

THE PHYSICS OF PARADOX

John Ashmead

Friday, November 19, 2010

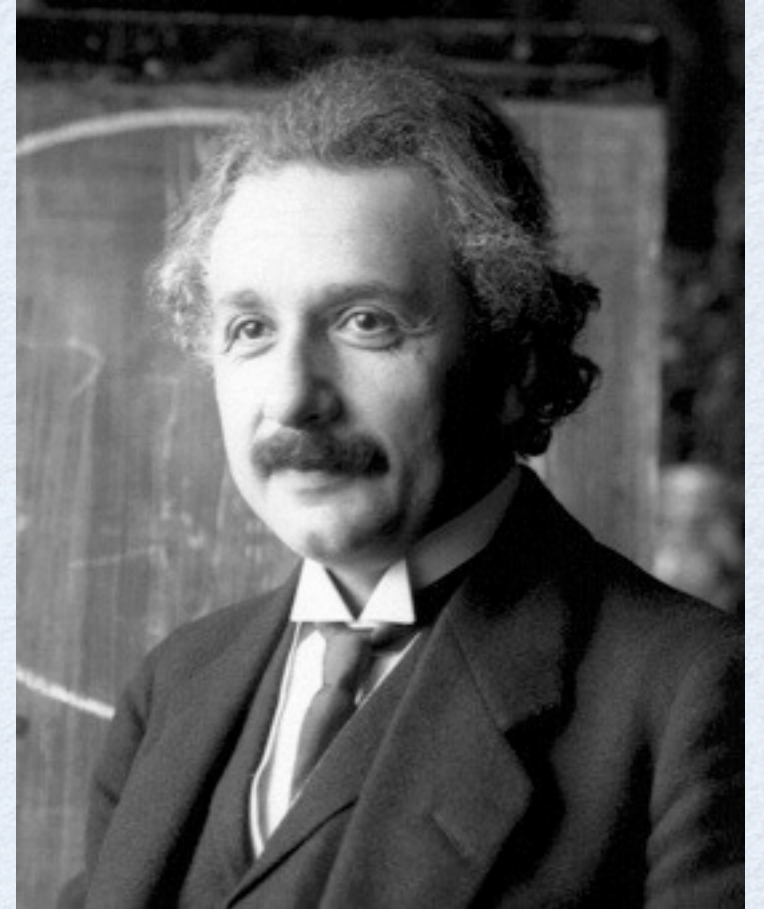
Parts of this talk were obscured by paradox noise, per my transcriptionist. You have been warned. The time police -- you know who you are -- are monitoring this talk. Premature or a-chronological revelation of the matters discussed here will be dealt with severely.

WHAT IS TIME?



What is time? If no one asks me,
I know. If I wish to explain it to
one that asketh, I know not.
— St. Augustine

Questions are more
important than answers.
— Einstein



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Every talk on time has to start with this quote, so this talk on time is going to start with this quote too. What is time?

Curious time so poorly understood, when it is the most popular noun in the English language. Explains why we are always running out of it.

6 QUESTIONS



- Why is time a problem?
- What kinds of time are possible?
- Could we travel in time?
- What possible paradoxes might be created by time travel?
- Can we avoid the paradoxes?
- If we can, what would this mean?

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That's Alice and the Caterpillar. Alice is putting a few questions to the Caterpillar. We have six. Why is time a problem? We kind of know that, but more seriously. What kinds of time are possible? Could we travel in time? What possible paradoxes might be created by time travel? How do we avoid the paradoxes without invoking the time police? The motto of the time police is that you won't just wish you had never been born. And if we can, what would this mean? So we're going to do six questions with no answers. It's like that play by Pirandello, six questions in search of an answer.

In real life, time also a problem, but in a different way.

We could have instantaneous time, block time, massively parallel time, and spreadsheet time. And a few others, but we haven't time for those.

From relativity, we get the impression that time is basically a space dimension. If this is true, we should be able to move about in it. In fact, most of the time machines in the physics literature are based on general relativity.

There are three kinds of paradox we might see: grandfather paradoxes, bootstrap paradoxes, & free will paradoxes. We will discuss.

So far every attempt to lay out a physically plausible time machine has turned out to be unworkable, even in principle. But there does not seem to be any over-arching principle that forbids them.

And, if we throw quantum mechanics into the mix, it seems there are reasonably straight-forward ways to contain the paradoxes. So time machines do not appear to be logical impossibilities.

Given the quantum mechanical ways of avoiding the paradoxes, we can actually arrive at a reasonably clear picture of what time travel might look like in practice.

WHY IS TIME A PROBLEM?

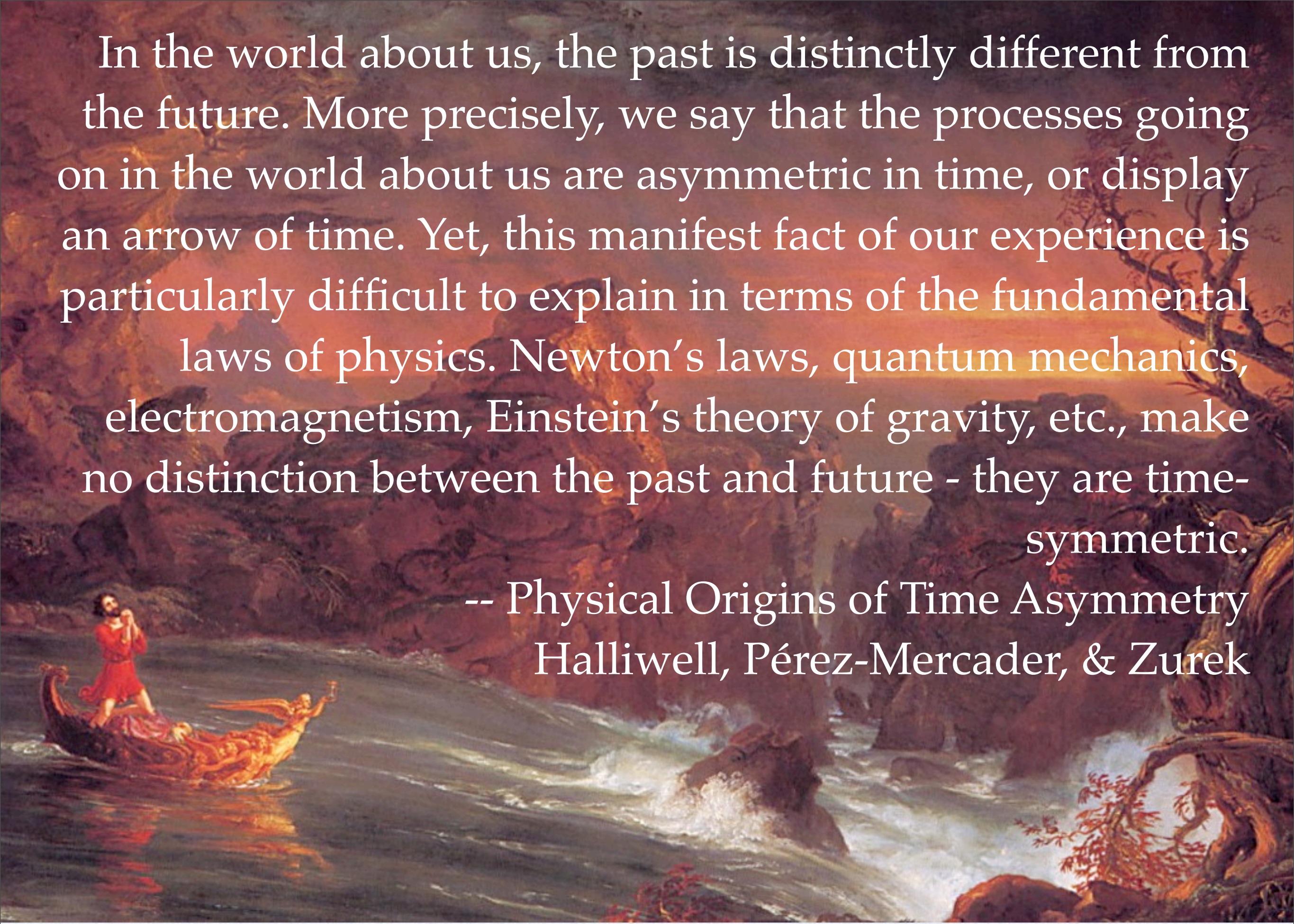


- At our level time goes one way, but laws of physics seem to go both ways
- In relativity, time is dynamic
- But in quantum mechanics, time is boring

The first question is why is time a problem? And here is another figure from Alice, with a problem. At our own level of time, time is all one way. It's always down hill, down river. There's going to be a lot of river metaphors in this. But that's okay. I mean it's not okay, but we're stuck with it. We're used to it. In relativity, in Einstein's special relativity, which you all know about, I hope, you'll know a little bit more anyway in a bit, time is dynamic; it's like a player. Time and space shift with each other like two space directions can turn into each other, time and space will turn into each other, too. But in quantum mechanics, time is boring. Quantum mechanics is fascinating, but the time part of quantum mechanics is really dull.

In the world about us, the past is distinctly different from the future. More precisely, we say that the processes going on in the world about us are asymmetric in time, or display an arrow of time. Yet, this manifest fact of our experience is particularly difficult to explain in terms of the fundamental laws of physics. Newton's laws, quantum mechanics, electromagnetism, Einstein's theory of gravity, etc., make no distinction between the past and future - they are time-symmetric.

-- Physical Origins of Time Asymmetry
Halliwell, Pérez-Mercader, & Zurek



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This is a local picture from Thomas Cole's The Voyage of Life. That's the third stage, manhood, when our hero is having a bit of a problem with rivers and rapids and so forth. Basically, the idea of this, and this is what everybody agrees, is that in all the laws of physics that we know, time can go forwards and backwards with no difficulty. If you're doing a physics of billiard balls, you can't tell from looking at the billiard balls which way they're going in time, until they sink into a pocket or something.

First question: why is time a problem

In our daily experience, time goes only one way. But in all the fundamental theories of physics, time appears in a way that is essentially symmetric. There does not seem to be any fundamental reason why we couldn't go backwards in time as well as forwards. In fact, we will discuss several physically plausible time machines, one of which might be created in the Large Hadron Collider at CERN, when it gets up to speed in the next few years.

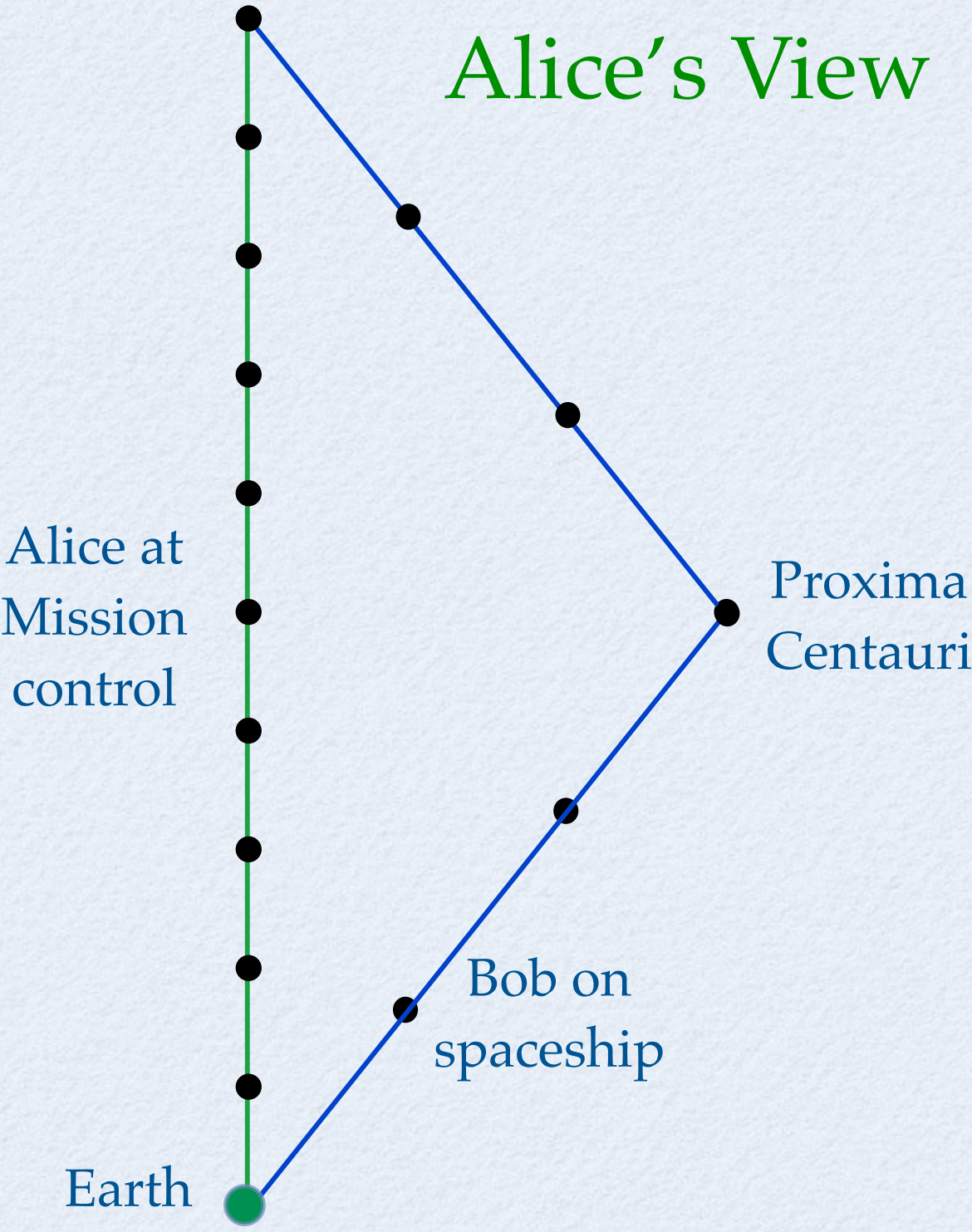
I do not myself think any of the specific proposals will actually work, but we may be getting closer to something that will.

