Einstein

How One Mild-Mannered Physicist Changed the Way We Understand Our World

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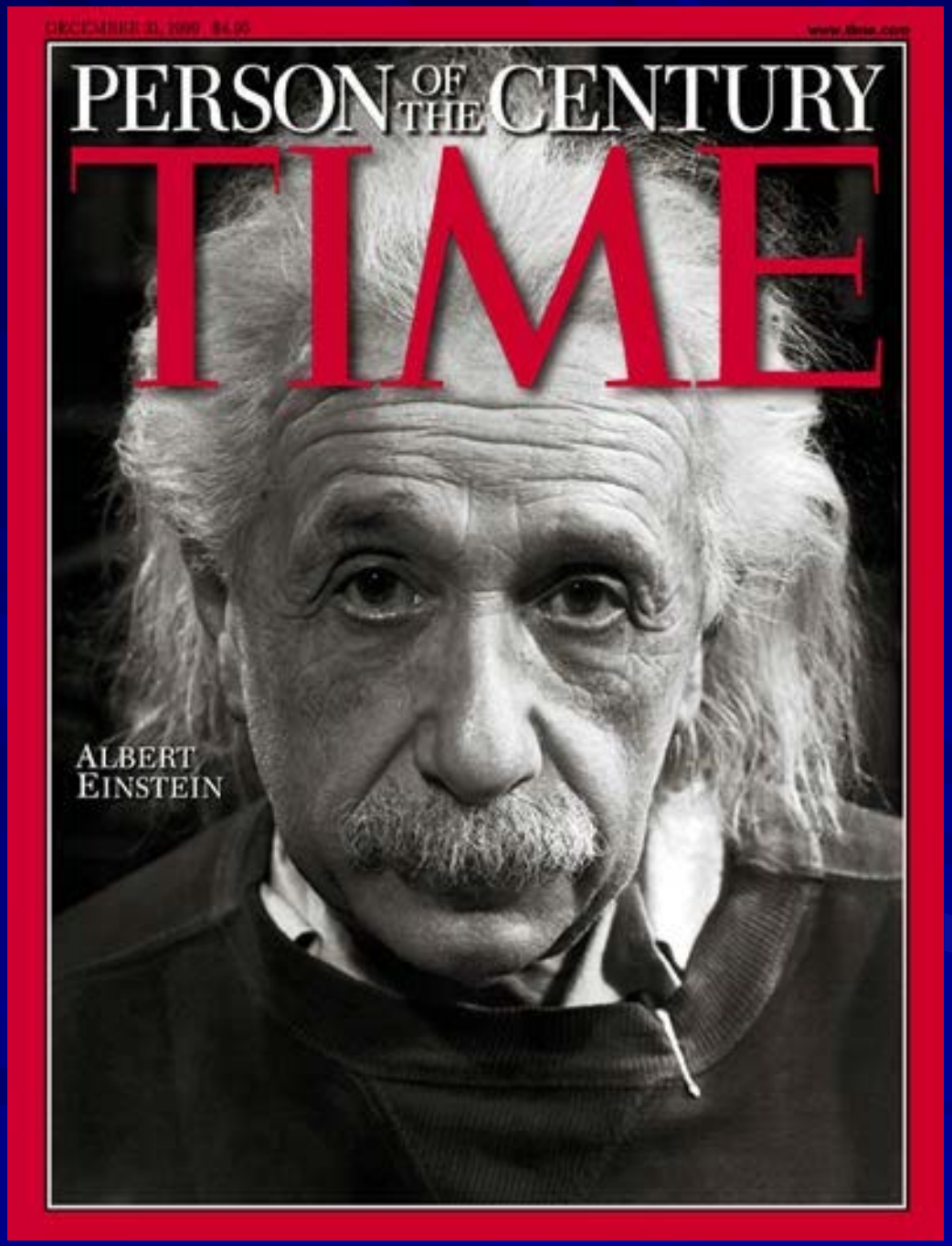
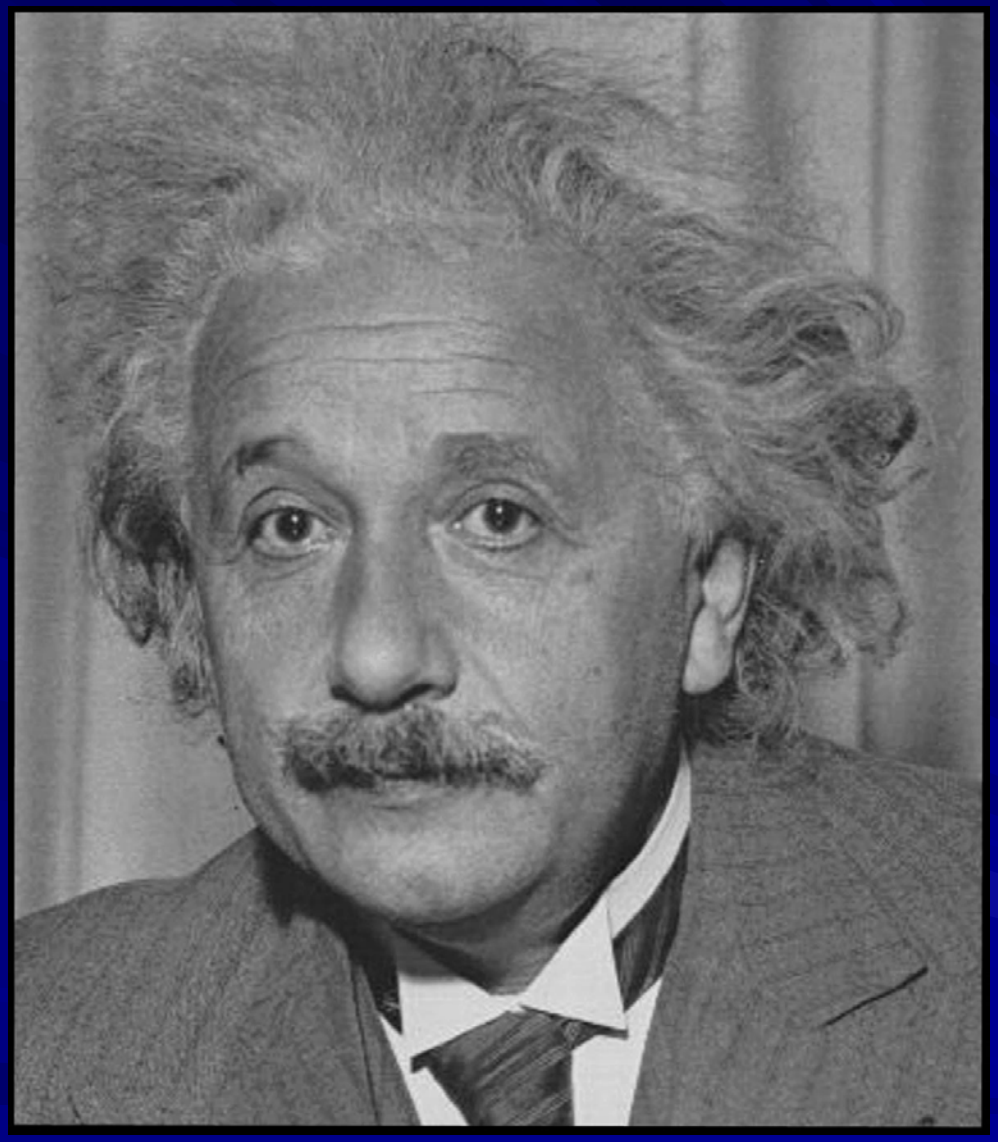
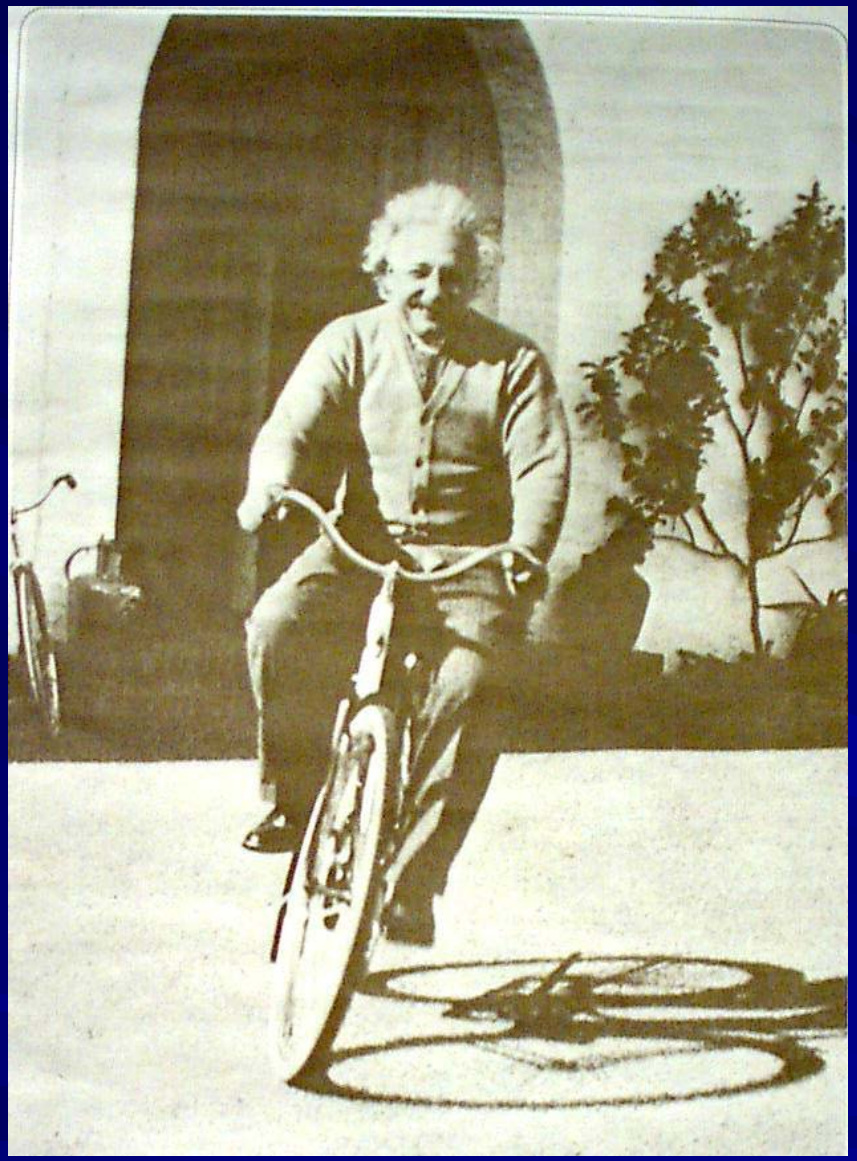
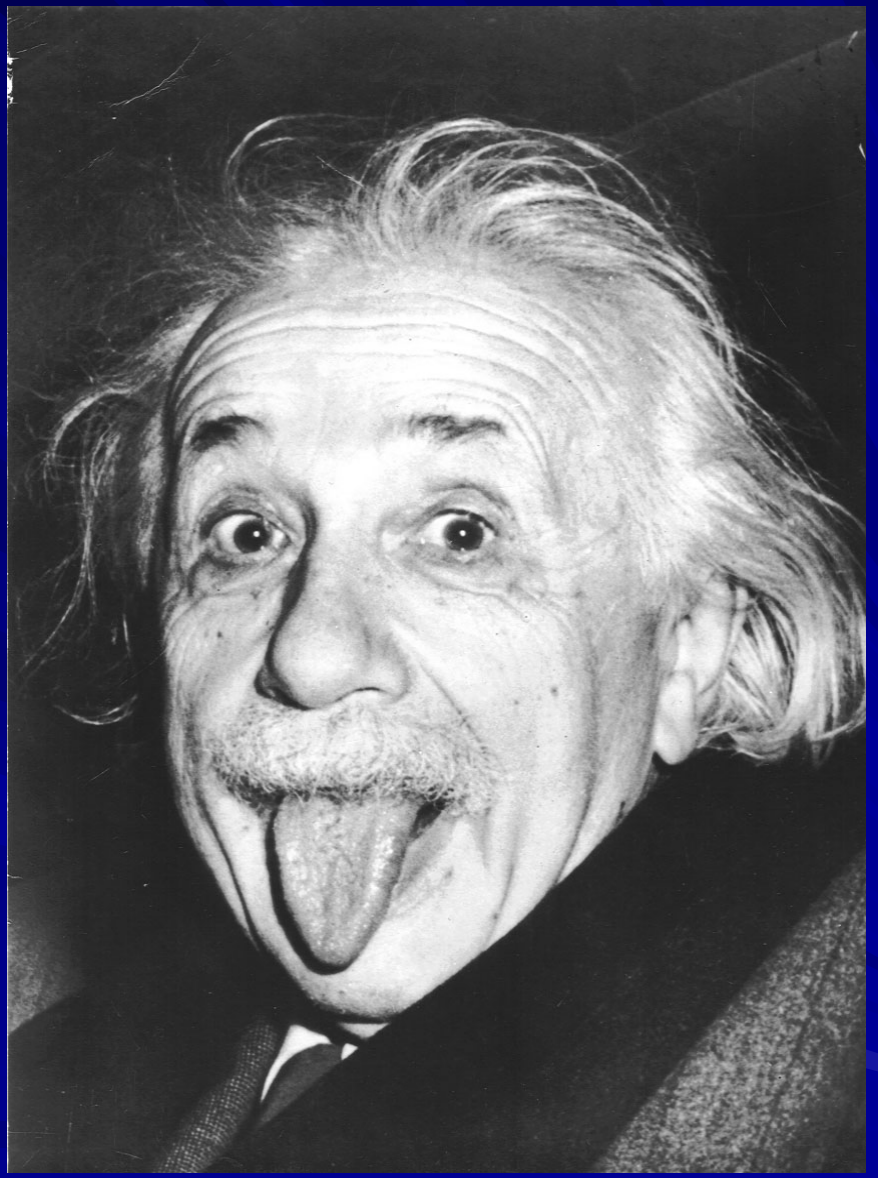
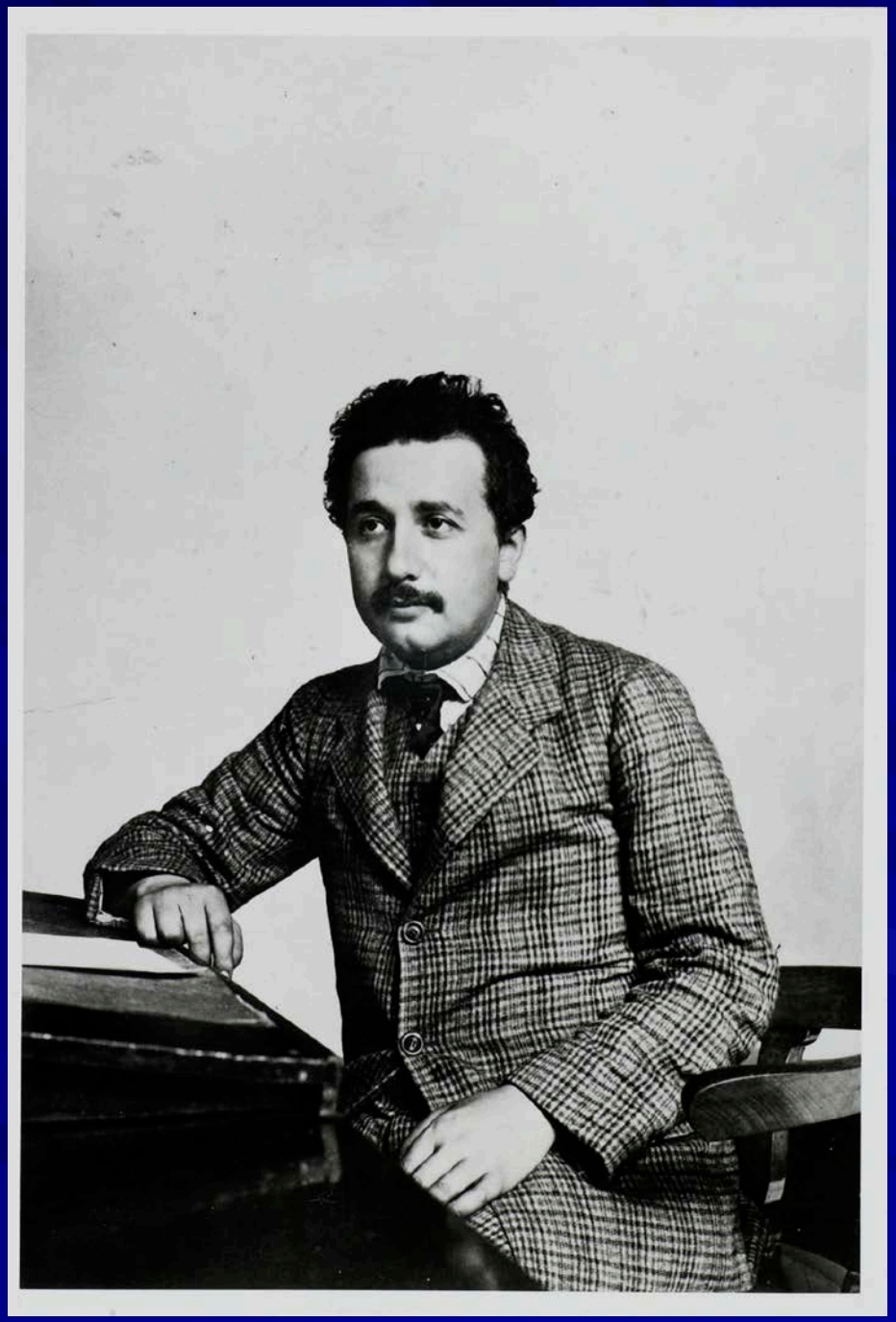
Hesburgh Lecture
Albany, NY
December 8, 2017


