Title: The Physics of Impossible Things

Date: Dec 03, 2008 07:00 PM

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Abstract: Some things can happen in our Universe, and others cannot. The laws of physics establish the boundary between possibility and impossibility. Physicists naturally spend most of their time thinking about the possible. In this lecture, however, we will make a brief reconnaissance across the frontier to study impossible things and discover the surprising connections between them. We will encounter standard science-fiction devices like time machines and faster-than-light spaceships -- as well as other, less-familiar prodigies including quantum cloners and bounded electromagnetic miracles. A safe return to the real world is unconditionally guaranteed.

 Benjamin Schumacher is Professor of Physics at Kenyon College, where he has taught for twenty years. He was an undergraduate at Hendrix College and received his Ph.D. in Theoretical Physics from the University of Texas at Austin in 1990, where he was the last doctoral student of John Archibald Wheeler.

 As one of the founders of quantum information theory, Professor Schumacher introduced the term qubit, invented quantum data compression (also known as Schumacher compression), and established several fundamental results about the information capacity of quantum systems. For his contributions he won the 2002 Quantum Communication Award, the premier international prize in the field, and was named a Fellow of the American Physical Society. Besides his interest in quantum information theory, Dr. Schumacher has contributed to other areas involving black holes, thermodynamics and statistical mechanics. He is the author of numerous scientific papers and a textbook, Physics in Spacetime: An introduction to special relativity.

 Professor Schumacher has been a visitor at Los Alamos National Laboratory, the Institute for Quantum Information at Caltech (where he was a Moore Distinguished Scholar), the Isaac Newton Institute of Cambridge University, the Santa Fe Institute, Perimeter Institute and the Universities of New Mexico, Montreal, Innsbruck and Queensland. At Kenyon College, Professor Schumacher teaches physics, but he also regularly ventures into astronomy, mathematics, scientific computing and the humanities.


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Ben Schumacher

Kenyon College

Physics of the Impossible

The Physics of Impossible Things

Benjamin Schumacher
Kenyon College

Three kinds of impossible

Three kinds of impossible

Absolute

Mathematical impossibility

Three kinds of impossible

Absolute	Relative
Mathematical impossibility	Physical impossibility

Three kinds of impossible

Absolute	Relative	Effective
Mathematical impossibility	Physical impossibility	Statistical impossibility

Three kinds of impossible

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We cannot imagine things otherwise.

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We can imagine things otherwise.

Three kinds of impossible

Absolute	Relative	Effective
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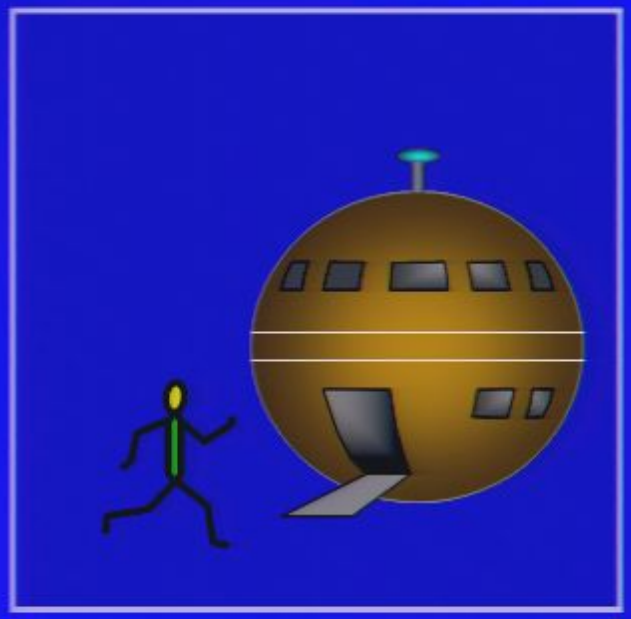
We cannot imagine things otherwise.

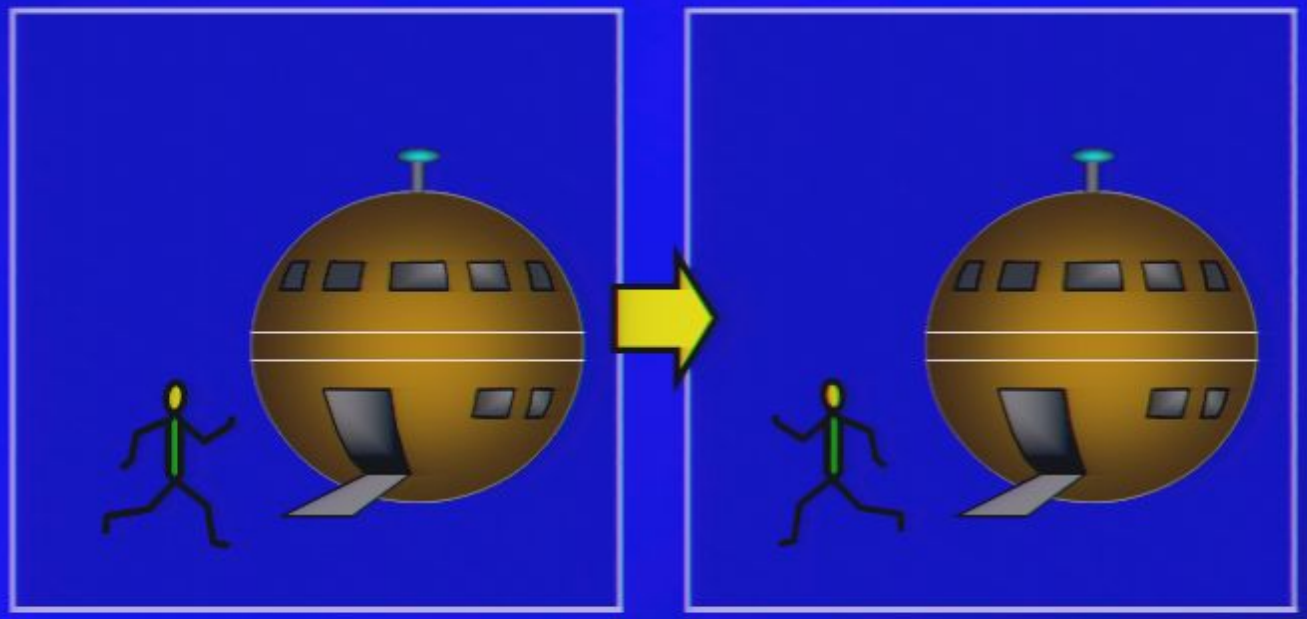
Back in time,
faster than light

Time travel



2008

Time travel



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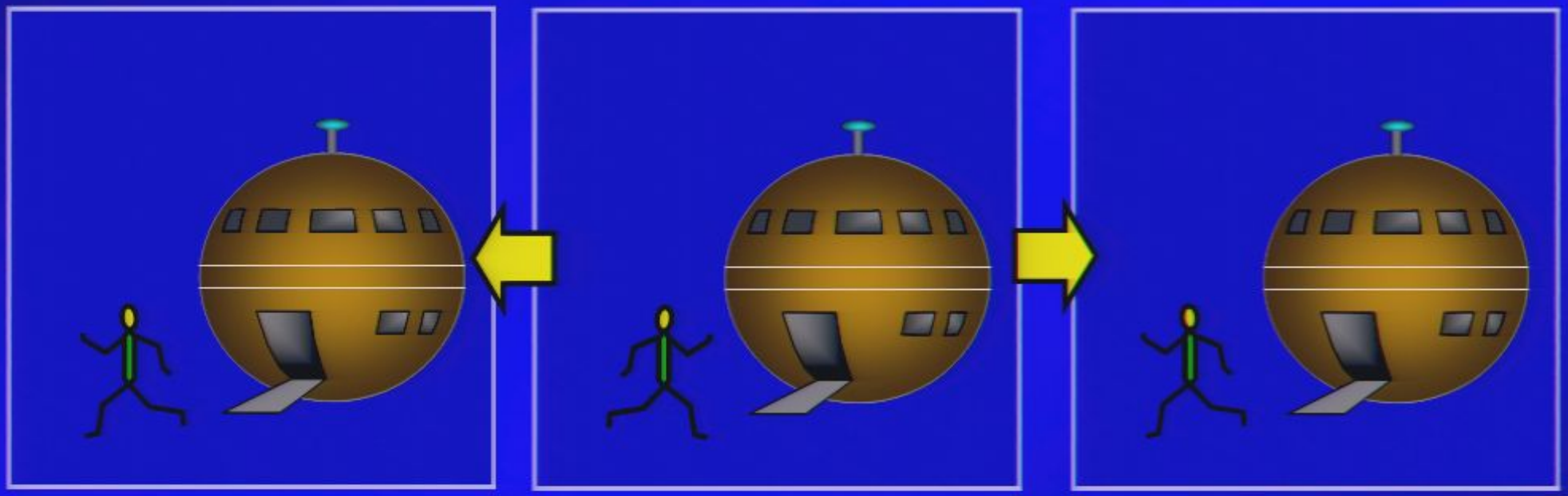
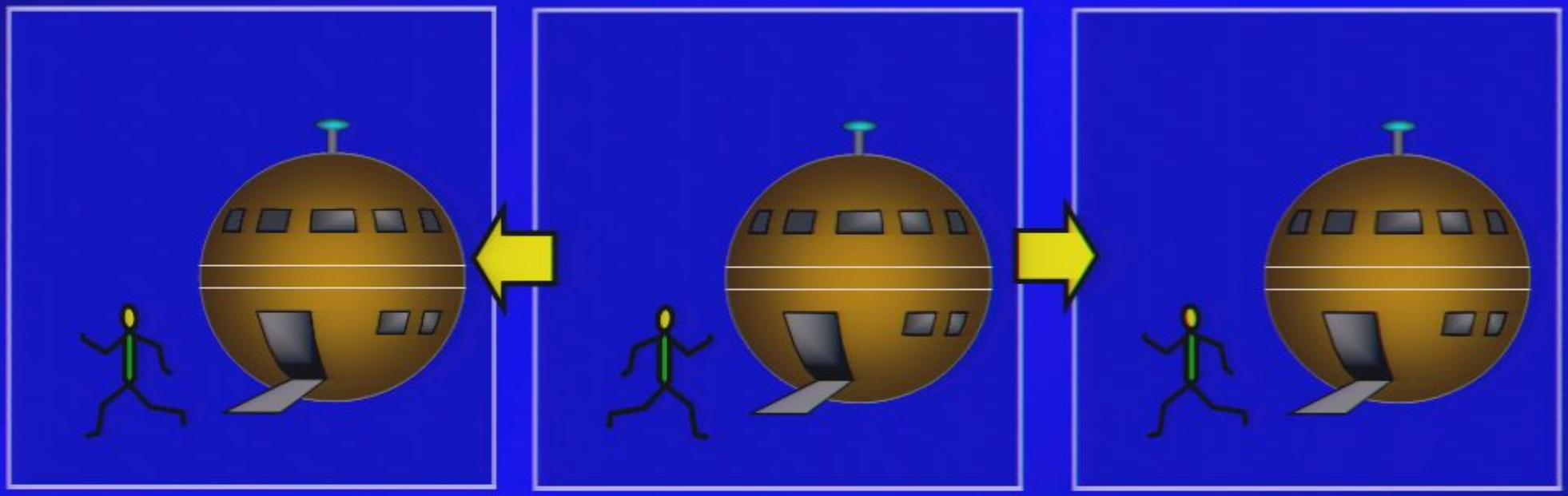
Time travel



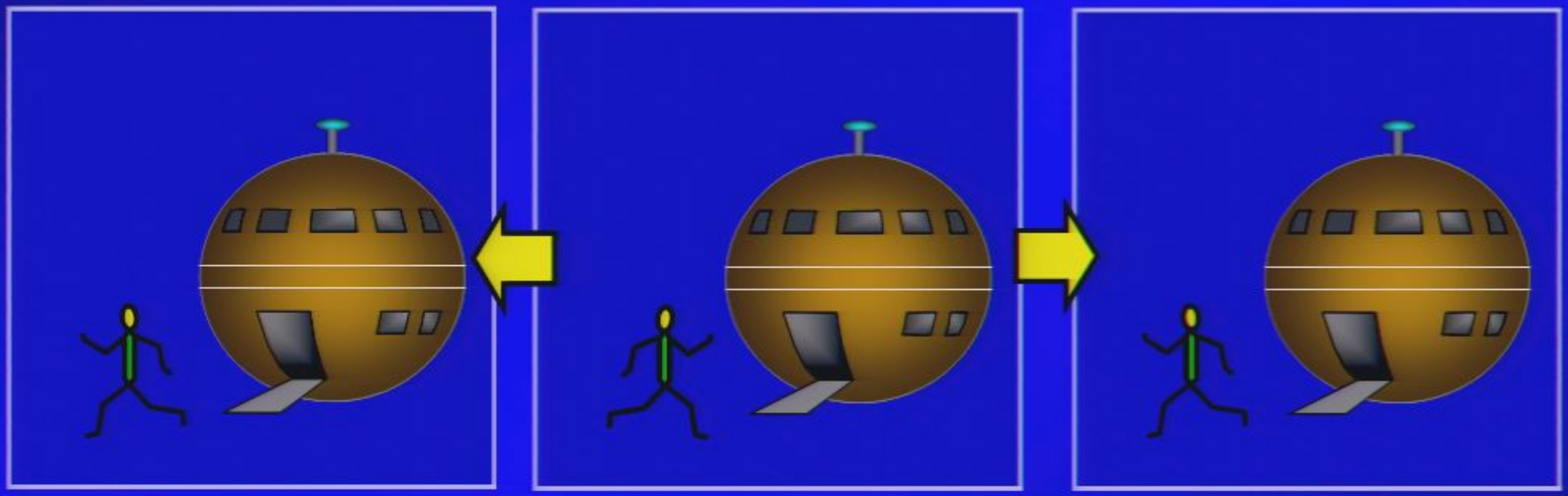
Time travel



1908 2008 2108

Possible!

Time travel



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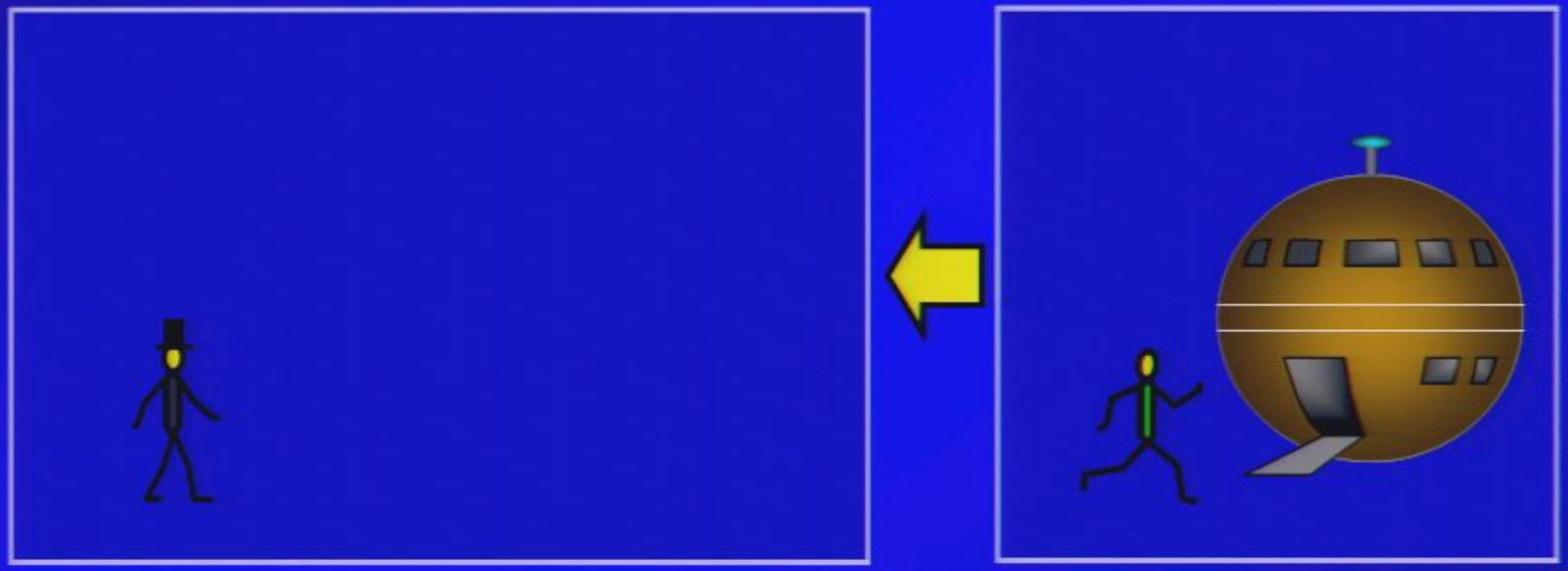
Impossible!

Possible!

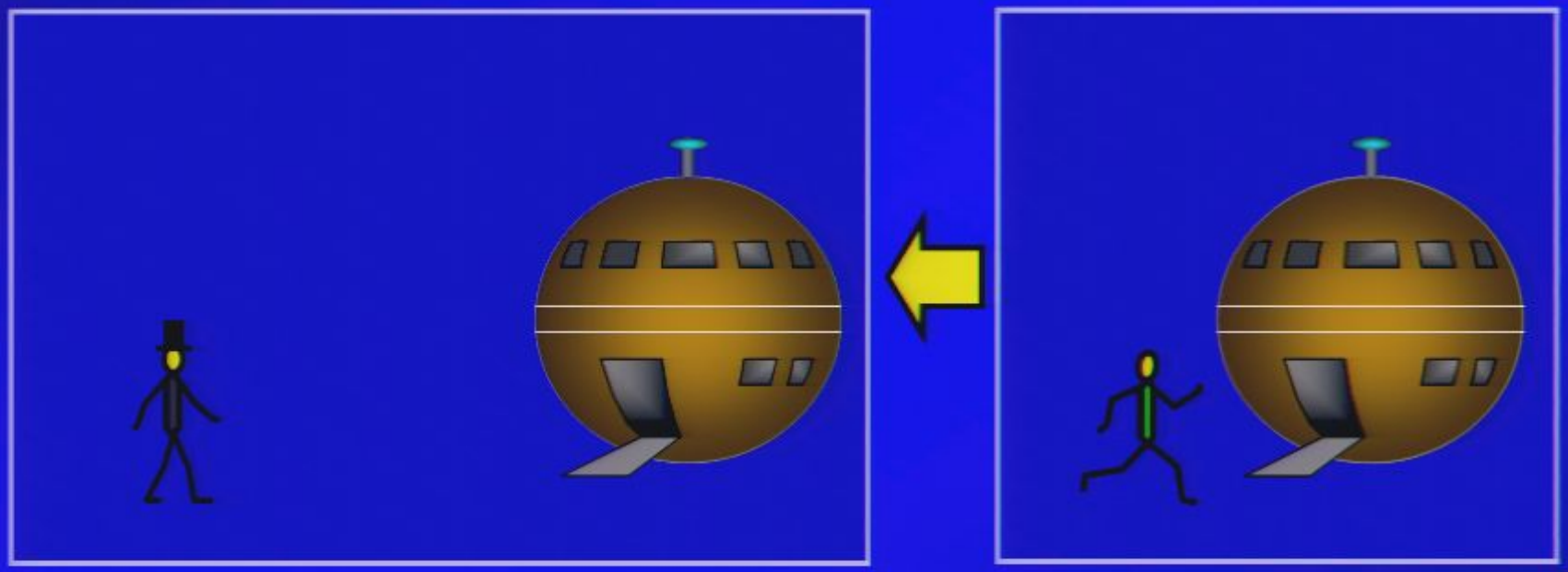
Grandfather paradox



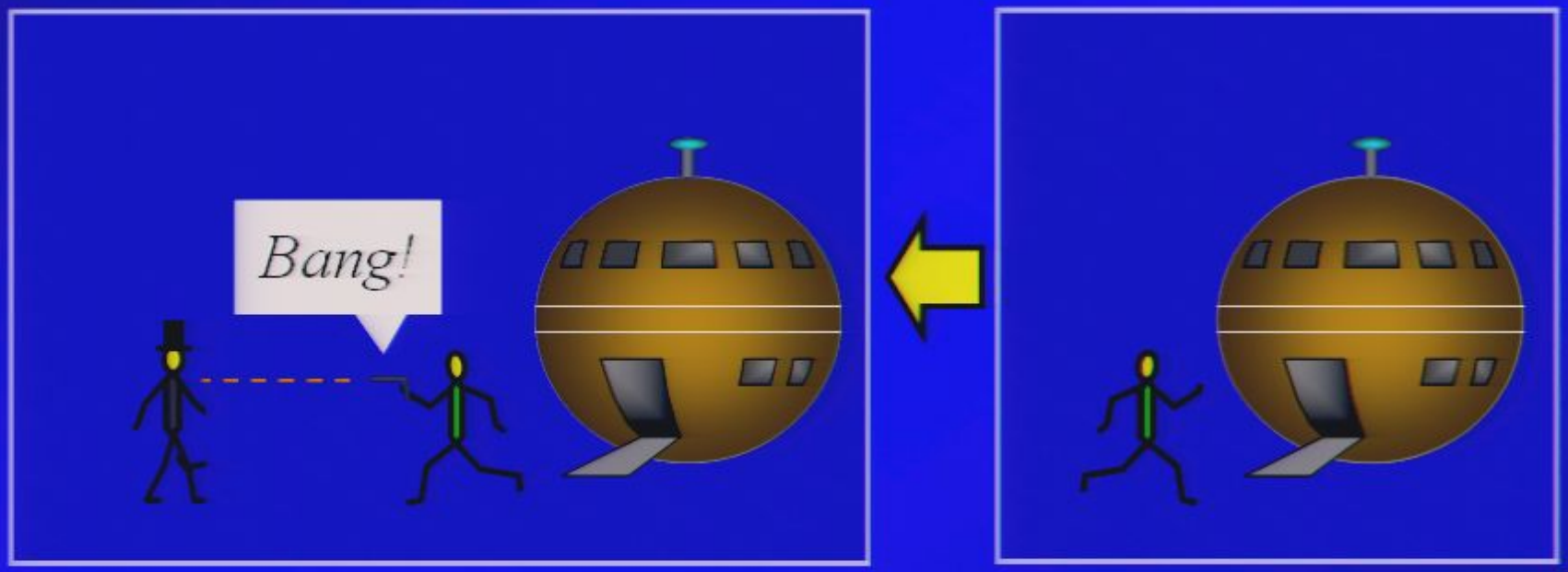
Past

Now

Grandfather paradox



Grandfather paradox

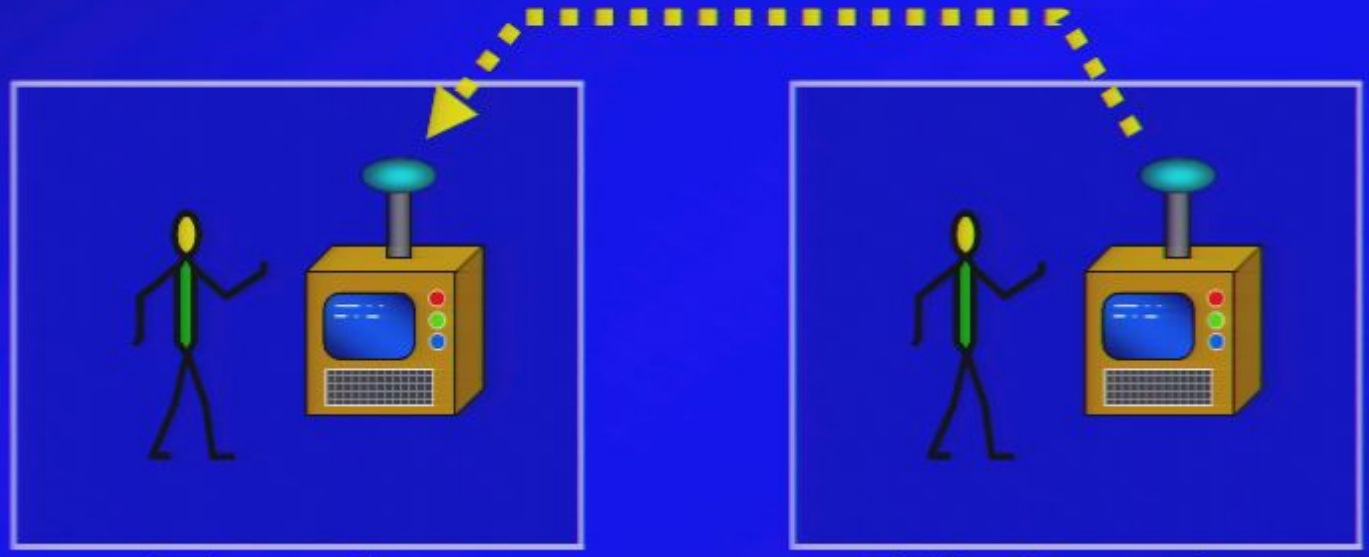


Telegraph paradox

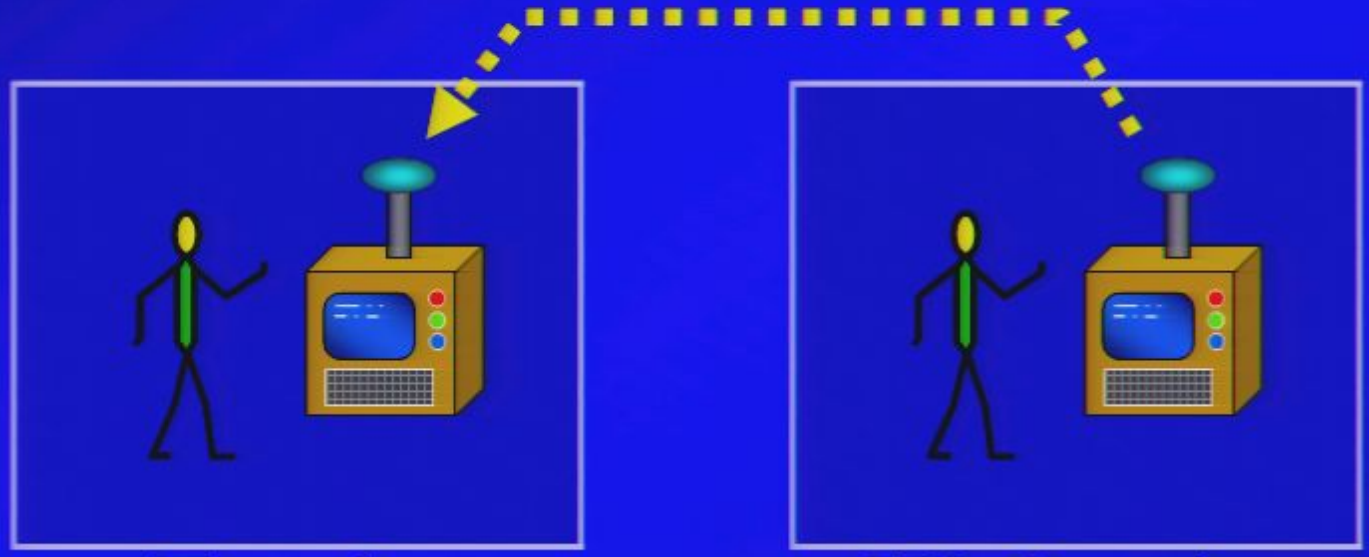
Tuesday

Wednesday

Telegraph paradox



Telegraph paradox



Plan: Send a message on Wednesday if and only if no message arrives on Tuesday.

