Beyond the horizon

What's out there beyond the cosmic horizon? More of the same? Astronomers tell us the visible universe is homogenous and isotropic – same mix of galaxies and dark matter and dark energy in the neighborhood of any observer anywhere, and from any galaxy anywhere the universe looks the same in all directions. But is it homogenous and isotropic out beyond the horizon? If we were teleported out there, would our neighborhood still look the same? Would the same laws of physics still apply? These are questions that puzzle modern cosmologists. Their tentative answers are mind-boggling.

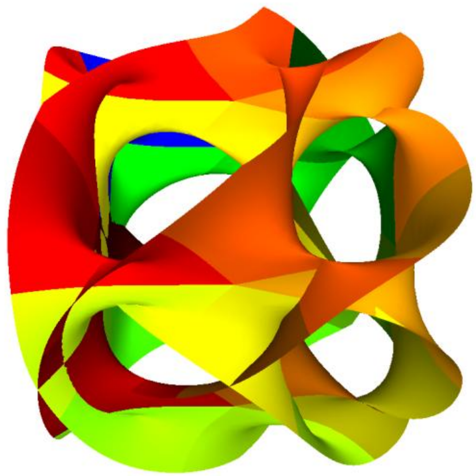
Here's some of what we know, based both on theory and on observation.

- Our universe originated in a period of exponentially rapid inflation.
- It is still expanding, and the expansion is accelerating.
- The cosmological constant (dark energy density) is very close to (but not quite) zero.
- The physical laws that govern our universe allow for the evolution of intelligent life.

Those last two points are important. The universe didn't have to be that way. If the cosmological constant Λ was even slightly larger, spacetime would have expanded so rapidly that local gravitational densities wouldn't have had time to form galaxies and stars and planets. If Λ was smaller, gravitational attraction from the enormous early mass-energy density would have pulled the universe back on itself, and it would have collapsed immediately. As another example of critical tuning, if the fine structure constant was smaller, nuclei wouldn't attract electrons, and atoms wouldn't form. There are many other apparent Goldilocks coincidences. Our universe is not too hot, not too cold, but just right. It is apparently fine tuned for the existence of life.

Is our universe specially designed such that we are here? Or what's up? String theory gives us an alternative what's up.

Back to the compact dimensions of string theory, 10 (or 11) dimensions for closed strings (or supergravity), 26 dimensions for open strings. The extra dimensions are compactified as strings and branes and other structures on a conformally invariant spacetime. The leading favorite candidate spacetime topologies are Calabi-Yau manifolds. Think of them roughly as swiss cheese, with holes tunneling through the extra dimensions and strings and branes wrapped around the handles between holes.



"Calabi-Yau Space" from the Wolfram Demonstrations Project
http://demonstrations.wolfram.com/CalabiYauSpace/
Contributed by: Andrew J. Hanson
Additional contributions by: Jeff Bryant

Figure 34.1. Projection of a Calabi-Yau space onto three dimensions.

Different configurations of holes and wrappings represent different physical laws, different universes. And the Calabi-Yau manifolds can morph into each other. Out pops a new universe. It happens all the time.

No longer mere universe, think multiverse. Beyond our cosmic horizon (piddly stuff, our near neighborhood) many cosmic horizons distant is the domain wall of our own universe. It's probably not a wall but topology wrapping the universe back on itself. Easier, though, to think of our universe as a bubble in the "bulk." The bulk experiences continual inflation, and new universes bubble out of the bulk. Each bubble universe has different Calabi-Yau topology, therefore different physical laws. String theory predicts a "landscape" of possible universes, on the order 10^{500} different Calabi-Yau-string-brane-flux-conifold-orbifold-bogglefold (CYB) configurations. 10^{500} different possible universes.

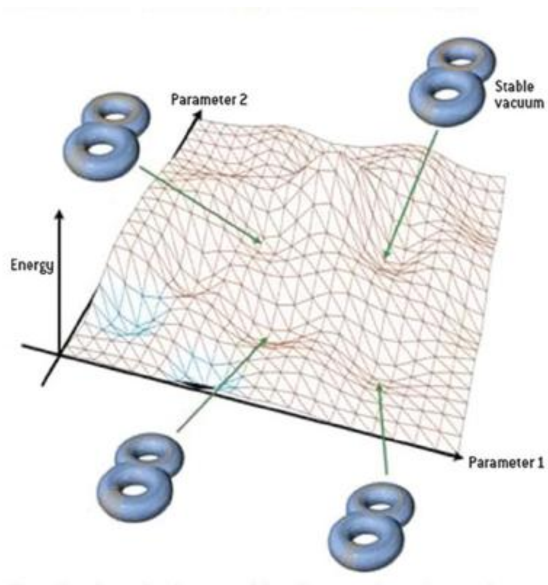


Figure 34.2. String energy landscape. Toroidal branes with different string configurations occupy different energy levels. Stable vacuum occupies the lowest energy valley. Image from the Stephen Hawking Center for Theoretical cosmology, Cambridge University. ctc.cam.ac.uk

Ours is just one among them. We are here by the roll of the dice. Roll 10^{500} times, and sometime you're likely to come up with a universe like ours. And somewhere out there in the multiverse chances are there's an identical you reading identical words.

Them's the chances associated with really big numbers.

What's the mechanism of bubble universe formation? Different CYB configurations have different energy. The string landscape – all possible CYB configurations – is like mountainous terrain with energy peaks and valleys. The bulk rolls down the energy hill (very slowly in this scenario). Quantum fluctuations in the CYB may tip a particular region in the bulk over into an energy valley. All the energy in the CYB transition is dumped into the creation of a new bubble universe. If that new bubble has a CYB configuration with very small cosmological constant, it will collapse back into the bulk. If it has a large cosmological constant, it will expand enormously rapidly, too rapidly for structures to form inside. If it has a cosmological constant like ours – and the remainder of its CYB configuration is like ours – it will evolve into a universe like ours.

No matter the inflation rate of the bubbles, the expansion of the bulk outstrips them, and it becomes very unlikely that two bubbles will bump into each other. On the other hand, quantum fluctuations within a bubble may tip the local CYB into a new, lower-energy state, and a bubble forms within a bubble. (No sense worrying it might happen in our neighborhood. We wouldn't see it coming.)

So what's out there beyond the cosmic horizon? Much more of our universe. And, beyond, a multiverse. There's lots left to explore. Even if string theory is the messy best we can do, we're just beginning to explore its landscape.

Figure 34.3. Artist's impression of the multiverse. New universes bubble out of the bulk.
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