PART 1:
The Stars & The Osprey

UNDERWRITER ANNOUNCEMENT [00:00]

ANNOUNCER:
This program was made possible in part by the John Templeton Foundation. The Templeton Foundation supports academic research and civil dialog on the deepest and most perplexing questions facing humankind.

STARRY NIGHT [00:15]

ALAN LIGHTMAN: My name is Alan Lightman. I'm a scientist and a writer. My family has a home on a small island in Maine. The island has no roads or bridges and there's no ferry service. One summer night, in the wee hours, I was coming back to the island in my boat. I was alone on the water. I was captivated by the quiet... and the stars overhead.

I decided to turn off the engine. I lay down in the boat and looked up. After a few moments, my world dissolved into that star-littered sky. The boat disappeared. My body disappeared. And I found myself falling into infinity. I felt as if I were part of the stars. I was merging with something much larger than myself. And the vast expanse of time, extending from the far distant past, long before I was born, and then into the far distant future long after I'll be gone... seemed compressed to a dot. What was happening to me?

As a scientist, I used to think that everything could be reduced to numbers. But at that moment in the boat, I believe you could have hooked up every neuron in my brain to a giant computer, and all of that data wouldn't have come close to explaining my experience. After a time, I sat up and started the engine again.

And so began my personal journey to understand how these different worlds relate: The world of atoms and molecules and the world of complex human experiences. In a material and impermanent cosmos, in the age of science...

What is it that has meaning? And how can we find it? My quest would lead me to the laboratories of Nobel-prize winning scientists, to conversations with philosophers and ethicists, and even to the private chapel of the Dalai Lama.

PROGRAM/ALAN INTRO [05:02]

That experience in the boat happened years ago. And I'm still trying to understand it. I'll confess, I'm still a materialist. I continue to believe that the universe is made of atoms and nothing more. But how could a thing made of atoms, and only atoms, feel what I felt in that boat looking up at the stars, or be entranced on misty mornings when the air shimmers with light... or feel part of ancient Earth when looking out over the ocean?

BIOLUMINESCENCE [05:50]

I've always loved the ocean.

My grandparents had a beach house. And when I was a young boy, I went for a visit. One evening I walked out on a pier, and I took a stick and waved it in the water. The ocean started glowing. I was totally mesmerized. I thought this was pure magic.

I scooped up the water and shouted to my grandparents that I had discovered something fantastic. After the water settled, I saw tiny bugs swimming around. And I realized that this magical glowing was coming from these little creatures in the water. I was a little disappointed, but I also thought: "Wow! Nature is capable of some pretty amazing stuff."

At the same time, I saw the material cause of that amazing stuff.

CLOCKWORK UNIVERSE [07:10]

What does it mean that our world is just material? And that everything follows the laws of cause and effect?

Is the world just one giant clock? Wind it up, and it ticks away, one cog linking to another?

As a scientist, I don't believe there's anything outside the material world, or any super-natural forces. But what about our consciousness? Our thoughts? Our paintings and our symphonies?

Our falling in love? Could all of that come from mere material, mechanically following the laws of cause and effect?

ALAN LIGHTMAN & ROBERT DESIMONE DISCUSS RESULTS [07:58]

And if everything is material, could neuroscience explain my starry night experience?

I recently had a brain scan and I was looking at this image, which is like what I saw that night in the boat.

ROBERT DESIMONE: Ha ha ha! Okay.

ALAN: And can you show me what my brain was doing?

ROBERT: What you are seeing in these areas that are shown in bright orange and yellow, this is the part of your brain that was active when you were staring up at the stars.

ALAN: What can you tell me about that experience that I was having by looking at that picture? That's what I want to know.

ROBERT: It tells me that, first of all, you were not using the problem-solving parts of your brain.

ALAN: So, you can tell that I was reflecting by looking at this picture. Can you tell what I was reflecting on?

