ASTROBIOLOGY

PART 2

A Brief History of Life. In part 2 - David Clark looks at some of the alternative theories about how and where life started in the universe.

Historical Perspectives

Historically there have been several differing views on the origin of life, some of which seem ludicrous given the knowledge we have now. In a few hundred years will the knowledge available then make today's accepted views seem similarly naive?

Divine Intervention

Theories about the creation of life have probably existed since the time when human beings developed thought, consciousness and an ability to discuss ideas. Common themes exist throughout all these theories though, and can be divided into categories. One, of course, is that the whole universe and everything in it were created by one god, a view espoused by today's relatively modern religions. Other religions revere more than one god, although one god is usually considered responsible for the creation and destiny of the universe. Earlier beliefs include ideas that have life emerging from under the earth, or that the Earth itself emerged from an oceanic world that existed before the Earth was created. Another theme is that of the 'cosmic egg', where the world breaks out from the shell, and yet another says that the world is the offspring of a primordial 'Earth mother' and 'sky father'. Like the universe itself, knowledge expands with time, and as more and more scientific knowledge has been gathered over the ages, less and less credence is placed in these theological and philosophical ideas, and yet throughout the world, a majority of people profess to believe in one God or another, including many eminent scientists. Science doesn't have the answer to everything!

Early Modern Science

The sixteenth and seventeenth centuries were perhaps the time when the paths of science and religion began to divide. Mediaeval philosophers saw no problem with trying to understand the natural world; ultimately it was all still part of God's universe. However, once the suggestion was made that perhaps the Earth wasn't the centre of everything, the gloves were off! These times saw a rapid increase in the study and questioning of the natural world. William Harvey in the early 1600's was the first to show that living things could be studied experimentally but many scientists still believed the theory of spontaneous generation, or abiogenesis, which said that living things developed from non-living matter, for example maggots developed from rotting meat. Even after it was shown that complex organisms couldn't occur this way it was still believed that micro-organisms did until Louis Pasteur disproved this in the nineteenth century. Even Charles Darwin, the father of modern theories of evolution, not much more than a century ago was reluctant to publicise his theories as not only was he likely to be condemned by fellow scientists but his ideas could at the time have been judged to be legally blasphemous.

So despite all the evidence it isn't until comparatively recently that it became generally accepted that life evolved at all, let alone might have begun on another planet. However, there have been notable instances of far-sighted individuals, although unfortunately their unconventional wisdom became the cause of their downfall.

Early Dissenters

In 1633, at the age of 69, Galileo Galilei was put on trial for teaching that the Earth went around the Sun. Because he recanted his beliefs leniency was shown and he merely suffered house arrest for the rest of his life. Perhaps he was a lot wiser than many of his fellow believers for on February the 17th, 1600, an Italian philosopher, astronomer, mathematician and former priest was gagged, bound to a stake and burned alive. A victim of Pope Clement VIII and the Venetian Inquisition, Giordano Bruno had believed and dared to say that the Earth circled the Sun and that the universe might be infinite and contain countless solar systems like that of the Sun, implying there might be life on these. The more fortunate Galileo was finally officially absolved of heresy in 1992. Which ridiculed beliefs of today might be conventional wisdom after the next four hundred years?

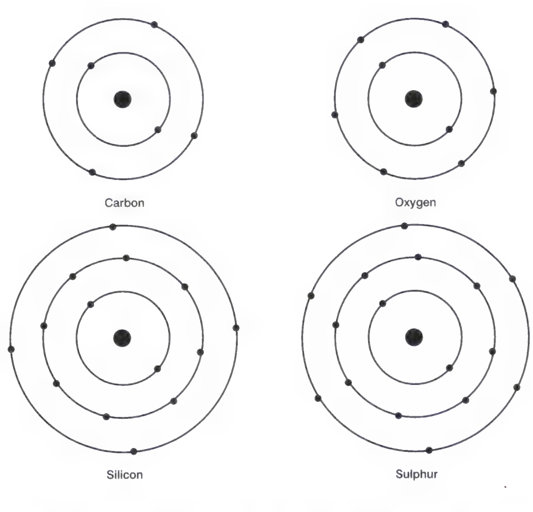
Modern Alternatives

One alternative theory for the beginning of life is that it did not begin on the surface of the planet at all but beneath the surface. Evidence for this possibility is the existence of organisms deep underground in caves where there is no light at all, and perhaps even more incredible the existence of organisms living around the 'black smokers' on the deep sea beds, where volcanic material is being ejected through the Earth's crust. There is an abundance of minerals around these and a source of energy, namely heat, that has nothing to do with sunlight. Interestingly these organisms, as do some others in sulphur rich environments, use the sulphur atom in their metabolism where 'normal' organisms use oxygen.

