Astronomy 330:

# Extraterrestrial Life

This class (Lecture 12):

Earth for Life

Next Class:

Life in the Solar System
**Stephanie Gerstetter**
**John Ryan**


**HW #5 due Sunday night.**

Music: *The Day Lassie Went to the Moon*— Camper Van Beethoven

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# HW #2

Saaya Nath
http://www.ufosightingsdaily.com/
A blog where people can post their "UFO sightings". There's not much good to this website.

Mary Lavoie
http://www.ufoabduction.com/telepathy14.htm
Aliens use telepathy to communicate with other aliens. They have a lack of aesthetically pleasing decor on their spaceships



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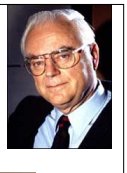
# Drake Equation



Frank Drake

**That's 24 planetary systems/year**

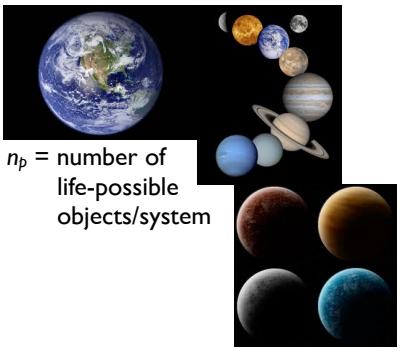
$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

| # of advanced civilizations we can contact in our Galaxy today | Star formation rate | Fraction of stars with planets | # of Earthlike planets per system | Fraction on which life arises | Fraction that evolve intelligence | Fraction that commun-icate | Lifetime of advanced civilizations |
|---|---|---|---|---|---|---|---|
| | 30 stars/ yr | 0.8 systems/ star | planets/ system | life/ planet | intel./ life | comm./ intel. | yrs/ comm. |

# Earth-like Planets?

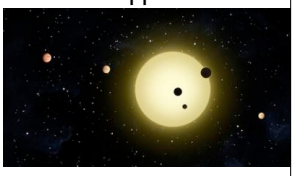
What does this term mean?

$$n_e = n_p \times f_s$$



$n_p$ = number of life-possible objects/system

$f_s$ = fraction of star systems that can support life



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Terrestrial planets and Gas Giants… but how many are valid planets/moons for np?

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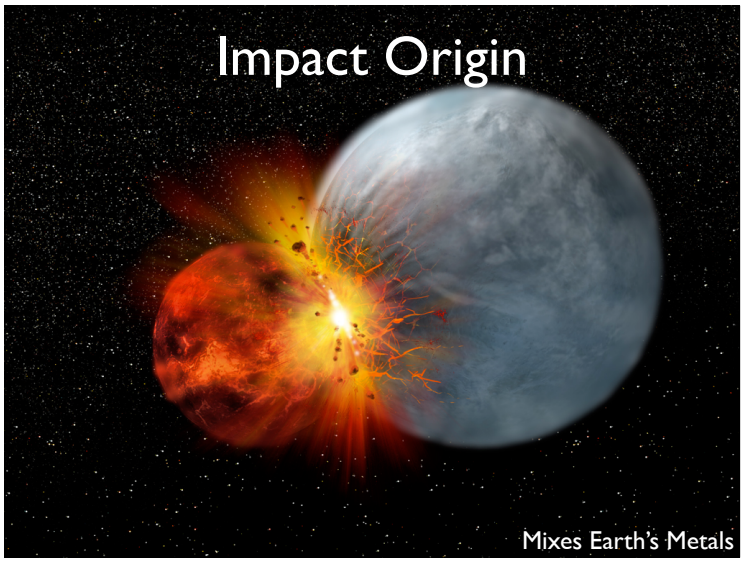


http://physicsgg.files.wordpress.com/2011/09/moon_earth.jpg

Collision of Earth with a Mars-sized body early in the solar system's history. Iron-rich core of the impactor sank within Earth. Earth's rotation sped up Remaining ejecta thrown into orbit, coalesced into the Moon

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# Moon's Impact

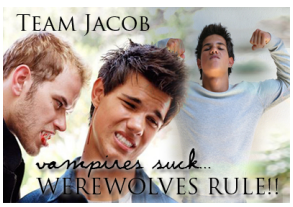
Is the Moon important to life?

Tides: Move water in/out of pools.

Stable axis tilt (23.5 degrees)

Metals! Dredge-up of metals during impact.

Culture?



# Question

Which of the following is not a way that the moon has affected Earth positively in the development of Life?

a) Tides

b) Axis Tilt

c) Werewolves

d) Surface Metals

e) Development of Culture

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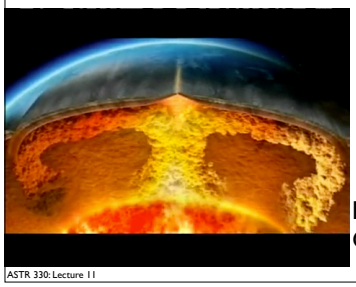
C

# Evidence?

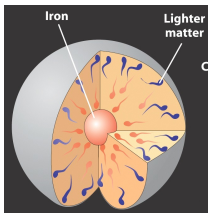
Surface only 3.0 gm/cm$^3$

5.5 gm/cm$^3$

Center must be more dense!



Molten material differentiates




Si O C

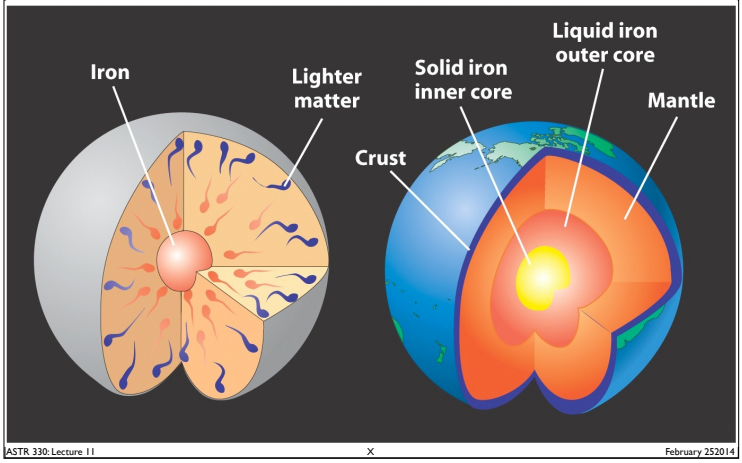
Fe Au Ag Ni

Magnetic Field: Good for Life



Not all metals sank, differentiation–lite? Luckily, not all of the iron sank to the center, else we would be still in the Stone Age.

