Astrobiology, space and the future age of discovery

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Astrobiology is the study of the origins, evolution, distribution and future of life in the Universe, and specifically seeks to understand the origin of life and to test the hypothesis that life exists elsewhere than on Earth. There is a general mathematics, physics and chemistry; that is, scientific laws that obtain on Earth also do so elsewhere. Is there a general biology? Is the Universe life-rich or is Earth an isolated island of biology? Exploration in the Age of Enlightenment required the collection of data in unexplored regions and the use of induction and empiricism to derive models and natural laws. The current search for extra-terrestrial life has a similar goal, but with a much greater amount of data and with computers to help with management, correlations, pattern recognition and analysis. There are 60 active space missions, many of them aiding in the search for life. There is not a universally accepted definition of life, but there are a series of characteristics that can aid in the identification of life elsewhere. The study of locations on Earth with similarities to early Mars and other space objects could provide a model that can be used in the search for extra-terrestrial life.

Keywords: astrobiology; exploration; induction; extra-terrestrial life; universality of scientific laws

1. Introduction

A major focus of space biological research is astrobiology (or using an earlier term, exobiology). Astrobiology is the study of the origins, evolution, distribution and future of life in the Universe, or, specifically, to understand the origin of life and to test the hypothesis that life exists elsewhere than on Earth. It raises fundamental questions not only in biology, physics and chemistry but also in philosophy, psychology, religion, theology and the way in which humans interact with their environment and each other. It is difficult to determine with certainty the first use of the term ‘astrobiology’. According to Janet Morrison, first curator of the archives of the NASA Astrobiology Institute, the earliest citation was that of Lawrence J. Lafleur of Brooklyn College who in 1941 wrote an article entitled ‘Astrobiology’ [1,2]. The term became more widely used with the establishment of the NASA Astrobiology Institute in 1998.

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One contribution of 17 to a Discussion Meeting Issue ‘The detection of extra-terrestrial life and the consequences for science and society’.
The following topics will be discussed in this paper:

— The universality of scientific laws and concepts. There is a general mathematics, physics and chemistry on Earth and in the Universe. Is there a general biology, i.e., is their life beyond Earth?

— The great period of exploration extending from the fifteenth to the nineteenth century resulted in many observations in different parts of the world, at different times and in all seasons. It was a period when inductive science flourished and observation resulted in new ideas, concepts and scientific laws. It was an ‘age of wonder’ as new discoveries were made and revealed to the literate and general population.

The exploration of space and the search for extra-terrestrial life is based in large part on the use of high platforms that were not previously available. This has resulted in masses of new data and the use of the inductive scientific process to generate new hypotheses, new experiments and, possibly, new laws of science. This large accumulation of new observational data increases the possibility for new wonders similar to the experience of the earlier explorations. Space exploration and travel are increasing and more nations are starting or enhancing their programmes. The future will yield even greater amounts of information, with the capability of combining data from many sources to amplify the value of the research.

The sequencing of the genomes of many species has also generated huge amounts of data. Information technology (IT) supports the analysis of these data and the comparison of the sequences and functions of many genes in many species. This has and will generate new concepts, as comparison has not been possible in the past.

2. The universality of scientific ‘laws’

Early observers of the night sky recognized that the same mathematics that pertained to phenomena on Earth also did so for objects in the sky. Newtonian and Einsteinian mathematics is, at least so far, applicable to observation in space and for planning and predicting orbits and deep space missions. Mathematics appears to be universal, but, as in all scientific investigations, exceptions are possible. Physics appears to be universal, although theories based on earlier observations can be altered or rejected by newer data. Chemistry also appears to be universal. The early spectrometric observations of objects in the Universe and recent observations on other planets and moons can be understood using chemical theories and experiments that were made on Earth.

Is there a general biology? Do the same laws and biological principles that are used to explain life on Earth apply elsewhere? Is our Universe life-friendly, with many locations where it has developed, or are we a lonely inhabited island in the cosmos? So far, that is a difficult question to answer in that there is no convincing evidence that life exists anywhere but here on Earth. There is a considerable body of evidence that there are locations where life could exist, perhaps under conditions in which most earthly life does not thrive but in which some forms of known life could survive and flourish. There is also a theoretical
belief that life must be present elsewhere because there are so many places for it to do so. The Drake equation provides a formula to make these predictions and, recently, the identification of more than 400 extra-solar planets has increased the accuracy of these estimates. But, probability is different from reality and time will tell how valid these predictions are. Having said that, the importance to the human psyche of knowing if life on Earth is not unique has impelled the growing number of scientific programmes to detect life elsewhere. It is the motivation for this Royal Society Discussion Meeting on ‘The detection of extra-terrestrial life and the consequences for science and society’ and many other meetings and programmes worldwide.