Molecular Self-Assembly

Another theory suggests that as conditions were so different to those of today, life may have originated from molecular 'self-assembly'. This is based on the discovery that under certain conditions of temperature and pressure, complex organic molecules form from simpler ones by the action of straight molecules physically linking with others. It does this by interlocking, like the links of a chain, rather than by chemically reacting with each other.

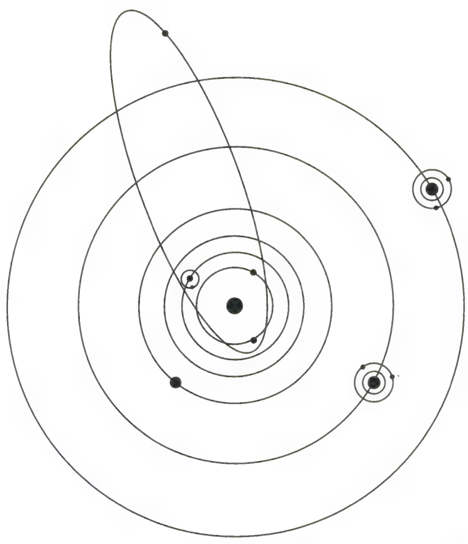
Figure 1 - Atoms



Atoms are composed of a positively charged nucleus (consisting of protons and neutrons) surrounded by negatively charged electrons in 'shells.' The inner electron shells are stable and shield the outer electrons from the nucleus, so that the outer electrons are free to interact with the electrons of other atoms. It is primarily the number of outer electrons present that determines how an element reacts and which compounds it will form, and so silicon is found to react similarly to carbon, and sulphur to oxygen.

Could life somewhere in the universe be made of silicon and sulphur instead of carbon and oxygen?

Figure 2 - Cometary orbit

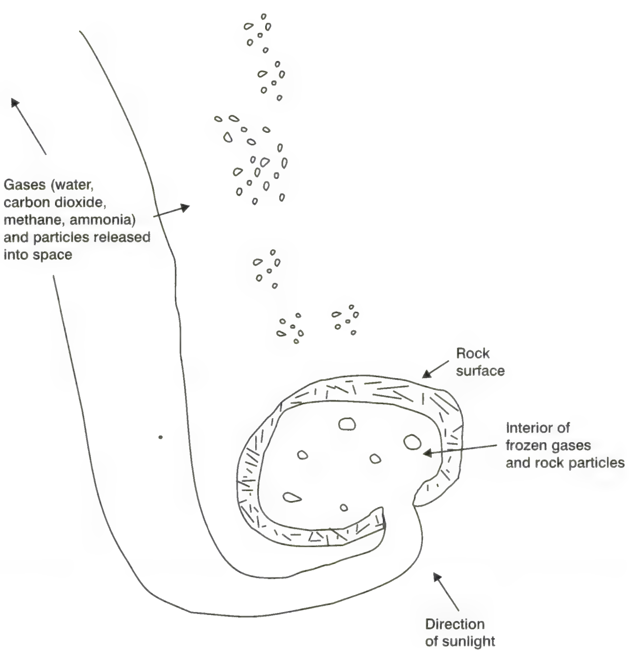


The path of many comets crosses the paths of planets. Could organic material or even primitive micro-organisms have been transferred from planet-to-planet by collisions?

