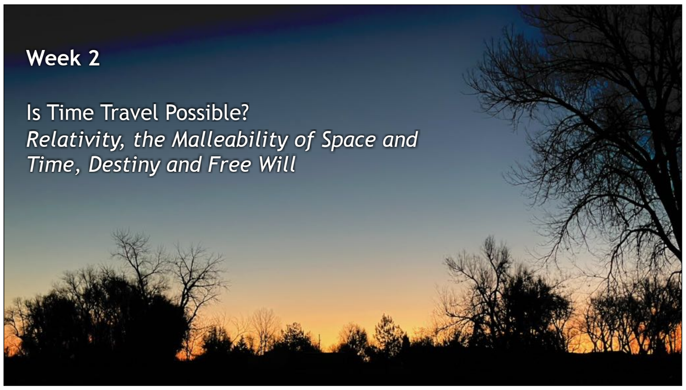


Week 2

Is Time Travel Possible?
Relativity, the Malleability of Space and Time, Destiny and Free Will

Is Time Travel Possible?

Answer #1: Not like this.

You can't build a time machine like you see in movies and cartoons.

Is Time Travel Possible?

Answer #2: Yes.

You came into this room before the hour.

It's now after the hour.

You have just moved forward in time.

Is Time Travel Possible?

Answer #3: Yeah. But it's pretty hard.

If you can travel back in time, can you have free will?

We'll talk.

Heat Engines

Temperatures are in Kelvin.

All temperatures are positive in Kelvin. The lowest possible temperature is zero.

Efficiency:

$$e = 1 - \frac{T_C}{T_H}$$

Reasoning From Equations

$$e = 1 - \frac{T_C}{T_H}$$

As a group, discuss:

What is the biggest value the efficiency can have?

Reasoning From Equations

$$e = 1 - \frac{T_C}{T_H}$$

As a group, discuss:

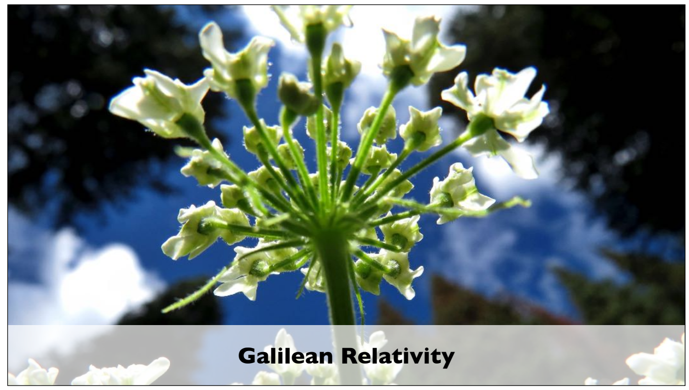
What is the smallest value the efficiency can have?

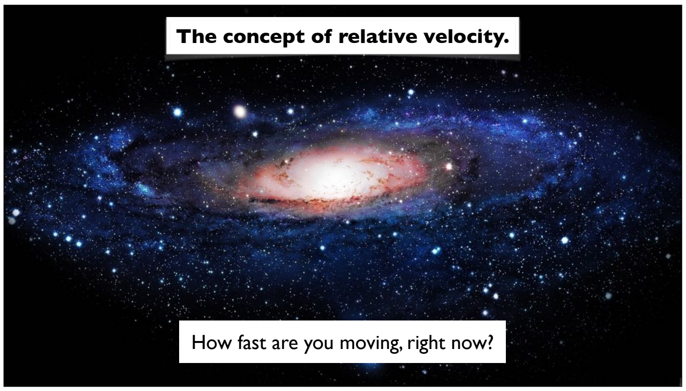
Reasoning From Equations

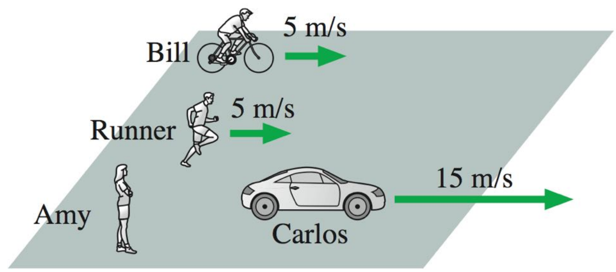
$$e = 1 - \frac{T_C}{T_H}$$

As a group, discuss:

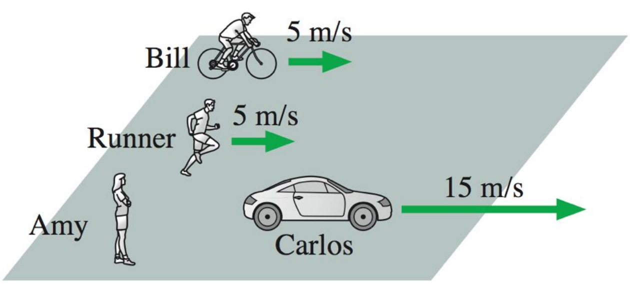
What are two ways you have increase the efficiency of the heat engine?







