33-120
Science & Science Fiction

Welcome!

Today:

***Modern Physics* – Einstein & Relativity (continued)**

- **Problem 1** due today

- **Problem 2** due next Friday, September 15
  - Time dilation on the ISS
  - Example calculation in class today

Announcements for Friday, September 8

- **Spacetime Team Project Day: Monday, 9/18 (a week from this coming Monday)**
  - **Einstein's *Principle of Equivalence***
  - **No lecture – gather data for project**
  - **Team assignments TBA next week**
  - **Pick up equipment next week**

Previews of coming attractions…

Doctor Who

"Blink"

Written by Steven Moffat

BBC (2007)

Last time…

What is the nature of space and time?

Part B. Einstein and *Modern Physics*

What is time? Is time travel possible?

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Doctor Who

The TARDIS

(a.k.a. “the blue box”)

Time And Relative Dimension In Space

What is time?
Is time travel possible?

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- **Special Theory of Relativity (1905)**
  - ***Spacetime* as a 4-dimensional "fabric"**
  - **Perception of space and time depend on relative motion**
  - **Speed of light constant for everyone**
  - **$E=mc^2$**

What is the nature of space and time?

Part B. Modern Physics: Einstein and Relativity

- **General Theory of Relativity (1916)**
  - **Gravity = distortion of *spacetime* near a large mass**
    - **gravitational time dilation**
    - **NOT instantaneous (effect propagates at speed of light)**
  - **Black Holes and Gravitational Waves**

What is the nature of space and time?

Part 2. Modern Physics: Einstein and Relativity

Planet of the Apes

Directed by Franklin J. Schaffner

20th Century Fox (1967)

What is time?
Is time travel possible?

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Calculation of time dilation and speed in *Planet of the Apes*

The constancy of the speed of light

Can anything travel faster than light?

