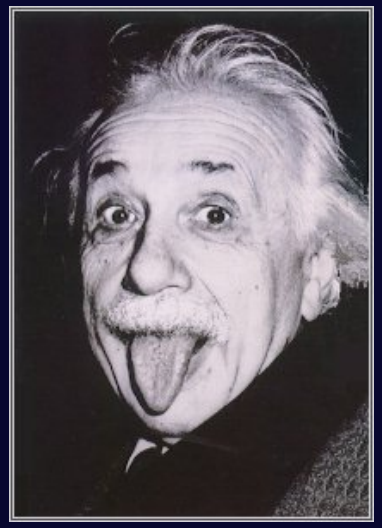
Einstein's Universe



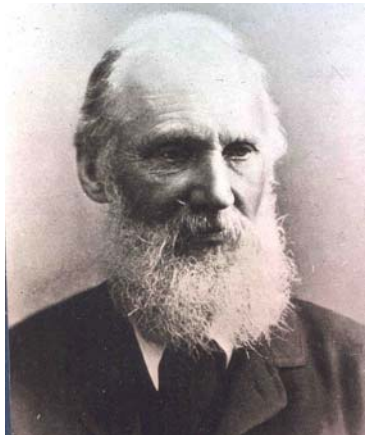
Dr Martin Hendry

Dept of Physics and Astronomy
University of Glasgow, UK

SNAP Workshop, 13th June 2007

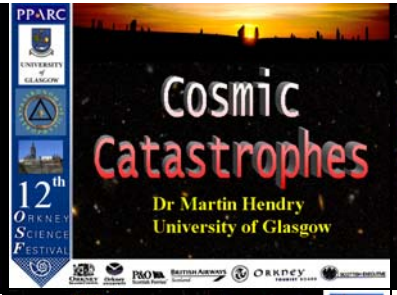
Who am I?…

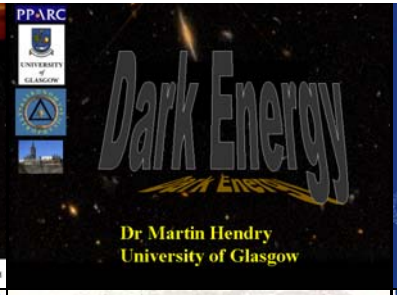
UNIVERSITY
of
GLASGOW

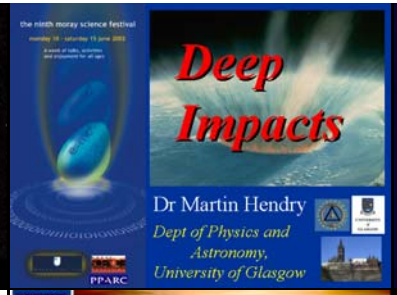


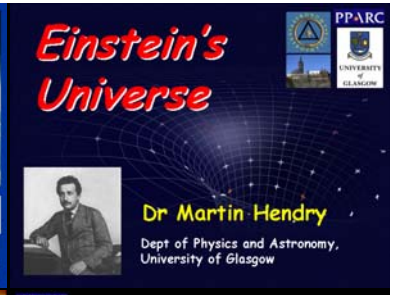
William Thompson
(Lord Kelvin)
1824 - 1907


In the Beginning
Dr Martin Hendry
University of Glasgow
PPARC
Odyssey 2001
The 2nd International Philosophy, Science & Theology Festival
Grafton NSW
The British Council

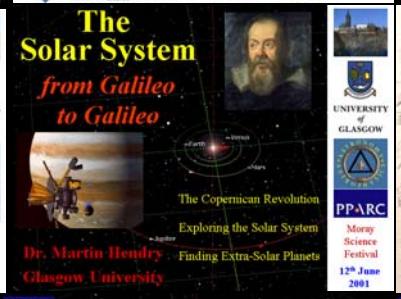

PPARC
12th Orkney Science Festival
Cosmic Catastrophes
Dr Martin Hendry
University of Glasgow


PPARC
Dark Energy
Dr Martin Hendry
University of Glasgow

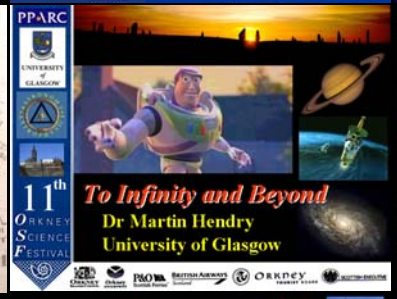

the ninth moray science festival
Deep Impacts
Dr Martin Hendry
Dept of Physics and Astronomy,
University of Glasgow
PPARC

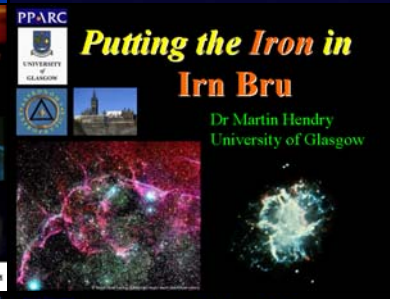

Einstein's Universe
PPARC
Dr Martin Hendry
Dept of Physics and Astronomy,
University of Glasgow

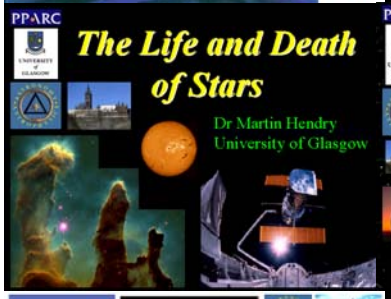

Extra-terrestrial life:
Is there anybody out there?...
Dr Martin Hendry
University of Glasgow
PPARC
Stirling Physics Meeting:
24th June 04


The Solar System
from Galileo to Galileo
The Copernican Revolution
Exploring the Solar System
Finding Extra-Solar Planets
Dr. Martin Hendry
Glasgow University
PPARC
Moray Science Festival
12th June 2001


A History of Astronomy
at Glasgow University
Dr. Martin Hendry
Dept of Physics and Astronomy
University of Glasgow


PPARC
11th Orkney Science Festival
To Infinity and Beyond
Dr Martin Hendry
University of Glasgow


PPARC
Putting the Iron in Irn Bru
Dr Martin Hendry
University of Glasgow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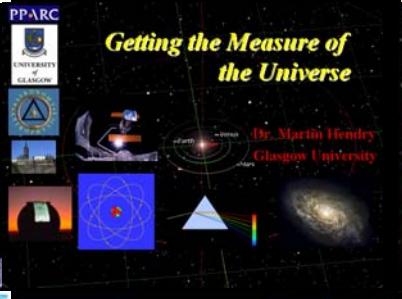
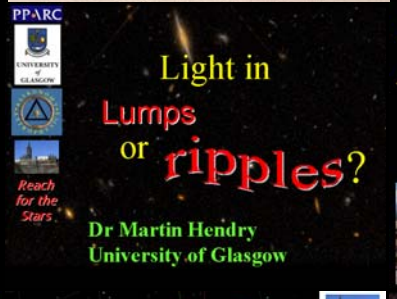
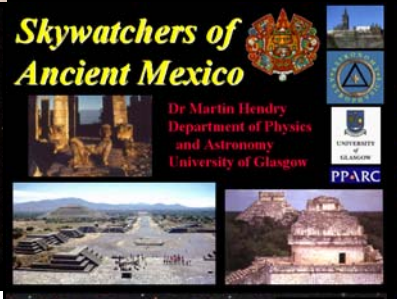
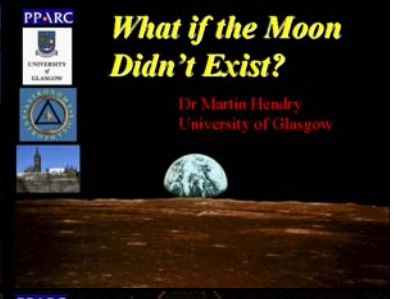
The Life and Death of Stars
Dr Martin Hendry
University of Glasgow


PPARC
Getting the Measure of the Universe
Dr. Martin Hendry
Glasgow University


PPARC
Light in
Lumps
or
ripples?
Reach for the Stars
Dr Martin Hendry
University of Glasgow


Skywatchers of Ancient Mexico
Dr Martin Hendry
Department of Physics and Astronomy
University of Glasgow
PPARC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What if the Moon Didn't Exist?
Dr Martin Hendry
University of Glasgow


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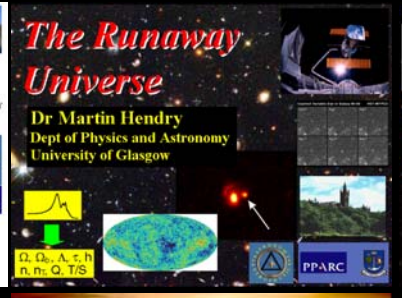
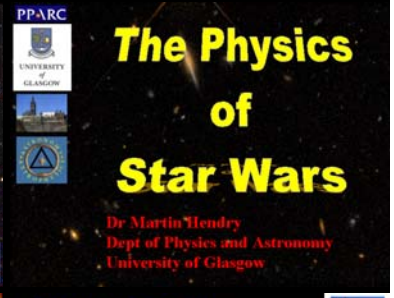
BORDERS
Overwhelmingly Large Telescopes
Dr. Martin Hendry
Dept of Physics and Astronomy
University of Glasgow


PPARC
BORDERS
A Recipe for Galaxy Formation
Dr. Martin Hendry
Dept of Physics and Astronomy
University of Glasgow


Rocket Science
Dr. Martin Hendry
Glasgow University
PPARC
Reach for the Stars


The Runaway Universe
Dr Martin Hendry
Dept of Physics and Astronomy
University of Glasgow
PPARC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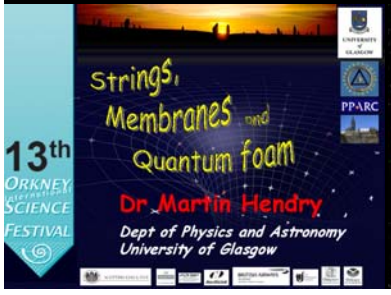
The Physics of Star Wars
Dr Martin Hendry
Dept of Physics and Astronomy
University of Glasgow


Strings, Membranes and Quantum foam
13th Orkney Science Festival
Dr Martin Hendry
Dept of Physics and Astronomy
University of Glasgow
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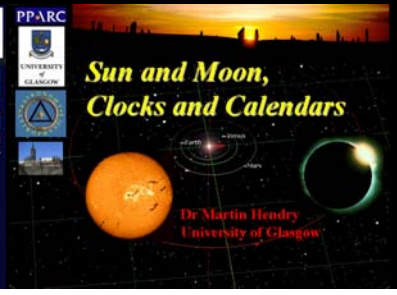
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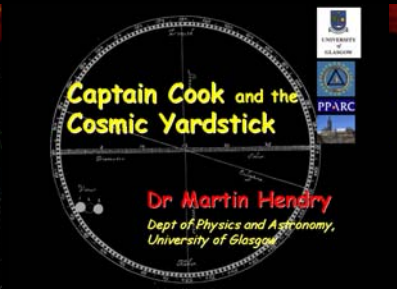
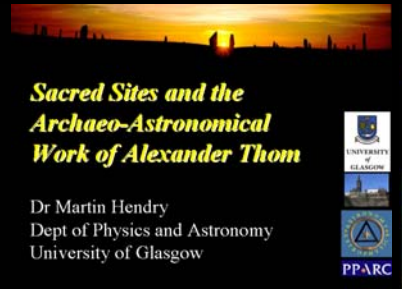
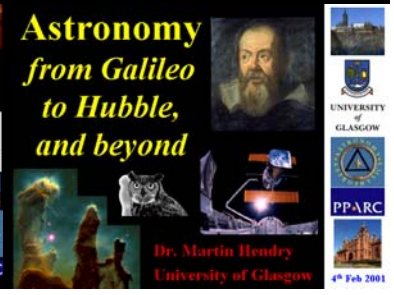
Sun and Moon, Clocks and Calendars
Dr Martin Hendry
University of Glasgow


Captain Cook and the Cosmic Yardstick
Dr Martin Hendry
Dept of Physics and Astronomy,
University of Glasgow
PPARC


Sacred Sites and the Archaeo-Astronomical Work of Alexander Thom
Dr Martin Hendry
Dept of Physics and Astronomy
University of Glasgow
PPARC


Astronomy from Galileo to Hubble, and beyond
Dr. Martin Hendry
University of Glasgow
PPARC
4th Feb 2001

Current list of ‘Reach for the Stars’ lectures

- The Physics of Star Wars
- Telescopes: from Galileo to Hubble
- Empire of the Sun
- The Life and Death of Stars
- Getting the Measure of the Universe
- Overwhelmingly Large Telescopes
- Five Millennia of Scottish Astronomy
- A History of Astronomy in Glasgow
- Crescent Moon Rising
- Stargazers of Ancient Mexico
- The Search Beyond the Sun
- Death of the Dinosaurs
- What if the Moon Didn’t Exist?
- Putting the Iron in Irn Bru
- Why Are We Here?
- Light in Lumps or Ripples
- Einstein’s Universe
- E.T. Life: Is There Anybody Out There?
- Life in the Universe
- In the Beginning
- Cosmology: the Final Frontier
- The Realm of the Nebulae
- Dark Energy
- Echoes of the Big Bang
- A Recipe for Galaxy Formation
- Hubble Vision
- The Runaway Universe
- From Quarks to Quasars
- The Future of the Universe
- Cosmology in the Third Millennium
- Rocket Science
- Deep Impacts
- To Infinity and Beyond
- Exploring the Sky

Further information from: **martin@astro.gla.ac.uk**

Or via: **http://www.physics.gla.ac.uk/**

Who am I?…

UNIVERSITY
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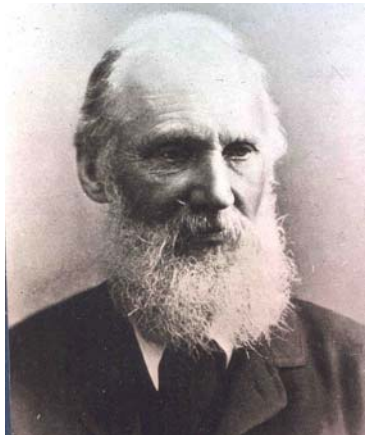


William Thompson
(Lord Kelvin)
1824 - 1907

"There is nothing new to be discovered in physics now. All that remains is more and more precise measurement"

einstein year

World Year of PHYSICS 2005

Einstein's "Annus Mirabilis": 1905

ON THE ELECTRODYNAMICS OF MOVING BODIES

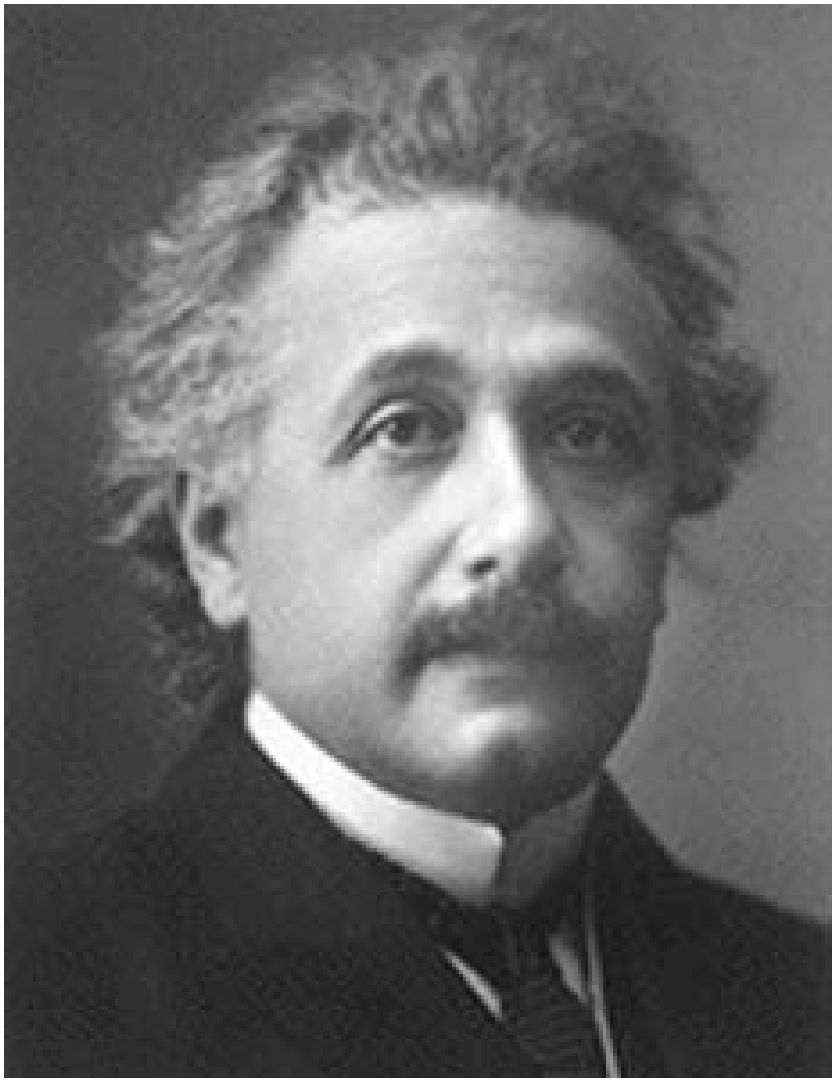
By A. EINSTEIN

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.



1916. № 7.

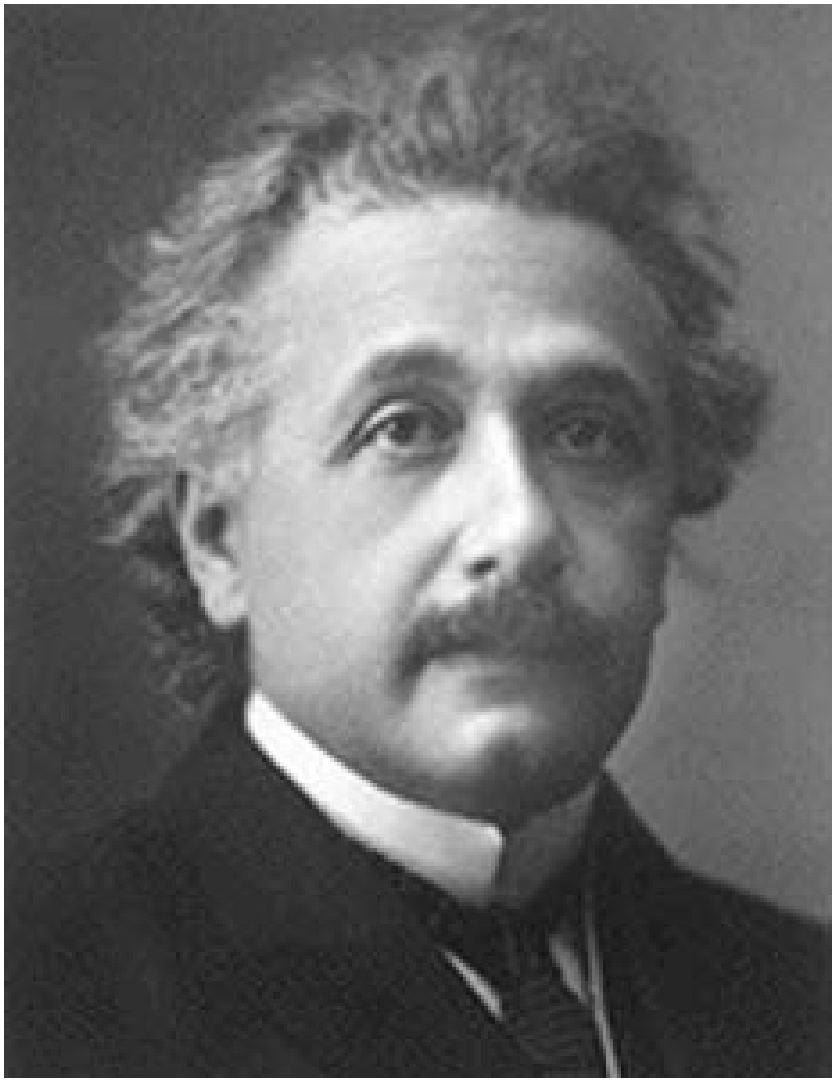
ANNALEN DER PHYSIK.

VIERTE FOLGE. BAND 49.

1. *Die Grundlage der allgemeinen Relativitätstheorie;* von *A. Einstein.*

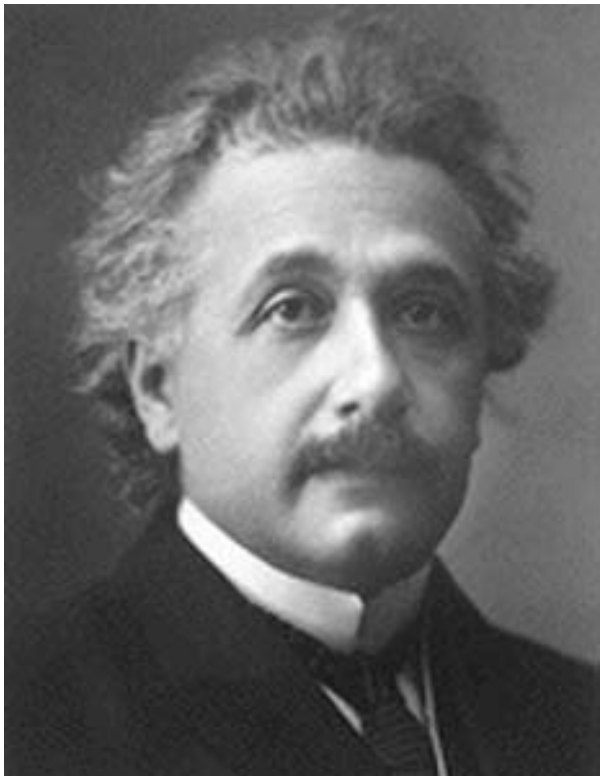
Die im nachfolgenden dargelegte Theorie bildet die denkbar weitgehendste Verallgemeinerung der heute allgemein als „Relativitätstheorie" bezeichneten Theorie; die letztere nenne ich im folgenden zur Unterscheidung von der ersteren „spezielle Relativitätstheorie" und setze sie als bekannt voraus. Die Verallgemeinerung der Relativitätstheorie wurde sehr erleichtert durch die Gestalt, welche der speziellen Relativitätstheorie durch Minkowski gegeben wurde, welcher Mathematiker zuerst die formale Gleichwertigkeit der räumlichen Koordinaten und der Zeitkoordinate klar erkannte und für den Aufbau der Theorie nutzbar machte. Die für die allgemeine Relativitätstheorie nötigen mathematischen Hilfsmittel lagen fertig bereit in dem „absoluten Differentialkalkül", welcher auf den Forschungen von Gauss, Riemann und Christoffel über nichteuklidische Mannigfaltigkeiten ruht und von Ricci und Levi-Civita in ein System gebracht und bereits auf Probleme der theoretischen Physik angewendet wurde. Ich habe im Abschnitt B der vorliegenden Abhandlung alle für uns nötigen, bei dem Physiker nicht als bekannt vorauszusetzenden mathematischen Hilfsmittel in möglichst einfacher und durchsichtiger Weise entwickelt, so daß ein Studium mathematischer Literatur für das Verständnis der vorliegenden Abhandlung nicht erforderlich ist. Endlich sei an dieser Stelle dankbar meines Freundes, des Mathematikers Grossmann, gedacht, der mir durch seine Hilfe nicht nur das Studium der einschlägigen mathematischen Literatur ersparte, sondern mich auch beim Suchen nach den Feldgleichungen der Gravitation unterstützte.

© 1916 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim



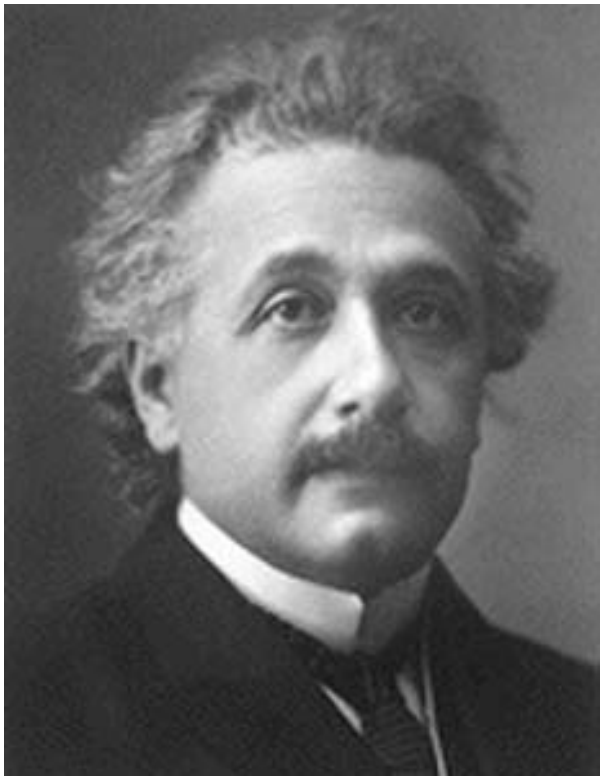
“The greatest feat of human thinking about nature, the most amazing combination of philosophical penetration, physical intuition and mathematical skill.”

Max Born



Colleague: *"Professor Eddington, you must be one of only three persons in the world who understand relativity!"*

Eddington: *" oh, I don't know..."*

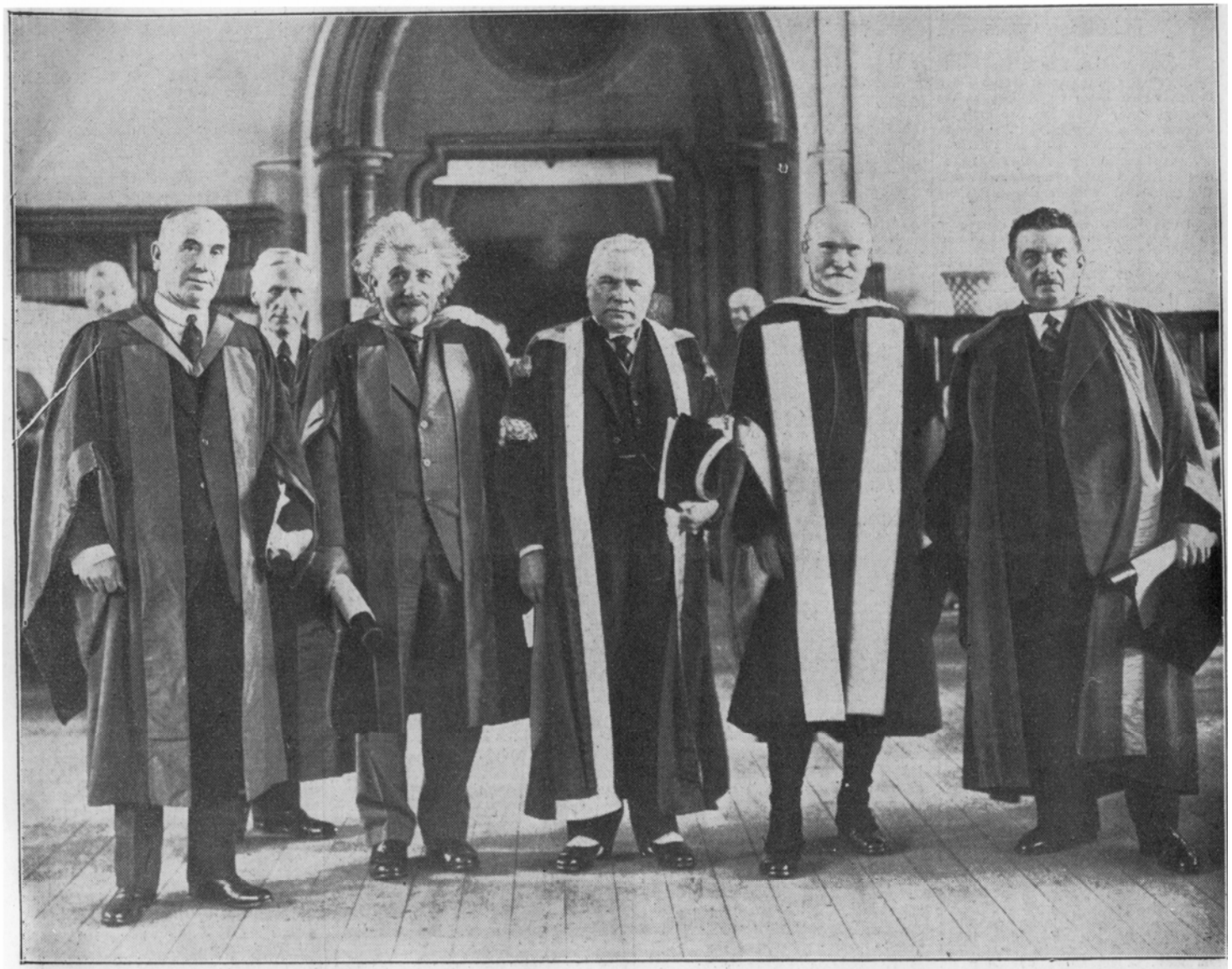


Colleague: *"Professor Eddington, you must be one of only three persons in the world who understand relativity!"*

Eddington: *" oh, I don't know..."*

Colleague: *" Don't be modest Eddington."*

Eddington: ***" On the contrary, I am trying to think who the third person is."***



A group of some of the honorary graduates taken after the ceremony in the Bute Hall of Glasgow University yesterday. Left to right—The Right Hon. Sir Robert S. Horne; Emeritus Professor William Blair-Bell, University of Liverpool; Professor Albert Einstein; Principal Sir Robert S. Rait; the Archbishop of Armagh and Primate of All Ireland; and M. Edouard Herriot, former Prime Minister of France.

