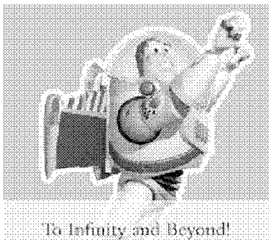
Is the Universe Infinite?



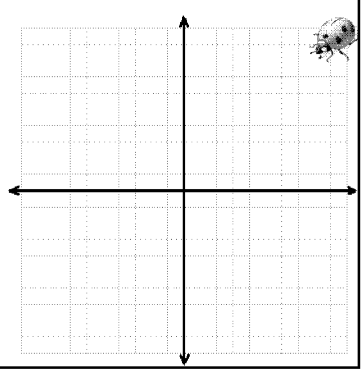
Monday, October 26

Next Planetarium Shows: Tue, Wed, at 6:30 pm

Newton's view of space:

rectilinear & rigid (not expanding or contracting)

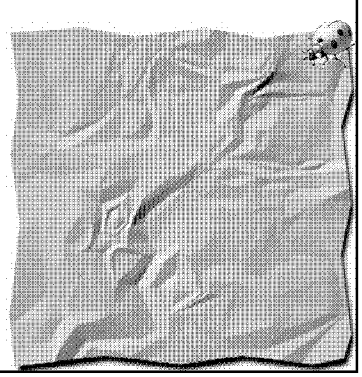
Think of a bug crawling over stiff graph paper.



Einstein's view of space:

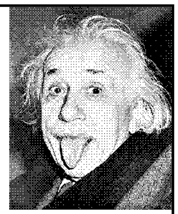
curved & wavy (can also expand or contract)

Think of a bug crawling over a rumpled rubber sheet.



Einstein's view of space is mathematically complicated.

However, it's better than Newton's when gravity is strong (near massive objects).

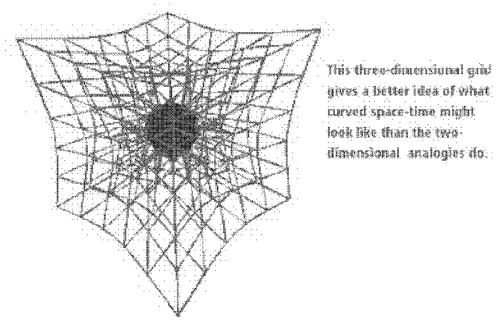


Einstein's triumphs:

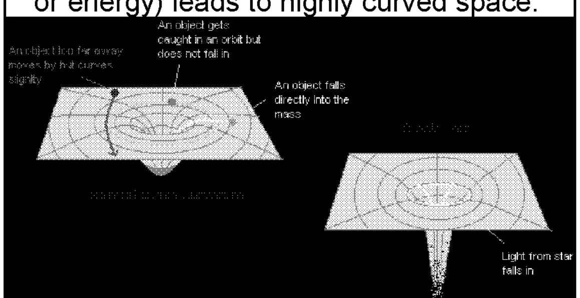
Gravitational lensing by the Sun.

Orbit of Mercury (closest planet to Sun).

Space is curved by the presence of **mass** and **energy**.

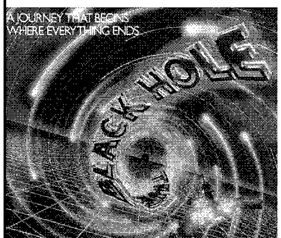


General rule: high density (of either mass or energy) leads to highly curved space.



Black holes cause extreme curvature.

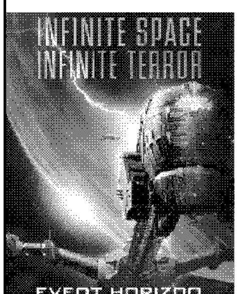
What's a black hole?



Newton:
a black hole is an object whose escape velocity is greater than the speed of light.

Earth: escape velocity = 11 kilometers/second
Sun: escape velocity = 600 km/sec
black hole: escape velocity > 300,000 km/sec

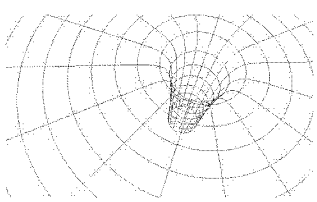
What's a black hole?



Einstein:
a black hole is an object smaller than its **event horizon**.