A famous limit

A famous limit

c = "speed of light"

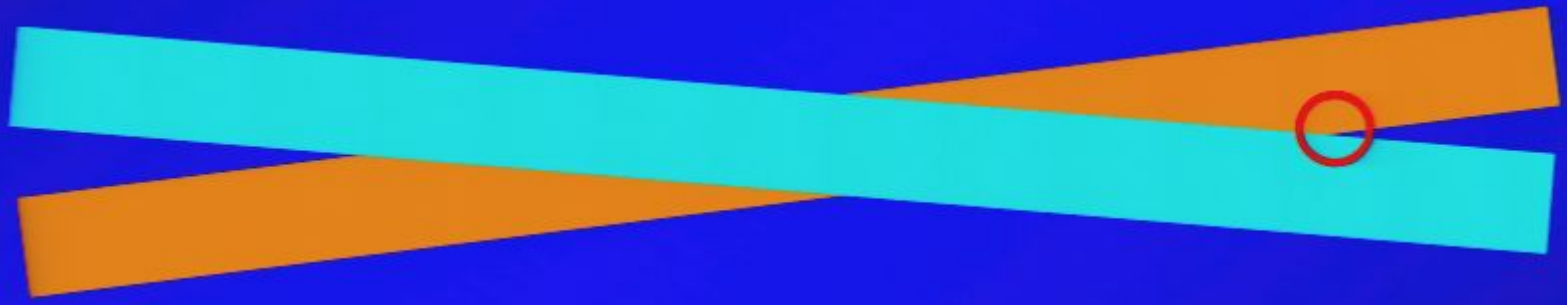
= 299,792 km/sec

The scissors effect

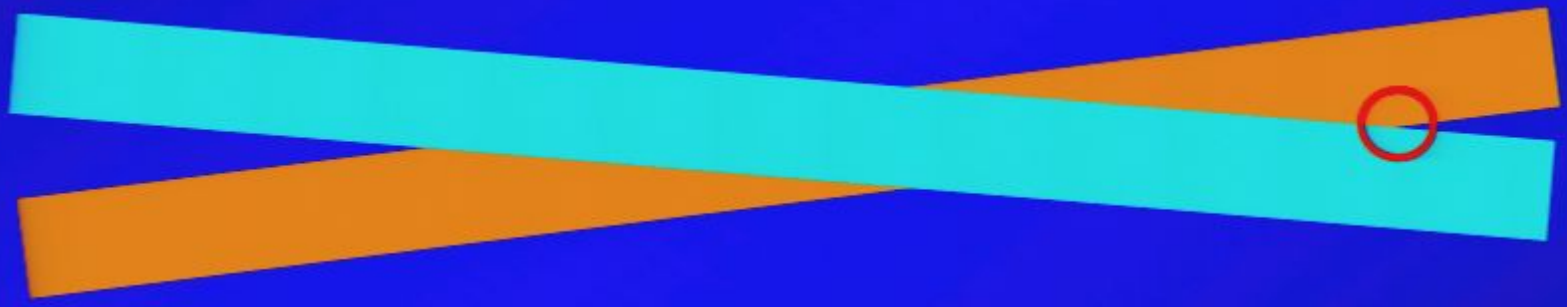
The scissors effect

The scissors effect

The scissors effect



The scissors effect



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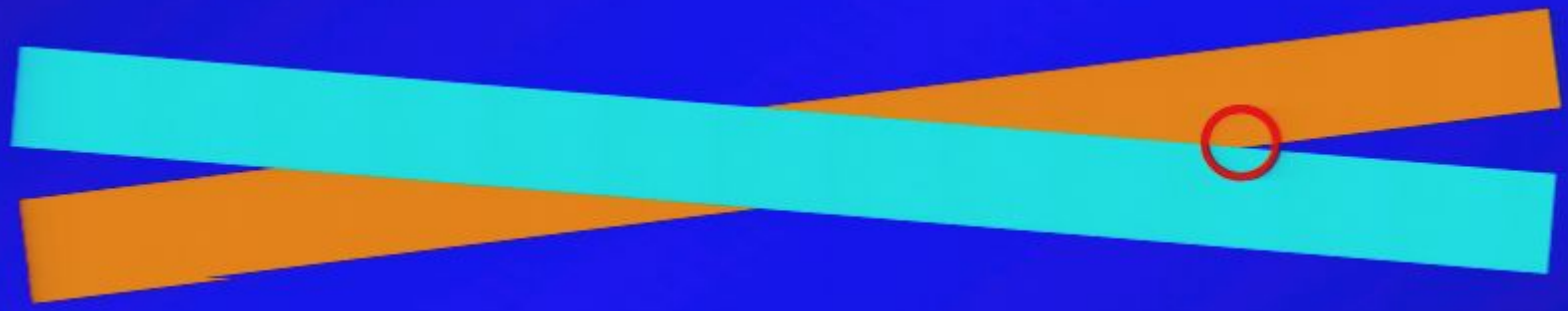

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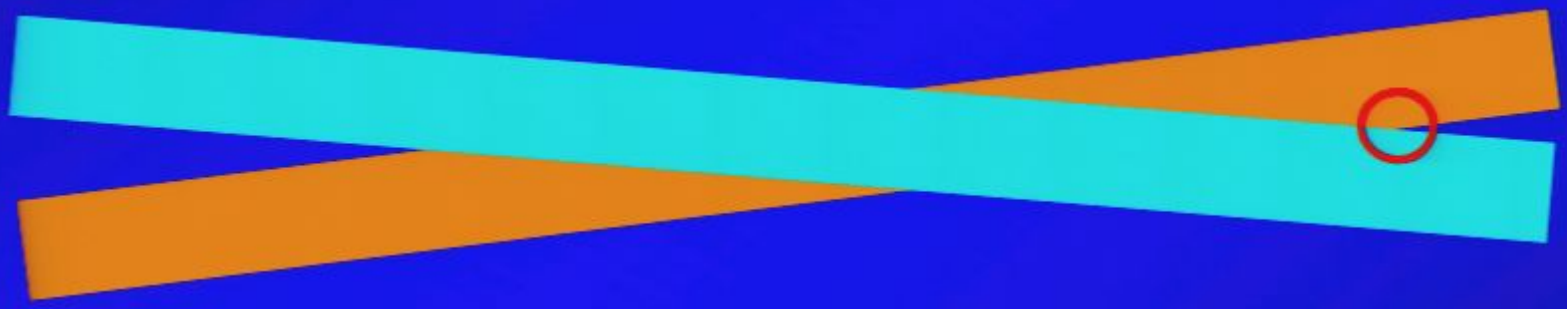
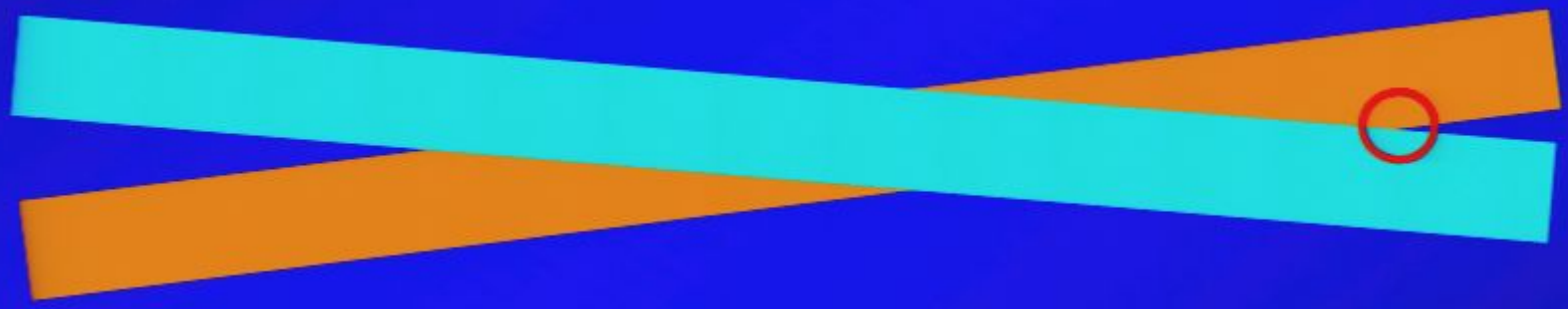


Even if the blades move slowly, the point of intersection can move faster than light!

The scissors effect



Even if the blades move slowly, the point of intersection can move faster than light!

Superlight!

Superlight!

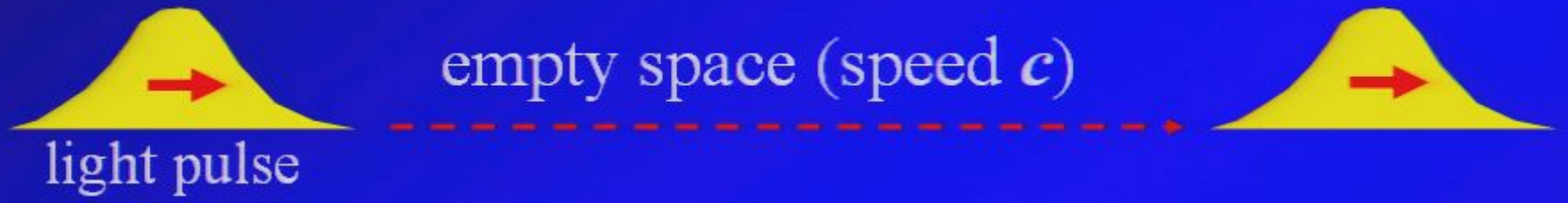
light pulse

Superlight!

light pulse

empty space (speed c)

Superlight!



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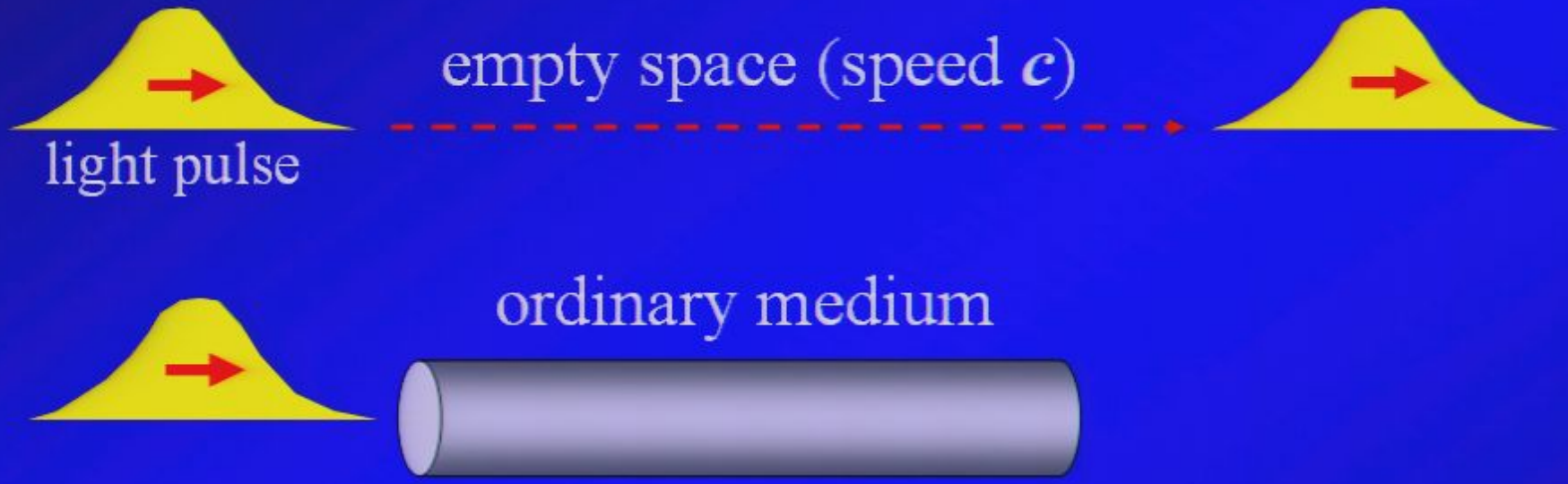

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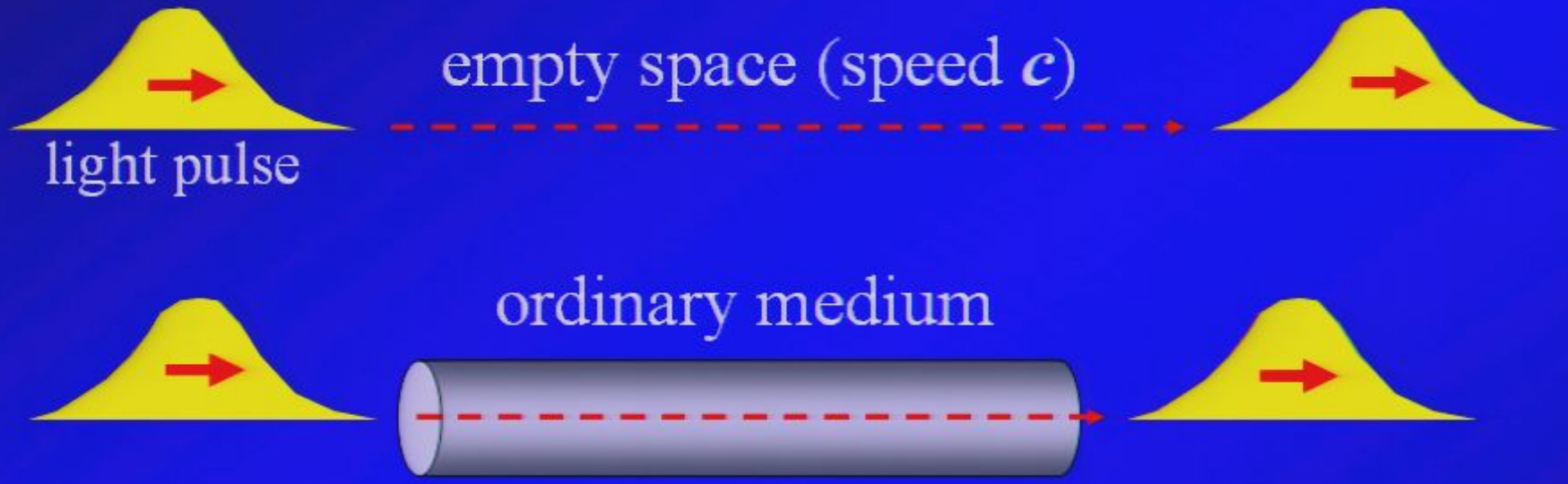

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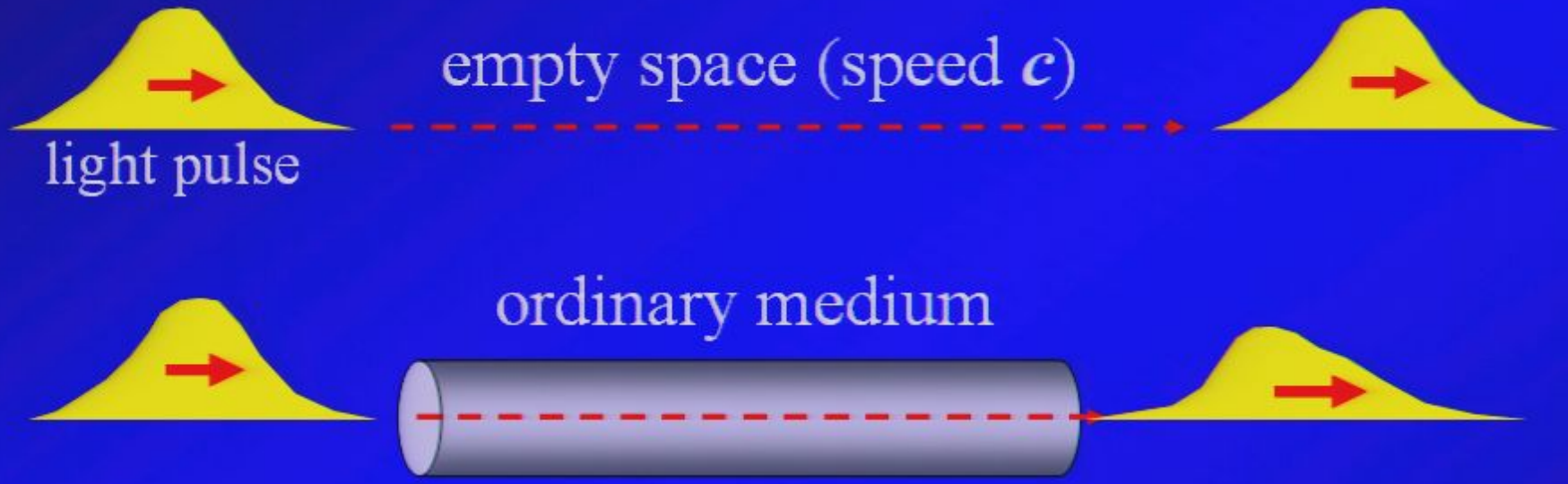

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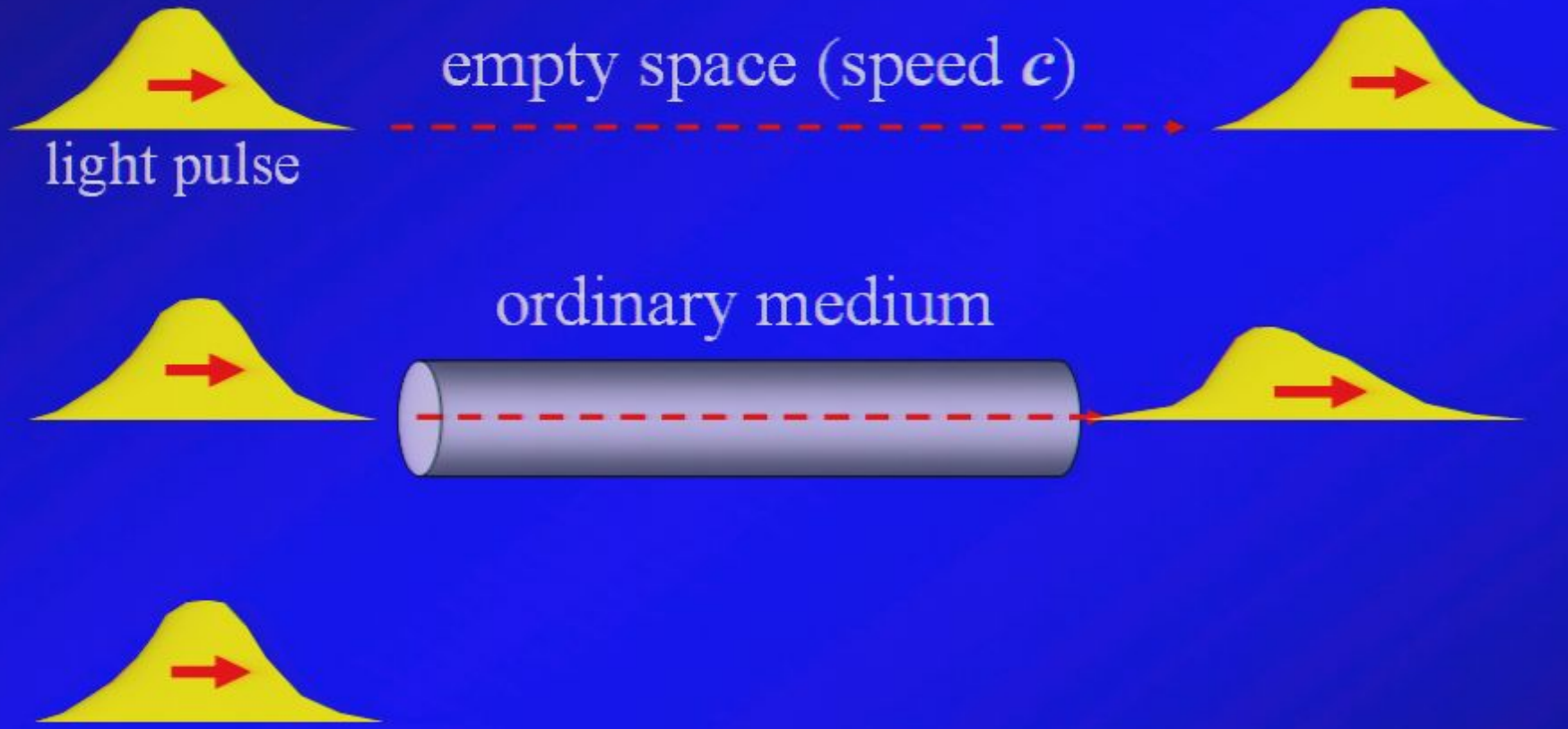

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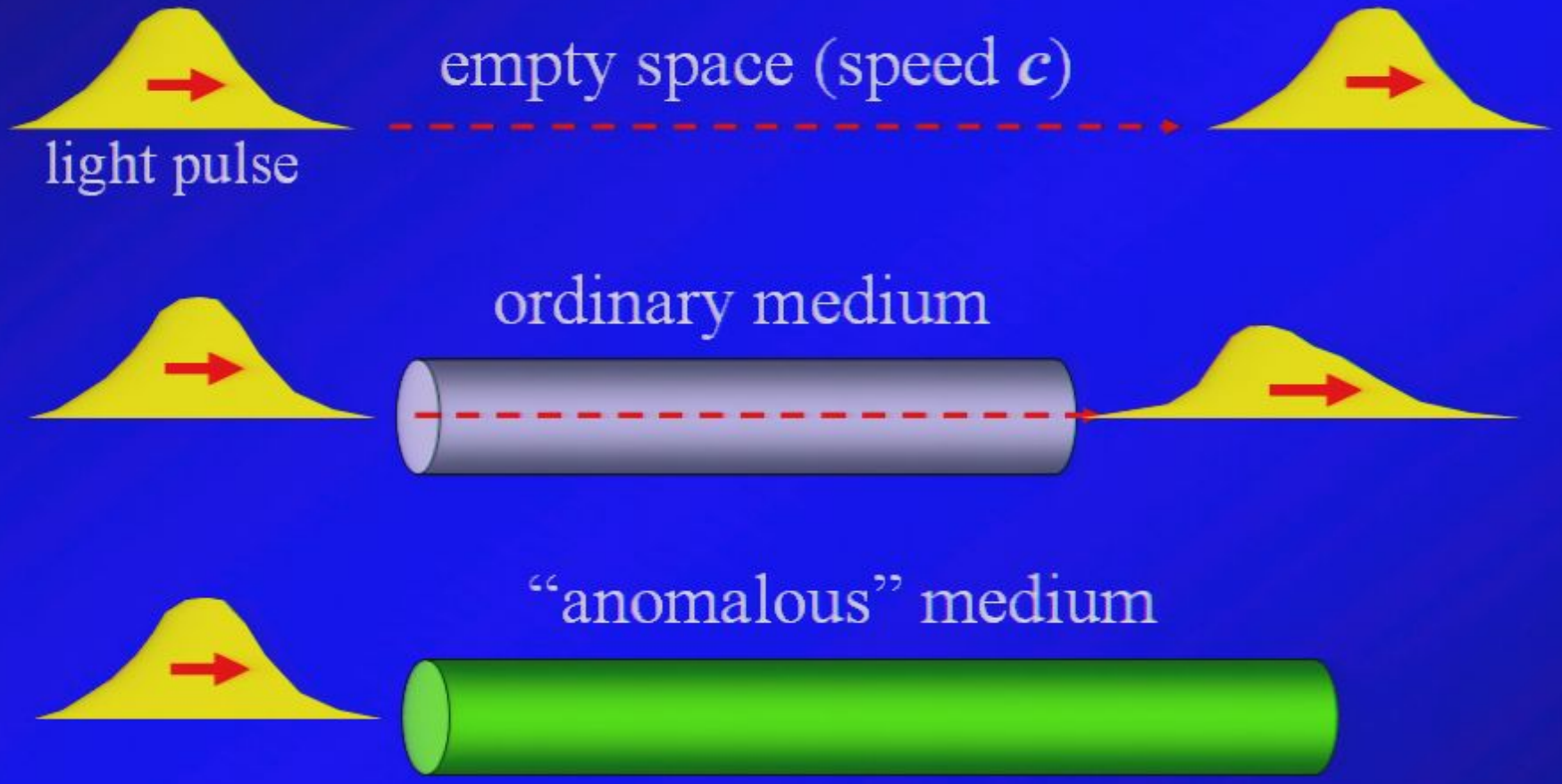
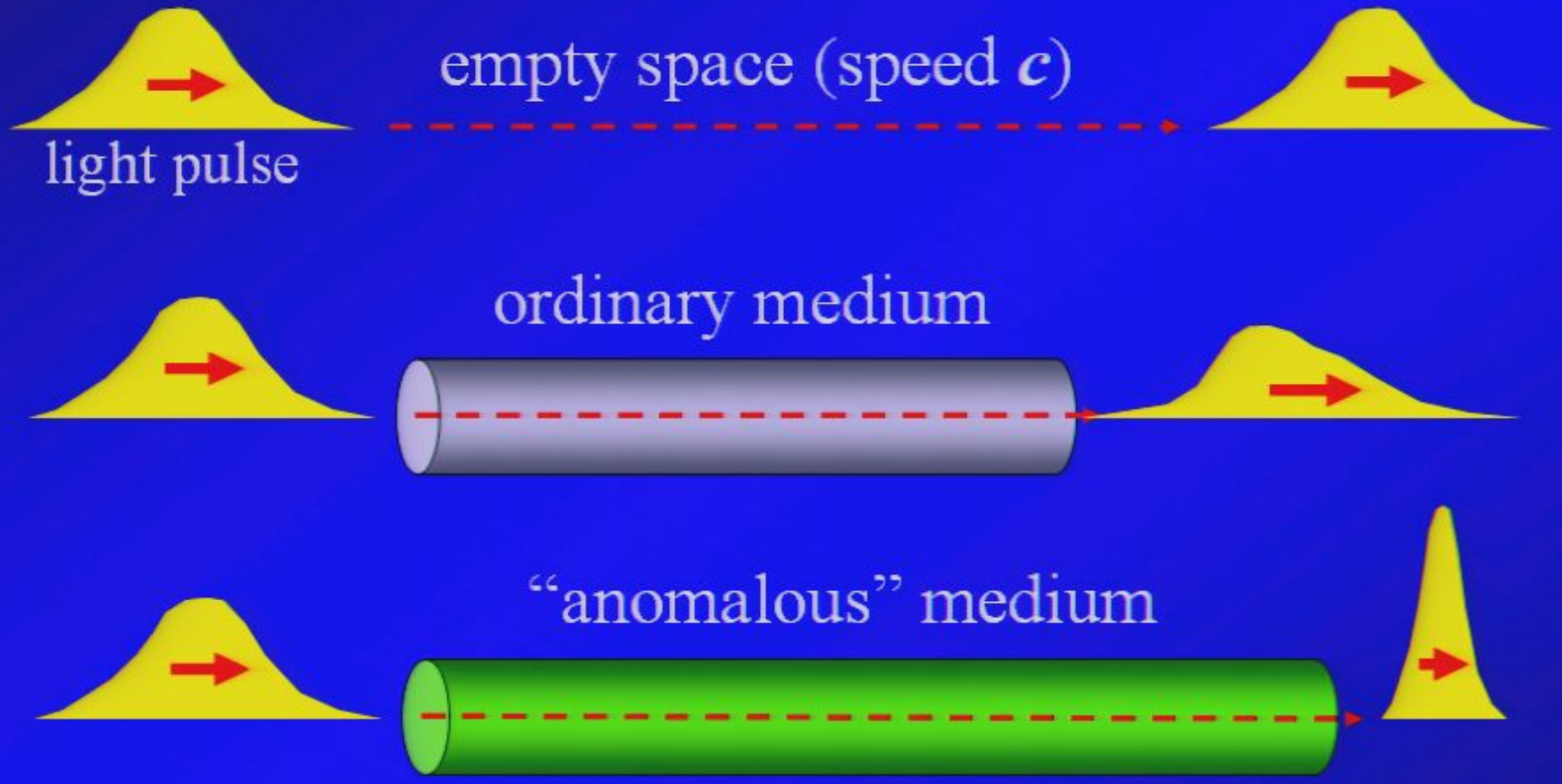

empty space (speed *c*)
light pulse
ordinary medium
"anomalous" medium

Superlight!