# Iron Differentiation



# Earth Structure

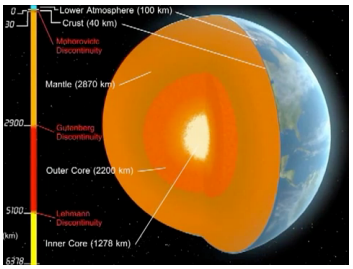
Heat: Radioactive Decay (SN Remnants)

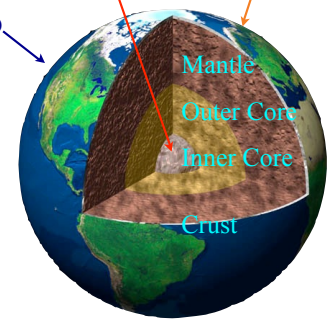
5000 K

290 K

Sea Floors < 200 Myrs

70% $H_2O$




Continents: Young & Old: up to 4.2 Byrs



- 70% of the Earth's surface is covered with water (Ocean basins, Sea floors are young, none more than 200 million years old
- 30% is dry land – Continents, Mixture of young rocks and old rocks, Up to 4.2 billion years old

Temperature increases as you go deeper underground. From around 290 K on surface to nearly 5000 K at center.

  - Heated by radioactive decay
  - Supernovae remnants
- Earth's magnetic field is established early on.. after the iron catastrophe… good for life.

# *Recycling Bio-elements*

- From gravity and radioactivity, the core stays hot.
- This allows a persisting circulation of bioelements through continental drift— melting of the crust and re-release through volcanoes.
- Otherwise, certain elements might get locked into sediment layers– e.g. early sea life.
- Maybe planets being formed now, with less supernovae, would not have enough radioactivity to support continental drifts and volcanoes.

http://www.pahala-hawaii.com/j-page/image/activevolcanoe.jpg

# Earth Surface

Crust: ~50 km thick

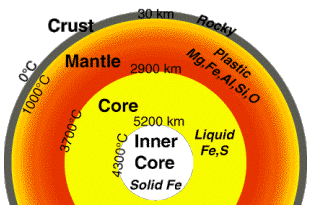
290 K

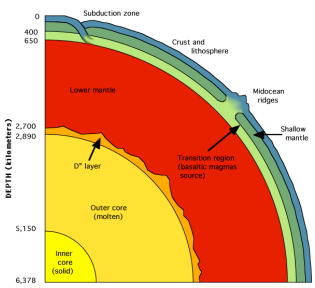
Silicate Rocks: Si + O + Al

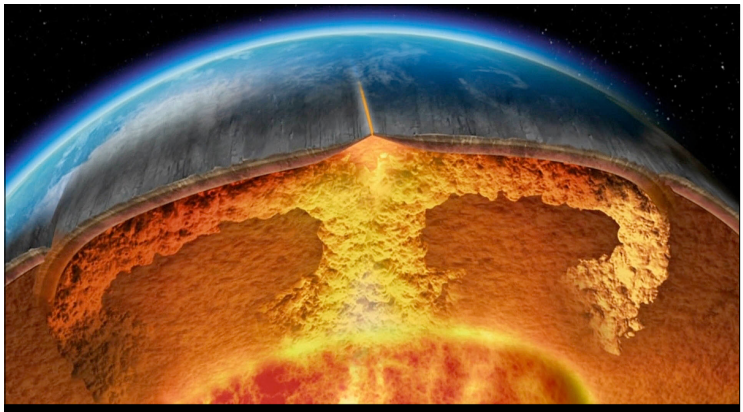
Insulating Layer

Also Abundant

O $H_2O$





The Earth's interior is composed of three parts: a thin, brittle outer crust called the lithosphere, a ductile mantle, and a solid iron-nickel core.



http://johnhanke.com/communities/8/004/008/944/648/images/4544220804.jpg

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# Question

Iron Differentiation refers to what phenomena?

a) Oxidation of surface Iron

b) Alien conspiracy

c) Stratification of Fusion processes in massive stars

d) Heavier molten materials sink to Earth's center

e) Awesome hard rock band name

iClicker



D

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http://www.planetside.co.uk/forums/index.php?action=dlattach;topic=14749.0;attach=38223;image

Hot, hot, hot. Even if the moon theory is incorrect, other smaller bodies were playing havoc on the surface. When they impact, they release kinetic energy and gravitational potential. In addition, some of the decaying radioactive elements heated up the Earth- stored supernova energy! The planetesimals melt, and the Earth went through a period of differentiation.

# Early Earth

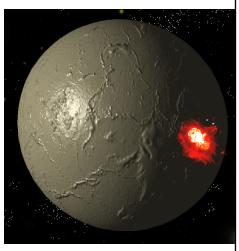
- No atmosphere
- No water
- High temp
- No life…….
- Big rocks keep falling on my head…

http://www.black-cat-studios.com/catalog/earth.html

# Earth's Atmosphere

First Atmosphere $H + He$

quickly lost, insufficient gravity



$H_20 + CO_2$


$H_20 + CO_2 + N_2$

$H_20$ } Oceans

$CO_2$ } $CaCO_3$





The inner disk had most gases blown away and the proto-Earth was not massive enough to capture these gases. Any impacts (e.g. the moon), would have blown any residual atmosphere away. The first atmosphere was probably H and He, which was lost quickly. First atmosphere escaped: Blown away by solar winds and impacts. Insufficient gravity to maintain.

The interior heat of the Earth helped with the Earth's early atmosphere. Volcanoes released gases (water vapor and CO2)

Another scenario is that impacted comets released – water (H2O), carbon dioxide (CO2), and Nitrogen (N2)– the first true atmosphere.
The water condensed to form the oceans and much of the CO2 was dissolved in the oceans and incorporated into sediments– such as calcium carbonate (CaCO3).

Mostly oceans and some solid land (all volcanic). Frequent impacts of remaining planetesimals (ending about 3.8 billion years ago). Impacts would
have sterilized the young Earth– Mass extinctions and maybe vaporized any oceans (more comets?).

# Question

What happened to the bulk of the $CO_2$ in the early Earth's atmosphere?

a) Escaped into space

b) Nothing, its still there

c) Trapped in rocks

d) Trick question, the only $CO_2$ is from human pollution

e) Captured by alien carbon tax credit

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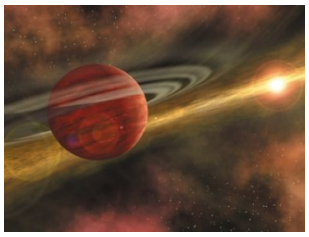
C

# *This New Planet*

- Impacts and volcanic activity created the continental landmasses.
- Little oxygen means no ozone layer– flooded with ultraviolet light on surface.
- Along with lightning, radioactivity, and geothermal heat, provided energy for chemical reactions.