Four people moving at different speeds.
All speeds are given with respect to the ground. (Or Amy.)



What is Carlos' velocity, relative to Bill?

The Speed of Light

299,792,458 meters per second

Or

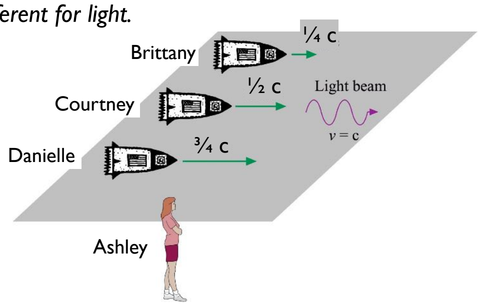
670,616,629 miles per hour

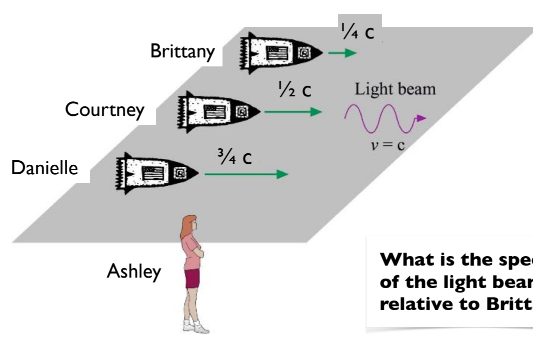
7 times around the world in 1 second

This is the speed that light travels at in a vacuum.
We use the symbol c to represent this speed.

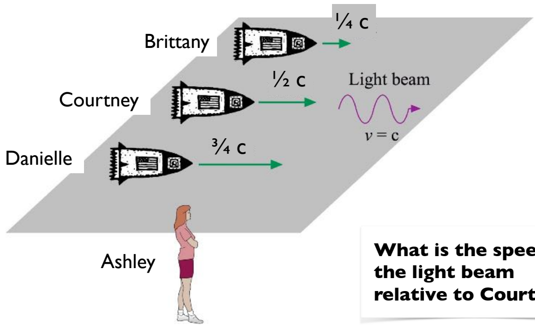
Special Relativity

It's different for light.

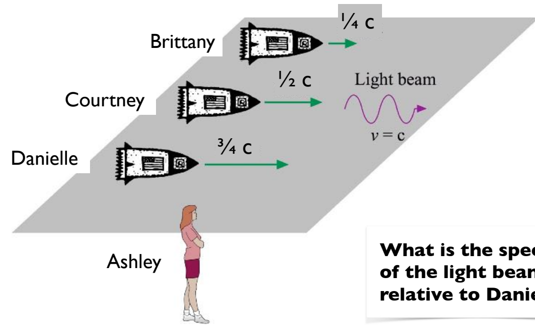




What is the speed of the light beam relative to Brittany?



What is the speed of the light beam relative to Courtney?



What is the speed of the light beam relative to Danielle?

The speed of light is constant, regardless of the motion of the observer.

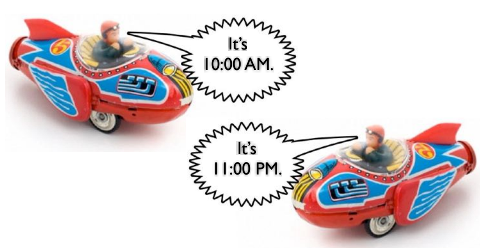
This is not something someone dreamed up. It's measurable, testable, true.

No matter how fast a rocket moves, it can't catch up with a beam of light.
The beam of light always moves away at the same speed:
The speed of light, c.

Because the speed of light is constant, as we noted,
Nothing can go as fast as light.
c is the universal speed limit.

If a rocket keeps firing its engines, its kinetic energy will increase, but it's speed will never exceed c, no matter how long this goes on.

Because the speed of light is constant,
because it does not depend on the motion of the observer,
space and time are not constant and unvarying.
Measurements of time and space are relative.
Different observers record different times and distances.



Time and Proper Time

Δt is a time interval

Δτ is a proper time interval

Proper time is "wristwatch time"

Time Dilation

Speed	K
Any reasonable speed	1.0
95% of c	3.2
98% of c	5.0
99% of c	7.1
99.5% of c	10
99.995% of c	100

$$\Delta\tau = \frac{\Delta t}{K}$$

Which is greater:

Time or proper time?

