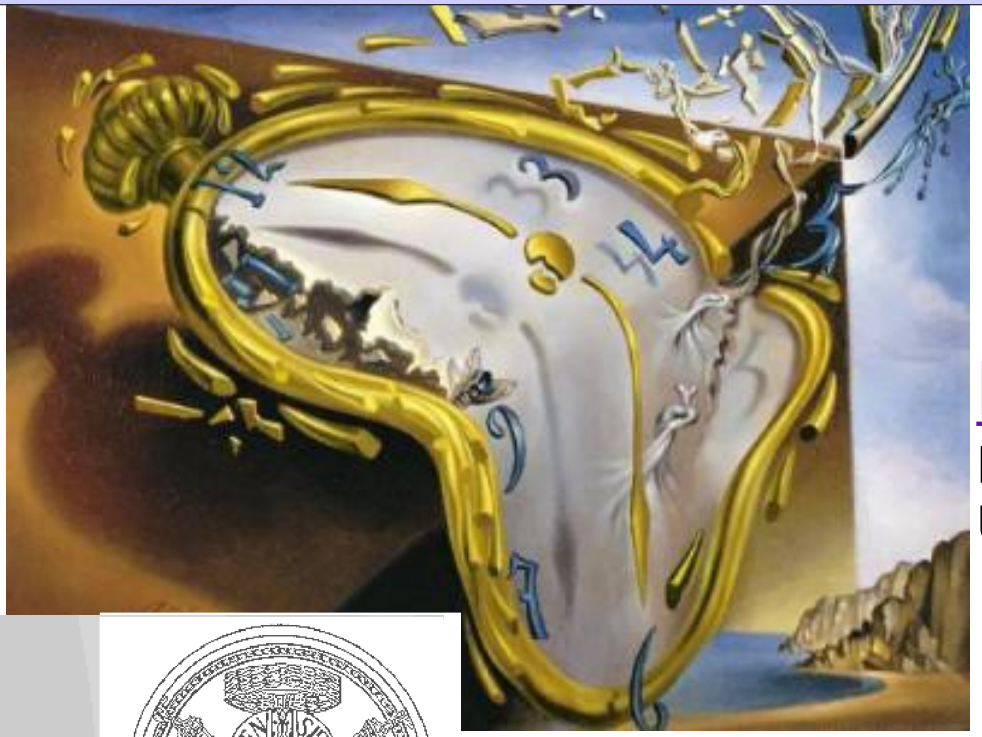
What is time?

Answers from modern physics



Lorenzo Maccone

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quantum information theory group

www.qubit.it

FQXi Foundation,

"The physics of what happens"

This is a fish

Its universe is a 10km cube of water...

Its universe is a 10km cube of water...

What would he think if we'd tell him about stars?

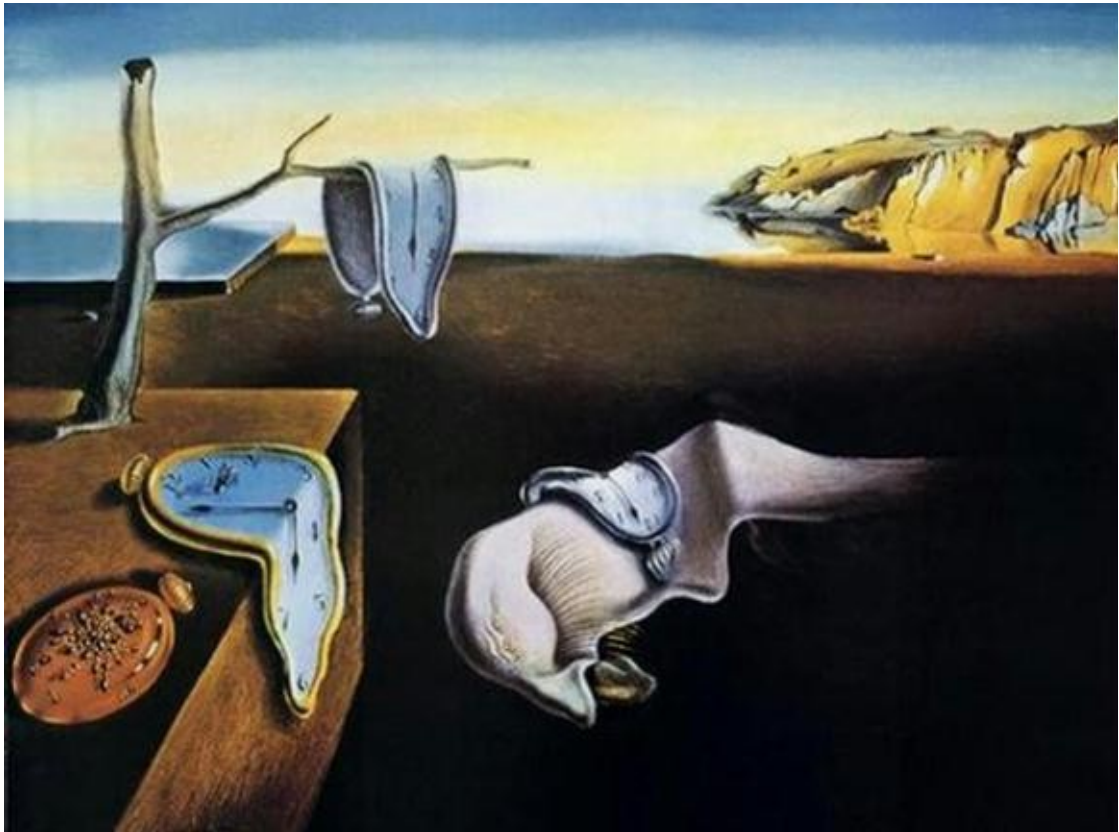
This is a fish

Remember the fish:
keep your mind open!

Its universe is a 10km

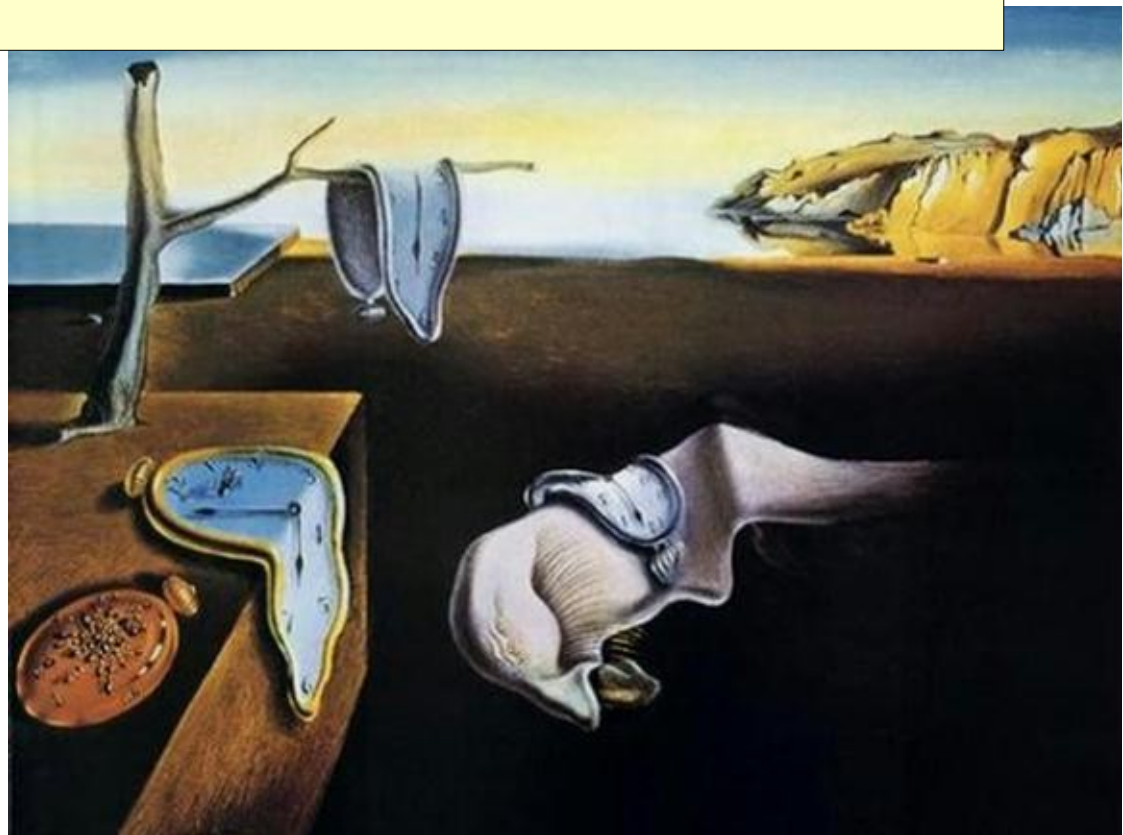
What would he think if we'd tell him about stars?

what am I going to talk about?



what am I going to talk about?

I'll give an intuition of the strangest and counterintuive aspects of time



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S. Augustine of Ippona (Confessions)

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BUT "time" is one of the most used nouns in all languages (in English it is in the top 10)!

... are there any doubts we're talking of things we don't know?!?

WHAT is time?

In physics?

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In physics?

> “Time is what is measured by a clock”
>
> ... but what is a clock?!

WHAT is time?

In physics?

"Time is what is measured by a clock"

... but what is a clock?!

... or a "coordinate"

something that measures the distance between events

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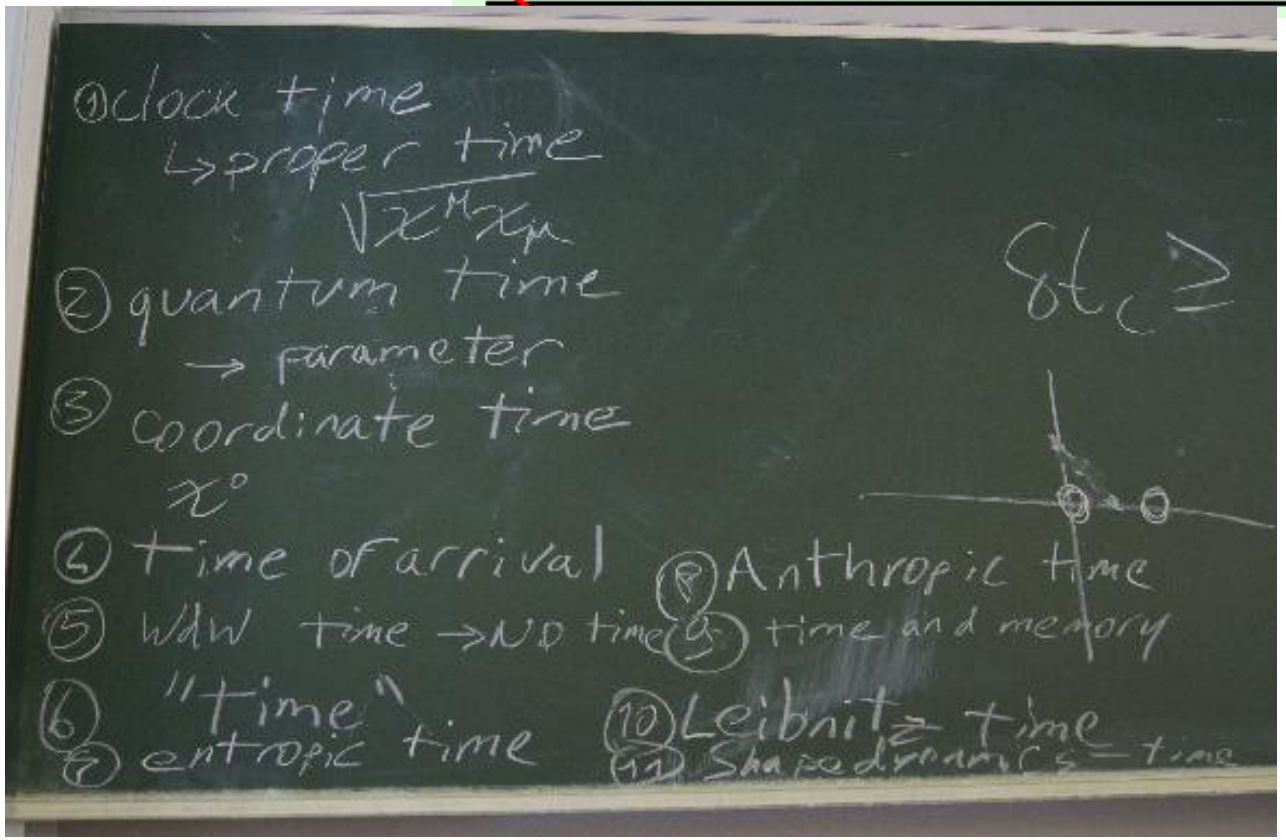
the two **main** meanings of time in physics

other meanings?

Table 2.1: Times.

Time notion	Property	Example	Form
Natural language time	memory	brain	?
Time-with-a-present	present	biology	R
Thermodynamical time	direction	thermodynamics	A
Newtonian time	unique	newtonian mechanics	M
Special relativistic time	external	special relativity	M^3
Cosmological time	spatially global	cosmological time	m
Proper time	temporally global	world line proper time	m^∞
Clock time	metric	clocks in GR	c
Parameter time	one dimensional	coordinate time	L^∞
No-time	none	quantum gravity	none



[Rovelli, “quantum gravity”]

use our intuition? FAIL!!

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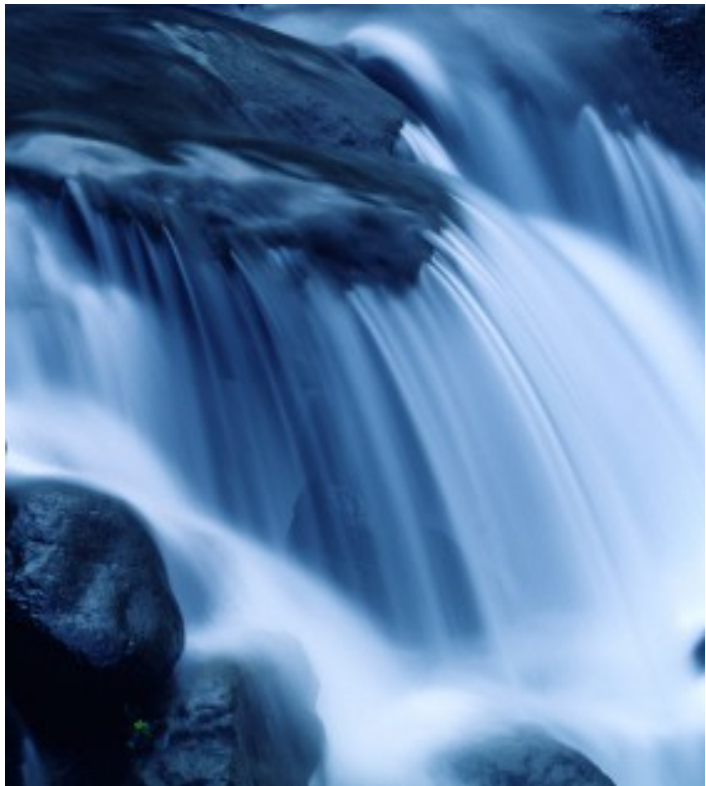

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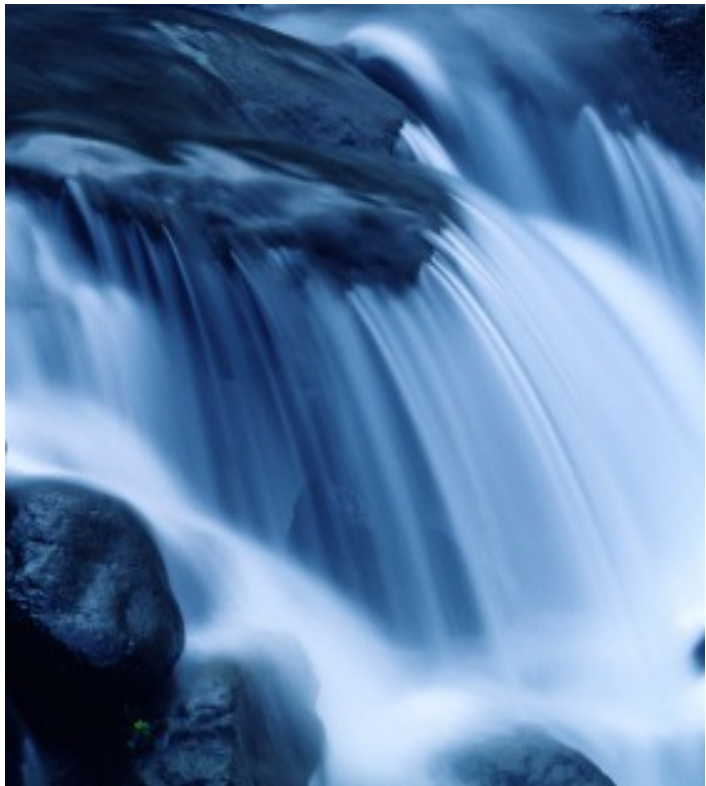

