Our galaxy is a member of a minor cluster of about 20 similar systems — like these four galaxies in the constellation Leo.

From the Outside In

by George Seielstad

The reason we human beings have trouble grappling with some of the larger social issues may be that we restrict ourselves to personal observations of our own immediate surroundings. Sometimes, of course, we extend these through reading and travel, but we still risk thinking too small. I suggest that it is time to try to acquire a cosmic approach, perhaps by taking an imaginary journey outward from Earth until we locate our place in space.

If we begin our journey by looking at our home planet from one of the LANDSAT or EROS satellites that orbit the Earth at a distance of a few hundred miles, a lot of the problems that plague us become insignificant. For example, a boundary dispute with a neighbor has no meaning when we try to view our property from this height.

At a distance of a few thousand miles, there is no way to determine where one country ends and another begins, which makes geopolitical boundaries completely arbitrary — and hardly worth all the international acrimony they generate.

Finally, at a distance of 240,000 miles — on the Moon — we can look back to our lonely little planet suspended magically in the dark. From this vantage point, there are at least three things to note about Earth. The first is its great beauty. It is dazzling, jewel-like, and brilliant against the black, cold, empty backdrop of interplanetary space.

Second, seen from this distance Earth looks delicate, fragile, and vulnerable. It seems especially so when you consider that all life on Earth is confined to a thin membrane encasing the planet — a membrane of air and water about as thick in relative scale as the skin on an apple.

The third point to notice — and appreciation of this fact may be the most important contribution of the entire space program — is that from the Moon we can see our planet as a single unit. It is a whole. We are all members of one family traveling on Spaceship Earth.

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For man, whose height seldom exceeds 2 meters, this journey of 384 million meters represents the extreme limit of his physical travels. Yet it nowhere approaches the limit of his imaginary travels, and within a cosmic context the distance is minuscule. Our nearest stellar neighbor, the Sun, is almost 400 times as far from Earth as the Moon. It is the Sun's sheer bulk that binds us in an orderly path through the heavens. It is so large that if we could hollow out its sphere, we could put about a million Earths inside it. In addition, the massive outpouring of its energy makes possible our very existence.

Despite its supremely critical role for earthbound creatures, our Sun is actually only ordinary. In terms of mass, size, temperature, chemical composition, power output, or countless other stellar variables, it typically exhibits rather average values. Even the Sun's possession of planetary companions is quite probably just one more property that it shares with innumerable other stars.

Within the confines of our local stellar family — the Milky Way Galaxy — lie hundreds of billions of like bodies. Many of them are so large that millions of Earths could fit comfortably within their interiors; yet from another vantage point they are so small that tens of millions of them could be strung like beads along a chain between the two nearest neighbors.

To comprehend the scale of our disk-shaped home galaxy, we need a very large unit of length. If we adopt as a measure the nearly 30 million solar diameters that separate the Sun from its closest stellar companion, Alpha Centauri, we need more than 20,000 such intervals laid end to end to span the entire disk. Within this colossal ensemble, our not-so-mighty Sun has an inconspicuous galactic address. It is located in one of the outer spiral arms of the galaxy about ⅔ of the way from the center to the disk's outer edge, and it orbits about the center once each 250 million years.

It might be nice if we could feel that our galaxy is somehow special, but I don't think it is. The Milky Way is a member of a minor cluster of about 20 similar galaxies — called the Local Group — existing together in space. Other groups, some many times larger and more populous — and perhaps groups of groups — stretch on and on and on, reaching distances of at least 3,000 times the diameter of the Local Group.

If our place in space is nothing special, what about our moment in time? Here again we tend to distort reality by working from the inside out. Historically, man has always viewed the sky as eternal and immutable. In periods of rapid and often turbulent change, people have found comfort in the dependability of the heavens, with their rhythmic, cyclic events that repeat faithfully and precisely. But this is another example of measuring epochs against a human standard. Our puny 70-year lifespans, while relatively long for an animal species here on Earth, are hopelessly inadequate for gauging the flow of cosmic history. In reality, the whole history of the universe has been one of constant change; it is an evolving, dynamic system.