How will the investigators know that life has been detected? It is fair to say that there is not an agreed upon definition of life. There are characteristics of life: reproduction; transmission of information; an order; systems in which there is diversity, variation and selection; complexity; the existence of a metabolism; the ability to change but yet maintain a certain stability. Davies [3] has described these in rich detail. If a phenomenon is found on space objects that has a sufficient but not easily defined number of these characteristics, then it is probable that life will be proclaimed. But, what if life elsewhere is radically different than life on Earth? How will it be detected? In science, we often create a model based on what is known and search for data that can be used to support or reject the model. If sufficient data are found that is contrary to that predicted from the existing model, the model will be rejected and another substituted in its place. The nature of this new model is difficult to predict, as the data to formulate it will arise from the testing of the existing model.

Another approach to understanding the origins of life on Earth, and therefore provide clues to its origin elsewhere, is to produce it experimentally in the laboratory. The fundamental approach to the study of biology is that chemistry is based on physics and mathematics and that biology is based on chemistry. Understanding the chemistry will lead to an understanding of biology and of life. The failure, so far, to fully create life by chemical means has led in the past to invoking non-chemical agents—the élan vital of Henri-Louis Bergson, Aristotle’s ‘life force’, ‘complexity’—to explain the leap from chemistry to biology. Electricity was implicated in the case of the Creature created by Victor Frankenstein in Mary Shelley’s novel [4].

The efforts to create biology from basic elements, including those thought to exist on early Earth, persists and forms a new programme for biochemistry (see, for example [5,6]). Impelled by the success of the genome project, DNA sequencing and synthesis are moving forwards very rapidly. The influenza virus implicated in the devastating 1918–1919 pandemic has been synthesized as has the phage T7. The largest DNA synthesis is of the 582,970 base pairs of Mycoplasma genitalium. These remarkable achievements can give insights into origins by a form of reverse engineering and also could be of practical value in the design of vaccines and of therapies [7]. The continuing addition of species genomes to the already large database provides another large source of new data that, using the advances in information technology, can lead to new ideas and concepts different from those that stimulated the sequencing.

A good hypothesis is one that is equally interesting if it is supported or rejected and, independent of support or rejection, stimulates new and interesting experiments and observations. The scientist ideally would want to have a neutral
attitude towards outcome in order to avoid bias towards favouring support, particularly of a hypothesis that he or she had created. The hypothesis can become identified with the scientist’s ego and in effect make it impossible to reject even with overwhelming evidence. Finding life elsewhere would be extraordinarily interesting and exciting. It would give the term ‘exobiology’ a new prominence in that there would now be a subject for study. But what if life is not found? It is difficult to reject a negative and it is probable that the search will continue beyond what some may consider a reasonable time. The realization that we are alone in the Universe will certainly require a re-examination of how we relate to nature and to others. This will be discussed by others in greater detail in this issue. Irrespective of the support or rejection of the life model, the search is bound to yield fascinating data that we cannot predict. It has already stimulated research that might not have been funded or considered interesting, but for the life search. These include the investigation of extreme bacteria, archaea viruses and other micro-organisms, pre-biotic chemistry, the distribution of organic chemicals in space, the search for meteorite impact craters, the ongoing quest to find water on Mars, the Moon, and elsewhere, and many others.

3. Exploration science and the inductive method

Improvements in navigation and the ability to build large sea-going sailing vessels led to an explosion of worldwide exploration in Europe from about the fifteenth to the nineteenth centuries. This was amplified by the growth of international and intercontinental trade and the expansion of European empires to other continents. There was a flourishing of the inductive process and empiricism in science; large amounts of new data were collected in places never before visited and at different times and under different conditions. Repeated observations of similar phenomena reinforced the validity of the observations. Associations of variables in combinations not previously encountered were made, and seeing them repeatedly increased the confidence that they were universal natural phenomena. From these observations, new ideas and hypotheses were derived that could then be tested by repeated observations in other parts of the world and by experiments.

An interesting early example are the observations of William Dampier (1651–1715), a curious figure in the history of exploration. He was, as noted in a memorial plaque in the village of East Coker, Somerset, his birth place, a ‘Buccaneer Explorer Hydrographer and some time Captain of the Ship Roebuck in the Royal Navy’, as well as a celebrated travel writer. He had circumnavigated the Earth multiple times, one of the few people of the time who had done so, and was able to observe similar phenomena in many locations. He experienced both hurricanes in the Atlantic and typhoons in the Pacific. He recognized that ‘only the name’ was the difference between them and that ‘both words have only one signification which is a violent storm’. His world-circling observations allowed him to unify the understanding of the phenomenon, hasten geophysical explanation, and lead to general laws of meteorology. He dedicated his book, A New Voyage Around the World published in 1697, to Charles Montague, Earl of Halifax, the President of the Royal Society (and, fortuitously, Chancellor Phil. Trans. R. Soc. A (2011)
of the Exchequer), stating that he had ‘a hearty zeal’ for ‘the promoting of useful knowledge’, the very phrase used in Benjamin Franklin’s *Proposal* for the establishment of the American Philosophical Society in 1763, which was modelled, in part, on the Royal Society [8].

