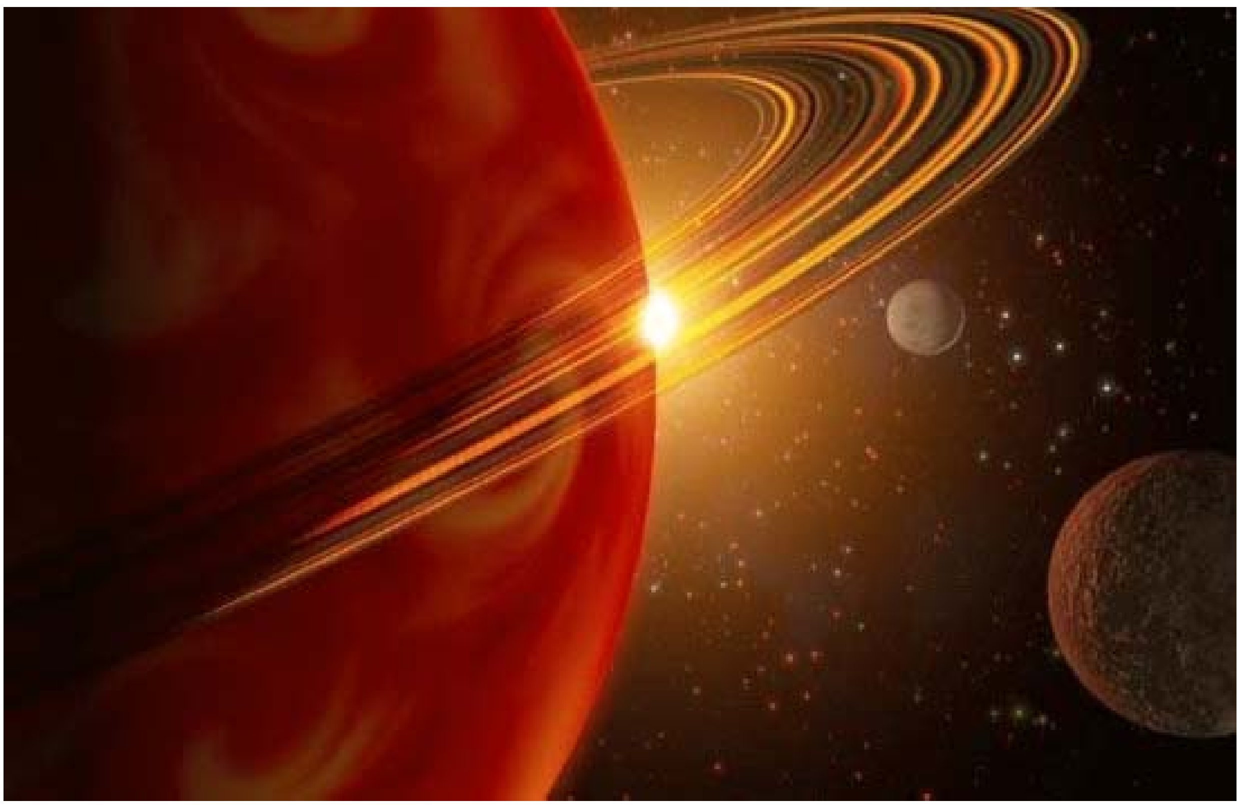
Student Name ____________________________

A103
THE SEARCH FOR HABITABLE PLANETS

LIFE IN THE UNIVERSE
A WORKBOOK

Fall 2005; Section 25482
MWF 1:25 pm-2:15 pm; SW 119
Prof. Richard H. Durisen



INTRODUCTION

Some of the most profound questions that human beings can ask about the Universe concern the origins of things – how did the world around us and we ourselves come to be? It is also natural to wonder how often creatures like ourselves might evolve on other planets. Are there other complex technological societies of intelligent beings who ask questions about the Universe around them? Although the existence of extraterrestrial life has few practical consequences for our day-to-day lives, people can and do have strong feelings and opinions about it. In many ways, speculation about intelligent extraterrestrials has taken the place in our psyche formerly occupied by myths about the "gods" in early human cultures. The question of whether there is life of any kind in the Universe outside the Earth, especially intelligent life, can be approached scientifically. Roughly speaking, in this context "scientific" means using arguments from concrete, verifiable evidence, where the arguments are constrained to be consistent with what we already know about the Universe. Although the question can be posed scientifically, there are currently no well-accepted scientific answers. Using the same common body of relevant information and scientific principles, some scientists can and do argue that intelligent life is common in the Universe, while others argue that it is rare. Unfortunately, there are no higher authorities to which a scientist can appeal for definitive answers. Science is, by its nature, a human activity based on strict rules of evidence.

