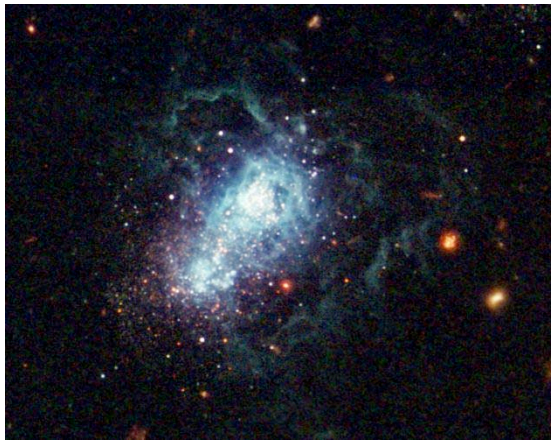
12/3/04

Final - Saturday, December 11, 7:00 PM

Painter Hall - 4.42 (NOT WELCH)

Review sheet for material since exam 4, some term-long themes, will be posted today.

Pic of the day: Young galaxy 1 Zwicky 18



Extra credit sky-watch reports are due by 5 PM on Monday, December 6 (or earlier!!).

Office hours during finals week:

Dunham: M-F 3 - 5 PM (3 -4 Wednesday)

Wheeler: M-F 2 - 3 PM (or by appointment)

Special Office Hours: RLM 15.216B

Tuesday 4 - 5 PM

Thursday 5 - 6 PM

String Theory

History - in 1960's physicists recognized that the equations corresponding to the strong nuclear force also described entities that could stretch and wiggle - strings

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

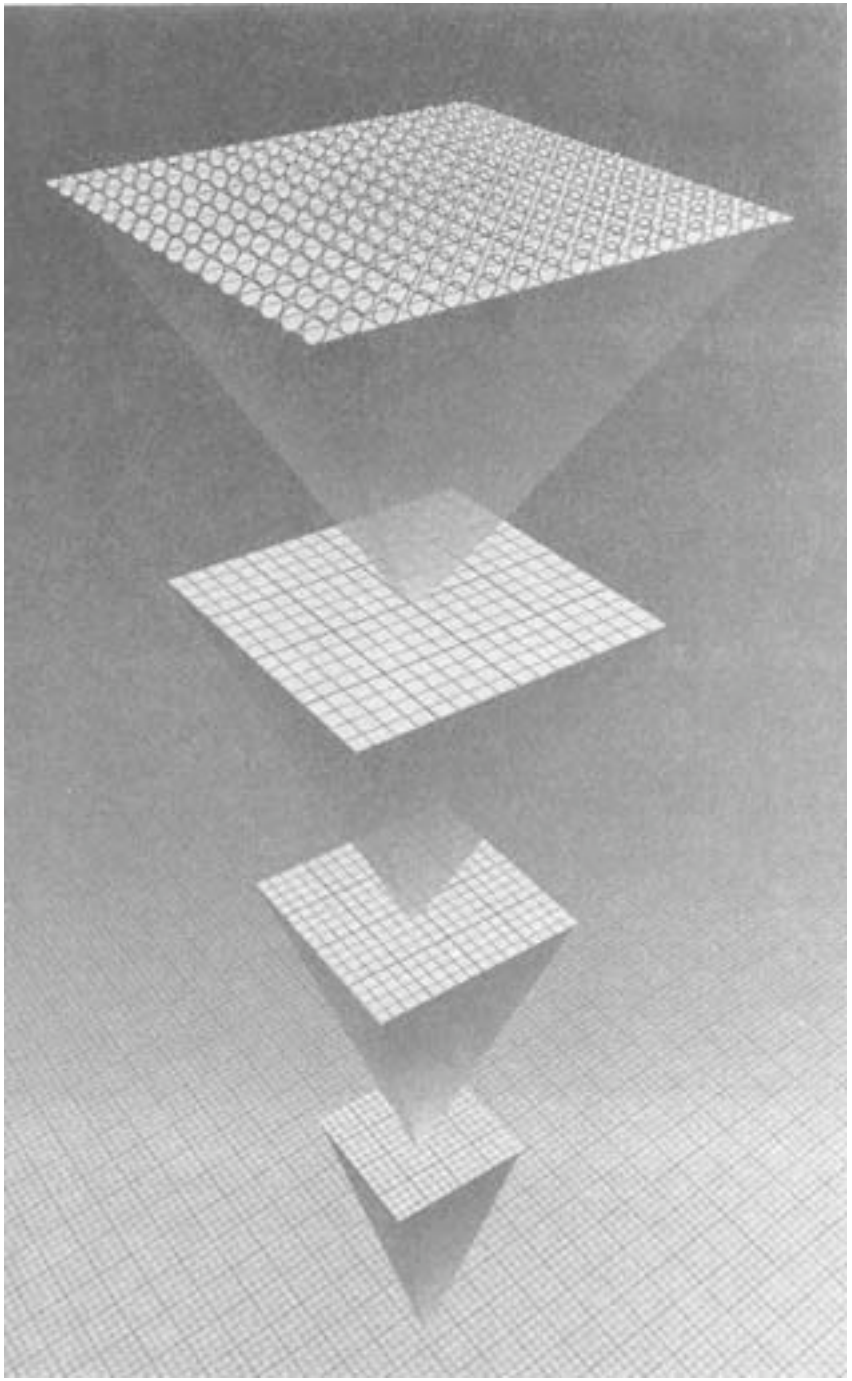
First notions: 3 big space dimensions + time