PERSON OF THE CENTURY
TIME
ALBERT
EINSTEIN









Outline

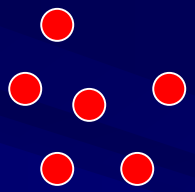
- An incredibly brief history of physics
- Einstein's early years
- 1905 - Einstein's *Annus Mirabilis*
  - Photoelectric Effect
  - Special Relativity
  - Energy and Matter
- General Relativity
  - 1920 – Einstein becomes a rock star
- The later years
- Some final remarks

Isaac Newton

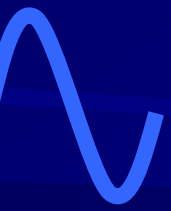
- 3 Laws of Classical Physics
- Invented Calculus
- Universal Law of Gravity

What is nature of light??

Newton: Light is corpuscular!

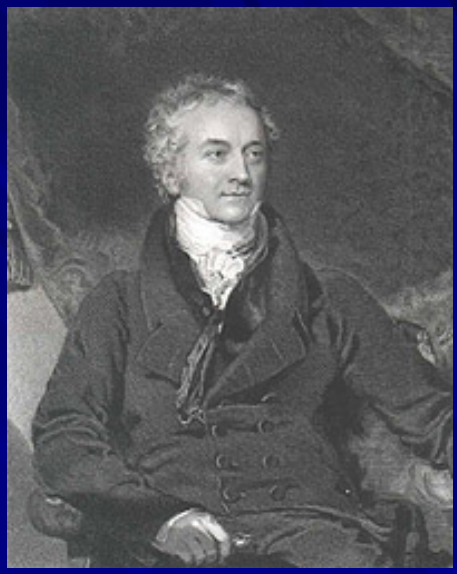


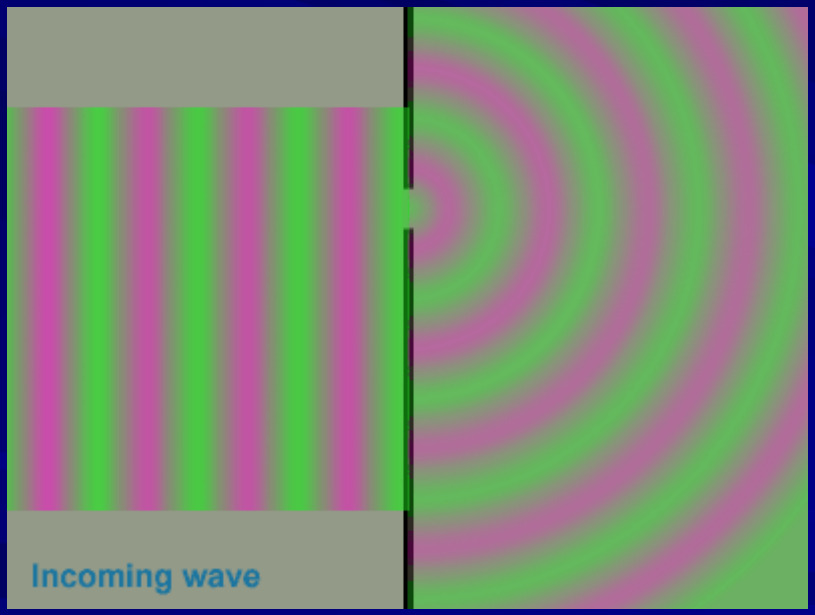
Most scientists: Light is wave-like!



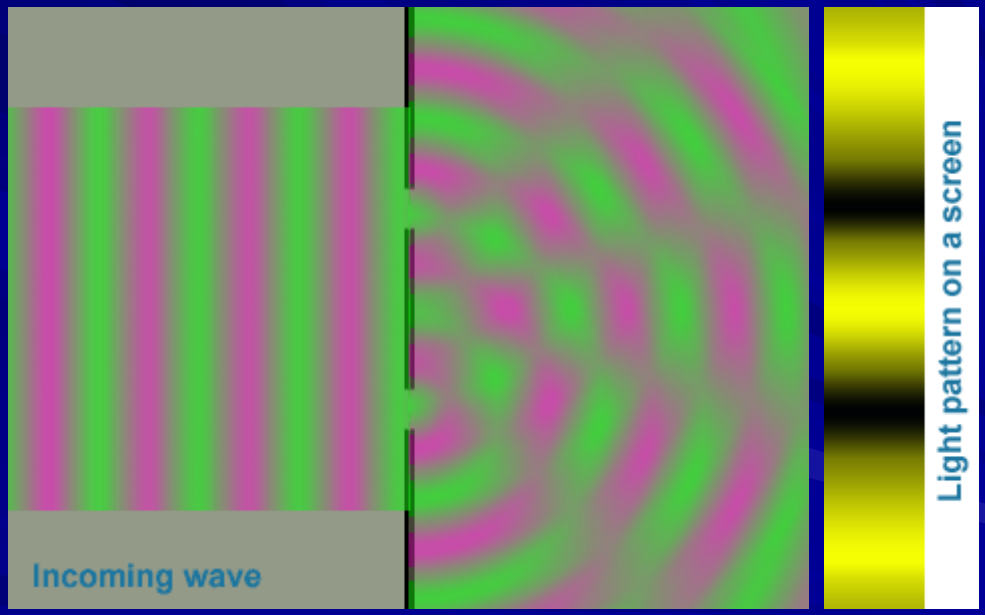
1801: Thomas Young reports existence of interference between light passing through 2 slits.

Young sees diffraction of light
→ Light is a wave!