This Workbook is designed to allow you to revisit the question of life in the Universe several times during the semester and track how your knowledge and opinions about this topic have changed. It attempts to guide your thinking by organizing one main question into a series of sub-questions. The question is, "Approximately how many technological civilizations are there in the Visible Universe?" As you will see, some of the sub-questions can now be answered with some certainty while others cannot be answered at all at the present time. I hope that this Workbook will help you formulate a more informed opinion than you had before, one that accounts for what we do know about the Universe. I will do my best not to prejudice you by giving my own answers and opinions, but I will share them with you toward the end of the course. The Workbook also contains a series of exercises on what makes a planet "habitable".

We will use this Workbook at irregular intervals. Part of the work will be done in class; part of it will be done outside of class using Web-based tools. If you miss an in-class Workbook session, make it up as soon as you can when possible. The Workbook itself will not be collected. The graded parts of the homework and in-class exercises are on tear out pages. These must be handed in by deadlines that will be announced. I will try to give you warning about when the Workbook will be used, but I recommend that you bring it to every class, just in case.

I hope you find this Workbook instructive and enjoyable!

TABLE OF CONTENTS

EXERCISE #1:
WHAT YOU THINK NOW

This exercise assesses your opinions and attitudes toward life in the Universe, before there has been much formal instruction in the course.

PART A

Working on your own, answer questions #1 to 3 below. You will be told how much time you have, and you will be signaled to stop. You will be giving these pages to a neighbor to read, so write legibly and in complete sentences.

1.) How common is life of any kind (including simple one-celled microbes) in the Universe outside the Earth? Indicate your opinion on the bar below but also write some words below the bar about what your answer means to you. (For example, you might choose "very common" and write, "Most stars have at least one planet with life.")

VERY RARE	RARE	COMMON	VERY COMMON

2.) How common are technological civilizations of intelligent life forms in the Universe? Indicate your opinion on the bar below and also write some words that explain what your answer means to you. (For example, you might say "very rare" and write, "I think ours is the only technological civilization in the Universe.")

VERY RARE	RARE	COMMON	VERY COMMON

3.) What reasons or arguments do you have for your opinions in #1 and 2? Give at least TWO distinct reasons for them, either scientific or personal. Please try to give at least one reason you consider scientific, i.e., based on scientific evidence or reasoning, and one that you consider personal.

Scientific Reason(s):

Personal Reason(s):

PART B

When I give the signal, stop writing your answers to Part A. Read over the questions on TEAR OUT FORM #1. Then join up with one or more near neighbors and exchange Workbooks. Read each other's answers and discuss them.

PART C

Upon the next signal, complete your discussions. Then fill out TEAR OUT FORM #1.

PART D

Hand in TEAR OUT FORM #1.

NOTE: If you miss the class in which this exercise is done, you can do it at home by teaming up with a classmate, roommate, friend, or family member, but you must submit TEAR OUT FORM #1 by the deadline announced in class.

TEAR OUT FORM #1

(5 Activity Points)

Student Name____________________________

Student I.D. #____________________________

Indicate your answers to the questions by checking the space that is closest to your answer. Show how you answered the questions on page 3 (First Answer) and then also indicate how you would now answer the questions after the discussion with your neighbor(s).

How common is life of any kind (including simple one-celled microbes) in the Universe outside the Earth?

	First Answer	After Discussion
VERY RARE	_____	_____
RARE	_____	_____
IN BETWEEN	_____	_____
COMMON	_____	_____
VERY COMMON	_____	_____

How common are technological civilizations of intelligent life forms in the Universe?

	First Answer	After Discussion
VERY RARE	_____	_____
RARE	_____	_____
IN BETWEEN	_____	_____
COMMON	_____	_____
VERY COMMON	_____	_____

Now proceed to the BACK of this form and answer the questions.

Answer the following questions IN COMPLETE SENTENCES.

What argument(s) presented by a neighbor did you find most interesting?

Did you agree with this (these) argument(s)? Why or why not?

Check the appropriate space below:

DISCUSSION DID NOT CHANGE MY OPINION _____

DISCUSSION CHANGED MY OPINION SLIGHTLY _____

DISCUSSION CHANGED MY OPINION GREATLY _____

Write one or a few sentences explaining why and how discussion did or did not change your opinion:

EXERCISE #2:
THE CHIP UNIVERSE

Before we discuss the question of intelligent life in the Visible Universe, we need to talk about the use of estimation in science and everyday reasoning.