The picture is the 3rd stage of Thomas Cole's The Voyage of Life (Childhood, Youth, Manhood, Old Age). This is Manhood.

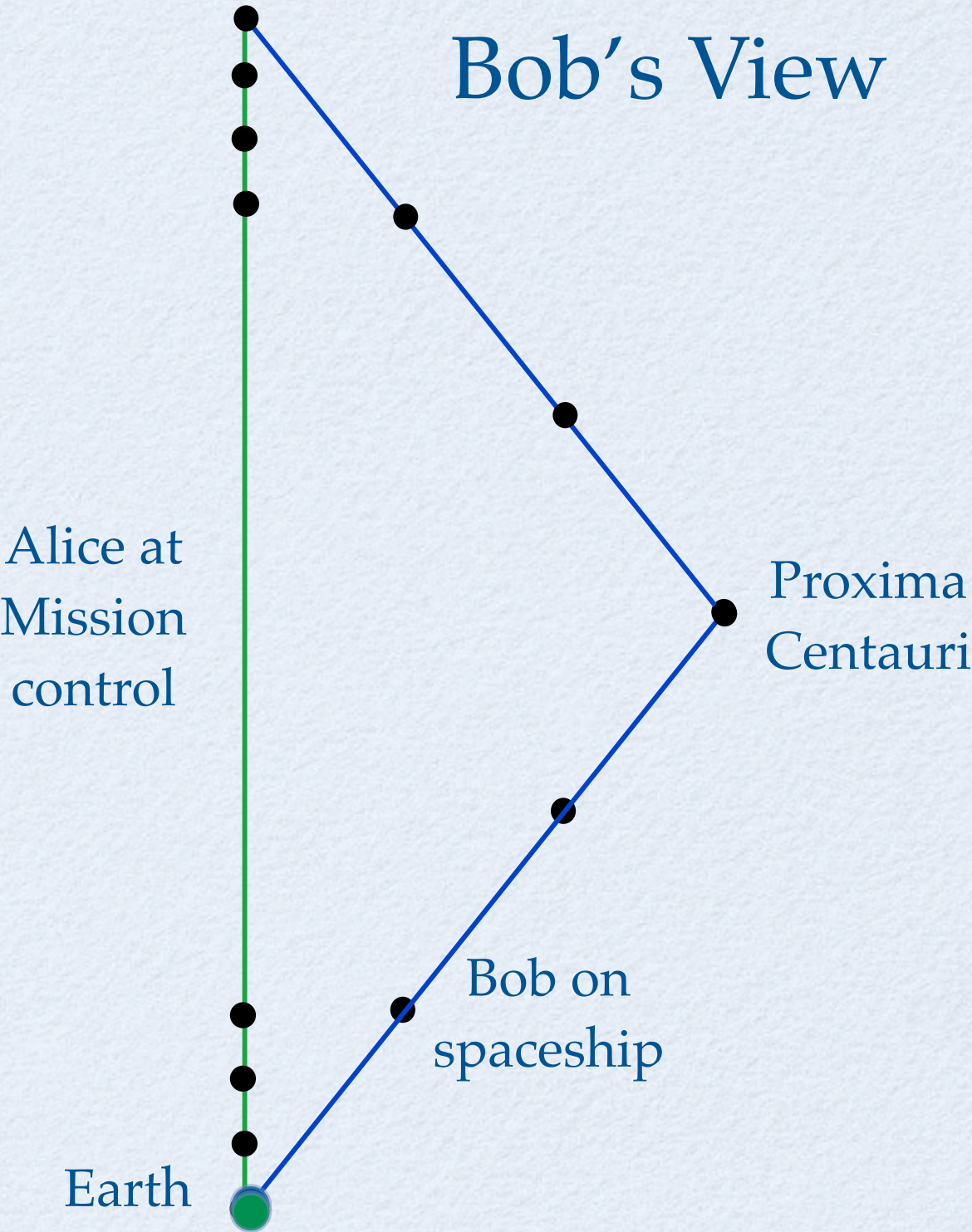
This is the first of many paradoxes. Paradoxes themselves very useful: indicate some limit of your understanding.

THE TWIN PARADOX

Alice's View



Bob's View



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The twin paradox in relativity. How many of you know about the twin paradox? A little under half. Have any of you read Heinlein's Time for the Stars? Quite a few, too. Basically, if you travel at high speed, you seem to be going slower, that as you get close to the speed of light, which is an absolute speed limit in this universe, you seem to be going slower and slower relative to everybody else. I worked out the actual math for this. When you do the case... I decided to pick as a star, Proxima Centauri, which is 4.3 light years away from here. And our spaceship, just to make the numbers definite, is going at 4/5 the speed of light. We're going to put Bob in the spaceship and Alice at mission control. Alice is going to sit at mission control monitoring Bob as he goes out to Proxima Centauri and then comes back. And we're going to start with what Alice thinks is going on. That's Alice busy aging one year per year back home. That's a little dot. I'm very proud of my skills with Keynote. She takes ten years for Bob to get back on account of, if you do the math, 4/5 the speed of light, four light years out here, that's ten years. No problem. But now Bob, Alice is looking at Bob, and Bob seems to take only three years of his time to get out to Proxima Centauri and three years back. When he gets back, he's six years older; Alice is ten years older. What gives? On the way out, Bob seems to Alice to be aging at 3/5 of her rate because he's so close to the speed of light. This sort of thing has been measured in all kinds of experiments in all kinds of big physics labs. There's nothing ambiguous. How many of you here use GPS? Exactly. The GPS clocks need to take account of the fact that satellites in orbit are going faster and therefore their time is slower. So that special relativity is important for you to get your car to where it's supposed to be going. Can't live without special relativity. In relativity, and this is why it's relativity, there's no privileged observer. Alice isn't special because she's sitting on earth. If Bob is on a spaceship, he thinks he's at rest, and Alice is jetting away at 4/5 the speed of light. So he must think Alice is going slower. If Bob thinks Alice is going slower, how come Bob's younger when he gets back? That's one of the many paradoxes we're going to mention here. And now another brilliant little dot of Bob going at one year per year his time. And one of your questions is how is it that if Bob is only taking three years of his time to get out to Proxima Centauri, he gets there when it's four light years away? The answer is that it's not just time that gets stretched, but space gets changed too. And because Bob's going so fast, he thinks the distance from him to Proxima Centauri goes from 4.3 light years to two and a fraction. So he thought Proxima Centauri was closer, and that's why three years was enough. Time and space both change when you're at high speed. What does he think about Alice? This is where it gets really amusing. He thinks Alice is aging much slower, and then really speeds up, and then ages slower again. Because for this part, he's looking back at her and he thinks she's going at 3/5 of his speed. Alice and Bob have the same view. Each thinks the other is slow. Actually, the twin paradox is normally very badly explained because the key little thing here is happening near Proxima Centauri. To get up to 4/5 the speed of light, you really have to jam the rockets on. The speed of light is 300,000 kilometers a second, 186,000 miles a second, 4/5 of that is 25,000 kilometers, which is a lot of kilometers. You have to accelerate enormously to get out to that speed. Then, you get here, you have to decelerate, because you don't want to crash into Proxima Centauri--that's the traffic report from hell--and you've got to accelerate to get back. So you have extraordinary acceleration right at this point. We know from general relativity, from Einstein's theory of general relativity which discusses gravity, that acceleration and gravity can't be distinguished between each other. Enormous acceleration is the same as enormous gravity. If you do the math, and Einstein wasn't able to do the math, and in fact, nobody's really worked this out perfectly, just approximately, so I'm not going to do it in this short space of time. The calculations are hard. You can do it numerically, but you can't do it analytically. He's in a huge gravity well, the moral equivalent of a huge gravity well. He just went deep into a star and came out again. His time slowed down enormously at the acceleration spot, so when I showed you the little ball going Alice was slow here and this point from here is Alice's graph matching when he's at Proxima Centauri. She does all of her aging, like six years, all the extra aging, while he's braking and then returning from Proxima Centauri. *Are you saying that the Twin Paradox can't be resolved in special relativity?* That is correct and that's why the explanations you've seen in the textbooks are crap. When I first took special relativity, I said, this is interesting, but I was at the Feymann Conference in Baltimore three years ago and there was a guy talking who was a Ph.D. physicist who was confused about the twin paradox, not realizing you have to go to general relativity to understand it.

Problem has gotten worse: in special & general relativity, the most natural view of time is from the block universe perspective, that sees all time laid out at once, the way a surveyor thinks of a river. Time is extended, just as space is. In fact, they are interchangeable. As Minkowski put it:

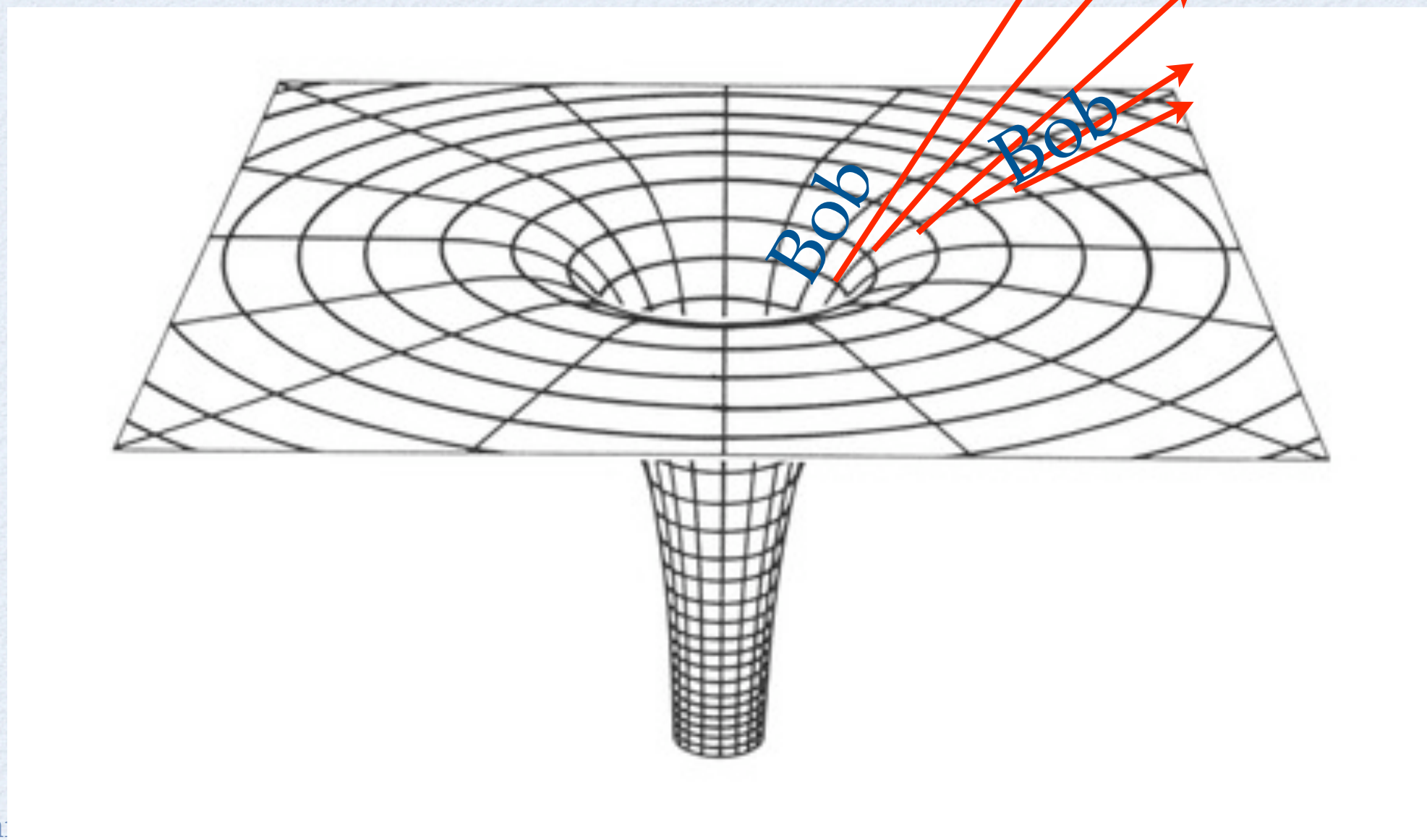
“Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality.”

