

Review for Test #4
Black Holes, Gamma-Ray Bursts, and Cosmology

Nature of Time in the vicinity of a black hole. Any observer always senses his or her own time as perfectly normal, but an observer at a large distance from the black hole where the force of gravity is small sees time passing more slowly for events occurring deep in the gravitational field of a black hole. Events right at the event horizon would show no passage of time to a distant observer. A distant observer watching another person falling toward the event horizon would perceive (other effects not interfering) that this second person gradually approached but never crossed the event horizon. An observer freely falling under the influence of no forces would plunge into the black hole after a finite (and normally short) passage of their own time.

Redshift—the redshift of the wavelength of photons received at a distance gets very large as the point of emission of the photon gets more deep in a gravitational field.

“Black Hole”—the large redshift of photons emitted near the event horizon coupled with the long passage of time between the arrival of these photons at a distant observer due to the apparent slowing of time means that events happening just outside the event horizon cannot, in practice, be “seen” by a distant observer.

Temperature of a black hole—according to Stephen Hawking, if one studies the event horizon with the Quantum Theory one finds that the gravitation energy (and hence mass) of a black hole can be converted into matter and anti-matter (mostly photons) with some of this material being ejected, carrying off the mass of the hole.

Black Hole Evaporation—For a black hole of ordinary stellar mass or larger the amount of mass loss is negligible in the age of the Universe and may be ignored. A black hole of less than asteroid size could totally evaporate within the age of the Universe.

The three fundamental properties of a Black Hole are those that can be measured from a distance - mass, charge, and spin. Other properties such as size and shape are specified once these basic properties are set.

Information Loss in Black Holes – Quantum theory insists information is preserved, black holes seem to destroy it.

Time-like space—interior to event horizon space drags in one direction, just as time drags you older.

Schwarzschild black hole—mass but no spin, no electrical charge. Time-like space leads to the singularity, so it cannot be avoided.

Rotating or Kerr black hole—the idealized mathematical solution of Einstein's equations developed by Kerr in which one assumes that all the mass is in the rotating singularity and that there is vacuum everywhere else.

Singularity in a rotating black hole—shaped like a ring, surrounded by “normal ” space so that it can be avoided in principle.

Time-like space in rotating black hole—the “in-going” time-like space is bounded on both sides by an event horizon so that it does not extend down to the singularity. Inside the inner event horizon is “normal” space surrounding the singularity. At the same place, but in the future, there is a region of “out-going” time-like space again bounded by two event horizons leading out to a normal Universe of flat space. In the future of that Universe is another in-going time-like space.

Inner “normal” space. Inside the rotating black hole the “normal” space will be one of huge gravity and tidal forces, but they are not infinite and one could survive in principle never emerging from the black hole, but also never hitting the singularity.

Through the singularity—passing through the ring of the singularity leads to another volume of “normal” space within the black hole surrounding the singularity, but it is not the same one that surrounds the singularity that is first encountered when entering the black hole.

Blue shift - in a real Universe matter and energy falling into a black hole will gain energy (blue shift) and that energy will probably alter the “vacuum” Kerr solution, so no extra Universes are accessible.

Clues for black holes – look for binary system where X-rays are produced in accretion disk before matter disappears down the black hole and Kepler’s law helps to determine mass greater than maximum mass of neutron star.

Cygnus X-1—First candidate black hole. Object of $10 M_{\odot}$ emits X-rays and orbits unevolved star of $30 M_{\odot}$. Small probability that $10 M_{\odot}$ object is itself a $9 M_{\odot}$ star transferring mass to a $1 M_{\odot}$ neutron star. The $9 M_{\odot}$ star could be lost in glare of $30 M_{\odot}$ star.

Black holes candidates with low mass companion stars—for these systems the “unseen” X-ray emitting star is more massive than the unevolved companion. No third ordinary star could remain unseen.

Black hole X-ray novae—all recently discovered black hole candidates sit undiscovered for decades then flare for a few months. Thought to be flushing instability in accretion disk, occurs in systems with low mass unevolved companions.

Black holes may also be surrounded by very hot, electron-positron pair-forming region which can produce high-energy X-rays or gamma-rays. Neutron stars could not, so gamma-ray could provide proof of black hole.

Superluminal sources – radio sources that appear to expand at greater than the speed of light. An optical illusion where a jet moving at 99% the speed of light, so that it chases its own light, is aimed at the Earth.

Some quasars, active galactic nuclei thought to contain supermassive black holes, display “superluminal” motion.

Some stellar mass binary black holes called micro-quasars or mini-quasars display “superluminal” radio jets; more circumstantial evidence for black holes since neutron stars are not observed to do this.