I call this example "CHIP UNIVERSE", a universe I will create for you in the lecture hall. CHIP UNIVERSE consists of red, white, and blue poker chips arranged in "groups". The red, white, and blue chips themselves represent celestial bodies; the green paint on the bottom of some chips can be thought of as representing the presence of life. Suppose you live on a white chip with green paint on the bottom. You are in fact part of the green paint. You are lonely and are interested in finding out whether there is any green paint on the other chips of CHIP UNIVERSE.

One approach is to estimate the total number of possible places that green paint (intelligent life) could be and then narrow down the number through multiplication by various probabilities. What do I mean by a "probability" in this context? Please indulge me in a brief digression. Suppose you were told that 600 ordinary six-sided game dice were thrown down randomly on a table and you were asked approximately how many would have the 6 facing upward?

N_6 = APPROXIMATELY HOW MANY DICE SHOW A SIX = [ ]

How did you do that? Write an explanation in your own words below.

Now, how might a scientist phrase this mathematically? She might write

N_6 = APPROXIMATELY HOW MANY DICE SHOW A SIX

f_6 = FRACTION OF THE DICE LIKELY TO SHOW A SIX

N_{dice} = TOTAL NUMBER OF DICE

$$N_6 = N_{dice} \quad f_6$$

$$100 = 600 \times 1/6$$

For, shorthand, one usually drops the multiplication sign in N_{dice} x f_6. The fraction f_6 represents the "probability" that the dice have a 6 facing upward. There is a "one in six chance" that any particular face is upward; in other words, we expect, on average, about one sixth (1/6) of the dice to have the 6 showing. So $f_6 = 1/6$. Of course, if you actually roll 600 dice, you are not likely to get exactly 100 sixes, but the number of sixes is likely to be close to 100. For example, I have given the class dice to roll. Let's see how many 6's the class gets in 600 rolls:

NUMBER OF SIXES ROLLED BY CLASS =

Now back to CHIP UNIVERSE. Suppose we have a difficult time seeing other Groups of chips, but we know how many chips they contain, on average. Studying our own group, we can get an estimate for the fraction of chips that are white. Suppose our scientists have some evidence that this peculiar green "life" paint will only stick to white chips. Let us now explore our Group and see how many white chips have green and then fill in all the number below.

N_G = # OF GROUPS OF CHIPS IN THE CHIP UNVERSE = [ ]

N_C = # OF CHIPS IN A TYPICAL GROUP = [ ]

f_{white} = FRACTION OF THE CHIPS THAT ARE WHITE IN OUR GROUP

= $\frac{\text{\# WHITE CHIPS}}{\text{TOTAL \# CHIPS}}$ = ________ = [ ]

f_{green} = FRACTION OF THE WHITE CHIPS THAT HAVE GREEN

= $\frac{\text{\# WHITE WITH GREEN}}{\text{TOTAL \# WHITE}}$ = ________ = [ ]

COMPUTATIONAL GUIDE
FOR THE CHIP UNIVERSE

$N_G\ N_C$	=		X		=	
$N_G\ N_C\ f_{white}$	=		X		=	
$N_G\ N_C\ f_{white}\ f_{green}$	=		X		=	

N_{green} = $N_G\ N_C\ f_{white}\ f_{green}$ = ______

$$N_{green} = N_G\ N_C\ f_{white}\ f_{green}$$

NOTE: If you miss the class in which this exercise is done, please read over the explanations about chip world as best you can. Then do the exercise on TEAR OUT FORM #2 as best you can and submit TEAR OUT FORM #2 by the deadline announced in class.

TEAR OUT FORM #2

(4 Activity Points)

Student Name____________________________

Student I.D. #____________________________

Now that you have some idea how estimates work, consider a similar problem. Suppose you want to estimate N_{rP} the number of red Porche sports cars registered in the State of Indiana. Devise a formula that breaks this question down into a number or numbers multiplied by several fractions. You could start with N_p = the total number of people in the State of Indiana and then multiple it by several fractions that narrow down toward the number of red Porches. You do not have to follow this suggestion; be creative, but plausible. Work with neighbors if you like. Write your equation below.

$$N_{rP} =$$

In the space below, define the terms that appear in your equation in the same way that we did on page 8 for the Chip Universe example:

BONUS (2 pts): On the back of this page, use your best guesses for the numbers and fractions in the equation and see what you get!

EXERCISE #3:
INTRODUCTION TO THE DRAKE FORMULA

The Drake Formula in its original form attempted to estimate the answer to the question:

How many technological civilizations are there now
in our own Milky Way galaxy?

For the purposes of this course, I have generalized this to the question:

"How many technological civilizations are there
in the Visible Universe?"

