Life and Consciousness in the Universe

Are We Alone?

The Search for Life in the Universe.

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One of the most profound questions humans can ask about their relationship to the cosmos is whether or not we are alone as sentient beings on a habitable planet. In the past decade, astronomers have shown that planets form readily around Sun-like stars, and about 100 million habitable planets are anticipated in the Milky Way galaxy. It's not yet known if any of them host life, but unless the events on Earth that led to life and to intelligence were a series of flukes, we are unlikely to be alone. The modern search for life and intelligence is described, along with possible outcomes, and implications for our self-image and our relationship to the larger Universe.

Chris Impey: It is a great pleasure to be at this conference, and of course a great honor that His Holiness opened the conference. In short, he is what could be called the "ultimate act" to follow. But I will do my best to hold your attention by talking about exciting new results in the cosmic context for life.

I think, although I have no evidence yet, that the Universe contains comedy and tragedy. I think the Universe contains suffering and compassion. And I think that these things happen on worlds other than our own. That is my conjecture: science is on the verge of discovering life elsewhere. That is the story I want to tell today.

The fact that biology exists in the Universe is remarkable, because life is in the middle of a range of sizes that spans 42 orders of magnitude, from the sub-atomic nucleus, to the largest structures containing thousands of galaxies. What's remarkable is that entities like us, at the middle of that range of scales, can hold both ends of the scale within our heads. The unity of the cosmos is symbolized by the Ouroboros—an ancient symbol found in cultures across the world—the snake that eats its tail. His Holiness has said that both science and the teachings of the Buddha tell us of the fundamental unity of all things. And that is amply borne out by science in the 21st century, and especially in my field, cosmology.

The Universe is a complex place, and it is remarkable that we can understand it at all. I use grains of sand both literally and as metaphors, because each grain of sand under a microscope is a tiny geological world, and yet in our study of the Universe we have to contemplate billions of these worlds. The complexity we see around us seems like magic, but it is not; it is the result of natural forces acting over cosmic time. The complex is actually simple, but the simple can be complex too. To describe something as simple as a pile of sand where you add grains to the top requires chaos theory and complex mathematics. One of the features of our complex Universe is that the parts are not always simply describable in terms of the whole. Emergence is the idea that the whole is more than the sum of its parts, that humans, for example, are more than just the chemicals we're made of. Here's an example: if you have a glass of water, it is obviously wet, it is transparent, it will dissolve things, and it is polar in its chemical properties. But a single water molecule cannot be wet, cannot be transparent, and cannot be a solvent. At what point does water become water? A brain can think, can be self-aware, can know death, and can create. But the components of which it's made can do none of these things. At what point does a brain become a brain?

And I submit the two other aspects that I am talking about are in this same category. The idea of life itself—at what point does something become living? And perhaps the Universe itself—at what point does something become what we call a Universe? To talk about something that has not yet been discovered, which is what life beyond Earth is, we have to use our imaginations, as we do in all forms of science. Scientists and artists and others have been doing this for hundreds of years. In the case of Isaac Newton, he imagined orbits and space travel three centuries before it was possible with technology. Even though we have no close up views of other worlds in space, space artists have been visualizing them for a century. In thinking about biology in other locations, we have to think outside the box, we have to go beyond Darwin and we simply don't know what that looks like.

Imagine that the Universe is composed of things that are, and things that are not, of things that happen, and things that don't happen, and our job as scientists is to find out which is which. The interesting point, both in physics and other forms of science, is that there are things that are possible that do not break any law of nature, which don't actually happen. It's a larger set of possibilities, and we don't know the boundaries of that set. A bigger problem—I'd rather call it an opportunity—is the imagination. It is not machines or robots or automata doing this work, it's people. Our imaginations are bigger than the worlds we imagine, and so we might imagine things in the Universe that are really there, but probably we cannot imagine all the things that exist. We can imagine things that are possible and do happen, and things that are possible but don't. We can even imagine things that are impossible, and there's nothing wrong with that.

How do we know the boundaries between these different sets? Let's start with the basic ingredients. The simple answer is that the Universe was made for life. By far the most abundant elements are hydrogen and helium, and they were there at the beginning. The next most abundant elements—carbon, nitrogen and oxygen—are just those elements that a biologist or chemist would say are essential for life. They're quite abundant, one part in a few thousand. These elements are forged in stars and ejected into space by the death of those same stars.

