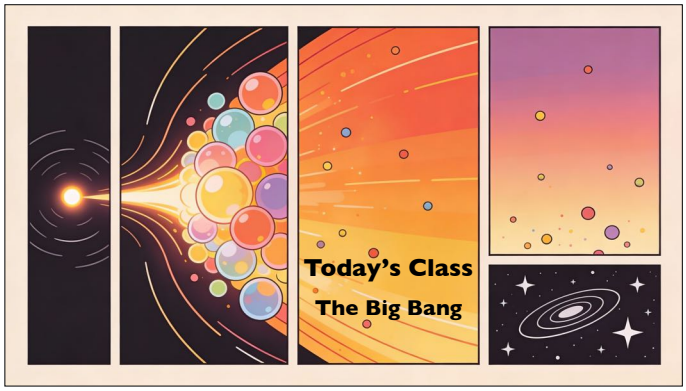
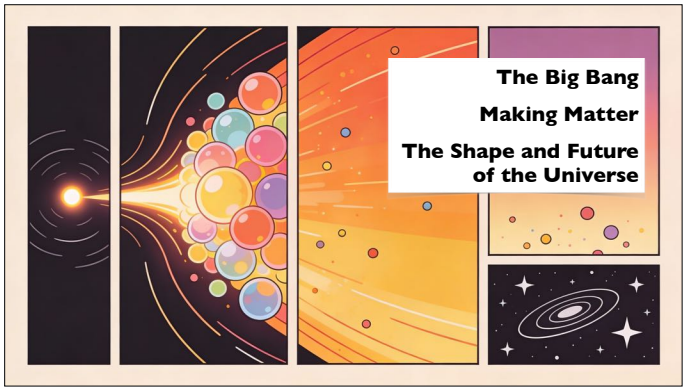
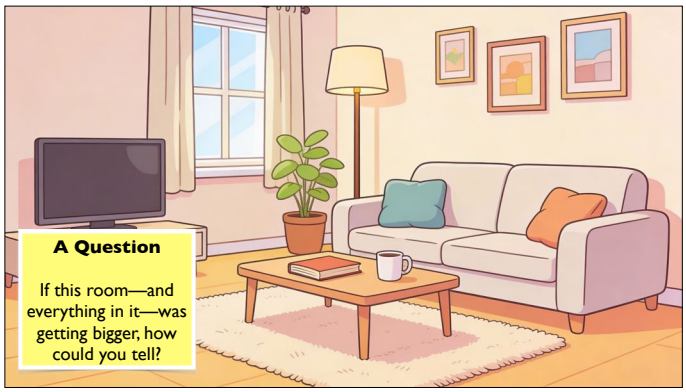