ROBERT: No. Ha ha ha ha! That's beyond our capability, right now, is to get the exact content of your self reflection.

ALAN: In addition to the fMRI, I was scanned in the M-E-G. Magnetoencelography reveals the millisecond-by-millisecond changes in electrical flows in the brain.

ROBERT: So, with the M-E-G, now you're getting this very fine temporal time course, and you can see the activity is changing rapidly, you know, as you're having different thoughts at different moments in time.

ALAN: But when I was lying in the boat, looking up at the stars, it didn't seem to me like things were happening rapidly. In fact, I didn't have any sense of time at all. I just felt this overpowering connectedness. Is there any way that I could see that in these, these blips here?

ROBERT: You may have felt that there wasn't a lot of activity going on in your brain, but I think that's the illusion.

ALAN: Well, I have to confess that even though I'm a scientist and a materialist, somehow seeing these wiggles it doesn't satisfy me that that has captured the experience that I had lying in the boat, looking up at the stars and maybe I'm just romantic, but it doesn't feel fully satisfying. Isn't it possible to have transcendent experiences and still believe in a world made only of atoms and molecules? I came to that belief quite early.

PENDULUM [10:37]

I was probably 10 or 11 when I built a laboratory of my own. I had read in a magazine somewhere that the time for a pendulum to make a complete swing was proportional to the square root of the length of the string. And so I made pendulums of different lengths. I timed their swings and lo and behold, this law that I had read about was true. It's enormously satisfying to prove something for yourself. It gives you a feeling of power that you can discover things on your own. That pendulum law was first discovered by Galileo around the year 1600. But I believed this law, not because the great man Galileo had discovered it, or because I had read it in Popular Science. I believed it because I had verified it myself.

ALAN AS POET, PHYSICIST, AND BLACK HOLES [11:49]

But I was always interested in the arts as well as in science. At age 13 or 14, I began writing poetry. I expressed in verse my loneliness, my admiration for a lavender sky.

When I got to college, I quickly discovered that I was a disaster in the laboratory. When I built things they blew up or they caught on fire. I realized that I would be a better theoretical physicist than an experimental one. Shortly after I started graduate school in physics, the first black hole was discovered in the constellation of the Swan. It was called Cygnus X-1. I calculated how gas would swirl around a black hole, and the tell-tale radiation it would produce. In the grand scheme of physics this work was not a big deal. But I had the extraordinary experience of discovering something completely new. Black holes are really spectacular. I mean, they're amazing. One of the most amazing objects in nature.

"PUSH THE BUTTON?" [13:05]

I wanted to talk to some leading scientists about their experiences with discovery. What did they find most rewarding? First, I returned to the McGovern Institute of Brain Research at MIT, which is headed by Robert Desimone. I asked him whether, if he could push a button and get an answer to the biggest questions about the origins of consciousness... Would you push the button?

ROBERT: Darn right I would! Ha ha ha ha! I'd push it in a millisecond! Are you kidding?! I think we still have a lot of work in front of us because at the end of the day, we don't just want to understand our brains, we want to be able to help people and we want to be able to cure problems.

ALAN: Fabiola Gianotti is now Director-General of CERN, the giant particle accelerator in Geneva, Switzerland. She worked on the discovery of the Higgs Boson, a fundamental subatomic particle. Would she push the button to learn the final laws of physics?

FABIOLA GIANOTTI: I think no, I would not push the button because I think what is important is not only the ultimate goal, but also the incredible path to get to there. And this is part, it's very much part of what we do as human beings. So I think equally fascinating is the path that brings us to there.

ALAN: Rai Weiss is a Nobel laureate for his four decades of work to detect gravitational waves, an achievement so difficult that even Albert Einstein thought it impossible. Would you push the button?

RAI WEISS: Of course I would. I'd want to find out. There's no danger in it. Of course, I'd push that button.

ALAN: Nergis Mavalvala is an immigrant from Pakistan. She's a MacArthur genius, and the first woman to be Dean of Science at MIT. Nergis has been a major contributor to building the instruments that detected gravitational waves.