To the best of our present knowledge, the universe began with a bang less than 20 billion years ago, and it has been expanding ever since. That means that the energy in it is getting more and more dilute, which is another way of saying that the universe is always getting cooler. Even today, however, we can recognize a faint afterglow of the ferocious heat that must have existed at that moment when all matter and energy exploded from a single point in space. This remnant radiation, which is at a temperature of approximately 3 degrees centigrade above absolute zero, can be measured with our radio telescopes, and it is the same no matter what direction we point them. This discovery, incidentally, resulted in the award of the Nobel Prize in physics last October, and one of the recipients was Robert Wilson, an alumnus of Caltech (see page 26).

The original matter in the universe was almost entirely hydrogen, but under the incredible conditions of density and temperature that existed in the early minutes, about 10 percent of the hydrogen fused into helium. Then for the first several billion years, the universe was a gaseous "sea" of these two simplest chemical elements intermixed with gradually cooling radiation.

These particles of matter were probably never spread perfectly uniformly throughout the whole universe, and any fluctuations in density that exceeded the average tended to feed upon themselves, creating regions of still greater density. Every atom within such an anomaly felt the gravitational attraction of every companion atom, and atoms passing by were sucked in. Eventually the aggregation of atoms grew so massive and heavy that it collapsed, isolating itself against the dispersive effects of expansion. These gigantic collections, containing hundreds or thousands of billions times more atoms than are present in our Sun, became galaxies. The formation of each required perhaps a billion years and took place about 10 to 15 billion years ago.

The situation inside a condensing proto-galaxy resembled, on a sharply diminished scale, the processes occurring in the universe at large; that is, aggregates built up around random increases in atomic density. The resultant ensembles quickly (usually in millions or tens of millions of years) collapsed under their own weight into stars. Within a given galaxy, the process first began shortly after its formation, and in many galaxies it continues today. Thus the stellar population of the Milky Way includes senior citizens 13 billion years old, as well as prenatal stars struggling to be born — and all ages in between.

The process of gravitational collapse of a proto-stellar cloud is unlikely to be perfectly efficient; that is, all the matter within such a cloud is not going to form into stars. The leftover matter may itself almost simultaneously condense into planets, and the leftovers of that process may in turn become planetary satellites.

We believe this is how the Sun and its minor companions of the Solar System came into existence some 4½ billion years ago. The history of our home planet, it seems, occupies only about a quarter of all of cosmic history.

The process of star formation is a continuing one in a galaxy, taking place in dark, dusty clouds where the density is so great that the regions are opaque. As the density of matter in a collapsing cloud increases, so do its pressure and temperature. Collisions between atoms become more frequent and more violent. Eventually some of the hydrogen atoms, of which such a cloud is mostly composed, will collide so hard that they will stick together, fusing into the next lightest element, helium.

The history of our home planet occupies only about a quarter of the totality of cosmic history

Each quartet of hydrogen atoms that is forged in the process of nuclear fusion into a single helium atom weighs *in toto* more than the product it creates. The difference in mass never disappears; it is converted into a form of energy — electromagnetic radiation or, more simply, light. And that energy, created in the star's center and subsequently released from its surface into the surrounding space, provides sustenance for the chemical reactions that constitute the living process.

This is not the only debt that living systems owe to the stars, because living matter consists of more than hydrogen and helium. The richness and variety of living substances in our tiny fragment of the universe derive to a considerable extent from the sizable inventory of chemical elements with which our planet is endowed. And this is bequeathed to us by previous stellar generations in whose mighty furnaces the hydrogen fuel is eventually exhausted.

In the case of the Sun, about 660 million tons of hydrogen are consumed every second — a process that has been going on for 4½ billion years and that will continue for another 4 to 5 billion years before the hydrogen is depleted. Other stars, formed earlier and/or more consumptive of their primordial fuel, reached their demise long ago. When this happened, the balance between the inward crush of gravity and the outward flux of energy was destroyed. A series of internal convulsions followed, each raising the star's central temperature, pressure, and density until the ash of the preceding reaction could become the fusion fuel of the successor. Thus, inside some stars, helium was combined into carbon, carbon and helium into oxygen, carbon into magnesium, and oxygen into sulfur, and so on all the way up to the element iron.