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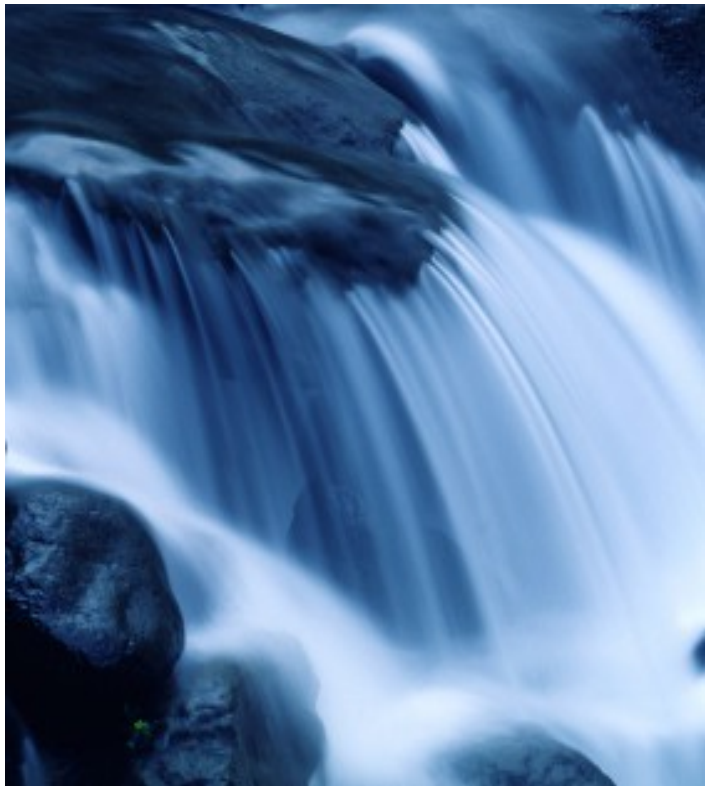
time doesn't “exist”



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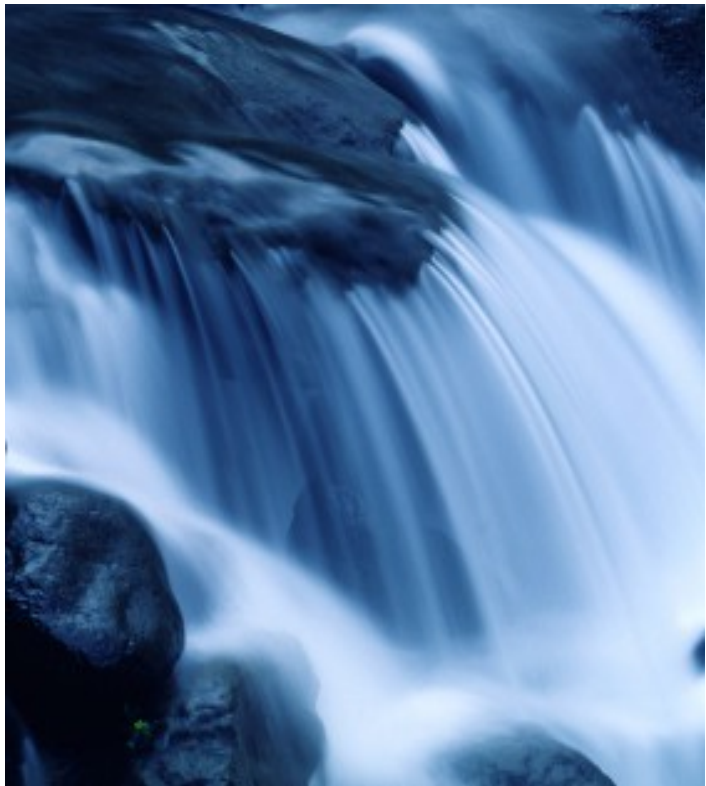

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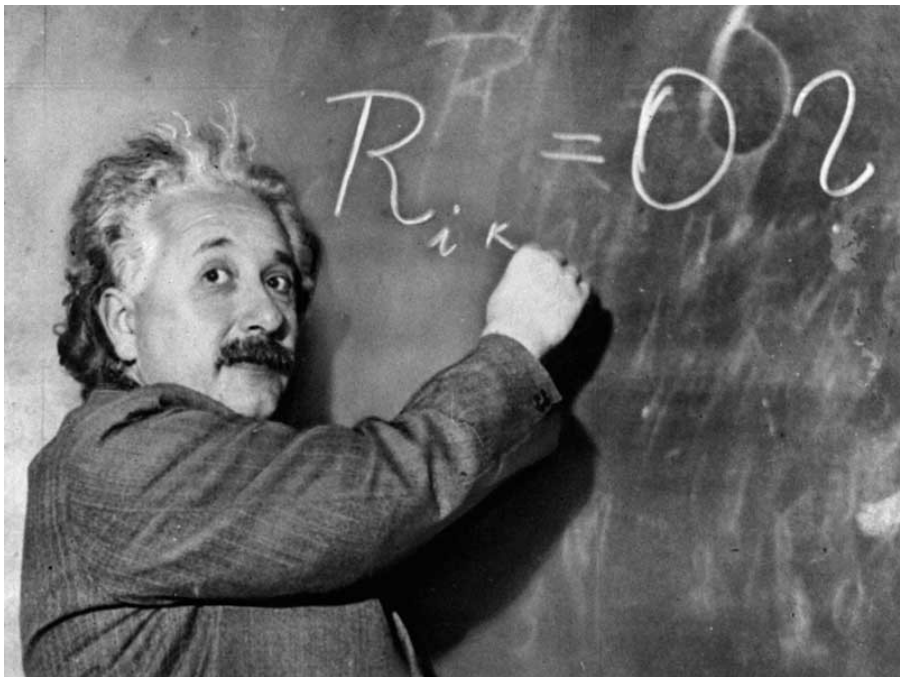
(past, present and future have different essence)



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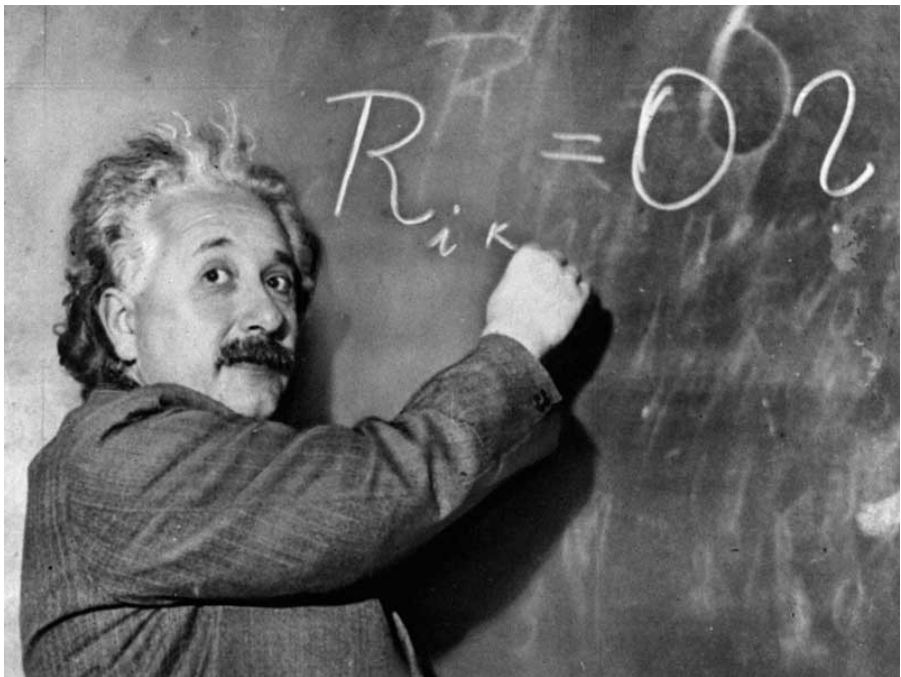

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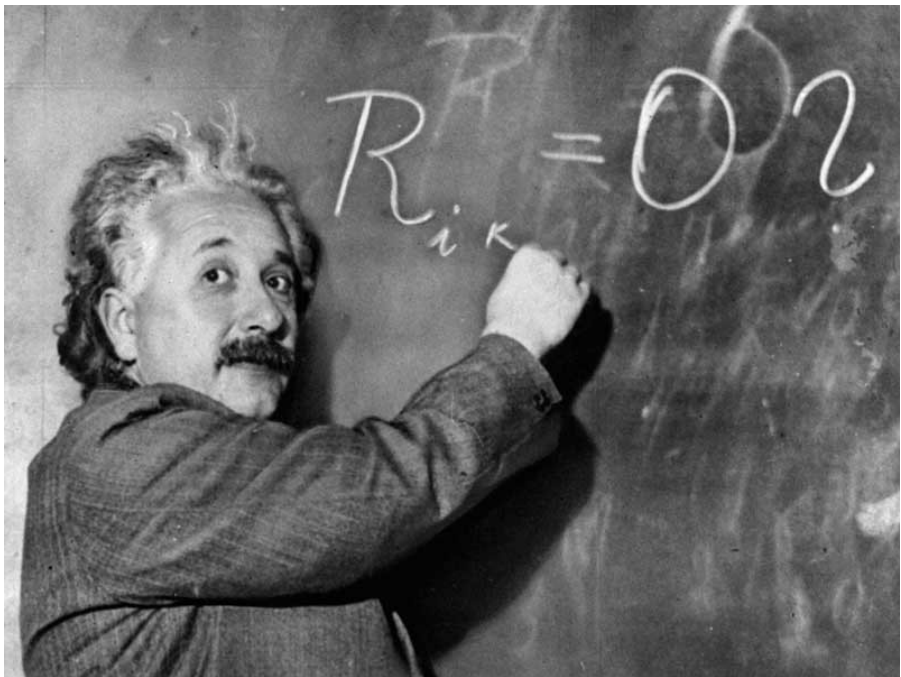
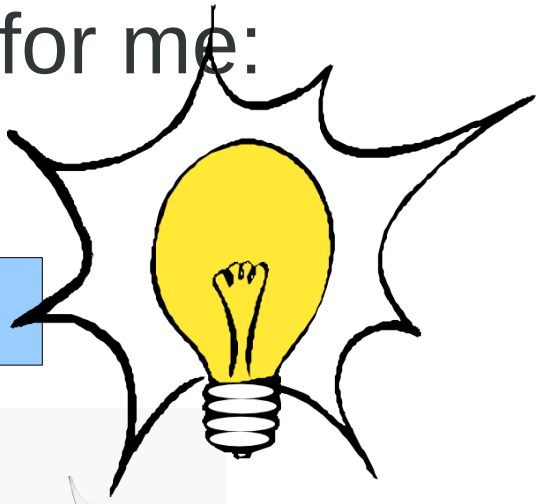
Why NOT?!



Relativity of simultaneity

Two events SIMULTANEOUS for me:



"the lamp is switched on"

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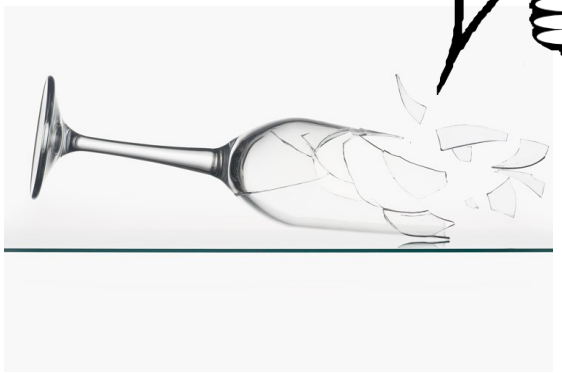

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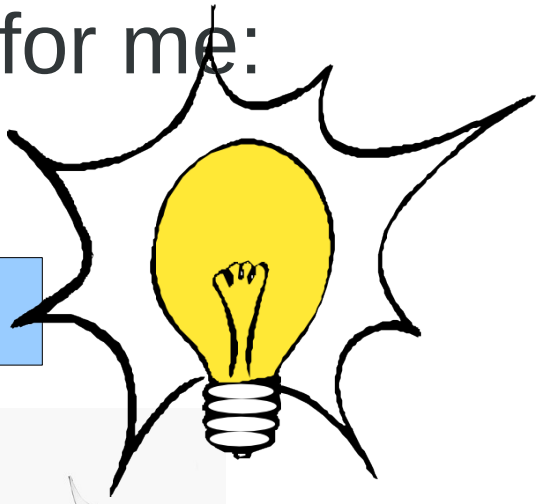

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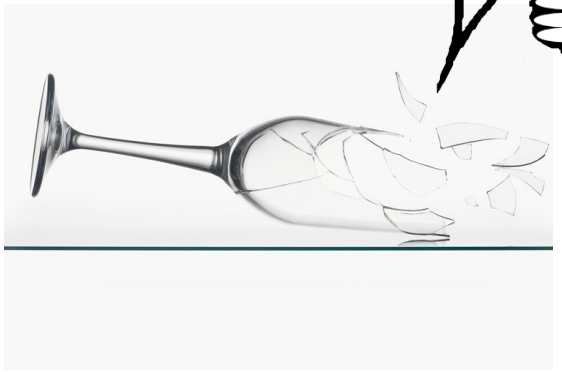

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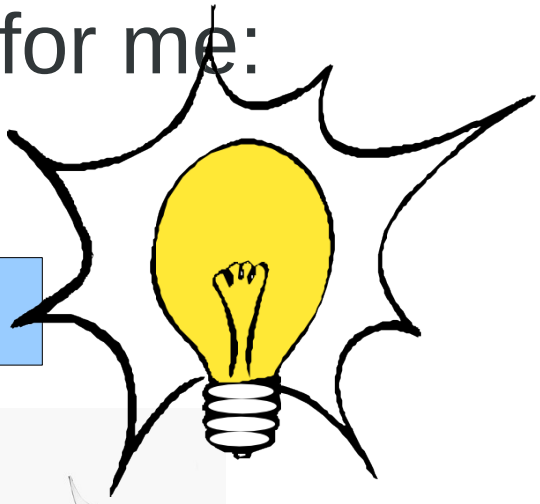

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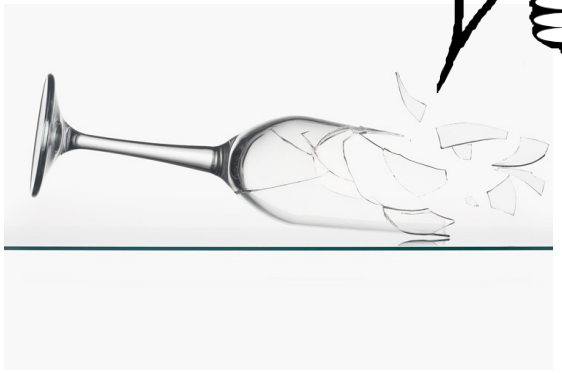

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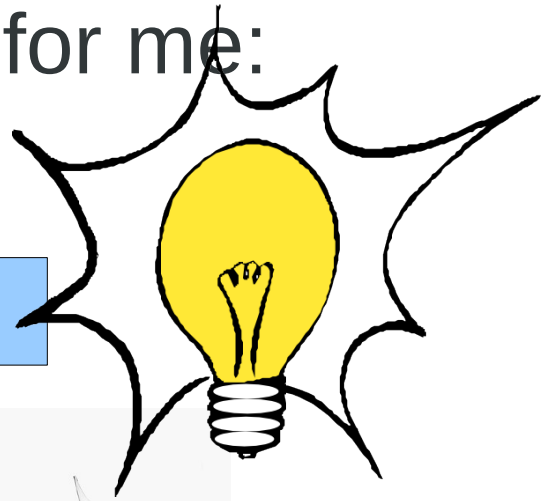

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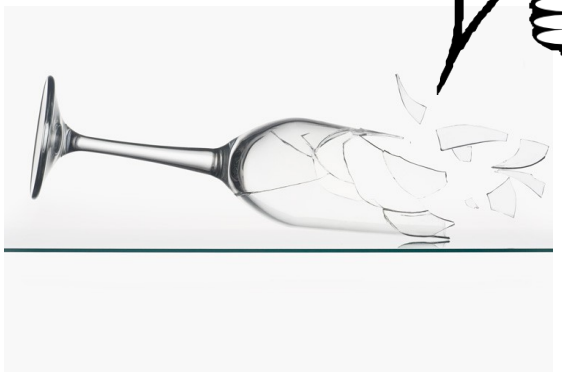

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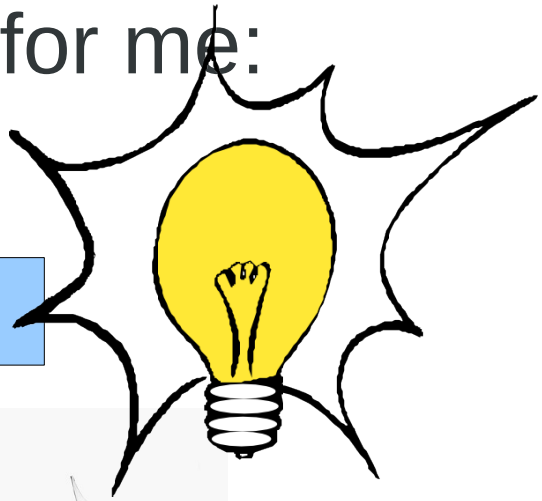

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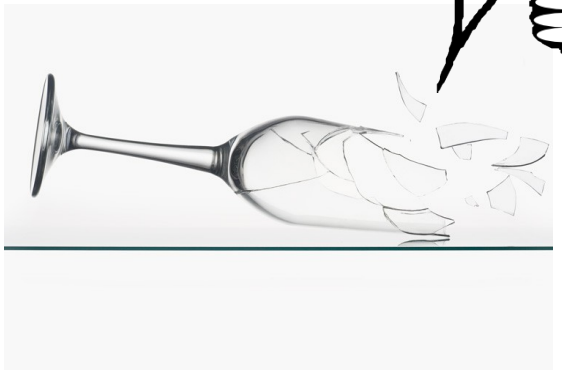

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→ relativity of simultaneity

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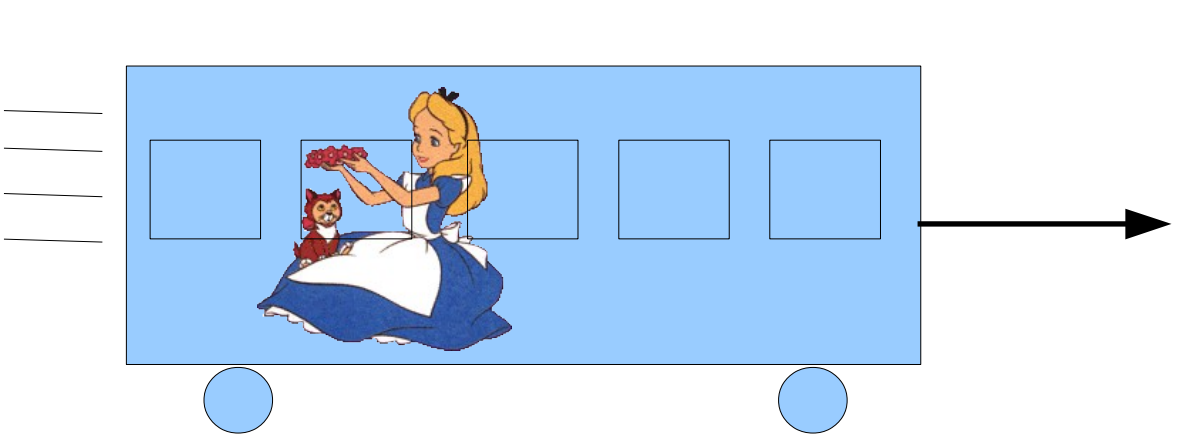
All events simultaneous to now are the “**present**”.

