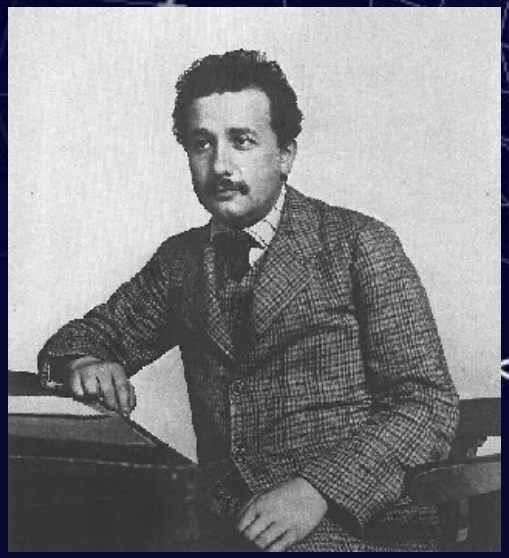
# Einstein's Universe




## Dr Martin Hendry

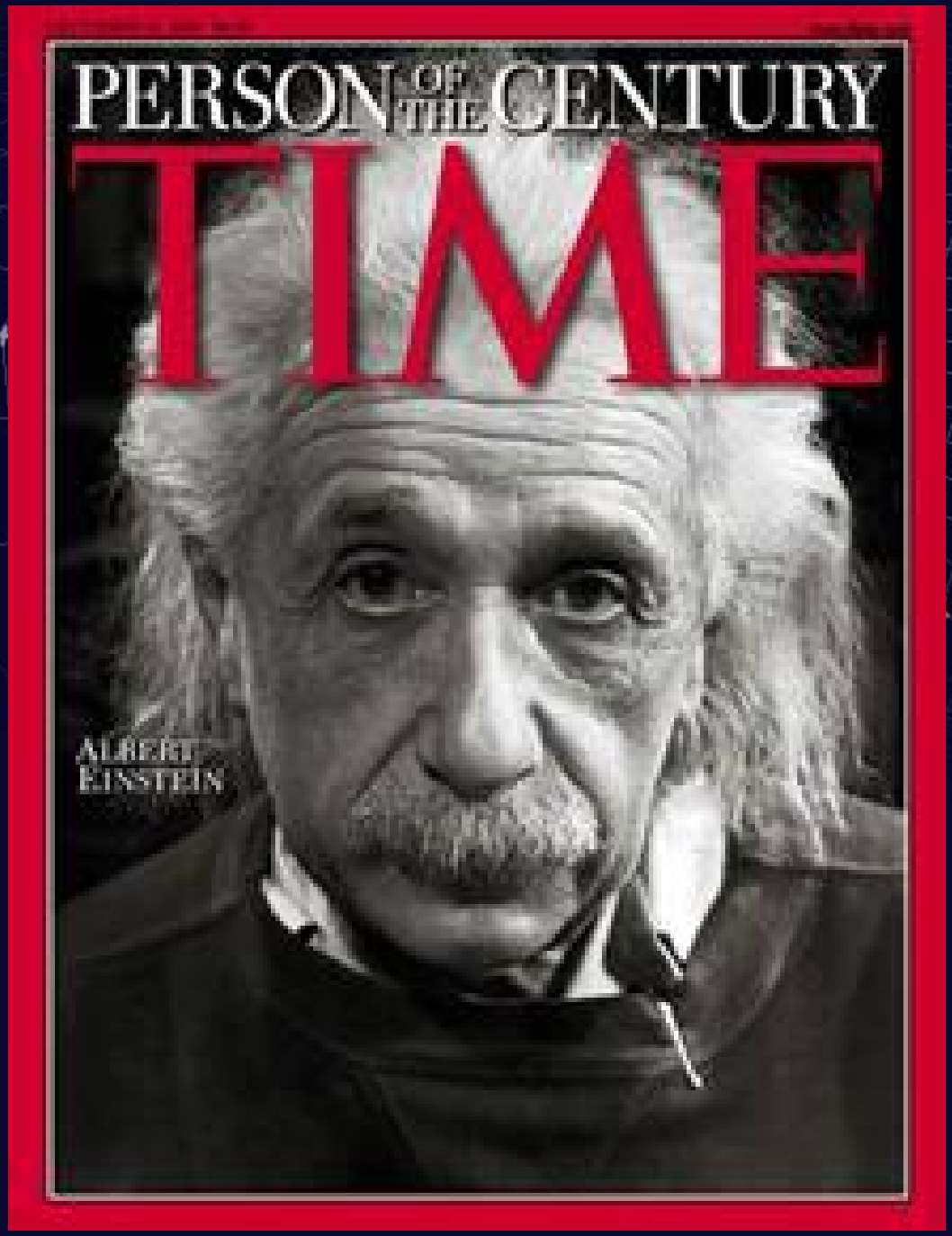
Dept of Physics and Astronomy,
University of Glasgow

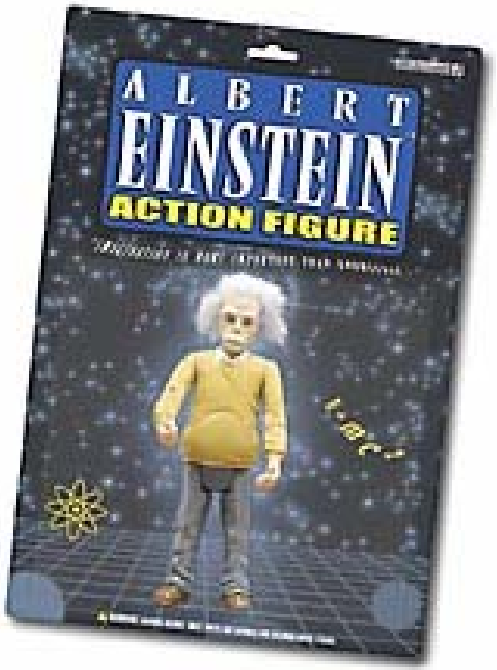

UNIVERSITY of GLASGOW

The Royal Society of Edinburgh

ASTRONOMY & ASTROPHYSICS

IGR


PERSON OF THE CENTURY
TIME
ALBERT EINSTEIN


ALBERT
EINSTEIN
ACTION FIGURE

einstein year

*Einstein's 'Miraculous Year'*

- **Relativity**
- Atomic physics
- Quantum physics

# Einstein Simplified

# 1905 – Theory of Special Relativity

"You can't tell if you're moving"

# Physics before Einstein:
## *"All the World's A Stage"*

- Newton's physics assumes absolute space and time, for all observers.

# Physics before Einstein:
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- Newton's physics assumes absolute space and time.
- We work out how things look to different observers using simple rules

# Physics before Einstein:

## *"All the World's A Stage"*

- Newton's physics assumes absolute space and time.
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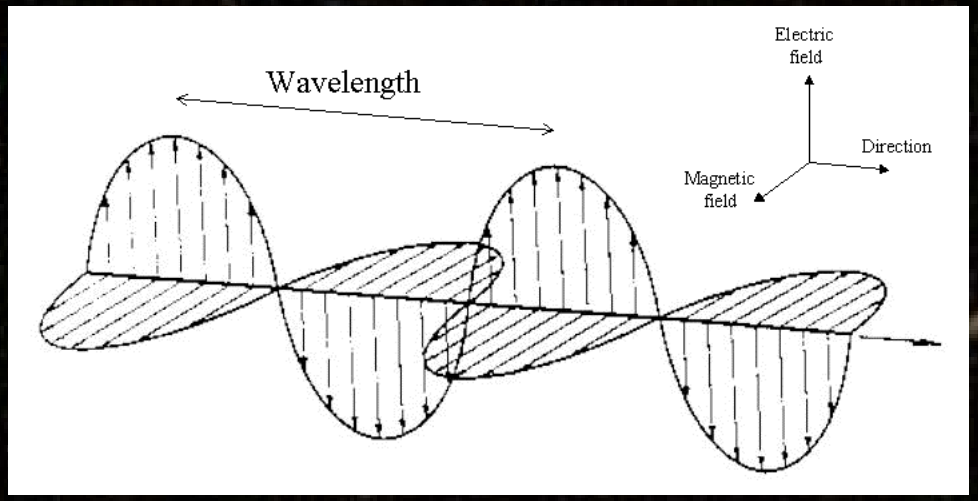
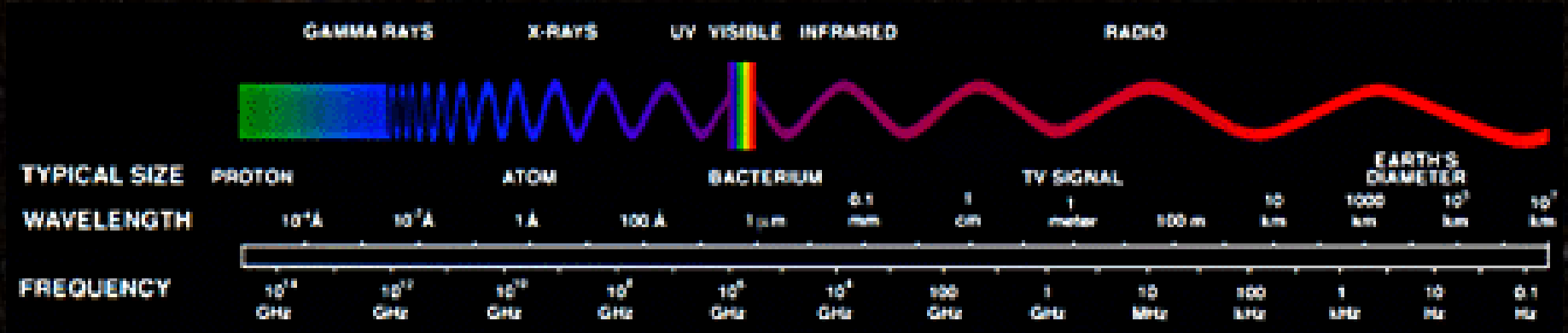
Viewed from the blue car's rest frame

# Physics before Einstein:

## *James Clerk Maxwell*

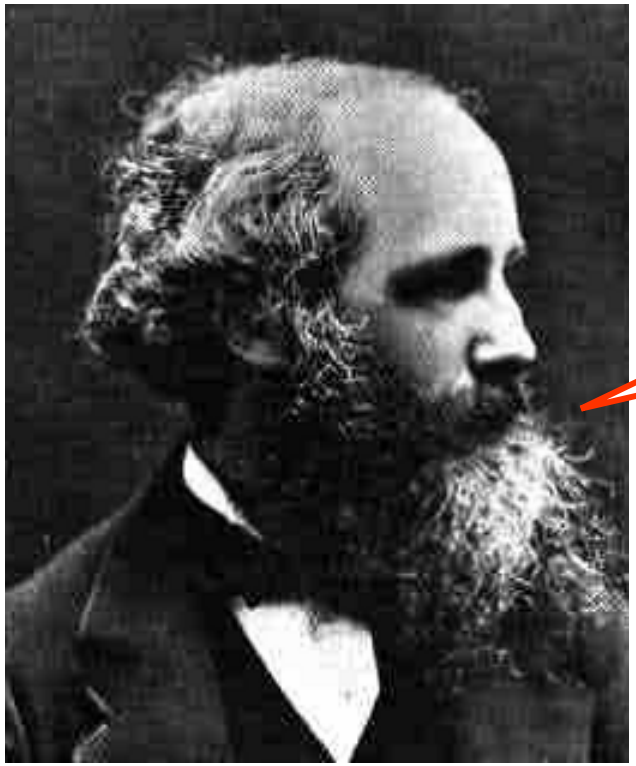



## Light is a *wave* – *electromagnetic radiation*



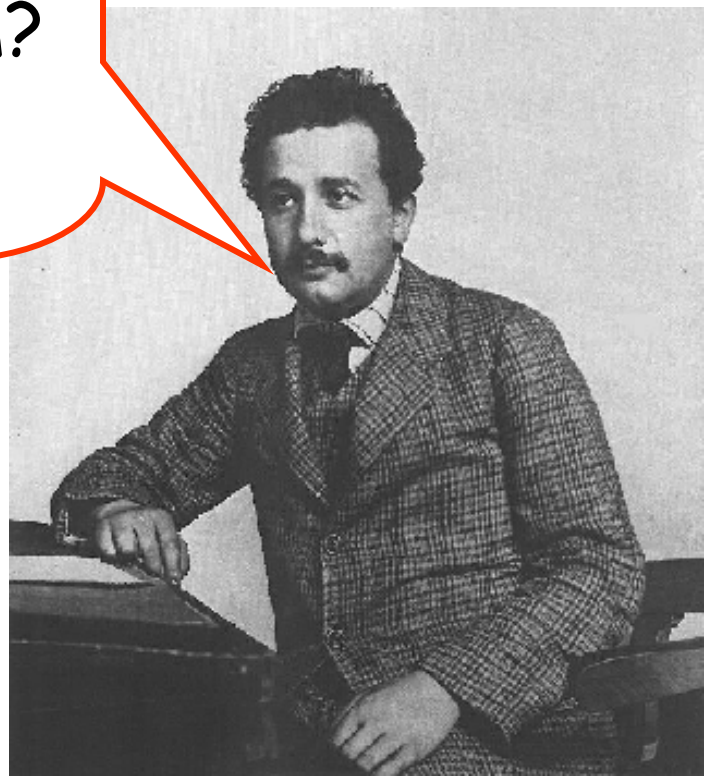
# Classical Physics:

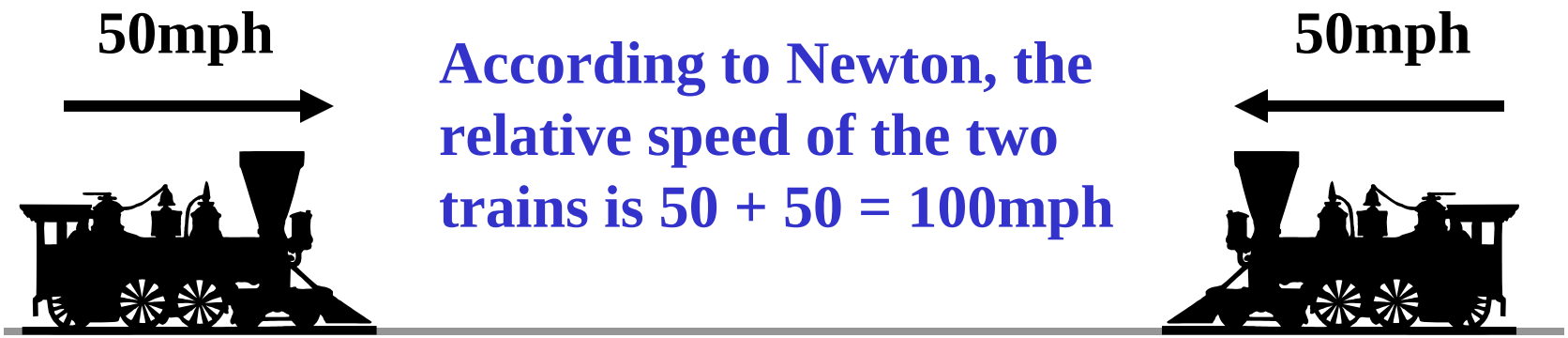
## *James Clerk Maxwell's theory of light*



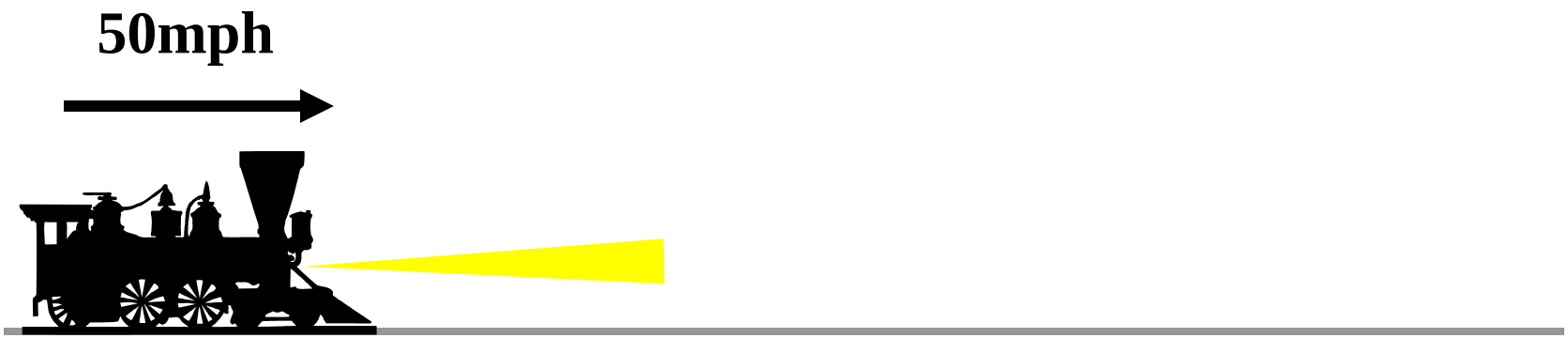
Light is a *wave* (caused by varying *electric* and *magnetic* fields)

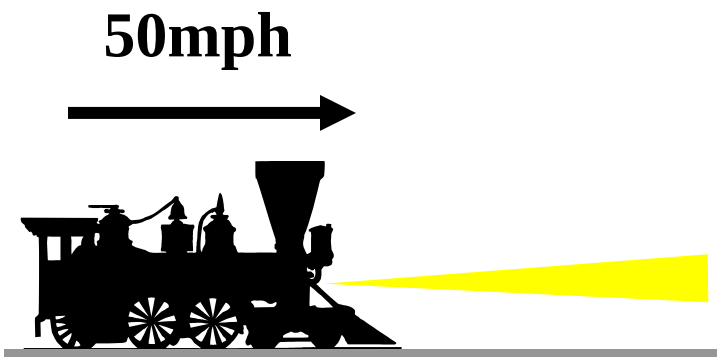
But what if I travelled *alongside* a light beam? Would it still wave?



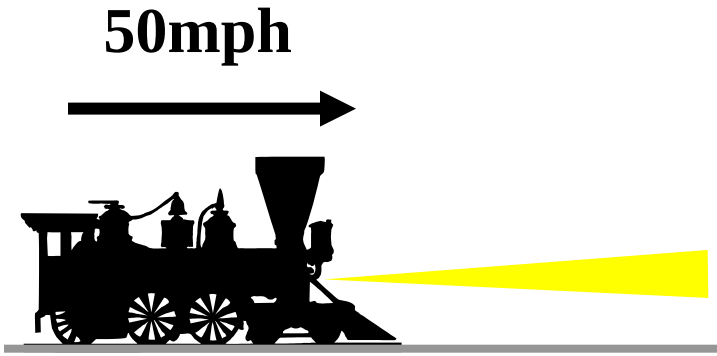



**According to Newton, the relative speed of the two trains is 50 + 50 = 100mph**


50mph




According to Einstein, the speed of light is *unchanged* by the motion of the train




According to Einstein, the speed of light is *unchanged* by the motion of the train

ON THE ELECTRODYNAMICS OF MOVING BODIES

By A. EINSTEIN

June 30, 1905

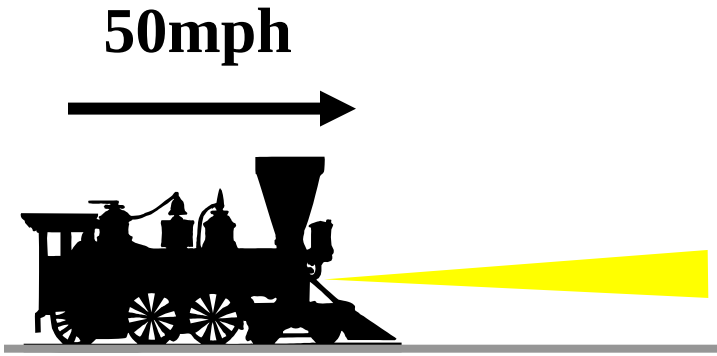
It is known that Maxwell's electrodynamics—as usually understood at the present time—when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena. Take, for example, the reciprocal electrodynamic action of a magnet and a conductor. The observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary view draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion. For if the magnet is in motion and the conductor at rest, there arises in the neighbourhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are situated. But if the magnet is stationary and the conductor in motion, no electric field arises in the neighbourhood of the magnet. In the conductor, however, we find an electromotive force, to which in itself there is no corresponding energy, but which gives rise—assuming equality of relative motion in the two cases discussed—to electric currents of the same path and intensity as those produced by the electric forces in the former case.

Examples of this sort, together with the unsuccessful attempts to discover any motion of the earth relatively to the "light medium," suggest that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest. They suggest rather that, as has already been shown to the first order of small quantities, the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good.[1] We will raise this conjecture (the purport of which will hereafter be called the "Principle of Relativity") to the status of a postulate, and also introduce another postulate, which is only apparently irreconcilable with the former, namely, that light is always propagated in empty space with a definite velocity $c$ which is independent of the state of motion of the emitting body. These two postulates suffice for the attainment of a simple and consistent theory of the electrodynamics of moving bodies based on Maxwell's theory for stationary bodies. The introduction of a "luminiferous ether" will prove to be superfluous inasmuch as the view here to be developed will not require an "absolutely stationary space" provided with special properties, nor

[1]The preceding memoir by Lorentz was not at this time known to the author.

1

- Measurements of space and time are ***relative*** and depend on our motion

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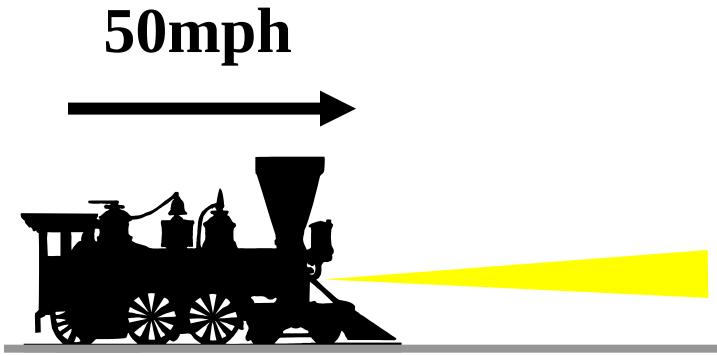
"The only reason for time is so that everything doesn't happen at once."