Time Dilation

Speed	K
Any reasonable speed	1.0
95% of c	3.2
98% of c	5.0
99% of c	7.1
99.5% of c	10
99.995% of c	100

$$\Delta\tau = \frac{\Delta t}{K}$$

Proper time intervals are always less than time intervals.

Time Dilation

Speed	K
Any reasonable speed	1.0
95% of c	3.2
98% of c	5.0
99% of c	7.1
99.5% of c	10
99.995% of c	100

$$\Delta\tau = \frac{\Delta t}{K}$$

If you are moving with respect to us, we see time as slowing down for you.

Time Dilation

Speed	K
Any reasonable speed	1.0
95% of c	3.2
98% of c	5.0
99% of c	7.1
99.5% of c	10
99.995% of c	100

$$\Delta\tau = \frac{\Delta t}{K}$$

That's why I might go on a bit late sometimes.

Time Dilation Effects

- You get on a spaceship today, at age 75.
- For 10 years (earth time) you cruise around at 0.995 c. (K=10)
- When you come back, how old are you?

$$\Delta\tau = \frac{\Delta t}{K}$$

Another Option

- You get on a spaceship today.
- You cruise around at 0.995 c. (K=10)
- How much time do you spend cruising in order to let 4 years elapse on Earth?

$$\Delta\tau = \frac{\Delta t}{K}$$

Length and Proper Length

λ is a length

L is a proper length

Proper length is one you measure with a ruler that is stationary with respect to the object you are measuring.

Length Contraction

Speed	K
95% of c	3.2
98% of c	5.0
99% of c	7.1
99.5% of c	10
99.995% of c	100

$$\lambda = L \times K$$

The proper length is always greater than the length.

Length Contraction Effects

- Your spaceship is 1000 feet long.
- You cruise past us at 0.995 c. (K=10)
- How long do we think your ship is?

$$\lambda = L \times K$$

Relativity Limerick, SFW Version

There once was a fencer named Fisk

Whose action was exceedingly brisk

So quick was his action

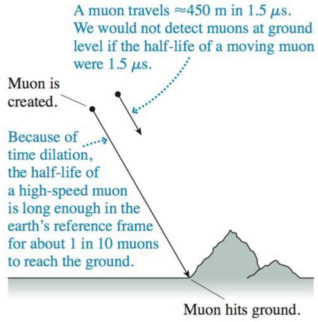
That relativistic contraction

Made his rapier shrink down to a disk.

The case of the muons

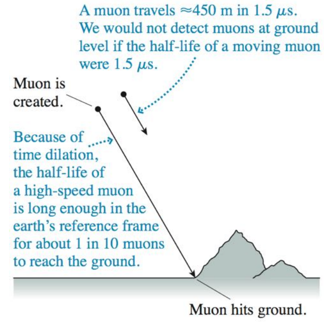
The muons shouldn't make it to the earth, but they do.

More time elapses for the earth than it does for the muons, so they last longer.



Back to the muons…

From the muon's point of view, why are they able to make it to the earth?



A Puzzle

30-foot-long pole

15-foot-long pole

Simultaneity

The most bizarre consequence of all.

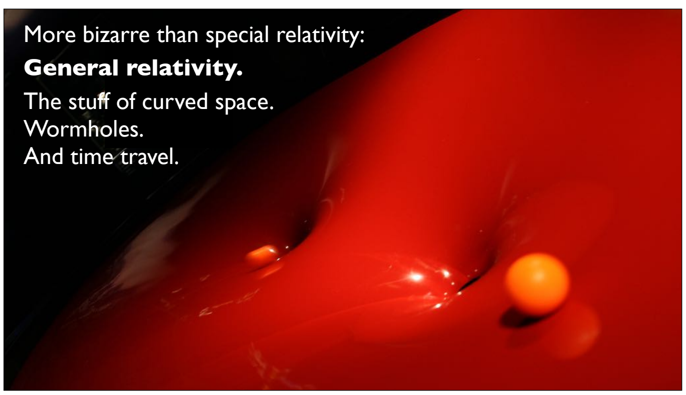
Did two events happen at the same time?

If they didn't happen at the same place…

The answer depends on who you ask.

It's relative.

In a nutshell:
Time, time intervals, distances and the spatial ordering of events are not absolutes.
They are only relative.