Many of you know that it takes light a long time to reach us from distant galaxies and might object to asking this question for that reason. Think of it this way: How many such civilizations might we find in the light signals arriving at Earth now from the entire volume of the Visible Universe if we could analyze this light with arbitrary precision?

Although my modified version of Drake's Formula takes the form of an equation, it is meant only as a crude estimate and is no better that the guesses put into it. It is useful in that it breaks the big question into smaller parts. Some of these smaller questions are easier to answer, but others are not. Breaking the problem down like this enables us to isolate where the uncertainties are. When we do this, it is easy to understand why the big question has no accepted scientific answer at present.

THE DRAKE FORMULA

The following modified version of the Drake Formula attempts to estimate N_{TC} = the number of technological civilizations in the Visible Universe. The Visible Universe is the part of the Universe from which light reaches us now. This can be thought of as a sphere with a radius of about 13.7 billion light years. Fill in your own best estimates for the numbers on this page. "Fractions" here are always less than one. As much as possible, use only power of ten numbers to keep the math simple. Then complete the computation guide on page 13. If you are having difficulty about what to do, please seek help from your neighbors.

$$N_{TC} = N_G\ N_*\ f_H\ n_H\ f_L\ f_I\ f_T\ f_S$$

N_G	=	NUMBER OF GALAXIES IN THE VISIBLE UNIVERSE	=	
N_*	=	NUMBER OF STARS IN A TYPICAL GALAXY	=	
f_H	=	FRACTION OF STARS THAT CAN HAVE HABITABLE PLANETS OR MOONS	=	
n_H	=	NUMBER OF PLANET OR MOONS AROUND EACH STAR ON WHICH LIFE COULD EVOLVE	=	
f_L	=	FRACTION OF SUCH PLANET SOR MOONS ON WHICH LIFE DOES EVOLVE	=	
f_I	=	FRACTION OF HABITABLE BODIES WITH LIFE ON WHICH INTELLIGENT LIFE EVLOVES	=	
f_T	=	FRACTION OF WORLDS WHERE INTELLIGENT LIFE BECOMES TECHNOLOGICAL	=	
f_S	=	FRACTION OF A STAR'S LIFE THAT TECHNOLOGICAL CIVILIZATIONS SURVIVE	=	

COMPUTATIONAL GUIDE FOR THE DRAKE FORMULA

$N_G N_*$	=		X		=	
$N_G N_* f_H$	=		X		=	
$N_G N_* f_H n_H$	=		X		=	
$N_G N_* f_H n_H f_L$	=		X		=	
$N_G N_* f_H n_H f_L f_I$	=		X		=	
$N_G N_* f_H n_H f_L f_I f_T$	=		X		=	
$N_G N_* f_H n_H f_L f_I f_T f_S$	=		X		=	

$$N_{TC} = N_G N_* f_H n_H f_L f_I f_T f_S =$$

This page is left free to provide a place for you to take notes as we go over the various factors in the Drake Formula.

NOTE: If you miss the class in which this exercise is done, you probably need to consult with one of your classmates before you attempt to fill out the Drake Formula and multiply the entries together. You must submit the Tear Out Form by the deadline announced in class.

TEAR OUT FORM #3:

(5 Activity Points)

Student Name____________________________

Student I.D. #____________________________

Fill in your entries and results from pages 12 and 13 in the spaces provided below. Also answer the questions on the BACK.

$$N_{TC} = N_G \, N_* \, f_H \, n_H \, f_L \, f_I \, f_T \, f_S$$

N_G	=	NUMBER OF GALAXIES IN THE VISIBLE UNIVERSE	=	
N_*	=	NUMBER OF STARS IN A TYPICAL GALAXY	=	
f_H	=	FRACTION OF STARS THAT CAN HAVE HABITABLE PLANETS OR MOONS	=	
n_H	=	NUMBER OF PLANET OR MOONS AROUND EACH STAR ON WHICH LIFE COULD EVOLVE	=	
f_L	=	FRACTION OF SUCH PLANET SOR MOONS ON WHICH LIFE DOES EVOLVE	=	
f_I	=	FRACTION OF HABITABLE BODIES WITH LIFE ON WHICH INTELLIGENT LIFE EVLOVES	=	
f_T	=	FRACTION OF WORLDS WHERE INTELLIGENT LIFE BECOMES TECHNOLOGICAL	=	
f_S	=	FRACTION OF A STAR'S LIFE THAT TECHNOLOGICAL CIVILIZATIONS SURVIVE	=	

$$N_{TC} = N_G \, N_* \, f_H \, n_H \, f_L \, f_I \, f_T \, f_S =$$

Answer the following two questions in COMPLETE SENTENCES.

