Braneworld: Extra Dimensions

Lecture 7 - November 12th, 2011

We have heard the story of the Universe's history, as far as we understand it. The next phase of understanding is to figure out the fundamental physics that explains the mysteries of dark matter, dark energy, and inflation. Today's lecture topic is a history of the idea that there are more than 3 spatial dimensions, which is also the history of string theory. Of course, as I once heard a string theorist say, "observations have told us that 3 spatial dimensions are a particularly interesting number to study." But it turns out that having more then 3 dimensions, even if the extra ones are hidden from us, can have a profound impact on the fundamental laws of physics.

There are two ways to hide extra dimensions:

- **Compactification**: this is the idea that the the extra dimensions are hidden because they're so small that we can't see them. This smallness, or "compactness," means that our experiments will be blind to them until the experiments can resolve the tiny length scales where the extra dimensions live. This is similar to the way that small blemishes are invisible in low-resolution photographs, but visible in high-resolution photographs.
- **Membranes:** usually shortened to "branes", this is the idea that our universe is a 4 dimensional membrane that lives in a higher dimensional space. To get a better idea: a sheet of paper is an approximately three dimensional membrane (two spatial dimensions plus time). Our world is like a "sheet of paper" in a bigger space! In this picture, the extra dimensions can be huge, but we can't see them because our forces are forced to stick on the brane.

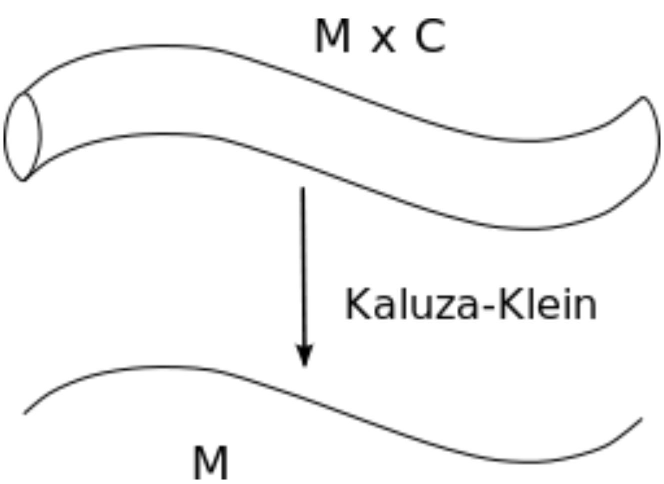
Kaluza and Klein, who proposed compactified extra dimensions way back in 1921.

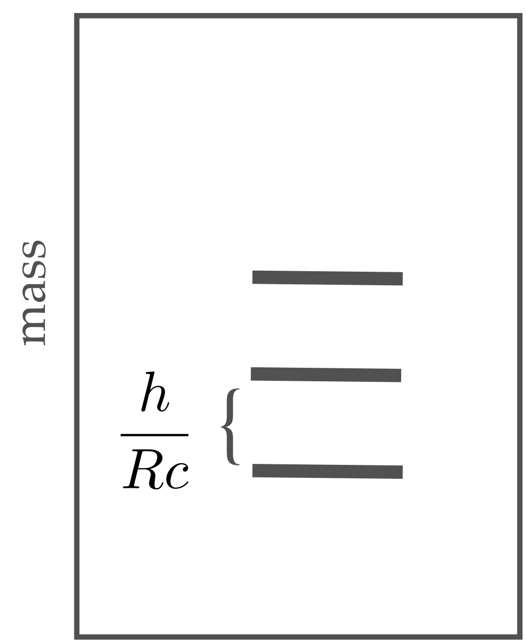
These ideas are both present in **string theory**, which I will give a brief introduction to as part of the lecture. I will also discuss higher dimensional models that are not part of string theory, like the braneworld model of Dvali, Gabadadze, and Porrati.

String theory is our best guess so far at the theory that will allow us to describe gravity in a way that also includes quantum field theory. String theory is a famous example of extra dimensions in physics, since it turns out that string theory requires a total of 10 dimensions (9 spatial dimensions plus time) for its equations to be self-consistent. String theory was so named because particles, like the electron, which are taken to be mathematical "points" in quantum field theory, are replaced by vibrating strings. We have since learned that string theory also includes membranes of every number of dimensions between 1 and 10, so that "string theory" could now be fairly called "membrane theory" -- though that's not as catchy.

You may well ask: what are all these extra dimensions good for, anyway? Aren't you crazy theoretical physicists just making things complicated? The answer is that it turns out that there are a lot of interesting new things that can happen in extra dimensions that can't happen in just our usual 4 dimensions:

- **Dark Matter:** in string theory, having extra dimensions is tied closely to a concept called supersymmetry, which is the idea that every particle has a pair-particle. Thus, the electron is paired to a "selectron", the neutrino to a "sneutrino", or the photon with a "photino". With all those extra particles around, it turns out to be easy to find one that can serve as the dark matter -- usually, one we called the "lightest neutralino."
- **Dark Energy:** Extra dimensions give us a few new ways of dealing with the dark energy crisis. For one, supersymmetry can conceivably solve the "cosmological constant problem," because of its abundance of symmetries. There are also ways to generate accelerated expansion using extra dimensions, some of them relying on the fact that it's relatively easy to allow gravity -- but not the other forces -- "leak" into the other dimensions.
- **Inflation:** The period of inflation was when the Universe was in a very dense, very high-energy state. If there are extra dimensions, their effects are most likely to show up in the inflationary period. Hence, many physicists hope to find proof of the existence of extra dimensions by studying inflation.





A rough mock-up of the Kaluza-Klein picture of extra dimensions: the extra "C" dimensions lead to a "tower" of higher-mass copies of particles caused by "windings" or constructive interference of the particles' wave-functions around the extra dimension