Astronomy Bizarre
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Review for Test #3
Neutron Stars and Black Holes

Neutron stars – mass of sun, radius ~ 10km, density like atomic nucleus, huge gravity at surface.

Discovery of pulsars – pulsating radio sources

Interpretation of pulsars as rotating magnetized neutron stars

Role of magnetic field to cause radiation, misalignment of rotation axis, magnetic axis

Production of pulses – probably related to strong electric, magnetic fields at magnetic poles

About 600 pulsars known, perhaps a billion neutron stars in the Galaxy.

Pressure support from quantum pressure of neutrons plus nuclear repulsion. Maximum mass of neutron star about 2 solar masses.

Neutron stars as binary X-rays sources.

X-ray pulsars – accreted gas channeled to magnetic poles, "pulsar" by lighthouse effect if magnetic axis is tilted with respect to the spin axis.

X-ray transients – 4 or 5 known in our Galaxy. Outburst every few years for a month. Probably a disk instability like a dwarf nova, but with the white dwarf replaced by a neutron star.

X-ray Bursters – about 30 known in our Galaxy. Burst every few hours for minutes. Probably the neutron star analog of a classical nova. Matter accretes on surface of neutron star. Hydrogen is supported by thermal pressure, burns to helium. Helium is supported by quantum pressure and is unregulated and explodes, producing the X-rays.

Magnetars – neutron stars with magnetic fields 100 to 1000 times stronger than the Crab nebula pulsar.

Soft gamm-ray repeaters – objects that emit intense bursts of low energy gamma rays and X-rays for a few minutes every few years. Periodic "pulses" after the initial flash. Observerd spin-down rates imply they are magnetars. One soft gamma-ray repeater actually caused aurorae and interfered with terrestrial radio communications August, 1998, another flared on the far side of our Galaxy, and was detected on December 27, 2004.

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.

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.

Einstein says space around gravitating object "flows" inward, cause of free fall inward.

Einstein says that all objects accelerate at the same rate near a gravitating object because that object curves the space around it and small objects fall on the same "straight" lines, independent of their own nature.

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 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—hence, "black hole" is a more accurate term than "frozen star" which does not connote the blackness.

Hawking Radiation—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 as if the black hole had a temperature.

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.

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 in a binary star system. 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. Seen in some quasars, active galactic nuclei thought to contain supermassive black holes. 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.

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.