

The Universe's Odyssey?

How our youthful universe may have explored the string theory landscape in search of a corner to call home.

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News

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FQXi Awardee: Saswat Sarangi

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Saswat Sarangi owes his career in physics to a twist of fate. When he was a 13 year-old schoolboy in Orissa in eastern India, his uncle bought him a copy of Stephen Hawking's *A Brief History of Time* as a birthday present. Unfortunately, the young Sarangi would have preferred a cricket bat, and the book remained unread for two years, until he found himself struggling to prepare for a physics test on electrons and their antiparticle counterparts, positrons. His textbook was no help, so he started flipping through Hawking's book.

"I'm sure I didn't understand much, but the words were fascinating. That's when I wanted to do physics," says Sarangi, now a post-doc at Columbia University in New York. Certainly, the workings of antiparticles no longer flummox him. Quite the opposite, in fact, as Sarangi's believes that "anti-universes" and their interplay with regular universes could help tackle one of

the prickliest problems in physics: why our universe is the way it is.

It's fashionable these days to talk of the *multiverse*, the near infinity of universes of which ours is just one.

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- Henry Tye

For some, the multiverse is a godsend because it provides an explanation, of sorts, for why our universe has its peculiar properties. Why is the energy density of the vacuum of space—the so-called *cosmological constant*—the size that it is? Why is the proton 1,836 times heavier than the electron? We

don't have a physical theory that explains these particular values; but in the context of a multiverse, we don't need one. It is likely that our universe has the special properties it does—giving rise to galaxies, stars, planets, and humans—by accident. Other universes could exist with different properties, but we wouldn't have evolved in them and hence wouldn't be around to argue about it.

The Anthropic Disease

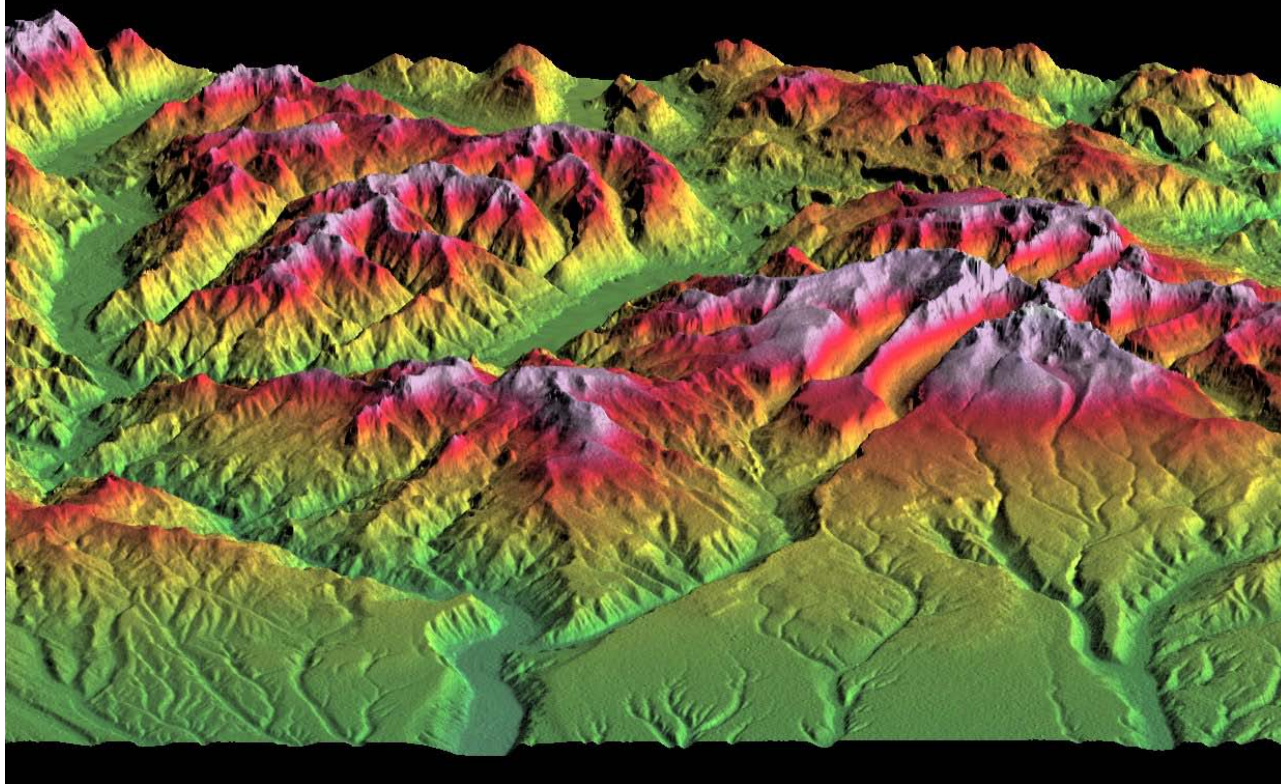
This is the "anthropic principle" and it doesn't sit well with Sarangi. "Some people have been trying to avoid this principle like a disease," he says. Sarangi finds the anthropic principle difficult to stomach because, in essence, it argues that there are some things about our universe that we cannot determine from first principles. It's like admitting defeat, and Sarangi doesn't want to give in just yet.

"[Sarangi] treats the anthropic principle as an admission of our ignorance today about our universe, not as a final resolution to the issue," explains Henry Tye, Sarangi's colleague and former Ph.D. advisor at Cornell University in Ithaca, New York. "He is not afraid to ask provocative questions."