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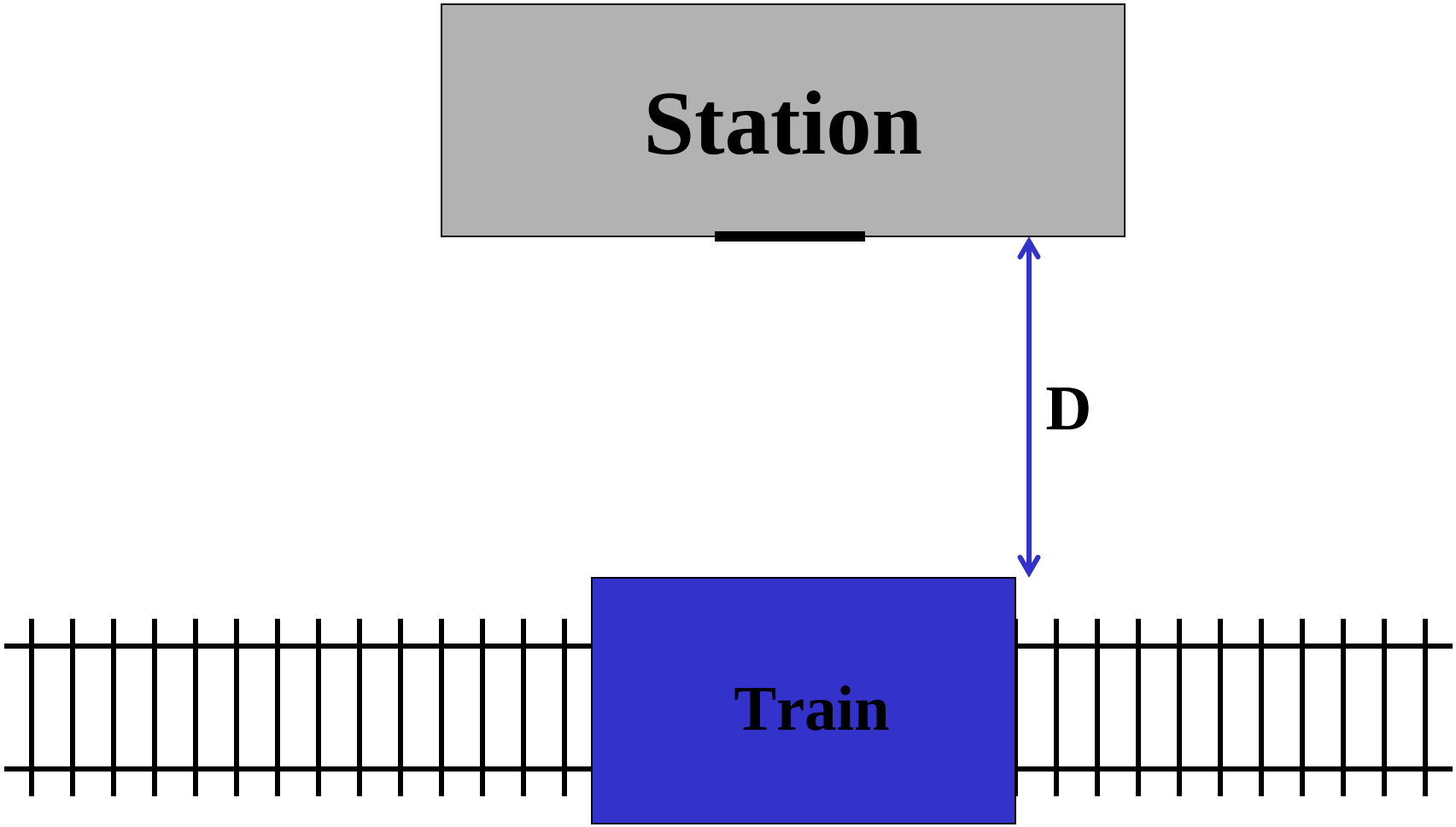
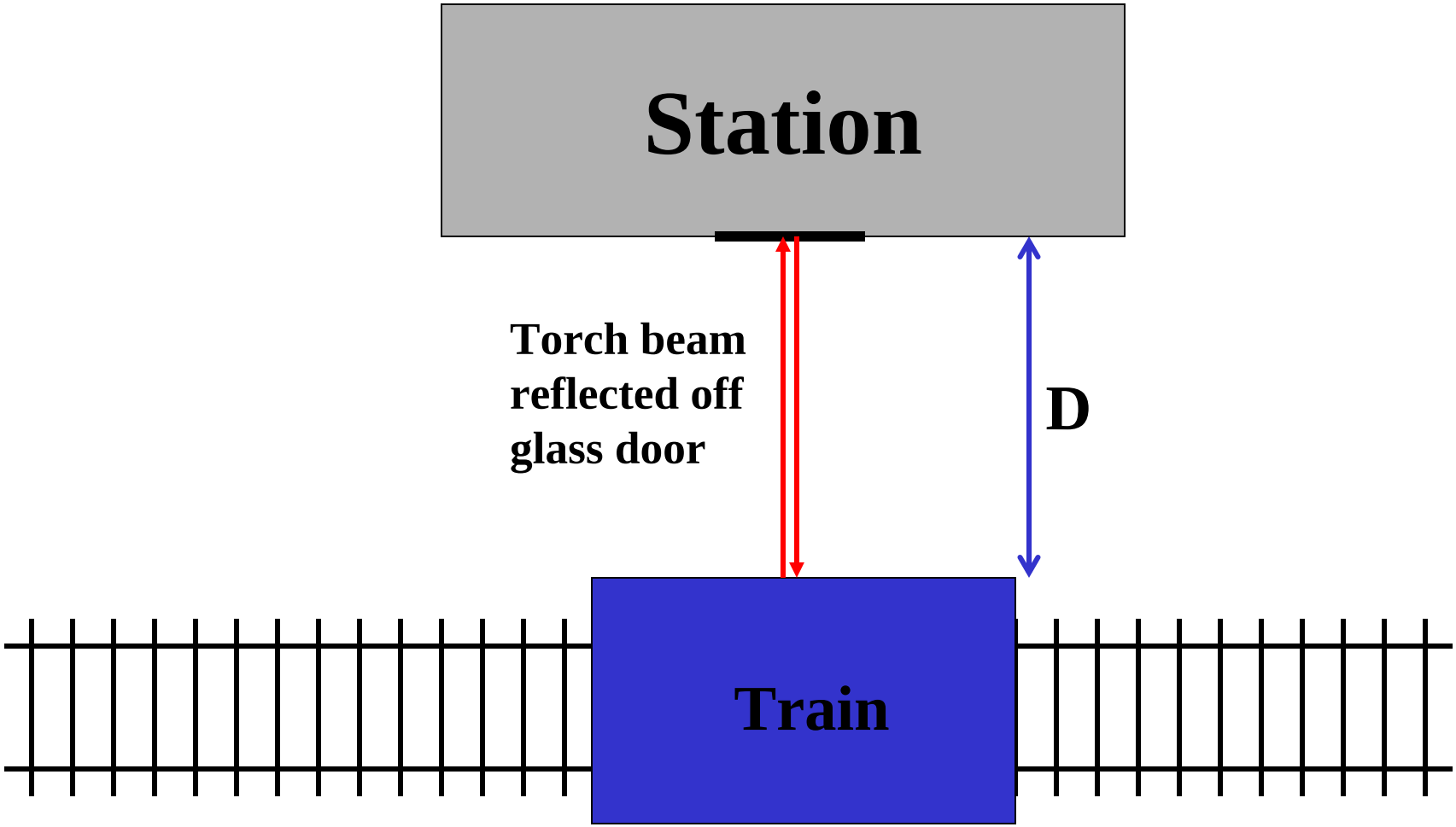
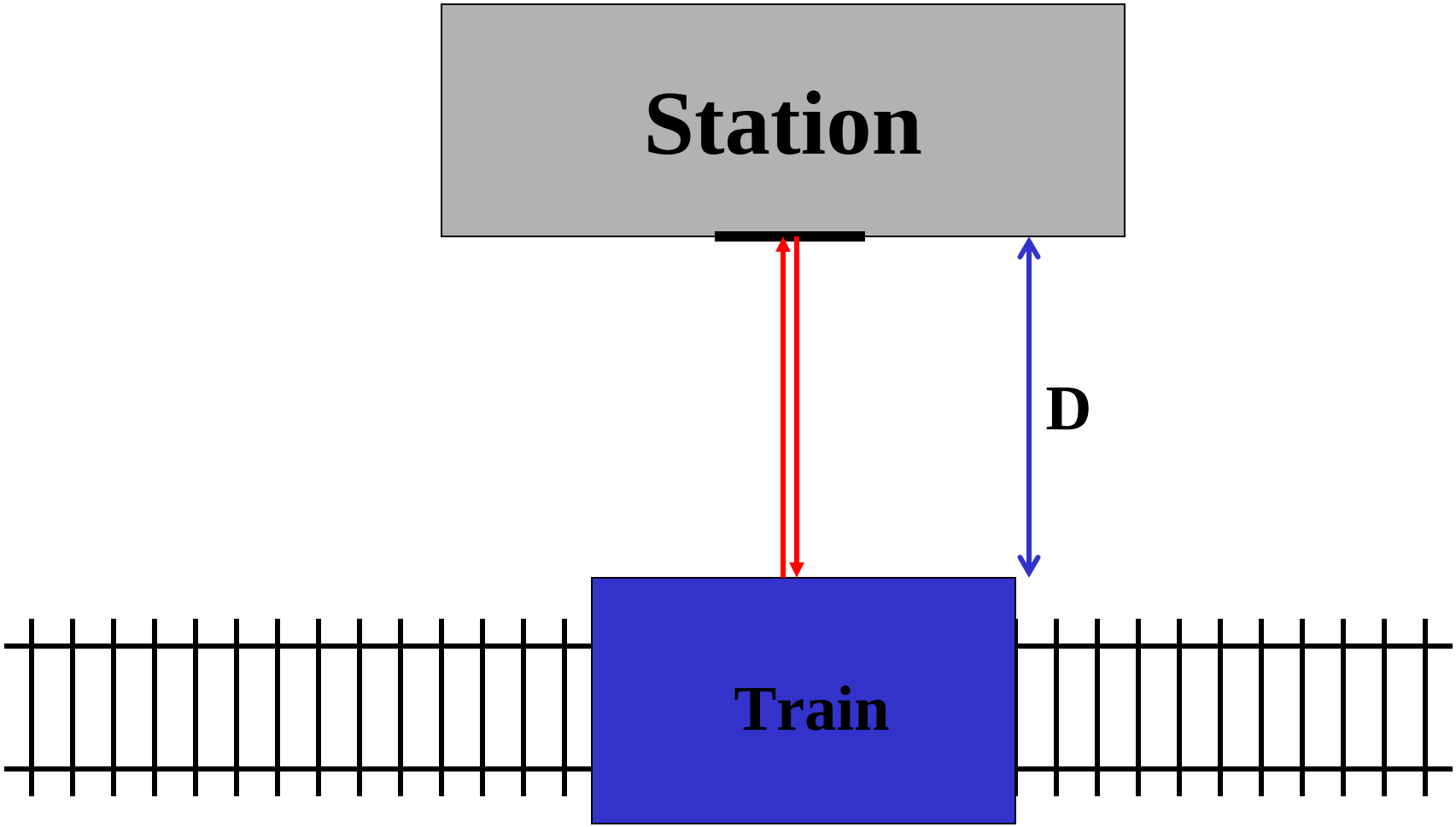
1

- Measurements of space and time are *relative* and depend on our motion
- Unified *spacetime*
- Equivalence of **matter** and **energy**

