

# Princeton University

## Planets and Life Symposium

Saturday, December 2, 2006

Peyton Hall Auditorium

Princeton University

### Agenda

Start	Duration	
8:00	45 mins	Coffee & Donuts
8:45	15 mins	<b>David N. Spergel</b> (Astrophysical Sciences). Introduction and goals of the meeting.
9:00	40 mins	<b>Christopher F. Chyba</b> (Astrophysical Sciences). <u>Keynote talk</u> - Astrobiology: the study of the living universe.
9:40	40 mins	<b>Tullis C. Onstott</b> (Geosciences). Earth's deep subsurface microbial environments and their implications for the search for life on Mars.
10:20	20 mins	Coffee break
10:40	40 mins	<b>Laura F. Landweber</b> (Ecology and Evolutionary Biology). Detangling unusual genes and genomes.
11:20	40 mins	<b>N. Jeremy Kasdin</b> (Mechanical and Aerospace Engineering). Planet finding missions and technology.
12:00	1 hour	Lunch
1:00	40 mins	<b>M. Amaya Moro-Martin</b> (Astrophysical Sciences). Debris disks and planets.
1:40	40 mins	<b>Ned S. Wingreen</b> (Molecular Biology). Biochemistry of early life: a perspective from nitrogen metabolism.
2:20	40 mins	<b>Edwin L. Turner</b> (Astrophysical Sciences). The ages and orbits of nearby "Earth-like" planets.
3:00	30 mins	Coffee break
3:30	40 mins	<b>Michael H. Hecht</b> (Chemistry). Novel proteins.
4:10	40 mins	<b>Kevin P. Hand</b> (Astrophysical Sciences). Progress in understanding the surface and subsurface chemistry of Europa.
4:50	40 mins	<b>Ruslan Belikov</b> (Mechanical and Aerospace Engineering). Lab tests of high contrast imaging for earth-like planet detection.
5:30	30 mins	Discussion about establishing an astrobiology community at Princeton.

## Program

### **Astrobiology: The study of the living universe (keynote).**

*Christopher Chyba*, Professor of Astrophysics and International Affairs

9:00-9:40

The NASA Astrobiology Institute has defined “astrobiology” to be “the study of the living universe.” Astronomy provides the context for the origin and evolution of life on Earth; conversely, discoveries about the terrestrial biosphere—from extremophile environments to the evolution of intelligence—inform our thinking about the prospects for life elsewhere. Kevin Hand and I have reviewed the field in *Annual Review of Astronomy and Astrophysics* 43, 31-74 (2005). Here I will pick a few topics that illustrate the interplay between terrestrial and extraterrestrial sciences, and try to complement the other talks in this symposium. My picks will include the environment of the early Earth and the origin of life, planetary protection, and time permitting, the evolution of intelligence. I will highlight uncertainties and outstanding questions throughout.

*Dr. Chyba is a Professor of Astrophysics and International Affairs at Princeton University, where he directs the Program on Science and Global Security at the Woodrow Wilson School. He also serves on the Board of Trustees of the SETI Institute, and prior to coming to Princeton, was Principal Investigator on the SETI Institute's NASA Astrobiology Institute team. His research currently focuses on the physics, chemistry, and potential biology of Jupiter's moon Europa.*

### **Earth's deep subsurface microbial environments and their implications for the search for life on Mars.**

*Tullis C. Onstott*, Professor of Geosciences (Geomicrobiology)

