Life in the Cosmos Workshop

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Ripley Center
Smithsonian Mall
Washington DC

Sponsored by the SI Consortium for Unlocking the Mysteries of the Universe
and the Office of the Under Secretary for Science

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Abstracts

Introduction to Life in the Cosmos Workshop 2012

Jeremy Drake
Harvard-Smithsonian Center for Astrophysics

Abstract: Good morning! I am pleased to welcome you to *"Life in the Cosmos"*, a two-day workshop in which we will probe the science needed to understand how, where and why life exists in the Universe. Such a workshop is timely. Flagship space-based observatories coupled with new grounded-based facilities have spurred a rapid growth in our understanding of star and planet formation during the last decade. There are currently 814 confirmed extrasolar planets and this number is continuously growing. Parallel rapid developments in biological, planetary and climate sciences mean that we are now poised to begin to answer key questions such as where did life originate, what is the probability that life exists elsewhere and what such life might be like? Perhaps more than any other scientific question, this topic is multidisciplinary: from the astrophysics describing the processes giving rise to stars and planets and their environments, the geology, geophysics and atmospheric physics of planets, to the chemistry and biology of organic matter and evolution of living organisms. Often studied in relative isolation, *Life in the Cosmos* aims to bring together scientists in these different fields to germinate new ideas and directions of study. Four main themes will be covered: —Planets, habitability and the Drake Equation —Fundamentals, origins and initial conditions —Life on Earth through time —Clues to life on other worlds from life on Earth.

Perspectives on Biodiversity Through Time: Trends, Mechanisms, and Constraints

Richard Bambach
National Museum of Natural History

Abstract: Biodiversity has increased over geologic time in a series of steps, each characterized by evolutionary events that opened new aspects of ecospace to use by the biosphere. Natural selection provides a mechanism for capitalizing on ne functional opportunities, but phylogenetic and morphogenetic features constrain and limit evolutionary opportunities. The major steps in evolution have been by chance "breakthroughs" that opened the way to new evolutionary megatrajectories. Disturbances, both sudden mass extinctions and a long-term periodic fluctuation in diversity, and both of which have poorly understood causal connections to geologic events, have been superimposed on the general trend to increasing diversity. Global diversity is the sum of individual clade histories and the general pattern of decrease in origination with no trend in extinction within clades suggests that faunal succession is brought about by the evolution of more competitive groups inhibiting or suppressing the success of origination in incumbent forms rather than by direct competitive elimination of incumbent taxa.

Is intelligent life inevitable? Paleobiological perspective from the neotropics

Andres Cardenas, Carlos Jaramillo
Smithsonian Tropical Research Institute

Abstract: If life has occurred on extra-solar planets we can only wait for interstellar signs of technology. This reality confronted us with a tough question: Is consciousness an evolutionary inevitable? We only know life on Earth, which has a record spanning ~ 3.8 billion years, therefore comprehensive understanding of the fossil record will allow us to generate assessments of how to answer the question above. Paleobiological examination of Neotropical rainforest reveals interplay between diversity dynamics, evolutionary innovations, constraints, and contingent events. This suggests that evolution through time lacks a specified direction and consequently independent origins of life in the universe would give rise to different histories, reducing the chance of the appearance of consciousness.

Prebiotic Chemical Space

Henderson Cleaves
Blue Marble Space Institute of Science

Abstract: It is generally believed that the origin of life occurred when environmentally supplied organic compounds became organized into evolvable self-replicating systems. These first systems may or may not have been formed from compounds similar to those found in modern biochemistry. Indeed, the possible chemical space (the space spanned by all possible stable molecules) and the suspected prebiotic chemical space are vastly larger than the chemical space of contemporary biochemistry, strongly suggesting that biochemistry has been extensively culled by natural selection, and is thus not representative of its chemical roots. Some new experimental and computational techniques for exploring the vast number of chemical possibilities are discussed.

