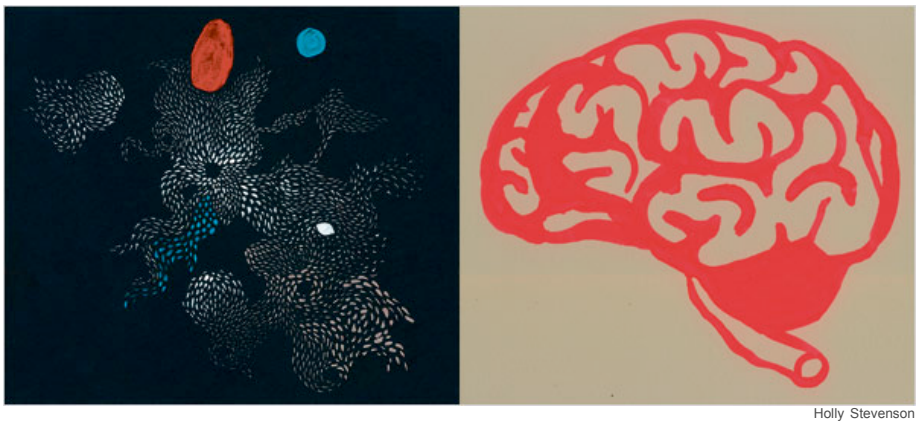
Big Brain Theory: Have Cosmologists Lost Theirs?



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It could be the weirdest and most embarrassing prediction in the history of cosmology, if not science.

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Boltzmann's Brain

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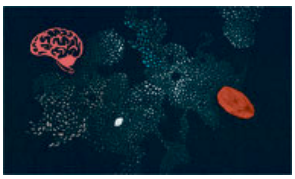

Holly Stevenson

If true, it would mean that you yourself reading this article are more likely to be some momentary fluctuation in a field of matter and energy out in space than a person with a real past born through billions of years of evolution in an orderly star-spangled cosmos. Your memories and the world you think you see around you are illusions.

This bizarre picture is the outcome of a recent series of calculations that take some of the bedrock theories and discoveries of modern cosmology to the limit. Nobody in the field believes that this is the way things really work, however. And so in the last couple of years there has been a growing stream of debate and dueling papers, replete with references to such esoteric subjects as reincarnation, multiple universes and even the death of spacetime, as cosmologists try to square the predictions of their cherished theories with their convictions that we and the universe are real. The basic problem is that across the eons of time, the standard theories suggest, the universe can recur over and over again in an endless cycle of big bangs, but it's hard for nature to make a whole universe. It's much easier to make fragments of one, like planets, yourself maybe in a spacesuit or even — in the most absurd and troubling example — a naked brain floating in space. Nature tends to do what is easiest, from the standpoint of energy and probability. And so these fragments — in particular the brains — would appear far more frequently than real full-fledged universes, or than us. Or they might *be* us.

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Alan Guth, a cosmologist at the Massachusetts Institute of Technology who agrees this overabundance is absurd, pointed out that some calculations result in an infinite number of free-floating brains for every normal brain, making it "infinitely unlikely for us to be normal brains." Welcome to what physicists call the Boltzmann brain problem, named after the 19th-century Austrian physicist Ludwig Boltzmann, who suggested the mechanism by which such fluctuations could happen in a gas or in the universe. Cosmologists also refer to them as "freaky observers," in contrast to regular or "ordered" observers of the cosmos like ourselves. Cosmologists are desperate to eliminate these freaks from their theories, but so far they can't even agree on how or even on whether they are making any progress.

If you are inclined to skepticism this debate might seem like further evidence that cosmologists, who gave us dark matter, dark energy and speak with apparent aplomb about gazillions of parallel universes, have finally lost their minds. But the cosmologists say the brain problem serves as a valuable reality check as they contemplate the far, far future and zillions of bubble universes popping off from one another in an ever-increasing rush through eternity. What, for example is a "typical" observer in such a setup? If some atoms in another universe stick together briefly to look, talk and think exactly like you, is it really you?

"It is part of a much bigger set of questions about how to think about probabilities in an infinite universe in which everything that can occur, does occur, infinitely many times," said Leonard Susskind of Stanford, a co-author of a paper in 2002 that helped set off the debate. Or as Andrei Linde, another Stanford theorist given to colorful language, loosely characterized the possibility of a replica of your own brain forming out in space sometime, "How do you compute the probability to be reincarnated to the probability of being born?"

