Faster than light

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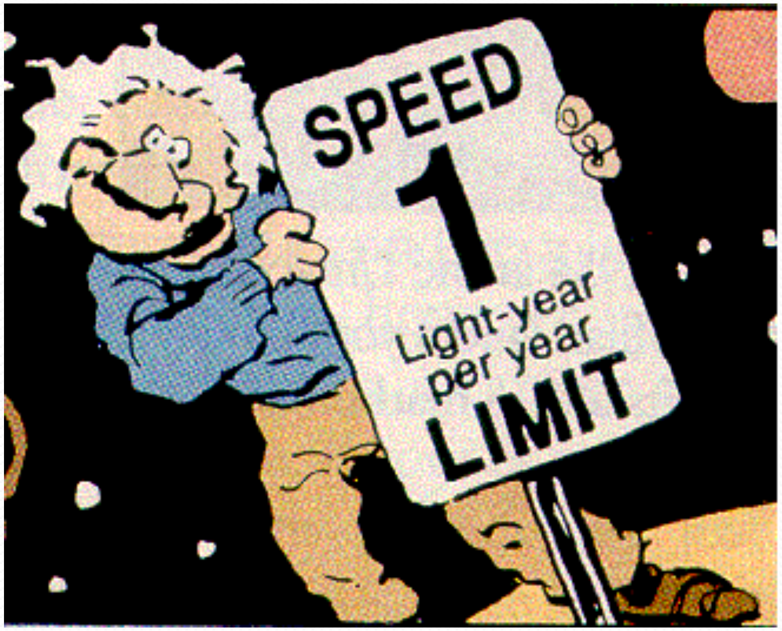
Cosmic speed limit

Ever since Albert Einstein published in1905 his Theory of Relativity, the fact than nothing can travel faster than light has become an essential part of our view of the Universe.



Light travels at 300,000 kilometers per second, that is, about a billion kilometers per hour. In everyday life this speed is so huge that it seems almost infinite.

Astronomical distances

But distances in space are HUGE!

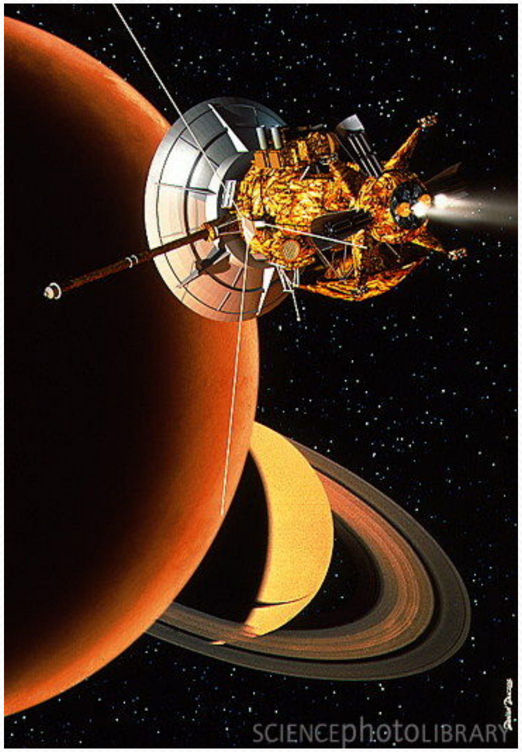
... Light takes 8 minutes to reach us from the Sun.

... 4 years from the closest star.

... 2 million years from the Andromeda Galaxy (in our cosmic backyard)

... And over 10 billion years from the most distant galaxies known.

Even within our solar system, the limit of the speed of light implies serious restrictions to communications: the instructions sent to interplanetary probes must be send sometimes hours in advance.



If we ever want to reach the stars, the speed limit imposed by light represents a big problem!

But … why can't we travel faster than light?

The simple answer is that the theory of relativity forbids it. There are two specific reasons why this is so:

I) The "mass" of an object (or rather its "inertia") increases with speed and in fact becomes infinite at precisely the speed of light.

II) The second reason is more complex, but much more fundamental, and is related to concept of "causality". It turns out that travelling faster than light violates causality, that is, effects can come before causes, with is of course absurd.

But let us back up a bit ..
What is “relativity”?

The concept of “relativity” goes back to Galileo, and comes from the fact that movement is always “relative to something”. In other words, there is no “absolute motion”, jus as there is no “absolute rest”. (Aristotle would not have agreed)

An observer inside a closed room with no windows, somewhere inside a ship in a calm sea, can not tell if the ship is moving with respect to distant land or if it isn’t.

No physical experiment can measure “absolute speed”. The results of all experiments are independent of the speed of the observer.

Einstein’s postulates

In 1905, Einstein tries to solve some puzzles related to the propagation of electromagnetic waves (light) and takes two basic postulates:

1. The principle of relativity (Galileo): The laws of physics are independent of the speed of the speed of the observer.
2. The speed of light is ABSOLUTE, independent of the speed of the source, or of the observer. It is a universal constant.

All the theory of “special relativity” can be derived from these two postulates.

The second postulate is crucial. It implies that the Galilean law of addition of velocities is wrong! This is because is one of the two velocities is the speed of light, then the sum must also be equal to the speed of light, regardless of the value of the other one.

Consequences of relativity

Einstein's two postulates have a series of consequences that turn upside down our concepts of space, time, mass and energy:

1. The flow of time is relative!

2. Distances are relative!

3. Simultaneity is relative!

4. Mass and energy are equivalent!

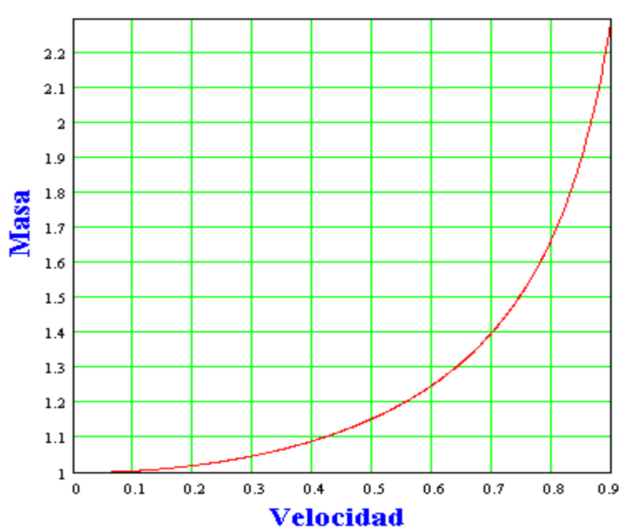
5. The mass (inertia) of an object increases with its speed!

