Hello.

My name is Stephen Hawking.

Physicist, cosmologist, and something of a dreamer.

Although I cannot move and I have to speak through a computer, in my mind I am free.

Free to explore the universe and ask the big questions.

Such as: "Is time travel possible?"

"Can we open a portal to the past ..."

"or, find a shortcut to the future?"

"Can we ultimately use the laws of nature to become masters of time itself?"

Time travel was once considered scientific heresy.

I used to avoid talking about it for fear of being labeled a crank.

But these days I'm not so cautious.

In fact, I'm more like the people who build Stonehenge.

I'm obsessed by time.

If I had a time machine, I'd visit Marilyn Monroe in her prime.

Or drop in on Galileo, as he turned his telescope to the heavens.

Perhaps I'd even travel to the end of the Universe

to find out how our whole cosmic story ends.

To see how this might be possible, we need to look at time as physicists do.

As the fourth dimension.

It's not as hard as it sounds.

All physical objects, even my wheelchair, exist in three dimensions.

Everything has a width, and a height, and a length.

But there is another kind of length, a length in time.

While a human may survive for eighty years, these stones will last much longer.

For thousands of years.

And a Solar system will last for billions of years.

Everything has a length in time as well as space.

Travelling in time means travelling through this fourth dimension.

To see what that means, let's do a bit of normal, everyday travelling just to get a feel for it.

A fast car makes it a bit more fun.

Drive in a straight line and you're traveling in one dimension.

Turn right, or left, and you add the second dimension.

Drive up or down a twisting mountain road and that adds height.

So, that's travelling in all three dimensions.

But how on Earth do we travel in time?

How do we find a path through the fourth dimension?

Let's indulge in a little science fiction for a moment.

Time travel movies often feature a vast, energy hungry machine.

The machine creates a path through the fourth dimension.

A tunnel through time.

A time traveler.

A brave, perhaps foolhardy individual, prepared for who knows what,

steps into the time tunnel and emerges who knows when.

The concept may be far fetched and the reality may be very different than this,

but the idea itself is not so crazy.

Physicists have been thinking about tunnels in time, too.

But we covered it from a different angle.

We wonder if portals to the past or the future could ever be possible within the laws of nature.

As it turns out, we think they are.

What's more, we've even given them a name.

Wormholes.

The truth is that wormholes are all around us.

Only, they are too small to see.

Wormholes are very tiny.

They occur in nooks and crannies in space and time.

You might find it a tough concept, but stay with me.

Nothing is flat or solid.

If you look closely enough at anything, you'll find holes and wrinkles in it.

It's a basic physical principle and it even applies to time.

Take this pool table.

The surface looks flat and smooth but up close is actually anything but.

It's full of gaps and holes.

Even something as smooth as a pool ball has tiny crevices, wrinkles and voids.

Now it's easy to show that this is true in the first three dimensions,

but trust me, it is also true of the fourth dimension as well.

There are tiny crevices, wrinkles and voids in time.

Down at the smallest of scales, smaller even than molecules,

smaller than atoms, we get to a place called the quantum foam.

This is where wormholes exist.

Tiny tunnels, or shortcuts, through space and time.

Constantly form, disappear and reform within this quantum world.

They actually link to separate places and to different times.

Unfortunately, these real-file time tunnels are just a billion-trillion-trillionths of a centimeter across.

Way too small for a human to pass through.

But here's where the notion of wormhole time machines is leading.

Some scientists think it may be possible to capture one and enlarge it many trillions of times.

To make it big enough for a human or even a spaceship to enter.

Given enough power and advanced technology perhaps a giant wormhole could even be constructed in space.

I'm not saying it can be done but if it could be, it would be a truly remarkable device.

One end could be here, near the Earth.

And the other far, far away near some distant planet.

Theoretically, a wormhole could do even more.

If both ends were in the same place and separated by time instead of distance,

a ship could fly in and come out still near the Earth but in a distant past.

Maybe dinosaurs would witness the ship coming in for a landing.

