Are We Alone?

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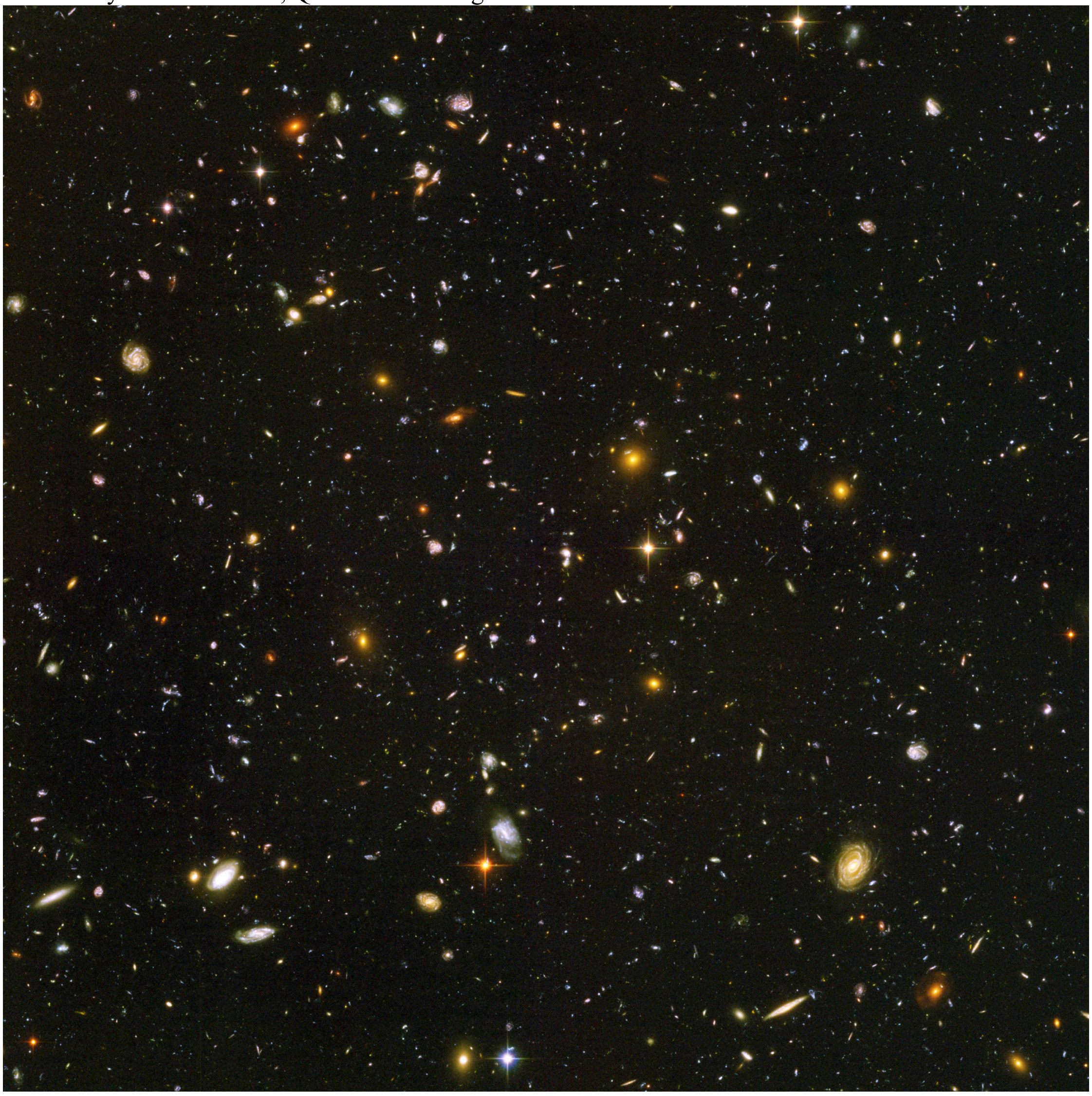

The Universe is very large -- possibly infinite. There are many places where life could emerge. With so many possibilities, most astronomers believe that life could very well be common in the universe. This image is the Hubble Ultra Deep Field, showing one ten-millionth of the observable universe. It contains ~ 10^4 of the ~10^{11} galaxies in the observable universe. There are about 10^{15} stars in this image. A large fraction of these stars probably have rocky planets orbiting in their habitable zones. About 75% of stars are older than the Sun and 95% will live longer than the ~10 billion year main sequence lifetime of the Sun. Thus, there are many environments in which life could have emerged and plenty of time for life to evolve into something interesting.

