



The Physics of Impossible Things

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"I can't believe *that!*" said Alice.

"Can't you?" the Queen said in a pitying tone.

"Try again: draw a long breath, and shut your eyes."

Alice laughed. "There's no use trying," she said 'one *can't* believe impossible things."

"I daresay you haven't had much practice," said the Queen. "When I was your age, I always did it for half-an-hour a day. Why, sometimes I've believed as many as **six impossible things** before breakfast."

Lewis Carroll

Through the Looking Glass

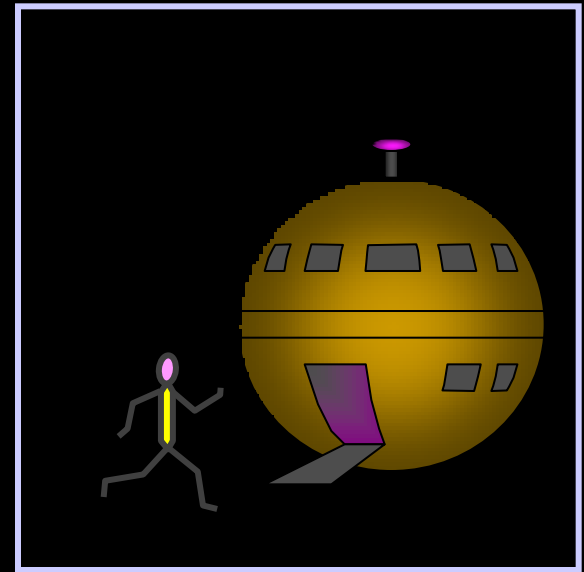


One Time travel

"I don't understand you," said Alice. "It's dreadfully confusing!"

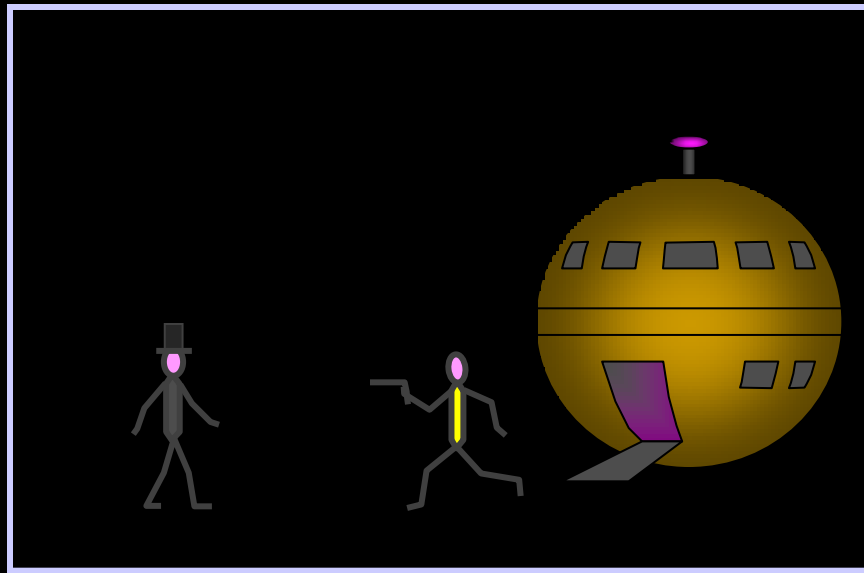
"That's the effect of living backwards," the Queen said kindly: "it always makes one a little giddy at first —"

The Grandfather Paradox

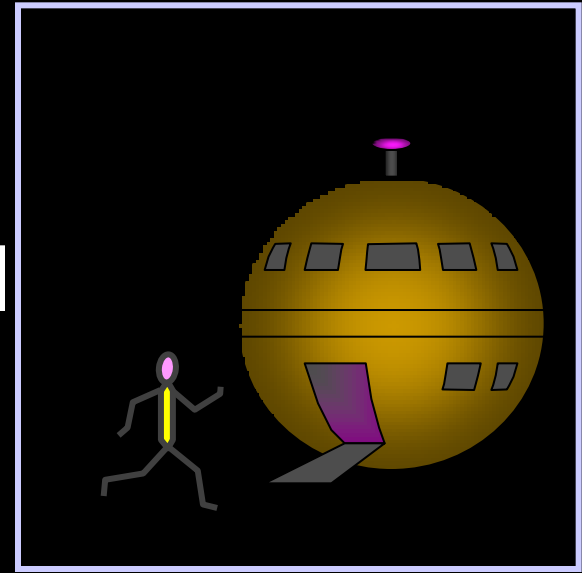


2013

The Grandfather Paradox

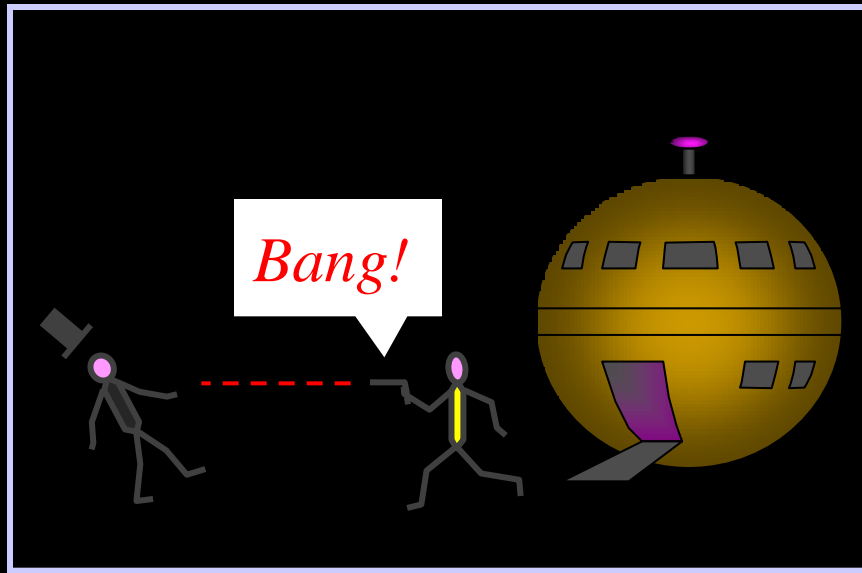


1913

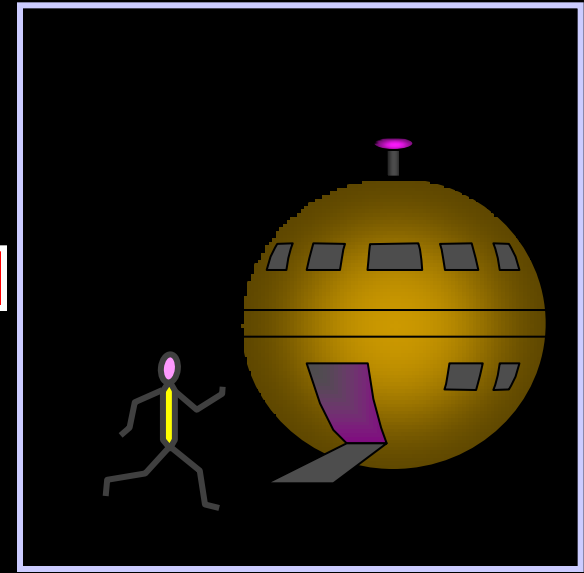


2013

The Grandfather Paradox

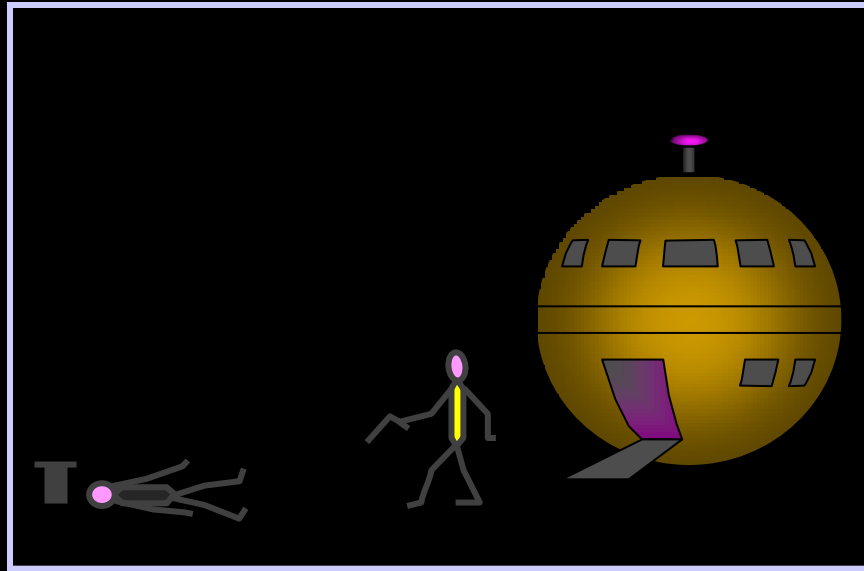


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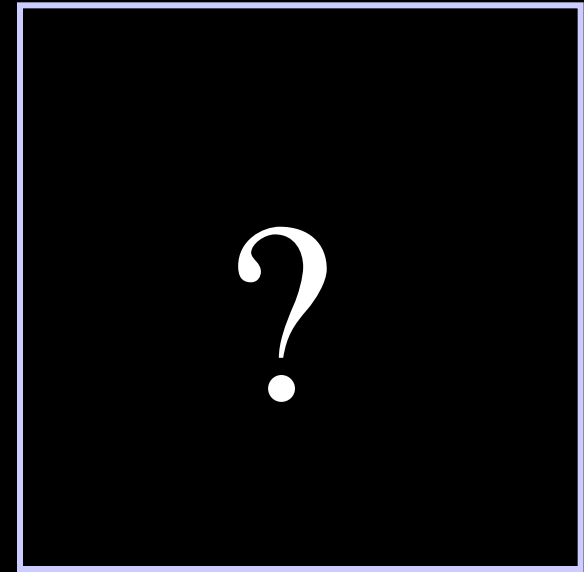


2013

The Grandfather Paradox



1913



2013

Two Time telegraph

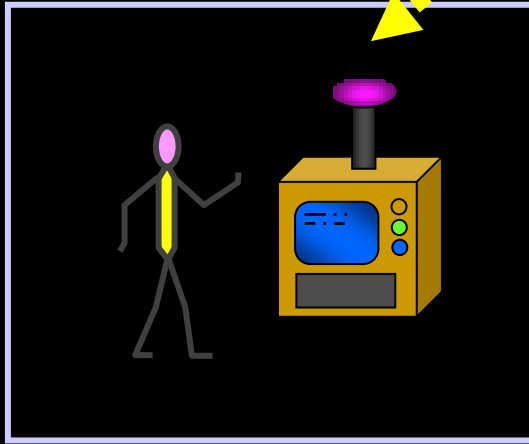
"It's a poor sort of memory that only works backwards," the Queen remarked.

"What sort of things do **you** remember best?" Alice ventured to ask.

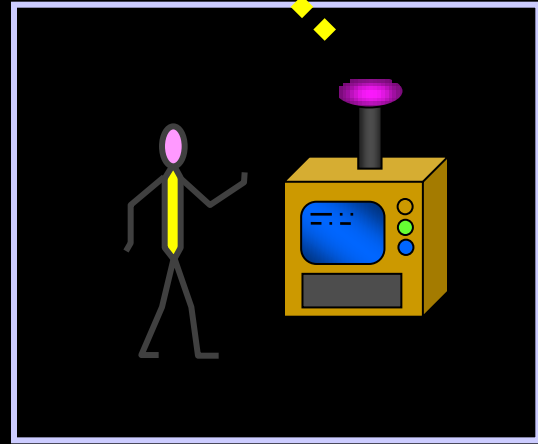
"Oh, things that happened the week after next," the Queen replied in a careless tone.



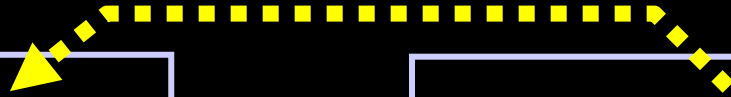
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Last week

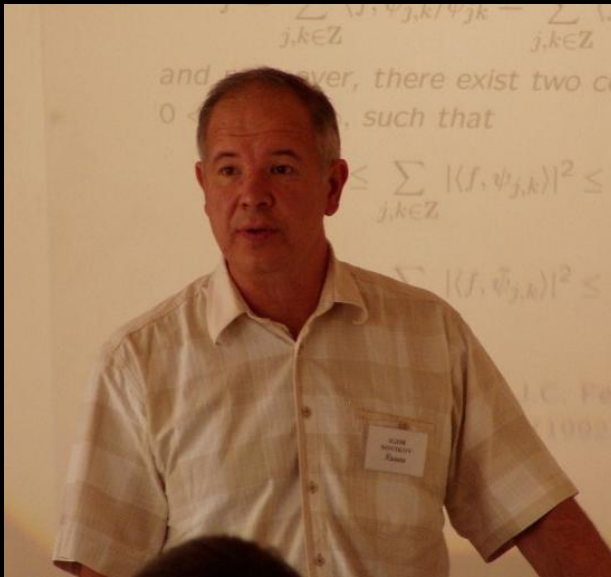


This week



The Consistency Principle

There must always exist a self-consistent version of history, even in the presence of time travel.

