ARIZONA STATE UNIVERSITY

GENERAL STUDIES PROGRAM COURSE PROPOSAL COVER FORM

Courses submitted to the GSC between 2/1 and 4/30 if approved, will be effective the following Spring.
Courses submitted between 5/1 and 1/31 if approved, will be effective the following Fall.

(SUBMISSION VIA ADOBE.PDF FILES IS PREFERRED)

DATE August 18, 2010

1. ACADEMIC UNIT: School of Earth & Space Exploration

2. COURSE PROPOSED: GLG 106 Habitable Worlds 4
   (prefix) (number) (title) (semester hours)

3. CONTACT PERSON: Name: Ariel Anbars Phone: x50767
   Mail Code: 871404 E-Mail: anbars@asu.edu

4. ELIGIBILITY: New courses must be approved by the Tempe Campus Curriculum Subcommittee and must have a regular course number. For the rules governing approval of omnibus courses, contact the General Studies Program Office at 965-0739.

5. AREA(S) PROPOSED COURSE WILL SERVE. A single course may be proposed for more than one core or awareness area. A course may satisfy a core area requirement and more than one awareness area requirements concurrently, but may not satisfy requirements in two core areas simultaneously, even if approved for those areas. With departmental consent, an approved General Studies course may be counted toward both the General Studies requirement and the major program of study. (Please submit one designation per proposal)

Core Areas

- Literacy and Critical Inquiry—L □
- Mathematical Studies—MA □
- Humanities, Fine Arts and Design—HU □
- Social and Behavioral Sciences—SB □
- Natural Sciences—SQ □

Awareness Areas

- Global Awareness—G □
- Historical Awareness—H □
- Cultural Diversity in the United States—C □

6. DOCUMENTATION REQUIRED.
   (1) Course Description
   (2) Course Syllabus
   (3) Criteria Checklist for the area
   (4) Table of Contents from the textbook used, if available

7. In the space provided below (or on a separate sheet), please also provide a description of how the course meets the specific criteria in the area for which the course is being proposed.

CROSS-LISTED COURSES: □ No □ Yes; Please identify courses: ______________________

Is this a multisection course? □ No □ Yes; Is it governed by a common syllabus? __________

Kip Hodges
Chair/Director  (Print or Type)  Chair/Director  (Signature)

Date: ______________________

Rev. 1/94, 4/95, 7/98, 4/00, 1/02, 10/08
Contents

1. Course Description
2. Course Syllabus
   a. Standard
   b. Detailed
3. Criteria Checklist
4. Criteria Justification (narrative)
5. Textbook TOC
**Rationale and Objectives**

In a relatively short time in the history of civilized societies, humankind moved from what was essentially an agrarian population into an industrial age, which in recent years has been profoundly shaped by such scientific and technological advances as genetic engineering, the computer, and space exploration. Our history of irrepressible ingenuity makes a compelling case for a future that will be even more profoundly influenced by science and technology. It is imperative that we react expeditiously and effectively to the problems and the promise that these advances create. We must ensure that technological change is directed to the benefit of society and that it will promote human dignity and values. Success in achieving this goal will depend upon the insight and knowledge of political and public opinion leaders, and the scientific enlightenment of educated citizens. To a significant degree, the ability of these individuals to understand the nature of the issues and the alternative courses of action will be determined by the quality of science presented at the nation's institutions of higher learning.

The recommendation of at least one laboratory course that includes a substantial introduction to the fundamental behavior of matter and energy in physical or biological systems derives from a number of considerations. First, all physical and biological phenomena have at their roots the fundamental principles governing the behavior of matter and energy. These principles have been shown over a period of time to be a value in reliably predicting and rationalizing a broad range of phenomena. Unless the lines to these roots are established, our understanding of the broader range of the sciences, and other fields upon which these sciences impinge, will be impaired. Second, because these fundamental principles have been experimentally established beyond reasonable doubt, the essentials of the scientific method can be clearly and coherently revealed by their study. Third, the study of the behavior of matter and energy illustrates the usefulness of mathematics in precisely describing and rationalizing certain physical phenomena, and the expressiveness of mathematical equation.

10/1989
Proposer: Please complete the following sections and attach appropriate documentation.

### ASU-[SQ] CRITERIA

#### I. FOR ALL QUANTITATIVE [SQ] NATURAL SCIENCES CORE AREA COURSES, THE FOLLOWING ARE CRITICAL CRITERIA AND MUST BE MET:

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
<th>Criteria Justification, Detailed Syllabus</th>
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<tbody>
<tr>
<td>![×]</td>
<td>![☐]</td>
<td><strong>A.</strong> Course emphasizes the mastery of basic scientific principles and concepts.</td>
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<td><strong>B.</strong> Addresses knowledge of scientific method.</td>
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<td><strong>C.</strong> Includes coverage of the methods of scientific inquiry that characterize the particular discipline.</td>
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<td><strong>D.</strong> Addresses potential for uncertainty in scientific inquiry.</td>
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<td>![×]</td>
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<td><strong>E.</strong> Illustrates the usefulness of mathematics in scientific description and reasoning.</td>
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<td><strong>F.</strong> Includes weekly laboratory and/or field sessions that provide hands-on exposure to scientific phenomena and methodology in the discipline, and enhance the learning of course material.</td>
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<td><strong>G.</strong> Students submit written reports of laboratory experiments for constructive evaluation by the instructor.</td>
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<td>![×]</td>
<td>![☐]</td>
<td><strong>H.</strong> Course is general or introductory in nature, ordinarily at lower-division level; not a course with great depth or specificity.</td>
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#### II. AT LEAST ONE OF THE FOLLOWING ADDITIONAL CRITERIA MUST BE MET WITHIN THE CONTEXT OF THE COURSE:

<table>
<thead>
<tr>
<th>YES</th>
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<th>Criteria Justification, Detailed Syllabus</th>
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<tbody>
<tr>
<td>![×]</td>
<td>![☐]</td>
<td><strong>A.</strong> Stresses understanding of the nature of basic scientific issues.</td>
</tr>
<tr>
<td>![×]</td>
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<td><strong>B.</strong> Develops appreciation of the scope and reality of limitations in scientific capabilities.</td>
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<td>![☐]</td>
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<td><strong>C.</strong> Discusses costs (time, human, financial) and risks of scientific inquiry.</td>
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**NOTE:** CRITERIA FOR [SQ] COURSES BEGIN ON PAGE 4.
### III. - [SQ] COURSES MUST ALSO MEET THESE ADDITIONAL CRITERIA:

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A. Provides a substantial, quantitative introduction to fundamental principles governing behavior of matter and energy, in physical or biological systems.

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<th>B. Includes a college-level treatment of some of the following topics (check all that apply below):</th>
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Criteria Justification, Detailed Syllabus

### [SQ] REQUIREMENTS CANNOT BE MET BY COURSES:

- Presenting a qualitative survey of a discipline.
- Focusing on the impact of science on social, economic, or environmental issues.
- Focusing on a specific or limiting but in-depth theme suitable for upper-division majors.
Proposer: Please complete the following section and attach appropriate documentation.

