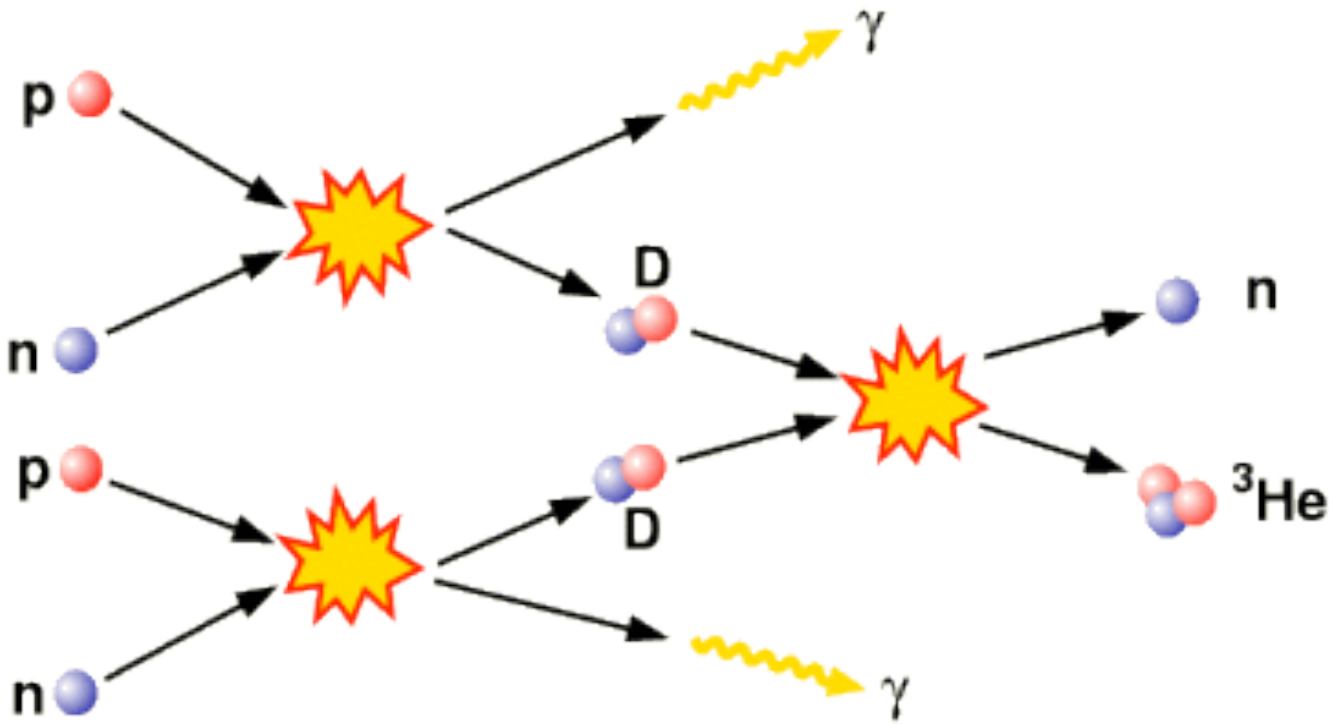
The Origin of the Elements



http://www.einstein-online.info/en/images/spotlights/BBNI/pn_to_he3.gif

Outline

- The true basics of life
- The age of the universe
- What elements do we need?
- The origin of hydrogen and helium

What is Required for Life?

- Carbon?
- Liquid water?
- Rocky planets?

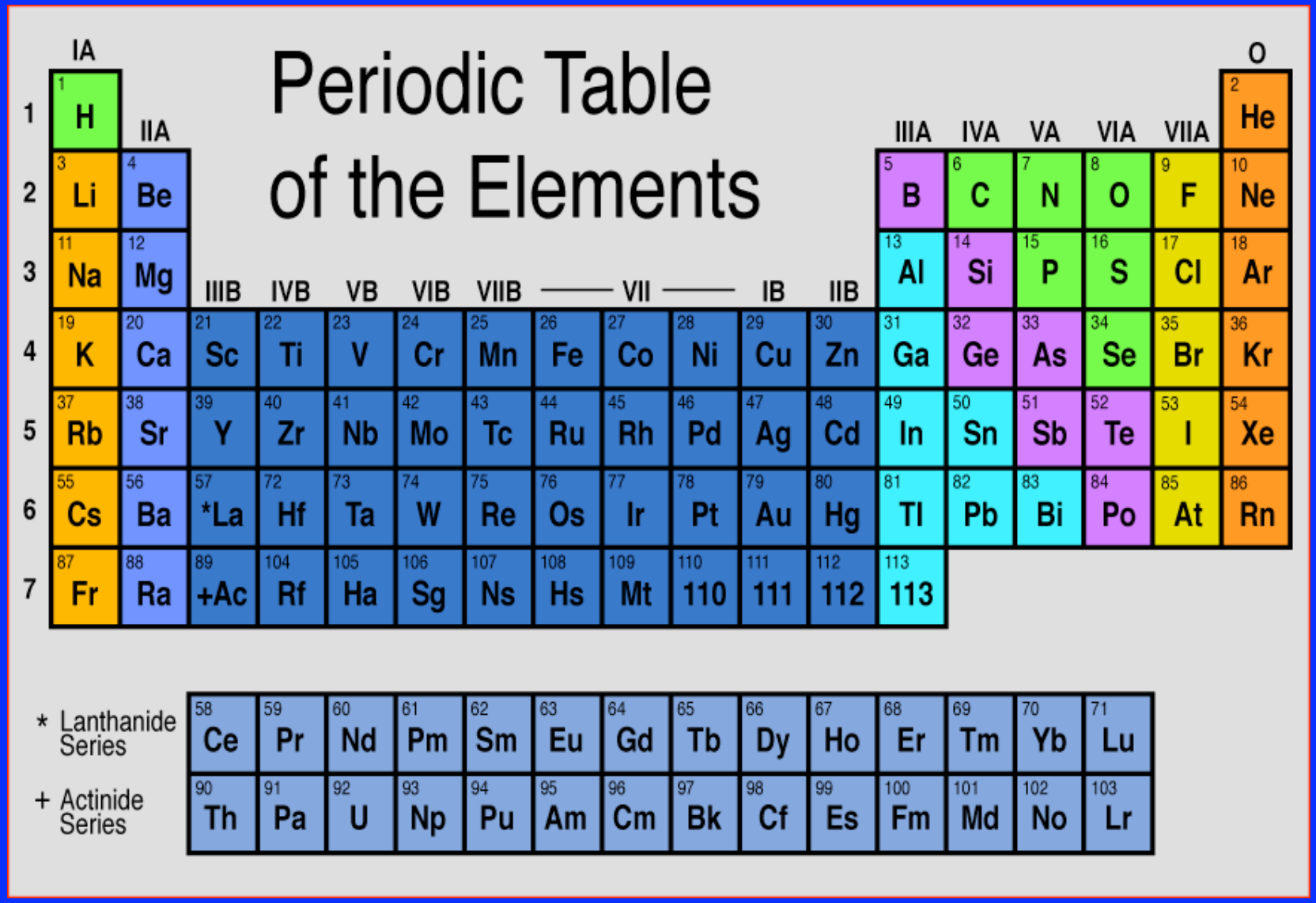
Since we don't know of other life yet, we have to be cautious.
What is *absolutely* necessary?

