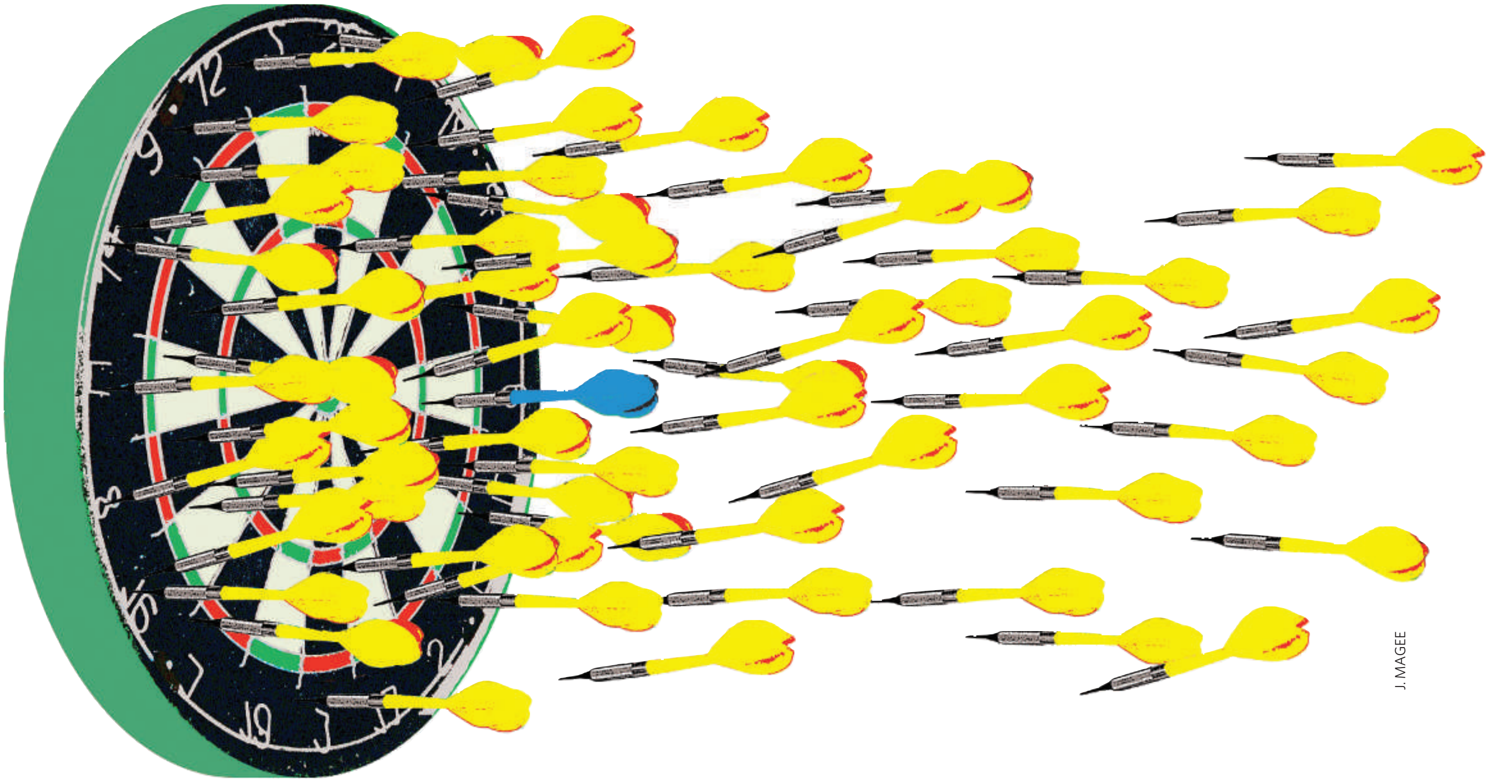


OUTRAGEOUS FORTUNE

A growing number of cosmologists and string theorists suspect the form of our Universe is little more than a coincidence. Are these harmless thought experiments, or a challenge to science itself? **Geoff Brumfiel** investigates.

