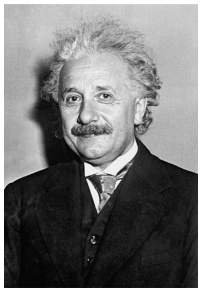
One, Two, Three…Relativity
The Universe of Albert Einstein

Part One:
The Nature of Science
and
The Theories of Relativity

Osher
Winter-Spring 2026

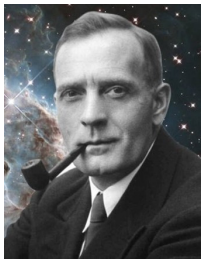
"The Joke"

Werner Heisenberg

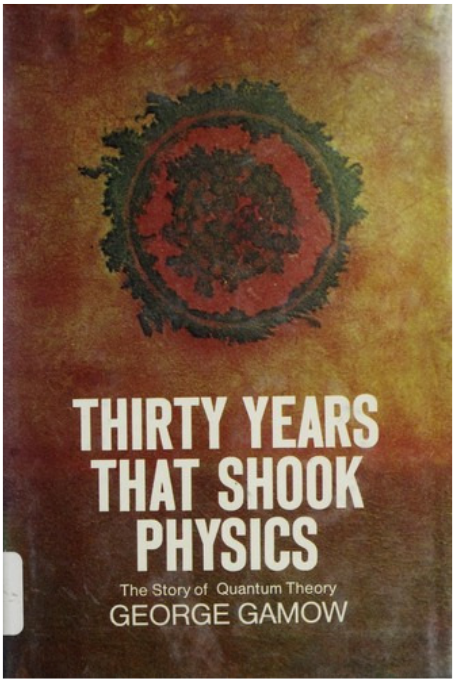


Albert Einstein

Erwin Schrodinger



Edwin Hubble



Theories of Relativity

Quantum Theory

(Galaxies)

Your Presenter

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- Nuclear Engineer at Dominion Energy
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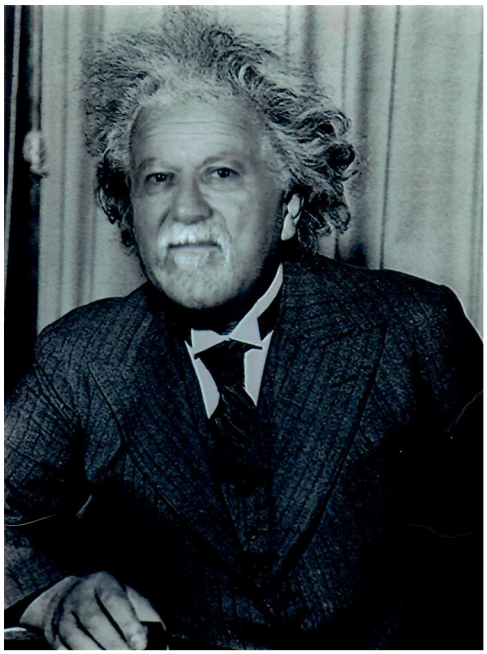


What Is Science?

Science is not a thing

Science is a Process

The Scientific Method

- The foundation of science is measurement (data), derived either by observation or from experiment.
- Scientific theories are attempts to makes some sense of the data by proposing relationships between measured quantities.
- A theory is only 'scientific' if it is falsifiable.

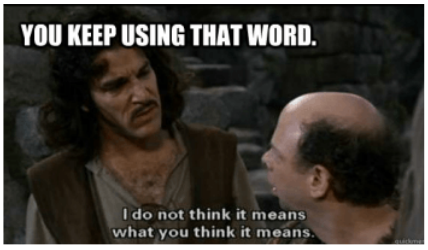
If you can't Measure it
It's NOT Science

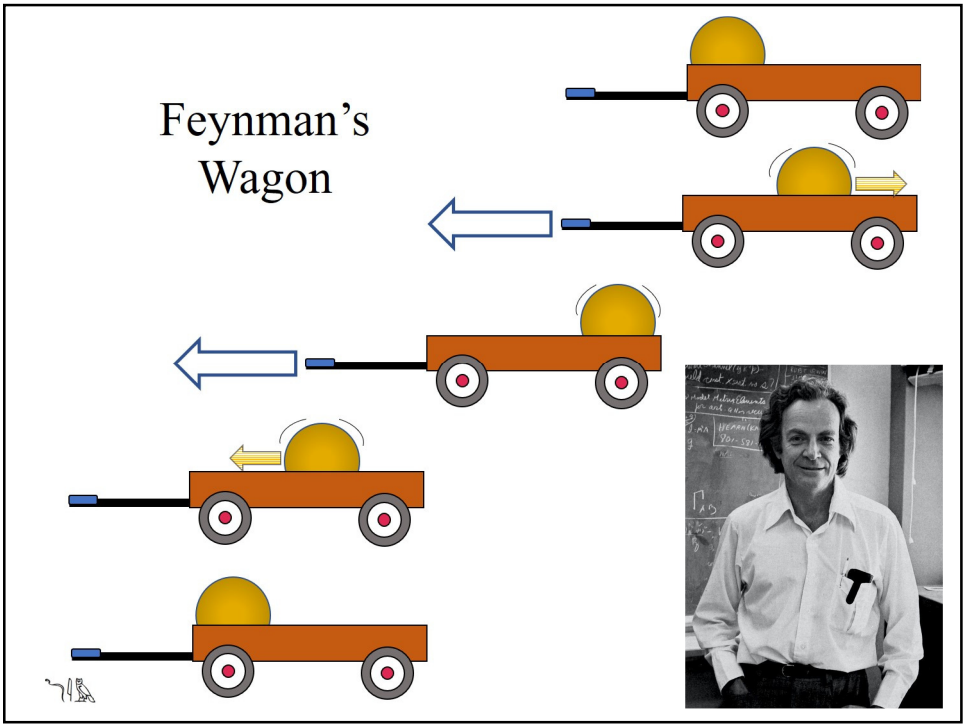
Some definitions of Science

- "A scientific theory is an **explanation** of **"why"** or **"how"** that is based on experiments and facts."
- "A scientific theory is a well-established **explanation** of some aspect of the natural world."
- "A scientific theory is an **explanation** of an aspect of the natural world that can be or that has been repeatedly tested and has corroborating evidence in accordance with the scientific method, using accepted protocols of observation, measurement, and evaluation of results."
- "A scientifically acceptable or plausible general principle or body of principles based on data and offered to **explain** phenomena."

- All these definitions include the words ***explanation*** or ***explain***.
- At the most fundamental level, Science does NOT explain anything.
- Instead, Science describes how the universe behaves by relating cause and effect which allows for prediction.

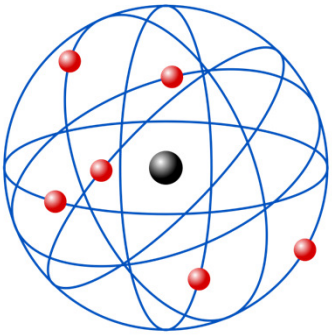
"You Keep Using That Word. I Do Not Think It Means What You Think It Means" – *The Princess Bride*





- The Laws of Physics (aka the Laws of Nature) describe how the Universe behaves through relating cause and effect
- They provide no insight as to why the universe behaves the way it does
- "The great tragedy of science - the slaying of a beautiful hypothesis by an ugly fact." – Thomas Huxley
- "All models are wrong, but some are useful." – George E.P. Box, British statistician
- Real Power of Science → **Prediction!**

ATOMS



- Democritus (460 – 370 BC) - Everything is composed of "atoms"
- John Dalton (1766-1844) – Small ball-like structures, that cannot be further divided
- Even at end of 19th century, most scientists doubted the existence of atoms

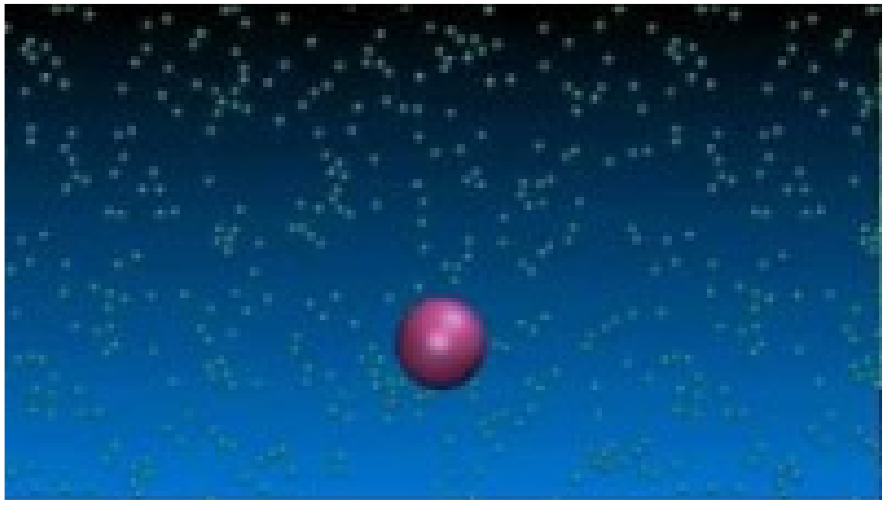
Ludwig Boltzmann
(1844-1906)

- Development of statistical mechanics
- Statistical explanation of the Second Law of Thermodynamics
- His theories required the existence of Atoms and Molecules

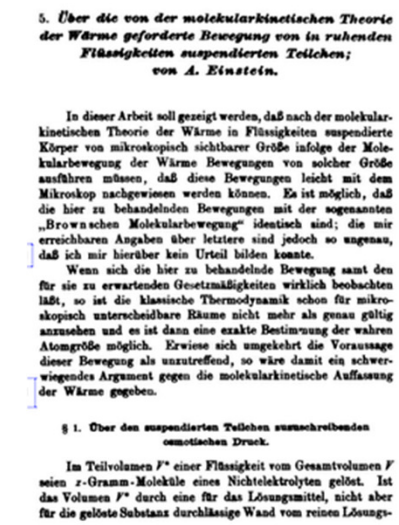
- Boltzmann was forced to resign in 1906 as Professor of Theoretical Physics at the University of Vienna due to deteriorating mental condition in his final years (bipolar disorder?)
- Four months later, hanged himself while on vacation with his wife and one of his daughters.