What numbers in the Drake formula did you find most difficult to estimate? Why?

Has this exercise changed your opinion about the existence of technological civilizations? Explain.

EXERCISE #4
AVERAGE SURFACE TEMPERATURES OF PLANETS

GENERAL

This exercise consists of three hand-in homework assignments which you will complete using a Web-based tool. Here we examine the question of a planet's "habitability", in other words, its suitability as an environment in which life can survive. Habitability depends on many factors. Here, as an example, we focus on one of the most important, a planet's surface temperature. The exercise explores the impact of four important influences on a planet's average surface temperature:

i) the mass of the nearest star
ii) the distance from the nearest star
iii) the albedo, or reflectivity, of the planet's surface and atmosphere
iv) the amount of greenhouse warming by the planet's atmosphere

Of course, life may be very different from what we find on Earth, but, if we use life as we know it on Earth as a conservative guideline, then habitability for *surface* life depends on having *average* planet surface temperatures in the range where liquid water is possible.

Some of you probably know that the amount of light emitted by a star changes with time. For simplicity, throughout this exercise, we assume that the star has the average light output typical of the longest-lived phase of its natural cycle. This is the phase when thermonuclear burning of hydrogen to helium at its center supplies all its energy. During this phase, the mass of a star determines its light energy output.

HOMEWORK: Part A

The Earth

The first step is to access the Planet Temperature Calculator. The link is available at http://www.astro.indiana.edu/educational_tools.shtml. Move through the program one page at a time, reading about each of the four major influences and entering a value for each influence. After reading the opening page, click CONTINUE. You will come to the MASS page. Start by entering values for Earth, which are given by the program. Read the paragraph about MASS and then enter a "1" in the space provided. Next to the space where you enter a value there is a button labeled NEXT. Click on this button and proceed to the DISTANCE page. Once again, read the information, enter Earth's value and click NEXT. Continue in the same way through the next two pages. After completing the GREENHOUSE page you will come to a REVIEW page where you should see the four values you have entered. At the bottom right of this page there is a CALCULATE button. Click on this button and you will go to a new page. This new page will display the approximate total life expectancy of your star and the average surface temperature of your planet, in degrees Kelvin, Celsius, and Fahrenheit. For this assignment, we will use temperatures in degrees Kelvin because that is the sensible physical temperature scale to use, but you should also check the results in degrees Celsius or Fahrenheit because these scales are probably more familiar to you. Enter your result on TEAR OUT FORM #4.

Other Planets

Now go to the table on TEAR OUT FORM #4 that lists some other objects in the Solar System. Compute their average surface temperatures based on the values in the table. You should keep the mass of the Sun equal to one for all these calculations, because these are all planets within our own Solar System. Record your answers in the spaces provided on TEAR OUT FORM #4. Answer the question that follows the table.

Submit this homework on TEAR OUT FORM #4.

HOMEWORK: Part B

Increased Greenhouse on Earth

Suppose human activity causes the greenhouse factor for the Earth to double by the next century. This is an unlikely large value, but it is hard to predict 100 years into the future, and our use of fossil fuels is increasing rapidly. How much does the average surface temperature of the Earth change, all else being equal? How much would the albedo due to cloud cover have to increase to bring the Earth's temperature back to its current value? Use the Planet Temperature Calculator to determine the answers to these questions, and then enter your results on TEAR OUT FORM #5.

Runaway Greenhouse on Earth

Now suppose that all the CO_2 on the Earth ends up in the atmosphere. This would produce a greenhouse factor close to 400, about twice the greenhouse effect of Venus. About 200 units of this greenhouse value would be due to the CO_2 itself and another 200 due to vaporization of the oceans. H_2O vapor is also a greenhouse gas. A greenhouse effect of this magnitude is called a "runaway" greenhouse because, at the resulting temperatures, there is no process that can remove the greenhouse gases from the atmosphere. The planet is stuck in this extremely hot state. What average surface temperature do you get? Enter your results on TEAR OUT FORM #5.This is pretty scary!

Snowball Earth

Some geophysicists claim there is evidence in Earth's history for one or more "Snowball Earth" events, where the Earth's oceans froze over temporarily due to formation of extensive ice sheets that produced a high albedo (reflectivity). Let's explore the parameters for such an event. Return all values to normal for the Earth. Keeping other factors the same, for what albedo does the Earth's average surface temperature fall below the freezing point of water? At this point, the oceans will freeze to a great depth. Use the Planet Temperature Calculator to determine what albedo reduces the average surface temperature of the Earth to the freezing point of water.