→ the present depends on the motion!



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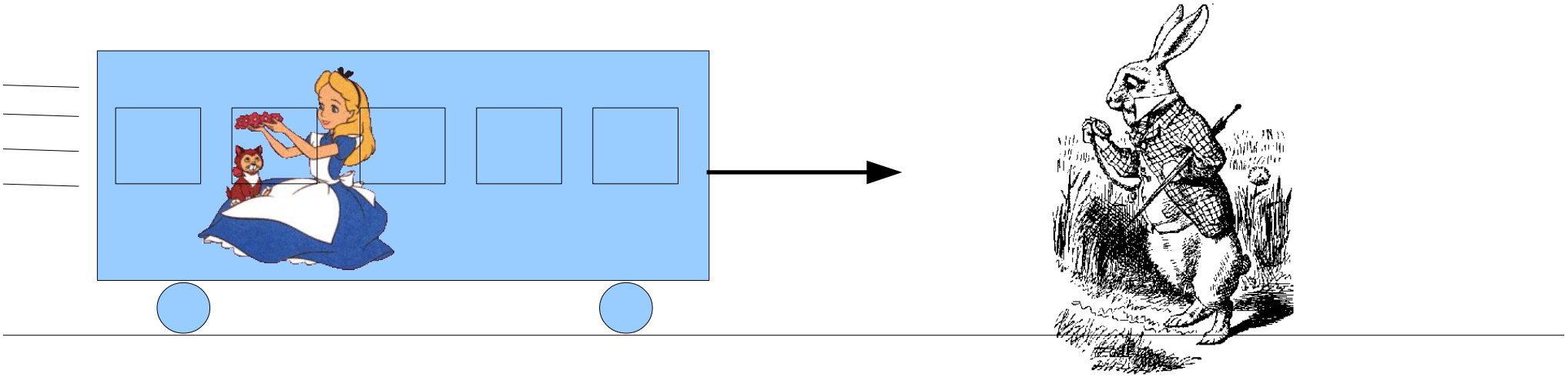

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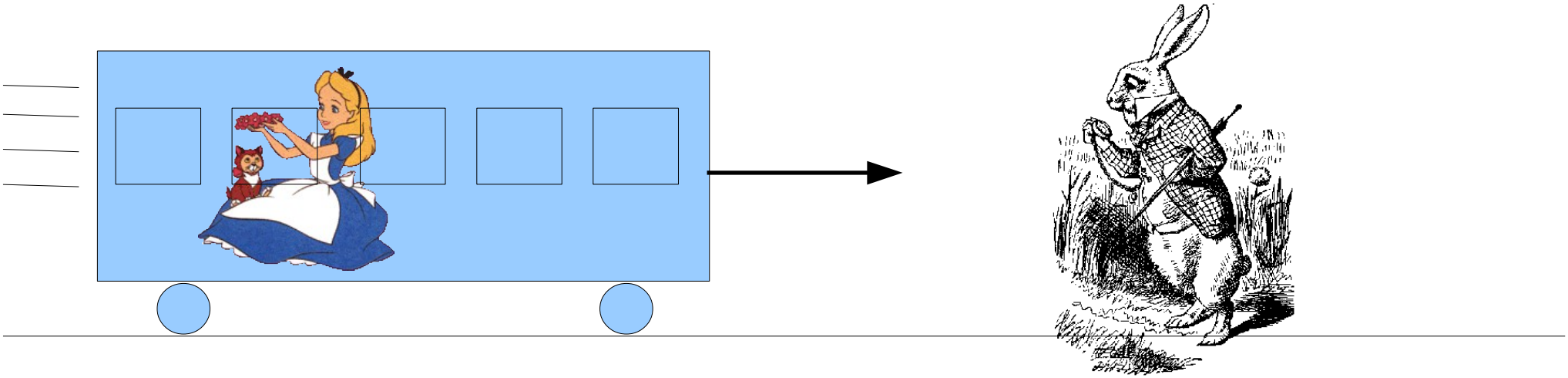

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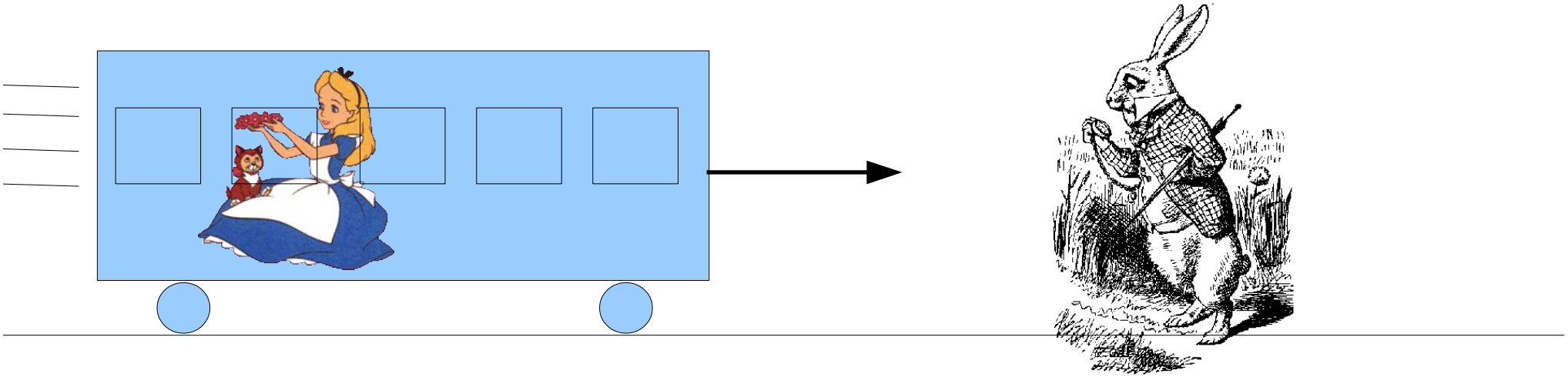

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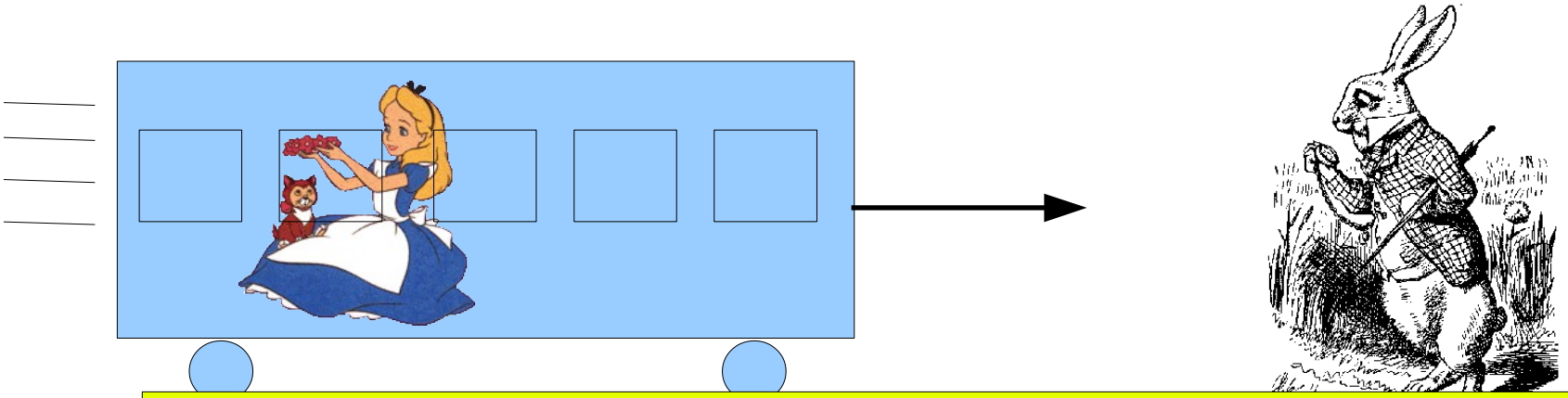

Alic … at the …

It's like saying that **"right" and "left" have different essence!**

(*whose* right?!)

For Alice the glass falls and the lamp is switched on at the same time, for Bob they don't!

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Relativita' della simultaneita'

The present depends on motion!!

if past-present-future have different essence,

A e B would disagree on what “exists” and what doesn't.

Relativity forces us to give the same “degree of existence” to past-present-future!!

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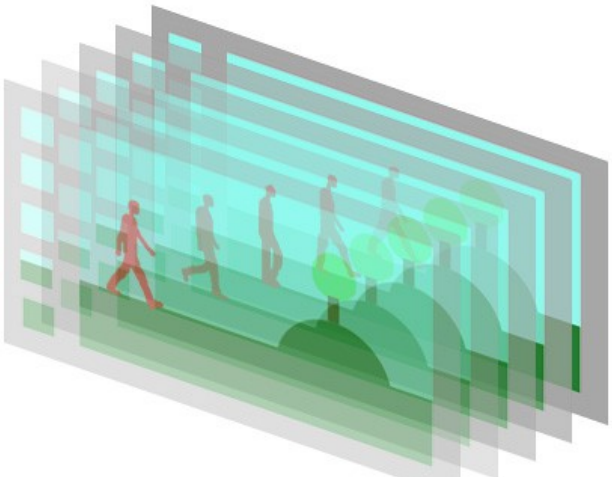

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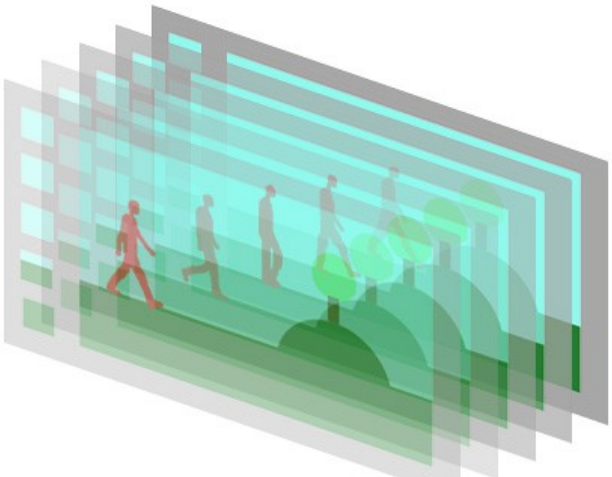

Relativity=division of spacetime into space and time is relative (to the observer)

Time is a **coordinate** (as space)

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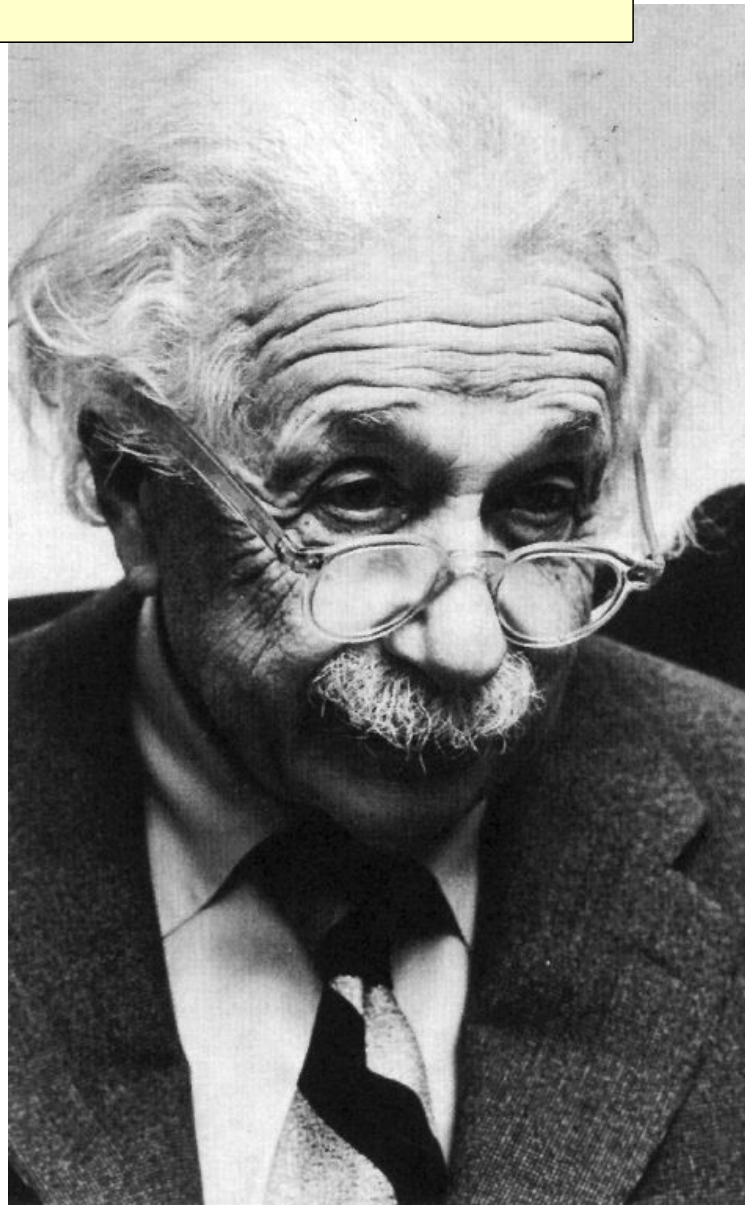

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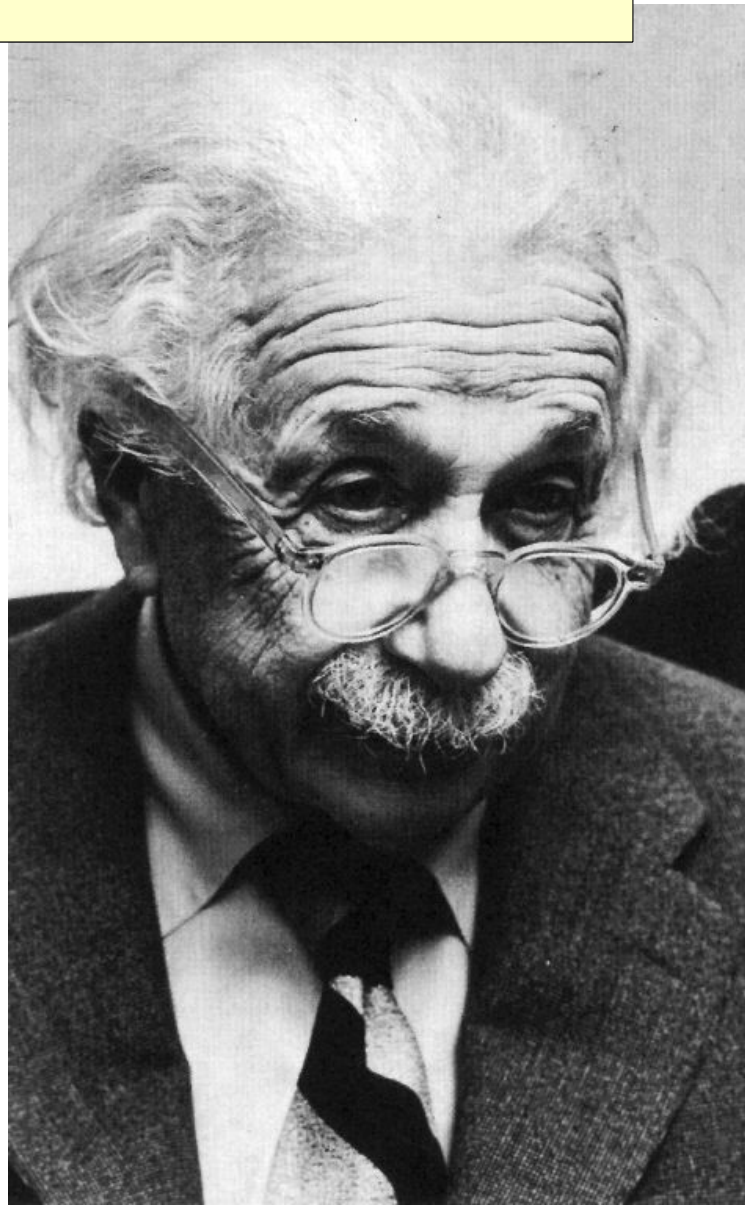
“For us who believe in physics, the difference between past, present and future is just an illusion, however persistent”

