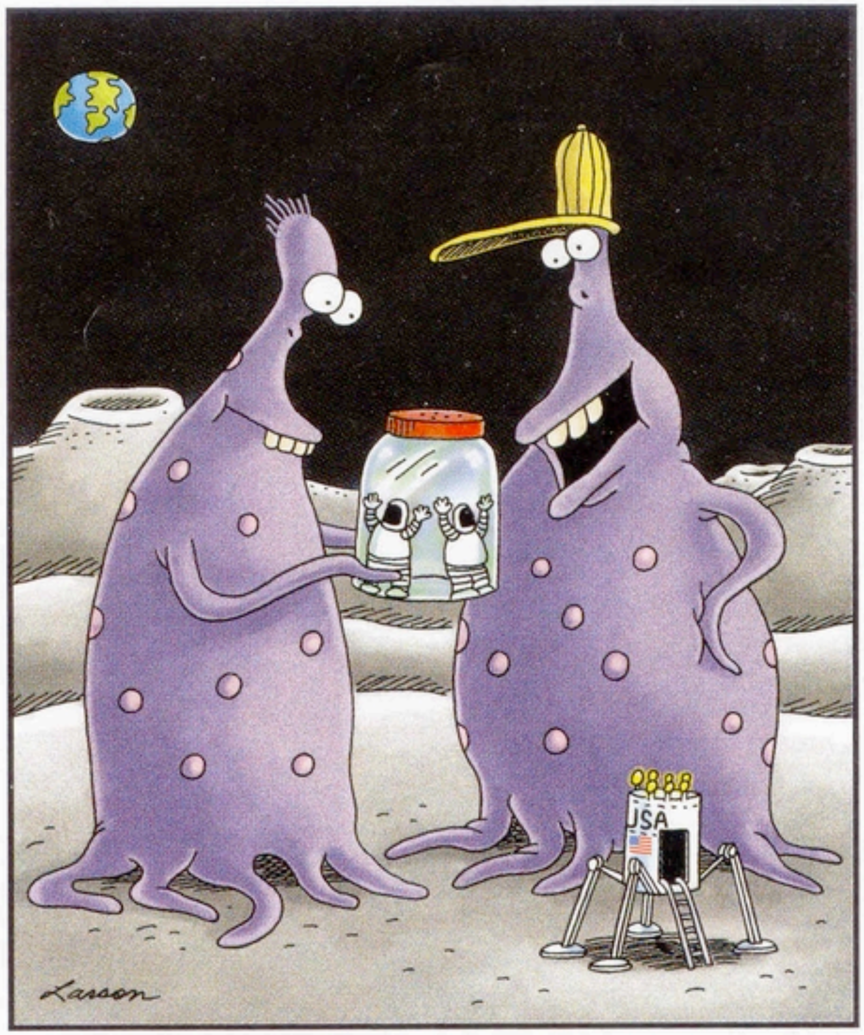
ASTR 380
The Requirements for Life



"Pretty cool, Dewey. Hey!
Shake the jar and see if they'll fight!"

Outline

- Chemical requirements
- Is water necessary?
- Type of star?
- Nature of solar system?
- Location in galaxy?
- An evaluation of other spots in our solar system

Midterm Results

- Average: 81%
  Nicely done!
- Numerical problem gave many trouble
  Remember, I link to websites that will help
- No letter grade assigned to just this exam
  Only class as a whole, at end

The Requirements for Life

Environmental Requirements for Originating Life:

- Chemical building blocks
- Energy
- a liquid medium
- stability

Environmental Requirements for Sustaining Life

- lowering the bar….

Looking at the Moon, Mercury and the Moons of Mars

The Environmental Requirements for Life

Chemical building blocks:

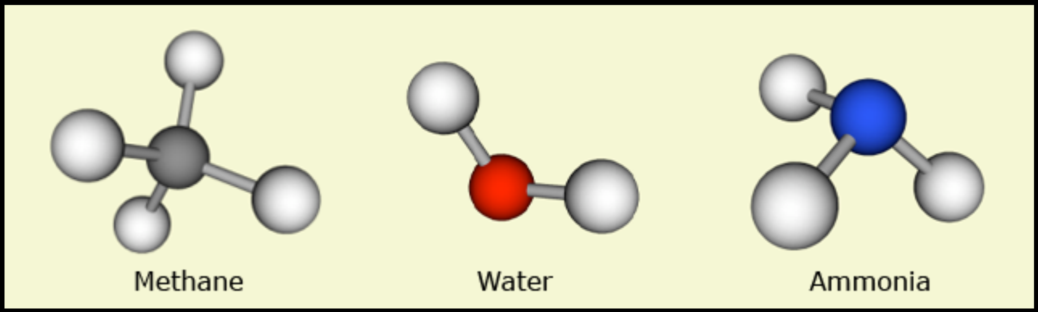
carbon, oxygen, nitrogen, hydrogen make up
96% of the mass of organisms on Earth

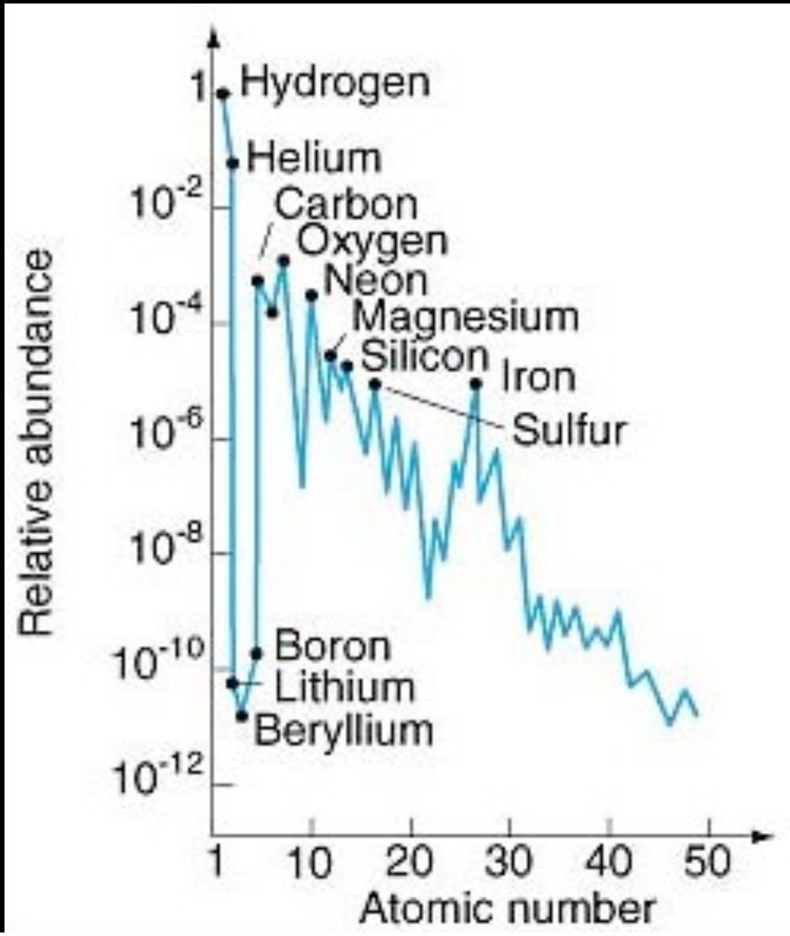
Why?

reasonable cosmic abundance

strong chemical bonds

complex chemistry possible

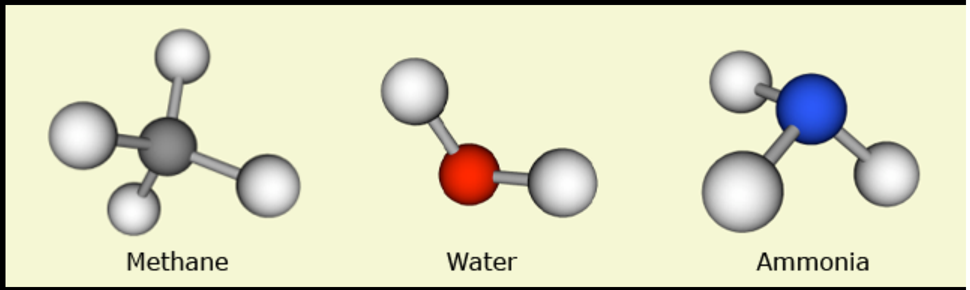




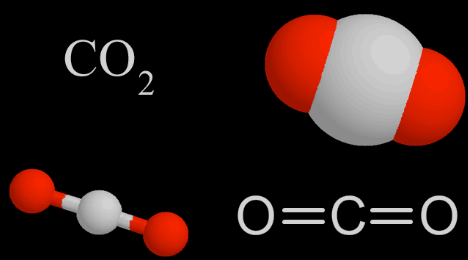
The Environmental Requirements for Life

Complex chemistry possible:

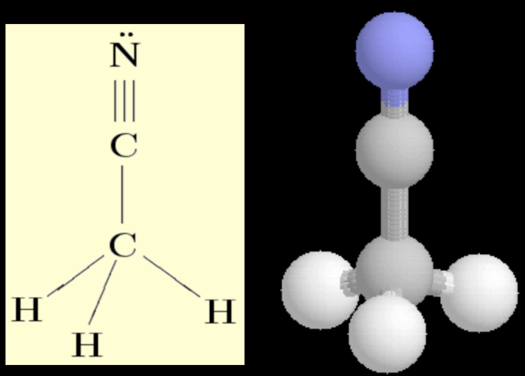
- Hydrogen forms 1 chemical bond
- Oxygen can form 2 chemical bonds
- Nitrogen can form 3 bonds
- Carbon can form 4 bonds