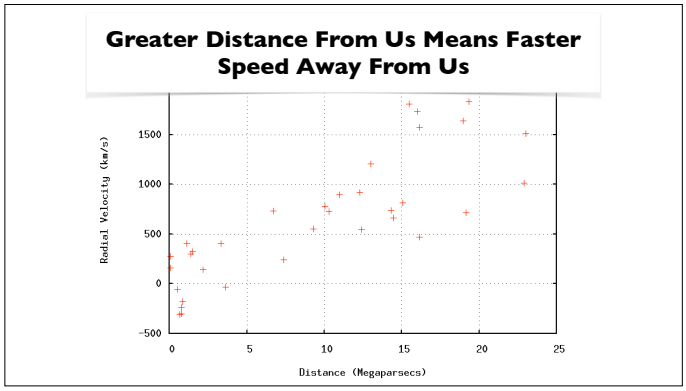


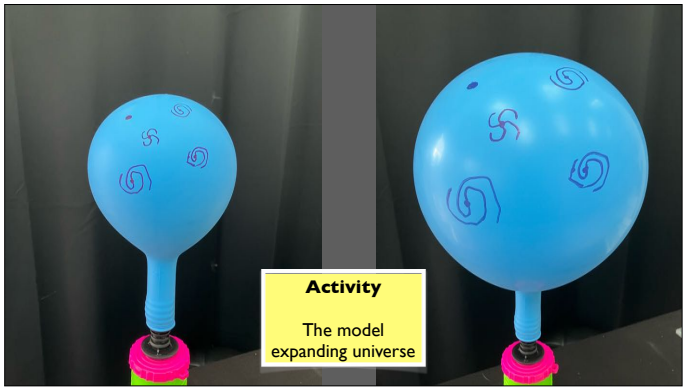


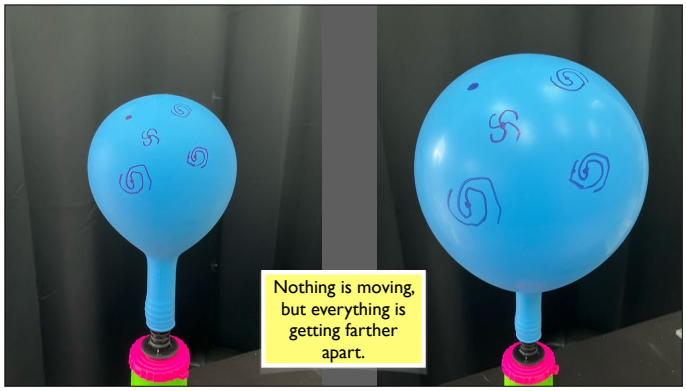
Remember:

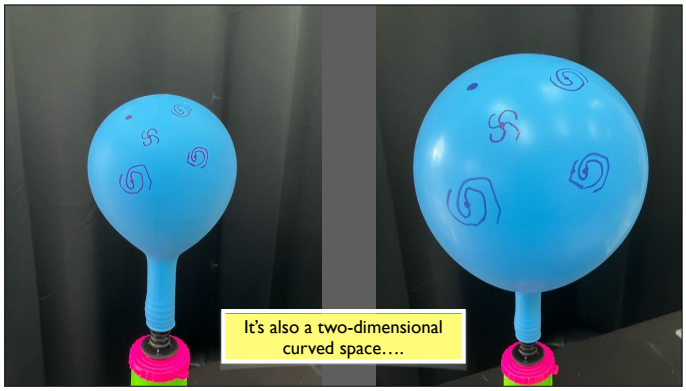
Distant galaxies always appear redshifted:

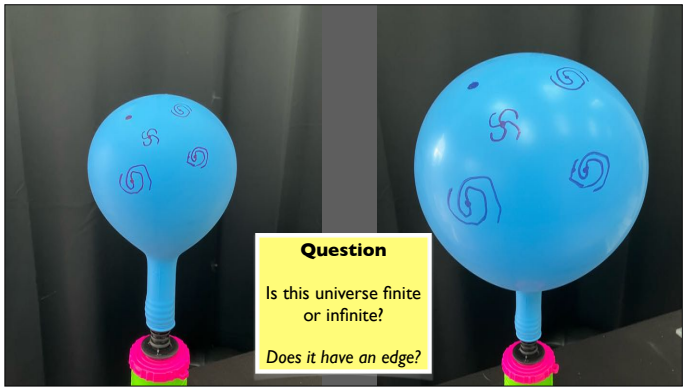
They are moving away from us.