One way the Earth can recover from a snowball condition is through buildup of CO_2 in the Earth's atmosphere. Set the albedo in the Planet Temperature solver to the snowball value you found above, now vary the greenhouse factor until get back to Earth's current average surface temperature. Enter your results on TEAR OUT FORM #5. On the back of TEAR OUT FORM #5, explain why CO_2 might build up in the atmosphere on an Earth with frozen oceans.

Submit this homework on TEAR OUT FORM #5.

HOMEWORK Part C

Habitable Zones

The Habitable Zone for life on the surface of a planet is *defined* as the range of orbit distances from a star for which an *Earth-like* planet can have liquid water on the surface. For this exercise, we will assume that the planet has a substantial enough atmosphere that the surface pressure is near the normal value for the Earth. Then whether or not liquid water will exist, on average, will depend on whether the average surface temperature is between the usual freezing and boiling points of water. Use the Planet Temperature Calculator to explore the boundaries of the Habitable Zone for a range of stellar masses. Set the albedo and greenhouse factor to their Earth values. Choose the mass of the star. Vary the distance of the planet from the star to find where you just reach the freezing and boiling points of water and enter the results on TEAR OUT FORM #6. A few choices of star mass are given in the table on TEAR OUT FORM #6. In addition, you should choose significantly higher and lower star masses to fill out the table. The full range of normal masses for stars is from 0.08 to about 100 times the mass of the Sun. Answer the question that follows the table on TEAR OUT FORM #6. You can now see how much the Habitable Zone differs for different types of stars.

Submit this homework on TEAR OUT FORM #6.

TEAR OUT FORM #4

(5 Activity Points)

Student Name____________________________

Student I.D. #____________________________

Earth's Average Surface Temperature

Enter below the value you obtained from the temperature solver for the Earth's average surface temperature. Express your answer in degrees Kelvin

____________________ Degrees Kelvin

Average Surface Temperatures of Other Planets and Moons

Complete the table below using the Planet Temperature Calculator. Look up numbers that are missing in the appendices of your textbook. Fill in the temperatures in degrees Kelvin.

Object	*Albedo*	*Greenhouse Factor*	*Distance from Sun*	*Average Surface Temperature*
Mercury	12%	0	__________ AU	__________ Degrees Kelvin
Venus	84%	200	__________ AU	__________ Degrees Kelvin
Mars	16%	0.2	__________ AU	__________ Degrees Kelvin
Europa	67%	0	__________ AU	__________ Degrees Kelvin
Titan	22%	1	__________ AU	__________ Degrees Kelvin
Triton	77%	0	__________ AU	__________ Degrees Kelvin

Your Reactions

Based on this table, what would you say about the habitability of solid surfaces throughout the Solar System based on what we know about life on Earth? Write in complete sentences. Use the other side of this page.

TEAR OUT FORM #5

(4 Activity Points)

Student Name____________________________

Student I.D. #____________________________

Earth's Current Average Surface Temperature

For reference, write in the space below the Earth's average surface temperature for normal Earth values of the various factors.

_____________________ Degrees Kelvin

Doubled Greenhouse on Earth

Now double the greenhouse factor keeping all other quantities the same. What is the resulting average surface temperature?

_____________________ Degrees Kelvin

With the doubled greenhouse factor, what value of the albedo do you have to use to bring the average surface temperature back to the normal value?

_____________________ Percent

Runaway Greenhouse on Earth

Set the greenhouse factor to 400 and set the albedo back to its normal Earth value. What is the resulting average surface tempearture?

_____________________ Degrees Kelvin

Snowball Earth

Return all factors to Earth normal. Now increase the albedo. At what albedo does the average surface temperature become equal to the freezing point of water?

_____________________ Percent

For this value of the albedo, what value of the greenhouse factor do you have to use to get back to Earth's current average surface temperature?

_____________________ Greenhouse Factor

NOTE: Go on to the back of this page and answer the question about recovery from Snowball Earth.

Recovery from Snowball Earth

Based on the Snowball Earth results, how do you think the Earth might recover from a deep freezing of the oceans based on what you know about the CO_2 cycle on Earth? Write in complete sentences.

TEAR OUT FORM #6

(5 Activity Points)

Student Name____________________________

Student I.D. #____________________________

The Habitable Zone for Planetary Surfaces

The Habitable Zone for stars is *defined* as the range of distances where liquid water is possible on the surface of an Earth-like planet. Complete the table below for the sizes of the Habitable Zones around stars of different mass when they are burning hydrogen to helium at their centers. Set the albedo and greenhouse factors equal to normal Earth values, then change the star's mass. With this fixed mass, vary the distance up and down until you reach the boiling and freezing points of water. Record the results below. For the entries with blank masses, find the habitable zones for two additional star masses, one lower than 0.50 and one greater than 2.00. The instructions for this TEAR OUT FORM tell you more about the possible range of masses for stars.

