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Organic chemistry in space and the search for life in our Solar System

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One of the most fascinating questions in planetary science is how life originated on Earth and whether life exists beyond Earth. Life on Earth originated approximately 3.5 billion years ago and has adapted to nearly every explored environment including the deep ocean, dry deserts and ice continents. What were the chemical raw materials available for life to develop? Many carbonaceous compounds are identified by astronomical observations in our Solar System and beyond. Small Solar System bodies hold clues to both processes that formed our Solar System and the processes that probably contributed carbonaceous molecules and volatiles during the heavy bombardment phase to the young planets in our Solar System. The latter process may have contributed to life's origin on Earth. Space missions that investigate the composition of comets and asteroids and in particular their organic content provide major opportunities to determine the prebiotic reservoirs that were available to early Earth and Mars. Recently, the Comet rendezvous mission Rosetta has monitored the evolution of comet 67P/Churyumov-Gerasimenko during its approach to the Sun. Rosetta observed numerous volatiles and complex organic compounds on the cometary surface and in the coma. JAXA's Hayabusa-2 mission has returned samples from near-Earth asteroid Ryugu in December 2020 and we may have some interesting scientific results soon. Hayabusa-2 also carried the German-French landing module MASCOT (mobile asteroid surface scout) that provided new insights into the structure and composition of the asteroid Ryugu during its 17-hour scientific exploration.

Presently, a fleet of robotic space missions target planets and moons in order to assess their habitability and to seek biosignatures of simple extraterrestrial life beyond Earth. Prime future targets in the outer Solar System include moons that may harbor internal oceans such as Europa, Enceladus, and Titan. Life may have emerged during habitable periods on Mars and evidence of life may still be preserved in the subsurface, evaporite deposits, caves, or polar regions. On Mars, a combination of solar ultraviolet radiation and oxidation processes are destructive to organic material and life on and close to the surface. However, the progress and the revolutionary quality and quantity of data on "extreme life" on Earth has transformed our view of habitability. In 2021, we will hopefully have three robotic missions arriving at Mars from China, the United Arab Emirates and NASA (Tianwen-1, Hope, and Mars2020 respectively). In 2022, ESA's ExoMars program will launch the Rosalind Franklin Rover and landing platform, and drill two meters deep into the Martian subsurface for the first time. Mars is still the central object of interest for habitability studies and life detection beyond Earth, paving the way for returned samples and human exploration.

Measurements from laboratory, field, and space simulations are vital in the preparation phase for future planetary exploration missions. This Cassini lecture will review the evolution and distribution of organic matter in space, including results from space missions, field and laboratory research, and discuss the science and technology preparation necessary for robotic and human exploration efforts investigating habitability and biosignatures in our Solar System.