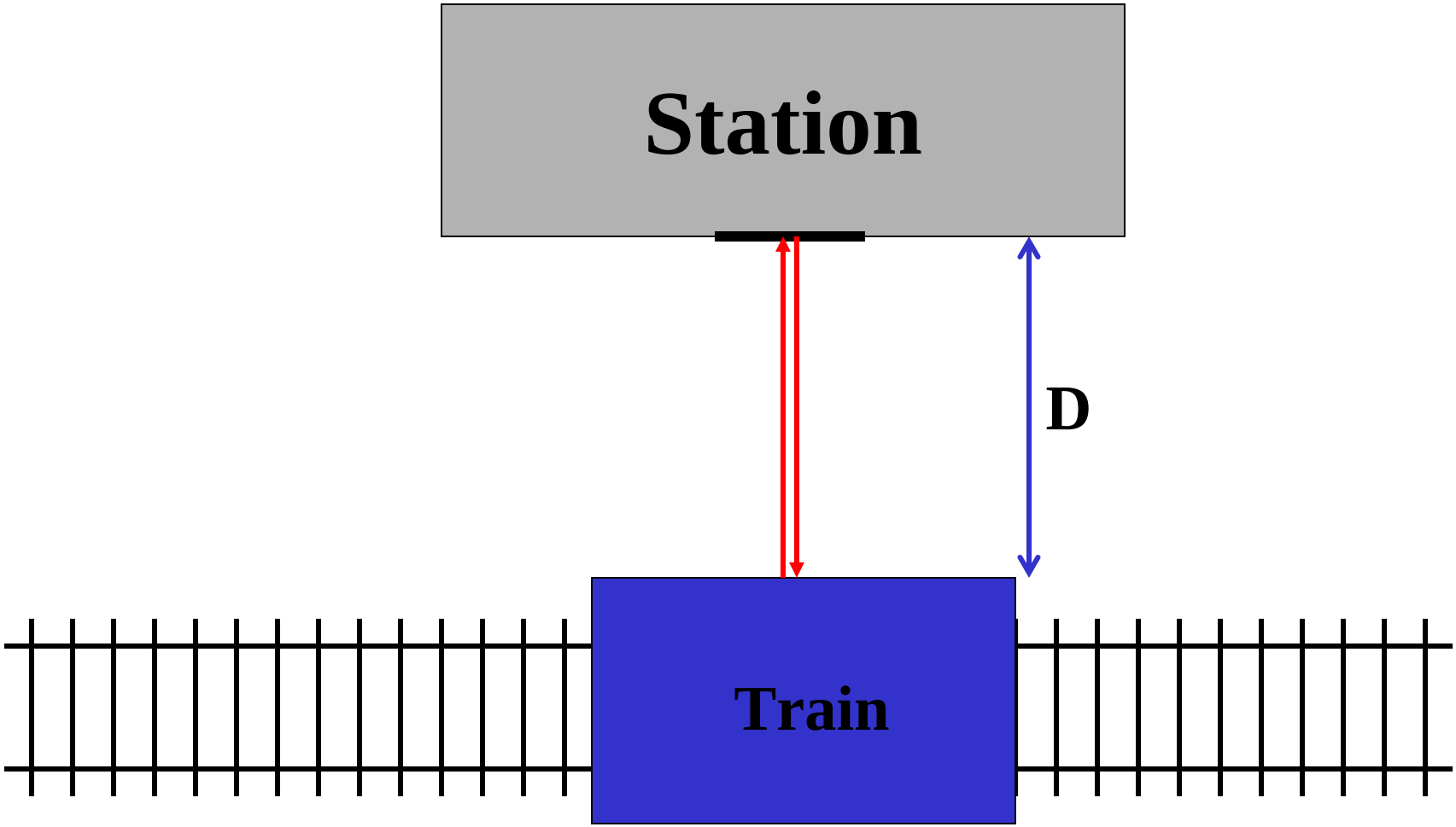
$$E = mc^2$$


Station
D
Train


Station
Torch beam reflected off glass door
D
Train

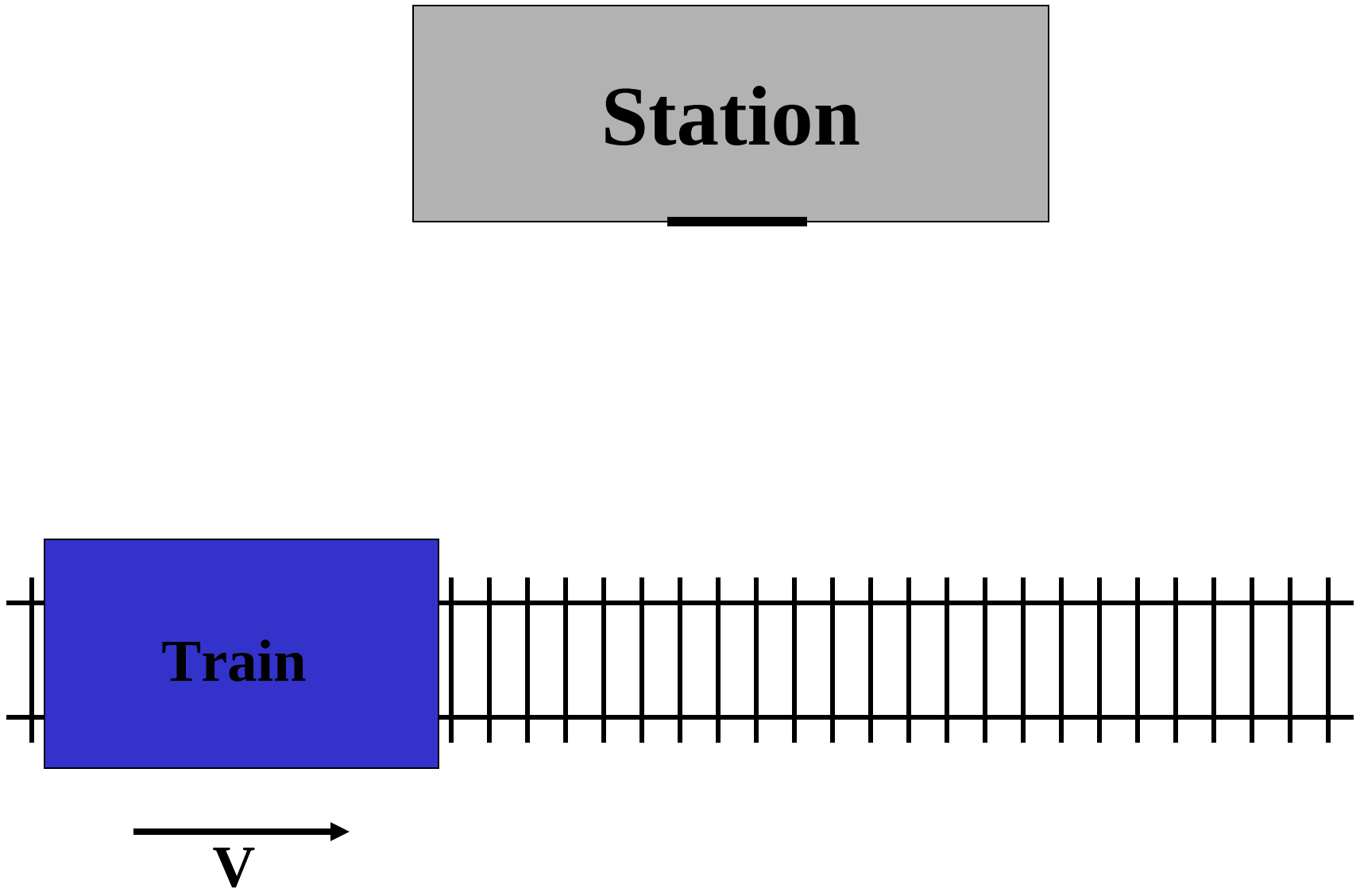



**Distance = speed x time**




**Distance = speed x time**

$$2D = ct_S$$


Station
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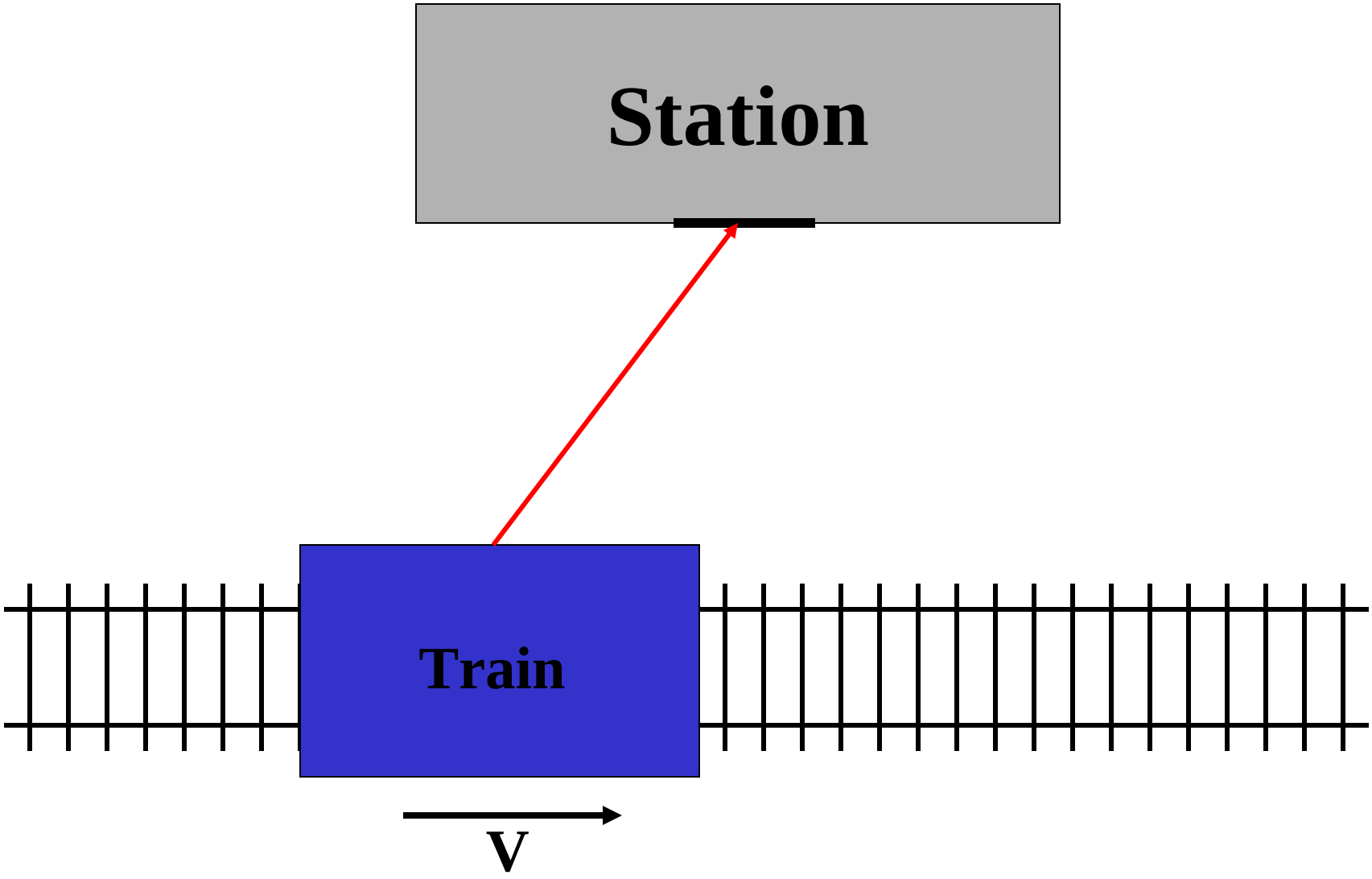
V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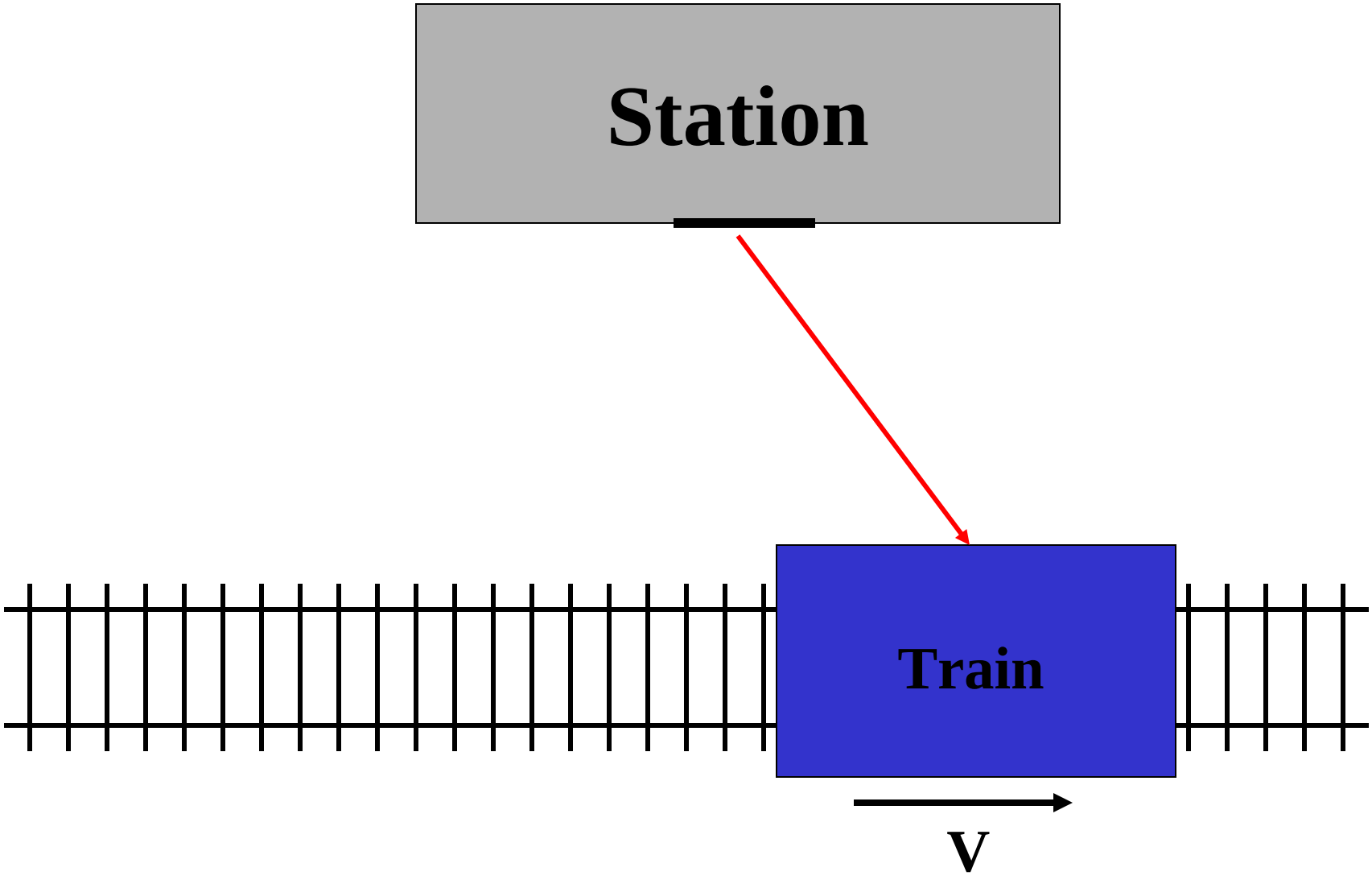
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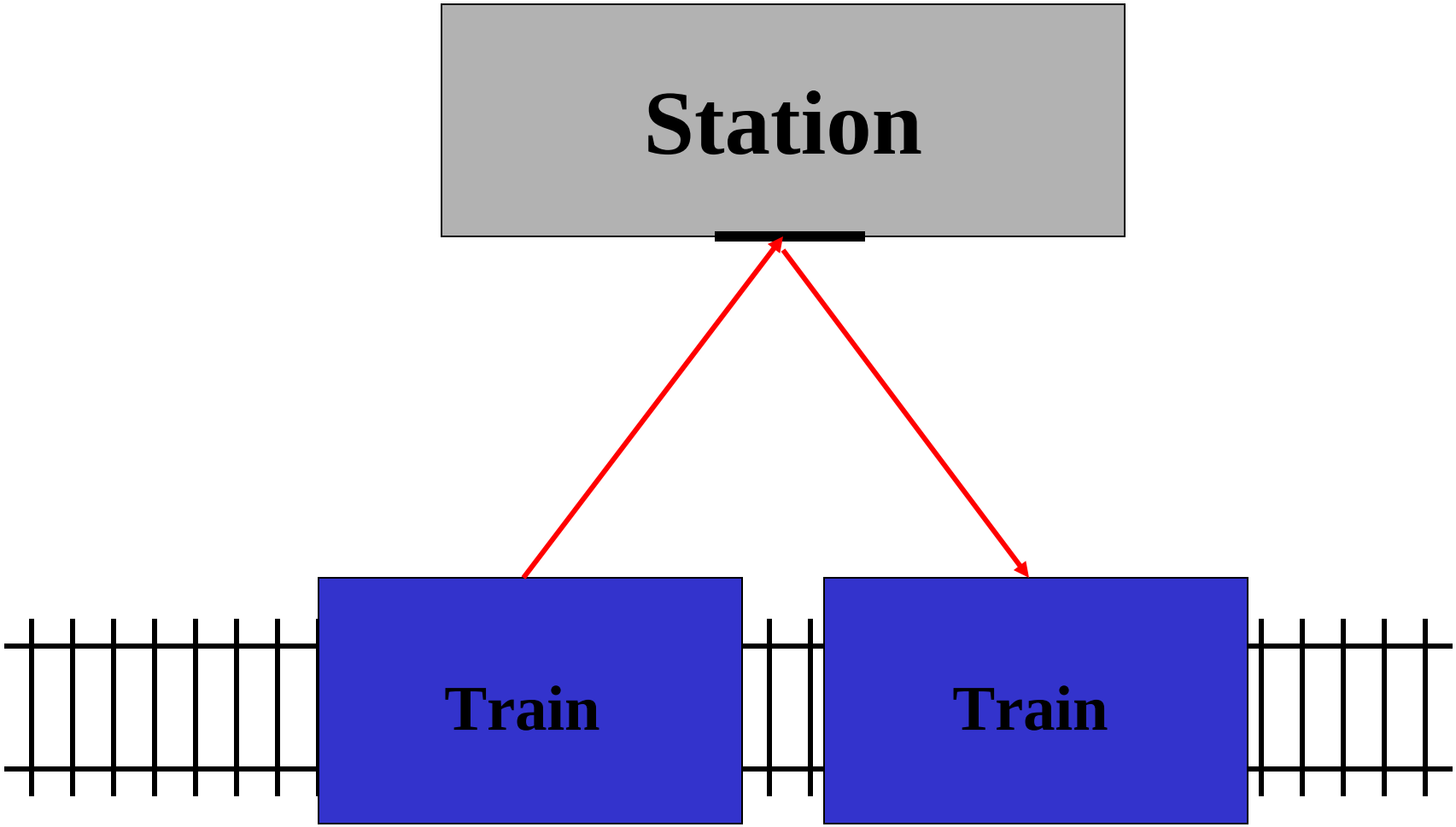
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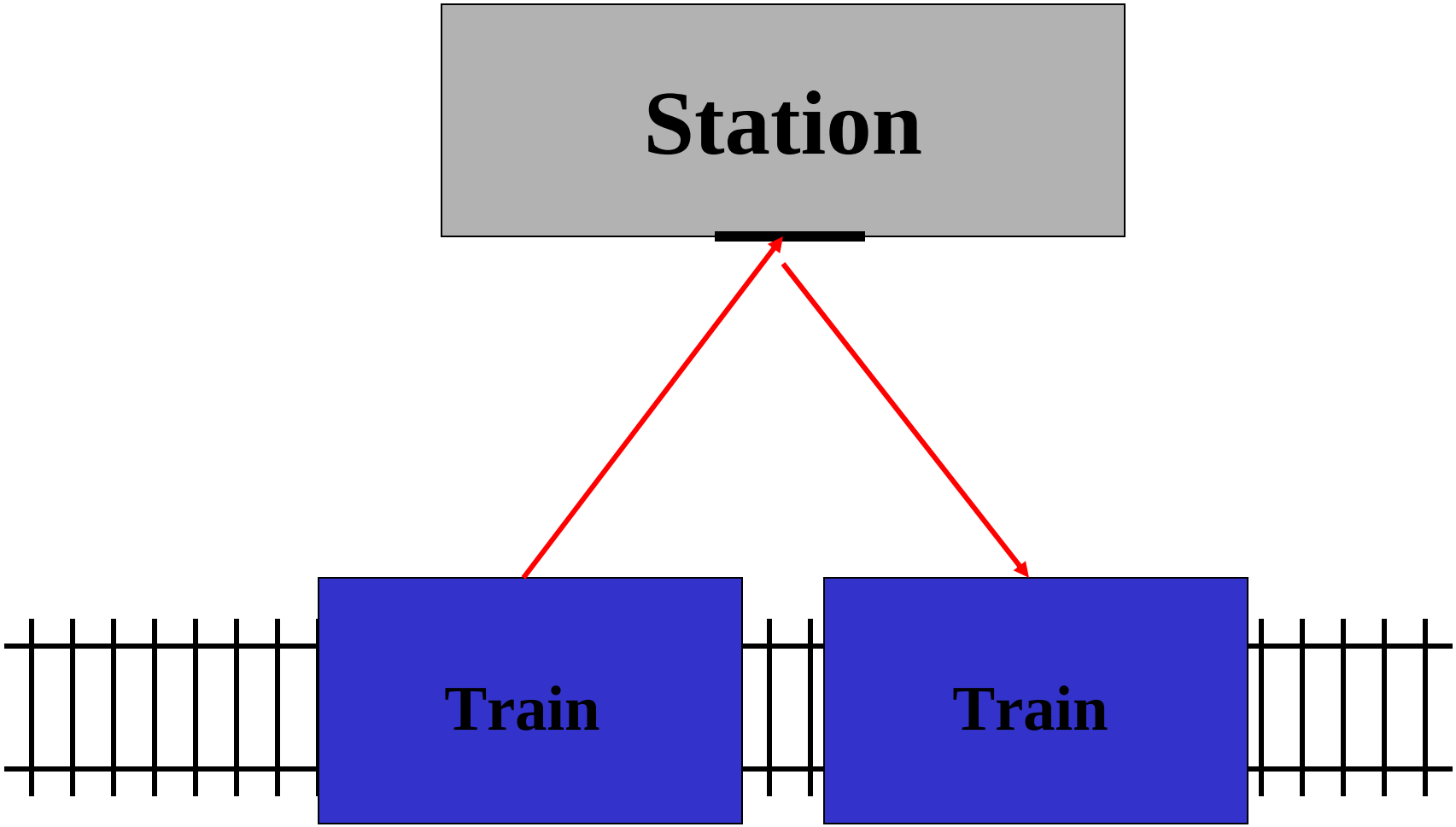
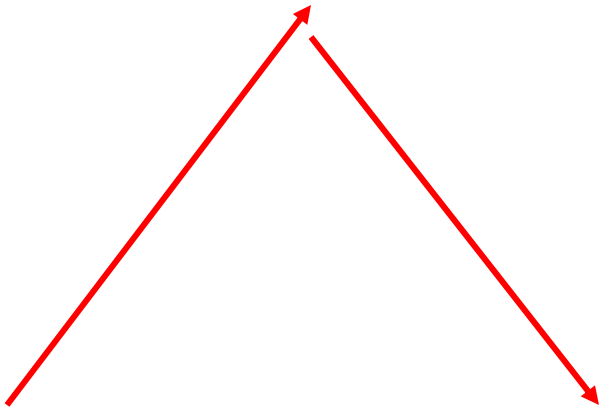



**Let's call the time measured on the train $t_m$**



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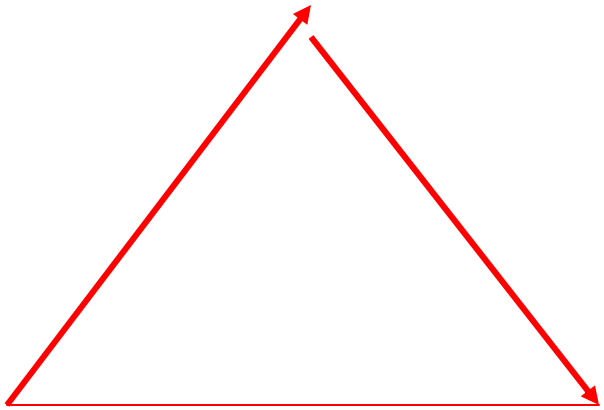

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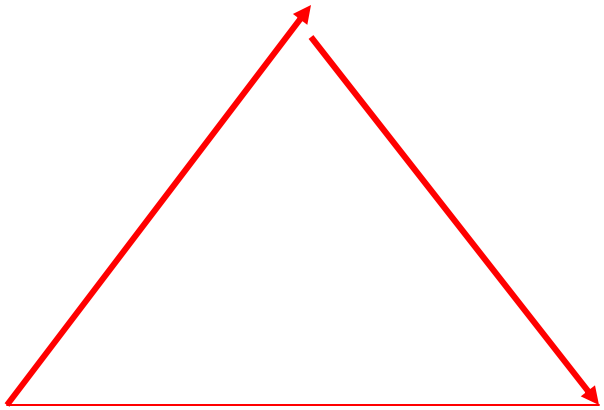
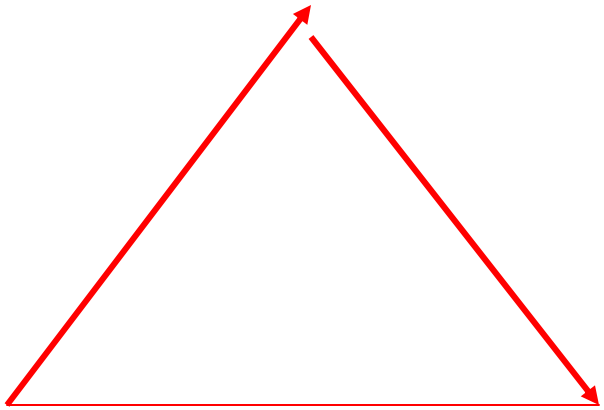


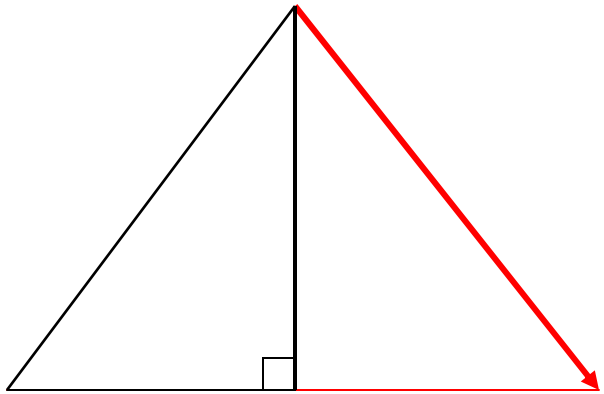
$vt_m$

**Let's call the time measured on the train $t_m$**

**The base of this triangle is $vt_m$**




**This is an isosceles triangle, so it's made up of two equal right angled triangles**

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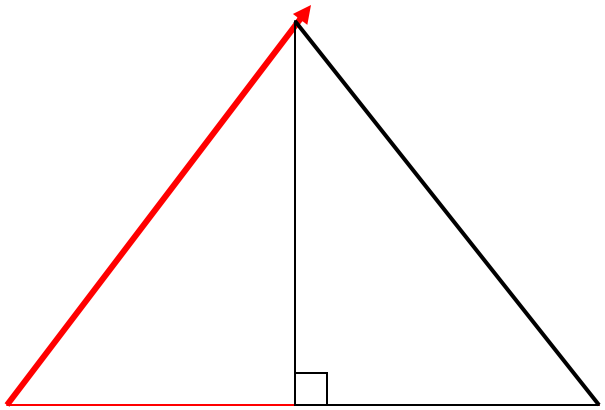


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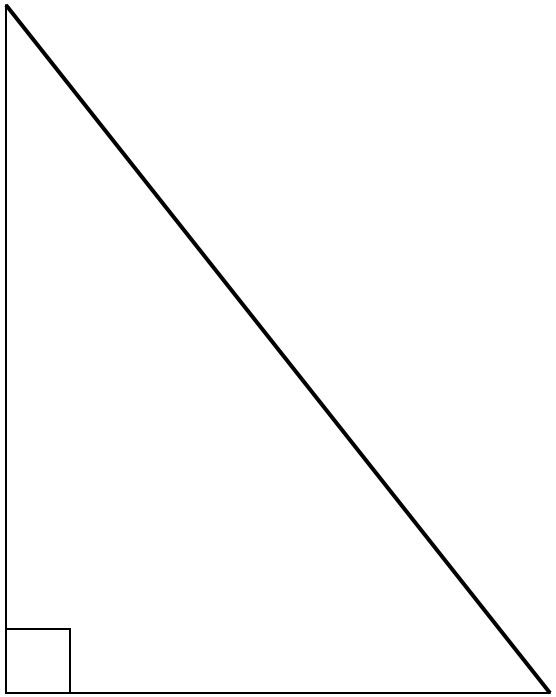
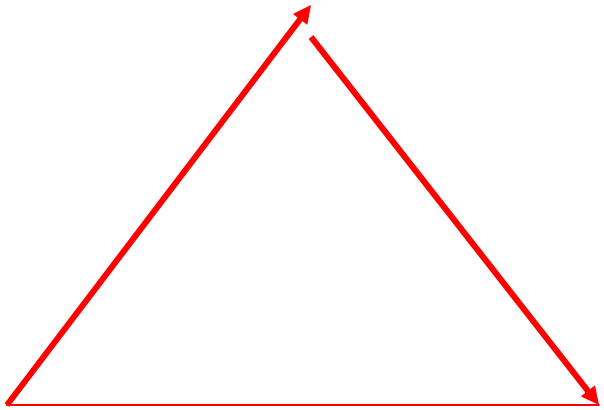
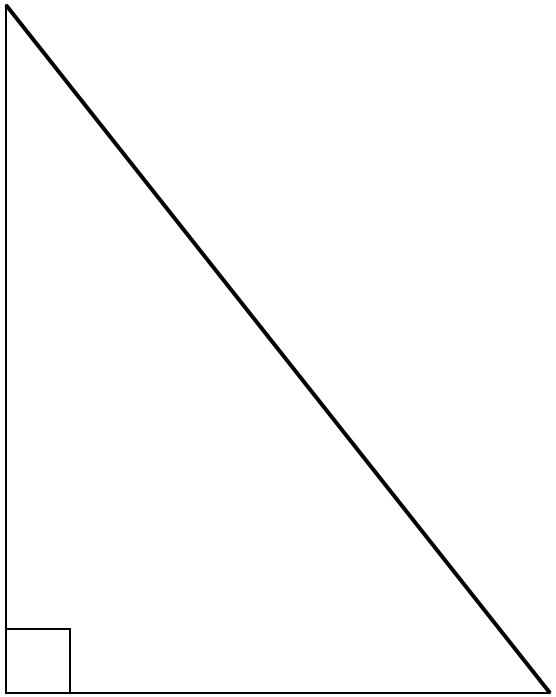


**Let’s look at this right angled triangle**



$\mathbf{vt_m}$

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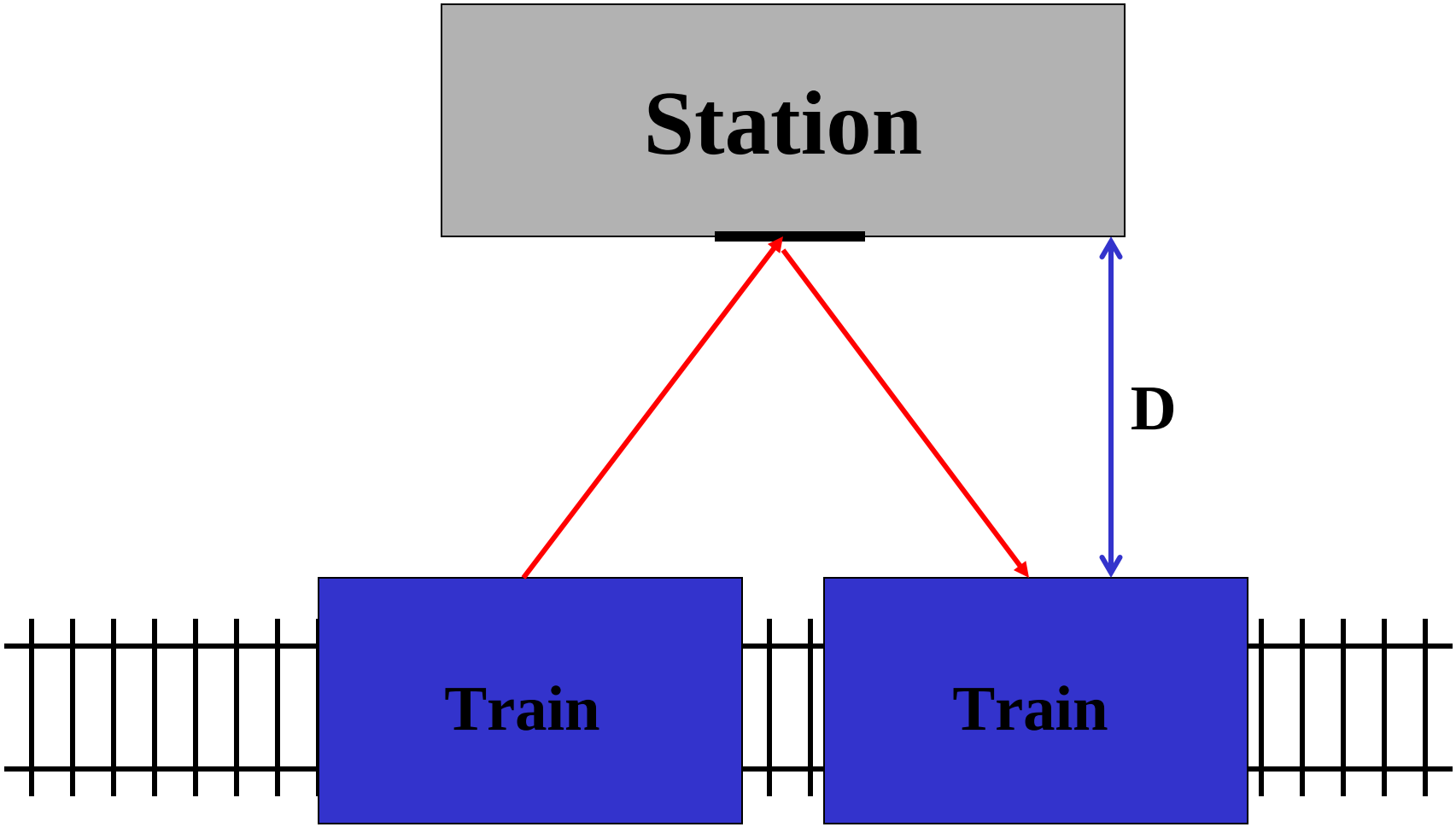
Station
D
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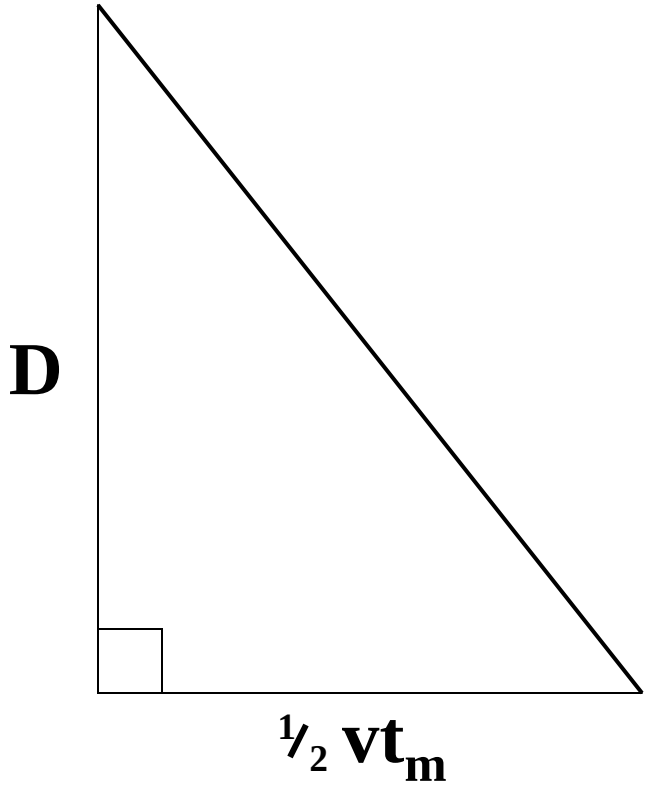