Push the button?

NERGIS MAVALVALA: Absolutely not. I would break the button because part of the journey is peeling back the layers to see what's, you know, what's down there. And I personally think, you know, nature will always have more to reveal. So, no. I would not push that button.

I may, you know, just give it a tiny tap just to see what the next thing is, but not go all the way.

ALAN: So many of these leading scientists mentioned the human dimension of science echoed by philosophers, and faith leaders...

HIS HOLINESS THE DALAI LAMA: Good morning!

ALAN: Like His Holiness the Dalai Lama.

DALAI LAMA: It is very useful, very good, now modern time, you see, now we simply not holding past belief. But, you see, always think, and investigate, investigate. That is good. That is sign, sign of progress.

If we just contented with what we believe for centuries, and then no further development. So, investigate, open mind, investigate. It's very useful. Very helpful.

ALAN: Rebecca Goldstein is a philosopher and novelist. She's also a MacArthur genius.

REBECCA GOLDSTEIN: We are nature coming to know itself. We are nature. We work according to the laws of nature. I find that awesome, like really awesome, wondrous, that through us nature has self-awareness.

NATURE AND THE MIRACULOUS [16:58]

ALAN: Rebecca's comments reminded me that we humans are not looking at nature from the outside. We're looking at it from the inside. The over-arching trees above us. The swift flight of birds. The slow motions of bugs. The way that sunlight shimmers around leaves. When we take the time, we can reconnect with our ancestral selves and the long chain of lives stretching back to primeval oceans and unblemished land. And here we are, now. Each of us is a very, very special arrangement of atoms and molecules. As an astrophysicist, I've learned how rare life is in the universe... life in any form. Even if we assume that most habitable planets have life, I estimate that only one billionth of one billionth of all matter in the cosmos is in living form. That's like one grain of sand on the Gobi Desert. Just think of that. Matter in living form is one grain of sand on the Gobi Desert! And the fact that we're here at all, why is there something rather than nothing? That's miraculous. So I don't believe in miracles. I don't believe in the supernatural, but I do believe in the miraculous.

We're not only that rare arrangement of atoms and molecules that pulses with life. We're living things with minds. We ask questions. We look for meaning. Humans have been searching for meaning for a very long time.

FONT-DE-GAUME AND LA FERRASSIE [18:57]

There are places on Earth where we can see evidence from long ago of what it means to be human. This is one such place, Les Eyzies, in the Dordogne region of France.

These caves were home to some of my ancestors and possibly some of yours, maybe 20,000 years ago. Their DNA remains in our bodies. I'd love to sit in a fire-lit cave with these people for an hour, and just acknowledge that we are connected in time, blood into blood. I don't know their names, but they lived those relatives of mine. Hand drawn shapes swerve and flow, following the natural contours of the stone walls.

One painting in particular captures my attention, an entire bison drawn from what appears to be a single flowing line. Making these images could not have been easy. Even today with flashlights, it's a challenging walk of several hundred yards, back into darkness. Imagine doing that with just a flickering, burning branch. Not only that, but some of the images are high above the path.

How did they reach that rocky canvas? And why did they make these paintings? At a time when life was brutish and short, were they trying to leave something behind, some piece of themselves that would last? In addition to these gorgeous paintings that showed great skill and artistry and a need to create and express what they were seeing in the world around them, this symbol here shows that they had the ability for abstract thinking. We don't know what it means, but surely it had some kind of meaning. What were they

thinking these early humans? Did they believe in an ethereal world? Did they believe in the invisible? What did they think of thunder and lightning... the sky overhead... their own beginnings and endings?

I wanted to learn more about early humans' use of symbols and how they treated their dead. I met with local expert, Bruno Maureille, at a nearby site called La Ferrassie. Eight skeletons were found at this site from a fetus to a mature adult male known as "La Ferrassie One." The placement of that body. Can you tell how it's placed, was that intentional or accidental?