empty space (speed *c*)
light pulse
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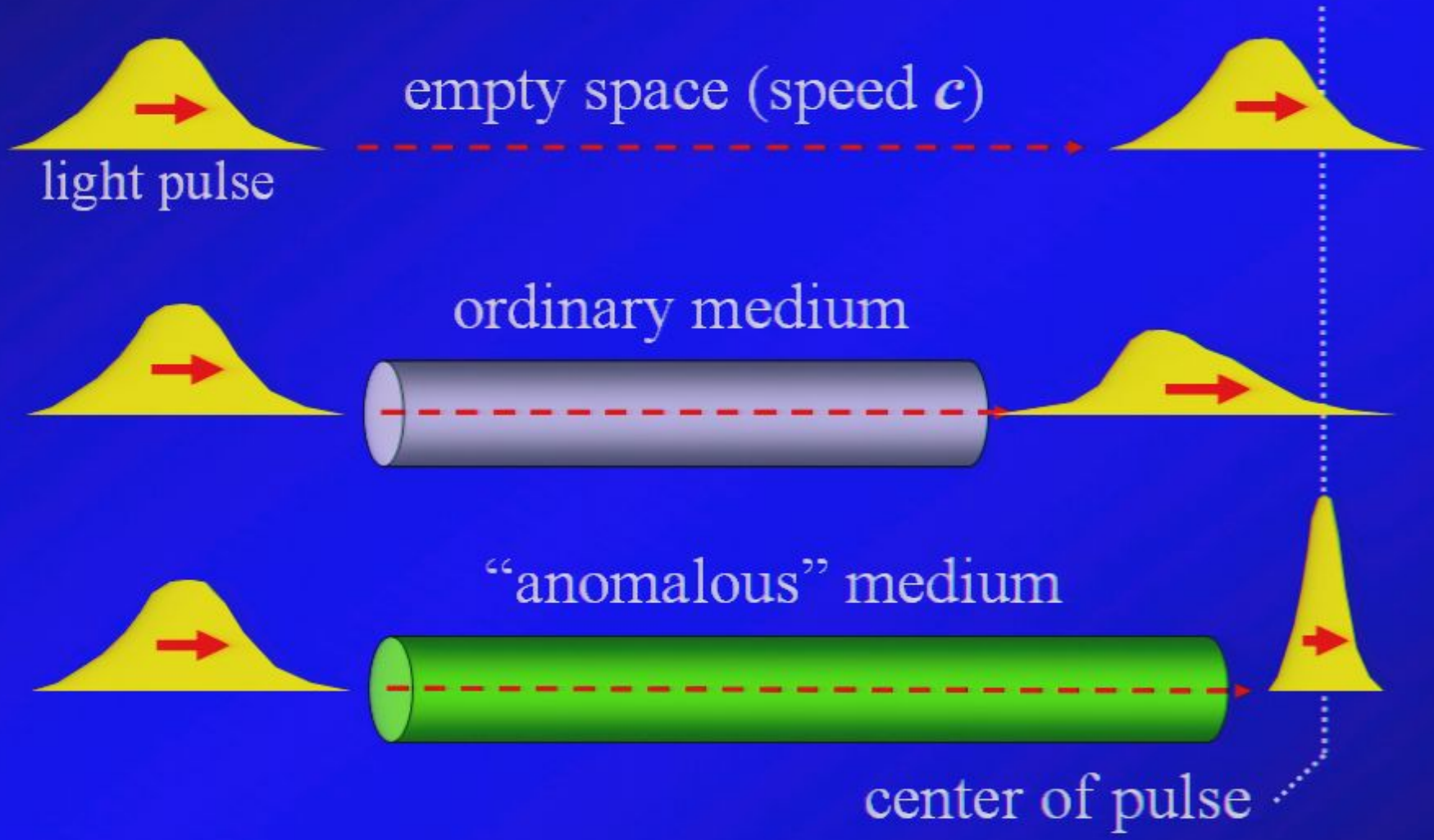
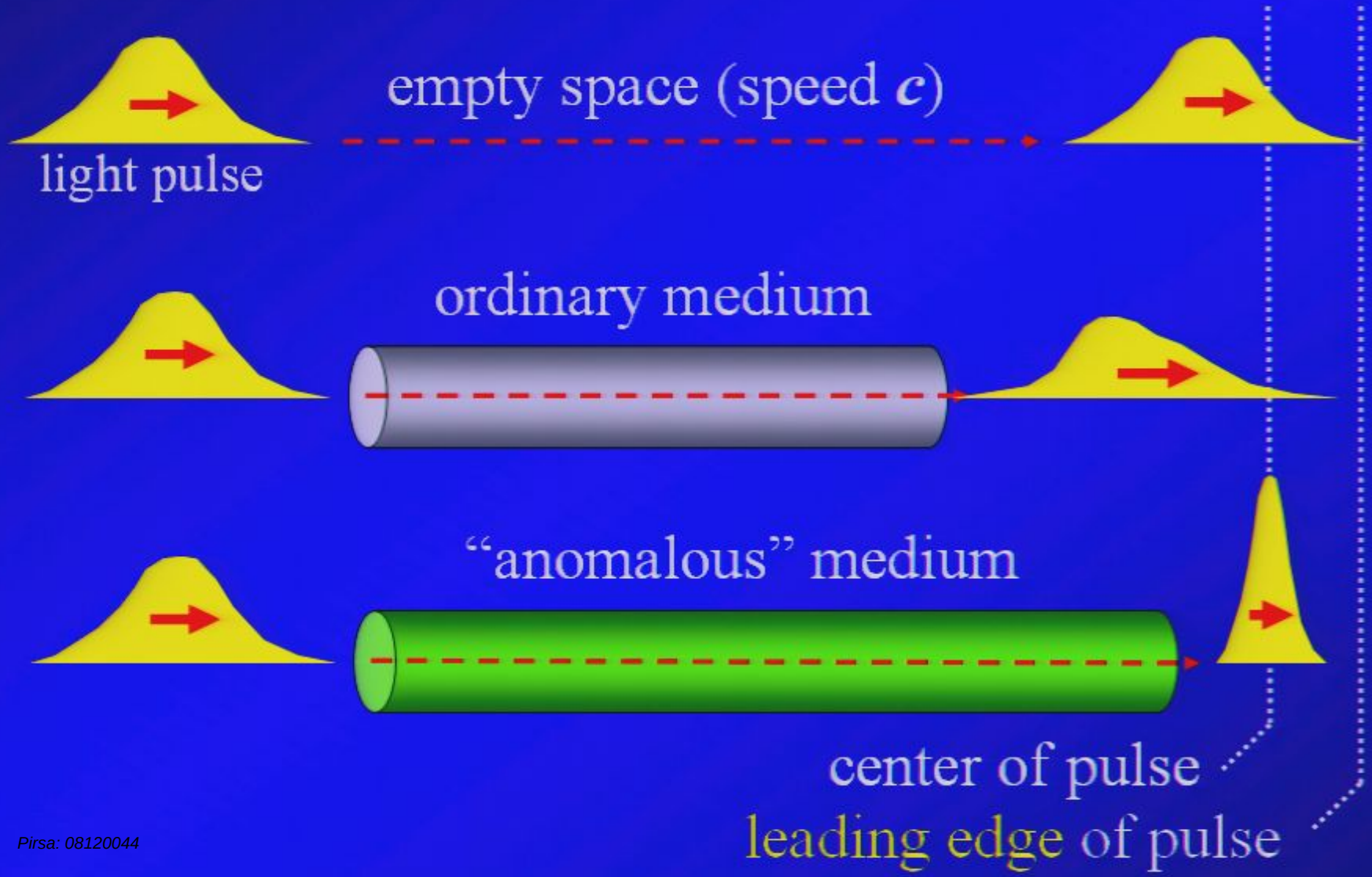

empty space (speed c)
light pulse
ordinary medium
"anomalous" medium
center of pulse

Superlight!


empty space (speed c)
light pulse
ordinary medium
"anomalous" medium
center of pulse
leading edge of pulse

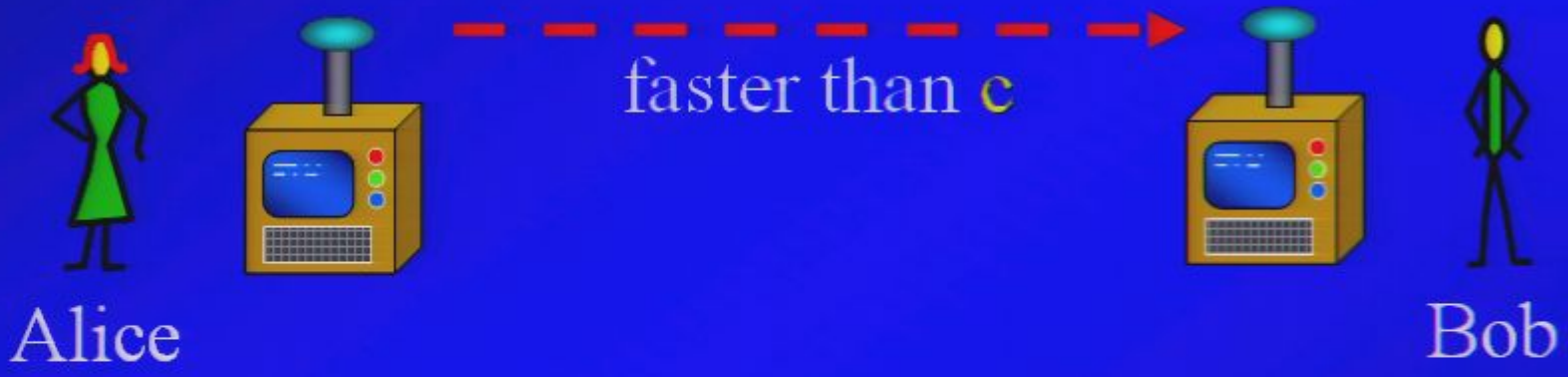
The speed of what?

The "speed of light" **c** is the maximum speed of *information transfer* in the Universe.

Faster-than-light signals?

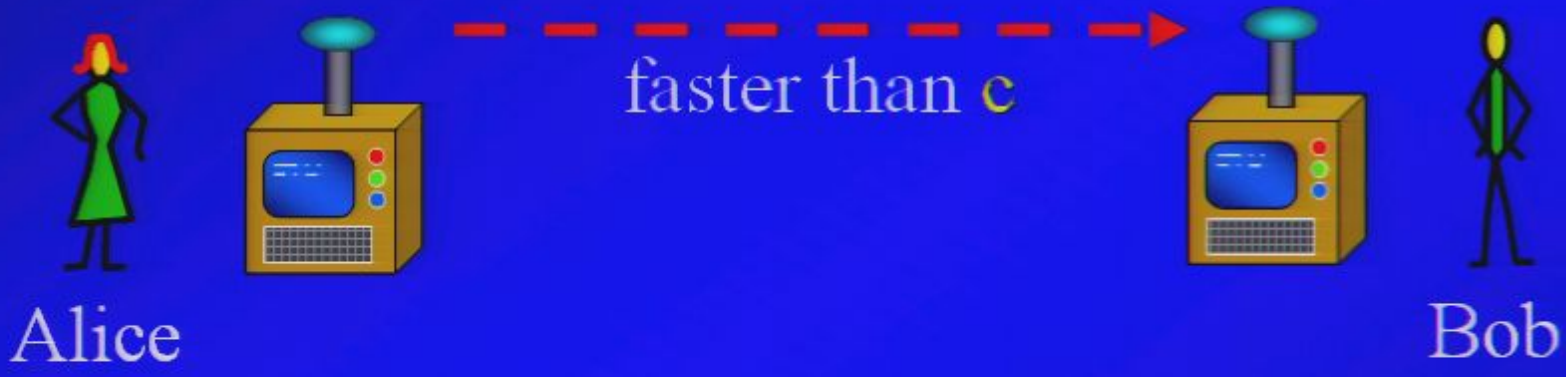
Faster-than-light signals?

Faster-than-light signals?



Why is this impossible?

Faster-than-light signals?



Why is this impossible?

We need to think in spacetime.

How to think in 4-D

Spac

How to think in 4-D

Spacetime = every point in space at every moment in time

How to think in 4-D

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= the "arena" of physics!

How to think in 4-D

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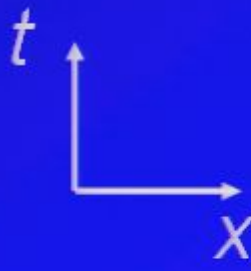
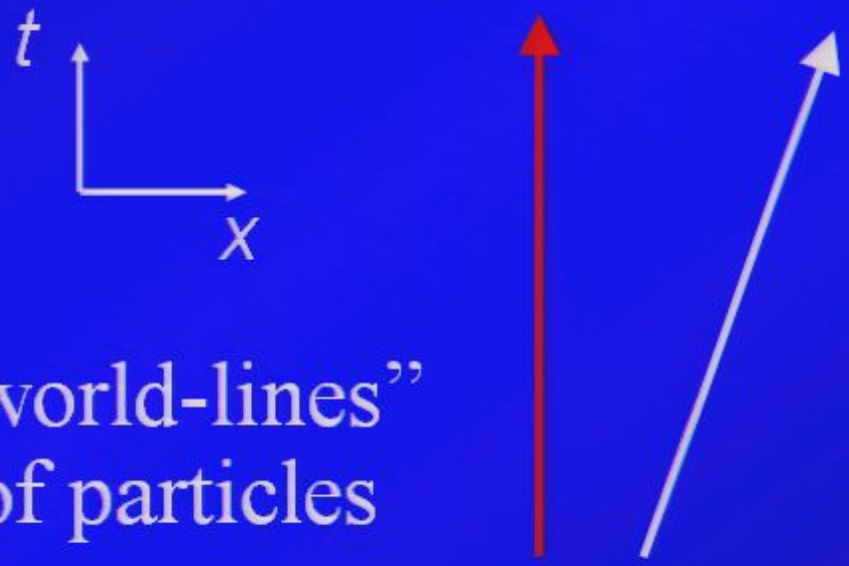


"world-lines" of particles

How to think in 4-D

Spacetime = every point in space at every moment in time

= the "arena" of physics!



"world-lines" of particles

How to think in 4-D

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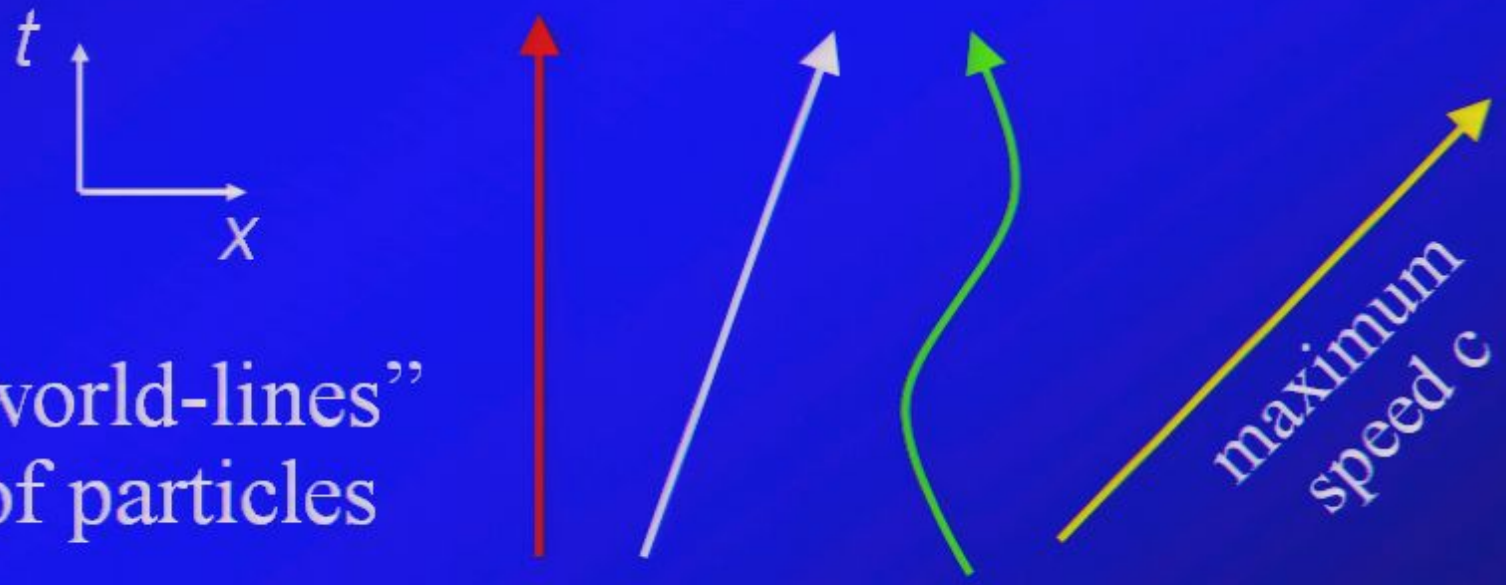

"world-lines" of particles

Moving clocks

Moving clocks

2nd most famous relativity fact:
Moving clocks run slowly.

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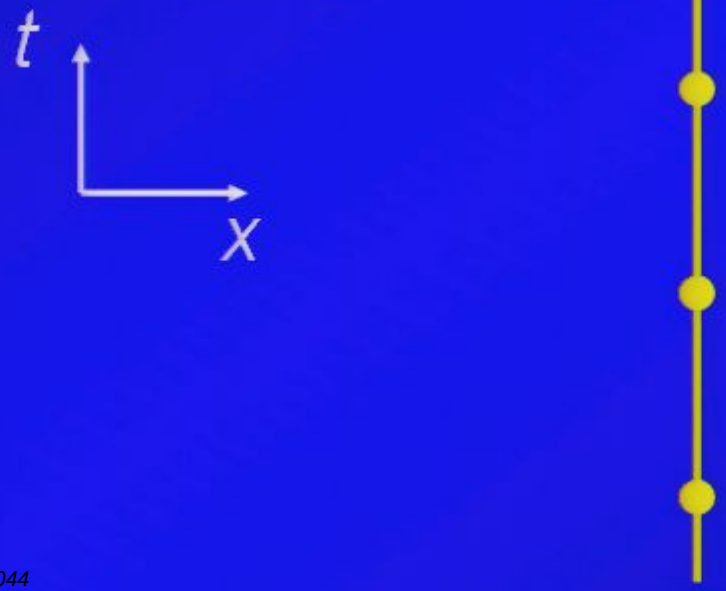

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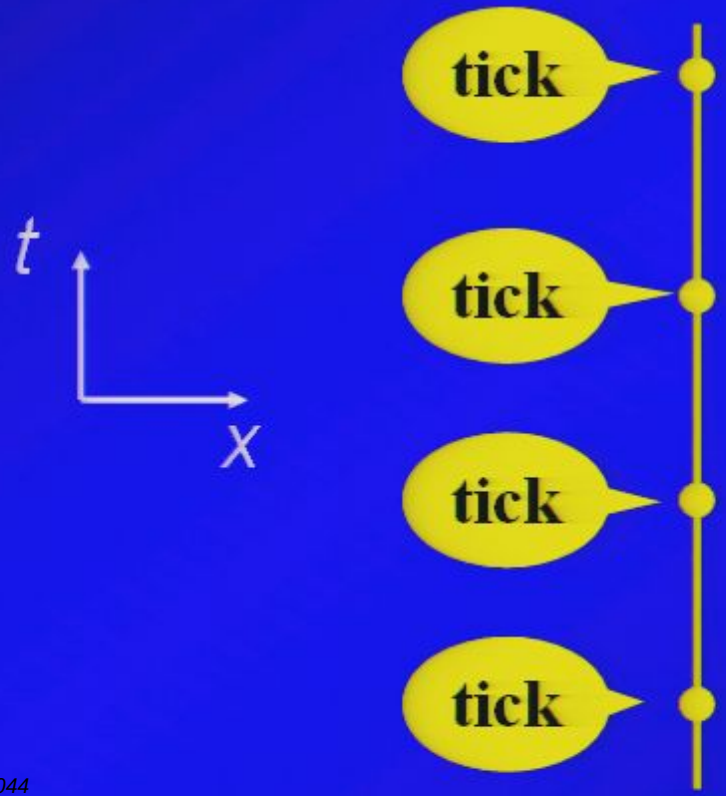

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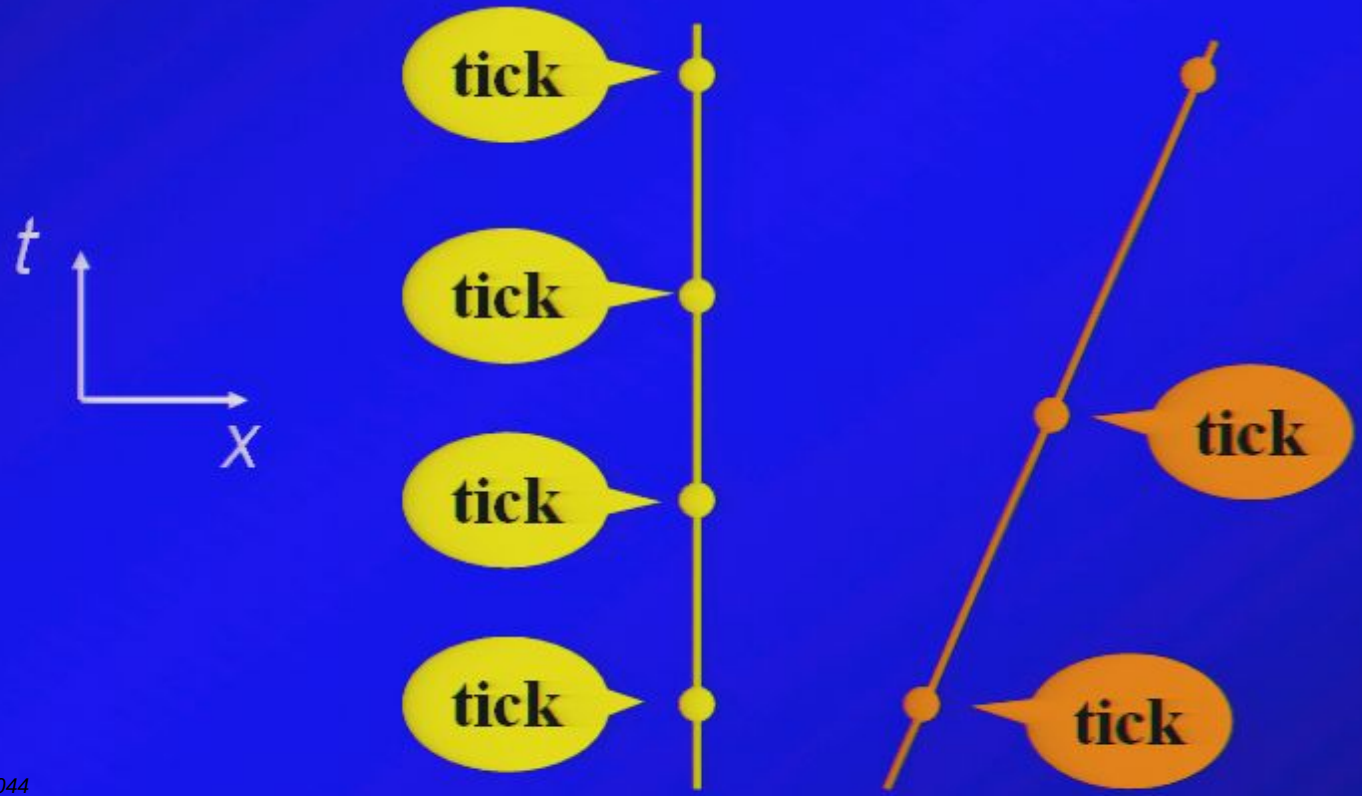

