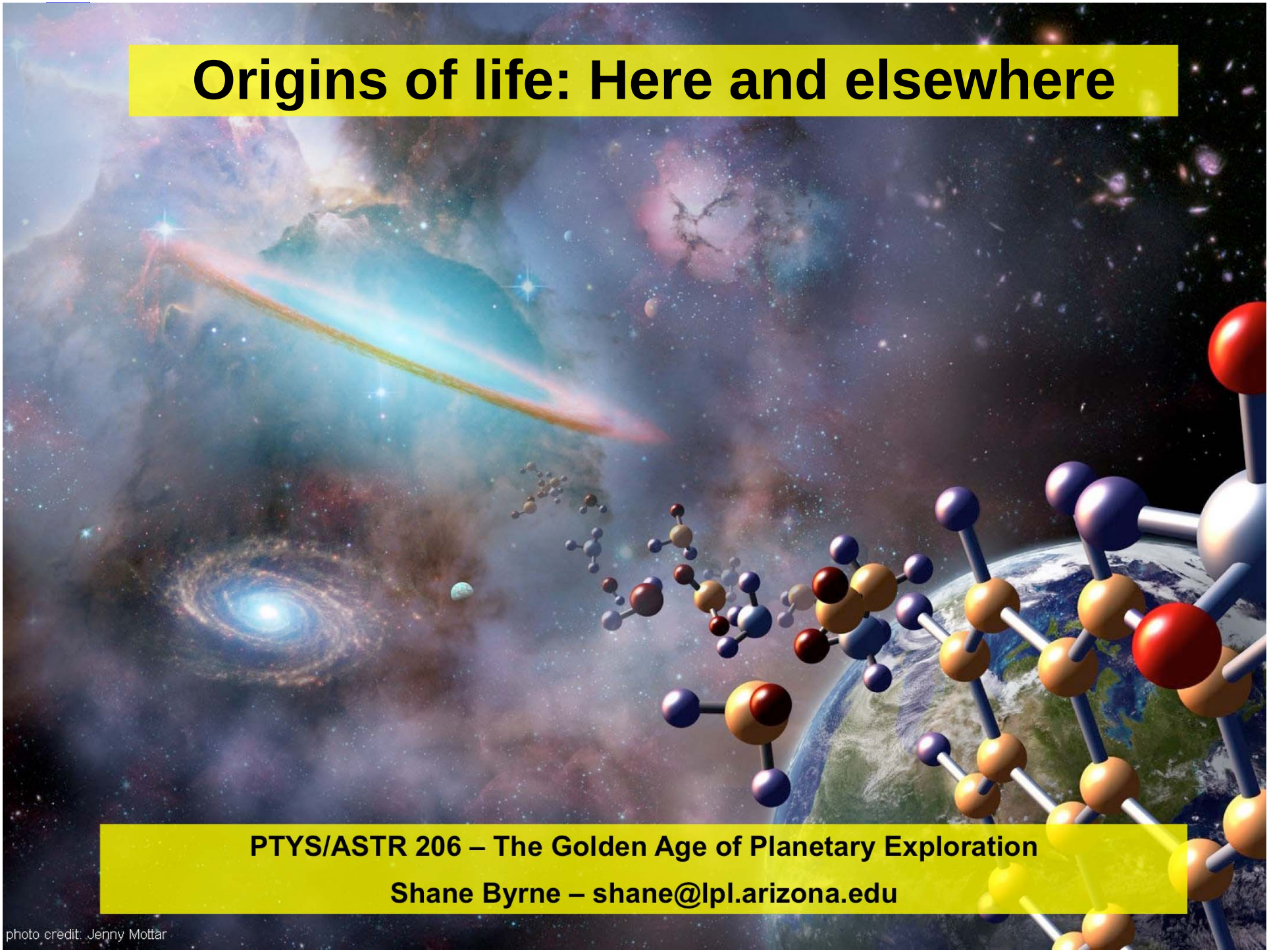
- **Announcements**
  - **HW6 due now for 50% credit**
  - **Last in-class activity today**
  - **Comments on the final**
  - **No ‘office hours’ today as we’ve run out of assignments**
    - **Ask for grades via email**
    - **Meetings about course material for anyone interested**
      - **We can set up a time by email**
      - **Or come talk to me after the lecture**

Origins of life: Here and elsewhere



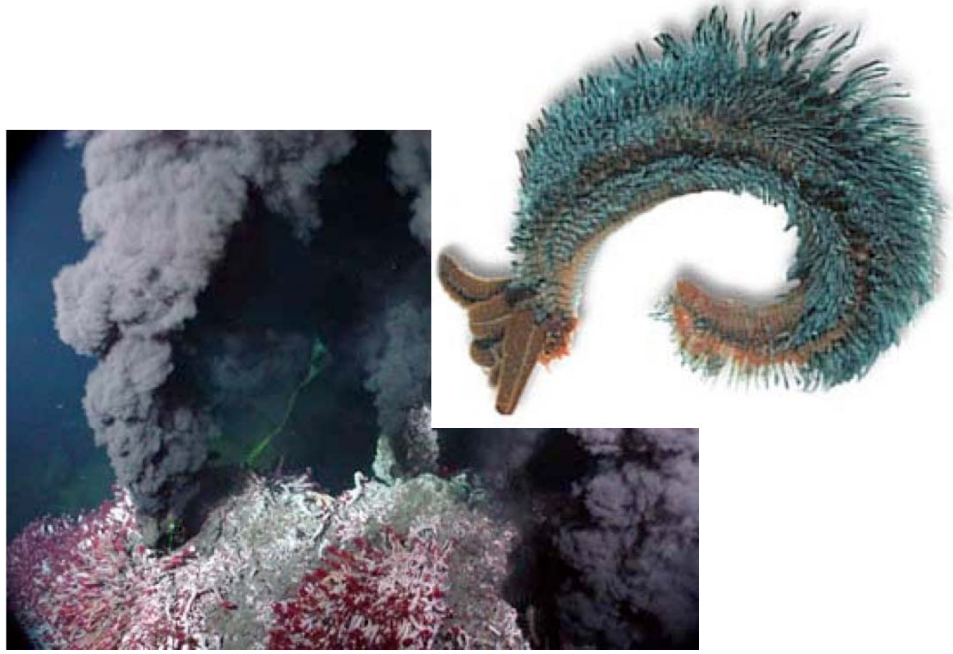
PTYS/ASTR 206 – The Golden Age of Planetary Exploration

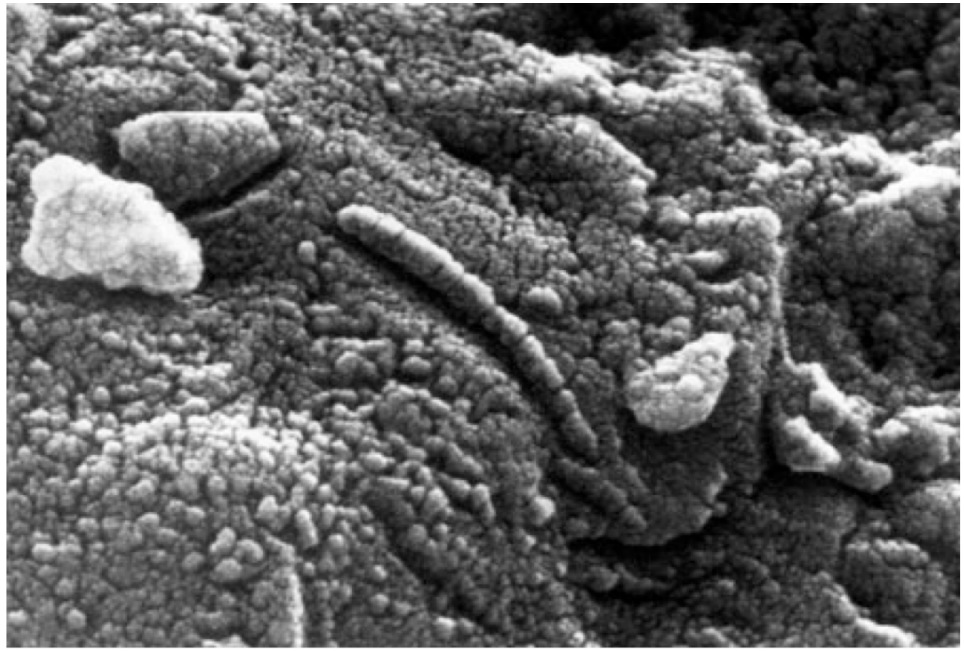
Shane Byrne – shane@lpl.arizona.edu

photo credit: Jenny Mottar

In this lecture…

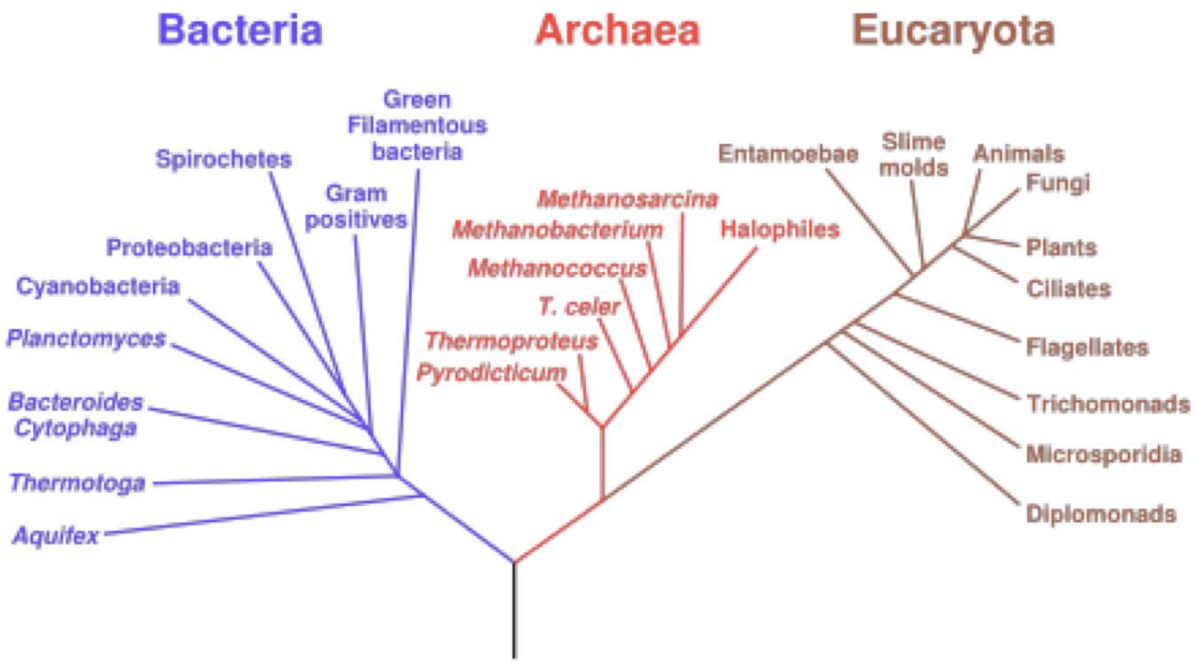
- Requirements for life
  - Carbon compounds
  - Energy
  - Liquid water
- Building a habitable planet
  - Galactic location
  - Planetary location
  - Planetary companions
- The Early Earth
  - Plates and Volcanoes
  - Impacts
  - Evidence for early oceans
- Life on Earth
  - Earliest evidence
  - Rise of Oxygen
- Life outside Earth?
  - Mars, Europa & elsewhere





- What's "Alive"?

- There's no formal definition
- Common characteristics proposed
  - Homeostasis
  - Organization
  - Metabolism
  - Growth
  - Reproduction
    - Including adaptation
  - Response to stimuli



Requirements

- **Three basic building blocks**

Carbon

Energy

Liquid water

- **Organic molecules require carbon**
  - **Manufactured in nuclear reactions in big stars**
  - **Carbon is an abundant material**
    - **But not on the Earth!**
  - **Life gathers and concentrates sparse elements like carbon**

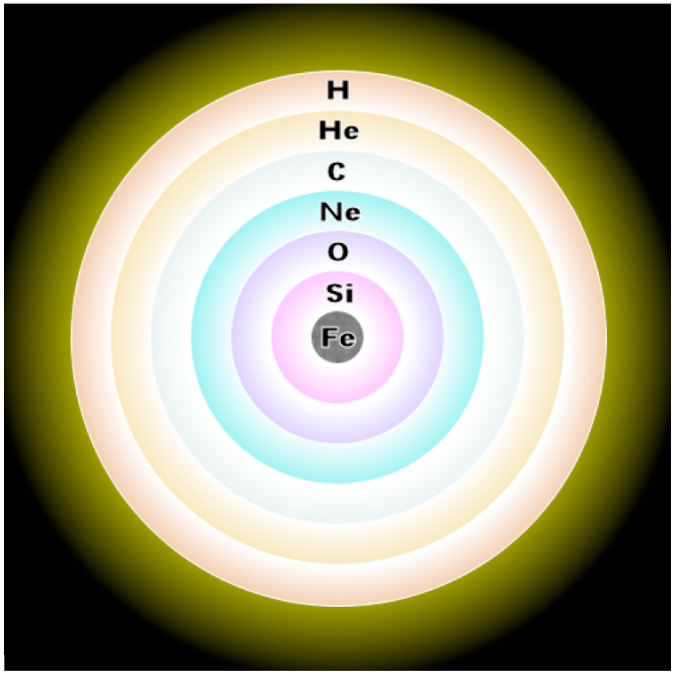
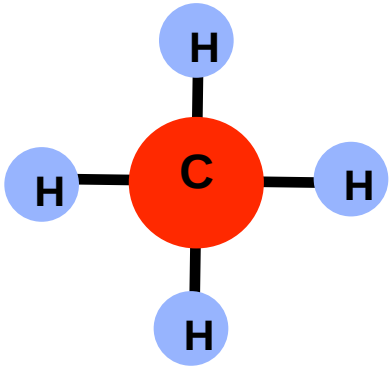
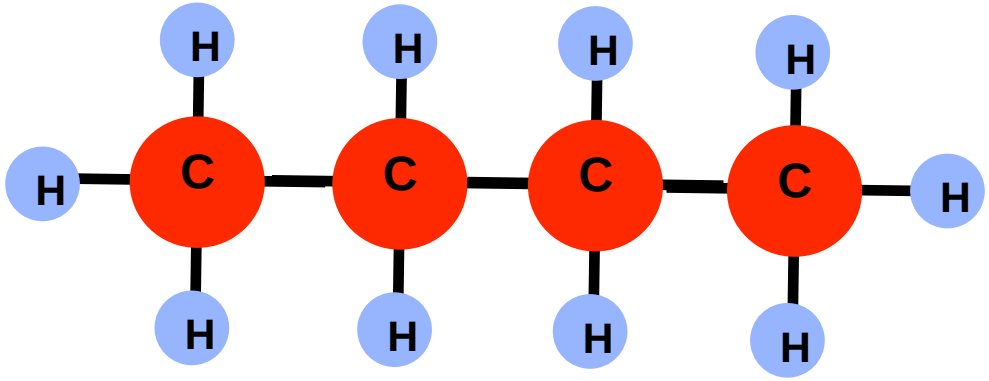


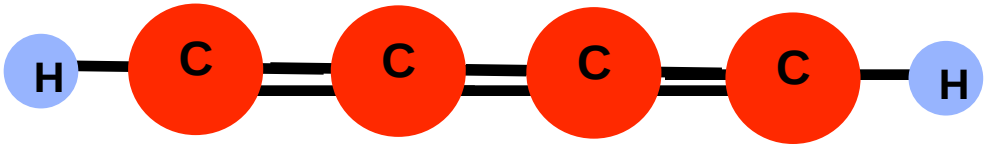
Table 1.1 The ten most abundant elements in the Universe, Earth and life (expressed as atoms of the element per 100 000 total atoms).