Case in point, the familiar twin paradox. Normally done with twins, to make the aging more dramatic.

Alice will stay at home on the earth while Bob jets out to Proxima Centauri & back. He will be traveling at a considerable fraction of the speed of light, so age much more slowly than Alice.

BLACK HOLES

Alice



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Another thing you need to understand general relativity for is black holes. We are all as familiar as we care to be with black holes. No one diagram of a black hole can give you a good picture because a black hole exists in four dimensions--in the three space dimensions--and in time. Well you can only get two dimensions on a standard screen. So we can't give you a good mathematical picture, but this is a typical picture of it. The little circle things here are orbit lines, or how far out you are, the wider the circle, the further from the black hole and the safer. The radial lines are really sort of time lines. Let's say Alice has very sensibly stayed back at mission control, Bob, with more fearlessness then judgment, has decided to take a spaceship in close to the black hole. And he's sending photographs back to Alice, one per minute or whatever time unit you have. He sends the first one out--I'm not sure how clear that all is--but the first one is this little red arrow here, and next one is a little bit later, and later, and later, and Alice thinks his time is getting slower and slower. *Eventually it seems to stop?* At the event horizon it stops. At a certain point, the gravity from the black hole is so strong even light can't get out. There's some exceptions which we don't have time to get into, but basically you stop getting photographs or messages back from Bob. We don't know what happens to Bob when he crosses the event horizon. General relativity says that he keeps on going in, but we know that general relativity doesn't include quantum mechanics, which is also true. So we don't know. *The other thing if I remember my general relativity, Bob doesn't actually perceive that he's crossed the event horizon.* That's correct. That's a very deep point. In one of Fred Saberhagen's Berserker novels, which I really enjoyed when I was at the right age for enjoying them, the sinister, evil, despicable robotic berserkers, who want to destroy all life, are outwitted by a fellow taking advantage of the time fluctuations near a black hole because he gets to hide, using the slower time, and come out and ambush the sinister, evil, but not all that bright or understanding of physics, berserkers. Good for him.

If you get close enough to a black hole, an outside observer will see your time as slowing down. If you cross the event horizon, you will seem to vanish.

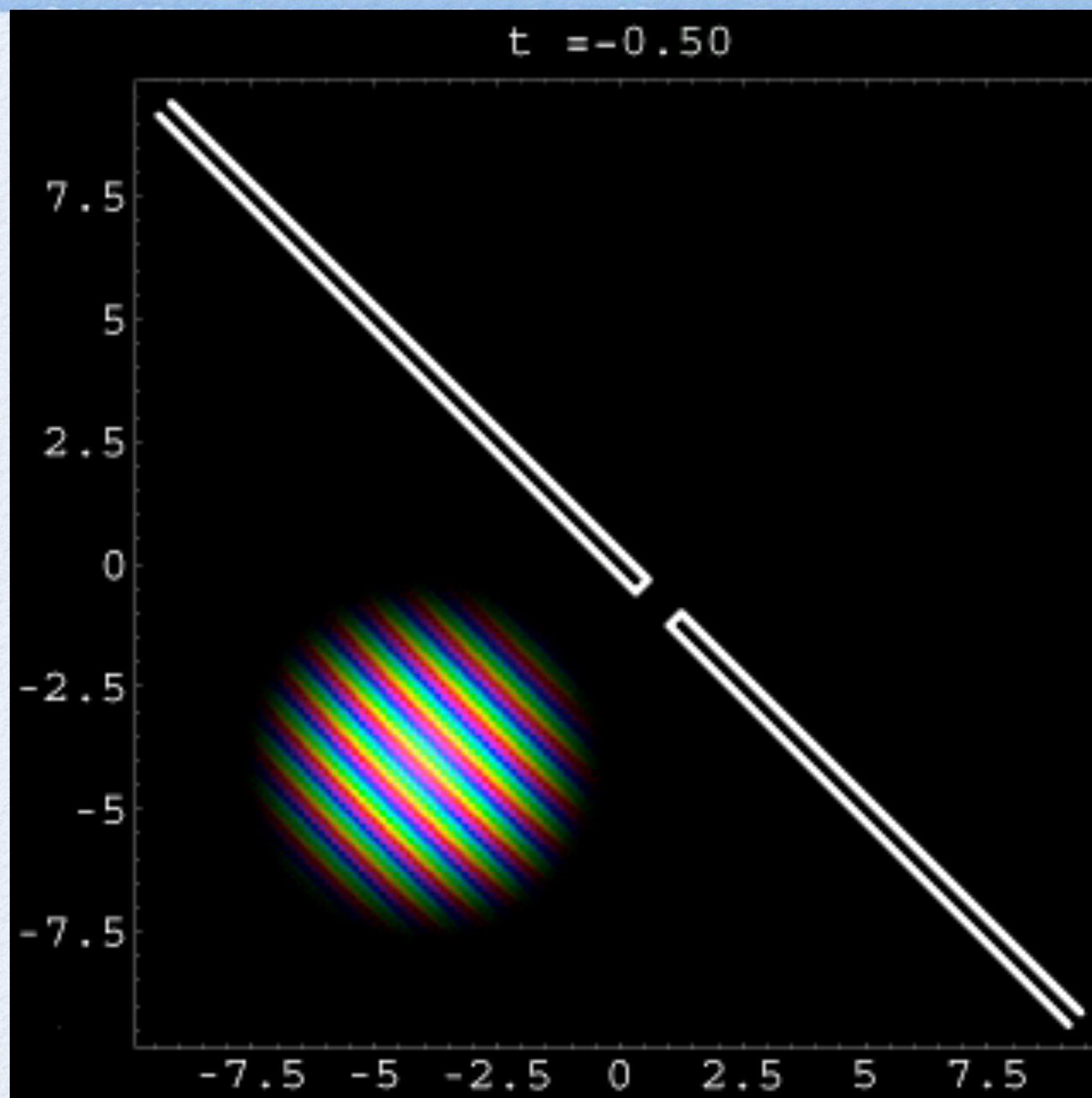
What actually happens is a bit of a mystery.

There are some themes & variations to go with this:

For instance, in quantum mechanics, information is never really lost. But if it went down a black hole, where is it? [Does Alice have to go underground to find out?]

Perhaps it is recovered when black holes evaporate. Which they can do. From something called Hawking radiation. Which we probably don't have time for.

SINGLE SLIT EXPERIMENT



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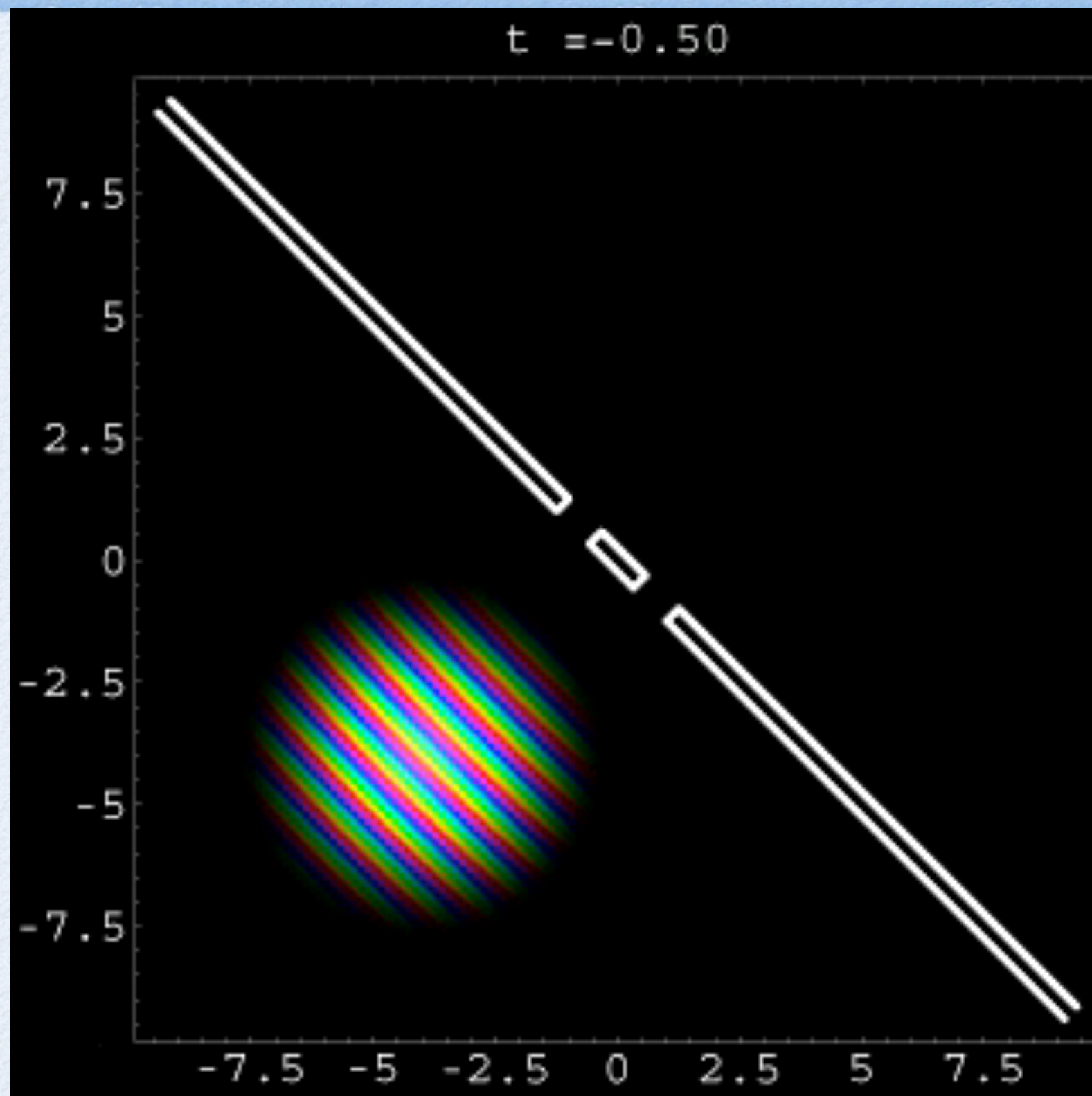
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Now we come to quantum mechanics and movie time. How many people have heard of the single and double slit experiments? This is a literate, in several senses of the word, audience. This is a quantum wave function going through a single slit and getting spread out. If it were a single particle here it would go out and there would be a little bit coming here, and a little bit coming here, and a little bit coming here, so that a particle looks like a wave. It's a particle and it's a wave. It's like a beer commercial. But you noticed that time just moved on forward. The stuff you saw coming back here is just a reflection off the wall. The stuff that didn't get through the slit was reflected back. This is double slit experiment where the particle goes through both slits at the same time, and you saw that pattern there, where there's an interference pattern. What happens is if you put a detector up here, you see spikes and troughs, and spikes and troughs so the particle doesn't go through one gate, it goes through both. Well that's weird. But again you saw how time just goes forward. So in relativity, time and space intermingle, they do the whole rotating thing which is a dance, but in quantum mechanics, time is boring, but space is gone a little bit strange. So this is that said in key words: relativity is smooth, localized--meaning at one spot, predictable, and time is interesting; quantum mechanics is quantized--comes in little chunks, it's fuzzy, it's uncertain, and time is boring. Both theories are true. So that's another paradox. We're going to have no shortage of paradoxes in this hour. And the thing is that quantum mechanics is what drives my laptop when its battery isn't failing and relativity runs our satellites and our rockets and so forth. They're both absolutely true, but they contradict each other in a very deep way. Right before I came down here, there was yet another paper in the physics archives, saying this is a hopeless situation and nobody's ever going to be able to make this fit without new physics. And that can even be true. *Then what's the point of publishing that paper?* Well, sometimes realizing that you don't know what you're doing is the most useful thing you can do. *And the thing is we're right on the edge of the new physics, because we've got dark matter, two or three other...* Dark matter, dark energy, in fact we're going to discuss those very briefly at one point later on. *Also there's the unexpected fact that neutrinos have mass. There's a number of little anomalies here.* So if you were suffering from a shortage of strange, we're going to fix that.

