Episode Book

EPISODE #6691

Why the Speed of Light Forces Time to Stretch

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SYNOPSIS

If the speed of light is identical for every observer, then distance and time have to bend to keep the math intact. Using Einstein's own thought experiments, this conversation unpacks special and general relativity without heavy equations. It walks through Galileo's ship, the bouncing-pulse light clock, length contraction, and why the twin paradox isn't actually a contradiction. Along the way, it sets up the leap from flat spacetime to gravity as curved geometry.

TRANSCRIPT



Corn

"Everything is relative" is the most quoted sentence in physics and the least understood. Daniel's asking us to fix that.



Herman

He names me specifically, so I'll take that seriously.



Corn

His prompt is, in his own words, he wants to come away with "an intuition for it rather than just the famous one-liners." Why does the speed of light being the same for everyone force time and space to stretch, and what does gravity-as-curved-spacetime actually mean. He wants the picture, not the slogan.



Herman

That's a good brief, because the theory was built out of pictures. Einstein did this sitting in a chair. The light clock, the elevator, the accelerating rocket, all thought experiments. Everyday analogies aren't a concession here, they're the native language of the subject.



Corn

Which is convenient, because neither of us can operate a particle accelerator.



Herman

Speak for yourself. Okay, the frame. There are two theories with one name. Special relativity, published September twenty-sixth, nineteen-oh-five, in a paper called On the Electrodynamics of Moving Body. That's the physics of space and time when you ignore gravity entirely. General relativity, published May nineteen-sixteen, folds gravity in, and folds it in by doing something strange: it stops treating gravity as a force and treats it as a property of the geometry of spacetime itself.



Corn

Special first. What's it built on?



Herman

Two postulates. That's it. One: the laws of physics are identical in all inertial frames, meaning any frame moving at constant velocity. That one's not even Einstein's, it goes back to Galileo in sixteen thirty-two. He described a ship sailing smoothly and said you can't tell, below decks with the windows shuttered, whether you're moving. Two: the speed of light in vacuum is the same for all observers, regardless of how the source or the observer is moving. That's about three hundred thousand kilometers per second. Roughly seven times around the Earth in a second.



Corn

Seven laps a second.



Herman

And that second postulate is the grenade. Because it sounds harmless, until you ask what it does to everything else. Because speed is distance over time, and if the speed won't budge no matter who measures it, then distance and time have to be the things that budge.



Corn

Let me make sure I've got the grenade pin pulled, though. Where does the second postulate even come from? Why did anyone believe it?



Herman

Because that's what Maxwell's equations of electromagnetism kept insisting. When you work out the speed of electromagnetic waves from Maxwell's theory, you get a number, and the number doesn't come with a footnote saying "relative to what." It's just the speed. And experiments kept agreeing, most famously the Michelson-Morley setup in eighteen eighty-seven, which tried to detect our motion through the supposed light-carrying medium and found nothing. No headwind. Einstein's move was to stop treating that as a puzzle and start treating it as a fact.



Corn

So the most counterintuitive sentence in physics comes from taking the equations at their word.



Herman

That's most of Einstein, honestly. The whole episode is that sentence, really.



Corn

No, the whole episode is that sentence cashed out. The famous compression, where we're headed, is Wheeler's line, John Archibald Wheeler: space-time tells matter how to move, matter tells space-time how to curve. That's general relativity in one breath. But you can't feel why that line is true until you've felt the light clock. So let's build it.



Herman

Go. I'll hold the mirrors.



Corn

You hold the mirrors.



Herman

Imagine two mirrors facing each other, one up, one down, and a pulse of light bouncing between them. Every round trip is one tick. That's your clock. Not a real clock you'd buy, but a perfectly honest one, because nothing travels faster or more predictably than light. Now leave the clock running and imagine it gliding past you sideways, at some serious fraction of light speed. Here's the question. What does the light pulse's path look like to you, standing still?



Corn

Angled. While it goes up and down between the mirrors, the whole clock has moved along, so from where I'm standing the pulse crosses diagonally. It's the ball thrown straight up inside a moving train. Inside the train it goes straight up and down. From the platform it



Corn (continued)

traces a long slanted line.



Herman

That's it, that's the whole derivation's setup. From your viewpoint, the pulse travels a longer path than it does when the clock sits still. Straight up and down when at rest, a zigzag of long diagonals when moving. Now bring in the postulate. Light's speed is the same for everyone, moving clock or not. Same speed, longer path. So what has to give?



