Searching for Life Across Space and Time: A Workshop

December 5-6, 2016

Irvine, CA

Statement of Task

(from then NASA Associate Administrator, John Grunsfeld)

The National Academies of Sciences, Engineering, and Medicine will appoint an ad hoc planning committee to organize a workshop that will focus on facilitating an expert dialogue on the current status of extraterrestrial life detection and related issues. Based on our current understanding of the nature and physical and chemical limits of life on Earth, the characteristics of worlds in our solar system and planets orbiting other stars, and the state of the art of relevant technologies, the workshop will address the following questions:

- What is our current understanding of the limits of life and life's interactions with the environments of planets and moons?
- Are we today positioned to design, build and conduct experiments or observations capable of life detection remotely or in situ in our own solar system and from afar on extrasolar worlds?
- How could targeted research help advance the state of the art for life detection, including instrumentation and precursor research, to successfully address these challenges?

A workshop report will document the workshop, including summaries of individual presentations and ensuing discussions. This report will not present consensus conclusions or recommendations.

Committee Members

James F. Kasting (Chair), Pennsylvania State University

William Bains, Massachusetts Institute of Technology, University of Cambridge

Tanja Bosak, Massachusetts Institute of Technology

Irene A. Chen, University of California, Santa Barbara

Kevin P. Hand, Jet Propulsion Laboratory

Christopher H. House, Pennsylvania State University

Victoria Meadows, University of Washington

Philip M. Neches, NAE, Teradata Corporation

Nilton O. Renno, University of Michigan

Dimitar Sasselov, Harvard-Smithsonian Center for Astrophysics

Gary Ruvkun, NAS, NAM, Harvard Medical School

Mark H. Thiemens, NAS, University of California, San Diego

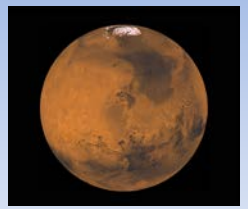
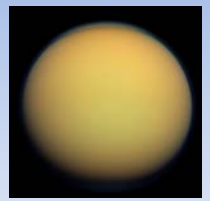
Nita Sahai, The University of Akron

Margaret Turnball, SETI Institute

NAS Staff

- David Smith—Workshop facilitator (charged with writing up the workshop report)
- Katie Daud, Dionna Williams—assistants

The (general) life detection problem

	In situ detection (Solar System)	**Remote detection (Exoplanets)**
Life as we know it		
Life as we don't know it		**?**

Workshop Agenda

1. Setting the stage
2. Habitable environments in the Solar System
   - Mars
   - Ocean worlds
3. Exoplanets
4. Poster session
5. Life detection techniques
6. Instrumentation

Summary of key points/ Questions raised*

- Session 1—Setting the stage
  - In the search for biosignatures, we must consider the origin of life, as well as the maintenance of life
    - John Baross: Hydrothermal vents may have played a role in the origin, or at least early evolution, of life
    - *Serpentinization* is a key process for providing surface area/hydrogen/trace metals
  - Free energy is an important consideration
    - Tori Hoehler: This is the most fundamental requirement for life
    - Eric Smith: Free energy gradients are also an essential factor in some theories of the *origin* of life (metabolism first, as opposed to control first)
    - Hoehler: Life as we know it only uses *redox* chemistry (transfer of electrons), as opposed to other sources of free energy

*OPAG-relevant points highlighted in red

- Our understanding of the evolutionary relationships between extant organisms is still changing
  - Baross: The rRNA tree may have a 2-domain structure rather than a 3-domain structure
  - This can have implications for the nature of the last common ancestor. Was LUCA a methanogen?

- Session 2—Habitable environments in the Solar System
  - Mars remains a likely abode for either extant or extinct life
    - John Grotzinger: MSL has provided new evidence for repeated formation of long-lived lakes
    - Direct evidence for serpentinization from observations of clays and magnetite
    - More small rovers are needed to explore diverse environments
    - Me: Arguments continue as to how to explain prolonged periods of warmth on early Mars. Can we reach consensus on this question?