Today…
Further discussion about time and time travel

Planet of the Apes

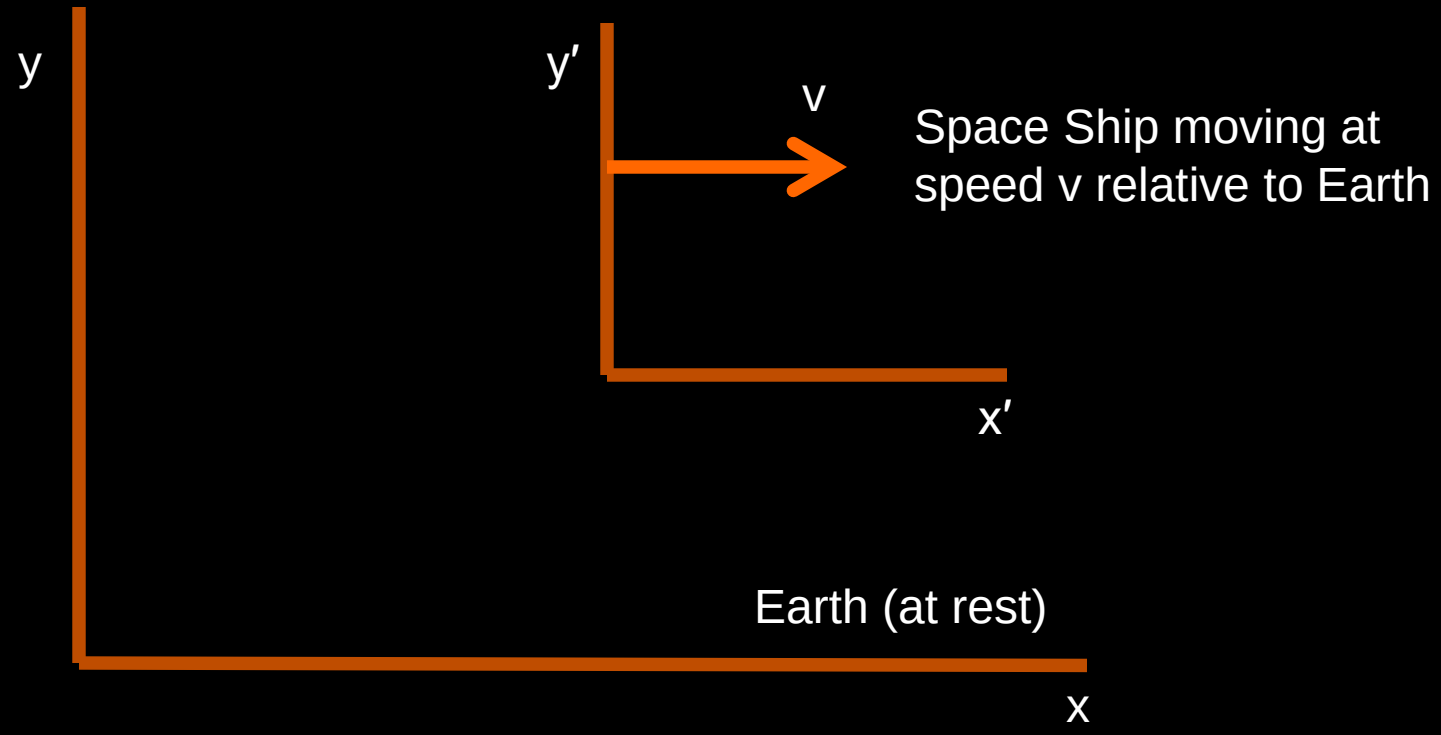
Space ship launch date: **01-14-1972**

Current date on space ship: **07-14-1972**

Current date on Earth: **03-23-2673**

6 months on ship = 702 years on Earth!

What is time?
Is time travel possible?



Time *slows down* in a moving reference frame.

Einstein: Relative motion changes your perception of time.

$$t = \frac{t'}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Time (t) passes more quickly at rest.

Time (t′) slows down in a moving frame.

Einstein: Relative motion changes your perception of time.

$$t = \frac{t'}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Ship time (moving): t′ = 6 months

Earth time (at rest): t = 702 years

How fast was the ship traveling? (v = ?)

Einstein: Moving clocks run slow relative to clocks at rest.

$$t = \frac{t'}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Solve time dilation equation for v/c:

$$\sqrt{1 - \frac{v^2}{c^2}} = \frac{t'}{t}$$

***Planet of the Apes*: What fraction of the speed of light (v/c) was the *average* speed of the ship?**

Solve time dilation equation for v/c:

$$\sqrt{1 - \frac{v^2}{c^2}} = \frac{t'}{t}$$

$$1 - \frac{v^2}{c^2} = \frac{t'^2}{t^2}$$

***Planet of the Apes*: What fraction of the speed of light (v/c) was the *average* speed of the ship?**

Solve time dilation equation for v/c:

$$1 - \frac{v^2}{c^2} = \frac{t'^2}{t^2}$$

$$\frac{v}{c} = \sqrt{1 - \frac{t'^2}{t^2}}$$

***Planet of the Apes*: What fraction of the speed of light (v/c) was the *average* speed of the ship?**

Plug in values for ship time (t′ = 6 months) and Earth time (t = 702 years)

$$\frac{v}{c} = \sqrt{1 - \frac{t'^2}{t^2}} = \sqrt{1 - \frac{(0.5\ y)^2}{(702\ y)^2}}$$

$$= \sqrt{0.9999994927}$$

$$\frac{v}{c} = 0.999999746$$

***Planet of the Apes*: What fraction of the speed of light (v/c) was the *average* speed of the ship?**

Plug in values for ship time (Δt′ = 90 sec.) and Earth time (Δt = 3 days)

$$\frac{v}{c} = \sqrt{1 - \frac{\Delta t'^2}{\Delta t^2}} = \sqrt{1 - \frac{(90\ s)^2}{(259,200\ s)^2}}$$

$$\frac{v}{c} = 0.999999940$$

***Planet of the Apes*: What fraction of the speed of light (v/c) is the *current* speed of the ship?**

Average: $\frac{v}{c} = 0.999999746$

Current: $\frac{v}{c} = 0.999999940$

Current speed > Average speed…

Acceleration!

***Planet of the Apes*:**
Compare average speed to current speed

$$t = \frac{t'}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Homework problem due next Friday, 9/15 :

Look up speed of the International Space Station

and calculate time dilation factor $\frac{\Delta t'}{\Delta t}$

Compare identical twins – one on ISS, one on Earth

Einstein: Moving clocks run slow relative to clocks at rest.

$$t = \frac{t'}{\sqrt{1 - \frac{v^2}{c^2}}}$$

- Moving clocks run slow relative to clocks at rest.
- Take a round trip at close to the speed of light.
- Come home after 6 months (ship time) and arrive hundreds of years in the future (Earth time).