Corn

The tick takes longer. Same speed, more distance, more time per tick.



Herman

The moving clock ticks slower. And notice what we used: the Pythagorean theorem. That's it. The diagonal is longer than the vertical, Pythagoras tells you by how much, and the slowdown follows exactly. No blackboard heavier than a triangle.



Corn

Which is lovely for a gadget made of mirrors. But my watch has gears, and Daniel's phone has a quartz crystal. Why should the mirror argument touch them?



Herman

Because if light clocks and mechanical clocks disagreed, you could break the postulates with a pair of them. Take your watch and my light clock, sync them at rest, send them off together. If the watch kept the old rate while the light clock slowed, the mismatch between them would let you compute your own absolute speed from inside the box. And postulate one says no experiment inside a closed box reveals your velocity.



Corn

Galileo's ship, again, with better instruments.



Herman

With the same conclusion. So all clocks that agree at rest must agree when moving: mechanical, electronic, quartz, atomic, biological. Which means it's not the instrument stretching. Time is.



Corn

Which is the point where a normal person's brain quietly files it under "physics things" and moves on with their day.



Herman

They shouldn't, because the numbers get vivid fast. The worked example everyone uses: a train passing at about zero point eight six the speed of light. People on the platform, with good instruments, measure two seconds between two events on that train. The engineer, looking at her own watch, reports one second. Not a trick of the instrument, not an illusion. Two different, equally correct answers to "how long did that take."



Corn

Because they're measuring along different paths through... no, that's the general relativity way of saying it.



Herman

It's actually the right way even here, but hold that thought. The everyday version: at the speeds of your morning, the effect is unmeasurably small. Nobody's commute is stretching their afternoon. It only becomes dramatic near light speed, which is why nobody felt this for all of human history until the math insisted.



Corn

And it's not just time, right? Space gets in on this too. I remember there's a thing where the train also measures shorter.



Herman

Length contraction, yes, and it's the same coin viewed from the other side. The platform measures the moving train as shorter along its direction of travel, by exactly the same factor that stretches the time. The two effects are locked together, because the speed of light has to come out the same for both parties, and the only way to keep the books balanced is for each side to measure the other's rulers short and the other's clocks slow. You can't get time dilation without also getting length contraction. They're one effect wearing two names.



Corn

So the universe isn't breaking the rules. It's re-pricing distance and time so the rule survives.



Herman

That's a very Wheeler way to put it. Here's the trap I want you to walk me through, because this is where it stops feeling like perspective and starts feeling like a fight. Two observers, moving past each other. Each one measures the other's clock as slow.



Corn

Wait, that's my line. Two observers, moving past each other. Each one measures the other's clock as slow.



Herman

Yes.



Corn

Both of them. Simultaneously. That sounds like a contradiction, one of them must be wrong.



Herman

It sounds like one, and it's the single best gotcha in the subject, and the resolution is beautifully mundane. Two people standing far apart, looking at each other. Each sees the other as small. You're not large while the distant one shrinks, you each see the other foreshortened, and nobody calls the police. It's perspective. Time dilation is the same thing with time in place of size. From each one's vantage, the other's clock runs slow, and there's no contradiction because "slow" is a relationship, not a property.



Corn

That one's going to follow me home. But here's what I want to push on. With the two people looking at each other, I understand why they never have to settle it. They just keep looking. The clocks, though. At some point the two observers could stop, walk toward each other, and compare watches side by side. Then somebody's got to be wrong.



Herman

And now you've invented the twin paradox, which is exactly the right instinct, because the moment you reunite the clocks, you've done something the two distant lookers never did. You've made them take the same path through the same place, and paths through spacetime, like roads between cities, can have different lengths. Two different lengths is not a contradiction, it's just two different trips.



Corn

The trouble people actually remember is the twin paradox, because it seems to weaponize this. One twin stays on Earth, one flies off at near light speed and comes back. If each sees the other's clock slow, shouldn't each expect the other to be younger when they meet? And when they meet, they can't both be younger, that's not how reunions work.



Herman

So who's younger?



Corn

The traveler. Always. And the reason is the symmetry is fake. The Earth twin spends the whole trip in one inertial frame, coasting. The traveler doesn't, there's a turnaround, a deceleration, a flip, an acceleration back. She occupies two frames stitched together, and the stitching is what breaks the tie.



Herman

Herman, that bit about the falling elevator and feeling no weight at all, I think our listeners could use something to hold onto right now.