Relativistic mass

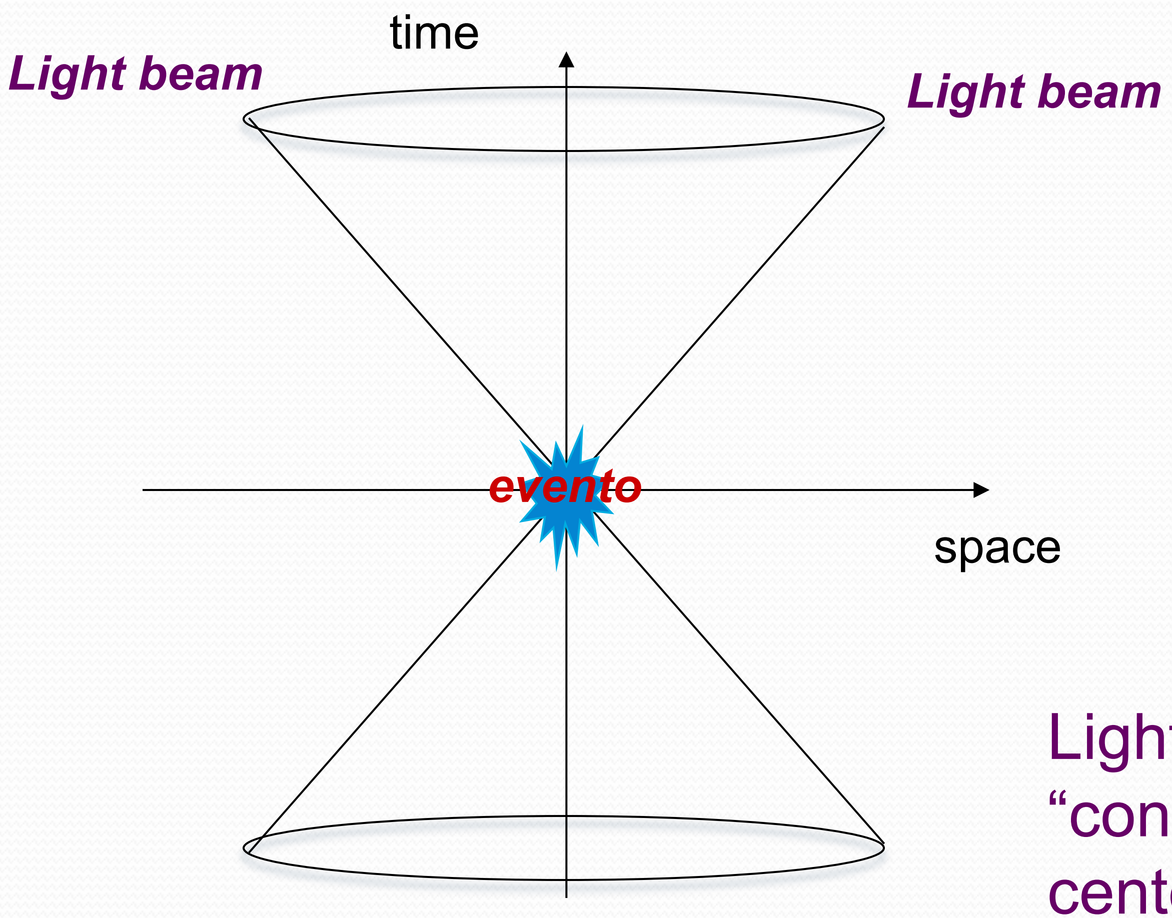
The mass of an object increases with speed. This is because kinetic energy is equivalent to mass, and so it adds to the objects inertia.

$$M = \frac{m_0}{\sqrt{1 - v^2/c^2}}$$

At the speed of light the mass becomes infinite! It is clearly impossible to push an object with infinite mass any faster, which implies that we can not go faster than light.