Albert Einstein



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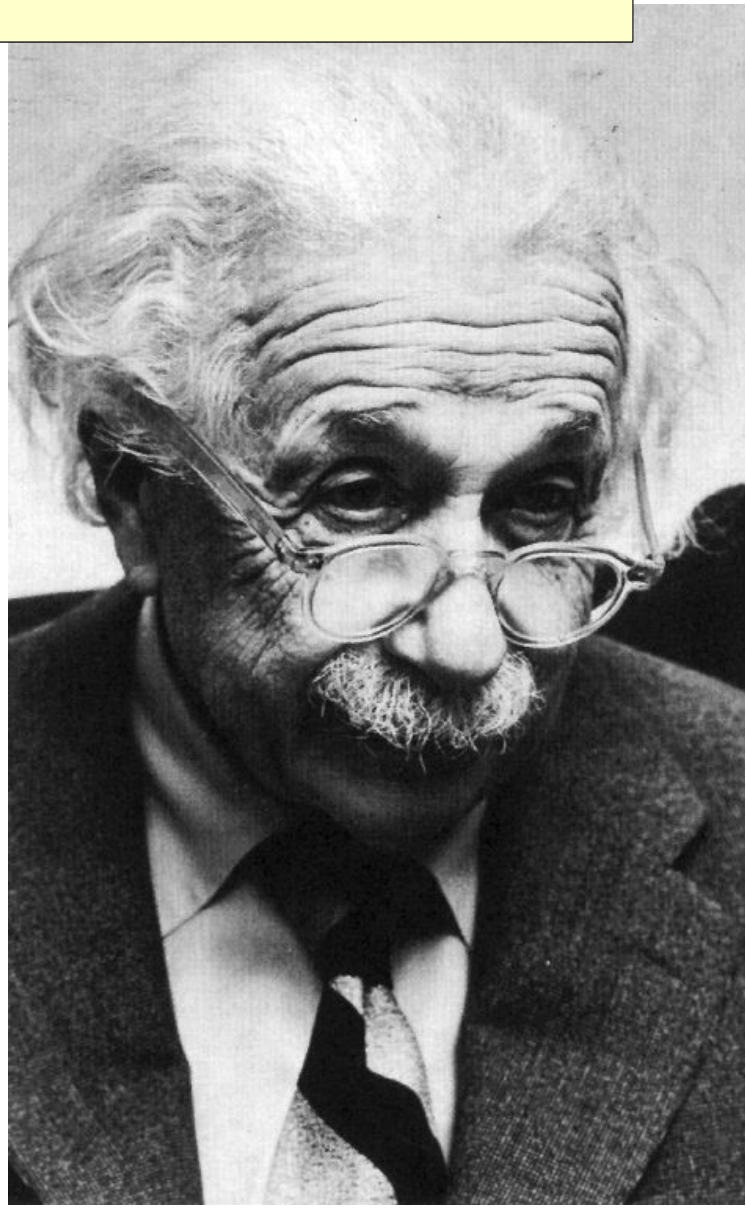
Albert Einstein, writing to console the widow of his dear friend Michele Besso (or to console himself?)

(May 21, 1955)



Past-present-future have the same degree of existence...

but what does it mean to say that time “exists”?

“absolute” vs. “relative” time

Philosophy question: if I block all change and movement, time would still exist?

“absolute” vs. “relative” time

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Newton: “Absolute, true and mathematical time, of itself, and from its own nature flows equably without regard to anything external”

Time “exists” even if nothing happens

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Who's right?

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None, but in part, both!

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but it's not **absolute**!

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Time is relational: I can only localize an event with respect to another.

Can I travel in time?

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- To the future (without return)?

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Yes! (almost trivial)

- To the past?

Yes! (maybe!)

...only theoretically!

Question 1:

time travel to the future
(without return)?

Time travel to the future (no return)

Time travel to the future (no return)

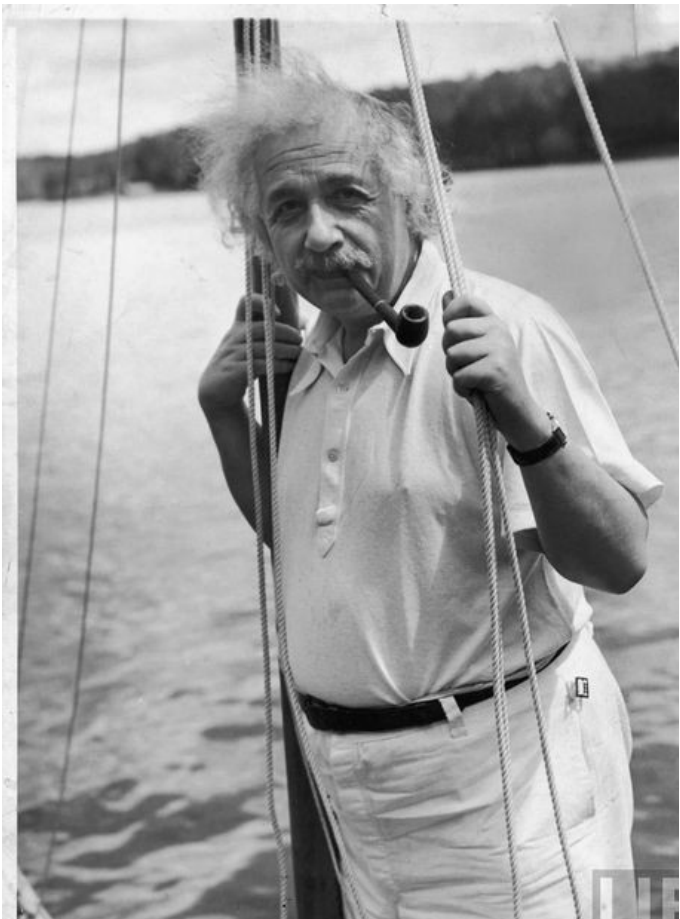
What?

I arrive to tomorrow before you... I.e. I arrive to your tomorrow in a few of (my) seconds. When we meet again, for me a few seconds went by, for you 24h.

Time travel to the future (no return)

How?!?

Simple! → Relativistic time dilation



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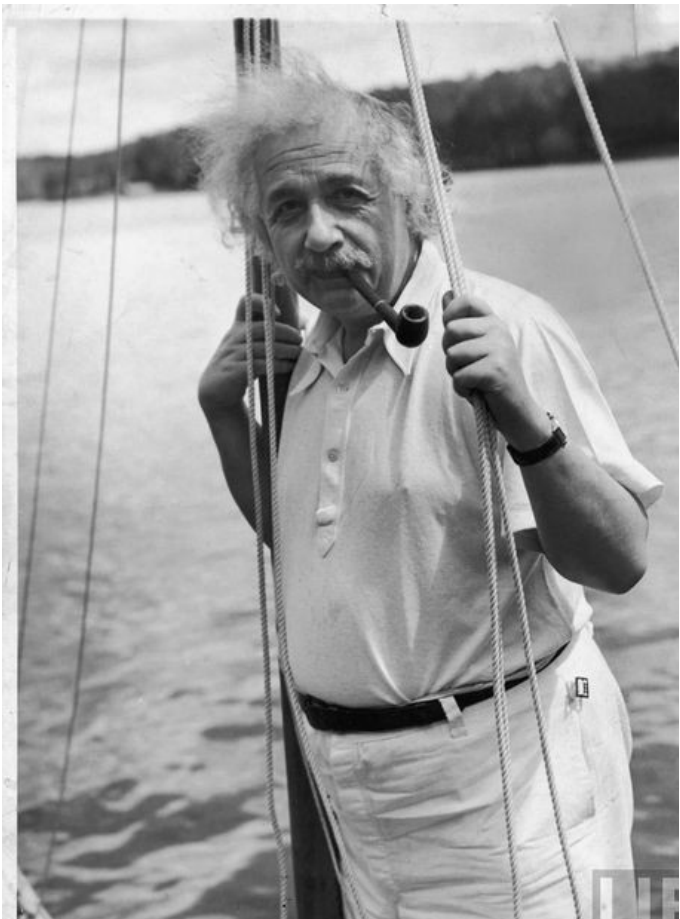
Time depends from the state of motion (why it's called relativity)



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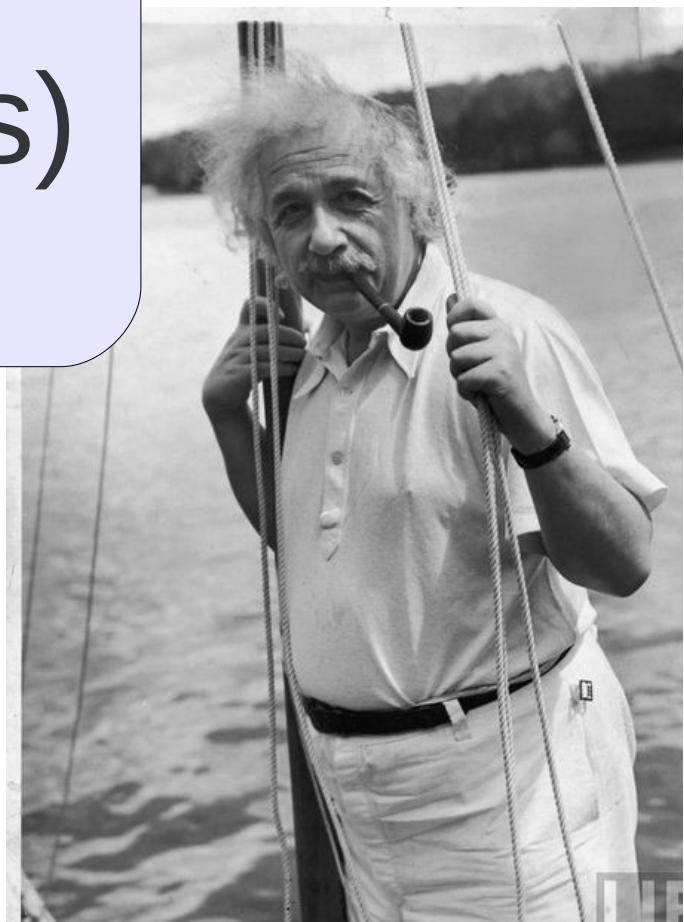
Time in systems that move (with respect to us) is slower than ours



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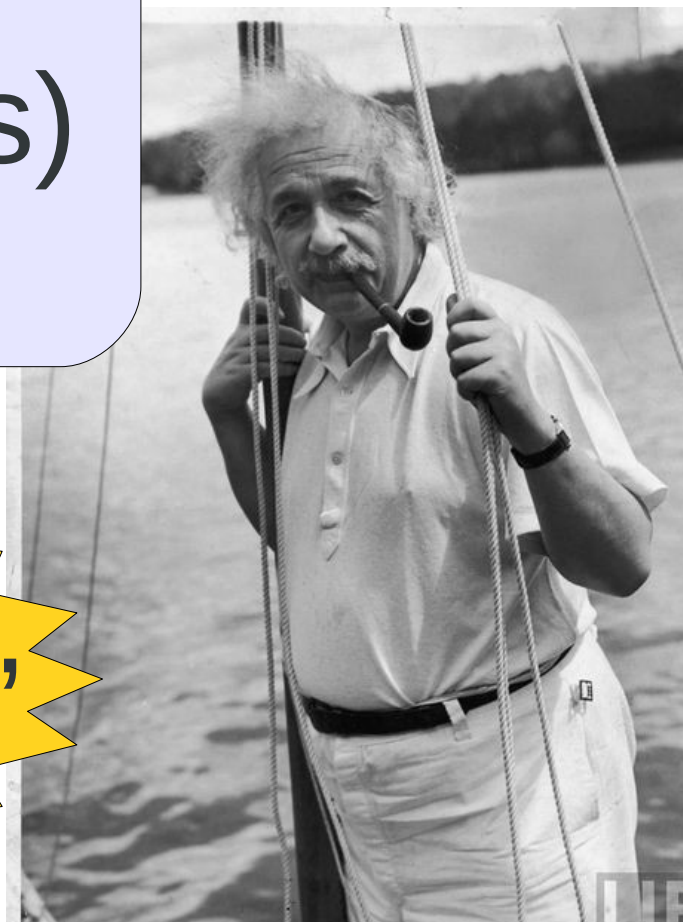

Is it sufficient to move, to travel in time?

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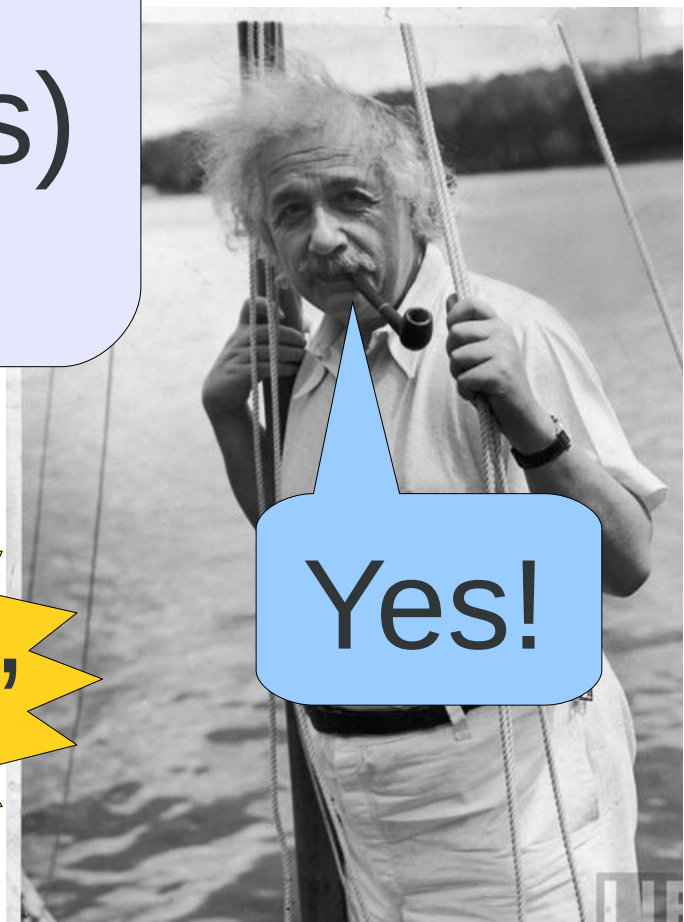
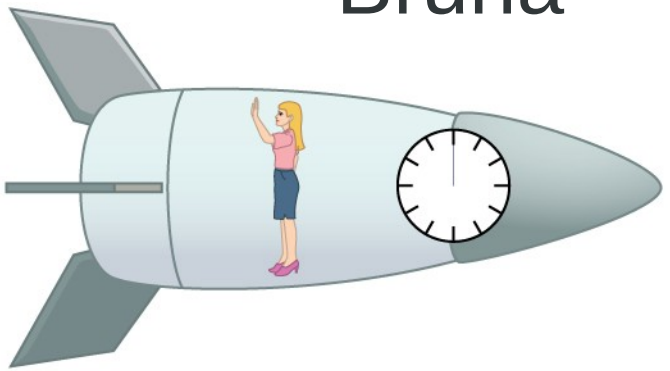


Twin paradox!

Twin paradox!

Alice

Bruna



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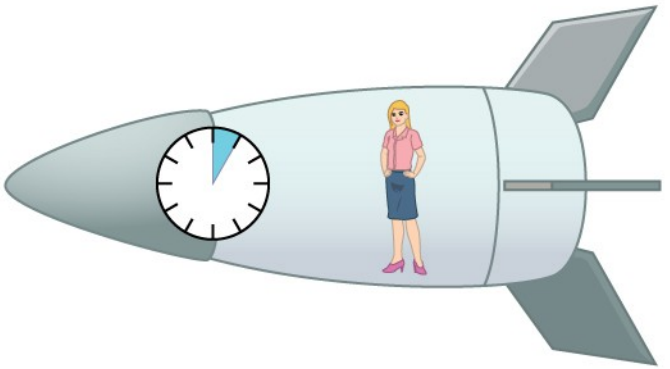

….then why don't we ever see this?!?

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Because we'd need to move at relativistic speeds ~c!!!!