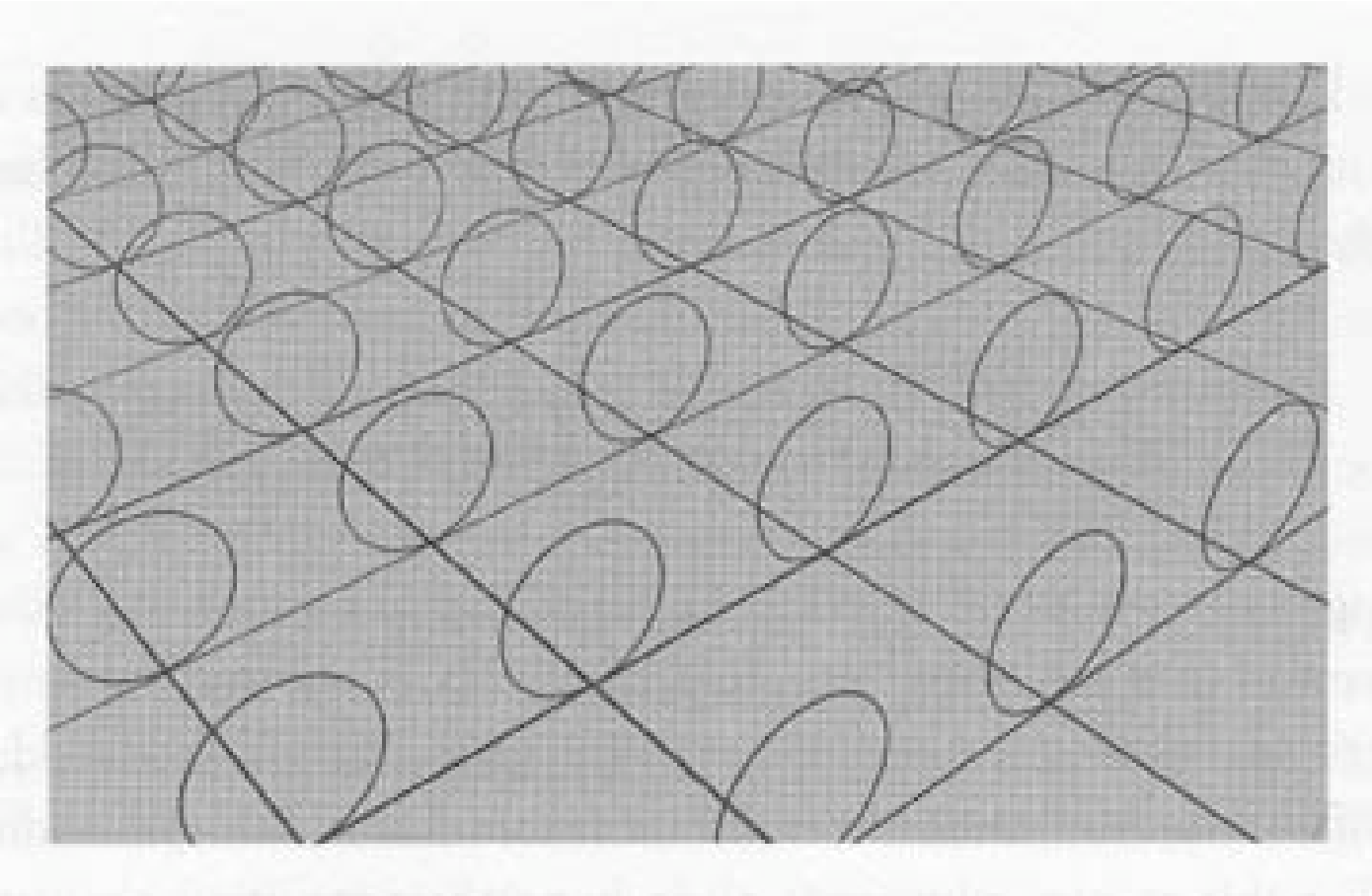
Other 7 dimensions tightly "wrapped up."