Now, I realize that thinking in four dimensions is not easy,

and that wormholes are a tricky concept to wrap your head around.

But hang in there - I thought up a simple experiment

that could reveal if human time travel through a wormhole is possible now,

or even in the future.

I like simple experiments. And champagne.

So I've combined two of my favorite things to see if time travel

from the future to the past is possible.

I'm throwing a party. A welcome reception for future time travelers.

But there's a twist - I'm not letting anyone know about it until after the party has happened.

Here is the invitation, giving the exact coordinates in time and space.

I'm hoping copies of it, in one form or another, will survive many thousands of years.

Maybe one day someone living in the future will find the information,

and use the wormhole time machine to come back to my party,

proving that time travel will one day be possible.

My time traveler guests could be arriving any moment now.

Five, four, three, two, one ....

What a shame.

I was hoping a future miss Universe was going to step through the door.

So why didn't the experiment work?

I think one of the reasons might be because of a well known problem with time travel to the past.

The problem of paradoxes.

Paradoxes are fun to think about.

The most famous one is usually called the grandfather paradox.

I have a new, simpler version I call the mad scientist paradox.

I don't like the way scientists in movies are often described as mad,

but in this case it's true.

This chap is determined to create a paradox.

Even if it costs him his life.

Imagine somehow he's build a wormhole.

A time tunnel that stretches just one minute into the past.

It may not sound like much, but even one minute of time travel can cause real trouble.

Through the wormhole the scientist can see himself as he was one minute ago.

But what if our scientist uses the wormhole to shoot his earlier self?

His now dead, killed before he'd even finished assembling the pistol.

So, who fired the shot?

It's a paradox. It just doesn't make sense.

It's the sort of situation that gives cosmologists nightmares.

This kind of time machine would violate a fundamental rule that governs the entire universe.

That causes happen before effects. And never the other way around.

I believe things can't make themselves impossible.

If they could, then there'd be nothing to stop the whole universe

from descending into chaos.

So I think something will always happen that prevents the paradox.

Somehow there must be a reason why our scientists will never find himself in a situation

where he could shoot himself.

And in this case, I'm sorry to say, the wormhole itself is the problem.

In the end, I think a wormhole like this one can't exist.

And the reason for that is feedback.

If you've ever been to a rock kick, you probably recognize this screeching noise.

It's feedback.

What causes it is simple; sound enters the microphone,

it's transmitted along the wires, made louder by the amplifier,

and comes out at the speakers.

But if too much of the sound from the speakers goes back into the mike,

it goes round and round in a loop, getting louder each time.

If no one stops it, feedback can destroy the sound system.

I think the same thing will happen with a wormhole.

Only with radiation instead of sound. As soon as the wormhole expands,

natural radiation will enter it and end up in a loop.

The feedback will become so strong it destroys the wormhole.

So although tiny wormholes do exist, and it may be possible to inflate one some day,

it won't last long enough to be of use as a time machine.

That's the real reason no one came to the party.

In fact I believe any kind of time travel to the past,

through wormholes or any other method is probably impossible.

Otherwise paradoxes would occur.

So sadly it looks like time travel to the past is never going to happen.

A disappointment for dinosaur hunters and a relief for historians.

But the story is not over yet.

This doesn't make all time travel impossible.

I do believe in time travel.

Time travel to the future.

Time flows like a river.

And it seems as if each of us is carried relentlessly along by time's current.

But time is like a river in another way.

It flows at different speeds in different places.

And that is the key to traveling into the future.

The idea was proposed by Albert Einstein over 100 years ago.

He realized there should be places where time slows down,

another where time speeds up.

He was absolutely right and the proof is right above our heads.

Out in space.

This is the Global Positioning System, or GPS.

A network of 31 satellites in orbit around the Earth.

The satellites make satellite navigation possible.

But they also reveal that time runs faster up here than it does down on Earth.

Inside each spacecraft is a very precise clock.

But despite being so accurate,

they all gain around a third of a billionth of a second every day.

