Agenda for Ast 309N, Dec. 4

- Repeat of the first-day survey (partic. credit)
- Thurs: Exam 3 (no make-up available). Office hours, help session on Tues., Wed. afternoons
- Quiz 8 feedback
- More on black holes: rotation, Hawking radiation
- More on gamma-ray bursts (GRBs)
- Review: answering questions from index cards (that haven't been addressed above)

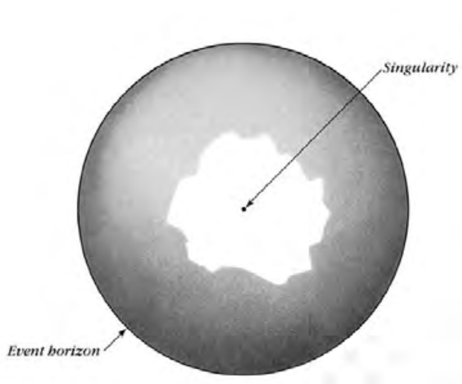
Basic Properties of Black Holes

Theory says that BH's have only three physically measurable properties:

- Mass
- Net Electrical Charge
- Rotation (Angular Momentum of Spin)

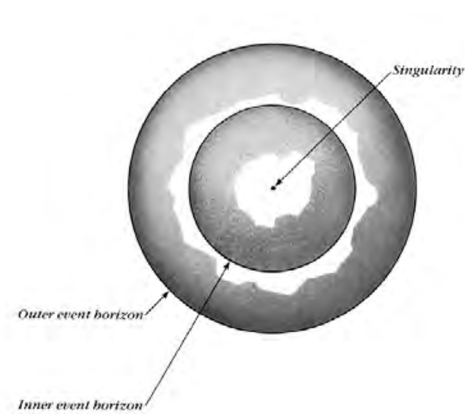
There are no other meaningful properties; thus is sometimes said that "black holes have no hair."

Structure of a "Simple" Black Hole



A plain black hole, with no net charge or rotation, has a very simple structure. It consists of the singularity, a central point where all the mass is located, and a hypothetical surface, the event horizon, surrounding it at a distance known as the Schwarzschild radius.

Electrically Charged Black Holes



A charged black hole has 2 event horizons; for large charges they could collide and annhilate, but in practice a black hole with a net charge would quickly render itself neutral by attracting oppositely charged particles.

Kaufmann, Fig. 5-4

Rotating Black Holes

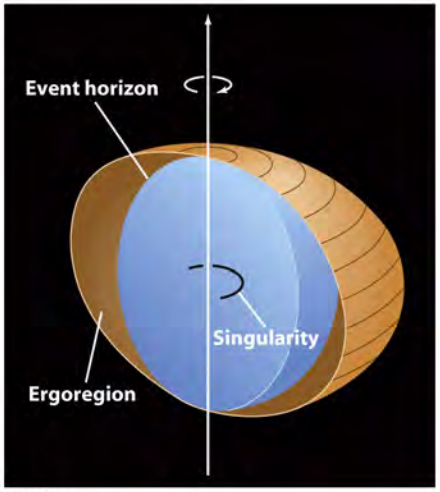


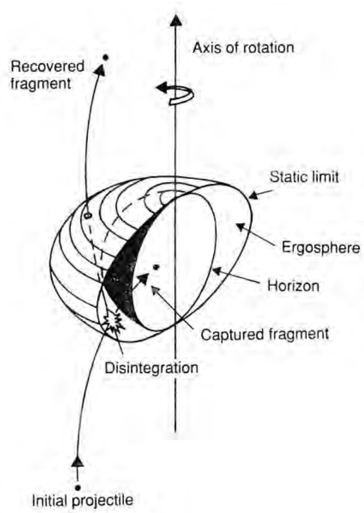
Figure 22-19
Universe, Eighth Edition

For a rotating black hole, the singularity becomes a ring instead of a point, and there is an outer, flattened boundary around the conventional spherical event horizon.