Shape of wrapped-up space determines how strings vibrate, what particles they represent.

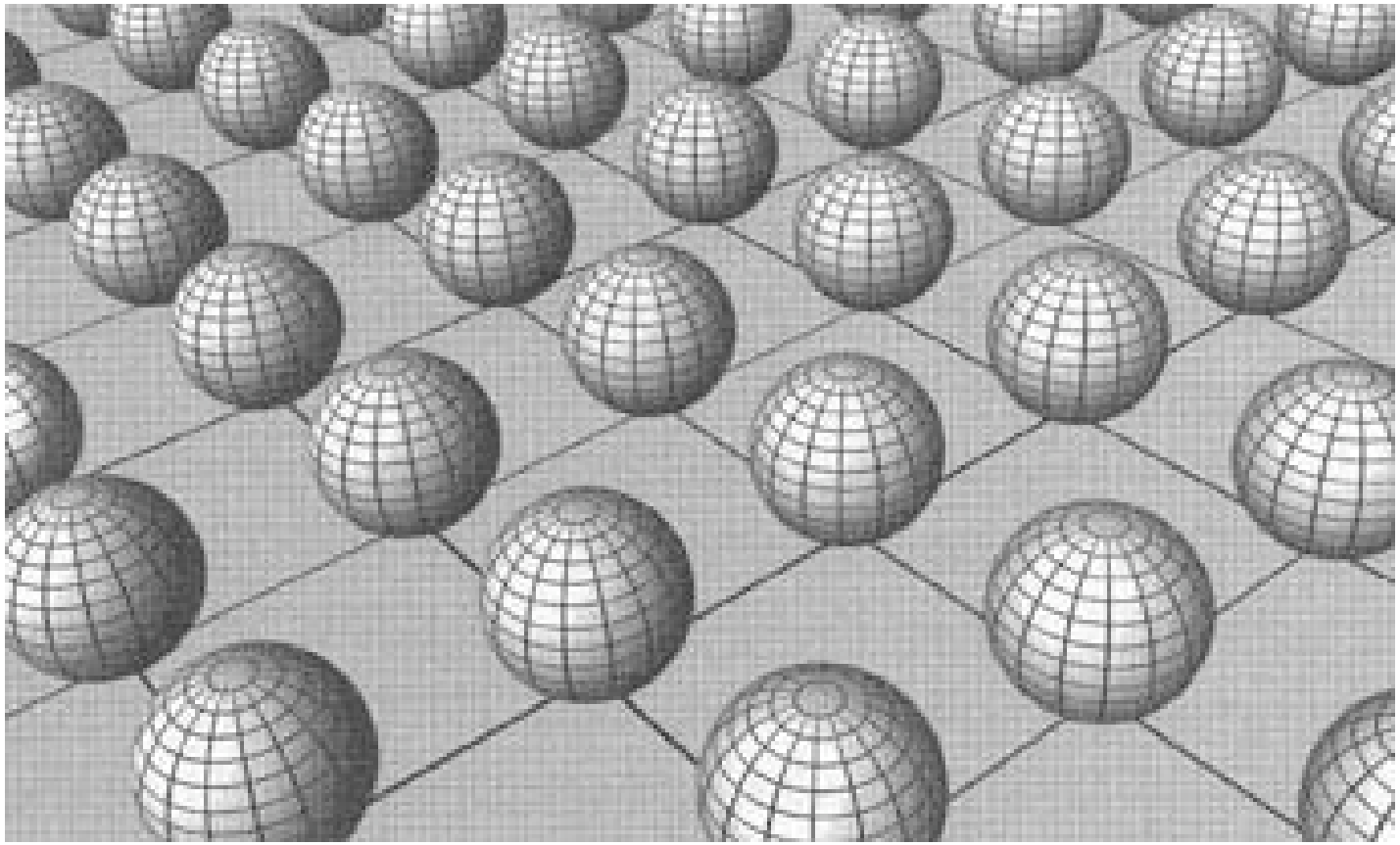
Schematic illustrations of how tiny “wrapped-up” extra dimensions could be associated with our 3D space - something like an embedding diagram of the higher dimensional space, so our 3D space is reduced to 2D and the higher dimensional wrapped spaces are reduced to 3D.

