The physics of time travel

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Outline

What is time?

The direction of time

Relativity and time

Quantum mechanics and time

Wrap up

What is time?

"The indefinite continued progress of existence in the past, present, and future regarded as a whole"*

**Google dictionary*

What about in a practical sense?

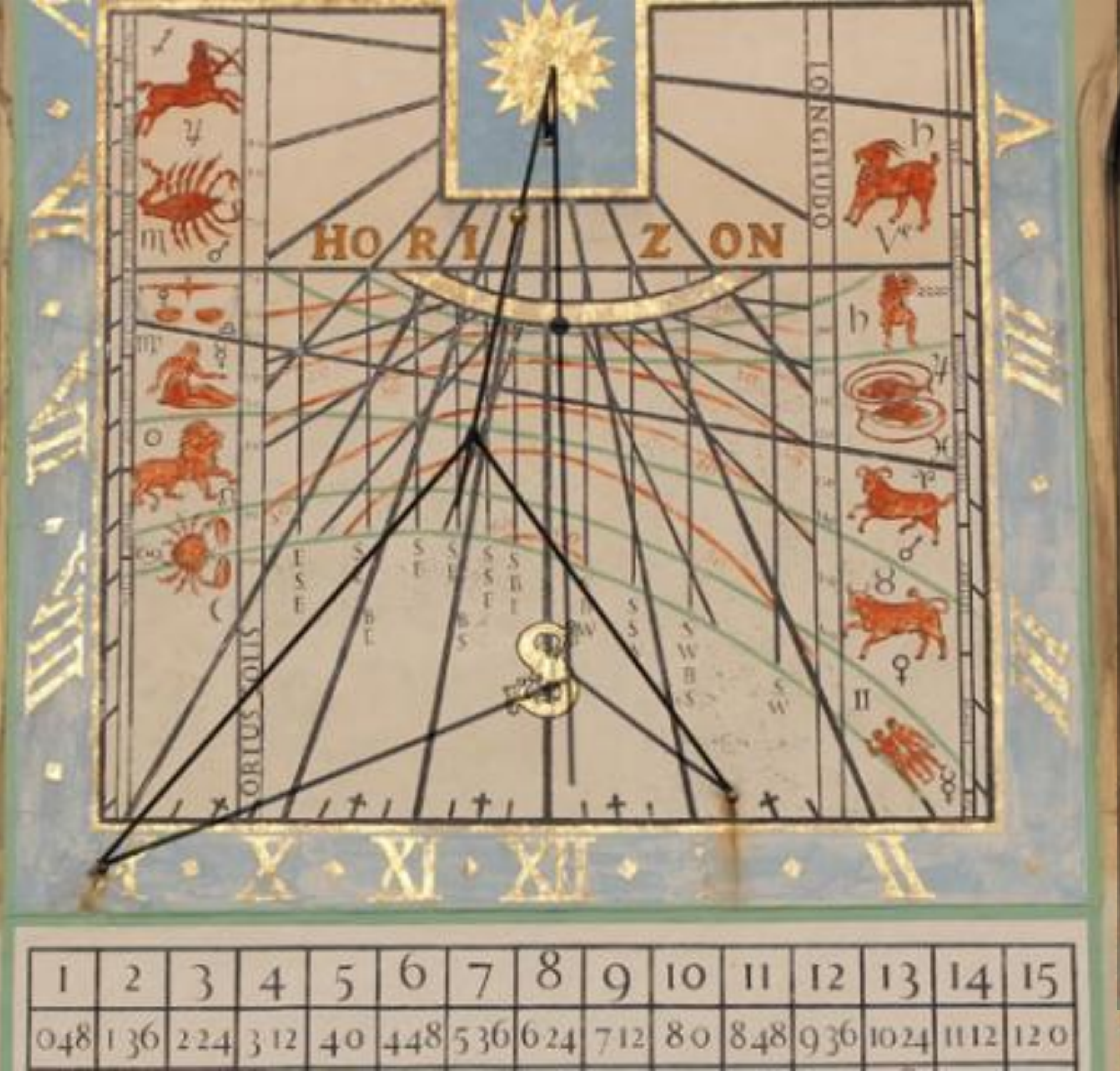
A Brief History of Time(keeping)

Since prehistory humans have used the sun and stars to define time.

Stonehenge at dawn of the summer solstice

Andy Roland/iStockPhoto.com

This sundial at Queen's College, Cambridge University was rumored to have been designed by Isaac Newton and built after his death in 1727.



"The sundial tells not only the hour of the day, but also the month, the zodiac sign, the time of sunrise and the hours of daylight. The curved, green lines mark the summer solstice, and the equinoxes. A table underneath provides the moon's hour-angle for each day of the lunar cycle, enabling the dial to be used as a moon-dial."
– Cambridge U.

Reading the sundial: shortly after noon on the winter solstice.

Cyclic Time

The astronomical picture gives us time as a cycle of events.

There are longer astronomical cycles than one year.

For example, the Earth's north pole is slowly precessing in a circle relative to its orbital axis with a period of 25,772 years.* This means the star identified as the "North Star" and the zodiac constellations change slowly over time.

