Chapter 14: Black Holes

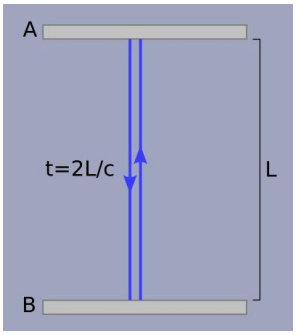
A. Result of the collapse of a star whose remnant exceeds 3 $M_{\odot}$.

1. Existence predicted by general relativity.

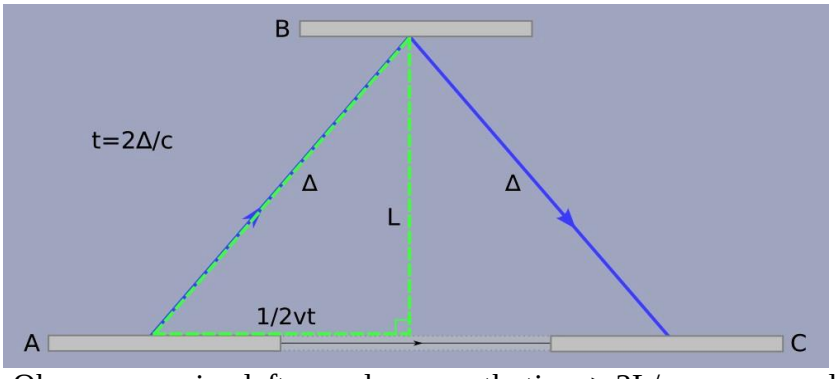
a. Special Theory of Relativity: describes how motion affects our measurements of distance, time, and mass.

Two basic ideas:
i. Your description of physical reality is the same regardless of the velocity at which you move.
ii. Regardless of your speed or direction, you always measure the speed of light to be the same.

Consequences:
i. **Length Contraction**. Length of moving objects decrease relative to a non-moving object.
ii. **Time Dilation**. Rate of a moving clock decreases relative to a non-moving object.



Observer at rest sees time 2L/c.



Observer moving left, sees longer path, time > 2L/c, same speed c.

$$t = \frac{2L/c}{\sqrt{1-(v/c)^2}}$$

The distance L that the rest observer sees is smaller than the distance Δ that the moving observer sees by the same factor $1/(1-v^2/c^2)^{1/2}$.

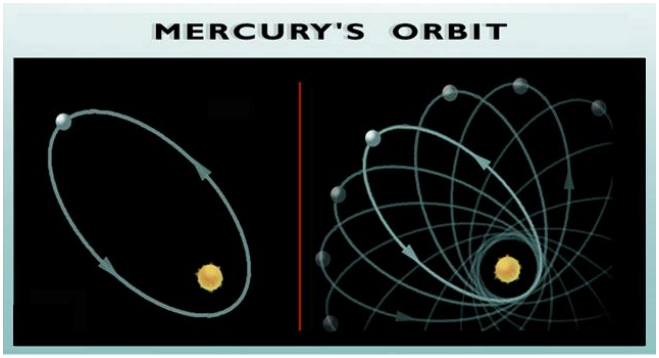
iii. **Relativistic Mass**. The mass of a moving object increases relative to a non-moving object. Think of the consequence of adding energy to an object in an effort to get to go faster. As you approach the speed of light the energy gets converted to matter by $E = mc^2$. So instead of going faster the object gets more massive.

b. General Theory of Relativity: extends Special Relativity to include the effects of gravity and acceleration. Newton's laws of motion are only valid for objects that have low mass, velocity, and low densities. The presence of matter warps space-time to produce gravitational attraction.