DOUBLE SLIT EXPERIMENT



RELATIVITY VS QUANTUM

Relativity:

- Smooth
- Localized
- Predictable
- But time is dynamic

Quantum mechanics:

- Quantized
- Fuzzy
- Uncertain
- But time is boring

How wonderful that we have met with a paradox. Now we have some hope of making progress. – Niels Bohr

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This is one of my favorite quotes. Bohr's "How wonderful that we have a paradox. Now we have some hope of making progress." Because you know the great disasters in this world come from, what I was calling to Connie Willis last night, aggressive incompetence. Not knowing you don't know what you're doing and just bulling ahead anyway. I'm not going to pick out any examples for you guys.

In relativity I include both the special & general theories.

Both relativity & quantum mechanics are extremely well-confirmed, if in separate domains.

Special relativity, i.e. relativity in flat space, with no gravity, has achieved an accommodation with quantum mechanics, in the area of quantum electrodynamics. There are some infinities, but they can be swept underneath the rug.

General relativity, special relativity in curved space, with gravity, seems very difficult to reconcile with quantum mechanics. Attempts to force a marriage result in intractable infinities, infinities you can't seem to work around.

But before discussing dynamics versus boring, we need to discuss what kind of time we are living in:

Four kinds of time:

Presentism: past & future do not exist

Block universe: all time exists at once, experienced sequentially

Multiverse: lots of universe, maybe we can travel among them, probably we can't.

Spreadsheet time: time travel is possible, and time travelers keep resetting the spreadsheet (accounting for the "wooshing" sound you sometimes hear when you wake up wonder, briefly, how you got "here" & where here is anyway, as if you had suddenly wandered into a Douglas Adams novel).

KINDS OF TIME?



- Fleeting instant
- Block universe
- Massively parallel
- Spreadsheet

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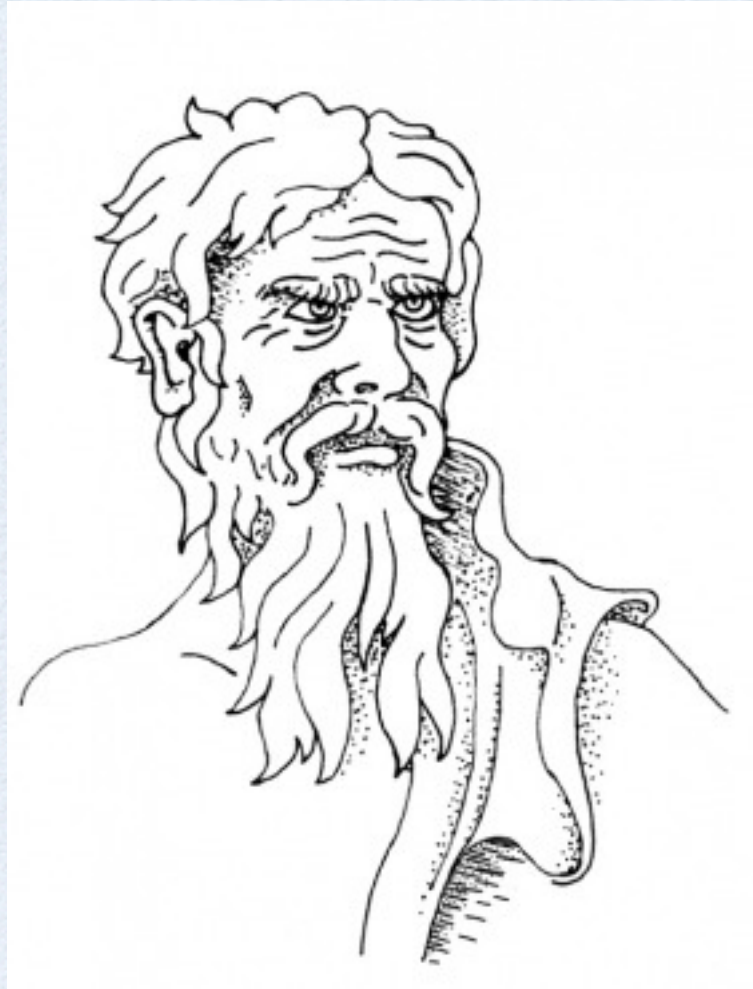
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Now we get to our second question which is, what kinds of time are there? And this is our friend Alice again going into the looking glass. There are four kinds we're going to discuss. The fleeting instant, which is what we live in--the moving finger writes and having writ not all your piety and wit can cancel half a line. And depressing it is. Then there's the block universe, which is that all time is laid out at one go. So the fleeting instant is like you're a white water rafter on the river and you just see the rapids in front of you. Then the block universe is like the whole river is laid out like you're a land surveyor or something. Then there are two other views which we'll discuss more fleetingly, the massively parallel theory of time, that there are many, many rivers. In some science fiction stories, you can go across from one river to the next, in fact in all science fiction stories you can go from one river to the next because otherwise you have no story. Why are you doing this? And then there is what I call spreadsheet time, which is where 90% of the time travel stories go, and it's really quite silly, but fun. This is that time is a spreadsheet, and you start at the top of the spreadsheet and it calculates down if you're doing a normal spreadsheet thing and the time traveler is like a little bit of math that jumps to the top of the spreadsheet, changes a cells and causes the recalculation to ripple down. In many stories there's a separate recalc time, as the wave of time change moves forward and gives Claude Van Damme only a few seconds to get into his time motorcycle or whatever he uses to stop the wave of rippling time. This make so little sense that you're really better off not thinking when you read these guys.

THE INSTANT & ETERNITY



You can't step in
the same river
twice
– Heraclitus



[What exists] is
now, all at once,
one and
continuous...
— Parmenides



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This argument, as I say, goes back two and a half thousand years. This is our friend Heraclitus, a Greek philosopher of 2500 years ago who was wont to say "you can't step in the same river twice," although you can use the same quotation in every talk you do. Then there's Parmenides, looking much more serious, this is a wild eyed fellow, this is a marble bust of the sober Parmenides, who wrote much worse, however, who said "what exists now, all at once and continuous", you know, all time exists a once. Of course, there's nothing to keep both views of the river true because the white water rafter and the surveyor both have legitimate views of time, or of the river, rather. So there's nothing to say that the fleeting instant and the block universe view aren't both true. This is a picture of the Nile river, which both Heraclitus and Parmenides knew about, and I bring this particular river up because the inhabitants of Egypt at the time used to use the same word for south and upstream, and for north and downstream, because they only had one river. It turned out the Egyptians were really crap sailors because of this confusion. So we want to be clear.

Kinds of time: present time only:

The Moving Finger writes; and, having writ,
Moves on: nor all your Piety nor Wit
Shall lure it back to cancel half a Line,
Nor all your Tears wash out a Word of it

This is the view implicit in quantum mechanics.

Block universe, all time exists at once, but is experienced sequentially. The river exists all at once, even if we can only experience one bit of it at a time. This view is forced on us by the relativity. For instance, in the twin paradox, Alice and Bob have different views of the present, the only straightforward way to combine them is to see all time as existing at once.

Choice of Nile not accidental: at one point the Egyptian words for North & downstream and for South & upstream were the same. We are perhaps guilty of a similar confusion with respect to time.

PARALLEL UNIVERSES

Symbol	Value	Meaning
N	1,000,000,000,000,000,000, 000,000,000,000,000,000 (Douglas Adams Big)	Ratio of fine structure constant to gravitational constant
ϵ	0.007	Strong force
Q	1 / 100000	Lumpiness of universe
D	3	# of space dimensions
Λ	0.7	Cosmological constant
Ω	1	Density of universe, compared to critical density

There's a little bit of evidence for parallel universes. A guy named Rees in 2002 or whatever wrote a wonderful book something like Just Six Numbers, which talks about the fact that our universe is strangely well-suited for us. First off, it's really big, so that there was time for us to evolve, this is n , the really big factor. I could explain that but I'd have to get a little bit technical. That is one with 36 zeros, that is Douglas Adams big, or Sagans and Sagans of bigness. He never said that. Until he died he said, "I never said that." But it doesn't do any good. Something being true just doesn't help. Then there's a little number called ϵ which is .007, which is how efficient it is to turn four hydrogen atoms into one helium. How much energy do you get out of fusion? Too much, too hot, too little, too cold and we don't exist. Then there is q , which is the lumpiness of the universe, currently set to 1/100000, too many lumps, everything turns into black holes, no us. Too little lumpiness, everything is flat and boring, just hydrogen gas, no us. The lumpiness is just about right. Then there's d , the number of space dimensions. Three is a good number. You know, it's not just for holy hand grenades anymore. It's that you can't have stable atoms or stable planetary systems if the number of space dimensions is two or four. And then λ is the cosmological constant. How much energy is there pushing things apart? Too much and too little again, is the Goldilocks problem. And ρ is the density of the universe compared to the critical density. For some weird reason, we are right on the cusp between so little density that we expand forever and everything is boring and so much density that we fall back into a single black hole. We're right at the edge and we've been at the edge for 13.72 billion years, which is a long time to be on the edge. And you thought you'd had some bad waiting experiences. So that was Just Six Numbers by Rees, R-e-e-s, if you want to look it up. And by the way, this is subject to a lot of discussion. There's nothing in this talk that's not subject to a lot of discussion. And some people say it's not so finely balanced, some people say these are the wrong numbers, you can go all over the map, but we're just going to go forward.

An interesting analysis by Max Tegmark in the Scientific American, of possible alternative universes.

One explanation of why we are here is that all physically possible universes exist, but only those where intelligent life can evolve into existence have intelligent life to wonder why the physical constants, e.g. Number of time & space dimensions, are what they are.

This is the Anthropic hypothesis. A lot of physicists regard it as cheating.

COINCIDENCE, MR BOND?

- It isn't that much of a coincidence
- Or, we just got insanely lucky
- Or, there are a nearly infinite number of universes out there
- And, only those hospitable to intelligence life will have sentients asking, did we get insanely lucky?

SPREADSHEET TIME



And who can forget the fading photographs?

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This is one of my favorite examples of spreadsheet time, where you go back to the past, change it, and then all the changes ripple forward and your previous future fades away, like the Cheshire Cat, to continue with our Alice metaphors. That's it for spreadsheet time. You can have an enormous amount of fun with this. It's like you go to the source of the river and you change the course of the river so it's flowing in a different channel. That's another way to think about spreadsheet time and use our river metaphors for it. The problem is that other civilizations in this galaxy or other galaxies are going to be doing the same thing, there'll be ripples everywhere and what do you mean by change, and it's very difficult, in fact it's frankly impossible, to produce a coherent version of spreadsheet time. Fun, but nonsense.

Spreadsheet time; there are really two kinds of time: the time that is "down" on the spreadsheet, and the time of the operator. Intuitively reasonable & -- like many intuitively reasonable things -- complete nonsense.

Consider all the other decision makers in the universe: at each choice point, does a new universe fork off? And what is a choice point? This is a problem for the Many Worlds Interpretation as well.

COULD WE TRAVEL IN TIME?



