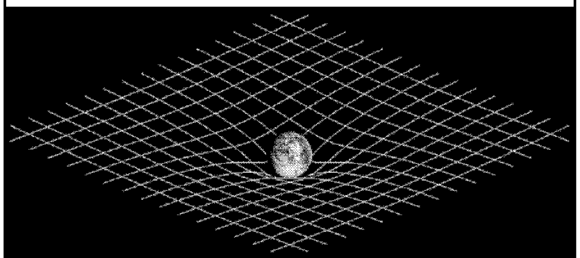
Newton vs. Einstein



Friday, October 23

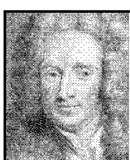
Next planetarium shows: Tue, Wed

Einstein – Newton smackdown!

Albert Einstein – 20th century

Isaac Newton – 17th century

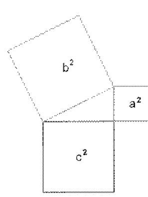
Two different ways of thinking about **gravity** and **space**.

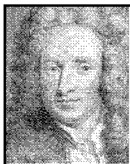


The Way of Newton:

Space is **static** (not expanding or contracting) and **flat**.

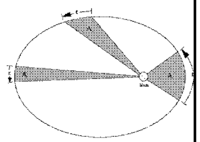
(“**Flat**” means that all Euclid’s laws of geometry hold true.)

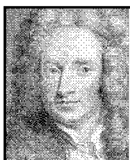




"Objects have a natural tendency to move on **straight lines** at **constant speed**."

However, we see planets moving on **curved orbits** at **varying speed.**

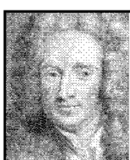




"There is a **force** acting on the planets – the force called **GRAVITY.**"

The gravitational force depends on a property that we may call the "**gravitational mass**", m_g.

$$F_g = G\frac{m_g M_g}{r^2}$$



Newton's 2[nd] law of motion gives the acceleration in response to **any** force (not just gravity)!

The acceleration depends on a property that we may call the "**inertial mass**", m_i.

$$a = F / m_i$$

If a gravitational force is applied to an object with **gravitational mass** m_g and **inertial mass** m_i, its acceleration is

$$a = \frac{F_g}{m_i} = \frac{GM_g}{r^2} \times \frac{m_g}{m_i}$$

Truly astonishing and fundamental fact of physics:

$$m_g = m_i$$

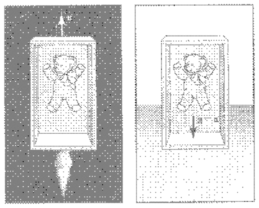
for every known object!

This equality is known as the "**equivalence principle**".

The equivalence principle led Einstein to devise his theory of **General Relativity**.

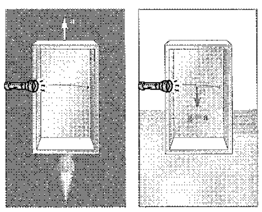
Let's do a "thought experiment", of the kind beloved by Einstein.

Two ways of thinking about a bear:

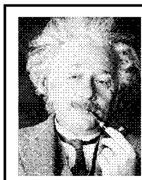


1) Bear has constant velocity, box is accelerated upward.
2) Box has constant velocity, bear is accelerated downward by gravity.

Two ways of thinking about **light**:



1) Light has constant velocity, box is accelerated upward.
2) Box has constant velocity, **light is accelerated downward by gravity**.

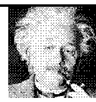


Einstein's insight:

Gravity affects the paths of photons, even though they have no mass!

Mass and energy are interchangeable: $\mathbf{E = mc^2}$

 **Newton**

 **Einstein**

Newton	Einstein
Mass & energy are very different things.	Mass & energy are interchangeable: $E = mc^2$
Space & time are very different things.	Space & time are interchangeable: part of 4-dimensional space-time.

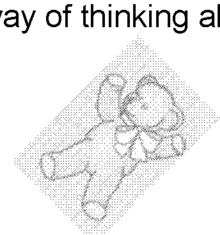
Light takes the shortest distance between two points.

In flat space, the shortest distance between two points is a straight line.

In the presence of gravity, light follows a curved line.

In the presence of gravity, space is not flat, but **curved**!

A **third** way of thinking about a bear:



3) No forces are acting on the bear; it's merely following the shortest distance between two points in space-time.

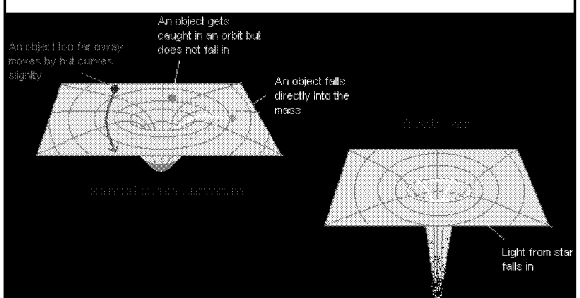
The Way of Newton:

Mass tells gravity how much force to exert; force tells mass how to move.

