Monday, May 1, 2017

Fifth exam and sky watch, FRIDAY, May 5. Lectures end of 30 to 38.

Review Sheet posted. Review Thursday, 5 – 6 PM WEL 2.308.

Reading for Exam 5: Chapter 9 – Sections 9.6.1, 9.6.2, 9.7; Chapter 10 - Sections 10.1-10.4, 10.9; Chapter 11 - all except Section 11.6 (abbreviated, focus on lectures); Chapter 12 - all; SKIP Chapter 13; **Chapter 14 – very abbreviated version** (focus on lectures).

Electronic Course Survey is now available. Please respond, your feedback is very valuable.

Astronomy in the news?

Elon Musk’s SpaceX launched a spy satellite for the National Reconnaissance Office and successfully landed the booster, saving money.

Goal:

To understand why we need a new theory of Quantum Gravity and the ideas involved in the attempt to construct that theory.

Skipping Chapter 13 on Worm Holes and Time Machines. To know whether they could exist, even in principle, we need a theory of quantum gravity.

Chapter 14: Quantum Gravity - The Final Frontier

The remainder of the class will be spent exploring various aspects of the most fundamental issue of modern physics: reconciling ***Einstein's theory of gravity*** as curved space with the ***quantum theory*** of how things behave at a fundamental microscopic level.

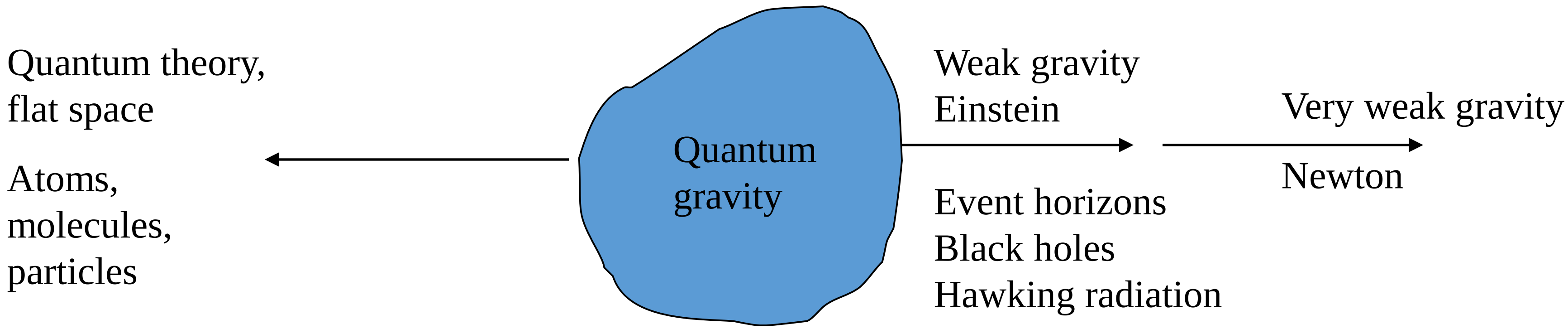
The problem - each of these great theories of 20th century physics contradict one another at a fundamental level.

Einstein's theory predicts ***singularities*** at the beginning of the Big Bang and in the centers of black holes where matter is crushed to a point with infinite density, time and space come to a halt. Quantum theory says the position of nothing, not even a singularity, can be specified exactly (the Uncertainty Principle applied to singularities).

Quantum theory is designed to work in flat, or gently curving space. It does not make sense when the curvature of space is tighter than the "wavelength," the uncertainty in position, of a particle.

In extreme conditions, each great theory of 20th century physics contradicts the other!

We need an embracing theory of ***quantum gravity*** that will reduce to ordinary gravity and ordinary quantum theory where they work well (away from singularities and with non-severe curvature - same thing!), but will also tell us what a “singularity” really is.



The world of the small

The world of the large

Can use current theories to "predict" the conditions for which the theoretical collision occurs, where the theory of **quantum gravity** is most crucially needed, effectively the **scale of length where quantum uncertainty and space-time curvature are equal**.

Planck length - about 10^{-33} centimeters, vastly smaller than any particle, but still not zero!

Planck density - about 10^{93} grams/cubic centimeter, huge, but not infinite!

Planck time - about 10^{-43} seconds, short, but not zero! Cannot predict earlier times in the Big Bang.

On the Planck scale, not just that the position of things would be uncertain in space, but that space and time themselves could be quantum uncertain, "up" "down" "before" "after" difficult if not impossible to define.

Spacetime becomes a "quantum foam" (a poetic concept without a mathematical/physical framework).

Goal:

To understand how string theory represents the current best candidate to be the needed theory of quantum gravity (Chapter 14)

String Theory

Best current candidate for a quantum gravity “theory of everything.”

String theory is a quantum theory, but it also intrinsically contains curved surfaces.

Particles like e-, p, n are not “points” but strings, otherwise identical loops of energy that vibrate in different modes

The different modes of vibrations give all the well-known particles and ***more***

Can't make notes with grains of sand, but with strings, you have Mozart

From Brian Greene - The Elegant Universe

Overtones of single string give different notes.

