U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

Astrobiology and the Search for Life Beyond Earth in the Next Decade

September 29, 2015
10:00 a.m.
2318 Rayburn House Office Building

Purpose

The Committee on Science, Space, and Technology will hold a hearing entitled *Astrobiology and the Search for Life Beyond Earth in the Next Decade* on Tuesday, September 29, in Room 2318 of the Rayburn House Office Building. This hearing will review the scientific methods employed to search for life, examine recent scientific discoveries in the field of astrobiology (the study of the origin, evolution, distribution, and future of life in the universe), and assess the prospects of finding life beyond Earth over the next decade. The hearing will include an overview of NASA's astrobiology programs and NASA's new Nexus for Exoplanet System Science ("NExSS") initiative. It will examine the techniques and capabilities necessary to determine the potential for the existence of microbial life within our solar system. The hearing will also investigate the scientific methods of exoplanet atmospheric spectroscopy and radio and optical astronomical surveys.

Witnesses

- **Dr. Ellen Stofan**, Chief Scientist, NASA
- **Dr. Jonathan Lunine,** David D. Duncan Professor in the Physical Sciences, and Director, Center for Radiophysics and Space Research, Cornell University
- **Dr. Jacob Bean,** Assistant Professor, Departments of Astronomy and Astrophysics, Geophysics, University of Chicago
- **Dr. Andrew Siemion,** Director, SETI Research Center, University of California, Berkeley

Background

Astrobiology is "the study of the origin, evolution, distribution, and future of life in the universe; the study of life as a planetary phenomenon; the study of the living universe; or the origin and co-evolution of life and habitable environments."[1] This multidisciplinary field encompasses the search for habitable environments in and outside of our solar system. It also includes the search for evidence of prebiotic chemistry, field research into the origins of life on Earth, and studies of the potential for life to adapt to challenges on Earth and in space.

NASA has been performing astrobiology research since the beginning of the U.S. space program. NASA's astrobiology program currently resides in the Planetary Science Division of the Science

[1] *Assessment of the NASA Astrobiology Institute*, National Research Council Report (2008) http://www.nap.edu/catalog/12071.html

Mission Directorate.[2] The Astrobiology Program has six elements: the NASA Astrobiology Institute, Exobiology and Evolutionary Biology, Planetary Science and Technology Through Analog Research, MatiSSE,[3] PICASO,[4] and the Habitable Worlds Program.

Recently, Dr. Ellen Stofan, NASA Chief Scientist, predicted that evidence of life will be found relatively soon – "I believe we are going to have strong indications of life beyond Earth in the next decade and definitive evidence within the next 20 to 30 years."[5]

Searching for Life within our Solar System

Extremophiles and Terrestrial Analogues

One aspect of astrobiology research which can be conducted without the considerable expense associated with space missions is the analysis of extremophiles (organisms that thrive in physically or geochemically extreme conditions that are detrimental to most life on Earth) and other potential terrestrial analogues to extraterrestrial forms of life.[6] Both macroscopic and microscopic analogues are investigated. By learning what sort of environmental 'fingerprints' terrestrial extremophiles leave, a wider search can be performed for potential life elsewhere. For example, to aid the search for life on Mars or Europa (one of the moons of the planet Jupiter with liquid water), the Mojave Desert was used as an analogue for its similar geological profile and (relatively) unshielded environment, in terms of solar radiation. The desert is home to a few varieties of hypoliths – organisms which survive by using semi-translucent rocks to trap moisture and to shield a portion of incoming ultraviolet radiation. Studies of these hypoliths have shown them to be versatile, able to inhabit quartz, carbonate, and talc, despite the different spectrum of light available after the filtering through material strata.[7] If such organisms as hypoliths developed on the planet Mars, they may have been able to adapt sufficiently to survive the higher radiation environment on Mars than is found on Earth.

