Interdisciplinary Science

PA2012

Habitable Worlds

University of Leicester

Contents

Welcome

Habitable Worlds is designed to combine much of the knowledge you have gained throughout the Interdisciplinary Science Degree. It concerns one of the greatest questions mankind has ever asked: are we alone? It is only recently that humanity has started to gain the tools that will allow a rigorous scientific analysis of the issues. Five weeks is not long to study the many intricate facets that make up this problem. But with being well versed in all the sciences you are in the ideal position to research this most intriguing problem.

This module has been designed to aid you in your search for answers, but bear in mind no one person you encounter can be considered an expert in the whole field; there are very few astrobiologists out there, and they certainly don't all agree on all the answers. You will need to research from multiple sources and may well end up disagreeing with one another on certain issues.

The task that runs the length of this module is a group report of 2500 words on 'New Bounds for the Drake Equation'. This is not an easy assignment and will require your entire group to be planning, drafting and writing over the whole 5 weeks if you are going to do the topic justice. The Drake Equation is our start and end point so use this as your guide throughout this module.

Module Authors

Dr Tom Stallard	Physics and Astronomy
Prof Derek Raine	IScience Centre
Dr Chris Willmott	Biochemistry
Dr Graham Wynn	Physics and Astronomy
Dr Matt Burleigh	Physics and Astronomy
Prof Mark Sims	Space Research Centre

Problem Statement 01

Drake Equation

"What do we need to know about to discover life in space?"

How can we estimate the number of technological civilizations that might exist among the stars? While working as a radio astronomer at the National Radio Astronomy Observatory in Green Bank, West Virginia, Dr. Frank Drake (now Chairman of the Board of the SETI Institute) conceived an approach to bound the terms involved in estimating the number of technological civilizations that may exist in our galaxy. The Drake Equation, as it has become known, was first presented by Drake in 1961 and identifies specific factors thought to play a role in the development of such civilizations. Although there is no unique solution to this equation, it is a generally accepted tool used by the scientific community to examine these factors.

SETI INSTITUTE

http://www.seti.org/Page.aspx?pid=336

--Frank Drake, 1961

The equation is usually written:

$$N = R^* \bullet f_p \bullet n_e \bullet f_l \bullet f_i \bullet f_c \bullet L$$

where,

N = The number of civilizations in The Milky Way Galaxy whose electromagnetic emissions are detectable.
R^* =The rate of formation of stars suitable for the development of intelligent life.
f_p = The fraction of those stars with planetary systems.
n_e = The number of planets, per solar system, with an environment suitable for life.
f_l = The fraction of suitable planets on which life actually appears.
f_i = The fraction of life bearing planets on which intelligent life emerges.
f_c = The fraction of civilizations that develop a technology that releases detectable signs of their existence into space.
L = The length of time such civilizations release detectable signals into space.

Within the limits of our existing technology, any practical search for distant intelligent life must necessarily be a search for some manifestation of a distant technology. In each of its last four decadal reviews, the National Research Council has emphasized the relevance and importance of searching for evidence of the electromagnetic signature of distant civilizations.

Besides illuminating the factors involved in such a search, the Drake Equation is a simple, effective tool for stimulating intellectual curiosity about the universe around us, for helping us to understand that life as we know it is the end product of a natural, cosmic evolution, and for making us realize how much we are a part of that universe. A key goal of the SETI Institute is to further high quality research that will yield additional information related to any of the factors of this fascinating equation.

Problem Statement 02

Michael Crichton, a science fiction author, stated that,

> "Speaking precisely, the Drake equation is literally meaningless, and has nothing to do with science. I take the hard view that science involves the creation of testable hypotheses. The Drake equation cannot be tested and therefore SETI is not science. SETI is unquestionably a religion."

Problem Statement 03

From the minutes of the US Senate Budget Appropriations Committee:

> ….. The original calculated values for the Drake equation have, in the past, been used as an argument for the funding of the Search for Extra-Terrestrial Intelligence (SETI). The US government is discussing whether the SETI programme should continue to receive funding. The economic case has already been assessed and the decision now rests on how likely it is that the programme will produce a successful result in the future. From his equation Drake originally estimated that the number of civilizations in our Galaxy with which communication might be possible is 10. The funding committee will only agree funding if this results is still 10 or greater. …..