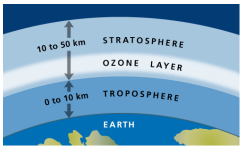
- **BUT, life on the surface not possible!**



# Earth's Atmosphere

Old Rocks show early atmosphere had little $O_2$

No Oxygen means no Ozone Layer




Currently:

78% N

21% O

Trace: $H_20$ + $CO_2$ + ...

Cyanobacteria manufacture Oxygen



Rocks with ages greater than 2 billion years show that there was little or no oxygen in the Earth's atmosphere. The current composition: 78% nitrogen, 21% oxygen, and trace amounts of water, carbon dioxide, etc. Where did the oxygen come from? Cyanobacteria made it. Life on Earth modifies the Earth's atmosphere.

# Question

From where did the Oxygen in our Atmosphere originate?

a) From Moon impact

b) Manufactured by Cyanobacteria

c) Weathering of rocks

d) Volcanoes

e) Comets

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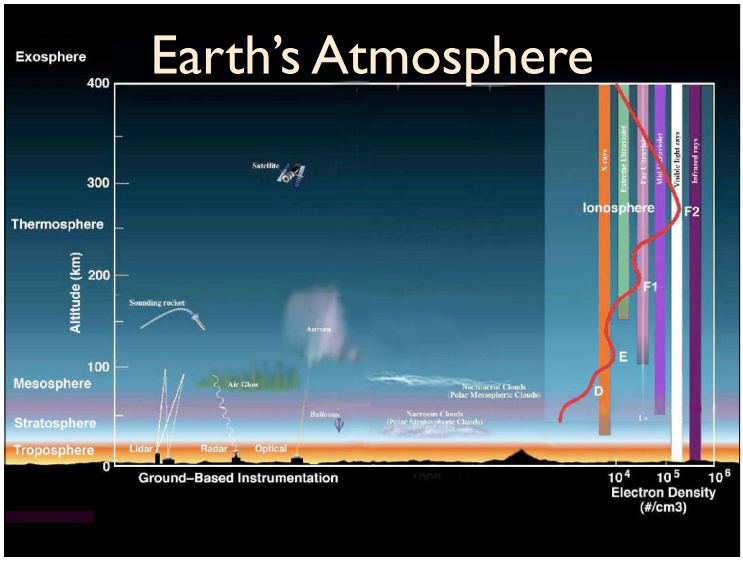
B




http://www.nasa.gov/images/content/463940main_atmosphere-layers2_full.jpg

Need to have enough pressure to keep water from boiling away at low temperature. Cooking at higher elevation requires more time. Boiling point lowered: water doesn't get as hot. If pressure too low, water goes directly from ice to vapor (like dry ice CO2). On the other hand, high pressure may make life more difficult to form. In addition, the range of temperature for Earth based complex life is less than 325K.

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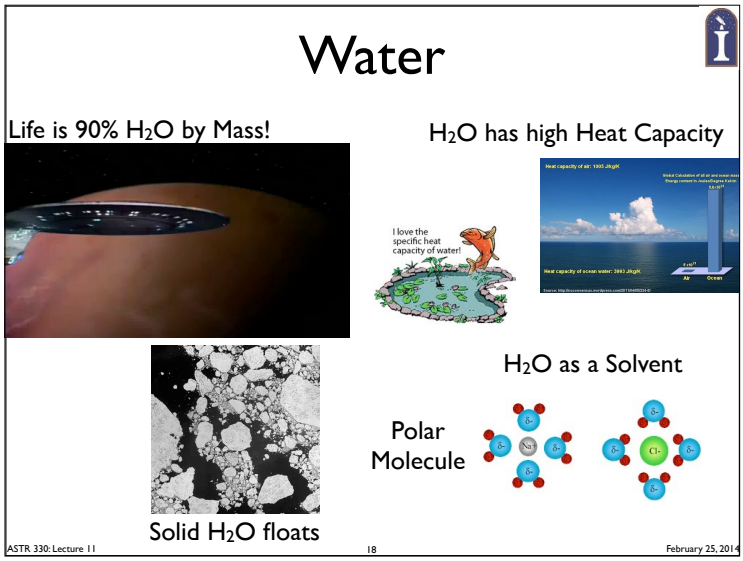


Primary role as a solvent
Dissolves molecules to bring nutrients and remove wastes. Allows molecules to "move" freely in solution.
Must be in liquid form, requiring adequate pressure and certain range of temperatures.

This sets a requirement on planets, if we assume that all life requires water.

Does it?

A very good temperature buffer. Absorbs significant heat before its temperature changes. When it vaporizes, it takes heat with it, cooling its original location

It floats when frozen. Good property for life in water. Otherwise, a lake would freeze bottom up, killing life. By floating to the surface, it can insulate the water somewhat.

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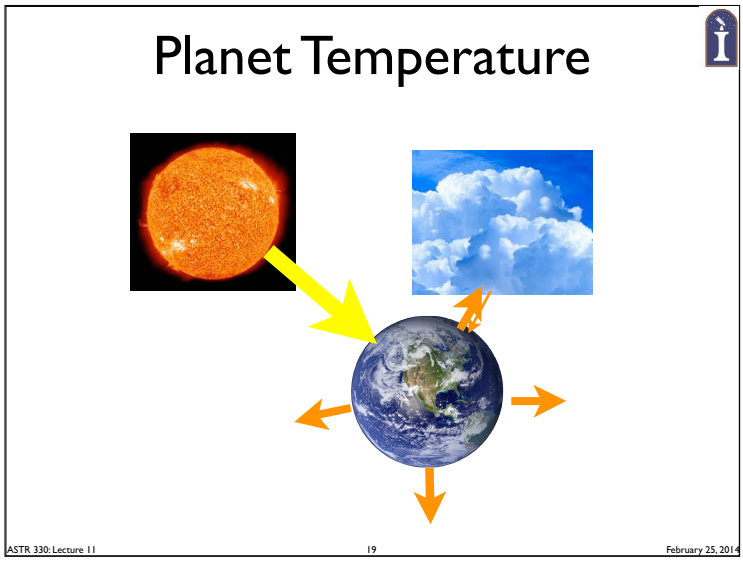
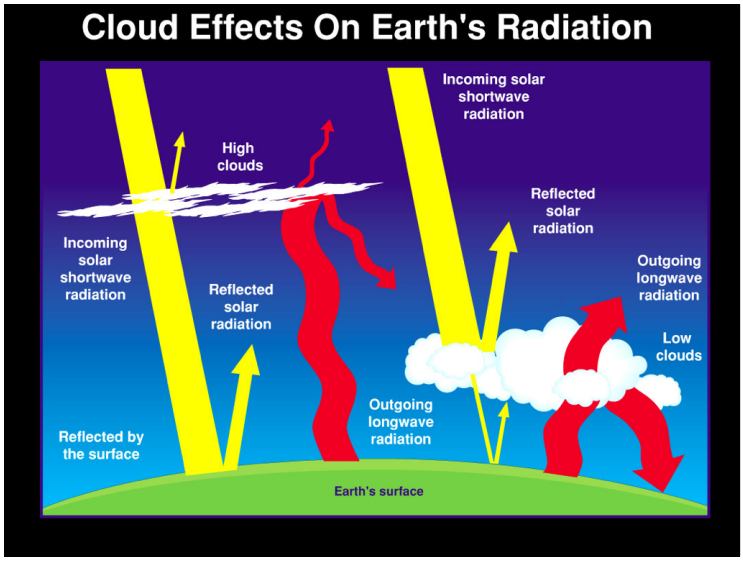



