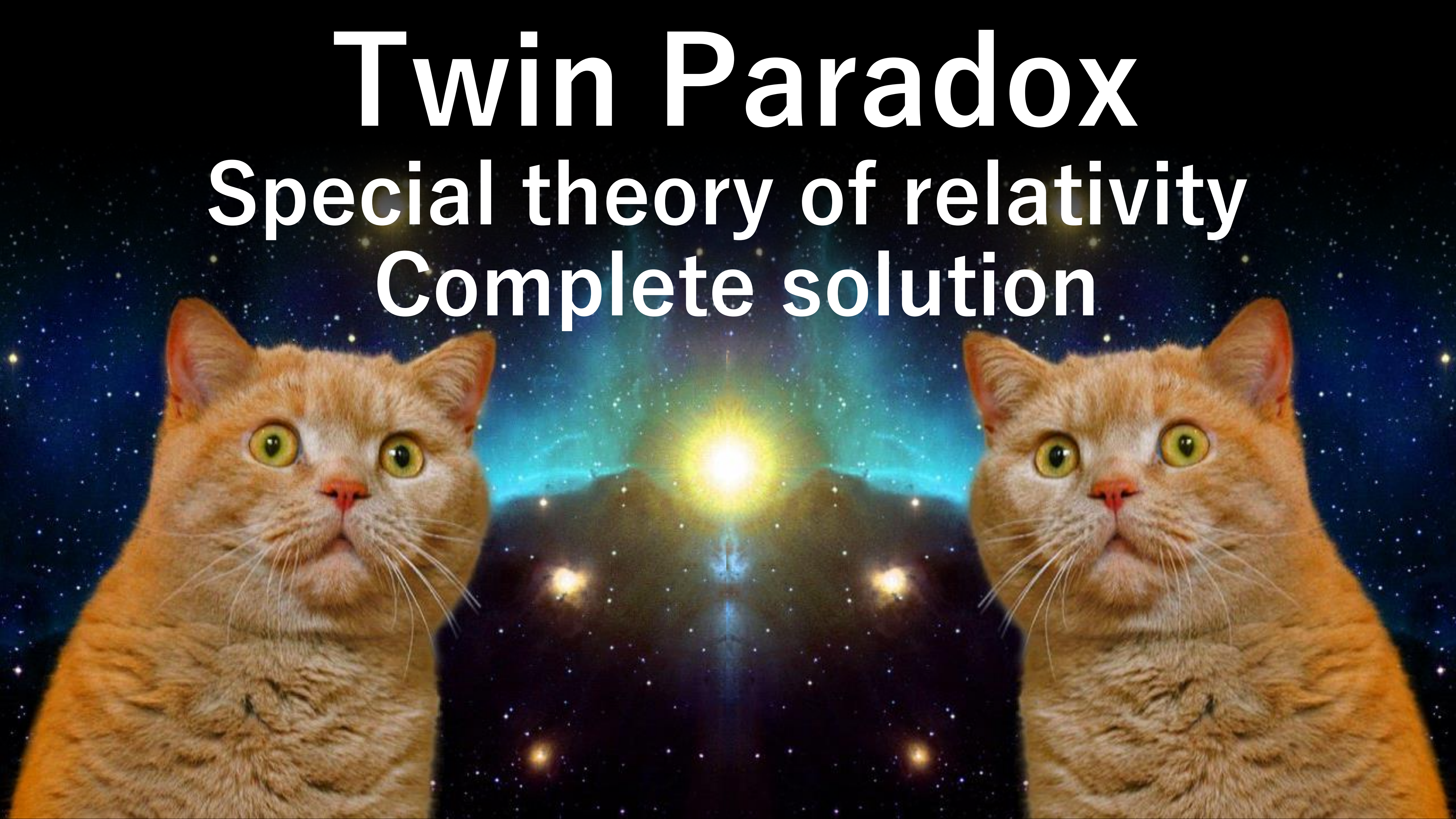
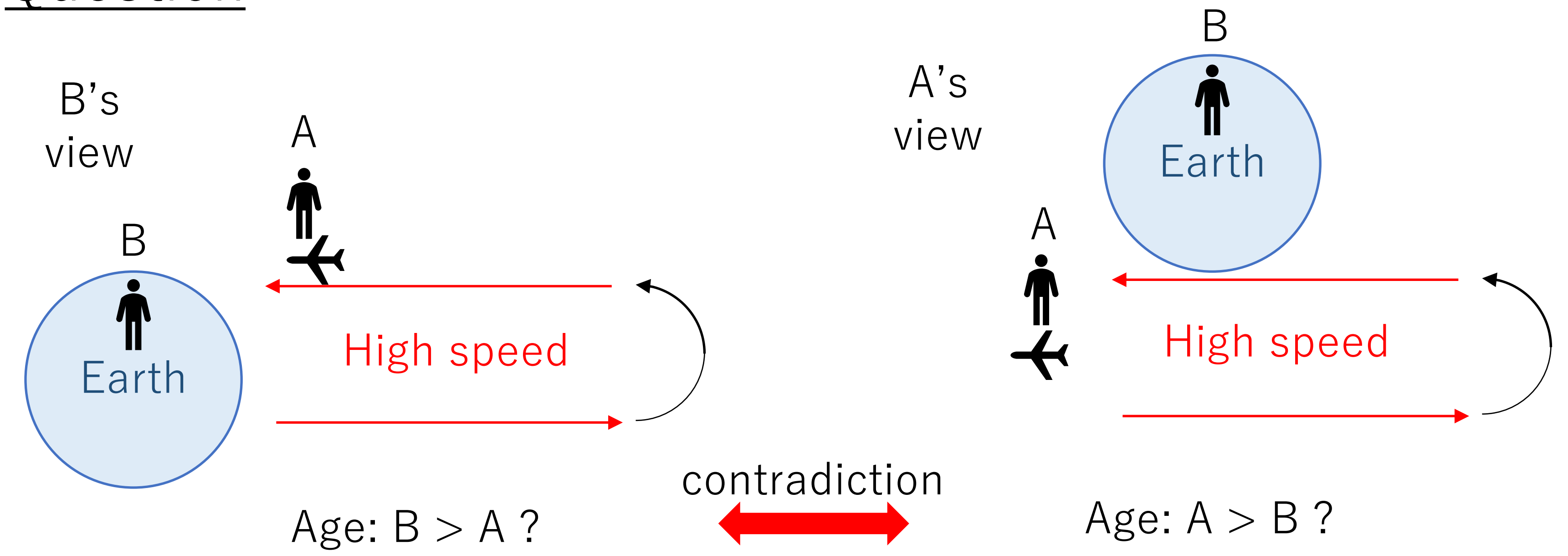