Staff

Dr Tom Stallard	tss@ion.le.ac.uk	Physics and Astronomy
Prof Derek Raine	jdr@le.ac.uk	IScience Centre
Dr Chris Willmott	cjrw2@le.ac.uk	Biochemistry
Dr Graham Wynn	Graham.Wynn@astro.le.ac.uk	Physics and Astronomy
Dr Matt Burleigh	mbu@star.le.ac.uk	Physics and Astronomy
Prof Mark Sims	mrs@star.le.ac.uk	Space Research Centre

Learning Objectives

After completing this module students should be able to:

- Define and understand the various components that constitute the Drake Equation.
- Describe the Big Bang and how it led to the formation of our universe.
- Understand how we measure the parameters of the stars, what causes the stars to radiate heat and light, and explain the evolution of stars on the main sequence.
- Show how stellar evolution is important to the creation of suitable conditions for life, and how this process varies within difference regions of the galaxy.
- Explain the various observing techniques that are currently being used to detect planets around other stars.
- Calculate the circular orbit of a planet, and discuss Keplar's Laws.
- Describe the formation of the solar system and show how newly discovered planetary systems differ in terms of formation process and the likelihood of them harbouring intelligent life.
- Understand the importance of the carbonate-silicate cycle and how it affects the different terrestrial planets.
- Describe the importance of the configuration of the rest of the solar system in the creation of intelligent life on Earth, and show how this affects the chances of intelligent life elsewhere in the galaxy.
- Describe what is currently understood about the essential starting conditions for life on Earth and how these lead to the first life forms.
- Discuss the current theories of how early life developed into single cell, then multi-cellular life, the way life affected conditions on Earth and developed as a result of these changes and the context of this history in relation to life elsewhere in the universe.
- Explain how extra-terrestrial life is likely to be similar to or different from life on Earth, where life is possible elsewhere within the solar system, and the likelihood that this will include intelligent life.
- Discuss the likelihood of creating intelligent life on another planet, given the same overall conditions as those found on Earth and understand explain how the Anthropic Principle affects the likelihood of intelligent life on other planets.

Reading List

Below is a list of reading materials that are recommended for this module. The first section contains materials that you would definitely require in order to complete the module. A supplementary list is also provided should you want to read & research further into any of the topics covered in this module.

Books

There are a number of astrobiology books available, each of which provides most of the essential information required. None cover every aspect completely. Use at least one of the following **:**

- Gilmour, I. (2004) *An Introduction to Astrobiology*, Cambridge University Press/Open University Press. LIB REF: 576.839 INT
- Plaxco, K. (2006) *Astrobiology : A Brief Introduction*, Johns Hopkins University Press. LIB REF: 576.839 PLA
- Lunine, J.I. (2005) *Astrobiology: Multi Disciplinary Approach*, Pearson Addison Wesley. LIB REF: 576.83 LUN

For planetary orbits:

- Breithaupt, J., (2003) *Physics: 2nd ed.* New York, Palgrave Macmillan.
- Tipler, P.A. (1999) *Physics for Scientists and Engineers 4th ed*. New York, W.H. Freeman and Company.

For biochemistry:

- Campbell N.A. and Reece J.B. (2005) *Biology* 7 Ed., Pearson Education Inc, USA

You will also be provided with two academic papers, each of which will be important in order to answer questions within the Core Learning Exercises.

Papers

Charbonneau, D., Brown, T.M., Latham, D.W. and Mayor, M. (2000) *Detection Of Planetary Transits Across A Sun-Like Star.* The Astrophysical Journal, 529:L45–L48, January 20

Lineweaver, C.H., Fenner, Y. and Gibson, B.K. (2004) *The Galactic Habitable Zone and the Age Distribution of Complex Life in the Milky Way.* Science Vol. 303, 2.

Thommes, E.W. et al (2008) *Gas Disks to Gas Giants: Simulating the Birth of Planetary Systems.* Science 321, 814.

Sagan, C., Thompson, W.R., Carlson, R., Gurnett, D. and Hord, C. (1993) *A Search for Life on Earth from the Galileo Spacecraft.* Nature 365, 715.