Waves thru single slit - diffraction

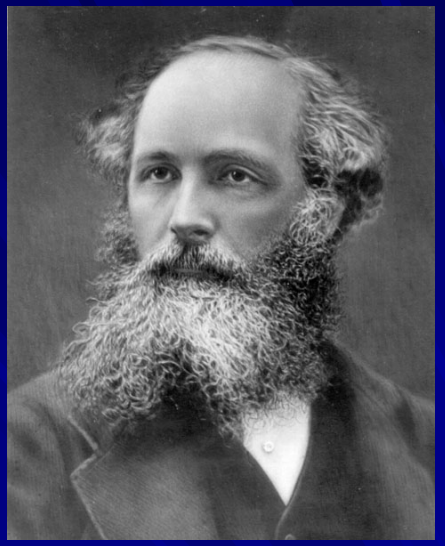


Waves thru double slit – diffraction and interference

$c = 1/\sqrt{\varepsilon_o \mu_o}$

James Clerk Maxwell

(let there be light)



Unified electricity and magnetism

$$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{q_{enc}}{\varepsilon_0}$$

$$\oint \mathbf{B} \cdot d\mathbf{A} = 0$$

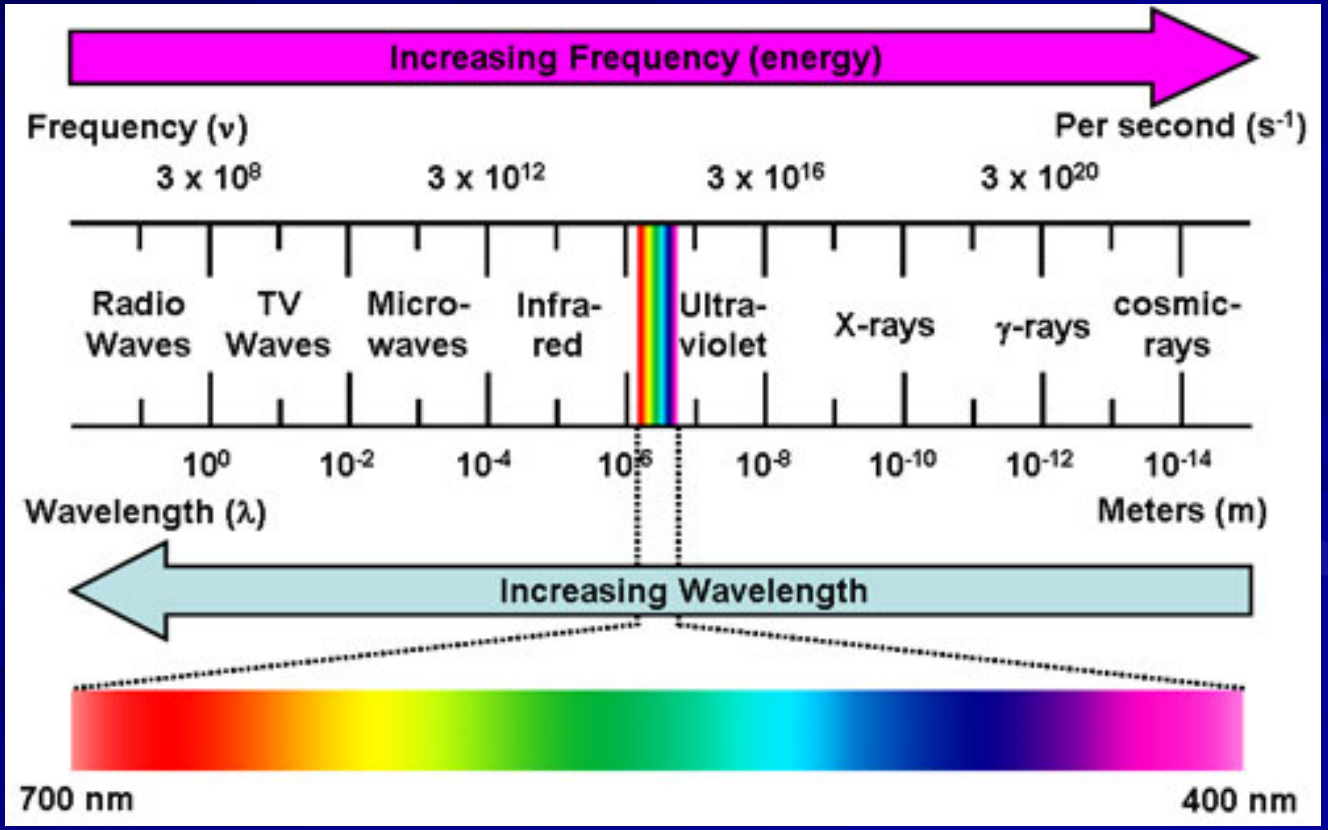
$$\oint \mathbf{E} \cdot d\mathbf{s} = -\frac{d\Phi_B}{dt}$$

$$\oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{enc}$$

$c = 1/\sqrt{\varepsilon_o \mu_o}$ = 300,000 km/sec = speed of light!

The Electromagnetic Spectrum

(Maxwell's Rainbow)



Anything else?

The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote...

-Michelson, 1894

Everything that can be invented has been invented.

-Duell, 1899

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

-Lord Kelvin, 1900

A bit about Einstein's youth

- Born March 14, 1879 in Ulm to a middle class Jewish family

- A little slow to speak but otherwise a fairly normal child, although rebellious to authority even at a young age

- Quit high school at 15, then came back and finished in Switzerland
- Graduated from ETH in Zurich in 1900 with an unexceptional record. Struggled for two years to find a job, would up in Bern at the patent office.

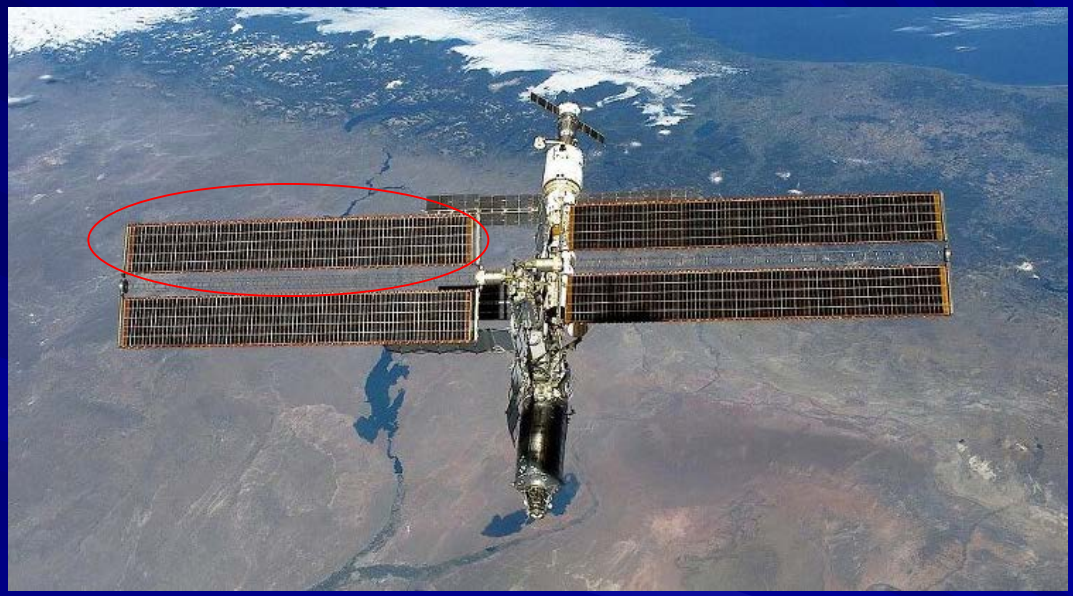
The Miracle Year

In 1905, the 26 year old Einstein published 4 seminal papers showing:

- The particle nature of light
- The existence of atoms as distinct objects
- The relativity of both space and time
- The equivalence of mass and energy

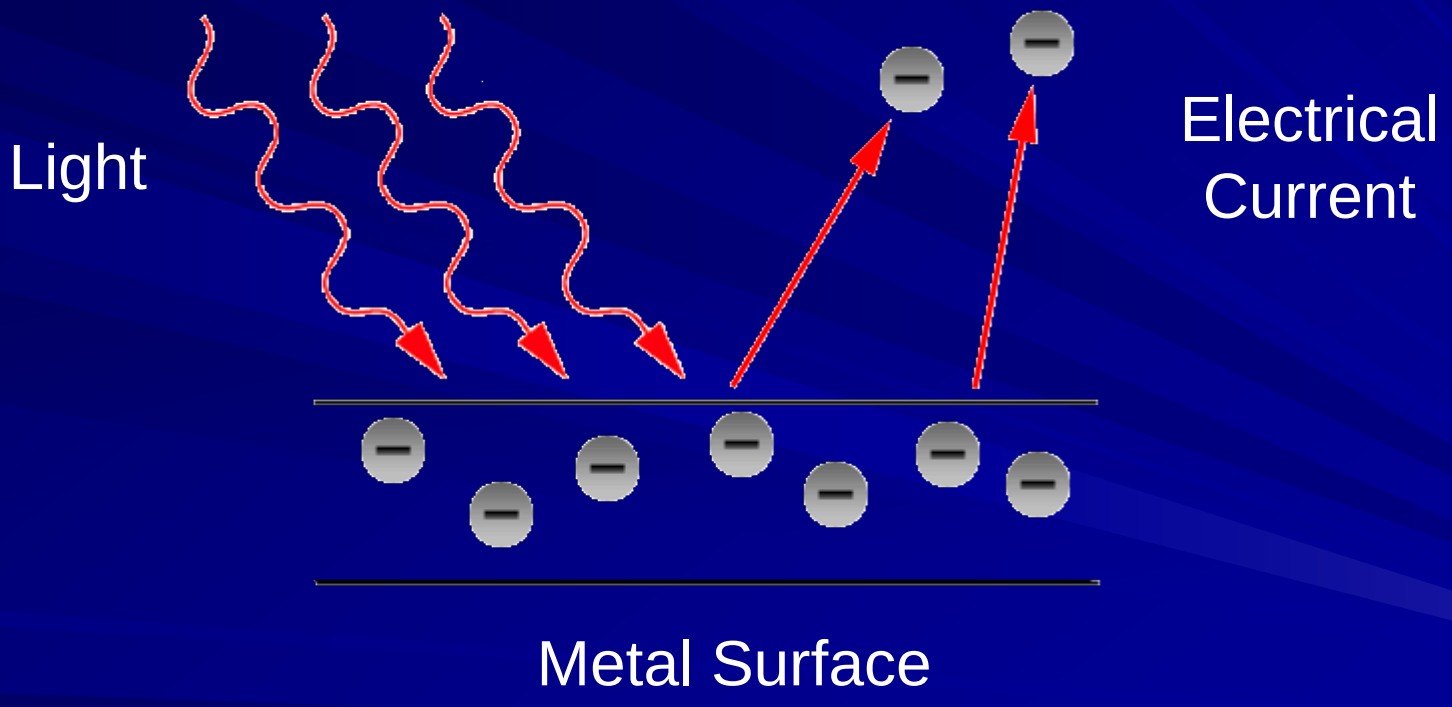
Each of these discoveries was worthy of a Nobel Prize