CH_4 H_2O NH_3



Carbon Dioxide



Methyl Cyanide CH_3CN

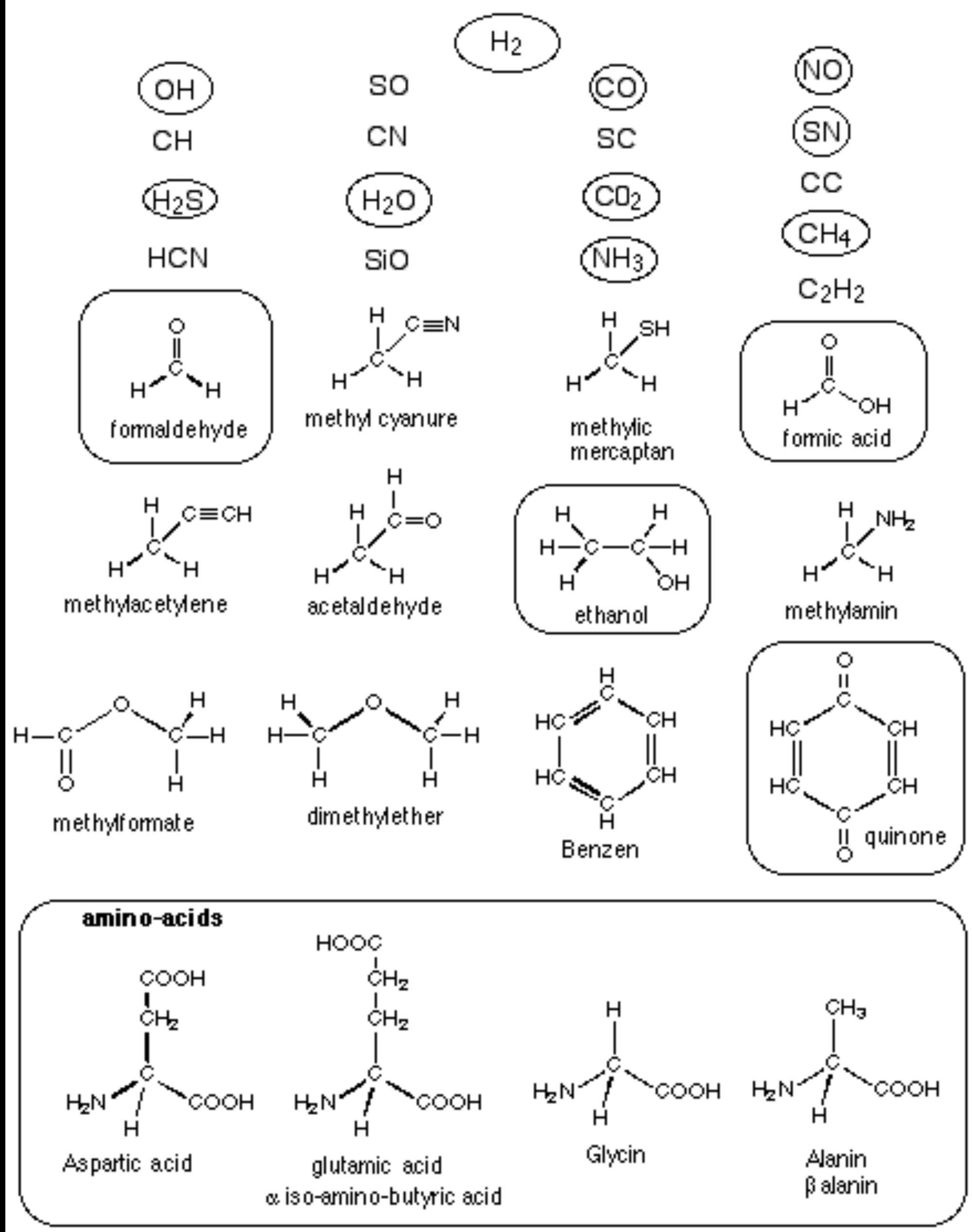
Methanol CH_3OH

The Environmental Requirements for Life

Complex chemistry possible with ability to form a variety of bonds.

Carbon can form chains and rings

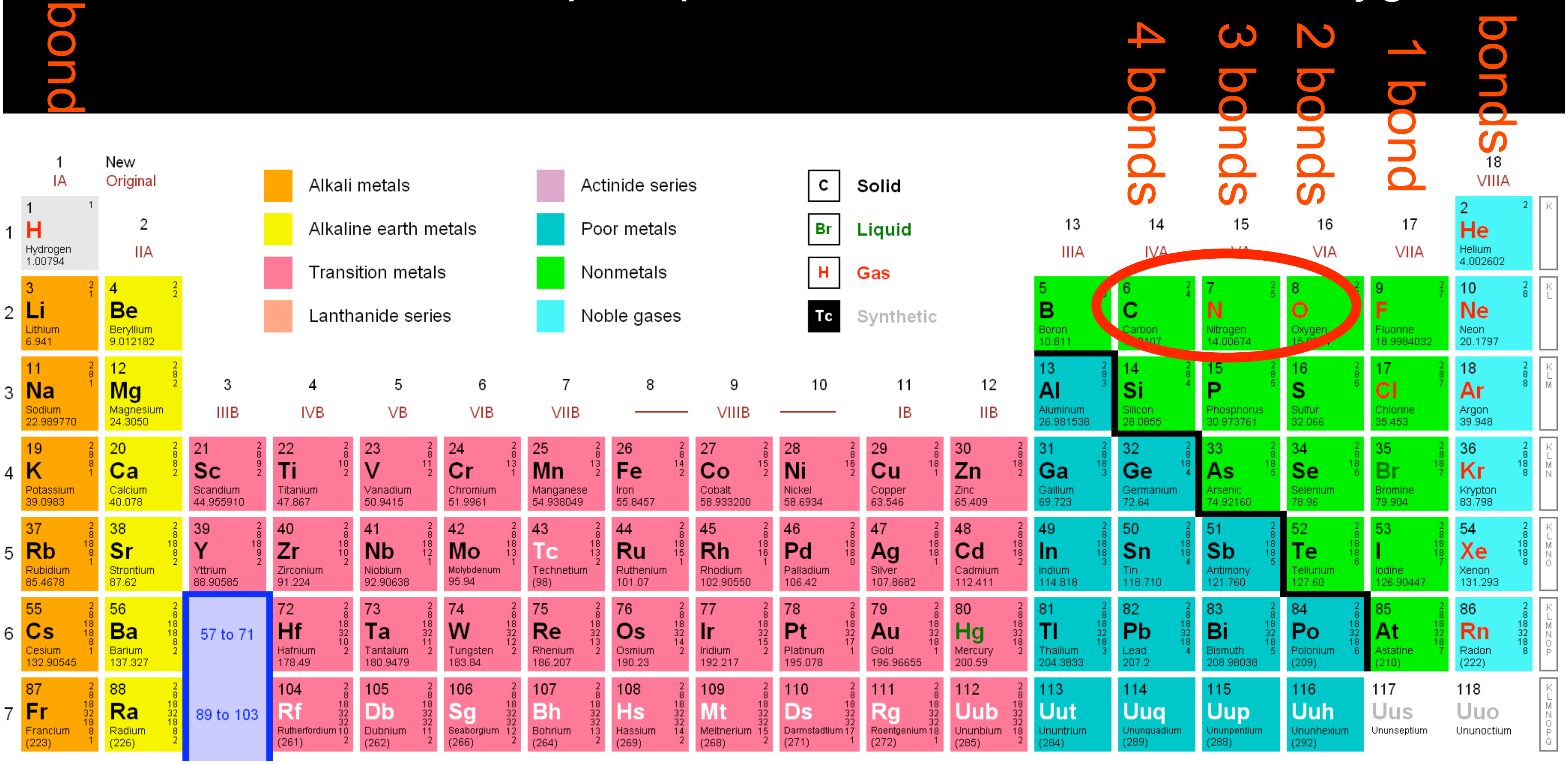
Other atoms like sulfur, calcium, iron, phosphorus play important roles in many essential bio-molecules



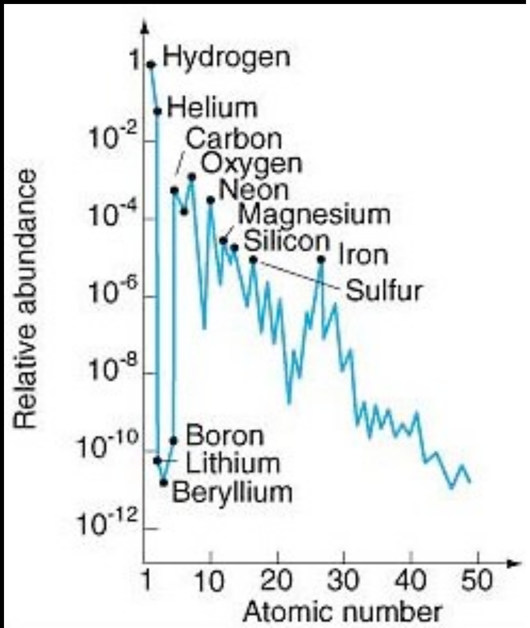
The Environmental Requirements for Life

What other chemistry might be good for life?