"There are just too many stars for there not to be life elsewhere."

As part of the Research School of Astronomy and Astrophysics at the Australian National University, I have been running the weekly Mt Stromlo colloquia for a few years. Each week, before I introduce the speaker, I ask him or her: How did you get interested in astronomy? What books are you reading? and What do you do for exercise? I also ask them: Do you think there is life elsewhere in the universe? I've been doing this for three years, so this may be the most comprehensive survey ever performed of professional astronomical opinion on the subject of ET. The overwhelming majority of astronomers believe that there is probably life elsewhere in the universe. It's not a strong conviction, but it is widely shared. As a follow up question, I ask them: What evidence is your opinion based on? The answer almost always goes something like this: "The universe is very large. There are just too many stars for there not to be life elsewhere." (Fig. 1 shows $\sim 10^{15}$ of these places). Our speakers teach Introduction to Astronomy courses all over the world -- so this is the dominant opinion that students all over the world are being exposed to. When I inquire further about whether extraterrestrial life is intelligent or not, the opinions diverge. Some say "yes", some say "maybe, but most will be simple bacteria" while others ask me "what do you mean by intelligence?" This usually occurs two minutes before the lecture is scheduled to start so I respond by handing them a laser pointer and a glass of water.

Scientific research is not done by surveys. We need evidence. In this article I want to take a closer look at the question "Are we alone?" and review the evidence that I think should be considered as we try to find an answer.

Is "Are We Alone" a meaningful scientific question?

Some astronomers believe that the question "Are we alone?" is not an important or meaningful question because it can not be addressed scientifically. They believe there is no evidence for life elsewhere and until there is, speculating about its existence is a waste of time. No meaningful evidence for the existence of extraterrestrails has come from the countless blurred images of UFO's, prankster's crop circles, Area 51 at Roswell, New Mexico or an army of sincere traumatized abductees. For 50 years, SETI scientists have eves-dropped with increasingly sensitive receivers on an increasingly large number of stars in our galaxy. So far, they have heard no signals. Our probes to Mars have found abundant evidence of water and ice, but so far no martians.
The brouhaha surrounding the discovery of evidence for life in the martian meteorite ALH84001 in 1996 seems to have been a false alarm. Organic molecules fall to the Earth in abundance embedded in carbonaceous chondrites, but they do not seem to contain evidence of life.

Our existence on Earth can tell us little about how common life is in the Universe or about the probability of the emergence of life from non-life on terrestrial planets because, even if this probability were infinitesimally small and there were only one life-harboring planet in the Universe, we would, of necessity, find ourselves on that planet. We know of only one example of life and it is terrestrial life. Until we find life elsewhere, astrobiology will be a field without a subject. We can look up at the sky and imagine anything we want…but that is art, not science. This view represents a view of science that I believe is too narrow-minded for many reasons.

Like many seemingly intractable questions "Are we alone?" can be broken down into bite-sized pieces – smaller questions that can sometimes be addressed directly (more often indirectly) by data. So let's break down the question "Are we Alone?" into a few addressable sub-questions. The word "we" means different things to different people. For example, "we" could mean "we homo sapiens", or "we the intelligent life forms of the Earth", or "we the life forms of Earth"….or "we the far from equilibrium dissipative systems of the Earth." Here are a few versions of the question "Are we alone?" with answers that depend strongly on what we mean by "we".

Are we homo sapiens alone in the universe? No.

Homo sapiens are not the only species on Earth. We are one of millions species. Since we are obviously not alone on Earth, we are not alone in the universe. Here we have interpreted "alone" to mean the absence of any other species.

Are we homo sapiens the only species of homo sapiens in the universe? Yes.

