Through the Wormhole—
Can we travel faster than light?

The universe is all of **breathtaking** sites, **depths** through powerful telescopes, but will we ever travel to these places and wonder, and see them with our own eyes?

Now scientists are designing **warp drives**, learning how to **pry open wormholes**, and looking for cracks in the fabric of the cosmos. To bring the entire universe **within our grasps**, they must break the fundamental laws of physics. Can we travel faster than light?

Space, time, life itself. The secrets of the **cosmos** lie through the **wormhole**.

Humans have always **gazed up** at the stars. For thousands of years we thought they were as close as the sun and the moon, almost close enough to reach out and touch. But now, we know just how **vast** the universe is. The closest star is about 25 trillion miles (25,000,000,000,000 miles = 4.02336e16 meters) away. The fastest spacecraft we have today would take more than 10,000 years to get there. To become true citizens of the cosmos, we have to do something that physics says is impossible; we have to travel faster than a **beam** of light.

As a child, I loved to be out under the Mississippi night sky, warming myself by a campfire. I'd spend hours staring at the dancing flames. What was this light made of? I wondered how it could seem **solid**, but then **vanish** into nothingness.

Shawn Carol is a theoretical physicist from the California Institute of Technology. The mysterious nature of light gets his mind racing. The speed of light is 186,000 miles per second, or 670 million miles per hour. Nothing goes faster than the speed of light; it really is the maximum speed limit for everything in the universe.

Light travels a million times faster than sound. It's fast enough to travel the earth 7 times in just one second; but the mystery of light goes much deeper than its breathtaking speed. The way it moves is different from everything else in the universe.

We're **gonna pretend** for the moment that I am not a respectable citizen, and will do a little bit of littering; we are going to add the velocity of my car, which is 30 miles an hour, and if I throw this slurpee in the same direction at 20 miles an hour, since this is an ordinary, everyday event, the total **velocity** of the slurpee is actually going to be 50 miles per hour. If I'm going backwards at 30 miles an hour and I throw the slurpee forward at 20, someone on the road will see the slurpee move backwards 10 miles an hour.

The speed of Shawn's car changes the velocity of Shawn's beverage, but light isn't governed by the same laws that govern cold drinks. When I push a beam of light out of the car, the total velocity is always the speed of light. Light would seem to be moving at the same speed no matter what my car was doing. You don't add the speed of light to the speed of the car. The speed of light is always the speed of light.

These strange rules for how light moves **inspired** Albert Einstein to rewrite the basic laws of the universe. He realized that space and time were not fixed and absolute, but connected and relative. It was an idea that led to the most famous equation in history, $E = mc^2$.

Time and space are really part of one **underlying** thing called spacetime, and how you **divide up** spacetime into time and space depends on how you're moving, so there are various **corollaries** of that. Once Einstein realized that time and space were the same thing. He realized that energy and mass are the same thing. $E = mc^2$ implies that the more energy you inject into a rocket, the more mass it gains, and the more massive it is, the harder it is to accelerate. Boosting it to the speed of light is impossible because in the process, the rocket will become infinitely massive. The energy it takes to accelerate increases and increases as you come closer to the speed of light. If in principle you wanted to go the speed of light, you need an infinite amount of energy to accelerate you that fast. So you're going to get more and more energy, but you're not going to get that much more speed.

Relativity makes light both our friend and foe. Its **tremendous** speed lets us communicate between any two points on earth almost **instantaneously**. On the other hand, because we could never move faster than light, we're stranded in the Solar System with the stars, and possibly our land.

This man believes he can help us escape our cosmic prison. He thinks he's found a way to bend Einstein's rules, and allow us to reach the stars. **Miguel Alcubierre**, a physicist in Mexico City, has invented the **warp drive**. The warp drive is a way to get from one place to another that is very different from the way we normally do it. So, normally we just move through space like we walk or we fly or whatever, but the warp drive theorists use space, lets space do the **motion**. Miguel's idea **stems from** another aspect of Einstein's theory of relativity, that the shape of space can be **distorted** by mass or energy. So the basic idea is, you **expand space** behind you – this actually makes you further away from the objects behind you, and **contract space** in front of you, getting closer to the objects in front of you, but you don't move at all.