Bonding structure suggest silicon, phosphorus, and sulfur.
silicon for carbon, phosphorus for N and sulfur for oxygen



The Environmental Requirements for Life



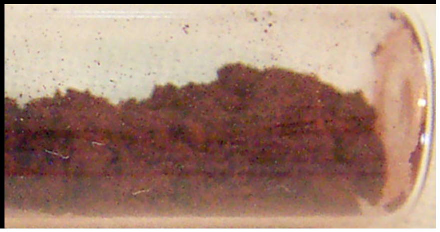
What other elements might be good for life?

Bonding structure suggests:
- silicon for carbon
- phosphorus for nitrogen
- sulfur for oxygen

But…..

SiO_2 = glass!
Silicon important in plants.

phosphorus is a solid at room temperature but is self-igniting when in contact with oxygen
It becomes a liquid at 317K = 111 F



The Environmental Requirements for Life

What other chemistry might be good for life?

Sulfur is solid at room temperature and becomes a liquid at 388K = 239 F

All three are insoluble in water!

But both sulfur and phosphorus are soluble in carbon disulfide which is a liquid between -112 C and 46C.

But carbon disulfide is flammable in the presence of oxygen and very reactive with other molecules in solution.

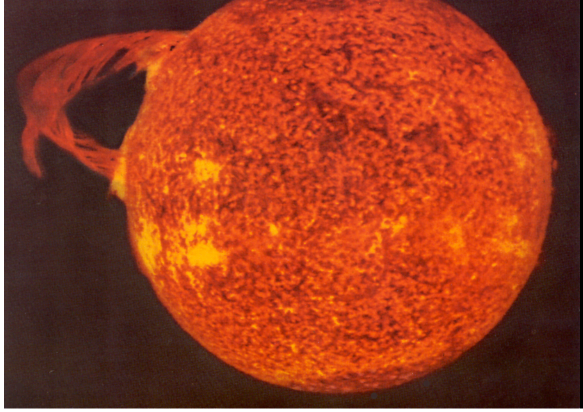
The Environmental Requirements for Life

Energy Requirements for Life:

The ultimate source of energy for much life on Earth now is the Sun.

- Plants harvest energy from sunlight
- Animals eat plants – sugars and starches
- Bacteria eat the complex molecules created by plants and animals.

The secondary source is geothermal activity which releases highly reactive molecules.



The Environmental Requirements for Life

Energy Requirements for Life:

Table 1. Planetary Data

Planet	Distance from Sun (AU)	Radius (km)	Albedo	Est. Temp (K)
Mercury	0.387	2439	0.06	100-700
Venus	0.723	6052	0.76	700
Earth	1.000	6371	0.30	288
Mars	1.524	3393	0.16	210-300
Jupiter	5.203	71,398	0.51	110-150
Saturn	9.54	60,000	0.50	95
Uranus	19.18	25,559	0.66	58
Neptune	30.06	24,800	0.62	56
Pluto	39.44	1140	0.4–0.6	40

Being farther from a star decreases the energy from sunlight – colder temperatures – less energy – less stored energy – chemical reaction, evolution, motion will go slower.

Tidal heating and geothermal activity might provide for some energy…. But would it be enough?

Also consider that evolution to complex multi-celled organisms requires even more energy!

The Environmental Requirements for Life

Does life require liquid water?

Life requires a way for molecules to be transported
to the organism: gas or liquid.

Life requires a way to move molecules within the cells.
liquid

Life requires a way to mediate/enable chemical reactions
liquid

In all life on Earth, water does all of these things….

The Environmental Requirements for Life

What are the alternatives to water?

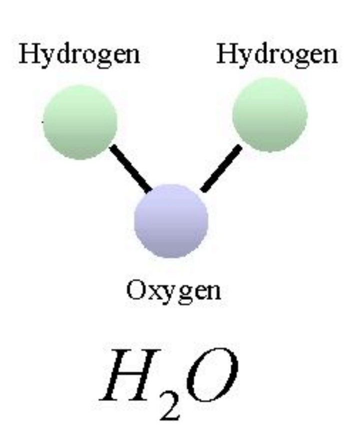
In standard Earth organic chemistry, ammonia methane, and ethane might be possible… but the liquid temperatures are cold.

All chemical reactions go slower at these cold temperatures.

Methane clathrates (methane and water) found on ocean floors suggest that alternative situations are possible….

Substance	Freezing Temperature	Boiling Temperature	Range
Water	0 C	100 C	100 C
Ammonia	-78 C	-33 C	45 C
Methane	-182 C	-164 C	18 C
Ethane	-183 C	-89 C	94 C

The Environmental Requirements for Life



Big advantages to water:

(1) Common molecule – found in comets

(2) Liquid over broad range of temperature

(3) Ice floats

(4) Water is a polar (= negative-positive charge separation) molecule which helps in dissolving things

(5) Water is a stable molecule so it does not enter into most reactions that occur in water.

The Environmental Requirements for Life

Stability:

It takes 10's to 100's of millions of years for life to happen. The environment must be stable on that timescale.

Implications:

- Day-night variations are not too extreme.
  --- no swings which can destroy molecules
- Seasonable variations are not too extreme.
  --- Planet is in reasonably circular orbit.
- Star is not too variable or short-lived.

Or are we being closed-minded?

- Organisms exist that can survive remarkable swings in environment
  Deinococcus radiodurans, for example
- Some large organisms require it
  E.g., plants needing fire to reproduce
- Could life evolve in such circumstances?
- How extreme is too extreme?

The Environmental Requirements for Life

Origin versus survivability:

There might be bacterial life on Earth which could survive on Mars on the polar caps….

There could be bacterial life on Earth which could survive on Mars 10 meters down in the soil.

If life exists on a moon of Jupiter, it is possible that life might survive if it were placed in the Jovian atmosphere. Maybe….

Endospores are dormant non-reproductive states entered by some bacteria to survive extreme heat, dry, poisons, and even in space for hours.

The Environmental Requirements for Life

Origin versus survivability:

The major change is that stability is likely less important!

In summary, life requires:

chemical building blocks – good arguments that C, N, O, and H are the best.

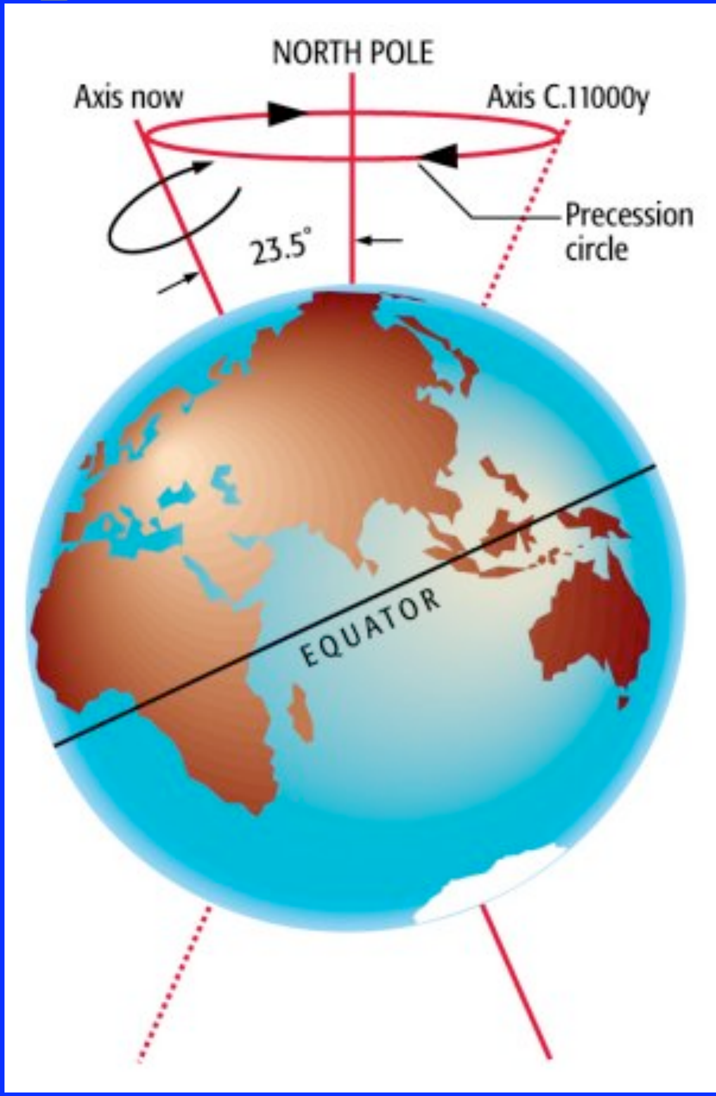
energy – reasonable arguments that the Sun is the best stable, long term source of energy

liquid – good arguments that water is best; ammonia and methane are possibilities.

stability – at least to get started (maybe!)

