The Elegant Universe
Synopsis – Hours 2 and 3

Hour 2
Chapter 1

Conflict between Gravity and Quantum Theory.

Quantum effects on space-time – expect bumpy, chaotic, turbulent. Notions of left-right, up-down, front-back, before-after, break down.

Chapter 2

4 Forces – electromagnetism, the weak nuclear force, the strong nuclear force and gravity.

Classic quantum theory – particles are points (electrons). The notion of particles as strings changes that picture in a fundamental way.

Sheldon Glashow – string theory is not testable (but can it be?).

Chapter 3

Gabriele Veneziano – recognized that Euler's Gamma equation described the action of the strong nuclear force.

Len Susskind – recognized that Euler's equation described entities that were "strings" that could stretch and wiggle and vibrate, rather than points.

Chapter 4

Standard Model of Particle physics – the mathematical and physical logic of the zoo of elementary particles.

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). The particles that are exchanged, giving attractive or repulsive forces in different circumstances are called "messenger particles." For the electromagnetic force, the messenger particle is the photon.

Grand Unification – the premise of Grand Unified Theory (GUT) is that at very high density and temperature as in the early Big Bang, the messenger particles are all the same and hence the forces (excluding gravity) are the same. Lower temperatures bring a "phase change" in the behavior of the messenger particles, somewhat like water freezing to ice, so their behavior becomes different and we think of the result as different forces even though they are fundamentally the same thing (ice is still H_2O).

Standard Model (and GUT) cannot explain gravity and predicted particles that can move faster (but never slower!) than light (so does Einstein's theory of special relativity).

String theory promises to fix those problems, but also 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.

Chapter 5

John Swartz – wrestled with mathematical inconsistencies in early string theories and discovered that the math of string theory contained exactly the math of Einstein's theory of Gravity. This was the first notion that string theory might be the long-sought theory of quantum gravity.

Massless particles – early string theories predicted the existence of a massless particle that was different than a photon. Swartz recognized that this predicted particle could correspond to the Graviton, the messenger particles needed for a picture in which gravity, like the other quantum forces was the result of an exchange of quantum particles (in this case between two masses).

Michael Green (no relation to Brian Greene) – worked with Swartz to rid the early string theory of anomalies.

Anomalies – mathematical inconsistencies in a physical theory in which, for example, a quantity would be predicted to have two different values depending on how you solved the equations. A logical inconsistency that would mean the equations were not describing nature.

Chapter 6

Size of strings, 10^{-33} cm, much, much smaller than a proton or neutron. If an atom were the size of the solar system, a string would be the size of a tree. Devising a direct test of how physics works at that scale is presently impossible, but there may be indirect tests of the predictions of string theory for larger, testable scales.

Action of strings - all strings fundamentally identical, different vibration corresponds to different, mass, charge, hence different particle.

Strings "calm the jitters" of quantum theory. Strings spread out point particles (in standard quantum theory, the electron has zero radius), so gravity theory and quantum fit mathematically. Need extra dimensions of space to make it work.

Chapter 7

Theodore Kaluza (German) in 1919 proposed an extra spatial dimension for electromagnetic theory.

Oscal Klein (Swedish) – suggested extra dimension, present at *every point* in normal 3D space, could be so tightly wrapped up, with the distance "around" them much smaller than an atom, that we cannot easily perceive them.

String Theory demands at least 6 extra dimensions.

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

Chapter 8

20 fundamental constants – examples, speed of light (c), strength of gravity (G), mass of electron. If any of these constants were different, the Universe would be very different, inhospitable to life, for instance. One goal of string theory (not yet realized) is to predict these constants.

Shape of wrapped up 6-D spaces of string theory may determine the vibration of strings and hence the values of constants.

5 string theories with 9D plus time.

Hour 3

Chapter 1

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

Topology – theory of fundamental shapes, a doughnut is equivalent to a teacup (one hole), but fundamentally different than a sphere (no hole).

String theory tames jitter in “quantum foam,” allows rips in space.

Large extra dimensions - Our 3D Universe could be floating in higher dimensional space.

Chapter 2

Summary - different string vibrations make all particles, explain all matter, forces of nature, Theory of Everything

Chapter 3

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

Chapter 4

Branes – surfaces or membranes in higher dimensional space. A sheet of paper (or any 2D surface) is a 2-brane in our normal 3D space. Our 3D Universe could be a 3-brane in a larger 4D hyperspace. Branes are intrinsic structures also predicted by string theory, especially M theory.

Chapter 5

Forces – the forces of standard quantum theory (electromagnetic, weak, strong), hence atoms and us, 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 and into the wrapped-up extra 6 dimensions (closed string loops, gravitons, that can float in the bulk). This could make gravity seem weaker than the other forces.

Chapter 6

Big Bang – origin of the Universe, the “singularity.”

Ekpyrotic theory – Big Bang was a collision of two 3D branes within the bulk (illustrative, but not widely accepted, testable in principle).

Chapter 7

Tests of string theory – traces left over from Big Bang, evidence of extra dimensions, the bulk. Searching for evidence of graviton “leaving” our 3D brane in atom smasher.

Supersymmetry – central prediction of string theory, for every known particle there should be a heavier “sparticle.” Not yet seen, would be strong circumstantial evidence for string theory.

Chapter 8

Too elegant to be wrong?