See this is a spaceship. Normally you would have to fly through space like that, and you cannot do this faster than the speed of light. But instead of that, let us contract space here, and expand it here, like this. Now you see, the spaceship is getting closer to this side, and further away from that side, but it's **actually** not moving at all **with respect to** the objects around it.

The beauty of Miguel's idea is that the spaceship actually stands still inside the bubble of spacetime. Since it's not moving, it doesn't gain any **mass**. And you can actually go at any speed because there are no limits in the laws of physics that tells you how fast you can **warp space**. You can do it at any speed you want.

Miguel's warp drive is an **ingenius** way around Einstein's cosmic speed limit, but it's still theoretical, and lacks one crucial **ingredient**: an exotic **substance** called negative energy, something that many scientists aren't even sure exists.

But one man does believe in negative energy. He even claims that he created it in his lab. The warp drive. It sounds like science fiction, but the idea of surfing across the universe in a warping bubble of space would make perfect sense to Einstein. There is one snag. A warp drive can only function with a mysterious power source, negative energy. And today, most scientists believe negative energy is just an unproven theoretical concept. But Steve Lamoreaux, an atomic physicist at Yale University, has made it his mission to track down this exotic form of energy, and he believes the answer is all around us in the **fabric** of space itself.

We normally think of the vacuum of space as being completely empty, but in fact there's energy density in empty space, and we call that the zero point energy of space. The theory of quantum mechanics predicts that empty space is actually constantly shimmering with microscopic pulses of energy, as particles pop in and out of existence. To make negative energy you have to find a way to suppress this constant chatter. Steve realized the way to do this was to change the shape of space.

There's a nice analogy: You have two ships on a rough ocean. One ship will tend to reflect waves from it, the other one does the same thing, so the wave density between the two ships is a little bit less compared to one left by itself which is surrounded by a rough sea. So if you put two ships on a rough sea, they'll be mutually attracted, and they'll come together.

Steve reasoned that if he created a narrow enough region of empty space like the area between the two ships, then some of the shimmering 0 point energy would not fit inside it. The energy of empty space outside the narrow region would be stronger, and force it to shrink. That force would be the signature of negative energy, and Steve set out to create it in his lab.

It was an idea that would consume him for more than a decade. We call the experiment the Time Machine, actually the Time Machine 2, this is the second version of the experiment. We call it that because I invested 15 years of my life in this major-ment. That's a lot of time. It's a time-wasting machine, more accurately defined.

Inside this vacuum chamber are two small metal plates sitting less than the width of a human hair apart from one another. To get them that close, and not touch, the metal has to be perfectly flat, down almost to the atomic level. The 0 point fluctuations of free space won't fit between those plates as well, so when we bring these two plates together, there are fewer fluctuations between the plates than there are outside the plates. The force builds up, and it actually gets stronger as the plates get closer together, and that force we refer to as rising from negative energy.

If you imagine taking two pieces of cardboard, putting it in a box with packing peanuts flying around, if you place it close enough together so the packing peanuts can't fit between them, there's more collisions on the outside, and essentially none on the inside, and these plates experience a force pushing them together. And an analogy to the peanuts being outside we have the photons outside pressing the two plates together. That's negative energy.

The 0 point energy fluctuations outside the plates are stronger than those between, so pressure from the outside pushes them together, or think of it another way; the negative energy between the plates expands space around it. Stages of meticulous labor have made him the first person on earth to have measured a force produced by negative energy, but the amount he has detected is miniscule. The force is equal to a red blood cell in the earth's gravitational field, so it's tiny. But if you add up thousands of these plates, like we have in our experiment, you can actually achieve a comparable and useful force. Steve's discovery may only be a baby step toward a warp drive, but he's confirmed that Miguel Alcubierre's warp drive theory does not violate the laws of physics.

The energy needed to warp space, and prepare a warp drive forward actually exists, but it's already opened the door to something else—the wormhole, a rip in the fabric of space itself. We've all heard of wormholes; they're cosmic shortcuts that put alien worlds practically on our doorstep. But how would we actually build one? And how would we use one? Travel by wormhole requires exotic technology, and the courage to jump into the unknown.