L

Larry

Time. It stretches. It bends. It slows down when you move fast, and you have always suspected it. Now, from the makers of the light clock, comes a fragrance that understands. Spacetime, by Equivalence. A single breath of it, whispered across your wrist, and the speed of light becomes the same for everyone in the room, no matter how they are walking. Gravity stops pulling. It simply curves, gently, toward you.

L

Larry

Spacetime by Equivalence. Because you are not falling. You are simply geometric.



Corn

How much is a bottle of Spacetime by Equivalence, and does it come in a travel size?



Herman

Corn, no. You'd wear it once and spend the whole evening explaining to people why they can't smell it, because by symmetry they're moving relative to you and it dilated.



Corn

Fine. Acceleration breaks the symmetry. That's the resolution?



Herman

It's not that acceleration "causes" the age gap in some mysterious way, it's that the two paths through spacetime have different lengths, and the traveler's is shorter. We're getting ahead of ourselves, that's really a general relativity sentence.



Corn

Then drop the elevator, because that's where you were headed anyway.



Herman

I was, I admit it. Everything so far has been relativity without gravity. Special relativity is the clean case, no gravitational fields anywhere. But Einstein noticed something in nineteen-oh-seven, and it bothered him until nineteen-fifteen, and the story of that eight years is the story of general relativity. He was sitting in the patent office in Bern, and the thought that struck him, in his own words later, was: if a man falls freely, he would not feel his weight. I was taken aback. He said that thought experiment made a deep impression on him and led him to the theory of gravity.



Corn

A man falling feels no weight. Which sounds like a physicist forgetting how landings work.



Herman

Stay in the air a moment. You're in an elevator, the cable snaps, you fall. During the fall, everything floats. Your keys hover beside you. A dropped pen doesn't drop, it just hangs there. You are in free fall, and the sensation is indistinguishable from floating in deep space, far from any gravity at all. Zero-g. You can't tell the difference from inside the elevator, no experiment can, that's the point.



Corn

The elevator's falling, the keys are falling, everything's falling together, so from inside, nothing's moving.



Herman

Nothing's accelerating, relative to anything you can see. And there's the mirror image of that, the other half of the equivalence principle, and it's the one that does the real damage to your intuitions. A windowless room. You're standing on the floor, everything feels normal, your coffee sits in its cup. Are you in a room on Earth, in Earth's gravity, or in a spaceship in deep space, no gravity anywhere, accelerating upward at nine point eight one meters per second per second?



Corn

There's no experiment inside the room that distinguishes them.



Herman

None. Drop a ball, it hits the floor in both cases. Pour the coffee, it falls the same in both. Weigh yourself, same number. Gravity at one g and a rocket's constant one g acceleration are physically identical from inside. Einstein's term for it was complete physical equivalence of a gravitational field and a corresponding acceleration of the reference system.



Corn

And the fake force version of that, I've felt that. You floor it and the seat pushes into me and my coffee sloshes backward like something grabbed it. Nobody grabbed it.



Herman

That backward shove is what physicists call a fictitious force, fictitious because it appears only in the accelerating frame. Spin in a circle and your arms want to fly out, nothing is pulling them. The driver-into-the-seat feeling, the coffee sloshing, the merry-go-round, all the same family. And Einstein's master insight was that the constant, familiar pull of Earth's gravity is fundamentally the same kind of thing as those. The floor is pushing up on you like an accelerating rocket floor. Gravity is the name we gave to the push because we never noticed we were accelerating.



Corn

Hold on, that's the part I have to sit with. You feel gravity only when something stops you from falling.



Herman

That's the reframe. The natural state, the free state, is free fall. That's the state with zero felt force. You feel weight in your chair because the chair is constantly interfering. And the falling object, the elevator with the snapped cable, has zero proper acceleration. The Earth's surface, the floor of the room, is what's accelerating.



Corn

The floor is accelerating me upward. Right now.



Herman

In the geometric formulation, yes. And once you accept the equivalence, gravity-as-force starts looking like the bookkeeping trick. It's what you write down when you insist on using a frame that isn't falling, the way centrifugal force is what you write down when you insist on a spinning frame.



Corn

So then a planet in orbit. Nobody's pulling it. What is it doing?



Herman

Going as straight as it can. That's what a geodesic is, the generalization of "straight line" to a curved geometry. On the Earth's surface, the straightest possible path between two cities is a great circle, that's why long flights arc north on the map. The map is flat, the territory isn't, and the straight path looks bent when you draw it on flat paper. A freely moving or falling particle, no forces on it, always moves along a geodesic of spacetime. The planet orbiting the Sun is following the straightest available path through a spacetime that the Sun's mass has curved. That straight path, projected down into three dimensions, looks like an ellipse.