- Wormholes
- Frame dragging
- The Large Hadron Collider

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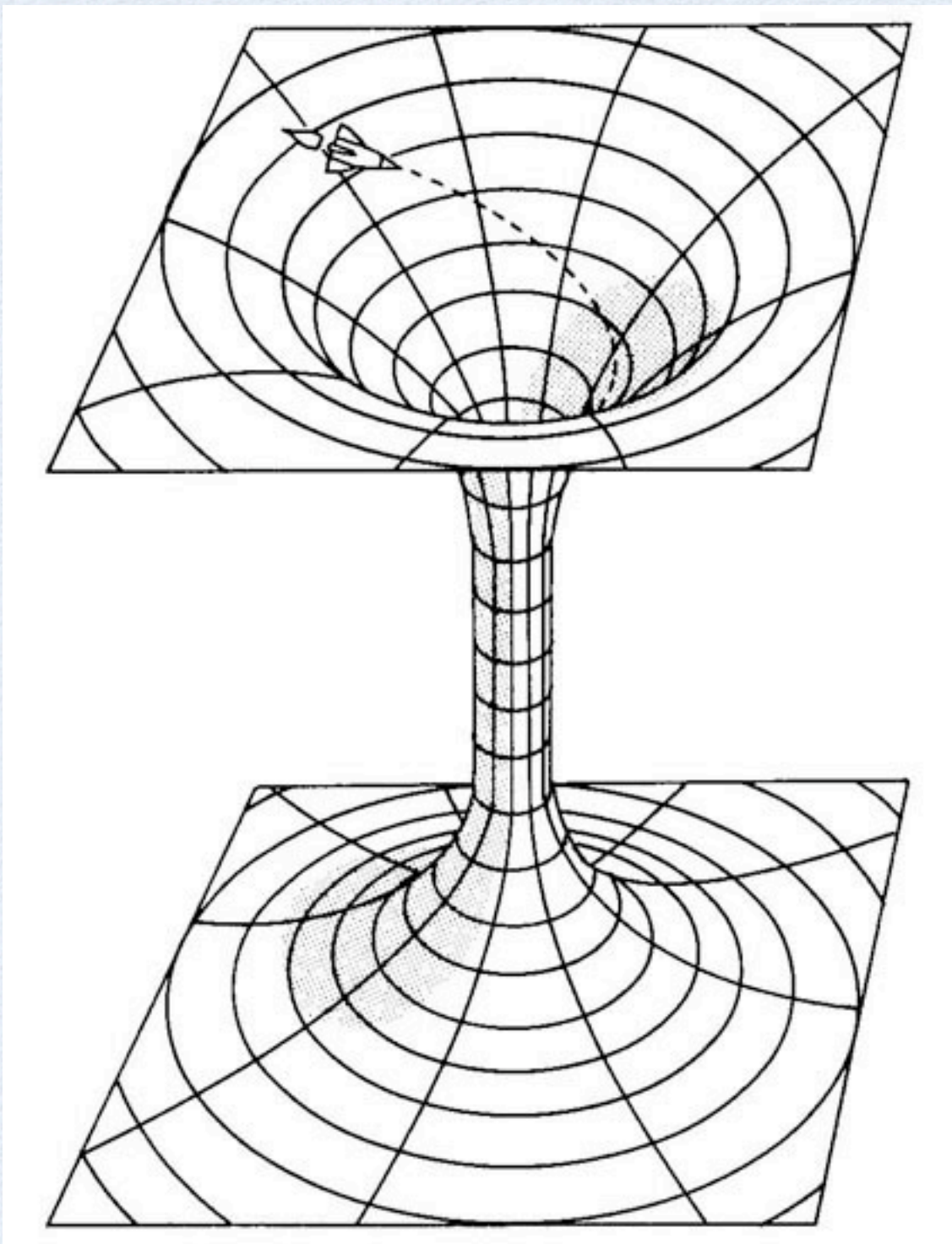
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So we're going to go with the block universe, one river, all laid out at once. But there are these other possibilities and more I haven't discussed. Our third question is, could we travel in time? This is everyone's favorite time traveler with everyone's favorite steampunk time machine. We are going to discuss three of the physically plausible time machines in the physics literature, not like the little bicycle, but stuff that you could imagine actually moving in time with: wormholes, frame dragging, which I will explain, and the Large Hadron Collider, which I will not explain but is very big.

Quite a few different physically plausible (taking plausible in the most elastic possible sense) time machines have been proposed. We'll look at a few. None really likely to work, but it is interesting that the ideas are getting less & less absurd.

List includes: wormholes, rotating massive objects, reflection in time, & quantum fluctuations.

WORMHOLES



- A wormhole is two black holes stitched together with mathematical sutures
- Needs negative energy / mass “stuff” to stay open

We'll start with wormholes. You'll notice the resemblance in this picture to the black hole picture? There are no accidents in this talk. Many questions, but no accidents. A wormhole is two black holes stitched together with mathematical sutures. That's actually true. Basically, a white hole is like a black hole only turned inside out, if you go into the black hole, that's a little tiny rocket ship going into the black hole, refraining from being squeezed into a noodle on the way through and coming out of the white hole. There are a number of problems with these guys. To hold open this little throat here, you need something called negative energy or mass. This is not anti-matter. Anti-matter had positive energy. This is negative energy. C'mon guys. A guy named Visser wrote a wonderful book on Laurentzian worm holes which is not an easy read, that was an understatement, and he said that every specific example of a wormhole that can be used to travel in time, he could refute but he couldn't refute all of them in principle, so he was a little annoyed. That's method A, where you go through the white hole and come out somewhere else.

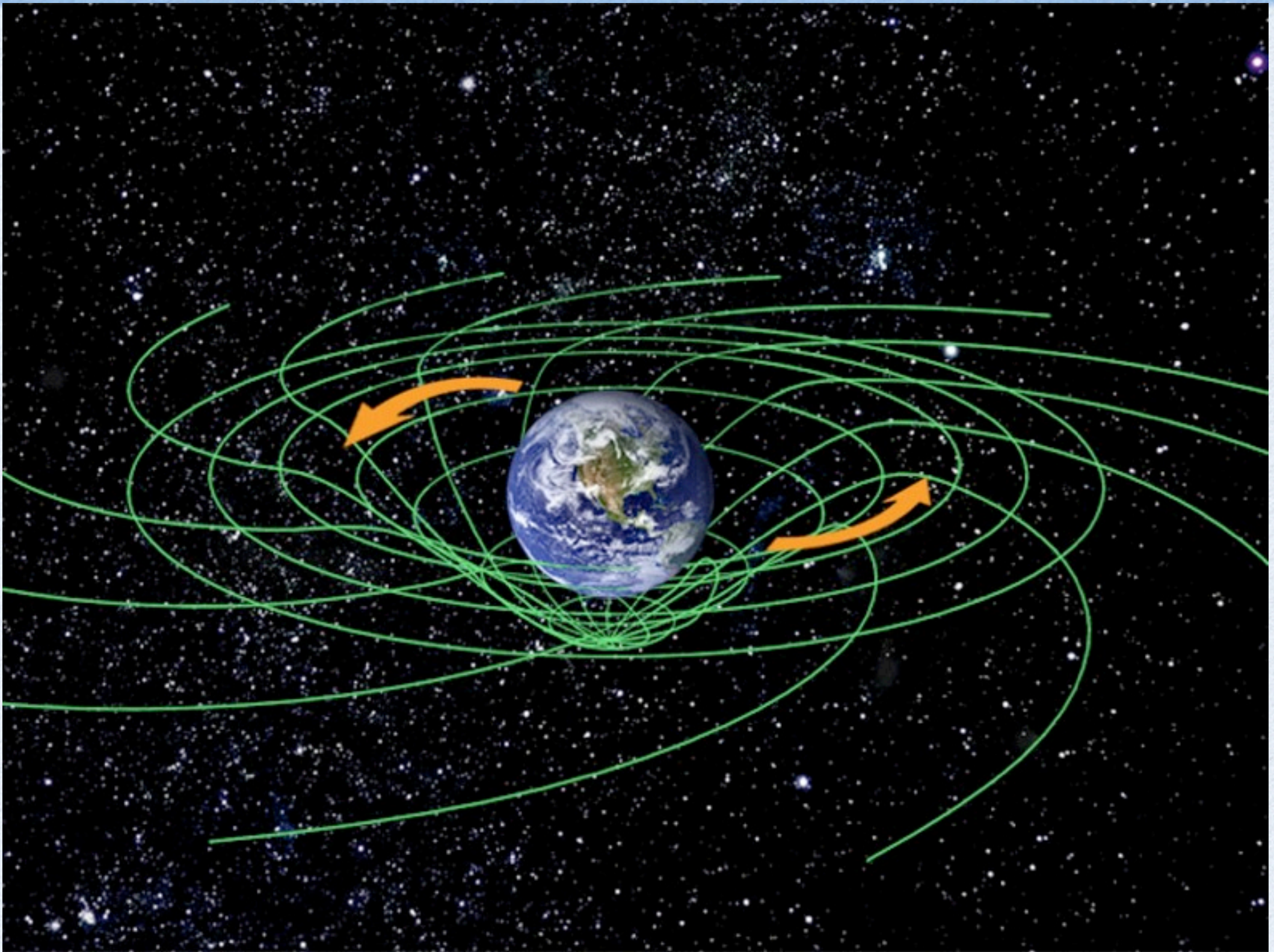
We can think of a wormhole as two black holes stitched together. The top one is the black hole our [frankly clueless] ship is headed into. The other is presumably a white hole that our [overoptimistic crew] are hoping to come out of. With a bit of hand-waving, no more magical than the original wormholes, one can suppose the “in” mouth is in the future, the “out” mouth in the past. There are ways of doing this described in Thorne's book in the handout.

This idea was invented by Thorne as a way to get from one place to another quickly. Sagan had requested a physically plausible way to get to a nearby star, for use by the heroine of his novel contact, and Thorne came up with this. [cue picture of wormhole as shortcut].

The point is not that this specific approach is plausible, but rather that General Relativity, as good as theory of gravity as we have been able to come up with, makes this sort of thing possible.

2nd picture is from http://mail.colonial.net/~hkaiter/Black_Holes.htm

FRAME DRAGGING



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Method B actually works. Frame dragging. As the earth spins around, it drags spacetime behind it. It turns out that Superman was right. When you go with the turn, you go into the future, when you go against the turn you go into the past. Superman was a little off on his numbers, though. The amount is like millionths of a second, it's been measured and it's not getting you anywhere you want to go. You're not getting back to your grandfather on this one.

It seems that in general relativity, not only do wormholes give a way to go backwards in time, pretty much any sufficiently massive system rotating sufficiently quickly can be used as well. The rotating system will pull time along with it - this is called frame dragging - and if it is big enough and fast enough and the orbiting spaceship is close enough, then the ship can find itself on an orbit going backwards in time.

In fact if you remember your superman comics, he used to travel in time by flying around the Earth clockwise to go forwards and counter clockwise to backwards in time. If we mean by clockwise going “with” the rotation of the Earth, that is actually right. And the effect has been measured. It is pretty small however, minute fractions of a second.

The first person to come up with this was Gödel, who used the entire universe, tho pointed out in his defense that that was hardly a practical way to go backwards in time. Einstein was, nevertheless, depressed that such orbits were even theoretically possible.

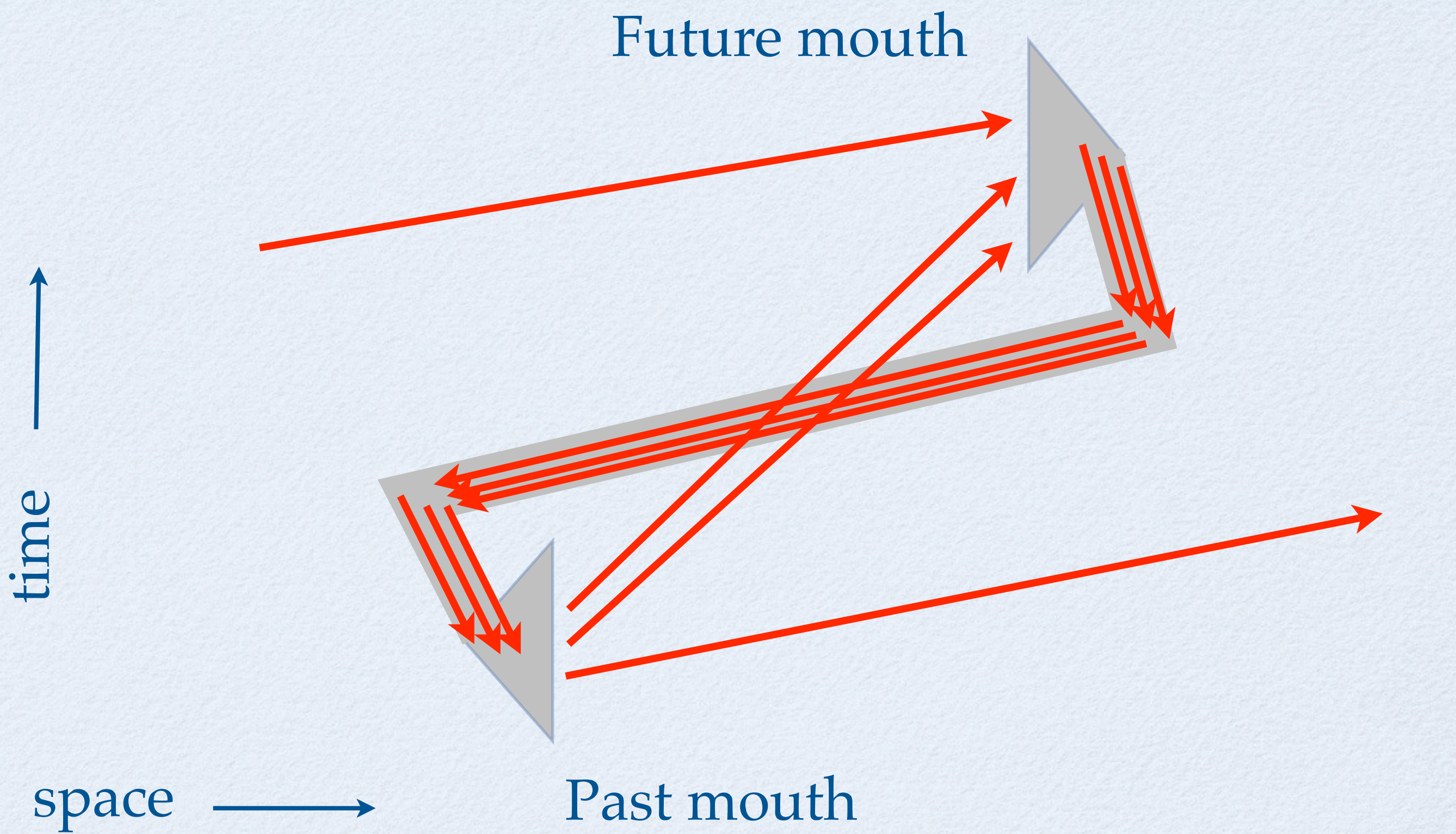
Tipler a bit later, wrote a paper “Rotating Cylinders & the Possibility of Global Causality Violation”, where an infinitely long cylinder is used. Niven wrote an SF story with exactly the same title arguing that if some galactic empire tried this by way of getting a leg up on a rival empire, the universe would just spit them out like a poorly digested theory.