Back to the Sci-Fi question:
Is time travel possible?

$$t = \frac{t'}{\sqrt{1 - \frac{v^2}{c^2}}}$$

- What would happen if v > c?
- What is the square root of a negative number?
- *Imaginary* time, not negative time!
- **Moving clocks run slower, but never backwards.**

Could Einstein's equation allow for time travel into the past?

- **Special Theory of Relativity**
  - ***Spacetime* as a 4-dimensional "fabric"**
  - **Perception of space and time depend on relative motion**
    - **Moving clocks run slow relative to clocks at rest.**
    - **Time travel is possible! (into the future but not the past)**

Review of Special Relativity so far…

- **Special Theory of Relativity, continued:**
  - **Speed of light constant for everyone**
    - **Only *massless* particles can travel at the speed of light.**
    - **Nothing can travel faster than light.**

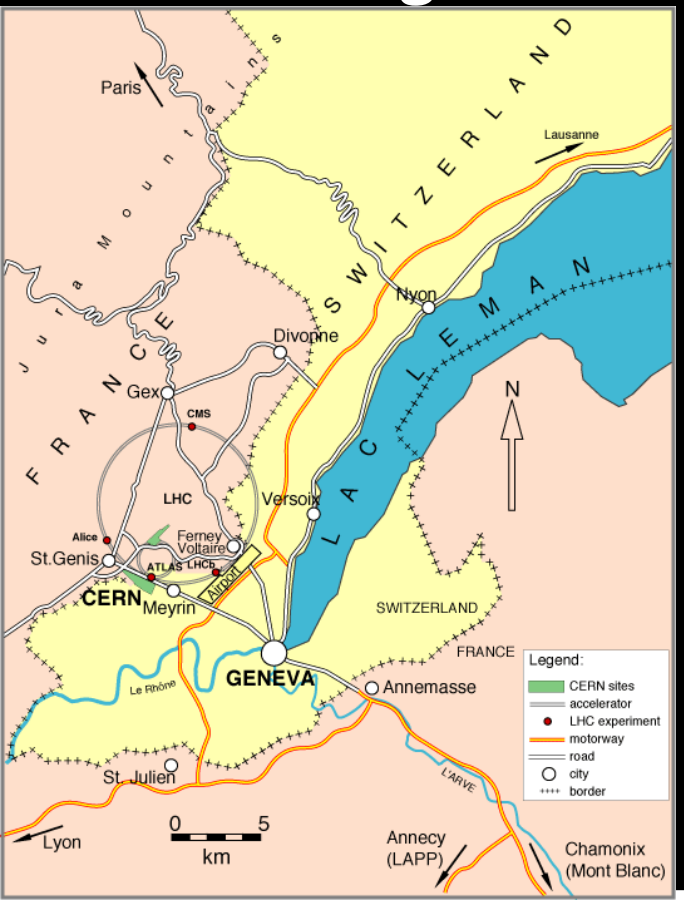
The constancy of the speed of light

The Big Bang Theory
"The Isolation Permutation"

Directed by Mark Cendrowski
Warner Brothers (2011)

Can anything travel faster than light?

Breaking News from CERN, 23 September 2011



Neutrinos from Large Hadron Collider (LHC)

Detected at Gran Sasso (Rome)

in less time than expected.

v > c ???

“Faster-than-light particles at CERN: paradigm-shifting discovery, or just another Swiss export, as full of holes as their cheese?”

- Sheldon Cooper, 11/03/2011

- Neutrino speed apparently exceeded speed of light by few parts per million.
- Einstein says nothing can travel faster than light.
- Is this a paradigm shift? (Was Einstein wrong?)

"Faster-than-light particles at CERN: paradigm-shifting discovery, or just another Swiss export, as full of holes as their cheese?"

- Sheldon Cooper, 11/03/2011

- **Several possible explanations…**
  - **A genuine paradigm shift**

    (comparable to relativity in early 20th century)
  - **An irreproducible mistake**

    (comparable to cold fusion in late 20th century)
  - **An identifiable mistake**

    (find it and fix it)

"Faster-than-light particles at CERN: paradigm-shifting discovery, or just another Swiss export, as full of holes as their cheese?"