The story of stars is our story, because we are made of stardust. For almost 13 billion years stars have been living and dying, and their stories are intertwined with our stories because they are made of the same elements from which we are made. In the sense that there has been successively more carbon, more nitrogen, more oxygen made by stars over cosmic time, the Universe has been getting more hospitable for life as time goes by.

What are the simplest things we can say about biology? With biology we have one example to study, and yet we are now wondering about hypothetical biologies. Things can look complicated and not be alive, and things can look simple and be alive. Biologists do not agree on the definition of life, and so as an astronomer, I feel quite comfortable in my ignorance. We can say life has order, that it organizes the chaos of the surrounding environment. Life uses energy, sometimes the direct manifested energy of the Sun; other times it lives further down the chain of life using other forms of life's energy. Life is interconnected in a profound way, in a hierarchy extending from the entire eco-system of the Earth, to individual organisms, down to the sub-parts of cells and the molecules that provide its functions. It has been known for a long time that a simple reductionist strategy in understanding biological systems fails, because behaviors are emergent and can't be understood purely in terms of their components.

What do we need to have life? Most scientists would agree that water is special. We need water. It's not a difficult requirement; water is the third most abundant molecule in the Universe. Not only are carbon, nitrogen and oxygen abundant but water, the medium in which life began and on which life still depends, is available everywhere. Carbon is special, and is the second most abundant element made in stars, and with carbon as the basis for chemistry, the possibilities are essentially infinite. Biology has a tool kit with as many tools as it wants. Did it have to make life that looks like us, or that works this way? Absolutely not, there are other possibilities if we're imaginative enough to think of them, and the Universe may indeed encompass some of these possibilities. It's hard to believe when you stare at or consider the difference between an elephant and a fungus and a butterfly, that these are all profoundly the same thing, examples of the same genetic code. All life on Earth is literally unified. The traditional tree of life was very comforting for our insecurities, because it placed us at the top of the tree, as the natural and perhaps inevitable result of evolution and natural selection over billions of years. In this view, we seem special, and it makes us feel good, but the truth is a little less comforting.

The modern tree of life is based on mapping DNA or RNA, the genetic material itself, and showing how it evolved over those same 4 billion years with gradual deviations. This is a powerful method because it doesn't depend on saying that something looks like something else. You cannot use the species method with bacteria, for example, and most life on Earth is bacterial. The modern tree of life looks very strange; most of the branches on the tree are unfamiliar. Off in the top right, you see plants and animals, but these are small parts of the tree of life in terms of the real estate of genetic information. All the apes, primates, including us, are the tiniest little twigs on the tree of life, a tree that is almost overwhelmingly composed of microscopic organisms. That's good for our sense of humbleness, I think.

We are all brothers in a very deep sense. If you think of marriage within the family, you might think the family you've married into and maybe the children born are half yours and half the other family. Our overlap with other species is much more profound than that; we share half or more of our DNA with yeast and wheat—yeast and wheat are our brothers too. Life on earth is incredible in its degree of diversity based on small percentages of the genetic material. This unity of course is very familiar in the Buddhist tradition where the connectedness of all living things is a foundation idea, but it's the foundation idea of modern biology as well. To go beyond this, I could also say that any two of you in the room, say any two of the Tibetans in the room, have more variations between your two sets of DNA than one of you and an African tribesman, or an Inuit fisherman, or someone who lives in Paris. This is remarkable. The genetic variation between two people, unrelated, living in the same village, is five or six times more than any two people plucked at random from the planet. And we make such a fuss of the tiny little genetic diversity that does exist between individuals.