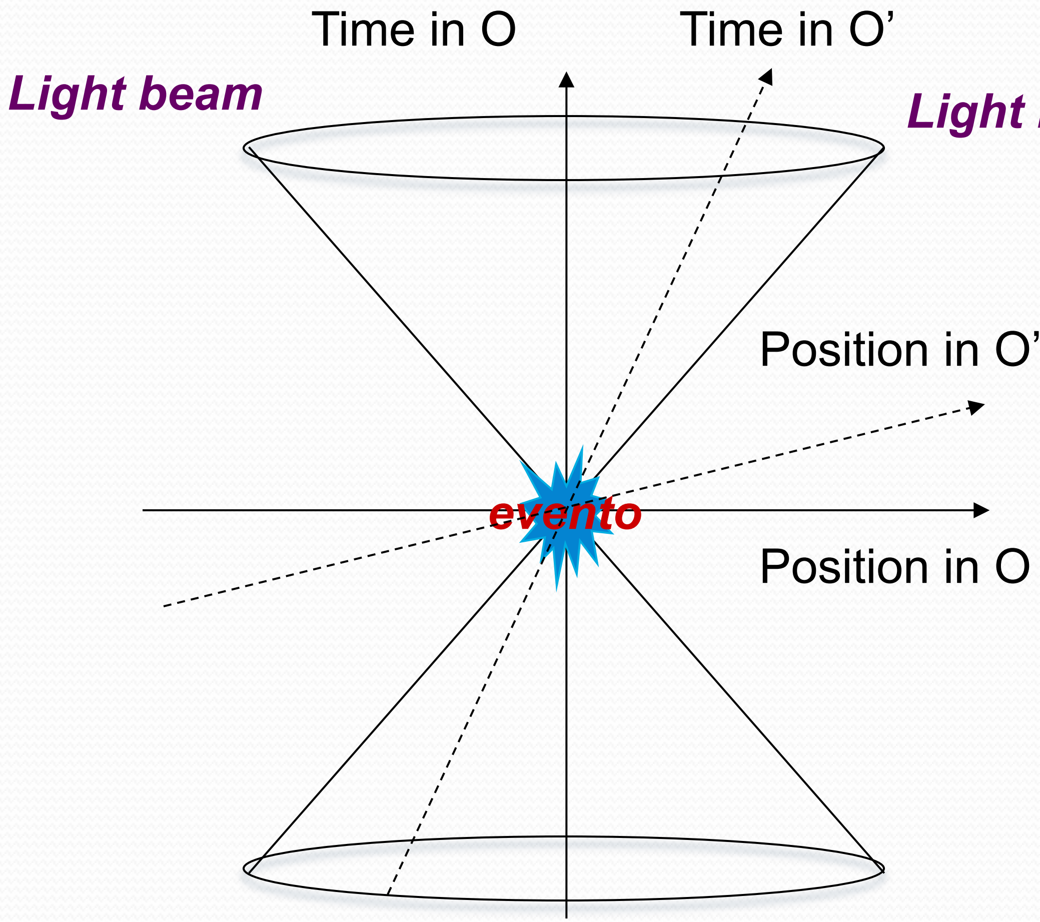


The light cone and causality



Light signales define a "cone" in space-time centered on a given event: the "light cone".

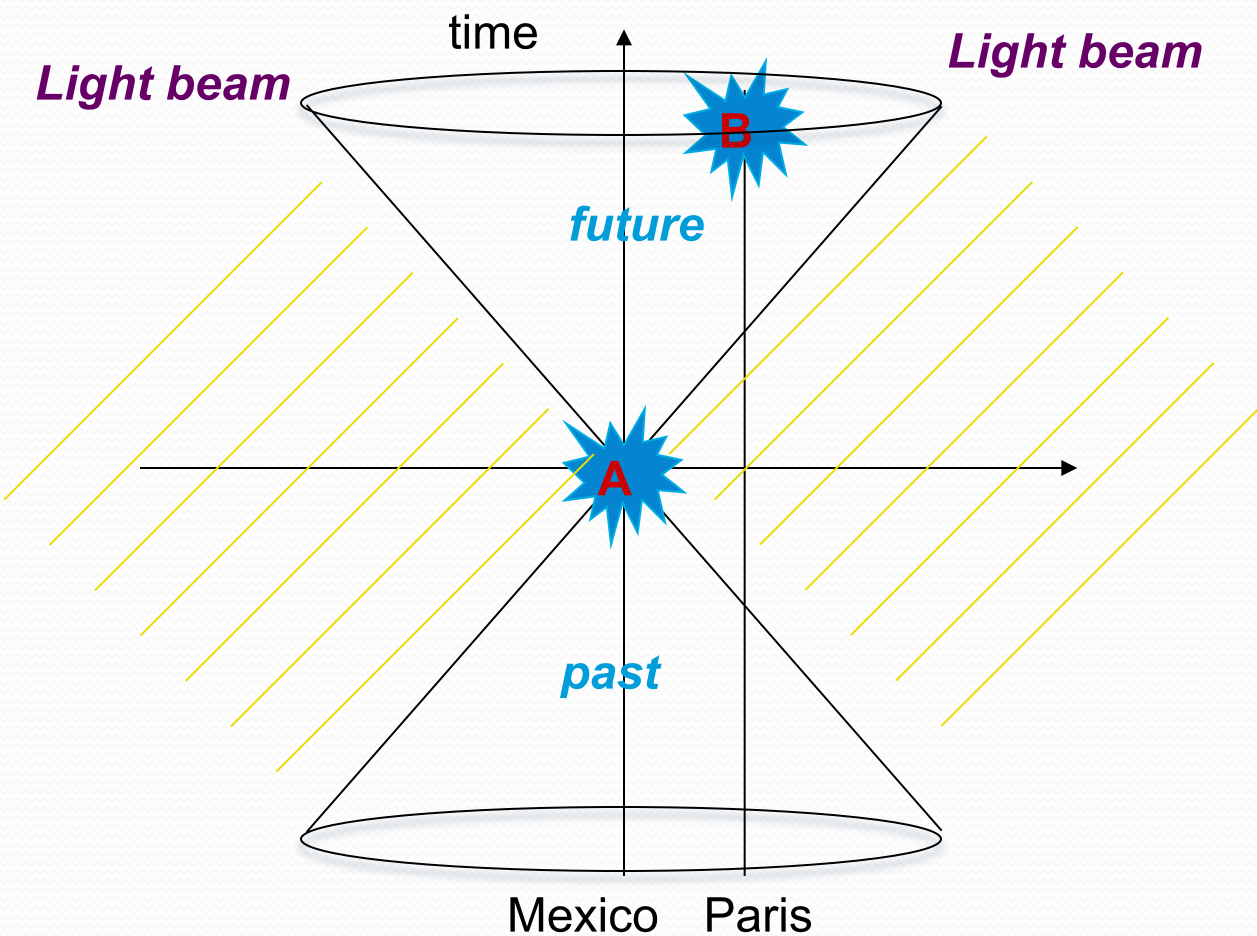
Relativity of simultaneity

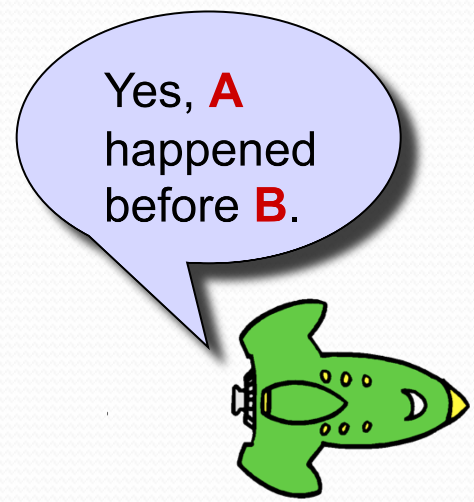


Observers that move relative to one another (O and O') do not agree on the simultaneity of events, nor on the time ordering of some events.

... But the always agree on where is the light cone of a given event.