Why Einstein?

- Enduring iconic status
- “Unconventional” approach
- Broader cultural impact
- Scientific legacy

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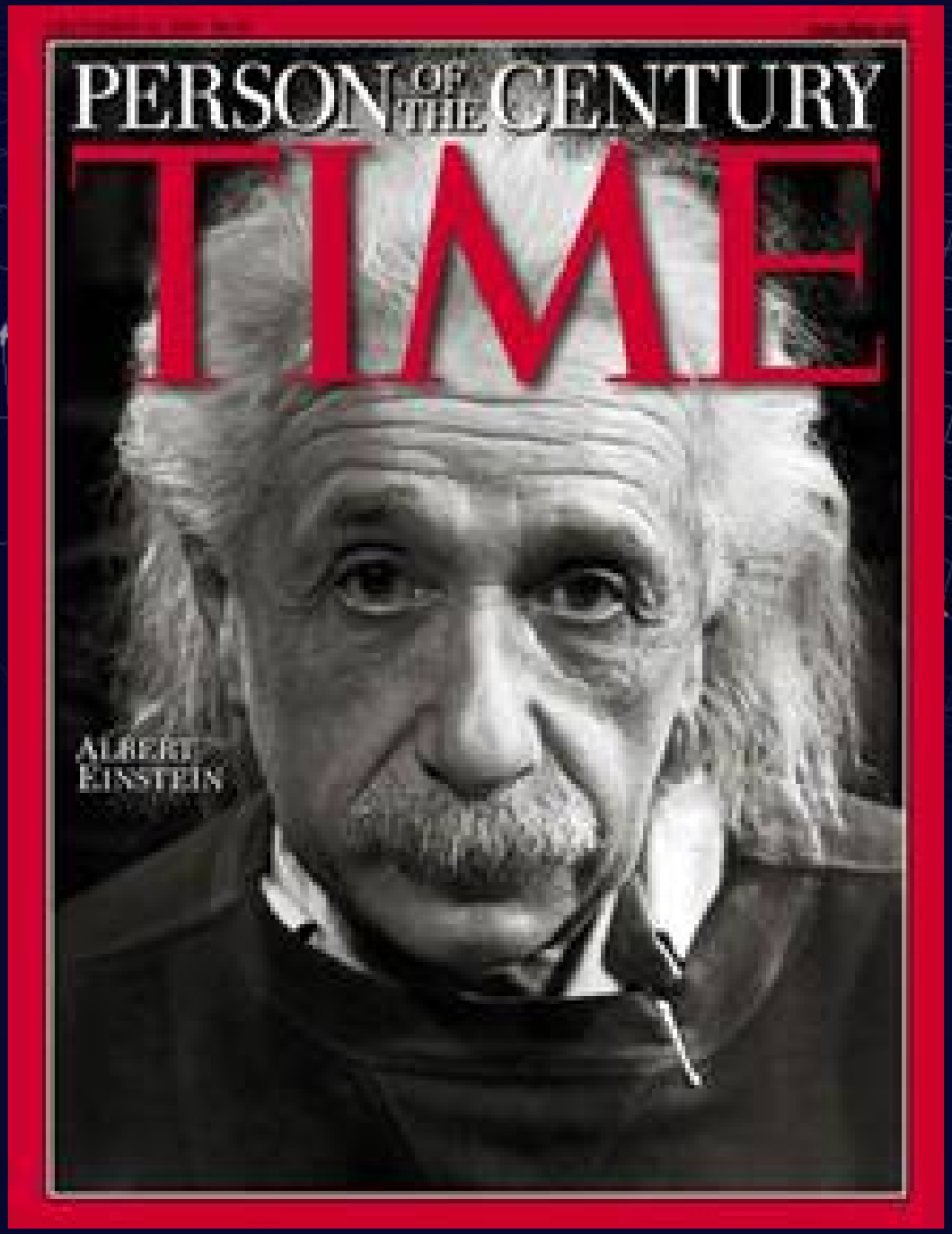
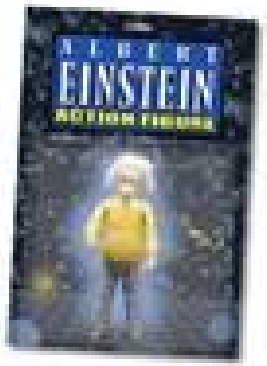

PERSON OF THE CENTURY
TIME
ALBERT EINSTEIN


ALBERT
EINSTEIN
ACTION FIGURE


If A equals success,
then the formula is:
A=X+Y+Z
X is work. Y is play
Z is keep your
mouth shut.


ALL NEW!
WEEKLY WORLD NEWS
THE WORLD'S ONLY RELIABLE NEWSPAPER
EINSTEIN'S BRAIN COMES TO LIFE
GOES ON
BUSH RENAMES

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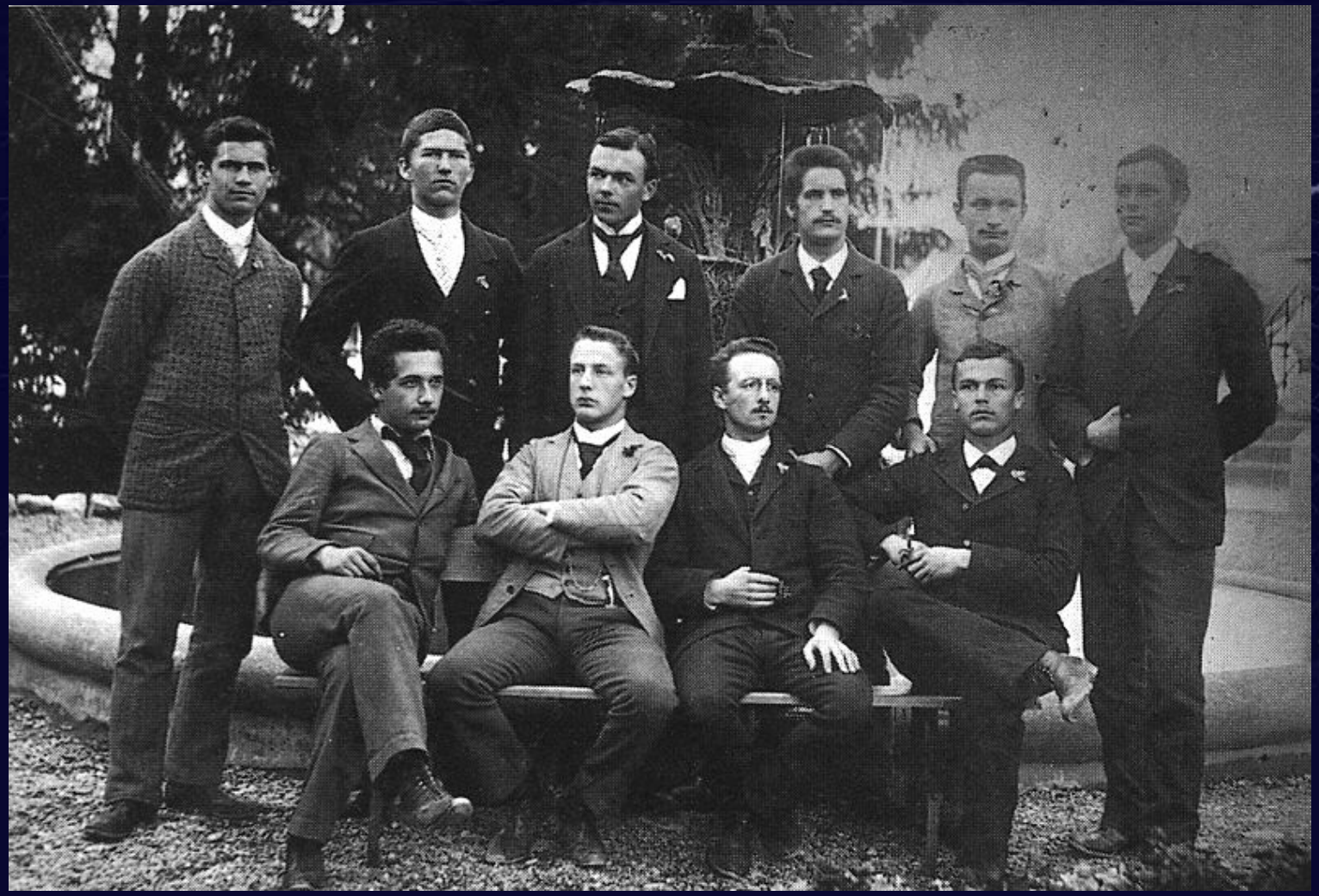
HERM



"The only thing that interferes with my learning is my education"

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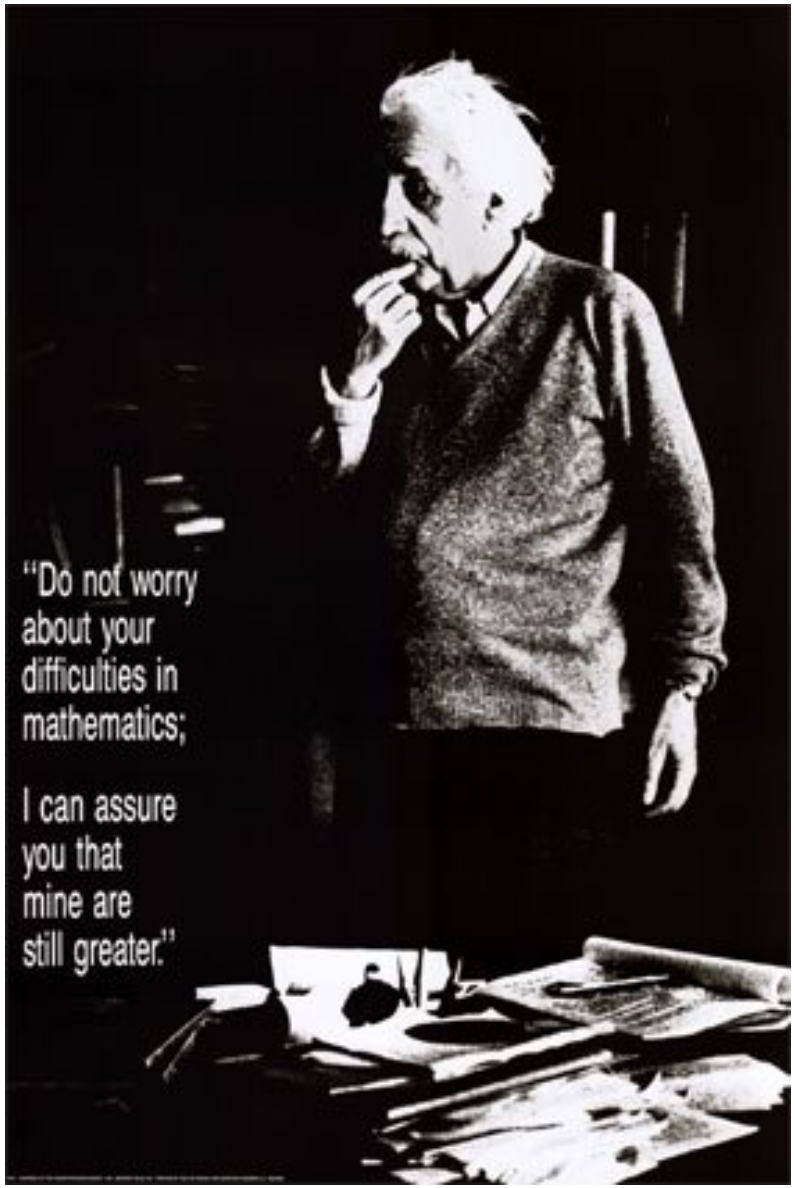
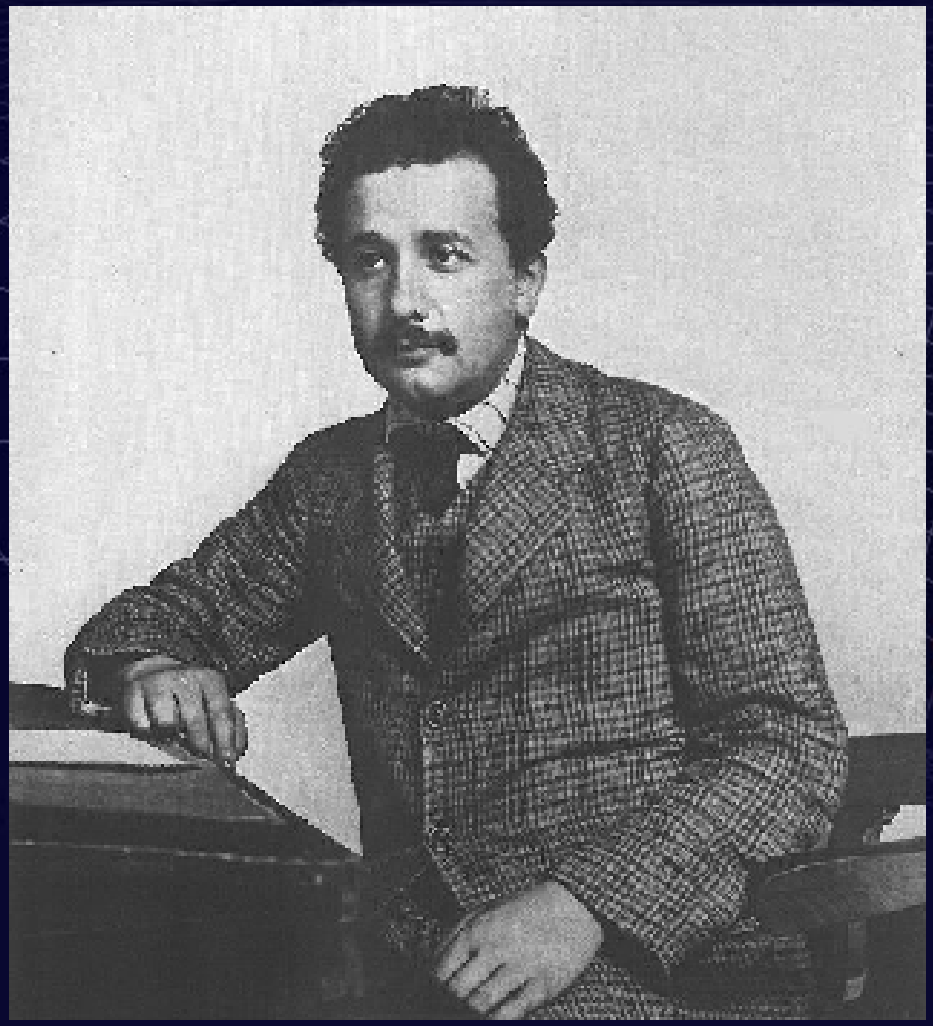
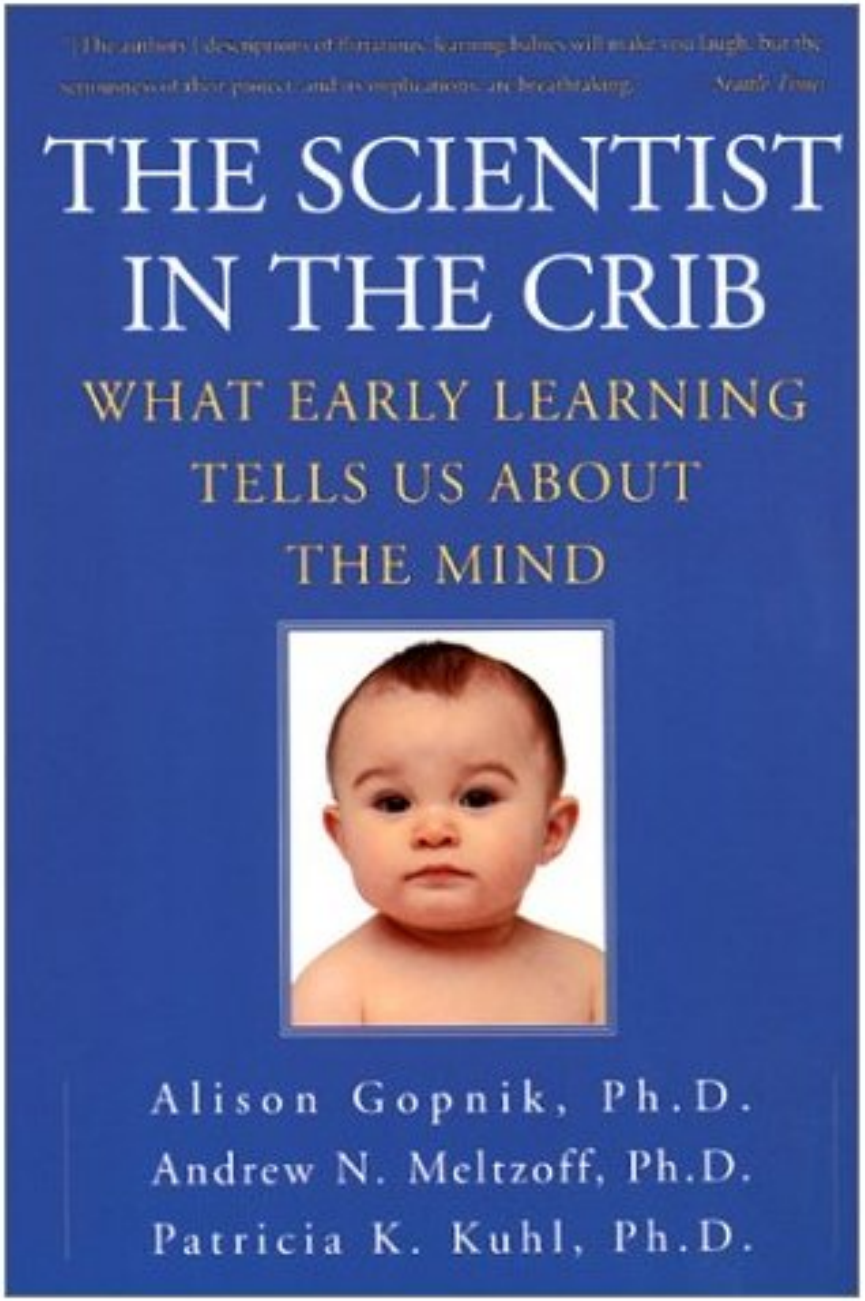


"Do not worry about your difficulties in mathematics; I can assure you that mine are still greater."



"Science is a wonderful thing, if one does not have to earn one's living at it"


THE SCIENTIST IN THE CRIB
WHAT EARLY LEARNING TELLS US ABOUT THE MIND
Alison Gopnik, Ph.D.
Andrew N. Meltzoff, Ph.D.
Patricia K. Kuhl, Ph.D.


SPACETIME
AND
GEOMETRY
Sean M. Carroll

Did we *really* land on the Moon?

Dr Martin Hendry
University of Glasgow

Why Einstein?

- Enduring iconic status
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"As long as I have any choice in the matter, I shall live only in a country where civil liberty, tolerance, and equality of all citizens before the law prevail."

Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island

August 2nd, 1939

F.D. Roosevelt,
President of the United States,
White House
Washington, D.C.

Sir:

Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:

In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium,by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

This new phenomenon would also lead to the construction of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

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World Year of PHYSICS 2005

einstein year

Einstein's Miraculous Year

- Relativity
- Atomic physics
- Quantum physics

1905 Special relativity

1916 General relativity

1923 Nobel prize for work on photoelectric effect

1905 – Theory of Special Relativity

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

Classical Physics:
All the World's A Stage

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

Classical Physics:
All the World's A Stage

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

Classical Physics:
All the World's A Stage

- Newton's physics assumes absolute space and time, for all observers.
- Working out how things look to different observers follows simple rules, in different *reference frames*

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All the World's A Stage

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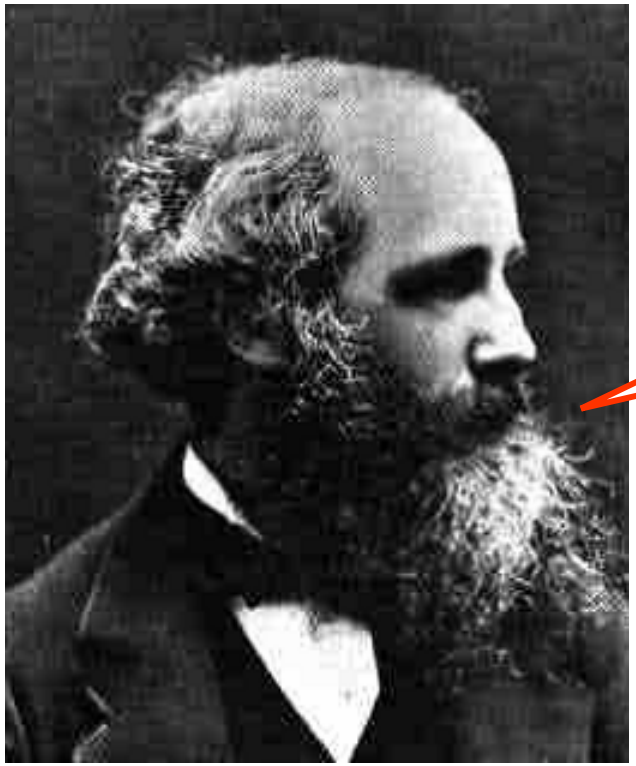
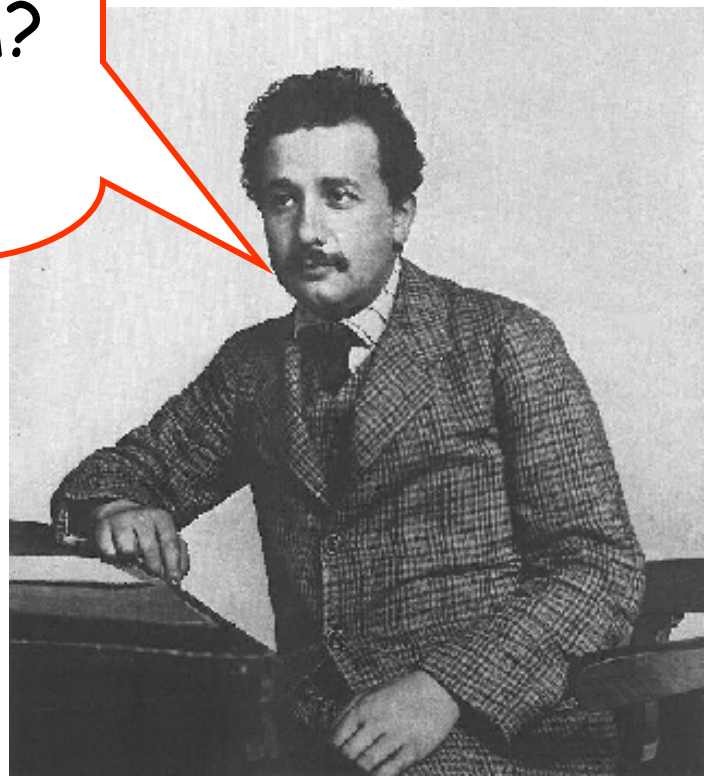
Classical Physics:

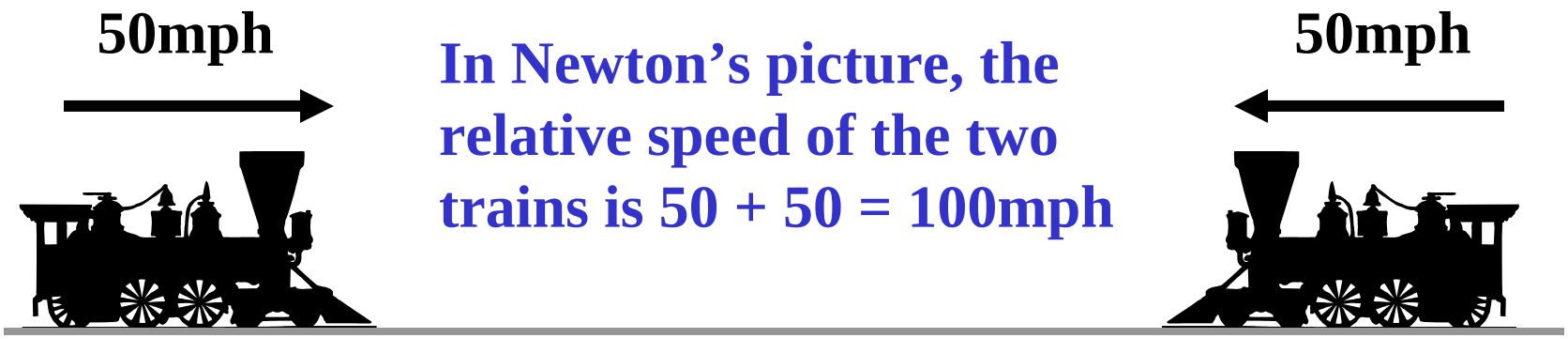
James Clerk Maxwell's theory of light



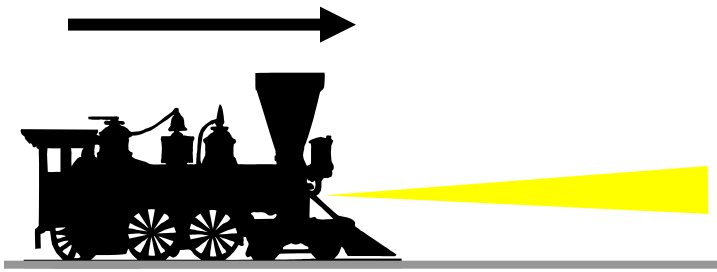
Light is a *wave* (caused by varying *electric* and *magnetic* fields)

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





In Newton's picture, the relative speed of the two trains is 50 + 50 = 100mph



In Special Relativity, 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

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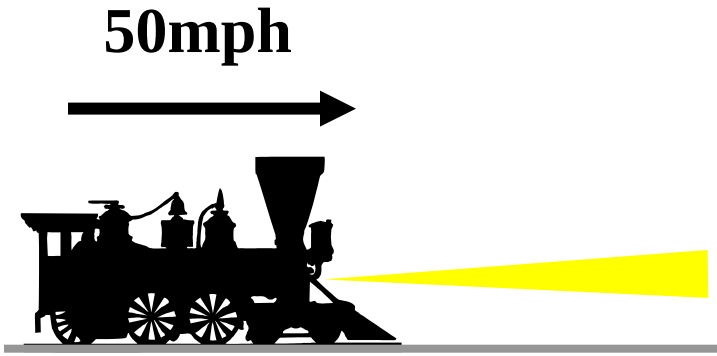

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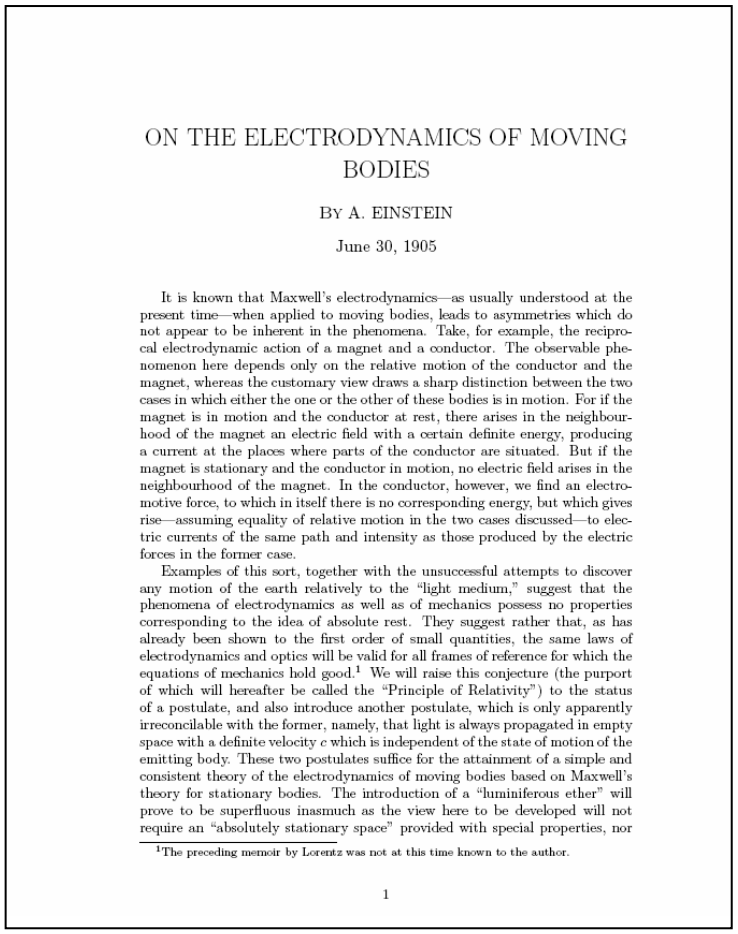

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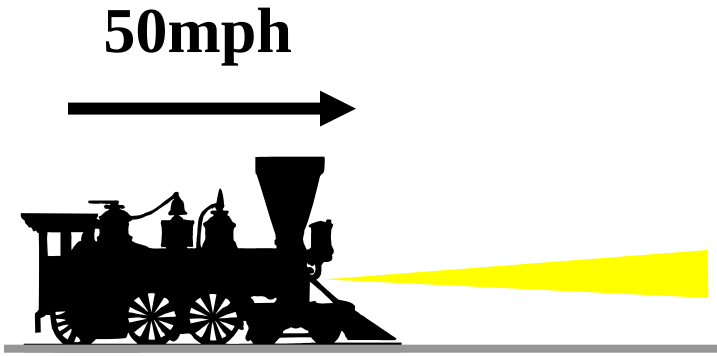
- Measurements of space and time are ***relative*** and depend on our motion



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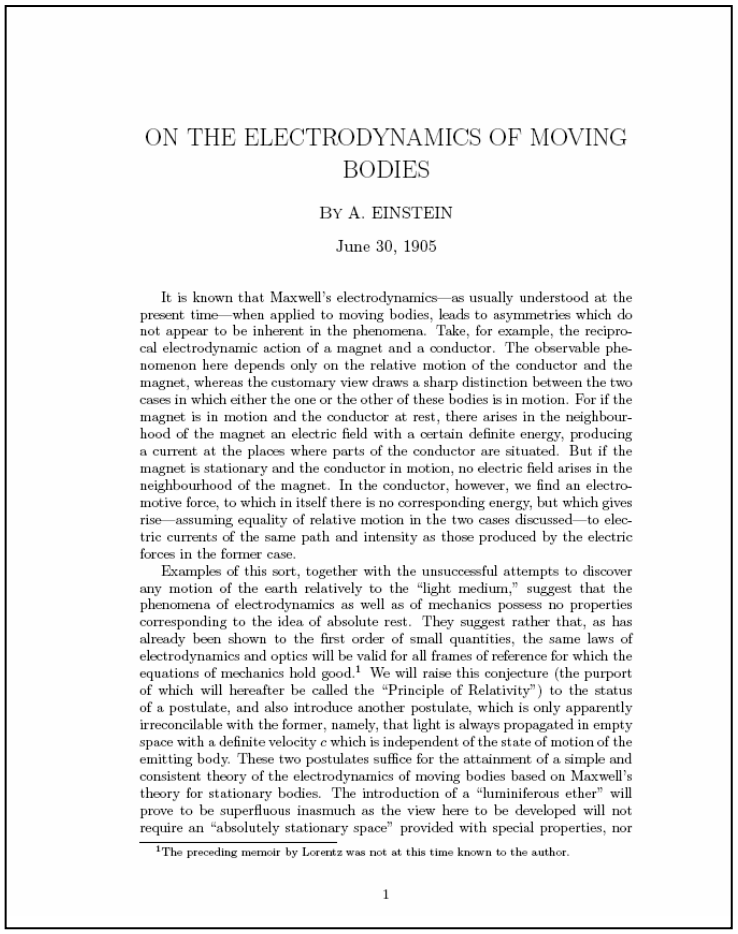

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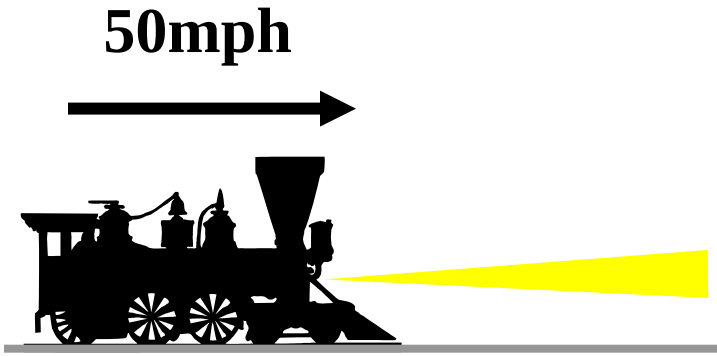
"The only reason for time is so that everything doesn't happen at once."