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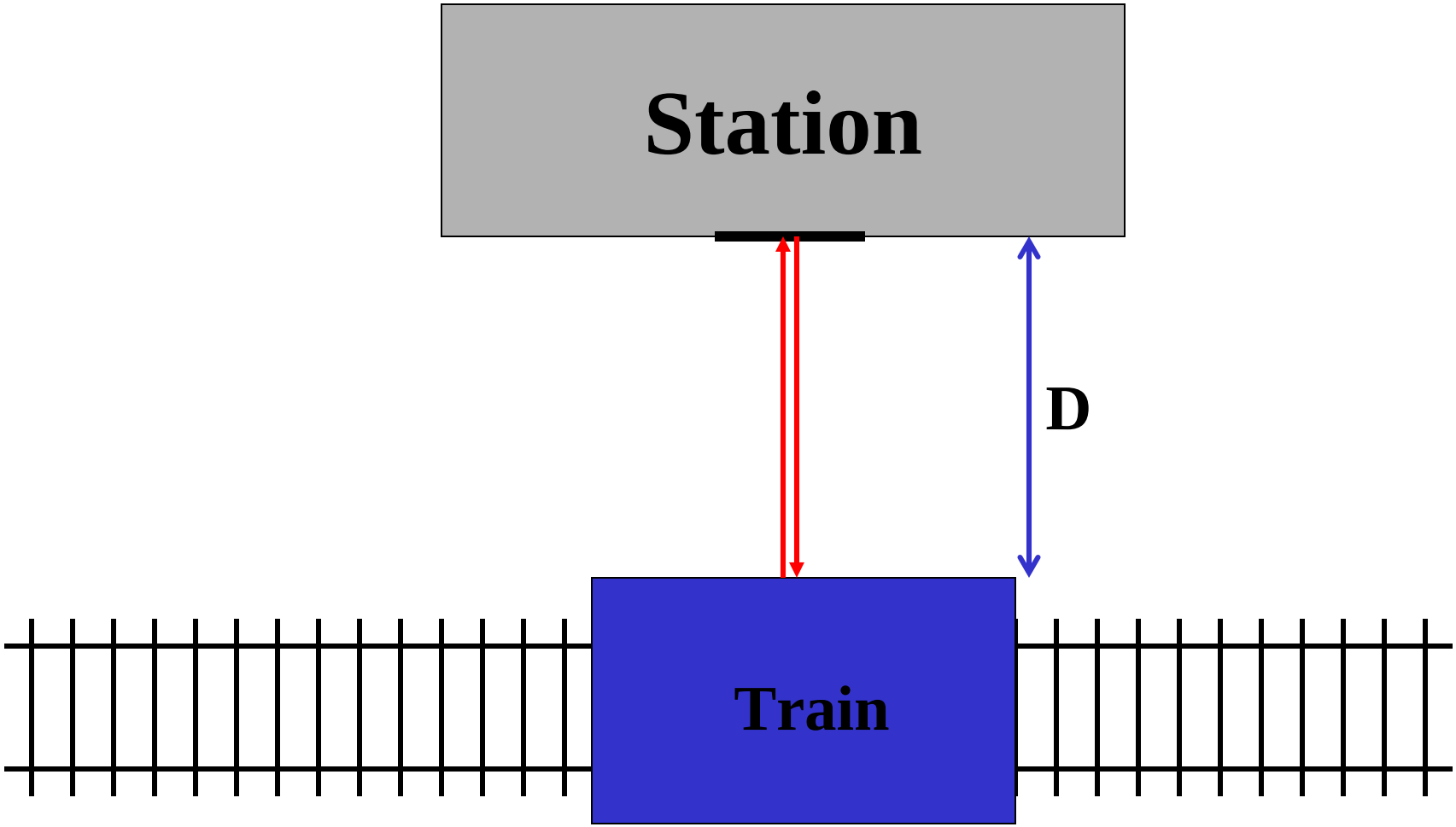
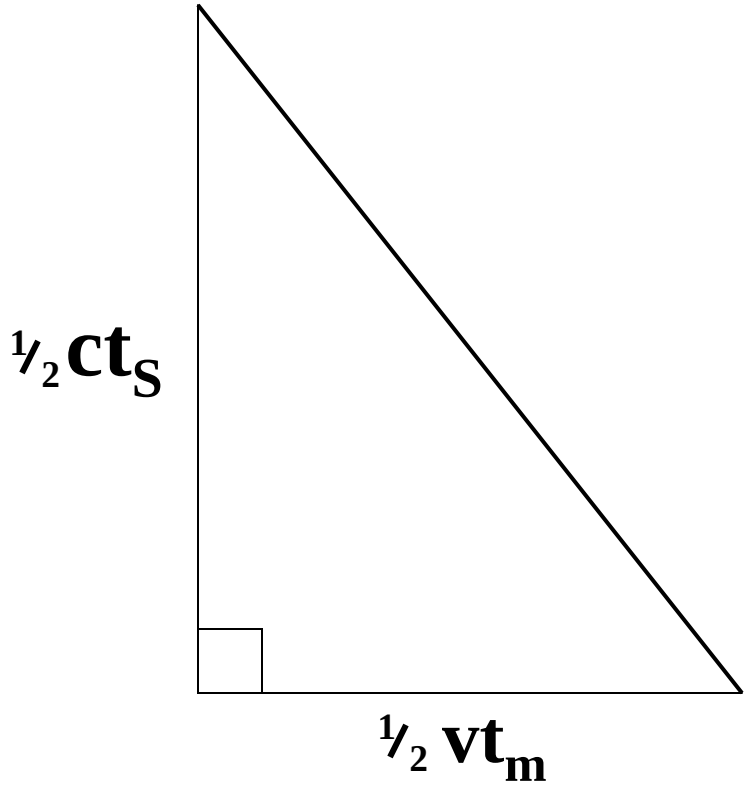



**Distance = speed x time**

$$2D = ct_S$$

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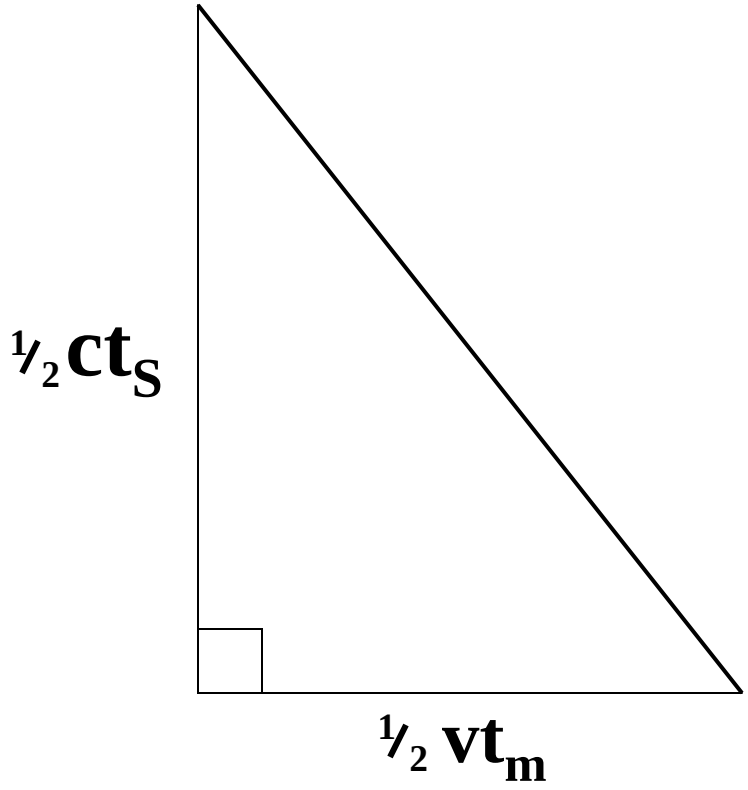
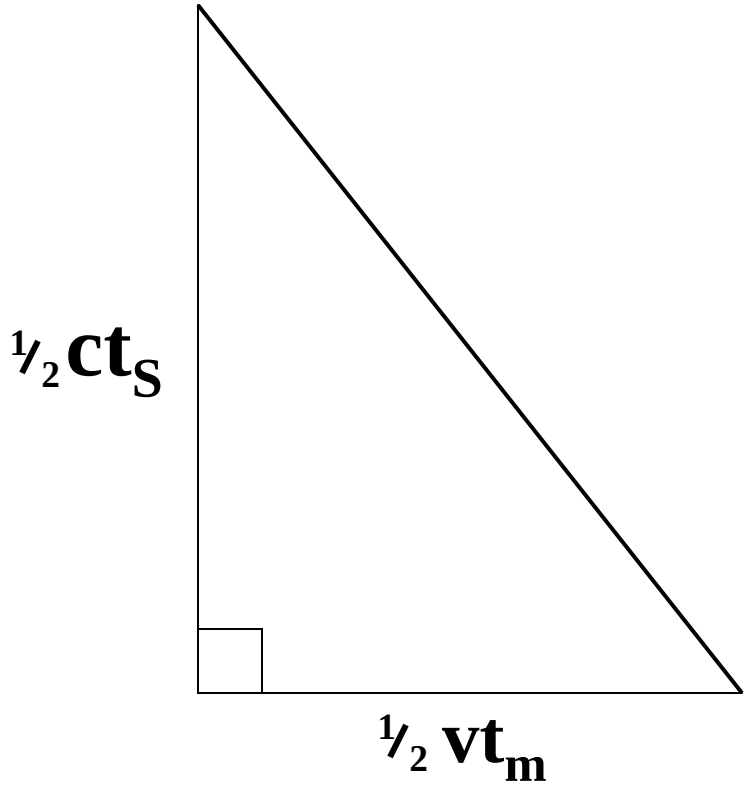



***If*** **the observer on the moving train measures the same speed of light, c …..**

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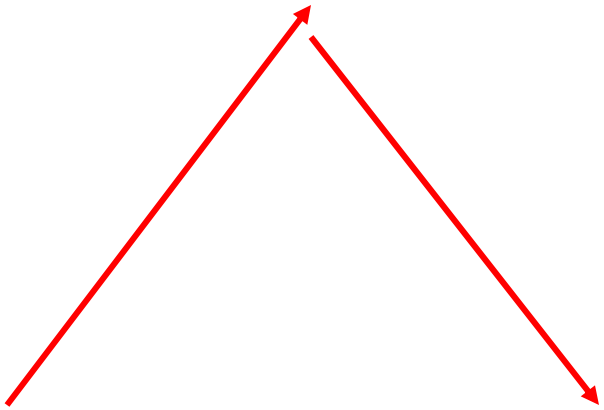
**Einstein's big idea!!!**



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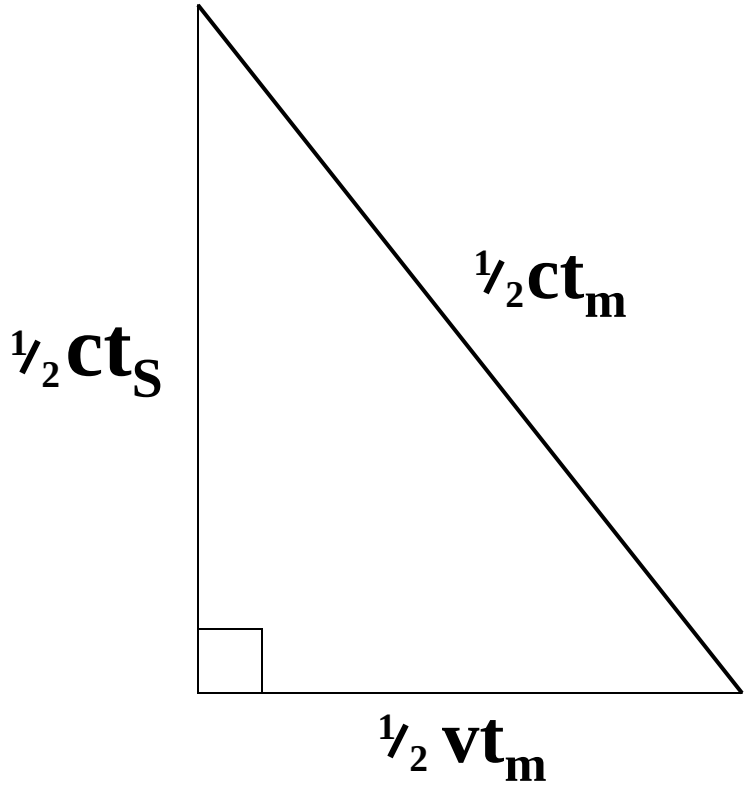
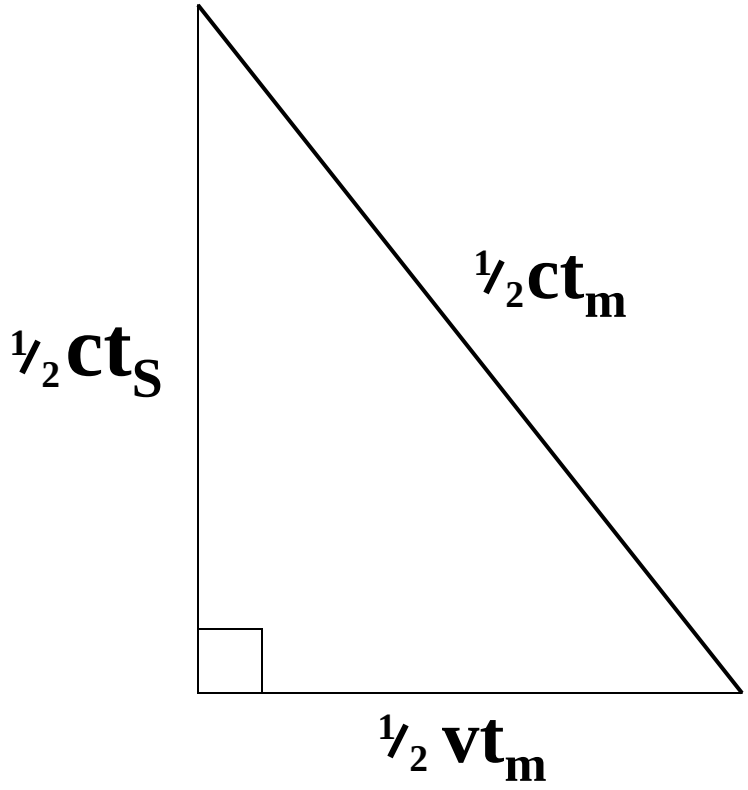
**The light travels a total distance** $ct_m$



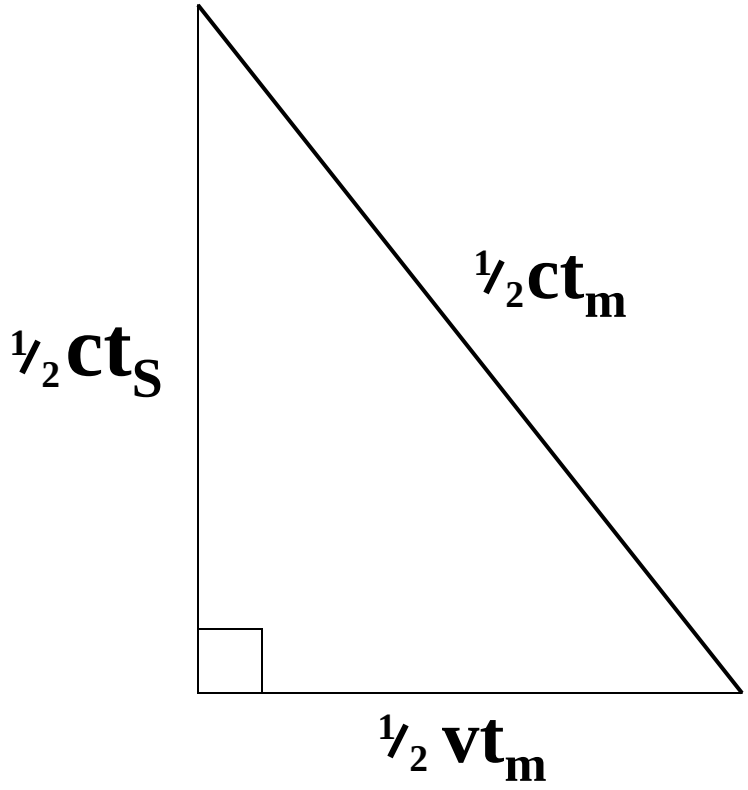

***If*** **the observer on the moving train measures the same speed of light, c …..**

**The light travels a total distance** $ct_m$




**Using Pythagoras' theorem,**

$$(ct_m)^2 = (vt_m)^2 + (ct_S)^2$$




**Using Pythagoras' theorem,**

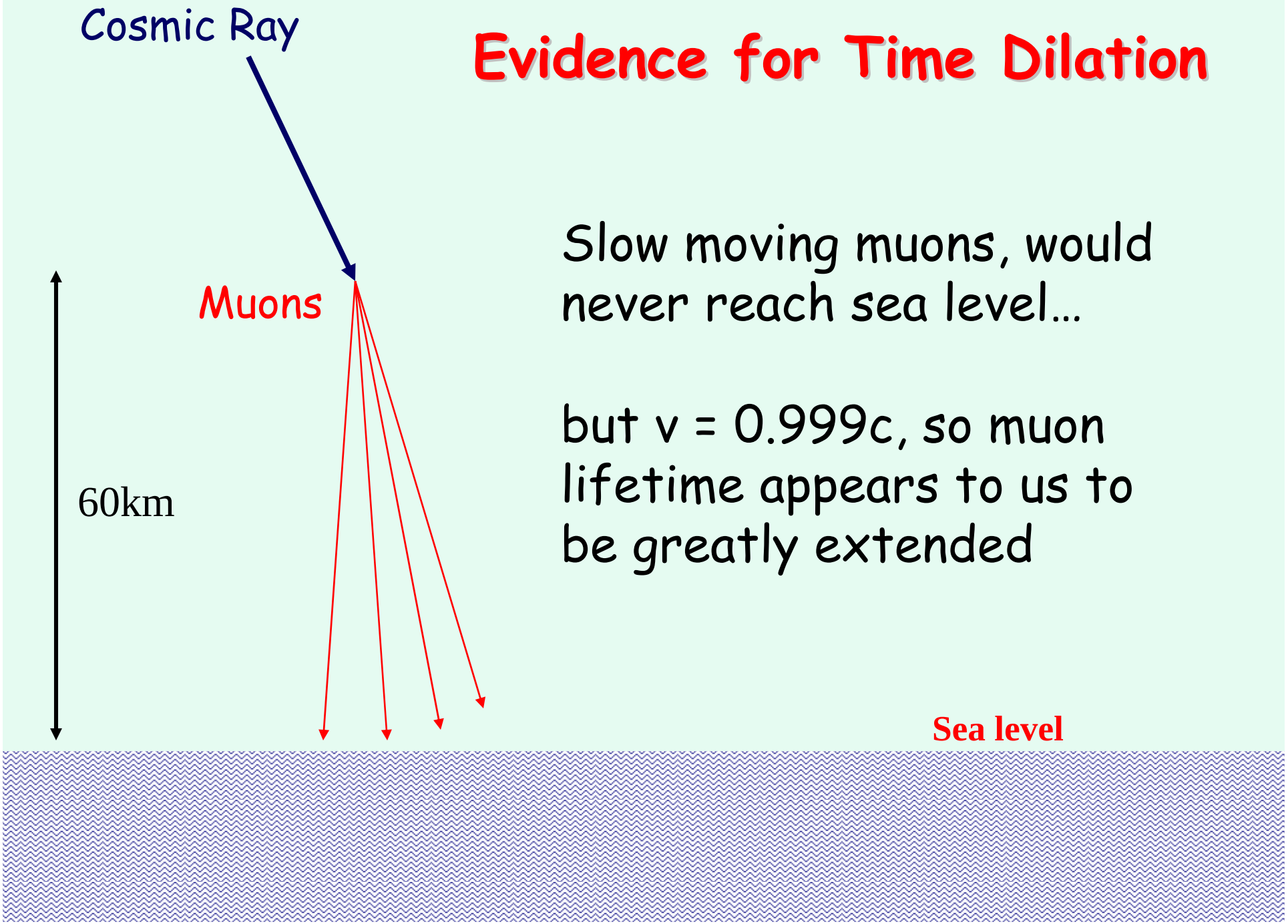
$$t_S = \sqrt{t_m\,(1 - v^2/c^2)}$$

It appears that time is running more slowly on the moving train!!

We need to think about a unified *spacetime*

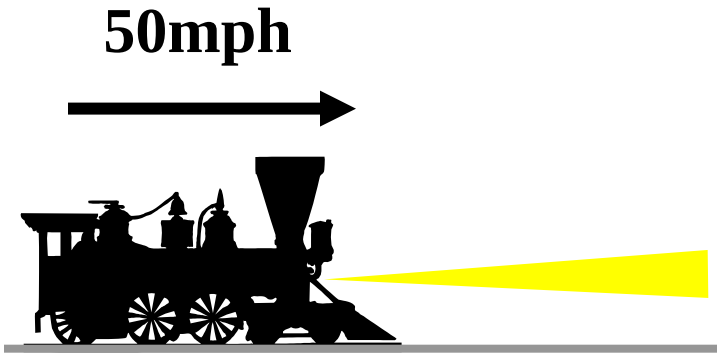
$$t_c = t_P \sqrt{(1 - v^2/c^2)}$$

# Evidence for Time Dilation




Slow moving muons, would never reach sea level…

but v = 0.999c, so muon lifetime appears to us to be greatly extended




According to Einstein, the speed of light is *unchanged* by the motion of the train

ON THE ELECTRODYNAMICS OF MOVING BODIES

By A. EINSTEIN

June 30, 1905

It is known that Maxwell's electrodynamics—as usually understood at the present time—when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena. Take, for example, the reciprocal electrodynamic action of a magnet and a conductor. The observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary view draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion. For if the magnet is in motion and the conductor at rest, there arises in the neighbourhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are situated. But if the magnet is stationary and the conductor in motion, no electric field arises in the neighbourhood of the magnet. In the conductor, however, we find an electromotive force, to which in itself there is no corresponding energy, but which gives rise—assuming equality of relative motion in the two cases discussed—to electric currents of the same path and intensity as those produced by the electric forces in the former case.

