Are we Unique?

Background and notes on OLLI course , April 2014

A bigger question than most people think, this query is at the heart of a lot of religious and scientific explorations and thinking. These days, it is a bigger question than ever in history. And to me it is one of the most fascinating, important and revealing questions we can ever ask. Religious people are often bristle at this query, may even be afraid of the question, or regard it as a lack of faith. Scientists on the other hand can be overwhelmed by the question and some of the answers they are seeing in the astrophysical world, and our explorations. No matter. Let's forge ahead and see where this leads. It is something I just love to ponder, and do so often. And how one answers this question (or not) is very telling about each person yet can be quite expansive. The possibilities, the scope of the answer, the knowledge we have about our universe in this 21st century, it leads to an all-out assault on our comprehension, our imaginations and our appreciation for wonder. For if nothing else, thinking about this question is wonder-full!! So here goes.

Let me refer to some bright minds who have broached this issue. One of the best introductions to this question and its contemplation is given by Bill Bryson, in his aptly titled book, *"A Short History of Just about Everything*". It begins with Bryson's introduction to the book. He gives a welcome and congratulations and says: " *I am delighted you could make it. Getting here wasn't easy I know. In fact I suspect it was a little tougher than you realize. To begin with, for you to be here now trillions of drifting atoms had somehow to assemble an intricate and intriguingly obliging manner to create you. It's an arrangement so specialized in particular that it has never been tried before and will only exist this once for the next many years we hope. These tiny particles will uncomplainingly engage in all the billions of deft, cooperative efforts necessary to keep you intact and let you experience the supremely agreeable but generally underappreciated state known as existence."*

Farther along he adds: *"Still you may rejoice that this happens at all. Generally speaking in the universe it doesn't so far as we can tell. This is decidedly odd because the atoms that so liberally and congenially flocked together to form living things on earth are exactly the same atoms that declined to do it elsewhere. Whatever else they may be at the level of chemistry, life is curiously mundane: carbon, hydrogen oxygen, nitrogen, a little calcium, a dash of sulfur, a light dusting of other very ordinary elements-nothing you wouldn't find in an ordinary drugstore-and that's all you need. The only thing special about these items is that they make you. That is of course the miracle of life."*

Now here's where it gets really interesting because I, along with Bryson find this time, the 21st century, to be remarkably unique and fabulous. *"To be here now (and this is quoting Bill Bryson again), alive in the 21st century and smart enough to know it, you also had to be the beneficiary of an extraordinary string of biological good fortune" (*and I will get back to this further along in this chapter).*"Survival on earth is a surprisingly tricky business. Of the billions and billions of species of living things that have ever existed since the dawn of time, most (99.99%) are no longer around. Life on earth you* *see, is not only brief but dismayingly tenuous. It is a curious feature of our existence that we come from a planet that is very good at promoting life but even better at extinguishing it."*

So not only have you been lucky enough to be attached since time immemorial to a favored evolutionary line but you have also been extremely, make that miraculously, fortunate in your personal ancestry. Consider the fact that for 3.8 billion years, a period of time older than the Earth's mountains and rivers and oceans, every one of your forebears on both sides has been attractive enough to find a mate, healthy enough to reproduce and sufficiently blessed by fate and circumstances to live long enough to do so."

With this in mind, this enormously lucky situation in which we "live", how can humans even grasp the scale of the universe? That 3.8 billion years of life on earth which Bryson mentions, how can any mortal human conceive of such a time period, let alone appreciate being the result of all the events one could imagine happening in that time period. The Hubble telescope has detected objects that are as much as we determine (or believe we can determine) 13 *billion* light years away. This means light is reaching us which left those "suns" 13 billion years ago. I'm not even sure how you know that something is 13,000,000,000 light years away. If you think about that, and you can surmise how that happens to be known, perhaps you could tell me. But I will trust that someone knows that the light that they're seeing at the very edges of the perception of the Hubble telescope is 13,000,000,000 light years away, and that somehow in those intervening 13 billion years something else may have happened. Those galaxies that we see that are (were, actually) 13 billion light years away may now be 26,000,000,000 light years away, or they may not even exist anymore. We'll never know in our short species history compared to these galaxies, and I doubt it matters. All this grand stuff that I am pondering here, it makes me stop and pause and breathe, and try to take in all that I am trying to conceive, and how I can grasp, digest, make it known to myself in some reasonable way.

But let me now move to the dangerous area of the spiritually human reaction to all this. I've already tried to express what I feel is the enormous good luck to be alive now, to be able to articulate these thoughts, to have the impetus in the evidence to stimulate these thoughts from science and our astronomical gifts, like the Hubble telescope. Because I can read, because of the lucky history I have with my ancestors all being successfully bred with each other, resulting in me, one cannot help but have a bit of humility about all this good luck. And there is the realization at the same time that this whole train of life which resulted in me cannot be anything other than true! The incomprehensible good fortune of being born in the United States of America in the second half of the 20th century (well almost, I was born in 1948) and to have come to the state of leisure and ability, with access to the information that science has brought us at this point in our history, makes me aware of such incomprehensible good fortune, that it is hard to even raise the magnitude of gratitude appropriate to the reality.

One of things that happens when you contemplate all this astrophysical reality, is that the scale is just so overwhelmingly impossible to grasp. We mortals can't conceive of

1 billion of anything, let alone a light year, which is how far light travels in one year. When I teach mathematical concepts, I try to convey things like the difference between a million of anything and a billion of those same things. These numbers are both beyond normal mortal experience and comprehension, so it is enormously difficult to find any way to convey these huge numbers in any meaningful context. There is one way which I have used often though. I've found this one analogy is fairly fruitful to conveying this huge numerical concept. It is the analogy of time, and the question goes like this: How many seconds is 1 million seconds? This turns out to be a comprehensible period of time that can give most people a sense of what 1 million of anything is. It's also reasonably easy to do the math. To get to this time period of a million seconds, we can simply follow the logical calculation of what period of time is a million seconds. We know of course , that there are 60 seconds in a minute, and 60 minutes in an hour, so an hour has 3600 seconds. (60×60=3600), and multiplying by 24 hours in the day, we determine that there are 86,400 seconds in a day, a reasonable number that most of us can grasp. If there are 86,400 seconds in a day, that means in 10 days there are 864,000 seconds, so we are getting very close to 1 million seconds with 10 days of time. A million seconds turns out to be approximately 11 and a half days. So, a time interval of 1 million seconds is a reasonably comprehensible 11 and a half days. Not a bad way to give a sense of a million of something. It has worked well for me in a teaching situation.

Now the giant leap forward to where things get really, really insightful: How long a period of time is 1 billion seconds? Well, a billion seconds is 1000 million, so 1 billion seconds is 11,500 days, a thousand times more days than 1 million seconds is. So how long a period of time is 11,500 days? Well it's about 31 1/2 years! So the difference between 1 billion seconds and 1 million seconds is the difference between 31 ½ years and 11 and a half days: the difference between half a normal human life, and a week and a half (or thereabouts). Now the revelation that really boggles the mind when you ask how long a period of time is a trillion seconds? Since it is 1000 billion seconds, that means it's 31,500 years: more than all historical time, more than the since the last Pleistocene Ice Age, an incomprehensible amount of time.

We're limited by the scale of our lives. It tends to keep us from really getting a clear idea, a full grasp, of the immensity and scope of the universe. But because the universe is so big and because the numbers of possibilities for life in the universe are so big, many scientists, many statisticians, many mathematicians, conclude that it is statistically certain that there must be some other forms of life in the universe, and probably this is true. Probably there are some other form(s) of life in the universe. But the even bigger question is: "Is there other intelligent life in the universe, and/or are we unique in that regard?" That's an "orders of magnitude" higher question.

This profound question must be framed by placing the constraint of contingency on evolutionary life. This means that the pathway through the evolutionary trajectory is vastly more like a pinball's path in a pinball machine, a vast , wide array of possibilities, than it is a destiny of outcome. And there are probably as many cases of planetary biologies which have become totally extinct, meaning that all life has been wiped out, and either ended for long periods, or had to begin anew when conditions were right. And there is always the threat of some enormous extra-terrestrial (or whatever you might call an extra-planetary object) crashing into the planet of nascent life and making it uninhabitable for eons. Life almost was eradicated in two of the (five) major extinctions on earth. So the prospect of total annihilation must be as probable as survival. That life is so *contingent,* that everything about the history of the earth, the number of major extinctions, the geological nature of the earth, the continental drift of the planet's surface continents, the climate changes, the impacts of comets and meteors and planetary cycles, the fact that we have a moon that gives us the intertidal zone, so much of this seems so unique to the earth and is such a contingent, improbable, and uncanny set of "just luckily right" circumstances which led to us, we humans. We soft-skinned creatures with internal skeletons and big brains, five fingers on the limbs and five toes on the on the feet, how did it all come about, and are we unique? Bryson again: *"Not one of your pertinent ancestors was squashed, devoured drowned, starved, stranded, stuck fast, untimely wounded, or otherwise deflected from its life quest of delivering a tiny charge of genetic material to the right partner at the right moment in order to perpetuate the only possible sequence of hereditary combinations that could be read that could result eventually astoundingly and all too briefly in you!"*

(Possibly play some final scenes from the Frank Capra Movie "It's a Wonderful Life" to introduce the concept of *contingency*.)