Our planet is riddled with passageways. We regularly travel through strong, stable tunnels, cut through massive mountains. Well, here we're entering a nice, solid tunnel. It's made of, it looks like concrete and reinforced steel. Very solid. A reliable means of transportation. I can drive my car in, I can come out, I know what's happening at all times.

Physicist Steven Chu is fascinated with the concepts of stability and instability, be they be in the stock market—sell, in real estate values—long, or in spacetime wormholes. One of the fundamental properties that we look at in physics, when we look at a particular system, is whether that system is stable, or unstable. An example would be a pen which is balanced like this. It might be Ok when it's exactly balanced, but even a slight bump will send it into a drastically different state. We decided to look at whether one can build a wormhole that had nice properties, such as, its behavior is predictable, and it's stable. Those are two criteria you'd like to have for a real wormhole.

The rules of building wormholes start with Einstein's theory of relativity, which tells you how to bend and shape space as if it were a flexible sheet. Imagine this sheet of paper, and imagine that you're an ant living on this sheet of paper. You wanna travel from this point to this point. You might have to walk all the way from here to here. But if the paper were curved, the long way around would involve walking all the way around the paper like this. But you could imagine that there were a little tube, connecting this point directly to this point and the ant could just slip through.

Now, when I pull the plug on this drain, the water's gonna swirl around, and it's going to drain out through the bottom. That's what people think of when they think of a wormhole; but that's actually more of a two-dimensional wormhole, whereas what we would see in our universe is a three-dimensional wormhole. Wormholes in science fiction have gaping entrances that a starship can dive into, but those two dimensional rain drains gloss over the true architecture of wormholes.

In this two-dimensional analogy, the opening of the straw is just a circle, but because we live in three-dimensions, the opening of the wormhole would actually be like the interior of a bubble. This is what the mouth of a real wormhole might look like, if they are lurking somewhere out there in space. But Steven wondered if we might be able to build our own from scratch.

A cosmic engineer would first create two mouths, and connect them. Then he would drag one of the mouths light years away, but the tunnel between the two mouths is not part of the whole space, and could remain very short. It’s a simple idea, but the vast amount of negative energy needed to keep the wormhole’s mouths and tunnel from collapsing is tricky stuff to control. Very challenging to stabilize a wormhole. All wormholes, as far as we know from general relativity, require this kind of special negative energy exotic matter. The question is whether that matter itself can be stable.

Steven crunched the numbers on how negative energy would react with normal matter on the fringes of the wormhole, to discover whether they could coexist in a stable way. And, we have proven mathematically they’re unstable. That would be a very dangerous device to use, because once you bump it a little bit, the entire device could just fall apart. If I try to get into an unstable wormhole, it’s like trying to put my finger into this bubble—it’ll just pop.

The negative energy needed to keep a wormhole open is inherently too unstable. A man-made wormhole would collapse the instant someone tries to step inside; but there might be another way, not by using cosmic shortcuts that we have built ourselves, but by searching for microscopic ones that could be hiding all around us. Just as empty space is fizzing with microscopic pulses of energy, some theorists believe it could also be riddled with microscopic holes.

There could be quantum wormholes left over from the Big Bang, or at very, very short distances you could have little fluctuations where spacetime just connects to itself in a funny way, and that would be a quantum wormhole. If they just happened as a little fluctuation, that’d be incredibly tiny, like 10^{-35} meters.

Microscopic quantum wormholes are quantum fluctuations in space that perpetually appear, disappear, and reappear again. Since we don’t have to construct their portals, Steven thinks they might be safe to enter; but before you try jumping into one, be aware! There’s a catch.

Quantum mechanical things are fuzzy. They’re intrinsically random and unpredictable. So if we were in a quantum wormhole, we might be shaken around, and we wouldn’t quite know where we were going to come out. You wouldn’t want to get into a tunnel that might end at the bottom of the Pacific

Ocean, or on a mountain top that you didn't want to be on. Quantum wormholes have no estimated times of arrival, and your destination is unknown. You could end up anywhere, or anyway.

Traveling faster than light through a wormhole would be a risky ride. You've got to be willing to role the dice. But, there may be a safer way for the cautious traveler. Imagine being able to move from here to there without ever moving at all.