Past and future

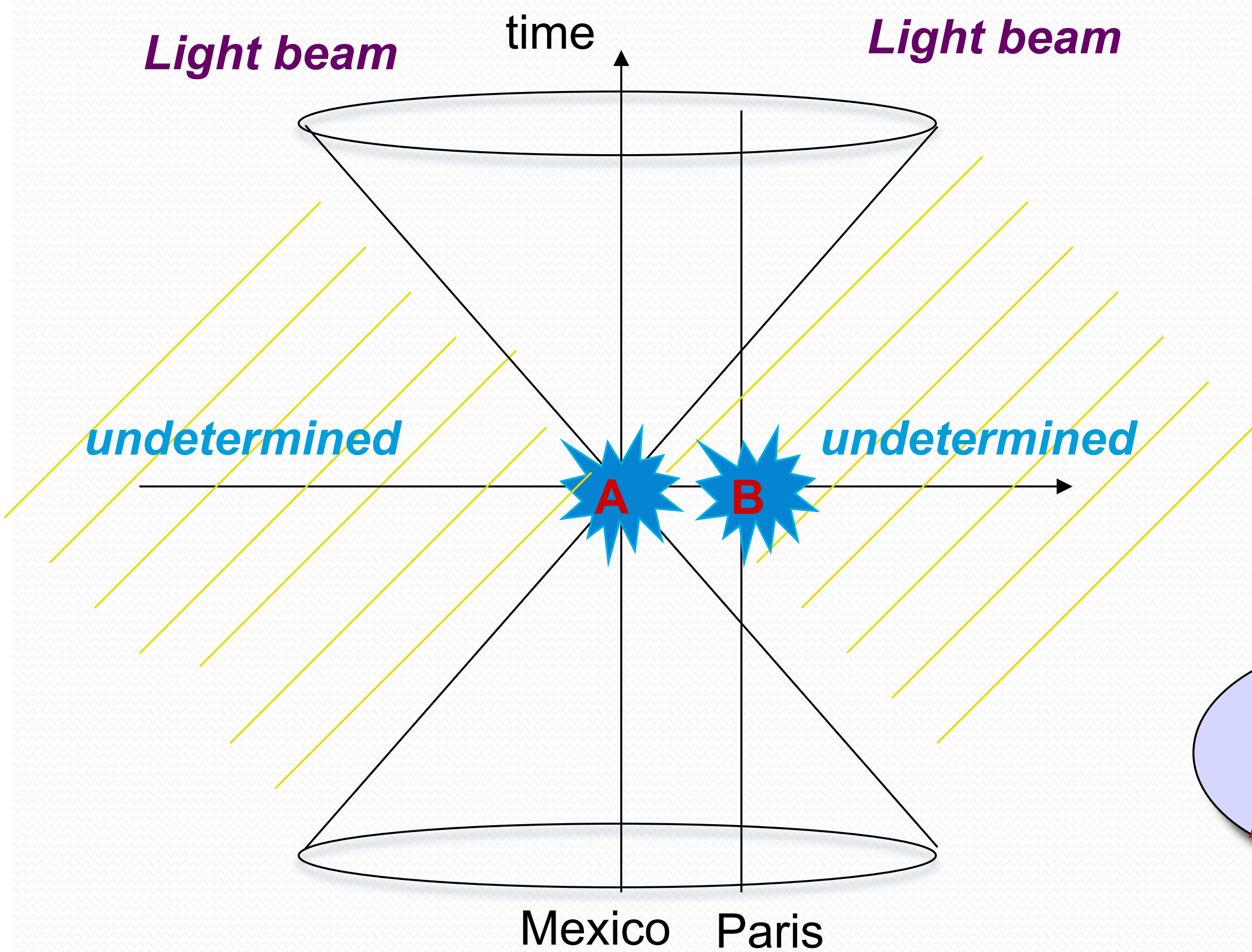


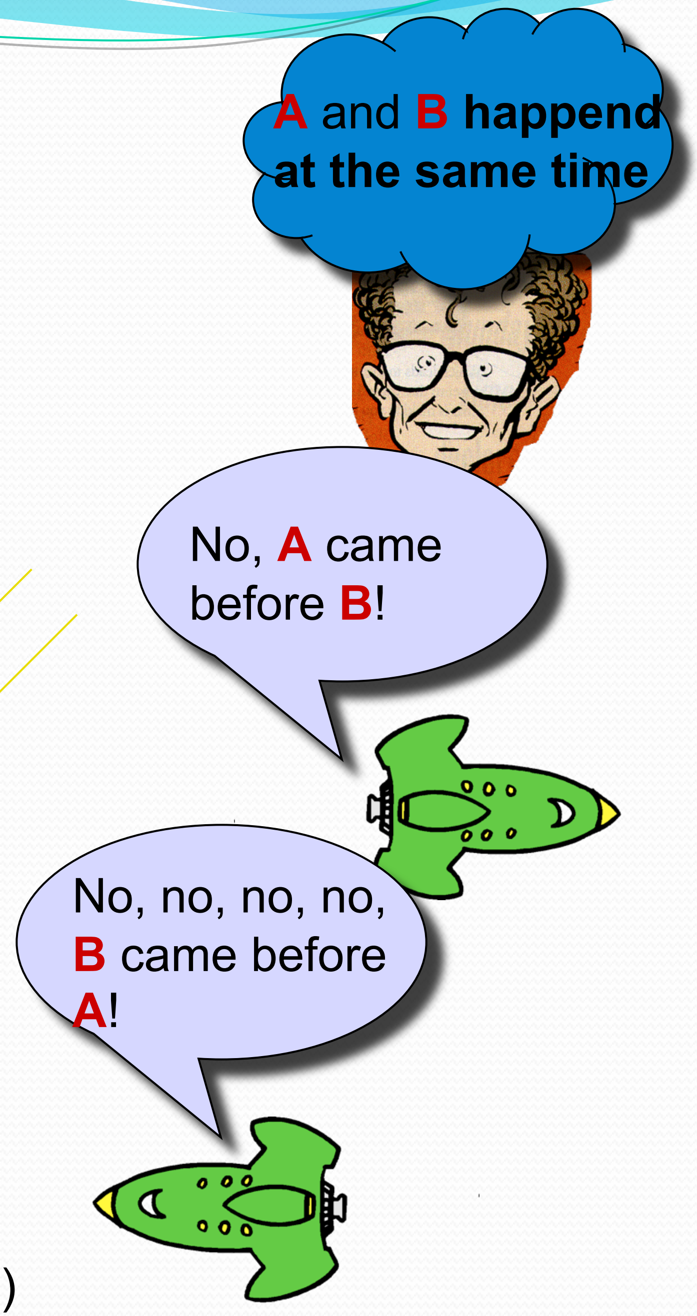


A: I sent a letter to my friend yesterday.

B: My friend received the letter today.