Life, Not As We Know It

Life on Earth is based on carbon and water. At the temperatures found on Earth the chemical bonds between carbon, hydrogen, oxygen and nitrogen are the most stable and hence most common, and the elements themselves are among the most common. At lower and higher temperatures other bonds become more stable, for example silicon bonds and silicon oxygen bonds, and there are other compounds that are liquid at lower temperatures. Typical examples are ammonia and hydrogen cyanide; these also are composed of hydrogen, nitrogen and carbon. There are organisms on Earth that use sulphur instead of oxygen, and in fact at cellular level oxygen is poisonous, needing specialist structures within the cell to use it; this is probably a consequence of the first organisms evolving in an environment where there was little oxygen significant amounts of oxygen in the atmosphere only came about when plants started to convert carbon dioxide to oxygen via photosynthesis. Could life based on these other compounds exist somewhere, and would it be recognisable as life to us since we have no experience of such life?

Figure 3 - The Structure Of A Comet.



Comets are typically 10km across

Life Began On Mars

Mars is historically a very popular location for extra-terrestrial life, both scientifically and in fiction (probably as a consequence of Giovanni Schiaparelli's discovery of the 'canals' of Mars), and in fact is currently thought to be one of the most likely candidates for the discovery of present or past life, though probably not in the form of small green-coloured beings! At the time the claim was that the 'canals' on Mars were evidence of the work of extra-terrestrial life; the fact that they weren't canals at all wasn't proved conclusively until 1969 with the Mariner spacecraft missions, nearly a century after the first suggestion.

Life From Other Planets

Also in the late nineteenth century the theory that life began somewhere in outer space and moved from planet to planet via radiation pressure became popular among some scientists. This theory is remarkably close to one of the currently favoured 'alternatives'. The original idea was that life came into existence at the same time as the planets (exactly how was not specified!) and 'drifted' through space, from planet to planet. Currently credible is the theory that life or pre-life (pre-biotic) compounds could have evolved elsewhere and been carried through space not by radiation pressure but in comets, asteroids or meteors.

The Evidence

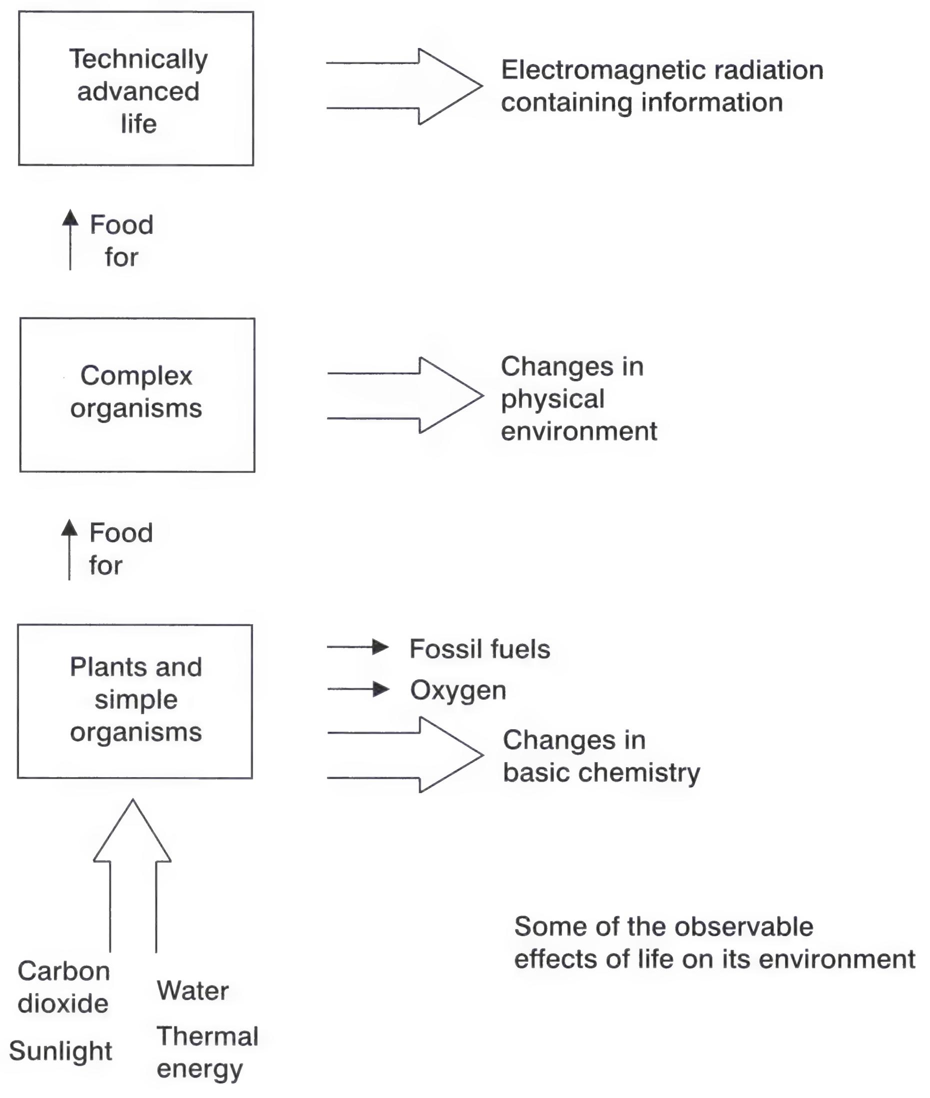
Going further and further back in time, less and less complex organisms are encountered until the point is reached where all life began, a single step from a non-living collection of chemicals to a living entity capable of maintaining its structure, interacting with its environment and replicating itself. At this point the environment would have been a liquid one, and the existence of water on a planet is one of the main criteria for the search for life there. Many things need to happen to reach even this stage however and the beginning of life can really be considered to go back to the point when stars, planets and galaxies began to form as the universe expanded and cooled, for it is this point when the pre-conditions for the many possibilities of life-forms began. Every element, every atom of every molecule throughout the universe exists as the consequence of the creation and destruction of stars, but these materials aren't confined to the surfaces of planets, and the same ones aren't found everywhere in the same proportions. These proportions, or relative abundance's, provide good clues as to what came from where, and when.