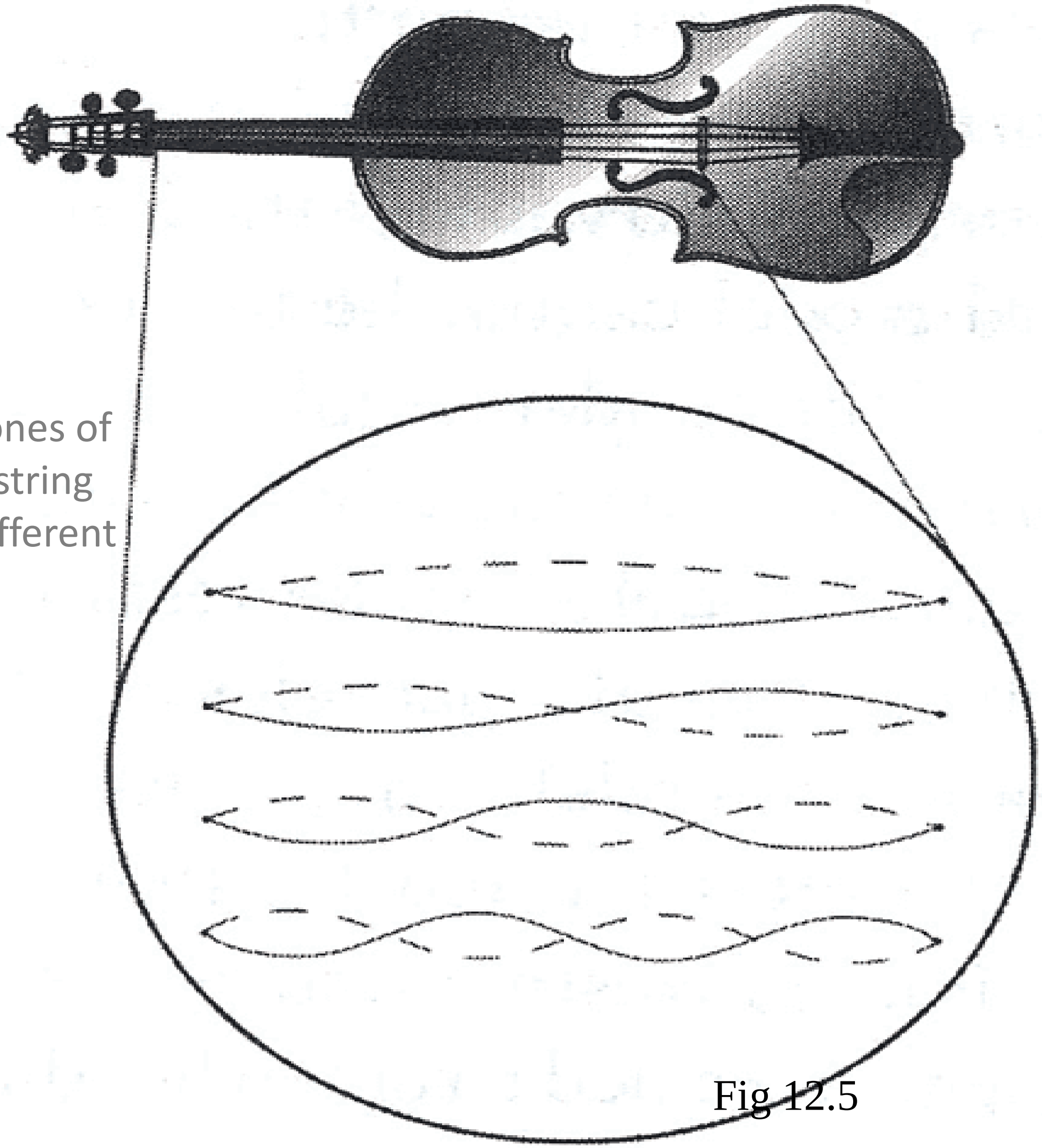


Fig 12.5

One particle

A different particle

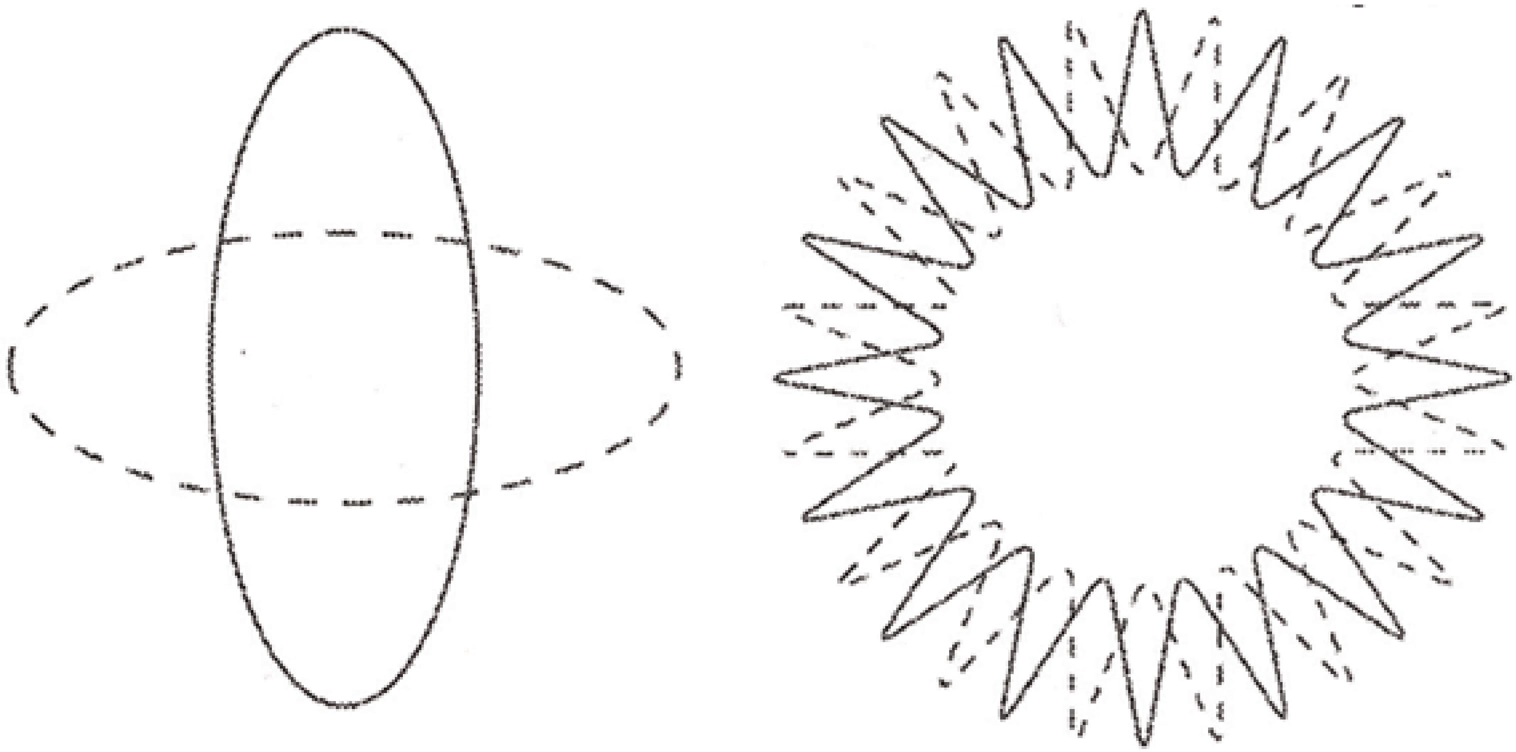


Fig 12.6

Same fundamental loop of string