Twin Paradox
Special theory of relativity
Complete solution

Twin paradox

Question

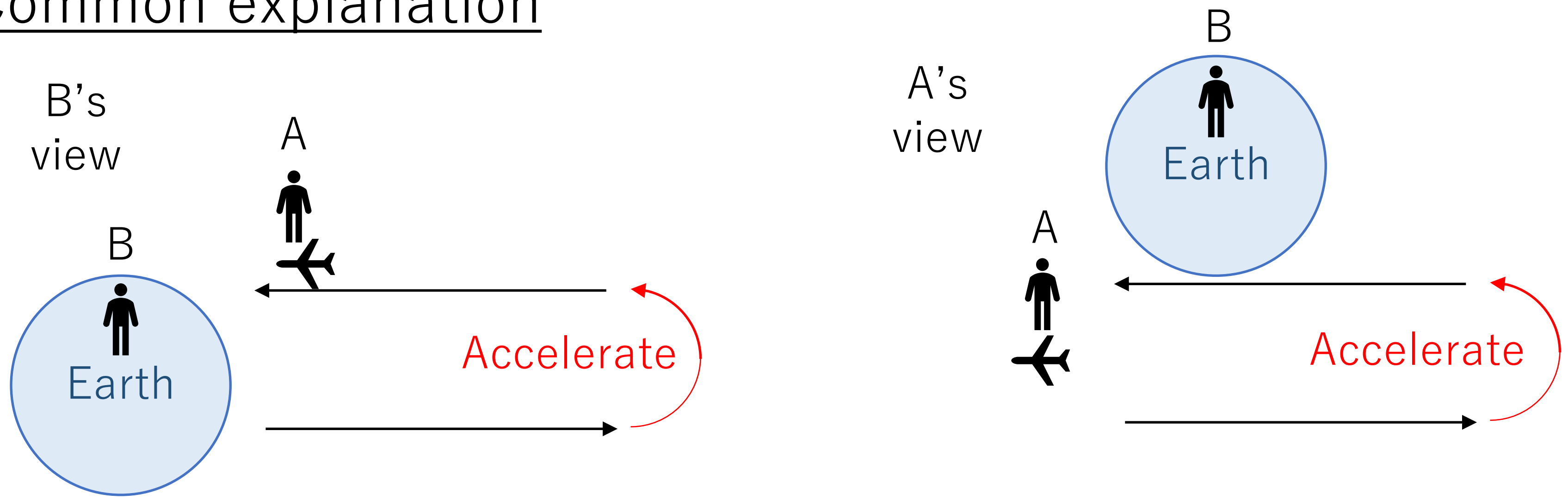


According to the theory of special relativity,
the faster you go, the slower time becomes.

The great detective solves the twin paradox once and for all.
This problem concerns which twin will be older when one of two twins returns from a space trip.
According to the special theory of relativity, the faster you move, the slower time flows.
Therefore, the person who returns from the rocket should be younger, as time will be slower.
However, from the perspective of the rocket, it appears that the Earth has moved.
Therefore, the person who remains on Earth should be younger, as time will be slower.
It is a contradiction for either twin to see the other as younger.
This is the twin paradox.

