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Yesterday is tomorrow

Do you ever dream of being able to travel in time? If you do, your dream is not totally impossible, at least in theory. Travel to the past or future is not just science fiction. It is also the subject of serious research and reflection by physicists. And it is not necessarily scientific heresy!

- We have all dreamt of being able to time travel, to go back in time to correct our mistakes, or go forward in time to see what the future has in store for us.

But what is time in actual fact? And what is space? We are all used to measuring time and space with units which we feel are constant like seconds or minutes for time, or metres and kilometers for space.

But in our everyday lives we sometimes have the feeling that space and time vary.

- for a marathon runner 10 km is a "short distance"; for you or me, with no training, it is interminable.
- and have you never felt that time flies when you are late? But if you are waiting for something time seems to take for ever to pass.

In actual fact it is our perception of time and space that is subjective. It depends on how we our feeling. Here on Earth a minute does last a minute and a metre does measure precisely one metre.

Marc Henneaux - Physicist - Institut Solvay – Université Libre de

Bruxelles
"Sometimes we do have the impression that time flows differently depending on our psychological state, but of course that's purely subjective. However we are feeling, time as shown by our watches flows in exactly the same way, neither faster, nor slower, whatever our mood. Physicists have revealed something rather different: time, as shown on a clock - and this is one of the major scientific revolutions of the early 20th century - this physical time can flows at different speeds, for example in the presence of gravity."

To grasp the idea of space and time not being fixed, but sort of flexible, scientists from Einstein onwards had to invent a new physical concept, which they called "space-time".

Philippe Spindel - Physicist – Université Mons-Hainaut
"According to Einstein's Special Theory of Relativity, space and time are not relative, they are inextricably linked, and the only concept, the only geometrical framework, within which we can reason is space-time, in other words space with an extra dimension, the time dimension, and specific geometrical properties which reflect physical laws, in particular the principle of relativity."

It is not easy to conceive of space and time as being linked, and what is more, capable of being distorted. Before looking at time, let's consider space. Imagine space as an elastic sheet and let's draw a triangle on the sheet: a simple mathematical law states that the sum of the angles of the triangle is 180°. Now imagine that we place a massive body, like our star the Sun, at the centre of the triangle.

If we remeasure the angles of the triangle and added them up, we'll end up with more than 180°! That is because the space around our star has been deformed by gravity, in other words by the Sun's force of attraction. This distorts the triangle. And we can observe that the heavier the body at the centre of the triangle, the greater the deformation of space and hence of the triangle. Exactly the same thing applies to the universe. Take any star in the sky. Light travelling from that star to an observer here on Earth naturally takes the shortest route. In the absence of any celestial body light simply travels in a straight line.

But if there is a massive body like a galaxy between the star and the observer, its gravity "distorts" the neighbouring space. The effect is that the path taken by the light is deviated, because of this distortion of space.

The effect for the observer is that the light comes from a point which is not where the star is! This is known as a "mirage", or a "gravitational lens".

Frédéric Courbin - Astrophysicist - Polit. Scient. Fédérale – Université de Liège

"What we can see here are four images of the same object affected by a gravitational lens, in this case the red galaxy you can see in the centre of the image. This massive galaxy distorts neighbouring space, and light no longer travels in a straight line as it would if there galaxy wasn't there. It travels along several equivalent paths to the observer and that is why we see four different images of a single object."

So space can be described in terms of distortions, or curvature: our Sun, though gravity, bends neighbouring space, and this curvature also determines the trajectories of the planets.

The same goes for the Earth: the Earth also bends neighbouring space, and that determines the trajectory of the moon.

And exactly the same thing applies to time. Time really is elastic, and this affects - guess what? - the GPS satellite navigation systems in cars. Time on Earth flows more slowly than time in orbiting satellites. Absurd? No, it's the truth.

The margin of error of a non-optimised GPS system

According to Einstein's theory, gravity has an effect on the flow of time. The stronger the gravity, the slower time flows. In orbit, the gravitational force is necessarily weaker than on the Earth's surface, which means that a minute on an orbiting satellite lasts slightly less than a minute on Earth.

That means that the GPS system in a car runs slow by 50 microseconds per day compared to the satellite.

That might seem insignificant, negligible, but isn't.

The GPS system calculates the time it takes a radio signal to travel between the satellite and the car. This signal travels at the speed of light, 300.000 km/s. Given that the position of the vehicle has to be calculated continually, even if the difference in the time taken in orbit and on the Earth's surface is only 50 microseconds, the effect can be a margin of error in determining the car's position of several tens of kilometers! The designers of the GPS system therefore had to find a way of synchronising the clocks in orbit and on the Earth.