Yes, I think we are the only species of homo sapiens in the universe. The evidence for this is that homo sapiens (just like every other species on Earth) is unique. We share three billion years of quirky, convoluted evolution with chimps, dogs, dolphins and chickens. Despite the minor differences which loom so large in our minds, these segmented, vertebrate, red-blooded tetrapods are our closest relatives on Earth and in the universe. Even among these closest relatives, once independent of our lineage, none has shown any signs of evolving into homo sapiens. There is no evidence for distinct species on different continents evolving into the same species. In addition, once extinct, species do not re-evolve. Therefore we homo sapiens are alone on Earth, and since Earth is where our closest relatives are, we are the only homo sapiens in the universe – and alone in that sense.

Are we, the possessors of human-like intelligence alone in the Universe?

Usually, when people ask the question "Are we alone?" they are assuming that we are alone on Earth because of our special human-like intelligence. That is, they are assuming a definition of intelligence that excludes all our terrestrial relatives (if their definition of intelligence didn't exclude all other terrestrial life forms, then the obvious answer is "No, we are not alone").
They are excluding all terrestrial life forms and postulating an imaginary general group of non-terrestrial organisms who are, in Carl Sagan's words "the

functional equivalent of humans" (Sagan, 1995). Most biologists refuse to take the idea of such an imaginary group seriously. In studying the variety of life on this planet, biologists see that "general" groups with only one species in them are unjustified contrafactual extrapolations. Thus, the assumptions that often motivate the question "Are we Alone?" are biologically inappropriate.

In the search for "intelligent" life in the universe, there seems to be a polarized debate between two camps. In one corner we have the non-convergentists (mostly biologists) who, after studying the biological record of evolution insist that the series of events that led to human-like intelligence is not a trend, but a quirky result of events that will never repeat themselves anywhere in the universe. Gould has been a spokesman for this group: "*Homo sapiens* is an entity, not a tendency" (Gould, 1989). The non-convergentists include Simpson (1964), Mayr (1994, 1995) and myself (Lineweaver 2005, 2009). The convergentists, on the other hand, subscribe to what I call the "Planet of the Apes Hypothesis."

The movie *Planet of the Apes* (1968) is set in a future in which humans, after a nuclear war, have forfeited their assumed supremacy over the "beasts." They lose the ability to speak and have to fight and forage in the fields. Three species of apes—chimps, gorillas and orangutan— take advantage of this recently emptied "intelligence niche." The apes learn how to speak English, ride horses, farm corn, take photographs, shoot rifles, and in general represent a hairy Victorian version of Sagan's postulated group of "functionally equivalent humans." The basic idea is that human intelligence is so useful that any species worth its salt is waiting in the wings for humans to trip up. When humans trip, the new species rushes in. This convergentist idea is widespread, but it is not good science. The convergentist "Planet of the Apes Hypothesis" is an appealing idea for many, but it disagrees with the best data we have. A series of independent, long-duration experiments in evolution were set up and left to run. The most straightforward interpretation of the results is that human-like intelligence is not a convergent feature of evolution. There is no "intelligence niche" toward which animal species have a penchant to approach. In the absence of humans, other species do not converge on human-like intelligence as a generic solution, or even a specific solution to life's challenges. These tests have been almost universally ignored.

The names of these tests are South America, Australia, North America, Madagascar, and India. About 180 million years ago, Pangaea broke up into Laurasia and Gondwana. About 140 million years ago Gondwana broke up into Africa/South America and Antarctica/Australia/India/Madagascar. About 125 million years ago India and Madagascar split from Australia/Antarctica. Africa and South America split about 100 million years ago—and New Zealand has been floating off by itself for about 100 million years. For landlocked species, these continents that drifted independently of each other for between 50 and 200 million years were crucial experiments in evolution. The time scale for tripling the size of the human brain in Africa was about 2–3 million years, while the time scale of the experiments was 50–200 million years. Thus, the experiments ran 10–100 times longer than was necessary to repeat the brain-size increase that happened in our lineage.

New Zealand is as close as we will get to the opportunity to study life on another planet. So it is important to examine what happened there during the last 100 million years of independent evolution. Which species are we to imagine is the one that evolved toward human-like intelligence? The kiwi? The tuatara? Obviously neither. Human-like intelligence did not evolve in New Zealand. Similarly, as South America drifted independently of Africa for 90 million years with lots of monkeys for much of that time, primates continued to evolve. Which of South America's species are we to imagine evolved toward human-like intelligence? Are howler monkeys or squirrel monkeys the species that evolved toward the "intelligence niche"? Consider Australia. Is the koala or the red kangaroo or the platypus the species in Australia that has been moving toward human-like intelligence? Five continents and millions of species evolving over tens or hundreds of millions of years are yelling at us upwind against our vanity: "There is no evidence for the 'Planet of the Apes Hypothesis.'

