Space and Time

Why space and time?

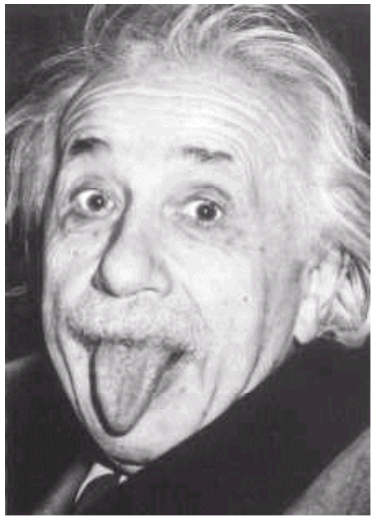
- Related to our work at Fermilab
- Hopefully related to things you're learning in school
  - Physics and astronomy, but also chemistry
- Some really interesting questions about the world
  - Where do things happen? In space ...
  - When do things happen? In time ...

Why Einstein?

- Because … he was Einstein!
- Easily the greatest physicist and scientist in modern history. One of the great men of the 20th century

School boy

1905: Clerk in Patent Office



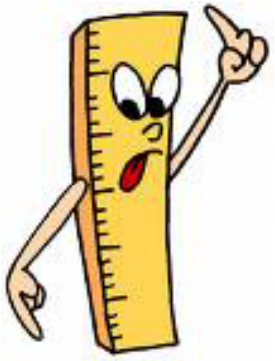
At older age!

What did Einstein do?

- Many, many discoveries. Easily could have won 3-4 Nobel prizes
  - He was a really smart man!
- I will talk today about his two theories of relativity (Special Relativity and General Relativity)
  - $E=mc^2$ (special relativity)
  - Black holes (general relativity)

Space and time (a student's perspective?)

- Space
  - This piece of paper is 8 inches long
  - It is 1.5 miles from the school to the store



- Time
  - I have to get up at 7 am
  - The bus is 20 minutes late

- But …
  - What do we mean by distance (such as 1.5 miles)?
  - What do we mean by a time (such as 7 am)?

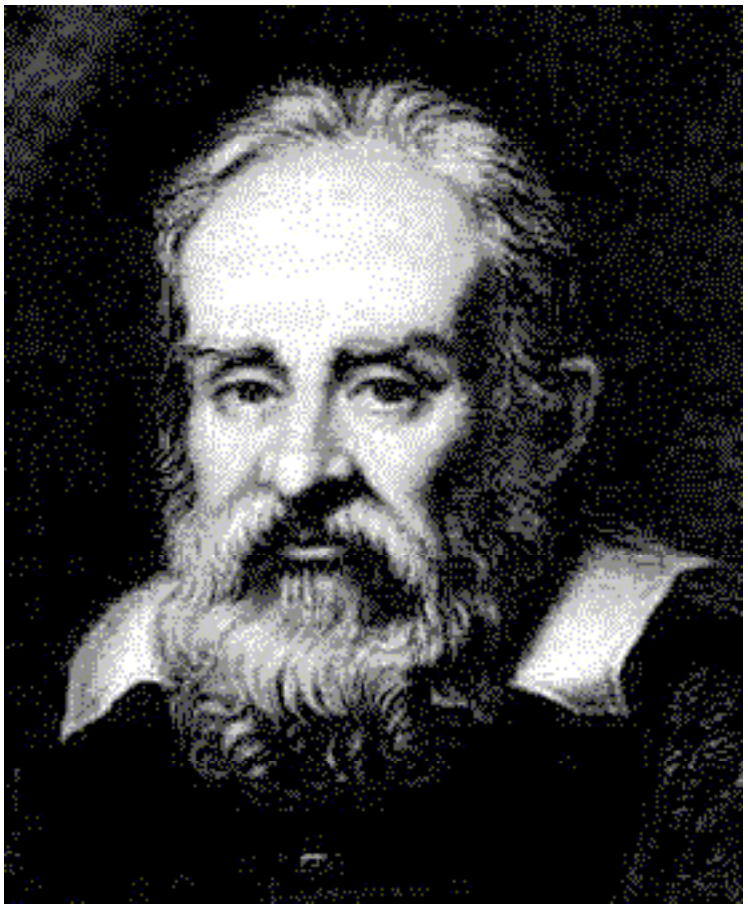
Space and time for Aristotle

- The “prime mover”
  - An unknown, priviledged being in THE state of perpetual, absolute rest
- Space
  - Defined by (x, y, z) coordinate system with respect to the prime mover
  - Unique and clearly defined
- Time
  - Time is measured by the prime mover’s clocks

Aristotle (384-322 BC)

Space for Galileo

- No such things as “absolute rest”
- The laws of nature and physics are identical for anybody moving with a constant speed along a straight line

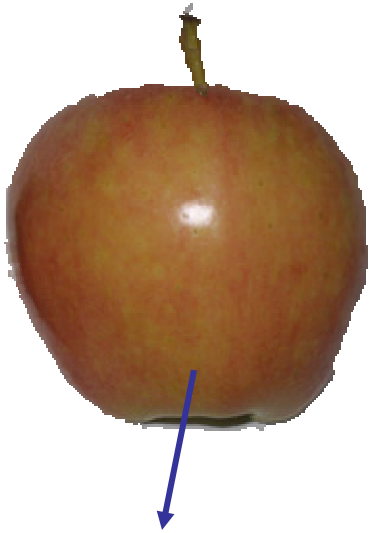


Galileo Galilei (1564-1642)

Space for Sir Isaac Newton

• “Absolute Space, in its own nature, without regard to any thing external, remains always similar and immovable. Relative Space is some moveable dimension or measure of the absolute spaces; which our senses determine, by its position to bodies; and which is vulgarly taken for immovable space ... And so instead of absolute places and motions, we use relative ones”

  – There exists absolute space, but we measure space only relative to other objects in space



Isaac Newton (1643-1727)

Time for Sir Isaac Newton

• “Absolute, True, and Mathematical Time … flows equably without regard to any thing external … Relative, Apparent, and Common Time is some sensible and external (whether accurate or unequable) measure of Duration by the means of motion, which is commonly used instead of True time; such as an Hour, a Day, a Month, a Year.”