Marc Henneaux - Physicist - Institut Solvay – Université Libre de Bruxelles

"The frequency of the clock on the satellite is adjusted slightly. It is slightly lower than for the GPS devices on Earth. This lower frequency compensates for the fact that time flows faster on the satellite than here on Earth."

Let's look at another example of the flexibility of time, due to speed this time. Beep Beep. An airline pilot clocks up many hours in flight over his career. Most the time this flight is at speeds around 1000 km/h.

And here again, according to Einstein, time as shown by the pilot's watch when in flight flows more slowly than here with the cows.

Overall, over a 40 year career, the pilot will have accumulated a delay of several tens of microseconds compared to an observer who has stayed on Earth for the whole time !!! Of course this delay is negligible on our scale, but bear in mind that 1000 km/h is not particularly fast. And this is a definite delay.

Now imagine we could build a rocket capable of travelling very fast, almost at the speed of light.

According to the theory of relativity time flows far more slowly for the astronauts on the rocket than on Earth. If the trip lasts several years the astronauts will have a surprise when they return to Earth. Our planet will be several thousand, or even several million, years older. The continents will have moved and maybe there won't be anybody left to describe the trip to…

Time flows differently on the rocket compared to time on Earth

So one way of travelling in time is to travel for long enough at a high enough speed. We don't currently have the technology to do this. And in any case we could only travel forward in time without being able to return…

In this scenario we imagine someone travelling into the future in a machine which doesn't move. The time traveller can see life passing faster outside his time machine.

Claude Semay - Nuclear physicist – Université Mons-Hainaut - FNRS

« He sees the Universe getting older quickly around him, but if we really could travel forward in time, it wouldn't be like that; to travel forward in time you have to be moving very fast, and that is only conceivable in a spaceship that travels at close to the speed of light. Furthermore the time traveller on such a spaceship would see all this information constricted to in a cone of light in front of him, an extremely bright cone of light. If he is travelling forward in time at a speed of say 1 year per

second, that means that in one second he would receive all the light energy he would normally receive in a year, which could be rather uncomfortable. The spaceship would therefore have to be equipped with a shield to protect the time traveller against all this radiation. »

These ideas are very appealing, but for the moment we don't have the technology to travel fast enough for time travel. As we said, to the speeds required are close to the speed of light, 300.000 km/s.

The Universe might however contain natural space-time machines.

The fabric of space-time can be subject to huge distortions, caused by what are known as black holes. Black holes are so massive and dense that they attract everything which comes near them. Even light cannot escape. It is now known that there are several types of black hole, classified according to their origin.

Jean-Pierre Luminet - Astrophysicist – Paris-Meudon Observatory - CNRS
« There are massive black holes, known as "stellar" black holes, because it is believed they form in the final stage in the life of massive stars, stars with 30 or 40 times the mass of the Sun. At the end of their life when these stars have exhausted their thermonuclear fuel, they are believed to explode forming a hypernova, which is a sort of super supernova. The heart of the star then turns into this extraordinary object called a black hole. »

A second type of black hole can be found in the centre of almost all galaxies. These were probably formed just after the big bang, and are thought to drive the galaxies' rotational movement.

But if black holes absorb all light they are invisible. how can one detect their presence?

Frédéric Courbin - Astrophysicist - Polit. Scient. Fédérale – Université de Liège
"Behind me, you can see a galaxy, a collection of stars where every gas particle is a star. At the centre there is a massive very compact black hole accreting matter. This matter burns up as it approaches the black hole releasing an enormous quantity of energy, which ionises neighbouring atoms. That is what you can see in red on the picture. That is how we can identify the presence of a massive object, a black hole, at the centre of a galaxy."

Last February astrophysicists all round the world observed what happens when a star passes too close to a black hole. And this is what they saw: the star is being literally pulled apart by the gravitational attraction of the black hole. The matter from which the star was composed will form a disc around the black hole which will last several million years before being swallowed up.

Peculiar movements of stars and other celestial bodies have also been observed. Gravitational attraction deviates them from their initial trajectory, an effect which can only be generated by a massive, dense body like a black hole.

And this is what an observer in orbit around black hole would see. The gravity is so strong that the surrounding space is deformed, and light rays coming from behind the black hole are distorted.

But why is the study of black holes so interesting? Quite simply because they could be very useful for travelling in space, and time.

