AST 309L Thurs Sept 4

- The major questions we'd like to answer, in context of scientific approaches (1.1-1.4)
- Gravity, orbital motion, Kepler's laws (2.2, 2.4)
- Sizes, distances, time, production of elements (3.2)
- Planetary worlds; planet formation (3.3)
- Physics we need: structure of matter, phase changes, properties of light (3.4)

Is it reasonable to suppose that “life” is common in the Galaxy? What evidence or arguments for or against? Compare with textbook question, Do we expect biology to be universal?

All life on Earth uses the same planetary-based biochemistry:

Elements (H, **C,** N, O + trace) -- unique for life? Common or rare? Could life be based on some other elements?

Complex organic molecules--life here is carbon-based. Why?

Is carbon unique in some way? Can complex organic molecules form easily, or do they require special conditions? Could some other atom play this role?

Water is essential to all organisms, important biochemical processes. But we don’t see much hydrogen around otherwise (it mostly escaped when Earth was young). *How did we get all this water? Should other planets get it too?*

Genome structure: All Earth organisms use exactly the same genetic code.

Planets: If life needs complex molecules, life needs planets--*is there reason to believe that planets (especially like Earth) should be common?*

(We return to this in ch.10, 11).

Elements of life: H, C, N, O common only here, or in our neighborhood, but not elsewhere? Are these produced in special,rare, events?

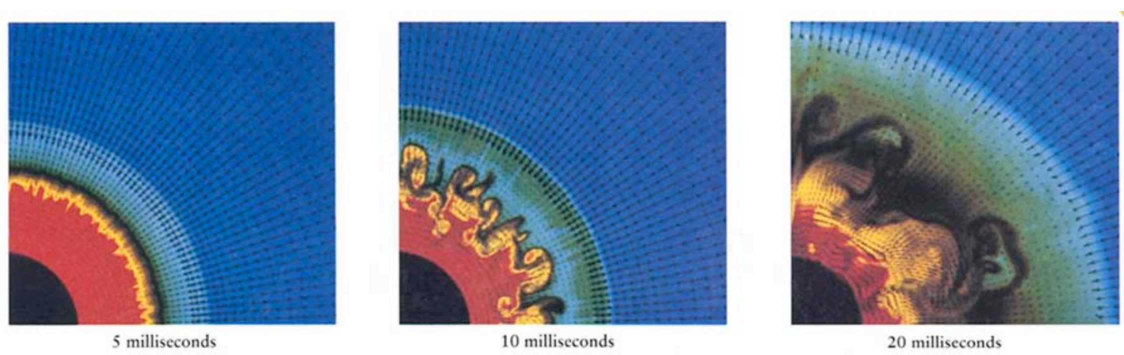
➡ ***No**, H, C, N, O are the most common elements in just about every object in the universe (recall how we could know such a thing)*. Only the total amount of 'metals" (heavier than He) varies, but their proportions are amazingly constant.

➡ Consider composition of Sun: 75%H by mass, ~ 1% C, N, O, everything else either helium (useless for life--inert), or much less abundant. Just about same for all known stars! Same is found in the gas of the interstellar medium, and in the stars and gas of the most distant galaxies.

Does it seem odd to you that the four most abundant elements are just those elements on which life is based, if those elements indeed have special properties? The "special properties" could have been some rare element, but no….

A supernova remnant

Simulation of supernova explosion (20 milliseconds)



Why are abundances of elements so universal?

