Cosmic Catastrophes
309N Spring 2012
(47650)
Wheeler
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Review for Test #4
Einstein's Gravity, Black Holes

Black Hole History – Mitchell, Laplace, escape velocity.

Conceptual problems with Newton's Theory of Gravity

Einstein says there is no "force" of gravity. Matter curves space and curved space tells matter how to move.

Dimension – determined by the number of mutually perpendicular directions in a given space

Space versus Hyperspace

Parallel propagation – the process of constructing a straight line; by extending a line segment parallel to itself. Guaranteed to produce the shortest distance between starting, ending points. Works in curved as well as flat space.

The nature of the curvature of a space in two, three (or higher) dimensions can be determined by doing geometry.

Three-dimensional space is regarded as "flat" if the result of doing geometry is the same as in ordinary flat two-dimensional space (sum of interior angles of triangles is 180 degrees, parallel lines remain parallel). If flat space geometry does not apply, the space is curved, or non-Euclidian.

Embedding diagram – a method of reducing a three (or higher) dimensional space to two-dimensional space that preserves the basic geometry and curvature of the original space. This allows us to "see" the curvature.

Einstein says the space around a gravitating object (Earth, a star, a black hole) is curved in the same sense as a cone poked in a rubber sheet. The circumference of a circle drawn around such an object is less than 2π times the radius and "straight lines," parallel propagated, the shortest distance between two points, curve around the object. One type of straight line in this kind of curved space follows the curved space and closes on itself. An orbit is interpreted as this kind of straight line.

Event Horizon – Since nothing with velocity less than or equal to the speed of light can pass backward through an event horizon, the information that an event occurred cannot pass through, so an event on the wrong side of an event horizon can never be known to an observer on the opposite side, hence the name.

Singularity – region in center of black hole where ordinary space and time cannot exist because of severe space time curvature and quantum uncertainty. The boundary of physics as we currently know it.

Tidal forces tend to draw any object into a "noodle" shape for two reasons: the force closer to the center is stronger and because two separated points the same distance from the hole tend to approach one another as they both try to fall directly toward the center.

Far away from a gravitating object, space is "flat" and there is no gravity. Black holes are "safe" from a distance.

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 deeper 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 events happening just outside the event horizon cannot, in practice, be "seen" by a distant observer, —hence, a "black hole."

Hawking Radiation—according to Stephen Hawking, if one studies the event horizon with the Quantum Theory one finds that the gravitational 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 as if the black hole had a temperature.

Surface of infinite redshift – the surface surrounding a black hole from which a distant observer would see photons shifted to infinitely long wavelength and zero frequency. Same as event horizon for non-rotating black hole, but not for rotating black 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 mass could totally evaporate within the age of the Universe.

According to Einstein, 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.

Normal space – can be highly curved, but is "normal" in the sense that one can navigate and return to a given point of origin.

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 sheet - 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 in a binary star system. Object of 10 $M_{\odot}$ emits X-rays and orbits un-evolved star of 30 $M_{\odot}$. Astronomers worried that the 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. This was ruled out by careful observations.

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

Supermassive black holes – all galaxies seem to have huge black holes, mass of millions to billions of solar masses, in their centers.

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 velocities 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.