# ASU--[SG] CRITERIA

## I. FOR ALL GENERAL [SG] NATURAL SCIENCES CORE AREA COURSES, THE FOLLOWING ARE CRITICAL CRITERIA AND MUST BE MET:

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<tr>
<td>Criteria (from checksheet)</td>
<td>How course meets spirit (contextualize specific examples in next column)</td>
<td>Please provide detailed evidence of how course meets criteria (i.e., where in syllabus)</td>
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<tr>
<td><strong>I. A. Course emphasizes the mastery of basic scientific principles and concepts</strong></td>
<td>The course requires students to master basic science principles across a number of disciplines in order to answer the basic question of &quot;what is a habitable world&quot;?</td>
<td>E.g. Lectures 7-10 (astronomy), 15-17 (astronomy/physics), 22-23 (chemistry), 25-28 (biology/chemistry), 30, 35, 38 (geology), 41-43 (sustainability/environmental science)</td>
</tr>
<tr>
<td><strong>B. Addresses knowledge of scientific method</strong></td>
<td>Each lecture and activity emphasizes the scientific method as a way to rigorously answer questions.</td>
<td>All labs</td>
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<tr>
<td><strong>C. Includes coverage of the methods of scientific inquiry that characterize the particular discipline.</strong></td>
<td>Each laboratory activity attempts to mimic real scientific investigations in the field of astrobiology and related disciplines.</td>
<td>All labs, but particularly: Labs 1, 4-6, 8, 11</td>
</tr>
<tr>
<td><strong>D. Addresses potential for uncertainty in scientific inquiry.</strong></td>
<td>The course lectures and labs explicitly discuss areas in which scientists are uncertain.</td>
<td>Lectures 1-4, 17, 25, 28, 35, 43, Labs 1, 11-15</td>
</tr>
<tr>
<td><strong>E. Illustrates the usefulness of mathematics in scientific description and reasoning.</strong></td>
<td>Students will be exposed to many physical phenomena that are well explained by mathematical relationships. These equations will be presented and used in the course.</td>
<td>Lectures 5-10, 14, 20, Labs 1-7</td>
</tr>
<tr>
<td><strong>F. Includes weekly laboratory and/or field sessions that provide hands-on exposure to scientific phenomena and methodology in the discipline, and enhance the learning of course material.</strong></td>
<td>Exploration-driven, computer-based laboratory exercises will be required each week.</td>
<td>All labs</td>
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<td><strong>G. Students submit written reports of</strong></td>
<td>Students will be required to submit written lab reports in which they will describe their observations,</td>
<td>All labs</td>
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<td>Laboratory experiments for constructive evaluation by the instructor.</td>
<td>initial hypotheses, and conclusions.</td>
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<td><strong>H. Course is general or introductory in nature, ordinarily at lower-division level; not a course with great depth or specificity.</strong></td>
<td>Habitable Worlds is a survey course designed to give an introduction to many disciplines of science towards the single goal of understanding habitability.</td>
<td>See IA above</td>
</tr>
<tr>
<td><strong>II. A. Stresses understanding of the nature of basic scientific issues.</strong></td>
<td>As a transdisciplinary course, Habitable Worlds will give students perspective on the nature of science that cannot be gained through a single disciplinary perspective.</td>
<td>See IA and ID above</td>
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<tr>
<td><strong>B. Develops appreciation of the scope and reality of limitations in scientific capabilities.</strong></td>
<td>By discussing how the real on-going science in astrobiology is done, Habitable Worlds give students a good understanding of what is and is not yet possible.</td>
<td>Lectures 15 – 18 among others Labs 4 – 6, 13</td>
</tr>
<tr>
<td><strong>C. Discusses costs (time, human, financial) and risks of scientific inquiry.</strong></td>
<td>Discussions will touch on the financial costs of space exploration as well as the possible risks associated with contacting advanced alien intelligence.</td>
<td>Not a formal component of lectures or labs at this time.</td>
</tr>
<tr>
<td><strong>III. A. Provides a substantial, quantitative introduction to fundamental principles governing behavior of matter and energy, in physical or biological systems.</strong></td>
<td>The course deals extensively with the behavior of electromagnetic radiation and its interaction with matter, specifically with respect to the ways in which planetary environments are affected by these interactions.</td>
<td>Lectures 7 – 32, 34, 38 – 43 Labs 3 – 12, 14, 15</td>
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<tr>
<td><strong>B. Includes a college-level treatment of some of the following topics:</strong></td>
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<tr>
<td>a. Atomic and molecular structure</td>
<td>Atomic and molecular structure are taught as the basis for understanding stellar composition and the effects of atmospheres on planetary climate.</td>
<td>Lectures 11, 23, 27 Lab 4, 7, 8</td>
</tr>
<tr>
<td>b. Electrical processes</td>
<td>N/A</td>
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<tr>
<td>c. Chemical processes</td>
<td>The course covers many chemical processes that are essential for life.</td>
<td>Lectures 19, 22, 25 – 28, 32, 39</td>
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<tr>
<td><strong>d. Elementary thermodynamics</strong></td>
<td>This course presents a sophisticated picture of the importance of thermodynamics to all life and the impact of energy balance on climate.</td>
<td>Lectures 20, 21, 25, 28, 32, 41 among others</td>
</tr>
<tr>
<td><strong>e. Electromagnetics</strong></td>
<td>Emission and absorption of radiation is essential to the existence of habitable planets as well as to our ability to observe and characterize distant planets, thus it is a major part of the course. Spectroscopy and hence the E-M spectrum are also major topics.</td>
<td>Lectures 8, 20, 21, 23 among others Lab 4, 7</td>
</tr>
<tr>
<td><strong>f. Dynamics and mechanics</strong></td>
<td>The methods of detecting far away planets rely on an accurate understanding of orbital motion.</td>
<td>Lectures 15, 16 Labs 5, 6</td>
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</tbody>
</table>
Course Description – Catalog

Are we alone in the Universe? If so, why? If not, where are our cosmic cousins? Such questions, once the domain of science fiction, are on the verge of being answered with science facts. Astronomers are discovering planets around other stars. Planetary scientists are exploring the worlds in our solar system. Biologists are unlocking the secrets of metabolism and evolution. Geoscientists are determining how the Earth supports life. And as we struggle to build a sustainable future for ourselves, all of us are finding out how technologically advanced civilizations rise... and how they might fall. Habitable Worlds surveys these topics. In the process, students master basic concepts from across the major areas of science and learn what makes the Earth a habitable world.

Course Description – Detailed

Habitable Worlds is an introductory (100-level) science survey course that will be offered for the first time in Fall 2010. It uses as a narrative theme the search for intelligent life beyond Earth. This theme lends itself to exposing students to key topics across a range of science disciplines – from physics and astronomy to chemistry to life sciences, as well as critical topics in geoscience, environmental science and sustainability science. Importantly, this topic also lends itself to teaching that complex questions can be approached by deconstructing them into a series of smaller questions, each of which is itself uncertain to a greater or lesser degree. Students learn implicitly that science is a process of exploration, cooperative and competitive, with the goal of placing increasingly tight bounds on the unknown.

Habitable Worlds is organized around the “Drake Equation” (Drake, 1961), which estimates the number of extraterrestrial civilizations which might exist simultaneously in the galaxy (N) - and hence how many civilizations there might exist with which we might communicate today:

\[ N = R_\ast \cdot f_p \cdot n_e \cdot f_i \cdot f_i \cdot f_c \cdot L \]

- \( R_\ast \) = The rate of formation of stars in our galaxy
- \( f_p \) = The fraction of stars that have planets
- \( n_e \) = The number of Earth-like planets orbiting each of these stars
- \( f_i \) = the fraction of those planets that harbor life
- \( f_i \) = the fraction of planets with life that are home to intelligent life
- \( f_c \) = the fraction of intelligent species that develop technological civilizations
- \( L \) = the average lifespan of a technological civilization

Students will progress from \( R_\ast \) to \( L \) during the course of the semester, learning about the key scientific topics and state of knowledge in each area. In doing so, they will be exposed to a range of basic science concepts in a problem-oriented manner that helps motivate learning. These concepts include conservation of energy and mass, the chemical elements and reactivity, spatial scales, geologic time, evolution, bioenergetics, the electromagnetic spectrum, thermal emission, spectroscopy, biogeochemical cycles, climate science and the impact of humans on planetary habitability (see syllabus).
The emphasis in teaching these science concepts is for students to attain qualitative and semi-quantitative understanding, but students will also be expected to master basic quantitative skills including the interpretation of charts and graphs and the use of simple equations and functional relationships to test hypotheses quantitatively. These concepts will be address heavily in laboratory exercises.

Importantly for our aims, the terms of the Drake Equation are organized from those with small uncertainties being directly addressed by current research ($R_\ast$), to those with uncertainties so large that current research aims to define their dimensions rather than to reduce them (L). Therefore, students will begin the semester by mastering topics in physics and astronomy that give us a firm foundation for assessing the number of Earth-like planets orbiting other stars, and will finish by considering the factors that might shape the future of human civilization on Earth. In between, they will learn fundamental topics in Earth system science and Earth history that inform current understanding of the criteria for planetary habitability. *Habitable Worlds* is therefore inherently structured to teach that science is a process of answering questions by reducing uncertainties, rather than simply an expanding body of knowledge.

The course is intended for students who are motivated by this profound topic to understand what makes the Earth – or any planet – conducive to supporting life. This target audience includes students studying for BA degrees, including prospective majors in the new BA in Earth & Environmental Sciences in ASU’s School of Earth & Space Exploration. However, *Habitable Worlds* is also a valuable elective for students studying for BS degrees because it shows how the natural science disciplines are applied and integrated in pursuit of questions at the frontier of knowledge. This perspective is unusual in introductory science courses at the undergraduate level.
Criteria Justification

ASU—[SQ] Criteria

I. CRITICAL CRITERIA

A. Course emphasizes the mastery of basic scientific principles and concepts

The search for habitable environments and life beyond Earth is fundamentally transdisciplinary. As a result, Habitable Worlds teaches a broad range of basic scientific principles and concepts in pursuit of an underlying question. Some examples include: the concepts of geologic time and cosmic distances; the electromagnetic spectrum; the emission and absorption of radiation by matter; the relationship between temperature, pressure and the phases of water; energy balance and its role in planetary climate; climate change (natural and anthropogenic); fundamentals of orbital mechanics (e.g., Kepler’s 3rd law); evolution; principles of biochemistry and bioenergetics; etc.

Importantly, and unusually for an introductory science course, Habitable Worlds exposes students to the ways in which many of these principles and concepts interact with each other to shape planetary habitability. This transdisciplinary perspective will help to contextualize the principles and concepts encountered, helping students to solidify their understanding.

The class does not assume prior experience in any of the fields covered.