The Apparent Conundrum of Life's emergence on Earth

George Cody
Carnegie Institution for Science

Abstract: It is generally understood that for life to emerge spontaneously it must have done so in an environment that is naturally conducive to abiological organosynthesis. Certain meteorites bare evidence of being ideal environments for extensive abiological organosynthesis, yet no credible evidence of life has ever been detected in such bodies; implying that this criterion is not a sufficient predictor for the emergence of life. It is also generally accepted that liquid water is essential for emergence of life. However, the chemistry that was expected for the spontaneous synthesis of potentially important biological precursors proceeds best under nominally anhydrous conditions. Nevertheless, life apparently emerged spontaneously on Earth. The solution to this conundrum appears to require a better understanding of precisely what the presence of water provides to the planet Earth such that it was conducive to the emergence of life.

Unlocking the Climate History of Early Mars

Robert Craddock
Center for Earth & Planetary Studies, Smithsonian

Abstract: The climate history of early Mars is reflected in a number of key geologic features. The best and most obvious evidence that the ancient climate was different in the past are the valley networks. These features look like dried river valleys, typically have a dendritic pattern, and are often related to slope. Often, the amount of erosion they represent rivals even the Grand Canyon here on Earth, attesting to the intensity of erosional processes that was supported by the climate when they were forming. However, they are not well-integrated with the surrounding cratered landscape. For example, few valley networks breach impact craters and flow through on the downslope side. This suggests that while water may have been transported through the valley networks, the amount of water never exceeded the local evaporation rates, and the time water flowed through the valley networks was often not long enough to fill the crater and top over the rim. The interpretation is that valley networks probably formed during a climatic optimum that occurred during the late Noachian period. The other piece of evidence that the climate was different are modified impact craters. Unlike the Moon, most craters in the older highlands do not have obvious ejecta blankets. The are also missing raised rims as well as central peaks or pits. Because modified craters are preserved at different stages of modification, and the amount of modification does not scale with crater diameter, it is obvious that crater modification occurred as the craters themselves were forming. Thus, it appears that rainfall and limited amounts of runoff occurred throughout the early history of Mars. Our goal is to determine how geologic processes reflected in crater modification and valley network development may have changed over time.

The real 1%: Volatiles in accretion and the rapid development of habitability

Lindy Elkins-Tanton
Carnegie Institution for Science

Abstract: The final stages of planetary accretion consist of violently energetic impacts. New observations of the Moon and Mercury indicate that accretion does not remove all volatiles from the growing planet. Models demonstrate that rocky planets that accrete with as little as 0.01 wt% water produce a massive steam atmosphere that collapses into a water ocean upon cooling. The low water contents required indicate that rocky planets may be generally expected to produce water oceans through this process, and that an Earth-sized planet would cool to clement conditions in just a few to tens of millions of years. Though this first atmosphere is subsequently changed and depleted past recognition, it may also have played an important role in determining the planet's surface and habitability.

The Early Evolution of Complex Life on Earth: Applications to Astrobiology

Douglas Erwin
NMNH and SFI

Abstract: The essential question of astrobiology is whether principles are as applicable to life elsewhere as they are to Earth. The origin and early evolution of animals (c. 750 - 520 Ma) involved innovations in ocean geochemistry, developmental patterning and ecological interactions. The initial divergence of major metazoan clades occurred about 200 Ma before their appearances in the fossil record, and that major developmental patterning systems also originated early. Ecosystem engineering, particularly by sponges and bioturbators, may have modified marine environments sufficient to construct adaptive opportunities for other clades. Under this view, the biological construction of niches was a critical component of a "self-generating" evolutionary diversification.