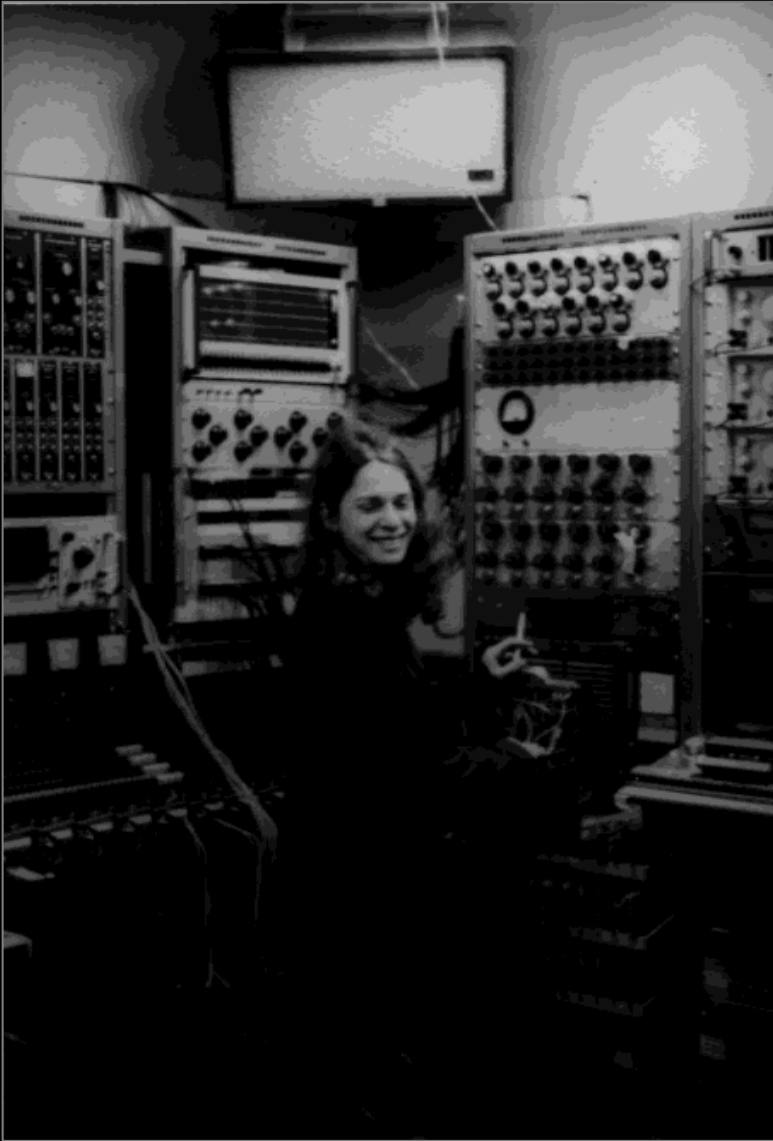


Igor Novikov
consistent field theory



David Deutsch
*consistent quantum
multiverse*

Three Ultra computers

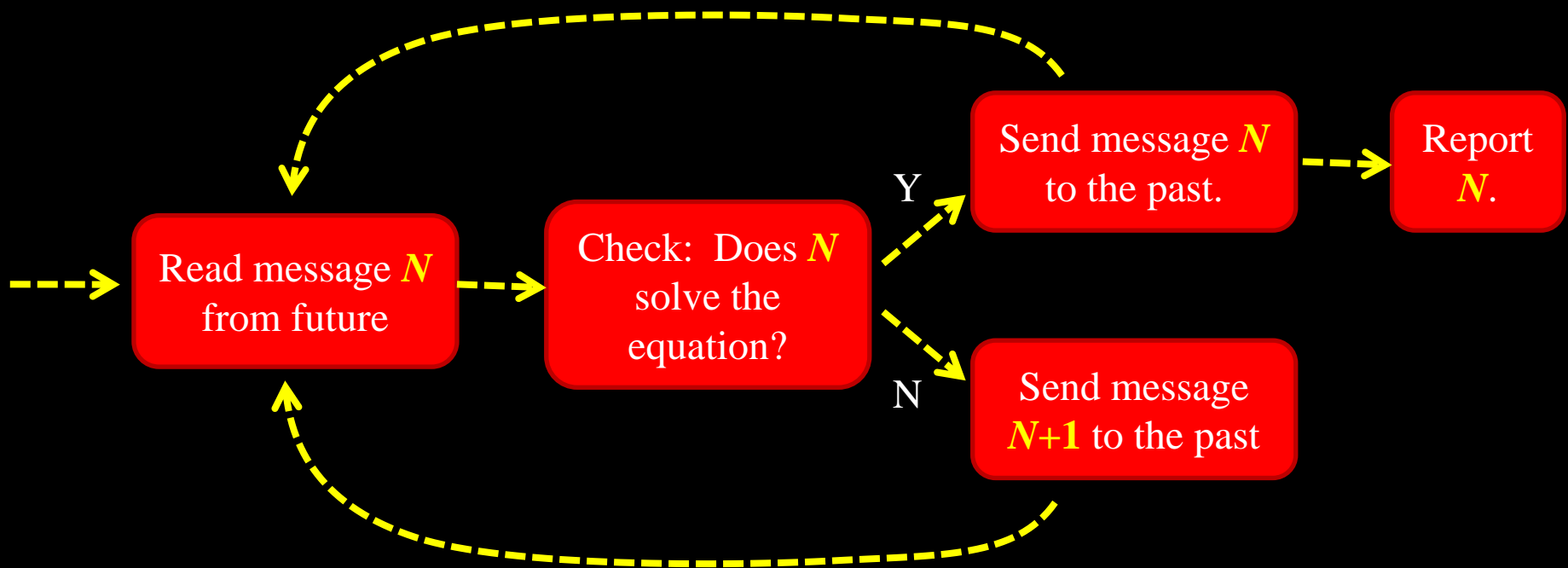


"Can you do Addition?" the White Queen asked. "What's one and one and one and one and one and one and one and one and one and one?"

"I don't know," said Alice. "I lost count."

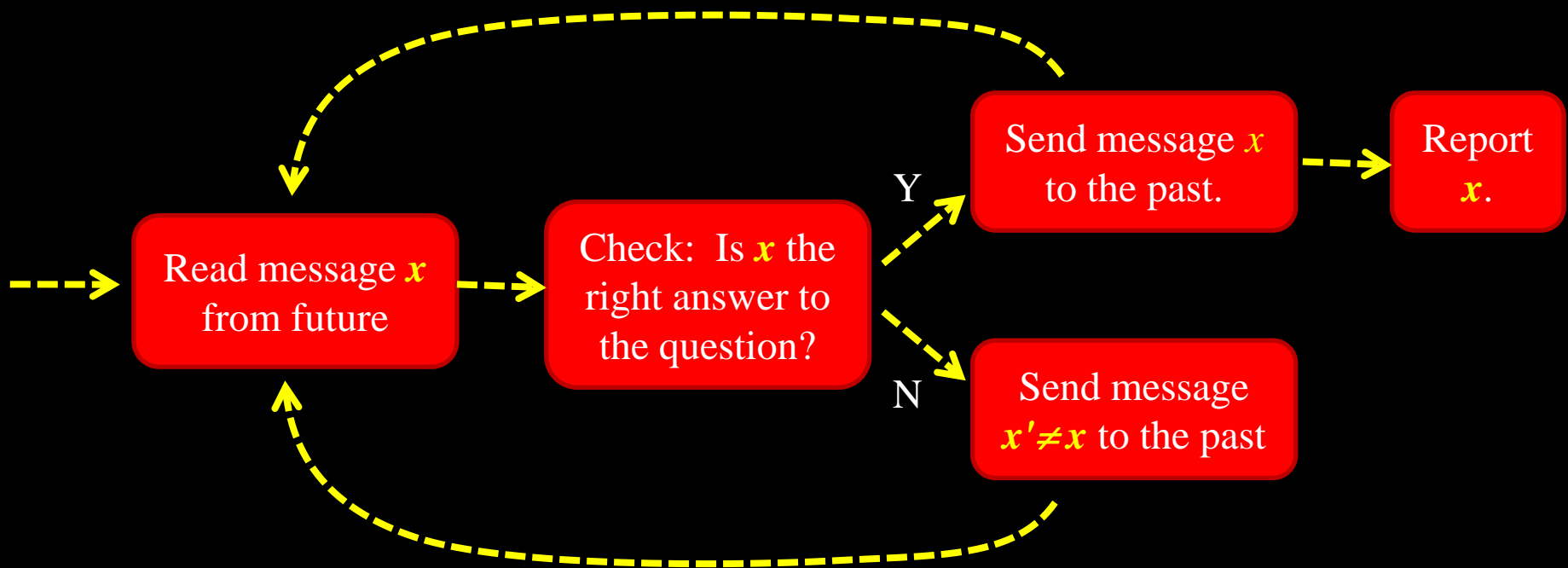
Find the solution

- Problem: Determine the positive whole number N that solves a given equation.
- Assume: Easy to **check** a particular N , but hard to find the right one!



The ultimate oracle

- Problem: Answer a given question, mathematical or otherwise.
- Assume: Easy to **check** a particular answer, but hard to find the right one!



Four Faster than light

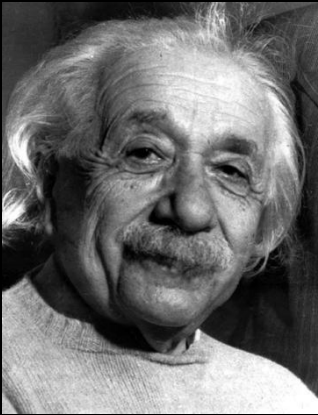


... and still the Queen kept crying 'Faster! Faster!' but Alice felt she **could not** go faster, though she had not breath left to say so.

The ultimate speed limit



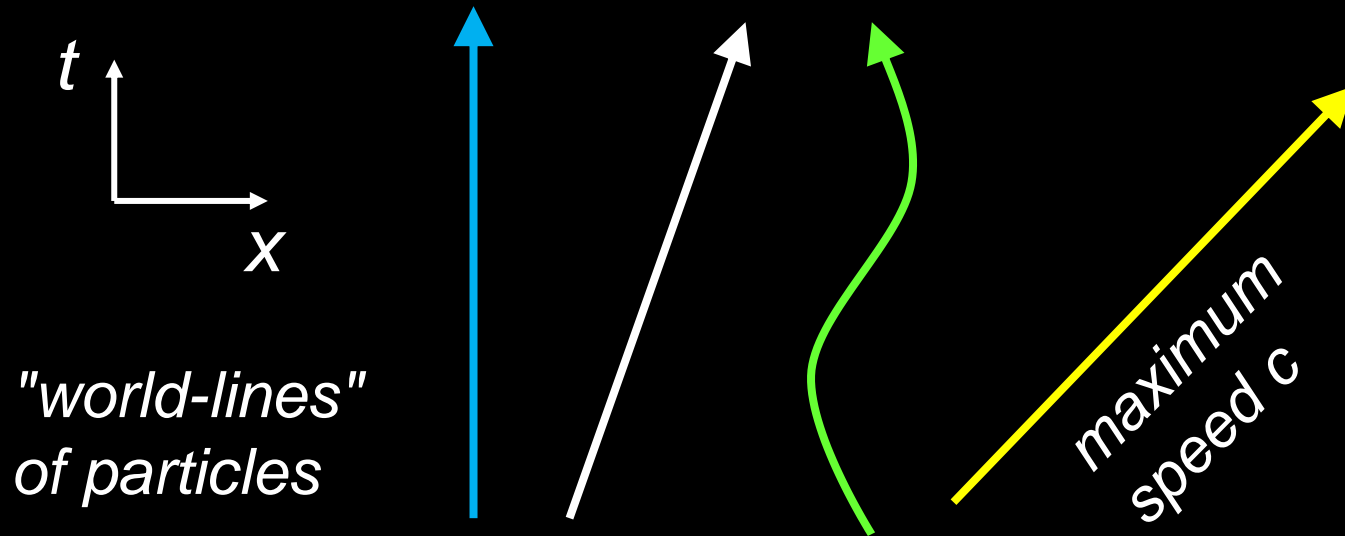
$$c = 299,792,458 \text{ m/s}$$



This is the maximum speed of **information transfer** in the Universe.

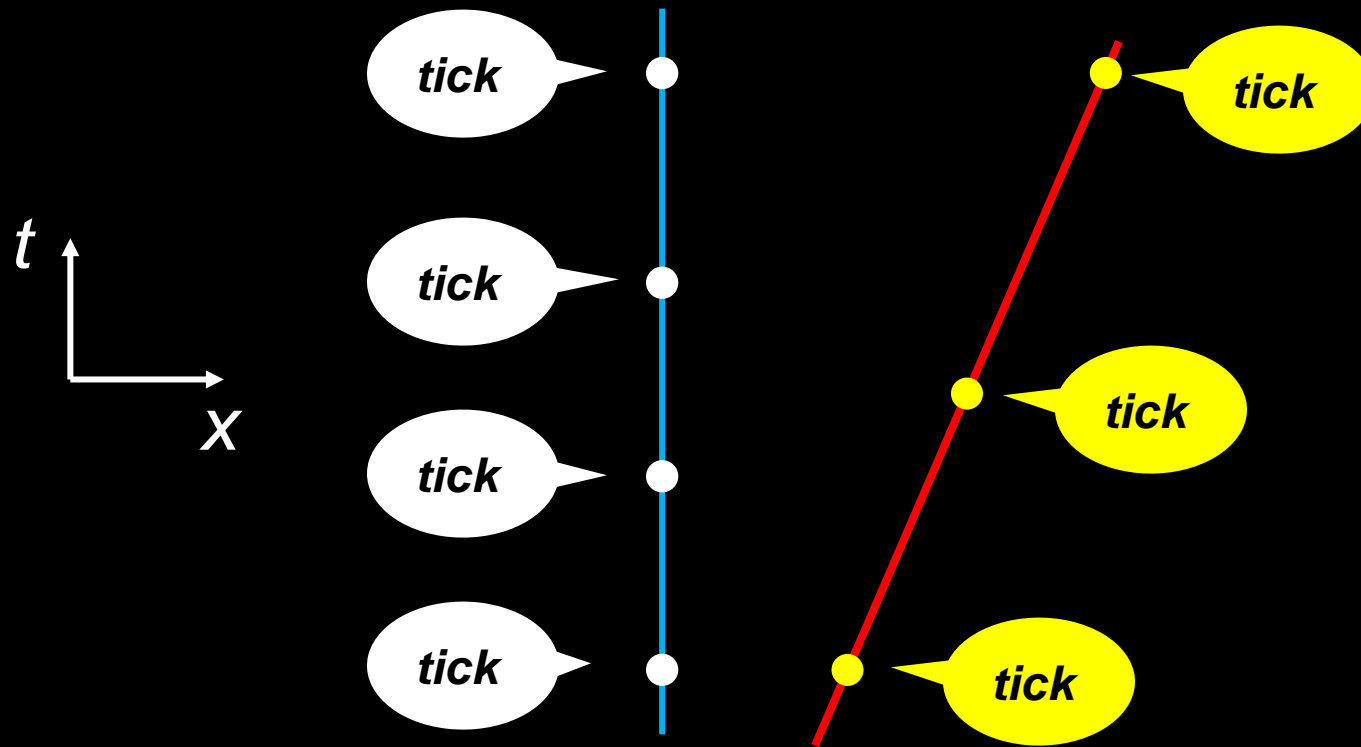
How to think in 4-D

Spacetime = every point in space at every moment in time
= the "arena" of physics!