The Planets

The relative concentrations of the elements making up each planet depends on the differing 'local' conditions present when the planet formed. The relative abundance of all elements throughout the universe is known, a sort of 'universal' relative abundance, and each planet's 'local' relative abundance can be found. This might be quite similar to that of other planets, or it might be greatly different. Our own solar system shows great differences between the make-up of the planets and their moons; it surely cannot be impossible that this pattern is repeated along with many other variations throughout the many systems in the galaxies of the universe. The giant planets (Jupiter, Saturn, Uranus and Neptune) have compositions closer to that of the universe in general than do the inner Earth-like planets. Because they are larger and colder, these 'gas' planets have held onto their atmospheres of mainly hydrogen and helium, and also methane, ammonia and water.

The fact that they were cold enough for some of the gases to freeze is the factor that makes the giants become, and stay, giants. The smaller hotter planets Mercury and Venus however probably lost their lighter gases at an early stage through a combination of high temperature and lack of high enough gravity, althoughVenus has a dense atmosphere of carbon dioxide. Earth retained its atmosphere, but the subsequent development of life meant that the early composition was converted to the current abundance of

Figure 4 - Figure 4. Ecology.



oxygen. Mars appears to have had an atmosphere and then lost most of it some considerable time later, but perhaps not before the time necessary for life to come into existence (life had developed on the Earth within the geologically short timescale of about one billion years after Earth formation). Could life have existed on Mars and then been extinguished when the atmosphere became insufficient to support it?

The relative abundance's of the elements composing the molecules of life on Earth, mainly hydrogen, carbon, nitrogen and oxygen, lie between the universal composition and the local Earth composition, fitting in with the theory that life evolved in a hydrogen-rich atmosphere and then evolved and oxidised the hydrogen, carbon, methane and ammonia to water, carbon dioxide and nitrogen, and once this stage was reached conditions were no longer suitable for the development of other life-forms, and the line of evolution leading to the present day was in place.

Any system of planets orbiting a star must have the same pattern, planets near the sun being small and hot, those further away being large and cold. Part of the work of astrobiology is to find a range of conditions which will support an environment where life can exist, then see if newly discovered solar systems hold planets within that range, giving a good starting point on which to base the search for life.

