Review for Test #5
Gamma-Ray Bursts, Cosmology, String Theory and Quantum Gravity

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. They are in galaxies at cosmological distances.

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

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

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

GRB030329 – Gamma-ray burst in March of 2003 proved that at least this burst was associated with a Type Ic supernova. Several others have been associated with supernovae since then, all Type Ic.

GRB 080916C was 12.2 billion light years away. It was equivalent to 9000 supernovae, the brightest optical event ever recorded.

GRB090423 is the most distant object for which a spectrum has been obtained, 13.1 billion light years away, when the Universe was only 600 million years old.

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

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.

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.

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" gravitating matter as we know it 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 has suggested 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. 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 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.

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.

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

Planck scale – the tiny scale (10^{-33} cm, 10^{-43} s, 10^{93} gm/cm^3) where Einstein's theory and quantum theory are predicted to collide, the implied "size" of the singularity. Strings are somewhat larger than this.

"Quantum Foam" – word description (in absence of quantitative mathematical theory) of the expected nature of space-time on the smallest level (Planck scale) where quantum effects compete with space-time curvature.

At the quantum foam level it is not just the position of an object in otherwise uniform space that is uncertain (the classic quantum view), but the nature of space itself must be quantum uncertain, as if everywhere were tiny, effervescent worm holes connecting space and time randomly and uncertainly.

Wormholes and time machines – according to Einstein's theory it is possible, in principle, to construct wormholes that lead from one place in 3D space to another. These wormholes will also automatically be time machines. We will not truly know whether they can exist or not without a theory of quantum gravity.

Carl Sagan's "Contact" - Catalyst of work on wormholes and time machines.

Exotic matter - like the tension in a rubber band only with an energy greater than the mass energy, mc^2. Rather than adding to the weight of gravity like ordinary pressure/energy, the "negative pressure" of exotic matter repels against gravity (related, in principle, to Dark Energy).

Worm holes - exotic matter could, in principle, be used to hold off the effects of gravity and maintain the opening of a worm hole to connect two distant places in the Universe.

Shape of a wormhole - a three dimensional worm hole is not a "tube" as it appears in its two-dimensional embedding diagram, but rather a spherical space that can be approached from any direction.

Travel through a worm hole - one would proceed "straight" along a radius toward the center of the spherical space, but eventually find oneself moving away from the center and out into normal space, without ever changing direction.

View inside a wormhole - one should be able to see through a worm hole looking along the radius toward the center of the spherical space, but if one looks "sideways," perpendicular to the radius, one would see light that traveled around the highly curved space and returned to its origin.

Time and Special Relativity - if two observers are in uniform motion, each will see the other aging more slowly.

The twin paradox - if one twin remains stationary, and the other is subjected to an acceleration, either by traveling out and back or by venturing in a stronger gravity, then the twin who has experienced the acceleration, not uniform motion, will be absolutely younger.

Time machines - if worm holes exist, then they can, in principle, be used to make a time machine through the twin paradox mechanism. After one end of the worm hole is accelerated and returned, it will thereafter be absolutely younger than the mouth of the worm hole that remained at rest or in uniform motion.

Grandfather paradox - the notion that since time machines can violate causality ("cause" before "effect") a situation, like traveling back in time to kill your Grandfather, can arise that can be neither true or not true.

Novikov consistency conjecture - the conjecture that physics must be self-consistent and simply does not allow paradoxes even if time travel exists.

The pool ball crisis - the idea that a simple mechanical example could be invented to show that time machines will always come with paradoxes. A pool ball rolling into one end of a worm hole can come out in the past and hit itself before it goes in, thereby preventing it from entering the worm hole in the first place.

Resolution of pool ball crisis - Novikov and Thorne and associates showed that the pool ball problem satisfies the consistency conjecture. No case was found that gave rise to a paradox. The past and future pool balls could just "kiss" with a slight deflection of the trajectory, but a "hard" collision with the first pool ball being knocked away from the worm hole, thus giving a paradox, simply did not and cannot arise.

Free will and time machines - if time machines exist and the consistency conjecture holds, then is everything pre-ordained, and there is no free will?

Changing the future - if the consistency conjecture is true, then the future cannot be "altered" by the acts of a time traveler who went back in time.

Vacuum energy and time machines - vacuum quantum energy could travel into the past, pile up, and create such a high gravity that any worm hole would be quickly sealed. This issue cannot be resolved without a complete theory of quantum gravity.

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.

Information – in string theory, a quantum theory, information is conserved, so must be re-radiated or otherwise saved in black hole evaporation.

Quantum View of Forces – the quantum theory views (mathematically) all forces as resulting from an exchange of particles, with different particles representing different forces (electromagnetic, weak, strong).

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 scale comparable to the Plank Scale. Thought to be necessary so that gravity would have inverse-with-distance-squared behavior.

Calabi Yau space – special 6-dimensional geometry that could be the shape of the wrapped-up 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 stuck on branes (string loops with both footprints on the brane), hence within the 3-brane of our Universe.

Gravity is a creature of space, it can leak into the 4D bulk. This could make gravity seem weaker than the other forces.

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

Small leakage of gravity – just as gravity declines like r^{-2} in 3D space, it could decline like r^{-3} in 4D space (clearly wrong!). Recent realization that it could leak more slowly even if the 4D bulk existed brought a revolution in thinking about large extra dimensions."

Brane world – further work showed that even if one of the extra dimensions is very large, gravity might still be nearly confined to the 3-dimensional brane of our Universe. Our Universe could be a 3-D brane floating in a huge surrounding 4-D bulk. Our Universe might be expanding into this 4-D bulk.

Brane-world theories – models of our Universe and cosmology exploring the possible existence and effects of a large extra dimension.

Ekpyrotic Universe - the idea that another 3-D brane floating in the 4-D bulk collided with ours creating the huge, but finite, temperatures that launched the Big Bang without requiring any "singularity."

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

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.

String theory cannot yet tell us what the "singularity" is within black holes or at the beginning of the Big Bang. One idea, the singularity within a black hole represents the birth of a new Universe.

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

Multiverse – the idea that there could be many 3-D universes separated in hyper space.

String landscape – the notion that string theory may have 10^{500} solutions, each with a different value of the physical constants, only a few of which are suitable for life. If the universe is infinite, every solution, including us, is replicated.

Bubble universes – the individual universes created in the multiverse.

Eternal Inflation – the notion that universes are constantly being "born" or "inflated" out of the "quantum foam" of Planck or string-like conditions.

Chaotic Inflation – variation of eternal inflation in which new bubble universes are constantly born "elsewhere" in hyperspace and the multiverse is fractal on large scales.

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

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 projections.