...or do precise measurements
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traveled to the future by 40 ns
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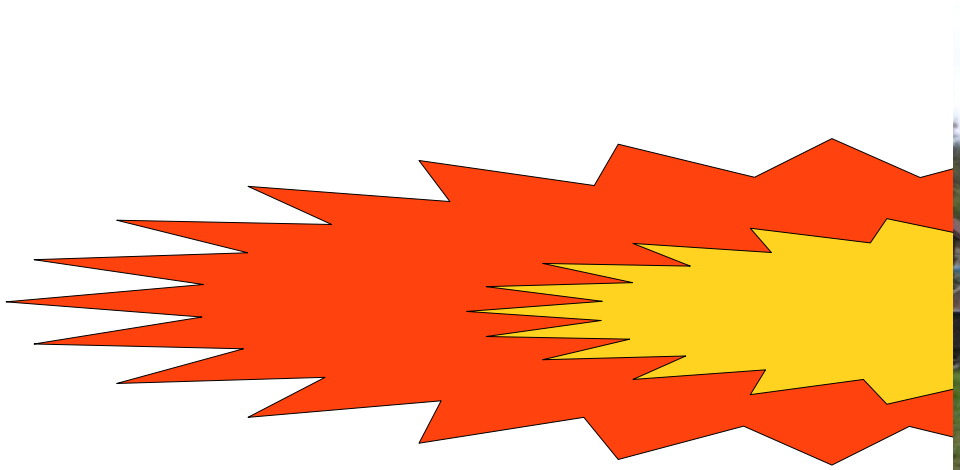
Atomic clocks

Hostess

How fast do I have to travel to go to your tomorrow in half your time?

(with respect to a stationary you?)



How fast do I have to travel to go to your tomorrow in half your time?

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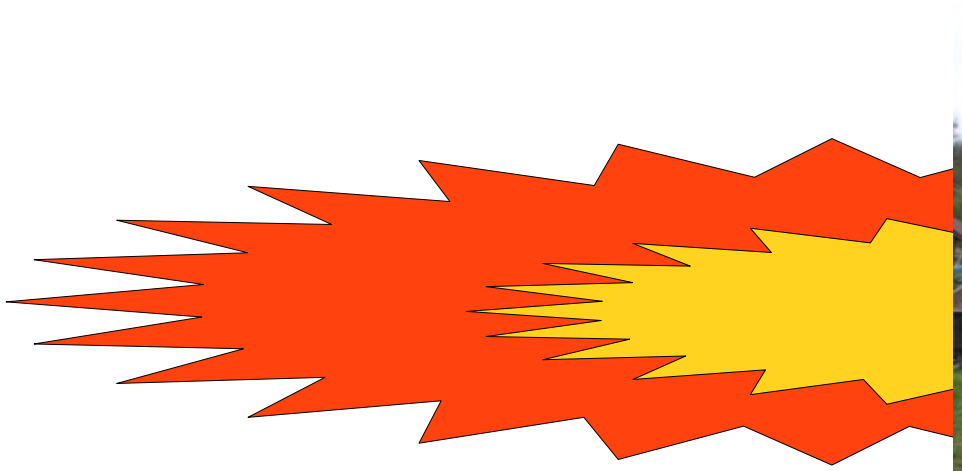
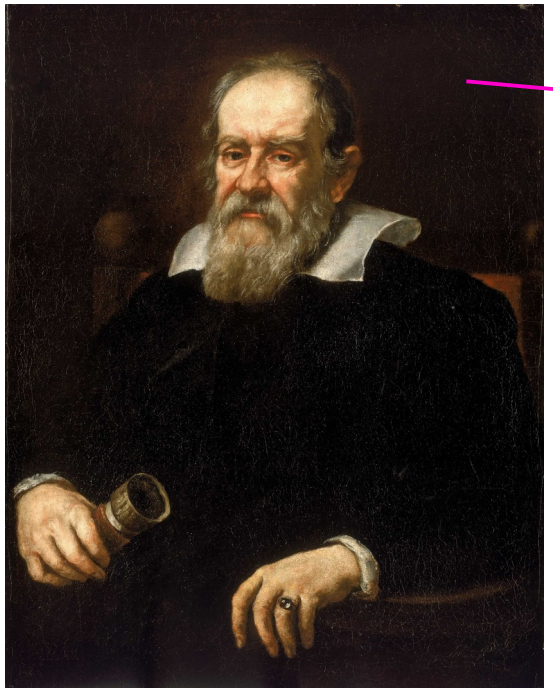
700 billion Km/h!!!

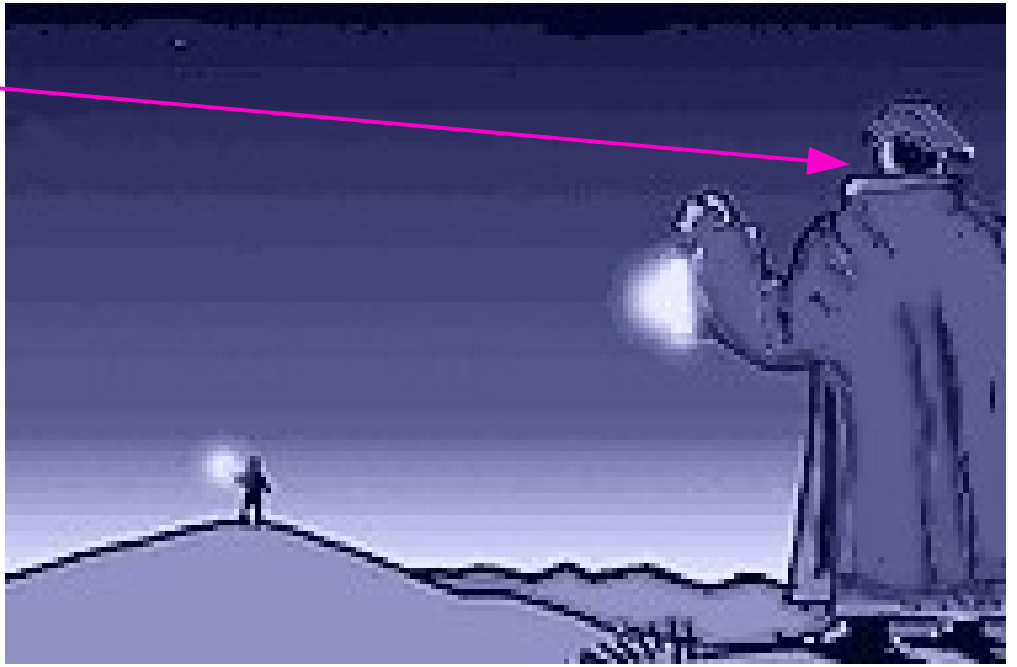
(200.000 Km/s)



Light moves very fast!

Galileo tried to measure it unsuccessfully





How far should he have sent the other person for a time delay of about a second?

Relativistic time dilation: through movement.
Other mechanism? **Gravity**

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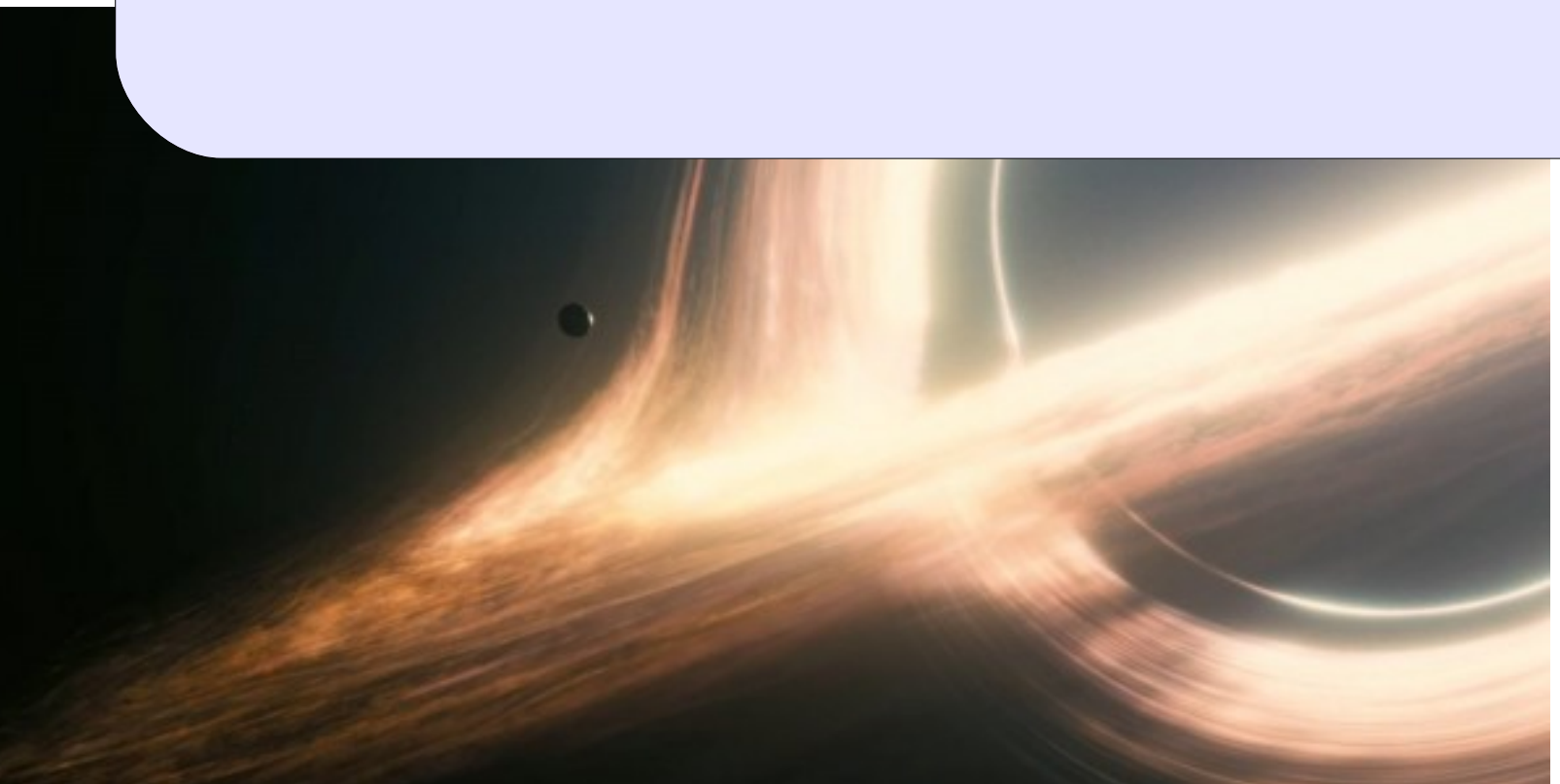
Time in systems in a larger gravitational (than ours) field flows slower (than ours)



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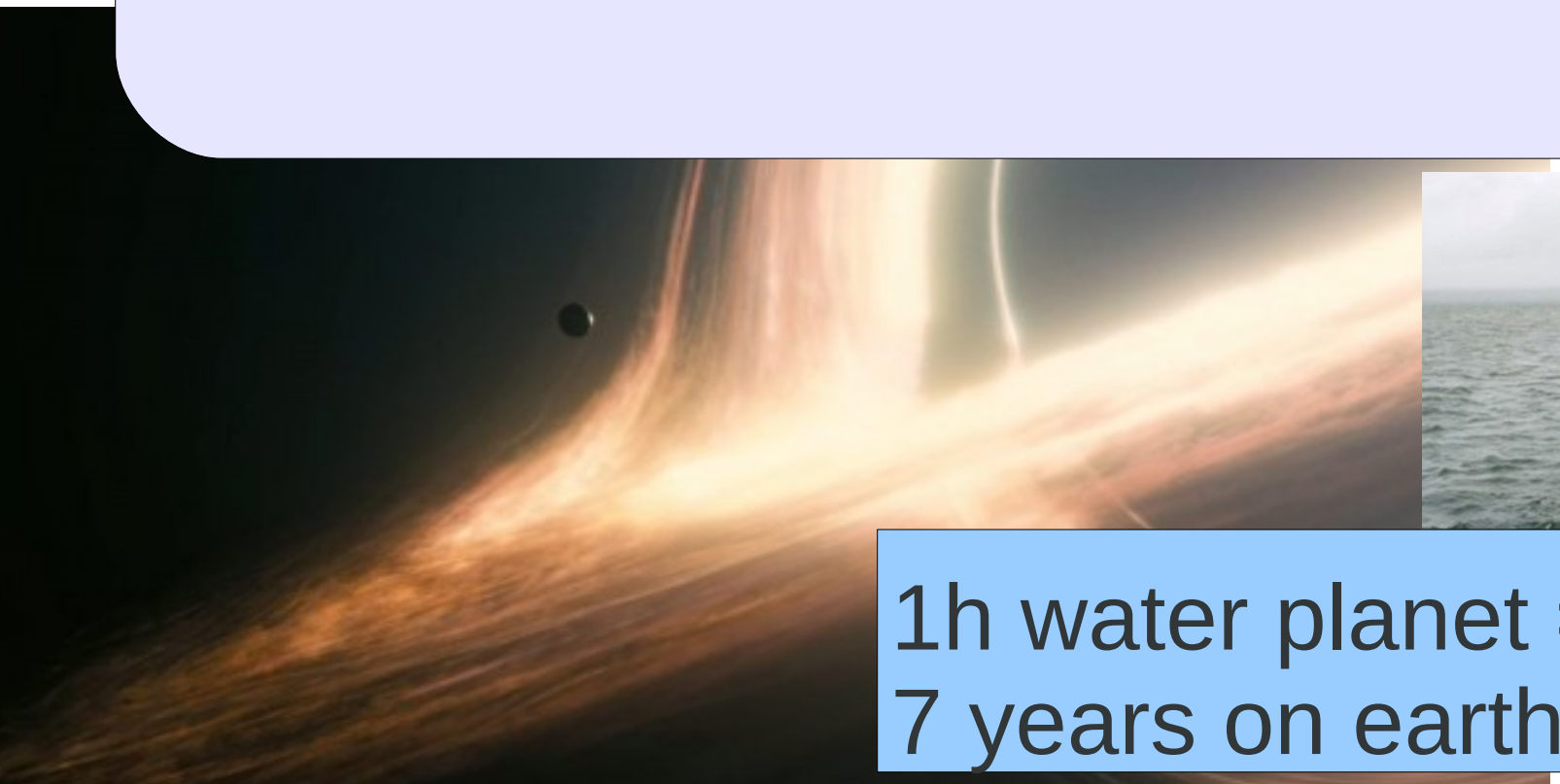
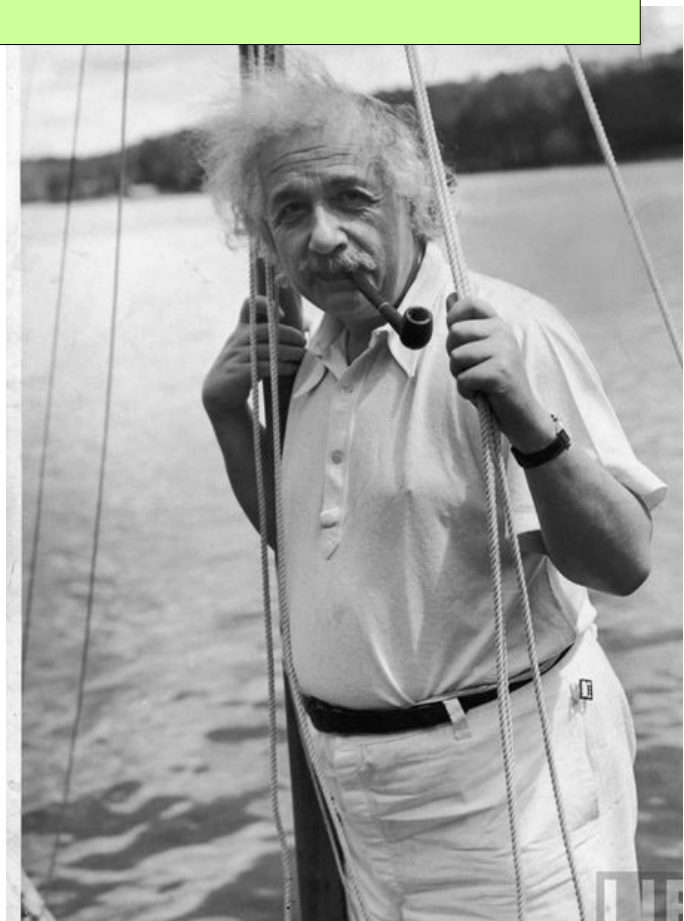


1h water planet =
7 years on earth.

Relativistic time dilation: through movement. Other mechanism? **Gravity**

... but a person at sea level ages slower (more gravity) than a person on the top of a mountain?



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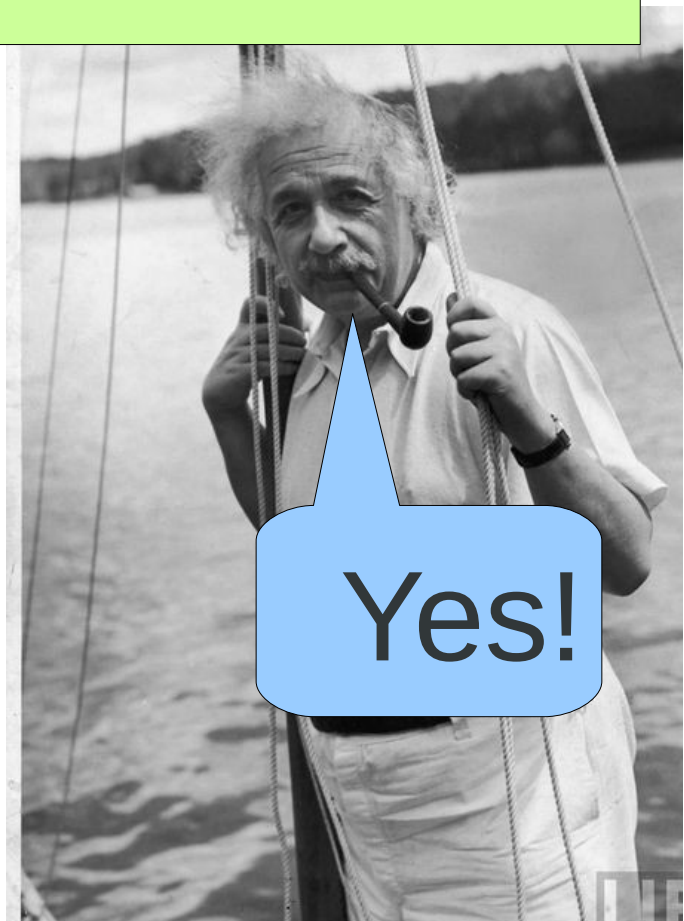

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One second for our head=
1.00000000000000001 second for our feet!