Rotating Black Holes

- GR predicts that in the ergosphere, space-time has a net rotation (a little like the co-rotating "magnetosphere" around a pulsar).
- This "frame-dragging," (Lense-Thirring) effect, may have observable effects on the accretion disks around black holes.
- Some such effects might already have been observed in X-ray binary systems and galaxy nuclei black holes (quasars).

Rotating Black Holes

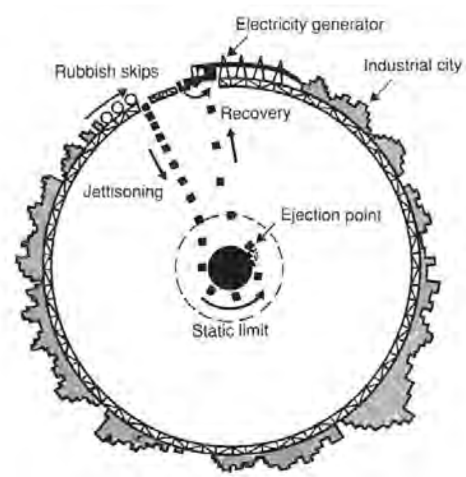


Rotating black holes could be energy sources: if an infalling particle splits into two pieces, one will fall in and the other will fly out at high velocity, gaining energy from the BH.

Some astrophysicists believe this is the origin of high-energy jets from BHs in galaxy nuclei (and maybe core-collapse Sne).

(J.-P. Luminet, Fig. 53)

"Penrose" Machine

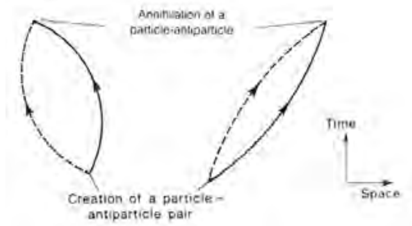


Extraction of energy from the ergosphere of a rotating black hole, as suggested by Roger Penrose.

(J.-P. Luminet, in "Black Holes," Fig. 54)

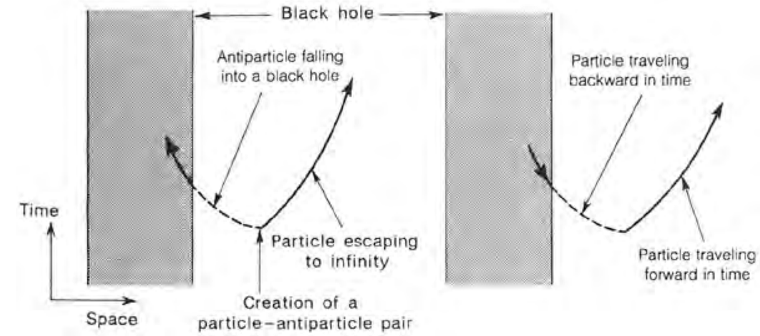
“Hawking” Radiation

According to quantum theory, on small scales in brief times, “virtual” pairs of particles/antiparticles are constantly being produced and annhilated (“quantum froth”).



If this happens near a BH, it is possible for one of the particles to fall in and the other to escape, because the event horizon has a non-zero “thickness” in quantum terms.

“Hawking” Radiation

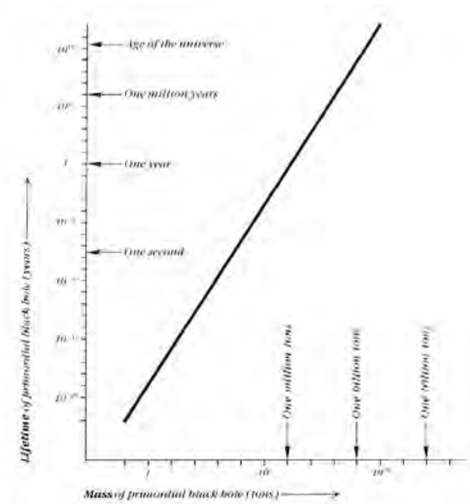


Particle pairs created near a BH; one falls in, the other escapes! Since the energy came from the BH, the BH loses mass by this “evaporation” process (Gribbin, Fig. 28)