Gravitational Time Dilation

$$\frac{\Delta t \text{ (in gravitational field)}}{\Delta t \text{ (not in gravitational field)}} = \sqrt{1 - \frac{2GM}{rc^2}}$$

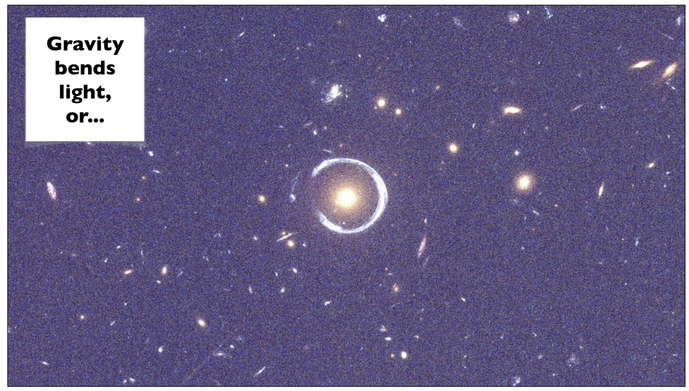
This is always less than 1.

Does gravity slow time down, or speed time up?

At The Surface of a Black Hole

$$\frac{\Delta t \text{ (in gravitational field)}}{\Delta t \text{ (not in gravitational field)}} = 0$$

Can you actually fall into a black hole?



Escape Velocity

If you could throw a rock (or shoot a rocket!) upward at 25,000 mph, it wouldn't come down.

This is the Earth's escape velocity.

Escape Velocity

If you could throw a rock (or shoot a rocket!) upward from the surface of Jupiter at 133,000 mph, it wouldn't come down.

This is the Jupiter's escape velocity.

Escape Velocity

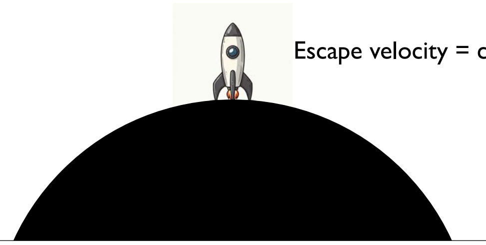
Why is Jupiter's escape velocity larger than Earth's?

Schwarzschild radius

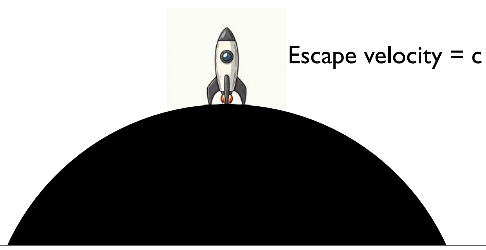
$$r = \frac{2GM}{c^2}$$

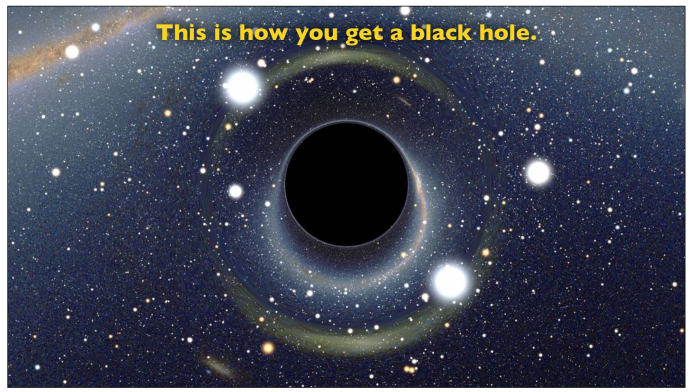
The criterion for a black hole.

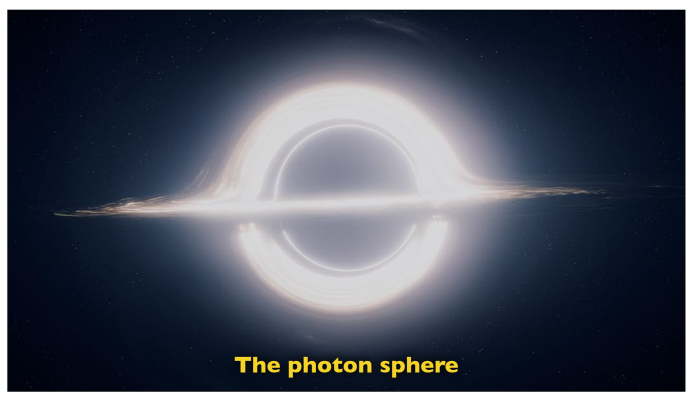
For an object meeting this criterion:

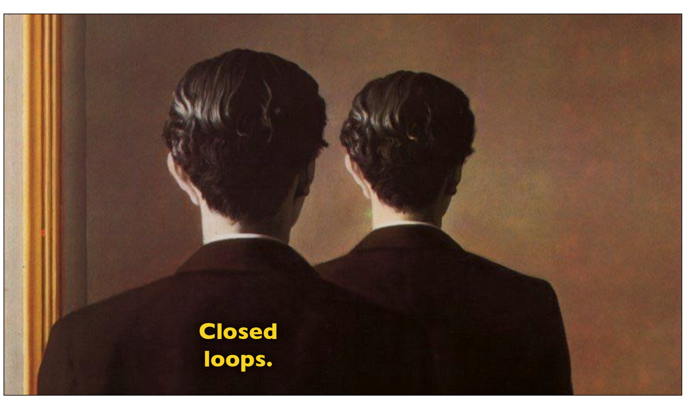


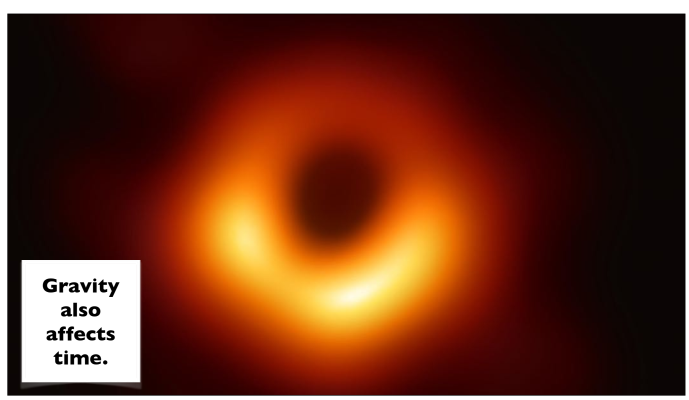
Can this rocket ever escape?











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Does time slow time down, or speed time up?

Schwarzschild radius

$$r = \frac{2GM}{c^2}$$

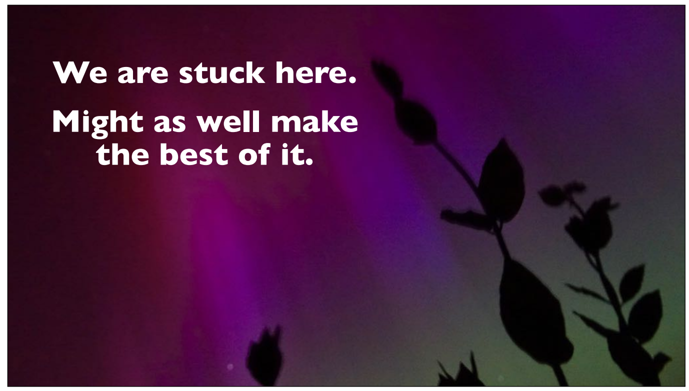
The criterion for a black hole.

An Interesting Question....

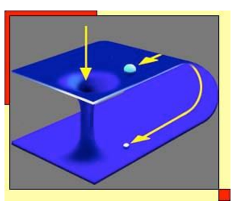
If you put in the mass of the part of the universe we can see…

$$r = \frac{2GM}{c^2}$$

You get the radius of the part of the universe we can see.



Is Time Travel Possible?



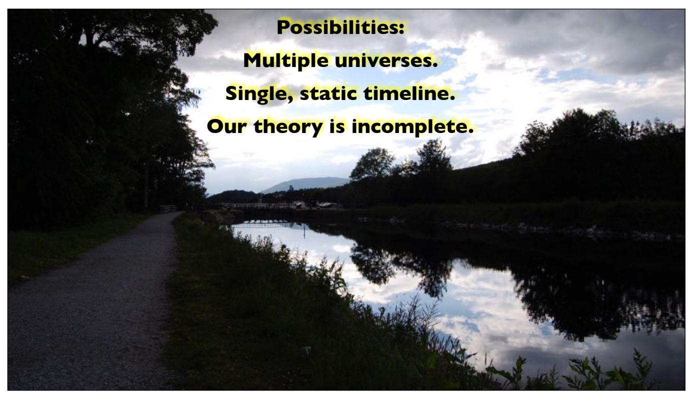
Backward in time:
Really difficult...

How to build a time machine in two steps:

1. Build a wormhole connecting two points in space.
2. Take one end, and move it around at high speed.

Time dilation makes time at the moving end slow down.

It's now a portal between two different points in space and *two different points in time...*



"Not only is the universe stranger than we imagine, it is stranger than we *can* imagine."

Arthur Eddington, who led the expedition that validated some of the predictions of Einstein's theory of general relativity.