Undetermined





A: I woke up in Mexico at 8:00 (local time)

B: My friend had a late lunch at 3:00 pm (local time)

Causality in relativity

In relativity, causality is defined by the light cones:

• Different observers DO NOT AGREE on the time order of events that are outside each others light-cones.

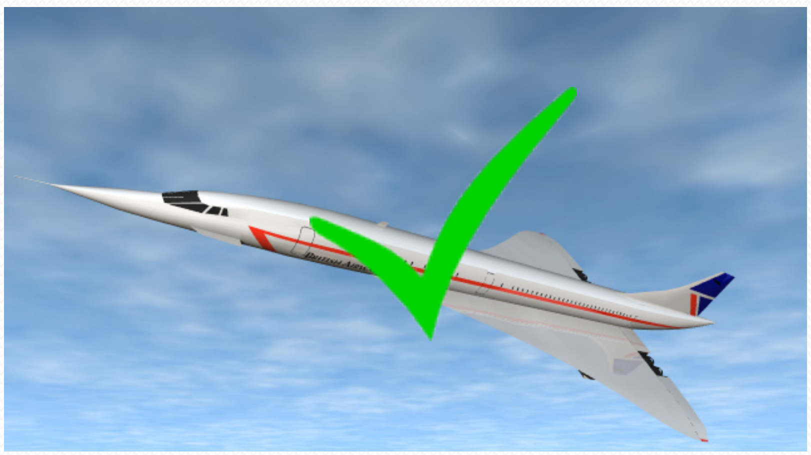
• But the ALWAYS AGREE on the time order of events inside each others light-cones.

This means that, if an object moves faster than light (outside the light-cone), then they will be perfectly reasonable observers that will see such an object arrive at its destination before it left!

Travelling faster than light violates causality!

The sound barrier and the light barrier

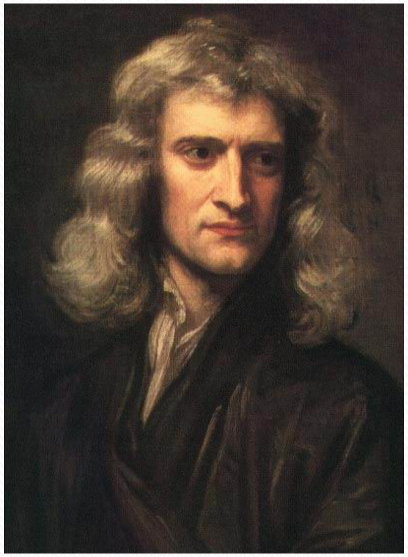
For centuries we have known that it is possible to move faster than sound (cannon balls do it all the time). Flying faster than sound was a technological problem, never a physical problem: it is very hard to make an airplane than can fly faster than sound in a stable way.

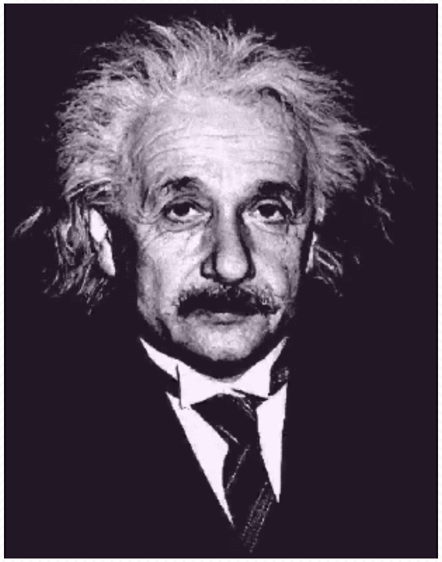


The light barrier is completely different, it is not a technological problem but a physical problem. It is forbidden by the laws of physics.

General relativity

As it turns out, one can use the second great contribution of Einstein to eliminate part of the problems with faster than light travel. This second great contribution is the theory of "General Relativity".





General relativity is in fact our modern theory of gravity. It replaces Newton's old law of "Universal Gravitation".

The principle of equivalence

"I had the happiest thought of my life …"

Albert Einstein, 1920

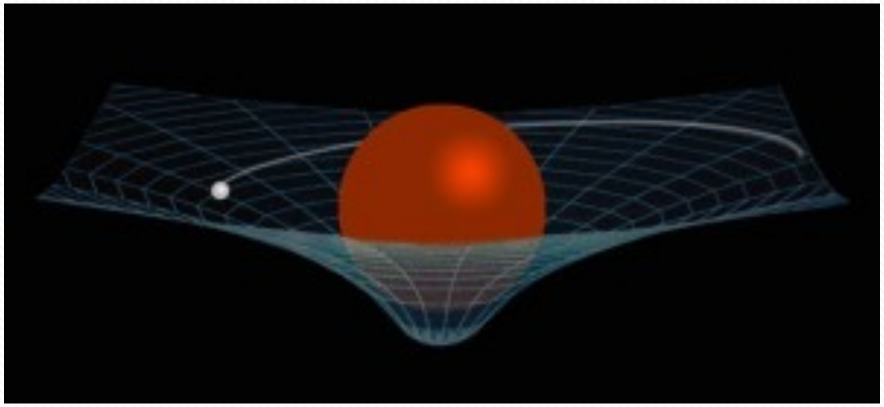
Principle of equivalence (Einstein, 1907):

- Galileo: All objects fall with the same acceleration in a gravitational field.
- Newton: The "inertial" and "gravitational" mass of an object are the same.
- Einstein: The laws of physics in free fall are identical to those of special relativity. In other words, in free fall the "force of gravity" vanishes.

