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Today

- Announcements:
  - HW#8 is due 26 March at 8:00am
  - HW#9 is due 2 April at 8:00am
  - Voting for the Spring Break Story Contest is now open. Voting will close on 2 April. The winner will be announced on 4 April.
- The Past – the Big Bang
- The Present, Future, and Time
- Black Holes, Wormholes and Back to the Future

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A summary of the forces of nature

Force	Strength	Carrier	Acts on	Range (m)
Strong	1	Gluon, g	quarks	10^{-15} size of a proton
Electromagnetic	1/137	photon	anything with charge	infinite
Weak	10^{-6}	Vector Bosons W^{+}, W^{-}, Z^{0}	quarks, electrons (leptons) , neutrinos	10^{-18} Only 0.001 width of proton
Gravity	$6x10^{-39}$	Graviton (?)	anything with mass	infinite

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Unification of Forces

- Wind, Waves, push, pull, etc. – all due to the electric force and atoms pushing against each other
- Electric and Magnetic – both due to the exchange of photons. Maxwell combined into electromagnetic.
- Weak and electromagnetic fit into one theory called electroweak theory (Weinberg in the 1970s)
- The strong force may be connected (unified with electroweak by a set of theories called supersymmetric theory)
- Gravity does not yet fit in.(Maybe string theory)

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At high temperature forces are "unified"

- Current theory says at very high temperature we don't see all the forces. We say they are "unified".
- Example: The Curie point of metals
- At the start of the Big Bang the 4 forces were unified.
- At the Universe cooled the forces became distinct – this is called spontaneous symmetry breaking

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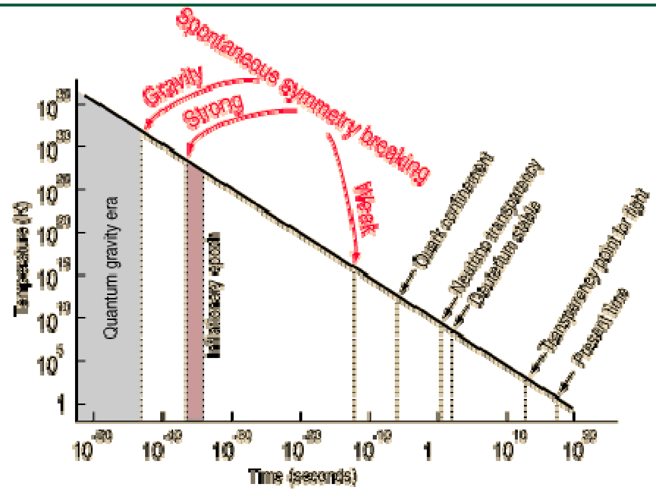
Big Bang Timeline (the early moments)



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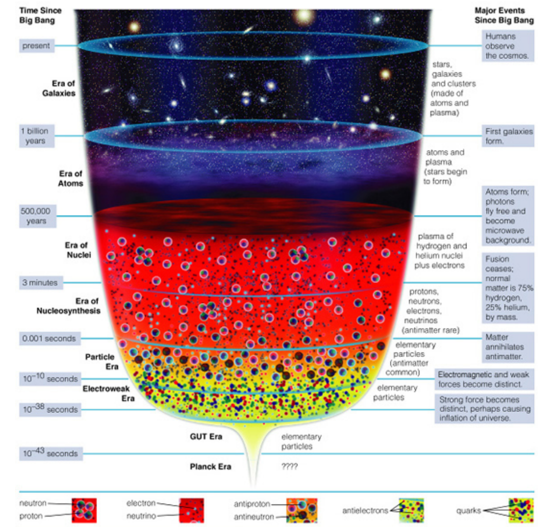
Picture of Events after the Big Bang

What we see as we look away from the Earth



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Why does time always move in one direction?

- Inflation during the Big Bang resulted in a universe that had a very low entropy, much too low for its size. It was like the Universe started with all heads.
- Hence, everything in the universe moves toward reaching the correct amount of entropy.
- Time has a direction because going back in time would imply the entropy could be decreased. That is very improbable.
- The universe tends toward increasing entropy.
- Remember the question: What is time?

