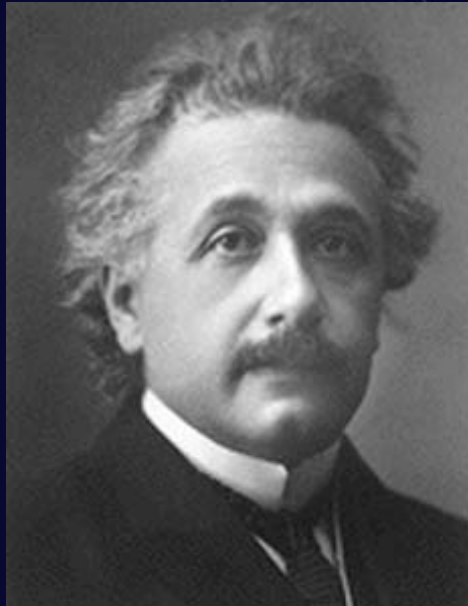


Einstein's Universe

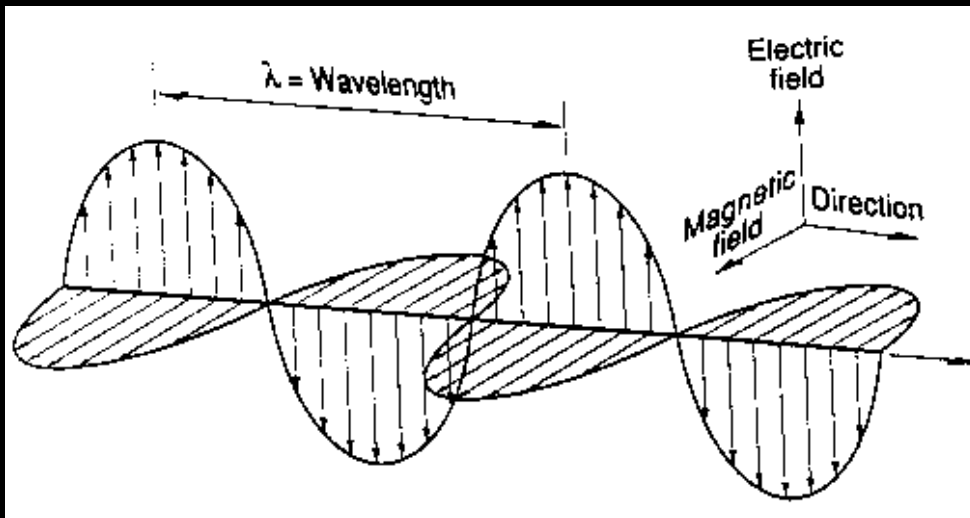
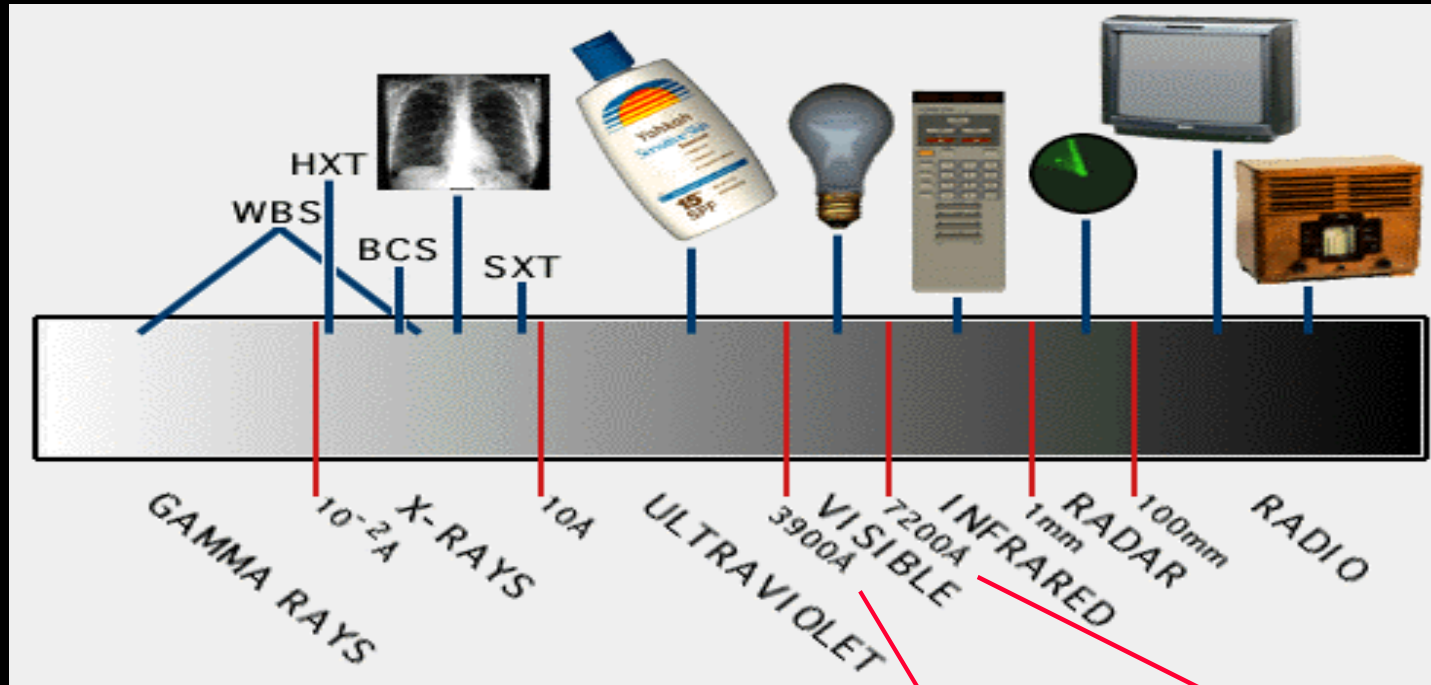


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GLASGOW



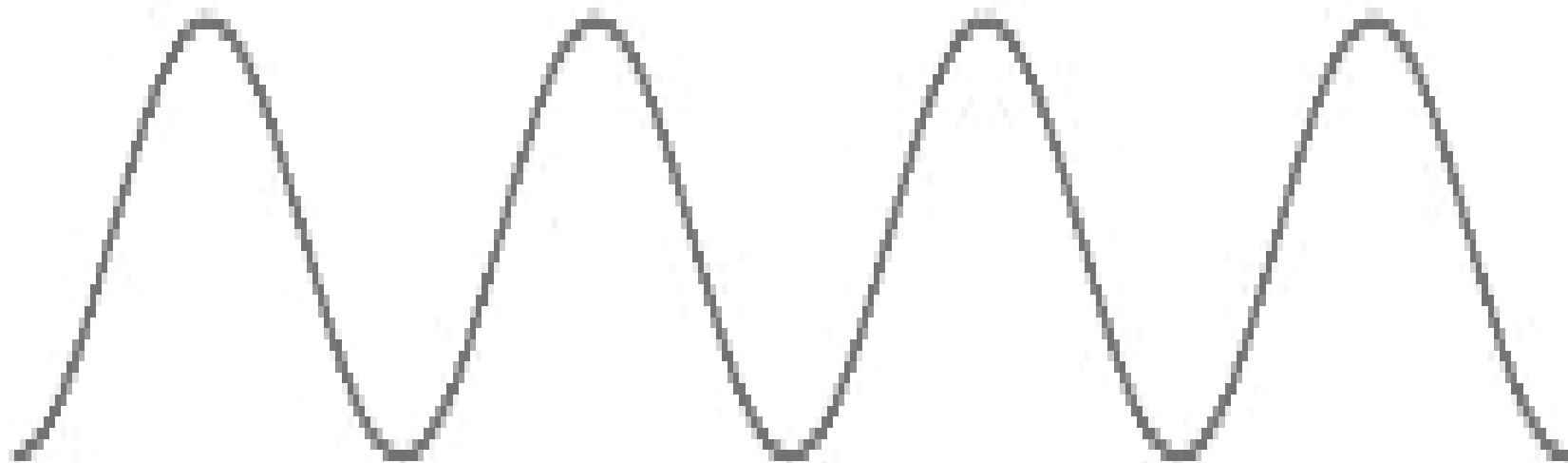
Dr Martin Hendry

*Dept of Physics and Astronomy
University of Glasgow, UK*

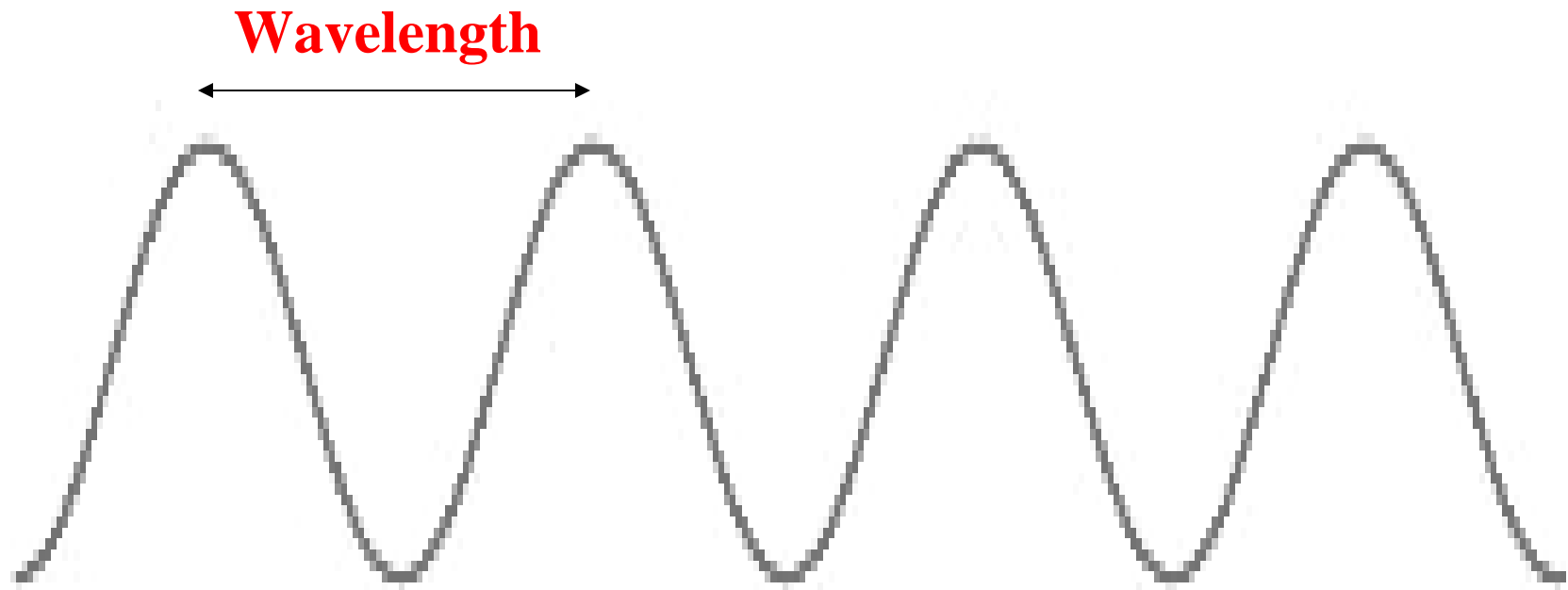


The Electromagnetic Spectrum

Light waves

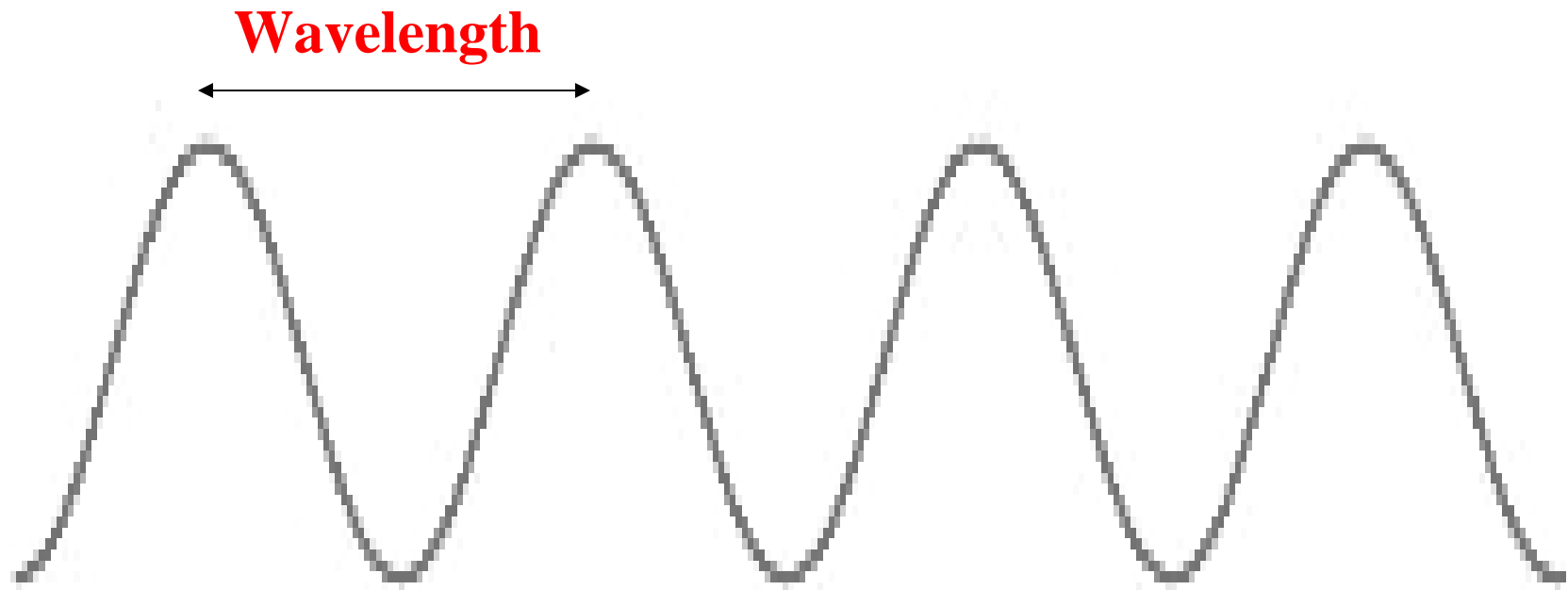


Light waves



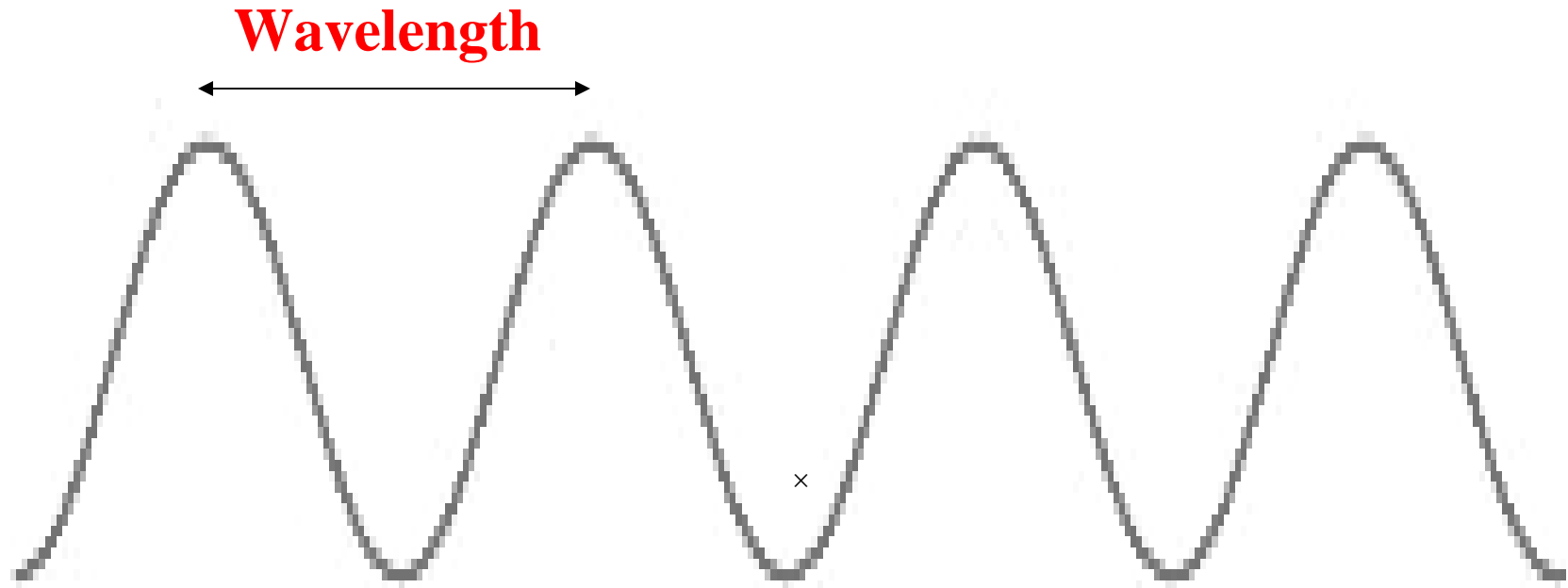
Frequency = No of waves produced
per second