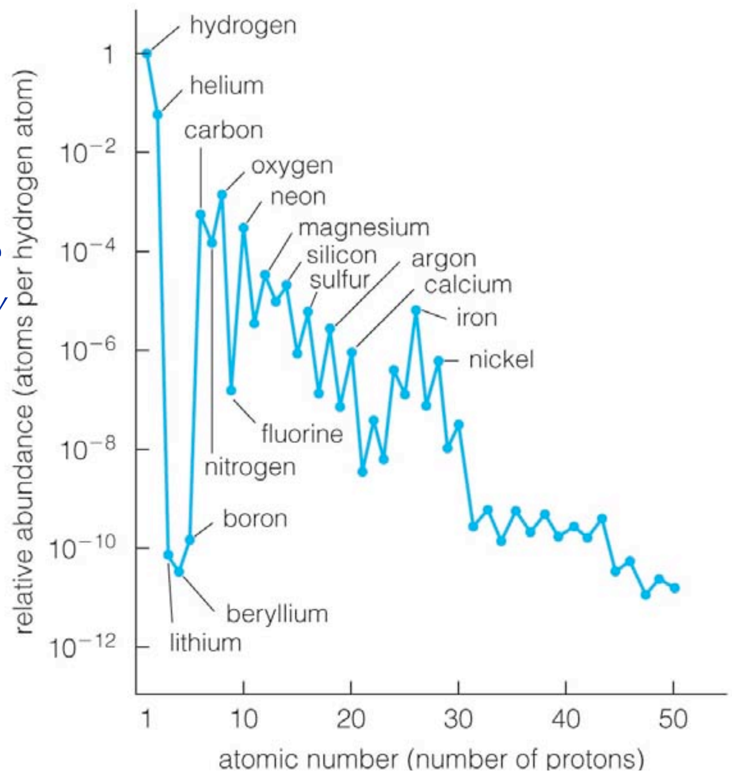
Hydrogen → has been around from the beginning (universe was originally only fundamental particles, including protons = *hydrogen (rest was electrons, photons, …, no other elements)*

Carbon, oxygen → produced by *triple alpha reaction*** in red giant stars, which later explode as supernovae. All stars become red giants, but *only massive stars produce supernovae; massive stars are rare (~ 1% of stars). So why is there carbon and oxygen everywhere?*

Nitrogen → the Earth's atmosphere is mostly nitrogen. Important? (*Yes*: Nitrogen doesn't react well with oceans, rocks, so our atmosphere is stable. But weird part to this: If not for the nitrogen cycle, involving bacteria, the nitrogen would have disappeared long ago.

****This is one of the best and first examples of a "contingency" that has nothing to do with biological complexity, only the lucky (for us) energy of a certain "resonance" level in the beryllium nucleus. Without it There would be no triple alpha reaction, and no carbon!**

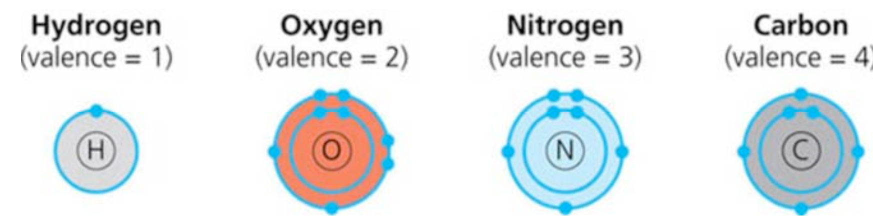
Abundances of elements vs. atomic number



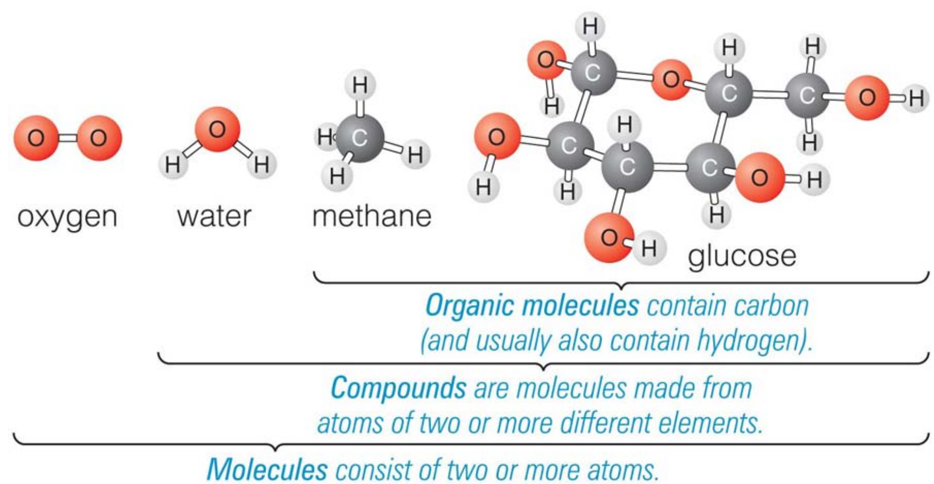
Carbon, organic molecules, variety of structures