Mars Exploration Program

NASA's Mars Exploration Program seeks to understand whether Mars was, is, or can be, a habitable world.[8] To discover the possibilities for past or present life on Mars, NASA's Mars Exploration Program is currently following an exploration strategy known as "Seek Signs of

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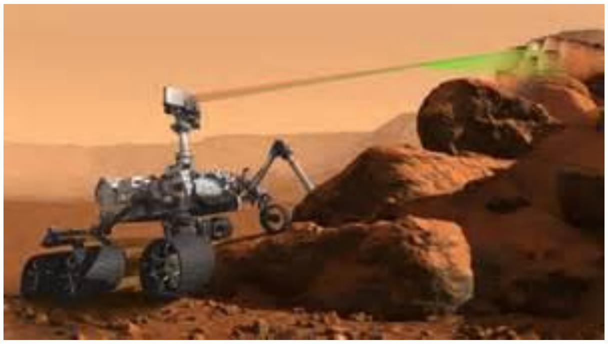
[2] NASA Astrobiology Program at http://astrobiology.nasa.gov/
[3] Maturation of Instruments for Solar System Exploration
[4] Pathfinder Instruments for Cloud and Aerosol Spaceborne Observations
[5] Abby Phillip, "Why NASA's top scientist is sure that we'll find signs of alien life in the next decade" *Washington Post* (April 8th, 2015), at http://www.washingtonpost.com/news/speaking-of-science/wp/2015/04/08/why-nasas-top-scientist-is-sure-that-well-find-signs-of-alien-life-in-the-next-decade/
[6] An extremophile is an organism adapted to unusual limits of one or more abiotic factors in the environment. Some of the extreme conditions are temperature, pH, high salinity, high levels of radiation and high pressure. The Encyclopedia of Earth at http://www.eoearth.org/view/article/160977/
[7] Heather D. Smith, Mickael Baqué, Andrew G. Duncan, Christopher R. Lloyd, Christopher P. McKay and Daniela Billi (2014). Comparative analysis of cyanobacteria inhabiting rocks with different light transmittance in the Mojave Desert: a Mars terrestrial analogue. International Journal of Astrobiology, 13, pp 271-277. doi:10.1017/S1473550414000056
[8] NASA Mars Exploration homepage at http://mars.nasa.gov/programmissions/science/

Life." This science theme is built on the prior science theme of "Follow the Water," which guided missions such as 2001 Mars Odyssey, Mars Exploration Rovers, Mars Reconnaissance Orbiter, and the Mars Phoenix Lander. The Mars Science Laboratory mission and its Curiosity rover mark a transition between the themes of "Follow the Water" and "Seek Signs of Life." In addition to landing in a place with past evidence of water, Curiosity is seeking evidence of organics, the chemical building blocks of life.

Curiosity looks for chemical elements that are the building blocks of life. These building blocks include six elements necessary to all life on Earth: carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur. In the past year, Curiosity made several major scientific discoveries relevant to the search for life, including measuring a spike in levels of the organic chemical methane in the local atmosphere of its research site and detecting other organic molecules in drill samples from a mudstone that once sat at the bottom of the lake that filled Gale Crater in Mars' ancient past.[9] Methane is important because it is an organic molecule often produced by life on Earth, although it can also be produced by different processes that do not involve living organisms. Curiosity provided the first definitive detection of organic molecules on the Martian surface when soil samples from the mudstone were analyzed. These samples also contained water.[10]

The follow-on to Curiosity is the 2020 Mars Rover mission. Mars 2020 will carry out in-situ exploration operations, including evaluations of habitability, preservation potential, and the presence of potential biosignatures within accessible geological materials. It will also collect samples of Martian material and seal them in individual tubes for possible return to Earth for more detailed analysis.



[9] P.R. Mahaffy, et al., "The Imprint of Atmospheric Evolution in the D/H of Hesperian clay minerals on Mars," *Science* Vol. 347 (January 23rd, 2015)

[10] Miriam Kramer, "Curiosity Rover Drills Into Mars Rock, Finds Water," Space.com (December 16th, 2014) at http://www.space.com/28030-mars-water-curiosity-rover.html

Europa Mission

Within our solar system, Jupiter's moon Europa is a leading candidate as a habitable environment which may include evidence of life.[11] For over 15 years NASA has developed concepts to explore Europa and determine if it is habitable based on characteristics of its vast oceans (twice the size of all of Earth's oceans combined), the ice surface–ocean interface, the chemical composition of the intriguing, irregular brown surface areas, and geologic activity providing energy to its system. For fiscal year 2015, NASA was appropriated $100 million for pre-formulation and formulation activities for a mission that meets the science goals outlined for the Jupiter Europa mission in the 2013 Planetary Science Decadal Survey.[12]

The instrumentation for the Europa mission was selected last month, and includes a mapping spectrometer, a magnetic sounding apparatus, and a dust analyzer.[13] Thermal, optical, and ultraviolet imaging systems are planned as well. Furthermore, potential landing probes such as the VALKYRIE (Very-deep Autonomous Laser-powered Kilowatt-class Yo-yoing Robotic Ice Explorer) continue to be investigated. VALKYRIE makes use of developing technologies in order to function on an extraterrestrial mission, including a laser power source and a minimally-contaminating design. It will be tested in the near future on frozen lakes and glaciers in Canada and Norway.[14]

