Name: _____

Habitable Zones – Student Guide

Exercises

Please read through the background pages entitled Life, Circumstellar Habitable Zones, and The Galactic Habitable Zone before working on the exercises using simulations below.

Circumstellar Zones

Open the Circumstellar Zone Simulator. There are four main panels:

- The top panel simulation displays a visualization of a star and its planets looking down onto the plane of the solar system. The habitable zone is displayed for the particular star being simulated. One can click and drag either toward the star or away from it to change the scale being displayed.
- The **General Settings** panel provides two options for creating standards of reference in the top panel.
- The **Star and Planets Setting and Properties** panel allows one to display our own star system, several known star systems, or create your own star-planet combinations in the none-selected mode.
- The **Timeline and Simulation Controls** allows one to demonstrate the time evolution of the star system being displayed.

The simulation begins with our Sun being displayed as it was when it formed and a terrestrial planet at the position of Earth. One can change the planet's distance from the Sun either by dragging it or using the planet distance slider.

Note that the appearance of the planet changes depending upon its location. It appears quite earth-like when inside the circumstellar habitable zone (hereafter CHZ). However, when it is dragged inside of the CHZ it becomes "desert-like" while outside it appears "frozen".

Question 1: Drag the planet to the inner boundary of the CHZ and note this distance from the Sun. Then drag it to the outer boundary and note this value. Lastly, take the difference of these two figures to calculate the "width" of the sun's primordial CHZ.

CHZ Inner Boundary	CHZ Outer Boundary	Width of CHZ

Question 2: Let's explore the width of the CHZ for other stars. Complete the table below for stars with a variety of masses.

Star Mass (M$_\odot$)	Star Luminosity (L$_\odot$)	CHZ Inner Boundary (AU)	CHZ Outer Boundary (AU)	Width of CHZ (AU)
0.3				
0.7				
1.0				
2.0				
4.0				
8.0				
15.0				

Question 3: Using the table above, what general conclusion can be made regarding the location of the CHZ for different types of stars?

Question 4: Using the table above, what general conclusion can be made regarding the width of the CHZ for different types of stars?

Exploring Other Systems

Begin by selecting the system 51 Pegasi. This was the first planet discovered around a star using the radial velocity technique. This technique detects systematic shifts in the wavelengths of absorption lines in the star's spectra over time due to the motion of the star around the star-planet center of mass. The planet orbiting 51 Pegasi has a mass of at least half Jupiter's mass.

Question 5: Zoom out so that you can compare this planet to those in our solar system (you can click-hold-drag to change the scale). Is this extrasolar planet like any in our solar system? In what ways is it similar or different?

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Question 6: Select the system HD 93083. Note that planet b is in this star's CHZ. Now in fact this planet has a mass of at least 0.37 Jupiter masses. Is this planet a likely candidate to have life like that on Earth? Why or why not?

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Question 7: Note that Jupiter's moon Europa is covered in water ice. What would Europa be like if it orbited HD 93083b?

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Select the system Gliese 581. This system is notable for having some of the smallest and presumably earth-like planets yet discovered. Look especially at planets c and d which bracket the CHZ. In fact, there are researchers who believe that the CHZ of this star may include one or both of these planets. (Since there are several assumptions involved in the determination of the boundary of the CHZ, not all

Planet	Mass
e	> 1.9 M_{Earth}
b	> 15.6 M_{Earth}
c	> 5.4 M_{Earth}
d	> 7.1 M_{Earth}

researchers agree where those limits should be drawn.) This system is the best candidate yet discovered for an earth-like planet near or in a CHZ.

The Time Evolution of Circumstellar Habitable Zones

We will now look at the evolution of star systems over time and investigate how that affects the circumstellar zone. We will focus exclusively on stellar evolution which is well understood and assume that planets remain in their orbits indefinitely. Many researchers believe that planets migrate due to gravitational interactions with each other and with smaller debris, but that is not shown in our simulator.

We will make use of the Time and Simulation Controls panel. This panel consists of a button and slider to control the passing of time and 3 horizontal strips:

- the first strip is a timeline encompassinging the complete lifetime of the star with time values labeled

- the second strip represents the temperature range of the CHZ – the orange bar at the top indicates the inner boundary and the blue bar at the botom the outer boundary. A black line is shown in between for times when the planet is within the CHZ.