What controls a planet's temperature? The amount of light received from its star. The amount of energy the planet reflects back. And any Greenhouse effects of the planet.




http://ircamera.as.arizona.edu/NatSci102/NatSci102/images/cloudeffect.jpg

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Earth's greenhouse effect raises the temperature by about 15%. Given a star's luminosity, a range of acceptable temperatures translates into a range of distances to the star. This range is called the star's habitable zone (HZ), as planets in this range have temperatures suited for life. Only a rough guideline.

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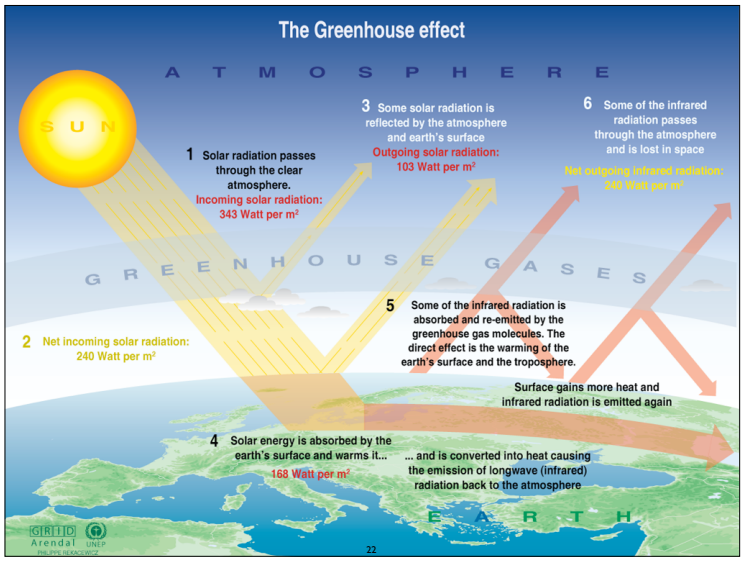


http://blogs.studentsarea.com/files/2012/09/greenhouse_effect1.png

# Question

The Greenhouse effect refers to what?

a) A cool alternative band

b) increased retention of heat by the Atmosphere

c) decreased retention of heat by the Atmosphere

d) The Carbon feedback cycle

e) Solar variability induced climate change

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B

# Earth's Atmosphere


$CO_2$ Cycles from Atmosphere (Greenhouse Gas) to Ocean (Buried Sediment) & Back

Temperature Rises:

Evaporation of Oceans

Increased Weathering: Traps $CO_2$ in rocks

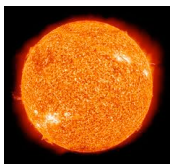
Less Greenhouse Gas: Temperature Drops

Stabilizes Earth's Temperature




# Solar Variability

As Sun ages it gets brighter!

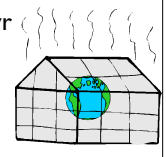


Younger Sun 70% as Luminous

20 K cooler

1% cooler

Freeze Epochs
2.8 Byr
700 Myr



Affect Habitable Zone?



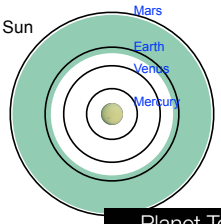
As the Sun ages, it gets slightly brighter. When it was younger, its luminosity was 70% current values. A young Earth should have been 20K colder- iceball! During our ice ages, the temperature only changed
by about 1%!

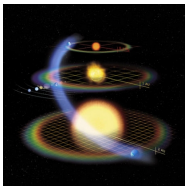
There is evidence that the Earth did nearly freeze over- 2.8 billion years ago and 700 million years ago. Probably changes in the Greenhouse gases. This implies that the habitable zone can vary with time, thus the real habitable zone is smaller than shown before? Some have postulated that real zone is only 0.95 to 1.01 AU! If the Earth were 1% farther away- Iceballed. And np would be very small ~ 0.1.

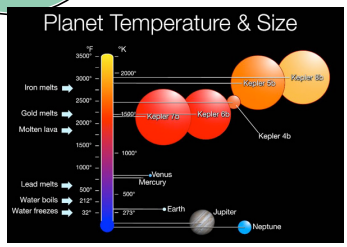
Most recent studies suggest an efficient planet negative-feedback mechanism (like a thermostat). CO2 cycles from atmosphere (greenhouse gas) and oceans (buried sediment especially carbonate rock). CO2 in atmosphere: temporarily dissolved CO2 in rainfall reacts with weathered rocks, trapping it.

Negative feedback process. Increase in temperature: evaporation of oceans, more rainfall, more weathering and CO2 reduction, so decrease in temperature.
This negative feedback stabilizes the Earth's temperature. Life increases the weathering of rock. Some have proposed that life also stabilizes the planet temperature. Regardless, the negative feedback helps with the habitable zone, so we can estimate perhaps np is more around 1- more Earth chauvinism?