Why are we here? It's a question that has troubled philosophers, theologians and those who've had one drink too many. But theoretical physicists have a more essentialist way of asking the question: why is there anything here at all?

For two decades now, theorists in the think-big field of cosmology have been stymied by a mathematical quirk in their equations. If the number controlling the growth of the Universe since the Big Bang is just slightly too high, the Universe expands so rapidly that protons and neutrons never come close enough to bond into atoms. If it is just ever-so-slightly too small, it never expands enough, and everything remains too hot for even a single nucleus to form. Similar problems afflict the observed masses of elementary particles and the strengths of fundamental forces.

In other words, if you believe the equations of the world's leading cosmologists, the probability that the Universe would turn out this way by chance are infinitesimal — one in a very large number. "It's like you're throwing darts, and the bullseye is just one part in 10^{120} of the dart board," says Leonard Susskind, a string theorist based at Stanford University in California. "It's just stupid."

One in a zillion

Physicists have historically approached this predicament with the attitude that it's not just dumb luck. In their view, there must be something underlying and yet-to-be-discovered setting the value of these variables. "The idea is that we have got to work harder because some principle is missing," says David Gross, a Nobel-prizewinning theorist and director of the Kavli Institute for Theoretical Physics in Santa Barbara, California.

But things have changed in the past few years, says astronomer Bernard Carr of Queen Mary, University of London, UK. String theorists and cosmologists are increasingly turning to dumb luck as an explanation. If their ideas stand up, it would mean the constants of nature are meaningless. "In the past, many people were almost violently opposed to that idea because it wasn't seen as proper science," Carr says. "But there's been a change of attitude."

Much of that change stems from work showing that our Universe may not be unique. Since the early 1980s, some cosmologists have argued that multiple universes could have formed during a period of cosmic inflation that preceded the Big Bang. More recently, string theorists have calculated that there could be 10^{500} universes, which is more than the number of atoms in our observable Universe. Under these circumstances, it becomes more reasonable to assume that several would turn out like ours. It's like getting zillions and zillions of darts to throw at the dart board, Susskind says. "Surely, a large number of them are going to wind up in the target zone." And of course, we exist in our particular Universe because we couldn't exist anywhere else.

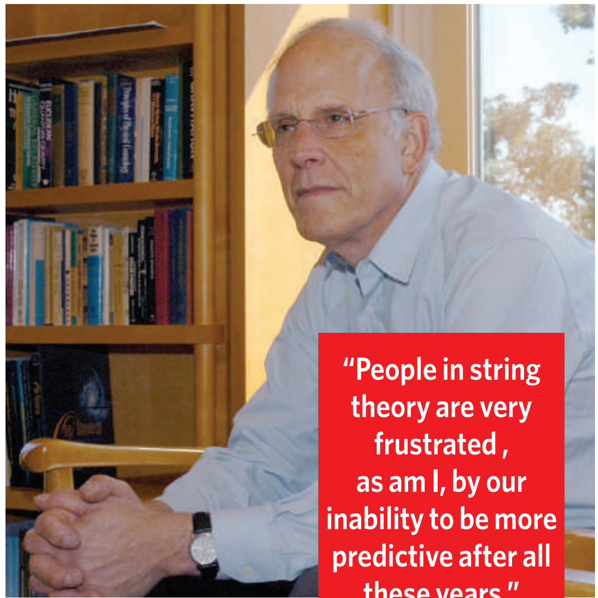
It's an intriguing idea with just one problem, says Gross: “It’s impossible to disprove.” Because our Universe is, almost by definition, everything we can observe, there are no apparent measurements that would confirm whether we exist within a cosmic landscape of multiple universes, or if ours is the only one. And because we can’t falsify the idea, Gross says, it isn’t science. Or at least, it isn’t science in any conventional sense of the word. “I think Gross sees this as science taking on some of the traits of religion,” says Carr. “In a sense he’s correct, because things like faith and beauty are becoming a component of the discussion.”