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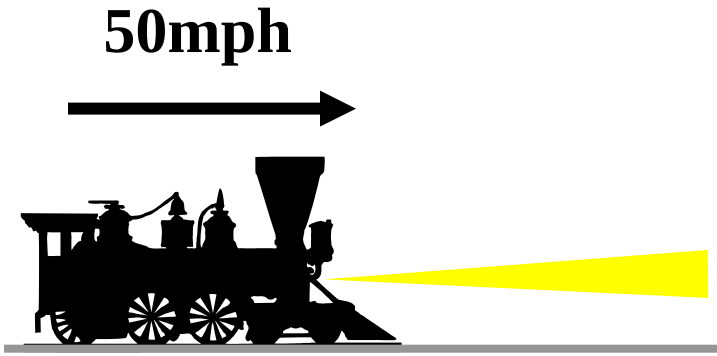
"Put your hand on a hot stove for a minute, and it seems like an hour. Sit with a pretty girl for an hour and it seems like a minute. THAT'S relativity."



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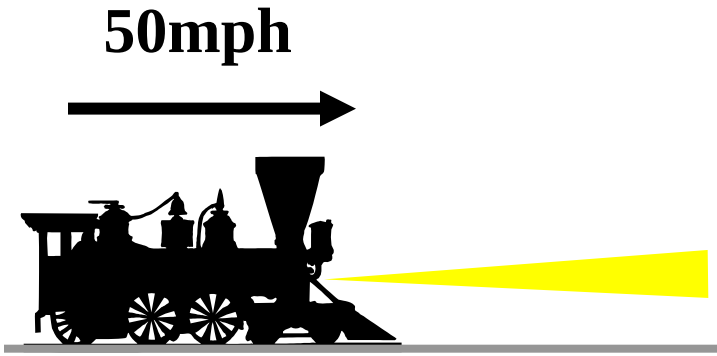
- Measurements of space and time are ***relative*** and depend on our motion
- Unified ***spacetime***



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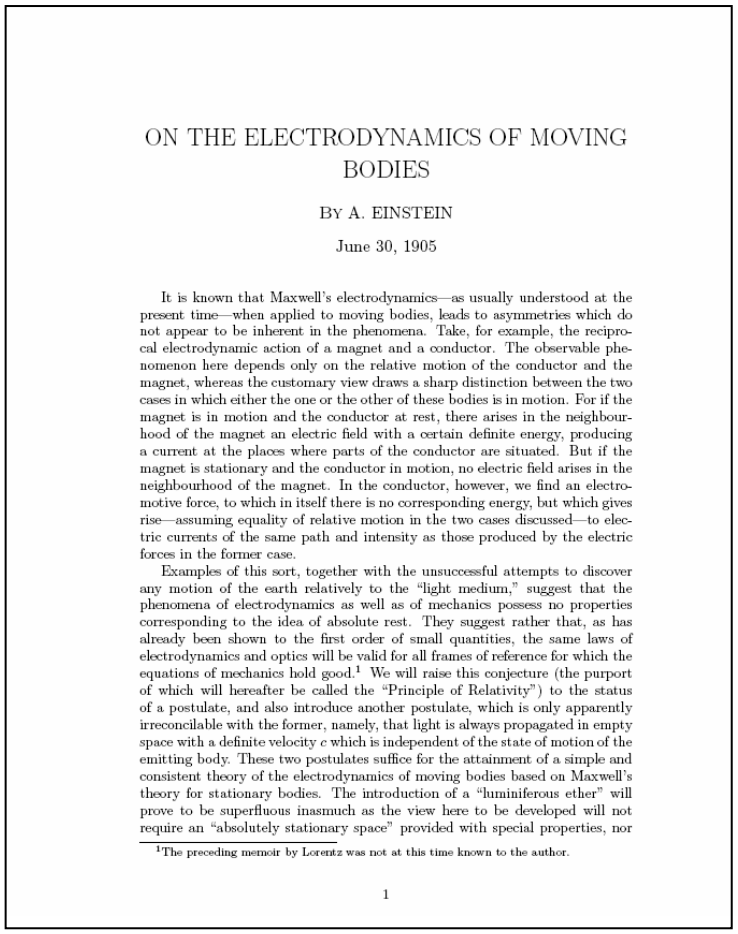

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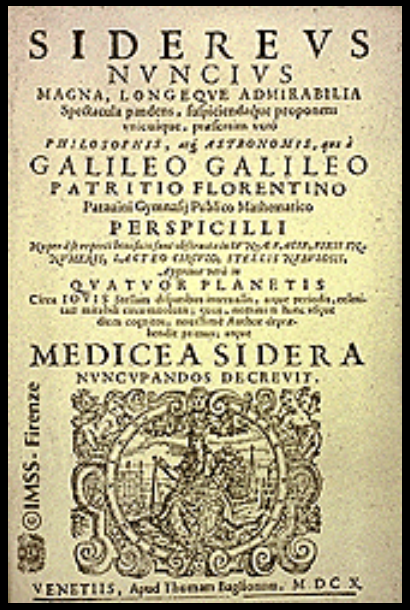
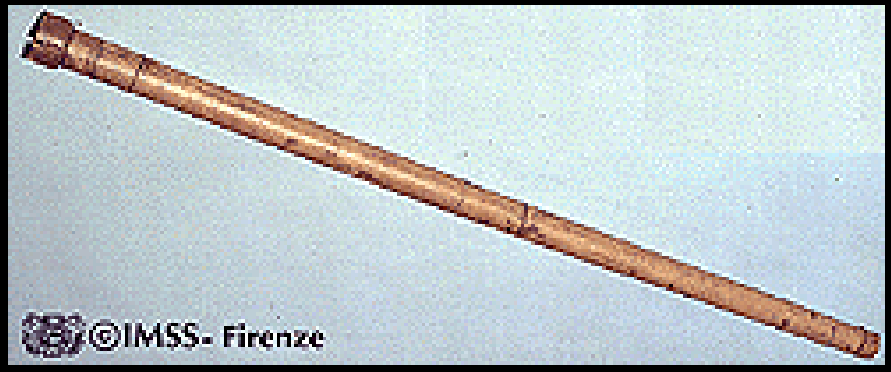
- Measurements of space and time are ***relative*** and depend on our motion
- Unified ***spacetime***
- Equivalence of **matter** and **energy**

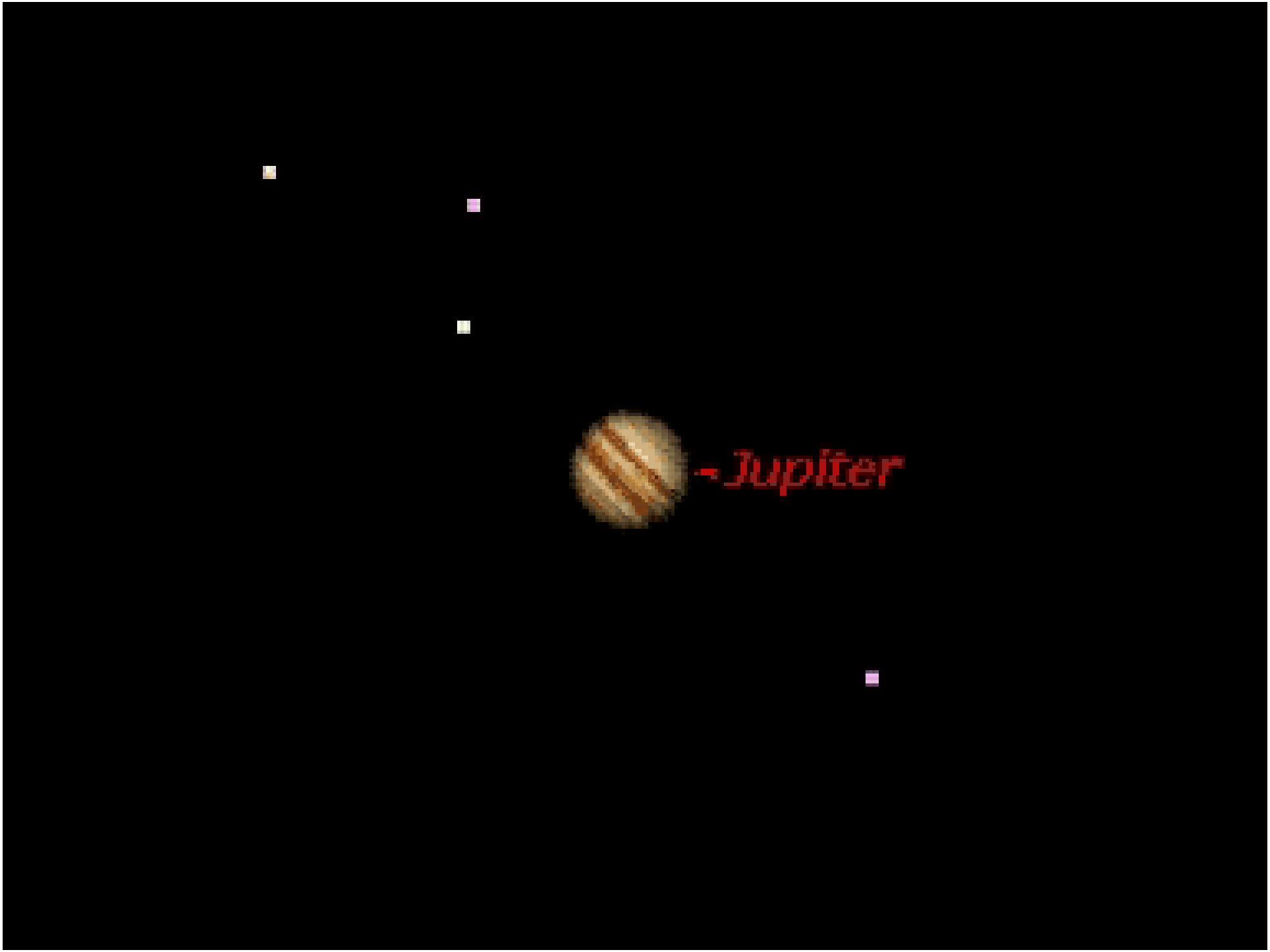
$$E = mc^2$$

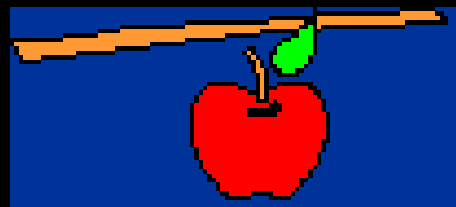
Galileo Galilei:
1564 – 1642 AD



Galilean Moons: 1610




Jupiter



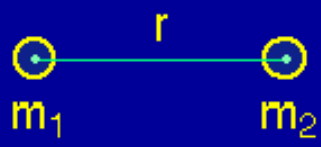
Isaac Newton:
1642 – 1727 AD

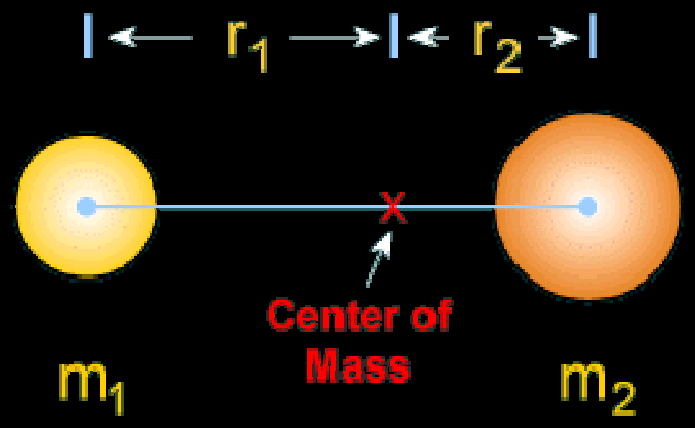
The Principia: 1684 - 1686

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.

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





Nowadays we can use radar:

Distance = Speed x Time

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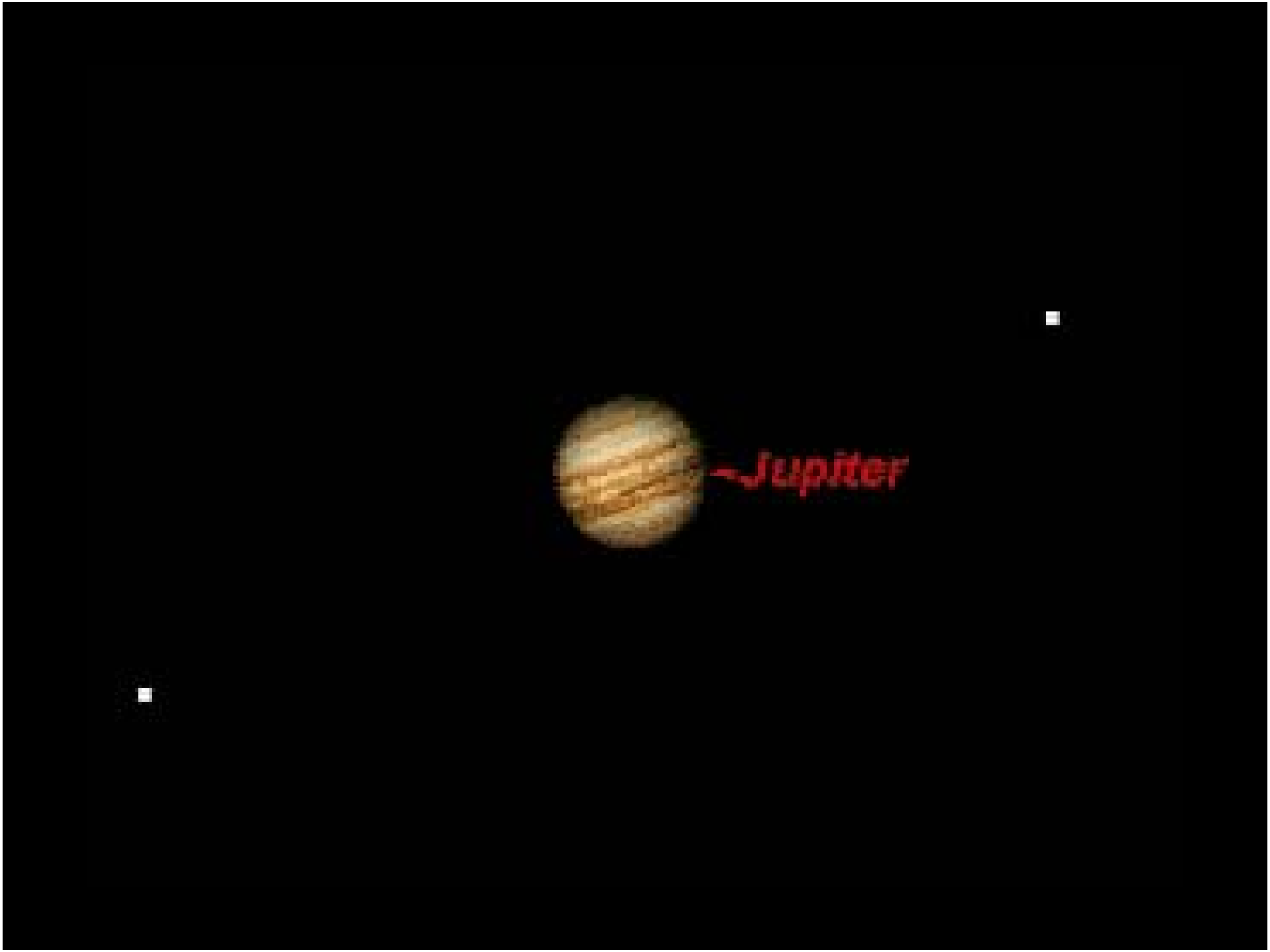
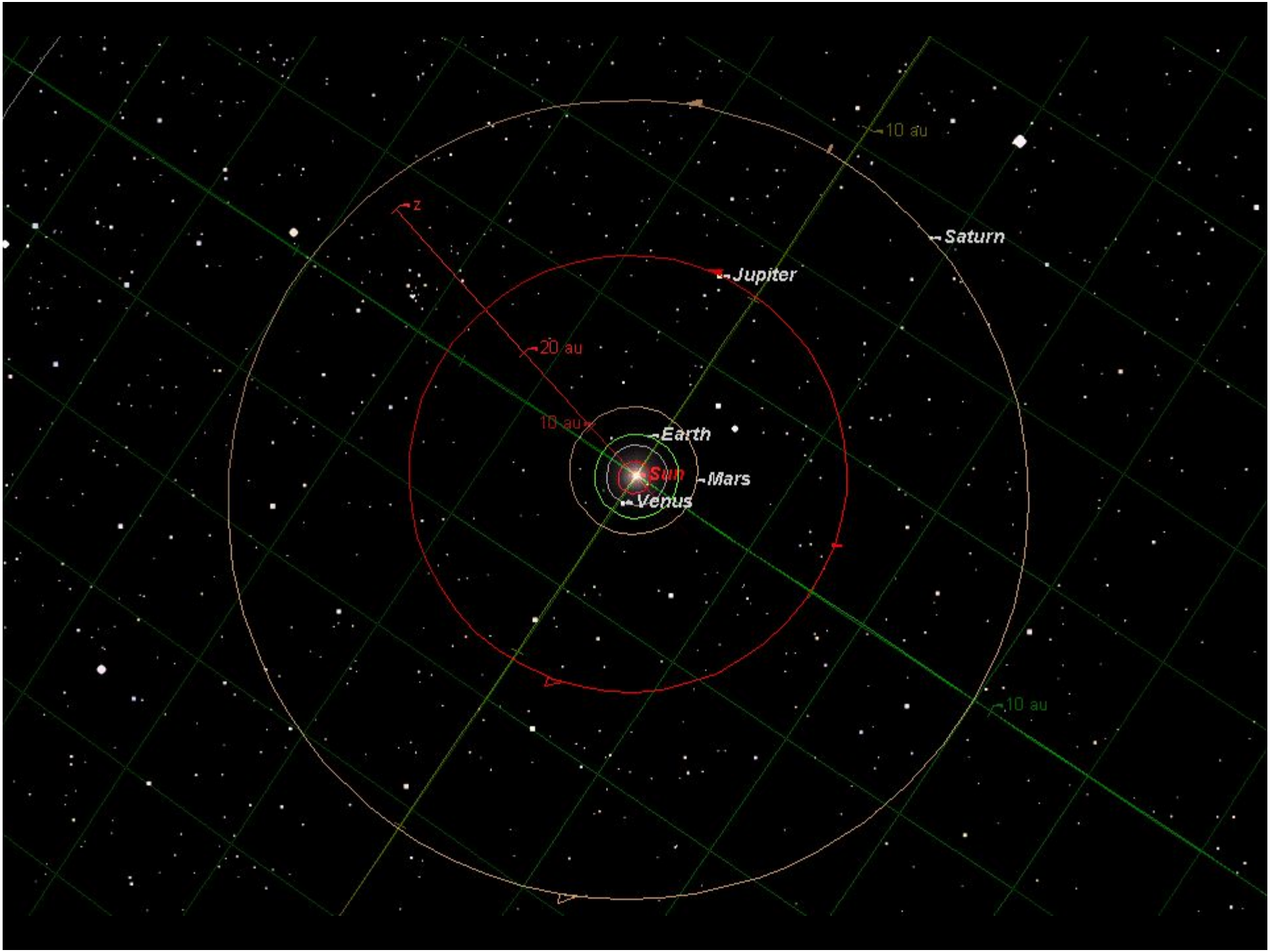
Distance = Speed x Time