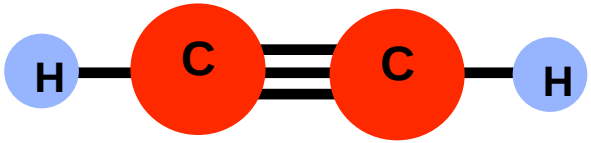
Order	Universe		Whole Earth		Earth's crust		Earth's ocean		Humans	
1	H	92 714	O	48 880	O	60 425	H	66 200	H	60 563
2	He	7 185	Fe	18 870	Si	20 475	O	33 100	O	25 670
3	O	50	Si	14 000	Al	6 251	Cl	340	C	10 680
4	Ne	20	Mg	12 500	H	2 882	Na	290	N	2 440
5	N	15	S	11 400	Na	2 155	Mg	34	Ca	230
6	C	8	Ni	1 400	Ca	1 878	S	17	P	130
7	Si	2.3	Al	1 300	Fe	1 858	Ca	6	S	130
8	Mg	2.1	Na	640	Mg	1 784	K	6	Na	75
9	Fe	1.4	Ca	460	K	1 374	C	1.4	K	37
10	S	0.9	P	140	Ti	191	Si	–	Cl	33

- **Why is carbon so useful?**
  - **Up to four bonds**
    - **Can bond in many different ways**
  - **Bonds with:**
    - **Hydrogen**
    - **Nitrogen**
    - **Oxygen**

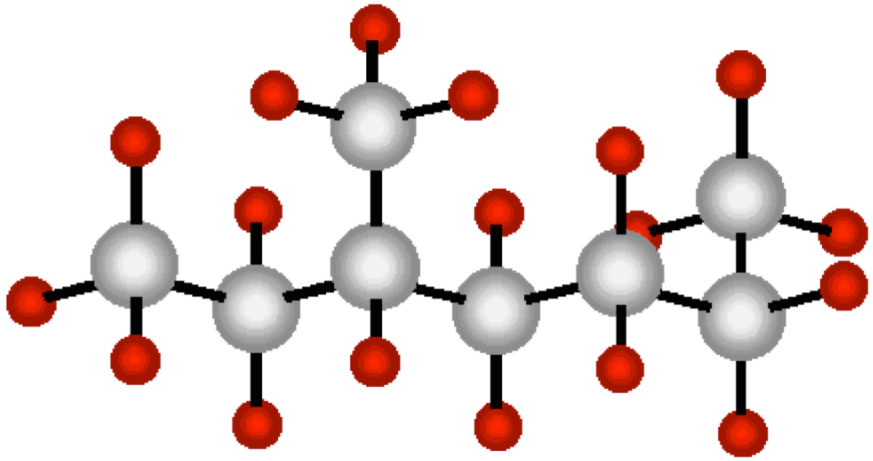


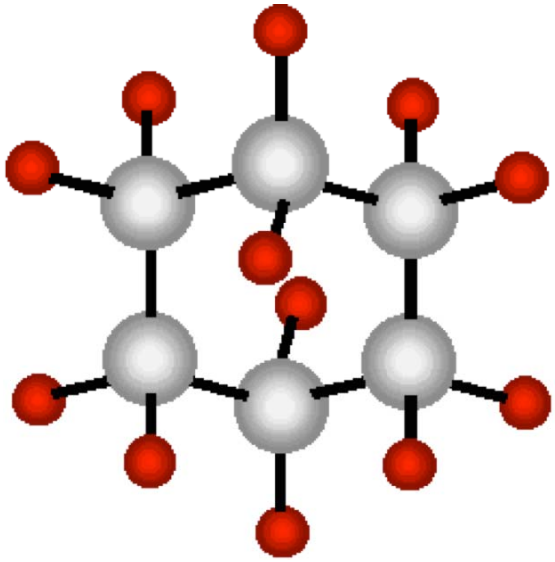


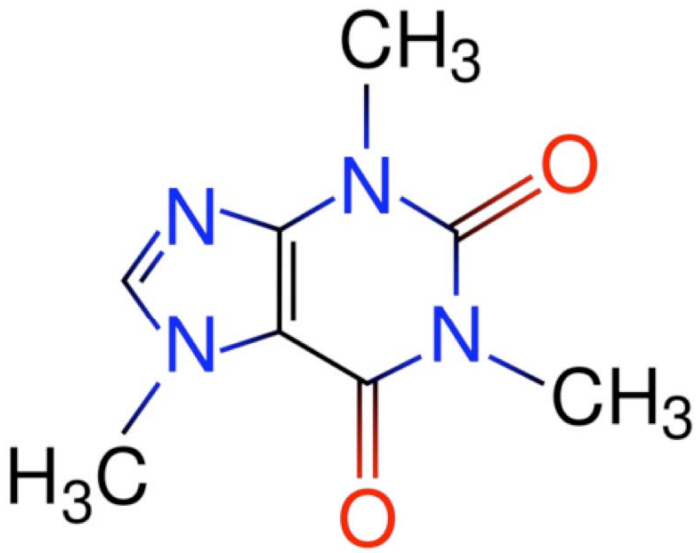




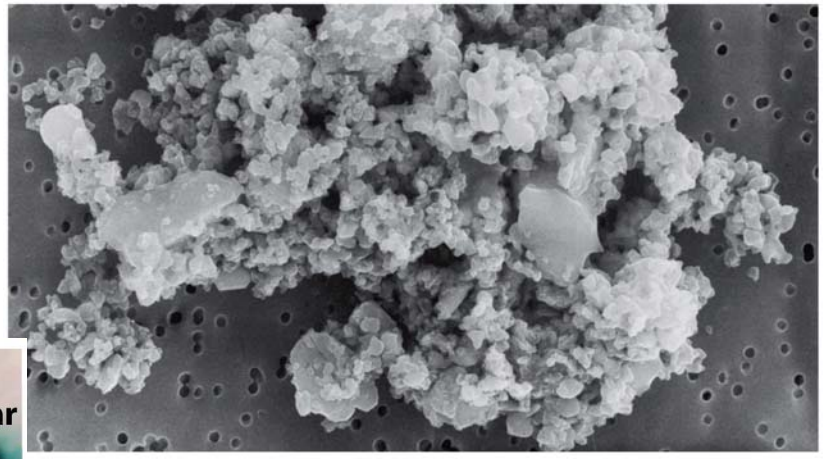
- **Organic molecules based on carbon can become huge**
  - **Non-linear and complex**
  - **Organic chemistry allows for very complicated reactions to take place**
  - **Reactions that lead to life**
    - **And caffeine….**







- **Luckily this stuff is everywhere**
- **Complex hydrocarbons have been detected in giant molecular clouds**



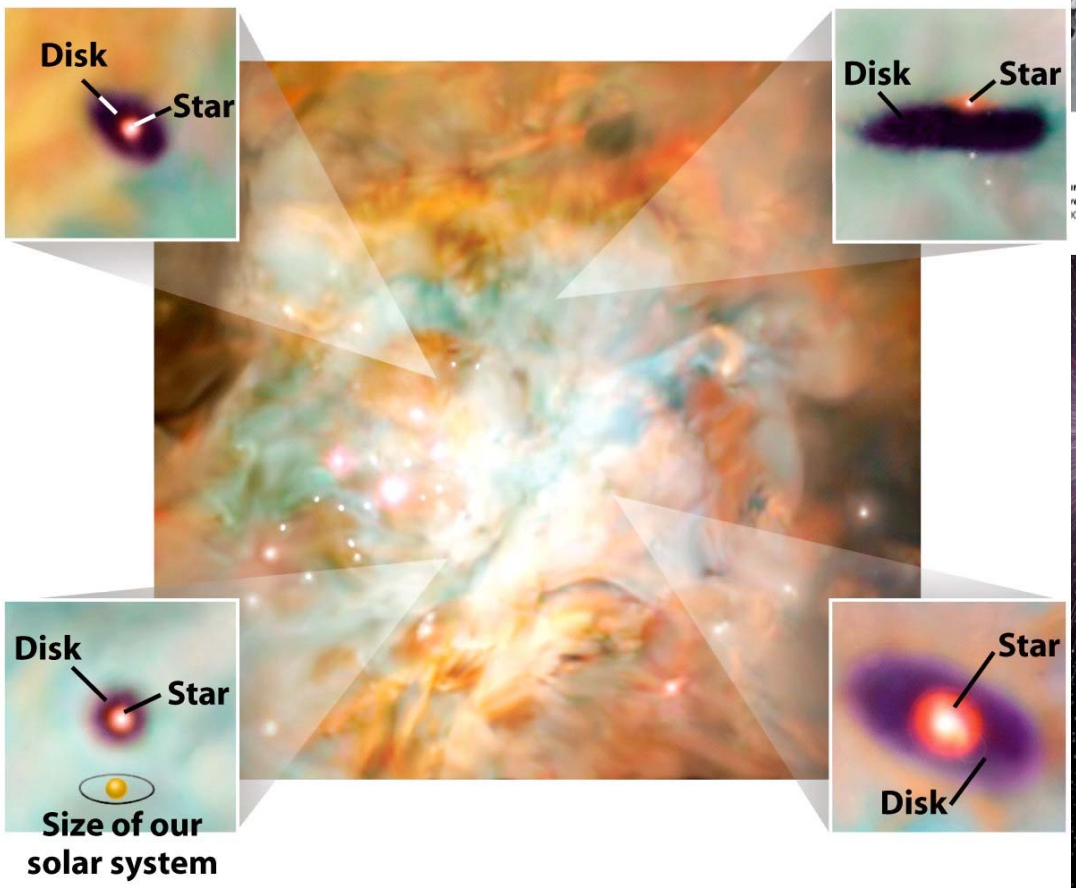


Figure 8-8b
Universe, Eighth Edition
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- …and they're not that hard to make on Earth

- Miller-Urey experiment
  - Put basic compounds together
    - Meant to simulate the atmosphere of the early Earth
  - Add some electrostatic discharges
  - You get complex organic molecules…

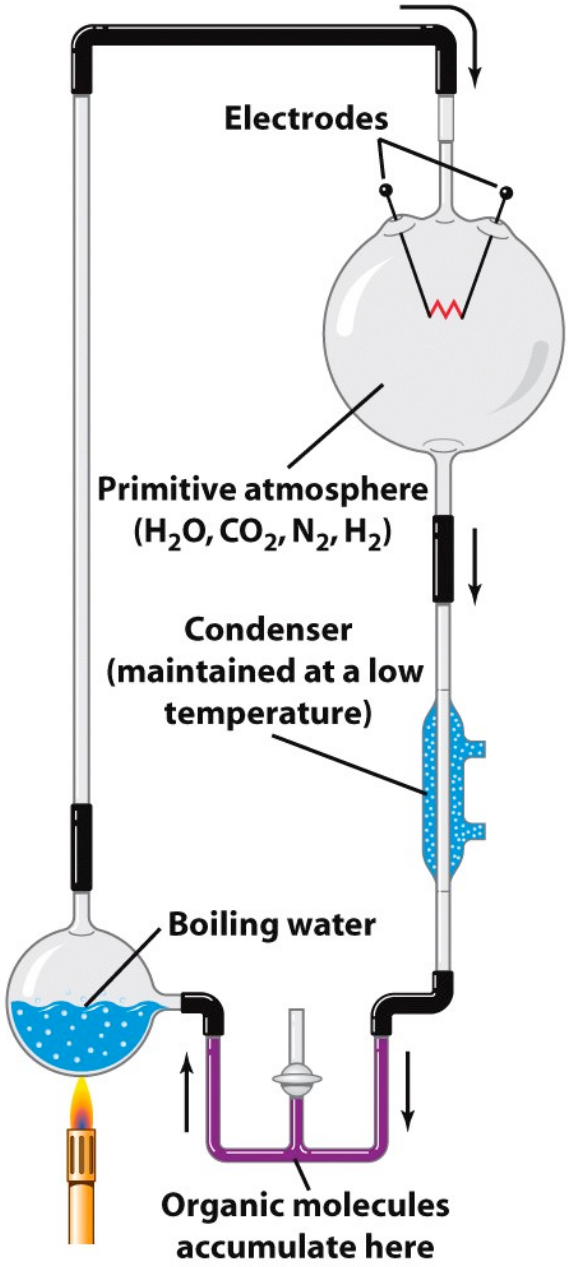


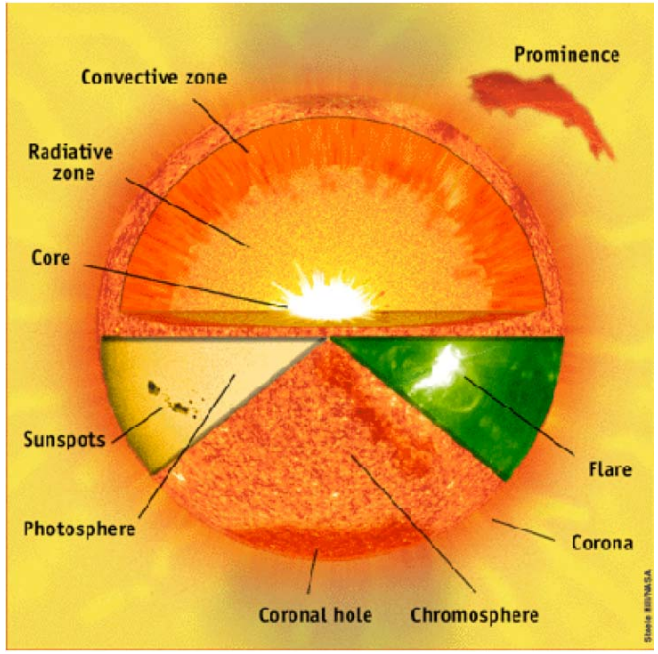
Figure 28-4
Universe, Eighth Edition

- **Carbon is rare on Earth**
  - **But common further out in the solar system**
  - **Carbonaceous meteorites**
  - **Dark material that coats icy bodies**
- **Easy to deliver carbon compounds to the early Earth**