Later Gott worked out a way to achieve similar effects with rather long cosmic strings.

And Mallett suggested using simply a rotating laser beam, since laser beams have energy & therefore can drag frames as well. But probably not enough.

All of these schemes have fatal problems, but it is interesting that people keep coming up with them. Next we discuss something that might even work [tho I do not think so].

LOOPING THRU A WORMHOLE

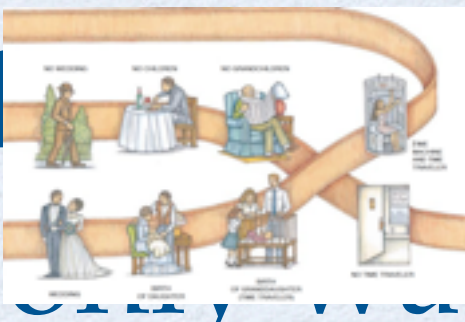


This is a third one, looping through a wormhole, but these are little baby okay wormholes. In the Large Hadron Collider, two different papers, one by Mironov and a few of his Russian buddies said you might, in the Large Hadron... does everybody here know what the large Hadron Collider is? Okay, it's a large hadron collider, you were ahead of me on that one, meaning large particle, like proton and neutron. By taking large hadrons and slamming them together like a Democrat and Republican, you can, produce information, if they're not Democrats and Republicans. Basically, this works at really high energies and might--it's turning on gradually, it's had some technical problems as all these things do--in the next couple of years it might create little baby wormholes. If string theory is true, which is also possible. So this is the future mouth of a little wormhole. This is that same wormhole diagram, but on its side, so I can get everything to work. *If you're creating little baby wormholes inside the supercollider, within the earth's atmosphere, aren't you in effect creating small black holes?* Yes, that's what you're doing. *Are you not risking having everything sucked in to them?* No, these are so small they evaporate. Hawking wrote some interesting stuff on how they do it. Again, that would detain us not only past the hour, but into next year. Small black holes get smaller, large ones get larger. *The other thing is, black holes aren't like magic. They have the same amount of gravity as any other object of that mass. It's just that it's packed into a smaller area. The theory of black holes is that they suck more mass in? But the mass has to get close enough to... If you've got something that smaller than an atom, how does something get close enough to it to vaporize it?*

So this is a particle coming into a future mouth. I had a lot of fun with this slide, so I hope you're grateful. It goes into the future, back to the past, gets out of the past mouth, and happens to wander into the future mouth again. These things happen. They are particles. They are not bright. It does the same thing again. It's a particle, it's not bright, it made the same mistake. And then it goes through again. This time it got away. Well, the point is it was spending a little bit of time--you see all these things are happening at the same time--these three tracks here or ten tracks or whatever, all exist simultaneously, kind of a weird relationship. It's rattling around like a penny in a tin cup, and these three may even interfere with themselves, causing certain things to happen at much greater quantities than otherwise expected, and because of this long time delay, it might age rapidly and decay into something else too early. So this is science, because there are detectable effects that depend on the particle going through the wormhole. We're talking a scientific time machine which can be detected by current experimental apparatus and is predicted by current theories. Sleep on that! That was kind of the high point of this whole talk, it's like a justification. We are at the edge of time machines. I'm not saying it's going to work. And in fact, I don't think this particular one will work, but somebody can put in the literature a proposal which is plausible. *It's interesting but the time between the two mouths is kind of short.* Very very.... remember the slide with all the zero's with the size of the universe? It's like half as many as that, but still a lot of zeros.

POSSIBLE PARADOX?

“Why on grandfather? It seems that the only way to prove that time travel is impossible is to cite a case of killing one's grandfather. This incessant murdering of harmless ancestors must stop. Let's see some wide-awake fan make some other method disproving the theory.”



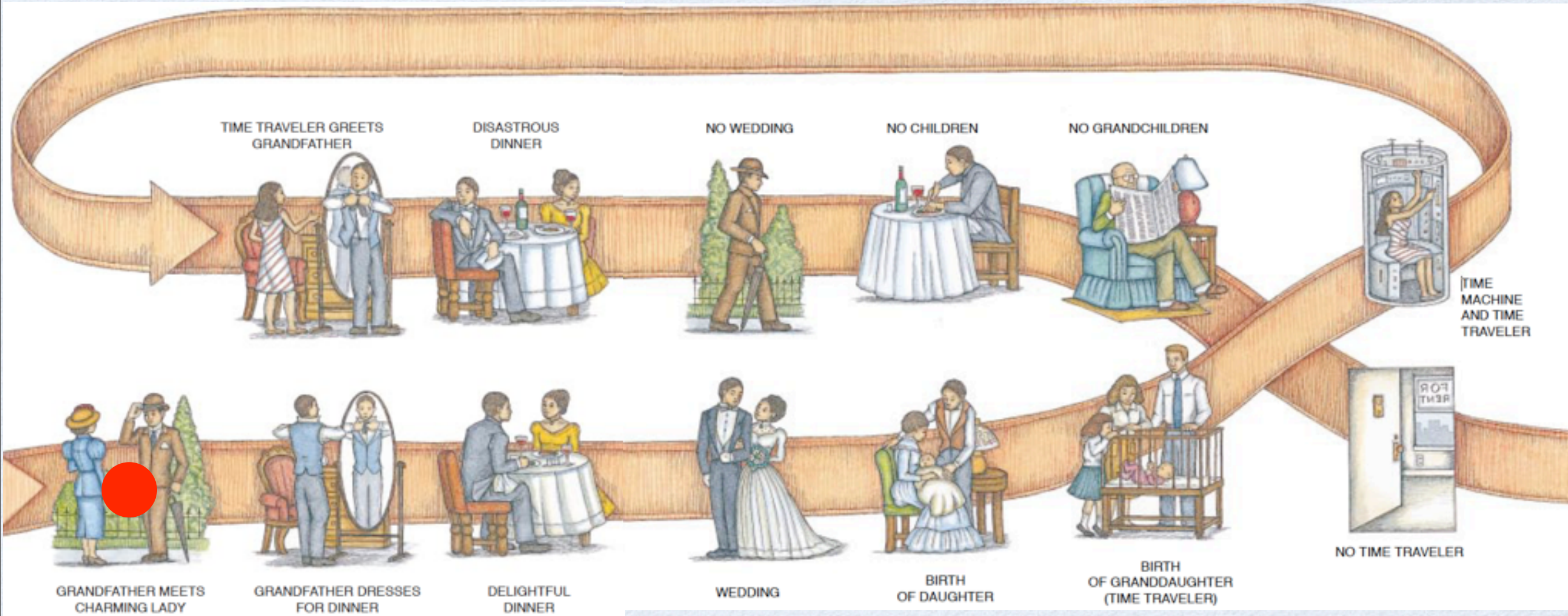
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This is one of my favorite quotes. Some of you may have seen this from me before. Basically, why all this murdering of grandfathers? What did they do to you? Okay, they smoked a really inferior brand of cigar, but aside from that, let's get a grip. There are three kinds of paradox, number one is your grandfather paradox, which we're going to do. The little pictures are the slides to come. This is a time travel talk, so it anticipates its own future. Then there are bootstrap paradoxes and there are free will paradoxes.

All time best single time travel quote. From Nahin's Time Machines book.

– Letter to editor at Astounding Stories (January 1933)

GRANDFATHER PARADOX



The quantum physics of time travel - Deutsch & Lockwood

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We'll start with grandfather paradoxes. This is too small to read. It's from the Scientific American article by Deutsch and Lockwood. Deutsch and Lockwood are nice people. They don't kill any grandfathers. This is the little couple gets together two generations ago, this is the grandfather to be, prepping himself in the mirror, they have a nice dinner, they get together, they get married, they have a kid, the kid has a daughter, a granddaughter, who gets into a time machine, which looks like the elevators in this hotel for some reason, and goes around --I'm going to get this going; this is what happens when you discover all the animation features in your Keynote presentation software; you can do all sorts of stuff like this--so this is granddaughter looping around, going back in her time machine, she goes back and says hi grandfather, good to meet you, and for some reason this throws him off his stride and the key dinner with grandmom to be goes disastrously, you know how when you over-anticipate something you have a really bad dinner, just like a date with too much stress on it? And he's thinking about two generations out, and the dinner goes south, and he winds up a lonely old man reading the paper with no granddaughter. Oops! Well, if you have spreadsheet time, or multiple time, she can maybe jump over to another continuum, but we're doing block time, one river, no changes. Okay, so that's paradox number one.

One of the less murderous demonstrations of the grandfather paradox. Charming after its fashion.

We will solve below for quantum Alice: she will finish in a superposition of born/unborn - some kind of time vampire I suppose

Violates block universe

BOOTSTRAP PARADOX



- An engineer goes 30 years into the future,
- Reads some patents a later version of himself filed,
- Take the (information in) the patents back in time,
- And files them.
- *Did the patents write themselves?*

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Paradox number two--this is from Heinlein, who was nuts for paradoxes: the book, The Door into Summer. An engineer goes 30 years into the future, reads some patents he had written earlier, takes the patent information back in time and files them. Did the patents write themselves? So that's the bootstrap paradox; there's no contradiction here, but how did you create something out of nothing? And in other stories, Da Vinci is a time traveler, he brings back a picture of the Mona Lisa, and then he paints it, using the picture. Who designed the Mona Lisa? That was very strange, maybe that's why all the spumata, quantum noise. We'll discuss that. *A parallel universe?* We're just doing one universe here, we're running a budget. *It's not actually a contradiction?* It violates the second law of thermodynamics, we got something out of nothing. We got a free lunch. It's not a level one paradox, a straight contradiction, you're right. It's a level two, how did that happen? Where did it come from? It's a "where did you come from?" paradox. Every so often something random fluctuates into existence, but not like this stuff.

Robert Heinlein has a character in The Door Into Summer named Leonard Vincent who is zapped through a time machine into da Vinci's era and is never heard from again. His protagonist speculates that the guy might have been da Vinci, but it's never settled in the context of the book. In another story a time traveler goes back to da Vinci's time & winds up as da Vinci, all those machines being the traveller's memories of fantastic devices from his (well in our future) time.

The patents are for things like Flexible Frank, Eager Beaver, & Protean Pete.

ALL YOU ZOMBIES

The By-laws of time:

- Never Do Yesterday What Should Be Done Tomorrow.
- If at Last You Do Succeed, Never Try Again.
- A Stitch in Time Saves Nine Billion.
- A Paradox May Be Paradoctored.

Physic

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The third one is All You Zombies, another Heinlein story. How many of you guys have read this story? A little under half. *With the right side of my brain.* Okay, so the right side of the brain has read this story, and the left side not. You can start this story anywhere you like. We can start with baby Jane, who shows up at an orphanage, grows up into a young girl, is seduced by a vile, treacherous, lecherous, seducer, has a baby which is stolen from her, as a side effect of the operation to deliver the baby gets turned into a guy, I'm not explaining the medicine here, not the physics either, writes unmarried mother stories, because she's a guy who really understands a women's point of view, runs into a bartender, he I guess now it is, complains about having been seduced, and the bartender says, well I have this time machine, I'll take you back to the time of seduction and you can protect your younger, girlish self. The male self goes back, can't find the vile, treacherous, lecherous seducer, eventually sleeps with his earlier girl self, also serious problems with chromosomes and the danger of lethal recessives, he got so lucky, because 23 pair of chromosomes had to pair up exactly with no duplication in a lethal recessive. *Heinlein's heroes don't have bad chromosomes.* Words to live by--that was good. And eventually the bartender who's a time traveler, shows up, picks up our hero, realizes that he just did something really really bad, takes him forward into the future, recruits him into the time police, which is this little bit of loop here, and eventually after a long successful career in the time police, where he memorizes these sayings, turns into the bartender and kicks off the whole cycle again. So it's all self-consistent. We know where the baby came from, but no human being would ever do anything so obnoxious. It's a free will problem. The writer's typewriter has been controlling everything way hard. *The other point is there's only one character in the entire book.* Yes. That was true of a lot of Heinlein's books.