But what is the speed of light?…


~Jupiter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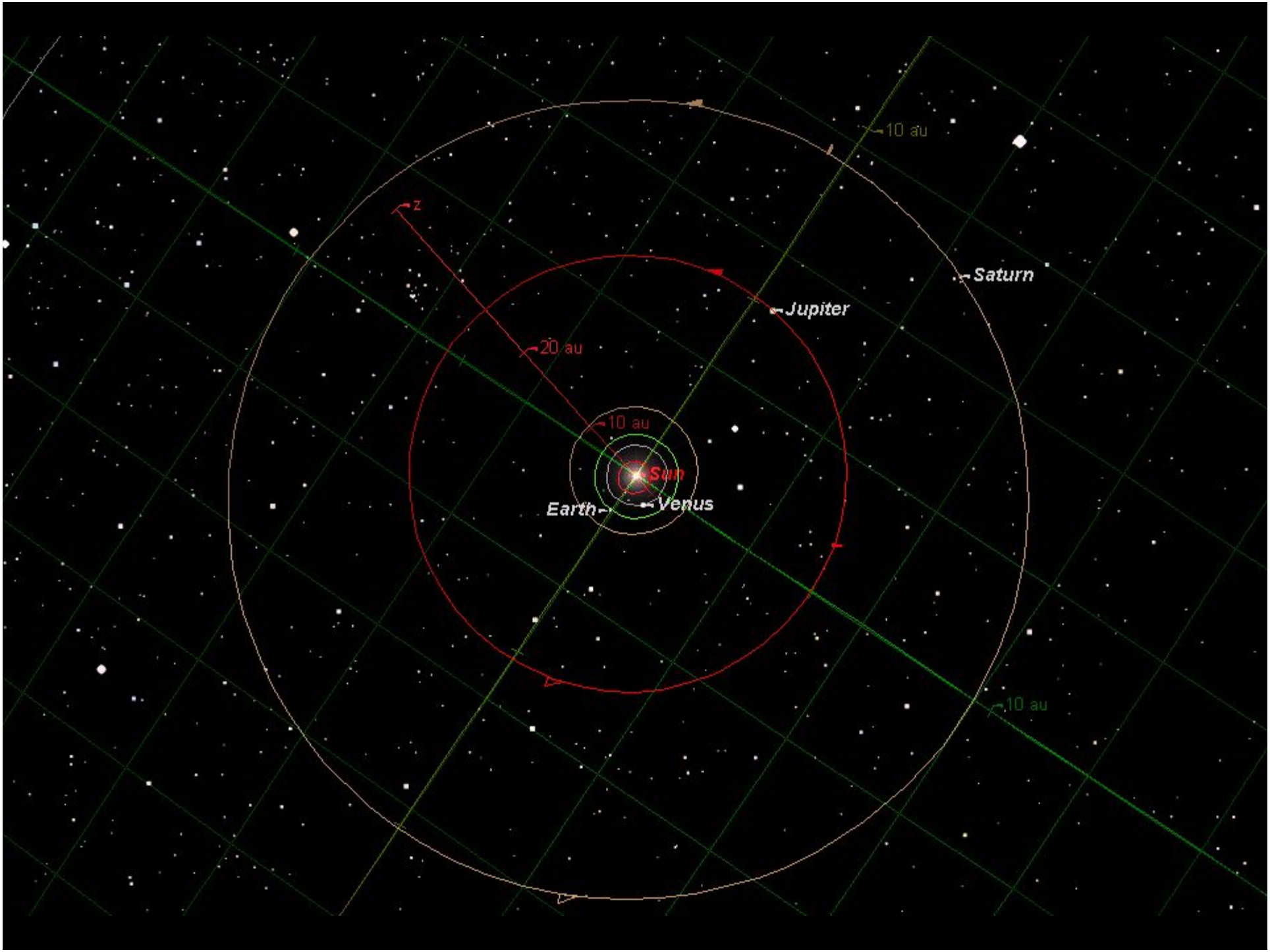
z
Saturn
Jupiter
20 au
10 au
Earth
Sun
Mars
Venus
10 au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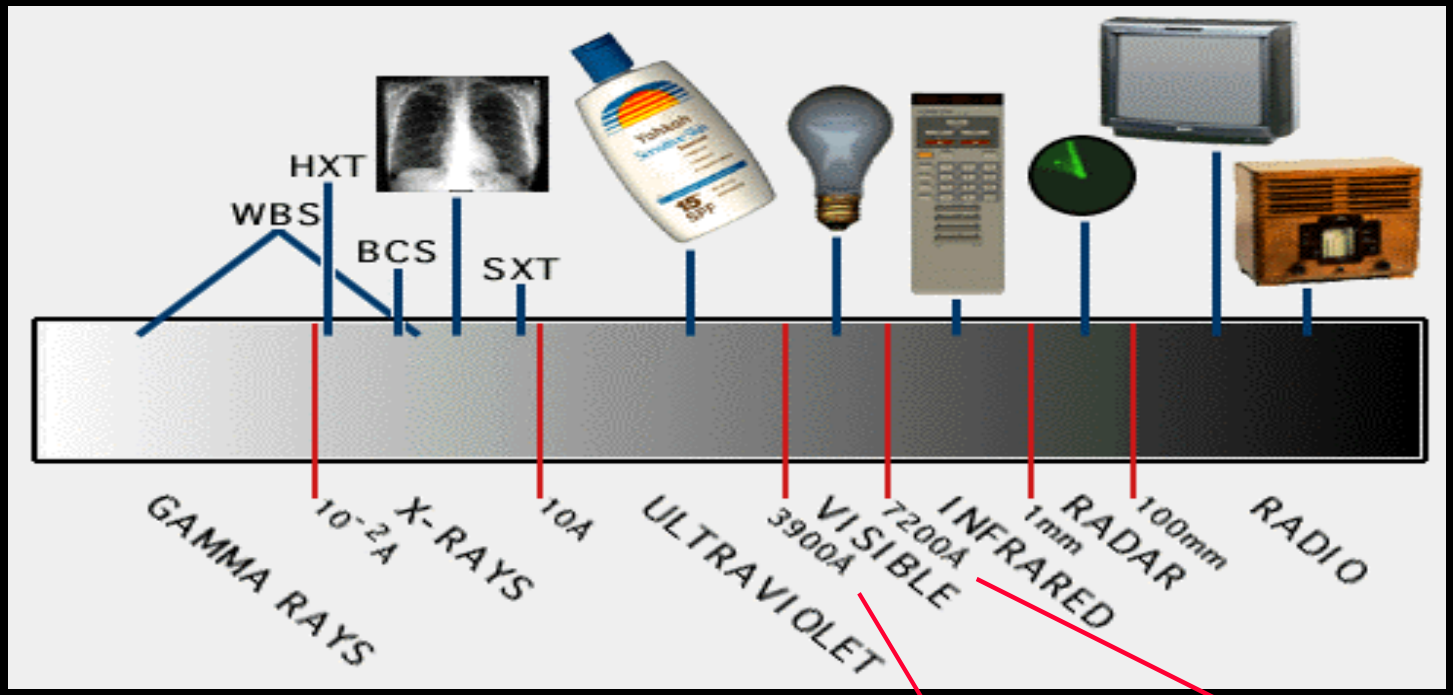
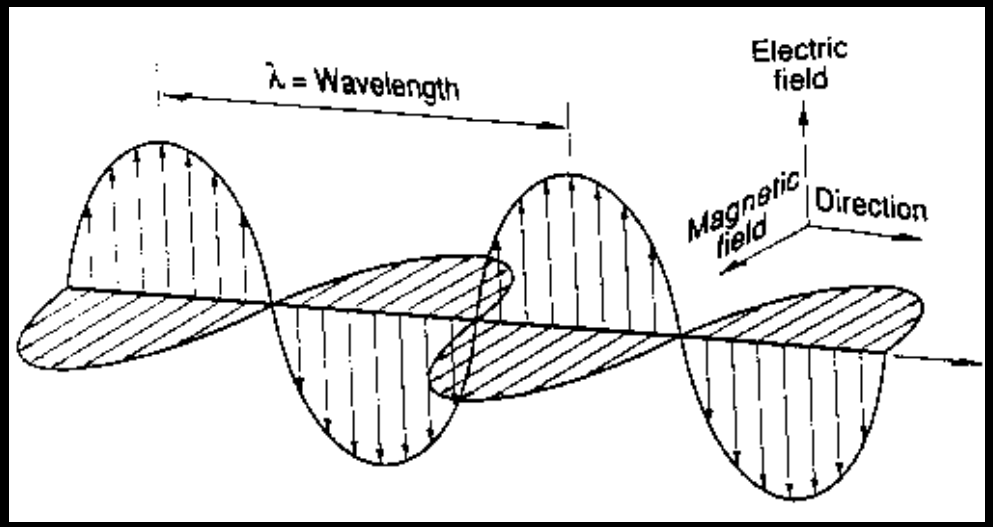
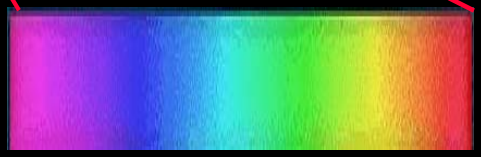
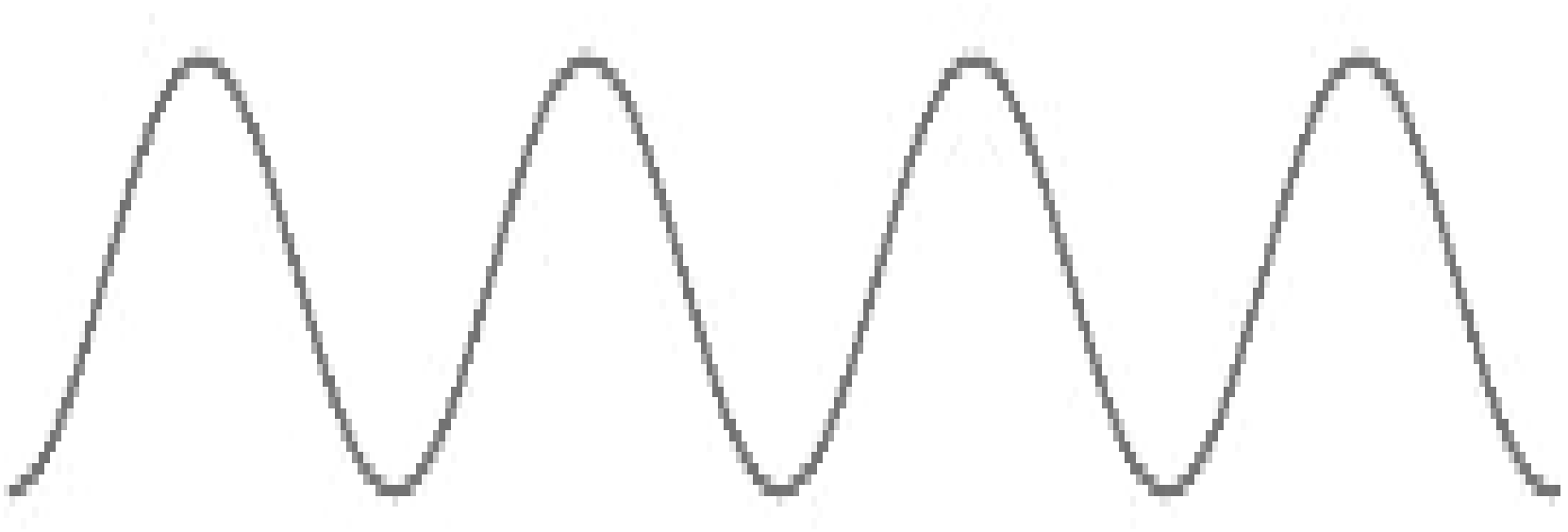




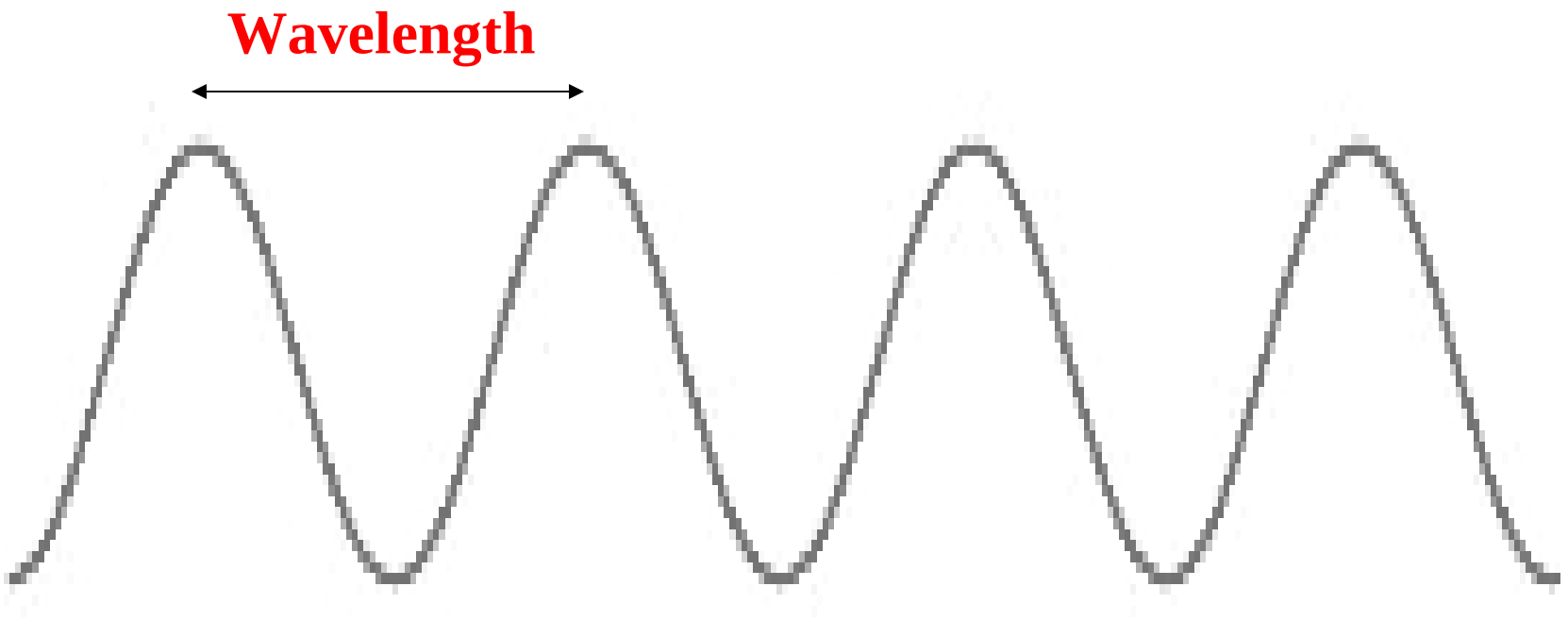


The Electromagnetic Spectrum

Light waves

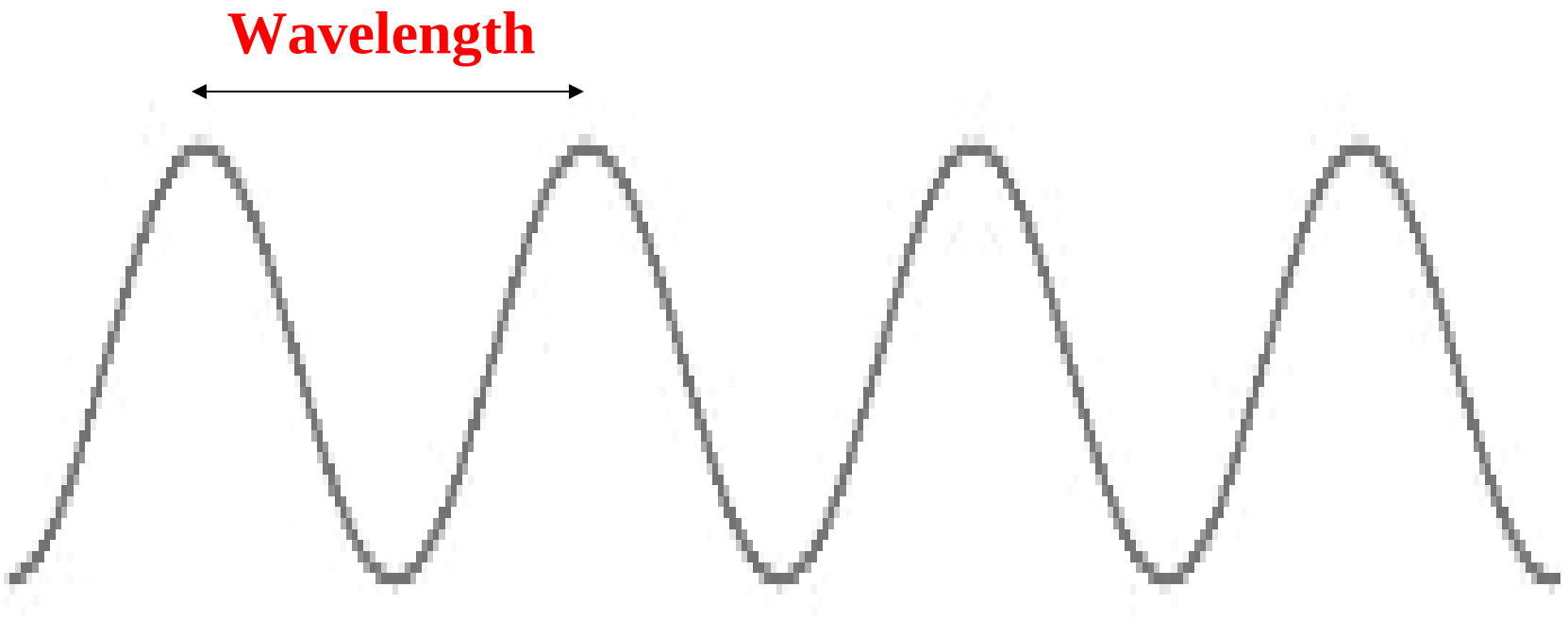


Light waves



Frequency = No of waves produced per second

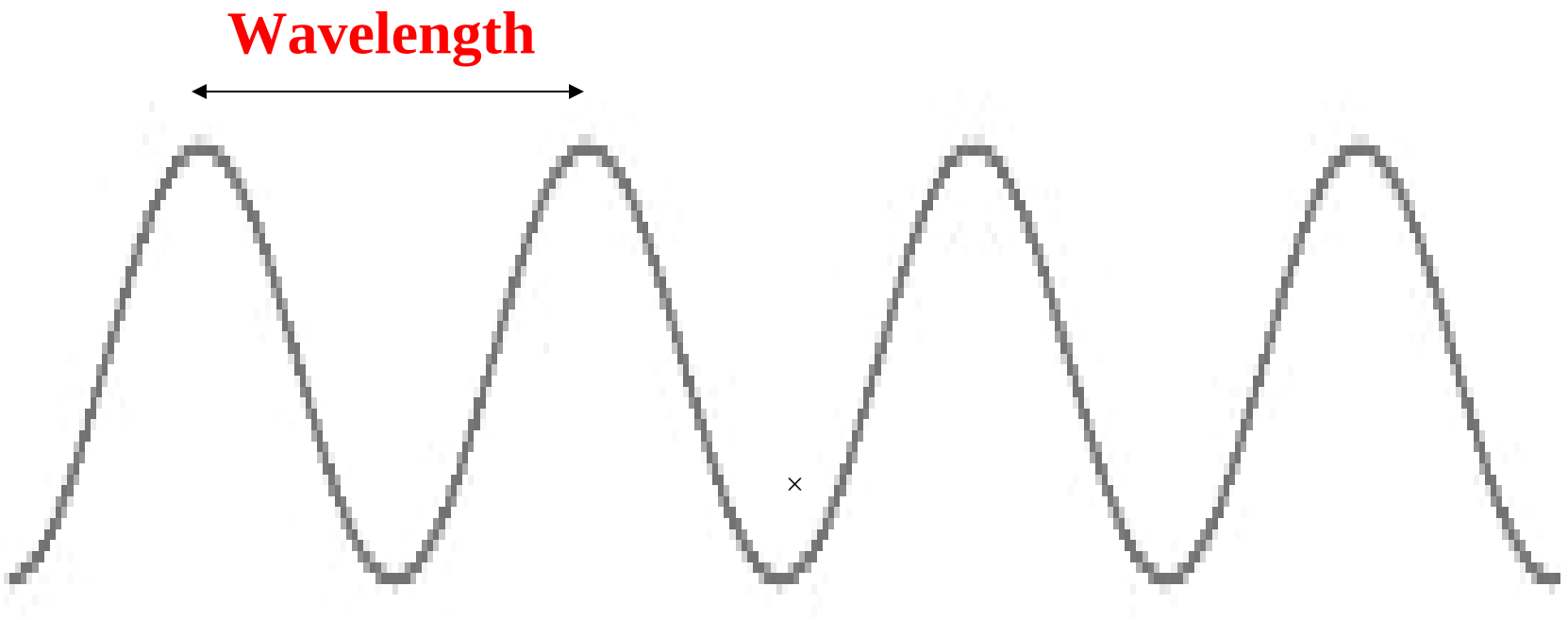
Light waves



Frequency = 2450 MHz

= 2450 Million waves per second

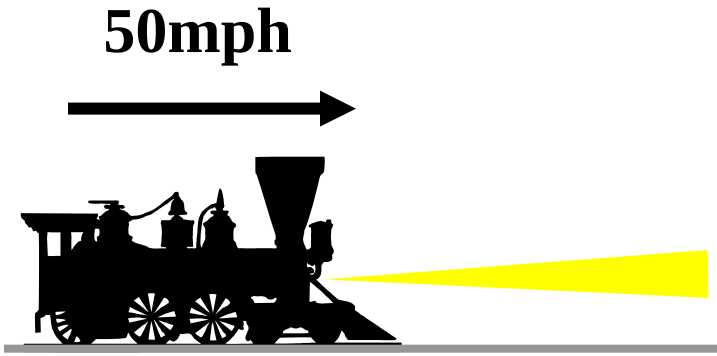
Light waves



Speed = 2450 million × wavelength

Light travels 300,000 km every Second……

……That's about 10 million, million kilometres every year!!!



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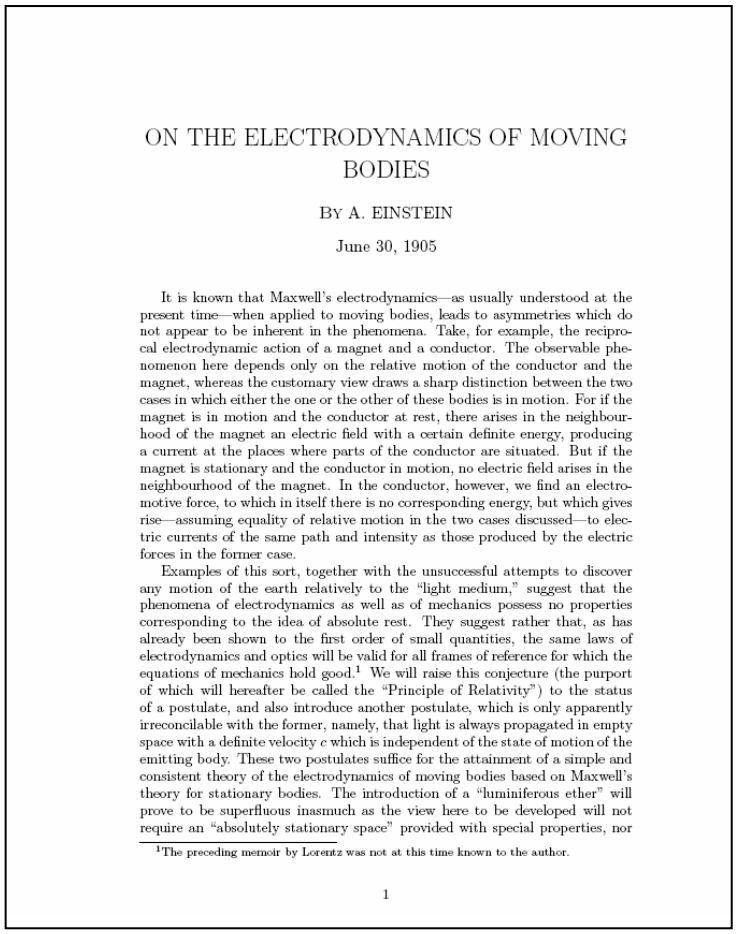

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June 30, 1905

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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

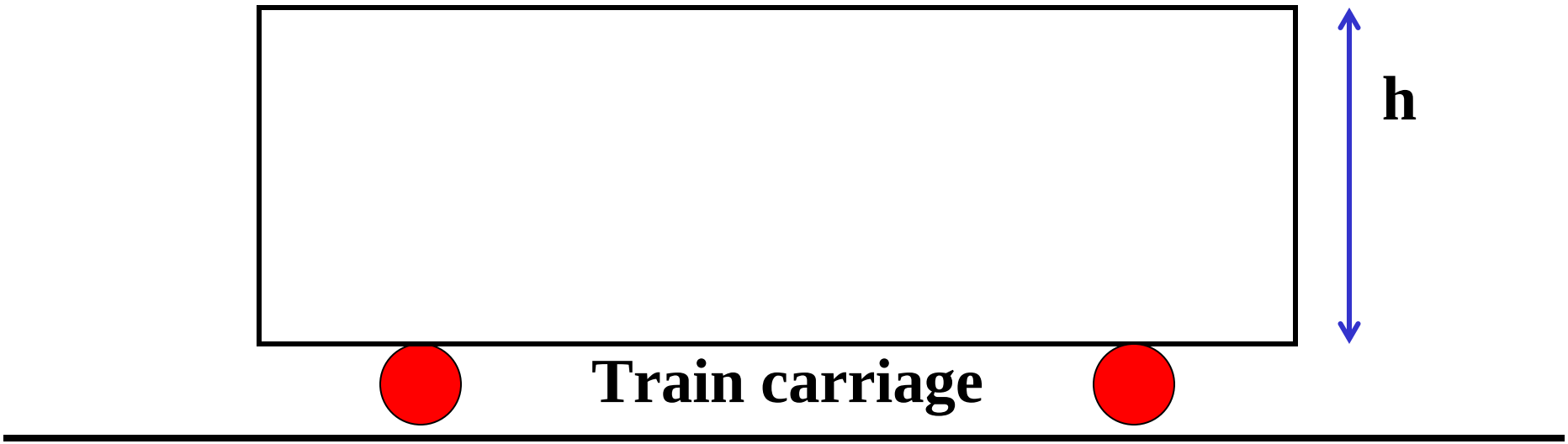
- Measurements of space and time are ***relative*** and depend on our motion
- Unified ***spacetime***
- Equivalence of **matter** and **energy**

$$E = mc^2$$

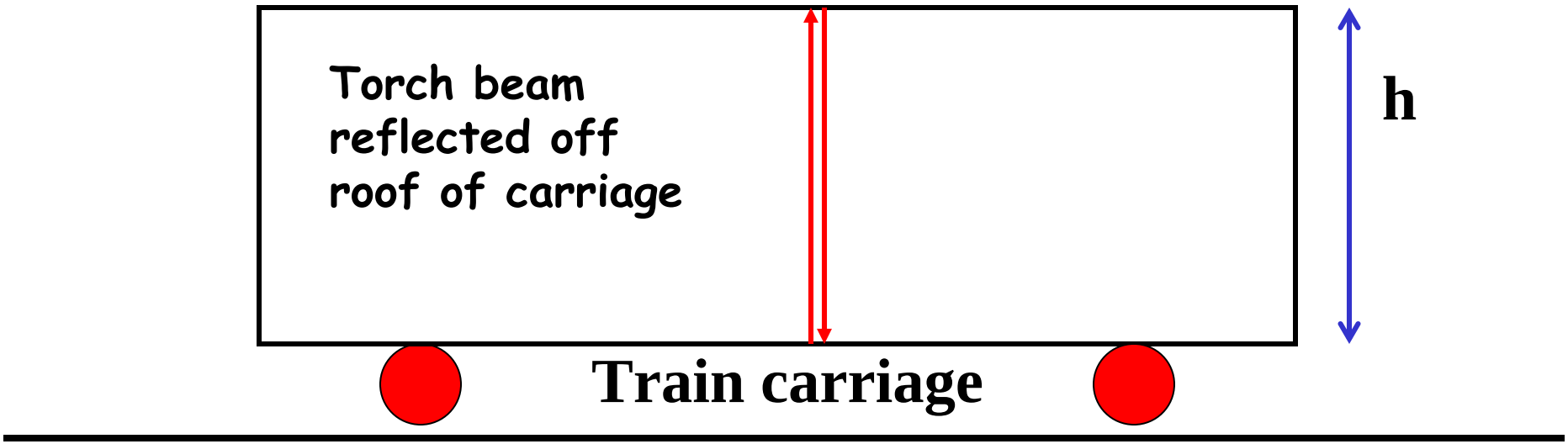
Special Relativity: 1905

Implies the speed of light must be constant, measured to be the same by any two observers, regardless of their relative motion"

This abolished completely Newton's idea that space and time were *absolute*

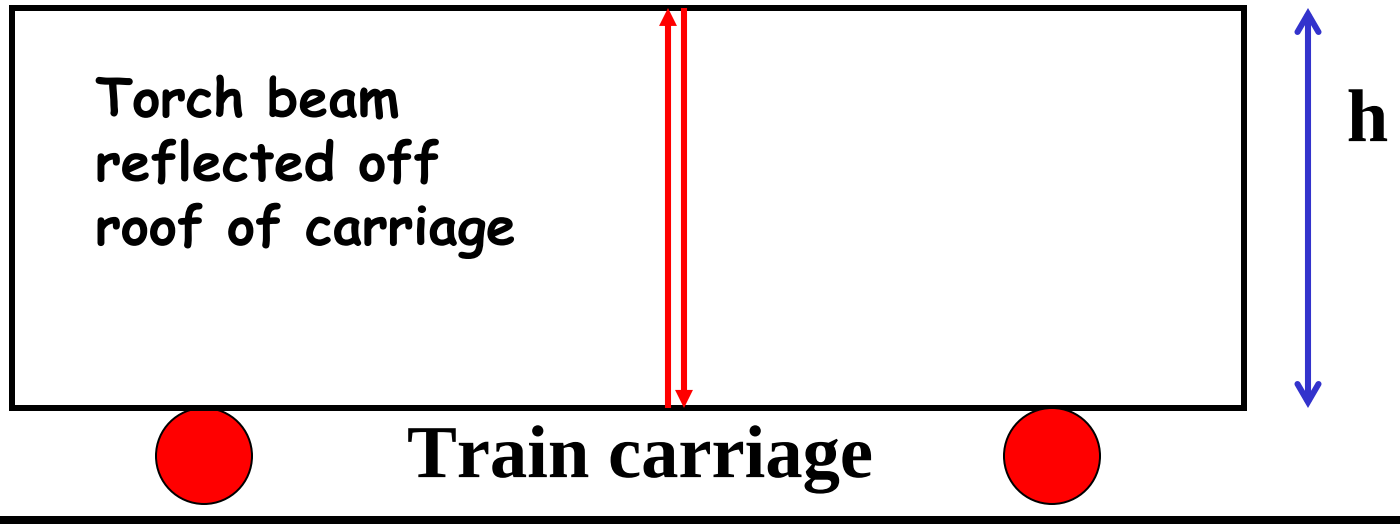


Let's try to see why!



Let's try to see why!