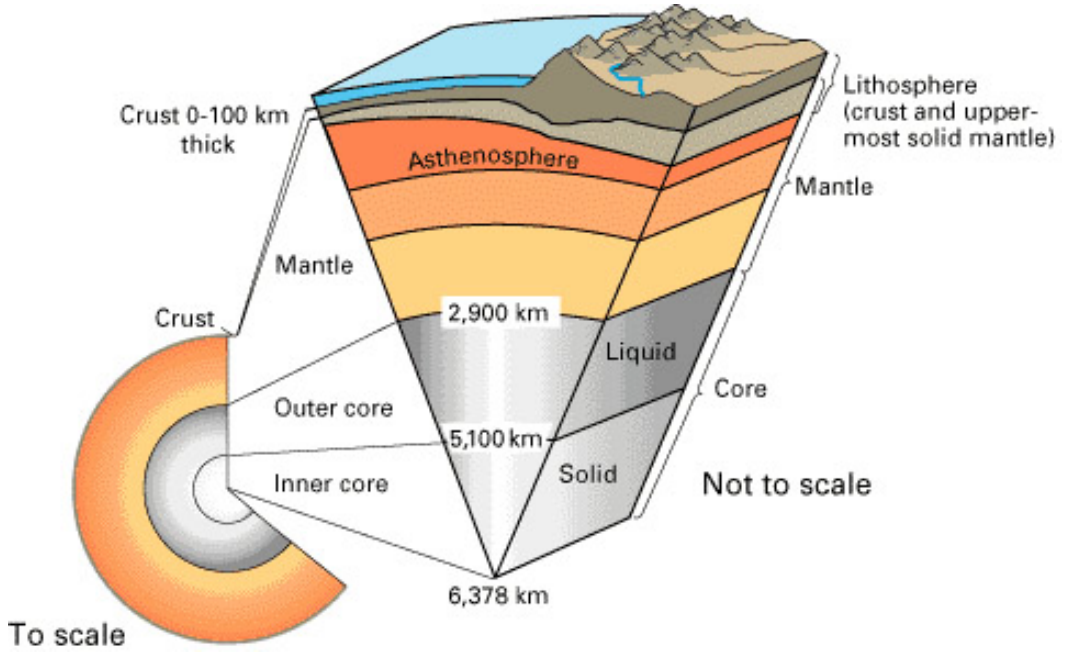
Figure 28-3a
Universe, Eighth Edition

Iapetus

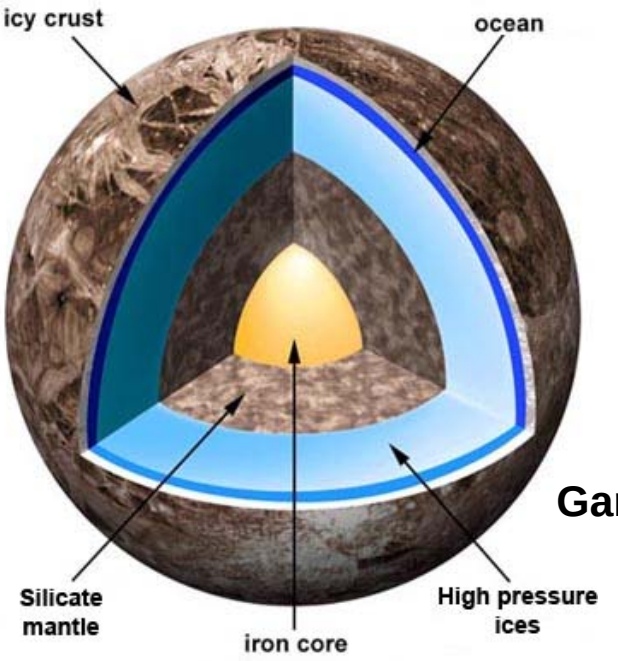
- Increasing complexity costs energy
- Growth & reproduction need energy
- Life needs an energy source



- Energy is available from
  - Stars
  - Internal heat sources
    - Radioactivity
      - Earth-like planets
    - Contraction
      - Jupiter
    - Differentiation
      - Helium rain on Saturn



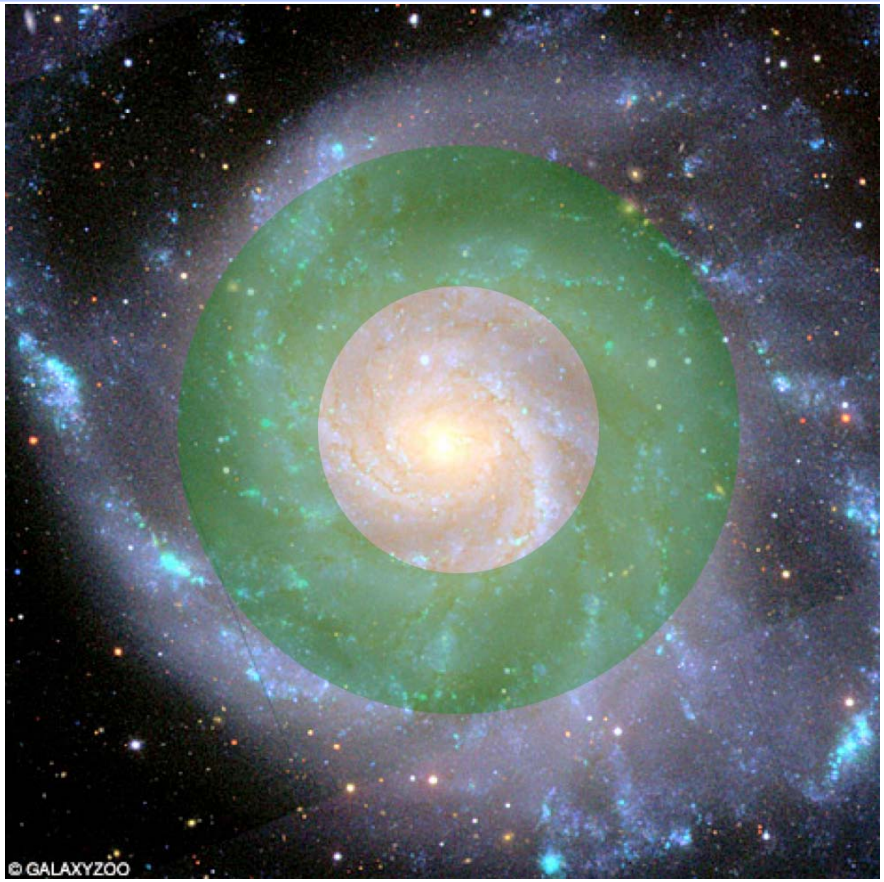
- Liquid water is an essential component
  - Medium to suspend reacting material
  - Gets molecules in contact with each other
    - Can dissolve many compounds easily
  - Radiation protection
- But it's pretty rare in our solar system
  - Limited to Earth's surface
  - Interiors of some of Jupiter's Moons
    - Along with Titan (and maybe Triton)

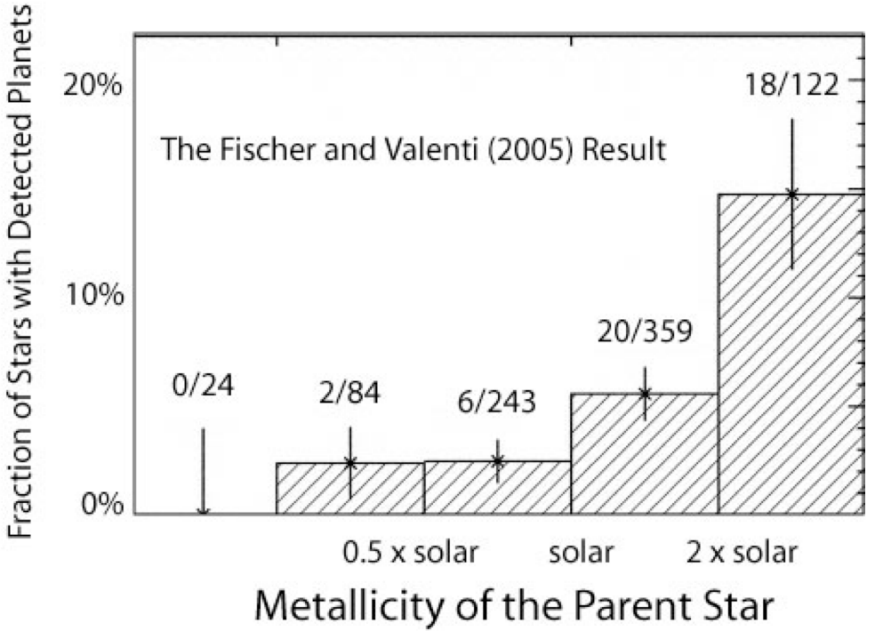


Ganymede

Building a habitable planet

- Galactic position plays a role
  - Central locations have many stars
    - Manufactures elements like carbon
    - …but…
    - Close stellar passages disrupt planetary systems
  - Stars in the outskirts are sparse
    - Solar systems are safe
    - …but…
    - Not as many heavy elements produced
    - Fewer planetary systems