Carbon is clearly unusual in the way it can form complex molecules with strong bonds that can bend, fold, and twist (protein folding, DNA packing,… ”conformations”).
Look at example below of atoms bonding to make molecules, then a small organic molecule. These can chain together to make “polymers.” That is what life apparently needs--very long chain molecules that can fold and bend and twist. *Could some other atom play this role?*

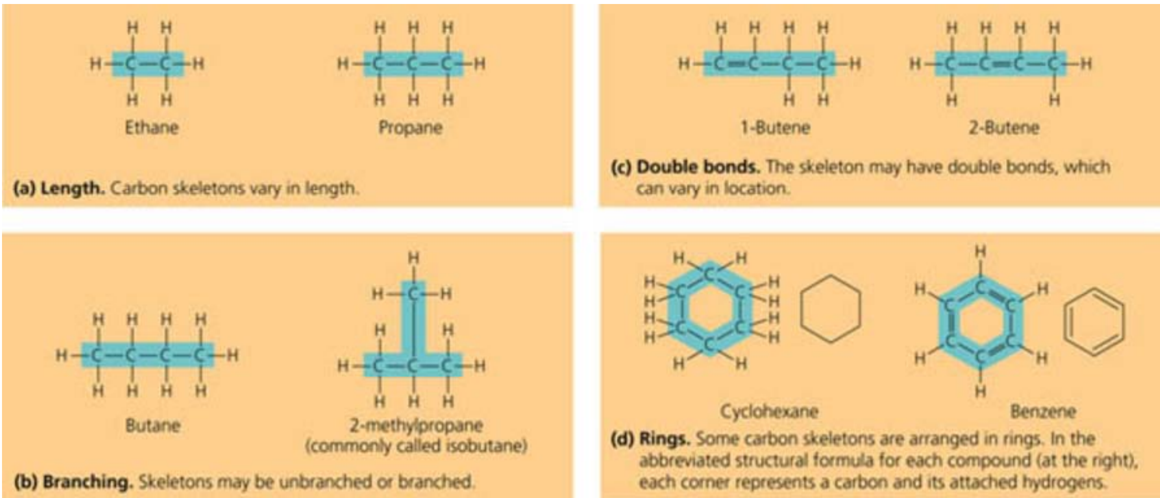
Atoms	e⁻ pairing	Covalent bond	Bond energy (kJ/mol)
H + H →	H:H	H—H	436
C + H →	C:H	C—H	414
C + C →	C:C	C—C	343
C + N →	C:N	C—N	292
C + O →	C:O	C—O	351
C + C →	C::C	C=C	615
C + N →	C::N	C=N	615
C + O →	C::O	C=O	686
O + O →	O:O	O—O	142
O + O →	O::O	O=O	402
N + N →	N:::N	N≡N	946
N + H →	N:H	N—H	393
O + H →	O:H	O—H	460



Carbon has *four* open electron subshells (valence =4) for bonding, so lots of possibilities



Why carbon? (cont'd)



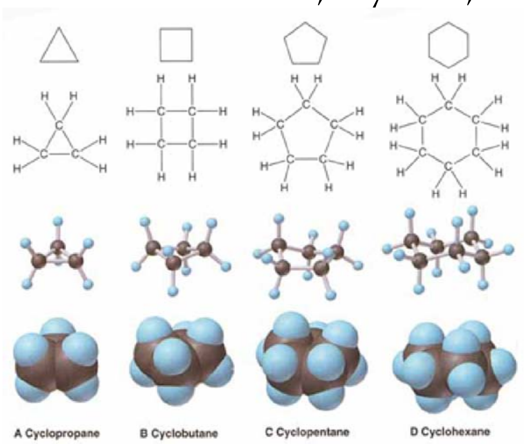
(a) Length. Carbon skeletons vary in length.

(c) Double bonds. The skeleton may have double bonds, which can vary in location.