Confirmations of General Relativity:

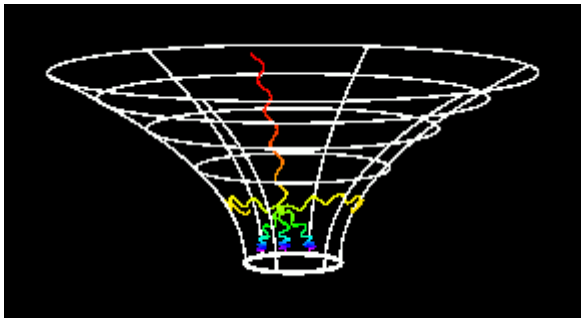
i. Deflection of star light by the Sun. Seen during solar eclipses.

ii. Precession of Mercury's perihelion. Observed precession is 43"/year more than what Newtonian physics predicts.



iii. Atomic clocks run slower in a moving airplane than stationary clocks.

iv. Gravitational redshifts are measured in the spectra of some stars.



Concept Test

According to Einstien a spaceship can never travel at the speed of light because

a) We haven't invented the warp drive yet.
b) the spaceship's mass would become infintely large.
c) it would require an infinite amount of energy.
d) b and c.

B. Properties of Black Holes:

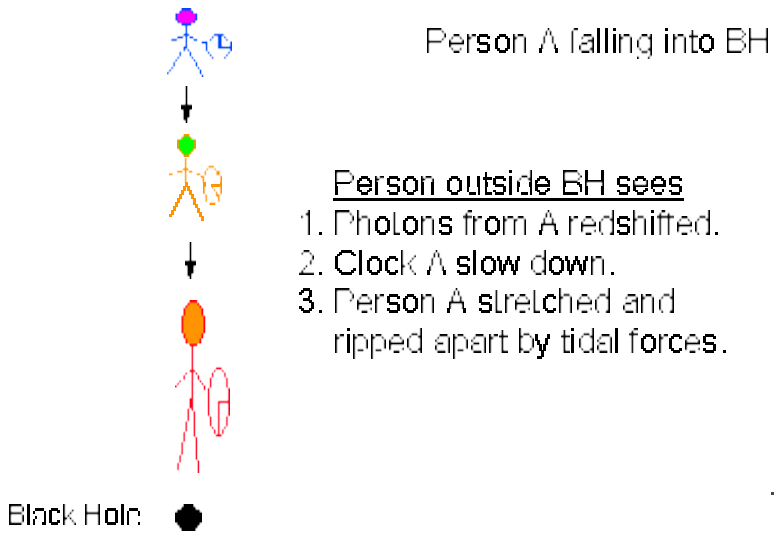
1. Singularity:
   a. infinite density.
   b. infinite gravitational field.

2. Escape velocity exceeds the speed of light.

3. Schwarzschild radius: critical radius at which the escape velocity exceeds the speed of light.

4. Event Horizon: surface of an imaginary sphere with a radius equal to the Schwarzschild radius and centered on the singularity.

5. Tidal forces: any thing that falls into a black hole will be stretched. Actually, will be torn apart.

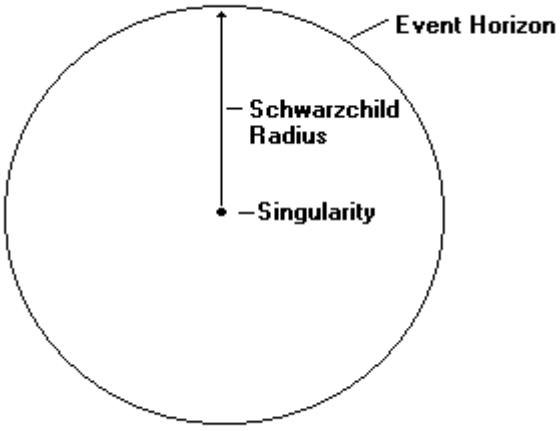


6. Gravitational red shifts: light emitted by a body falling into a black hole is red shifted by the strong gravity (photons must expend energy) as seen by an observer outside of the black hole. This is a prediction of Einstein's general theory of relativity.