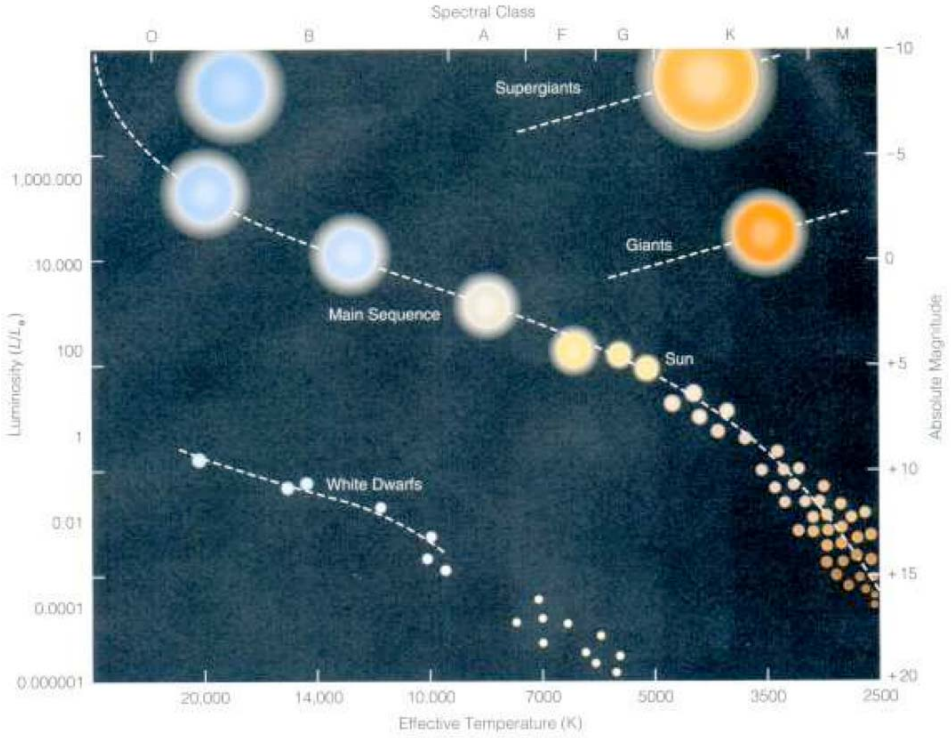




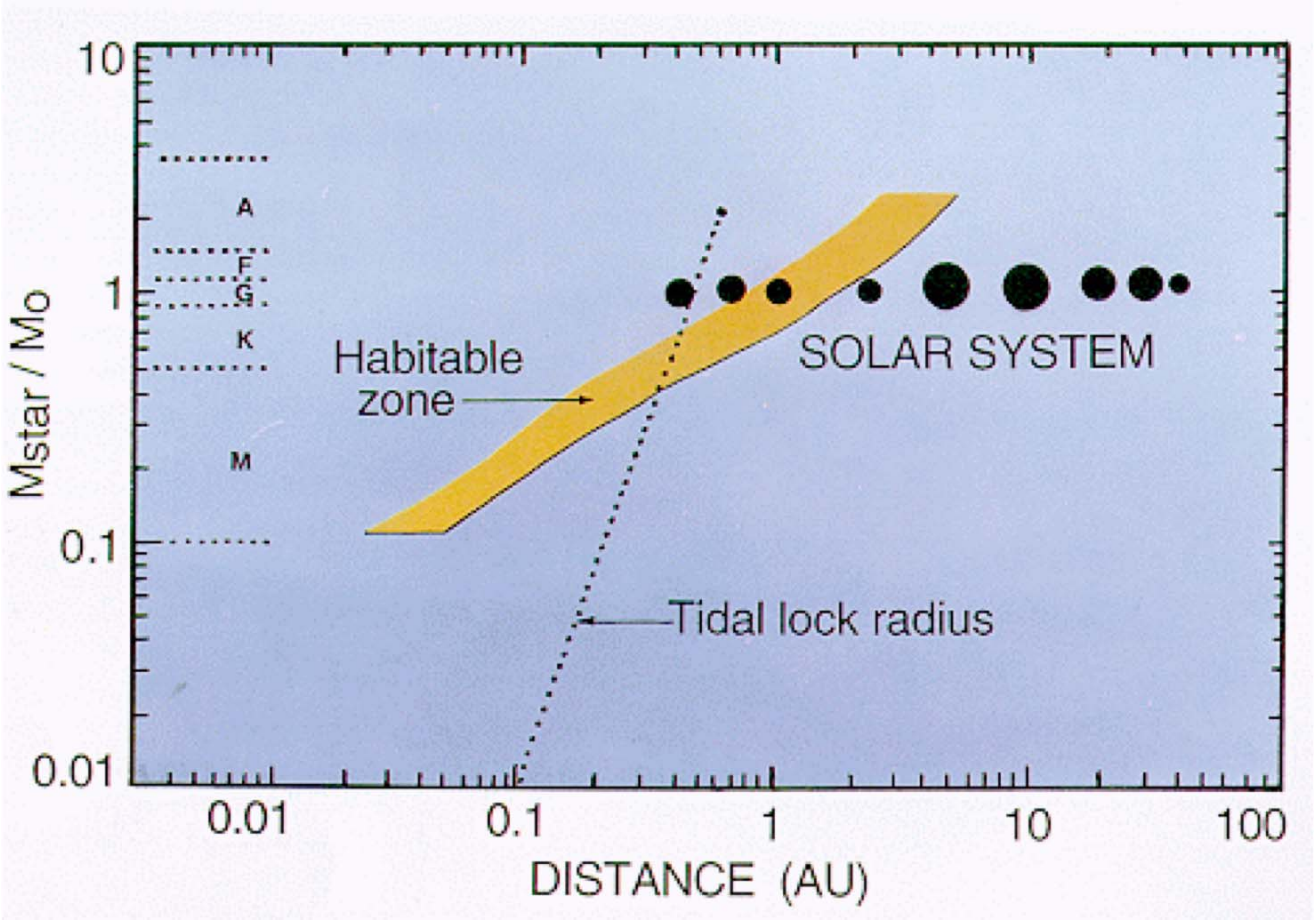
- You need the right kind of star

- Supermassive stars burn up their fuel and explode
  - They live only a few million years
  - Not enough time to develop life
    - Or even planets

- Very small stars last almost forever
  - Long after the galaxy is a cold dead place these little stars will still be shining feebly
  - They don't supply much solar energy to planets
  - The planetary systems also tend to be low-mass



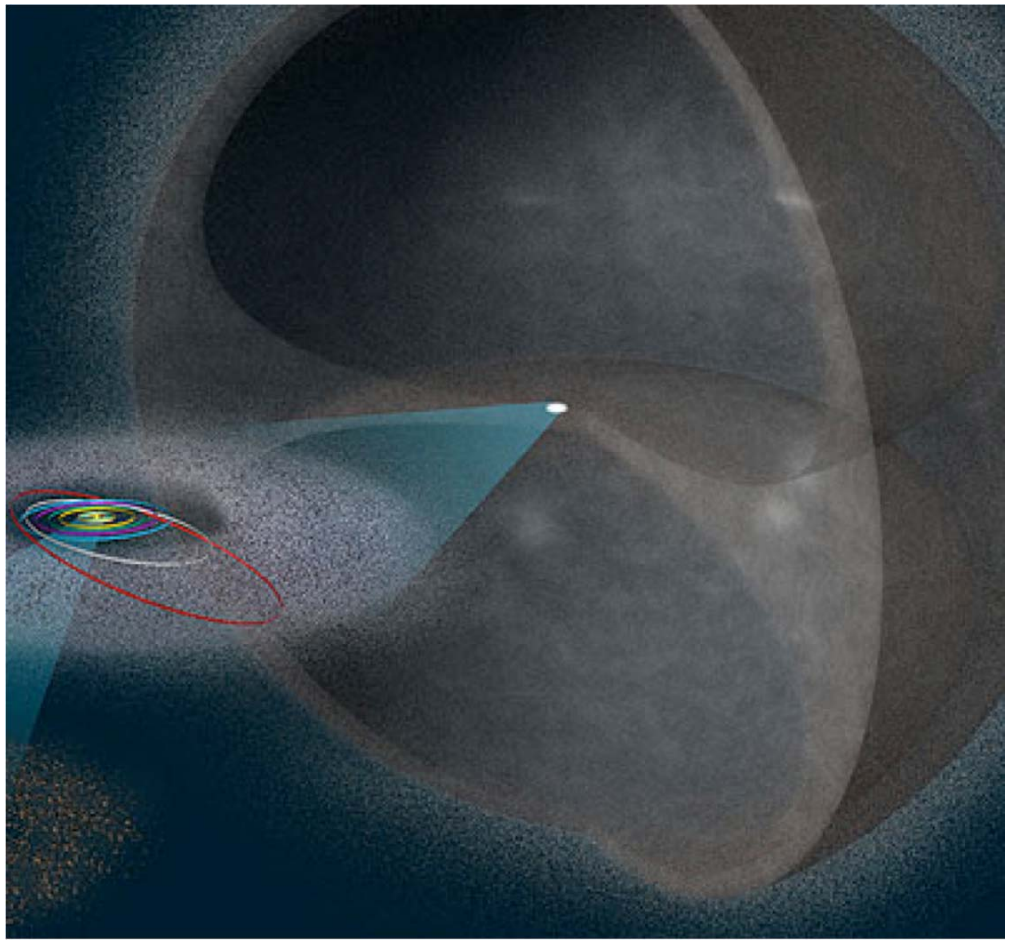
- **A planet must lie in the habitable zone**
  - **Temperature range where liquid water is stable on the surface**
  - **Depends on how bright the star is**
  - **Carful… if you get too close you'll be tidally locked**
    - **Fry one side of the planet**
    - **Freeze the other**



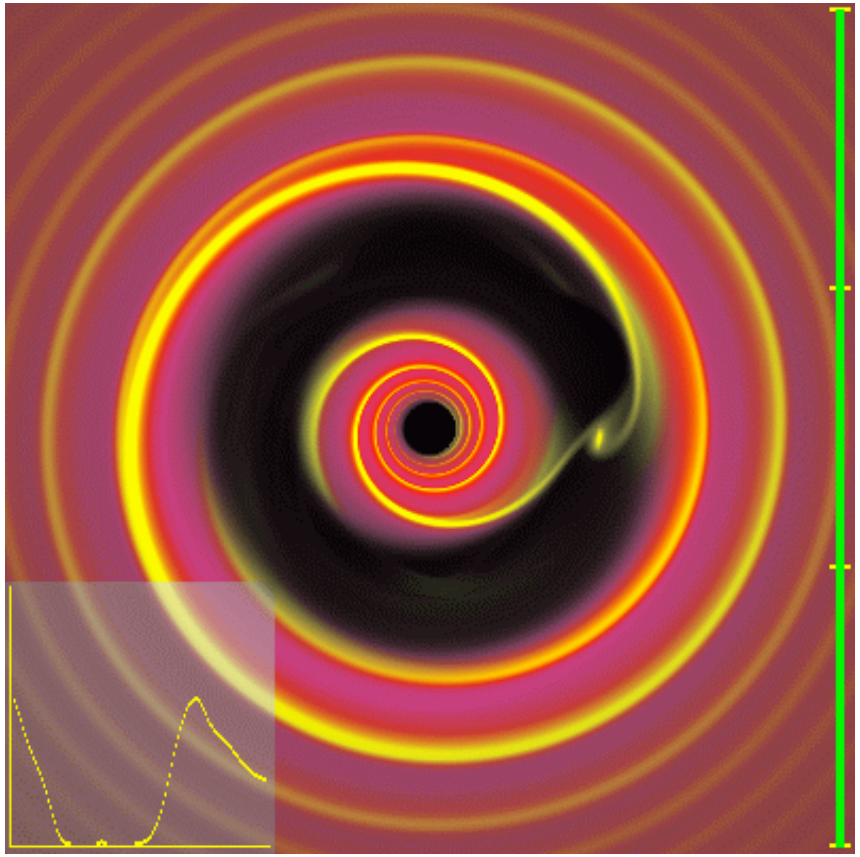
- **Giant planets are helpful**
  - They can get rid of a lot of the small bodies
  - Fewer impacts
  - More conducive to life

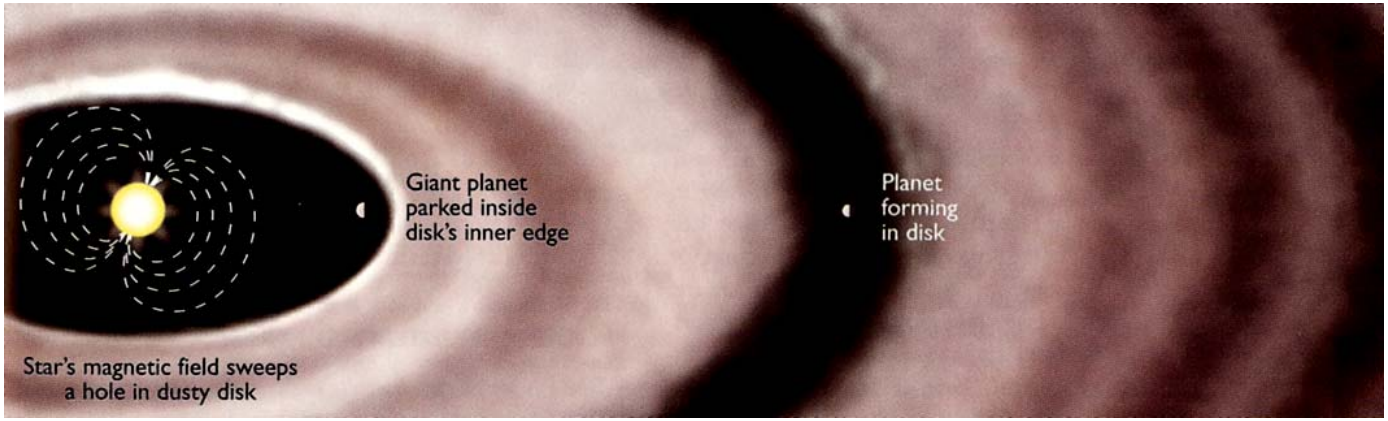
…but…

  - Giant planet migration can also cause more impacts
    - Late heavy bombardment in out solar system



- **Giant planets can also be a menace…**
  - **Giant planets migrate into the inner solar system**
  - **Pretty much wreak any Earth-like planets in that region**





- **This happened to many systems**

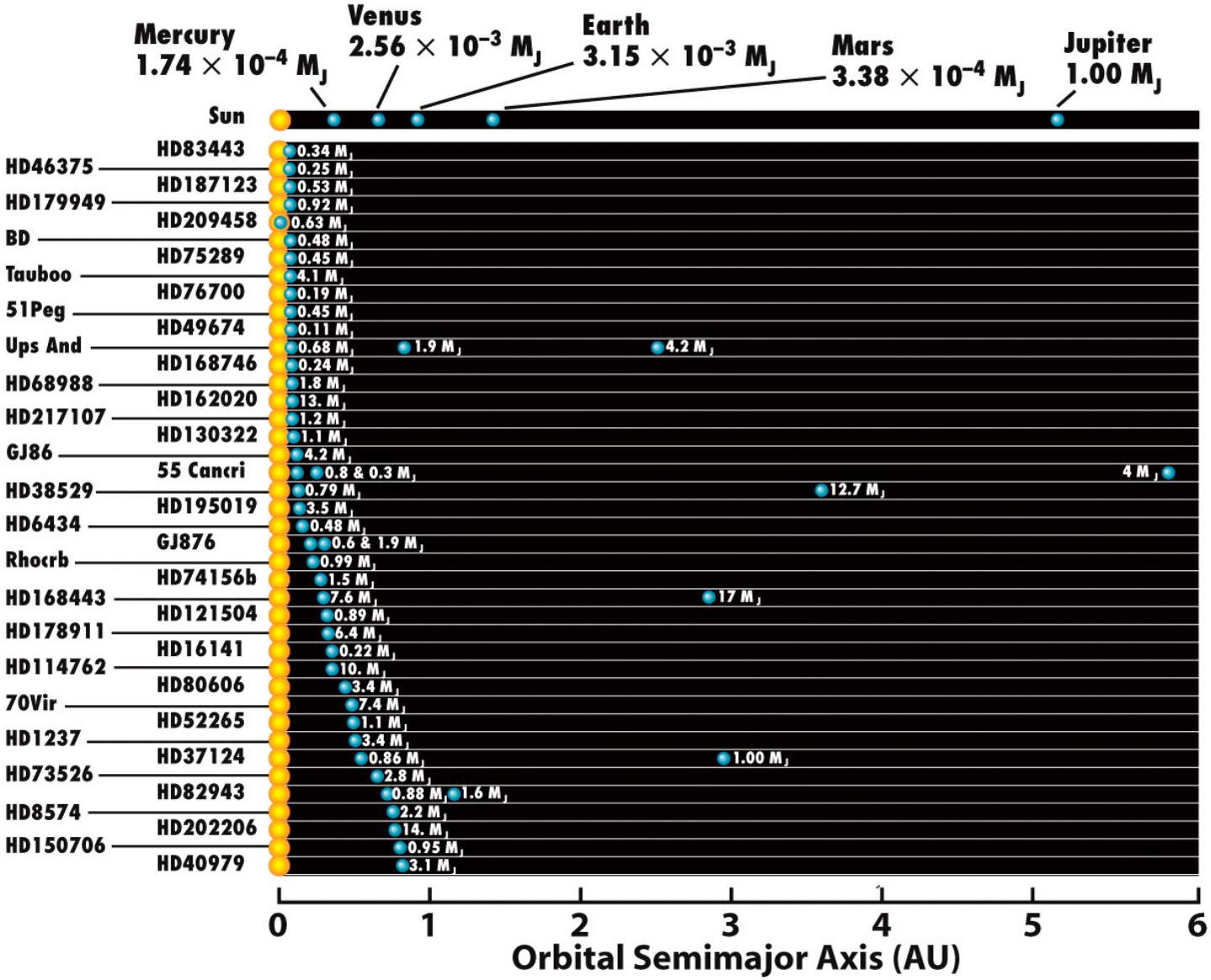
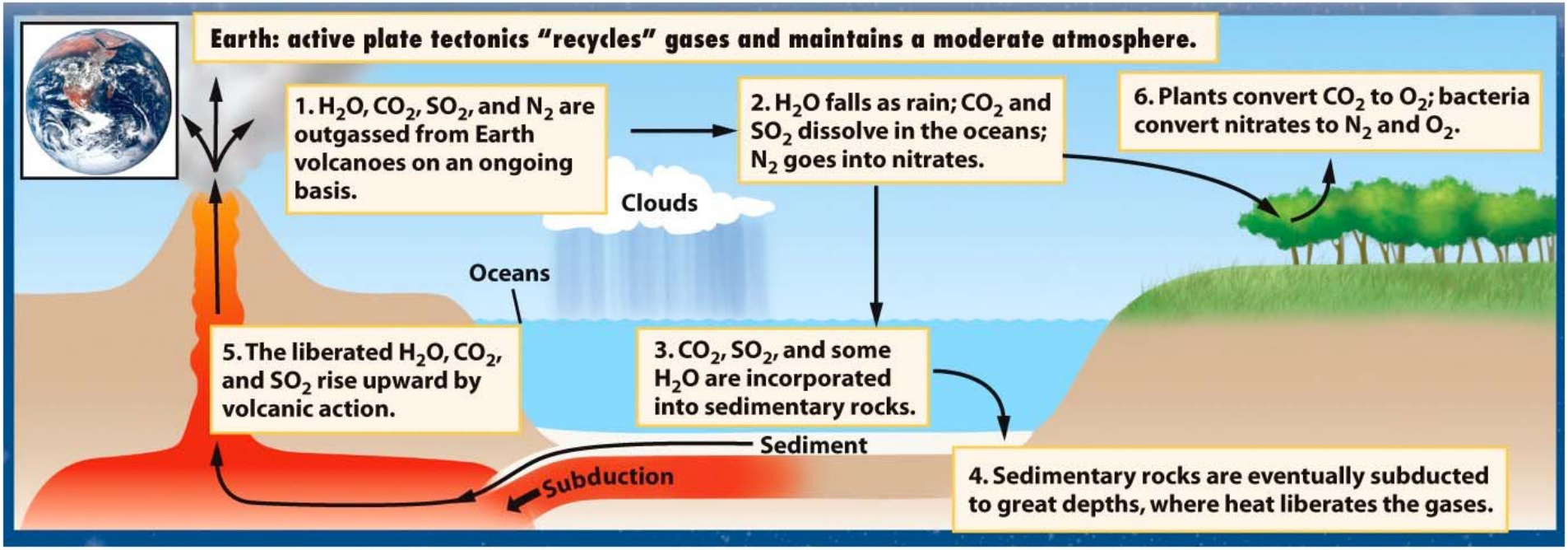