Life on Earth has found its way into places far more inhospitable than those familiar to us. Some of you may find this room a little cold, but that is because we are frail and weak. Life on Earth can be in places where it rains once in a century. Don't feel bad about being cold, but life elsewhere can exist below the freezing point of water. It does this because it invented anti-freeze so the cells don't break. Life on earth exists in the deep darkness and near the super-heated water of volcanic vents under the ocean, independent of the Sun, so if you've heard someone say life needs a star, that's not true. Life just needs energy of some form. Life can exist with the radiation equivalent to standing 100 meters from an atomic bomb exploding, and it does quite well with that. Such microbes do this by repairing their genetic material hundreds or thousands of times faster than we do. Life can be found in the equivalent of battery acid or drain cleaning fluid. Life can be found 10, 20, 30 miles underground in complete darkness, living off the tepid glow of radioactive material in the rock itself. This is the range of life on one planet, our planet. What might be the range of life on other planets that we've only just discovered? We don't know.

Microbes maybe don't seem interesting enough to spend much time talking about, but remember that we live on a microbial world; it's their world, not ours. When we are gone, they will be quite happy to take it over again. Indeed, there are more microbes in your gut than individual cells in the human body. We represent the end of an outcome of 4 billion years of evolution, with branching points and random influences. It would be very hard to look at life on the early Earth and predict us, especially the last part of the story that led us to develop from the apes, and before that from small mammals that we might not even recognize as very intelligent. Is this a fluke? How likely or unlikely are we, and has anything like us evolved on other planets? The thing that we think might mark us out from other creatures is our intelligence. But even there, it pays to have a little humility, or curiosity perhaps, about other modes of intelligence. Among different species of animals there is a relationship between the mass of the body and the mass of the brain, a very simplistic view of intelligence, of course. In these terms we do not have the largest brains on Earth. We are near the upper edge, but nothing special. There are social insects, whose behaviors are quite complex, whose engineering works rival ours in some senses. The point is not whether an ant or termite is intelligent, but that evolution doesn't stand still. There are many more species of insects than there are primates or animals. Evolution will take them into directions that we can only just imagine. What will be the result of the cooperative behaviors they exhibit after many more years of evolution? Or what might social insects have done, or figured out how to do, on other worlds?

What about the octopus? This creature exists in a three-dimensional maze that is confusing even to experienced human divers. This creature has nine brains, one at the center of its body, and eight at the periphery. This creature's skin is a video display device with a billion pixels. This creature has very complex behavior, and it has some quite clever tricks. The octopus is a cephalopod that diverged from our lineage in the tree of life 300 million years ago. I think of this as the alien among us, who lives on Earth, with whom we cannot communicate. We have no idea if this creature has feelings or suffers pain. We don't know the nature of its intelligence or its mind. While we go out to look for life in the Universe, we should remember what and whom we share the planet with. We should remember the aliens among us.

We are a very egocentric species. For better or worse, this is our planet. We are the masters, no question, but we don't know a lot about the creatures we share it with, and when we talk about intelligence and sentience, and suffering and pain, and emotional states, there is an enormous amount we don't know. As an astronomer, I would speculate that perhaps in 50 years we'll find a planet with life on it. Maybe there is some amazing creature on that planet, just a little bit like an elephant. You know, if we found such a thing, it would be the most amazing discovery. We'd think it was wonderful. We'd do everything we could to understand, study, and preserve these strange creatures, far away. But we already have the elephants, and we already have the dolphins, they are right here, and who knows what goes on inside their heads. For another type of extraterrestrial perspective, let me just point out how recent our supremacy is: the brain size of humans mostly evolved in the last few hundred thousand years. The brains of dolphins and toothed whales evolved over 40 or 50 million years' history, and this is in terms of brain to body mass ratio. What you see is that if aliens have come to the Earth for most of the last 50 million years, and wondered where the brainy creatures were, they would have gone into the oceans. Just in the last million years have we eclipsed the marine mammals. Indeed, our time on top may be short. It's a transient place in the history of the Earth. Impermanence is not just a feature of individuals, but of species as well.

Exobiology is the search for and study of life beyond earth. If we were to find life elsewhere, it would be a revolution equal to the Copernican revolution, which showed we were not the center of the Universe. Since the time of Copernicus, we have found that we are but one star among many, in one galaxy among many. We are not even made of the stuff that the Universe is made of, which is primarily dark matter, the dark energy. The discovery of other life forms would be yet another level of displacement of our centrality in the scheme of things. But I don't think it would be a surprise, and I don't think it will be unwelcome. In this subject we are still in a high state of ignorance. Most of the microbial world is not understood, and I have already told you how amazing some of their capabilities are. We have just poked around the Solar System, studied a few places. These are expensive and difficult missions. We have just begun to find habitable worlds beyond our Solar System. It's a brand new field of research. In terms of searching for intelligent signals, from aliens elsewhere, the search has already begun. For 50 years astronomers have been searching for signals from intelligent aliens. They have heard nothing, a result that's been called the "Great Silence." But the Universe is so large that we cannot yet conclude that we are alone.