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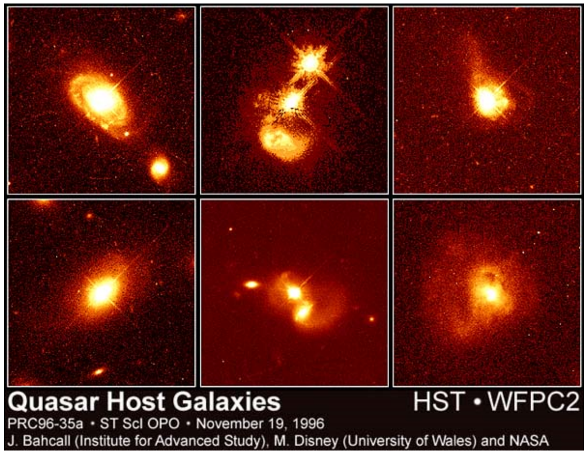
A Cosmic Mystery - Quasars

• Astronomers observe very luminous objects out near the edge of the visible Universe. What could these be? They have a luminosity 100 times an entire galaxy, but the size must be much smaller than a galaxy since the luminosity changes quickly. These objects were called quasars.

• Two other strange objects: Radio galaxies and active galaxies

• Quasars (quasi-stellar objects) with velocities of more than 95% of the speed of light have been observed. By the Hubble Law (speed is related to distance) this means they are very far away.

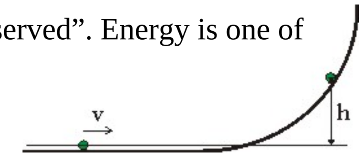
Pictures of Quasars by the Hubble Telescope



Conservation of Energy

In nature certain quantities are "conserved". Energy is one of these quantities.

Example: Ball on a hill

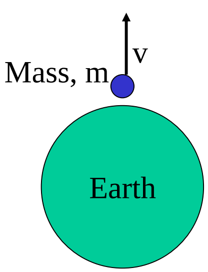


A 1.00 kg ball is rolled toward a hill with an initial speed of 5.00 m/s. If the ball roles without friction, how high, h, will the ball go?

$$KE = \frac{1}{2}mv^2 \quad PE = mgh\,;\, g = 9.80\frac{m}{s^2}$$

$$\frac{1}{2}mv^2 = mgh \rightarrow h = \frac{v^2}{2g} = \frac{(5\,m/s)^2}{2\cdot 9.80\frac{m}{s^2}} = 1.28\,m$$

Escape Velocity



The velocity to completely escape the gravity of a planet is:

$$KE(leaving) = PE(far\ away)$$

$$\frac{1}{2}mv^2 = \frac{GmM_{planet}}{R_{planet}}$$

$$v = \sqrt{\frac{2GM_{planet}}{R_{planet}}}$$

The escape velocity for the Earth is about 11 km/s.

Large Mass in a small region

What is the escape velocity for an object with the mass of the Sun and a radius of 10 km?

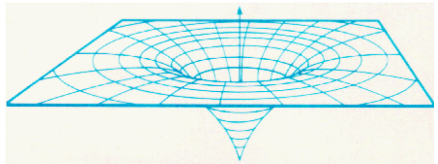
M_{sun}=1.99E+30 kg   G=6.67E-11 Nm^2/kg^2

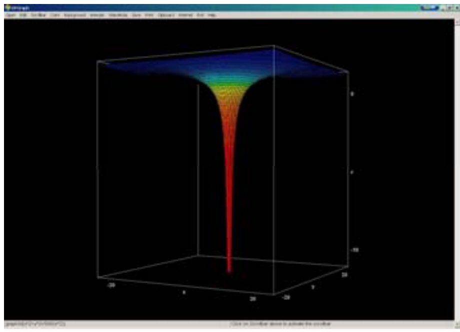
$$v = \sqrt{\frac{2GM}{R}} = \sqrt{\frac{2\cdot 6.67E-11\cdot 1.99E31}{10000}} = 5\times 10^8\,\frac{m}{s}$$

This is greater than the speed of light!

Black Holes

The concentrated mass stretches space.





The “hole” in space is so deep that light can not escape.

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Black Holes

- Black holes act as a lens and we see light from stars behind. They don’t necessarily look “black”.
- They range from 3 solar masses to more than a billion solar masses.
  - Small ones are formed by the collapse of a large star
  - Larger ones form at the center of galaxies
- We can tell they exist because of thing orbiting nothing, and the radiation given off as things fall into them.
- Black holes are not cosmic vacuum cleaners. If the Sun were a black hole (with the same mass) the Earth would still orbit it.

