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Lee Smolin

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Black holes in cosmological natural selection

Lee Smolin, in "Time, laws, and the future of cosmology" (PHYSICS TODAY, March 2014, page 38), proposes cosmological natural selection as an explanation for why the standard model seems fine-tuned to suit a universe that can support life. In his proposal, black holes generate new universes with new fundamental parameters. The universes with parameters most suitable for black hole formation spawn more offspring and are thus preferred. Smolin then notes that the majority of black holes arise as supernova remnants, which would imply that the universe should be fine-tuned to create supernovae.

In his picture, it happens that universes tuned to create supernovae are also conducive to the formation of life. I wonder, though, what if humans are able to create microscopic black holes—for example, in particle accelerators? And what if, eventually, we create them prolifically? Then fine-tuning the universe to create black holes would imply fine-tuning the universe to create the intelligent life that would create the most black holes.

That life-centric variant of cosmological natural selection would also explain why our intelligence seems nicely suited to understanding natural laws and perhaps even playing the central role of an observer in quantum mechanics. One might wonder, "Why is it that the equations we invent in our minds seem to work at describing the universe?" And the answer would be, "Because if the laws of the universe and our brains were not compatible, we would never be able to learn how to create microscopic black holes."

We may need to build bigger particle colliders. They could be our only reason for existing.

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■ **The natural-selection scenario** that Lee Smolin describes for universes selects for ones most likely to produce black holes. That is not the same thing as selecting for a universe that has the same characteristics as ours or for a universe that has characteristics conducive to biological life. It's easy to imagine a universe more likely than ours to produce black holes but less likely to produce biological life. For example, gravity in our universe is much weaker than the other forces. It's reasonable to suggest that probably in most universes, there is less of a disparity between gravity and the other forces. If gravity was much stronger, all matter would quickly collapse into black holes before the first stars had a chance to form. Such a universe would be full of black holes and have no life.

In a universe that has gravity the same strength as in ours but has orders of magnitude more baryonic matter, the matter would collapse into black holes. Or consider a universe in which the strength of gravity and the amount of baryonic material are the same as in ours, but the Schwarzschild radius is larger. If less mass in a given volume would form a black hole, then it would be easier to form black holes.

Speculation about a hypothetical universe with different characteristics or laws of physics isn't even necessary. If in our universe stellar black holes were a small percentage of all black holes, then maximizing the number of black holes would not require maximizing the number of stars. It was hypothesized that black holes could have been created at the Large Hadron Collider at CERN. In that scenario, primordial black holes would have been copiously produced during the Big Bang and would greatly outnumber stellar black holes.

Also, it's possible that micro black holes could appear in the internal loops of all Feynman diagrams. If that's the case, the black holes in the internal loops of Feynman diagrams would far outnumber primordial black holes produced in the Big Bang, which in turn would far outnumber stellar black holes. Selecting for a universe that produces black holes does not require selecting for a universe that maximizes the number of stars.

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■ **Smolin replies:** Paul Sorensen proposes an application of cosmological natural selection (CNS) according to which intelligent beings would be motivated to create artificial black holes, which would tune the ensemble of universes to favor those that are hospitable to intelligent life. Versions of that idea were proposed by Louis Crane and Edward Harrison, although Sorensen's version is different in proposing that it could explain why the universe's laws are comprehensible to us. His idea is elegant, but let's wait till the few predictions of CNS are thoroughly tested and confirmed, all the objections have been answered, and alternative explanations for the selection of the laws have been disconfirmed before engaging in speculation about implications that will be hard to test.

Meanwhile, Jeffery Winkler proposes two ways that the parameters of the laws of nature could be varied to increase the number of black holes in the universe. Both are addressed in the appendix of my book *The Life of the Cosmos* (Oxford University Press, 1997) and related papers.