Some current hypotheses say that the entire universe is one long cycle of growth and collapse.†

**First described by the Greek astronomer Hipparchus in 129 BCE.* (Encyclopædia Britannica, *online edition*)

† L. Baum, P. H. Frampton (2008). Modern Physics Letters A. 23 (1): 33–36.

A Brief History of Time(keeping)

Since prehistory humans have used the sun and stars to define time.

The scientific definitions of second, hour, day, year, etc., were all based on astronomical observations until…

1967,* when the second was defined by frequencies emitted by particular atoms (atomic clocks).

*Bureau International des Poids et Mesure, *The International System of Units (SI)*, 8th ed. 2006.

Which Way, Time?

The laws of physics (e.g. Newton’s Laws and Schrödinger's Equation) don’t specify which direction time runs.

Forward and backwards are the same.

One potential consequence of this is that the future is just as determined as the past.

Awesome video series by minutephysics and Caltech’s Sean Carrol: https://www.youtube.com/watch?v=yKbJ9IeUNDE

The clockwork universe

We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect* which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes.

Pierre Simon Laplace
A Philosophical Essay on Probabilities (1814)

Engraving of Laplace by James Posselwhite (Source: Royal Society of London)

** The "intellect" was later given the name "Laplace's Demon."*

Which of these is running forward?

Physics tells us the sand at the bottom of the glass has more entropy, in the form of added heat and from the radiation of sound as the sand falls.

Note that energy arguments are not sufficient to determine the direction of time. If we could somehow re-organize the lost heat and sound, we could make the sand run backwards.

pitzaman/Tenor.com

The passage of time leads to disorder

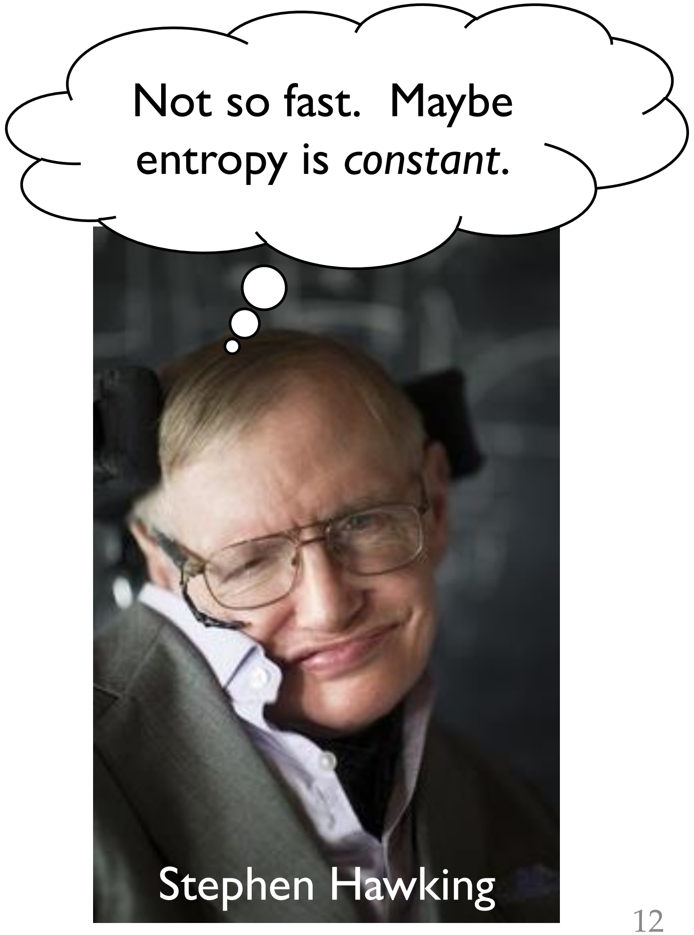
Rather than appealing to the laws of motion, the laws of thermodynamics seem to set the order of time.

The Second Law of Thermodynamics states that the entropy (disorder) of a closed system increases over time.*

This gives cause and effect clear meanings.

It also makes *dissipation* a marker of time.

** First stated by Rudolf Claussius in 1854. This modern formulation is due to Max Planck, 1926.*



My clock is not your clock

Enter Einstein.

Einstein began with the simple premise that the *Laws* of Physics must be the same for every observer.

In order to give this statement mathematical teeth, it requires *different observers to measure different values regarding the same events*.

In particular, the speed of clocks and the lengths of rulers depend on their motion (velocity and acceleration)*.

Albert Einstein, ca. 1905 (Berne History Museum)

** The dependence on velocity is called Special Relativity (1905) and the dependence on acceleration (also gravity) is called General Relativity (1915).*

The Light Fantastic

The one Law of Physics that has the deepest implications is part of Maxwell’s Equations of Electricity and Magnetism*, which say light in the absence of matter travels at exactly the speed

299,792,458 meters per second.†

Per Relativity, all observers must agree on this speed.

The rest of the consequences of Relativity are derived starting from this one point.

** Maxwell, J. C. (1865). Philosophical Transactions of the Royal Society of London 155, 459–512.*

† This is now considered an exact number, not subject to verification. Combined with the definition of 1 second based on atomic clocks, it defines the length of 1 meter.

Maxwell originally had 20 equations. Modern math has combined these into one!

