

THE LIVING UNIVERSE: Why is the Universe the Way it is?

McLaughlin Planetarium, Royal Ontario Museum

Scene 1: Introduction

As far as we know, life exists on only one planet in the entire Universe. While we might think of that planet as Spaceship Earth, isolated from the cosmos through which it travels, life on our world is intimately connected to the Universe beyond.

The existence of life on Earth depends on the Moon and on other planets in the Solar System.

It depends on the Sun, and is connected to the hundreds of billions of stars in the Milky Way Galaxy.

It is connected to the billions of galaxies that lie beyond our own, and on events that happened at the beginning of time.

Organic is connected to inorganic; the very small is connected to the very large; the present is connected to the distant past and the remote future. As we explore these connections, we are led on a search for understanding about our place in the Universe, and come face to face with questions about our existence.

Scene 2: The Formation of the Planets

Billions of years ago, before there was a star we now call the Sun, there was a huge cloud of gas and dust in interstellar space.

The shockwave from an exploding star compressed the cloud, and it began to shrink. The cloud grew denser as it became smaller, and temperatures within it rose.

After millions of years, the core of the cloud became so dense that nuclear reactions were ignited. Hydrogen fused into helium, releasing energy. The Sun was born.

An immense disk of gas and dust continued to circle the new star. This protoplanetary disk condensed into pieces of rock and ice. Rock and ice collided and formed into larger pieces, called planetesimals. Planetesimals collided and eventually formed into a family of nine planets and their moons.

The Earth harbours life, in part, because of its distance from the Sun. If we could have moved the Earth slightly *farther* from the warmth

of its parent star when it was still young, it would have evolved into a planet similar to Mars.

If we could have moved the Earth *closer* to the Sun, it would have become more like Venus. Because of its proximity to the Sun, the temperature on Venus has always been higher than the boiling point of water. Because there aren't any oceans to absorb carbon dioxide, Venus's atmosphere is made of that gas and almost nothing else. This thick blanket of carbon dioxide traps heat from the Sun like panes of glass of a greenhouse, raising the temperature to four hundred and sixty degrees Celsius. Hot, dry Venus supports no life.

Only the Earth moves through the region of the Solar System where it is neither too cold, nor too hot for water to remain a liquid. This region of the Solar System through which we travel in comfort is called the habitable zone. Had the Earth been closer to or farther from the Sun, life as we know it—which depends on water—would probably not exist.

Scene 3: The Earth and its Large Moon

But life, in order to survive, needs more than just a planet orbiting within a star's habitable zone. It needs a planet with a large moon—a moon like ours.

If we made the other planets the same size as the Earth, we would see that their moons are very small compared to the planets they circle.

Giant Jupiter has sixteen moons, all much smaller than the Gas Giant.

Mars has two moons, but they too are much smaller than their parent and, in fact, resemble asteroids more than anything.

Pluto is one of two exceptions. It has a relatively large moon named Charon that is more than half the diameter of the planet.

The other exception is the Earth. Our moon is nearly a quarter the diameter of the planet it orbits. Because of its size, the Moon provides us with much more than just romantic evenings and poetic inspiration.

The Earth, as it circles the Sun once a year, travels along a flat plane, like a marble rolling

around in a circle on top of a table. The Earth's axis of rotation—the line through the north and south poles—doesn't point straight up from that plane, but lies at an angle of about twenty-three degrees from the vertical. As a result of this angle, different parts of the Earth receive different amounts of energy from the Sun at different times of the year. We call the resulting yearly changes in weather conditions, the seasons.

The angle, however, varies slightly over periods of thousands of years. Sometimes it's a degree or so *less* than twenty-three degrees, and the Earth spins more upright. As a result, winters are warmer and summers are cooler.

Sometimes it's a degree or so *more* than twenty-three degrees, and the Earth spins less upright. Winters become colder and summers hotter. Such variations are one of the causes of ice ages.

All the while, the other planets in the Solar System pull at the Earth, and this gravitational tug of war threatens to turn our planet on its side. If the Earth ever lost this struggle, the axis of rotation would lie closer to the plane of its orbit. In other words, the Earth would circle the Sun while lying on its side.

Our climate would change drastically. First one pole, then the other, would point toward the Sun. On an Earth like this, nights would last six long, frigid months. Days would last as long, and be as hot as the nights were cold.

Such catastrophic changes would happen over a relatively short span of only millions of years—short enough that life might have difficulty adapting to the changes in climate, and perish.

What does our moon have to do with a tilting axis and changing climate? According to the calculations of one group of astronomers, we have been saved from such catastrophic changes by the gravity of our relatively large celestial companion. Its presence overpowers the gravitational influence of the other planets and keeps the Earth's axis of rotation steady. As a result, it keeps our climate relatively constant and the planet suitable for life. Without the Moon, we might not be here.