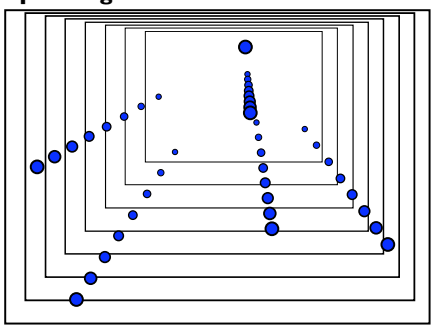




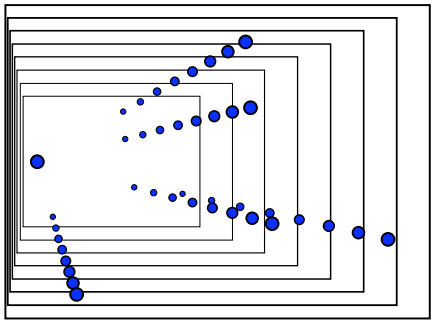


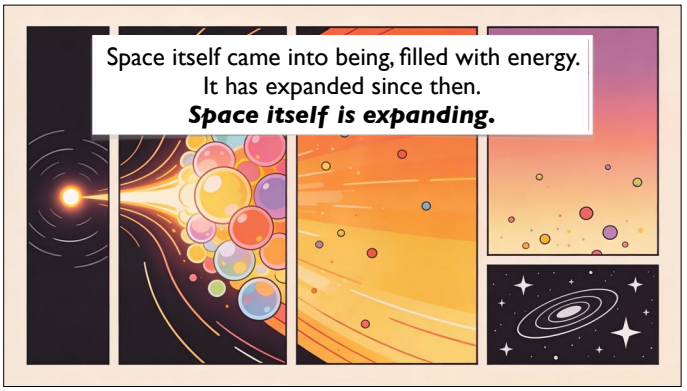


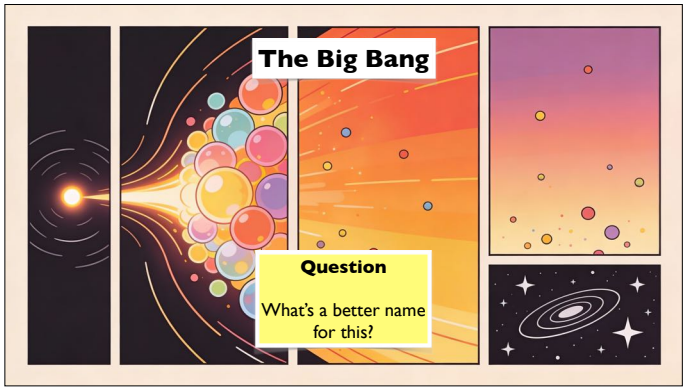
Expanding Colorado: Fort Collins View



Expanding Colorado: Grand Junction View







Remember:
The most famous equation in the world:

$$E = mc^2$$

Mass can be converted to energy, and vice versa.

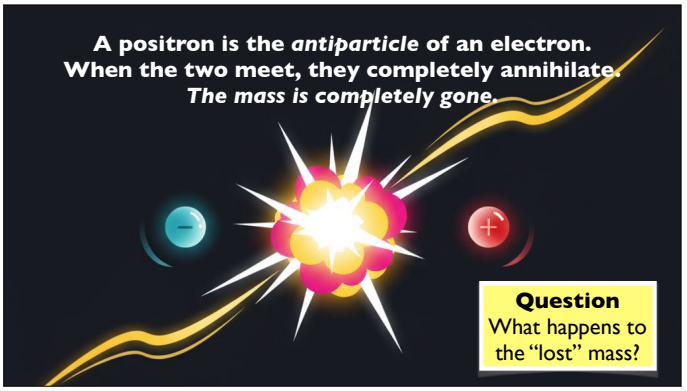
Other decay modes

Beta-minus decay

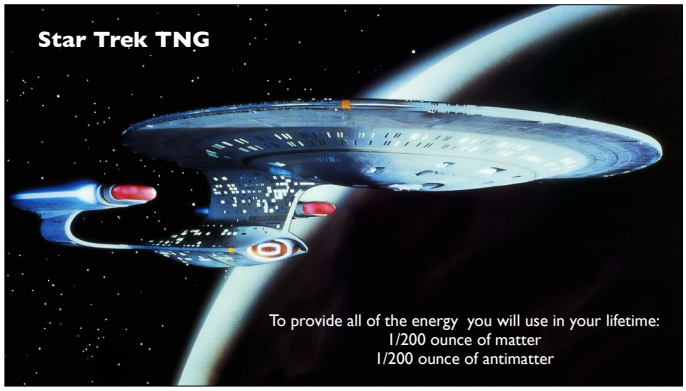
$$^{14}_{6}\mathrm{C} \Rightarrow {}^{14}_{6}\mathrm{C} + \mathrm{e}^{-}$$ **Electron**

Beta-plus decay

$$^{18}_{9}\mathrm{F} \Rightarrow {}^{18}_{8}\mathrm{O} + \mathrm{e}^{+}$$ **Positron**