From Brian Greene - The Elegant Universe

To be mathematically self-consistent

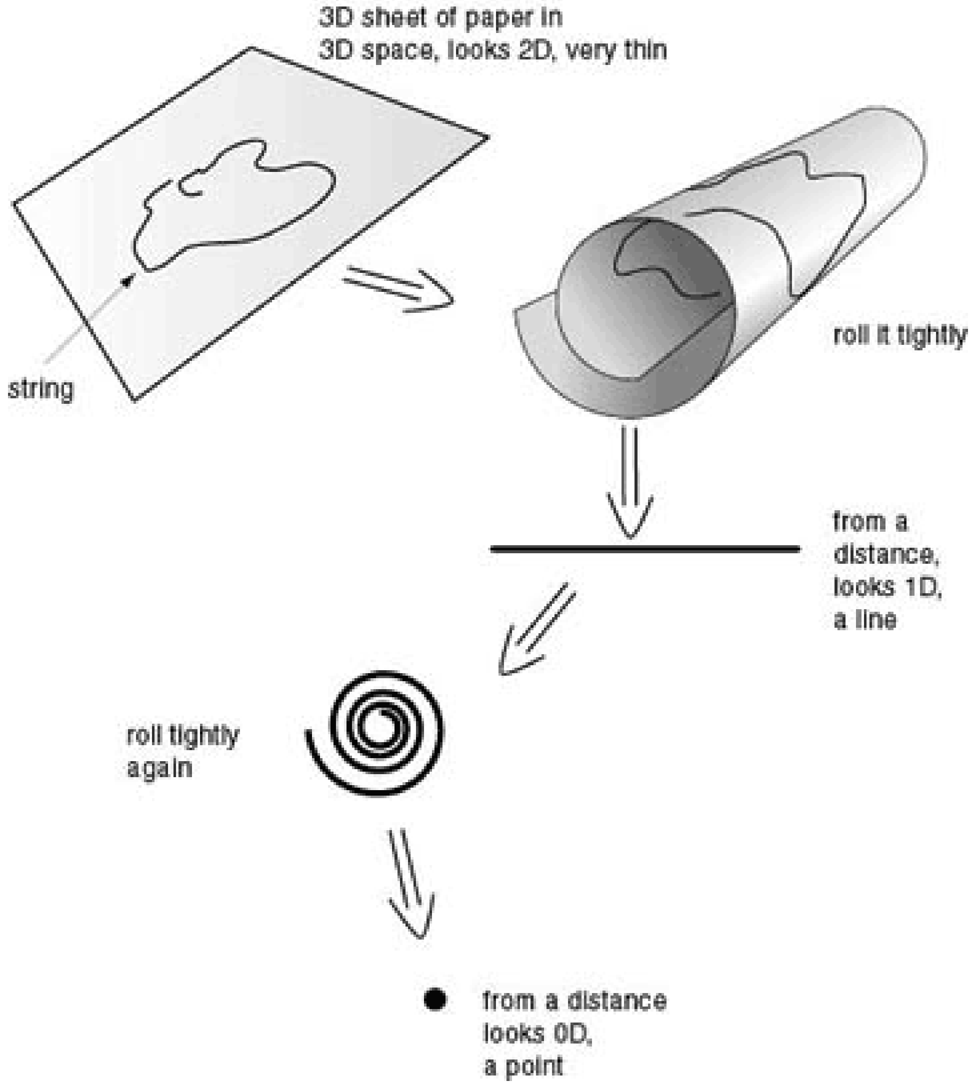
Space in which strings vibrate has ***10 space dimensions*** + time