B. Addresses knowledge of scientific method

Habitable Worlds is organized around an ongoing scientific endeavor: the search for habitable—and inhabited—worlds beyond the Earth. As such, the course does not teach a body of knowledge but rather teaches how the scientific principles and concepts encountered in the course are used to develop and test hypotheses in a quantitative manner. This is the essence of the scientific method, and so the course is inherently designed to expose students to science as a process of investigation.

To reinforce this message, the lectures and activities associated with each unit of the course—i.e., with each term of the Drake equation—are motivated by a framing question. For example, in the f_p unit, lectures are motivated around the question: “Are planets rare?” Before this unit begins, students will be asked to develop hypotheses around this question (e.g., “hypothesis: all stars host at least one rocky planet”) and to devise approaches to test these hypotheses based on their prior knowledge. Lectures and lab activities will subsequently expose students to the hypotheses that are actually being tested, and the ways in which they are being tested.

Students also learn about the scientific method by applying it in laboratory exercises. The motivating principle behind these exercises is that students will learn general and specific scientific ideas by interacting with realistic simulations and examining realistic (sometimes real) data. These exercises will be computer-based, in preparation for making this course available online in the future. The scientific method is encountered in these exercises by having students
formulate hypotheses at the outset of each activity. They are then given the tools necessary to
test their hypotheses and are required to explain how it was validated or not by their
explorations. In this way, students will gain direct insight into the formal method of science.

C. Includes coverage of the methods of scientific inquiry that characterize the particular
discipline.

Most of the laboratory exercises are designed to mimic real scientific investigations, so that
students will have an understanding of specific methods of inquiry that are in use today.

For example, one focus of *Habitable Worlds* is the search for planets orbiting other stars
("exoplanets")—an activity at the cutting edge of astronomy. A series of computer labs will first
introduce students to the basic orbital mechanics that underlie the common methods of exoplanet
detection. Students will then analyze realistic astronomical data, using an online simulation
engine (several of which are available) to "discover" their own exoplanets. In this way they will
become familiar at the conceptual level with methods used in this branch of astronomy.

Another type of example is "virtual field trip" exercises. These exercises use extremely high-
resolution Gigapan imagery, immersive spherical imagery, and video clips, woven together using
FLASH in a web-based interface. Using this platform, students can explore and interrogate a
field setting in an open-ended manner, at multiple scales, guided by a framing question. These
technologies enable students to see a given feature of interest, whether it is a hot spring in
Yellowstone, an ancient fossil, or a rock formation on Mars, at multiple scales—just as if they
were there performing a real field investigation. Thus, students can look at the big picture for
geologic context and then zoom in to look at specific features on the millimeter to centimeter
scale. Such activities mimic the visual, exploratory nature of geology and planetary science. An
early prototype can be found at: http://habitableworlds.courses.asu.edu/VFT_dev.html.

Yet another type of exercise leverages the Google Earth platform—specifically, the Google
Earth web plug-in and API. Using this platform, we can build on visual examination of datasets,
at which the Google Earth platform excels, with the aim of taking students beyond visualization
to learn how to collect, plot, and interpret data quantitatively. In doing so, students learn
methodologies common in geochemistry, planetary science and ecology. Although such data
analysis is not a native part of the Google Earth API, it can be accomplished by tying spatial
coordinates to a back-end SQL database. In this manner, a coordinate specified by a student's
mouse click, captured by the API, automatically triggers a script that looks up the data value for
that point in an SQL database. The data are reported immediately to the student as entries in a
table and points on a chart, both of which are also web-embedded using the Google charting API.
The entire experience is seamless, allowing students to focus on exploration, data and
interpretation. A prototype is at: http://habitableworlds.courses.asu.edu/GE_dev.html (option-
click or alt-click to select points for plotting).

D. Addresses potential for uncertainty in scientific inquiry.

The Drake Equation, which is the backbone of *Habitable Worlds*, is not so much an equation as
it is a framework for breaking down the topic of life in the universe so as to isolate the key terms
and assess their uncertainties. As a result, *Habitable Worlds* intrinsically exposes students to the existence of uncertainty in scientific knowledge.

This message is reinforced in the laboratory exercises, many of which feature actual data or simulations of actual data that include simulated noise. For example, in a Google Earth-based exercise that explores the geochemical limits of life in the ocean, students will explore a large set of ocean data through correlation plots (X-Y) to determine which factor controls the distribution of life in the oceans. The key relationship is a positive correlation between the abundance of life (as represented by satellite chlorophyll data) and the abundances of the key nutrients nitrate and phosphate in seawater. Students will see that this correlation is never perfect, because real datasets are noisy due to myriad factors beyond the control of the observer. Further, they will learn that in some regions of the oceans the relationship is completely obscured by the influences of other variables. They will even see that in some regions the strongest correlations are between chlorophyll and temperature, which turns out to be an excellent example of correlation not equaling causation. In short, this exercise will show students that the physical, chemical, and biological world is a very complicated place and that scientific inquiry provides an approach to sorting through the complexities but does not eliminate them from view.

Finally, students will be exposed to some of the controversies in various areas of relevant science, such as the ongoing debate about the earliest evidence of life on Earth.

E. Illustrates the usefulness of mathematics in scientific description and reasoning.

By organizing *Habitable Worlds* around the Drake Equation, students are immediately exposed to the notion that mathematics is an essential framework for scientific reasoning. This is one of our motivations in designing this “SQ” course in this manner. They also learn quickly that multiplicative probabilities determine the probability of an outcome.

Further, within each unit many topics are treated using various forms of mathematics. While the course does not overtly emphasize the use of equations, students will be exposed to various important functions and relationships through plots that show how variables relate to each other (e.g., the relationship between temperature and emission energy embodied by the Planck function, or the relationship between orbital distance and period described by Kepler’s 3rd Law). They will be required to understand and apply some basic concepts such as the inverse square law and energy balance using simple equations.

F. Includes weekly laboratory and/or field sessions that provide hands-on exposure to scientific phenomena and methodology in the discipline, and enhance the learning of course material.

Students are assigned laboratory exercises each week that require them to investigate key science concepts in an iterative, inquiry-driven manner (see answer to C above). In a typical exercise, students will be required to develop a hypothesis at the outset of the exercise. They will then obtain data or make observations to test their hypothesis. These will be group exercises, since the goal is to motivate and enhance concept mastery rather than to be evaluative; evaluation will come via exams.
A critical aspect of most of these exercises is that they are computer-based, be they interactive simulations, dataset explorations or “virtual field trips”. Our philosophy is that appropriately designed exercises of this sort offer a more effective and engaging “hands-on” exposure to many scientific phenomena than do many physical laboratory exercises. One of our goals in developing this course is to evaluate this hypothesis, particularly in preparation for offering this course online.

G. Students submit written reports of laboratory experiments for constructive evaluation by the instructor.

Students will be required to submit weekly lab reports that include statements of hypotheses, a description of methods, presentation of data obtained in each exercise, and interpretation of their results. Importantly, a correct invalidation of a flawed hypothesis will be considered as meritorious as validation of a correct one.

These reports will be assessed by the TA and the teaching staff.

H. Course is general or introductory in nature, ordinarily at lower-division level; not a course with great depth or specificity.

Habitable Worlds is by nature a survey course, since it covers topics ranging from astronomy to biochemistry to anthropology. There is insufficient time to delve into any topic in depth. Instead, students will learn the distilled, key aspects of each subtopic, and will be exposed to some of its scientific underpinnings.

II. AT LEAST ONE OF THE FOLLOWING CRITERIA

A. Stresses understanding of the nature of basic scientific issues.

Habitable Worlds provides students with insights into the motivation underlying a number of areas of scientific research because it is organized around an ongoing transdisciplinary research endeavor. As such, the course will leave students with a better understanding of the nature of science and the goals of scientific research than is typical of introductory science courses.

This course also provides an unusual focus on the interconnections between different fields of scientific inquiry, particularly how aspects of biology, physics, chemistry, geology, and astronomy work together to determine whether a particular planetary environment could be habitable. Hence, Habitable Worlds stresses the transdisciplinary nature of much of cutting edge science.

Finally, Habitable Worlds provides unusual exposure to the fact that the frontier in most scientific areas is characterized by uncertainty and, in some cases, controversy.
B. Develops appreciation of the scope and reality of limitations in scientific capabilities.

From the outset, students in Habitable Worlds will confront the fact that our understanding of habitability beyond the Earth is limited. As the course progresses, they will learn the reasons for these limitations, both in terms of the challenge posed by each subtopic and the limitations imposed by the realities of astronomical and microscopic distances and of geologic time. They will also learn about the techniques and technologies that scientists use to tackle these challenges, and the limitations in these capabilities.

For example, in learning about how we detect planets orbiting other stars, students learn about the difficulty in directly imaging these planets and hence the need for indirect methods of detection. Students are taught the methods by which exoplanets are detected – transits, astrometry and Doppler shifts of stellar spectra – and the basic physics underlying these methods. Through this knowledge, they will gain an appreciation of the limitations of these methods when applied from the Earth’s surface, particularly when it comes to detecting Earth-sized planets. They will learn about ongoing efforts to detect planets from an orbiting observatory (the Kepler space telescope) that overcomes some of these limitations.