Distance = speed x time



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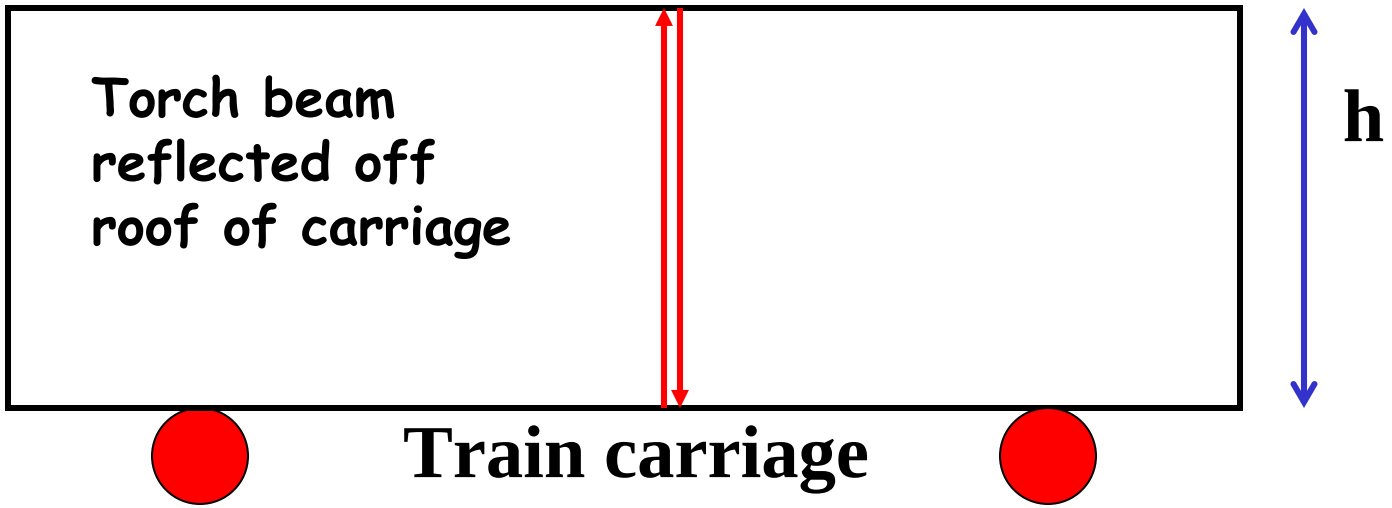
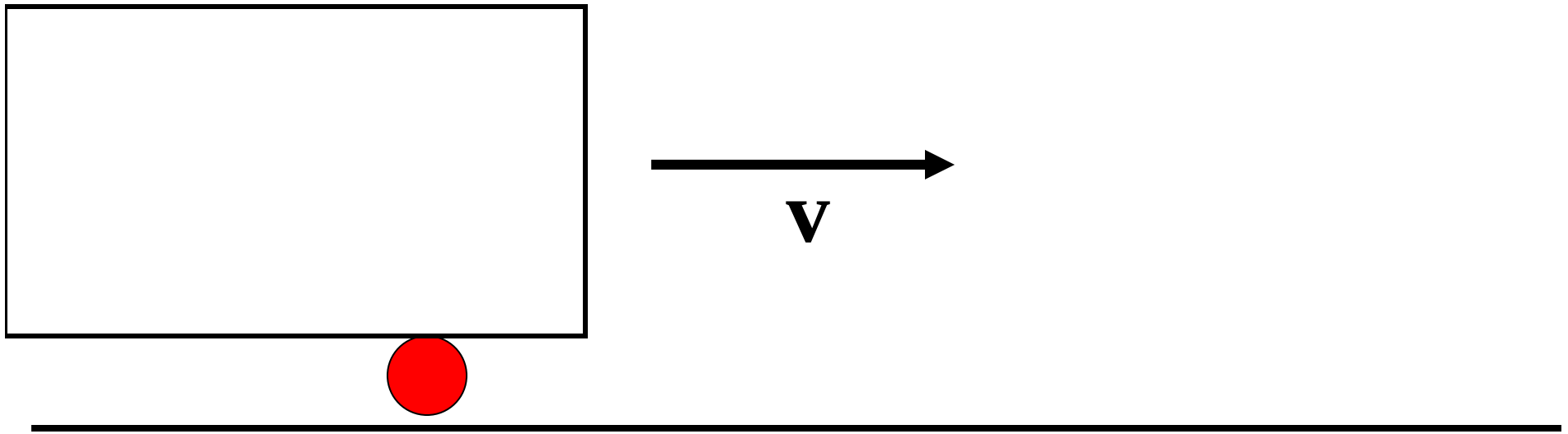


$$2h = c \times t_c$$

Now viewed from the platform…

Now viewed from the platform…



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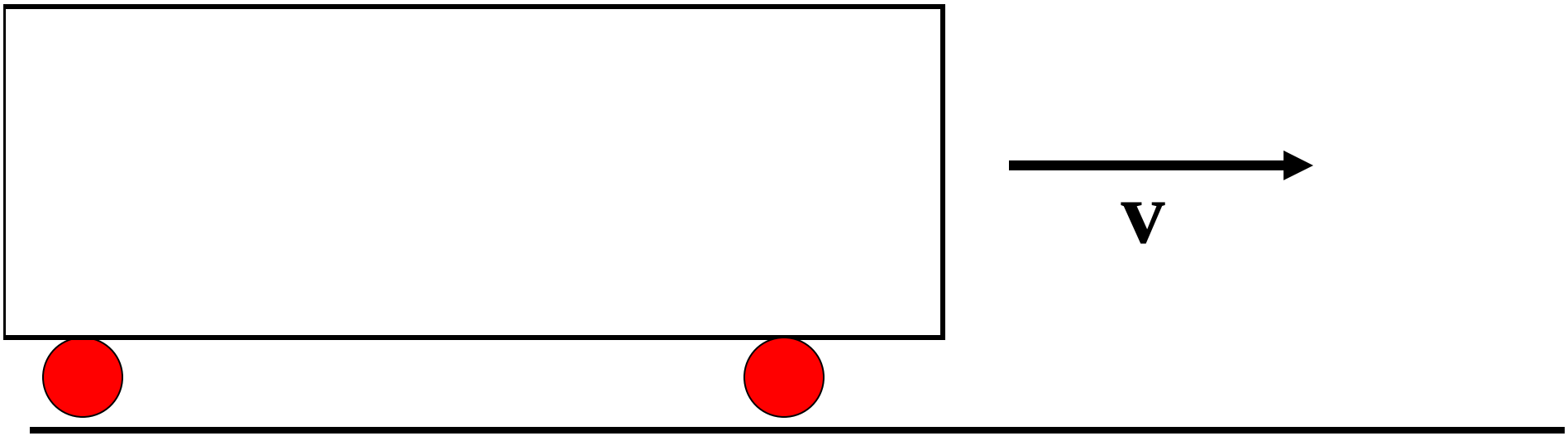

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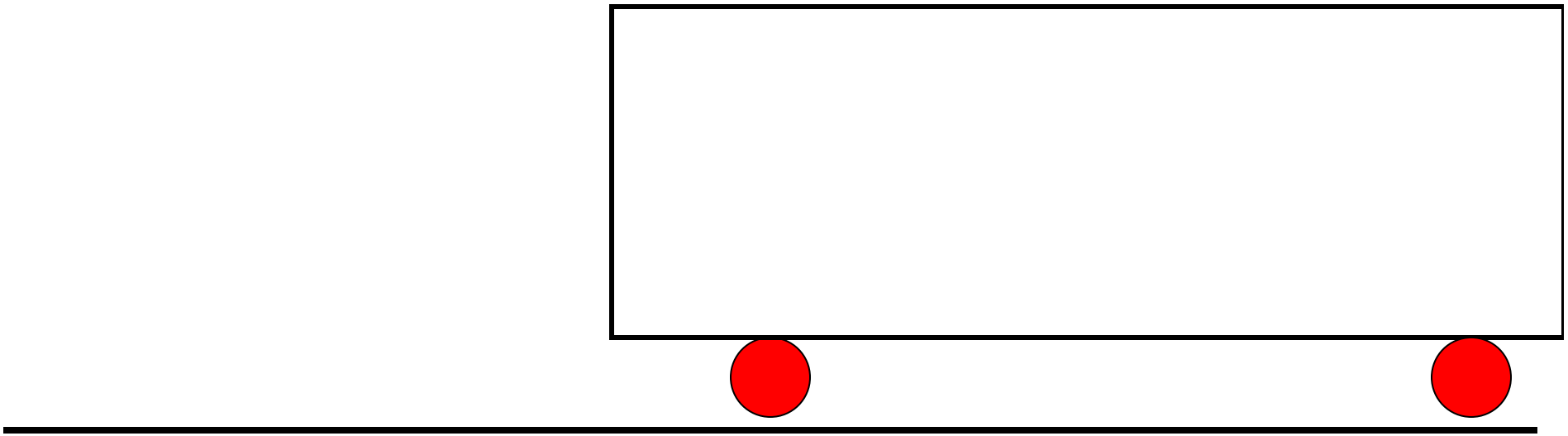

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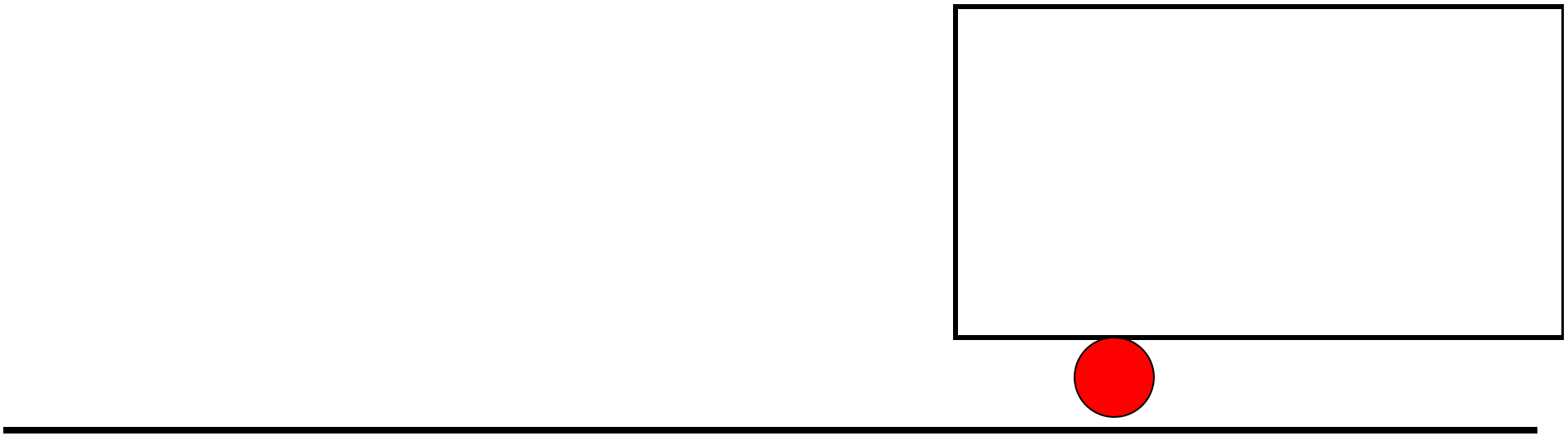

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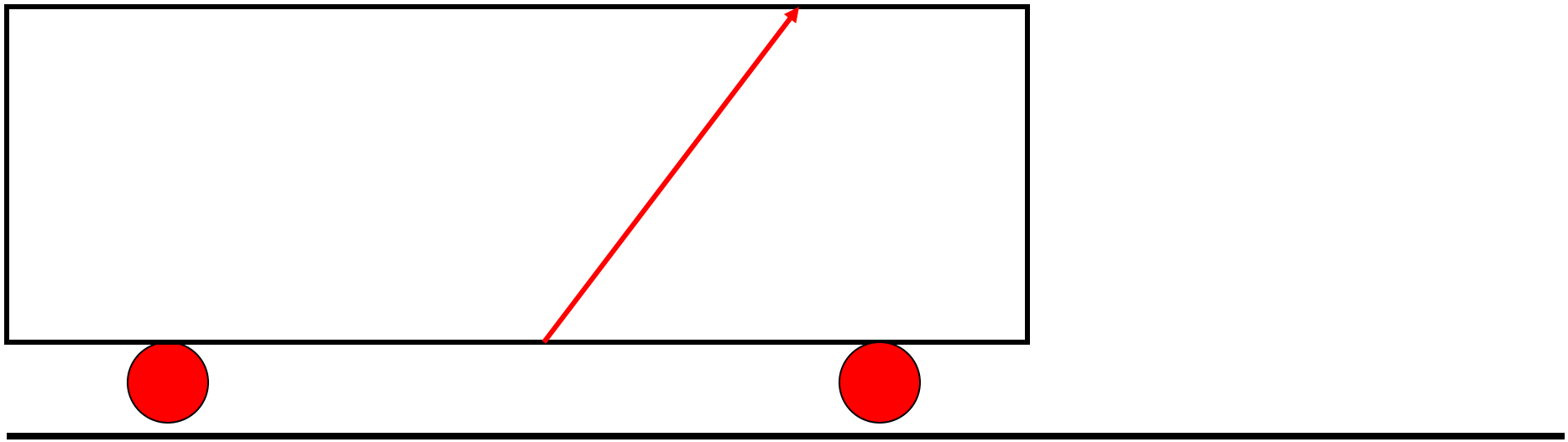

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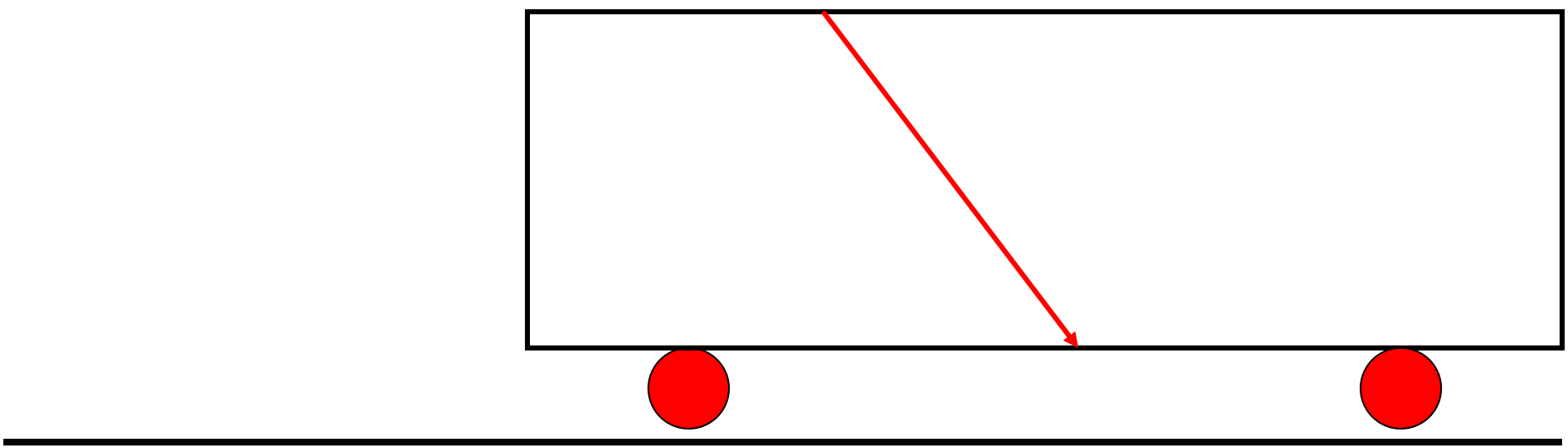
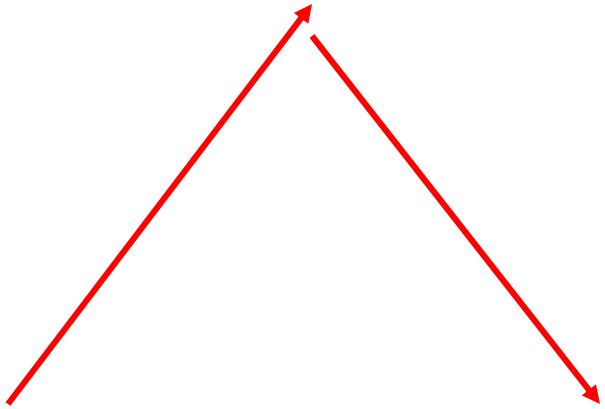


Let's call the time measured on the platform t_p

Now viewed from the platform…



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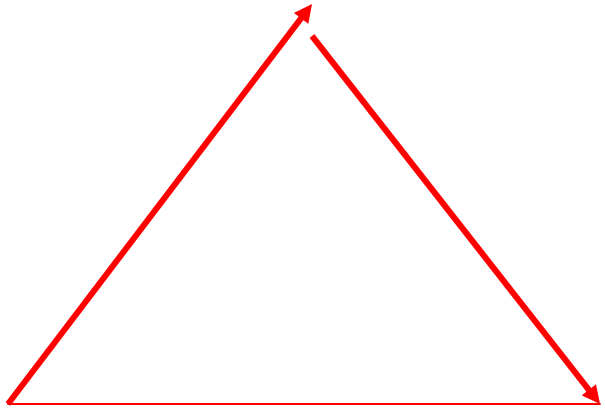

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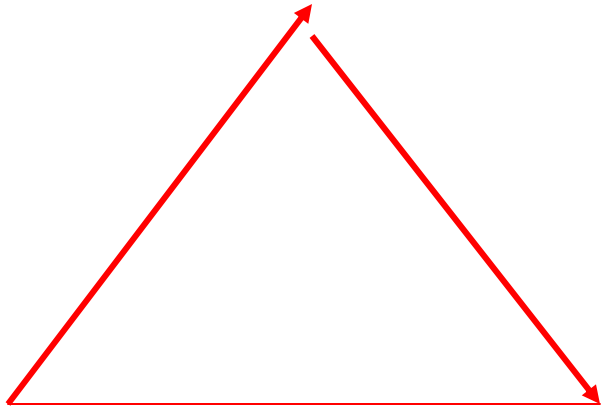
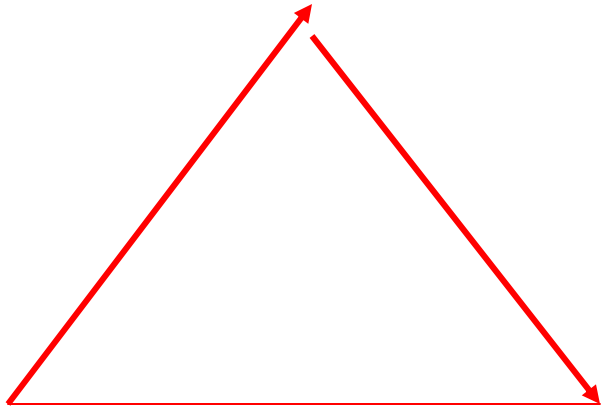


$v\ t_P$

The base of this triangle is $v\ t_P$

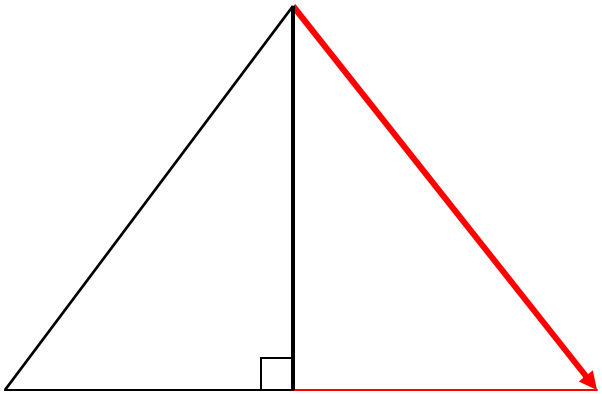
Now viewed from the platform…



$v\ t_P$

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

Now viewed from the platform…



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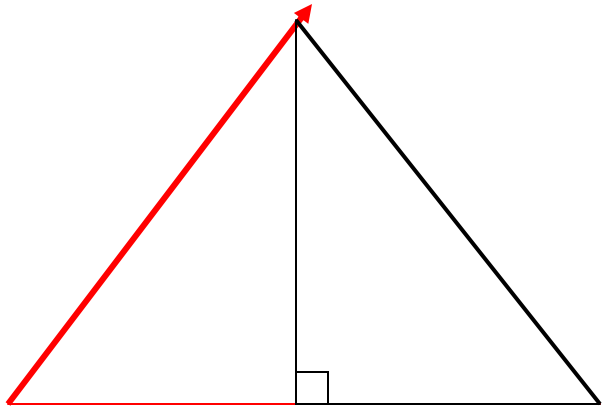

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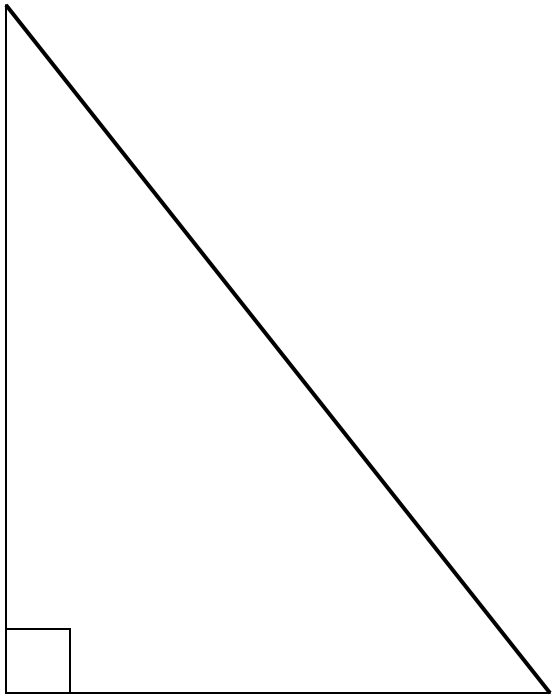
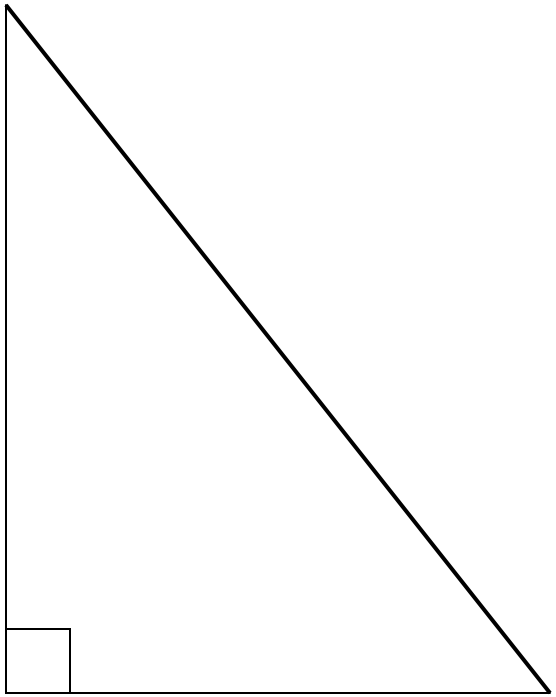


Let's look at this triangle.

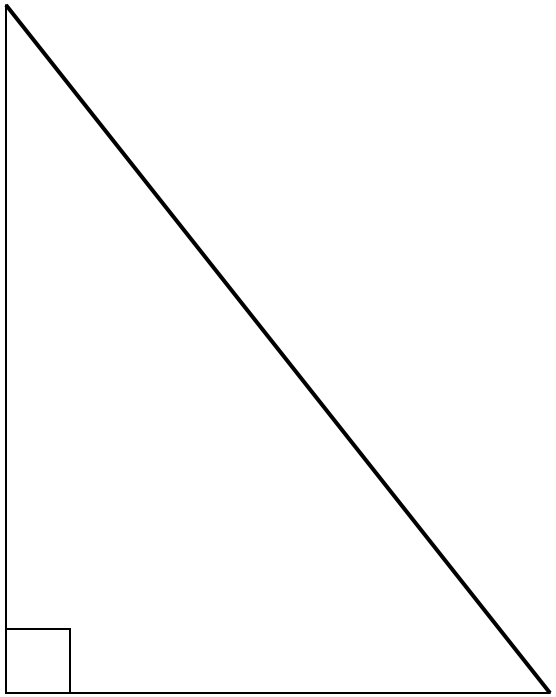
What's the length of its base?



$\frac{1}{2}\, v\, t_P$

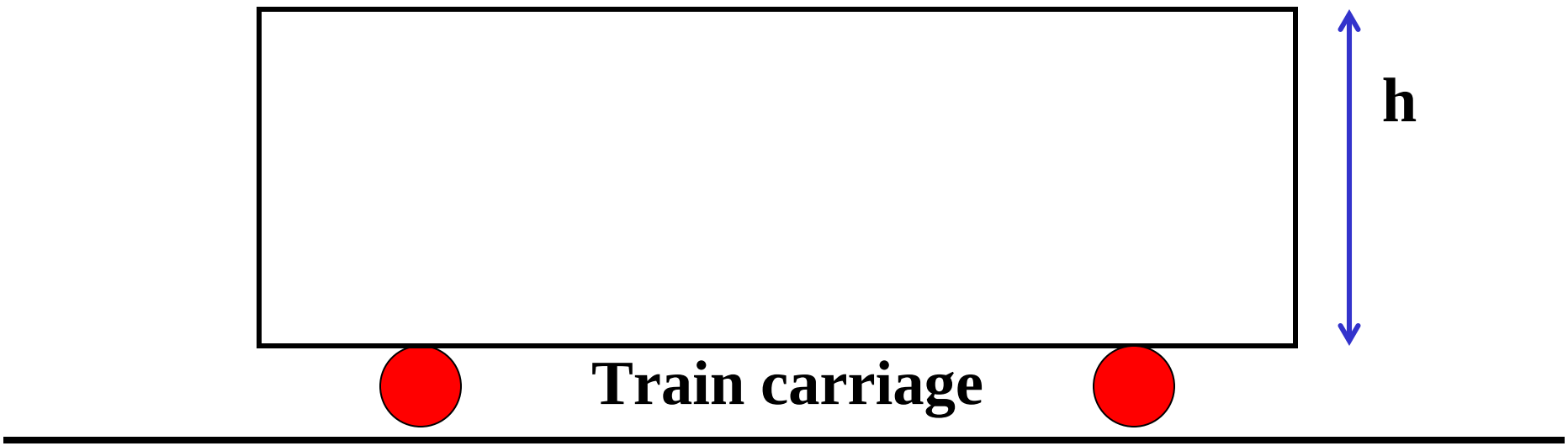
Let's look at this triangle.

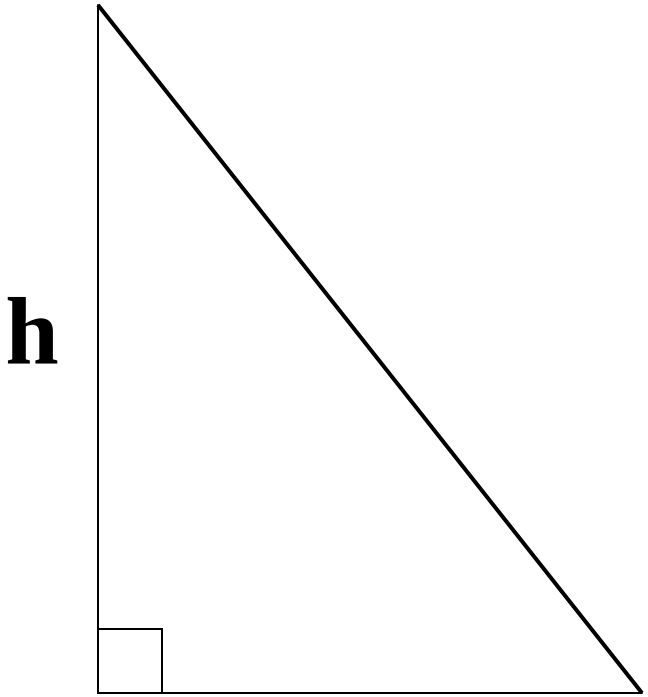
What's the length of its base?