Curvature of space-time

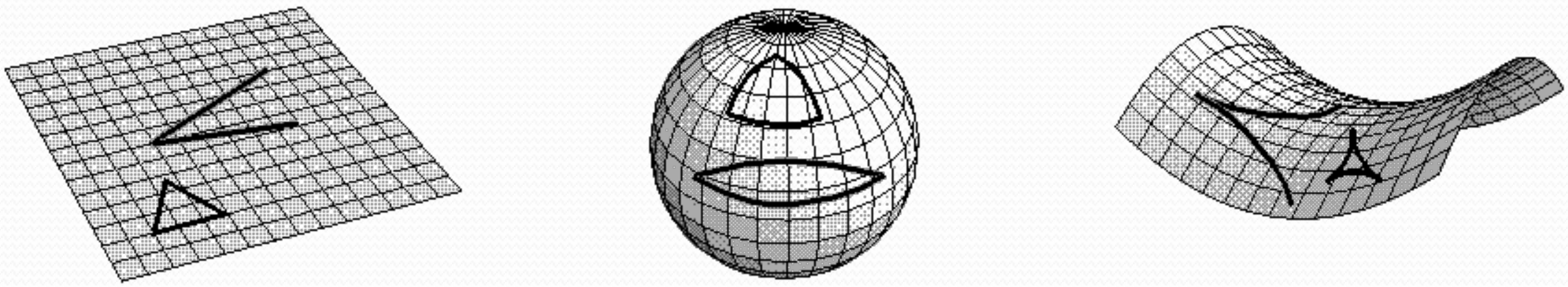
The principle of equivalence implies that the trajectory of an object in a gravitational field is a property of “space”, sine it is the same for any object (this is very different to what happens with electric and magnetic fields).

If objects follow curved paths it must be because space itself is “curved”.

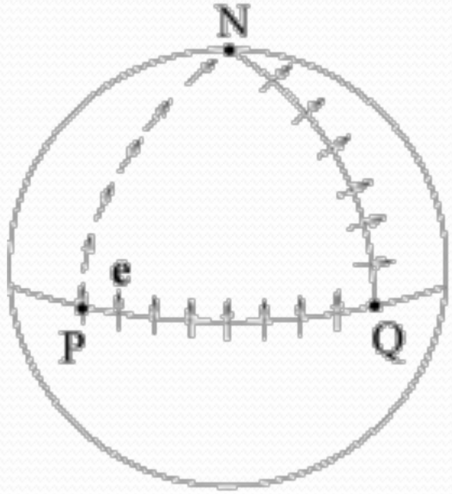


According to General Relativity (GR), space and time are not fixed: The geometry of space and the floe of time can be altered by the presence of large concentrations of mass-energy (gravity). In other words, gravity is equivalent to the “curvature” of space-time.

But … What is curvature?



In flat space, parallel lines remain parallel, lines that cross keep always the same angle and the angles inside a triangle always add to 180 degrees. In a curved space none of these statements are true any more.

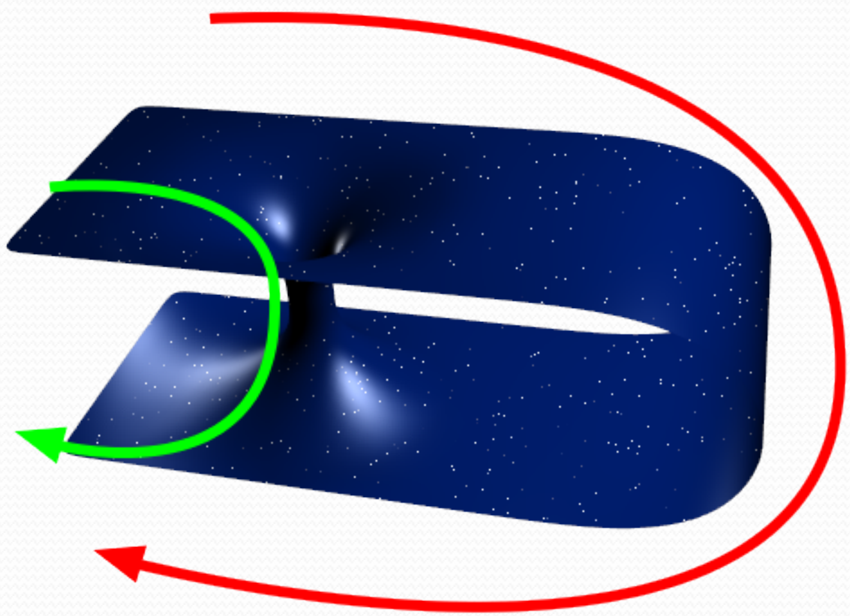


Also, in a flat space, if we transport a vector around a closed path it comes back the same. In a curved space it does not.

Now let’s use curvature to cheat!

If we accept that the geometry of space can be altered, then there are several ways one can think off that will allow us to cheat and move faster than light.

One idea is to simply make a short “tunnel” that connects two distant regions of space.



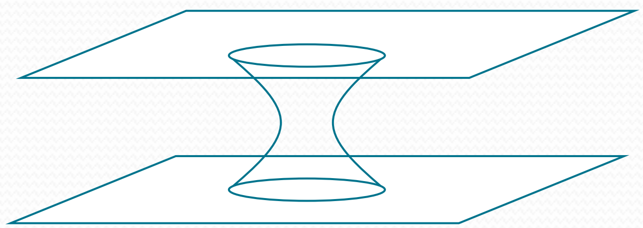
Such tunnels are known an “Einstein-Rosen” bridge, or less technically as “wormholes”.

When we go through a wormhole we move a very short distance but find ourselves suddenly very far from where we started.

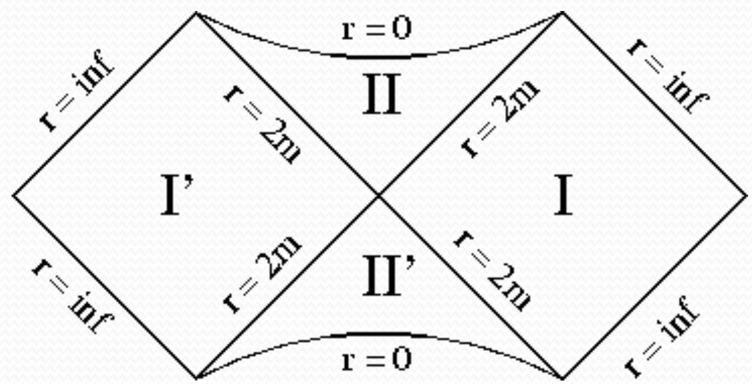
Wormholes and black-holes

But, are wormholes allowed in GR?

Actually, yes!, The first solution ever found (the Schwarzschild solution of 1916), that describes a spherical black-hole in fact also contains a wormhole. This was discovered by Einstein and Rosen 1935 (but beware, a black-hole and a wormhole are different things).