There is another book that talks about this question in a different way, and that book is *"Wonderful Life",* by Stephen Jay Gould. Gould selected this title because the best cultural example of contingency he could cite was the theme of the movie cited above, and which he describes as the inspiration for the title of his own book. I will draw on my memory a bit for this discussion so that I don't have to quote it all. Gould uses the title *Wonderful Life* because it is reminiscent of the movie, *"It's a Wonderful Life"*, the Frank Capra movie of the late 40s in which Jimmy Stewart and Donna Reed star. Through a series of miraculous movie-based interludes, Jimmy Stewart is allowed to see what life would be like without him. In other words he gets a chance to see how he has affected every other life around him, the point of this entire story being that life is contingent: every life affects every other life in some known and some unknown ways. This is very much the point made in Gould's book, and is the meaning of the term contingency in an evolutionary sense: everything is contingent upon everything else. It's not only well demonstrated in the movie, but it is a resoundingly strong thread through Stephen Jay Gould's book. He uses the title to drive home the point of this contingency that the movie so well exemplifies in a human context. Life is full of contingent events. The analogy that I find most striking and useful is that he talks about the analog of using videotape to monitor the progress of life. If you could have videotaped life as it was evolving over 3.8 billion years or so, and you were able to rewind the tape and play it forward again, you would not get the same result. That is very much a reflection of what is described in the previous paragraphs by Bill Bryson: that strange and unlikely, enormously improbable sequence of events that has led to you and me and all the other human beings on earth, 7 billion of them by now. The existing present is a rare, extraordinary circumstance which could never be duplicated, an unlikely set of conditions that could not be reproduced. It is contingent on an entire sequence of events that is entirely probabilistic and mostly unpredictable. The only conclusion I can draw from this is that we are incalculably, utterly, remarkably lucky. And we already know that in a genetic and physical sense we are precisely unique. We shall live only once as a unique set of expressed genes and never again. Is life on the planet equally unique, only to be produced once in this precise ecosystem in constant flux?

Let me give you some more examples of just how I have come to the conclusion that there is no conclusion, but that we are probably for the most part, quite unique or at least VERY RARE in the universe. Note that I don't say life is unique at all, but we may well be. Carl Sagan, a good, eccentric, pot-smoking, exuberant scientist/explorer of all the history of science and human endeavor, tried to investigate the probabilities of intelligent life in the universe. Cynically, I'll interject here that I'm presuming that I think there is intelligent life in the universe (us). I know this is an arrogant human trait, but there is some evidence that we are more intelligent than most creatures. Not only has Carl Sagan written a book with a Russian compatriot on how to search for intelligent life in the universe, but he has also written a book called *Cosmos* and another book called *Contact*. Cosmos is an exploration of the astrophysical universe and how we have come to know what a remarkable universe it is. It is a treatise I highly recommend and it is also brought me to some of the insights that I am explaining here.

In *Contact* on the other hand, Carl Sagan uses a science fictional story to predict how human beings might react politically, socially, culturally, and religiously to a possible first contact with intelligent life from elsewhere in the universe. He poses this to have occurred in the 1990s. In the movie *Contact* (and it's a fabulous book, too) the outcome is never really conclusive, but it does ultimately conclude that we are not alone and that we seek to find out if we are alone because we are so lonely, and we long to not be alone in this vast universe. This is a very interesting perspective.

One of the other comments of merit in this area of ultimate questioning was elicited by Bill Moyers when he interviewed Murray Gell-Mann, a very objective Nobel Laureate in physics, about whether he thought we were alone in the universe. He resorts to a rather astoundingly relevant POGO the possum comic strip by Walt Kelly, wherein Pogo says: "**Thar's only two possibilities: Thar is life out there in the universe which is smarter than we are, or we're the most intelligent life in the universe. Either way, it's a mighty sobering thought." (from http://en.wikiquote.org/wiki/Walt_Kelly)** Well whether we're one of millions of other life forms in the universe that we haven't contacted yet or whether we're the only intelligent creatures in the (at least nearby) universe, it is indeed a mighty daunting revelation. Either way we have many discoveries to possibly encounter, but because of our limitations (which may be illusory and for the moment only) we will be frustrated by the fact that they may all be so far away from each other, that we have no technical means at our disposal to make contact (in spite of the magical way it is done in the movie *"Contact"*). If we are the only "intelligent " life form capable of extraterrestrial contact, then what a remarkable utterly fantastic thing it is to be alive on this planet, and all the more so, for it may be unique. And doesn't that imply a huge responsibility to treasure it all so much more, and protect the earth and bring us to a point of some universal cosmic responsibility for that awareness? Of course, the great frustration is we'll probably *never know*!

So yes, this is my favorite pondering. The question keeps recurring in my mind. Recently I have been visiting regularly the Hubble telescope webpage. The Hubble telescope itself is a remarkable endeavor considering all of the things that we waste money on, like nation states warring against each other, threatening each other with huge military weaponry, using drones to murder each other with their technical machines, and interpersonal violence and cruelty. The fact that we spent millions and millions of dollars to put a phenomenal telescope into orbit around the earth so that we could learn more about the universe is testimony to at least a potent curiosity, and no small compensation for the horrors we have wrought. It may even indicate that there is some worthiness in us for making such discoveries. And yes I know my views are vaguely moralistic and sentimental, but I am indeed sentimental about my world and its main threat to existence. But the Hubble--has it ever paid off! If you have not spent time personally looking at this great achievement given to humanity and available to all those who have visited the online site and viewed the wonders revealed and unveiled in those photographs, I highly urge you to seize the wonder I promised at the beginning of this chapter. The Hubble space telescope has been gleaning things about the universe for nearly 15 years and we're hardly through yet. We keep discovering new things, keep asking for new things, keep putting new probes into the sky, finding new planets around other suns, that give us more and more inclination to believe that we are not alone, that there are more and more planets out there and that maybe all the things that were seeing are only an indication that there may be as many as 10% or more of all suns which have some planets orbiting around them. (The Hubble and space education site is: http://outreachoffice.stsci.edu/ , and will totally suck you into a Hubble addiction, promise. A subset of the overarching site is the direct Hubble site which is, (duh!) http://hubblesite.org/ . This is where the photo archives are located.

To give you even more scale about what this may mean, it is important to realize that at the beginning of the 20th century, 113 years ago, we only knew that there was one galaxy and we were a part of it. That galaxy is the Milky Way. It was the only galaxy known in 1900 and now we know that not only is our galaxy not unique, but there are about 180 billion stars in our Milky Way galaxy, and through the lens and distillations of the Hubble telescope revelations, we now know there may be as many as 180 billion *galaxies* in the universe. Even saying this incomprehensibly incomprehensible number makes me swoon in wonder.

To attempt to give an idea of just how broad, how far across, how huge the Milky Way galaxy is, I will give you the common astrophysical numbers for the distance involved. It is about 100,000 light years across: as is said often by humble astronomers and scientific journalists alike, the universe is very, very big. I have been living in the interior of Alaska for 43 years. Light that left our sun in 1970 when I first arrived in Fairbanks is now less than 1% of the way across that galaxy. It's only 43 light years out of

100,000 light years on its journey. That isn't even 1/1000th of the way across just our own stellar neighborhood, and at the speed of light, no less. I am impressed by this. I expect you are as well.

Good time to insert the "Powers of ten" films from the web…)

How much of life's contingency is residual in the geology and the geological history of the earth? I should qualify that perhaps, and call it the astrophysical history of the earth because it really didn't become geology until the earth became a planet. I say this because I have recently been reviewing some of the theoretical origins of the universe, the planets, the solar system, and the galaxies as part of the Big Bang theory exploration. Most of the awareness of what I've been citing in this chapter has come about in the last hundred years. The tools we now have to discern some of the things we have confidence in, have only recently become available. These include radio astronomy, the Hubble telescope, and satellite data acquisition. It's hard not to be astonished and grateful to be alive now to know all these things which we can know. We can't know for certain that everything we now perceive is correctly interpreted, We have no certainty, no ultimate knowledge. But we can know patterns that give us an idea of how these things happened. I am attempting here to show how contingent the earth's history and all it has led to are. Everything we see depends on the entire set of all the marvelous unique and optimal conditions which earth provided and now provides, many of which are "just right", and yet may be infinitesimally rare. Some of those contingencies I'll now cover.

First, comparing the earth to the rest of our solar system, now considered be eight planets, (we've sort of given up on Pluto) ours is by far the only one hospitable to any kind of complex life. It is so different in that respect, being the water planet, with three quarters of our surface covered by water, that it is far beyond an adequate description to call it unique in the solar system. It is breathtakingly, wonderfully, fecund and rich, full of contingent possibilities for life continuing and prospering. But how come? What is so right, what is so enormously positive about the position in the solar system, the chemistry, the history of our planet, that makes it so, so wonderful a place for life to emerge? How unique are these factors in making it so?