Mars, with its small moons, may have suffered just such a troubled past. Phobos and Deimos, only about twenty and ten kilometers respectively, can't exert the steadying gravitational grip of our Moon.

Photographs of the Martian polar ice caps show alternating layers of ice and frozen mud, stacked like pancakes. This is what you would expect to see if Mars had experienced periods of warmth and cold as its axis tilted chaotically. And

without a large moon like ours, there is nothing to prevent it from happening again.

Scene 4: Comets, Asteroids and the Gas Giants

In July, 1994, virtually every telescope on Earth pointed toward the planet Jupiter. Cameras and scientific instruments aboard robot spacecraft like Galileo, itself bound for the giant planet, turned toward Jupiter to record a once in a lifetime event.

More than twenty chunks of Comet Shoemaker-Levy 9—chunks of dust and frozen gas—plunged into the Gas Giant's atmosphere, one after another over a week-long period.

The impacts were tremendous, sending fireballs high above the clouds of Jupiter's upper atmosphere.

The explosions created great disturbances, some larger than the Earth itself. They had little long-lasting effect, however, because of Jupiter's enormous size. Such impacts on our home planet, on the other hand, would have a devastating effect and dire consequences for life.

The last great impact on Earth happened sixty-five million years ago, when dinosaurs ruled the world and our ancestors, the early mammals, cowered in their shadows.

An asteroid the size of a city fell from space. The initial shock wave and explosion were followed by fire, fire by smoke, smoke by falling debris. Intense heat from the blast and blaze was followed by darkness and a killing cold that, ultimately, wiped out the dinosaurs.

Recently, calculations have shown that it may be more than luck that saved us from going the way of Triceratops and Tyrannosaurus Rex, and that life on Earth may be connected to the presence of two other giants: Jupiter and Saturn.

After the planets formed billions of years ago, leftover material filled the Solar System. Comets, asteroids and planetesimals crisscrossed the orbits of the planets, colliding with them frequently.

Over time, however, the gravity of Jupiter and Saturn altered the orbits of trillions of the smaller bodies. The new orbits led the debris out of the Solar System and into interstellar space.

What if the gravitational broom of Jupiter and Saturn were not strong enough to sweep the Solar System clear of debris? What if they had only

been the size of, say, Neptune and Uranus? Then, the Earth might have suffered through a rain of asteroids and comets a thousand times more intense and for a much longer period. Life might never have gained a foothold on our planet beneath such a cosmic barrage. We may owe our presence here today to those distant, giant worlds.

Scene 5: Stellar Evolution and the Sun

No planet, whatever its characteristics, could support life without a source of energy—and ours is the Sun. A vast sphere of hydrogen and helium gas, over a hundred times the diameter of the Earth, it burns with the energy of a process called nuclear fusion.

In the Sun's core, intense pressures and temperatures fuse together particles called protons. In the process, a negatively charged electron is lost and one of the protons becomes a particle called a neutron.

They are joined by another proton to form an atomic triplet; two triplets then join to form the nucleus of a helium atom.

During the fusion process, matter is transformed into energy, emitted as gamma rays. In fact, every second, the Sun converts four and a half billion kilograms of matter into energy. That's as much mass as forty CN Towers.

Eventually, the energy makes its way out of the Sun's core and across million of kilometres of space. It reaches us as life-giving light and heat.

And yet, ninety percent of the stars in the Milky Way galaxy differ from the Sun, and might not be able to support life even if they had planets.

Stars burn at different rates and give off different amounts of energy, depending on their mass. If the Sun were *more* massive, pressures and temperatures in its centre would be much greater, and it would consume its nuclear fuel rapidly. It would die after only millions, rather than billions of years—long before life could appear on any of its planets.

If the Sun were *less* massive, it would give off much less energy. Its habitable zone would be very narrow and, because of this, less likely to contain a planet. As well, the habitable zone of such a small, cool star would be very close to it. Any planet this close would always keep one side turned toward the star, just as our Moon keeps one sided turned toward us.

Could life exist on such a world? It's possible, even though one side of the planet would experience perpetual day, and the other side would

experience perpetual night. It's possible, but much less likely.

As it is, our Sun has burned steadily and strongly for billions of years, giving the Earth a stable, nurturing climate long enough for life to survive.

Scene 6: Life on Earth, Life in the Universe

A star shining strongly for billions of years.

A planet orbiting within the star's habitable zone.

A large moon to stabilize the planet and keep it from wobbling.

Gas Giant planets to sweep away deadly cosmic debris.

After some four and a half billion years, these connections between the cosmos and our world have resulted in the living planet.

But, if the conditions needed for life are so numerous and so special, does this mean we are alone in the Universe?