Examples of this sort, together with the unsuccessful attempts to discover any motion of the earth relatively to the "light medium," suggest that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest. They suggest rather that, as has already been shown to the first order of small quantities, the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good.[1] We will raise this conjecture (the purport of which will hereafter be called the "Principle of Relativity") to the status of a postulate, and also introduce another postulate, which is only apparently irreconcilable with the former, namely, that light is always propagated in empty space with a definite velocity $c$ which is independent of the state of motion of the emitting body. These two postulates suffice for the attainment of a simple and consistent theory of the electrodynamics of moving bodies based on Maxwell's theory for stationary bodies. The introduction of a "luminiferous ether" will prove to be superfluous inasmuch as the view here to be developed will not require an "absolutely stationary space" provided with special properties, nor

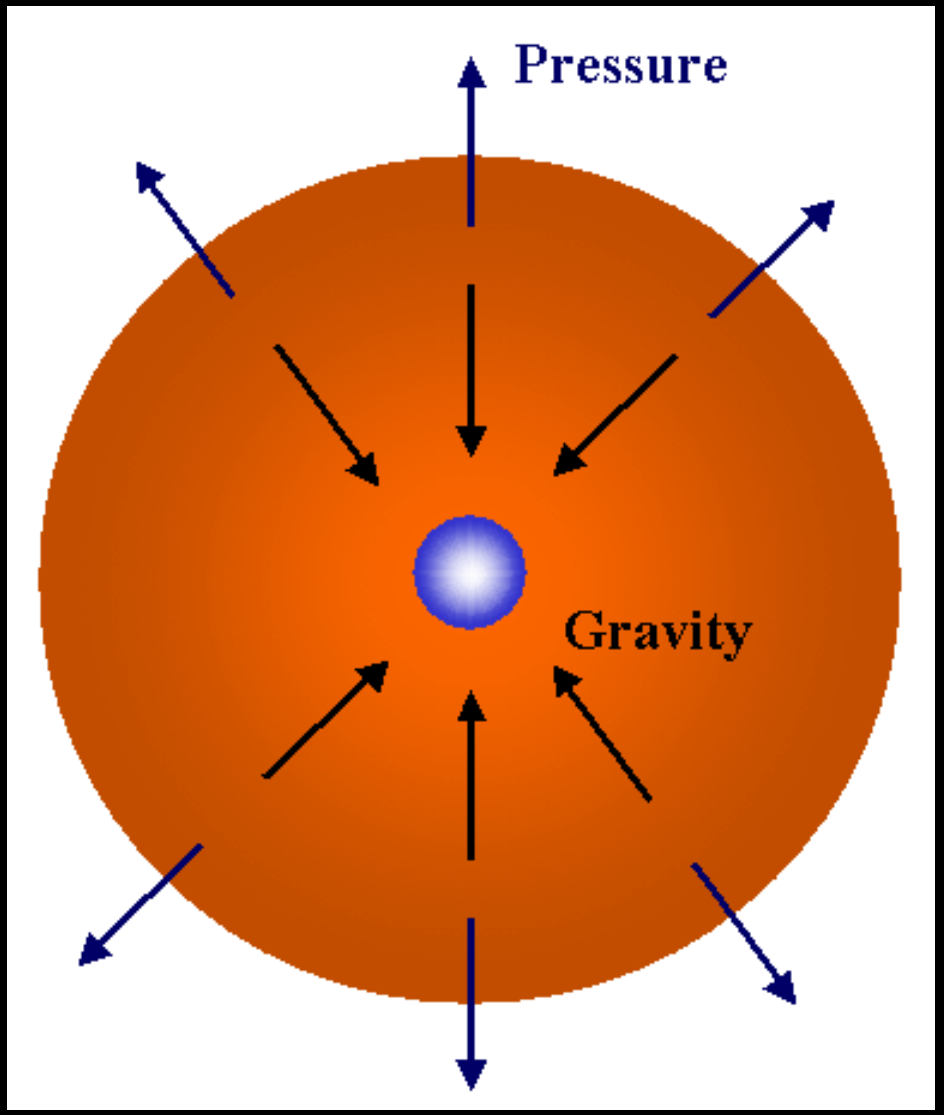
[1]The preceding memoir by Lorentz was not at this time known to the author.

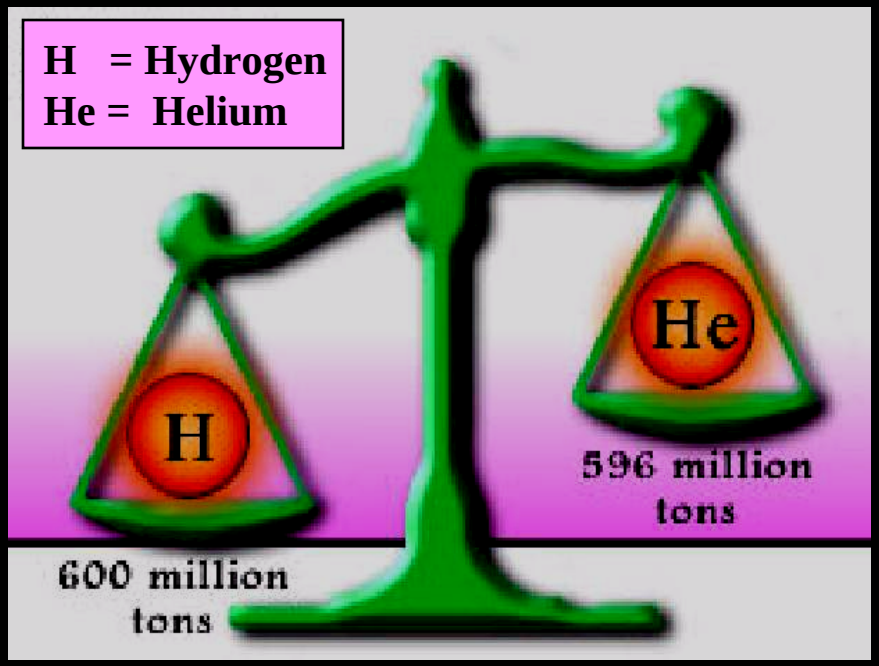
1

- Measurements of space and time are *relative* and depend on our motion
- Unified *spacetime*
- Equivalence of **matter** and **energy**

$$E = mc^2$$

# Hydrogen fusion – fuelling a star's nuclear furnace




$E = mc^2$

# Einstein's Relativity

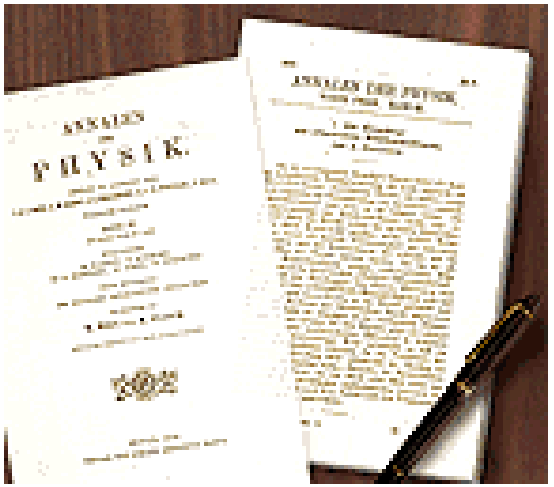
300,000 $kms^{-1}$

The speed of light is the **ultimate speed limit** in the Universe

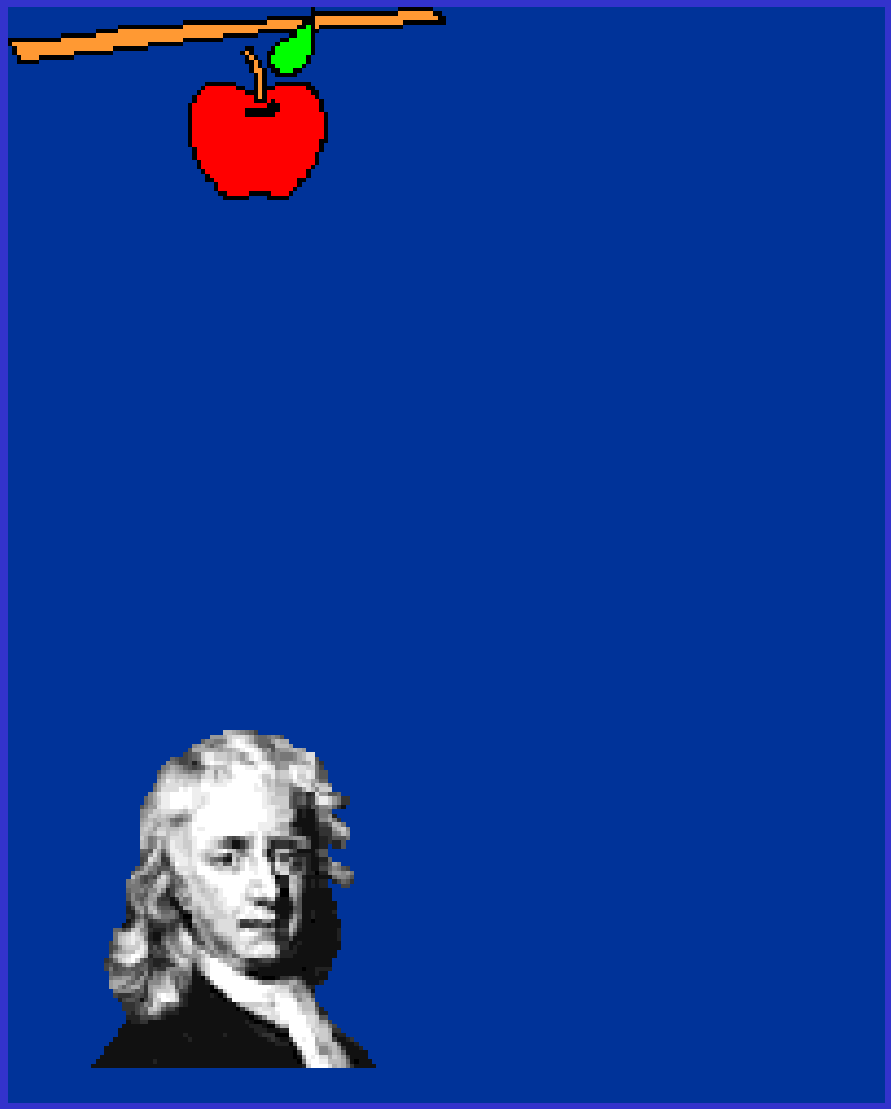
# Einstein's Relativity

What about accelerated observers?

How does gravity fit into this?




**General Relativity: 1916**

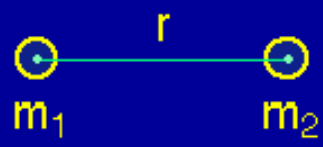




## Law of Universal Gravitation

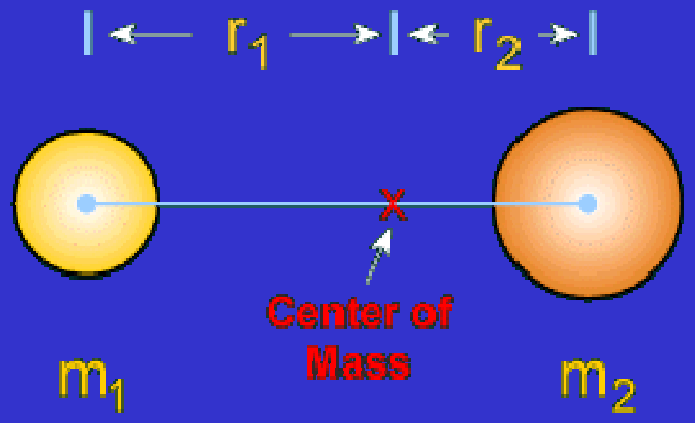
Every object in the Universe attracts every other object with a force directed along the line of centers for the two objects that is proportional to the product of their masses and inversely proportional to the square of the separation between the two objects.

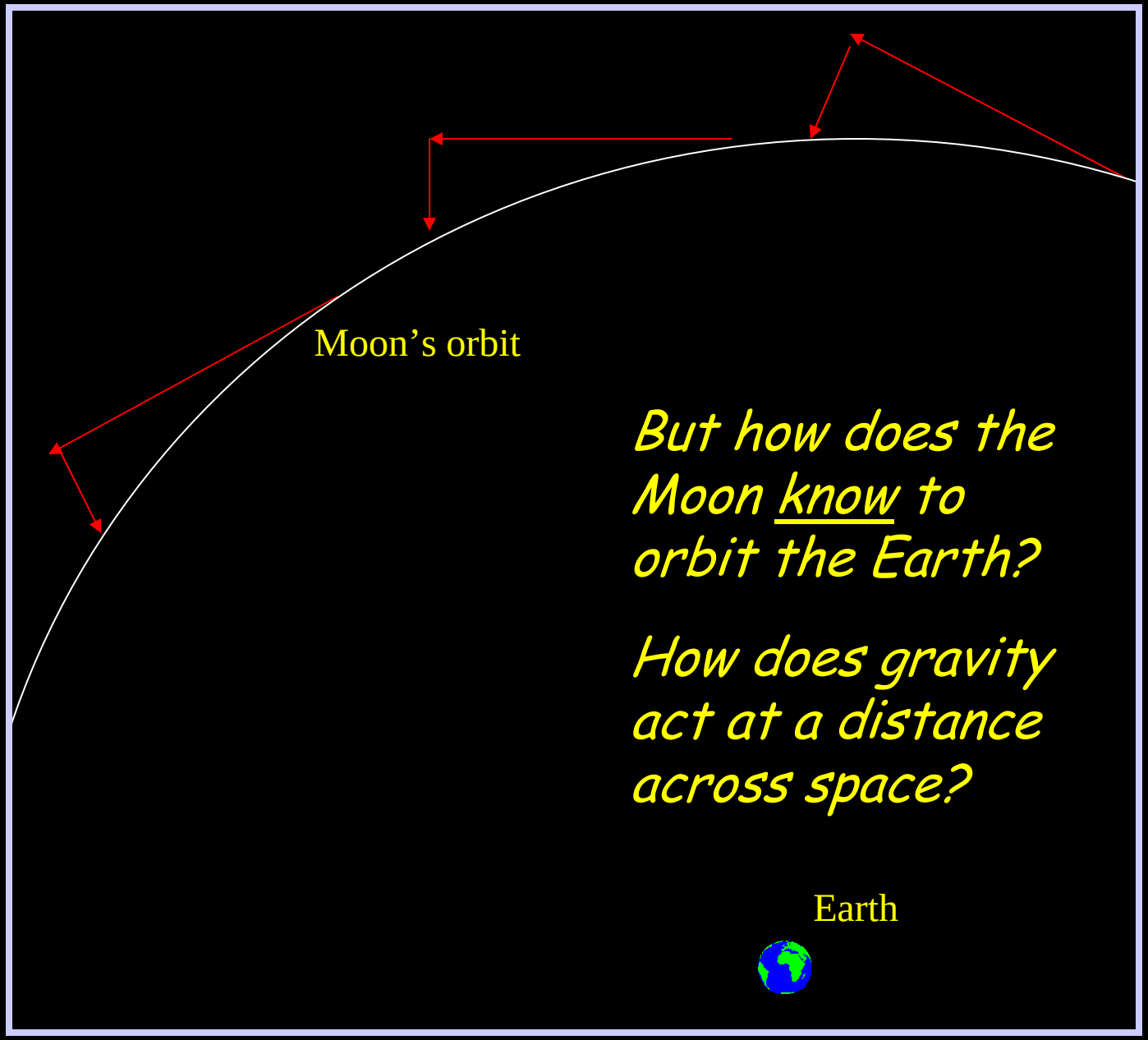
$$F_g = G\frac{m_1 m_2}{r^2}$$




Isaac Newton:
1642 – 1727 AD

*The Principia: 1684 - 1686*

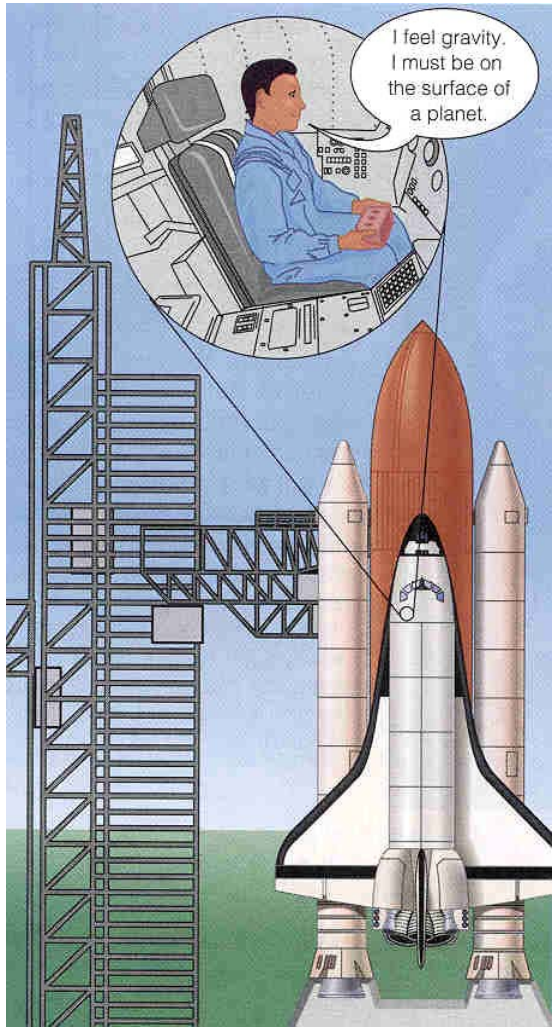


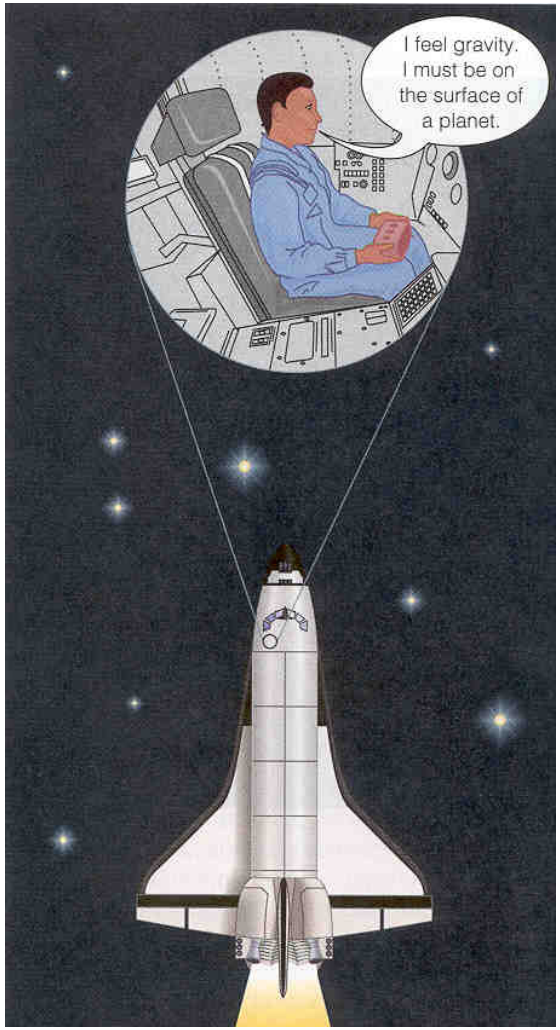

Moon's orbit
But how does the Moon know to orbit the Earth?
How does gravity act at a distance across space?
Earth

# Gravity in Einstein's Universe

Gravity and acceleration are ***equivalent***

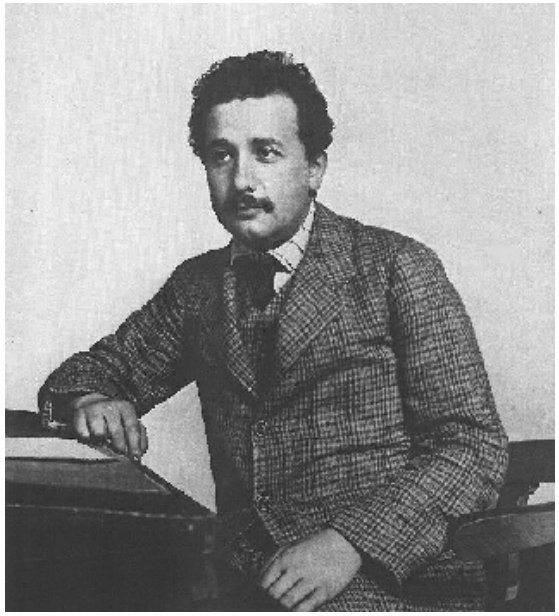
Gravity is not a force acting *through* space and time, but the result of mass (and energy) warping spacetime itself