From Brian Green - The Elegant Universe

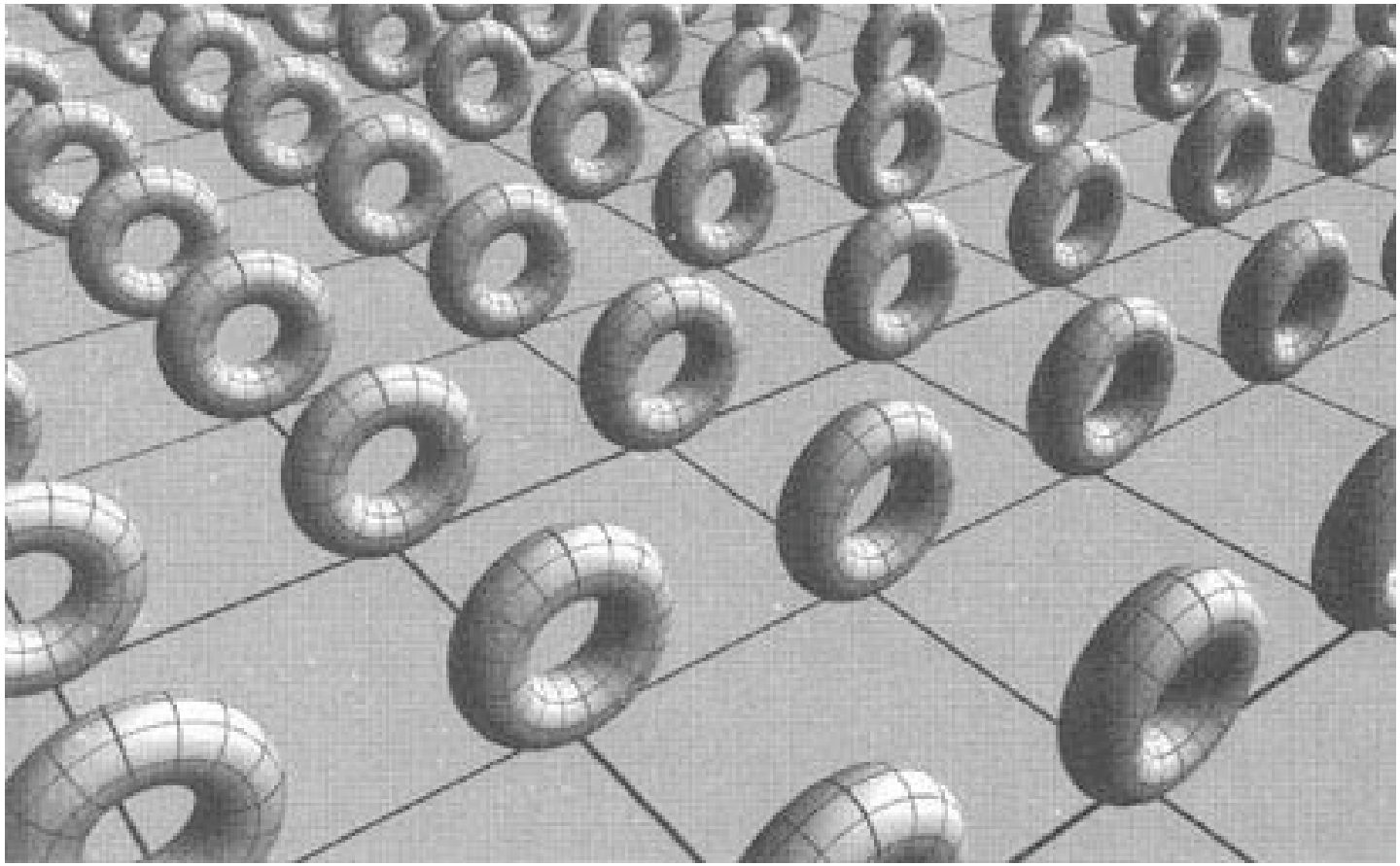




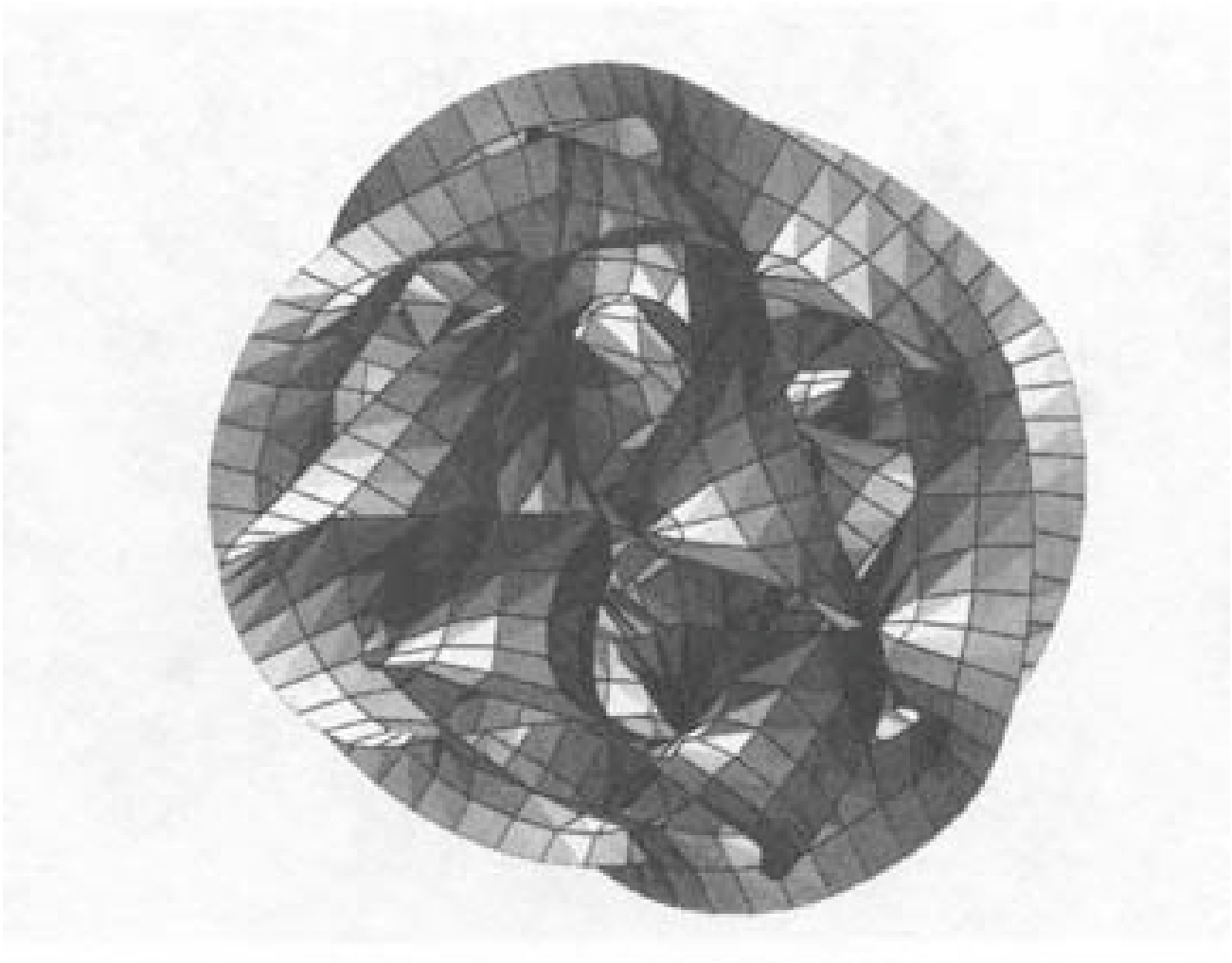
At each point in the 2D space (not just at the intersections of grid lines), there is a little 1D loop of one wrapped-up extra dimension.