Star Mass	*Inner Edge of Habitable Zone*	*Outer Edge of the Habitabel Zone*
____________	________________ AU	________________ AU
0.50 (K-type)	________________ AU	________________ AU
1.00 (G-type) The Sun	________________ AU	________________ AU
2.00 (A-type)	________________ AU	________________ AU
____________	________________ AU	________________ AU

NOTE: Now go to the back of this page and answer the questions.

Your Reactions

Based on this table, what conclusions do you draw about habitable zones around different types of stars?

By definition the Habitable Zone is defined for the *surface* of an *Earth-like* planet. There are many other considerations for habitability of a real planet besides just type of star and distance to the star. Discuss one. Does this additional factor tend to increase or decrease the size of the region around the star where life might be found? Write in complete sentences.

EXERCISE #5
YOUR DRAKE FORMULA ANSWERS NOW USING A WEB-BASED TOOL

GENERAL

This course is drawing to a close, and we have covered a substantial amount of background material related to the question of Life in the Universe. Let us return to the Drake Formula and see whether your opinions have changed. The work for this exercise must be done outside class using a Web-based tool at http://www.astro.indiana.edu/educational_tools.shtml. Go to the Drake Formula Solver link. Now that you understand the principles behind the Drake Formula, the solver will save you the trouble of doing the multiplications. This way you have the opportunity to vary your answers until you have a result you are satisfied with.

INSTRUCTIONS

1.) I will give you tips on use of the Web page in class. In case you miss this class, here are some basic instructions for using the Drake Formula Solver in conjunction with this Workbook.

2.) Read the "Introduction" on the Web page.

3.) Go to "Drake Formula" by clicking on the button of that name.

4.) The Drake Formula page is set up to use scientific notation when you input you choices for the factors. Various types of help and explanations are available. Spend some time familiarizing yourself with the page. Then fill in your numbers and click the "Feedback" button. Follow any instructions that appear. After clearing up all problems, click on the "Continue" button. For simplicity, I recommend that you leave the number in front of the power of ten as a "one" and only work with the exponent of the power of ten. Remember, this is only a crude estimate.

5.) There are <u>FOUR</u> subsequent pages that explore the implications of your entries in the Drake Formula. On each of these pages, you are asked whether you are satisfied with various consequences of your choices. If you are not, then you are directed to go back to the Drake Formula and modify your answers until you are satisfied. Go back and forth between the Drake Formula and the four pages until you have <u>ONE</u> set of inputs for the Drake Formula that gives answers that satisfy you on <u>ALL</u> four pages. You may have to make compromises for your results on one page to get answers you can accept on another. The four pages give your answers to the following four questions:

   a) How far away is the nearest technological civilization?

b) How many technological civilizations ever existed?

c) How many habitable bodies are there in the Visible Universe and how many of them have ever had life?

d) How many habitable bodies in the Visible Universe have ever had "intelligent" life?

6.) Enter the results in the Workbook on the pages that follow.

7.) Think about your results. Compare them to what you thought in Exercises #1 and #3, then fill out TEAR OUT FORM #7 and submit it. Please note that your answers on the TEAR OUT FORM have to make sense. If you think technological civilizations are common, then you should have and answer for N_{TC} that agrees with this. The point is that the numbers you put into the Drake Solver are YOUR choices. If the solver gives a number that does not agree with what you think, then you need to revise some of your choices for the various factors in the equation. The TEAR OUT FORM will be graded in part on the consistency of your answers.

YOUR FINAL DRAKE FORMULA

In the boxes provided below, record your final choices for the Drake Formula input factors and the result computed for N_{TC} by the Solver.

N_G	=	NUMBER OF GALAXIES IN THE VISIBLE UNIVERSE	=	
N_*	=	NUMBER OF STARS IN A TYPICAL GALAXY	=	
f_H	=	FRACTION OF STARS THAT CAN HAVE HABITABLE PLANETS OR MOONS	=	
n_H	=	NUMBER OF PLANETS OR MOONS AROUND EACH STAR ON WHICH LIFE COULD EVOLVE	=	

f_L	=	FRACTION OF SUCH PLANETS OR MOONS ON WHICH LIFE DOES EVOLVE	=	
f_I	=	FRACTION OF HABITABLE BODIES WITH LIFE ON WHICH INTELLIGENT LIFE EVLOVES	=	
f_T	=	FRACTION OF WORLDS WHERE INTELLIGENT LIFE BECOMES TECHNOLOGICAL	=	
f_S	=	FRACTION OF A STAR'S LIFE THAT TECHNOLOGICAL CIVILIZATIONS SURVIVE	=	
N_{TC}	=	NUMBER OF TECHNOLOGICAL CIVILIZATIONS IN THE VISIBLE UNIVERSE	=	

Below, fill in the results from the other pages of the Solver for the same choices of input factors listed above.

