cool!

1:19:30 RS: Thanks again.

1:19:32 HM: There's a question from Carl [Chalk]: "Wouldn't this break rules of special relativity by having information travel faster than speed of light? For example, the photon hitting the planet many years in the future, but it's still negotiated at this present."

1:19:50 TB: What happens is that there's this concept called information, and the information is the part that cannot travel, at least information as we know, faster than the speed of light. So obviously, if you have ordinary waves going forward in time, and advanced waves going backward in time, you're playing games with the idea of light speed limitations. Something in the future is affecting you, *right now*, which I would argue is actually the truth for all of us: We're being affected by issues in the future that we don't know about.

But what you can't do, at least by any mechanism that we can see — and certainly by the physics itself — is the transfer of information. [That's] because classical physics and information are tied very tightly together; you can't separate the two. The ability to create information *is* the ability to create time… is the ability to create *causality*. You can't separate those concepts.

So, if you're talking about sending a signal *backward* in time — a signal that's detectable and measurable, at least by implication — that gets trickier! Although this would be delightful for people to explore in more detail and ask, "What does it mean?" Again, that recoil effect is not fully captured in some of the equations, so there's a little fuzziness about saying, "How, exactly, does that work?" Inside of that fuzziness, there are probably some [very interesting hidden implications] of how this interaction with the future works.

But for conventional, causal information, that's the part that *triggers* these collapses. So, when you do the Wheeler Paradox — when you try to get the little lever to swivel away and block the [falling pellet] — that is creating a situation [that] would be a paradox, and it's *preventing* that [paradox].

So, the necessity of *creating* information essentially locks you out of creating these parallel definitions of what time is [in any experimentally accessible fashion]. The universe seems very conservative about the definition of time! It says, "I only want one time! I'll tolerate little variations on it for a while. But in the end, once you create the information, it's *locked*. That's my bottom line. I won't let you get out of that!" So, I think there are fascinating issues [involved in all of this], and again, I would promote these kinds of [experiments] as a way of exploring [the deeper nature of time and causality].

[On the other hand], is there a way to transfer something [back through time] that we would consider useful [even if it is] not what we would qualify as Kolmogorov complexity, or [any of the other] the usual definitions of information? That's a trickier question. There could be things involved with this. Quantum computing — the fact that we can do some levels of quantum computing — [that useful processes occur across time]. [Another argument in favor of utility across time is] that biological [systems seem to have] some way of bending probabilities [related to forward and backward waves in time].

I love biological systems. They're always bending probabilities! We call them enzymes, and we treat them as if they're mundane. But [if we tried to build] actual mechanical representations of systems like [enzymes, we] would have a hard time building physical machines [capable of doing] what an enzyme does [at speed high enough to be useful]. Enzymes seem able to do things with the probability that we would find impossible [to make work].

So, I think there are clues in biochemistry that certain configurations [of matter] can make use of "something" [that leverages more complicated, but "not quite information," relationships across time. Call it quantum computation, [if you wish,] but there's some kind of [very interesting and decidedly useful probability-bending] relationship there.

Other questions?

1:23:48 HM: I noticed Dr. [Jarek] Duda keeps posting some links [and a lot of questions]. One of the questions is, "Is a photon a wave carrying energy, momentum and angular momentum, like a wave behind a marine propeller?"

1:24:07 **Jarek Duda** (JD): So, I will talk about this tomorrow. [First,] thank you for that nice talk.

[I think observing advances waves] for electromagnetics is more difficult. I think for gravitational waves, it's much easier to observe advanced waves, so I have asked you, so because the problem is that for electromagnetics, there is a difference between transmitter and receiver. In time symmetry, that they are switched, so we should be careful about here, but LIGO transmitter is length, and length is asymmetric, so you should be, should see both retarded and advanced wipes, if they exist.

So, my point is that maybe already some of events seen by LIGO might be, might be advanced. It has seen only, like, 400 events, and only one had a recommended counterpart. The remaining 30, nearly 400 could be advanced, because we haven't seen electromagnetic counterparts. So there are many arguments that sum of events of LIGO might be already advanced.

So, one is the lack of electronic counterpart, and this is the clearest.

Another argument is that there are some events which seem too early to be retarded. Like, there are some mergers which need more time, so maybe they're not retarded, but maybe they're advanced.

And there is a third time of argument, that there is this, there are these jitter time rises. They see these, these vibrations of the universe, and they say they are caused by supermassive black holes. However, the number is insufficient now.

