

## Review Sheet 5 String, Branes, and Hyperspace

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The past is all around us. As we look into distant space in any direction, we are looking back into the past. The early conditions of the Big Bang are in every direction we look.

History of the Universe – revealed as we look out in space, back in time:  
<http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/07/image/j>

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

Planck scale – the tiny scale ( $10^{-33}$  cm,  $10^{-43}$  s) 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.

4 Forces – electromagnetism (already combining the electric force and the magnetic force in a single mathematical/physical framework since Maxwell), the weak nuclear force, the strong nuclear force – and 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.

Early history of string theory – recognition that equations that corresponded to the strong nuclear force also described entities, strings, that could stretch and wiggle.

Standard Model of Particle physics – the mathematical and physical logic of the zoo of elementary particles. The Standard Model incorporates the unification of electromagnetism and the weak nuclear force into the electroweak force (Steve Weinberg's Nobel Prize work), but treats the strong force as a separate quantum force.

Grand Unification – the premise that at very high density and temperature as in the early Big Bang, all the forces (excluding gravity) are the same.

Grand Unified Theory (GUT) – the attempt to broaden the Standard Model to include unification between the electroweak force and the strong force, but still without gravity.

Analyzing particles created in atom smashers – magnetic fields cause charged particles to spiral giving a means of measuring mass and electrical charge.

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).

Messenger particles - the particles that are exchanged, giving attractive or repulsive forces in different circumstances. For the electromagnetic force, the messenger particle is the photon.

Higher dimensions - string theory demands (through its mathematics) at least 10 dimensions (9 space + 1 time), rather than the 4 dimensions (3 space + 1 time) of standard quantum theory and Einstein's theory of gravity.

String theory as theory of quantum gravity - discovery that the math of string theory contains exactly the math of Einstein's theory of gravity and that string theory predicts a massless particle that could be the messenger particle of gravity, the graviton. Strings spread out point particles so gravity theory and quantum fit mathematically. String theory allows rips in space, tames jitter in "quantum foam."

Size of strings,  $10^{-33}$  cm, much, much smaller than a proton or neutron.

Kaluza and Klein – proposed higher, but tightly wrapped up extra dimensions.

Calabi –Yau space – geometry of tiny, wrapped-up 6D space.

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

Worm hole – link or bridge through hyperspace from one point in 3D space to another, must "rip" space to make.

M Theory – in 1995 Ed Witten showed how to combine 5 string theories into single M Theory, 10D + time.

Branes – surfaces or membranes in higher dimensional space suggested in M theory. Any 2D surface is a 2-brane in our 3D space.

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), 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 revolution in thinking about large extra dimensions.

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

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

Supersymmetry –for every known particle there should be a heavier "sparticle." Detection would be strong circumstantial evidence for string theory.

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.

Dark Energy – the space-time fluctuations of the quantum foam might give an energy to empty space, but simple estimates give the wrong answer for the Dark Energy by a factor of  $10^{120}$ . Recent theories explore whether the Dark Energy could be some manifestation of the 4D bulk, other 3D branes?