For instance, consider the simple example of the Earth's moon. Our moon is about one quarter the size of our planet and Earth is the only planet in the entire solar system which has a moon substantially close to the size of the home planet. There are of course, other moons in the solar system, such as Titan, that are large. But none of the other moons of other planets are so substantially significant in size compared to their planets. This has several effects on earth and none of them are insignificant. First and perhaps foremost of the primal effects of the moon, is that the moon stabilizes planetary tilt of the Earth's axis. Rather than allowing it to precess wildly over geologic time, it has stabilized the tilt from the plane of the ecliptic (the plane of the earth's orbit around the sun). It has therefore, been a major factor in stabilizing Earth's climate. If the Earth's axis varied wildly and regularly over geologic time, the eradication of species by climate change could be bad, perhaps even fatal. For instance, Uranus has an axial tilt of 97.77 degrees,from the ecliptic, so its axis of rotation is approximately parallel with the plane of the Solar System. This gives it seasonal changes completely unlike those of the other major planets. Other planets can be visualized to rotate like tilted spinning tops on the plane of the Solar System, whereas Uranus rotates more like a tilted rolling ball. Near the time of Uranian solstices, one pole faces the Sun continuously while the other pole faces away. Only a narrow strip around the equator experiences a rapid day–night cycle, but with the Sun very low over the horizon as in the Earth's polar regions. At the other side of Uranus's orbit the orientation of the poles towards the Sun is reversed. Each pole gets around 42 years of continuous sunlight, followed by 42 years of darkness (Wikipedia, Sromovsky, 2006, University of Wisconsin Madison). Certainly no polar ice caps and radical changes year-to-year could result from such variability.

So the moon stabilized Earth's climates, stabilized seasonality, and probably gave the earth a much more durable, sustained climatic regime for eons. This is especially important for the tropics where the speciation and evolutionary diversity is highest. This long history of stability is once again something very contingent. It just is what happened. But how unique is this moon? Could our lovely glowing moon be quite unique in the Universe, and in planetary context?

A recent theory of the origin of the moon's emergence which has come into broad acceptance by many astronomers and more so by geologists going to the moon rocks and obtaining lunar rocks, really made it clear that much of the moon's lithosphere is very similar to the earth's except that the moon has no metallic iron and nickel core so it has no magnetic field. Therefore it is much less dense and consequently has one sixth the gravity that the earth does. However another thing that the moon does is influence tidal variations . Tidal variations may have been very very instrumental in preparing oceanic life forms, with its very frequent, cyclical tidal exposures and flooding, to making creatures adaptable to breathing air. By providing substantial portions of the day during which tidal zones are flooded and then not flooded, then flooded and not flooded, creatures that could move into the tidal zone would have an advantage in escaping predators. They would have substantial evolutionary pressure to develop breathing capabilities in air. By having developed abilities to live in air and all of those consequent changes, the moon may have had a huge effect on the emergence of life on land, and may be much more important to evolution on earth than is first imagined. The evolutionary advantage of being able to breathe air and open a new ecological niche on dry land without the old enemies is certainly a factor in evolution. How important this all was, is speculative of course, but it seems to me that logic would indicate it is perhaps quite significant, and probably accelerated the evolutionary possibility of life on dry land. emphasized by were enabled in fact by the Moon's tidal influence on the earth which seems to have been substantial for a long time recently I investigated theories on the origin of the moon how did it come about why is it that of all the planets in our interplanetary speed sequence that the four inner planets Mercury Venus Earth and Mars Earth is the only one with a large moon.

The latest hypothesis on perhaps the winning hypothesis so far of how the moon was created was developed by two planetary science Institute senior scientist Dr. William K Hartmann and Dr. Donald R Davis. They were the first to pose a leading modern hypothesis of the moon's origin. This hypothesis appeared in a paper published in 1975 in the journal *Icarus*. It theorizes that there was originally a giant impact between two large planetary bodies very early in the history of the formation of the earth. The earth may have been in fact largely molten at the time, but it's hypothesized that an object similar to perhaps the size of Mars collided with Earth in a way that a large amount of the Earth's upper crust was slung out into near Earth orbit and coalesced as the moon. This description was published in a collection of papers by the Lunar and Planetary Institute in 1986 in a book titled the *Origin of the Moon*, edited by one of the scientists proposing this theory and others for the moon's origin. This book remains a prime reference on the subject.

Considering this "moon creation event" was apparently unique, at least in our solar system and that the moon is instrumental in many factors in stabilizing the earth: our orbit, stabilizing this climate of the earth, the precession of the axis of the tilt, it seems that the this may be an enormously rare contingent event which once again all biological systems on earth are heir to.

Charles Darwin's son rote a paper in 1878 on the Earth-moon-sun dynamics , focusing on the implications for a sable planet. A most foresighted family, it seems. (he was a Cambridge man). Here is the best website I found for theoryies and graphic of the formation of the moon: http://www.fas.harvard.edu/~planets/sstewart/Moon.html
(show in class)

So, many many aspects of life on earth of our planet, our planets geology and physics are very important to life being able to prosper. How unique are they? Before I leave the subject of the moon's influence on life on earth, let me just add that the timing of the creation of the moon was crucial as well. If it had happened after life first appeared, it may have ended life right then. So again, contingency in the timing was crucial. Granted, such he events do seem more likely in the presumed early history of the solar system, but it is one more set of factors which makes the moon-earth system more unique than just a simple planet orbiting around a star in some corner of the galaxy. Earth may be more propitious for life because it has a moon that is large in comparison to its size, and which consequently acts to stabilize it and provide for a tidal zone around the oceans. These factors do not appear to be insignificant.

Another feature which is enormously important to the event convention of life is the fact that we have a planet that has a metallic core which gives us a rather strong and protective magnetosphere because of our earth's metallic core. This magnetic field is important because the onslaught of the high energy particles in the solar wind would otherwise be very damaging to life. This "protection" includes some of the shielding aspects which keep damaging radiation from penetrating the earth because our magnetic field deflects these charged particles form entering our atmosphere directly . This marvelous field is undetectable to humans directly, and is also one of the causes of the aurora borealis, which we in the north are so blessed to be witness to. This wonderful magnetic field protects us from radiation damage, but it does something even more important. It also protects us from something not normally considered these days, and that is the sweeping away of the atmosphere by the solar wind. Just from impact and the pressure of some of the large solar mass ejections this was made clear in some of the first discoveries of why Mars, for instance, has nothing more than a remnant atmosphere. It has been postulated (rather substantially correctly in my opinion) that one of the reasons is the weakness of the Martian magnetosphere. Mars appears to NOT have a metallic core. As such, although I cannot cite the source except from memory,I remember seeing some illustrations of this fact that some of the planetary orbiters around Mars have actually witnessed: some of the solar impacts on that atmosphere, and documented the fact that some of the atmosphere was swept away by these impacts. The Martian atmosphere is maybe about1 to 5% of the atmosphere of the earth and having an atmosphere is certainly very very important to containing the constituents of life. The gaseous constituents of our atmosphere are crucial (obviously) to our life and that entire existence of our atmosphere is somewhat contingent upon the existence of a metallic core of the planet. So with that insight, we might ask, how important is a metallic core for the biologically suitable planet, how durable is the magnetic field in time, and how common is it in planets of the right size and distance from the star which lights it? This is one more set of factors which must be present in order to provide this spaceship Earth with its the potential for fostering life, protected from radiation protected from solar wind, protected from high energy particles and the subsequent damage to life from high levels of radiation.

One more thing: since you can have the atmosphere be protected, the atmosphere in turn protects you from much of the reign of meteor material: meteorites, meteoroids that otherwise would fall to the surface unimpeded by an atmosphere. Meteor showers are in fact it an stellar example of how othe protective characteristics of our atmosphere keep us safe from harm. These meteors are regularly burning up in the atmosphere rather than pelting us with a rain of meteoric material. On the surfaces of the moon and planets like Mercury, which have no atmosphere, their meteoric rain is evident by the huge impact craters pock-marking them.

I have tried to build a very interesting case for the contingency and uniqueness of our planet, because it all leads to how unique the emergence of consciousness and intelligent life may be on a planet.   I'm going to go back now to the *"Wonderful Life"* book by Stephen Jay Gould which is one of my primary sources in this contingent thinking.