C. Discusses costs (time, human, financial) and risks of scientific inquiry.

Habitable Worlds does not substantially address this topic. However, the course will touch on: the financial costs of space exploration relative to other activities; the possible risks associated with contacting an advanced alien intelligence; and the time it may take before we can determine with confidence whether or not the Earth is unusual in harboring life.

III. ADDITIONAL CRITERIA

A. Provides a substantial, quantitative introduction to fundamental principles governing behavior of matter and energy, in physical or biological systems.

Habitable Worlds introduces students to a number of fundamental principles governing the behavior of matter and energy in physical and biological systems. These include thermal emission of radiation by stars and planets; absorption of radiation by atoms and by molecules in planetary atmospheres (hence, also basics of atomic and molecular theory); the inverse-square relationship of brightness and distance; nuclear fusion in stars; planetary motion; the electromagnetic spectrum; the effects of pressure and temperature on the phases of matter; conservation of energy (1st Law of Thermodynamics) in governing planetary climate and bioenergetics; release and consumption of energy by (bio)chemical reactions (exothermic vs. endothermic reactions); etc. These topics are all treated quantitatively, albeit at the freshman level and with an emphasis on conceptual understanding rather than derivation of formulae.

A particularly relevant design criterion for Habitable Worlds is that the course develops a basic understanding of the emission and absorption of radiation (energy) by matter and its relationship to planetary climate, reinforcing these topics through repeated exposure in different contexts. The building blocks are encountered early in the course when studying how stars work, how they...
affect their surroundings and how we learn about stars from spectroscopic observations (hence, the basics of thermal emission and atomic absorption of radiation). When introducing planets, students learn about absorption of radiation by gas molecules. When learning what makes a planet “Earth-like” with respect to temperature, they apply conservation of energy to learn how the balance between absorbed and emitted radiation determines the temperature of a planet that has no atmosphere, and hence how an atmosphere can warm a planet (i.e., the greenhouse effect). Students then encounter the greenhouse effect several more times as the course progresses, including the effects of climate on evolution, the possible role of a “climatic optimum” in fostering the development of technologically advanced civilization, and the ways in which anthropogenic perturbation of climate could destabilize our own civilization.

B. Includes a college-level treatment of some of the following topics:

a. Atomic and molecular structure

Related to the course’s treatment of electromagnetic radiation is the important idea that all matter can interact with radiation. Students learn that the exact nature of this interaction is determined by atomic and molecular structure. As a result, students learn that the chemical composition of stars can be determined from their atomic spectra, and that the makeup of atmospheres can be determined from molecular spectra. They also learn that the molecular structures of atmospheric gases determine why some gases absorb infrared radiation, leading to planetary warming (the greenhouse effect), while others do not. These implications of atomic and molecular structure are rarely considered at the high school level.

Students will also learn about life as a fundamentally chemical phenomenon, and so will learn about various molecular structures (e.g., amino acids, proteins, nucleic acids) in this context.

b. Electrical processes

Not applicable.

c. Chemical processes

The driving force for chemical processes is the release (or absorption) of energy during chemical reactions. Students will learn this fundamental concept in the context of understanding how different types of organisms obtain energy from their environment to build the complex macromolecules necessary for life (e.g., proteins, nucleic acids, carbohydrates), and in understanding how such energetic considerations affect the ability of organisms to survive in extreme environments.

Students will also encounter the phase transitions of water in the context of variations in planetary temperature and pressure. In particular, they will learn that it is impossible for liquid water to be stable at pressures below the triple point (e.g., roughly the atmospheric pressure of Mars today) and the ways in which this directs the search for life.


d. Elementary thermodynamics

The conservation of energy is a major theme in *Habitable Worlds*. It appears when students learn about what determines planetary climate (i.e., the balance between energy absorbed from space vs. thermal emission of energy back to space). It also appears when students learn about the basics of bioenergetics (i.e., chemitrophy, phototrophy etc.). And it appears in discussions of sustainability science at the tail end of the semester. Hence, students come away from this course with repeated exposure to the 1st Law of Thermodynamics, in applied contexts that are not encountered in typical high school curricula.


e. Electromagnetics

The emission and absorption of radiation is a major topic in *Habitable Worlds* because it is fundamental to planetary climate, and hence to planetary habitability. These phenomena can only be understood in the context of the electromagnetic spectrum. Hence, students become familiar with the spectrum qualitatively and in its quantitative sense in terms of wavelengths of light.

Students also become familiar with the fact that objects emit electromagnetic radiation, and that the intensity and wavelength distribution of this radiation changes with temperature (i.e., the Planck function). This topic is rarely taught at the high school level.


f. Dynamics and mechanics

In learning about how we detect extrasolar planets students develop a basic understanding of orbital dynamics and mechanics of planetary systems. For example, the “transit” method of detection requires careful measurement of the intensity of light from a star in order to detect the partial eclipse of the star due to the transit of a planet between the star and the observer. The periodicity of such eclipses provides information about the distance of the planet to its host star, via application of Kepler’s 3rd law (which can be explained by Newton’s gravitational laws).

Another method of planet hunting involves detecting the motion of the host star as it and the planet orbit the center-of-mass of the planet-star system. This motion is detected directly (“astrometry”) or indirectly by the Doppler shift of the spectrum of the star.
Instructor: Professor Ariel Anbar  
Office: PSF-630  
Phone: 965-0767  
Email: anbar@asu.edu  
Office Hours: TBD

TA Staff: TBD

**Informal Description**
Are we alone in the Universe? If so, why? If not, where are our cosmic cousins? Such questions, once the domain of science fiction, are on the verge of being answered with science facts. Astronomers are discovering planets around others stars. Planetary scientists are exploring the worlds in our solar system. Biologists are unlocking the secrets of metabolism and evolution. Geoscientists are determining how the Earth supports life. And as we struggle to build a sustainable future for ourselves, all of us are finding out how technologically advanced civilizations rise... and how they might fall. *Habitable Worlds* surveys these topics. In the process, students learn basic concepts from across the major areas of science.

**Formal Description**

*Habitable Worlds* surveys key concepts in the natural sciences that determine the distribution of Earth-like planets, life and intelligent civilizations in the Universe.

The course is intended for students who are motivated by this profound topic to understand what makes the Earth – or any planet – conducive to supporting life. The target audience includes students studying for BA degrees, including prospective majors in the new BA in Earth & Environmental Sciences in ASU’s School of Earth & Space Exploration. The course will eventually carry SQ credit for these students. However, *Habitable Worlds* is also a valuable elective for students studying for BS degrees because it shows how the natural science disciplines are applied and integrated in pursuit of questions at the frontier of knowledge. This perspective is unusual in introductory science courses at the undergraduate level.

*Habitable Worlds* is organized around the “Drake Equation”, which estimates the number of extraterrestrial civilizations with which we might communicate in our galaxy (N):

\[ N = R_s \times f_p \times n_e \times f_i \times f_l \times f_c \times L \]
\[ R_s = \text{The rate of formation of stars in the galaxy} \]
\[ f_p = \text{The fraction of stars that have planets} \]
\[ n_e = \text{The number of Earth-like planets orbiting each of these stars} \]
\[ f_l = \text{the fraction of those planets that harbor life} \]
\[ f_i = \text{the fraction of planets with life that are home to intelligent life} \]
\[ f_c = \text{the fraction of planets with intelligent life that develop technological civilizations} \]
\[ L = \text{the average lifetime of a technological civilization} \]

Students will progress from \( R_s \) to \( L \) during the course of the semester, learning about the key scientific topics and state of knowledge in each area. In doing so, they will be exposed to a range of basic science concepts in a question-oriented manner that helps motivate learning. These concepts include conservation of energy and mass, the chemical elements and reactivity, spatial scales, geologic time, evolution, bioenergetics, the electromagnetic spectrum, thermal emission, spectroscopy, biogeochemical cycles, climate science and the impact of humans on planetary habitability.

The emphasis in teaching these science concepts is for students to attain qualitative and semi-quantitative understanding, but students will also be expected to master basic quantitative skills including the construction and interpretation of quantitative charts and graphs and the use of simple equations to test hypotheses quantitatively.

Importantly, the terms of the Drake Equation are organized from the best understood \( (R_s) \) to the least understood \( (L) \). Therefore, *Habitable Worlds* takes students from deductive to inductive reasoning, and is inherently structured to teach that science is a process of answering questions by reducing uncertainties, rather than simply an expanding body of knowledge.

The course includes a laboratory component that is being developed for SQ credit.