Where planets are formed: Protoplanetary disk evolution and planet formation in different Galactic environments

Mario Guarcello
Harvard-Smithsonian Center for Astrophysics

Abstract: The large majority of stars in our Galaxy (about 90%) form in concentrated groups or "clusters", embedded within giant clouds of gas. These clusters typically hold together for about 10 Myrs before drifting apart. This timescale is similar to the time it takes for gas giant planets and planetesimals to form within a "protoplanetary disk" of gas that surrounds newly-born stars, and for residual gas in the disk to dissipate. There is a good chance, then, that the cluster environment might affect the early phase of planet formation. Massive stars (M¿15 solar masses) can literally blow away and evaporate protoplanetary disks, and gravitational interactions with nearby cluster members can disrupt them. In this talk I will review these effects, and how they can affect protplanetary disk evolution and planet formation depending on the size of the parental cluster. I will use this information to understand how numerous planetary systems can be in our Galaxy and what was the likely environment in which our Solar System was formed.

The relevance of extremophiles for understanding life in the universe

Adrienne Kish
Université Paris-Sud 11

Abstract: From acidic hot springs to high altitude deserts exposed to intense solar irradiation, extreme environments on Earth are host to variety of hardy organisms. These "extremophiles" provide the only available case studies for the survival of life under the types of extreme environmental conditions found on other planetary bodies. Information gained from ground-based and spaceflight studies of extremophiles has changed our definitions of what it means to survive, what constitutes a "habitable zone", and how life evolves with changes in environmental conditions. Results from extremophile research are relevant to the origins of life, the evolution of life on Earth, habitable worlds, planetary geochemistry and geomicrobiology, and the detection of life on other planetary bodies.

Super-Earths and Life - a fascinating puzzle

Lisa Kaltenegger
Max-Planck Institüt für Astronomie

Abstract: A decade of exoplanet search has led to surprising discoveries, from giant planets close to their star, to planets orbiting two stars, all the way to the first extremely hot, rocky worlds with potentially permanent lava on their surfaces due to the star's proximity. Observation techniques have now reached the sensitivity to explore the chemical composition of the atmospheres as well as physical structure of some detected planets and find planets of less than 10 Earth masses and 2 Earth radii (so called Super-Earths), among them some that may potentially be habitable. Three confirmed non-transiting planets and several transiting Kepler planetary candidates orbit in the Habitable Zone of their host star. Observing mass and radius alone can not break the degeneracy of a planet's nature due to the effect of an extended atmosphere that can also block the stellar light and increase the observed planetary radius significantly. Even if a unique solution would exist, planets with similar density, like Earth and Venus, present very different planetary environments in terms of habitable conditions. Therefore the question refocusses on atmospheric features to characterize a planetary environment. How can we read a planet's spectral fingerprint and in those find signatures of life on other planets? We will discuss how we can find the first habitable new worlds in the sky.

Kepler and the Search for Habitable Planets

David Latham
Harvard-Smithsonian Center for Astrophysics

Abstract: Transiting planets are special. The amount of light blocked by the planet as it passes in front of its host star sets the size of the planet (relative to the star). If an orbit can be derived from Doppler spectroscopy of the host star, the light curve also provides the orientation of the orbit, leading to the mass of the planet (again relative to the star). The resulting density for the planet can be used to constrain models for its structure and bulk properties. We are on the verge of using these techniques to characterize a population of Super Earths, planets in the range 1 to 10 Earth masses that may prove to be rocky or water worlds. Space missions such as Kepler, Plato, and TESS promise to play key roles in the discovery and characterization of Super Earths. Transiting planets also provide remarkable opportunities for spectroscopy of planetary atmospheres: transmission spectra during transit events and thermal emission throughout the orbit, calibrated during secondary eclipse. Spectroscopy of Super Earths will not be easy, but is not out of the question for the James Webb Space Telescope or the next generation of giant ground-based telescopes. Our long-range vision is to attack big questions, such as "Does the diversity of planetary environments map onto a diversity of biochemistries, or is there only one chemistry for life?" A giant first step would be to study the diversity of global geochemistries on super-Earths and Earth analogs.

The Faint Young Sun Paradox: Is There Even Life on Earth?