Precession of Equinoxes

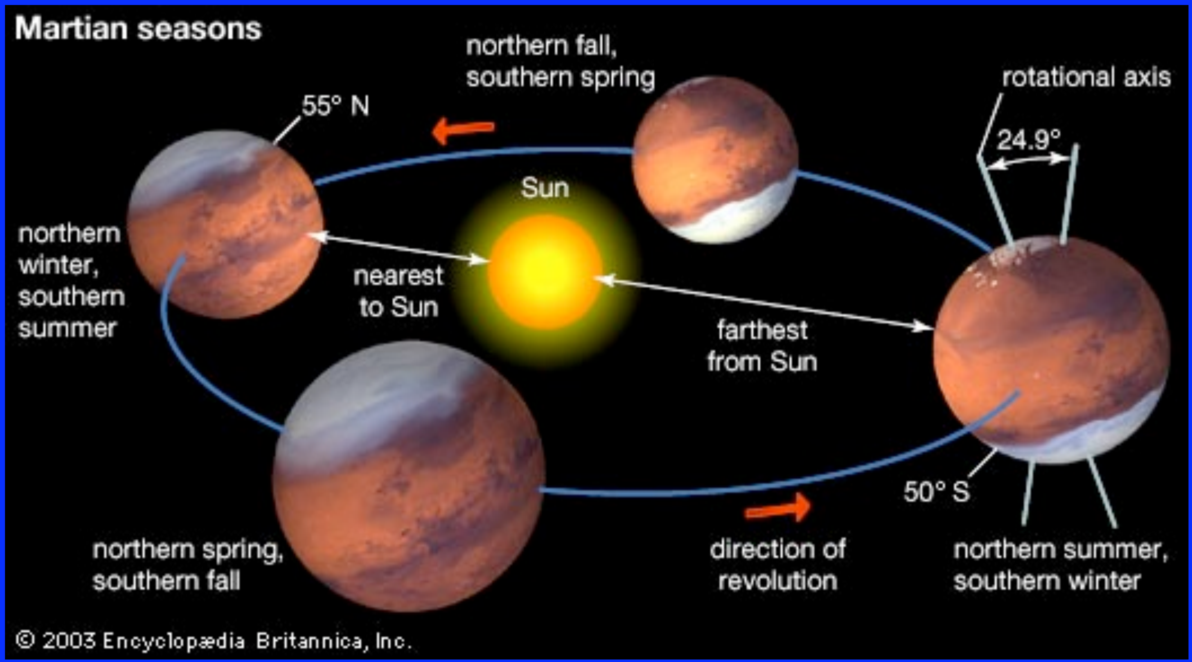
- Over 26,000 yrs, Earth's axis moves
- But tilt remains 23.5 degrees
  Stabilized by Moon
- Therefore, seasons are never too extreme



http://www.tectonic-forces.org/images/fig1.jpg

What About Mars?

- Currently, obliquity close to that of Earth
- But over millions of years, varies from 10 to 50 deg
- At large tilts, would have extreme seasons
- Is this a disqualifier?



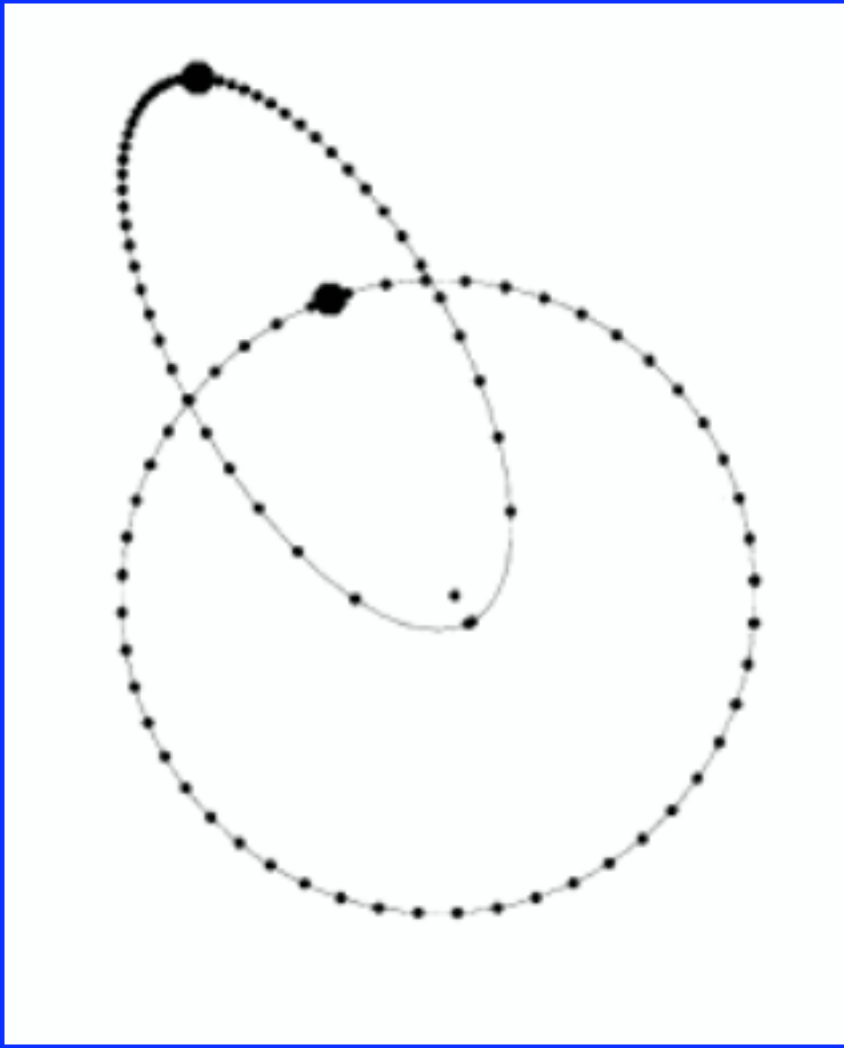
http://updatecenter.britannica.com/eb/image?binaryId=73524&rendTypeId=4

Pros and Cons of Climate Change

- Suppose we had a more variable climate
- Disadvantage
  Might be tougher on complex organisms, which tend to specialize to environment
- Advantage
  Changes over millions of years might stimulate evolution
- Which do you think would win out?

Eccentric Orbits: Ejection

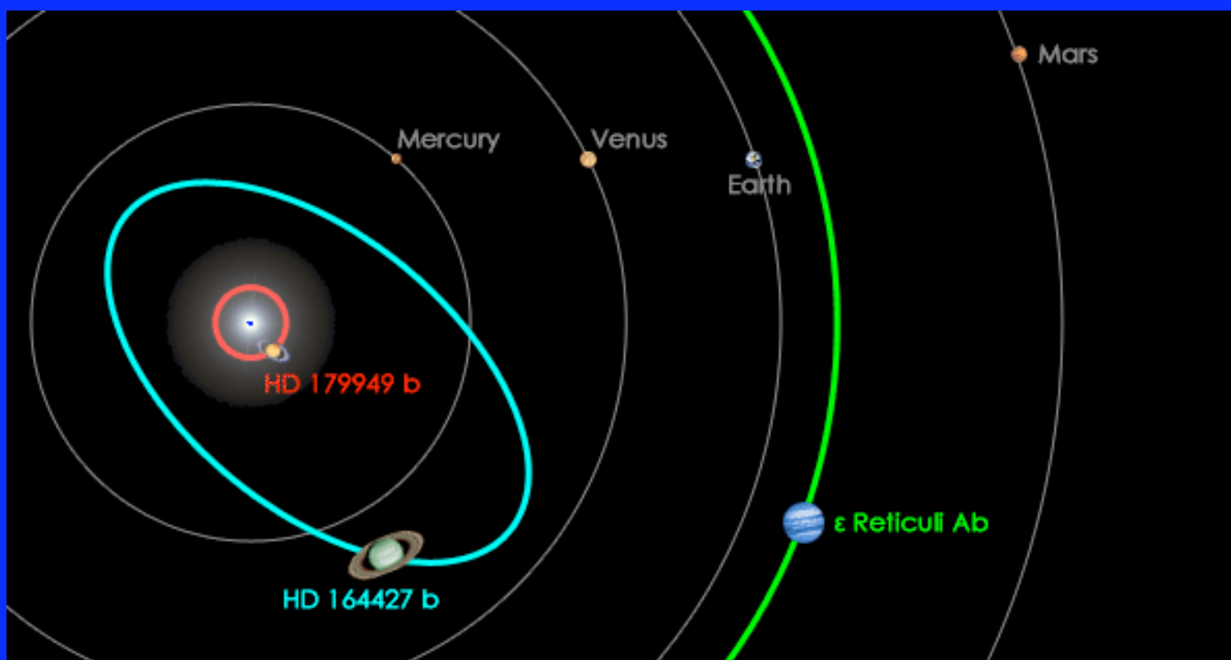
- Planets in Solar System have nearly circular orbits
- What if they didn't?
- If two orbits cross, one planet will be ejected eventually
- Therefore, planetary systems can't form this way



http://www.oklo.org/wp-content/images/analoghydro1.gif

Eccentric Orbits: Climate

- Nested eccentric orbits can be stable
- But distance variation means wide swings in temperature, extreme climate variation
- What are consequences?