Light waves



Frequency = 2450 MHz
= 2450 Million waves
per second

Light waves



$$\text{Speed} = 2450 \text{ million} \times \text{wavelength}$$







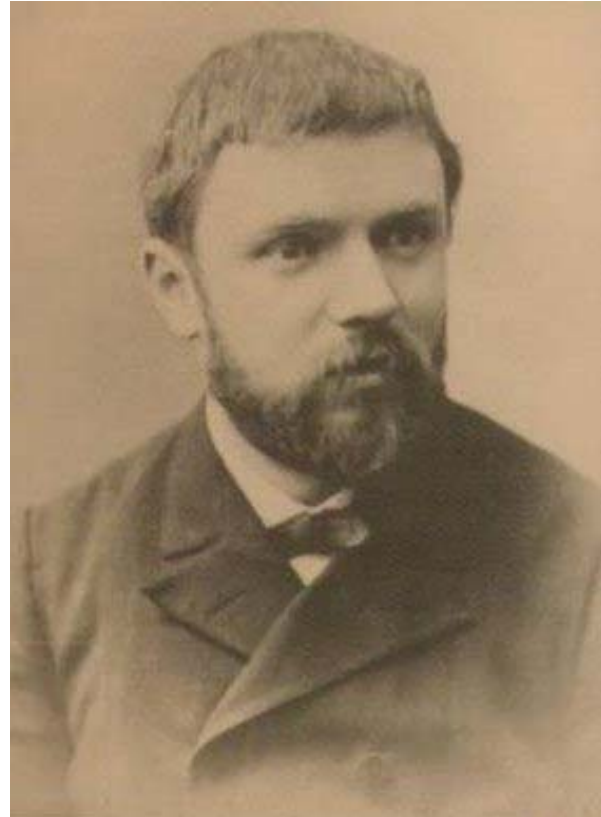
**Light travels 300,000 km every
Second.....**