I think these long term experiments in terrestrial evolution are the best evidence we have to evaluate whether human-like intelligence is a convergent feature of evolution. The evidence suggests that we should not expect human-like intelligence to evolve in other terrestrial species. Since extraterrestrials will be even less closely related, we should not expect extraterrestrial human-like intelligence. Thus, we, the possessors of human-like intelligence are probably alone in the Universe.

Are we the terrestrial life forms alone? Maybe.

Much of current astrobiological research is focused on learning more about the early evolution of the Earth and about the origin of life. We may be able to extrapolate and generalize our knowledge of how life formed here to how it might have formed elsewhere. Indirect evidence suggesting that life may be common in the Universe includes:
1) Sun-like stars are common.
2) Formation of Earth-like planets in habitable zones around these stars may be a common feature of star formation.
3) Life is made of the most common elements in the universe; CHONSP, carbon, hydrogen, oxygen, nitrogen, sulfer and phosphorus.
4) Life is based on water, which is the most common tri-atomic molecule in the universe.
5) Life is based on the LEGO principle: common monomers (found in meteorites) are assembled together into polymers. Amino acids are chained together into proteins, fatty acids are chained together into lipids, simple sugars are chained together into carbohydrates and nucleotides are chained together

into RNA and DNA.
6) Sources of free energy such as starlight and reduction – oxidation pairs are common (Nealson and Conrad, 1999).

I consider these facts to be good indirect, circumstantial evidence for the existence of life elsewhere in the universe. However, it is difficult to translate the ubiquity of the ingredients of terrestrial life into a frequency of extraterrestrial life. If the ingredients for life are everywhere, what about the recipe, and the cooking conditions? How easy is it to polymerize these ubiquitous monomers? These common elements and molecules are necessary prerequisites but they may not be sufficient. Biochemists working in the lab, and cosmochemists studying the reactions in interstellar molecular clouds, and microbiologists studying the redox chemistry of deep sea hydrothermal vents, have not yet found a plausible chain or network of molecular processes or autocatalytic reactions that can bridge the current gap that exists between non-life and life. However, much progress has been made in understanding the details of the most fundamental biochemical reactions.

Thus, we have indirect evidence that suggests that life (as we know it) may be common in the universe but the evidence is circumstantial and incomplete. "Maybe" seems to be the best answer we have to this version of the question "Are we alone?"

Are we, the far from equilibrium dissipative systems of the Earth, alone in the universe? No.

So far we have assumed that we know what life is. However, this is problematic. If we were parochial enough to define language as anything that resembles English, and then traveled to China, we would conclude that "No evidence for language has been found in China." The meaningfulness of this statement depends entirely on how meaningful our definition of language is. Similarly, the meaningfulness of the statement "No evidence for life has been found beyond earth" depends entirely on how meaningful our definition of life is. Without knowing the cosmic range of life forms, how can we determine if our terrestrial-life-based definitions are meaningful in a cosmic context?

Many hours of human thought have been dedicated to constructing definitions of life suitable for application elsewhere in the universe. Biology textbooks are full of definitions of life. These definitions have been sculpted around the flora, fauna and fungi we know on earth. They usually mention growth, self-regulation, self-reproduction and chemical complexity. Some definitions are blatantly tautological: "Life is what is common to all living beings". I am not convinced that these standard definitions of life based on terrestrial examples are broad enough to have reasonable expectations of universality. Neither was Einstein:

> *"Whether there are some general characteristics which would apply not only to life on this planet with its very special set of physical conditions,*

but to life of any kind, is an interesting but so far purely theoretical question. I once discussed it with Einstein, and he concluded that any generalized description of life would have to include many things that we only call life in a somewhat poetical fashion." (Bernal 1949).

