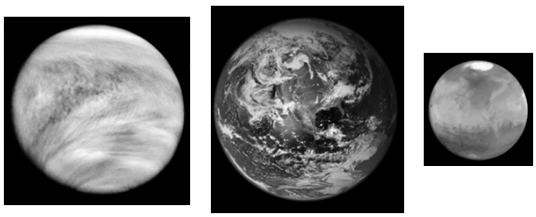
Lecture 30

Goldilocks and the Three Planets



Astronomy 141 – Winter 2012

This lecture considers the Habitable Zone around the Sun.

The temperature of a planet's surface, depends on the Sun's distance and luminosity, and on the planet's Albedo.

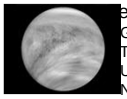
Proximity plus greenhouse effect determines how hot or cold the surface is relative to stable liquid water.

The size of a planet determines how big an atmosphere, if any, a planet can retrain.

The Habitable Zone is the region around the Sun where stable liquid water can exist on the surface.

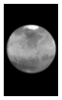
The Continuously Habitable Zone is the region around the Sun were liquid water is stable for the life of the Sun.

Mercury
- No geological activity
- No atmosphere
- Hot day side, cold night side



Venus
- Geological activity, no plate tectonics
- Thick CO_2 atmosphere
- Uniform extremely hot temperature
- No water in any form!

Earth
- Geological activity, plate tectonics
- N_2 and O_2 atmosphere
- Moderate temperatures
- Abundant liquid water



Mars
- No geological activity or tectonics
- Thin CO_2 atmosphere
- Cold temperatures
- Solid water, past liquid water?

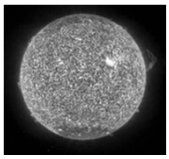
The no-atmosphere temperature depends on the Sun's distance and Luminosity, and the Albedo.

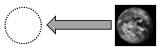
$$T_{eq} \approx 278\text{K}\ \frac{(1-A_b)^{1/4}}{\sqrt{D_{AU}}}\left(\frac{L_{Sun}}{L_{now}}\right)^{1/4}$$

L_{Sun} = Luminosity of the Sun
L_{now} = Luminosity of the Sun *today*
D_{AU} = Distance to the Sun in AU
A_b = Albedo (surface reflectivity)

1. *Objects further from the Sun are cooler.*
2. *Shinier objects are cooler at a given distance.*
3. *A brighter Sun makes objects hotter.*
4. *A fainter Sun makes objects cooler.*

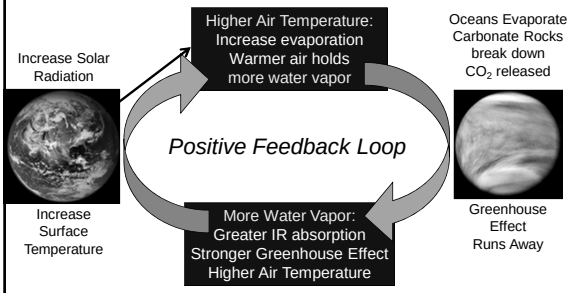
What happens if we move the Earth closer to the Sun?



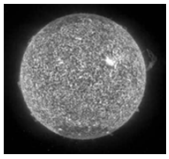


Sunlight gets Brighter, and Temperature goes UP.

Raising global temperature too much would lead to a Runaway Greenhouse Effect



Moving the Earth closer to the Sun leads to a runaway greenhouse effect, making it like Venus.

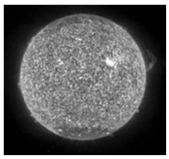


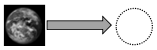
Too Hot!

How close is too close?

"Runaway Greenhouse" occurs at 0.84 AU
"Moist Greenhouse" might occur at 0.95 AU
Higher temperatures → water in upper atmosphere
Water in upper atmosphere gets destroyed by UV rays

What happens if we move the Earth farther away from the Sun?





Sunlight gets Fainter, and Temperature goes DOWN.

Earth's temperature would be 273K (freezing point of H_2O) at a distance of 1.07AU, but greenhouse might extend this.

If you move too far from the Sun, liquid water freeze-out begins.

Cold air can't hold as much water vapor

Water precipitates out as snow.

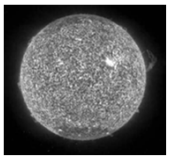
Snow is shiny, lowering the planet's albedo, leading to greater cooling (reflect sunlight back into space).

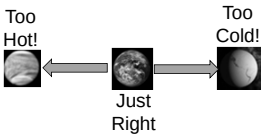
US Coast Guard

Would lead to a runaway freeze-out

Estimate is runaway begins between 1.4 and 1.7AU.

The net result is to setup a classic Goldilocks Problem.