$\frac{1}{2}\, v\, t_P$

What about its height?


h
Train carriage



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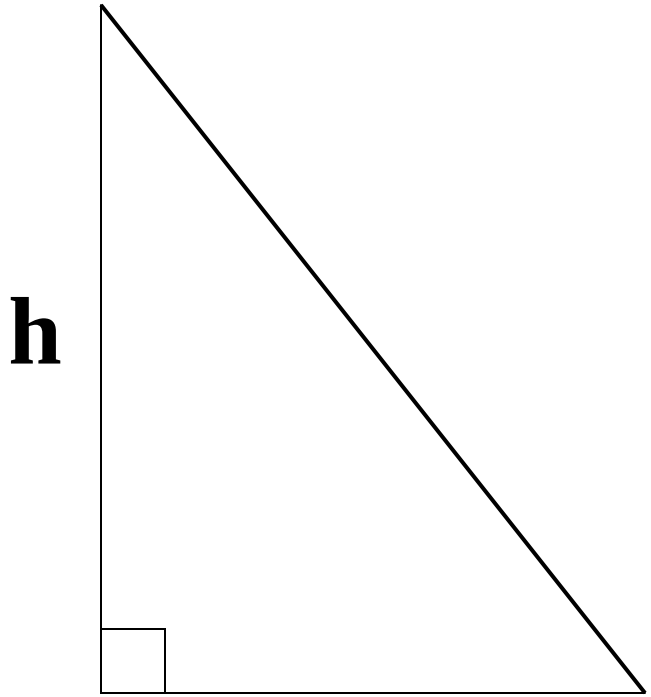
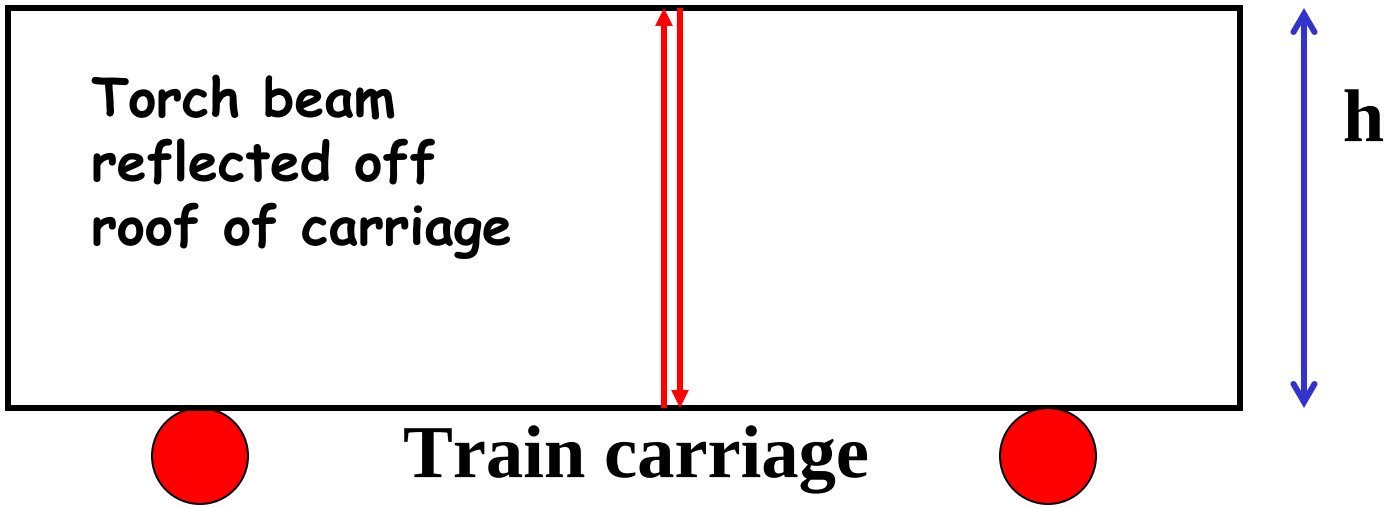


Remember: $2h = c \times t_c$

Distance = speed x time



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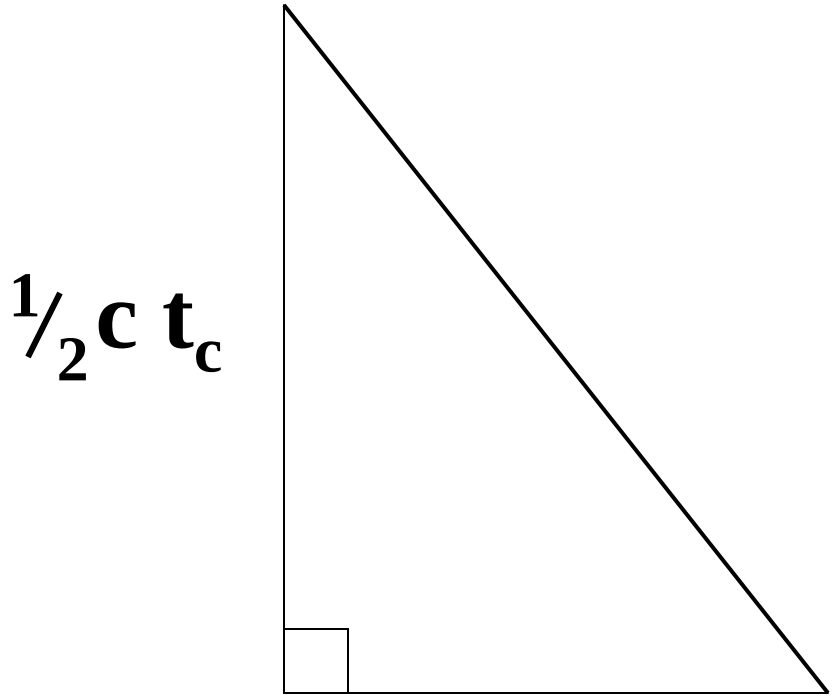

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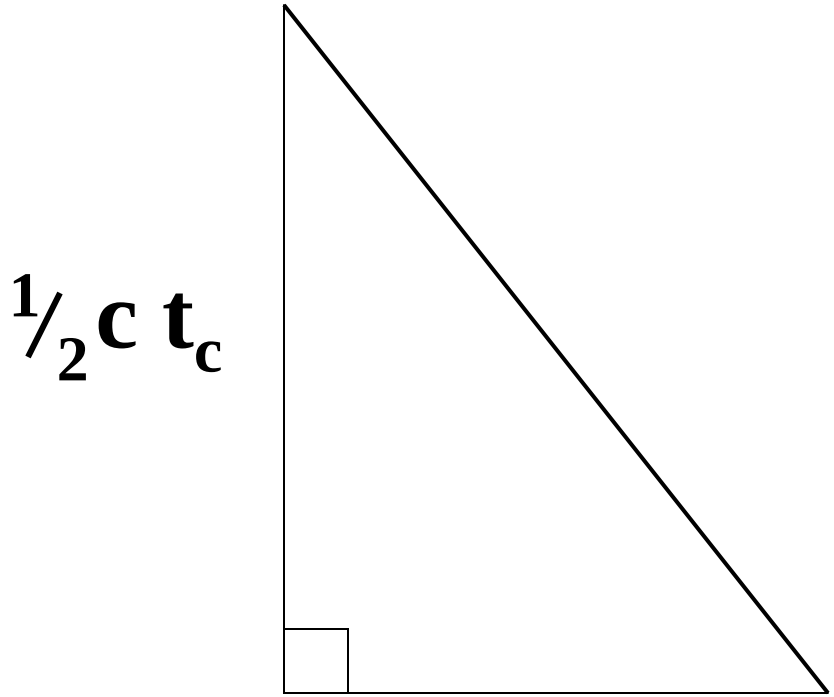
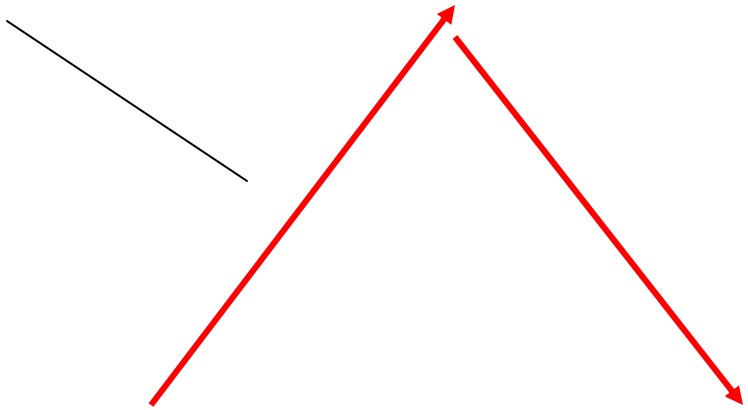


If both observers measure the same speed of light, c…

Total distance

= c x t_P



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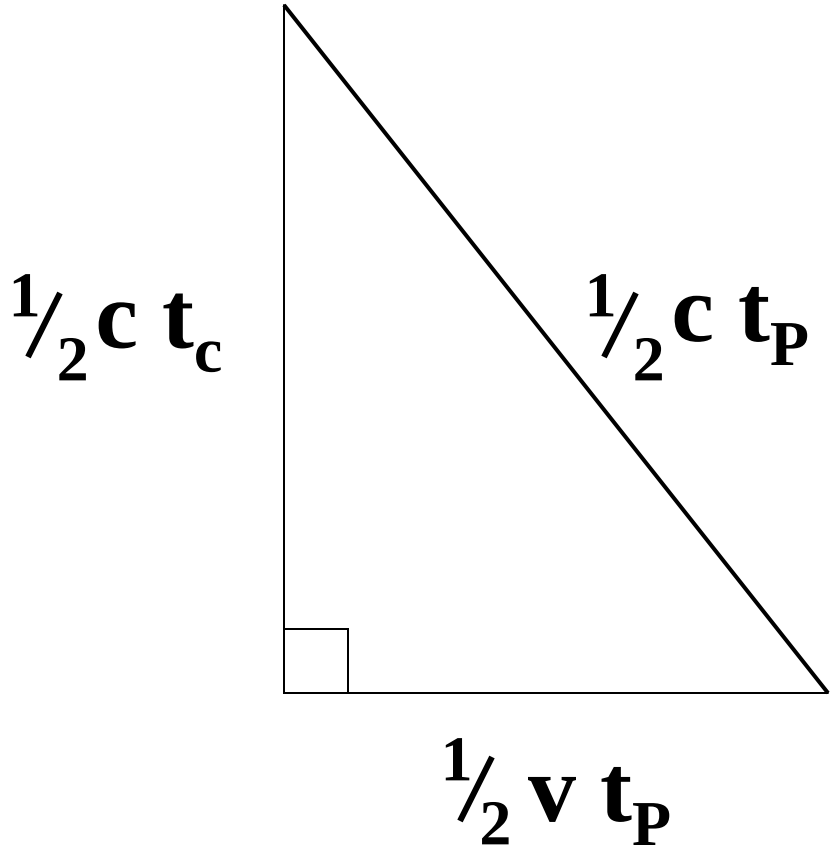

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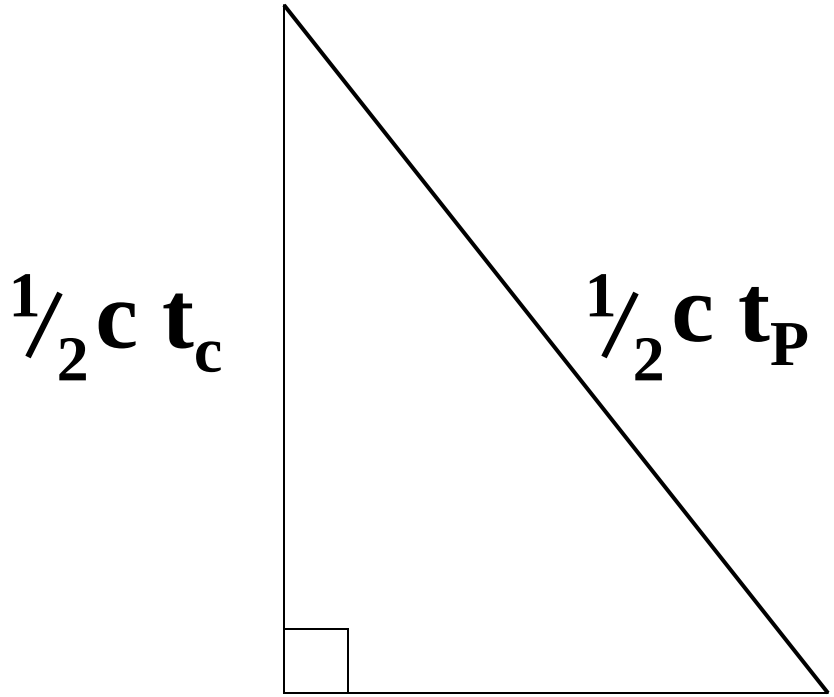
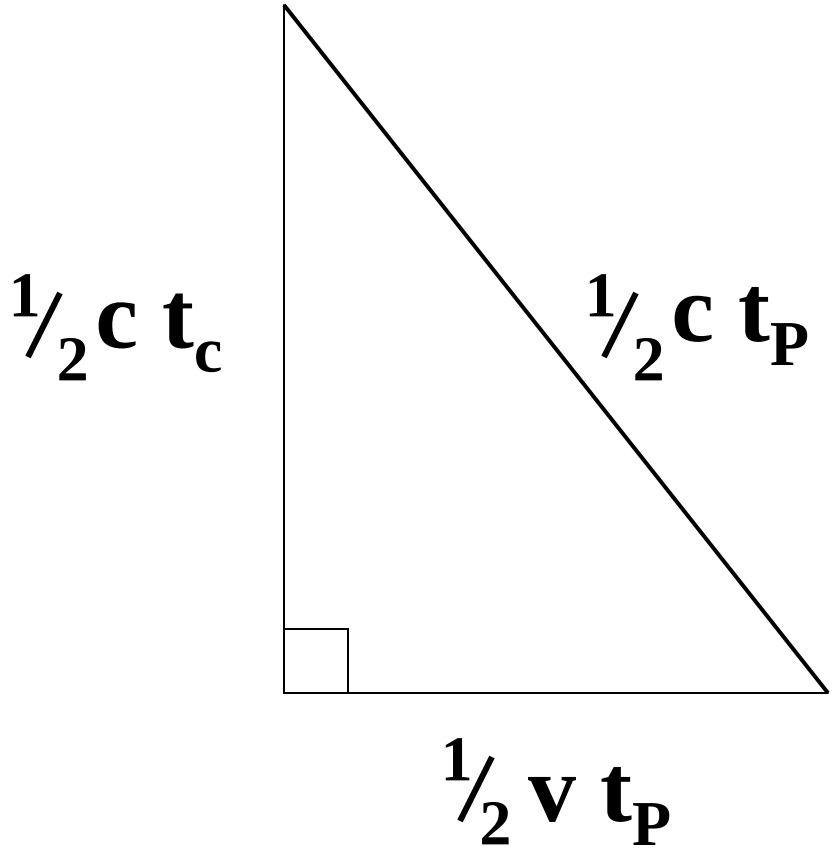


Using Pythagoras' theorem,

$$(ct_P)^2 = (vt_P)^2 + (ct_c)^2$$



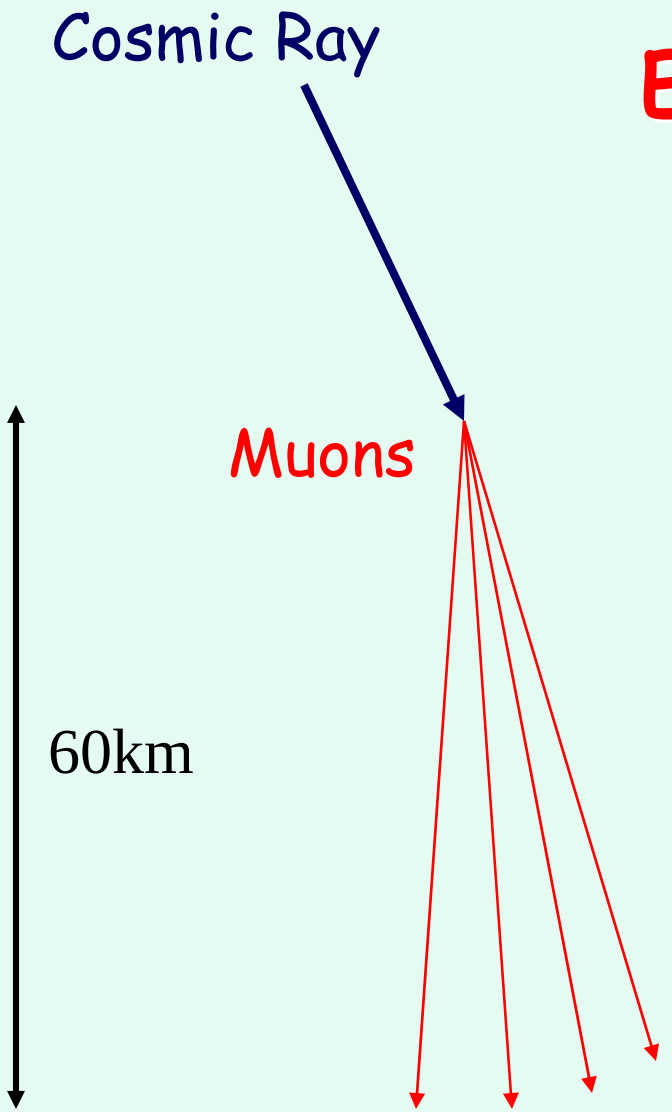
$$t_c = t_P \sqrt{(1 - v^2/c^2)}$$

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

Einstein's Relativity

300,000 kms^{-1}

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

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

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

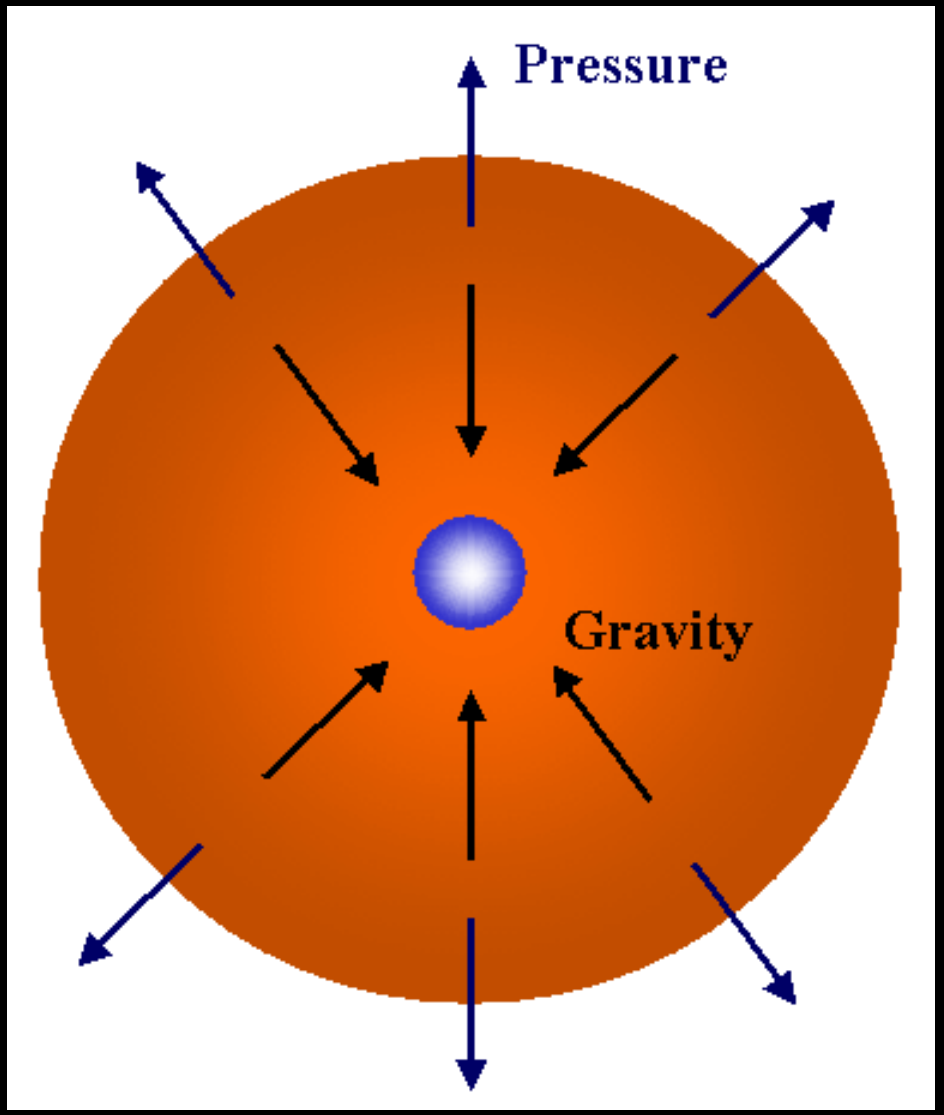
Just as special relativity shows that space and time are inextricably connected, so too are energy and momentum

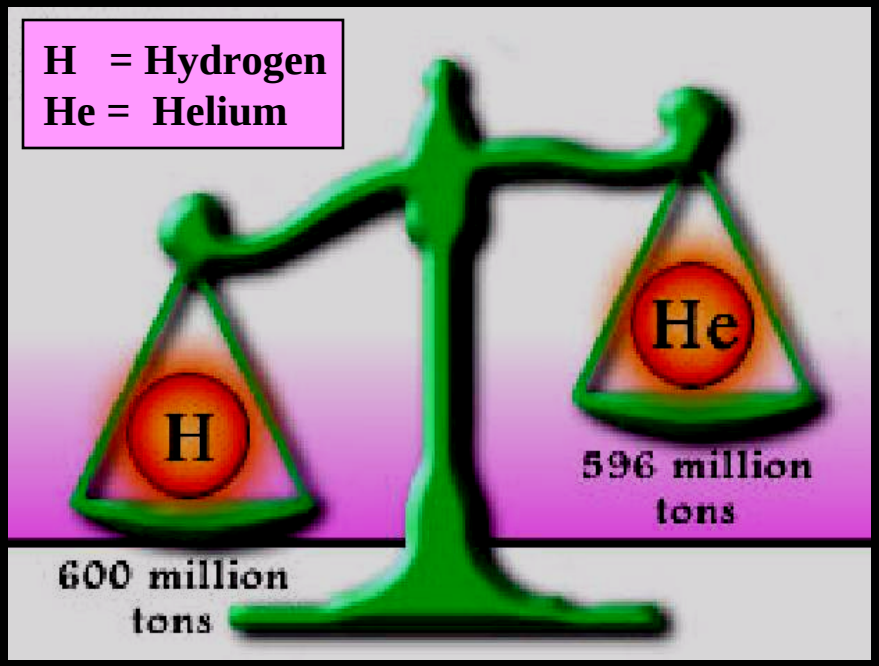
Particles have a particular **rest mass**, which is the mass you would measure if the particle is at rest

Mass and energy are equivalent

$$E = mc^2$$

Hydrogen fusion – fuelling a star's nuclear furnace

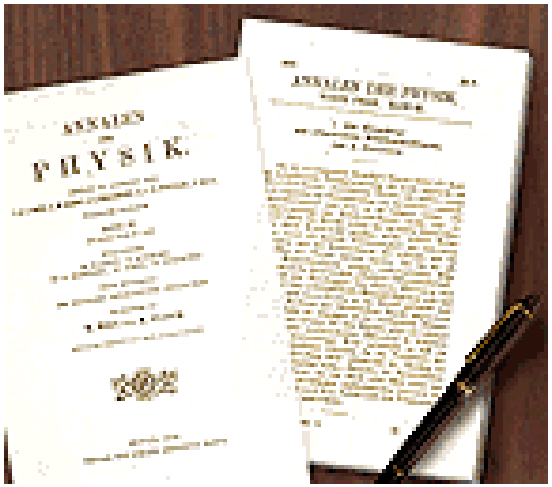




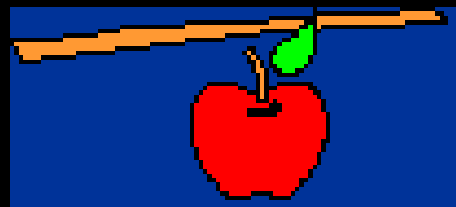
$E = mc^2$

Einstein's Relativity

How does gravity fit into this?



General Relativity: 1916



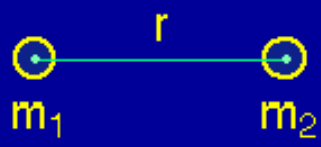
Isaac Newton:
1642 – 1727 AD

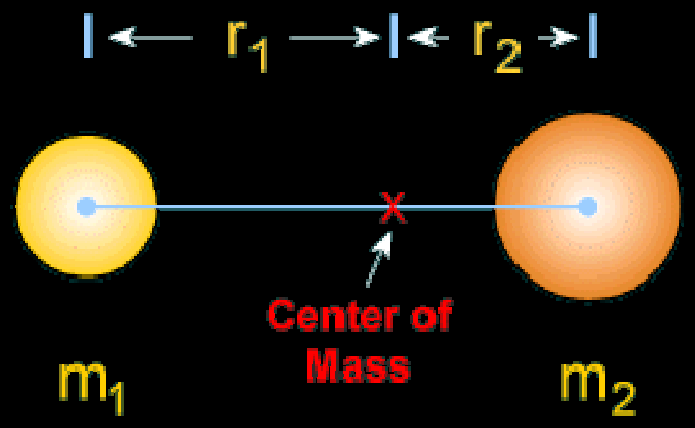
The Principia: 1684 - 1686

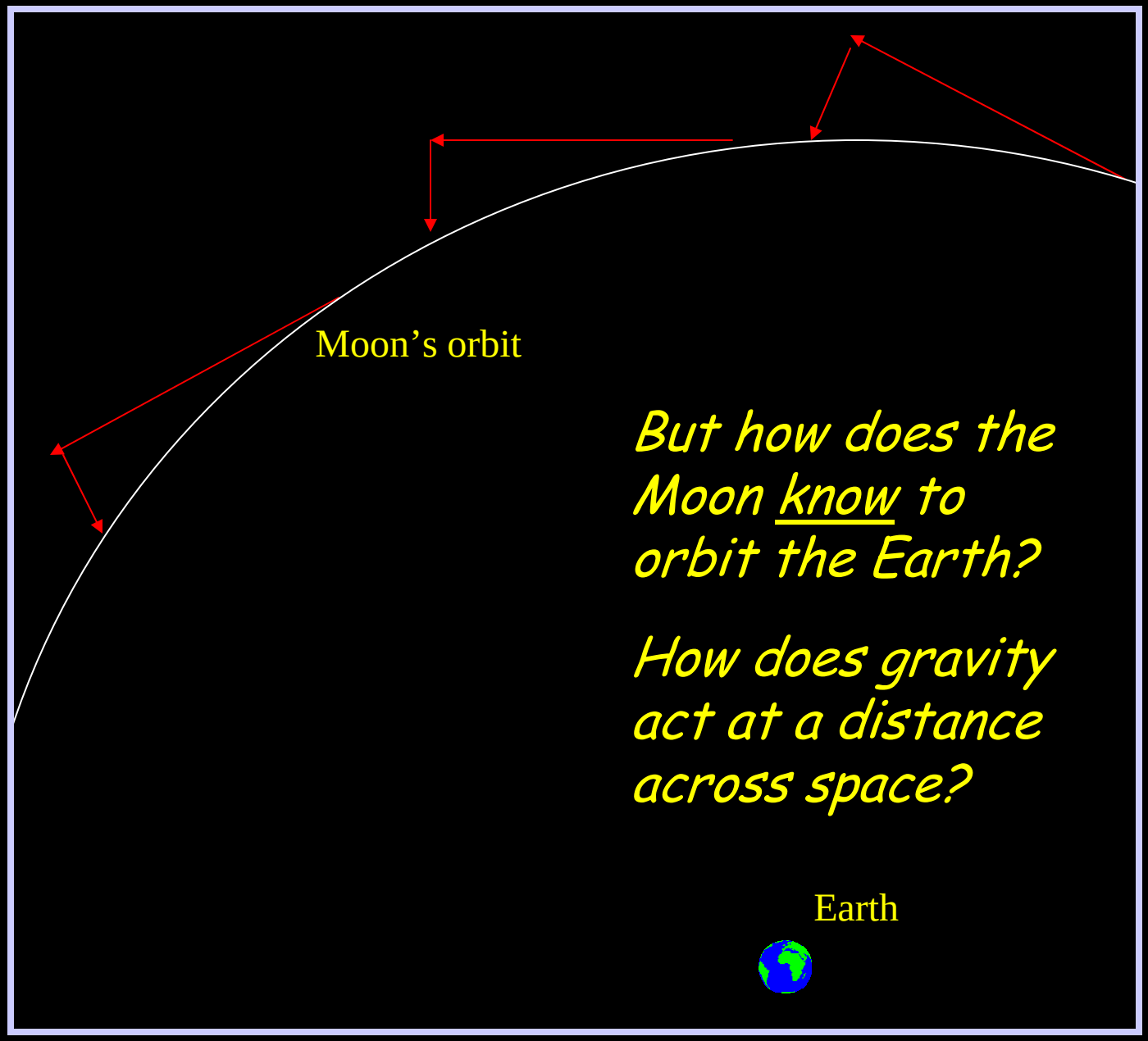
Law of Universal Gravitation

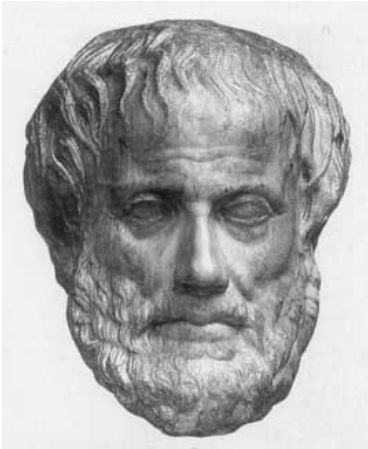
Every object in the Universe attracts every other object with a force directed along the line of centers for the two objects that is proportional to the product of their masses and inversely proportional to the square of the separation between the two objects.