Well, mankind's first journey to the stars looks a long way off. We won't master the technology of wormholes and warp drives for centuries, at least. But there's another way to zip around the cosmos. We could turn our bodies into information, and send that information from place to place at the speed of light.

Chris Monroe and Steve Rolsten are quantum physicists at the University of Maryland. They're pioneers of teleportation. There work is all about events taking place in two separate locations, events which normally have no connection whatsoever.

We're going to demonstrate a simple experiment using standard coins just to show the randomness of individual coins, and the randomness between the two coins. Alright, flip. Heads, tails. Tails, tails. So as you can see with two regular coins, we get completely random results between each other. If Chris and Steve could make the two coins always land the same way, then they would have succeeded in teleporting the information on the coin, heads or tails, from one place to the other. And, they had an idea of just how to do this. They would use quantum entanglement, a strange effect that could create a length between microscopic objects.

When a bomb explodes and two pieces of shrapnel come flying out, each one moves independently, and is unaffected by the other. Now imagine a bomb in a subatomic world. Two particles of shrapnel fly out, but this time quantum entanglement means the way one moves is entirely dependent on the other. If one piece is spinning clockwise, you can deduce that the other piece is moving counterclockwise.

If Steve and Chris' coins were entangled, whenever Steve tosses heads, Chris would toss tails. If Steve tosses tails, Chris would toss heads. So even though the coin flip on one side is completely random, there are correlations between the two coins, and this is the defining feature of entanglements.

Physicists have been struggling to use entanglement to teleport matter from place to place for more than two decades. Steve and Chris are the first to succeed. They begin with two atoms of an element called ytterbium. The experiment is, we start with two trapped atoms. They're across the table from each other. These atoms are sort of levitated with fields, like a levitated train. They're in a vacuum chamber so nothing touches them. They're as close as you can get to perfect isolation.

Steve and Chris write quantum information called cubics into the first atom using microwave radiation. The cubics become the atom's heads or tails. Then we exact both atoms with this fast pulse of light. If we do it right, we can make sure that the photon is then entangled with the internal state of the atom. Photons become the messages carrying the atom's information across the lab. Chris and Steve aim the photon from each atom at the same target. When they meet, they become entangled, which in turn entangles the two atoms they came from. They've been nowhere near each other, they've never seen each other, but now these two atoms, which are across the table from each other, are now entangled, and they somehow share the inforrmation we first wrote into the first atom.

That's called quantum teleportation because the information, in a sense, never really made a trip. There's never any physical interaction. It's all because of this magic of entanglement that allows us to do that. And, I think Einstein had the best words to describe it. He called entanglement spooky action at a distance. Steve and Chris have successfully transferred the information from the one atom to the other. In other words, they teleported the atom. It's the first time anyone has ever beamed matter across space at the speed of light.

And they're already working on more ambitious teleportation experiments. But, the good news is this idea works with matter more complex than a single atom, say a few hundred atoms. A few hundred atoms would be progress, but the real question is whether we will ever be able to teleport all of the several thousand trillion, trillion atoms in an entire person from one place to another. To turn a pile of organic matter into a copy of you, or me – it's a tall order.

Well, we have a cherry pie, and the pie is in a particular state. All of the atoms, mostly carbon, and organic molecules make up this pie, but they're obviously in a state we all recognize as a cherry pie. It looks pretty good. In order for Chris to import the atoms inside the cherry pie, he needs to gather information about every single one of them, which gets a little messy. All the atoms in here are representative of a cherry pie, but it certainly doesn't look like a cherry pie, and the reason is the atoms aren't arranged in the right way. There are about 10 to the 27th atoms in this tin; that's a billion, billion, billion atoms. Consider the number of possibilities that a billion, billion, billion atoms can be arranged. It's a number that's so ungodly huge, we don't even have enough space in the universe to write it down.

Teleporting a human being is far beyond our capabilities, for now. But Steve and Chris believe, if it is possible, quantum entanglement will be how it's done. Quantum mechanics has been verified repeatedly in the lab, our labs, and many around the world. Over and over again for decades we've continually verified quantum mechanics as an accurate description of nature. If I have fundamentally quantum mechanical, teleportion better involve quantum mechanics. I would say that if there's a different way to teleport objects, then somehow there's a different theory than quantum mechanics out there, and we just don't know it yet.