First notions:

3 big space dimensions + time

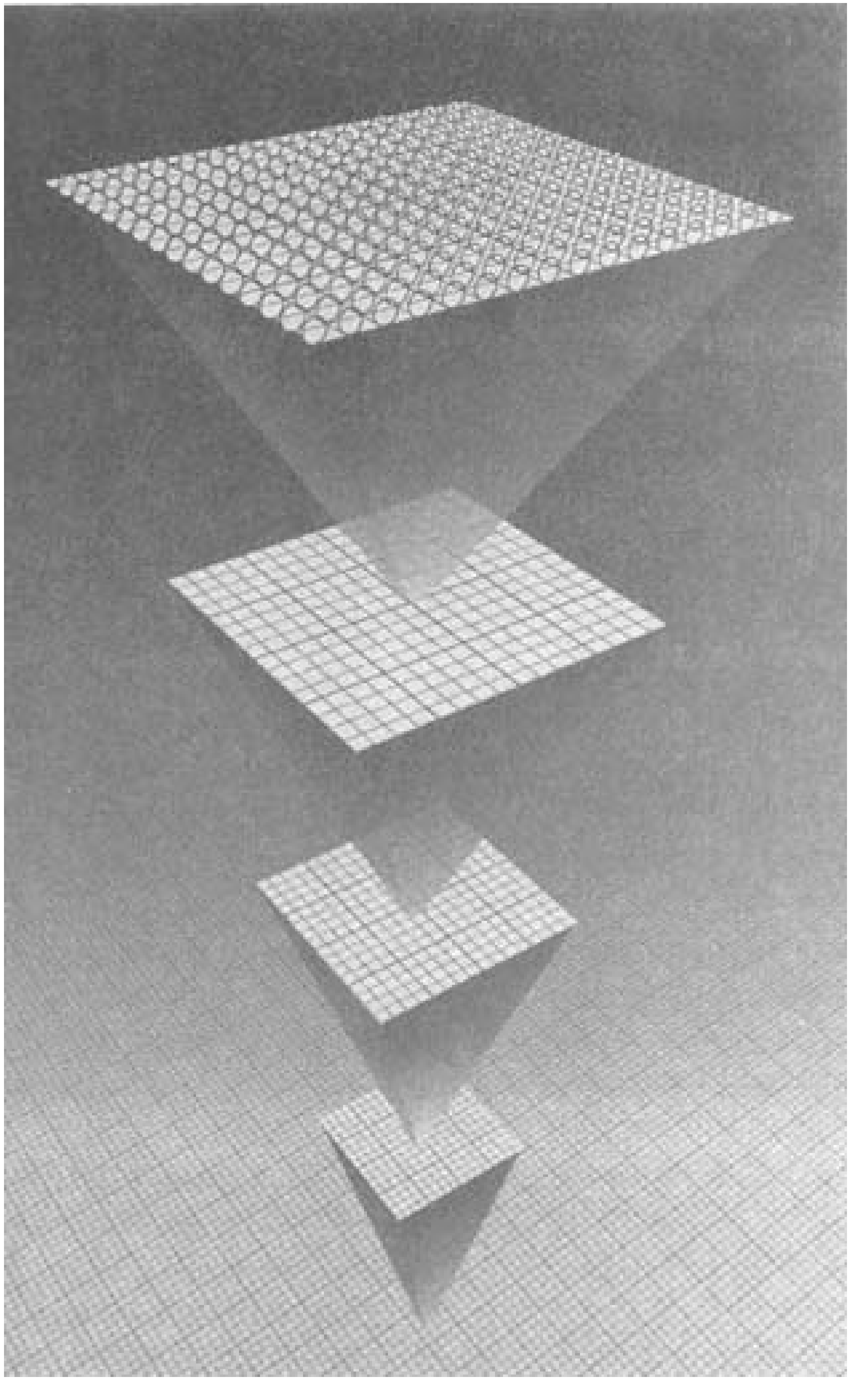
Other 7 spatial dimensions "wrapped up" on "string length scale," not known precisely, somewhat larger than the Planck scale, but very tiny so we cannot easily "see."