Supplementary Reading List

Additional reading may help to fill out details that are covered briefly within books covering the broad topic of astrobiology. The books in the main reading list should provide references that will allow a more detailed reading. In addition a more detailed view of astrobiology can be found in:

- Sullivan, W.T. (2007) *Planets and Life: The Emerging Science of Astrobiology*. Cambridge University Press. LIB REF: 576.839 PLA

- Kauffman, S.A. (1995) *At Home in the Universe*. Viking.

- Kauffman, S.A. (1993) *The origins of order : self-organization and selection in evolution.* Oxford University Press LIB REF: 577 KAU

BUT you are expected to be able to find many of your own sources, and hence must maintain a good regular updated reference guide for use within your group.

A Guide to Module pacing

Session	Topic	Preparation
FS01	The Drake Equation	Read the Wikipedia page “Drake’s Equation”. http://en.wikipedia.org/wiki/Drake_equation
FS02	Expert Session preparation	Research the properties of stars
ES01	Stellar Evolution	
LS	Measuring Stars	
FS03	Expert Session preparation	Lineweaver et al., (2004)
ES02	Stellar Evolution	
FS04	CLE01 Workshop	Work on CLE 01
FS05	Formation of the Solar System	Read about the Big Bang Read about the formation of the solar system and read through the Thommes et al., 2008 paper.
FS06	Atmospheric Chemistry	Ozone practical script
LS	Ozone Practical	
FS07	Habitats for life	Read about the Carbon-Silicate Cycle, Plate Tectonics and Weathering, (e.g. Lunine Section 11.5, 344-348) and about Habitable Zones.
ES03	Life on Other Planets	
FS08	Planet hunting	Charbonneau et al., (2000)
ES04	Planet Hunting Techniques	
FS09	Calculating orbits	Breithaupt and Tipler (Circular orbits and Kepler’s laws)
ES05	Kepler’s Laws and orbits	
FS10	Poster preparation	
FS11	Drake equation report	Drake equation report draft
LS	Mars Rover	
FS12	CLE03 Workshop	
FS13	Origin of Life	
ES06	Origin of Life	
FS14		
ES07	Biochemistry	
FS15	CLE04 Workshop	

FS16	Final Facilitator meeting	

Facilitation Sessions

Facilitation Session 01: The Drake Equation

Preparation

Read through all the deliverables and learning outcomes for the course. Read the problem statements and locate the problem.

Facilitation Session 02

Preparation

Come to the session prepared to discuss your findings on the properties of stars and stellar evolution

Facilitation Session 03

Preparation

Read through Lineweaver et al., 2004 paper

You should be prepared to discuss:

- How to plan for the expert session on stellar evolution
  How does stellar evolution impact on the Drake equation?

- The importance of location within the galaxy

The Lineweaver et al., 2004 paper discusses research into the effect of where in the Galaxy a star is formed. You should come to the session prepared to discuss the paper and the conclusions, and how these relate to what you've read about the star formation process, in particular the amounts of metals within each type of star.

Facilitation Session 04

Core Learning Exercise 01 Workshop

Preparation

Come to the session prepared to discuss Core Learning Exercise 01 and its relation to the problem.

Facilitation Session 05: Formation of the Solar System

Preparation:

Come to the session prepared to discuss where the elements (including Hydrogen and Helium) come from. Trace this back as far as possible.

Read about the formation of the solar system and read through the Thommes et al., 2008 paper

Come to the session prepared to discuss:

- How gas giants form

Discuss in the group what the timescale limits on the formation of gas giants, and how do Hot Jupiters get so close to the star? Another important question, more specific to your report, is how has Jupiter helped life on Earth.

- The effect of the gas disk on planetary formation

The Thommes et al., 2008 paper is a very recent result that is very exciting, because it answers a fundamental problem with our understanding of planetary formation: Why is our system so different from all the others we've been finding recently. You should discuss the paper and the results that it concludes, especially how different types of planet affect the likelihood of intelligent life forming.

Facilitation Session 06: Ozone computer practical

Preparation

- Come to the session prepared to discuss your poster research.