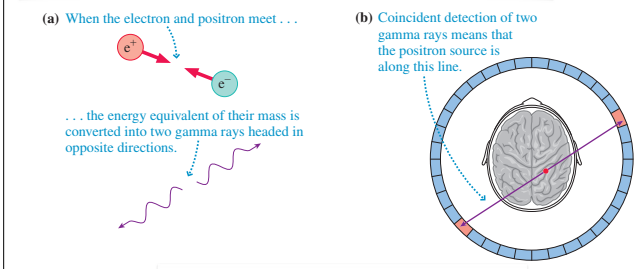


Star Trek TNG

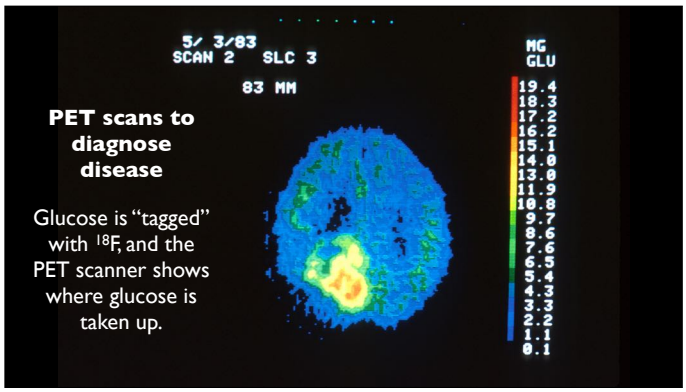


To provide all of the energy you will use in your lifetime:
1/200 ounce of matter
1/200 ounce of antimatter

In case you think this is only science fiction....



Positron Emission Tomography

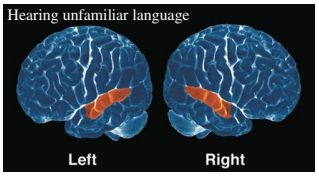


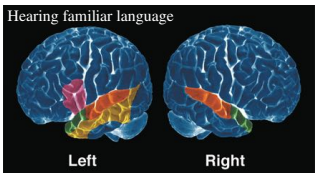
PET scans to diagnose disease

Glucose is "tagged" with ^{18}F, and the PET scanner shows where glucose is taken up.

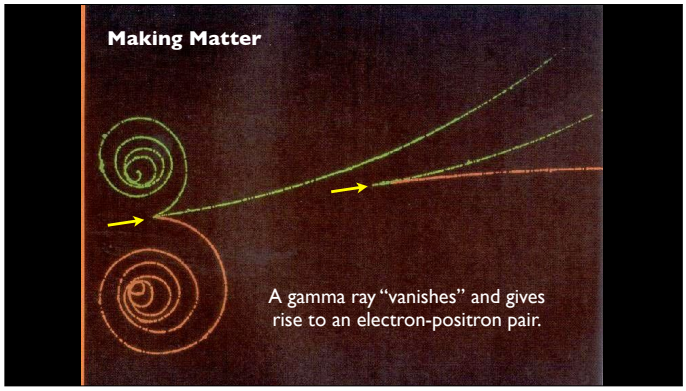
PET scans to research brain activity

This is also done with ^{15}O. Much shorter half-life, lower dose, more rapid results.



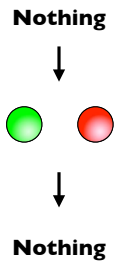


Making Matter

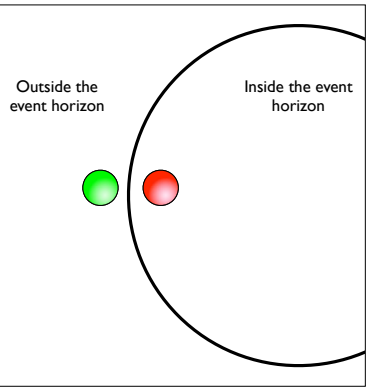


A gamma ray "vanishes" and gives rise to an electron-positron pair.