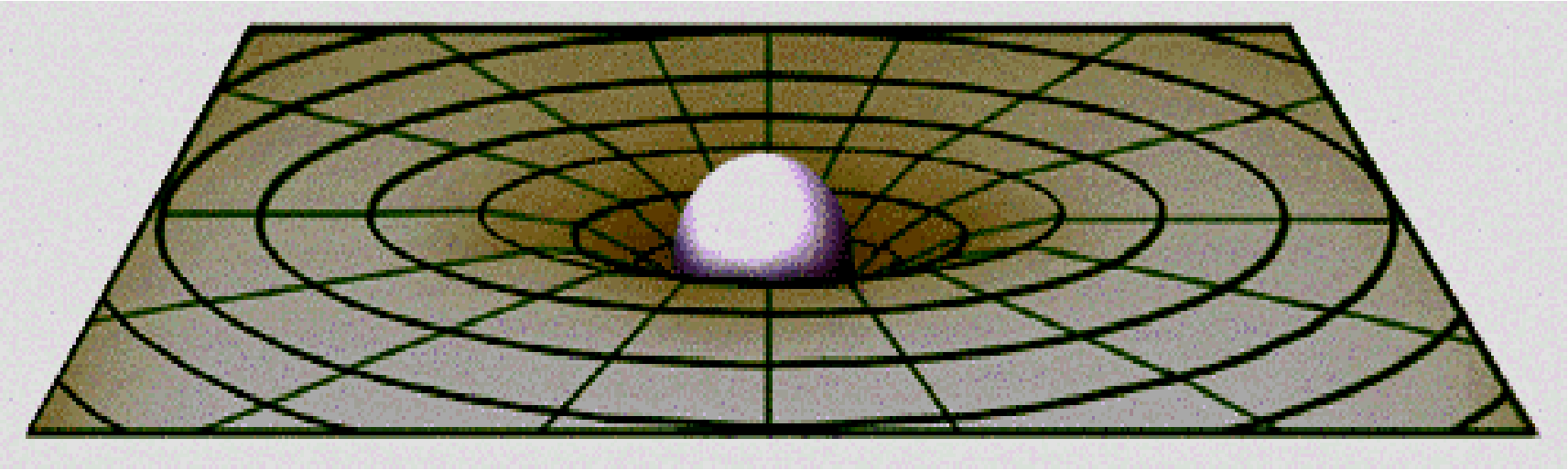


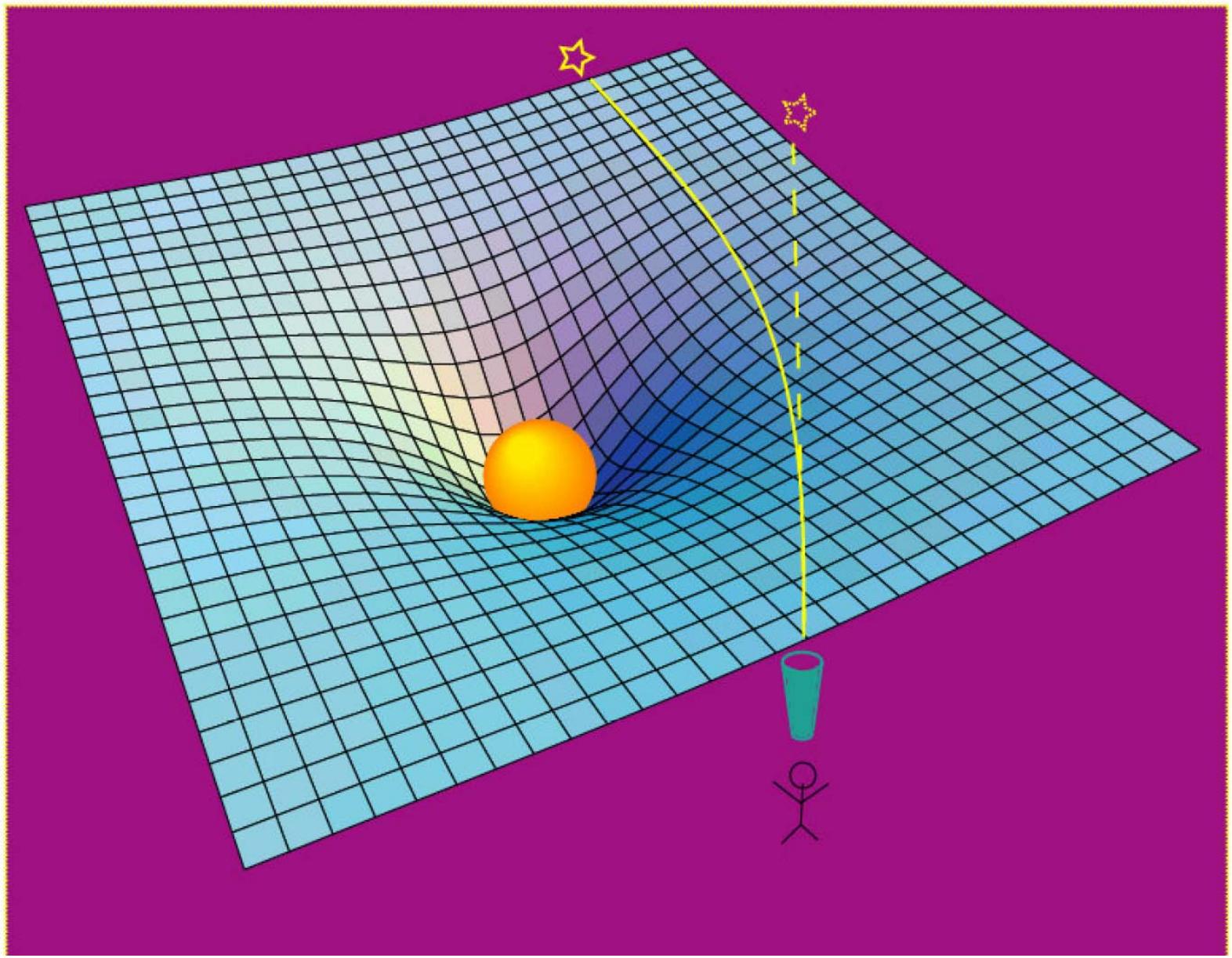



# Gravity in Einstein's Universe

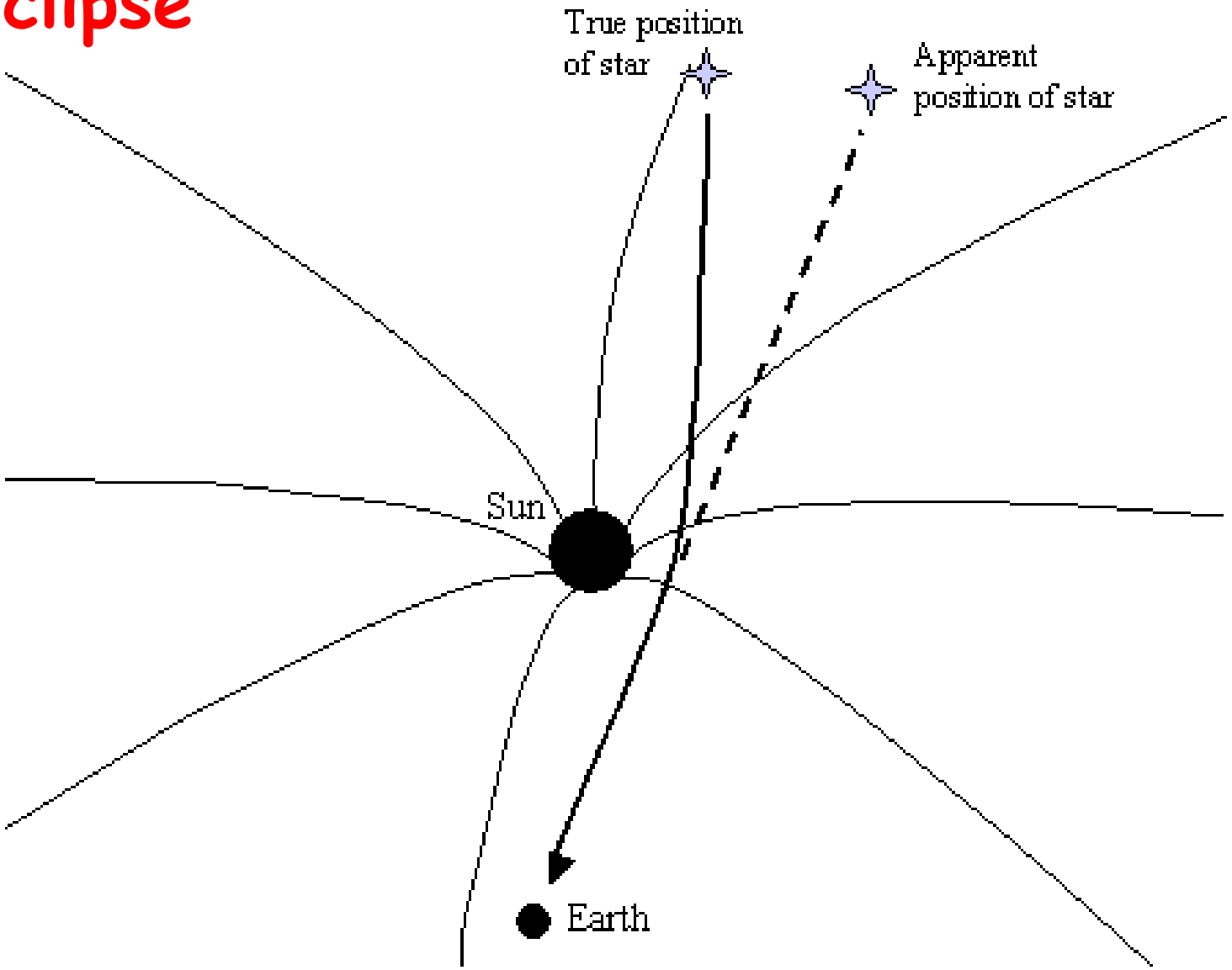
"Spacetime tells matter how to move, and matter tells spacetime how to curve"







# We can see gravitational lensing during a Solar Eclipse



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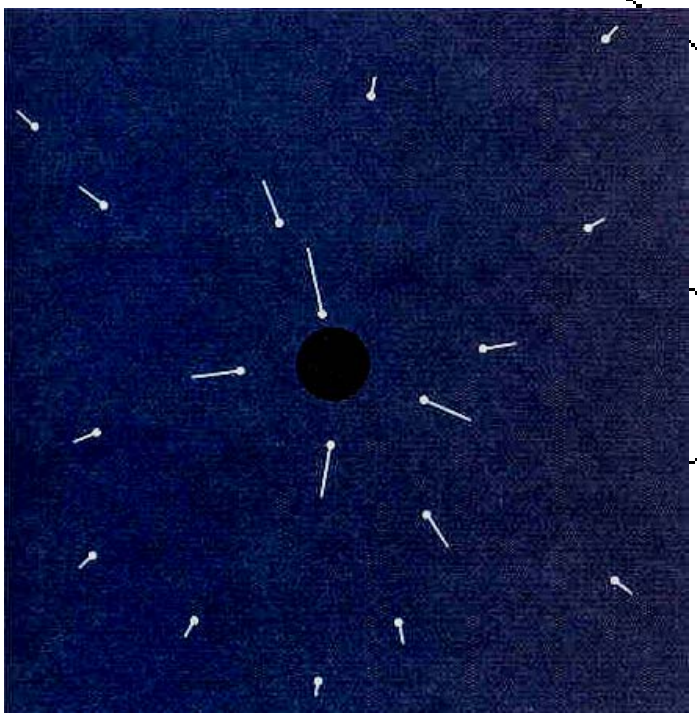
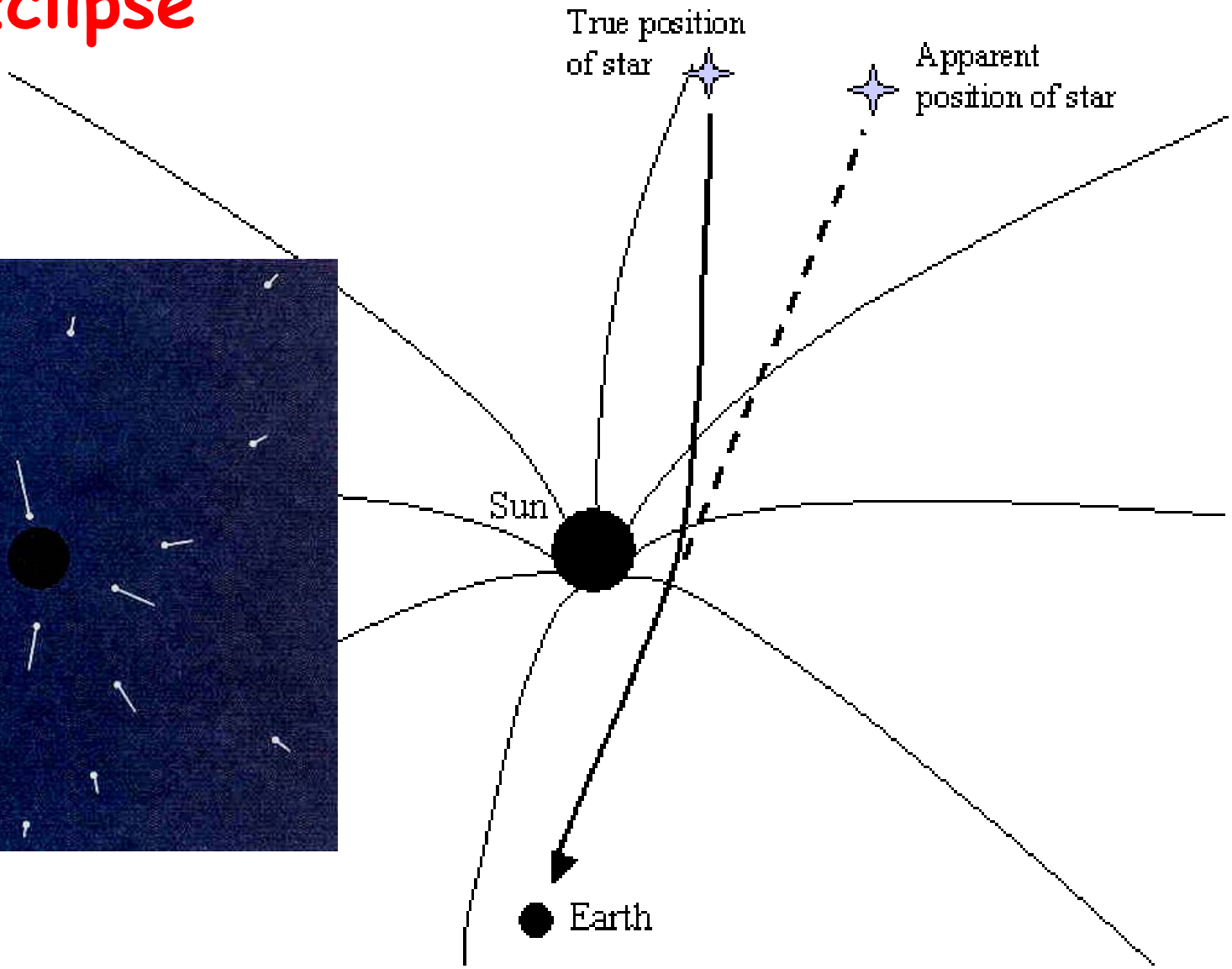
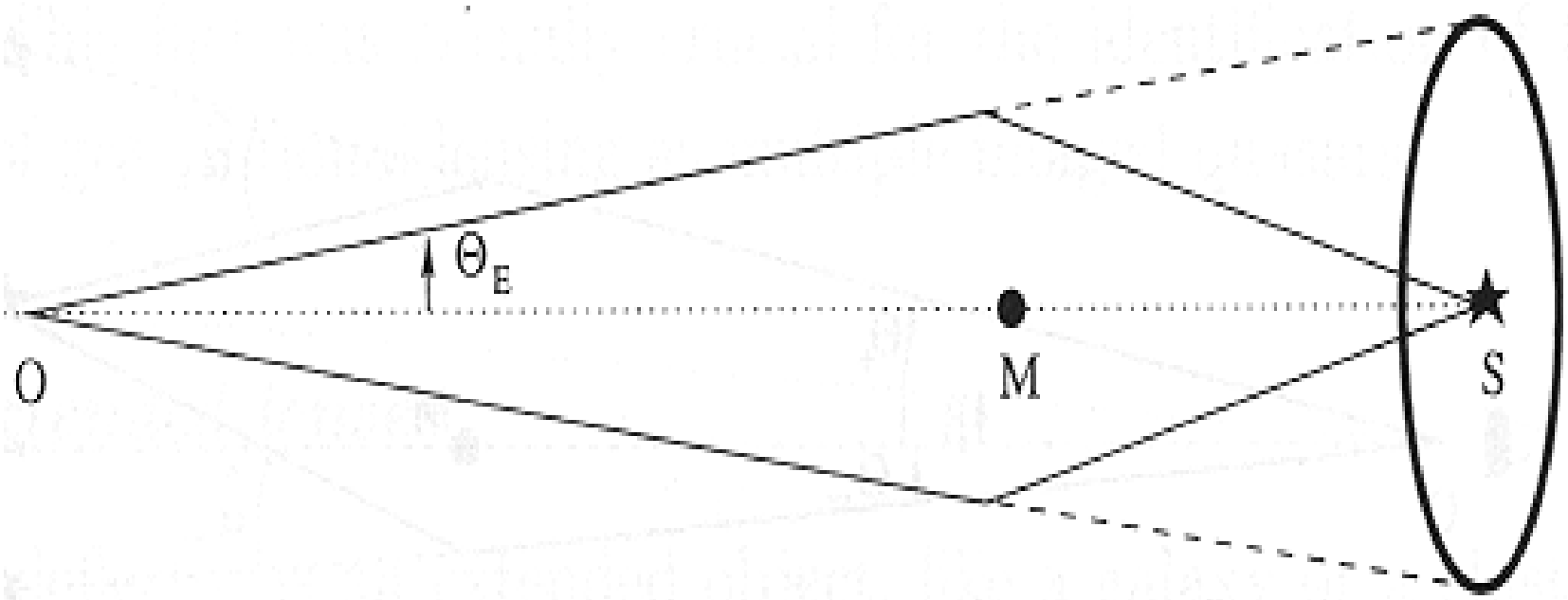
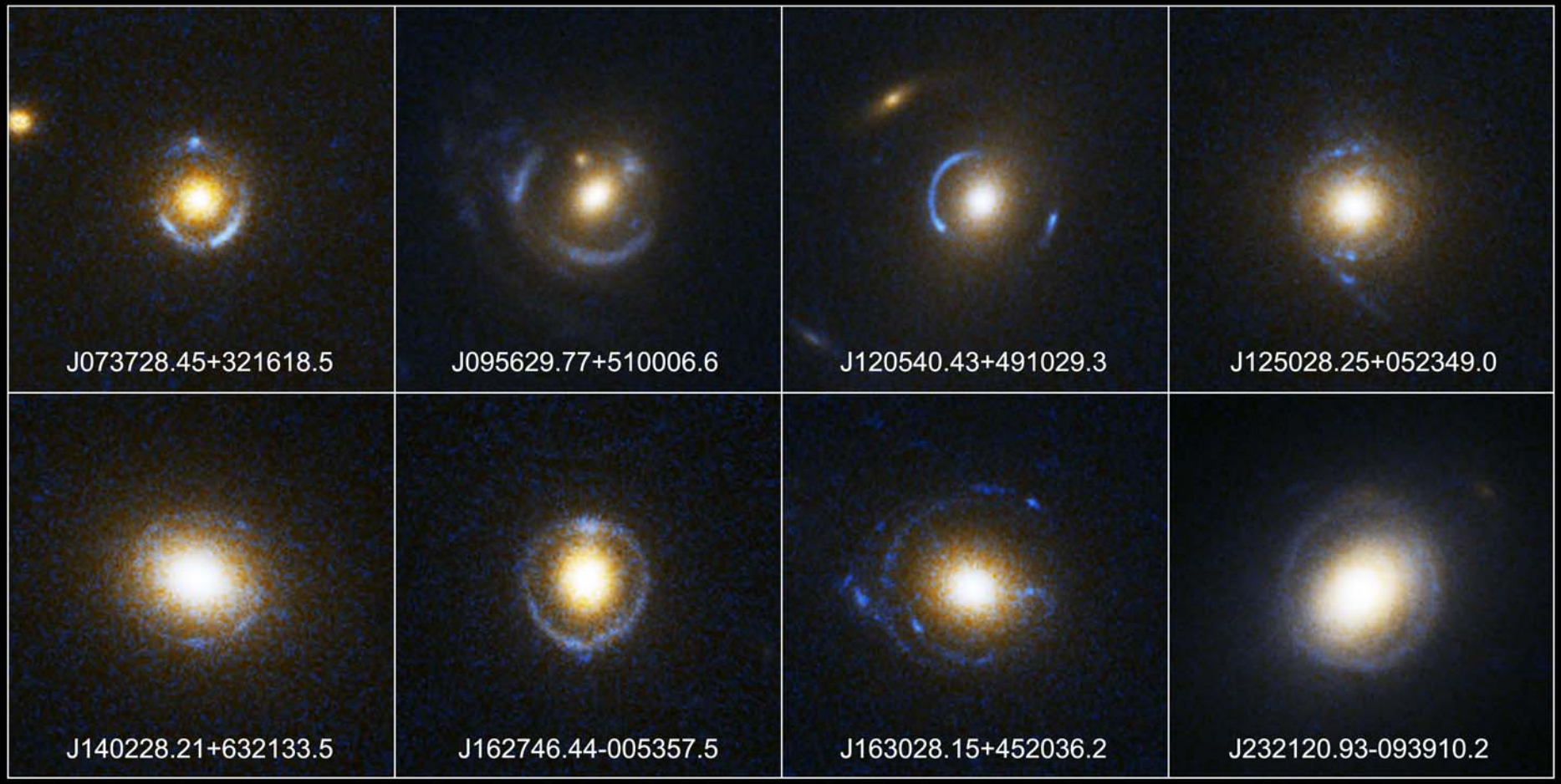




# Einstein Ring






# Einstein Ring Gravitational Lenses

*Hubble Space Telescope* • Advanced Camera for Surveys

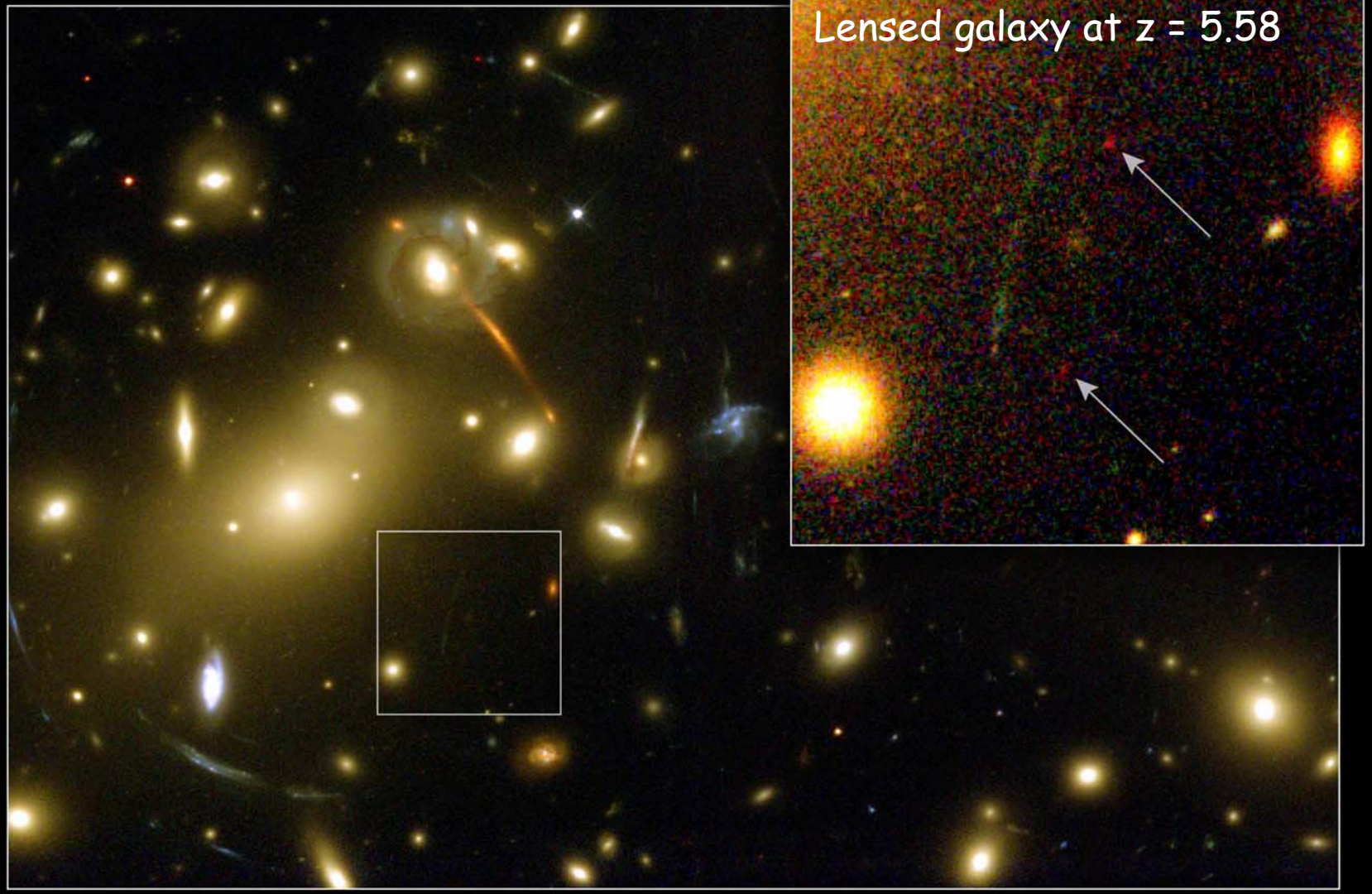
NASA, ESA, A. Bolton (Harvard-Smithsonian CfA), and the SLACS Team