Figure 8-17 part 1
Universe, Eighth Edition



Earth, Venus, Mars

All start with CO_2 and water in their atmosphere

Mars, Earth

CO_2 and water goes into rocks

Earth

Rocks recycled by plate tectonics

Rock cycle

Mars

No plate tectonics–CO_2 stuck in rocks

Runaway icehouse

Venus

Water not stable as liquid

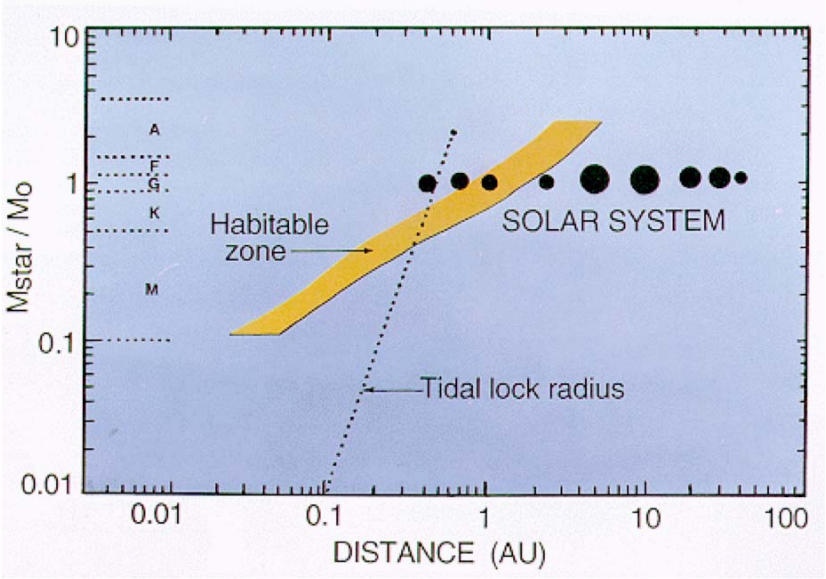
Venus

CO_2 stays in atmosphere

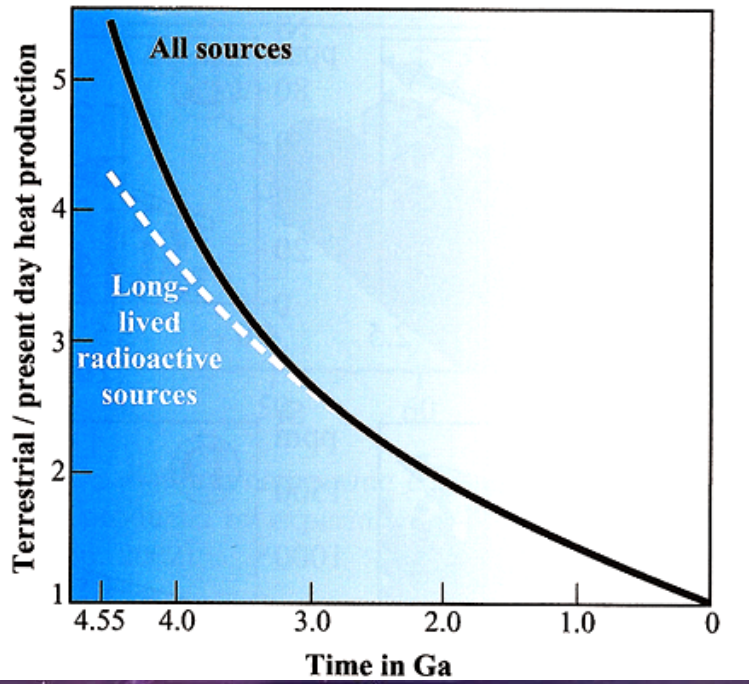
Runaway greenhouse

The Early Earth

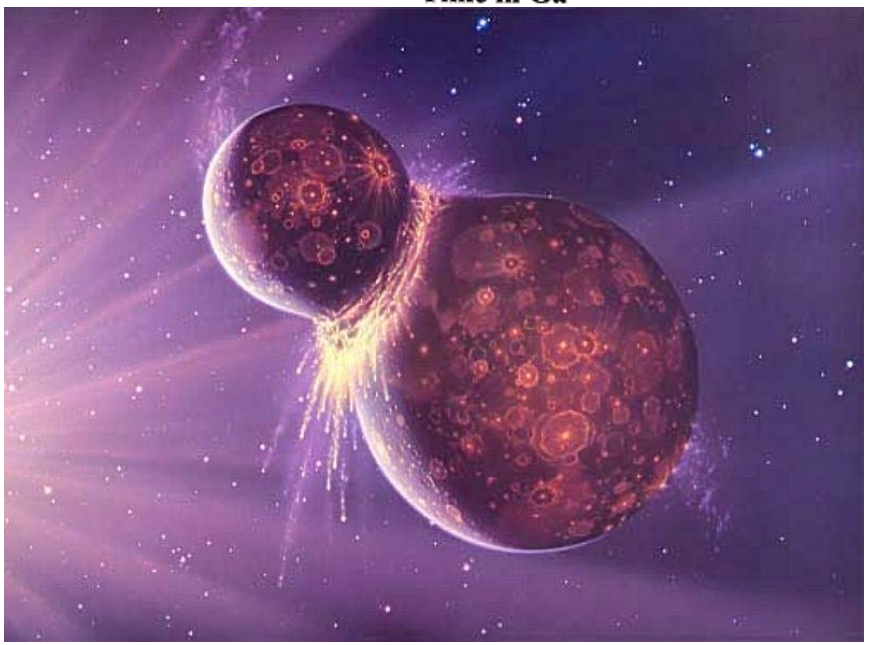
- We know life arose in at least one place…
  - The solar system is half way out in the galaxy
    - Safe from other stars
    - Enough raw material to build planets
  - Earth orbits a mediocre star
    - Big enough to power life
    - Small enough to last a long time
  - Earth is in the habitable zone
    - Liquid water is common
  - We have a nearby friendly gas giant planet – Jupiter
    - Cleared away many small bodies
    - Didn't migrate close to the sun and kill us all
  - Earth seems to have struck the balance in regulating atmospheric CO_2
    - Plate tectonics



- Earth initially forms and differentiates
- Radioactive elements power geologic activity

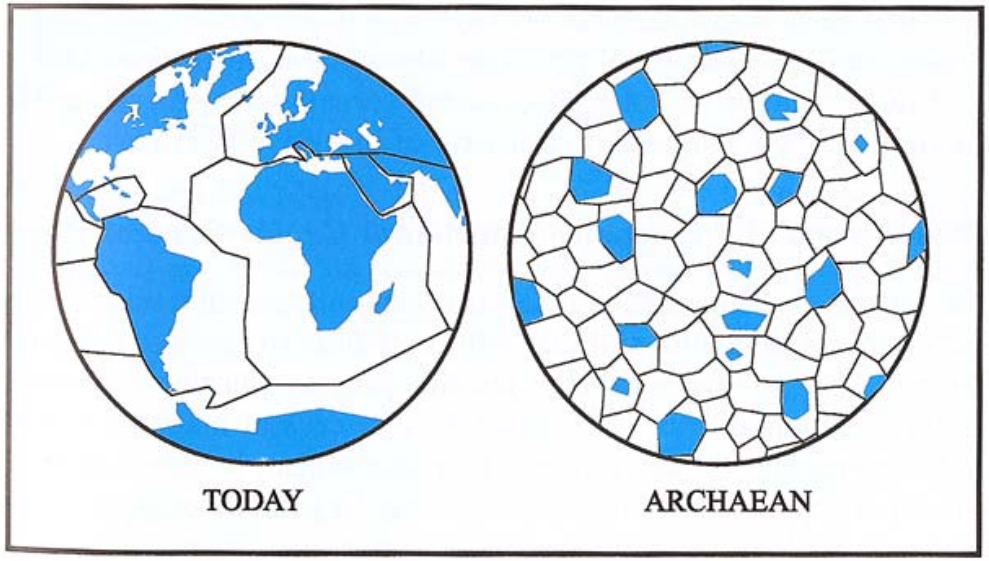


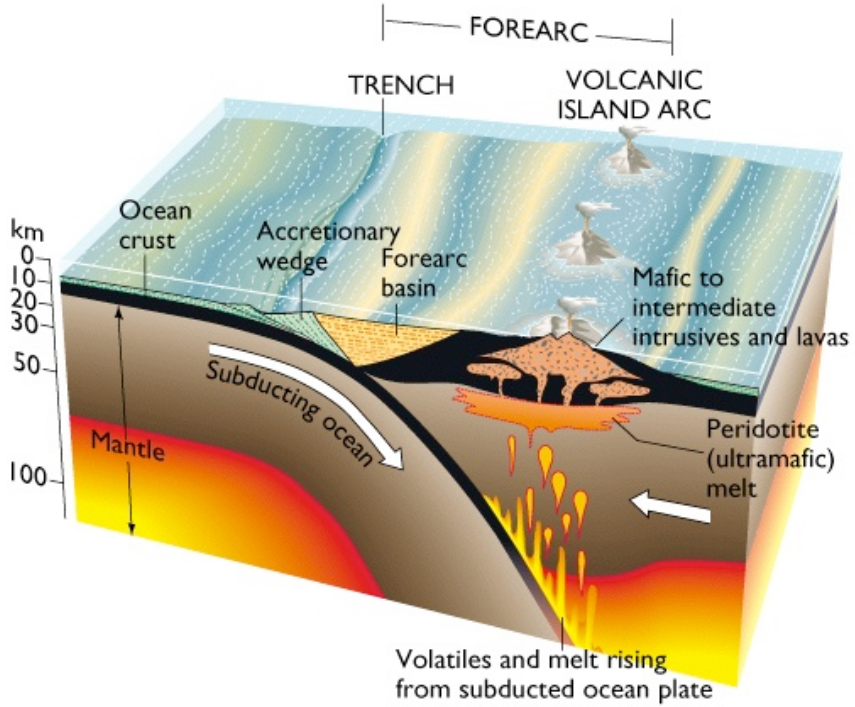
- Large moon-forming impact
- Earth mostly molten
- Inner solar system gets cleaned up over the first 100 million years
  - Many big collisions
  - No atmospheres or oceans are stable
- Initial crust is oceanic crust



- Volcanoes produce secondary atmosphere of steam and CO_2
- Continental fragments produced from reprocessing of oceanic crust
- Earth cools water forms oceans
  - CO_2 starts to dissolve
  - Venus-style greenhouse avoided
- Hadean and Archaean geologic periods

- **Plate tectonics swaps hot mantle material for cold crustal material**
  - **Important way for Earth to lose heat**
- **More heat to lose in the early Earth so plate tectonics was probably more active**
  - **Many smaller plates**
- **Ocean-ocean plate interactions**
  - **Subduction**
  - **Produces continental rock**





- **Starting with only oceanic crust we can manufacture continental crust as ocean arc islands**

- **These continental fragments get shuffled around**
  - **Eventually they stick together to form the first continents**