9:40-10:20

Recent observations have detected trace amounts of CH<sub>4</sub> heterogeneously distributed in the Martian atmosphere, which indicated a subsurface CH<sub>4</sub> flux of  $2 \times 10^5$  to  $2 \times 10^9$  cm<sup>-2</sup>s<sup>-1</sup>. Four different origins for this CH<sub>4</sub> were considered: (1) volcanogenic; (2) sublimation of hydrate-rich ice; (3) diffusive transport through hydrate-saturated cryosphere; and (4) microbial CH<sub>4</sub> generation above the cryosphere. Based upon geochemical, isotopic and microbial studies of deep fracture water samples from South Africa Au mines, we developed a diffusive flux model for the martian crust for He, H<sub>2</sub>, and CH<sub>4</sub>. This model distinguishes between abiogenic and microbial CH<sub>4</sub> sources based upon their isotopic composition, and couples microbial CH<sub>4</sub> production to H<sub>2</sub> generation by H<sub>2</sub>O radiolysis. For a He flux of  $10^5$  cm<sup>-2</sup> s<sup>-1</sup> this model yields an abiogenic CH<sub>4</sub> flux and a microbial CH<sub>4</sub> flux of  $10^6$  and  $10^9$  cm<sup>-2</sup> s<sup>-1</sup>, respectively. This flux will only reach the martian surface if CH<sub>4</sub> hydrate is saturated in the cryosphere; otherwise it will be captured within the cryosphere. The sublimation of a hydrate-rich cryosphere could generate the observed CH<sub>4</sub> flux, whereas microbial CH<sub>4</sub> production in a hypersaline environment above the hydrate stability zone only seems capable of supplying  $10^5$  cm<sup>-2</sup> s<sup>-1</sup> CH<sub>4</sub>. The model predicts that He/H<sub>2</sub>/CH<sub>4</sub>/C<sub>2</sub>H<sub>6</sub> abundances and the C and H isotopic values of CH<sub>4</sub> and the C isotopic composition of C<sub>2</sub>H<sub>6</sub> could reveal the different sources. Cavity ring-down spectrometers represent the instrument type that would be most capable of performing the C and H

measurements of CH<sub>4</sub> on near future rover missions and pinpointing the cause and source of the CH<sub>4</sub> emissions.

*Dr. Onstott is a Professor of Geosciences at Princeton University, where he has been since starting grad school in 1976. He holds a B.S. in Geophysics from the California Institute of Technology and M.A. as well as a Ph.D. in Geology from Princeton University. His research focuses on the activity and survival of bacteria and other microorganisms in the deep subsurface (> 0.5 km) and their impact on the geochemistry and mineralogy of their environment.*

### **Detangling unusual genes and genomes.**

*Laura F. Landweber, Professor of Ecology and Evolutionary Biology*

10:40-11:20

Ciliated protozoa represent some of the most diverse microbial eukaryotes on our planet. They have two types of genomes in one single-cell: a somatic nucleus that encodes all proteins and a germ-line nucleus used only in conjugation. The somatic genomes of some ciliates are composed of short "nano-chromosomes", each encoding just one or a few genes. In *Oxytricha trifallax* approximately 95% of the germ-line genome is destroyed in the process of forming these nanochromosomes. This illustrates one creative real-time solution to two basic problems in biology of gene-finding and "junk DNA": throw away almost everything that is not a gene. Furthermore, a large fraction of all *Oxytricha* genes appear to be scrambled, that is, segments of genes can be both interrupted and present in a permuted order. In one case, the segments for two independent genes are intertwined on two separate germ-line loci that together create the functional somatic versions. I will describe our current understanding of scrambled genes, based on experiments in our lab that survey the origin, evolution, and developmental processing of scrambled genes.

*Dr. Landweber is an Associate Professor of Ecology & Evolutionary Biology at Princeton University. She received her A.B. from Princeton in 1989 and her Ph.D. from Harvard in 1993. Before starting her faculty position in 1994, she was a Junior Fellow of the Harvard Society of Fellows. She has served on several panels, working groups, and advisory committees for the NSF, NIH, NHGRI, and NASA and has co-chaired the NHGRI Comparative Genome Evolution Working Group since 2003. A recipient of Burroughs-Wellcome Fund (1994) and Sigma Xi (1999) young investigator awards, she was elected a 2005 Fellow of AAAS for probing the diversity of genetic systems in microbial eukaryotes, including scrambled genes, RNA editing, variant genetic codes, and comparative genomics in protists.*

### **Planet finding missions and technology.**

*N. Jeremy Kasdin, Associate Professor of Mechanical and Aerospace Engineering*

11:20-12:00

One of the great scientific accomplishments of the last 15 years has been the discovery of over 200 extrasolar planets. This has motivated an entire generation of scientists to open new avenues of research and has spurred an explosion in instrumental techniques for discovering and characterizing planets both on the ground and from space. In this talk I will give an overview of the various ground approaches being used and in the planning stages for planet searches. I will also discuss NASA's plans for a series of space missions, culminating with the Terrestrial Planet Finder, to discover and characterize earthlike planets. I will review a number of the technologies

under consideration and highlight our work here at Princeton on high-contrast imaging for planet finding.