We tend to make assumptions because in science sometimes you have to make assumptions in order to progress. But if all we look for is life situated on planets using carbon chemistry, with DNA, or something like it, as a replicating molecule, then we may have missed most of what's out there. I have already mentioned that life doesn't need a star. It's not even obvious that it needs a planet and it might not need carbon. Last, in that outer sphere of ignorance, life might be unrecognizable to us. We have just begun to look outside. This is an image of our home, a famous image made with the Voyager spacecraft looking back toward the Earth from a billion miles away. The pale blue dot is seen here against the rings of Saturn, and we want to know how special it is.

There are places not far from home that are interesting for biology. This is the icy surface of Europa, one of the moons of Jupiter. This moon has a kilometer thick icy crust covering tens of kilometers of deep water; the entire moon is a water world. We have designs that could land a probe on the ice pack, melt through it, and search for life. Not funded, but it's an interesting thing to do. Earth is not the only place in the Solar System covered by water.

This world looks Earth-like. You see clouds, a shoreline, and a river delta. This is Titan, a large moon of Saturn. Titan has an atmosphere, made of the stuff we breathe, nitrogen, and twice as thick. But because it's a frigid world, where the chemistry is based on ethane and methane, if there is life here it would be unlike anything on Earth. Life 2.0.

The closest target for astronomers is of course Mars. Mars has disappointed us, because after decades of speculation and science fiction, we learned 35 years ago that it is a desert, with a thin atmosphere, flooded with ultraviolet rays and cosmic rays that would seem to sterilize the surface. But we have had tantalizing evidence that the arid Mars surface may hide a water world underneath. The water evaporates into space, but we have evidence that Mars can be wet from time to time. And where there is water, there might be life.

Astronomers have finally started to find distant worlds, the first only 18 years ago. For centuries we wondered if there were planets around other stars. Now we know there are. Imagine a familiar part of the sky, the constellation of Cancer, and one of the brightest stars in this constellation, some 20 light years away. We can't visit it with spacecraft, but we can with our telescopes. Going through the Solar System, across the light years, we found a system of four planets, mostly large like Uranus and Neptune. But this Solar System is very far from home, the first, it turns out, of many. How have astronomers done this? By a clever trick, the planet itself is invisible. Earth as seen from afar would be a billion times fainter than the Sun, Jupiter a hundred million times fainter. We cannot see the planet by reflected light. Instead, we see the planet by the wobble it exerts on its parent star by the force of gravity. So we look for the wobbling star, and infer the planet. If the orbit is like this, we have an additional possibility, which is to observe the slight dimming of the star as the planet crosses its face. Both of these effects have now been observed over a hundred times, and that's how we know there are planets around other stars. We also know, in this case from theory, that these are going to be "water worlds," many of them. Some will be baked dry like Mercury; some will be frigid worlds as in the outer Solar System. But a substantial number of Earth-like worlds should exist according to theory and computer simulation.

Here is the state of this exciting field just 15 years after it started: each red dot in the graph is a planetary system. In many cases, multiple planets have been found. This line shows you how the detection has improved in the last few years from Jupiter towards Earth-like planets. We are approaching the detectability of Earth-like planets. NASA's Kepler Satellite is going to fill in that space. Finding an Earth-like planet is exciting, but how would we know if it's alive? It is, after all, likely to be tens of light years away, maybe hundreds. This is how we will find out: we will take that feeble reflected light from the planet, and spread it into a spectrum, and look for the indicators of life indirectly. You can see the spectra of Mars, Venus, and the Earth. They all show carbon dioxide, but Earth alone shows a very strong signature of oxygen, ozone, and water. The oxygen is the tracer of life on this planet. If the biosphere shut off overnight, if every living creature died, the 20% of oxygen in the atmosphere would disappear in less than a million years, a blink of an eye geologically. It is sustained only by the biosphere. Reversing that, we want to look for oxygen and ozone and other gases as indirect traces of life. The Earth-like planets we find won't exactly be like our Earth. They will be subtly and interestingly different. And I have to break one piece of bad news to you: finding another Earth will not relieve us of our obligation to look after this one because the next nearest Earth will be tens maybe a hundred of light years away with no way to go there if we mess up this planet. We could, however, potentially communicate with other beings on those worlds if they exist. Let me now get to the last part of my talk, the frontier of the subject.