Petrus Martens
Montana State University

Abstract: There is an astounding problem in the mismatch between solar luminosity and terrestrial climate in the first several billions of years of the Earth's existence, an issue known as the "Faint Young Sun Paradox". In brief the paradox is this: The geological and biological record support that the Earth's biosphere was considerably warmer than currently during the origin of life on Earth and for several billions of years thereafter. Yet, stellar evolution calculations support the Sun starting up at about 75% of its present luminosity, and linearly increasing in time up to its current level. Climate models predict a "Snowball Earth" for such a low solar constant. Recent observations point towards the Sun for a resolution of the paradox. Most important are the results from the Mars Rovers that show that Mars has had periods with a seeming abundance of liquid water over billions of years. If both Mars and Earth both have had liquid water over their history then it is reasonable to look for a common cause, i.e. a more luminous Sun than simulations indicate. One possibility for a brighter young Sun would be if the Sun had only about 5% more mass at its origin than it has now, and consequently, has lost the excess mass through the solar wind. A comparison with observations of other Sun-like stars in earlier phases of their evolution indicates that their observed spin-down rates are consistent with much higher mass losses, potentially enough for a 5% mass loss over the Sun's lifespan. Calculations and simulations tentatively support this hypothesis. The question remains what observations can be made to verify or discard the existence of a massive solar wind through much of the Sun's history.

Ionizing radiation bursts and the Earth

Adrian Melott, Brian Thomas, Dimitra Atri, Drew Overholt
University of Kansas

Abstract: A gamma-ray burst within our galaxy could have catastrophic consequences for the Earth, as could a supernova within 30 light years. Data suggest an average interval of a few hundred million years for such catastrophic events. Results include major destruction of the ozone layer. Similar events will also put muons on the ground and about 1 km down into the oceans with significant damage to DNA and proteins. The Sun itself may emit flares and bursts of protons which are sufficient to affect the Earth. An event in 1859 if repeated today would cause widespread power disruption and about $2 trillion in damage to the world economy. A more intense event could cause atmospheric effects similar to a supernova. We do not know how bad Solar events can get.

Zapping Charlemagne's Power Grid: A Solar Superflare in AD 774?

Adrian Melott[1], Brian Thomas[2]
[1]University of Kansas, [2]Washburn University

Abstract: Radiocarbon data indicate a jump in 14C synthesis in AD 774-775. I show that, contrary to the original publication, this is consistent with a solar superflare close to current upper limits. Such a solar proton event would cause moderate ozone depletion, but not a mass extinction event. About 20 times more powerful than the famous 1859 Carrington Event, it would be disastrous for modern electromagnetic technology.

How to make a planet: the disk-planet composition connection

Karin Oberg
University of Virginia

Abstract: Planets and planetesimals form in the protoplanetary disks surrounding young stars. We know from both our own Solar System and the ever increasing number of discovered exoplanets that planet formation is a complex process that can have a highly variable outcome both in terms of planet mass and planet composition. I will present our current understanding of what disk conditions results in what kind of planets in terms of mass and in terms of bulk composition. I will also discuss where organic material form in disks and thus where we can expect organic-rich planetesimals to form. While more complex volatile organics will rarely be a bulk constituent, their connection to origins of life makes them an important ingredient when considering planet compositions. Special attention will be paid to the role of icy grains and snowlines for both bulk and trace volatile planet compositions.

Surface conditions on Earth through time

Nathan Sheldon
University of Michigan

Abstract: The origin and evolution of life on Earth represent complex interactions between life itself and the environmental conditions at the Earth's surface. The window for habitability on the early Earth was largely regulated by three controls: 1) temperature, 2) pO2, and 3) pCO2. To maintain the equable temperatures indicated by proxy and model results, the greenhouse gas load must have changed dramatically because of the "faint young Sun paradox." Given that other greenhouse gas levels are tied to pO2, the primary control responsible for the equable conditions is the atmospheric pCO2 level. Because atmospheric CO2 is both a product and a reactant in the interactions between the Earth and its biosphere, life itself is ultimately the thermostat that has maintained the habitability of the planet.