Corn

The orbit is the shadow of the straight line.



Herman

That's a good way to say it. And it's not being pulled by any invisible rope, Newton's rope. It's just coasting, straight, through bent spacetime.



Corn

And I'd like to be careful here, because I can already hear a listener doing what I did the first time I heard this. If the planet is going straight, why doesn't it fly off? What is the curve curving, exactly? Because when I picture a bowling ball on a rubber sheet, the marble rolls around because gravity, the real kind, is pulling it down into the dip. The analogy seems to be using the thing it's explaining.



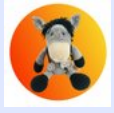
Herman

You've found the exact flaw in the rubber sheet, and it's the most honest objection in the business. The bowling ball on the sheet works because Earth's gravity pulls everything down into the dimple, so it's smuggling the answer in through the back door. The real thing being curved is not space, it's spacetime, all four dimensions together, and the curvature that matters for orbits is mostly the time part. Clocks run slightly faster at the top of a mountain than in a valley, because they're higher out of the gravity well. A planet moving through a region where time itself runs at slightly different rates gets steered, the way a cart with two wheels on different terrain turns toward the slower side. The orbit isn't the marble circling the dip. It's the planet coasting straight through a landscape where time flows unevenly, and the straight line through that landscape, seen from outside, closes into an ellipse.



Corn

So the rubber sheet is a poster, not a working model.



Herman

It's a poster. A beautiful one. But the working model has time in it, and you can't draw time on a rubber sheet.



Corn

Which, I have to say, I'm braced for you to defend, because you love an elegant mechanism and this one has the best furniture in physics. But here's my problem with it as advertised.



Herman

Go on.



Corn

"Gravity is not a force" gets said like a metaphysical verdict, like Newton was simply wrong about a fact. If it's just the geometric formulation, then the force picture should still work for something.



Herman

It works for nearly everything, and this is the caveat that keeps the whole thing honest. Take the geodesic equation, the straightest-path rule, and evaluate it in the slow-speed, weak-gravity limit, everyday speeds, everyday fields. It reduces to Newton's law of gravitation. It becomes Newton. Which is why NASA can still land spacecraft on Mars with essentially Newtonian arithmetic and nobody gets hurt. Newton isn't wrong, Newton is the shadow that general relativity casts at the speeds and fields we live in. Same reason a flat map of your neighborhood isn't wrong, the curvature just doesn't show up at that scale.



Corn

The map isn't wrong, it's just small.



Herman

And there's a second payoff I love, because it explains something Newton couldn't. Why do heavy things and light things fall at the same rate? In Newton, that's a coincidence. The mass that resists acceleration and the mass that responds to gravity just happen, unexplained, to be the same number. In Einstein, it's structural. The same mass that curves spacetime is the mass that moves through the curved spacetime. Drop the hammer and the feather, they're both just following the same-shaped geometry. The equal falling of all bodies becomes, in Einstein's own phrase, a matter of course.



Corn

That's the kind of thing that makes me believe it. Not the bending of light, the coincidence disappearing.



Herman

Then you'll like the evidence run, because it's brisk and it's all one direction. Light bending, predicted from the equivalence principle, measured by Eddington's expeditions in nineteen-nineteen, the newspaper headline moment. Gravitational redshift, light climbing out of a gravity well loses energy and reddens, predicted in nineteen-eleven, and the sensitive confirmation didn't come until nineteen fifty-four. And gravitational waves, ripples in the geometry itself, the first direct detection was announced in February twenty-sixteen by Advanced LIGO, two black holes merging over a billion light years away, and the wiggle they measured in a four-kilometer arm matched the prediction.



Corn

Give me a sense of scale on that LIGO detection, because I've heard the number and I refuse to believe it.



Herman

Believe it. The arm is four kilometers long, and the passing wave changed its length by about a ten-thousandth of the width of a proton. They built the machine to detect that, and it did. It's the most sensitive ruler ever constructed, and it's in a tunnel in Washington State.



Corn

And in the pocket. We did a whole episode on GPS once, the Einstein in your pocket angle, so I'll keep this to one line.



Herman

Keep it to one line and make it a good one.