Is Carbon Required?

Special Properties of Carbon

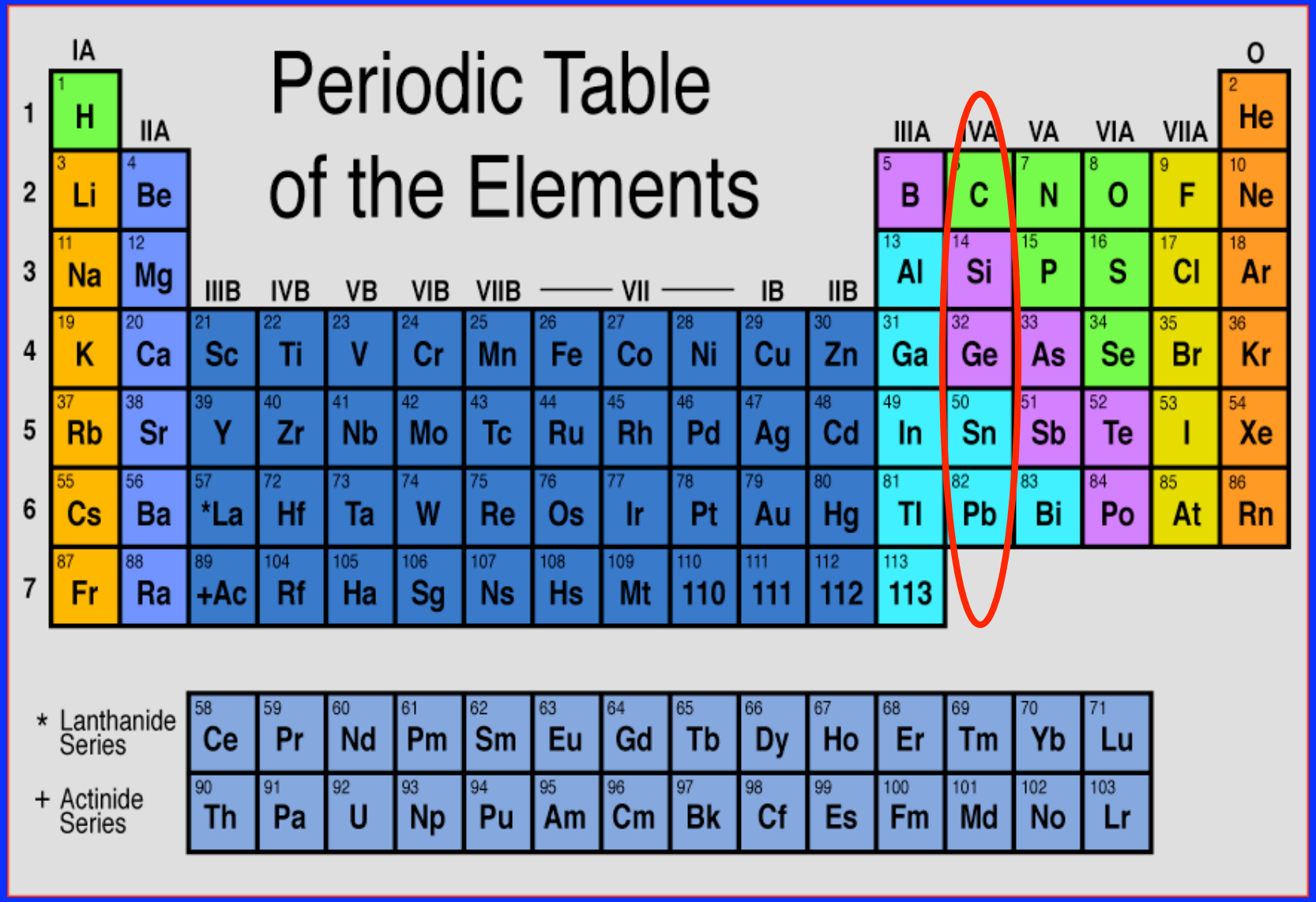
- Four available bonds per atom
- Very high boiling point (4827 C)
- Bonds almost equally strong with carbon and with other elements (e.g., O, H)
- Different forms: diamond, graphite, buckyballs. Diamond is hardest substance
- Which of these is important for life?

Possible Carbon Alternatives?



http://facstaff.gpc.edu/~pgore/PhysicalScience/periodic-table.gif

Possible Carbon Alternatives?



http://facstaff.gpc.edu/~pgore/PhysicalScience/periodic-table.gif

Example: Silicon-Based?

- Maybe
- Lots of sand on Earth, though, and yet no life based on silicon
- In future, might be artificial Si-based life

Is Water Required?

Special Properties of Water

- “Universal solvent”; many materials dissolve but are not destroyed in water
- Can exist as solid, liquid, or gas in Earth conditions
- Ice is less dense than water, so floats
- Water has high surface tension
- Which of these are important?