**Course Objectives**
1. To introduce students to basic concepts in geoscience, life science, chemistry, physics and astrophysics in an integrative manner around the theme of planetary habitability.
2. To provide a broad audience of students with an introduction to the science of habitability and topics surrounding the distribution of Earth-like planets, the characteristics that make Earth habitable, the characteristics that might make other planets habitable, and the future habitability of our planet.
3. To excite students about the relevance of the basic sciences and quantitative thinking to their lives in the context of the larger-scale aspects of Earth and Environmental Studies and space exploration.
4. To expose students to science-as-it-really-is: An ongoing process of exploration and discovery, driven by the scientific method but not beholden to it.
5. To educate students about the history of life on Earth, the keys to sustaining life on Earth, and the impacts of human activities for future habitability of Earth.
Student Learning Objectives
After taking this course students will be able to:
1. Utilize basic concepts in geoscience, life science, chemistry, physics and astrophysics to describe and understand essential features of the world around them, qualitatively and quantitatively
2. Define the characteristics that are essential to habitable environments.
3. Critically compare and contrast the potential habitability of different planets
4. Critically assess potential changes in Earth’s environment that may occur as a result of human impacts or environmental processes

Curricular Articulation
This course is one of the introductory courses that can be chosen by students to fulfill their required disciplinary core for the BA major in SESE. It will provide students with tools and material that will help prepare them for success in the upper division electives. At the same time, the course is designed to enable non-science majors to meet their programmatic science course requirements, to include laboratory credit.

Prerequisites
None. Exposure to basic sciences and mathematics at the Arizona high school level is the only expectation.

Textbooks
Strongly Recommended:  
Life in the Universe by Bennett & Shostak, 2nd ed (“B&S”)
Suggested:
The Earth System by Kump, Kasting & Crane, 3rd ed (“KKC”)
How to Find a Habitable Planet, by Kasting (“Kasting”)  
Earth: Portrait of a Habitable World, by Lunine (“Lunine”)

Website
The class has a website powered by a combination of Blackboard and Wordpress blogging. PowerPoint or Keynote slides presented in class will be posted on Blackboard, but not always before class. This material is provided as a courtesy, not an entitlement. Announcements, discussions and other tidbits will appear on the blog.

Communication
Important information will be sent by email, so students must:

- Be sure the email address ASU has for you is valid.
- Be sure to check that account regularly.
- Make sure that email account is not clogged.
Assignments, Assessment and Grading

The lecture portion of the class will include problem sets (roughly one per course module), two midterm exams, ~ 20 in-class quizzes, and a final exam. Points will also be allocated for participation in online discussions. The laboratory portion of the class involves inquiry-based group exercises every week that each culminates in an on-line lab report. Grading is as follows:

<table>
<thead>
<tr>
<th>Assignment</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quizzes</td>
<td>100 (25 x 5 pts each)</td>
</tr>
<tr>
<td>Problem Sets</td>
<td>180 (~9 x 20 pts each)</td>
</tr>
<tr>
<td>Lab Reports</td>
<td>225 (15 x 15 pts each)</td>
</tr>
<tr>
<td>Midterm Exams</td>
<td>200 (2 x 100 pts each)</td>
</tr>
<tr>
<td>Final Assignment</td>
<td>200</td>
</tr>
<tr>
<td>Discussions</td>
<td>60</td>
</tr>
<tr>
<td>Surveys</td>
<td>45 (9 x 6 pts each)</td>
</tr>
</tbody>
</table>

**Total** 1000 points

**Bonus Points** up to 100

Grade averages:  
- ≥ 90% A  
- ≥ 80% B  
- ≥ 70% C  
- ≥ 60% D  
- < 60% E

Grade boundaries will be adjusted if scores are too low to achieve an appropriate distribution of grades, but this will not likely be necessary.

Note below that virtually all activities can be done collaboratively, except for exams. This means that if you can find an effective group to work with, it is possible to get 60% of the points in this class with the help of your peers. If you then perform at only the 50% level on exams you should be in “B” territory by semester’s end.

**Quizzes:** Brief exercises, either online or in class, will be administered through the semester at a pace of 1 – 2 per week. They are unscheduled so as to encourage class attendance and attention to the class blog. Roughly half the quizzes will be designed to help you understand a key concept, and half to assess your mastery of recent lecture material. In most cases, you will be able to work on quizzes in pairs or small groups. All together, quizzes are worth the same as a midterm exam.

**Problem Sets:** Roughly 9 problem sets worth 20 points each will be administered via Blackboard, in multiple-choice format, tied to each of the 9 modules of the course. This number may vary depending on the length of each module as the semester develops. You may work together on problem sets, but you must submit your own.
**Lab Reports:** Fifteen inquiry exercises or assignments will be conducted during the semester. These exercises can be carried out in groups, with reports submitted using an online template that will be provided.

**Midterm Exams:** Two 100-point exams will be given during the semester. Because the course content builds through the semester, you can expect each exam to be somewhat cumulative in nature. No exams will be dropped. Exams are open-book and open-note, but communication devices and devices that connect to the Internet are not allowed except with permission of the instructor.

**Final Assignment:** The course will conclude with a final assignment. This may be an exam or a project, as will be discussed in class. Either way, the assignment will be worth 200 points. The content of the assignment will be cumulative.

**Discussions:** You are expected to participate in discussions on the class blog with at least two substantive comments each week, valued at 2 points/comment.

**Surveys:** Your impressions of this new course as it progresses are very valuable to me. You are encouraged to respond to surveys that we will post on Blackboard. Survey responses will be anonymous, but Blackboard will track how many survey questions you complete.

**Bonus:** As many as 100 bonus points may be made available through the semester for extra discussion comments, extra quizzes, optional seminars, and other extra credit assignments.

**Missed Exams:** None of the graded exams will be dropped. Therefore, it is imperative that you be present for every exam. *Plan travel and other events accordingly.* An alternate exam *may* be administered prior to the scheduled time *only* in cases where travel for a university-sanctioned business or function, which cannot be rescheduled, interferes with an exam date. *If such plans do interfere with an exam date, then it is your responsibility to schedule an alternate exam date prior to the scheduled date. This alternate date must be finalized at least two weeks prior to the scheduled exam date.* You must show documentation from an appropriate university official for an early exam to be administered. An alternate exam will not be administered after the original exam date.

In cases of sudden illness or unanticipated emergency that prevents you from attending a scheduled exam, the final exam percentage will be substituted *if credible documentation is provided to the instructor of illness or emergency. This option can only be exercised once.* Because all exam dates are scheduled at the beginning of the semester, personal travel, work schedules, traffic, etc. *do not* constitute grounds for a make-up exam.

There will be no makeup in-class quizzes. However, your lowest three will be dropped.
Late Assignments: Partial credit will be awarded for late assignments. For problem sets, the amount of credit is 75% if submitted prior to release of the answer key, 50% after release, declining 10% each subsequent week to a floor of 20%. For lab reports, 50% credit will be given for late submission.

Academic Honesty
The rules for collaborative work in this class are generous. Aside from exams, you are encouraged to work together. Therefore, academic misconduct and academic dishonesty on exams will not be tolerated. Students engaging in misconduct or dishonest practices on exams will be dealt with to the fullest severity permitted according to the guidelines established by the university (http://provost.asu.edu/academicintegrity)

Disabilities
If you have a disability that would impact your performance in this class, you must notify me at the start of the semester so that we can make suitable arrangements.

General Rules
- Show up on time.
- Control disruptive behavior (e.g., talking).
- Turn off phones or other distracting electronic devices.
- No audio or video recording without consent of instructor
- If you have questions or concerns, ASK the instructor or TA ASAP!
Lectures, Labs, Readings

Note: The readings listed here are recommended but not required. They are provided as additional aids to learning. We will try to make them available on Blackboard as the semester progresses.

Unit 1: Unclose Encounters
Schedule: Aug. 20, 23, 25, 27
Topics: Drake Equation; Where are they?; What are they?
Concepts: Planetary dynamics; Mathematical reasoning; scientific method
Lab #1: Drake Dilemmas
Reading: B&S, Chpt. 1: A Universe of Life? pp 1 - 12
B&S, Chpt. 12: SETI, pp 398 - 404; 425 - 432
Selections from The Eerie Silence (Davies)

Unit 2: Scaling our Limitations
Schedule: Aug. 30, Sep. 1
Topics: Scales of Space; Scales of Time
Concepts: Numeric reasoning; geologic time; planetary and cosmic distances
Lab #2: Powers of 10
Reading: B&S, Chpt 3.2, Structure, Scale & History of the Universe, pp 51 - 70
Lunine Chpt 2, Largest and Smallest Scales, pp 8 - 17
Lunine Chpt 5, Cosmic and Terrestrial Ages, pp 47 - 53

Unit 3: When You Wish Upon... Which Star? (Drake term: $R_p$)
Schedule: Sep. 3, 8, 10, 13, 15, 17
Topics: The Physics of Stars
Concepts: E-M spectrum; Planck, Wien and Stefan-Boltzmann Laws; inverse-square law; atomic absorption and composition; nuclear fusion
Lab #3: The Rainbow Connection
Lab #4: Spectroscopic Fingerprints
Reading: B&S, Chpt 11.1, Distant Suns, pp 360 – 369
B&S, Chpt 11.3, Classifying Stars, pp 388 - 393