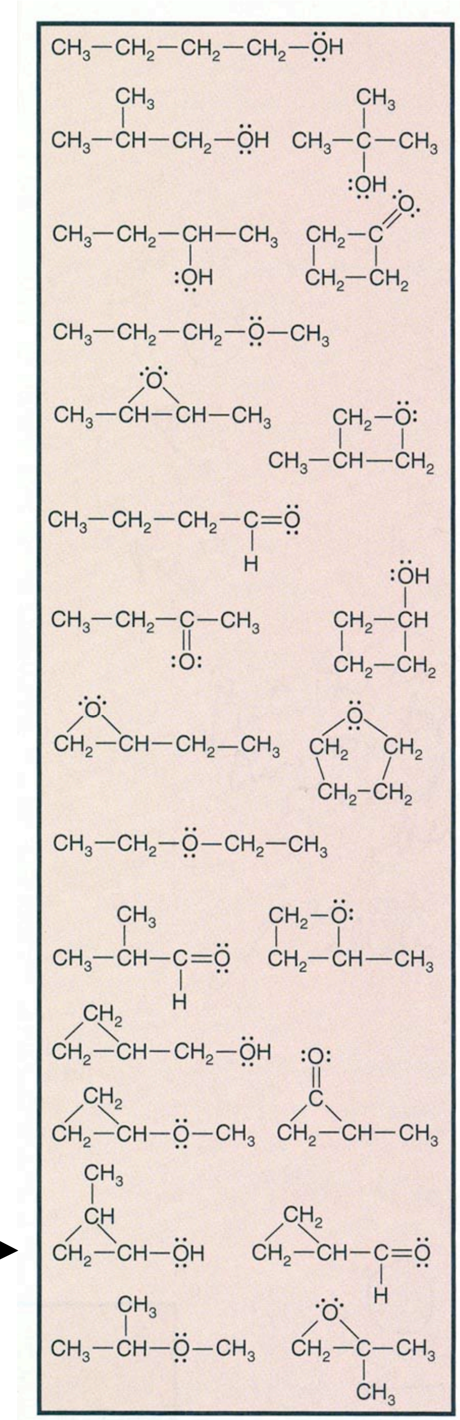
(b) Branching. Skeletons may be unbranched or branched.

(d) Rings. Some carbon skeletons are arranged in rings. In the abbreviated structural formula for each compound (at the right), each corner represents a carbon and its attached hydrogens.

Linear, cyclic, branched,…

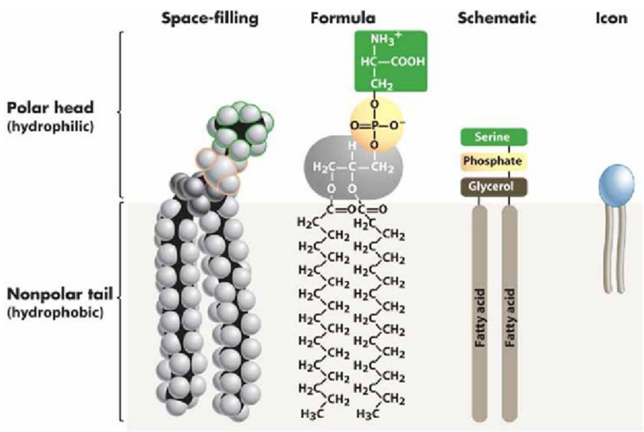


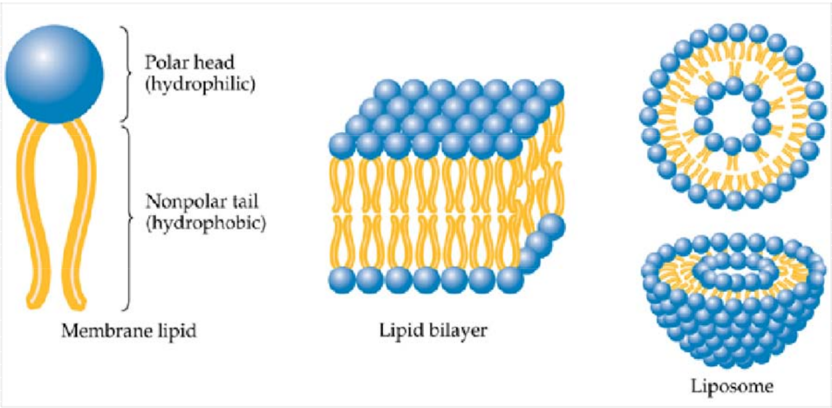
Can produce many structures by combinations of rings, chains, branches,…