Unknown to Boltzmann, a validation of his ideas had already been proposed at the time of his death

Brownian Motion



The nails had been driven into the coffins of the skeptics of the existence of atoms by the 1905 publication of this paper



5. *Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen;*
von A. Einstein.

In dieser Arbeit soll gezeigt werden, daß nach der molekularkinetischen Theorie der Wärme in Flüssigkeiten suspendierte Körper von mikroskopisch sichtbarer Größe infolge der Molekularbewegung der Wärme Bewegungen von solcher Größe ausführen müssen, daß diese Bewegungen leicht mit dem Mikroskop nachgewiesen werden können. Es ist möglich, daß die hier zu behandelnden Bewegungen mit der sogenannten „Brownschen Molekularbewegung" identisch sind; die mir erreichbaren Angaben über letztere sind jedoch so ungenau, daß ich mir hierüber kein Urteil bilden konnte.

Wenn sich die hier zu behandelnde Bewegung samt den für sie zu erwartenden Gesetzmäßigkeiten wirklich beobachten läßt, so ist die klassische Thermodynamik schon für mikroskopisch unterscheidbare Räume nicht mehr als genau gültig anzusehen und es ist dann eine exakte Bestimmung der wahren Atomgröße möglich. Erwiese sich umgekehrt die Voraussage dieser Bewegung als unzutreffend, so wäre damit ein schwerwiegendes Argument gegen die molekularkinetische Auffassung der Wärme gegeben.

§ 1. Über den suspendierten Teilchen zuzuschreibenden osmotischen Druck.

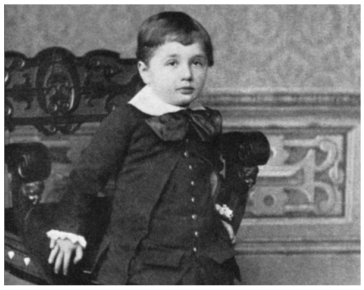
Im Teilvolumen V^* einer Flüssigkeit vom Gesamtvolumen V seien z-Gramm-Moleküle eines Nichtelektrolyten gelöst. Ist das Volumen V^* durch eine für das Lösungsmittel, nicht aber für die gelöste Substanz durchlässige Wand vom reinen Lösungs-

"On the movement of small particles suspended in a stationary liquid demanded by the molecular-kinetic theory of heat"

At the time of its publication, the author was working in the Swiss Patent Office in Bern.

Albert Einstein (1879 – 1955)

- Born in Ulm, Germany
- Parents of Jewish descent but family was irreligious
- Given a magnetic compass at age five
- Miserable in school due to rote learning method



Albert Einstein

- Delayed speech. Inability to learn languages.
- Gymnasium (high school) education was Latin and Greek
- Spoken English about 300 words
- Uncle introduced him to the Pythagorean theorem
- Poor Russian Jew dinner guest introduced him to books on natural science

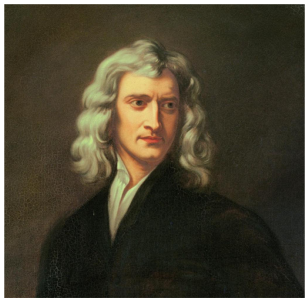
Albert Einstein

- Entered Zurich Polytechnic Institute at age 17
- Studied practical (applied) physics. Graduated 1900.
- Expenses paid by relatives but could hardly afford to feed himself
- Temporary teacher and tutor but fired by employer
- 1902 Swiss Patent Office

- 1903 married Serbian physics student Mileva Maric
- First son born 1904

1905 – the annus mirabilis ('miracle year')

- Brownian motion
- Photoelectric effect
- Theory of special relativity
- Mass-energy equivalence → $E = mc^2$



1666 – Sir Isaac Newton's Miracle Year

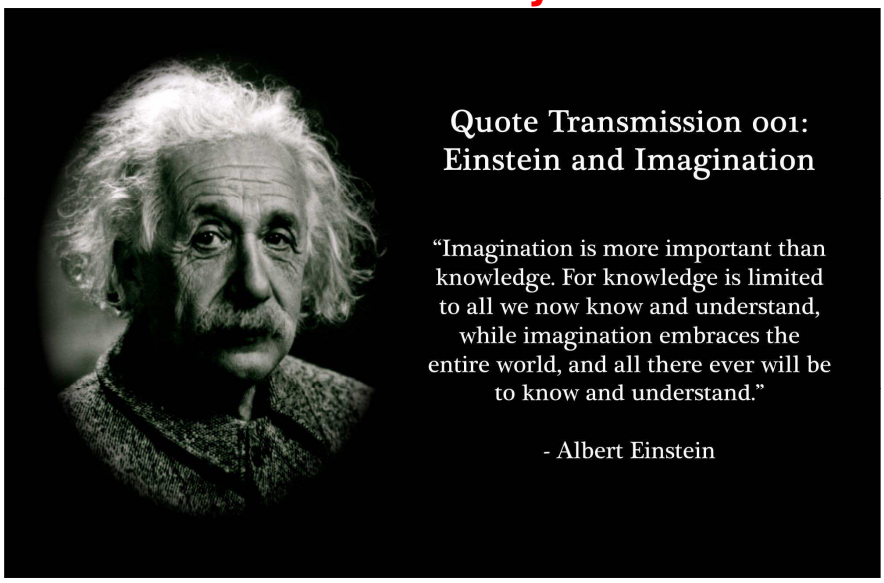
- Developed the Calculus
- Formulated the Laws of Motion
- Theory of Graviation
- Marked the start of the Scientific Revolution

Who was Friedrich Adler?

Friedrich Adler, c. 1917 (1879-1960)

- Physics student friend of Einstein was socialist Friedrich Adler
- In 1909/1910 when offered assistant professorship at Zurich, Adler insisted it be given to Einstein
- In 1916 Adler assassinated the Austrian minister – president Count Karl von Sturgkh
- Condemned to death but released in last days of WWI

The Special and General Theories of Relativity



We'll start with the Special Theory of Relativity.

But first we need to take a detour to discuss three topics.

The first topic is
Units of Measurement

If you can't measure it, it's NOT Science

Basic Units of Scientific Measurement

Length – A measure of space

Mass – A measure of the amount of matter

Electric Charge

Time

Most other units of measurement are a combination of the above.

Speed = distance(length)/time

Current = charge/time

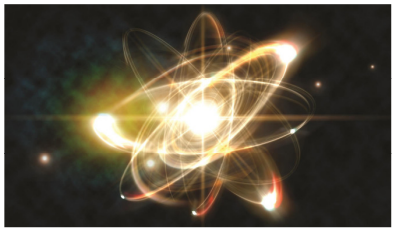
Acceleration = (change in speed)/time

Force = Weight = mass x acceleration

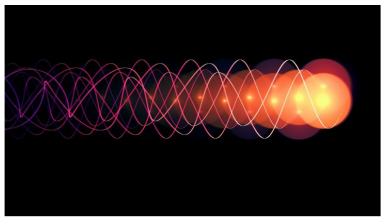
The Second Topic is …

LIGHT!

