WHY WE ARE PROBABLY THE ONLY INTELLIGENT LIFE IN THE GALAXY

PART 3

Beyond Us

ALONE IN THE MILKY WAY

BY JOHN GRIBBIN :: *ILLUSTRATION BY ARMANDO VEVE*

ASTRONOMERS HAVE NOW FOUND THOUSANDS OF PLANETS ORBITING OTHER stars in the Milky Way, and 100 billion more stars in the galaxy presumably host planets of their own. Given the sheer number of worlds out there, scientists find it easy to hope that some of them must be harboring sentient beings. After all, could Earth really be unique among so many planets?

IN BRIEF

With so many exoplanets out there in the galaxy, it seems reasonable to hope that life may be prevalent. But a series of unusual coincidences occurred to give rise to our intelligent civilization, and it is quite unlikely such serendipity has taken place elsewhere.

The timing of our solar system's birth in the history of the galaxy was fortuitous, for example, as is our location in the Milky Way. Furthermore, several features of our planet are very rare, and the conditions that sparked the evolution of life here might be irreproducible.

Perhaps most unlikely of all was the development of our technological species from those first sparks of life—a feat that is probably unique.

It could. Optimism about the possibilities of intelligent extraterrestrial life ignores what we know about how humans came to exist. We are here because of a long chain of implausible coincidences—many, many, many things had to go right to result in the situation in which we find ourselves. This chain is so implausible, in fact, that there is good reason to conclude that humans most likely are the only technological civilization in the galaxy. (Let us leave aside the other countless galaxies in the cosmos because, as the saying has it, "in an infinite universe, anything is possible.")

SPECIAL TIMING

THE COINCIDENCES BEGIN with the manufacture of heavy elements, which include everything heavier than hydrogen and helium. The first stars were born in clouds of these two lightest elements, the residue of the big bang, more than 13 billion years ago. They cannot have had planets, because there was nothing to make planets from—no carbon, oxygen, silicon, iron or any other metals (with cavalier disregard for chemical subtleties, astronomers call all elements heavier than hydrogen and helium metals).

Metals are created inside stars and spread through space when stars throw off material as they die, sometimes in spectacular supernova explosions. This material enriches interstellar clouds, so each successive generation of stars made from the clouds will have a greater metallicity than the one before it. When the sun came into being about 4.5 billion years ago, this enrichment had been going on for billions of years in our galactic neighborhood. Even so, the sun contains roughly 71 percent hydrogen, 27 percent helium and just 2 percent metals. Its composition mirrors that of the cloud that made the solar system, so the rocky planets, including Earth, formed from only that tiny amount of elemental construction material. Stars older than the sun have even fewer metals and, correspondingly, less chance of making rocky, Earth-like planets (giant gaseous planets, such as Jupiter, are easier to form but not as likely to host life). This means that even if we are not the only technological civilization in the galaxy, we must be one of the first.

