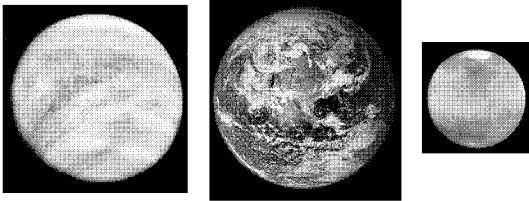


Thursday, November 4
Goldilocks & the Habitable Zone



Quiz #3 tomorrow!

Goldilocks & the Habitable Zone
Key Concepts

- 1) Equilibrium temperature depends on distance from Sun, albedo, & luminosity of Sun.
- 2) The Habitable Zone is the region where stable liquid water can exist on a planet's surface.
- 3) The Continuously Habitable Zone is where liquid water can exist for the Sun's lifetime.

Equilibrium temperature depends on distance from Sun, albedo, & the **Sun's luminosity**.

$$T_{\text{eq}} = 278\text{K} \frac{(1-A)^{1/4}}{\sqrt{d}} \left(\frac{L}{L_{\text{now}}} \right)^{1/4}$$

L = luminosity of the Sun

L_{now} = luminosity of the Sun *right now*

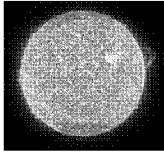
d = distance to the Sun in AU

A = albedo (reflectivity)

Brighter Sun \Rightarrow hotter planet.

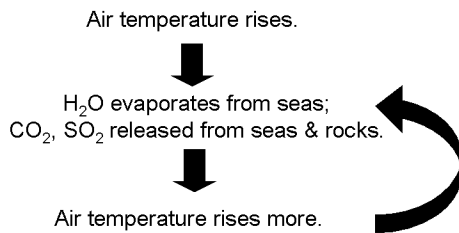
Fainter Sun \Rightarrow cooler planet.

What if we move the Earth closer to the Sun?

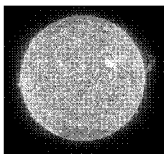


Flux of sunlight increases; temperature goes **up**.

Raising global temperature can lead to a **runaway greenhouse effect**.



Moving the Earth too close to the Sun creates a runaway greenhouse effect, making it like Venus.

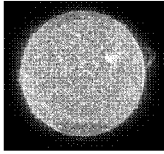


Too Hot!



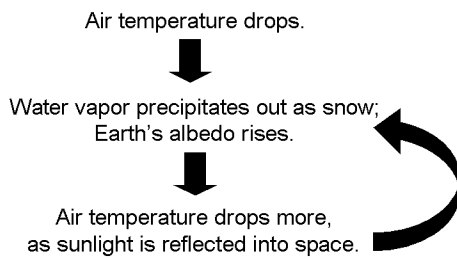
How close is too close?
"Runaway greenhouse" would occur at 0.84 AU.

What if we move the Earth farther from the Sun?

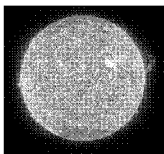


Flux of sunlight decreases; temperature goes **down**.

Lowering global temperature too much leads to a **runaway freeze-out**.



Moving the Earth too far from the Sun creates a runaway freeze-out, making it a "Snowball Earth".

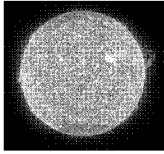


Too Cold!



How far is too far?
"Runaway freeze-out" would occur at 1.4 to 1.7 AU.

It's a classic "Goldilocks" problem.



Too Hot!



Just Right



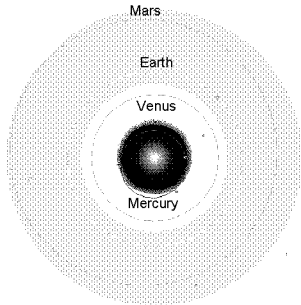
Too Cold!

We can define a **Habitable Zone** around the Sun where liquid water is stable on a planet's surface at a pressure of 1 atmosphere.

The Sun's Habitable Zone right now:

Conservative:
0.95 – 1.4 AU

Optimistic:
0.84 – 1.7 AU



A planet's **size** also influences its habitability.

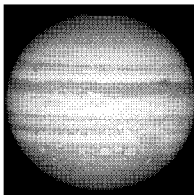
Too small:

It can't retain its atmosphere.
Its interior solidifies, and its magnetic field disappears.



Too big:

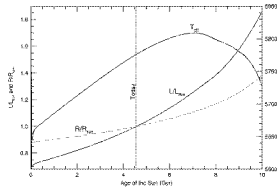
It has a crushingly heavy,
hydrogen-rich reducing atmosphere.



Planets with 0.2 to 10 times the Earth's mass are "just right".

The Sun gets brighter as it ages.

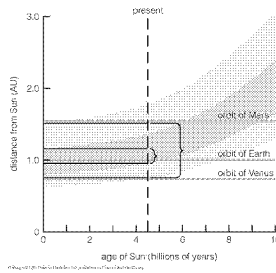
4.5 Gyr ago, the Sun was 30% fainter, & the Earth was 8.5% cooler (disregarding the greenhouse effect in the Earth's primordial atmosphere).



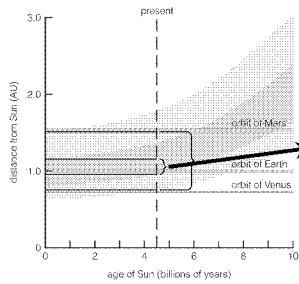
3.2 Gyr from now, the Sun will be 36% brighter, & will trigger a runaway greenhouse effect on Earth.

As the Sun ages, the Habitable Zone moves outward and becomes wider.

The Earth has been in the Sun's Habitable Zone since its formation.
Eventually, the Earth will be outside the Habitable Zone. ("Too hot" rather than "just right").

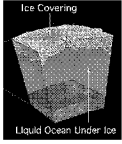


Continuously Habitable Zone: the range of distances where a planet can have stable liquid water on its surface from formation until now.



Given conservative assumptions, the Continuously Habitable Zone is quite narrow!

Wild card:
Sunlight isn't the only source of energy.



Europa is far outside the Habitable Zone, but it has liquid water (melted by tidal heating) and might harbor life.

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

Quiz Tomorrow
Bring your number 2 pencil!