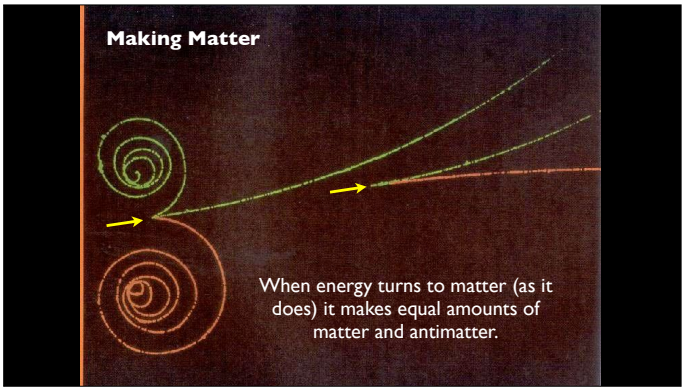
Electron-positron pairs can also pop into existence out of the vacuum, and then go away again.



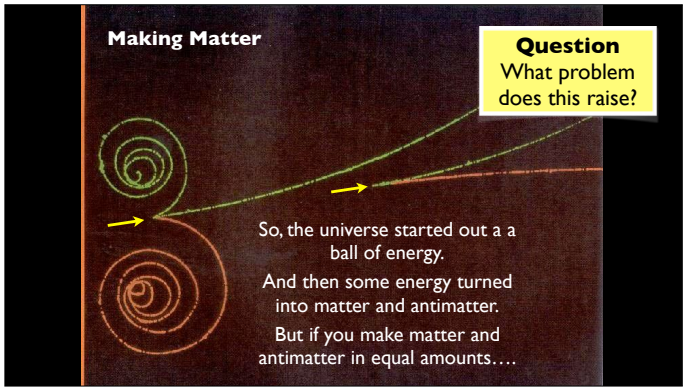
This can make black holes "evaporate".