Survival of Desiccation

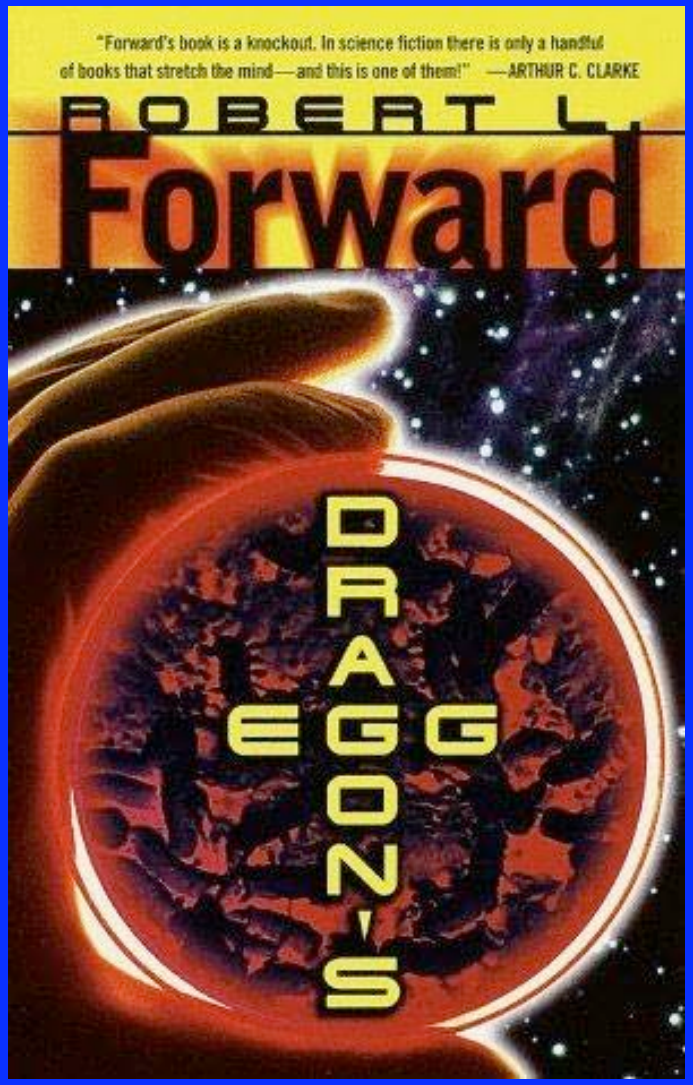
- Many creatures can survive without water
- However, none that we know can grow and reproduce without water
- Could methane (CH_4) or ammonia (NH_3) work?

Bdelloid rotifer

Is a Rocky Planet Necessary?

Is a Rocky Planet Necessary?

- Surface, liquids seem nice for life
- But could life emerge on a star? In interstellar space? On gas giant? Elsewhere?
- What do you think?



Life on a neutron star???

Heavy Elements Needed?

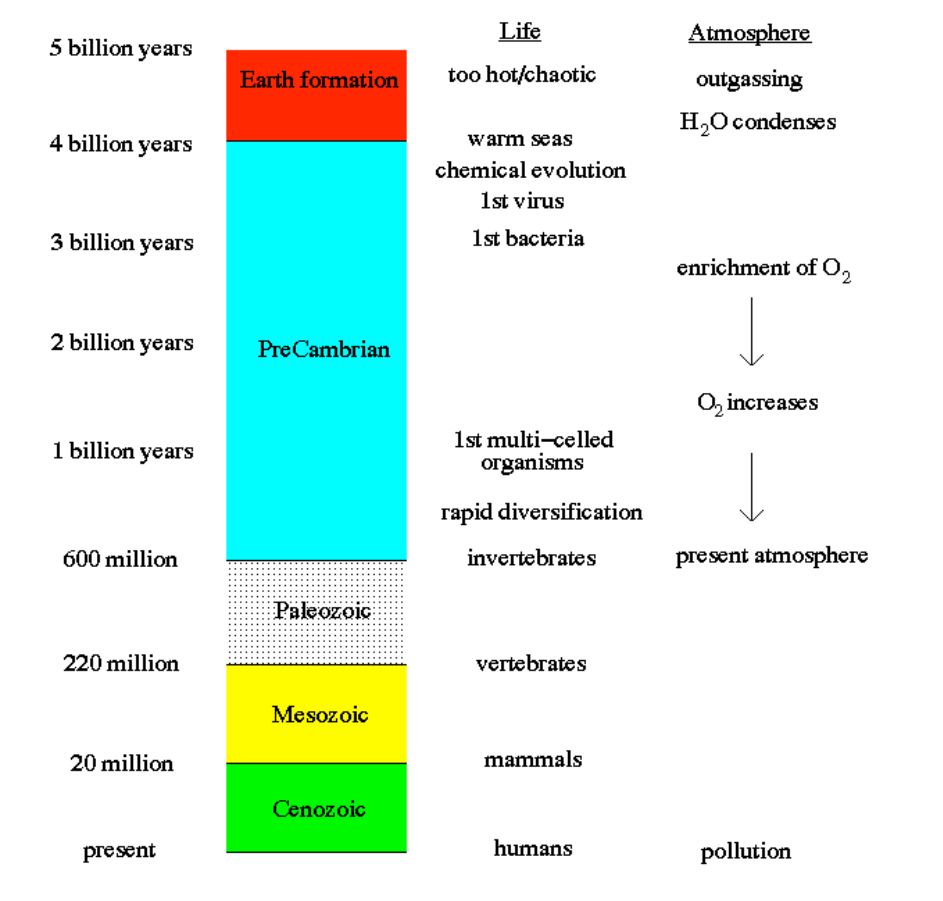
- Do we need elements beyond hydrogen and helium?

Heavy Elements Needed?

- Carbon seems pretty important. For life on Earth, also oxygen, nitrogen, sulfur
- If silicon etc. substitute for carbon, those are still heavy
- If methane, ammonia, or whatever substitute for water, those still require carbon or nitrogen.

A Long Time!

- On Earth, took 3 Gyr to go from life to multicellular life
  Short, fast, average???
- We do know that big changes require millions of years here
- Reasonable to expect elsewhere



http://athene.as.arizona.edu/~lclose/teaching/a202/life_timeline.gif

Speedup or Slowdown of Life?

- Suppose Earth had fewer radioactive elements, or more protection from UV
  Fewer mutations
- Would life have progressed faster (not as many mistakes) or slower (not as many prospects for innovation)?

