Exploring and expanding the Goldilocks zone

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At the table in the kitchen, there were three bowls of porridge. Goldilocks was hungry. She tasted the porridge from the first bowl.

"This porridge is too hot!" she exclaimed.

So she tasted the porridge from the second bowl.

"This porridge is too cold," she said.

So she tasted the last bowl of porridge.

"Ahhh, this porridge is just right," she said happily and she ate it all up.

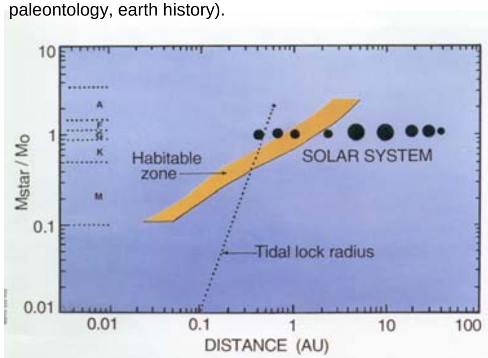
www.dltk-kids.com/rhymes/goldilocks_story.htm

"Exercise"

The proposed "exercise" consists of a set of discussions designed to generate ideas for a term project in a mid-level course: *Planetary Geology and Astrobiology*. Prerequisites are introductory geology and mineralogy. Preference for admission is given to those students who have had mid-level courses beyond mineralogy.

The discussion topics should engage students with some of the primary ideas in astrobiology. The integrating theme is the Goldilocks zone, or habitable zone (HZ), that is associated with many stars. Kasting and Catling (2003) refer to this zone as the "liquid-water HZ."

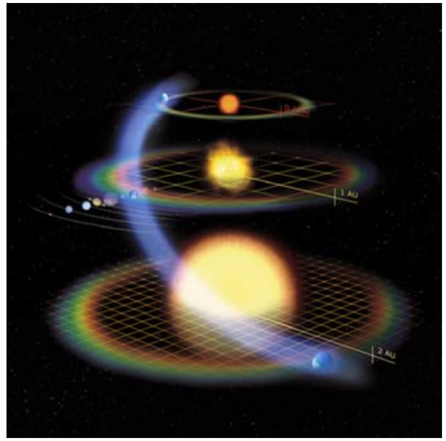
Identified below (in the form of questions) are *some* of the astrobiological topics that might be explored. Some of them should be elaborated by posing quantitative questions that make use of specific data sets. Advice needed! Many of these topics could be adapted to other courses in the curriculum (e.g., paleontology, earth history).



www.geosc.psu.edu/~kasting/PersonalPage/Resint2.htm

How does the size of the star affect the position of the HZ?

Students who have taken an astronomy course might know that stars much larger than the Sun have relatively short lifetimes (limiting time for significant evolution?). A planet in the HZ around a small star would eventually become tidally locked, thus leading to vastly different environments in each hemisphere. (See figure above.)



sci.esa.int/science-e/www/object/index.cfm?fobjectid=29428

How does the HZ change with time?

The Continuous Habitable Zone (CHZ) is characterized by the possibility of liquid water over the lifetime of a star. (See figure above.)

	Venus	Earth	Mars
Distance from Sun (AU)	0.72	1	1.52
Flux (W/m^2)	2,643	1,370	593
Albedo	0.8	0.3	0.22
Effective Temperature (K)	220	255	212
Observed Temperature (K)	730	288	218
Greenhouse Effect (K)	510	33	5

www.atmos.washington.edu/2002Q4/211/notes_greenhouse.html

What is the role of greenhouse gases in expanding or reducing the HZ?

Contrast greenhouse effects on Venus, Earth, and Mars. (See figure above.)

What is the role of water in defining the HZ?

If water is present, carbon dioxide can be sequestered as calcium carbonate. Where sedimentation occurs, additional carbon dioxide can be buried in the form of organic matter. Both processes help reduce the possibility of a runaway greenhouse.

What are energy sources for the HZ?

The energy flux from the Sun traditionally defines the HZ. But liquid water may also occur within some of the icy satellites (e.g., Europa, Enceladus) due to heat from tidal friction (e.g., Gilmour, 2003; Irwin and Schulze-Makuch, 2001).

How does the size of a planetary body help determine the possibility for life?

A liquid core is probably necessary to generate a magnetic field, which shields damaging cosmic rays from the surface. If the planetary body is too small (high surface-to-volume ratio), the heat generated through accretion, gravitational compression, and unstable isotopes may escape too quickly (Mars?).

Escape velocity (or escape speed) at the surface is a function of planetary mass and radius. Small planets lose their atmospheres too rapidly.

Brief exercise in proper use of units: Given mass and radius, calculate escape velocity. Once units mastered, try different combinations of mass and radius at *HyperPhysics* (hyperphysics.phy-astr.gsu.edu/hbase/vesc.html).

Gas movement is a function of temperature; if gas molecules approach 1/6 the escape velocity, they are likely to be lost to space (thermal escape) (Zarnecki, 2003). A good example of this effect may be seen in the D/H ratio on Mars and Earth. Which biologically important gases are more likely to be lost by thermal escape? The probability can be quantified (e.g., average speed of carbon dioxide is 80% that of nitrogen gas).

How might obliquity affect the extent of the HZ?

Earth's Moon apparently prevents wide swings in Earth's obliquity. Mars is thought to go through variations of much greater magnitude (and such swings are probably periodic, like those of Earth). How might obliquity affect the possibility for liquid water on a planetary body? How might obliquity affect evolution (compare Snowball Earth hypothesis)?

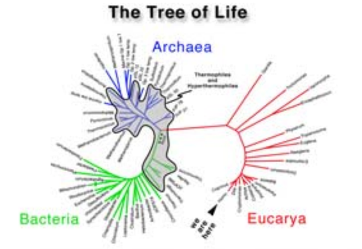
References

Gilmour, I., 2003, A habitable world, *in* Gilmour, I., and Sephton, M. A., eds., An introduction to astrobiology: Cambridge, Cambridge University Press, p. 43-84.

Irwin, L. N., and Schulze-Makuch, D., 2001, Assessing the plausibility of life on other worlds: Astrobiology, v. 1, no. 2, p. 143-160.

Kasting, J. F., and Catling, D., 2003, Evolution of a habitable planet: Annual Review of Astronomy and Astrophysics, v. 41, p. 429-463.

Zarnecki, J. C., 2003, Mars, *in* Gilmour, I., and Sephton, M. A., eds., An introduction to astrobiology: Cambridge, Cambridge University Press, p. 85-126.



www.astro.washington.edu/endsofworld/

How has our knowledge of extremophiles expanded our concept of the HZ?

Students might pick particular extremophiles (see figures above and below) and determine their specific environmental tolerances. Such tolerances could then be compared with physical characteristics (e.g., temperature, pressure, salinity, surface chemistry) of selected planetary bodies.

Environment	Extremophiles
Temperature	psychrophiles
	mesophiles
	thermophiles
	hyperthermophiles
Radiation	*not named*
Salinity	halophiles
pH	acidophiles
	alkaliphiles
Desiccation	xerophiles
Pressure	piezophiles
	barophiles
Vacuum	*not named*
Oxygen	anaerobes
	microaerophiles
	aerobes
Chemical extremes	*various*

adapted from Gilmour, 2003

comments