BRUNO MAUREILLE: No. It was intentional. To do an intentional burial, it's something which is unique to humans. You can see here, we have the head of the individual. We have the left upper limb, the right one. And he is more or less in a kind of a semi-fetal position. So it is a position which doesn't seem to be natural if someone would have died accidentally. So we are considering that it was really an intentional burial, made by Neanderthals many thousands years ago.

ALAN: So, tell me the meaning of this photograph.

BRUNO: Oh, yeah. So here we have an engraved representation of a female sex, which is more or less 40,000 years old. It has been discovered at La Ferrassie on the block of limestone.

ALAN: That would suggest to me that these early humans were capable of some kind of abstract thinking since they used symbols rather than literal pictures?

BRUNO: For sure. No problem with these people.

ALAN: Do you think that symbolism was somehow connected to meaning for them? Their attempt to find meaning in the world?

BRUNO: For sure. Their representations are related to the seasons, to the different seasons of these people. So there, there was something, there was a meaning...

...which was a new comprehension of the natural environment. Humans were naturally consider themself as a part of this nature.

The thing which is interesting at La Ferrassie is that we have these Neanderthal burials which means that they have more or less the same idea of the consequences of the death of a member of the group. And they're wanting to protect the dead individual.

GALILEO & THE TELESCOPE [24:12]

ALAN: Everything in the universe is impermanent and passes away. Even the stars eventually burn out... and turn into cold embers floating in space. But we human beings

have always longed for permanence.

We build cathedrals to last for centuries, and we believed that at least the heavens were permanent. The person who dispelled that belief was the Italian mathematician and physicist Galileo Galilei.

I'm in Florence, Italy, where he lived most of his life. Galileo is considered the first modern scientist. He started by experimenting with everyday objects, rolling balls down slopes, and observing pendulums. And around the year 1600, he discovered the law for the motion of pendulums, the same timeless law that I verified myself as a boy four centuries later. But what really brought me to Florence was Galileo's revolutionary work with the telescope.

The sixteenth and seventeenth centuries were a time of new ideas about light, perspective, and the appearance of things. Painters were experimenting with converging lines in their pictures of the world, showing how perspective could arrange things in space. Scientists measured the speed of light. The telescope was the jewel of these discoveries. Crude spyglasses had been invented in Holland, but used only for military work. Galileo realized that by varying the placement of lenses and the length of the tube, he could improve the design and make things appear much closer than they would appear to the naked eye.

I wanted to see Galileo's original instruments, preserved in this museum. The ancient Greek philosopher Aristotle thought that the Earth was the center of the universe and that the Moon, the Sun, and the stars sat on surrounding spheres. According to Aristotle, the heavenly bodies were all made of some immortal, perfect, indestructible stuff, which he called the "ether." The Moon was a pure white sphere in the sky.

There they are: the only two surviving telescopes made by Galileo himself. He was one of the very first people to point a telescope at the sky. It amazes me how simple Galileo's first telescopes were. Pretty much just a tube with two lenses. But with these simple instruments Galileo saw craters on the Moon and spots on the Sun. He forever changed our conception of the heavens, and our understanding of where we humans fit in the universe. Galileo first published his observations in "Sidereus Nuncius", which means the "Starry Messenger."

Paolo, I've been told that this is an exact replica of Galileo's telescope. It, it is a beautiful object...

PAOLO GALLUZZI, HONORARY PRESIDENT, MUSEO GALILEO: Beautiful object.

ALAN: If I, um, look out of this telescope, the... the field of view where... the amount that I can see is very small. It's like holding a dime at arm's length.

PAOLO: Yeah.

ALAN: Was that a problem for Galileo?