Unit 4: Prospecting for Planets (Drake term: $f_p$)
Schedule: Sep. 20, 22, 24, 27, 29, Oct. 1
Topic: Are planets rare? Detecting planets outside our Solar System
Concepts: Types of planets; gravity; Kepler’s 3rd law; center of mass; Doppler effect; light curves
Lab #5: Wobble Exploratorium
Lab #6: Transit Exploratorium
Reading: B&S, Chpt 11.2, Extrasolar Planets, pp 369-384
Kasting, Chpt 11, Indirect Detection of Planets, pp 195-210
Kasting, Chpt 12, Transits, pp 221 - 235

MIDTERM EXAM #1: OCTOBER 13
Covers Units 1 - 4

Unit 5: The Habitable Zone (Drake term: n_e)
Schedule: Oct. 4, 6, 8, 11, 15, 18
Topic: Is the Earth unique? Conditions for “Earth-like” planets
Concepts: Phases of water; water stability across P and T; sublimation; Beer’s Law; molecular spectroscopy; energy balance; greenhouse effect; carbon cycle; plate tectonics
Lab #7: Temperatures in the Solar System
Lab #8: Habitable Zone Hunt
Reading: B&S, Chpt 10, pp 328 - 342
B&S, Chpt 8, pp 264 - 279
KKC Chpt 3, Global Energy Balance, pp 36 – 53
Kasting, Chpt 9, Is the Earth Rare? pp 147 – 164
Kasting, Chpt 11, Habitable Zones pp 171 – 192
KKC Chpt 8, Recycling of the Elements, pp 149 – 173

Unit 6: Conditions for Life and its Detection (Drake term: f_l)
Schedule: Oct. 20, 22, 25, 27, 29, Nov. 1, 3, 5, 8, 10
Topic: Is life likely to be common or rare? What can we infer from Earth?
Concepts: Basic biochemistry; evolution; genomic “tree of life”; origin of life theories; extremes of life; requirements for life; history of life and climate on Earth; carbon cycle; life detection (Solar System and extrasolar)
Lab #9: What Life Needs
Lab #10: Limits to Life (Yellowstone Virtual Field Trip)
Lab #11: Life Detection: Mars
Lab #12: Life Detection: Beyond
Reading: B&S, Chpt. 4, Habitability of Earth, pp 99 - 138
B&S, Chpt. 5, Nature of Life on Earth, pp 148 - 185
B&S, Chpt. 6, Origin & Evolution of Life on Earth, pp 190 - 214
KKC Chpt 10, Origin of Earth and of Life, pp 148 - 217
Kasting Chpt 14, Spectroscopic Search for Life, pp 258 – 276
Kasting Chpt 13, Long Term Climate Stability, pp 32 – 53
KKC Chpt 12, Long-term Climate Regulation, pp 233-250
KKC Chpt 11, Effect of Life on the Atmosphere, pp 210 – 230
KKC Chpt 19, Climate Stability on Earthlike Planets, pp 379 – 391

Unit 7: Inquires into Intelligence (Drake term: f_i)
Schedule: Nov. 12, 15, 17
Topic: Is intelligent life likely to be rare?
Concepts: Emergence of animal life and Homo sapiens; impacts and extinctions; concepts of intelligence
Lab #13: Contingency and Complexity (Flinders Virtual Field Trip)
Reading: B&S, Chpt. 6.4, Impacts & Extinctions, pp 215 - 220
B&S, Chpt. 6.5, Human Evolution, pp 221 - 225
B&S, Chpt. 12.2, The Question of Intelligence, pp 405 - 409

MIDTERM EXAM #2: NOVEMBER 22
Covers Units 5 – 7 (prior material also fair game)

Unit 8: Civilization and Communication (Drake term: f*)
Schedule: Nov. 19, 24, 29
Topic: How do advanced civilizations arise and how might we find them?
Concepts: Climate optimum; energy; communications
Lab #14: SETI Signals
Reading: B&S, Chpt. 12.3, Searching for Intelligence, pp 410 - 424
Others TBD

Unit 8: All Good Things... (Drake term: L)
Schedule: Dec. 1, 3, 6
Topic: How long do we have?
Concepts: Climate change; planetary sustainability; carrying capacity; geoengineering; stellar evolution
Lab #15: Sustaining Civilization
Reading: B&S, Chpt. 10.4, The Future of Life on Earth, pp 343 - 347
B&S, Chpt. 10.5, Global Warming, pp 343 - 347
KKC Chpt 15, Global Warming, pp 295 – 335
Kasting Chpt. 7, Future Evolution of Earth, pp 116 - 121
Table of Contents
Life in the Universe (2nd Edition)

I. Introducing Life in the Universe
   1. A Universe of Life?
   2. The Science of Life in the Universe
   3. The Universal Context of Life

II. Life on Earth
   3. The Habitability of Earth
   4. The Nature of Life on Earth
   5. The Origin and Evolution of Life on Earth

III. Life in the Solar System
   6. Searching for Life in Our Solar System
   7. Mars
   8. Life on Jovian Moons
   9. The Nature and Evolution of Habitability

IV. Life Among the Stars
   10. Habitability Outside the Solar System
   11. The Search for Extraterrestrial Intelligence
   12. Interstellar Travel and the Fermi Paradox

Epilogue: Contact — Implications of the Search and Discovery
# Habitable Worlds

**Unit 1**

**Objective**
Introduce Drake Equation and motivate students with some mind-stretching ideas

<table>
<thead>
<tr>
<th>Lectures</th>
<th>Date</th>
<th>Title</th>
<th>Topics</th>
<th>Key Concepts</th>
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</thead>
<tbody>
<tr>
<td>#1</td>
<td>20-Aug-10</td>
<td>Welcome</td>
<td>1 Course syllabus and structure</td>
<td>Science in a social context</td>
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<td></td>
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<td>2 Motivational words</td>
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<tr>
<td>#2</td>
<td>23-Aug-10</td>
<td>Context of Our Quest</td>
<td>1 Cosmic context</td>
<td>Planetary dynamics intro</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>2 Drake defined</td>
<td>Mathematical reasoning</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>3 The &quot;sustainable&quot; Drake Equation</td>
<td>Mathematical reasoning</td>
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<tr>
<td>#3</td>
<td>25-Aug-10</td>
<td>Where are They?</td>
<td>1 Habitable worlds</td>
<td>Logic; scientific method</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 Fermi's paradox</td>
<td>Mathematical reasoning</td>
</tr>
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<td></td>
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<td>3 UFOs? No.</td>
<td>Scientific method</td>
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<tr>
<td>#4</td>
<td>27-Aug-10</td>
<td>What are They?</td>
<td>1 Life as we know it</td>
<td>Thermodynamic intro</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 Sentience vs. slime</td>
<td>Evolution intro</td>
</tr>
</tbody>
</table>

**Readings**

Bennett & Shostak, Chpt. 1: A Universe of Life? pp 1 - 12
Bennett & Shostak, Chpt. 2: The Science of Life in the Universe, pp 16 - 38
Bennett & Shostak, Chpt. 12: SETI, pp 398 - 404; 425 - 432
Selections from The Eerie Silence (Davies)

**Lab #1**

Drake Dilemmas

*Students use the Drake equation to construct scenarios consistent with hypotheses they are given.*
**Habitable Worlds**  
GLG 106  
MWF 12:55 - 1:45

**Unit 2**  
**Question** Scaling our Limitations  
**Objective** How is our search limited by scales of space and time?  
Develop a sense of relevant physical and temporal scales

<table>
<thead>
<tr>
<th>Lectures</th>
<th>Date</th>
<th>Title</th>
<th>Topics</th>
<th>Key Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>#5</td>
<td>30-Aug-10</td>
<td>Scales of Space</td>
<td>Human scale</td>
<td>Measurement</td>
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<td></td>
<td></td>
<td></td>
<td>Looking outward</td>
<td>Planetary &amp; cosmic scales</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Looking inward</td>
<td>Nano and micro scales</td>
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<tr>
<td>#6</td>
<td>1-Sep-10</td>
<td>Scales of Time</td>
<td>In the blink of an eye</td>
<td>Speed of light</td>
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<td>Ages of the Earth</td>
<td>Origin and age of Earth</td>
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<tr>
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<td></td>
<td>Cosmic time</td>
<td>Origin and age of Universe</td>
</tr>
</tbody>
</table>

**Readings**  
Bennett & Shostak, Chpt 3.2, The Structure, Scale and History of the Universe, pp 51 - 70  
Lunine Chpt 2, Largest and Smallest Scales, pp 8 – 17  
Lunine Chpt 5, Cosmic and Terrestrial Ages, pp 47 – 53

**Lab #2**  
Powers of 10  
A. Students must locate various items in the correct place on a timeline and on a dimensional scale (linear and log)  
B. Students use Google Earth to determine how close they have to be to Earth to find evidence of life
## Habitable Worlds

