String theory: where next?

We fudge considerably when we speak of "string theory." It's hardly a tidy package like Newton's laws or relativity or quantum mechanics.   It's a mash-up of a whole bunch of ideas – open strings and closed strings, branes, compact dimensions, conformal-invariant manifolds, and other structures we've only briefly mentioned.

It's not the "final theory" of physicists' dreams, a theory that ties quantum electrodynamics, quantum chromodynamics, and gravity into one neat bundle. Its equations do not uniquely generate the familiar particles of our world, and it requires supersymmetry. Our world certainly is not supersymmetric. On the other hand, its mathematics are internally consistent, it includes particles that resemble the ones we know, and it can claim some remarkable successes.

String theory has come full circle. It started as an attempt to describe the strong interactions. What ties quarks together in a proton? How do quarks interact? It provided some promising insights, but quantum chromodynamics pushed it aside. In the attempt, however, string theorists realized that their equations predicted gravitons, in fact required their presence. It was a theory of gravity at the smallest scales, and the string community charged off on a mission to wrap up the Standard Model with gravity in one grand web of string. That's still in the works, and still the great hope. But, lo and behold, along the way string gurus discovered that the dualities of string theory allow them to simplify the calculations of quantum chromodynamics. We've rediscovered the strings in the nucleus.

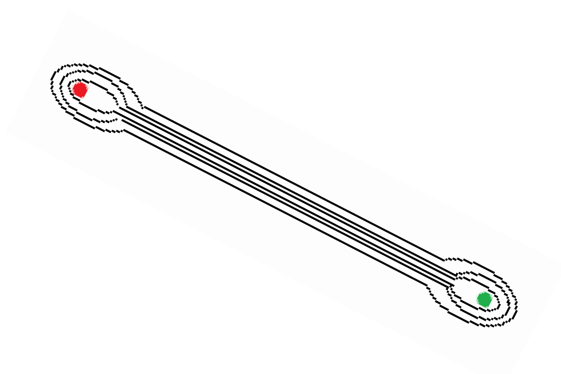

Figure 35.1. Color field lines between quarks (a la QCD) form flux tube that can be modeled as a string.

And more. We've seen that string theory has enabled enormous advances in our understanding of black holes. Strings provide the hidden degrees of freedom in the thermodynamics of black holes. We model the event horizon as a brane, and everything of importance happens on the horizon. Dualities of the theory allow us to describe events in terms of interactions on the horizon.

More recent, and of great excitement, is the advent of AdS/CFT duality. String theory has demonstrated that the 5-dimensional mathematics of Anti-de-Sitter (AdS) space are dual to the 4-dimensional maths of conformal field theory (CFT). (Maldacena, 1998) So it's possible, for example, to calculate the dynamics of a strongly interacting quark-gluon plasma in terms of gravitational interactions at the event horizon of a black hole. This simplifies the calculations, and particle physicists now study high energy particle collisions as if they were probing black holes. (Kovtun et al, 2005)

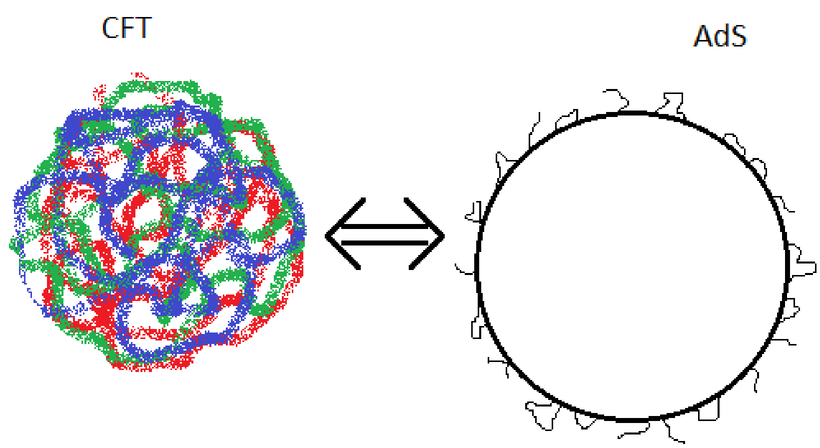

Figure 35.2. "Dual-ing" theories. Quark-gluon plasma of QCD on the left, dual to stringy brane of black hole horizon on the right.

Even condensed-matter physics has been influenced by string theory. One would think the mundane ceramics of circuit boards far removed from esoteric strings. But here, too, physicists have made progress understanding the quantum electrodynamics of high temperature superconductors by mapping two-dimensional quantum systems onto event horizons. (Sachdev, 2012)

Not bad for a crazy idea fifty years ago to tie two quarks together. From ceramics to the cosmos. It's still beginnings, and with 10^{500} stringy universes to explore, there's plenty yet to be discovered.

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Maldacena, J. M. 1998. *Adv. Theor. Math. Phys.* 2:231.
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