PAOLO: It was a big problem because you can imagine you see on "Sidereus Nuncius" this drawing of the full Moon. But he couldn't ever see through the lenses of the telescope, the full Moon. He could see one third of the Moon at a time. So, can you imagine the mechanics of drawing these pictures? I mean, he had to look at, try to memorize what he saw, go to the piece of paper and, and trying to... to create in a disc one third. And then he go back again, and try to focus on the second third. And going back. So, such a terribly difficult thing.

ALAN: Why do you think that the "Starry Messenger," the "Sidereus Nuncius", today is not given the same respect as, say, Darwin's "Origin of the Species" or Newton's "Principia"?

PAOLO: The "Sidereus" has a different organization. It's just a kind of report of experiments. Moreover, the "Sidereus Nuncius" has been written in less than two weeks. And, we are scholars, and we know that writing a book in two weeks is quite a challenge, especially crucial book like this one. And this was, of course, under the pressure of the fear of being anticipated by others, and might have discovered the same things, or more things than he could. So, he had to be as fast as possible in spreading the news. "Nuncius" means news, spreading the news. And so he wrote as quick as possible.

ALAN: Sounds like Google and Apple rushing new products in the market!

PAOLO: New products, "breaking news." Ha ha ha.

ALAN: Are there any signs when you look at the book that it was written quickly?

PAOLO: Many signs, Alan. You see that while he was going to the printer to check the proofs, the galleys of this book, he was still at night looking at the stars, and he was discovering new details, but the book was already printed. So, if you go to page 18, after page 18, you see these two pages...

ALAN: No, no page numbers.

PAOLO: No page numbers. What means this? And the page numbering starts again after these four pages following the earlier one, which means that it has been added. So this, this is quite a mess, this book.

ALAN: Maybe quite a mess in pagination, but quite revolutionary nevertheless, no?

PAOLO: Well, the "Sidereus Nuncius" is a milestone in... nobody can discuss that. I mean, 1610 is a... is a milestone in the history of the development of human

understanding of nature.

ALAN: Why do you think that Galileo's discovery was so revolutionary?

PAOLO: Well, it was changing something that for millennia were believed out of dispute. And imagine that the Moon was totally different from what poets, scientists, literary man had described before, was something that was really breaking news. Nobody would've ever arrived at imagining that there were valleys and there were mountains on the Moon. I imagine the first readers of the "Sidereus" were struck much more from the few images than by the descriptions that he was giving or what he observed.

Alan leaves the Museo, carrying a replica telescope.

ALAN: But after Galileo, the heavens were no longer heavenly. Galileo realized that the Moon and Sun are not perfect bodies. The immortal ether didn't exist. Everything in the cosmos is made of the same stuff. And everything passes away.

I wanted to see what Florence would look like through the replica telescope, from high up on San Miniato. Galileo's story had me thinking about permanence and impermanence. Why do we human beings long so for permanence, against all the evidence presented to us by nature? What's the point, I ask myself, of something that's here today and gone tomorrow, like a meal, or a letter, or a pair of shoes? Or a human life? A flicker in the vast hallways of time.

I think we associate permanence with meaning. We also associate permanence with divinity and perfection. But isn't perfection a manufactured idea? Nothing we see around us is perfect. Maybe the moment is all there is. Maybe I should be content with the moment.

In my opinion, one of the most important implications of Galileo's work was the realization that heaven and Earth are made out of the same material. But Galileo couldn't have known that everything is made out of the same atoms, forged at the centers of stars. That conclusion would have to wait three and a half centuries for modern physics and astronomy.

"BIG BANG TO US" [33:56]

One enduring and provocative question: where did it all come from? The planets, the stars, and, of course, us. Where did it all come from?

It's a long story. In 1929, American astronomer Edwin Hubble confirmed the astounding fact that all the galaxies are moving away from each other, like dots on the surface of a balloon that's being blown up. The universe is expanding. Before 1929, most scientists, including Einstein, thought that the universe was static, eternal and unchanging, with

no beginning. But Hubble's discovery showed a universe in motion. Physicists worked out the math that described a universe that was changing in time. If the expansion of the universe is run backwards, the galaxies get closer and closer together. The universe grows more and more dense, and hotter and hotter, until a definite time in the past when all the matter of the observable universe was squeezed into a region smaller than a single atom. About 14 billion years ago. The Big Bang.