The trouble with iron is that there is no way to fuse iron atoms into a unit that is lighter than the sum of the atoms of which it is made. So the star stops burning altogether, touching off a catastrophe. The core implodes violently, locking up some of its matter forever in exotically constituted stellar corpses. The star's outer layers are spewed into space, the expelling explosion also triggering some exotic nuclear reactions to produce elements heavier than iron. Future stars will therefore coalesce from a chemically enriched environment.

Thus stars are continually being born, living to advanced ages, and then dying. The net results of such cycles are to remove some matter from the pool future stellar generations must draw upon, while enhancing the chemical variety of the remainder. As time goes on, the chemical composition of the universe grows richer.

When these chemical elements are mixed for a long enough time in close proximity, the inevitable happens: They link together to form molecules. The next step up in the organizational structure of matter occurs. Radio astronomers are detecting in space a rapidly growing number of molecular species, more than 30 to date. Most of them are organic, which are the types peculiar to living organisms, and some are surprisingly complex — ethyl alcohol, for example, a compound of nine atoms. Equally remarkable is the ubiquity of these molecules. These crucial links of the chain that represents evolutionary life itself are scattered throughout the Milky Way and in other galaxies as well. In short, the raw materials from which living systems derive exist at a vast number of locations within the universe.

Of course, multi-atom molecules — even organic ones — are a very long way from being living systems. But we know that adding some energy to a broth of fairly simple molecules produces amino acids, life's fundamental building blocks. In one of the classic experiments, an electric spark discharged in a mixture of steam, ammonia, methane, and hydrogen sufficed. Presumably these ingredients — energy from a parent star and molecules inherited from earlier stellar generations — were present in Earth's primitive atmosphere some 4½ billion years ago. And there is no reason to suppose that these conditions were unique to our planet. Analyses of meteorites that come to Earth from distant reaches of the solar system reveal that amino acids have formed elsewhere as well.

How have we progressed from relatively short chains of amino acid molecules to the long, intricate spiral arrangements that constitute the essence of today's living systems? Slowly, to be sure. In fact, it has taken billions of years in the case of Earth, and it is doubtful that the process can be significantly speedier elsewhere. Although many details of the exact sequence by which life evolved here remain to be discovered, there is a growing conviction that living matter originated from the nonliving; that, having once done so, all life has sprung from other life; and that the process seems universal, given only some precursory molecules, an energy input, and ample time in a suitable environment.

I don't mean to suggest that other people — other humans exactly like ourselves — are scattered about the universe. Every living system interacts with the environment in which it lives. It draws energy and raw materials from the environment and returns different by-products to it. So the things that live within each environment depend on the nature of that environment, which depends in turn on what lives within it. This interdependence means that each such interacting biosystem will be unique.

We humans can therefore properly view ourselves as natural — or even inevitable — products of a cosmic evolutionary scheme that was set in motion nearly 20 billion years ago. Possibly we are members of a "family of living matter" that in richness and variety exceeds our wildest speculations. After all, we are limited by knowledge of only that tiny spectrum of life adapted to survival in one particular environment, the Earth's biosphere.

In this view, life is a continuum traceable to the beginning of all space and time at the Big Bang itself. While each of us, and all other individual living systems as well, lives only momentarily, a pattern and structure persists in our descendants. As individuals we are insignificant and momentary participants in a dynamic, evolving system that vastly transcends us; but as a species we are a necessary link between the cosmic past and all that is yet to come.

Among all the living organisms here on Earth, man does possess one unique ability. He can accumulate knowledge and transmit it to successive generations. Communication itself is not unique to man; whales and dolphins, for example, are masters of it. But man's ability to communicate across generations is unique; it is a function of his intelligence. Each generation of human beings starts from an informational base and adds to it. Like an inverted pyramid, the entire structure continues to expand. Consequently human society — linked together by an intricate communications network binding man not only to his contemporaries but also to his predecessors — has evolved more rapidly than has the human species itself. Together we can perform tasks of which no individual is capable.