Quasars – sources as bright as 100 to 100,000 ordinary galaxies in the center of some distant galaxies. From the rapid variation of the light (hours to days) can be no larger than a solar system; suspected supermassive black hole.

Eddington Limit – critical luminosity proportional to the mass of a gravitating object such that if the object is brighter than this the gas surrounding the object will be blown away.

Mass limit – an accreting object must have a mass large enough that its Eddington Limit luminosity is greater than the observed luminosity. The large luminosity of quasars demands that the source of gravity be 100 million to 1 billion solar masses; probably a supermassive black hole.

Event horizon of a supermassive black hole would be about the size of the Earth’s orbit; consistent with size limit from variation in luminosity of quasars.

Normal galaxies – orbits of stars near the center indicate most have supermassive black holes. These black holes must not be accreting matter at a high rate or they would be very bright. They may have been quasars in the past.

Milky Way Galaxy – contains a 4 million solar mass black hole as determined by orbits of stars near the center.

Galaxy/Black Hole connection – The velocity of stars that respond to the bulge mass of a galaxy are correlated with the mass of the central supermassive black hole despite the fact that they are presently much too far from the black hole to sense its gravity. The bulge mass is always about 800 times the black hole mass. This suggests that the processes that cause the development of whole galaxies are nevertheless closely linked to the growth of the black hole when both first formed.

Intermediate mass black holes – 1000 to 10,000 solar mass black holes. First suspected from very bright X-ray sources in other galaxies requiring large masses so the Eddington limit would not be violated. More recent evidence is based on the motion of stars near the center of old globular star clusters. The mass of the black hole is deduced to be about one thousandth of the cluster mass, suggesting that globular clusters and their black holes formed by the same combined mechanism as whole galaxies and their supermassive black holes.

Gamma-ray bursts – flashes of gamma-ray energy detected by satellites about once per day lasting about 10 to 30 seconds.

Distribution in space – the gamma-ray bursts occur randomly all over the sky, so they are not associated with our Galaxy.

Optical Counterparts – discovered only in 1997, these allow gamma-ray bursts to be associated with other phenomena. They are in galaxies at cosmological distances.

The energy of a gamma-ray burst is focused in a jet moving at near the speed of light, with an energy comparable to a supernova.

GRB030329 – Gamma ray burst in March of 2003 proved that at least this burst was associated with a Type Ic supernovae.

Swift satellite – new satellite to discover and study gamma-rays bursts launched November 17, 2004.

ROTSE Telescopes – network of 4 robotic, fast response telescopes, one at McDonald Observatory, to study the optical afterglow of gamma-ray bursts.

Gamma-ray bursts and cosmology - gamma-ray bursts are so bright they might be the first objects observable as stars first began to form and die at the end of the “Dark Ages” after the Big Bang cooled off.

Big Bang – the initial expansion of the Universe from a condition of very high density and temperature (“singularity”).

Expansion of the Universe – space expands and pulls all distant galaxies apart with a speed that increases with distance. There need not be a 3-D center, a 3-D edge nor a 3-D outside to our 3-D Universe.

Age of the Universe is about 13.7 billion years, determined from the distance to supernovae (and other things) and the velocity of recession as measured by the Doppler shift.

Traditional Types of Universes – “flat” infinite in extent, will expand forever approaching zero velocity; “open” infinite in extent, will expand forever at a finite velocity; “closed” finite in extent and volume, will recollapse (neglecting cosmological constant).

Dark Matter – the vast majority of the gravitating material in the Universe emits no detectable radiation and is not, nor has ever been, composed of “ordinary” gravitating matter as we know it composed of protons, neutrons and electrons.

Supernovae as sign posts – comparing the apparent brightness to the known intrinsic brightness allows a measure of distances.

Type Ia supernovae – brightest, best current tool for measuring distances. Exploding white dwarf in a binary system.

Accelerating Universe – measurement of supernovae has suggested that the expansion of the Universe is not decelerating at all at the current time, but accelerating.

Cosmological Constant – if the Universe is accelerating, there seems to be an extra force associated with empty space. In the context of Einstein’s theory of gravity, this force could be provided by the cosmological constant. Physically, this quantity is associated with an energy of the vacuum of space, a Dark Energy that anti-gravitates.

Composition of the Universe – about 2/3 Dark Energy, about 1/3 Dark Matter, only about a few percent “ordinary” matter.

Shape of the Universe – flat. The sum of the Dark Energy, Dark Matter and “ordinary” matter is exactly right, within observational uncertainty, to render the Universe flat. Theory suggests it is essentially exactly flat.

Most recent result from supernovae – the accelerating phase took over from the earlier decelerating phase about five billion years ago.

With the Dark Energy, the Universe could expand to become a dark void, everything could be pulled apart in a Big Rip, or the Universe could recollapse to a singularity.