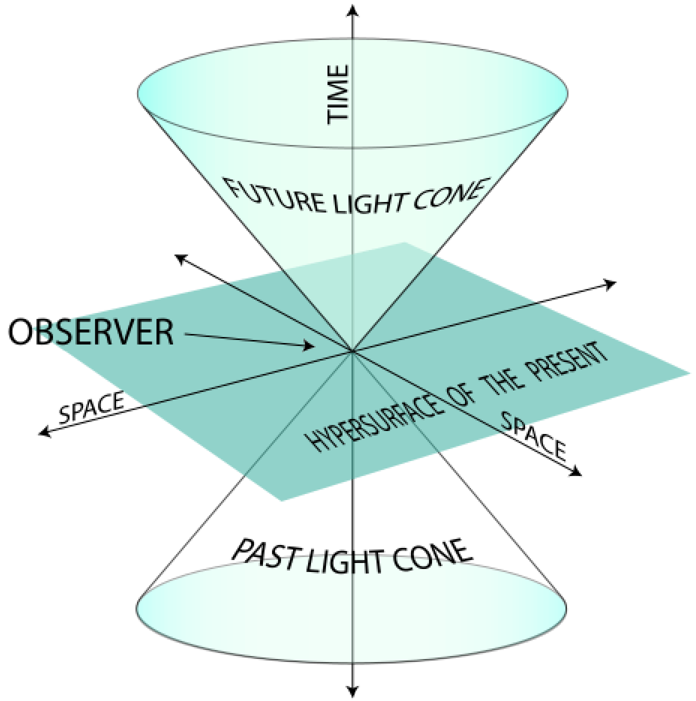
Causality in Relativity

Relativity also says that no object with mass may travel at or faster than the speed of light.

This makes light the arbiter of causality.

If two events are too far apart in space and time to pass light between them, then they cannot be causally related.

If light can go between two events, then the direction of light sets the order in time.



Time as a series of events

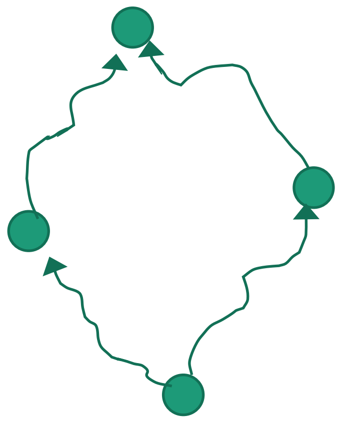
Because we have a definite arbiter of causality, we can define sequences of events chained together by the possible passage of light.

Such a chain of events is what we mean by *timeline*.

If two events are too far apart in time and space for light to travel between them, then they cannot influence each other.

These two events could possibly have a common ancestor or jointly influence the same future event.

So, the crew of the Voyager, 70,000 light-years away from Earth, can't have any influence on current events there.



Relativity does not induce paradoxes

Every observer will agree on the events that occur, and more specifically, on the causation of events, but perhaps not the *order* of events.

What differs between observers are the records of time and position, but Einstein gave us equations to translate from one observer to another.

If we know what one observer sees, we can calculate what any other observer would have seen by equations called the Lorentz Transformations.

Therefore, Relativity does not imply the universe is subjective.

When causation exists, it defines a particular order of events.

When no causal link exists, the order may be arbitrary.

Does anybody really know what time it is?

Because of relativity, every clock has its own speed. So, how do we define time?

We could pick one clock to be the "master clock." This would work as long as it is trustworthy. Some spinning stars (pulsars) are steady enough that they make good clocks.*

The best human-made atomic clocks are slightly better though, being accurate to 1/10th of a second over the age of the universe.†

