Astrobiology

Study Week

Astrobiology is the study of life’s relationship to the rest of the cosmos: its major themes include the origin of life and its precursor materials, the evolution of life on Earth, its future prospects on and off the Earth, and the occurrence of life elsewhere. Behind each of these themes is a multidisciplinary set of questions involving physics, chemistry, biology, geology, astronomy, planetology, and other fields, each of which connects more or less strongly to the central questions of astrobiology. Stimulated by new capabilities for scientific exploration on and off the Earth, astrobiology seems to be establishing itself as a distinct scientific endeavor.

The study of Astrobiology is a quite appropriate subject for the Pontifical Academy of Sciences which has a multi-disciplinary membership. The study week being undertaken by the Pontifical Academy of Sciences has an ambitious agenda: to bring together leading scientists in these diverse fields, to share the latest results of their own research and provide a broader perspective of how these results impact other areas of astrobiology. To accomplish these goals successfully will not be easy, because the language – really, to be honest, the jargon – of each of the fields represented by the speakers is not broadly understood. How does one explain to an astronomer the intricacies of chemical markers of biological activity in ancient Earth sediments? Or conversely, how can a molecular biologist be briefed with adequate depth on the latest astronomical techniques for detecting planets? The paradox of astrobiology is that, while one might regard it as a rather narrow and specialized endeavor, one cannot hope as an individual to adequately understand the span of traditional disciplines that form the backbone of the field. The study week, then, is very much a cross-disciplinary education for experts in one field to gain insight and understanding in other more distant disciplines – but always under the reasonably well-defined rubric of astrobiology. This is nothing new: for the 13 years that astrobiology has been recognized as a nascent field unto itself, scientists have been educating each other in an effort to understand one another's fields. But oftentimes this comes in the environment of the frenetic 'annual conference', that phenomenon of modern scholarship in which the maximum number of talks is packed into the space of a few days, leading to a kind of intellectual bazaar in which scientists shop for nuggets of information (usually, for convenience, in their own discipline), check to make sure that competitors are not hawking the very wares they seek to proffer, or (rarely), venture forth into sessions outside of their own expertise, to puzzle over just what is being said. More focused workshops in astrobiology, as in other sciences, of course occur; but most often in one subfield. In any given month geologists might be meeting in Vancouver to pour in depth over the latest results on the most ancient appearance of fossils in the terrestrial rock record, while in Rio astronomers pour over new data on the abundance of the life-forming elements in nearby starforming regions, and in Potsdam planetary scientists discuss the latest evidence for life occurring beneath the oxidizing surface of Mars. The present study week is not a unique event, but it is a relatively rare one. A focused week in which (relatively) cloistered astrobiologists confront each other's fields of research and try to understand them is a difficult but heady undertaking. To make this feasible in a practical amount of time, we have carefully selected speakers who can make their own particular fields of research understandable to astrobiologists from other fields, indeed even to the intelligent layman, and who can connect their research to the broader problems of astrophysics. The program is organized into eight sessions. Session 1, on The Origin of Life, concerns the difficult problem of the mechanisms by which molecules became organized in such a way as to permit life to begin. Life as we know it on Earth is built on a structure of proteins and nucleic acid polymers which carry the information to build the proteins from their constituent amino acids. While complex, life is a very specific and selective organic chemistry: out of the broad range of possible organic acids that abiotic systems can produce, life utilizes just a handful; likewise, life largely utilizes just left-handed amino acids and right handed sugars. There is much more to the biochemistry of life than this, but it is exemplary of the challenge chemists and biochemists face in understanding how the cacophony of abiotic organic chemistry evolved into the structured symphony of life. Likewise, teasing out of the scant geologic record of the early Earth some indication of the environmental conditions under which life formed is an extremely difficult task, because geologic activity – the forces of tectonics, erosion, impacts of asteroidal material – have largely erased the evidence of the Earth's environment in its first half-billion years after formation. Session 2, Habitability Through Time, concerns the problem of how the Earth has been able to sustain life over its long geologic history. Here the geologic record is more ample than that during the time life is presumed to have begun (and, it should be made clear, we have no precise understanding of when that in fact occurred). But now the processes are more complex: a variety of scales of space, time and energy come into play. The Sun itself, which is often tacitly regarded as the stable sustainer of the liquid water essential for life as we know it, was approximately 30% less bright early in the Earth's history than it is today. Yet geological evidence for liquid water on Earth's surface when the Sun was so faint suggests that our atmosphere must have provided a much stronger greenhouse effect than, and been quite different from, that of today. Episodes of severe glaciation in the geologic record suggest that from time to time the atmospheric 'thermostat' failed. How life – even at the molecular level – and the environment have interacted over geologic time is the subject of Session 3, Environment and Genomes. Molecular signatures of the biochemical reactions sustaining life remain in the geologic record, giving us hints of the changes over vast periods of time. Lessons from life forms that live in extreme environments, such as submarine vents and the Earth's driest deserts, aid the interpretation of this record. The relatively sudden appearance of animal life late in the Earth's history remains a mystery whose solution might be found in both the environment of the time and the workings of the genome. Earth seems to be unique in our solar system in terms of its abundant life, and yet we cannot be sure that life is not present on Mars or elsewhere in the solar system. Session 4, Detecting Life Elsewhere, explores the prospects and techniques for finding life in a variety of environments elsewhere in the solar system, beyond Mars to the asteroids and the moons of Jupiter and Saturn. Whether or not life exists elsewhere within our own solar system, the vast Milky Way Galaxy of which we are a part contains over 100 billion stars. If planets are a common feature of such stars, might life be as well? The next three sessions explore in a systematic fashion the detection, formation, and properties of planets around other stars: 'extrasolar planets'. Session 5, Search Strategies for Extrasolar Planets, explains the various techniques used to find planets around other stars and determine their properties. Already, about 380 extrasolar planets are known, and the number of stars searched suggests that at least 10% of stars similar in properties to our own Sun have at least one planet. Session 6, Formation of Extrasolar Planets, details progress in understanding how planets form as a part of the process of the formation of stars. Two outstanding questions are what determines when a rocky planet like the Earth will form versus a gas giant like Jupiter, and is the process of planet formation materially different around stars much smaller than our Sun. Finally, Session 7, Properties of Extrasolar Planets, brings to bear computer modeling, astronomical data and a bit of speculation on the question of the properties of extrasolar planets as a function of the properties of, and distances from, their parent stars. Ultimately, much of the fascination of astrobiology comes from the question of whether sentient life forms exist on other worlds, and whether forms of life alien to our own in fact coexist with us – today – on our own home world. Session 8, Intelligence Elsewhere and Shadow Life, explores both these issues.

The search for intelligent life elsewhere is being conducted by listening to the cosmos with radio telescopes in an effort to pick up a signal of inarguably artificial origin. A search for life with a biochemistry different from that of all the known life on Earth – what has been termed 'shadow life' – on our own planet is a fascinating possibility but one fraught with daunting difficulties.

Astrobiology is an effort to use a diverse range of scientific techniques, focused on targets from the molecules in cells to the vast cosmos around us, to provide a deeper appreciation of humankind's place in the cosmos. It is a recognition of the remarkable intricacies of all that is within and around us and a 21st century realization of the psalmist's recommendation (Ps 111:2) to delight in its study.

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