7. Time dilation: apparent slowing of a clock falling into a black hole, as seen by an observer outside the black hole. Another prediction of Einstein's general theory of relativity.

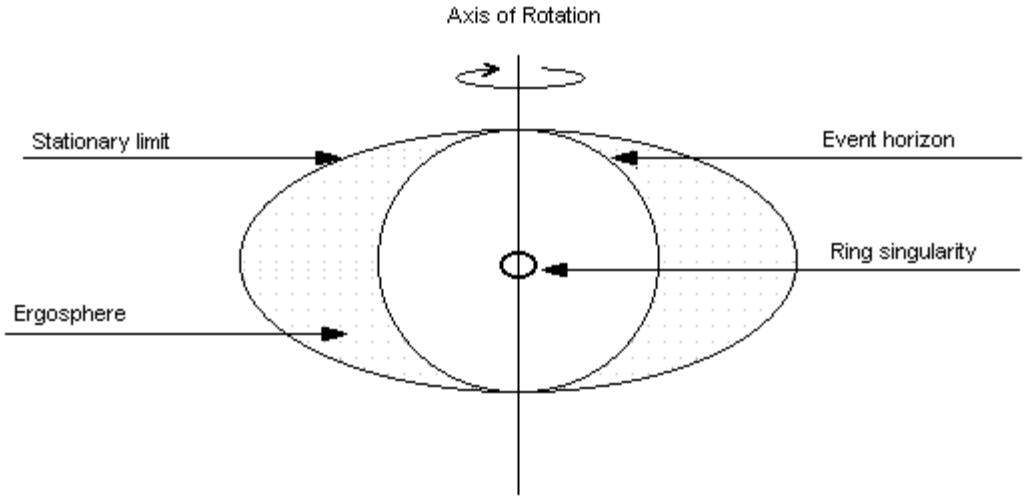
8. Principle of Cosmological Censorship: nature hides any singularities inside an event horizon so as to protect us from the breakdown of the laws of physics.

9. Non-rotating black holes - Schwarzschild black holes.



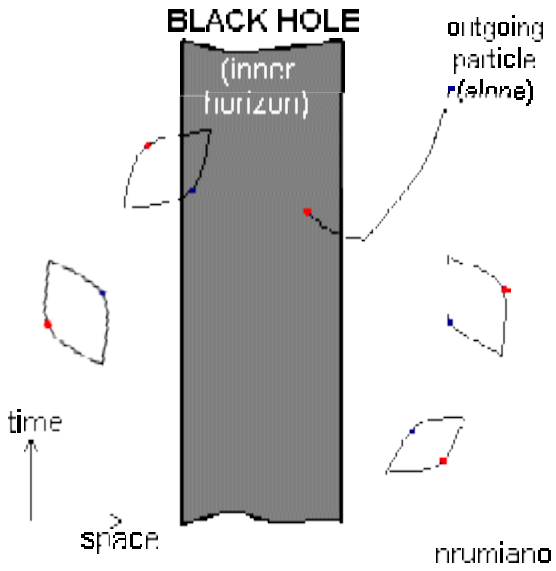
Schwarzchild Black Hole

10. Rotating black holes - Kerr black holes.



11. Primordial black holes. Tiny black holes that may have formed during the Big Bang.

12. Black Hole Evaporation (Hawking Radiation: Pair creation/annihilation (electron and positron) near a black hole can result in one of the particles being trapped and the other escaping. A 5 $M_{\odot}$ black hole will evaporate in 10^{62} years.



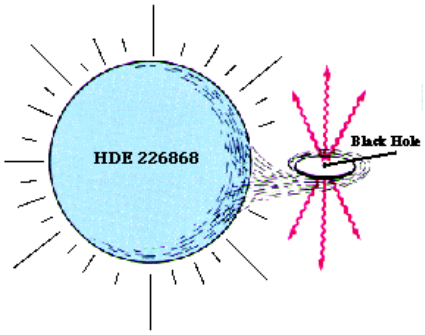
C. Observational evidence:

1. Binary star systems: Cygnus X-1.

- Single blue B-type supergiant orbiting an invisible companion of 8 $M_{\odot}$.