- Sheldon Cooper, 11/03/2011

- Papers published to explain it…
  - Claimed support for quantum gravity
- Actual explanation…
  - An identifiable mistake
  - Faulty connection in timing circuit
  - No paradigm shift, after all
  - Quantum gravity papers retracted

"Faster-than-light particles at CERN: paradigm-shifting discovery, or just another Swiss export, as full of holes as their cheese?"

- Sheldon Cooper, 11/03/2011

- **Newton's Law of Gravitation:**

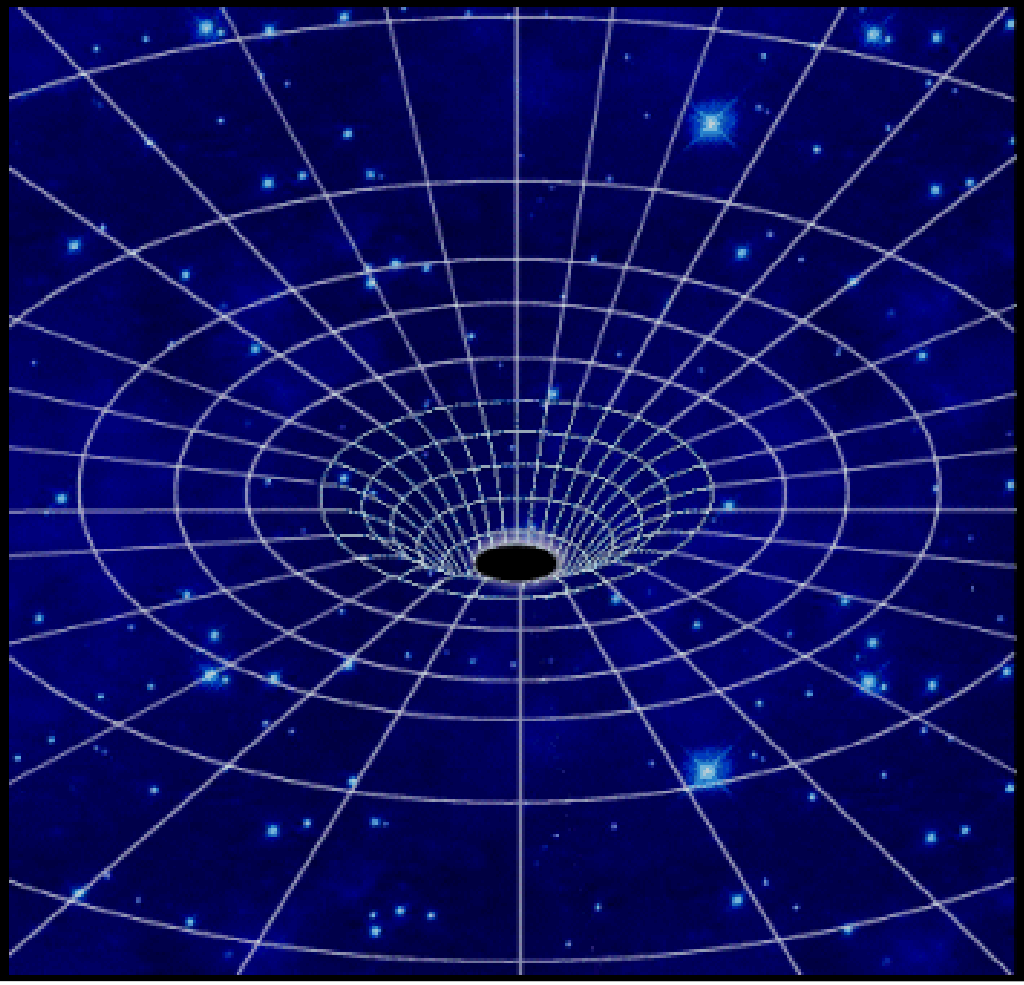
$$F = \frac{Gm_1m_2}{r^2}$$

  - Force is proportional to product of masses
  - Inversely proportional to distance squared
  - G = Newton's gravitational constant
  - Acts instantaneously over any distance

Comparing Newton's Law of Gravity to Einstein's concept of gravity

- **General Theory of Relativity**
  - **Gravity = distortion of *spacetime* near a large mass**
    - **gravitational time dilation**
  - **Black Holes (extreme distortion)**
  - **Gravitational waves**
    - **Effects of gravity propagate at speed of light, NOT instantaneously**