Twin paradox

Common explanation



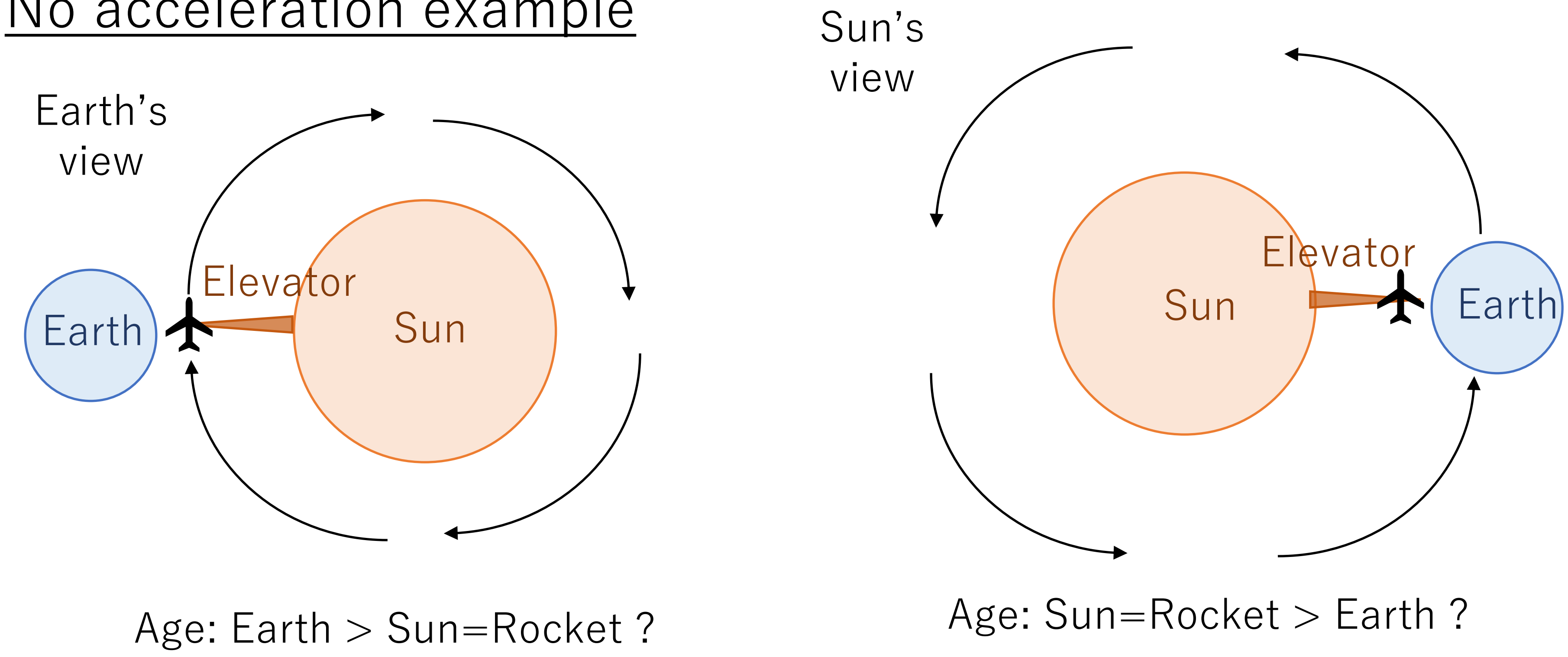
Time slows down when accelerating.

Which one is accelerating?

The common explanation is that the rocket is accelerating, so it's not symmetrical.
The rocket decelerates and accelerates when it departs, arrives, and makes a U-turn at the turnaround point.
It is explained that time slows down when it accelerates.
However, from the rocket's perspective, it looks like the Earth is decelerating and accelerating and making a U-turn.
In the first place, the special theory of relativity simply says that the greater the speed, the more time slows down, and acceleration is irrelevant.
So, let's try a thought experiment where there is no acceleration.

Twin paradox

No acceleration example



First, stop the Sun's rotation.
Install an orbital elevator that can reach from the Sun to the Earth.
Attach a rocket to the end of the orbital elevator.
When viewed from the Earth, the rocket appears to be orbiting the Sun at a constant speed and returning.
Although it's not as fast as the speed of light, the rocket's time should be slightly slower.
Meanwhile, when viewed from the Sun, the Earth is orbiting the Sun at a constant speed.
Time on Earth should be slower than the Sun.
Since the rocket is fixed to the Sun, time on Earth should also be slower when viewed from the rocket.
Depending on whether the Earth or the Sun is used as the reference, the order of which time slows is reversed.

Twin paradox

Three Solutions

Age of the twins

(1) $(A>B)$ AND $(A<B)$

(2) $A=B$

(3) $(A>B)$ OR $(A<B)$

If you have the preconceived notion that the rocket will be slower, you will make a biased inference.
Let's discard the preconceived notion and consider all the possibilities.
When the paradox is resolved, the ages of twins A and B will be one of the following three.

Twin paradox

Solution(1)

Age of the twins

(1) (A>B) AND (A<B)

contradiction

A's world

B's world

If we use the multi-world interpretation,
contradictions are okay.

The first solution is to affirm that the person looks younger from both angles.
The claims of both men are contradictory, so they cannot be true at the same time.
However, in the many-worlds interpretation, this can be interpreted as the worlds having branched out.
However, accepting any contradiction is the same as giving up on any explanation.

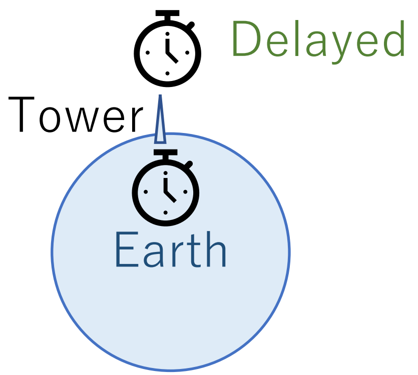
Twin paradox

Solution(2)