**.....That's about 10 million,
million kilometres every year!!!**

Making Sense of Einstein's Universe



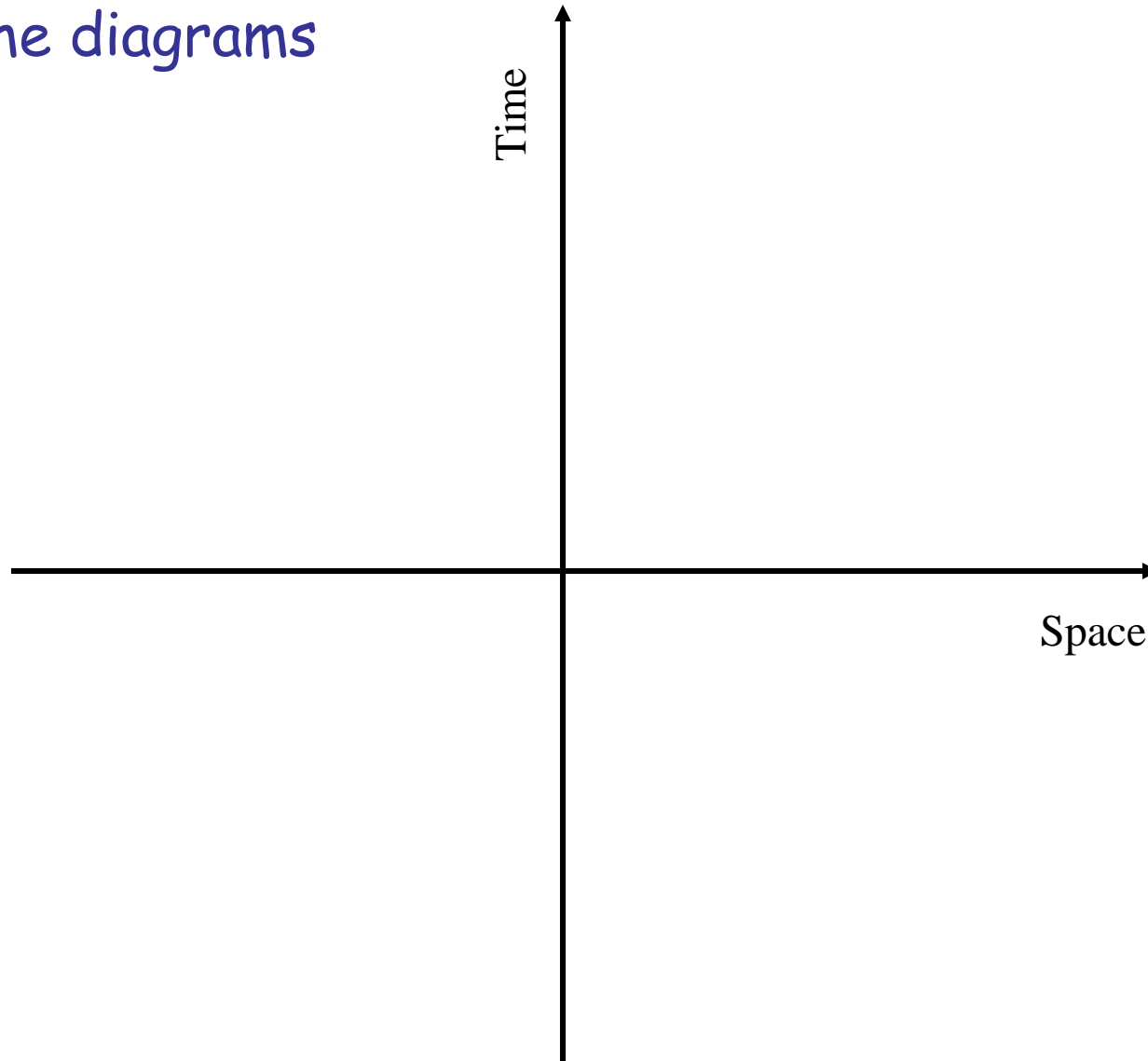
Hermann Minkowski



Henri Poincaré

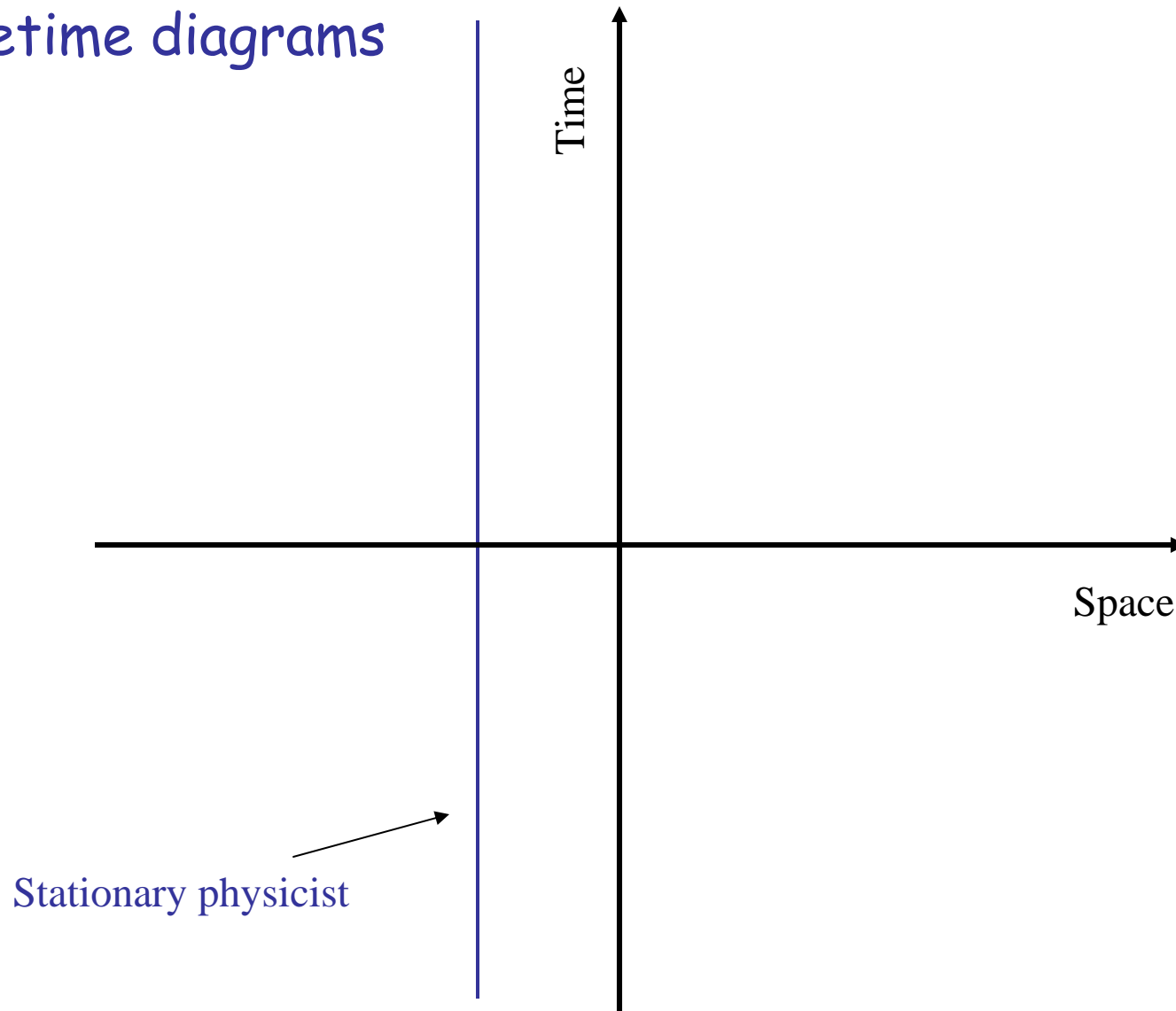
Making Sense of Einstein's Universe

Spacetime diagrams



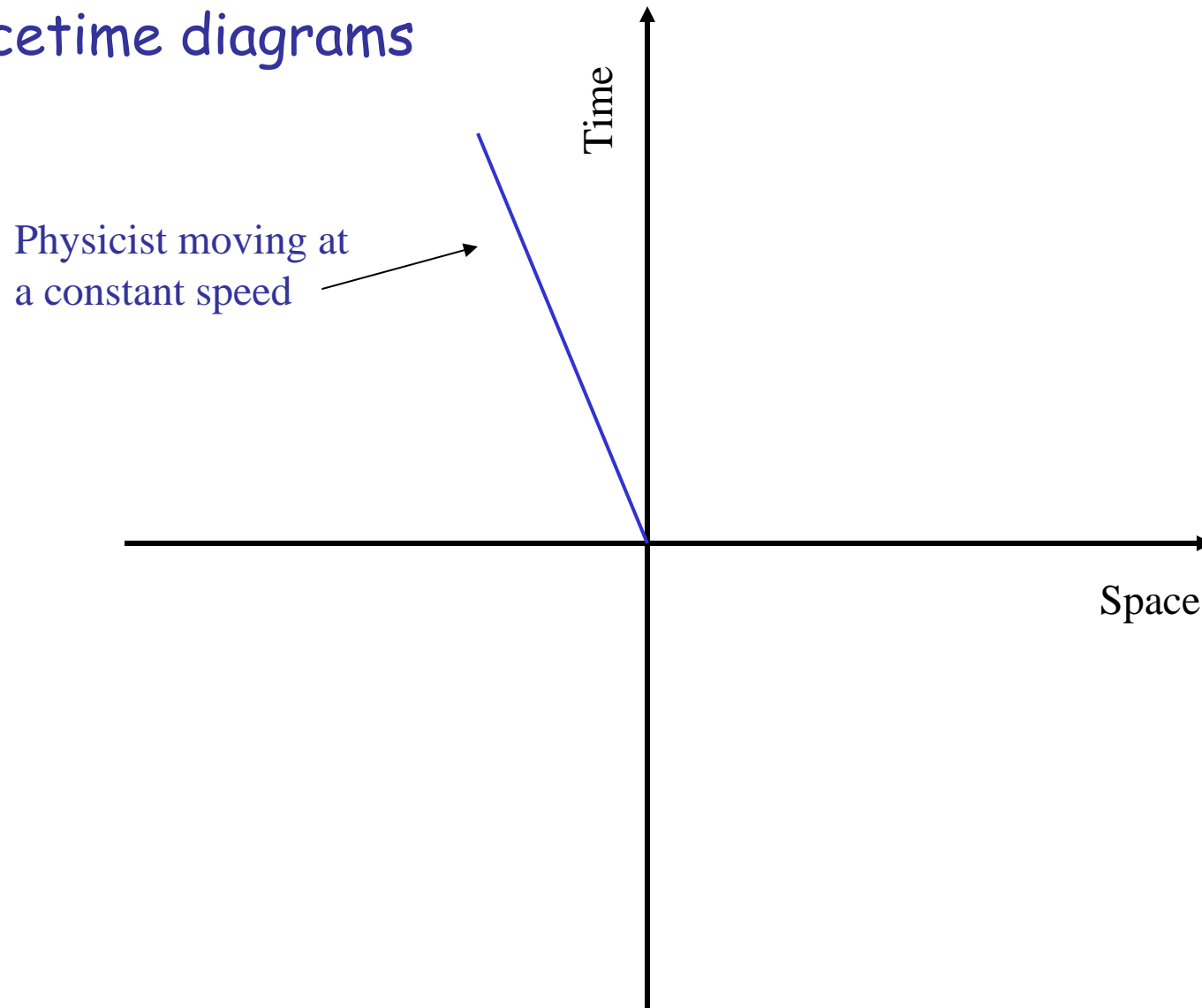
Making Sense of Einstein's Universe

Spacetime diagrams



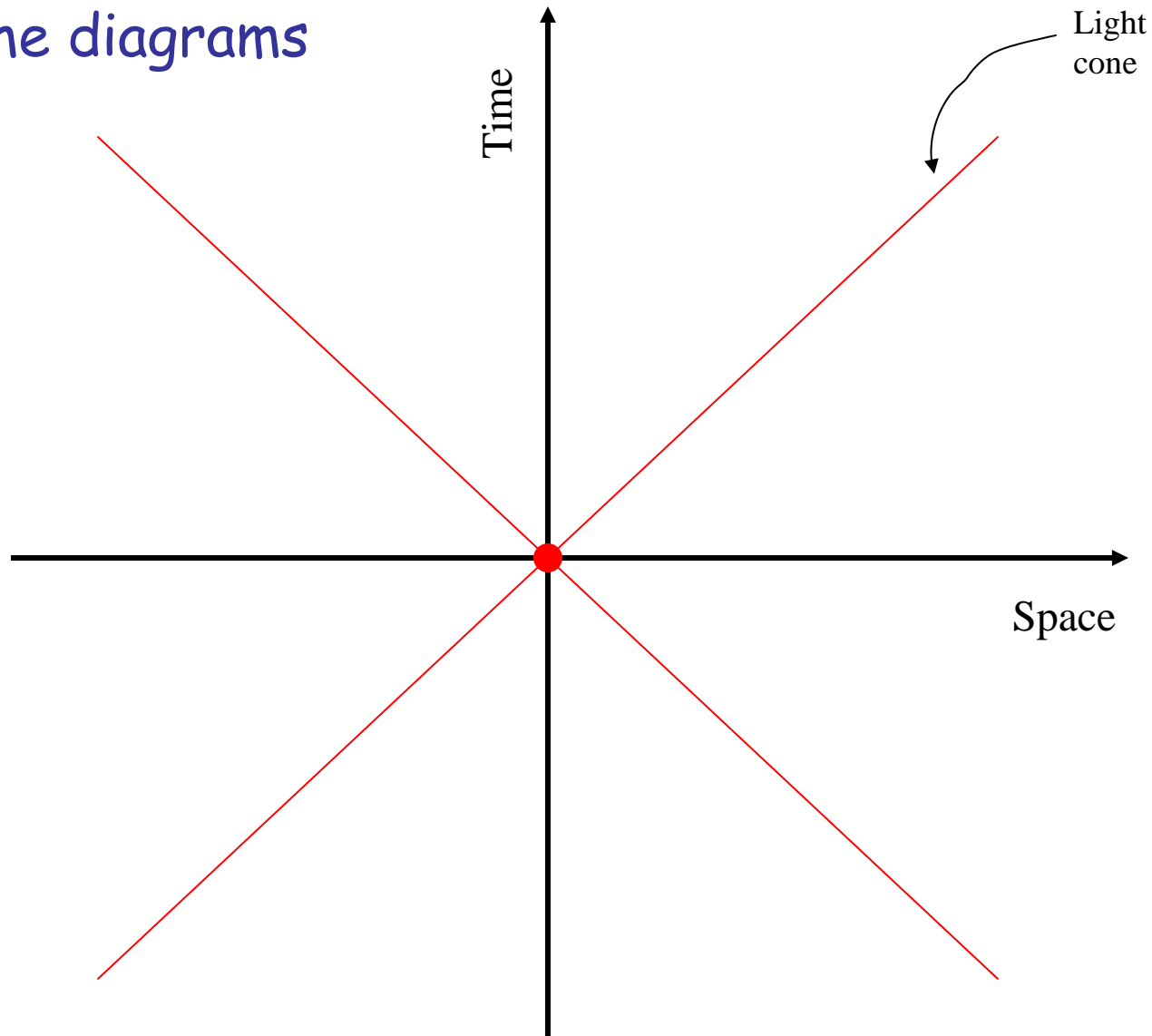
Making Sense of Einstein's Universe

Spacetime diagrams



Making Sense of Einstein's Universe

Spacetime diagrams



Making Sense of Einstein's Universe

Spacetime diagrams

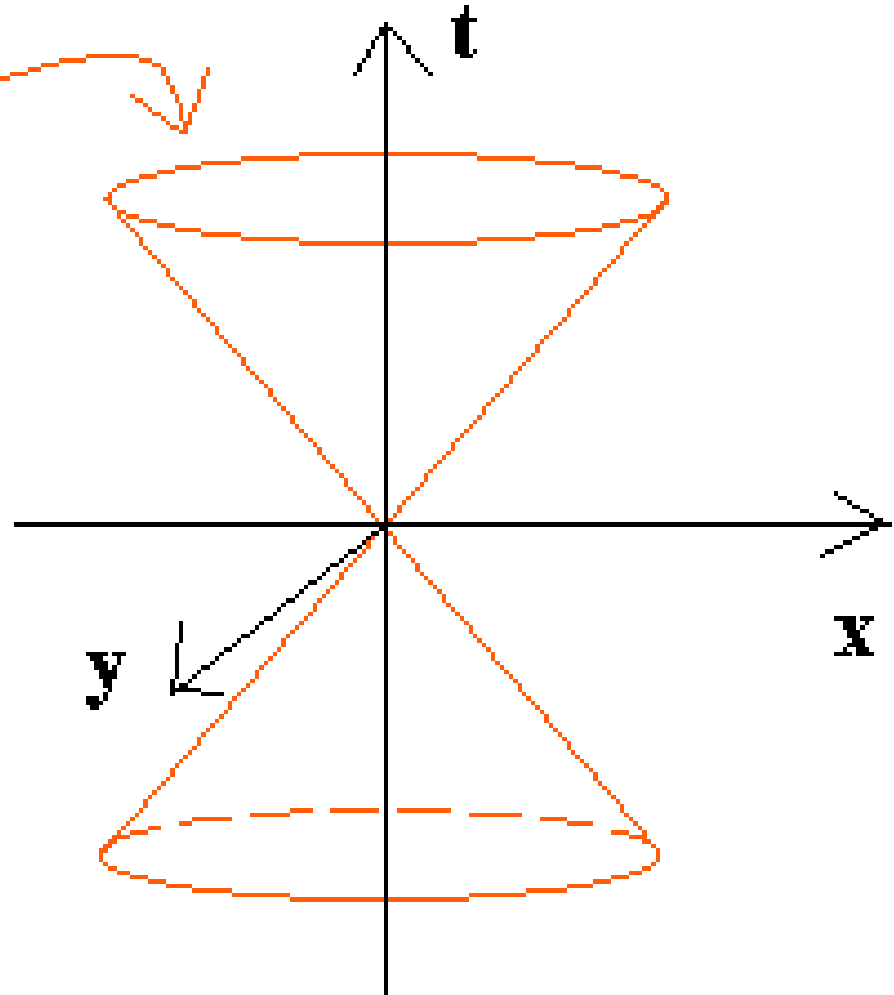
light cone

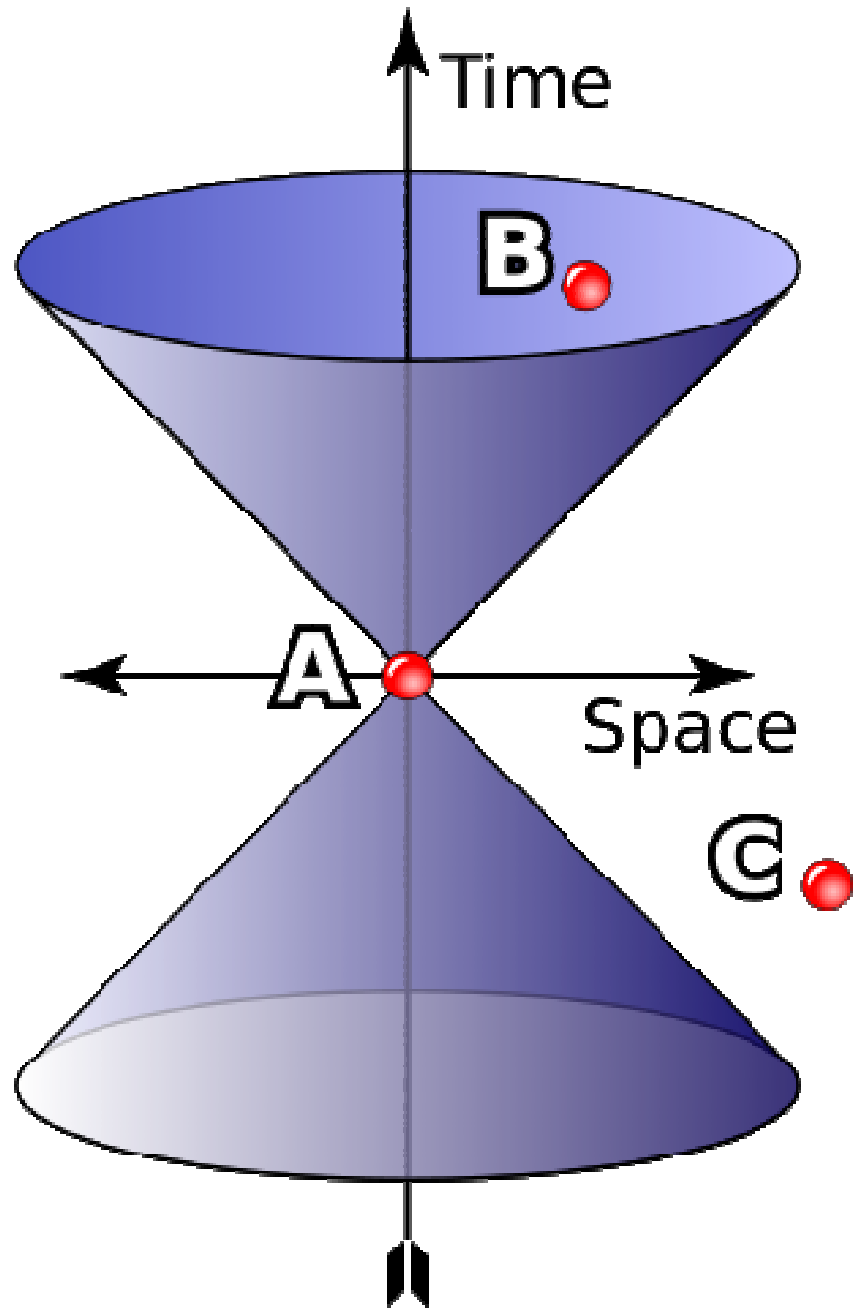
Intervals between events in spacetime can be:

timelike

spacelike

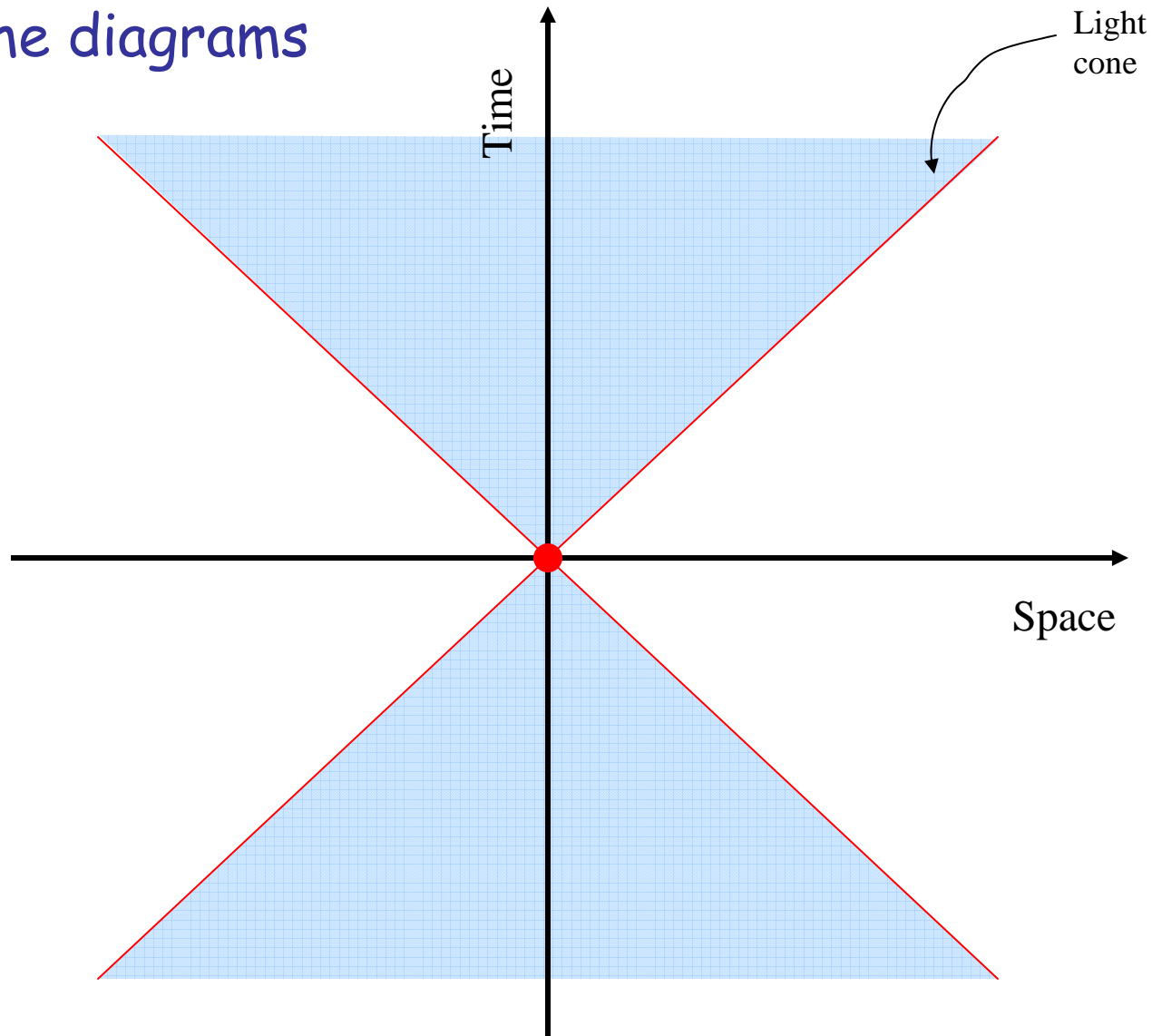
lightlike





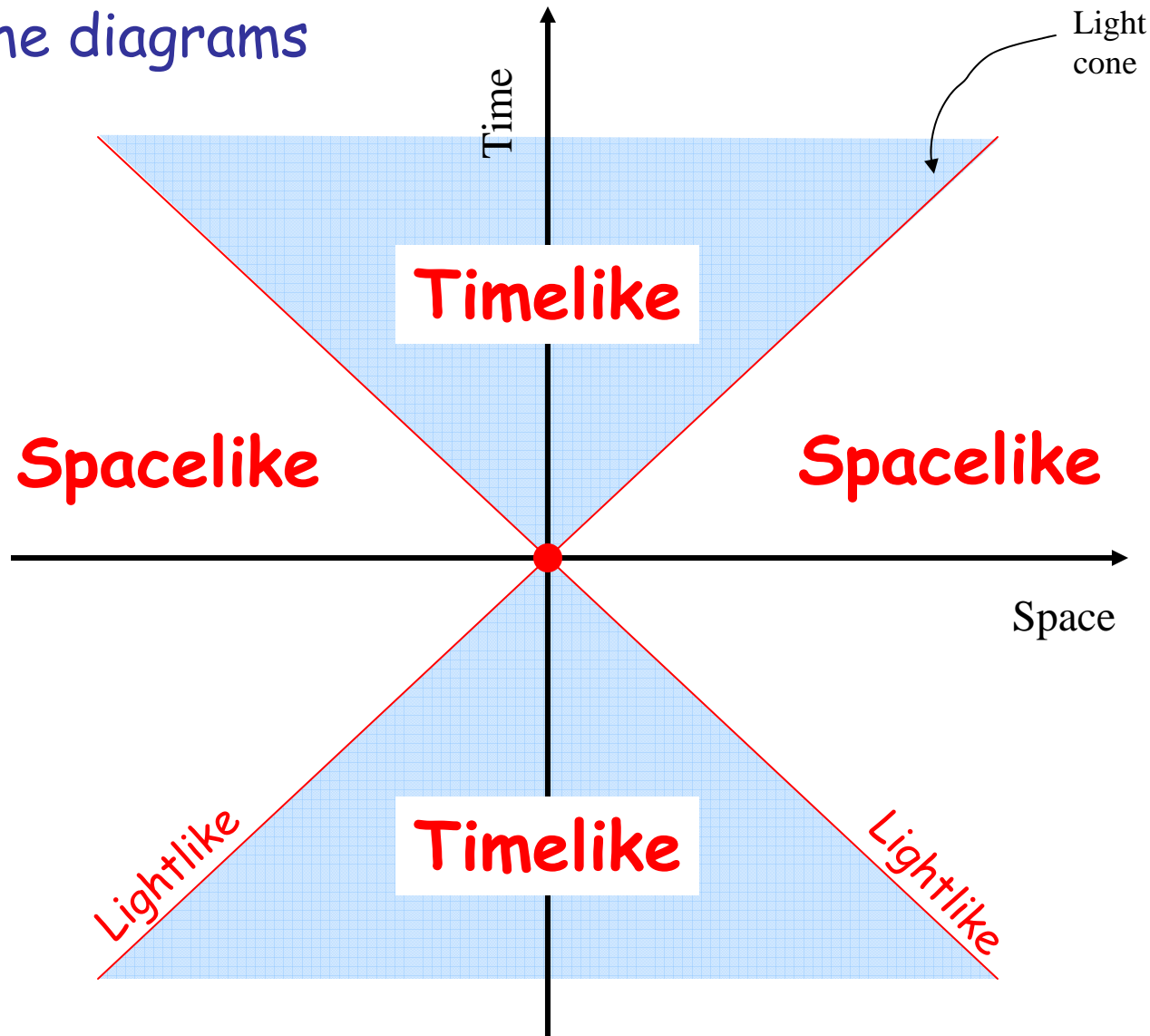
Making Sense of Einstein's Universe

Spacetime diagrams



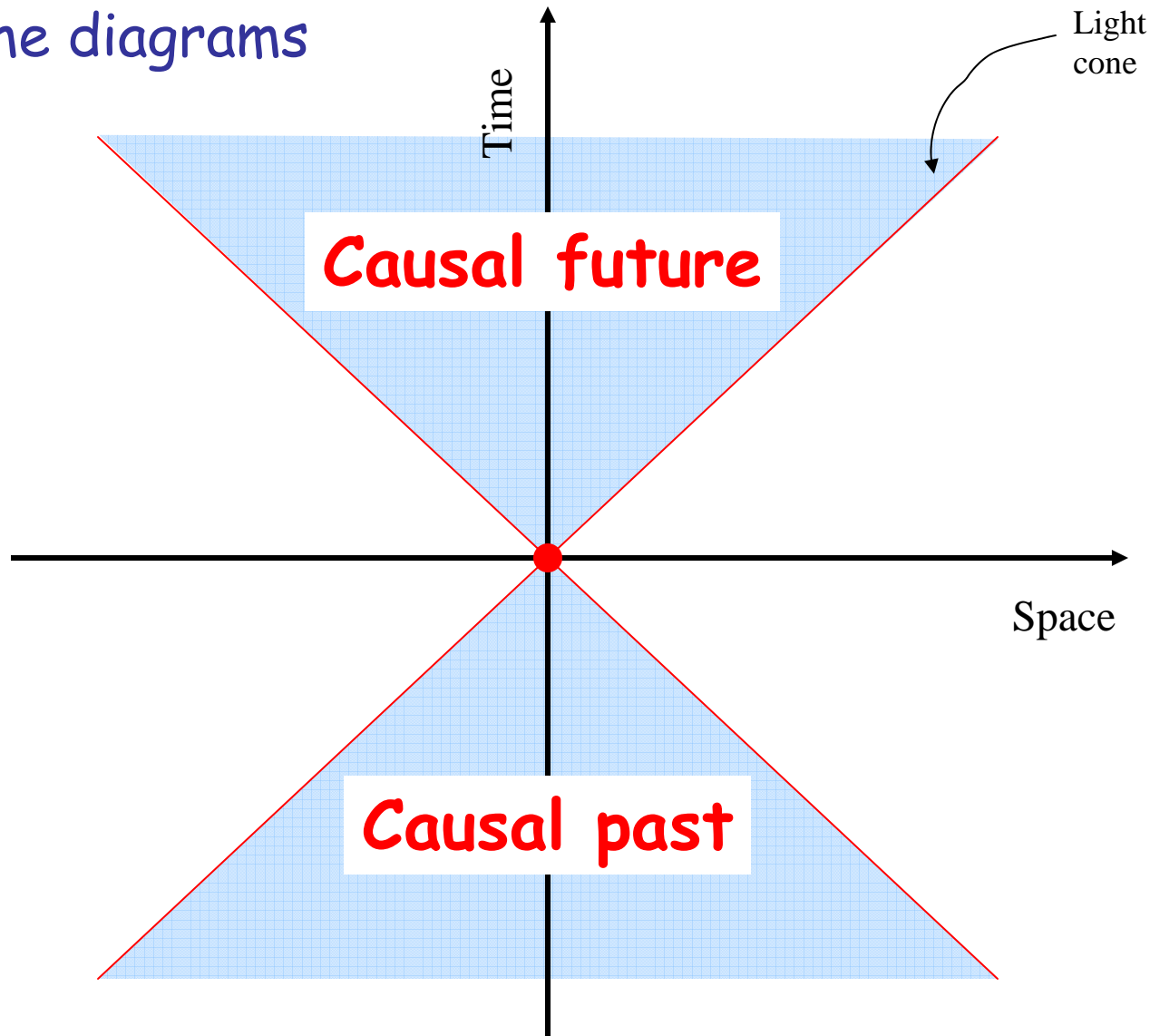
Making Sense of Einstein's Universe

Spacetime diagrams



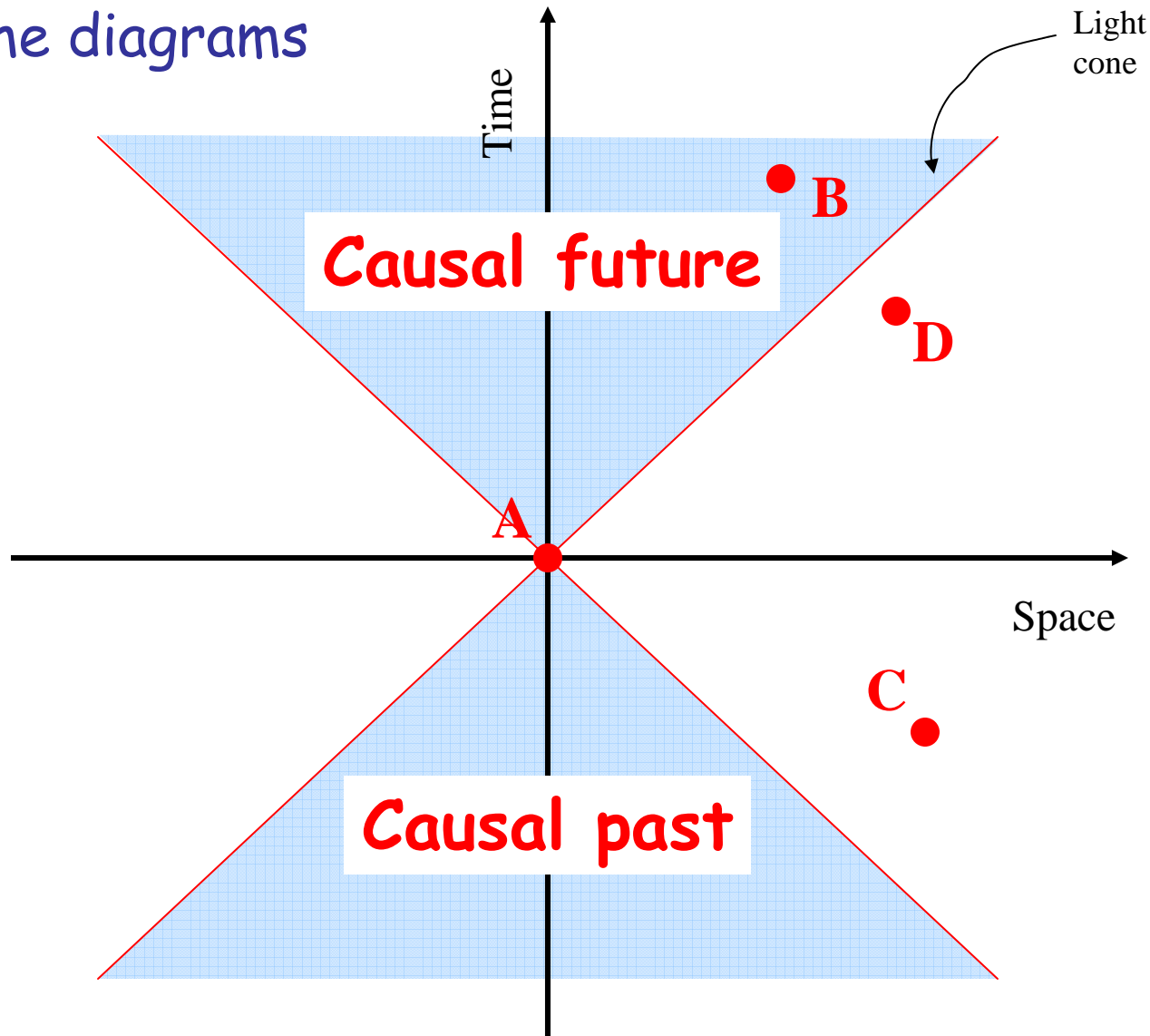
Making Sense of Einstein's Universe

Spacetime diagrams



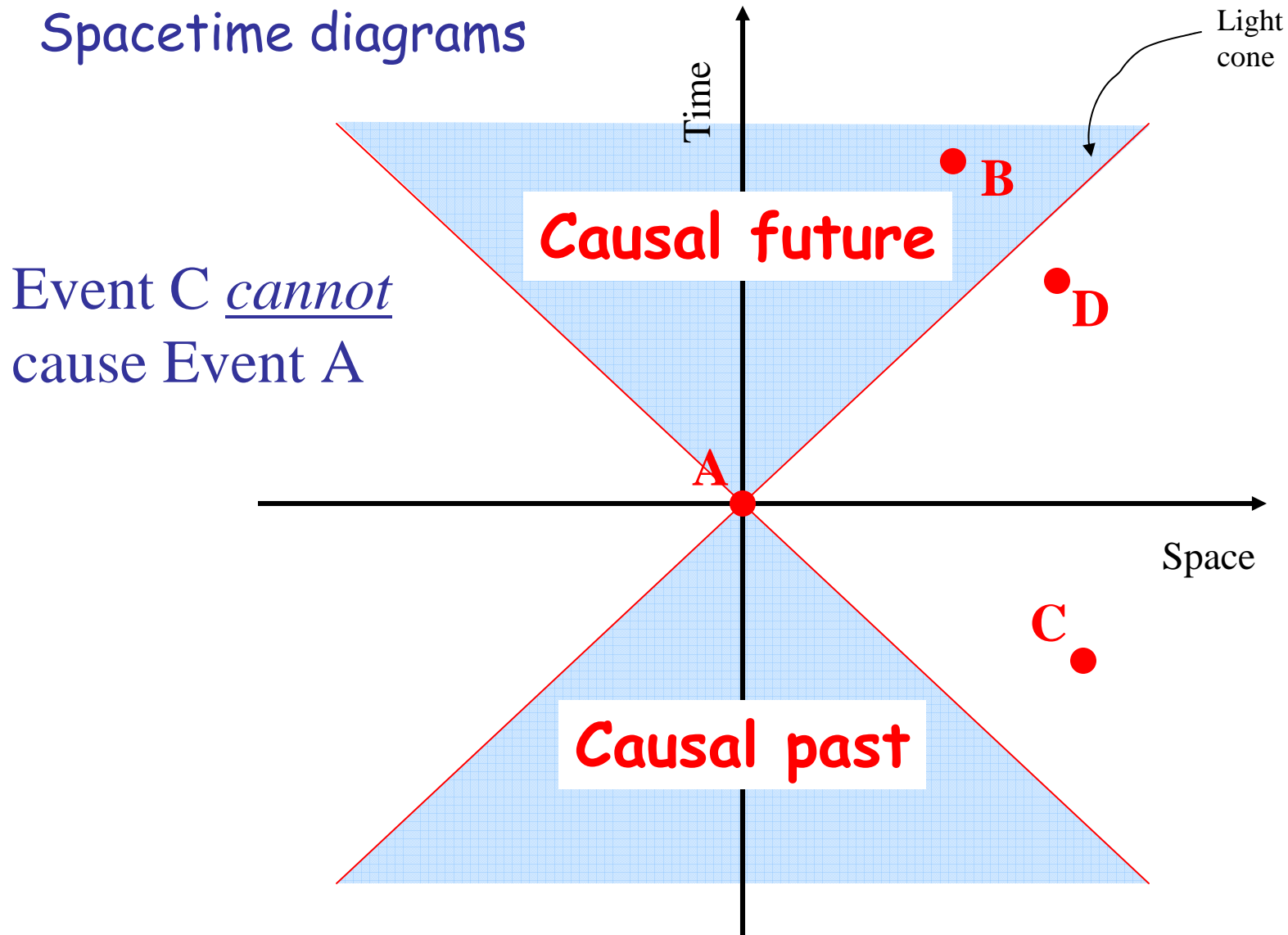
Making Sense of Einstein's Universe

Spacetime diagrams



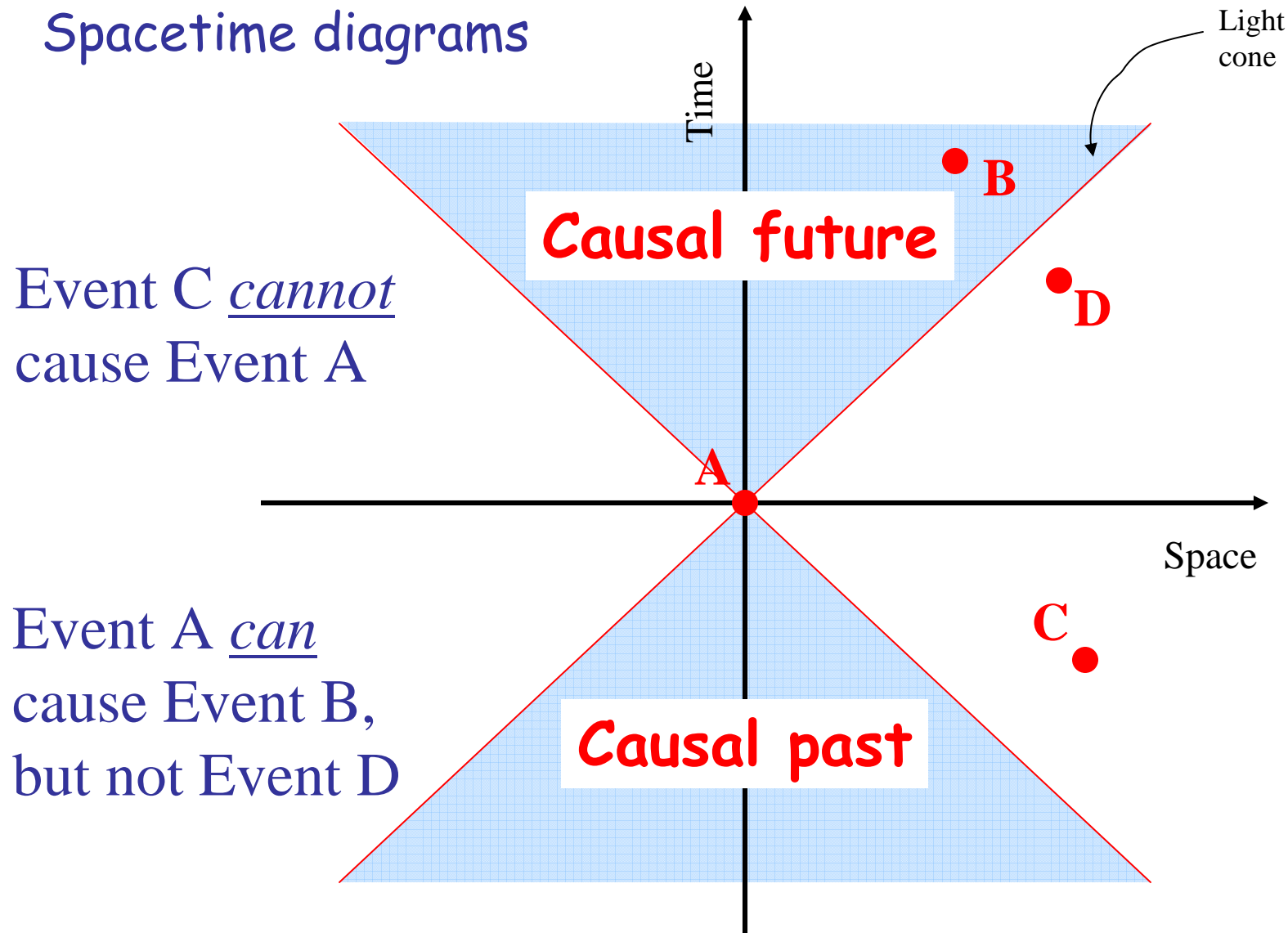
Making Sense of Einstein's Universe