- Ocean worlds are another place where life might have originated and evolved
  - Europa and Enceladus are highest on the priority list
  - Kevin Hand: Detection of life on life on one of these worlds would almost certainly indicate an independent origin of life
  - Finding DNA-based life would therefore indicate *convergence* toward a universal type of biology
  - Many of the requirements for life are arguably present on these worlds (water, biologically important elements, water-rock interactions, hydrothermal vents?)
  - Free energy is still an important consideration
    - Reduced materials could be provided by the mantle
    - Oxidants could be provided by crustal overturn
    - Is the available free energy sufficient to create/sustain life?

- NASA has multiple different pathways that it might pursue to detect biosignatures
  - Ellen Stofan: Humans can play a key role in looking for life on Mars, e.g., by enabling deep drilling
  - Others have argued that we should delay human exploration of Mars, either for cost reasons or to avoid biological contamination until the planet has been better studied

- Session 3—Exoplanets
  - Remote detection of biosignature gases has been studied more and more intensively in recent years
    - Vikki Meadows: The simultaneous presence of O_2 and CH_4 (or N_2O) is still the best available remote biosignature
    - O_2 by itself is an ambiguous biosignature (but hopefully we can identify false positives from the planetary context)
    - Thermodynamic disequilibrium by itself is not necessarily a biosignature, as chemoautotrophic life (e.g., methanogens) would tend to drive an atmosphere *towards* equilibrium

- We should remain cognizant of the fact that nature may surprise us and that life on extrasolar planets may be different from what we know
  - William Bains: Ammonia might be a possible biosignature on a hydrogen-rich super-Earth
  - Regardless of the merit of this particular suggestion, we need to approach this question with open minds, lest we be accused of looking for our keys under the lamppost
  - We want to study non-Earth-like worlds, anyway, for their own intrinsic interest
- Detection of life on exoplanets may start to become possible within the new few years
  - JWST may be able to do transit spectroscopy on an Earth-like planet around an M star (not discussed here)
  - Nick Siegler: WFIRST will not find Earth-like planets, but it will find other non-transiting planets and test space-based coronagraphs
  - Matteo Brogi: Proxima Centauri b may be characterized from the ground, especially when new 30-40 m telescopes are constructed

- Session 5—Life detection techniques
  - NASA has been looking for extraterrestrial life for at least 4 decades
    - Ben Clark: The Viking life detection experiments did not tell us what we had hoped to learn from them, but they nevertheless provided lots of useful information
    - Viking provides a cautionary tale about thinking carefully about 'false positives' before announcing any results
  - Looking for DNA-based life is relatively easy
    - Gary Ruvkun: Send an Oxford Nanopore machine to Mars!
    - We have an *extraordinary* database on DNA-based life on Earth. This could enable us to discriminate between terrestrial contamination and alien life
    - Was life transferred from planet to planet? From star to star?
  - Many aspects of water-based life are likely to be replicated elsewhere, regardless of whether DNA is involved

- Steve Benner: Molecular systems cannot arise without life
  - Is this a challenge to the 'metabolism first' hypothesis for life's origin promoted by Eric Smith?
- Life in liquid water will be based on biopolymers with repeating charges, and hence should be easy to detect even if it is not DNA-based
- Some hypotheses for life's origin require *dry land* to allow for formation of borate evaporates, but this idea is speculative

- Session 6: Instrumentation
  - Detection of life in plumes (Morgan Cable)
    - Questions?
  - Detection of life on extrasolar planets using LUVOIR or HabEx (Shawn Domagal-Goldman)
    - Questions?
  - Detection of organics on Mars (Jen Eigenbrode)
    - Questions?

Parting thoughts

- Many questions still remain concerning biosignature detection and interpretation
- The National Academy has two decadal surveys looming on the horizon
  - Astronomy and Astrophysics starting in 2018 (2019?)
  - Planetary Science starting roughly a year later
- It would be nice if the astrobiology community could organize itself ahead of these surveys and provide a coherent set of principles/suggestions to feed into both of them
  - It is possible that the National Academy will be commissioned to organize a more thorough study and write a more detailed report on the biosignatures question