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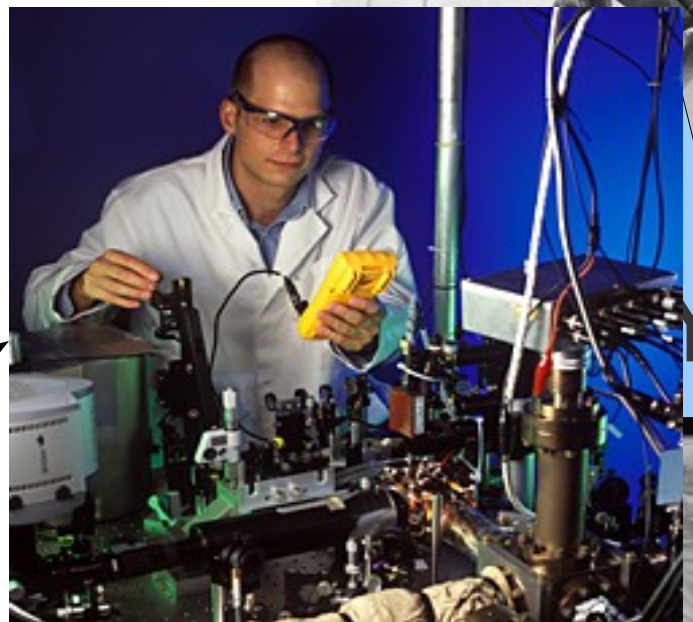
16 zeros!!! The effect is almost negligible.



C. W. Chou, D. B. Hume, T. Rosenband,
D. J. Wineland Science 329, 1630 (2010)

This strange “time dilation”...

…should we care about it?!?

This strange “time dilation”...

…should we care about it?!?

without relativity, gps wouldn't work!!
Satellites are fast and are in a weaker gravitational field: they lose 40 microsec per day

40 microseconds=
40 millionths of a second

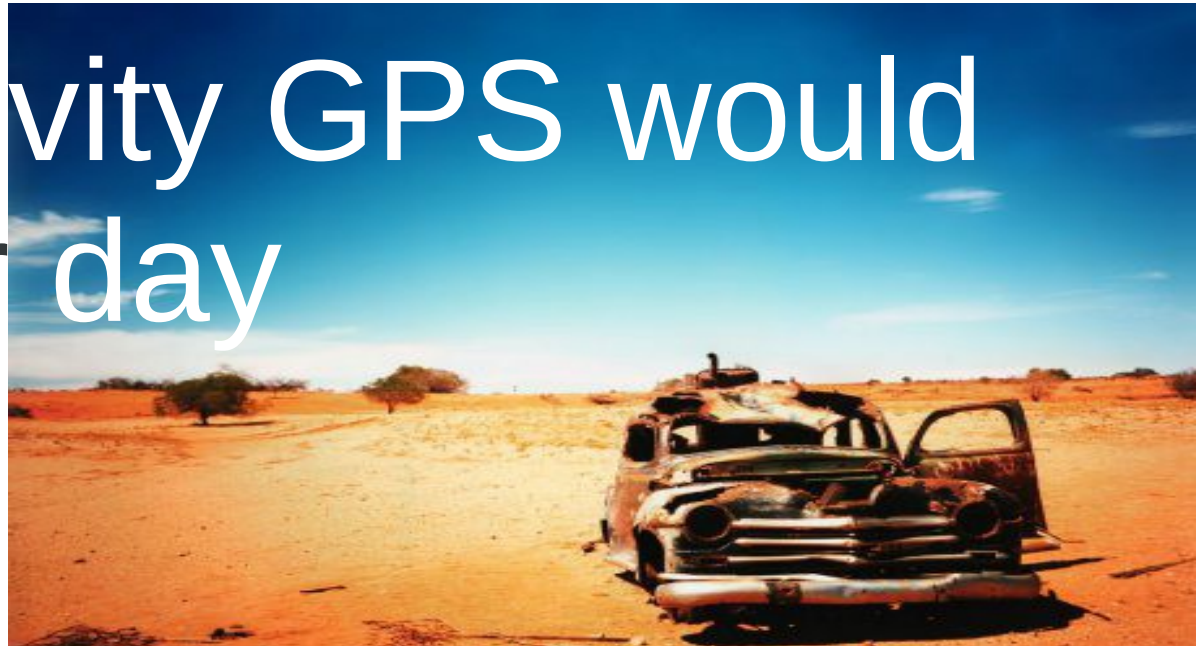
Negligible!?

40 microseconds=
40 millionths of a second

Negligible!?

NO! a microsecond=300 m (GPS signals travel at light speed).

Without relativity GPS would lose 1Km per day



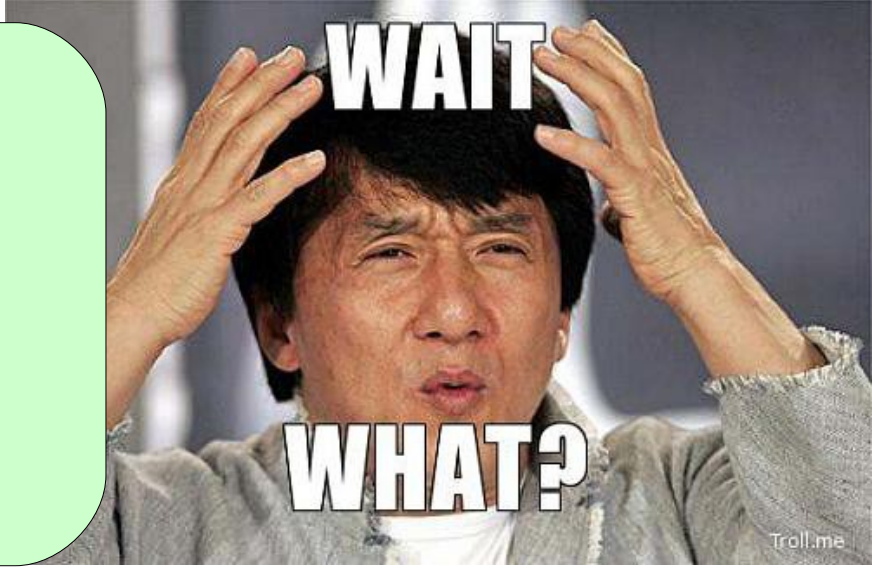
Question 2:

Time travel to the past?

- To the past?

Yes! (maybe!)

...only theoretically!



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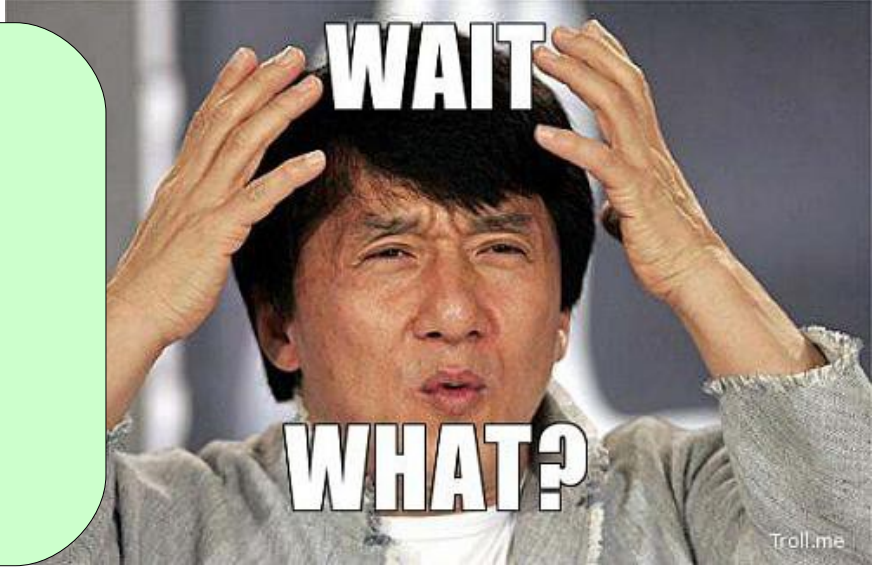

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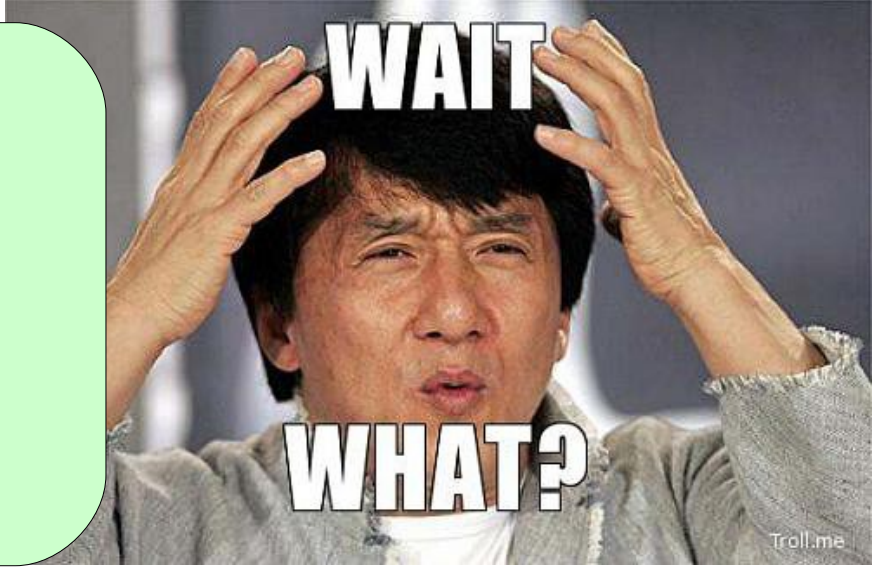

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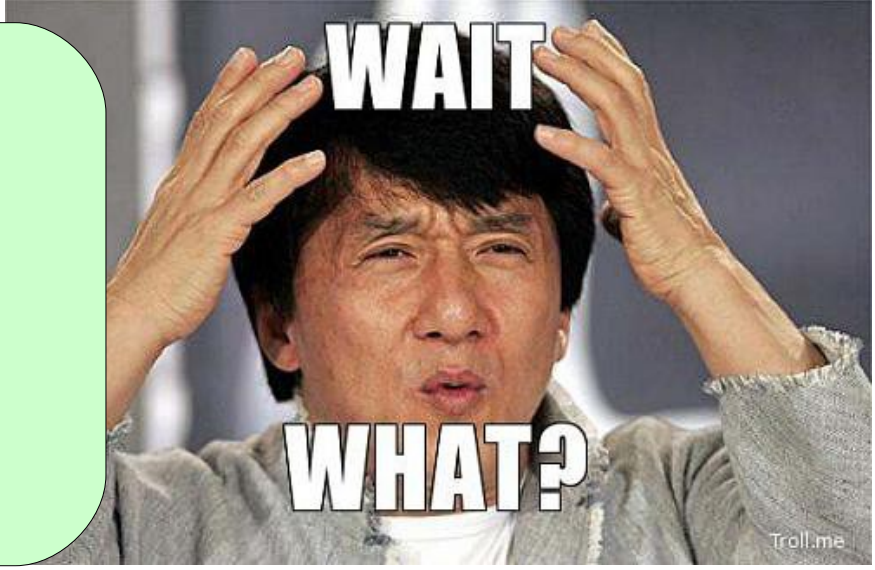

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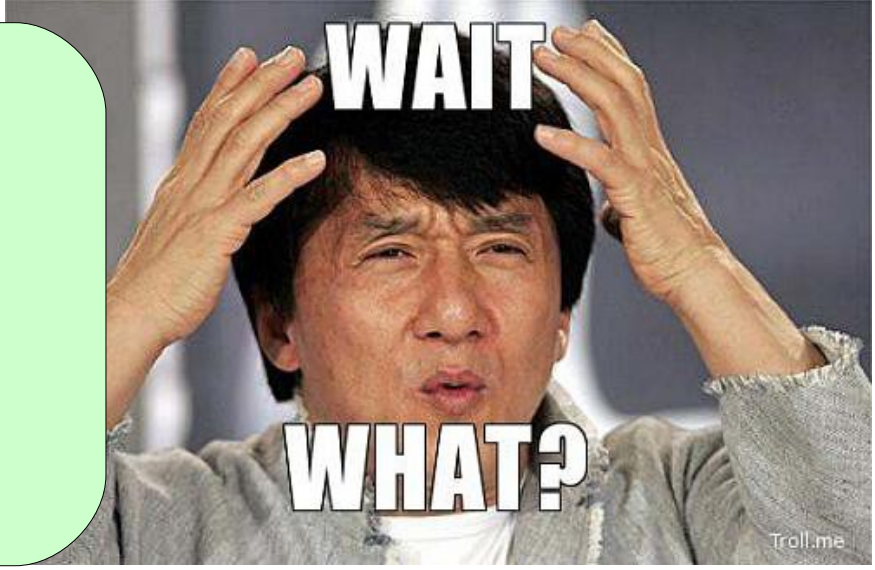

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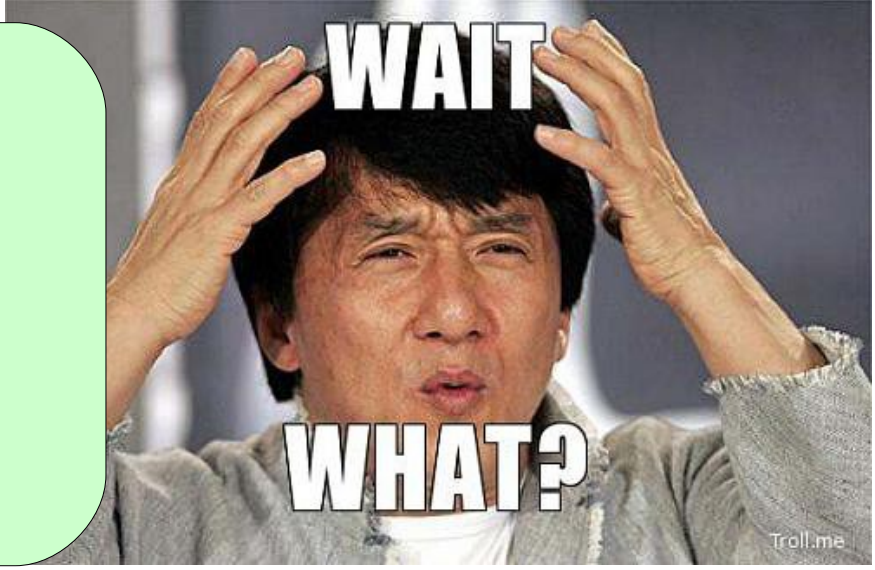

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(black holes rotating at relativistic speeds!)

General relativity predicts time travel to the past

Kurt Gödel's discovery, the greatest mathematical logician of history, and great friend of Einstein

This discovery was Einstein's 70th birthday present

[Palle Yourgrau, a world without time]

Goedel: “general relativity predicts time travel”

Einstein's reply?