The Boltzmann brain problem arises from a string of logical conclusions that all spring from another deep and old question, namely why time seems to go in only one direction. Why can't you unscramble an egg? The fundamental laws governing the atoms bouncing off one another in the egg look the same whether time goes forward or backward. In this universe, at least, the future and the past are different and you can't remember who is going to win the Super Bowl next week.

"When you break an egg and scramble it you are doing cosmology," said Sean Carroll, a cosmologist at the California Institute of Technology.

Boltzmann ascribed this so-called arrow of time to the tendency of any collection of particles to spread out into the most random and useless configuration, in accordance with the second law of thermodynamics (sometimes paraphrased as "things get worse"), which says that entropy, which is a measure of disorder or wasted energy, can never decrease in a closed system like the universe.

If the universe was running down and entropy was increasing now, that was because the universe must have been highly ordered in the past.

In Boltzmann's time the universe was presumed to have been around forever, in which case it would long ago have stabilized at a lukewarm temperature and died a "heat death." It would already have maximum entropy, and so with no way to become more disorderly there would be no arrow of time. No life would be possible but that would be all right because life would be excruciatingly boring. Boltzmann said that entropy was all about odds, however, and if we waited long enough the random bumping of atoms would occasionally produce the cosmic equivalent of an egg unscrambling. A rare fluctuation would decrease the entropy in some place and start the arrow of time pointing and history flowing again. That is not what happened. Astronomers now know the universe has not lasted forever. It was born in the Big Bang, which somehow set the arrow of time, 14 billion years ago. The linchpin of the Big Bang is thought to be an explosive moment known as inflation, during which space became suffused with energy that had an antigravitational effect and ballooned violently outward, ironing the kinks and

irregularities out of what is now the observable universe and endowing primordial chaos with order.

Inflation is a veritable cosmological fertility principle. Fluctuations in the field driving inflation also would have seeded the universe with the lumps that eventually grew to be galaxies, stars and people. According to the more extended version, called eternal inflation, an endless array of bubble or "pocket" universes are branching off from one another at a dizzying and exponentially increasing rate. They could have different properties and perhaps even different laws of physics, so the story goes.

A different, but perhaps related, form of antigravity, glibly dubbed dark energy, seems to be running the universe now, and that is the culprit responsible for the Boltzmann brains.

The expansion of the universe seems to be accelerating, making galaxies fly away from one another faster and faster. If the leading dark-energy suspect, a universal repulsion Einstein called the cosmological constant, is true, this runaway process will last forever, and distant galaxies will eventually be moving apart so quickly that they cannot communicate with one another. Being in such a space would be like being surrounded by a black hole.

Rather than simply going to black like "The Sopranos" conclusion, however, the cosmic horizon would glow, emitting a feeble spray of elementary particles and radiation, with a temperature of a fraction of a billionth of a degree, courtesy of quantum uncertainty. That radiation bath will be subject to random fluctuations just like Boltzmann's eternal universe, however, and every once in a very long, long time, one of those fluctuations would be big enough to recreate the Big Bang. In the fullness of time this process could lead to the endless series of recurring universes. Our present universe could be part of that chain.

In such a recurrent setup, however, Dr. Susskind of Stanford, Lisa Dyson, now of the University of California, Berkeley, and Matthew Kleban, now at New York University, pointed out in 2002 that Boltzmann's idea might work too well, filling the megaverse with more Boltzmann brains than universes or real people.

In the same way the odds of a real word showing up when you shake a box of Scrabble letters are greater than a whole sentence or paragraph forming, these "regular" universes would be vastly outnumbered by weird ones, including flawed variations on our own all the way down to naked brains, a result foreshadowed by Martin Rees, a cosmologist at the University of Cambridge, in his 1997 book, "Before the Beginning."

The conclusions of Dr. Dyson and her colleagues were quickly challenged by Andreas Albrecht and Lorenzo Sorbo of the University of California, Davis, who used an alternate approach. They found that the Big Bang was actually more likely than Boltzmann's brain.

"In the end, inflation saves us from Boltzmann's brain," Dr. Albrecht said, while admitting that the calculations were contentious. Indeed, the "invasion of Boltzmann brains," as Dr. Linde once referred to it, was just beginning.