We physicists believe that the infant universe consisted of rapidly fluctuating energy fields.

Some of that energy turned into subatomic particles, like raindrops condensing out of a supersaturated cloud. At the same time, the universe was rapidly expanding and thinning out. In the first few minutes after the Big Bang only the smallest and simplest atoms were created. The universe was thinning out and cooling too rapidly for any larger atoms to form. The creation of those atoms, like carbon and oxygen, would have to wait a couple of hundred million years for the first stars to form, and later the first galaxies. Inside vast clumps of gas, smaller regions collapsed under their own weight, forming dense hot cores. Eventually, these cores became hot and dense enough to start nuclear fusion reactions. The first stars were born.

In the life of more massive stars, the fusion of small atoms continued to produce larger and heavier atoms. Three helium atoms could fuse to produce carbon, life's most essential element, followed by still heavier elements like oxygen. Within ten billion years or so, most stars die a relatively quiet death, exhausting their nuclear fuel and eventually turning into cold, dark cinders in space. But a massive star, ten times the mass of our Sun and larger, ends its life in a violent explosion, called a supernova.

When a star explodes, it spews its gas, including its heavy atoms, into space. This image, based on data from NASA's Chandra X-ray Observatory, shows the atoms of sulfur, calcium, iron and silicon. Here are the building blocks of planets... and life. When many supernovas explode in roughly the same place and at roughly the same time, they produce a fountain of gas that shoots up into space and then rains back down on the galaxy, seeding it with large atoms. The gas in the Milky Way that created our solar system had been enriched by the heavy atoms produced in earlier supernovas. Every atom in our bodies, except for hydrogen and helium, was forged in a star.

It is astonishing but true that if I could attach a small tag to each of the atoms in my body and travel with them backwards in time when they were part of the soil and the air and the water, back to the formation of the Earth from a giant gas cloud in space, I'd find that those atoms, those exact atoms, originated in particular stars in the sky. Those stars are now long gone. But we are here. Now. Alive to tell this story of our cosmic origins.

SHOPPING FOR ATOMS [39:33]

Atoms from stars. Can it all just be material? Could we be all material? Just stuff? I read somewhere that you could build an entire human body for about five hundred bucks.

Alan in a supermarket.

So, just suppose I could go shopping for the atoms that make up my body. In terms of matter, each one of us is 65% oxygen... 18% carbon... 10% hydrogen... 3% nitrogen... 1.4% calcium... 1.1% phosphorous and a smidgeon of other atoms.

Oh, and one hundredth of an ounce of zirconium!

CASHIER: And your total is $538.66

ALAN: We're just stuff. And we're pretty cheap.

So, we know what we're made of, in terms of atoms and elements. But is that all we are? A long-standing debate in biology concerns whether living matter has some special quality not present in non-living matter. The two sides of the debate have been called the "Mechanists" and the "Vitalists." Mechanists believe that a living creature is just so many microscopic levers and gears, chemicals and currents, all subject to the known laws of physics and chemistry and biology. Vitalists, on the other hand, argue that there's a special quality of life, some non-material or spiritual or transcendent energy, that enables a jumble of tissues and chemicals to vibrate with life. Plato and Aristotle were vitalists. As is the Dalai Lama. Isaac Newton and Baruch Spinoza were mechanists, like the discoverers of DNA, Crick and Watson. In the nineteenth century, German physiologists tried to resolve the vitalist versus mechanist debate. First, they calculated the energy consumed in food. Personally, I prefer peanut butter to a ham sandwich, but for the sake of science, here we go. Each gram of fat, carbohydrate, and protein is worth so many units of energy.