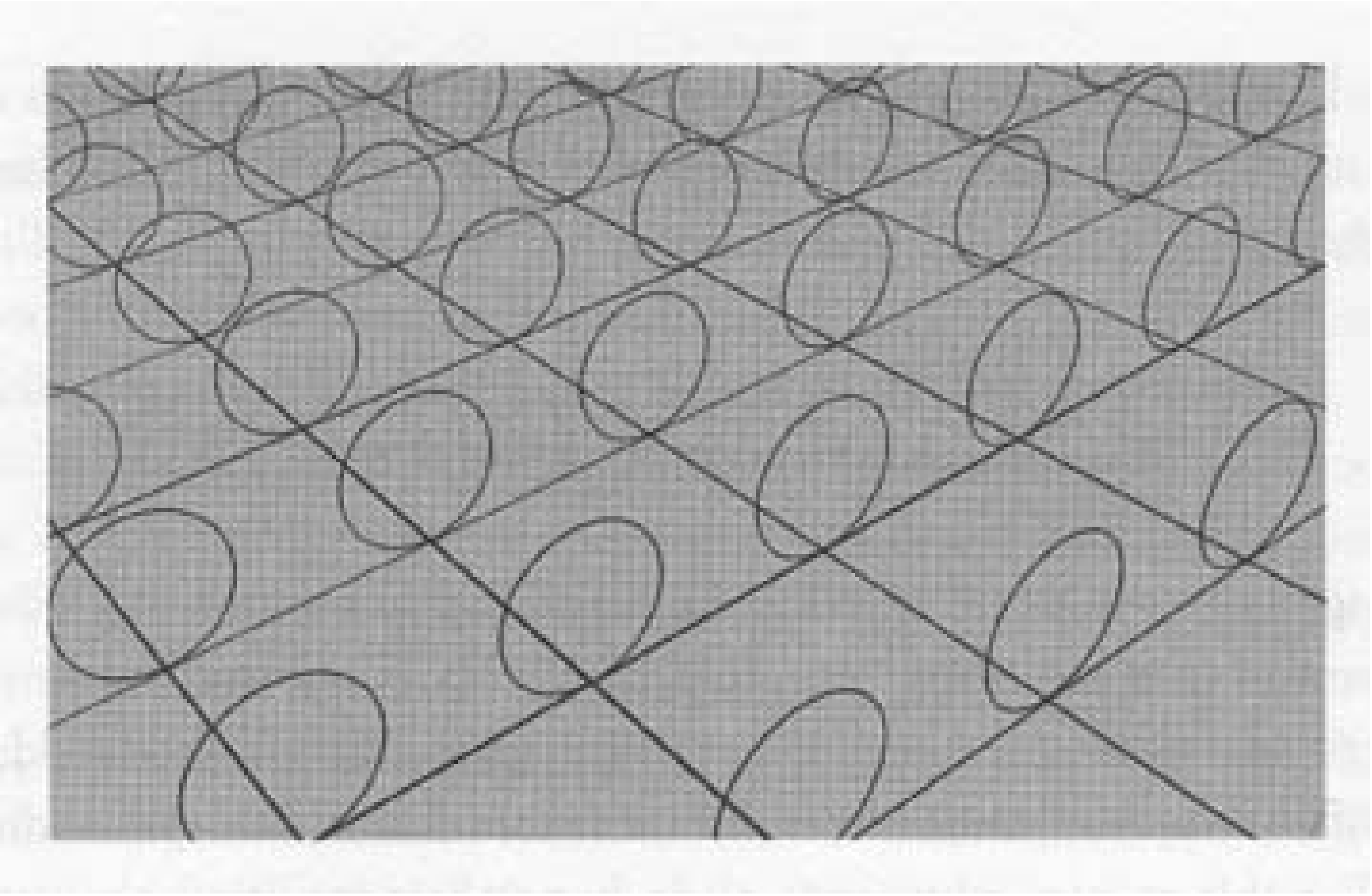
Fig 12.3


3D sheet of paper in
3D space, looks 2D, very thin
string
roll it tightly
from a
distance,
looks 1D,
a line
roll tightly
again
from a distance
looks 0D,
a point