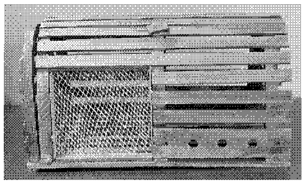
What's an "event horizon"?

A surface such that photons (& other particles) **inside** the event horizon can't ever move **outside**.



"What happens inside the event horizon stays inside the event horizon."

Black hole as lobster trap: once an object enters the event horizon, it can’t exit.

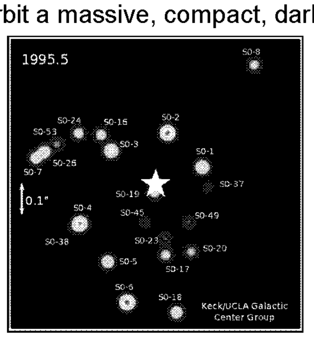


Size of event horizon is proportional to **mass** of black hole: for Sun’s mass, it’s 3 kilometers (about 2 miles).

If black holes are compact and (by definition) black, how do we see them against the blackness of the sky?

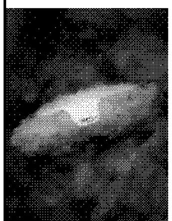
We can detect their gravitational influence on luminous matter – like stars.

Stars near the Galactic Center (8000 parsecs away) orbit a massive, compact, dark object.



Mass = 2 million times the Sun’s mass

The **simplest** explanation of the object at our galaxy's center is that it's a supermassive black hole (SMBH).

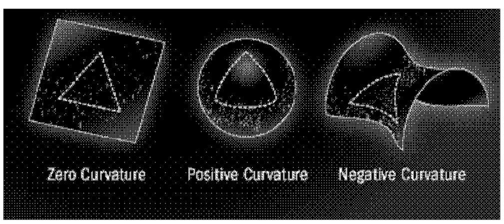


Other galaxies have SMBHs, too.

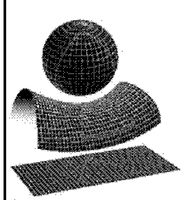
When an SMBH accretes lots of gas, we see it as a "**quasar**" (**quasi**-stellar object).

Locally, dense knots of mass (& energy), such as black holes, cause strong curvature.

Globally, the **average** density of mass & energy in the universe causes an **average** curvature.



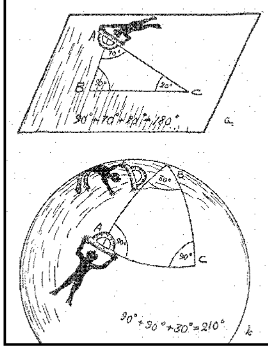
Is the universe infinite?



If space is **positively** curved, space is **finite**, but without a boundary.

If space is **negatively** curved or **flat**, space is **infinite** (unless a boundary or edge is imposed).

Measuring the curvature
is easy, in principle.

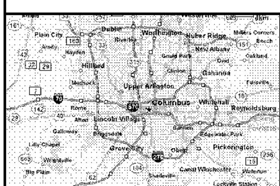


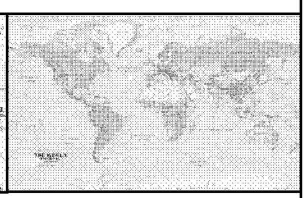
Flat: angles of triangle add to 180°

Positive: angles add to **>180°**

Negative: angles add to **<180°**

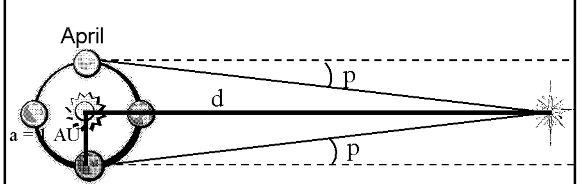
Curvature is hard to detect on scales smaller than the radius of curvature.