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Consider our ability to construct modern aircraft. Of the thousands of workers it takes to assemble an airplane, no one individual can claim he knows how to do all the tasks required. Nor can any one among the designers and planners successfully operate all the machinery involved in the aircraft's construction. Yet somehow an organizational structure — the modern aerospace corporation — has evolved, and it can produce an aircraft that flies.

Now, of course, bees can also jointly accomplish goals that are impossible for individual bees — building a hive, for example. But there is something chillingly 1984-ish about the activity of a bee, because he has no choice about what he will build or how it will be designed. He is preprogrammed to build a hive exactly like the hives of all generations of bees before him. Man, on the contrary, can alter his design at will, or choose not to build airplanes at all, or decide — perhaps using the same individuals — to build instead mass transit systems or grand pianos. And therein lies our unique potential for greatness — and for folly.

Again, let's not be parochial. Intelligence is so great an advantage in coping with an environment that it may be developed in every biosystem blessed with sufficient evolutionary time to acquire it. All living things are wholly dependent upon their surroundings, so they will have powerful incentives to acquire sensory apparatus for mapping out those surroundings. Then they will need some greater capacity for processing the flood of incoming sensory data, plus a memory bank to store possible reactions to the different sensations, and a decision-making capacity for selecting among these possible reactions. May we not at least speculate that this sequence leads toward intelligence, and that it has a certain inevitability wherever evolving living systems interact with a changing environment?

This view of the entire universe from the outside in has revealed abundant, widely distributed supplies of the raw materials of which living matter consists. Likewise omnipresent, we believe, are sites suitable for harboring and nurturing these "seeds" of life. Wherever the seeds take root, they most likely will grow steadily toward higher levels of complexity and greater intelligence. Ultimately, if there is time, species will evolve whose intelligence will permit an expanding knowledge of their surroundings. With that knowledge will come power.

In this progression, there are certain thresholds, some of them critical. In every such "biocivilization" the dominant species may eventually acquire enough potential power to modify the entire biosystem. At this critical juncture, that species either learns to channel its power to useful purposes, or it self-destructs — and retrogresses drastically in an evolutionary sense.

Earth is precariously poised at exactly this point today. Man possesses recently acquired global capabilities. His collective arsenal, for example, can destroy all life on the planet. His exponentially mushrooming numbers threaten to overburden the entire biosphere. Because of his insatiable appetite for material resources, he may irreparably scar the Earth's surface and then flood it with unwanted debris. He can alter the global climate or poison its entire air and water supply.

Does the long evolutionary thread leading to our existence end here and now on this one small planet?

These global powers have multiplied so rapidly that man's social, cultural, economic, and political systems have not kept pace. In just 100 years the rate of communicating messages has accelerated from the speed of the Pony Express to the speed of light. Military encounters have changed from cavalry charges to nuclear holocausts. Agriculture has shifted from using beasts of burden to air-conditioned tractors. Organizationally, the family farm has largely given way to the corporate enterprise.

It is hard to conceptualize this astonishing rate of change, but it may help to imagine Earth's entire history condensed into a single year ending just now. In those terms, man's earliest, most primitive ancestors appeared only 8 hours ago. Fire was unknown until just the last hour, and art — cave paintings, stone engravings, and the like — began within the last 5 minutes. The Christian era has been with us for a mere 14 seconds; the Industrial Revolution for just 2. The last 100 years occupy ⅔ of a second on this scale. But in that fleeting interval — two-millionths of one percent of Earth's history — man's population has doubled and then redoubled.

Surely we have come to a fork in the road. Can we accelerate our social adjustments to this pace, learn to channel our awesome global powers to useful purposes? Or does the long, long evolutionary thread leading to our existence end here and now on this one small planet? It is possible that the seeds of higher systems are scattered in great abundance throughout the universe, but it is likely that very few will survive to become mature biocivilizations. Ours could be one of the lucky ones. It's up to this generation on this planet to make the choice. □