Age of the twins

(2) A=B

Time Dilation by Gravity

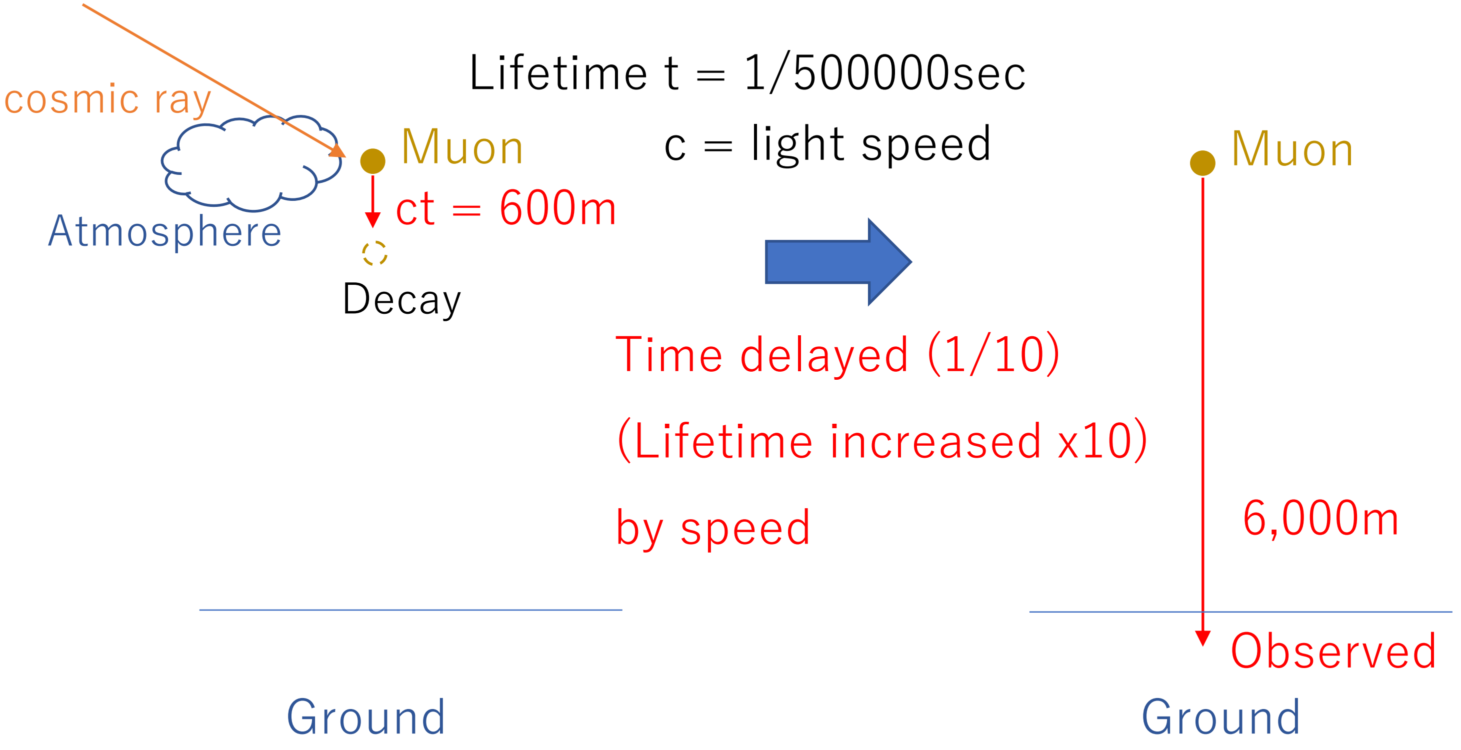


Time Dilation
- By Speed : Special theory of relativity
- By Gravity : General theory of relativity

The second solution is when time doesn't actually dilate.
The phenomenon of time dilation has been investigated through experiments.
It has been confirmed that time is slower at the top of the Skytree than at the ground's surface.
This is not a delay due to speed, but a delay due to gravity.
The special theory of relativity discusses the effects of speed when gravity can be ignored.
On the other hand, the general theory of relativity is a theory of the distortion of space-time due to gravity.

Twin paradox

Time Dilation by Speed



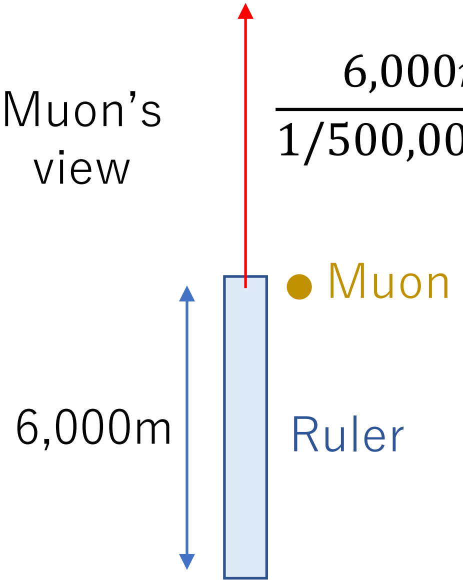
A familiar example of time dilation due to speed is the extension of the lifetime of muons that come from space.
When cosmic rays collide with the atmosphere, particles called muons are produced.
A muon's lifetime is 1/500,000 of a second before it decays.
In 1/500,000 of a second, light can only travel about 600 m.
For that reason, muons would decay before reaching the Earth's surface and should hardly be observed.
However, because muons travel close to the speed of light, time slows down and their lifetime is about 10 times longer.
They travel about 6,000 m during their lifetime, so muons that reach the Earth's surface have actually been observed.