How then do we construct a definition of life general enough to give us some confidence in its universality? If our intuitive ideas about what is or is not alive are too parochial, where can we hunt down some generality? Physicists and chemists are qualified to practice their trade on the planets around Alpha Centauri or anywhere in the universe, but biologists will probably have to retool. So maybe we can rely on physicists to come up with a usefully broad definition of life. Inspired by the work of Schrödinger (1944), Prigogine (1980) and Schneider and Kay (1995), I think a definition of life based on general thermodynamic principles will prove more useful in an extraterrestrial context than our current terrestrial-life based definitions.

When a chemical system is in equilibrium, no reactions take place. The temperature is constant. There is no heat flow and no chemical gradient. Equilibrium is another name for death. When thermal gradients, chemical concentration gradients or electric potential gradients are large enough, Gibbs free energy becomes available and organized structures emerge spontaneously that act to reduce the gradient and dissipate the free energy. In a fundamental sense, these spontaneous and ubiquitous structures are nature's way of reducing gradients and obeying the second law of thermodynamics (Lineweaver 2006).

Convection cells in the solar photosphere are organized structures maintained by the temperature gradient between the hot subsurface and cooler surface of the Sun. Bernard cells are an example of the same phenomena in the lab. Whirlpools exploit gravitational potential energy to maintain their structure while hurricanes and dust devils run on temperature and pressure gradients. Where there is a gradient or a far from equilibrium situation, dissipative structures emerge to remove the gradient and exploit the available free energy to maintain the structure that is doing the dissipation. These gradients are all over the universe and thus, so too are the structures associated with them.

It is clear that DNA-based life belongs to this group of far from equilibrium dissipative systems ("FFEDS"). It is also clear that FFEDS is a larger more generic group that includes more than just DNA-based life. This thermodynamic generalization of the concept of life to include FFEDS is a paradigm shift that I believe is scientifically justified and is not just a semantic game. Pretending that all "life" has to resemble DNA-based terrestrial life out of some sense of scientific conservatism seems more like a semantic game to me. When we get used to referring to far from equilibrium dissipative structures as "life", I suspect that our previous definitions of life will seem as parochial as equating life with just flora, fauna and fungi.

One argument against the idea of FFEDS = life, is that hurricanes and convection cells and stars contain no information within themselves that is passed on when they reproduce. Stars for example are far from equilibrium dissipative structures metabolizing the free energy made available by a nuclear potential energy gradient. A star has no DNA inside itself and no internal structure that is passed on to the next generation of stars. However, when a massive star dies, it explodes and infuses the surrounding molecular hydrogen with heavy elements that enhance the ability of the clouds to lose energy and collapse to form more stars. The shockwave from the explosion also plays a role by kick-starting gravitational collapse. Thus, there are important links from one generation of stars to the next. However, the information controlling and sculpting the next generation of stars is in the modifications of the stellar environment, not centralized in some coded molecule.

The information content of DNA came from the environment as generation after generation of organisms were selected and filtered. Does it matter whether the information to form another system is contained centrally or distributed? In our traditional view of life we may be exaggerating the importance of whether the information and conditions that affect reproduction are stored internally in DNA or externally in the composition of the material that will form the new FFEDS. Survival is the issue, not whether the gradient that led to a FFEDS has been set up actively by centrally stored information or passively by decentralized information.

The detection of extraterrestrial life, based on a more general definition of life may seem absurd to the army of biochemists invested in looking to manufacture traditional life in the lab. According to the new definition, life is easy to make – just let the water out of the tub or blow smoke rings or just boil water and watch the convection cells. With a shift in focus to the most general, universal features of life -- a more generic redefinition of life -- we start to see life everywhere.

The non-prevalence of terrestrial life in the universe is becoming a data set that should give us pause and motivation for a more general view of life. I have argued that the traditional definitions of life are too narrow. These definitions don't include viruses and often include meaningless statements about 'self-reproduction' based on an exaggerated sense of independence from other life forms. It is possible that the universe and the life forms in it are not usefully defined by our traditional definitions of life. Therefore we should take seriously a different more universal definition: life = FFEDS.

With this more universal definition of life, we can say with conviction that we have detected extraterrestrial life and that life on Earth is not alone in the universe. We are not alone! Thus, the answer to the question "Are we Alone?" depends on what we mean by the words, "we", "life" and "alone".

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