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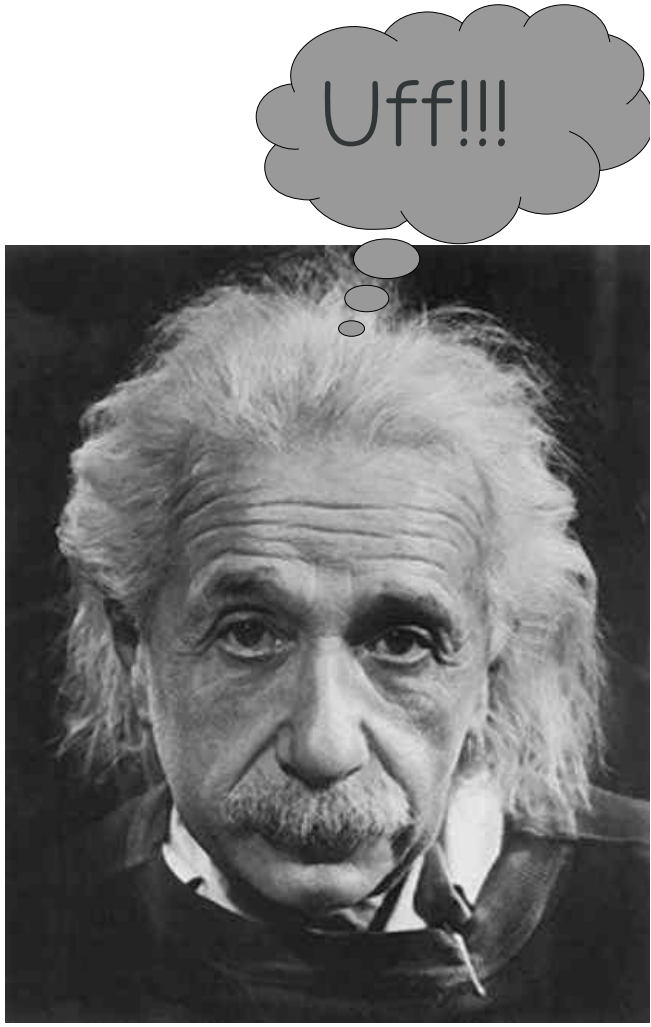

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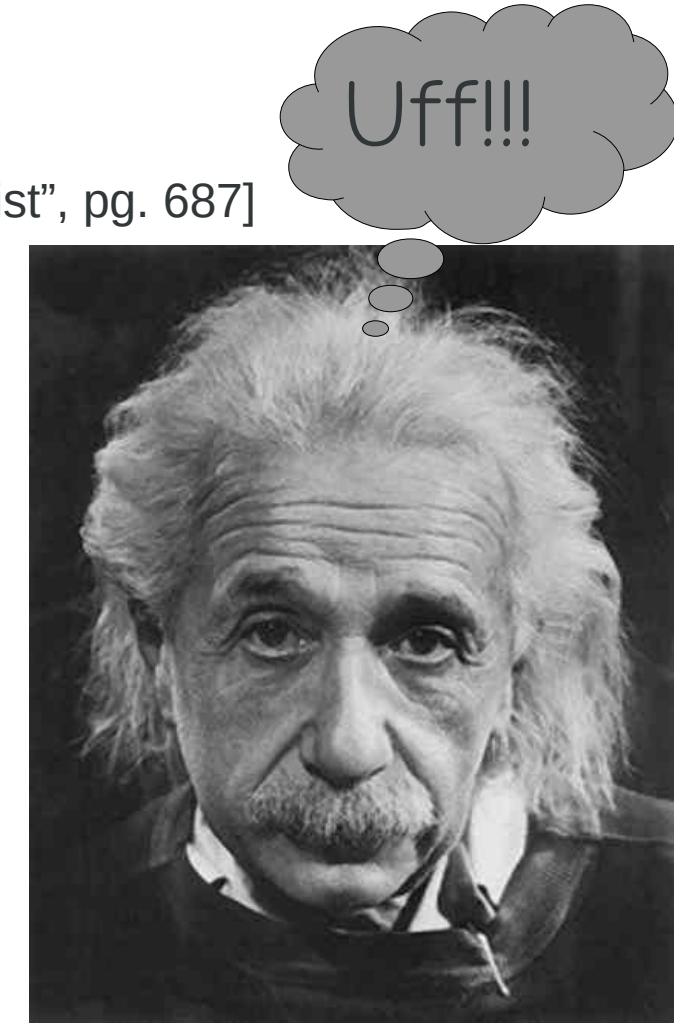
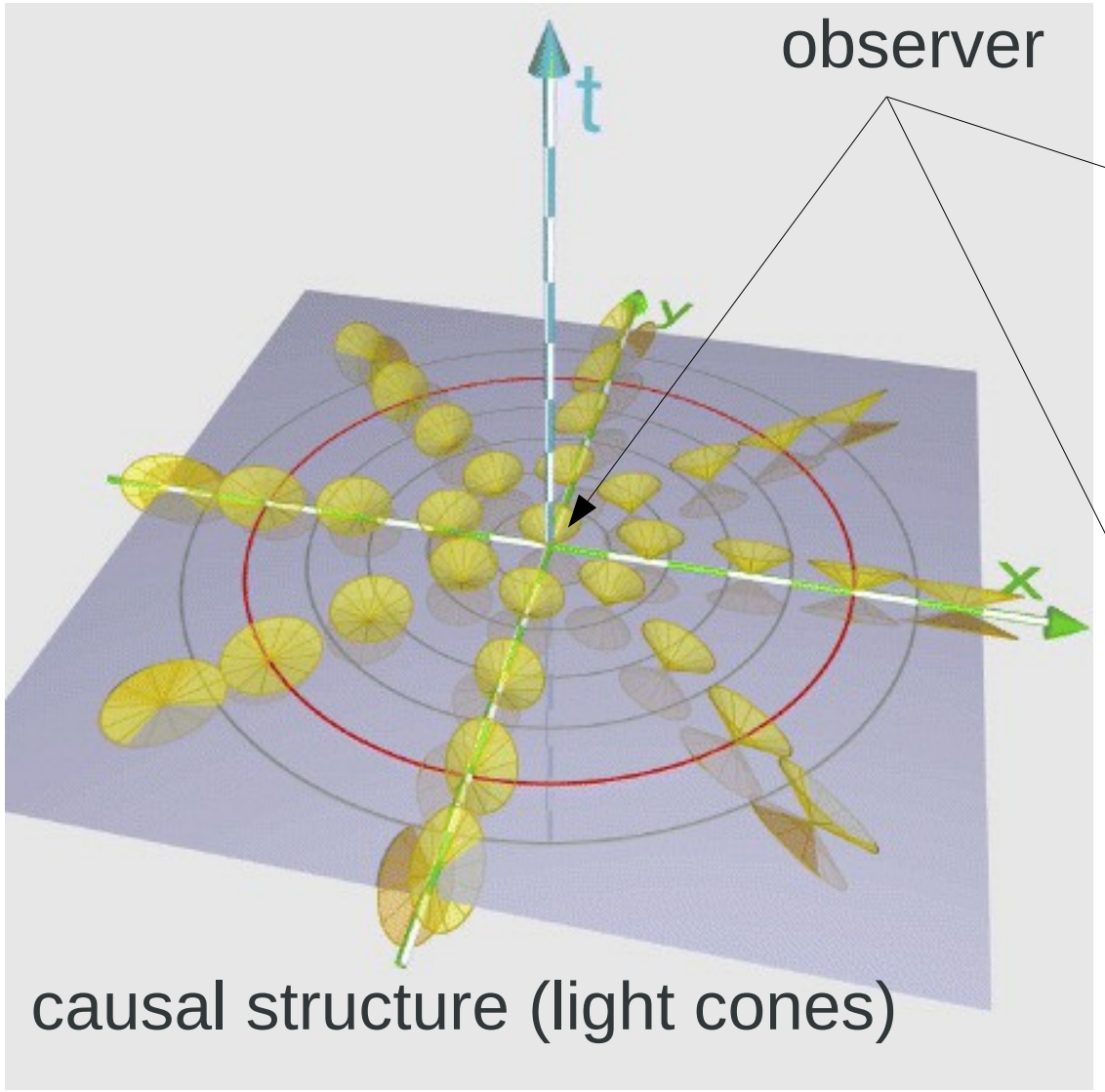
Einstein's reply?

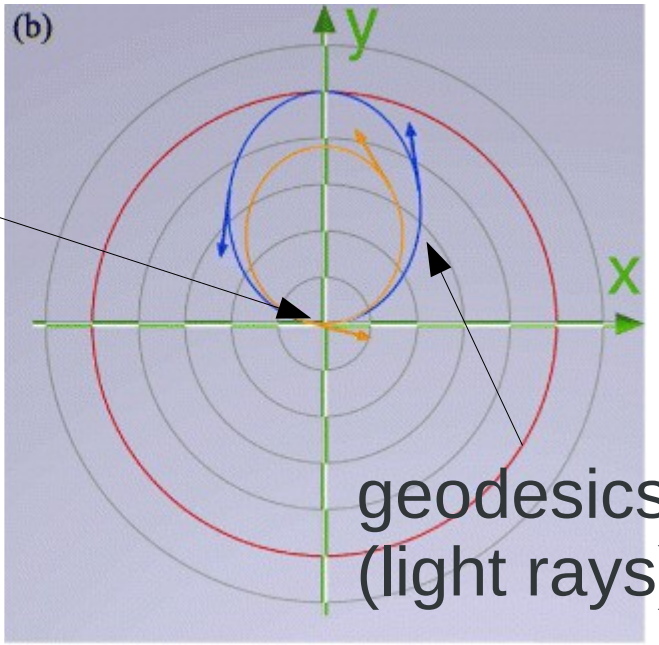
[A. Einstein, in P.A. Schilpp “Albert Einstein Philosopher-Scientist”, pg. 687]

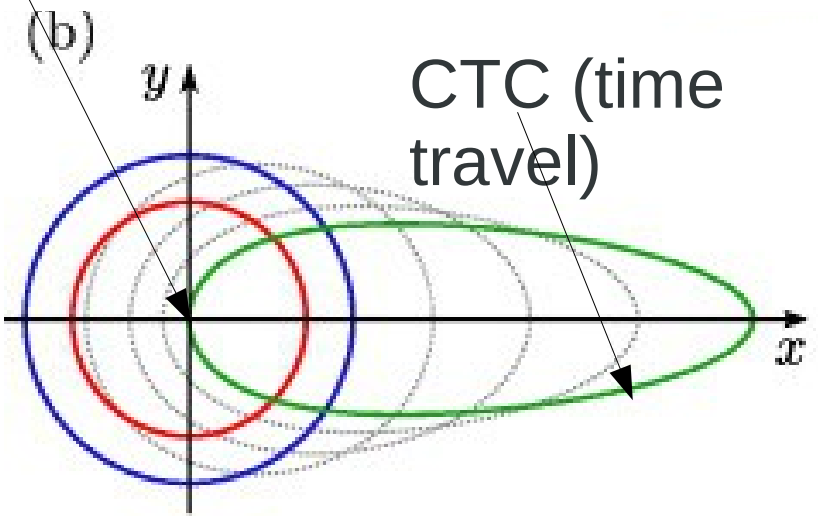


- this is a problem for the theory (time travel paradoxes)
- Perhaps physics prevents it?

Gödel's universe: a universe that “rotates on itself”.







Visualization of the Gödel universe

http://iopscience.iop.org/1367-2630/15/1/013063/article

Gödel's universe: a universe that “rotates on itself”.

Ours?

Gödel's universe: a universe that “rotates on itself”.

Ours?

Ours doesn't...

So... we can't use Goedel's trajectories to travel in time

back to time travel

Temporal paradoxes

back to time travel

Temporal paradoxes

Two types are known:

1. Grandfather paradox
2. Monna Lisa paradox

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I go to the past and kill my grandfather before he meets my grandmother

..then I can't be born, so I can't kill my grandfather.

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logical contradiction → I need to avoid that!!!

Solutions:

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1. Time travel is impossible:

general relativity + quantum mechanics=no time travel

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(with Kip Thorne)

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Leonardo took it from me, I took it from him!

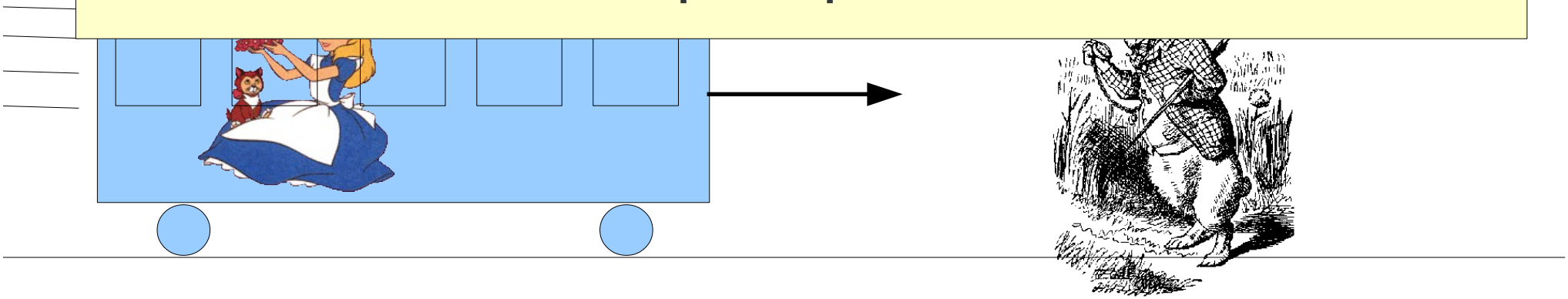
No logical contradiction!

Avoiding these paradoxes is then much more difficult!

known solutions require QM

Summary: Relativity

Relativity forces us to give the same “degree of existence” to past-present-future!!!!



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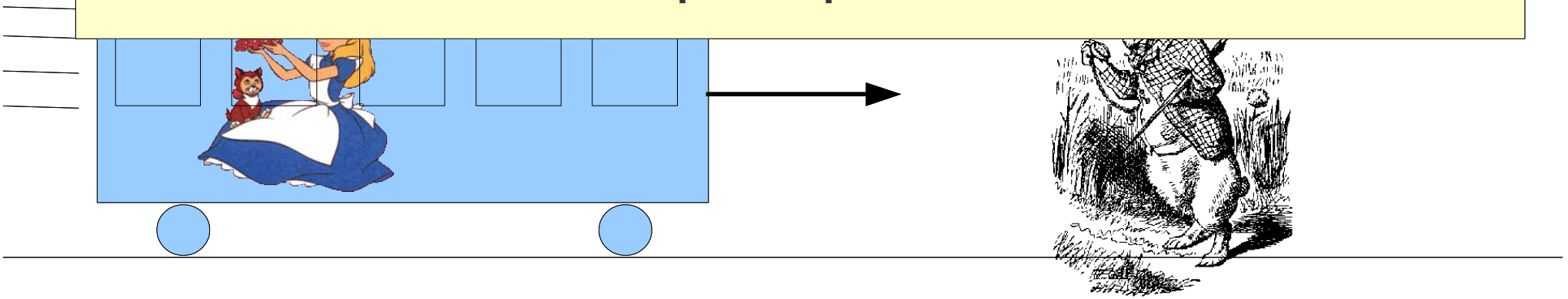


Relativity allows for time travel (theoretically)

Relativity+quantum mechanics

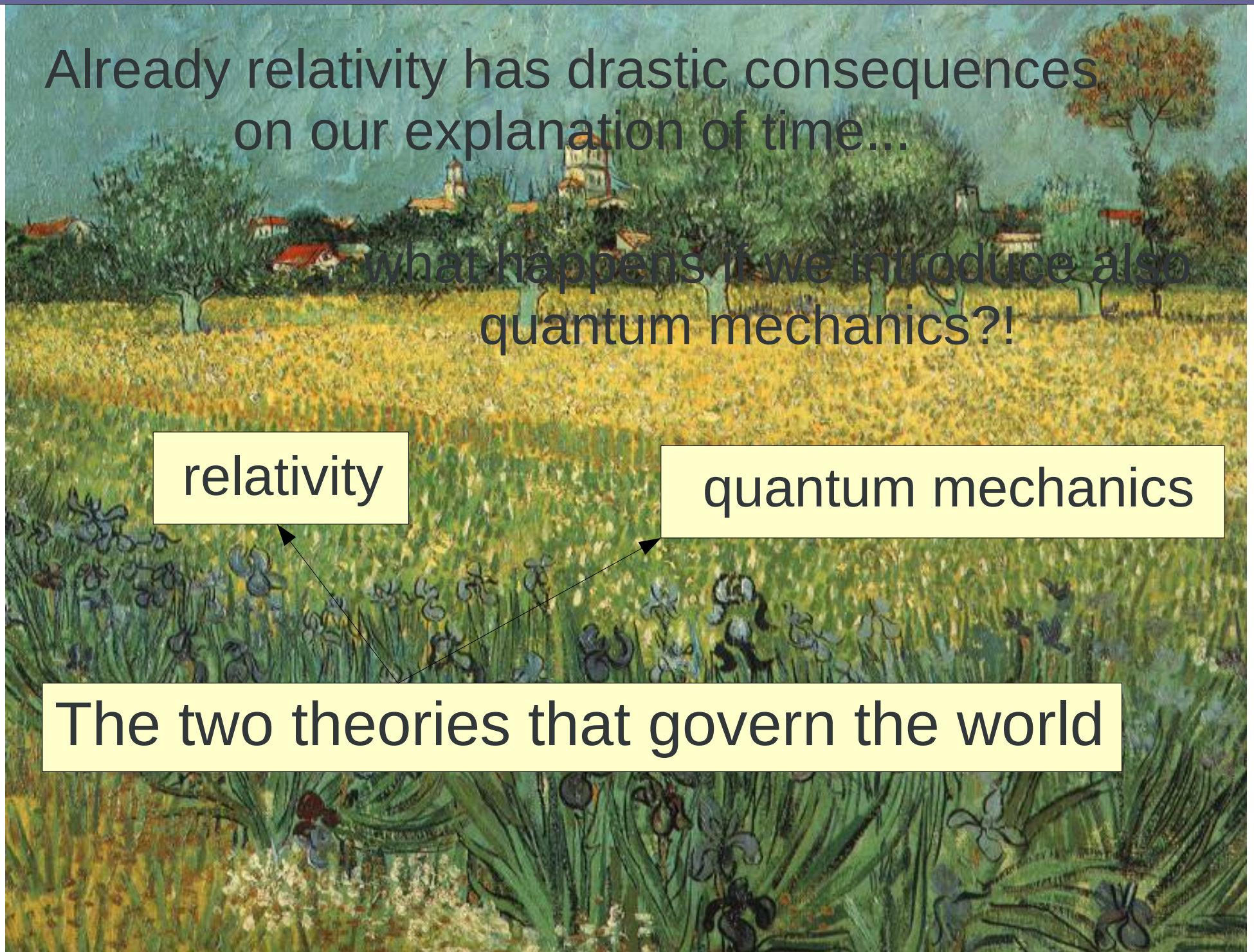
Already relativity has drastic consequences on our explanation of time...

Relativity+quantum mechanics

Already relativity has drastic consequences on our explanation of time...

