Astronomy Bizarre
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Review for Test #4
NEUTRON STARS AND BLACK HOLES

Discovery of pulsars - pulsating radio sources

Interpretation of pulsars as rotating magnetized neutron stars (i.e. not pulsation, not white dwarfs)

Importance of pulsar in Crab Nebula - fast period, not a white dwarf.

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, ejection of electrons, annihilation of positrons

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

Neutron stars as binary X-rays sources.

X-ray pulsars - accreted gas channeled to magnetic poles, neutron star spins faster as it accretes.

X-ray transients – 4 or 5 in 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 in the Galaxy. Burst every few hours for minutes. Probably the neutron star analog of a 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. Often found in globular clusters.

Millisecond pulsars - rotating near breakup speed for neutron stars, about 1000 times per second, but old, not young. Probably born in a binary, spun up by mass accretion. Low magnetic field so small energy loss, slow spin-down.

Binary millisecond pulsar - "black widow" system, the pulsar emits gamma rays which are helping to erode, destroy the companion star. Perhaps why most millisecond pulsars are observed as single pulsars.

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

Soft gamma-ray repeaters – objects that emit intense bursts of gamma rays and X-rays for a few minutes every few years. Observed spin-down rates imply they are magnetars. One soft gamma-ray repeater actually interfered with terrestrial radio communications August, 1998.

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.

Schwarzschild Radius—the distance of the event horizon from the center of a black hole. For a non-rotating, non-charged, black hole the size of the event horizon is 3 kilometers x (mass/solar mass) i.e. if the Sun were a black hole its event horizon would be 3 kilometers in radius (the Sun is actually about a million kilometers in radius).

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

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," 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.

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

Far away from a gravitating object, space is "flat" and there is no gravity.

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.

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

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 which 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.

Schwarzschild black hole—mass but no spin, no charge.

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.

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 3 $M_\odot$.

Cygnus X-1—First candidate black hole. Object of 10 $M_\odot$ emits X-rays and orbits unevolved star of 33 $M_\odot$ 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 33 $M_\odot$ 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 very hot, electron-positron pair-forming region which can produce high-energy X-rays or gamma-rays.