The most difficult part of making a poster is in knowing what to put into it, so it is essential that you start to research the planetary body you've been assigned. Draw up a plan of research and decide how you're going to divide the research work amongst the group.

- Read the laboratory script on the Ozone layer and be prepared to discuss it in preparation for the computing practical.

Facilitation Session 07: Habitats for Life

Preparation

Read about the Carbon-Silicate Cycle, Plate Tectonics and Weathering, (e.g. Lunine Section 11.5, 344-348) and about Habitable Zones.

You should come to the session prepared to discuss:

- The Carbon-Silicate Cycle

How does the Carbon-Silicate Cycle regulate the atmosphere and what are the implications if different inputs and outputs from the cycle were to be stopped? How does this apply to the other terrestrial planets?

- Habitable Zones
- Where water exists in the solar system

Finding out where there is water in the Solar System may take some digging around. Plan how you are going to research the answers. This question may also be useful later, when you are producing your poster.

Facilitation Session 08: Planet hunting

Preparation

Read the Charbonneau et al., 2000 paper, and come to the session prepared to discuss it.

Facilitation Session 09: Calculating orbits

Preparation

Read about circular orbits and Kepler's laws in Breithaupt (Tipler has further details).

You should come to the session prepared to discuss

- How to calculate the properties of a circular orbit under gravity from Newton's laws of motion
- Why Kepler's laws are so important

Although understanding the mathematics behind circular orbits is important, most planets, including all the planets within the Solar System, move in elliptical orbits. Kepler was the first scientist to prove this and his laws of planetary motion revolutionised the understanding of orbits at the time. While the Learning Objectives do not require you to derive Kepler's laws, you will need to understand the meaning of terms such as a planet's semi-major axis and eccentricity.

Facilitation Session 10

Preparation

You should be prepared to discuss what are you going to put into your poster.

While you will deal with the problems of how to put a poster together in the skills session, it is important to remember not to get too caught up in the design process. Just as important as how you communicate information is what information you communicate. You will need to discuss with the others in your group what you researched, as each of you will be expected to answer questions individually on the poster as a whole.

Facilitation Session 11: Drake Equation Report update

Preparation

- Fermi's paradox.

Given the age of the universe, why haven't we been contacted by another more advanced civilization yet?

Bring a draft of your Drake Equation report and be prepared to discuss it.

Facilitation Session 12

Core Learning Exercise 03 Workshop

Facilitation Session 13: Origin of Life

Preparation

Consider the following questions:

- Proteins that function as enzymes in a contemporary cell are chains of 300 or more amino acids. How many amino acids are used in earth life forms?
- How many possible proteins are there of length 300?
- The minimal viable cell has about 3000 protein enzymes. What is the probability of a complex life forms arising by random accumulation of the right molecules?
- What is the solution to this problem?

Planning for the expert session:

The conditions for life to begin are particularly important for the Drake equation and is perhaps the least well understood. Gaining an understanding of the likelihood that life could begin (and the arguments surrounding this) is essential for your report.

Facilitation Session 14: Biochemistry

Preparation

Read Campbell & Reece Chapter 26.1. Come to the session prepared to discuss how organic molecules are made pre-biotically; which molecules are essential for life and why?

Facilitation Session 15

Core Learning Exercise 04 Workshop

Facilitation Session 16

Preparation

Come to the session prepared to discuss your report on the Drake Equation and to raise, *as a group*, any outstanding issues.

Deliverables

Please name your deliverables in accordance with the standard naming convention (see the handbook for details). A sample filename is provided for you to cut and paste - please complete with submission date and username/group letter as appropriate.

All deliverables to be submitted to iscience@le.ac.uk

Please note that although deliverable deadlines (except for CLEs) are at the end of the module, you are strongly urged not to leave all work on the deliverables until the final weekend! In particular, if you would like formative feedback on your works-in-progress from your facilitator and/or experts, please provide them with draft copies in good time.