The Photoelectric Effect

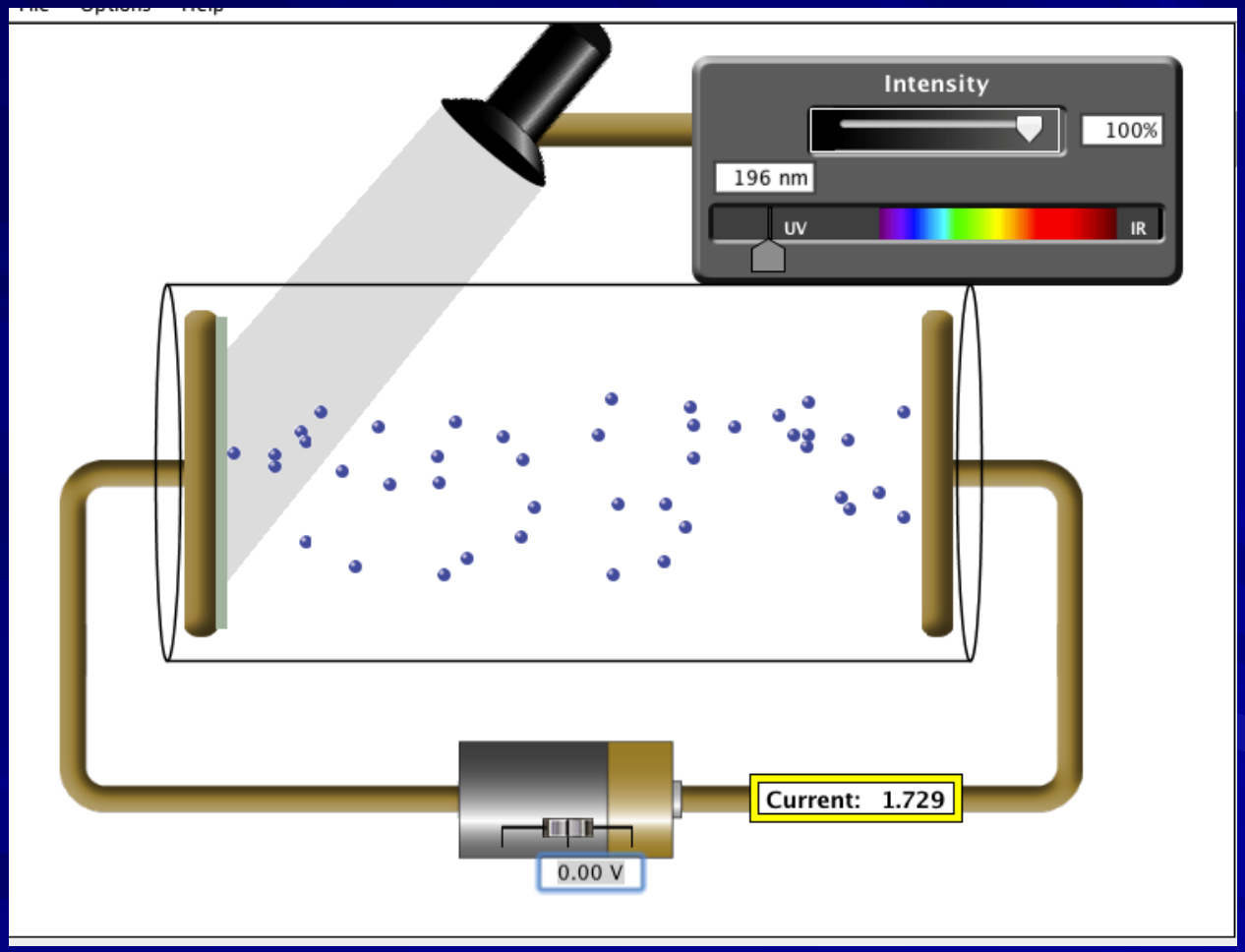


→ **how the color of light affects voltage and current.**

By 1900, many experiments had demonstrated the “photoelectric effect”

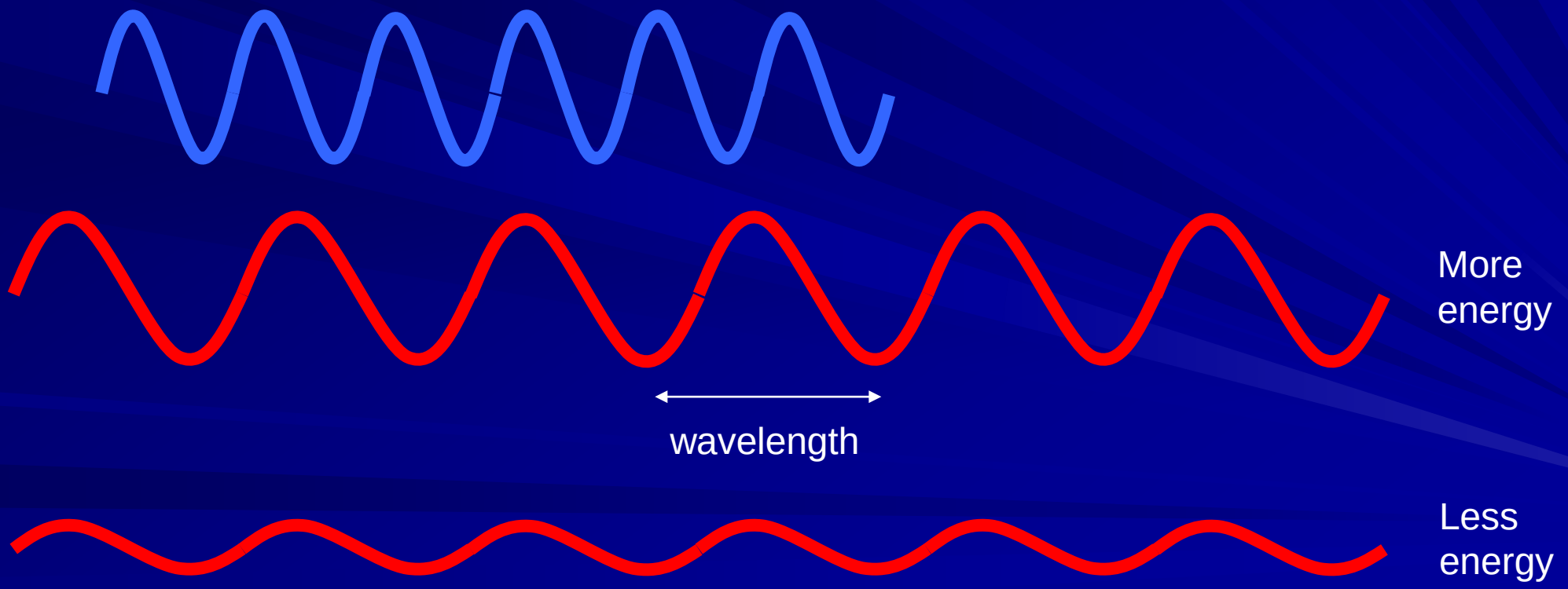


Photoelectric Effect



Remember: Maxwell showed that light is an *electromagnetic wave*.

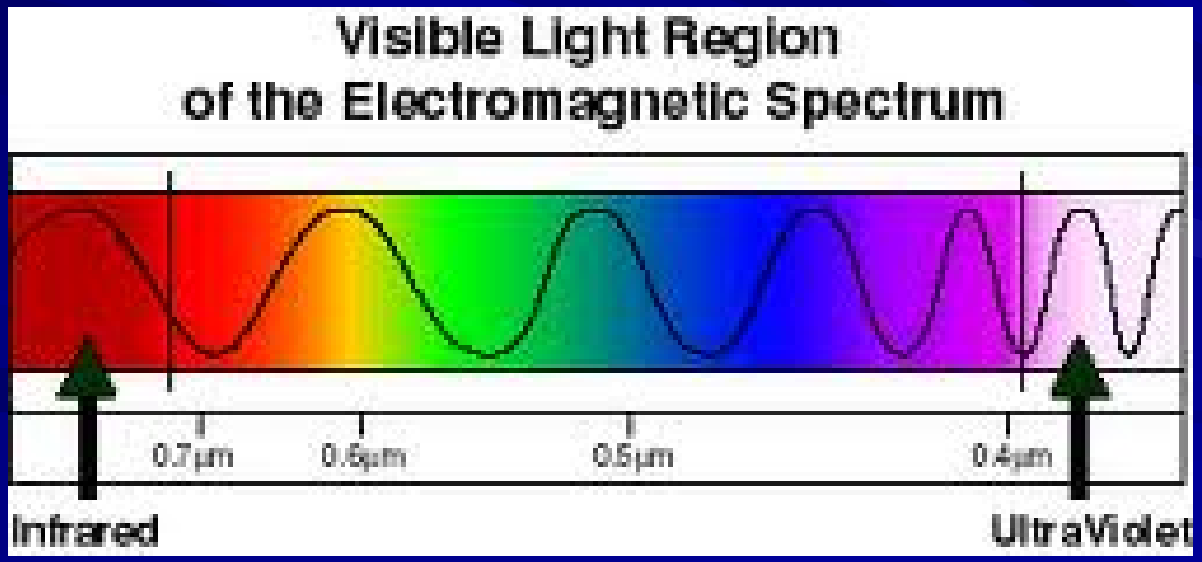
Colors are determined by wavelength,
Brightness by amplitude (= height),
Energy determined by brightness.



What everyone expected:

- Bright light will make faster electrons than dim light
- With bright light, electrons come out sooner than with dim light
- Color of light not important

frequency



wavelength

What they found:

- Bright light makes more electrons than dim light, but they aren't moving any faster.
- Blue light makes faster electrons than red light. Sometimes red light doesn't even work.
- Whether you use bright or dim light, the electrons come out instantaneously

Einstein's Solution

Light is sometimes a wave

– and sometimes a particle!

Light travels through space as a wave,

- and hits atoms as a particle!

Particle state of light is a PHOTON

Energy of a photon = frequency × h

Planck's constant

And….

Bright light "contains" more photons than dim light
→ will hit more electrons.

Blue photons have more energy than red photons
→ will hit electrons harder and make them come out faster

If a certain color photon does not have enough energy
→ no electrons will come out

Whichever color knocks out an electron
→ the electron comes out instantaneously

Special Relativity

With a deceptively simple theory, Einstein showed not only that space and time are relative – they are entangled!

The results are astonishing and bizarre, yet without them your GPS wouldn't work at all!

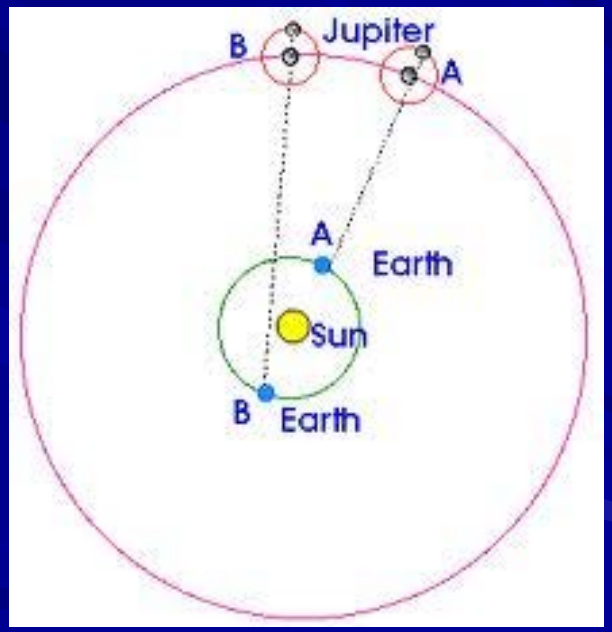
(And my own research wouldn't be possible, either)

By 1900, it was known that light was an electromagnetic wave (Maxwell), with a speed of 300,000 km/sec

(to the moon and back in about 3 seconds – *see Big Bang Theory*!)

Galileo

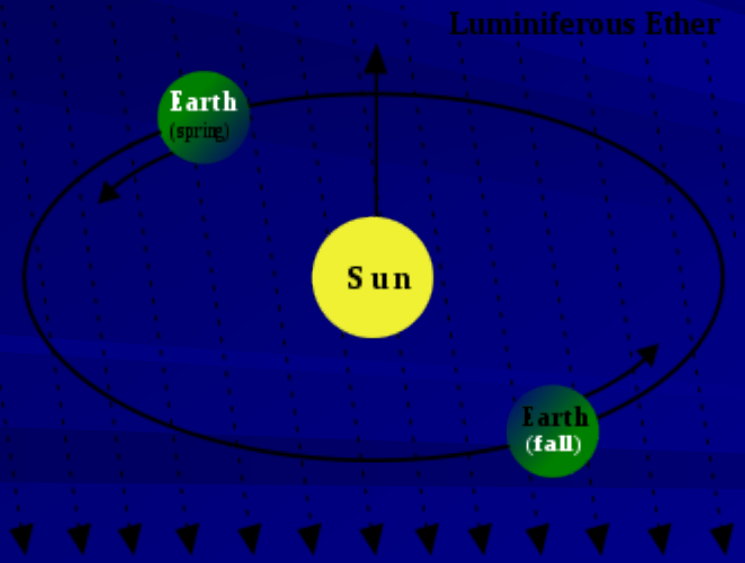
"If not instantaneous, it is extraordinarily rapid!"



Roemer

One problem: If light is a traveling wave, what is it traveling through?

The “luminiferous ether” disproved in 1887 by Michelson and Morley



No absolute reference frame!