And yet in the overlapping circles of cosmology and string theory, the concept of a landscape of universes is becoming the dominant view. “I really hope we have a better idea in the future,” says Juan Maldacena, a string theorist at the Institute for Advanced Study in Princeton, New Jersey, summing up the views of many in the field. “But this idea of a landscape is the best we have today.” The stakes are high: string theorists know that pursuing an unverifiable theory could look like desperation, but they fear that looking for meaning in a meaningless set of numbers may be equally fruitless.

Kepler’s error

At the core of this dilemma is a concept known as the anthropic principle: the idea that things appear the way they do because we live at a certain spot in the Universe. It’s not a new concept, and has previously been regarded more as philosophy than science.

But some scientists say that it offers a useful change of perspective. “It’s very important to take into account stuff like this, or you can come to completely incorrect conclusions about the Universe,” argues Max Tegmark, a cosmologist at the Massachusetts Institute of Technology, Cambridge. “For example, you might assume our Solar System is typical, but a typical point in space is some intergalactic void where you can’t see a single star.”



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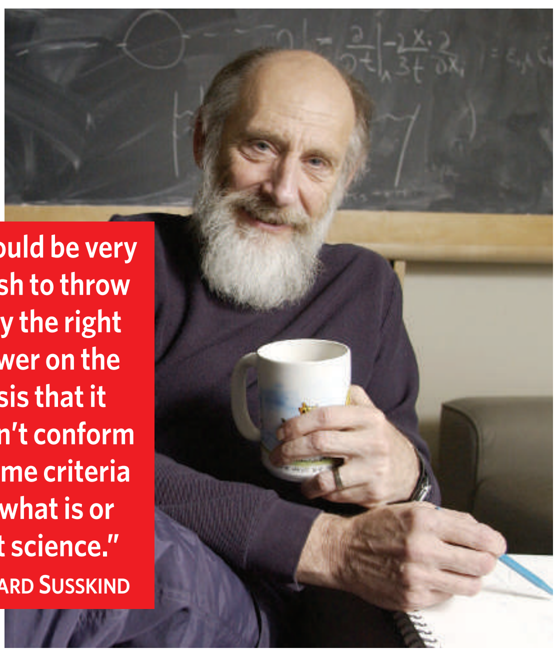
“People in string theory are very frustrated, as am I, by our inability to be more predictive after all these years.”
DAVID GROSS

Failing to consider our observational location has burned scientists in the past. The sixteenth-century German astronomer Johannes Kepler spent years trying to understand what seemed to be the even, geometrical spacing of our planets from the Sun. Kepler searched for meaning in the planets because he thought our Solar System was unique; today’s scientists understand that our Solar System is but one of probably billions in the Galaxy. Under such circumstances it seems reasonable to assume the planets are spaced according to little more than random chance.

In much the same way as Kepler worried about planetary orbits, cosmologists now puzzle over numbers such as the cosmological constant, which describes how quickly the Universe expands. The observed value is so much smaller than existing theories suggest, and yet so precisely constrained by observations, that theorists are left trying to figure out a deeper meaning for why the cosmological constant has the value it does.



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“It would be very foolish to throw away the right answer on the basis that it doesn’t conform to some criteria for what is or isn’t science.”
LEONARD SUSSKIND