The orbits of three planets: "HD 179949 b", "HD 164427 b" and "Epsilon Reticuli Ab" from three other star systems in comparison with each other, and also with our own inner solar system. © Gavin Rymill 06

http://www.gavinrymill.com/dinosaurs/extra-solar-planets/extra-solar-planets-reticulum.gif

Eccentricity and Climate

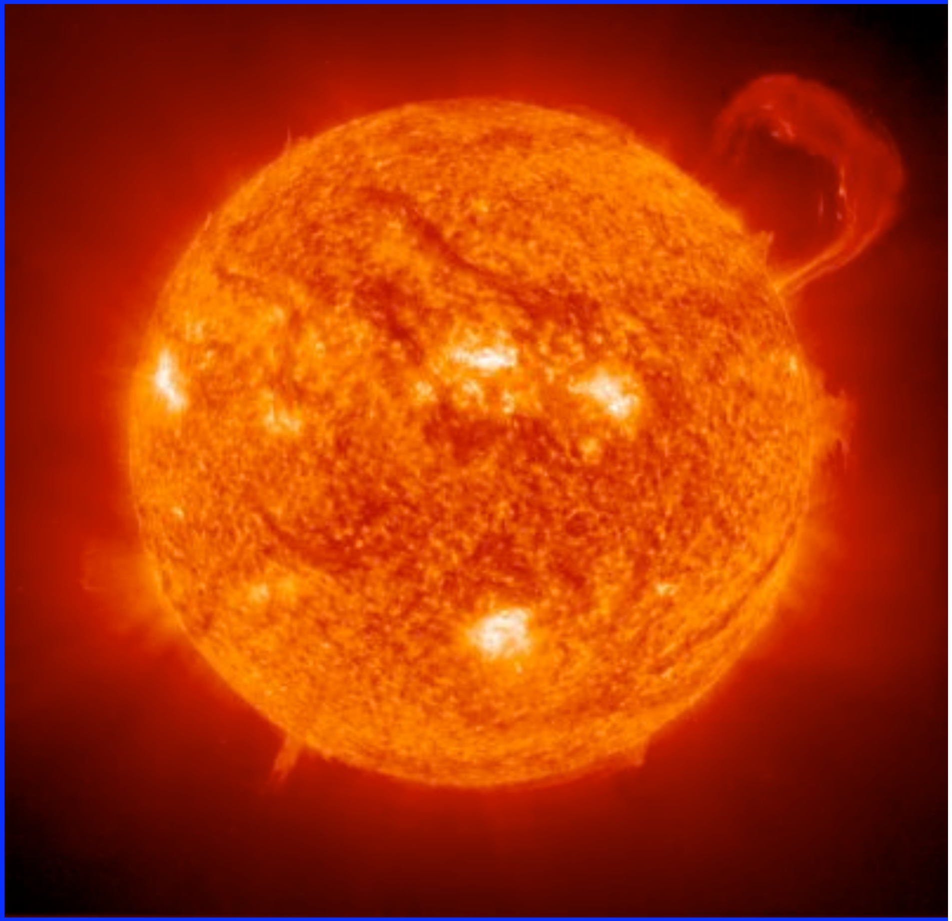
- At poles, go from zero solar illumination to illumination comparable to our winter
- But temperature doesn't change by nearly that much! Why not?
  Winds, reradiated heat
- High eccentricity could change illumination by much larger factor
- Stronger winds? Might compensate, though

The Example of Venus

- Venus has thickest atmosphere of terrestrials (90x Earth's pressure)
- "Day" is very long; about 120 days, noon to noon Without atmosphere, huge day/night change
- But with atmosphere, temperature is nearly constant over whole planet; day, night, equator, pole
- No atmosphere (Moon) means much more extreme swings
- Lessons?

Our Friend, the Sun

- Long-lived
  Now 4.6 Gyr old
  Time for evolution
- Very stable in short term
- But over its history, has increased its brightness by 30-40%
- How do other stars compare?



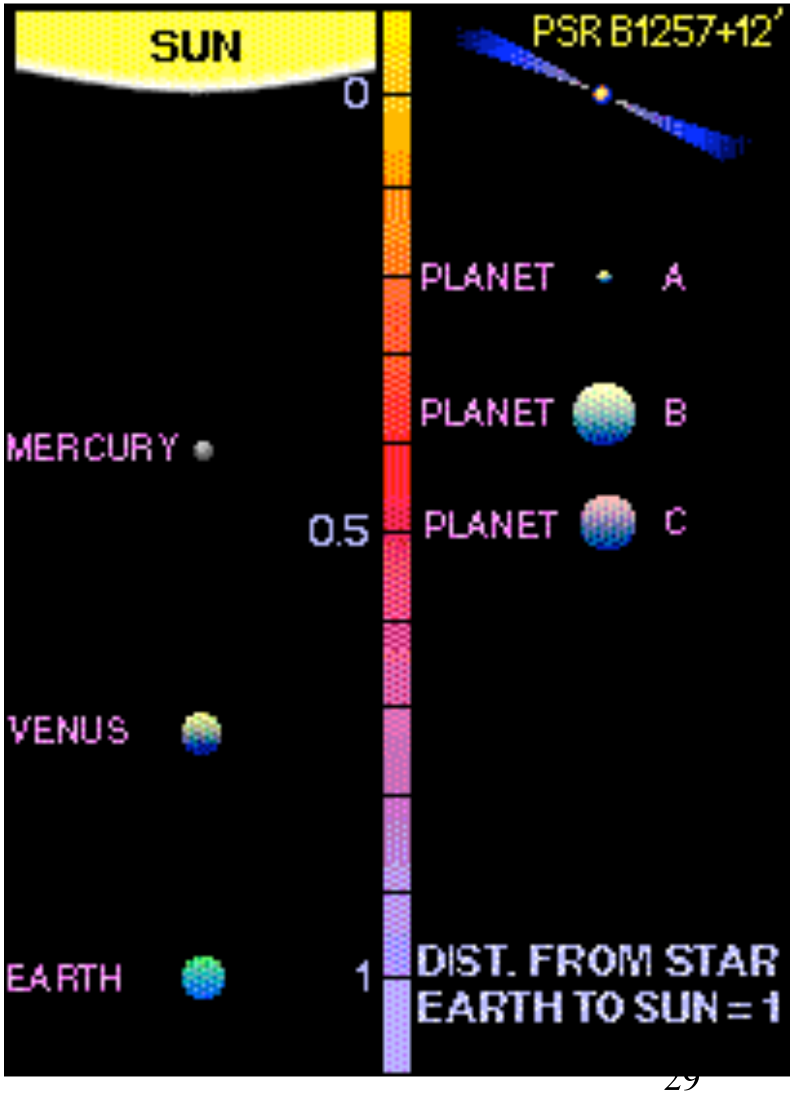
http://z.about.com/d/space/1/5/Y/Q/sun_tour.jpg

Other Stars: Preview

- We'll discuss this more later, but...
- Big stars live a short time
- Small stars live a long time but have larger flares, hence short-term changes in brightness
- How critical do you think it is to have a star much like our Sun?

Planets Around a Pulsar

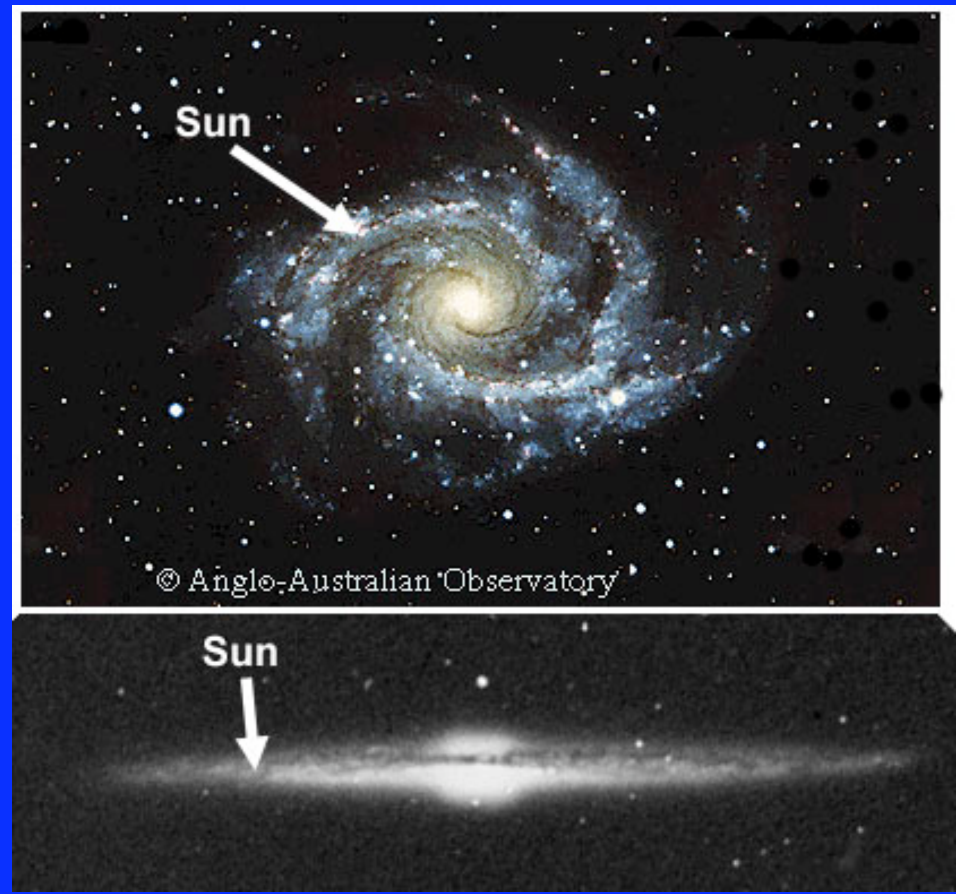
- First extrasolar planets discovered!
- Lots of energy, but in form of high-energy particles
- Subsurface life?



http://www.daviddarling.info/images/pulsar_planets.gif

Our Sun in Milky Way

- Sun is close enough to our galactic center that heavy elements are numerous
- But not close enough that nearby supernovae happen frequently
- How critical a balance do you think has to be struck?



