***Letter from Leonard Susskind***

When I was asked if I would be willing to continue a debate with Lee Smolin on the *Edge* website my initial reaction was to say no. The problem is that the easiest ideas to explain, which sound convincing to a general audience, are not always the best ideas. The unwary layman says to himself, "Yeah, I understand that. Why is this other guy making it so complicated?" Well the answer is that those simple ideas, that sound like you understand them, often have deep technical flaws and the correct ideas can be very difficult to explain. All a person like myself can do is to say, "Trust me. I know what I'm doing and he doesn't. And besides, so-and-so agrees with me." That doesn't make a good impression. It can be a no win situation.

Why did I agree to do it? Partly because I love explaining physics. Mostly—I don't know why. But *here goes nothing* as they say.

In a nutshell, here is the view of physics and cosmology that Smolin is attacking:

1. In the remote past the universe inflated to an enormous size, many orders of magnitude bigger than the observed portion that we can see. Most of the universe is behind the cosmic horizon and cannot be directly detected.

2. The mechanism of inflation leads to a diverse universe; filled with what Alan Guth calls pocket universes (PU's ). We live in one such PU. Some people call this super-universe the "Multiverse." I like the term "Megaverse". This growth and continuous spawning of pocket U's is called, in the trade, *eternal inflation*.

3. String theory leads to a stupendously large "Landscape" of possibilities for the local laws of nature in a given pocket. I will call these possibilities "environments". Most environments are very different from our own, and would not permit life: at least, life as we know it.

4. Combining 1,2 and 3—the universe is a megaverse filled with a tremendously large number of local environments. Most of the volume of the megaverse is absolutely lethal to life. Some small fraction is more hospitable. We live somewhere in that fraction.

That's it.

There are good reasons for believing 1—4 based on a combination of theoretical and experimental physics. In fact I don't know anyone that disagrees with 1. Assumption 2 is not quite a consequence of 1 but its difficult to avoid 2 in conventional inflation theories.

The physics that goes into it is a very familiar application of trustworthy methods in quantum field theory and general relativity. It's called *Coleman de Luccia* semi-classical tunneling by instantons, based on a very famous paper by the incomparable Sidney Coleman and his collaborator Frank deLuccia. It is the same physics that has been used from the 1930's to explain the decay of radioactive nuclei.

String theorists are split on whether 3 is a good thing or a bad thing but not about whether it is correct. Only one string theorist seriously challenged the technical arguments, and he was wrong. In any case Smolin and I agree about 3. I think we also agree that most of the Landscape is totally lethal to life, at least life of our kind. Finally 4. There's the rub. As far as I am concerned 4 is simply 1+2+3. But Smolin has other ideas and 4 just gets in the way.

Let's suppose for the moment that these 4 points are correct. What then determines our own environment? In other words why do we find ourselves in one kind of PU rather than another? To get an idea of what the issues are, in a more familiar context, lets replace 1—4 with analogous points regarding the ordinary known universe.

1'. The universe is big—about 15 billion light years in radius.

2'. The expansion of the universe led to a huge number of condensed astronomical objects — at minimum 10[23] solar systems.

3'. The laws of gravity, nuclear physics, atomic physics, chemistry thermodynamics allow a very diverse set of possible environments, from the frozen cold of interstellar space to the ferocious heat of stellar interiors, with planets, moons, asteroids and comets somewhere in between. Even among planets the diversity is huge—from Mercury to Pluto.

4'. The universe is filled with these diverse environments, most of which are lethal. But the universe is so big, that statistically speaking, it is very likely that one or more habitable planets exists.

I don't think anyone questions these points. But what is it that decides which kind of environment we live in—the temperature, chemistry and so on? In particular what determines the fact that the temperature of our planet is between freezing and boiling? The answer is that *nothing does*. There are environments with temperatures ranging from almost absolute zero to trillions of degrees. Nothing, determines the nature of our environment—except for the fact that we are here to ask the question! The temperature is between freezing and boiling because life (at least our kind) requires liquid water. That's it. That's all. There is no other explanation. [1]

This rather pedestrian, common sense logic is sometimes called "The Anthropic Principle." Note that I mean something relatively modest by the A.P. I certainly don't mean that everything about the laws of physics can be determined from the condition that life exists— just those things that turn out to be features of the local environment and are needed to support life.

Let's imagine that the earth was totally cloud bound or that we lived at the bottom of the sea. Some philosopher who didn't like these ideas, might object that our hypotheses 1'—4' are un-falsifiable. He might say that since there is no way to observe these other regions with their hostile environments—not without penetrating the impenetrable veil of clouds—the theory is un-falsifiable. That, according to him, is the worst sin a scientist can commit. He will say, "Science means falsifiability. If a hypothesis can't be proved false it is not science." He might even quote Karl Popper as an authority.