Winkler suggests that Newton's constant, G, could be increased, which would lead to matter collapsing directly into black holes, without having to go through the stages of massive stars and supernovae. However, CNS only predicts that our universe is a local maximum of the number of black holes produced. Also, G is a dimensional constant, so what we can vary is the dimensionless ratio m, the nucleon mass in Planck units. A small increase in m will not increase the spontaneous collapse of matter to black holes. That process, so far as we know, never happens in our universe, because to overcome the Fermi degeneracy pressure requires a very large number, $N \sim 1/m^3 \sim 10^{57}$, of nucleons together in a very small volume. Slightly increasing m will decrease N, but not by enough to drive spontaneous collapse. Moreover, copious black hole formation via stellar collapse requires the cooling of giant molecular clouds, which, in turn, requires plentiful carbon and oxygen, since the main coolant is carbon monoxide. But it's not possible to have sufficient quantities of both elements without delicately tuned coincidences among the physical constants, which are disrupted when m is varied. Thus a world with a slightly larger m may have many fewer stellar-made black holes without any increase in the number of black holes formed by spontaneous collapse.

Winkler's second proposal is to increase the baryon fraction of the universe. But that comes at a cost: Inflation constrains the total energy-density content of the universe. Increasing the baryon content at the expense of dark matter could result in less galaxy formation and, hence, fewer black holes. Decreasing the dark energy gives more time for galaxies to collide before the accelerating expansion disrupts clusters. And that process turns spiral galaxies with cold disks into hot ellipticals that don't form massive stars—again resulting in fewer black holes.

Winkler further proposes that virtual black holes vastly outnumber real ones, but there is no reason based in a real calculation to suppose that virtual black holes exist or that they must spawn new universes.

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Bell tones from the piano

Murray Campbell's article "Evaluating musical instruments" (Physics Today, April 2014, page 35) was quite interesting. A statement in the section "What makes an excellent piano?" particularly caught my eye. Campbell writes, "Some pianists believe that by merely altering the manner in which the key is depressed, it is possible to change the timbre of a single note, without altering its loudness. It is hard to see how that can be true."

In one of Camille Saint-Saëns's piano concertos—I forget which one—a key is struck in such a way that it produces a bell-like tone. I asked a virtuoso pianist about it after hearing him play the concerto (this was 30 years ago), and he said that what we heard was a harmonic. He had to strike a key in a certain way to achieve it, and each piano was different in regard to the technique required. He said that to get it right for the concert, he had to experiment with that particular Steinway. I'd love to learn more about the technique involved.

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■ **Campbell replies:** Although I don't recognize the musical context Jon Orloff refers to, he raises several interesting points about "harmonics" in piano music. The term is used to describe a common technique in violin and guitar playing in which the player touches the string lightly at a distance L/n from the bridge, where L is the string length and n an integer. The light touch suppresses the modes of vibration of the string when it is sounded, except for modes that have a node at the point touched.

To obtain this effect on the piano, the player reaches inside the instrument with one hand to touch the string while playing the keyboard with the other. I don't think the technique was used at the time when Camille Saint-Saëns was composing. A more likely explanation has been suggested by Anders Askenfelt, the piano acoustics expert at KTH in Stockholm. A carefully judged and forceful accent on the relevant note gives a sound rich in upper "harmonics." Depressing the sustaining pedal just before the note is struck allows sympathetic vibrations from unstruck strings to contribute to the mix of high-frequency components, which are, in fact, slightly inharmonic. The high-frequency components decay faster than the lower frequencies, and the resulting sound has some similarity to that of a struck bell.

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Energetic flares in the search for habitable exoplanets

Exoplanet searchers will, I suspect, find the article "Warm planets orbiting cool stars" by John Johnson (Physics Today, March 2014, page 31) interesting and encouraging.

In his section on habitable zones, I wish Johnson had considered the effect of flares among low-mass stars of the M-class main sequence. The internal structure of those stars, coupled with rapid spin, can produce frequent energetic flares. They are important to the discussion because a planet whose temperature places it within the habitable zone would be vulnerable to carbon-chemistry damage from the flares' ionizing radiation. "Life on a planet near one of these flare stars might be quite difficult."[1]

Earth is shielded from the Sun's less-frequent flares by its magnetic fields. An extrasolar planet orbiting a flare star