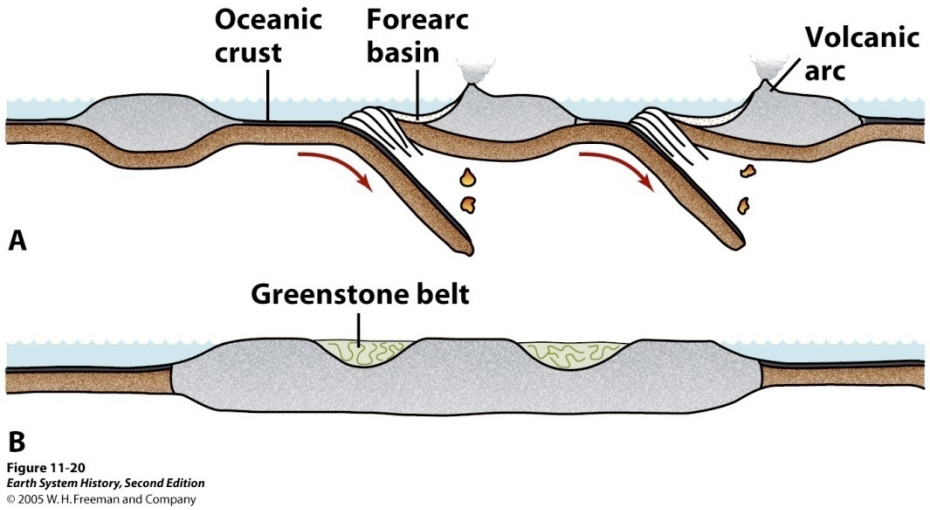
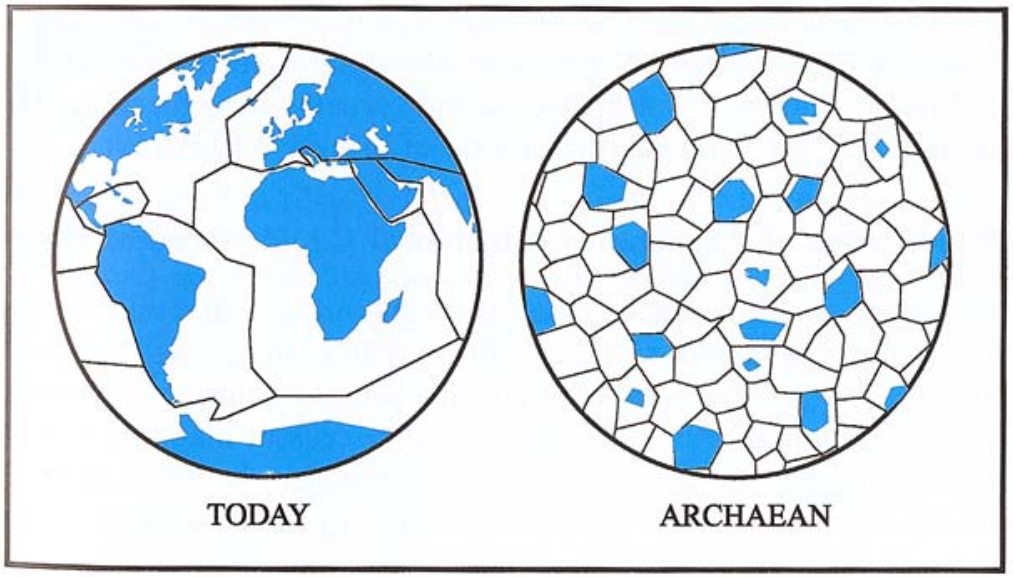


Figure 11-20
Earth System History, Second Edition

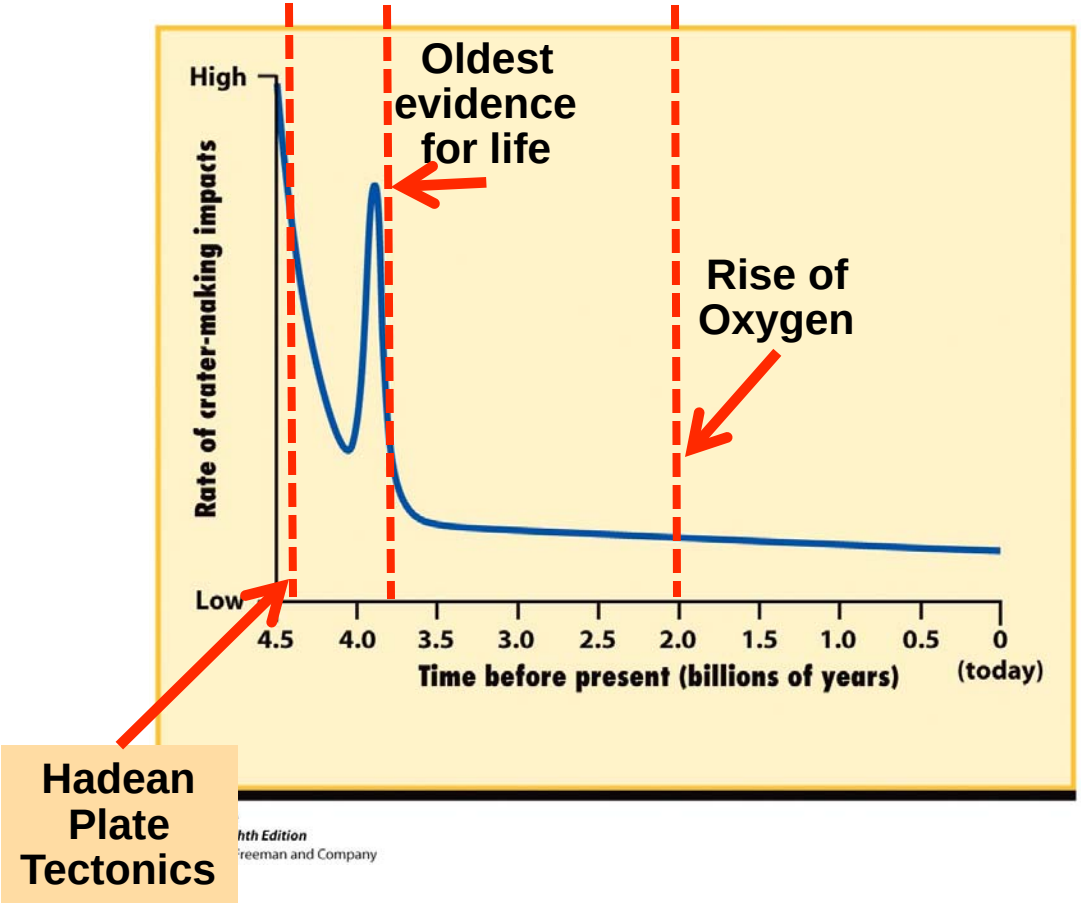


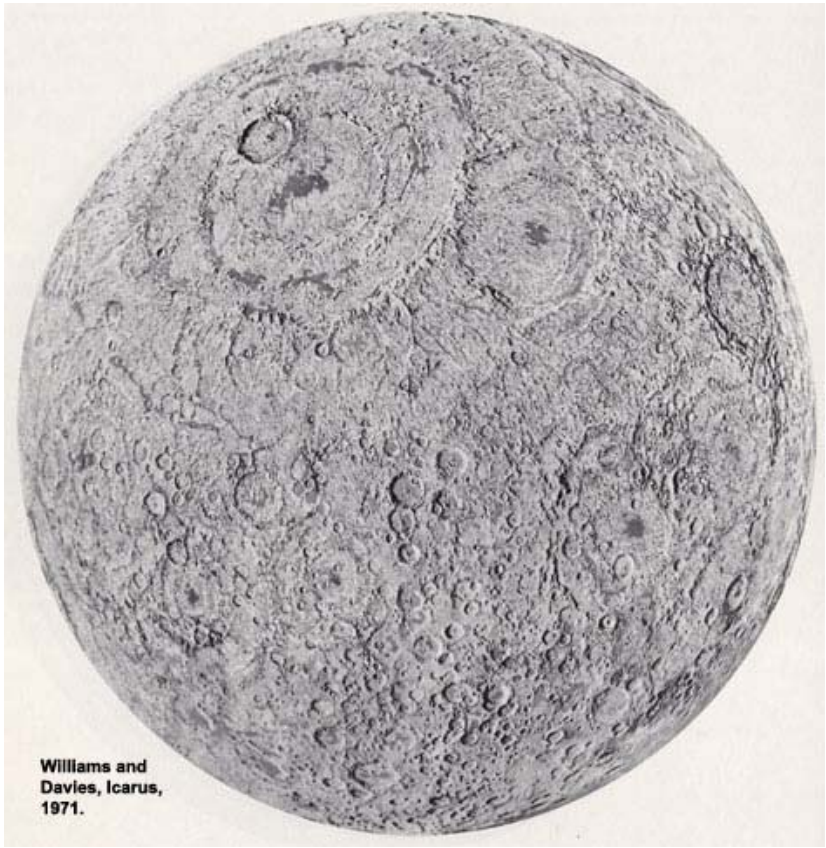
- How long did this take?

- New work on analysis of Zircon crystals
  - Virtually indestructible
  - Survive long after the original rock is eroded away
  - Dated back to 4.4 Gyr ago
    - Earth formed 4.5Gyr ago

- Results
  - Formed with continental rocks
    - i.e. plate tectonics was operating
  - Formed in the presence of water
    - i.e. oceans already existed

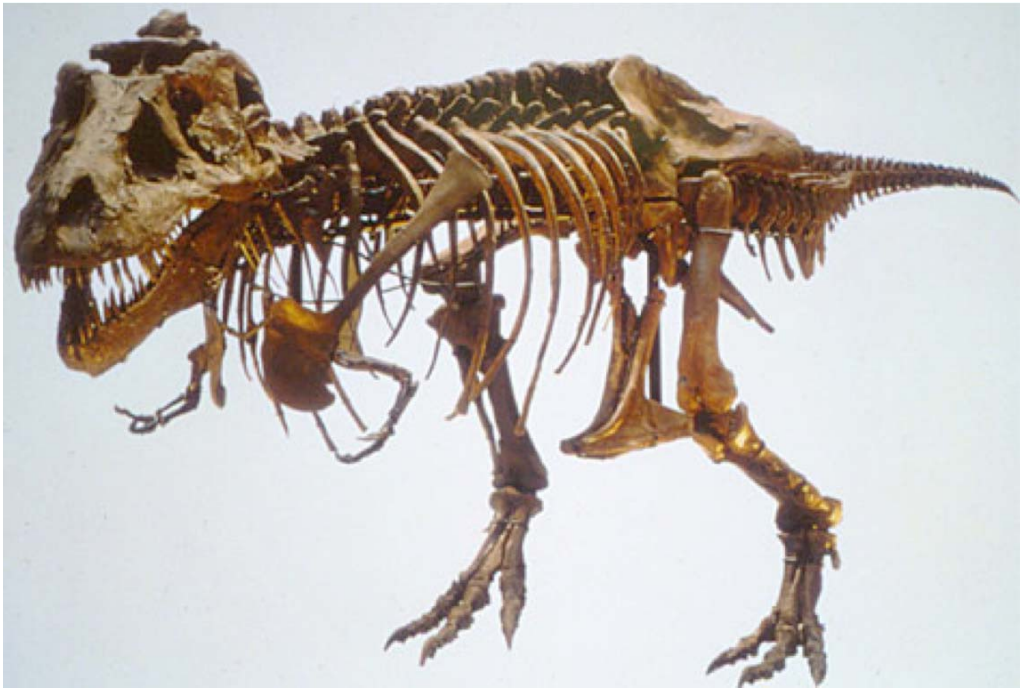
- Large impacts still occurring
  - Vaporizes oceans
  - Recovery time of 1000s of years
  - Still not a good time for life – but things start to calm down
- Late heavy bombardment occurred 3-8 to 4 billion years ago
  - Lunar crater record – Jupiter's inward migration
  - Existing life? Probably could not survive…

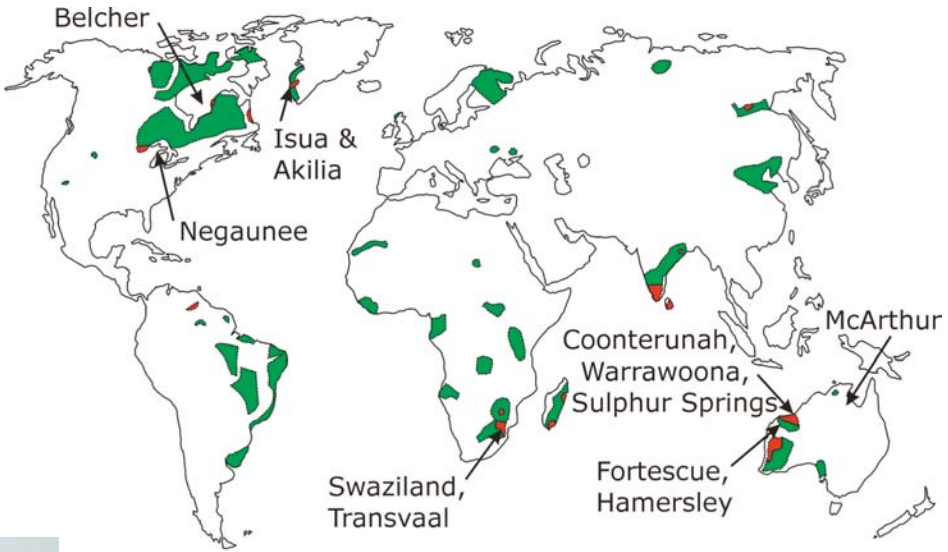




Life on Earth

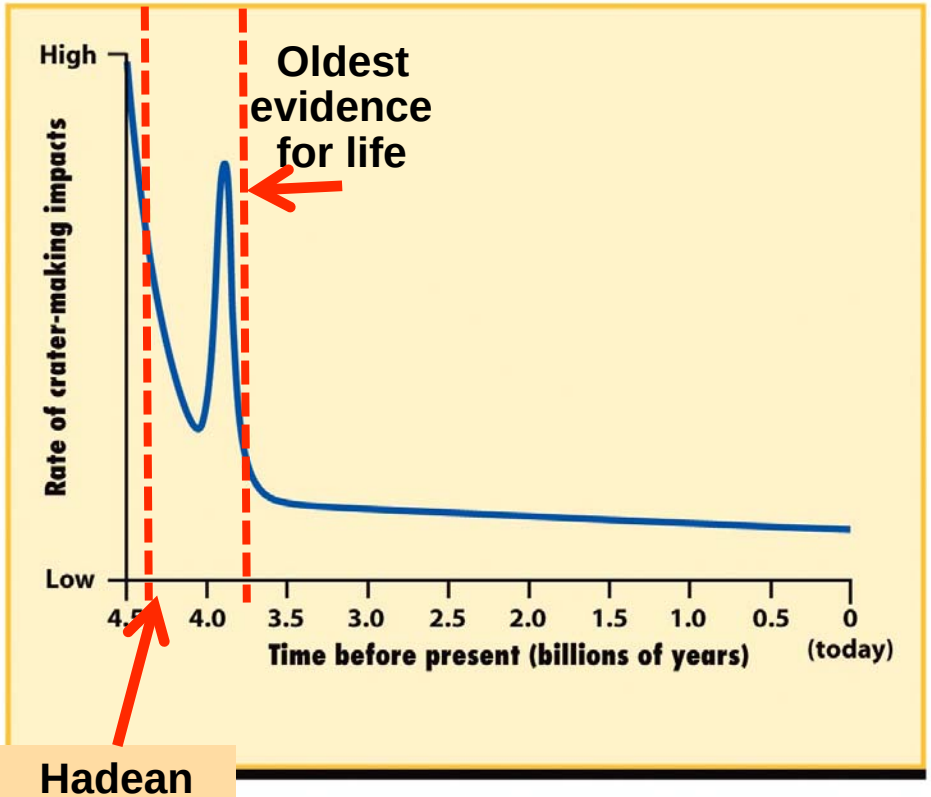
- **Finding ancient evidence of life on Earth is complicated…**
  - **Fossils only cover the most recent periods**
    - **Because recent rocks are well preserved**
    - **Because older life was not multi-cellular**

