Is string theory in trouble?

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Ever since Albert Einstein wondered whether the world might have been different, physicists have been searching for a "theory of everything" to explain why the universe is the way it is. Now string theory, one of today's leading candidates, is in trouble. A growing number of physicists claim it is ill-defined and based on crude assumptions. Something fundamental is missing, they say. The main complaint is that rather than describing one universe, the theory describes 10^{500}*, each with different constants of nature, even different laws of physics.*

But the inventor of string theory, physicist Leonard Susskind, sees this "landscape" of universes as a solution rather than a problem. He says it could answer the most perplexing question in physics: why the value of the cosmological constant, which describes the expansion rate of the universe, appears improbably fine-tuned for life. A little bigger or smaller and life could not exist. With an infinite number of universes, says Susskind, there is bound to be one with a cosmological constant like ours.

The idea is controversial, because it changes how physics is done, and it means that the basic features of our universe are just a random luck of the draw. He explains to Amanda Gefter why he thinks it's a possibility we cannot ignore.

Why are physicists taking the idea of multiple universes seriously now?

First, there was the discovery in the past few years that inflation seems right. This theory that the universe expanded spectacularly in the first fraction of a second fits a lot of data. Inflation tells us that the universe is probably extremely big and necessarily diverse. On sufficiently big scales, and if inflation lasts long enough, this diversity will produce every possible universe. The same process that forged our universe in a big bang will happen over and over. The mathematics are rickety, but that's what inflation implies: a huge universe with patches that are very different from one another. The bottom line is that we no longer have any good reason to believe that our tiny patch of universe is representative of the whole thing.

Second was the discovery that the value of the cosmological constant - the energy of empty space which contributes to the expansion rate of the universe - seems absurdly improbable, and nothing in fundamental physics is able to explain why. I remember when Steven Weinberg first suggested that the cosmological constant might be anthropically determined - that it has to be this way otherwise we would not be here to observe it. I was very impressed with the argument, but troubled by it. Like everybody else, I thought the cosmological constant was probably zero - meaning that all the quantum fluctuations that make up the vacuum energy cancel out, and gravity alone affects the expansion of the universe. It would be much easier to explain if they cancelled out to zero, rather than to nearly zero. The discovery that there is a non-zero cosmological constant changed everything. Still, those two things were not enough to tip the balance for me.

What finally convinced you?

The discovery in string theory of this large landscape of solutions, of different vacuums, which describe very different physical environments, tipped the scales for me. At first, string theorists thought there were about a million solutions. Thinking about Weinberg's argument and about the non-zero cosmological constant, I used to go around asking my mathematician friends: are you sure it's only a million? They all assured me it was the best bet.

But a million is not enough for anthropic explanations - the chances of one of the universes being suitable for life are still too small. When Joe Polchinski and Raphael Bousso wrote their paper in 2000 that revealed there are more like 10^{500} vacuums in string theory, that to me was the tipping point. The three things seemed to be coming together. I felt I couldn't ignore this possibility, so I wrote a paper saying so. The initial reaction was very hostile, but over the past couple of years people are taking it more seriously. They are worried that it might be true.

Steven Weinberg recently said that this is one of the great sea changes in fundamental science since Einstein, that it changes the nature of science itself. Is it such a radical change?

In a way it is very radical but in another way it isn't. The great ambition of physicists like myself was to explain why the laws of nature are just what they are. Why is the proton just about 1800 times heavier than the electron? Why do neutrinos exist? The great hope was that some deep mathematical principle would determine all the constants of nature, like Newton's constant. But it seems increasingly likely that the constants of nature are more like the temperature of the Earth - properties of our local environment that vary from place to place. Like the temperature, many of the constants have to be just so if intelligent life is to exist. So we live where life is possible.

For some physicists this idea is an incredible disappointment. Personally, I don't see it that way. I find it exciting to think that the universe may be much bigger, richer and full of variety than we ever expected. And it doesn't seem so incredibly philosophically radical to think that some things may be environmental.

In order to accept the idea that we live in a hospitable patch of a multiverse, must a physicist trade in that dream of a final theory?

Absolutely not. No more than when physicists discovered that the radii of planetary orbits were not determined by some elegant mathematical equation, or by Kepler's idea of nested Platonic solids. We simply have to reassess which things will be universal consequences of the theory and which will be consequences of cosmic history and local conditions.

So even if you accept the multiverse and the idea that certain local physical laws are anthropically determined, you still need a unique mega-theory to describe the whole multiverse? Surely it just pushs the question back?

Yes, absolutely. The bottom line is that we need to describe the whole thing, the whole universe or multiverse. It's a scientific question: is the universe on the largest scales big and diverse or is it homogeneous? We can hope to get an answer from string theory and we can hope to get some information from cosmology.

There is a philosophical objection called Popperism that people raise against the landscape idea. Popperism [after the philosopher Karl Popper] is the assertion that a scientific hypothesis has to be falsifiable, otherwise it's just metaphysics. Other worlds, alternative universes, things we can't see because they are beyond horizons, are in principle unfalsifiable and therefore metaphysical - that's the objection. But the belief that the universe beyond our causal horizon is homogeneous is just as speculative and just as susceptible to the Popperazzi.

Could there be some kind of selection principle that will emerge and pick out one unique string theory and

one unique universe?

Anything is possible. My friend David Gross hopes that no selection principle will be necessary because only one universe will prove to make sense mathematically, or something like that. But so far there is no evidence for this view. Even most of the hard-core adherents to the uniqueness view admit that it looks bad.

Is it premature to invoke anthropic arguments - which assume that the conditions for life are extremely improbable - when we don't know how to define life?

The logic of the anthropic principle requires the strong assumption that our kind of life is the only kind possible. Why should we presume that all life is like us - carbon-based, needs water, and so forth? How do we know that life cannot exist in radically different environments? If life could exist without galaxies, the argument that the cosmological constant seems improbably fine-tuned for life would lose all of its force. And we don't know that life of all kinds can't exist in a wide variety of circumstances, maybe in all circumstances. It a valid objection. But in my heart of hearts, I just don't believe that life could exist in the interior of a star, for instance, or in a black hole.

Is it possible to test the landscape idea through observation?

One idea is to look for signs that space is negatively curved, meaning the geometry of space-time is saddle-shaped as opposed to flat or like the surface of a sphere. It's a long shot but not as unlikely as I previously thought. Inflation tells us that our observable universe likely began in a different vacuum state, that decayed into our current vacuum state. It's hard to believe that's the whole story. It seems more probable that our universe began in some other vacuum state with a much higher cosmological constant, and that the history of the multiverse is a series of quantum tunnelling events from one vacuum to another. If our universe came out of another, it must be negatively curved, and we might see evidence of that today on the largest scales of the cosmic microwave background. So the landscape, at least in principle, is testable.

If we do not accept the landscape idea are we stuck with intelligent design?

I doubt that physicists will see it that way. If, for some unforeseen reason, the landscape turns out to be inconsistent - maybe for mathematical reasons, or because it disagrees with observation - I am pretty sure that physicists will go on searching for natural explanations of the world. But I have to say that if that happens, as things stand now we will be in a very awkward position. Without any explanation of nature's fine-tunings we will be hard pressed to answer the ID critics. One might argue that the hope that a mathematically unique solution will emerge is as faith-based as ID.

Leonard Susskind

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