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**INTRODUCTION TO LIFE IN THE UNIVERSE:**

**“Are we alone?”**

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Fifty years ago, the Miller experiment took the search for the chemical origins of life to a new level with the laboratory synthesis of compounds required for life under conditions that resembled the early environment of the Earth. Since that time, scientists from around the world have built on these seminal results, developing a multi-disciplinary field that explores the fundamental questions of life's origin and emergence from the outer reaches of the universe to the finest details of microfossils seen in an electron microscope.

At the Seventh Trieste Conference on the *Chemical Evolution and the Origin of Life*, over one hundred scientists from many countries gathered to discuss and debate the current state of knowledge in the field. Highlights included the Cyril Ponnampereuma Lecture by George Coyne on Cosmic Evolution, Frank Drake's pre-dinner talk on the future of SETI, and the Abdus Salam Lecture by Stanley Miller himself, reflecting on the history and current state of chemical evolution experiments. This volume contains papers describing the research and results presented during these deliberations. These papers clearly demonstrate the health and vibrancy of the field seen fifty years after the Miller experiment.

In those fifty years, great advances have been made in many disciplines affecting the chemical evolution and origin life. Advances in biology, biochemistry and related fields have allowed the exploration of the mechanisms and processes of life at the molecular and atomic scale. Astronomical explorations have revealed a universe rich in the building blocks of life. Exploration of our own planet has demonstrated that primitive life emerged very early in Earth's history, and we have found life flourishing today under extreme environmental conditions previously believed to be completely inimical to any biologic activity. Beyond the Earth, reconnaissance of most of the solar system has revealed a remarkable diversity of planetary environments, greatly expanding our concept of the 'habitable zone' in the solar system. Finally, as other planetary systems around distant stars are being discovered at an ever-increasing rate, we find ourselves asking the question "Are we alone?" in the context of new, quantitative information in all these fields.

The program of the conference featured reviews and new research contributions related to all of the above. Looking at the various contributions and listening to the debates from my perspective as a planetary scientist, I was struck by several general currents running through the proceedings:

First, the conclusions and insights from the original Miller experiment have proved to be remarkably robust. Laboratory equipment and measurement capabilities have vastly

improved in the last fifty years. Ideas about the chemistry of the early Earth's atmosphere and the physics and chemistry of the solar nebula and planet formation have also evolved greatly. Nevertheless, the Miller experiment has remained the underpinning for understanding the chemical processes leading to the production of biologically interesting compounds, to the extent that modern variants of the experiment are still being performed routinely to provide samples for comparison with comet surfaces, Titan's aerosols and interstellar material.

Second, the search for the earliest evidence for life on Earth illustrates both the tremendous sensitivity and sophistication of our current technical capabilities but also the frustrations of trying to wrest unambiguous results from the fragmentary records available to us from that early era. Interpretations of claims made on the basis of the fossil record, micro- and "nano-" fossils, and bio-markers of various kinds are still being advanced, challenged and hotly debated. It is notable that many of these issues arise also in one form or another with respect to interpretation of the Martian meteorite results. Clearly, this on-going debate should make us appropriately cautious and inform our approach to evaluating future searches for evidence of extra-terrestrial life.

Third, the convergence of research on terrestrial life in extreme environments and exploration of the diverse worlds of our solar system is expanding the range of investigations into sites for pre-biotic chemistry and possible habitats for extra-terrestrial life. The following are just a sampling of the exciting research areas related to our expanding exploration of our local cosmic neighborhood:

Interstellar dust grains and cometary material have long been regarded as potential windows to the original material from which the planets formed and reservoirs of pre-biotic organic compounds. The prospects of sample return from the NASA Stardust mission and the approaching launch of ESA's Rosetta promise an exciting new chapter in our understanding of these materials.

Evidence for liquid water flowing on the surface of Mars in past epochs has driven a new wave of Mars exploration. Results from NASA's Odyssey mission have provided maps of likely subsurface ice deposits even at low latitudes. During the meeting, the results from past missions were reviewed and prospects for future exploration explored. At the time of the meeting two NASA rovers and the ESA Mars Express mission with the Beagle 2 lander were headed toward Mars. As these proceedings go to press, the Beagle 2 appears to be lost, but both Spirit and Opportunity rovers and the Mars Express Orbiter are returning exciting new data, beginning a new phase of Mars exploration.

Other planetary environments of intense interest to the conferees are possible subsurface oceans on the icy satellites of the outer solar system. Raised as a theoretical possibility over twenty-five years ago, oceans under the icy crusts of Europa, Ganymede and Callisto are strongly suggested by a number of lines of evidence from the Galileo mission. Magnetic field data taken during close fly-bys of these

satellites showed perturbations from induction magnetic fields created by the time-varying Jupiter magnetic field (Ganymede also has a large, permanent dipole field presumably generated in its core). The best current explanation for this behavior is the presence of a global electrically conducting layer near the surface. Rock and ice are poor electrical conductors, but saline ocean water would be consistent with the data.

Europa is particularly interesting because of its geologically young, lightly cratered surface. Tidally produced fracture patterns and chaotically disrupted regions reminiscent of melting and/or solid-state convective activity in the ice crust suggest that the ocean has been in communication with the surface in recent geologic times. Gravitational data suggest a total water plus ice thickness of about one hundred kilometers, raising the possibility that this satellite has a volume of liquid water in its oceans over twice that in all of Earth's oceans. NASA is studying a future mission, the Jupiter Icy Moons Orbiter, which would return to the Jupiter system and, using nuclear ion-drive propulsion, orbit each of the icy satellites and study them in detail.

Saturn's large icy satellite Titan is another fascinating world for study of natural organic synthesis. With a massive nitrogen/methane atmosphere (surface pressure ~1.5 Earth's despite its low gravity), Titan represents an extraordinary natural laboratory where versions of the Miller experiment have been conducted in its atmosphere for perhaps billions of years. Its atmosphere rich in hydrocarbons and aerosols and its surface probably a mixture of water ice and liquid hydrocarbons, Titan is believed to be an ideal place to study pre-biotic processes and compounds. The NASA Cassini mission carrying ESA's Huygens probe to Titan will arrive at Saturn in July 2004, and Titan will be one of the major targets of its projected four-year mission of exploration.

Finally, the discovery of extra-solar planetary systems around other stars has added a new dimension to the discussions of life in the universe. Discussions at the conference ranged from the nature of these systems and the types of environments for life they might harbor to methods of detecting the presence of life by remote observations of these systems. It is clear that we are now only looking at the first hints of what will be in the future a large, exciting field of study.

The discussions of this Trieste Conference and the papers in this volume represent a "snap-shot" of the status of our understanding of the chemical evolution of life and the current issues related to life in the universe – fifty years beyond the Miller experiment and at the opening of the next century of exploration. We can only speculate about and eagerly anticipate the advances the next fifty years may bring.