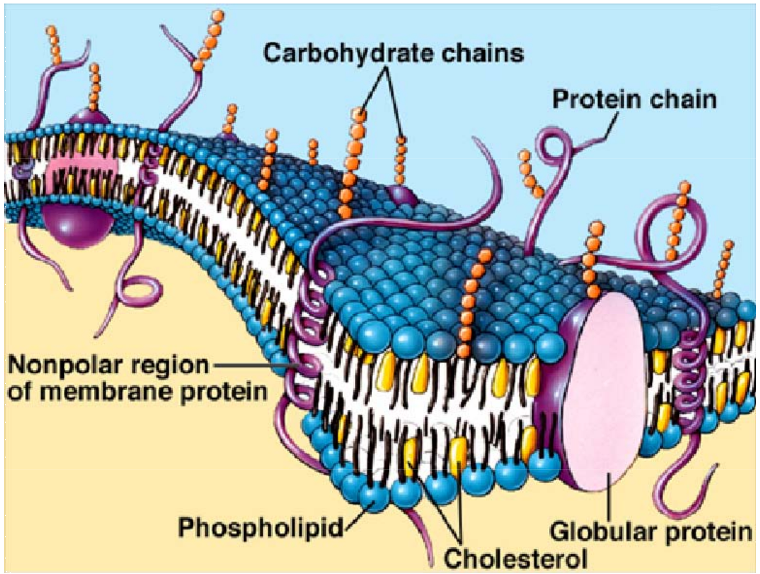


One biological example: Membrane structures

Starting only with hydrocarbon chain molecules (left) and water, easy to produce small membrane-like structures (right), which self-organize and (over time) have developed into the "lipid bilayer" (bottom) used as a cellular compartment by all organisms.







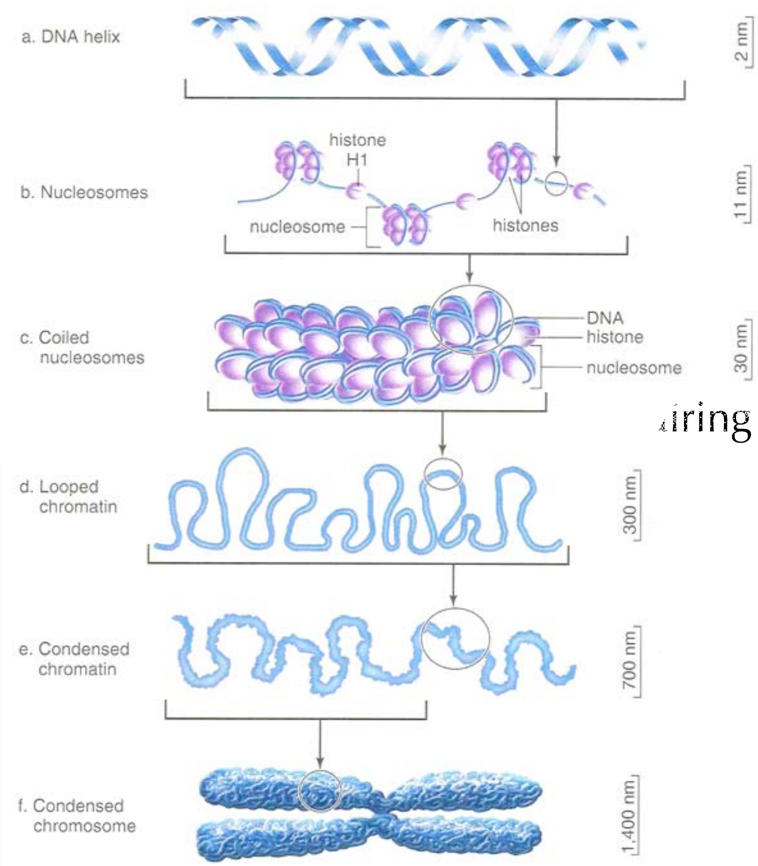
Genome structure: All Earth organisms use exactly the same genetic code. Same 4 bases ("letters"ATCG), triplet codons ("words") 3 letters long, same protein functions, … In this sense, biology is indeed universal, but only on planet Earth. Why should it be similar elsewhere?