Microbes are interesting, but there is a sense of companionship that we are looking for here. We want to know if we are alone, or not, and what that means. Here is the perspective on the number of worlds in the Universe we think might host life based on current research. The number of grains of sand you might hold in your hand is the number of stars that have been inspected for planets. The number about which we have enough information to show they might be habitable in terms of our form of biology may be less than a hundred, or the number of grains of sand that would stick to your finger. Projecting into the Milky Way, the number of habitable worlds is the number of grains of sand in a sand box, each one potentially hosting biology, each one potentially hosting sentient creatures with hopes, dreams, fears, longings, unknown to us. These grains of sands are representatives of just our galaxy. In the Universe there are a hundred billion galaxies. The number of habitable worlds in the Universe is the number of grains of sand on a long beach. How significant is our life then if a modest fraction of these worlds are alive? The number is a billion habitable worlds in the Milky Way, a hundred million of which are roughly Earth-like. The complete census is a billion billion in the Universe. What odds would you place now on us being special or unique?

The bounty of astrobiology is not just about space—it's about time. Life on Earth started about 4 billion years ago, but the Universe had 8 billion years before Earth even formed to be doing biological experiments. In other words, there could be creatures that got to our stage of evolution and then went on a few billion more years. What would that be like? We don't know, and I don't even think it's possible to visualize that many inhabitable worlds. If we spent just five seconds looking at each habitable world in the Milky Way—just one galaxy—it would take 10,000 years of inspection. Space travel is in its infancy; for now we will just have to use our imaginations.

In advance of finding life anywhere else, and without knowing whether that life would be intelligent, astronomers are trying to communicate by sending messages into space. These attempts at communication might seem feeble, and they are more symbolic than anything else. This plaque or picture is attached to the first spacecraft to leave the Solar System. It's our message in a bottle, now 12 billion miles from Earth. But even as fast as its feet can carry it beyond the edge of the Solar System, it will be a hundred thousand years before it approaches another star.

We have even sent a record into space with 110 of the world's languages represented, with our music, with images of us. It represents us, but again it may not be a realistic attempt at communication, especially when the aliens are likely to have unknown function and unknown form. Other attempts involve radio telescopes, which are efficient ways to send information across the gulf of interstellar space. Experiments have improved dramatically because of Moore's law, the advances in electronics, and the ingenuity of the people who conduct these experiments, but we have heard nothing. Now they are listening rather than sending, and they are not discouraged because the capability is improving so rapidly. To put a number on that, if there were civilizations on any of the nearest hundred million stars the lasers or radio telescope technology that we have now are sensitive enough to detect them.

What are the forms of alien life? I have no idea. I do not think they have been represented in science fiction, and I am pretty sure they are not represented on TV or in the movies that I have seen. I think they are maybe stranger than we can imagine. It's motivating, however, to look for such creatures and to wonder what we might learn from them. The physicist Enrico Fermi posed a very interesting question 60 years ago. Recognizing that our technology is young and that we are unlikely to be the first intelligent civilization in the Universe, he asked: "Where are they?" Going further, a very modest extrapolation of our technology will let us travel beyond our Earth, either physically or with our robotic eyes and ears. In fact, Fermi also knew, even then, how many likely sites for life there would be. The question is where are they? It is well posed and one answer is that we are indeed alone, truly alone, which would be an amazing outcome in our vast Universe so seemingly full of biological potential. We might hope to learn from such species, if we find them. Do they share our fears and dreams? Are there civilizations that have compassion, but no suffering? What happens out there in the multitudes of the planets? We still need to get over ourselves a little more, remembering that the aliens may relate to us as we are to bacteria, or they may not be interested. Or they may think of us in a slightly different way, one less comfortable. Perhaps to them we are food. Going there is not yet on the cards; our space program is in its infant stages. Having been part of teaching the first cohort of monks in the leadership program, I know whom I would choose as our next cohort of astronauts, remembering that space is hazardous and things can go wrong when you are an astronaut. I would like to see monk astronauts if we are serious about space travel.