– There exists an absolute time, but we measure relative time only

$$\iiint_{z} \vec{x}^{\,2} dx$$

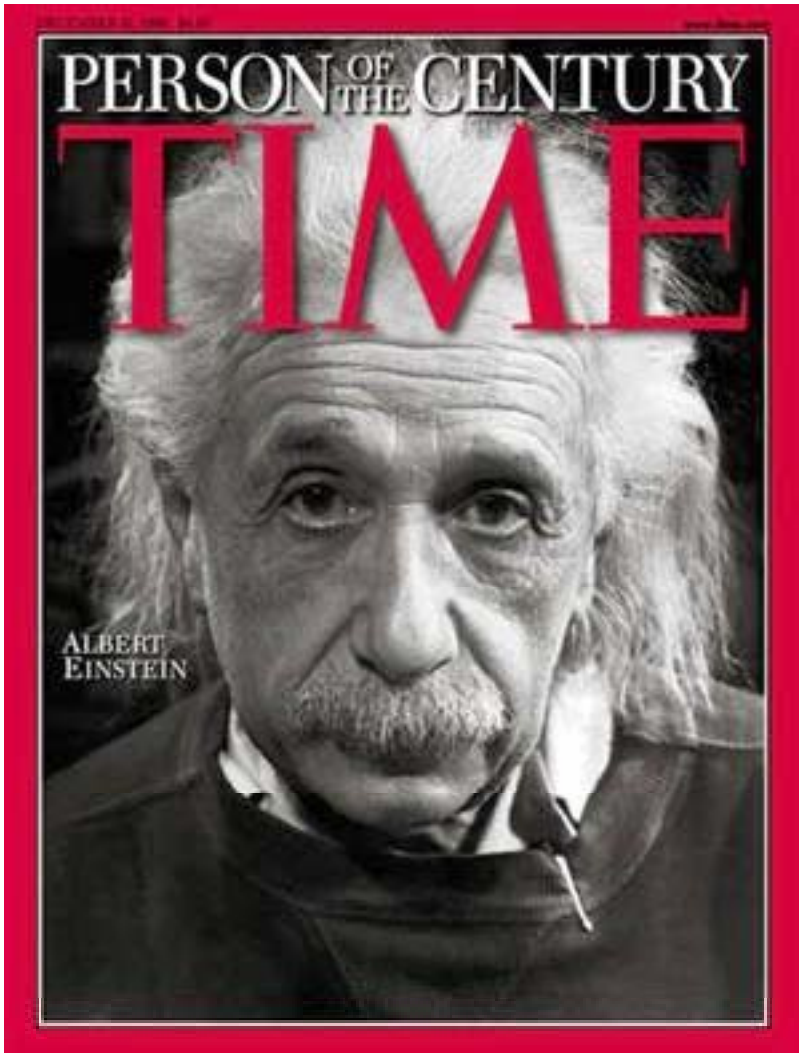
Isaac Newton (1643-1727)

Einstein's genius

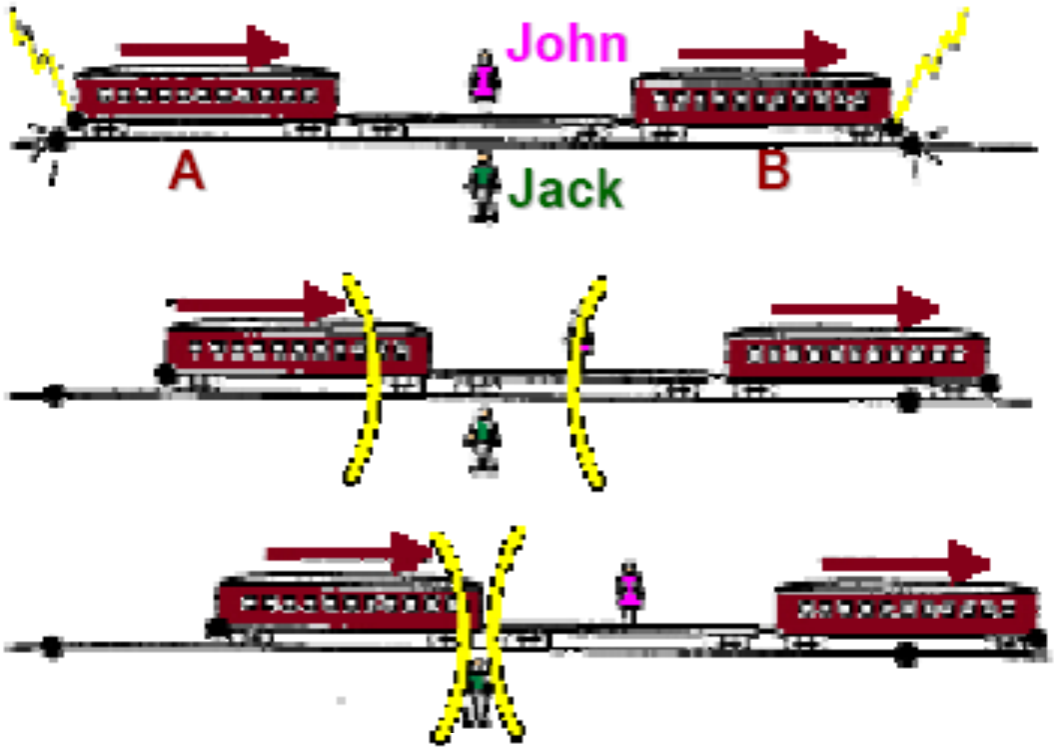
Change the definition of time:

"It might appear possible to overcome all the difficulties attending the definition of 'time' by substituting 'the position of the small hand of my watch' for 'time' ".

Example:
By " 'That train arrives here at 7 o'clock,' I mean something like this: 'The pointing of the small hand of my watch to 7 and the arrival of the train are simultaneous events' "
- famous 1905 Einstein paper



So what?

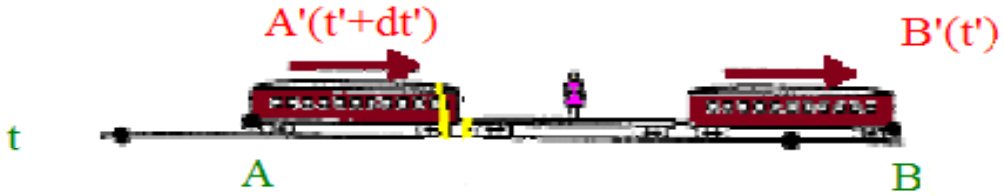


From the point of view of Jack, lightening struck both train cars at the same time

From the point of view of John, lightening struck car B first and then car A later

Simultaneity is relative - things occurring at the same time at one place may occur at different times in another place!

So how do we measure things?



Need signals to talk about space and time!

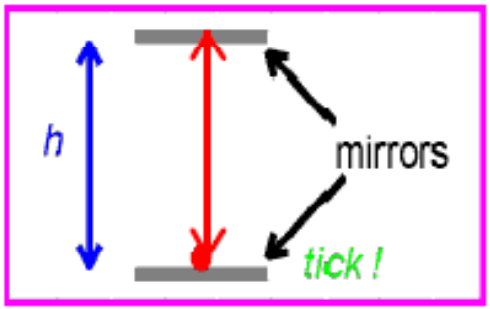
John sends out a **signal** to mark the ends of the train that he's on

From the point of view of someone on the ground, the signal takes longer(shorter) to reach the right(left) side of the train

Relativity of simultaneity -> relativity of distance! A moving train appears to be shorter!

How do we measure time?

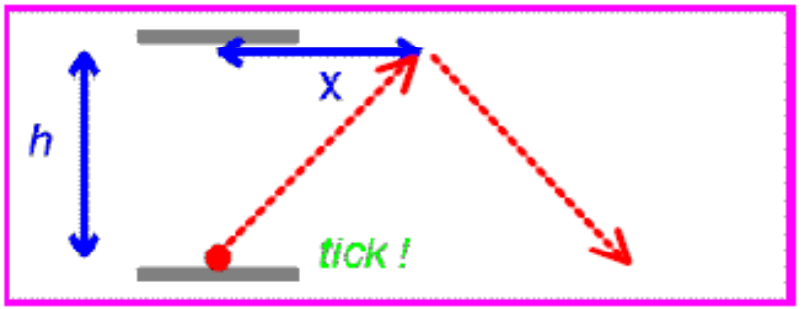
Stationary clock:



$$t_0 = \frac{h}{c}$$

c=speed of light

Moving clock:



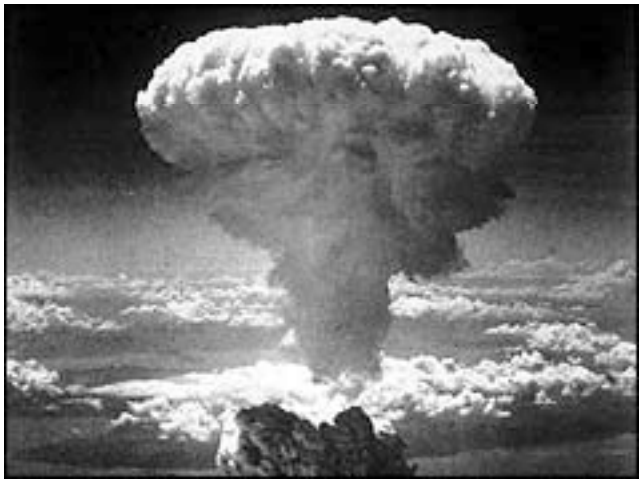
$$t = \frac{\sqrt{h^2 + x^2}}{c}$$

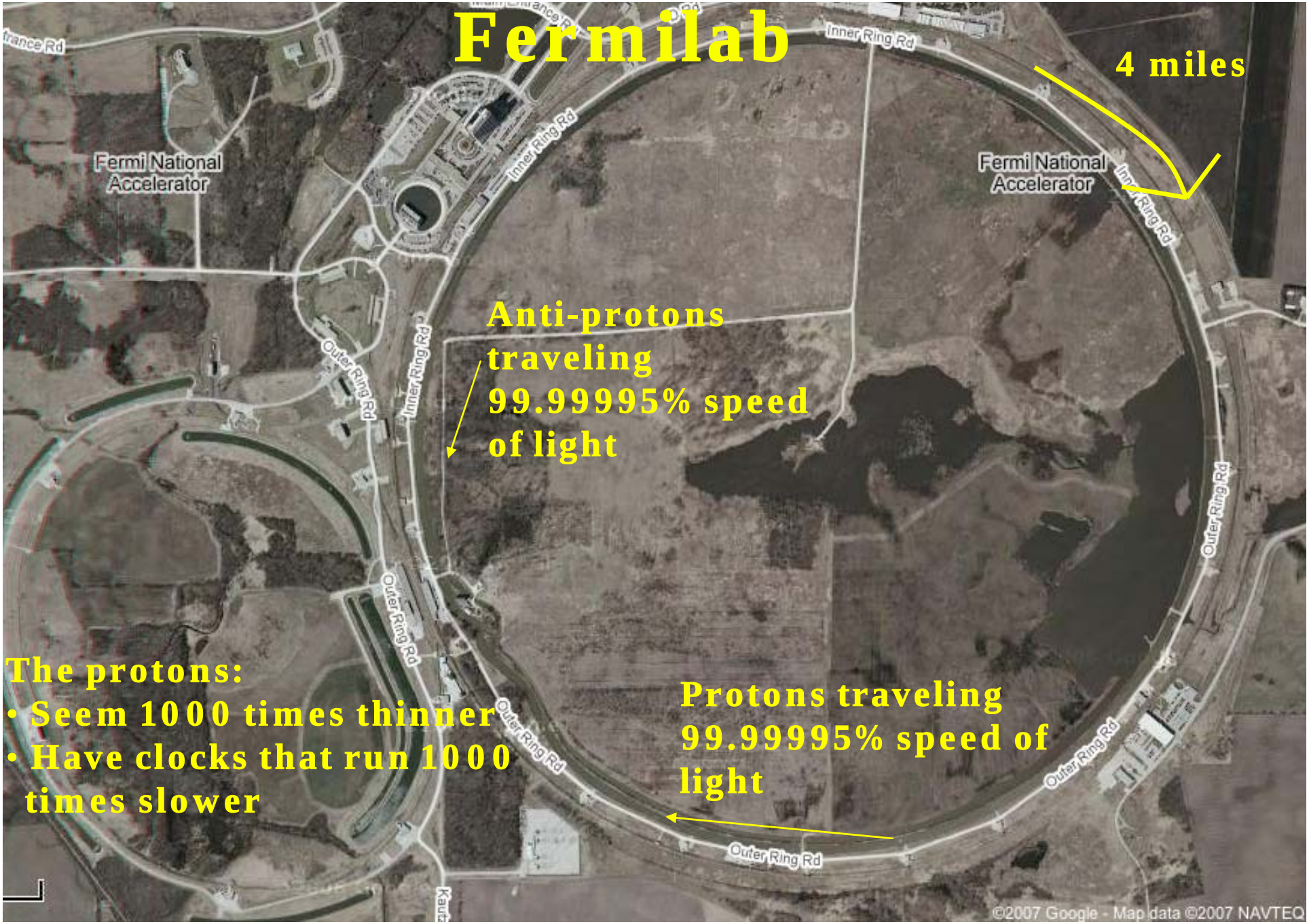
Imagine a clock that measures time by how long it takes light to bounce back and forth ...

Relativity of distance -> relativity of time!

Putting it all together

- The only way we can measure time and distance is by sending signals
  - Time and distance are relative
- The fastest signal travels at the speed of light
  - Nothing can travel faster than light
- Moving objects appear smaller and slower in space
  - But the effect is really small for everyday movement
- A result of the theory of special relativity: $E=mc^2$