Why isn't there be more than one form of coding for proteins and process of reproduction?

Note that life didn't have to *begin* this way…

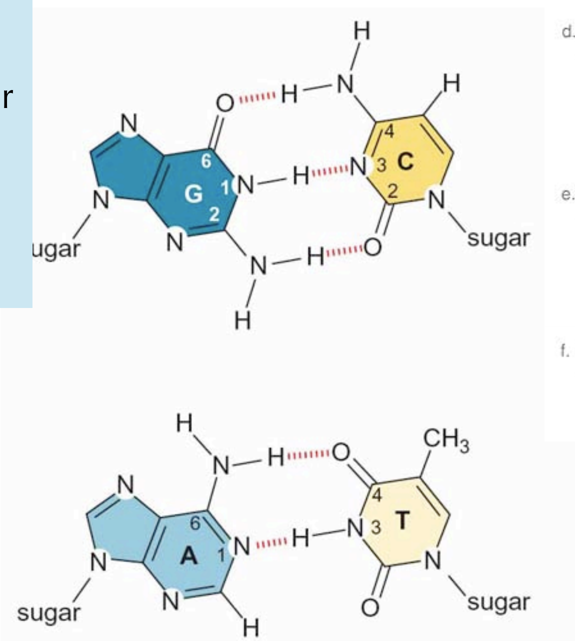
(Was the present genetic code the original genetic code?)

DNA packing: How could a process this complex have been "learned" by nearly all (eukaryotic) organisms?



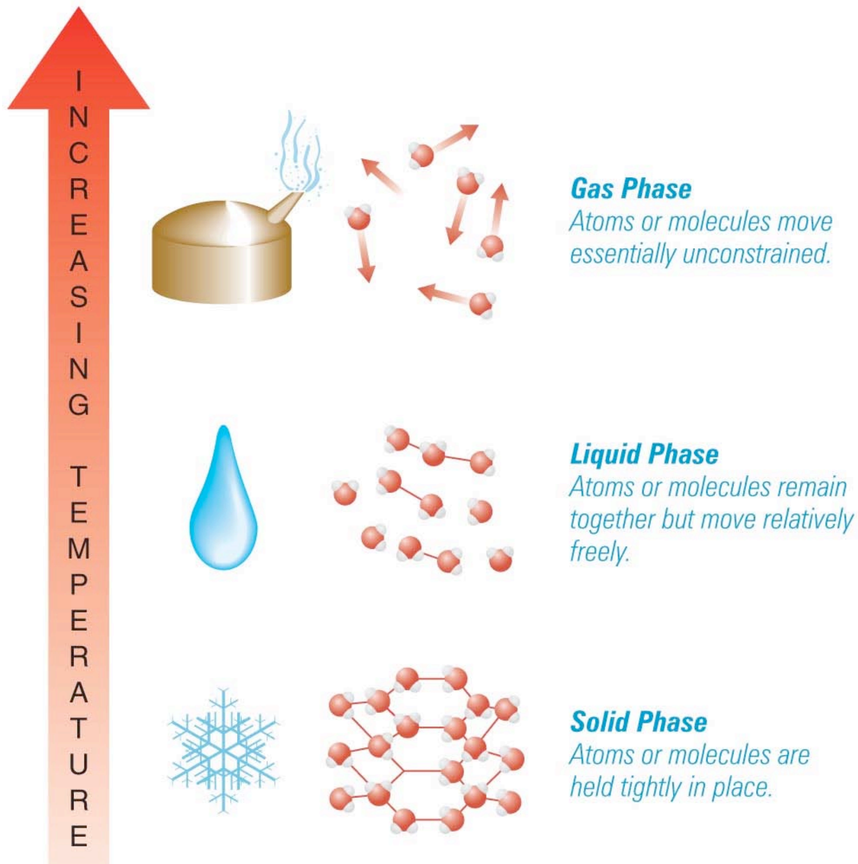
Four and only four ring molecules called bases are used in *all* organisms to code for thousands of proteins, and Help in replication.

Picture shows *base pairing*.



Why planets? If oceans and solid surfaces, what is required to get solids and liquids? To get planets at all? If difficult, life could be rare

As temperature rises, all materials undergo *phase changes* between solid, liquid, and vapor, at certain critical temperatures.
Memorize critical temperatures of water.
Where will such temperatures be likely to arise?