Ignoring *neutrinos*, the 'observable' universe can be thought of as being entirely composed of MATTER …

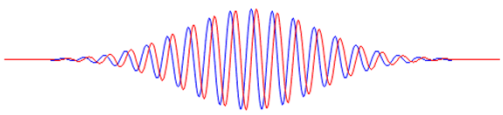


and LIGHT

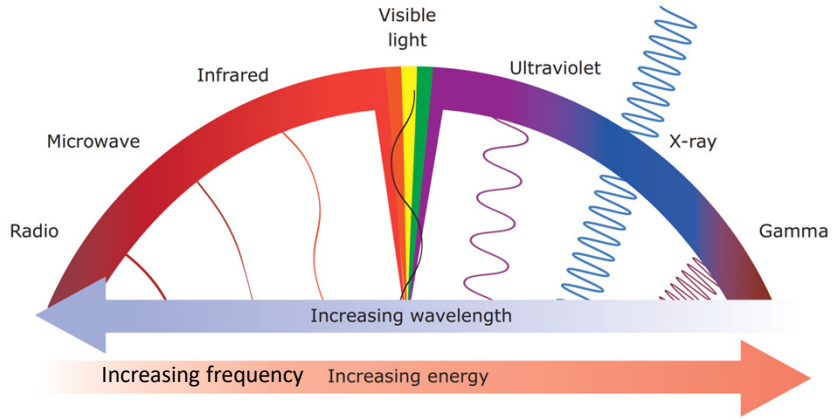


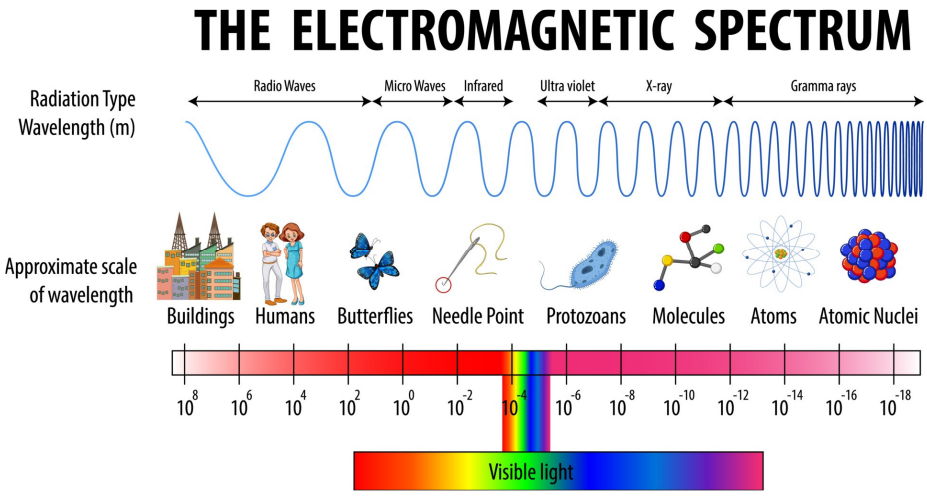
The Nature of Light

- Composed of small packets of energy called **photons**
- Behave like waves → characterized by having a frequency ν and a wavelength λ
- All photons travel at the same speed, the speed of light **c**
- $c = \lambda\nu$ → (cm)(1/sec) = cm/sec



- The technical name for light is **electromagnetic radiation**
- Visible light is only a small part of the range of electromagnetic radiation





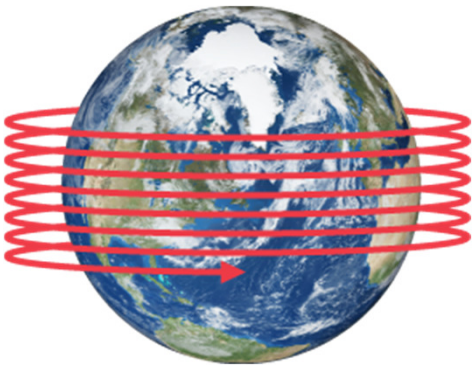
In the interest of brevity, we will refer to **electromagnetic radiation** (e.g., radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays)
as simply **Light**

c – Speed of Light

A photon is the fastest known thing in the universe.

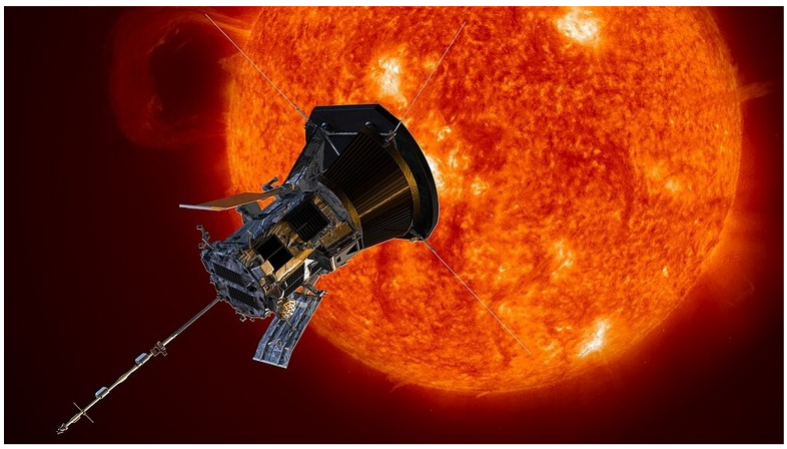
c = 186,000 miles per second
= 300,000 kilometers per second

If light followed a curved path, a photon would circle the Earth more than seven times in one second



Fastest Spacecraft

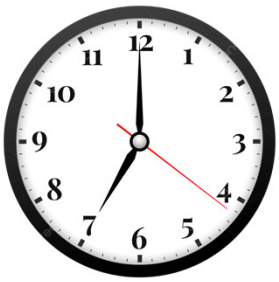
- Parker solar probe, 2024
- 430,000 mph (0.064% c)
- Within 3.8 million miles of Sun (2,500 °F)



The third topic is

Time

Measurable interval between two events, allowing us to order them and quantify how long one occurs after another.



Time and Light are the Two GREATEST MYSTERIES OF NATURE!

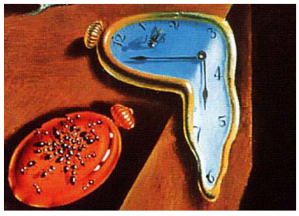
In the *beginning* God created the heaven and the earth. – Genesis 1.1

And God said, Let there be *light*: and there was *light*. – Genesis 1.3

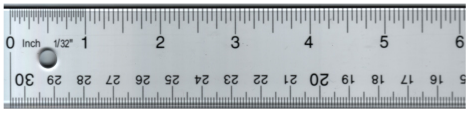
Recap: The Special Theory of Relativity revolutionized our concepts of:

LIGHT

TIME



MEASUREMENT



The Special Theory of Relativity – 1905

1. The laws of physics are invariant (identical) in all inertial frames of reference (that is, frames of reference with no acceleration).
2. The speed of light in vacuum is the same for all observers, regardless of the motion of the light source or observers.

The Special Theory deals with unaccelerated motion—that is, things that move in a straight line with a constant speed

In the Special Theory of Relativity, Einstein shook the foundations of Science by destroying the classical concepts of Light, Time and Space

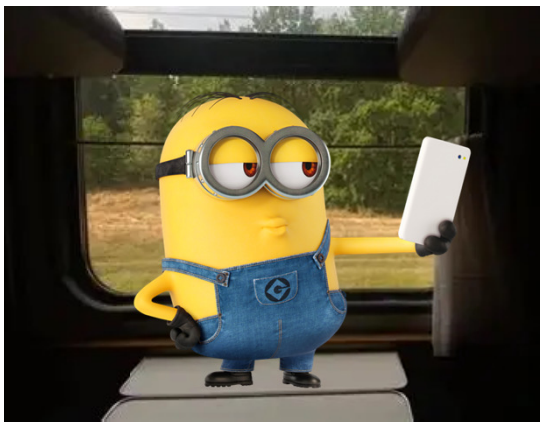
We start with a discussion of Relative Motion Jargon → "Inertial Frame of Reference"

- Anything moving in a straight line at a constant speed

To help us understand relative motion, we have enlisted the aid of …

Kevin Stuart Bob

Frame of Reference



- Bob is in a train car moving at 20 mph with respect to the outside trees.
- But to Bob it appears that the trees are moving 20 mph and he is standing still.

- As long as Bob is moving in a straight line at a constant speed, there is no experiment he can perform to prove that he is moving and not the trees.

Frame of Reference

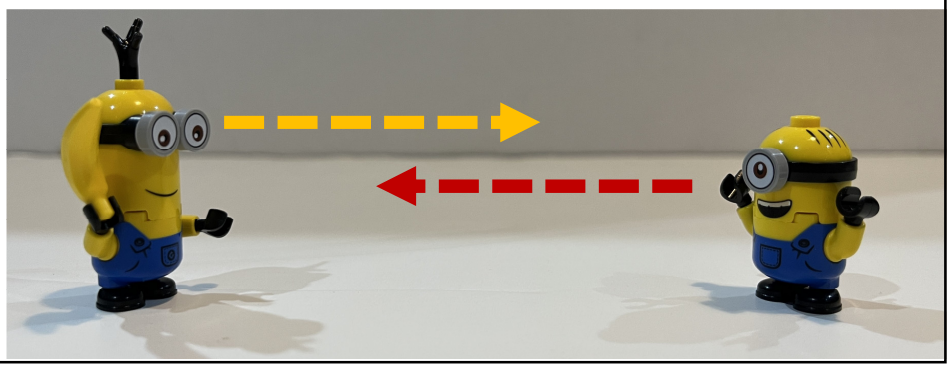
- Bob on the ground tosses a ball into the air.
- Bob in a train car moving in a straight line at a constant speed tosses a ball into the air.
- In both cases, Bob sees no difference in the ball's trajectory