Franklin himself recognized the value of correlating observations over time and place. He and his grandson Temple made observations on water temperature during their return to Pennsylvania from Paris in 1785, thus helping to determine the course of the Gulf Stream. Knowledge of the location of the Stream expedited the Atlantic crossing, an example of the useful knowledge that Franklin and others of his time sought so arduously. Another example of the value of observations in more than one place concerned the understanding of the ‘northeaster’ storms that often inflict the eastern seaboard of the USA. Based on communication with his brother, he learned that a storm that he experienced in Philadelphia was in Boston soon after. He recognized that ‘northeasters’ travel from southwest to northeast even though the wind direction is about the opposite.

A prime example of worldwide exploration are the voyages of Captain James Cook, hired by the Royal Society to observe the transit of Venus and explore the Pacific Ocean. The HMB *Endeavour* departed England in 1768 and proceeded to the Pacific, making many new discoveries. In this and in subsequent expeditions he and his party made scientific observations, collected artefacts and, characteristic of the multiple goals of exploration, claimed land for the British Crown. The field studies were guided by an initial goal—i.e. the transit of Venus to determine the distance of the Earth to the Sun. But, additional observations independent of the original project could then be used to formulate new ideas subsequently tested in other locations and by experiments in the laboratory and the field. It was a rich period for empirical and inductive science.

The Enlightenment attitude encouraged exploration and the production of new knowledge. It ushered in the Age of Wonder, the period in which the literate population and particularly the Romantics ‘discovered the beauty and terror of science’ [9]. A pioneer in this quest was Alexander von Humboldt, the German scientist who had travelled through South America and Mexico (1799–1804), collecting specimens and data in many different environments and times. He visited the American Philosophical Society in Philadelphia and met many of its members during his short sojourn in the USA (May–July 1804), was elected a member on 20 July 1804, and maintained a correspondence with Jefferson and other members after his return to Europe. He recognized the interconnectedness of things, the importance of coordinating similar information at different stations on different lands and seas. He was a pioneer of the ecological approach to natural sciences, and of integrating different disciplines in the investigation of an area or a phenomenon. In his later years, Humboldt attempted to set down all of knowledge in *Cosmos* [10], his multi-volume, widely read work, perhaps the last attempt by a single person to pull together all knowledge of the natural world. He influenced Darwin, who had his books on his voyage on the *Beagle*, and many other explorers and scientists worldwide. The data that Darwin collected on this round-the-world trip, which included all seasons and many environments, and the data and the artefacts he amassed during the voyage and after his return to his home at Down House, generated the universal formulation of the theory of evolution. The many new observations in places
that were accessible only with difficulty generated new ideas, hypotheses, laws and concepts. Basic to all this was the necessity to be able to communicate observations from and to scientists in different parts of a nation and the world, and to have the opportunity to discuss them in person or by post. The scientific societies that flourished during this period were designed to serve these purposes.

The Lewis and Clark expedition, funded by the military and led by US Army artillery officers, departed St Louis for the west and the Pacific coast in 1804. The expedition was conceived by Jefferson, who at that time was the President of both the United States and the American Philosophical Society; the Society received many of the artefacts returned by the explorers and also their journals, which are still retained in the library of the Society. It was the first of the US government expeditions to explore the natural history of the newly acquired Louisiana Purchase and beyond. It had multiple purposes: natural history, anthropology and ethnology, the study of Indian languages (of particular interest to Jefferson), mapping trade routes to the West (they were unsuccessful in finding a much desired water route), establishing a basis for territorial claims, defying the Spanish colonial power in the south-west, and other uses. This is reminiscent of many of these travels of exploration of the time and many since then that combine scientific, political and commercial goals.

Another project that was based on the collection of data worldwide was the so-called Magnetic Crusade. The ‘Crusade’, which began about 1838, was initially stimulated by Humboldt and moved forward by John Herschel, the son of the astronomer, and his colleagues. It was a worldwide programme to obtain geomagnetic observations across Europe and around the world using, in large measure, the outposts of the British Empire as well as the cooperation of scientists from several countries. It led to the establishment of scientific stations around the world that were used to collect other information as well as the geomagnetic measurements. The crusade also stimulated the dispatch of seaborne missions to the Antarctic and elsewhere to increase the number of measurements but also permit the collection of other kinds of data.