- X-rays emitted implying a high temperature gas is present.

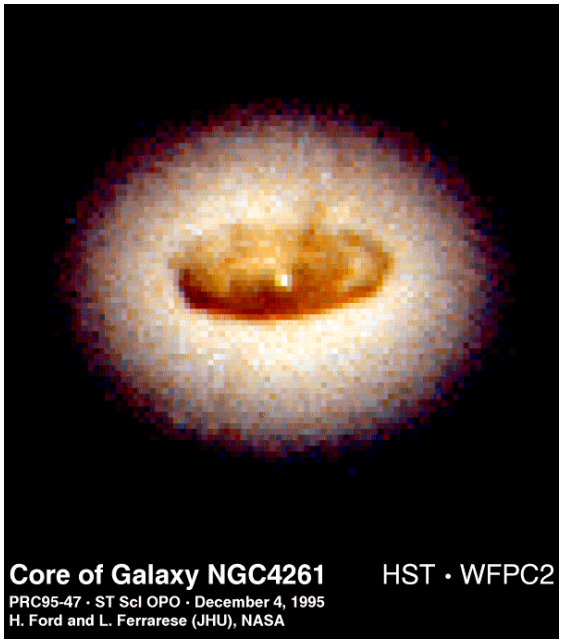
- X-rays fluctuate rapidly implying that the emitting region is about 300 km across.



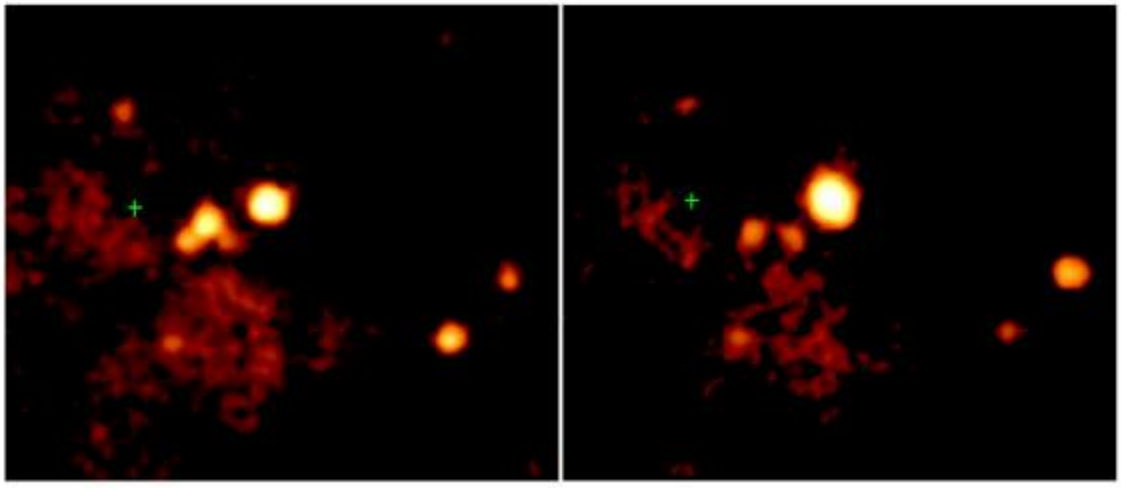
2. About a half dozen objects like Cygnus X-1 are known.

3. Black hole candidates in other galaxies.

a. Supermassive black holes.



b. Mid-mass black holes.



Mid-mass black hole candidate in M82. The small + is the galaxy center. The black hole candidate is the object that is turning on and off between the images.

Concept Test

Will the Sun ever become a black hole?

a) Yes.
b) No.