June 1905 – Einstein's 2 Postulates

1) The Laws of Physics are the same for observers in all inertial reference frames

2) The speed of light c is the same for observers in all inertial reference frames

Classical Physics

20 mph

60 mph

Relative speed is 40 mph

Relativity

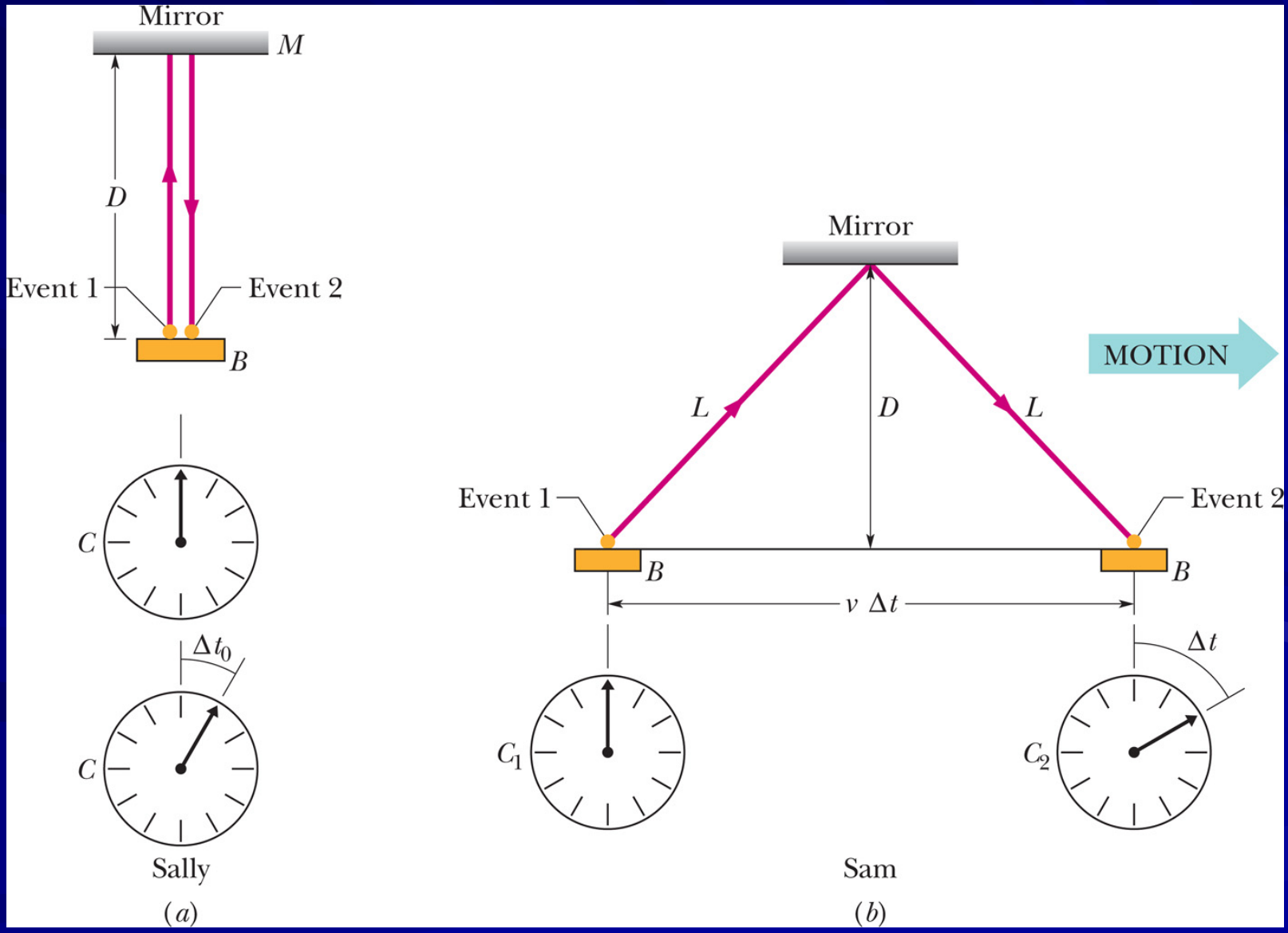
150,000 km/s

Light

300,000 km/s

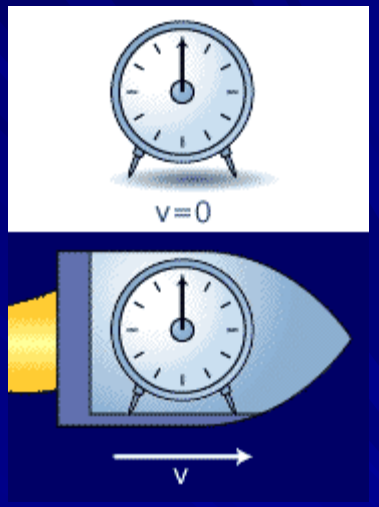
Relative speed is 300,000 km/s!

Time Dilation: Einstein showed that we can travel into the future, a la “Planet of the Apes”



Relativity has many weird implications:

1. Nothing can move faster than c.



2. Time slows down as we move faster;

3. Distances shrink as we move faster;

4. Our mass increases as we move faster;

… none of which we are aware of as we travel.

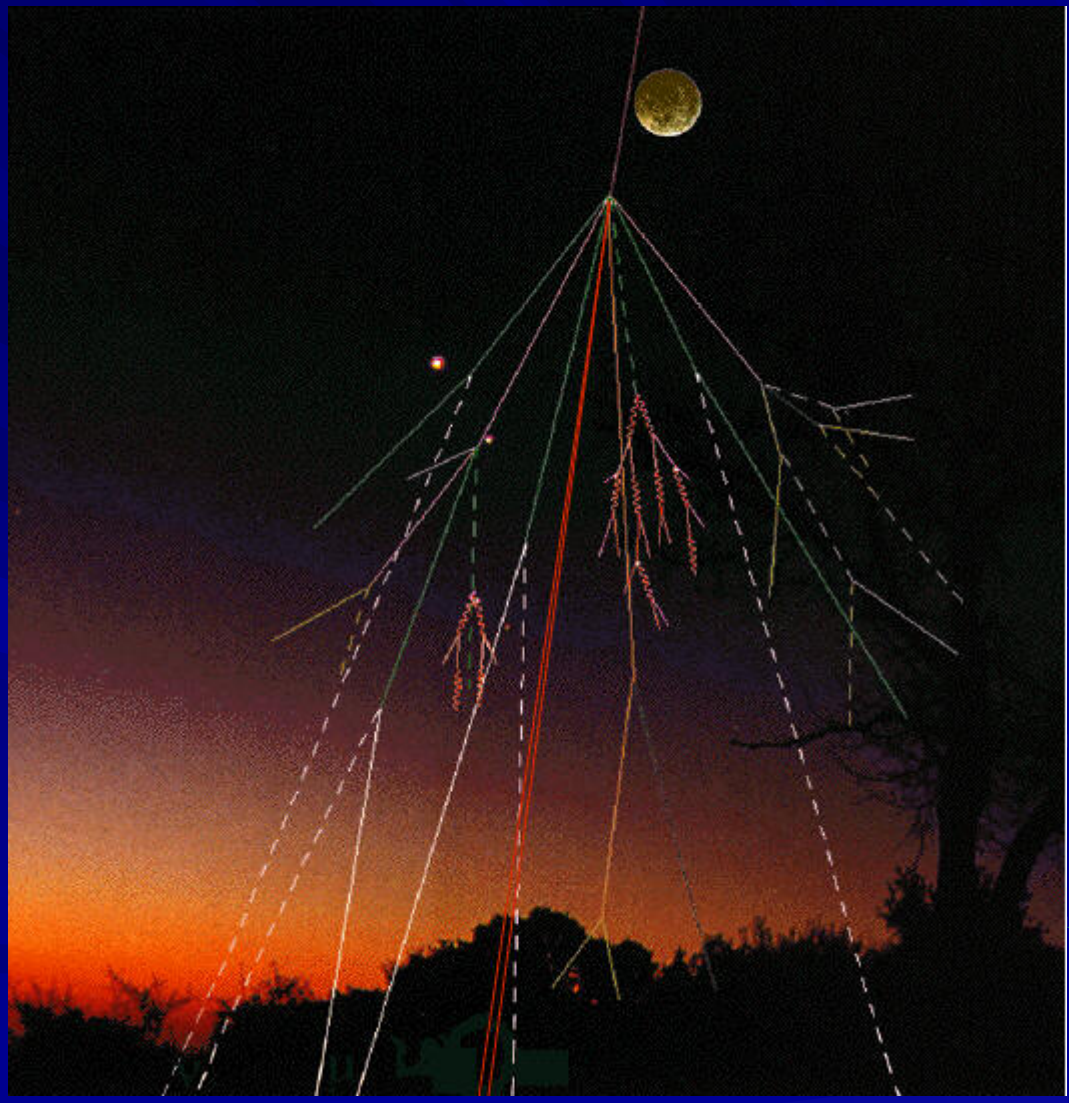
Cosmic Rays – A real life example of special relativity

Move at ~ 99.95% speed of light

At rest, a muon lives about
2 millionth's of a second before
decay

Classically, they will only travel
about 600 meters, but they
make it all the way down!

The muon's "clock" slows down!



So, why does this all seem so strange so us?

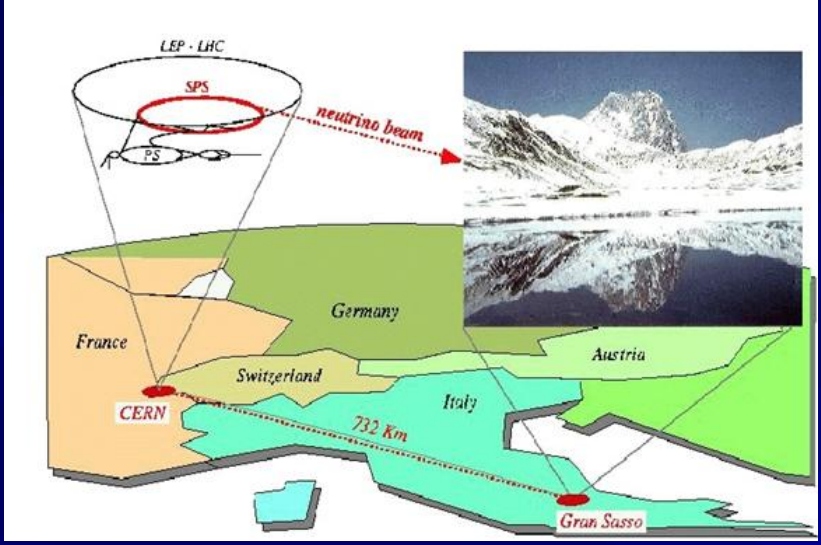
Because relativistic effects are only significant for the very small and very fast, and we are big and slow!

For example, flying on a 747 your clock slows down by about 0.000000000007%

Philosophical implications of this are many:

- There is no absolute distance or time scale in the universe.
- Everyone carries with them their own definition of “meter” and “second” which will not always agree with those of others – they are now relative!
- No two events can be said to be simultaneous unless they occur at exactly the same place.
- Time travel is possible, but only into the future – never back!
- Space and time connected – time is just another dimension, except one in which motion is only one-way.
- Our intuitions cannot be trusted beyond their natural domain!

September 2011 – Was Einstein Wrong?



"Faster than light particles found, claim scientists"

Particle physicists detect neutrinos travelling faster than light, a feat forbidden by Einstein's theory of special relativity

The Guardian

"Tiny Neutrinos May Have Broken Cosmic Speed Limit"

Roll over, Einstein?

New York Times

As if all of this wasn't enough, in September 1905 Einstein published one more surprising (and now very famous) result

Mass and Energy are interchangeable!

All objects with mass possess some amount of energy, even when they are not moving.