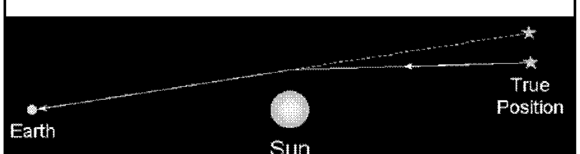
The Way of Einstein:

Mass-energy tells space-time how to curve; curved space-time tells mass-energy how to move.

Objects with lots of mass (& energy) curve space (& distort time) in their vicinity.



Mass & energy cause space to curve. This curvature causes an **observed** bending of the path of light.



This is called “gravitational lensing”.

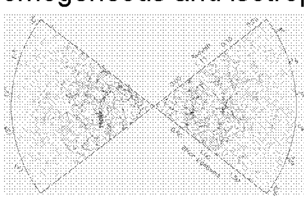
The Big Question:

How is space curved on large scales (bigger than clusters of galaxies)?

That depends on how mass & energy are distributed on large scales.

The Cosmological Principle:

On large scales (bigger than clusters of galaxies) the universe is homogeneous and isotropic.

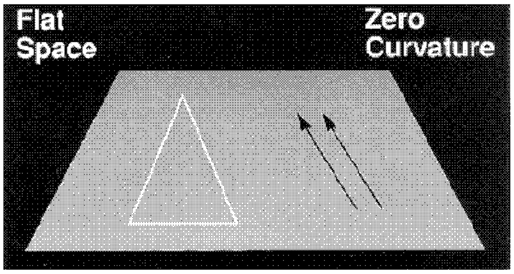


homogeneous = the same everywhere
isotropic = the same in all directions

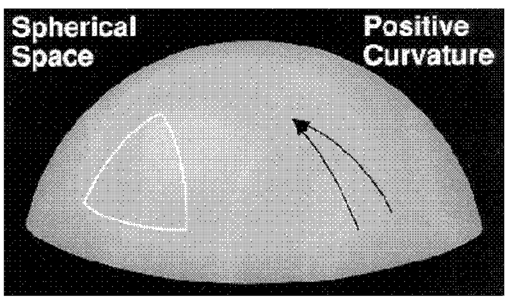
There are **three** ways in which space can have homogeneous, isotropic curvature on large scales.

(Apology: describing the curvature of 3-dimensional space is difficult; I'll show 2-dimensional analogs.)

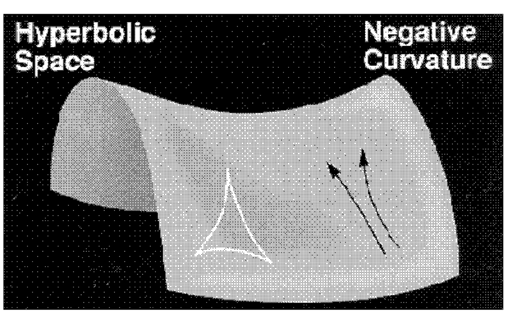
(1) This space is **flat**
(or Euclidean):

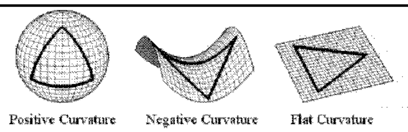


(2) This space is
positively curved:

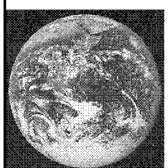


(3) This space is
negatively curved:





If space has **positive curvature**, it has a **finite volume**, but **no boundary**.



Analogy: the Earth's surface has **positive curvature**. It has a **finite area**, but **no edge.**

About faster-than-light motions…

$$v = H_0 d$$

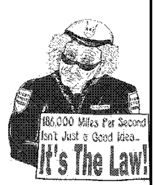
If $d > c/H_0$, then $v > c$.

Should we be worried that very distant galaxies are moving away faster than the speed of light?

No, not really.

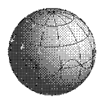
Einstein's theory of special relativity (1905) deals with the special case in which space is flat & static.

Special relativity states that things can't move through space faster than the speed of light.

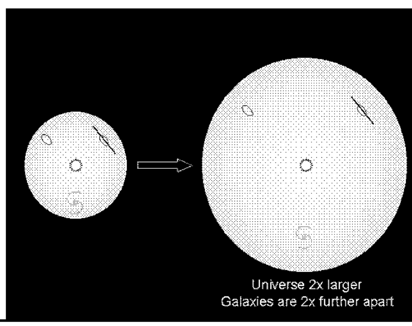


Einstein's theory of general relativity (1915) deals with the general case in which space can be curved & expanding.

General relativity states that space itself can expand faster than light.



Two galaxies **can** be moving away from each other faster than light **if** their motion is associated with the expansion of space.



Monday's Lecture:

Is the Universe Infinite?

Reminders:

Read Chapter 7 by Monday.
Planetarium shows **Oct 27 & 28.**
Midterm exam **Friday, October 30**.