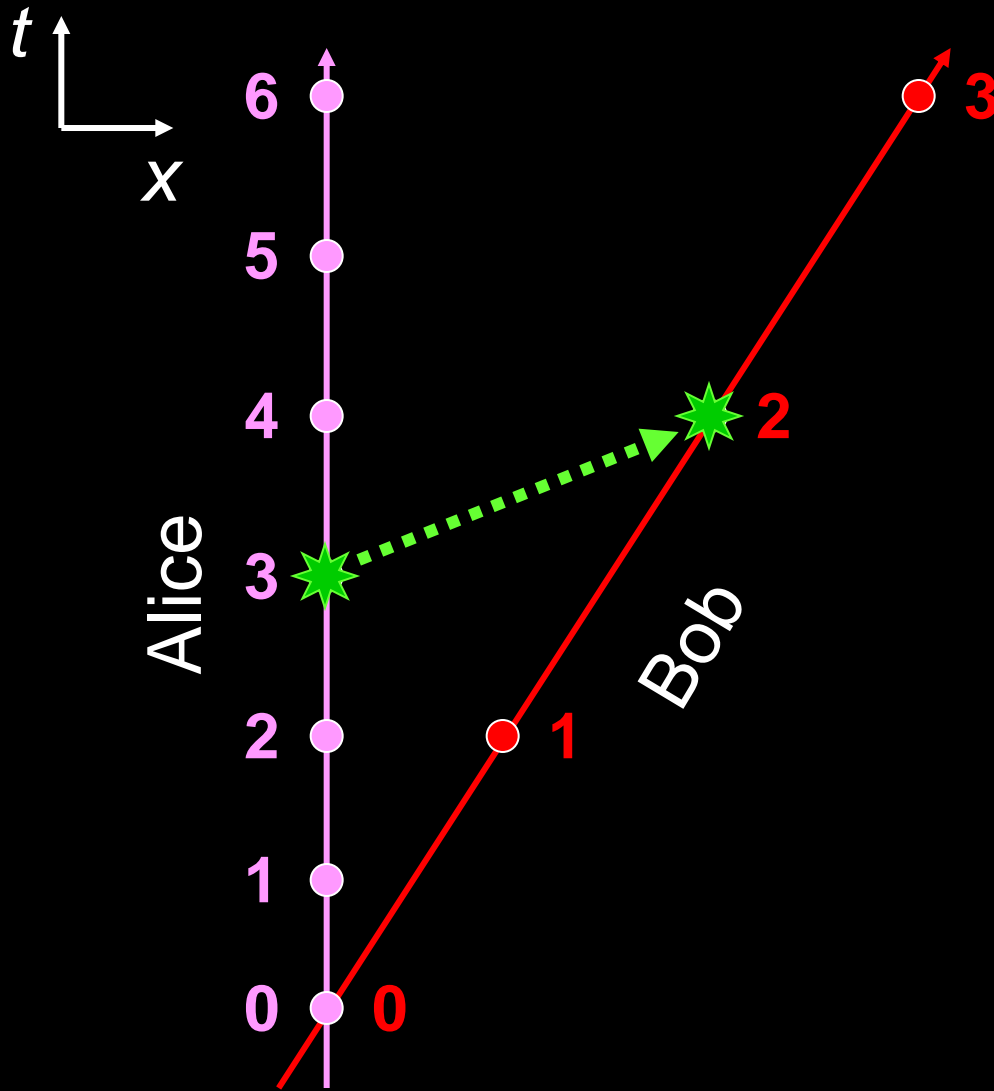


Moving clocks

Famous relativity fact: Moving clocks run slowly.



A faster-than-light message?



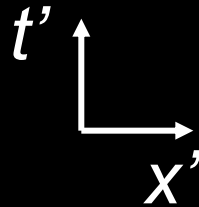
Alice's "frame"

Message:

Alice 3 \rightarrow Bob 2 (FTL)

A faster-than-light message?

Bob's "frame"



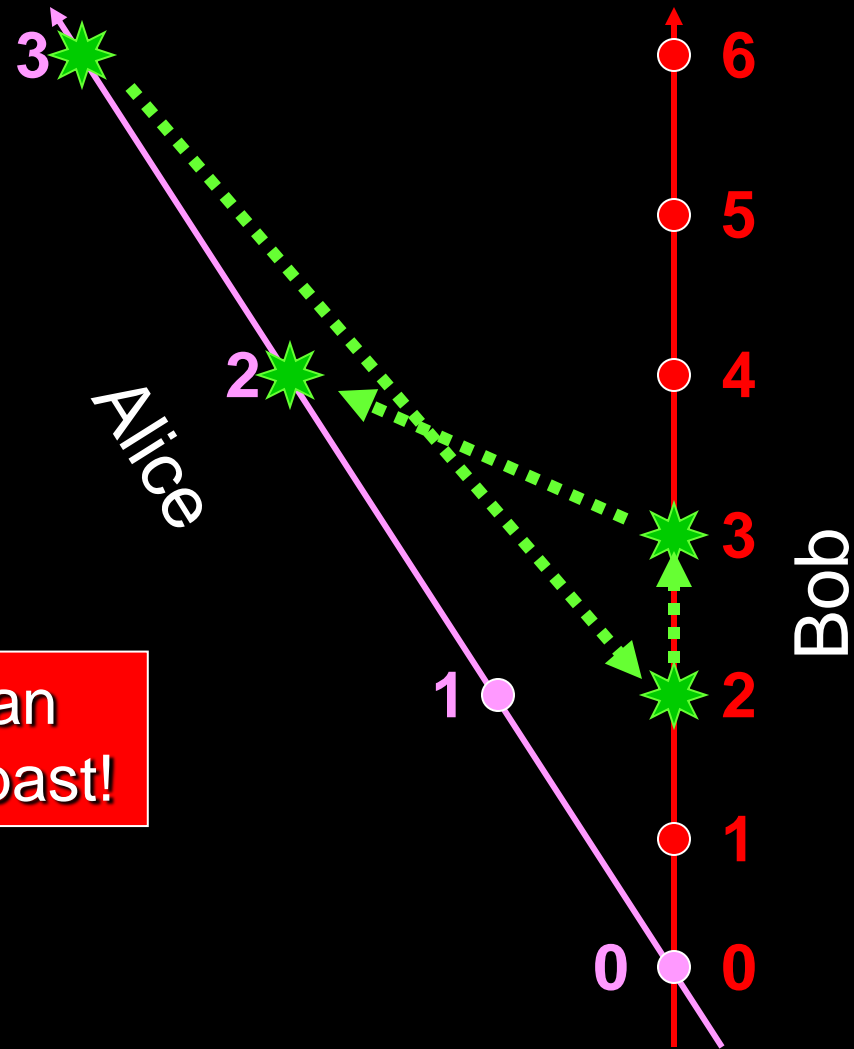
Messages:

Alice 3 → Bob 2 (FTL)

Bob 2 → Bob 3

Bob 3 → Alice 2 (FTL)