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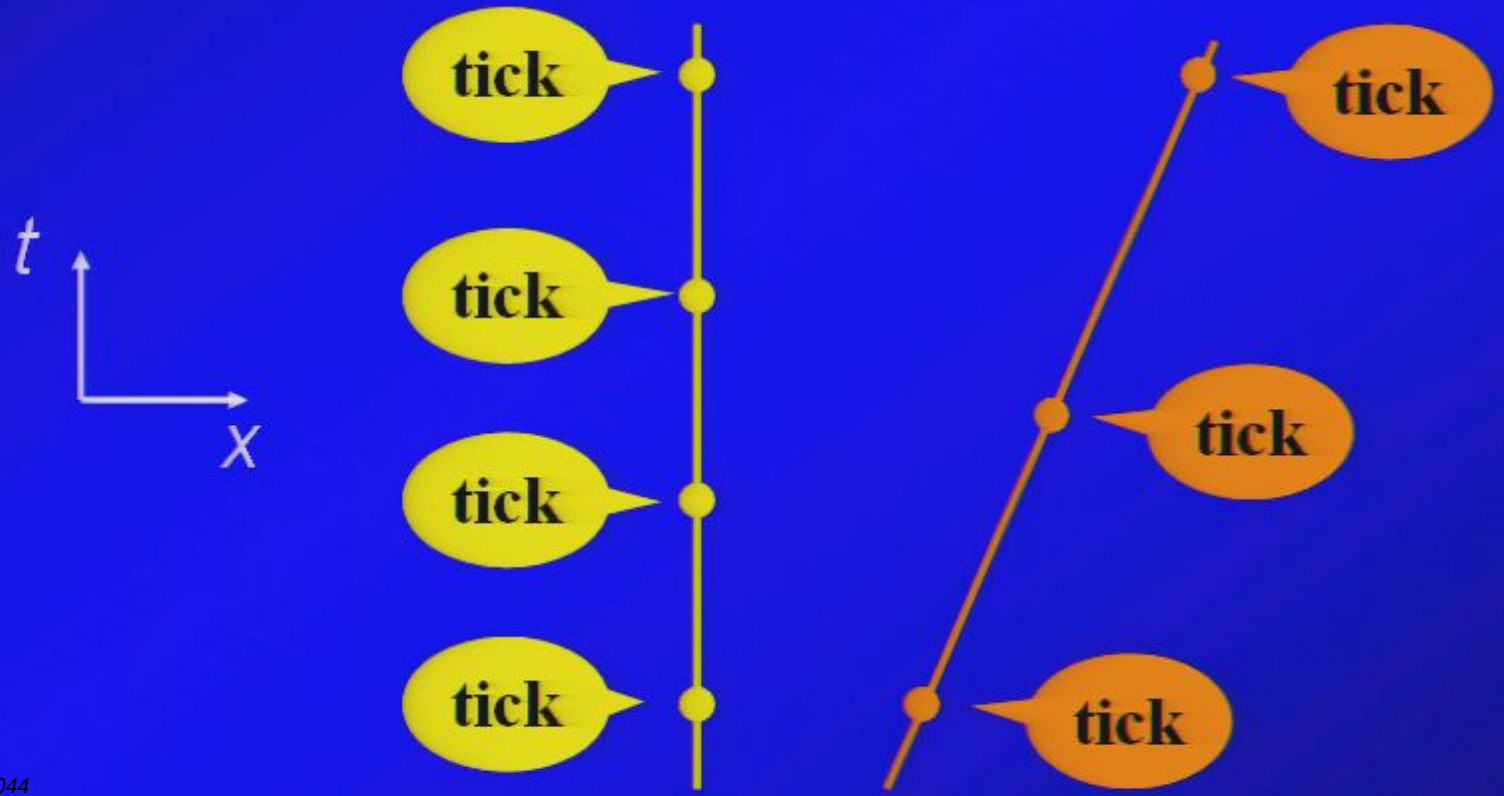

Faster than light signals?

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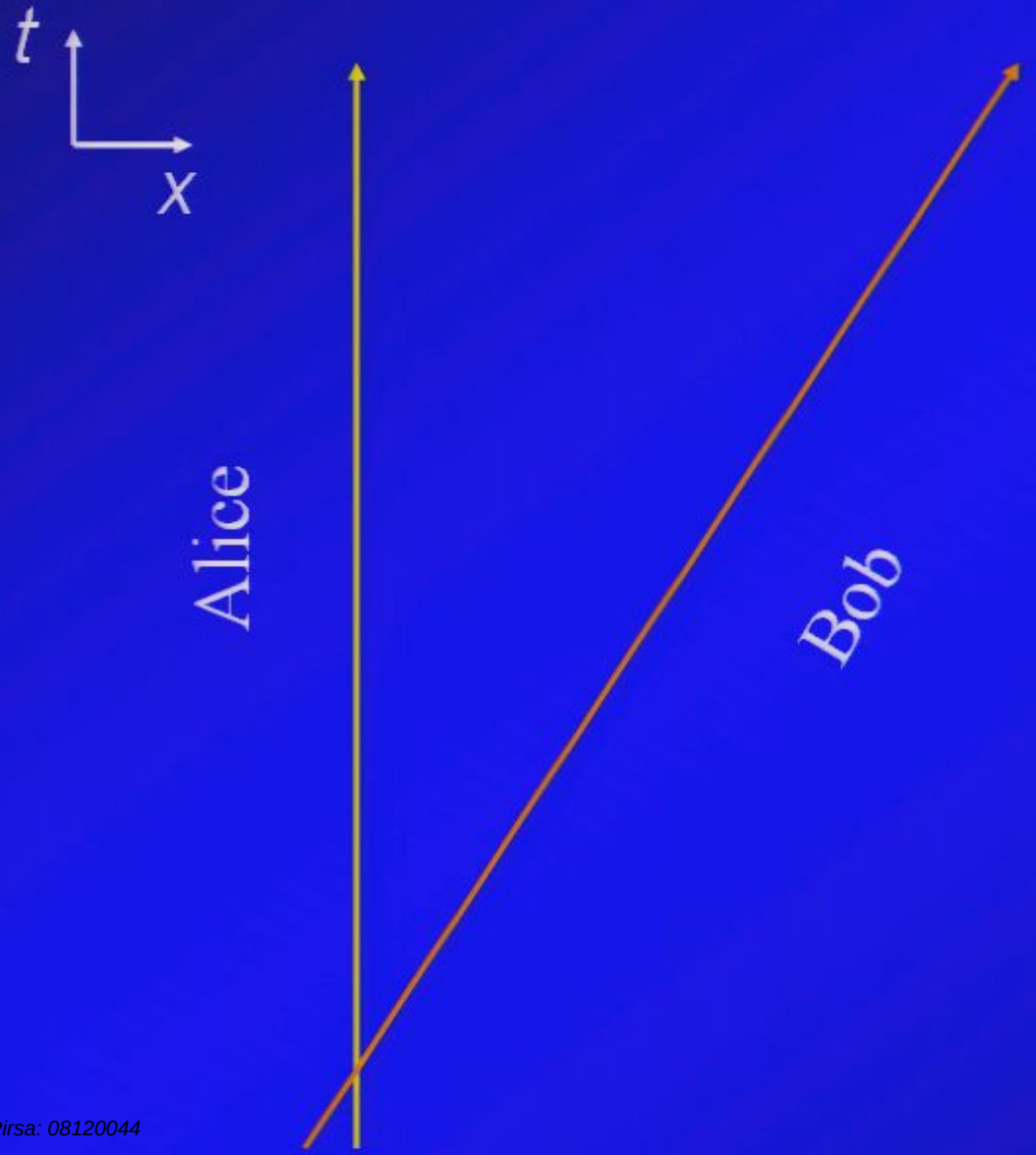
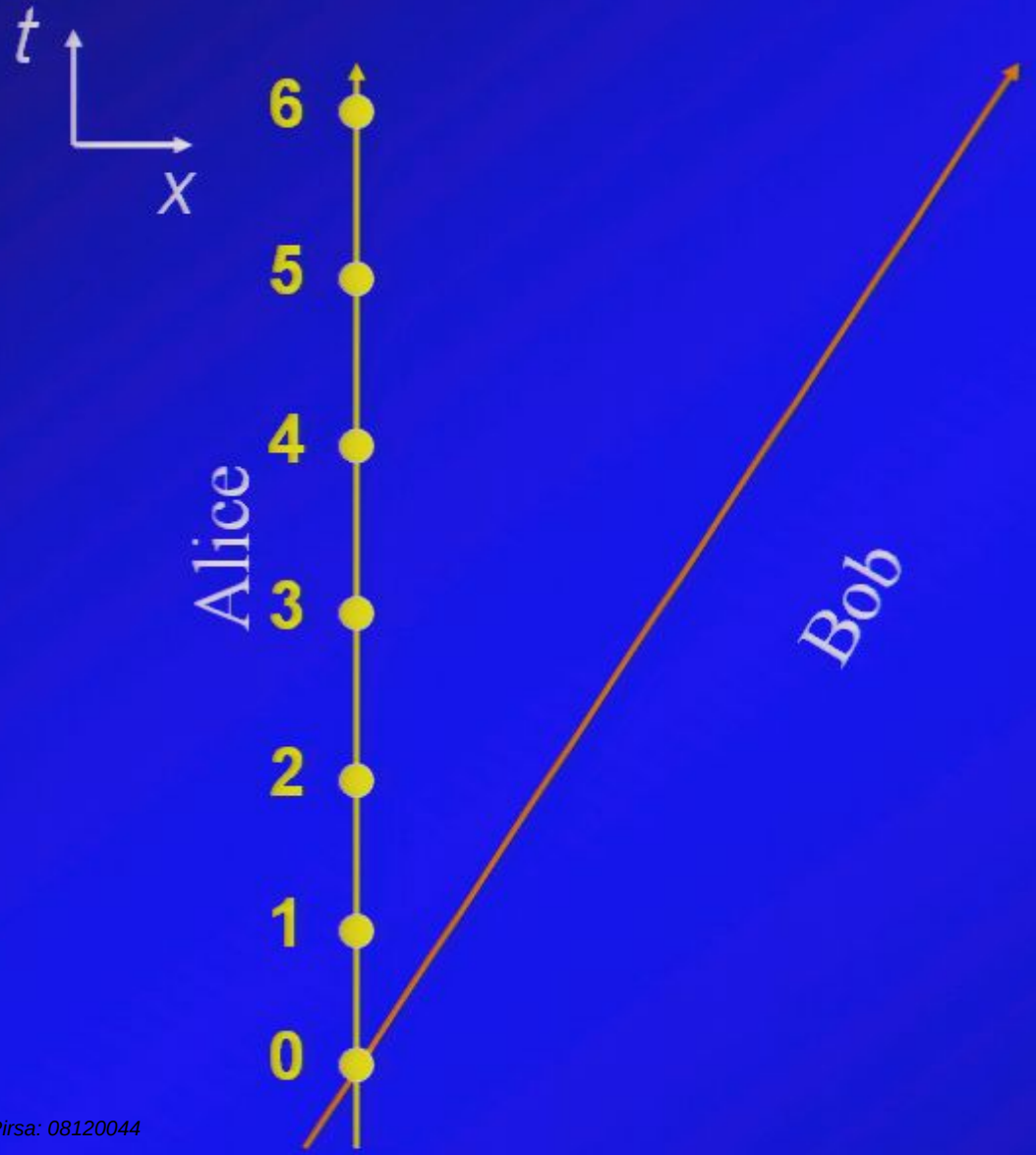


Alice's "frame"

Faster than light signals?



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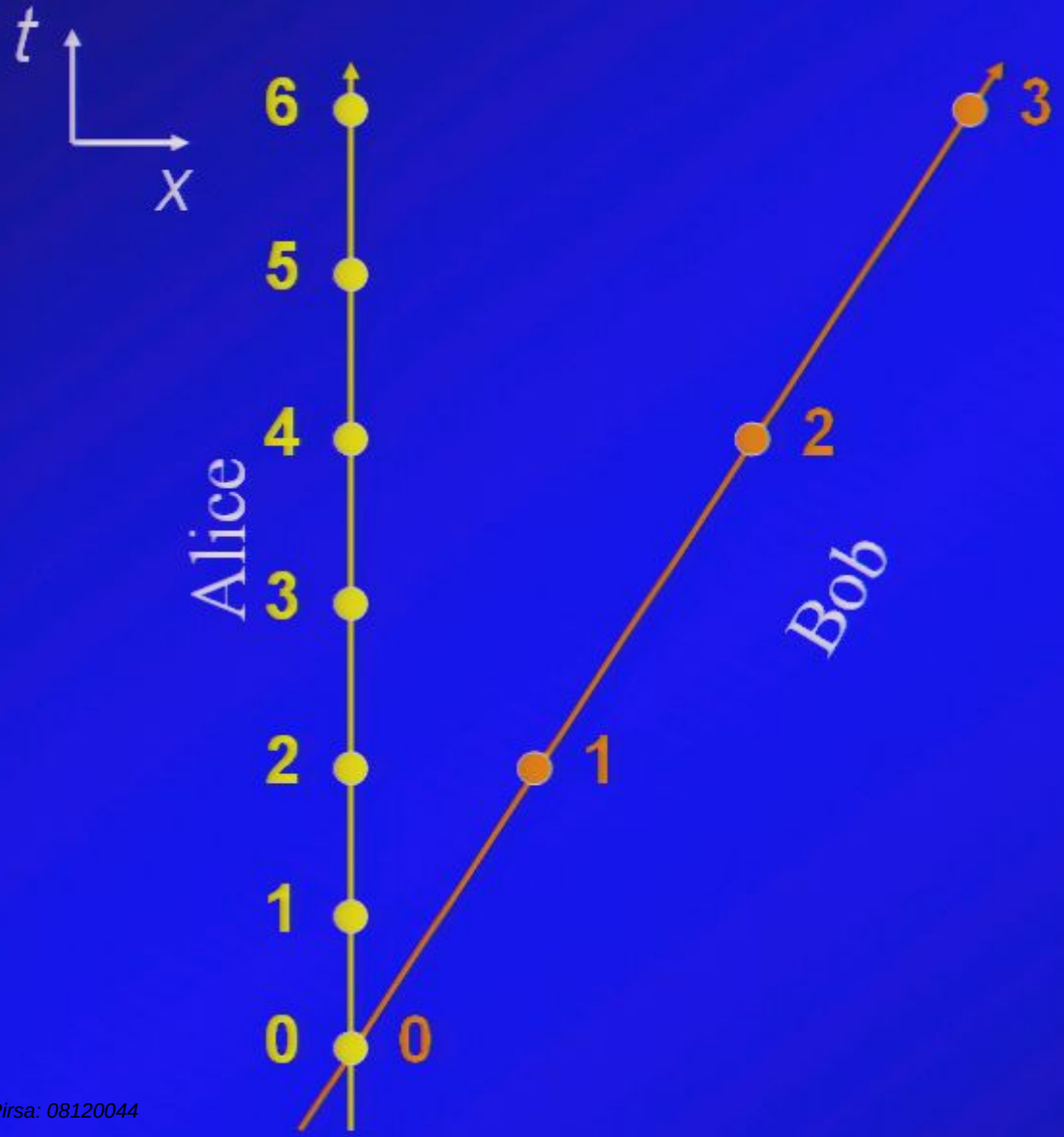

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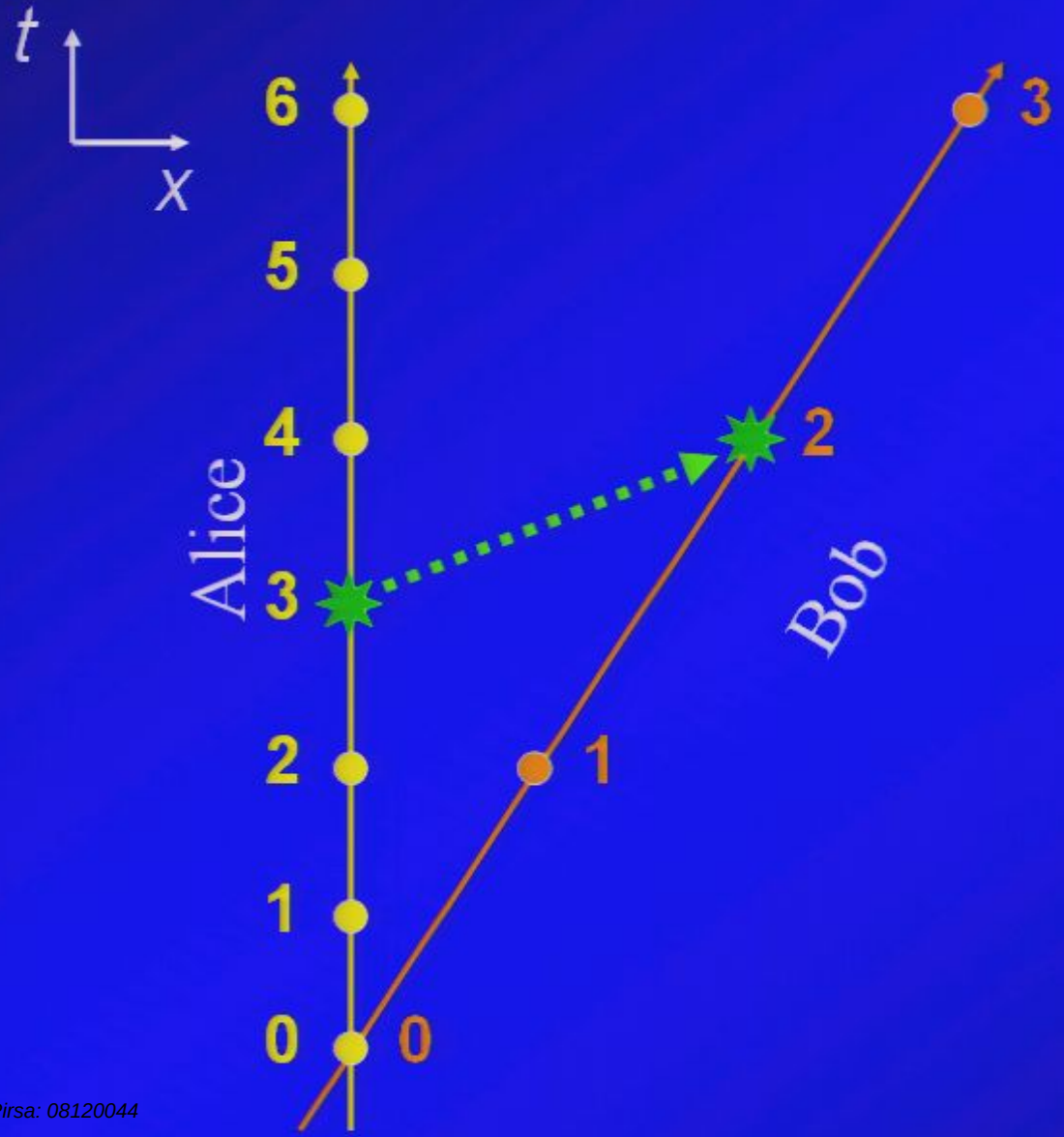


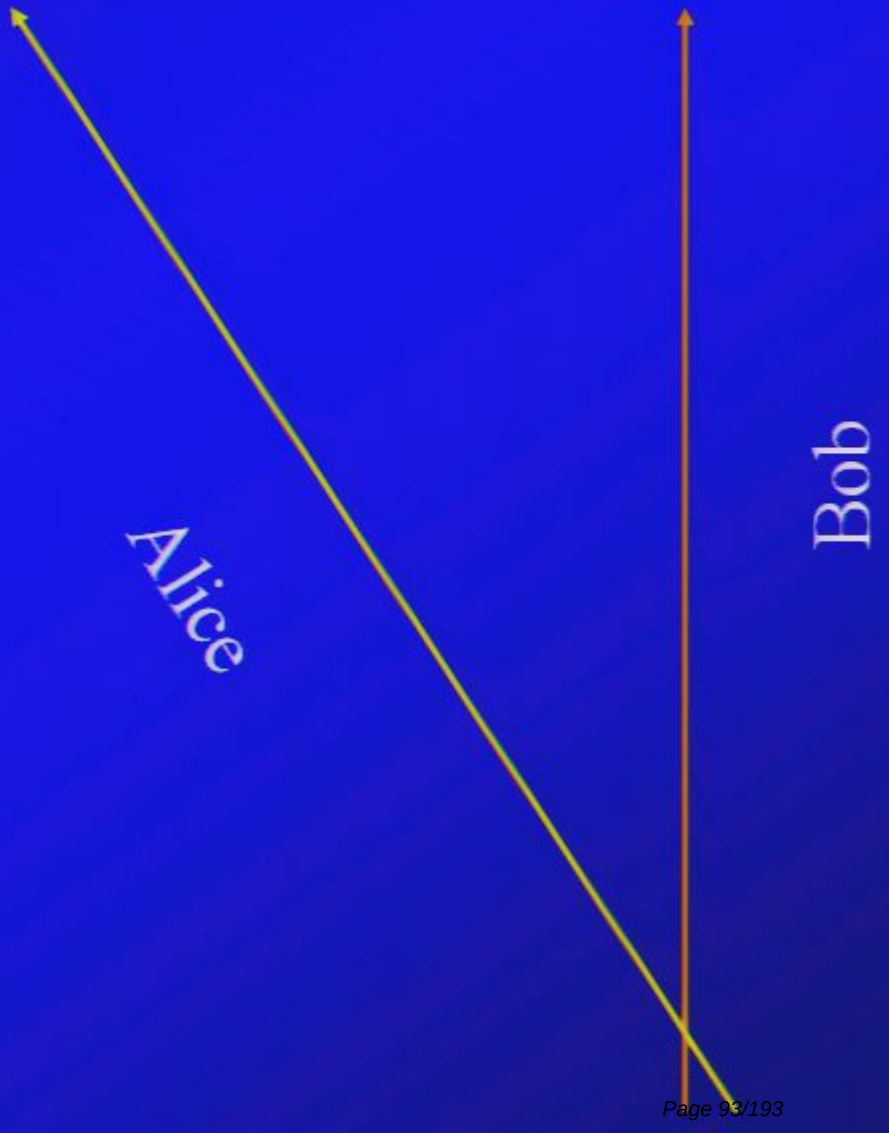
Alice's "frame"

Signal:

Alice 3 → Bob 2

Faster than light signals?