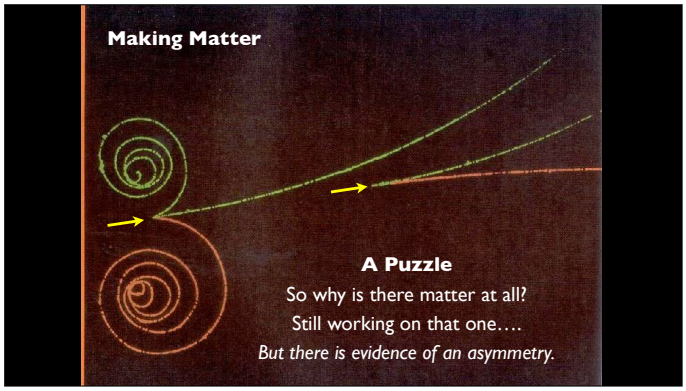


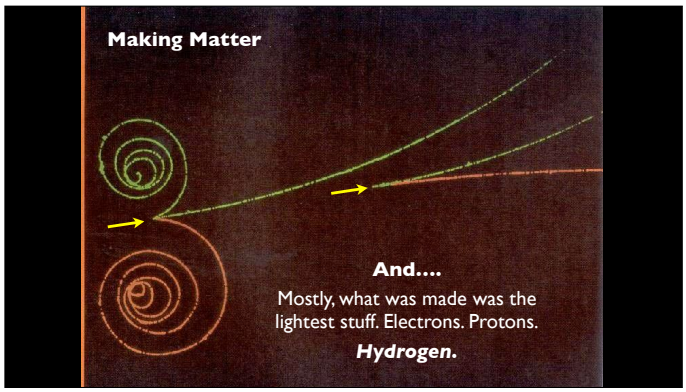
Making Matter

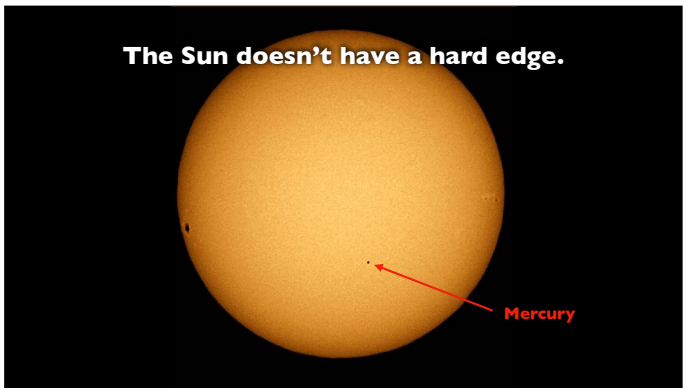


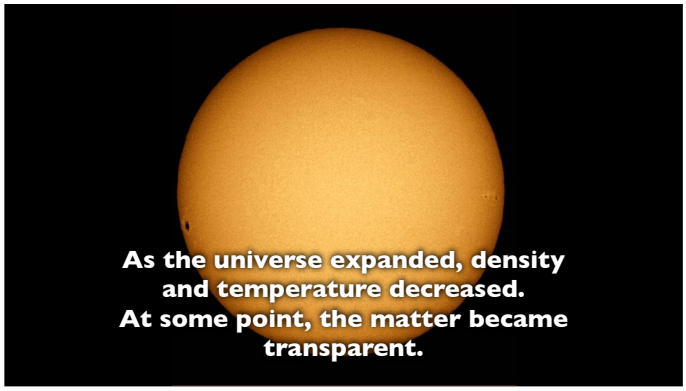
When energy turns to matter (as it does) it makes equal amounts of matter and antimatter.

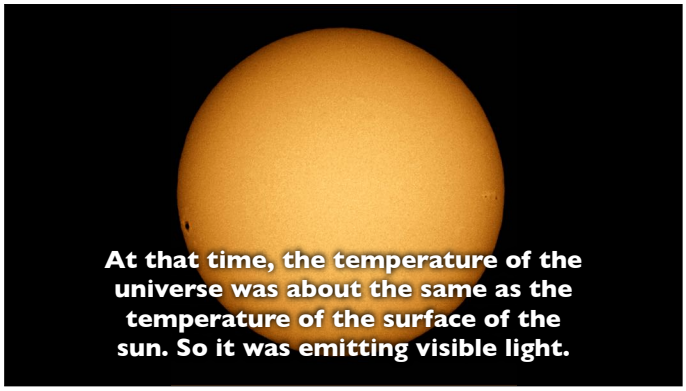

Making Matter
Question
What problem does this raise?
So, the universe started out a a ball of energy.
And then some energy turned into matter and antimatter.
But if you make matter and antimatter in equal amounts….

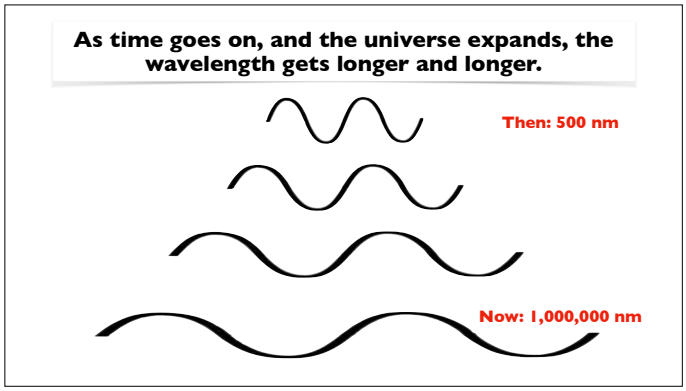

Making Matter
A Puzzle
So why is there matter at all?
Still working on that one….
But there is evidence of an asymmetry.

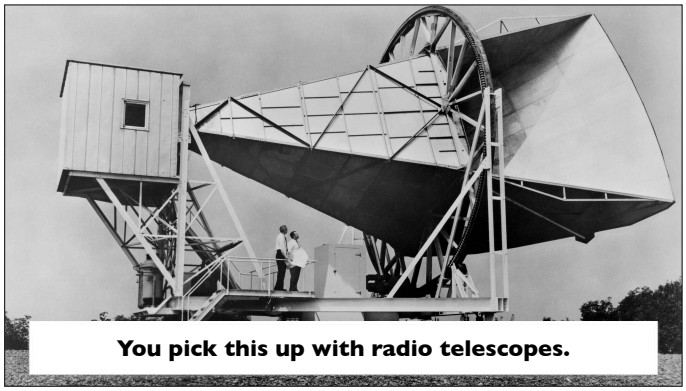

Making Matter
And….
Mostly, what was made was the lightest stuff. Electrons. Protons.
Hydrogen.