STScI-PRC05-32

# Gravitational Lens in Abell 2218

HST • WFPC2

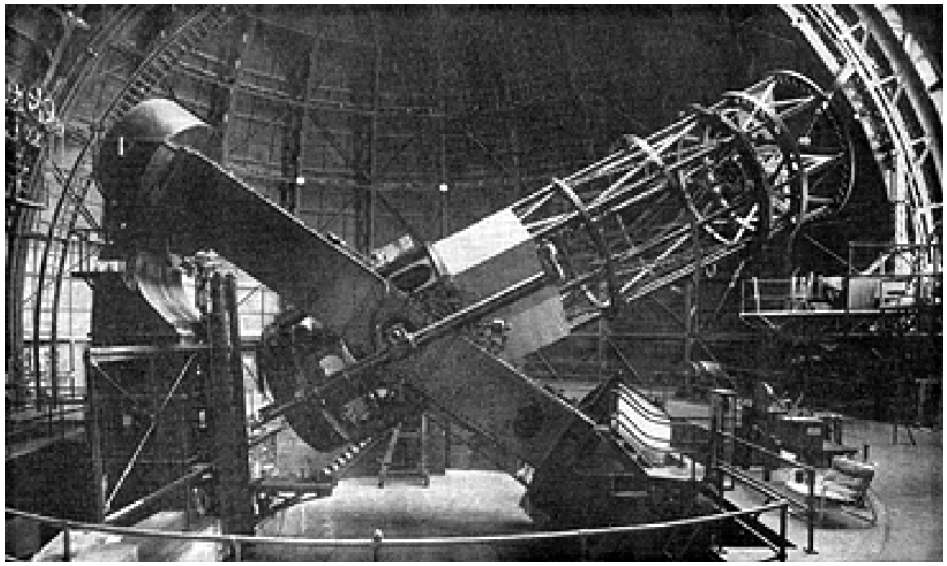
PF95-14 · ST ScI OPO · April 5, 1995 · W. Couch (UNSW), NASA

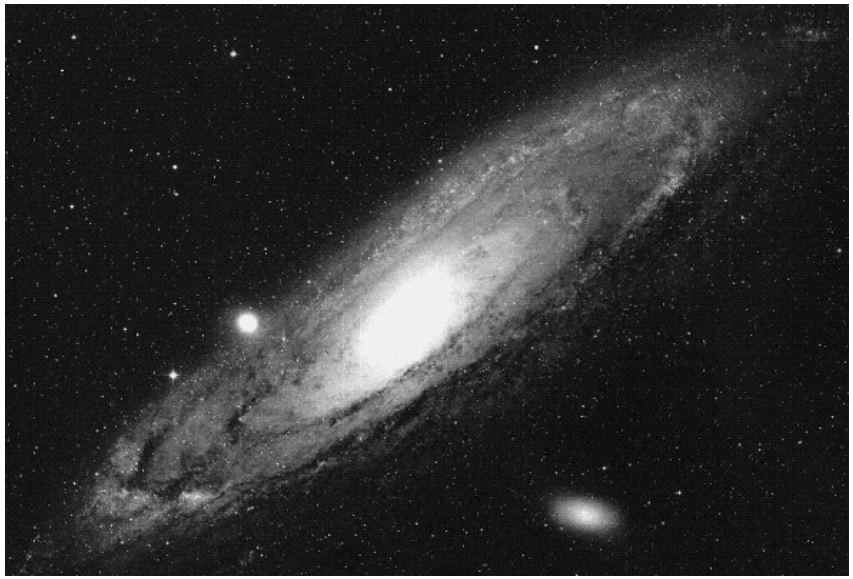



**Distant Object Gravitationally Lensed by Galaxy Cluster Abell 2218**
**Hubble Space Telescope** • WFPC2

NASA, ESA, R. Ellis (Caltech) and J.-P. Kneib (Observatoire Midi-Pyrenees) • STScI-PRC01-32

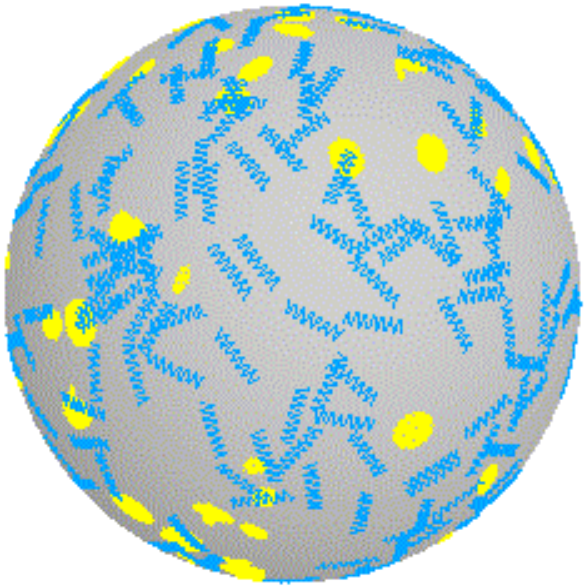
Edwin Hubble

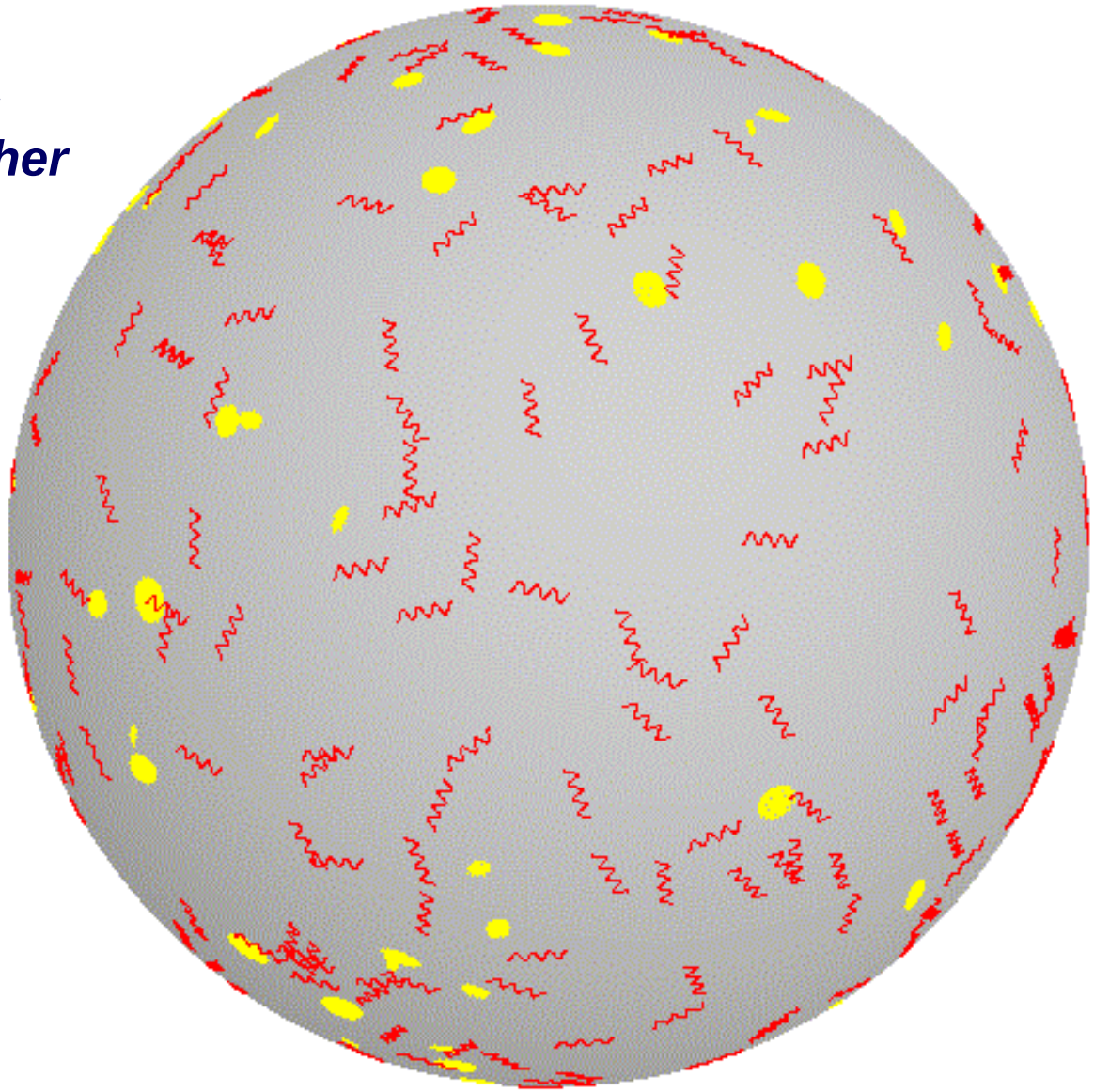




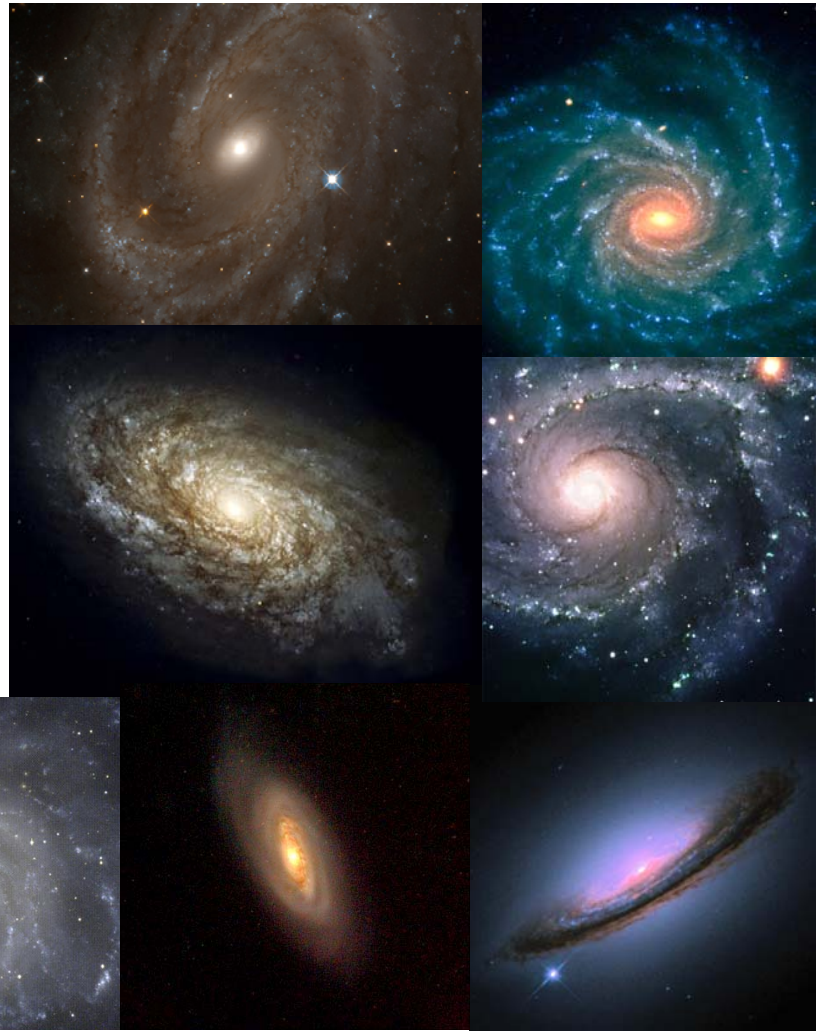
***Spacetime is expanding like the surface of a balloon.***

***As the balloon expands, galaxies are carried farther apart***





# How fast is the Universe expanding?



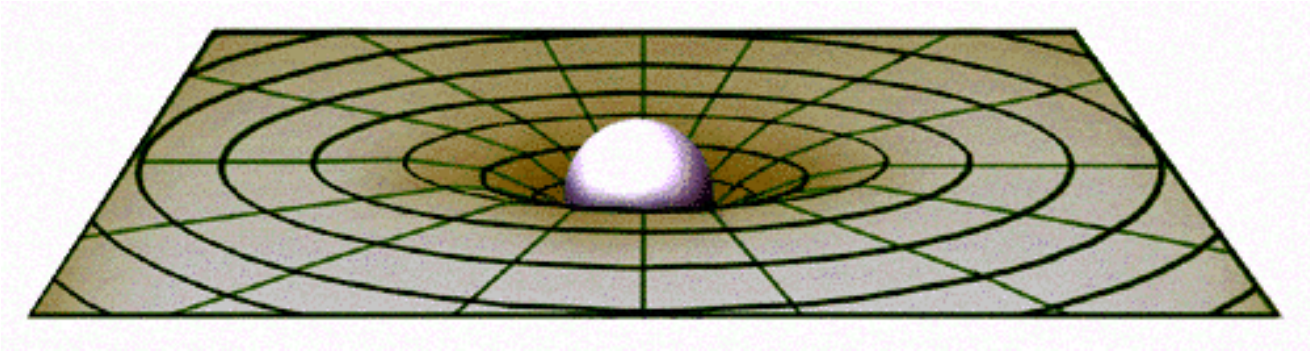
*Hubble space Telescope*
*Key Project: 1990-2000*

# *Will the Universe continue to expand forever?*

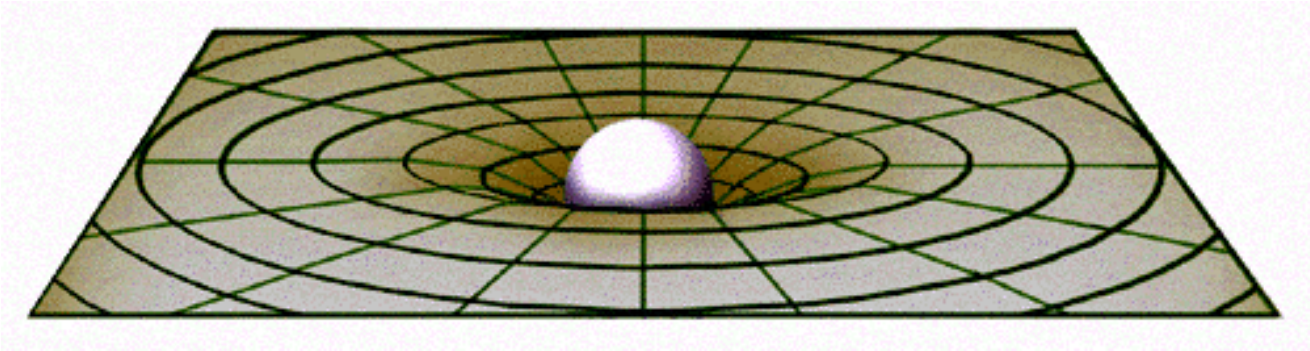
To find out we need to compare the expansion rate now with the expansion rate in the distant past…

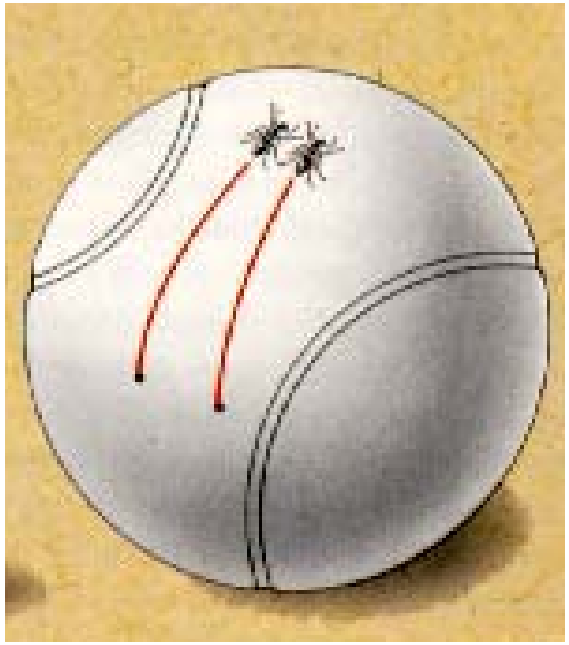
***Is the Universe speeding up or slowing down?***

Answer depends on the **shape** of the Universe



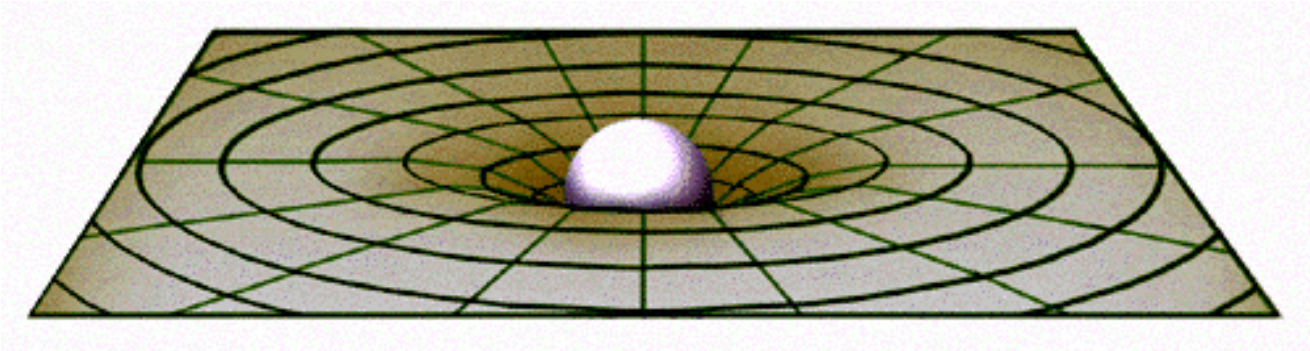
Answer depends on the **shape** of the Universe

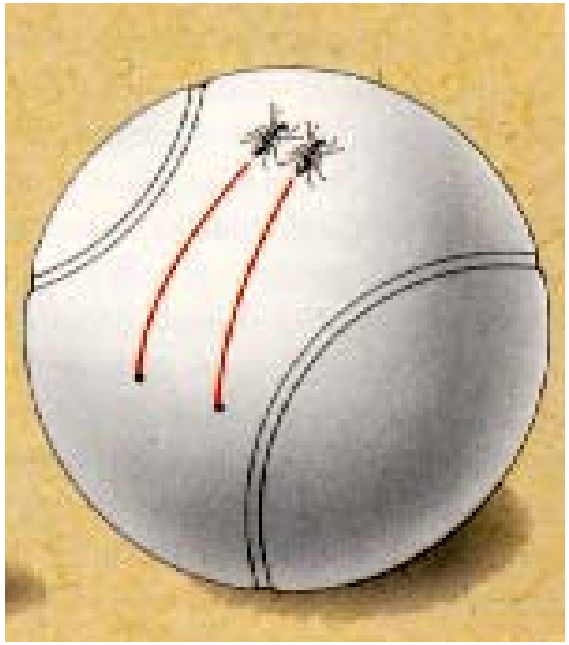




**Closed**

# Answer depends on the **shape** of the Universe





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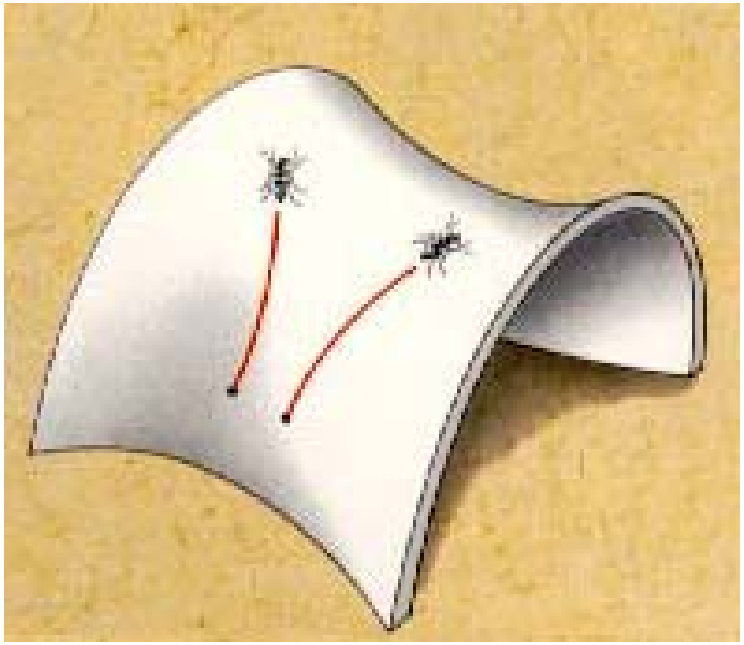
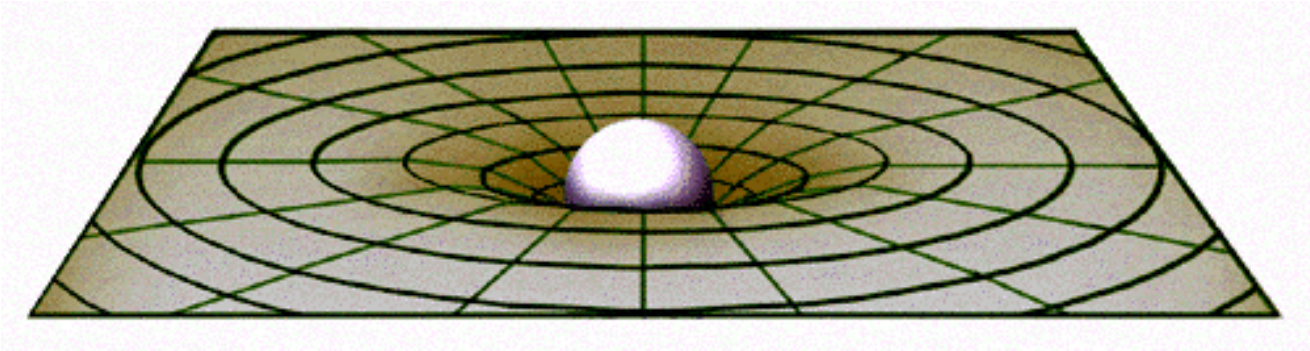
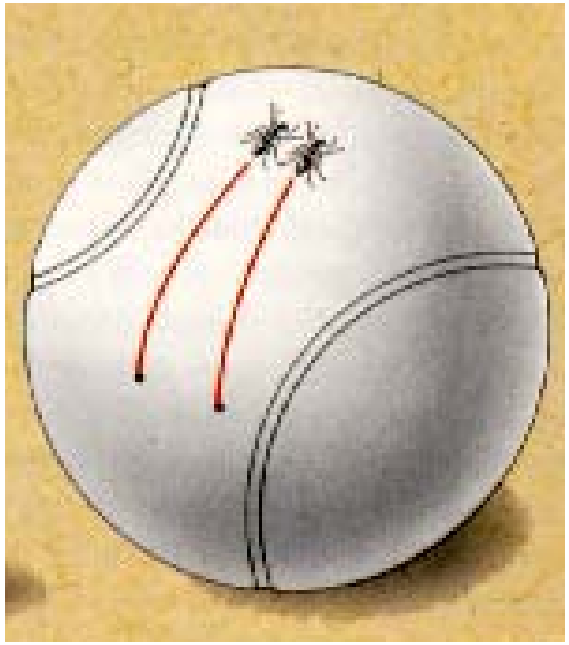