Frame of Reference

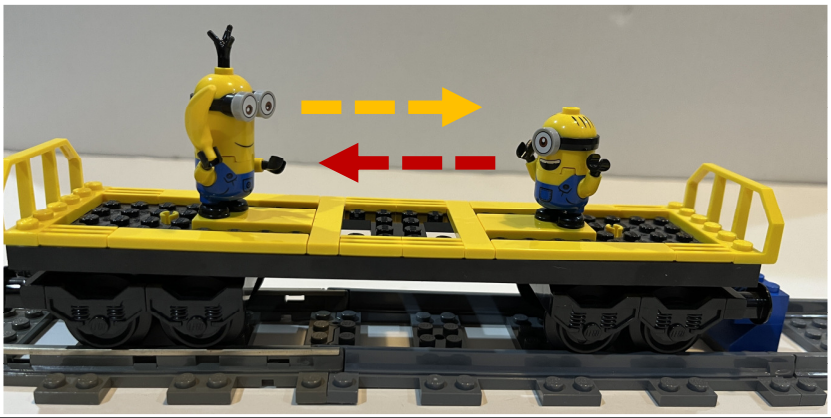
- Bob is on a train that is accelerating → that is:
  - Speed is changing and/or
  - Direction is changing
- The trajectory of the ball now changes!
- Bob now can sense that he is moving

Measured Speed of a Body is RELATIVE to the Observer

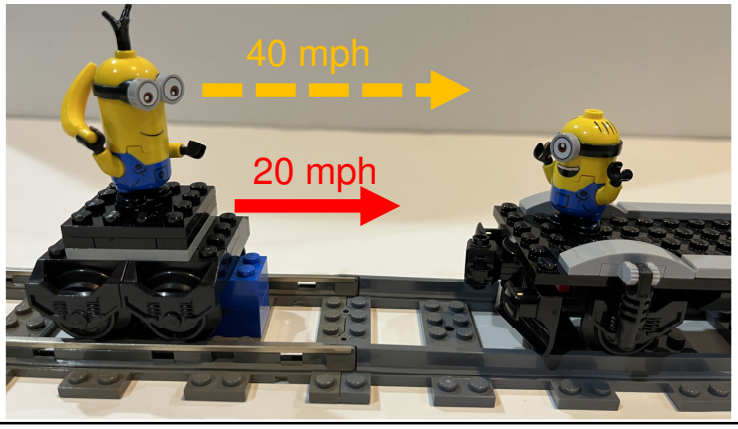
- Kevin tosses a banana to Stuart at a speed of 40 mph as measured by Kevin.
- From Stuart's point-of-view, the banana is moving towards him at 40 mph (yellow arrow)
- From the banana's point-of-view, Stuart is moving towards it at 40 mph (red arrow)



- Kevin tosses a banana to Stuart at a speed of 40 mph while both are standing on a moving flatcar.
- It doesn't matter how fast the flatcar is moving (ignore air resistance), things are exactly as if they were both stationary on the ground



- Kevin tosses a banana at a speed of 40 mph
- Stuart's car is not moving.
- Kevin's car is moving towards Stuart at 20 mph.
- Stuart measures the speed of Kevin's car as 20 mph and the speed of the banana as 40 + 20 = 60 mph

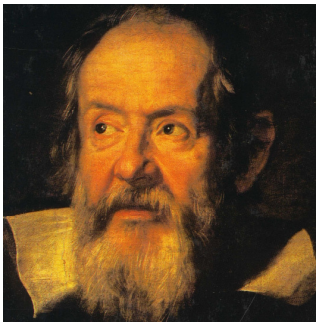


How fast are you moving?
It's RELATIVE!

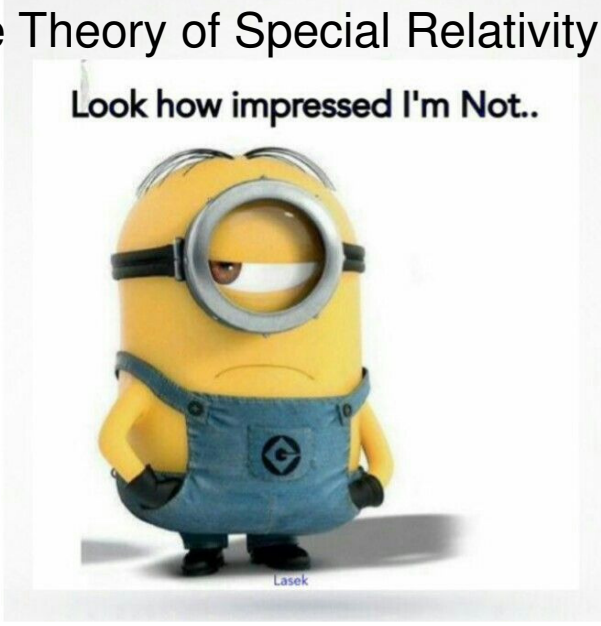
- Relative to me, you are not moving
- Relative to the person driving the automobile on the street outside, about 20 mph
- Relative to the center of the Earth, 831 mph (at 37° North latitude)
- Relative to the Sun, 67,000 mph
- Relative to the center of the Milky Way, 490,000 mph
- Einstein part of "The Joke"

Bored?

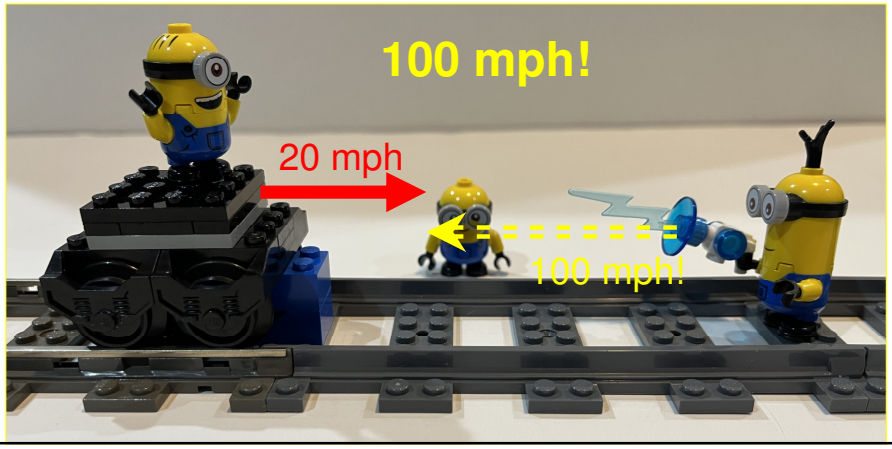
This was all worked out by Galileo Galilei, the founder of modern science, in the 17th century



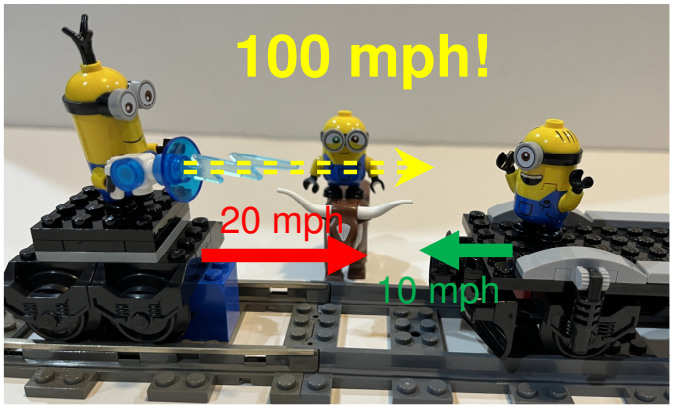
So, What's the Big Deal Then About the Theory of Special Relativity?



- Assume in the Minion Universe that the speed of light is **100 mph**
- Stuart is on a train car moving 20 mph
- Kevin shoots a photon at Stuart
- Bob, standing on the ground, measures the speed of the photon as 100 mph
- What is the speed of the photon as measured by Stuart?



- Kevin is on a train car moving 20 mph
- Stuart is on a train car moving 10 mph
- Kevin shoots a photon at Stuart
- What is the speed of the photon measured by Kevin?
- What is the speed of the photon measured by Stuart?
- What is the speed of the photon measured by Bob?



Why?

Postulate 2 of the Theory of Special Relativity:

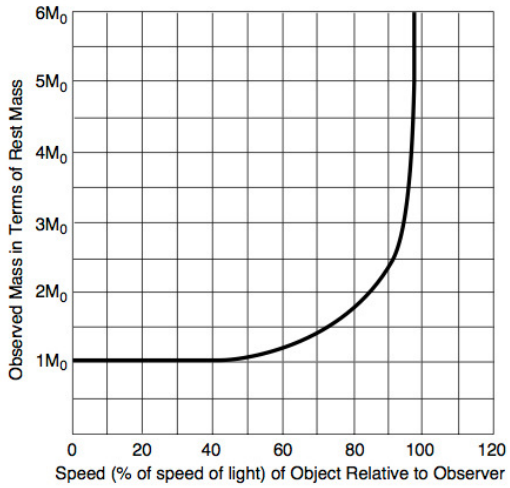
The speed of light is the same for all observers, regardless of the motion of the light source or observers.

"Wait a minute," yells Stuart. "That's just a statement. It doesn't explain ***Why?***"

Warning! It gets even *WEIRDER*!

No material object can have a speed that equals or exceeds the speed of light.