Many today think we are *not* alone, and point radio antennas toward the sky, searching for a signal from another intelligent life form. They're encouraged in the quest by the growing evidence that Sun-like stars, planets, and the ingredients necessary for life are plentiful throughout the Milky Way galaxy.

While the conditions needed for life are numerous, there are likely very many systems in the Milky Way galaxy with those conditions. After all, when we look at the Milky Way, we are looking at the light of hundreds of billions of stars. Even if only a small fraction of those stars are like the Sun, a small fraction of hundreds of billions is still billions.

As well, there is growing evidence that planets orbit many stars. Below the belt of Orion is a faint patch of light. Photographs taken through large telescopes show the patch to be an enormous cloud of gas called the Great Nebula.

The keen vision of the Hubble Space Telescope reveals even more. Proto-planetary disks—great clouds of dust and gas—surround young stars deep within the nebula. Astronomers expect these disks, and many others they've found elsewhere, to eventually evolve into planets. Worlds on which life can take root appear to be plentiful.

What's more, astronomers have found simple proteins and other organic molecules—the building blocks of life—in even the harsh environment of interstellar clouds. There appears to be no shortage of the chemistry that leads to life.

But, our existence in the Universe is connected to more than just moons, planets, and stars. Life depends on the entire Universe being a certain way. It depends on the speed at which galaxies fly away from each other; on the age of the Universe; on the strength of gravity and the other forces; and on the very nature of matter.

It is life's dependence on these conditions that has made some scientists and philosophers ponder the question: Are we here by chance, or is there a reason the Universe contains life? They look back to the beginning of time and ask: Why is the Universe the way it is?

Scene 7: The Big Bang

Some fifteen billion years ago, time, space and energy did not exist. Then, in an explosive beginning we call the Big Bang, the Universe was born.

The Universe began from a point of near-infinite density and zero size. Energy filled the early Universe; it was so hot that matter could not exist. The cosmos expanded and cooled though, and protons, neutrons and other particles formed. More and more matter was created until—eventually—galaxies, stars and planets appeared.

After billions of years, we see the effect of the Big Bang: the galaxies rush from each other, propelled by the explosive beginning of time.

But imagine a Universe that expands only slightly *faster*. In such a Universe, gravity can't collect hydrogen and helium into great clouds; the clouds don't condense into galaxies and clusters of galaxies; stars and planets don't appear and, without them, there is no life. Instead, the Universe contains only hydrogen and helium, spread thinly throughout space.

Or, image a Universe that expands only slightly *slower*. Matter collects into galaxies, but their gravitational attraction for each other stops their outward rush. After a relatively short time, the Universe collapses in a reverse Big Bang—a Big Crunch—long before we arrive on the scene.

Had the Universe expanded only slightly faster or slower at the beginning of time—by only a fraction of a percent—we might not be here.

In this way, life is connected to the explosive birth of the Universe, billions of years ago.

Scene 8: Supernovas and the Age of the Universe

In February, 1987, astronomers in the southern hemisphere saw something that hadn't been seen for hundreds of years. In a faint patch of light called the Large Magellanic Cloud, a supernova signaled the death of a star.

The Large Magellanic Cloud is actually a galaxy, relatively nearby, in orbit around our own galaxy. Not only was the supernova a goldmine of discoveries for astronomers, it was a reminder that life on Earth depends on dying stars and on a Universe old enough to contain them.

Stars create not only helium from hydrogen through the fusion process. They also create heavier elements needed for the existence of life. Carbon, oxygen, nitrogen and phosphorus—the stuff that we're made of—are all forged in stellar furnaces.

When massive stars explode, the resulting supernovas create these and heavier elements and cast them into space. There, they join other atoms in great nebulas, where they are eventually "recycled" when those nebulas condense into stars and planets. For example, the proto-planetary disks seen in the Great Nebula in Orion likely contain heavy elements created in supernovas.

When the Universe began, these heavier elements didn't exist. The Universe contained only hydrogen, helium and a scattering of other light elements. But humans and other life-forms have a long list of ingredients, and before life could appear, generations of stars had to live and die in order to create those ingredients. That process took billions of years; we couldn't have arrived on the scene any sooner than we did.

Scene 9: Why is the Universe the way it is?

The Universe, then, appears finely-tuned for life; the forces and particles and rate of expansion are what they must be in order for life to be present. Should we be surprised?

Imagine, for a moment, that the Sun was the only star in the entire cosmos—and its nine

planets, the only planets. We might very well be forced to ask how it came to be that the only system of planets in existence possessed all the characteristics necessary for life.

By the same token, if there is only one Universe and it possesses all the characteristics necessary for life, shouldn't we then ask whether life in this Universe is remarkable? If a Universe only slightly different from ours could not contain living creatures, is there some reason why the Universe is the way it is, why it supports life?

Are the connections between life and the cosmos merely coincidence or are they part of a grand design? For thousands of years, the intelligent life forms on this planet have been trying to answer these questions.