Here I insert a contrary article to Gould's interpretation of what happen , lo those many years ago a the end of the Cambrian: an explosion of life which underwent an extinction, through which a creature lived to be the proto ancestor of vertebrates, The Pikaea.   BUT, Simon Conway Morris says rather different things than Gould does: The concluding chapters survey the theoretical significance of the new interpretations. Conway Morris is keen to explain how and why the Cambrian explosion took place, constructing a theory

that combines genetic triggers for structural innovations with an ecological pressure generated by the origin of predators. His real concern, though, is to refute the claim that the explosion requires the postulation of evolutionary forces that are no longer in operation. The main plank of the argument is the denial of Gould's alleged diversity of form. Using cladistic analysis, Conway Morris argues that the Burgess Shale creatures can all be fitted into known phyla, or show intermediate states that actually throw light on the process by which the known phyla diverged from one another. He notes that Harry Whittington and Derek Briggs, the Cambridge paleontologists who made the first modern studies of the Burgess Shale species, were influenced by Sidnie Manton's thesis that the arthropods are polyphyletic. According to Manton, there was no "arthropod Eve," no single ancestor from which all modern arthropods are descended. The chelicerates (spiders and scorpions), crustaceans (crabs and prawns), uniramians (insects and myriapods) and the extinct trilobites had each independently evolved the characteristic arthropod structure. On such a model it would not be surprising that some other, equally independent, arthropod types might have appeared in the Cambrian and then become extinct. Modern studies have now shown that all the Burgess Shale arthopods can be accommodated within a scheme that explains their origin in monophyletic terms—from a single common ancestor in which the basic arthropod structure was developed.
Meanwhile, *Wiwaxia* (from the Burgess shale) and the halkieriids (from Greenland) show how the mollusks and brachiopods evolved from the annelid worms. Major transformations are involved, of course, but nothing that requires the postulation of evolutionary forces outside the range of what can be studied in more recent times.
Conway Morris thus claims that Gould's scenario for the origin of animals is disproved: There was no vast radiation and no winnowing out of many early phyla by extinction. But the disagreement between the two paleontologists is more fundamental than this, because Conway Morris thinks that Gould's whole rerunning-the-tape idea is misleading if it is meant to imply that the outcome could be significantly different from what we observe. He certainly does not want to imply that evolution is directed by mysterious goal-directed forces. But he appeals to the widespread existence of convergence to argue that at least in its broad outlines, the outcome of evolution is predetermined. Convergence occurs when two lines of evolution independently develop the same or very similar structures, as when ichthyosaurs (reptiles) and whales (mammals) independently evolved a fish-like body plan. This occurs because certain structures are simply the best for certain adaptive purposes—any vertebrate wanting to swim in the water is going to evolve in the same direction. Conway Morris believes that the combined limitations of the developmental pathways triggered by genetics and the demands of the environment mean that the possible outcomes of the evolutionary process are very limited. We can conceive of all sorts of alien creatures, but they could never exist in the real world—and what can exist is pretty much confined to what we actually see. So rerunning the tape would produce more or less the same results, although the details might be different. There would be something like whales swimming in the modern seas, although they might have evolved from different mammalian ancestors.
Curiously, Conway Morris has himself demolished the most effective case for the power of convergence—Manton's theory of the independent origin of the arthropod body plan by several different phyla. In fact, the possibility of a polyphyletic origin for the arthropods goes back to Walcott's time and may have influenced his original

interpretations of the Burgess Shale creatures. But it has now been disproved and with it the best example of the power of convergence to predetermine the outcome of evolution. Instead, Conway Morris offers us the parallels between the marsupials and the placental mammals, his best example being the independent evolution of a marsupial very much like the saber-toothed tiger. The main problem with this argument (and it is not a new one) is the kangaroo. If convergence is so powerful, how was it possible for the kangaroos to proliferate into a major component of the Australian fauna whereas nothing like them ever became dominant among the placentals of the rest of the world? Gould's interpretation of the Cambrian explosion may have been demolished, but this reviewer, at least, remains unconvinced by Conway Morris's argument that the outcome of evolution is predetermined. If placental kangaroos had taken charge outside Australia, who knows what the world would look like now.

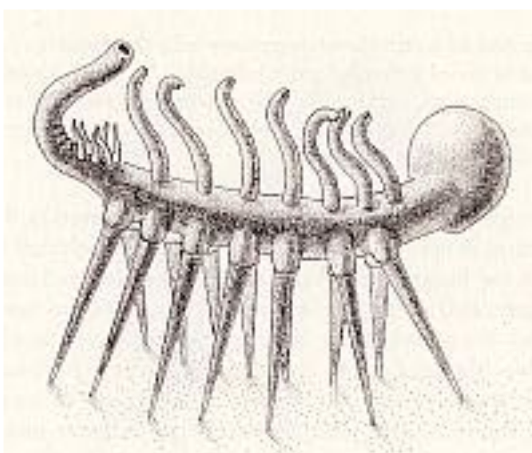
There is thus far more at stake here than the nature of the Cambrian explosion. Conway Morris is quite clear about how far he wants to extend the power of convergence: It guarantees the emergence of high intelligence (in mollusks like the octopus and in vertebrates) and of human spiritual faculties (in the Neandertals as well as our own ancestors). In the end, he wants us to believe that something very like human nature was bound to emerge sooner or later from the evolutionary process. This contrasts with Gould's position, which follows a materialist tradition pioneered by the founder of modern Darwinian paleontology, George Gaylord Simpson, who insisted that humans were a most unlikely product of so haphazard a process. Gould's Marxist leanings are well known, and we can see why he would favor a viewpoint that leaves the human race to figure out its own moral values with no hints provided by any transcendental source. Conway Morris's opposition to this is driven by a more traditional perception of the human situation. He tells us that our intelligence is a gift, that we shall be called into account and that the evils perpetrated by humanity make sense only if they can be redeemed. For him, we are not only the intended outcome of evolution—we may also be the unique embodiments of spiritual faculties in the universe. His last chapter is a brief but clear-cut rejection of the popular assumption that there are many life-bearing planets throughout the galaxy. Evolution is predetermined, but it has only happened once.

To a historian of science such as myself, the books by Gould and Conway Morris seem themselves like a rerunning of the tape of history, but in this case there is a loop that was first played in the late-19th century and is now repeating itself almost exactly. For all the new discoveries and the modern apparatus of cladistic analysis, the alternative visions of the nature of history are as clear today as they were to the biologists who tried to defend their belief in a purposeful universe against the assault of Darwin's *Origin of Species*. Gould himself once wrote about the "eternal metaphors" of paleontology, and on that point, Conway Morris has merely confirmed his claim that the rival visions of nature are still in play.

Source: http://www.americanscientist.org/bookshelf/pub/cambrian-conflict-crucible-an-assault-on-goulds-burgess-shale-interpretation

CHAPTER 2 Wonderful Life and its Contingency

According to legend, a janitor at the Institute for Advanced Studies in Princeton once asked: "*So what is it all about then, Professor Einstein?*" Undoubtedly, like most people, he wanted assurances that there is meaning and purpose in life, and that science was making progress in substantiating this.
Unfortunately, science by its very nature will never be able to answer questions such as "*Why am I here?*". Nevertheless, scientific discoveries have profound implications for our understanding of our own place in the cosmos. We now know that our sun is only one out of several hundred **billion** stars in our own galaxy, and that our galaxy is only one out of several hundred **billion** galaxies in the observable universe. It has been estimated that there are some 10^{22} stars in the universe - a 1 followed by 22 zeros.
The first planet orbiting another star was discovered in 1995. As of August 2009, 358 exosolar planets have been identified. We now have reason to believe that the number of planets in the universe is comparable to the number of stars.
The greatest question now confronting science is: "*Are we alone?*" It seems inconceivable that the Earth should be unique in harboring life, but to assess the chances of life evolving on other planets, and of complex life, we need to understand how Earth life originated and evolved. The starting point, of course, is Darwin's Theory of Evolution, arguably the greatest discovery in the history of science.
You may well wonder why I choose to discuss a somewhat controversial 20th century book on Darwinian evolution rather than "*On the Origin of Species*", which after all I had discovered in my Grandfather's library during my teens. — I have been thoroughly convinced of the validity of Darwin's theory throughout my adult life, but it is only after reading Gould's "*Wonderful Life*" (pointed out to me around 1990 by my colleague, Christer Magnusson), that I have come to fully appreciate the implications of Darwin's theory, and to question some of my own fundamental beliefs.