- The bottom strip also shows the length of time the planet is in the CHZ in dark blue as well as labeling important events during the lifetime of a star such as when it leaves the main sequence.

Stars gradually brighten as they get older. They are building up a core of helium ash and the fusion region becomes slightly larger over time, generating more energy.

Question 8: Return to the **none selected** mode and configure the simulator for Earth (a 1 $M_\odot$ star at a distance of 1 AU). Note that immediately after our Sun formed Earth was in the middle of the CHZ. Drag the timeline cursor forward and note how the CHZ moves outward as the Sun gets brighter. Stop the time cursor at 4.6 billion years to represent the present age of our solar system. Based on this simulation, how much longer will Earth be in the CHZ?

Question 9: What is the total lifetime of the Sun (up to the point when it becomes a white dwarf and no longer supports fusion)?

Question 10: What happens to Earth at this time in the simulator?

You may have noticed the planet moving outwards towards the end of the star's life. This is due to the star losing mass in its final stages.

We know that life appeared on Earth early on but complex life did not appear until several billlion years later. If life on other planets takes a similar amount of time to evolve, we would like to know how long a planet is in its CHZ to evaluate the likelihood of complex life being present.

To make this determination, first set the timeline cursor to time zero, then drag the planet in the diagram so that it is just on the outer edge of CHZ. Then run the simulator until the planet is no longer in the CHZ. Record the time when this occurs – this is the total amount of time the planet spends in the CHZ. Complete the table for the range of stellar masses.

Star Mass ($M_\odot$)	Initial Planet Distance (AU)	Time in CHZ (Gy)
0.3	**0.157**	**380**
0.7		
1.0		
2.0		
4.0		
8.0		
15.0		

Question 11: It took approximately 4 billion years for complex life to appear on Earth. In which of the systems above would that be possible? What can you conclude about a star's mass and the likeliood of it harboring complex life.

Tidal Locking

We have learned that large stars are not good candidates for life because they evolve so quickly. Now let's take a look at low-mass stars. **Reset** the simulator and set the initial star mass to 0.3 $M_\odot$. Drag the planet in to the CHZ.

Question 12: Notice that the planet is shown with a dashed line through its middle. What has happened is that the planet is so close to its star that is has become tidally locked due to gravitational interactions. This is analogous to Earth's moon which always presents the

same side towards Earth. For a planet orbiting a star, this means one side would get very hot and the other side would get very cold. (However, a thick atmosphere could theoretically spread the heat around the planet as happens on Venus. In answering the following questions, please put aside this possibility.)

Question 13: What would happen to Earth's water if it were suddenly to become tidally locked to the Sun? What would this mean for life on Earth?

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Question 14: Complete the table below by resetting the simulator, setting the initial star mass to the value in the table, and positioning the planet in the middle of the CHZ at time zero. Record whether or not the planet is tidally locked at this time. If tidal locking reduces the likelihood of life evolving on a planet, which system in the table is least conducive towards life?

Mass	Tidally Locked?
0.3 $M_\odot$	
0.5 $M_\odot$	
0.8 $M_\odot$	
1.0 $M_\odot$	No

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CHZ Summation

We have seen that low-mass stars have very small CHZs very close to the star and that planets become tidally locked at these small distances. We have seen that high-mass stars have very short lives – too short for life as we know it to appear.

The combination of these two trains of thought is often referred to as the Goldilocks hypothesis – that medium-mass stars give the optimal opportunity for complex life to appear.

GHZ

Now we are going to investigate habitability zones on the scale of the entire Milky Way Galaxy. The two competing factors that we will look at are 1) the likelihood of planets forming (since we assume that life needs a planet to evolve on), and 2) the likelihood of life being wiped out by a cosmic catastrophe.

Open up the Milky Way Habitabilty Explorer. Each of the two factors described above are illustrated in a graph as a function of distance from the galactic center.

Question 15: What factor influences the rate of planet formation? How does this vary as a function of a star system's distance from the center of the Milky Way?

Question 16: What sort of events can wipe out life on a planet? How does the likelihood of extinction for life vary depending upon a star system's distance from the center of the Milky Way?

Question 17: Present a version of the Goldilock's Hypothesis for the GHZ that is similar in character to that which we stated for the CHZ earlier.