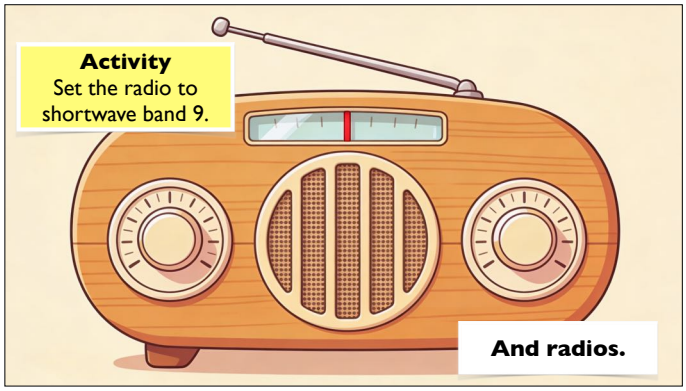

The Sun doesn't have a hard edge.
Mercury

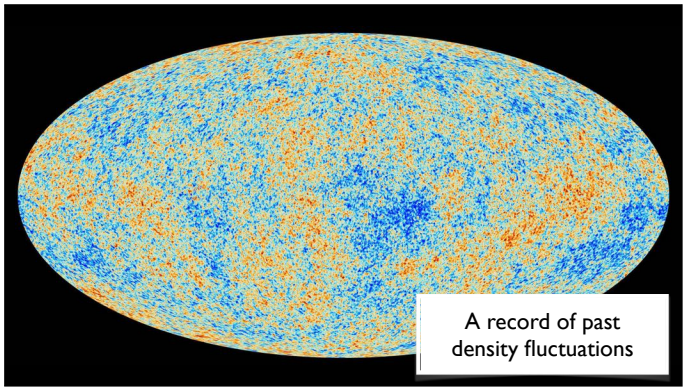

As the universe expanded, density and temperature decreased.
At some point, the matter became transparent.


At that time, the temperature of the universe was about the same as the temperature of the surface of the sun. So it was emitting visible light.


As time goes on, and the universe expands, the wavelength gets longer and longer.
Then: 500 nm
Now: 1,000,000 nm

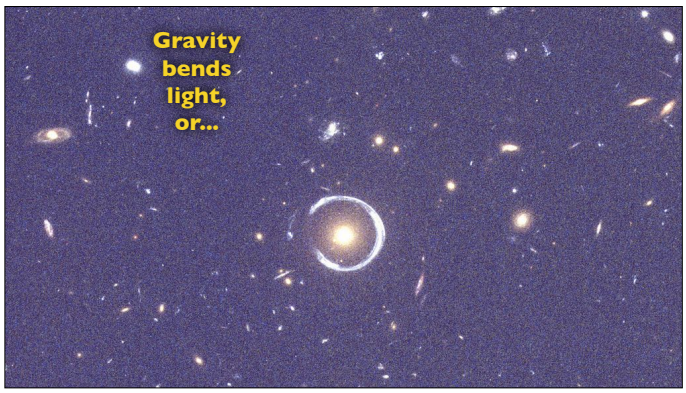

You pick this up with radio telescopes.


Activity
Set the radio to shortwave band 9.
And radios.