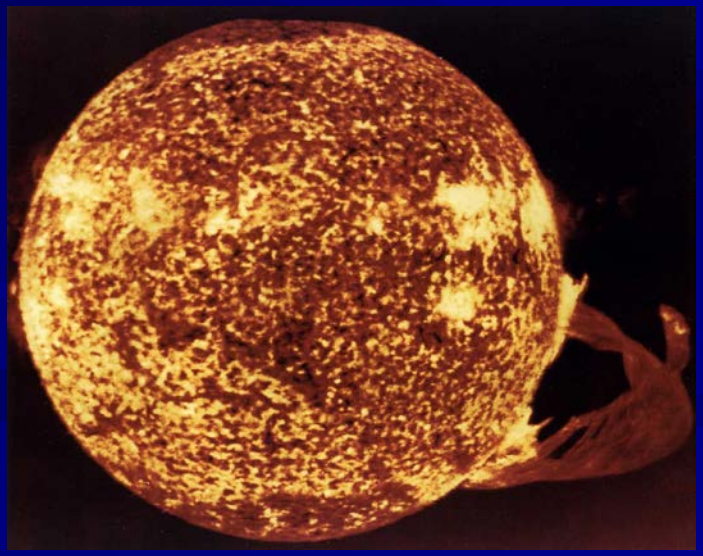
Rest energy: $E = mc^2$

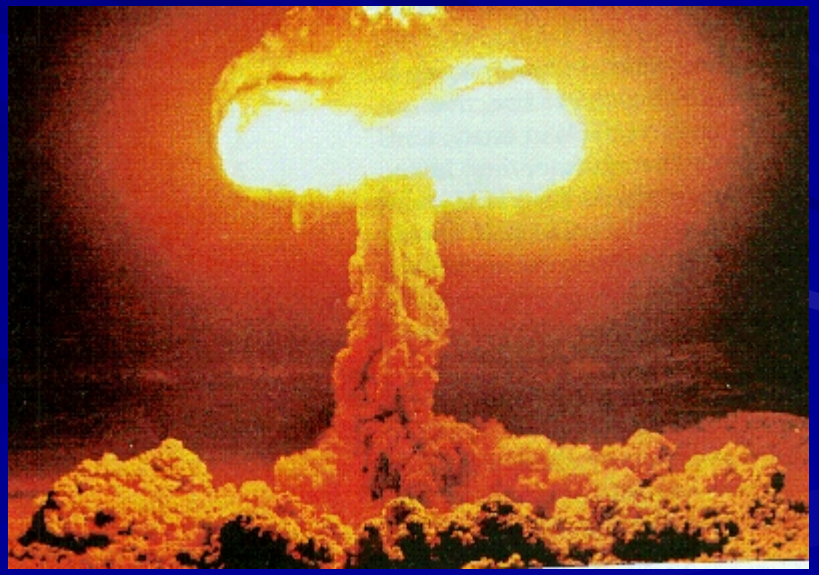
Even small masses possess huge stores of energy:

- A 100 mg aspirin has enough energy to power a home for 200 years!
- A human body contains as much energy as we now get from 1 billion barrels of crude oil!

The consequences of this simple equation are many and profound

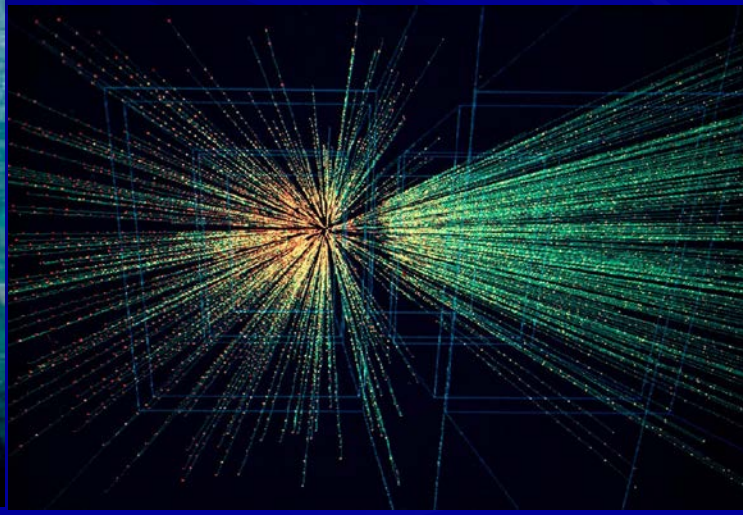
Matter → Energy





And Energy → Matter!

CERN in Geneva, Switzerland



Why Einstein?

- Great intellect and imagination
- Powerful mathematical abilities
- An independent thinker
- Strong faith in Maxwell's equations
- Outside the main stream of academia (?)

Einstein and Newton

"Newton, forgive me. You found the only way which in your age was just barely possible for a man with the highest powers of thought and creativity. The concepts which you created are guiding our thinking in physics even today..."

After the Miracle Year

1909 – Leaves patent office to take Associate Professor post at University of Zurich

1911 – Appointed Professor of Theoretical Physics at the German University of Prague

1912 – Appointed Professor of Theoretical Physics at ETH, Zurich

1914 – Appointed Professor at University of Berlin and Director of the Kaiser Wilhelm Institute

1915 – Completes General Theory of Relativity

General Relativity

Special relativity is only valid for observers moving at constant speed with respect to each other

Einstein next looked at accelerating reference frames, including gravity (why is the mass in Newton's 2nd Law the same as in his Law of Gravity?)

Unlike special relativity, the math is very complex – it took Einstein about 10 years to get right

The resulting theory is very complicated (even for physicists), but once again predicts amazing results

General Relativity

Einstein became fully aware of the complexity of this problem as he struggled to solve it. In a letter to Sommerfeld in October, 1912 he wrote:

"I am now occupied exclusively with the gravitational problem, and believe that I can overcome all difficulties with the help of a local mathematician friend. But one thing is certain, never before in my life have I troubled myself over anything so much, and that I have gained great respect for mathematics, whose more subtle parts I considered until now, in my ignorance, as pure luxury! Compared with this problem, the original theory of relativity is childish."

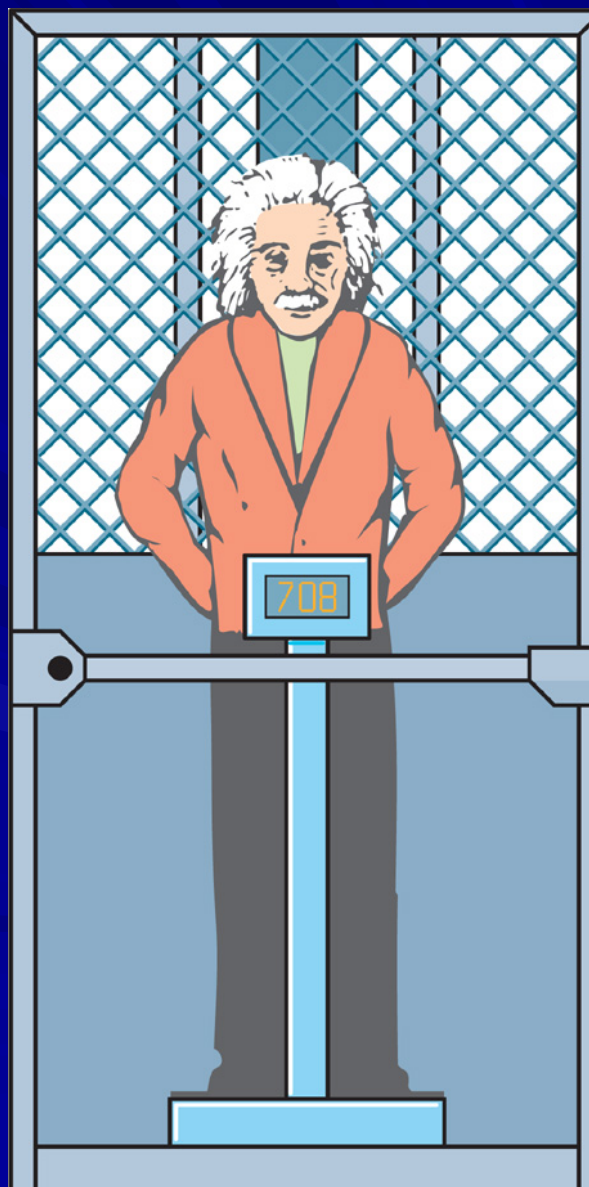
Let’s look at riding up in an elevator

When you first start to go up, you feel pushed down and a scale would show that you weigh more

When you are going up at a constant speed, the scale will show your normal weight

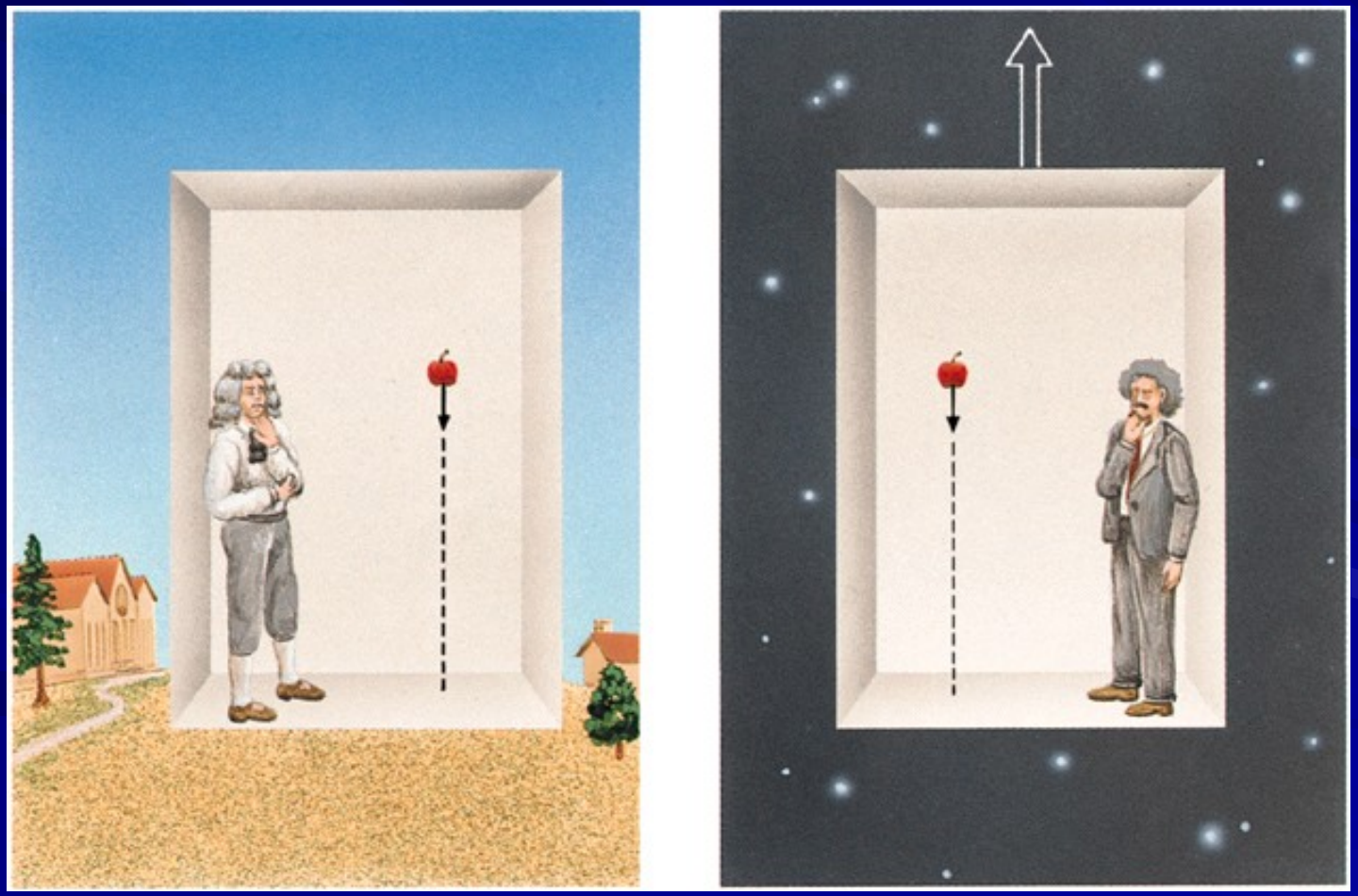
When the elevator starts to slow down at the top, You feel lighter and the scale would show you weigh less

Same effect as if gravity were changing!