So again, should we consider only the past supermassive black holes, or maybe also the future, from advanced waves? There are many arguments that JWST may have already seen advanced waves. This is a really difficult question if given event is retarded or advanced. They automatically assume, without any reflections, that they are retarded, but if you ask, they could be advanced, and it's very difficult to distinguish them.

1:26:13 TB: I look forward to your talk tomorrow, and by the way, I would encourage people to go to Jared's talk tomorrow. If you want to dive in deeper in some of the mathematical issues on this, extraordinary mathematician and a good track record for a lot of stuff, so I look forward to your talk tomorrow.

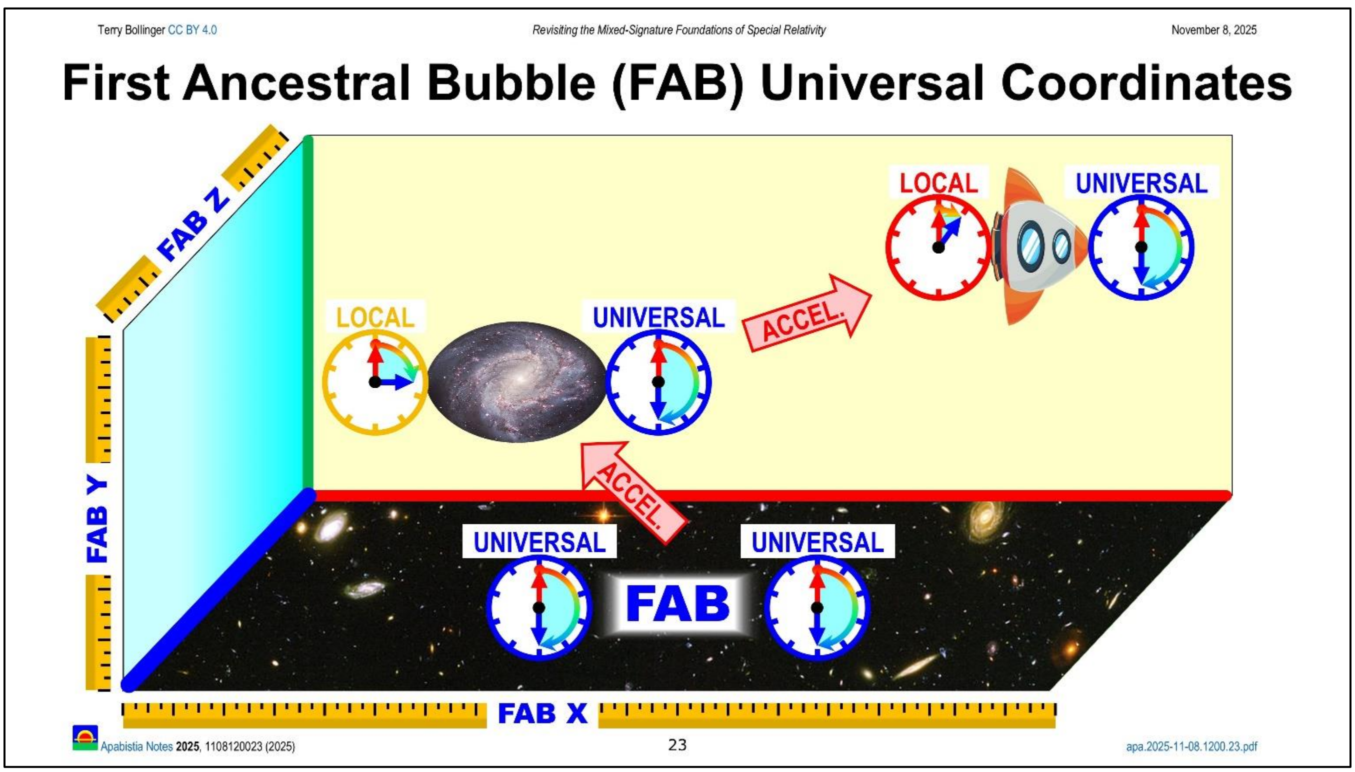
I just think we need to explore the nature of time a lot more deeply, and the wave structure of time, if we put it that way. I think we're missing some possibilities there, so I look forward to your talk.

1:26:46 JD: Thank you.