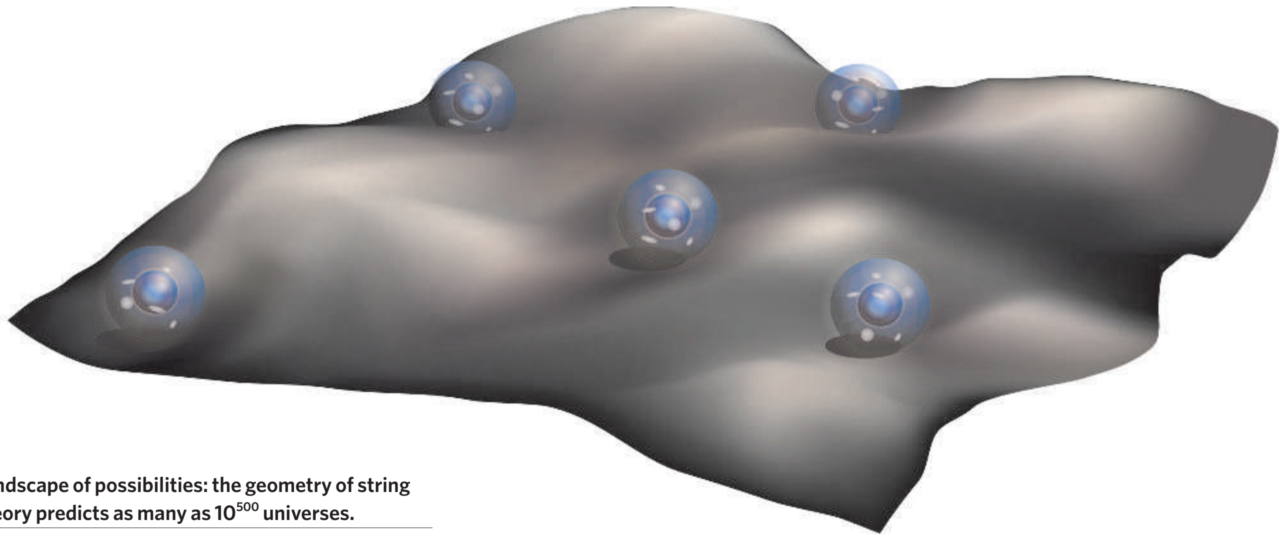
Many are still searching for some great unifying theory that would explain these variables. But others have started to believe that, like Kepler, today’s physicists are looking for meaning where there is none. “In recent years, it was looking more and more to me like the laws of nature were environmental,” says Susskind, who has just written a book making this argument (L. Susskind *The Cosmic Landscape: String Theory and the Illusion of Intelligent Design*. Little Brown, 2005). He suspects that there are many universes, all with different values for these variables. Just as human life had to evolve on a planet with water, he says, perhaps we also had to evolve in a Universe where atoms could form.

Until recently, Susskind was in the minority. Hints of multiple universes, however, were given by a cosmological theory known as inflation. Inflation is the leading theory of the early Universe; it postulates that a period of rapid early expansion created the flat and uniform cosmos we see today. One version of inflation theory, devised in the early 1980s, suggests that inflation occurred even before the Big Bang. In this version, the expanding cosmos was foamy and energetic, says Steven Weinberg, a researcher at the University of Texas, Austin. “Every once in a while, one part of the Universe would expand and become a Big Bang,” he says. “And these Big Bangs would all have different values for their fundamental constants.”

Strings attached

In 1987, Weinberg made a prediction that turned out to support the idea of an anthropic Universe. Preliminary observations indicated that the cosmological constant was zero, but Weinberg reasoned that if the constant was constrained by our anthropic perspective then it would be small, so as not to interfere with the formation of galaxies, stars and planets, but non-zero, because it would be essentially random. “That prediction has since been confirmed by observations of supernovae and the microwave background,” says Weinberg, who admits he was a reluctant convert to the idea.

The latest circumstantial arguments for multiple universes come from string theory.



Landscape of possibilities: the geometry of string theory predicts as many as 10^{500} universes.

String theory posits that tiny strings vibrating in the fabric of space-time give rise to the multitude of particles and forces in the macroscopic Universe. Although string theory lacks experimental support, it attracts broad interest because it seems to offer a route to a grand theory of everything — a way to unify relativity with quantum mechanics.

But as theorists developed string theory, they discovered that the equations gave rise to multiple solutions, each of which represented a universe with different physical properties. "The hope always was that we would understand why one solution was picked out," says Joe Polchinski, a string theorist at the Kavli Institute. But despite their best efforts, after two decades theorists are still stuck with a million different solutions for the equations, and therefore a million potential universes.