In an interview Dr. Linde described these brains as a form of reincarnation. Over the course of eternity, he said, anything is possible. After some Big Bang in the far future, he said, "it's possible that you yourself will re-emerge. Eventually you will appear with your table and your computer."

But it's more likely, he went on, that you will be reincarnated as an isolated brain, without the baggage of stars and galaxies. In terms of probability, he said, "It's cheaper."

You might wonder what's wrong with a few brains — or even a preponderance of them — floating around in space. For one thing, as observers these brains would see a freaky chaotic universe, unlike our own, which seems to persist in its promise and disappointment.

Another is that one of the central orthodoxies of cosmology is that humans don't occupy a special place in the cosmos, that we and our experiences are typical of cosmic beings. If the odds of us being real instead of Boltzmann brains are one in a million, say, waking up every day would be like walking out on the street and finding everyone in the city standing on their heads. You would expect there to be some reason why you were the only one left right side up.

Some cosmologists, James Hartle and Mark Srednicki, of the University of California, Santa Barbara, have questioned that assumption. "For example," Dr. Hartle wrote in an e-mail message, "on Earth humans are not typical animals; insects are far more numerous. No one is surprised by this."

In an e-mail response to Dr. Hartle's view, Don Page of the University of Alberta, who has been a prominent voice in the Boltzmann debate, argued that what counted cosmologically was not sheer numbers, but consciousness, which we have in abundance over the insects. "I would say that we have no strong evidence against the working hypothesis that we are typical and that our observations are typical," he explained, "which is very fruitful in science for helping us believe that our observations are not just flukes but do tell us something about the universe."

Dr. Dyson and her colleagues suggested that the solution to the Boltzmann paradox was in denying the presumption that the universe would accelerate eternally. In other words, they said, that the cosmological constant was perhaps not really constant. If the cosmological constant eventually faded away, the universe would revert to normal expansion and what was left would eventually fade to black. With no more acceleration there would be no horizon with its snap, crackle and pop, and thus no material for fluctuations and Boltzmann brains.

String theory calculations have suggested that dark energy is indeed metastable and will decay, Dr. Susskind pointed out. "The success of ordinary cosmology," Dr. Susskind said, "speaks against the idea that the universe was created in a random fluctuation."

But nobody knows whether dark energy — if it dies — will die soon enough to save the universe from a surplus of Boltzmann brains. In 2006, Dr. Page calculated that the dark energy would have to decay in about 20 billion years in order to prevent it from being overrun by Boltzmann brains.

The decay, if and when it comes, would rejigger the laws of physics and so would be fatal and total, spreading at almost the speed of light and destroying all matter without warning. There would be no time for pain, Dr. Page wrote: "And no grieving survivors will be left behind. So in this way it would be the most humanely possible execution." But the object of his work, he said, was not to predict the end of the universe but to draw attention to the fact that the Boltzmann brain problem remains.

People have their own favorite measures of probability in the multiverse, said Raphael Bousso of the University of California, Berkeley. "So Boltzmann brains are just one example of how measures can predict nonsense; anytime your measure predicts that something we see has extremely small probability, you can throw it out," he wrote in an e-mail message.

Another contentious issue is whether the cosmologists in their calculations could consider only the observable universe, which is all we can ever see or be influenced by, or whether they should take into account the vast and ever-growing assemblage of other bubbles forever out of our view predicted by eternal inflation. In the latter case, as Alex Vilenkin of Tufts University pointed out, "The numbers of regular and freak observers are both infinite." Which kind predominate depends on how you do the counting, he said..

In eternal inflation, the number of new bubbles being hatched at any given moment is always growing, Dr. Linde said, explaining one such counting scheme he likes. So the evolution of people in new bubbles far outstrips the creation of Boltzmann brains in old ones. The main way life emerges, he said, is not by reincarnation but by the creation of

new parts of the universe. “So maybe we don’t need to care too much” about the Boltzmann brains,” he said.

“If you are reincarnated, why do you care about where you are reincarnated?” he asked. “It sounds crazy because here we are touching issues we are not supposed to be touching in ordinary science. Can we be reincarnated?”

“People are not prepared for this discussion,” Dr. Linde said.

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