Herschel recognized that there would be a large amount of data collected at the research stations and on board ship. He believed that intelligent people, irrespective of their scientific training, could collect, record and help in the analysis of the large amount of data that would be assembled [11]. This has a resonance in the current programmes in ‘Citizen Science’ based on the same expectations. For example ‘Galaxy Zoo’ has enlisted about 100,000 volunteers to categorize galaxies imaged electronically by the Sloan Sky Survey. (For further information see Galaxy Zoo and Citizen Science at www.zoo1.galaxyzoo.org.) The citizen scientists are often the first to actually see the images, which are stored electronically and distributed on the internet. They are also encouraged to report unusual observations that may not relate directly to the classifications and to originate their own scientific papers. The programme has now been extended to include craters on the Moon and to analyse the images to be collected by the recently launched Lunar Reconnaissance Orbiter Camera. Other projects that involve classifications that are not well done by computers, which lack human capabilities for abstraction, are and will be included.

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4. Exploration of space and the search for extra-terrestrial life

The range of dimensions experienced in the study of life’s origin and distribution in the cosmos ranges from the micro- and millimetres of viruses, bacteria and archaea viewed in the microscope, to the billions of light years in the images and measurements of the early Universe garnered by the flotilla of space-borne and terrestial telescopes now available to science. If life does exist elsewhere, it may be in the form of microorganisms similar to those found in extreme locations on Earth. Astrobiology has focused on their study and has enriched a field that had not been studied intensively previously. Many space missions are directly or indirectly related to how life started from the cosmic beginning and how organisms might survive in space and planetary environments. There are currently about 60 active space missions, including 15 astrophysics missions, many of which contribute to the extra-terrestrial project. The Kepler mission satellite has recently been added to the search for extra-solar planets, including Earth-sized planets. Within a few days of acquiring first light, four new planets were discovered to add to the more than 400 already identified. The Sofia airborne infrared telescope will soon acquire first light and add to our knowledge of the infrared-detectable objects in space. The Mars Exploration Rovers are still operative, although one is now stranded in a sand trap, six years after landing on a mission originally designed for a 90 day sojourn. They have established that Mars was at one time a wet planet that could have supported life. The massive amount of water in the interior of the Jovian moon Europa, and on other planets and moons, the methane environment of the Saturnian moon Titan, and other locations identified by space- and Earth-based instruments are possible locations for life.

Did life start elsewhere in our Solar System and/or Galaxy and arrive here ready to flourish, or was Earth the source of life on other planets if life exists there? This has stimulated interest in the study of the 170 or so meteorite impact craters on Earth, and of craters on the Moon, which better reflect the incidence of impacts over the years. If life is found elsewhere, will it be directly related to ours, or will it be a new generation of life? The shuttle Columbia, that tragically crashed with the loss of seven lives on 1 February 2003 as it was descending over Texas, had on board live Caenorhabditis elegans in aluminium containers. Most of them survived the fire and impact, indicating that life can survive the last part of the journey from space to Earth [12].

The massive amount of data coming from these and many other missions provide a very rich source for new ideas and concepts that have not and could not be made until the high platforms were provided by the national and international space programmes. An advantage for this age of intense inductive science is the availability of computer resources and advances in IT that allow the storage and distribution of the data to many laboratories, and methods for display of data that could reveal patterns not readily seen without computers. There are also computer-based facilities to combine data from many sources and combine them in a resource available to the scientific community so that observations from many sites can be combined in one location and facilitate ‘putting the dots together’. These IT developments have much broader impacts; ‘The technical and sociological changes catalysed
by the Virtual Observatory in astronomy are now affecting virtually all scientific research disciplines’ [13]. They could also be extended to uses other than scientific.

Missions often take a long time to plan, fund and receive and interpret data. The time scales are comparable to those of explorers under sail, or even longer. A mission can extend through the entire length of a career, and beyond. These missions are often generational in character—reminiscent of the generations it took to build major cathedrals—and a scientist may have to depend on his/her or someone else’s children and grandchildren to reap the full harvest of a project that they initiated.

Science has advanced rapidly in the past but the current rates are nothing short of astounding. We are in an age of wonder no less exciting than that of the earlier explorers.

5. Conclusion

The search for extra-terrestrial life is a major programme for space exploration. It requires the resources of multiple scientific and other disciplines. The vast amount of data collected over time and place are similar to the early expeditions of exploration into previously unknown places. The current search is aided by much more sensitive and rugged instrumentation and by the use of computers to store the data, allow multiple comparisons and display patterns not readily seen without them. Empirical and inductive methods are required to use the large data base.

The sense of wonder generated by the explorations of the Age of Enlightenment is also part of contemporary research and exploration.

References