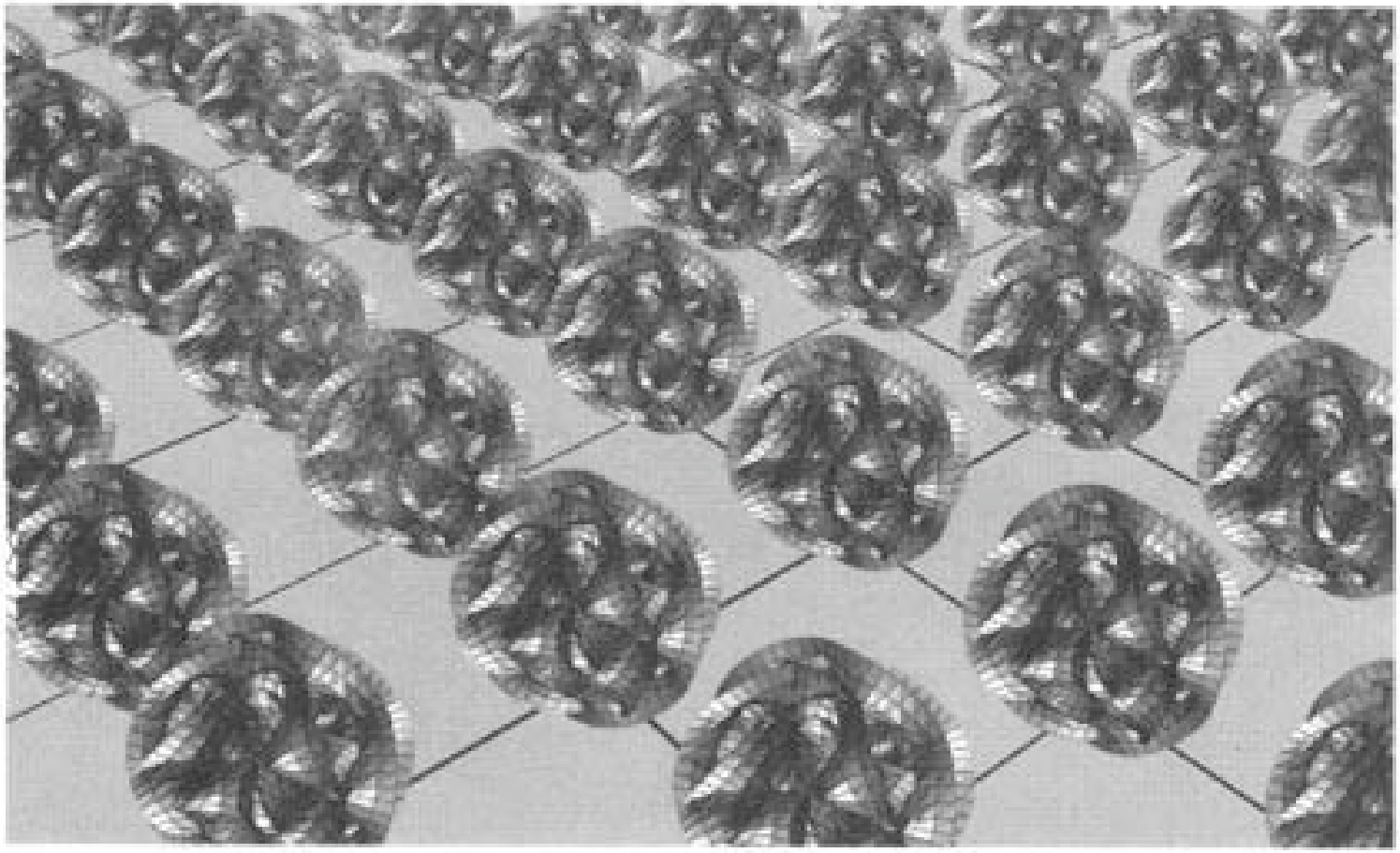
At each point in the 2D space (not just at the intersections of grid lines), there is a little 2D “sphere” of two wrapped-up extra dimensions.