The four types of materials present in the protoplanetary solar nebula (Table 3.1 in textbook)

	Examples	*Typical Condensation Temperature*	*Relative Abundance (by mass)*
Hydrogen and Helium Gas 	hydrogen, helium in nebula	do not condense	98%
Hydrogen Compounds 	water (H_2O) methane (CH_4) ammonia (NH_3)	<150 K	1.4%
Rock 	various minerals	500–1,300 K	0.4%
Metals 	iron, nickel, aluminum	1,000–1,600 K	0.2%

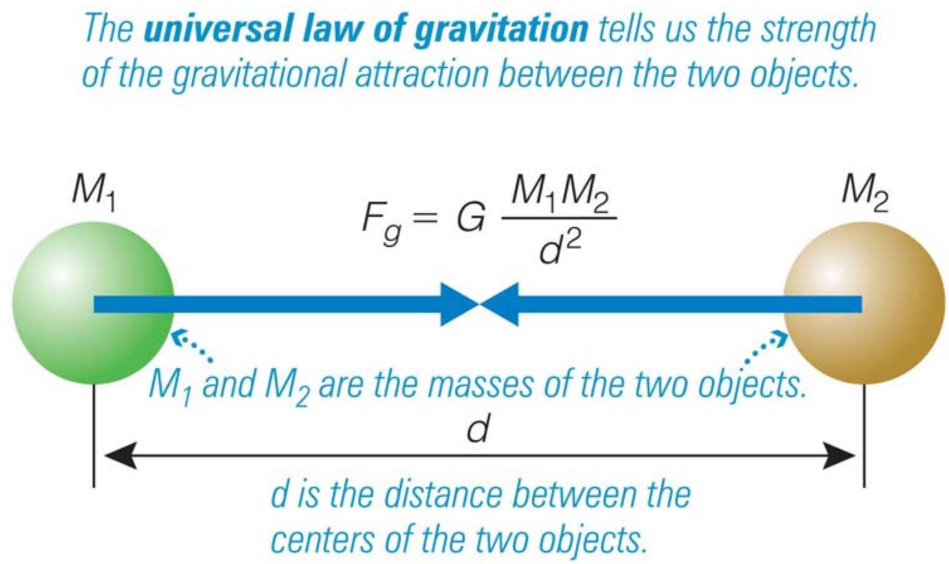
Next: Review of some background physics

1. **Gravity, orbital motion, Kepler's laws**
2. **Light (on next set of slides)**

Gravity: Newton's inverse square law

Starting with this force-distance law for gravity, and Newton's laws of motion, we can understand the orbital motions of objects, and will be able to calculate the *masses of extrasolar planets.*

Newton's law of gravity is very *useful,* allows us to calculate masses of objects in orbit, *even if we can't see them* (black holes, exoplanets).



Theories, models: What is gravity?

This is relevant to attempts at communicating with extraterrestrial civilizations, a major assumption for which is that extraterrestrials will have a similar understanding of "science" as we do.

See pp. 41-42 in text for some discussion. Look at questions 41, 48, 59 at end of Chapter 2. Notice that the word "model" is not used. Only "fact", "theory", etc.

- Don't confuse the fact that a model is useful for calculations with an actual understanding of a phenomenon. We don't understand what gravity is, we only understand how to describe it usefully, and which model for gravity seems to work best, "operationally."
- Einstein's theory of relativity is a better model, but does it "explain" gravity? It associates gravity to deformations of space-time, which is certainly better than just saying "the force" and leaving it there, but what is explained?
- Other suggestions about nature of gravity: Part of a unified field theory that includes all the forces, with gravity and others having been separated by "symmetry breaking" phase transitions of space-time during the early days of the universe; OR: What you get when "branes" that are three-dimensional structures (our universe is one) in higher-dimensional universes, interact (the "braneworld" interpretation); there are a few other exotic interpretations of gravity.
- Would a million year old civilization understand gravity as more than some better model? Would it even have the concept of "gravity," or our conceptions of matter as composed of a collection of fundamental particles, our notion that the best way to represent the "external" world is through mathematics?