Twin paradox

Speed of time in both views

Muon's view

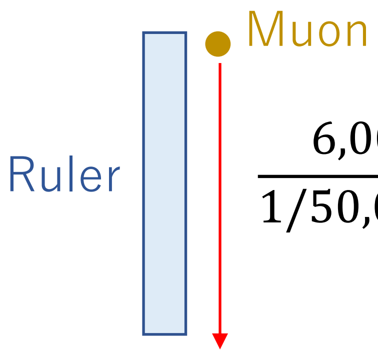
$$\frac{6{,}000m}{1/500{,}000sec} = 10c$$



Ruler's speed of time × 10

Ruler's view

Muon's lifetime ×10



$$\frac{6{,}000m}{1/50{,}000sec} = 1c$$

Muon's aging speed of time ×1/10

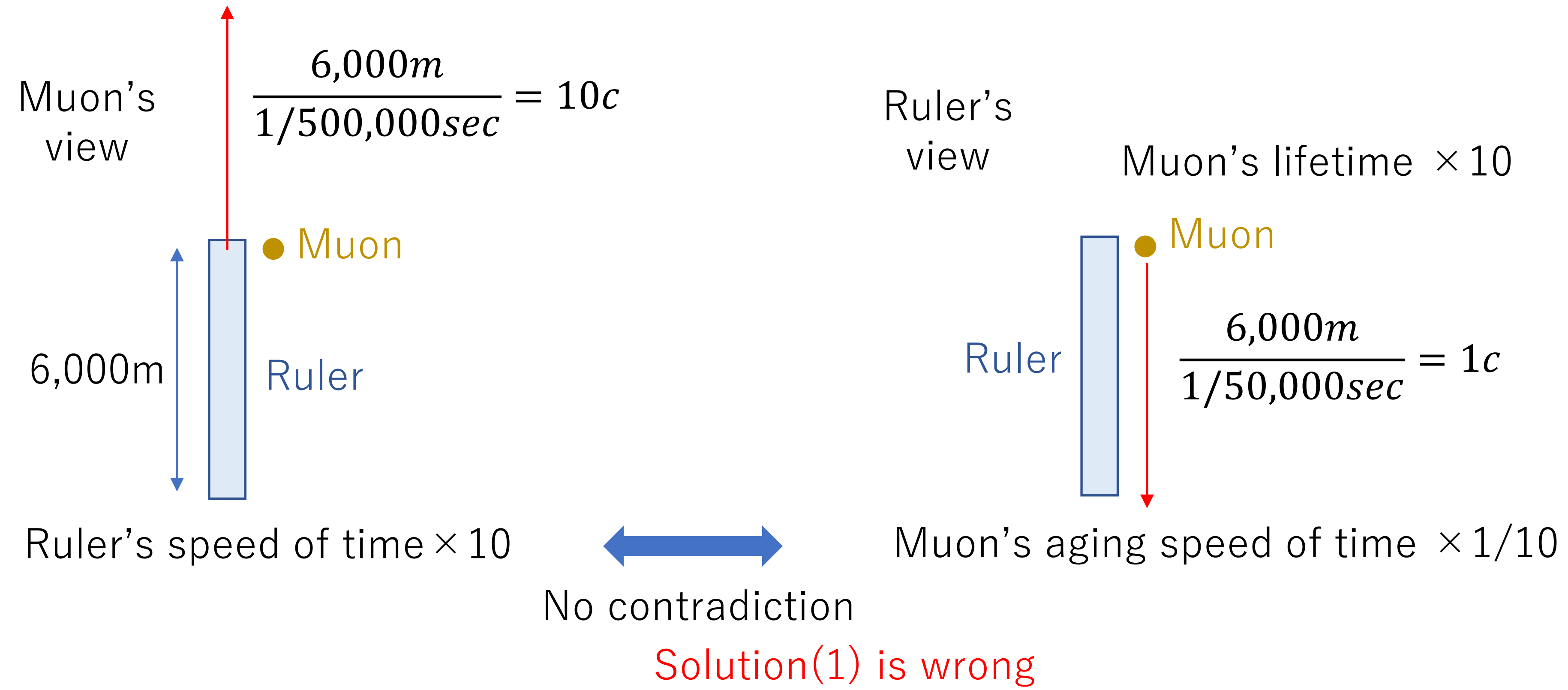
No contradiction

Solution(1) is wrong

Let's look at this phenomenon from the muon's perspective.
A 6,000m ruler is placed on the surface of the earth.
From the muon's perspective, it appears as if the ruler has moved 6,000m in 1/500,000th of a second of its lifetime.
At the speed of light, it should only move 600m in 1/500,000th of a second.
In other words, the ruler appears to move at 10 times the speed of light.
In other words, the flow of time outside appears to be 10 times faster.