Sarangi came to Cornell after studying physics at the Indian Institute of Technology in West Bengal, just as another pair of physicists was stirring up string theory. Joseph Polchinski and Raphael Bousso had discovered that string theory doesn't provide a unique "theory of everything" that can explain the properties of our universe, as hoped. Instead, string-theory equations offer at least 10^{500} solutions. Each solution points to a different universe with different values for fundamental constants and even different laws of physics. And nothing in



WILL IT BE EASIER FOR A UNIVERSE TO EXPLORE THE STRING LANDSCAPE
than it is for humans to traverse the Andes Mountains, imaged here by NASA's Shuttle Radar
Topography Mission?



string theory seems to favor one solution over another. All are equally likely.

Leonard Susskind of Stanford University coined the phrase “Landscape of String Theory” to describe this theoretical wealth of possible universes. “Everyone became excited about the landscape,” says Sarangi. “People were fighting about whether it was there or not.”

Roaming the Landscape

For Sarangi, the important question is: Could a universe that starts off in some random place in the landscape, with random properties, somehow end up in a more stable region of the landscape, such as the one in which our universe resides? Our universe is obviously in some stable or pseudo-stable state because for the last 13 billion years, it has maintained the same basic parameters, such as the electron mass. But, asks Sarangi, did our universe start off elsewhere in the landscape, with different proper-

ties and laws, but then finally end up where it did?

People were fighting about whether the landscape was there or not.

- *Saswat Sarangi*

The purpose behind this question is to show that—despite the landscape and the multiverse—string theory can still predict why we find ourselves in a universe like ours, without having to resort to the unsavory anthropic principle. A universe could start off with random properties but end up looking like ours.

It helps to develop a mental picture of the landscape of string theory as a terrain of hills and valleys, where each valley represents a point of temporary stability. (Because there are hundreds of different parameters in the theory that can change, the landscape

is actually a hyper-dimensional terrain, with valleys representing the most energetically stable values for each parameter.)

“The multiverse picture is simply that there are different universes separated from us in space and time, and these universes are sitting in different valleys,” says Sarangi.

A universe that arises randomly settles into the nearest valley. But what are the odds that this universe could explore the landscape and find its way to a different stable region? The key to answering this is to look at conditions in the early universe, when the infant universe went through a period of exponential expansion, known as *inflation*. While string theory predicts that a landscape exists, inflation shows how such a landscape can be realized. When and how inflation ends in a patch of spacetime dictates its properties and each patch is a universe in its own right. This gives rise to the multiverse.

During the inflationary era, the

universe is at its most dynamic; if it's ever going to explore the multiverse, this is probably the time. An inflating universe that sits in a valley will be separated by hills from other lower, more stable, valleys. All it has to do to reach them is climb over that hill. But how can it overcome this mountain?

The Anti-Universe

It's possible that the intrepid universe could use a quantum trick to get it to the other side of the hill. In quantum systems, particles often "tunnel" through high-energy barriers that—according to classical physics—they should not be able to cross (see diagram, below). Could an inflating universe do the same?

Saranghi thinks so. Until now, it was thought that quantum tunneling during inflation was impossible since inflation lasts for a relatively short period and should be over long before the universe has had a chance to tunnel anywhere. But last year, Saranghi and his colleagues found a special corner of the landscape where quantum tunneling happens so quickly that a universe has enough time to tunnel to another part of the landscape while it is still inflating.

Bizarrely, it helps if the hill is very large. At first, as you increase the size of the hill, quantum tunneling is suppressed; but then the rate of tunneling dramatically increases, says Saranghi. "We were very excited by this. This is the first example where you can get exponentially fast quantum tunneling, even though your hill has a large size."

So what's behind this strange effect? Something similar is actually observed in the lab, when you fire an electron at an electromagnetic field that represents a "barrier." Initially the electron cannot get over this hill. But as you increase the size of the barrier, things change. At the top of the hill, there is enough energy for the vacuum to start spontaneously spawning pairs of electrons and positrons. Usually, these electron-positron pairs immediately annihilate each other. But occasionally, a positron will roll down the hill and annihilate the electron that's trying to cross the hill. The positron's partner then

rolls down the other side of the hill. Effectively, an electron has tunneled through the extremely high barrier.

Something analogous but far more mind-boggling could be happening to a quantum universe in the multiverse. Replace the electron with a universe, the positron with an anti-universe, and you get the picture.

Isn't this a bit far-fetched? No, not at all, says string theorist Brian Greene of Columbia University, with whom Saranghi now works. "It's a direct analogue of the case which is understood: the particle and anti-particle," says Greene.

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- Brian Greene

Saranghi and colleagues Gary Shiu of the University of Wisconsin, Madison, and Benjamin Shlaer of the University of Colorado, Boulder, will be using their \$50,000 grant from the Foundational Questions Institute to work out how likely it is for universes to explore the landscape via quantum tunneling.

Besides investigating cases where universe and anti-universe pairs help achieve tunneling (known as "Dirac-

Born-Infeld tunneling) they are also looking at "resonance tunneling," a phenomenon seen in the lab in which an electron can burrow through two adjacent hills that have identical properties. It may be possible that universes can perform a similar feat. And with the help of Greene's string-theory smarts, they plan to simulate tens of thousands of hills and valleys in the multi-dimensional landscape to see whether tunneling can actually take place.

Greene is confident that Saranghi has the chops to tackle this formidable problem. "He's a very mild-mannered but vehement physicist, who really stays on an issue until he resolves it," says Greene. "It's a great combination."

Of course, it's possible that the simulation will show that there simply isn't enough quantum tunneling for a universe with random properties to make its way to our neck of the landscape. But just maybe the team will find that there is enough exploration and that random universes should find themselves in stable corners, where they would take on properties like those of our universe. "That would be very exciting," says Saranghi.

CAN A UNIVERSE MIMIC A TUNNELING ELECTRON?

(Credit: Max Planck Institute for Quantum Optics)