From our perspective we would probably laugh at the poor deluded fellow. The correctness of the idea is obvious and who cares if they can falsify it.

Even worse, he wouldn't even be correct about the falsifiability. Here is a way that the anthropic reasoning might be proved false without penetrating the veil of clouds: Suppose an incredibly accurate measurement of the average temperature of the earth gave the answer (in centigrade) T=50.0000000000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000000000 degrees. In other words the temperature was found to be exactly midway between freezing and boiling, to an accuracy of one hundred decimal places. I think we would be justified in thinking that there is something beyond the anthropic principle at work. There is no reason, based on the existence of life, for the temperature to be so symmetrically located between boiling and freezing. So discovering such a temperature would pretty convincingly mean that the existence of life is not the real reason why the temperature is between 0 and 100 degrees.

Smolin's chief criticism of 1—4 is that they are un-falsifiable. But it is not hard to think of ways of falsifying the Anthropic Principle. In particular Weinberg's prediction that *if* the anthropic principle is true, then the cosmological constant should not be exactly zero, is very similar to the example I just invented. Weinberg attempted to falsify the anthropic principle. He failed. The Anthropic Principle survived. You can read about the details in Weinberg's book *Dreams of a Final Theory*.

By un-falsifiable Smolin probably means that other pocket universes can never be *directly* observed because they are behind an impenetrable veil, i.e. the cosmic event horizon. Throughout my long experience as a scientist I have heard un-falsifiability hurled at so many important ideas that I am inclined to think that no idea can have great merit unless it has drawn this criticism. I'll give some examples:

From psychology: You would think that everybody would agree that humans have a hidden emotional life. B.F. Skinner didn't. He was the guru of a scientific movement called behaviorism that dismissed anything that couldn't be directly observed as unscientific. The only valid subject for psychology according to the behaviorist is external behavior. Statements about the emotions or the state of mind of a patient were dismissed as un-falsifiable. Most of us, today, would say that this is a foolish extreme.

From physics: In its early days of the quark theory, it's many opponents dismissed it as un-falsifiable. Quarks are permanently bound together into protons, neutrons and mesons. They can never be separated and examined individually. They are, so to speak, hidden behind a different kind of veil. Most of the physicists who made these claims had their own agendas, and quarks just didn't fit in. But by now, although no single quark has ever been seen in isolation, there is no one who seriously questions the correctness of the quark theory. It is part of the bedrock foundation of modern physics.

Another example is Allan Guth's inflationary theory. In 1980 it seemed impossible to look back to the inflationary era and see direct evidence for the phenomenon. Another impenetrable veil called the "surface of last scattering" prevented any observation of the inflationary process. A lot of us did worry that there might be no good way to test inflation. Some—usually people with competing ideas—claimed that inflation was un-falsifiable and therefore not scientific.

I can imagine the partisans of Lamark criticizing Darwin, "Your theory is un-falsifiable, Charles. You can't go backward in time, through the millions of years over which natural selection acted. All you will ever have is circumstantial evidence and an un-falsifiable hypothesis. By contrast, our Lamarkian theory is scientific because it is falsifiable. All we have to do is create a population that lifts weights in the gym every day for a few hours. After a few generations, their children's muscles will bulge at birth." The Lamarkists were right. The theory is easily falsified—too easily. But that didn't make it better than Darwin's theory.

There are people who argue that the world was created 6000 years ago with all the geological formations, isotope abundances, dinosaur bones, in place. Almost all scientists will point the accusing finger and say "Not falsifiable!" I'm sure that Smolin would agree with them and so would I. But so is the opposite—that the universe was not created this way—un-falsifiable. In fact that is exactly what creationists do say. By the rigid criterion of falsifiability "creation-science" and science-science are equally unscientific. The absurdity of this position will, I hope not be lost on the reader.

Good scientific methodology is not an abstract set of rules dictated by philosophers. It is conditioned by, and determined by, the science itself and the scientists who create the science. What may have constituted scientific proof for a particle physicist of the 1960's—namely the detection of an isolated particle—is inappropriate for a modern quark physicist who can never hope to remove and isolate a quark. Let's not put the cart before the horse. Science is the horse that pulls the cart of philosophy.

In each case that I described—quarks, inflation, Darwinian evolution—the accusers were making the mistake of underestimating human ingenuity. It only took a few years to indirectly test the quark theory with great precision. It took 20 years to do the experiments that confirmed inflation. And it took 100 years or more to decisively test Darwin (Some would even say that it has yet to be tested). The powerful methods that biologists would discover a century later were unimaginable to Darwin and his contemporaries. What people usually mean when they make the accusation of un-falsifiability is that they, themselves, don't have the imagination to figure out how to test the idea. Will it be possible to test eternal inflation and the Landscape? I certainly think so although it may be, as in the case of quarks, that the tests will be less direct, and involve more theory, than some would like.