Flat = **good** approximation	Flat = **bad** approximation

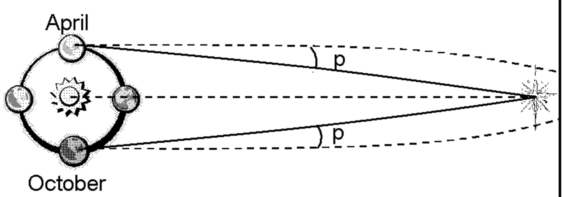
Measuring parallax (flat space)



$p = 1/d$

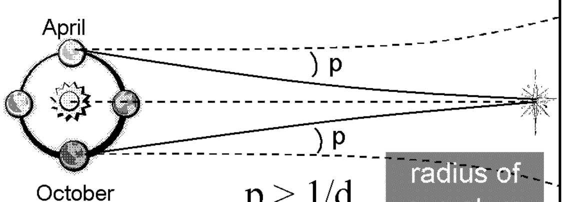
p in arcseconds, d in parsecs

Parallax (positive curvature)



$p < 1/d$

Parallax (negative curvature)

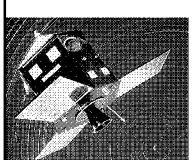


$p > 1/d$

radius of curvature

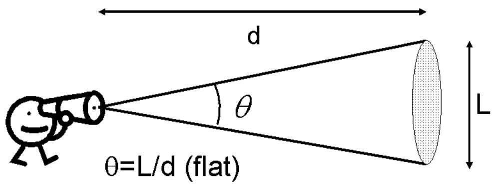
As $d \rightarrow$ infinity, $p \rightarrow 1/R$

The smallest parallax you measure puts a lower limit on the radius of curvature of negatively curved space.



Hipparcos measured p as small as 0.001 arcsec; radius of curvature is **at least** 1000 parsecs.

We need **Bigger** triangles to measure the curvature accurately!



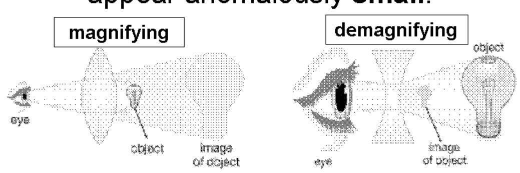
θ=L/d (flat)

θ>L/d (positive)

θ<L/d (negative)

Positively curved space is a **magnifying** lens; distant galaxies appear anomalously **large**.

Negatively curved space is a **demagnifying** lens; distant galaxies appear anomalously **small**.

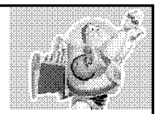


And the answer is…

Distant galaxies are neither absurdly small in angle nor absurdly large.

If the universe is curved, radius of curvature is bigger than the Hubble distance (c/H_0 = 4300 Mpc).

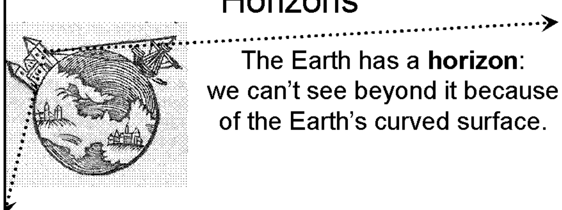
Is the universe infinite?



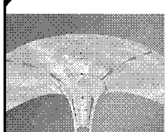
We **can't** know for sure, because we can only see a finite portion of it.

This portion is called "the **observable universe**", and is bounded by the "**cosmological horizon**".

Horizons

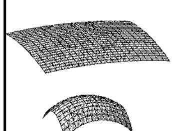


The Earth has a **horizon**: we can't see beyond it because of the Earth's curved surface.



A black hole has an **event horizon**: we can't see into it because photons can't escape.

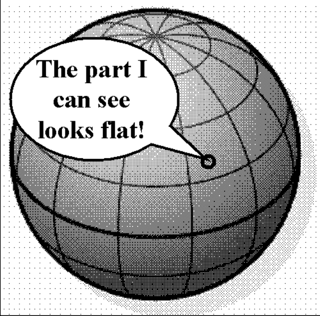
The Ultimate Horizon



The universe has a **cosmological horizon**: we can't see beyond it because photons from beyond haven't had time to reach us.

Distance to cosmological horizon is roughly equal to the Hubble distance (c/H_0 = 4300 Mpc).

Suggestion: space is **positively** curved, but with a radius of curvature much larger than the Hubble distance (4300 Mpc).



This gives the universe a huge (but **finite**) volume.

Wednesday's Lecture:

Dark Energy

Reminders:

Problem Set #4 due on Wednesday.
Planetarium shows **Oct 27 & 28, 6:30 pm.**
Midterm exam **Friday, October 30**.