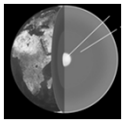
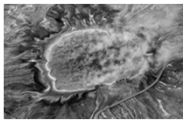
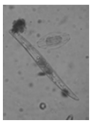
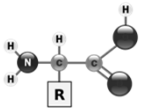
Lecture 25:

The Requirements for Life

Astronomy 141 – Winter 2012

This lecture explores the requirements for life, and the factors affecting planetary habitability.

The basic requirements are a source of energy, complex chemistry, a liquid solvent medium, and protection from UV.

Sunlight is the main source of energy, but it depends on distance and how shiny a body is.

Extremophiles on Earth suggest non-solar energy may also be a factor in habitability.

Liquid water is an ideal solvent, but other liquids might work.

A planet's size determine its interior heat, magnetic field, and ability to retain an atmosphere.

Basic Requirements for Life

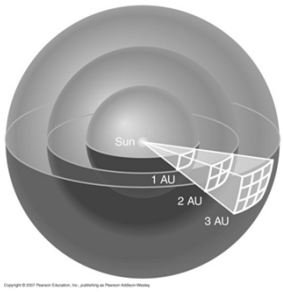
Source of Energy
- Energy to fuel chemical reactions
- Warmth to permit liquid water (other liquids?)

Complex Chemistry
- Elements heavier than H and He
- Carbon as building block of complex molecules

Liquid Solvent Medium
- Place for complex chemistry to occur

Protection from harmful UV light
- Mutations inhibit emergence of complex life
- Ozone layer, underwater, or underground

The Sun is the main energy source in the Solar System – how much depends on your distance.



The Sun's brightness depends your distance.

$$B = \frac{L}{4\pi D^2}$$

B = Brightness of Sunlight
L = Sun's Luminosity
D = Distance from Sun

Inverse-Square Law of Brightness

The amount of Solar Heating depends on your distance from the Sun and how reflective you are.

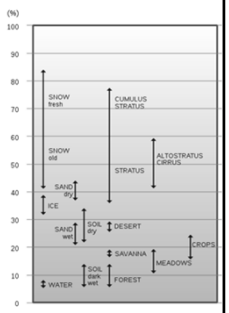
$$T_{eq} \approx 278\text{K}\ \frac{(1-A_b)^{1/4}}{\sqrt{D}}$$

D = distance in AU
A_b = Albedo

Albedo is a measure of a body's reflectivity

More distant objects are cooler.

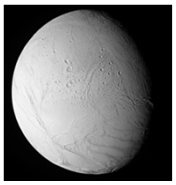
Shinier objects are cooler.



Examples

Moon (dark rock)
A = 0.12
D = 1 AU

$T_{eq} \approx 270$ K



Enceladus (Icy Moon of Saturn):
A = 0.99
D = 9.54 AU

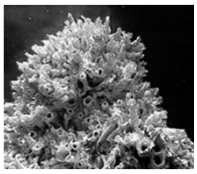
$T_{eq} \approx 30$ K

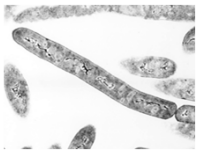
An atmosphere with a greenhouse effect would act to increase these temperatures.

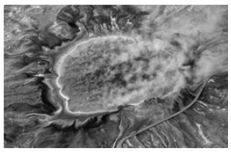
Extremophiles on Earth remind us that sunlight is not the only energy source.

Hot Life:
Microbes surviving in boiling geysers pools and deep ocean thermal vents.

Dark Life:
Bacteria that thrive many kilometers beneath the Earth or deep in polar ice.







The complex chemistry of life appears to require a liquid "solvent" to occur in.

Provides a medium for chemical reactions.

Carries nutrients in and wastes out.

Helps maintain proper thermal balance (high heat capacity).

Provides protection from the outside environment.

Liquid Water is the ideal solvent for the chemistry of life.

Water is Abundant

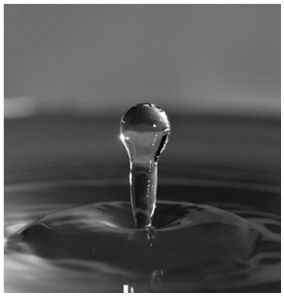
Liquid from 0 – 100°C (ideal for most reactions)

Dissolves most chemicals

Large heat capacity

Less dense when it freezes

High surface tension



But, there are other liquid solvents…

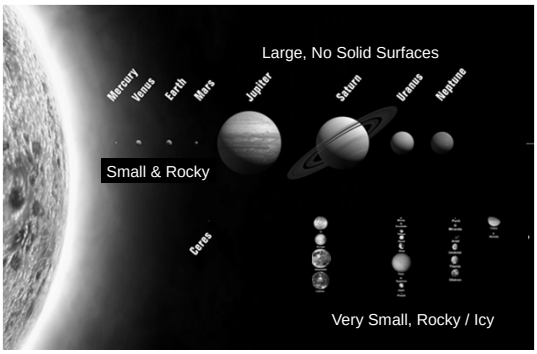
Water (H_2O): liquid from 0 to 100°C
(100°C range)