I think we will get there eventually. If we look at the history of transportation, we might project that in a century so we will be able to travel to the stars. Whether it is with robots, or by ourselves, we will find out the answer. If there is companionship there, we will find out. It may take a while, but again, if anyone got to this stage before us, they could, in a very short time, just a few million years, travel the galaxy. These would be the ancients of the galaxy, the wise ones who have been there, who have been everywhere.

In the end, having posed a few questions, as in all good science, more questions are raised than are answered. In a Universe with ten thousand billion billion stars, and an enormous number of habitable planets, it is therefore very likely, given the raw ingredients, that a myriad of life forms may exist. We do seem special in some ways and we should treasure that. But we are not special in any cosmic sense. And astronomy, of course, has not yet been able to answer the question that underlies all these considerations, a question that lies beyond the domain of science: Why are we here?

Discussion

Rajesh Kasturingan: You were saying how difficult it is to map out the potential signs of life, or the elements that might make up life. With the use of modern technology, couldn't we do a massive data mining of the various spectra and automatize some of the search—so what Google does for web searches, couldn't we do the same thing in searching for life on other planets?

Chris Impey: That's a good question. Yes, but only at the level of finding planets. With zero planets detected before 1995—and now approaching 1,000—we are harvesting planets easily. Indeed, the citizen scientist, or the public, can even get involved in these efforts. The trouble is that the next step of the game of finding life signs on a planet is very much harder. Analyzing the spectra of planets' atmospheres is ultimately harder than detecting a planet in the first place. If I may use an analogy: if the Earth is the size of a soccer ball, you are looking for something that's the size of a soccer ball and a 100,000 miles away, and it is also next to a light source that is a billion times brighter than the soccer ball. So it's very hard for telescopes to isolate the spectrum from a planet that is in such close proximity to the star, and we are still five or ten years away from finding a facility that can attempt it. In a sense, that's why the radio astronomers searching directly for intelligent life feel they have a slight advantage. Though they spend a lot of time looking at noise, any potential signal they might observe is likely to stand out above the noise and wouldn't be obscured by the parent star.

Monastic Graduate: I have two questions and they are interrelated. Scientists have made many great achievements and one of these achievements is finding other planets. My first question is: Since there are so many things that we need to learn about our planet, so many problems here at home, why are scientists so interested in looking for another planet, or other planets, in other solar systems and in other parts of the Universe? My second question is: If somehow we happen to find a planet with life on it, do we have any plans, or do scientists have any plans, to help sentient beings on those other planets and how will we, the people on Earth, benefit from that kind of discovery?

Chris Impey: In response to your first question, part of the answer is very simple; it's just pure curiosity that causes us to look beyond ourselves and our immediate situation. I guess the analogy I would use is the way humans spread across the earth 50 to 100 thousand years ago, starting with less than a million humans coming from Africa within a very short time, and hundreds of generations spreading across Asia, through the Americas and to the southern tip of South America. They didn't have to; it would have been more comfortable, if they had cared about comfort, to stay where they were. For example, on the way from Siberia to Patagonia, they passed through southern California; why didn't they just stay there? I think you know. We are curious, and that curiosity is built into our DNA, and some part of it we express outwards. Another answer, the scientifically practical answer, is that sometimes it's easier to look out than look in. The deepest hole we have ever dug in the Earth is no deeper than the thickness of the skin on an apple. It's very hard to do, so even learning about our own planet directly can be harder than looking out with a telescope. Then a third, more philosophical, reason we do it when we have so many problems at home, and why it's not a bad thing, is that it speaks to our cosmic situation. It tells us more about ourselves, if we are alone, unique, or part of a tapestry of life that also exists elsewhere in the Universe.