For many, the Universe is the way it is because it is the creation of a divine being. The religious beliefs of many cultures describe different divine beings, and different reasons for why the Universe is the way it is.

This belief, and the preeminence of humanity, was reflected in early western models of the cosmos: the Earth was the centre of the Universe—and the Sun, Moon, planets and stars revolved around us, carried along by perfect crystalline spheres.

Even the seventeenth century astronomer, Johannes Kepler, looked for the “design” behind the Universe. At the time, there were six known planets: the Earth, and the five planets visible in the night sky. Kepler thought the blueprint for the distances between their orbits lay in the dimensions of five “perfect” solids, nested one inside another. No matter how hard he tried though, he failed to find a match.

While Kepler would use the tools and methods of science in his work, he still believed his search would ultimately reveal nothing less than “the Hand of God”. Such answers, however, are based on religious beliefs and lie beyond the realm of modern science.

Other answers do not. Scientists and philosophers continue to search for the “design” behind the Universe in mathematics, and in an idea called the Anthropic Principle.

Scene 10: The Anthropic Principle

According to the Anthropic Principle, the Universe is the way it is because it *must* support life; the Universe would not exist at all without the

presence of intelligent life to perceive it and make it real.

A tree falling in an empty forest makes no sound, according to this thinking, unless someone is present to hear the sound. In the same way, the Universe would not exist without a life form to perceive it.

While we generally think of life as being the consequence of the physical Universe, the Anthropic Principle argues that the physical Universe is the consequence of life. The force of gravity, for example, could not be stronger or weaker since we wouldn't be here if it were. In other words, the Universe is the way it is in order to support intelligent living beings.

There are others who adopt a weaker version the Anthropic Principle. They argue that there's nothing special about our existence and that we are here merely by chance. They reason that the Universe we see supports life, simply because if it didn't, we wouldn't be here to observe it. We are here because the Universe *can* support life—no more, no less.

Is the strong Anthropic Principle pseudoscience, or the answer to a centuries-old search for meaning? Is the weak version meaningless, or a useful scientific idea? Or, as some speculate, is there another explanation for our living Universe?

Scene 11: Other Universes

Despite the long list of conditions needed for life on Earth—a steadily-shining Sun, a large moon, Gas Giant planets—there is nothing remarkable about our existence here because it's likely there are many planetary systems in our galaxy and the galaxies beyond. It's not surprising that amongst all the systems of stars and planets believed to be out there, at least one harbours life.

Perhaps then, there's nothing special about our existence in the Universe as a whole because there are many universes other than ours—whole universes, separate and unconnected to ours. Perhaps the Universe we see when we point a telescope at the night sky is only one of many.

And if each is slightly different from ours, then some of those universes can support life and others cannot. We, naturally, exist in a universe capable of supporting life—just as we, naturally, exist within a planetary system capable of supporting life. If those other universes exist, our presence in this universe isn't so remarkable.

Other universes? While the idea sounds like science fiction or fantasy, scientists seriously speculate about universe other than our own.

According to quantum theory—which describes the properties of subatomic particles and the four fundamental forces—an infinite number of universes come into existence whenever an infinite number of possibilities exist.

Suppose a game of poker is in progress in our universe. A player needs one card—say, the ten of hearts—to complete a Royal Flush and win the pot. The dealer holds the ten of hearts in the deck of cards still to be dealt, along with twenty-six other cards that won't win the player the pot.

According to quantum theory, dealing the next card creates twenty-seven universes, each slightly different from the other. In one of those universes, the player is dealt the ten of hearts and he goes home a winner. But in twenty-six other realities, he is dealt a different card and loses.

Such alternate universes exist—at least according to quantum theory—and each is slightly different.

Another theory also suggests that our Universe is only one of many. According to the Inflationary Universe theory, our cosmos didn't just explode into existence with the Big Bang; it also inflated like a balloon.

The theory says that whenever a tiny amount of matter experiences conditions similar to those found shortly after the Big Bang, it can inflate and become an entirely new universe. The newly-born universe exists in another dimension, quite separate from our own.

Again, the picture painted is one of countless universes, like countless planetary systems, each slightly different from each other. With such a wealth of universes, it isn't so remarkable that at least one—ours—is able to support life.

Scene 12: The Search for Meaning

As we explore the connections between life and the cosmos, we come face to face with questions about our existence: Are there other universes beyond ours? Or only one? Does the Universe contain life by chance, or by design?

Why is the Universe the way it is?

These questions have been asked by the greatest thinkers in history, and by the youngest minds looking up at the night sky for the very first time. The search for answers is one that may go on forever.

Whether mystical or scientific, the quest is our attempt to make sense of things. It illuminates the connections between life on Earth and the distant cosmos, and our never ending search for meaning.