Ammonia (NH_3): liquid from −78 to −33°C
(45°C range)

Methane (CH_4): liquid from −182 to −164°C
(18°C range)

Ethane (C_2H_6): liquid from −183 to −89°C
(94°C range)

Life also needs a place to stand (or swim)…

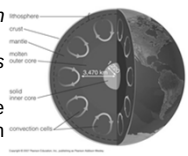


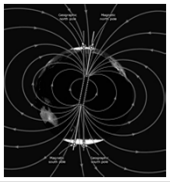
The internal heat of a planet is a factor in its potential for habitability.

Internal heat drives *convection*

Convection drives *plate tectonics*

Plate tectonics play a role in the CO_2 Cycle critical for global temperature regulation



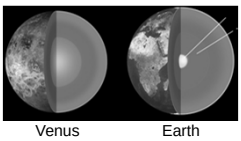


Convection and rapid rotation combine to generate a magnetic field

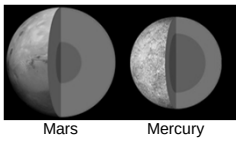
This can protect the atmosphere from damage by the Solar Wind.

The cooling time of a body scales as the size of the body.

Planets or Moons more than 50% the mass of the Earth are still hot and molten inside today.



Venus Earth

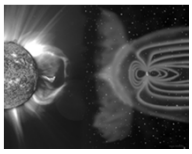


Mars Mercury

Planets or Moons less than 50% the mass of the Earth have solidified by the present day.

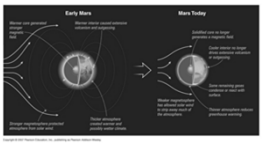
Planetary magnetic fields protect atmospheres from stripping by the Solar Wind.

The Solar Wind is made of charged particles, but charged particles cannot cross magnetic field lines.

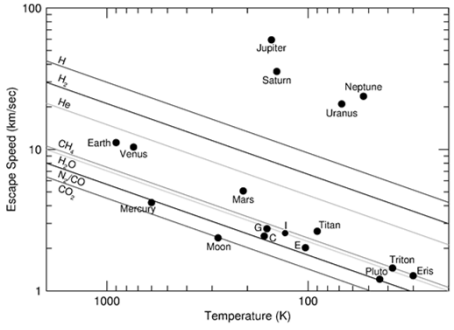


Earth's magnetic field shields our atmosphere from the Solar Wind.

Mars has solidified and has no magnetic field, so it lost its early atmosphere faster.



The ability of a planet to retain atmospheric gasses depends on its mass and its temperature.



Another factor in a body's habitability is the size of the atmosphere (if any) it can retain.

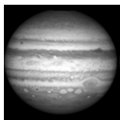
If a body is too small…

Gravity is too weak to hold onto an atmosphere

Depends on the local temperature

Mercury

If a body is too large…

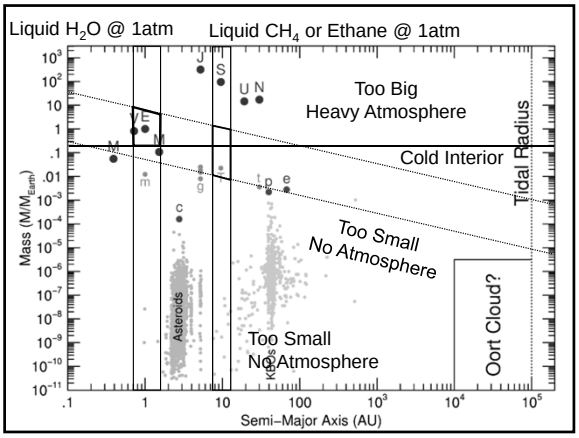


Jupiter

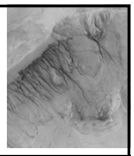
Builds a heavy Hydrogen/Helium atmosphere.

Conditions: too hot and too high pressure

Reducing Chemistry instead of Oxygen Chemistry

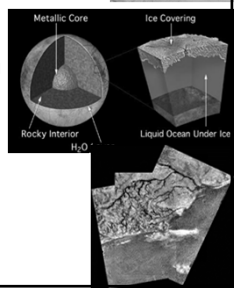


Where might we look for life elsewhere in our Solar System?



Mars

May have had liquid water and a thicker atmosphere in the past.



Europa

Liquid water oceans? & tidal heating

Protected by outer shell of ice

Enceladus

Liquid water under protective ice

Complex organics

Titan

CH_4 chemistry & complex organics