Bob's "frame"



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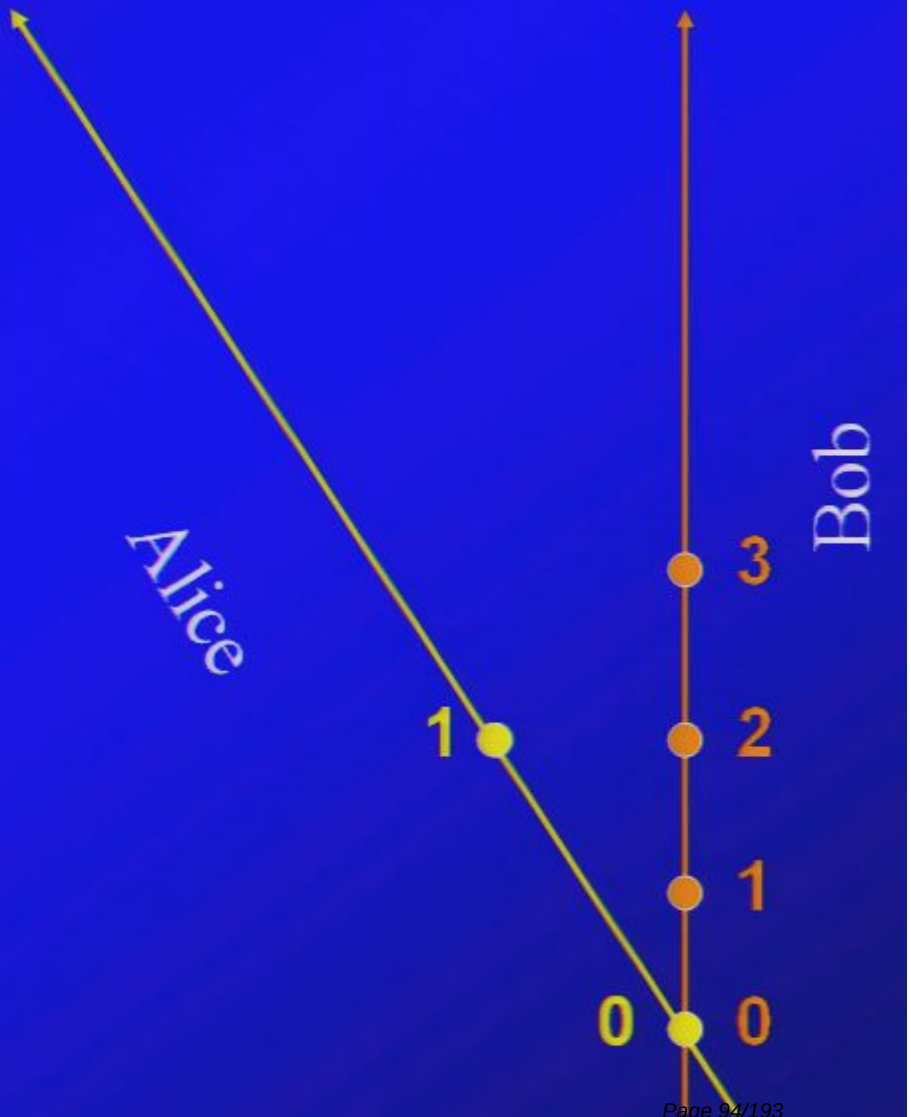

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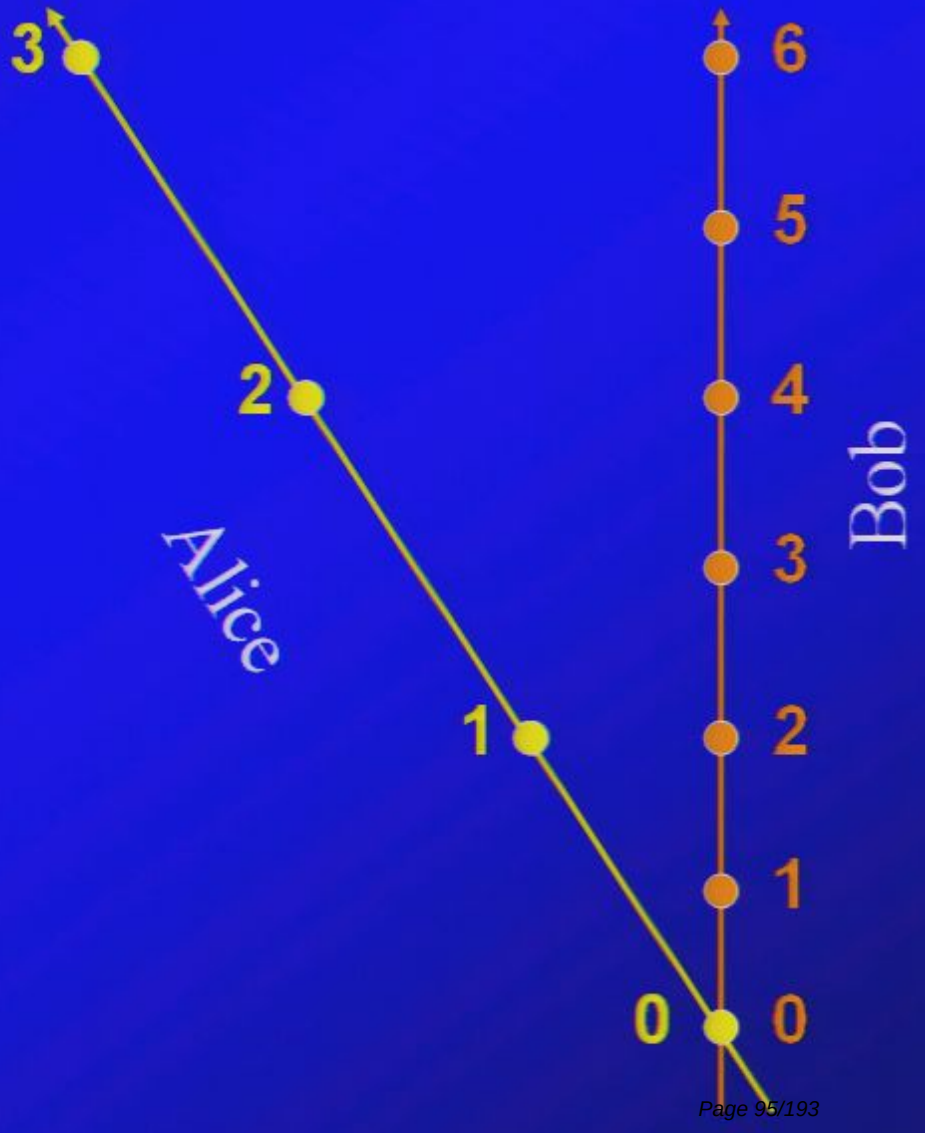

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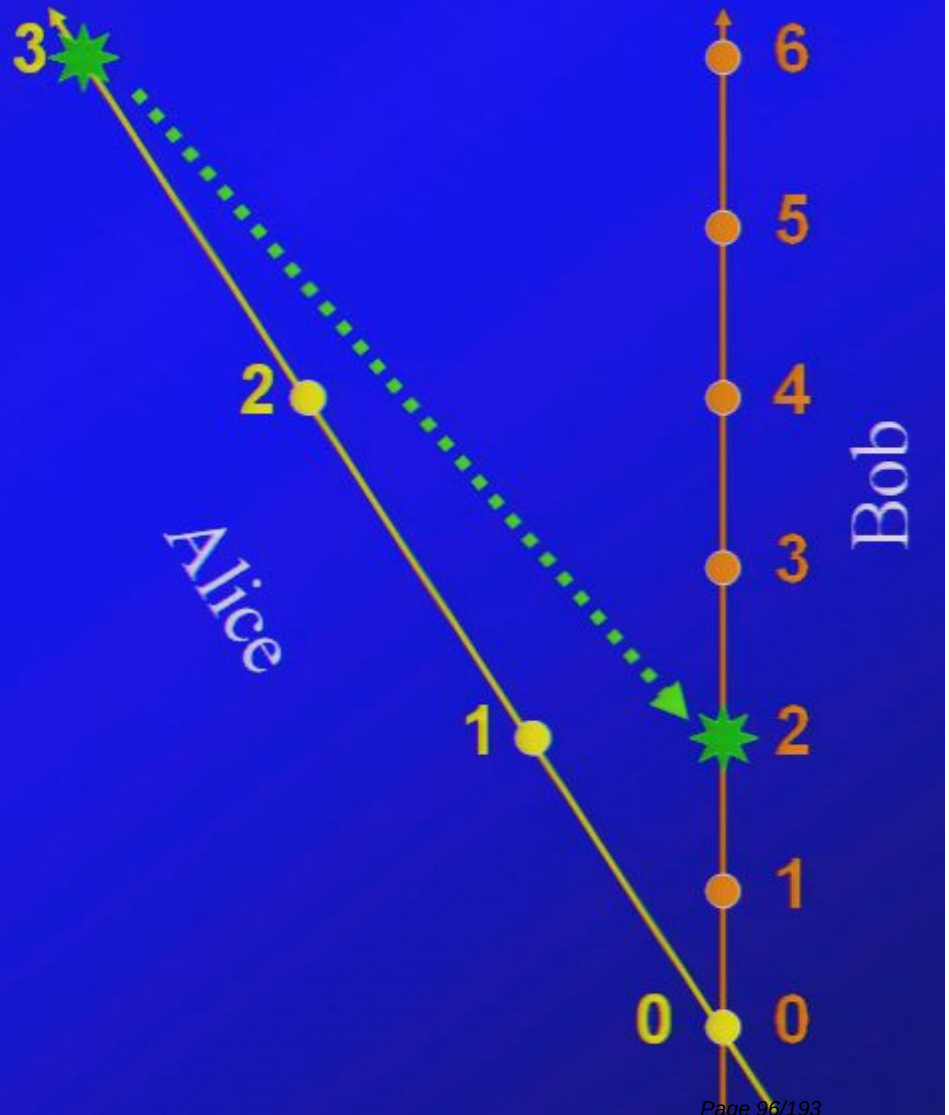


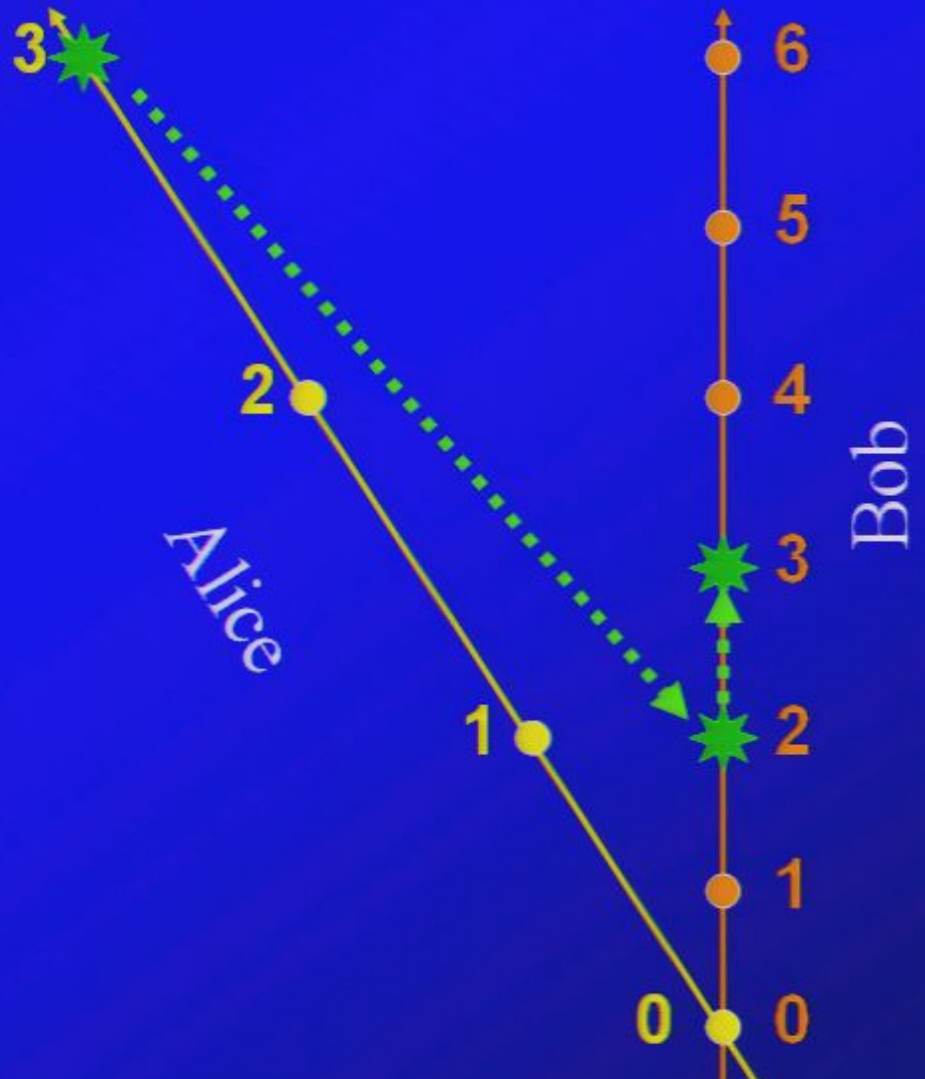
Faster than light signals?

Bob's "frame"

Signals:

Alice 3 → Bob 2

Bob 2 → Bob 3



Faster than light signals?

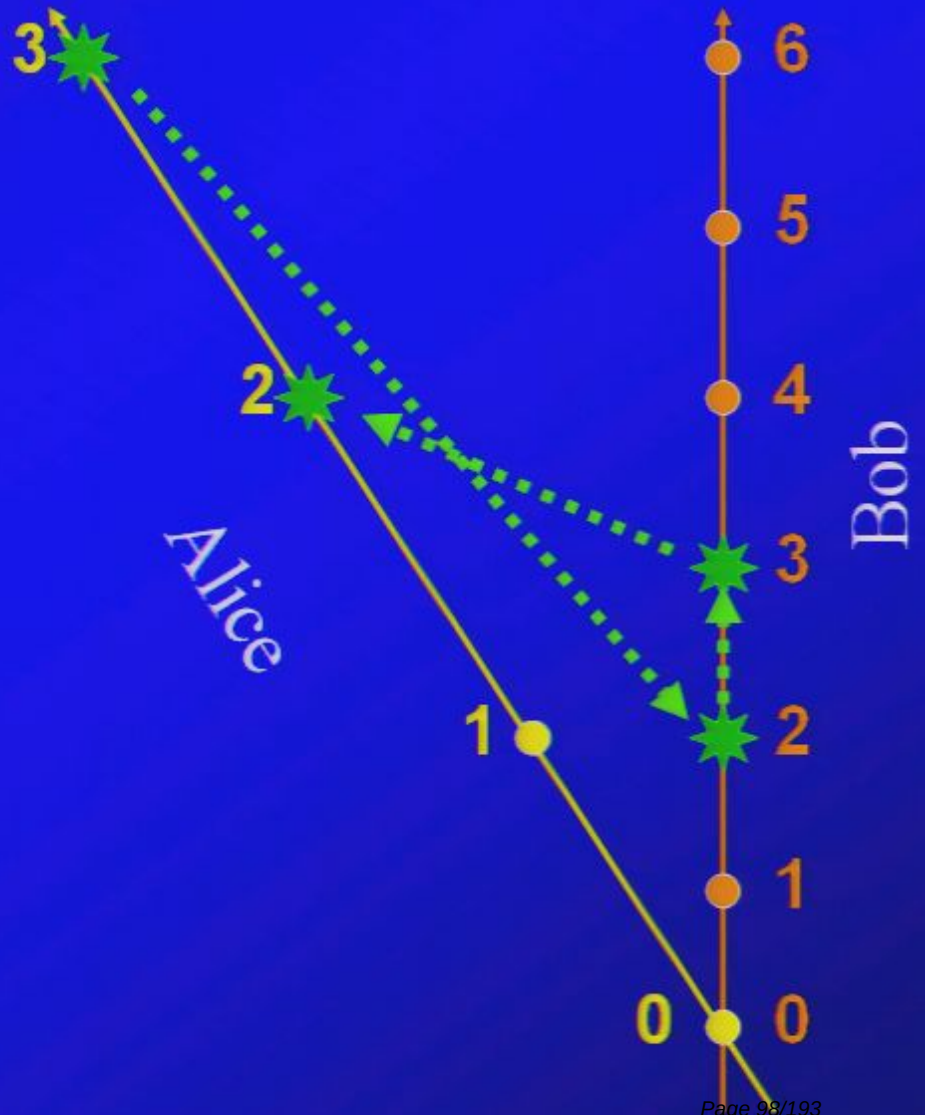
Bob's "frame"

Signals:

Alice 3 → Bob 2

Bob 2 → Bob 3

Bob 3 → Alice 2



Faster than light signals?

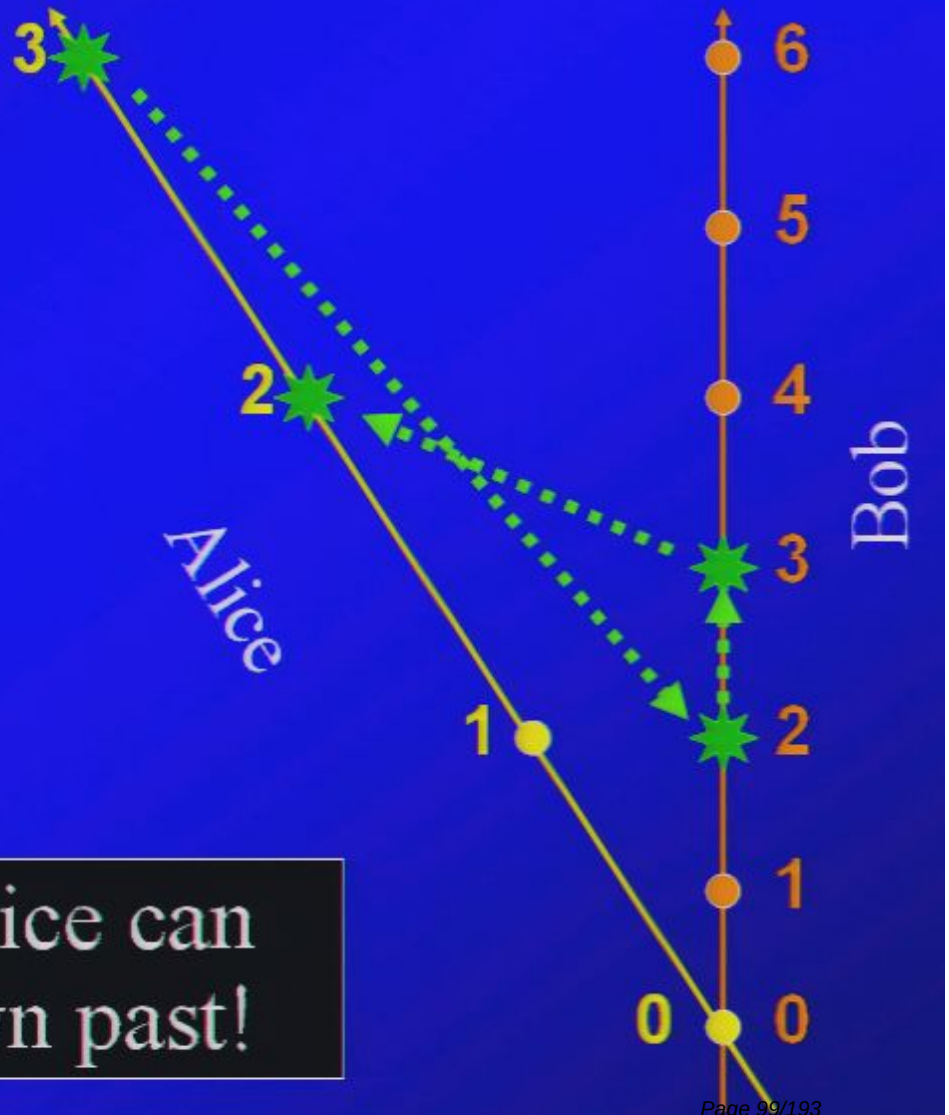
Bob's "frame"

Signals:

Alice 3 → Bob 2

Bob 2 → Bob 3

Bob 3 → Alice 2



Using Bob as a relay, Alice can send a signal into her own past!

Some quantum impossibilities

Photon polarizations

Photon polarizations

horizontal

vertical

diagonal

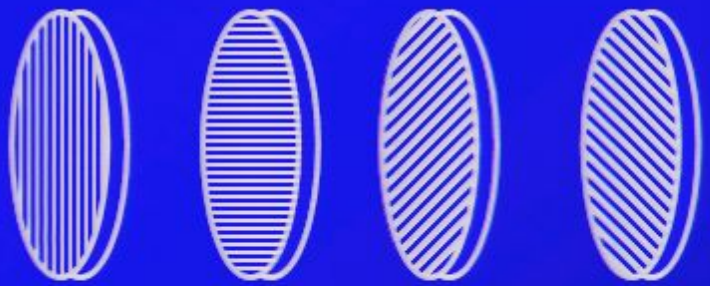
Photon polarizations

horizontal

vertical

diagonal

Filters

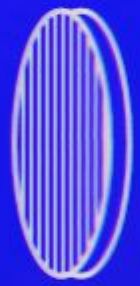


Photon polarizations

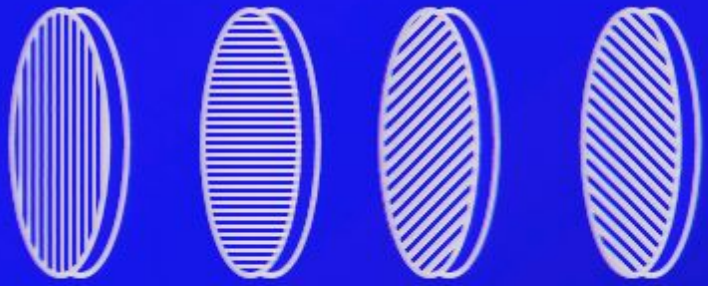
horizontal

vertical

diagonal



Filters

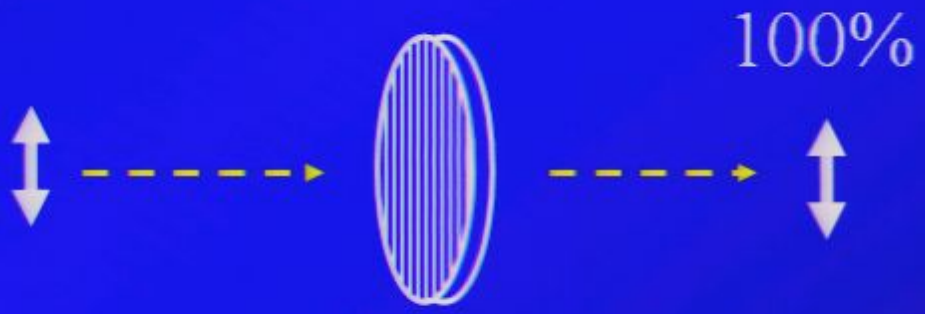


Photon polarizations

horizontal

vertical

diagonal



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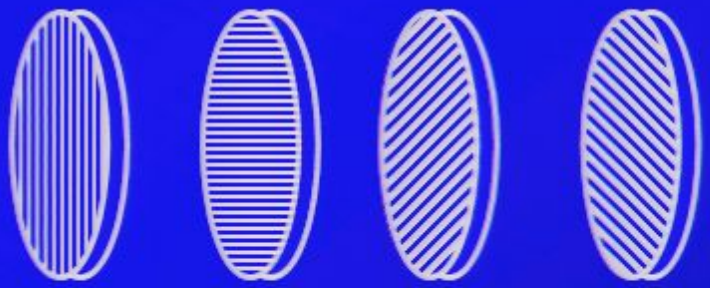

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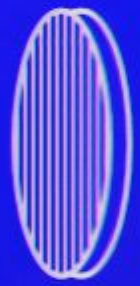

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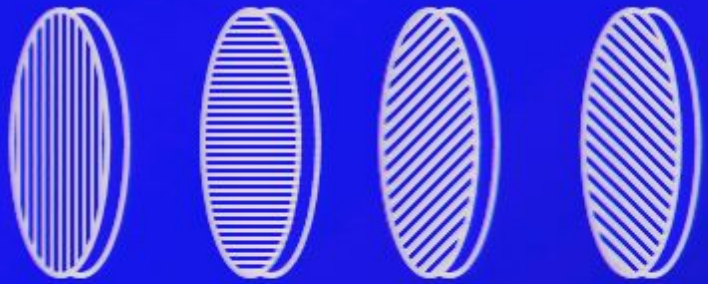

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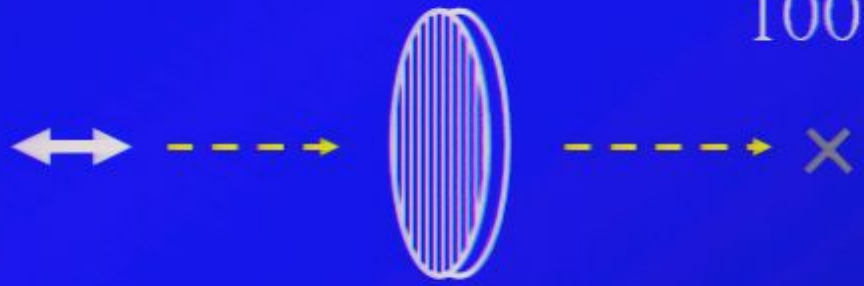

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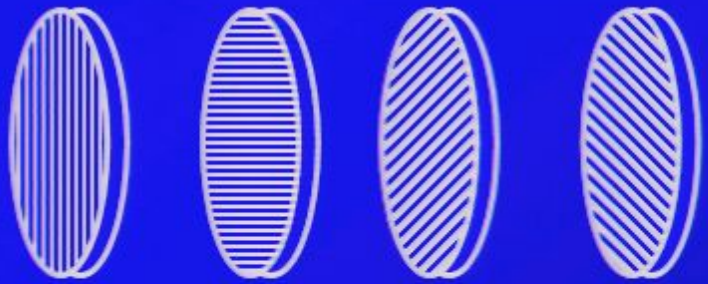

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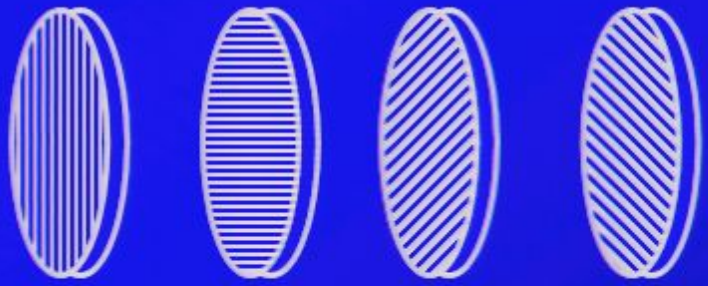

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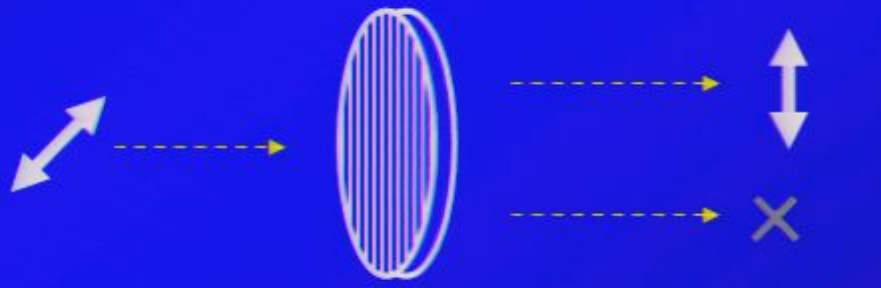

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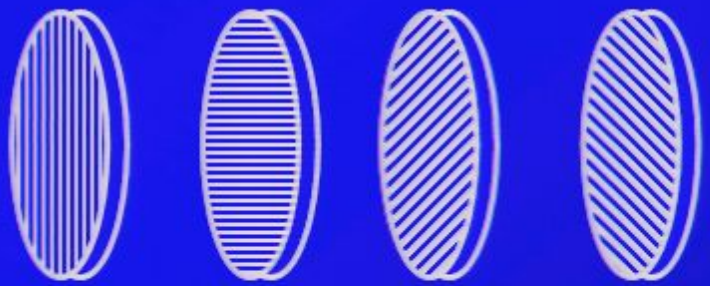

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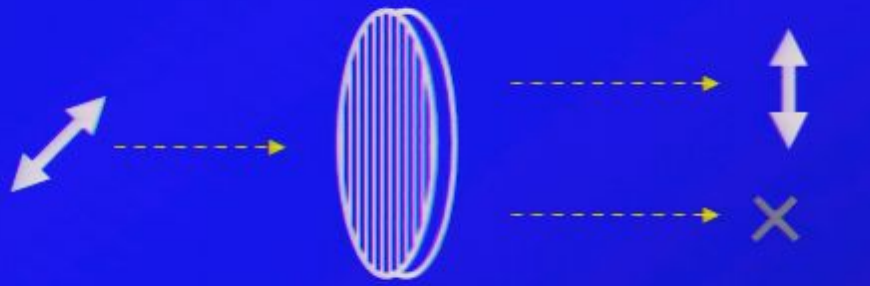

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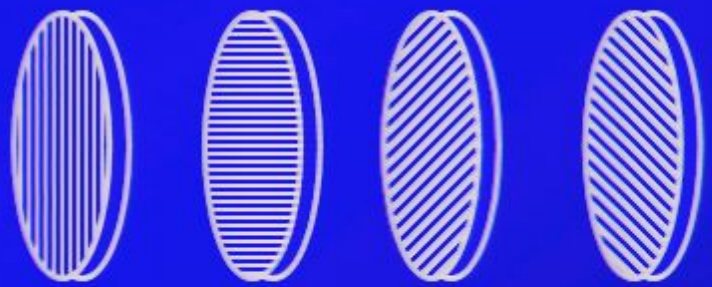

No device can reliably distinguish all four polarizations -- no perfect polarization analyzer (PPA)!