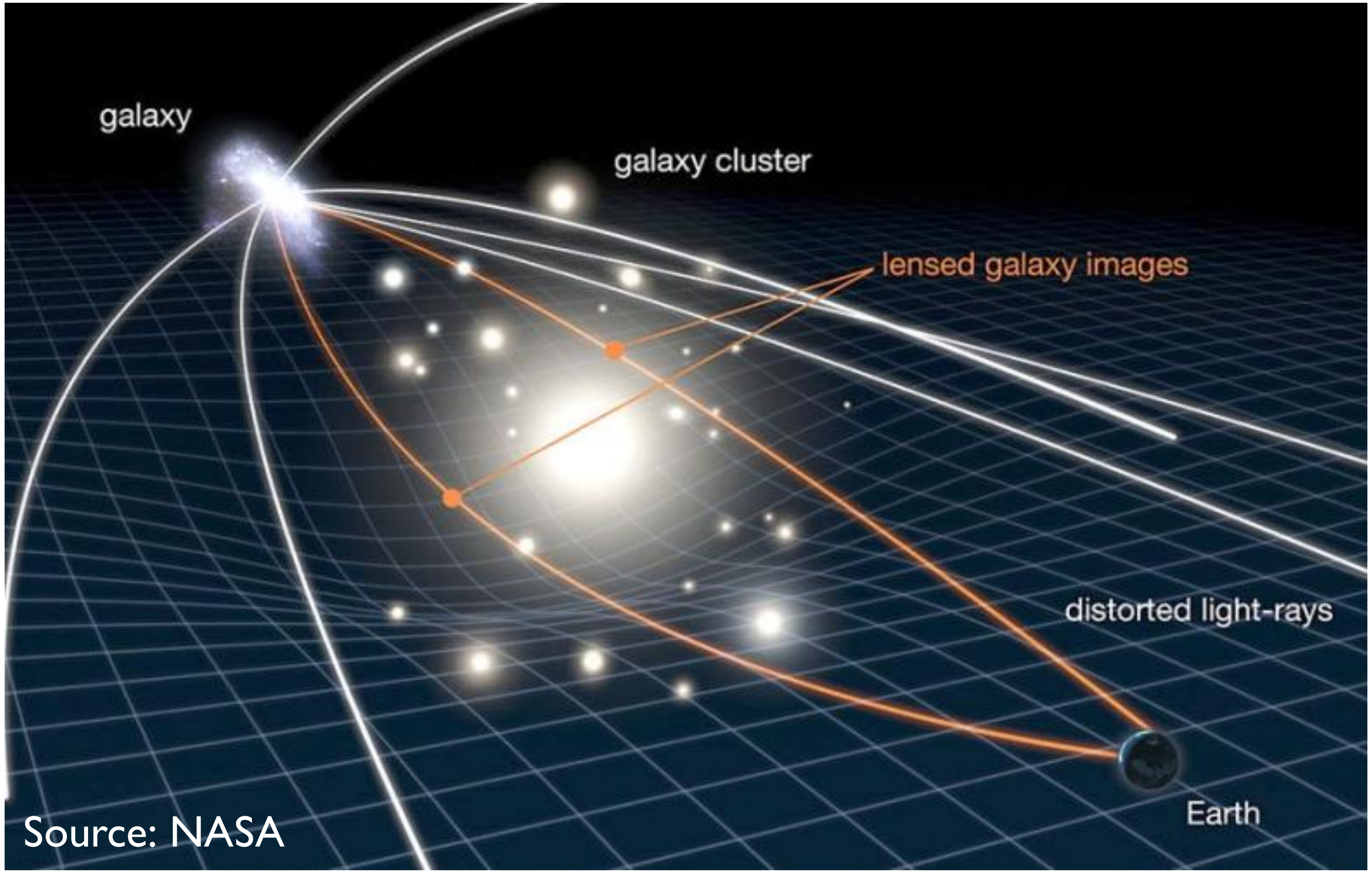
Better yet, build many clocks and average them. This is our actual solution. Time is set by *treaty*.‡

**Matsakis, D. N., et al.; (1997). Astronomy and Astrophysics. 326: 924–928.*

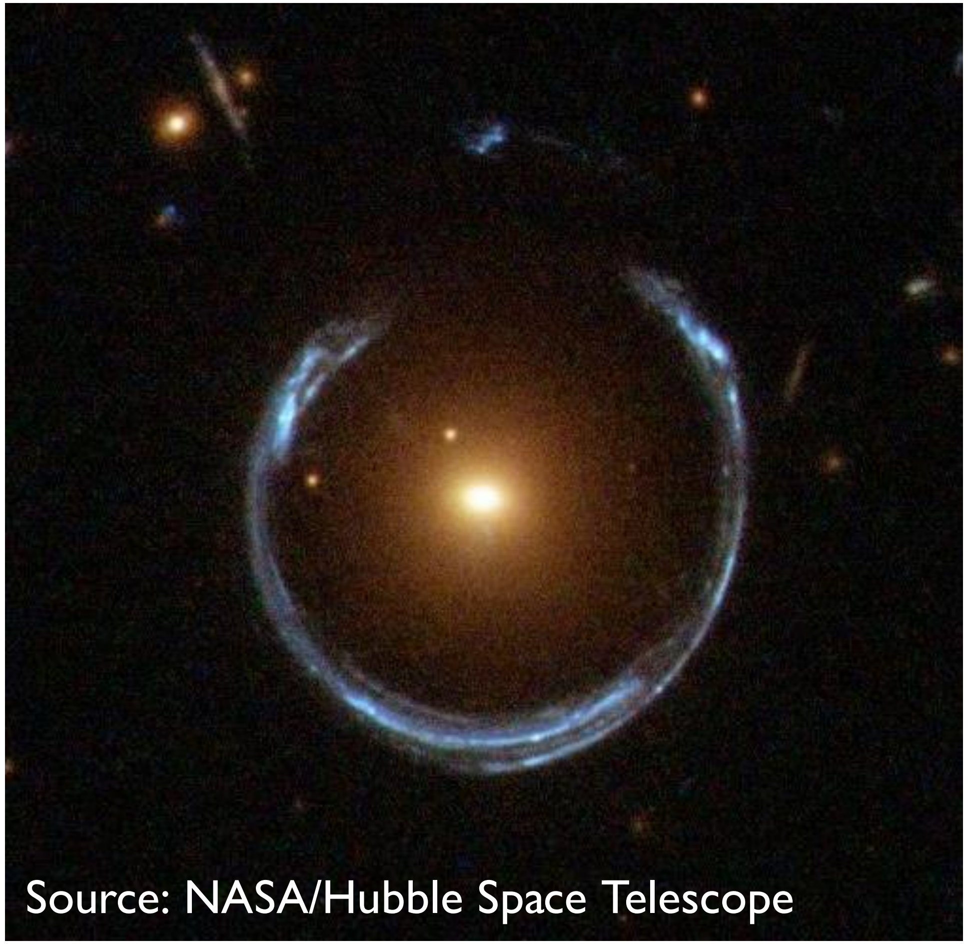
†Marti, G. E., et al. (2018). Physical Review Letters. 120 (10): 103201

‡c.f. Wikipedia "International atomic time."