Corn

The satellites are moving fast, so their clocks run slow by special relativity, and they're higher out of Earth's gravity well, so their clocks run fast by general relativity, and both corrections get applied, because if they didn't, your position would drift by kilometers a day. Every fix you've ever gotten from your phone is the theory passing a test.



Herman

And the human-scale number, the one I'd send home with Daniel: an astronaut on the International Space Station, six months up there, orbiting at about seven point seven kilometers per second, comes back about five milliseconds younger than she left, relative to everyone who stayed.



Corn

Five milliseconds. Half a hundredth of a second, the price of six months in orbit.



Herman

There's a flip side people find moving. If you could keep up a comfortable one g of constant acceleration, accelerating forever, ship time, you could cross the entire observable universe within one human lifetime. Everyone you left behind would be long gone, that's the price. But the traveler makes it.



Corn

That's the most expensive one-way ticket in physics and it's one g.



Herman

It's just geometry the whole way down. I sometimes think the whole theory is Wheeler's sentence with the plumbing showing. Space-time tells matter how to move, matter tells space-time how to curve. The Sun's mass curves the spacetime around it, the planets read the curvature and follow their geodesics, and the whole solar system is that one exchange repeated.



Hilbert

It was seven point six six kilometers per second, not seven point seven. And the number you want is the neighbour's, not the spec sheet's.



Corn

The neighbour's what?



Hilbert

Herman, you said an astronaut comes back five milliseconds younger. Fine. But nobody measures that from a spec sheet. You measure it against a clock somebody actually kept. In my building, nineteen eighty-four, the neighbour below me worked at the observatory and kept a pendulum clock against the radio signal. He claimed it lost on him. I kept a stopwatch on the stairwell for four months. Dropped a tennis ball down the stairwell and timed it, floor by floor, every morning. Marked each time in pencil on the doorframe, in case the tape went missing. The ball never came off the height by more than the width of the pencil line. His clock was fine. He'd been reading it through the glass of his spectacles, that was the whole drift.



Corn

Four months of dropping a tennis ball down a stairwell, marked in pencil, to settle a clock you didn't own.



Hilbert

He lent me the stopwatch. It seemed rude not to check it.



Corn

Does the stopwatch come in a version that survives being dropped down a stairwell for four months.



Herman

It apparently just did. And that's actually the honest control, isn't it. You want the reading held against something local and dumb and repeatable, not the book value. The five milliseconds is real, but it's a computed figure, the kind you confirm by keeping a better clock next to a worse one and watching the gap. That's literally what GPS does, the satellite clocks are corrected against ground references continuously.



Corn

So somewhere out there is a doorframe with pencil marks proving a pendulum clock innocent. That's the five-millisecond story at household scale, everyone measuring their own second slightly differently and needing someone to keep score.



Herman

And the scorekeeping only matters because the seconds really are different. Not apparently different, not instrumentally different. Two clocks, two paths, two honest answers.



Corn

You said earlier you'd send Daniel home with the astronaut number. I'd send him with the floor. You feel weight because the floor won't let you fall. I've been sitting here an hour and I can feel my chair being unreasonable about it.



Herman

It's been accelerating you upward the entire episode. Sloths spend their lives hanging from branches, so Corn has a personal relationship with the question of what's holding him up.



Corn

My branch and I have an arrangement. It doesn't drop me and I don't ask what it's doing.



Herman

That's Newton's position, basically.



Corn

One thing we haven't said, and it matters for where Daniel's intuition should land: this isn't the final word. Nobody has a self-consistent theory of quantum gravity. Relativity and quantum mechanics, the two best theories we have, refuse to sit in the same room, and nobody knows yet how gravity unifies with the other three interactions.



Herman

So the picture we've built today, the curved stage, the flexing clocks, it's the best picture anyone has, and it is a picture, one day to be folded into something bigger. Einstein spent his last decades on that unification and didn't get it.



Corn

Which is oddly comforting. The theory that ate absolute time still has a fence at the end of its garden. If you want the thing to sit with this week, sit with the chair. You've never once felt gravity. You've felt furniture.



Herman

And our thanks, as always, to Hilbert Flumingtop, producing this show from behind a desk he keeps exactly where he keeps it.



Corn

If this was your kind of episode, go back for episode ten forty, The Einstein in Your Pocket; and episode ninety-one, The Story Behind the Show. This has been My Weird Prompts. If today's episode finally made relativity click, a review wherever you listen helps other people find the show. Find everything else at my weird prompts dot com.



Herman

See you soon, and take the elevator.



Corn

Slowly. Preferably the one with the cable attached.

SOURCES

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