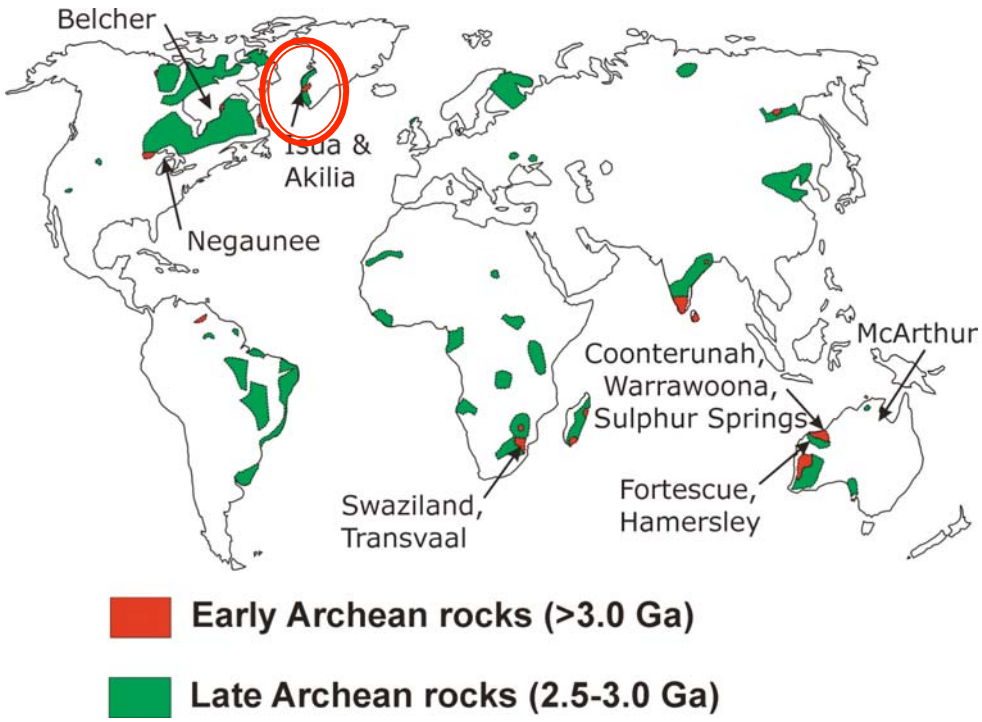




There aren't many Archaean rocks left…

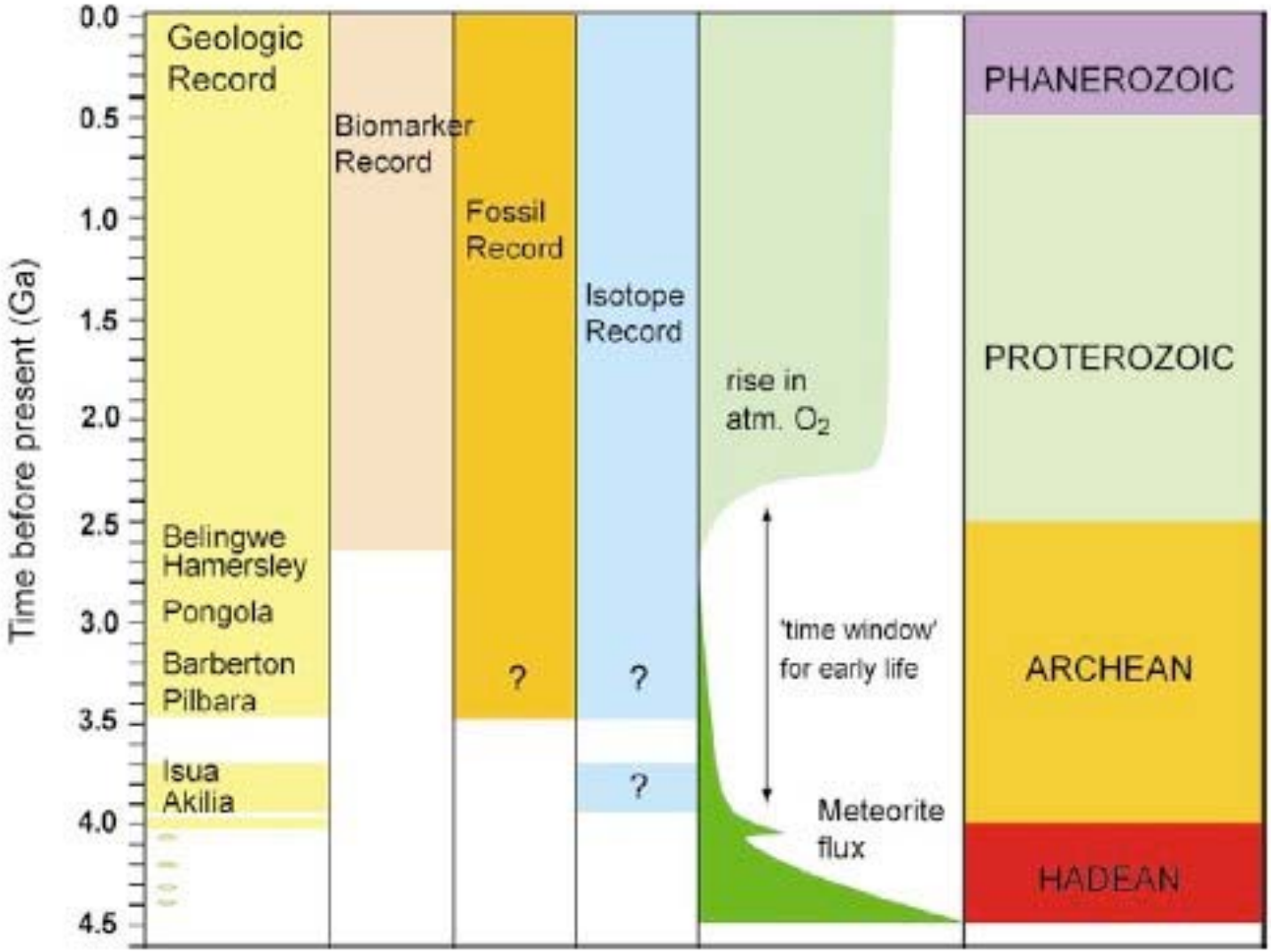
- **Earliest evidence for life is geochemical**
  - **Carbon has many isotopes ^{12}C, ^{13}C, ^{14}C**
  - **Isotope ratios of living things is very distinctive**
  - **These ratios are found in rocks in Greenland – Age 3.85 billion years ago**
  - **End of late heavy bombardment period – 3.8 billion years ago**
    - **Life appeared very quickly once conditions permitted it**



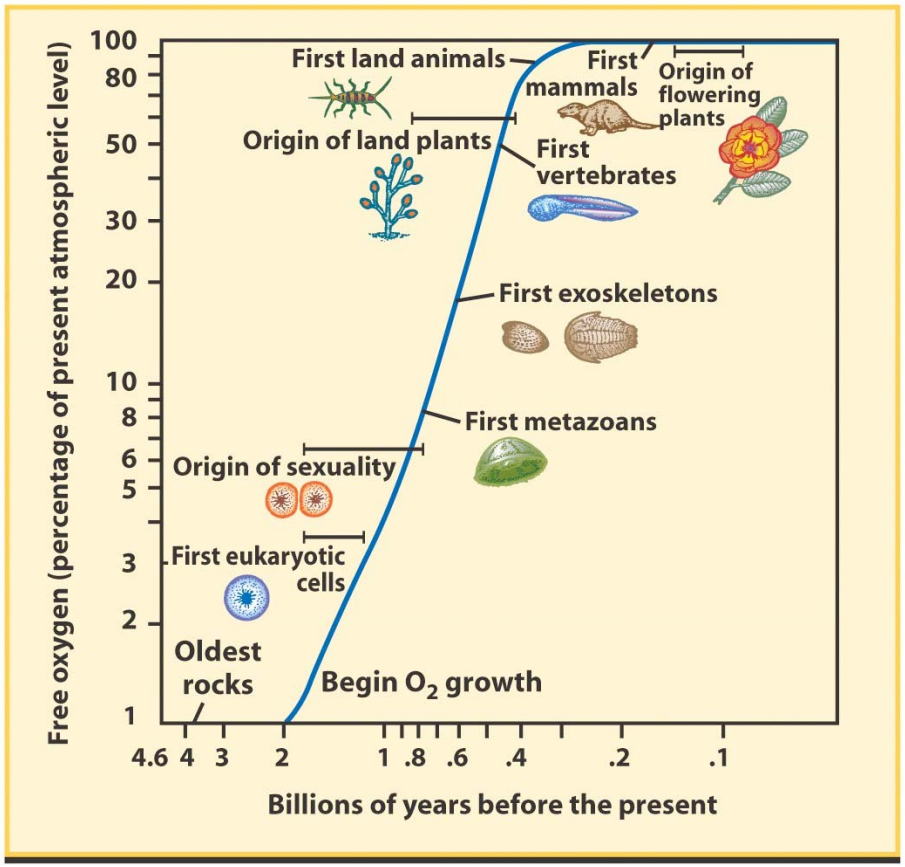


- **First physical fossil evidence comes later**
  - **Stromatilites – 3.5 billion years ago**
  - **Colonies of cyanobacteria – used CO_2 for energy and emit Oxygen**
  - **Precipitate calcium carbonate which gets fossilized**

- **The Archaean saw the start of life**
  - **At least the life that stuck around**
  - **That life had an unexpected effect…**



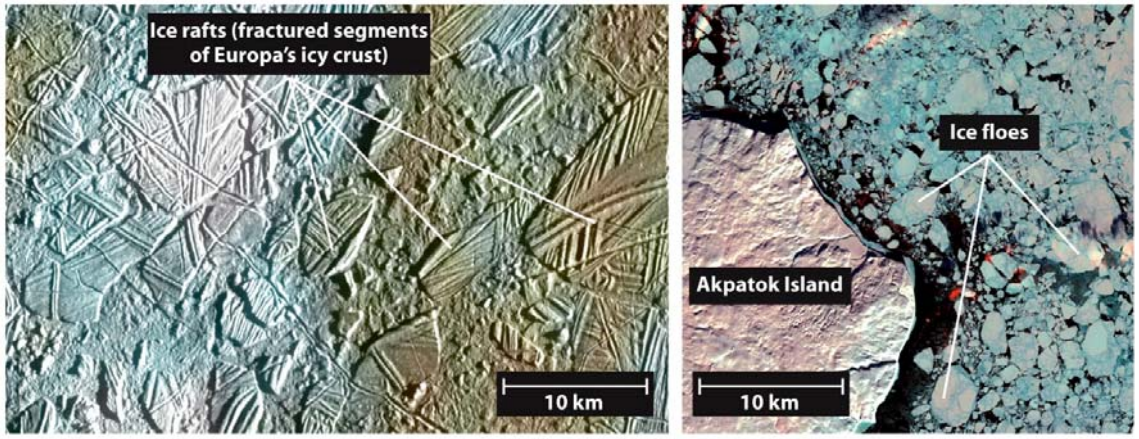
- Life basically terraformed the Earth
  - But almost wiped itself out in the process
  - Appearance of oxygen was a major crisis
- The stromatilites and bacterial mats used CO_2 and produced Oxygen
  - ~2.7 billion years ago O_2 started coming out of the oceans
  - And oxidizing everything in sight
  - Created banded iron formations
- These organisms used to dominate the globe
  - Now a new kind of Oxygen-using lifeform has taken over



Life outside the Earth

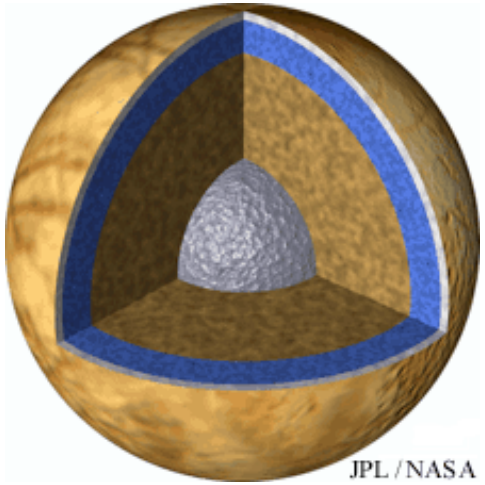
- **Two main candidates**
  - **Mars**
    - Ancient wet climate
    - Warmer temperatures in the past
    - A rock record that goes back to the early solar system