Fermilab
4 miles
Fermi National Accelerator
Fermi National Accelerator
Inner Ring Rd
Outer Ring Rd
Anti-protons traveling 99.99995% speed of light
Protons traveling 99.99995% speed of light
The protons:
• Seem 1000 times thinner
• Have clocks that run 1000 times slower
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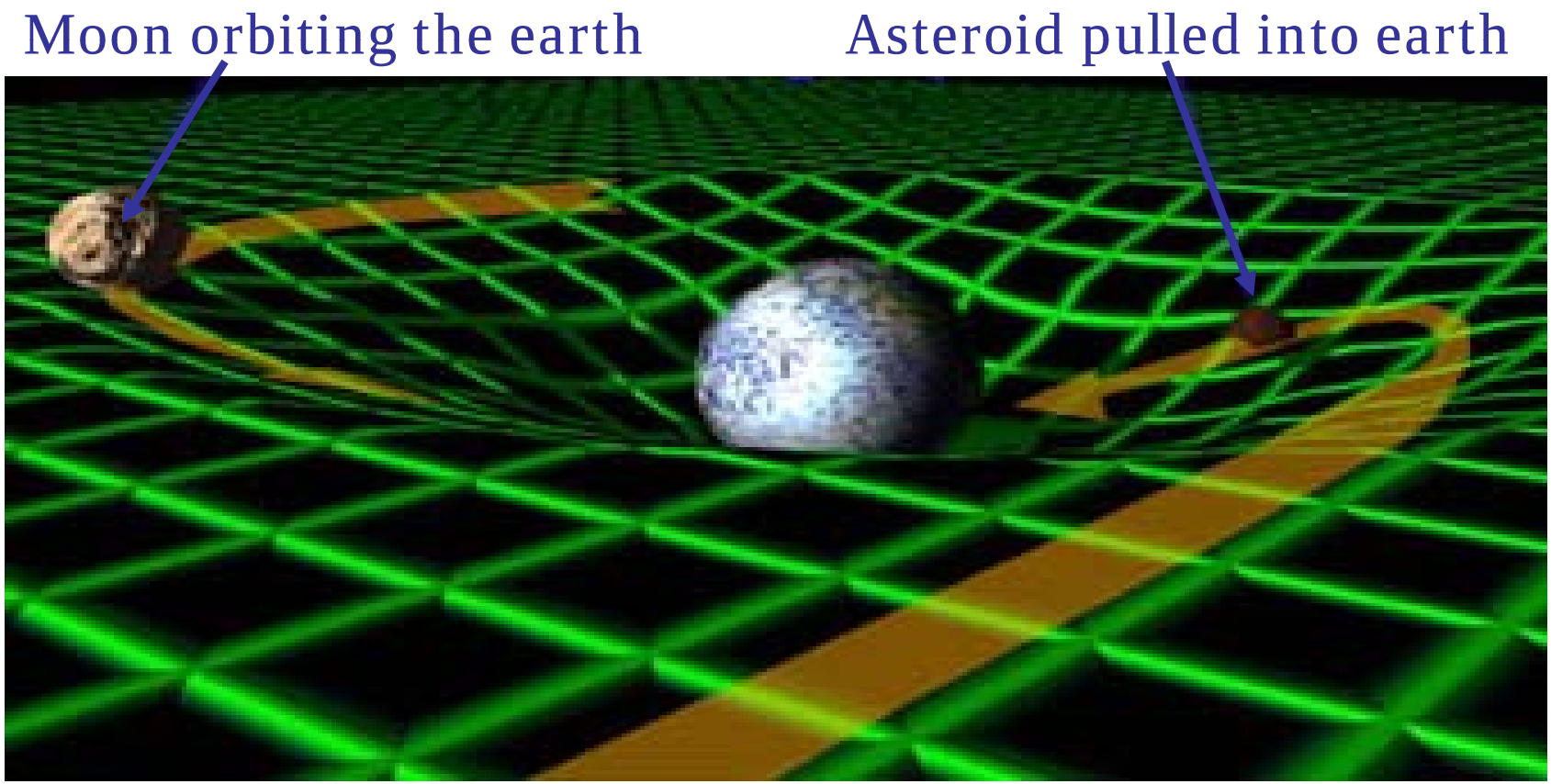