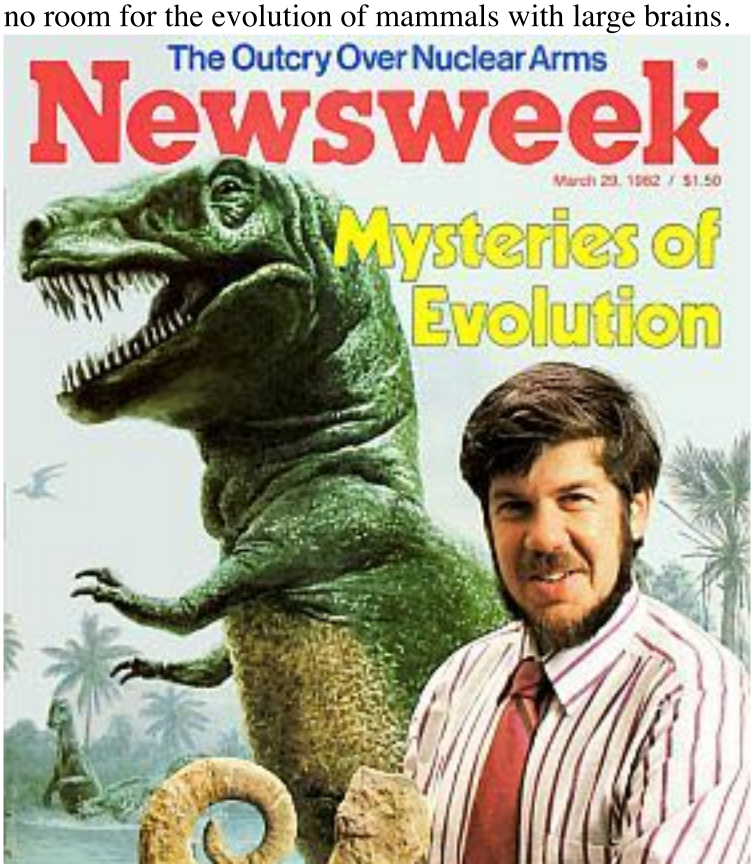
Hallucigenia, a Burgess Shale fossil named for its bizarre morphology. Later fossils indicate that the "top" appendages are actually legs, while the "bottom" spikes are protective, so the image is upside-down!

Drawing by Marianne Collins.

Gould's book deals with a particularly fascinating period in the development of life on Earth, known as the *Cambrian Explosion*, some 540 million years ago, when larger animals (visible to the naked eye) suddenly turned up in the fossil records. "*It is as though an orchestra began playing without sounding a single note to tune up*" (P. Ward). It was a period of extraordinary richness, when nature seemed to be experimenting with a large number of designs and body plans. All life forms that exist today have ancestors in the fossil record from that epoch. In addition, a large number of strange creatures without known descendants appeared within the space of just a few million years.

The Cambrian "explosion" presented a tough problem for Darwin's theory, which postulated a slow gradual process of evolution from simple organisms to increased complexity. Always the embodiment of honesty, he devoted an

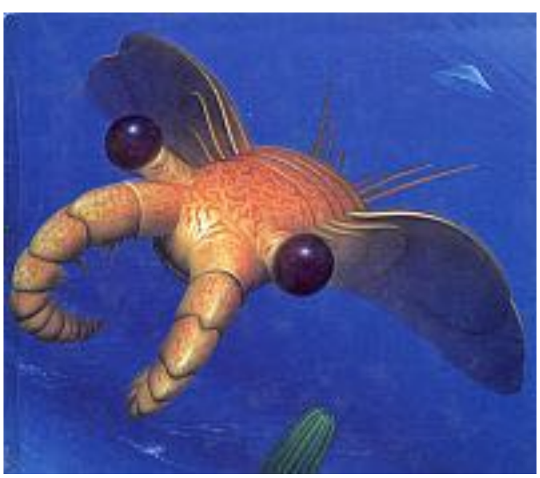
Gould makes three points in particular. One is the concept of *punctuated equilibrium*, a theory that he advanced together with Niles Eldredge in 1972. It states that rather than proceeding smoothly over time, evolution is characterized by episodes of rapid change interspersed with long periods of stasis, when organisms evolve at a much slower pace. Actually, this is in accordance with Darwin's view as expressed in the *Origin of Species* (ch. 4 and ch. 10). Evolution occurs mainly in response to environmental change, and if there is no change in the environment over millions of years, organisms would already be well adapted, and there would be little pressure for major modification. Of course, Darwin can only have had vague ideas about the stability of the Earth's environment over its history. The other point is that the Cambrian Explosion really was a gigantic lottery, and that the outcome just as easily could have been completely different. Gould counts some 25 widely different animal body plans which were soon reduced to just the four that have survived to this day (vertebrates, exoskeletons, worms...), "all the others died without issue", i. e. went extinct. Why did some designs gain supremacy, while others were doomed to failure? Gould argues that the standard answer, i.e. that the surviving groups were better adapted to their environment, is unconvincing. There is no way to predict that a certain group is going to survive, while another is doomed to extinction. If the tape were rewound to the beginning of the Cambrian Explosion, and the dice were cast once more, it is highly unlikely that the outcome would be the same. [For my younger readers: a tape recorder was a 20th century device that preceded solid state memories.] Furthermore, organisms evolve to adapt to a particular environment. There is no correlation between adaptation to the environment and the ability to survive catastrophic environmental change. When the environment changes quickly and unpredictably, all bets are off. The dinosaurs held sway for more than a hundred million years until they were wiped out by an extraterrestrial impact 65 million years ago. In all probability, in the absence of catastrophe they would still dominate the domain of large-bodied vertebrates, leaving no room for the evolution of mammals with large brains.



The third point is that evolution has no inherent direction. The traditional view of the march of life toward ever increasing complexity, culminating in the emergence of *homo sapiens* some 50,000 years ago, is a misinterpretation of how evolution actually works. Intelligence, in particular, should not be seen as the culmination of the evolutionary process. In evolutionary terms, the higher animals are in no way better adapted than bacteria or plants. Our line of hominids is the outcome of one of Nature's myriad random experiments, and until quite recently we remained just a curiosity among the millions of animal species. "*In Darwin's scheme, we are a detail, not a purpose or embodiment of the whole*." — Over the eons there is a slow drift in the direction of greater complexity, but that is just the result of random processes similar to "the drunkard's walk" or Markov chains.

There are many intelligent animals. Consider the cuckoo which lays its egg among other eggs in a nest of a different bird species. The cuckoo egg hatches before the others, and the first thing the newborn cuckoo does, is to kick the other eggs out of the nest, thus eliminating competition for its foster parents' care. But this is hard-wired intelligence, pure instinct. In all probability, the young cuckoo has no sense of purpose. — Conscious intelligence is much more rare, and it is not clear that in general it gives much of a competitive edge in the struggle for survival and replication.

It is not surprising that Gould's view of the evolution of man as the result of blind chance and a series of improbable accidents — and that "rewinding the tape" would produce a quite different result — has run into strong opposition even among scientists. Simon Conway Morris, one of the heroes in Gould's book, points to functional convergence among different species as support for his view that regardless of genetic makeup, evolution does have a trend. Birds and bats are quite different groups, yet they have evolved wings for flight. Fish and dolphins have similar shapes, etc. Also, since Gould's book was written, many more fossils have been found and analysed. The Cambrian Explosion may have been a little more gradual and less explosive than previously thought, and the view that a large number of fundamentally different forms of life went extinct in short order has been criticized. — To me, the view that evolution <u>inevitably</u> leads to intelligence and consciousness seems colored by wishful thinking, however much I may wish the opposite to be true.



The cover of "The Crucible of Creation" by
Simon Conway Morris.

Unfortunately, there have also been personal attacks on Gould having more to do with professional jealousy than with science — not an uncommon occurrence in the scientific community. Gould, who was a brilliant writer and speaker with a large audience, has been vilified as "the Sagan of the geosciences". (Carl Sagan was an astronomer with a gift for making science understandable and exciting to the general public. He held the opposite view from Gould on the prospects for intelligent life in our galaxy.) In addition, Gould, as a confirmed atheist and socialist, predictably triggered some strong animosity among religious and political opponents.

I must confess that during most of my adult life, I have accepted Darwinian theory without much thought, taking comfort in the implied view that evolution must have led to the emergence of countless intelligent and conscious creatures in the universe. Gould's view of the history of life as a fundamentally random process has certainly given me pause.

In 2000, Peter Ward and Donald Brownlee published "*Rare Earth - Why Complex Life is Uncommon in the Universe*". They argue persuasively, that far from the gradual, more or less predictable, progress of life from simple bacteria to *homo sapiens* that most of us have come to associate with Darwinism, complex life on Earth is in fact a result of a wildly improbable sequence of accidents. The good news is that simple bacterial life seems likely to occur on innumerable worlds. We might yet discover alien forms of life in our own Solar system. Ward and Brownlee are encouraged by the early development of life on Earth shortly after our planet's surface had solidified and cooled down to the boiling point of water. Also, the recent discovery of extreme microbes near deep-sea volcanic vents indicates that solar energy may not be necessary for life. These "archeans" seem to be a more primitive life form than bacteria and may have survived repeated sterilizations of the Earth's surface. Once bacterial life is established, it is extremely difficult to stamp out.

Ward thinks that there is a distinct possibility that alien bacterial life exists in the Solar system. He is critical of the fact that NASA's Genesis mission, which brought a sample of solar wind to the Earth in 2004, was not adequately protected from potentially infecting us with dangerous microbes.

In contrast, the evolution of complex life, such as animals, has been possible only due to an improbable chain of favorable circumstances. Earth life as we know it would not have been possible if our sun had not been of the right size to burn steadily for billions of years, and the Earth located far enough from the galactic center to be reasonably safe from cosmic radiation from energetic events and nearby supernovae. — We live in a narrow habitable zone in the Solar system. A little closer to the Sun and the climate would be too hot. A little farther out and our planet would be frozen. — The Earth's magnetic field shields us from lethal solar ultraviolet radiation.