Schwarzschild

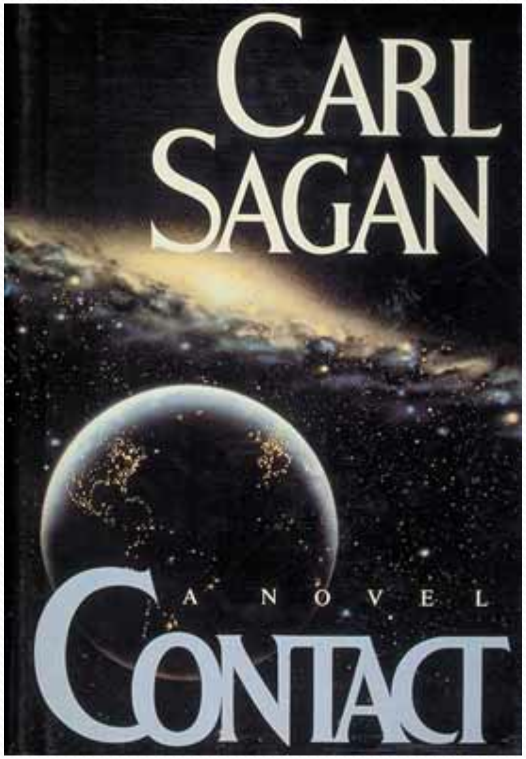


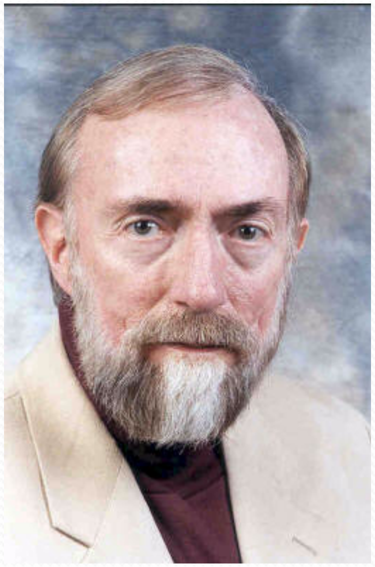
But the wormhole inside a Schwarzschild black-hole is quite useless because:

1. It is dynamical, and closes in on itself so fast that not even light can get through.
2. It actually leads to a separate "parallel" Universe, and not to another region of our Universe.
3. We have no idea how to make one.

Traversable “wormholes”

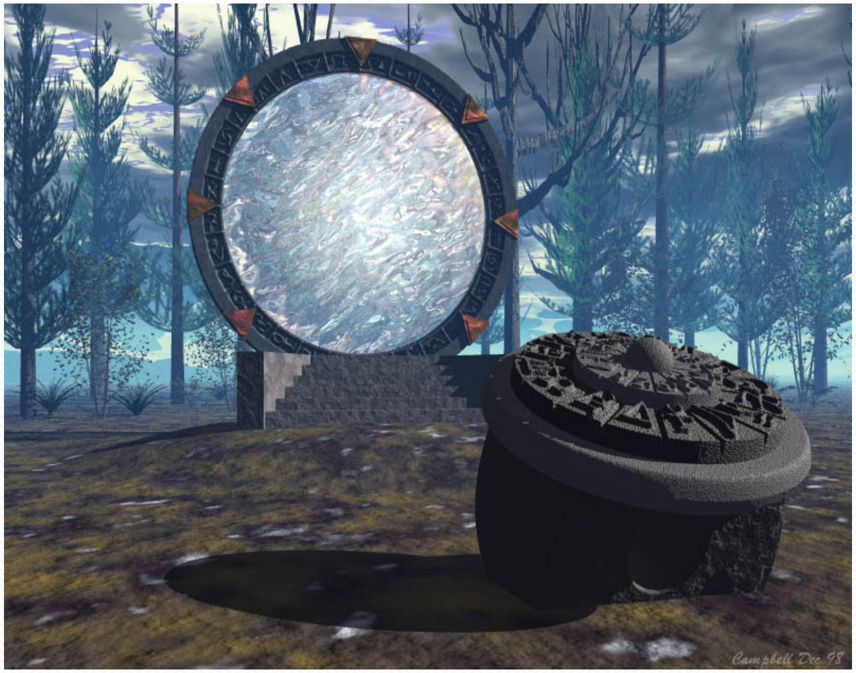
In the 1980´s, Carl Sagan was writing a science fiction novel (“Contact”). He needed his characters to travel to a distance star faster than light. But as a scientist he couldn’t say “they just did”, he needed something better. He decided to ask his friend Kip Thorne.





Kip, together with his student Michael Morris, studied under what conditions one could have “traversable” wormholes in GR.

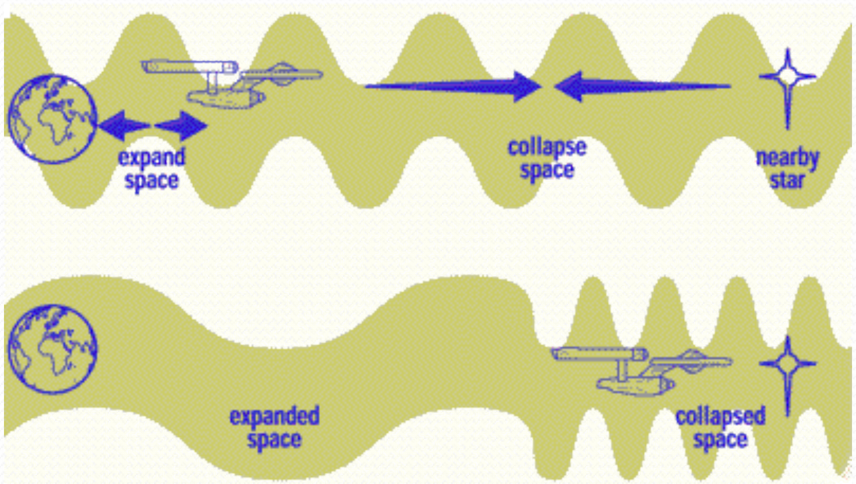
Wormholes in science-fiction



Wormholes have been used for decades in science-fiction, sometimes under different names: “portals”, “stargates”. Some authors imagine doorways that take us to the stars in a single step (effectively a door-sized, and extremely, short, wormhole).

Warp drives

Another idea for travelling faster than light using GR is known as the “warp drive” spacetime (or warp bubble). This was suggested by Alcubierre (i.e. myself) in 1994.