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






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



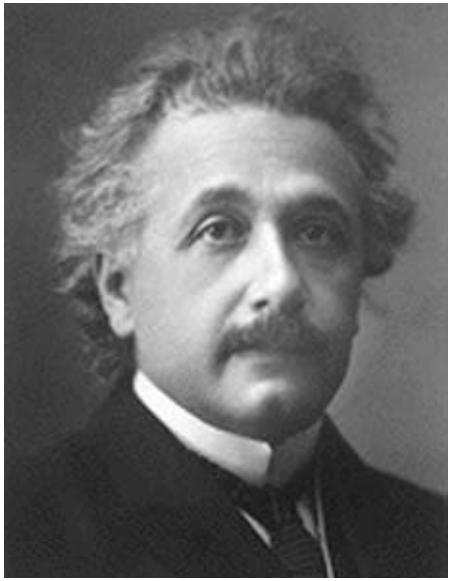
Aristotle's Theory:

1. *Objects move only as long as we apply a force to them*
2. *Falling bodies fall at a constant rate*
3. *Heavy bodies fall faster than light ones*

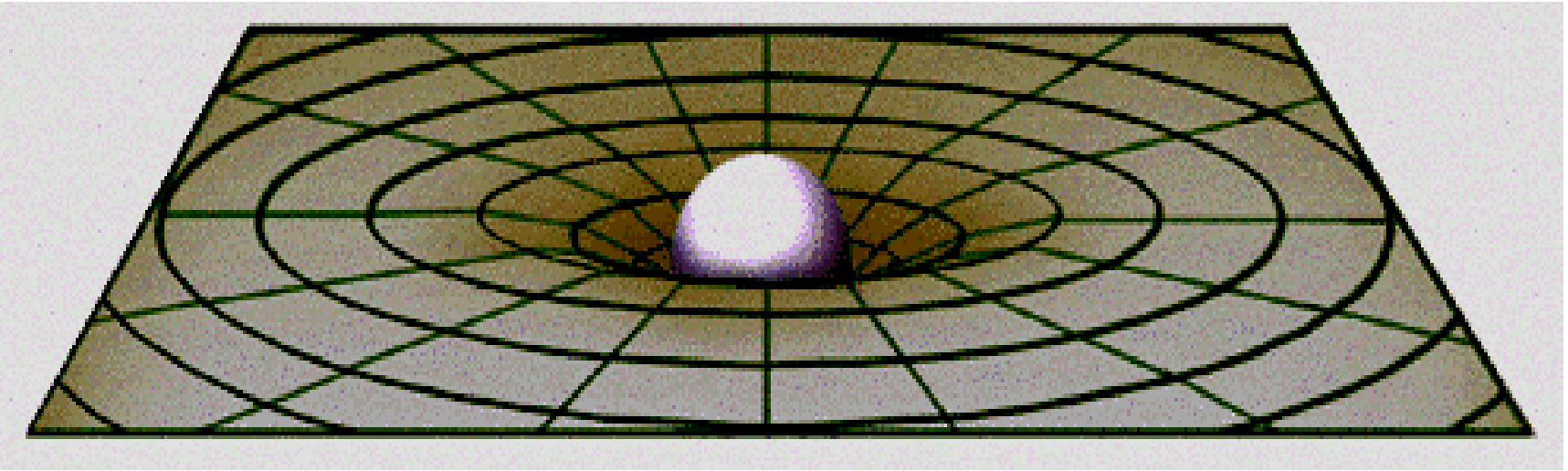
Galileo's Experiment:

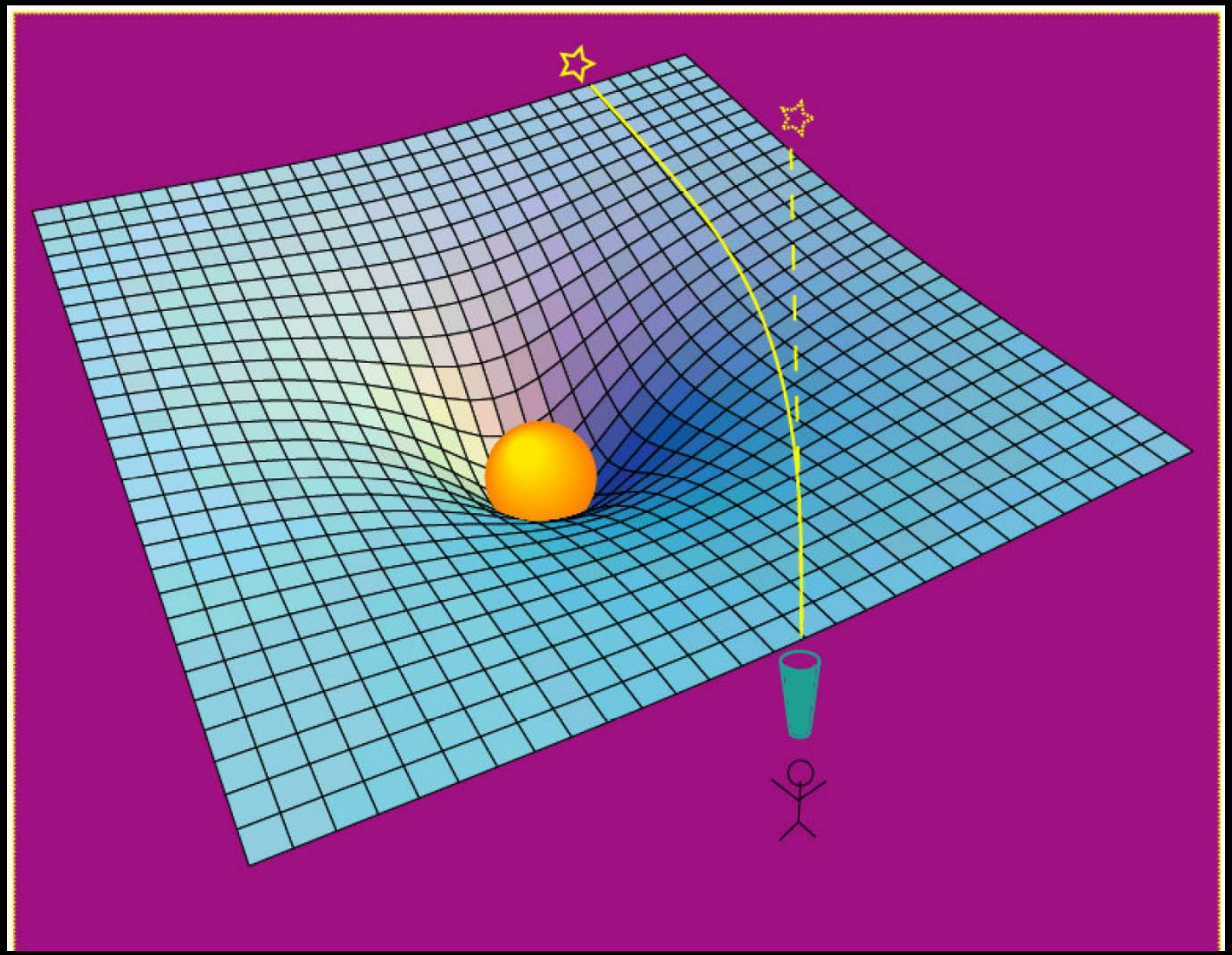
1. *Objects keep moving after we stop applying a force (if no friction)*
2. *Falling bodies accelerate as they fall*
3. *Heavy bodies fall at the same rate as light ones*

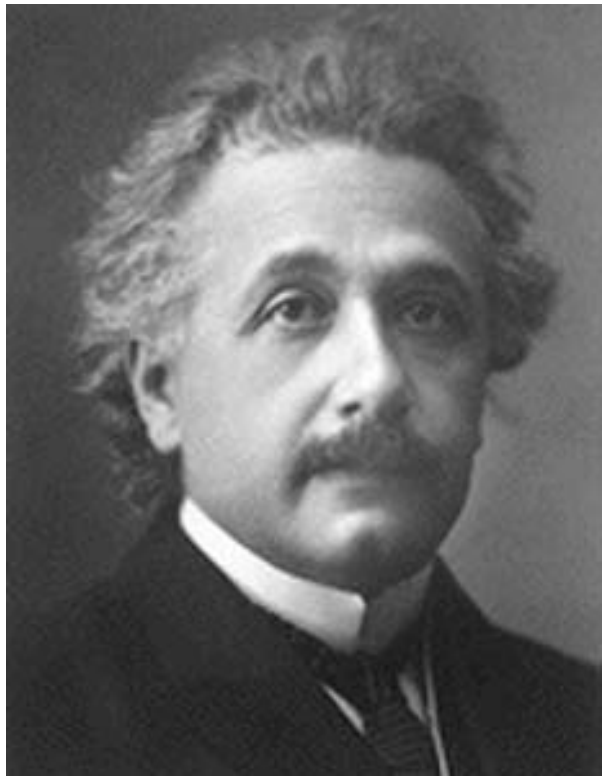
Gravity in Einstein's Universe



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

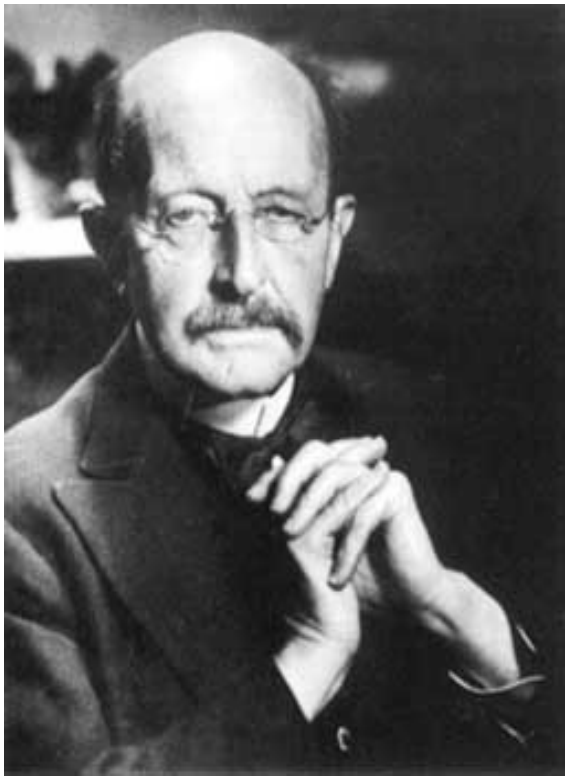


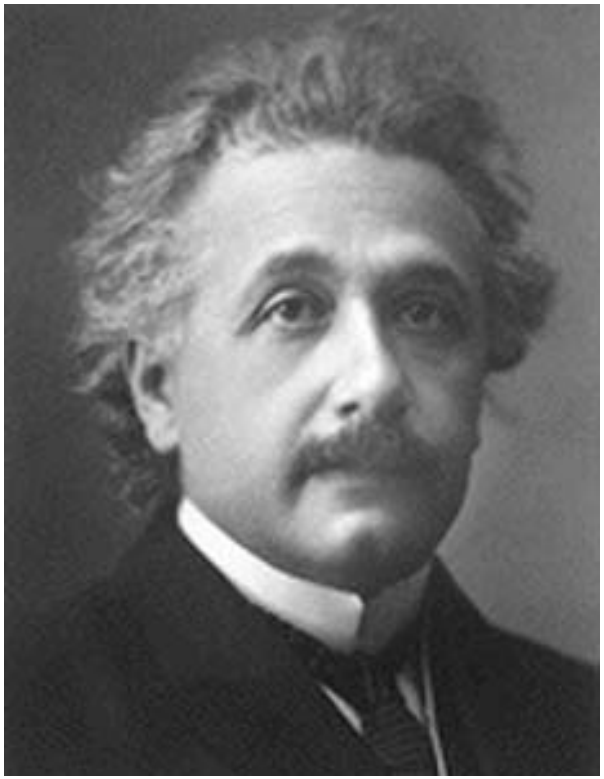


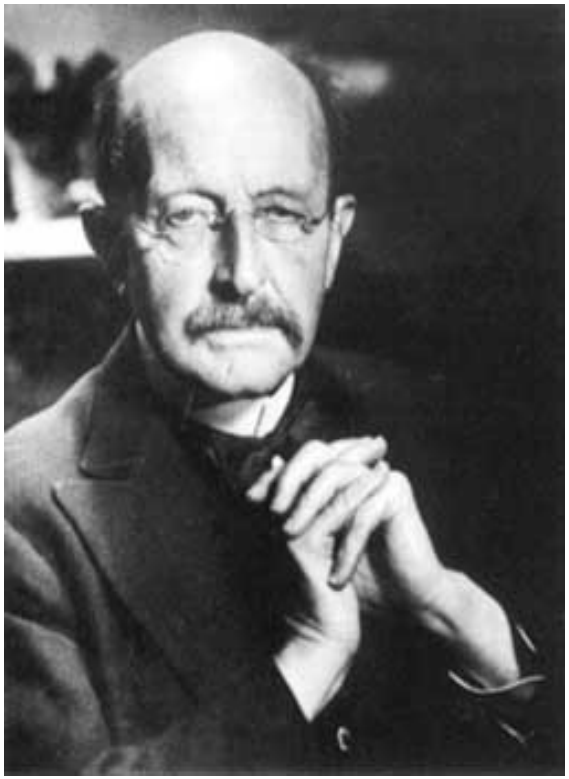


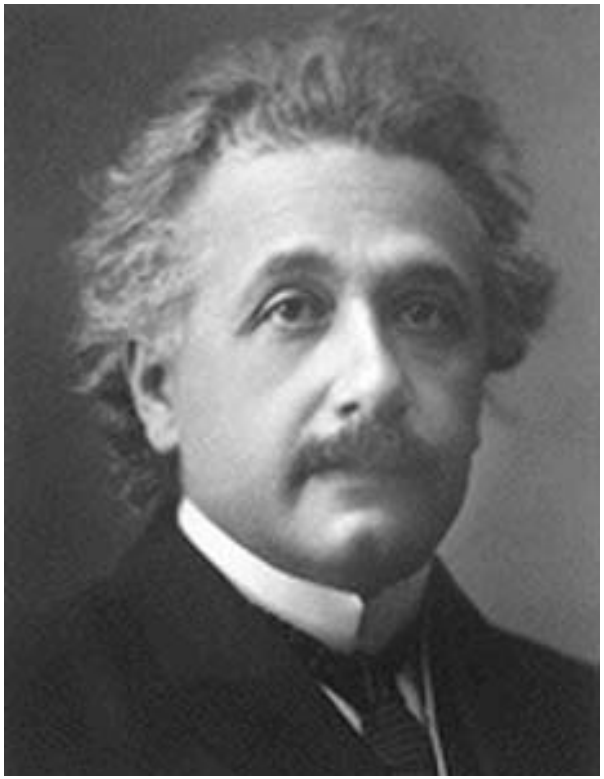
1919 expedition, led by Arthur Eddington, to observe total solar eclipse, and measure light deflection.

GR passed the test!



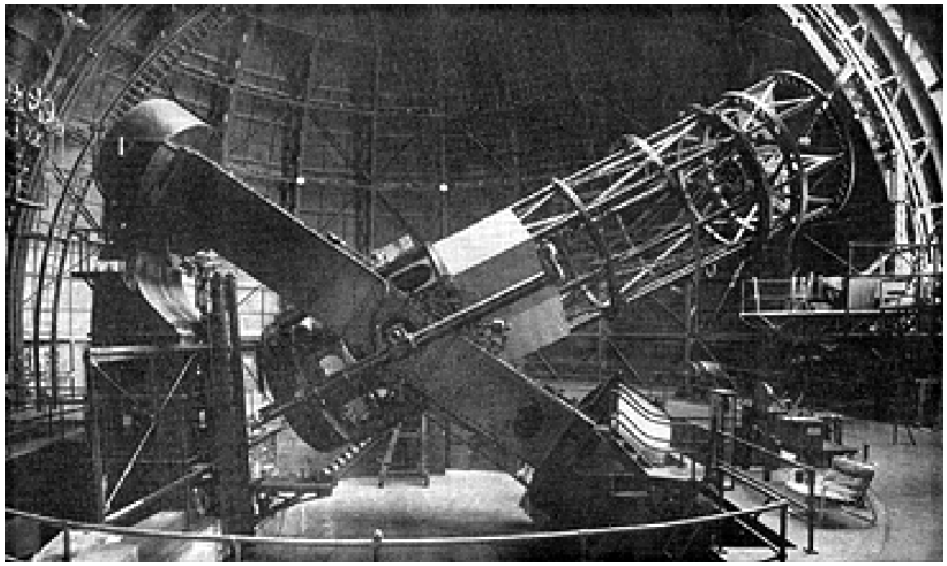


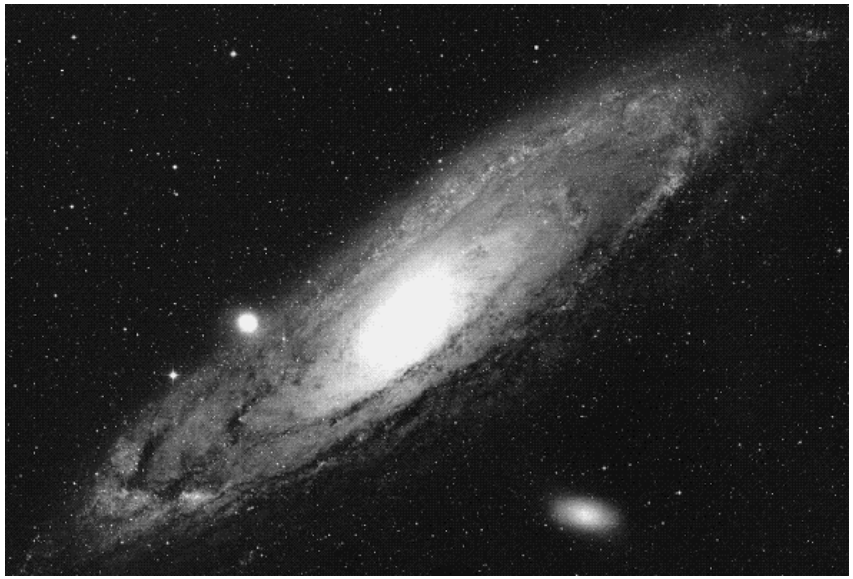




"He was one of the finest people I have ever known….but he didn't really understand physics. During the eclipse…he stayed up all night to see if it would confirm the bending of light by the gravitational field. If he had really understood general relativity, he would have gone to bed the way I did."

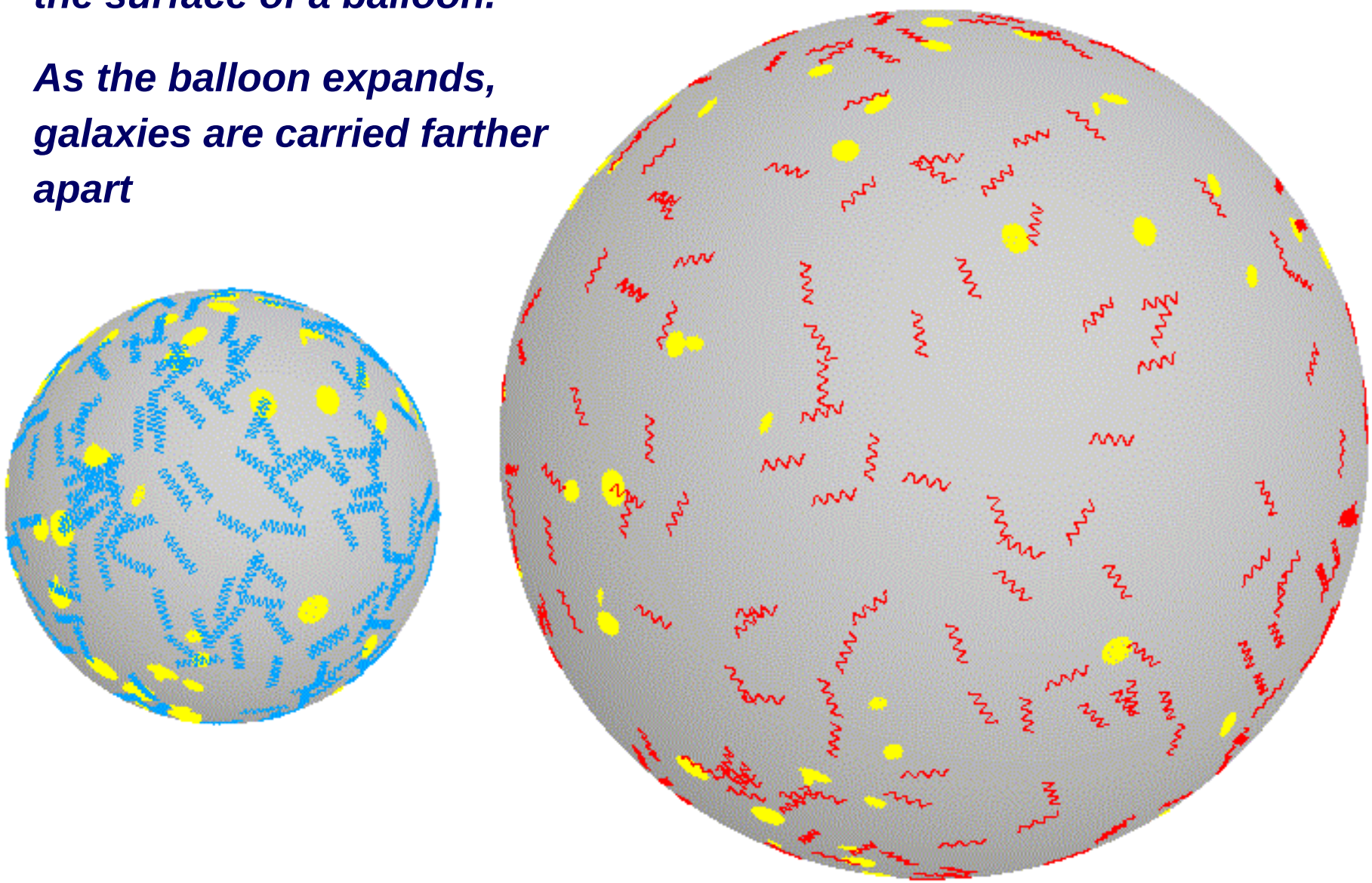
Edwin Hubble





Spacetime is expanding like the surface of a balloon.

As the balloon expands, galaxies are carried farther apart

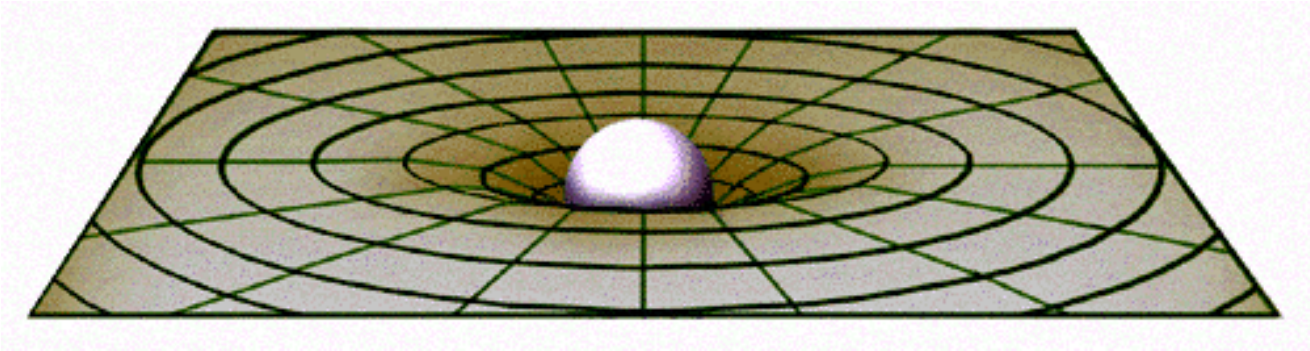


Will the Universe continue to expand forever?

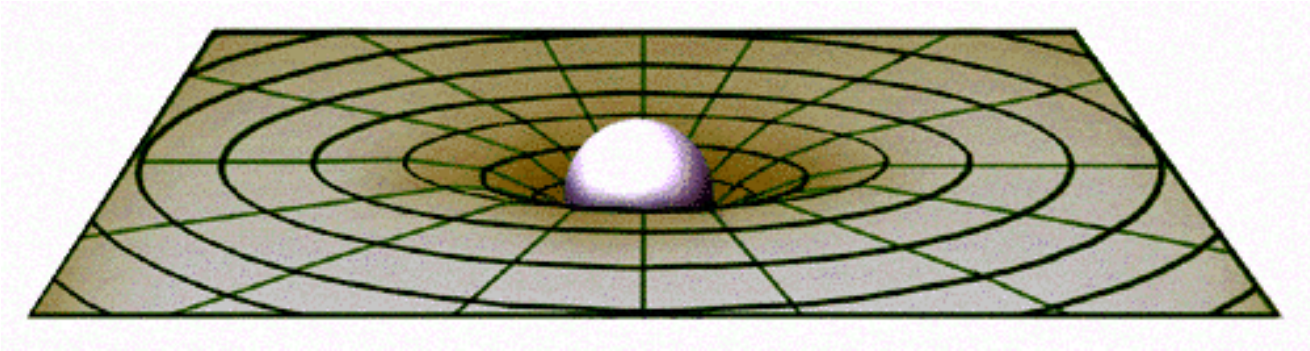
To find out we need to compare the expansion rate now with the expansion rate in the distant past…

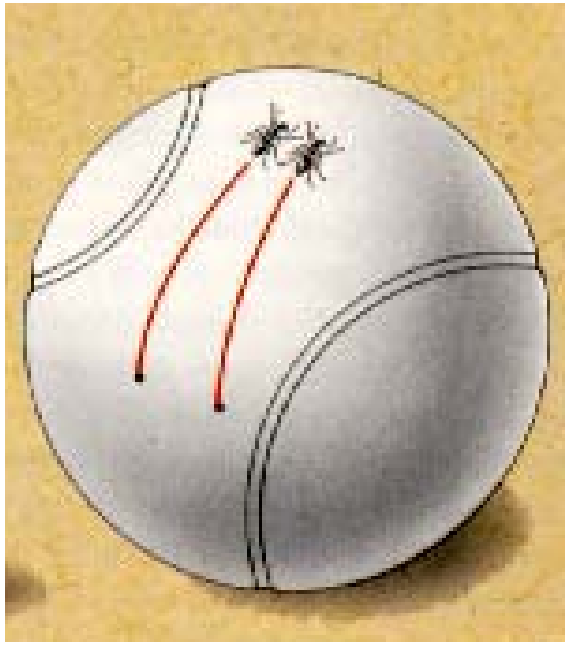
Is the Universe speeding up or slowing down?

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



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





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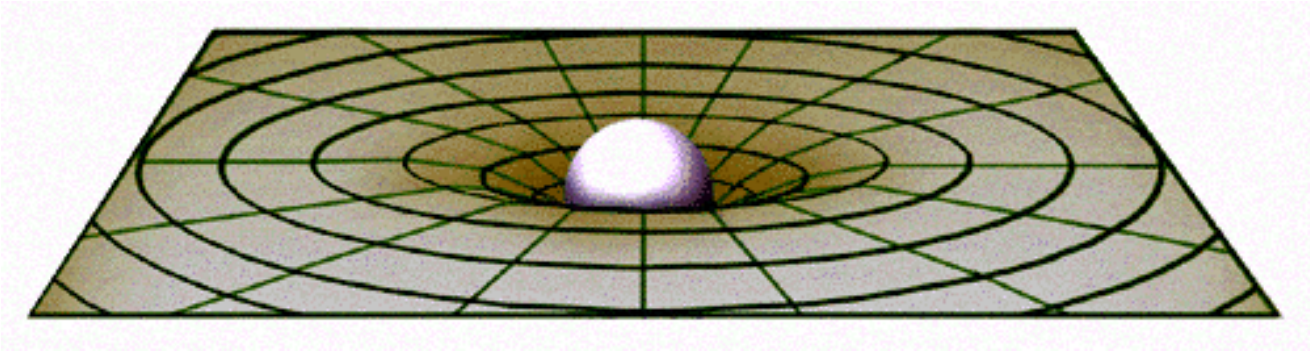
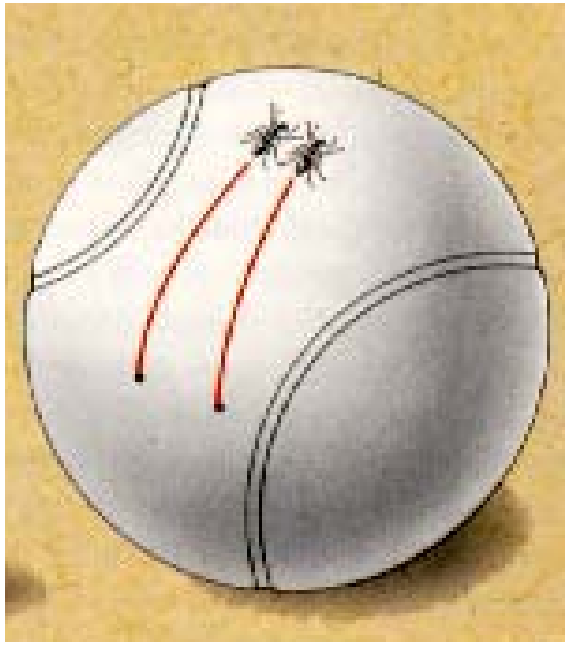
Answer depends on the **shape** of the Universe





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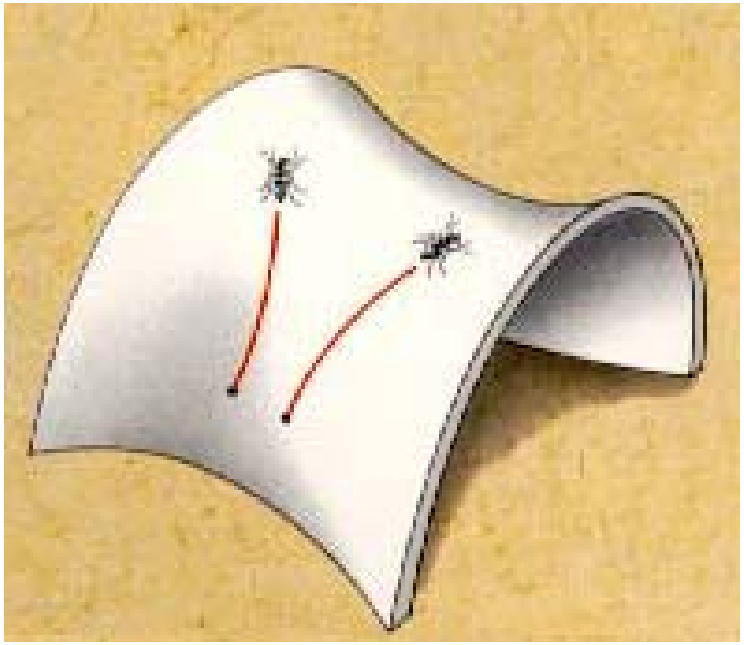

