A Brain Puzzle for Modern Cosmology

How Bohmian mechanics avoids Boltzmann brains

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It is often said that if a monkey were to press keys on a typewriter in a random fashion, he would sooner or later type the works of Shakespeare. Rather later, of course. It is an exercise in probability calculus to figure out how long on average we would have to wait for that. In a similar way, if a lot of atoms or elementary particles were to fly around in a random fashion, sometimes meeting and sticking together in random configurations, then sooner or later they would form a human brain in exactly the state that YOUR brain is presently in. The result is called a Boltzmann brain, after Ludwig Boltzmann (1844--1906), who was among the first to study probabilistic aspects of the motion of the atoms in a gas. A Boltzmann brain is thinking what you are presently thinking, and has false memories of events that never happened to it.

Of course, the time we would have to wait for a Boltzmann brain to occur is extraordinarily long, longer than $10^{10^{10}}$ years. So what's the problem? It is this: if the universe continues to exist for an infinite amount of time (or just much more than $10^{10^{10}}$ years), and if the late universe will look like a gas in thermal equilibrium, then Boltzmann brains are nearly certain to occur, in fact repeatedly, by chance alone. That is why this scenario is relevant to contemporary cosmology. Actually, the standard model of cosmology (Lambda-CDM) implies that Boltzmann brains emerge sooner or later from vacuum fluctuations.

A lot of questions arise about Boltzmann brains. For example, how can you know whether or not you are a Boltzmann brain? There are good responses, which boil down to the answer that although you can never know with certainty, it would be irrational for you to believe that you are a Boltzmann brain, in part because you have more reason to trust your own memories than you have to trust any physical theory on which the probability of Boltzmann brains could be based.

But another trouble remains. Even if you are confident that you are not a Boltzmann brain, it is likely that your favorite physical theory predicts, if the space-time volume of the universe is infinite (or just extraordinarily large), that Boltzmann brains exist, even many of them, more than ordinary brains that have come into existence through childhood, and (prior to that) birth, and (prior to that) biological evolution, and (prior to that) the formation of stars and planets. This prediction is a problem because if most observers are Boltzmann brains, then we too should expect to be Boltzmann brains. But we are confident that we are not Boltzmann brains. Therefore, the theory arguably makes a wrong prediction. And the question is, given that Boltzmann brains just arise by chance sooner or later, how can any physical theory avoid predicting that huge numbers of Boltzmann brains exist?

One way out of the problem is that the duration of the universe might be finite, and not extraordinarily large. For example, if the universe began in a big bang about 13 billion years ago and will end in a big crunch that happens, say, 10^{20} years from now, and if the spatial 3-volume of the universe is at no time larger than, say, 10^{100} cubic light years, then the entire history of the universe is perhaps not large enough for monkeys to type more than a line of Shakespeare or for Boltzmann brains to form. But the Lambda-CDM model of cosmology predicts that there will be no big crunch, that the universe has infinite duration (and asymptotically the geometry of de Sitter space-time).

Now Bohmian mechanics, a theory of quantum mechanics with particle trajectories named after David Bohm (1917--1992), has a surprising alternative solution. In a version of the theory applicable to curved space-time and a field ontology, it turns out that in the late universe with de Sitter geometry, all matter comes to rest relative to the expansion of the universe. So instead of incessant chaotic motion as in a classical gas in thermal equilibrium, the configuration ultimately stops moving, as if frozen. As if the monkey did not continue typing forever. As a consequence, Boltzmann brains are not likely to form (and, moreover, even if a brain configuration did form, it is debatable whether it would count as a Boltzmann brain because it does not function like a normal brain).

Finally, there is another way in which Bohmian mechanics works better than many other theories of quantum mechanics for the purposes of cosmology, and that concerns the formation of galaxies. According to standard rules of quantum mechanics, wave functions do not collapse without the intervention of observers. But possibly, in the first 12 billion years of our universe, there were no intelligent observers. And collapse plays a key role in the passage from a symmetric superposition of all possible configurations of galaxies to an asymmetric particular configuration. Bohmian mechanics offers a natural way out, as the particle trajectories can form an asymmetric configuration even if the wave function of all matter in the universe remains a big superposition.

Both kinds of cosmological fluctuations, galaxy formation and Boltzmann brains, are analyzed in the Bohmian framework in our article.