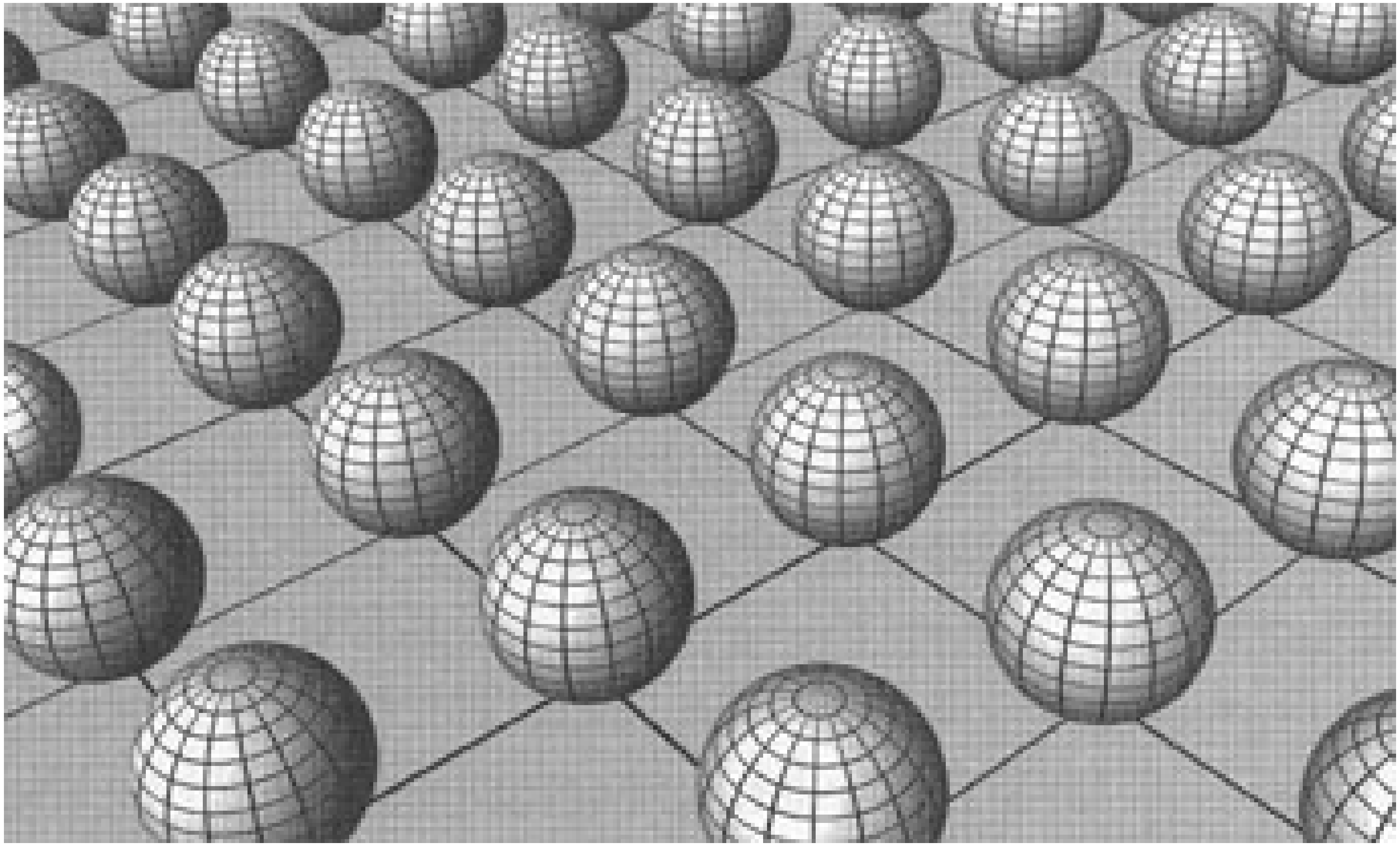
Schematic illustrations of how tiny “wrapped up” extra dimensions could be associated with our 3D space - something like an embedding diagram of the higher dimensional space, so our 3D space is reduced to 2D and the higher dimensional wrapped spaces are reduced to 3D.