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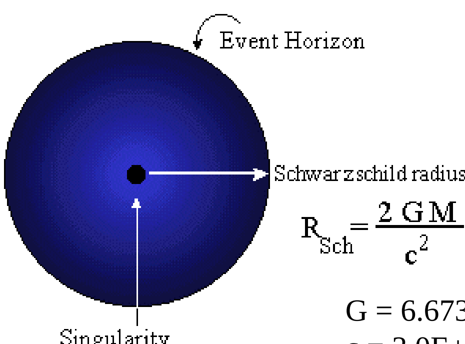
Parts of a black hole



$$R_{Sch} = \frac{2\,G\,M}{c^2}$$

G = 6.673E-11 N m^2/ kg^2
c = 3.0E+8 m/s
M = mass of the black hole

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Black hole radius example

We normally refer to the size of a black hole by its Schwarzschild radii. This is the distance inside of which nothing can escape.

What is the radius of a black hole with the mass of our Sun?
M_{sun} = 1.99E30 kg
G = 6.67E-11 N*m^2/kg^2

$$r = \frac{2GM}{c^2} = \frac{2 \cdot 6.67E-11 \cdot 1.99E30}{(3.00E8)^2} = 1470\ m$$

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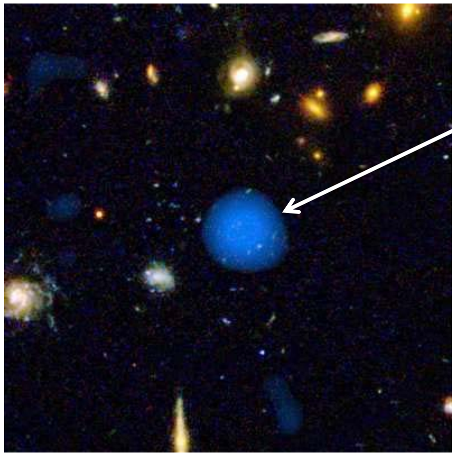
X-Rays given off by material falling in a black hole



Region heated by X-rays

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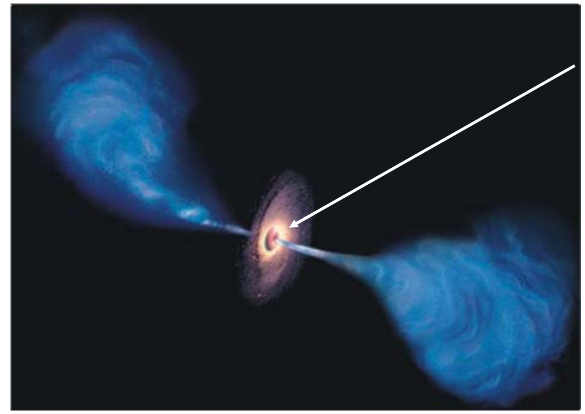
Model for Quasars, Radio Galaxies, Active Galaxies



Supermassive black hole 10^9 M_{sun}

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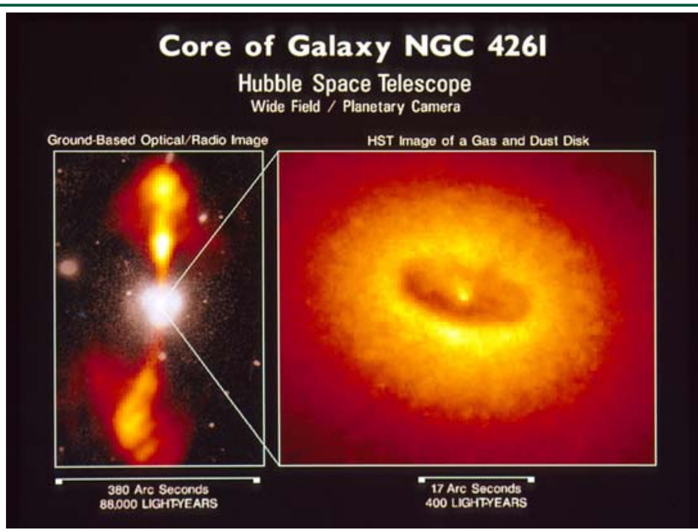
A radio galaxy – A real picture