**Open**

Answer depends on the **shape** of the Universe





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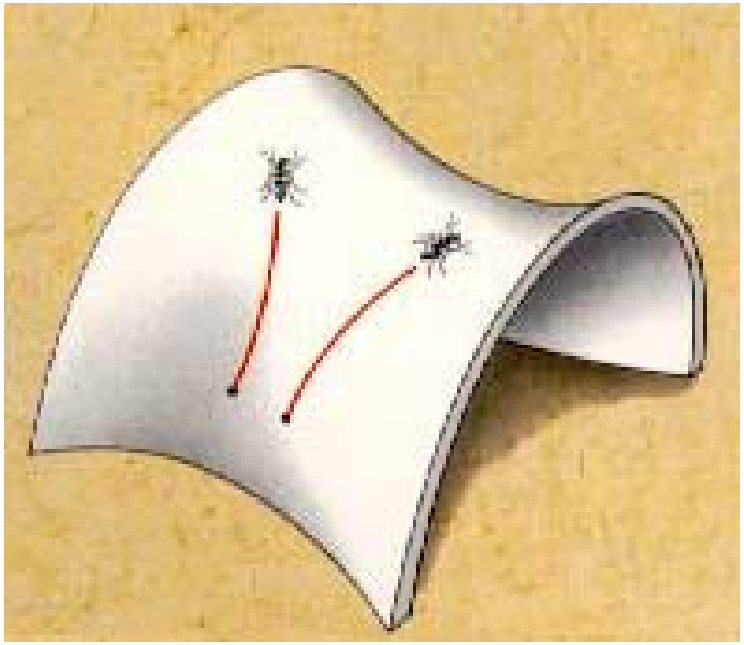
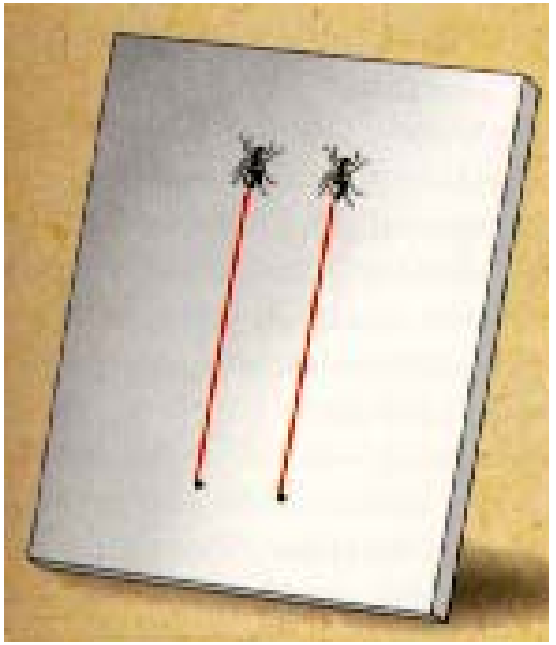


**Open**



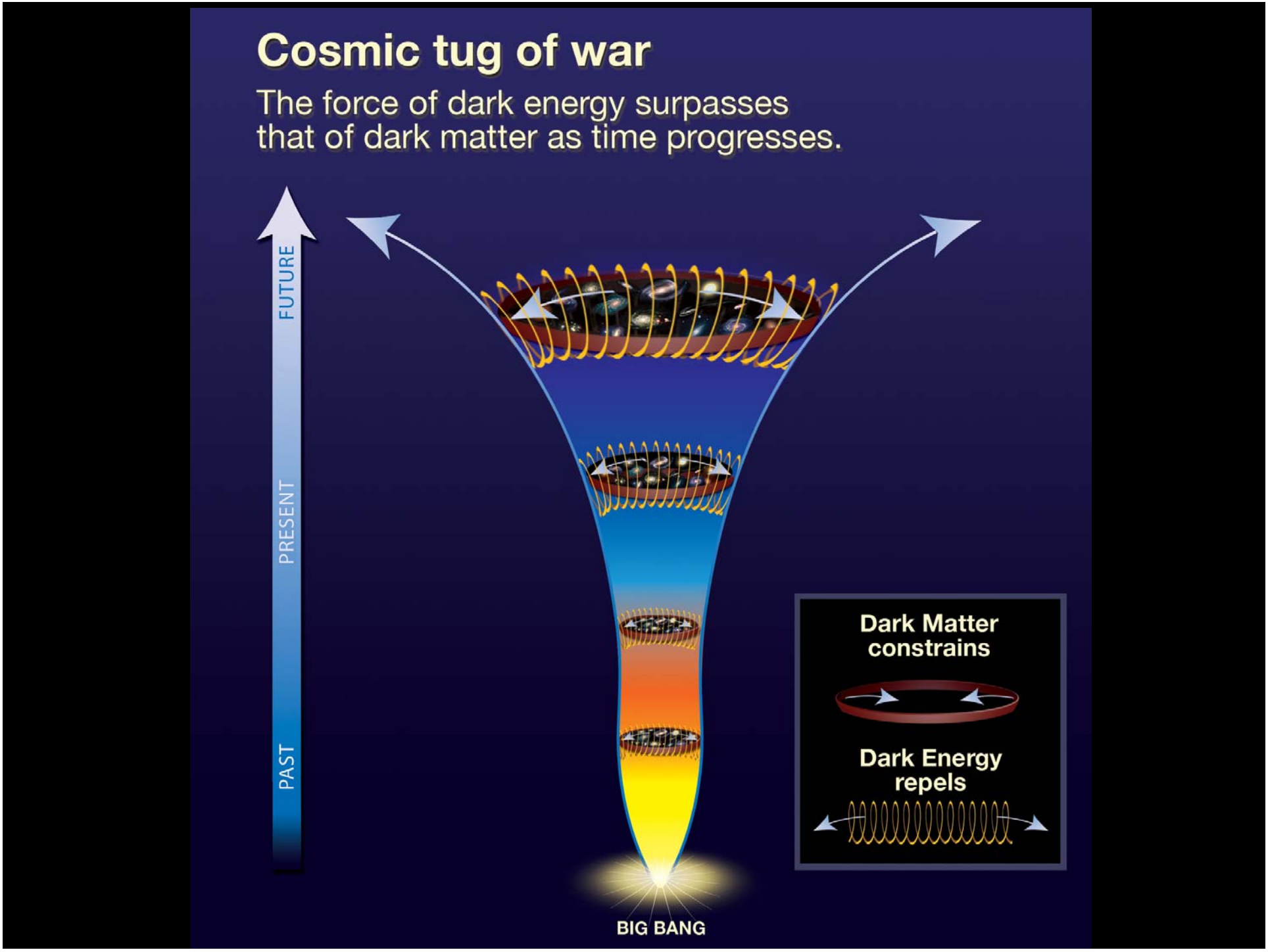
**Flat**

*What have we found?*
**The shape of the Universe is FLAT**
**The Universe will continue to expand for ever**
**The expansion is accelerating**

*What is driving the cosmic acceleration?…*

# Dark Energy

Dark Energy


Cosmic tug of war
The force of dark energy surpasses that of dark matter as time progresses.
FUTURE
PRESENT
PAST
BIG BANG
Dark Matter constrains
Dark Energy repels

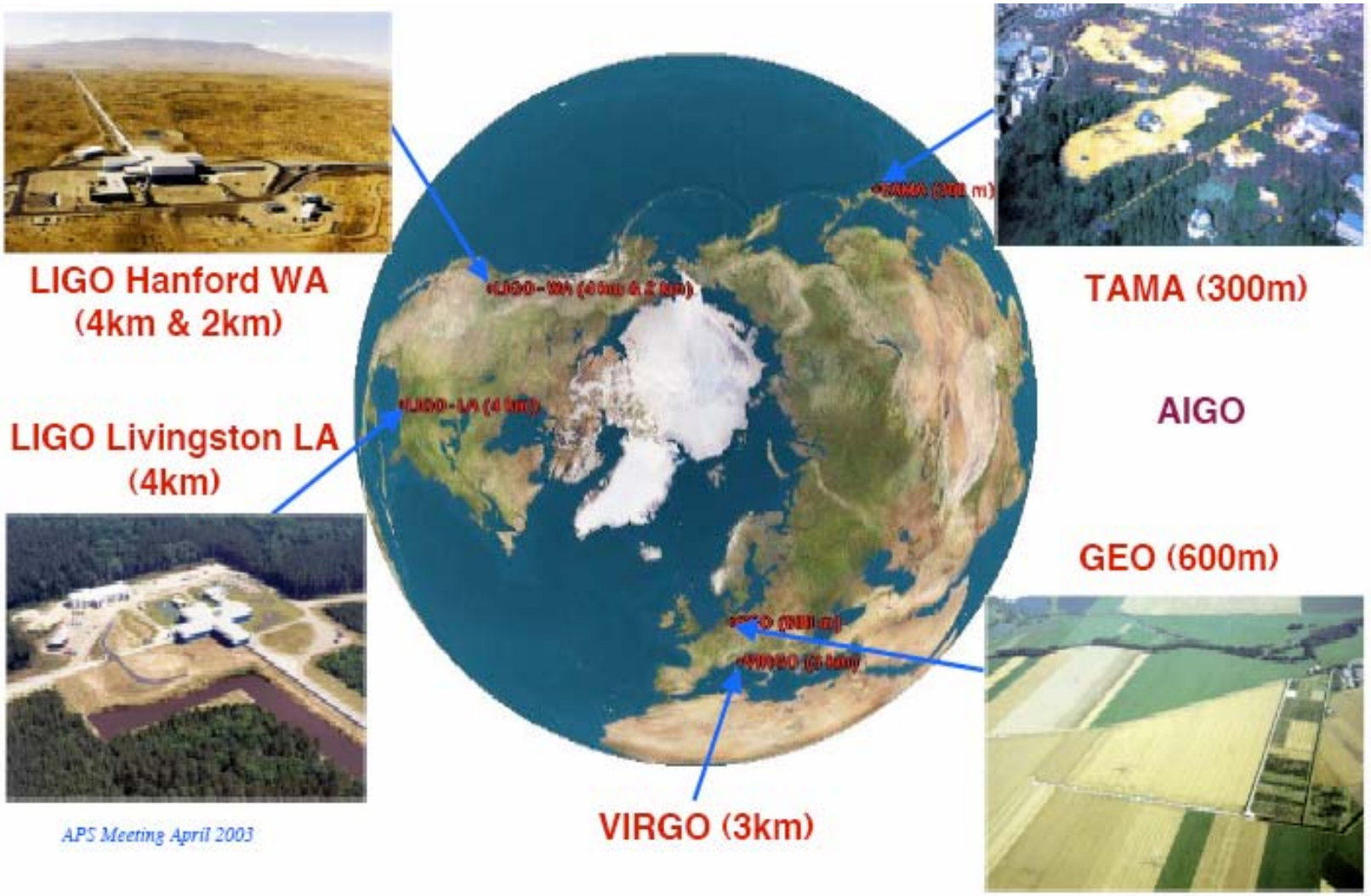
# Gravity in Einstein's Universe

## *Gravitational Waves*

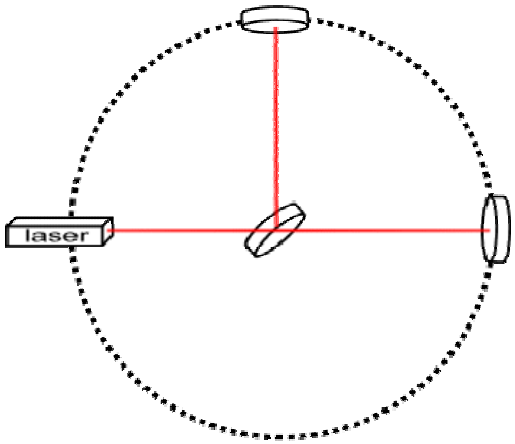
# Gravity in Einstein's Universe

## *Gravitational Waves*

# Worldwide network of gravitational wave detectors

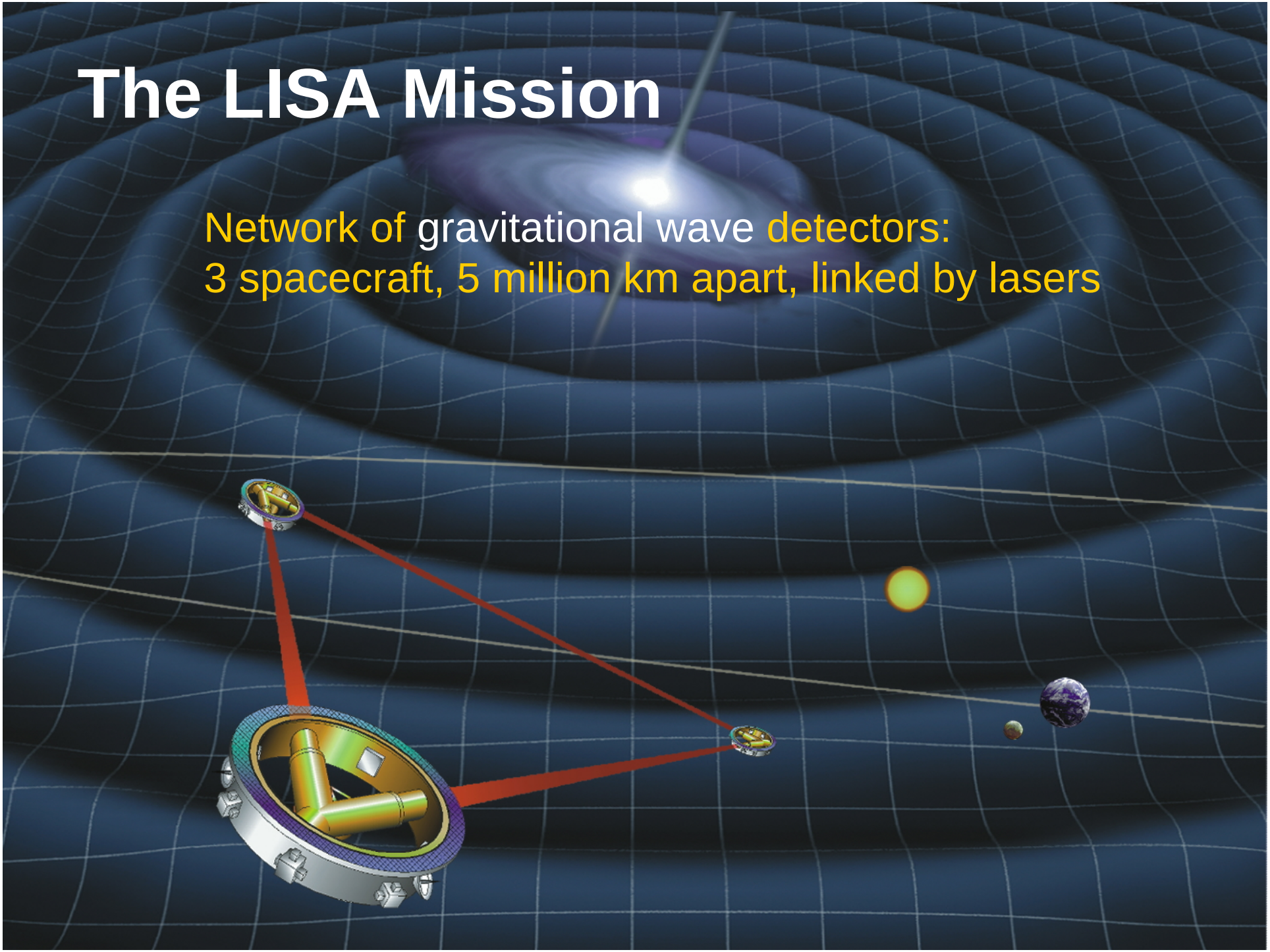


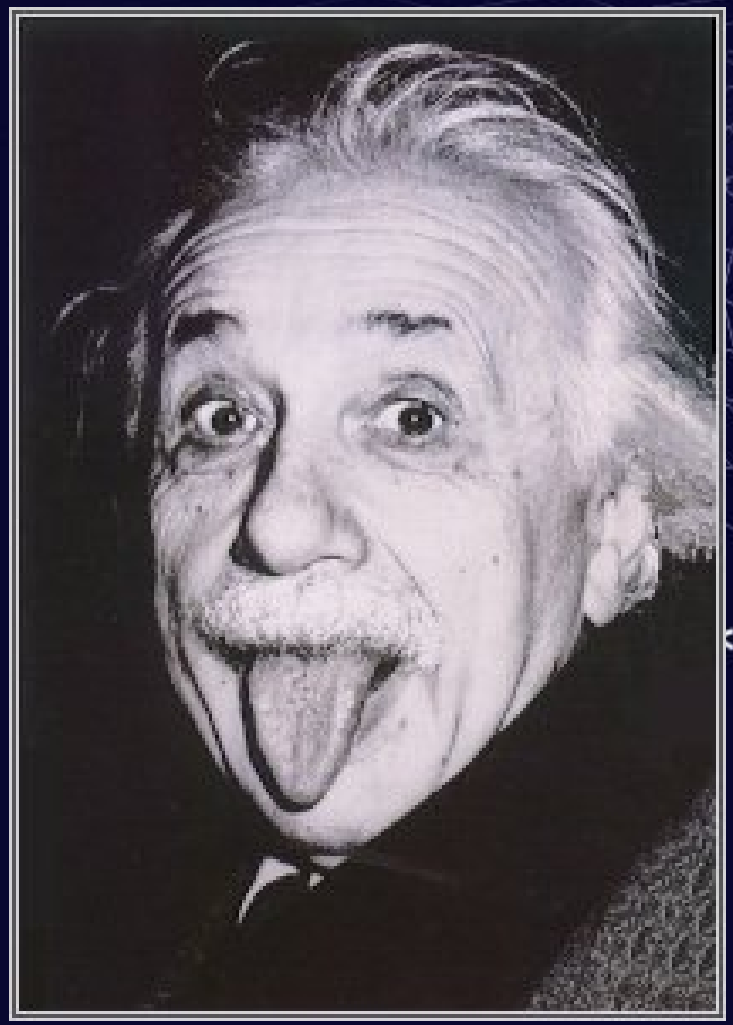
# Worldwide network of gravitational wave detectors

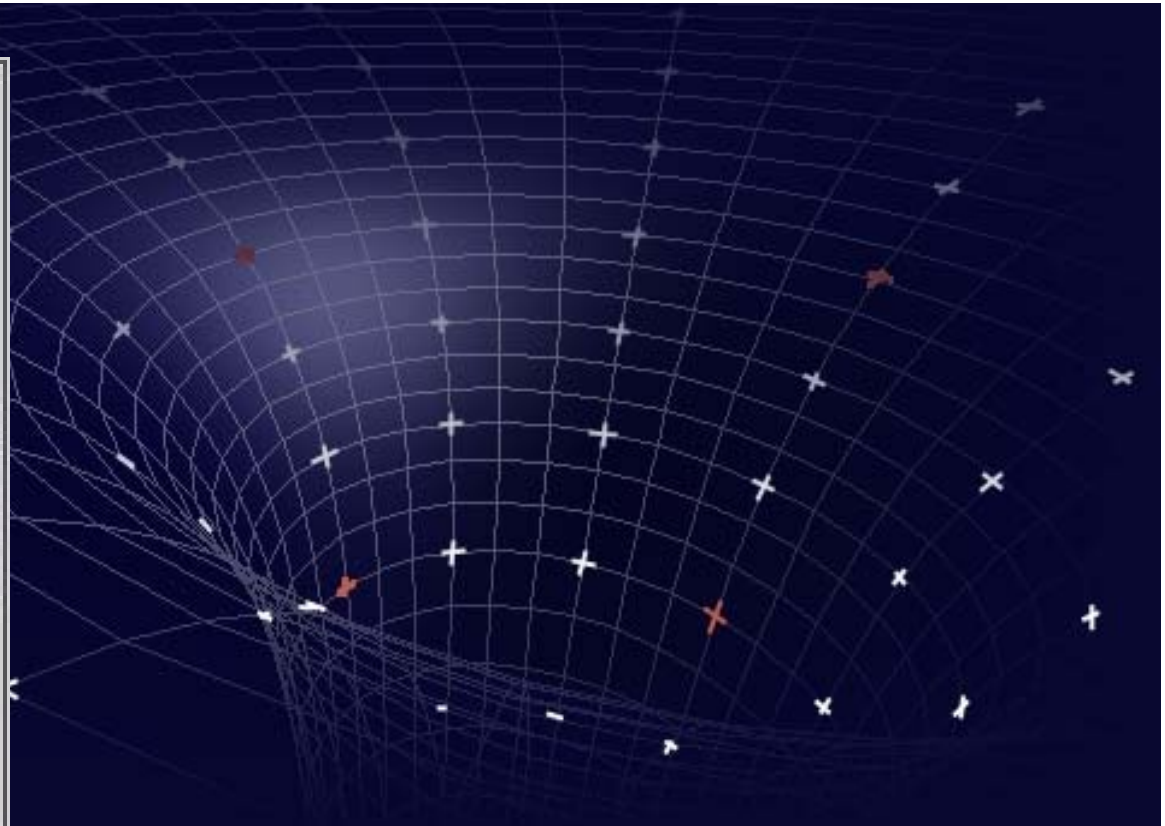


# The LISA Mission

Network of gravitational wave detectors:
3 spacecraft, 5 million km apart, linked by lasers







The hardest thing in the world to understand is the income tax