Twin paradox

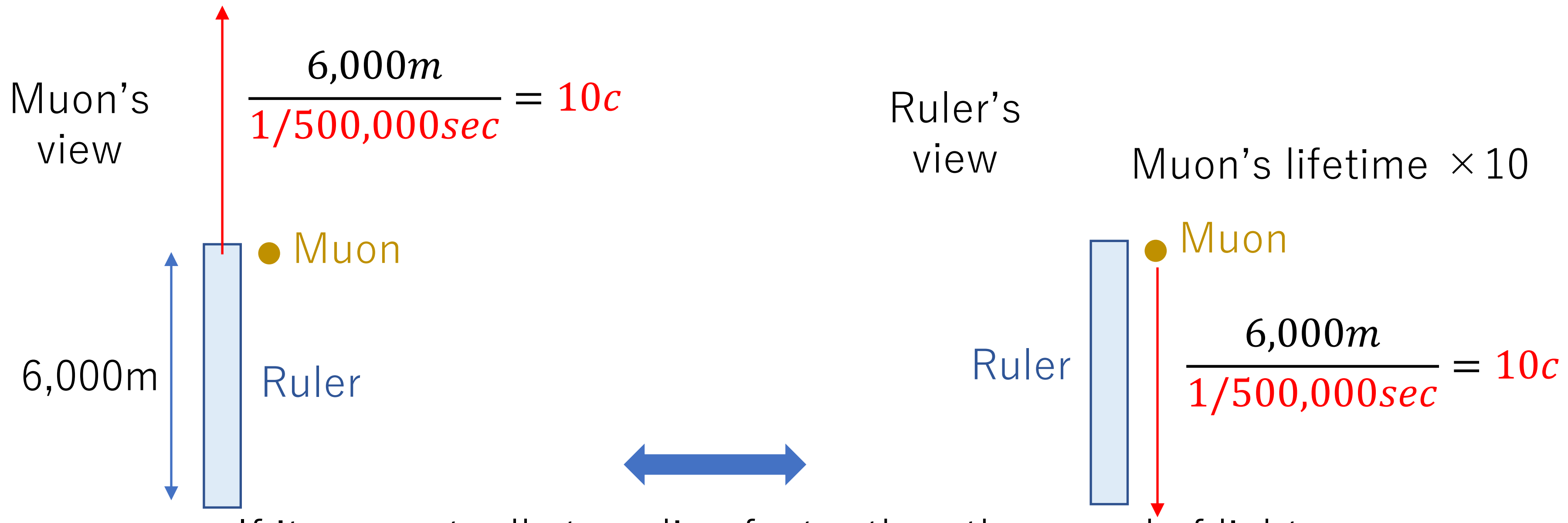
Speed of time in both views



On the other hand, when viewed from a ruler, the muon appears to be moving at almost the speed of light.
From the outside, it appears to take 1/50,000 of a second for the muon to travel 6,000 m.
Its lifetime appears to have extended by 10 times, from 1/500,000 to 1/50,000.
In other words, the aging rate of the muon has become 1/10.
In other words, the flow of time for the muon appears to be 1/10 slower.
There is no contradiction in which time appears to be delayed for each other.
Solution (1), which attempts to resolve the contradiction through a multi-world interpretation, is incorrect.

Twin paradox

Solution(2) Time doesn't slow down



If it was actually traveling faster than the speed of light,
it could be explained without time dilation.
Cosmic rays have not been observed traveling faster than the speed of light.
Solution(2) is wrong

However, this experimental fact alone is not enough to say that the muon experienced time dilation.
It is possible that the muon actually traveled at 10 times the speed of light.
Whether viewed from the muon or from outside, this means that it traveled 6,000 m in 1/500,000 of a second.
Under this assumption, it can be explained how the muon reached the Earth's surface without any time dilation from either perspective.
Paradoxically, if the experimental facts were to be explained without time dilation, cosmic rays would be allowed to travel faster than the speed of light.
Such observational results do not seem to exist, so solution (2) also appears to be incorrect.

Twin paradox

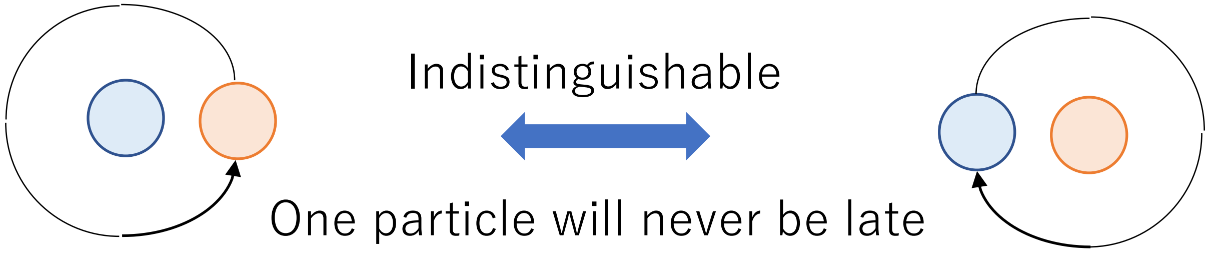
Solution(3)

Age of the twins

(3) (A>B) OR (A<B) Which time will be delayed is objectively determined

In the case of the Earth and a muon, the muon is delayed

If there are only two identical particles in the universe



The idea that time necessarily slows down if there is relative velocity is incorrect.

The third solution is that it is objectively determined which object will slow down.
In the case of the Earth and a muon, it is an experimental fact that time slows for the muon.
However, if the two objects are completely symmetrical, time should not slow down.
Consider a case where there are only two identical elementary particles in the universe.
We cannot distinguish whether B is orbiting around A, or whether A is orbiting around B.
When we cannot distinguish between them, it is inconceivable that one of the objects would slow down.
The idea that time will always slow down if there is a relative velocity is incorrect.
The special theory of relativity is only approximately true under special conditions where there is no gravity.

Twin paradox

General theory of relativity

Gravity distorts space-time.

The strength of gravity is the same from any viewpoint.

Time dilation due to gravity is objectively determined.

(Curvature of space-time) = (Energy (Mass) and Momentum)

The dilation of time is determined by the objective quantity of momentum.

Which one is moving depends on the viewpoint.

Since it is a fact that time slows for muons, there must be an objective way to determine which is slowed.
On the other hand, time dilation due to gravity rather than speed is easy to understand and objective.
That's because where gravity is strong, gravity is strong no matter what perspective you look at it from.
The general theory of relativity is interpreted as the conserved properties of energy and momentum, which distort space-time.
Therefore, it can be said that time dilation is determined by the objective quantity of momentum.
However, what is moving changes depending on the perspective, if anything.