“Hawking” Radiation

- There is a kind of “luminosity” characterized by a “Hawking temperature,” which is inversely proportional to the BH mass. (Small BH’s radiate more than big ones do!)
- This radiation represents a loss of mass-energy, and as it loses mass, the radiation goes faster. Eventually it “runs away” and the BH evaporates! The “lifetime” of a BH of 10^{15} gm (a small asteroid) is 15 b.y.

“Hawking” Radiation



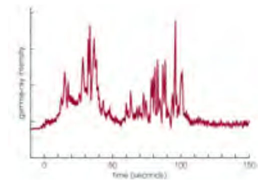
The “lifetime” of a BH to evaporate by Hawking radiation is proportional to its mass; only low-mass black holes will evaporate over the age of the Universe; stellar mass black holes live a lot longer!

(Kafumann, Fig. 11-3)

Recommended Websites on Black Holes

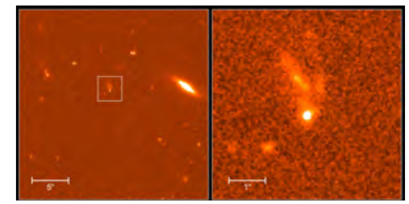
- Andrew Hamilton's site at U. Colorado:
http://jila.colorado.edu/~ajsh/insidebh/index.html
- Robert Nemiroff, author of the APOD, posted some simulations of relativity at
http://apod.nasa.gov/htmltest/rjn_bht.html
- An older site on General Relativity and Black Holes, hosted at the U. Illinois computer center:
http://archive.ncsa.illinois.edu/Cyberia/NumRel/GenRelativity.html or BlackHoles.html

Gamma-Ray Bursts



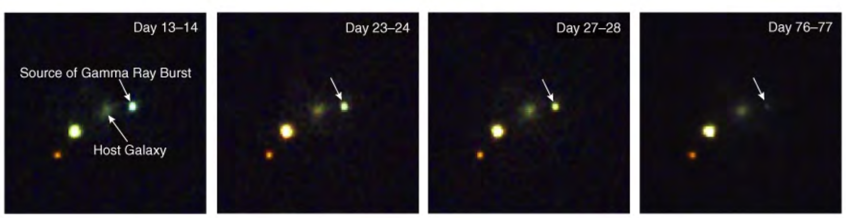
Bursts of gamma-rays from space were first detected in the 1960s by U.S. spy satellites (Velas)

It really was a great mystery for decades; were the sources nearby, or extremely distant?



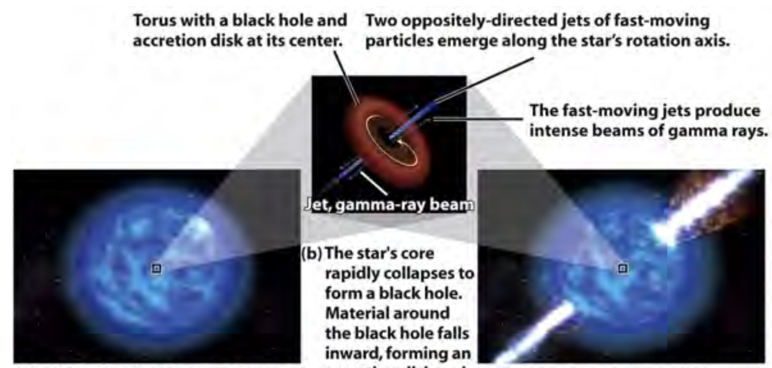
The discovery that GRBs were located in distant galaxies was important in establishing that their tremendously luminosities

Long-Period GRBs: Related to Supernovae



- Long-duration GRBs appear to come from a kind of supernova explosion, in which a black hole forms
- Evidence: supernova-type spectra from some GRBs
- Energies higher than for "standard" SNe, but if the radiation is beamed, the luminosities are less extreme

The "Collapsar" Model for GRBs



(a) After shedding its outer layers of hydrogen and helium, a rapidly rotating supergiant star of more than 30 $M_\odot$ reaches the end of its lifetime.

