Toomey, David. 2013. "Thoughts on Weird Life, Scientific Speculation, and the Spaces between the Disciplines." *Social Epistemology Review and Reply Collective* 2 (3): 15-18. http://wp.me/p1Bfg0-GL

Thoughts on Weird Life, Scientific Speculation, and the Spaces between the Disciplines

David Toomey, University of Massachusetts

Weird Life in brief, is about theoretical organisms and theoretical ecologies. But it has another, rather more implicit subject as well, one that became more and more evident to me during revisions, and which might be of interest to participants in the Collective. It's not difficult to see the book as a series or set of portrayals of scientists working at the limits of their knowledge, or as a set of case studies of what can happen when they push against those limits.

Some of the limits are internal to the field and are represented in language. For instance, there are at least nine specialties within biology: anatomy, taxonomy, physiology, biochemistry, molecular biology, ecology, ethology, embryology, and evolutionary biology. Practitioners in each of these specialties tend to define life — their core subject — rather differently. A physiologist, for instance, might call it "a system capable of eating and metabolizing," and a molecular biologist might call it "a system that contains reproducible hereditary information coded in nucleic acid molecules." To biologists in their day-to-day work, the differences in these characterizations are of little practical consequence, and pressed for a more general definition of life, many would say some thing like, "I know it when I see it." But when scientists begin to search for life unlike any we know, on Earth or elsewhere, they may *not* know it when they see it, and at that time a universal definition would become necessary. It's a problem described at length and most recently by philosopher Carol Cleland (who argues that biologists would be well-advised to develop a *theory* of life), but it's been in the air at least since 1960, when it was central to discussions held by NASA's Office of Life Sciences. If anything is clear from this, it's that if and when a candidate for weird life is found, the intra-disciplinary boundaries and the limits of the language that defines those boundaries would become painfully apparent.

There is an interesting set of cases in a natural phenomenon may have fallen into the gap between disciplines: specifically, biology and chemistry. A majority of microbiologists suspect that the lower limit for a cell's size is set by *ribosomes*, the (relatively) large molecules of proteins and RNA that work inside all cells to link amino acids and make new proteins. If they are to squeeze ribosomes inside themselves, cells must be a least a few hundred nanometers across, and it is for this reason that most microbiologists think that smaller cells are impossible.

Nonetheless, there have been at least three reports of very, very small things that — to their discoverers at least — seemed to be living or once living. In 1990, Robert Folk, an emeritus professor at the University of Texas at Austin, discovered in sedimentary rocks tiny structures that he took to be tiny fossils, the calcified remains of organisms a mere 30 nanometers across. In 1996, Australian geologist Philippa Uwins and her colleagues, examining sandstone bore samples from a deep-ocean borehole off the coast of western Australia, found tiny filaments that under an electron microscope looked like blobs in a lava lamp. In 1988, Finnish biochemist Olavi Kajander found particles measuring a mere

20 nanometers across inside cells. Believing them to be living, he called them "nanobacteria."

At present, the preponderance of evidence is that none of these findings is an organism, living or once living (see Young and Martel for a review), and most microbiologists have given these findings a wide berth. One reason is that the work done so far — Kajander's in particular — has generated controversies that give pause to scientists concerned for their careers and reputations. Although nanoparticles may be very important, representing a class of forms somewhere between nonlife and life unknown to science, they fall into a no-man's-land between chemistry and biology, and further research in the area has been inhibited, among other reasons, by disciplinary boundaries and all those boundaries imply. A number of scientists approached the subject, got near enough to see that it had little to do with their field, and took a pass. Microbiologist John Cisar, who led an NIH study that countered Kajander, noted, "I'm not saying there's nothing there. It's just that we were looking at it from a microbiologist's perspective. And when we didn't find any signs of life, we moved on" (quoted in Asaravala).

Much of *Weird Life* describes organisms that are *purely* theoretical, or, one might say, theories of possible organisms. These theories too have been shaped and more to my point here — circumscribed and in some cases inhibited — by scientific specialization.

Silicon-based life is a common trope in science fiction, the most famous example being the "horta" featured in an episode of the original *Star Trek* television series. Most biologists who've considered the possibility of silicon-based life think it unlikely. Norman Pace, the internationally respected microbiologist who did pioneering work on phylogeny, might have been speaking for many when he told a journalist, "I would never say never," but, "I'm not at all optimistic about finding non-carbon life" (quoted in Fox). There are several reasons for such reservations, at least one of which turns out to be unfounded. Many biologists believe that unlike carbon, silicon can bond with only a few elements. In fact though, under certain circumstances — most notably very cold temperatures—silicon bonds stably with a great many elements. Microbiologists are likely to be innocent of the possibilities that cryogenic chemistry presents for silicon simply because the pertinent research on the subject (see for instance, Muller) is published in journals they (microbiologists, that is) are unlikely to read.