Twin paradox

Momentum

Momentum = Mass × Velocity

Mass of Muon << Mass of Earth

When momentum is constant

Velocity of Muon >> Velocity of earth

High speed   Nearly stopped

↑

The object with the smaller mass will have time slower.

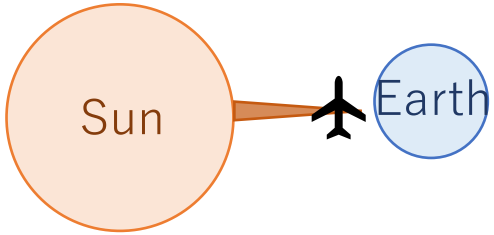
If the mass is the same, time does not slow down.

Muons arrive with a constant momentum.
From the muon's perspective, it is the Earth that is moving.
Momentum is mass multiplied by velocity.
Therefore, when momentum is constant, if the mass is large, the speed will be smaller.
From the muon's perspective, the Earth appears to be moving at only a slight speed.
If the mass difference is large, as in the case of the Earth and muon, it seems objectively safe to say that time will slow down for the lighter object.
The smaller the mass ratio, the smaller the delay, and we infer that if the masses are the same, there is no time delay.
However, that alone cannot be used to objectively determine it.

Twin paradox

Mass

Rocket << Earth << Sun



Rocket's time is slower than the sun’s.

contradiction

Rocket is fixed on sun.

Time doesn't slow down.

Sun << Black Hole

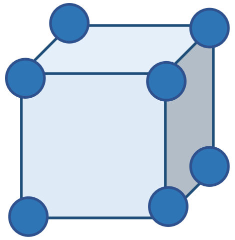
No matter how large the mass is,
if it's far enough away there shouldn't be any effect.

When considering time dilation due to a certain momentum,
it is necessary to consider only the mass that is influenced by that momentum.

The rocket is lighter than the Earth, but lighter than the Sun.
Time on the Earth is slower than on the Sun, and time on the rocket is slower than on the Earth.
Therefore, time on the rocket is slower than on the Sun.
However, if the rocket was fixed to the Sun, the time on the rocket and the Sun should be the same, which is a contradiction.
Also, far out in the universe, there are black holes that are heavier than the Sun.
Intuitively, no matter how large the mass is, if it is far enough away there should be no effect.
When considering time dilation due to a certain momentum, it is necessary to consider only the mass that is affected by that momentum.

Twin paradox

Solid



The solid is subject to the same momentum.

Atoms in a solid are held in fixed positions relative to one another by interactions.

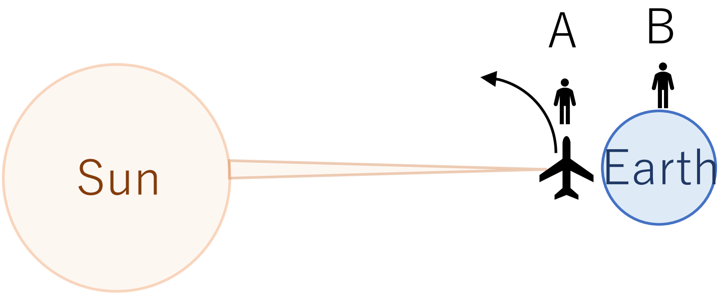
We need to consider only the mass within the range
where momentum is transferred through the interaction.

The strength of the interaction determines the amount of mass
that affects time dilation.

Atoms in a solid move as a group, so they can be said to be under the influence of the same momentum.
Atoms in a solid are fixed in position relative to each other due to interactions.
In other words, it seems sufficient to only consider mass within the range where momentum is transferred by interactions.
The amount of mass affected is determined depending on the strength of the interaction.

Twin paradox

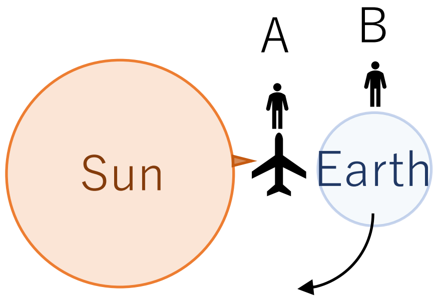
Two answers to the twin paradox



Gravity felt by rockets:

Sun < Earth

Age: A < B



Gravity felt by rockets:

Sun > Earth

Age: A > B

Let's consider the case where the rocket is far enough away from the Sun that it hardly feels the Sun's gravity.
In that case, we can ignore the mass of the Sun and consider the rocket to be moving around the Earth.
Therefore, the rocket's time will be slower than the Earth's.
Now, let's consider the case where the Earth is close to the Sun.
In that case, we can ignore the mass of the Earth and consider the Earth to be moving around the Sun.
Therefore, the Earth's time will be slower than the Sun's.
The rocket is fixed to the Sun.
In the opposite case to before, the Earth's time will be slower than the rocket.

Twin paradox

Observer

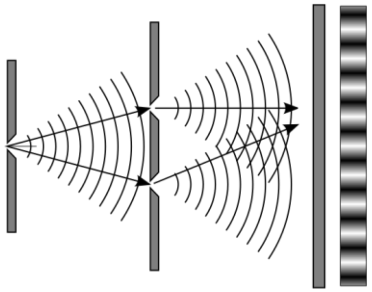
Time dilation is objectively determined, regardless of the observer.

The observer cannot decide subjectively,
but must decide objectively.

The same is true in quantum theory,
the observer is objectively determined.