(b) The star's core rapidly collapses to form a black hole. Material around the black hole falls inward, forming an accretion disk and jets.

(c) The jets blast through what remains of the supergiant star. If one of the jets and its beam is directed towards Earth, we see a gamma-ray burster.

Figure 22-15
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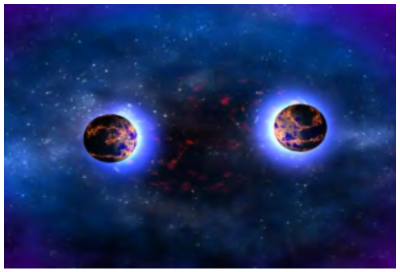
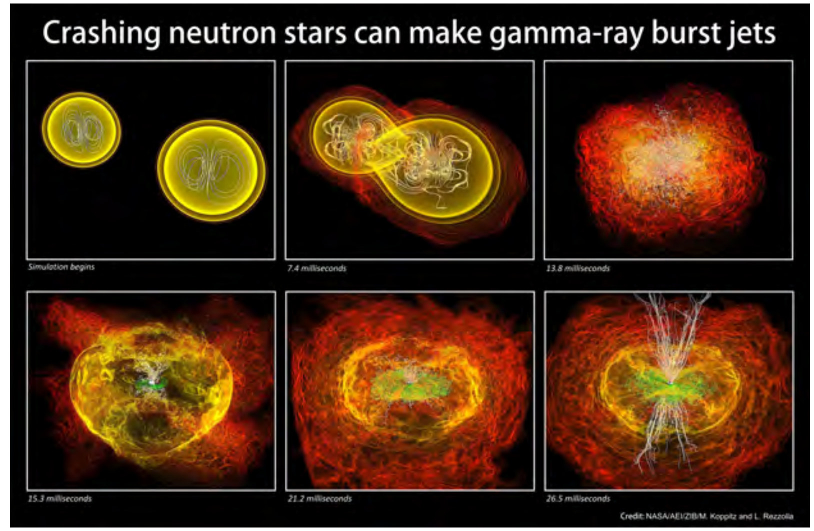
Short-Period GRBs: Merging NS?

The short-period GRBs are thought to have a different origin, possibly the merger of two neutron stars, such as the binary pulsar. The gravity waves are most intense towards the very end of the "in-spiral," as the stars begin to merge.



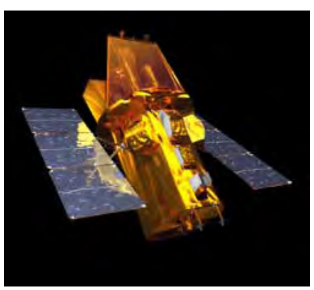
Short-Period GRBs: Merging NS?



SWIFT: NASA Mission on GRBs

NASA's SWIFT spacecraft has been detecting GRBs in γ-rays, X-rays, ultraviolet, & optical light (since 2004).

www.nasa.gov/mission_pages/swift/main/index.html



See NASA web pages for press releases and short videos of notable events and observations, not just of GRBs but other sources of gamma rays.

Semester Take-Away Points

- What you see – how things look – depends (literally!) on your viewpoint. (ex: transiting exoplanets, pulsars)
- Many of the atoms in our body and planet (almost all that are not H or He) were synthesized in stars. (It really is true that we are made of "star stuff.")
- Gravity rules! For massive bodies that are far apart, such as planets and stars, the cumulative force of gravity dominates motions. Astronomers use orbits and observed motions to deduce mass.