1:26:48 **Caetano Peng** (CP): Terry, can I ask a question? I have a kind of a *mechanistic* view of the universe. I sometimes think that universe might be a kind of *metamaterial* universe, where what we perceive as *past*, *present*, and *future* might all be *physically* connected. So, what you see as waves going *forward* and *backward* may be just a kind of elastic waves that are reflecting back-and-forth, back-and-forth. The same [idea applies to] what we perceive as time, as well. It says, "Time reversal is just waves, elastic waves." The speed of light itself is an elastic wave of the stuff of the universe itself, not a constant in isolation. It's a property of the universe as a *physical entity*.

1:28:19 TB: *[Note: I added the paragraph below to this transcript to help explain of why I jumped to the seemingly tangential topic of hierarchical, multi-level inertial frames, since the reason for my jump was not clear. For this reply only, all green text was added after the talk and during transcription.]*

[Caetano, although I do not accept any version of an aether — which I believe is what you are describing — your description intrigues me because I think it's topologically equivalent to the "First Ancestral Bubble (FAB) Universal Coordinates" concept on slide 23 of my November 8, 2025 Meetup presentation *Revisiting the Mixed-Signature Foundations of Special Relativity*. The slide is below and at https://sarxiv.org/apa.2025-11-08.1200.23.jpg. The similarity is that the FAB concept requires that the oldest, largest coordinate frame in our universe — which is roughly equivalent to the inertia frame of the Cosmic Microwave Background (CMB) — enables universal use of a set of coordinates that are topologically indistinguishable from the coordinate system of a physical aether located in that same FAB frame. With FAB, assuming a physical aether becomes an unnecessary complication that depends too much on the extremely complex properties of condensed matter physics.]



One of the things [I should mention] — and again, this is somewhat accidental — [is that] originally, this talk was going to be focused more on sparse information and bottom-up inertial frame emergence. [That would have been much more relevant to your question] because there's a [close relationship between bottom-up inertial frame emergence and the concept of a CMB-equivalent, universe-spanning First Ancestral Bubble (FAB) single-frame, Euclidean-like coordinate system.]

[Since I instead ended up focusing on Wheeler-Feynman forward-backward time reconciliation,] I'm going to avoid it! But [hierarchical inertial frame coordinate systems are such a powerful and] *fun* area, especially the idea of *microscopic* domains of spacetime emerging, [since incomplete spacetime instances at the smallest levels of available mass and information are likely the deeper source of forces and the Standard Model of particle physics.]

[Okay, I'm not going to avoid it after all, since your question is very interesting and frame hierarchies are relevant.]

And by the way, [another way] I think [hierarchical inertial frames are] *connected* with [your question is] because when you look at things like quantum field theory, there's a concept of creation of [large volumes of] space [full of virtual, not-quite-real] particles. I think [that when we look at this volume of space filled with not-quite-real virtual particles, *and* recognize that all quantum field theories lock themselves include singular inertia frames — e.g., via the emission and absorption points in a Feynman QED diagram — then] we're seeing into this more amorphous wave structure that you're talking about, [which in that context does have a sparse-matter, sparse-energy, frame-locked interpretation that shares some of the properties of your denser-matter aether idea].

In other words, when you have a well-defined inertial frame, I'm betting that that inertial frame has a very well-developed *structure* of forward and advanced [waves]. [When applied to the largest, most universe-spanning ancestral coordinate system, you get something that has the same topology as an aether while keeping full relativistic invariance. The priority of some frames remains invisible within that frame, and shows up only when you examine the full history and full set of clocks available in the entire universe.]

(I tend to use the word "forward" instead of retarded, just because I [don't like the derogatory implications of that term has for many people. However, its origins are completely innocuous:] It comes from camshaft terminology, [from retarded] and advanced [adjustments of a rotary engine cam shaft].)

I think if you look [carefully], it's hard not to think there's some kind of connection [between the interplay of forward and backward Maxwell waves and how one creates] a well-defined inertial frame, and the [fact that the coordinate systems of] inertial frames can occur at multiple levels.

Don't let anybody tell you that there's only *one* [set of] inertial frame [metrics applicable just] because everybody [in the frame is] moving [differently from anyone else in the universe]. You have *multiple* inertial frame [coordinate systems] applicable to *every* event, and they're *not* isolated. You cannot ignore the other, [larger, more encompassing frames from which a smaller frame emerged historically]. It doesn't work that way! Everything [in a smaller frame] is embedded in [the] causality [of any larger, more encompassing frames].

If you have a train moving at nearly the speed of light, it's *still* observable. Every clock on it, you can set it up so you can measure *exactly* what it is at a moment in *your* time. So, [what] that says is that whatever *their* measurement [system in a smaller frame] is, it is *still* embedded in *your* frame.