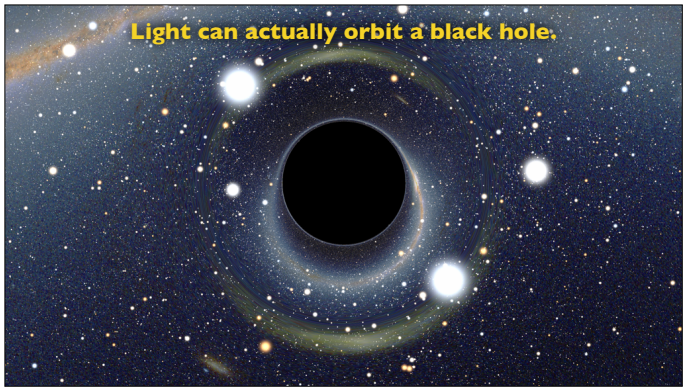

A record of past density fluctuations

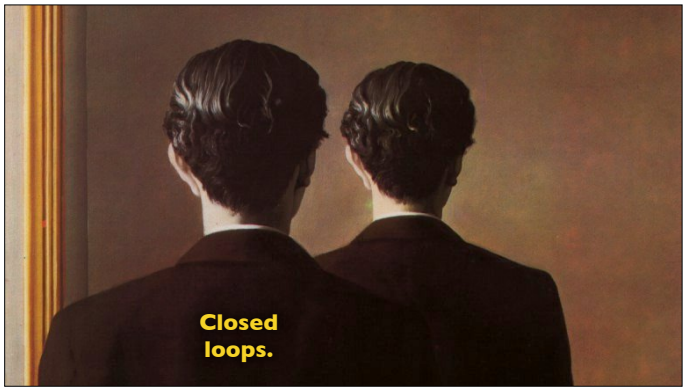

Question
What is the shortest distance between two points?


How do you define a straight line?

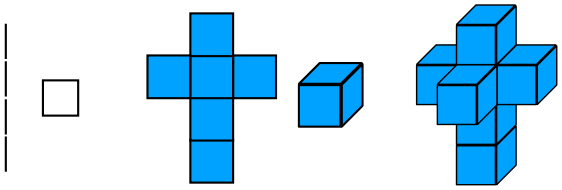

Gravity bends light, or...


Gravity curves space.


Light can actually orbit a black hole.


Closed loops.

A digression on topology.



1 dimension
4 lines
Fold to make a square
Finite, no edge.

2 dimensions
6 squares
Fold to make a cube
Finite, no edge.

3 dimensions
8 cubes
Fold to make a hypercube
Finite, no edge.

A universe that is finite, but with no edge.

Remembering High School Geometry

Perimeter /Area

Question
What is the sum of the angles in a triangle?

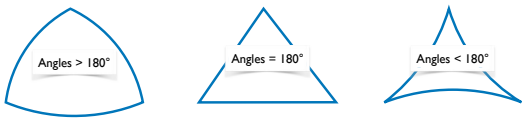
Remembering High School Geometry

Perimeter /Area

Activity
On the balloon, can you make a triangle with 3 90° angles?

Three Geometries, Three Destinies

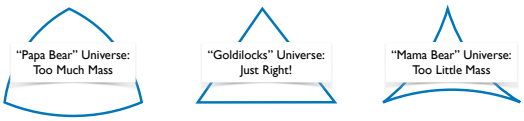
Spherical | **Flat** | **Hyperbolic**



The curvature of space is determined by the amount of matter present. This determines the overall geometry of space too.

Three Geometries, Three Destinies

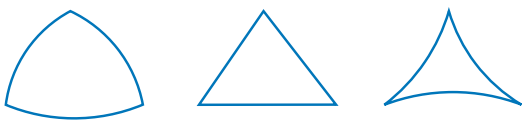
Spherical | **Flat** | **Hyperbolic**



Gravity curves space. So the amount of gravity (and thus the amount of matter) determines the geometry.
And the destiny....

Three Geometries, Three Destinies

Spherical | **Flat** | **Hyperbolic**



The universe is finite, but there is no edge. It will expand for a while, then collapse.

The universe is infinite. It will expand forever.

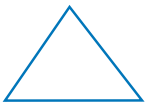
The universe is infinite. It will expand forever.

Three Geometries, Three Destinies

Spherical | **Flat** | **Hyperbolic**

This makes sense in terms of gravity, too. More means more gravity, which means more force opposing the expansion.

Three Geometries, Three Destinies

Spherical	Flat	Hyperbolic
		
When the universe contracts, it will lead to a singularity—and perhaps another Big Bang?	Eventually, matter is so dispersed that that stars and galaxies won't form. Things kinda fizzle.	Eventually, matter is so dispersed that that stars and galaxies won't form. Things kinda fizzle.