Paradoxes of free will:

On September 20, 1945, the Bartender drops off baby Jane at an orphanage. She grows up there. She dreams of joining one of the "comfort organizations" dedicated to providing R&R for spacemen.
Nearly 18 years later, the man who refers to himself as "an unmarried mother" is dropped off at April 3, 1963, by the Bartender. He meets and after some weeks of dating seduces the 17-year-old Jane, who has an intersex condition. From Jane's point of view, he then disappears; actually, he has been retrieved by the Bartender.
Jane becomes pregnant. After giving birth by C-section, she is found to be a "true hermaphrodite" who has been severely damaged by the pregnancy and birth; on waking she learns that she has been subjected (without her consent) to a "sex change" which reassigns her sex to male.
On March 10, 1964, the Bartender steals the baby and takes it back in time to the orphanage. Jane, now male, becomes a stenographer, and then a writer. Whenever he is asked his occupation, he replies, somewhat truculently, "I'm an unmarried mother—at four cents a word. I write confession stories." He becomes a regular at the bar where the narrator, the Bartender, works.
On November 7, 1970, the Bartender meets the Unmarried Mother, conducts him into the back office, and takes him back to 1963 to "find" the man who got him pregnant. He returns to the bar, seconds after going into the back room, and yells at the customer playing "I'm My Own Grandpa". From his own point of view he has carried out his mission of ensuring his existence.
On August 12, 1985, the Bartender brings the Unmarried Mother to the Rockies base and enlists him in the Temporal Bureau.
On January 12, 1993, the Bartender, who is also Jane/mother/father, arrives back at his base from 1970 to think about his life.

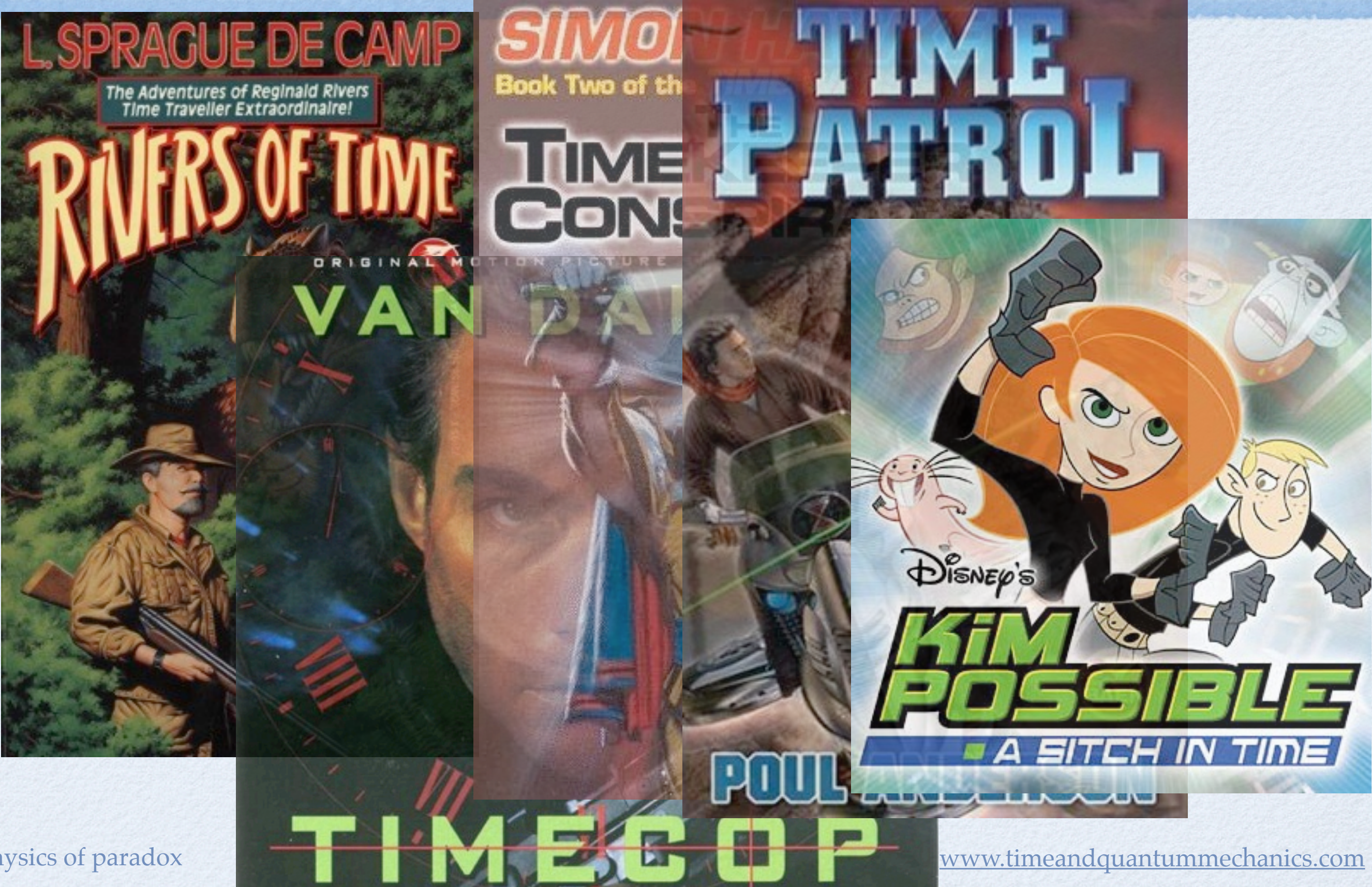
Bit like Heinlein who was not strong on characterization, most of his characters seem to have been younger or older versions of himself.

Heinlein's goal was to write the ultimate time paradox story. He may have succeeded. One of the more confusing elements is that the hero's whole career as a time cop happens off-stage, from where the drifter is recruited by the bartender to when the drifter becomes the bartender.

If our lad/lass/child/drifter/bartender goes off the rails at any point, the entire loop breaks. And if the chromosomes don't pair up exactly right, he/she/whatever can we move on now is at serious risk for a double-lethal recessive.

What would happen if Dostoyevsky's underground man wandered in.

Tales of the time police



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We avoid paradoxes in most time travel stories by the time police, and Kim Possible is not only a great heroine, but she's got a time monkey. Who can resist a story with time monkeys? But the universe should not require the use of the time police to keep itself consistent. So if we have a block universe, what consistency rules would we insist on in order to insure that we don't have paradoxes? Could we make up such rules? There are two views on this. Hawking wrote, "the laws of physics do not allow the appearance of closed timelike curves." I read a paper of his recently, in prepping for this talk, and his view is that if you try to invent a time machine, it will turn out to have some problem, like Visser was saying earlier. You just can't build it. So Hawking's view is that you avoid the paradox because we can't do it because we got lucky.

It shouldn't require either the time police or "space-time forces" to prevent paradox.

The lead story, from whence the quote, is "A Gun for Dinosaur". The hunter on the cover is actually a study of L. Sprague de Camp himself.

Compare & contrast with A Sound of Thunder.

2 CONSISTENCY PRINCIPLES

- Hawking: “The laws of physics do not allow the appearance of closed timelike curves.”
- Novikov: You can have closed timelike curves, and even travel along them. But if you go back in time, you can’t change anything that is already known.

Novikov's view is that it's okay to have closed timelike curves--a closed timelike curve is where you go up to the future and come back to the past and go up to the future. You can go along a closed timelike curve and go back to your past, provided you don't change anything. You can interact with the past but only in ways that don't invalidate your own personal past. *Heinlein actually used that in some of his stories. So did Poul Anderson.* Yeah, but the problem is the free will paradox, would people have acted like that, is the issue.

Quite a few paradoxes.

Those who argue that closed timelike curves can't appear included Hawking himself and Visser, who wrote an entire book on wormholes & related ideas. Visser has written that “the universe appears to exhibit a ‘defense in depth’ strategy [to forbid time machines]”. He admitted he couldn't find any general principle to forbid all time machines, but each specific example appears to be balked by one problem or another, e.g. It needs negative mass stuff to hold it open.

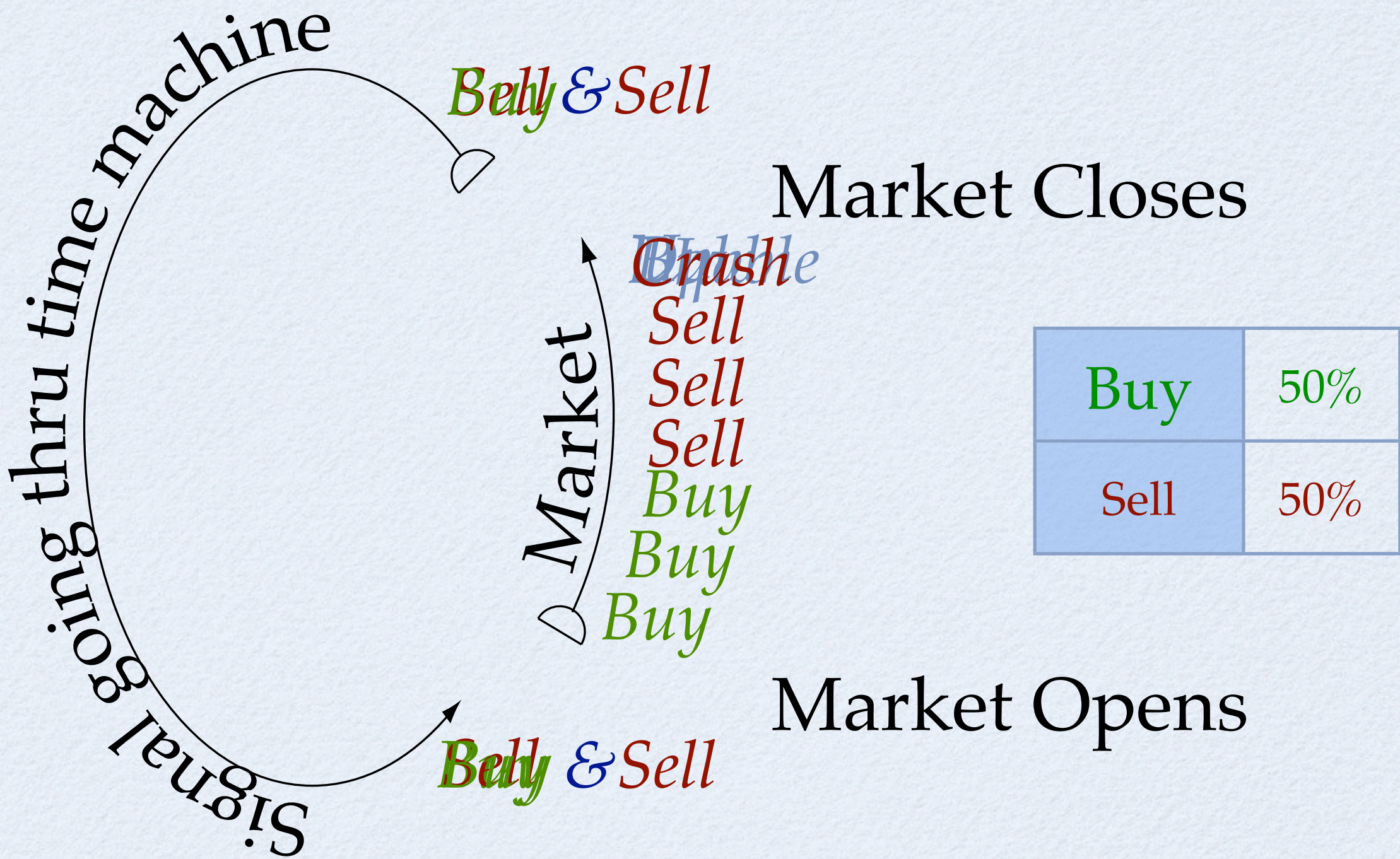
And quite a number of workers have proposed specific methods of throwing out the inconsistent trajectories. Curiously enough, this is much easier to do using quantum mechanics than classical mechanics.

One can think of time as a violin (cue Einstein): just as only certain harmonics can persist in a violin, only certain notes can be played in time.

In 1972 Peres & Schulman showed that closed timelike loops built with tachyons could be made self-consistent, in 1988 Thorne & Klinkhammer showed that playing billiard balls with wormholes could be done in a way that would not get you thrown out of the pool hall, in 1991 Deutsch showed that very general quantum mechanical time machines would always have at least one solution that was self-consistent, in 2005 Greenberger & Svozil showed that a simple apparatus with two mirrors and a time machine could be treated self-consistently, and in 2010, just a few months ago, Lloyd & collaborators found another way to make general quantum mechanical time machines self-consistent. So it can be done, though it is not entirely clear what the physically correct approach is.

We're going to look at the Peres & Schulman problem, the Thorne & Klinkhammer solution, & the Greenberger & Svozil solutions, focusing at bit on that last because it is particularly simple & because I rather like it.