Moons of Saturn

Two of Saturn's moons (Enceladus and Titan) are now believed to possess subsurface oceans, making them very attractive candidates for habitable environments within our planetary neighborhood. On Enceladus, recent analysis of the particulate matter ejected from plumes of water indicate hydrothermal processes in excess of 90 degrees centigrade occurring beneath the ice of the moon.[15] Titan has evidence of both subsurface oceans and stable bodies of surface liquid hypothesized to be hydrocarbon lakes.[16]

Habitable Exoplanets Around Other Stars

[11] Europa Study Team, "Investigating Icy World Habitability Through the Europa Clipper Mission Concept" Workshop on Habitabiolity of Icy Worlds, held February 5th – 7th, 2-14, in Pasadena, California at http://www.hou.usra.edu/meetings/icyworlds2014/pdf/4012.pdf

[12] P.L. 112-235

[13] NASA JPL Press Release, "NASA's Europa Mission Begin with Selection of Science Instruments" (May 26th, 2015)

[14] NASA Astrobiology Science Homepage at https://astrobiology.nasa.gov/astep/projects/nra/nnh11zda001n-astep/valkyrie-phase-2/

[15] Hsu, Postberg, et al., *Ongoing Hydrothermal Activities within Enceladus*, Nature 519, 207–210 (March 12th, 2015)

[16] J. Kawai, S. Jagota, et al., *Titan Tholins as Amino Acid Precursors and their Solubility in Possible Titan Liquidispheres*, Chemistry Letters Vol. 42 (2013) No.6 , 633-635

An extrasolar planet, or “exoplanet,” is a planet that orbits a star other than our own. Astrobiologists and astrophysicists work together to discover and categorize exoplanets. Once such a planet is detected, the scientific challenge is to determine how to recognize – across the vast distance of interstellar space – whether that planet could (or does) support life.

The characterization of exoplanets and the identification of exoplanet biosignatures are supported through the science of atmospheric spectroscopy. Due to fortunate chance alignments of their orbits with our line of sight, some exoplanets alternatively pass in front of and behind their parent star as seen from Earth, providing a unique opportunity to analyze the atmospheres of these distant worlds. This is possible by observing the exoplanet and its parent star during a primary (or secondary) transit, when the planet passes in front of (or behind) the star. The planet's atmospheric constituents can be revealed by analyzing the characteristic absorption lines they imprint in the spectrum of the star when the star's light passes through the planet's atmosphere during a primary transit. Secondary transits provide an alternative method. Just before or after a secondary transit, the combined light from the star and exoplanet is seen. When the planet is entirely behind the star's disk, only the light from the star is seen. Taking the difference of these two signals reveals the spectrum of the exoplanet alone, which can be analyzed to identify the composition of the planet's atmosphere.

As the search for exoplanets continues, findings have exceeded expectations. As of September 10, 2015, there are 1,890 confirmed exoplanets, of which 31 meet the qualifications to be considered potentially Earth-like and habitable (i.e. within the circumstellar habitable zone with conditions roughly comparable to Earth) and many more could be home to new forms of life. [17,18] In light of the discoveries, it is now estimated that over 90 percent of stars in our galaxy have at least one planetary body, and that more than 70,000 exoplanets are likely to be identified by current missions within the next ten years.[19]

NASA-sponsored telescopes involved in exoplanet research include the Kepler Spacecraft Observatory, Large Binocular Telescope Interferometer (LBTI), the Hubble Space Telescope, the Spitzer Telescope, and the Stratospheric Observatory for Infrared Astronomy (SOFIA). Exoplanet research will also be conducted by the James Webb Space Telescope (JWST), the newly announced Explorer mission Transiting Exoplanet Survey Satellite (TESS), and potentially the Wide Field Infrared Survey Telescope (WFIRST).

Search for Extraterrestrial Intelligence (SETI)

In 1993, Congress cancelled funding to NASA’s SETI program and NASA has not had a SETI program since.[20] However, there are a number of SETI research programs underway in the United States funded by organizations other than NASA, with most gathering under the aegis of the non-profit SETI Institute. These researchers conduct experiments searching for electromagnetic signatures in wavelengths from radio to visible light.