The system has to correct for the drift.

Otherwise that tiny difference would upset the whole system,

causing every GPS device on Earth to go out by about six miles a day.

You could just imagine the mayhem that would cause.

The problem doesn't lie with the clocks.

They run fast because time itself runs faster here than it does down below.

And the reason for this extraordinary effect is the mass of the Earth.

Einstein realized that matter drags on time, slows it down like the slow part of a river.

The heavier the object, the more it drags on time.

And this startling reality is what opens the door to the possibility of time travel to the future.

I admit this is a difficult concept to understand,

so let's take a simple example.

This is the great pyramid of Giza.

It weights over forty million tons, and like all heavy things it's actually slowing down time.

The effect is small; billions of times smaller than that of the Earth.

But if we exaggerate it drastically, you can see the principle at work.

Close to the pyramid everything is slowed down.

Again, like the sluggish part of a river.

Here. time itself is passing slower compared to how it's passing further away.

But what if people near the pyramid look outwards?

They must see the opposite effect.

Because they are slowed down, they must see time in the distance as running fast.

It's a simple result of the mass of the pyramid.

This distortion opens the door to the possibility of time travel.

So what we need to really travel in time is something much more massive than the pyramid.

And I know just the thing.

Right in the center of the Milky Way, 26 thousand light years from us,

lies the heaviest object in the entire galaxy, hidden by a vast cloud of gas and stars.

It's a super-massive black hole, containing the mass of four million suns.

Crushed down into a single point by its own gravity.

The closer you get to the black hole, the stronger the gravity.

Get really close, and not even light can escape.

So it's wrapped in a sphere of darkness fifty million miles in diameter.

A black hole like this one has a dramatic effect on time,

slowing it down far more than anything else in the galaxy.

That makes it a natural time machine.

I like to imagine how a space ship might some day be able to take advantage of this spectacular phenomena.

Of course, it would first have to avoid being sucked in.

The trick, I think, would be to aim just after the sight, so they'd miss it.

They'd have to be on exactly the right trajectory and speed, or they'd never escape.

Get it right, and the ship would be pulled into orbit, a giant circle thirty million miles in diameter.

Here it would be safe, its speed would be enough to keep it from falling any further in.

If a space agency would controlling the mission from Earth,

or anywhere else far away from the black hole,

they'd observe that each full orbit took sixteen minutes.

But for the brave people on board, close to this massive object,

time would be slowed down.

And here the effect would be far more extreme than near the pyramid or planet Earth.

The cruise time would be slowed down by half.

For every sixteen minute orbit, they'd only experience eight minutes of time.

Round and round they go, experiencing just half the time

of everyone far away from the black hole.

The ship and its crew would be travelling through time.

Imagine they circled the black hole for five of their years.

Ten years would pass elsewhere.

When they got home, everyone on Earth would have aged five years more than they had.

The crew of the spacecraft would return to a future Earth.

They would have made a journey not only in space but in time.

So a super-massive black hole is a time machine.

But of course it's not exactly practical.

It has advantages over wormholes in that it doesn't provoke paradoxes,

plus it won't destroy itself in a flash of feedback, but it's pretty dangerous,

it's a long way away and it doesn't take us very far into the future.

Fortunately, there is another way to travel in time.

And this represents our last and best hope of building a real time machine.

Travelling through the fourth dimension will never be a walk in the park,

but it turns out there is a surprisingly straightforward way to do it.

You just have to travel very, very fast.

Much faster than even the high speed required to keep out of the super-massive black hole.

This is because of another strange fact about the universe.

There's a cosmic speed limit.

One hundred and eighty-six thousand miles per second.

Also known as the speed of light.

Nothing can exceed that speed.

I realize this sounds weird but, trust me, it's one of the best established principles in science.

Believe it or not, travelling at near the speed of light transports you to the future.

To explain why, let's dream up a science fiction transportation system.

Imagine a track that goes right around the Earth.

A track for a super fast train.