# Habitable Zone

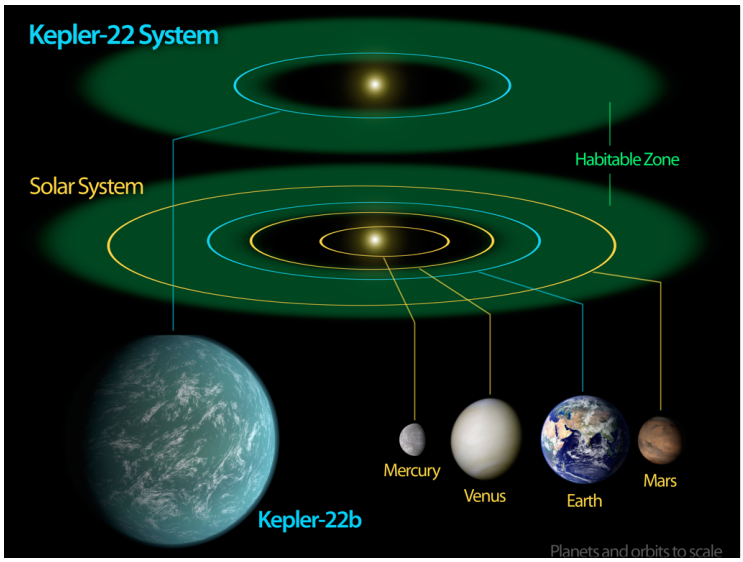






Definitions:

- Long-Lived Star
- Planets with stable orbits
- Liquid Water
- Heavy Elements: CNO
- Protection from UV






# Question

Which of the following items is least important to the size of the habitable zone around a star?

a) Mass of host star

b) Distance to host star

c) Stable planet orbit

d) Liquid Water

e) Iron differentiation

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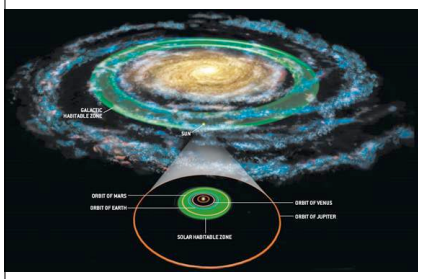
E

# Galactic HZ?




Stars of sufficient age and metallicity

Relative quiet stellar zones

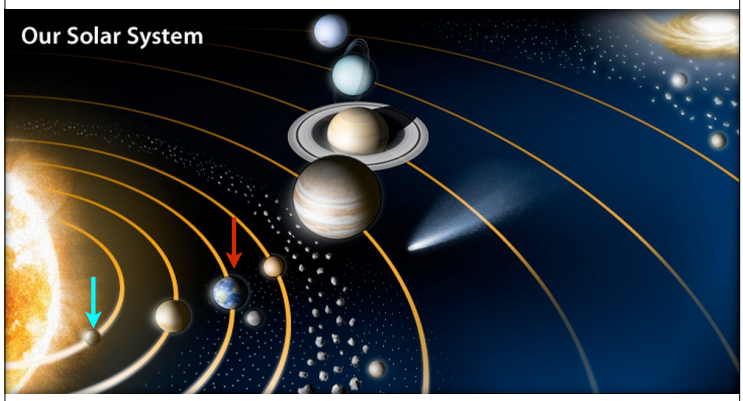
MW: Annulus 6kly wide, 25 Kly from GC

Controversy: Stars migrate, so perhaps no GHZ?



http://en.wikipedia.org/wiki/Habitable_zone#Galactic_habitable_zone

# Life in the Solar System?






We want to examine in more detail the backyard of humans. What we find may change our estimates of ne.

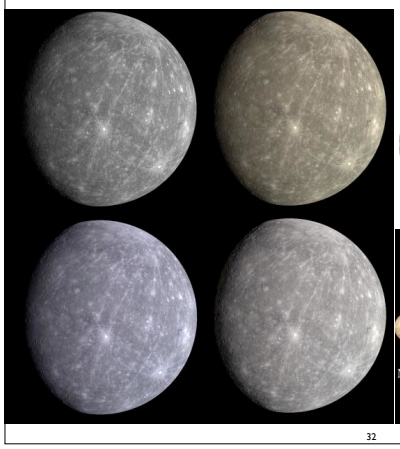
# Earth-Mercury Comparison

Mercury is the closest planet to the Sun. Mercury has the most elliptical orbit of any planet and orbits in a 3:2 spin resonance.

| | |
|---|---|
| Radius | 0.38 Earth |
| Surface gravity | 0.38 Earth |
| Mass | 0.06 Earth |
| Distance from Sun | 0.39 AU |
| Average Temp | 167 C (> 600 C Sunward) |
| Year | 87.97 Earth days |
| Length of Day | 58.6 Earth days |
| Atmosphere | Vacuum |

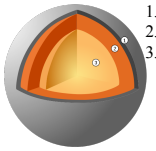
http://nssdc.gsfc.nasa.gov/planetary/factsheet/mercuryfact.html

# Mercury

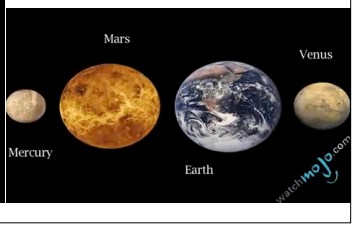


No Atmosphere: Low Gravity

Surface Temp: 100-700K



1. Crust - 100-200km thick
2. Mantle - 600km thick
3. Nucleus - 1,800km radius

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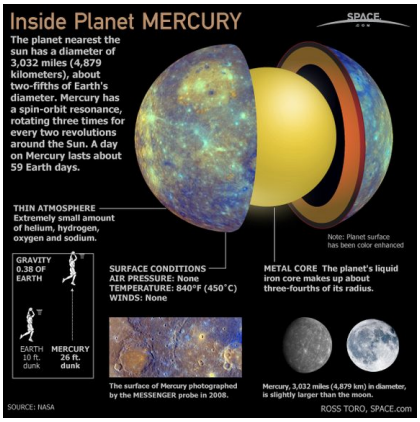
# Mercury

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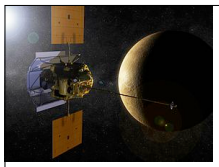


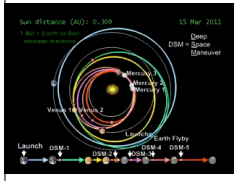
# Messenger

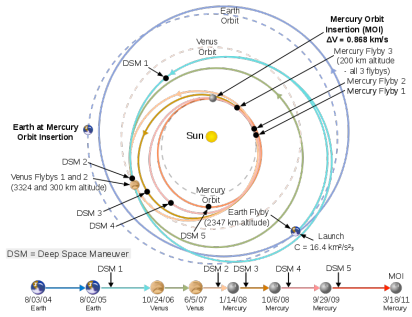

Launch: Aug 2004

Imaging Devices

Spectrometers

Magnetometers



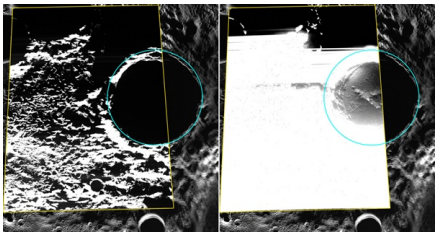


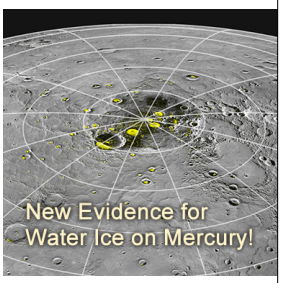

x

# New Results

Messenger confirms detection of water ice at North Pole.