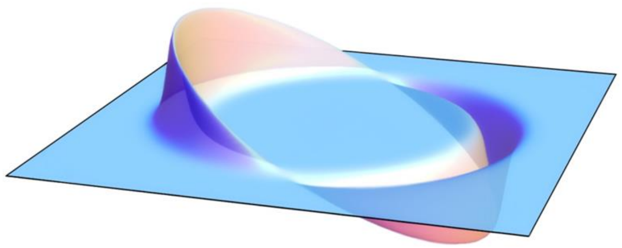
General Relativity: The fabric of space and time



Source: NASA


Source: NASA/Hubble Space Telescope

Bending the rules: Faster than light



Alcubierre's "warp field" (source: Wikipedia)

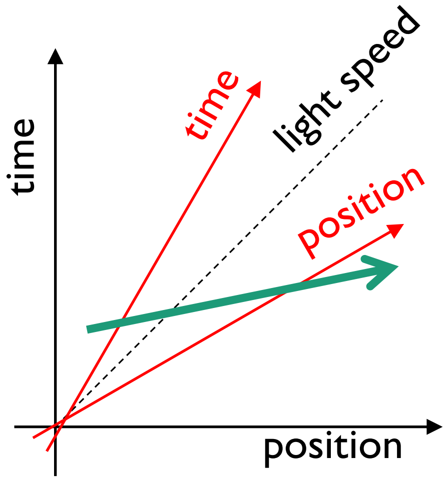
In 1994, Miguel Alcubierre published a solution to the equations of General Relativity that is basically the "warp field" described by *Star Trek*.

The catch is that it requires a source of "negative energy." There are a couple of ideas for creating negative energy,* but no experimental proof.

** The Casimir Effect and Dark Energy. These are real things, but beyond current technology.*

Any faster-than-light travel would be perceived as backwards time travel by some external observers.

Relativity saves us from any paradoxes because the events at either end of the FTL travel are too far apart in space to be causally related.



Bending the rules: Wormholes

A wormhole is a hypothetical bridge between one point in space and time and another. The equations of General Relativity allow it, but we have never observed one.

A stationary wormhole would allow FTL travel, but with the same logical restrictions as a warp drive.

An accelerating wormhole could be used as time machine,* but this requires a machine to move it. The earliest time accessible would be the instant that the machine is turned on.

The Wikipedia page for "wormhole" has a lot of good information about the science.

The ST:Voyager episode "Eye of the Needle" (S1E7) features a worm hole between the Delta Quadrant of the galaxy and the Alpha Quadrant. It is too small to travel through, but the Voyager crew are able send messages.

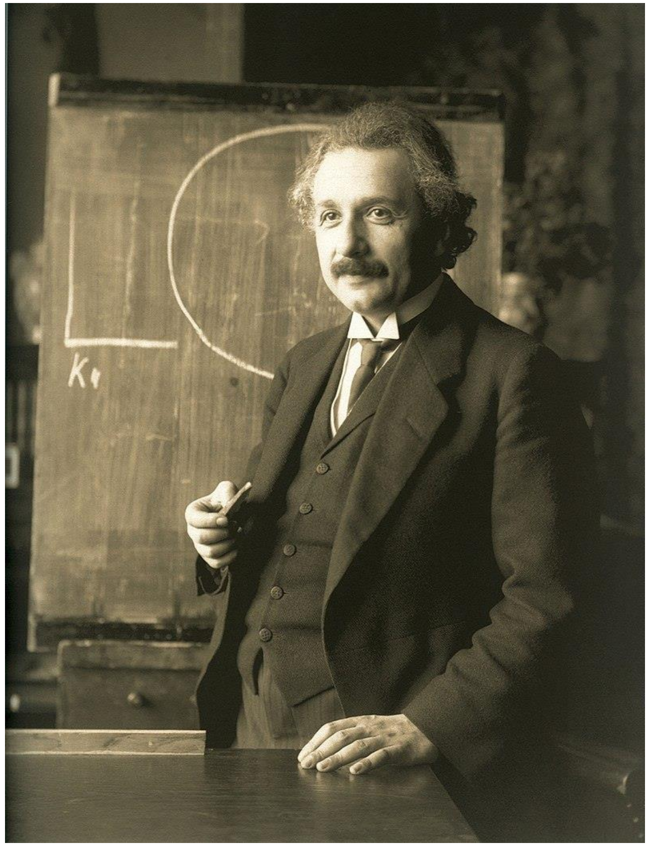
**Morris, M.; Thorne, K.; Yurtsever, U. (1988). Physical Review Letters. 61 (13): 1446–1449*

Question Time!

Einstein did all of these things!

Albert Einstein was awarded the Nobel Prize in 1921 for his work on….