What about the other definition of space (all the stuff up in the sky and in the universe?)

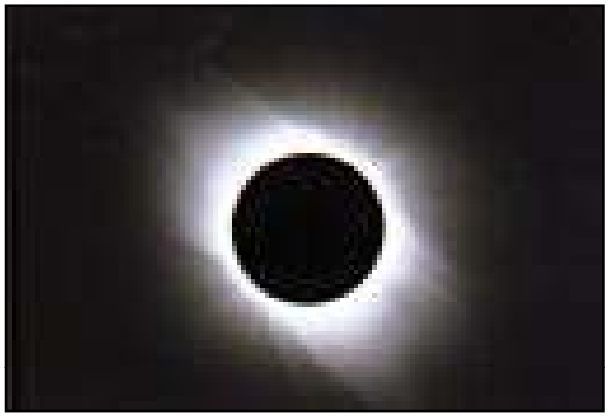
Einstein's General Relativity

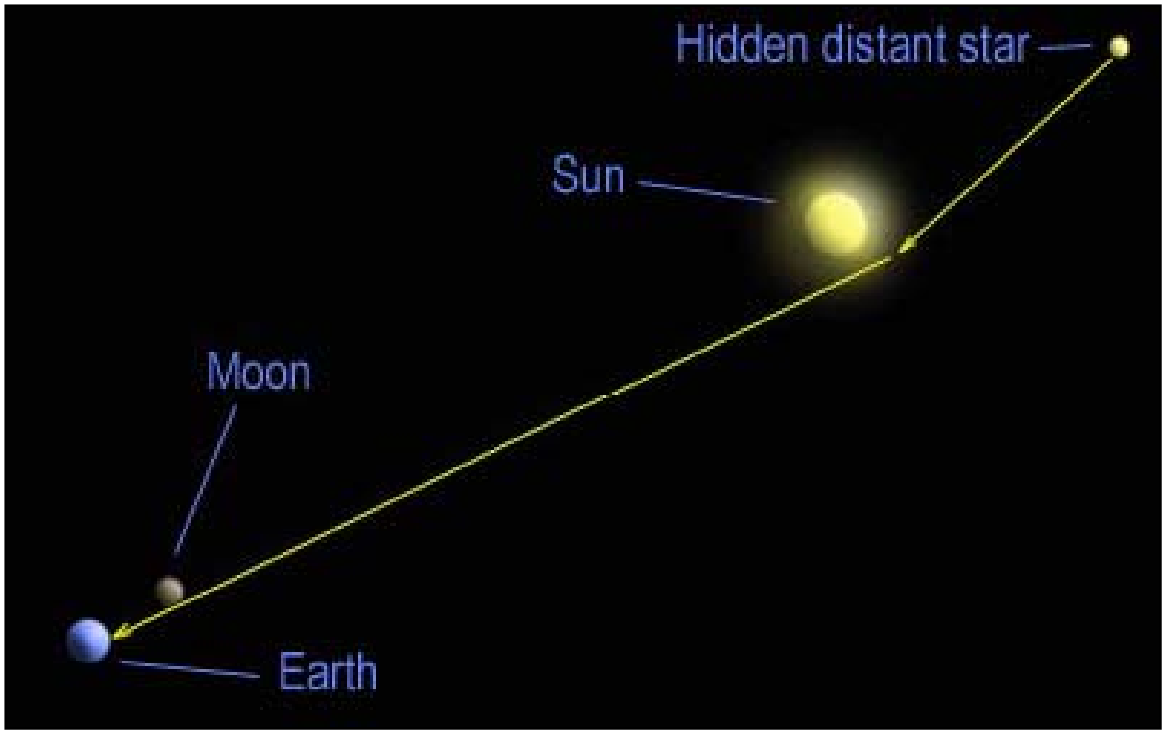
- We already know that space and time are intertwined
- Gravity is a distortion of space and time itself