Don Davis/NASA

Water probably was brought to the Earth by comet impacts. Throughout its history, our planet has been pummeled by asteroid and comet impacts. Our moon was created from the collision of a Mars-sized planetoid with the Earth. During the heaviest bombardment, which occurred early in Earth's history, its surface may have melted repeatedly. Any oceans would have been vaporized. As recently as 65 million years ago, the Earth was hit by an object that created a 180-km diameter impact crater and caused the extinction of the dinosaurs. A more severe extinction event occurred 250 million years ago, when 90 percent of all marine species died out. Yet, the Earth may have been fortunate. Simulations indicate that there would be many more objects crossing the Earth's orbit if the giant planet Jupiter had not been available at just the right distance from the sun. Jupiter absorbs or deflects comets and asteroids through its strong gravitational pull, sending some of them off into interstellar space, others on a collision trajectory with the sun. — The Moon may also have played a role, forcing the Earth's precession angle (governing the seasons) to be reasonably stable over geologic time scales. — Plate tectonics (continental drift) is thought to have been a key factor, acting as a planetary thermostat. When sedimentary rocks are subducted deep into the mantle, carbon dioxide is returned to the atmosphere. This tends to warm a planet that would otherwise become progressively colder. — The Earth has been provided with an adequate supply of iron, phosphorus and other substances needed by living organisms etc.

Of course, this "Goldilocks theory" (that the Earth is just right for complex life while few other planets are likely to be similarly favored) is far from universally agreed upon. It is awfully risky to base a statistical argument on a sample of one. Until recently we had no idea that there is primitive life powered by volcanic vents on the sea floor, and life itself may find ways to evolve which we cannot imagine. — I have previously discussed the probability of intelligent life in our galaxy elsewhere on this web site.

As long as there is a sense of direction and purpose to biological evolution, most of us are willing to accept it as a well-established fact. (Although one of my nieces as a child said: *Dad says that we come from apes, and apes came from dinosaurs. But where did the dinosaurs come from? Nah, I still think God did it*.) Even the Pope now embraces evolution. It is the view of evolution as a random process without direction or purpose that is creating resistance even among educated people. But it is interesting that Mark Twain wrote: *If the Eiffel Tower were now representing the world's age, the skin of paint on the pinnacle knob at its summit would represent man's share of that age; and anybody would perceive that the skin was what the tower was built for. I reckon they would, I dunno.*

Charles Darwin (1809-1882) around the time of the publishing of "On the Origin of Species" in 1859.

Darwin was ambiguous on this matter. He acknowledged the existence of general laws that regulate life in a broad sense. But the details lay in a realm of contingency undirected by laws, i. e. chance. "*I cannot persuade myself that a beneficent and omnipotent God would have designedly created the Ichneumonidae with the express intention of their feeding within the living bodies of Caterpillars*." He was very reticent on the subject of religion. He mentions the Creator in *On the Origin of Species* — but not in the first edition. In his autobiography he describes himself as an agnostic. He had two strong reasons not to challenge religious beliefs outright: his wife was intensely religious, and he knew that *On the Origin of Species* would create a furor when it was published in 1859. By then he had spent over 20 years compiling his evidence for evolution, and when the book was published, he presented it as an abstract of a more complete treatise to follow. When he let a few friends in on his secret, he described it as "confessing to murder". His resolve to publish may have been strengthened by the devastating death of his 10-year old daughter in 1851.

Of course, science can never rule out the possibility of divine intervention. The supernatural is by definition beyond the realm of nature, but the need to turn to supernatural causes to explain natural processes has never been smaller.

According to Christian faith, "*not a sparrow will fall to the ground apart from the will of your Father*". In a German novel describing the battle of Stalingrad, I once read about a soldier who told the chaplain. "*For me, God has died at Stalingrad*." The chaplain replied: "*Yes, you are right, he has died here, but not just once. He has died together with every soldier who died here*." Personally, I find that kind of compassionate god much more appealing than an omnipotent puppet master; a god who <u>listens</u> to prayer rather than performs miracles à la carte in response. "*Please God, let my team win!*" — For those who prefer an interventionist god, well there is still the Big Bang and the Laws of Nature. In an article in Scientific American, I saw the Big Bang explained as "a quantum fluctuation". Somehow, that seems a little flat...

I cannot close without mentioning a fascinating 20-year ongoing experiment showing evolution in action and lending support to Gould's thesis that the outcome would not be the same if "the tape were rewound". The paper was published in 2008. From the abstract:

> The role of historical contingency in evolution has been much debated, but rarely tested. In the experiment, twelve initially identical populations of *Escherichia coli* [a common bacterium in the human gut] were founded in 1988. They have since evolved in a glucose-limited medium that also contains citrate, which E. coli cannot use as a carbon source under our [containing oxygen] conditions. No population evolved the capacity to exploit citrate for >30,000 generations, although each population tested billions of mutations. A citrate-using (Cit+) variant finally evolved in one population by 31,500 generations, causing an increase in population size and diversity. The long-delayed and unique evolution of this function might indicate the involvement of some extremely rare mutation. Alternately, it may involve an ordinary mutation, but one whose physical occurrence or phenotypic expression is contingent on prior mutations in that population. We tested these hypotheses in experiments that "replayed" evolution from different points in that population's history. We observed no Cit+ mutants among 8.4×10^{12} ancestral cells, nor among 9×10^{12} cells from 60 clones sampled in the first 15,000 generations. However, we observed a significantly greater tendency for later clones to evolve Cit+, indicating that some potentiating mutation arose by 20,000 generations. This potentiating change increased the mutation rate to Cit+ but did not cause generalized hypermutability. Thus, the evolution of this phenotype was contingent on the particular history of that population. More generally, we suggest that historical contingency is especially important when it facilitates the evolution of key innovations that are not easily evolved by gradual, cumulative selection.

Public acceptance of evolution
theory in Europe, Japan and
U.S.A. in 2005.

Jon Miller, et al./Science

One of the difficulties in evolution theory is to explain how complex structures can evolve in small steps, each of which enhances "fitness". This has been referred to as "climbing Mount Improbable". If several steps were needed to achieve a positive effect, one would expect that either several mutations would have to occur simultaneously, which would border on the miraculous, or one mutation would stay dormant through successive generations until a second mutation, perhaps much later, would complete the step forward in combination with the first mutation. It is this second scenario that has now been experimentally verified. It means that evolution can proceed in larger steps, where a number of mutations are involved before a beneficial change is effected. The experiment clearly disproves a claim made by the intelligent-design school of thought: *If the development of many of the features of the cell required multiple mutations during the course of evolution, then the cell is beyond Darwinian explanation*.
Darwin's theory of evolution is now universally accepted among scientists, based on its predictive power, and based in particular on evidence from molecular biology. Among the general public it is not uncommon to hear it questioned: "*After all it is just a theory*". But so is the theory of gravity. In science there are no sacrosanct truths, only models that best fit the available data. After 150 years, the theory stands unchallenged and rock solid.

Further reading

1. "Wonderful Life — The Burgess Shale and the Nature of History", Stephen Jay Gould, 1989, ISBN 0-393-02705-8.
2. "Rare Earth — Why Complex Life is Uncommon in the Universe", Peter D. Ward and Donald Brownlee, 2000, ISBN 0-387-98701-0.
3. "The Crucible of Creation — The Burgess Shale and the Rise of Animals", Simon Conway Morris, 1998, ISBN 0-19-850256-7.

Next we turn to the second reference above, a book entitled: Rare Earth-Why Complex Life is So Uncommon in the Universe”:
In their book *Rare Earth*, published by Copernicus Press in 2000, Peter Ward and Donald Brownlee point at Drake's (and other physicists') mistakes in a long and depressing discussion, a discussion that took the wind out of more than one SF author's sail.

The book presents what the authors call “*the rare Earth hypothesis*”: simple (bacterial) life is very common in the universe; complex life (multi-cellular life forms, or animals -- let alone intelligent life) is very rare. The first part of the hypothesis is easy to understand, and few scientists will argue with it: indications of simple life were already discovered on rocks originating on Mars, and even here on Earth in conditions that were, until recently, considered completely hostile to life (such as temperatures higher than 100 degrees Celsius, in which 'extremophile' bacteria were found to exist). The second part is the interesting one, and it suggests that the existence of simple life does not necessarily lead to the evolutionary development of complex life, for any number of reasons.

Drake's mistake was basically in the assumption that all it takes for a planet to develop life is being in the proper distance from a proper star. The truth, Ward and Brownlee suggest, is that we have to look at each and every attribute of Earth, and re-estimate its importance for supporting life. Drake's equation is a statistical calculation, but with no other example for life, we're doing statistics with N=1.

Well then, what are the special attributes of Earth that we have to take into account when attempting to run this calculation?