At each point in the 2D space (not just at the intersections of grid lines), there is a little 2D “torus” of two wrapped-up extra dimensions. A torus has a distinctly different “topology” or “connectedness” than a sphere.



Representation of a Calabi-Yau space, with 6 wrapped-up extra dimensions



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.

Mathematics of string theory is complex.

Only approximate solutions so far, but:

String theory "contains" Einstein's Theory mathematically on spatial scales where string "loops" are tiny, just as Einstein's theory "contains" Newton's theory of gravity on 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.

In the 1990's, physicists discovered that the equations of string theory predict not only 1D strings, but "surfaces."

These surfaces can be of any dimension less than the total of the space containing them.

In analogy to membranes, they are called ***branes*** of dimension p, or ***p-branes***.

"Volume" in which a brane is immersed is known as the ***bulk***.

Some strings are loops with their ends attached to branes; other strings are closed loops that can float off away from the brane, into the bulk.

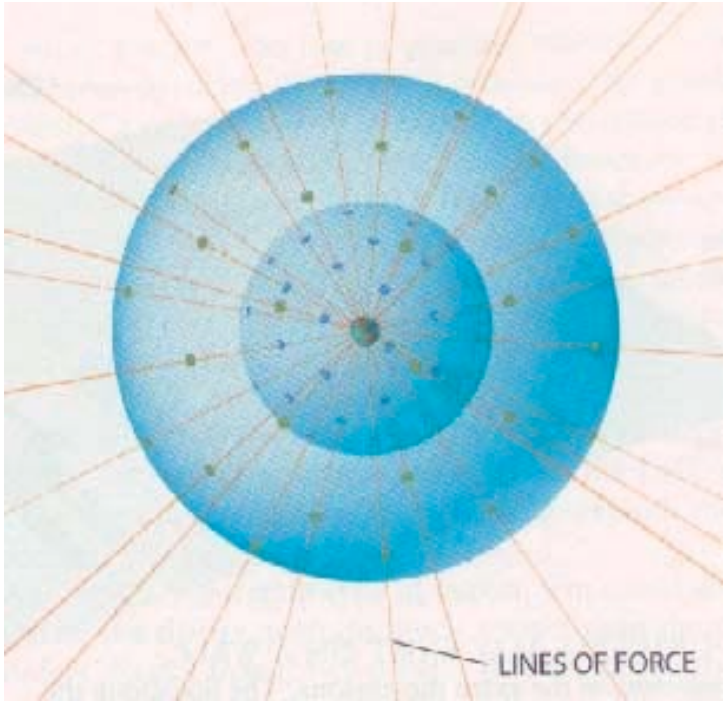
This led to a revolution in our perspective on the Universe.

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

Gravity probes all space, whatever its dimension, gravity is a creature of space/time

Behavior of light and gravity in 3D

lines of force flow out through larger area at larger distance, the strength (lines of force per unit area) is thus diluted by 1/area $\propto 1/r^2$ in 3D



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 no where to go.