Planet Satellites

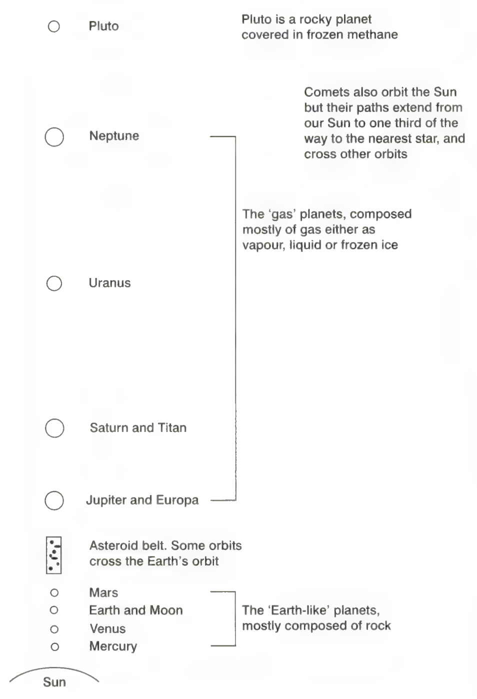
The satellites, or moons, of the planets were either formed at the same time as their parent planet, perhaps by catastrophic collisions which split the larger planet, or were independent bodies that were captured by larger ones. (Some are believed to be the result of the breaking up and then the reformation of a planet-sized body). This explains how one planet can be surrounded by moons with greatly different characteristics. The size and hence gravity reflects the capability of a planet to capture another body and so as might be expected the larger planets have more satellites than the smaller ones.

Additionally, if the planet was hot at the time of satellite formation or capture then the satellites reflect a similar pattern to the planets around the sun in that the nearer ones tend to be rocky whereas the outer ones tend to be mainly frozen water and gases. The simple rules that guide the formation of planets, moons and solar systems must surely mean there are many similar systems in the universe with the range of conditions and materials necessary for life to come into existence.

Asteroids, Comets and Meteors

Asteroids, comets and meteors are all believed to originate in the asteroid belt, between Mars and Jupiter, and are pieces of material 'left-over' from when the planets formed. As such they haven't suffered the changes that usually occur to material on the planets, for example physical processes such as weathering and volcanic activity. Comet interiors are primarily water (80%) and some people believe that the continuous bombardment of Earth by small comets was sufficient for this to have provided the Earth's water. Comets are equally important as a possible source of pre-biotic chemicals, as they contain many carbon, hydrogen, nitrogen and sulphur compounds like the frozen gases carbon monoxide (CO) and carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), and carbon disulphide (CS_2). They also hold small pre-biotic chemicals such as hydrogen cyanide (HCN), methyl cyanide (CH_3CN), and formaldehyde (HCHO), as well as larger molecules such as amino acids, purines and pyrimidines, chemicals found in all Earth life.

The larger molecules have been found in the meteorites known as carbonaceous chondrites that have been collected on Earth. The material composing a comet, ice and rock particles surrounded by a rocky shell, is slowly shed through the action of the Sun's heat or more dramatically through collisions as it orbits the solar system. The comets orbit the Sun like the planets, but the path is elliptical and can range from nearer to the Sun than the Earth, to around one third of the distance to the nearest star (Alpha Centauri, 4.3 light years away). The gases dissipate into space, but the particles remain in the same orbit as the parent comet, and these paths cross the paths of the planets, including the Earth, causing meteor showers. These can be seen dramatically at night as shooting stars, but in fact these collisions occur continually, adding around 400 tons of material to the Earth, including these pre-biotic molecules, every day. The comets have orbit periods that range from that of Halley's Comet's at 76 years to those of several millions of years - did one of



Some of the components, and relative distances in, the Solar System

Figure 5 - the Solar System

these passes bring the material that gave the 'kick start' to the evolution of life? Materials from Mars, the Moon and Venus have been found in meteorites that have hit the Earth; they must have picked up that material on another collision. Could others have come from somewhere else in the solar system or beyond, transporting materials from another planet which was already carrying life or on its way to developing it?

These then are some of the basic facts largely accepted by current thinking. But as our knowledge of our own Earth and the life on it has increased, the number of possible alternatives has become larger, increasing the probability of the existence of life somewhere else. Our current knowledge of Earth micro-organisms shows that some bacteria can survive radiation, vacuum and extremes of temperature, which raises another incredible possibility.

