Astronomy Bizarre Wheeler
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Review for Test #4

BLACK HOLES, GAMMA-RAY BURSTS AND COSMOLOGY

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.

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 2 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 total 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 black hole mass is always about 1% of the total galaxy 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 1% 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.

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.

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).

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.

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.

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.

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. In particular, Doppler shifts have been measured and they are at cosmological distances.

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

Swift satellite – new satellite to discover and study gamma-rays bursts to be launched sometime after 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.

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

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.