Back to a *useful* description of the effect of gravity: How do two objects move under their mutual gravitational attraction? Treat the objects as points (no size, just mass) and you have "the two-body problem." Need to solve Newton's laws of motion (F=ma is all we need), with his law of gravity (which tells you the force to put in that equation). Solution gives detailed mathematical representation of orbital motion, but Kepler's laws are a useful way to represent those equations in simpler fashion. First law say bound orbits will be ellipses, but let's skip right to laws 2 and 3, which contain what we need to detect extrasolar planets.

Kepler's 2nd law: "Law of equal areas," but what's important is that an object in orbit around a star speeds up when nearest the star, moves slowest when farthest.

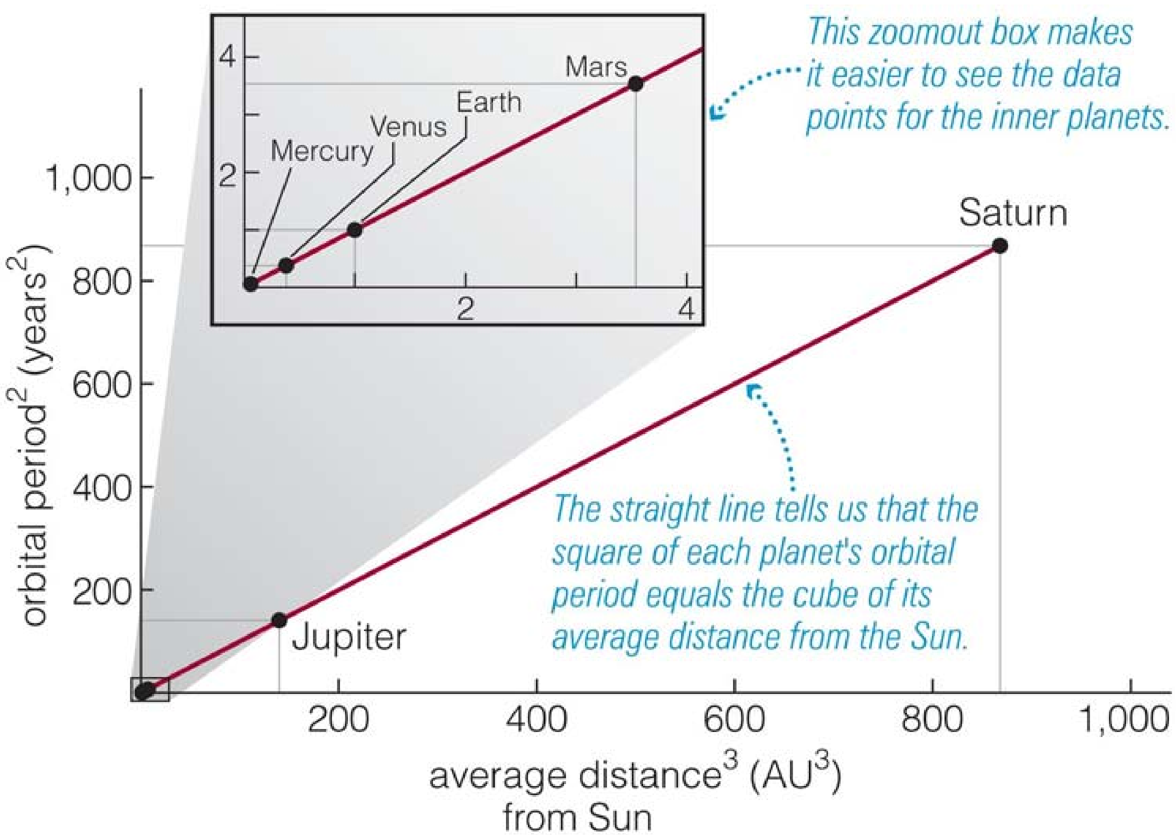
Kepler's 3rd law: for any two objects in orbit about each other:

(Period)^2 = (orbital size)^3/(sum of masses)

This is the most important of Kepler's laws for us.

Make sure you understand the graph below (from your textbook) showing this relation for the planets of our solar system.

Then think about how you might still obtain the masses even if you didn't know the orbital size directly…What more would you need?



Now try end of chapter questions before we move on to a review of light, i.e. the electromagnetic spectrum