We're going to use this imaginary train to get as close as possible to the speed of light,

and see how it becomes a time machine.

On board our passengers have the one way ticket to the future.

The train begins to accelerate, faster and faster.

Soon it's circling the Earth, over and over again.

To approach the speed of light means circling the Earth pretty fast.

Seven times a second.

But no matter how much power the train has, it can never quite reach the speed of light,

since the laws of physics forbid it.

Instead, let's say it gets close, just shy of that ultimate speed.

Now something extraordinary happens.

Time starts flowing slowly on board, relative to the rest of the world.

Just like near the black hole, only more so.

Everything on the train is in slow motion.

This happens to protect the speed limit, and it's not hard to see why.

Imagine a child running forwards up the train.

Her forward speed is added to the speed of the train, so couldn't she

break the speed limit simply by accident?

The answer is no.

The laws of nature prevent the possibility by slowing down time on board.

Now she can't run fast enough to break the limit.

Time will always slow down just enough to protect the speed limit.

And from that fact comes the possibility of travelling large distances into the future.

Imagine the train left the station on January the 1st, 2050.

It circles the Earth over and over again, for one hundred years, before finally coming to a halt,

on New Year's day, 2150.

The passenger would have only lived one week, because time

is slowed down that much inside the train.

When they got out, they'd find a very different world from the one they left.

In one week, they'd have travelled a hundred years into the future.

Of course, building a train that could reach such a speed is quite impossible,

but we have build something very like the train.

At the world's largest particle accelerator at CERN, in Geneva, Switzerland.

Deep underground, in a circular tunnel 60 miles long is a stream of trillions of tiny particles.

When the power is turned on, they accelerate from 0 to 60 thousand miles per hour

in a fraction of a second.

Increase the power and the particles go faster and faster,

until they are whizzing around the tunnel at 11 thousand times a second,

which is almost the speed of light.

But just like the train, they never quite reach that ultimate speed.

They can only get to 99.99 percent of the limit.

When that happens, they too start to travel in time.

We know this because of some extremely short-lived particles called pi mesons.

Ordinarily, they disintegrate after just 25 billionth of a second.

But when they are accelerated to near-light speed, they last 30 times longer.

These particles are real-life time travelers.

It really is that simple.

If we want to travel into the future we just need to go fast.

Really fast.

And I think the only way we're ever likely to do that is by going into space.

The fastest manned vehicle in history was Apollo 10.

It reached 25 thousand miles per hour.

But to travel in time we'll have to go more than two thousand times faster.

And to do that we'd need a much bigger ship.

A truly enormous machine.

The ship would have to be big to carry a huge amount of fuel.

Enough to accelerate it to nearly the speed of light.

Getting to just beneath the cosmic speed limit would require six whole years at full power.

The initial acceleration would be gentle because the ship would be so big and heavy.

But gradually it would pick up speed and soon would be covering massive distances.

In just one week it would have reached the outer planets, gas giants like Neptune.

After two years it would reach half light speed and be far outside our solar system.

Two years later it would be travelling at 90% of the speed of light,

and passing our closest star system,

Alpha Centauri around 30 trillion miles away from Earth,

and four years since launch the ship begins to travel in time.

For every hour of time on the ship, two hours pass on Earth,

a similar situation to the spaceship that orbited the massive black hole.

But there's more to come.

After another two years of full thrust, the ship would reach each its top speed,

99 percent of the speed of light.

At this peed, a single day on board is a whole year of Earth time.

Our ship would be truly flying into the future.

The slowing of time has another benefit.

It means we could, in theory, travel extraordinary distances within one human life time.

A trip to the edge of the galaxy would take just eighty years.

But the real wonder of our journey is that it reveals just how strange the universe is.

It's a universe where time runs at different pace in different places.

Where the most extreme objects imaginable, giant black holes

twist and warp both time and space.

It's a place where tiny wormholes exist all around us.

And where ultimately, if we could develop the right technology,

we could use our understanding of the laws of physics

to become time voyagers through the fourth dimension.