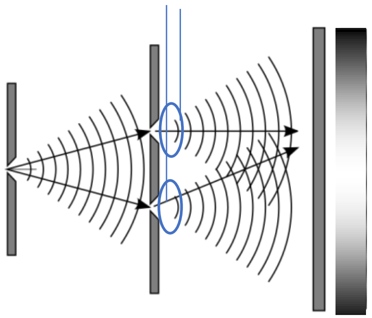
Double slit experiment

Impossible to distinguish
which path was taken



Interfere

Sensors (observers)
distinguish paths

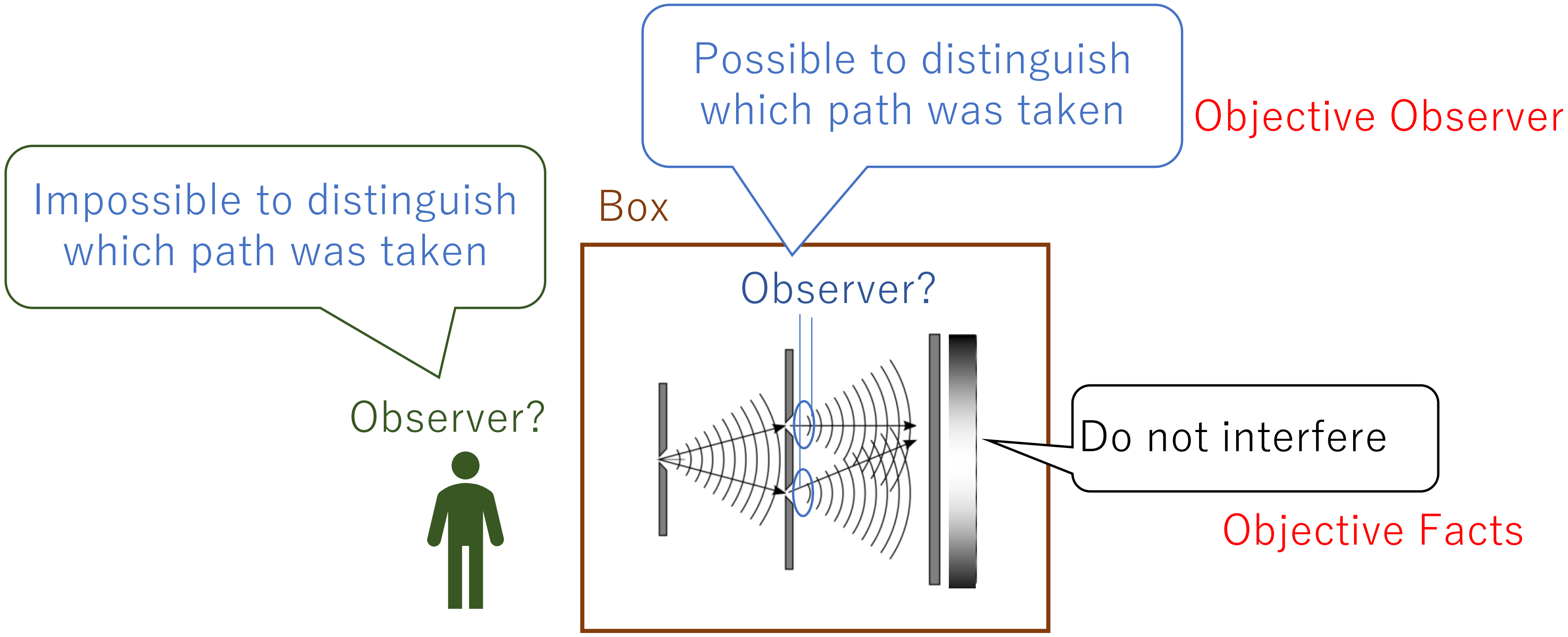


Do not
interfere

In conclusion, time dilation is objectively determined regardless of the observer.
It can be said that the observer is not something that can be determined subjectively, but is determined objectively.
The observer is objectively determined, just as in quantum theory.
In the double slit experiment, interference occurs because it is impossible to distinguish which path the photon has taken.
If a sensor is installed that can determine which path the photon has taken, interference will no longer occur.

Twin paradox

Objective Observer



We put the entire test setup into a box, making it impossible to tell what is going on inside.
A human observer outside cannot tell which photon has passed through which path.
The inability to tell the difference does not mean that the interference patterns will reappear.
In fact, there is no case of interference despite the presence of sensors that can distinguish the paths.
The box is an ordinary room, so the experiment is being carried out unconsciously.
This objective fact shows that the observer is a sensor, not a human.
The subjective setting of the observer does not change the objective fact.

Twin paradox

Objective observer

If we are to discuss objective facts, we need to have an objective observer.

Objective observer: One who makes distinctions through interaction

common
- Special theory of relativity: Distinguishing which time is delayed
- Quantum theory: (example) Distinguishing which path to take

Causes of the twin paradox

The special theory of relativity allowed
the freedom to subjectively determine the observer.

If you are discussing objective facts, you need to set an objective observer.
An objective observer is one who makes distinctions through interaction.
The sensor in the box is an observer because it interacts with photons and distinguishes their paths.
The observer in special relativity and the observer in quantum theory are similar.
An observer in special relativity is one who distinguishes which time is slowed due to the interaction.
Do you understand the twin paradox?
In special relativity, there was a degree of freedom to subjectively decide the observer, which was the cause of the paradox.
We have seen that if we want to have an objective discussion about special relativity, we need to decide on an objective observer.
That's all.

Contact Information

For inquiries,

please contact us here.

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