• *Proper distance from the star*. If a planet orbits its sun too closely or too far away, liquid water would not exist. There isn't much margin for error here: a change of 5 to 15 percent in Earth's distance from the Sun would lead to the freezing, or boiling, of all water on Earth.
• *Proper distance from the center of the galaxy*. The density of stars near the center of the galaxy is so high, that the amount of cosmic radiation in that area would prevent the development of life.
• *A star of a proper mass*. A too-massive star would emit too much ultra-violet energy, preventing the development of life. A star that is too small would require the planet to be closer to it (in order to maintain liquid water). But such a close distance would result in tidal locking (where one face of the planet constantly faces the star, and the other always remains dark -- as with the moon in its orbit around Earth). In this case one side becomes too hot, the other too cold, and the planet's atmosphere escapes.
• *A proper mass*. A planet that is too small will not be able to maintain any atmosphere. A planet that is too massive would attract a larger number of asteroids, increasing the chances of life-destroying cataclysms.
• *Oceans*. The ability to maintain liquid water does not automatically imply that there will be any on the planet's surface. It looks like Earth acquired its own water from asteroids made of ice that crashed here billions of years ago. On the other hand, too much water (i.e., a planet with little or no land) will lead to an unstable atmosphere, unfit for maintaining life.
• *A constant energy output from the star*. If the star's energy output suddenly decreases, even for a relatively short while, all the water on the planet would freeze. This situation is irreversible, since when the star resumes its normal energy output, the planet's now-white surface will reflect most of this energy, and the ice will never melt. Conversely, if the stars energy output increases for a short while, all the oceans will evaporate and the result would be an irreversible greenhouse-effect, preventing the oceans from reforming.
• *Successful evolution*. Even if all of these conditions hold, and simple life evolves (which probably happens even if some of these conditions aren't met), this still does not imply that the result is animal (multi-cellular) life. The evolution of life on Earth included some surprising leaps; two worth mentioning are the move from simple, single-cellular life to cells which contain internal organs, and the appearance of calcium-based skeletons. It appears like the first of these leaps took more time than the evolution from complex single-celled life to full-blown humans.

- • *Avoiding disasters*. Any number of disasters can lead to the complete extinction of all life on a planet. This include the supernova of a nearby star; a massive asteroid impact (like the one that probably caused the extinction of dinosaurs, and 70% of all other life-forms at the time); drastic changes of climate; and so on.

There are also a few attributes that seem, at first, to be completely unrelated to life and not required for its development. Ward and Brownlee argue strongly for the importance of the following attributes:

- *The existence of a Jupiter-like planet in the system*. Apparently, Jupiter's large mass attracted many of the asteroids that would have otherwise hit Earth. Could life evolve in a system with no Jovian planet? On the other hand, too many Jovian planets, or one that is too large, could lead to a non-stable solar system, sending the smaller planets into the central sun or ejecting them into the cold of space.

- *The existence of a large, nearby moon*. Apparently Luna, Earth's moon, is atypically large and close. Both of Mars's moons, for example, are minor rocks by comparison. What does this have to do with life? Well, it turns out that Luna kept (and still keeps) Earth's tilt stable. Without Luna, the tilt would have changed drastically over time, and no stable climate could exist. If the tilt would have stabilized on a too-large or too-small value, the results could also be disastrous; Earth's tilt is "just right".
- *Plate tectonics*. Surprisingly enough, it seems like plate tectonics are required for maintaining a stable atmosphere. Plate tectonics play an important role in a complex feedback system (explained in detail in the book) that prevents too many greenhouse gases from existing in the atmosphere. No other planet (except maybe for Jupiter's moon Europa) is known to have plate tectonics. Is this a rare phenomenon, but required for life?

The bottom line is that many additional factors must be added to Drake's equation. One must keep in mind that as any term in such an equation approaches zero, so too does the final product. For most terms, we have no way of reliably estimating their true value, but it seems like at least some of these values are extremely low.

Two important things should be noted about this book. First, about what it *does not* contain: although I am sure many people will see the Rare Earth Hypothesis as another proof for the existence of a god, this notion of a proof is completely unrelated to the authors' ideas. The hypothesis claims that the conditions for creating complex life are rare; but we know for a fact that at least in one case, all the required conditions were met. Additionally, anyone who insists on taking the ideas of this book as a proof for god's existence will also have to accept the authors' prepositions about the age of the universe, the age of planet Earth, and more importantly, the theory of evolution.

Second, about what the book does contain: the book discusses at length all the issues I've listed above, and more. The problem is that sometimes one gets the feeling that these issues are discussed in *too much* detail, and the authors tend to repeat themselves, or to delve too deep into some of the less-important aspects of their theory. This is certainly not your common popular-science book; it relies on very up-to-date research results (including some results that were not even published when the book went to press). The writing gets technical on many points in astrophysics, biology, chemistry, and geology (as well as the new field of astrobiology, of course). Over 25 pages of bibliography and references are included.

The theory's weakest point, however, is obvious. The authors admit (after 281 pages of discussion) that their base assumption was that every complex life-form would be similar in many ways to life on Earth: "We assume in this book that animal life will be somehow Earth-like. We take the perhaps jingoistic stance that Earth-life is every-life, that lessons from Earth are not only guides but also *rules*. We assume that DNA is the only way, rather than only one way" (p. 282).

For me, reading this book was a fascinating and awe-inspiring experience. The most important conclusion (apart from SETI being a huge waste of resources) is an unavoidable cliché, which the authors avoided presenting directly, even though it stares into the reader's face from every page and each paragraph: What we have here is rare, maybe even unique. We should try a little harder to make sure it survives.

How Rare Is the Earth?

- Posted 10.21.11
- NOVA

What are the chances that there are many other planets in the universe as hospitable to intelligent life as ours? Peter Ward, a paleontologist at the University of Washington and coauthor (with Don Brownlee) of *Rare Earth: Why Complex Life is Uncommon in the Universe*, argues that while simple life-forms like extremophiles can exist in harsh conditions, complex life requires much more benign and stable conditions. As a result, Ward believes that we are effectively alone in the universe.

Peter Ward is a paleontologist and professor of Biology and of Earth and Space Sciences at the University of Washington. He is the author of many popular works, including more than a dozen books. Ward is currently researching the nature of the Cretaceous-Tertiary extinction event. Enlarge Photo credit: Courtesy Peter Ward/NASA

ALONE OR JUST LONELY?

NOVA: What first got you thinking about the possible existence of alien intelligence?

Peter Ward: Well, who isn't, actually? I mean, what person really isn't thinking at least about ourselves and our aloneness or not? We are so immersed in aliens, you can't get away from it. I would say that the top four of the 10 greatest box office hits of all time were dealing with alien life in some way or another. And somewhere along the line you have to start asking yourself, well, what are the chances?

Don Brownlee and I started [working on the book] *Rare Earth* sitting together at a lunch table. We knew each other, but barely. I think the conversation started where I was saying, "Well, you know, I'm just sick and tired of all the damn alien shows. [Finding aliens is] hardly likely at all." And he said, "Really? I think the same thing." And off it went.

In *Rare Earth* you talk about how we're very lonely in the universe. But lonely doesn't mean alone. Do you think there probably is alien intelligence somewhere?

Yeah. I think there absolutely has to be. The numbers are just so great. In the first two billion years of the universe, you certainly didn't have life, because you just had hydrogen and helium. That's a pretty boring universe. But once we started building elements, you could have a little more complex chemistry going on, organic chemistry, and then off it went. But we're far enough along in this whole universe, it's highly probable. I would say it's so probable that I don't see how you could bet against it.

Carl Sagan hit the nail on the head—"Billions and billions," right? People made fun of him for that. But the reality is, he was quite right. The numbers are so staggering: billions and billions of galaxies, with billions and billions of stars. This was becoming close to the infinite number of monkeys and typewriters.

"If there's no higher plant life, there's not going to be higher animal life."

You've said in your book that for all intents and purposes, we're alone. But can you imagine a finding that would really change the odds of finding alien intelligence?

There is a very simple way, I think, to look for alien intelligence. It requires the ability to image Earth-like planets. We'll be there soon. Once you can image an Earth-like planet, all you need to do is start looking in the spectrum for a really strong signal from mercury.

From mercury?

Yeah. If you think about it, how do we make streetlights? They're all called mercury vapor lights. The strongest streetlights in the world are made from one or two elements that actually give off a very strong signal. Any engineer is going to settle on the same way of making a light. There's not going to be some supernatural light out there.

You can pick up the spectral signal from our world from a long way away. You've seen the pictures of the night side of the planet covered with lights. That's going to send a very strong signal out there.

There's another simple way to figure out if a planet is even worth looking at. And that is, what type of rivers does it have? Dave Montgomery and I published a paper in *Science* in 2000. We pointed out that, prior to the Devonian Period, there were no meandering rivers on Earth. There was no Mississippi meandering across the floodplain. All rivers were braided, because you can't have the normal rivers you find on Earth today without plants for banks to be built.

This is pretty clear-cut in Washington State—trees go away, the rivers change from meandering to braided streams. So just start imaging the rivers on a planet, and you'll know if there's higher plant life or not. If there's no higher plant life, there's not going to be higher animal life.