First speculated in 1991 from radio observations






34

There is water on Mercury. Time to colonize?

Water ice is present, but it is covered by a thin layer of dark material inferred to consist of frozen organic-rich compounds." In the images of those areas, the dark deposits display sharp boundaries. This result was a little surprising because sharp boundaries indicate that the volatile deposits at Mercury's poles are geologically young, relative to the timescale for lateral mixing by impacts.

---

# Question

What was detected on Mercury that is important for Life?

a) Water Ice

b) Atmosphere

c) Greenhouse effect

d) 3:2 Spin Resonance

e) Quantum Magnetic Flux Capacitance

iClicker

35

A

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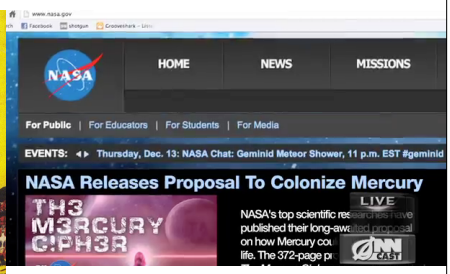
# Life on Mercury

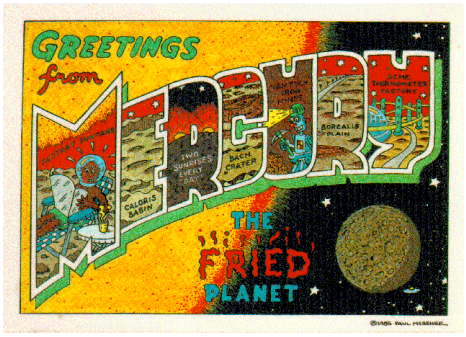




So water + possible organics?

But deep gravity well & missing elements.

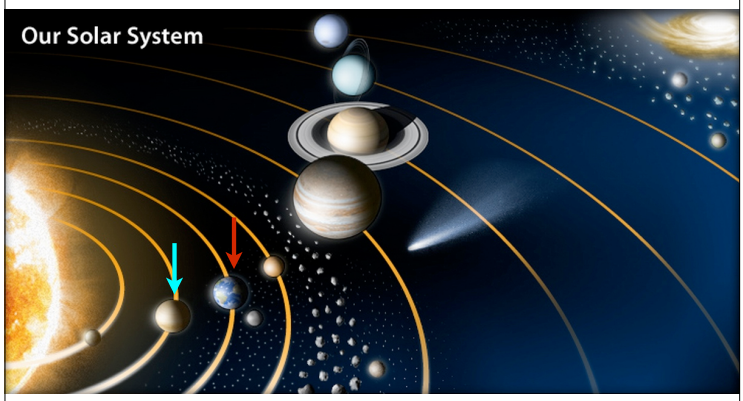

36

# Goodbye Mercury




37

# Life in the Solar System?

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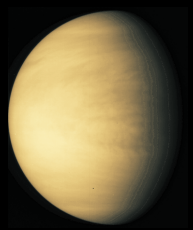
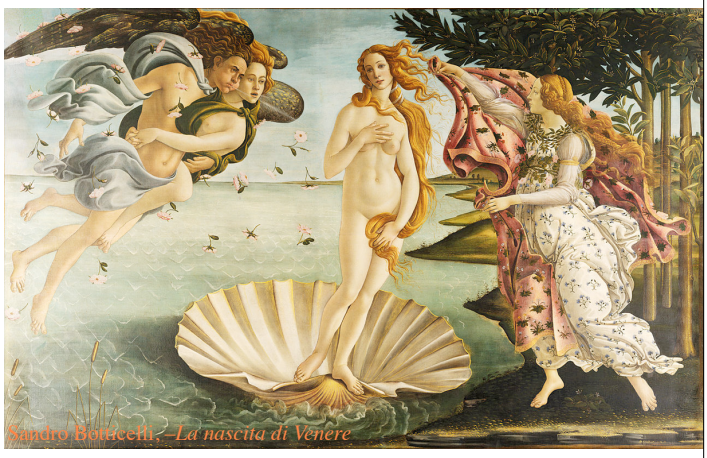
# Earth-Venus Comparison



Venus is the hottest planet, the closest in size to Earth, the closest in distance to Earth, and the planet with the longest day.

| | |
|---|---|
| Radius | 0.95 Earth |
| Surface gravity | 0.91 Earth |
| Mass | 0.81 Earth |
| Distance from Sun | 0.72 AU |
| Average Temp | 475 C |
| Year | 224.7 Earth days |
| Length of Day | 116.8 Earth days |
| Atmosphere | 96% $CO_2$ |

# Venus



Sandro Botticelli, *La nascita di Venere*



# Venus


A Carboniferous Time-Warp

Nobel Prize in Chemistry

1870

Richard Proctor

1918

Svante Arrhenius

Closer to Sun so hotter.
Temperate Latitudes would be swamps.
Low lifeforms, uniform across planet.



http://www.daviddarling.info/encyclopedia/V/Venuslife.html

# Venus

# Venus was her name ...

http://ferrebeekeeper.files.wordpress.com/2012/04/venus-surface.jpg

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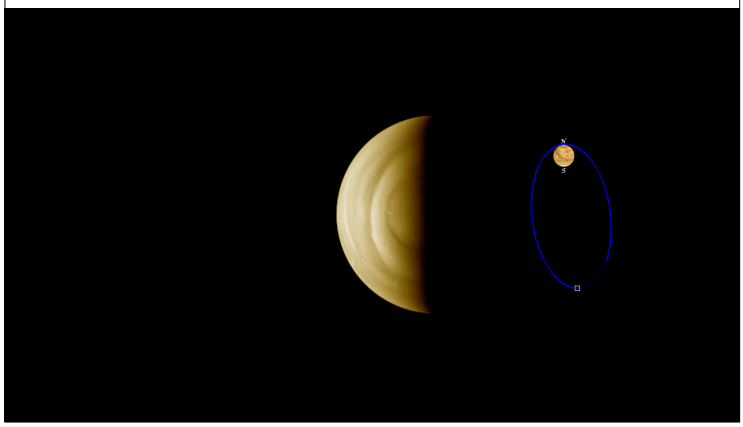
# Our Twin

Venus Express: ESA



ESA's Venus probe captured images over a full orbit on January 7th-8th, 2012 and a partial orbit on June 1st, 2012. The orbiter comes as close as 155 miles from the surface of the 2nd planet.