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[17] NASA Exoplanet Science Institute at http://exoplanetarchive.ipac.caltech.edu/
[18] Planetary Habitability Laboratory at http://phl.upr.edu/projects/habitable-exoplanets-catalog/results
[19] M. Perryman, J. Hartman, et al., “Atmospheric Exoplanet Detection with Gaia” *The Astrophysics Journal* (November 19th, 2014).
[20] NASA History Program Office at http://history.nasa.gov/garber.pdf

On July 20, 2015, Yuri Milner and Stephen Hawking announced an unprecedented $100 million global Breakthrough Listen Initiative to support the search for intelligent life beyond Earth.[21] This 10 year program will include a survey of the 1,000,000 closest stars to Earth, scanning the center of our galaxy, the entire galactic plane, and also listen for messages from the closest 100 galaxies. This will be the largest scientific search ever undertaken for signs of intelligence life, covering 10 times more sky than and 5 times more radio spectrum than previous SETI programs.[22] All data will be made available to the public. This program will use the 100 meter Robert C. Byrd Green Bank Telescope in West Virginia, the Automated Planet Finder Telescope at Lick Observatory in California, and is in negotiations to use the Arecibo Telescope in Puerto Rico.

NASA Astrobiology Roadmap

Approximately every five years, NASA publishes an Astrobiology Roadmap which provides guidance for research and technology development across the NASA enterprises that encompass the space, Earth, and biological sciences. The Roadmap addresses three basic questions: how does life begin and evolve, does life exist elsewhere in the universe, and what is the future of life on Earth and beyond? The last roadmap was published in 2008.[23] The next roadmap was to be published in 2014. The new roadmap is expected to assess how well the astrobiology program has accomplished these goals, how the field has grown and evolved, and what its focus should be in the coming years.

Nexus for Exoplanet System Science (NExSS)

The Nexus for Exoplanet System Science (NExSS) was announced last April.[24] NExSS is a NASA virtual institute designed to foster interdisciplinary collaboration in the search for life on exoplanets. Led by the Ames Research Center, the NASA Exoplanet Science Institute, and the Goddard Institute for Space Studies, and ten universities and two research NASA institutes, NExSS will help organize the search for life on exoplanets from participating research teams and acquire new knowledge about exoplanets and extrasolar planetary systems. The work of NExSS scientists will provide a foundation for interpreting observations of exoplanets from future exoplanet missions such as the Transiting Exoplanet Survey Satellite (TESS), the James Webb Space Telescope (JWST), and the Wide-field Infrared Survey Telescope (WFIRST).

[21] Breakthrough Initiatives Press Release "Yuri Milner and Stephen Hawking Announce $100 Million Breakthough Initiative to Dramatically Accelerate Search for Intelligent Life in the Universe" (July 20th, 2015)
[22] Id.
[23] Available at NASA Astrobiology Roadmap webpage, at https://astrobiology.nasa.gov/roadmap/
[24] NASA JPL Press Release, "NASA's NExSS Coalition to Lead Search for Life on Distinct Worlds" (April 21st, 2015)

NASA Astrobiology Program Funding[25]

Activity	$Ms		
	FY 14[26]	FY 15[27]	FY 16[28]
NASA Astrobiology Institute	$27.786	$23.748	$24.107
Exobiology and Evolutionary Biology	$17.424	$13.729	$12.500
Planetary Science and Technology Through Analog Research	$0.000	$4.180	$8.200
Maturation of Instruments for Solar System Exploration (MatiSSE)	$0.600	$6.300	$3.000
Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO)	$0.300	$1.900	$1.800
Habitable Worlds	$0.000	$2.200	$4.400
Nexus for Exoplanet System Science (NExSS)	N/A	$5.433	$5.668
TOTAL	**$46.110**	**$57.490**	**$59.675**

As shown in the table above, NASA's overall support for astrobiology programs increases from $46.1M in FY14 to almost $59.7M in FY16, including the Astrobiology-related portions of the MatiSSE and PICASSO general planetary science instrument development programs. Some of the subaccount adjustments are the result of a broader restructuring of the Planetary Science Division's research and analysis subaccounts. This restructuring, the first in over a decade, was designed to ensure that SMD mission-enabling activities continue to be closely linked to the strategic goals of the agency and of SMD. This includes identifying and understanding habitable environments and understanding the origin and evolution of life on Earth and how it guides our search for life elsewhere in the universe.

[25] Program funding numbers provided by NASA
[26] Actual funds expended
[27] Estimated funds based on obligated and expended to date
[28] Notional estimate based on President's Budget Request