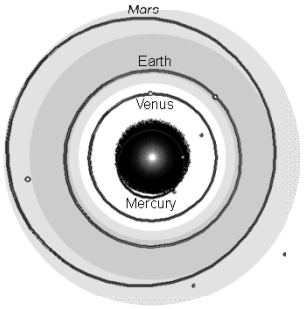


Defines the Habitable Zone around the Sun where liquid water is stable on the surface.

The Sun's Habitable Zone Today

Conservative:
0.95 – 1.4 AU

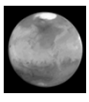
Optimistic:
0.84 – 1.7 AU



Region around the Sun where liquid water is stable on the surface of a planet at a pressure of 1 atmosphere.

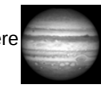
The size of a planet also influences its habitability.

Make the Earth too small…
Too small to retain a warm atmosphere
Interior cools, losing the magnetic field

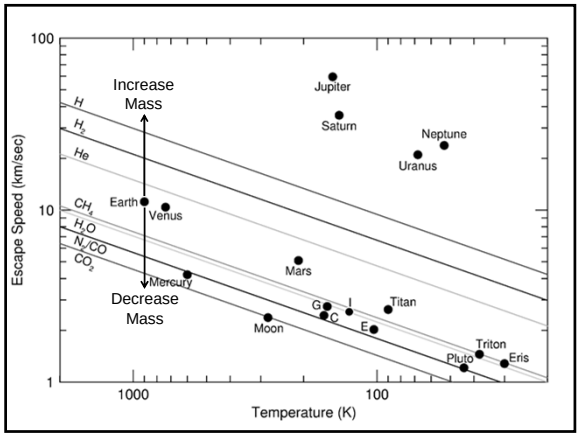


Example: Mars
In the optimistic habitable zone, but too small to retain its atmosphere for more than 1Gyr.

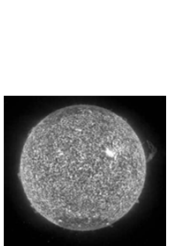
Make the Earth too big…
Builds a heavy Hydrogen-rich reducing atmosphere
Too hot and too high pressure for liquid water.

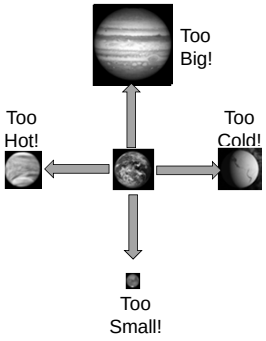


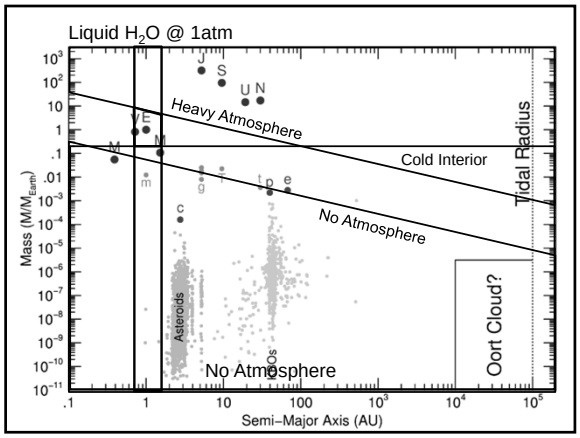
Size limits at 1 AU distance: ~0.2 – 10 M_E



The Full Planetary Goldilocks Problem

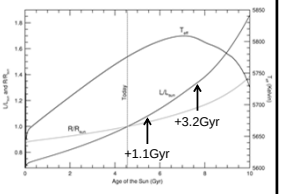






The Sun gets brighter as it ages…

4.5 Gyr Ago:
Sun was ~30% fainter than it is today.
Earth was 8.5% cooler (near freezing, but more CO_2 for the greenhouse effect)



The Sun will continue to get steadily brighter…

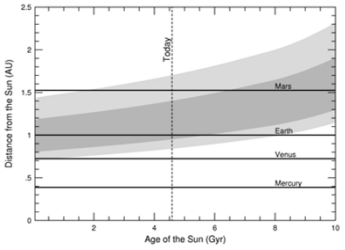
1.1 Gyr in Future: Sun will be 10% brighter
Triggers a Moist Greenhouse Effect on Earth

3.2 Gyr in Future: Sun will be 36% brighter
Triggers a Runaway Greenhouse Effect on Earth

As the Sun ages, the habitable zone moves outward and grown wider.

Earth has been in the Sun's Habitable Zone since formation.

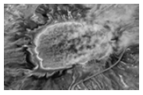
Mars and Venus were always on the edges.



Eventually the Earth will find itself outside the Sun's habitable zone.

The Continuously Habitable Zone is range of distances where a planet can have stable liquid water on its surface for the entire lifetime of the star.

But, there are other sources of energy than Sunlight…



Chemical Energy utilized by deep-sea vent and hot springs extremophiles.

Tidal Heating and Radioactivity, like in Io, Europa, and Enceladus.

The concept of a habitable zone should guide our thinking, but not restrict it.