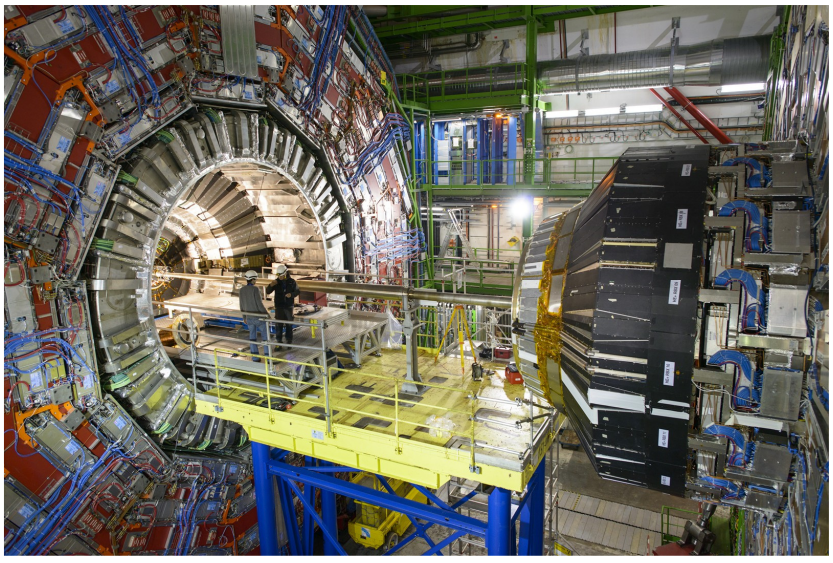
Why?
As the speed of an object increases, its mass as measured by an observer also appears to increase.



The greater the speed of an object, the more and more energy it takes to accelerate it to even faster speeds.
To accelerate any material object to the speed of light takes an INFINITE amount of energy.
Consider a spaceship with a mass of one ton.

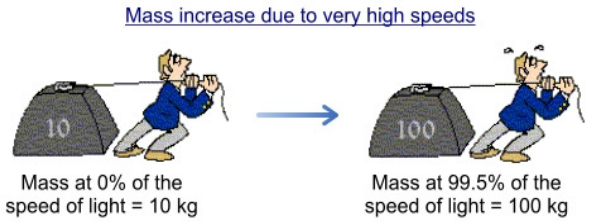
v/c	New Mass, tons
10%	1.005
50%	1.154
90%	2.294
99%	7.089
99.9%	22.4
99.99%	70.7
99.999%	223.6
100%	∞

Evidence? → Proton behavior in a particle accelerator, e.g., the Large Hadron Collider



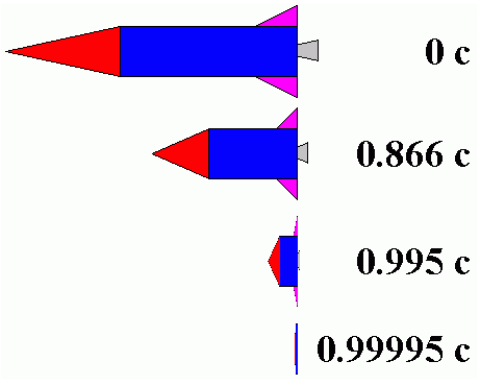
In the collider, protons are accelerated to nearly light speed by 9,300 superconducting electromagnets

- Proton completes 11,245 laps of 27 km circuit in a second → circling the Earth ~7 ½ times per sec.
- According to classical physics (no mass increase), proton would be traveling 118 times the speed of light



It gets even *WEIRDER*!

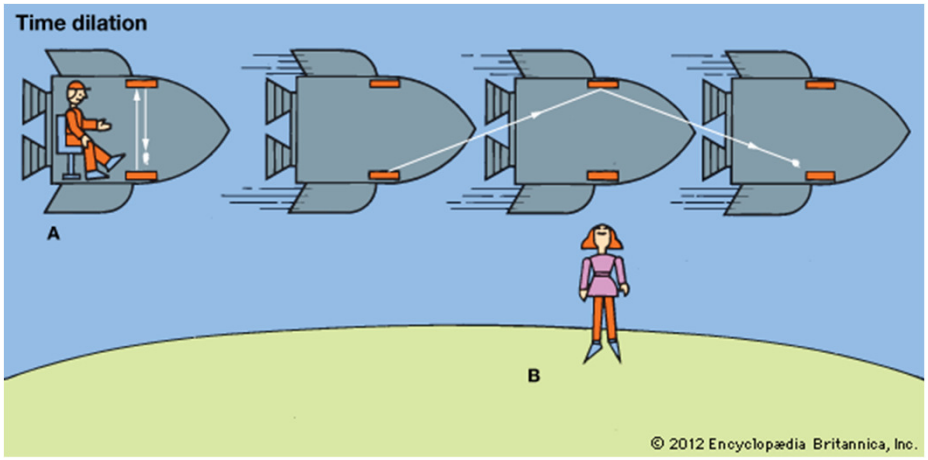
- Size of object traveling near the speed of light as seen by an observer doesn't appear to grow …
- It appears to shrink in size in the direction of motion!



And even *WEIRDER*!

- Clocks traveling at speeds near that of light as seen by an observer appear to slow down!
- People traveling at speeds near that of light as seen by an observer would appear to age at a slower rate

TIME DILATION!



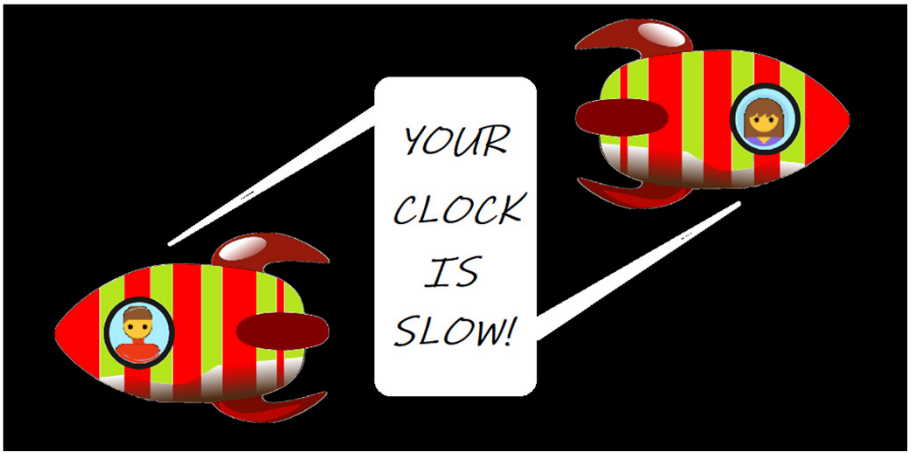
- To the observer on the ground, the path of the photon appears longer, *d*, compared to that of the astronaut on the ship.
- The speed of light *c* is constant.
- c = d/t → t = d/c Since *d* has increased, t must increase.

Perplexed?
Who better than Calvin's dad to explain relativistic time dilation.

The "boldness" of Einstein's proposal.
Instead of time and space being the basic constructs of reality, he proposed that a velocity (length divided by time) be a constant.
To preserve the constancy of the speed of light, space and time have to appear *distorted* to an observer.

Important: All these weird effects are what an observer moving with respect to the object sees! If you were in a spaceship traveling near the speed of light, everything inside the spaceship (your mass, size, time) would appear normal.

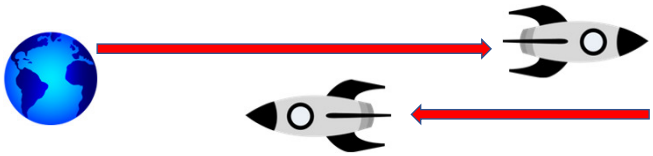
THE TWIN PARADOX!



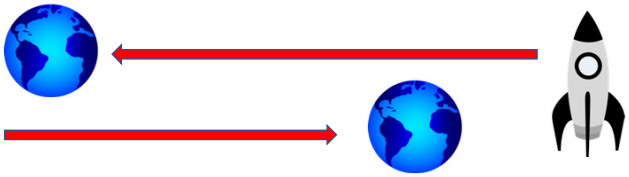
At the start, both twins are the same age. One twin boards a spaceship and takes a round trip into deep space at relativistic speeds.

Twenty years pass on the Earth before the space traveling twin returns.

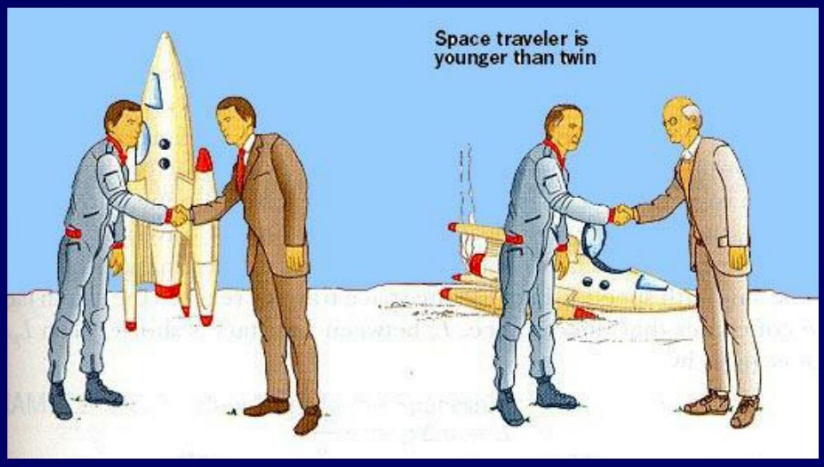
From the viewpoint of the twin on the Earth, the Earth has stood still. It is the spaceship that has moved.