New insight: (1999) - Can have ***large extra dimensions*** and gravity will still leak only a little, still weaken very nearly as $1/r^2$.

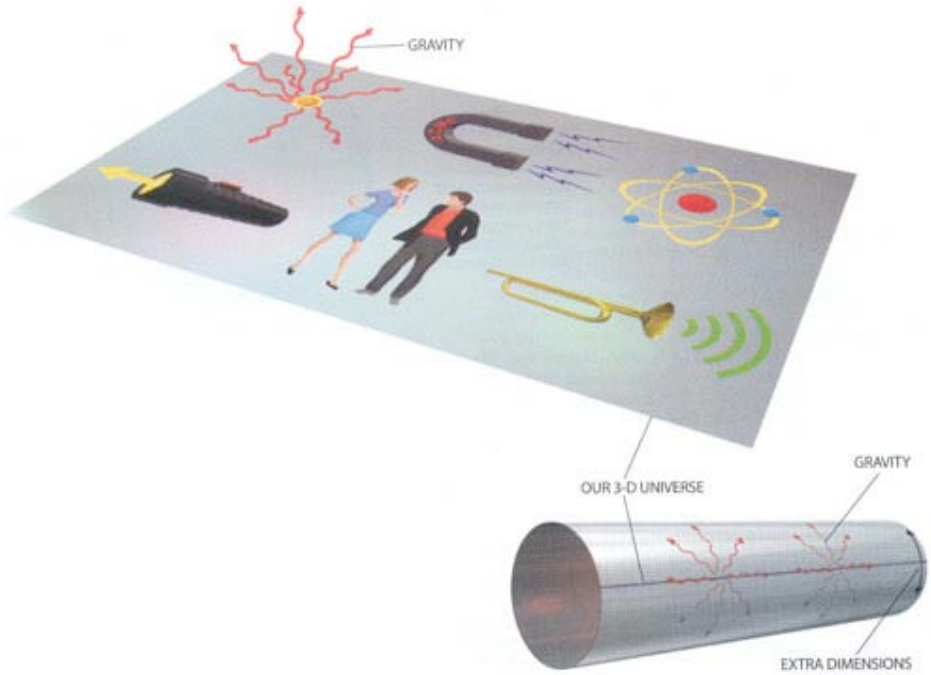
Our 3D Universe could be a 3D brane in a 4D bulk

There could be a real, large, hyperspace in which our Universe is embedded.

In this picture, ordinary forces, electromagnetism, nuclear forces, correspond to “open” strings that have ends stuck on the 3D brane,

These strings cannot “go” into the 4D bulk, we cannot “see” the 4D bulk.

Balls on 2D brane, sound into 3D bulk



Gravity corresponds to closed loops of strings that are not stuck on the brane, they can float off into the bulk, but in a way that gravity still weakens very nearly like $1/r^2$.

Brane world cosmologies: exploring possibility that our Universe is a 3D brane floating in a 4D bulk, with 6 wrapped-up dimensions plus time

Example: Ekypyrotic Theory (Greek *ekypyrosis* = conflagration)

Two 3D branes collide in 4D bulk
hot, dense "Big Bang" but not infinite density
no singularity
different gravity waves - could be a test.

Singularity in black holes, quantum foam $\Rightarrow$ nested "loops" of strings?

The 4D Bulk: is this where our Universe curves to when it curves, expands to when it expands - Maybe…

Bubble Universes: When a black hole forms does a new Universe spring into existence "elsewhere" in 4D hyperspace?

Is this real, or just mathematical fantasy?

Must be able to test: Physicsts are straining to devise such tests.

Does gravity behave a little differently than $1/r^2$, for instance like $1/r^{2.0001}$, that would be hint of higher dimensions?

Curved space near event horizons of black holes might be different than standard Einstein gravity - can that be measured with X-rays?

Anti-protons emitted from primordial black holes?

Is the Dark Energy that drives the acceleration of the Universe some manifestation of a “nearby” 3D Universe only a little distance away from our Universe in the 4D bulk.

Take Away Message:

Hyperspace might be real…

Stay tuned!