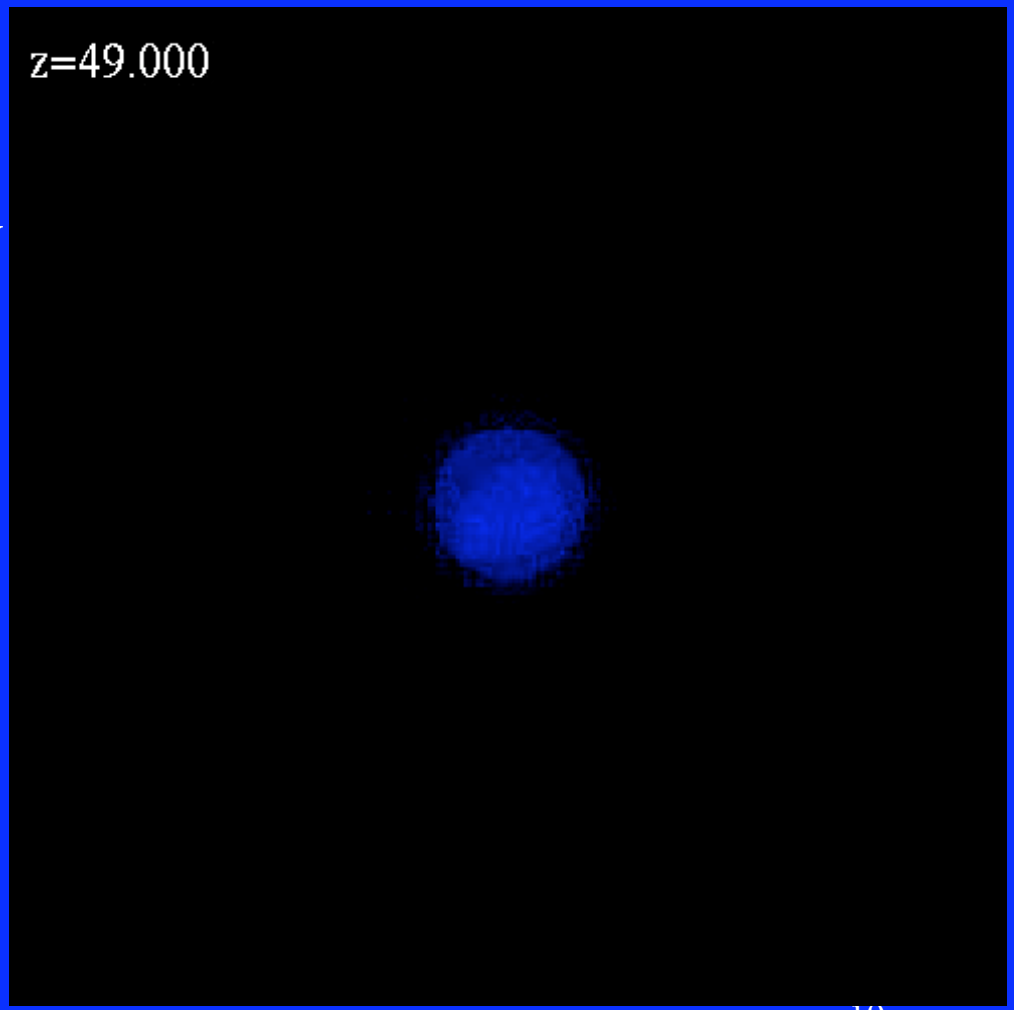
Complex Chemistry

- All Earth life has H, C, N, O, P, S
  Is this critical?
- Don't know, but if we are limited to H, He, complex molecules can't form
- Assume need atoms heavier than He

http://www.daviddarling.info/images/glycine.jpg

A Non-Uniform Universe

- Completely uniform means no complexity
- Need some structure to distinguish parts



Movie by Ben Moore

The Age of Earth and the Universe

- Claim: billions of years
- But how do we know?
  Oldest human ~100 yr
  Civilization ~10,000 yr
- In general, how can we measure things far outside our realm of experience?

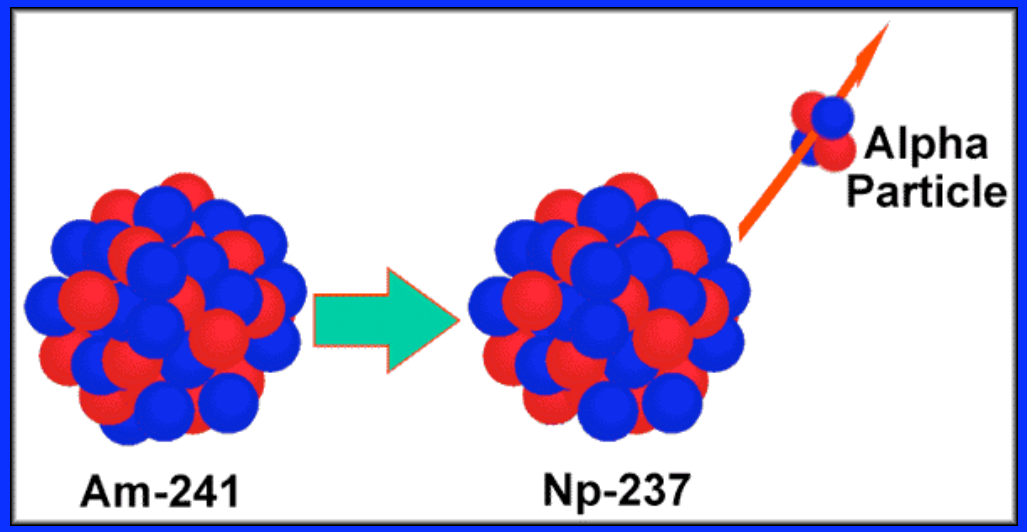
http://auxtbcr.info/Articles/Age%20of%20Earth.JPG

Inference Outside Experience

- Have model for how things behave
- Model extensively tested in many circumstances, giving correct answer
- Therefore, believe answers in realms we don't experience directly
  But in such cases we need multiple checks to our answers

Radioactive Decay, Part 1

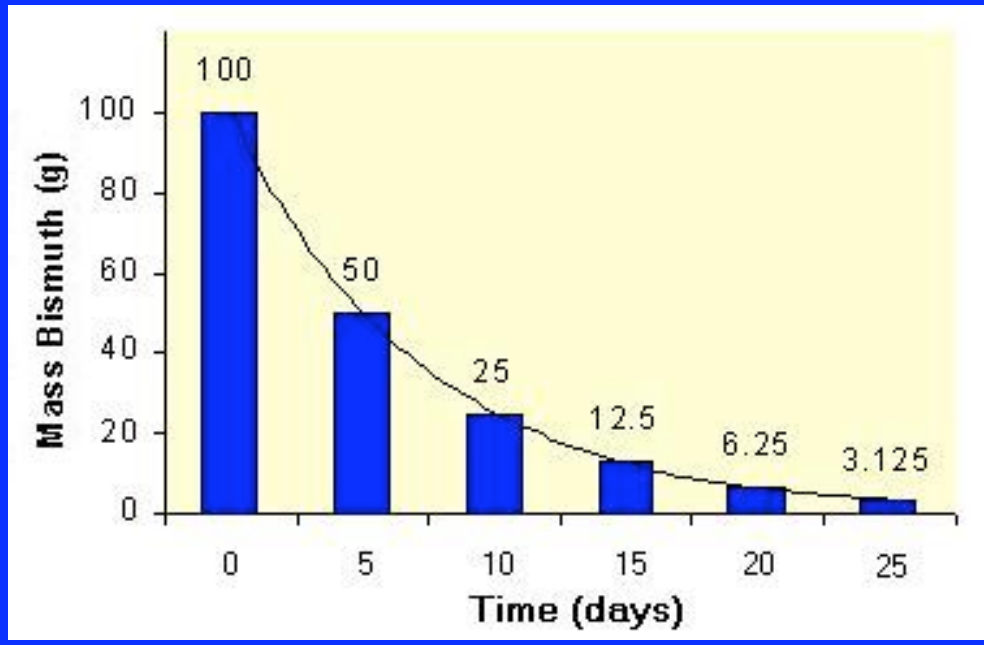
- Atoms made of electrons and nuclei (protons, neutrons).
- Type of element depends only on proton number
- Some nuclei decay eventually into other nuclei: unstable