THE MEDEA HYPOTHESIS

Your book *The Medea Hypothesis*, which proposes that life is inherently suicidal, suggests that complex life doesn't last long. If true, what impact does this have on the possibility of finding alien intelligence?

Well, that's certainly what Don Brownlee thinks is the most important part of the Drake equation. [The Drake Equation is used to estimate the number of detectable extraterrestrial civilizations in the Milky Way.] How long do complex civilizations stay complex? We're going to come to that test here pretty quickly in the next century or the next millennium. If we continue to increase carbon dioxide, producing what I think will be a runaway sea-level rise, then we're going to put this to the test. When you have too many people and no food and civilization falls into chaos, how much civilization is retained? How long will an intelligent species survive?

Can you tell us more about the Medea hypothesis and how that figures into the lifetime of an advanced civilization?

The only reason Medea came to my mind is that she was chasing a very wayward life. [Editor's note: Medea is a figure in Greek mythology who kills her own children by accident.] The fact that life seems to screw everything up for itself over and over and over really negates the sort of wonderful thought that Mother Earth is going to bail us out over and over. Mother Earth doesn't bail us out. Life is a very complex phenomenon that's very selfish, and it leads to population disasters over and over.

I argue that the only way out is intelligence. Intelligence is the only way that you can stop this whole process of life killing off life on the planet. Inevitably it's going to happen here. Carbon dioxide is going to drop to the point that the planet can no longer produce plant life. And then, 20 million years after that, the oxygen is gone and there go the animals. So without us radically changing things really quickly, the Earth becomes uninhabitable for complex life in a half a billion to a billion years. That's all Medean.

What do you think about the idea that in another couple hundred years it won't be biological life, it'll be synthetic life?

Oh, I think it's coming. And interestingly, I just did a whole day shoot for Morgan Freeman on the *Through the Wormhole* series just on that particular question. For some reason, I seem to be pigeonholed with the future evolution of humans. I wrote a paper about that in *Scientific American*, and all of a sudden that's me. There are a lot of people who know a hell of a lot more about it than I do. But I really do think that we're going to find this synthesis of the machines and us.

THE RARE EARTH EQUATION

In your version of the Drake Equation, which you called the Rare Earth Equation, you replaced the factor "communicating civilizations" with "complex metazoans." Why complex metazoans and not communicating civilizations, or intelligent life?

Well, we just wanted to up the ante. Every argument has always been what is the percentage of planets that have complex intelligent, communicating species? And we started out thinking about this, but we wanted to separate it in our book. So we made it even simpler. What is the percentage of planets with worms?

You know, there is going to be some fraction of the planet with worms, where the worms finally evolve into human being-like equivalents. But the odds against even getting worms, it occurred to us, was so high that this would make our argument even stronger, which it did—the fact that animals were tough to get to. And why is that? Well, to have animals, you absolutely have to have oxygen. But it took more than two billion years to get there.

"How can you get to be a complex civilization without metal and electricity?"

It doesn't seem like there have been many people who've gone out on a limb and assigned a value to the Drake Equation, or to the Rare Earth Equation. Have you?

No. We always stayed away from that. Every once in a while, every two or three years, we get a paper where somebody goes out on a limb and tries it. We were never interested in trying to come up with an absolute number. All we wanted to do was point out the conditions and the problems to get there.

It's even starker than that. Let's say you had a water world. Would those creatures ever communicate? How in the world would you ever smelt metal underwater? How in the world could you ever produce electronics underwater? I mean, we know what happens when you put water on electronics—it shorts out because the electrons go everywhere.

How can you get to be a complex civilization without metal and electricity? Maybe you could have these creatures in the opposite of a scuba suit, where they're in water, right? They've got these little water lumps walking around on the land, and they produce telescopes. But underwater creatures are probably not going to have any sense of what the cosmos is, or care.

THE EVOLUTION OF INTELLIGENCE

Do you think the evolution of complexity is the natural order of things? Is that always going to happen? Is intelligence always going to evolve?

On the first question, complexity is already going to happen if you get an advantage being complex. The advantage that takes place is locomotion and movement. You cannot move rapidly or move at all, really, unless you have multi-cellularity. And once you have that, to be able to move well you need muscles. You need some sort of skeleton to thrust against.

So if any aspect of speed is better at finding food, which it is, or escaping predators, which it often is, then that's going to evolve. But intelligence, on the other hand—why weren't there intelligent dinosaurs? Or why didn't intelligence come in the mammal-like reptiles? Or why did it take the entire Cenozoic Era to get the primates with big brains?

Intelligence has a very high negative aspect to it. Maintaining a big brain is a real problem for organisms. Nervous systems and that much mass require so much oxygen that it's really a burden to the animal. You only get as intelligent as you have to be. And for finding food, the big cats, the big dogs, for 30 million years, they've been very good at it. And there's been no reason for them to get better at it.

There were special circumstances and accidents that created a world in which hominids could actually be pushed into high intelligence. And the fact that it did not happen prior to this is just that there aren't many body plans or many evolutionary scenarios where you need to have brains our size.

"That's why I laugh when I see all these science fiction stories about how we'll get even bigger heads. You know, no one talked to the women about that!"

Is there a downside to being intelligent aside from the cost of the food?

There's certainly a downside for childbearing because obviously humans have an enormously high death rate in childbearing. Head size and the female human pelvis were on a collision course. And we really were walking a very thin knife-edge here. So many babies died in pre-civilization childbirth that you had this strong evolutionary pressure to reduce head size so you could have a greater longevity and a greater number of females surviving. That's why I laugh when I see all these science fiction stories about how we'll get even bigger heads. You know, no one talked to the women about that!

Some people find the suggestion that we're very lonely arrogant because it seems like yet another example of humans believing we're special.

We are special. I mean, we're certainly special in the solar system. We're certainly special on Earth. You know, why not be special and enjoy it? And why have a guilt feeling about it?

There is also the argument that it's arrogant to think that intelligence like ours is pre-ordained. Are these kinds of discussions what happens when there aren't enough data?

Oh yeah. And this is a case where there certainly aren't enough data. But the really interesting thing that's been happening is still the exoplanet searches. That's the greatest breakthrough in any of this discussion in the last decade. Because even 10 years ago we really thought that maybe planets were only present around 15 percent of stars.

In fact, the recent discovery of a planet orbiting a multiple-star system, that really increases the odds. So yeah, there could be tons of planets out there. The trouble is, we haven't found one Earth-like planet yet.

SETI

Do you think SETI, the Search for Extraterrestrial Intelligence, is a futile search?

No. I used to think so; it's such a long shot. Personally, I don't think they'll ever find a signal anywhere. But as long as there are people willing to fund it, and it doesn't cost the public anything, why not? You've got really, really interesting people working away at it.

I had to laugh at that movie *Contact*, where Jodie Foster plays this brilliant astronomer coming out of grad school who goes right into SETI and gives up her position at Harvard. There's no reality to that. Ph.D. astronomers now, they're not going into SETI. The people who go into SETI are late-career people who've got nothing else to lose.

Britain's Science Council recently spent a year working on a new definition of science, which says that "Science is the pursuit of knowledge and understanding of the natural and social world, following a systematic methodology based on evidence." What do you think of that definition? And how do you think the search for alien intelligence fits into that?

Well, I teach 250 people starting tomorrow, and my first lecture is always, "What is science?" What I like to tell them is that science is a verb, not a noun. They kind of look at me like, "What?" It isn't just accumulated knowledge. It's the acquisition and then using that knowledge. You never stand pat, because that isn't science. That's just an encyclopedia.

"We don't go to lunch and talk about, 'Well, what do you think about the chances for intelligence today?'"

What about SETI? Is it predictive?

The way SETI is predictive is that it takes into account the findings from astronomy, exoplanets, planetology, all that stuff. SETI has to take into account all that knowledge so that they can target. They don't want to target everything. They want to go for the stars with the highest probability. Well, how do they know which ones those are? That comes from all the various disciplines and a whole giant knowledge set.

We don't yet know enough about the conditions necessary to keep complex life alive for a long time. We're still working on that, and that will help SETI. And there's no reason that SETI has to die out in the next 50 years. We're in this for the long haul. We humans are going to be here for a long time. Maybe SETI, a thousand years from now, has so refined the search that they've increased their instrumentation that they finally do find something way out there.

At the end of the day it seems like the question of the existence of extraterrestrial intelligence is not if but how many. Do you agree?

Every reasonable person I've talked with, once they know the numbers, give it a probability. It's never yes or no. It's just "the chances are." That's about as far as it goes. People don't talk about it that much. And we don't go to lunch and talk about, "Well, what do you think about the chances for intelligence today?" It just doesn't come up, because it's non-retrievable from a scientific point of view right now. Other than SETI, it doesn't seem worth anybody's while. There are other things to worry about, like funding.

Interview of Peter Ward conducted in September 2011 and edited by Lauren Aguirre, Director of New Media for NOVA