Finally, I would point out that the accusation of un-falsifiability is being thrown by someone with his own agenda. Smolin has his own theory based on ideas about the interior of black holes. There is of course, absolutely nothing wrong with that, and Smolin is completely candid about it.

Smolin believes (as I and most cosmologists do) that there is a sense, in which the universe, or perhaps I should say *a* universe, can reproduce, parent universes spawning baby universes. Perhaps, here is a good time to talk about a linguistic point. The word universe was obviously intended to refer to *all that exists*. It was not a word that was intended to have a plural. But by now, physicists and cosmologists have gotten used to the linguistic discord. Sometimes we mean all that exists, but sometimes we mean an expanding region of space with particular properties. For example we might say that in our universe the electron is lighter than the proton. In some other distant universe the electron is heavier than the proton. Guth's term—pocket universe—may be a better term but it tends to ruin the prose.

Although we agree that some form of universe-reproduction can occur, Smolin and I disagree about the mechanism. Just the ordinary expansion of the universe is a form of reproduction. For example, if the radius of the universe doubles, you can either picture each cubic meter stretching to 8 cubic meters, or you can say that the original cubic meter gave birth to seven children. Inflation is the *exponential* expansion of space. It can be understood as an exponentially increasing population of regions. Moreover, according to absolutely standard principles, some of the offspring can be environmentally different than the parent. In this sense a population of PU's exponentially reproduces as the universe inflates. The modern idea of eternal inflation is that the universe eternally inflates, endlessly spawning PU's such as our own. The analogy with the *tree of life* is apt. Any species eventually becomes extinct but the tree keeps on growing by shooting off new branches and twigs. In the same way a given PU will eventually end but eternal inflation goes on. Just as the population of organisms will be numerically dominated by the fastest reproducers (bacteria) the volume of space will be dominated by the most rapidly inflating environment: an environment I might add, that is totally lethal. If eternal inflation is part of the story of the universe, we can conclude that our local environment is by no means typical. The typical region of space will be one with the largest possible cosmological constant. For Smolin's alternative reproduction mechanism to be relevant, eternal inflation must not occur for some unknown reason.

Smolin's picture of reproduction is that it takes place in the interior of black holes. He believes that in the deep interior of every black hole, the dreaded singularity is a source of a new universe that arises out of the infinitely compressed and heated matter as it contracts and (according to Smolin) subsequently rebounds and expands. By this hypothetical mechanism, a new infant universe is created inside the black hole. The idea is that the child can expand and grow into a genuine adult universe, all hidden from the parent, behind the horizon. Moreover the child universe must have different properties than the parent for Smolin's cosmological natural selection to work. Random mutation is a necessary ingredient to natural selection.

Smolin adds one more assumption that follows the biological paradigm. In ordinary biology the child inherits information about the parents' traits through the genetic code, which may be altered by mutation, but *only a tiny bit*. Smolin must assume that the offspring only differ by *very small amounts* from the parent. More precisely he assumes that the constants of physics in the offspring universe are almost the same as in the parent universe. Without this assumption natural selection wouldn't work.

And what does this setup select for? As in life, evolution selects for maximal ability to reproduce. This, according to Smolin, means that PU's whose properties maximize the tendency to produce black holes, will dominate the population. So Smolin argues that our laws and constants of nature are tuned to values that maximize black hole production. According to Smolin, no anthropic reasoning is needed and that makes his theory "scientific".

This is an extremely clever idea. You can read about it in one of Smolin's papers that you can find on the net. Open your web browser to http://www.arxiv.org/. That's where physicists publish their work these days. On the General Relativity and Quantum Cosmology archive, look up gr-qc/9404011. That is one of the first papers that Smolin wrote on "Cosmological Natural Selection." The paper, from 1994, is clear and enjoyable to read. But for some reason it hasn't caught on with either physicists or cosmologists. In fact when I went to track down subsequent papers on the subject, to see if new developments had taken place, I found that there were only 11 citations to the paper. Four of them were by Smolin and two others were critical of the idea—one, incorrectly so, in my judgment.

I'm not sure why Smolin's idea didn't attract much attention. I actually think it deserved far more than it got. But I do know why I was skeptical. Two details, one very technical and one not so technical, seem to me to undermine the idea.

The first, not so technical objection: Frankly, I very much doubt that our laws maximize the number of black holes in the universe. In fact the meaning of the number of black holes in a given universe is unclear. Suppose that in our pocket universe, every star collapses to a black hole eventually. Then in the part of the universe that we presently observe, the number of black holes will eventually be about 10[22]. But suppose that as time goes on, all the black holes in a given galaxy eventually fall into a central black hole at the galactic center. Then the final number will be more like the number of galaxies—about 10[11]. Smolin of course prefers the larger number since he wants to argue that our universe has more black holes than any other possible universe. But strictly speaking, according to the rigorous definition of a black hole, the smaller number is the correct one. But let me be generous and use a looser definition of *black hole,* so that anything that temporarily looked like a black hole, is counted. But with this rule, it is easy to change the laws of physics so that many more black holes would have been present in the past.