From Brian Greene - The Elegant Universe

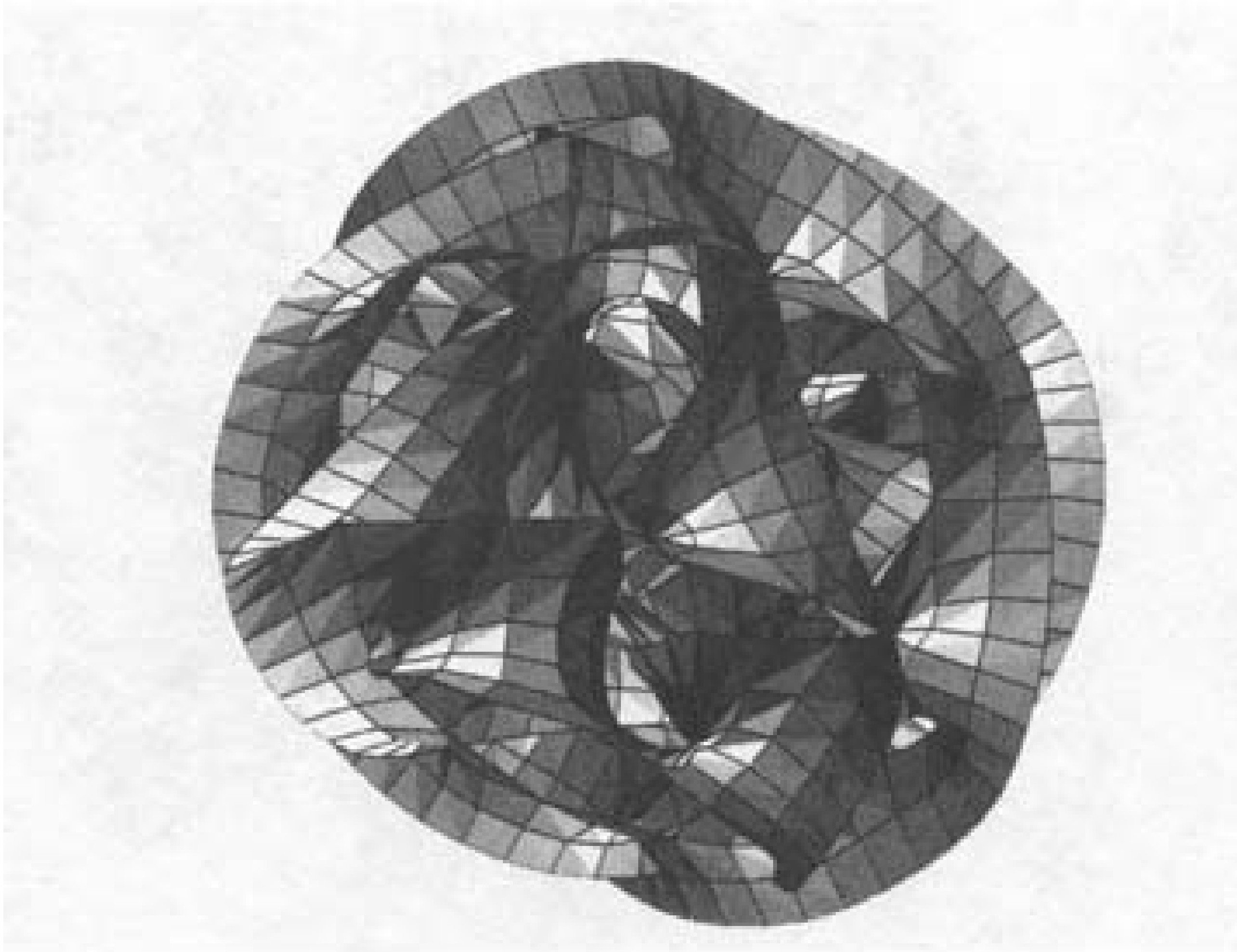




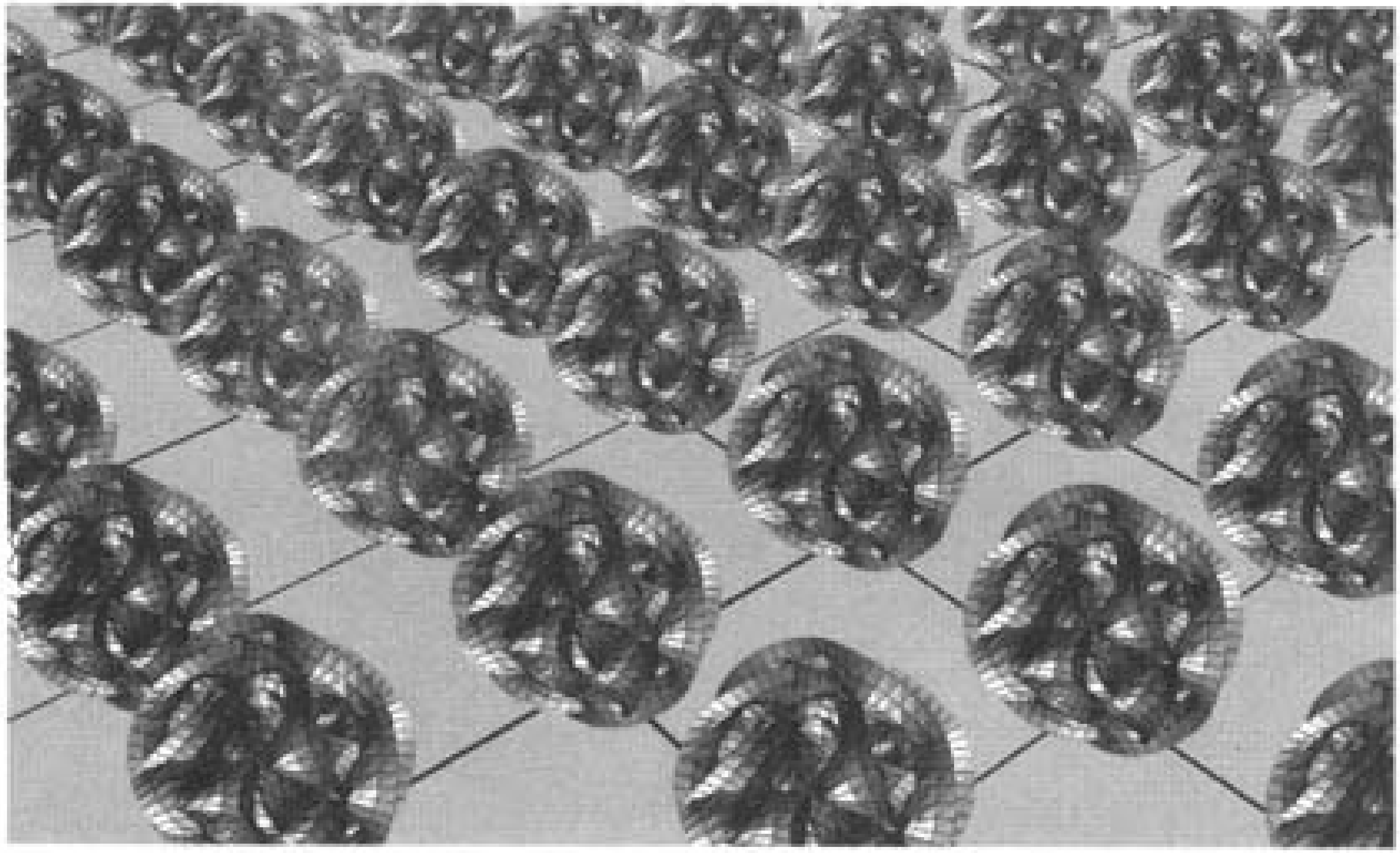
At each point in the 2D space (not just at the intersections of grid lines), there is a little 1D loop of one wrapped up extra dimension. From Brian Greene:The Elegant Universe



