ELSI Symposium IV:
Early Earth, Venus & Mars: Three Experiments in Biological Origins
Jan. 12 - Jan. 15, 2016

Summary

The symposium comprised a half-day long trio of overview talks, followed by three days of theme-oriented talks, one theme per day. The themes were: Day 1 - The formation of Venus, Earth and Mars; Day 2 - Planets as integrated systems; Day 3 - Starting conditions for prebiotic chemistry. Each day contained a half- to three-quarter-hour discussion of each group of talks, and a final two hour long discussion to summarize major points.

The introductory talks enlightened us generally in each thematic area. Our knowledge of planetary accretion is changing rapidly due to observational and computational advances. In particular the roles of orbital migration, pebble accretion, and volatile distribution in protoplanetary disks are being reexamined. We also learned that small rocky planets up to five Earth masses are relatively common in exoplanet surveys. The focus on defining a water existence zone might involve processes other than simple insolation, such as ingassing or burial of water in a planetary interior. Thus systematics based on the distance from the central star may be of questionable value. Finally, we heard that what life needs is simply a source of enthalpy to scavenge that is in excess of thermal fluctuations. It could be based on a variety of chemistries, not just redox reactions involving oxygen.

The talks under the theme of the Formation of Venus, Earth and Mars began by informing us of the limitations to the observations of protoplanetary disks. Spatial resolution is lacking to tell the difference between a Venus, Earth or Mars region in an accretion disk. Pebble accretion allows planets to grow unbelievably fast - to Jupiter mass in a few Keplerian orbital times, solving one problem of classical accretion models. Unfortunately, the model does not lead to any particular compositional zonation in disks and does not solve the volatile zonation problem with present knowledge of its character. The Earth appears to have been born dry, with water added at a later stage -- perhaps during the late veneer or with cometary volatile input.

The Earth's volatiles contain a component that was inherited early in its accretion history, no more than 100 Ma after the solar system formed. It also started accreting from rather dry materials, with volatiles added later. Venus superficially appears dry of water, but it may be buried in the planet's interior. A magma ocean and an early water-rich atmosphere may have been stripped of hydrogen by greater insolation due to its proximity to the Sun and the resulting oxygen buried in its magma ocean, whose lifetime is extended by the hot, opaque atmosphere. Alternatively, the left-over oxygen could have been buried by impacts that rusted ejecta and buried it in the early-formed lithosphere.

In the theme of Planets as Integrated Systems, exoplanet search criteria for water-bearing conditions was a key element of discussion. Remote study of exoplanet atmospheres is not possible, but study of the atmospheres of the solar system's planets is. Even as close as they are, the whole system's interconnected chemical interactions must be modeled for a successful prediction of observed properties, not simply a few reactions. The composition of exoplanets can perhaps be systematized by thermochemical modelling based on a few key parameters provided by the central star's composition: Fe/Si and Mg/Si. Outcomes are imperfect, but can be improved if more prior information is available, in particular, the star's age.

Returning to our own solar system, Venus may have had water in its atmosphere early in its development. Its D/H ration is 150 times the Earth's suggesting the loss of a few to a few hundreds of meters of planet-covering water depth. A speculation is that perhaps life originated there and seeded the Earth. Planets can be treated as integrated thermodynamic engines, characterized by their dissipation. Speculatively, life allows a planet to evolve to higher levels of dissipation for a given energy input (chiefly insolation). A way to characterize planetary evolution is afforded by the study of nitrogen isotopes. On Earth, they flag the influence of biotic processes at ~3.2 Ga.

The theme of Starting Conditions and Requirements for Prebiotic Chemistry opened with discussion of various forms of chemical disequilibrium. All one needs is a source for chemotrophs, such as a black smoker analogue of a mid-ocean ridge vent system operating on a rocky planet covered with an ice-mantled ocean. On Earth, the early atmosphere was apparently reducing, which facilitates the production of the amino acids relevant to prebiotic chemistry. Another ingredient required for prebiotic chemistry is tectonic activity. They create the environments in which kinetic barriers to reactions delay the attainment of equilibrium. Life has to operate faster to take advantage of these energy sources; without kinetic hinderance, life is impossible. One can view life as complexity emerging as a consequence of dissipative structures, with the required ingredients of redox bifurcations, catalytic metal availability, and pH-driven disequilibria.

Finally, we heard, speculatively, that Mars might have had the right conditions for the origin of life before the Earth, and transport of Martian rocks to the Earth could have seeded it. The preservation of older rocks on Mars makes it, in a sense, a better laboratory for the study of early conditions than the Earth is.

Take-home messages from this particular gathering:

There is tremendous energy in the exoplanets community, enabled by the rapid growth of imaging data and likely to become even stronger in the coming decades. At least one major emphasis in that community at this time is on diversity and surprise. Our effort to compose a narrative about chance and necessity in the fates of the inner solar system planets seems to have met a response that no well-formed narrative can be posed before we have come to grips with the necessary and contingent factors that shaped the solar system as a whole, among the possibilities for planetary systems.

A second useful observation, which recommends care going forward, is that part of the enthusiasm for exoplanet studies is as a means to the end of finding extraterrestrial life. At the same time as this motivation is strong and important with respect to public support (and the interest of many researchers), the connections between what we can realistically hope to learn about exoplanets for several decades, and the conditions required for life, are still thin. We should try to avoid sacrificing sound research on exoplanets as objects of interest in their own right by casting too narrow a field of inquiry. We must also, however, merge the understanding of structures and histories that already exists separately in planetary studies and in life-science studies, to frame questions of life's origin as usefully as possible.

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