That gets us to the second question. Because it's such a new science not as much thought has been given to how we will behave, or what we will do, if we discover intelligent life. But some thought has been given to ethical issues of life beyond Earth, for example, and this may surprise people. NASA has given a lot of thought to exploring the Solar System and not contaminating it. Every mission that goes to Mars, now and in the future, will be designed not to contaminate Mars, and to clean up after the mission, leaving no debris. Of course, enormous protection is planned if we ever bring a Mars rock back to the Earth in case the microbes that it might contain would hurt us, so there is the idea of protection. Within the space community there is a tension between two ideas. The first idea is that space is there for us to take—that just as civilizations on the Earth traveled around the Earth and made empires, so we will take asteroids, take other planets. There is also a movement in the space community that wishes not to alter anything, to never alter a world you find, to just look at it and learn without changing it, not just Mars, but everywhere else as well. The ideas are now forming of how to protect and preserve and learn. Then, of course, there is a hope that we might learn something really substantial if we ever found a certain intelligent life form. It would be something really important for us. It's unlikely they would know exactly what we know, or feel what we feel. Fear should not govern us in this. It would be bad for us to be afraid. Stephen Hawking has famously said that we shouldn't tell them we are here with radio and telescopes, because they might come and destroy us. I don't agree with him.

Monastic Graduate: When you talk about evolution on this planet, and living beings evolving from a single cell to large mammals, which organisms have evolved the smallest and largest brain sizes? And is there more to intelligence than just brain mass?

Chris Impey: I am not a neuroscientist, but there are large marine mammals, for example whales, that have bigger brains. But brain function is not simply related to size. Brains have evolved over more than half a billion years. More interesting to me is that there could be other architectures of brains that we really don't know how to measure, and so size could be a completely unreliable measure of brain capacity or sophistication.

Geshe Jangchup Choeden: I appreciated your presentation—very beautiful. Astrobiology is quite a young field of science so from that point of view I think it could be very difficult to be sure that there is life out there. You presented Fermi's question. He appears to believe that there is life out there. The question is, where? It's not like asking is there any life out there? That's a very different question. What is the logic behind Fermi's position?

Chris Impey: You raise an important point. I will generalize, but I have talked to enough scientists to know that there is truth in the generalization. Life scientists tend to be much more pessimistic about the possibility of life elsewhere than physical scientists and astronomers. I think that is simply because life scientists look at the many conditions that apparently had to be satisfied, the twists and turns in the path of evolution, the fact that life on Earth was simple for a very long time, and took a long time to become complex and intelligent, and even then, intelligence exists in only a small number of species out of millions and millions. They would consider it unlikely. But there are also people who look at the other side of the coin. The astronomers say the ingredients are everywhere, the conditions are everywhere, on one planet life radiates to every possible evolutionary niche and some that are hard to imagine. Thus, if you give it another environment, it will just do something different. But there is no way to win that argument. Science is empirical; you have to see, you have to go and look. There are reasonable arguments on both sides. I recognize the strength of each side, and that to me is the reason one is compelled to look, however hard it is. As for knowing for sure, you're right, evidence for a habitable planet is in our hands now, and out of the known 1,000 exoplanets about 50 are habitable. We have habitable planets, in a traditional sense. Some are within two times of the mass of Earth, but saying they are habitable and saying they are inhabited is much harder. The experiment will take like 10 to 20 years, but I think it will happen because there is much motivation to do it.

David Presti (Moderator): There are a large number of very interesting questions from the audience, and we will try to get to them now. Several of the questions speak in a very interesting way to interface, to the connections between mind and cosmology that are relevant to the topic of astrobiology. We may defer those questions until later today, and ask a simpler one now. As you mentioned in the beginning of your talk, even biologists disagree on how to define life. To the best extent possible, how would you define a living entity, and are there any scientific studies that are trying to create life, or the basis of life, in the laboratory, and doing that with elements that are not the standards, such as carbon, oxygen and nitrogen?