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





*fast-moving
particle*



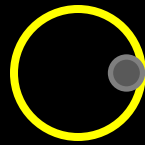


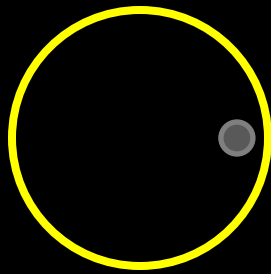


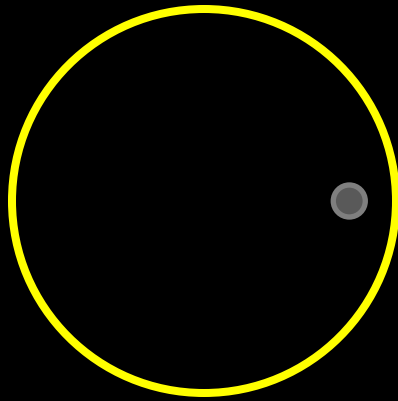


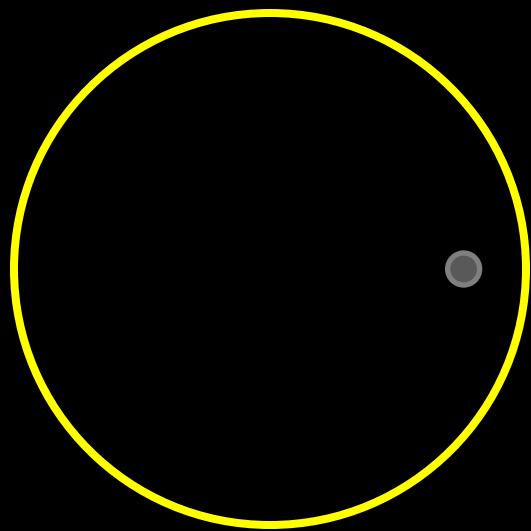




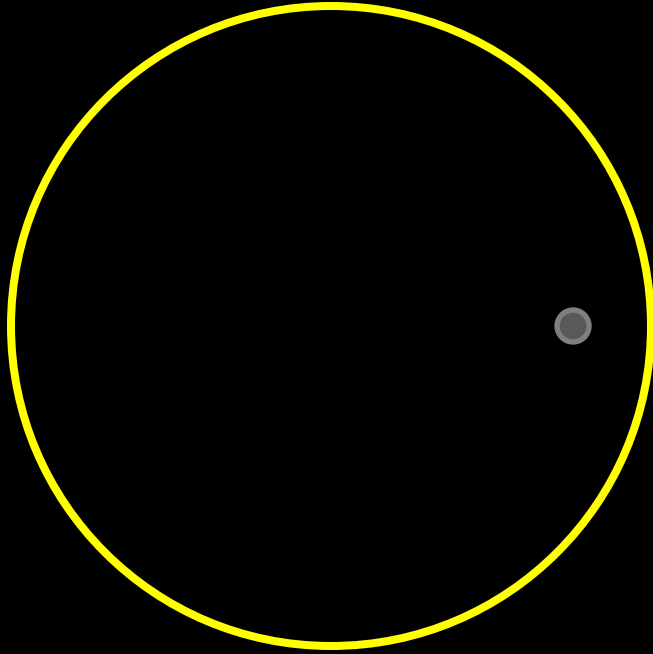


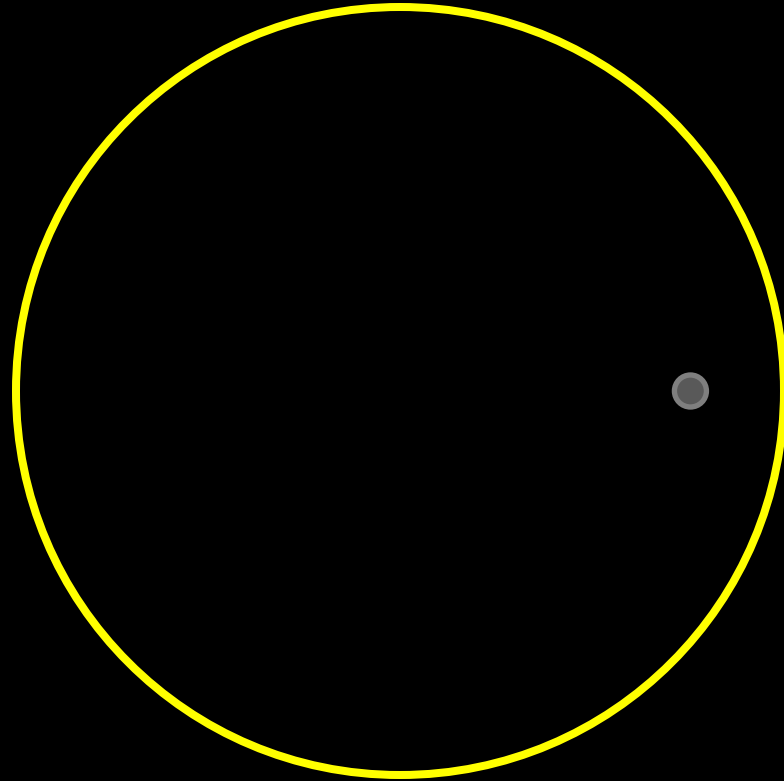


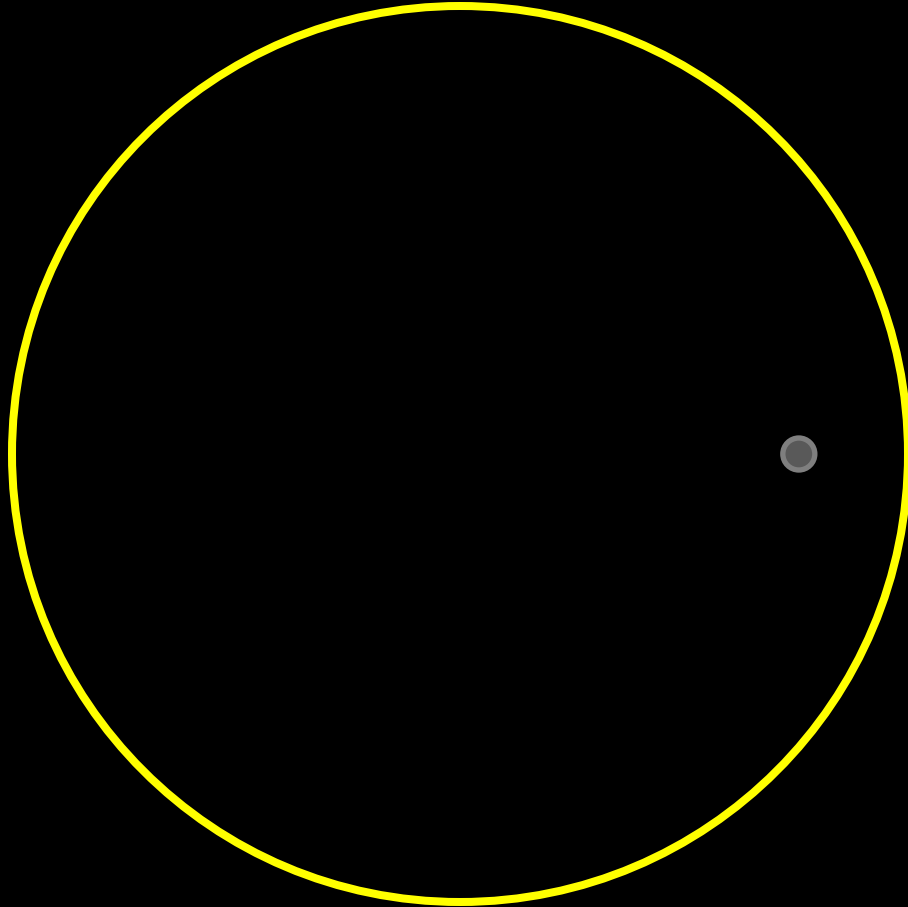


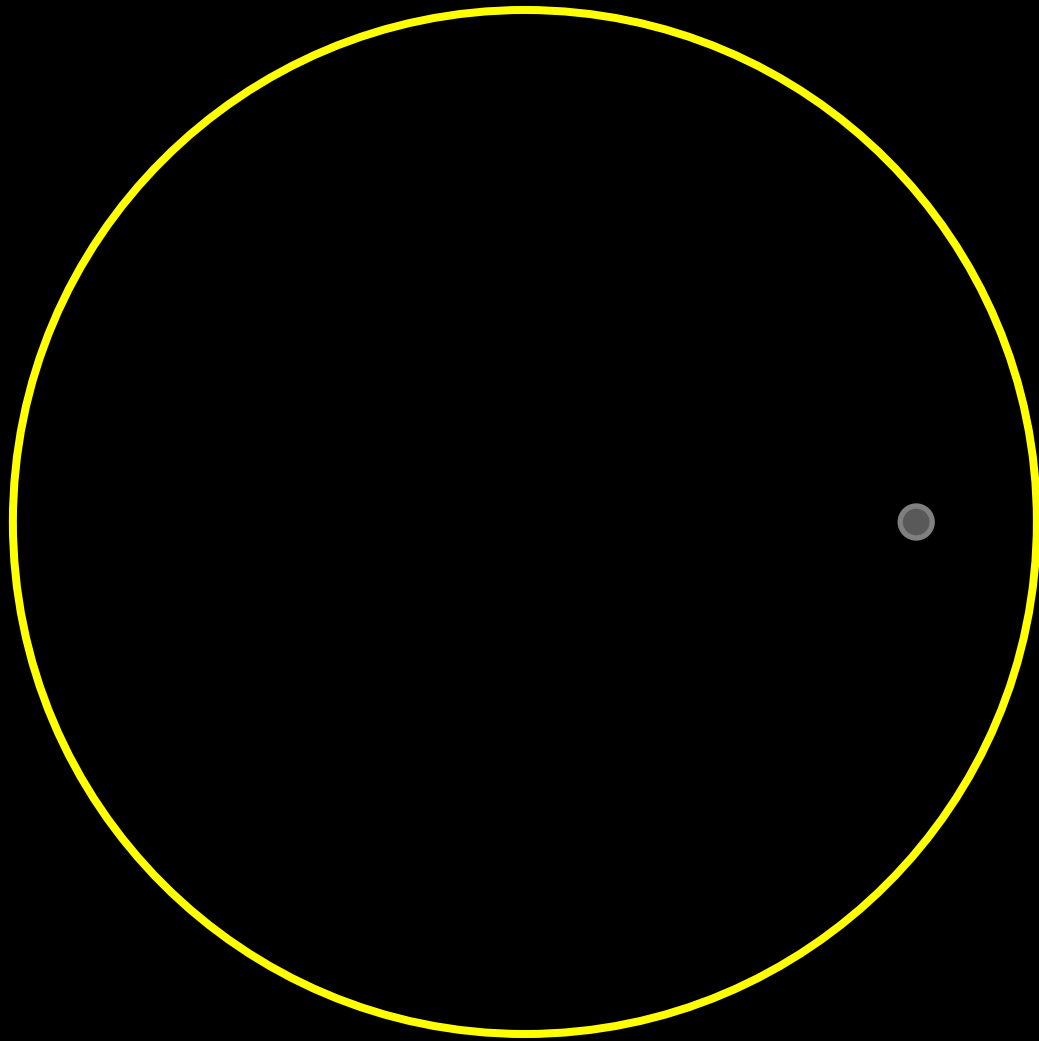


time 10





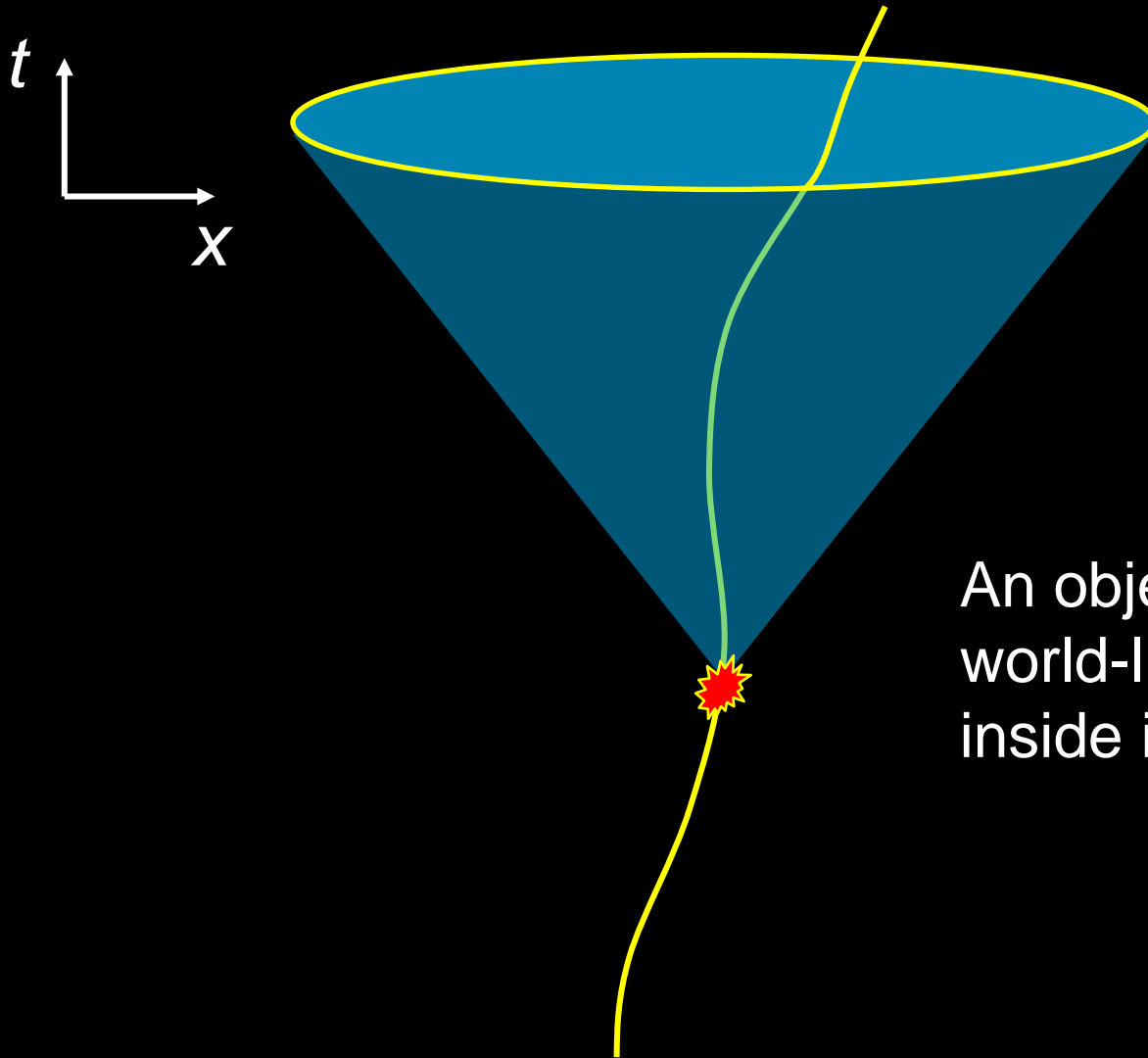






Particle must always
remain inside its own
light bubble.

The spacetime view

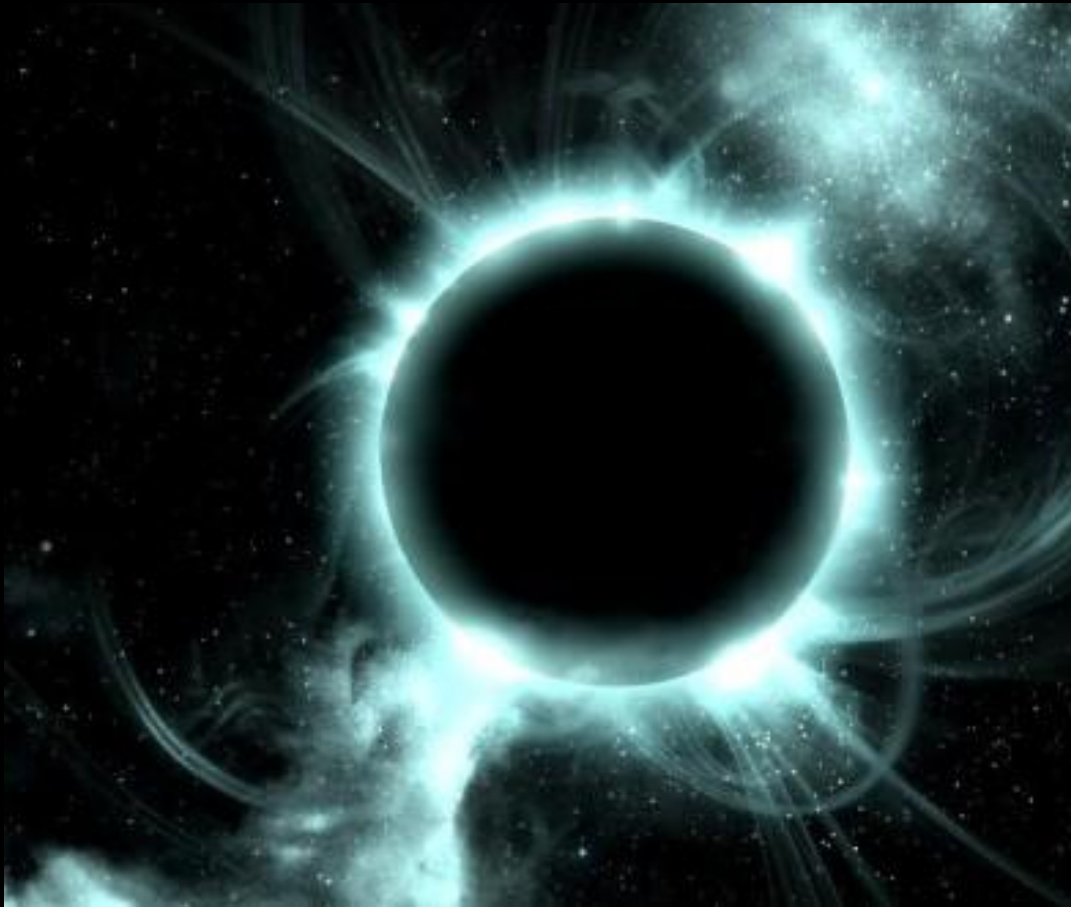


An object's future world-line always lies inside its **light cone**.