http://lhs.lps.org/staff/sputnam/chem_notes/alpha.gif

Radioactive Decay, Part 2

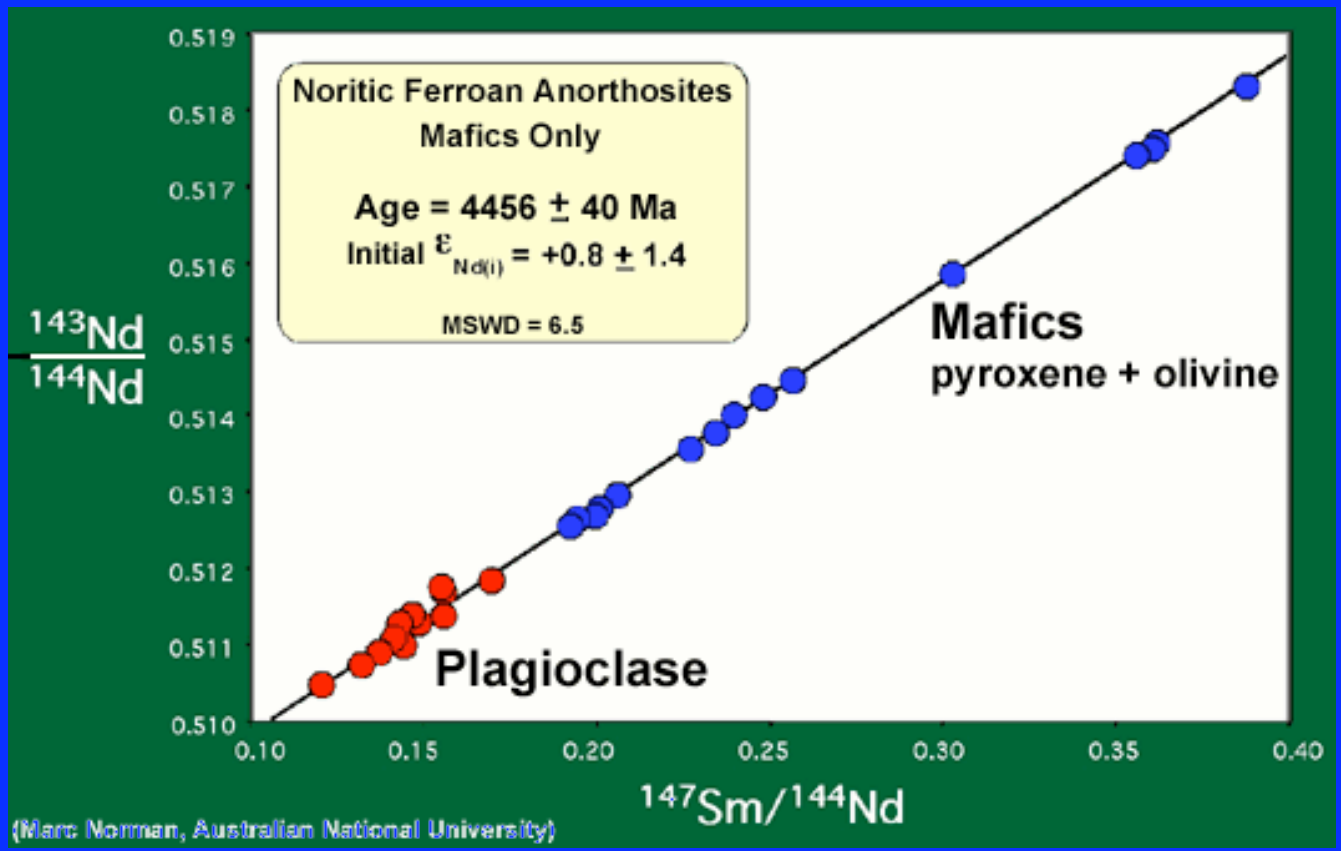
- Decay is statistical: can't predict in advance
- Concept of half-life: time needed for half of nuclei to decay
- Half-life is robust against temp, press, etc.
- Thus, fraction left acts as great clock!



http://www.visionlearning.com/library/modules/mid59/Image/VLObject-784-021205011203.j

What About Initial Abundance?

- Don't know initial abundance; big problem?
- No! Isochron dating. Parent, daughter, non-radiogenic daughter. Straight line self-checks



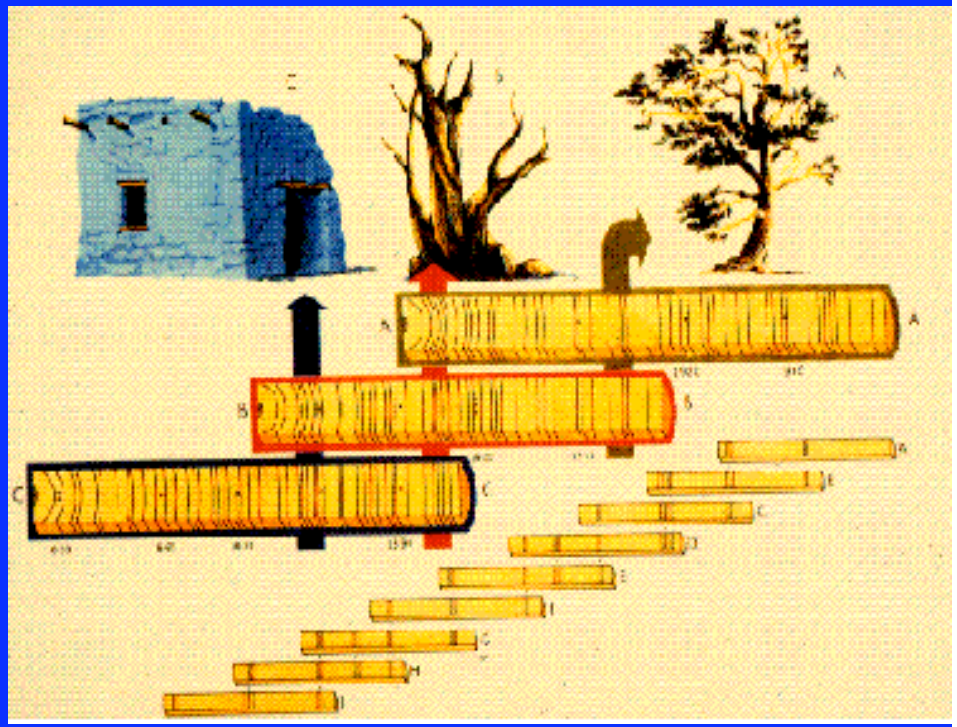
Example: Carbon-14

- Normal carbon: C-12
- C-14 decays to N-14
  5730 yr half-life
  Balance for live things
  Decreases after death
- Can check for historical dates
- But what about over longer time scales?