Terrestrial Effects of Ionizing Radiation Events

Brian Thomas
Washburn University

Abstract: Astrophysical events such as supernovae, gamma-ray bursts, and solar events (flares and coronal mass ejections) have been recognized as potential threats to life on Earth and other terrestrial planets. This talk will review the effects of such events on Earth's atmosphere and biosphere, focusing primarily on depletion of stratospheric ozone. This depletion leads to enhanced solar UV radiation at the Earth's surface, which can significantly and negatively affect any exposed organisms. I will also discuss current efforts to better understand this biological impact.

Phosphorus limitation during long-term ecosystem development

Benjamin Turner[1], F. Andrew Jones[2], Etienne Laliberte[3], Edward Vicenzi[4], Jeremy Drake[5]
[1]Smithsonian Tropical Research Institute, [2]Oregon State University, [3]University of Western Australia, [4]Smithsonian Materials Conservation Institute, [5]Smithsonian Astrophysical Observatory

Abstract: Phosphorus is a fundamental requirement for life on earth, yet many ecosystems show evidence of extreme phosphorus deficiency. This arises because stable land surfaces undergo a progressive decline in phosphorus availability over thousands to millions of years, a consequence of gradual phosphorus loss in runoff and chemical transformations of phosphorus into recalcitrant forms. In the absence of rejuvenating disturbance, such as tectonic activity, the decline in phosphorus availability leads to severe biological phosphorus limitation, a decline in plant biomass, and marked changes in the composition and diversity of plant and microbial communities. Little information is currently available on microbial communities on ancient land surfaces, but these are likely to offer clues to how life might look on low tectonic exoplanets, assuming extra-terrestrial life evolved to depend on phosphorus in the same manner as on earth.

Plate Tectonics: An end member or outlier process?

Thomas Watters, Michelle Selvans
CEPS/NASM, Smithsonian Institution

Abstract: Speculation about the habitability of Earth-like extrasolar planets has led to the hypothesis that plate tectonics is a necessary condition of life because of its contribution to geochemical cycling. Exploration of our solar system has revealed a variety of tectonic systems, some that resemble those formed by terrestrial plate tectonic and some that are distinctly different. Recent and current planetary missions to Mercury, Venus, the Moon, and Mars allow comparisons between tectonic systems on these Earth-like bodies and those formed by plate tectonics. The picture that has emerged is that each terrestrial planet in our solar system has a unique tectonic evolution and that these objects do not represent a spectrum with clear end members.

Alternative biochemistries: Characterization of arsenic in a bacterium

Felisa Wolfe-Simon
Lawrence Berkeley National Laboratory

Abstract: Seeking life elsewhere in the Universe would be aided by characterizing what additional elements can support life on Earth and increasing our understanding of alternative biochemistry. Life-as-we-know-it has co-evolved with Earth. One approach to identifying alternative biochemistry uses the changing chemical history of Earth as a guide to the elements that would be biologically accessible. Another complimentary approach is to characterize life in extreme environments. Life depends on access to nutrients in the environment. While elements carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur are fundamental to microbial survival, trace nutrient elements like iron, molybdenum and copper show dramatically different profiles depending on environmental conditions. These elements are known nutrients but also can be toxic at higher concentrations. For low or limiting concentrations of one nutrient element microbes may utilize another element to serve similar functions often, but not always, in similar macromolecular structures.
Well-characterized elemental swaps occur in a range of biomolecules including manganese for iron, tungsten for molybdenum, selenium for sulfur and sulfur for phosphorus or oxygen. Are there other elements that could interchange? How flexible is the elemental composition of microbial life on Earth? For example arsenic has many similar chemical properties to phosphorus. To test this hypothesis, we isolated a bacterium from Mono Lake, which has high arsenic levels. We have characterized how this bacterium grows in arsenic-containing medium. We have determined that the bacterium uptakes arsenic intracellularly and have done some biophysical characterization.

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