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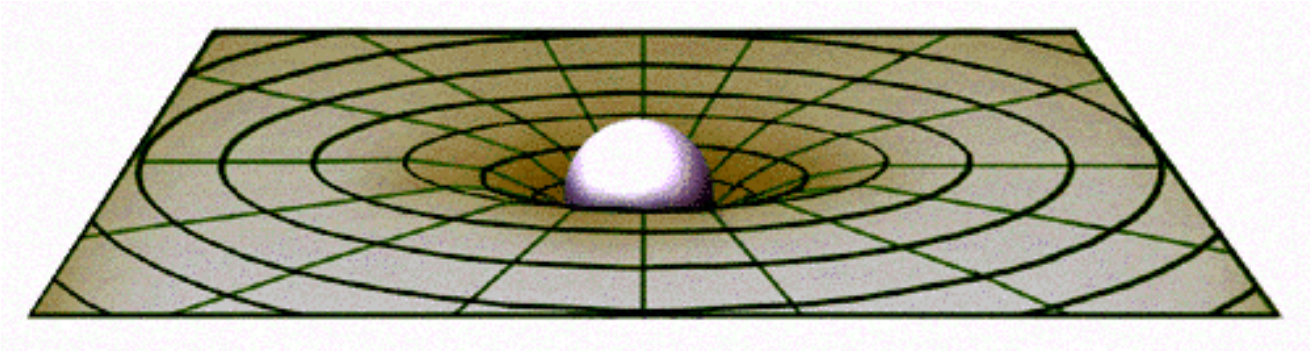
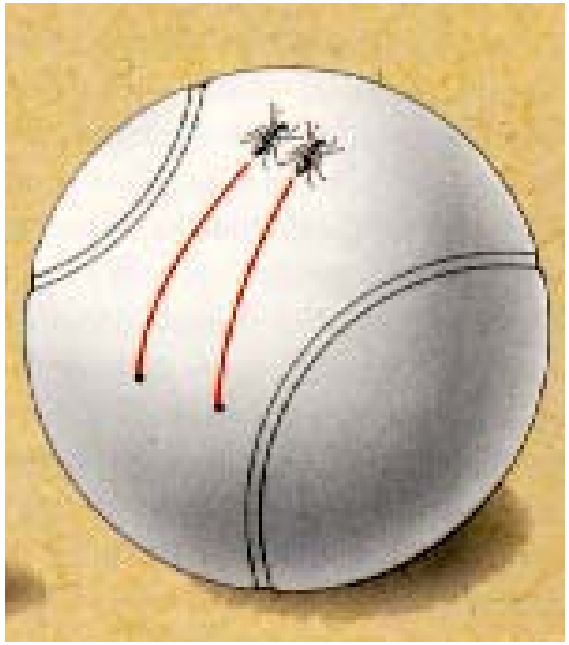
Answer depends on the **shape** of the Universe





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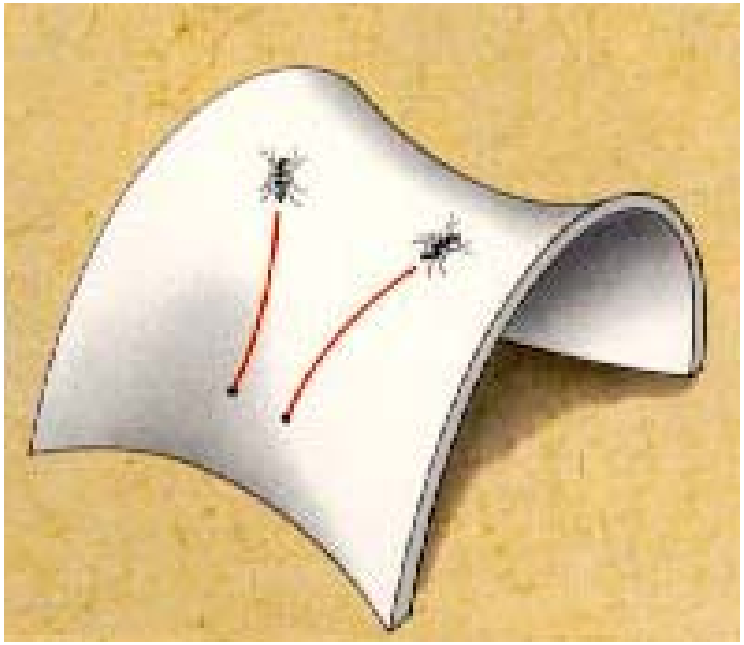

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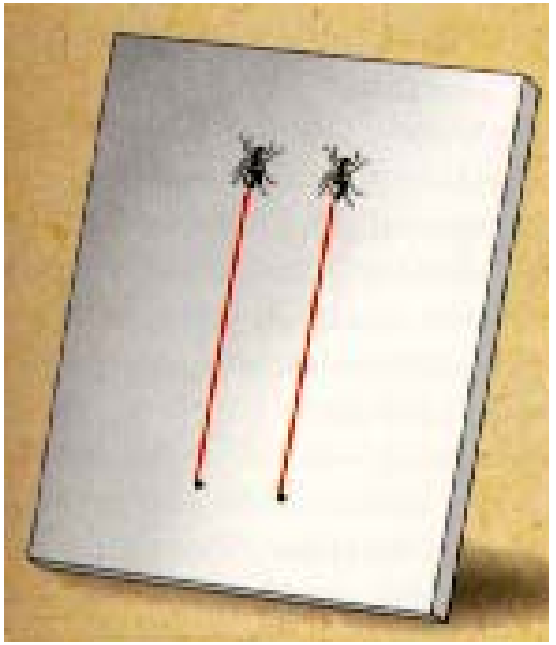


Flat

Summary:

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

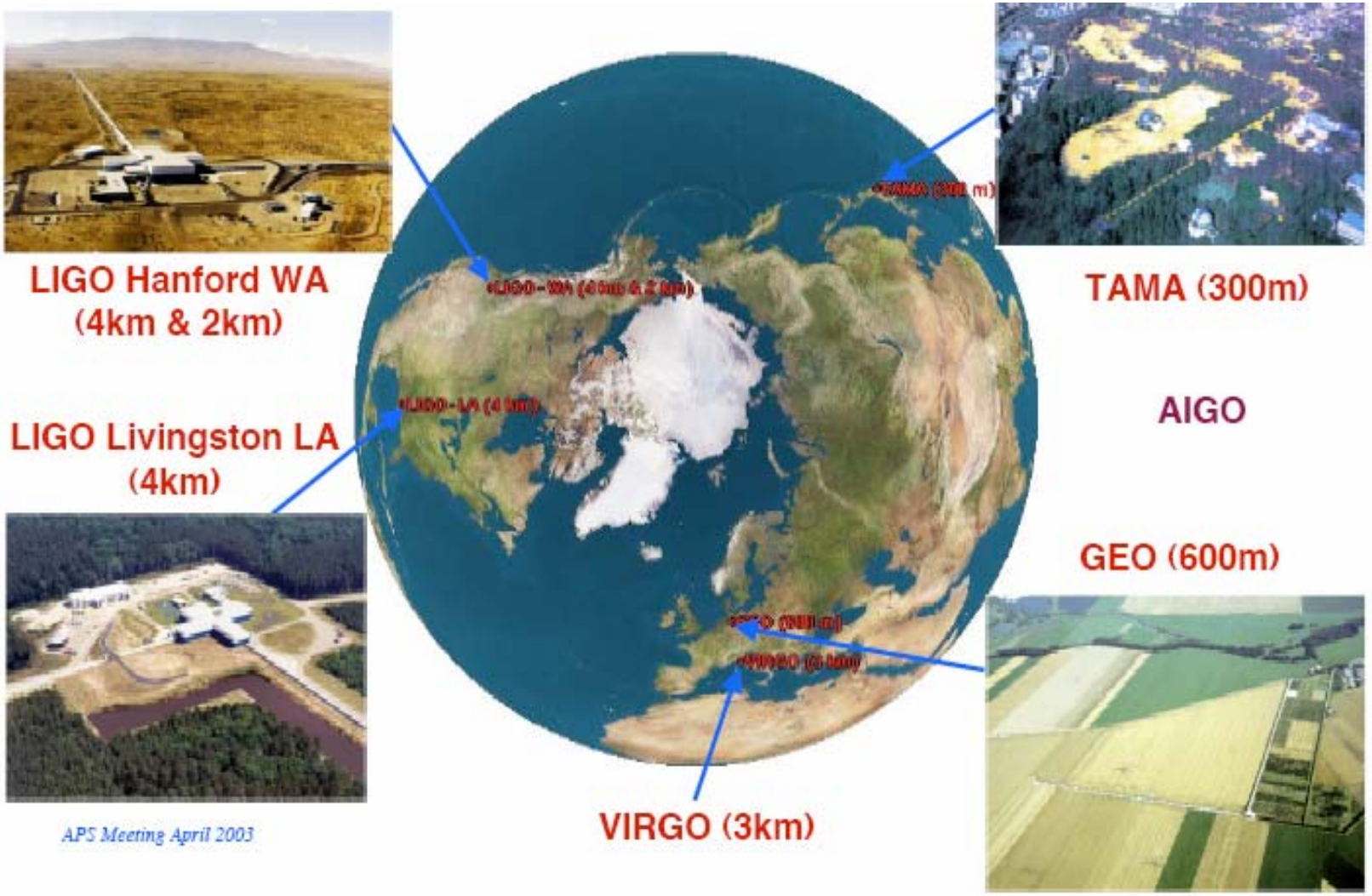
Gravity in Einstein's Universe

Gravitational Waves

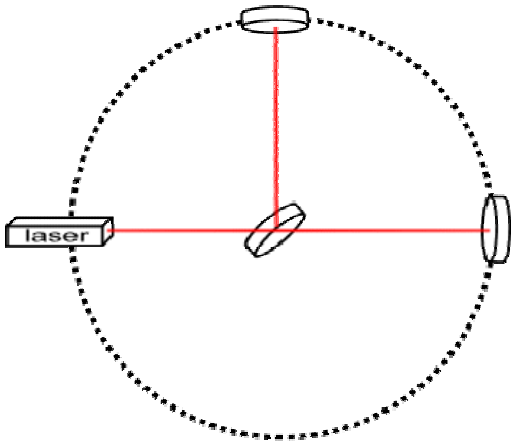
Gravity in Einstein's Universe

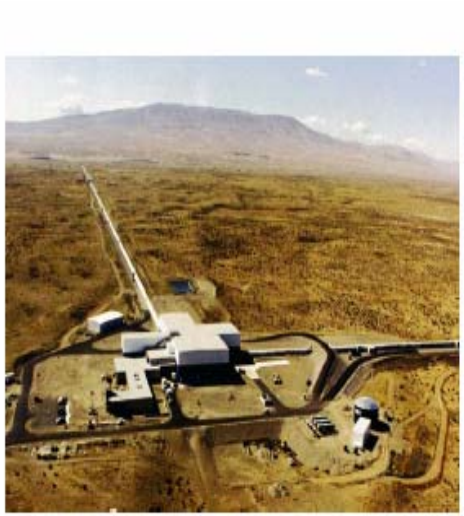
Gravitational Waves

Worldwide network of gravitational wave detectors



Worldwide network of gravitational wave detectors

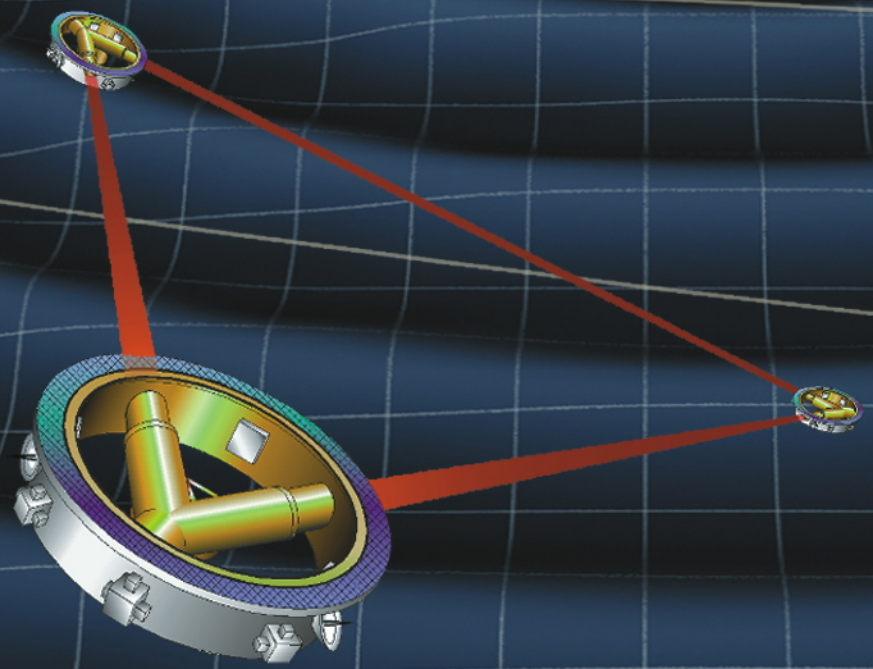


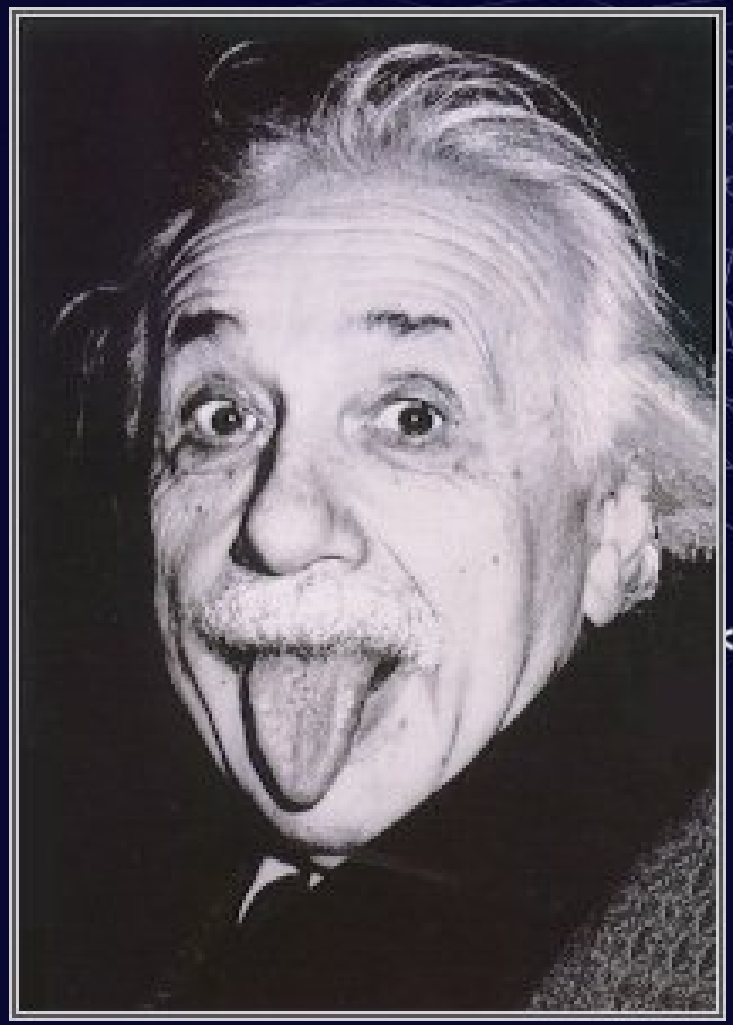


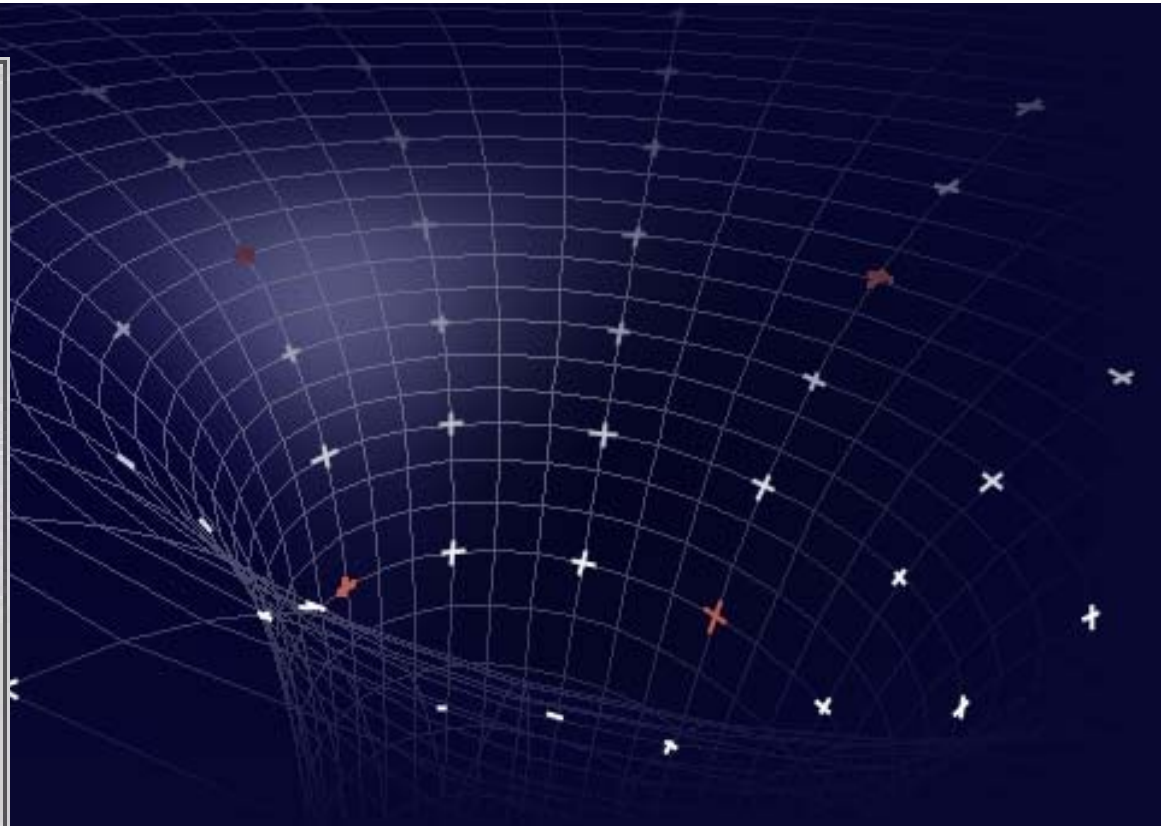
The LISA Mission

NASA / ESA project, scheduled for ~2015

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

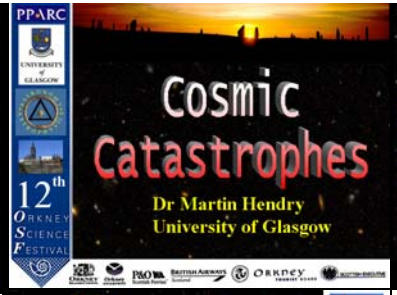






The hardest thing in the world to understand is the income tax


In the Beginning
Dr Martin Hendry
University of Glasgow
PPARC
Odyssey 2001
The 2nd International Philosophy, Science & Theology Festival
Grafton NSW
The British Council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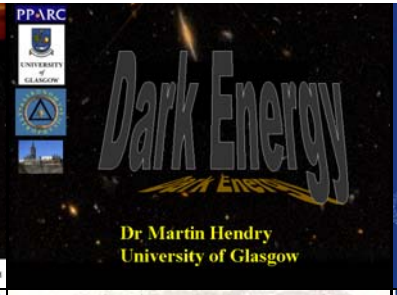
12th Orkney Science Festival
Cosmic Catastrophes
Dr Martin Hendry
University of Glasgow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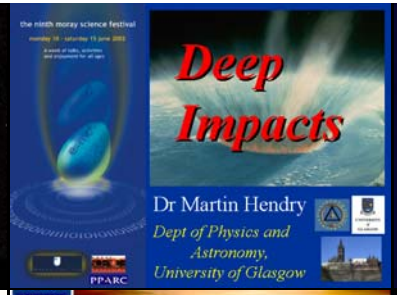
Dark Energy
Dr Martin Hendry
University of Glasgow


the ninth moray science festival
Deep Impacts
Dr Martin Hendry
Dept of Physics and Astronomy,
University of Glasgow
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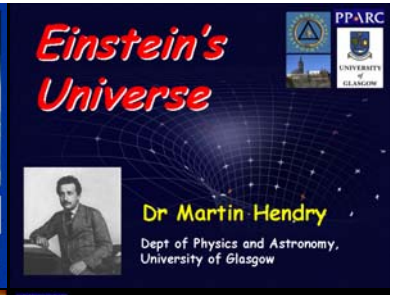
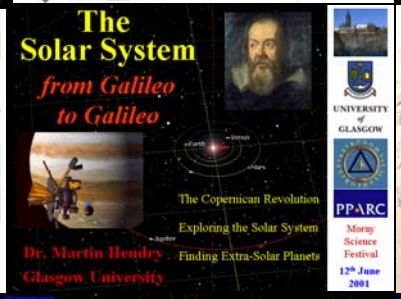
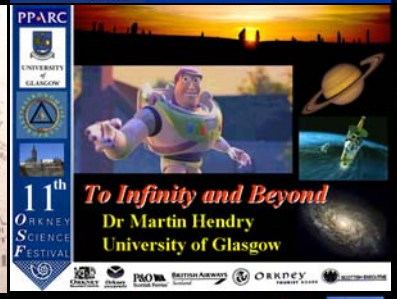

Einstein's Universe
PPARC
Dr Martin Hendry
Dept of Physics and Astronomy,
University of Glasgow


Extra-terrestrial life:
Is there anybody out there?...
Dr Martin Hendry
University of Glasgow
PPARC
Stirling Physics Meeting:
24th June 04


The Solar System
from Galileo to Galileo
The Copernican Revolution
Exploring the Solar System
Finding Extra-Solar Planets
Dr. Martin Hendry
Glasgow University
PPARC
Moray Science Festival
12th June 2001


A History of Astronomy
at Glasgow University
Dr. Martin Hendry
Dept of Physics and Astronomy
University of Glasgow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11th Orkney Science Festival
To Infinity and Beyond
Dr Martin Hendry
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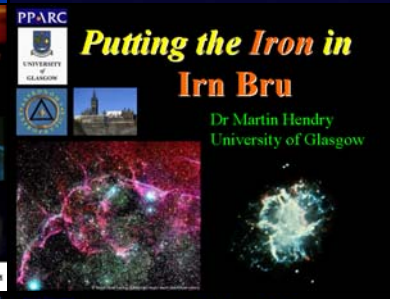
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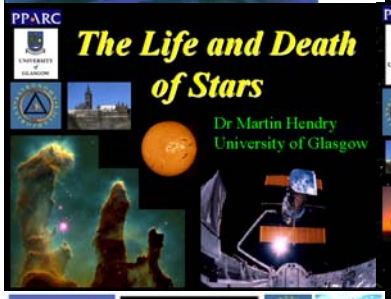
Putting the Iron in Irn Bru
Dr Martin Hendry
University of Glasgow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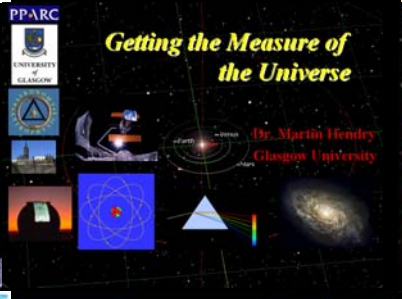
The Life and Death of Stars
Dr Martin Hendry
University of Glasgow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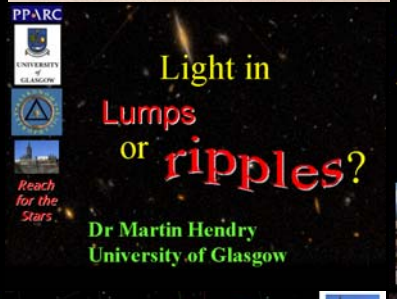
Getting the Measure of the Universe
Dr. Martin Hendry
Glasgow University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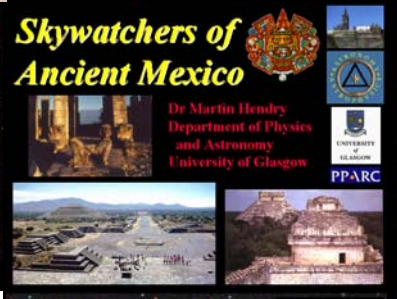
Light in
Lumps
or
ripples?
Reach for the Stars
Dr Martin Hendry
University of Glasgow


Skywatchers of Ancient Mexico
Dr Martin Hendry
Department of Physics and Astronomy
University of Glasgow
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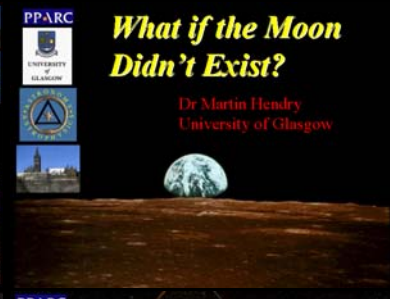
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What if the Moon Didn't Exist?
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Rocket Science
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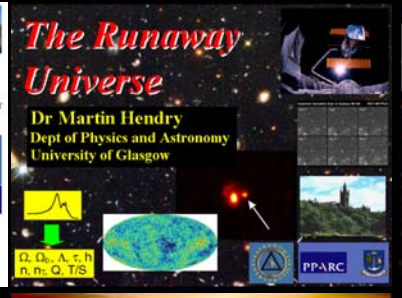
Reach for the Stars


The Runaway Universe
Dr Martin Hendry
Dept of Physics and Astronomy
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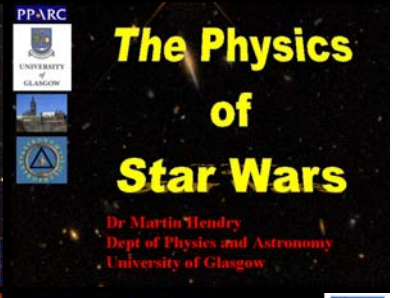
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The Physics of Star Wars
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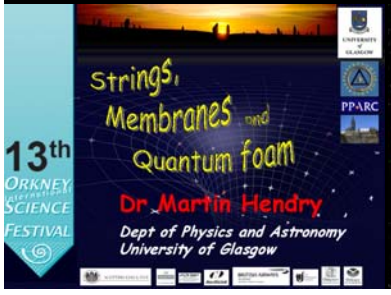
Strings, Membranes and Quantum foam
13th Orkney Science Festival
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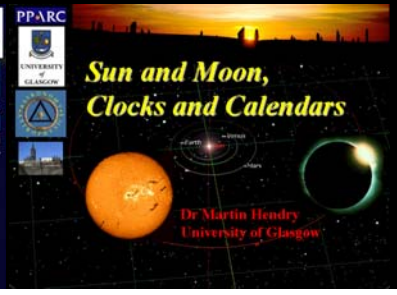
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Sun and Moon, Clocks and Calendars
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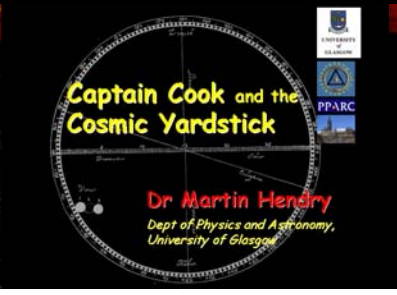
Captain Cook and the Cosmic Yardstick
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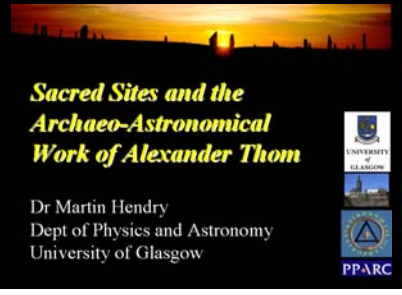
Sacred Sites and the Archaeo-Astronomical Work of Alexander Thom
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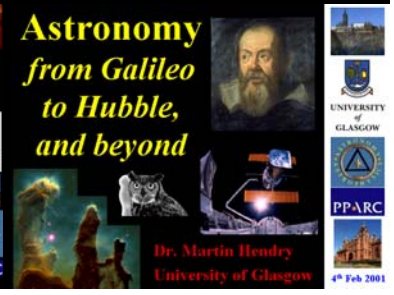
Astronomy from Galileo to Hubble, and beyond
Dr. Martin Hendry
University of Glasgow
PPARC
4th Feb 2001

Current list of ‘Reach for the Stars’ lectures

- The Physics of Star Wars
- Telescopes: from Galileo to Hubble
- Empire of the Sun
- The Life and Death of Stars
- Getting the Measure of the Universe
- Overwhelmingly Large Telescopes
- Five Millennia of Scottish Astronomy
- A History of Astronomy in Glasgow
- Crescent Moon Rising
- Stargazers of Ancient Mexico
- The Search Beyond the Sun
- Death of the Dinosaurs
- What if the Moon Didn’t Exist?
- Putting the Iron in Irn Bru
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- Cosmology: the Final Frontier
- The Realm of the Nebulae
- Dark Energy
- Echoes of the Big Bang
- A Recipe for Galaxy Formation
- Hubble Vision
- The Runaway Universe
- From Quarks to Quasars
- The Future of the Universe
- Cosmology in the Third Millennium
- Rocket Science
- Deep Impacts
- To Infinity and Beyond
- Exploring the Sky

Further information from: **martin@astro.gla.ac.uk**

Or via: **http://www.physics.gla.ac.uk/**