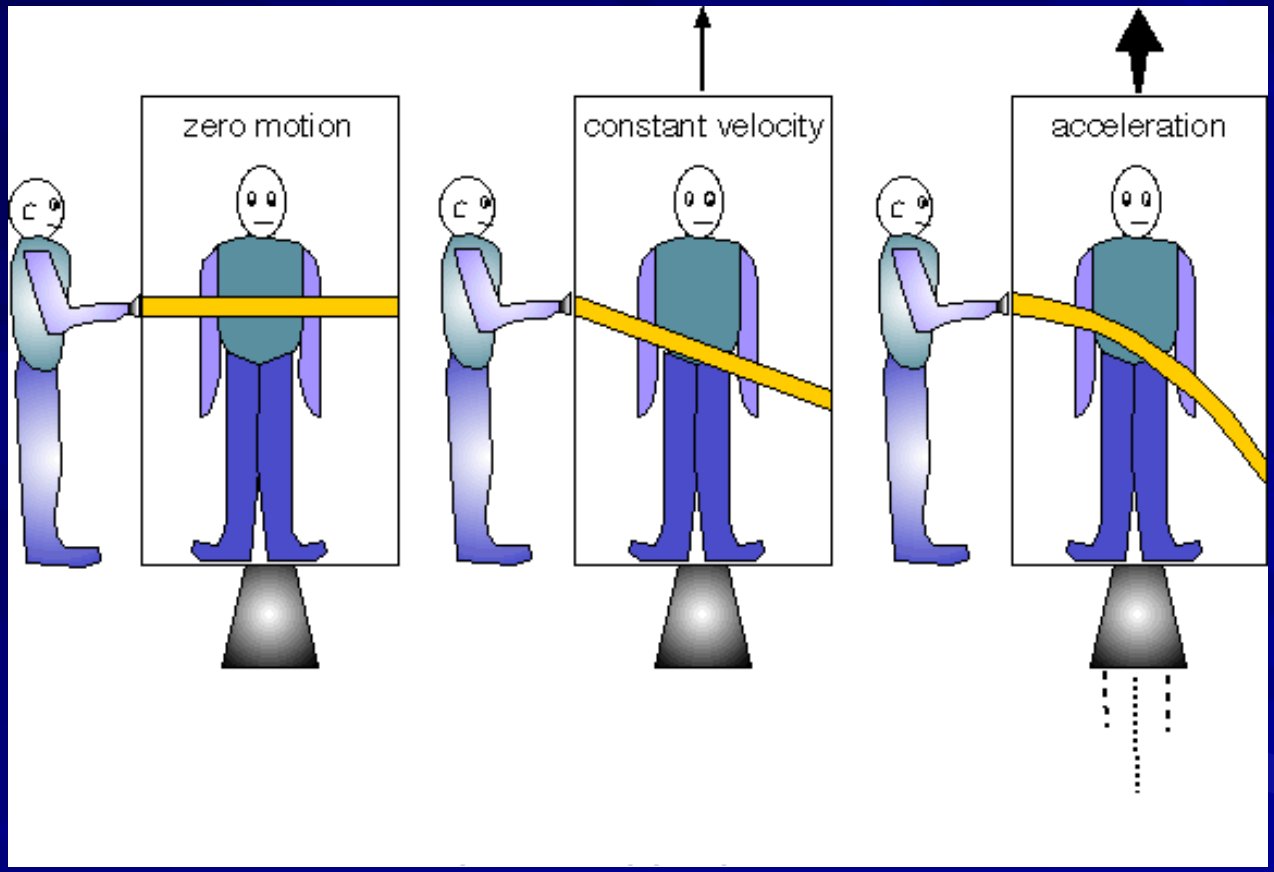


Equivalence Principle

No experiment can distinguish between constant acceleration and gravity

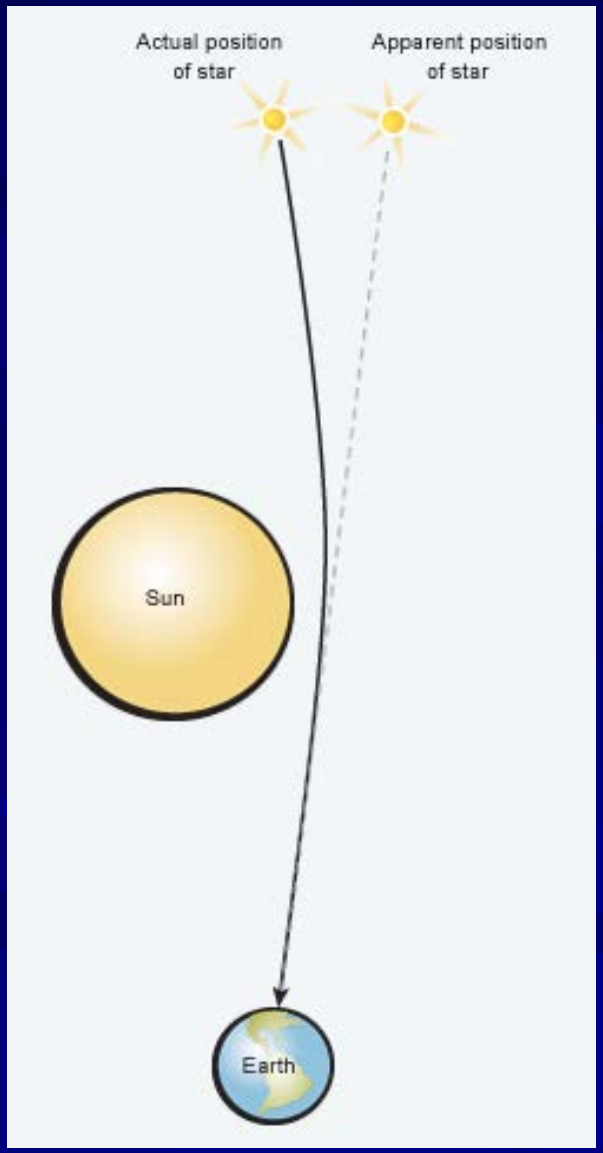


For an observer in an accelerating reference frame, a beam of light will appear to bend



Equivalence principle → a beam of light will also be bent by gravity!

1919 – Arthur Eddington and the Solar Eclipse



LIGHTS ALL ASKEW IN THE HEAVENS

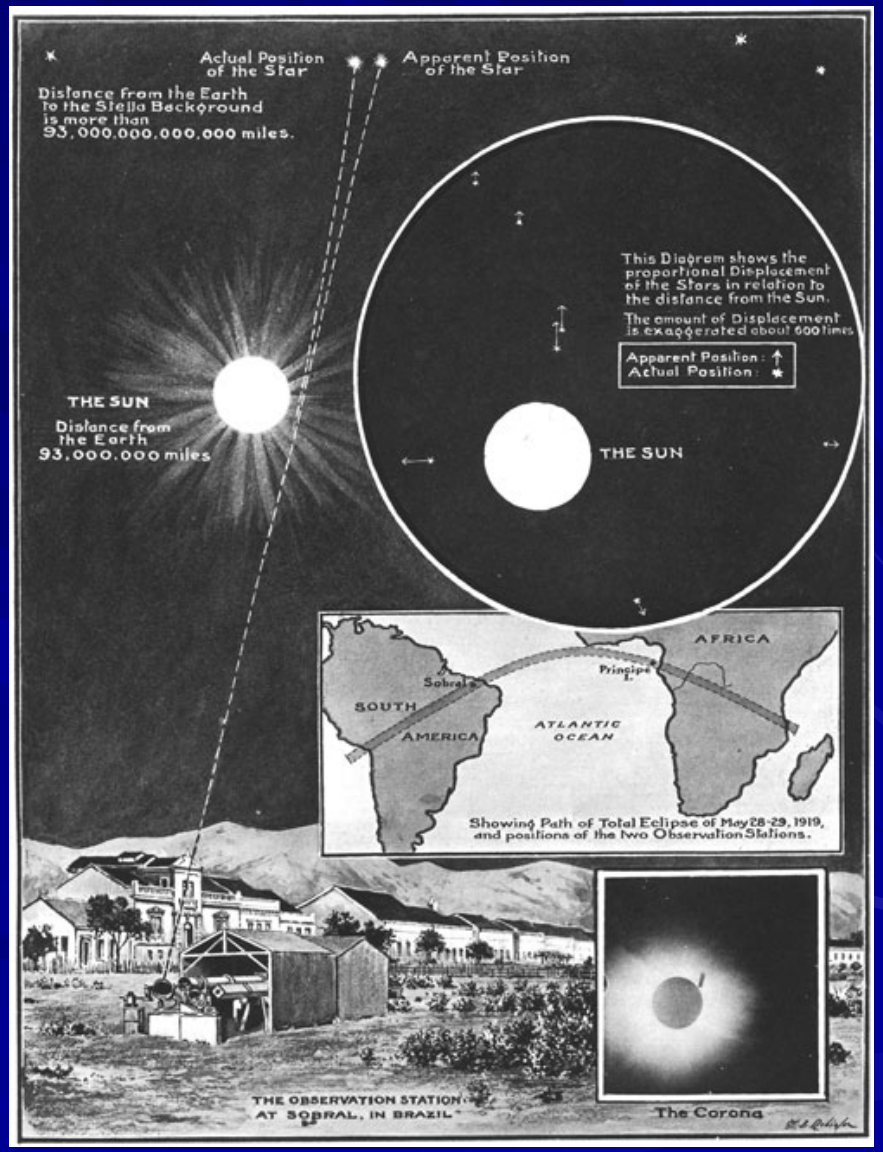
Men of Science More or Less Agog Over Results of Eclipse Observations.

EINSTEIN THEORY TRIUMPHS

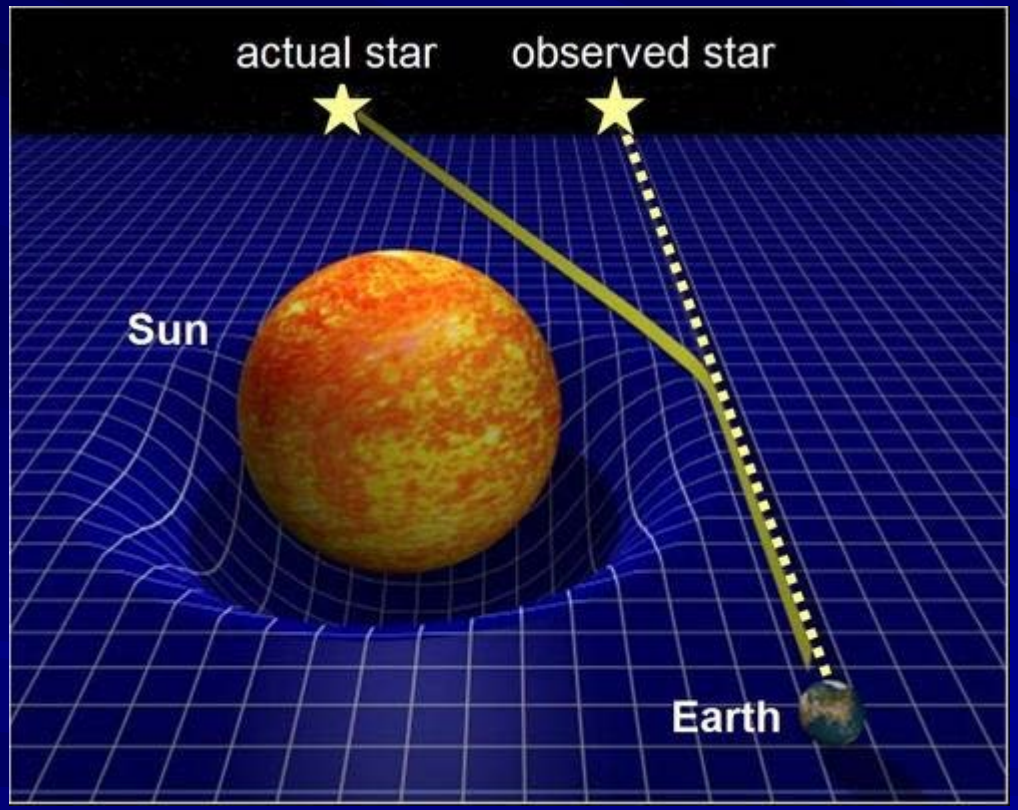
Stars Not Where They Seemed or Were Calculated to be, but Nobody Need Worry.