This landscape of solutions, as it became known in the community, was both troubling and intriguing. On the one hand, the theory stubbornly refused to yield a single solution resembling our own cosmos, but then, some argued, that might also explain the cosmological constant's apparent randomness. If these many solutions actually represent millions of universes, then the idea that one had worked out just right for us wasn't so far-fetched.

Ignorance is bliss

The snag was that one million universes wasn't enough. To explain the perfectly adjusted cosmological constant one would need at least 10^{60} universes, says Polchinski. Then, in 2000, he and Raphael Bousso at the Lawrence Berkeley National Laboratory in Berkeley, California, calculated that there could be a lot more than a million solutions. "The calculation had such topological complexity that you could potentially get 10^{500} universes," Polchinski says. With so many solutions, says Weinberg, it becomes easier to imagine that we happen to live in a Universe that seems tailored for our existence.

Easy to imagine, hard to prove. Because other universes would be causally separated from our own, it seems impossible to tell whether our cosmos is the only one, or one of many. Most scientists find this disturbing. Talk of a Universe fine-tuned for life has already attracted supporters of intelligent design, who claim that an intelligent force shaped evolution. If there's no way to tell whether the values of scientific constants are a coincidence, the movement's followers argue, then why not also consider them evidence of God's handiwork?

The anthropic reasoning behind the landscape of universes is disturbing on another level, says Gross. Most theories grow stronger with each observation that matches their predictions. However, for the anthropic principle, random chance is the main factor. Patterns and correlations, the stones from which scientific theories are built, weaken it. In other words, he says: "The power of the principle is strongest where you have ignorance."

That may be, but measurements that could support anthropic reasoning are in the works. In 2007, researchers at Europe's CERN particle physics centre in Geneva, Switzerland, will turn on the Large Hadron Collider, a massive accelerator that will probe particle energies never before seen by researchers. The accelerator might detect so-called supersymmetric particles, predicted by some as a way of unifying the strong and weak nuclear forces with the electromagnetic force, an important step in uniting all the forces of physics within a single theory.

These particles could also hint at whether we live in one of many universes, says Nima Arkani-Hamed, a string theorist at Harvard University in Cambridge, Massachusetts. If the collider detects certain types of supersymmetric particles, he says, it will indicate another fine-tuning in the cosmos — the ratio of the weak nuclear force to the strength of gravity. The anthropic argument is the same: if the number was off by as little as one part in 10^{30}, then we would not be here to discuss it.

It might seem that the detection of a second, perfectly tuned number would only exacerbate the debate, but Arkani-Hamed argues that it will have the opposite effect. Unlike the cosmological constant, which has had a controversial history even in cosmology, this fine-tuning would appear in the standard model, which most physicists consider to be the most complete physical theory ever developed and tested. It would strengthen the case for the arbitrary nature of certain fundamental constants, Arkani-Hamed contends: "These measurements wouldn't directly prove or disprove the landscape, but they would be a very big push in that direction."

Leap of faith

Still, many scientists distrust the concept and continue to seek alternative explanations. Among them is Lisa Randall, also at Harvard. Randall suspects that multiple universes are a mirage resulting from the unrefined equations of string theory. "You really need to explore alternatives before taking such radical leaps of faith," she contends. And with no foreseeable way to detect other universes, Gross feels that such leaps of faith should not be taken. "I feel that it's a rather extreme conclusion to reach at this point," he says.

Susskind, too, finds it "deeply, deeply troubling" that there's no way to test the principle. But he is not yet ready to rule it out completely. "It would be very foolish to throw away the right answer on the basis that it doesn't conform to some criteria for what is or isn't science," he says.

Gross believes that the emergence of multiple universes in science has its origins in theorists' 20-year struggle to explain the finely tuned numbers of the cosmos. "People in string theory are very frustrated, as am I, by our inability to be more predictive after all these years," he says. But that's no excuse for using such "bizarre science", he warns. "It is a dangerous business." ■

Geoff Brumfiel is *Nature*'s physical sciences Washington correspondent.