> **Jean-Pierre Luminet - Astrophysicist – Paris-Meudon Observatory - CNRS**
> *"At the bottom of a black hole they might not be a node in space-time, known as a singularity, which nothing could pass through. It could instead connect the inside of the black hole to another region in space-time, where symmetrically to the black hole matter and energy would emerge spontaneously. That is called a "white hole", or a "white fountain". The connection between the two has been christened "wormhole", like the tunnels earthworms make in soil. This is only a mathematical prediction, but the idea is that if wormholes actually exit, particles, or in science fiction space vessels, could use these wormholes predicted by the calculations as short cuts to travel in space and time."*

So a wormhole is a sort of tunnel outside our own three-dimensional space.

But as we have seen, a wormhole needs a black hole, and also a white hole. White holes, like black holes, are also though to have been observed, in the form of quasars. These are objects like stars, but which emit as much energy as several galaxies. It is thought that this huge quantity of energy comes from the other end of the tunnel, the black hole, where all the matter is sucked in.

So you can see how a wormhole could enable us to travel in space, but how could it be used for time travel?

Claude Semay - Nuclear physicist – Université Mons-Hainaut - FNRS

"Once you have a wormhole, you can turn it into a time machine. The first thing to understand is that the two mouths of a wormhole, the two entrances, can be arbitrarily far apart in space yet close together when travelling thought the wormhole: in this example the two mouths are 1 metre apart though the throat of the wormhole but are 100 metres apart in ordinary space. And that could just as well be 1 million km or 1 billion km. Given that, we can see how to turn a wormhole into a time machine. You take one of the mouths of a wormhole and you take in on a journey through space, very fast. In this way you can produce a time difference between the two mouths. Once you have returned the mouth close to the other, time at each mouth will be different, rather like for the passengers on a space rocket which returns to Earth after a long space voyage. They will be younger than people who had stayed on Earth."

The only problem is that the closest black hole to us is at 30,000 light years away (10,000,000 times the distance between the Earth and the Sun). In this scenario we built the entrance to a wormhole here on Earth.

Philippe Spindel - Physicist – Université Mons-Hainaut

"That is a nice artist's impression, but according to our current understanding of physics it is theoretically and technologically impracticable. Making a wormhole requires the bringing together of large quantities of negative energy in a macroscopic region. But physics teaches us that negative energy can only exist on a microscopic scale, as fluctuations."

The only solution is therefore to travel to a black hole, try our luck and jump in. Any volunteers?

Once time travel becomes possible a whole series of worrying prospects are opened up. These are known as temporal paradoxes.

The best known amongst physicists is the so-called "billiard ball paradox".

Imagine we make a small wormhole on our billiard table. Let's suppose that the wormhole enables us to travel back in time by several seconds between the entrance and the exit.

Imagine we now shoot a ball into the wormhole. It should in theory emerge a few seconds earlier, and collide with its younger self. That means it couldn't have entered the wormhole in the first place, hence the paradox. To resolve this physicists imagine a slightly modified scenario.

Marc Henneaux - Physicist - Institut Solvay – Université Libre de Bruxelles
"The billiard ball does emerge from the other end of the wormhole, does travel towards its younger self and touches it. So a collision does take place, but it is not violent enough to stop the ball from entering the wormhole and travelling back in time. That is a coherent solution."

But this solution implies an infinite number of balls coming back from the future, meeting their earlier selves, going on for ever…

Another well-known paradox is of matricide. Imagine you travel back in time, to before you were born, and kill your mother, or at least prevent your parents from meeting: you'll create another paradox..

Marc Henneaux - Physicist - Institut Solvay – Université Libre de Bruxelles
« In this case, a solution which some people put forward, given that living creatures are involved, is to take about free will and say there is a supernatural force which will prevent someone killing their mother before they are born.»

Finally, we can ask ourselves whether travel in space-time is reasonable. From a scientific point of view, it is conceivable, although not achievable with today's low level of technology.

We would need to achieve very high speeds to travel forward in time, or a wormhole to travel back.

But from a human perspective, despite the huge problems, the idea of just using a tunnel or a door to travel back in time to correct our mistakes is enormously attractive.

Bertrand Hespel - Philosopher of science - FUNDP
"If we could travel back in time, we would be in a certain sense 'masters of our destiny'. This would be the proof that we are indeed entirely free. This is certainly a rather naive way of viewing freedom, but there is something of it in our desire to imagine that we could go back in time and undo what has been done and replace it with something else."

So time travel is not impossible. But achieving it raises technical, and especially philosophical difficulties.