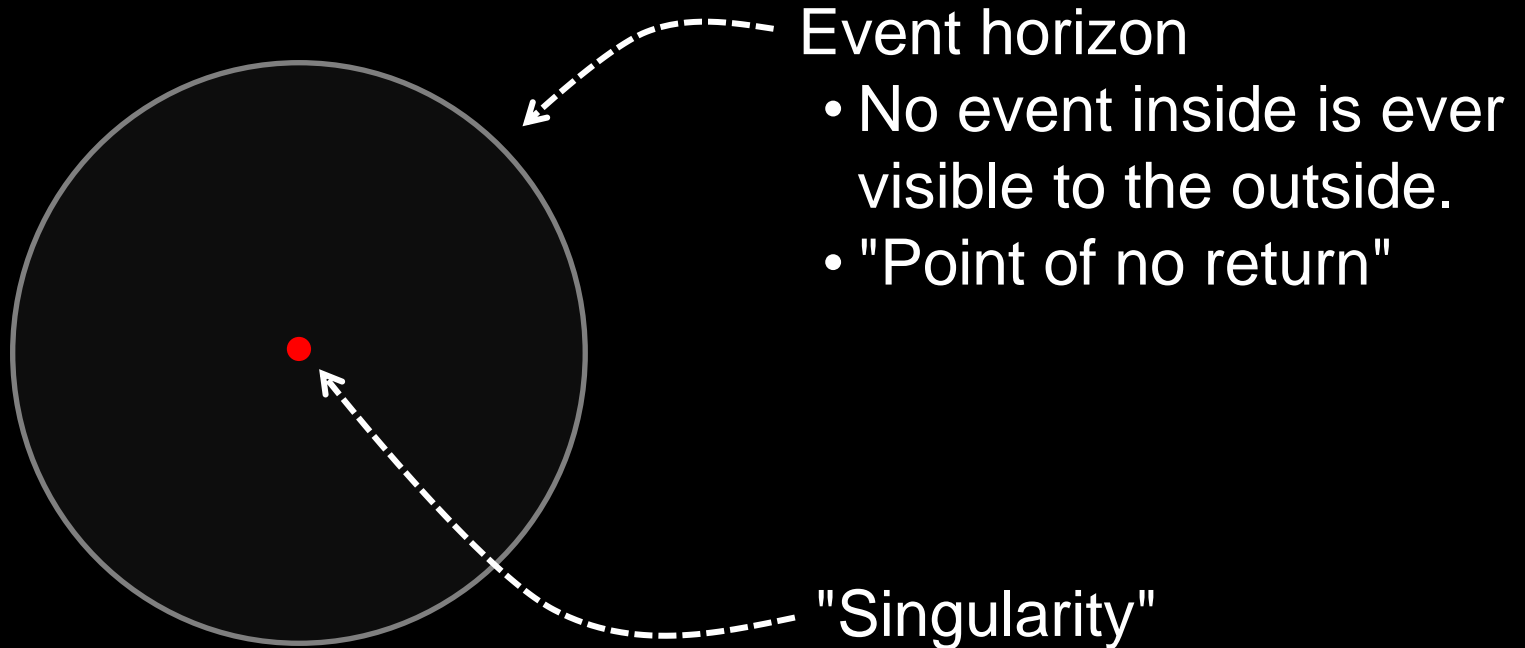
Five Escape from a black hole

"Well, in **our** country," said Alice, still panting a little, "you'd generally get to somewhere else -- if you ran very fast for a long time, as we've been doing."

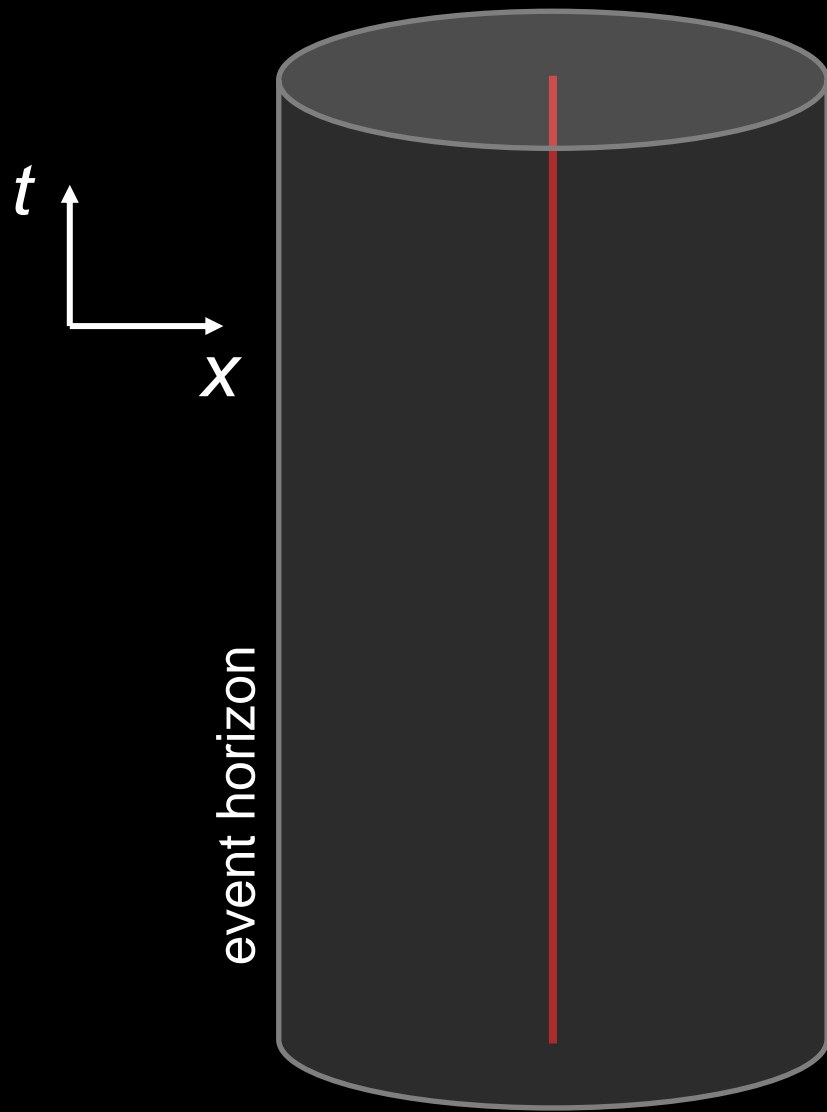
"A slow sort of country!" said the Queen. "Now, **here**, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!"



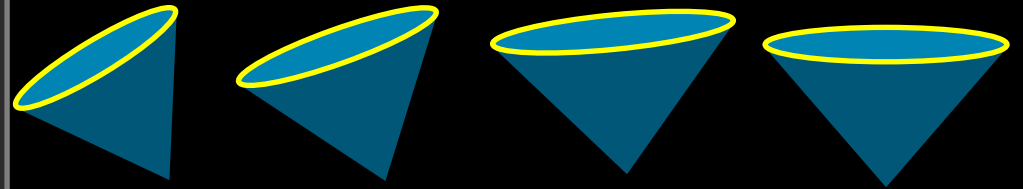
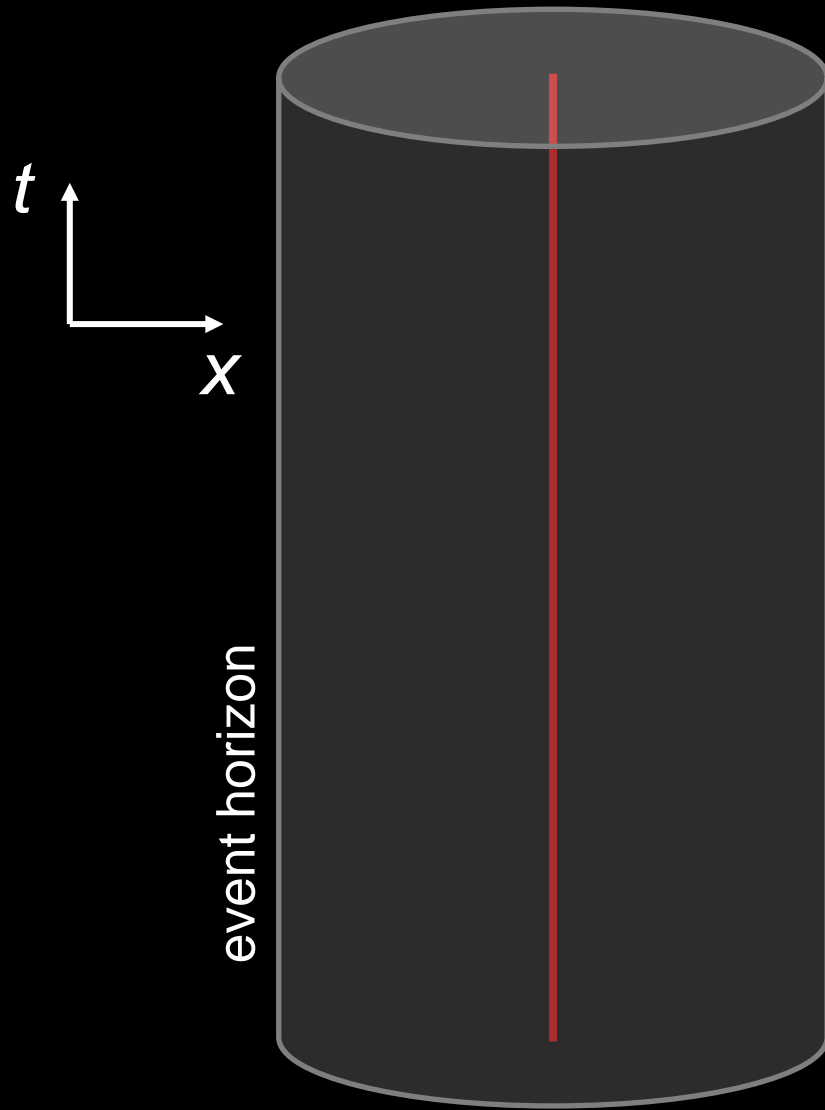
Black hole anatomy



Black hole anatomy

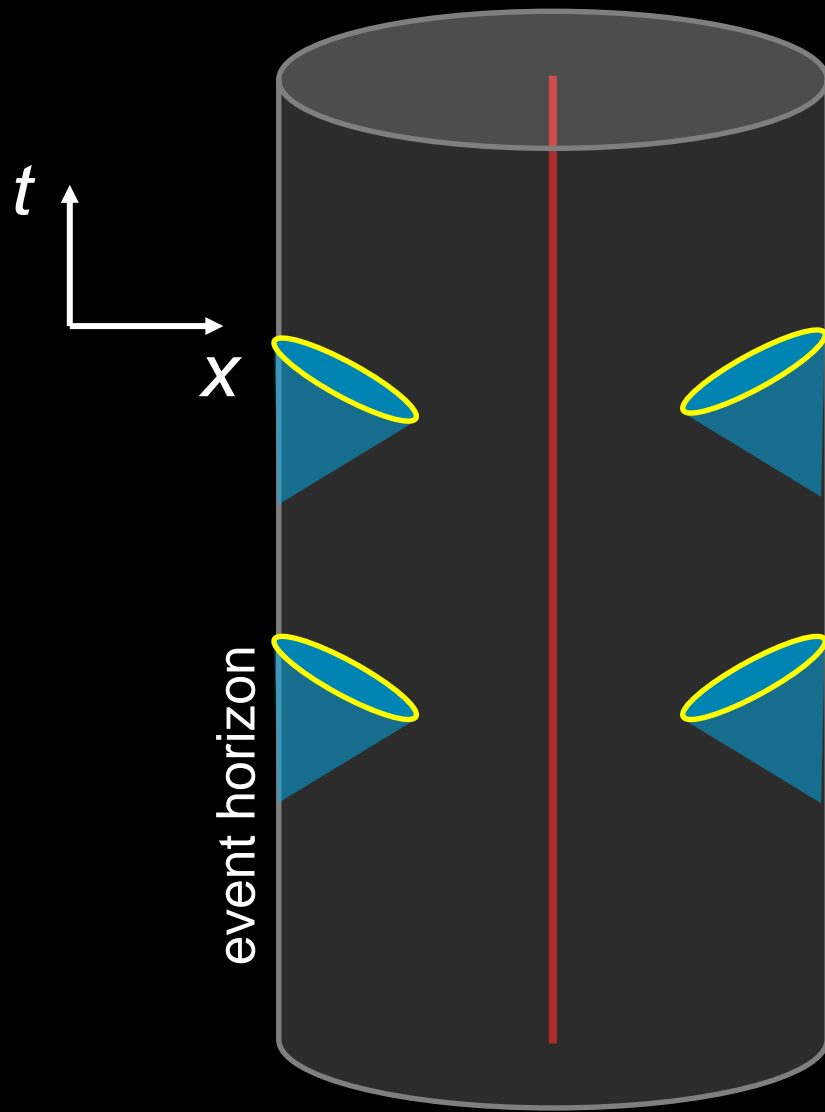


Black hole anatomy

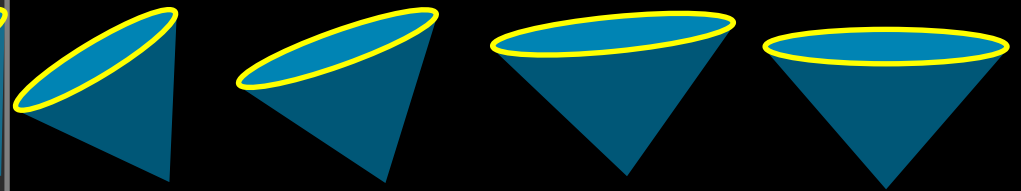


Black hole gravity distorts spacetime geometry. Light cones "tilt inward" near black hole.