At each point in the 2D space (not just at the intersections of grid lines), there is a little 2D “sphere” of two wrapped-up extra dimensions. From Brian Greene: The Elegant Universe.



Representation of a Calabi-Yau space, with 6 wrapped-up extra dimensions. Calibi-Yau space gives string vibrations the properties of known particles. From Brian Greene: The Elegant Universe.



At each point in the 2D space (not just at the intersections of grid lines), there is a little 6D Calibi-Yau space of six wrapped-up extra dimensions.
From Brian Greene: The Elegant Universe.

Mathematics of string theory is complex.

Only approximate solutions so far, but:

String theory “contains” Einstein’s Theory mathematically on large enough spatial scales that string “loops” are tiny, just as Einstein’s theory “contains” Newton’s mathematical theory of gravity on length scales where gravity is weak.

Can solve string theory near the event horizon (much larger than string scale) to determine the temperature of a black hole, get exactly Hawking’s answer - deep connection between string theory and black holes.

Cannot yet solve for “singularity,” but prospect to do so. Singularity would not be zero size and infinite density, but some behavior on the string length scale, not quantum foam, but some “stringy” nature.

Information fallen into black holes could be retained in string vibrations (or radiated away in “stringy” Hawking radiation).

Goal:

To understand why physicists argued that any “extra” dimensions had to be tiny and wrapped up, how that restriction was removed, and what that means for our view of the Universe.

Concept check:

What is the “inverse r-squared law?”

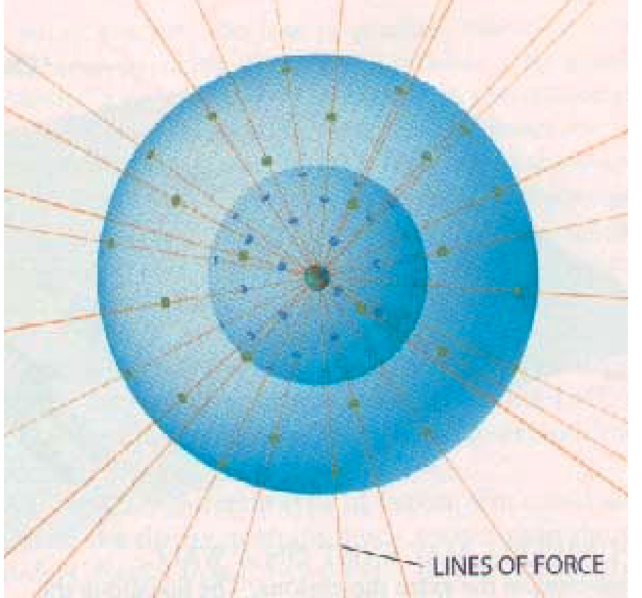
Old argument: there could ***not*** be a ***large*** 4th spatial dimension

Behavior of light, electrical force, and gravity in 3D

The luminosity or lines of force flow out through larger ***area*** at larger distance. The strength (brightness or lines of force per unit area) is thus diluted by 1/area $\propto 1/r^2$ in 3D.

Area is one dimension less than volume.

The "2" in the inverse square law is exactly "1" less than the total number of large dimensions, "3"



Light and electricity might be stuck in 3D, but gravity probes all space, whatever its dimension. Gravity is a creature of space/time

Extend the argument to higher dimensions than 3.

An "area" is one dimension less than the total "volume" corresponding to a given dimension of space.

If gravity extends to a fourth dimension, where "volumes" scale like r^4 and "surfaces" scale like r^3, then gravity would be diluted in 4D by 1/ "area" $\propto 1/r^3$ in 4D.

Obviously wrong! Even Newton knew that gravity weakens as the inverse of distance squared, not as distance cubed!

Implication (it was long thought): IF there is a 4th (or higher) dimension it must be "wrapped up" so gravity has nowhere to go.