**GLG 106**

**Fall Semester, 2010**

**MWF 12:55 - 1:45**

### Unit 3

**Question**
When You Wish Upon... Which Star? ($R_s$)

**Objective**
Can we narrow the list of stars to search?

Learn astro/phys concepts that affect which stars could harbor life

### Lectures

<table>
<thead>
<tr>
<th>#</th>
<th>Date</th>
<th>Title</th>
<th>Topics</th>
<th>Key Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>#7</td>
<td>3-Sep-10</td>
<td>Here Comes the Sun</td>
<td>Characteristics of the Sun&lt;br&gt;Brightness-distance</td>
<td>Temperature, energy&lt;br&gt;Inverse square law&lt;br&gt;Reading plots, functions</td>
</tr>
<tr>
<td>#8</td>
<td>8-Sep-10</td>
<td>The Stellar Menagerie</td>
<td>Colors of stars&lt;br&gt;Colors and temperatures A&lt;br&gt;Colors and temperatures B</td>
<td>E-M spectrum&lt;br&gt;Thermal emission (qual)&lt;br&gt;Planck Law; Wien's Law</td>
</tr>
<tr>
<td>#9</td>
<td>10-Sep-10</td>
<td>How Stars Work</td>
<td>Luminosity and temperature&lt;br&gt;Nuclear fusion</td>
<td>Stefan-Boltzmann Law&lt;br&gt;Atoms, nucleosynthesis</td>
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<tr>
<td>#10</td>
<td>13-Sep-10</td>
<td>Why Size Matters</td>
<td>Mass, pressure and luminosity&lt;br&gt;Mass and stellar evolution/lifetime</td>
<td>Pressure as force</td>
</tr>
<tr>
<td>#11</td>
<td>15-Sep-10</td>
<td>Starstuff</td>
<td>Composition of cosmos&lt;br&gt;Absorption of light by atoms&lt;br&gt;Absorption lines in stellar spectra</td>
<td>Atoms&lt;br&gt;Photons and electrons&lt;br&gt;Beer's Law</td>
</tr>
<tr>
<td>#12</td>
<td>17-Sep-10</td>
<td>Integration: Habstars</td>
<td>Where to Wish Upon?</td>
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</tr>
</tbody>
</table>

### Readings

Bennett & Shostak, Chpt 11.1, Distant Suns, pp 360 - 369

Bennett & Shostak, Chpt 11.3, Classifying Stars, pp 388 - 393

### Lab #3

The Rainbow Connection

An interactive exploration of color-temperature relationships (E-M spectrum, Planck and Wien, etc.)

### Lab #4

Stellar Fingerprints

Students match stellar absorption spectra to atomic absorption "fingerprints" of the elements
# Habitable Worlds

**GLG 106**

**MWF 12:55 - 1:45**

## Unit 4

**Question**
Are planets rare?

**Objective**
Master astro/phys concepts that underlie planet hunting

### Lectures

<table>
<thead>
<tr>
<th>#</th>
<th>Date</th>
<th>Title</th>
<th>Topics</th>
<th>Key Concepts</th>
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</thead>
<tbody>
<tr>
<td>#13</td>
<td>20-Sep-10</td>
<td>Planetary Properties</td>
<td>Terrestrial planets</td>
<td>Planet characteristics</td>
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<td>Gas giants</td>
<td>Solar system structure</td>
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<td>Dwarf planets and other objects</td>
<td>Solar system formation</td>
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<tr>
<td>#14</td>
<td>22-Sep-10</td>
<td>Observational Obstacles</td>
<td>Brightness of planets</td>
<td>Albedo and reflection</td>
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<td>Relative brightness</td>
<td>Applying Stefan-Boltzmann</td>
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<td>Indirect imaging (dust)</td>
<td>Uncertainties &amp; limits</td>
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<tr>
<td>#15</td>
<td>24-Sep-10</td>
<td>Indirect Detection: Wobble</td>
<td>Stellar wobble and astrometry detection</td>
<td>Center of gravity</td>
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<td>Doppler detection</td>
<td>Doppler effect</td>
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<td>Outcome: Mass and orbit</td>
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<tr>
<td>#16</td>
<td>27-Sep-10</td>
<td>Indirect Detection: Transits</td>
<td>Eclipses and light curves</td>
<td>Cross sections</td>
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<td>Light curve periodicity</td>
<td>Kepler's 3rd Law</td>
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<td>Searches and Census</td>
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<td>Hot Jupiters</td>
<td>Observer bias</td>
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<td>Super Earths</td>
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<tr>
<td>#17</td>
<td>29-Sep-10</td>
<td>State of the Search</td>
<td>Searches and Census</td>
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<td>Hot Jupiters</td>
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<td></td>
<td>Super Earths</td>
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<td>#18</td>
<td>1-Oct-10</td>
<td>Integration: Prognosis</td>
<td>Waterworlds and other Exotica</td>
<td>Density = mass/volume</td>
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<td>Whither Earth 2.0?</td>
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</tbody>
</table>

## Readings

Bennett & Shostak, Chpt 11.2, Extrasolar Planets, pp 369-384
Kasting, Chpt 11, Indirect Detection of Planets, pp 195-210
Kasting, Chpt 12, Transits, pp 221 - 235

## Lab #5

"Wobble" Exploratorium  
http://astro.unl.edu/naap/esp/animations/radialVelocitySimulator.html
Students learn to detect planets via perturbation of stellar motion (astrometry and Doppler)

## Lab #6

Transit Exploratorium  
http://astro.unl.edu/naap/esp/animations/transitSimulator.html
Students learn to detect planets via dips in stellar light curves (Kepler Telescope method)
Habitable Worlds
GLG 106

Unit 5
Question
Is the Earth unique?
Objective
Understand the conditions conducive for water on planets. Focus on T, P and the greenhouse effect.

<table>
<thead>
<tr>
<th>Lectures</th>
<th>Date</th>
<th>Title</th>
<th>Topics</th>
<th>Key Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>#19</td>
<td>4-Oct-10</td>
<td>The Ways of Water</td>
<td>Life as aqueous chemistry&lt;br&gt;Freezing and boiling @ molecular level&lt;br&gt;Water phase diagram</td>
<td>Solutions and solutes&lt;br&gt;Phases of water&lt;br&gt;Molecules</td>
</tr>
<tr>
<td>#20</td>
<td>6-Oct-10</td>
<td>The Habitable Zone: A Simple Story</td>
<td>Solar flux vs. distance&lt;br&gt;Energy balance and thermal emission&lt;br&gt;T on Mercury, Moon, Mars, Pluto</td>
<td>Inverse square law&lt;br&gt;Conservation of energy&lt;br&gt;Stefan-Boltzmann law</td>
</tr>
<tr>
<td>#21</td>
<td>8-Oct-10</td>
<td>The Habitable Zone: Not so Simple</td>
<td>Iceball Earth (no greenhouse)&lt;br&gt;Greenhouse Effect&lt;br&gt;The Carbon Cycle</td>
<td>Greenhouse effect&lt;br&gt;Molecular absorption spectra&lt;br&gt;Plate tectonics</td>
</tr>
<tr>
<td>#22</td>
<td>11-Oct-10</td>
<td>Mars: Under Pressure?</td>
<td>Water on Mars (lack thereof)&lt;br&gt;Pressure, boiling and sublimation&lt;br&gt;Size matters</td>
<td>Pressure as a force&lt;br&gt;Application of phase diagram&lt;br&gt;Atmospheric escape</td>
</tr>
<tr>
<td>#23</td>
<td>15-Oct-10</td>
<td>Got Gas?</td>
<td>Absorption of light&lt;br&gt;Absorption spectra of gases&lt;br&gt;Atmospheric detection</td>
<td>Beer's Law&lt;br&gt;Molecular spectra</td>
</tr>
<tr>
<td>#24</td>
<td>18-Oct-10</td>
<td>Sisters and Satellites</td>
<td>Venus: Sweatering sister&lt;br&gt;Europa: Put a lid on it&lt;br&gt;Titan: Life as we don't know it</td>
<td>Runaway greenhouse&lt;br&gt;Plate tectonics&lt;br&gt;Geomorphology</td>
</tr>
</tbody>
</table>

Readings
Bennett & Shostak, Chpt 10, pp 328 - 342
Bennett & Shostak, Chpt 8, pp 264 - 279
KKC Chpt 3, Global Energy Balance, pp 36 - 53
Kasting, Chpt 9, Is the Earth Rare? pp 147 - 164
Kasting, Chpt 11, Habitable Zones pp 171 - 192
KKC Chpt 8, Recycling of the Elements, pp 149 - 173

Lab #7
Temperatures in the Solar System
Exploration of temperatures on bodies in the Solar System, and controlling factors

Lab #8
Habitable Zone Hunt
Interactive exercise in which students determine location of habitable zone around different stars
### Habitable Worlds