---

# Venus

Venus is Hell!


Hot enough to melt lead!

Runaway Greenhouse Effect

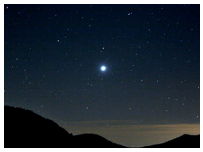
Almost no $H_2O$

Sulfuric Acid Rain

# Our Twin

3rd brightest object in sky
= UFO!

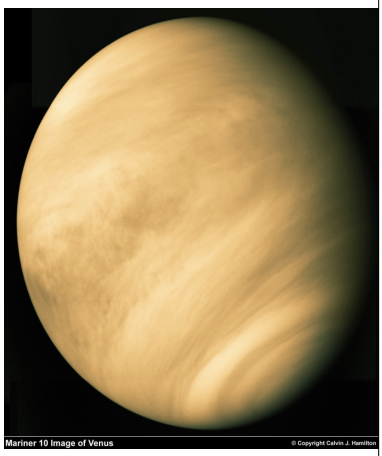
Morning/Evening Star



Hottest Planet: Greenhouse Effect

Thick clouds of $CO_2$

Surface Pressure: 90 atm
=1 km underwater






# Question

Venus is sometimes misclassified as

a) a planet

b) an unidentified flying object

c) the morning star

d) the evening star

e) the Sun

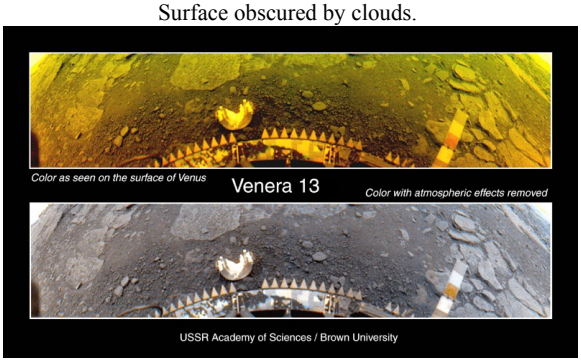
iClicker



B

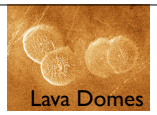
# Venus Surface

Surface obscured by clouds.




Mostly Basalts-like rocks, indicative of volcanoes

# Venus Surface

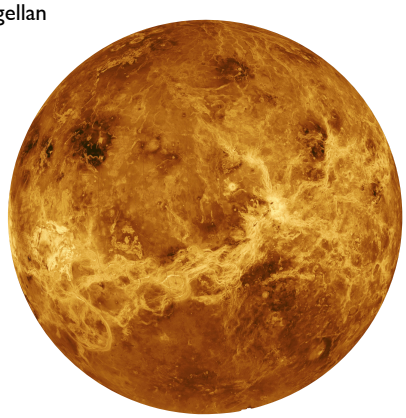



Mapped via RADAR by Magellan

Smooth lava flows

Many large volcanoes

Ongoing volcanism



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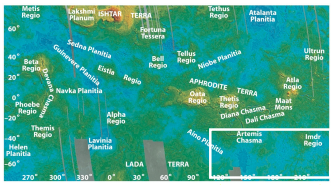
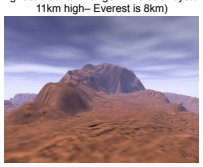
# Surface Features




Maxwell Montes (65N 5E)
(Highest mountain range in the solar system
11km high– Everest is 8km)

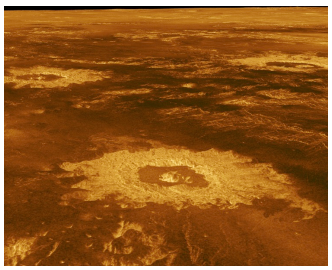


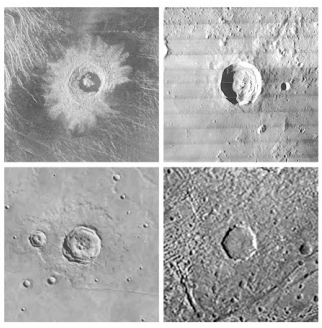
http://www.geology.smu.edu/~dpa-www/venus.html

50

2:10

# Impacts on Venus





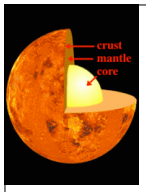
~1000 craters, generally clustered

No heavy bombardment

Surface young? < 500 Myr

51

– Possibility: Extreme temperatures soften rock, making the surface subject to catastrophic volcanic upheaval



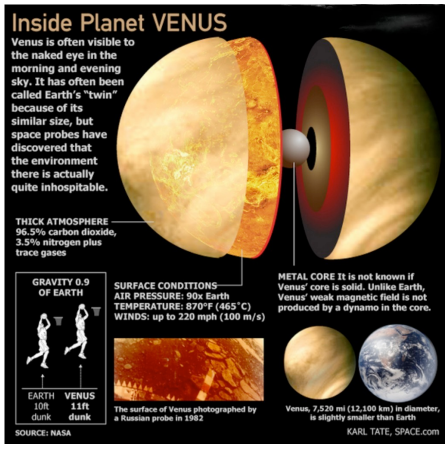

# Inside Venus

Slow rotation:
Retrograde!

Similar size to Earth

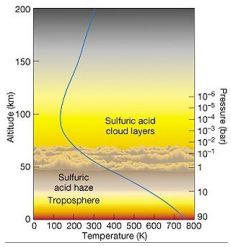
Iron core?

No magnetic field





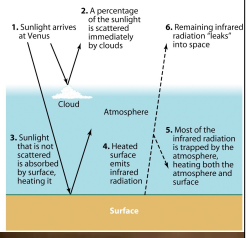

# Venus Atmosphere

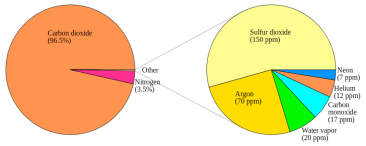


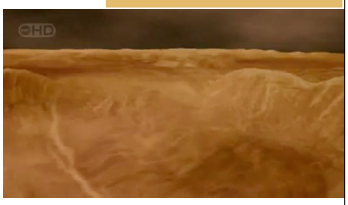

Runaway Greenhouse

on Earth ~ 35 K hotter

on Venus ~ 300 K hotter






On Earth, greenhouse gasses insulate us. Keep Earth 35 K warmer than it would be otherwise. On Venus, massive amounts of CO2 keep it incredibly hot
Almost 300 K warmer! The hottest planet in the Solar System.