A MARKET IN TIME



A whole bunch of people have been attacking this problem for the last ten years. In earlier versions of this talk I had a lot of examples of this type of problem, and it was taking too long, so I'm just going to use one. Greenberger and Svozil have said that if you have a closed timelike curve, and this a time machine and this is the stock market, or any market you like. It doesn't really matter for our example. You can send a quantum signal back, and everything is quantum mechanical, and it would tell you here, here's some information from the future, and then you do something with it, maybe buy or sell and go into the market and the market reacts, and you pay attention to that and send some information back. You can do the quantum mechanics and when you do the quantum mechanics and grind through the calculations. I actually made a point of tracking every equation in this thing and checking their work. It turns out that the paradoxes are self-canceling. So I'm going to walk through this, because this is an important point. Let's say the market goes up, and you decide to buy. You send a signal--buy--it's going to go up. So you buy now, and that's okay. You're not significant. Maybe it goes up a little bit less or something, but it goes up. At close of market, the stock or whatever went down. You're going to send a message back to sell and you sell and you'll be fine. Now let's say it goes up and people notice that you're really good at predicting the market. And I'd like to thank Ferne for a lot of help, Ferne over here, for a lot of help on getting this one not as wrong as it was earlier. And the market goes buy, buy, buy, cause this guy knows what he's doing. We've got a little bubble out. You've just created a little market bubble. And you send a signal--buy, there's a bubble coming up--and the buy goes back, and you're doing all this but at a certain point you get a tipping point and other people say, well wait a minute, why are all these imbeciles buying? This is ridiculous. This is a bubble. I'm going to sell. And they go, sell, sell, sell, crash. And now what happens? You're going to want to send a sell message back. And you're going to get a sell message here, and now what we have is total confusion. What actually happens, if Greenberger and Svozil are to be believed, is that if you're using like up means buy and down means sell, your little radio circuit or whatever kind of time machine you have, it really doesn't matter is going to show 50 % with ups and 50% with downs. *That works in quantum mechanics, but it doesn't work with the market because in the market, unless you're coming in at the bottom with a lot of money, you can't produce a bubble by yourself.* Yeah, there are many problems with this, but the basic takeaway here is that if the information you are transmitting would create a paradox and it's a quantum mechanical circuit, the result of the information will be to produce an average of the yesses and nos or whatever the paradox aspect was. I'll grant that there are many problems with the specifics of a market example, but you pick the subject and if you are quantum mechanical and our atoms wouldn't exist if quantum mechanics weren't true, so you're all quantum mechanical, get over it, let's move on here, nothing to see guys, half will be up, half will be down, or whatever it is.

Here we look at a simplified version of the Greenberger & Svozil experiment.

Can use spin 1/2 particles. Can be set to point up or down. We'll make up green or good news, down red or bad news.

First setup a Greenberger & Svozil apparatus, assign our signal a wave function and give the market a -- somewhat bigger -- wave function. The little D's are detectors.

We detect what the market is going, and send a signal back. We're cheerful people here, we assume that the market is going up. We send back green. And we buy a bit, not enough to do anyone else any harm, just a bit for that rainy day that might be just around the corner.

No problem, we're too small to notice, the wave function of the market is unchanged.

But now we have been doing this for a while, we are big enough to "move the market". When they see us buy, they buy to, price goes down and we would have rather sold, quite frankly. And versa vice. Oops.

What does our signal show now?

It turns out that any system which can have spin up & down also can have spin left & right. Or other possibilities. But not just up & down. We'll stick with left & right here.

It turns out the solutions of our equations, doing the G & S trick, and no matter how little the market notices are pure left & pure right. We'll go with left here because obviously some leftists are responsible for this.

And what if we force the detector to go cheerful buzz on up, annoyed whine on down? 1/2 cheerful, 1/2 sad, but neither useful. All we are really getting is noise!

Paradox noise.

PARADOX NOISE



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In the literature, what would this look like? There are a number of wonderful examples of this done right, of actually this effect. Sagerhagen's After the Fact, where a couple of guys go back and try and save Lincoln. And all they hear on their time radio is the crackle of paradox noise. What date was I supposed to be at? What theater was that? Crackle, crackle, crackle... and they can't get to save Lincoln. In Connie Willis's Doomsday Book, the time machines are subject to slippage, meaning you aim the time machine at something and if your arrival there would create a paradox, you'll be in the wrong spot or the wrong time. You're in a Wolfman Jack song, could have been the right place must have been the wrong time. So that's how time protects itself. That's what it would look like in practice. It's just the time machine won't work. Well, we knew that. You could get close, but you can't ever create a paradox. In Twelve Monkeys, it seems the same kind of thing is happening. How many of you have seen Twelve Monkeys? Again, about half. You know, he keeps going back trying to prevent the plague, but he fails, cause he never winds up at the right place or the right time. But what he does get is even more information about the plague, which is useful to his future. So he can get non-contradictory information back.

"YOUR ONLY CHANCE LIES IN PREVENTING THE ASSASSINATION OF PRESIDENT ABRAHAM LINCOLN ..."

"What?"

A burst of audio and visual static reduced reception to unintelligible noise. Then the paradox-generated interference was gone again, as suddenly as it had come.

" . . . Fourteenth of April at Ford's Theater --" blast, crackle.

WHAT DOES THIS MEAN?



- What does paradox noise look like?
- Can you avoid it?
- Can you use it?

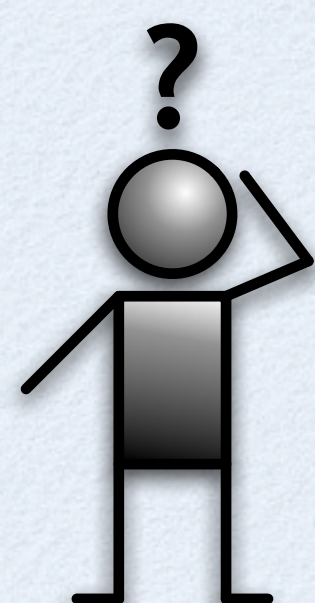
What does all this mean? Which takes us to the last question and the last five minutes. This is Oedipus consulting with the sphinx. You all know the story of Oedipus? He got information, or his parents did, from the future, saying your son will marry his mother and kill his father. This is a negative in every society, so that they dump the loser, but it doesn't happen, and he gets taken in by a friendly king. And then when he's a young man, he hears the same prophecy, he thinks it's the king and queen who adopted him, and he goes over to his native city of Thebes, and it turns out that he's fulfilling the prophecy rather than contradicting it. So the paradox noise in this case is he didn't understand which king and queen the prophesy referred to. That's paradox noise. A perfect quantum mechanical example from two and a half thousand years ago. You have to love it.

Looks like noise, frankly

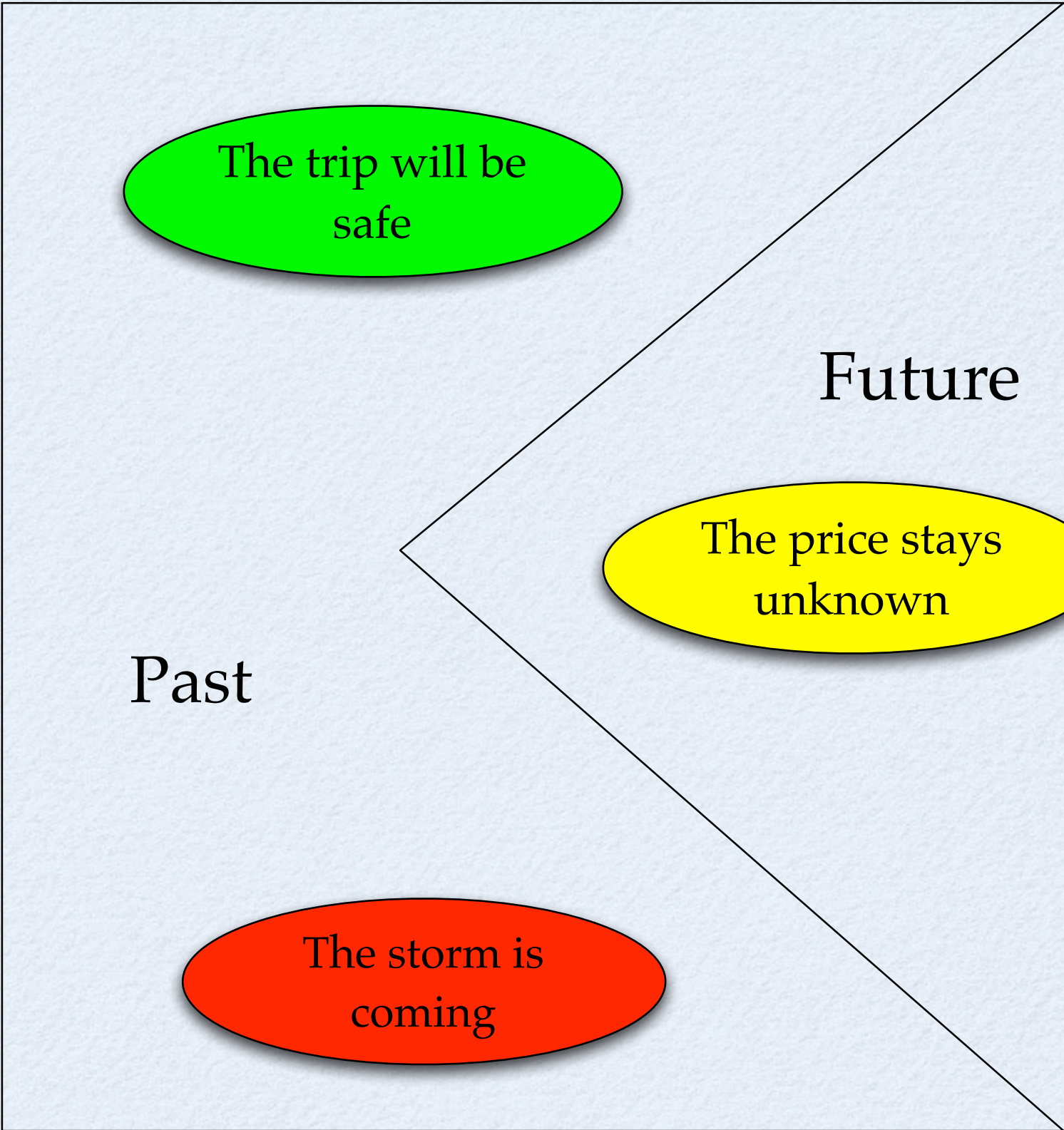
Avoid, yes.

Use, yes.

CRYSTALLIZING TIME



Now



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So what does it look like? How do you avoid it? How do you use it? This is us now. And let's say we look into the future and we get some good news. The trip will be safe, no contradiction. We get to take the trip. We hear the storm is coming, that's what is says on the little red thing, and okay, not what we wanted to hear, but no contradiction. And then we look at the price in the future and if our knowledge of the price would somehow create a paradox, the price stays unknown. So that's what it would look like if this is all true.

Crystallizing time (Halpern)

Self-fulfilling: macbeth, oedipus rex

Self-refuting: 1984, Brave New World

TIME IN TIME TO COME

- Everything not forbidden is compulsory. — Gellmann
- If at first an idea does not sound absurd, there is no hope for it. — Einstein
- The only way of discovering the limits of the possible is to venture a little past them into the impossible. — Clarke

There are a couple of principles I want to leave you with, we're at the penultimate slide here. This is Gell-Mann's Totalitarian Principle, Gell-Mann I think got the Nobel Prize, although not for this principle, but basically in the laws of physics, anything which is not forbidden by some conservation law, like conservation of energy or paradox, is compulsory. We'll eventually find it. They predicted anti-matter because it was a solution of the quantum mechanical equations, and eventually we saw it. Everything which can happen, will. And this is very inspirational. And basically we know we have to jump out of the box somehow on this one. The first step will seem absurd. So here's more absurdity.

And this is Arthur Clarke, another one of our heroes, the only way to discover the limits on the possible is to venture a little past them. There's a wonderful line by Oberg, saying you want to keep an open mind, but not so open that your brains fall out. On the other hand, if the brains don't get a little fresh air, you know, where is inspiration?

ATROPOS -- AKA FATE #3



- Time travel may be possible
- But if so, paradoxes will be self-canceling
- Whether the paradox is intended or not

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So basically at this point, time travel is possible, or little wormholes might be possible if string theory is true and the Large Hadron Collider works as Mironov says. Time travel is not forbidden by paradox because it's self-canceling. This is Atropos, third of the three Greek fates, Clothos spins the thread, Lachesis weaves the thread, and Atropos tidies up with her shears. This is from Neil Gaiman's Sandman, by the way.

Time travel may be possible, paradox is self-canceling, and this has nothing to do with free will or anything. The paradoxes are self-canceling by the way the equations work out. So no grandfather paradox, no bootstrap paradox--you still have to do the work--no free will paradox.

Clotho is the fate that spins the thread, Lachesis weaves it, & Atropos cuts it off

2nd law of thermodynamics

No perpetual motion machines

You don't know where the perpetual motion machine will fail, only that it will.

Lenz's law

If a paradox can be paradoctored, the universe is self-medicating

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When “highly” improbable
just isn’t improbable enough!



Don’t get lost, take Oceanic!



The terminal alternative!

THANKS!

- Ferne Welch
- Nathan Evans & Colleen Cahill
- Margaret Trebling
- Library of Congress & Capclave
- Philcon

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