How Far Are They?

The average number of technological civilizations in each galaxy = ______

The distance, in light years, to the nearest neighbor technological civilization = ______

How Many Technological Civilizations Ever Existed?

The number of technological civilizations that have ever existed in the Visible Universe = ______

In our Milky Way galaxy, the number of technological civilizations that have so far appeared = ______

<u>How Many Habitable Bodies With Life?</u>

The number of habitable planets and moons in the Visible Universe	=	
The number of planets and moons in the Visible Universe that have had at least simple forms of life	=	
The number of habitable planets and moons in our own Milky Way galaxy	=	
The number of planets and moons in our own Milky Way galaxy that have had at least simple life	=	

<u>How Many Habitable Bodies With Intelligent Life?</u>

The number of planets and moons in the Visible Universe that have had "intelligent" life	=	
The number of planets and moons in our own Milky Way galaxy that have had "intelligent" life	=	

<u>FINAL QUESTIONS</u>

TEAR OUT FORM #8 asks several questions about how likely you think it is that we will ever find life of any kind outside the Earth.

TEAR OUT FORM #7

(5 Activity Points)

Student Name____________________________

Student I.D. #____________________________

How common is life of any kind (including simple one-celled microbes) in the Universe outside the Earth?

	Answer on Page 3	Your Answer Now
VERY RARE	_____	_____
RARE	_____	_____
IN BETWEEN	_____	_____
COMMON	_____	_____
VERY COMMON	_____	_____

How common are technological civilizations of intelligent life forms in the Universe?

	Answer on Page 3	Your Answer Now
VERY RARE	_____	_____
RARE	_____	_____
IN BETWEEN	_____	_____
COMMON	_____	_____
VERY COMMON	_____	_____

NOTE: Now proceed to the back of this form and, in the appropriate spaces, give your input numbers for the Drake Formula Solver and the results you obtained from it.

List your input numbers for the Drake Formula in the spaces provided below in power of ten or scientific notation:

N_G = ___________ N_* = ___________ f_H = ___________ n_H = ___________

f_L = ___________ f_I = ___________ f_T = ___________ f_S = ___________

Based on these input paratmeters, the Drake Formula Solver computed that

N_{TC} = the number of technological civilizations in the Visible Universe = ________________

The distance, in light years, to the nearest neighbor technological civilization = ________________

In our Milky Way galaxy, the number of technological civilizations that have so far appeared = ________________

The number of planets and moons in our own Milky Way galaxy that have had at least simple life = ________________

The number of planets and moons in our own Milky Way galaxy that have had "intelligent" life = ________________

Explain briefly how your results above are consistent with your entries under "Your Answer Now" on the other side of the page. Write in complete sentences.

TEAR OUT FORM #8

(5 Activity Points)

Student Name___________________________

Student I.D. #___________________________

Answer the following questions based on the numbers you obtained on pages 30 to 32, as well as other information you have learned in this course. Note that there are questions on BOTH SIDES of this page. Write in complete sentences.

How likely do you think is that we will make contact with other technological civilizations? How and when is it likely to happen, if at all?

How likely do you think it is that we will find simple life elsewhere in our own Solar System, for example on Mars or Europa?

How easy will it be for us to find evidence of simple and/or intelligent life outside our own Solar System?

TEAR OUT FORM #9
FEEDBACK
(3 Activity Points)

Student Name___________________________

Student I.D. #___________________________

This TEAR OUT FORM is an opportunity for you to give me feedback about this course in general and the Workbook in particular. Any serious responses to these questions will receive full credit, as long as they are written in complete grammatical sentences. Note that there are questions on BOTH SIDES of this page.

What aspect(s) of this class did you most interesting or enjoyable?

What aspect(s) of this class did you least interesting or enjoyable?

Describe <u>at</u> <u>least</u> <u>one</u> significant way in which your opinions about life in the Universe have been changed by this course. If your opinions were not changed but simply weakened or strengthened, please explain that instead. Be as specific as you can.

Please share your comments or suggestions about this Workbook, the Web-based Drake Formula Solver, the Planet Temperature Solver, and how they were used in this course.