A BOOK FOR 12 WISE MEN

No More in All the World Could Comprehend It, Said Einstein When His Daring Publishers Accepted It.

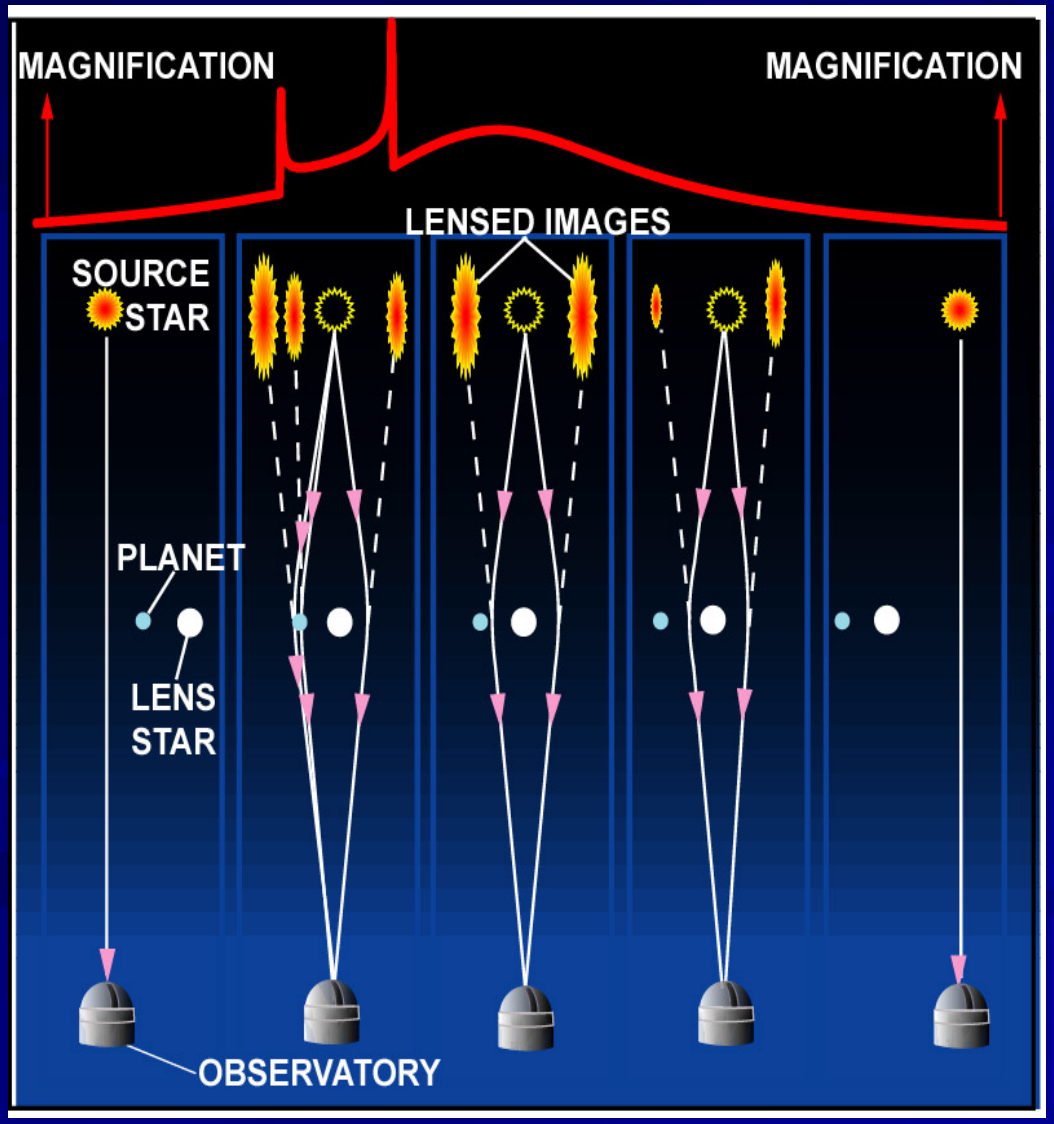


General Relativity and Curved Space



In Einstein's theory, there is no "force of gravity". Rather, the presence of mass curves the space around it.

“Einstein Rings” and the search for other planets



“there is no great chance of observing this effect”

Now one of several techniques used to discover exoplanets

Moving disturbances in the field will generate spacetime waves which propagate at the speed of light through universe!

Gravity waves are waves in the fabric of spacetime.

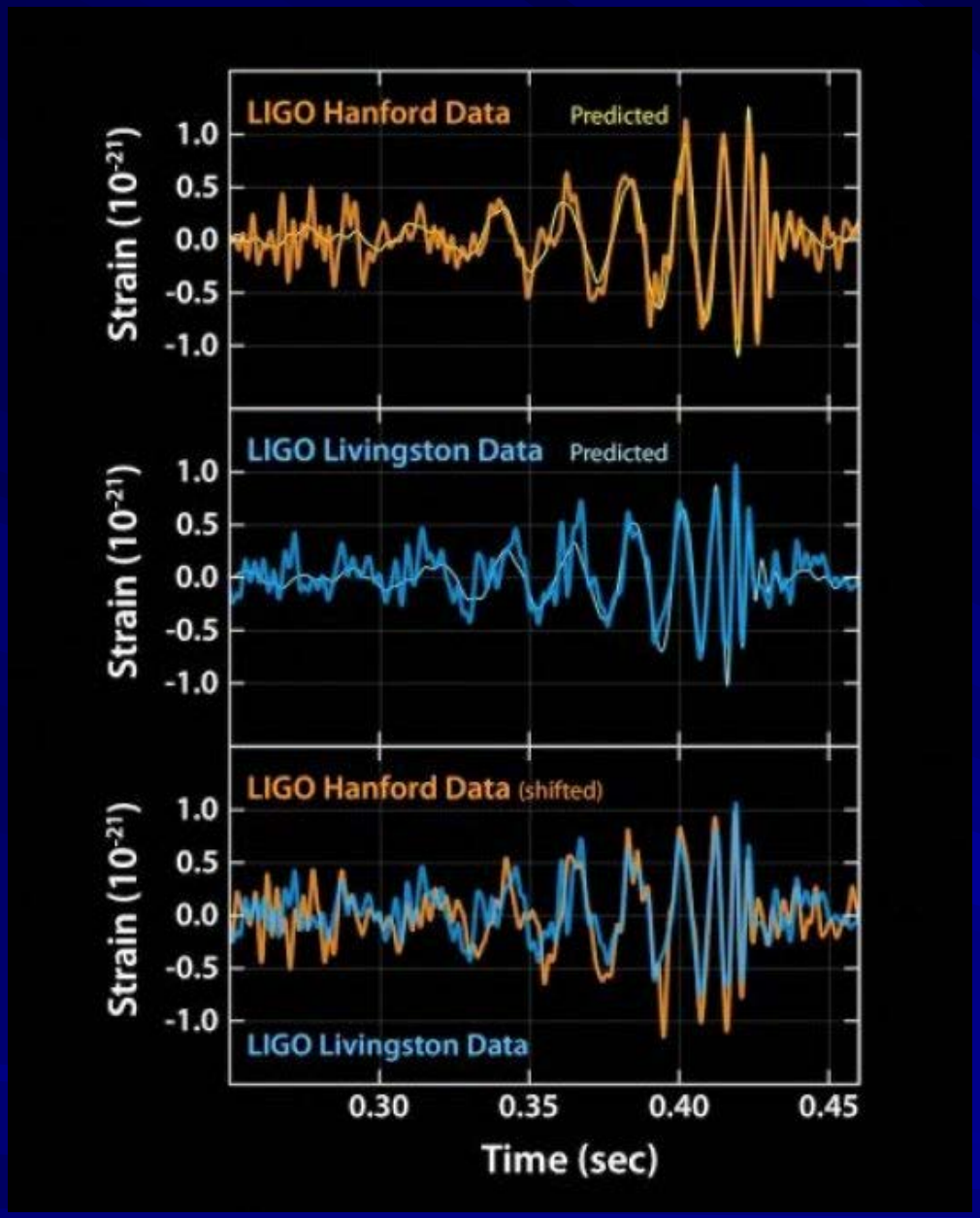
Motion of large masses generates “large” waves, but still very hard to detect.

As wave passes through a region, the space and everything in it grows and shrinks.

We use this fact to detect the gravity waves.

LIGO: Laser Interferometry Gravitational Observatory

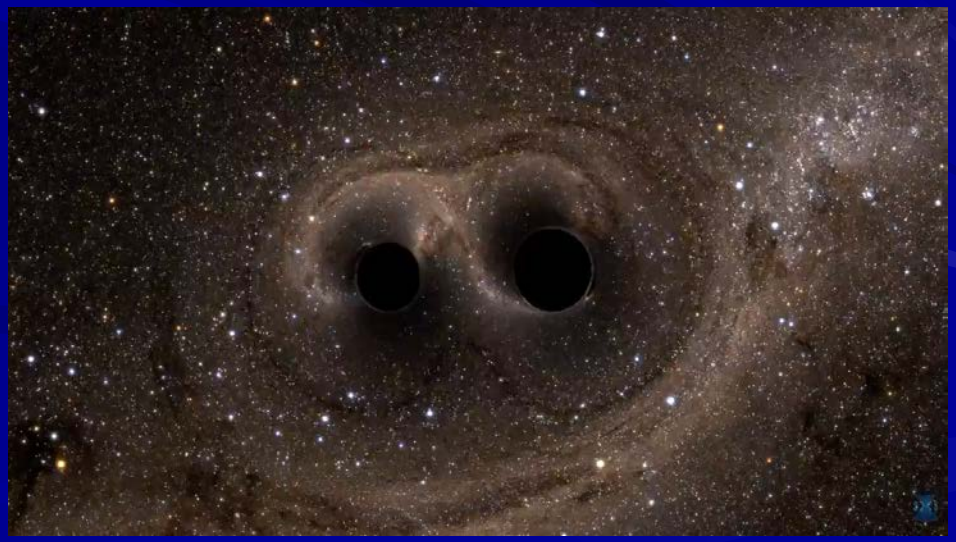
Two pairs of 2.5-mile long laser cavities in Washington and Louisiana.



Signal lasted only a fraction of second.

Total change in length of cavities was less than 1/1000 of width of a proton!

The data matches a model for two black holes colliding with masses equal to 29 and 36 solar masses, 1.4 billion light-years



1921 Nobel Prize in Physics

“For his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect."

Why not Relativity?

“[The Theory of Relativity] pertains essentially to epistemology and has therefore been the subject of lively debate in philosophical circles. It will be no secret that the famous philosopher Bergson in Paris has challenged this theory, while other philosophers have acclaimed it wholeheartedly. The theory in question also has astrophysical implications which are being rigorously examined at the present time.”

The Later Years

1933 – Although at the height of his fame, the rampant anti-semitism of Nazi Germany forces Einstein to leave for the United States, settling in Princeton, N.J.

1939 – Einstein writes a letter to FDR warning that Germany is working on an atomic bomb and urges U.S. to do the same

1940 – Einstein becomes an American citizen

1952 – Einstein declines an offer to succeed Chaim Weizman as the President of Israel

The Later Years – Science

Quantum Mechanics

Einstein: “God does not play dice with the universe.”
Bohr: “Einstein, stop telling God what to do!”

Einstein’s “biggest blunder”

A cosmological constant to keep the universe static

A grand theory of everything

We are part of the way there – perhaps string theory is the answer?

Einstein and Religion

Einstein did not believe in a personal God who concerned himself with the fates and actions of human beings.

"I cannot conceive of a God who rewards and punishes his creatures, or has a will of the kind that we experience in ourselves."

But he did believe in:

A "God who reveals himself in the harmony of all that exists."

"A spirit is manifest in the laws of the universe in the face of which we, with our modest powers, must feel humble."

On the supposed incompatibility of science and religion he said:

“Science can only be created by those who are thoroughly imbued with the aspiration toward truth and understanding. This source of feeling, however, springs from the sphere of religion . . . I cannot conceive of a genuine scientist without that profound faith.”

And:

“Science without religion is lame, religion without science is blind.”

April 18, 1955

Albert Einstein dies peacefully in his sleep