Even light is bent by gravity!

The position of a star observed during an eclipse confirmed Einstein's theory

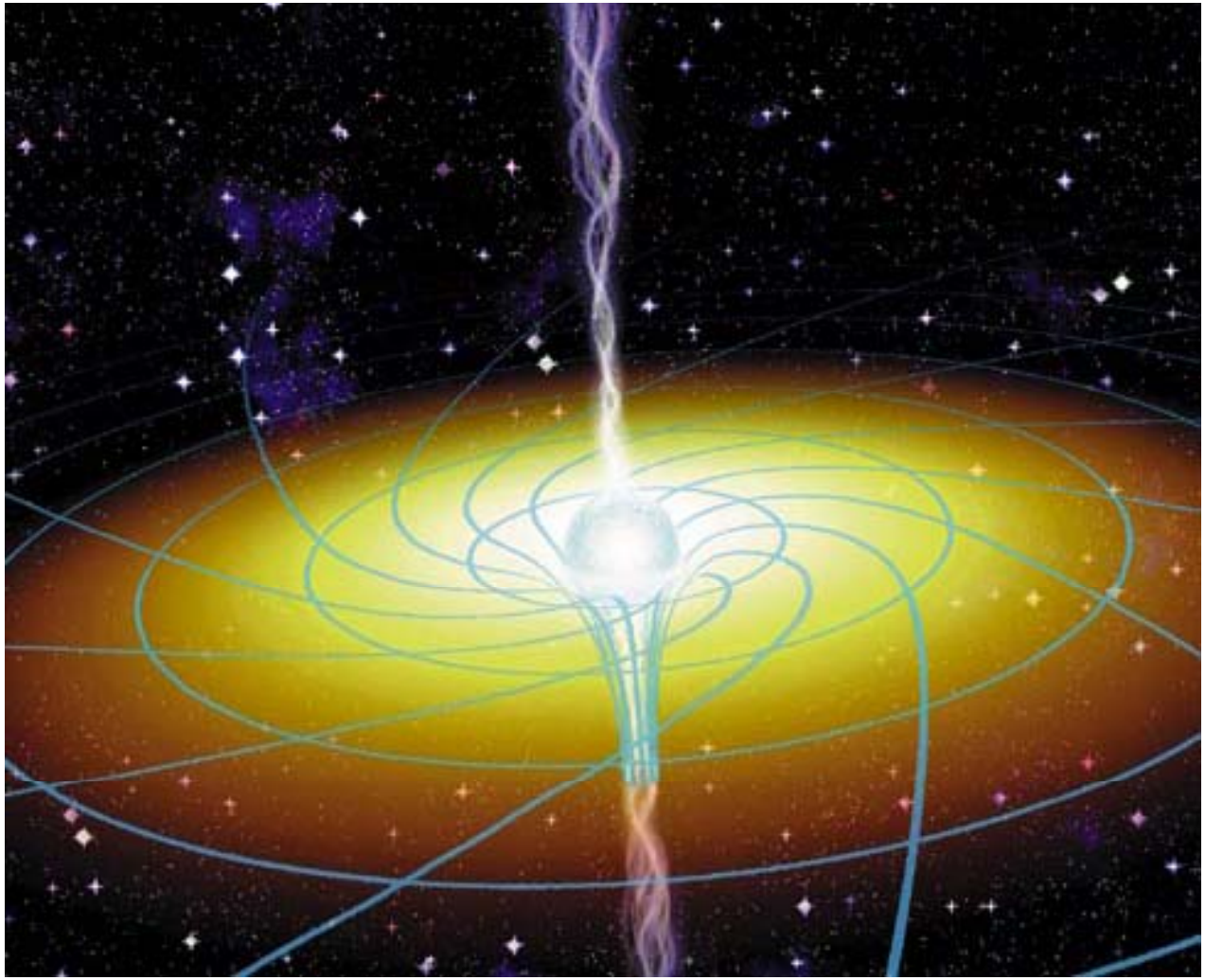




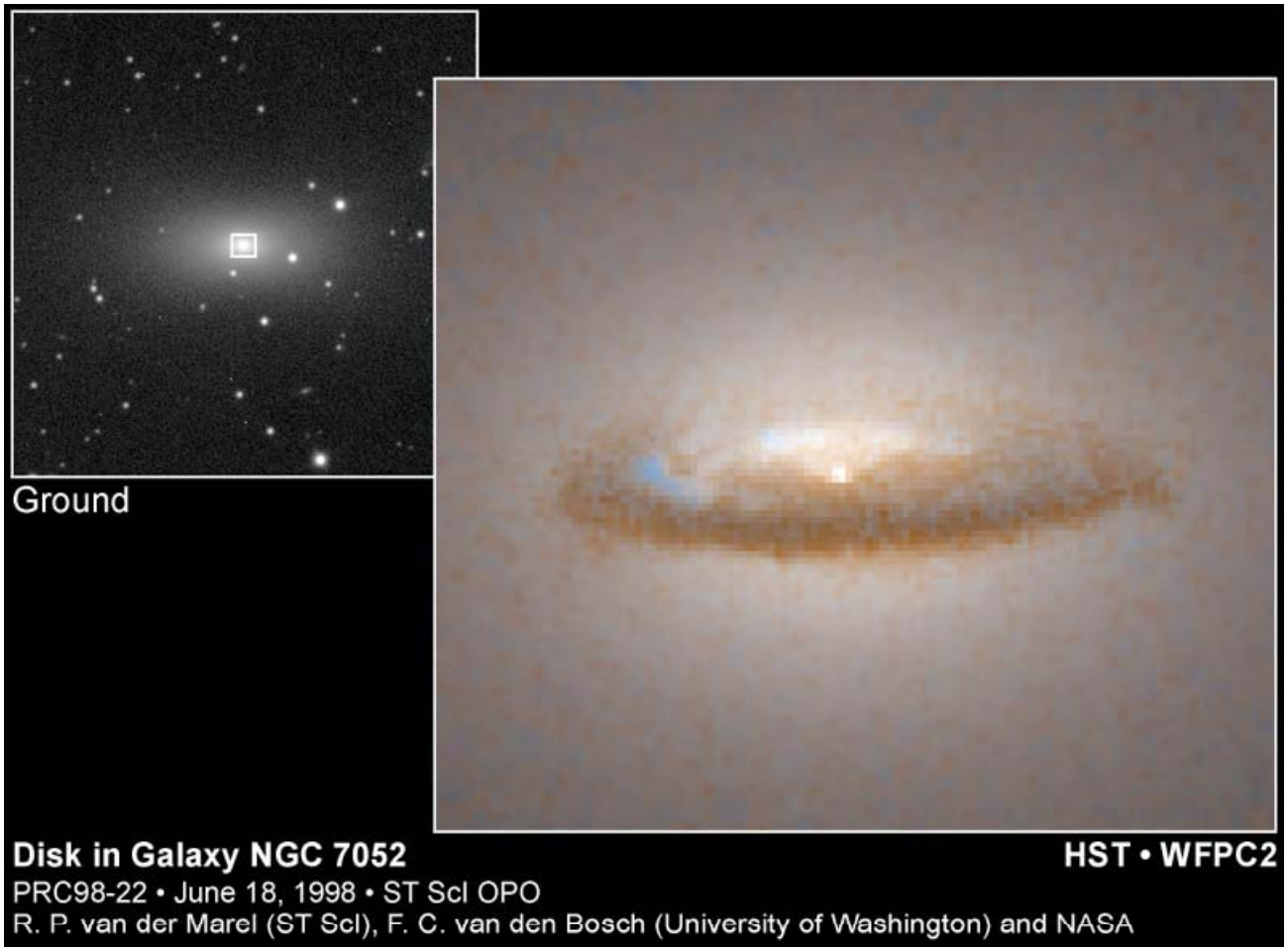
Black holes

Dying stars can become black holes - gravity to an extreme! At some point, even light cannot escape!

So named as “black holes” because you cannot see them ... but you can see stuff around them