Possibility of Life in the Inner Solar System

The Moon, Mercury, and the Moons of Mars

Moon

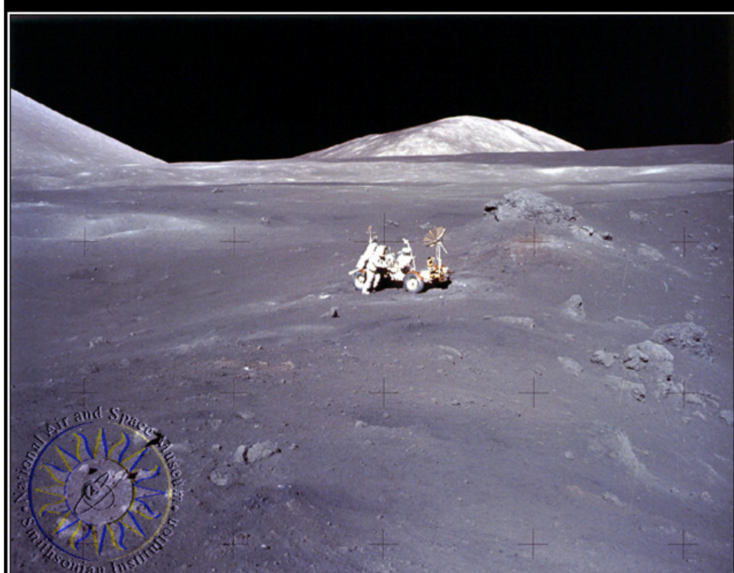
Mercury

Deimos

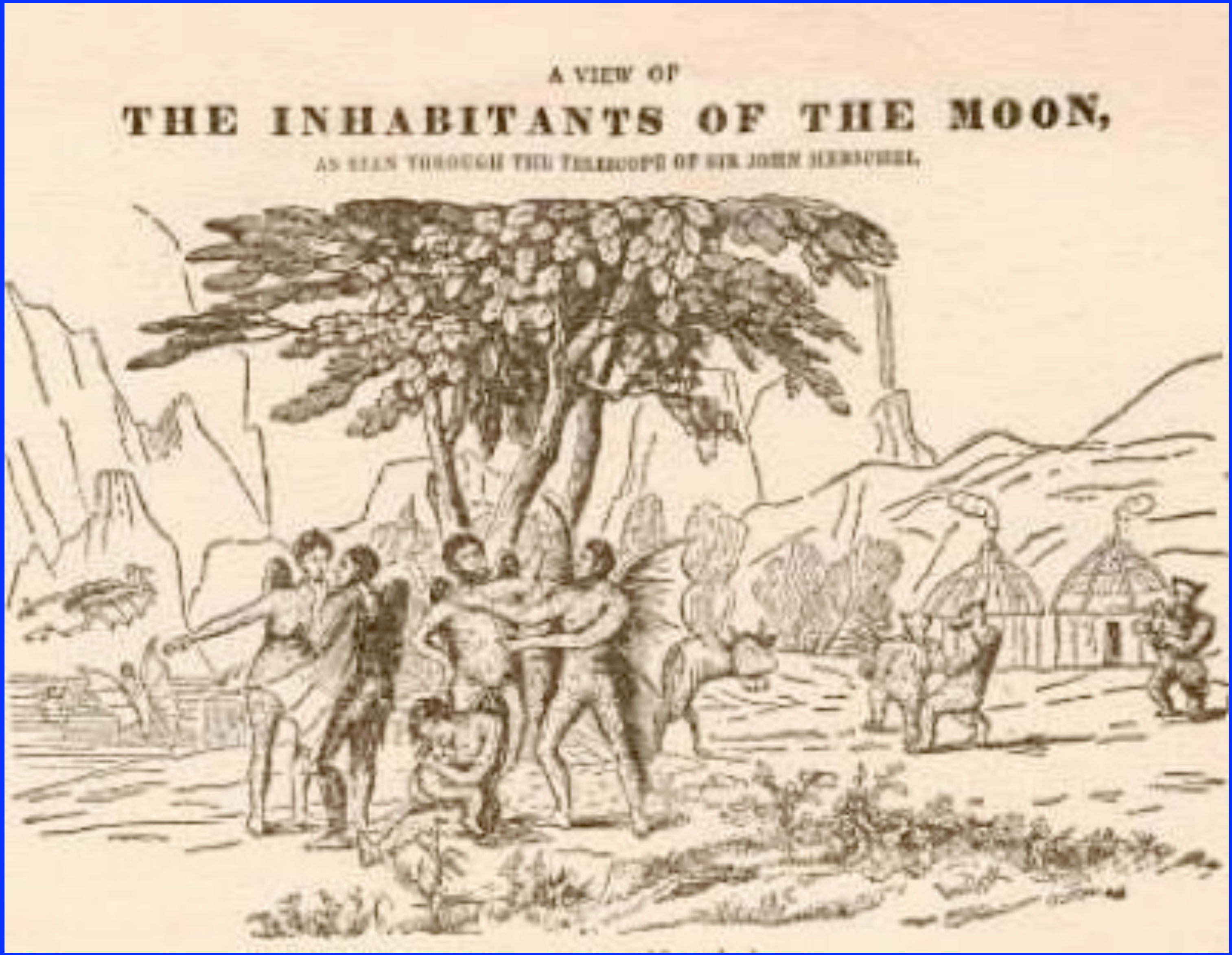
Phobos

Possibility of Life in the Inner Solar System

The Moon – Been there. Done that.



NY Sun, August 1835



Possibility of Life in the Inner Solar System

The Moon – Brought back rocks ☺

No atmosphere
No liquid on surface
Rocks show no evidence for life or complex organics

Ice might have been found in shadows of craters at pole – where sunlight never hits.

Ice is probably collected from comet hits on Moon.

Possibility of Life in the Inner Solar System

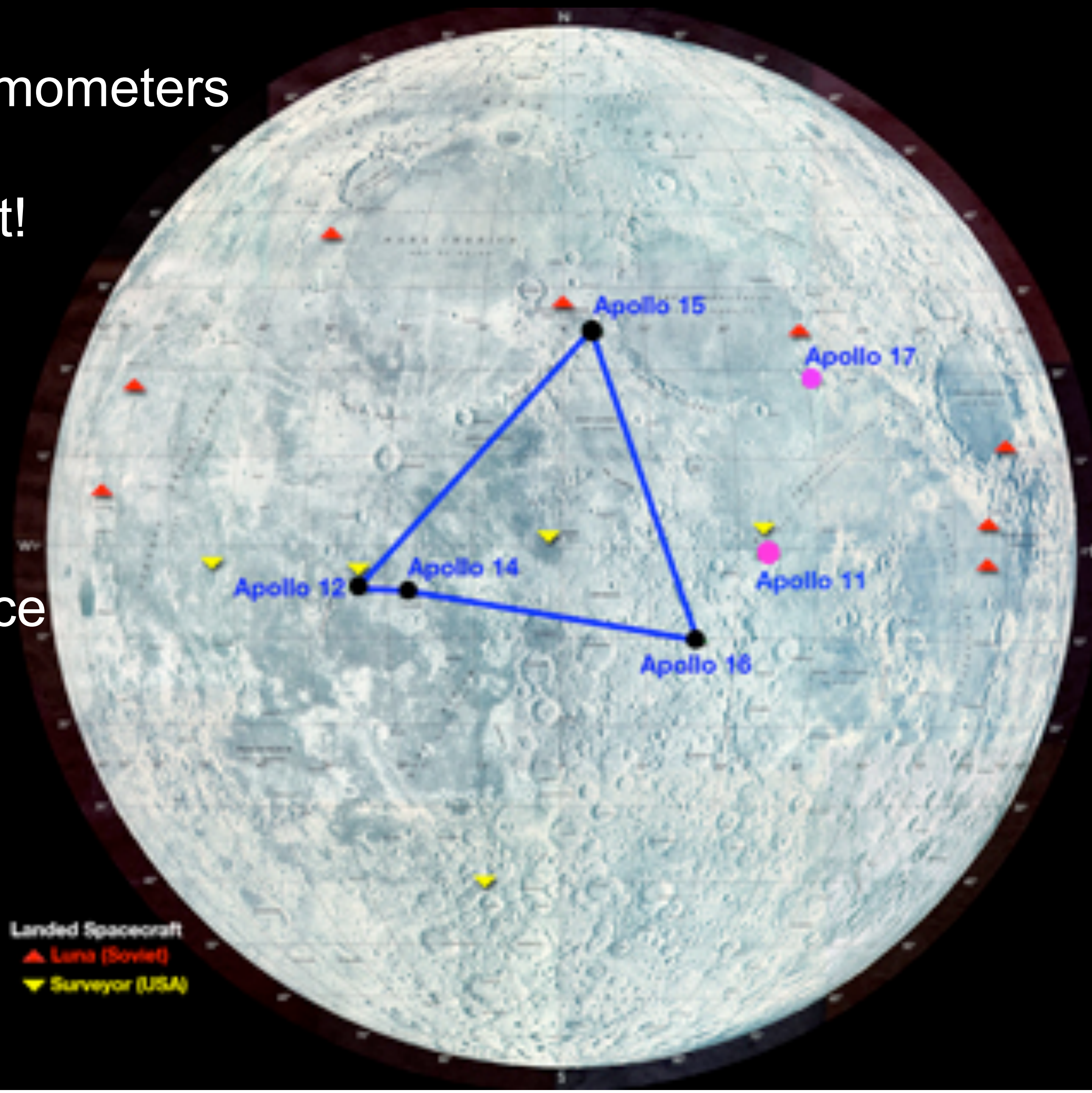
The Moon – left seismometers

Moon quakes exist!