Spacetime diagrams



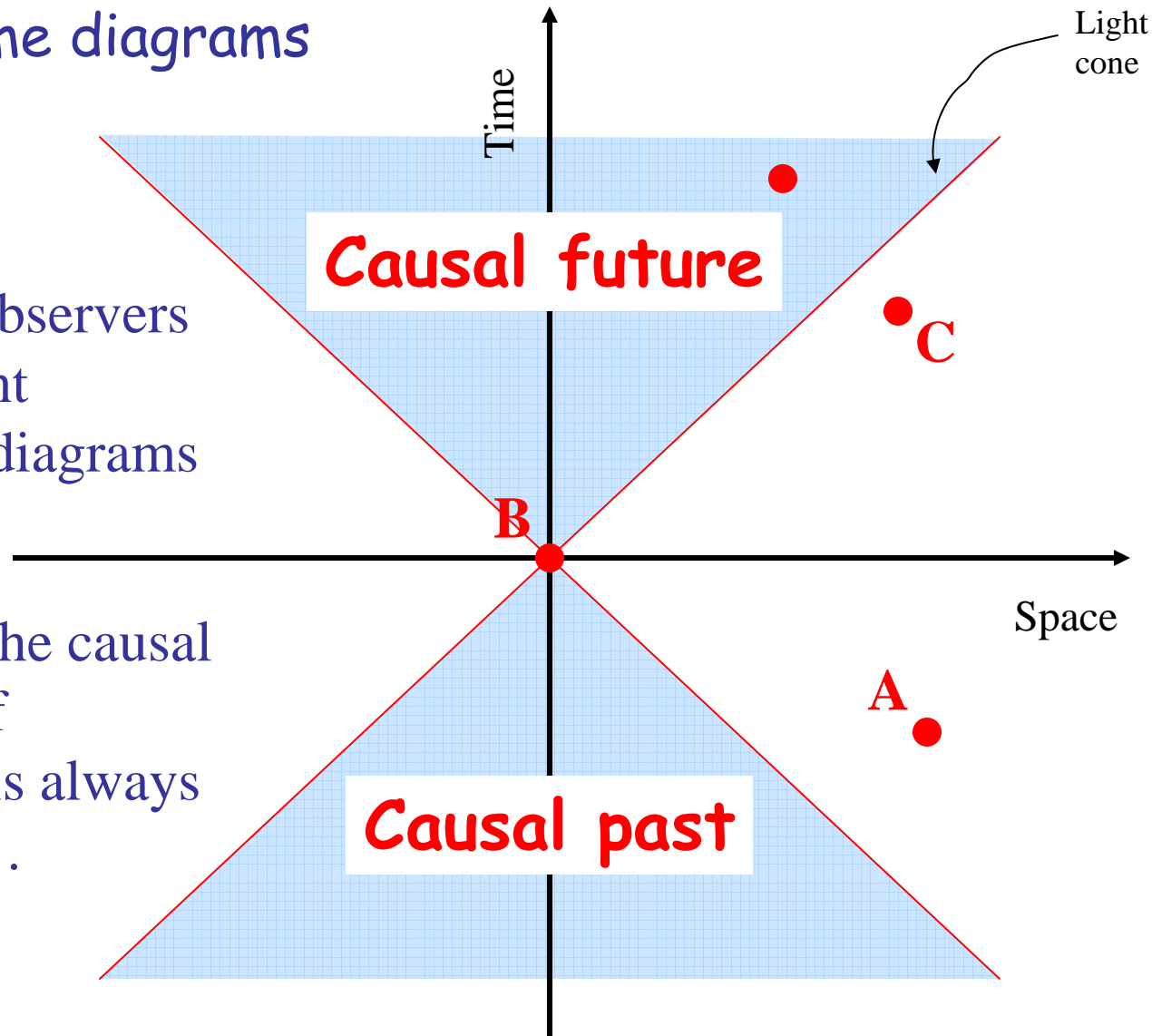
Making Sense of Einstein's Universe

Spacetime diagrams



Making Sense of Einstein's Universe

Spacetime diagrams



Different observers
see different
spacetime diagrams

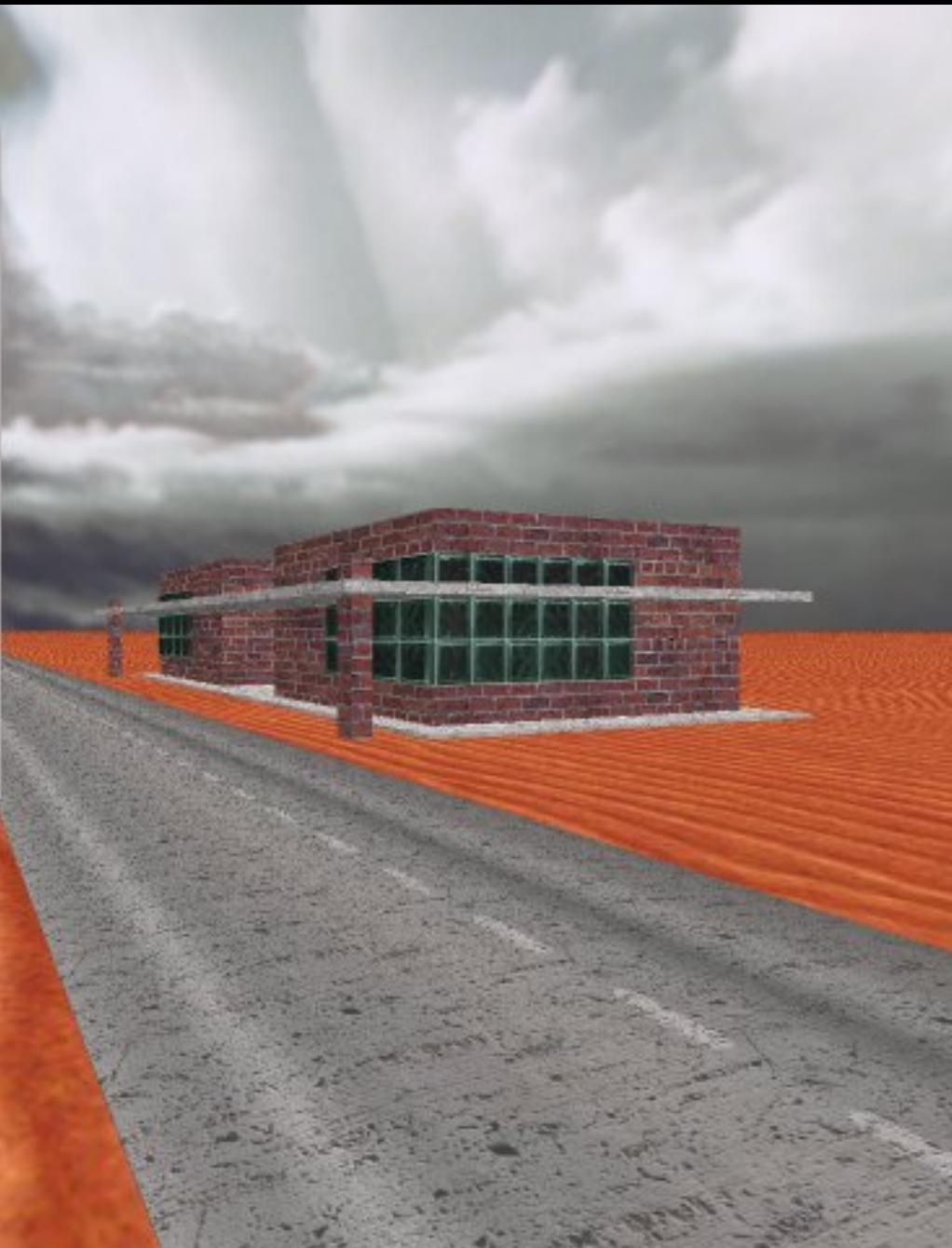
However, the causal
structure of
spacetime is always
preserved...

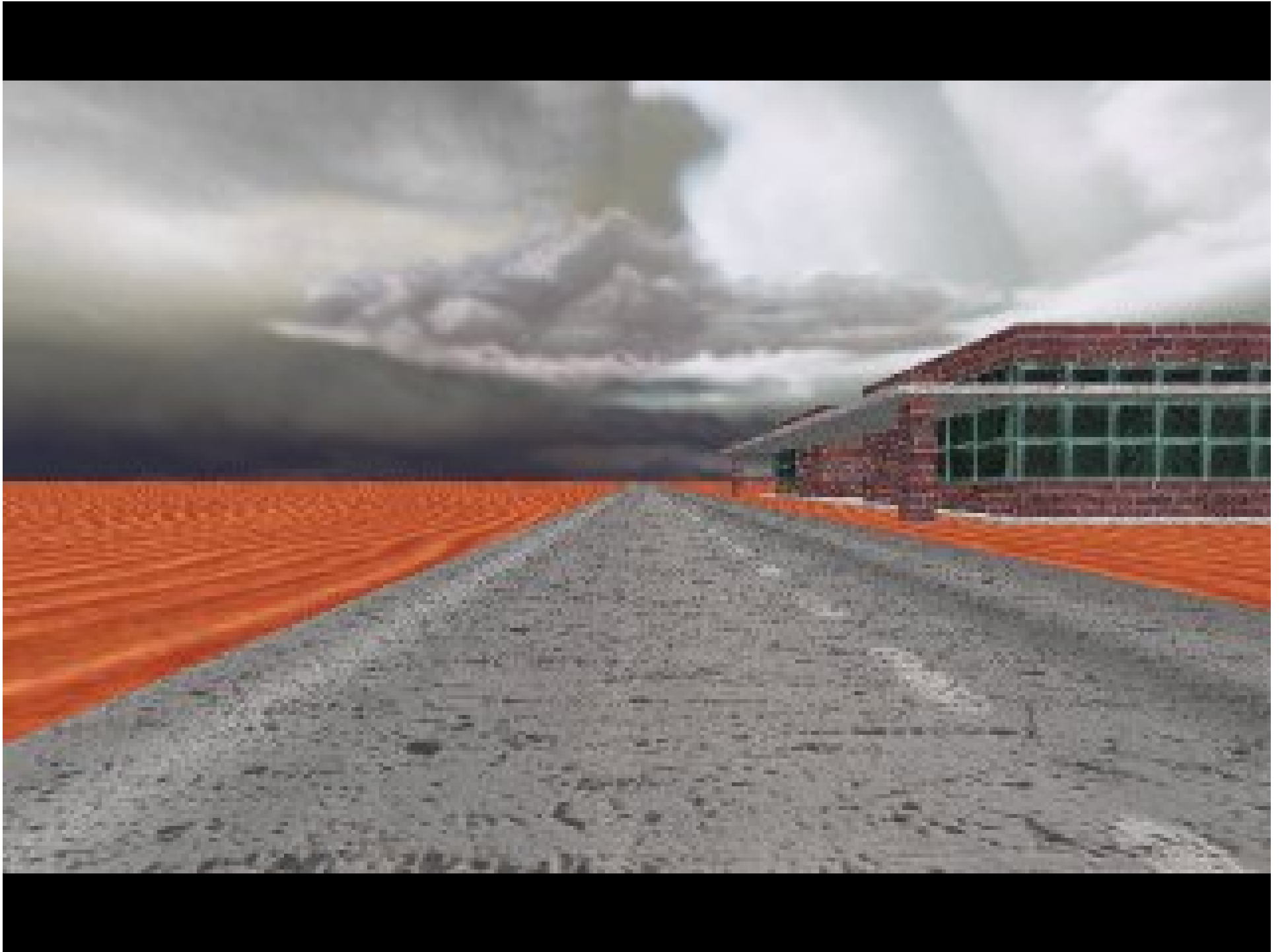
Different observers, moving at different relative speeds, will see a distorted view of their surroundings and will disagree over whether events are *simultaneous*.