  - **Europa**
    - A current-day liquid ocean
    - In contact with a rocky core



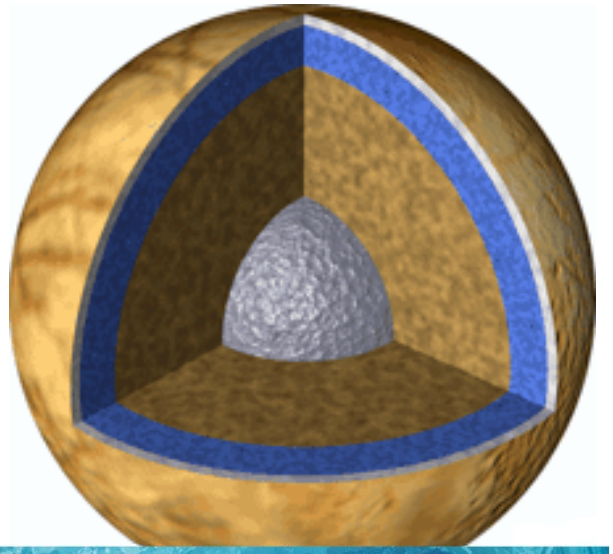
(a) Ice rafts on Europa (b) Ice floes on Earth

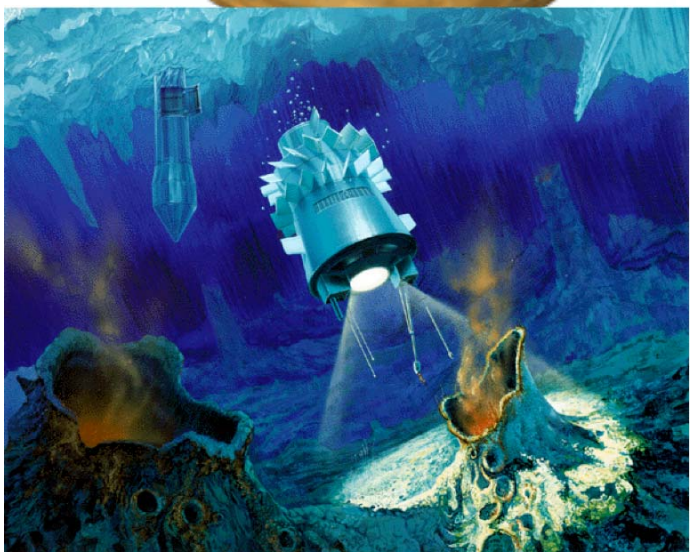
Figure 13-13
Universe, Eighth Edition

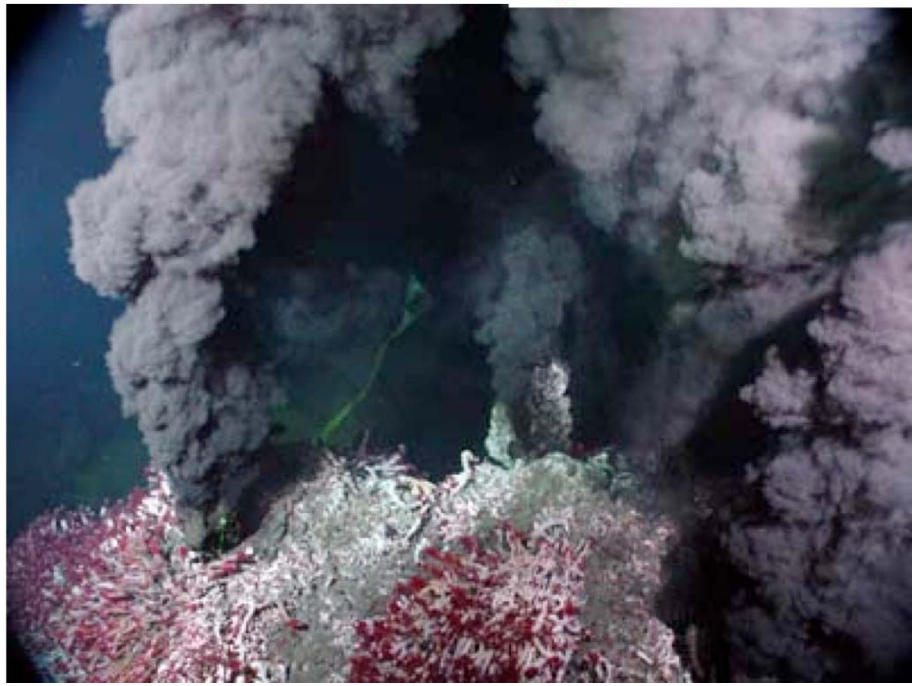


JPL / NASA

- **Jupiter's tidal flexing pumps heat into Europa's interior**
  - **Keeps the ocean liquid**
  - **Probably drives volcanism in the inner rocky core**







- **In the case of Mars the chances of current life are pretty slim**
  - **Surface is chemically very oxidizing**
    - **Destroys organic molecules**
  - **Water is not liquid (usually)**
  - **Temperatures are low (not much energy to drive life)**

…but…

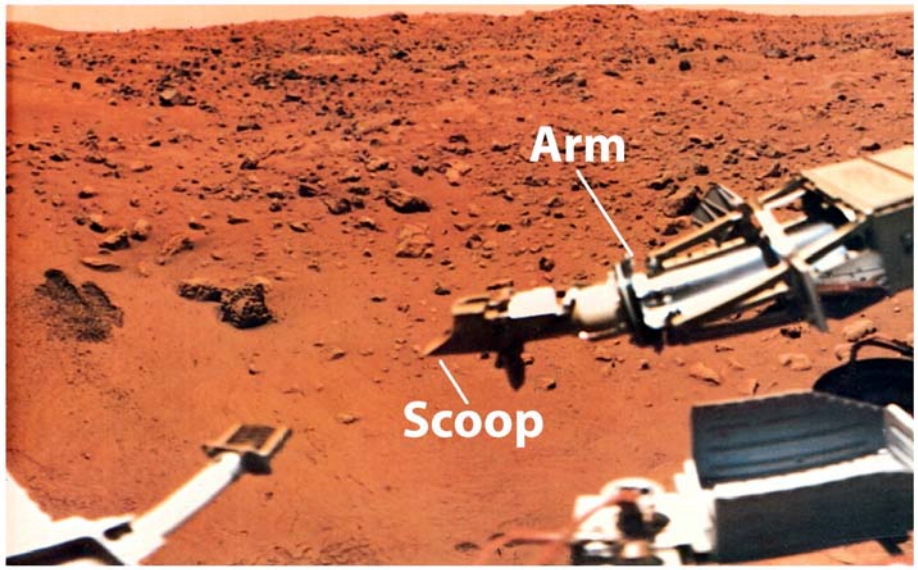
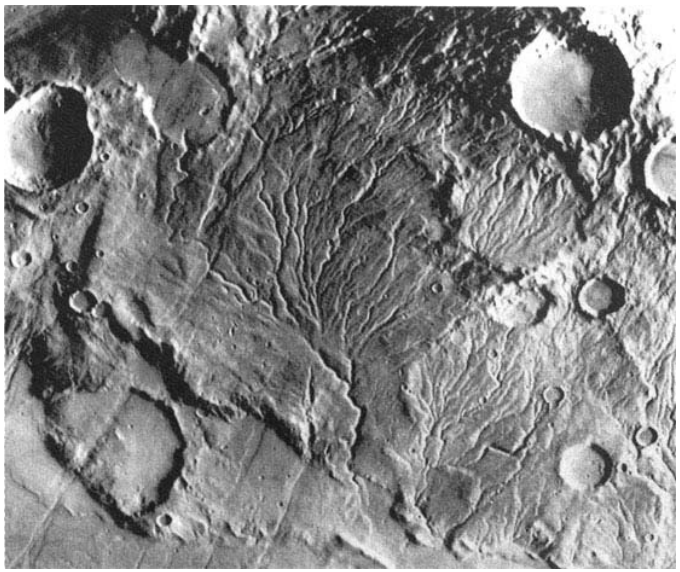


Figure 28-5
Universe, Eighth Edition

Viking lander one had a biological experiment package

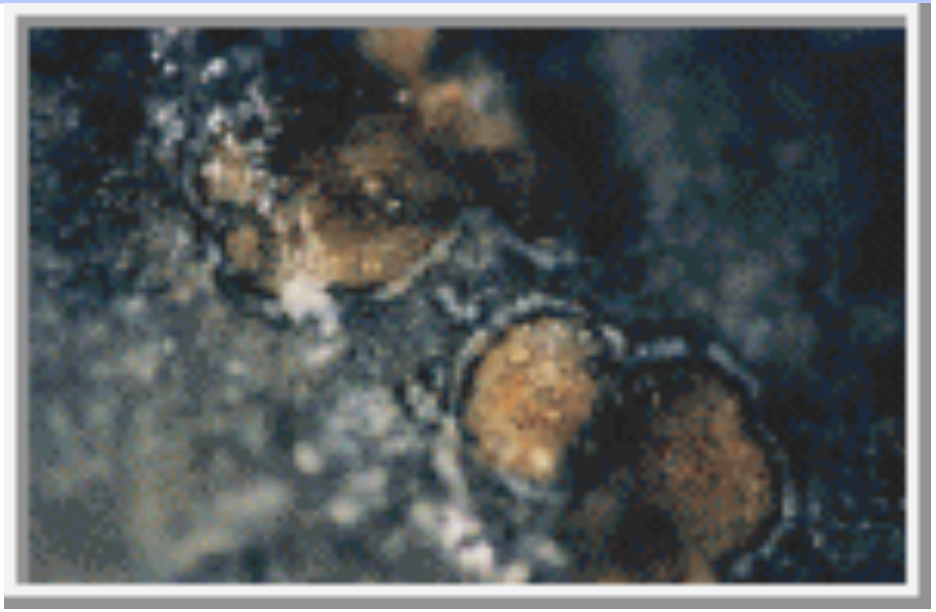
- **Chances of life on early Mars are quite good**
  - **Warmer climate**
  - **Liquid water**



- **We have an interesting sample of ancient Mars here on Earth**
  - **Meteorite ALH0084001**

- **Timeline**
  - **4.5 billion years ago**
    - **Rock solidifies**
    - **Oldest rock we have**
  - **3.6-4 billion years ago**
    - **Rock was fractured**
    - **Carbonate minerals form in cracks**
    - **Bacteria live in the rock**
    - **Rock gets 'fossilized'**
  - **16 million years ago**
    - **Rock is blasted off Mars by an impact**
  - **13 thousand years ago**
    - **Rock lands in Antarctica**
  - **25 years ago**
    - **Someone finds it…**

- **What was in this meteorite?**
  - **Organic compounds on the fractures**
    - **But this stuff is commonplace**
  - **Carbonate globules**
    - **Looks a lot like things terrestrial bacteria produce**
  - **Magnetite grains**
    - **Look a lot like remains of terrestrial magnetic bacteria**
  - **"Fossils"**
    - **Look like fossilized bacteria**
    - **Except they're about 1000 times smaller than terrestrial bacteria**



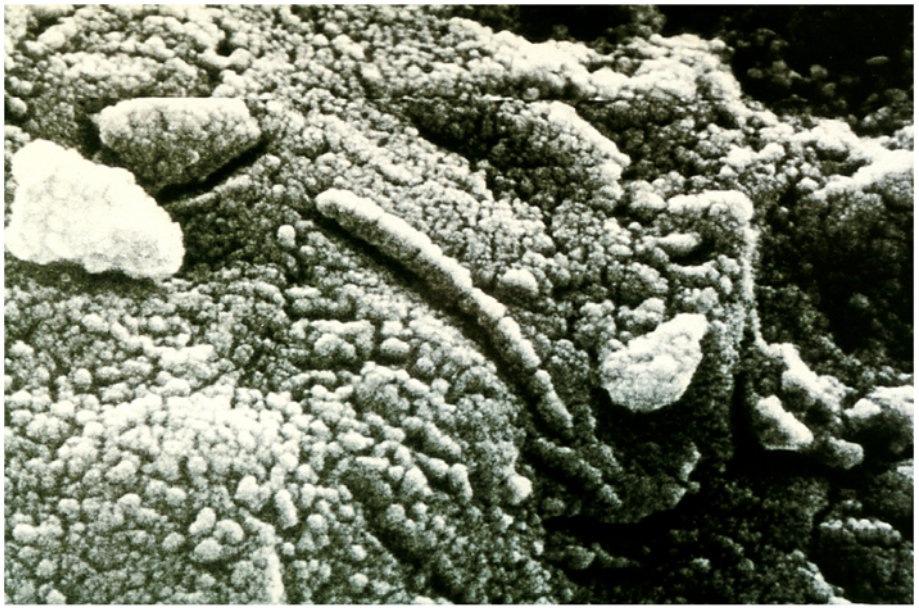


Figure 28-9b
Universe, Eighth Edition

- **People aren't so sure now…**
  - **Most people don't consider this conclusive**
  - **Lots of debate, but we need new information to solve this one**

In this lecture…

- Prerequisites for life
  - Organic compounds, energy and liquid water
- Prerequisites for a habitable planet
  - Galactic location, Star-type, position in the habitable zone and friendly gas giants
- The Early Earth
  - Unsuitable for life until after late heavy bombardment
  - Early life appeared very fast
  - Life changed Earth's atmosphere to be oxygen rich
- Astrobiology
  - Europa's subsurface ocean may harbor life today
  - Ancient Mars may have harbored life

Next: Final next week – on Tuesday

- Reading
  - Chapter 28 to revise this lecture

- **Notes on the final: TUESDAY MAY12TH AT 11AM**
- **Questions will be multiple choice (usual scan-tron)**
- **Topics**
  - **About 50% recycled questions from the mid-terms (word for word)**
  - **Everyone can get a high mark on this**
  - **Most of the remaining 50% will be on material covered since the second mid-term**
  - **A handful of new questions will cover the entire course**
  - **This test will be longer than the mid-terms - 1.5 hours**
  - **About 75 questions**