Extreme Life Forms On Earth

The number and variety of species of plants and animals, birds and insects, bacteria and fungae on Earth is spectacular, each with its own special adaptations to its own environment. Nevertheless the great majority survive only within a relatively narrow range of conditions, particularly with respect to temperature and moisture. More and more micro-organisms in particular however, are being found that are capable of surviving severe environments, and some are known to survive in temperatures ranging from -15°C to 113°C, in acid and alkali conditions from pH 0 to pH 11, in the radiation drenched cooling waters of nuclear reactors, in the vacuum of space, in beads of amber (and for literally millions of years), in 30% salt solutions, and in the dark, cold and high pressure at the bottom of deep sea trenches. Additionally it is recognised that some of the extreme environments on Earth are similar to the environments of some of the planets and moons of the solar system. Parts of Antarctica are very dry (and cold!) and similar to the surface of Mars. Also in Antarctica, a large lake is known to exist beneath four kilometres of ice (Lake Vostock); the same type of lake is believed to exist beneath the icy surface of Jupiter's moon Europa. The organisms present in the Antarctic lake have been isolated from the rest of the planet for millions of years, pursuing their own independent evolution. What similarities might these two places exhibit? Could it have been guessed that bacteria accidentally introduced into a camera sent to the moon with the Surveyor 3 probe and retrieved by the Apollo 12 astronauts would come back to life on Earth in a petri dish, as if nothing had happened to them in three years of exposure to the moon's cold, vacuum and radiation?

This then raises the further dramatic possibility that not only could life exist in the more extreme conditions of another planet, but also that the life that evolved on Earth could have begun its existence on another planet and was transported to Earth via meteorite hits. Could our most ancient predecessors have been carried from planet to planet by rocky spacecraft?

These alternative theories are controversial - what evidence would be needed to prove them? How would that evidence be found? Scientists are discovering that the best way to find what to look for in space is to examine the Earth first.

Environment

Once life has started and gained a foothold, then its immediate environment begins to be affected. Local chemicals are absorbed or converted and waste products are introduced. The population grows and must either move to find new sources of nutrient or adapt to the changed environment. For different species to survive together resources must be shared. If this is done successfully an increasing number of individuals and types form an ecosystem. The chemical nature of the environment is altered. Samples of the environment need to be analysed to find out how it is changing, and why.

Biospheres, Nutrient Cycles and Activity

Collections of ecosystems themselves interact, and form a biosphere, the layer of a planet that contains life. As life evolves this grows from perhaps initially the surface of the oceans, and then eventually covers land masses too, and eventually stretches from the bottom of the deepest ocean into the atmosphere. Areas of land and sea can change colour on the short timescale of the yearly seasons, or over longer periods with the development and interaction of different species. Images of the surface over periods of time are needed to see this.

Food Webs, Pyramids and Energy Flow

Energy from the sun, and heat from deep sea thermal vents, is used by countless simple organisms to convert simple chemicals such as carbon dioxide and water to more complex organic chemicals. These organisms become food for a smaller number of more complex organisms that can't produce the basic materials themselves, and these in turn become food for a yet smaller number of even more complex creatures, and so on. This is a food chain composed of numbers that decrease as they increase in complexity, a pyramid structure. There is interaction between the food chains; a food web develops, and material and energy interconvert. Temperatures of large regions of a planet can change. Infrared imaging is a good way of showing regions of differing temperature.

Populations, Co-operation and Intelligent Activity

Collections of individuals of a species form a population, and co-operate to make the most of their environment. Where capable, species physically alter their environment; buildings are made, towns and cities develop; roads and motorways grow. Large areas consist of angular shapes, and at night lights that can't occur by chance dot the planet surface. Close-up or ultra-high resolution images are needed to see these from space.

The Final Stage? - Technological Sophistication

Information needs to be exchanged to run these systems effectively. Eventually communication needs to be made across time and distance; letters aren't fast enough; telephone wires can't be made long enough, or reach enough people easily enough; radio communication is needed. Electromagnetic radiation spills into space, and can easily be detected with suitable electronic equipment.

Signs Of Life

Any living activity then, no matter how primitive, leaves its own signature, which we can observe if the appropriate scientific technique is used. To find life elsewhere we need to look for these signatures and make deductions from the results of those searches. In the concluding part of this series I'll be looking at what might be found, where it might be found, and at the science and technology of the equipment being used to find it.