That microbiologists are unaware of work in cryogenic chemistry may produce is a small-scale example of disciplinary biases and their consequences. On the matter of weird life, disciplinary boundaries may circumscribe scientific speculation on a much larger scale as well.

Much hypothesized weird life might be called 'modestly weird.' Examples would be life using different chemical pathways in cells, different bases in its DNA, or most famously, in the largely discredited report of Wolfe-Simon *et. al.,* life substituting phosphorus in its DNA with arsenic. And much hypothesized weird life might be called 'extremely weird.' Examples would be living interstellar clouds of dust grains and complex molecules organized by electromagnetic forces, or creatures made of densely packed atomic nuclei and surviving on the crusts of neutron stars by means of a metabolism relying on a nuclear chemistry. In fact, it seems that most hypothetical weird life is one or the other--that is, modestly weird or extremely weird. Weird life then, is represented by a broad range of speculation with most of the data points at either end, and a wide gap between them. I suspect that these extremes (and the gap) may be explained by specializations and the biases they instill.

This is not the first time specializations led scientists, on a matter of some speculation, to rather different conclusions. In the 1970s, several astronomers and astrobiologists made informed estimates of the number of extant extraterrestrial civilizations in the Milky Way Galaxy, estimates ranging from fewer than 1,000 to 1 billion. The most extreme positions (the low estimates and the high ones) were articulated succinctly in a debate between planetary scientist turned astrobiologist Carl Sagan and evolutionary biologist Ernst Mayr. Sagan took the view that extraterrestrial intelligence was common, Mayr that it was rare and perhaps unique to our own species. In part working to undermine Sagan's position, in part attempting to place matters in a larger picture, Mayr observed that their conclusions split along disciplinary lines. Sagan's formal training was not in biology; it was in planetary science, a disciplinary specialty of astronomy. Sagan and others who estimated large numbers of extraterrestrial civilizations, so said Mayr, relied a flawed reasoning attributable to their professional backgrounds:

> When one looks at their qualifications, one finds that they are almost exclusively astronomers, physicists and engineers. They are simply unaware of the fact that the success of any SETI [Search for Extraterrestrial Intelligence] effort is not a matter of physical laws and engineering capabilities but essentially a matter of biological and sociological factors. These, quite obviously, have been entirely left out of the calculations of the possible success of any SETI project. (http://www.astro.umass .edu/~mhanner/Lecture_Notes/Sagan-Mayr.pdf)

Similarly, I think, specializations might greatly influence and circumscribe speculation of the nature of weird life. Many biologists who have considered alternative forms of life are inclined to suspect that if life exists elsewhere in the universe, it has a biochemistry much like that of life we know. It is not surprising that hypotheses for weird life that is *modestly* weird (using say, certain amino acids not used by familiar life) were put forth by microbiologists. Ideas for life that is *extremely* weird, like life in the vicinity of black holes and the atmospheres of white dwarf stars (Adams and Laughlin) and life in other universes (Harnik *et al.*), were conceived by theoretical physicists and astrophysicists.

It's reasonable to suppose that the reason for some of the gap is the nature of the fields of study, the perspectives that come with study in those fields, and the sort of intellect those fields attract to begin with. On the one hand, and to generalize, theoretical physicists are likely to be less interested in the particulars of a given phenomenon than they are in the underlying principles those particulars represent. Astronomers are cognizant of billions of stars as potential suns, the tens of billions of planets now estimated to be orbiting them, and the vast timescales over which the universe has existed and is likely to continue to exist. To a biologist pessimistic about the likelihood of weird life, a theoretical physicist might say that the particulars of biochemistry and chemistry are not as important as life’s most basic needs: energy and matter. And an astronomer would contend that those needs are met in many places in our universe, and have been met for billions of years. On the other hand — and to generalize further — a biologist is more likely than is a theoretical physicist to be aware of the fantastically complex chemical reactions that occur within a living cell, and the improbably long series of steps that led from amino acids to that cell. To a physicist or astronomer optimistic about the probability or inevitability of weird life, a biologist might counter that he fails to appreciate the intricacies of chemistry and biochemistry that would be necessary to produce it.

Contact details: dtoomey@english.umass.edu

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