1. Special Relativity
2. General Relativity
3. Quantum Mechanics
4. Convincing F. Roosevelt to build the atomic bomb
5. Explaining the motion of dust motes



Albert Einstein, 1921. Photo by F. Schmutzer (Wikipedia)

The death of Laplace's Demon

At the dawn of the 20th century, scientists thought all of the Laws of Physics had been discovered. There were only a couple of minor loose ends to tie up and the universe would be solved.

One of these loose ends, the spectrum of light emitted from hot objects (blackbody radiation,) eventually led to the end of predictive determinism, thus slaying Laplace's Demon.

Solving this problem needed an inherently random description of nature: quantum mechanics.

Superior Forge & Steel Corp.
Pittsburgh, PA

Relativity also invalidates Laplace's Demon, by preventing it from knowing everything at one moment, because that information itself can travel no faster than the speed of light.

Quantum mechanics in one page

Max Planck solved the blackbody equations* by assuming that energy comes in indivisible chunks, later called "quanta."

This set off a series of falling dominoes:

1. Einstein postulated that the quanta are real, not just mathematical ideas.
2. Millikan did the experiment proving Einstein right.
3. Bohr used this idea to explain the light emitted by hydrogen atoms (i.e. the color of starlight).
4. Schrödinger showed that these earlier steps mean that *all matter is made of waves*.

All of these steps are more than ideas, they are mathematical or experimental proofs!

** Planck, Max (1901). Annalen der Physik. 4th series. 4 (3): 553–563.*

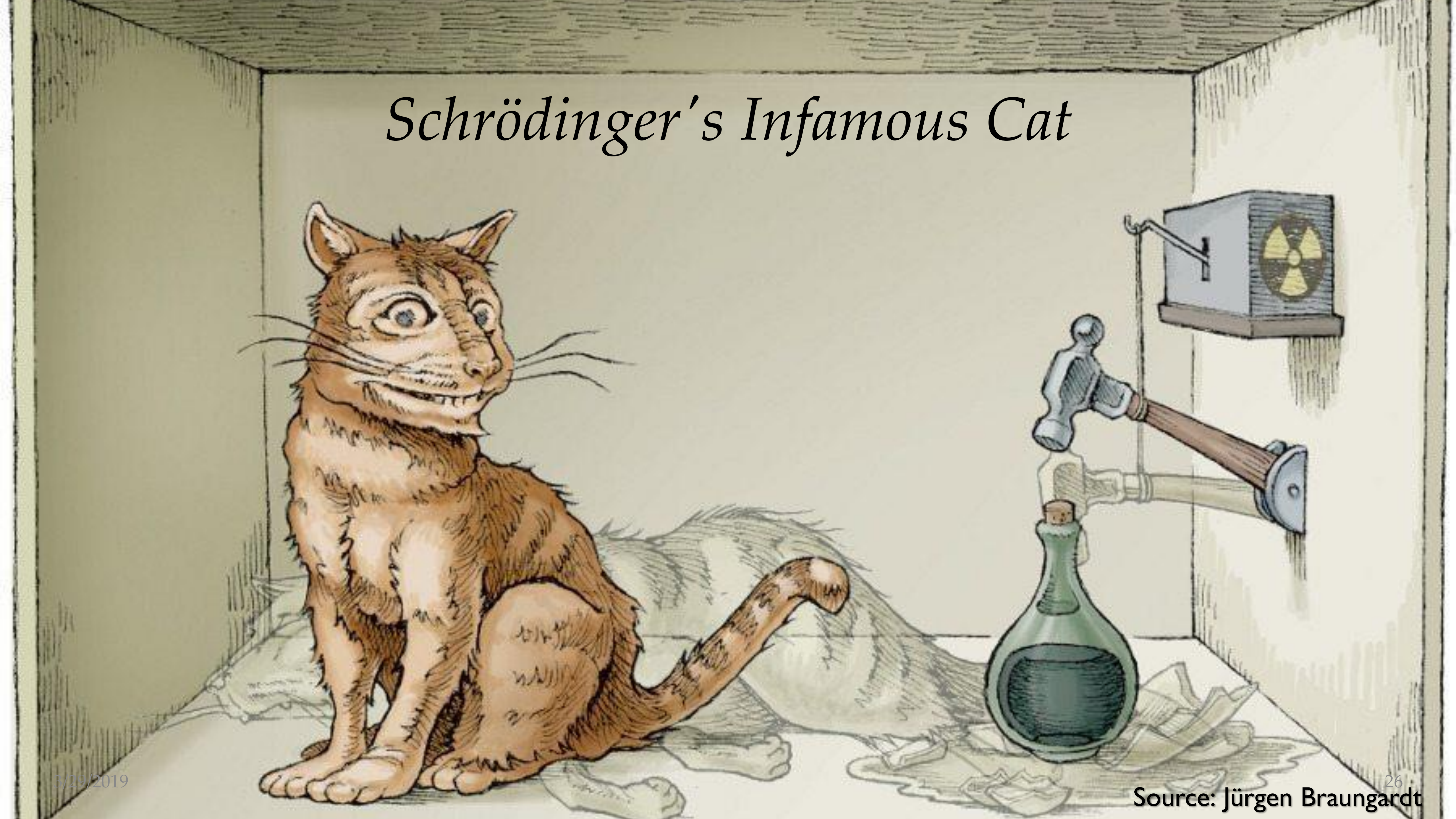
[1]Einstein, A. (1905). Annalen der Physik. 17 (6): 132–148. This is Einstein's Nobel Prize, not Relativity!