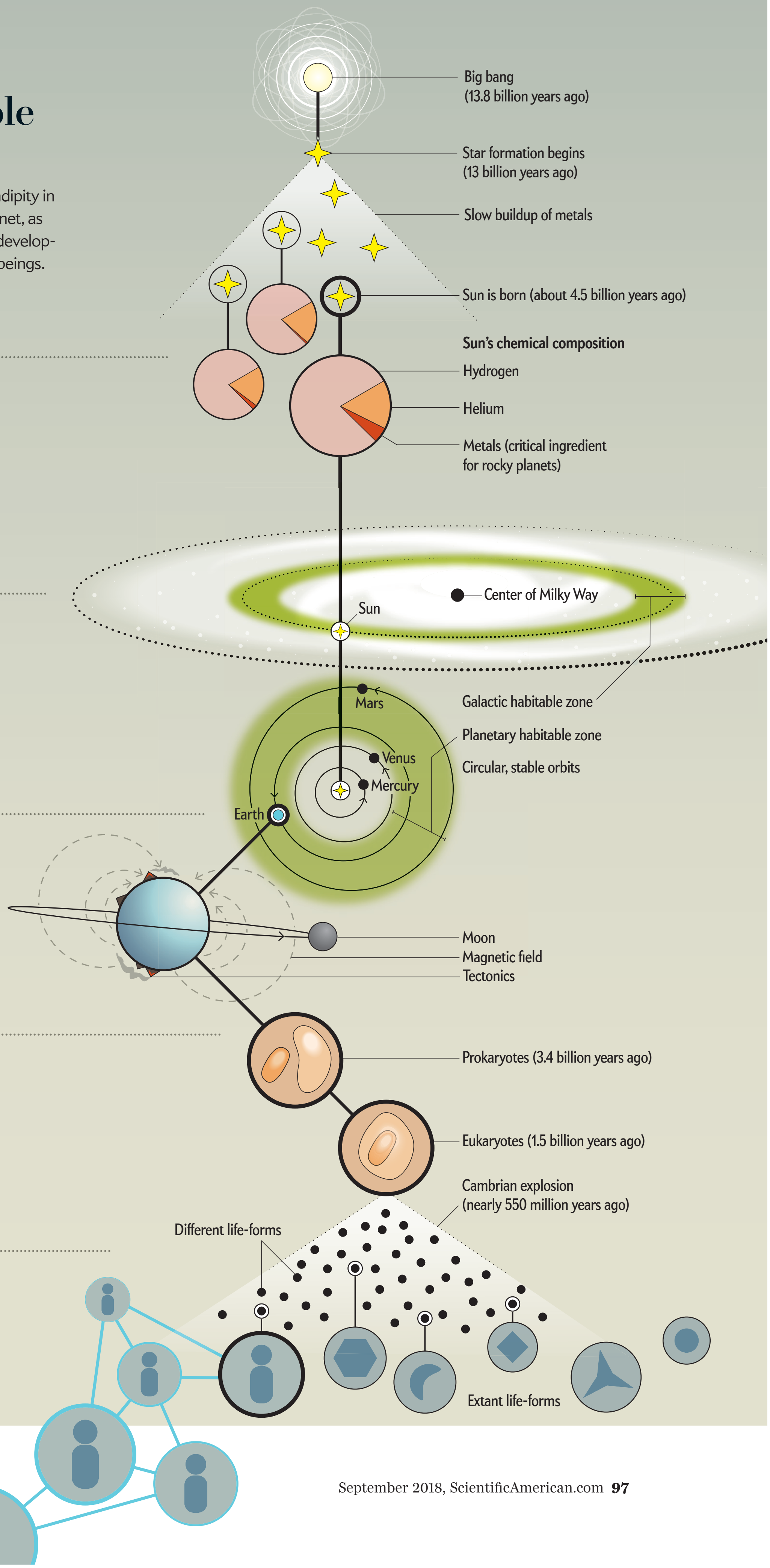
SPECIAL LOCATION

OUR PLACE IN THE MILKY WAY is also propitious. The sun is located in a thin disk of stars about 100,000 light-years across; it is roughly 27,000 light-years from the galactic center, a little more than halfway to the rim. By and large, stars closer to the center contain more metals, and there are more old stars there. This situation is typical of disk galaxies, which seem to have grown outward from the center.

More metals sounds like a good thing from the point of view of making rocky planets, but it may not be so good for life. One reason for the extra metallicity is that stars are packed more densely toward the center, so there are many supernovae, which produce energetic radiation—x-rays and charged particles known as cosmic rays—that is harmful to planets of nearby stars. The galactic center also is home

Chain of Improbable Coincidences

Many things had to go right for us to exist. Serendipity in the timing and location of our home star and planet, as well as lucky conditions on Earth and fortuitous developments in the evolution of life, resulted in human beings.



Timing

If the sun and Earth had been born any earlier in galactic history, our planet would likely have had too few metals (elements heavier than hydrogen or helium) to form life. These elements are created during stellar deaths, and it took billions of years for enough stars to form and die to enrich the materials that built our solar system.

Location

The sun lies in a Goldilocks zone within the Milky Way—not too close to the galactic center, where stars are more crowded and dangerous events such as supernovae and gamma-ray bursts are common, and not too far, where stars are too sparse for enough metals to build up to form rocky planets.