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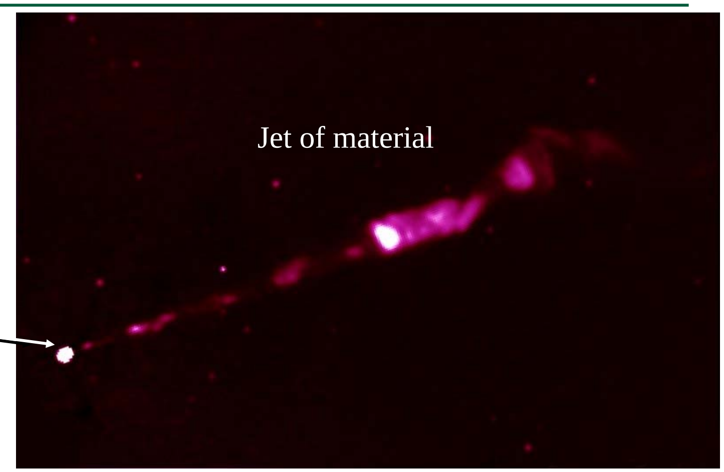
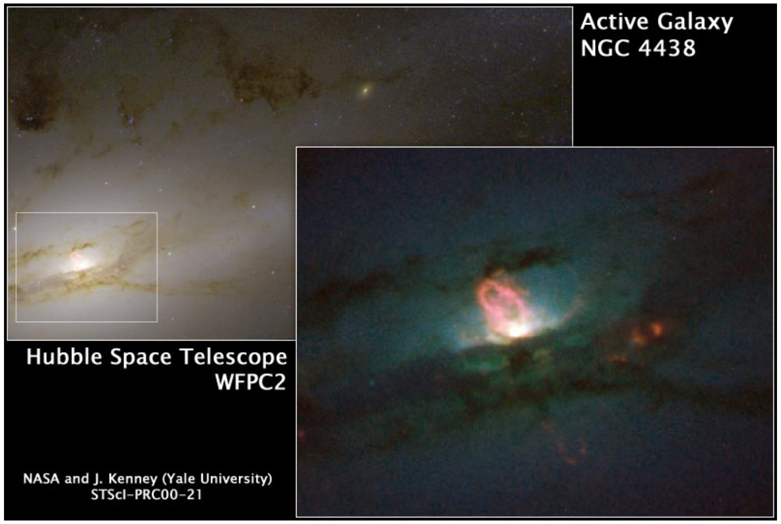
Active Galaxies/ Quasars



Galaxy

At the center is a billion solar mass black hole

Picture of an Active Galaxy (quasar)



How do we weigh a black hole?

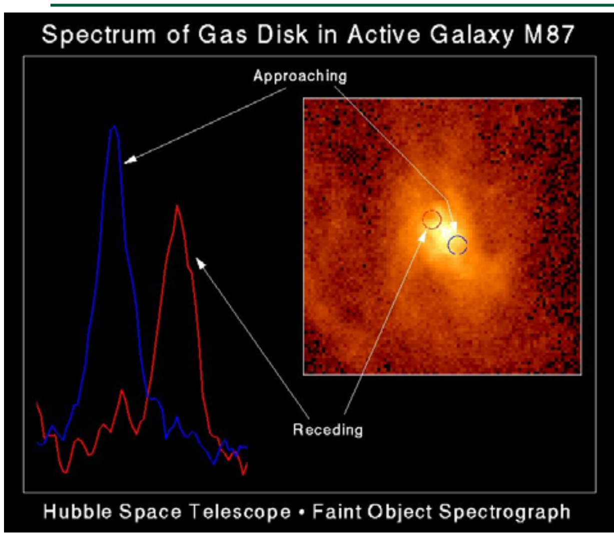
A black hole mass can be determined by how fast things orbit it.

Recall: Stronger force means more acceleration and faster rotational speed.

How do we measure speed?

- One way is to just measure distance/time.
- Another is to use the Doppler effect. The change in pitch is proportional to the speed of the object.