*Dr. Kasdin is an Associate professor at Princeton University in the Mechanical and Aerospace Engineering department. Prof. Kasdin received his BSE from Princeton University in 1985 and his MSE and Ph.D. in 1991 from Stanford University's department of Aeronautics and Astronautics. From 1991 to 1998 Prof. Kasdin was a project manager and the chief systems engineer for NASA's Gravity Probe B spacecraft, a satellite test of Einstein's General Theory of Relativity (GP-B was launched in April, 2004). Prof. Kasdin joined the Princeton faculty in September, 1999, where he researches space systems design and control and space telescope optics. Prof. Kasdin is currently the principal investigator for the Princeton Terrestrial Planet Finder project. This interdepartmental team is studying techniques for a large visible light telescope to image extrasolar earthlike planets.*

### **Debris disks and planets.**

*M. Amaya Moro-Martin, Astrophysical Sciences*

1:00-1:40

Using data from the Spitzer Space Telescope Legacy Science Program "Formation and Evolution of Planetary Systems" (FEPS), we have searched for debris disks around 9 FGK (solar-type) stars (2-10 Gyr), known from radial velocity studies to have one or more massive planets. Only one of the sources, HD 38529, has excess emission above the stellar photosphere; at 70 microns the signal-to-noise ratio in the excess is 4.7, while at wavelengths < 30 microns there is no evidence of excess. The remaining sources show no excesses at any Spitzer wavelengths. Applying survival tests to the FEPS sample and the results for the FGK survey published in Bryden et al. (2006), we do not find a significant correlation between the frequency and excess luminosity of debris disks and the presence of close-in planets. Because we expect massive planets to form in systems that are initially rich in planetesimals, but the observations indicate that systems with giant planets do not preferentially show debris, there is the possibility that massive planets play an important role in the evolution of debris disks by efficiently grinding away or ejecting planetesimals from an initially massive disk, possibly in a Late Heavy Bombardment type of event. Our result also suggests that massive planets may not be required to produce debris, which is supported by collisional cascade models and the observations and theoretical models that indicate that debris disks are more prevalent than massive planets.

*Dr. Moro-Martin is a Lyman Spitzer fellow and Michelson fellow in the department of Astrophysical Sciences at Princeton University. She holds a B.S. in Physics from Universidad Complutense de Madrid (1998) and a Ph.D in Astronomy from the University of Arizona (2004).*

### **Biochemistry of early life: a perspective from nitrogen metabolism.**

*Ned S. Wingreen, Professor of Molecular Biology*

1:40-2:20

Perhaps the oldest record of early life on Earth is to be found in metabolism. The basic metabolic pathways predate the modern era of proteins and DNA, and may reveal information about conditions experienced by the original living organisms. As an example, I will discuss the case of nitrogen metabolism. The patterns of utilization of L-glutamine and L-glutamate, the two central intermediates of nitrogen metabolism, suggest that early life may have experienced conditions of nitrogen-limited growth.

*Dr. Wingreen is a Professor of Molecular Biology at Princeton University. He holds a B.S. in Physics from the Californial Institute of Technology and an M.S and Ph.D. degrees in Physics from Cornell University.*

### **The ages and orbits of nearby "Earth-like" planets.**

*Edwin L. Turner, Professor of Astrophysical Sciences*

2:20-3:00

In planning future searches for, and characterization studies of, biologically interesting terrestrial exoplanets in the Solar Neighborhood, it is important to understand their likely astrophysical properties. Following a description of the current status of work on this topic, arguments will be presented that 1) the typical ages of nearby terrestrial planets are likely to be substantially less than that of the Earth, with a median value in the vicinity of 2-3 Gyr, and 2) the current conventional definition of the Habitable Zone (the range of distances from its primary star at which a terrestrial planet is considered to be of biological interest) is too restrictive and idealized to be appropriate for the design of multi-billion dollar space missions.