Caused by:

- impacts
- tides from Sun
- heating of surface

Moon is no longer molten.



Possibility of Life in the Inner Solar System

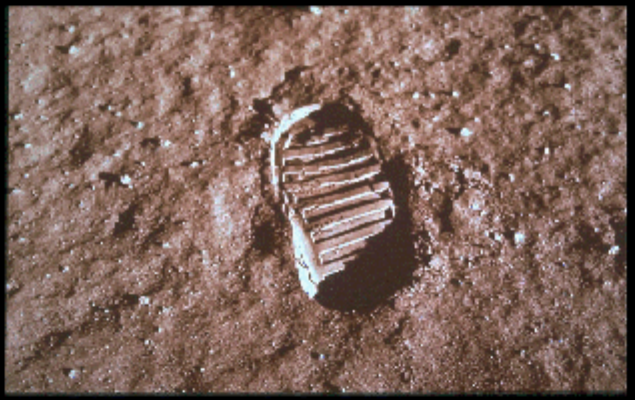
The Moon versus our checklist:

chemical building blocks: light on amounts of C, N, and O

energy: lots of sunlight

liquid: No. And no atmosphere

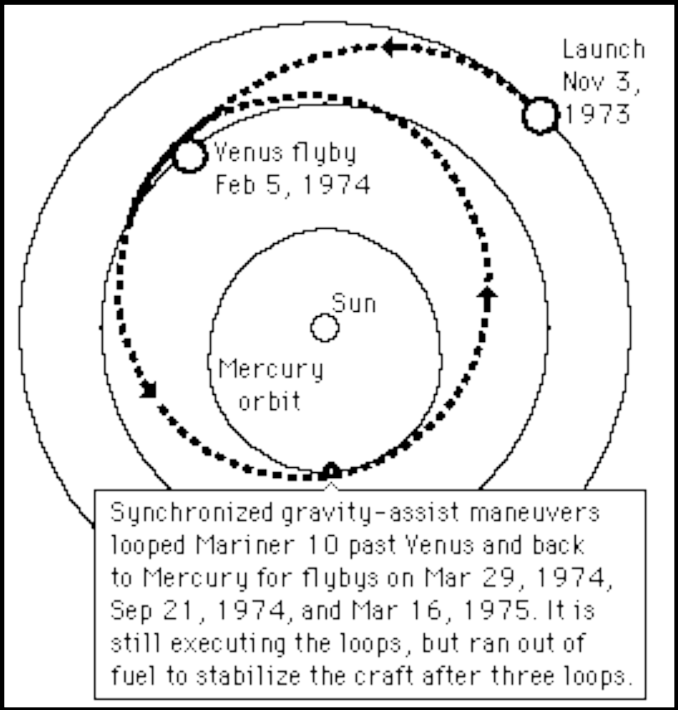
stability: Except near poles, 29 day day-night cycle
average day temperature = 107 C
average night temperature = -153 C

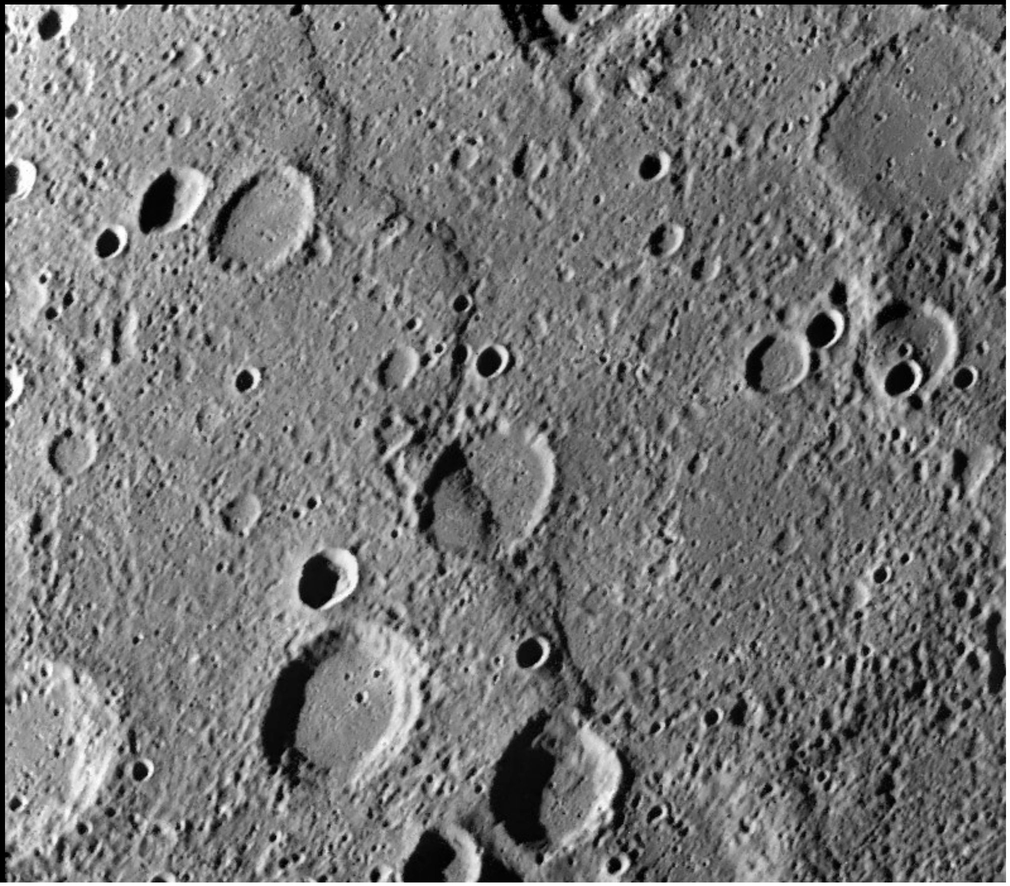


Possibility of Life in the Inner Solar System

Mercury: Mariner 10 spacecraft took pics in 1974

A flyby with the cameras rolling.





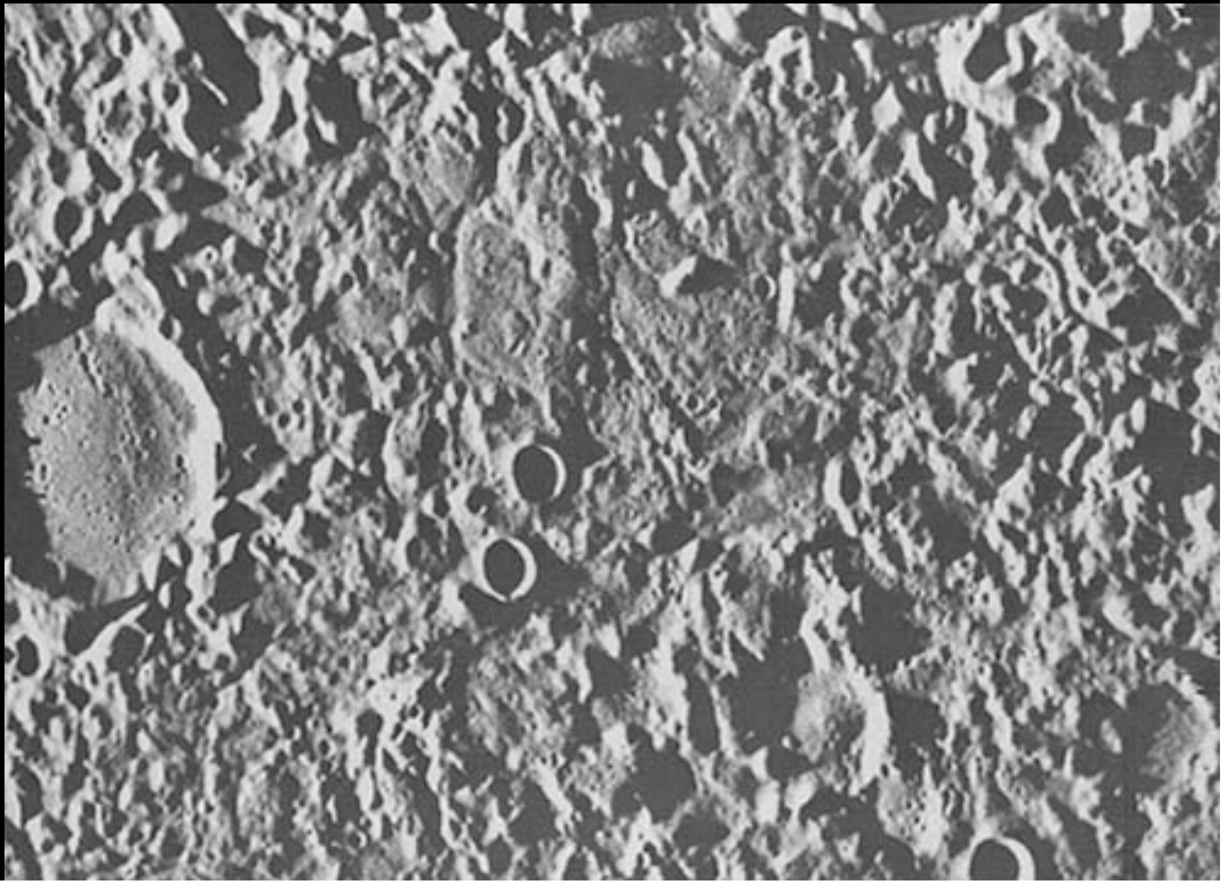
Possibility of Life in the Inner Solar System

Mercury:

- Old, very cratered surface
- No evidence of volcanic activity
- Has very thin atmosphere which is constantly escaping

No evidence for water

Core may still be molten but inactive mantle.