Black hole anatomy

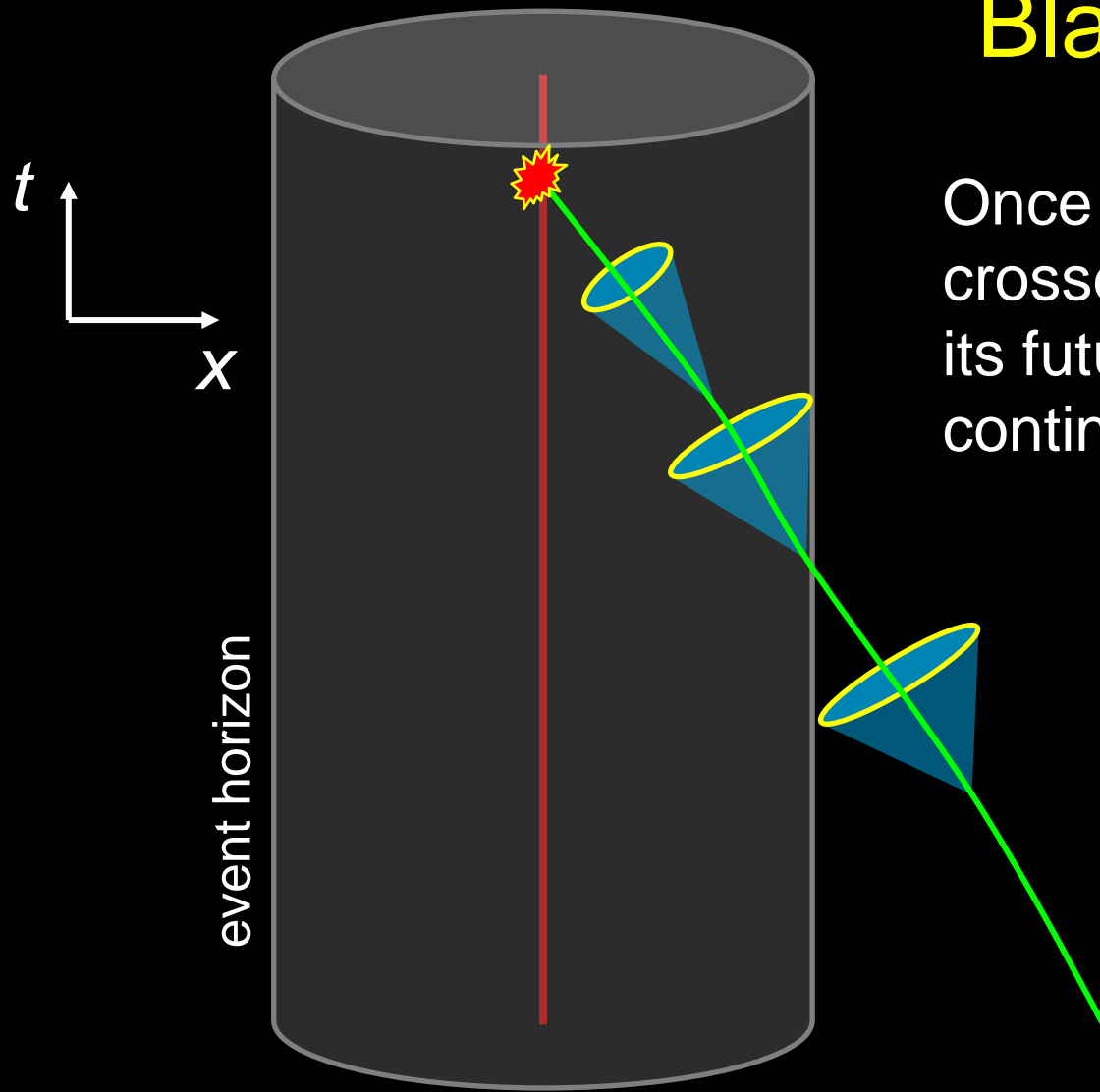


Event horizon consists of trapped "outward moving" light rays.



Black hole gravity distorts spacetime geometry. Light cones "tilt inward" near black hole.

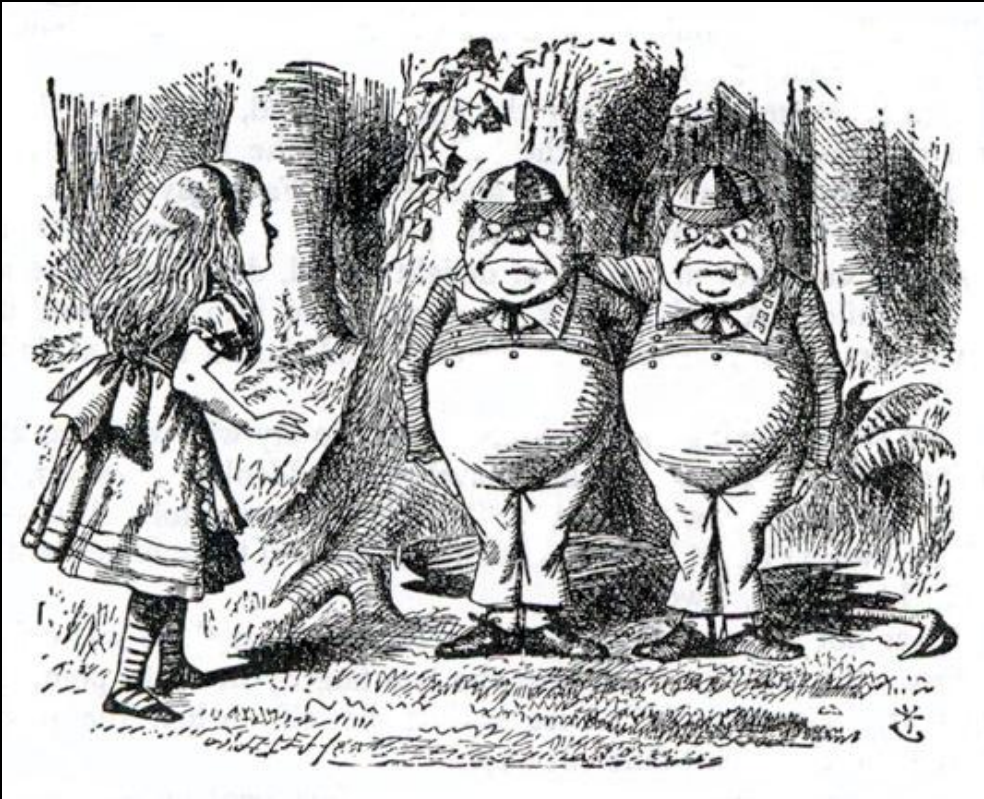
Black hole anatomy



Once an in-falling body crosses the event horizon, its future world line **must** continue inward.

Otherwise, it would "go faster than light"

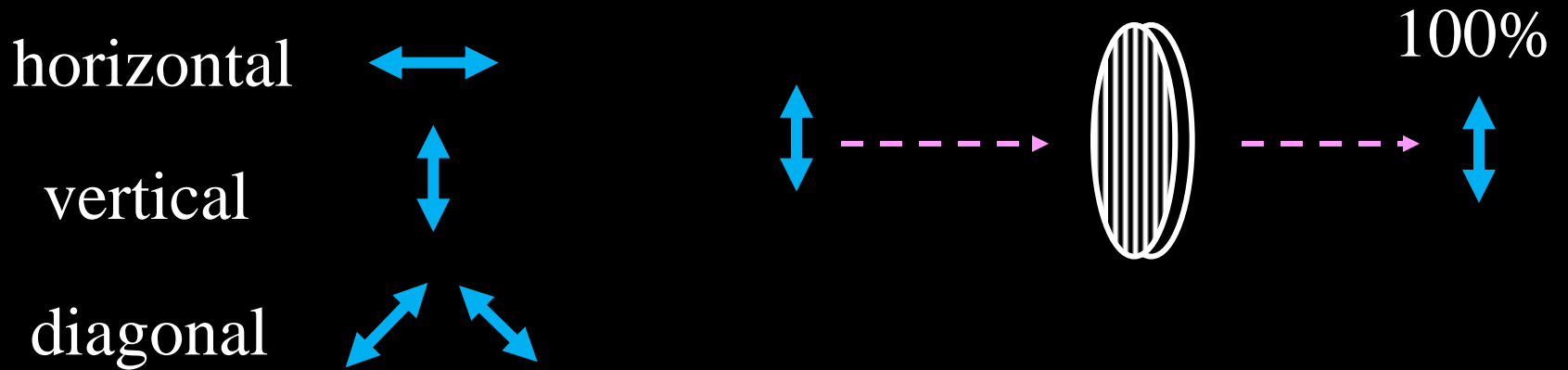
Six Quantum cloning



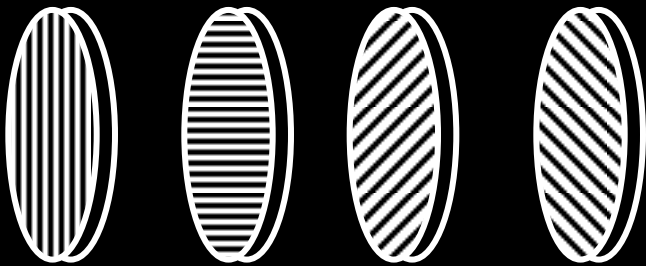
"Ditto," said Tweedledum.

"Ditto, ditto!" cried Tweedledee.

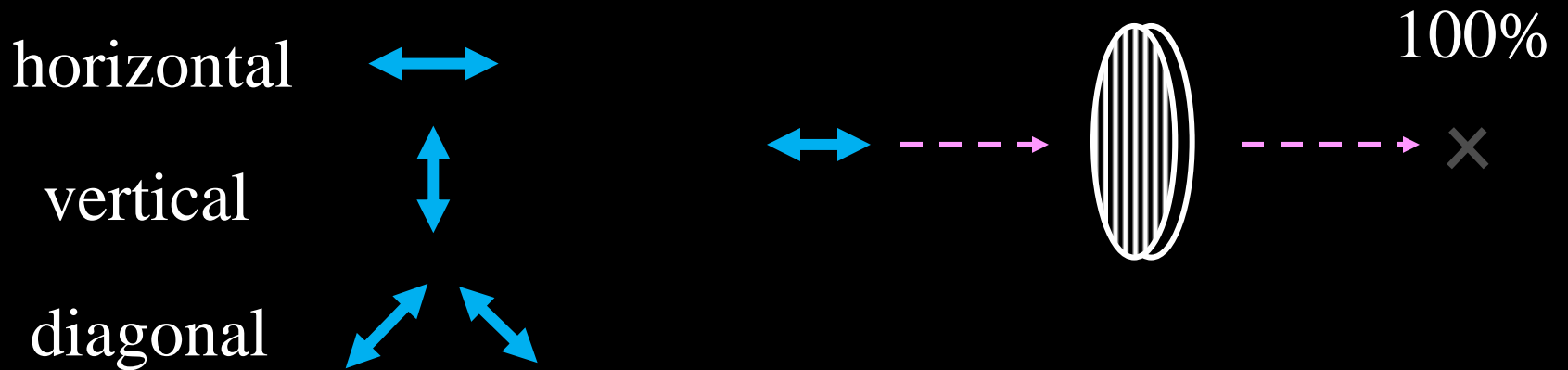
Photon polarization



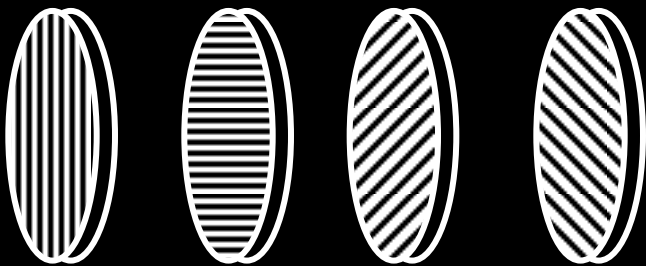
Filters



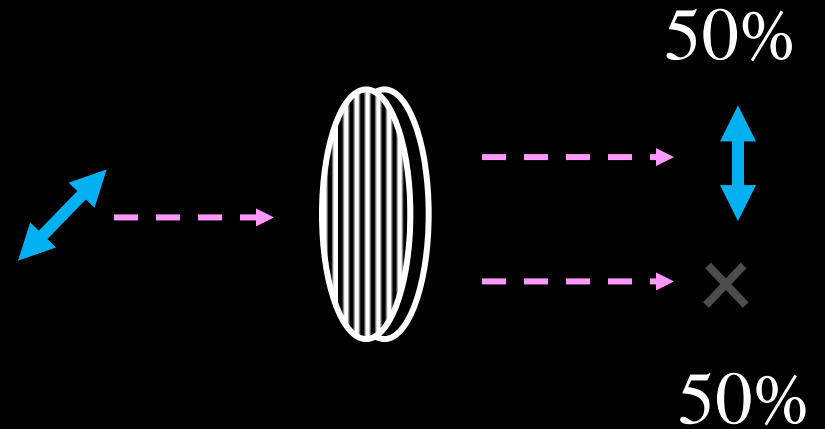
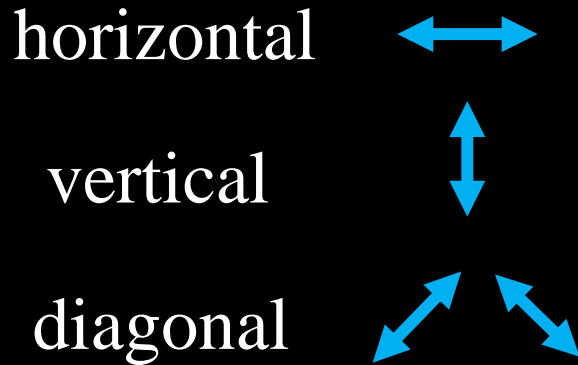
Photon polarization