General Relativity (published 1916):
Another way to mess with your perception of time



General Relativity:
Fabric of spacetime distorted (stretched) near large mass

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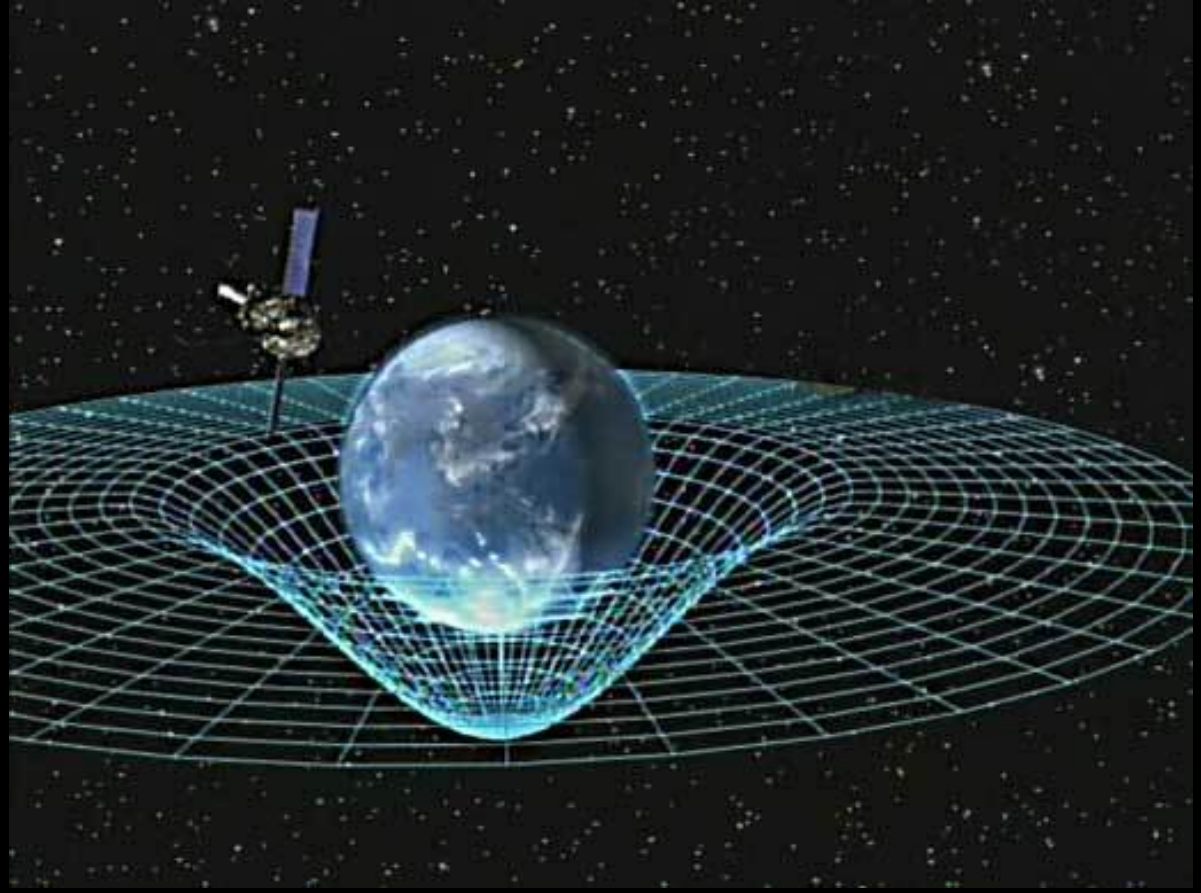
- **Gravitational Time Dilation:**

$$t_r = t_\infty \sqrt{1 - \frac{2Gm}{rc^2}}$$

  - t_r = time at some distance r from a mass m
  - t_∞ = normal time (infinitely far from the distortion)
  - G = Newton's gravitational constant

General Relativity:
Clocks run more slowly when closer to large mass



https://www.ligo.caltech.edu/page/what-are-gw

GPS: A Practical application of Relativity

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Next time…
How the GPS system works; Properties of Black Holes

Barry Luokkala

Teaching Professor of Physics

Carnegie Mellon University

Q&A…