... what happens if we introduce also quantum mechanics?!

Relativity+quantum mechanics



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- The universe evolves

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joins relativity and quantum mechanics $\hat{H}|\Psi\rangle = 0$

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The state of the universe is stationary

...but!!!

"Problem of time" in modern physics

(many proposed solutions: it tells us that quantum general relativity is still unknown)

all our intuitions of time turn out to be wrong!!

One after another, **the characteristic features of time have proved to be approximations,** mistakes determined by our perspective, just like the flatness of the Earth or the revolving of the sun. The growth of our knowledge has led to a slow **disintegration of our notion of time.** What we call “time” is a complex collection of structures, of layers. Under increasing scrutiny, in ever greater depth, time has lost layers one after another, piece by piece.

(Carlo Rovelli)

Are physicists all crazy?

these ideas make you wonder.....

Are physicists all crazy? or have they lost touch with reality?

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it's necessary to abandon the limitations of our senses and our common sense to understand reality!!!

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The truth is that

it's necessary to abandon the limitations of our senses and our common sense to understand reality!!! (e.g. Plato!)

True scientists know this: they study for years to elimate their prejudices against reality.

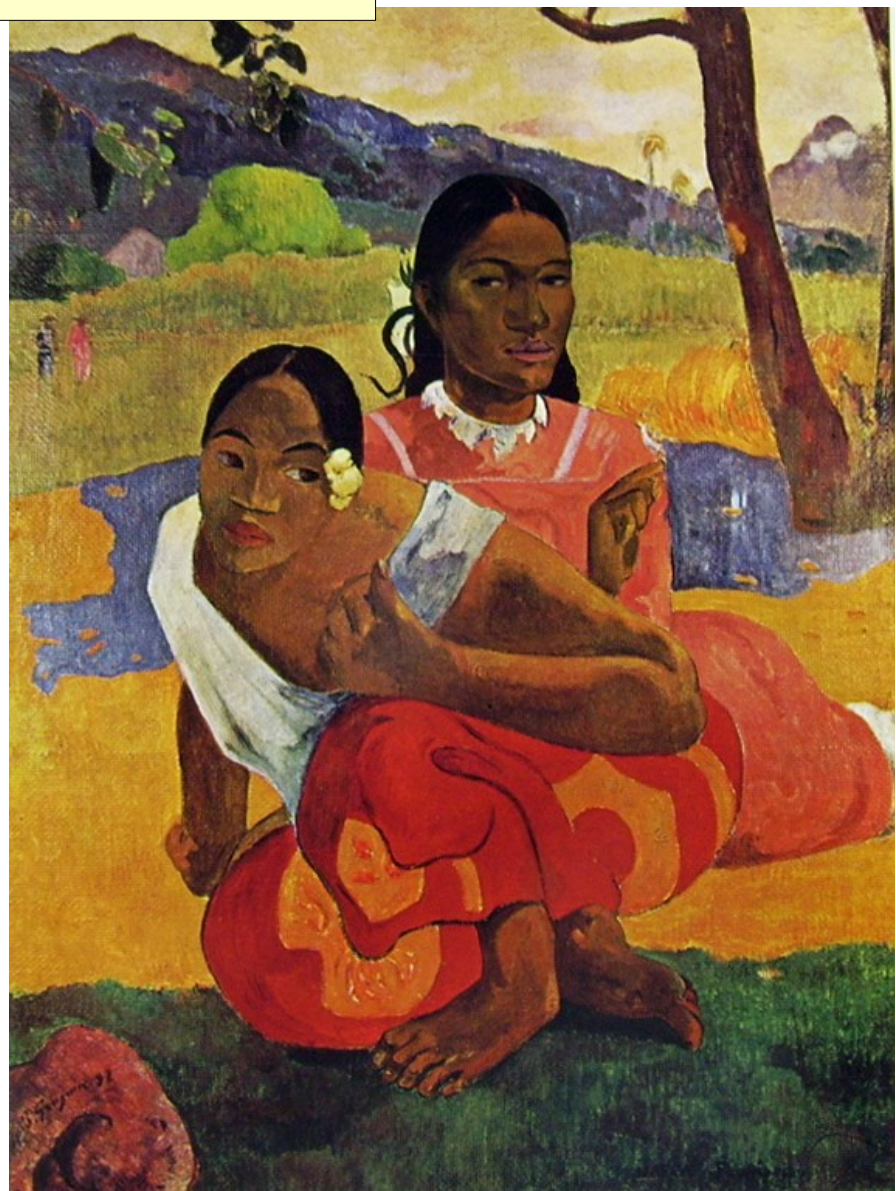
Physicists are ***not*** crazy

it's physics that is very strange...

REMEMBER THE FISH:
Don't be fish: tackle modern physics with ***open minds***

I close my eyes to see

("Je ferme les yeux pour voir.")
Paul Gauguin



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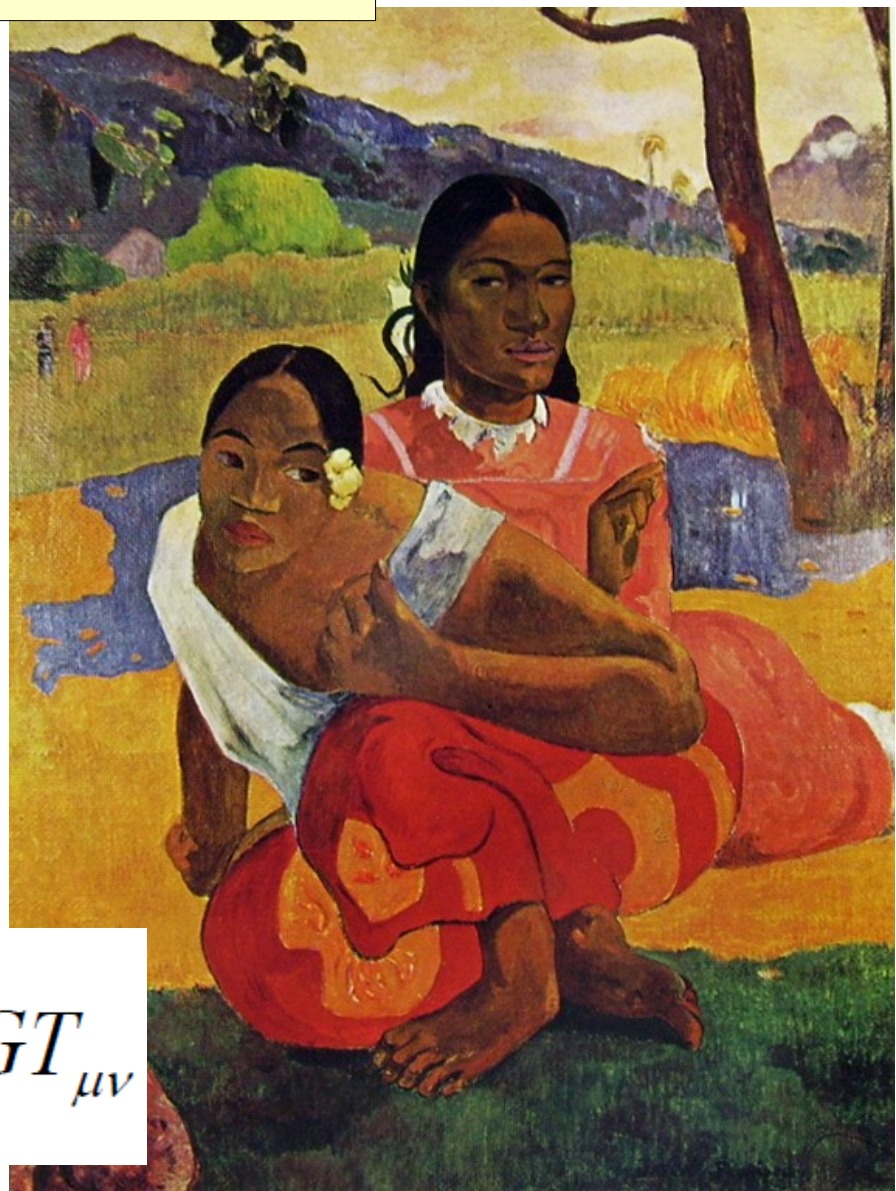


It's impossible to “see” the results from relativity and quantum mechanics

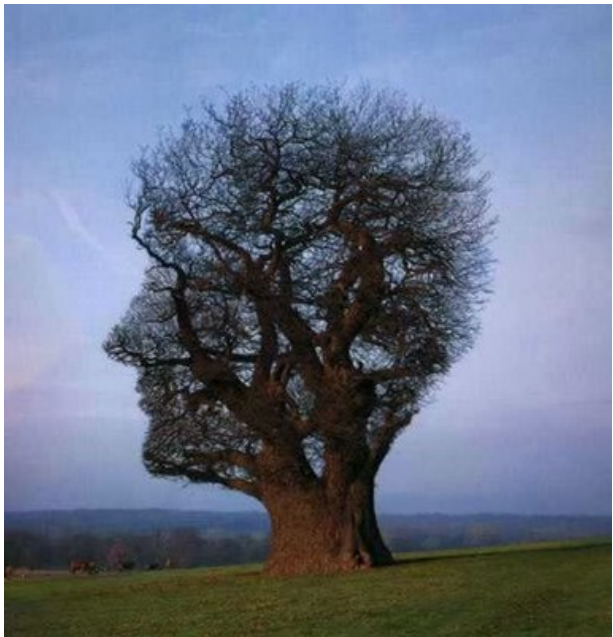
> You have to use the eyes of the mind, helping yourself with mathematical formalism: the language of physics

$$H(t)|\psi(t)\rangle = i\hbar\frac{\partial}{\partial t}|\psi(t)\rangle$$

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = 8\pi G T_{\mu\nu}$$

What did I say?

- time= “what's shown on a clock”, “a coordinate”



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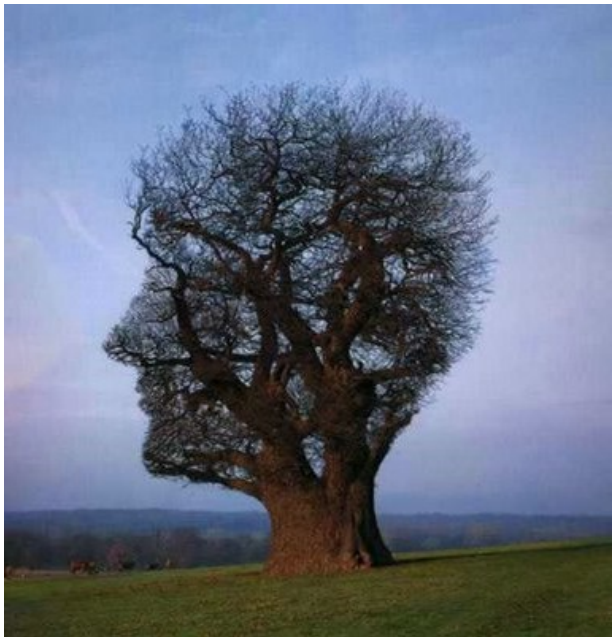

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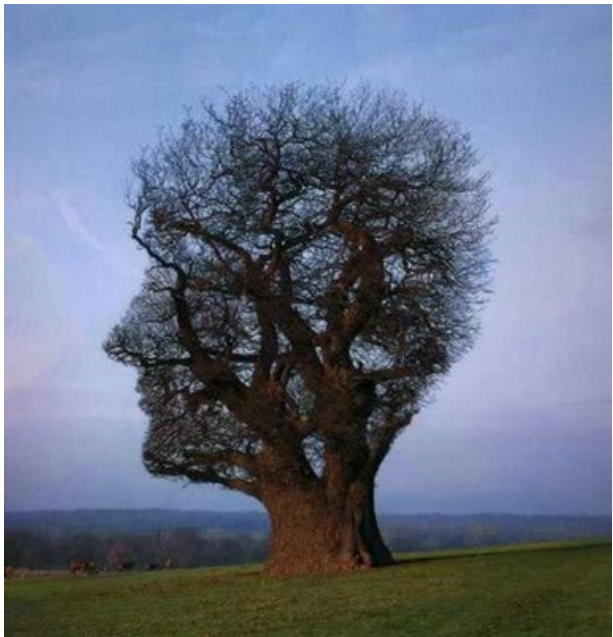
relativity

Past-present-future have the same essence (block universe)



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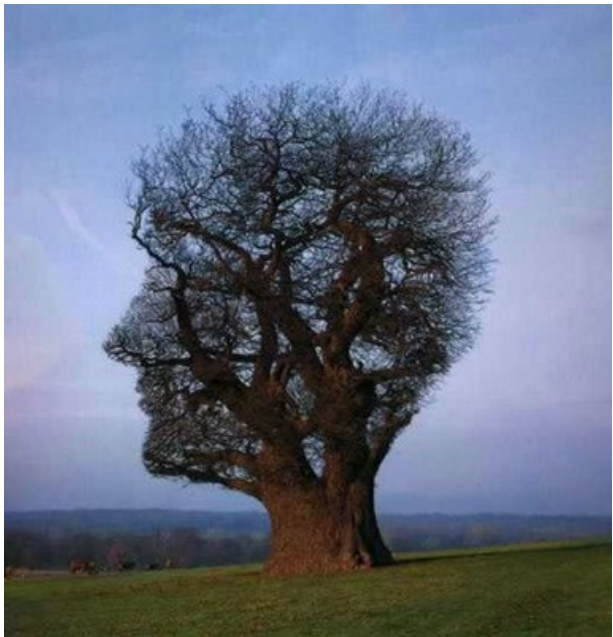

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relativity

- The universe evolves → NO (?)

relativity+quantum mechanics

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- time= “what's shown on a clock”, “a coordinate”
- Time “flows” → NO!
- The present “exists”, the past and future don't → NO!

relativity

Past-present-future have the same essence (block universe)

- Time travel → Yes (only theoretically)

relativity

- The universe evolves → NO (?)

relativity+quantum mechanics

- The language of science

CURIOUS?Want to know more?

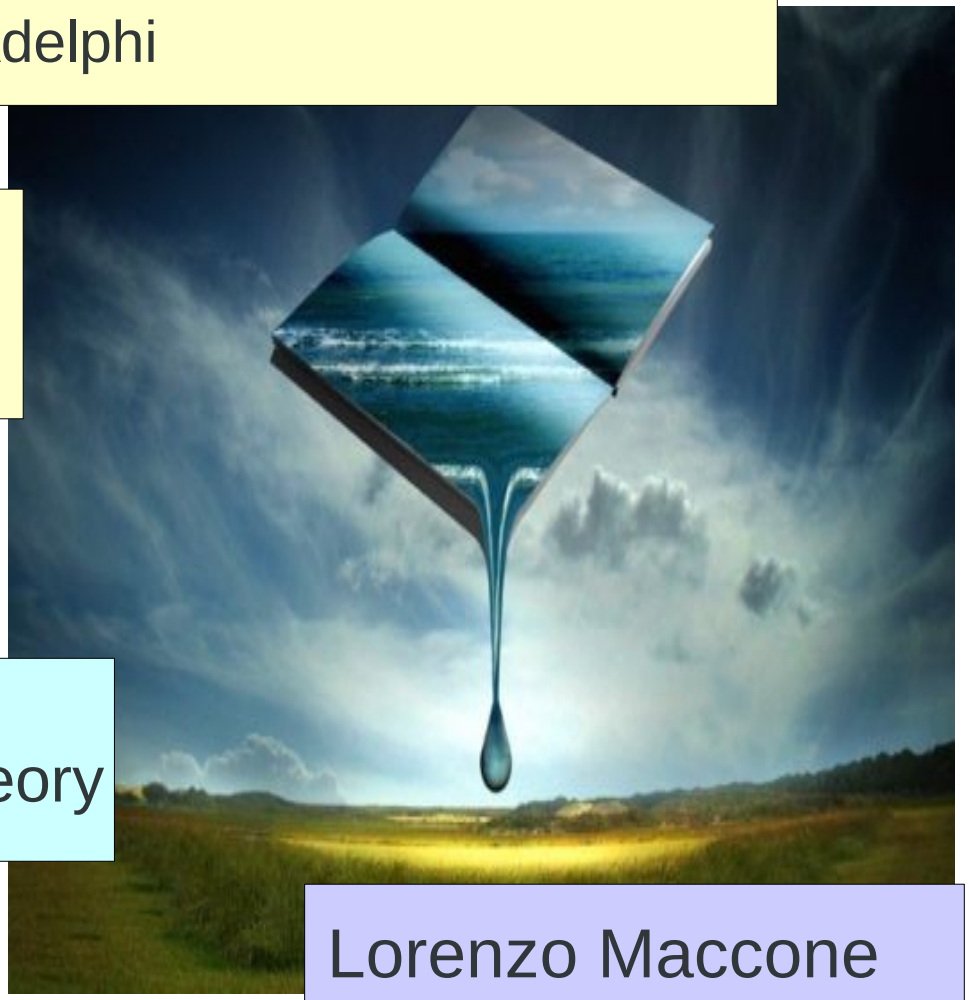
Paul Davies
I misteri del tempo.

Mondadori

Carlo Rovelli
L'ordine del tempo

Adelphi

Palle Yourgrau,
Un mondo senza tempo.



Mauro Dorato
Che cos'e' il tempo?

Carocci (2013)

Pedro Ferreira
The perfect theory

Technical literature:
C. Rovelli, “Quantum Gravity”,
Sec 2.4.4: “Meanings of time”.

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