Possibility of Life in the Inner Solar System

Mercury versus our checklist:

chemical building blocks: 70% metallic and 30% silicate
may have lost much C, N, O in a late large
collision.

energy: lots and lots of sunlight

liquid: No. Nearly no atmosphere

stability: Due to 59 day long rotation (Mercury day)
and very slight atmosphere…
night time lows = -183 C
daytime highs = 427 C

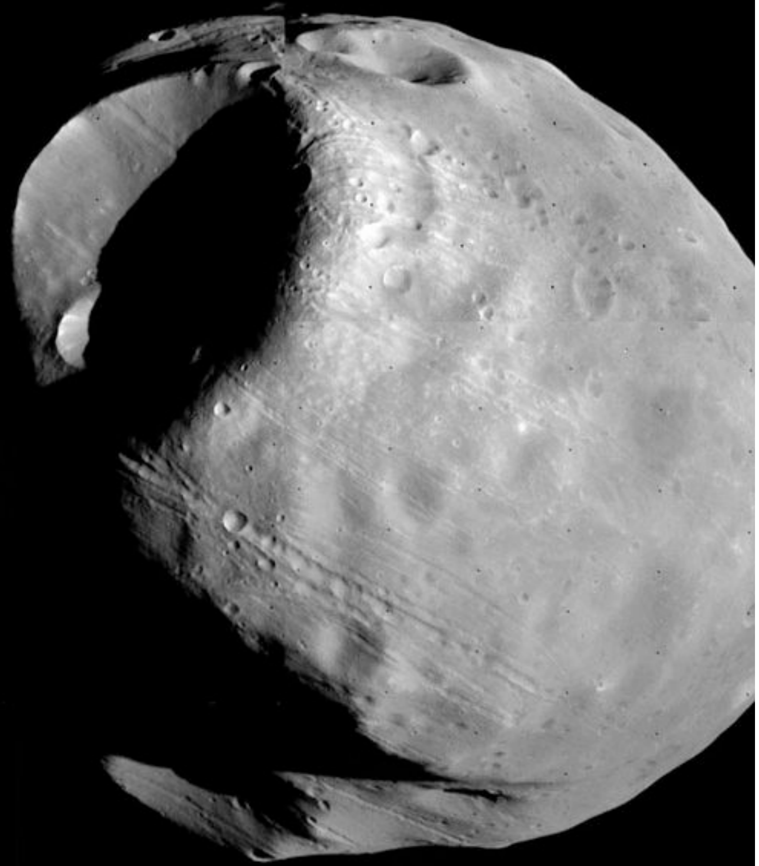
Possibility of Life in the Inner Solar System

Moons of Mars:

10-30 km in size, irregular shaped.

Deimos

Phobos



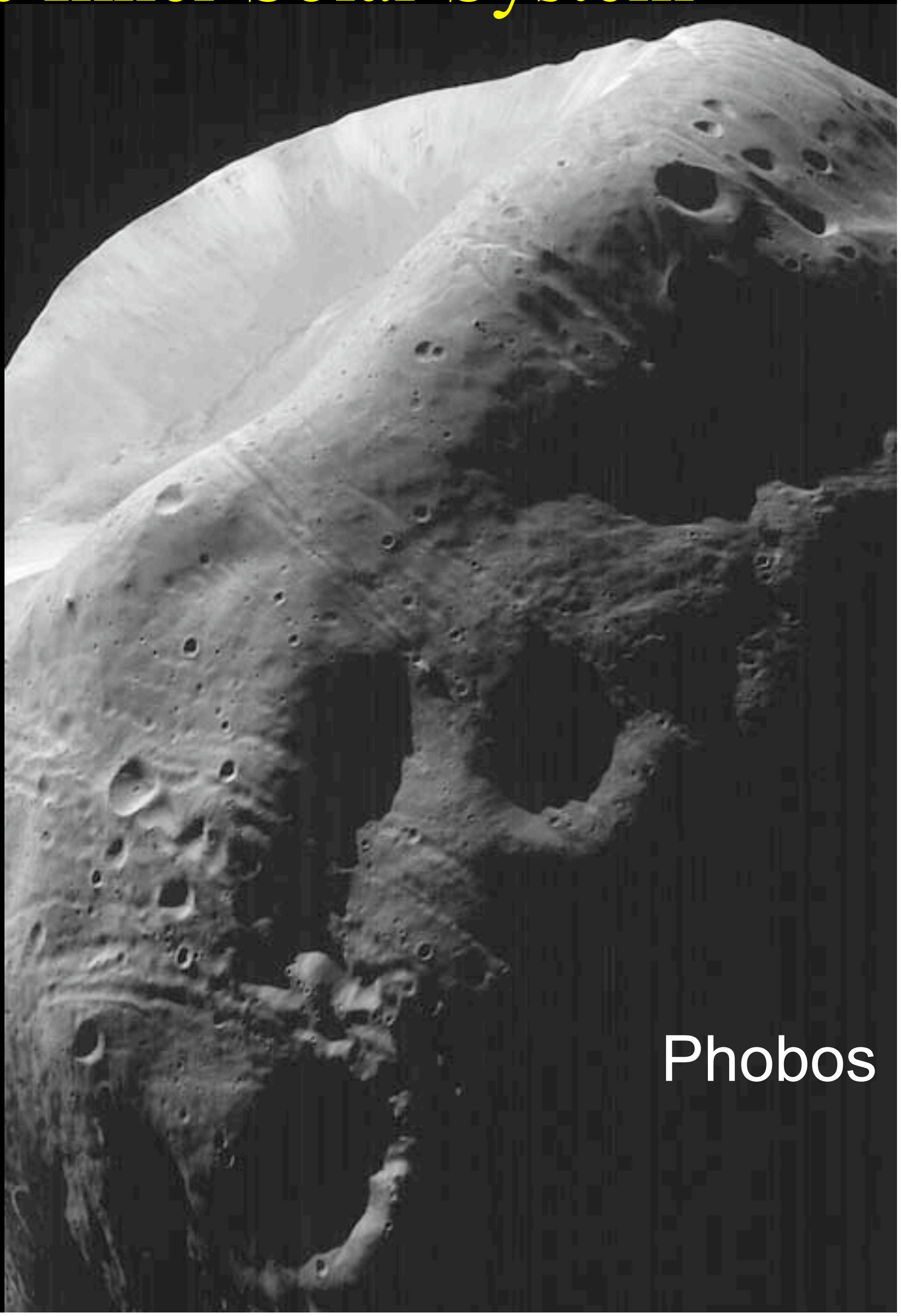
Possibility of Life in the Inner Solar System

Moons of Mars:

Both moons appear very similar to carbonaceous asteroids.

They are likely captured asteroids.

Surface temperature is around -40 C on average



Phobos

Possibility of Life in the Inner Solar System

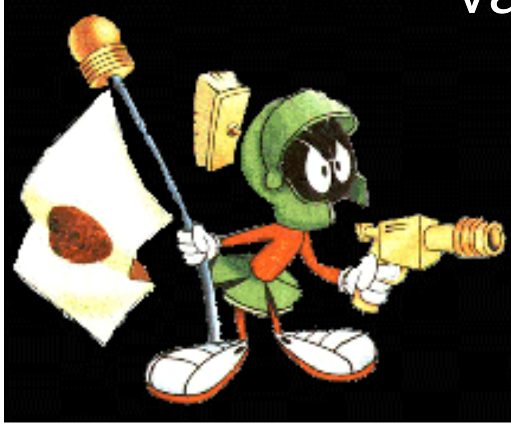
The Moons of Mars versus our checklist:

chemical building blocks: Carbonaceous asteroids so good C,N,O

energy: reasonable sunlight

liquid: No. No ices. No atmosphere

stability: Probably reasonable but no data on temperature variations at specific locations on moons



Summary

- As far as we can tell, carbon chemistry and liquid water are really good for life
- We are indeed in a good place for this, but it is not clear how strong the requirements are
- Moon, Mercury, moons of Mars not great for life