Astronomy Bizarre
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Review for Test #5

Black Holes, Gamma-Bursts, Cosmology, String Theory and Quantum Gravity

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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 Kerr 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.

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 the mass to be 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.

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

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

Afterglow – fading radiation in radio, optical, and X-rays lasting for weeks or months after main burst, collision of ejected material with matter surrounding the star.

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

About 100 gamma-ray bursts occur for every one pointed at the Earth.

Gamma-ray bursts occur in star-forming regions in spiral galaxies, so associated with massive, short-lived stars and hence core collapse.

Gamma-ray bursts are specifically associated with Type Ic supernovae.

The most popular idea is that gamma-ray bursts represent the birth of black holes, but the birth of magnetars is also considered.

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

Dark Ages – the time after the Big Bang when the Universe had expanded and cooled and there were not yet any stars or galaxies.

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 after the end of the "Dark Ages."

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 13.8 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 Dark Energy).

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" gravity matter as we know it that is composed of protons, neutrons and electrons.

Clumping of Dark matter was critical to convert smoothly spread matter into clumps and hence the galaxies and stars we see today.

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

Type Ia supernovae – bright, uniform behavior make them a tool for measuring distances. Exploding white dwarf in a binary system.

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

Dark Energy – if the Universe is accelerating, there seems to be an extra force associated with empty space. 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 a few percent "ordinary" matter.

Shape of the Universe – flat in three dimensions. 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.

Conflict between Gravity and Quantum Theory – Need quantum gravity to understand the singularity at the birth of Big Bang and in black holes.

Classic quantum theory – particles are points (electrons) that also have quantum wave-like properties, or are made up of point particles (protons are made of three quarks). The notion of particles as strings changes that picture in a fundamental way.

String Theory – "particles" are actually strings in a space of 10 dimensions plus time. The theory "contains" Einstein's General Relativity and has been used to compute the temperature of a black hole from basic theory.

Strings and space – the shape of the wrapped-up spaces determine how the strings can vibrate and hence what particle they represent.

Extra dimensions – in the first version of string theory, all the extra dimensions were "wrapped up" on a very tiny scale.

Calabi Yau space – special 6-dimensional geometry that could be the shape of the wrapped-up dimensions.

Newton had concept of "force" of gravity, Einstein's theory (which is mathematically the same as Newton's for weak gravity), had concept of gravity as curved space, string theory (which is mathematically the same as Einstein for safe distances from any singularity) has concept of gravity as a quantum force for which the messenger particles are gravitons propagating in 10 spatial dimensions.

Finite extra dimensions – the realization, guided by string theory, that some of the extra dimensions could be "large." Only gravity could go there.

Branes – surfaces or membranes in higher dimensional space suggested in string theory. Any 2D surface is a 2-brane in our 3D space. In higher dimensional spaces, higher dimensional "slices" are possible, "P" is the dimension of the brane, hence P-brane.

Bulk – the large (not wrapped-up) extra dimension in which our 3D Universe is hypothesized to exist. There could be parallel 3D universes (3-branes) floating in the 4D bulk (with 6 wrapped-up dimensions at each point in those spaces).

Forces – the forces of standard quantum theory (electromagnetic, weak, strong), are struck on branes (string loops with both footprints on the brane), hence within the 3-brane of our Universe.

Graviton – a "closed" loop of string that can leave our 3D brane and float in the 4D bulk.

Brane world – Our Universe could be a 3-D brane floating in a huge surrounding 4D bulk. Our Universe might be expanding into this 4-D bulk.

Dark Energy – Recent theories explore whether the Dark Energy could be some manifestation of the 4D bulk, other 3D branes?

Multiverse – the brane world idea that there could be many 3-D universes separated in hyperspace.

Black holes and the multiverse – when a "singularity" forms in a collapsing black hole, a new bubble universe might be born "elsewhere" in hyperspace.

Holographic Universe – the notion that all the "real" information about the content of the Universe is on the 2D horizon surrounding us and that we, of 3D space, are mere holographic projections.

Tests of string theory – traces left over from Big Bang, evidence of extra dimensions, the bulk.