From the viewpoint of the twin in the spaceship, the spaceship stood still. It is the Earth that has moved.



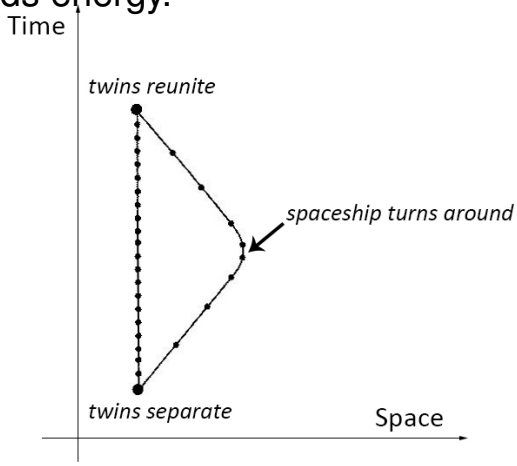
Special Relativity: Twin Paradox



- Speed of light is constant.
- Time and distance are able to change.

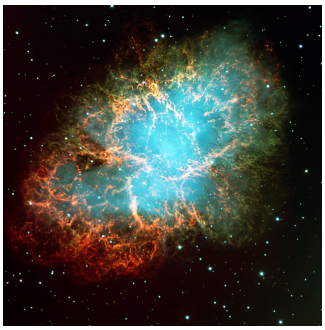
EXPLANATION?

What breaks the symmetry of the relative motion of the twins is that the traveling twin has to deaccelerate and accelerate to turn around, that is, he expends energy.



Matter and Energy

$E = mc^2$

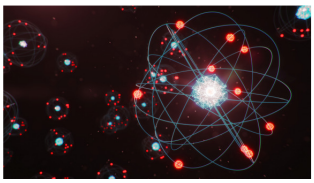


- Matter (mass) and energy are two different manifestations of the same phenomenon.
- Matter can be thought of as "condensed" or "frozen" energy.

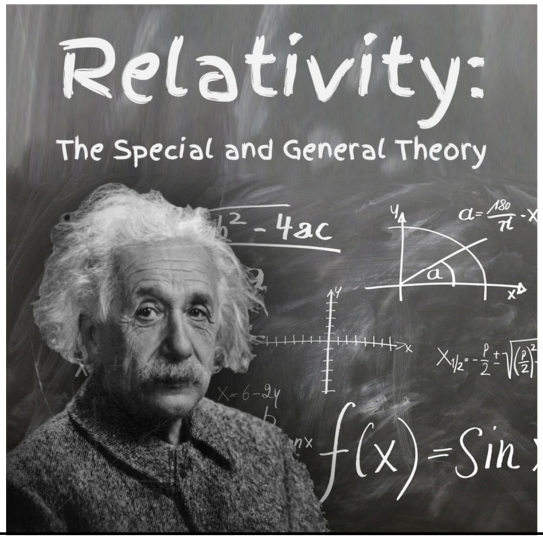
VCU Department of Mechanical & Nuclear Engineering

Evidence for $E = mc^2$ Nuclear Power

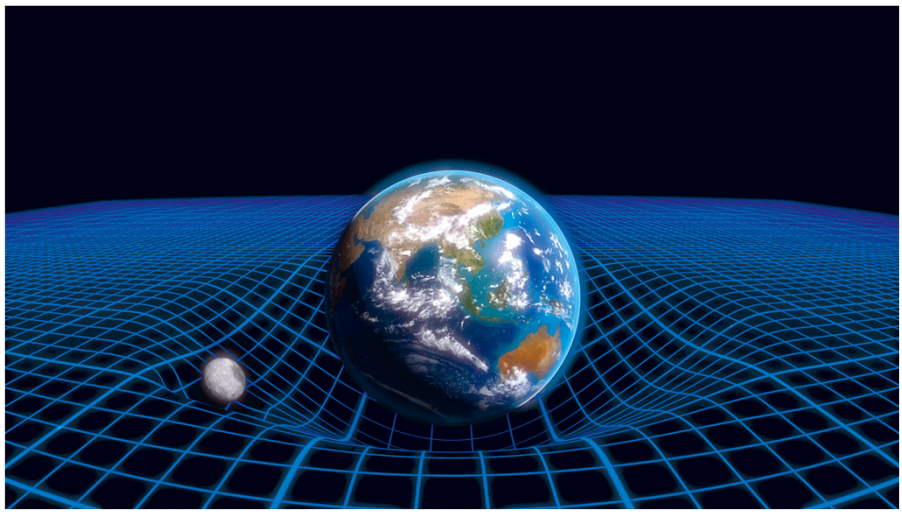
If indeed the Special Theory of Relativity is an accurate description of how nature works, then it must apply over all dimensions—from the realm of subatomic particles to realm of the galaxies!

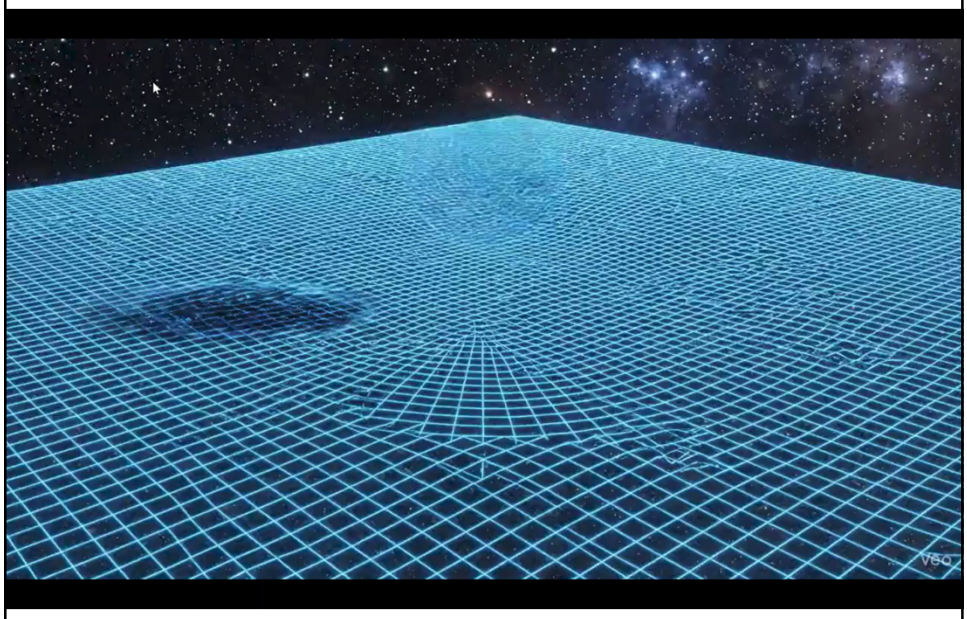


General Theory of Relativity - 1915

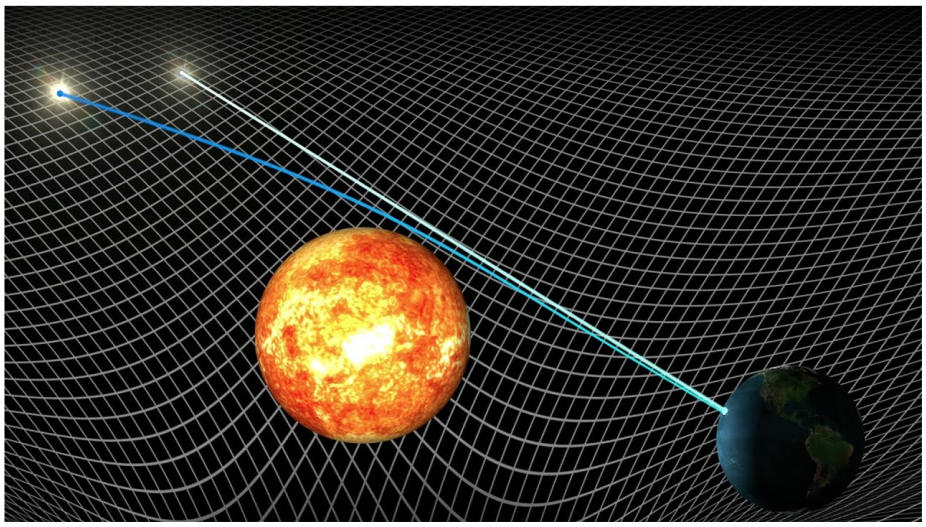


- Space has substance and the presence of a large mass (planet, star, etc.) bends space
- Gravity is the result of this "bending" of space by mass