# Life on Venus

Venus & Earth similar C + N

Oxygen on Earth: *Life*



Venus: too hot for liquid $H_2O$

Venus: No ocean to trap $CO_2$

Venus: No life to process C into sedimentary rocks

Earth: C dissolved in Oceans

Earth: C locked up in rocks & life



It really should have been more like Earth, but the atmosphere is much different. Earth's atmosphere is mostly O2 from life, but early Earth was N. Earth and Venus have similar amounts of carbon & nitrogen, but…

Earth's carbon is locked up. Dissolved in the oceans. Locked into rocks and life

Venus' carbon is in its atmosphere. Too close to the Sun for liquid water. No oceans to trap the carbon dioxide. No life to process the carbon into sedimentary rocks

# Life on Venus

What Happened?

Lost $H_2O$

Heats Atmosphere & Planet

$H_2O$ climbs into atmosphere: Broken apart by UV

H escapes into *Space*!

O binds to something else: C?

*Irreversible Process!*

$H_2O$ trapped in Tropopause @ 14 km

55

Apparently Venus lost its H2O– no oceans and no sediments. Probably the atmospheric temperature was hot enough for water to travel high enough to be broken apart by UV radiation, the H was lost and the O reacted with something else. Irreversible procedure! Which is why greenhouse effect is worrisome here too! The Earth traps water vapor in the cool tropopause at 14km.

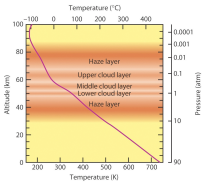
# Life on Venus

Surface is out too hot: Molten Lead

No cool polar regions

Life in the clouds (50 km)?

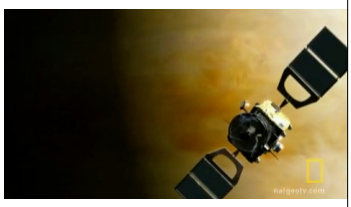
Maybe started on younger Venus's surface?




Chemical hints:

$S^{2-}$ and $SO_2$ exist, why?

Where is the CO?



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Surface is far too hot. If lead is liquid, think of what heat would do to complex organic polymers. No cooler polar regions exist. Heat is uniform! But, high in the clouds it should be cooler?! Maybe life can still exist in the clouds? At 50 km up, the temperature is not too hot and the pressure is 1 atmosphere.

High clouds in the atmosphere contain chemicals that hint at the presence of some kind of biological activity. Hydrogen sulfide and sulfur dioxide – two gases that react with each other– exist in the clouds. So, something may be producing them. Hardly any carbon monoxide, which should be there. So something may be removing CO.

One possibility is that microbes living in the clouds could be combining sulfur dioxide with carbon monoxide and possibly hydrogen sulphide or carbonyl sulphide in a metabolism similar to that of some terrestrial micro-organisms (extremophiles). Given that the temperature on Venus was once much cooler, there may once have been oceans on the planet. Life could have started there and retreated to stable niches once the runaway greenhouse effect began.
Maybe a mission to scoop up some atmosphere?

# Question

Where might Venus potentially harbor life?

a) In the cooler polar regions

b) Deep under the planet's surface

c) On its moon, Eros.

d) In the atmosphere

e) Nowhere, aliens kidnapped all venetian life

iClicker

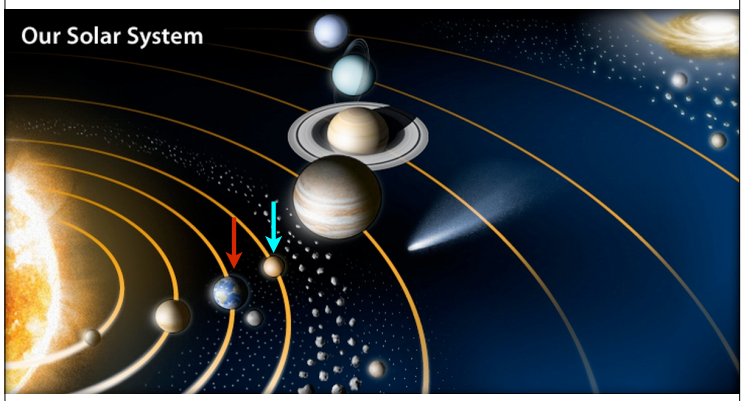
57

D

# Goodbye Venus

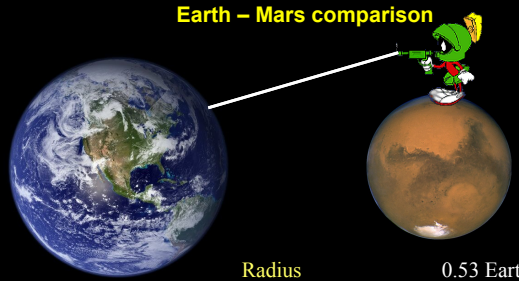



# Life in the Solar System?






## Earth – Mars comparison



Mars has the Solar System's largest Volcano, Olympus Mons–27 km tall, and two moons: Phobos & Deimos.

| | |
|---|---|
| Radius | 0.53 Earth |
| Surface gravity | 0.38 Earth |
| Mass | 0.11 Earth |
| Distance from Sun | 1.5 AU |
| Average Temp | -63 C |
| Max Temp | 20 C |
| Year | 687 Earth days |
| Length of Day | 24 hours 39 minutes |
| Atmosphere | $CO_2$ 95% |

# ♂ Mars

Jacques-Louis David, –*Mars désarmé par Vénus*

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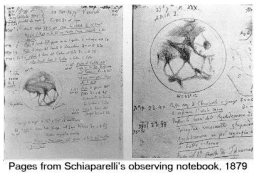
# Mars

Giovanni Virginio Schiaparelli

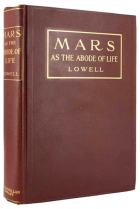
Regular, linear marking on surface



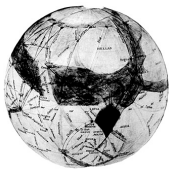
Pages from Schiaparelli's observing notebook, 1879

Canali: Italian for channels

English: Canals




Percival Lowell



Evidence of Intelligent Life

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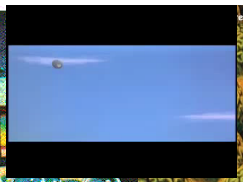
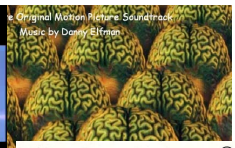
Similar to the Earth in many ways. Life was argued to exist on Mars. The astronomer Schiaparelli announced that he saw regular linear markings on the surface, which he named canali. Technically, in Italian means channels, but it was mistranslated to canals. Evidence for intelligent life? Mapped a civilization? Not true, but influenced culture.

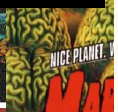
# Mars












Mars Visitors

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