So you have these multiple levels of frames. But *within* each of those frames, I think there's a connection that ties [the matter in that frame] with things like quantum field theory, where everybody's in agreement.

The [role of the forward-and-backward Maxwell] wave structures [is that they] are kind of resonating with each other and giving good definitions [of Euclidean coordinate systems at multiple, overlapping scales].

So I think there's [a lot of] interesting stuff going on with [your idea that there should exist a single, universal coordinate system in which all waves behave like phenomena within a single, aether-like medium]. [So] yes, no disagreement about the idea that there's something more complicated going on, and that it involves things that are not at all what we think of as the usual [one-way-only] speed of light.

And yet, that speed of light [rule for all classical physics] is so powerful as a tool for understanding what is going on. So that, too, is a connection: Information ties us to this concept of a speed of light very, *very* powerfully.

1:30:58 CP: Thank you. Thank you, very much.

1:31:02 TB: Other questions?

1:31:04 HM: Yeah, I noticed, George [Zipperlen] posed a question: "Shannon information is about a single transmitter and single receiver. [What about] the Kolmogorov complexity of the whole system? The relationship between [these two definitions of information] is not clear to me."

1:31:23 TB: I like Kolmogorov complexity. When people have questions now about large language models, I reflexively go to Kolmogorov complexity because Kolmogorov complexity says, what is the single *most reduced* form of the information in the total system?

And that is a *very* hard question, because if you saw a string out of the middle of the billionth digits of pi, you would think it's completely random. So you [may] think there shouldn't be a compression, but you have to be very, very careful…

[network dropouts]

1:32:07 TB: The question was about Kolmogorov complexity versus Shannon. Shannon is transmission. Kolmogorov is essentially a measure of the entire complexity of the system in its most reduced form. And the comment I was making earlier is that one of my cautions about large language model systems, AI-based and large language models.

The Kolmogorov complexity of those systems is always pretty much exactly the same as the training data that went into it. So, you can recover whatever you've trained it on, but that's it. Anything beyond that tends to be a random combination — a very convincing random combination, but you don't have any further insights.

Beyond what was actually in the training deal — which is why they talk about scaling them so much, [since] you want to scale them up to a huge size so you have more answers — but you still just wind up reaching a threshold. You still have a finite Kolmogorov complexity of an LLM system. By its nature, that's what it is. It's a carefully factored storage of a huge amount of data. And you can still recover the original data; you can still recover entire books, because that's what's in it.

So occasionally, I'll refer to an LLM as a database, and people take offense at me because I do that. And I was going like, "Why *do* I refer to it [that way]?" And I realized it was because of Kolmogorov complexity.

In physics, I think both of those concepts are important and relevant. The Shannon [definition of information], of course, is more the transmission side. And is there a forward-backward [in time] Shannon definition? Probably there is. There's some kind of thing where you have advanced, [backward-in-time] and forward [in time]waves that are interacting in some fashion, occasionally forming discrete units, like photons: Photons as a collapse, as we talked about earlier.

But I think there's an intriguing set of options for doing that. Kolmogorov complexity: That's got to be a part of this. The definition of an inertial frame is going to have a Kolmogorov complexity.

I love Kolmogorov. He just was amazing, right? If you've never heard of them, or you're not familiar with them, and you're interested in information, look at Kolmogorov's work. It is a very different take from Shannon.

Other questions?

1:34:31 HM: Josh said thank you.

1:34:35 TB: Thank you, [Josh].

1:34:38 HM: And other excellent, excellent thought-provoking presentation. Much thanks, Terry.

1:34:44 TB: Well, thank you a lot, I appreciate it. It's always good to see your [colorful logo]. I love your logo — there's something about that logo I really like. It's colorful in just the right way.

1:34:55 RS: You make my day, Terry, thank you.

1:34:58 TB: Any other questions? Going once… Okay, why don't we give it a wrap here? And thank you, everybody, for participating. It's great, great questions, really enjoyed it, and looking forward to Jared's talk, Mark.

1:35:19 HM: Yes, tomorrow at 10 [AM Eastern Time].

1:35:21 TB: Tomorrow! Everybody, [please] remember tomorrow.

1:35:22 JD: Thanks, thanks.

1:35:25 HM: Yes, and Jordan said, thank you, Terry, great talk.

1:35:29 TB: Thank you, thank you all.

1:35:31 HM: Thank you, and see you tomorrow.

1:35:33 TB: See you guys tomorrow.