A quantum amplifier?

A quantum amplifier?

A quantum amplifier?

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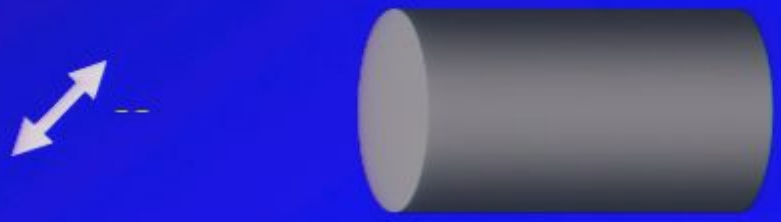

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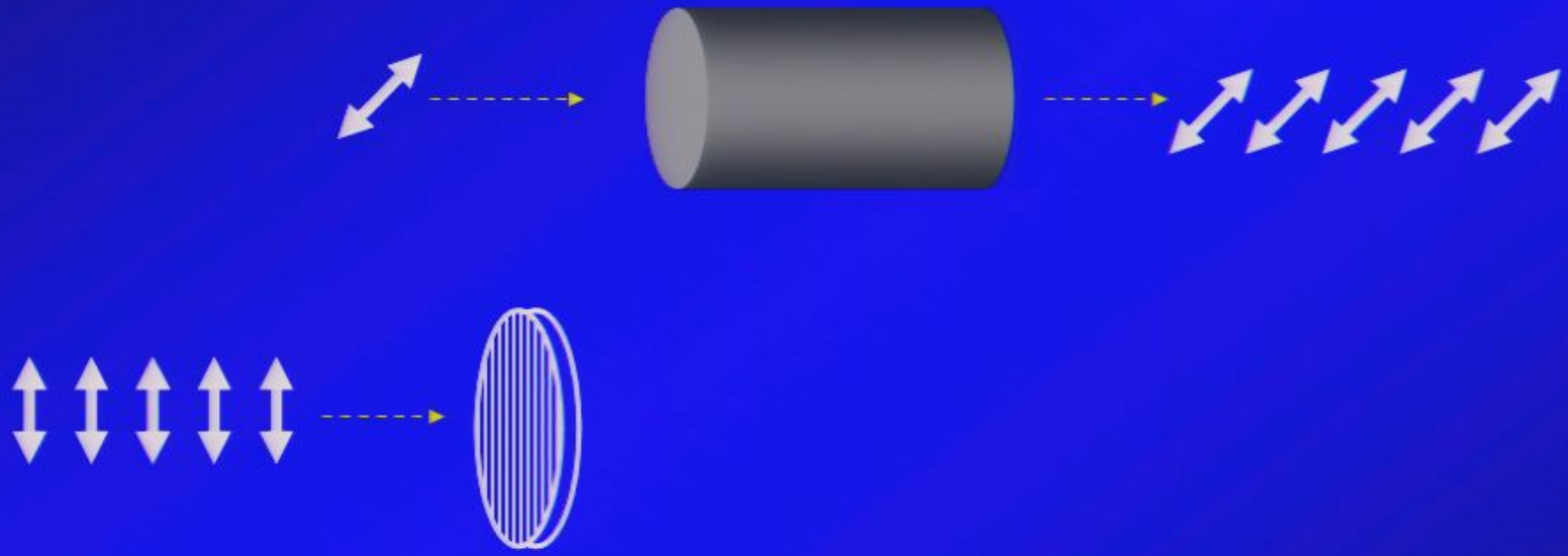

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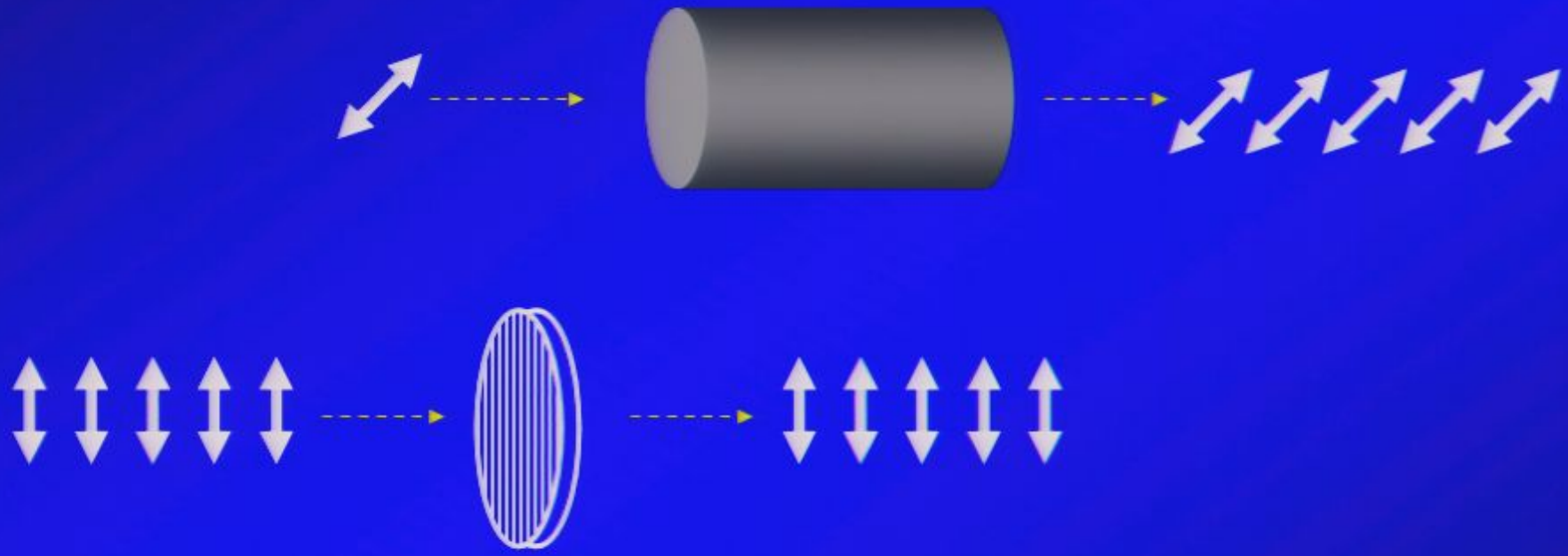

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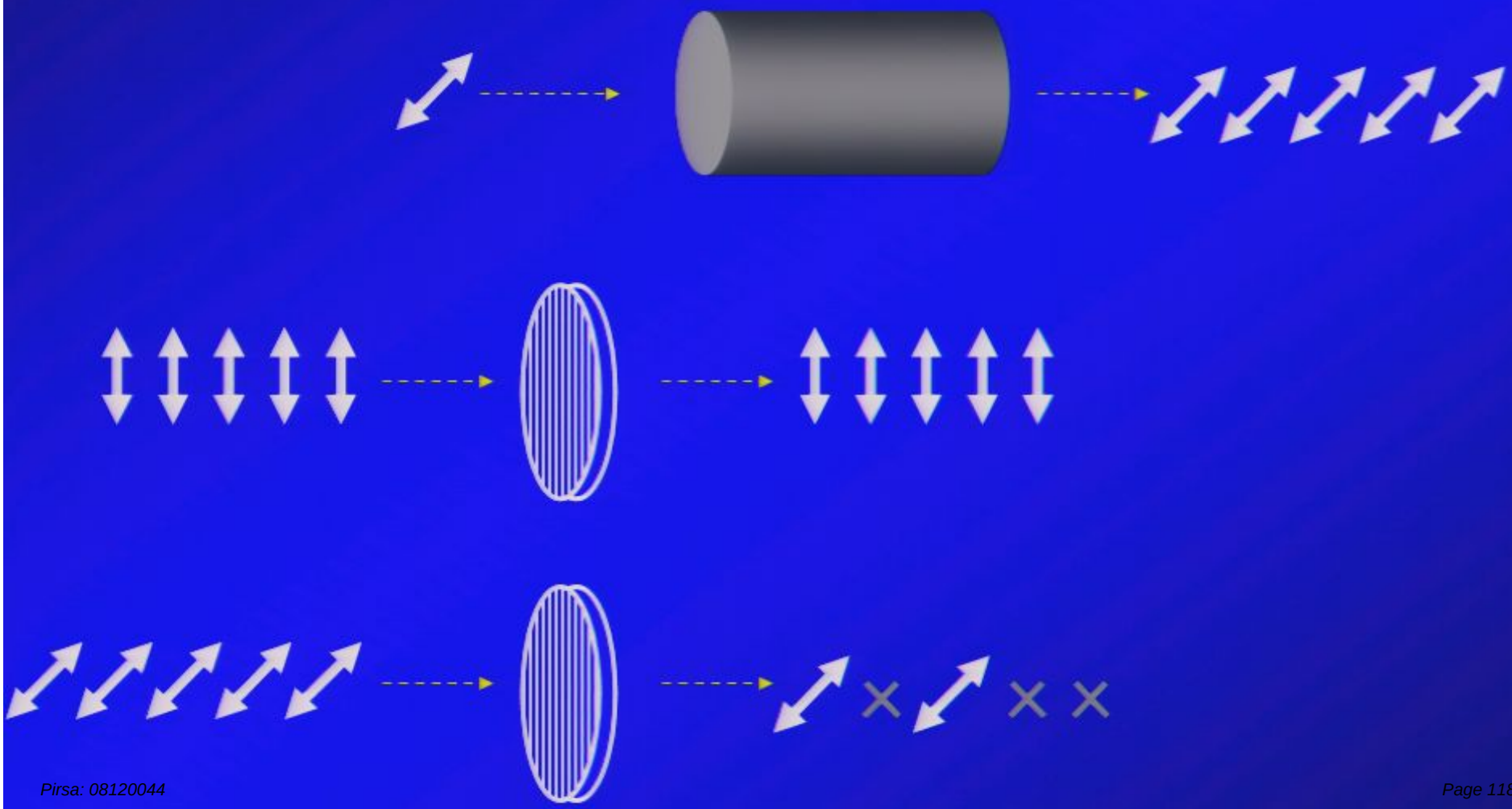

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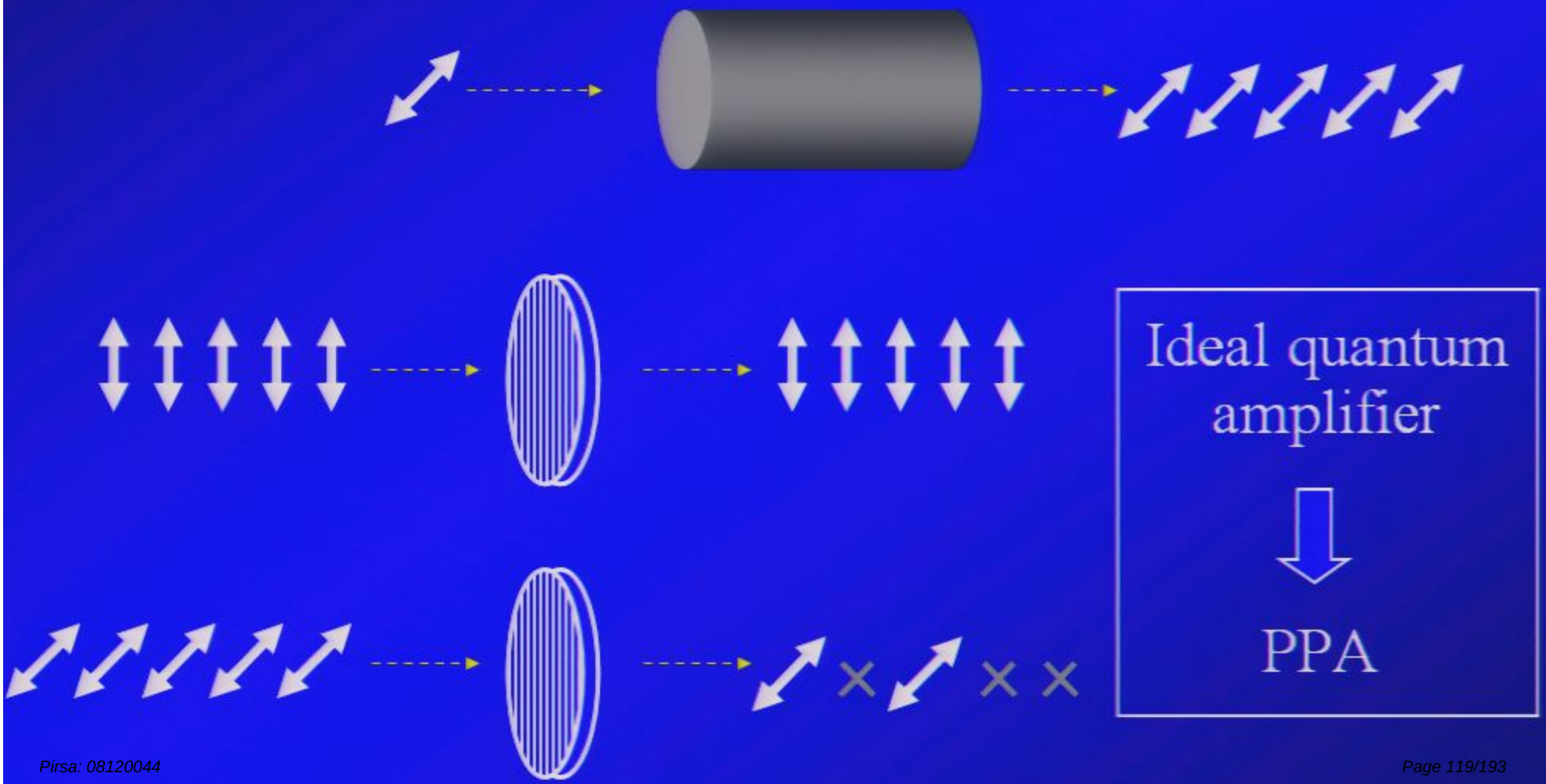

Quantum cloning

Quantum cloning

unknown ?

"blank paper" ⟷

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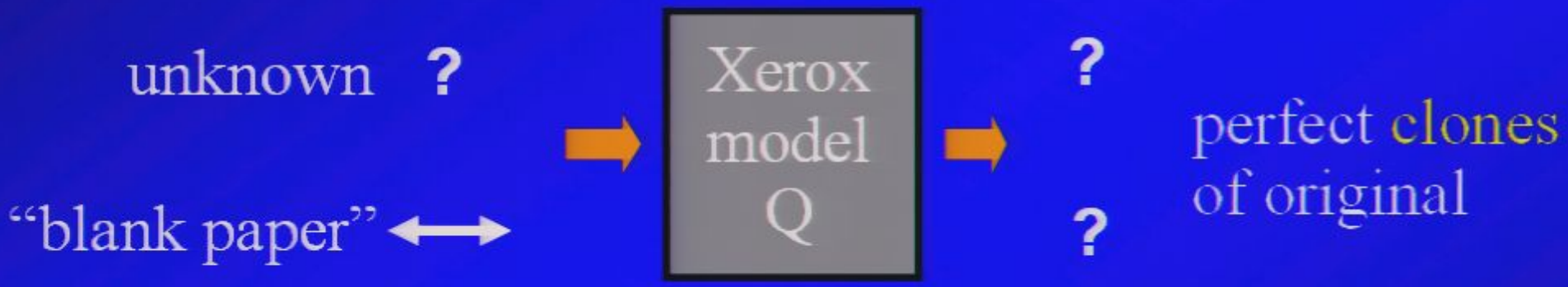

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perfect clones of original

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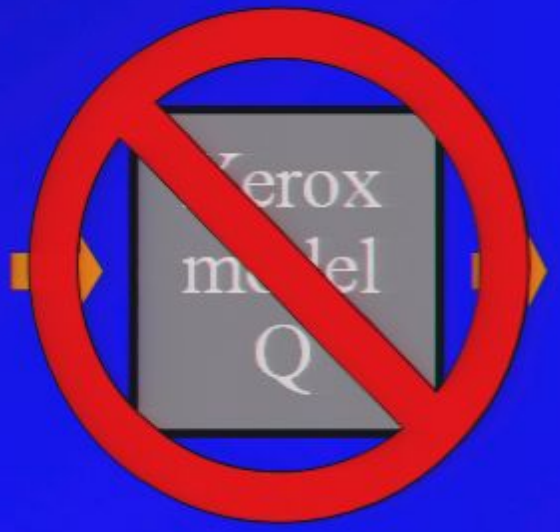

?

?

perfect clones of original

"Quantum information cannot be perfectly copied."

Quantum entanglement

Quantum entanglement

Quantum entanglement

Quantum entanglement

two-photon
source

Same measurements on both sides
always lead to opposite results.

Quantum entanglement

two-photon
source

Alice sets her polarizer vertically.

Then Bob receives

Quantum entanglement

Alice sets her polarizer vertically.

Then Bob receives

50% ↕ and 50% ↔

Quantum entanglement

two-photon
source

Alice sets her polarizer diagonally.

Then Bob receives

Quantum entanglement

Alice sets her polarizer diagonally.

Then Bob receives

50% ⤢ and 50% ⤡

Sending signals?

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Sending signals?

- Alice controls which of these Bob gets.

Sending signals?

- Alice controls which of these Bob gets.
- Bob cannot tell them apart -- without a PPA!

Sending signals?

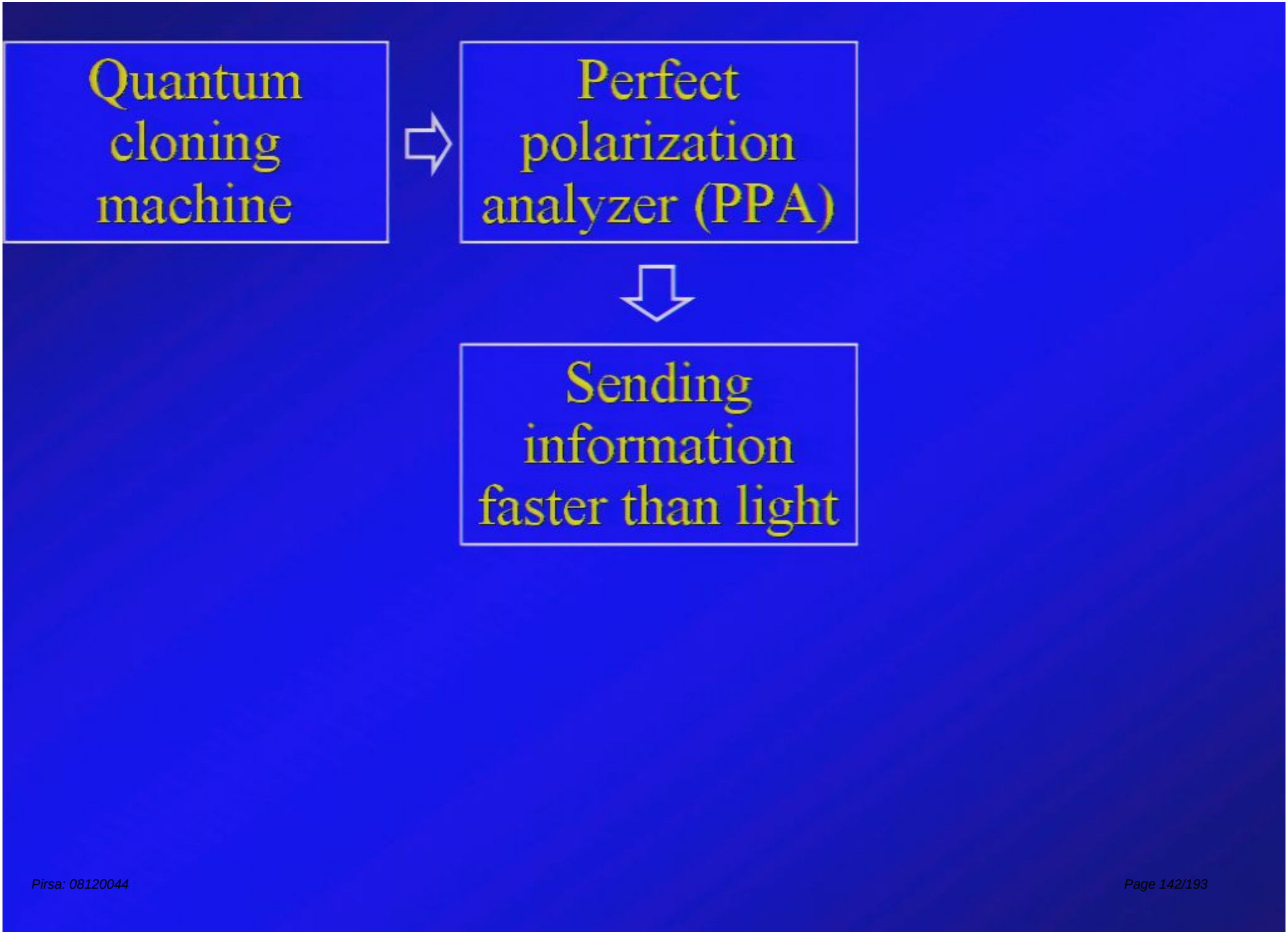
- Alice controls which of these Bob gets.
- Bob cannot tell them apart -- without a PPA!
- Given a PPA, Alice can send Bob a message faster than light.