This can still lead to some interesting **aberrations** and **paradoxes**.

See, for example, Anthony Searle's website
“Visualising Special Relativity”

(link on the course website)





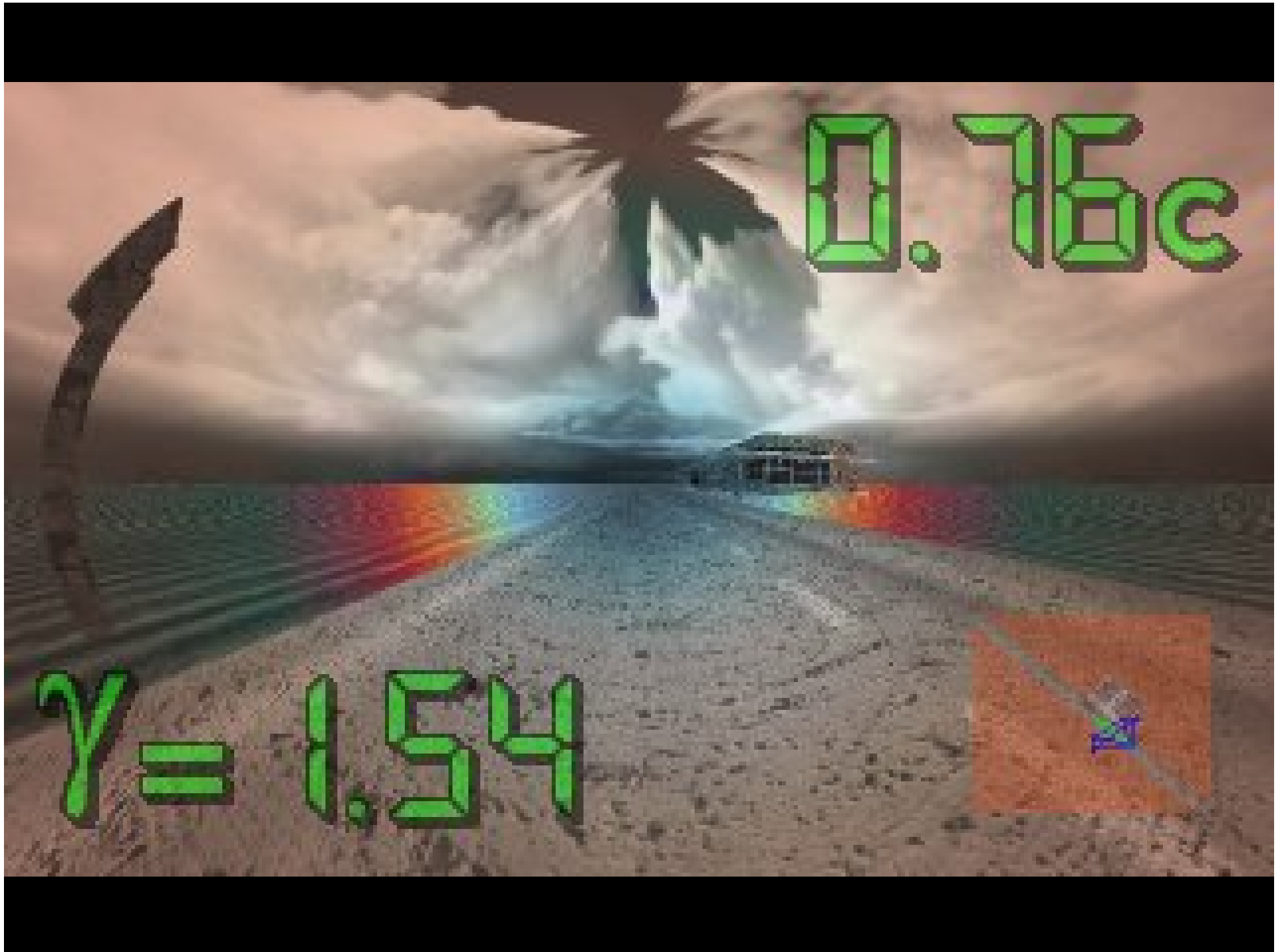
$0.76c$

$\gamma = 1.54$



$0.76c$

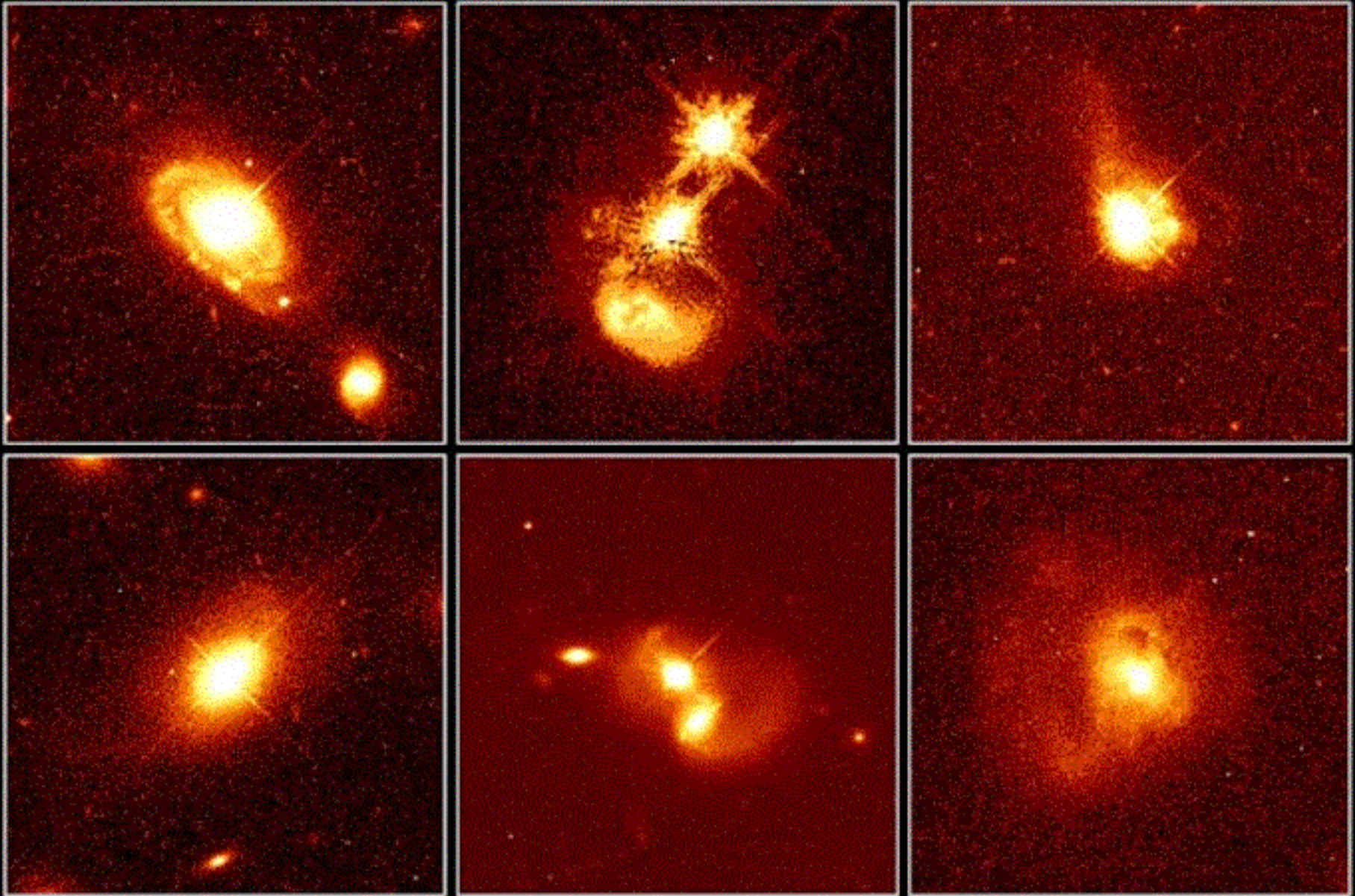
$\gamma = 1.54$



$0.76c$

$\gamma = 1.54$





Quasar Host Galaxies

HST • WFPC2

PRC96-35a • ST ScI OPO • November 19, 1996

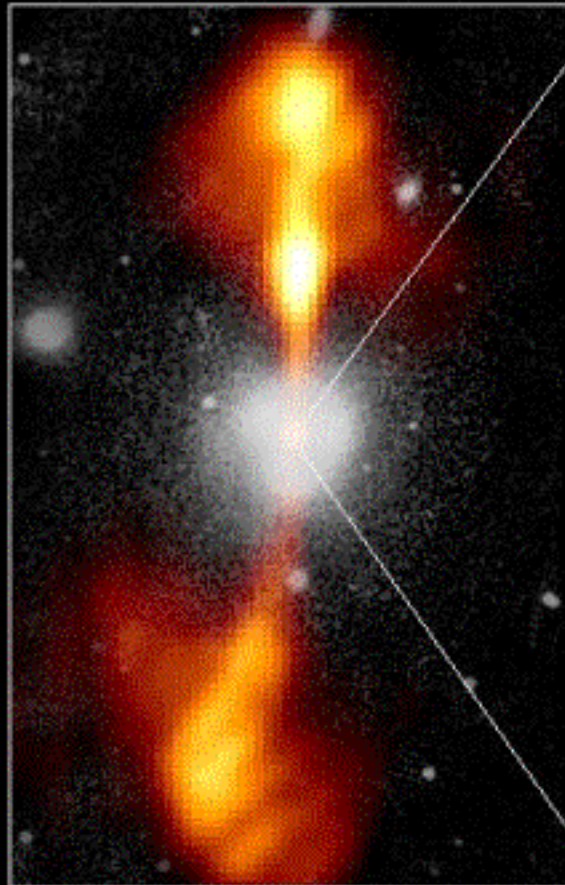
J. Bahcall (Institute for Advanced Study), M. Disney (University of Wales) and NASA