If for example, the minute density contrasts in the early universe, which had the un-naturally small numerical value of 10[-5] were not so weak the universe would have been dominated by small black holes. Those black holes might have coalesced into larger black holes, but I said I would be generous and count them all.

Combine the increase of density contrast with an increase in the strength of gravity and a rapid inflation prehistory and you can make stupendous numbers of black holes. In fact if gravity were made as strong as it could reasonably be, every elementary particle (except photons and gravitons) would be a black hole!

I have exactly the opposite opinion from Smolin's. If the universe were dominated by black holes all matter would be sucked in, and life would be completely impossible. It seems clear to me that we live in a surprisingly smooth world remarkably free of the ravenous monsters that would devour life. I take the *lack* of black holes to be a sign of some anthropic selection.

Now I come to one of those technical objections, which I think is quite damning but which may mean very little to a layman. Smolin's idea is tied to Hawking's old claim that information can fall into a black hole and get trapped behind the horizon. Smolin requires a great deal of information to be transferred from the parent universe to the infant at the bouncing singularity. But the last decade of black hole physics and string theory have told us that **NO** information can be transferred in this way!

Some readers may recognize the issue that I am talking about. Anyone who has read the recent New York Times article by Dennis Overbye knows that the ultimate fate of information falling into a black hole was the subject of an long debate involving Stephen Hawking, myself, the famous Dutch physicist Gerard 't Hooft and many other well known physicists. Hawking believed that information does disappear behind the horizon, perhaps into a baby universe. This would be consistent with Smolin's idea that offspring universes, inside the black hole, remember at least some of the details of the mother universe. My own view and 't Hooft's was that nothing can be lost from the outside world—not a single *bit*. Curiously the cosmological debate about Cosmological Natural Selection revolves around the same issues that came to the attention of the press a week or two ago. The occasion for the press coverage was Hawking's recantation. He has reversed his position.

Over the last decade, since Smolin put forward his clever idea, the black hole controversy has largely been resolved. The consensus is that black holes do not lose any information. I'll cite some of the most influential papers that you can look up yourself: HEP-TH 9309145 , HEP-TH 9306069, HEP-TH 9409089, HEP-TH 9610043, HEP-TH 9805114, HEP-TH 9711200. Incidentally, the combined total number of citations for these six papers is close to 6,000. Another paper, co-authored very recently, by the author of one of these classics, directly attacks Smolin's assumption. In fact it was one of the 11 papers that I found citing Smolin's paper. If you want to look it up, here is the archive reference: HEP-TH 0310281. I warned you that I would say "And besides, so-and-so agrees with me." I apologize, but at least you can go check for yourself.

The implication of these papers is that no information about the parent can survive the infinitely violent singularity at the center of a black hole. If such a thing as a baby universe makes any sense at all, the baby will have no special resemblance to the mother. Given that, the idea of an evolutionary history that led, by natural selection, to our universe, makes no sense.

I'm sure there are physicists that are unconvinced by the arguments of the abovementioned papers, despite the number of citations. They have all the right in the world to be skeptical but the average reader of this page should know that these people are swimming against the tide.

Finally let me quote a remark of Smolin's that I find revealing. He says "It was worry about the possibility that string theory would lead to the present situation, which Susskind has so ably described in his recent papers, that led me to invent the Cosmological Natural Selection (CNS) idea and to write my first book. My motive, then as now, is to prevent a split in the community of theoretical physicists in which different groups of smart people believe different things, with no recourse to come to consensus by rational argument from the evidence."

First of all, preventing a "split in the community of theoretical physicists" is an absurdly ridiculous reason for putting forward a scientific hypothesis.

But what I find especially mystifying is Smolin's tendency to set himself up as an arbiter of good and bad science. Among the people who feel that the anthropic principle deserves to be taken seriously, are some very famous physicists and cosmologists with extraordinary histories of scientific accomplishment. They include Steven Weinberg [2], Joseph Polchinski [3], Andrei Linde [4], and Sir Martin Rees [5]. These people are not fools, nor do they need to be told what constitutes good science.

————————————————

[1] Of course you might say that the distance to the sun determines the temperature. But that just replaces the question with another, "Why is our planet at the precise distance that it is?"

[2] Professor of Physics, University of Texas and Nobel Prize winner 1979.

[3] Professor of Physics, Kavli Institute for Theoretical Physics.

[4] Professor of Physics, Stanford University, Winner of many awards and prizes including the Dirac Medal and Franklin Medal.

[5] Astronomer Royal of Great Britain.