Then the scientists tabulated the energy required for muscular contractions and movement, body heat, and other physical activities, and compared that energy to the energy input from food. After doing the math, the physiologists put away their pencils and announced that the energy used by a living creature equals the energy consumed in food. Still, it's hard to believe that I'm only a collection of levers and gears. If the mechanists are right, what's the difference between matter that's alive and matter that's dead? Could we actually make life from scratch?

SZOSTAK: LIFE IN THE LAB [43:41]

Creating life from simple chemistry would be the ultimate proof of the materiality of living organisms and us. It's quite possible that this breakthrough will occur in Jack Szostak's

laboratory. Professor Szostak won the 2009 Nobel Prize for his work on how DNA ages. But then he moved on to a completely new subject: the origins of life on Earth.

Alan converses with Jack Szostak:

I have a friend who's a pretty smart guy. And he thinks that life could not have originated on Earth because there wasn't time to create all of the molecules needed for life.

JACK SZOSTAK: There's lots of evidence, and lots of really modern, recent evidence that it's actually quite easy to make the molecules of life and that they can be made very quickly.

ALAN: What does it take for us to decide that a thing is alive?

JACK: We're most interested in, once you have the right chemical building blocks, how do they come together to make a simple cell, something that can grow and divide and start evolving and eventually lead to more complicated forms of life. What I care about is a system that can start to evolve in a Darwinian sense.

In life today, the double stranded DNA molecule carries the information for making a living organism. The simpler RNA molecule contains the same information, but has the added ability to build proteins and other elements of a cell. In other words, RNA is both architect and builder. That's why many biologists, including Szostak, think that life on Earth began with RNA.

JACK: Basically both RNA and DNA can encode information. but in the early days we think RNA was the vessel of information and also carried out biochemical functions. So, we've been trying to understand how RNA emerged from the earlier chemistry, and especially how RNA could replicate before the evolution of, for example, protein enzymes.

ALAN: Where do you think was the location of the first life? Was it Darwin's ponds? Was it, vents in the ocean? Was it surface volcanoes? Was it a glob of clay?

JACK: We think surface environments are definitely important because a lot of the chemistry requires ultraviolet light from the early Sun. And we think that you probably need a kind of a fluctuating environment, you know, where things can, can dry out and then get wet again, where temperature fluctuations occur.

ALAN: As part of their work, Jack and his team have to simulate the very different atmosphere that existed on early Earth.

JACK: So, on the inside of this plastic enclosed area there's an atmosphere with no oxygen. And that's really important for a lot of the chemistry that we do because on the early Earth, there was no oxygen in the atmosphere. So, most of the lab at the moment is working on these questions of RNA synthesis, emergence, replication. But the other

half of what we need to create a simple living system is that membrane boundary, the vesicles that form from simple lipids.

ALAN: A vesicle is basically a compartment that contains RNA and other stuff of the cell. Szostak is trying to understand how vesicles and RNA can be created from the simple chemicals present in early Earth.

STEPHANIE ZHANG: I came to this lab because I'm very fascinated by the idea of the proto-cells, which is the primitive cell forms on the early Earth.

JACK: So, what Stephanie has done is she's created these vesicles, which originally were all fairly large, like these. And then she's added into the solution more of the fatty acid molecules that make up the membranes. They go into the membrane and cause it to grow. And then the membrane starts to fluctuate and the vesicles divide and start generating all the smaller vesicles that you can see forming. And it's so simple, right? There's no fancy cellular machinery. There's nothing that's evolved. It's just very, very basic chemistry and physics that's driving everything that we see.

ALAN: Other researchers are experimenting with how simple chemistry can copy information, and even evolve, in conditions completely unlike those on early Earth.

KYLE STROM: So, one very interesting thing about these reactions is that the liquid that's in here is not water. This is chloroform for these ones which is a very different solvent than water.

ALAN: So, if you can prove that you can get a non-RNA molecule to replicate in a liquid environment that's not water, would that increase the possibility of life elsewhere in the universe?