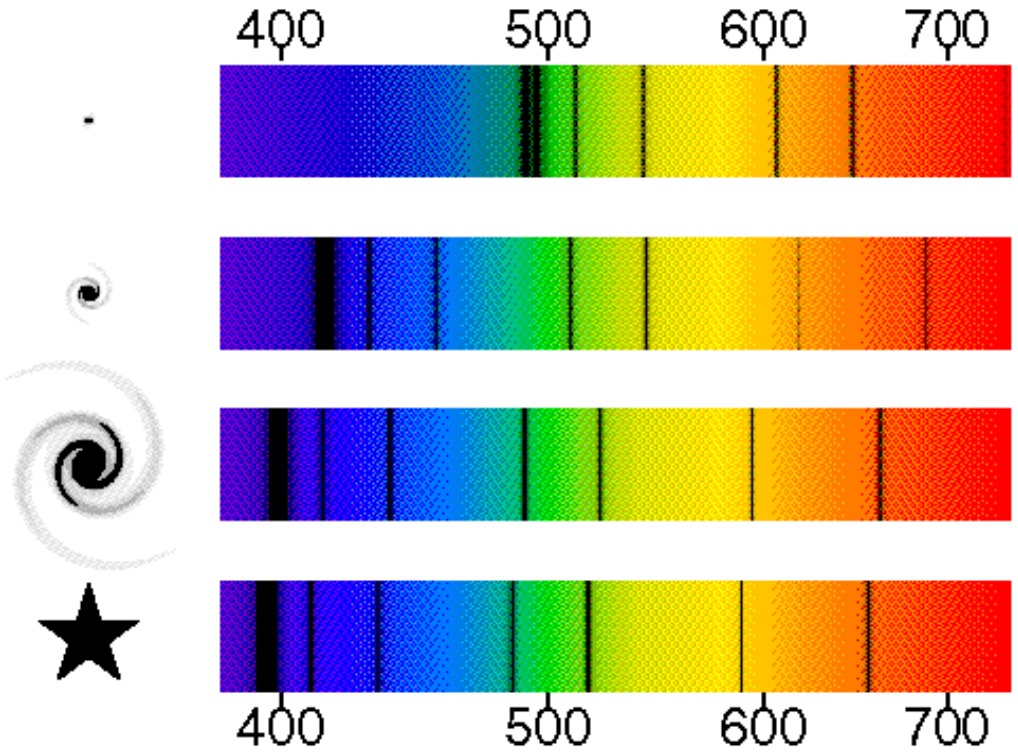


Black hole evidence



Hubble telescope observing a disk of dust orbiting around a black hole!

Relative motion in the Universe

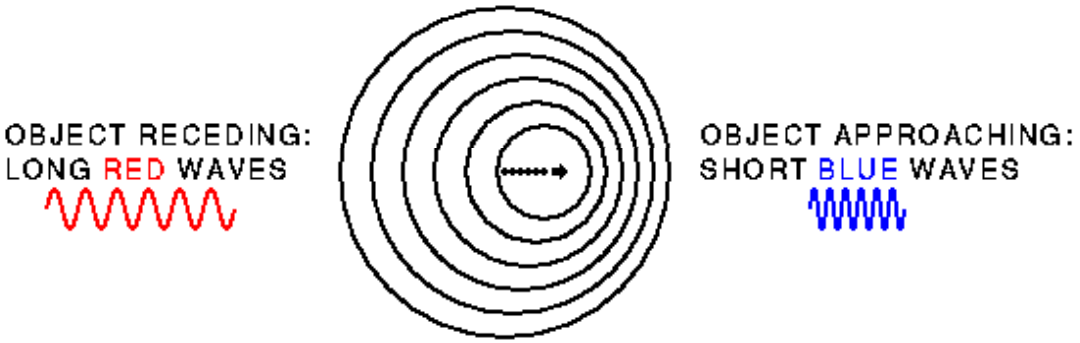


Red shift

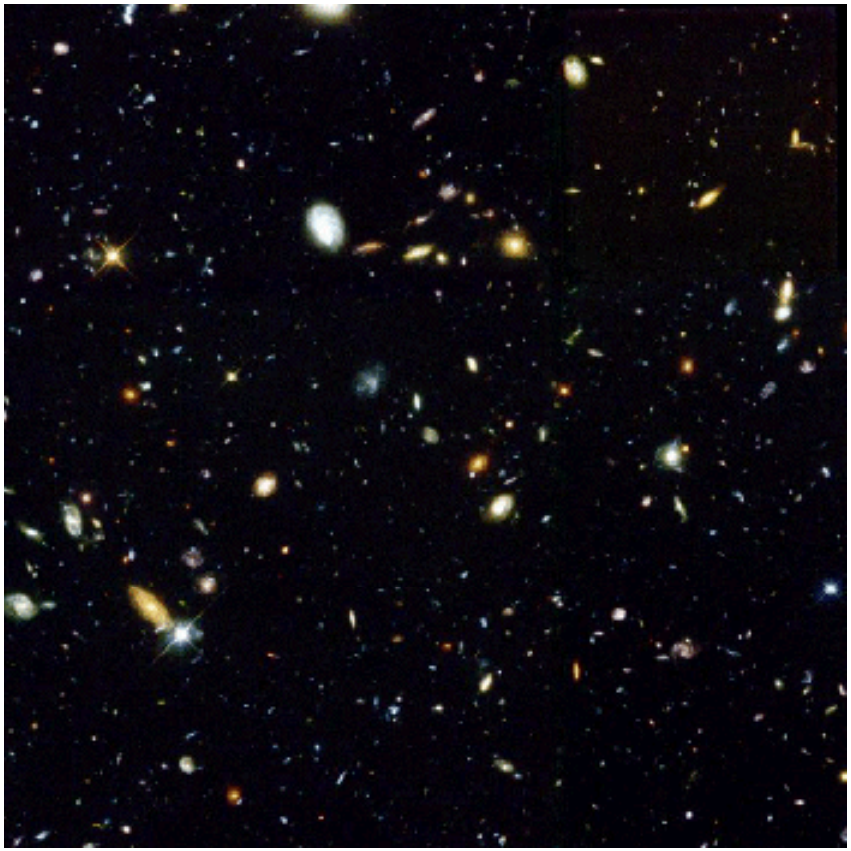
(Object moving away)

Red shift

(Object moving away)



The Universe is expanding!



A small view from the Hubble Space Telescope. Each blob is a galaxy with 100,000,000,000 stars!

The stars are all moving away from us, and away from one another

The Big Bang: The Universe was really tiny at its birth 13.5 billion years ago

Summary

- Space and time are relative
- Moving things look shorter and move slower
- Space-time is bent by matter
- Light is bent by matter
- Redshift and blueshift of light is used to detect relative motion in the universe
- The present universe is expanding
- If you want to learn more about the universe, Einstein or smashing protons and anti-protons together ...

Fermilab

- Come visit Fermilab!
- Lots of fun science demos at the lab's Lederman Science Center
- Walk the prairies
- See the lab's bison
- Come for ask-a-scientist
- www.fnal.gov