[2]Millikan, R. (1914). Physical Review. 4 (1): 73–75.

[3]Niels Bohr (1913). Philosophical Magazine. 26 (151): 1–24.

[4]Schrödinger, E. (1926). Physical Review. 28 (6): 1049–1070.

Schrödinger's Infamous Cat



Source: Jürgen Braungardt

Schrödinger's Infamous Cat

The Cat was Schrödinger's attempt to sabotage his own work by *reductio ad absurdum*.* The story goes…

1. A cat is placed in an isolated box with a jar of poison that is opened if a particular radioactive atom decays.
2. We close the box and wait.
3. Some time later, we open the box and observe if the cat is dead or alive.

By the equations of Quantum Mechanics, during step 2, the cat is in an indeterminate state of being both dead and alive simultaneously.*

**E. Schrodinger, Naturwissenschaftern. 23 : pp. 807-812; 823-823, 844-849. (1935)*

The history of quantum mechanics can be told through the various neuroses of the players: Planck, Millikan, Schrödinger, Bohr, Dirac, etc.

**Yes, we can do the experiment, but we use atoms instead of killing cats.*

Measurements are mysterious, still

In quantum mechanics, measurements are sudden, violent,* actions.

When we perform any measurement (looking into the cat's box), the system is forced into a definite state randomly chosen from the possibilities.

The system evolves by Schrödinger's Equation when we are not looking, but the math of what happens during the measurement process itself is still unknown, spawning many "interpretations" of Quantum Mechanics.

**"Violent" in the classical sense – forcing one's will on another.*

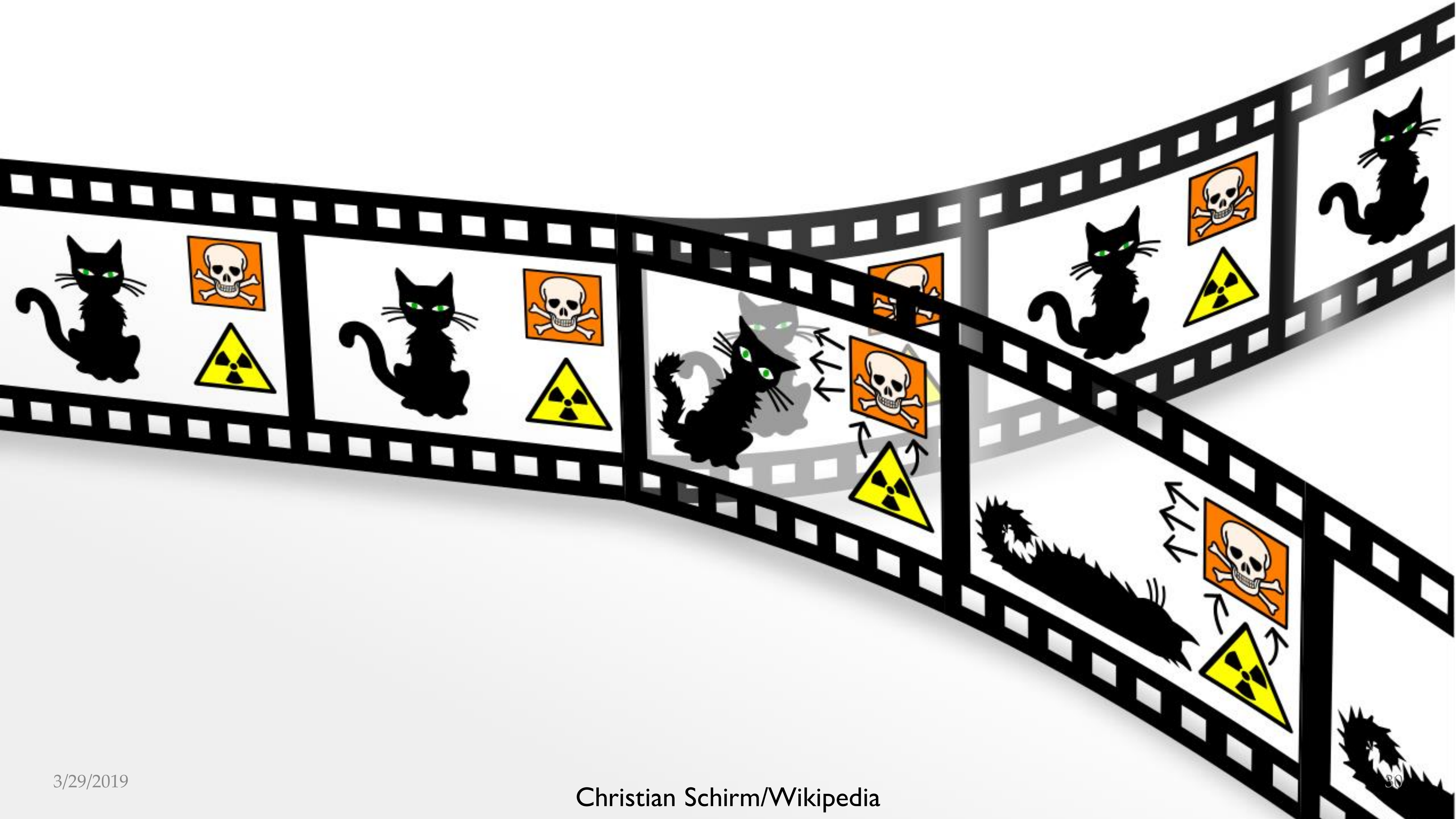
Here I'm using Bohr's "Copenhagen" Interpretation of the laws of quantum mechanics. Another viewpoint will come…