KYLE: It's hard to say really absolutely, but I certainly think it would.

ALAN: It seemed to me that Jack would have some pretty clear thoughts on that Mechanism versus Vitalism debate that had been puzzling me. My understanding is that almost all biologists today are Mechanists rather than Vitalists.

JACK: Absolutely. I mean, nobody has ever come across anything that requires any supernatural explanation. I think it's because we understand more and more about biology in terms of its molecular structure and organization.

ALAN: So, are we all just atoms and molecules?

JACK: It's not just atoms and molecules! It's, it's the organization. There are layers and layers of emergent phenomena, where when you have collections of molecules, and sources of energy, you get interesting new and often surprising phenomenon, you know, common in life, but also in other purely physical systems. If you combine informational

molecules that can replicate with some kind of physical, spatial localization, for example, membrane-bound vesicles, then you have new phenomenon that can occur, like Darwinian evolution. And so now you're off and running in a totally new ballgame.

ALAN: You once said that you hoped that when we do succeed in creating something that we would call a living thing, you hoped that the public understands that the creation of life is totally natural.

JACK: If we can show that there is a kind of continuous pathway of straightforward steps that connects chemistry, the environments of a young planet to the emergence of biology, then I think it would be logical to just accept life as another natural phenomenon. I mean, it's no less wonderful or beautiful because we understand that there's a natural origin for it. And so understanding how we're a product of nature, right from the beginning, I think builds on, on that view that we're not something separate and different, but we're a part of nature. And we should accept that and live with that.

OSPREY ENCOUNTER [51:35]

ALAN: A few years ago, I had an astonishing reminder of our oneness with nature.

It happened on that little island in Maine. There's an osprey's nest about a hundred feet from our house.

Every year, the same pair of birds returns to the nest and starts a new family. First, they gather materials to repair the damage done by the winter storms. In April, the mother osprey lays eggs. In early June, the chicks hatch. The father osprey uses his speed and sharp talons to catch fish to feed the growing family.

And by August, the baby ospreys are now juveniles and almost as big as their parents. They are strong enough to take their first flight, their maiden voyage away from the nest.

One summer, a few years back, on a sunny August afternoon… the juvenile of that season took flight for the first time. I'd been watching this baby bird getting bigger and bigger and bigger, and she was watching me. And probably to her, it looked like I was in my nest. On this particular day, her maiden flight, she did one loop around the island and then headed straight towards me, at what seemed like the speed of an F-15.

My first instinct was to run back into the house. But something kept me standing there. Something magical happened. For about a half second, we made eye contact. And just in that split second, there was so much that was conveyed between us. Then she suddenly made a dazzling climb and veered up and away, over the house. What was exchanged between us in that moment? To me, it was a look of connectedness, of mutual respect. I felt like that bird was telling me, "We're kindred spirits, we've shared this land together."

Life in our universe is a flash in the pan, a few moments in the vast unfolding of time and space. But a realization of the scarcity of life makes me feel some profound connection to other living things. Our lives may be flickers but some experiences endure. Atoms transcending atoms... The miraculous in the material.

END ANNOUNCEMENTS [56:11]

For background of the science presented in this program and for interviews with the people profiled as well as a discussion guide, web exclusive videos and much more, please visit searchingformeaning.org

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SEARCH DEEPER

CONVERSATIONS
- Rai Weiss
- Nergis Mavalvala
- Bruno Maureille
- Paolo Galluzzi
- Jack Szostak
- Robert Desimone
- Fabiola Gianotti

LOCATIONS
- McGovern Institute
- Font-de-Gaume Cave
- La Ferrassie
- Museo Galileo
- Jack Szostak's Lab

WEB SPECIALS
- The Great Osprey Rescue

ALAN'S RUMINATIONS
- The Big Bang
- Element Production in Stars
- The Expanding Universe Equation
- Memories of a first time TV host/on camera "talent"

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