We are still a long way from traveling from star to star (speed limit 186,000 mph), as fast as a beam of light, but what if everything we thought we understood about light is actually wrong? We live in a universe with a speed limit: 670 million miles per hour. Well, that's what Albert Einstein said. But what if Einstein was wrong?

John Webb has big plans. He wants to rewrite the laws of the universe, and it all begins with barcodes. Here we are in the supermarket and I'm buying a few things. This lettuce, for example, um, we know what it is, it has a lot of information on the lettuce. It tells us on the packet, we can see what it is, but encoded in this patent here, and picked up by the lazer here that's gonna scan it, is a set of information. And when the cashier scans it, the lazer beam will look at the white gaps between the black lines, and we get the price, and so there's a lot of information stored in the barcode.

John is an astrophysicist at the University of New South Whales. The barcodes he studies are not on packages of lettuce, but on light coming from distant galaxies. If you split the light coming from these galaxies into a rainbow, you'll discover that certain colors are missing. Those dark bands called spectral lines are caused by chemical elements in the clouds of interstellar gas, absorbing certain frequencies of starlight.

We learn a great deal from spectral lines. From their positions you can identify elements that have particular frequencies, so you can see whether things like hydrogen or helium, or other elements are present. But John realized his starlight barcodes could tell him about something much more important than what stars are made of; it could give him a glimpse into one of the most fundamental constants of the universe, the strength of the electromagnetic force.

In physics every force has a particle that carries it. Electromagnetic force is carried by light, or photons. The electromagnetic force keeps atoms glued together with a constant exchange of photons that bounce from the nucleus to it's orbiting electrons. When light passes through atoms on interstellar gas, it can interfere with this exchange of photons, and knock an electron out of its orbit, but only if the light has exactly the right amount of energy. The barcode of missing light tells you precisely how strong the electromagnetic force is.

Over the last decade, or so, there's been an amazing change in technology. One can now measure the things in distance, probably, more precisely than has ever been measured on earth. That provides a very strong motivation for studying the early universe. We can measure what conditions were like, we can measure what physics was like, whether the laws of physics were there in the very remote regions of the universe as the same as they are on earth. That's pretty amazing.

Why should we care about any of this? **Richard Feynman** had a very good answer to this one. He said that physics is like sex. Sure, there are some practical outcomes, but that is not why we do it. People wanna know about the universe, they want to know what it's like. It satisfies intellectual curiosity, and it's very much akin to enjoying art, or even music. You get satisfaction from it, at least a lot of people do.

So John began searching the heavens for glowing clouds of gas, billions of light years away. He used the **Keck Telescope in Hawaii** to look at the northern sky, and the **Very Large Telescope** in Chile, which looks out on the southern sky. And when he looked at his barcodes, he discovered something totally unexpected.

This is what a cloud of gas would look like if we were looking at it in the laboratory on earth. When we look in the southern hemisphere, [there's] something slightly different. This line has moved the red end of the spectrum, and another line here has moved toward the blue end of the spectrum, so there's a change in both the spacing of the spectra lines. It looks slightly different in the southern hemisphere. If you now go to the northern hemisphere, the exact opposite direction on the sky, this line has now shifted instead of to the right, to the left., and this line has shifted to the right instead of to the left, so the patterns now look different. It's a little bit as if you were in a supermarket drunk, looking at the barcode and the patent has changed.

These shifting barcodes can only be caused by one thing, something that seems impossible, a change in one of the fundamental laws of physics. When we first saw the results, it was hard to accept that they were correct. What we found is, when you look in one direction on the sky, the strength of the electromagnetic force appears to decrease with increasing distance from us, and when you look in exactly the opposite direction on the sky, the converse is true, the strength of the electromagnetism seems to increase as you move to greater distance.

Electromagnitism is the force transmitted by light. So if the strength of the electromagnetism is not constant, it means that the properties of light itself are changing. If John Webb is right, he's overturned one of the basic laws of the universe. Once the laws of physics are allowed to vary in those equations, things have to be rewritten. So, it's back to the drawing board for certain fundamental principles in physics.