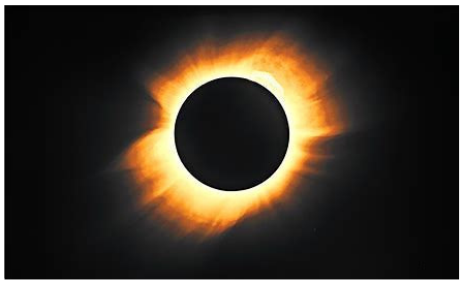




Even light paths are bent near massive objects due to space curvature

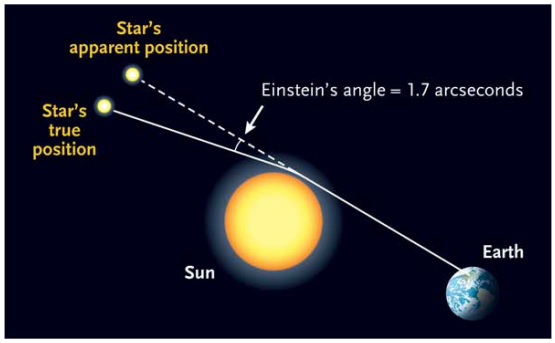


Confirmation -1919 Solar Eclipse

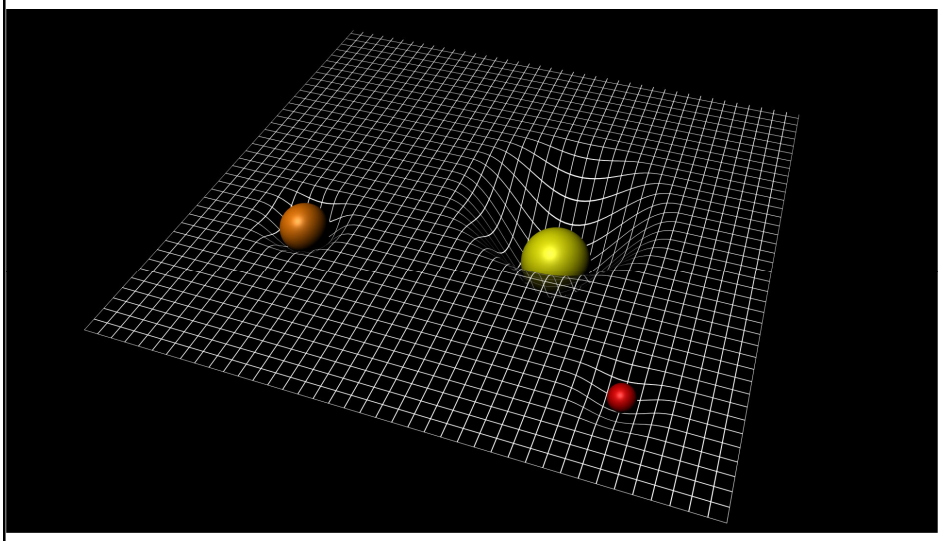


- Photons behave like they have mass
- Light trajectory altered by gravitational pull

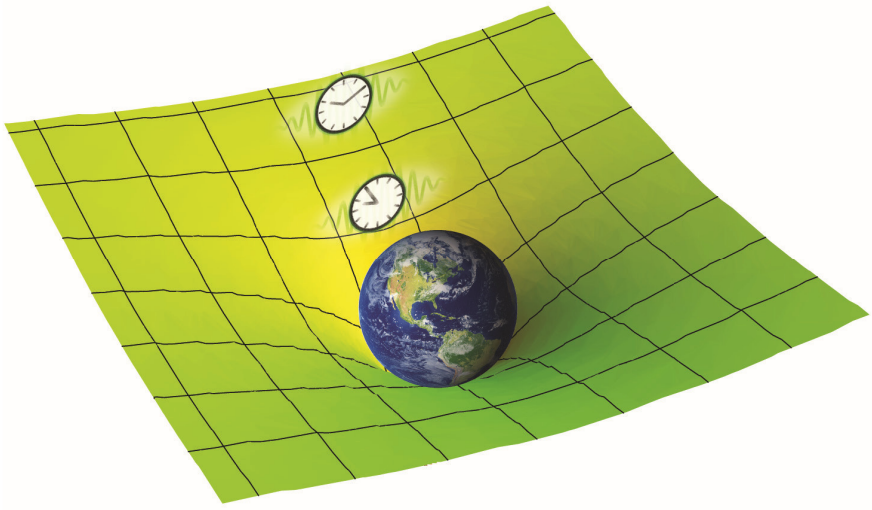
Sir Arthur Eddington



The larger the mass, the greater the curvature of spacetime in the vicinity of the mass → the greater the gravitational attraction



Time slows down in the vicinity of large masses



Confirmation - GPS

Why time slows down in presence of mass?

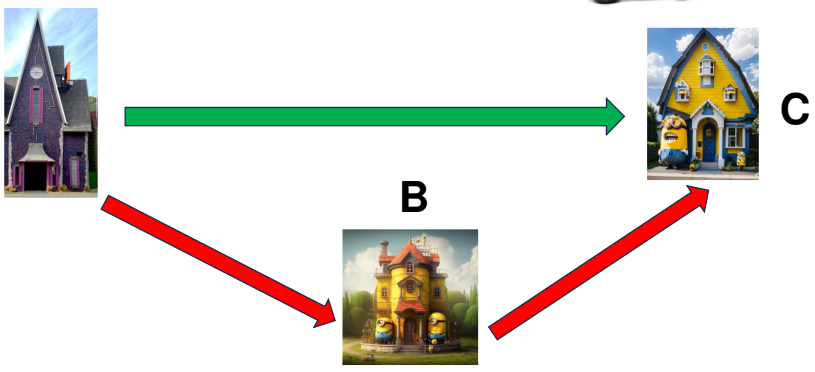
Trajectory of photon in empty space is straight

Trajectory of photon near a mass is curved

- c (speed of light) is constant
- c = distance/time
- Since distance traveled by photon near a mass must be greater to cover same effective distance as photon in empty space, time taken must increase

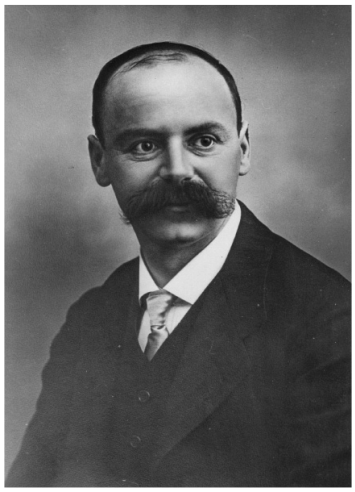
Analogy for time slowing down

Minion car only has one speed, 20 mph

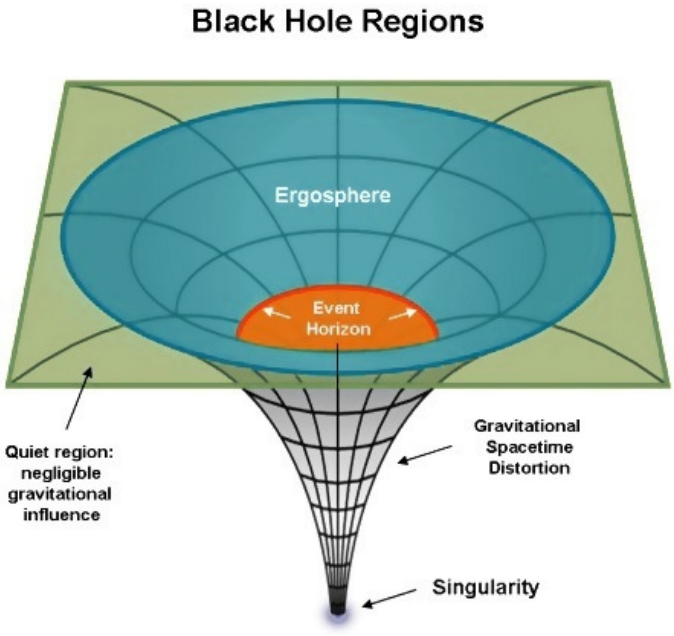


Time required to travel from **A to B to C** is greater than time required to go directly from **A to C**

Karl Schwarzschild (1873-1916) produced the first exact solutions to Einstein's field equations of General Relativity leading to the concept of the Black Hole.