http://www.thetartan.org/system/asset/image/1823/small/mummyfin.jpg

Dendrochronology

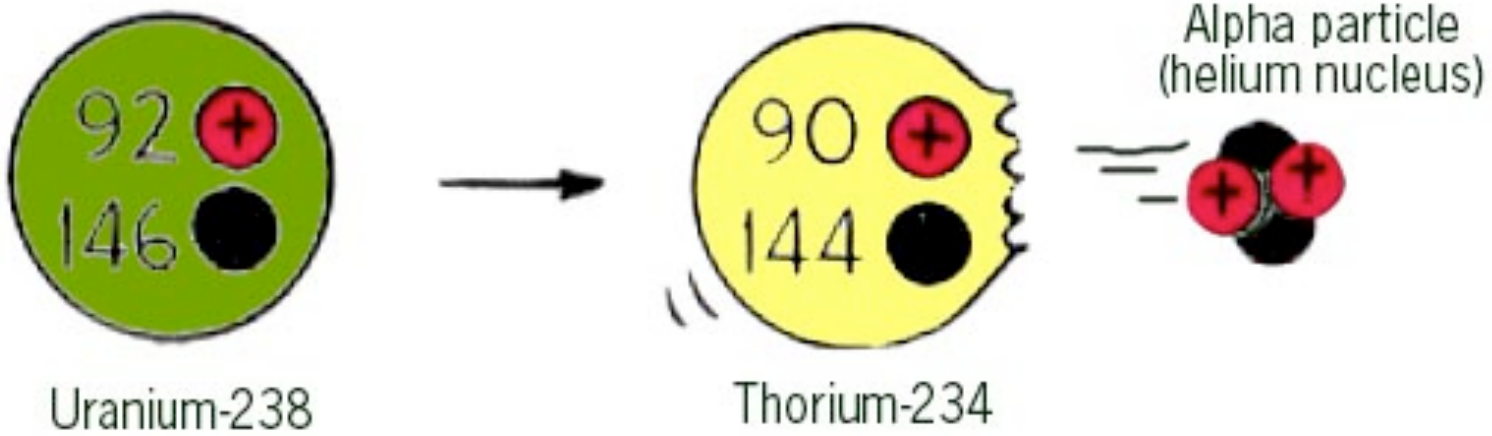
- Tree ring dating!
- Oldest individual trees (bristlecone pine) can live 5,000 yr
- But tree rings can be overlapped, date to 9,000 yr
- Excellent calibration with radiocarbon



http://www.ltrr.arizona.edu/lorim/xdate.gif

Longer Decays: E.g., Uranium

- Uranium decays to thorium
- Half-life 4.5 billion years
- Well-matched to age of Earth



http://sol.sci.uop.edu/~jfalward/physics17/chapter14/uraniumthoriumalpha.jpg

Results of Radioactive Dating

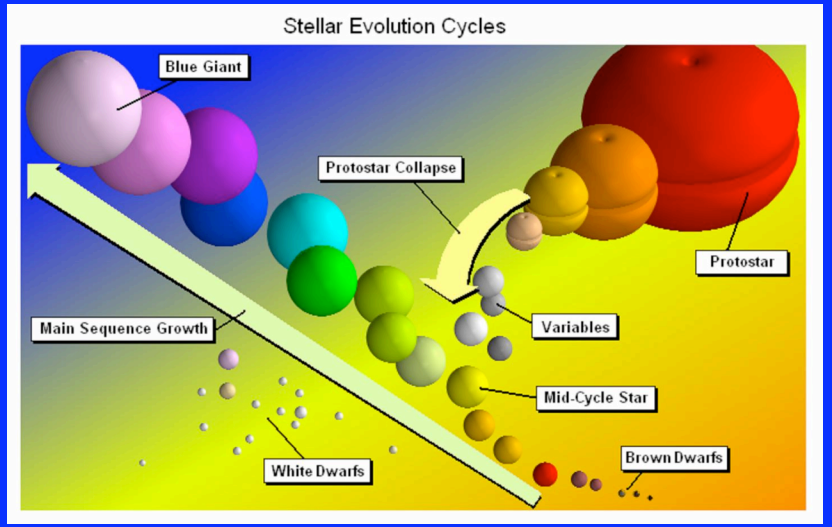
- Solar System is 4.55 Gyr old
- Extremely consistent, many samples
- Low uncertainty
- Universe must be at least this old
- What other methods can we use?

Chondrite, 4.55 Gyr old

http://farm3.static.flickr.com/2108/2201855875_b8a61c75d8.jpg?v=0

Stellar Evolution

- We only see snapshots of star lives, but understand them well
  Small things live long
- Cluster of stars
  Formed at same time
  How big is biggest?
  Use to find age
- Oldest: 11-13 Gyr



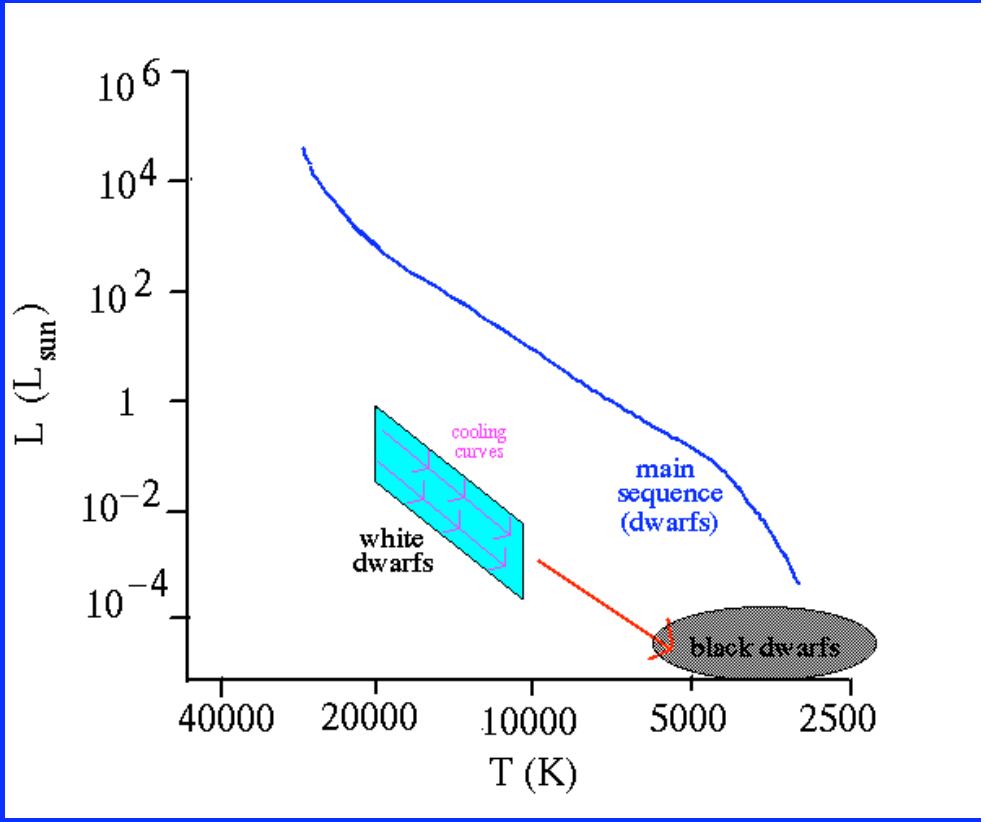
http://www.aetheoraem.com/StellarEvolutionJPG.JPG