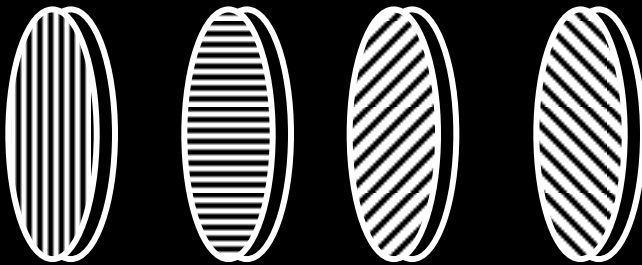
Filters



Photon polarization



Filters



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

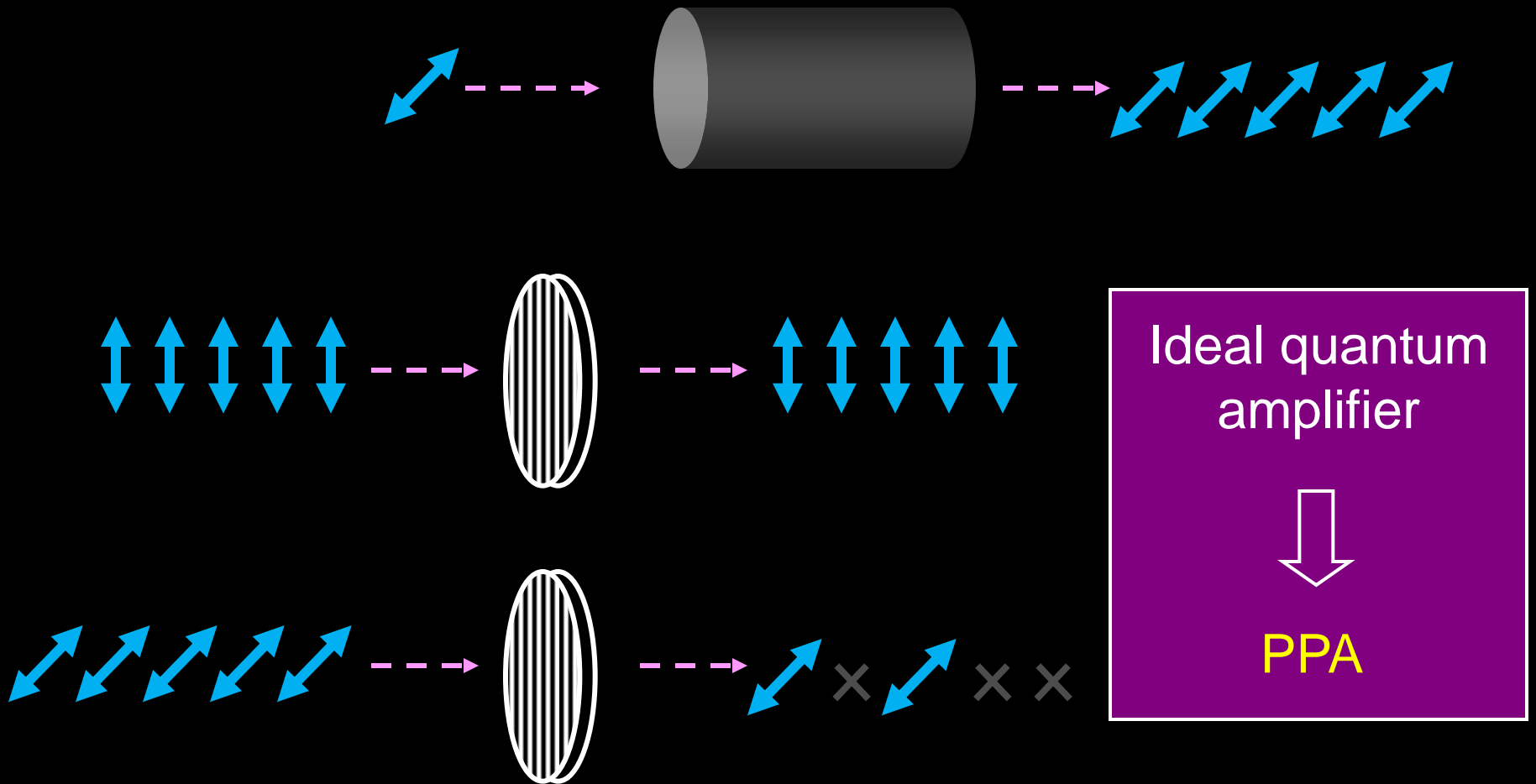
A photon amplifier?



A photon amplifier?



A photon amplifier?

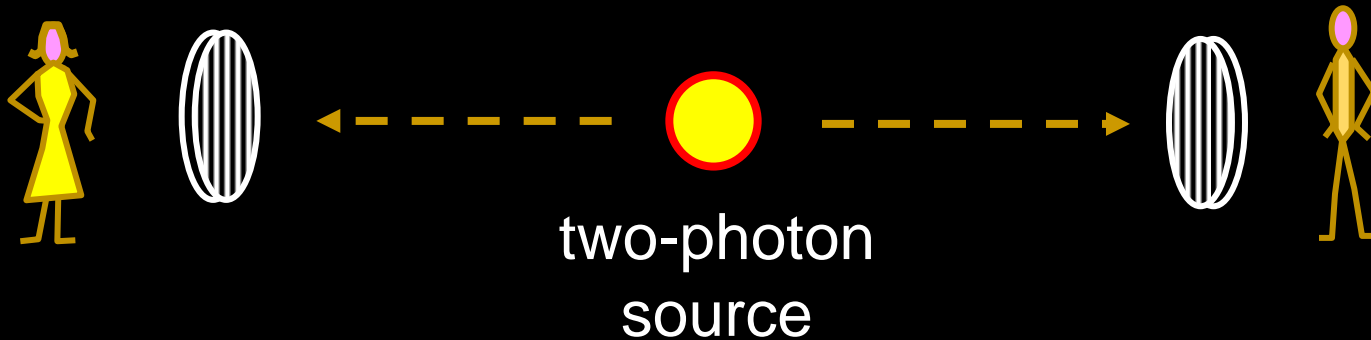


Quantum cloning



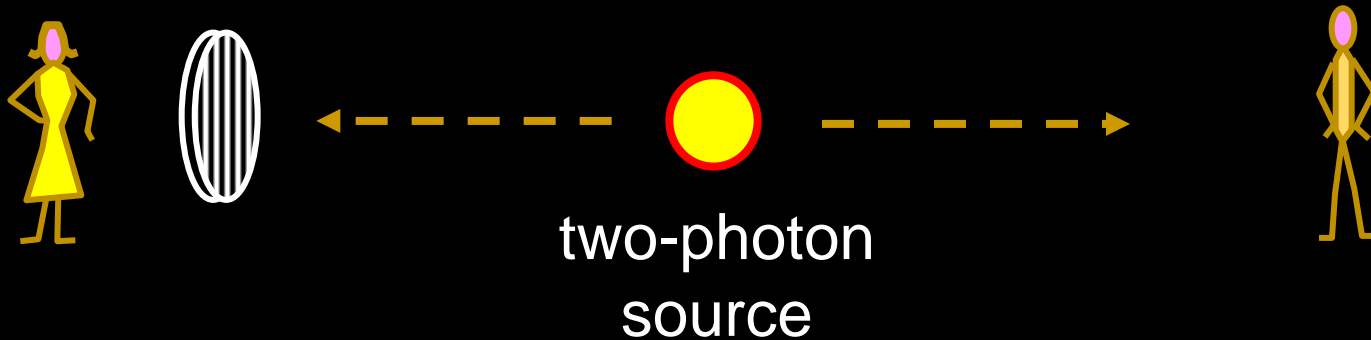
"Quantum information cannot be perfectly copied."

Quantum entanglement



Same measurements on both sides always lead to **opposite** results.

Quantum entanglement

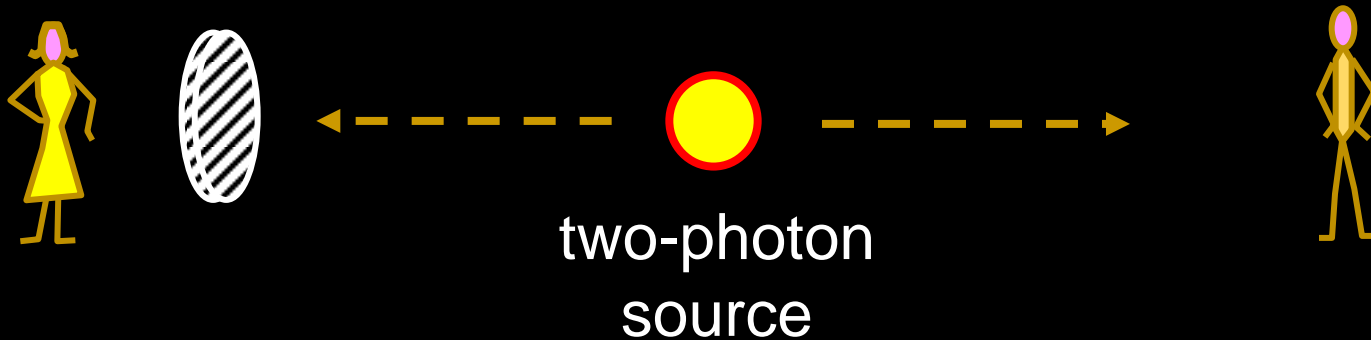


Alice sets her polarizer vertically.

Then Bob receives

50%  and 50% 

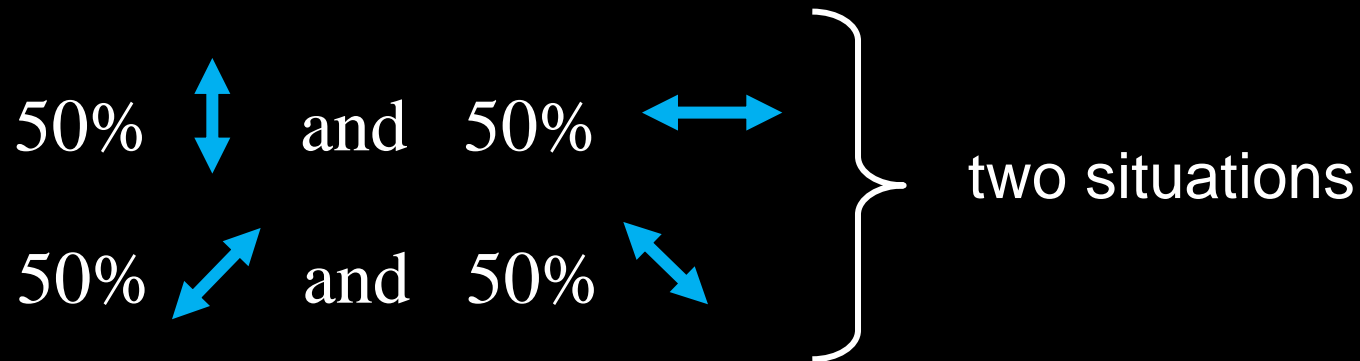
Quantum entanglement



Alice sets her polarizer diagonally.
Then Bob receives

50% ↗ and 50% ↘

Faster than light!?



- Alice controls which of these Bob gets.
- Bob cannot tell them apart -- without a **PPA!**
- Given a PPA, Alice can send Bob an **instantaneous message** -- i.e., she can send information faster than light!

Seven Bounded Electromagnetic Miracles



She ate a little bit, and said anxiously to herself "Which way? Which way?", holding her hand on the top of her head to feel which way it was growing; and she was quite surprised to find that she remained the same size. To be sure, this is what generally happens when one eats cake; but Alice had got so much into the way of expecting nothing but out-of-the-way things to happen, that it seemed quite dull and stupid for life to go on in the common way.

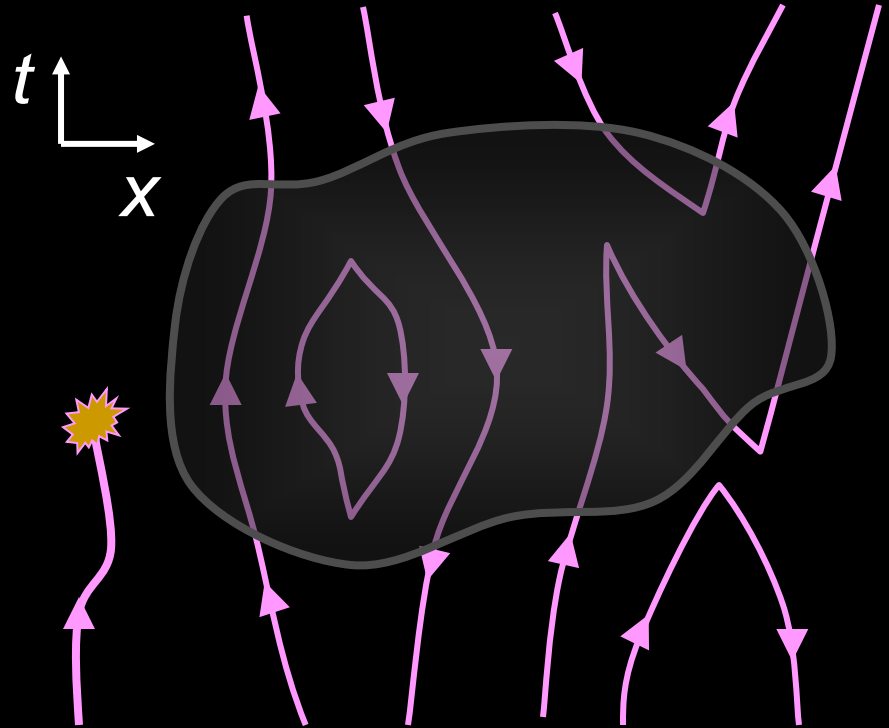
The conservation of charge

No process can create or destroy a net electric charge.

Spacetime view

World lines of unit charges.
Arrows tell + or - charge.

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

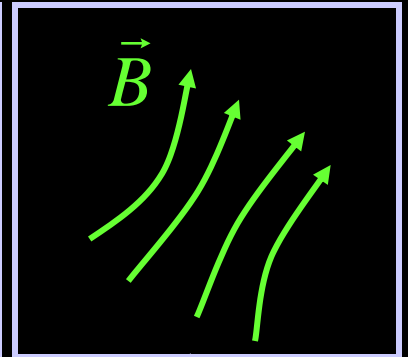
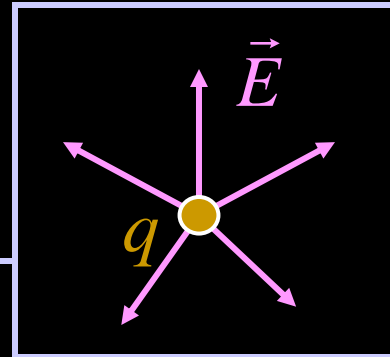


Field equations

Maxwell equations

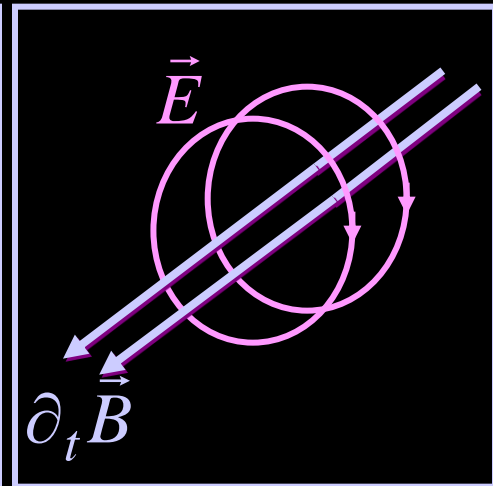
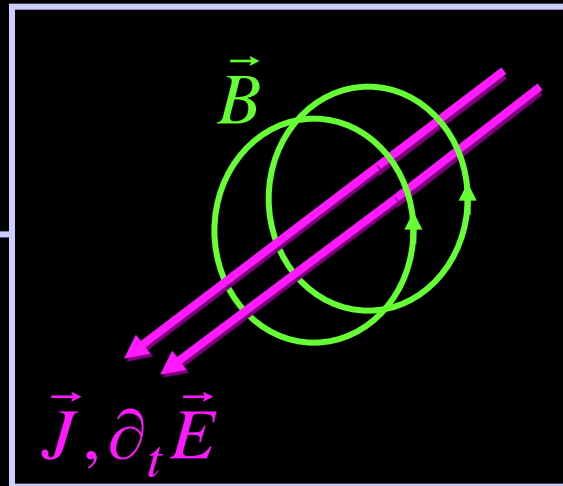
$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0}$$

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



$$\vec{\nabla} \times \vec{B} = \mu_0 \vec{J} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t}$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$



Field equations

Maxwell equations

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0}$$

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

$$\vec{\nabla} \times \vec{B} = \mu_0 \vec{J} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t}$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

Wonderful fact:
Maxwell equations *imply*
conservation of charge.