cloning

Quantum cloning machine

Quantum cloning machine

Perfect polarization analyzer (PPA)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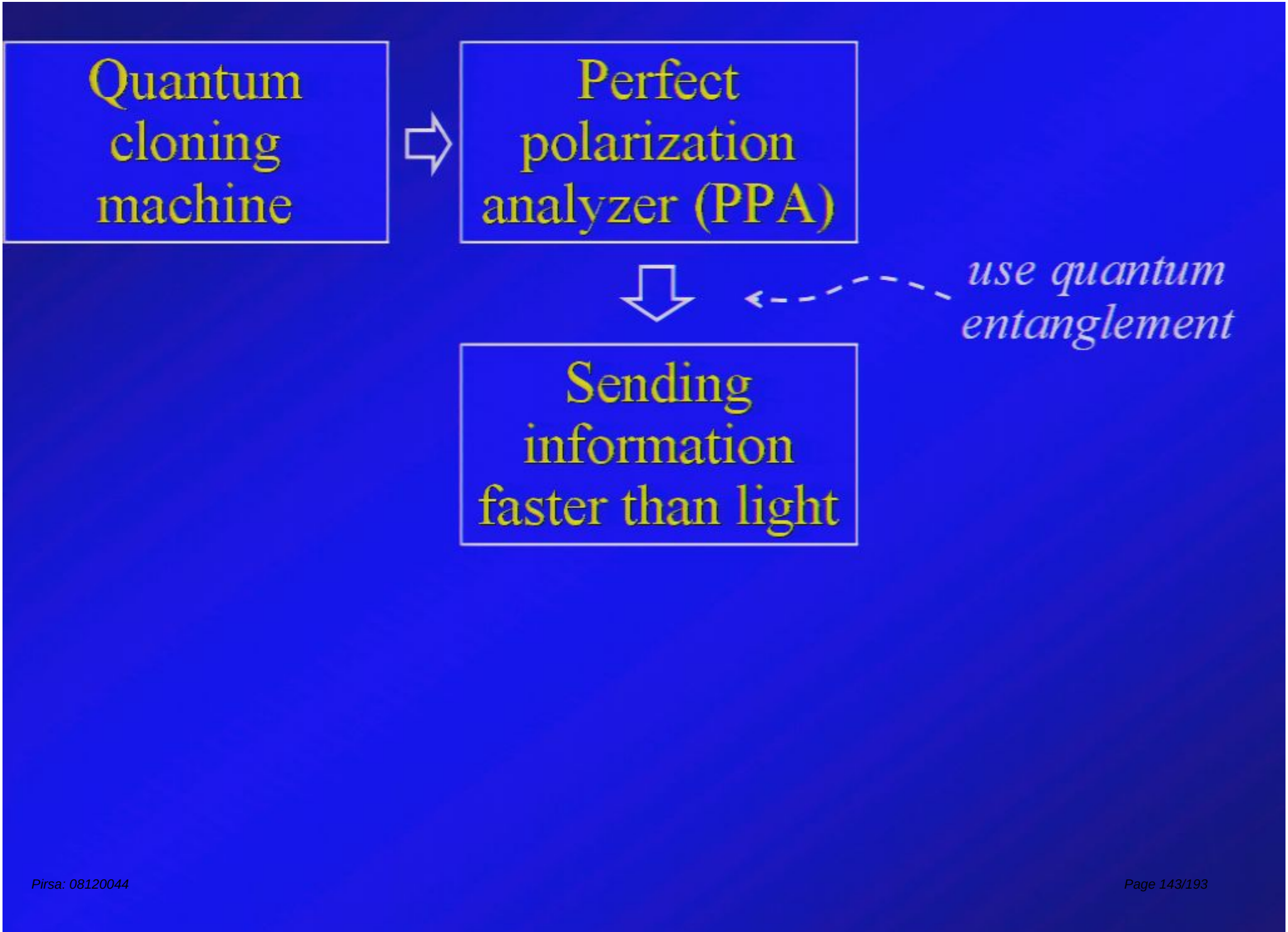
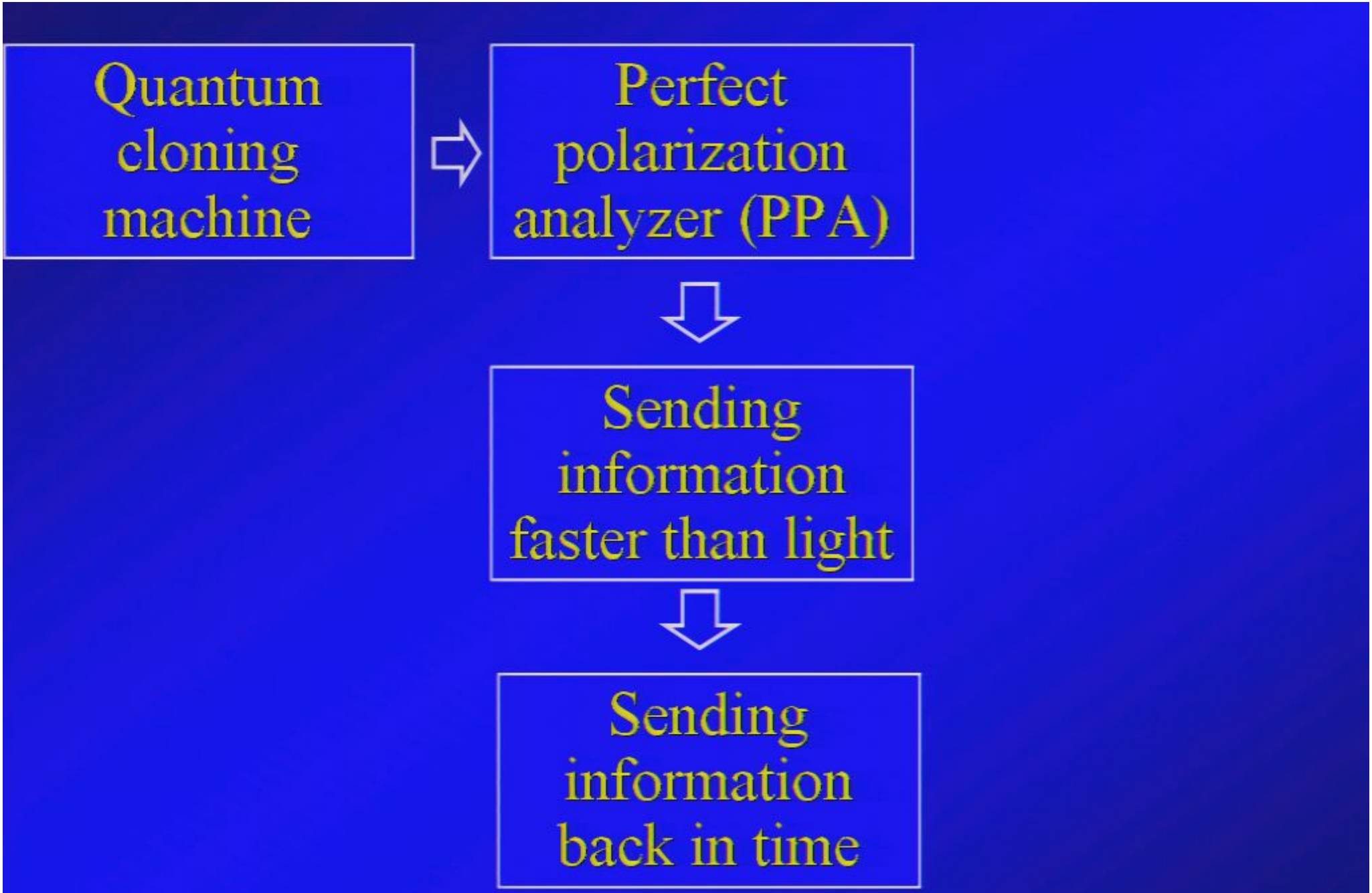
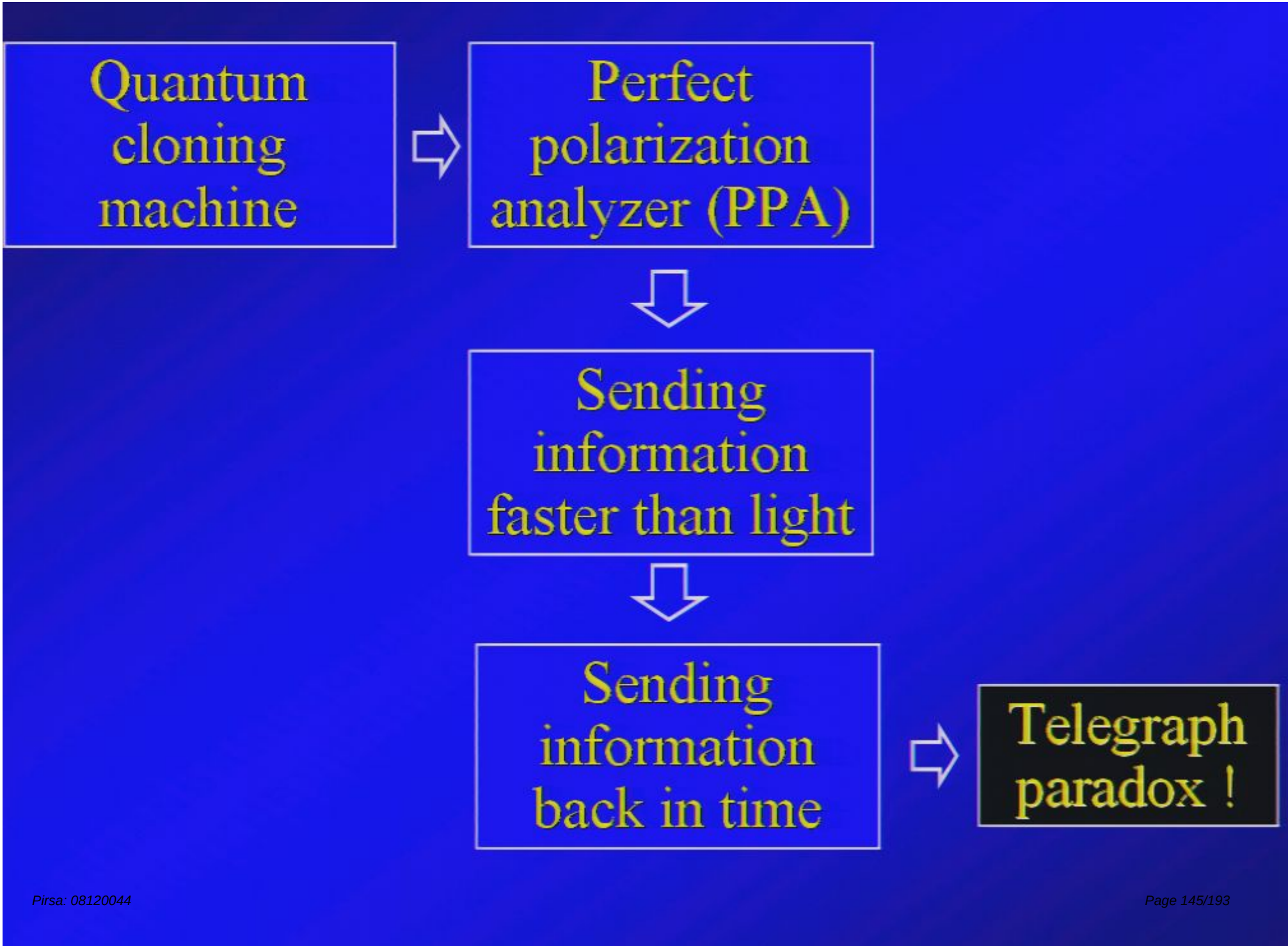
Perfect polarization analyzer (PPA)
Sending information faster than light


Quantum cloning machine
Perfect polarization analyzer (PPA)
use quantum entanglement
Sending information faster than light


Quantum cloning machine
Perfect polarization analyzer (PPA)
Sending information faster than light
Sending information back in time


Quantum cloning machine
Perfect polarization analyzer (PPA)
Sending information faster than light
Sending information back in time
Telegraph paradox !

Bounded electromagnetic miracles

The conservation of charge

The conservation of charge

No process can create or destroy a net electric charge.

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Spacetime view

The conservation of charge

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Spacetime view

World lines of unit charges

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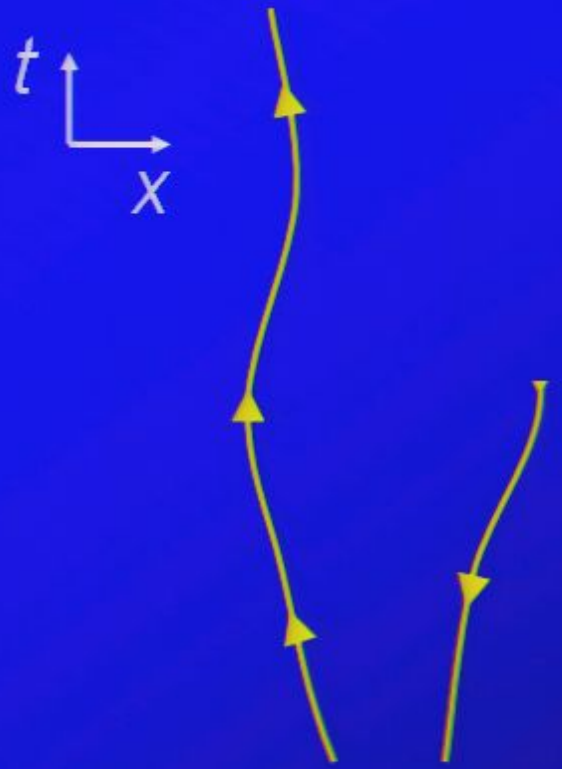
World lines of unit charges

Arrows tell + or - charge



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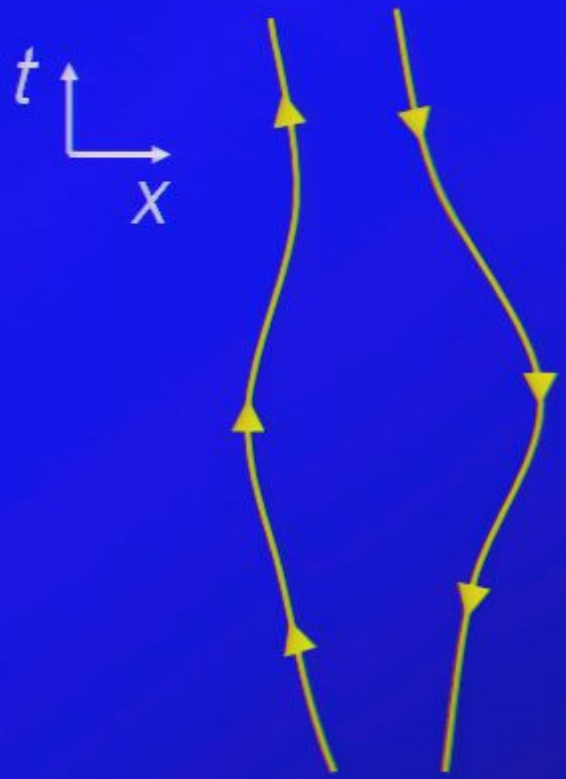

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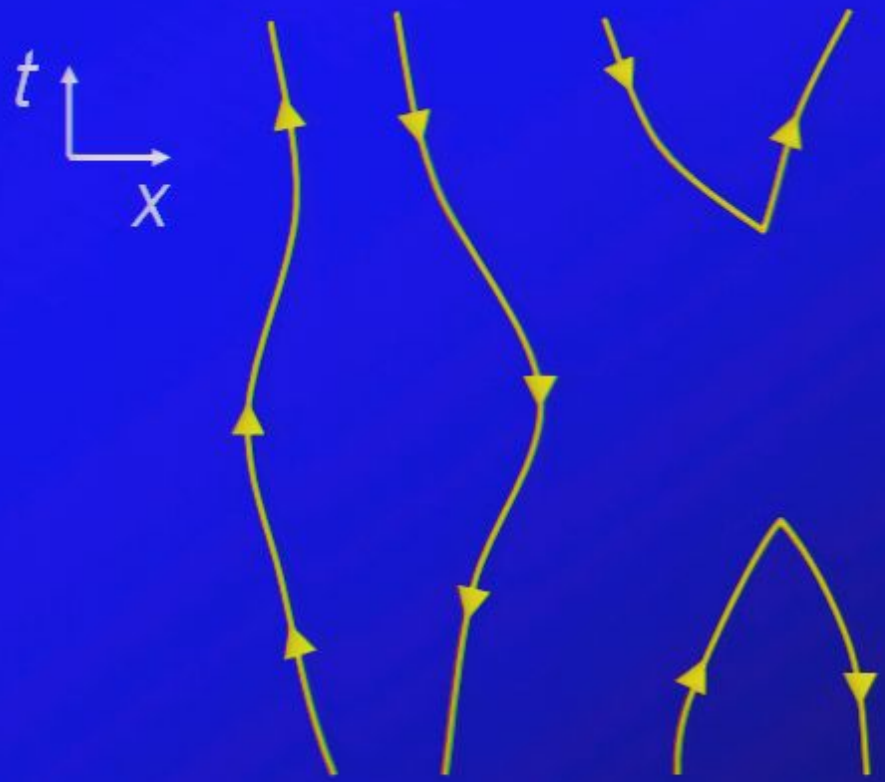

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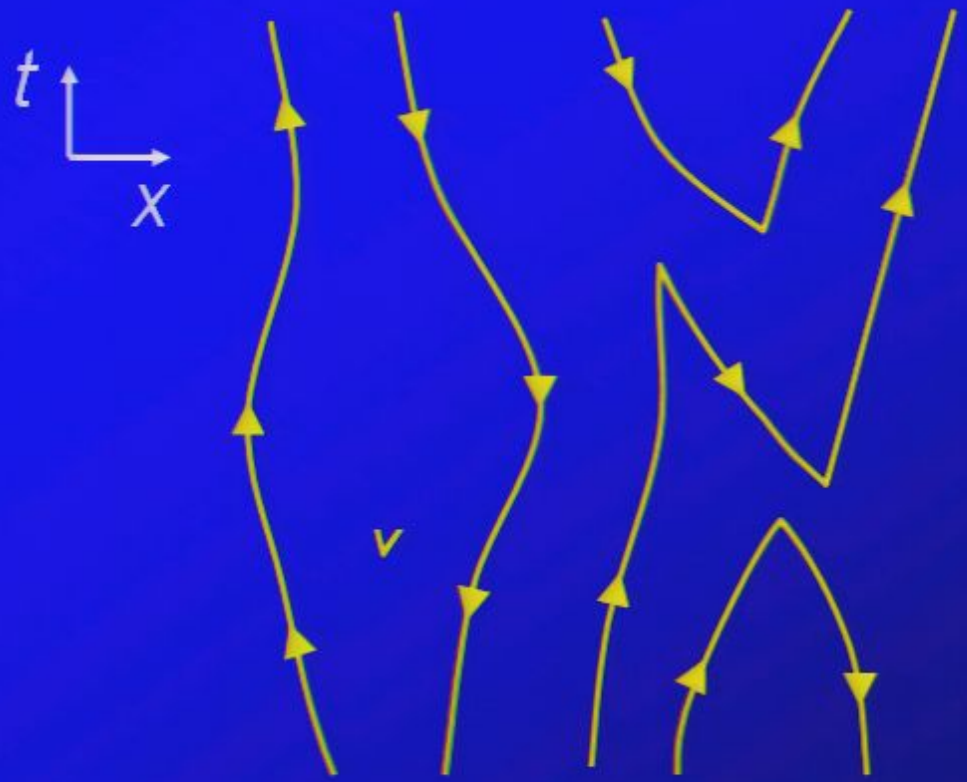

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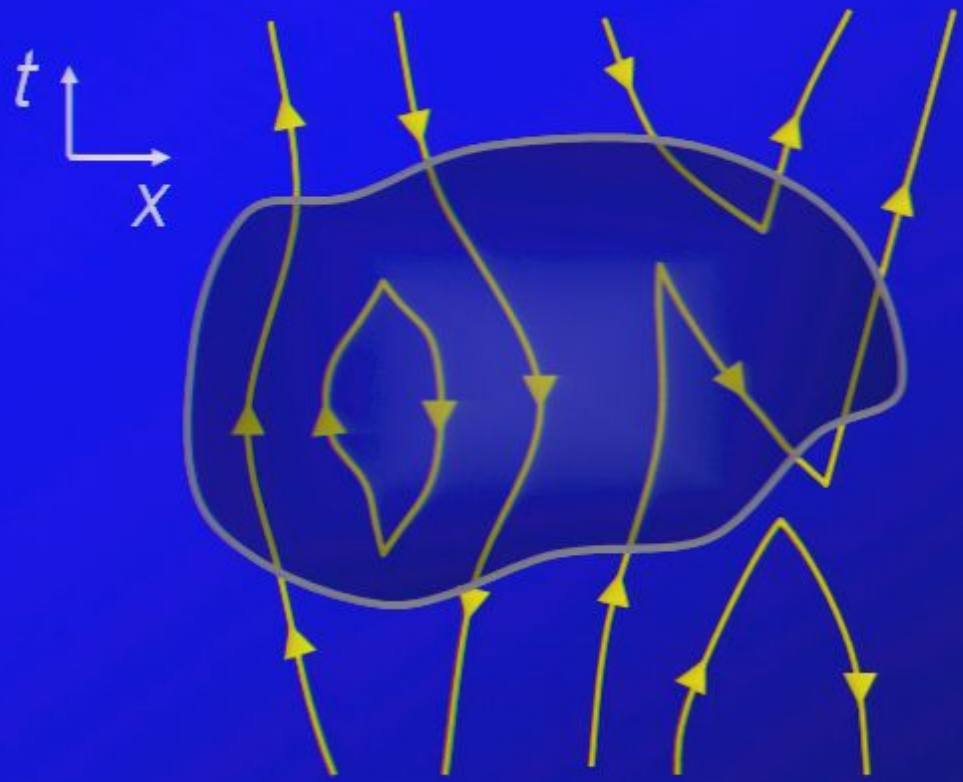

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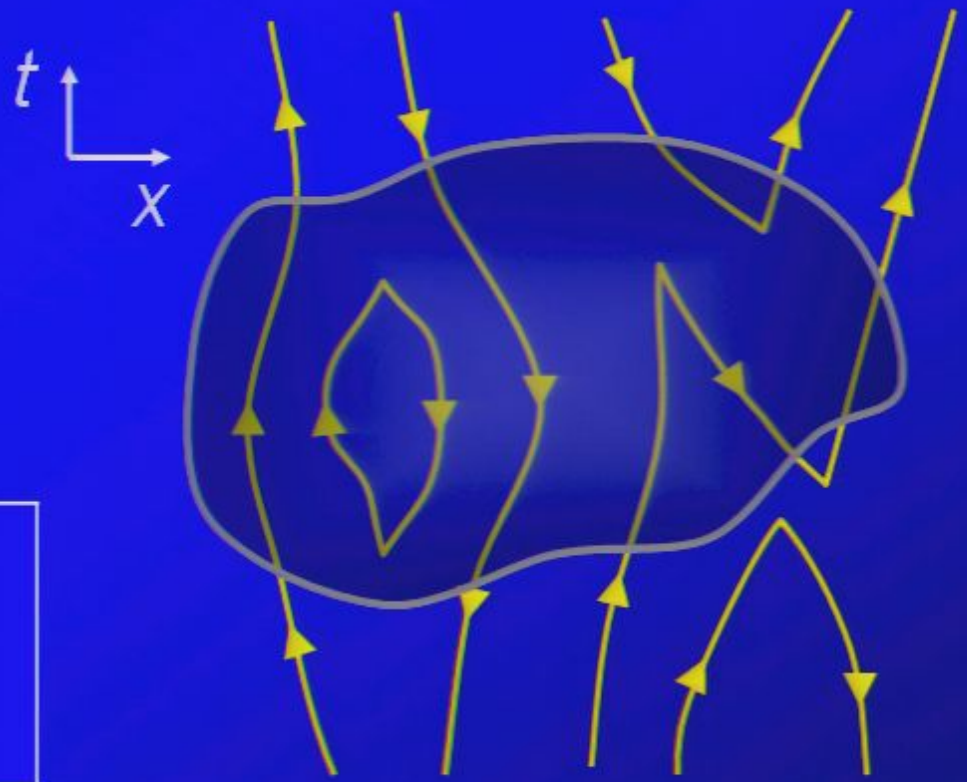

The net number of charge lines that enter or leave a spacetime region is zero.

Field equations

Field equations

Maxwell equations

$$\vec{\nabla} \cdot \vec{E} = \rho / \varepsilon_0$$

$$\vec{\nabla} \cdot \vec{B} = 0$$

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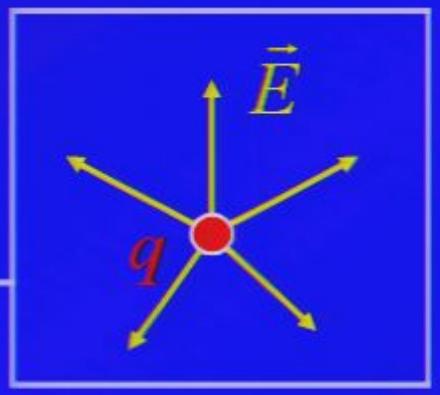

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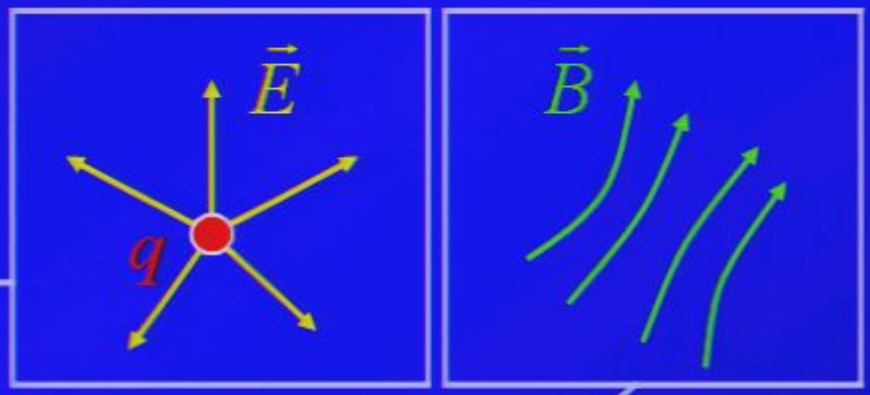

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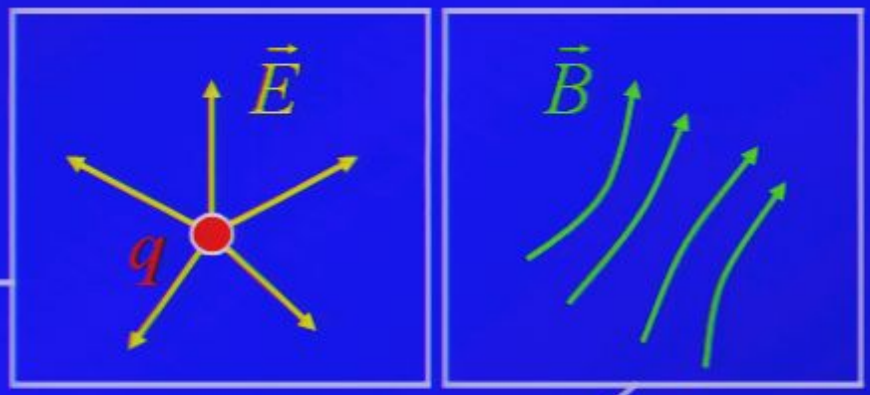

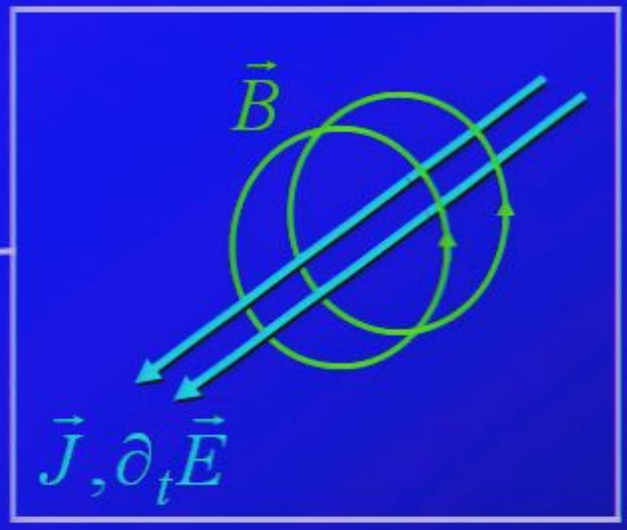

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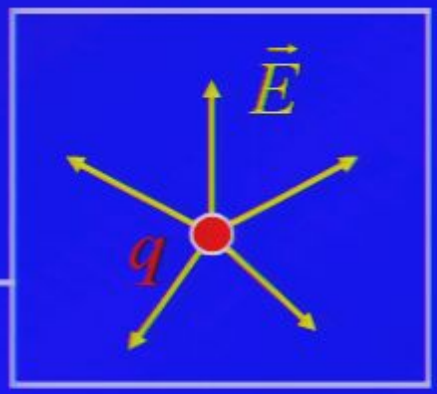

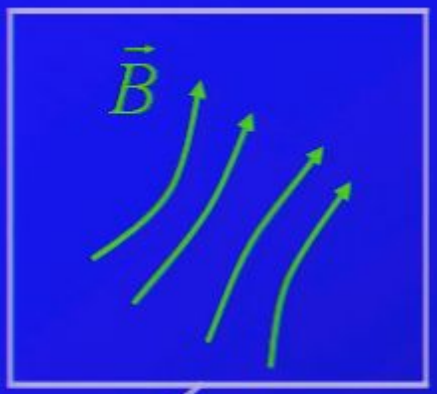

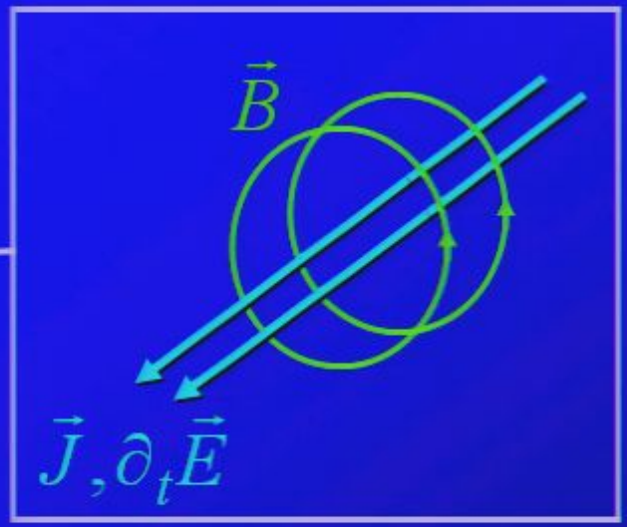

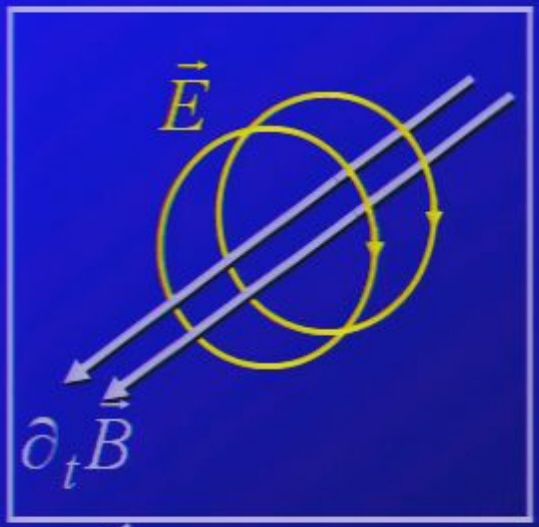

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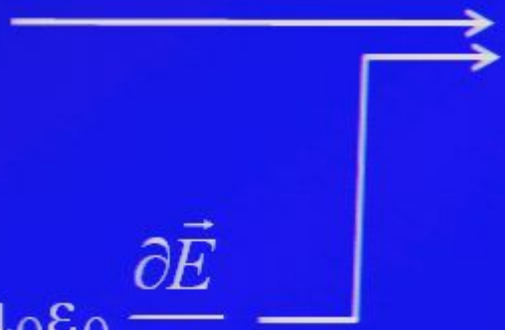

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Wonderful fact:

Maxwell equations *imply* conservation of charge.