Chris Impey: In the 1940s Erwin Schrodinger wrote a book called *What is Life?* He used the informational, thermodynamic argument that life is something that can harness order from the chaos of the natural environment. It organizes, and essentially stores information, and propagates, and the last ingredient is evolution—a mechanism to evolve the information. If you just call it information that liberates you, because DNA and the genetic information of human organisms and all creatures on earth is one genetic code. However, there are many possible genetic codes, and there are other ways to code information other than macromolecules. The theorists of the subject, theoretical biologists, a small breed, actually try to imagine very different bases for life. The more extreme view is that life doesn't need biology at all, that you could have information organized in other ways, perhaps physically through electric or magnetic fields, and other means. This sounds like science fiction, but science fiction is based on science too. There is much speculation because we start with the thing we know but we don't want to get stuck there.

In terms of the second question, the question is whether we can tell the story of how we got here. It's very important to be able to tell that story scientifically. The answer is not yet, because the story is lost in the mists of time. Can we trace the pathway from molecules with 20 or 30 atoms, which exist naturally on the early Earth, to a developed, living cell? The answer is no, not in the lab. Scientists did experiments in the 1950s, and they have been updated, but they have never reached anything like a replicating molecule. A series of lab experiments in the last two decades have basically taken pieces of the puzzle, and if there is a linear path between big molecules and a simple cell, we have paved with lab experiments 20% of that road, maybe 30%. It's been shown, for example, how molecules can become more complex naturally, on clay surfaces, which is a template for reproduction. It has been shown how oily material and water naturally form proto-cells much smaller than present day cells, and that those cells will concentrate chemicals, increase the rate of reactions and naturally subdivide. But bridging the gap from simple molecules to a chemical form of natural selection is actually a very hard task, and may never be done in the lab. All these events took place on the surface of the earth 4 billion years ago, and there is essentially zero evidence remaining because it's almost impossible to find rocks that old; the ones you do find are tortured by volcanism, heat and pressure. There is no trace of what happened; this is an historical science, not an empirical science in the normal way.

David Presti (Moderator): A composite question from the audience. If there are indeed many potentially inhabitable worlds even in our own galaxy, and if there have been billions of years of evolutionary time available before the formation of life on the earth, there may have been time for many advanced civilizations to develop and explore the Universe. Is it possible then that many of the phenomena that are often attributed to extraterrestrials here on Earth could in fact be true? And do astrobiologists and cosmologists interested in extraterrestrial life take those kinds of reports seriously?

Chris Impey: These are important questions because in popular culture and media there is widespread storytelling involving UFOs or alien visitation. The ironic situation is that while most astronomers might believe on statistical grounds that there are likely to be intelligent civilizations somewhere in the galaxy, they equally believe they haven't visited Earth. But, with so many individual reports that would need to be refuted, I could not discuss this in the next few minutes, or even the next few hours.

In general, extraordinary claims require extraordinary evidence. If scientists claim to find microbial life in another world, those claims will be scrutinized at a very high standard before they are believed. For claims that intelligent aliens visited the Earth to be validated, they require the highest standard of critical review. Because there is a complete lack of physical evidence that could be analyzed in independent labs, this presents a fatal flaw for the UFO cases, fatal. Photographs are not significant evidence. Eyewitness reports are famously fraudulent, even if they were not made with the intention to mislead. I won't and can't discard all of the anecdotal evidence, but as a scientist you have to put all your effort where the most benefit lies and where the most fruitful exercise is for the scientists involved.

Another answer, and maybe the most likely one, is that we are very isolated in time and space. The great distances between worlds in time and space are difficult chasms to overcome with technology, even technology that far surpasses ours. The energy requirements are bounded by robust laws of physics. The isolation aspect could be significant, and may indeed be the case.

Another answer is simply because they don't care. For example, dolphins and orcas, I believe are intelligent, are sentient, have emotional states. There is evidence that elephants are aware they have mortality. But these creatures, as far as we know, even if they evolve, will not develop telescopes and spacecraft, and that's not a fault of their own. If other planets have such creatures, we don't know about them.

There is even a cultural layer, the business of very active exploration in the history of the world, from colonization to exploration of space, which in our culture has its genesis in a bitter super-power rivalry between the United States and the Soviet Union. Lots of weapons were created. This landscape of projective exploration, and often conquest, is a very Western mode of operating, and maybe if these activities had been more informed by Buddhist philosophy in the mid-20th century none of that would have happened. We wouldn't have the space program, we would have tried to take care of business on Earth, and maybe other creatures elsewhere are doing the same thing and therefore we don't know they are there.