Globular cluster M80

http://www.astrographics.com/GalleryPrints/Display/GP0046.jpg

Cooling of White Dwarfs

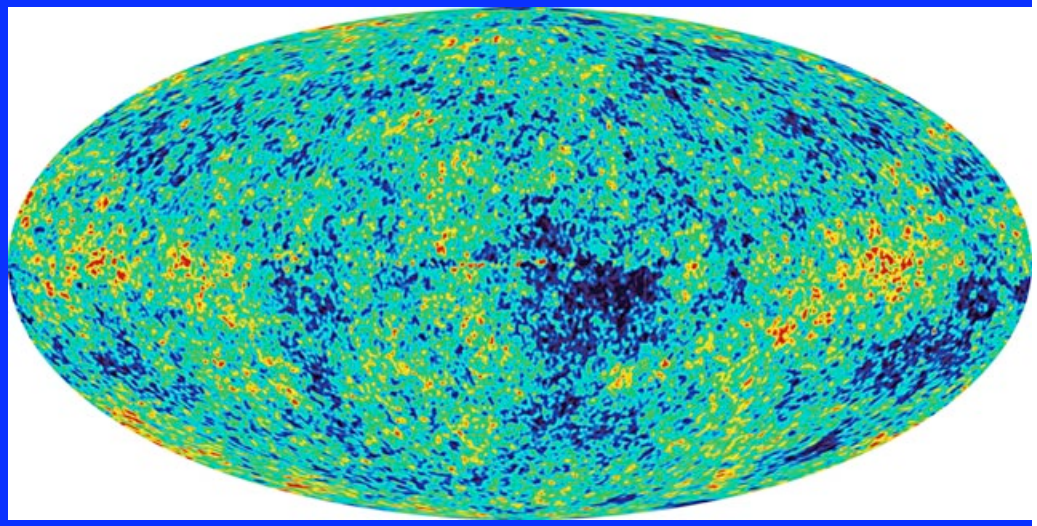
- WD: size of Earth, mass of Sun
  Endpoint of some stars
- No energy source, so they just cool forever
- Simple objects: measure temp to find age
- Result: some >12 Gyr



http://abyss.uoregon.edu/~js/images/wd_cooling.gif

Background Radiation

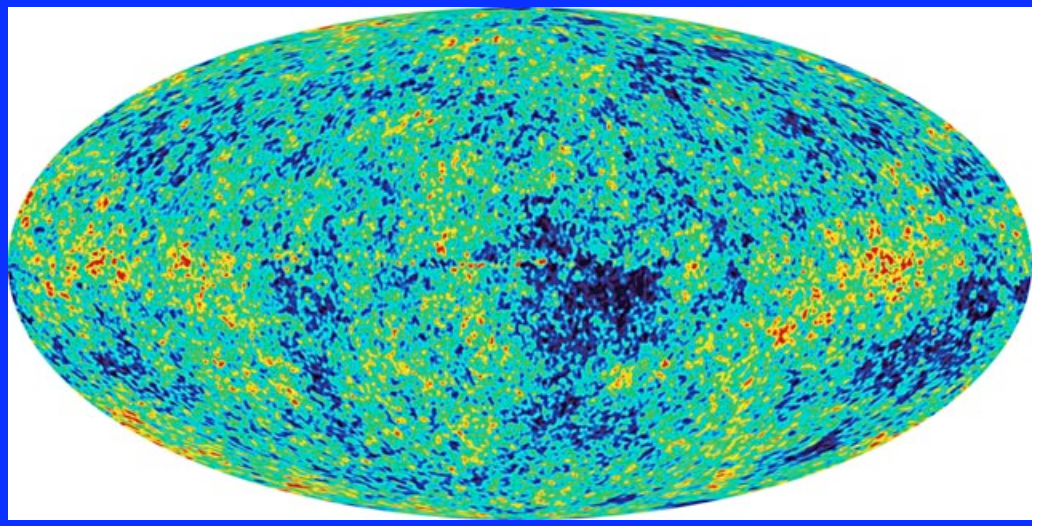
- Universe became transparent after expanding
- Radiation from them has informative bumps
- Tells us that the universe is 13.7 Gyr old
- Note: consistent with other estimates



Microwave photo of sky from NASA's WMAP satellite

Background Radiation, Part 2

- We learn a lot more from this radiation
- Overall content of the universe
- Geometry of the universe
- Initial smoothness of the universe



Microwave photo of sky from NASA's WMAP satellite

How Quickly Could Life Develop?

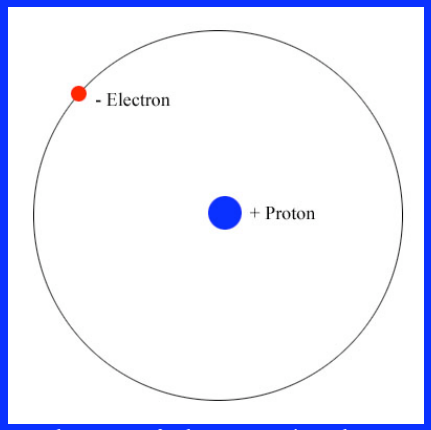
- A thousand years after Big Bang?
- A million?
- A billion?

Basically, enough time was needed for molecules to form.
When did this happen?

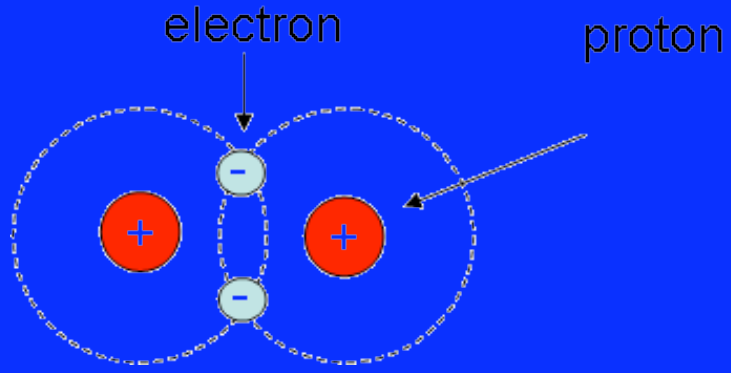
Is Hydrogen Enough?