Could Einstein be wrong? Could the speed of light be different in different parts of the cosmos? On the other side of the world, one cosmologist is sure the answer is yes. He believes that light can move much faster than we think, and that out there in the universe, there are super highways to the stars.

Back at the dawn of the space age, it was all about having the right stuff. The first people who journeyed to the stars will need it too. They will be venturing into the absolute unknown, and perhaps for the first time, traveling faster than light.

Theoretical physicist **João Magueijo** thinks there may be regions of outerspace where faster than light travel is possible. He developed this radical theory because without it, he couldn't explain the way the universe looks. When we look out into the Universe, everything looks the same in every direction. This is a problem because during the time the Universe has lived, there really isn't enough time for light travel around—for features to be shared—around the Universe, and these we call an homogenated problem. The homogenated problem, the fact that all galaxies, and all matter are ably spread around the Universe, no matter where we look, is one of the biggest puzzles in cosmology. The problem is scientists don't think there has been enough time since the Big Bang for matter to spread out so evenly.

Imagine the Big Bang was a big party. As soon as the party starts, everyone instantly has a glass of the same kind of wine. How would a waitress have time to serve everyone a glass of wine so quickly? If she can only move at the speed of light, she won't have time to reach everyone before they disperse, like the Big Bang Universe. Most scientists solve this problem with a theory called cosmic inflation. The idea is that the room stayed small for longer at the beginning of the time, giving the waitress enough time to serve everyone. Then, a mysterious magnifying force inflates the room very rapidly, everyone gets a drink, and the waitress hardly breaks a sweat.

Cosmic inflation says the Universe started as an imaginably small pin point, concentrating all the energy of the Universe, and at the first trillionths of a trillionths of a trillionths of a second, the Universe doubled, and doubled, and doubled in size. The initial smoothness of that single point then spread to the vast distances we can see nowadays. But inflation is not proven, it's just a theory.

João has an alternative to it, a provocative theory that might bring the Universe within our reach. What if instead of changing the rate of expansion, we change the speed limit, the speed of light. That's what we call **the varying speed of light theory.** Under the varying speed of light theory, our waitress serves to everyone faster at the beginning of the Universe, and then slowed down to the current speed, leaving us with cameras wondering how she managed to serve such a large universe in such a short time. João's theory solves the homogenated problem just as effectively as cosmic inflation, but it also thumbs it's nose at Einstein's golden rule.

This does not actually contradict Einstein's principle, that the speed of light is the speed limit. We're only saying that the speed limit changed throughout the life of the Universe. And João's theory means there might be a way to break today's cosmic speed limit because there could be pathways to the space where the speed of light remains faster.

These pathways are called cosmic strings. And with the varying speed of light theory, light traveled faster at the beginning of the Universe, and cosmic strings could be regions where this higher speed limit is to leave force. The idea is that in the first moments of the Universe, tiny fractures formed in spacetime. Since then, these fractures expanded along with everything else in the cosmos, and are now billions of light years long. Cosmic strings might serve as high speed lines cutting across regions where otherwise you'd be moving at a crawl.

You could think of cosmic strings like the tube in London. Where on the surface there's a speed limit, but obviously down there there isn't one. On the surface, Einstein's limit is the law. The tube below is the cosmic string, a faster way across town. If we could fit a spacecraft into the corridor of [a] high speed limit created around the cosmic string, fast travel throughout the Universe would become possible.

Cosmic strings have yet to be found, and the variation in the speed of light is still just a theory. But slowly and steadily, scientists like João Magueijo and John Webb are chipping away at Einstein's cosmic speed limit. We begin to wonder what if it changes from place to place in the Universe, or maybe it was different early on in the Universe's history, and if the speed of light is changing, then a lot of what we thinks about physics could be different in the early Universe to today. Around the world scientists are testing new technologies, and probing deep into the heart of physics to uncover new laws of the Universe, to find a way for us to escape our Island Earth.

We are still along way from becoming citizens of the cosmos. The stars remain almost unimaginably far away, but wherever science goes next, our hopes to explore this final frontier will never be dimmed, and one day, we Will reach it, because what man can imagine, man can do.