Core of Galaxy NGC 4261

Hubble Space Telescope

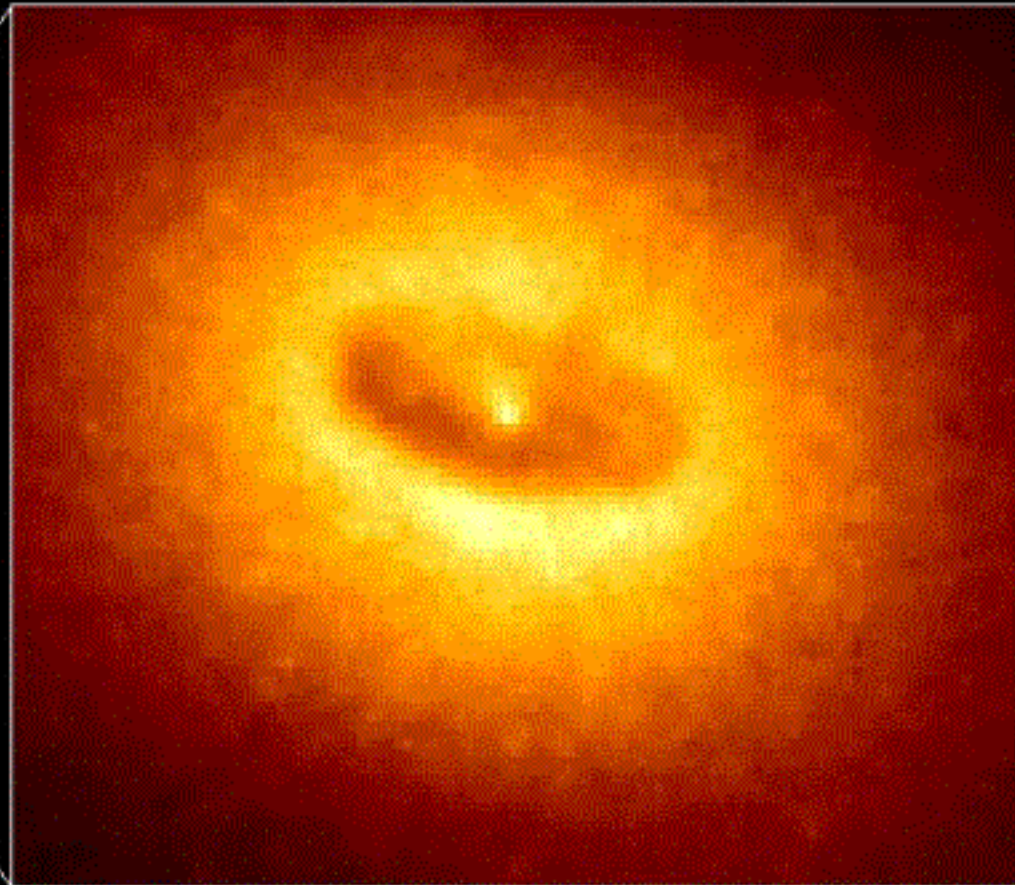
Wide Field / Planetary Camera

Ground-Based Optical/Radio Image

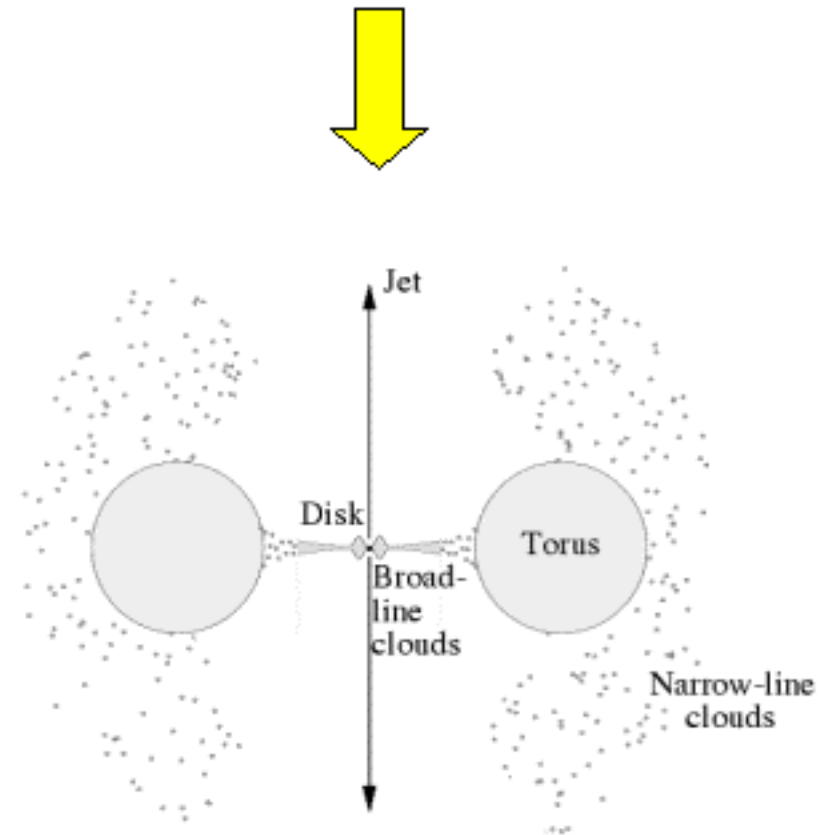
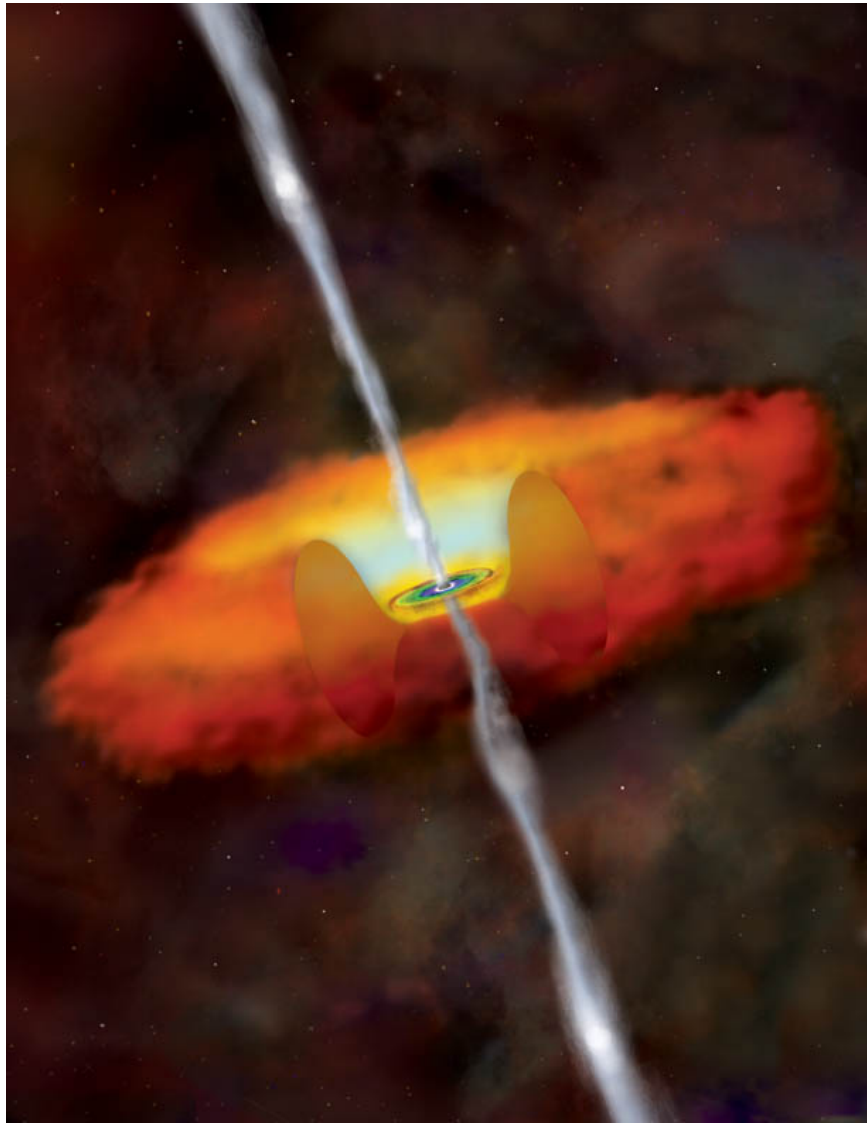


380 Arc Seconds
88,000 LIGHTYEARS

HST Image of a Gas and Dust Disk



17 Arc Seconds
400 LIGHTYEARS



Different observers, moving at different relative speeds, will see a distorted view of their surroundings and will disagree over whether events are *simultaneous*.

This can still lead to some interesting **aberrations** and **paradoxes**.

See, for example, Anthony Searle's website
“Visualising Special Relativity”

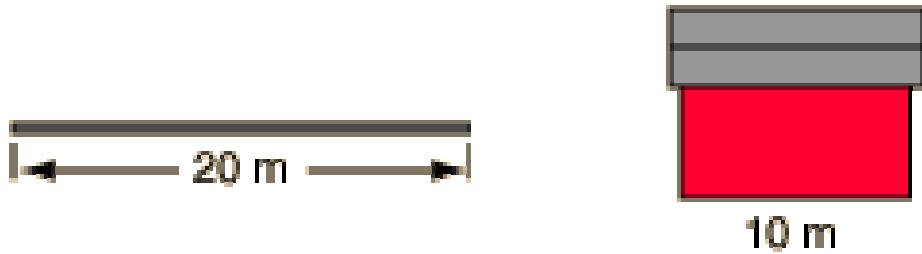
(link on the course website)

The Pole in the Barn Paradox

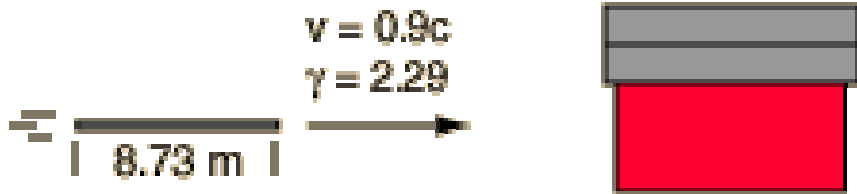
With thanks to: <http://hyperphysics.phy-astr.gsu.edu/hbase/relativ/polebarn.html>

<http://www.rdrop.com/~half/Creations/Puzzles/pole.and.barn/index.html>

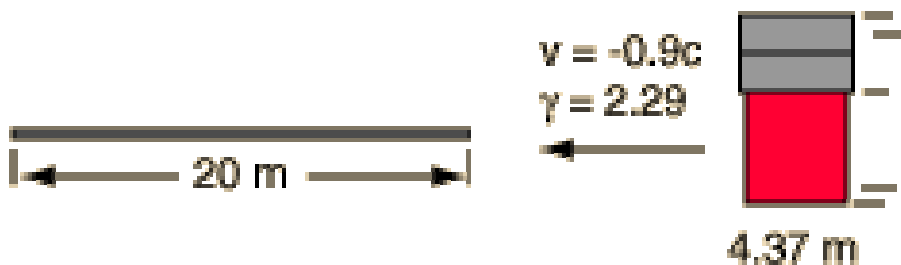
The Pole in the Barn Paradox



A 20 meter pole and a 10 meter barn in their perspective when in the same rest frame.



If the pole has speed $0.9c$, then it is length-contracted by a factor of 2.29 and short enough to fit momentarily within the barn, at least as seen by an observer in the barn.



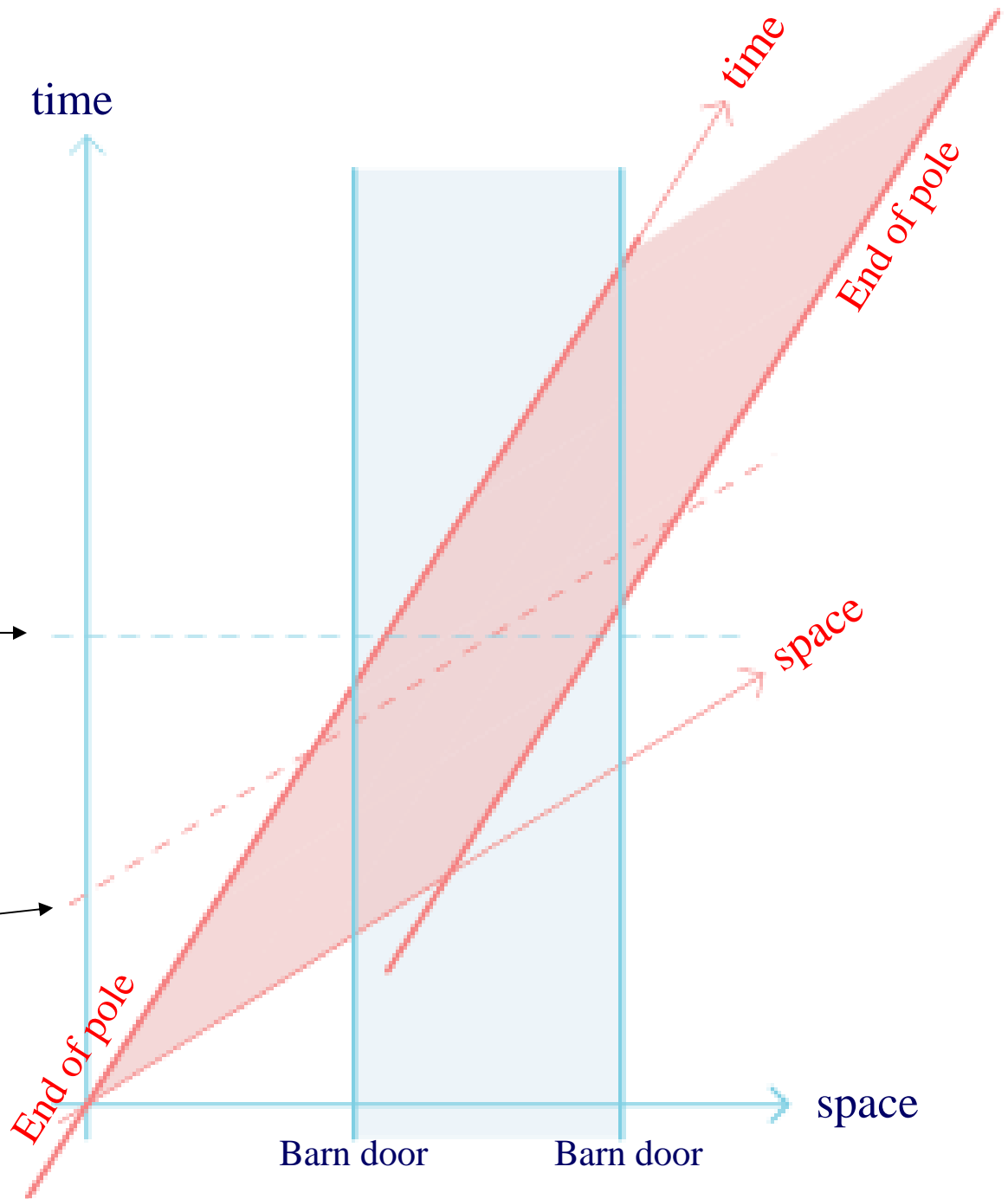
But from the point of view of the pole, the barn is contracted and the pole will never fit inside it.