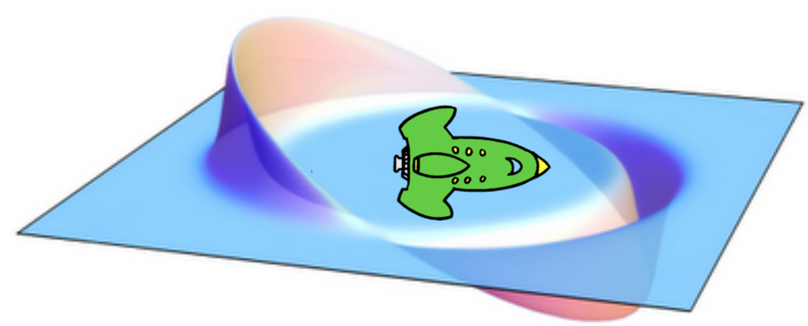


With this method, one does not move “through space”, but rather “with space” (similar to a travelator in an airport).

Contraction and expansion

The idea behind a warp drive comes from the expansion of the Universe: distant galaxies move away from each other. The further they are, the faster they move.

In fact, very distant galaxies move away from each other faster than light. This DOES NOT contradict relativity, since in reality it is not the galaxies moving, but rather the space in between expanding!



For a “warp drive” we would need to create a violent localized expansion of space behind us, and an opposite contraction of space in front of

The spaceship would sit inside a “bubble” of undisturbed flat space, and would fill no acceleration whatsoever!

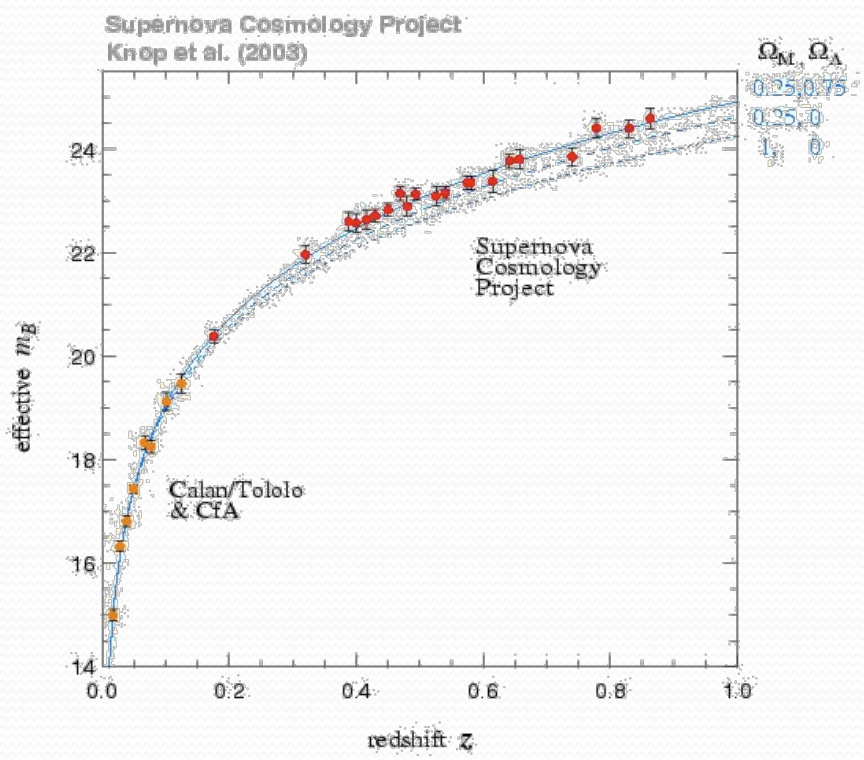
Negative energy (antigravity)

Both wormholes and warp drives have a serious drawback: in order to curve space in the desired way they require “negative energy”, that is a form of mass-energy that produces a gravitational repulsion instead of an attraction, or in other words, antigravity. And the require huge, star-sized quantities of it.

We have never found antigravity in nature. But as far as why know it is not forbidden!

Better find it by next week, or the next episode will be rather boring ...

Does antigravity exist?



Until recently, any form of antigravity was pure speculation. But today this has changed!

The study of supernovae at cosmological distances has shown without a doubt that the expansion of the Universe is in fact accelerating.

This can only be understood if we have some energy field that produces some form of antigravity: the so-called "dark energy".

And what is dark energy? We don't know yet, it is one of the big mysteries of modern physics.

Time paradoxes

But beware: in relativity, any method to travel faster than light can in principle be used to travel back in time (a time machine).

¡Horror! Physicist hate time travel to the past because it brings with it a series of nasty paradoxes.

1. *Logical inconsistencies or the grandfather paradox:* I travel 70 years to the past and kill my grand father before he has any children. But in that case I was never born, so how did I travel to the past?

2. *Strange loops or, where is the watchmaker?:* An old man gives me a nice gold watch. I travel to the past and meet a kid and like him so much that I give the watch to him. The child grow to be be the old man that gave me the watch. Who made the watch?

3. *Information from nothing or, who invented that?:* I travel to the past and meet and old Beethoven, almost deaf, tired and unwilling to write music. I hum to him the "Ode to Joy". He loves it and composes his 9th symphony around. Who composed the Ode?

Conjectures

Time travel paradoxes are so nasty that they make most physisists believe that time travel is impossible.

Stephen Hawking has even postulated his “chronology protection conjecture” that essentially states that the laws of physics prohibit time travel to the past.

The conjecture has not been proven (it wouldn’t be a conjecture it it had), but there are good arguments in its favor based on quantum field theory.

Notice that the conjecture does not prohibit faster than light travel. It just states that is a method to travel faster than light exists, and one tries to use it to build a time machine, something will go wrong: the energy accumulated will explode, or it will create a black hole.

Conclusions

So, can we travel faster than light?

- It is forbidden in special relativity.
- General relativity seems to allow it by creating some particular distortions of the geometry of space. But they all seem to require antigravity, which has not been discovered (but cosmology hints to some form of antigravity in the dark energy).
- And if it is possible, we must confront the problem of time travel to the past and the causality problems is causes.

We do not have the final answer ... But we have discovered that the question can indeed be asked in a meaningful way. And also than not all the doors are closed. Time will tell ...

Thank you!

There was once a young lady called Bright
who could travel much faster than light.
She departed one day
in a relative way
and returned on the previous night

(Anonymous)