**GLG 106**

**Fall Semester, 2010**

**Unit 6** Conditions for Life... and its Detection (f)

**Question** Is life likely to be common or rare, and how will we find it?

**Objective** Understand the requirements for life and the means of detection

<table>
<thead>
<tr>
<th>Lectures</th>
<th>Date</th>
<th>Title</th>
<th>Topics</th>
<th>Key Concepts</th>
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<tbody>
<tr>
<td>#25</td>
<td>20-Oct-10</td>
<td>What is Life?</td>
<td>Metabolism</td>
<td>Energy and entropy</td>
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<td>Replication</td>
<td>Oxidation-reduction</td>
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<td>Life as we don't know it</td>
<td>Evolution</td>
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<td>#26</td>
<td>22-Oct-10</td>
<td>Powering Life as We Know It</td>
<td>Heterotrophy</td>
<td>Conservation of energy</td>
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<td>Chemoautotrophy</td>
<td>Molecules and reactions</td>
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<td>Phototrophy</td>
<td>Photosynthesis</td>
</tr>
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<td>#27</td>
<td>25-Oct-10</td>
<td>Building Life as We Know It</td>
<td>Cell walls</td>
<td>Lipids</td>
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<td>Proteins</td>
<td>Amino acids</td>
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<td>DNA, RNA</td>
<td>Nucleic acids</td>
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<tr>
<td>#28</td>
<td>27-Oct-10</td>
<td>Origin of Life</td>
<td>Miller experiment</td>
<td>Prebiotic chemistry</td>
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<td>Impact frustration/timing/setting</td>
<td>Planetary context</td>
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<td>Geologic evidence</td>
<td>Lunar impact record</td>
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<tr>
<td>#29</td>
<td>29-Oct-10</td>
<td>Early Evolution: Genomes</td>
<td>Genomic trees</td>
<td>Phylogenetic (parsimony)</td>
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<td>Extremophiles and the common ancestor</td>
<td>Eukarya, prokarya, archea</td>
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<td>Kingdoms of life</td>
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<tr>
<td>#30</td>
<td>1-Nov-10</td>
<td>Early Evolution: Geology</td>
<td>Stromatolites and microfossils</td>
<td>Body vs. trace fossils</td>
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<td>Rise of atmospheric O₂</td>
<td>Oxidation-reduction</td>
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<td>Timescale</td>
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<td>#31</td>
<td>3-Nov-10</td>
<td>Limits to Life</td>
<td>Acidophiles</td>
<td>Acidity</td>
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<td>Thermophiles</td>
<td>Salinity/evaporation</td>
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<td>Halophiles</td>
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</tbody>
</table>
# Lectures | Date       | Title                                | Topics                                      | Key Concepts               |
#32     | 5-Nov-10   | Life on a Planetary Scale           | Water, Energy, Nutrients                    | Water cycle, Photic zone, Nitrate and Phosphate, Chlorophyl |
#34     | 10-Nov-10  | Beyond the Solar System             | Atmosphere composition, Habitable zone revisited | Spectroscopy |

**Readings**

- Bennett & Shostak, Chpt. 4, Habitability of Earth, pp 99 - 138  
- Bennett & Shostak, Chpt. 5, Nature of Life on Earth, pp 148 - 185  
- Bennett & Shostak, Chpt. 6, Origin & Evolution of Life on Earth, pp 190 - 214  
- KKC Chpt 10, Origin of Earth and of Life, pp  
- Kasting Chpt 14, Spectroscopic Search for Life, pp 258 - 276  
- Kasting Chpt 3, Long Term Climate Stability, pp 32 - 53  
- KKC Chpt 12, Long-term Climate Regulation, pp 233-250  
- KKC Chpt 11, Effect of Life on the Atmosphere, pp 210 - 230  
- KKC Chpt 19, Climate Stability on Earthlike Planets, pp 379 - 391  

**Lab #9**  
What Life Needs  
* A Google Earth exploration of ocean productivity and nutrients. habitableworlds.courses.asu.edu/gE_dev.html  

**Lab #10**  
Limits to Life  
* A Virtual Field Trip of microbial ecosystems in the hot springs of Yellowstone National Park  

**Lab #11**  
Life Detection: Mars  
* Google Mars exploration of habitability and hypothetical life signs on Mars  

**Lab #12**  
Life Detection: Beyond  
* Interactive exploration for biological fingerprints in hypothetical spectra from extrasolar planetary atmospheres
### Habitable Worlds
GLG 106

**Unit 7**
**Inquiries into Intelligence (f_i)**
**Question**
Is intelligent life common or rare?
**Objective**
Understand what we mean by "intelligence" and the evolutionary history of complex and intelligent life on Earth

<table>
<thead>
<tr>
<th>Lectures</th>
<th>Date</th>
<th>Title</th>
<th>Topics</th>
<th>Key Concepts</th>
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</thead>
<tbody>
<tr>
<td>#35</td>
<td>12-Nov-10</td>
<td>Creeping Complexity</td>
<td>Origin of eukaryotes&lt;br&gt;Rise of animals&lt;br&gt;Mass extinctions</td>
<td>Evolution of complex life&lt;br&gt;Phylogeny/taxonomy&lt;br&gt;Life history</td>
</tr>
<tr>
<td>#36</td>
<td>15-Nov-10</td>
<td>Hello!</td>
<td>Big Brains&lt;br&gt;Language&lt;br&gt;Tools and technology?</td>
<td>Neuroscience&lt;br&gt;Linguistics</td>
</tr>
<tr>
<td>#37</td>
<td>17-Nov-10</td>
<td>Here Come Humans</td>
<td>Human origins and evolution</td>
<td>Anthropology</td>
</tr>
</tbody>
</table>

**Readings**
Bennett & Shostak, Chpt. 6.4, Impacts & Extinctions, pp 215 - 220
Bennett & Shostak, Chpt. 6.5, Human Evolution, pp 221 - 225
Bennett & Shostak, Chpt. 12.2, The Question of Intelligence, pp 405 - 409

**Lab #13**
Rare Earth? Contingency and Complexity
*Virtual Field Trip of the Flinders region in South Australia, home to the oldest animal fossils (the Ediacara fauna)*
Habitable Worlds
GLG 106

Unit 8
Civilization and Communication ($f_c$)

Question
How do advanced civilizations arise and how might we find them?

Objective
Understand conditions that led to the rise of human civilization

<table>
<thead>
<tr>
<th>Lectures</th>
<th>Date</th>
<th>Title</th>
<th>Topics</th>
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<tbody>
<tr>
<td>#38</td>
<td>19-Nov-10</td>
<td>Cracking Climate</td>
<td>Glacial eras</td>
<td>Pleistocene climate</td>
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<td>Crops and climate</td>
<td>Climatic optimum</td>
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<td>Population growth</td>
<td>Exponential growth</td>
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<td>#39</td>
<td>24-Nov-10</td>
<td>Expanding Energy</td>
<td>Biofuels</td>
<td>Energy</td>
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<td>Fossil fuels</td>
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<td>Nuclear and alternatives</td>
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<td>#40</td>
<td>29-Nov-10</td>
<td>What's the Frequency?</td>
<td>Rise of radio</td>
<td>Radio frequency technology</td>
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<td>Tuning in to ET</td>
<td>Signal:noise; uncertainty</td>
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<td>Beyond radio</td>
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</tbody>
</table>

Readings
Bennett & Shostak, Chpt. 12.3, Searching for Intelligence, pp 410 - 424
Other readings TBD

Lab #14
SETI Signals
An exploration of signal:noise challenges and uncertainty, as applied to the search for ET radio signals
Habitable Worlds

Fall Semester, 2010

Unit 9
Question All Good Things... (f_{i})
Objective How long do we have?
Sustainability, climate change and other potential limits to advanced civilization

<table>
<thead>
<tr>
<th>Lectures</th>
<th>Date</th>
<th>Title</th>
<th>Topics</th>
<th>Key Concepts</th>
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</thead>
<tbody>
<tr>
<td>#41</td>
<td>1-Dec-10</td>
<td>Sustaining Civilization</td>
<td>Water&lt;br&gt;Mineral resources&lt;br&gt;Energy resources</td>
<td>Resource limitations&lt;br&gt;Carrying capacity</td>
</tr>
<tr>
<td>#42</td>
<td>3-Dec-10</td>
<td>Tragedy of the Commons</td>
<td>Global warming&lt;br&gt;Anthropogenic climate change&lt;br&gt;Geoengineering</td>
<td>Climate change</td>
</tr>
<tr>
<td>#43</td>
<td>6-Dec-10</td>
<td>The Good Don't Die Young</td>
<td>Lifespan of the biosphere&lt;br&gt;The once and future Sun&lt;br&gt;Fermi redux</td>
<td>Carbon cycle limits&lt;br&gt;Stellar evolution</td>
</tr>
</tbody>
</table>

Readings
Bennett & Shostak, Chpt. 10.4, The Future of Life on Earth, pp 343 - 347
Bennett & Shostak, Chpt. 10.5, Global Warming, pp 343 - 347
KKC Chpt 15, Global Warming, pp 295 – 335
Kasting Chpt. 7, Future Evolution of Earth, pp 116 - 121

Lab #15 Sustaining Civilization
A game-based exercise to understand trade-offs between resource use, climate and population