- H can form molecules with itself: H_2
- However, longer chains are unstable
- From comp sci perspective, not enough information!
- Needs other atoms

Only possibilities:



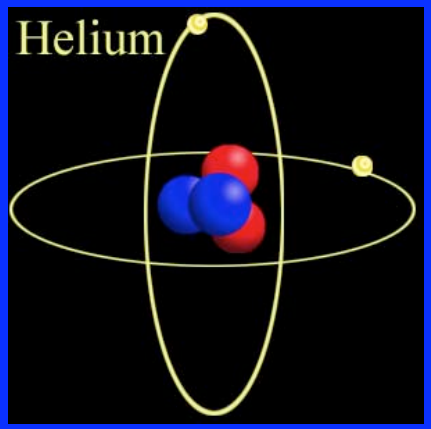
http://www.kwugirl.com/cyberspace/atom.jpg



http://www.hydro.com.au/handson/students/hydrogen/images/h2.gif

How About Helium?

- Even worse!
- Helium already fills both slots in inner electron shell
- It is the least interactive of all elements
- Nothing doing!



http://aspire.cosmic-ray.org/labs/star_life/images/helium.jpg

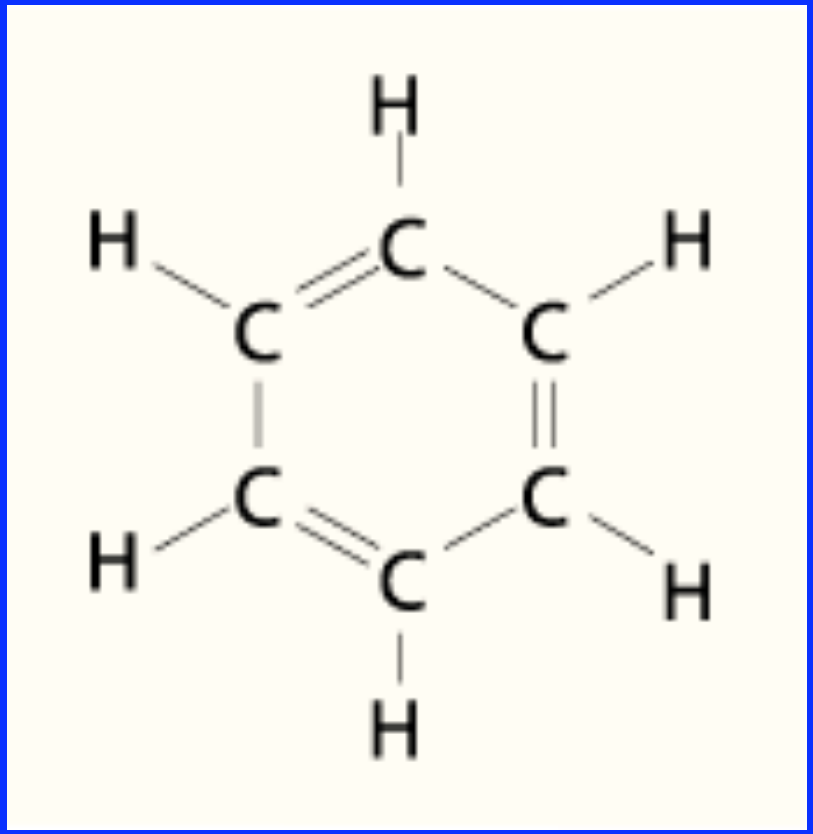
http://awsmposters.com.au/catalog/images/pirates%20keep%20out.jpg

Lithium, Beryllium, Boron?

- To be open-minded, maybe these work
- But the fraction of mass in these atoms is tiny
  All $<10^{-9}$ of hydrogen
- Look for others

Carbon, Nitrogen, Oxygen?

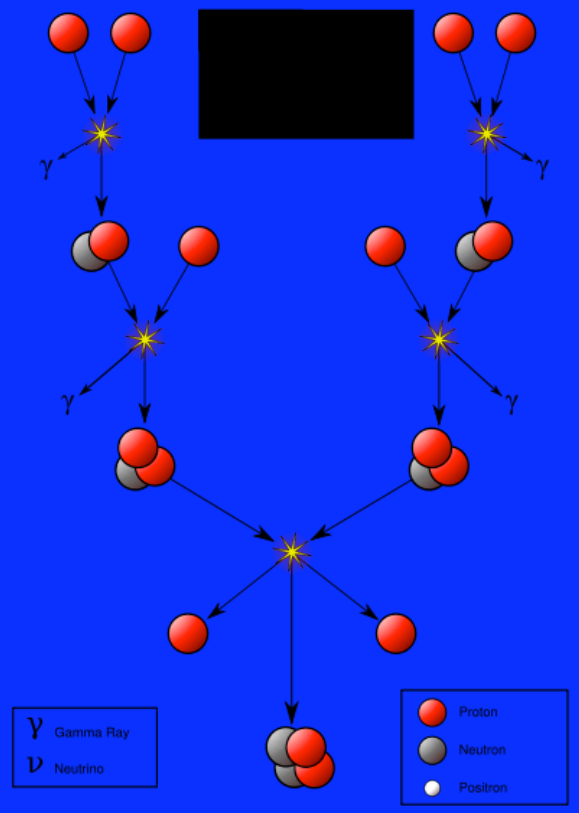
- Finally!
- These are common and have very flexible chemistry (especially carbon)
- We probably need them
- Have they existed since the beginning of the universe?



http://www.chemistrydaily.com/chemistry/upload/9/9c/Benz1.png

Formation of H, He

- No!
- Early universe was too hot for nuclei
- Cooled down, and some H came together to form He
- But not enough time for much of anything else



http://upload.wikimedia.org/wikipedia/commons/thumb/8/8d/Big_Bang_nucleosynthesis.svg/424px-Big_Bang_nucleosynthesis.svg.png

Heavier Elements?

- No evidence of C, N, O until several hundred million years after Big Bang
- How might these be produced?
- Also, what about phosphorus and sulfur. Are these essential as well?
- What about iron or other trace elements in our bodies?

Summary

- Universe is about 13.7 Gyr old
  Plenty of time for life, in principle
- Need complex chemistry
  H and He not enough!
- Early universe, however, formed only H, He
- Where did the rest of the elements originate?