*Dr. Turner is a Professor in Astrophysical Sciences who has worked on problems in cosmology for most of his career but who has been devoting increasing time and attention to exoplanets and astrobiology for about the last 5 years. He is one of the four instructors of the Princeton's inter-departmental sophomore level astrobiology course. He spends about 10% of his time at the University of Tokyo Physics Department.*

### **Novel proteins.**

*Michael H. Hecht, Professor of Chemistry*

3:30-4:10

Proteins are the molecular machines of life, and evolution has generated a large diversity of proteins to perform the myriad functions essential for life on earth. A protein is a chain of amino acids that folds into a specific 3-dimensional structure capable of carrying out a specific biological function. There are 20 amino acid "building blocks." Therefore, for a protein that is 100-amino acids long, there are 20<sup>100</sup> possible sequences. This number is so large that a hypothetical collection containing one molecule of every 100-mer protein would fill a space larger than Avogadro's number of universes. Clearly, life on earth has *not* sampled all possible protein sequences. Our laboratory is exploring protein "sequence space" to assess how easy (or difficult) it is to produce novel proteins that resemble proteins on earth. We are addressing the following questions:

- Do most sequences fold into well-ordered 3-dimensional structures?
- Are there simple rules to constrain the search into regions of sequence space that are most productive (i.e. that yield well folded proteins)?
- Are such rules encoded in the universal genetic code?
- Of those novel proteins that actually fold, what fraction is capable of biological function?

To answer these questions, we design and synthesize vast collections of *de novo* proteins. We have discovered simple rules that enable construction of novel proteins, which never existed on Earth, but which are nonetheless well-folded and catalytic active.

*Dr. Hecht received his BA in Chemistry from Cornell and his Ph.D. in Biology from MIT. He did post-doctoral research on protein design with Profs. David and Jane Richardson in the Department of Biochemistry at Duke Medical School. In 1990, Hecht joined the faculty at Princeton, where he is now Professor and Associate Chair of the Chemistry Department. He also has an affiliated appointment in the Department of Molecular Biology. Research in the Hecht laboratory focuses in two areas: The first deals with the design of novel proteins. The second is concerned with the molecular determinants of Alzheimer's disease and the search for compounds that can be used as novel anti-Alzheimer's therapeutics.*

### **Progress in understanding the surface and subsurface chemistry of Europa.**

*Kevin P. Hand, Astrophysical Sciences*

4:10-4:50

This talk will address recent developments in our understanding of Europa's surface and putative subsurface ocean. Numerical work addressing the relationship between the ice and ocean will be presented. Results from laboratory work addressing the radiolytic chemistry of Europa's surface will also be presented. The implications for habitability and robotic detection of life will be discussed.

*Kevin Hand is a graduate student in the Department of Geological & Environmental Sciences at Stanford University. He is currently in residence in the Department of Astrophysical Sciences at Princeton University, where he works with Professor Christopher F. Chyba on issues related to the origin and distribution of life in the solar system.*

### **Lab tests of high contrast imaging for earth-like planet detection.**

*Ruslan Belikov, Mechanical and Aerospace Engineering*

4:50-5:30

At first glance, taking a photo of an earth-like planet orbiting another star seems like a problem far beyond any foreseeable technology that should be confined to the realm of science fiction. Amazingly, it turns out that this problem, while very difficult, seems to be within reach of the next generation of space telescopes and high-contrast imaging systems. NASA is planning a mission called the Terrestrial Planet Finder Coronagraph (TPF-C) for this task, which is currently planned to be a space telescope with a 3.5 x 8m mirror with a specialized high-contrast imaging system called a coronagraph to eliminate the starlight. The problem in a nutshell is that a typical earth-like planet will be on the order of  $10^{10}$  times brighter than its host star and very close to it as seen from Earth (on the order of 100 milliarcseconds and smaller). This requires an imaging system capable of achieving a contrast level of  $10^{10}$  with very high resolution. In order to meet this challenge, our group at Princeton is developing what we call the Shaped-Pupil Coronagraph. In my talk, I will describe our system, show our current lab results ( $4 \times 10^{-8}$  contrast), and talk about the remaining challenges and how we plan to surmount them.

*Dr. Belikov is a Michelson postdoctoral fellow in the Department of Mechanical and Aerospace Engineering at Princeton University. He holds a B.S. in Electrical Engineering as well as Applied Math and Engineering Physics certificates from Princeton University, and M.S. and Ph.D. in Electrical Engineering from Stanford University. He currently works with Professor Kasdin in the Princeton TPF group on designing and building high-contrast imaging systems for earth-like planet detection.*

In memory of Edward Stiefel