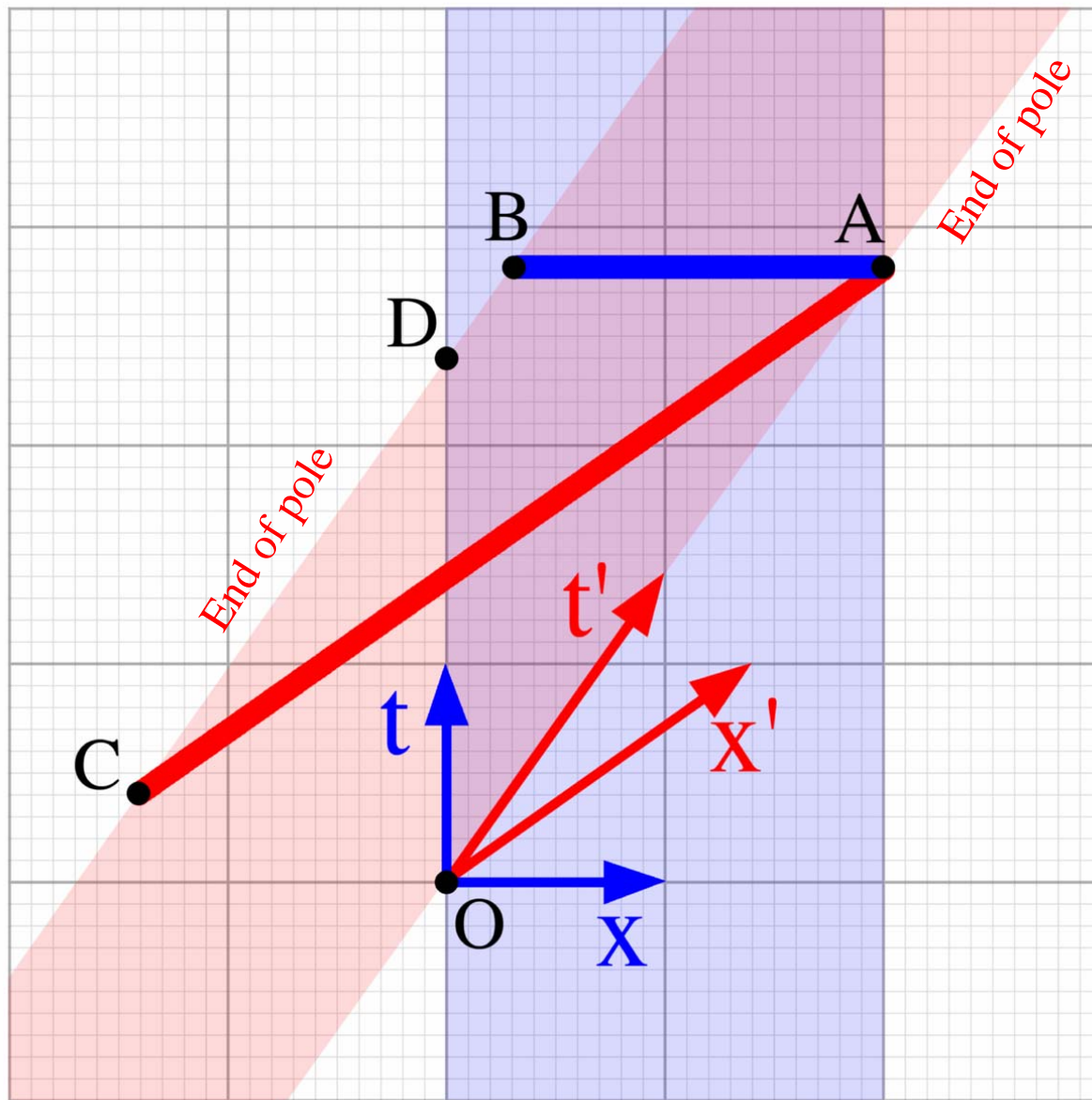
Blue lines:
Barn frame

Red lines:
Pole frame

Looks like, in barn frame,
pole lies entirely inside barn

Looks like, in pole frame,
barn lies entirely inside pole





Barn door

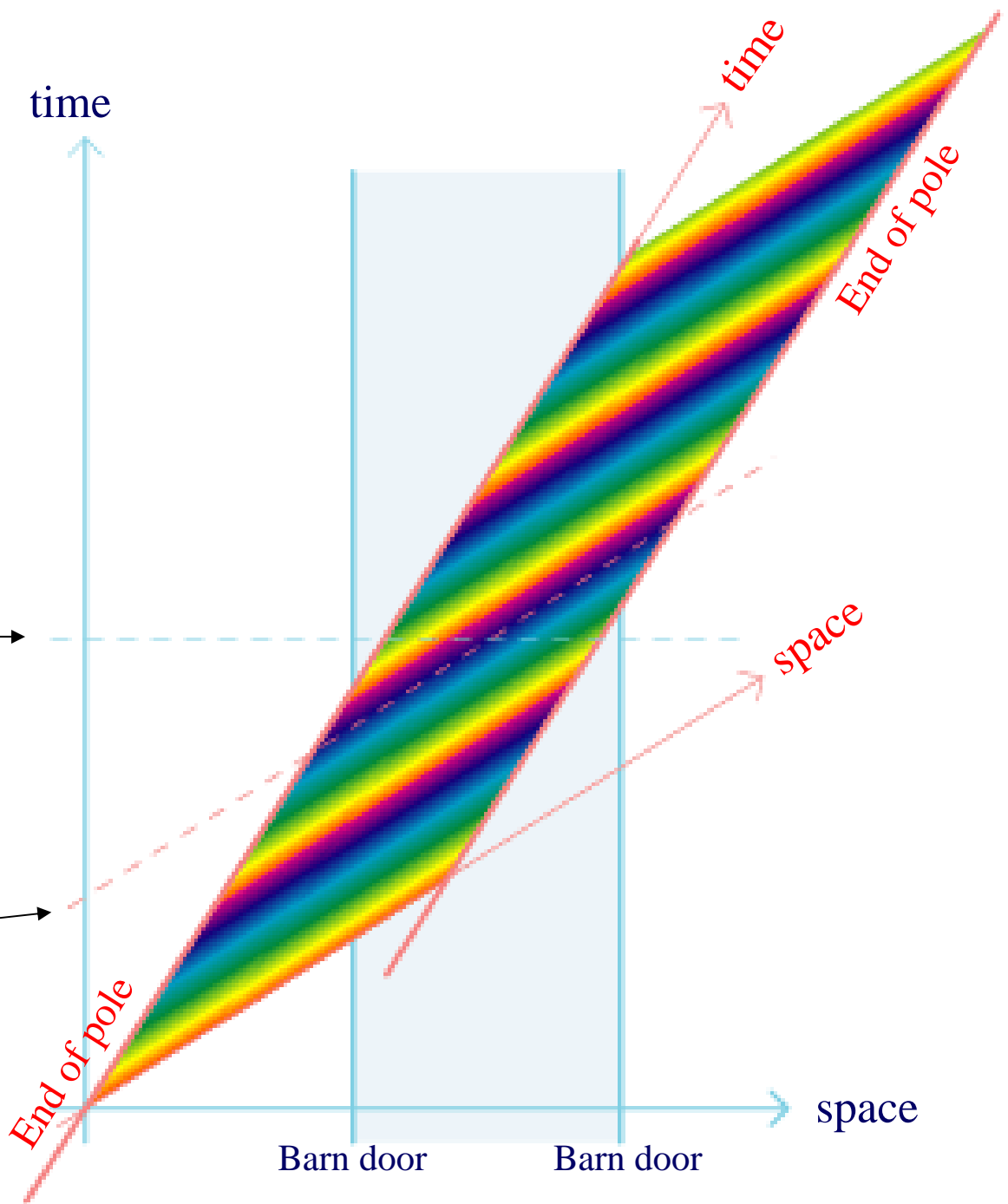
Barn door

Blue lines:
Barn frame

Red lines:
Pole frame

Looks like, in barn frame,
pole lies entirely inside barn

Looks like, in pole frame,
barn lies entirely inside pole



Barn door

Barn door

space

End of pole

time

End of pole

space

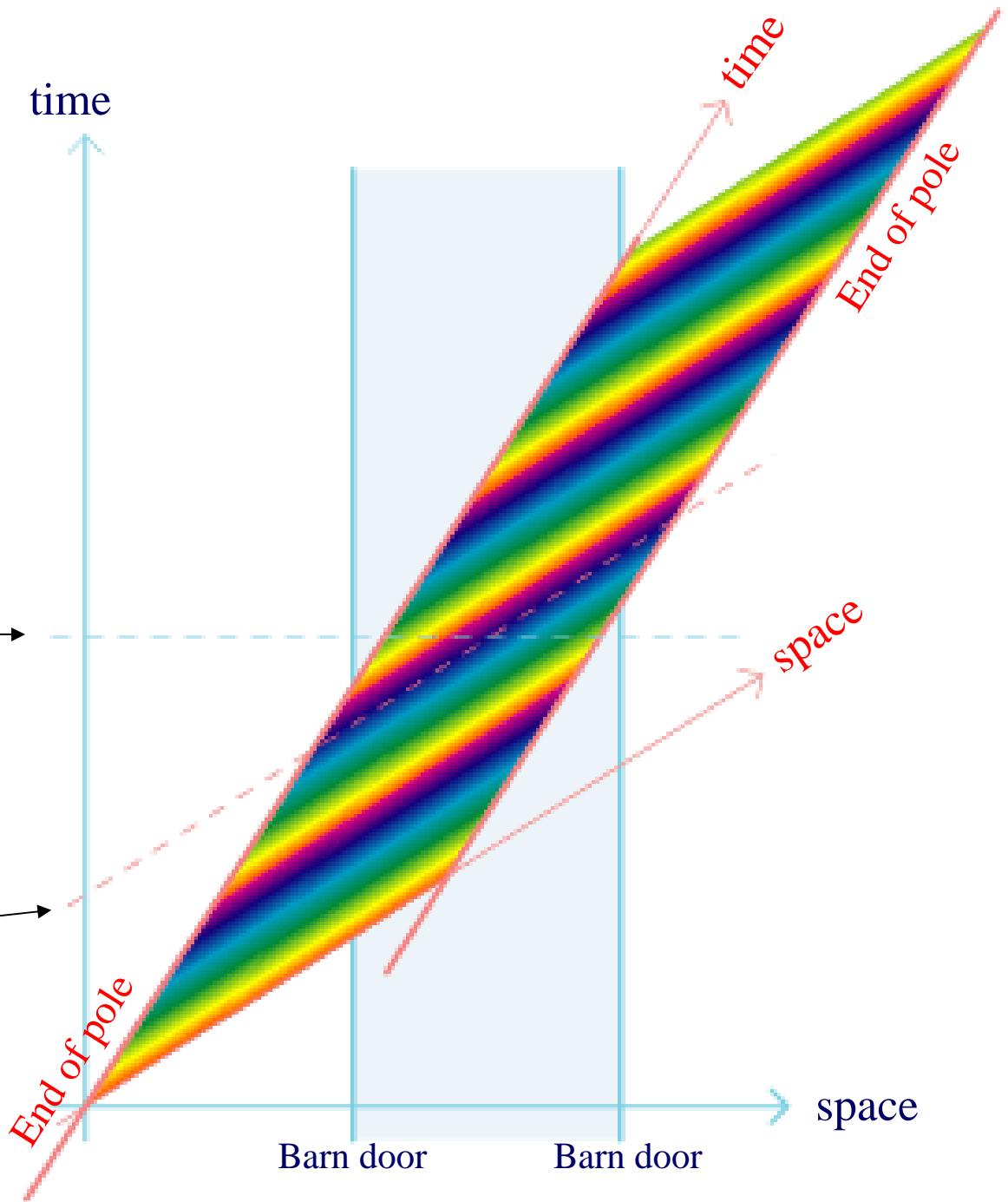
Blue lines:
Barn frame

Red lines:
Pole frame

Looks like, in barn frame,
pole lies entirely inside barn



Looks like, in pole frame,
barn lies entirely inside pole



Just as special relativity shows that space and time are inextricably connected, so too are energy and momentum

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Particles have a particular **rest mass**, which is the mass you would measure if the particle is at rest

Just as special relativity shows that space and time are inextricably connected, so too are energy and momentum

Particles have a particular **rest mass**, which is the mass you would measure if the particle is at rest

Mass and energy
are equivalent

$$E = mc^2$$

DOES THE INERTIA OF A BODY DEPEND UPON ITS ENERGY-CONTENT?

BY A. EINSTEIN

September 27, 1905

The results of the previous investigation lead to a very interesting conclusion, which is here to be deduced.

I based that investigation on the Maxwell-Hertz equations for empty space, together with the Maxwellian expression for the electromagnetic energy of space, and in addition the principle that:—

The laws by which the states of physical systems alter are independent of the alternative, to which of two systems of coordinates, in uniform motion of parallel translation relatively to each other, these alterations of state are referred (principle of relativity).

With these principles* as my basis I deduced *inter alia* the following result (§ 8):—

Let a system of plane waves of light, referred to the system of co-ordinates (x, y, z) , possess the energy l ; let the direction of the ray (the wave-normal) make an angle ϕ with the axis x of the system. If we introduce a new system of co-ordinates (ξ, η, ζ) moving in uniform parallel translation with respect to the system (x, y, z) , and having its origin of co-ordinates in motion along the axis of x with the velocity v , then this quantity of light—measured in the system (ξ, η, ζ) —possesses the energy

$$l^* = l \frac{1 - \frac{v}{c} \cos \phi}{\sqrt{1 - v^2/c^2}}$$

where c denotes the velocity of light. We shall make use of this result in what follows.

Let there be a stationary body in the system (x, y, z) , and let its energy—referred to the system (x, y, z) be E_0 . Let the energy of the body relative to the system (ξ, η, ζ) moving as above with the velocity v , be H_0 .

Let this body send out, in a direction making an angle ϕ with the axis of x , plane waves of light, of energy $\frac{1}{2}L$ measured relatively to (x, y, z) , and simultaneously an equal quantity of light in the opposite direction. Meanwhile the body remains at rest with respect to the system (x, y, z) . The principle of

*The principle of the constancy of the velocity of light is of course contained in Maxwell's equations.

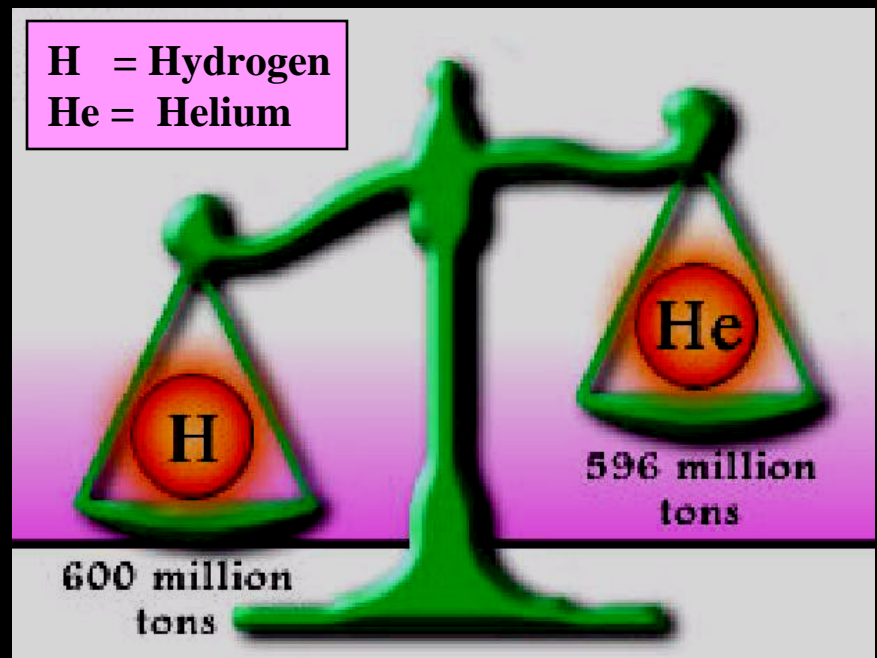
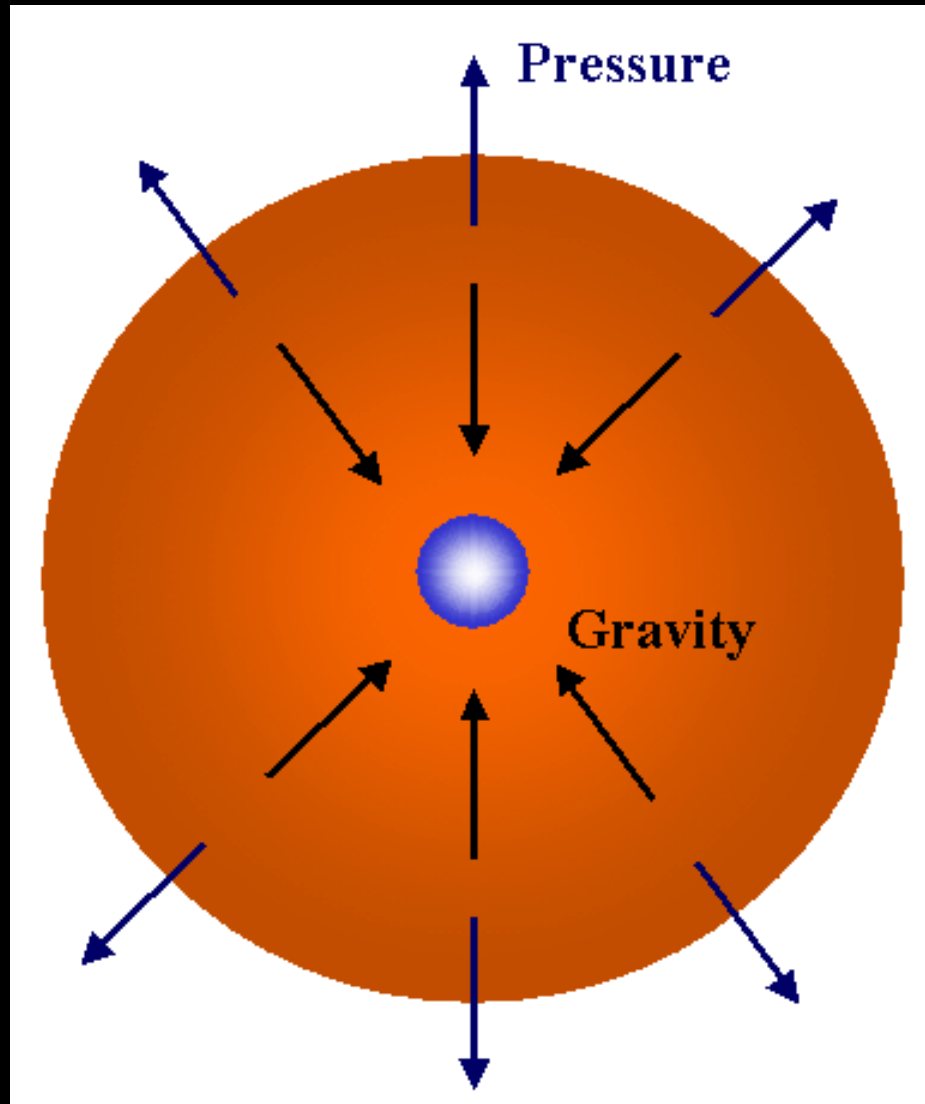
If a body gives off the energy L in the form of radiation, its mass diminishes by L/c^2 . The fact that the energy withdrawn from the body becomes energy of radiation evidently makes no difference, so that we are led to the more general conclusion that

The mass of a body is a measure of its energy-content; if the energy changes by L , the mass changes in the same sense by $L/9 \times 10^{20}$, the energy being measured in ergs, and the mass in grammes.

It is not impossible that with bodies whose energy-content is variable to a high degree (e.g. with radium salts) the theory may be successfully put to the test.

If the theory corresponds to the facts, radiation conveys inertia between the emitting and absorbing bodies.

Hydrogen fusion – fuelling a star's nuclear furnace



$$E = mc^2$$