Large enough mass will result in space collapsing in on itself forming a Singularity → a Black Hole from which not even light can escape

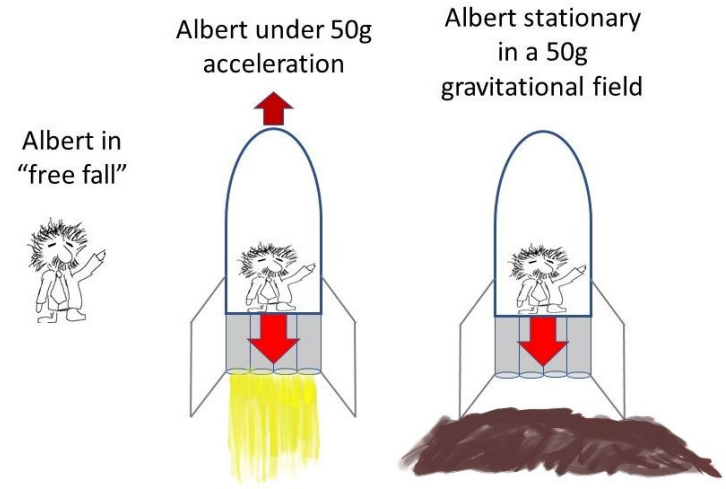


A Black Hole is a **Singularity**

- A singularity is a mathematical abstraction that has no dimensions and functions take on infinite values
- Matter at the center of a black hole would be infinitely dense
- **Event Horizon** – Theoretical boundary around a black hole beyond which no light can escape

- *Escape velocity*: Minimum speed necessary for an object to ignore the effect of the gravitational pull of an astronomical body
  - Earth = 25,000 mph
  - Sun = 1,380,000 mph
- Light is subject to gravitational pull
- The *event horizon* is that distance from a black hole where the escape velocity is equal to the speed of light
- Michell and Laplace (1783 and 1795) formulate the concept of a Newtonian black hole

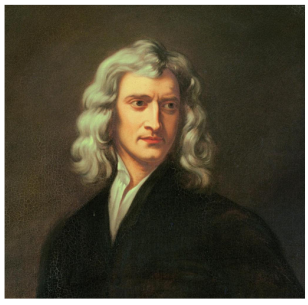
Principle of Equivalence



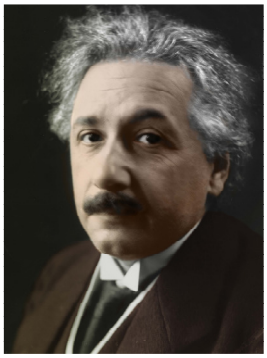
- Charged particles undergoing acceleration radiate energy.
- If acceleration and gravity are equivalent, what doesn't a charged particle at 'rest' radiate energy?

Newton's Theory of Gravity vs. Einstein's

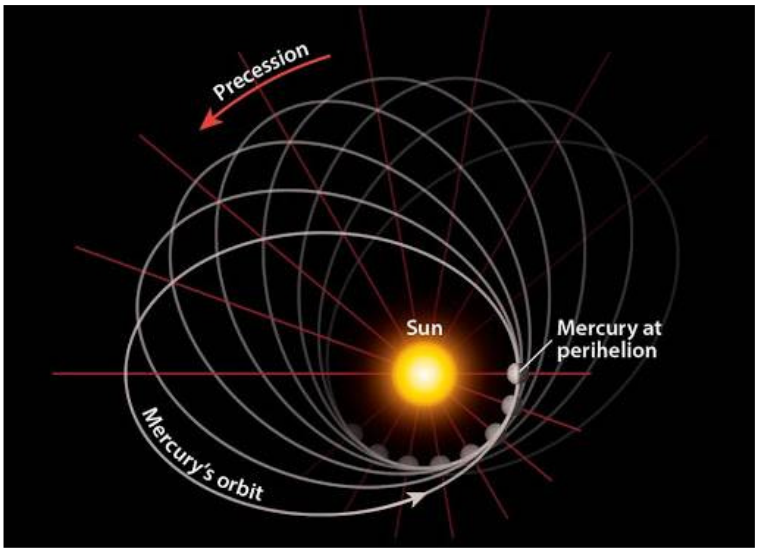
- Newton's theory of gravitation
- Action at a distance → effects of gravity propagate at infinite speed



Einstein: Effects of gravity propagate with the speed of light

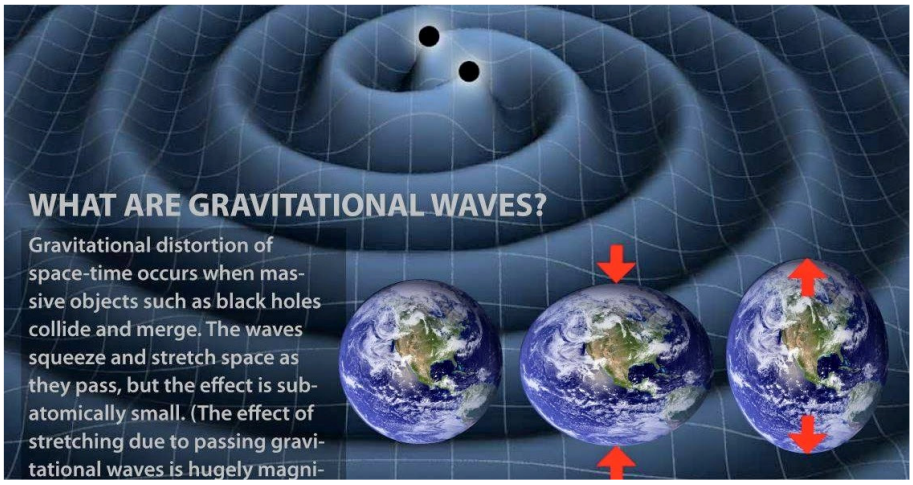


Einstein's theory was able to accurately predict the observed angular precession of the orbit of Mercury



Note: Diagram greatly exaggerated

Gravitational Waves

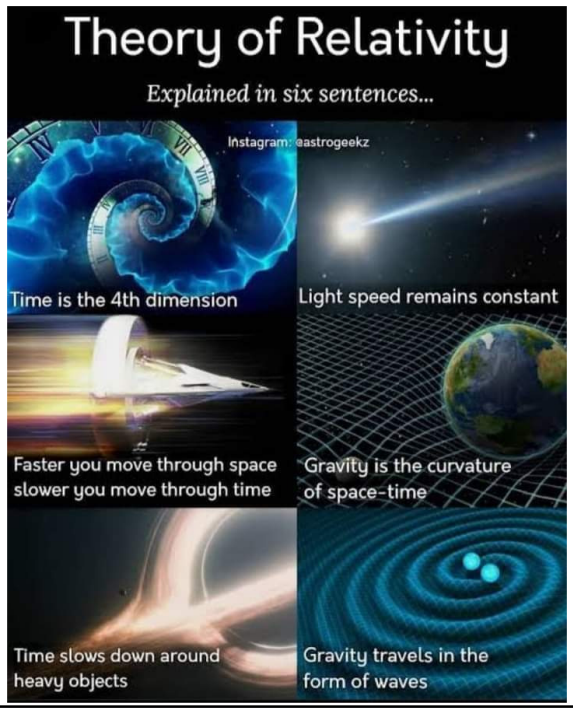


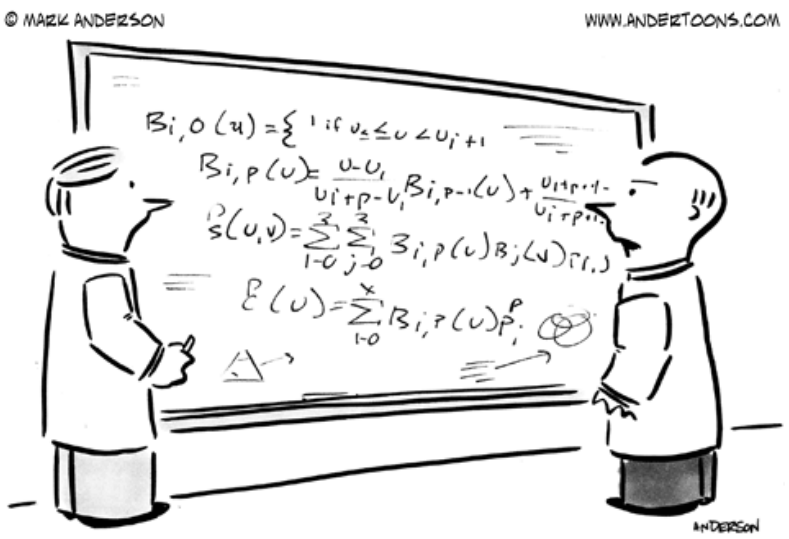
2017 Nobel Prize in Physics awarded for the observation of gravitational waves. (Rainer Weiss, Barry Barish, Kip Thorne)

Note: Diagram greatly exaggerated

Detection of Gravitational Waves

- Laser Interferometer Gravitational-Wave Observatory (LIGO) – 2 labs Handford, WA and Livingston LA
- Mirrors spaced 4 km apart over an effective span of 1,120 km (700 mi)
- Gravitational wave results in a change of length of less than one ten-thousandth a proton's diameter
- Equivalent to changing the distance to Proxima Centauri by one hair's width





"What the hell is *that* supposed to mean?!"

What good is it?

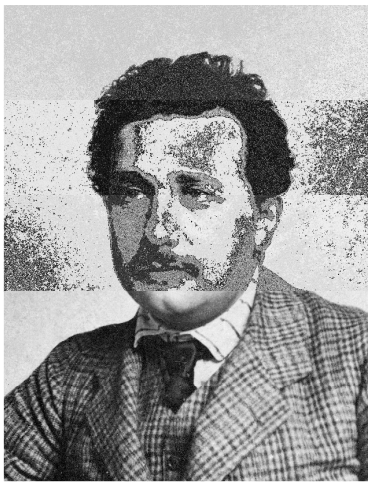
- Atomic and thermonuclear bombs
- Nuclear energy
- Particle accelerators – PET (Positron Emission Tomography) scans
- Global Positioning System (GPS)

Without correcting for relativistic effects, GPS errors would accumulate about 10 km per day

In 1921 Einstein received the Nobel Prize in Physics for "his services to theoretical physics, and especially for his discovery of the law of the photoelectric effect."

Which brings us to
QUANTUM THEORY

The Nobel Prize money was awarded to his first wife, Mileva Maric, as part of their 1919 divorce settlement



Postscript: Einstein's Chauffeur