DELIVERABLE	TYPE	FILENAME	DUE	**WEIGHT**
Core Learning Exercise 01	Individual	PA2012_I_CLE01_*username_yymmdd*	Week 2 Day 1	30%
Core Learning Exercise 02	Individual	PA2012_I_CLE02_*username_yymmdd*	Week 2 Day 1	
Core Learning Exercise 03	Individual	PA2012_I_CLE03_*username_yymmdd*	Week 4 Day 1	
Core Learning Exercise 04	Individual	PA2012_I_CLE04_*username_yymmdd*	Week 5 Day 1	
Life On Other Planets Poster	Pair	PA2012_P_D01_LifeOnOtherWorldsPoster_*groupletter_yymmdd*	Week 5 Day 1	10%
Life On Other Planets Presentation	Individual	PA2012_I_D02	Week 5 Day 2	10%
Drake Equation Report	Group	PA2012_I_D03_DrakeEquationReport_*groupletter_yymmdd*	Week 5 Day 3	50%

All deliverables are due in at 9am unless otherwise stated

The Friday facilitation session of each week is a workshop to help you with your CLEs (due the following Monday). You should therefore make an attempt to complete these BEFORE the workshop.

These will be marked and contribute to your overall mark, but their primary purpose is ensure that everyone achieves the core learning outcomes, and are approaching the material at an appropriate level. Although your group should help each other out, the work should be completed individually as these questions are also designed to be practice for your module exam.

Core Learning Exercise 01: Stars

1. How do we know the Big Bang occurred? [10]

2. Why do Stars Exist for most of their Lifetime in a state of relative equilibrium on the Main Sequence? [10]

3. Describe the fusion reaction that dominates within the Sun. [10]

4. A main sequence star has an Apparent Magnitude of 8.1 and is measured to be at 147 light years distant.

   a. What is the Absolute Magnitude and Luminosity of the star? [5]

   b. What is the star's spectral type and temperature? [5]

5. Describe how a type II supernova occurs? [10]

6. Describe the difference between Population I, II, and III stars. [10]

7. Explain the 'supernova danger factor', as described in Lineweaver et al., 2004. [10]

8. Explain why stars far from the centre of the galaxy are unlikely to allow life to form, again using Lineweaver et al., 2004. [10]

9. How common are binary and multiple star systems? [10]

10. Is the Sun a 'typical' star within the galaxy? [10]

Core Learning Exercise 02: Planets

1. What reasons are there for the 'inner' planets (inside the Asteroid Belt) to be small and rocky, whilst the ‘outer’ planets tend to be large and gaseous? [10]

2. Why then do we find Jovian-like planets orbiting very close to their parent stars in other star systems? [10]

3. Why do most exoplanets detected so far have high eccentricities, according to Thommes et al., 2008? [10]

4. Given this theory, what is the other common planetary system configuration not yet detected, and why does such a system form? [10]

5. Why are the results described in Thommes et al., 2008 important for the development of intelligent life? [10]

6. Explain how volcanism on Earth can regulate the surface temperature and how this might be essential to producing intelligent life. [10]

7. Define what the ‘Habitable Zone’ around a star is. [10]

8. How does the overall composition of the atmospheres of Venus and Mars compare and for what reasons are they different. [10]

9. Where might liquid water currently exist outside of the Habitable Zone within our solar system? [10]

10. Why is the Moon important to the development of life on Earth? [10]

Core Learning Exercise 03: Observing other Solar Systems

1. A small planet is in a circular orbit around a star.

   a. Define the standard gravitational parameter **μ** for this case. [5]

   b. Calculate the length of the planet's year in days, if $\omega = 2.42\text{x}10^{-7}\ s^{-1}$ [5]

2. State Kepler's laws of planetary motion. [5]

3. Explain why the Radial Velocity technique for detecting planets can only provide a minimum mass for the planet. [10]

4. Given the result of question 3, explain why Charbonneau et al., 2000 were able to publish the first direct calculation of a planet's mass? [5]

5. How did Charbonneau et al., 2000 confirm that planets in close orbit around their parent star would not be destroyed over a period of time significantly shorter than the lifetime of the system? [5]

6. Explain why gravitational microlensing is not useful in making a systematic search for planets around stars in the local vicinity of the Sun? [5]