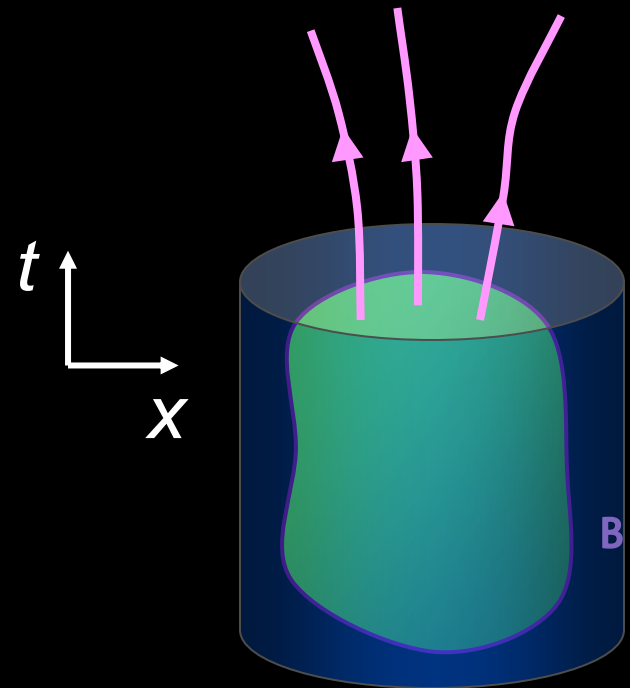
Bounded miracles

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

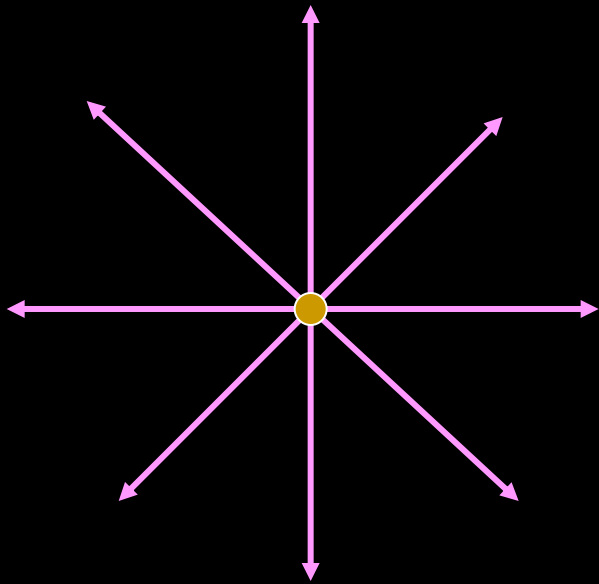
Bounded electromagnetic miracle (BEM): Maxwell equations are true *except* in a limited region of space and time.

Is a BEM enough to violate conservation of charge?

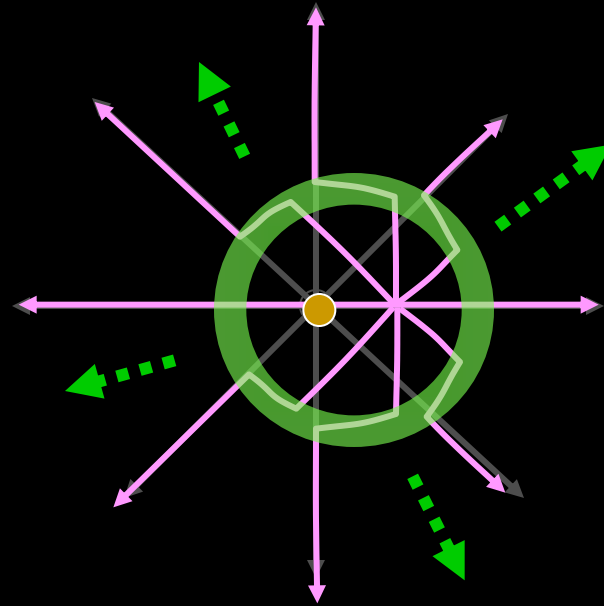
No!



Why not?

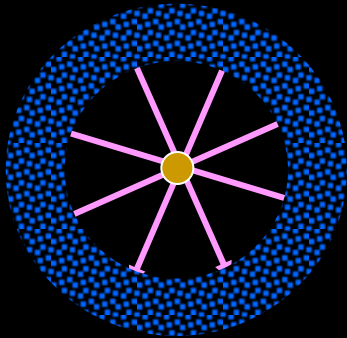


Charge surrounded
by radial E-field.



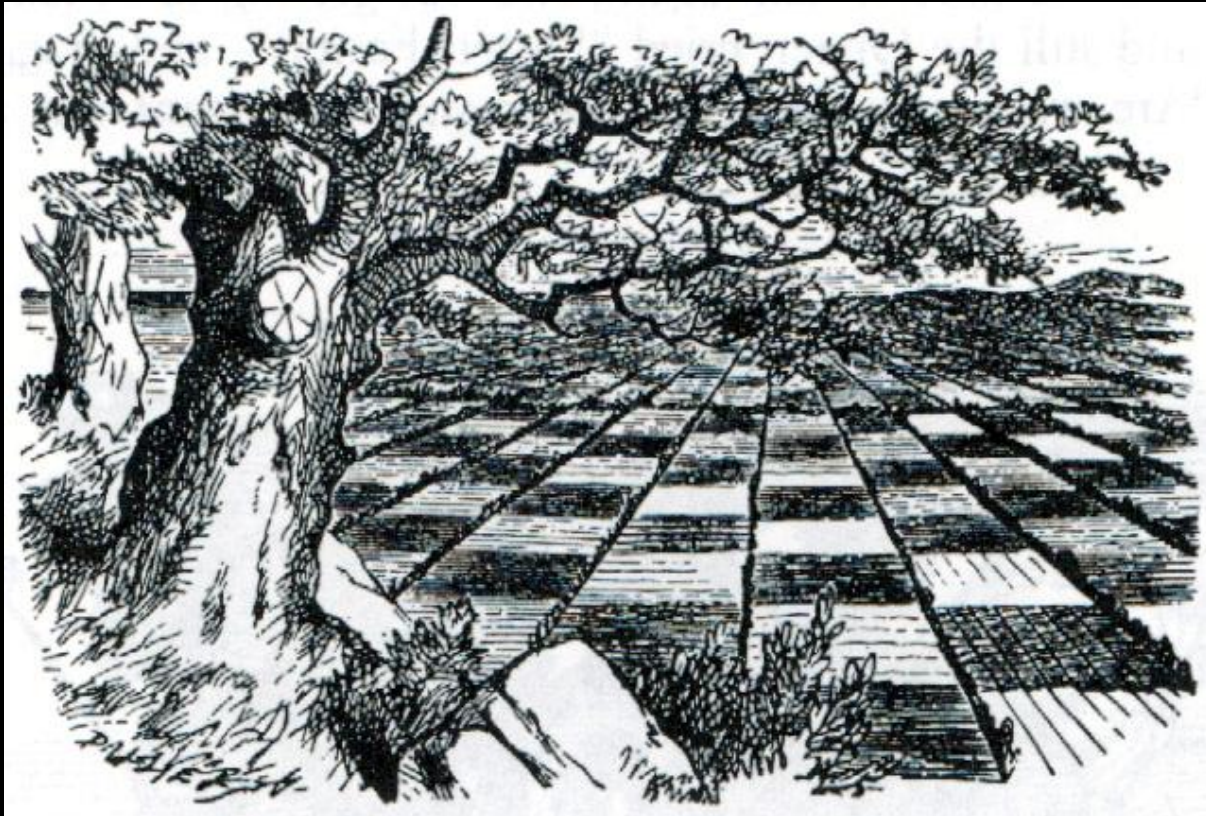
Field changes when
charge moves.
Only **transverse** changes
can propagate outward.

Charge from nowhere?



No field. Now a 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!

Postscript
A map of the world

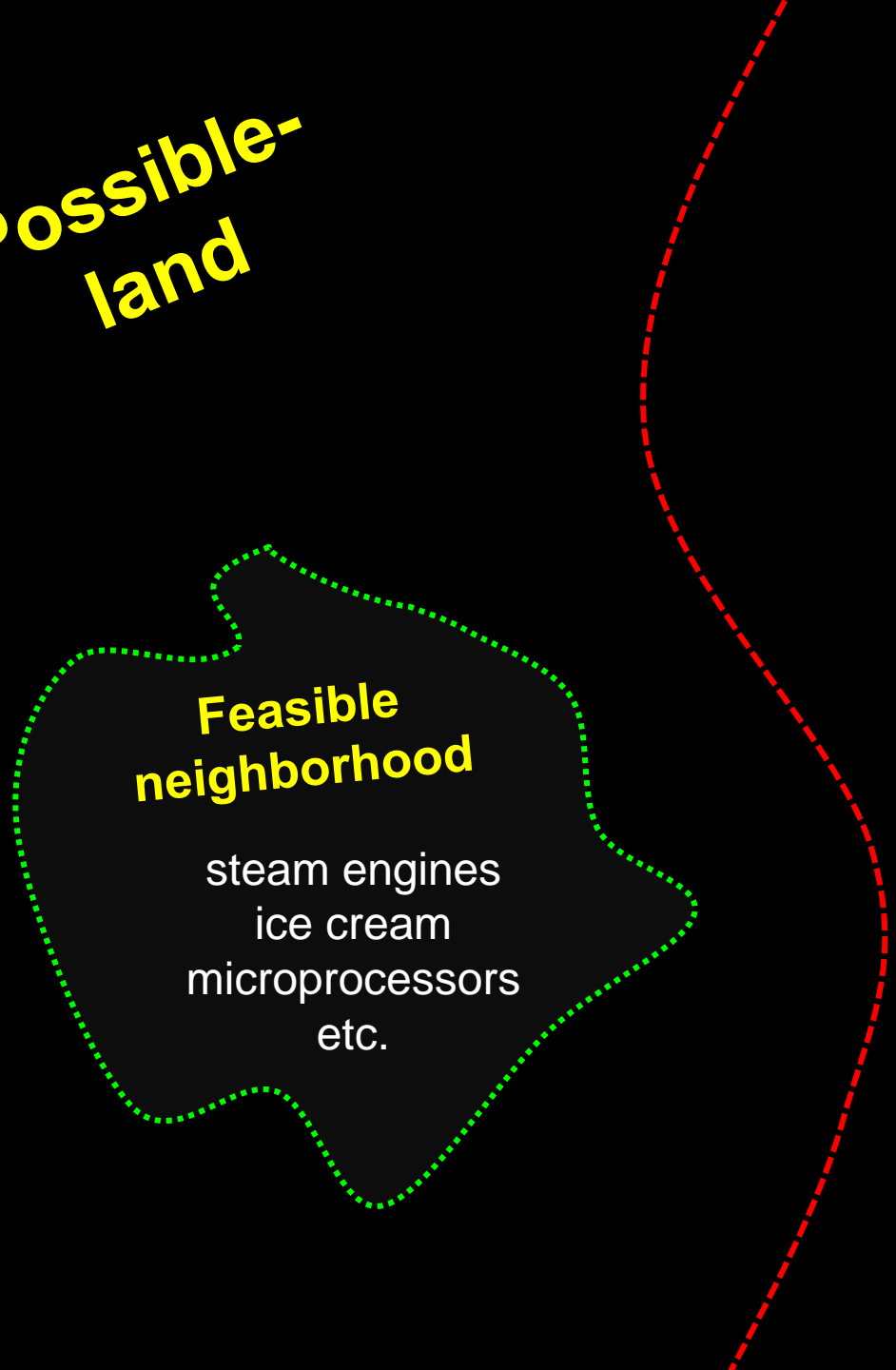


**Possible-
land**

**Impossible-
land**

**Feasible
neighborhood**

steam engines
ice cream
microprocessors
etc.



Possible-land

Impossible-land

Feasible neighborhood

steam engines
ice cream
microprocessors
etc.

Perpetual motion machine (2nd kind)

Cloning quantum particles

Escaping from inside a black hole

Perfect polarization analyzer (PPA)

Sending information faster than c

Time travel (into the past)

Sending information into the past

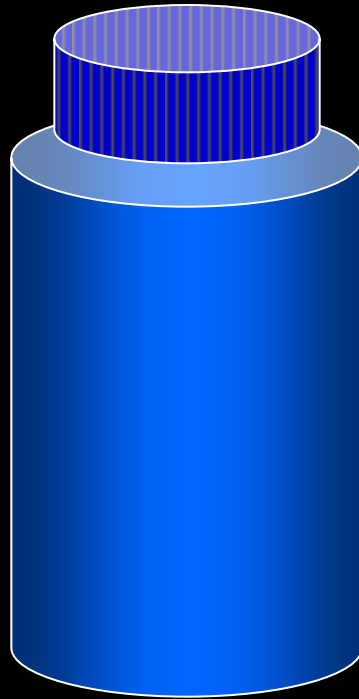
Ultra computers



"I know what you're thinking about," said Tweedledum; "but it isn't so, nohow."

"Contrariwise," continued Tweedledee, "if it was so, it might be; and if it were so, it would be; but as it isn't, it ain't. That's logic."

The thermos bottle joke



Finis