Planetary Conditions

Within our solar system, Earth is in the right location for hospitable temperatures and liquid water (the planetary habitable zone). Earth is also lucky to have a magnetic field that repels harmful radiation and plate tectonics to replenish surface nutrients and stabilize the temperature. Our moon is likely behind both boons; it also prevents Earth from tipping too far on its axis.

Early Life

Single-celled organisms (prokaryotes) formed just a billion years after our planet was born, but more complex cells (eukaryotes) took two billion years more to arise from a fluke merging of cells. Even then, it was almost another billion years before multicellular life-forms proliferated in an event called the Cambrian explosion.

Technological Civilization

Once multicellular life arose, the development of an intelligent species was far from assured. We still do not know how humans advanced so far beyond our close animal relatives, but even our species may have come close to extinction several times, DNA evidence shows.

Illustration by Jen Christiansen

to a very large black hole, Sagittarius A*, which produces intense outbursts of radiation from time to time.

Then there is the problem of even more energetic events called gamma-ray bursts. Using recent gravitational-wave studies, astronomers learned that some of these explosions are caused by merging neutron stars. Observations of gamma-ray bursts in other galaxies show that they are more common in the crowded inner regions of galaxies. A single burst could sterilize the core of the Milky Way, and statistics based on studies of other galaxies suggest that one occurs in ours every one million to 100 million years.

Farther from the center, all these catastrophic events have less impact, but stars are sparser and metallicity is lower, so there are fewer rocky planets, if any. Taking everything into account, astronomers such as Charles H. Lineweaver of the Australian National University infer that there is a “galactic habitable zone” extending from about 23,000 to 30,000 light-years from the galactic center—only about 7 percent of the galactic radius, containing fewer than 5 percent of the stars because of the way they are concentrated toward the core. That region still encompasses a lot of stars but rules out life for the majority of them in our galaxy.

The sun is close to the middle of the habitable zone, but other astronomical idiosyncrasies distinguish our solar system. For example, there is some evidence that an orderly arrangement of planets in nearly circular orbits providing long-term stability is uncommon, and most planetary systems are chaotic places, lacking the calm Earth has provided for life to evolve.

SPECIAL PLANET

ALL THE TALK OF EARTH-LIKE PLANETS obscures another critical distinction. Astronomers have found around 50 of these worlds, but when they say “Earth-like,” all they mean is a rocky planet in the habitable zone that is about the same size as ours. By this criterion, the most Earth-like planet we know is Venus—but you could never live there. The fact that you can live on Earth is the result of fortuitous circumstances.

The two planets differ in several important ways. Venus has a thick crust, no sign of plate tectonics and essentially no magnetic field. Earth has a thin, mobile crust where tectonic activity, especially around plate boundaries, brings material to the surface through volcanism. Over Earth’s long history, this activity has carried ores up to where humans can mine them to provide the raw materials for our technological civilization. Plate tectonics has also brought nutrients to the surface to replenish those that get depleted by the cells living there, and it is crucial for recycling carbon and stabilizing the temperature over long timescales. Earth also has a large metallic (in the everyday sense of the word) core that, coupled with its rapid rotation, produces a strong magnetic field to shield its surface from harmful cosmic radiation. Without this screen, our atmosphere would probably erode, and any living thing on the surface would get fried.

All these attributes of our planet are directly related to our moon—another feature that Venus and many other Earth-like planets lack. Scientists’ best guess is that the moon formed early in the solar system’s history, when a Mars-size object struck the nascent Earth a glancing blow that caused both protoplanets to melt. The metallic material from the two objects settled into Earth’s center, and much of our planet’s original lighter rocky material splashed out to become the moon, leaving Earth with a thinner crust than before. Without that impact, Earth would be a sterile lump of rock like Venus, lacking a magnetic field and plate tectonics. The presence of such a large moon has also acted as a stabilizer for our planet. Over the millennia Earth has wobbled on its axis as it goes around the sun, but thanks to the gravitational influence of the moon, it can never topple far from the vertical, as seems to have happened with Mars. It is impossible to say how often such impacts occur to form double systems such as Earth and its moon. But clearly they are rare, and without our satellite we would likely not be here.