Rotation around a Supermassive Black Hole



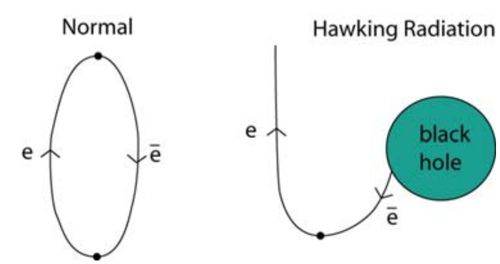
The mass of the central object is 3 billion times the mass of our sun (1.99E30 kg)

Its size is smaller than our solar system

Hawking Radiation

Black holes eventually evaporate, but it takes 10^{100} years.

Vacuum fluctuations cause a particle-antiparticle pair to appear close to the event horizon of a black hole. One of the pair falls into the black hole whilst the other escapes. By this process the black hole loses mass, and to an outside observer it would appear that the black hole has just emitted a particle.



Problem: The Uncertainty Principle

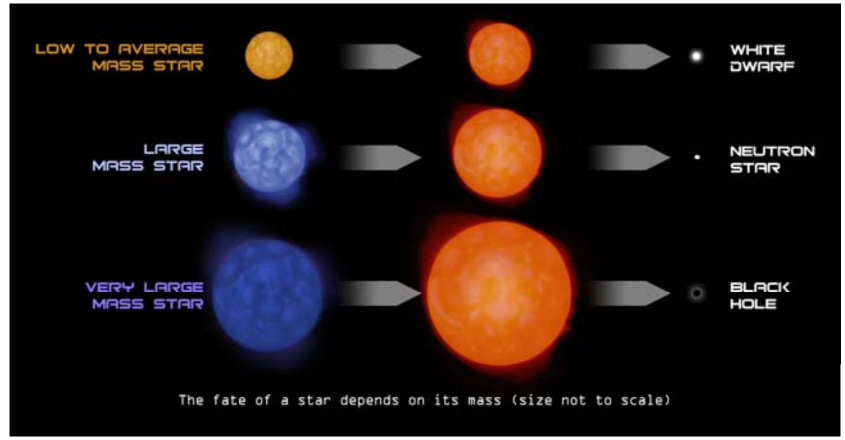
$$\Delta E \Delta t = \frac{h}{4\pi}$$

For a short time, Δt, energy does not have to be conserved and particles (adding up to, but not exceeding energy h/4πΔt) can be created.

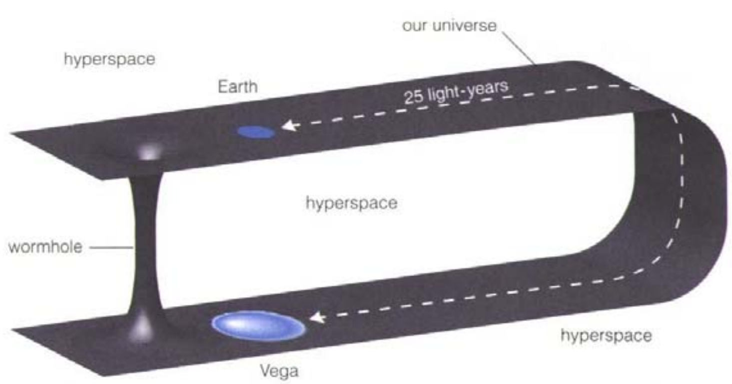
This says that scale black holes are constantly created. If they are created light could not escape and …

There is a problem with quantum mechanics and gravity. No one knows the solution.

Where do black holes come from?



Wormholes



Wormholes

- Wormholes are a possible solution to Einstein's equations.
- Wormholes are not stable. Some type of exotic material (that acts as antigravity) is necessary to keep one end open.
- If there are wormholes, there must be white holes. No white hole has ever been observed.
- We think a white hole is not stable since material would collect near the opening and collapse the white hole to a black hole.

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Back to time travel

- We need some type of material to keep the black and white wormholes stable. Possible since the Universe appears to be filled with such a substance.
- The wormhole entrance has to be big enough so tidal forces are not too large.
- One end of the wormhole must be flown at near the speed of light for some time.
- Perhaps these are just technical difficulties an advance civilization can overcome.

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What is the Fate of the Universe?

- The current age of the Universe is 13.7 billion years (or about 10^{10} years).
- 10^{100} years: All stars will have used up their nuclear fuel.
- 10^{100} to 10^{150} years: The “Dark Ages”
- 10^{150} years: All black holes will have evaporated.
- 10^{1000} years: The Universe will reach its lowest energy state.