Bounded miracles

To create or destroy charge, we must violate the Maxwell equations somewhere.

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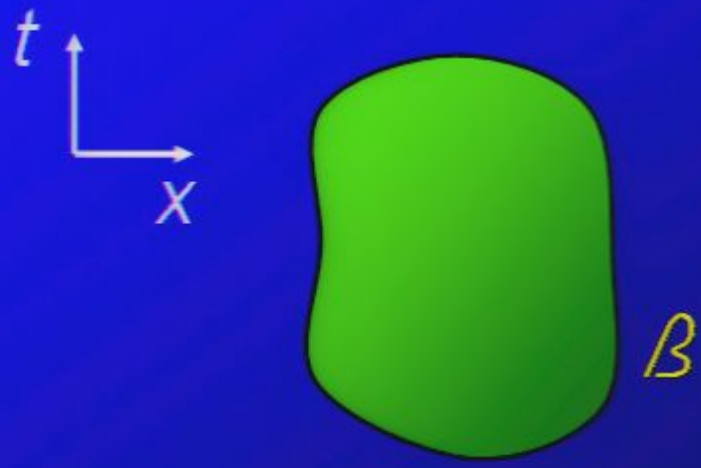

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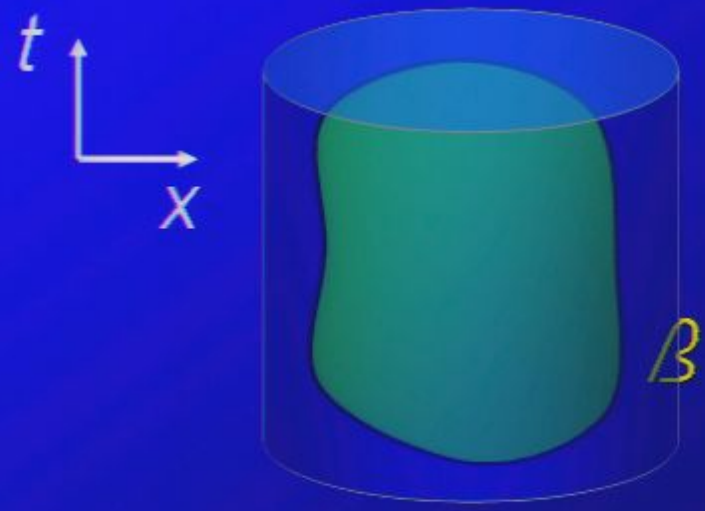

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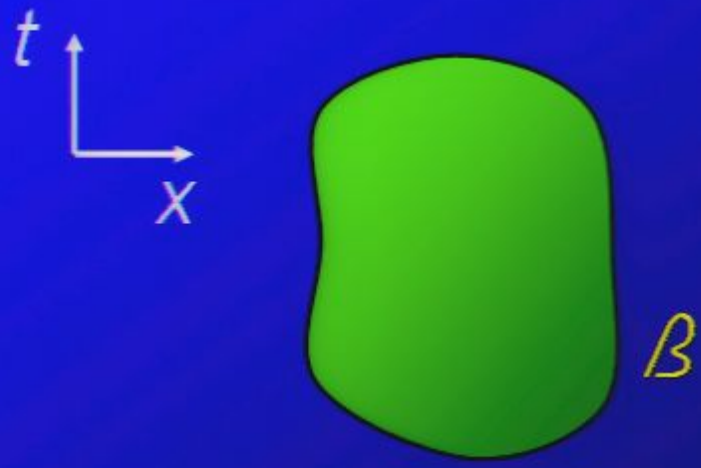

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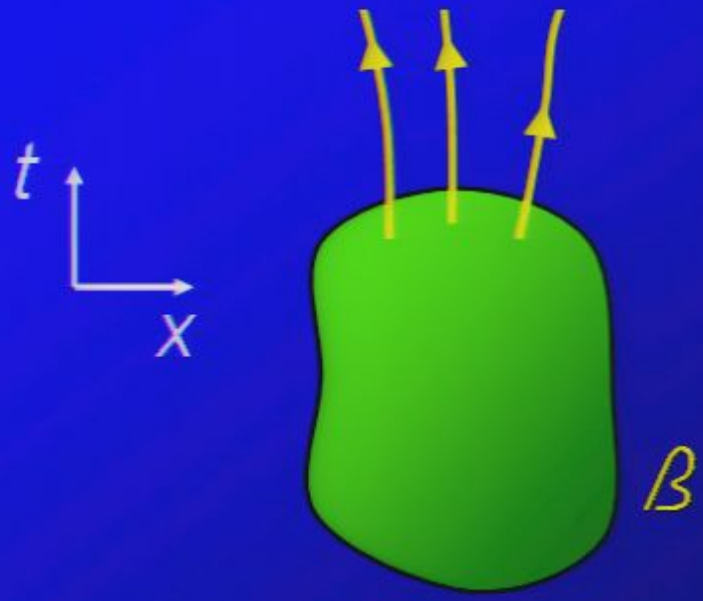

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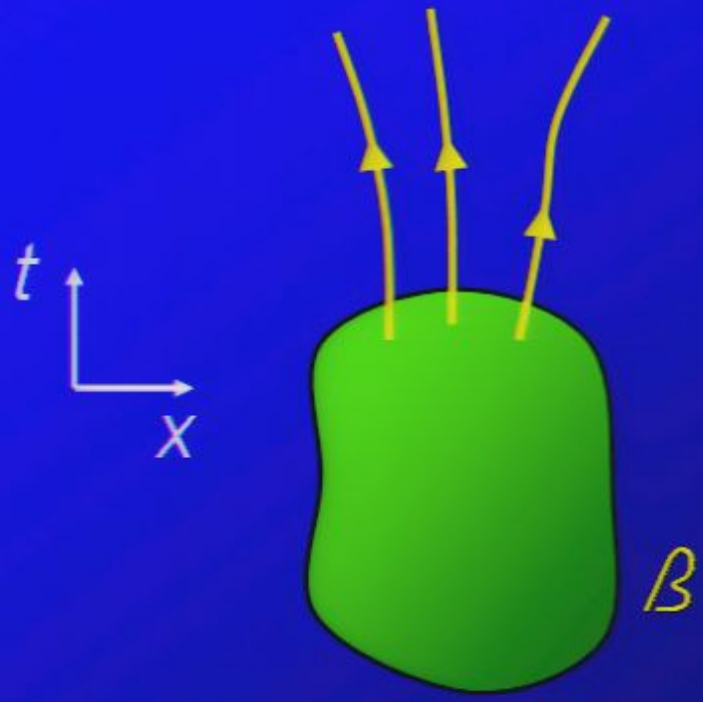

Bounded miracles

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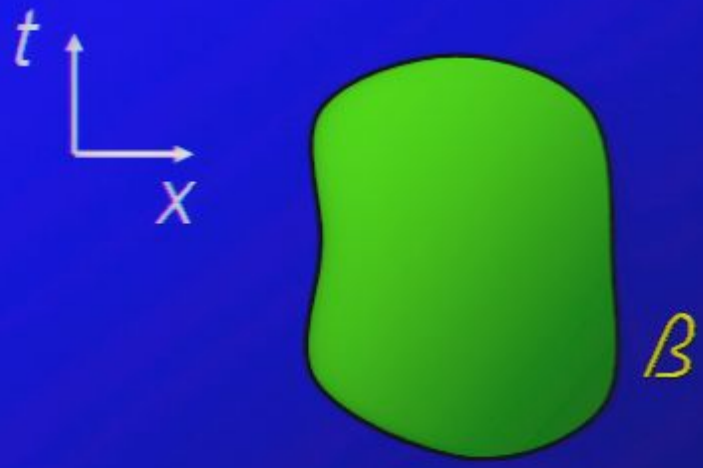
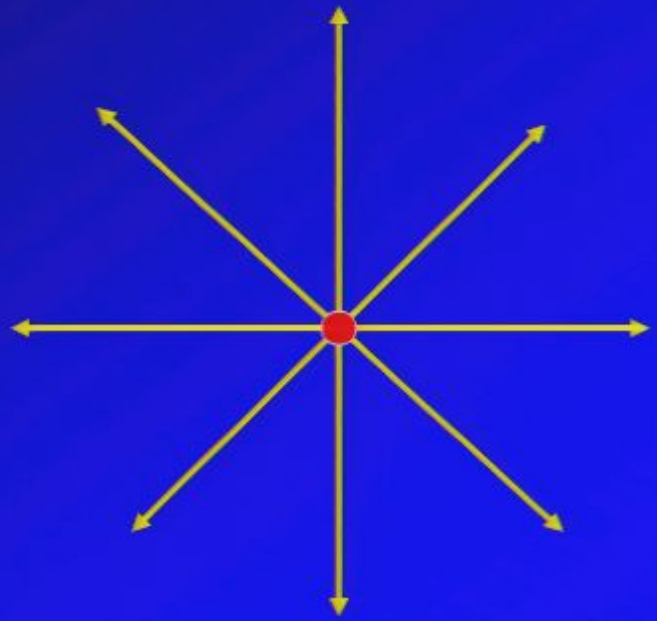
No!



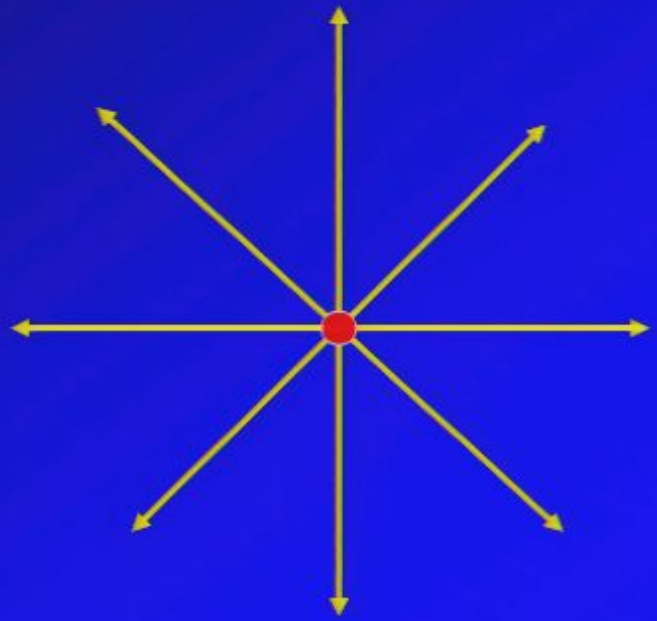
Why not?

Why not?



Charge surrounded by radial E-field.

Why not?



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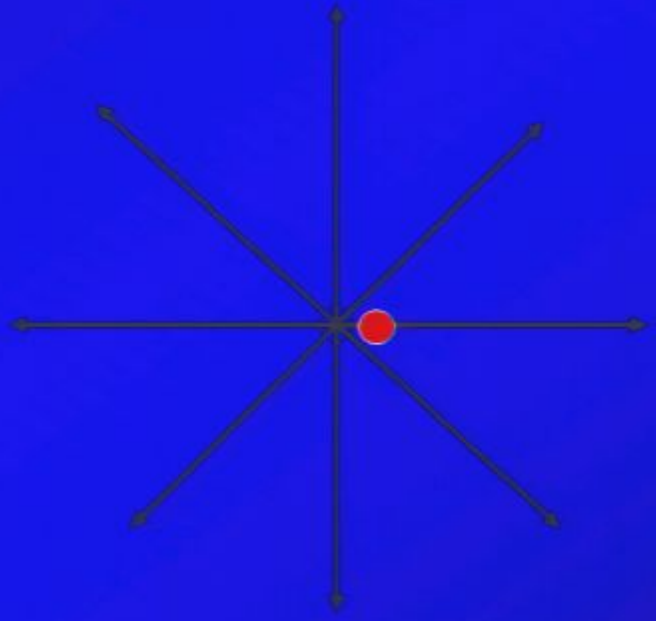
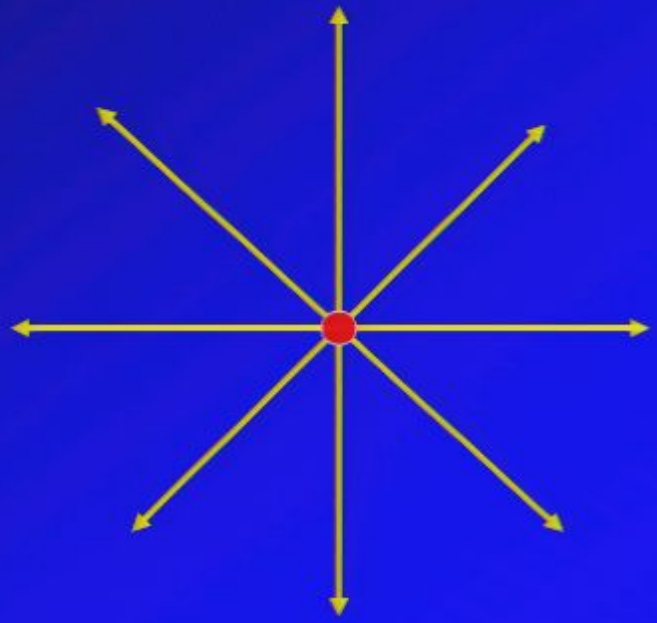


Field changes when charge moves.

Why not?



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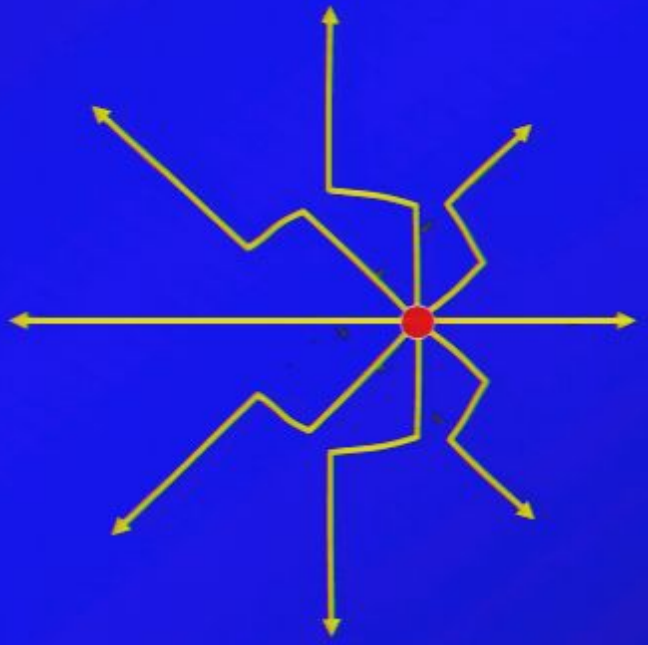

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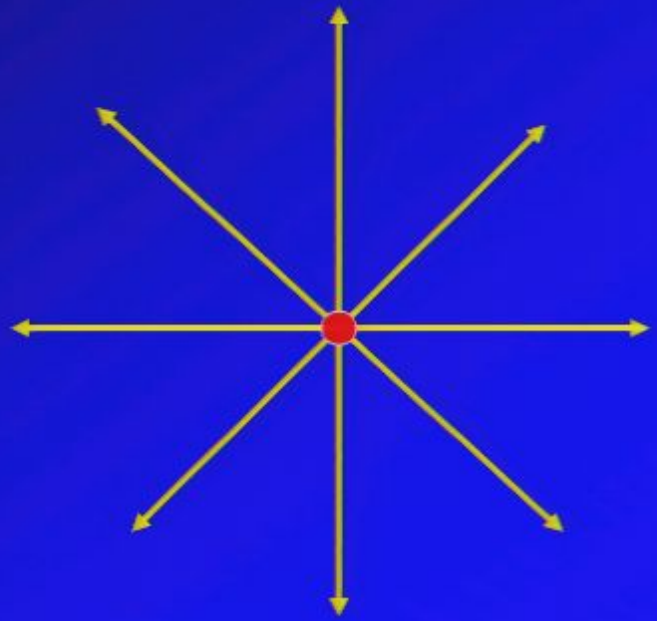

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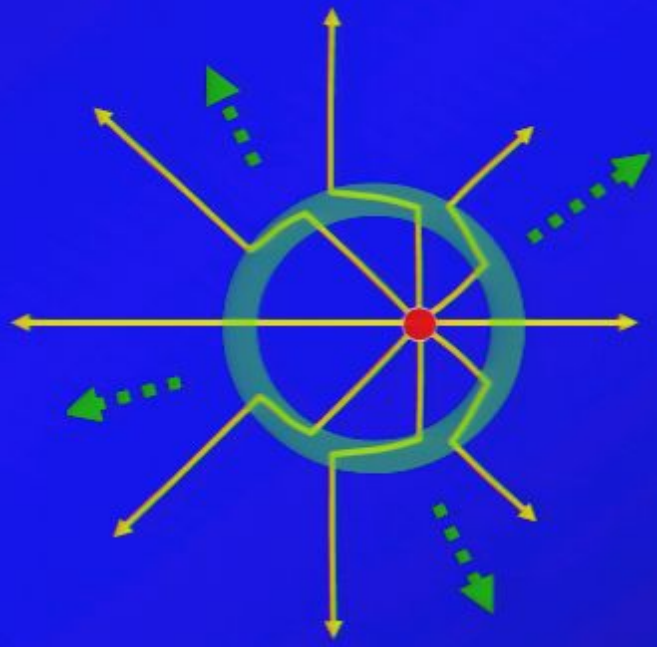

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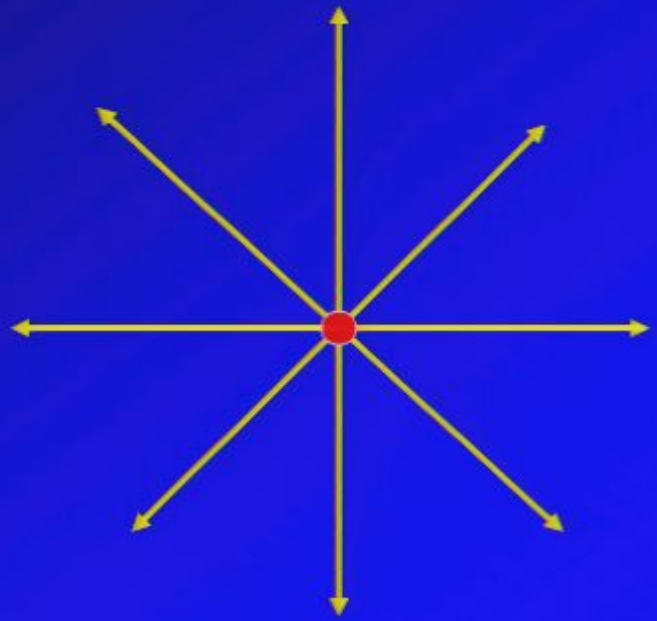

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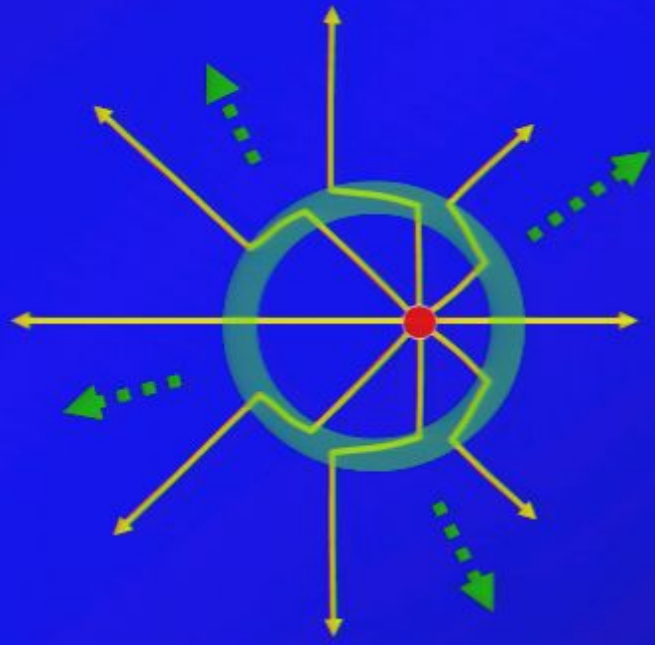

Field changes when charge moves.

Only transverse changes can propagate outward.

Charge from nowhere?

Charge from nowhere?

No field. Then charge appears!

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Later: Change in E-field has propagated outward, but …

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Field change is not transverse -- cannot keep spreading outward.

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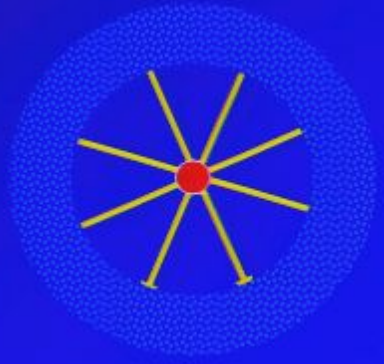


No field. Then charge appears!

Later: Change in E-field has propagated outward, but …

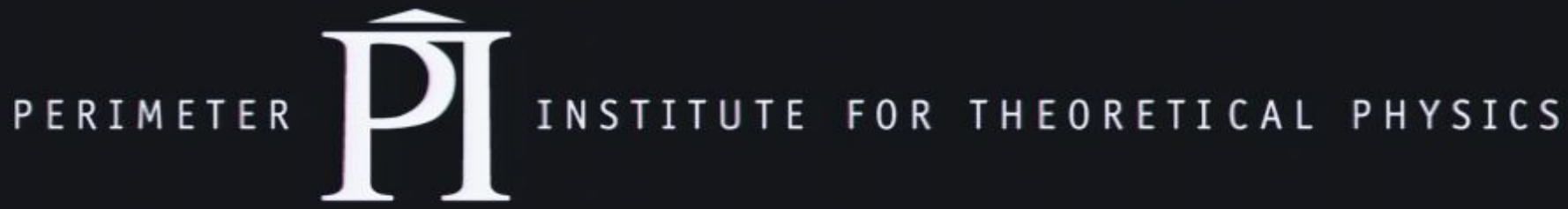
Field change is not transverse -- cannot keep spreading outward.

The "information" about the new charge cannot reach the outside world!

The moral of the story

The thermos bottle joke

Finis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