SPECIAL LIFE

ONCE THE EARTH-MOON SYSTEM settled down, life emerged with almost indecent rapidity. Leaving aside controversial claims for evidence of even earlier creatures, scientists have found fossil remains of single-celled organisms in rocks 3.4 billion years old—just about a billion years younger than Earth itself. At first, this sounds like good news for anyone hoping to find extraterrestrials—surely if life got started on Earth so soon, it could arise with equal ease on other planets? The snag is that although it started, it did not do much for the next three billion years. Indeed, microbes that are essentially identical to those original bacterial cells still live on Earth today—arguably the most successful species in the history of life on our planet and a classic example of “if it ain’t broke, don’t fix it.”

These simple cells, known as prokaryotes, are little more than bags of jelly, containing the basic molecules of life (such as DNA) but without the central nucleus and specialized structures such as mitochondria, which use chemical reactions to generate the energy needed by the cells in your body. The more complex cells, the stuff of animals and plants, are known as eukaryotes, and they are all descended from a single merging of cells that occurred about 1.5 billion years ago.

The merger involved two types of primordial single-celled organisms: bacteria and archaea. The latter

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are so named because they were once thought to be older than bacteria. The evidence now suggests that both forms emerged at about the same time, when life first appeared on Earth—meaning that however life got started, it actually emerged twice. Once it was here, it went about its business largely unchanged for about two billion years. That business involved, among other things, "eating" other prokaryotes by engulfing them and using their raw materials.

Then came the dramatic turning point: An archaeon engulfed a bacterium but did not "digest" it. The bacterium became a resident of the new cell, the first eukaryote, and evolved to carry out specialized duties within it, leaving the rest of the host free to develop without worrying about where it got its energy. The cell then repeated the trick, becoming more complex.

The similarities between the cells of all advanced life-forms on Earth show that they are descended from a *single* single-celled ancestor—as biologists are fond of saying, at the level of a cell there is no difference between you and a mushroom. Of course, the trick might have happened more than once, but if it did, the other protoeukaryotes left no descendants (probably because they got eaten). It is a measure of how unlikely such a single fusion of cells was that it took two billion years of evolution to occur.

Even then, not much happened for another billion years or so. Early eukaryotes got together to make multicellular organisms, but at first these were nothing more than flat, soft-bodied creatures resembling the structure of a quilt. The proliferation of multicellular life-forms that led to the variety of life on Earth today only kicked off nearly 550 million years ago, in an outburst known as the Cambrian explosion. This was such a spectacular event that it is still the most significant one in the fossil record. But nobody knows why it happened—or how likely it is to happen elsewhere. Eventually that eruption of life produced a species capable of developing technology and wondering where it came from.

SPECIAL SPECIES

THE PROGRESSION from primitive to advanced species was not easy. The history of humanity is written in our genes, in such detail that it is possible to determine from DNA analysis not only where different populations came from but how many of them were around. One of the surprising conclusions from this kind of analysis is that groups of chimpanzees living close to one another in central Africa are more different genetically than humans living on opposite sides of the world. This can only mean that we are all descended from a tiny population of humans, possibly the survivors of some catastrophe or catastrophes.

DNA evidence pinpoints two evolutionary bottlenecks in particular. A little more than 150,000 years ago the human population was reduced to no more than a few thousand—perhaps only a few hundred—breeding pairs. And about 70,000 years ago the entire human population fell to about 1,000. Although this interpretation of the evidence has been questioned by some researchers, if it is correct, all the billions of people now on Earth are descended from this group, which was so small that a species diminished to such numbers today would likely be regarded as endangered.

> Even if we are not the only technological civilization in the galaxy, we must be one of the first. Is another such civilization likely to exist today? Almost certainly no.

That our species survived—and even flourished, eventually growing to number more than seven billion and advancing into a technological society—is amazing. This outcome seems far from assured.

As we put everything together, what can we say? Is life likely to exist elsewhere in the galaxy? Almost certainly yes, given the speed with which it appeared on Earth. Is another technological civilization likely to exist today? Almost certainly no, given the chain of circumstances that led to our existence. These considerations suggest we are unique not just on our planet but in the whole Milky Way. And if our planet is so special, it becomes all the more important to preserve this unique world for ourselves, our descendants and the many creatures that call Earth home. SA

MORE TO EXPLORE

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FROM OUR ARCHIVES

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