Don’t kill the cat, split the universe

Hugh Everett* tried to work around the suddenness of “state collapse” by proposing a different solution: all possibilities happen, but in different universes.

**Everett, Hugh (1957). Reviews of Modern Physics. 29 (3): 454–462.*

The various interpretations of quantum mechanics are the subject of ongoing “holy wars.” We don’t yet have experimental technology to settle the debate with data.



Christian Schirm/Wikipedia

Many Worlds = Many Timelines

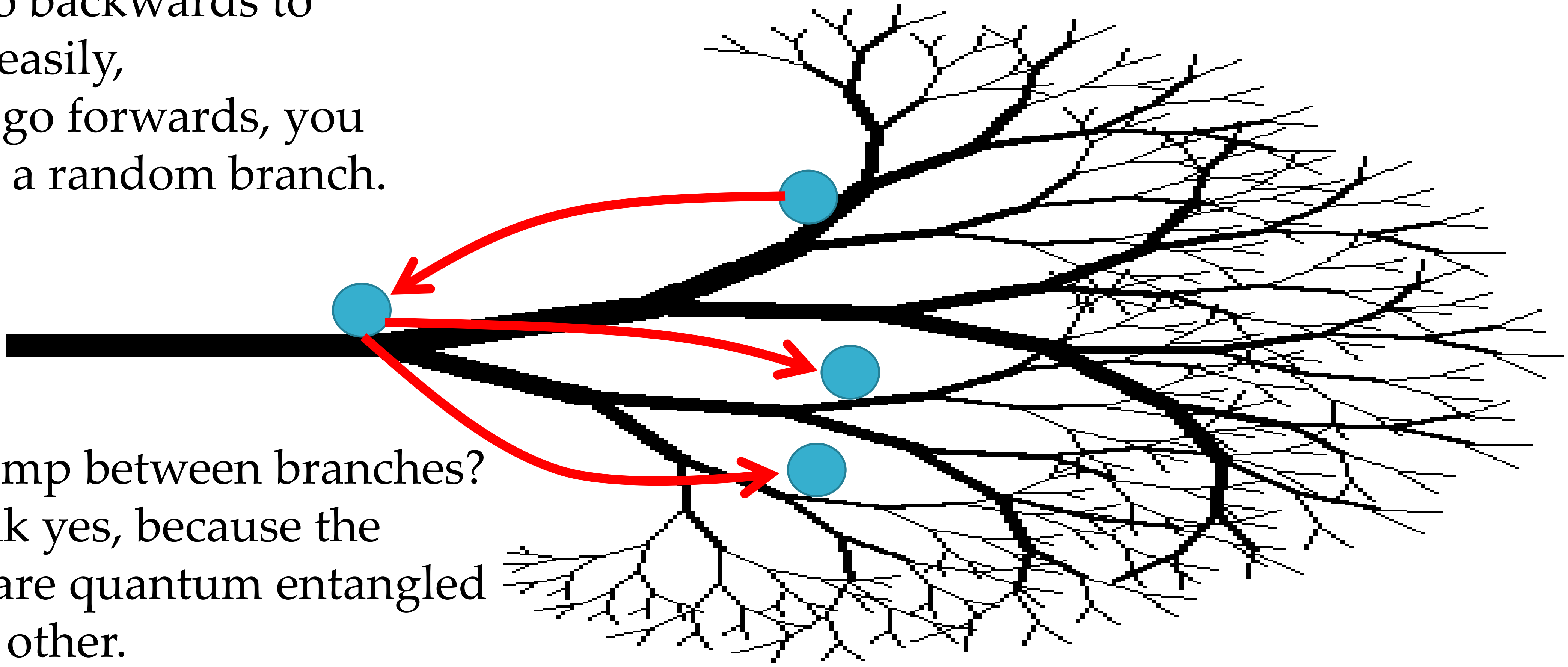
Others later named Everett's idea as the "Many Worlds Interpretation," but we could easily call it "Many Timelines."

If this is the true picture of the universe, what does it say about time travel?

Everett himself called this idea "relative states."

Branching time

You can go backwards to your past easily, but if you go forwards, you end up on a random branch.



Can we jump between branches? Some think yes, because the branches are quantum entangled with each other.

The end of (our) time

I hope you now have some sense of the science of time, and how we might build plausible explanations of time travel.

In case I wasn't clear, to the best of our knowledge, *time travel is not possible in our universe*, but with some small changes to the Laws of Physics, we can start dreaming.

I'll leave the last word to Byron:

> *'Tis strange but true for truth is always strange;*
> *Stranger than fiction*