7. Why has the SETI chosen to use radio wavelengths in its search for intelligent life? [5]

8. What are the arguments against attempting to actively communicate with intelligent life around other stars? [5]

Core Learning Exercise 04: Life

1. Where have the organic chemicals that make up Life on Earth come from? [5]

2. Where else are these chemicals found? [5]

3. Why is panspermia an unlikely source for life on Earth? [5]

4. Sagan et al. (1993) used data from the Galileo telescope to prove the existence of life on Earth.
   a) Describe the evidence of life on Earth, as detected by the Galileo mission? [5]

   b) Describe where there is alternative non-life-based explanations for this evidence, and where no such evidence exists? [5]

5. When did life first begin on Earth and how do we know this? [5]

6. What is meant by the "cells first" and the "RNA world" approaches to the origin of life. What are the problems posed by each approach? [5]

7. What is the probability of a length of DNA with the code for a *given* protein of length 300 amino acids arising by the chance assembly of the four bases? [5]

8. What is meant by an autocatalytic network?
   What is Kauffman's argument for the inevitability of life arising under the right conditions? [10]

Deliverable 01: Poster

Life on Other Planets

We only know of one place where life has come into existence, evolved and prospered, our own planet: Earth. As such we are hampered in our search for life other Worlds as we tend to look for conditions similar to the Earth, in particular the presence of liquid water, a nitrogen-oxygen atmosphere and light as the primary source of energy. This does not mean, however, that life can not exist outside these norms.

Posters are one technique scientist use to present their work at conferences. A poster allows them to cover a scientific topic in a clear and understandable way, so that anyone can see the poster throughout the week and read about the science for themselves. However, in order to allow more direct understanding, conferences also have a dedicated poster session in which a scientist stands by their poster and is available to describe the poster and answer questions on it to anyone who wants to know more.

Your group will be presented with a particular body in our solar system other than the Earth. Your task will be to produce a poster for a general scientific audience that will show the potential habitats in which life could have evolved and whether that life could still exist today.

You will then split into pairs to present the poster, explaining it to fellow scientists and answering their questions.

You will be assessed on the design of your poster and the scientific content within the poster.

PA2012_P_D01_LifeOnOtherWorldsPoster_*groupletter_yymmdd*

Deliverable 02: Presentation

You will be assessed on your poster presentation skills.

PA2012_I_D02

Deliverable 03: Drake Equation Report

A Group Report of around 2500 words

PA2012_I_D03_DrakeEquationReport_*groupletter_yymmdd.pdf*

Supplementary Material

- Charbonneau, D., Brown, T.M., Latham, D.W. and Mayor, M. (2000) *Detection Of Planetary Transits Across A Sun-Like Star.* The Astrophysical Journal, 529:L45–L48, January 20

- Lineweaver, C.H., Fenner, Y. and Gibson, B.K. (2004) *The Galactic Habitable Zone and the Age Distribution of Complex Life in the Milky Way.* Science Vol. 303, 2.

- Thommes, E.W. et al (2008) *Gas Disks to Gas Giants: Simulating the Birth of Planetary Systems.* Science 321, 814*.*

- Sagan, C., Thompson, W.R., Carlson, R., Gurnett, D. and Hord, C. (1993) *A Search for Life on Earth from the Galileo Spacecraft.* Nature 365, 715.

Meta tags

Author: Burleigh, M.; Raine, D.; Sims, M.; Stallard, T.; Willmott, C.; Wynn, G.

Owner: University of Leicester

Title: Interdisciplinary Science Habitable Worlds Student Document

Classification: PA2012 / Habitable Worlds

Keywords: Astronomy; Physics; Geology; Biology; Astrobiology; Problem-Based Learning; sfsoer; ukoer

Description: Habitable Worlds examines one of the greatest questions mankind has ever asked: are we alone? This module has been designed to aid you in your search for answers, but bear in mind no one person you encounter can be considered an expert in the whole field. You will need to research from multiple sources and may well end up disagreeing with one another on certain issues

Language: English

File Size: 1.9MB

File Format: PDF

Version: 1.0

Additional Information

This module pack is the open student version of the teaching material. An expanded module pack for facilitators and additional information can be obtained by contacting the Centre for Interdisciplinary Science at the University of Leicester. http://www.le.ac.uk/iscience

This pack is the Version 1.0 release of the module.